UGAMP

UK Universities Global Atmospheric Modelling Programme

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Issue 18 **November 1997** **Editor: Glenn Carver** **Director: Alan O'Neill**

Newsletter

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Climate Variability Research

Field Studies & Model Intercomparisons

Monsoon, Storm Tracks, Coupled Modelling, Radiation schemes & Group News

The growth of the 1997 El Niño (top figure) has been dramatic and significantly faster than normal and by the summer a mature El Niño pattern was in place with substantial sea surface temperature anomalies in the E. Pacific (bottom figure). See article by Julia Slingo on page 16.

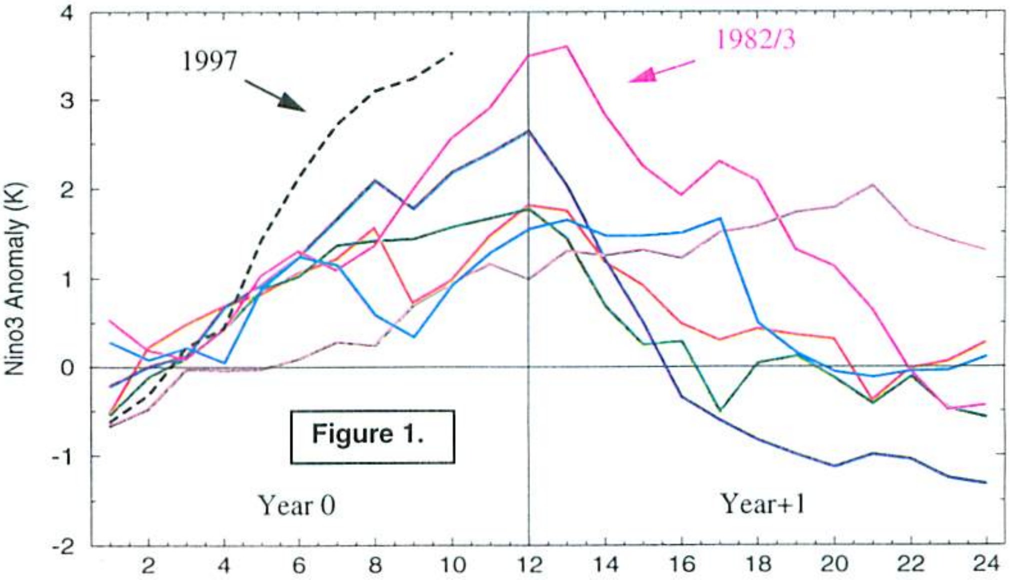

Figure 1.

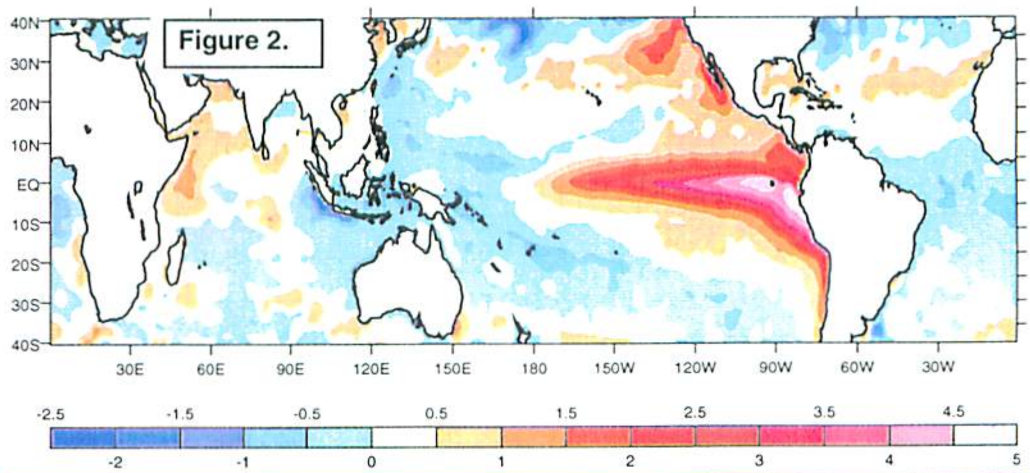

Figure 2.

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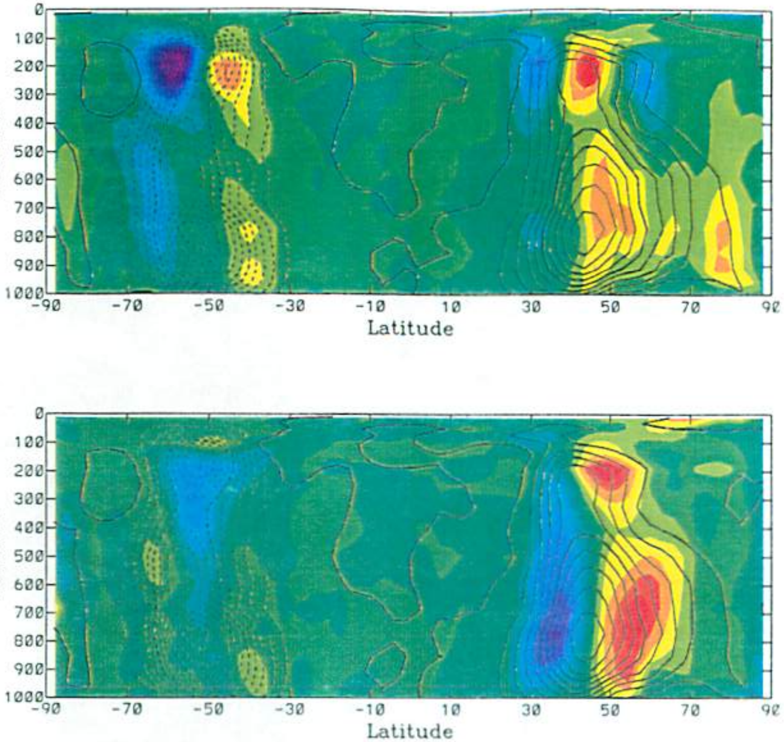

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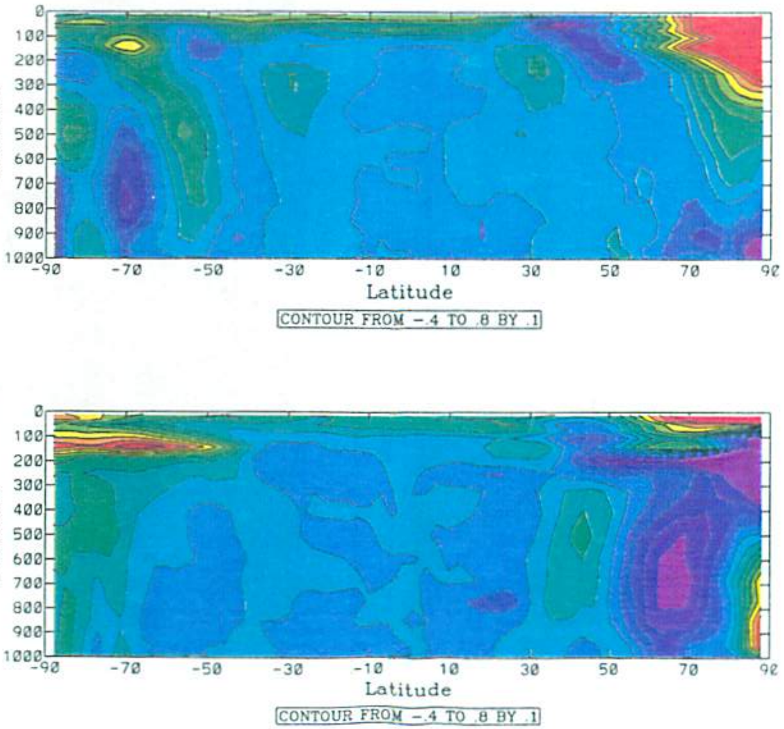

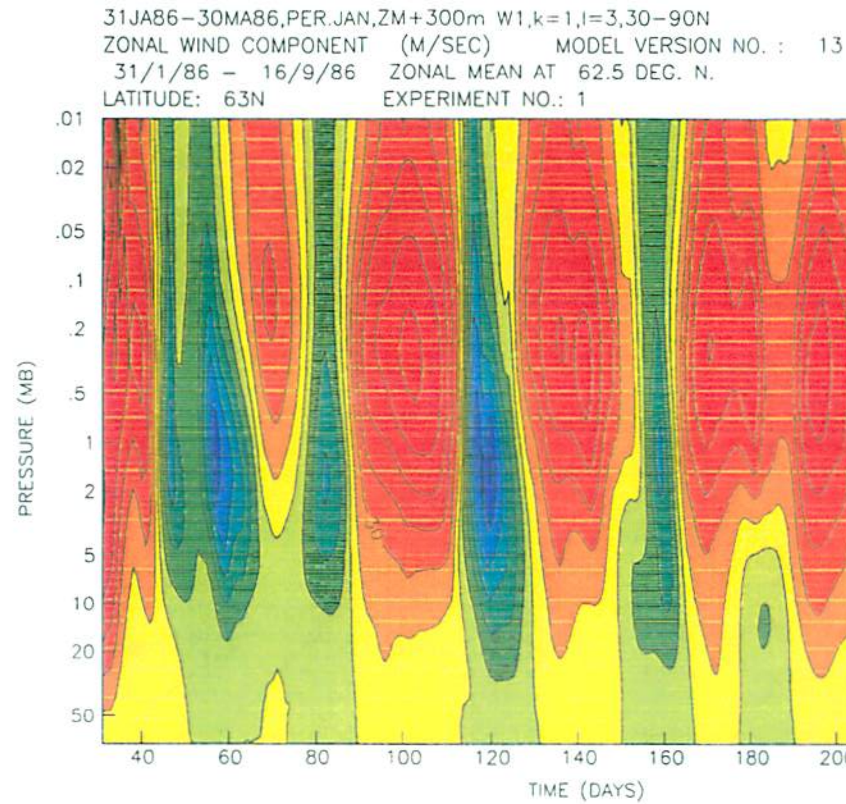

Figure 3. Difference in temperature (K) between solar maximum and solar minimum; S1 - S0 (a), S2 - S0 (b).

Figure 4. Contours show northward transient eddy heat flux (contour interval 1Km/s). Colours show difference between solar maximum and minimum (contour interval 0.1Km/s, zero-line between dark and light green); S1 - S0 (a), S2 - S0 (b).

Figure 5. (right) Zonal mean wind near 60N as a function of height and time in a primitive equation model of the stratosphere under perpetual January conditions: an irregular series of major stratospheric warmings occurs with an average period of about 40 days. However, if the wave amplitude is reduced by 100m to represent a relatively undisturbed year, then the time between consecutive warmings more than doubles.

EDITORIAL

Climate variability is one of the most important research topics facing atmospheric science. So it is appropriate that we focus on some aspects of the UGAMP research being undertaken to understand this problem. Whilst nearly all of the UGAMP science plan projects have a bearing on climate, we choose to highlight research which directly dicusses climate change and feedbacks, long term trends in data and multi-annual model calculations, for both the atmosphere and the oceans. Many of the other articles in this newsletter, not included in the section on climate variability are relevent to climate research.

Many UGAMP and UGAMP related personnel are involved in major international projects; broadly divided into measurement field campaigns and model intercomparisons. We also focus on the role UGAMP is playing in these international programmes.

The dates and location of the 1998 UGAMP Meeting have been decided. It is to be held at Cambridge University from the 23rd to 25th of September. The meeting is to be organised by Drs. John Pyle and Glenn Carver and it will be held in the Chemistry Department.

Congratulations are due to Dr. John Thuburn, who has just been appointed as a lecturer in the Meteorology Department at Reading University. John has been involved in UGAMP from the beginning. Appointed as the "middle atmosphere coordinator" in the early days of UGAMP, John has been a key figure in developing UGAMP's model resources: the USMM and more recently the coupled atmosphere-ocean model to name a few. Many of UGAMP researchers owe John a measure of thanks for his innovations, support and scientific advice over the years. I'm sure I speak for the rest of UGAMP when I wish him well in his new post.

Last, my thanks to Anne Pinnock at CGAM, Reading for all her help in collating and proof-reading many of the articles for this newsletter.

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DIRECTOR'S COMMENT

I hope you have all seen a copy of the "glossy" detailing UGAMP's scientific achievements from 1992 to 1997. It took a lot of work to prepare, particularly by Mark Rodwell, now employed at the Hadley Centre. But the effort was worthwhile: it brought UGAMP a lot of credit. It served as a final report on this five-year period of work, and I was pleased to accept congratulations on your behalf from NERC's Atmospheric Science and Technology Board. There's no resting on laurels in UGAMP, however. The Board also accepted our science plan for the next five years. I shall arrange for it to be placed on the web, so that you can thrill to its boldness and relevance to the big climate issues.

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The UGAMP Newsletter is distributed to all UGAMP sites, all Scientific Steering Group (SSG) members and the Natural Environment Research Council. An Internet edition of the Newsletter is also to be found on the World-Wide Web at the address: http://www.atm.ch.cam.ac.uk/acmsu/newsletter.html.

UGAMP CLIMATE VARIABILITY RESEARCH

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Climate variability is a key research area for most UGAMP science plan projects. In this section we highlight a selection of articles that discuss climate change and feedback, trends in long term datasets and results from multi-annual model integrations. Many other newsletter articles also relate to climate.

Solar Variability and Climate Change

Experiments have been carried out to investigate the impact of changes in solar irradiance, together with solar-induced changes in stratospheric ozone, on the climate of the lower atmosphere. The model used was the UGCM (19 levels up to 10hPa) at T42 resolution in perpetual January mode. Several simulations have been carried out with different assumptions concerning solar irradiance and ozone. Here the results of three of these will be discussed: the first, S0 – representing solar minimum, acts as a control run; the next two both have an increase in total solar irradiance of 0.08% (typical of change from periods of minimum to maximum activity over the 11-year solar cycle) concentrated in the 0.25-0.68 micron band of the model's radiation scheme. Run S1 assumes a change in zonal mean ozone as predicted by a 2-D chemical model; this shows a monotonic increase with height above the tropopause with little latitudinal variation. Run S2 assumes a change in ozone column derived from TOMS data with no vertical variation above the tropopause but quite strong latitudinal variation. All runs were for 1260 model days with the first 180 days dropped from the subsequent analysis.

Figure 3 (see colour figure on page 2) shows the temperature difference between S1 and S0 and between S2 and S0. In both cases the lower stratosphere has warmed and the troposphere shows a vertical banding structure. This pattern appears, to a greater or lesser extent, in all the solar maximum experiments that have been carried out and is statistically robust. Associated with this the tropical Hadley cells broaden slightly and the sub-tropical jets move polewards about 70km. Mid-latitude eddy patterns are also affected; for example Figure 4 (see colour figure on page 2) shows changes in the transient northward eddy heat flux. The poleward shift is particularly clear in the summer hemisphere in S1 and the northern hemisphere in S2.

The response described above can be explained in terms of the extra energy supplied to the tropical Hadley circulation. The precise response depends on the latitudinal distribution of this energy, as well as its magnitude, and this is why the various ozone distributions produce rather different results. Figure 6 shows changes in downward irradiance in the lower stratosphere; note that the heating, due to the increases in both solar irradiance and ozone, causes an increase in downward longwave irradiance. As this is much more strongly absorbed in the troposphere, and as the sea surface temperatures are fixed in these experiments so that much of the extra solar energy is 'lost', the effect of the changes in longwave irradiance is as important as those in the shortwave.

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Trends in Stratospheric Water Vapour detected by the Halogen Occultation Experiment

Analysis of the HALOE water vapour dataset from 1992 to 1996 inclusive has shown that there has been a global increase in the mixing ratio at stratospheric levels between 30 km and 60 km. This increase has been modelled as a linear trend and is found to be statistically significant given both the uncertainty and the variability in the measurements, based on the student-t distribution, at the 95% confidence level. Our analysis supports the findings of Oltmans and Hofmann (1995) and further suggests that the observed trend in stratospheric H_2O is both global and extends throughout the stratosphere.

The global average H_2O trend varies between (approx.) 40 ppbv yr^{-1} in the lower levels to a maximum of (approx.) 90 ppbv yr^{-1} at 45-50 km before falling back to (approx.) 65 ppbv yr^{-1} at 60-65 km. Analysis of the trends in the methane data since 1992 reveal a decline in CH_4 concentrations in the altitude region 35-50 km. The combined budget of $2CH_4$+H_2O was also considered. This revealed a trend, approximately constant with height, of (approx.) 65 $\pm$ 1.3 ppbv yr^{-1} which is similar to that found for water vapour alone in the upper stratosphere. From

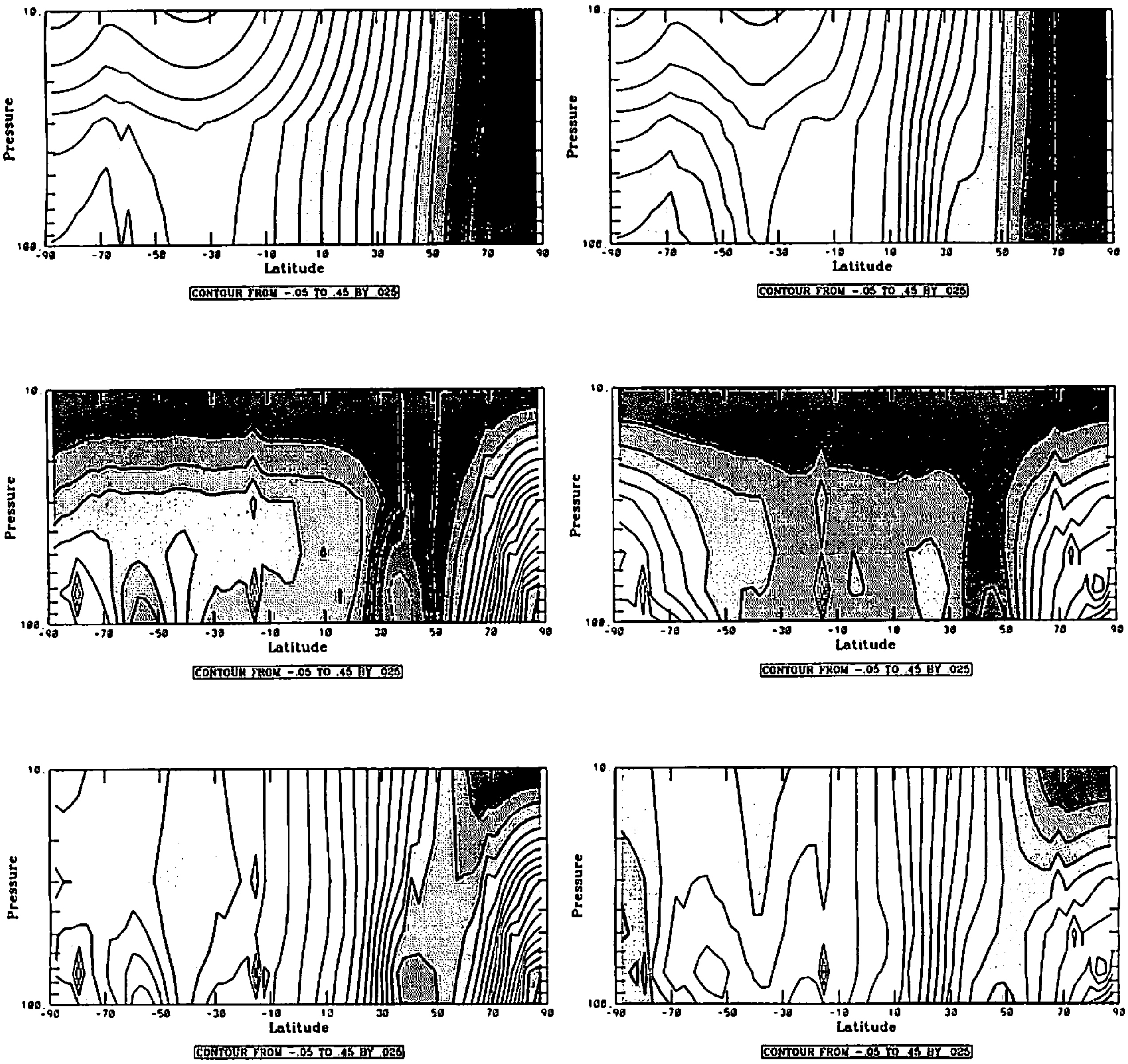

Figure 6. Difference in downward irradiance; solar (top), longwave (middle) and net (bottom) for S1 - S0 (left) and S2 - S0 (right).

this we infer that the fall in methane mixing ratios, caused by oxidation, is responsible for the increase in water vapour in excess of 65 ppbv yr^{-1}. However, the remaining trend is harder to explain. This represents an increase in the concentration of the chemically active hydrogen budget, predominantly in the form of water vapour. This may in part be due to the rising concentrations of tropospheric methane seen since industrialisation. Present rates of increase of tropospheric methane of between 4.5-11.2 ppbv yr^{-1} do not seem consistent with a stratospheric H_2O trend of (approx.) 65 ppbv yr^{-1}. Thus it would seem that there is an additional source of water vapour affecting the stratospheric observations. We have considered three other possible mechanisms which may account for these observations. The first, that the observed increase of water vapour, over and above that due to CH_4 changes, could be accounted for by a small change (of the order of a few tenths of a degree) in the effective tropopause injection temperature may derive support from observations of trends in tropical deep convective cloud amount. A volcanic source of additional water vapour loading in the stratosphere, although theoretically possible appears not to be evidenced by observations immediately following the eruption of Mount Pinatubo and the absence of the expected vertical structure. Lyman alpha variations due to the solar cycle would appear to enhance the trends in the upper stratosphere (and mesosphere) only (Chandra et al. 1997).

A 2-D radiative-chemical-dynamical model has been used to investigate the sensitivity of stratospheric ozone to changes in water vapour and methane concentrations of the order determined from the HALOE dataset over the time scale for the doubling of CO_2. This gave rise to an additional enhancement of mid-stratospheric ozone of (approx.) 1-2% compared to that due to doubling CO_2 alone of (approx.) 5-10%. Conversely, the ozone loss rates in the upper stratosphere, above 50 km, were further increased. The chemical mechanisms for this have been identified; water vapour acts as a source of HO_x which, in the lower stratosphere destroys NO_x (the principle sink for ozone in the lower stratosphere) while in the upper stratosphere HO_x destroys ozone catalytically as well as causing an increase in Cl/ClO-catalyzed destruction as the HCl reservoir reacts with OH.

References

Chandra, S., C.H. Jackman, E.L. Fleming and J.M. Russell III, The seasonal and long term changes in mesospheric water vapour, Geophys. Res. Lett., **24**, 639-642, 1997.

Oltmans, S.J. and D.J. Hofmann, Increase in lower-stratospheric water vapour at a mid-latitude site from 1981 to 1994, Nature, **374**, 146-149, 1995.

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Upper Tropospheric Humidity – Validation of Models and Climate Change Signals

John Harries, Helen Brindley and I have been working on the spectral signatures of climate change. Instead of looking at temperature fields, the idea is to use the outgoing radiances at the top of the atmosphere as a means of looking for climate change. One of the main points of the work has been to find practical examples using existing datasets. This is easier said than done since such a study requires data over the entire period of operation of an instrument. For TOVS data, this means everything from 1979 onwards - an enormous quantity of data in the raw form. Another consideration is the calibration between different instruments. Luckily Bates and co-workers have produced a monthly mean HIRS12 dataset which is fully intercalibrated. HIRS12 is sensitive to upper tropospheric water vapour between about 250mb and 550mb. We can use this dataset both for looking for climate change and for validating climate and forecast models, a not unrelated task. In both cases model profiles of humidity and temperature are used to forward simulate the radiances observed by the satellite. Some kind of statistical comparison can then be made between the simulations and the data. Since upper tropospheric relative humidity is strongly related to the circulation patterns it could be a good place to look for signals of climate change.

Using a climate simulation run of the Hadley Centre GCM (HADCM2) we have simulated the changes in HIRS12 expected between 1865 and 2045. Spatial correlation statistics were used to look for the climate change signal emerging in the observed data. The simulations revealed significant regional changes in upper tropospheric relative humidity with the most interesting effects in the tropics. The observational data also showed significant regional trends in its 17 year period. HIRS12 shows a strong ENSO signal in the Pacific and high interannual variability in the tropics as a whole which is the main reason why over 17 years (apart from the short timescale) climate change will be difficult to detect in HIRS12.

The model validation side of things is another current task and we hope to use both HIRS12 and METEOSAT water vapour radiance data, also sensitive to upper tropospheric humidity. We are trying to develop a METEOSAT cloud cleared water vapour radiance dataset for this purpose though eventually clear sky radiances should be available from EUMETSAT. The current plan is to start off looking at just one month of ECMWF Re-Analysis data and comparing with METEOSAT – HIRS12 is assimilated into ERA. The high temporal resolution of METEOSAT will give us the ability to look at the ERA data on synoptic scales. The methods we are developing will aid the evaluation of climate models. If any other models need validating against water vapour radiances, we'll be happy to help.

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Interannual Meteorological Variability and Mid-latitude Ozone

We have recently run the 3D chemical-transport model SLIMCAT to investigate the effect of interannual meteorological variability on ozone at middle latitudes in the years 1991-97. The model was forced by UKMO analyses and used the Cariolle ozone scheme, which is a simple parameterization of ozone photochemistry and perturbed chlorine chemistry on polar stratospheric clouds (PSCs). In Figure 7a we show the observed TOMS total ozone column at 45-50 N with

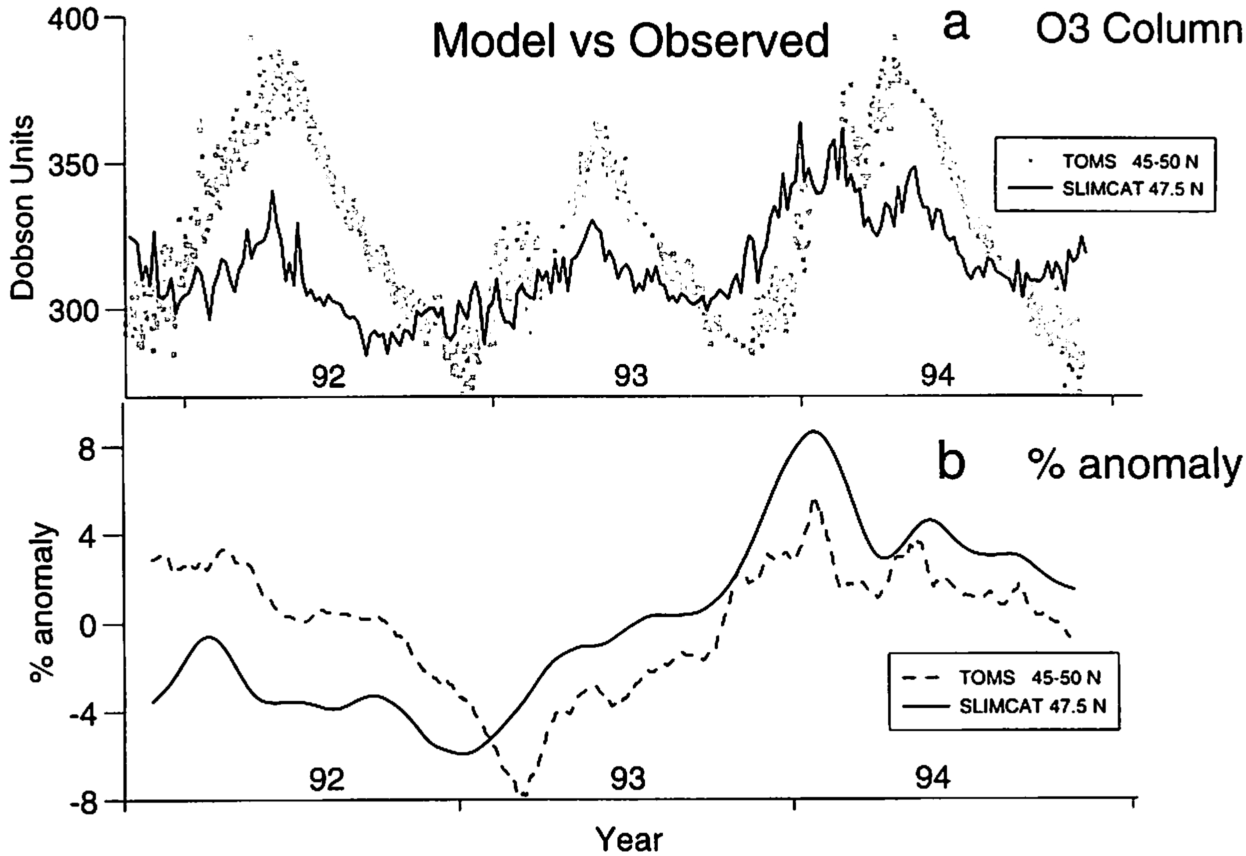

Figure 7. (a) Observed zonal mean total column ozone from TOMS data (45-50N) and calculated zonal mean column ozone from model run (47.5 N).
(b) Calculated anomaly from 1992-94 average in zonal mean column ozone from TOMS data and from the modelled O_3 tracer.

the calculated O_3 column from the model at 47.5 N in 1992-94 and in Figure 7b the corresponding percentage anomaly for the same set of data. The model calculates its lowest ozone during winter 1992-93 and is in reasonable agreement with the observations. This follows the Mt. Pinatubo eruption (June 1991), but in this calculation cannot be due to chemistry on the enhanced aerosol surface area which was not included in the model. This result therefore demonstrates the importance of the circulation on the year to year ozone variation. The model also indicates (not shown here) a contribution of the Arctic polar loss to mid-latitude ozone depletion each year during springtime, its influence being seasonal and not accumulating through the years.

Forthcoming Publication

Effect of interannual meteorological variability on mid-latitude ozone, P. Hadjinicolaou, J.A. Pyle, M.P. Chipperfield, and J.A. Kettleborough will appear in Geophysical Research Letters.

