MEMORANDUM **MOD Form 4A**

To Andy Smith
Room 2.32
R25
Rutherford Appleton
Laboratory
Chilton Didcot
Oxon

Date 6 August 1992

~~Your ref.~~

From P Roberts
Room 250
Meteorological Office
London Road
BRACKNELL

Tel. 0344 420242
Extn 6467

~~Our ref.~~

Subject Met Office Users' Guide to AAM data

Enclosed is a copy of the Users' Guide to AAM data sets that we discussed by telephone. The sections about computer systems and data set names are fairly irrelevant, but most of the scientific notes and those about the structure of the data sets are still good so far as I know, although not including data after 1987. I hope there will be some more up to date notes before too long.

I've started setting up the Washington coded UK Met Office AAM data, but there are a few problems with the archive data set here so I'll need to look at those first.

Best wishes

Rank/ Appointment

Name in Block Letters P ROBERTS

Signature P Roberts

ATMOSPHERIC ANGULAR MOMENTUM FLUCTUATIONS AND CHANGES IN THE EARTH'S ROTATION :

METEOROLOGICAL OFFICE USERS' GUIDE TO DATA SETS AND CODES

by

M.J. BELL and K.D.B. WHYSALL

Meteorological Office Internal Report

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Geophysical Fluid Dynamics Laboratory,
Meteorological Office(Met. O. 21),
London Road,
Bracknell,
Berks. RG12 2SZ

SUMMARY

This users' guide documents data sets and computer codes developed or collected in the Meteorological Office (by the Geophysical Fluid Dynamics, Met. O. 21) during a series of investigations, starting in 1979, of the total angular momentum of the atmosphere and short-term changes in the Earth's rotation.

CONTENTS

INTRODUCTION

For about a century, the rotation of the Earth has been known to vary by small but measurable amounts. Some of the observed changes have long been recognised as being due to the exchange of angular momentum between the solid Earth and the atmosphere (for references see Munk and McDonald 1960, Lambeck 1980). With the advent of modern astronomical techniques and global atmospheric analyses, Hide et. al. (1980) and Barnes et. al. (1983) were able to make detailed assessments of the extent to which fluctuations in the atmosphere's angular momentum are responsible for the observed changes in the length of the day and instantaneous position of the Earth's pole of rotation. Their work spurred a number of related studies (see appendix D) and resulted in the compilation of atmospheric angular momentum (AAM) data sets by a number of groups in several countries.

The atmosphere's angular momentum and its effect on the Earth's rotation is important for a variety of reasons. Geophysicists would like to be able to allow for the atmosphere's contribution to the Earth's motion so that they can study other effects, such as that of the Earth's liquid core. Atmospheric analyses and forecasts may also be used to improve the determination and prediction of changes in the Earth's orientation in space, which is of increasing importance to the space agencies. Finally fluctuations in atmospheric angular momentum provide an illuminating aspect of the large scale behaviour of the atmosphere.

This report documents the data sets and FORTRAN and job control code that are currently available in the Office and is designed to help the atmospheric angular momentum project to change hands as people come and go. The first four chapters describe the format, location, and contents of the available data sets and are suitable for distribution as documentation to JPL, CIRT and other centres. Chapters 5 and 6 provide brief descriptions of relevant FORTRAN code. A glossary of terms is given in appendix A and brief introductions to the COSMOS system and the RJE link to the ECMWF are presented in appendices B and C respectively. Useful addresses and the contents of the filing system for the angular momentum project are listed in appendices E and F.

CHAPTER 1

GLOBAL AND HEMISPHERIC "ANALYSIS" DATA

1.1 EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS (ECMWF)

Main data set name

M21.BEC1286.DATA

Source

Produced by the Geophysical Fluid Dynamics Laboratory, U.K. Met. Office, using meteorological data sets provided by the ECMWF.

Contents

Contains daily values of the wind and pressure term contributions to each of the three components of the EAAM from the northern and southern hemispheres.

Period

From 1st Dec. 1979 to 31st Dec. 1986. The current data set (see Locations) is updated about once a month.

Times of validity

Some of the data are valid at 12Z and the rest at 00Z;

Period	Hour
01 / 12 / 79 - 30 / 11 / 80	12Z
01 / 12 / 80 - 15 / 03 / 82	00Z
16 / 03 / 82 - 29 / 02 / 84	12Z
01 / 03 / 84 - 15 / 03 / 84	00Z
16 ~~15~~ / 03 / 84 - 31 / 12 / 86	12Z

All data after 1986 is expected to be valid at 12Z. June 1987 →
average over 00, 06, 12, 18Z.

Format

Each set of daily values uses 3 records. The data is preceded by a 62 record header. The following code reads the header and the first 100 days' data from 1st Dec. 1979.

```
CHARACTER*75 A
DIMENSION NOD(100),IDATE(100)
DIMENSION X1PN(100),X1PS(100),X1WN(100),X1WS(100)
DIMENSION X2PN(100),X2PS(100),X2WN(100),X2WS(100)
DIMENSION X3PN(100),X3PS(100),X3WN(100),X3WS(100)
```

```
      DO 10 N=1,62
         READ(IUNIT,600)A
 10   CONTINUE
      DO 20 N=1,100
        READ(IUNIT,610)NOD(N),IDATE(N)
     1                ,X1PN(N),X1PS(N),X1WN(N),X1WS(N)
     2                ,X2PN(N),X2PS(N),X2WN(N),X2WS(N)
     3                ,X3PN(N),X3PS(N),X3WN(N),X3WS(N)
        X3PN(N)=-X3PN(N)
        X3PS(N)=-X3PS(N)
        X3WN(N)=-X3WN(N)
        X3WS(N)=-X3WS(N)
 20   CONTINUE
 600  FORMAT(A)
 610  FORMAT(I4,I8,1P,4E16.5/(12X,1P,4E16.5))
```

After the second DO loop

NOD(N) contains the number N

IDATE(N) contains the date for which the functions are valid;
eg. IDATE(1) = 79120100 = YYMMDD00
(the hour for which the data is valid is not recorded. The 7th and 8th places in IDATE are always zero). The other arrays contain evaluations of the EAAM functions as originally defined if one reads

X as χ (see Barnes et. al.(1983) eqns. (5.1) to (5.3))
1 as the component with its rotation axis aligned with 0E
2 as the component with its rotation axis aligned with 90 E
3 as the component with its rotation axis aligned with the principal axis of the Earth's inertia tensor, pointing nearly along the mean axis of the Earth's rotation
P as denoting the pressure (also called matter) term
W as denoting the wind term
N as northern hemisphere
S as southern hemisphere

The data is stored in 80 byte records blocked by 4800. χ_3 is dimensionless whilst the units for χ_1 and χ_2 are radians (see Barnes et. al. (1983) eqns. (5.1) to (5.3), which are reproduced in appendix A).

The data which according to IDATE covers the period from 16 Mar. 1984 to 31 Mar. 1984 applies infact to the period from 15 Mar. 1984 to 30 Mar. 1984; eg the records with IDATE = 84031600 store data valid (at 12Z) on 15 Mar. 1984.

Model and data assimilation schemes (in Jan. 1986)

The forecast model uses a hybrid (sigma/pressure) 16 level vertical grid and a spectral horizontal representation with triangular truncation at wavenumber 106. It contains parametrisation schemes which represent sub-grid scale radiative and convective processes, precipitation and boundary layer turbulence.

The analyses are performed on a global non-staggered 1.875 longitude- latitude grid on 15 standard pressure levels (1000,850,700,500,400,300,250,200, 150,100,70,50,30,20,10mb) using a 3 dimensional optimal interpolation scheme (in which the mass and wind fields are interdependent). The first guess field is a 6 hour forecast. The data cut off time for the 12Z forecast is 20.45Z. The forecast suite is fully documented by three manuals;

Lonneberg, P. and Shaw, D. (eds.) 1986: ECMWF Research Manual 1: ECMWF data assimilation scientific documentation.

Louis, J.F. (ed.) 1986: ECMWF Research Manual 2: ECMWF forecast model adiabatic part.

Louis, J.F. (ed.) 1986: ECMWF Research Manual 3: ECMWF forecast model physical parametrisation.

Inhomogeneities

Improvements to the ECMWF numerical model and hence the assimilation procedure occur frequently. Details of changes are recorded in the quarterly ECMWF Forecast Reports and ECMWF Newsletters (back copies kept in file D/Met 0 21/6/7/1/5).

Major changes affecting χ_3^P particularly have occurred on

Date	NOD	Alteration to model
01/04/81	488	new orography and surface fields
21/04/83	1238	gridpoint model replaced by T63 spectral model
01/02/84	1524	new (envelope) orography
02/05/85	1979	increase in spectral resolution to T106
13/05/86	2355	19 level model introduced
15/07/86	2418	orographic gravity wave drag parametrisation introduced

Locations

1. M21.BEC1286.DATA is stored on COSMOS in file 1 of tape 210116 in the format described above. It is backed up on file 1 of tape 210117 and on file 1 of the archive tape 880613.
2. M21.BECM87.DATA on COSMOS disk USR407 is the continuation of M21.BEC1286.DATA, starting on 1st Jan. 1987. A copy of this data, M21.BECM87.COPY, is also stored on USR407. (These data sets do not include the 62 record descriptive header).
3. At ECMWF on the UKJ filespace. Data set UKJ.B79D60CA covers the period 1/12/1979 to 15/10/86. UKJ.B86Jymmc is extended every other month and covers the period from 1/1/86 to the mmth month of the yth year. If c is the letter A the first 15 days of the last month are included in the data set whilst if c is the letter B the whole of the last month's data is present (eg UKJ.B86J7JAB would cover 1/1/86 to 31/1/87). The data set contains both the chi and psi functions. Its format is described in section 5.2.

Relevant programs

1. The codes used to update the main data sets are described in section 5.2.
2. Plotting programs such as M21.BSRCELIB.FORT(BANGMOM7) present the data graphically. A sample set of job control for this program is held in M21.BANGLIB.CNTL(BANGM1).
3. M21.BANGLIB.CNTL(BTCEC1) can be used to copy M21.BEC1286.DATA to a no-label tape for distribution.

Auxiliary notes

The EAAM functions are calculated as part of the Met. Office / Reading University Joint Diagnostics Project using the archived ECMWF initialized data. The accessed data is stored on standard pressure levels. The integrals over the depth of the atmosphere which appear in the definitions of the wind terms are approximated by integrals from 1000mb to 50mb.

1.2 JAPANESE METEOROLOGICAL AGENCY (JMA)

Main data set name

M21.BJMA1286.DATA

Source

Produced by the International Latitude Observatory of Mizusawa (ILOM), Japan, using meteorological data sets provided by the JMA.

Contents

Daily mean or twelve hourly values of the wind and pressure terms of each of the three components of the EAAM function from the northern and southern hemispheres. There are two pressure terms; one calculated with and one without the inverted barometer correction (see appendix A).

Period

From 02/01/84 - 31/12/86. The data set is being updated about once every three months at the ILOM. (The original data set starts on 28/09/83, but our copy does not contain the first two months of data).

Times of validity

Mean daily values from 2 Jan. 1984 to 30 Jun. 1986, and values at 00Z and 12Z from 01 Jul 1986 to 31 Dec 1986.

Format

The data for each epoch uses 3 records. The following code reads the first 100 sets of data

```
      DIMENSION X1WN(100),X1PNN(100),X1PIN(100),X1VS(100),X1PNS(100),X1PIS(100)
      DIMENSION X2WN(100),X2PNN(100),X2PIN(100),X2WS(100),X2PNS(100),X2PIS(100)
      DIMENSION X3WN(100),X3PNN(100),X3PIN(100),X3WS(100),X3PNS(100),X3PIS(100)
      DIMENSION IDATE(4)
      DO 10 N = 1,100
        READ(IUNIT,20) IDATE,X1WN(N),X1PNN(N),X1PIN(N),X1VS(100),
                             X1PNS(N),X1PIS(N)
        READ(IUNIT,20) IDATE,X1WN(N),X1PNN(N),X1PIN(N),X1VS(100),
                             X1PNS(N),X1PIS(N)
        READ(IUNIT,20) IDATE,X1WN(N),X1PNN(N),X1PIN(N),X1VS(100),
                             X1PNS(N),X1PIS(N)
        X3WN(N)=-X3WN(N)
        X3WS(N)=-X3WS(N)
   10 CONTINUE
   20 FORMAT(1X,4I2,6F11.6)
```

The notation is as in section 1.1 except that IDATE(1) = INTEGER YEAR - 1900; IDATE(2) = INTEGER MONTH; IDATE(3) = INTEGER DAY OF MONTH; IDATE(4) = INTEGER HOUR OF DAY (blank indicates daily mean value). The letters PN indicate that the pressure term was calculated without using the inverted barometer correction whilst PI indicate that the IB correction was used. All values have been multiplied by 10^7. The data set has 80 byte records blocked by 4800 bytes. Data is missing from 16 Jan 1984 to 22 Jan 1984 (inclusive) and on 15 Feb 1984.

Model and data assimilation schemes (in 1986)

The analysis is performed on a 2.5 x 2.5 degree latitude-longitude grid, at the surface and on 14 standard pressure levels (850,700,500,400,300,250,200,150, 100,70,50,30,20,10mb), using a 2D multi-variate "optimum" interpolation method for the wind and geopotential height in the troposphere, and a two-dimensional functional fitting method in the stratosphere (i.e. at 70 mb and above). The basis functions for the functional fitting vary sinusoidally with longitude and are B-spline functions of latitude. The first guess field is the 12 hour forecast. The data cut-off time is 6 hours after the map time. All the data within +/- 6 hours of the map time are used without any locational correction, but the observation errors are weighted according to their time difference from the analysis hour..

The forecasts are performed with a 12 sigma level T 42 spectral model which has a comprehensive set of parametrisation schemes. Details of the forecast suite are given in

Kashiwagi, K., 1987: On the impact of space-based observing systems in the JMA global forecast/analysis system. To appear in J. Met. Soc. Japan.

Kanamitsu, M., Tada, K., Kudo, T., Sato, N., and Isa, S., 1983: Description of the JMA operational model. J. Met. Soc. Japan, 61, 812 - 828.

Inhomogeneities

None known other than the times of validity detailed above.

Locations

1. M21.BJMA1286.DATA is stored on COSMOS on the fifth file of each of 3 tapes; tapes 210116, 210117 and archive tape 880613.
2. M21.BJMA86A.DATA is on file 8 of tape 841844. This provisional version of the JMA data contains only global values and pressure terms calculated with the inverted barometer correction. The period covered is 28 Sep 1983 - 31 Oct 1985. Data at 00Z and 12Z are available between 28 Sep 1983 and 04 Dec 1983 and mean daily values from 01 Dec 1983 to 31 Oct 1985. Data is missing in the intervals 05 Dec 1983 to 11 Dec 1983, 26 Dec 1983 to 01 Jan 1984, 16 Jan 1984 to 22 Jan 1984 and on 15 Feb 1984. The formatted 80 byte records are blocked by 4800 bytes. Each record may be read using

```
      READ(IUN,600)JUL,ID,CH,X1,X2,X3
 600  FORMAT(I5,1X,3(I2),1X,1A,3(E14.7)
```

where JUL records the integer modified Julian date, ID is the date (eg 830928 for 28 Sep 1983), CH is the character T (total) or P (pressure) or W (wind), and X1, X2 and X3 the contributions to the corresponding EAAM components.

3. M21.BJMA1085.DATA is on the fourth file of three tapes; tapes 210116, 210117 and archive tape 880613. It was formed from data set 2 taking just one set of values per day (the 00Z value when available) and filling in gaps using data immediately adjacent to them. Its two record header is followed by data in the format used by the main UKMO data set (see section 1.4).

Relevant programs

1. M21.BANGLIB.CNTL(BTRJMA) was used to make M21.BJMA1085.DATA from M21.BJMA86A.DATA
2. Routines BANPOST and BANPOS2 can plot data from M21.BJMA1085.DATA.

Auxiliary notes

The EAAM functions are calculated at the ILOM using analysis fields on 2.5 by 2.5 degree horizontal grids between the surface and 10mb provided by the JMA. The pressure terms are evaluated from a sea-level pressure field calculated on a 2.5 by 2.5 degree grid, geopotential heights on standard pressure levels and thicknesses, using a cubic spline interpolation scheme and the standard JMA spectral representation of topography.

1.3 NATIONAL METEOROLOGICAL CENTER (NMC)

Main data set names

Period	Data set name	file number on tape 841844
01/07/76 - 31/08/83	M21.BNMC84A.DATA	13
01/09/83 - 30/09/84	M21.BAER85A.DATA	14
01/10/84 - 31/12/84	M21.BNMC85B.DATA	15
01/01/85 - 31/03/85	M21.BNMC86B.DATA	17
01/04/85 - 30/06/85	M21.BNMC86C.DATA	18
01/07/85 - 31/10/85	M21.BNMC86D.DATA	19
01/11/85 - 31/01/86	M21.BNMC86A.DATA	16
01/12/85 - 31/03/86	M21.BNMC86E.DATA	20
05/02/86 - 31/05/86	M21.BNMC86F.DATA	34
02/05/86 - 31/07/86	M21.BNMC86G.DATA	35
01/08/86 - 31/10/86	M21.BNMC86I.DATA	36
01/10/86 - 31/12/86	M21.BNMC87A.DATA	37
02/12/86 - 28/02/87	M21.BNMC387.DATA	38

Source

Produced at the National Meteorological Center, U.S.A. and distributed through the Geodetic Research and Development Laboratory and the NASA Jet Propulsion Laboratory (J.P.L.); see appendix E for addresses.

Contents

Contains twelve hourly values of the wind and pressure term contributions to each of the three components of the EAAM functions from the northern and southern hemispheres. Two pressure terms are calculated; one with and one without the inverted barometer correction (see appendix A).

Period

From 1 Jul. 1976 to 28 Feb. 1987. New data is sent to us every six months.

Times of validity

All data are valid at 00Z or 12Z.

Format

The data for each epoch uses 3 records. The following code reads the first 100 sets of data

```
      DIMENSION X1WN(100),X1PNN(100),X1PIN(100),X1WS(100),X1PNS(100),X1PIS(100)
      DIMENSION X2WN(100),X2PNN(100),X2PIN(100),X2WS(100),X2PNS(100),X2PIS(100)
      DIMENSION X3WN(100),X3PNN(100),X3PIN(100),X3WS(100),X3PNS(100),X3PIS(100)
      DIMENSION ID(4)
      DO 10 N = 1,100
        READ(IUNIT,20)ID,X1WN(N),X1PNN(N),X1PIN(N),X1WS(N),X1PNS(N),X1PIS(N)
        READ(IUNIT,20)ID,X2WN(N),X2PNN(N),X2PIN(N),X2WS(N),X2PNS(N),X2PIS(N)
        READ(IUNIT,20)ID,X3WN(N),X3PNN(N),X3PIN(N),X3WS(N),X3PNS(N),X3PIS(N)
        X3WN(N)=-X3WN(N)
        X3WS(N)=-X3WS(N)
   10 CONTINUE
   20 FORMAT(1X,4I2,6F11.6)
```

The notation is the same as in section 1.2. All values have been multiplied by 10^7.

M21.BAER85A.DATA also contains garbled data for the period 01 Oct. 1984 - 31 Dec. 1984. The format for M21.BAER85A.DATA is slightly different from the standard one. It is

```
FORMAT(1X,4I2,2X,6F11.6).
```

M21.BNMC86G.DATA includes data for 1 Feb. 1986 to 28 Feb. 1986. Data is unavailable over numerous short periods.

Model and data assimilation schemes (in Jan. 1986)

The analysis is performed on a quasi-equal area grid with approximate spacing of $\Delta\phi = 2.25°$ in latitude and $\Delta\lambda = 4.5°$ in longitude at 12 standard pressure levels between 1000mb and 50mb using a 2D optimal interpolation scheme in which the mass and wind fields are interdependent. The first guess field is a 6 hour forecast by an 18 level sigma coordinate spectral model which has rhomboidal 40 truncation. The data cut off time is three and a half hours. More details concerning the forecast and analysis systems are given in

Dey, C.H., and Morone, L.L., 1985: Evolution of the National Meterological Center global data assimilation system: January 1982 - December 1983. Mon. Weath. Rev. , 113, pp 304 - 318.

Dey, C.H., Ballish, B.A., and Phoebus, P.A., 1987: 1985-1986 summary of changes to NMC operational global analyses. National Weather Service Office Note, 327.

Inhomogeneities

To obtain a homogeneous time series for the pressure components the constant 6.990411 E-07 must be added to the hemispheric pressure components in all of the data sets other than M21.BNMC84A.DATA and M21.BNMC85B.DATA.

The forecast and analysis systems have been substantially modified on the following dates

Date	Alteration to model
27/05/80	gridpoint model replaced by a R24 spectral 12 sigma level model; OI altered
14/08/82	analyses moved from sigma to isobaric levels
28/05/86	forecast model resolution increased to R40 and physical parametrisations improved

Locations

1. On COSMOS tape 841844 in the files listed on page 1-6 and the format described above. Files 5 - 13 and 27 - 31 of tape 210076 contain copies of these data sets.
2. Some of the data from 1. has been re-organized into a format identical with that described in detail in section 1.1, except that descriptive headers are absent. It is stored on COSMOS tapes 210116, 210117 and archive tape 880613 in files 6 - 9

Period	Data set name	File number
01/07/76 - 30/11/79	M21.BNM1179A	6
01/07/76 - 30/11/79	M21.BNM1179I	7
01/12/79 - 31/12/86	M21.BNM1286A	8
01/12/79 - 31/12/86	M21.BNM1286I	9

All the data is valid at 00Z. The data sets with names ending in "A" have matter terms calculated without the inverted barometer correction, whilst those ending in "I" were calculated using that approximation. Where data was missing from the original data sets values from the preceding or following days have been used to fill in the gaps. These data have been earmarked by non-zero values in the last two elements of IDATE. Only wind data was available from 25 Aug. - 31 Aug. 1980; the pressure data has been filled in using data from adjoining days and the last two elements of IDATE given non-zero values.

Relevant programs

1. Members of M21.BANGLIB.CNTL which begin with the letters BTRNM have all been used to read tapes from JPL or to convert data sets from the NMC format to the ECMWF format.
2. Programs used to plot ECMWF data can be used with the data in the reorganised format (i.e. 2. above).

Auxiliary notes

The wind terms are calculated using data on standard pressure levels; since 31 Aug. 1983 the wind integrals have extended from 1000mb to 50mb.

1.4 UNITED KINGDOM METEOROLOGICAL OFFICE (UKMO)

Main data set name

M21.BUKM1086.DATA

Source

Produced by Paul Whitfield of Met O 20 using the update analysis of the 15-level Met. Office numerical model.

Contents

Daily values of the global wind and pressure terms for each of the three components of the EAAM functions.

Period

From 01/05/83 to 31/10/86. The data set will not be updated (because it has been superceded by the forecast data set documented in section 4.3).

Time of validity

All the data are valid at 00Z.

Format

Each set of daily values uses one record. The data set has no header. The following code reads the first 100 days data from 01/05/83.

```
     DIMENSION X1P(100),X2P(100),X3P(100),X1W(100),X2W(100),X3W(100)
     DIMENSION X1(100),X2(100),X3(100),IDATE(100)
     DO 10 I = 1,100
      READ(IUNIT,20)IDATE(N),X1P(N),X2P(N),X3P(N),X1W(N),X2W(N),X3W(N),
    1         X1(N),X2(N),X3(N)
 10  CONTINUE
 20  FORMAT(I8,3X,9E13.5)
```

After the DO loop IDATE(N) contains the date and time for which the data are valid; eg. IDATE(1) = 83050100 . All the data are for 00Z. The data are stored on 133 byte records blocked by 3857. Data were not available for only 4 dates; 27/5/83, 31/5/83, 11/6/83 and 12/9/83. The previous day's value has been inserted for each of these dates and the last two digits of IDATE set to 99.

Model and data assimilation schemes (in 1985)

The present global UKMO operational model uses a 15 level sigma coordinate vertical grid extending up to about 25 mb and a latitude - longitude grid with gridlength $\Delta\phi = 1.5°$ in the N - S direction and $\Delta\lambda = 1.875°$ in the W - E direction. The model contains physical parametrisation schemes which represent large-scale precipitation, deep convection, radiation, momentum transports due to sub-grid scale orographically induced gravity waves, and the vertical transfer of heat, moisture and momentum through the boundary layer.

Corrections to the initial model variables at each gridpoint are calculated from quality controlled observational data valid within 3 hours of the forecast start time using a 3D univariate "optimum" interpolation scheme. A proportion of these corrections and increments calculated using the geostrophic and hydrostatic relations are added to the forecast values at each gridpoint at each timestep in the 6 hour period preceeding the forecast. Gravity wave noise is reduced by damping horizontal divergence during this assimilation period.

The forecast suite is documented by several reports all of which are available on request from Met O 2b , U.K. Met. Office. The two most relevant documents are

Bell, R.S. (ed.) 1985: Operational numerical weather prediction system documentation paper no. 3. - The data assimilation scheme.
Dickinson, A. (ed.) 1985: Operational numerical weather prediction system documentation paper no. 4. - The weather prediction model.

Inhomogeneities

The topography used in the forecast model was changed on 3 Oct. 1984 and a parametrisation of gravity wave drag introduced on 12 Dec 1984.

Locations

1. M21.BUKM1086.DATA is stored on file 2 of COSMOS tapes 210116, 210117 and archive tape 880613 in the above format. The data was calculated from archived update analyses on standard pressure levels. The surface pressure had to be recalculated from the mean sea level pressure and a topographic data set. The wind term integral extended from 1000mb to 30mb.
2. M21.BUKM1186.DATA on file 3 of tapes 210116, 210117 and 880613 records twice daily (00Z and 12Z) UKMO analysis values of the EAAM functions for November 1986. The wind intgrals extended only from 950 mb to 50 mb and the pressure terms were evaluated using surface pressure fields. The data format follows that of the UKMO forecasts data sets (see section 4.3).
3. Twice daily analysis values are available in the forecast data sets, detailed in section 4.3, from 27 Nov. 198~~7~~.6

Relevant programs

1. M21.BUKM1086.DATA was calculated by program M20.GAJOBLIB.CNTL(ARCHEAM).
2. Members of M21.BANGLIB.CNTL whose names start with the letters BTCUK copy the main data set to tape for distribution.
3. Members BANGUK, BANPOST and BANPOS2 of M21.BSRCELIB.FORT can be used to plot the data in M21.BUKM1086.DATA.

CHAPTER 2

LENGTH OF DAY AND POLE POSITION DATA

2.1 CENTRE INTERNATIONAL DE LA ROTATION TERRESTRE (CIRT)

Data set name

There are several data sets; see Locations

Source

Produced by the Centre International de la Rotation Terrestre (CIRT), Paris. The CIRT takes over from the Bureau International de l'Heure (BIH) on 1st Jan. 1988.

Contents

Pentad values of the length of the day and raw values of the pole's position. The coordinates of the pole are raw values taken from BIH monthly circular D, page 3, Table 1. The length of the day is calculated from UT1R - UTC smoothed weakly by Vondrak's method (see appendix A and BIH Annual Reports part A table 7). It is taken from BIH circular D, page 3, Table 2.

Period

01/01/1967 to the present. Updated every one or two months.

Time of validity

0 hours UTC (i.e. 00Z).

Format

Each set of pentad values uses 1 record. The following code reads the first 40 pentad values

```
      DIMENSION BIH1(40),BIH2(40),BIH3(40)
      DO 10 N = 1,40
        READ(IUNIT,20)BIH1(N),BIH2(N),BIH3(N)
   10 CONTINUE
   20 FORMAT(2F7.4,F6.2)
```

After the DO loop BIH1(N) contains the displacement of the pole along the Greenwich meridian and BIH2(N) contains the displacement of the pole in the direction 90W. The unit in which BIH1 and BIH2 are calculated is seconds of arc. BIH3(N) + 86 400 000 is the length of the day in milliseconds. The date for which each datum is valid appears on the right hand side of each record. The data is stored in 80 byte records blocked by 4800.

Model description

The BIH produces "combined solutions" for UT1 (see appendix A) and the pole's position which are combinations of results from several different observing techniques. The computation of UT1 and the pole coordinates was initiated by the BIH in 1967, when only optical observations (timings of the meridian crossings of selected stars) were available (Feissel, private communication). Since 1973, observations produced by various space geodetic techniques have been incorporated into the BIH combined solution (BIH Annual Report 1984). As a general rule, data from new techniques has been used as soon as its systematic deviation from the "standard" BIH results can be accounted for, with residual errors smaller than the effects of random errors (BIH Annual Report 1980). Section A-1 table 6 of each BIH Annual Report lists the source and type of each time series which contributed to the combined solution during the year. The relative weightings are also displayed in the 1981 and 1983 reports; in 1981 optical astrometric techniques took 87% of the weight, but by 1983 VLBI had 69% of the weight.

Inhomogeneities

The BIH aims to minimise the effects of any inhomogeneities in the observations of the Earth's rotation. For the purposes of comparison with atmospheric angular momentum estimates, it is usual to suppose that the BIH combined solution for UT1 and the polar position have no inhomogeneities.

Locations

1. On USR407 in data set M21.BBIH79.DATA in the above format. The data set covers the period 07/11/79 to the present (it is updated monthly).
2. On USR407 M21.BBIH75.DATA in the above format. This data covers the period 03/12/75 to 03/02/85.
3. On tape 210063 in the above format, although instead of the excess length of day, the quantity UT1-TAI is given. This must be differentiated with respect to time to obtain the excess length of day (see appendix A). This data covers the period 01/10/67 to 01/09/84. There are 3 files on the tape, giving UT1-TAI and the polar position with varying degrees of smoothing. The first file contains raw data, the second strongly smoothed data, the third weakly smoothed data (BIH Annual Reports part A, table 7). This is a standard format for BIH data dissemination.

Relevant programs

1. These data are used in nearly all the plotting routines.
2. The last dataset mentioned above is read and plotted using the member KBIH in library M21.BSRCELIB.FORT.

2.2 RESULTS FROM PROJECT MERIT

The IAU/IUGG report MERIT-COTES, 1986: Observational Results on Earth Rotation and Reference Systems Part III. ed. Feissel, M. contains the determinations of the Earth's rotation made during the MERIT campaign. A copy is held in File D/Met021/6/7/2/1.

2.3 ADDITIONAL EARTH ROTATION PARAMETER TIME SERIES

Data set name

M21.BBIH86A.DATA

Sources

The Goddard Space Flight Center (whose data is labelled by code 3301), the National Geodetic Survey (code 1203) and the BIH (code 463) All data were sent via Mme. Feissel (BIH).

Contents

Calculations of the x and y coordinates of the pole, UT1 - UTC, thee length of day and the standard error on all four quantities by all three centres.

Period

Centre	Modified Julian day	Date
GSFC	44341 - 46269	12/04/80 - 23/07/85
NGS	44509 - 46454	27/09/80 - 24/01/86
BIH	44239 - 46484	01/01/80 - 23/02/86

Time of validity

All the data is valid at .000 MJD.

Format

All three sets of measurements are on the same data set. The sets are separated by single records filled with '9' s. All other records have the same format. The following code reads the data for the first epoch

```
    READ(IUNIT,10)ISER,AMJD,XPO,YPO,AUT,ALOD,SXPO,SYPO,SUT,SLOD
 10 FORMAT(4X,I4,F10.0,2(2F8.0,F9.0,F6.0))
```

After the READ statement is executed ISER contains the numerical code of the series, AMJD the MJD of the epoch, XPO and YPO the x and y coordinates of the pole in seconds of arc, AUT contains UT1 - UTC in seconds, ALOD the length of the day in milliseconds, SXPO and SYPO the estimated standard errors for XPO and YPO in seconds of arc, SUT the standard error for UT1 - UTC in seconds and SLOD the standard error for the l.o.d. in milliseconds.

There are measurements by GSFC at 302 epochs in all. They are sampled daily at times and every five days at others. The 449 epochs sampled by the NGS appear to be erraticly spaced. The BIH give 450 pentad values.

Model descriptions

The BIH combined solution has been described in 2.1. The NGS and GSFC data are VLBI measurements (see appendix A).

Inhomogeneities

The inhomogenities of the BIH combined solution are discussed in section 2.1. There are no known inhomogenities in the NGS and GSFC data.

Locations

On file 14 of tape 210076 and file 21 of 841844.

Auxiliary notes

Some of the data has been plotted by hand. Agreement between measurements of the l.o.d. by different centres is excellent.

2.4 CORRECTIONS DUE TO SOLID EARTH TIDES

Movements of the Moon and Sun relative to the Earth give rise to solid earth tides which alter the moment of inertia of the Earth's mantle and thereby give rise to fluctuations in the length of day. These fluctuations are conveniently represented by a superposition of sinusoidal oscillations of various periods. Yoder, C.F., Williams, J.G., and Parke, M.E., 1981: Tidal variations of Earth rotation. J. Geophys. Res., 86, 881-891 tabulates the amplitudes and phases of the principal periods for UT1. M21.BSRCELIB.FORT(TIDAL) which was supplied by the BIH and is their standard routine applies these corrections to the standard BIH data. The tidal corrections account for more than one half of the residual fluctuations in the length of day (over the last ten years) after atmospheric fluctuations have been deducted. Program TIDAL may be used to calculate the corrections to UT1 or to the length of day.

CHAPTER 3

GRIDPOINT DATA SETS FOR BOX ANALYSES

Dataset name

M21.BBARPE.DATA

Source

Produced by Klaus Arpe of ECMWF from the zonal wind analysis fields stored in the ECMWF tape archive.

Contents

Zonal winds averaged over all longitudes on 5 degree latitude spacings at 13 standard pressure levels, namely,

1000,850,700,500,400,300,250,200,150,100,70,50,30mb.

The data at the 70mb level are not always present.

Period

From 1/11/80 to 31/12/82.

Time of validity

Data is 12 hourly (00Z and 12Z) except for the last day of each month, when only 00Z is available. For the period 00Z on 1/4/82 to 00Z on 19/8/82, the data is 6 hourly. There are no missing days.

Format

Each latitude-pressure grid of zonal mean wind uses one "block". The format of the data is

```
35(F8.2,12F6.2/)
```

Each block has a header giving the date and time for which the data is valid, in the form,

```
U-MEAN YYMMDDHH
```

Short sections of the data depart from this format. Subroutine READANG, in library M21.BSRCELIB.FORT reads the data set allowing for these changes. The data is stored in 80 byte records blocked by 22400 bytes. To use READANG

```
CALL READANG(U,35,12,NDAY,IHOUR,IDATE1,IDATE2)
```

with

U an array with dimensions U(12,35,NDAY)

NDAY= number of days in period to be extracted.

IHOUR= hour required (00Z or 12Z)

IDATE1= first date of period to be extracted

IDATE2= last date of period to be extracted

(IDATE1 and IDATE2 are of the form, YYMMDD.)

If IDATE1=800101, IDATE2=821231, and NDAY=1095, then the entire dataset is read. When returned by READANG, the array U will contain the zonal mean wir at 12 levels and 35 latitudes (85 N to 85 S, on a 5 degree spacing) for NDAY days at the time IHOUR. READANG does not return data on the 70mb pressure level.

Model description

The fields are products of the ECMWF analysis scheme described in section 1.1.

Inhomogeneities

There are no obvious inhomogeneities in the data set. Changes in the ECMWF model/analysis scheme apply as in section 1.1.

Locations

1. M21.BBARPE.DATA is stored on file 8 of tape 841843, file 32 of tape 110076 ~~210076~~ and on file 10 of archive tape ~~880613.~~

Relevant programs

1. The data is used by M21.BSRCELIB.FORT(KANG8082) which calculates the angular momentum in specified boxes (see section 6.1).

Auxiliary notes

None.

CHAPTER 4

GLOBAL AND HEMISPHERIC FORECAST DATA

4.1 ECMWF

A OPERATIONAL DATA

Main data set names

M21.BECMWF.DATA(FECmmyy) in which mm is the number of the month and yy the year number ; eg member FEC0187 covers January 1987.

Source

Operational calculations by ECWMF using the forecast model described in section 1.1, supplemented by data compiled by G. Sakellarides of ECMWF.

Contents

Analyses and one to ten day forecasts of the contributions to the wind and matter terms of all three components of the EAAM functions from both the northern and southern hemispheres.

Period

From 1st. Jan 1986.

Times of validity

12Z analyses and forecast values at 24 hour intervals out to 240 hours.

FORMAT

No desriptive header precedes the data. The code below reads the first epoch's set of analysis and one to ten day forecast values

```
      DIMENSION ID(4),IFOR(11),X1PN(11),X1PS(11),X1WN(11),X1WS(11)
      DIMENSION X2PN(11),X2PS(11),X2WN(11),X2WS(11)
      DIMENSION X3PN(11),X3PS(11),X3WN(11),X3WS(11)
      DO 10 I = 1,11
        READ(IUNIT,20)ID,IFOR(I),X1PN(I),X1PS(I),X1WN(I),X1WS(I)
     1                       ,X2PN(I),X2PS(I),X2WN(I),X2WS(I)
     2                       ,X3PN(I),X3PS(I),X3WN(I),X3WS(I)
 10   CONTINUE
 20   FORMAT(4I2,2X,I4,1X,1P,4E16.5/(15X,1P,4E16.5))
```

ID records the time and date for which the analyses and forecasts are valid as yymmddhr; eg 87050112 stands for 12Z on 1st Jun. 1987. IFOR is the forecast hour; 0 indicates analysis values and 240 10-day forecast values. After the DO loop, the (n+1)th element of each EAAM array ($0 \leqslant n \leqslant 10$) contains the 24[illegible]. n hour forecast which is valid at the same time as the other members of the [illegible]ray. The other notation is the same as in section 1.1.

Forecast model description

The forecast model is described in section 1.1.

Inhomogeneities

None known.

Locations

1. Previous months' data are stored as members of library M21.BECMWF.DATA. Member Fmonyy stores data for month mon of year yy.
2. The ECMWF MARS operational archives include the EAAM functions amongst the standard budget values (code 128). Operational archiving of analysis, initialized analysis and forecast EAAM data began on 7 April 1987. Analysis and initialized analysis values at 00Z, 6Z, 12Z and 18Z each day and output from each day's 12Z f/c, at 6 hourly intervals out to 120 hours and 12 hourly intervals thereafter, are all stored. Data can be retrieved from this archive using program X1X2X3 of library M21.BSRCELIB.FORT (see below).

RELEVANT PROGRAMS

1. M21.BSRCELIB.FORT(X1X2X3) sends a MARS retrieval job to the ECMWF CRAY which extracts EAAM data from the operational archive and produces a file in the format described above on the UKJ ECMWF CYBER filespace. The bulk of this code was written by G. Sakellarides of ECMWF.
2. M21.BSRCELIB.FORT(BECRAY) sends a CRAY job to ECMWF which converts a month's ECMWF f/c data in CRAY bit binary into ASCII character code.
3. The members of M21.BSRCELIB.FORT with prefix BFRP can be used with UKMO and ECMWF f/c data. They can plot f/c and analysis time series and scatter diagrams and calculate some statistical quantities for many combinations of components.

Auxiliary notes

All model levels are used in evaluations of the wind terms. The top model level is very close to 10mb.

B ARCHIVED DATA

Source

Calculated by K.D.B. Whysall from forecast fields retrieved from the ECMWF tape archives.

Contents

1. Forecasts of the contributions to the wind component of the axial effective angular momentum from northern and southern hemispheres at 10 days (240 hours).
2. Forecasts of the contributions to the wind component of the axial effective angular momentum from northern and southern hemispheres at all available forecast times (12,24,36,48,.....240 hours) for the month of August 1985.
3. As for 2., but for December 1985.

Period

1. From 01/08/85 to 28/02/86.
2. From 01/08/85 to 31/08/85.
3. From 01/12/85 to 31/12/85.

Format

The data sets are unformatted and can be read using the following FORTRAN code,

1.
```
      DIMENSION X3FN(212),X3FS(212)
      READ (IUNIT) X3FN
      READ (IUNIT) X3FS
```
The first value of each array is the ten day forecast made on the 1/8/85, and valid for the 11/8/85. The X3FN array contains the northern hemisphere forecasts, and the X3FS array, the southern hemisphere forecasts.

2.
```
      DIMENSION X3FN(310),X3FS(310)
      READ (IUNIT) X3FN
      READ (IUNIT) X3FS
```
The first ten values in each array are the 10 forecasts made on 1/8/85, the second ten, the forecasts made on the 2/8/85, etc.

3. as 2 above.

The units are 10^{25} kg m^2 s^{-2}.

Locations

1. On disk usr407, data set M21.BFAGFB
2. On disk usr407, data set M21.BAGALL
3. On disk usr407, data set M21.BDCALL

Auxiliary notes

The calculations used data on standard pressure levels from 1000mb to 50mb.

4.2 NMC

Main data set names

M21.BNMC.DATA(NMyys) stores data for Jan - Mar if s is A, Apr - Jun when s is B, Jul - Sep when s is C, and Oct - Nov when s is D, in year yy.

Source

Produced at the National Meteorological Center, U.S.A. and distributed through Atmospheric and Environmental Research Inc. (see appendix E).

Contents

Analyses and 12 to 240 hour forecasts of the contributions to the wind terms of the axial EAAM function from both the northern and southern hemispheres.

Period and times of validity

From ~~10th~~ 1st Nov. 1985. There is one set of forecast values, calculated from the 00Z analysis, per day. The forecast hours are 0,12,24,36,..240. New data is sent at the end of each quarter.

Format

The data has no descriptive header. The code below reads one day's forecasts.

```
      DIMENSION ID(4)
      DIMENSION COMX3WN(21),COMX3WS(21),COMX3W(21)
      DO 10 I= 1,21
        READ(IUNIT,40)ID,FJUL,COMX3WN(I),COMX3WS(I),COMX3W(I)
   10 CONTINUE
   40 FORMAT(4I4,F8.2,3E15.5)
```

ID(1)	is the integer year - 1900	date when the forecast was made
ID(2)	is the integer month	
ID(3)	is the integer day of month	
ID(4)	is the forecast lead time in hours.	
FJUL	is the Julian date - 2446065.5	
COMX	is to be read as C . Ω . χ with C the principal moment of inertia of the solid Earth, Ω the Earth's angular velocity and χ ,chai, the EAAM function.	

A considerable number of forecasts are missing. The data are stored in 80 byte records blocked by 4800. The units are 10^{26} kg m^2 s^{-2} .

Forecast model

As described in section 1.3.

Inhomogeneities

A major model improvement (descrbed in section 1.3) was introduced on 28/05/86.

Locations

1. On COSMOS disk USR407, in library M21.BNMC.DATA.
2. A set of twice daily (00Z and 12Z) analysis values from 1 Nov 1985 is stored in member NMVER of M21.BNMC.DATA. The format is the same as that for the f/c data (one record per verification hour), except that ID(4) is the hour of the verifying data.

Relevant programs

1. Members of M21.BSRCELIB.FORT with prefix BFNM produce time series plots and statistics for the forecasts which are directly comparable with those produced for the UKMO and ECMWF forecasts by members with prefix BFPL.

Auxiliary notes

The wind integrals are calculated using data on standard pressure levels from 1000mb to 100mb.

4.3 UKMO

Main data set names

M21.BUKMO.DATA(Fmmmyy) in which mmm are the first three letters of the month and yy the year; eg member FJAN87 covers January 1987.

Source

Operational calculations by Met O 2b using 15 level forecast model.

Contents

Analyses and one to six day forecasts of the contributions to the wind and matter terms of all three components of the EAAM functions from both the northern and southern hemispheres.

Periods and times of validity

From 00Z 27th Nov. 1986 - 00Z 3rd Feb. 1987 analyses and one to six day forecasts are available for both 00Z and 12Z. After 00Z 3rd Feb. 1987 analyses and one to six day forecasts made at 00Z are available together with analyses at 12Z. Updated every 12 hours.