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Multiannual Simulations With the SLIMCAT Stratospheric CTM

Until now, the "state-of-the-art" of 3D chemical transport modelling, both within UGAMP and elsewhere, has been to perform seasonal length simulations of up to about 6 months. For example, the chemical transport model (CTM) would be initialised in November and integrated through to the following April, giving a simulation of a single Arctic winter and spring. This approach has been very useful, for example, for diagnosing seasonal ozone depletion, but it has a number of limitations. The CTM runs are sufficiently short that the results are sensitive to the model initialisation, the runs are not long enough to reveal any small trends in the model, and the runs

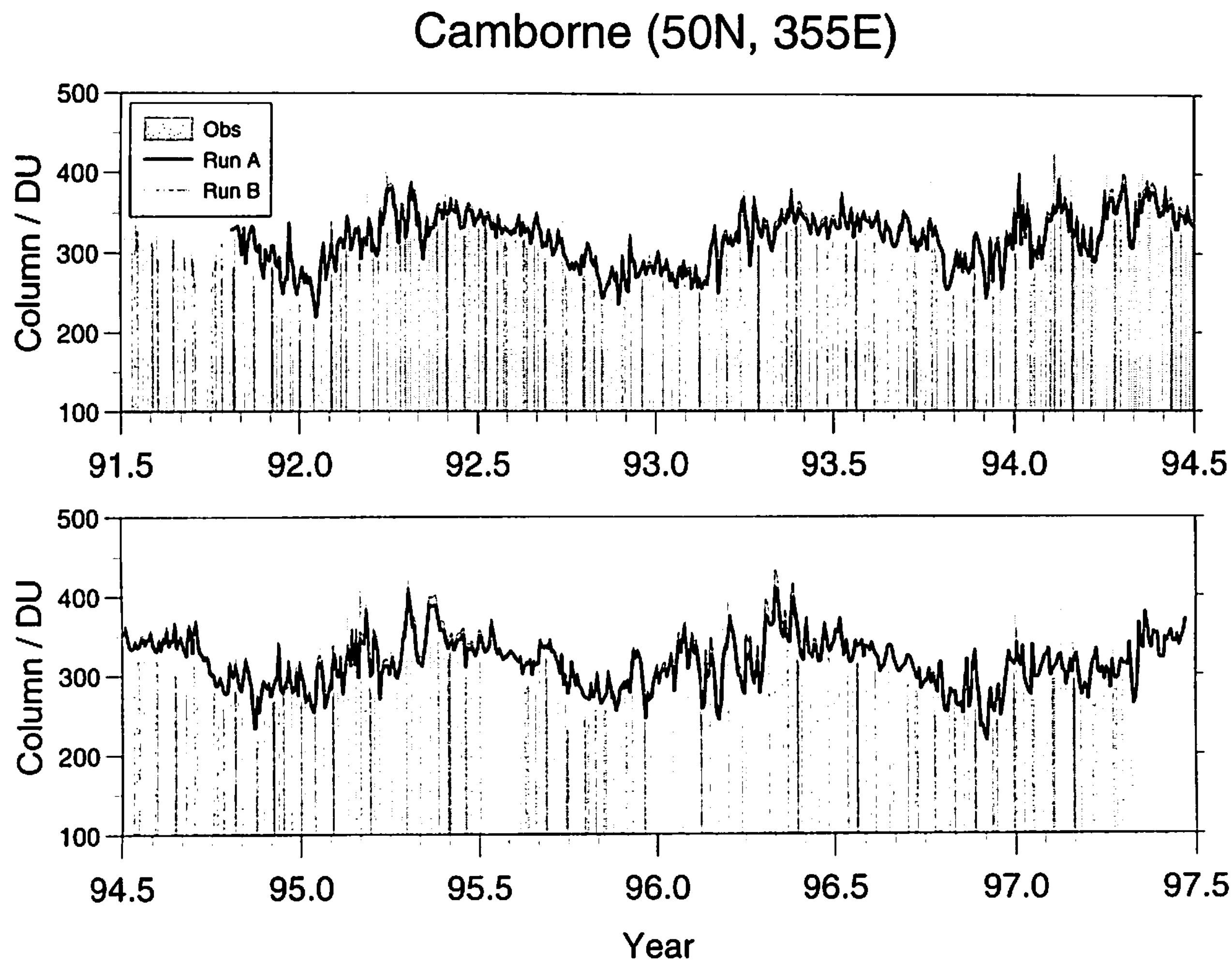

Figure 8. Comparison of observed column O_3 at Camborne (50N, 355E) with output from the SLIMCAT 3D model (Run A). The model values include an estimated tropospheric contribution. Data courtesy of M. Molyneux (U.K. Met. Office).

cannot be used to study interannual variability. Therefore, I have recently updated the SLIMCAT CTM to permit multiannual simulations, and I have performed the first 6 year runs. These 'off-line' chemical simulations are an important step in the progression to fully coupled chemistry runs in a GCM. The SLIMCAT CTM uses an isentropic vertical coordinate, and so it is appropriate for stratospheric studies. For these multiannual runs I updated the chemistry scheme to also integrate a number of tropospheric source gases (e.g. CFCs) and the scheme now contains 35 chemical tracers. The model was run at the modest resolution of 7.5x7.5 degrees with 12 levels between 335 K and 2700 K. The runs were forced with UKMO UARS analyses and so I started the model run in October 1991 and ran it through to September 1997. I performed this run on the University of Cambridge Hitachi vector computer and 90 days of model integration fitted into a 3 hour job. Figure 19 (see colour figure on page 29) shows the zonal mean field of active chlorine (ClO_x=ClO + $2Cl_2O_2$) on the 480 K isentropic surface over the six years of the run. The strong, regular activation of chlorine in the Antarctic winter is clearly reproduced, with ClO_x values up to 2.8 ppbv. As expected, the activation of chlorine in the Arctic winter is weaker, and shows much more interannual variability associated with the different meteorological conditions. The 'warm' winter of 1993/94 gives weak activation, while the recent cold winters of 1994/95, and especially 1995/96, give stronger activation. Figure 8 shows the comparison of column ozone observed by the UKMO station at Camborne with the SLIMCAT results. The quantitative comparison is extremely good with no sign of a model 'drift'. The model captures the observed variability on a range of timescales from day-to-day variability, through the seasonal cycle to interannual differences. This comparison is especially good when noting that the 3D CTM combines a 'best' chemistry scheme with analysed winds and temperatures and there are no tuned (or tunable) model parameters, as such. Figure 9

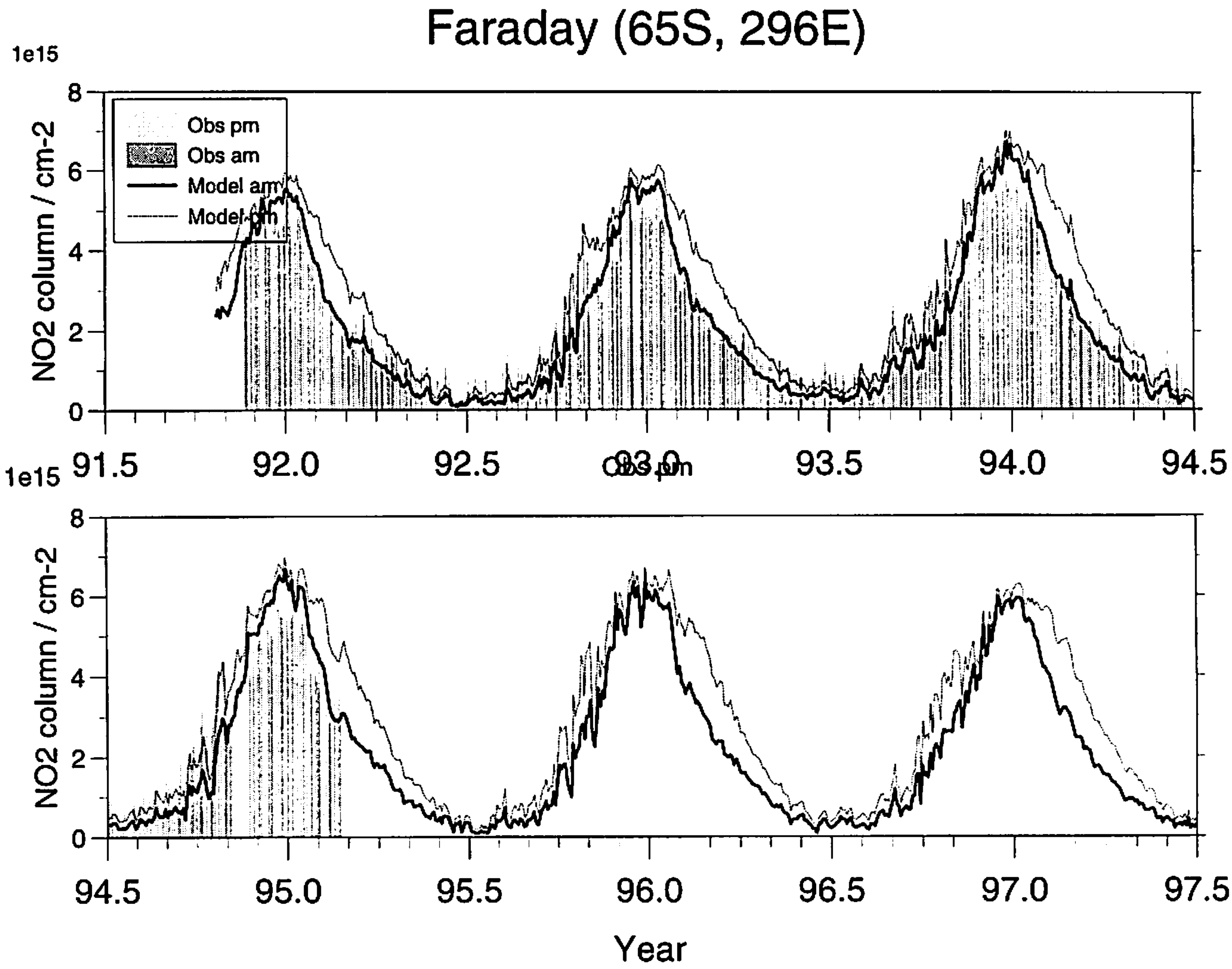

Figure 9. Comparison of observed morning and evening column NO_2 at Faraday (65S, 296E) with output from the SLIMCAT 3D model sampled at 90 degrees solar zenith angle. Data courtesy of H.K. Roscoe (British Antarctic Survey).

shows the comparison of column NO_2 observed at Faraday by the British Antarctic Survey with the model. For this relatively short-lived species the model captures the strong seasonal variation well, including the more subtle changes in the morning and evening differences.

The brief results presented above are very encouraging indeed, and herald a new stage in 3D (stratospheric) modelling. These multiannual runs will permit many more experiments, especially experiments which address long timescale phenomena such as interannual variability and mid-latitude ozone depletion. These long runs also improve the shorter, seasonal investigations as uncertainty in the initialisation is removed and all of the model chemical fields are determined by the 3D model dynamics and chemistry. This 6 year model integration contains a simulation of all of the major stratospheric species over a time period containing many measurement campaigns (e.g. UARS, EASOE, SESAME). Anyone interested in comparing data with the model runs should contact me.

These long simulations are also an essential step in developing, and more importantly testing, the chemical schemes which will be used in future coupled chemistry-climate GCM simulations. The next major step in the SLIMCAT/TOMCAT model development will be to combine the 'stratospheric' and 'tropospheric' models into a single CTM, to give, *inter alia*, a better representation of the tropopause region.

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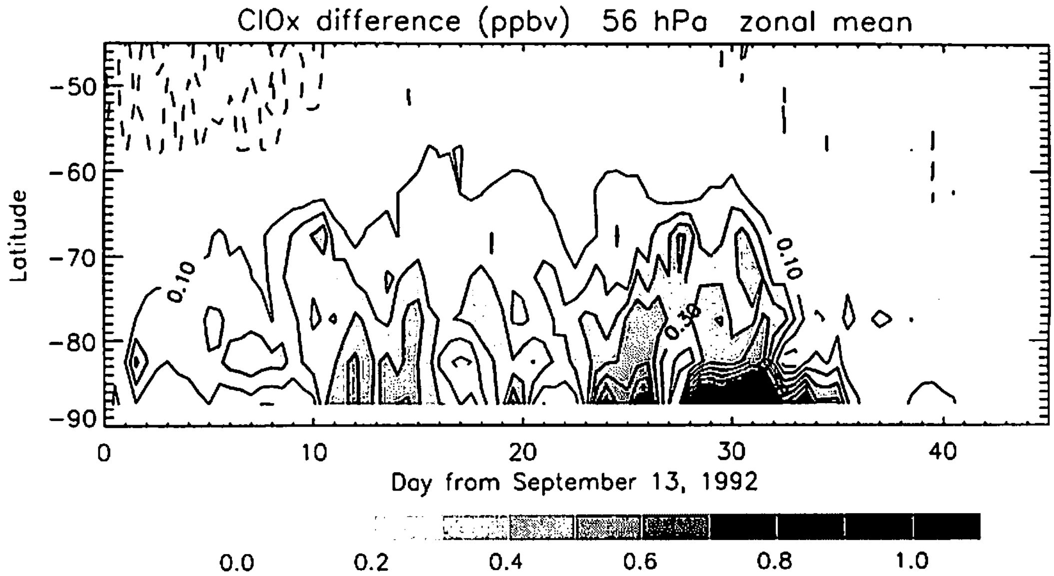

Figure 10. Time versus latitude section of the reactive chlorine from an interactive run of the COSMIC model including heterogeneous chemistry minus the equivalent field from a run of the chemical transport model with the same chemistry but forced by winds and temperature from a run of the COSMIC model with no heterogeneous chemistry. The plot is a zonal mean at 56 hPa.

Chemical Radiative Feedback in the Stratosphere

The early years of the next century will see stratospheric ozone at its most vulnerable to attack by anthropogenic influences. Halogen loading of the stratosphere will likely peak around the year 2000 and then slowly decline, but the upward trend in the atmospheric burden of greenhouse gases, particularly CO_2, will continue for many years. The increase in greenhouse gases is expected to cause the stratosphere to cool, and may lead to more widespread or prolonged occurrences of polar stratospheric clouds. These clouds are the primary agents for releasing chlorine in the polar vortices into active forms, and, because they remove nitrogen compounds from the stratosphere by sedimentation, the greater the prevalence of clouds, the longer into spring can the enhanced reactive chlorine persist. Thus the next decade or so, when the chlorine loading is near its peak and stratospheric temperatures will probably be falling is especially critical for global ozone. Moreover, ozone, by absorbing solar ultra-violet radiation, plays the major role in heating the stratosphere so any increased downward trend in ozone amounts may be exacerbated by positive feedback between the ozone loss and stratospheric cooling. Consequently, forecasting the probable and possible responses of ozone to the changing atmospheric conditions over the coming years requires a good understanding of the various interactions between radiation and chemistry.

To date, most 3-D models of the atmosphere have used fixed, climatological ozone fields for the radiative calculations, but for the reasons outlined above, there is now a need for models in which the radiation and chemistry schemes are allowed to interact. This was the motivation for developing the COSMIC model which comprises the UGAMP stratosphere-mesosphere model coupled with the TOMCAT off-line chemistry-transport model to give, effectively, a single mechanistic model of the middle atmosphere with an interactive chemistry scheme. Ian MacKenzie has been using the COSMIC model to investigate feedback between radiation and chemistry during the southern winter of 1992. Radiative and dynamical effects of the ozone hole were investigated by comparing runs that included heterogeneous chemistry and hence developed an ozone hole, with otherwise identical control runs with no heterogeneous chemistry and no ozone hole. Temperatures in the two runs started to diverge significantly from around the middle of September, and by late-October the lower stratosphere of the run with heterogeneous chemistry was up to 12K colder than that of the control run. The temperature decrease was due to an excess radiative cooling of a few tenths of a kelvin per day in the ozone-depleted runs, partially offset by an increased dynamical heating. In the mid and upper stratosphere a strengthened general circulation in the ozone-depleted runs, along with an enhanced longwave radiative heating rate, led to slightly higher temperatures at the high southern latitudes in these

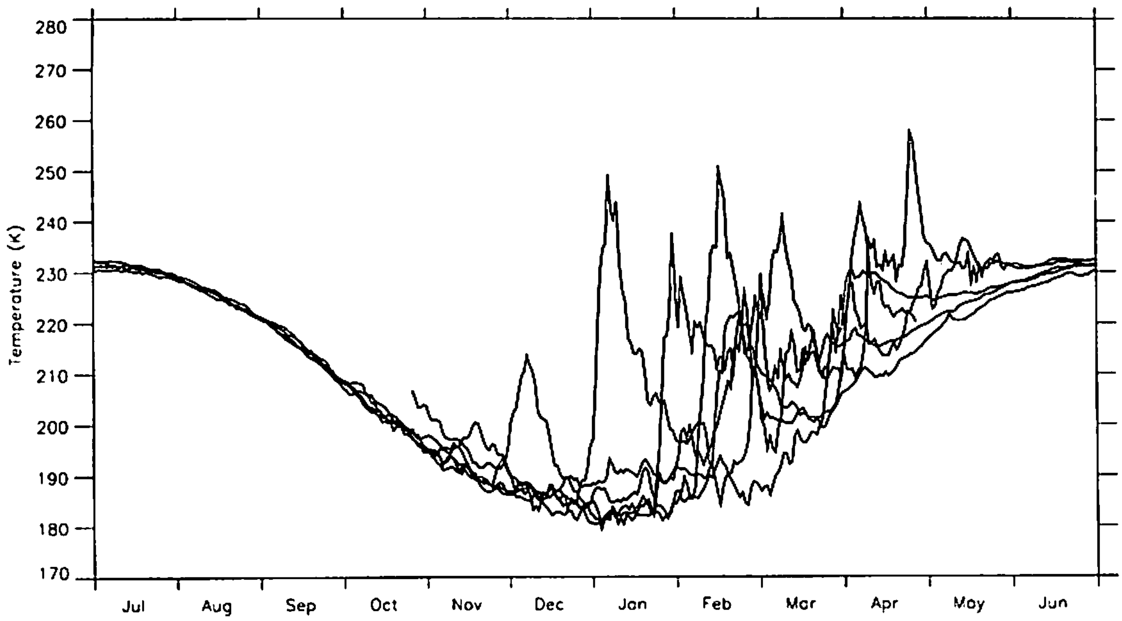

Figure 11. North pole temperatures (K) at 10 hPa in the model. The lines show the evolution of north pole temperature simulated by the UM, for the full period of the model run. The grey shading shows the envelope of several years of north pole temperatures (K) from the UKMO analyses (for the period October 1991 to October 1996).

runs than in the control runs. However, the initially smooth evolution of the temperature difference at the upper levels was interrupted around the middle of October by more transient events associated with differences in wave activity which caused a temporary reversal in sign of the temperature difference. As a result, the temporal evolution of the vertical profile of the temperature difference has a distinctive structure as shown in Figure 21. (see colour figure on page 30). This structure was found to be insensitive to small changes in the initial conditions and in the lower boundary forcing.

The effect on the chemistry of the physical changes wrought by using the depleted ozone in the radiative calculations was investigated by running the chemical transport portion of the COSMIC model, with heterogeneous reactions included, on its own, forced with winds and temperatures from an interactive control run that had no heterogeneous reactions. Results from this run were compared with those from the corresponding fully coupled run with same chemistry scheme. It was found that the lower temperatures in the coupled run have a limited impact on the ozone destruction because the largest temperature differences develop after the polar stratospheric clouds have dissipated, so there is no substantial difference in the time-evolution of the reactive chlorine (ClO_x) between the two runs (Figure 10). Also, when the largest differences in the ClO_x do arise, towards the end of the period of enhancement, the ozone has been very nearly removed from the lower stratosphere, limiting the scope for extra ozone loss in the run with greater ClO_x. Nevertheless, the chemical-radiative feedback does cause local reductions of up to about 30 Dobson units in the Antarctic ozone column in mid-October. Analysis of the movement of passive tracers indicates that the slight increase in the diabatic descent rate resulting from the feedback of the depleted ozone on the radiation does not significantly alter the transport of ozone within the lower vortex, the rate of which is low in comparison to the rate of chemical ozone destruction. A paper on the above work is in preparation.

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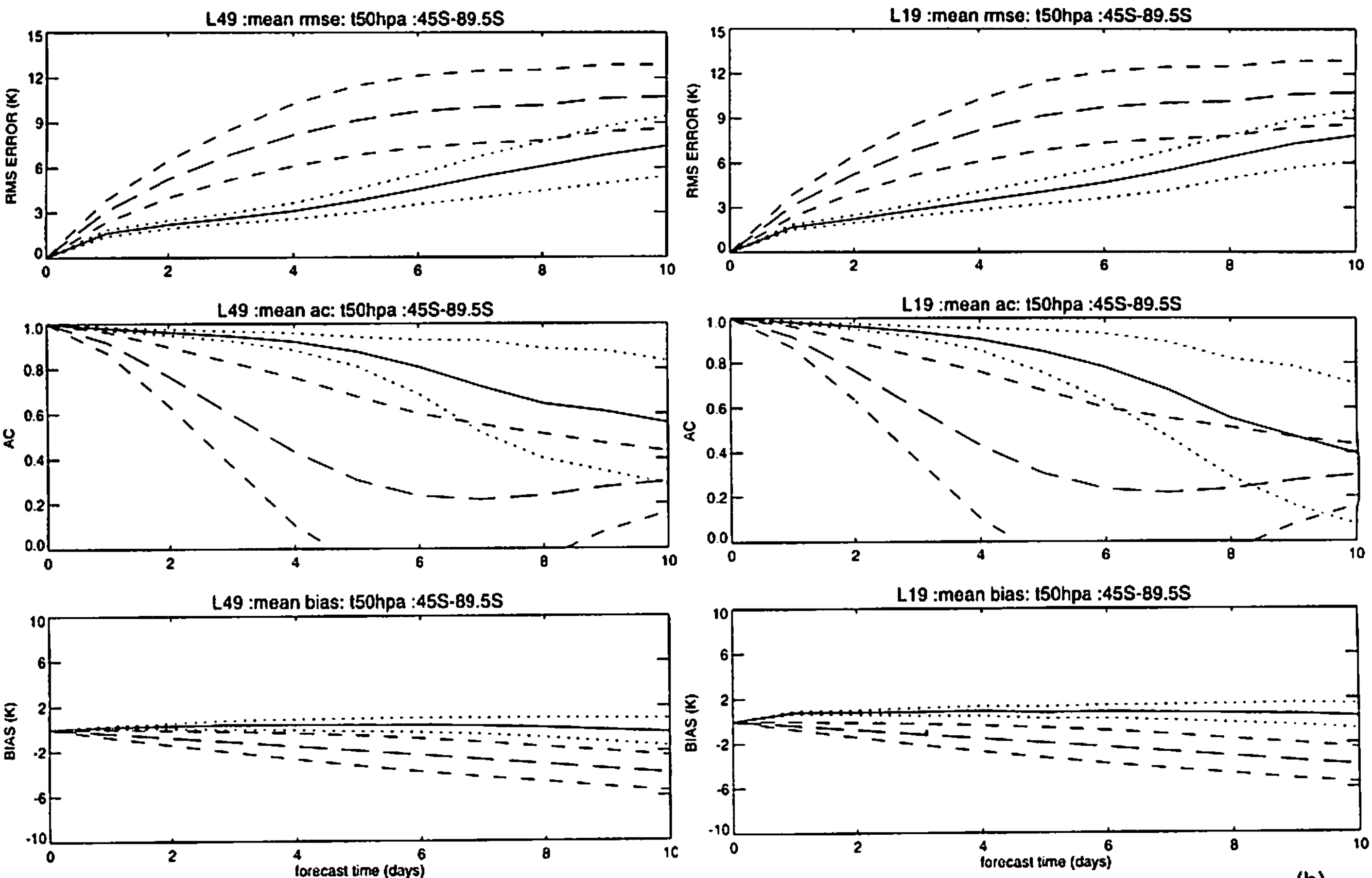
Numerical Simulations of the Variability and Predictability of the Stratosphere

The common thread running through the middle atmosphere studies at CGAM is the impact of the stratosphere on tropospheric climate, which is one of the UGAMP science themes (co-ordinated by Lesley Gray and William Lahoz). The specific areas of study are: (a) use of the Unified Model (UM) to study the natural variability of the stratosphere; (b) use of the UM to study stratospheric predictability; (c) use of the mechanistic UGAMP Stratosphere-Mesosphere



(a) (b)

Figure 12. (a) Monthly averaged statistics for 50 hPa temperature (for latitudes 45°S to 89.5°S), October 1994, and the 49-level version of the UM: root mean square (RMSE: units of K – top panel); anomaly correlation (AC – middle panel); bias (units of K – bottom panel). The solid line denotes the mean of the statistic for the model forecast; the dotted lines denote the 1-sigma standard deviation of the statistic for the model forecast; the long-dashed line denotes the mean of the statistic for the persistence forecast; the short-dashed lines denote the 1-sigma standard deviation of the statistic for the persistence forecast. (b) As (a) but for the 19-level version of the UM.

Model (USMM) to elucidate the mechanisms responsible for stratospheric variability.

(a) Natural variability in the stratosphere

This work at CGAM (in collaboration with the UKMO) is the beginning of studies to investigate ways of improving the stratospheric representation in the UM, and whether these improvements (whether it be a higher upper boundary or higher resolution in the stratosphere) can have a significant impact on the skill of medium range and longer term climate simulations. The UM is one of the participating models in the EU-funded EuroGRIPS project (see separate reference to international collaborations in this newsletter). In this article we focus on the representation of the stratospheric circulation by a 49-level stratosphere-troposphere configuration of the UM (see also the UGAMP Newsletter 16). The performance of the 49-level version of the model is discussed in more detail in Swinbank et al. (1997).

A five-year integration of the UM has been carried out and the model's simulation of the stratosphere and its seasonal evolution compares well with global analyses produced by the UKMO troposphere-stratosphere data assimilation system (Lorenc et al. 1991, Swinbank and O'Neill 1994). The contrast between the winter circulation in the two hemispheres is well simulated. The zonal mean winds show strong interannual variability in northern winter, while the southern hemisphere winter jet is much less variable (Figure 20; see colour figure on page 29). In northern winter the model spontaneously produces two major warmings and a number of minor warmings (Figure 11). In southern winter and spring the model reproduces well the break-up of the polar vortex and elements of the flow regime that often precedes this break-up.

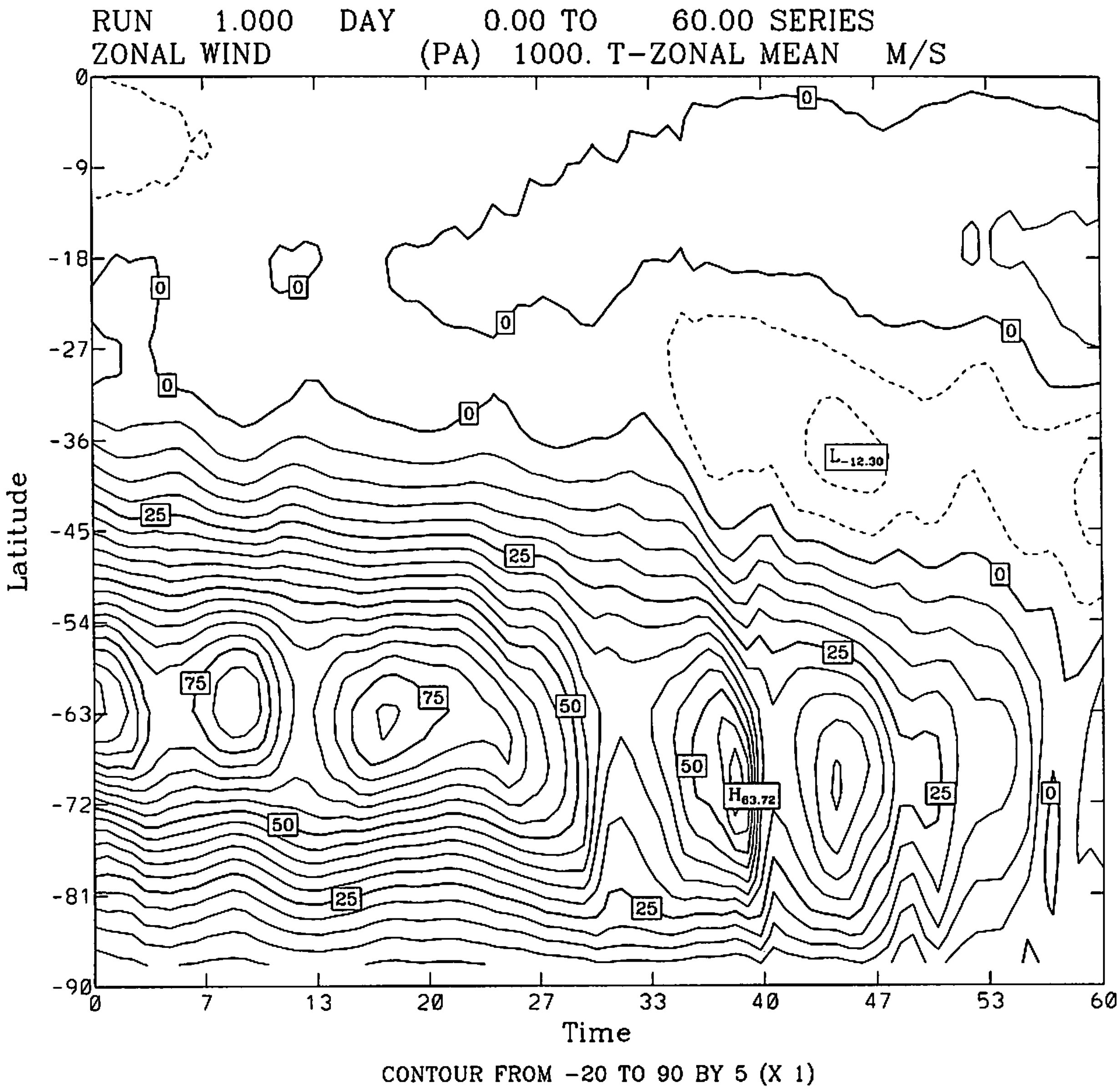


Figure 13. (a) Time series (time v latitude) of zonal wind (m/s) at 10 hPa from the model control run.

The model does, however, exhibit a number of shortcomings. Lack of conservation of potential vorticity prevents the model from capturing some of the ingredients of the flow regimes associated with stratospheric warmings and with the merger of anticyclones. There is a cold bias in the stratosphere throughout the year, with a maximum cold bias over the winter pole near the stratopause. This temperature bias appears to be due to a cooling bias in the long-wave part of the radiation scheme. The model also has unrealistically strong planetary waves in the upper stratosphere, although amplitudes in the upper troposphere and lower stratosphere are in good agreement with those derived from the UKMO analyses.

Ongoing work includes testing the impact of changing the radiation scheme in the 49-level version of the UM. Ding Ming Li is carrying out a run where the HADAM2b version radiation scheme (used in the run described by Swinbank et al.) is replaced by the Edwards-Slingo radiation scheme (Edwards and Slingo 1996), while retaining as much as possible of the HADAM2b physics. It is hoped this experiment will help to explain the cold bias observed in the HADAM2b 49-level version of the UM.

(b) Stratospheric predictability in the UM

The predictive skill of the UM is being examined in the southern hemisphere lower stratosphere during spring by applying conventional verification statistics

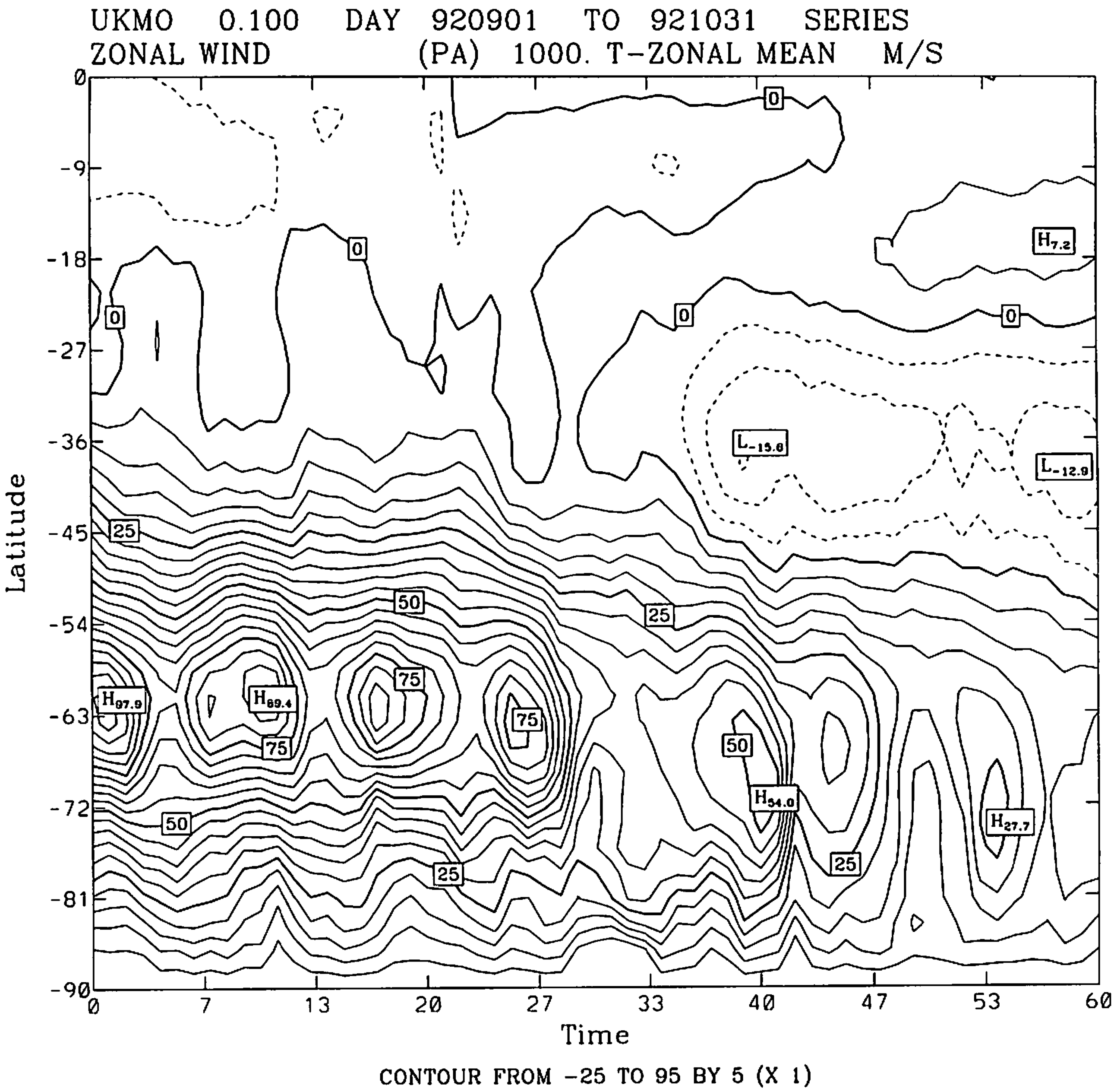


Figure 13(b). As Figure 13(a) but for the UKMO analyses.

used in Numerical Weather Prediction (NWP) studies. (This work has benefited from discussions with Mike Blackburn, Colin Jones and Alan O'Neill at CGAM, Mike Harrison and Ruth Evans at the UKMO, Agathe Untch at ECMWF, and Phil Mote at NWRA, USA.) By comparing two versions of the model, one with a well-represented stratosphere (with 49 vertical levels – see Swinbank et al.) and a second with a model top at about 5 hPa (with 19 vertical levels – see Hall et al. 1995), it is concluded that a well-represented stratosphere improves the forecast skill of temperature at 50 hPa by at least one day from between 7 to 8 days to 9 days (Figure 12). The skill at predicting geopotential height and zonal wind at 50 hPa also shows a similar improvement. By contrast, the forecast skill in the mid troposphere of both these models is very similar (being about 6 days for geopotential height at 500 hPa). Both versions of the model are a significant improvement over persistence (which has a significant skill of about 2 to 3 days in all cases looked at). Both versions of the model have a higher forecast skill in the lower stratosphere than in the mid troposphere; this is associated with the different flow regimes present in the stratosphere (dominated by a quasi-stationary polar vortex) and the troposphere (dominated by synoptic-scale motions). There is evidence that poor model forecast skill in the troposphere may impact its skill in the lower stratosphere. These preliminary results are discussed in more detail in Lahoz (1997), where some of the caveats associated with this work are outlined.

Future work will involve several lines of enquiry. The first will investigate whether the higher forecast skill of the 49-level version of the model compared to that of the 19-level version is due to a higher model lid or to higher vertical resolution in the lower stratosphere. A second line of enquiry will investigate whether the larger (planetary) scales in the mid troposphere are as predictable as the lower stratosphere for forecasts in the range 1-10 days. Both of these are now under way. Further lines of enquiry will focus on stratospheric predictability during northern winter, and its dependence on such factors as tropospheric blocking, stratospheric warmings and the phase of the quasi-biennial oscillation (QBO). Seasonal predictability in the stratosphere and the troposphere, which is a time scale that may be long enough for the stratosphere to have a significant impact on the tropospheric predictability, will be investigated as well; this work is likely to benefit from the results of the EU-funded project PROVOST (Prediction of Climate on Seasonal to Inter-annual Timescales), and discussions are under way to outline potential collaborations.

(c) Simulations of the Southern Winter Final Warming with the USMM

By focusing on the 1992 southern winter, the USMM is being used to simulate the southern winter final warming and test if changes in the external forcing affect the flow regime. The model is verified by comparison against the UKMO analyses (op. cit.). These simulations show that: (a) the control simulation of the model captures the observed flow regime (Figure 13), (b) the stratospheric variability in the model, and in particular its high frequency variability, is affected by the variability of the tropospheric forcing of the model. There is evidence that the flow regime during the southern winter final warming is influenced by a combination of the following mechanisms: internal stratospheric variability, tropospheric forcing (i.e. no control from internal stratospheric variability), and a deep quasi-stationary mode existing throughout the stratosphere and, at least, the upper troposphere.

Early results from this work have appeared in the Proceedings of the First SPARC General Assembly (Lahoz and O'Neill 1997). A paper which extends the results of Lahoz and O'Neill is being prepared by William Lahoz, Alan O'Neill and John Thuburn.

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An Oceanic Rossby Wave?

In our attempt to understand the mechanisms for decadal climate variability in the North Atlantic we are starting to look at some of the sub-surface data. One of the few sources of sub-surface data are the Ocean Weather Ships, with apparently good quality records going back to the early sixties.

We have found an interesting signal at OWS Echo, in mid-Atlantic at 48W, 35N. In the top panel of Figure 22 (see colour figure on page 30) is displayed the temperature anomaly after the mean and annual cycle have been removed at each level (all of the data have a six-month smoothing applied). For the seven years of our record there is a very obvious oscillation in the temperature anomaly. The mixed layer depth here is at most 400m in this period, so most of the signal is independent of changes in mixed layer properties, which are driven by the atmosphere.

The lower panel compares the depth of a given salinity surface with the temperature anomaly averaged between 400m and 1000m depth. The striking correlation indicates that the temperature anomaly is due to the water column moving up and down, and with it the thermocline, with a period of about four years.

One mechanism for raising and lowering the water column is wind-driven Ekman divergence and convergence near the surface, but so far no corresponding signal has been found in the observed wind-stress curl. Another possibility is that it is due to a passing oceanic Rossby wave. We might expect such a wave to have a surface signal: the correlation between this deep signal and the winter time sea-surface temperature anomaly is about 0.6. Surface signals do exist in other datasets with the right kind of wavelength, but we have not yet been able to identify them unequivocally with Rossby waves.

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Decadal Predictability in the North Atlantic?

If the comparative predictability of the oceans is to be exploited to forecast natural fluctuations in the climate, a necessary (but not sufficient) condition is an ability to forecast Sea Surface Temperature (SST). Much of the variability in North Atlantic SST can be explained as a local oceanic response to atmospheric variability. To the extent that this is the only important mechanism, predictability of SST is unlikely to exceed the typical decorrelation time of anomalies in the mixed layer, i.e. a few months. Non-local processes in the ocean (advection, Rossby wave propagation), however, may be a source of predictability on longer timescales.

We have recently found evidence that decadal fluctuations in North Atlantic SST may be significantly predictable. Figure 23 (see colour figure on page 31) (from Sutton & Allen, 1997) shows the correlation between low frequency fluctuations in local wintertime SST and low frequency fluctuations in wintertime SST averaged over the region 80-60° W, 31.5-38.5° N (the vicinity of Cape Hatteras) as a function of lag in years. SST fluctuations appear to propagate across the Atlantic following the strong SST gradients that are associated with the Gulf Stream and North Atlantic Current (NAC).

An examination of the SST anomalies that give rise to the correlations shown in Figure 23 (see colour figure on page 31) reveals propagating anomalies. The propagation speed, at ~1.7 cm/s, is surprisingly slow, but it nonetheless seems likely that the propagation is advective. Also of interest is an apparent 12-14 year periodicity that can be identified in the propagating signals. Both the periodicity and the propagation are encouraging for the prospects of forecasting decadal fluctuations in North Atlantic SST.

A great deal of further work is required to clarify the mechanisms that explain the intriguing correlations shown in the figure, and to evaluate whether they imply a usefully predictable signal. Progress in several areas is required. First, we need to better understand how mixed layer processes interact with advection and wave propagation in the ocean to determine decadal variability in SST (see article by Ben Edgington). Secondly, we need to understand to what extent the atmosphere is affected by the decadal fluctuations in SST, and whether any such influence implies useful predictability.

To address the second question we have begun a series of experiments with the Unified Model. We are performing ensembles of integrations with a particular focus on elucidating any influence SST anomalies may have on the position or intensity of the North Atlantic Storm Track. We wish to test the hypothesis that the atmosphere is especially sensitive to SST in regions of cyclogenesis. A key such region is situated off the SE coast of the USA. SSTs in this region may be influenced by fluctuations in the strength of the Gulf Stream, raising the possibility of coupled ocean-atmosphere modes of decadal variability.

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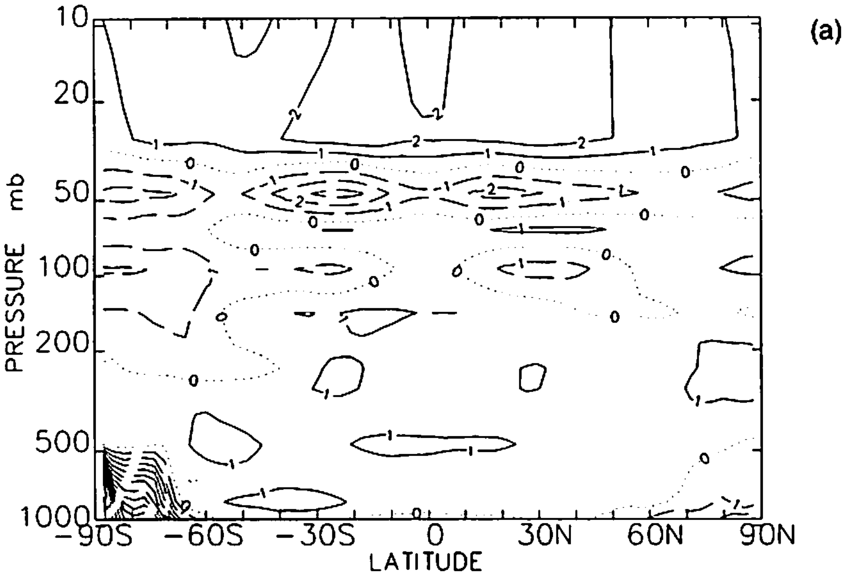
1997 El Niño and Influence of Atmospheric Intraseasonal Variability

The growth of the 1997 El Niño has been dramatic and significantly faster than normal (Figure 1: see colour figure on page 1) and by the summer a mature El Niño pattern was in place with substantial sea surface temperature anomalies in the E. Pacific (Figure 2: see colour figure on page 1). It developed in association with strong atmospheric intraseasonal variability, characterised by a series of Madden Julian Oscillations (MJO) with strong Westerly Wind Bursts (WWB) embedded in the active phase of the MJO. The rapid growth and strength of the 1997 El Niño were not predicted well in advance and the key question is: What role did the MJO and WWBs play in the development of the 1997 El Niño? A project to address this question is underway in collaboration with Mike Davey and Sarah Ineson at the Hadley Centre. We plan to use the Met. Office TOGA OGCM, forced with ECMWF operational analyses for the winter and spring of 1996/97 in a series of sensitivity experiments to investigate the response of the ocean to individual MJO and WWB events as well as to a series of such events. In addition the sensitivity of the ocean response to idealized WWBs is being investigated as part of a project to build up a climatology of WWBs and their relationship with the MJO and El Niño, based on ECMWF reanalyses and operational analyses.

If the intraseasonal activity turns out to be a key element of the 1997 El Niño then the important question is whether this level of intraseasonal activity could have been predicted and whether it is sensitive to the boundary forcing, specifically sea surface temperature (SST). We have attempted to address this question in an analysis of the MJO activity in a 4-member ensemble of 45 year integrations with the UM (HADAM2a), forced by observed SSTs for 1949-94. The reproducibility of the activity of the MJO from year to year has been determined, and the results have shown that, for the uncoupled system, with the atmosphere being driven by imposed SSTs, there is no reproducibility for the interannual variability in the activity of the MJO. The behaviour of the MJO is not controlled by the phase of ENSO and would appear to be chaotic in character (Slingo et al. 1997).

If this result is correct then it has serious implications for the predictability of the tropical ocean-atmosphere system. However we know that models, including those used for seasonal prediction, do not simulate the MJO very faithfully, although the UM is better than most. There is mounting evidence that the MJO influences the ocean on intraseasonal timescales, suggesting that it may be a coupled phenomenon which requires an interactive ocean surface to produce the correct organization of convection and its eastwards propagation (Sperber et al. 1997; Sperber and Slingo 1997). A project has commenced to investigate this possibility. Using ERA data, the relationship between convection, surface fluxes and SST at intraseasonal timescales is being studied in detail and will form the basis of sensitivity experiments, initially with the aquaplanet version of the UM.



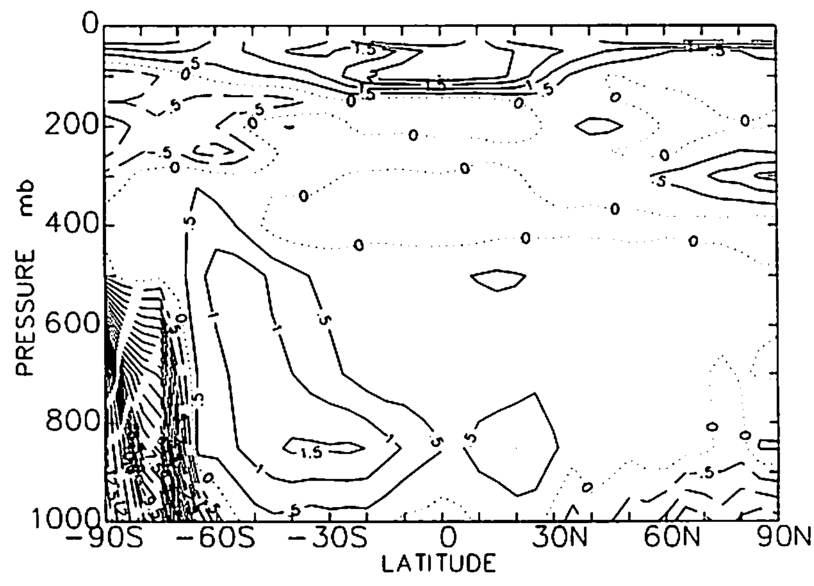
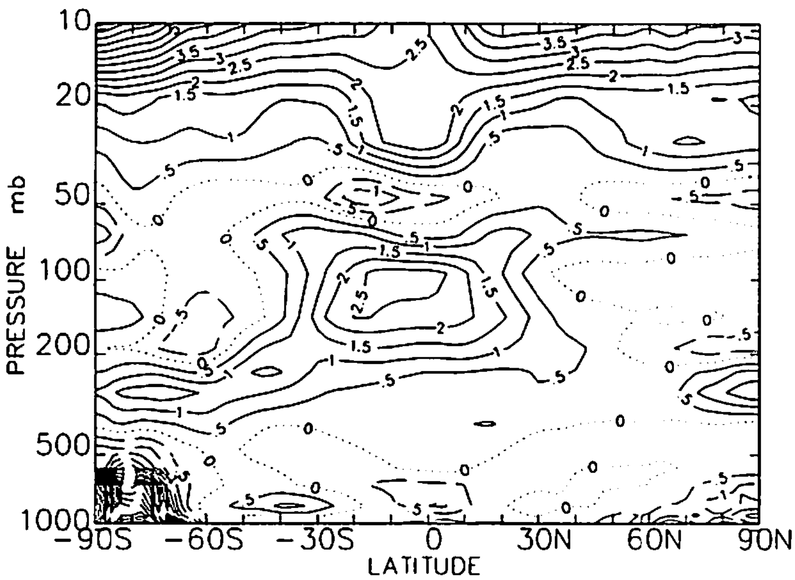


Figure 14. Differences in zonally averaged annual climatological fields. a) Temperature in ECMWF operational analyses 1990-91 minus ERA 1979-93, contour 1K. b) Temperature in JDP 1983-89 minus ERA 1979-88, contour 0.5K.



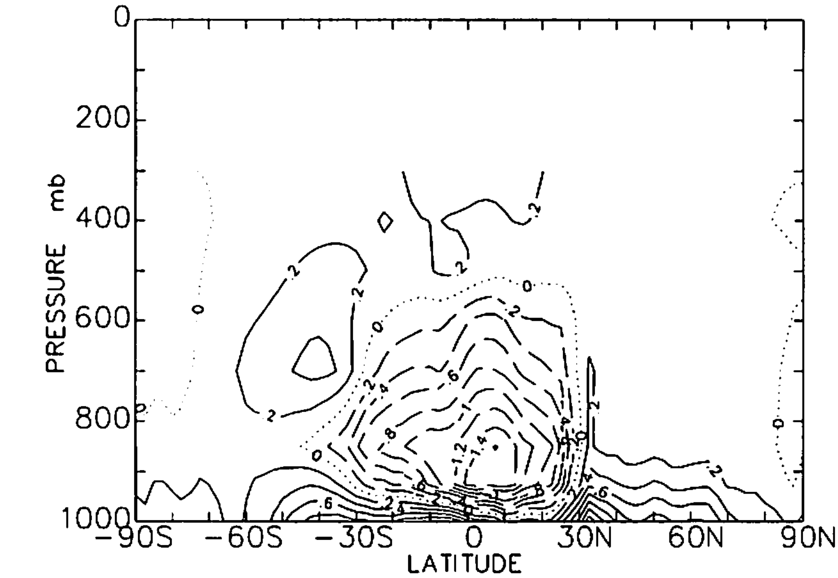


Figure 14. Differences in zonally averaged annual climatological fields. c) Temperature in NCEP 1982-94 minus ERA 1979-93, contour 0.5K. d) Specific humidity in NCEP 1982-94 minus ERA 1979-93, contour 0.2g/kg.

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Comparison of Zonally Averaged Climatologies from the Atmospheric Reanalysis Projects

The most basic climatological fields from the ECMWF Reanalysis Project (ERA) have been compared with the NCEP/NCAR reanalysis and with the previous operational analyses from ECMWF which were used in the Joint Diagnostics Project (JDP) at Reading. Systematic differences between the reanalyses reflect both the observational data usage and the behaviour of the assimilating models. The comparison indicates the accuracy to which the basic climatological fields are now known, providing limits for the evaluation of GCM simulations of present day climate.

One of the benefits of a reanalysis of historical data using a "frozen" assimilation system is that the resulting analyses are free from the step changes present in operational analyses associated with improvements in the model and data analysis over time. An example of this benefit is evident in zonal mean temperature in the lower stratosphere in Figure 14(a) which shows the difference between the 15-year ERA climatology and the ECMWF operational analyses in 1990-91. At this time a new radiative parametrization in the ECMWF model did not damp 2-grid temperature oscillations, allowing them to grow in the absence of data constraint in the lower stratosphere (Li and Shine 1992). Oscillations in the operational analyses at the time were of sufficient magnitude to contaminate interannual variability in lower stratospheric temperature.

Figure 14(b) shows seasonal temperature differences between ERA and the JDP 6-year climatology for 1983-1989 using the ECMWF operational analyses. Ignoring the extrapolation below Antarctica, there are large scale differences in the data sparse regions of the Southern Hemisphere storm-track, where the JDP climatology is more than 1K warmer for all seasons, and around the tropical and Southern Hemisphere tropopauses. Elsewhere the two climatologies generally agree to within 0.5K, presumably reflecting the greater degree of observational constraint there.

The NCEP and ERA climatological temperatures in Figure 14(c) are generally in better agreement than the JDP-ERA comparison, particularly in the data rich Northern Hemisphere, but there are still systematic differences. Temperature differences in the Southern Hemisphere troposphere are smaller and less consistent between seasons than for JDP, but there is a systematic easterly bias (not shown) of NCEP relative to ERA (or westerly bias of ERA relative to NCEP) in the tropics, and a corresponding lower troposphere temperature difference.

The NCEP tropical tropopause is systematically warmer than ERA by 2.5K, similar to the JDP-ERA difference. The vertical shear of zonal wind in the subtropical lower stratosphere (not shown) is consistent with the temperature differences and the structures agree well with those seen by Pawson and Fiorino (1996). It is difficult to attribute the colder ERA tropopause to data usage or analysis / model behaviour without parallel reanalysis for shorter periods using modified model versions at ECMWF or NCEP, but modelled tropopause temperatures are known to be sensitive to vertical resolution and model formulation.

The ERA and NCEP climatologies also differ at the Southern Hemisphere tropopause, with a vertical dipole in temperature difference and corresponding thermal wind signal. The difference structure appears to migrate with season, being closest to the pole in (local) summer and at the lower latitude of the subtropical jet in (local) winter. There is a similar signal near the North Pole.

Climate simulations of specific humidity and the hydrological cycle are generally more model dependent than temperature and zonal wind, so it is not surprising to see significant differences in zonally averaged specific humidity between the reanalysis climatologies in Figure 14(d). The NCEP climatology is up to 1.5g/kg drier than ERA in the tropical lower troposphere in all seasons, with a larger lapse of specific humidity in the planetary boundary layer. There are also major discrepancies in latitudinal structure, particularly in northern summer at the latitude of the Asian monsoon. The low level differences are questionable, given a crude extrapolation below orography used in deriving the isobaric ERA climatology but, if valid, suggest large uncertainties in atmospheric moisture structure. Trenberth and Guillemot (1997) found a dry bias of approximately 10% in NCEP precipitable water relative to the NVAP climatology, primarily in the ITCZs, consistent with the differences here.

The comparisons here use different periods between the climatologies but there is evidence from several sources that this does not affect the conclusions drawn so far. The origin of the major differences and their geographical distributions, particularly those for moisture, will be a focus of future work.

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FIELD CAMPAIGNS AND MODEL INTERCOMPARISONS

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UGAMP researchers play key roles in national and international programmes such as field campaigns and model intercomparisons. In this section we review some of these activities.
Of particular note is the role UGAMP will play in the forthcoming Third European Stratospheric Experiment on Ozone (THESEO), a European wide project to understand the reasons for mid-latitude ozone loss.

Field Campaigns

THESEO: An Introduction

The Third European Stratospheric Experiment on Ozone (THESEO) is a successor to the European Arctic Stratospheric Ozone Experiment (EASOE) in 1991/92 and to the Second European Stratospheric Arctic and Mid-Latitude Experiment (SESAME) in 1994/95, and will build upon the scientific and technical advances that have been made over the last few years. This new European campaign will take place in 1998 and 1999.

The primary goal of THESEO is to improve our understanding of the processes underlying the observed mid-latitude trends. It is explicitly recognised that this can only be achieved through a better understanding of the chemical and dynamical links with other regions, i.e. with the lower stratosphere in both the sub-tropics and in the Arctic, and with the upper troposphere and upper stratosphere at mid-latitudes. This aim is an ambitious one – the processes occurring over mid-latitudes are more complex and variable than in the vortex, and any perturbations to the ozone amount or the chemical composition are likely to be smaller than in the polar vortices.

Measurements will be made at locations from the tropics to the Arctic. A number of critical questions about the processes occurring inside the vortex remain unanswered, not least the reasons why models continue to calculate less ozone loss than is observed. A balloon campaign involving perhaps 15 large balloons will take place in Kiruna in January and February 1999. A number of long duration balloon flights using Montgolfier Infrared or superpressure balloons will be made which should provide continuous, quasi-Lagrangian measurements of species such as O_3, CH_4 for periods of several weeks. The large balloon activities will be linked to the ozonesonde and small balloon programmes which will be measuring the ozone loss inside the vortex. The main focus of the Match ozonesonde effort will be directed toward determining mid-latitude ozone loss rates and it is planned to make greater use of the lidar network to increase the number of available measurements. This will be complemented by the chemical measurements made from large balloons and from the ground-based network.

A number of aspects of the large-scale circulation will be investigated. The input into the tropical stratosphere will be one of the aims of the APE-THESEO project involving the M-55 Geophysika and the DLR Falcon which are collaborating with the INDOEX project and will fly in the Indian Ocean in early 1999. In the Arctic a series of tracer measurements will be used to infer the diabatic descent rate, and to study the mixing processes. The linkages of these two regions with the mid-latitudes will be studied through a combination of ground-based and aircraft measurements, closely linked to models. Aircraft will also be used to investigate the complex processes occurring in the lower stratosphere and upper troposphere.

In order to maximise the scientific benefit of all the measurements taken during THESEO, full use of the state-of-the-art three dimensional chemical transport models that have been developed in recent years needs to be made during the campaign. This is an area where UGAMP has particular expertise. A great number of measurements will be made that particularly focus on issues relating to transport and dynamics, and it is hoped that these would also be of interest to the UGAMP community. It is hoped that the measurement strategy can be guided by the models. The results of THESEO should make an important contribution to improving our modelling and predictive capability.

Finally full use must be made of the data collected by European satellite instruments (GOME since 1995, POAM-3 and future launches of ODIN, Envisat). This resource will be growing in the coming years and it is essential that we gain maximum scientific benefit from it.

More information can be found on the Coordinating Unit's web page: http://www.ozone-sec.ch.cam.ac.uk.

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APE-THESEO

This project will comprise the second mission of the Geophysica high-altitude research aircraft. The mission will be to the tropics, to study the microphysical processes in tropical cirrus, the transport of tracers across the tropical tropopause, and the transport of tracers in the tropical lower stratosphere.

The project is concerned with three basic questions:

1. What controls the low water content of the stratosphere and the troposphere-stratosphere flux of trace species;
2. What are the mechanisms of cloud formation in the tropical tropopause region and lower stratosphere, and what impact does this cloud formation have on ozone depletion and troposphere-stratosphere exchange of gases and particles; and:
3. What role do the tropics play in the origin of the global stratospheric aerosol layer?

APE-THESEO will address the three questions above by undertaking a study of microphysical and transport processes occurring at the tropical tropopause near cumulonimbus clouds and cirrus decks. The specific scientific objectives to be addressed by APE-THESEO are:

(a) In what ways, and to what extent, do overshooting cumulonimbii dehydrate air that is in the stratosphere, or that is moving into the stratosphere;

(b) How, and to what extent, do nuclei for the maintenance of the global stratospheric aerosol layer originate from the upper tropical tropopause; and

(c) How much mixing between troposphere and stratosphere, and between the mid-latitude stratosphere and the tropical stratosphere, occurs over the Indian ocean in northern winter?

APE-THESEO has combined with the Indian Ocean Experiment (INDOEX), an international multi-platform experiment taking place in the tropics in northern winter 1999. The main objectives of INDOEX are related to the effect of aerosols on climate, and to man's effect on the chemistry of the remote troposphere.

For more details of INDOEX, see: http://www-indoex.ucsd.edu/.

The APE-THESEO platforms

The DLR Falcon, equipped with the OLEX lidar, will act as a pathfinder for the Geophysica and will provide information on ozone and aerosol below thick cirrus decks that cannot be penetrated by the lidar on board the Geophysica. The pathfinding role, in the tropics, will be particularly important to detect subvisible cirrus at the edge of tropical cumulonimbus clouds (hot towers) so that the Geophysica can be directed there. The Falcon/OLEX system is the only system in the world with proven expertise in carrying out pathfinding operations for stratospheric research aircraft, having performed this task during winter 1996/97, as part of the APE-POLECAT mission.

Some relevant technical details of the aircraft are given in the table below.

Table 1: Technical aspects of the APE-THESEO aircraft

	Geophysica	Falcon
Ceiling	21km	13.7 km
Range	3500 km	3700 km
Duration	6 h	5 h
Scientific payload	1500 kg	1000 kg
Max. take-off weight	24 000 kg	13 200 kg
Runway length required	2 000 m	2 000 m
Instrument bay	unpressurised	pressurised
Electrical supply	60 KVA at 115 VAC 3 kW at 27.5 VDC	220 VAC 16.8 kW at 28VDC

The Geophysica Payload

Lidars feature heavily in APE-THESEO. They are essential instruments for this study, because they can provide one-dimensional snapshots, and two-dimensional near-instantaneous composites, of cloud and aerosol structure. Two lidars will be on board Geophysica: one looking up, another, less powerful, looking down. In situ aerosol measurements will retrieve particle size distribution and index of refraction. Information on particle shape will be available from lidar and scatterometer polarization measurements. Cloud element analysis will be provided by a package consisting of a counterflow virtual impactor inlet, a condensation nucleus counter, and the two spectrometers: a Lyman-α water vapour spectrometer and a HNO_3 spectrometer. Measurements of long-lived trace gases will also be

made in situ, along with measurements of the key species water vapour and ozone.
Additional instruments are actively being sought. There are at present proposals to add on board an in-situ cloud particle size, distribution, and shape measuring probe, a radiometer, and a turbulence probe. The addition of radiometric measurements in particular would enable us to take a direct part in address the main INDOEX objective of determining radiative forcing by aerosols and clouds.

Modelling Activities

Modelling activity will play a major role in APE-THESEO. Forward trajectory calculations may be used to track atmospheric constituents for flight planning. CTM integrations (from Martyn Chipperfield's SLIMCAT) will generate global fields of chemical species for the lower stratosphere. Trajectory model integrations, using the Trajectory Mapping technique, will also generate synoptic maps providing global constituent mapping. Two groups will develop microphysical box models. One group will develop models of visible and sub-visible cirrus clouds. The other group will concentrate on modelling the evolution of stratospheric aerosol particles, and their effect on heterogeneous chemistry.
Further information from:

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THESEO: MEridional TRansport of Ozone in the lower stratosphere (METRO)

METRO is a 2yr EC funded project within the framework of the THESEO campaign (THird European Stratospheric Experiment on Ozone). METRO is due to start in early 1998. The goal of METRO is to improve our knowledge of the mechanisms involved in the meridional transport of air in the lower stratosphere and its impact on the ozone budget at middle latitudes. A large database of observations of polar laminae and subtropical intrusions will be obtained using a network of ground stations equipped with ozone, temperature and aerosol lidars as well as lidars and radars for wind profiling. In addition, cases of filamentation at the edge of the polar vortex and subtropical intrusions will be observed with a network of ground based stations and an airborne ozone lidar. Observations will be interpreted with a set of high-resolution transport models.
The METRO project is coordinated by CNRS in France, and the scientific coordination is split with CNRS in charge of polar studies and University of Wales in charge of sub-tropical studies.

A number of polar and sub-tropical studies will be carried out. Objectives of the polar studies may be summarised as follows:

- to obtain a well documented database of height-time cross-sections of polar filaments as they pass above the observing sites,
- to obtain a detailed description of filaments in a few cases using an airborne lidar,
- to simulate the characteristics of observed filaments using a set of high resolution transport models
- to observe the redistribution of air masses and ozone during a major warming or a final warming,
- to evaluate mesoscale motions in the filaments (associated for instance with gravity waves) from temperature and wind measurements in order to estimate the efficiency of the irreversible mixing taking place in the filaments,
- to evaluate the volume of air of polar origin exported to mid-latitudes during the filamentation events that we will observe.

The objectives of the subtropical part of the project will be:

- to obtain, by means of the lidar/radar network, detailed measurements of intrusions of subtropical air to the midlatitude lower stratosphere,
- to conduct case studies of particularly well-observed events, using ECMWF analyses, an enhanced 3D stratosphere-mesosphere model and contour advection, to determine how well the events are simulated by the models and analyses,
- to conduct sensitivity analyses on the model simulations for these case studies,
- to use the 3D stratosphere-mesosphere model for preliminary estimates of the flux of subtropical air to midlatitudes during the period of THESEO.

Sub-tropical modelling at Cambridge

At Cambridge, we are responsible for the modelling of the sub-tropical case studies during METRO. We have funds for a new post-doc to carry out some of the modelling work. The modelling will consist of two main parts: contour advection modelling and the development of a high vertical resolution model to simulate the 3D development of intrusions into the mid-latitudes. At the time of writing it has not yet been decided which existing model to enhance to develop the high vertical resolution model. The case study data will provide an opportunity to extend the results of Waugh (1996) by comparing with actual measurements. Some of these case studies will be done in collaboration with our METRO partners to study the combined effect of transport from polar and tropical regions to mid-latitudes.

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THESEO: Towards the Prediction of Stratospheric Ozone II (TOPOZ II)

This EC funded project has the goals of validating and improving chemical transport models in the tropical lower stratosphere and the midlatitude lowermost stratosphere. It will involve UGAMP related researchers at Oxford and Cambridge (Chemistry) together with personnel from Utrecht, Karlsruhe, Oslo, L'Aquila and NILU.