Format

No desriptive header precedes the data. The code below reads the first epoch's set of analysis and one to six day forecast values

```
      DIMENSION ID(4),IFOR(7),X1PN(7),X1PS(7),X1WN(7),X1WS(7)
      DIMENSION X2PN(7),X2PS(7),X2WN(7),X2WS(7)
      DIMENSION X3PN(7),X3PS(7),X3WN(7),X3WS(7)
      DO 10 I = 1,7
        READ(IUNIT,20)ID,IFOR(I),X1PN(I),X1PS(I),X1WN(I),X1WS(I)
     1                      ,X2PN(I),X2PS(I),X2WN(I),X2WS(I)
     2                      ,X3PN(I),X3PS(I),X3WN(I),X3WS(I)
 10   CONTINUE
 20   FORMAT(4I2,2X,I4,1X,1P,4E16.5/(15X,1P,4E16.5))
```

ID records the time and date of the analyses and forecasts as yymmddhr; eg 86112712 stands for 12Z on 27/11/86. IFOR is the forecast hour; 0 indicates analysis values and 144 6-day forecast values. The forecasts are valid IFOR hours after date ID. After the DO loop the (n+1)th element of each EAAM array ($0 \leqslant n \leqslant 6$) contains the 24 . n hour forecast. The other notation is the same as in section 1.1. Data are missing at the following times

00Z	12Z
03/12/86	02/12/86
19/02/87	18/02/87
23/03/87	19/02/87
07/09/87	06/09/87
22/09/87	21/09/87
16/10/87	03/11/87

There are two different sets of values for 00Z on 28 Dec 1986. The data is stored in formatted records of length 80 bytes blocked by 4800 bytes.

Forecast model description

The forecast model is described in section 1.4.

Inhomogeneities

None known.

Locations

1. Previous months' data are stored as members of library M21.BUKMO.DATA. Member Fmonyy stores data for month mon of year yy (e.g. FJAN87 stores the forecasts made in January 1987).
2. The most recent data are stored on USR407 in files M21.BUKFOR.DATA and M21.BUKFR2.DATA. These data sets are updated every 12 hours.
3. Backup tapes 210078 and 210021 and archive tape 880612 are devoted to backing up the forecast data sets stored in M21.BUKMO.DATA. File 1, called M21.BUKDEC86.DATA, includes the few days of data for Nov. 1986 as well as that for Dec. 1986. Subsequent months are stored separately in chronological order (eg file 4 is a copy of FMAR87).

Relevant programs

1. M21.BSRCELIB.FORT(M21BEA2) calculates the EAAM functions. It is released twice daily (after the 00Z and 12Z operational forecasts).
2. Members of M21.BSRCELIB.FORT with prefix BFRP can be used with the UKMO and ECMWF f/c data to plot f/c and analysis time series and scatter diagrams and to calculate some statistical quantities for many combinations of components.

Auxiliary notes

The wind terms are calculated using data on all 15 sigma levels, so the integrals are from the true surface to about 25mb.

CHAPTER 5

CODES FOR ROUTINE WORK

5.1 DATA PLOTTING

Files D/Met O 21/6/7/2/5 volumes 1-3 (Rm 251) contain copies of all diagrams related to the angular momentum project which are kept in Met O 21. Volume 2 is of particular importance being a well ordered selection of the more important and recent plots. A comprehensive presentation of the fluctuations in the contributions to the EAAM functions using all the analysis data described in chapter 1 is being prepared by Mr. S. Nitsas.

Library M21.BSRCELIB.FORT on USR407 contains several programs which produce plots of the angular momentum time series on calcomp film. The members which use the forecast data have been indicated in section 4.3. The plots produced by the other members, using "analysis" data only, may be classified as follows;

1. 18 month plots from 1st October of any year to 31st March of the year after the next with time along the x axis.
    1a. Plots of contributions to or differences between evaluations of $C \Omega \chi_3$.

    1b. Separate plots on comparable scales of fluctuations in the length of day and fluctuations of $C \Omega \chi_3$.

2. The motion of the pole as calculated by BIH, the motion assuming it is forced solely by fluctuations in $\underline{\chi}$, and the time series of $\underline{\chi}$, on a plot in which the Greenwich meridian is along the - y axis and 90E is along the x axis.

3. Plots covering the period 1 Dec 1979 to 1 Jan 1986 or 1 Jan 1987 with time along the x axis, showing
    3a. contributions to $C \Omega \chi_3$ or differences between $C \Omega \chi_3$ as calculated by different sources

    3b. a comparison of $C \Omega \chi_3$ and variations in the l.o.d.

    3c. $\chi_1(t)$ and $\chi_2(t)$.

The tasks which the various members of M21.BSRCELIB.FORT perform are listed below.

BANGDIF

Produces a plot of type 3b of the fluctuations in the l.o.d. as given by the BIH which are not accounted for by fluctuations in $C \Omega \chi_3$ (ECMWF). The residual may be substantially reduced by removing the fluctuations in the l.o.d. due to solid earth tides using program TIDAL.

BANGUK

Produces plots of types 1 - 3 using UKMO data (i.e. M21.BUK1086.DATA) supplemented by ECMWF data and BIH data. In plots 1a and 3a C Ω χ_3 (UK) and C Ω χ_3 (UK) - C Ω χ_3 (ECMWF) are presented.

BANGMOM7

Produces plots of types 1 - 3 using only ECMWF and BIH data. In plots 1a and 3a the northern and southern hemisphere contributions to C Ω χ_3 are plotted along with the totals.

BANPOST

Produces plots of type 3 only but can be used with ECMWF and NMC data or UKMO and JMA data. Plots of type 3a with the northern and southern hemisphere contributions as well as the total C Ω χ_3 can only be produced with ECMWF and NMC data.

BANPOS2

Produces plots of type 3b only for ECMWF, NMC, UKMO and JMA data in a slightly neater format than BANPOST.

CANGMWP

Produces plots of type 3c for contributions to the wind and matter terms of χ_1 and χ_2 from the northern and southern hemispheres separately.

CPOLM

May be used to experiment with the forcing of the polar motion; the period of smoothing of the atmospheric forcing may be increased, or the polar motion may be forced by a constant excitation function or a sinusoidally varying function of selected amplitude and period.

All of these programs use the same subroutines. PLOT1 draws the axes for the plots of types 1 and 3. PLOT2 merely draws a box enclosing the graphs. SOLVEM calculates the polar motion forced in the absence of friction by the equatorial EAAM function from a given starting position. TRIM performs triangular smoothing of data and is regularly applied to the time series of $\underline{\chi}$ presented on plots of type 2. Finally AVX when applied to the ECMWF data removes discontinuities caused by forecast model and data assimiliation technique changes. It should not be applied directly to data from other sources.

5.2 UPDATING AND TRANSFERRING DATA

UPDATING THE ECMWF EAAM DATA SETS

The Met. Office/Reading University Joint Diagnostics Project calculates daily values of the EAAM functions twice each month, producing data sets at ECMWF whose names are of the form

UKR.mmyyc

with mm the number of the month (eg 12 for December)
yy the year number (eg 86 for 1986)
and c either the letter A if the data is for the first half of the month (from 1st to 15 th) or B if it is for the second half.

The calculations are performed by DECK CALSTAT fo UPDATE library UKR.RCALDAY. The data sets contain both the chi and the psi functions. Each day's data occupies six unformatted records. The following code reads one day's data

```
READ(IUNIT)IDATE,X1PN,X1PS,X1P,X2PN,X2PS,X2P,X3PN,X3PS,X3P
READ(IUNIT)IDATE,X1WN,X1WS,X1W,X2WN,X2WS,X2W,X3WN,X3WS,X3W,ANGM
READ(IUNIT)PSNU,PSSU,PSU,PTNU,PTSU,PTU
READ(IUNIT)PSNU2,PSSU2,PSU2,PTNU2,PTSU2,PTU2
READ(IUNIT)X1N,X1S,X1,X2N,X2S,X2,X3N,X3S,X3
READ(IUNIT)AM1,AM1SEC,AM2,AM2SEC,IDATE,IT
```

The notation for the chai functions is the same as that in section 1.1.
N.B. All the axial components are calculated with formulae which differ in sign from the definition of Barnes et. al. (1983).
IDATE is of the form yymmddhh (e.g. 12 Z on 1st. Mar. 1987 would have IDATE = 87030112). IT is the number of days from the start of the data set (IT = 0 for the first day).
ANGM = $- C\Omega \chi_3^w$.
AM1, AM2, AM1SEC and AM2SEC seem to have been intended to be evaluations of the polar postion but do not appear to be reliable.
Variables whose first letters are PS store the principal contributions to the wind terms of the first equatorial component of psi. ψ_2^w is stored in variables whose first letters are PT. (The pressure terms for the psi and chai functions are identical.) Northern and southern hemisphere and global evaluations are stored for each term. The formulae used for the global values PSU, PTU, PSU2 and PTU2 are most easily written in terms of

$$I\,[\,f\,] = \frac{-\,1.43\ R^3}{(C - A)\ g\ \Omega^2} \int_{50\,mb}^{1000\,mb} \int_{\phi=-\pi/2}^{+\pi/2} \int_{\lambda=c}^{2\pi} f \quad d\lambda\, d\phi\, dp$$

$$PSU = 2\,\Omega\, I\,[\,(\,u \cos\lambda - v \sin\lambda \sin\phi\,) \sin\phi \cos\phi\,]$$

$$PTU = 2\,\Omega\, I\,[\,(\,u \sin\lambda + v \cos\lambda \sin\phi\,) \sin\phi \cos\phi\,]$$

$$PSU2 = 1/R\ I\,[\,(\,u^2 \cos\lambda - u\, v \cos\lambda\ \sin\phi\,) \sin\phi\,]$$

$$PTU2 = 1/R\ I\,[\,(\,u^2 \sin\lambda + u\, v \cos\lambda\ \sin\phi\,) \sin\phi\,]$$

First approximations to the psi functions are given by

$$\psi_1^w = PSU + CPSU2$$

$$\psi_2^w = PTU + PTU2$$

(cf the appendix of Barnes et. al. (1983)) in which

$$CPSU2 = 1/R\ I\,[\,(\,u^2 \cos\lambda - u\, v \sin\lambda\ \sin\phi\,)\ \sin\phi\,].$$

Member BECRJE of library M21.BANGLIB.CNTL is used to read the new data set extract the EAAM functions and produce a data set on NAS142 in the format described in section 1.1. CYBER JCS messages and accounting information which are also written to this data set are then deleted (using ISPF option 2). BECPY from the same library is then used to eliminate "unrecognisable characters" inserted by the Remote Job Link. The resulting data set can be appended onto M21.BECM87.DATA by editing the latter and using the COPY facility within ISPF option 2.
UKJ.B86Jymmc at ECMWF is updated from COSMOS using M21.BANGLIB.CNTL(BECMER) which is set up to append 3 half monthly data sets to UKJ.E86mmyc at once. UKJ.B79D60CA and UKJ.B86ymmc are the only data sets which retain the psi functions and the times of validity. Changes in the latter can be detected by M21.BANGLIB.CNTL(BECMAR) which was used to produce the table in section 1.1. BECMAS is used to check that UKJ.B86Jymmc has been successfully updated before the half monthly data sets are purged.

TRANSMISSION OF TELEX MESSAGES TO C.I.R.T.

Telex messages containing analysis and forecast values of EAAM functions for the previous week are sent to C.I.R.T. each Wednesday afternoon.

Message contents

Each record of the message is of the form
ID,IFOR,X3P,X3WN,X3WS
where
ID = YYMMDDHH e.g. 87063012 indicates 12Z on 30th June 1986. This is the time at which the forecast was made.
IFOR = HHH e.g. 120 indicates a 120 hour f/c. The forecasts are valid at a time HHH hours after time ID.
X3P is the chai three pressure term (globally integrated)
X3WN and X3WS are chai three wind for the northern & southern hemispheres.

Only analyses from 12Z on the previous Wednesday to 00Z on the present Wednesday at 12 hourly intervals and forecasts from 00Z on the present day for 24, 48, 72, 96, 120 and 144 hours ahead are sent.

Procedure

The messages are prepared and transmitted in the following manner

1. On Wednesday morning M21.BSRCELIB.FORT(FWEEK) is accessed using ISPF 2 and all its data deleted. All analyses and forecasts from the preceeding week are copied to the empty data set from M21.BUKFR2.DATA. Finally all the 24 - 144 hour forecasts, except those from the morning's forecast run are deleted.
2. The job in M21.BANGLIB.CNTL(TELEXS) is submitted (without alteration).
3. Between 14.15 and 14.45, the job in M21.BANGLIB.CNTL(TELEXE) is submitted, again without alteration.

The code in member TELEXS selects the date, forecast hour, X_3^p, X_3^w(NH) and X_3^w(SH) from each set of analyses or forecasts for a given epoch. It produces a data set, M21.BFTEL.DATA, whose contents are submitted to Met O 5b by member TELEXE. The job output from job T21BBTLT submitted in step 2 above (which can be browsed on ISPF 3.8) includes a copy of the data as it will be received in Paris. The subroutines in member TELEXS and the organisation of 'M21.BFTEL.DATA' are documented in 'M12.MCLIB.TEXT(TLXDOC)' which can be browsed on ISPF.

DATA DISTRIBUTION AND RECEPTION.

We are able to exchange magnetic tapes and floppy disks with interested groups. File D/Met O 21/6/7/1/2 is a record of the data and accompanying letters that have been distributed over the years. Inadequate documentation, disorderly data or lack of attention to the receivers' facilities can waste a lot of their time and cause considerable ill feeling and should be painstakingly avoided.

TAPES

M21.BANGLIB.CNTL(BTCEC1) copies M21.BEC1286.DATA to the first file of a "no label" tape, reads what has been written and produces a copy of it on microfiche. Particular care needs to be taken over the DD statement (cf JCL Manual pp 175-262). Members of M21.BANGLIB.CNTL with the initial letters BTR have all been used to read tapes from BIH and JPL and may serve as useful starting points with new arrivals. It is prudent to make a copy of any new tape before attempting to read it. Unless the accompanying documentation is excellent a preliminary character read and copy to microfiche by BTRCAR is usually worthwhile. For further notes concerning tapes see appendix B.

FLOPPY DISKS

COSMOS does not have any floppy disk drives but Met. O. 21's JASPER (which is centred on a VAX 11/730) has two and can access COSMOS through HERMES. A reasonable working knowledge of VAX computers is assumed in this subsection. For further information (including passwords) see JASPER's SYSTEM MANAGER (Doug Johnson) or Mike Bell.

To transfer data between HERMES and COSMOS one needs to logon to HERMES. Our username is JASPER. Formatted files with 80 byte records can be copied from COSMOS to HERMES by entering the command GETCRD and replying to the self-explanatory prompts. Similar files can be transferred from HERMES to COSMOS by using the complementary command PUTCRD. PUTCRD generates several copies of the data set being sent which can lead to failiures due to the JASPER QUOTA being exceeded. The link between HERMES and COSMOS is somewhat slow at present but it is possible to send large quantities of data if necessary.

When logged on to user BELL on system JASPER one may copy a file F1.DAT in directory [JASPER] on HERMES to a new file F2.DAT in directory [BELL] on JASPER by using the command

```
COPY HERMES"JASPER password"::F1.DAT F2.DAT
```

To copy F2.DAT on JASPER to F3.DAT on HERMES the command

```
COPY F2.DAT HERMES"JASPER password"::F3.DAT
```

can be used.

JASPER has two floppy disk drives; the left hand drive is referred to as DY0 and the right as DY1. A brand new disk on the left hand drive is initialised with single density (by default) and the disk name BELLT1 by the command

```
INI DY0: BELLT1
```

The disk can then be mounted by the command

```
MO DY: BELLT1
```

Before files can be written to the floppy (using command COPY) a directory must be created. It is advisable whilst creating the directory to set its protection so that the world (i.e. any user) can read, execute and write to it. The command

```
CREATE/DIR/PROT=(W:REW) DY0:[BELLT2]
```

sets up a directory BELLT2 on the disk BELLT1 with appropriate protection. To avoid uncertainties in distributed data, sections of M21.BEC1286.DATA from COSMOS which have been transferred to JASPER have been written to floppy disk using the FORTRAN programs READFLOP and READFL2 from directory [BELL.MISC].

CHAPTER 6

CODES FOR EXPLORATORY WORK

6.1 BOX ANALYSES

Library M21.BSRCELIB.FORT on USR407 contains 2 programs which calculate both the wind and matter terms of the axial EAAM function in regions of the atmosphere or "boxes". Member KANGMOM calculates the two terms in boxes with boundaries in height, latitude and longitude, and is currently set up to read unformatted zonal wind (u) and surface pressure (p_s) data on a regular latitude-longitude grid of 5x5 degrees. The data used by the programs was retrieved from the ECMWF tape archives using GETDATA (see appendix C) and is not documented in this report. Member KANG8082 uses the zonal mean wind data set in M21.BBARPE.DATA (see section 1.3) and so only calculates the wind term in latitude-pressure boxes.

The boundaries of the boxes are specified in DATA statements (at the beginning of each program) in terms of "line number", e.g. for 35 latitude circles from 85 N to 85 S, line number LAT=1 corresponds to 85 N, LAT=18 corresponds to the equator, etc. For the 12 pressure levels, LEV=1 corresponds to 1000mb, LEV=12 corresponds to 30mb. For the 72 longitude points, LNG=1 corresponds to the Greenwich meridian and LNG=72 to 355 E.

The 2- or 3- dimensional arrays that contain the box values of the appropriate terms of the axial EAAM function are written to unformatted data sets on USR407 for subsequent analysis and plotting.

6.2 MOUNTAIN TORQUE

The members KMTNH and KMTSH in library M21.BSRCELIB.FORT on USR407 calculate the "mountain torque" - the couple between the atmosphere and solid Earth created by pressure differences across orography. The formula used is,

$$T_m = R \cos \phi \int_{\lambda_0}^{\lambda_0 + \Delta\lambda} p_s \quad \partial H / \partial \lambda \, d \lambda$$

(see Wahr and Oort 1984) where p_s is the surface pressure, H the orographic height, ϕ is latitude, λ is longitude, R the mean radius of the Earth, and T_m the mountain torque per latitude circle.

The mountain torque is calculated over various longitude ranges, set in DATA statements as in the box analysis programs (section 3.1). The data used by the programs vAS retrieved from the ECMWF tape archives using GETDATA (see appendix C) and IS not documented in this report.

The programs use finite differencing to evaluate the partial derivative of the height field. Care must be taken in defining the boundaries of the longitude integrals because boundaries at differing heights give rise to erroneous values of mountain torque.

6.3 FORECASTS

The forecast data described in section 4.1 B was calculated using FORTRAN code based on that developed for the box analyses (section 6.1).

APPENDIX A

GLOSSARY OF TERMS

1. GEODETIC / ASTRONOMICAL TERMS

CONVENTIONAL INTERNATIONAL ORIGIN

- the reference position of the Earth's rotation pole. It corresponds (very nearly!) to the mean position on the Earth's surface of the rotation pole from 1900AD to 1905AD as determined by the International Latitude Service.

MODIFIED JULIAN DAY AND DATE

The Julian Day Numbering system is a convenient chronological system used by astronomers in which the day starting at Greenwich mean noon on Jan 1st 4713BC is assigned day number 0. By simple extension the Julian Date (JD) of any instant is its Julian day number plus the fraction of the day elapsed since the preceeding noon and its Modified Julian Date (MJD) is its Julian Date minus 2,400,000.5. Thus the Julian date for 18UT on June 24th 1973 is JD 2,441,858.25 and its MJD is 41,857.75.

TAI (International Atomic Time)

- an internationally agreed time system, co-ordinated by the BIH, which is based on the vibrations of caesium atoms maintained at several centres.

UTO, UT1, UT1R and UT2

- are interrelated time systems in which the time unit (the day) is defined to correspond to one complete rotation of the Earth about its axis of rotation. UTO is established from determinations of the diurnal motions of the stars (made for example by telescopic observations or VLBI) and the mean solar motion around the ecliptic. UT1 is UTO corrected for variations in the meridian of the observing systems due to the observed motion of the pole of rotation. The remainder of UT1 after fluctuations in the Earth's rotation due to solid Earth tides (cf 1.2.4) have been eliminated is UT1R. Finally UT2 is UT1 after estimates of its annual and semi-annual oscillations have been subtracted. The definitions of these time systems have evolved with the precision of their determination. McNally, D., 1974: Positional Astronomy secs 2.1, 3.1 - 3.3 and 5.1 - 5.3 give a clear exposition of the basic terminology and Capitaine, N., 1986: Earth rotation parameters: conceptual and conventional definitions. Astron. Astrophys., 162, 323 - 329, examines some subtle differences between conceptual definitions of the Earth rotation parameters and what is determined in practice.

UTC (Coordinated Universal Time)

UTC is the basis of civil time. It was once a smoothed version of UT2 but since Jan 1st 1961 its rate has been determined by TAI. Since Jan 1st 1972 UTC has had the same rate as TAI and only differed from it by an integral number of seconds (cf BIH Annual Reports Part B table 10). UTC is adjusted, when necessary , by the insertion or deletion of a leap second to keep it within 0.9 seconds of UT1

LENGTH OF DAY (L.O.D.)

- the time taken by the Earth to complete one rotation. It is usually expressed as the difference from a reference value, Λ_0 , of 86 400 seconds. The BIH evaluate it from the gradient of time series of UT1 or UT1R which have been smoothed by applying a weak Kalman filter (cf BIH Annual Reports part A table 7)

$$\text{lod} = -d/dt\ (\ \text{UT1-TAI}\ )\ .\ \Lambda_0$$

Because of the applied smoothing this evaluation will be very close to

$$\text{lod(day m-1/2)} = -\ (\ \text{UT1 - TAI}\ )\text{(day m)} \quad +\ (\ \text{UT1 - TAI}\ )\text{(day m-1)}$$

The signs of these formulae are consistent with one's expectations because if the Earth's rotation rate decreased, UT1 hours would become longer according to UTC time, and the l.o.d. as defined would increase.

NB. the length of the day and the duration of the day are the same thing.

VLBI (Very Long Baseline Interferometry)

- an astronomical observing technique involving the intercomparison of the phase of radio waves received at two sites which are as far apart as possible. Knowledge of the length of the baseline between the sites and the distance of the radio source (usually a quasar) enables a precise determination of the orientation of the baseline with respect to an inertial frame. A sequence of such determinations will define the Earth's rotation in space. See Paquet, P., How to measure the Earth rotation, in Cazenave (1986).

2. METEOROLOGICAL TERMS

ANALYSIS SCHEMES

Meteorological data are obtained world-wide by many methods and from many sources (e.g. balloon ascents, ship reports, pilot reports and satellites). The data are therefore of variable quality and unevenly spaced both in time and geographical coverage. Meteorological data analysis schemes check the quality of data and interpolate what is available onto regular latitude-longitude grids. The schemes in use at most major meteorological centres are based on a statistical technique called optimal interpolation in which the interpolation is determined by background fields provided by short range forecasts valid at the analysis hour.

INITIALISATION

- the process of adjusting the fields of pressure and velocity to set up initial conditions for a numerical prediction model. This is needed because an imbalance of the mass and momentum fields in the initial data would excite high-frequency motions during the numerical integration. At most centres (e.g. ECMWF, NMC and JMA) the initialisation is performed after the analysis but at the UKMO a single scheme performs both tasks simultaneously.

3. THE ATMOSPHERE AND THE EARTH'S ROTATION

EAAM FUNCTIONS

The three EAAM functions (χ_1 , χ_2 , χ_3), formulated by Barnes et. al. (1983), can be regarded as the components of the atmospheric angular momentum (AAM) vector. To be more precise, they form a pseudo-vector because the equatorial components of AAM are multiplied by C / (C - A) to form χ_1 and χ_2. Their formulation includes Love numbers which parametrize the effect of the lack of rigidity of the Earth on its response to atmospheric forcing. Hence $C\ \Omega\ \chi_3$ is the axial AAM which would force the same rotational fluctuations on a rigid body, with the same principal moments of inertia as the Earth, as the true axial AAM forces on the (non-rigid) Earth. Similarly, (C - A) χ_1 and (C - A) χ_2 are the equatorial AAM components which would force the same wobble of the pole of rotation of a perfectly rigid body, with a free Eulerian frequency close to that of the observed Chandler wobble, as the true AAM forces on the (non-rigid) Earth. The EAAM functions are defined by the formulae presented below.

INVERTED BAROMETER CORRECTION

- a correction made to the matter terms of all three EAAM functions when attempts are made to allow for the deformation of the ocean under a variable atmospheric load. It assumes that the ocean responds like an inverted barometer to variations in atmospheric pressure. For every millibar (mb) of atmospheric pressure above the mean over the global ocean surface, the ocean surface is locally depressed by 1 cm (see p 100 of Munk and McDonald 1960). The effect of the correction is to nullify the contributions to the EAAM terms over the oceans. It implies a compensatory mass transport between ocean basins which can only be valid for sufficiently long period fluctuations. It may be that for annual fluctuations the inverted barometer correction would be more realistic if applied to individual ocean basins. For this and other reasons the dynamical basis of the correction merits further study.

DEFINITIONS OF EAAM FUNCTIONS

The definitions of the EAAM functions introduced by Barnes et. al. (1983) are reproduced below.

$$\chi_1 = \chi_1^{\mathrm{P}} + \chi_1^{\mathrm{W}} = \frac{-1.00\bar{R}^4}{(C-A)g}\oiint p_s \sin\phi \cos^2\phi \cos\lambda \, \mathrm{d}\lambda \, \mathrm{d}\phi$$
$$- \frac{1.43\bar{R}^3}{\Omega(C-A)g}\oiiint (u\sin\phi \cos\phi \cos\lambda - v\cos\phi \sin\lambda) \, \mathrm{d}\lambda \, \mathrm{d}\phi \, \mathrm{d}p, \quad (5.1)$$

$$\chi_2 = \chi_2^{\mathrm{P}} + \chi_2^{\mathrm{W}} = \frac{-1.00\bar{R}^4}{(\mathrm{C}-\mathrm{A})g}\oiint p_s \sin\phi \cos^2\phi \sin\lambda \, \mathrm{d}\lambda \, \mathrm{d}\phi$$
$$- \frac{1.43\bar{R}^3}{\Omega(C-A)g}\oiiint (u\sin\phi \cos\phi \sin\lambda + v\cos\phi \cos\lambda) \, \mathrm{d}\lambda \, \mathrm{d}\phi \, \mathrm{d}p, \quad (5.2)$$

$$\chi_3 = \chi_3^{\mathrm{P}} + \chi_3^{\mathrm{W}} = \frac{0.70\bar{R}^4}{Cg}\oiint p_s \cos^3\phi \, \mathrm{d}\lambda \, \mathrm{d}\phi + \frac{\bar{R}^3}{C\Omega g}\oiiint u\cos^2\phi \, \mathrm{d}\lambda \, \mathrm{d}\phi \, \mathrm{d}p. \quad (5.3)$$

The surface and volume integrals are defined as

$$\oiint (\;) \, \mathrm{d}\lambda \, \mathrm{d}\phi \equiv \int_{-\frac{1}{2}\pi}^{+\frac{1}{2}\pi} \int_0^{2\pi} (\;) \, \mathrm{d}\lambda \, \mathrm{d}\phi$$

and

$$\oiiint (\;) \, \mathrm{d}\lambda \, \mathrm{d}\phi \, \mathrm{d}p \equiv \int_0^{p_s} \int_{-\frac{1}{2}\pi}^{+\frac{1}{2}\pi} \int_0^{2\pi} (\;) \, \mathrm{d}\lambda \, \mathrm{d}\phi \, \mathrm{d}p.$$

APPENDIX B

AN INTRODUCTION TO COSMOS

INTRODUCTION

A new COSMOS user is best introduced to the system by logging on at a TSO (Time Sharing Option) terminal with a colleague and being shown how to use the basic commands of ISPF (the Interactive System Productivity Facility), the libraries which will be used and some sample FORTRAN programs and JCL (Job Control Language) code. This appendix aims to supplement such an introduction by outlining i) the facilities available on COSMOS ii) the principal ways of getting things done on COSMOS, namely using ISPF and submitting jobs iii) various ways of storing data and iv) directing the reader to the useful and important reference material, copies of which are available in the computer reference "library" in Room 251. (The COSMOS Users' Guide is held on microfiche in Room 251; personal copies can be supplied).

FACILITIES ON COSMOS

COSMOS has three central processors (two IBM3081's and a CYBER205). These have access to on-line magnetic DISKS and mountable TAPES. Data on the disks can be accessed and manipulated directly from TSO terminals using ISPF. Results can be directed to disks, tapes, TSO terminals, paper, microfiche or film. All output not directed to TSO or local printers is collected from Receipt and Dispatch (R and D), which is by the entrance to the main computer room in the Richardson Wing.

ACCESS TO AND MANIPULATION OF PRE-EXISTING DISK DATA SETS USING TSO

One logs directly onto TSO using one's personal userid and password. The commands available in TSO are documented partially in TSO Command Language Summary (found near many terminals) and fully in TSO Command Language Reference.

ISPF is accessed by entering the command ISPF . One can then BROWSE a formatted data set (option 1), extend and alter it in EDIT (option 2), make a copy of it (option 3.3) and delete it or allocate space for new data sets (options 3.1 and 3.2). ISPF is designed to be easy to use and has an extensive tutorial facility which may be accessed from the main menu by entering HELP, or by pressing key PF1. It is documented fully in ISPF/PDF Program Reference and more briefly in COSMOS Users' Guide ch 5.

SOME MISCELLANEOUS POINTS ABOUT USING ISPF

Data sets should be viewed using option 1 rather than 2 (unless the intention is to alter or extend them) for two reasons. Accidental alterations to the data set which could occur in EDIT cannot occur in BROWSE and large data sets are expensive to load in EDIT and may need additional region (requested when logging on); they should be accessed in small sections if possible.

After a period of use libraries become full because previous versions of the library members, though inaccessible, are nevertheless still occupying disk space. These may be deleted by submitting a compress job (ISPF option 3.F A).

Two data sets or different parts of a data set may be displayed simultaneously on a terminal by using the split screen facility invoked by key PF2. I[illegible]fter editing a data set it cannot be saved ("SYSTEM ABEND D37"), split the screen and compress the library. The split screen mode is exited by typing "=x" on the command line of the unwanted half of the screen.

JCL AND JOB SUBMISSION

Any task which cannot be done using TSO or ISPF must be accomplished by submitting a batch JOB to the system. Job instructions are coded in Job Control Language (JCL). A good introduction to JCL is given in Introduction to JCL. Further information is available in chapter 4 of the COSMOS Users' Guide. A definitive statement of the syntax of JCL is given in the (surprisingly lucid) JCL manual. Probably the best way to start with JCL is to read a sample JCL code developed within the branch in conjunction with the Introduction to JCL and learn from these enough to adapt the existing codes to one's own uses. It is as essential to be accurate with JCL as it is with FORTRAN. Explanations of JCL errors are available in sets of manuals (some of which are in Room 251). Deducing JCL errors from JCL error messages is an art which takes some time (and patience) to acquire. Further help may be available from Met. O. 21 or the Enquiry Bureau (Room G10, Met O 12).

A JOB is usually submitted by editing a disk data set containing the required JCL code (ISPF option 2) and typing in "sub" on the command line. Computer units are classified as "day", "night" or "weekend" and are rationed; consult HSO(Computing) about availability.

DATA STORAGE ON DISK

There are two main types of disk data sets; direct access and sequential. Libraries, which are partitioned and have members, are special cases of sequential data sets. Each branch is allocated space on one or more disks. Met O 21 has space on USR407. New data sets are given some of the branch space; new members of libraries are not given new space as they must fit into the library's existing space.

Space may be allocated by using ISPF 3.2 or by appropriate use of a JCL DD statement within a job; the data set name, organisation, record format and length and blocksize must be specified. New libraries also need directory blocks (which record member names etc.) Section 6 of the COSMOS Users' Guide and chapter 2 of the Programming Techniques Guide give guidance on most of these points.

DATA STORAGE ON TAPE

Outside user tapes are submitted to and withdrawn from the COSMOS system at R and D.

Copies of important data sets should be made on a backup tape. This can be done for sequential data sets using JCL based on M21.BANGLIB.CNTL(GENCOP). HSO(Computing) (at present Ms. Pat Roberts) MUST be consulted as to which tape and file number should be used. It is vital to take special care when writing to tapes. The tape and file numbers must be checked carefully to ensure that the correct values are specified. Files with numbers higher than the one used will be overwritten or difficult to access after the write job.

Tapes and tape processing in the Met. Office gives a useful introduction to using tapes. Chapter 7 of the COSMOS Users' Guide and chapters 3 and 10 of the Programming Techniques Guide should also be consulted (chapter 10 contains notes on many Utility prgrams for manipulating both tape and disk dataa sets). When sending data on tapes to other centres it is usually advisable to use the no labels option in the JCL DD statement and to write the data formatted with either EBCDIC (default) or ASCII characters (see JCL). However if the other computer is IBM compatible it may be acceptable to send unformatted, machine code, data.

A new automated tape management system is at present being introduced on COSMOS; in its final form it will be based primarily on data set names. (Further information from HSO(Computing) or Enquiry Bureau (Room G12 Met O 12).)

DATA SET NAMES(DSNs)

Conventions for forming data set names are described in chs. 4 and 5 of COSMOS Users' Guide; note that there are differences between naming ISPF/TSO data sets and "other" COSMOS data sets, and that whereas disk DSNs may have 44 characters (including full stops) tape DSNs will be truncated from the left if they are longer than 17 characters. No two data sets on one disk may have identical names, and although at present two datasets on one tape may have the same name this will not be allowed by the new tape management system.

USEFUL SUBROUTINE PACKAGES

There are several valuable sets of standard subroutines available on the COSMOS system; they include
i) the CALCOMP package for producing graphical presentations of data on film. It is clearly documented in the CALCOMP manual and the COSMOS Users' Guide (ch.9).
ii) the NAG scientific subroutines package. Documentation is available in the Enquiry Bureau (Rm G10) and Room 256.
iii) the SAS statistical software and graphical package; documentation available in Rm 251.

REFERENCES (all available in Room 251)

COSMOS Users' Guide (microfiche)
Programming Techniques Guide
JCL Manual
Introduction to JCL (Met O. 12 Aspects of Programming booklet)
TSO Command Language Reference
TSO Command Language Reference summary
ISPF/PDF Program Reference
Tapes and Tape Processing in the Met. Office (Met O 12 Aspects of Programming booklet)
CALCOMP manual

APPENDIX C

THE REMOTE JOB ENTRY (RJE) LINK TO ECMWF

INTRODUCTION

There is a Remote Job Entry (RJE) link from the Met. Office to ECMWF which enables jobs to be run on the ECMWF system without personal visits being made to the Centre itself. The ECMWF computer system is based around a CRAY X-MP/48 super-computer, with two small CYBER (835 and 855) machines acting as "front ends". Most smaller jobs are run on the CYBERs. The CDC NOS/BE users' guide and CDC NOS/BE reference manual, which document the facilities on the ECMWF CYBERS and their job control statemtents (JCS), are available for reference in Room 251 along with ECMWF Computer Bulletin B1.0/1: An Introductory Guide to the ECMWF Computing Facility.

Met O. 21 have used the UKJ user identifier and account GBMETO21 at ECMWF but after 1988 all EAAM data sets and jobs will use the Met. O. 13 identifier (UKJ) and account (GBMETO13).

SUBMITTING A FORTRAN JOB TO THE ECMWF SYSTEM FROM COSMOS

The file KMTNHEC in library M21.BANGLIB.CNTL includes an example of the JCL required to submit a job across the RJE link and run it at ECMWF. The JCL which sends the job across the RJE link, submits a card stream containing CYBER JCS to the ECMWF CYBERs. Line printer output at ECMWF (on stream 6) is routed back to COSMOS and placed on the disk NAS142, where it is retained for approximately 24 hours during which time it can be browsed and edited using ISPF. The job submitted by KMTNHEC reads data stored in a file called KPAP81 on the TEMP disk at ECMWF. It writes accessed data both to stream 6 and to a file called KAP81SP on the UKJ filespace at ECMWF. Returned data needs to be stripped of surrounding messages using EDIT and read and rewritten to elimiminate "unrecognisable" filler characters inserted during transfer by the link.

JOBS TO RETRIEVE DATA FROM THE ECMWF TAPE ARCHIVES

ECMWF has an obligation under its charter to archive the analysis and forecast fields it produces, as well as the original data transmissions it receives from the Global Data Telecommunications network. They are currently stored on tape, but the system is expected to be modernised within the next year. At present data may be retrieved from the ECMWF archives either by the new, mainly interactive, MARS system or by submitting GETDATA jobs.

Preliminary documentation of the MARS package is available in D/Met O 21/6/7/1/5. (This file also contains back copies of the quarterly ECMWF newsletters.) More up-to-date information about MARS is kept by the Met Office's computer liaison officer with ECMWF; currently A. Dickinson (PSO) Met O 13. Member X1X2X3 of M21.BSRCELIB.FORT submits a MARS job to retrieve archived EAAM data (see section 4.3).

Member state users (e.g. the Met. Office) wishing to use the GETDATA facility should submit FINDATA jobs, which submit GETDATA jobs charged to a central account rather than the user. A successful GETDATA job sets up a file on the TEMP disk at ECMWF containing the requested data and "file descriptor records" which give information about the data (see ECMWF research manual 2, referenced on p 1-2, for further details). The subroutine READ on the UKJ filespace at ECMWF can be used to strip the file of the descriptors. GETDATA is designed to be easy to use. It will produce data on a regular latitude-longitude grid, whose spacing is specified by the user. It requires a list of parameters describing the requested data, such as data type (i.e. U, V, PS - for zonal wind, meridional wind and surface pressure), the levels at which data are required (i.e. 1000mb, surface etc.), whether the data is to be unpacked from the concise form in which it is stored, and the period and geographical extent of the information required.

An example of a FINDATA/GETDATA job is stored in GETDATU on library M21.BANGLIB.CNTL. This particular job is requesting global zonal wind fields at 12 pressure levels; the comments at the beginning explain the other parameters used. GETDATU has a supplementary section which calls the routine READ. There is an extensive manual on the GETDATA procedure, ECMWF Computer Manual B6.7/2, kept in MET O 11, Room 412.

KEEPING DATASETS ON THE ECMWF SYSTEM DISKS

Data sets on the TEMP disk at ECMWF have a theoretical "life" of 5 days, but in practice, as the disk fills up they are deleted WITHOUT WARNING if they have not been accessed within 2 days. In order to minimise this risk to data sets which are required for longer than 48 hours, they can be accessed (ATTACHed) using the simple JCS in member KATTACH of M21.BANGLIB.CNTL.

Files on the UKJ filespace at ECMWF have a similarly limited life-expectancy. Every couple of months lists of files on the UKJ filespace which have not been attached for 50 days are forwarded through the Met. Office liaison officer. Files which are not attached for a period of 90 days are liable to be wiped from the UKJ filespace. The main files kept by the AAM project can be accessed by submitting member BECATT of M21.BANGLIB.CNTL across the RJE link. Redundant files should be purged so that our file space allocation is not exceeded.

APPENDIX D

SOME REFERENCES

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APPENDIX E

USEFUL ADDRESSES

ATMOSPHERIC AND ENVIRONMENTAL RESEARCH, INC., 840 Memorial Drive,
Cambridge, MA 02139, USA.
(Rosen, Dr. R.D., Salstein, Dr. D.A.)

CENTRE INTERNATIONAL DE LA ROTATION TERRESTRE, 61, Avenue de l'Observatoire,
F75014 Paris Cedex, France.
(Feissel, Mme M.)
The CIRT will replace the Bureau International de l'Heure (BIH) on Jan 1st. 1988. It will operate the International Earth Rotation Service (I.E.R.S.).

EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS, Shinfield Park, Reading,
Berkshire, RG2 9AX, England.
(Simmons, Dr. A.J.)

GEODETIC RESEARCH AND DEVELOPMENT LABORATORY, NOAA-NGS, Rockville,
MY 20852, U.S.A.
(Carter, Dr. W.E.)

INTERNATIONAL LATITUDE OBSERVATORY, Time and Latitude Section,
Mizusawa, Iwate 023, Japan.
(Naito, Dr. I.)

JET PROPULSION LABORATORY, Earth Orientation Measurements Group, California
Institute of Technology, 4800 Oak Grove Drive, Pasadena, California
91109, U.S.A. Telex 675429.
(Dickey, Dr. J.O., Eubanks, Dr. T.M.)

METEOROLOGICAL OFFICE, London Road, Bracknell, Berkshire, RG12 2SZ,
United Kingdom.
(Director of Research; Hide, Dr. R., Geophysical Fluid Dynamics Laboratory; or Bell, Mr. M.J., Synoptic Climatology Branch)

NATIONAL METEOROLOGICAL CENTER, Climate Analysis Center, Washington D.C. 20233,
U.S.A.
(Miller, Dr. A.J.)

APPENDIX F

THE FILING SYSTEM FOR THE ATMOSPHERIC ANGULAR MOMENTUM PROJECT

D/Met021/6/7/1 : Data collection and dissemination.

- /1 : Documentation of incoming data sets from all sources.
- /2 : Dissemination of data.
- /3 : IERS and BIH reports.
- /4 : Reports from co-operating meteorological centres.

D/Met021/6/7/2 : General Literature.

- /1 : Books, reviews and conference procceedings.
- /2 : Published papers and preprints.
- /3 : JPL internal reports, lectures etc.
- /4 : Met. O. 21 internal and published reports (including bibliographies and monthly accessions lists).
- /5 : Miscellaneous diagrams.

D/Met021/6/7/3 : Research Projects.

- /1 : Past projects.
- /2 : Current projects.
- /3 : Correspondence on research.

D/Met021/6/7/4 : Liaison.

- /1 : IERS and BIH.
- /2 : IAG Special Study Group 5.98 (Atmospheric excitation of the Earth's rotation).
- /3 : ECMWF.
- /4 : Department of Geodesy, University of Oxford.
- /5 : Research proposals.

Dr Lesley Gray

Atmospheric Model Intercomparison Project (AMIP)* of the Working Group for Numerical Experimentation (WGNE) of the World Climate Research Programme (WCRP)

A proposal for a sub-project to study:

Atmospheric Angular Momentum in Global Numerical Models

by

R. Hide[1,3] (Principal Investigator)
J. O. Dickey and S. L. Marcus[1]
R. D. Rosen and D. A. Salstein[2]

[1] Space Geodetic Science and Applications Group
Jet Propulsion Laboratory,
California Institute of Technology,
4800 Oak Grove Drive
Pasadena, California 91109-8099, USA.
Tel: 818-354-3235; Fax: 818-393-6890

[2] Atmospheric and Environmental Research Inc. (AER)
840 Memorial Drive
Cambridge, Massachusetts 02139, USA.
Tel: 617-547-6207; Fax: 617-661-6479

[3] c/o Oceanography Group,
Sub-Department of Atmospheric, Oceanic
and Planetary Physics,
Clarendon Laboratory, Parks Road.
Oxford OX1 3PU England. UK.
Tel: 0865-272084; Fax: 0865-311540

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*AMIP is being coordinated through the Program for Climate Model Diagnosis and Intercomparison (PCMDI), Director, Dr. W. Lawrence Gates, of the Lawrence Livermore National Laboratory (LLNL) of the University of California, Mail Stop L-264, PO Box 808, Livermore, California 94550, USA: Tel: 510-422-7626; Fax: 510-422-7675

1. INTRODUCTION

The Earth's atmosphere super-rotates relative to the underlying planet at about 10 m s^{-1} on average. If transferred to the underlying planet, the angular momentum associated with this super-rotation would reduce the length of the day (LOD) by about $3x10^{-3}$s (3 msec). Geodetic observations going back several decades reveal more or less irregular LOD fluctuations of up to about 1 msec on interannual, seasonal, and intra-seasonal timescales, and detailed studies (see Sections 2 and 3) using modern meteorological and geodetic data have established that these fluctuations are largely of meteorological origin. Fluctuations in the equatorial components of atmospheric angular momentum (see Section 2) associated with non-axisymmetric features of the global atmospheric circulation make a substantial contribution to the observed wobble of the rotation axis of the solid Earth with respect to geographical coordinates, including the Chandlerian wobble at the resonant period of 14 months.

The fluctuating torques at the Earth's surface that are implied by meteorologically-induced fluctuations in the Earth's rotation are produced by (a) tangential stresses in turbulent boundary layers and (b) normal (pressure) stresses acting on irregular topography and other departures of the shape of the Earth's surface from that of a sphere, including the equatorial bulge. These stresses are transmitted directly to the solid Earth over continental regions and indirectly over the oceans. The determination of the extent to which the stresses are represented correctly in global numerical models of the circulation of the atmosphere is clearly a matter of importance in the formulation of diagnostic schemes for assessing how well the models perform. It is readily shown that large errors in the treatment of energetic processes can be expected in simulations based on models that fail to represent atmospheric angular momentum (AAM) fluctuations satisfactorily.

Thanks to the First GARP Global Experiment (FGGE) of the Global Atmospheric Research Programme (GARP), in 1979 it was possible for the first time to obtain useful daily determinations of the total AAM for comparison with geodetic data on LOD variations and polar motion. Manifold subsequent developments following this early work include practical arrangements for producing and disseminating routine daily or more frequent determinations of all three components of the AAM vector. These are now made from analysis (and in some cases also from forecast) fields by several meteorological centers, namely the European Centre for Medium-range Weather Forecasts (ECMWF), Japanese Meteorological Agency (JMA), United Kingdom Meteorological Office (UKMO), and United States National Meteorological Center (USNMC). Plans are now in hand at these centers for producing routine determinations of surface torques, which will supplement the AAM data and facilitate diagnostic studies.

The Atmospheric Model Intercomparison Project (AMIP) of the World Climate Research Programme (WCRP) is one of the main activities of the WCRP's Working Group on Numerical Experimentation (WGNE), in its efforts to refine atmospheric models and improve their ability to produce useful forecasts of changes in weather and climate. As a **possible contribution toward the achievement of this goal, the authors of this proposal would promote the thorough investigation of the extent to which the distribution of angular momentum and its exchange (a) between the atmosphere and the underlying planet, and (b) between different parts of the atmosphere, on timescales ranging from days to several years, can be represented correctly by the models being tested.** Specific dynamical phenomena produce strong signatures in AAM fluctuations. For example, the axial component of the total AAM shows a characteristic seasonal variation and pronounced 'broad-band' intraseasonal fluctuations. In addition, it exhibits interannual variations, on quasi-biennial and quasi-quadrennial timescales, which are well-correlated with ENSO events and are evidently associated with large-scale disturbances propagating from tropical to extra-tropical regions. These dynamical phenomena interest all AMIP investigators and we confidently expect to see fruitful collaboration with other groups as the work progresses.

/

2. DATA REQUIRED AND PROPOSED INTERCOMPARISONS

The absolute angular momentum of the atmosphere, a three-dimensional vector $H_i = H_i(t)$ (where t denotes time), can be written as the sum of two terms

$$H_i \equiv H_i^p + H_i^w \tag{2.1}$$

where

$$H_i^p \equiv \oiiint \rho \, \varepsilon_{ijk} x_j \varepsilon_{klm} \omega_l x_m \, d \text{ (volume)} \tag{2.2a}$$

and

$$H_i^w \equiv \oiiint \rho \, \varepsilon_{ijk} x_j u_k \, d \text{ (volume)}, \tag{2.2b}$$

respectively the 'matter' and the 'wind' contributions to H_i. Here $\rho(x_i, t)$ and $u_k(x_i, t)$ denote the mass density and wind velocity respectively at a general point, x_i, $i = 1, 2, 3$, within the atmosphere, over the whole of which the volume integral is taken. The usual summation convention is used for repeated suffixes and ε_{ijk} is the alternating tensor with values 0 or ± 1. The frame of reference used has its origin at the center of mass of the whole Earth (solid inner core, liquid outer core, 'solid Earth', hydrosphere, atmosphere) and is aligned with the principal axes of inertia of the 'solid Earth' (mantle, crust and cryosphere). With respect to an inertial frame, the rotation of the solid Earth has angular velocity $\omega_i(t)$, $i = 1, 2, 3$.

All components of H_i vary with time as a consequence of dynamical interactions between the atmosphere and the underlying planet, which produce measurable fluctuations in ω_i. It is customary to write

$$\omega_i(t) \equiv (\omega_1(t), \omega_2(t), \omega_2(t)) \equiv \Omega\,(m_1(t), m_2(t), 1 + m_3(t)), \tag{2.3}$$

where $\Omega = 7.292115 \times 10^{-5}$ radians per second is the mean angular speed of sidereal rotation of the solid Earth in recent times. Over timescales that are short compared with those of geological processes, the magnitudes of the dimensionless quantities $m_1(t)$, $m_2(t)$ and $m_3(t)$ are all very much less than unity, so that for the purpose of determining H_i from meteorological data using equations (2.2), it is sufficient to set $m_i = 0$, so that $\omega_i = (0, 0, \Omega)$.

The non-zero meteorological contributions to $m_i(t)$ are, of course, important in the study of fluctuations in the Earth's rotation. If L_i, $i = 1, 2, 3$, is the net torque acting on the Earth's atmosphere then

$$L_i = dH_i/dt = \dot{H}_i + \varepsilon_{klm}\, \omega_j\, H_k, \qquad (2.4)$$

where dH_i/dt and $\dot{H}_i$ are the time rates of change H_i in an inertial frame and in the rotating frame respectively. When $\omega_i = (0, 0, \Omega)$ we have

$$L_1 = \dot{H}_1 - \Omega H_2,\ L_2 = \dot{H}_2 + \Omega H_1,\ L_3 = \dot{H}_3. \qquad (2.5)$$

It is well known that L_i cannot be determined accurately from surface drag and pressure force determinations, owing to limited measurements, parametrization difficulties and the high degree of cancellation involved. But it can be determined indirectly with useful accuracy from mass and wind observations at all levels within the atmosphere by using the expressions given by equations (2.4). Through the action of L_i, angular momentum is exchanged back and forth between the atmosphere and the underlying planet, the surface of which is subjected by the atmosphere to an applied torque equal to $-L_i$. Most of the angular momentum exchanged, which in magnitude can be a considerable fraction of that of H^{w}_{i}, goes into the massive solid Earth, whose moment of inertia is some 10^6 times that of the atmosphere. This produces (a) tiny but measurable changes in the length of the day

$$\Lambda(t) = \Lambda_0/(1+ m_3(t)), \text{ where } \Lambda_0 \equiv 2\pi/\Omega, \tag{2.6a}$$

as well as (b) movements of the poles of the instantaneous axis of rotation of the solid Earth relative to its axis of figure, as specified by the quantity

$$m(t) \equiv m_1(t) + \mathrm{i}\, m_2(t) \tag{2.6b}$$

where $\mathrm{i} \equiv \sqrt{-1}$) (see equation (2.3)). Indeed, the strongest torques acting on the solid Earth are generated by atmospheric motions, which produce easily-detectable changes in Λ of up to about 1 msec in magnitude (corresponding to change in $|m_3|$ of about 10^{-8}) and displacements of the pole of rotation of several metres (corresponding to changes in $|m|$ of about 10^{-6}).

The torque $-L_i$ produced by atmospheric motions on the underlying planet is due to (*a*) tangential stresses in the turbulent boundary layers over the continents and oceans, and (*b*) normal stresses acting on orography and the Earth's equatorial bulge. Owing to the rigidity (albeit slightly imperfect) of the solid Earth, all three components of the 'continental' part of $-L_i$ are transmitted to the solid Earth directly and fully. The oceanic part of $-L_i$ gives rise to a dynamical response in the oceans which requires further investigation, but the case when the whole of the applied torque is assumed to be passed on by the oceans to the solid Earth virtually instantaneously (i.e. in no more than a few hours) can be taken as realistic for most practical purposes, particularly when dealing with the axial component of $-L_i$ and the changes in Λ that it produces. Thus, the oceans act as an intermediary in the angular momentum exchange process, by transmitting the applied stresses in the atmospheric boundary layer over the oceans to the continental margins and ocean bottom. It is a convenient circumstance that, owing to the slowness and scales of ocean currents in comparison with atmospheric winds, in the budget of angular momentum between the solid Earth and its overlying fluid layers, the hydrosphere (in spite of its much greater moment of inertia than that of the atmosphere, by a factor of about 300) produces effects which can be neglected to a first approximation.

The task of improving the performance of numerical models of the atmosphere by identifying and correcting weaknesses in their formulation requires systematic work on soundly based diagnostic methods for testing model performance. The inclusion of atmospheric angular momentum (AAM) analyses and forecasts in such tests has been advocated for two main reasons. The most obvious is the unique opportunity it provides, in principle at least, for comparing on a clear-cut physical basis the output of a global quantity from the models with observations that are completely independent of meteorological data, namely those of short-term fluctuations of the rotation of the solid Earth. Secondly, considerations of AAM fluctuations bear directly on fundamental aspects of the energetics of the global atmospheric circulation and cannot be separated from them. In the absence of energy sources, the atmosphere would rotate with the solid Earth like a rigid body (i.e., $u_i = 0$ everywhere), for this would be a state of minimum kinetic energy of the whole system for given total angular momentum. Differential solar heating produces atmospheric winds, the kinetic energy of which derives from the available potential energy of the atmosphere (which is associated with gravity acting on the density field maintained by the heating) through the action of vertical motions. Angular momentum is thereby redistributed without any change occurring in the total amount in the whole system (since solar heating produces no net torque). The largest contribution to the kinetic energy of the atmosphere associated with atmospheric winds is that made by the zonal 'super-rotation' at an average speed U (say) of about 10 m s^{-1}, namely $\frac{1}{2}MU^2$ where M is the total mass of the atmosphere. Observed fluctuations in the axial component of AAM amount to a considerable fraction of $MU\bar{R}$ in magnitude (where $\bar{R}$ is the mean radius of the solid Earth), and there are compensating fluctuations in the axial component of the angular momentum of the solid Earth. Concomitant fluctuations in the kinetic energy associated with the super-rotation amount to a considerable fraction of $\frac{1}{2}MU^2$. By energy conservation arguments, these can only be produced by dynamical processes involving non-linear interactions between the zonal wind field, the non-zonal wind field, and the field of available potential energy in the atmosphere. Successful models of the global circulation of the atmosphere must of course represent these interactions correctly. (For further details see Bell *et al.* 1991.)

In the theory of the interactions between the atmosphere and underlying planet that give rise to fluctuations in H_i, the analysis is facilitated by using in place of H_i the dimensionless AAM functions χ_i, $i = 1, 2, 3$, (see Barnes, *et al. 1983).* They can be defined as follows:

$$\chi_1 \equiv \chi_i^P + \chi_i^w = \int_{-\pi/2}^{\pi/2} \xi_i(\phi,t) d\phi = \int_{-\pi/2}^{\pi/2} \left[\xi_i^P(\phi,t) + \xi_i^w(\phi,t)\right] d\phi, \qquad (2.7)$$

where $$(\xi_1^P, \xi_2^P) \equiv \frac{-1.098R^4}{g(C-A)} \int_0^{2\pi} p_s \cos^2 \phi \sin \phi \ (\cos \lambda, \sin \lambda) \ d\lambda, \qquad (2.8a)$$

$$(\xi_1^w, \xi_2^w) \equiv$$
$$\frac{-1.5913R^3}{g(C\text{-}A)\Omega} \int_0^{P_s}\int_0^{2\pi} \cos \phi \left\{ u \sin \phi \ (\cos \lambda, \sin \lambda) - v \ (\sin \lambda, -\cos \lambda) \right\} d\lambda dp, \qquad (2.8b)$$

and

$$(\xi_3^P, \xi_3^w) = \left(\frac{0.753R^4}{gC_m} \int_0^{2\pi} p_s \cos^3\phi \ \mathrm{d}\lambda, \ \frac{0.998R^3}{gC_m\Omega} \int_0^{P_s}\int_0^{2\pi} u \cos^2\phi \ \mathrm{d}\lambda \ \mathrm{dp}\right). \qquad (2.9)$$

In these expressions, (ϕ, λ) denote latitude and longitude respectively, $p_s(\phi, \lambda, t)$ is the surface pressure and $u(\phi, \lambda, p, t)$ and $v(\phi, \lambda, p, t)$ are the eastward and northward components respectively of the wind velocity at pressure level p. We take $R = 6.3674 \times 10^6$ m for the mean radius of the solid Earth, $\Omega = 7.2921 \times 10^{-5}$ rad s^{-1} for its mean rotation rate, $g = 9.810$ m s^{-2} for the mean acceleration due to gravity, $C = 8.0376 \times 10^{37}$ kg m^2 for the polar moment of inertia of the whole Earth, $(C-A) = 2.610 \times 10^{35}$ kg m^2 where A is the corresponding equatorial moment of inertia, and $C_m = 7.1236 \times 10^{37}$ kg m^2 is the polar moment of inertia of the Earth's mantle and crust. The coefficients 1.098, 1.5913, 0.753 and 0.998 incorporate the so-called 'Love number' corrections, which allow for concomitant meteorologically-induced tiny but dynamically significant changes in the inertia tensor of the slightly deformable solid Earth, using the most up-to-date geophysical data (see Eubanks 1993). The dimensionless pseudo-vector χ_i is related to the AAM vector H_i, with the equatorial components (χ_1, χ_2) and (H_1, H_2) scaled differently from the axial components χ_3 and H_3. Routine determinations of χ_i have been made for several years at several meteorological centers (using older values of the "Love number" corrections, namely 1.00, 1.43, 0.70 and 1.00 respectively in place of 1.098, 1.5913, 0.753 and 0.998, C_m in place of C and A_m in place of A in equations (2.8)).

Any change in H_3 is accompanied by an equal and opposite change in the axial component of the angular momentum of the solid Earth (since the fluctuations in the azimuthal motion of the underlying liquid core of moment of inertia ~$0.1C$ are effectively decoupled from those of the solid Earth on the short timescales with which we are concerned here). In terms of the dimensionless quantities m_3 and χ_3 this can be expressed as

$$\dot{m}_3 + \dot{\chi}_3 = 0 \qquad (2.10)$$

with solution

$$m_3(t) + \chi_3(t) = m_3(t_0) + \chi_3(t_0), \qquad (2.11)$$

where $m_3(t_0)$ and $\chi_3(t_0)$ are constants of integration equal respectively to m_3 and χ_3 at some initial instant $t = t_0$. The dominant contribution to fluctuations in χ_3 comes from the 'wind' term χ_3^W, which depends on the distribution in the meridional plane of the average with respect to longitude λ of the eastward (westerly) wind speed.

When applied to changes in the equatorial components of H_i, Euler's dynamical equations give

$$i\sigma^{-1}\dot{m} + m = \chi - i\,\Omega^{-1}\dot{\chi} \tag{2.12}$$

where $\chi \equiv \chi_1 + i\,\chi_2$ and

$$\sigma \equiv \sigma_R + i\,\sigma_I \tag{2.13}$$

is a complex frequency. $2\pi\sigma_R^{-1}$ is the observed Chandlerian period (434 days) and σ_I is the inverse time constant that measures the rate at which various damping processes would attenuate the Chandlerian wobble if the excitation mechanism were suddenly turned off. Estimates of $\sigma_R/2\pi\sigma_I$ range from 10 to well in excess of 10^2.

For the proposed investigations, our data requirements are as follows:

(a) determinations of $H_i(t)$ and $L_i(t)$, $i = 1, 2, 3$, every 6 hours as well as corresponding values of $H_i^W(t)$, $H_i^P(t)$ and the contributions $L_i^{(O,B)}(t)$, $L_i^{(C,B)}(t)$ and $L_i^{(T)}(t)$ to $L_i(t)$ from the oceanic boundary layer, continental boundary layer and topography respectively;

(b) gridded values of the integrands of $H_i(t;, \phi, \lambda, p)$ and $L_i(t, \phi, \lambda)$, etc.

With these data we would:

(1) perform direct intercomparison studies of $H_i(t), L_i(t)$ etc. over the whole period covered by AMIP and compare with values from operational analyses;

(2) exploit the best available geodetic data on Earth rotation changes for the purposes of AMIP;

(3) investigate detailed temporal behavior and spatial morphology of fluctuations on intraseasonal, seasonal and interannual timescales;

(4) carry out detailed case studies of the 1982-83 ENSO event and of the particularly intense intraseasonal fluctuations in 1988.

3. FURTHER COMMENTS AND SELECTED REFERENCES

The study of the angular momentum balance of the Earth-atmosphere-ocean system has proven quite relevant to many issues related to climate dynamics. Earth rotation variations provide a unique and truly global measure of natural and man-made changes in the atmosphere, oceans, and cryosphere, on timescales ranging from days to centuries. The variation of AAM on time scales down to about a week has been convincingly linked to changes in the length-of-day. Oscillations on intraseasonal timescales have been shown to involve AAM changes propagating across the tropics, with contributions from orographically-forced oscillations in the extratropics. The accurate characterization of the seasonal AAM cycle involves the whole atmosphere from 1000 to 1 mb, with stratospheric winds playing a crucial role.

Interannual variations, including the El Niño/Southern Oscillation and Quasi-Biennial Oscillation, have clear signatures in records of both length-of-day and atmospheric angular momentum. Teleconnections between different latitude bands have been discovered in AAM data on these time scales, offering clues to the global structure of interannual climate variations. On even longer time scales, changes in the various components of the climate system can influence decadal variations in the Earth's rotation, the knowledge of which can help geophysicists to understand more about the internal structure of the Earth. The study of the angular momentum balance of the Earth-atmosphere-ocean system enforces a truly interdisciplinary perspective, drawing upon and contributing to the fields of meteorology, oceanography, and geophysics. The performance of the various models in replicating AAM variations across this entire spectrum of time scales is thus central to the realistic simulation of climatic variability in the Earth system.

The literature on atmospheric angular momentum fluctuations, particularly in relation to fluctuations in the Earth's rotation, has expanded rapidly during the past decade, but it is not well represented in meteorological journals. Useful bibliographies can be found in the following papers:

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The Sub-bureau for Atmospheric Angular Momentum of the International Earth Rotation Service: A Meteorological Data Center with Geodetic Applications

David A. Salstein,*
Deirdre M. Kann,⁺
Alvin J. Miller,** and
Richard D. Rosen*

Abstract

By exchanging angular momentum with the solid portion of the earth, the atmosphere plays a vital role in exciting small but measurable changes in the rotation of our planet. Recognizing this relationship, the International Earth Rotation Service invited the U.S. National Meteorological Center to organize a Sub-bureau for Atmospheric Angular Momentum (SBAAM) for the purpose of collecting, distributing, archiving, and analyzing atmospheric parameters relevant to earth rotation/polar motion. These functions of wind and surface pressure are being computed with data from several of the world's weather services, and they are being widely applied to the research and operations of the geodetic community. The SBAAM began operating formally in October 1989, and this article highlights its development, operations, and significance.

1. Introduction

Angular momentum is a three-dimensional quantity that in the absence of external torques is conserved; it is therefore a fundamental measure of the state of any closed system. Numerous studies have examined the balance of angular momentum within the earth system, involving all parts of the planet, including its atmosphere, oceans, solid shell (crust and mantle), and core. It is the atmosphere, though, that is most variable, exchanging relatively large proportions of its momentum with the solid earth below, compared with the other components. Indeed, on a wide range of time scales between several days and years, considerable agreement exists between changes in the angular momentum of the atmosphere and those of the solid earth, which are evident as small but important changes in the rotation of the planet.

Variations in the axial component of the earth orientation vector, and hence the rotation rate, are reckoned by geodesists as variations in "universal time," or its derivative, the length of day (LOD). Variations in its two equatorial components indicate movements in the position of the earth's pole relative to its crust, a wobble of the planet. Historically, both LOD changes and polar motions were determined from conventional astronomical measurements. In recent years, however, a number of sophisticated space geodetic techniques have supplanted the older optical methods to produce well-resolved and highly accurate values of earth orientation. The scientific need for monitoring changes in earth rotation relates to understanding a number of geophysical processes involving the planet's interior structure, as well as its enveloping oceans and atmosphere. Precise knowledge of the earth's orientation is also important for purposes of navigation, especially in the tracking of interplanetary spacecraft.

Because of the importance of earth-rotation parameters and their intimate connection with atmospheric angular momentum, the Paris-based International Earth Rotation Service (IERS), an organization that serves the needs of the geodetic community, invited the U.S. National Meteorological Center (NMC) to formalize earlier cooperative efforts by organizing and maintaining a specialized data center that would obtain and disseminate atmospheric angular momentum values from the world's weather centers. This data center, known as the Sub-bureau for Atmospheric Angular Momentum (SBAAM), has been operating within the Climate Analysis Center of NMC/NOAA since October 1989 and receives scientific advice from members of the earth sciences research community. Its operations have involved the participation of

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*Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts
⁺Research and Data Systems Corporation, Greenbelt, Maryland
**NOAA/NWS/Climate Analysis Center, Washington, D.C.

$$\chi_1^P = \frac{-1.00\,R^4}{(C-A)g} \int\int p_s \sin\phi \cos^2\phi \ \cos\lambda \ d\lambda\, d\phi$$

$$\chi_1^W = \frac{-1.43\,R^3}{\Omega(C-A)g} \int\int\int (u \sin\phi \cos\phi \cos\lambda - v \ \cos\phi \sin\lambda)\ d\lambda\, d\phi\, dp$$

$$\chi_2^P = \frac{-1.00\,R^4}{(C-A)g} \int\int p_s \sin\phi \cos^2\phi \ \sin\lambda \ d\lambda\, d\phi$$

$$\chi_2^W = \frac{-1.43\,R^3}{\Omega(C-A)g} \int\int\int (u \sin\phi \cos\phi \sin\lambda + v \ \cos\phi \cos\lambda)\ d\lambda\, d\phi\, dp$$

$$\chi_3^P = \frac{0.70\,R^4}{Cg} \int\int p_s \cos^3\phi \ d\lambda\, d\phi$$

$$\chi_3^W = \frac{R^3}{C\Omega g} \int\int\int u \cos^2\phi \ d\lambda\, d\phi\, dp$$

R = radius of earth
C = axial moment of inertia of earth
A = equatorial moment of inertia of earth
Ω = mean rotation rate of earth
g = acceleration of gravity
u = zonal wind
v = meridional wind
p_s = surface pressure
p = pressure
ϕ = latitude
λ = longitude

FIG. 1. Formulas for the χ_1, χ_2, and χ_3 components according to Barnes et al. (1983). The χ_1 and χ_2 terms are dependent on wavenumber-1 harmonics of winds and pressures, whereas χ_3 depends on their zonal means.

several major meteorological centers which supply a variety of atmospheric parameters. In addition to contributing data for the geodetic purposes just mentioned, the SBAAM data have also proved to be useful diagnostic parameters in monitoring aspects of climate and the behavior of weather analysis and forecasting models. Although the SBAAM was initially established for a two-year period, the decision was recently made to continue its operations.

This paper will describe the datasets produced by the SBAAM, how they are used by the geodetic community, and their potential meteorological applications. In the next section, the relationship between changes in atmospheric angular momentum and earth orientation is briefly reviewed. The organization of the IERS is presented in section 3. The remainder of the paper focuses on the organization, research, and future plans of the SBAAM.

2. Scientific background

It has been recognized since at least the time of Starr (1948) that the angular momentum of the atmosphere need not remain constant and that exchanges with the underlying planet can occur. The variable nature of atmospheric momentum indicates that momentum transfer is intimately linked to the subtle changes that occur in the earth's orientation. The topic of the earth's variable rotation has been reviewed in a number of comprehensive books and papers including those of Munk and MacDonald (1960) and Lambec (1980), who provide a theoretical basis as well a earlier observational evidence of various forcing terms Oort (1989), Hide and Dickey (1991), Herring (1991 and Rosen (1993) discuss recent geophysical view and results using modern observing systems.

A formal derivation of the dynamic relation between the atmosphere and solid earth was developed by Barnes et al. (1983). Their expressions for the atmospheric excitation functions for changes in earth orientation are easily applied to operational calculations and so were adopted by the SBAAM. These expressions, reproduced in Fig. 1, involve both motion terms represented by volume integrals of winds (*W*), and mass terms, represented by surface integrals of pressure (*P*). The first two functions, χ_1 and χ_2, are the equatorial components and are associated with the excitation of polar motion. The axial component χ_3 is associated with changes in LOD. The formulas relating earth-orientation parameters and these excitation terms are described in detail in Barnes et al. (1983) Briefly, the equatorial relationships involve a transfer function between pole position and its two excitation terms χ_1 and χ_2 consisting of a convolution with the earth's free mode (a strong oscillation in polar motion with a 14-month period, discovered by Chandler in the nineteenth century). Less complicated is the axial relationship, in which changes in LOD are merely proportional to the excitation χ_3.

Significant variations in all three components of the excitation functions occur on many scales. The axial component, χ_3^W, proportional to the relative atmospheric angular momentum due to zonal winds, varies by as much as 100% seasonally, essentially doubling between Northern Hemisphere summer and winter due to the strong annual cycle of the jet stream in that hemisphere. The resulting change between seasonal extremes in LOD can be as much as 2 ms (Rosen and Salstein 1983). Furthermore, χ_3^W is well correlated with LOD on time scales varying between several days and years (Rosen et al. 1990; Dickey et al. 1992b). (The χ_3^P term, related to meridional transports of mass that change the atmosphere's polar moment of inertia, appears to be of lesser importance than the χ_3^W term on most time scales.) This close relationship can be seen for the two-year period displayed in Fig. 2. In particular, the strong annual signal is evident, as well as a semiannual one. Shorter, intraseasonal momentum fluctuations on the 40–60-day time scale are mirrored in the LOD signal as well (Langley et al. 1981). Changes in LOD on longer, interannual time scales not evident in this figure have been related to the El Niño–Southern Oscillation phenomenon, due to the strong wind anomalies associated with ENSO events (e.g., Salstein and Rosen 1986; Dickey et al. 1992a). Some evidence also exists for a signal of the stratospheric quasi-biennial oscillation in the LOD series (Chao 1989).

With regard to the equatorial components of earth orientation, the strongest signal contains variations on the order of 10 m in pole position, occurring at the resonant 14-month Chandler period, but a suitable explanation for its maintenance against dissipation is not yet available. In contrast, shorter variations of polar motion have been more clearly identified with specific geophysical causes. Earth wobble has a strong annual component associated in part with both groundwater storage and the atmosphere (Kuehne and Wilson 1991; Chao 1988). On intraseasonal time scales, motions of the pole occur with a magnitude of about 60 cm. The evidence for atmospheric pressure forcing of these rapid polar motions is strong (Eubanks et al. 1988) and contributions from wind may play a role as well (Gross and Lindqwister 1992). As an illustration of the relationship between the atmosphere and earth in the equatorial plane, we show in Fig. 3 a two-year comparison of $\chi_{1,2}^P$, filtered to focus on high frequencies, with a set of excitation values inferred from observed pole-position variations using a mathematical inversion technique (Salstein and Gambis 1991). Statistically significant coherences between such se-

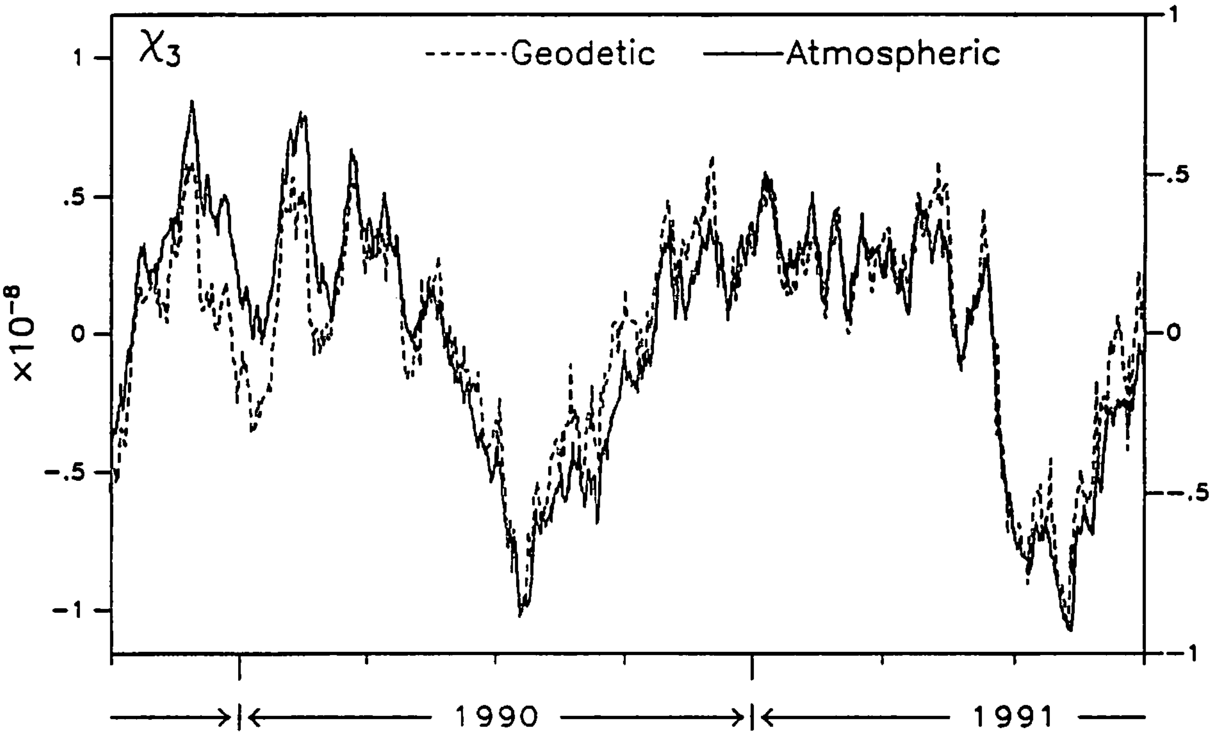

FIG. 2. Comparison of χ_3^W, the atmospheric excitation due to winds, and changes in the length of day as measured by a VLBI technique (Robertson 1991), for October 1989–September 1991. The nondimensional excitation term (scale at left-hand side), which is proportional to the relative momentum of the atmosphere with a factor of 5.13 x 10^{33} kg m^2 s^{-1}, is also proportional to changes in the length of day (scale on the right-hand side). There is excellent agreement on most time scales; the low-frequency difference represents the effects of geophysical phenomena unrelated to the atmosphere.

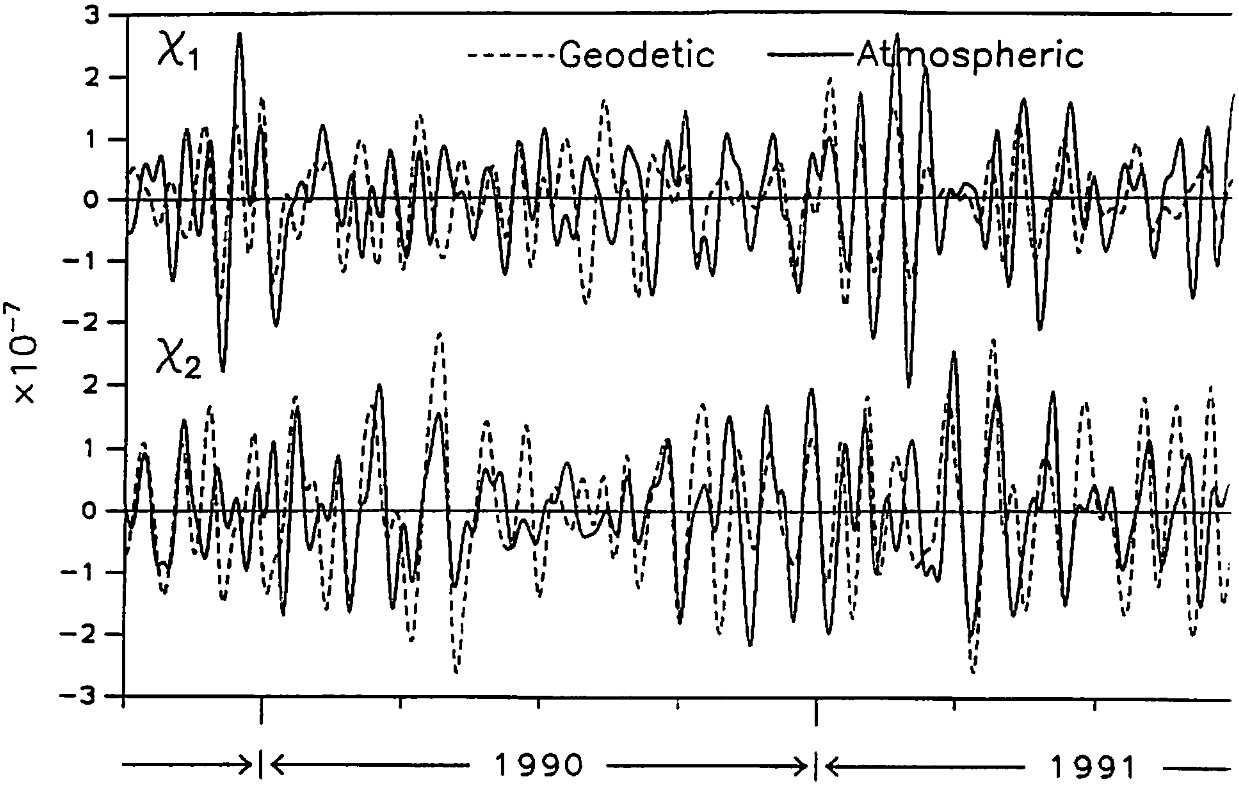

FIG. 3. Comparison of χ_1^p and χ_2^p, the atmospheric excitations for polar motion due to surface pressure, with excitations that are nee to produce the polar motion observed by a combination of techniques (IERS 1991) for October 1989–September 1991. The excitation ter which have been filtered to highlight time scales between a fortnight and a season, are given in nondimensional units. Significant cohere between the atmospheric and geodetic series occurs for frequencies within this range.

ries generally exist for periods as short as 10 days. The meteorological excitations that are most related to these rapid polar-motion functions are caused primarily by airmass variations over the North Atlantic, North Pacific, Siberia, and the southern oceans (Salstein and Rosen 1989).

The degree to which changes in the mass distribution of the global ocean impact LOD changes and polar motion is an important unknown. A zero-order approach to dealing with the problem is to not involve the ocean at all by assuming it rigid. A relatively simple alternative is to assume a state of static ocean equilibrium with the overlying atmosphere, the so-called inverted barometer (IB) hypothesis (Gill and Niiler 1973). Simply stated, under IB conditions, any change in air mass over the ocean will depress the water surface below areas of high atmospheric pressure and raise sea level beneath low pressure areas. The ocean water so displaced has the same mass as that part of the atmosphere greater than its mean value over the ocean, with an approximate equivalence of 1 mb of atmospheric pressure to 1 cm of sea level. Because of oceanic mass redistribution under IB conditions, the solid earth below the ocean will not be affected by local changes of atmospheric pressure, but rather by the mean change of surface air pressu over the entire ocean. The sensitivity of the pressu excitation terms to the introduction of an IB model comparable to the terms themselves; however, t degree to which the IB response occurs, and reduc the importance of the pressure variations over t ocean, is still under investigation. Therefore, it h become the general practice to calculate the excit tion terms assuming both a non-IB and a pure response of the oceans. In fact, though, some sort dynamic, intermediate, ocean response to variatio in atmospheric pressure is perhaps most likely and the object of current research using both analytic means (Dickman 1988) and modeling approache (Ponte et al. 1991).

3. The International Earth Rotation Servic

While advances were occurring in understandi the relationship between atmospheric angular m mentum and earth orientation, significant improv ments were being achieved in the production of t relevant geophysical series. To facilitate the collecti and assimilation of the geodetic data, and to stu their implications, the IERS was organized jointly by the International Astronomical Union and the International Union of Geodesy and Geophysics and began operations on 1 January 1988. The IERS is a successor to the International Polar Motion Service and the earth-rotation section of the Bureau International de l'Heure. The IERS has four major responsibilities: 1) to define and maintain a conventional terrestrial reference system based on high-precision geodetic monitoring stations; 2) to define and maintain a conventional celestial reference based on fixed extragalactic radio sources important in measuring earth orientation; 3) to determine the earth-orientation parameters relative to these systems, namely the terrestrial and celestial coordinates of the pole and universal time; and 4) to organize the observation, analysis, collection, archival, and dissemination of appropriate data (IERS 1991).

The organization of the IERS is depicted in Fig. 4. The various components of the IERS report to the Central Bureau, which is located at the Observatory of Paris. All pertinent data are received by the Central Bureau, which, in turn, produces and distributes sets of earth-orientation parameters optimally combined from the various contributions. Monthly bulletins are produced containing near-real-time values of these parameters. An annual report contains final values of the earth-orientation parameters analyzed later, as well as information detailing the precision, analysis techniques, and other aspects concerning the production of these parameters. In addition, special bulletins and technical notes containing complementary information are produced as necessary.

The earth-orientation datasets received by the Central Bureau are provided by the four current coordinating centers, each of which represents a principal observing technique. Geodetic techniques typically measure the length and orientation of baselines between observing stations, and sets of these baselines can be used to develop a time series of the three-dimensional orientation of the earth. Very Long Baseline Interferometry (VLBI) employs a global network of radio telescopes that simultaneously track extragalactic radio sources. Pairs of signals from observing sessions are correlated to measure phase delays yielding relevant baseline positions. Satellite laser ranging (SLR) provides the IERS with a generally rapid source of earth-rotation data. In SLR, laser pulses are transmitted to reflectors on an artificial satellite with a highly stable orbit, such as the Laser Geodynamic Satellite (LAGEOS), in orbit since 1976. The round-trip travel time is used to determine distances between a station and the satellite and, in turn, a network of SLR stations yields a suitable reference frame and a set of earth-orientation parameters. The lunar laser ranging (LLR) technique is conceptually identical to SLR with targets consisting of arrays of reflectors on the moon that were installed by the Apollo astronauts first in 1969. Although the laser return rate at the large lunar distance is much lower than that of an SLR system, LLR data are useful in studying the long-term variations in the earth's rate of rotation. Finally, the new Global Positioning System (GPS) uses a radiometric technique similar to that of the VLBI; however, instead of tracking extragalactic sources, a constellation of artificial satellites, eventually numbering 24, transmits radio signals that are measured by receivers on the ground. GPS is potentially an important technique, whose ability to produce accurate, high-frequency earth-orientation parameters was studied in a special experiment in mid-1992.

Other components of the IERS depicted in Fig. 4 are its two sub-bureaus, which are each devoted to specialized tasks. The Rapid Service Sub-bureau provides current earth-orientation information, including weekly predictions of these parameters for up to 90 days. The organization and activities of the SBAAM are addressed in the remaining sections of this paper.

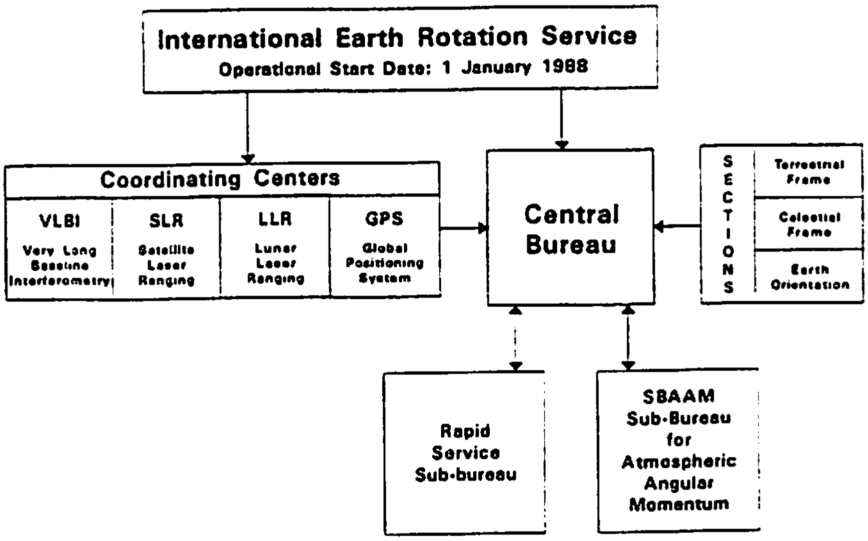

FIG. 4. Organization of the IERS. The International Earth Rotation Service, whose Central Bureau is housed at the Observatory of Paris, is concerned with the earth's orientation and reference frames. It combines and analyzes earth-rotation data from coordinating centers. The SBAAM, housed at NMC, collects and distributes relevant atmospheric data.

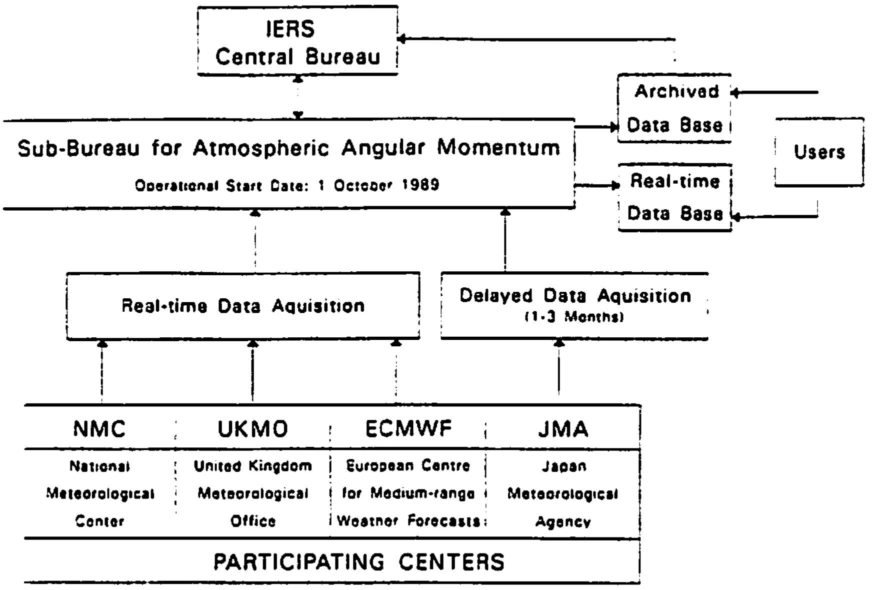

FIG. 5. Operations of the SBAAM. The SBAAM receives data in either real-time or delayed mode from participating meteorological centers and supplies it to interested users and the Central Bureau.

4. Mission of the SBAAM

During the 1980s, a special study group of the International Association of Geodesy (5-98: Atmospheric excitation of the earth's rotation; Dickey 1984) was active in highlighting the importance of earth-atmosphere dynamic interactions. Through its efforts and those of other interested scientists, the requirements for a specialized meteorological center were established. After finalizing data formats and seeking the cooperation of various meteorological centers, the SBAAM officially began operations on 1 October 1989. During the first two years of operation, the SBAAM has succeeded in serving as a focal point for the collection, archival, and distribution of atmospheric parameters relating to earth orientation.

The SBAAM is maintained by the Climate Analysis Center of NMC, and its organizational structure is depicted in Fig. 5. As a component of the IERS, the SBAAM is responsible for providing archived datasets to the Central Bureau together with related technical material. The SBAAM also provides atmospheric angular momentum data and associated parameters, in near-real-time or delayed modes, to interested parties. Data from four meteorological centers are received by the SBAAM. Participating centers besides NMC are the United Kingdom Meteorological Office (UKMO); the European Centre for Medium-Range Weather Forecasts (ECMWF); and the Japan Meteorological Agency (JMA), values from which are processed by personnel of the National Astronomical Observatory (NAO) of Japan. major goal of the SBAAM is th rapid receipt of data from a meteorological centers. As illu trated in Fig. 5, three of the cen ters provide data in near-re time, and it is thus possible f users to receive SBAAM da quickly, within 24–36 hours. Da from all centers are availab from the archived database.

For several years prior to th start of the SBAAM, componen of atmospheric angular momentum from both atmospher analyses and forecasts had bee computed at a number of meteorological centers, and thes values were archived in a var ety of formats. It was an impo tant mission of the SBAAM tha a consistent set of parameter be compiled in order to facilitat evaluation and intercompariso Thus, values of the excitation functions are collecte as uniformly as possible from the different meteorological centers.