One aim of the project is to see how well off-line chemical transport models (such as SLIMCAT) reproduce the 'tape recorder' signal in water vapour which has been seen in satellite measurements in the tropical lower stratosphere. This will require the transport models to reproduce the correct mixing of midlatitude air into the tropics together with the correct mean vertical ascent and vertical mixing. The sensitivity of changes in horizontal and vertical resolution in the transport models will be examined. An important opportunity for the project will be to assess the impact of changes in the ECMWF assimilation scheme. Annual integrations will be performed for the years 1992-1993, 1996-1997 when there was the change to the 3D variational scheme, and 1998-1999 when ECMWF will use a 4D variational scheme and have more levels in the stratosphere.

The project will have direct benefit to UGAMP from another of the activities by performing further transport model integrations using winds from the UGAMP AMIP II integration of the Unified Model. This should give a direct comparison of how the Unified Model performs with regard to transport in the tropical lower stratosphere and in midlatitude stratosphere/troposphere exchange compared with ECMWF analysis and observations.

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ACSOE: Flying around the Azores

This summer the MRF (Meteorological Research Flight) Hercules flew missions from the Azores (small islands off the Portuguese coast) for the NERC programme ACSOE (Atmospheric Chemistry Studies in the Oceanic Environment) (see Figure 15.). These flights were especially concerned with the oxidation of trace species in the troposphere over oceans. As the Azores is situated in the middle of the North Atlantic it is an excellent place to make these measurements.

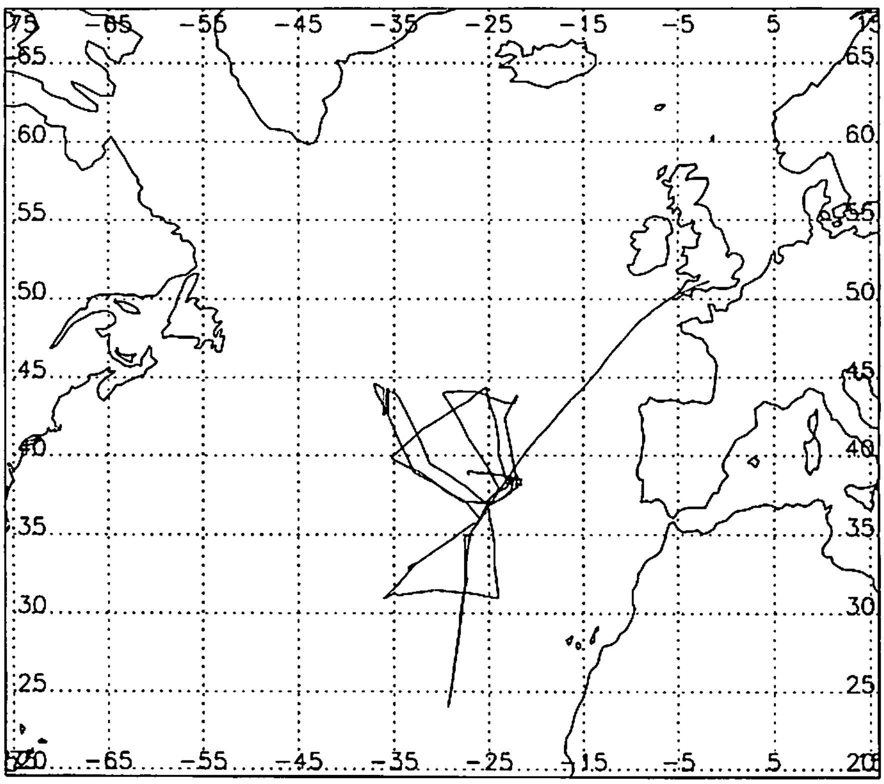

Figure 15. Science flights flown during the campaign

The MRF Hercules is equipped to measure many trace gases, which are key to the understanding of the oxidation processes in the troposphere.

The ACSOE flights linked with international programmes taking place at the same time. Over the summer, aircraft from NOAA flying as part of NARE II (second North Atlantic Regional Experiment) and the EU programme POLINAT 2 (POLlution from aircraft emissions In the North ATlantic flight corridor) flew in the North Atlantic. A coordinated programme of flying between the groups was possible, benefiting all the projects.

To help plan the flights ECMWF forecast and analysis fields were transferred to the Cray at RAL each morning. Domain filling back and forward trajectories were calculated over the North Atlantic, and the results transferred to the Azores by modem (and made available to the other groups by WWW). Air which was forecast as being of interesting origin could then be targeted by the aircraft. Forecast forward trajectories were calculated to allow air measured by the other aircraft to be followed and an attempt made at an intercepting the same air mass.

Early results of the campaign look very interesting. Many polluted layers were found over the remote North Atlantic. Initial back trajectory analysis of these plumes suggest that they originate from both the East and West coast of the USA. Stratospheric-tropospheric exchange events were observed in the forecast meteorological fields and flights were organized to investigate the composition of this air. By flying far south of the Azores latitudinal gradients in species could be measured.

The data collected during the flights will provide insights into the oxidative capacity of the North Atlantic, the ozone budget, mixing mechanisms, processing of urban air plumes and many other topics.

ACSOE Publication number ACP029

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Evaluation of Modelled Ozone using MOZAIC data

The off-line global 3-D transport model, TOMCAT, is constantly being improved. TOMCAT is now running with full tropospheric chemistry, i.e. methane oxidation and non methane oxidation schemes, using the ASAD integration package developed by Carver et al. (1997). The model uses an accurate non-diffusive transport tracer advection scheme from Prather (1986) and Tiedtke (1989) mass flux scheme for the moist convective transport of tracers. A realistic non-local vertical mixing scheme based on the scheme developed for the NCAR CCM23 model by Holtslag and Boville (1993) has been implemented.

Main tropospheric gases emissions varying seasonally (NO_x, CH_4, CO) or constant emissions (C_2H_6, C_3H_8 and CH_3CHO) are included in the model. NO_x emission sources are based on anthropogenic, biomass burning, aircraft and lightning (depending on the convective cloud top height and updraft velocity from Price and Rind). Physical sinks for trace gases are also included (wet and dry deposition).

The model has been run with an horizontal resolution of T21 (~5.6x5.6) for two periods (summer '94 and winter '95) and a one year run is almost finished. The initial distribution of chemical species are taken from a 1990s steady state run of the UGAMP-2D model and adapted for TOMCAT by adjusting the initial profiles so as to match the 2D tropopause with the dynamical tropopause (PV = 3.5) from the analyses.

The ozone distribution calculated by TOMCAT has been compared to ozone data collected on Airbus A340 passenger aircraft as part of the MOZAIC (Measurement of Ozone by Airbus In-service Aircraft) project. MOZAIC makes continuous measurements of ozone and relative humidity worldwide on five Airbus A-340 passenger aircraft. The project is funded by the EU and Airbus Industrie (n.b. the data are unpublished; all enquiries should be directed to the coordinator of MOZAIC, Dr. Alain Marenco, Laboratoire d'Aerologie, 14 Avenue Edouard Belin, 31400, Toulouse, France. Email: mara@aero.obs-mip.fr).

The model results are compared to a seasonally averaged data at cruise altitude in the upper troposphere and lower stratosphere (Figure 25: see colour figure on page 31) and to individual vertical profiles collected over particular cities during takeoff and landing (Figure 26.: see colour figure on page 32). The upper troposphere/lower stratosphere is reproduced by the model. Low ozone mixing ratios (less than 100 ppbv, characteristics of the troposphere) are found equatorwards of the sub-tropics with higher stratospheric mixing ratios towards the poles. Day to day variability over a northern hemisphere location like Frankfurt is generally very good and ozone is modelled well with the correct range of ozone concentrations.

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Model Intercomparisons

UGAMP contribution to AMIP 2

The Atmospheric Model Intercomparison Project (AMIP) was an international collaboration whereby all participating GCM groups performed a model

UKMO Unified Model layers

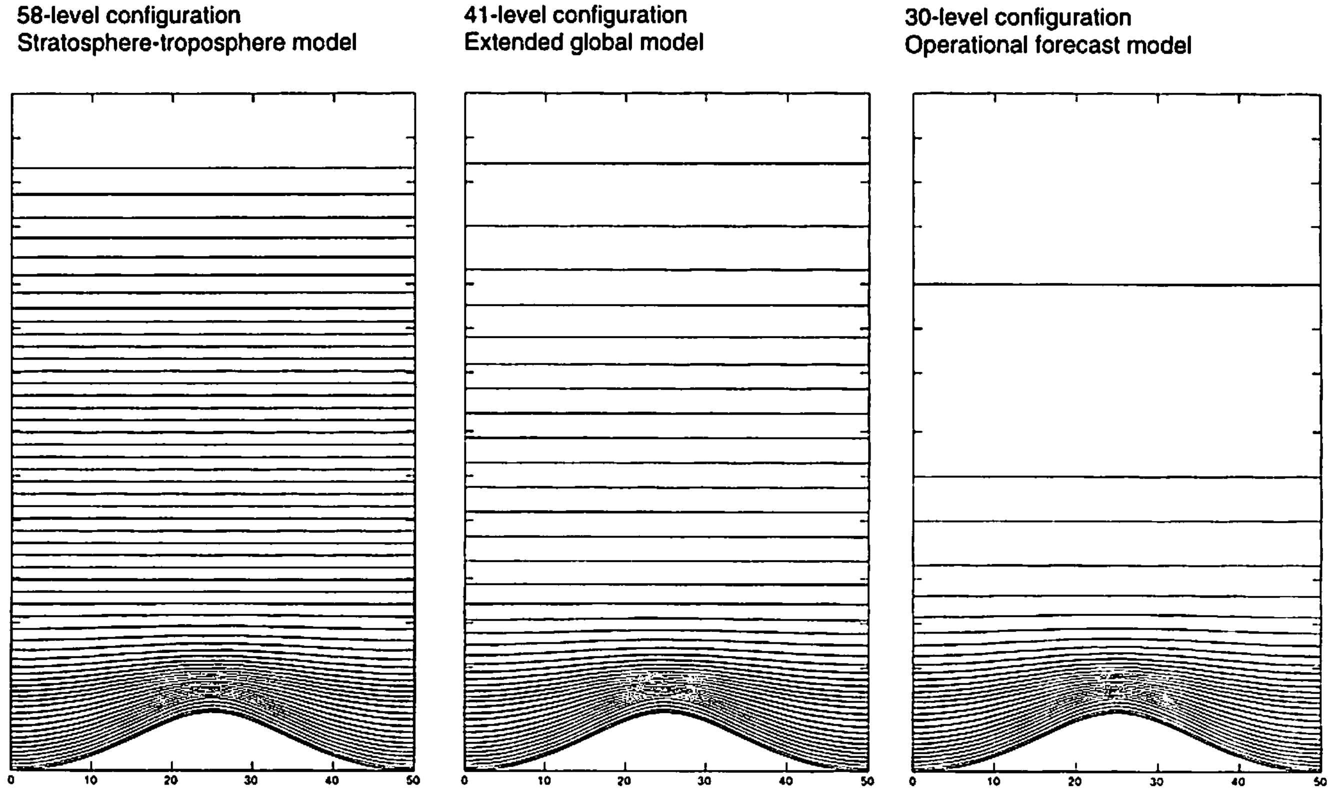


Figure 16. Vertical distribution of levels in Unified Model versions.

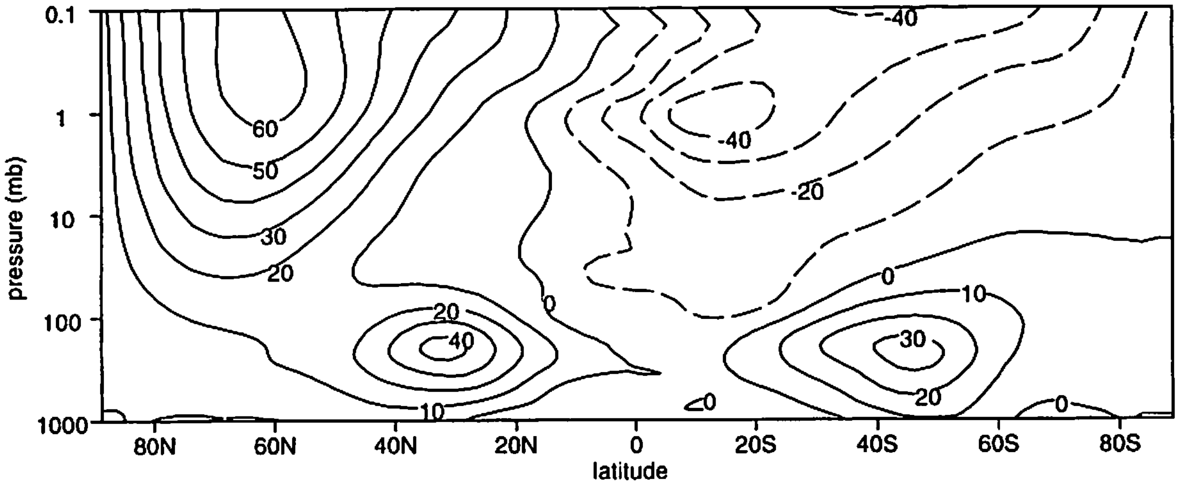
integration for the period 1979-88, using identical surface and solar forcing. AMIP2 is an extension of the original AMIP experiment. The integration period is now January 1st 1979 to March 31st 1996. All GCMs will run with identical Sea Surface Temperatures (SSTs) and Sea Ice distributions. They will use the same orbital parameters, solar constant, CO_2 and ozone distributions. The UGAMP contribution to AMIP2 will address the question of the role of the stratosphere in the representation of the tropospheric climate. It will also offer a well constrained model integration of the troposphere and middle atmosphere.

UGAMP will enter AMIP2 with a version of the U.K. Met. Office (UKMO) Unified Model (UM). The UKMO will also participate in AMIP2 with the UM. The two integrations will utilize identical physical parametrizations and dynamical formulations. Both 17 year integrations will be performed on the UKMO Cray T3E. The UKMO contribution will be at a horizontal resolution of 3.75° x 2.75° and 19 levels in the vertical. The model top will be at 0.5mb with a very coarse vertical resolution in the stratosphere and upper troposphere. The UGAMP model will consist of an identical horizontal resolution and 58 levels in the vertical. The model top will be at 0.08mb with increased vertical resolution in the upper troposphere and throughout the stratosphere. Figure 16 shows the vertical configuration of the UGAMP UM. Also shown is a 30 level configuration. This model has the same vertical levels as the UKMO AMIP2 model above 50mb. The poor vertical resolution in the stratosphere is clearly evident. The UGAMP UM will represent gravity wave drag (GWD) as a simple Rayleigh friction term above 20mb. Below 20mb the standard GWD scheme will be used (Palmer et al. 1986).

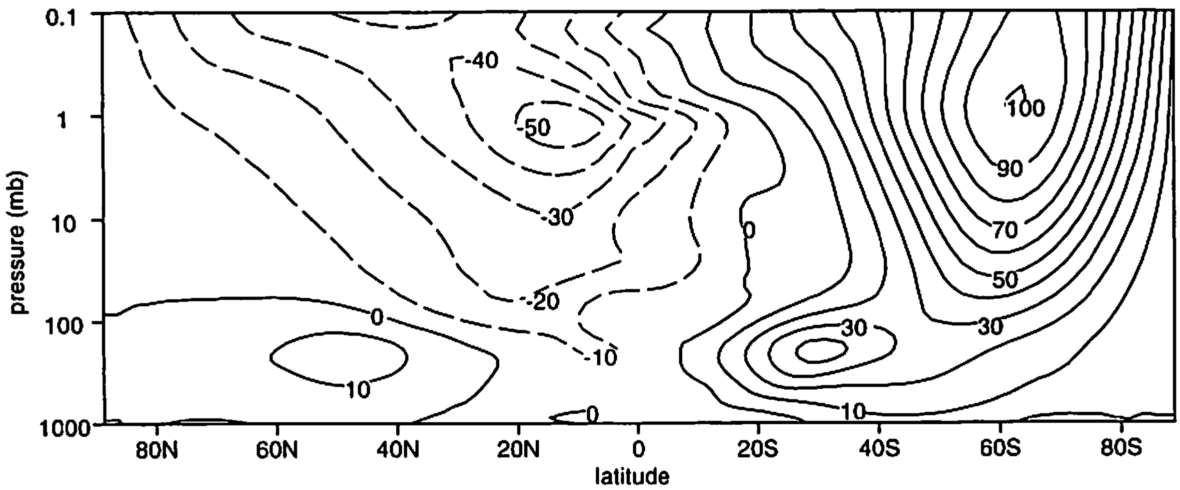
Previous integrations of the vertically extended UM have utilised a spatially and temporally fixed value of water vapour above ~40mb. The UGAMP model will allow the radiation parametrization to see observed monthly mean climatological values of water vapour above ~40mb. This water vapour field is smoothly merged with the prognostic field below. The prognostic water vapour field above ~40mb is available for advection by the model dynamics, but will not influence the radiation above this level. It is expected this will allow some insight into the transport of water vapour in the stratosphere and the problem of water vapour loss from the stratosphere in the UM. It is important to note there is no chemical source of water vapour in the stratosphere/lower mesosphere in the UM.

A number of passive tracers will also be included in the 17 year integration. Passive tracers do not interact with the model physics or dynamics and are advected by a higher order accurate positive definite advection scheme (Roe 1985). The details of the tracers have yet to be finalised. It is likely there will be two tracers. One will have a simple specified source at the surface and a sink in the top model layer. The second will have a specified source in the top model layer and a sink at the surface. It is anticipated this will provide useful information about transport processes in the UM. Preliminary tests have been performed with some simple tracer distributions with encouraging results.

A test run of the UGAMP UM has now run 3 years. The output is being assessed to ensure the model is running stably and producing reasonable results. Figure 17. shows the 1979-81 3 year mean DJF and



DJF 3 year mean. Zonal mean U component of wind. 58 Level UM.



JJA 3 year mean. Zonal mean U component of wind. 58 level UM.

Figure 17. This figure shows the 1979-81 3 year mean DJF and JJA zonal mean zonal wind field.

JJA zonal mean zonal wind field. Figure 27 (see colour figure on page 32) shows the mean DJF and JJA Mean Sea level Pressure and Monthly Accumulated precipitation for the same 3 year period.

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EUCREM and the Development of Convective Parametrization in UGAMP

The third and last workshop of the European Cloud-Resolving Modelling Programme (EUCREM) due in Reading at the end of November, gives a chance for a general review of the Programme and of our contribution to it. EUCREM is a collaborative research project, centred on two objectives; one objective was to develop the existing Cloud Resolving Models (CRMs) using observed cases of convection. The other was to improve the parametrization of convection in Single Column versions (SCMs) of large scale models.

The five observational cases that have been selected encompass a wide range of convective behaviour: oceanic cumulus and stratocumulus, organised squall lines over land and over tropical oceans and a case of convective development triggered by an Arctic cold air outbreak. The CRM simulations of the cases were completed last May and the results were presented in the Hague, in the 2nd EUCREM workshop. The intercomparison was very successful in identifying common problems in the CRM simulations, particularly problems related to the specified initial conditions. In all models a strong sensitivity was noted to discontinuities in the initial profiles and to the prescribed surface and radiation fluxes.

The oncoming workshop will focus on the results of the SCM models and the intercomparison is expected to be very informative, given the number of different parametrization schemes that are being tested. Schemes being tested by the EUCREM partners are the Tiedtke scheme, the Emanuel scheme, a boundary layer mixing scheme that includes parametrization of entrainment at the boundary layer top, a scheme based on a CAPE adjustment closure and our Betts-Miller adjustment scheme. The sensitivity of the simulations to the initial profiles has also been observed in our simulations with the Betts-Miller scheme. Interesting parametrization issues to be addressed in the forthcoming workshop involve the interaction of turbulence and moist convection, the coupling of convection to boundary layer processes and the effect of the large scale forcing. It is hoped that the wealth of observational and model data that are being generated in this final stage of EUCREM will provide a high quality benchmark for future studies of convective modelling.

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The Palaeoclimate Modelling Intercomparison Project (PMIP)

The PMIP has been endorsed by both IGBP/PAGES and WCRP/WGNE, and 17 modelling groups are participating. The main purposes of PMIP are to compare climate models driven by the same palaeoclimate forcing, in order to better understand the mechanisms of climate change and to test the ability of the models to reproduce climatic conditions radically different from today (Joussaume and Taylor, 1995).

For each PMIP experiment, the boundary conditions have been precisely specified. Because each modelling groups uses exactly the same boundary conditions, differences between simulations must reflect differences in model structure and parametrizations. The model intercomparisons are then designed (a) to identify similarities and differences in the simulated climates, and (b) to isolate the mechanisms responsible for the differences. Performing model-data comparisons allow us to evaluate the climate model, identify which components of the models are reliable and justify confidence we may have in future climate change predictions.

In its initial phase, PMIP focused on two time periods: the Mid-Holocene (6,000 years ago) to examine the effect of changes in the seasonal and latitudinal distribution of insolation, and the Last Glacial Maximum (21,000 years ago) to examine the effects of large ice sheets and lowered CO_2 on atmospheric circulation. These two periods correspond to extreme climatic conditions and are relatively well documented by proxy-data.

The palaeoclimate group at Reading is participating in PMIP, and have performed all recommended simulations and are involved in a few subprojects, in which Dr. Paul Valdes coordinates the subproject "The simulated midlatitude large scale circulations changes at the Last Glacial Maximum". In addition, we have also performed some sensitivity studies. During the Mid-Holocene (6ka), the seasonality of insolation was enhanced. The first order effect of changes in insolation is an enhanced summer warming of the northern hemisphere land. This is illustrated in Figure 43 (see colour figure on page 59). All models

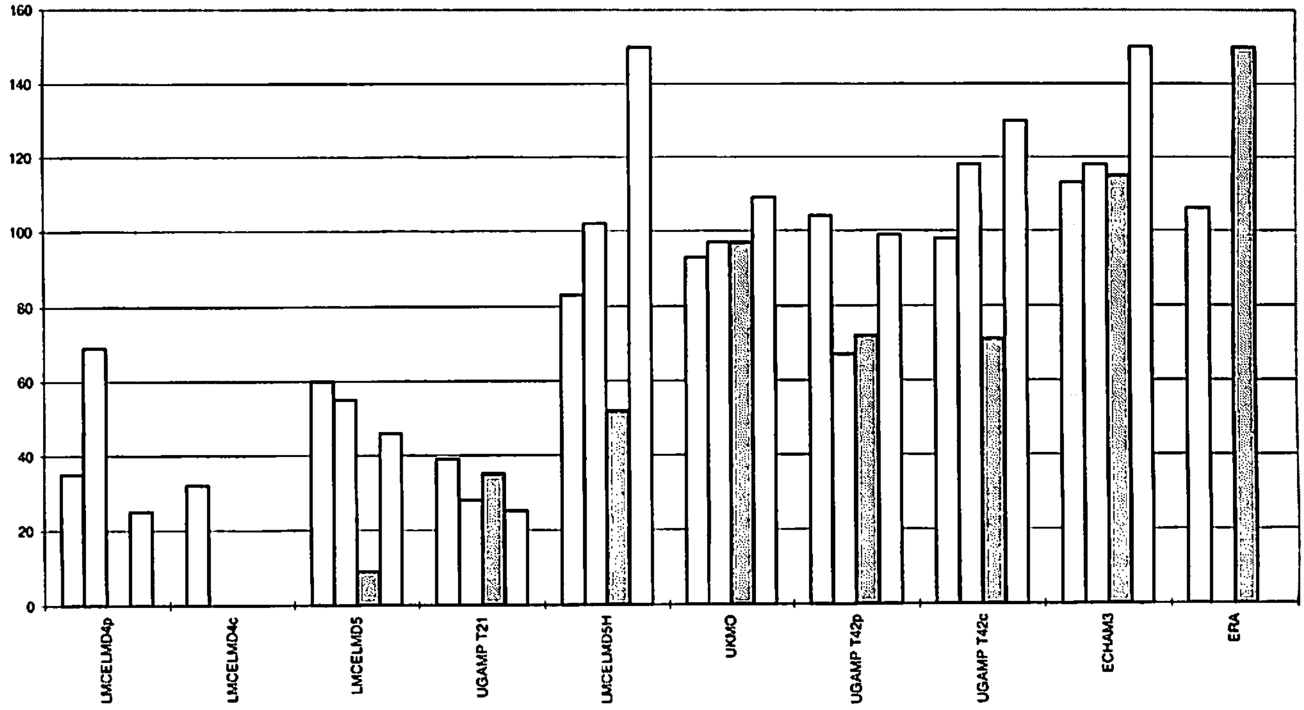

Figure 18. The index of the zonal extent of stormtrack in DJF for both PD and LGM simulations for various models. The horizontal resolution of models increases from left to right. The medium shaded and unshaded bars represent the North Pacific stormtrack for the PD and LGM, and dark and light shaded bars represent the North Atlantic stormtrack for the PD and LGM.

simulate a warming in JJA season over most of the continents, but the magnitude and pattern appear to be model dependent. Due to the enhanced land-ocean temperature contrast, the monsoon circulation is enhanced and penetrates further north into the continent in the 6ka simulation. As a result, the monsoon rainfall over south Asia and north Africa is increased. However, the inter-model standard deviations of the simulated changes in both surface temperature and precipitation are also larger in monsoon regions, indicating that the magnitude of the changes and extent of the changes in both temperature and precipitation are highly model dependent.

Preliminary model-model intercomparisons indicate that the large increase in monsoon precipitation in the 6ka simulation is associated with the large increase in surface temperature and large decrease of the mean sea level pressure over the Eurasian continent. Snow mass changes over Eurasia among models in 6ka simulations in winter/spring may also be partly responsible for the surface temperature change differences in the summer. The analysis also indicates that model resolution is not the dominant factor to explain the differences in response to insolation changes. The presence of extensive ice sheets and sea ice at the LGM induces significant changes in the baroclinic structure of the atmosphere at mid-latitudes. Shown in Figure 18 is the zonal extent index of the North Atlantic and North Pacific stormtracks in DJF season for the PD (present day) and LGM simulations for various models. It clearly indicates for both PD and LGM simulations that the stormtracks are sensitive to the model horizontal resolution. The low horizontal resolution models underestimate both the strength and the extent of the stormtracks. Compared with the PD simulations, generally most models show zonal extension (downstream development) of stormtracks in the LGM simulations. These changes in stormtrack induce significant changes in precipitation over the northern hemisphere midlatitudes.

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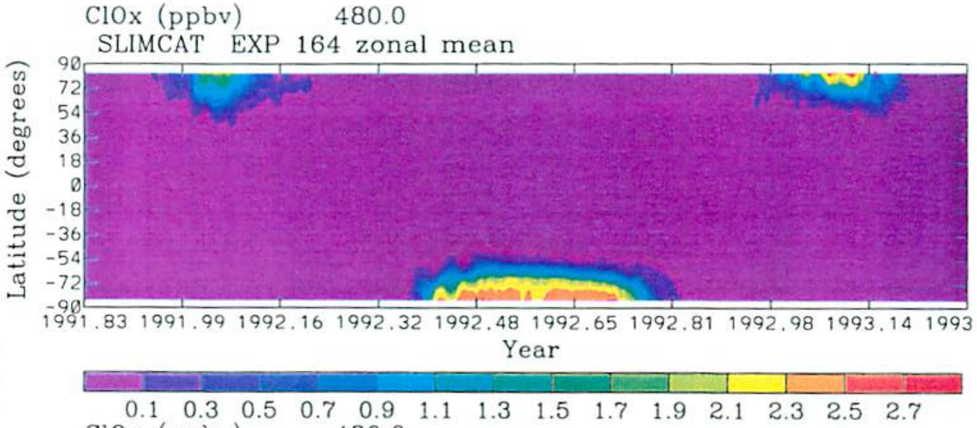
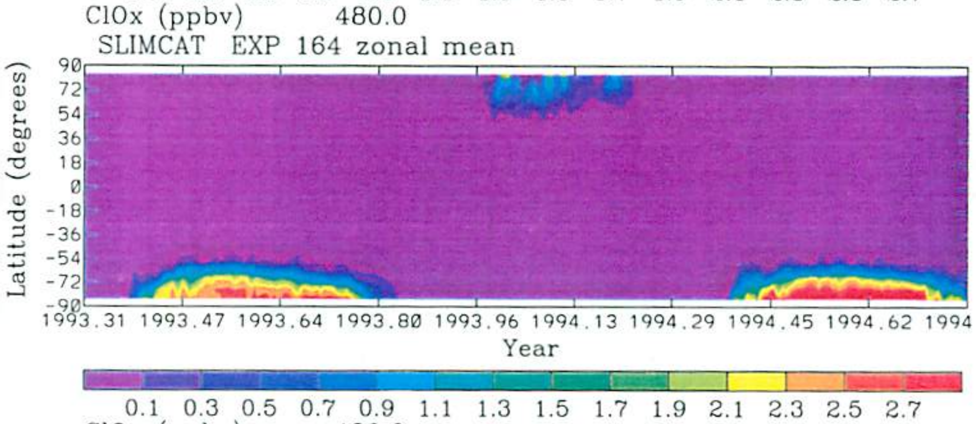
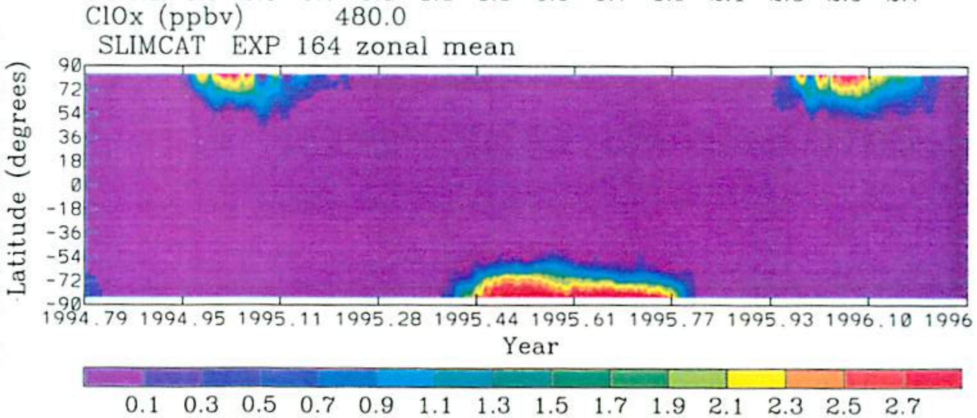






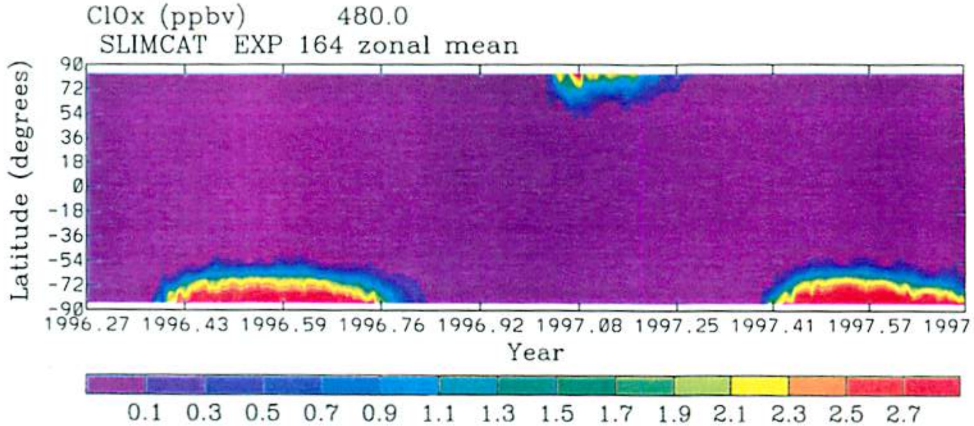
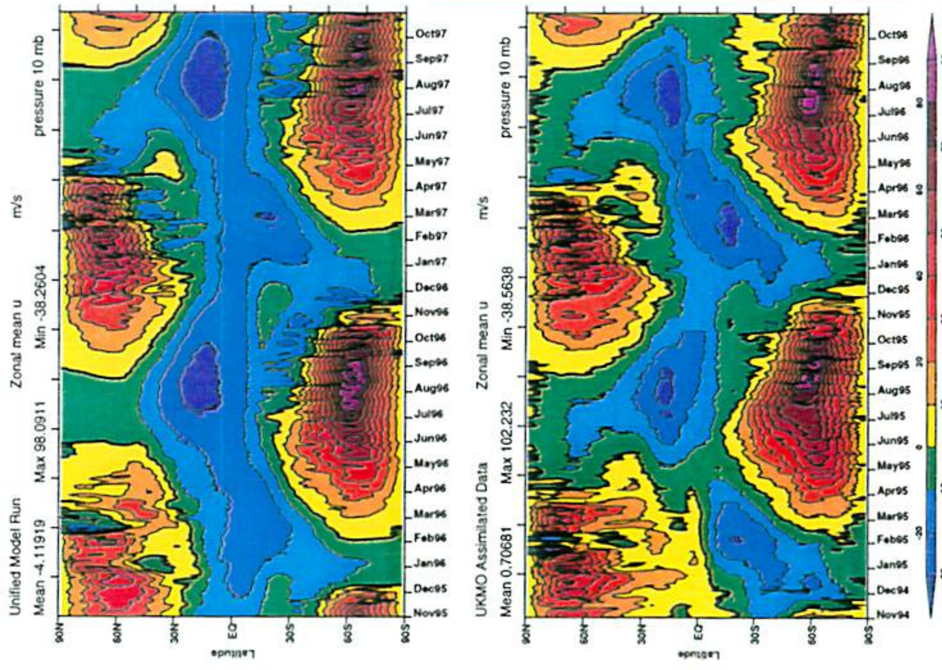


Figure 19. (above and right) Time series of zonal mean $ClO_x = ClO + 2Cl_2O_2$ on the 480K isentropic surface (about 18 km) from the SLIMCAT 3D model run.

Figure 20. (left) Time series (time .v. latitude) of zonal wind (m/s) for the model (November 1995 - October 1997; top panel) and the UKMO analyses (November 1994 - October 1996; bottom panel).



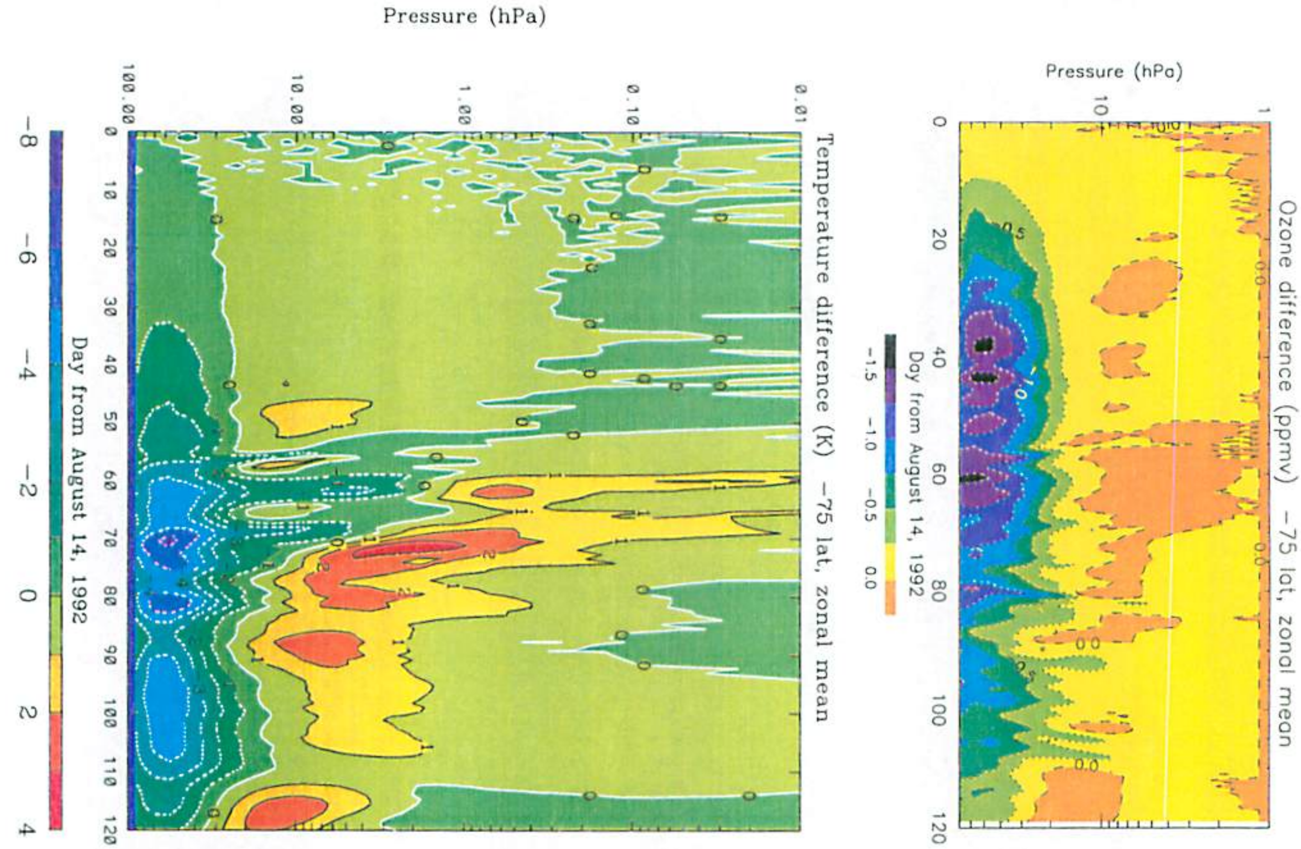
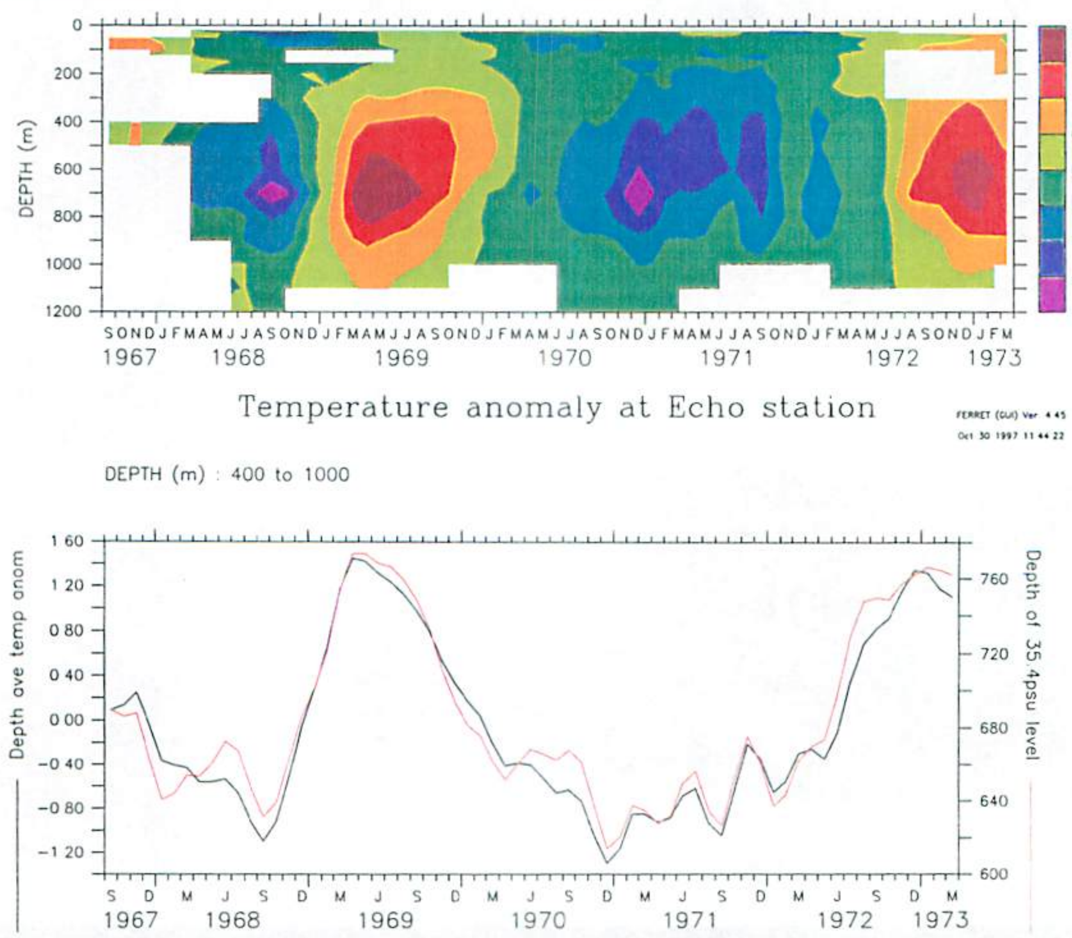


Figure 21. (above) Time versus pressure sections of the ozone and temperature fields from a run of the COSMIC model with heterogeneous chemistry minus the equivalent fields from an otherwise identical run with no heterogeneous chemistry. The plots are zonal means at 75S.

Figure 22. (below) Temperature anomaly at OWS Echo.



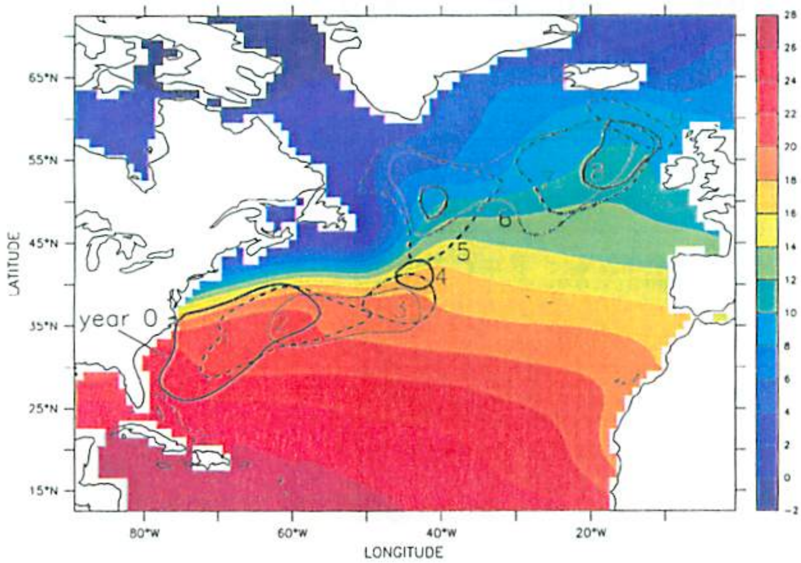


Figure 23. (above) Correlation between low frequency fluctuations in local wintertime SST and low frequency fluctuations in wintertime SST averaged over the region 80-60°W, 31.5-38.5°N (the vicinity of Cape Hatteras, VCH) as a function of lag. The contours pick out the regions where lag-correlation with VCH is maximised. The numbers next to each contour indicate the lag in years. In all cases VCH SST leads local SST. The contour value is 0.8 for lags of 0 to 8 years and 0.75 for the lag of 9 years. The contours are superimposed on the SST field averaged over all winters between 1945 and 1989 (colour scale in °C).

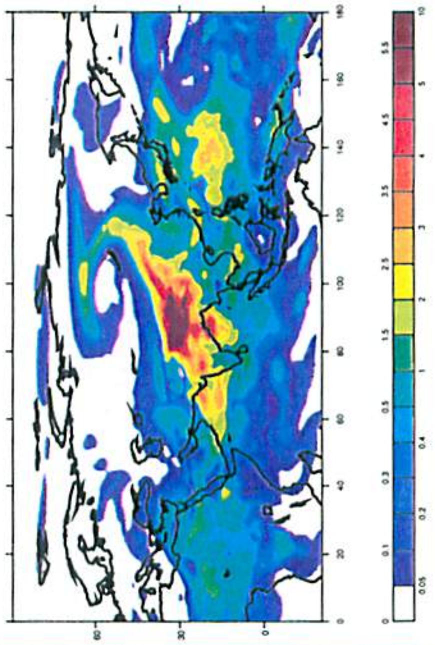
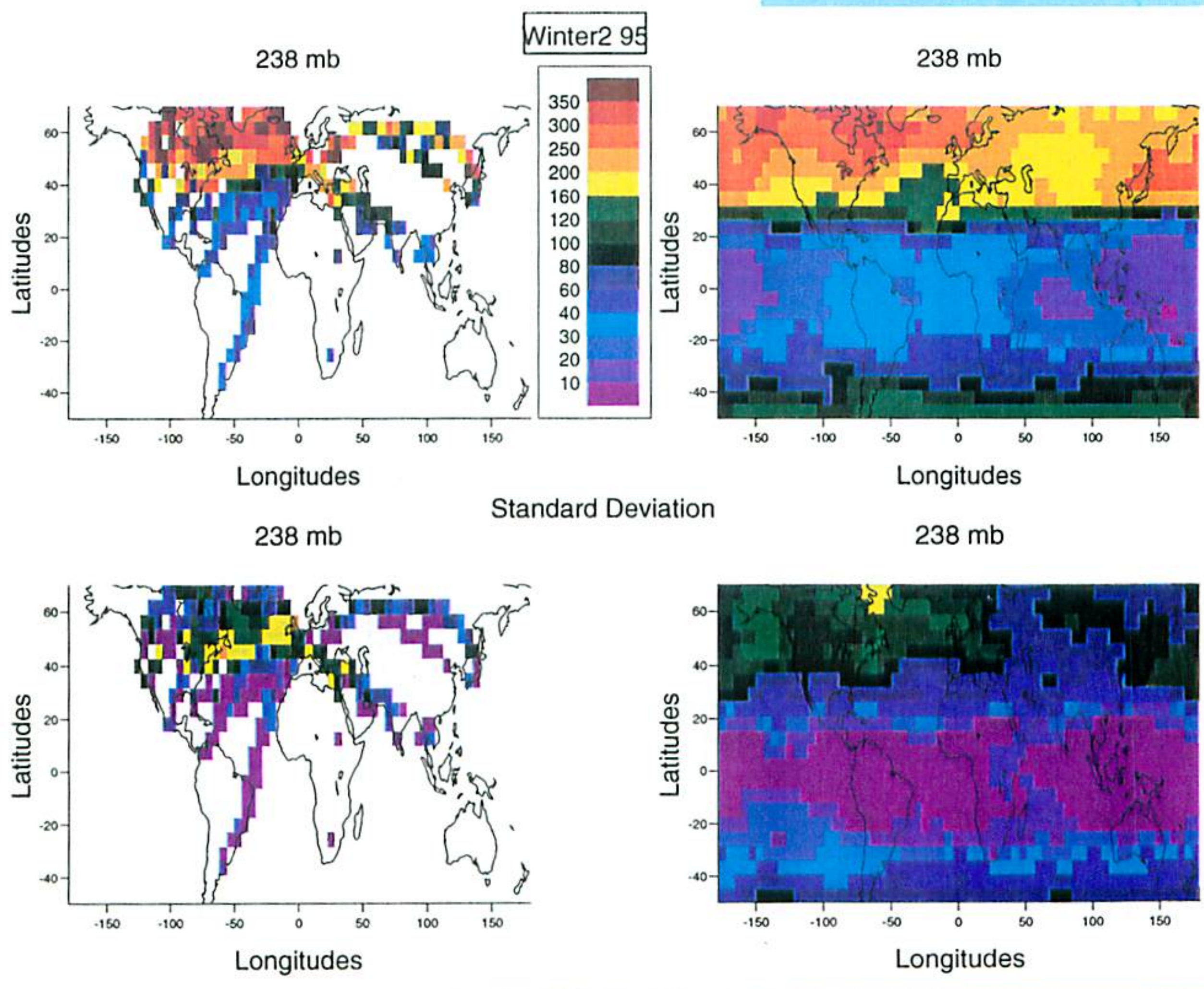


Figure 24. (above) Specific humidity in g/kg on the 340 K surface, 26 July 1988.

Figure 25. (below) Comparison of model results with seasonal averaged aircraft data.



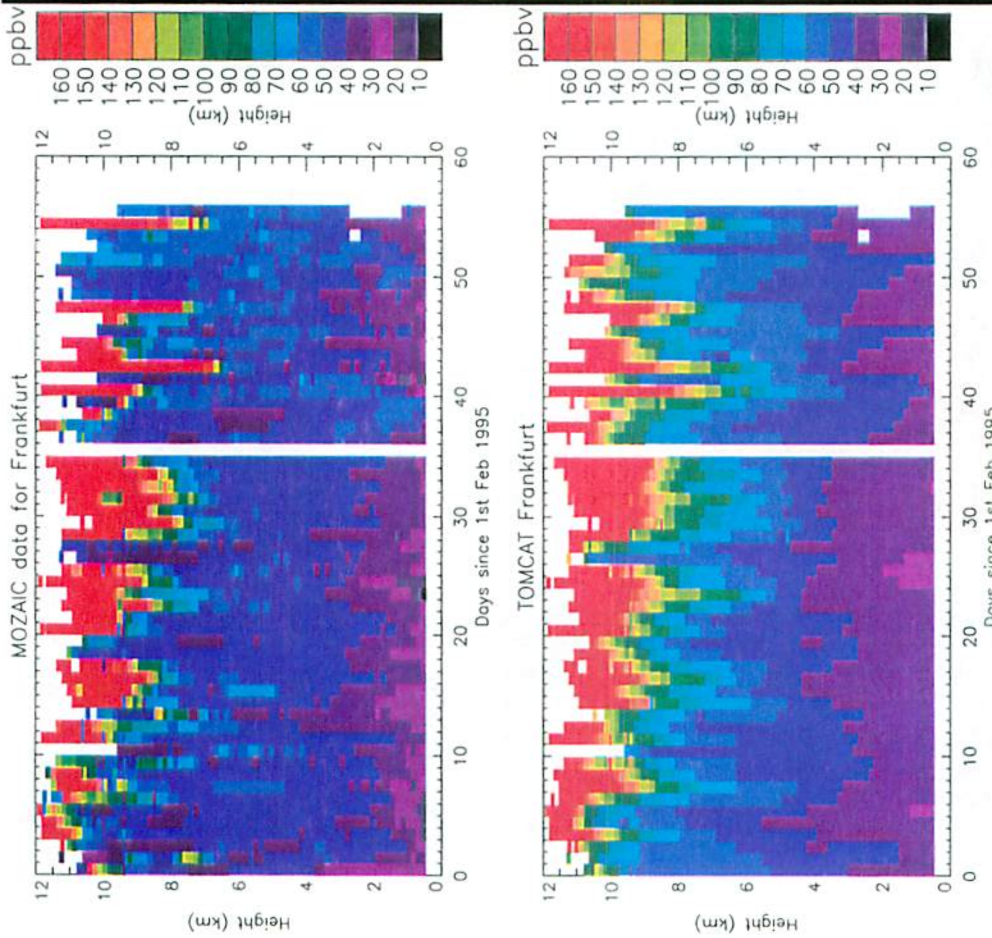
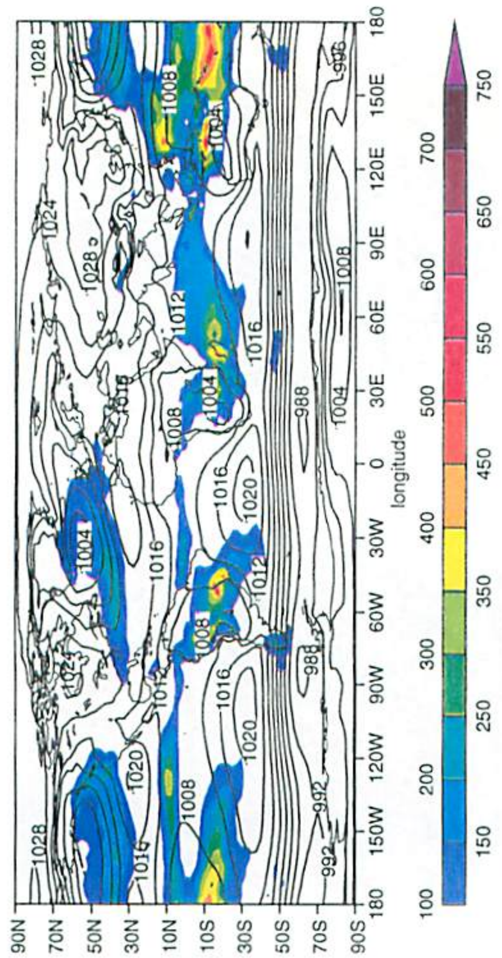
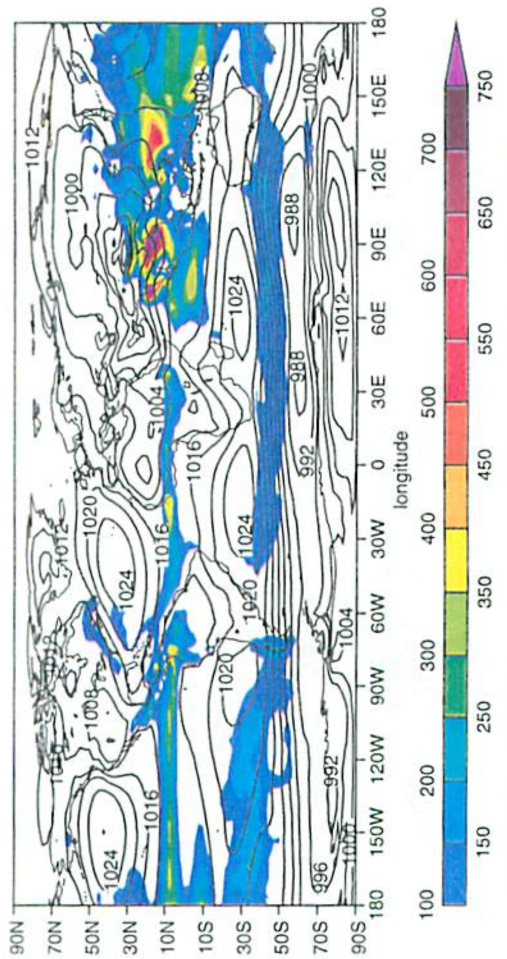


Figure 26. Model results compared to aircraft data during takeoff and landing

Figure 27. (below) The mean DJF and JJA Mean Sea level Pressure and Monthly Accumulated precipitation for 1979-1981.



DJF 3 year mean. Precipatation accumulation (mm/month) and MSLP (mb). 58 level UM.



JJA 3 year mean. Precipatation accumulation (mm/month) and MSLP (mb). 58 level UM. Figure 3.

STORM TRACKS

Understanding Storm Tracks using an Intermediate General Circulation Model

Understanding the basic processes important to storm tracks is the principle aim of this project. Storm tracks are regions of high synoptic activity. In the northern hemisphere these are located in the Atlantic and Pacific Ocean basins. Knowledge of what fundamental dynamical mechanisms are responsible for such organization of activity, including the seeding of synoptic events, is required. Recent idealized work has shown that disturbances with structure, confined in the horizontal and vertical, and located in the low troposphere, are most efficient in leading to the formation of deep sustained midlatitude systems. This can be understood in terms of the shear leading to the unshielding of the PV distribution and the growth by untilting (Venetian blind mechanism) with an associated upward propagation. An idealized storm track model set-up, such as that developed by Valdes and Hoskins, will be used to determine the characteristics of seeding events and the impact of physical parametrizations on the seeding mechanisms. Experiments will be performed to investigate the effect of various parameterization schemes of radiation, surface fluxes, turbulence and moist convection on the model storm evolutions. Introducing localized variations of friction, moisture and sea surface temperature should indicate the relative importance of these processes in organizing the storm tracks. The basic understanding sought is highly relevant to the North Atlantic Oscillation, future European climate change, European seasonal forecasting and palaeoclimate studies.

In tandem, the tool used to achieve this scientific objective, a climate circulation model, is being developed in collaboration with others at Reading. This model is an intermediate general circulation model (IGCM), so called because it lies in terms of complexity and sophistication somewhere between idealized dynamic models and full general circulation models. It will include modular code for various parametrizations of radiation, convection and surfaces processes. The model will be executable on parallel machines, facilitating very fast high resolution integration, and also be very portable between different machines, thus making it available to a large base of users.

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Doppler Correction of the Storm Track Intensity

The aim of the work is to define a measure for the intensity of a storm track which is not influenced by the variability of the mean circulation. The intensity of a storm track is commonly measured in terms of Eulerian diagnostics such as the eddy kinetic energy or the square of the meridional wind anomaly of those disturbances, which have periods between 2 and 6 days (Blackmon, 1977). Figure 28 shows a Hovmoeller plot of the meridional wind of the season 1984/85 filtered with an 2 to 6 day Lanczos filter (Duchon, 1979). A storm track measure such as this one distinguishes between disturbances according to their velocity relative to the ground. But the velocity relative to the ground depends not only on the phase velocity of the disturbances but also on the advection speed.

The zonal wind speed is in Figure 28 overlaid on the meridional wind anomaly. In the areas where the zonal wind is weak (hatched), advection makes the disturbances move much slower than they would do at other times or places. The advection speed is especially low at the time of blocking in the European area at about half way through the time series causing an exclusion of the disturbances from the storm track measure. The strong time and space variability of the zonal wind speed implies that the common storm track measures may not capture the time and space variability of the storm track well, especially at the eastern end of the stormtrack over Europe and America, where the zonal wind is low in comparison to the areas over the oceans. But it is especially in these areas that the intensity of the storm track is of interest since it strongly influences the European/North American climate.

A method was developed to eliminate the influence of the advection speed onto the storm track measure, that is to introduce a Doppler Correction. This method consists of a filtering of the data by an Multichannel

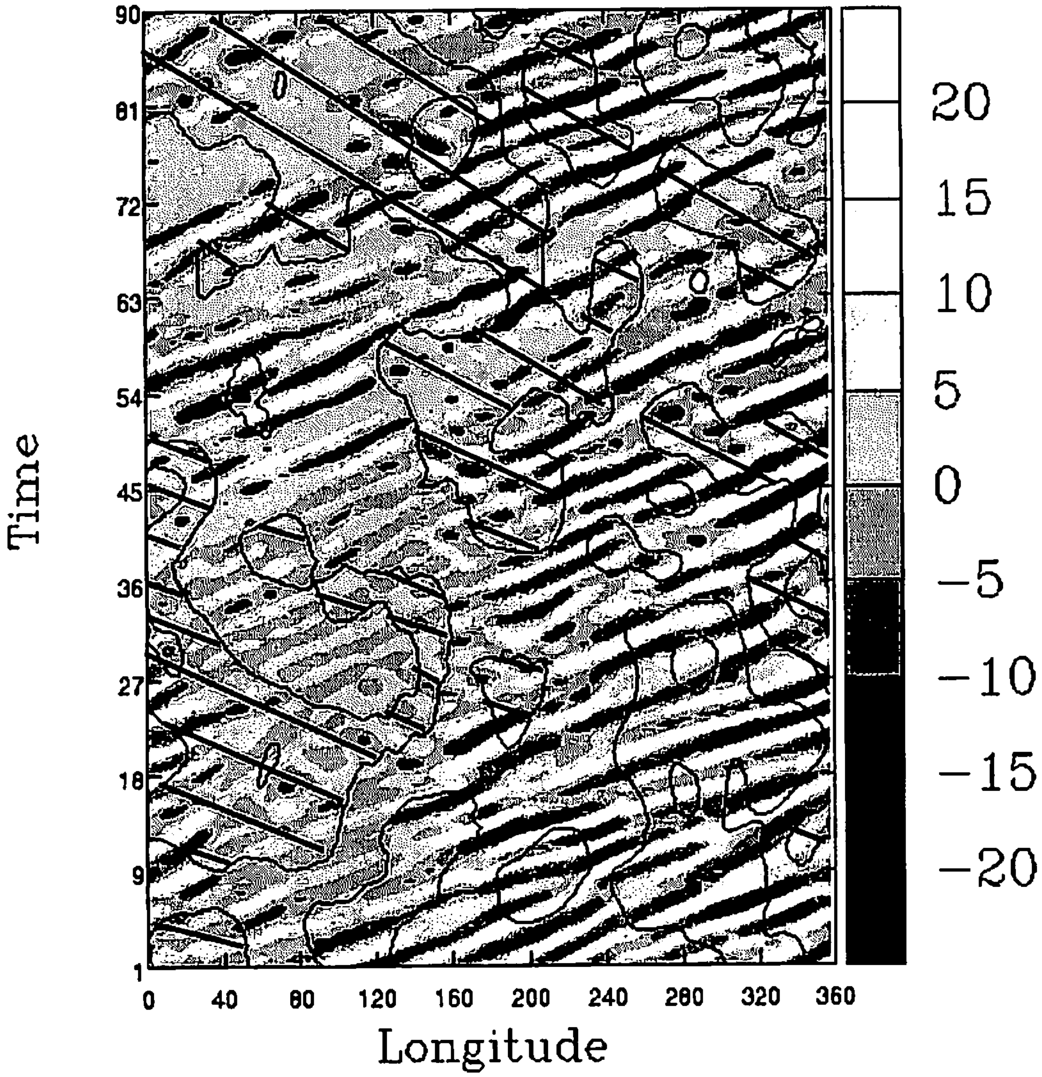

Figure 28. Hovmoeller plot of the 2-6 day band-pass filtered meridional wind anomaly at 300 hPa (in m/s) and contours of the 10 day low-pass filtered zonal wind anomaly at 700 hPa (areas of wind speeds lower than 5 m/s are hatched and isolines are plotted every 5 m/s) for the winter 1984/85.

Singular Spectrum Analysis (MSSA) (Vautard, 1995) in which the filter band changes with time according to the advection speed of the disturbances. Figure 29 shows the time series of two different measures of the storm track activity (the square of the filtered meridional wind anomaly) for the east European area (0W-59W and 34N-66N), the intensity without Doppler correction (dashed) and the Doppler corrected storm track measure (continuous). It can be seen that the Doppler correction has the effect of increasing the estimate of the intensity of the storm track at the time of blocking and to decrease the estimate shortly after when the mean flow is very strong. In the former case the Doppler correction reflects the fact that the very slow advection speed makes the disturbances move very slowly relative to the ground and therefore includes disturbances which have periods longer than 6 days. In the latter case Doppler correction excludes disturbances which have periods between 2 and 6 days because the advection speed is very high.
A publication about this technique is in preparation and further applications are planned.