Because the whole set of excitation componen (Fig. 1) is relevant to studies concerning earth orientation, the SBAAM sought to include all components expressed as hemispheric integrals, in its database The calculation of wind parameters involves the computation of integrals over the depth of the atmosphere which, however, varies among the analysis mode used at the different centers. Calculations of the NM wind-based functions to a standard, 100-mb, level ar performed, but are difficult for other centers becaus their computations use the model nondimensiona sigma levels. Some of the centers also calculat excitation terms with the IB correction in parallel.

Other meteorological parameters related to glob momentum are also included in the SBAAM files Zonal mean zonal wind values [u], from which the χ wind term is calculated, and zonal mean temperature [T], whose gradients are related in the extratropics t zonal winds, are also archived and have proved usef in studying regional contributions to the behavior of th global parameters (Rosen and Salstein 1983; Dicke et al. 1991, 1992a). Forecasts of zonal mean zon winds proved especially valuable in resolving th source of momentum forecast errors, including biase (Rosen et al. 1991). Also, because there is evidenc that the orbits of geodetic satellites are affected by th fluctuating gravitational field associated with the redistribution of mass in the atmosphere (Schutz et a

1989; Chao and Au 1991), routine specification of the atmospheric mass field, expressed as a low-order spherical harmonic expansion (full triangular truncation to wave 4 and zonal modes to wave 20), as well as mean global surface pressure, are also SBAAM parameters. Lastly, because of some uncertainty about the most appropriate domain to define the World Ocean in the context of IB calculations, two special sets of SBAAM parameters are produced using different ocean domains beyond the basic. Results from this test will be discussed in the next section.

Analysis values of parameters are typically provided every 12 h, and forecast values once daily, from the start time of each center's model given at up to 12-h increments of lead times out to the model's limit. The participation of each of the meteorological centers has been essential to the success of the SBAAM, even though complete SBAAM files are not produced by every center. A summary of the data contributions from the four participating centers is given in Table 1.

TABLE 1. SBAAM data from meteorological centers.

	ECMWF	JMA	NMC	UKMO
Analyses				
χ^W[a]	•	•	•[b]	•
χ^P	•	•	•	•
χ^P(IB)		•	•[c]	
$[u]$	•[d]		•	
$[T]$			•	
p-harmonics			•	
Forecasts				
χ^W, χ^P	3, 5, 10 days		1–10 days	1–6 days
$[u]$			1–10 days	

[a] χ^W terms to top of model, currently for ECMWF, 10 mb; JMA, 10 mb; NMC, 50 mb; UKMO, ~25 mb.
[b] χ_3^W also available to 100 mb.
[c] Including alternate World Ocean formulations.
[d] Through 1990 only.

The SBAAM system retrieves and makes available data in as near-real time as possible to permit their use for purposes requiring rapid access, such as in spacecraft navigation. The NMC data are produced, of course, on site and are available quickly. Prior to July 1990, the UKMO files were sent to the SBAAM on floppy disks; however, they are now rapidly transmitted on the Global Telecommunications System (GTS). For the ECMWF, transmittal on the GTS has just been established. During this transition period from delayed mode to rapid transmission, a gap in the ECMWF files was created, which we expect to fill from archives.

During the first two years of SBAAM operations, it was decided that its file structure would remain unchanged. We are now in the process of reviewing recommendations for potential improvements to the system, including provisions for acquiring data at the two "off times," 0600 and 1800 UTC. It is expected that, starting in 1992, the NMC and ECMWF analysis parameters will be calculated at 6-h intervals. These higher-frequency observations will be especially useful in light of the IERS intensive observing campaigns planned for summer 1992 (Dickey 1991). Also, efforts are under way to supplement the calculation of SBAAM parameters at NMC on pressure levels with those on direct model-based nondimensional sigma levels. Other related developments are discussed in section 6.

5. Assessment of SBAAM parameters

The availability of the angular momentum terms from a number of different weather centers provides an opportunity to compare diagnostic products derived from a diverse group of forecast and analysis systems. The small number of global and hemispheric SBAAM parameters make them attractive as compact measures of discrepancies among analyses and forecasts of the contributing centers themselves (Bell et al. 1991), in addition to their connection with geodetic applications. In principle, geodetic measurements form an independent constraint so that a meteorological analysis that better agrees with LOD or polar-motion series may be providing a more accurate product in one integrated sense.

a. Analysis quantities

By examining a parameter produced by different centers, we can form estimates of analysis errors in the relevant SBAAM quantities. Such an approach was followed by Rosen et al. (1987), who compared momentum globally and in zonal belts from both the NMC and ECMWF systems and determined that a steady decrease has been taking place over several years in the difference between the winds and, hence, momentum, of the two centers' analyses. Corresponding differences in momentum values in high latitudes of the Southern Hemisphere were especially large compared with their counterparts in high northern latitudes, but that difference too has been decreasing with time. We have also examined aspects of the commonality in the excitation terms by means of an empirical orthogonal function approach applied to the four χ_3^W time series for 1990. The first two modes are

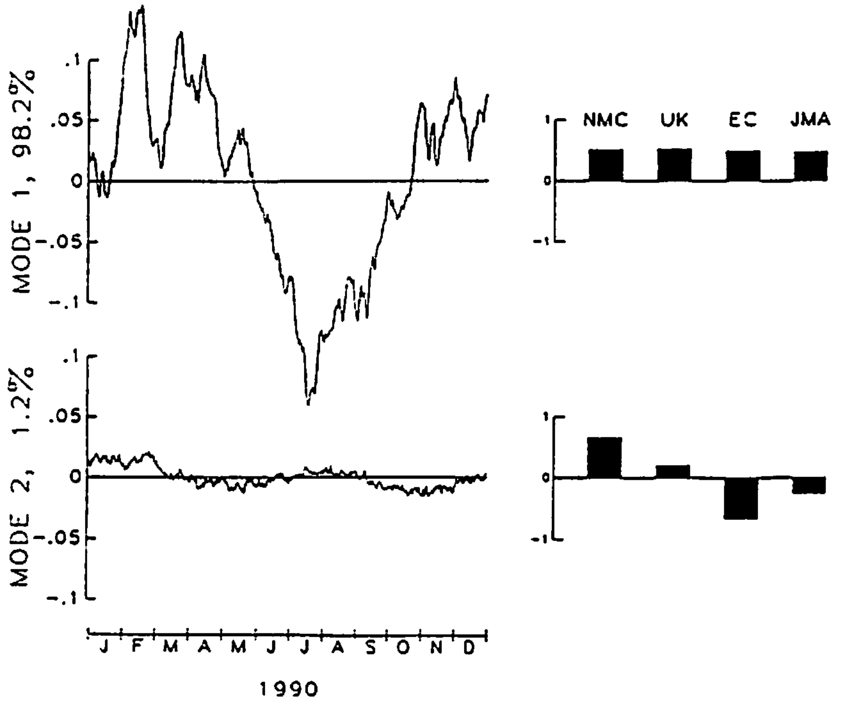

FIG. 6. Empirical orthogonal function results, using the method described by Salstein et al. (1983), for the first two modes, assessing the commonality of the χ_3^W terms from four analyses. Eigenvector functions (bars on right) are nondimensional and represent the contribution of each center's analyses to a mode. The time series for each mode (curves on left) represents the projection of the data series onto the mode, and hence reflects the temporal variability of the mode's contribution.

displayed as the groups of four bars in Fig. 6, together with their associated time series. The first mode, with almost equal weights from the four centers, accounts for nearly all (98.2%) of the total variance and its time series reflects the important seasonal cycle as well as coherent subannual signals. Of the small remainder, most is present in the second mode, weighted largely by the opposite loadings from NMC and ECMWF, indicating a negative correlation between the χ_3^W signals that occur after the strong first mode is removed. This second mode has a time series with a marked semiannual component. Because the wind terms are integrated to the top analysis level of each center, some differences among the centers, including the amplitude of the annual and semiannual components in χ_3^W, can be attributed to the variation of that level (Rosen and Salstein 1985). Such comparisons can, of course, be performed for all the SBAAM parameters that are produced by all the centers. Figure 7 shows the NMC analysis values of the full three-dimensional set of global atmospheric angular-momentum excitation components for the period since October 1989, which includes the portions due to winds, pressures, and pressures as modified by the oceanic IB response. In general, these curves are quite similar to those from the three other ce ters, as demonstrated above f the χ_3^W term; however, some d crepancies might be due to t different vertical coordinates (which center contributions we calculated.

The mass term is less impc tant in forcing LOD than is t motion term on most time scal because of a relatively stat zonal mean pressure distrib tion. The χ_3^P term, however, h been shown to be particula sensitive to model changes th have occurred throughout t years, which tend to involve t boundary topography. Indee the large jumps in χ_2^P and χ_3^P see during March 1991 in Fig. 7 a associated with the replaceme of silhouette orography wi mean orography at NMC, in co junction with the adoption of higher-resolution model. Earlie when silhouette orography w first introduced in the NMC ana sis cycle in 1986, these term took equally large jumps. Oth developments and model moc fications at the centers have produced a number noticeable changes in the pressure-based terms. addition, different models of orography in use at t four centers cause disparate mean values of t pressure-related terms (not shown), especially thos of the axial χ_3 contribution. Physically, howeve changes in the χ_3 terms, rather than mean values, a those signals dynamically relevant to LOD variation

The integrals forming the equatorial wind- an pressure-related terms have a wavenumber-1 depe dence in longitude and are thus subject to diurn influences. Such variations in the $\chi_{1,2}^W$ terms, which a modulated by the annual cycle, are clearly observe Bell et al. (1991) attribute them to an atmospheric tid response of the wind field. Because of the presence this diurnal signal in sub-bureau data, it is reco mended that at least twice-daily values be included analyses with these data.

For the equatorial pressure components, the χ term has a much stronger annual signal than χ because of the longitudinal phase in their formul tions. The absolute weights in the expression definin χ_2^P (Fig. 1) maximize at 90°E and 90°W, longitudes th have relatively more land area than others, wherea nodes of χ_2^P occur at 0° and 180° longitude, primaril

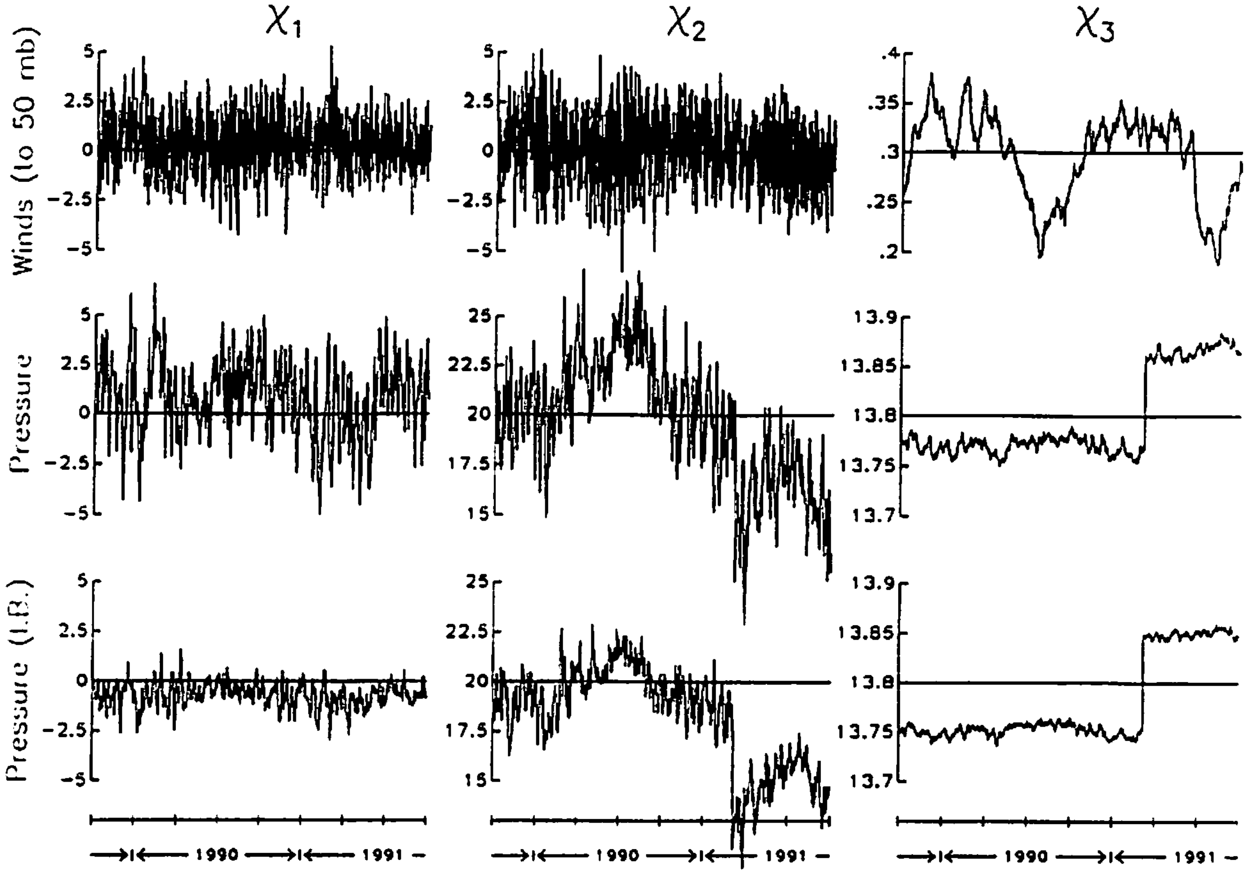

FIG. 7. Twice-daily values of the global effective atmospheric angular momentum functions χ_1, χ_2, and χ_3 for wind, pressure, and pressure as modified by an inverted parameter (IB) oceanic response, from the NMC analysis system since the start of SBAAM operations, given in nondimensional units, multiplied by 10^{-7}.

oceanic regions. The reverse is the case for the orthogonal χ_1^P function. This feature explains the difference in the variability between the two terms. The magnitude of the annual term in χ_2^P decreases with the introduction of the IB formulation but is not eliminated, as this term reflects a largely nonocean signal. Overall, though, the effect of the IB on all χ^P terms is strong, as is evident in Fig. 7, in line with the relatively large size of the World Ocean domain. Indeed the reduction in variance of the NMC χ_1^P, χ_2^P, and χ_3^P terms after the introduction of the IB calculation (and after removing the March 1991 surface pressure jump) is 88%, 66%, and 52%, respectively.

At present we are reexamining the formulation of the inverted barometer correction to the surface pressure terms. The conventional calculation of the IB correction involves replacing the atmospheric surface pressure at every point over the World Ocean by the mean value of surface pressure over that domain. However, certain portions of the ocean are not so connected to the global ocean as are others, and perhaps ought not to be included in the definition of the World Ocean used for this purpose. Also, evidence exists that those shallow and constricted parts of an ocean basin near to the continental margins are least likely to have an IB response (Ponte et al. 1991). Thus, in addition to the basic IB run, we have run two further experiments, each with a different definition of the World Ocean, for the purpose of computing IB excitation terms. In one experiment, the dynamically isolated and ice-covered Arctic Ocean was removed from the World Ocean, and in a second experiment, the Arctic Ocean as well as most inland seas were removed. We show in Fig. 8 the impact of these choices on the polar motion–related excitation terms using the three ocean definitions for calendar year 1990. In general, the signal of the pressure terms calculated using the modified IB definitions fall between the basic IB and the non-IB cases, though closer to the basic IB case. The amount by which the variances of the polar excitation terms from the modified IB cases exceed those of the basic IB case is as high as 38%. In the future, inclusion of a dynamic model for the World Ocean, such as is outlined by Ponte et al. (1991), may

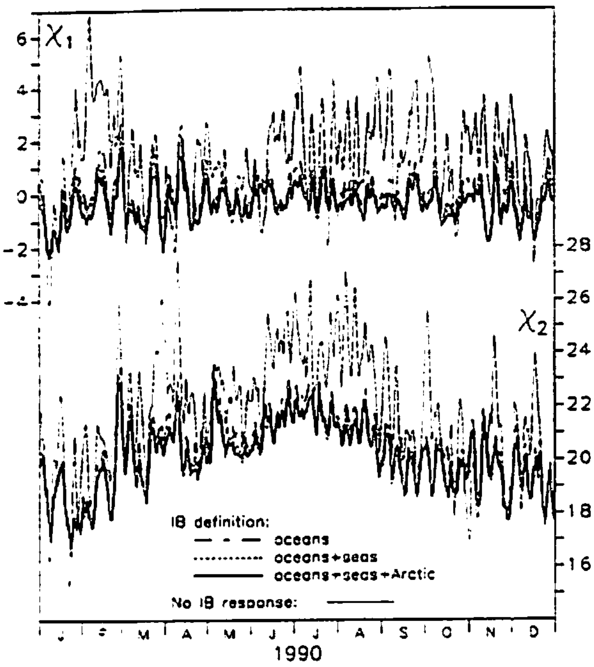

Fig. 8. Values of the global χ_1^p (scale on left) and χ_2^p (scale on right) resulting from three World Ocean definitions, as described in text, for the inverted barometer (IB), and for the pressure terms without the inverted barometer model, for 1990. Units are nondimensional, multiplied by 10^{-7}.

enable us to modify the IB formulation by incorporating more complex time and space variability.

b. Forecast quantities

Forecasts of the atmospheric excitation terms, when available in rapid mode, may be useful in helping to produce predictions of earth-orientation parameters needed in spacecraft tracking. Forecasts made earlier solely with geodetic parameters have been improved with the inclusion of meteorological data, as with a Kalman-filtering approach (Freedman and Dickey 1991). Nevertheless, it is important to assess the skill of the meteorological forecasts alone by verification and comparison techniques. The highly variable χ_3^w term is a primary parameter, as it is especially important in modeling predictions of LOD. On the left side of Fig. 9a are daily forecast errors for this term computed from the ECMWF system with lead times of 3, 5, and 10 days. This error is simply the difference between the dynamical forecast and the observed ECMWF analysis at the verifying time. For this term, a notable forecast bias in the early part of the period existed, which apparently was related to excessive forecasts of tropical easterly zonal winds within the ECMWF model. These errors were reduced in May 1990 with the introduction of a procedure that enhances evaporation (Miller et al. 1992). Examination of the NMC χ_3^w forecast series also reveals the general presence of a negative bias, whose magnitude has changed over the years, as is shown in Fig. 9b for a forecast lead time of 10 days. The larger bias since late 1989, comparable to the early 1990 ECMWF bias in Fig. 9a, appears related to errors across the tropical and subtropical mid- to upper-troposphere, generally exceeding those documented by Rosen et al. (1991) for earlier NMC model versions.

The highly variable χ_3^w term is a primary parameter, as it is especially important in modeling predictions of LOD.

To place such model forecast errors in context, we also show in Fig. 9a a set of statistical, persistence-based errors for the ECMWF system. The variances of these errors are clearly larger than those of the dynamical forecast, when a simple bias during each model version, before and after May 1990, is removed. Furthermore, persistence model errors have relatively more power at longer, intraseasonal time scales than do the model-produced errors, reflecting the strength of intraseasonal behavior in the χ_3^w term.

Using the dynamic and persistence-based forecast errors, we assess the dynamic forecasts in Fig. 10 for certain selected terms from NMC, ECMWF, and UKMO, the three centers that provide such data. We have chosen the χ_1 and χ_2 pressure terms and the χ_3 wind, those which have primary responsibility in producing changes in polar motion and LOD, respectively. The skill, *S*, which involves a comparison of the root-mean-square errors (σ) from both the forecast (*f*) model and the persistence-based (*p*) forecast, is given by the expression:

$$S = (\sigma_p - \sigma_f)/\sigma_p \times 100\%,$$

where skill can range from any negative value to 100% (Rosen et al. 1991). In this formulation, any value greater than zero indicates some utility of the forecast technique over persistence. The previously mentioned biases in χ_3^w at the various centers were first removed before calculating *S*. The skills of the three forecast quantities for the period, as a function of lead time, are shown in Fig. 10. It can be seen that skill is positive out to 10 days (with one exception, χ_1^p at 10 days from NMC). Skill of momentum forecasts against other statistical competitors such as damped persistence has been found to be generally positive, as well (Rosen et al. 1991). Evaluations have been made using other techniques, including scatter plots of time series of forecast and analysis changes, and their related correlations. Such comparisons of SBAAM-type quantities from UKMO and ECMWF have been performed by Bell et al. (1991), who indicate the general usefulness of forecasts at least up to 5 days.

Although the result of assessing forecast skill in Fig. 10 is based on simply removing a single bias over the entire tenure of a model version, biases should be removed in a more appropriate fashion when including SBAAM data in operational geodetic forecast procedures. A method to remove the systematic error from momentum forecasts using results from a recent past training period has been considered; interestingly, forecast skills do not appear to be especially sensitive to the precise length of the training period chosen, beyond a threshold of several weeks. In addition to this after-the-fact correction, approaches that apply "nudging," or repeated adjustments, during model integrations are being studied (Saha 1992).

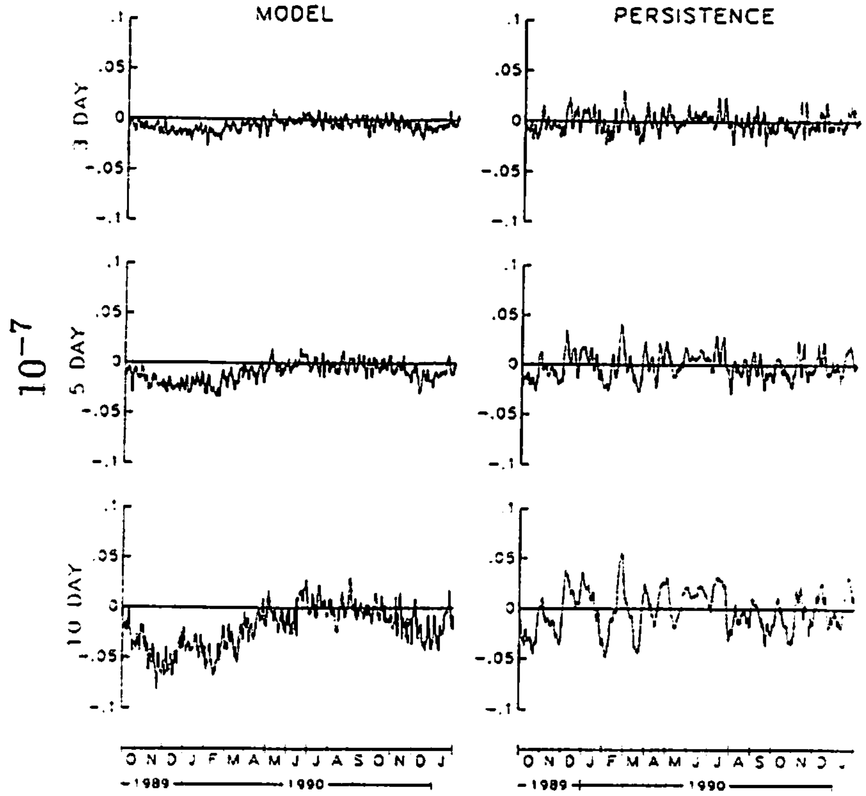

Fig. 9a. Forecast errors of χ_3^W at 3, 5, and 10 days for model- and persistence-based forecasts from ECMWF, given in nondimensional units, multiplied by 10^{-7}.

6. Future enhancements of meteorological analysis techniques and data

Developments in a number of arenas relevant to the interests of the sub-bureau promise better quality in atmospheric excitation functions in coming years. For example, there are efforts underway at NMC and other weather centers to produce analysis fields not subject to the vagaries of model changes. The Climate Data Assimilation System and its counterpart in producing historical analyses, the reanalysis effort (Kalnay and Jenne 1991), will lead to terms produced by the sub-bureau that do not have artificial discontinuities and

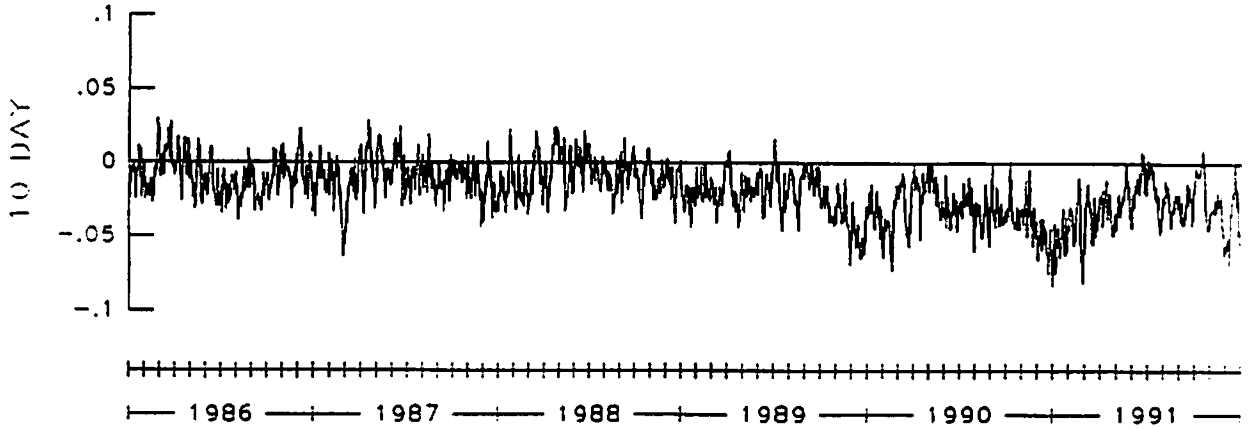

Fig. 9b. Forecast errors of χ_3^W at 10 days for model-based forecasts from NMC for 1986–1991, given in nondimensional units, multiplied by 10^{-7}.

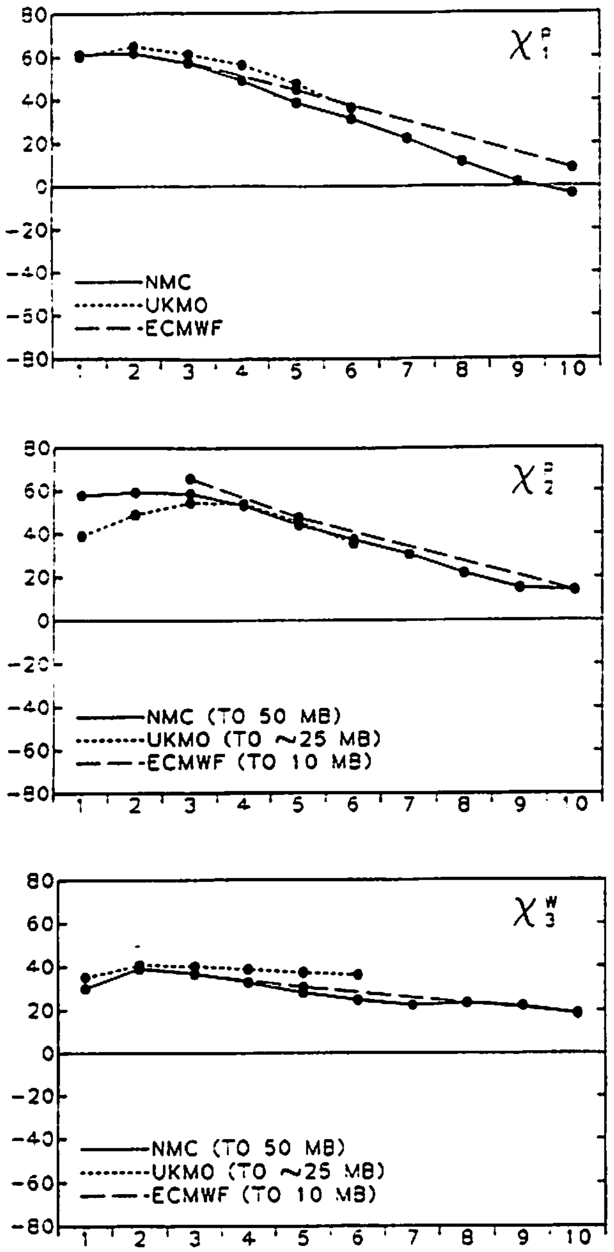

Fig. 10. Global forecast skills for the NMC, UKMO, and ECMWF models for χ_1^p, χ_2^p, and χ_3^w at lead times of 1–10 days for 1990. Biases have been removed from the χ_3^w term. Units are percent.

hence will be more useful for geophysical studies of the long-term dynamics of the earth.

Finer horizontal resolution and the extension of meteorological models beyond their current vertical domains will be useful to our efforts as well. In particular, the inclusion of higher stratospheric levels in the analysis will improve calculations of the seasonal terms of the angular momentum balance. In general, developments in both data-assimilation and forecast procedures should improve the quality of SBAAM products.

In the near future, we will see the incorporation at some weather centers of calculations of those torques that dynamically link the earth and atmosphere (White 1991). These torques, which are exerted on the atmosphere by pressure differences across mountains and by friction at the earth's surface, will be included in the SBAAM database. Similar calculations at the Canadian Climate Centre using fields from a general circulation model were presented by Boer (1990), who also reviewed the mechanisms involved.

New instrumentation will be welcome in coming years for studying the angular momentum budget as well as the interfacial torques. Although we anticipate that some of the datasets from such novel instruments will be assimilated into the analyses supplied to the sub-bureau, special datasets are likely to be produced as well. Already, the Special Sensor Microwave Imager (SSM/I) is determining values of ocean surface wind stress since its 1987 launch, aiding our understanding of momentum transfer between atmosphere and ocean. Also useful for the sub-bureau will be the high-altitude winds from the Upper Atmosphere Research Satellite, and scatterometer sea level winds and stresses from the *ERS-1* satellite, both launched in mid-1991. Starting in the late 1990s, other instruments may also be available to help improve SBAAM quantities. The Laser Atmospheric Wind Sounder is intended to monitor winds through the depth of the troposphere from space, by using a lidar signal reflection off aerosols and clouds. As for improvements to the surface pressure terms, important in studying polar motion, sounding techniques, including those from the AIRS instrument on the Earth Observing System will yield better inputs to the weather forecasting and analysis systems from which these terms are derived.

7. Summary

We have highlighted the operations of the Subbureau for Atmospheric Angular Momentum, a center that collects meteorological data to aid in the assessment of the geodetic parameters, length of day and polar motion. Central functions of the sub-bureau include studying the contributions from the participating meteorological centers, and improving the formulation of the various terms. Cooperation with the Central Bureau of the IERS, especially in structuring methods of comparisons of meteorological and geodetic parameters, is ongoing. With current data, statistically significant values of coherence between respective meteorological and geodetic excitation terms exist for periods as short as 1–2 weeks; improvements in both data types are likely to reduce that threshold to even shorter periods. Because of the steady progress made in meteorological and geodetic calculations, as well as gains in understanding relevant ocean dynamics, we expect that the role of the SBAAM will be increasingly vital in the study of earth-orientation changes and the dynamics of the earth system.

Routine electronic access for sub-bureau analysis and forecast files at NMC is available to the scientific community. Also, files are archived on both magnetic tape and floppy disks, and are available from the SBAAM in these formats. A set of user notes to support these services is available. Additionally, data prior to its operational start date, including NMC analysis values since 1976 and ECMWF forecast values since 1986, are available from the sub-bureau.

The sub-bureau activities are under the direction of A. J. Miller, NOAA/NWS/Climate Analysis Center, Washington, D.C. 20233, Tel: 301-763-8071. For information on obtaining SBAAM data and user notes, contact D. A. Salstein, Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge, MA 02139, Tel: 617-547-6207, e-mail: dsalstein@aer.com.

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C  TITLE FOR ECMWF DERIVED DATA SET
C
C    EFFECTIVE ATMOSPHERIC ANGULAR MOMENTUM (EAAM) FUNCTIONS TIME
C  SERIES PRODUCED BY THE GEOPHYSICAL FLUID DYNAMICS LABORATORY, OF
C  THE U.K. METEOROLOGICAL OFFICE (MET. O. 21), BRACKNELL, BERKS.,
C  RG12 2SZ, ENGLAND, U.K., TELEPHONE 0344 420242 EXT. 2592;
C  TELEX 849801.
C
C    EAAM FUNCTIONS INCLUDE LOVE NUMBER CORRECTIONS FOR DEPARTURES
C  FROM PERFECT RIGIDITY OF THE SOLID EARTH THUS FACILITATING THEIR
C  USE IN COMPARISONS WITH EARTH ROTATION DATA. THE EAAM FUNCTIONS
C  WERE INTRODUCED AND DEFINED IN:
C
C    BARNES R.T.H.,HIDE R.,WHITE A.A., AND WILSON C.A. 1983
C    ATMOSPHERIC ANGULAR MOMENTUM FLUCTUATIONS, LENGTH-OF-DAY
C    CHANGES AND POLAR MOTION. PROC. R. SOC. LOND. A 387, 31-73.
C    EQUATIONS (5.1) TO (5.3). REFERRED TO AS BHWW(1983).
C
C   SEE ALSO
C
C    HIDE R.,F.R.S. 1984. ROTATION OF THE ATMOSPHERES OF THE EARTH
C    AND PLANETS. PHIL. TRANS. R. SOC. LOND. A 313, 107-121. APPENDI
C
C    EAAM FUNCTIONS DATA ON THIS TAPE ARE BASED ON INITIALIZED
C  METEOROLOGICAL DATA SETS PROVIDED TO THE U.K. METEOROLOGICAL
C  OFFICE BY EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS.
C  CORRESPONDENCE CONCERNING THESE EAAM DATA SHOULD BE ADDRESSED TO
C  HEAD OF GEOPHYSICAL FLUID DYNAMICS LABORATORY AT ABOVE ADDRESS,
C  WHO SHOULD BE GIVEN NOTICE OF PREPARATION OF ANY PUBLICATIONS
C  THAT MAKE USE OF DATA. AUTHORS OF SUCH PUBLICATIONS ARE REQUESTED
C  TO ACKNOWLEDGE SOURCE OF EAAM FUNCTIONS DATA.
C
C     DATA SET FORMAT
C
C    THERE ARE THREE RECORDS PER DAY.
C
C    SAMPLE READ STATEMENT OF THE THREE RECORDS FOR THE NTH DAY:
C
C       READ(15,50)NOD(N),IDATE(N)
C      1         ,X1PN(N),X1PS(N),X1WN(N),X1WS(N)
C      2         ,X2PN(N),X2PS(N),X2WN(N),X2WS(N)
C      3         ,X3PN(N),X3PS(N),X3WN(N),X3WS(N)
C    50 FORMAT(I4,I8,1P4E16.5/(12X,1P4E16.5))
C
C    NOD - THE NUMBER N
C    IDATE - DATE FOR WHICH RECORDS ARE VALID EG 791201 1ST DEC 1979
C    X - TO BE READ AS KHAI
C    1 - COMPONENT WITH ROTATION AXIS ALIGNED WITH GREENWICH MERIDIA
C    2 -    "      "       "       "       "       "    90 E
C    3 -    "      "       "       "       "       "    PRINCIPAL AXIS
C        OF EARTH'S INERTIA TENSOR. N.B. X3 HAS THE OPPOSITE SIGN TO
C        X3 AS DEFINED IN BHWW(1983) (5.3) AND HIDE(1984) (A 3).
C    P - PRESSURE (ALSO CALLED MATTER) TERM
C    W - WIND TERM. THIS IS CALCULATED USING ONLY THE PART OF THE
C        ATMOSPHERE BETWEEN 1000 MB AND 50 MB.
C    N - NORTHERN HEMISPHERE
C    S - SOUTHERN HEMISPHERE
C
C    PERIOD COVERED: 1ST DEC 1979 TO PRESENT
```

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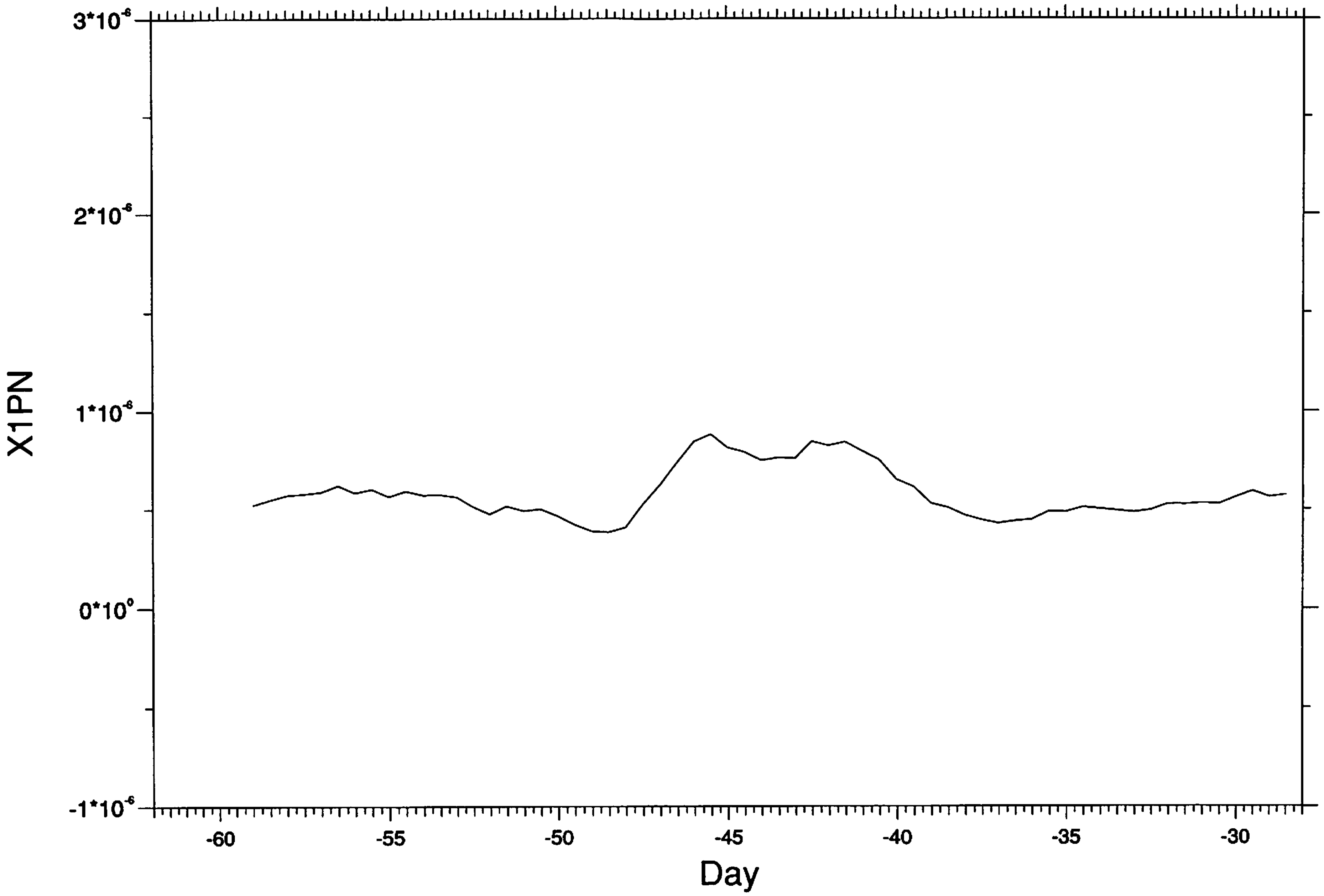
C
C    MOST DATA VALID AT 00Z BUT SOME AT 12Z
C
   1  791201      5.83686E-07    -4.42971E-07    -3.67839E-08      1.1
                  2.10037E-06    -5.09365E-07    -1.67835E-07      1.4
                 -6.91453E-07    -6.99229E-07    -1.64251E-08     -1.8
   2  791202      4.96386E-07    -3.96946E-07    -3.04073E-07     -1.6
                  2.00005E-06    -5.35248E-07    -1.53877E-07     -5.4
                 -6.91166E-07    -6.99517E-07    -1.68405E-08     -1.8
   3  791203      4.54480E-07    -4.89347E-07     1.50207E-08      3.3
                  1.96095E-06    -5.29681E-07    -1.23170E-08     -8.1
                 -6.91237E-07    -6.99308E-07    -1.69861E-08     -1.7
   4  791204      4.59634E-07    -6.41484E-07    -1.71904E-07     -2.4
                  1.89593E-06    -4.96989E-07     3.91063E-08     -1.2
                 -6.91178E-07    -6.99340E-07    -1.68995E-08     -1.6
   5  791205      5.92054E-07    -6.66972E-07    -1.83575E-07     -6.1
                  1.80381E-06    -4.22453E-07    -7.32591E-08      1.5
                 -6.90922E-07    -6.99147E-07    -1.66931E-08     -1.6
   6  791206      5.45124E-07    -6.87178E-07    -2.30410E-07      5.6
                  1.84632E-06    -4.12807E-07     9.95857E-08      3.6
                 -6.90904E-07    -6.98791E-07    -1.65528E-08     -1.5
   7  791207      5.29910E-07    -6.60036E-07    -6.80906E-08      2.8
                  1.87841E-06    -3.78728E-07    -2.58116E-07     -2.0
                 -6.90684E-07    -6.98945E-07    -1.77224E-08     -1.5
   8  791208      6.17841E-07    -6.64372E-07    -2.06368E-07      1.2
                  2.01034E-06    -2.86127E-07    -1.42389E-07     -6.3
                 -6.90663E-07    -6.98880E-07    -1.80014E-08     -1.5
   9  791209      7.64168E-07    -6.90215E-07     1.55266E-07      3.5
                  2.07320E-06    -3.67343E-07    -1.42182E-07     -1.8
                 -6.90748E-07    -6.98838E-07    -1.85958E-08     -1.5
  10  791210      7.11815E-07    -6.36623E-07    -7.95593E-08      8.2
                  2.04542E-06    -3.04686E-07    -2.45949E-07     -9.8
                 -6.90877E-07    -6.98737E-07    -1.88676E-08     -1.6
  11  791211      6.02969E-07    -5.72195E-07     4.26973E-08      1.9
                  2.07074E-06    -3.64270E-07    -2.38252E-07     -5.3
                 -6.90831E-07    -6.98407E-07    -1.92794E-08     -1.6
  12  791212      4.69510E-07    -4.88778E-07     1.73250E-07      2.4
                  2.13751E-06    -4.49889E-07    -5.02087E-08      7.7
                 -6.90486E-07    -6.98295E-07    -1.92077E-08     -1.5
  13  791213      3.64078E-07    -4.73097E-07     1.80567E-08      1.1
                  2.15729E-06    -4.58099E-07     1.13281E-07      1.2
                 -6.90316E-07    -6.98495E-07    -2.00997E-08     -1.5
  14  791214      2.82203E-07    -5.48446E-07    -2.62105E-08     -1.9
                  2.12871E-06    -4.86369E-07     1.08403E-07      6.0
                 -6.90240E-07    -6.98616E-07    -2.06155E-08     -1.5
  15  791215      2.78523E-07    -7.16356E-07     1.46684E-07     -1.3
                  2.00372E-06    -4.76009E-07     1.02477E-07      1.2
                 -6.90364E-07    -6.98737E-07    -2.10530E-08     -1.5
  16  791216      2.16082E-07    -7.56497E-07     1.47337E-07     -1.1
                  1.94502E-06    -4.16526E-07    -9.23015E-08      8.2
                 -6.90463E-07    -6.98839E-07    -2.10965E-08     -1.4
  17  791217      7.36047E-08    -7.62266E-07     8.57687E-08     -6.8
                  1.95384E-06    -4.27752E-07    -2.02220E-08      1.1
                 -6.90708E-07    -6.98726E-07    -2.11175E-08     -1.4
  18  791218      1.29772E-07    -6.36403E-07     1.23972E-07     -6.2
                  1.94910E-06    -5.13981E-07    -1.97061E-08      5.1
                 -6.90515E-07    -6.98857E-07    -2.09470E-08     -1.4
  19  791219      1.22354E-07    -6.48348E-07     1.20465E-07     -1.0
                  1.91893E-06    -6.06905E-07    -8.35181E-08      9.6
```

		-6.90628E-07	-6.98882E-07	-2.07408E-08	-1.4
20	791220	2.41377E-07	-6.27012E-07	1.13372E-07	-2.7
		2.01212E-06	-5.71518E-07	1.64018E-08	2.0
		-6.90830E-07	-6.98780E-07	-2.02416E-08	-1.4
21	791221	3.53845E-07	-5.08205E-07	1.35146E-07	-9.9
		2.02382E-06	-5.34406E-07	-1.03113E-07	2.3
		-6.90826E-07	-6.99044E-07	-2.01862E-08	-1.3
22	791222	4.44739E-07	-4.00063E-07	5.20625E-08	-1.1
		1.96599E-06	-5.74289E-07	-1.07007E-07	4.2
		-6.90923E-07	-6.98977E-07	-1.93667E-08	-1.3
23	791223	3.39790E-07	-4.29795E-07	7.80070E-08	1.1
		1.88020E-06	-6.68464E-07	-2.29010E-07	2.4
		-6.90663E-07	-6.98774E-07	-1.86687E-08	-1.3
24	791224	2.24361E-07	-5.45125E-07	3.59464E-08	9.3
		1.89089E-06	-6.80181E-07	-2.19180E-09	2.2
		-6.90653E-07	-6.98955E-07	-1.86666E-08	-1.3
25	791225	1.44817E-07	-8.23507E-07	1.33592E-08	1.2
		1.85478E-06	-6.87204E-07	-1.55666E-07	1.0
		-6.90756E-07	-6.99296E-07	-1.88014E-08	-1.3
26	791226	1.77224E-07	-8.20655E-07	1.92727E-09	1.6
		1.85615E-06	-5.30670E-07	-1.88844E-08	5.2
		-6.90732E-07	-6.99493E-07	-1.85648E-08	-1.2
27	791227	2.64390E-07	-7.09845E-07	-1.79314E-07	1.9
		1.92004E-06	-4.75868E-07	-1.76121E-08	5.1
		-6.90558E-07	-6.99434E-07	-1.88547E-08	-1.3
28	791228	3.41099E-07	-6.68634E-07	-1.09697E-07	1.8
		2.02225E-06	-5.09418E-07	-6.57024E-09	-1.1
		-6.90592E-07	-6.99106E-07	-1.92490E-08	-1.3
29	791229	4.88305E-07	-6.50277E-07	1.21882E-08	1.3
		2.04748E-06	-4.73863E-07	1.04579E-07	-2.1
		-6.90405E-07	-6.98904E-07	-1.96264E-08	-1.3
30	791230	5.62571E-07	-5.35216E-07	8.90300E-09	2.0
		1.98978E-06	-4.34258E-07	6.19784E-08	9.9
		-6.90229E-07	-6.98773E-07	-2.00040E-08	-1.3
31	791231	4.82630E-07	-4.56596E-07	2.27697E-08	2.3
		1.99742E-06	-3.76521E-07	-8.38819E-08	1.1
		-6.90105E-07	-6.98760E-07	-2.06797E-08	-1.3

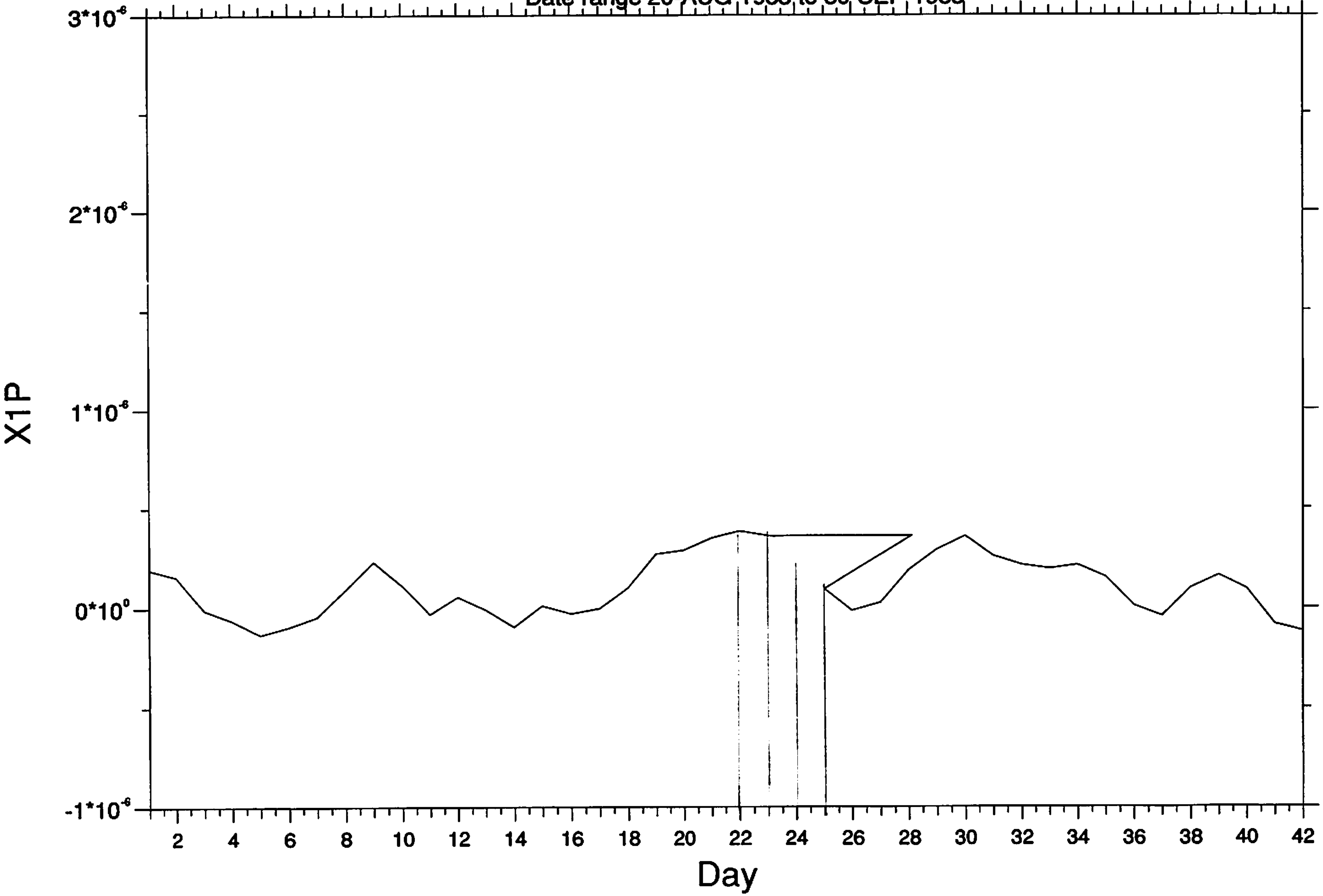
Effective Atmospheric Angular Momentum - UKMO dataset
Allegedly 30-APR-1988 to 30-JUN-1988



RAL GDF (User Andy Smith)

Plotted at 11:04:16 on 18-FEB-93

Effective Atmospheric Angular Momentum - UKMO dataset
Component X1P : rotation axis aligned with Greenwich Meridian;
pressure term; global data
Date range 20-AUG-1983 to 30-SEP-1983



RAL GDF (User Andy Smith)

Plotted at 15:02:00 on 5-MAR-93

Bit of ECMWF data

```
 33  800102       4.37702E-07     -6.85281E-07      1.06109E-08      1.04305E-07
                  1.93134E-06     -5.15841E-07      4.55439E-08      1.32307E-07
                 -6.90033E-07     -6.98238E-07     -2.05438E-08     -1.34627E-08
 34  800103       4.49198E-07     -7.47275E-07      1.06940E-07      1.82627E-07
                  1.94156E-06     -5.47160E-07     -5.35560E-08      5.73529E-08
                 -6.90118E-07     -6.98269E-07     -2.09873E-08     -1.40031E-08
 35  800104       3.92824E-07     -6.68641E-07      1.26111E-08      1.88917E-07
                  1.96231E-06     -4.62666E-07      1.34258E-08      1.83098E-07
                 -6.90266E-07     -6.98325E-07     -2.11653E-08     -1.32279E-08
```

Bit of UKMO data

```
83 5 2 0     0       4.82312E-07      1.69870E-06      1.38863E-06
                     7.55454E-09      2.14906E-07      3.34178E-08
                     4.89867E-07      1.91361E-06      1.42205E-06
83 5 3 0     0       6.30355E-07      1.42816E-06      1.38858E-06
                     1.98939E-07      6.69427E-08      3.26034E-08
                     8.29294E-07      1.49511E-06      1.42118E-06
```

Bit more UKMO data

```
88 1 2 0     0       7.96864E-07     -5.49084E-07     -5.30362E-08     -9.86233E-
08
                     1.95337E-06     -3.53284E-07      1.01069E-07      6.61286E-
08
                     6.91328E-07      6.97788E-07      2.03089E-08      1.43894E-
08
88 1 212     0       7.98691E-07     -5.88160E-07     -5.06796E-08      9.55919E-
09
                     1.95659E-06     -4.22648E-07     -9.27279E-08      1.81090E-
07
                     6.91152E-07      6.98055E-07      2.00450E-08      1.44977E-
08
88 1 3 0     0       7.57931E-07     -6.74134E-07     -6.86485E-08     -1.30628E-
08
                     1.94220E-06     -3.50852E-07      5.95388E-08      2.13684E-
08
                     6.91080E-07      6.97959E-07      2.03652E-08      1.41652E-
08
88 1 312     0       7.12672E-07     -6.67279E-07      1.29383E-07      9.83927E-
08
                     1.98271E-06     -3.93012E-07     -1.09045E-07      2.69011E-
07
                     6.91028E-07      6.98065E-07      2.08050E-08      1.42613E-
08
```

Bit of UKMO Washington data

```
 90010100    0 90010100
   0.00496    4.65526 -99.99999    0.13611   -5.08688 -99.99999
   1.35509   19.46022 -99.99999   -2.89762   -4.38598 -99.99999
   0.20089    6.89963 -99.99999    0.11143    6.98989 -99.99999
 90010112    0 90010112
   1.05624    5.23988 -99.99999    0.40426   -5.33084 -99.99999
   1.41955   19.51624 -99.99999    1.07980   -4.40288 -99.99999
   0.20179    6.90024 -99.99999    0.10908    6.98991 -99.99999
 90010200    0 90010200
  -0.09144    4.93844 -99.99999   -0.65481   -5.33942 -99.99999
   1.13814   18.89119 -99.99999   -2.91186   -4.15192 -99.99999
   0.19922    6.89976 -99.99999    0.10925    6.99115 -99.99999
```

Mr Andy Smith - for information

Professor Raymond Hide, Room 1, The Observatory
c/o NERC Oceanography Unit
c/o Dept. of Atmospheric, Oceanic and Planetary Physics
Clarendon Laboratory
Parks Road
Oxford OX1 3PU

Tel.: (0865) 272084
Fax: (0865) 311540

4th August 1993

Dr. Lesley J. Gray
Room 2.28, Building R25
MAS, SSD
Rutherford Appleton Laboratory
Chilton
Didcot
Oxon

Our ref: HR 2.2.1

Dear Lesley,

Transfer of atmospheric angular momentum (AAM) and Earth rotation (ER) data to RAL for dissemination via JANET

(1) I was disappointed to learn that the Committee responsible for allocating priorities to atmospheric sciences projects at RAL gave at its last meeting very low priority to the completion of the abovementioned task. Please will you bring this letter to the attention of the Chairman of the Committee with the request that the Committee reconsider its earlier decision at its next meeting, which I am told is due to take place in September.

(2) The Committee might have been influenced by the facts that (a) there is not yet a widespread demand for these data within the UK scientific community, which JANET was set up to serve, and (b) the emphasis of current in-house projects at RAL is in other areas of research relating to climate processes. The Committee might not have appreciated that in spite of their comparatively small size, making them easy to handle, the data sets involved are of central importance to any realistic study of the dynamics and energetics of large-scale-atmospheric flows. Their ready availability would strengthen existing research in the UK and could stimulate significant new work.

(3) I know that RAL is keen not only to serve the UK atmospheric sciences community but also to strengthen and extend its own in-house research in atmospheric sciences in various ways, including the widening of its contacts with UGAMP research. I appreciate that the Committee might have seen a stronger case had I been spending more of my time working at RAL. Most of the material (collected over many years) that I need for my work in this area is still in Oxford, but I am looking forward to transferring it to RAL and making it available to atmospheric scientists there when your current space problems have been resolved to the point of being able to provide me with a small room.

(4) No numerical model that fails to reproduce AAM fluctuations satisfactorily can be trusted in its treatment of other phenomena. For this reason, the Atmospheric Model Intercomparison Project (AMIP) of the Working Group for Numerical Experimentation (WGNE) of the World Climate Research Programme (WCRP) accepted a proposal from me (as Principal Investigator) and two groups of colleagues in the USA for a sub-project on AAM fluctuations, on intraseasonal, seasonal and interannual timescales.
This work is producing interesting new results and leading to what promises to be fruitful collaboration with the UGAMP, Hadley Centre, ECMWF and other modelling groups. AMIP is being coordinated by Dr. Lawrence Gates of the Lawrence Livermore Laboratory in California, and I hope to spend some time there later this year and also at CalTech in Pasadena working on AMIP with my colleagues on the AAM sub-project.

(5) The effort required to complete the transfer of AAM and ER data to RAL for dissemination via JANET will not be large, but the task will involve the cooperation of several individuals and institutions (Hadley Centre, UGAMP, ECMWF, RAL and possibly the International Earth Rotation Service (IERS) in Paris and the IERS Sub-Bureau for AAM at the National Meteorological Center (NMC) in Washington DC. Before the end of August, Paul Berisford of UGAMP and I, in consultation with Chris Hall, Mike Bell and Pat Roberts of the Hadley Centre, Andy Smith of RAL and others, will produce a plan for implementing the task as efficiently as possible, hoping that the Committee will give us the necessary encouragement when it meets next month.

With best regards

Yours sincerely

Raymond

Raymond Hide.

Replied
29/7/93

PROFESSOR RAYMOND HIDE, Room 1, The Observatory,
c/o NERC Oceanography Unit
c/o Dept. of Atmospheric, Oceanic and Planetary Physics
Clarendon Laboratory
Parks Road
Oxford OX1 3PU

Tel.: (0865) ~~272096~~ 272084
Fax.: (0865) 311540
~~or 272424~~

13 July 1993.

Dr Paul Berrisford,
Department of Meteorology,
University
READING, Berks.

cc. Dr Mike Bell
Hadley Centre,
Meteorological Office
BRACKNELL, Berks.

Ms Pat Roberts
c/o. Dr Mike Bell.

Mr Andy Smith
Atmospheric Physics
Division
Space Dept.
Rutherford
Appleton
Laboratory
(RAL). CHILTON,
Oxon.

Atmospheric AM data

Dear Paul,

Several weeks ago we discussed on the telephone progress towards the completion of the project to get ECMWF and UKMO atmospheric angular momentum (AAM) data into the JANET system. You emphasised the need for a discussion of the format to be used but indicated that the need was not urgent. We agreed that a meeting of those named above to take place in August, possibly at RAL, would be useful, and I agreed to take the initiative. The main purpose of this note is to ask all recipients to let me know what dates in August (and early September) they would find convenient, and I will then fix the date and venue. (RAL is preferred because this is where the data will end up!). Yours - Raymond

58 Rectory Close
Bracknell
Berkshire
RG12 7BD

Telephone
0344 484631

13 June 1994

Dear Andy

Enclosed is a copy of the addendum to "Atmospheric Angular momentum fluctuations and changes in the Earth's rotation: Meteorological Office Users' Guide to data sets and codes" by M J Bell and KDB Whysall (Met O 21 IR87/3); I think you had a copy of this Users' Guide itself earlier on?

Best wishes

Pat

ADDENDUM TO MET O 21 IR87/3 - "ATMOSPHERIC ANGULAR MOMENTUM FLUCTUATIONS AND CHANGES IN THE EARTH'S ROTATION : METEOROLOGICAL OFFICE USERS' GUIDE TO DATA SETS AND CODES"

by M J BELL and K D B WHYSALL

Met O 21 IR87/3 (above) was issued in December 1987 and provided comprehensive reference notes. Since then new data have accumulated along with changes in handling and storing both earlier and more recent data sets. This note records details of the later situation and should be used along with the existing Users' Guide (above) much of which remains valid.

The note 'PhD and AAM files stored on tape' by Mike Bell (8 June 1989) also still contains relevant information.

A text library of this addendum is kept as MS13.MBIR87AD.TEXT on cartridge 028517 and 019999, file 121 (see Appendix B)

N P Roberts
April 1994

UNITED KINGDOM METEOROLOGICAL OFFICE (UKMO)

{see chapters 1.4 and 4.3 of Met O 21 IR87/3}

I Regularly updated operational data

Source

Calculations by CFO continued first with the 15 level model and then from 12 GMT 12 June 1991 with the Unified Model; programs and archived data are now kept by CFO and CF6 (MOS and Output Products)

Contents and times of validity

As stated in Met O 21 IR87/3 Chapter 4.3 until 18 October 1989 when analyses and forecasts for days one to six again began to be made at both 00 GMT and 12 GMT

Format

From 12 GMT 18 April 1990 UKMO AAM analysis and forecast data have been transmitted regularly to the National Meteorological Centre (NMC), Washington DC, USA in a format for international exchange('Washington Code') agreed with NMC; the UKMO archive is now kept in this code and copies of data from 00 GMT 27 November 1986 (when the AAM forecasts began) onwards converted to it.
A copy of the code specification and other notes are included at Appendix A

Forecast Model

See Unified Model Documentation Paper No 1 by M J P Cullen

Data sets and locations

1. Analysis and forecast data are stored monthly as members Fmmyy or Nmmyy of library COP.BUKMO.DATA. F indicates members coded in the 'old' format described in Met O 21 IR87/3 chapter 4.3, and N indicates members in 'Washington Code'; mmmyy are the first three and last two characters respectively of any particular month and year. Currently (March 1994) the library contains F files from January 1988 (FJAN88) to December 1989 and N files from January 1990 to February 1994 (NFEB94).
2. The long term archive of analyses and forecasts is kept on cartridge 023768 (back up copy 018266) with data set names COP.BUKmmmyy.DATA where mmmyy is coded as in para.1 above. File 1 (COP.BUKDEC86.DATA) contains output from 00 GMT 27 November 1986 to 12 GMT 31 December 1986, while the record currently ends with file 87 (COP.BUKFEB94.DATA).

Missing data

a. Some 00 GMT originated forecast values from 22 April 1988 are missing.
b. Because of a timestepping problem with the Unified Model from its start at 00 GMT 12 June 1991 until 18 May 1992 calculations only advanced the AAM wind terms by 6 hours instead of 24 hours each time. Only analyses, forecast pressure terms and the 96 hour (which was in fact the true 24 hour) wind term forecasts were kept. The fault was corrected with effect from 00 GMT 19 May 1992
c. No record has been kept of other possible missing data since the end of 1987.

II Other UKMO AAM data

These data are stored on cartridge 028517 (catalogued) (back up copy 019999 (uncatalogued)) in the care of Dr M J Bell, FR division. (See also Appendix B)

1. Data referred to in Met O 21 IR87/3. M21.BUKMO1086.DATA and M21.BUKM1186.DATA have been renamed MS13.MBUK1086.DAT and MS13.MBUK1186.DAT and are on 028517 and 019999 files 61 and 62
2. A library containing analyses twice daily and forecasts to six days of EAAM hemispheric data (cf COP.BUKMO.DATA above) has been set up in the 'old' format (see Met O 21 IR87/3 chapter 4.3) for the period 27 November 1986 to 31 August 1992 and is kept as MS13.MBUKMO.DATA on 028517 and 019999,file 100. The library has been extended to 30 November 1993 and kept as MS13.MBUKMO2.DAT on 028517 and 019999, file 120 (These data also existed as MEJ1.CCOPUKMO.DATA on disk USR407 or USR003)
3. The UKMO EAAM analysis data have been sorted into (approximately) annual data sets as follows:

Data in 'old' format

```
MS13.MBUKMO.Y1983   ) Daily global values for the period
  "     "  .Y1984   ) 1 May 1983 to 31 Oct 1986 (see
  "     "  .Y1985   ) Met O 21 IR87/3 chapter 1.4) kept on
  "     "  .Y1986   ) cartridge 028517 and 019999,
                      files 90 to 93

MS13.MBUKMO.Y1987   ) Twice daily hemispheric values for the
  "     "  .Y1988   ) period 1 Nov 1986 to 31 Aug 1992 (see
  "     "  .Y1989   ) Met O 21 IR87/3 chapters 1.4 and 4.3)
  "     "  .Y1990   ) kept on cartridge 028517 and 019999,
  "     "  .Y1991   ) files 94 to 99
  "     "  .Y1992   )
```

(Data set names for the above 'old' format data sets on disk USR407 or USR003 begin MEJ1.CCOP--- instead of MS13.MB---)

Data in 'Washington Code'

```
MS13.MBUKMO.W1987    )
  "     "  .W1988    ) Twice daily hemispheric values for the
  "     "  .W1989    ) period 1 Nov 1986 to 31 Aug 1992 kept
  "     "  .W1990    ) on cartridge 028517 and 019999,
  "     "  .W1991    ) files 106 to 111
  "     "  .W1992    )
```

(Data set names for the above 'Washington Code' data on disk USR407 or USR003 begin MEJ1.CC--- instead of MS13.MB---)

Copies of all of these annual analyses data sets have been sent to the Rutherford Appleton Laboratory, Chilton Didcot, Oxon and arrangements have been made for a regular supply of current analysis data to be made to the Laboratory through the INTERNET system.

EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS (ECMWF)

I Analysis data (see chapter 1.1 of Met O 21 IR87/3)

Source

Produced by co-operation between UK Meteorological Office, Bracknell and the Department of Meteorology, Reading University as part of the Joint Diagnostics Project (JDP).

Format

The format has continued as described in Met O 21 IR87/3 chapter 1.1

Times of Validity

As stated in Met O 21 IR87/3 chapter 1.1, then from 1 January 1987 to 31 May 1987 data are valid at 12 GMT and from 1 June 1987 onwards they are the mean of values at 00,06,12 and 18 GMT.

Forecast Model

Further developments in and changes to the ECMWF forecast model are described in the quarterly ECMWF Forecast Reports and in the meteorological articles in the ECMWF Newsletter (issued every three months); a list of still valid articles appears at the back of each issue of the newsletter.

Data sets and locations (see also Appendix B)

1. M21.BEC1286.DATA has been renamed MS13.MBE1286.DAT and is on cartridge 028517 and 019999, file 60. Its continuation data set (previously M21.BECM87.DATA) now includes data from 1 January 1987 to 31 December 1988, has been renamed MS13.BEC1288.DAT and is on 028517 and 019999, file 69.
2. Data from January 1989 to August 1992 are kept as a library of monthly data sets MS13.MBECJDP.DATA on cartridge 028517 and 019999, file 88. MS13.MBECJDP2.DAT on 028517 and 019999, file 119 contains similar data from January 1989 to November 1993. (These data were kept on disk USR407 or USR003 as MEJ1.CCECIBM.DATA along with a working library MEJ1.CCECJDP.DATA with monthly members coded in the 'old' UKMO format (see Met O 21 IR87/3 chapter 1.4))
3. These ECMWF AAM analysis data have been sorted into (approximately) annual data sets as follows:

```
MS13.MBEC.JDP1980  ) Daily hemispheric values for the period
  "    " .JDP1981  ) 1 December 1979 to 31 August 1992 kept
 and similarly     ) on cartridge 028517 and 019999,
 for each year to  ) files 75 to 87
MS13.MBEC.JDP1992  )
```

(Data set names for these annual data on disk USR407 or USR003 were of the form MEJ1.CCECJDP.Y1980 and similarly to MEJ1.CCECJDP.Y1992)

Updating and transferring data

This has proceeded by methods similar to those described in Met O 21 IR87/3 chapter 5.2, although new job control routines were written for the work at ECMWF when a CRAY Y-MP computer was installed, and data there were stored by ECFILE. The shell scripts may be found in library MS13.MBECMWF.CTL (see Programs section below)

A copy of the existing long term record of ECMWF AAM calculations has now been transferred to the Rutherford Appleton Laboratory, Chilton Didcot, Oxon and arrangements have been made for the regular supply to the Laboratory of current data which will no longer be accumulated at UKMO.

II Forecast data (see chapter 4.1 of Met O 21 IR87/3)

ECMWF forecasts and initialised analyses continued to be accumulated on M21.BECMWF.DATA (later MEJ1.CCECMWF.DATA on disk USR407 or USR003) mainly as described in Met O 21 IR87/3 chapter 4.1 until December 1988; however times of validity are for the most part 00 GMT analysis and 72, 120 and 240 hour forecasts, with only May, June and July 1987 having analysis and forecasts at 24 hour intervals to 240 hours. Similar data from 1 January 1986 to 31 December 1988 are now kept as separate monthly data sets on cartridge 028517 and 019999, files 1 to 36. Data set names are of the form MS13.MBECmmyy.BHS, where mm is the month number (01 to 12) and yy the last two digits of the year number (86, 87 or 88); BHS refers to Bell, Hide and Sakellarides for and by whose work the data were derived.

A second set of ECMWF operational data was written to M21.BECMW2.DATA (later MEJ1.CCECMW2.DATA) on USR407 or USR003, containing twice daily (origin 00 GMT and 12 GMT) forecast values to 24, 48 and, except for December 1987 and January 1988, 96 hours, along with uninitialised analyses for 00, 06, 12 and 18 GMT. The forecast data are for December 1987 to December 1988 and the analyses for December 1987 to January 1989; they are now kept as a library of monthly data sets in MS13.MBECBHS.DATA on cartridge 028517 and 019999, file 89.

Routines for extracting all of these forecast data may be found in MS13.MBECMWF.CTL (see Programs section below)

Data sets M21.BFAGFB, M21.BAGALL and M21 BDCALL, referred to in Met O 21 IR87/3 chapter 4.1.B, have not been kept.

UNITED STATES NATIONAL METEOROLOGICAL CENTRE (NMC)

I Analysis data (see chapter 1.3 of Met O 21 IR87/3)

Data sets have been renamed as follows:

M21.BNM1179A	renamed	MS13.MBNM1179.NIB
M21.BNM1179I	renamed	MS13.MBNM1179.IBC
M21.BNM1286A	renamed	MS13.MBNM1286.NIB
M21.BNM1286I	renamed	MS13.MBNM1286.IBC

They are kept on cartridge 028517 and 019999 files 65, 66, 67 and 68 respectively.

Data sets on tape 841844 referred to at the beginning of chapter 1.3 of Met O IR87/3 (on page 6) have not been kept and new data are no longer being received.

II Forecast data (see chapter 4.2 of Met O 21 IR87/3 and 'PhD and AAM files stored on tape' by Mike Bell)

NMC analysis, forecast and verification data (of the form and content described in Met O 21 IR87/3 chapter 4.2) continued to be accumulated until the end of May 1989, when the supply ceased.

The members of M21.BNMC.DATA were written to separate files on tape 843074 which have been copied to cartridge 028517 and 019999, files 37 to 59 with data set names of the following forms:

a. Initialised analyses and 12 to 240 hour forecasts of EAAM wind terms:
MS13.MBFNMyys.DAT
Where yy are the last two characters of any one year
s is a season of up to three months
From November 1985 to August 1987 s is coded as A for January, February, March, B for April, May, June, C for July, August, September and D for October, November, December or part of these spells.
From September 1987 to May 1989 s is coded as A for December, January, February, B for March, April, May, C for June, July, August and D for September, October, November.

b. Uninitialised verification analyses:
MS13.MBNMVER.DAT contains data from 1 November 1985 to 31 August 1987.
MS13.MBVNMyys.DAT contain seasonal data from September 1987 to May 1989, with yys coded as described in a. above.

JAPANESE METEOROLOGICAL AGENCY (JMA)

(see chapter 1.2 of Met O 21 IR87/3 and 'PhD and AAM files stored on tape' by Mike Bell 8 June 1989)

Data sets and locations

M21.BJMA1286.DATA has been renamed MS13.MBJM1286.DAT and is kept on cartridge 028517 and 019999, file 64.
M21.BJMA1085.DATA has been renamed MS13.MBJM1085.DAT and is kept on cartridge 028517 and 019999, file 63.
M21.BJMA88.DATA has been renamed MS13.MBJMA88.DAT and is kept cartridge 028517 and 019999, file 70.
M21.BJMA86A.DATA has not been kept.

PROGRAMS

(see Met O 21 IR87/3 and the note 'PhD and AAM files stored on tape' by Mike Bell.
There were some changes of location between those stated in Met O 21 IR87/3 and the 'PhD and AAM files' note; the latter is the more recent reference.
Data set names found in job control statements in the libraries may be those set up for data kept on disk USR407 or USR003.
See also Appendix B for lists of AAM and related data kept on cartridge)

1. M21.BANGLIB.CNTL (MEJ1.CCANGLIB.CNTL on USR407 or USR003) has been renamed MS13.MBANGLIB.CTL and is kept on cartridge 028517 and 019999, file 103; a later version of this library has been written to MS13.MBANGLB2.CTL on 028517 and 019999, file 114.

a. Members remaining as described in the 'PhD and AAM files'note: BFSC7A, BFSC83, BFTEMP, DUSC83, DUSC84, DUSNEW (added soon after note written), DUT7A, DUT7B, DUT8A, DUT8B, DUT88B.

b. More recent sets of IBM job control for plotting various time series of UKMO and ECMWF analysis data using BFRNEU and related routines (from M21.BSRCELIB.FORT (see below)):
BANGANN, BANGFIL, BANGMDD, BANGMOM, BANGSEA, BANG3M

c. Routines for reading, writing and converting UKMO analyses in 'old' format and in 'Washington Code':
ANGMMCNV (used by CF6, supplied for information only),
BANGCON, BANGCONW, BANGDISW, BANGRDW, BANGRD1, BANGRD2,
BANGRRD, BANGWASH

d. Routine for reading Werner Wergen's data from tape and setting them up in a direct access data set on disk:
BTCWW

2. M21.BSRCELIB.FORT (MEJ1.CCBSRCE.FORT on USR407 and USR003) has been renamed MS13.MBSRCE.FRT and is kept on cartridge 028517 and 019999, file 102 with a later version MS13.MBSRCE2.FRT on 028517 and 019999, file 116. The member list is unchanged from the 'PhD and AAM files' note but some additional facilities have been added to members BFRNEU and TLINE.

3. M21.BANGOLD.FORT (MEJ1.CCANGOLD.FORT on USR407 and USR003) has been renamed MS13.MBANGOLD.FRT and is kept on cartridge 028517 and 019999, file 101. Member list unchanged from that in 'PhD and AAM files' note.
A later version MS13.MBANGOL2.FRT on 028517 and 019999, file 115 also contains the following additional routines copied from M21.DEADSRCE:
KALCMP, KANGMOLD, KANGMOM, KANGMOM2, KANG8082, KCORZON,
KHTPLT, KMTNNH, KMTNSH, KNEWPLT, KOREL, KTIDES, KTRYCOR,
KTRYCR2, KZONKE, KZONPLT,READANG

4. M21.BLOD.COMB (MEJ1.CCLOD.COMB on USR407 or USR003) has been renamed MS13.MBLOD.COMB and is kept on cartridge 028517 and 019999, file 105. Member list unchanged from that in 'PhD and AAM files note'

5. M21.BECMWF.CNTL (MEJ1.CCECMWF.CNTL on USR407 or USR003) has been renamed MS13.MBECMWF.CTL and is kept on cartridge 028517 and 019999, file 104, with a later version MS13.MBECMWF2.CTL on 028517 and 019999, file 117

a. Members remaining as described in 'PhD and AAM files' note:
FCANAL (Updated for use with CRAY Y-MP system), FCFORE, FCOPONE, FCOPTWO, JDPCOPY, WWCOP, WWCRAY, WWREAD
Members MASCOP, MASREAD, MASTIM and MASWRIT were kept on MS13.MBECMWF.CTL but deleted from MS13.MBECMWF2.CTL.
(The job control in many of these routines may need to be updated).

b. Members not kept:
CRTRANS, CYUTIL, JDPREAD

c. New members:
FCOPTHR - copies data from ECMWF JDP data set into 'old' format for use with BFRNEU plotting program.
JDPTRAN - Selects and transfers half month JDP data sets from ECFILE through the CRAY Y-MP system to COSMOS.
Routines to perform various data manipulating and housekeeping tasks:
(Some of these may only be found on MS13.MBECMWF2.CTL)
CHARRD, ECCHAR, ECCOMP, ECCOS, ECFICOS, ECFILDAT, ECFILE, ECHK ECJDPCOP, ECJDPCP2, ECJDPRD, ECLIST, ECSEND, ECSEND2, ECSEND3, ECSEND4, ECTRA, FILE

OTHER DATA

1. Werner Wergen's FGGE year Rossby modes data set (see 'PhD and AAM files stored on tape' by Mike Bell, page 2), previously kept as M21.BWERGEN.DATA on tape 210116, file 12 has been renamed MS13.MBWERGEN.DAT and is kept on cartridge 028517 and 019999, file 71 (see also Programs section 1d above)

2. The Klaus Arpe data set of zonal mean zonal winds and an associated set of AAM data (see Met O 21 IR87/3 chapter 3 and 'PhD and AAM files stored on tape' by Mike Bell, page 2) previously kept as M21.BBARPE.DATA and M21.KARPDAT2 on tape 841843, files 8 and 10 have been renamed MS13.MBARPE.DATA and MS13.MBARPE2.DATA and are kept on cartridge 028517 and 019999, files 112 and 113.

3. Program libraries used by Kim Whysall for PhD studies are kept as MS13.MBWHYSAL.CTL, MS13.MBWHYSAL.FRT and MS13.MBWHYSA2.FRT on cartridge 028517 and 019999, files 72, 73, and 74.

```
DATA SET: MEJ1.CCIR87AD.TEXT                                    PDS DIRECTORY
DATE: 94/04/26                TIME: 13:32                              PAGE:      12

NAME         PAGE

AFRONT          1
BUKMO           2
CECMWF          5
DNMC            7
EJMA            8
FPROGRAM        9
OTHERDAT       11
```

APPENDIX
A

National Meteorological Center

SBAAM User Notes

January 1990

Appendix I

The NMC spectral fields are produced using the following formulae for the transformation routines:

$$f(\lambda,\phi) = (2 - \delta_{0m}) \sum_{m=0}^{M} \sum_{n=m}^{N+J} (a_n^m \cos m\lambda - b_n^m \sin m\lambda) P_n^m(\mu) \qquad (1)$$

where δ_{0m} is the Kronecker delta function, μ- sin ϕ, and J-0 or M depending on whether the truncations is triangular of rhomboidal, respectively. The Legendre functions are defined as:

$$P_n^m(\mu) = \frac{1}{2^n n!}\left[\frac{(2n+1)(n-m)!}{2(n+m)!}\right]^{1/2} (1-\mu^2)^{m/2} \frac{d^{m+n}}{d\mu^{n+m}} (\mu^2 - 1)^n \qquad (2)$$

Definition (2) results in:

$$\int_{-1}^{1} P_n^m P_{n'}^{m'} \, d\mu - \delta_{nn'} \, \delta_{mm'} \qquad (3)$$

The Met. Office

Facsimile Transmission

DATE: 6th April 1990 TIME: 14:45 (HH:MM)

To:
Name: Dr Deirdre Kann
Company: Climate Anal. Cen. NMC
Fax No.: 0101 301 763 8395

From:
Name: Dr Howard Lyne
Branch: Met O 8 Room No.: R212
Fax No.: 0344 854412

TOTAL No. of pages transmitted including this sheet: 2

If you do not receive all pages as indicated, please telephone:

BRACKNELL (0344) 854414

MESSAGE

Dear Deirdre

Re: Your fax of 23rd February concerning AAM

Thanks for the efforts made by yourselves at NMC to allow us to send our AAM data via the GTS links. We intend to start sending the data following our 12 UTC run of the 18th April. A print of an example is attached, and conforms closely to the MOMANAL file format employed by the sub-bureau.

You will notice two differences:

(a) missing data indicator is -99.99999. The sub-bureau specification of -99. is not consistent with the format F9.5, and we find it more convenient to conform with the latter.

(b) character transmissions cannot exceed 68 words per line and so we have been forced to shorten the lines containing the AAM components. We have made no commitment to supplying the contributions due to wind below 100mb (first and fifth words) and so these have been omitted to leave a line of format 6(1X,F9.5). We do intend to supply inverted barometer values eventually, and their locations are occupied by missing data indicators. Alas I can give no time-scale for their inclusion, but it is unlikely to be this year.

Please let me know if either of the above will cause you problems.