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Statistics of Trajectories in the North Atlantic Storm Track

Aspects of the Lagrangian behaviour of the North Atlantic storm track are studied by calculating 3-D back trajectories using winds from ECMWF analyses and climate runs of the UK Met Office Unified Model (UM). The origins of trajectories over whole seasons are examined using probability density estimates

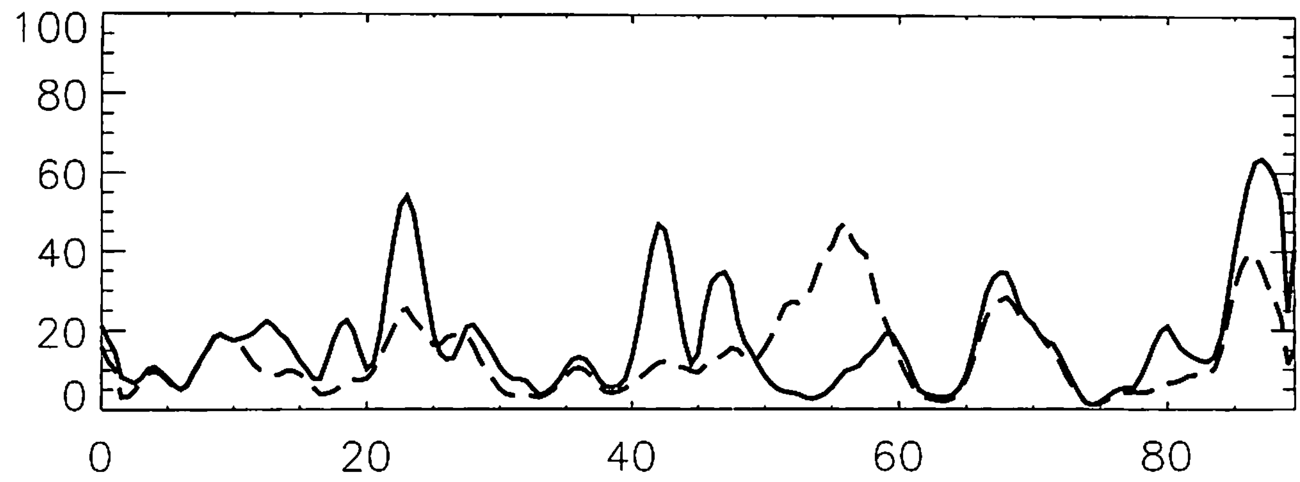


Figure 29. Time series of the area averaged (0W-59W and 34N-66N) storm track intensity without (dashed) and with (continuous) Doppler correction (in m^2/s^2).

which are quite insensitive to errors in the trajectory calculations. These estimates can therefore differentiate the impacts of storm track regimes on atmospheric tracers. The representation of Lagrangian behaviour in the UM has a strong influence on the distribution of water vapour which in turn impacts on the response of the model climate to imposed changes, such as double carbon dioxide.

This trajectory data set is also being employed to examine statistics of dispersion including cluster displacement, spread and shape, and the average strain rate experienced along trajectories. The aim is to provide quantitative climatological information on the origins of air and the typical rates at which air masses are stirred together. Preliminary results suggest that interannual variability is particularly strong for trajectories arriving over the European side of the Atlantic.

Routine Trajectory Calculations at the ECMWF

Back trajectories have been routinely calculated at the ECMWF for the whole of 1995, 1996 and 1997. The trajectories are 5 days long and arrive at 900hPa in three clusters centred over western Europe, the mid-Atlantic storm track region and the eastern USA. Throughout 1995 the trajectories were released daily, at 12UT, and for 1996 the release frequency was increased to once every 6 hours. Since the end of September 1996 the trajectories have been calculated using a new package, called 'Offline' (see Methven 1997, UGAMP technical report 44, for more details). Now meteorological fields, including potential temperature, specific humidity and potential vorticity, are interpolated to the particle positions in the same manner as the winds. All these trajectories have been archived at the British Atmospheric Data Centre (BADC) and are available to any U.K. researchers.

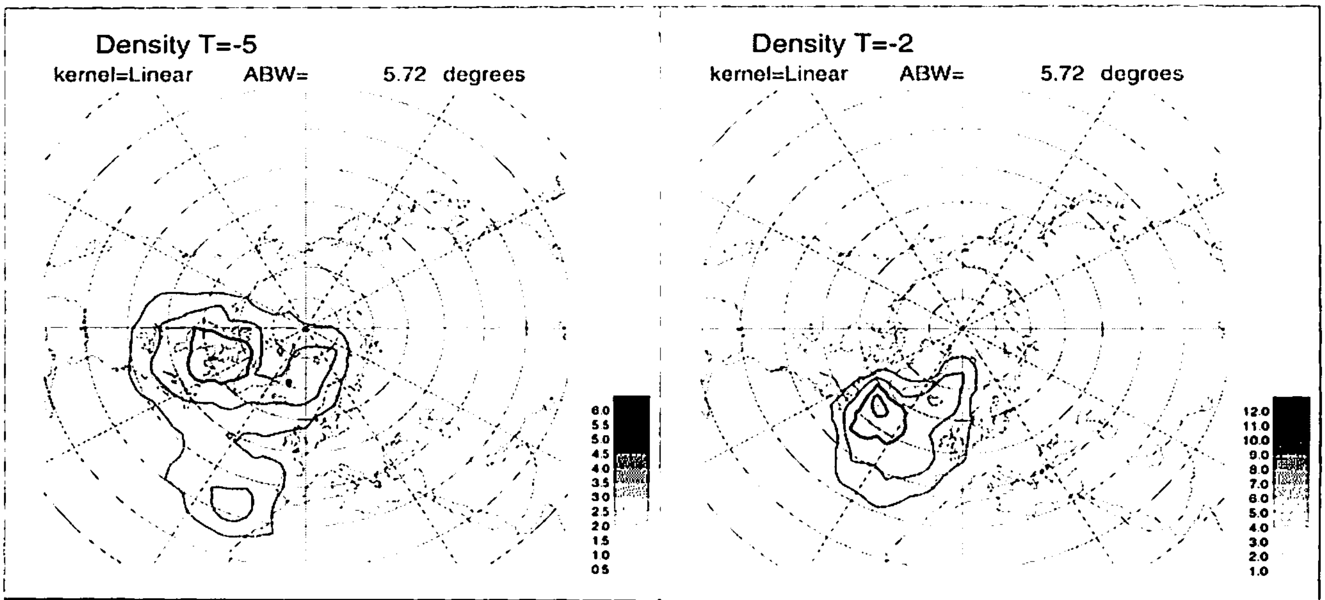
Probability Density of Origin

Trajectories arriving at one instant over a particular region may have disparate origins with very different chemical signatures. Moreover, trajectories in the North Atlantic storm track region vary greatly from day to day. The aim here is to quantify the probability that air arriving over western Europe has originated from a given area when averaging over a season. The simplest method would be to count the number of trajectories originating from each lat-long grid box. However, here we use kernel estimation methods which have been developed by Kevin Hodges at the Environmental Systems Science Centre (ESSC). These have two major advantages over grid box counting methods: there is no area bias due to box definition and the estimation is much more robust and smooth than 'binning'. The number density of particles is estimated by summing kernel functions which are placed at the position of each trajectory at a given time before arrival. Each kernel has a finite spread which smooths the density estimate and this spread is wider where density is low. The spread is determined by a maximum likelihood estimation which aims to keep both the bias and variance of points about the estimate to a minimum. The procedure is similar to finding a weighted average of a set of points, where a larger kernel spread is used where uncertainty is greater. The density function is normalised so that its integral over all solid angles equals one.

Figure 44 (see colour figure on page 59) shows the probability densities for air origin at 2 days and 5 days before arriving over Western Europe. These distributions have been calculated using all trajectories which arrive in the European cluster, daily, for winter (DJF) 1995/1996, amounting to some 15288 trajectories. One can immediately see that this winter was one where air typically originated from central Europe, although at 5 days back the spread of origin is wide and extends right across the Atlantic.

In contrast, the previous winter (1994/1995) was typified by a predominance of westerly flow. The maximum probability density is situated on the far side of the Atlantic at only 2 days back; at 5 days back the density is spread widely but is a maximum over NE Canada (see Figure 30).

Figure 30. Probability densities



Acknowledgments

Kevin Hodges (ESSC) created the probability density algorithm and provided the programme for it. Thanks also to Chunkey Lepine, Sam Pepler, Lesley Gray, Mike Bithell, Andy Smith and Peter Chiu at BADC for making helpful suggestions concerning the trajectory calculations, plotting the trajectories for ACSOE and for archiving the data. John Methven is funded by a project with the Hadley Centre for Climate Prediction and Research.

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Coupled Atmosphere-Ocean Modelling

Coupled Ocean-Atmosphere Modelling News

The recent period has seen several new developments in UGAMP coupled ocean-atmosphere modelling activities. The ten year integration of our tropical ocean-global atmosphere coupled GCM has been completed. Analysis of the results is well under way. (See article on an intriguing drift in the phase of the seasonal cycle.)

In parallel with this work on the tropics we have been developing a programme of research focused on the role of ocean-atmosphere interactions in the climate (especially climate variability) of the North Atlantic Region. This work has been stimulated by observational evidence we obtained suggesting significant decadal predictability of North Atlantic Sea Surface Temperatures. We are following up this work with a wide range of studies aimed at better elucidating the mechanisms involved. These studies include further analyses of observational data in addition to studies with atmosphere models, ocean models and coupled models. Of particular note is our involvement in the EC SINTEX project, which is a major collaboration between coupled ocean-atmosphere modelling groups around Europe. As part of SINTEX, and in collaboration with the Hadley Centre and the Southampton Oceanography Centre, we will be developing a new coupled GCM specifically designed for studying ocean-atmosphere interactions in the Atlantic sector.

Our group has recently been strengthened by two new members. Steve Jewson has returned to the U.K. as a postdoc in Reading after a period in Australia. Graham Gladman is a new PhD student whose project involves a collaboration with the Hadley Centre.

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Drift in the Seasonal Cycle of a Coupled GCM

In the January 1997 newsletter we reported some initial results from a tropical ocean, global atmosphere coupled GCM. At the time we had completed about 4 years of integration, and we were greatly encouraged because, despite a significant drift in the mean tropical Pacific SST and large initial fluctuations during the first year, the seasonal cycle of tropical Pacific SST during years 2-4 shows several realistic features: it is dominated by an annual, rather than a semiannual signal, with warmest temperatures in the east around March, and the seasonal SST anomalies propagate westwards (Figure 45(a); see colour figure on page 60). However, as we extended the integration out to 10 years we found a gradual drift in the phase of the annual cycle, with coldest temperatures in the east pacific occurring several months late.

We have found that the drift in the phase of the annual cycle of SST is related to the mechanism of westward propagation of seasonal anomalies; this mechanism gradually becomes distorted in the later years of the integration. In the early years of the integration, and perhaps in reality, the seasonal cycle operates as follows. During northern summer the ITCZ in the east Pacific at around 10°N intensifies, intensifying the local Hadley circulation and leading to a few months of strong northward wind stress on the sea surface near the equator. This cools the SST there by evaporation and by wind-driven entrainment of cooler, deeper water into the ocean mixed layer. For example, note the peaks near 100°W around August and September in Figure 45 (see colour figure on page 60), which shows an estimate of wind-driven entrainment on the equator. This cooling in the east enhances the zonal temperature gradient further west. Then, as predicted by simple models of the tropical circulation, this enhanced zonal temperature gradient leads to enhanced low level westward wind and westward wind stress. The enhanced westward wind stress in turn leads to enhanced wind-driven mixing, augmented by enhanced upwelling, and to some extent enhanced evaporation, and hence ultimately to cooling to the west of the original cooling. See, for example, the peaks near 130°W at the end of years 2 and 3 in Figure 45(c). This offers an explanation for the period and phase of the annual cycle and the westward propagation in seasonal SST anomalies.

Figure 45(b) and Figure 45(c) illustrate how this mechanism becomes distorted in the later part of the integration. The shading in figure Figure 45(b) shows the near equatorial zonal temperature gradient, overplotted with the -0.07 Nm^{-2} contour of zonal wind stress. It shows that the peak in zonal temperature gradient occurring at the end of each year, which is in the central Pacific at the end of year 2, gradually moves further east each year. We don't yet understand the reason for this, although it is probably related to the mean climate drift of the coupled GCM. The accompanying maximum in zonal wind stress also migrates eastward. Figure 45(c) shows that the region of enhanced wind-driven entrainment associated with the westward wind stress maximum also migrates eastward. Thus, by the end of year 9, there is a peak in wind-driven entrainment in the east Pacific associated with the burst of northward wind stress during northern summer, followed by a further peak, also in the east Pacific, associated with the burst of westward wind stress. As a result, the east Pacific SST continues to cool right through to the beginning of the following year, giving a lag of several months in the phase of the annual cycle.

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MONSOON RESEARCH

Intraseasonal and Interannual Variability of the Asian Summer Monsoon

A comprehensive atlas describing the Asian Summer Monsoon, including its seasonal evolution, and its interannual and intraseasonal variability, has been prepared for the period 1979-95, covering the AMIP II period. Data from the ECMWF Reanalyses (ERA) for the period 1979-93 and the ECMWF operational analyses for the period 1994-95 are used. In addition to analyses, satellite observations of monthly and daily mean OLR and observed precipitation, including All-India Rainfall, for the same period are also used. The main purpose of these diagnostics is to understand the monsoon and to validate the model results (Annamalai et al. 1998).

The study reveals that the seasonal mean monsoon may be influenced by intraseasonal and synoptic events. As found in the modelling study of Ferranti et al. (1997), a strong similarity exists in the spatial patterns of the dominant modes of intraseasonal and interannual variability which may have implications for predictability. The statistical properties of the monsoon depressions (important rain-bearing synoptic events) have been analysed using an objective tracking algorithm. The interannual variability of the monsoon has been studied both in terms of regional rainfall indices and larger scale circulation anomalies. The character of weak and strong monsoons depends on the nature of the index used to define the interannual variability. The sub-seasonal variations in the behaviour of the monsoon suggests that the slowly varying boundary conditions, such as SST, may exert a strong influence during the onset and retreat phase of the monsoon season, but not necessarily during the established part of the monsoon season.

A detailed intercomparison of the monsoon behaviour between ERA and NCEP/NCAR reanalyses has also been done (Annamalai et al. 1997). In data sparse areas, such as the Indian Ocean, the analyses depend heavily on the first guess supplied by the forecast model. The consistency between these two analyses indicates the degree to which they represent the truth and hence their reliability when used for model validation. The higher horizontal resolution used in ERA is evident in the orographic nature of the precipitation over India and the NCEP/NCAR reanalysis has too little precipitation over the West Pacific and much more over China. Thus the major differences between the two reanalyses are partly related to the nature of the heating distribution in the forecast models. In general, both reanalyses have their own limitations when used for interannual variability studies of the monsoon (Figure 46; see colour figure on page 60)

Recognising the crucial role played by the intraseasonal oscillations on the monsoon circulation and precipitation, a series of idealised experiments using the latest version of the UM (HadAM3), in perpetual July mode, are being carried out. The basic aim is to understand the role of slowly varying boundary conditions such as SST, soil moisture on the intraseasonal variability of the monsoon.

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From PROVOST (Prediction Of climate Variations On Seasonal to interannual Timescales) to PRISM (Predictability Experiments for the Asian Summer Monsoon)

The principal scientific basis for seasonal prediction in the atmosphere is that lower boundary conditions, such as SSTs, are less chaotic and may therefore be at least partially predictable. Even though the atmosphere is chaotic, these lower boundary conditions can 'lend' predictability to the atmosphere. The impact of boundary forcing anomalies on atmospheric variability depends, however, on their location, season and strength. The purpose of the PROVOST programme is to quantify this dependence more explicitly. In order to do this, ECMWF have run ensemble integrations with an atmosphere-only GCM (IFS cy13r4 at resolution T63L31) over seasonal time scales with the observed, prescribed SST.

Each ensemble is 120 days long and consists of 9 members, initialized from consecutive 12z analyses, i.e. in the northern summer case for 22-31 May. (Similar experiments were run for each season, but here we focus on the monsoon season). The integrations span the ECMWF reanalysis period (1979- 1993) using reanalysis as initial conditions, and with observed SSTs as boundary forcing. The results of these integrations can be investigated to find, for example, under what circumstances and to what extent, the Asian Summer Monsoon is predictable.

Figure 42 (see colour figure on page 59) shows the All India Rainfall (AIR) defined as the mean precipitation over all land points between 60-100E, 5N-30N for June to September. The grand mean for all ensemble members and all years is 776mm with a standard deviation of 89mm. This can be compared with the mean and standard deviation for ERA of 877mm and 89mm respectively. The skill of the ensembles is limited when compared with the AIR from ERA and from the observed record of Parthasarathy et al. (1995).

To investigate possible factors that influence the seasonal mean behaviour of the monsoon, the circulation and surface anomalies associated with strong/weak monsoons have been constructed by compositing ensemble members where the AIR exceeds ± 1 standard deviation. The results show that the changes in the circulation are largely consistent with those seen in ERA for strong/weak monsoons. For example, strong monsoons are associated with an enhanced southerly flow over the Bay of Bengal and into the monsoon trough; the easterly trades over the West Pacific are also strengthened. However, no clear relationship with SST can be identified which suggests that the interannual variability of the simulated monsoon is not strongly controlled by the boundary forcing.

Several studies have pointed to the potentially important role played by land surface anomalies, such as Eurasian snow cover, particularly in the months preceding the monsoon. The design of the PROVOST experimentation, in which the integrations are initialized when the onset of the monsoon is already established, means that the potential impact of springtime land surface anomalies cannot be assessed. Also the snow cover analysis in ERA had several problems which resulted in a poor representation of its interannual variability. For these reasons a new set of ensembles are being prepared, specifically designed to isolate the role of land surface vs. SST anomalies in the monsoon's seasonal predictability by performing parallel ensembles with observed and climatological SSTs. The experimentation is also designed to address the question of how much the springtime land surface anomalies are themselves a remote response to the SST forcing. This new project, named PRISM, is being run jointly with CINECA and ECMWF through an ECMWF Special Project.

n.b. a CDROM containing the results from the PROVOST ensembles for all seasons is available. Contact bernd@met.reading.ac.uk for more information.

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Water Vapour and the Asian Summer Monsoon

The ECMWF Re-Analysis data have been used to investigate the water vapour distribution in the upper troposphere. Water vapour is a very important greenhouse gas and it is crucial to understand the processes that determine its distribution. Of special interest is the transport of water vapour across the tropopause, from the tropical troposphere into the extratropical stratosphere.

Our study focuses on the effect of Asian summer monsoon on the moisture budget of the upper troposphere. We find that the region of the Asian summer monsoon is a very important moisture source for the upper troposphere. Moist air out of this region can be transported far north into the extratropical lower stratosphere during northern summer. This occurs through interaction with middle latitude synoptic disturbances. An example of an interaction that occurred in July 1988 is shown in Figure 24 (see colour figure on page 31). This way of moistening the northern lower stratosphere has not been investigated before, and could have significant effects on stratospheric chemistry or alter the radiative properties of the lower stratosphere.

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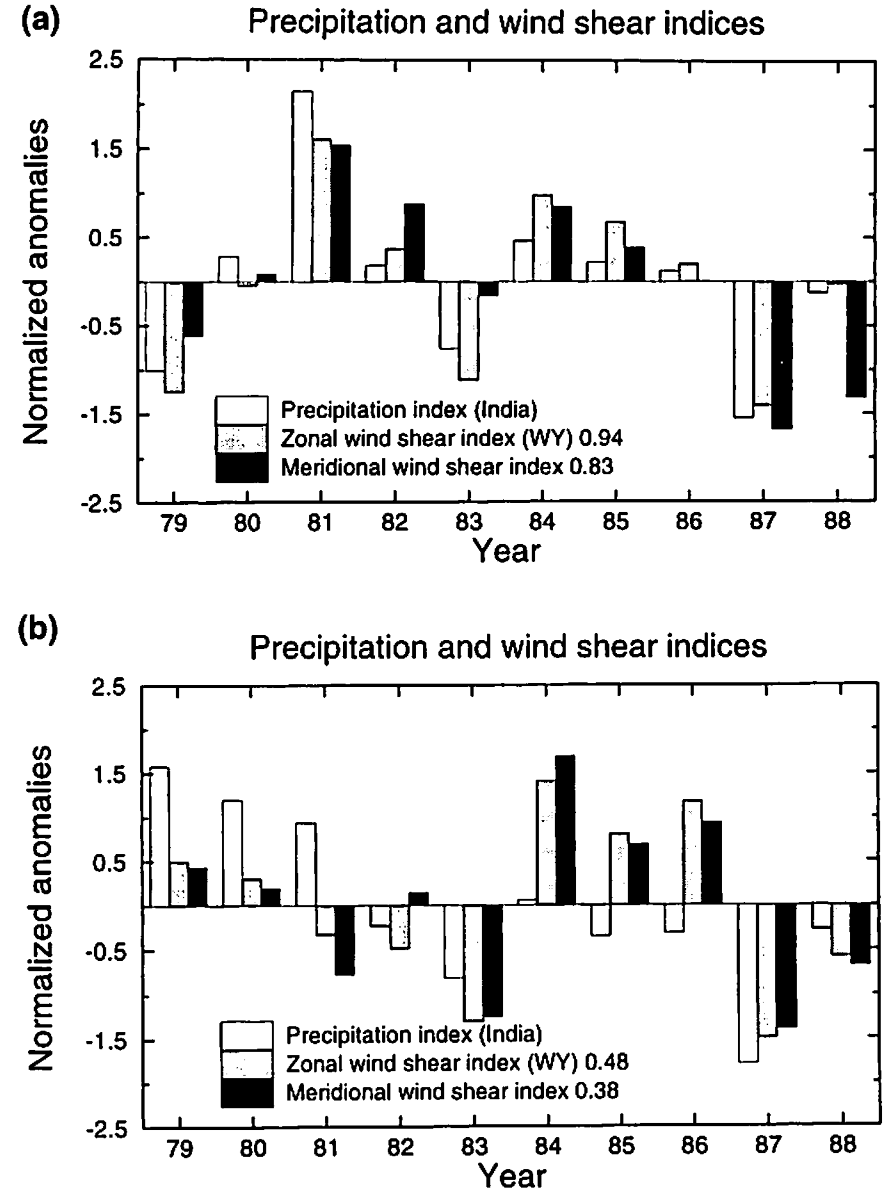

Figure 31. Normalized precipitation in JJAS over India (5-30N, 70-90E, land only) and wind shear indices in May, June and July over (0-20N, 40-110E). (a) AMIP-A simulation. (b) AMIP-B simulation. The numbers are the correlation coefficients between wind index and precipitation index.

The Model Simulated Asian Summer Monsoon Variability: Sensitivity to Land Surface Parameterization Schemes

The mean Asian summer monsoon and its interannual variations are analysed based on a 10 year AMIP simulation using the UGAMP GCM with the no-flux bottom boundary condition (hereafter as the AMIP-A simulation) and compared with the simulation with the fixed bottom boundary condition (Ju and Slingo, 1995, hereafter as the AMIP-B simulation). It is shown that both mean monsoon evolution and its interannual variations are sensitive to the land surface parameterization schemes, in which the snow mass and soil moisture have an important impact. Shown in Figure 31 are the two normalized dynamical monsoon indices and precipitation over India for the two simulations. Generally, the two dynamical indices are highly correlated in both simulations. In the AMIP-A simulation, the interannual variations of precipitation over India are in agreement with the dynamical monsoon indices. However, in the AMIP-B simulation, they are not consistent with each other, indicating that the interannual variations of large scale circulation and regional scale precipitation are decoupled by the constraint of the fixed bottom boundary condition.

The variations of the strength of the Asian summer monsoon are related to the variations of large scale circulation over Asia in previous winter/spring seasons. The interannual variation of the model 200hPa zonal wind averaged over Asia in DJFMA and the monsoon zonal wind indices in MJJ are shown in Figure 32. A strong Asian summer monsoon is preceded by weak upper tropospheric westerlies over south Asia and vice versa. This is consistent with other GCM studies of Barnett (1989) and Yang and Webster (1996), and an observational study by Webster and

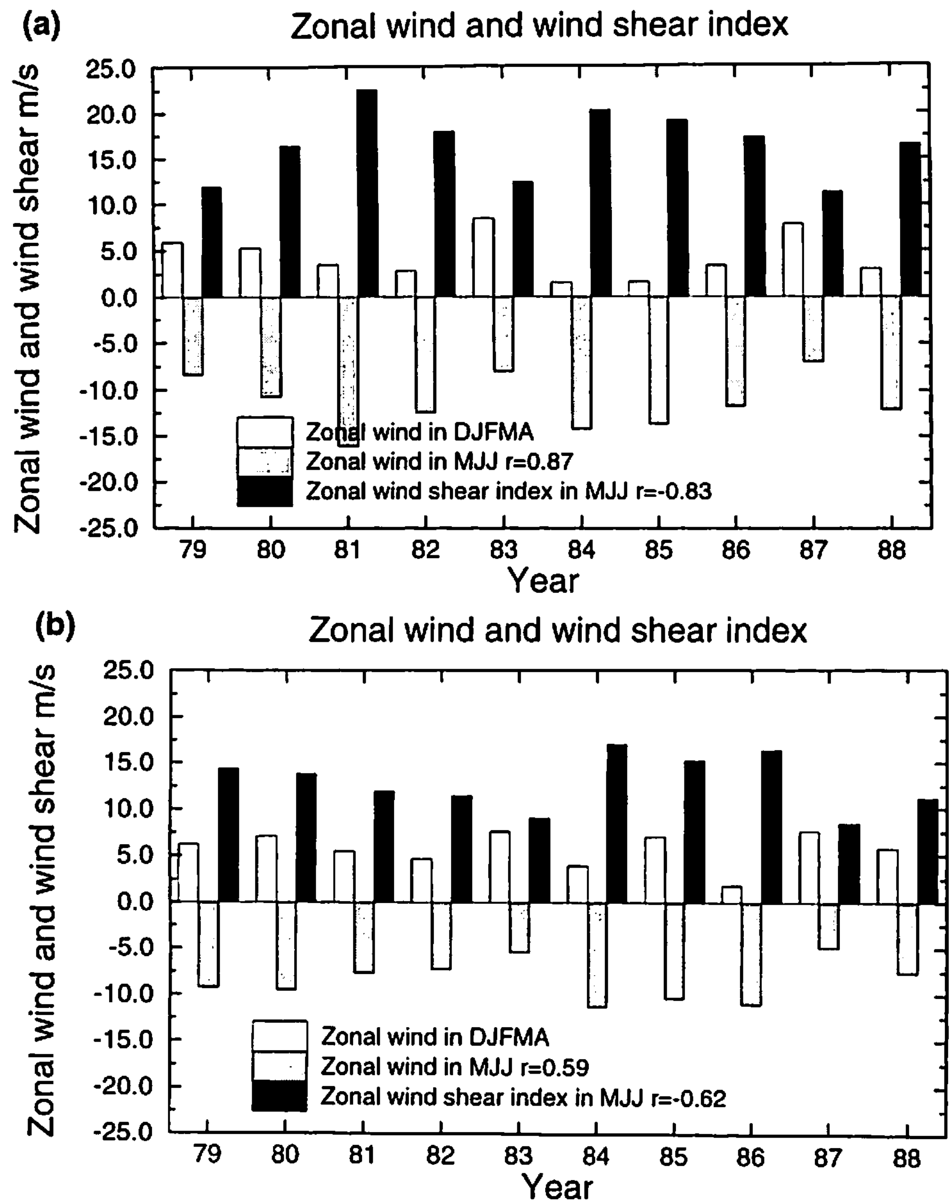

Figure 32. Zonal wind at 200 hPa in DJFMA, MJJ and zonal wind shear index over (0-20N, 40-110E). (a) AMIP-A simulation. (b) AMIP-B simulation. The numbers are the correlation coefficients between zonal wind indices in MJJ and that in DJFMA.

Yang (1992). This implies the importance of the indirect impact of SST anomalies on monsoon variations through their effect on winter/spring circulation and land surface processes. Figure 32 also indicates that the persistency of wind anomalies from winter to summer is stronger in the AMIP-A simulation. Although the large scale monsoon circulation is predominately modulated by SST anomalies, land surface processes (snow mass and soil moisture) have a very important feedback. They are the factors responsible for the mean monsoon differences in the two simulations. They also have important feedbacks to the monsoon interannual variations. It is therefore necessary to develop a good land surface scheme in order to better simulate the seasonal to interannual variations of the monsoon.

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Intercomparison of Parametrizations for Water Vapour Continuum

Some of the most commonly used representations of the water vapour infrared continuum have been investigated in terms of their impact on (a) the radiation fields of a 3-D cloud-free climatology, based on the GEDEX dataset (NASA 1992) and (b) the climate of the UGCM. The water vapour models used were: (P1) the pre-existing parametrization in the ECMWF model (based on Roberts et al. 1976), (P2) the parametrization of Zhong and Haigh (1995) (based on Clough's CKD_0 model), (P2b) a version of P2 updated to CKD_2.2 and (P3) a version of CKD_0 modified according to the aircraft measurements of Rudman et al. (1994).

Results show significant impacts of the continuum models:

- Outgoing longwave radiation (OLR) decreased between P2 and P1 by up to 6 W/m^2 in the sub-tropics in the clear sky case (see Figure 33) and by a global mean of 4 W/m^2 in the GCM runs.
- The difference between P2 and P2b was small but P3 showed a further decrease in OLR of up to 2W/m^2 at low latitudes. The zonal mean OLR for all the runs is shown in Figure 34.
- The effect of P2 was to reduce downward thermal radiation at the surface (STR) at low latitudes and increase it at high latitudes while P3 increased it everywhere but especially in mid-latitudes.
- The GCM results showed a global average increase in STR of 2.0 W/m^2 between P2 and P1 and of 1.2 W/m^2 between P3 and P2.

The changes in atmospheric infrared transmission have significant impact on the heating rates and thus on the temperature and humidity fields of the GCM. Figure 35 shows an upper tropospheric cooling of over

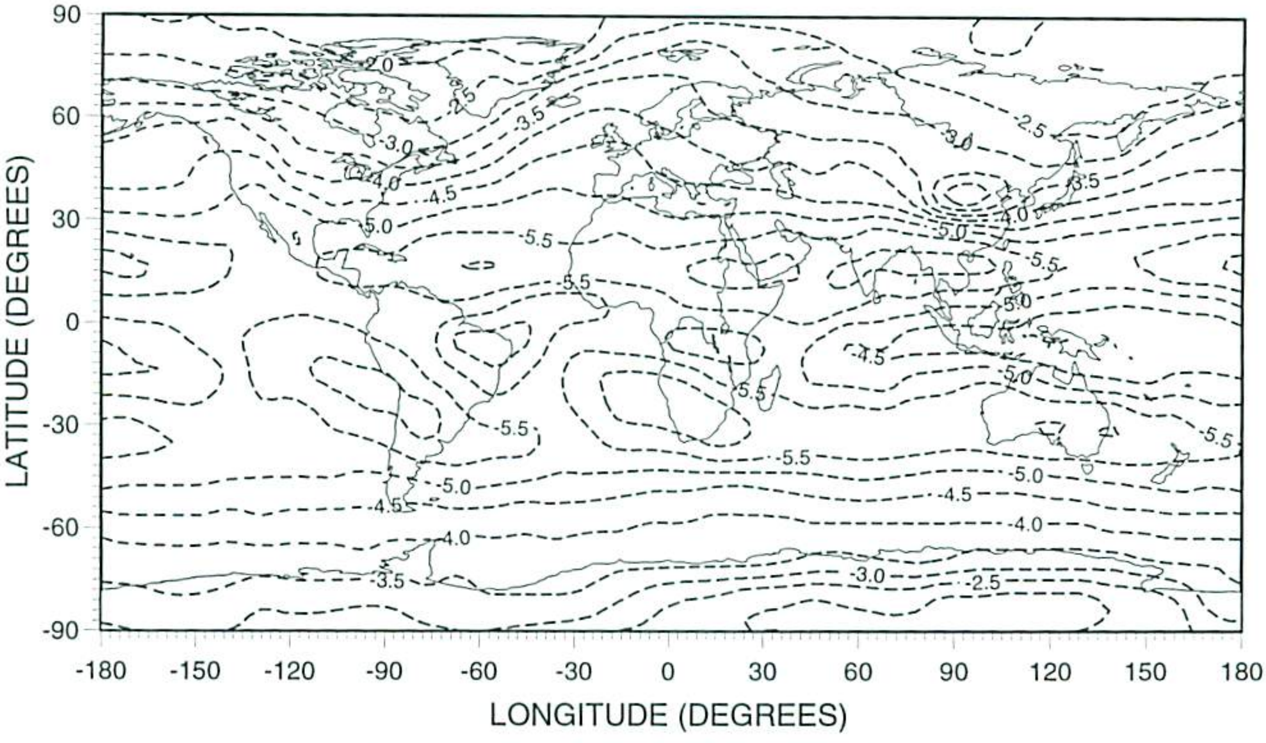

Figure 33. Off-line OLR difference between P2 and P1.