Yours sincerely

Howard Lyne

Howard Lyne
Central Forecasting Division

```
FXXX30 EGRR 060000
 90040600    0 90040600
  -0.94515   5.74650 -99.99999   1.50171  -8.33918 -99.99999
   1.82846  21.09247 -99.99999   0.10260  -5.80604 -99.99999
   0.18737   6.89385 -99.99999   0.15198   6.99107 -99.99999
 90040600   24 90040700
   0.43535   6.06600 -99.99999   0.79318  -9.14631 -99.99999
   2.14392  20.98343 -99.99999   0.25875  -3.04102 -99.99999
   0.18288   6.89221 -99.99999   0.15349   6.99212 -99.99999
 90040600   48 90040800
  -0.59075   5.38851 -99.99999   1.98930  -7.56241 -99.99999
   3.32639  21.18053 -99.99999  -0.25533  -0.62947 -99.99999
   0.18073   6.89272 -99.99999   0.15679   6.99277 -99.99999
 90040600   72 90040900
  -2.12629   5.92736 -99.99999   2.35879  -6.01125 -99.99999
   4.67072  22.23004 -99.99999  -0.67424  -0.65840 -99.99999
   0.17647   6.89207 -99.99999   0.16070   6.99112 -99.99999
 90040600   96 90041000
  -1.35490   7.36727 -99.99999   0.94304  -5.83745 -99.99999
   4.27711  22.53918 -99.99999  -1.18602  -1.65916 -99.99999
   0.17175   6.89053 -99.99999   0.16517   6.98855 -99.99999
 90040600  120 90041100
   0.10523   8.56965 -99.99999  -0.57690  -6.24882 -99.99999
   2.91602  21.57166 -99.99999  -0.94782  -2.16332 -99.99999
   0.16968   6.89109 -99.99999   0.16989   6.98559 -99.99999
 90040600  144 90041200
   0.08903   8.36761 -99.99999  -0.38719  -5.96690 -99.99999
   1.72555  20.58461 -99.99999  -0.63890  -2.41692 -99.99999
   0.16899   6.89062 -99.99999   0.17257   6.98353 -99.99999
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USED BY	DATE	FILE	DSN	RECFM	LRECL	BLKSIZE	REMARKS (copy) 019999
		1	MS13.MBEC0186.BHS	FB	80	4800	
		2	" .MBEC0286. "	"	"	"	
		3	" .MBEC0386. "	"	"	"	
		4	" .MBEC0486. "	"	"	"	
		5	" .MBEC0586. "	"	"	"	European Centre for Medium Range
		6	" .MBEC0686. "	"	"	"	Weather Forecasts (ECMWF)
		7	" .MBEC0786. "	"	"	"	Analysis and forecast data
		8	" .MBEC0886 "	"	"	"	Jan 1986 to Dec 1988
		9	" .MBEC0986. "	"	"	"	MARS extracted for Bell, Hide and
		10	" .MBEC1086. "	"	"	"	Sakellarides work (BHS)
		11	" .MBEC1186. "	"	"	"	
		12	" .MBEC1286. "	"	"	"	
		13	" .MBEC0187. "	"	"	"	
		14	" .MBEC0287. "	"	"	"	
		15	" .MBEC0387. "	"	"	"	
		16	" .MBEC0487. "	"	"	"	
		17	" .MBEC0587. "	"	"	"	
		18	" .MBEC0687. "	"	"	"	
		19	" .MBEC0787. "	"	"	"	
		20	" .MBEC0887. "	"	"	"	
		21	" .MBEC0987. "	"	"	"	
		22	" .MBEC1087. "	"	"	"	
		23	" .MBEC1187. "	"	"	"	
		24	" .MBEC1287. "	"	"	"	
		25	" .MBEC0188. "	"	"	"	
		26	" .MBEC0288. "	"	"	"	
		27	" .MBEC0388. "	"	"	"	

APPENDIX B

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EXPDT
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		28	MS13.MBEC0488.BHS	FB	80	4800	
		29	" .MBEC0588. "	"	"	"	
		30	" .MBEZ0688. "	"	"	"	ECMWF
		31	" .MBEZ0788. "	"	"	"	Analysis and forecast data
		32	" .MBEZ0888. "	"	"	"	Jan 1986 to Dec 1988 (continued)
		33	" .MBEC0988. "	"	"	"	MARS extracted for Bell, Hide and
		34	" .MBEC1088. "	"	"	"	Sakellarides work (BHS)
		35	" .MBEC1188. "	"	"	"	
		36	" .MBEZ1288. "	"	"	"	

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		37	MS13.MBNMVER.DAT	FB	80	4800	
		38	" .MBFNM85D. "	"	"	"	
		39	" .MBFNM86A. "	"	"	"	
		40	" .MBFNM86B. "	"	"	"	
		41	" .MBFNM86C. "	"	"	"	US National Meteorological Centre
		42	" .MBFNM86D. "	"	"	"	Analyses and 12 to 240 hour forecasts
		43	" .MBFNM87A. "	"	"	"	of EAAM wind terms (MS13.MBFNM---.DAT)
		44	" .MBFNM87B. "	"	"	"	and associated verification analyses
		45	" .MBFNM87C. "	"	"	"	(MS13.MBNMVER.DAT and MS13.MBVNM---.DAT)
		46	" .MBVNM87D. "	"	"	"	from Nov 1985 to Jun 1989
		47	" .MBFNM87D. "	"	"	"	
		48	" .MBVNM88A. "	"	"	"	
		49	" .MBFNM88A. "	"	"	"	
		50	" .MBVNM88B. "	"	"	"	
		51	" .MBFNM88B. "	"	"	"	
		52	" .MBVNM88C. "	"	"	"	
		53	" .MBFNM88C. "	"	"	"	
		54	" .MBVNM88D. "	"	"	"	
		55	" .MBFNM88D. "	"	"	"	
		56	" .MBFNM89A. "	"	"	9040	
		57	" .MBVNM89A. "	"	"	"	
		58	" .MBFNM89B. "	"	"	"	
		59	" .MBVNM89B. "	"	"	"	

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		60	MSIB.MBEC1286.DAT	FB	80	4800	
		61	" .MBUK1086."	"	133	3857	Well organised EAAM analysis data from:
		62	" .MBUK1186."	"	80	4800	European Centre for Medium Range
		63	" .MBJM1085."	"	133	3857	Weather forecasts (EC)
		64	" .MBJM1286."	"	80	4800	United Kingdom Meteorological Office (UK
		65	" .MBNM1179.NIB	"	"	"	US National Meteorological Centre (NM
		66	" .MBNM1179.IBC	"	"	"	Japanese Meteorological Agency (JM)
		67	" .MBNM1286.NIB	"	"	"	
		68	" .MBNM1286.IBC	"	"	"	
		69	" .MBEC1288.DAT	"	"	"	
		70	" .MBJMA88."	"	"	"	
		71	" .MBWCRGEN."	"	2920	29200	Werner Wergen's FGGE year Rossby modes data set
		72	" .MBWHYSAL.CTL	VS	4256	4260	K Whysall PhD studies libraries - 'unloaded'
		73	" .MBWHYSAL.FRT	"	"	"	to cartridge using IEBCOPY which must
		74	" .MBWHYSA2.FRT	"	"	"	also be used to restore them to disk
		75	" .MBEC.JDP1980	FB	80	4800	
		76	" " .JDP1981	"	"	"	
		77	" " .JDP1982	"	"	"	Daily ~~totals~~ hemispheric of EAAM analyses
		78	" " .JDP1983	"	"	"	originated for the Joint Diagnostics
		79	" " .JDP1984	"	"	"	Project (JDP) from the European
		80	" " .JDP1985	"	"	"	Centre for Medium Range Weather
		81	" " .JDP1986	"	"	"	Forecasts forecast model program
		82	" " .JDP1987	"	"	"	
		83	" " .JDP1988	"	"	"	
		84	" " .JDP1989	"	"	"	
		85	" " .JDP1990	"	"	"	
		86	" " .JDP1991	"	"	"	
		87	" " .JDP1992	"	"	"	

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(continued) REMARKS (copy) 019999

USED BY	DATE	FILE	DSN	RECFM	LRECL	BLKSIZE	REMARKS
ibraries of monthly datasets unloaded ith IEBCOPY which must e used to restore them to disk		88	MS13.MBECJDP.DATA	VS	4816	4820	ECMWF (JDP) daily EAAM analyses - mid Dec 1988 to Aug 1992
		89	" .MBECBHS. "	"	"	"	ECMWF - Bell Hide and Sakellarides (BHS) MARS extracted EAAM analysis and forecast data Dec 1988 to Jan 1989
		90	" .MBUKMO.41983	FB	80	4800	Daily global values of EAAM analyses originated at the UK Meteorological Office
		91	" " .41984	"	"	"	
		92	" " .41985	"	"	"	
		93	" " .41986	"	"	"	
		94	" " .41987	"	"	"	Twice daily hemispheric values of EAAM analyses originated at the UK Meteorological Office
		95	" " .41988	"	"	"	
		96	" " .41989	"	"	"	
		97	" " .41990	"	"	"	
		98	" " .41991	"	"	"	
		99	" " .41992	"	"	"	
brary of monthly data sets unloaded with IEBCOPY which must be used to restore to disk		100	" " .DATA	VS	4256	4260	~~Analyses (twice daily) and forecasts (to 6 days) of EAAM~~ hemispheric data from mid Nov 1986 to Aug 1992
		101	" .MBANGOLD.FRT	"	"	"	Libraries with routines for manipulating many kinds of EAAM and related data - 'unloaded' to cartridge using IEBCOPY which must be used to restore them to disk
		102	" .MBSRCE.FRT	"	"	"	
		103	" .MBANGLIB.CTL	"	"	"	
		104	" .MBECMWF.CTL	"	"	"	
		105	" .MBLOD.COMB	"	"	"	
		106	" .MBUKMO.W1987	FB	80	4800	Twice daily hemispheric values of EAAM analyses originated at the UK Meteorological Office and coded in 'Washington code'
		107	" " .W1988	"	"	"	
		108	" " .W1989	"	"	"	
		109	" " .W1990	"	"	"	
		110	" " .W1991	"	"	"	
		111	" " .W1992	"	"	"	
		112	" .MBARPE.DATA	"	"	22400	Klaus Arpe data set of zonal mean zonal winds
		113	" .MBARPE2.DATA	"	"	22400	Associated AAM data
		114	" .MBANGLB2.CTL	VS	4256	4260	Later versions of libraries on files 103 and 101 above
		115	" .MBANGOL2.FRT	"	"	"	

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USED BY	DATE	FILE	DSN	RECFM	LRECL	BLKSIZE	REMARKS (copy) 019999
		116	M813.MBSRC02.FRT	VS	4256	4260	Later versions of libraries on
		117	" .MBECMWF2.CTL	"	"	"	files 102 and 104 above
		118	" .MBCCLIB.CTL	"	16016	16020	Library copied from MET1,CCLIB,CNTL
		119	" .MBECJDP2.DAT	"	4816	4820	Later versions of libraries on
		120	" .MBUKMO2.DAT	"	16016	16020	files 88 and 100 above
		121	" .MBIR87AD.TEXT	"	"	"	Text library of addendum to
							Met O 21 IR87/3
							All of the above libraries in files
							114 to 121 have been 'unloaded'
							to cartridge using IEBCOPY which
							must be used to restore them to disk

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MEETING ON TUESDAY 14 JULY 1992 TO DISCUSS TRANSFER OF ATMOSPHERIC ANGULAR MOMENTUM AND RELATED DATA FROM UKMO AND ECMWF TO RAL.

<u>Present</u>. Lesley Gray (RAL)
Raymond Hide (Robert Hooke Inst).
Michiko Masutani (Reading U.)
Patricia Roberts (Reading U).
Paul Beresford

The quantities produced routinely every 12 hours from GNWP analyses and forecasts are the following:

χ_1 , χ_2 , χ_3 – dimensionless measures of the two equatorial and axial components of the atmospheric angular momentum. (AAM)

$\chi_1^P , \chi_1^W ; \chi_2^P , \chi_2^W ; \chi_3^P , \chi_3^W$ – where $\chi_1 = \chi_1^P + \chi_1^W$, etc respectively the contributions of the mass field and wind field to χ_1, etc

$\chi_1^{P,NH} , \chi_1^{P,SH} ; \chi_1^{W,NH} , \chi_1^{W,SH}$ etc. – respective contributions from Northern and Southern Hemisphere.

In the future, additional quantities such as surface tractions and net torque, more finely banded contributions to χ_i, etc. are likely to be produced.

APPENDIX. ATMOSPHERIC EXCITATION OF SHORT-TERM CHANGES IN THE LENGTH OF THE DAY AND POLAR MOTION

The dimensionless atmospheric 'effective angular momentum' (e.a.m.) functions mentioned in §2 above, which facilitate the analysis of the dynamical interaction of the atmosphere with the solid Earth, comprise the equatorial components χ_1 and χ_2 and the axial component χ_3 of the pseudo-vector χ_i, $i = 1, 2, 3$, (see BHWW, especially §5), where (χ_1, χ_2, χ_3) are defined as follows:

$$\chi_1 \equiv \frac{-1.00\,\bar{R}^4}{(C-A)\,g}\oiint p_s \sin\phi\cos^2\phi\cos\lambda\,\mathrm{d}\lambda\,\mathrm{d}\phi$$
$$\frac{-1.43\,\bar{R}^3}{\Omega(C-A)\,g}\oiiint(u\sin\phi\cos\phi\cos\lambda - v\cos\phi\sin\lambda)\,\mathrm{d}\lambda\,\mathrm{d}\phi\,\mathrm{d}p, \quad \text{(A 1)}$$

$$\chi_2 \equiv \frac{-1.00\,\bar{R}^4}{(C-A)\,g}\oiint p_s \sin\phi\cos^2\phi\sin\lambda\,\mathrm{d}\lambda\,\mathrm{d}\phi$$
$$\frac{-1.43\,\bar{R}^3}{\Omega(C-A)\,g}\oiiint(u\sin\phi\cos\phi\sin\lambda + v\cos\phi\cos\lambda)\,\mathrm{d}\lambda\,\mathrm{d}\phi\,\mathrm{d}p, \quad \text{(A 2)}$$

$$\chi_3 \equiv \frac{0.70\,\bar{R}^4}{Cg}\oiint p_s\cos^2\phi\,\mathrm{d}\lambda\,\mathrm{d}\phi + \frac{\bar{R}^3}{\Omega C g}\oiiint u\cos^2\phi\,\mathrm{d}\lambda\,\mathrm{d}\phi\,\mathrm{d}p. \quad \text{(A 3)}$$

The surface and volume integrals are defined as:

$$\oiint(\ )\,\mathrm{d}\lambda\,\mathrm{d}\phi \equiv \int_{-\frac{1}{2}\pi}^{+\frac{1}{2}\pi}\int_0^{2\pi}(\ )\,\mathrm{d}\lambda\,\mathrm{d}\phi,$$

and

$$\oiiint(\ )\,\mathrm{d}\lambda\,\mathrm{d}\phi\,\mathrm{d}p = \int_0^{p_s}\int_{-\frac{1}{2}\pi}^{+\frac{1}{2}\pi}\int_0^{2\pi}(\ )\,\mathrm{d}\lambda\,\mathrm{d}\phi\,\mathrm{d}p. \quad \text{(A 4)}$$

In these expressions, (ϕ, λ) denote latitude and longitude respectively, $p_s(\phi, \lambda, t)$ is the surface pressure, where t denotes time, and $u(\phi, \lambda, p, t)$ and $v(\phi, \lambda, p, t)$ are the eastward and northward components of the wind velocity at pressure level p_0. In the calculations presented here we follow BHWW who took $\bar{R} = 6.37 \times 10^6$ m for the mean radius of the solid Earth, $\Omega = 7.29 \times 10^{-5}$ rad s^{-1} for its mean rotation rate, $g = 9.81$ m s^{-2} for the mean acceleration due to gravity, $C = 7.04 \times 10^{37}$ kg m^2 for the polar moment of inertia of the solid Earth (i.e. crust and mantle) and $(C-A)/C = 0.00333$, where A is the corresponding equatorial moment of inertia. The pressure integral is evaluated between the limits 5×10^3 to 10^5 Pa (50–1000 millibar) rather than 0 to p_s because wind data are available only on specific isobaric levels.

Atmospheric Angular Momentum analysis data available at UK Meteorological Office, Bracknell.

Data originated by:

I UK Meteorological Office

a) 1 May 1983 to 31 October 1986