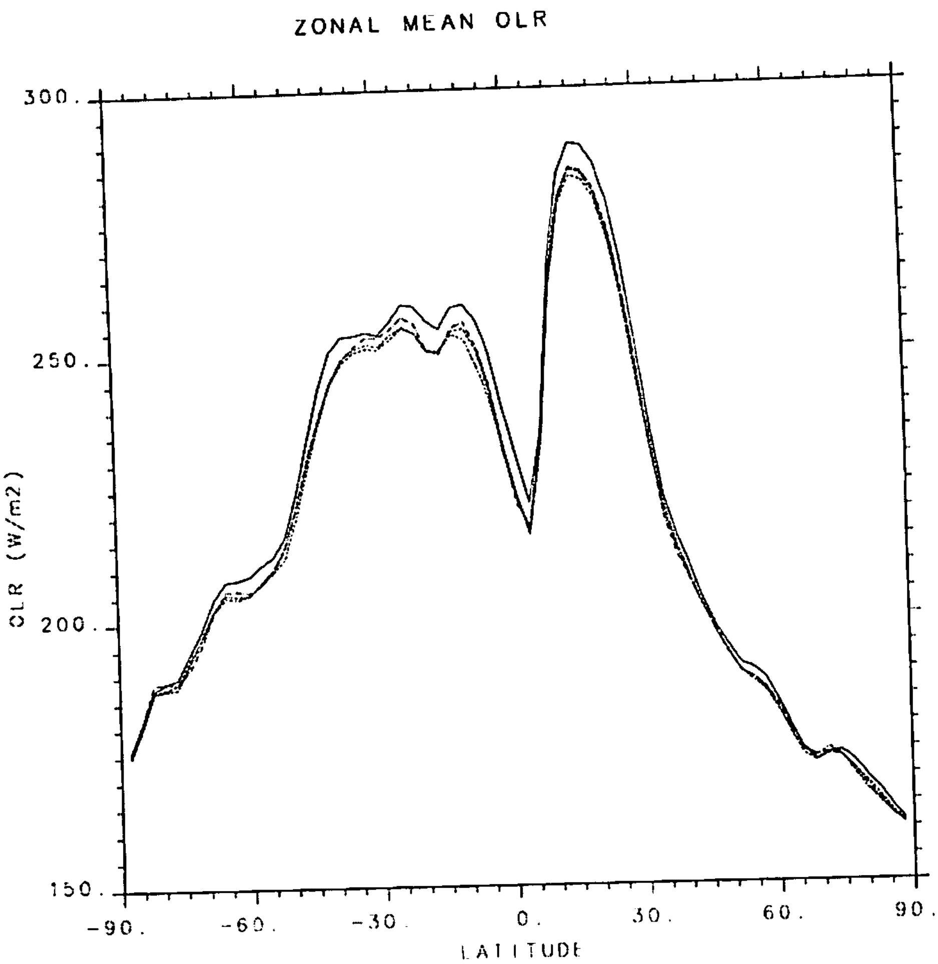

Figure 34. GCM zonal mean OLR for P1 (solid line), P2(dash-dotted), P2b (dashed) and P3 (dotted).

2K and high latitude lower tropospheric warming of around 1.5K between P2 and P1. This decrease in static stability causes an increase in the strength of the Hadley circulation of about 10% and increases in mid-latitude eddy fluxes.

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Comparison of Radiation Schemes

The U.K. Meteorological Office (UKMO) Unified Model (UM) is becoming the model of choice in the UGAMP community, particularly in studies of the impact of the stratosphere on tropospheric climate. Therefore, it is important to know how the recently developed and adopted radiation scheme, the Edwards-Slingo scheme, performs in the stratosphere in comparison with other radiation schemes.

Using standard mid-latitude summer and tropical profiles of temperature, water vapour and ozone, calculations of heating rates in the infrared region have been carried out using the Edwards-Slingo scheme. These results have been compared with calculations with the same profiles but using line-by-line models from GFDL and Atmospheric and Environmental Research Inc., and with a modified Morcrette scheme. Also, the following two methods: 9-band and correlated-K (which are defined using different spectral files in the Edwards-Slingo scheme) were tested. The 9-band scheme was designed mainly for tropospheric use.

The Edwards-Slingo scheme with correlated-k shows (Figure 36) the best agreement with line-by-line results from the ground up to the stratopause (near 1mb); while the 9-band method has a cooling bias of more than 1 K/day in the middle stratosphere. This was expected as the scheme was designed for the troposphere rather than for the stratosphere. The modified Morcrette scheme also agrees well with both line-by-line calculations in the troposphere and lower stratosphere; however, it has a systematic warm bias of more than 0.5K/day for levels above the middle stratosphere (20mb). Further calculations show that this warm bias is due to differences in the way the water vapour heating calculation is carried out in the schemes. Above about 50km in the mesosphere, the modified Morcrette scheme and the 9-band method from Edwards-Slingo produce the best agreement with line-by-line results, while there is a systematic warming bias of more 0.6K/day using the correlated-k method – this is mainly due to a bias in the calculations of CO_2 heating and may be corrected by the generation of a new spectral file with more terms in the correlated-k fitting function. Work to remedy this is currently under way.

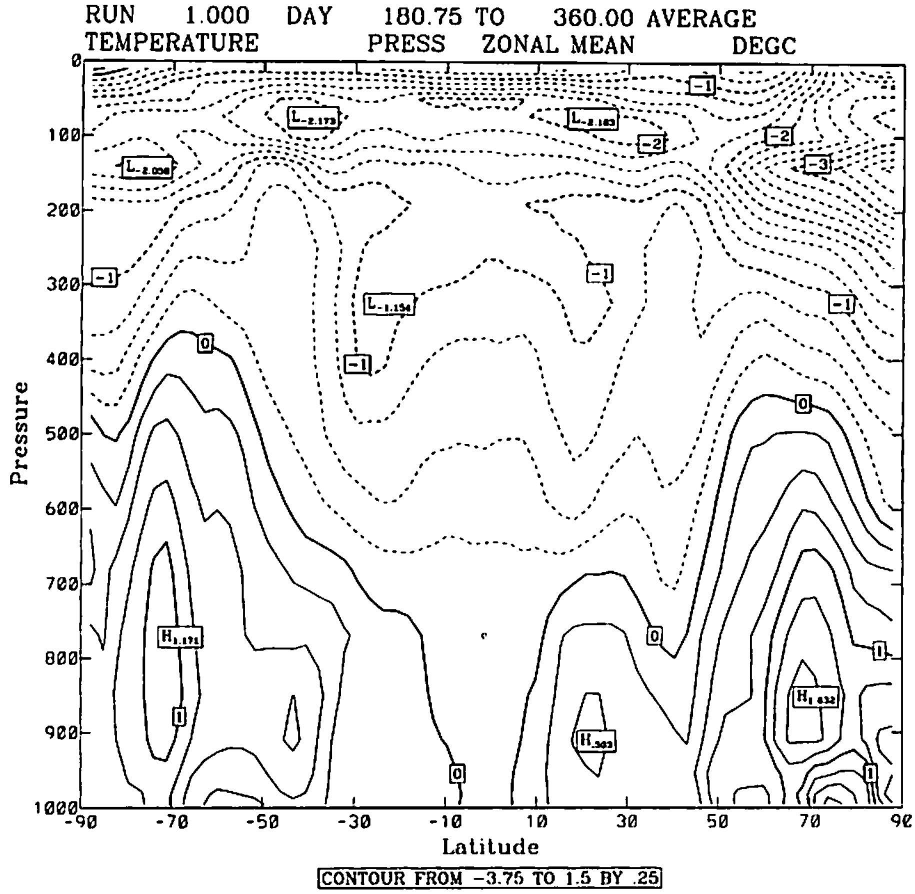

Figure 35. GCM difference in zonal mean temperature between P2 and P1.

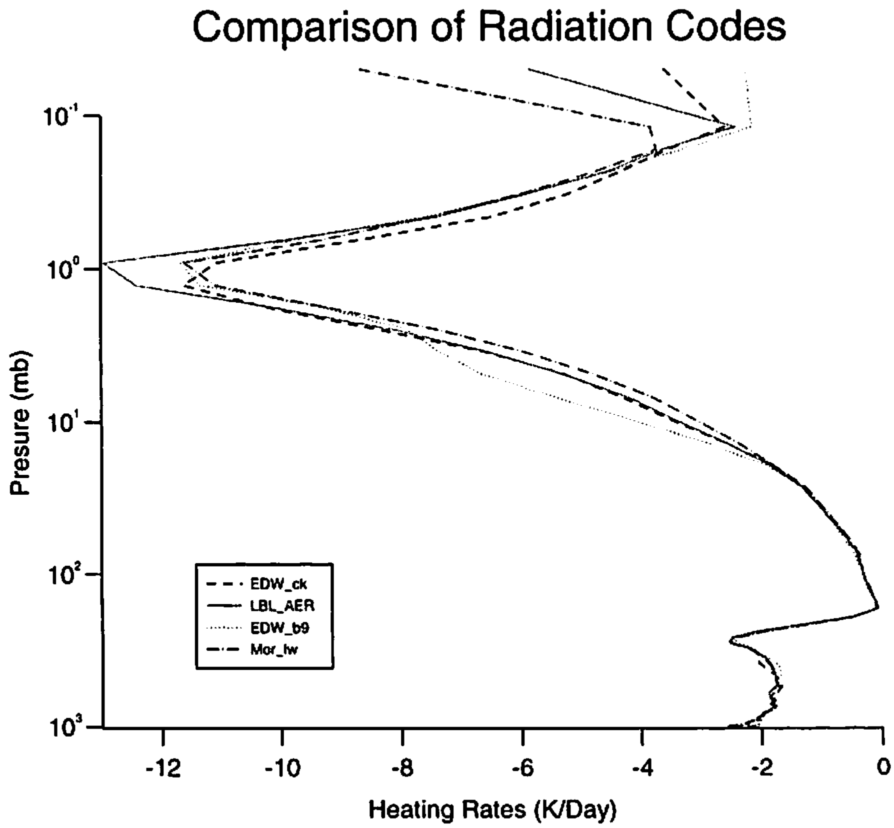

Figure 36. Comparison of radiation schemes.

In the solar heating short wave region both the Morcrette and the Edwards-Slingo 6-band scheme give very similar heating rates from the ground up to about 70km; they differ above this level because the absorption by oxygen is not considered in the Edwards-Slingo scheme, but is considered in the modified Morcrette scheme.

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COMPUTING, DATA AND WORLD WIDE WEB NEWS

Issue No. 18

November '97

National High Performance Computing (HPC) Facilities

Introduction

This year has seen the introduction of interim upgrades for both the HPC services at RAL and EPCC. NERC has procured a Fujitsu VPP300 to supplement the Cray J90 service at RAL and EPSRC and NERC have bought a Cray T3E to supplement the Cray T3D service at EPCC. The process of replacing all these facilities, HPC97, is now well underway and is on schedule to provide a new service in late 1998.

Fujitsu VPP300

NERC has procured a 3 processor Fujitsu VPP300, which has a peak speed of 2.2 Gflops and a memory of 2 Gbytes per processor. This new machine, called fuji, is to provide a much needed enhancement for all NERC HPC users. Apart from the fact that each processor of this vector parallel machine is at least 5/6 times faster than a single J90 processor, it is important for you to try porting your codes to this new machine for the following reasons. First, we cannot increase the UGAMP allocation on the J90 for April 1998 to March 1999, as NERC's allocation is already at its maximum of 30% of the machine. Secondly, the J90 will be turned off in July 1999 and so you need to consider the portability of your codes. It certainly has proved an interesting and well worthwhile exercise getting UMAP to run on fuji using both 32 bit and 64 bit arithmetic and producing UTFs, DRS and NETCDF files. Finally, the accounting mechanism used by RAL will be installed on fuji by December 1997 and the normal NERC allocation procedure will be in place by April 1998, so use the new machine now while it is effectively 'free'.

Cray T3E

EPSRC, together with a small (10%) contribution from NERC, have procured a Cray T3E with 112 application processors and 8 command processors. These command processors act like a front end machine in that they run all the compilers, editors and login shells etc. The T3E application processors have more memory and a bigger cache than the T3D processors and they are about 4 times faster. The T3E at Edinburgh is not yet in its final configuration and there are still some teething problems, but from tests I have run it is going to provide a useful addition to the National HPC facilities.

HPC97

HPC97 is the name of the project to procure a new National HPC service with the possibility of using PFI, Private Finance Initiative. Information about the progress of HPC97 can be found on the EPSRC web page http://www.epsrc.ac.uk/hpc/hpc97/.

UGAMP has an active role in this project as I am on the HPC97 Project Working Group (PWG) who, as the name implies, do all the work of preparing documents and carrying out the evaluations etc. Alan O'Neill is a member of the HPC97 steering panel, who ensure that the Research Council's interests are satisfied by the recommendations of the PWG.

The aim of HPC97 is that a new National HPC Service should be in operation by the end of 1998. There still remains a strong possibility that a second service could be procured a few years after that.

Conclusion

The application for the April 1998 to March 1999 UGAMP allocation on both the Fujitsu VPP300 and the Cray J90 needs to be ready by December 1997. If there are any special UGAMP HPC requirements, then please contact me. The allocation procedure for the Cray T3D and T3E is different in that there is an inter research council allocation panel that determines the 6 monthly group allocations, which are then divided into 2 month 'use it or loose it' chunks. I prepare 6 monthly reports for this allocation panel reporting on work done on the T3D and T3E and justifying the new allocation requested so again, if there are any special UGAMP requirements, then please contact me as soon as possible. The whole HPC allocation procedure is currently under review and it is likely to be changed for the new HPC service. I would also welcome any comments you have about any aspect of HPC97.

Lois Steenman-Clark (Reading Univ., CGAM)

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News from the British Atmospheric Data Centre (BADC)

The BADC is NERC's "designated data centre" for the atmospheric sciences and is based at RAL. The past year has been a very busy one - with much of our work concentrated on establishing and improving the access to data from the Met. Office and the ECMWF. An agreement signed last year by the NERC and the Met. Office allows us to make data from the Met. Office available to the scientific community for research purposes. Since then we have built up a considerable archive of meteorological data – the main components being radiosonde and surface synoptic data covering Europe for the period 1990 to the present, and surface climate (daily) measurements for the UK since computerised records began in the late 50's. These data sets are proving extremely popular with our users.
The same data agreement covers access to the ECMWF analysis data and the BADC has an archive of both initialised and uninitialised reanalysis (ERA) data for 1979 – Feb. 1994 in spectral (T106) form. In addition operational data is available at the same horizontal resolution for March 1994 – present and is updated monthly. The majority of the users of these data are UGAMPers working directly from the RAL CRAY, but in a push to broaden the appeal of the ECMWF data to a wider community, we have been working on producing 2.5 degree gridded pressure-level data using the ECMWF's MARSINT software. These data are complemented by the gridded surface fields, and are available on-line for 1991 to the present to coincide with the UARS/ERS missions. Our thanks to Paul Berrisford at Reading for extracting the analyses for us from the ECMWF.
A CD-ROM jukebox has been purchased to provide web-based access to the BADC's collection of 3rd-party data on CD and these data can now be browsed on the web.
For more information about these or other data sets, visit our web pages at http://www.badc.rl.ac.uk/.

Simon Williams (BADC)
Email: s.r.williams@rl.ac.uk

Monthly Mean ERA Data

Full resolution monthly mean ERA data is now available from RAL. Forecast surface, surface, pressure and isentropic level fields are available for each month of ERA (1979-1993) (note that Nov. '81 is not yet available due to corrupted data). Pressure and isentropic level data files each contain 16 fields on 17 levels. Fields such as u, v, PV and diabatic heating are in the dataset. All data is in DRS format.
In addition to the above, 15 year monthly climatologies are also available e.g. jan7993 etc. Soon I will produce individual seasonal means and their climatologies.
I am currently producing pressure and isentropic level monthly mean transient data. There are 17 fields on 17 levels for each of these. To date I have processed from 1979 to mid 1985. Again, when these are complete I will produce climatologies and seasonal products as above.
More information on this data can be found in the RAL Cray directory ~pb8/TNAMES.

Paul Berrisford (Reading Univ., CGAM)
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CGAM web site

The CGAM (Met. Dept., Reading Univ.) web site at http://www.met.rdg.ac.uk/ugamp/ugamp.html has been updated since the last Newsletter. One of the most notable updates is the online version of the UGAMP brochure, highlighting some of UGAMP's achievements during the period April 1992 to March 1997.
Other additions include:

(a) Email groups. The listing of groups and recipients is at http://www.met.rdg.ac.uk/ugamp/contacts/email.html.
(b) A search tool for which groups you are in: http://www.met.rdg.ac.uk/ugamp/search/search.html.

Listings of UGAMP technical, internal reports and published papers are at: http://www.met.rdg.ac.uk/ugamp/publications/publications.html.
Any comments on the web site and its future development are much appreciated.

Andy Heaps (Reading Univ., CGAM)
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Royal Meteorological Society Millennium Conference Web Pages

The Royal Meteorological Society is holding a major international conference in 2000AD to celebrate it's 150th anniversary. The conference will be held at St. John's College, Cambrige from 10-14th July 2000.
The conference is entitled 'Meteorology at the Millennium'.
A set of web pages devoted to the conference are now available at:
http://itu.rdg.ac.uk/rms/conf2000/index.htm
Further details of the conference and an online form for registering for further information are also available.

Glenn Carver
(Millennium Conference Organising Committee)
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UGAMP GROUP NEWS

Issue No. 18

November '97

Cambridge, Chemistry (ACMSU) News

Personnel Changes

Since the last Newsletter in January, there have been a large number of personnel changes in the group. First however, although old news by now, congratulations are due to Martyn Chipperfield who, earlier this year was awarded a 5yr NERC fellowship. The fellowship was awarded for Martyn's proposal to build a chemical transport model extending from the surface into the stratosphere.

We welcome back two familiar faces to the group. Prof. Gerard Jennings visited us early in the year and he is now back for another stay as a visiting scientist. Also, Zoe Stockwell is now back in the group as a post-doc after having completed her Ph.D. in January and working briefly in Holland for the Dutch Met. service. We also welcome back Peter Good, who had to put his Ph.D. on hold after developing RSI. Peter is now able to work with the use of speech recognition software in a near total "hands-off" mode and we hope he is able to complete his Ph.D. successfully. We also welcome back Christos Giannopopulous who had to take a break in his Ph.D. for a brief spell in the Greek armed forces.

Our support programmer and computer graphics guru Owen Garrett left us in the summer for a new job running a new web service for a local publishing company. Owen provided an excellent level of support whilst in the group and his presence is sorely missed (particularly by me!). However, I'm delighted to be able to report that as a replacement, we have appointed Dr. Heng Wang as our new graphics expert. We could not have found someone better qualified for the post as Heng has a Ph.D. in computer graphics and an M.Sc. in atmospheric science! Heng's job will be to promote scientific visualisation and provide computer support. Her email address is: heng@atm.ch.cam.ac.uk.

We have also had to say goodbye to Steve Billett who was working on applying adaptive grid methods to problems of atmospheric chemistry. Steve moved to a new post-doc at Cranfield University. Also, Slimane Bekki finally(!) got a job with the French Met. Service but is on secondment and still works in the group. Kate Searle has now finished her Ph.D. and will leave the group at the end of the year to join the UK Met. Office. Best wishes to her in her new job.

Details of all Centre for Atmospheric Science personnel, including those who've left can be found on the web page:
http://www.atm.ch.cam.ac.uk/cas/cas_members.html.

Recent UGAMP Publications

Carver, G.D., Brown, P.B., and Wild, O., The ASAD atmospheric chemistry integration package and chemical reaction database, Comp. Phys. Comm., **105**, 197-215, 1997.

Chipperfield, M.P, M. Burton, W. Bell, C. Paton Walsh, Th. Blumenstock, M.T. Coffey, J.W. Hannigan, W.G. Mankin, B. Galle, J. Mellqvist, E. Mahieu, R. Zander, J. Notholt, B. Sen, and G.C. Toon, On the use of HF as a reference for the comparison of stratospheric observations and models, J. Geophys. Res., 102, 12901-12919, 1997.

Hansen, G., T. Svenoe, M.P. Chipperfield, A. Dahlback and U.P. Hoppe, Evidence of substantial ozone depletion in winter 1995/96 over northern Norway, Geophys. Res. Lett., 24, 799-802, 1997.

Jacob, D.J., M.J. Prather, P.J. Rasch, R.-L. Shia, Y.J. Balkanski, S.R. Beagley, D.J. Bergmann, W.T. Blackshear, M. Brown, M. Chiba, M.P. Chipperfield, J. de Grandpre, J.E. Dignon, J. Feichter, C. Genthon, W.L. Grose, P.S. Kasibhatla, I. Kohler, M.A. Kritz, K. Law, J.E. Penner, M. Ramonet, C.E. Reeves, D.A. Rotman, D.Z. Stockwell, P.F.J. Van Velthoven, G. Verver, O. Wild, H. Yang, and P. Zimmermann, Evaluation and intercomparison of global atmospheric transport models using 222Rn and other short-lived tracers, J. Geophys. Res., 102, 5953-5970, 1997.

Lary, DJ, Lee, AM, Toumi, R, Newchurch, MJ, Pirre, M, Renard, JB, Carbon aerosols and atmospheric photochemistry, J. Geophys. Res., 1997, **102**, No.D3, pp.3671-3682

Lutman, ER, Pyle, JA, Chipperfield, MP, Lary, DJ, Kilbane-Dawe, I, Waters, JW, Larsen, N, Three-dimensional studies of the 1991/1992 northern hemisphere winter using domain-filling trajectories with chemistry, J. Geophys. Res., 1997, **102**, No.D1, pp.1479-1488

Rex, M., N.R.P. Harris, P. von der Gathen, R. Lehmann, G.O. Braathen, E. Reimer, A. Beck, M.P. Chipperfield, R. Alfier, M. Allaart, F. O'Connor, H.

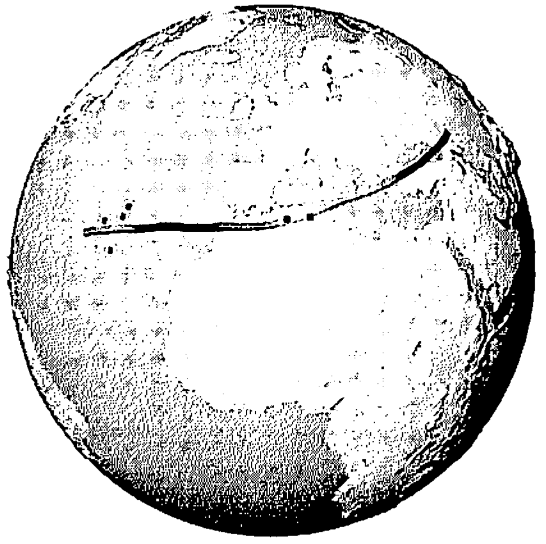

Figure 37.

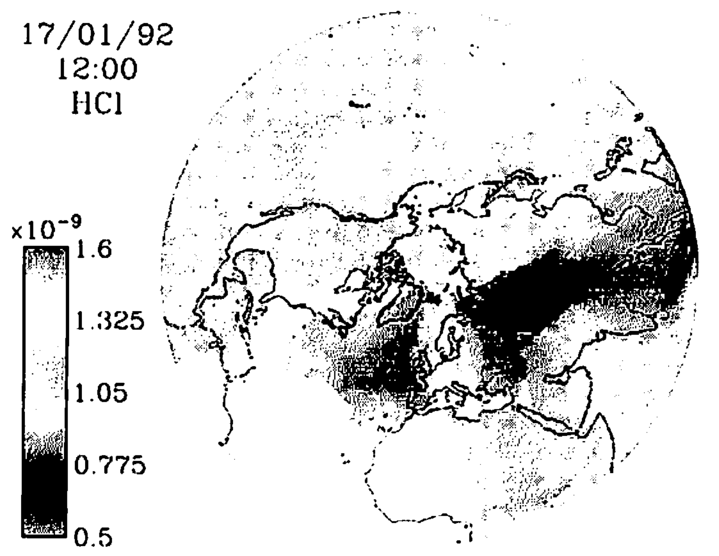

Figure 38.

Dier, V. Dorokhov, H. Fast, M. Gil, E. Kyro, Z. Litynska, I.S. Mikkelsen, M.G. Molyneux, H. Nakane, J. Notholt, M. Rummukainen, P. Viatte, and J. Wenger, Prolonged stratospheric ozone loss in the 1995-96 Arctic winter, Nature, 389, 835-838, 1997.
Stockwell, D.Z., Kritz, M.A., Chipperfield, M.P., and Pyle, J.A., Validation of an off-line 3-D chemical transport model using observed radon profiles — Part II: Model results, Accepted by J. Geophys. Res., September, 1997.

Glenn Carver (Cambridge Univ., Chemistry)
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Cambridge Data Assimilation

Highlights. Good progress has been made towards producing the first ever self consistent analyses of atmospheric constituents. A lot of software, data manipulation, and visualisation software has been written and tested. This progress has been made in spite of the long term illness of one of the key members of our small, 3 person, group.

Overview of work achieved to date.
1. A flexible chemical 4D-Var suite which automatically generates the chemical model, its adjoint, and detailed documentation given a list of required constituents has been completed.
2. The flexible chemical 4D-Var suite has been extended to include bulk phase reactions within sulphate aerosols and cloud droplets.
3. Reactions on sulphate aerosols plays a key role in the chemistry and so ISAMS 12.1μm extinction data has been used to derive the sulphate aerosol surface area.
4. The flow tracking, equivalent PV latitude-theta, coordinate system has been used to generate our initial guess fields.
5. The HALOE instrument is one of the 2 chemical instruments still functioning on UARS and makes valuable measurements of HCl, but only at sunrise and sunset at a very limited range of latitudes each day. The value of these observations has been considerably enhanced by the generating pseudo observations using flow tracking, equivalent PV latitude-theta, coordinate system.

Visualization. Using NAG's Explorer package we are able to rapidly transform the mass of both satellite and model data into meaningful and productive information. The modular nature of Explorer allows each individual process involved in visualising the data to be neatly packaged and reused wherever possible.
A large number of these modules have been written to perform many tasks including importing data files in a variety of formats, gridding and interpolating data, the generation of visual output such as line and surface plots, and the generation of sequences of frames intended for video presentation. Other modules generate coastlines and 3-D world maps, molecule models and allow for the overlaying of graphical images such as logos etc.
For example, we are able to plot parcel trajectories overlaid onto a globe or map. In Figure 37 the trajectory is coloured according to the temperature along it. Nearby satellite observations may also be plotted, in this example they are indicated by the squares.
Figure 38 shows a 2-dimensional projection of our 4D-Var analyses. In this case, however, instead of looking

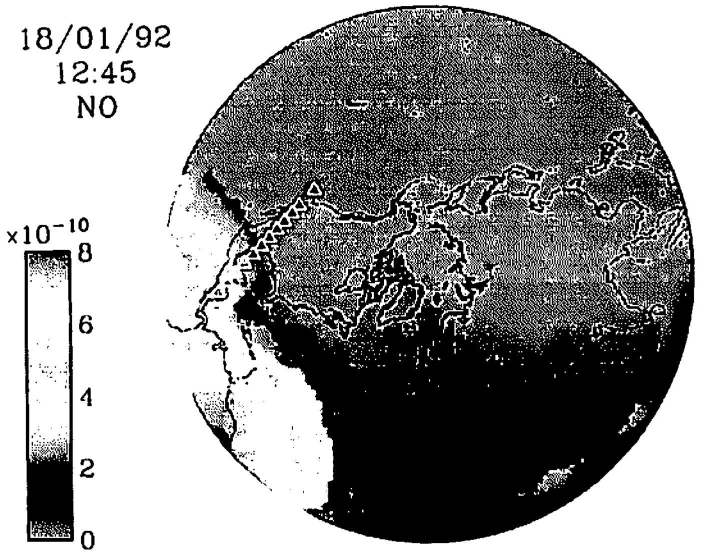

Figure 39.

at the evolution of one air parcel, we see a snapshot of all air parcels at one instant in time. These data points are then 'krigged', or gridded, to produce the smooth, coloured field shown.

In order to compare our analyses with the satellite observations, we can overlay satellite observations. The following two figures (Figure 39 and Figure 40) are examples of such diagrams. The observations are shown as filled triangles; the same colour map is used for both model results and satellite observations.

4D-Var Analyses. Two examples of our 4D-Var chemical analyses for a specie with a very pronounced diurnal cycle, NO, are shown here.

The variety of satellite data available is perhaps only matched by the variety of formats in which it is packaged. In order to make immediate use of the available resources, it is necessary to convert the data into a standard, local format. These files may be read into our chemical 4D-Var scheme as well as our analysis packages. We have developed a small selection of software for use with UARS data that will do precisely this conversion.

The reactions on the surface of sulphate aerosols is being accounted for using aerosol surface areas derived from UARS measurements of aerosol extinction. Using ISAMS 12.1μm data along with water concentration observations and UK Meteorological Office potential vorticity and temperature data these values may be calculated at each point along our model trajectory.

The lack of global coverage of the satellite data means that it is useful to generate what we term 'Pseudo-Observations' using the flow tracking, equivalent PV latitude-theta, coordinate system. These pseudo observations are not direct observations but ones that are interpolated to lie exactly along our model trajectories. The window we use to select observations takes into account the expected variations in the data in each of space, altitude and time. Combining our 4D-Var analyses with the flow tracking, equivalent PV latitude-theta, coordinate system to generate these pseudo observations is expected to be a major step forward in the production of our chemical analyses.

Techniques are being developed to allow the automated analysis of our large data sets in order to produce long term descriptions of various atmospheric features. The polar vortices is one such feature and we hope to extract information on the size of these vortices along with the time of their formation and destruction, and how this impacts on the chemistry.

David Lary (Cambridge, Chemistry)
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Cambridge, DAMTP News

There have been a number of changes to the atmospheric dynamics group at Cambridge since the last newsletter. At present the group members are: Oliver Buhler, Kieran Chawdhary, David Dritschel, Michael Greenslade, Stephen Griffiths, John Hampson, Peter Haynes, Sai-lap Lam, Michael McIntyre, Ali Mohebalhojeh, Nicholas Pinhey, David Poet, David Sankey, Emily Shuckburgh, Alexander Stegner, David Tan, Jurgen Theiss, Jacques Vanneste, and Chris Warner. Nicholas Pinhey will be leaving us very shortly to work in the business computing world. We have a new student David Poet and a new Postdoctoral research scientist Jacques Vanneste who are both working on mixing. Alexander Stegner is working with David Dritschell on instability and

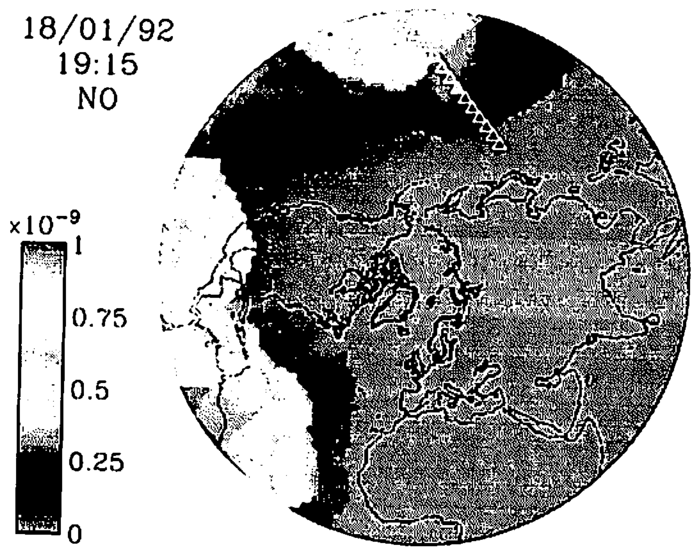

Figure 40.

interactions between isolated large scale vortices, investigated using the CASL f-plane shallow-water algorithm.