Daily values at 00 GMT

Global wind and pressure terms for each of the three components of the EAAM functions

b) 1 November 1986 to 31 March 1992
Twice daily values at 00 and 12 GMT

Wind and pressure terms for all three components of the EAAM functions for both northern and southern hemispheres

II European Centre for Medium Range Weather Forecasts (ECMWF) (Joint Diagnostics Project)

a) 1 December 1979 to 30 November 1980
Daily values at 12 GMT

b) 1 December 1980 to 15 March 1982
Daily values at 00 GMT

c) 16 March 1982 to 29 February 1984
Daily values at 12 GMT

d) 1 March 1984 to 15 March 1984
Daily values at 00 GMT

e) 15 March 1984 to 31 May 1987
Daily values at 12 GMT

f) 1 June 1987 to 31 March 1992
Mean of daily values at 00, 06, 12 and 18 GMT

Wind and pressure terms for all three components of the EAAM functions for both northern and southern hemispheres

III Japanese Meteorological Agency (JMA)

a) 28 September to 4 December 1983
Twice daily values at 00 and 12 GMT
b) 1 to 4 and 12 to 25 December 1983
Mean daily values
c) 1 to 25 December 1983
Daily values at 00 GMT

[Global wind and pressure terms with inverted barometer correction for each of the three components of the EAAM functions

d) 2 January 1984 to 30 June 1986
Mean daily values
and daily values at 00 GMT
e) 1 July 1986 to 31 December 1987
Twice daily values at 00 and 12 GMT

[Wind and ※ pressure terms for all three components of the EAAM functions for the northern and southern hemispheres

IV National Meteorological Centre (NMC)

a) 1 July 1976 to 28 February 1987
Twice daily values at 00 and 12 GMT

[Wind and ※ pressure terms for all three components of EAAM functions for the northern and southern hemispheres

b) 1 November 1985 to 31 May 1989
Daily values at 00 GMT

[Wind terms for the axial EAAM function for both northern and southern hemispheres

※ Note that two pressure terms are calculated for each of these datasets, one with and one without the inverted barometer correction

UNIVERSITY OF OXFORD DEPARTMENT OF PHYSICS
(Sub-department of Atmospheric, Oceanic and Planetary Physics)
Enquiries: *Telephone* 0865-272901 or 272096, *Fax* 0865-272923

(Emeritus) Professor Raymond Hide, C.B.E., F.R.S.
Telephone 0865-272084 (work) or 0865-56521 (home); *Fax* 0865-311540 or 272923;
Postal address: c/o Oceanography Group (SD AOPP), Clarendon Laboratory,
Parks Road, Oxford OX1 3PU, England, U.K.

Dr M.J. Bell,
Meteorological Office
H 21
BRACKNELL, Berkshire
Tel. 0344-856434

26 July 1994

Dear Mike

Addendum to Met O21 IR87/3 "Atmospheric angular momentum fluctuations and changes in the Earth's rotation: Met Office Users' guide to data sets and codes" by M J Bell and K D B Whysall

As you know, Pat Roberts produced the above last April, and we now have to take steps to get the information into the right hands. Several weeks ago, when you and I discussed this matter, I told you that Andy Smith of RAL is of the opinion that the information (ie the whole report) should be made available as a preamble to the data set being kept up to date at RAL by the group controlling the Geophysical Data Facility there, which ensures that data can be obtained via JANET. You said you would find out whether the whole report is available as a disk for giving to Andy Smith, so that he can incorporate the information into his system (Otherwise a lot of typing will have to be done)

May I leave it to you to complete this operation by working directly with Andy at RAL and, if necessary with Pat Roberts. It would be helpful if Paul Beresford of Reading University and I could be informed of any snags and when the operation has been completed.. It should be possible for this to be done, as in the past, without a meeting to discuss what is needed, but if recipients of this letter think otherwise they should let me know. (My time is running out here and I am very conscious of the need to settle a number of matters before the end of the summer.)

With best regards

Yours

Raymond

cc. Ms Pat Roberts
58 Rectory Close
Bracknell
Berks

Dr Paul Berrisford
Dept. of Meteorology
UNIVERSITY
READING
BERKS
Tel 0734-318953

Mr Andy Smith
Space Sciences Department,
Bldg. R25 R.A.L.
CHILTON, OXON. Tel 0235-446373

MEMORANDUM **MOD Form 4A**

To Andy Smith
Room 2.32
Rutherford Appleton
Laboratory
Chilton Didcot
Oxon

Date 27 July 1992

Your ref.

From P Roberts
Room 250
Meteorological
Office
London Road
BRACKNELL

Tel. 0344 420242 Extn 6467

~~Our ref.~~

Subject UKMO AAM DATA

Here are the disk data and other notes that we spoke about in today's telephone conversation.

Best wishes

Paul Roberts

Rank/
Appointment ....

Name in
Block Letters P ROBERTS

Signature ....

MEMORANDUM

MOD Form 4A

To Andy Smith
Room 2.32
Rutherford Appleton
Laboratory
Chilton Didcot
Oxon

From P Raikes
Room 250
Meteorological
Office
London Road
Bracknell
Berkshire

Tel. 0344 [illegible]

Date 27 July 1992

Your ref.

Subject UKMO [illegible] DATA

Here are the data
plots and the notes that
we spoke about in Monday's
telephone conversation.

Best wishes

[illegible]

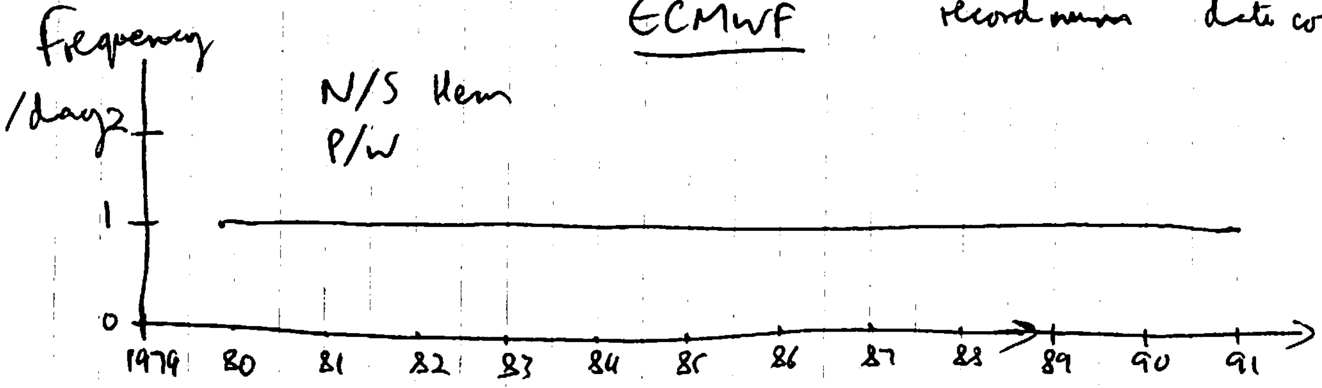
Rank/ Appointment

Name in Block Letters

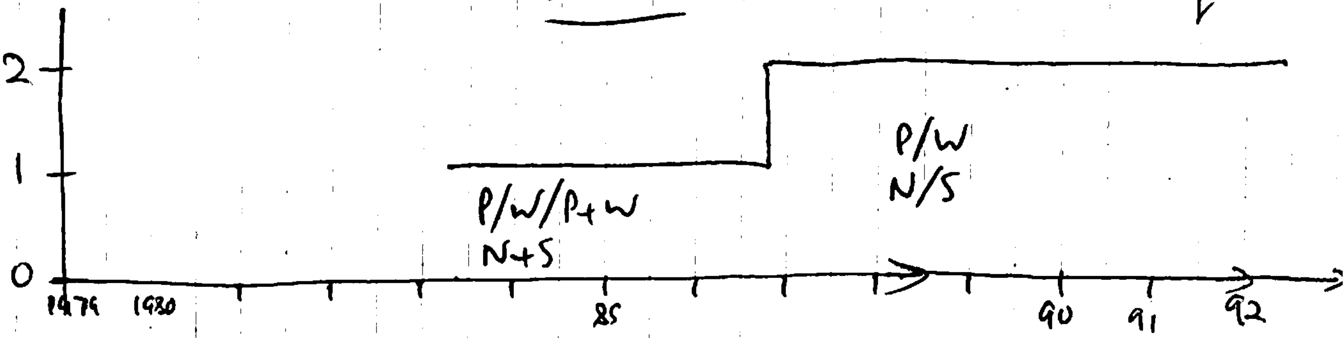
Signature

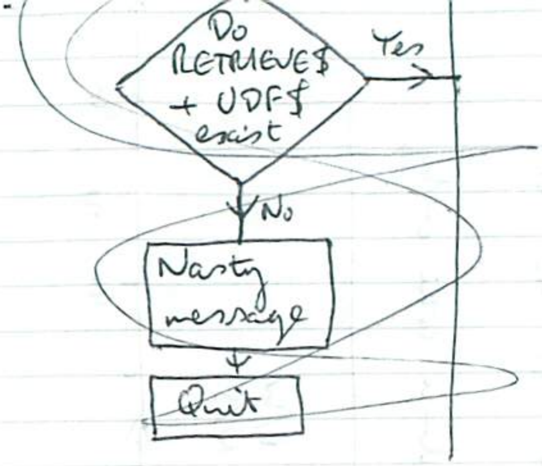
EAAM

ECMWF record num date code



UKMO date code only




Do RETRIEVE$ + UDF$ exist
Yes
No
Nasty message
Quit

ATMOSPHERIC ANGULAR MOMENTUM

The effective atmospheric angular momentum (EAAM) functions consist of a time series of love number corrections for departures from perfect rigidity of the solid earth. Data are available for wind and pressure (or matter) in ~~either~~ each hemisphere. ~~along~~ Three components are provided with rotation axis aligned with (1) Greenwich meridian, (2) 90E and (3) principal axis. ~~The data are based on initialized met. data from ECMWF.~~

- retrieve time-series of data
- browse ~~dat~~ / plot / ~~stats~~ ftp subset of data
- ftp all data + program to read it.

data_set - - - - ECMWF
start_date 1.12.79
end_date 1.12.91

data_set . . . . . ECMWF
start_date 1.12.79
end_date 1.12.91
parameter . ——— ~~pressure~~ matter
component - ——— green_merid
~~hemisphere~~ ——— north_hem
lat_range

Andy — is there any chance of getting these 3 menus set up so that we can show them tomorrow? Don't worry if it's not possible — we can show them on paper. Also, I'd be grateful if you could get hold of a photocopy of the Barnes ~~to~~ paper from the library.

thanks,
Lesley

APPENDIX
A

National Meteorological Center

SBAAM User Notes

January 1990

INTRODUCTION

This document describes the data sets generated for the IERS Sub-Bureau for Atmospheric Angular Momentum (SBAAM) which is housed at the U.S. National Meteorological Center (NMC). At present, only those data produced by NMC itself are available for inclusion in the rapid access data base of the SBAAM. We anticipate that in the future, data sets from other agencies will be available as well. Currently, two sets of files are created by a series of jobs run daily at NMC. One set is available on a daily basis to customers of a dial-up service. The second set is stored on disk at NMC and is transferred to both a magnetic tape and a floppy disk at the end of each month. The following sections include some general comments on the production of the data sets, and the contents and formats of each file. The production of these SBAAM data sets is still in the development stage, and changes in the structure and contents of the files may be necessary. This document will be updated should any changes be necessary. Users of the SBAAM data sets are advised to make certain that they are on the current SBAAM mailing list. All inquiries can be directed to:

Dr. Deirdre Kann
National Meteorological Center
WWB, W/NMC53, Room 808
5200 Auth Rd.
Washington, DC 20233
TEL: 301-763-8071
FAX: 301-763-8395

1. Production of SBAAM Data Sets

Parameters provided by NMC for the Sub-Bureau are derived from NMC's Global Data Assimilation System (GDAS) and Medium Range Forecasting (MRF) model. After the GDAS and MRF production runs are completed, secondary jobs are run to perform additional calculations and to archive the data. The series of jobs that produce the SBAAM data sets are then submitted. Therefore, in the rare case of a production failure all Sub-Bureau parameters for a given time period would not be produced. In the less extreme case of a production delay or secondary job failure, a portion of the parameters could be lost. In any case, the missing value indicator is -99. (Note that this value has been changed from the previous value of -999., which could not be expressed in several of the predetermined formats.)

2. Content and Structure of the 'Dial-Up' Files

The Climate Analysis Center (CAC) of NMC supports a Climate Dial-Up Service through which the two files produced for the Sub-Bureau and an additional file for researchers can be accessed. Files are transferred to the dial-up service once per day and are kept in a 10-day rotating file. Users of the Sub-Bureau who are interested in subscribing to this service may contact Deirdre Kann at the number or address given on page 1 of this document.

Three files are available for each day under a particular menu selection (currently number 14) - MOMENTUM. Upon selecting that menu item, the subheadings MOMENTUM, MOMUZON and MOMANAL will appear. In the next subsection, the contents of MOMANAL will be described and the formats which were used to write the files will be given. Similar descriptions will then be given for MOMENTUM and MOMUZON.

a) MOMANAL

The MOMANAL file contains analysis values of Sub-Bureau parameters, which are calculated twice daily for analysis times 00 and 12 UTC. Note that these values are obtained from NMC fields which have been initialized. Five different data types are provided for each analysis time, and each type is preceded by a header with the year, month, day, and hour of the analysis time. For each day n selected, the analysis parameters for 12 UTC on day n-1 appear first and are followed by the analysis parameters for 00 UTC on day n. The series of jobs that create the Sub-Bureau data sets is completed each day by 20 UTC. Transfer to the dial up service occurs near 12 UTC the following day.

The first portion of the file contains the three components of effective atmospheric angular momentum functions as described by Barnes et al., (1983). The three lines after the header contain 8 values of X1, X2, and X3, respectively. The 8 values are those for wind-northern hemisphere to 100 mb, wind-northern hemisphere to top of model, pressure-northern hemisphere, and pressure + inverted barometer-northern hemisphere and the same four terms for the southern hemisphere. All data values are true values multiplied by 10**7. Presently, the only component of wind to 100 mb which is calculated by NMC is X3. Note that in past data sets provided by NMC all values of the third component of Barnes et al. were multiplied by a minus sign (as a result of an earlier formulation). We have taken this opportunity to change the sign. Also note that the inverted barometer correction involves applying the mean atmospheric surface pressure over the whole world ocean to every point over the world ocean. The definition of the world ocean for this purpose is a topic currently under study.

Next, zonal mean zonal winds (m/s) at 5 degree latitude intervals for 12 mandatory pressure levels (1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 and 50 mb) are given. The resulting array has dimensions (37x12) and is written from north to south with the level varying first, i.e. ((uzon(lat,lev),lev=1,12),lat=1,37).

Zonal mean temperatures (K) follow and are arranged and written in the same configuration (but with different format) as the zonal mean zonal winds. Given after the temperatures is a single value of the mean surface pressure (mb) over the globe.

Finally, coefficients of a triangular truncation to wave number four (T4) and the zonal components to wave 20 (R20Z) are given for the uninitialized surface pressure (sfc p) expressed with and without the inverted barometer calculation. The arrays are ordered as follows:

i) T4 coefficients of analyzed surface pressure (30 coefficients);
ii) zonal coefficients of sfc p to wave 20 (21 coefficients);
iii) T4 coefficients of sfc p with inverted barometer correction (30 coefficients); and
iv) zonal coefficients of sfc p to wave 20 with inverted barometer correction (21 coefficients).

The T4 field is originally made up of 15 COMPLEX words, which can be expressed as 30 REAL words. The zonal coefficients only contain the real component of the complex word. Therefore, when the 30 REAL coefficients of either T4 field are written, five of these numbers are zero. The coefficients are stored as follows:

$$A_{\text{n(total wave number)}}^{\text{m(zonal wave number)}}$$, i.e., ((a(n,m),n=m,4),m=0,4).

The array of zonal coefficients to wave 20 consists of 21 REAL numbers, the first five of which can be found in the T4 array. A more complete description of the coefficients can be found in Appendix I.

The MOMANAL file is written with the following formats:

PARAMETER	FORMAT
header, X1, X2, X3	(1X,4I2,3(/,8(1X,F9.5)))
header, zonal mean zonal winds	(1X,4I2,45(/,10(1X,F7.2)))
header, zonal mean temperatures	(1X,4I2,41(/,11(1X,F6.2)))
header, mean surface pressure	(1X,4I2,1X,F9.3)
header, sfc p coefficients (header, then 4 arrays each written separately)	(1X,4I2) (5(1X,1PE15.8))

Recall that these parameters will appear first for a 12 UTC analysis and are repeated for the 00 UTC analysis.

b) MOMENTUM

The MOMENTUM file is the second file specifically structured for the Sub-Bureau. It contains 21 sets of forecast values (00-h to 240-h) of the effective atmospheric angular momentum components at 12-hour intervals starting at 00 UTC. The results are globally integrated. Each set of forecasts is preceded by a header with the year, month, day, hour from which the forecast was made, followed by the lead time of the forecast, followed by the year, month, day, and hour for which the forecast is valid. The forecast values are written in three consecutive lines. Each line contains 4 values of X1, X2, and X3 respectively, with the 4 values as wind-global to 100 mb, wind-global to top of model, pressure-global, and pressure + inverted barometer-global. Wind-global to 100 mb is calculated only for the X3 term at this time.

The 21 forecasts in the file are written using the format:

PARAMETER	FORMAT
header and forecasts	(1X,4I2,1X,I3,1X,4I2,3(/,4(1X,F9.5)))

c) MOMUZON

This file contains additional information which has been found to be useful for research, but will not be archived for the Sub-Bureau. It contains forecasts of effective atmospheric angular momentum which have been integrated over each hemisphere, and forecasts of the zonal mean zonal wind. Each field has the same configuration as it had for the analysis file. The forecasts are given for the following lead times: 00-

h, 12-h, 24-h, 36-h, 48-h, 72-h, 96-h, 120-h, 144-h, 168-h, 192-h, 216-h and 240-h.

The 13 forecasts in the file are written using the format:

PARAMETER	FORMAT
header, X1, X2, X3 fcsts	(1X,4I2,1X,I3,1X,4I2,3(/,8(1X,F9.5)))
zonal mean zonal wind fcsts	(45(10(1X,F7.2),/)))

Note that there is only one header per forecast time, the zonal mean zonal winds are not preceded by a header. It is important to emphasize that these values will not be archived in any form at NMC.

3. Content and Structure of the Archived Files

All parameters discussed in Section 2, parts a and b will be archived for the Sub-Bureau, and are written in the same order and with the same formats as previously discussed. The monthly data are written in two files. The first file has the analysis parameters at 00 and 12 UTC written consecutively for the entire month. The second file has the globally integrated forecasts for the entire month.

Therefore, the format used for writing File 1 is:

PARAMETER	FORMAT
header, X1, X2, X3	(1X,4I2,3(/,8(1X,F9.5)))
header, zonal mean zonal winds	(1X,4I2,45(/,10(1X,F7.2)))
header, zonal mean temperatures	(1X,4I2,41(/,11(1X,F6.2)))
header, mean surface pressure	(1X,4I2,1X,F9.3)
header, sfc p coefficients (header, then 4 arrays each written separately)	(1X,4I2) (5(1X,1PE15.8))

This set of formats is used twice for each day of the given month.

The format used for writing File 2 is as follows:

PARAMETER	FORMAT
header and forecasts	(1X,4I2,1X,I3,1X,4I2,3(/,4(1X,F9.5)))

The format is repeated 21 times for each day of the month.

When archiving onto a 6250 bpi magnetic tape, the two files are written with BLKSIZE=12960, LRECL=80, and RECFM=FB. On a high density floppy disk, the analysis parameters are in a file named SBANL.mon, and the forecasts are in a file named SBFCST.mon, where mon is the first three letters of each month. These files are written with a record length of 80. If you cannot read a tape or floppy with these specifications, please contact the Sub-Bureau.

Appendix I

The NMC spectral fields are produced using the following formulae for the transformation routines:

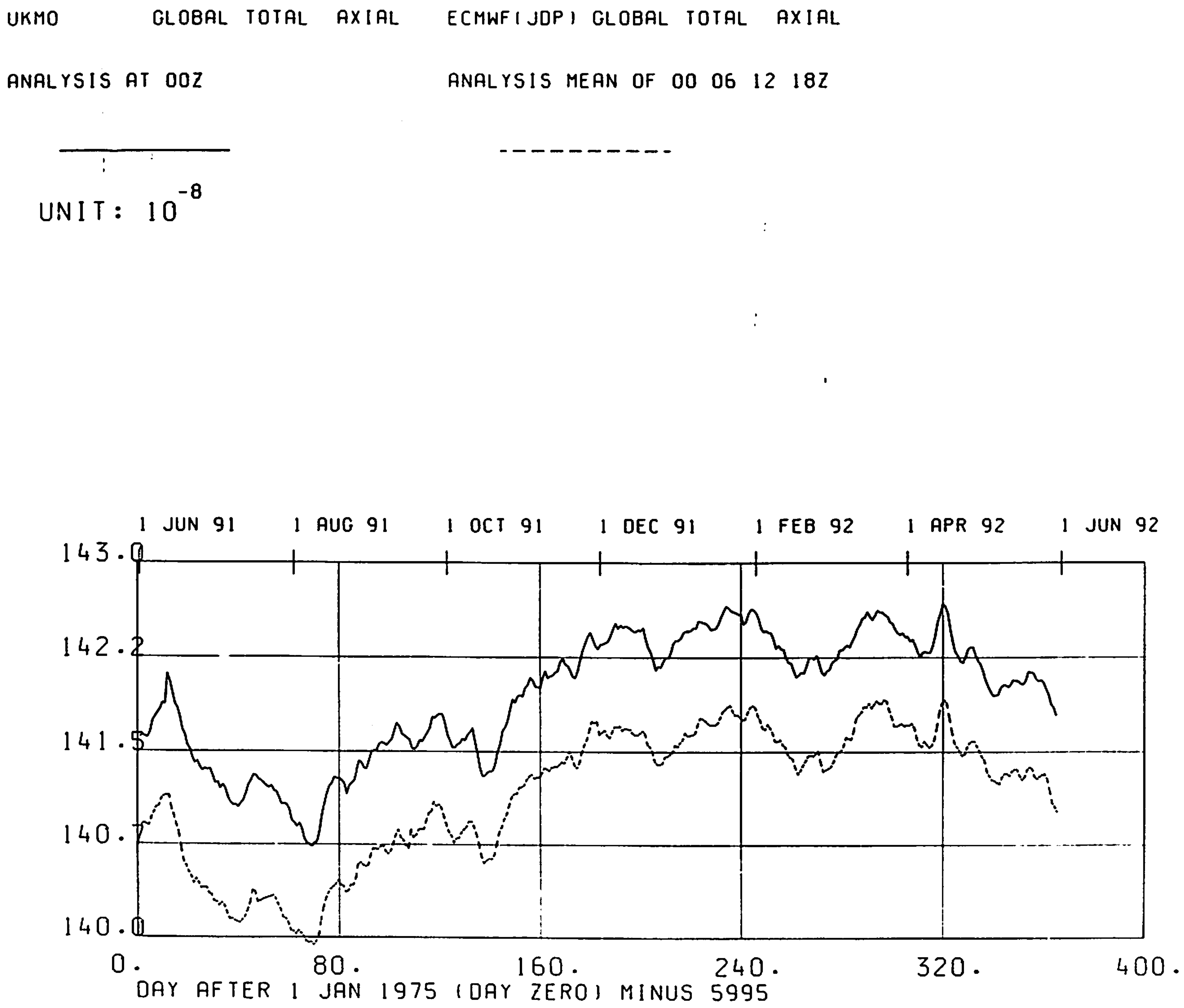
$$f(\lambda,\phi) = (2-\delta_{0m}) \sum_{m=0}^{M} \sum_{n=m}^{N+J} (a_n^m \cos m\lambda - b_n^m \sin m\lambda)\, P_n^m(\mu) \qquad (1)$$

where δ_{0m} is the Kronecker delta function, $\mu - \sin\phi$, and $J-0$ or M depending on whether the truncations is triangular of rhomboidal, respectively. The Legendre functions are defined as:

$$P_n^m(\mu) = \frac{1}{2^n n!}\left[\frac{(2n+1)(n-m)!}{2(n+m)!}\right]^{1/2} (1-\mu^2)^{m/2} \frac{d^{m+n}}{d\mu^{n+m}} (\mu^2-1)^n \qquad (2)$$

Definition (2) results in:

$$\int_{-1}^{1} P_n^m P_{n'}^{m'}\, d\mu - \delta_{nn'}\, \delta_{mm'} \qquad (3)$$


UKMO GLOBAL TOTAL AXIAL
ANALYSIS AT 00Z
ECMWF(JDP) GLOBAL TOTAL AXIAL
ANALYSIS MEAN OF 00 06 12 18Z
UNIT: 10^{-8}
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
143.0
142.2
141.5
140.7
140.0
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995

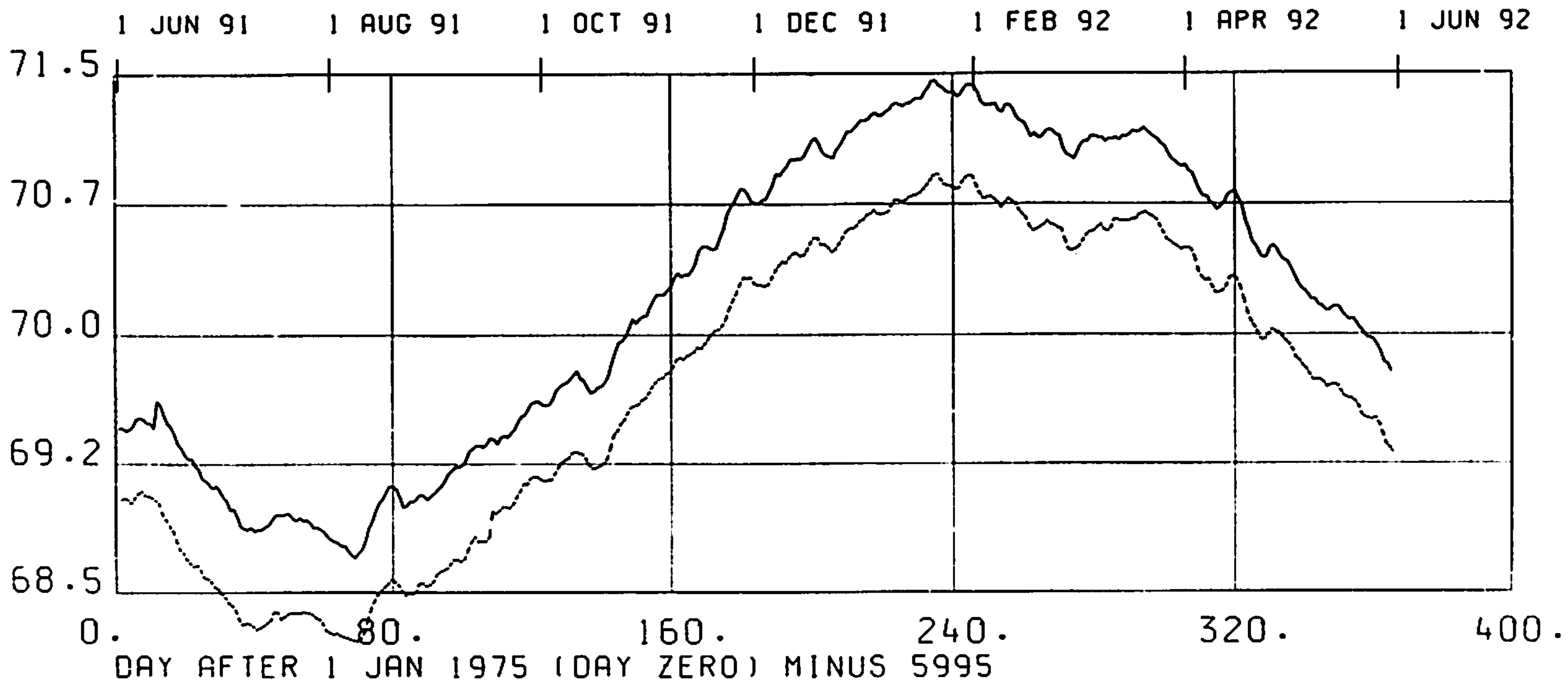
UKMO N.H. TOTAL AXIAL

ANALYSIS AT 00Z

ECMWF(JDP) N.H. TOTAL AXIAL

ANALYSIS MEAN OF 00 06 12 18Z

UNIT: 10^{-8}

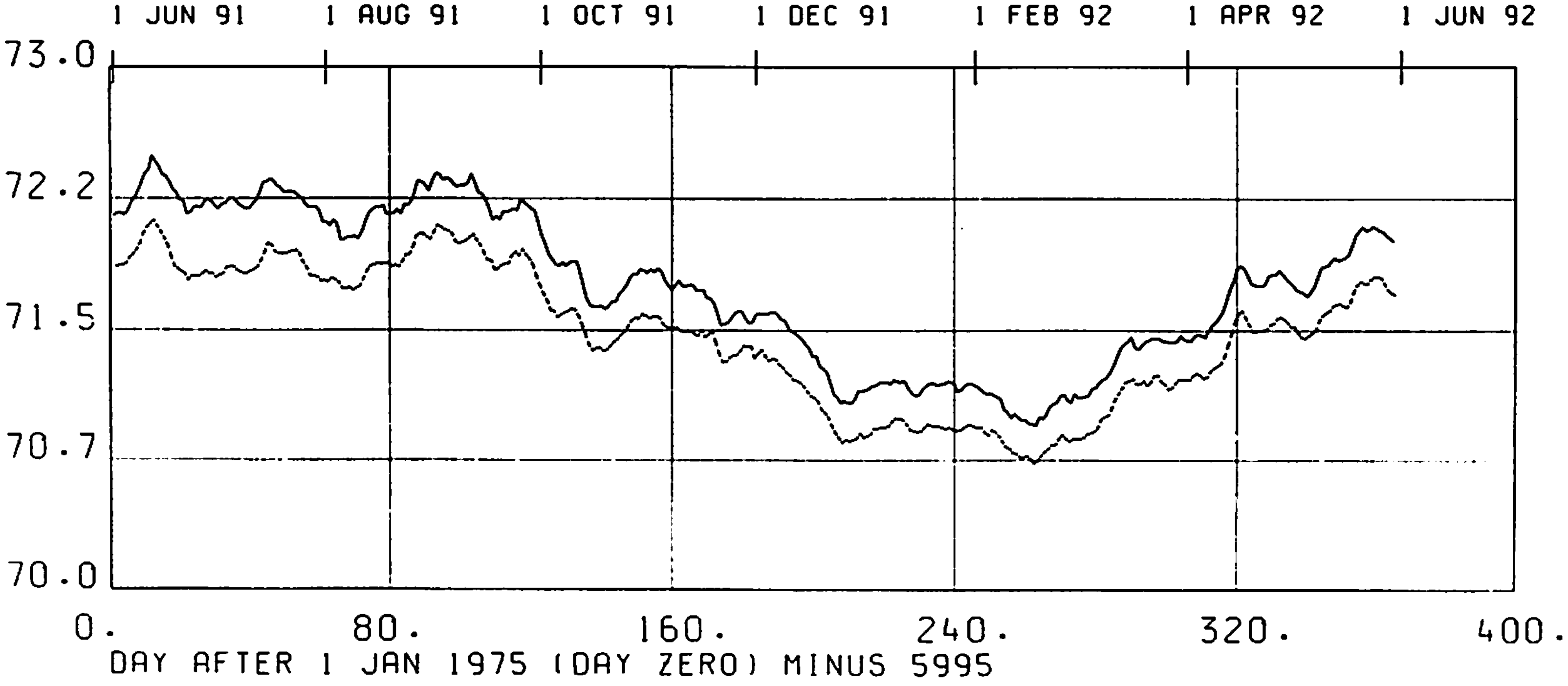


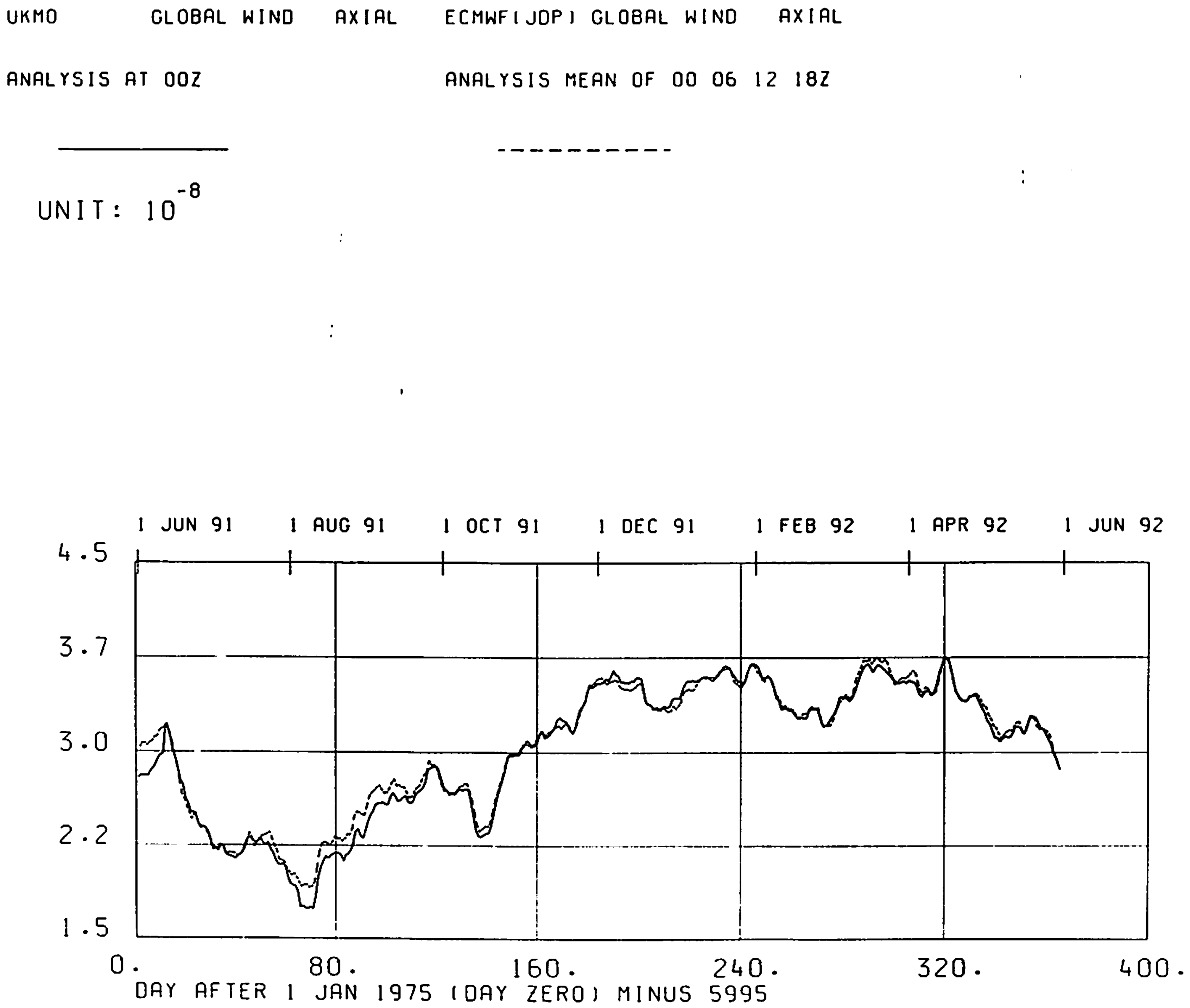
UKMO S.H. TOTAL AXIAL ECMWF(JDP) S.H. TOTAL AXIAL

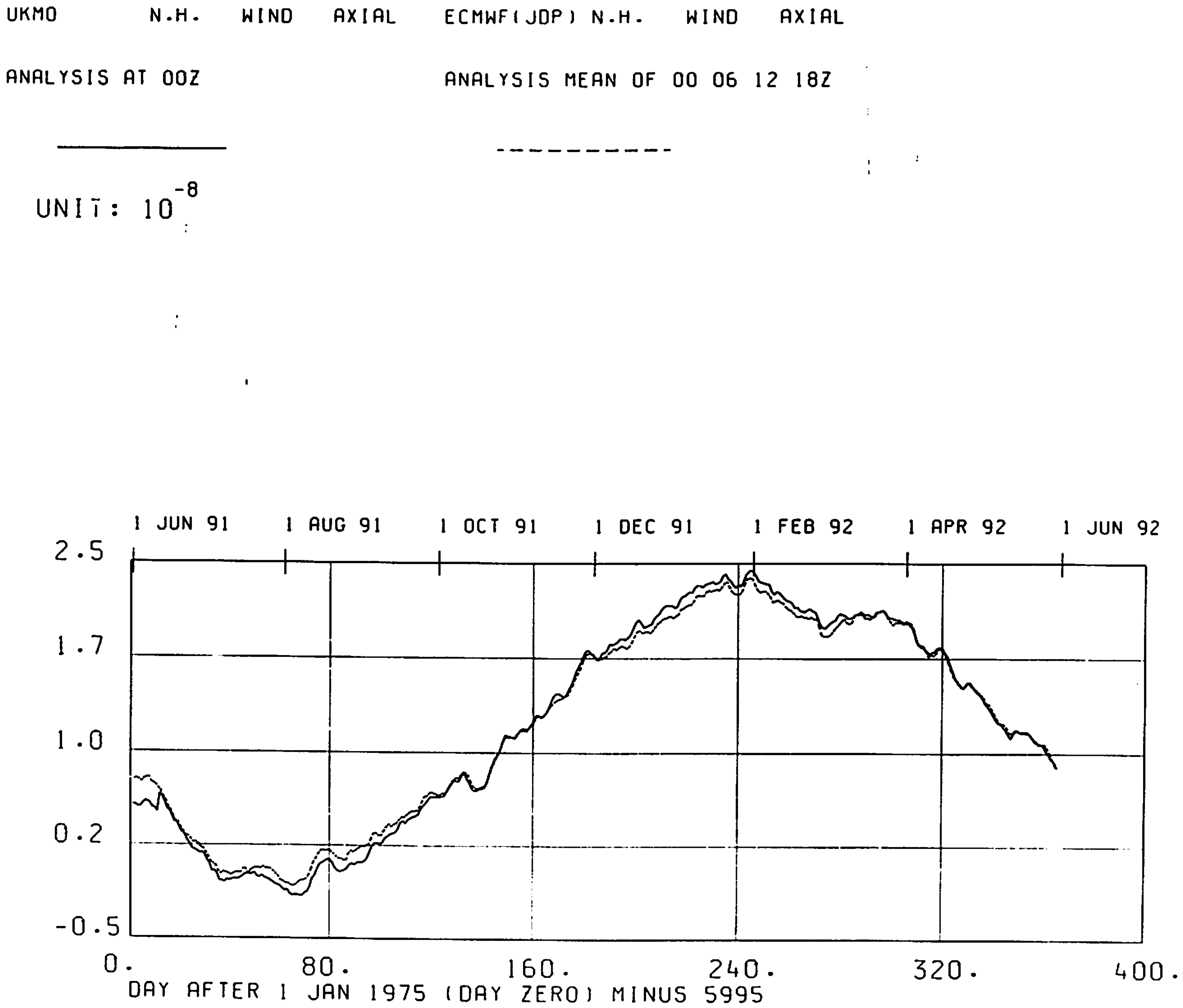
ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

———— - - - - - - - - - -

UNIT: 10^{-8}

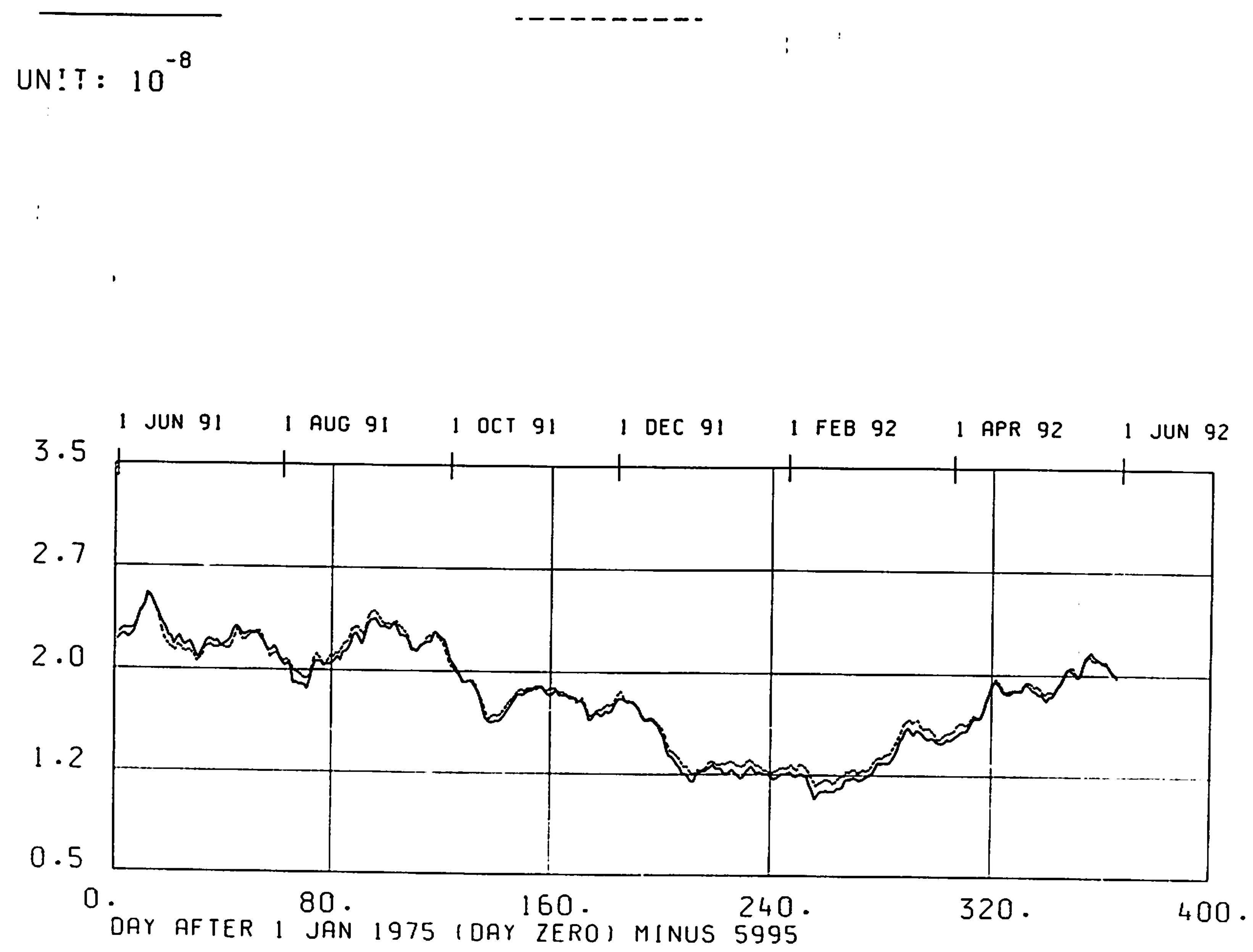


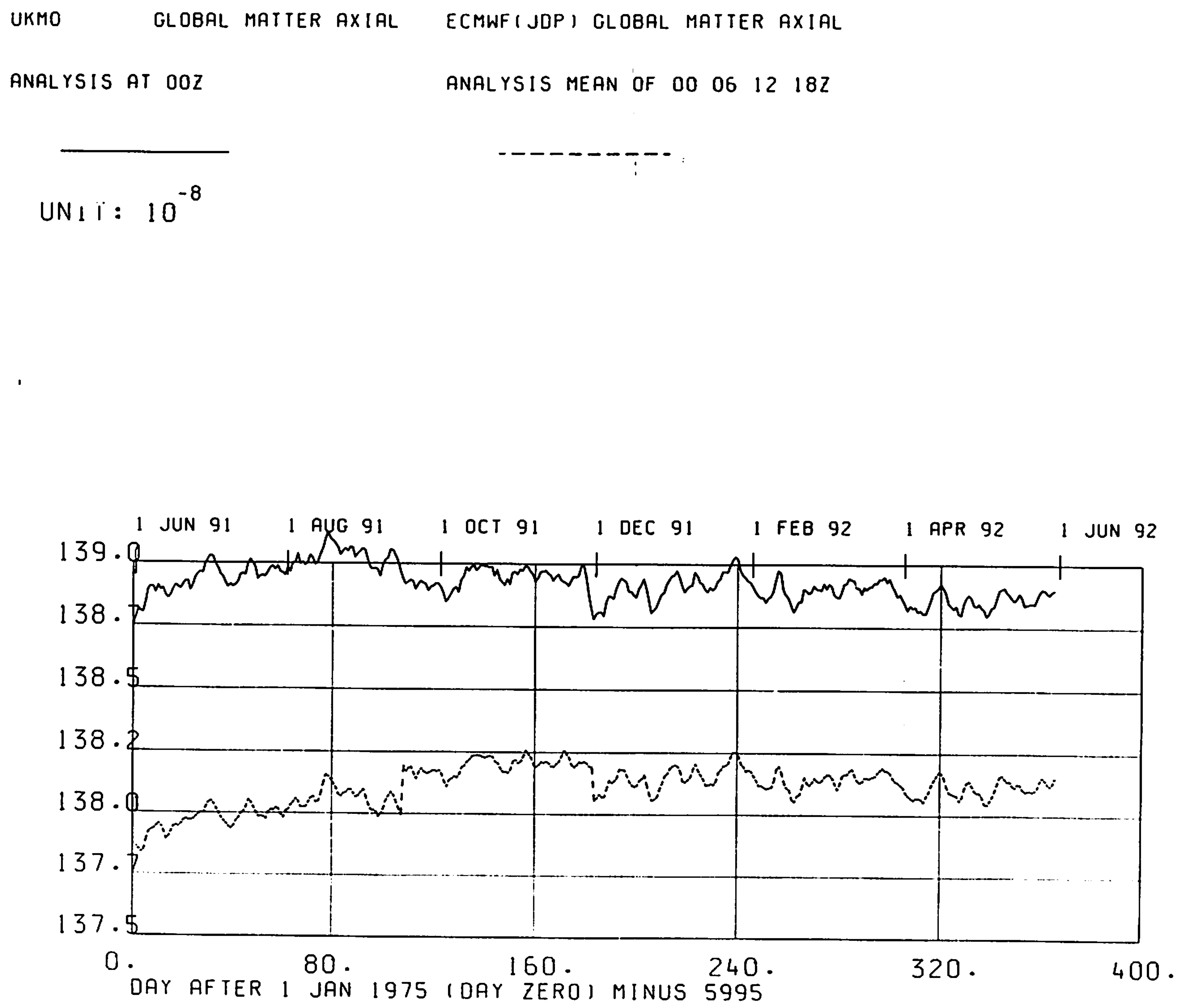

UKMO GLOBAL WIND AXIAL
ANALYSIS AT 00Z
ECMWF(JDP) GLOBAL WIND AXIAL
ANALYSIS MEAN OF 00 06 12 18Z
UNIT: 10^{-8}
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
4.5
3.7
3.0
2.2
1.5
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995


UKMO N.H. WIND AXIAL
ANALYSIS AT 00Z
ECMWF(JDP) N.H. WIND AXIAL
ANALYSIS MEAN OF 00 06 12 18Z
UNIT: 10^-8
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
2.5
1.7
1.0
0.2
-0.5
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995

UKMO S.H. WIND AXIAL ECMWF(JDP) S.H. WIND AXIAL

ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

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ANALYSIS AT 00Z
ECMWF(JDP) GLOBAL MATTER AXIAL
ANALYSIS MEAN OF 00 06 12 18Z
UNIT: 10^-8
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
139.0
138.7
138.5
138.2
138.0
137.7
137.5
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995

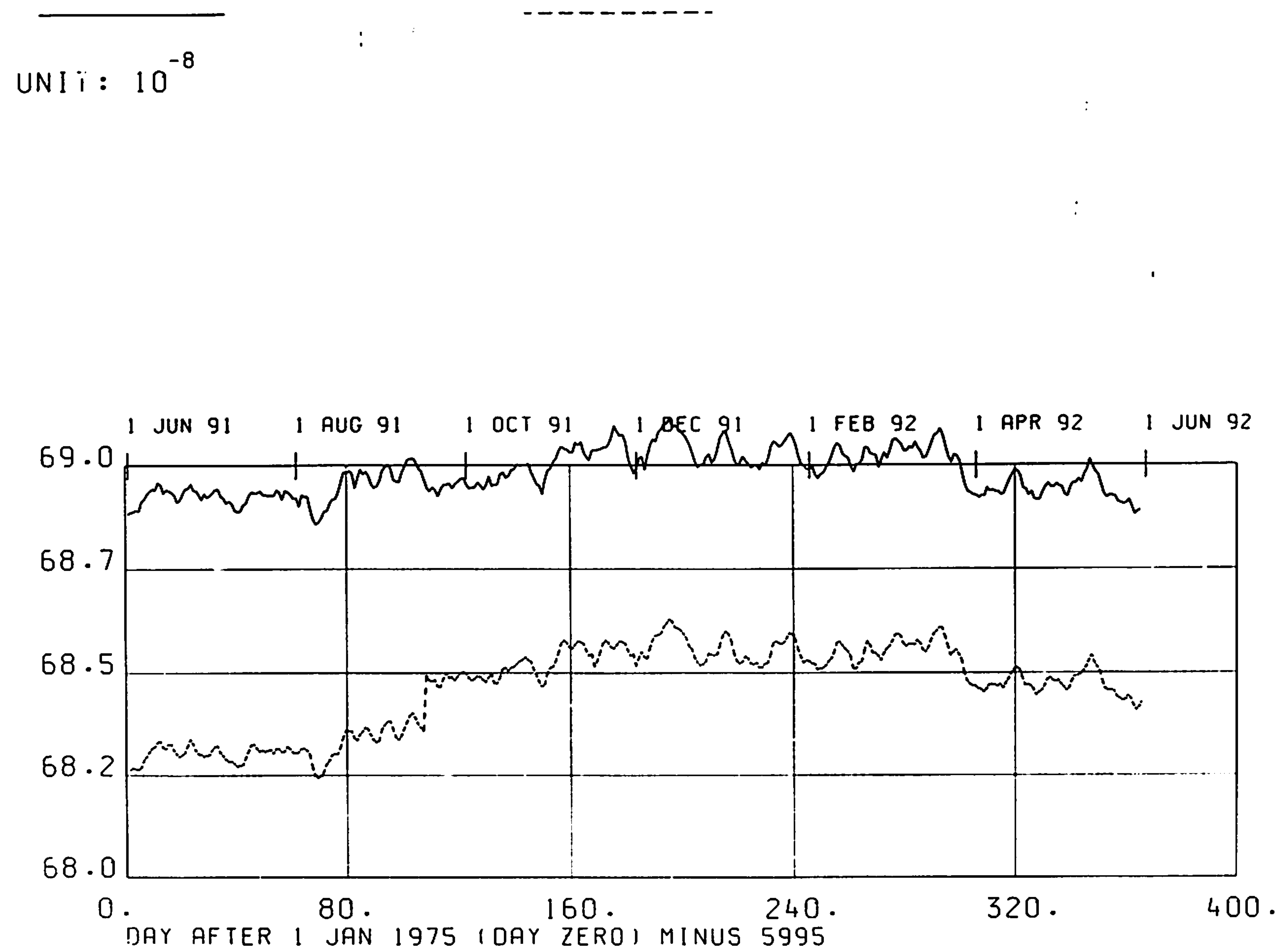
UKMO N.H. MATTER AXIAL

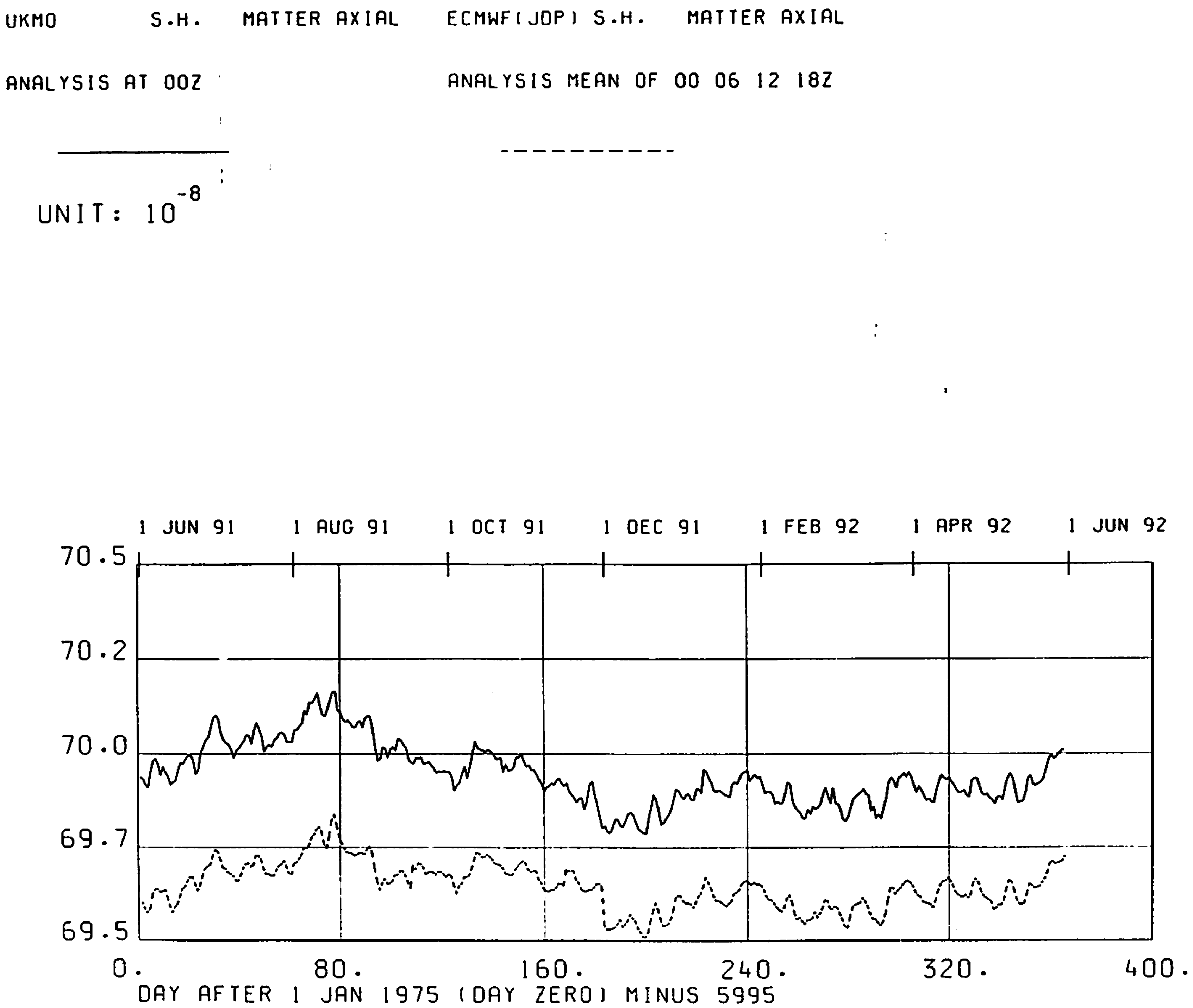
ANALYSIS AT 00Z

ECMWF(JDP) N.H. MATTER AXIAL

ANALYSIS MEAN OF 00 06 12 18Z

UNIT: 10^{-8}




UKMO S.H. MATTER AXIAL
ANALYSIS AT 00Z
ECMWF(JDP) S.H. MATTER AXIAL
ANALYSIS MEAN OF 00 06 12 18Z
UNIT: 10^-8
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
70.5
70.2
70.0
69.7
69.5
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995

UKMO GLOBAL TOTAL EQ. 2

ANALYSIS AT 00Z

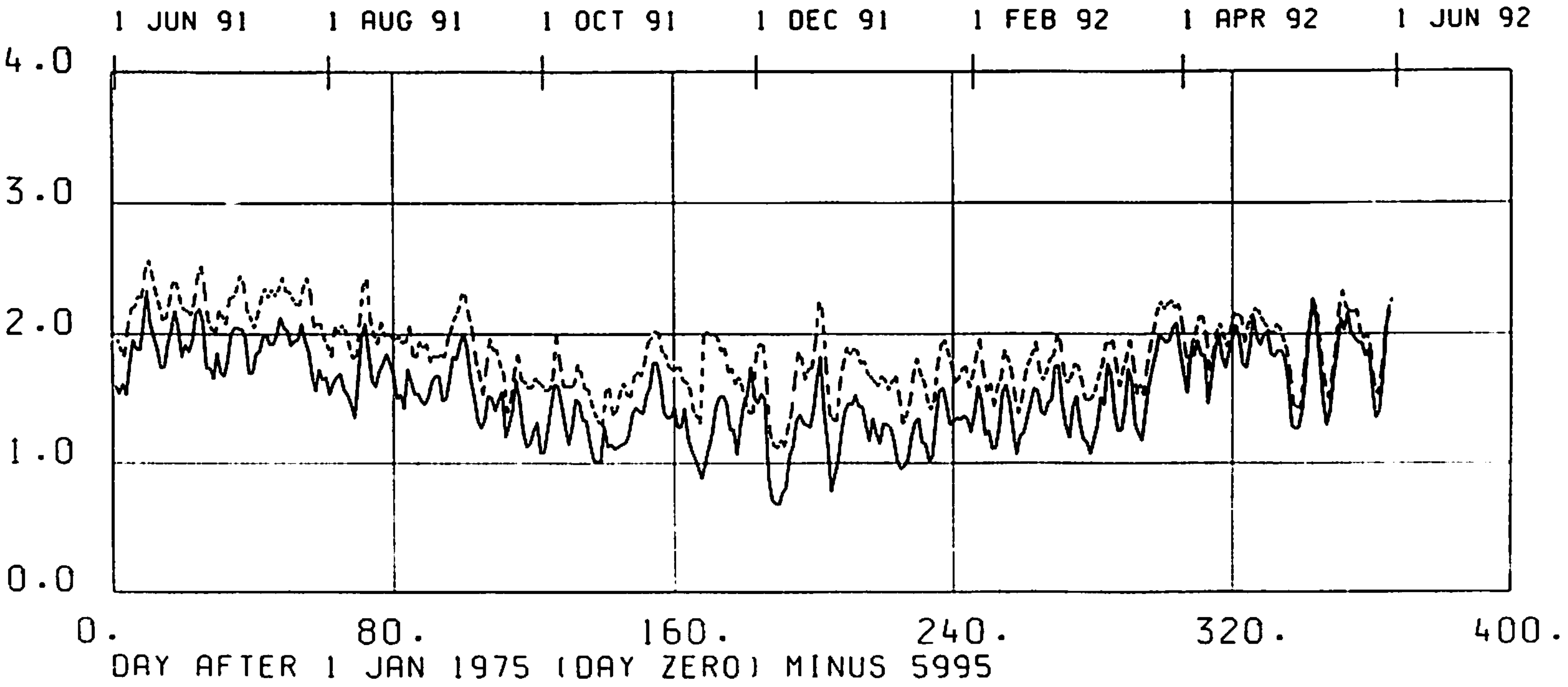
———————

ECMWF(JDP) GLOBAL TOTAL EQ. 2

ANALYSIS MEAN OF 00 06 12 18Z

- - - - - - - - - - -

UNIT: 10^{-6}

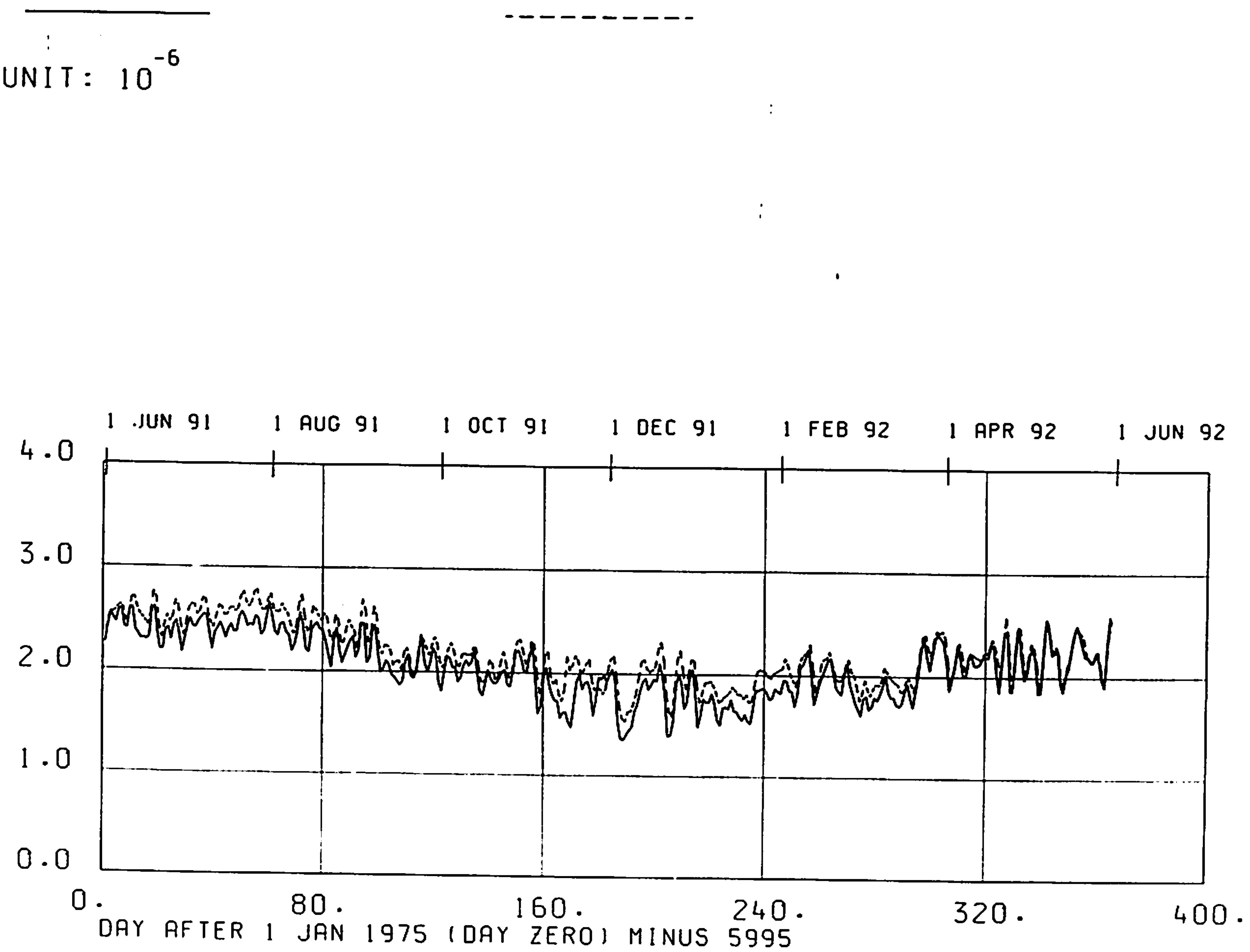


UKMO N.H. TOTAL EQ. 2

ANALYSIS AT 00Z

ECMWF(JDP) N.H. TOTAL EQ. 2

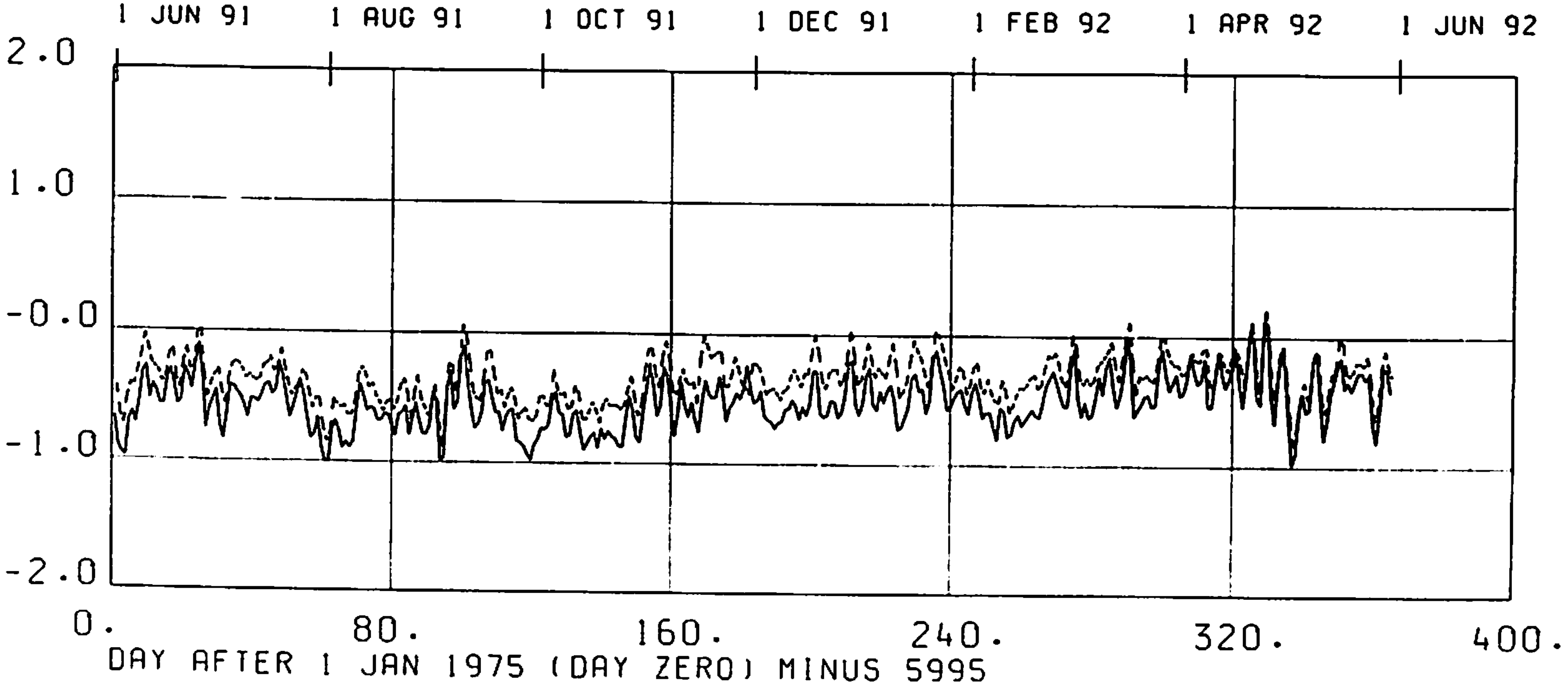
ANALYSIS MEAN OF 00 06 12 18Z



UKMO S.H. TOTAL EQ. 2 ECMWF(JDP) S.H. TOTAL EQ. 2

ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

UNIT· 10^{-6}



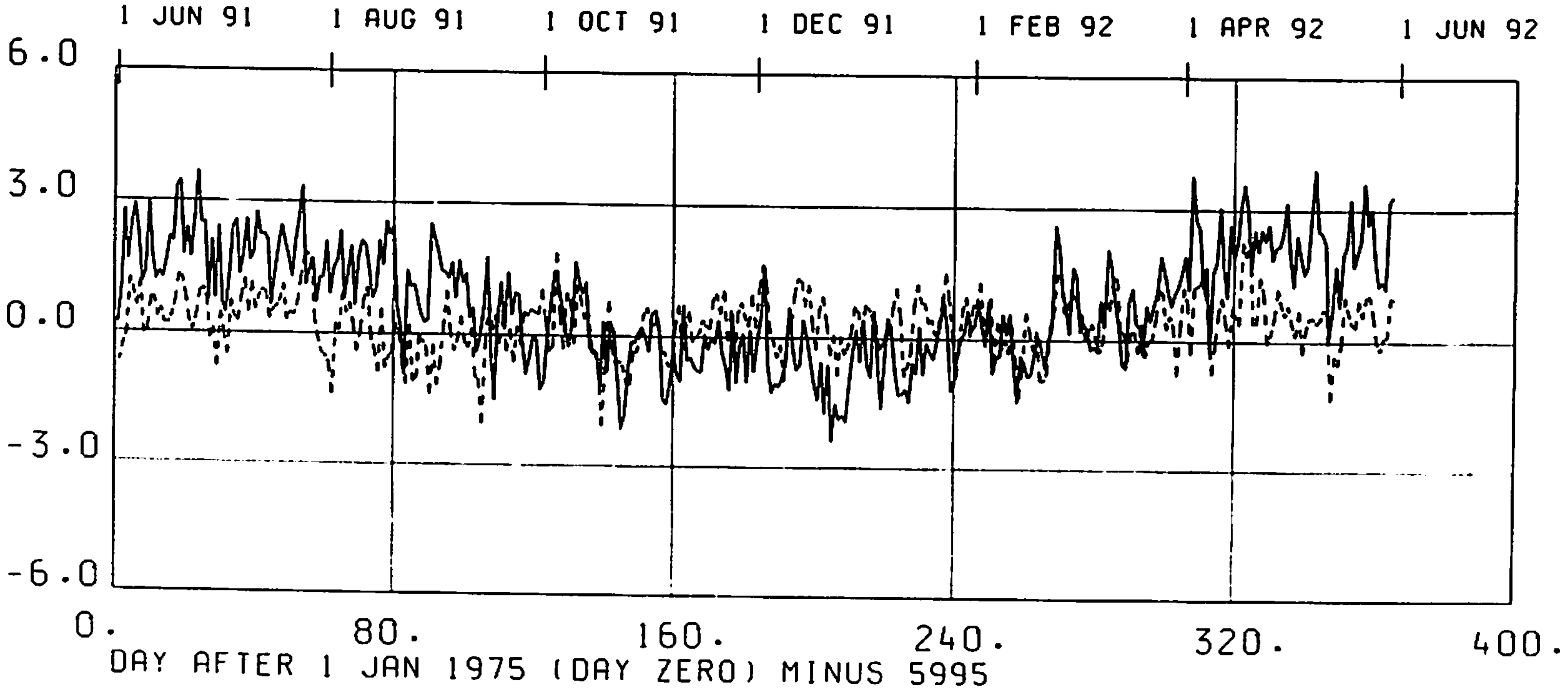
UKMO GLOBAL WIND EQ. 2

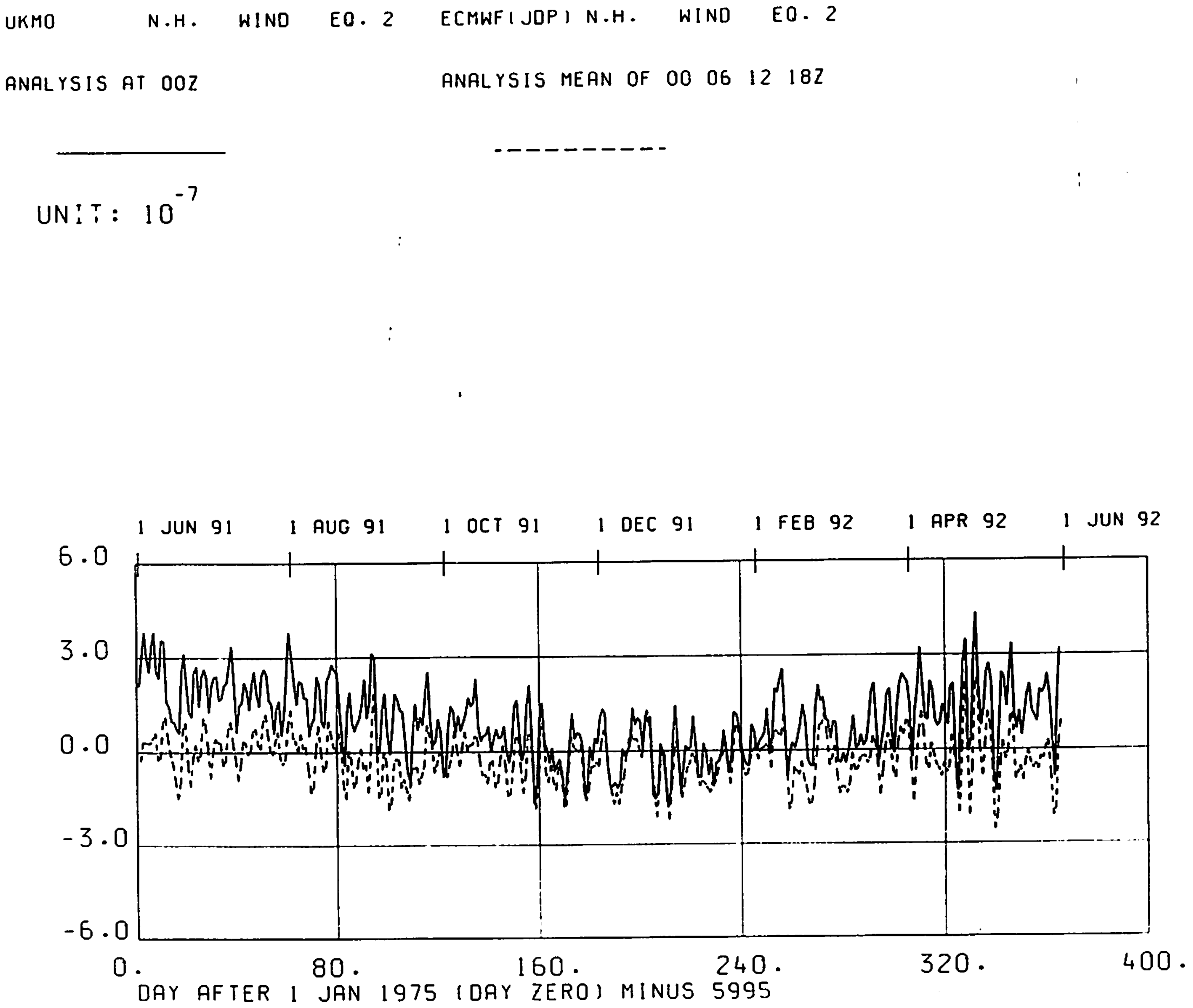
ANALYSIS AT 00Z

ECMWF(JOP) GLOBAL WIND EQ. 2

ANALYSIS MEAN OF 00 06 12 18Z

UNIT: 10^{-7}

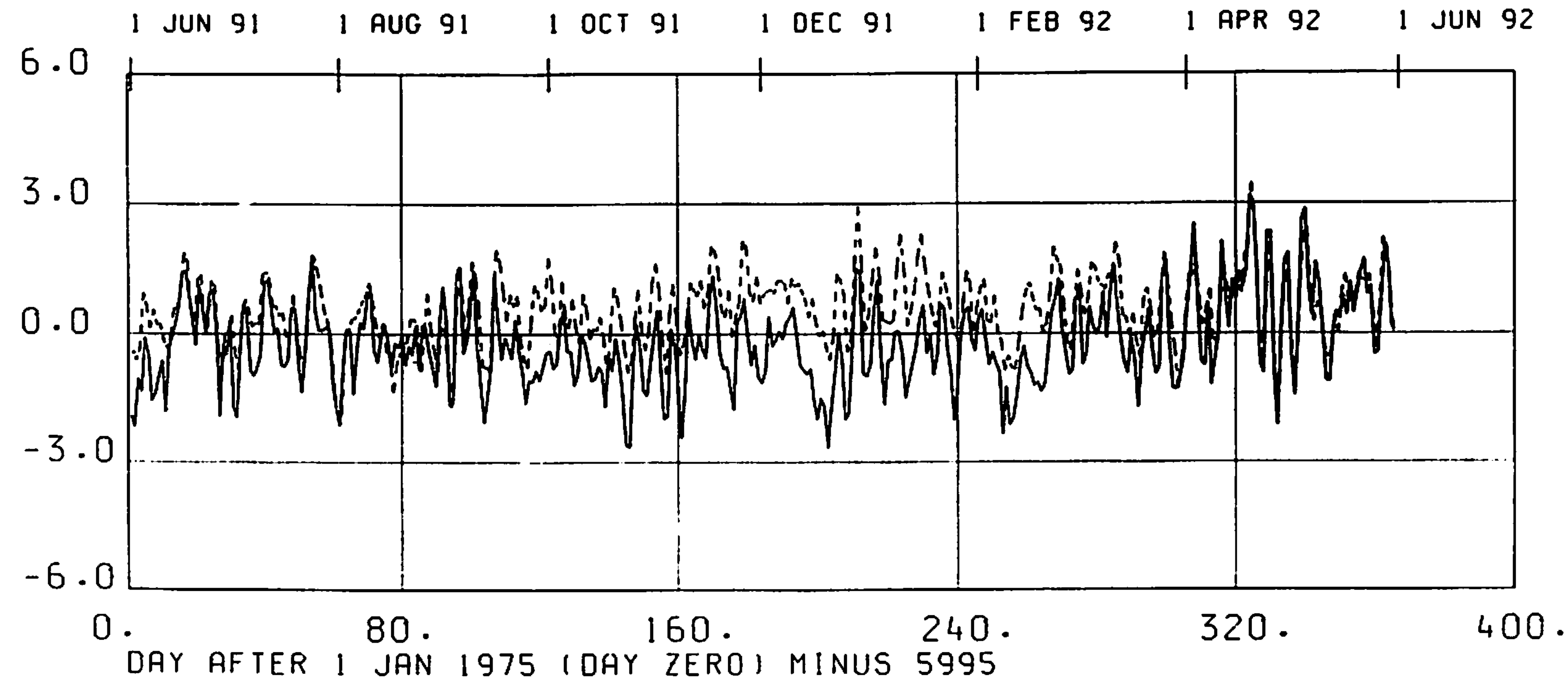


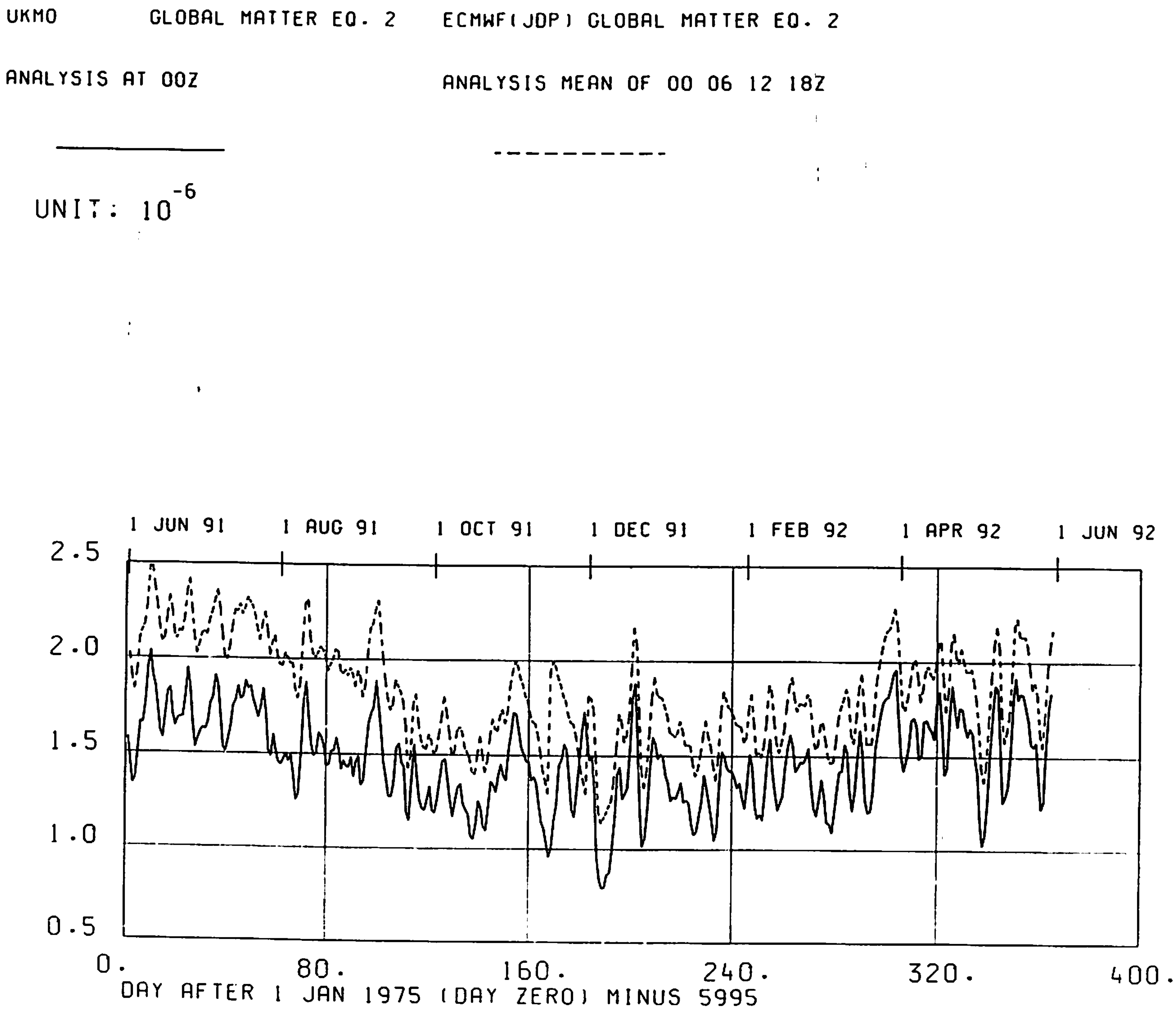

UKMO N.H. WIND EQ. 2
ANALYSIS AT 00Z
ECMWF(JDP) N.H. WIND EQ. 2
ANALYSIS MEAN OF 00 06 12 18Z
UNIT: 10^-7
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
6.0
3.0
0.0
-3.0
-6.0
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995

UKMO S.H. WIND EQ. 2 ECMWF(JDP) S.H. WIND EQ. 2

ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

UNIT: 10^{-7}



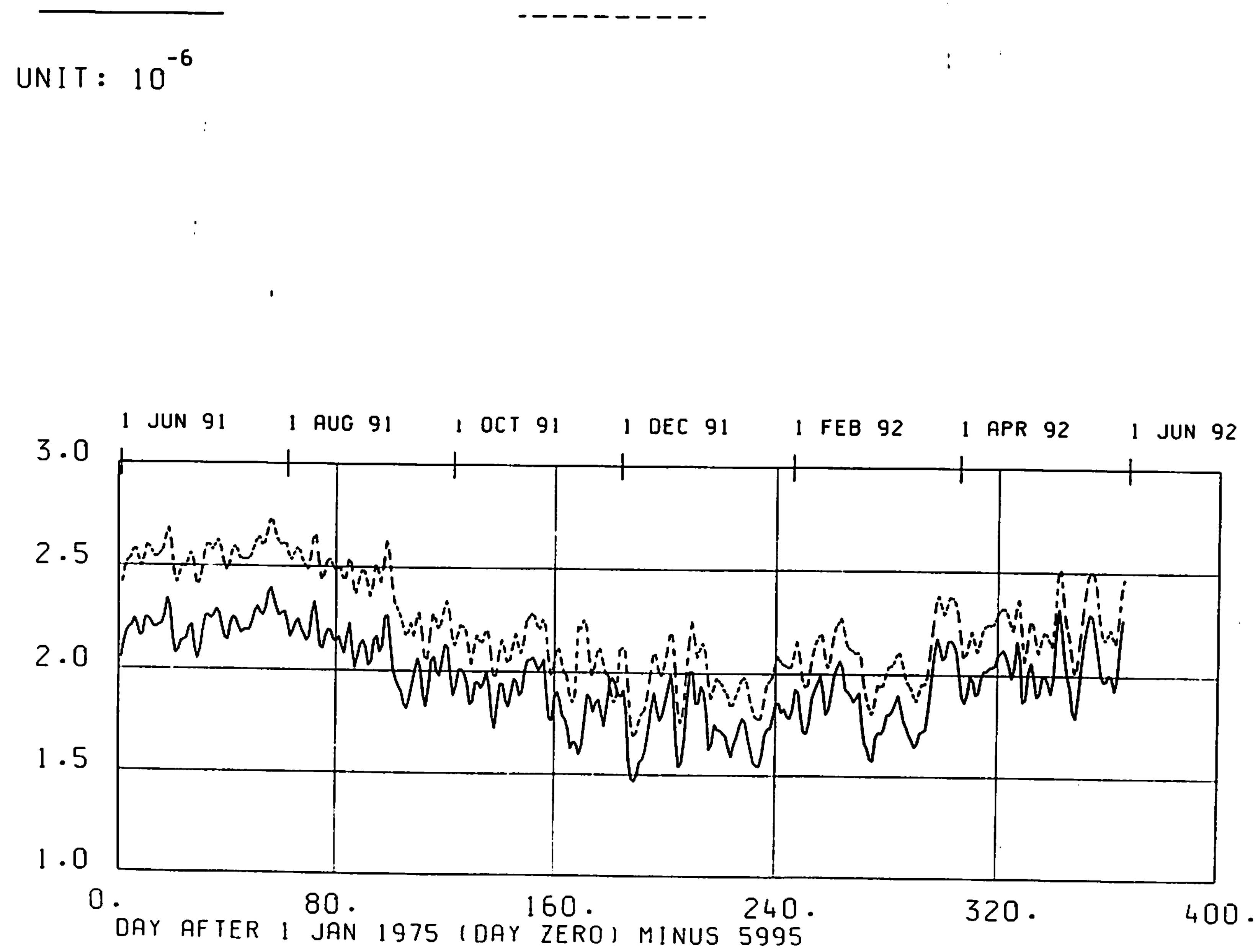

UKMO GLOBAL MATTER EQ. 2
ANALYSIS AT 00Z
ECMWF(JDP) GLOBAL MATTER EQ. 2
ANALYSIS MEAN OF 00 06 12 18Z
UNIT: 10^-6
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
2.5
2.0
1.5
1.0
0.5
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995

UKMO N.H. MATTER EQ. 2

ANALYSIS AT 00Z

ECMWF(JDP) N.H. MATTER EQ. 2

ANALYSIS MEAN OF 00 06 12 18Z



UKMO S.H. MATTER EQ. 2 ECMWF(JDP) S.H. MATTER EQ. 2

ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

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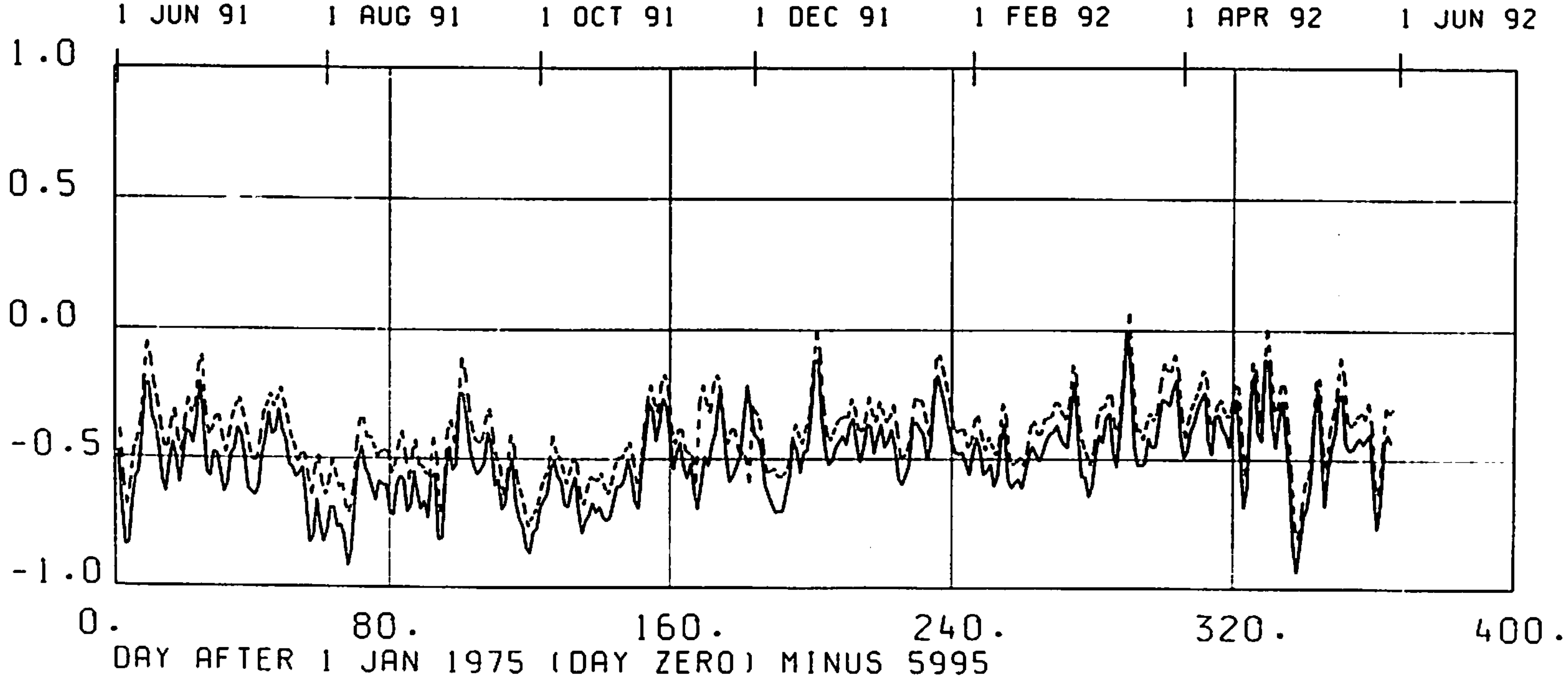
UNIT: 10^{-6}



UKMO GLOBAL TOTAL EQ. 1

ANALYSIS AT 00Z

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ECMWF(JDP) GLOBAL TOTAL EQ. 1

ANALYSIS MEAN OF 00 06 12 18Z

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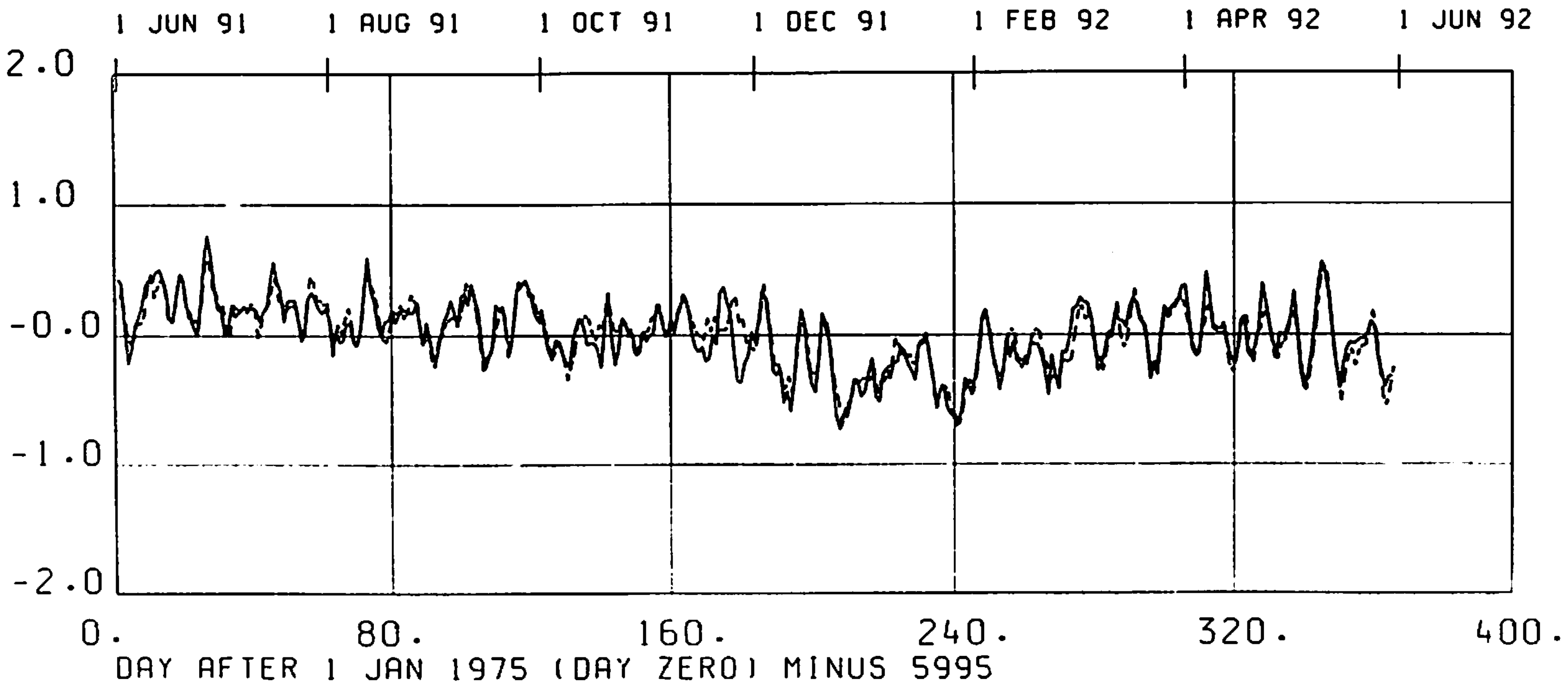
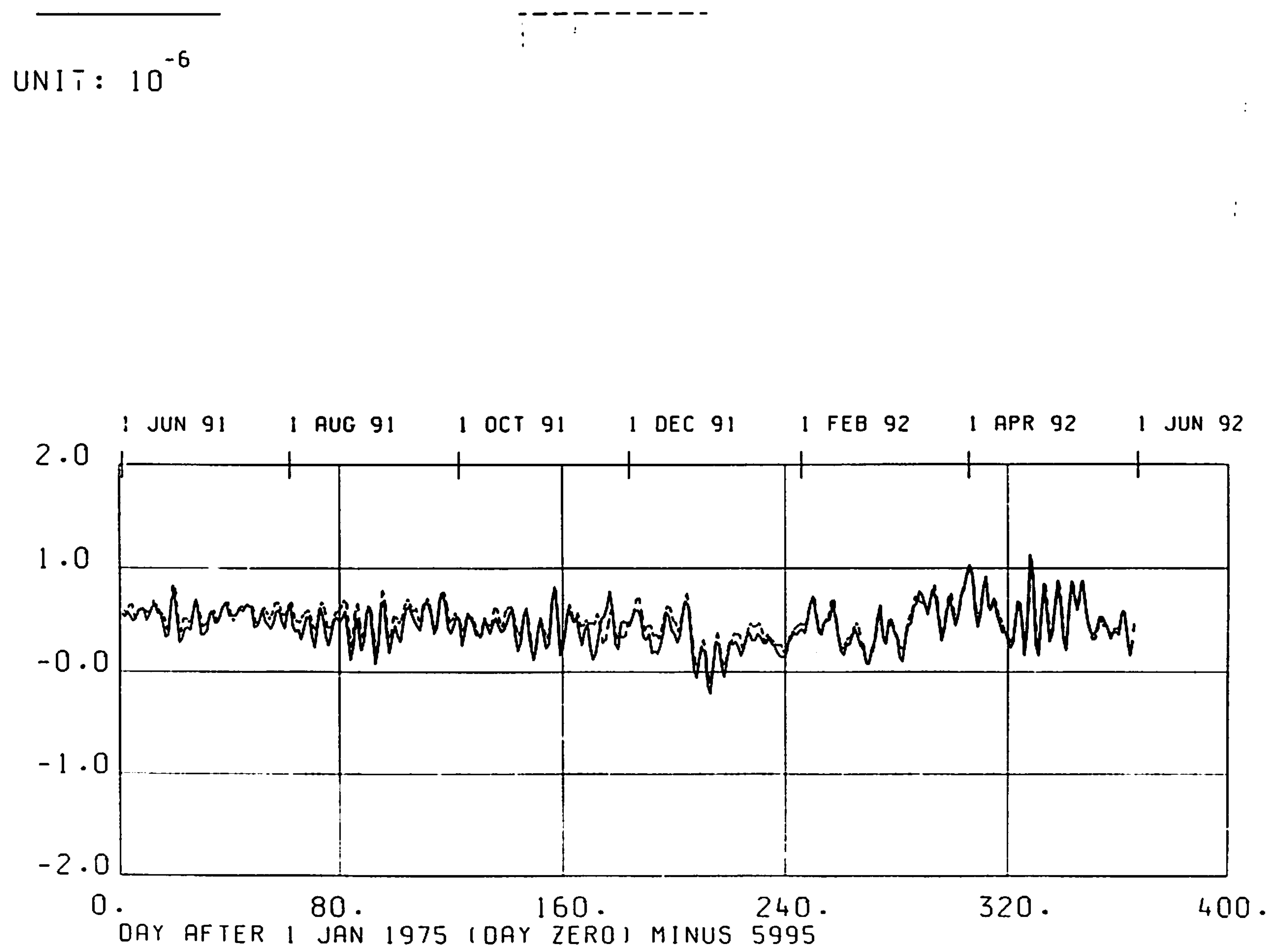
UNIT: 10^{-6}



UKMO N.H. TOTAL EQ. 1 ECMWF(JOP) N.H. TOTAL EQ. 1

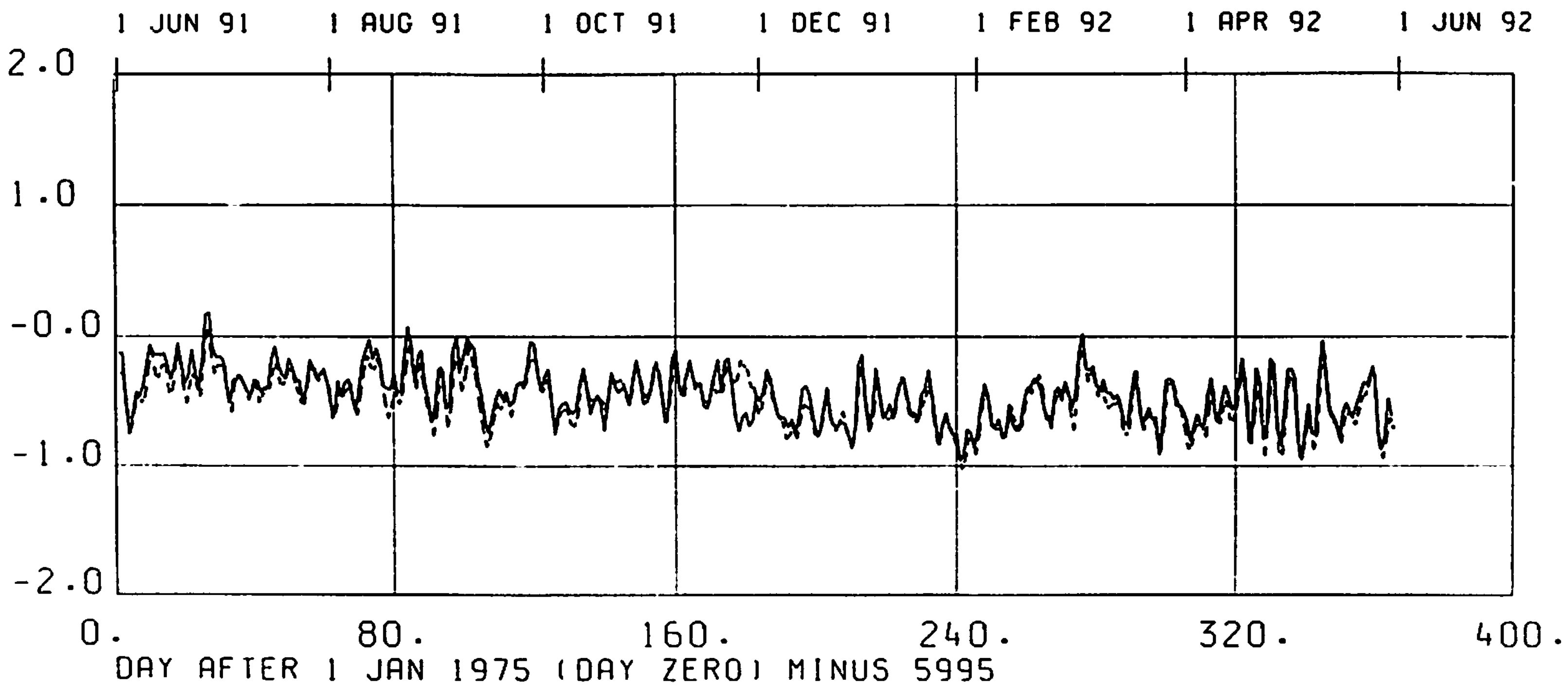
ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

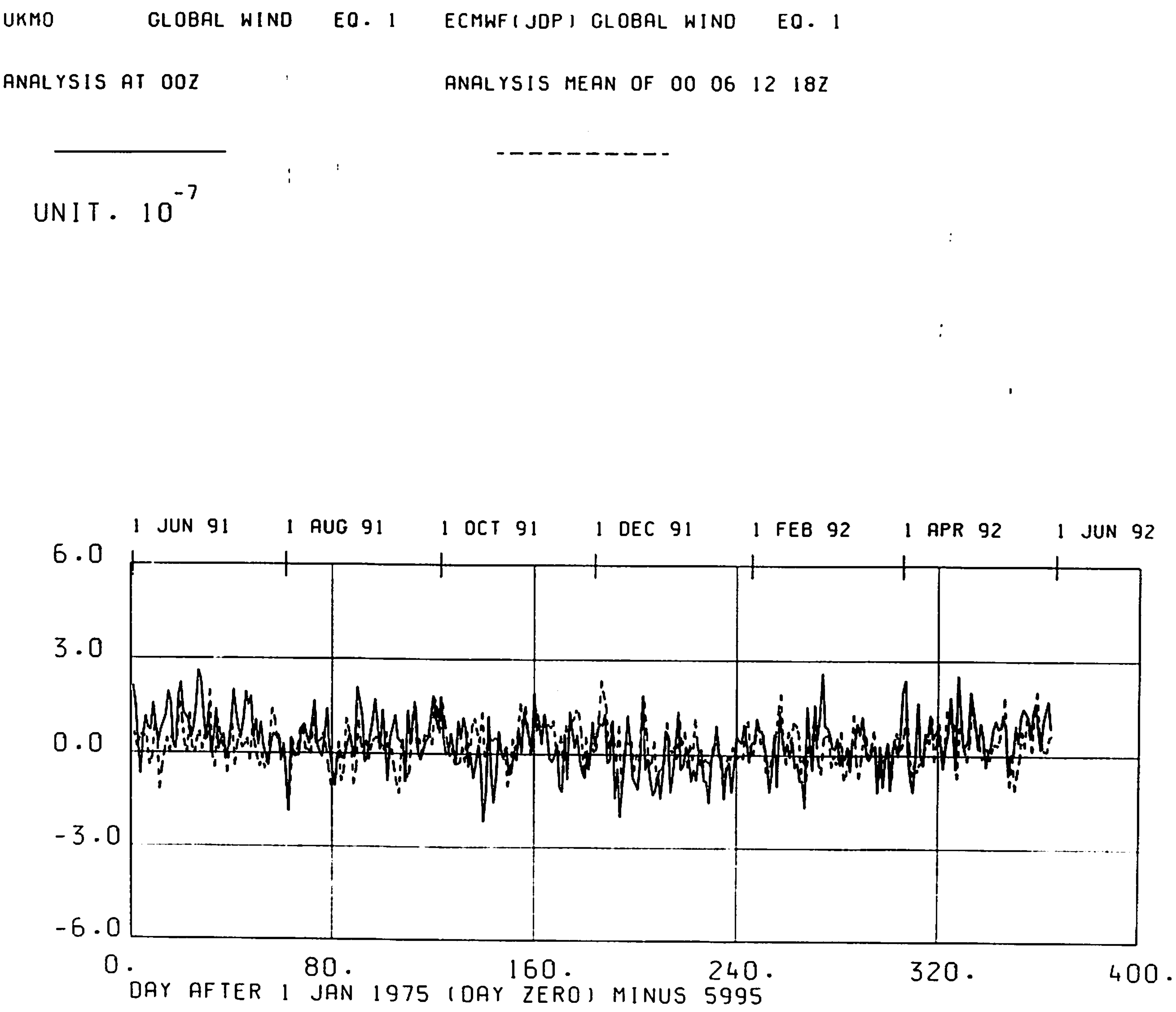


UKMO S.H. TOTAL EQ. 1 ECMWF(JDP) S.H. TOTAL EQ. 1

ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

UNIT: 10^{-6}




UKMO GLOBAL WIND EQ. 1
ECMWF(JDP) GLOBAL WIND EQ. 1
ANALYSIS AT 00Z
ANALYSIS MEAN OF 00 06 12 18Z
UNIT. 10^{-7}
1 JUN 91
1 AUG 91
1 OCT 91
1 DEC 91
1 FEB 92
1 APR 92
1 JUN 92
6.0
3.0
0.0
-3.0
-6.0
0.
80.
160.
240.
320.
400.
DAY AFTER 1 JAN 1975 (DAY ZERO) MINUS 5995

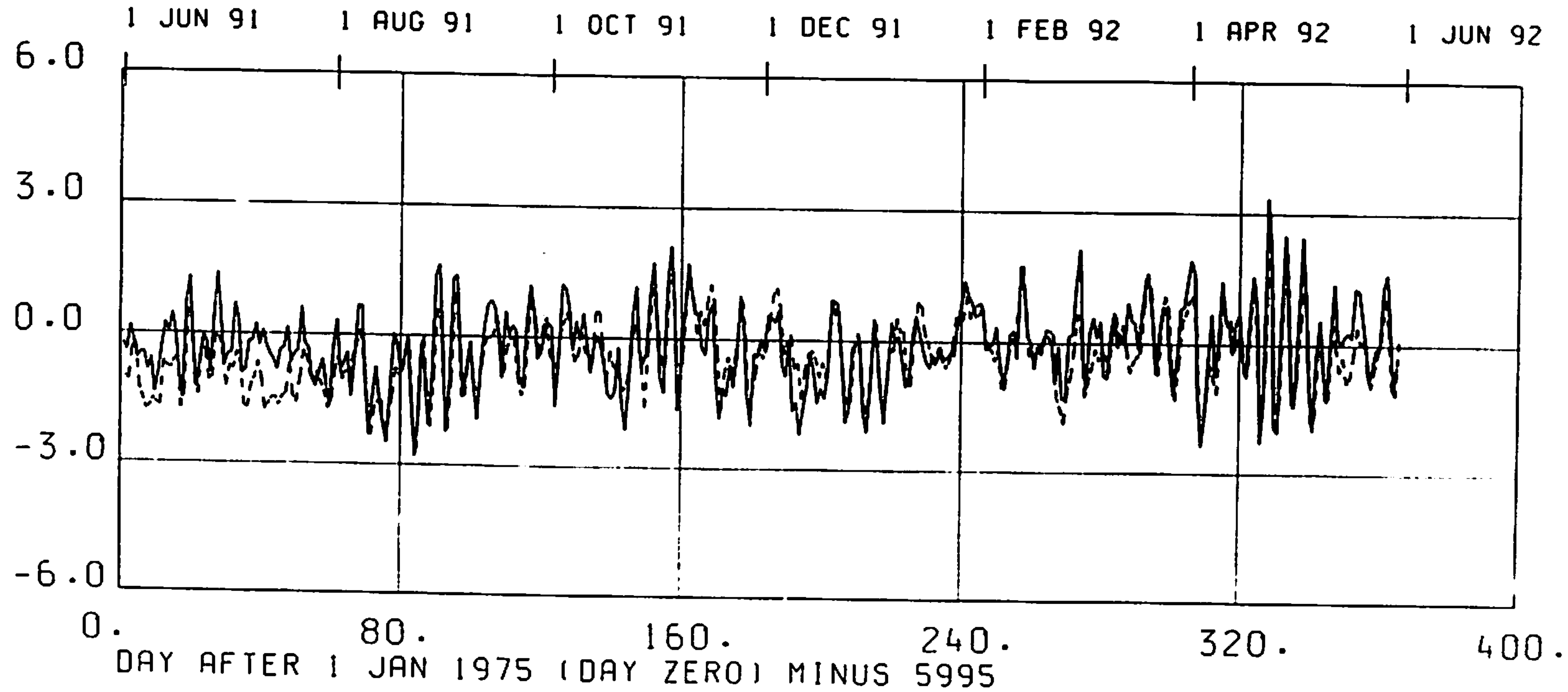
UKMO N.H. WIND EQ. 1

ANALYSIS AT 00Z

ECMWF(JDP) N.H. WIND EQ. 1

ANALYSIS MEAN OF 00 06 12 18Z

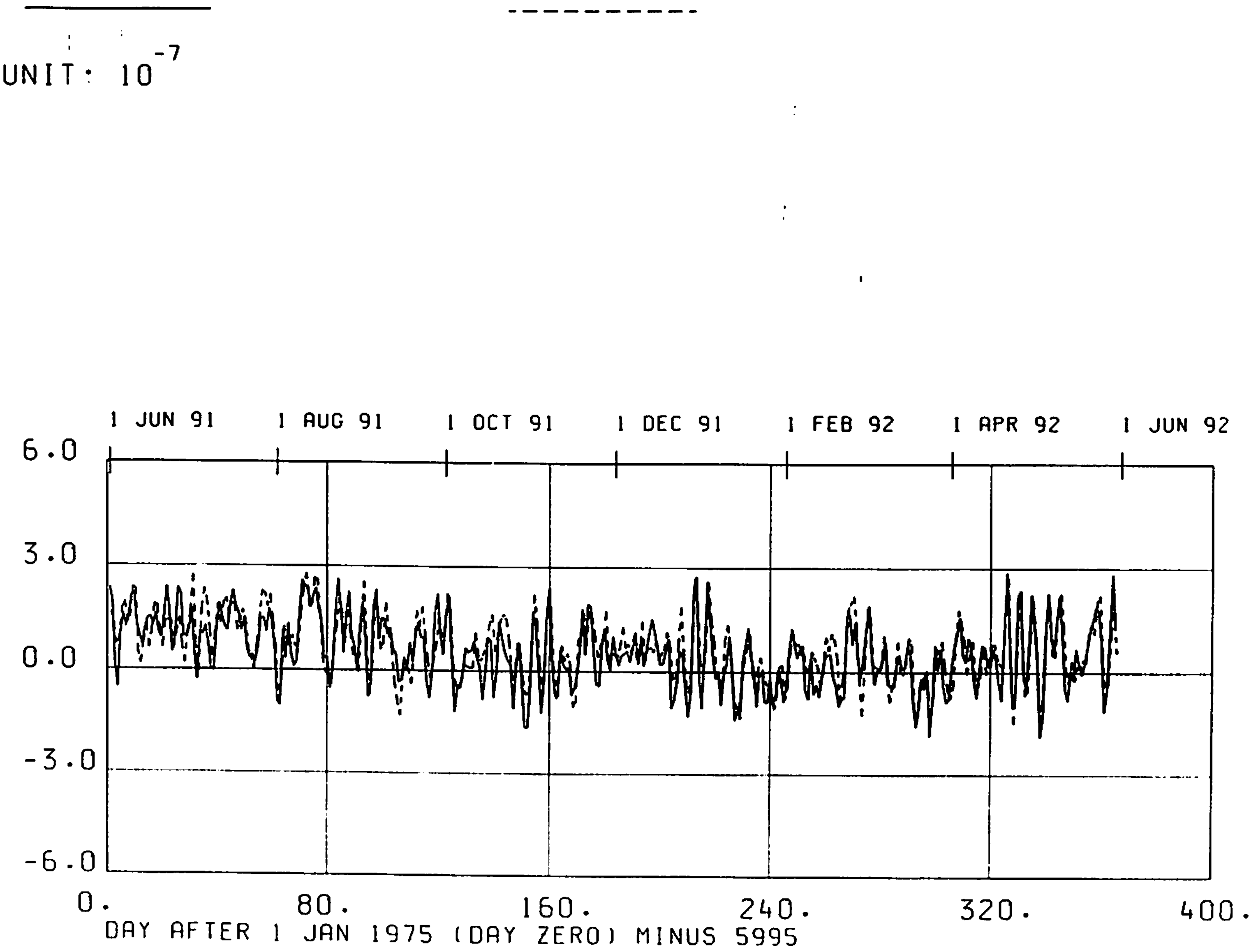
UNIT: 10^{-7}



UKMO S.H. WIND EQ. 1 ECMWF(JDP) S.H. WIND EQ. 1

ANALYSIS AT 00Z ANALYSIS MEAN OF 00 06 12 18Z

UNIT: 10^{-7}



UKMO GLOBAL MATTER EQ. 1

ANALYSIS AT 00Z

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ECMWF(JDP) GLOBAL MATTER EQ. 1

ANALYSIS MEAN OF 00 06 12 18Z

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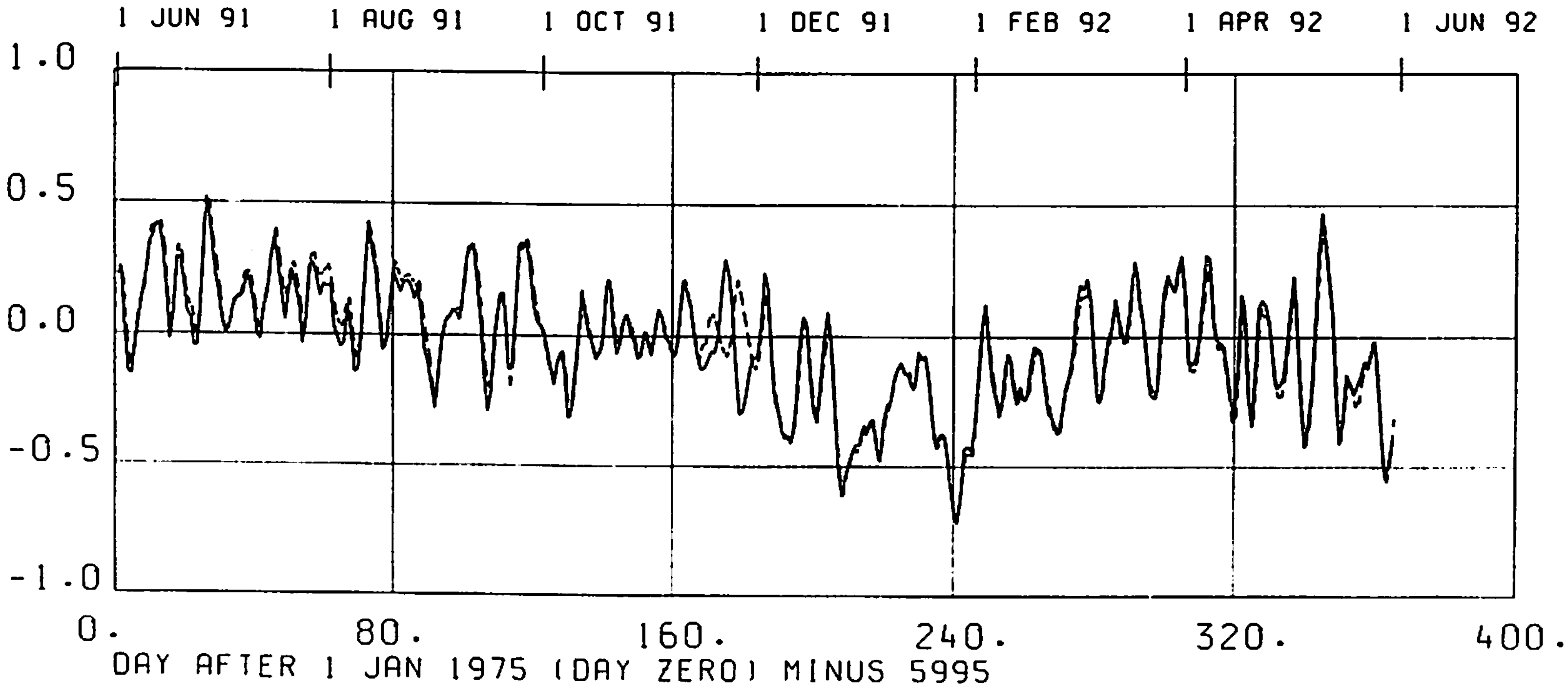
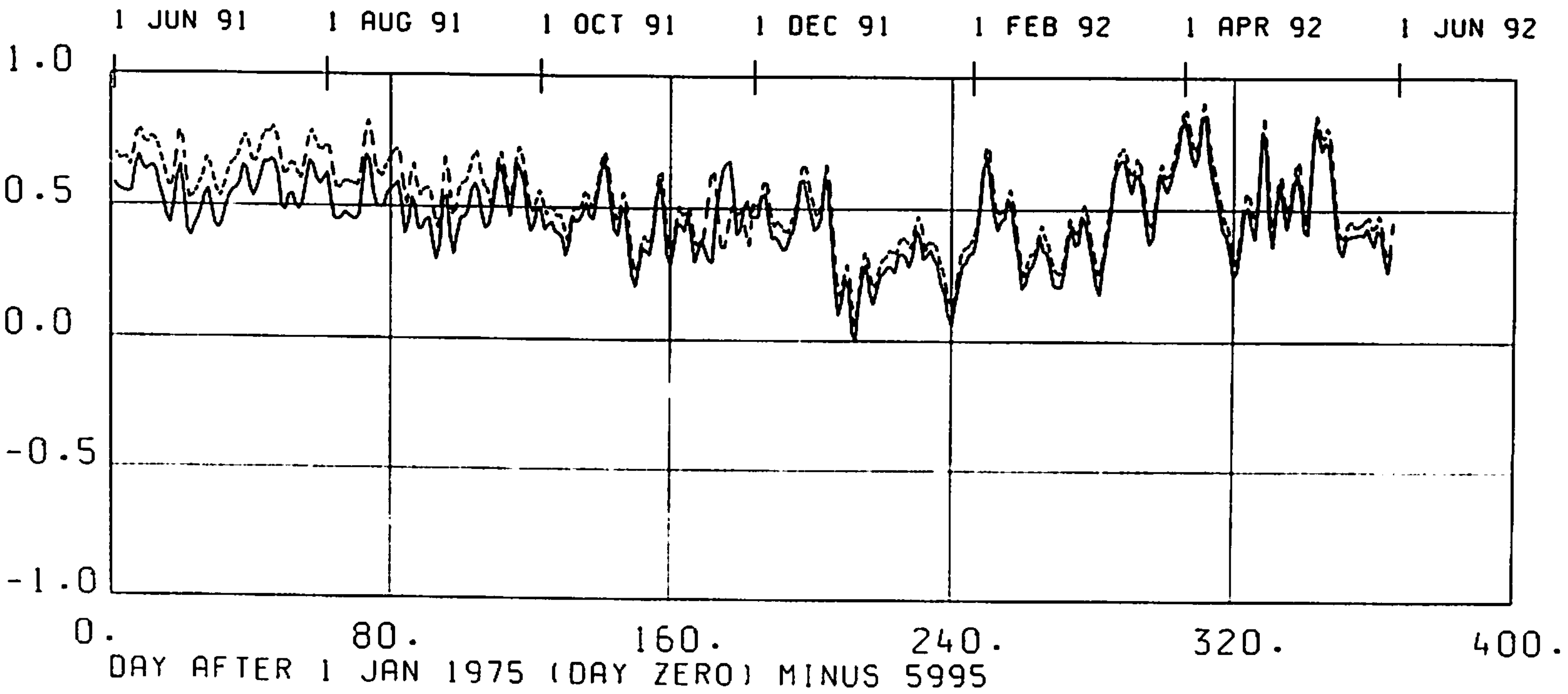
UNIT: 10^{-6}

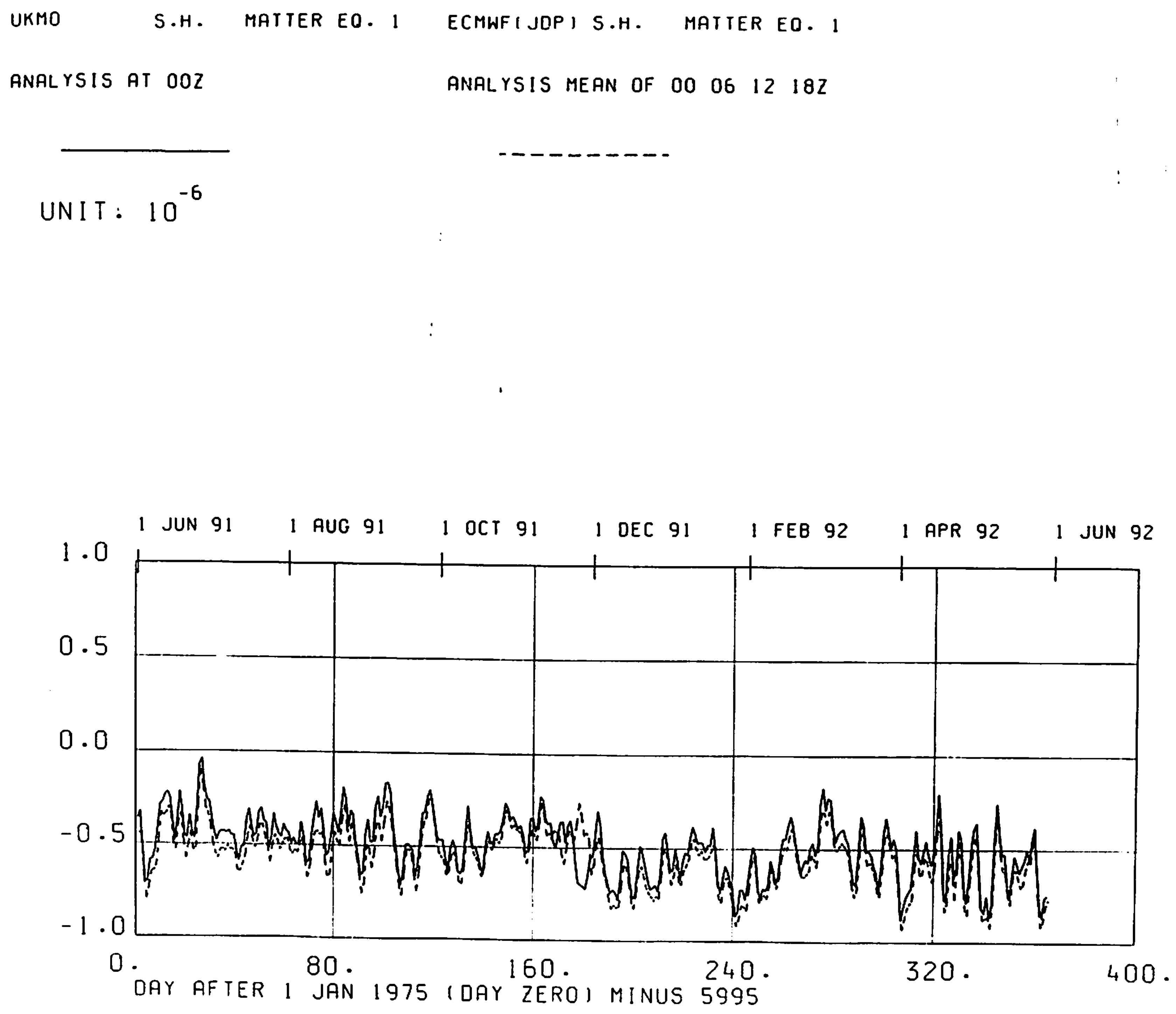


UKMO N.H. MATTER EQ. 1
ANALYSIS AT 00Z
———————

ECMWF(JDP) N.H. MATTER EQ. 1
ANALYSIS MEAN OF 00 06 12 18Z
- - - - - - - - - - -

UNIT: 10^{-6}





UKMO S.H. MATTER EQ. 1

ANALYSIS AT 00Z

ECMWF(JDP) S.H. MATTER EQ. 1

ANALYSIS MEAN OF 00 06 12 18Z

UNIT: 10^{-6}