We will shortly be joined by Claude Souprayen (a new Postdoctoral research scientist) from the Service d'Aeronomie in France, and by Karine Sartelet (a new student) who will both be working on the EC research contract: The Impact of Gravity Waves on Climate (IGWOC). IGWOC will run for three years and is a collaborative research effort involving the Max Planck Institut für Meteorologie in Hamburg, Germany the University of Oxford, the Laboratoire de Météorologie in Paris, France and the Service d'Aeronomie in Paris, France.

Atmospheric Gravity Waves

Work is proceeding on an ultra-simple spectral gravity wave parametrization for use in global circulation models (GCMs). The parametrization has been successfully tested in a single column model using climatological winds and temperatures. The parametrization has been optimised for speed to permit full GCM runs to be carried out. Early results using the EUGCM were reported at the UGAMP conference. Work is now proceeding on an implementation of the ultra-simple parametrization suitable for use in the Met Office's Unified Model. This implementation is being developed in collaboration with the Met Office; both the Hadley Centre and the Physical Processes Division are interested and have offered practical assistance including the possibility of carrying out test runs at Bracknell. A paper describing the ultra-simple spectral gravity wave parametrization will shortly be submitted to the Journal of Atmospheric Science.

We are developing our own version of the Hines gravity wave parametrization. Our version of the Hines parametrization and our ultra-simple parametrization have been compared in a series of single column tests. The two parametrizations behave somewhat differently in that the ultra-simple parametrization deposits gravity wave pseudomomentum flux over a wider range of altitudes than the Hines parametrization. A version of the Hines parametrization suitable for use in the Unified Model is also being developed.

As mentioned above, there will be a considerable expansion in gravity-wave related research effort at Cambridge starting in November 1997. Two new research scientists join the group to work on the EC-funded IGWOC contract and simultaneously I begin a three year NERC-funded research project to develop more realistic gravity wave propagation models that will permit detailed comparisons with observational data.

Chris Warner (Cambridge Univ., Applied Maths.)
Email: cdw13@damtp.cam.ac.uk

[An article by Emily Shuckburgh was received too late to be included here. Please see the web edition for the article. Ed]

Nicholas Pinhey departure

As I am just about to leave DAMTP, having rediscovered the real world out there, I'd just like to say "Goodbye and thanks for the experience" to all those UGAMPers whom I've had the pleasure of working with over the last 5 years. I'm actually going to be working for Motiv (http://www.motiv.co.uk), an internet consultancy company here in Cambridge, so if you want any serious web pages, security issues,... Oh yes, and if there are still any users of xtumap and you want further upgrades, you'll have to hassle Roger Brugge about it.

Nicholas Pinhey (Cambridge Univ., Applied Maths.)
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Edinburgh News

Personnel Changes

We welcome Vicky West who has joined the Meteorology department as a postgraduate student working on trends and interannual variations in stratospheric composition, initially with a 2-D model but probably moving on to a UGAMP 3-D model.

Recent Publications

Mote, P.W., P.A. Stott and R.S. Harwood, Stratospheric flow during two recent winters simulated by a mechanistic model, Mon. Weather Rev., in press. 1997.

Ian MacKenzie (Edinburgh)
Email: iam@met.ed.ac.uk

Oxford News

Welcome to Paul McCloghrie, who has just started with us as a NERC D.Phil. student. He will be looking for patterns in the long term variation between the troposphere and stratosphere over the northern hemisphere in winter, using monthly mean data and the Unified Model.

Maisa Rojas Corradi, a D.Phil. student from Chile, is studying travelling planetary waves in the middle atmosphere. Some of these waves are thought to be initiated by instabilities of the mean flow. To study this possibility, an instability analysis is performed, using the primitive equations linearized about a zonal-mean state. The flow is perturbed and eigenvalue calculations give us the fastest growing mode. So far a one-dimensional code has been tested, and a two-dimensional version is currently being developed.

Sophia Oliver (NERC D.Phil. student) has been using the linear tidal model of Wood and Andrews (1997) to simulate diurnal and semidiurnal tides in the middle atmosphere. Comparisons have been made with tidal simulations made by Warwick Norton using the (nonlinear) UGAMP EUGCM. Some structural similarities are apparent between the linear and nonlinear model simulations of the diurnal tide, but none are obvious for the semidiurnal tide. This may be because of differences in the thermal forcing between the models. The forcing mechanisms in the models are therefore being adapted to conform more strictly with each other. Comparisons with observational data are planned. A long-term aim is to study the extent to which linear approximations can be used in tidal simulations.

Alan Iwi (UGAMP D.Phil. student) is investigating the influence of extratropical warmings on tropical dynamics and transport in the middle atmosphere. Several stratospheric warmings are simulated in perpetual January runs of the UKMO Stratosphere-Mesosphere Model, and the model shows that diabatic ascent, inertial instability and barotropic instability are all enhanced at low latitudes during these warmings. The effect on equatorial material transport is being investigated using the SLIMCAT chemical transport model.

Euain Drysdale (NERC D.Phil. student) is forcing equatorially confined waves in a version of the UKMO Stratosphere-Mesosphere Model. These waves drive mean-flow accelerations in the zonal wind over the equator and, under the right conditions, can create an oscillation resembling the equatorial Quasi-Biennial Oscillation. The model at present is being modified in several areas. The vertical resolution is being increased from 1km to 500m and a more realistic background state is being introduced. It is hoped that a realistic quasi-biennial oscillation can be forced in the model and the variability in this QBO will be investigated.

Warwick Norton has an article on TOPOZ II elsewhere in this issue. Among several other things, he is using the Unified Model to study climate variability associated with changes in tropical and extratropical SSTs.

David Andrews has completed a first draft of his undergraduate textbook 'An Introduction to Atmospheric Physics', which is to be published by Cambridge University Press. He, Jim Holton and Conway Leovy are considering bringing out a new edition of 'Middle Atmosphere Dynamics', first published ten years ago. Some constructive comments on this proposal have already been received from UGAMP colleagues – any further comments will be welcome!

David Andrews (Oxford Univ.)
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Reading News

CGAM News

Headline news from Reading is John Thuburn's appointment as a lecturer in the Department from January 1998. Congratulations to John, who is one of UGAMP's longest serving members, having moved to Reading from Oxford in 1988. John intends to concentrate on his research on numerical techniques and remain very much an active part of UGAMP.

This year has seen two new UGAMP Principal Investigators among the teaching staff at Reading. Chris Thorncroft's research concentrates on the climate and weather systems of West Africa and the tropical Atlantic, and he is currently coordinator of an EU funded project in this area. David Marshall's research is in large scale oceanography, with particular interests in western boundary currents.

From somewhat further afield, Steve Jewson arrived recently from Melbourne to work on the coupled modelling project, and Bernd Becker, who travelled the rather shorter distance from ECMWF, is working on monsoon variability in the SHIVA project, with the added goal of a PhD. We also welcome Dr. Satyan to work on the Asian Monsoon, on a 6 month visit arranged through the British Council Link Programme with the Hadley Centre. He is Deputy Director and Head of the Climate and Global Modelling Division at the Indian Institute of Tropical Meteorology in Pune, India.

Some familiar faces have moved on this year. Dave Knowles is still to be seen running around campus in record beating times, while Mark Rodwell has moved to the Hadley Centre, working with Dave Rowell in Chris Folland's group. Anna Ghelli left in January to work for the Italian Meteorological Service and Valentina Pavan also returned to Italy, to continue her research in Bologna.

The Department has seen a large number of students completing their PhDs this year. Congratulations to Jake Badger and Steve Woolnough, who are now PDRAs in the group, Jake working on the development and use of the Reading spectral model as an intermediate GCM, and Steve working on the Intraseasonal Oscillation and its role in seasonal predictability.

In addition to Steve, two more of Ian James' students have completed, Ian Homer and Gareth Hesford. In the palaeoclimate area, Dave Cameron is soon to join the UK Met. Office to work on data assimilation and Paul Markwick has moved to Robinsons Exploration Consultants.

The new term has seen the arrival of several new PhD students. Chris Hewitt is an external student with the Hadley Centre, working on coupled simulations of the last glacial maximum; Graham Gladman is working on coupled modelling of the North Atlantic, and Leon Barry is working on the tropopause and the temperature structure of the extratropical troposphere.

The Department has recently begun a cooperation agreement with the Chinese Academy of Sciences, comprising visits and collaborative research with scientists in the Institute of Atmospheric Sciences in Beijing.

Mike Blackburn (Reading Univ.)
Email: mike@met.rdg.ac.uk

"Low frequency" group at Reading

Our small group is largely concerned with the internal variability of the midlatitude flow, and with matters which relate to this. We are particularly interested in the mid-latitude storm tracks, their effects on low frequency variability and some of the factors which make the storm tracks themselves variable.

U. Burkhardt has been studying internal variability of storm tracks in analyses and the SGCM. She is reporting on some of her work separately in this issue.

G. Garric is studying the impact of sea ice on the development of baroclinic disturbances in the Southern Hemisphere. There is the prospect of very strong feedbacks between the distribution of sea ice and synoptic scale weather systems. Even changing a

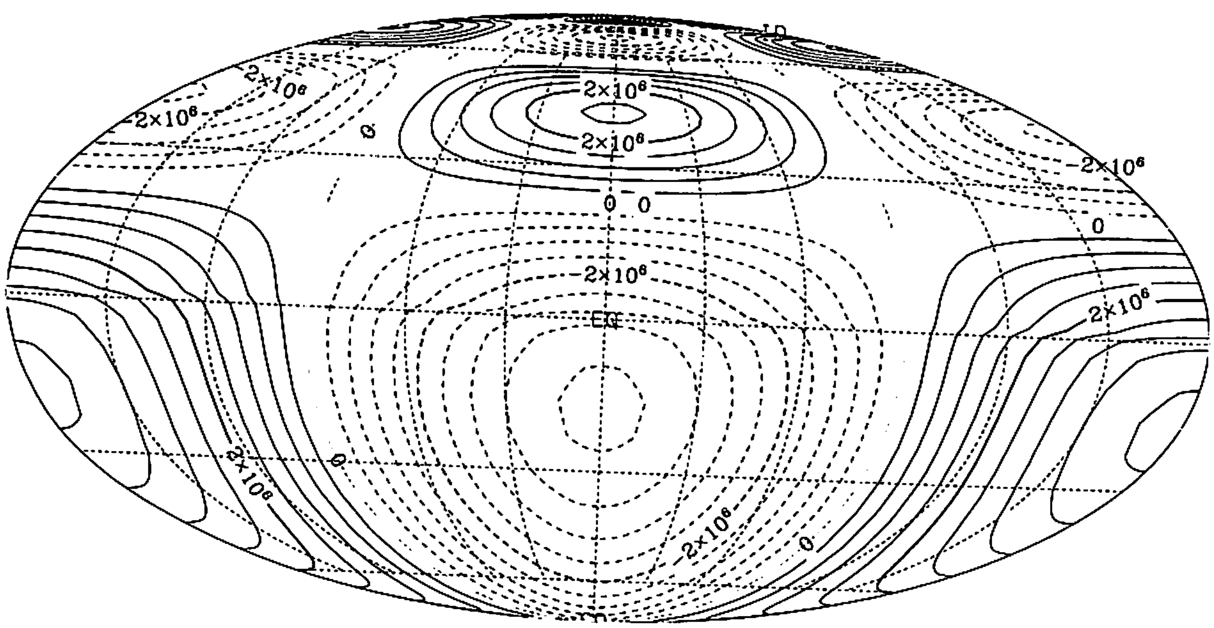

Figure 41. The projection of the stretched-grid stream function (Rossby Wave) onto a regular grid. 48% of the model grid points are located south of 60 degrees South.

small fraction of a sea ice field into open water can increase the heat flux into the atmosphere by an order of magnitude or more. Our project is to gain a clearer understanding of the nature and range of magnitudes of the feedbacks between sea ice cover and atmospheric weather systems. We are currently using a "simplified" global circulation model (SGCM) in which a sophisticated dynamical scheme is married to idealized representations of friction, heating and of sea ice dynamics. The current step consist of introducing co-ordinate transforms in order to increase the resolution of the Antarctic regions in the model. The mapping is a magnification of the sphere where the stretching pole is the South Pole (see Figure 41).

S. Hare is looking into the possibility that midlatitude baroclinic instability in the middle latitudes might be significantly affected by the presence of meridional circulations. On the mesoscale, such circulations are known to have an important effect on the formation of frontal waves and secondary cyclone centres. Meridional circulations are particularly strong at jet entrances and exits and may be related to tropical features such as regions of enhanced convection.

A. Scaife of the UK Meteorological Office is working with our group on the inter-annual variability of the stratospheric circulation. Troposphere variability such as ENSO provides interannual variability in steady planetary waves near the tropopause and may affect the occurrence of sudden stratospheric warmings. Figure 5 (see colour figure on page 2) shows zonal mean wind near 60N as a function of height and time in a primitive equation model of the stratosphere under perpetual January conditions: an irregular series of major stratospheric warmings occurs with an average period of about 40 days. However, if the wave amplitude is reduced by 100m to represent a relatively undisturbed year, then the time between consecutive warmings more than doubles.

A. Valente is studying mesoscale flow over mountains with a view to improving gravity wave drag parametrizations, particularly over Antarctica. Stratified flow over mesoscale orography originates gravity waves that propagate upwards. For flows with directional shear, the vertical propagation of these waves and the surface drag are modified when non-linearity becomes important. The parametrization of these effects in synoptic and large scale models hasn't been taken into account so far, and could be especially relevant in the Antarctic region where the wind backs sharply with height in the boundary layer. Directional shear in a layer with depth comparable to the orography's height reduces the intensity of downslope windstorms. On the other hand, it can enhance vertical wave propagation for sufficiently high mountains. Several experiments are being performed with a mesoscale model to assess these effects of directional shear (Figure 47: see colour figure on page 60)

I.N.James, U. Burkhardt, G. Garric, S. Hare, A. Scaife & A. Valente (Reading Univ.)
Email: I.N.James@rdg.ac.uk

Transport and Mixing in a Shallow Water Simulation of the Lower Stratosphere

In newsletters 12 and 14 I described a shallow water model based on advection of potential vorticity (PV) on a hexagonal-icosahedral grid. The use of PV as a prognostic variable, combined with the use of schemes designed to avoid numerically generated noise, facilitates the calculation and interpretation of PV-based diagnostics, such as PV maps and conserved integrals within and around PV contours. Here I present one example of the use of such diagnostics to examine transport and mixing in a simulation of the lower stratosphere.

The simulation consists of an initially zonally symmetric cyclonic vortex disturbed by a lower boundary zonal wavenumber 1 forcing of amplitude 720m. Over the 60 days of the simulation several anticyclones form in the "surf zone", fed by tongues of low latitude low PV air, and several tongues of high PV air are stripped from the edge of the vortex.

The mass of air within the PV=Q contour, $\mathcal{M}(Q) = \int_{PV>Q} h dA$, would be conserved in adiabatic frictionless flow. Graphs of $\mathcal{M}(Q)$ versus time for various PV contours show unambiguously and quantitatively several features, most of which are well known: shrinking of the main vortex; sharpening of the vortex edge; sharpening of PV gradients in the subtropics; and increasing mass in the surf zone.

The cross-contour mass flux $\mathcal{V}$ is also of interest. It is associated entirely with irreversible processes like friction, diabatic heating, and small scale mixing. It can be calculated as a residual in the mass budget for a PV contour.

Figure 42 shows $\mathcal{V}$ calculated in this way for nine PV contours. Contour (1) is nearest the equator while contour (9) is nearest the middle of the vortex. It shows several interesting features, many of which contrast dramatically with more traditional measures of mean transport such as the mass-weighted zonal mean northward velocity $\bar{v}^*$. The cross-contour transport $\mathcal{V}$ is episodic: it occurs in events of typically 3-5 days duration — some of the larger events are highlighted in the figure. Events of both signs occur, though those near the vortex edge (contours (6) and (7)) are predominantly negative (i.e. mass flow towards lower PV) while those in the subtropics (contours (1) and (2)) are predominantly positive. In other words,

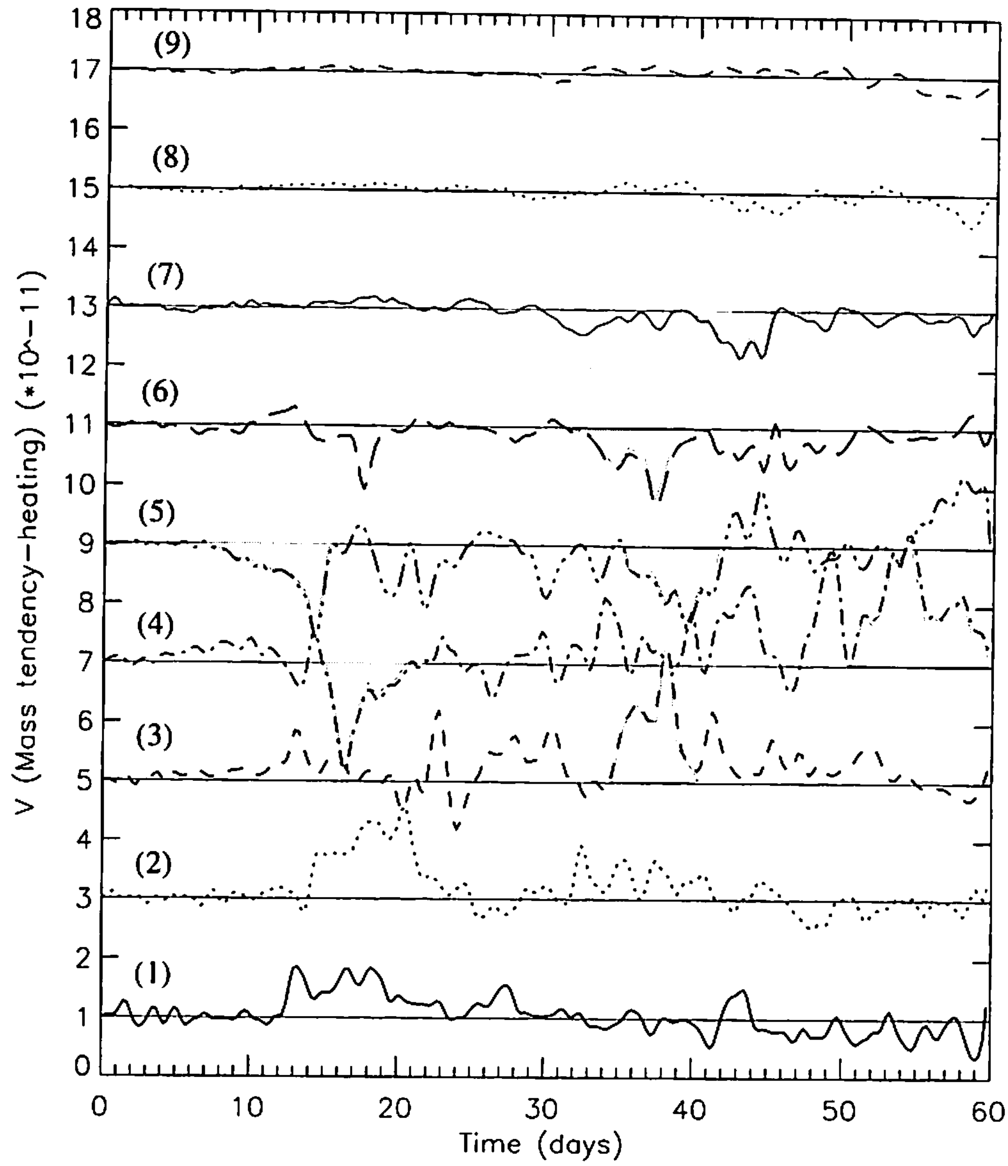

Figure 42. Cross-PV-contour mass flux $\mathcal{V}(Q)$ for nine PV contours. The zero for each curve, indicated by a solid straight line, is offset along the $\mathcal{V}$-axis for clarity. Some of the larger transport events are highlighted by shading.

there is net entrainment into the surf zone from both sides. In the interior of the vortex (contours (8) and (9)) there is little cross-contour transport. Inspection of daily PV maps reveals that most of these transport events appear to be associated with synoptic events: positive transport with tongues of low PV air feeding anticyclones; negative transport with tongues of high PV air stripped from the vortex edge. The net transport out of the vortex can be quantified using these diagnostics; it turns out to be a small fraction (less than one half) of the mass of the vortex. This is consistent with other estimates based, for example, on contour advection calculations, and is inconsistent with the version of the "flowing processor" hypothesis that requires several vortex masses to be transported horizontally out of the vortex during the course of the winter. These transport events are intimately associated with small scale mixing of PV and, therefore, with small scale chemical mixing. The possible implications of these results for the chemistry of ozone depletion, including midlatitude ozone depletion, have yet to be worked out.

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Recent Reading Publications:

Dong, B.-W. and James, I.N., 1997: The effect of barotropic shear on baroclinic instability. Part I: Normal mode problem. *Dyn. Atmos. Oceans*, **25**: 143.

Dong, B.-W. and James, I.N., 1997: The effect of barotropic shear on baroclinic instability. Part II: The initial value problem. *Dyn. Atmos. Oceans*, **25**: 169.

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ıank, R., C.S. Douglas, W.A. Lahoz, D. Podd, A. ·, and W. Norton, 1997: The stratosphere-phere configuration of the UK Meteorological : Unified Model. *Proceedings of the First C General Assembly*, WMO/TD No. 814, 67-70.

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ıerford Appleton Laboratory News

ırd Kennaugh, who was employed through the ıMP Special Topic on the variability of the sphere has completed his project and has recently ɛd to Imperial College. His work on the inter-al variability of the stratosphere associated with ıuasi-biennial oscillation (QBO) went extremely and produced 4 published papers*. These ded both observational studies using satellite rvations of tracer species from UARS and ɛlling to interpret the distribution of the tracers he processes that influence the distributions. This has improved our understanding of the formation ‹ the observed 'double peak' in tracer species, tl influence of the QBO in the upper and mi stratosphere and the factors that determine trac distributions in the lower stratosphere subtropics, tl latter being the subject of much current interest. V were extremely sorry to see Richard depart and wi him well. His work will be continued, howev through a successful response-mode funded gr entitled 'the internal variability of the stratosphere a implications for the detection of climate change'.

* Ruth, Kennaugh, Gray and Russell, 1997. Seaso semiannual and interannual variability seen measurements of methane made by the UA Halogen Occultation Experiment. To appear ir Geophys. Res.

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Contour lengthening rates near the trop pause

In a paper recently accepted for publication Geophys. Res. Lett. we present the results of conto advection calculations using winds derived from t UK Universities Global Atmospheric Modelli Programme (UGAMP) model. Contours are initialis using PV values on a set of potential temperatu surfaces which span the stratosphere and tropospho in order to examine the mixing properties stratospheric and tropospheric air on a timescale o few days. We show that the contour stretching rates not convey any information about the location of tropopause, although the lower layers of stratosphere are vigorously mixed with troposphere over this time. The results suggest that stratosphere becomes more isolated from troposphere with increasing potential temperatu with mixing confined to a narrow region in subtropics at the higher levels (greater than 330K).

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MEETING REPORT

EuroGRIPS Meeting Report (28-29 August 1997, Reading U.K.)

First, the status of the GCM-Reality Intercomparison Project for SPARC was discussed. The temperatures from the GRIPS datasets have been compared with ECMWF data at 100 hPa. and, in the zonal mean, the models generally show a cold bias at both poles. S. Beagley (Canadian Middle Atmosphere Group) will co-ordinate a series of gravity wave drag experiments, and U. Langematz (FU-Berlin) will co-ordinate a radiation scheme comparison.

Afterward, the status of the Unified Model (UM – used by the UKMO and CGAM, Reading), the ARPEGE model (used by CNRM, at Meteo-France Toulouse), and the FU-Berlin (FUB – used by the FU of Berlin) model were discussed

The behaviour of the planetary waves, stratospheric warmings and southern hemisphere vortex mergers in a recent 5-year run from the UM were discussed and it was shown that, in general, the model behaved in a realistic manner by comparison with the UKMO stratospheric analyses. Other activities which were discussed were stratospheric predictability, the impact of changing the radiation scheme (the HADAM2b version of the model described at this meeting, which does not use the Edwards-Slingo scheme, has a cold bias in the stratosphere), the intercomparison of radiation schemes, and the impact of changing the vertical resolution. For details of the forthcoming AMIP II run, also discussed at the meeting, see the article by Colin Jones.

The behaviour of a recent version of the ARPEGE model was discussed. It was shown that features such as the shape of the jet and the tropopause temperature were improved with respect to a previous version. The model has a cold bias at both poles (similar to that in the UM, but slightly stronger), and the south pole time series in the model has (unrealistically) a major warming event. Other future activities include implementing a semi-Lagrangian scheme, and an improved gravity wave drag scheme, and incorporating an interactive ozone scheme in the model. CNRM will carry out an AMIP II integration with a semi-Lagrangian scheme.

Some recent changes in the FUB model were described. The radiation scheme has changed and as a result, the polar warm bias in the model has disappeared (the FUB model was, seemingly, unique in having a warm bias at the pole – now the model has a cold bias). A series of ozone climatologies were compared using the new version of the model, and it was found that the model was quite sensitive to changes in the ozone distribution. Other activities include the development of a semi-Lagrangian scheme, changing the vertical resolution, and preparing for an AMIP II integration with the Hamburg MPI ECHAM4 model.

It is hoped that two reports, one on stratospheric warmings and another on tropical waves, will be produced by March 1998 in time for the next GRIPS meeting, due to be held at NASA Goddard Space Flight Center (NASA GSFC).

More details about the EuroGRIPS meeting in August 1997 can be found in:
http://www.met.rdg.ac.uk/~wal/eurogrips97_mtg1.html

Details of the GRIPS meeting held in Berlin during March 1997 can be found in:
http://www.met.rdg.ac.uk/~wal/grips.html

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UGAMP Affiliated Sites

University of Reading, Department of Meteorology (CGAM)
University of Cambridge, Department of Chemistry (ACMSU)
Rutherford Appleton Laboratory
University of Cambridge, Department of Applied Mathematics and Theoretical Physics
University of East Anglia, School of Environmental Sciences
University of Edinburgh, Department of Meteorology
University of Leicester
University of London, Imperial College, Department of Space and Atmospheric Physics
Southampton Oceanography Centre

Acronyms

ACMSU......Atmospheric Chemistry Modelling Support Unit, Centre for Atmospheric Science, Chemistry Department, Cambridge University.
ACSOE......Atmospheric Chemistry Studies in the Oceanic Environment; a NERC funded programme.
AMIP........Atmospheric Model Intercomparison Project; a programme to compare the performance of General Circulation Models.
BADC.......British Atmospheric Data Centre.
CGAM.......Centre for Global Atmospheric Modelling, Meteorology Department, University of Reading. The coordinating centre for UGAMP.
CTM.........Chemical Transport Model. Often called an 'offline' model, it uses previously analysed or computed winds and temperatures to model the chemistry of the atmosphere.
DAMTP......Department of Applied Mathematics and Theoretical Physics, University of Cambridge.
ECMWF......European Centre for Medium Range Weather Forecasts, Reading, UK.
ERA.........ECMWF Re-analysis data, covering the period 1979-1993.
GCM........Global Circulation Model.
IFS..........Integrated Forecasting System of ECMWF.
ISAMS.......Improved Stratospheric and Mesospheric Sounder.
JDP..........The Joint Diagnostics Project. A partnership between the UGAMP and the UKMO to analyse and distribute atmospheric data.
MJO.........Madden Julian Oscillation.
MOZAIC.....Measurement of Ozone by Airbus In-service Aircraft.
NERC........Natural Environment Research Council
SGCM.......UGAMP's Simple Global Circulation Model.
SMM........The UKMO's Stratosphere-Mesosphere Model.
UGAMP......UK Universities Global Atmospheric Modelling Programme; funded by the NERC.
UGCM.......UGAMP Global Circulation Model.
USMM.......UGAMP Stratosphere-Mesosphere Model.
UKMO.......United Kingdom Meteorological Office.
UM..........The UKMO's Unified Model.

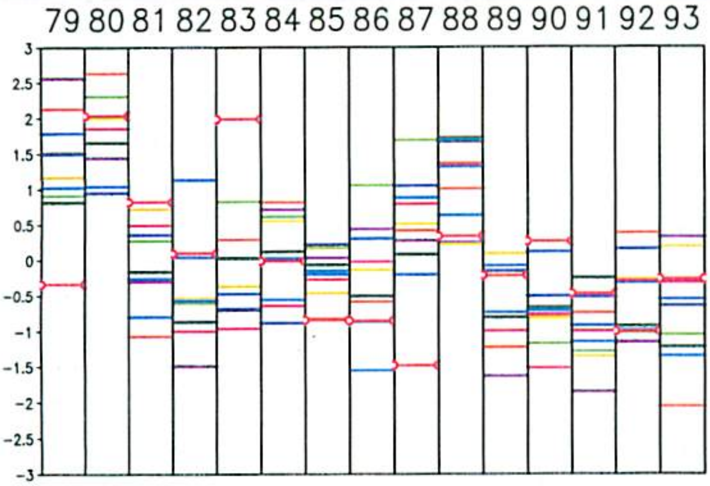
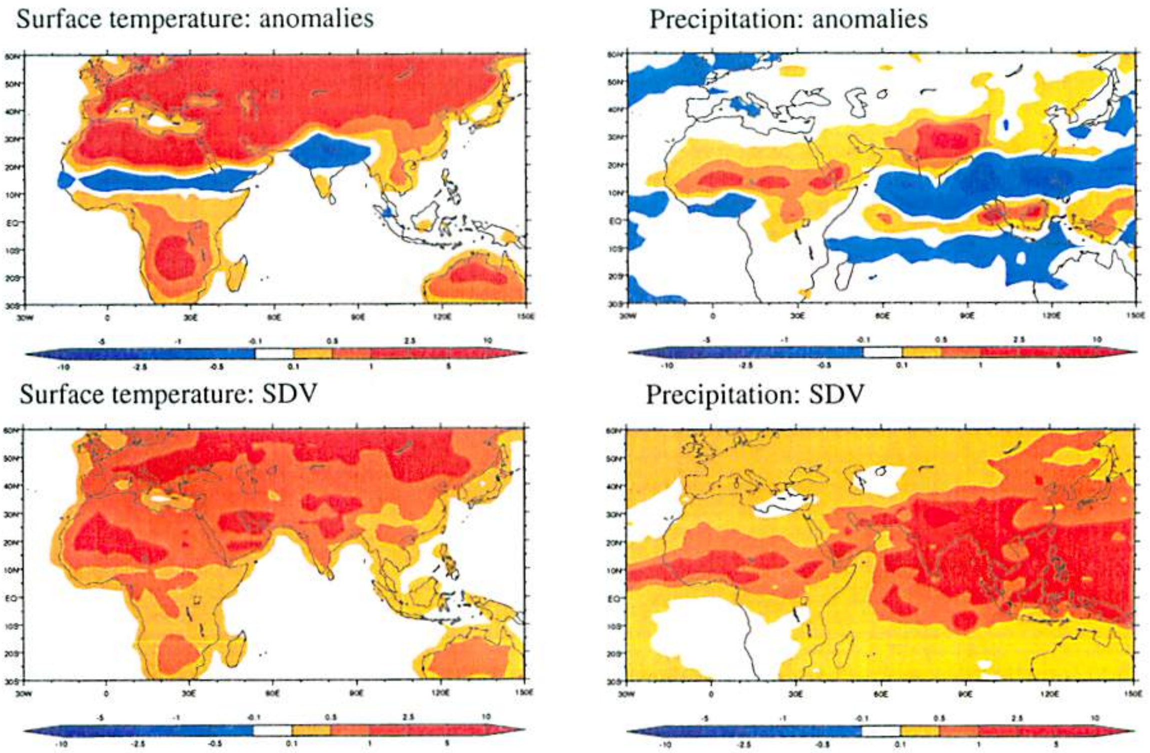
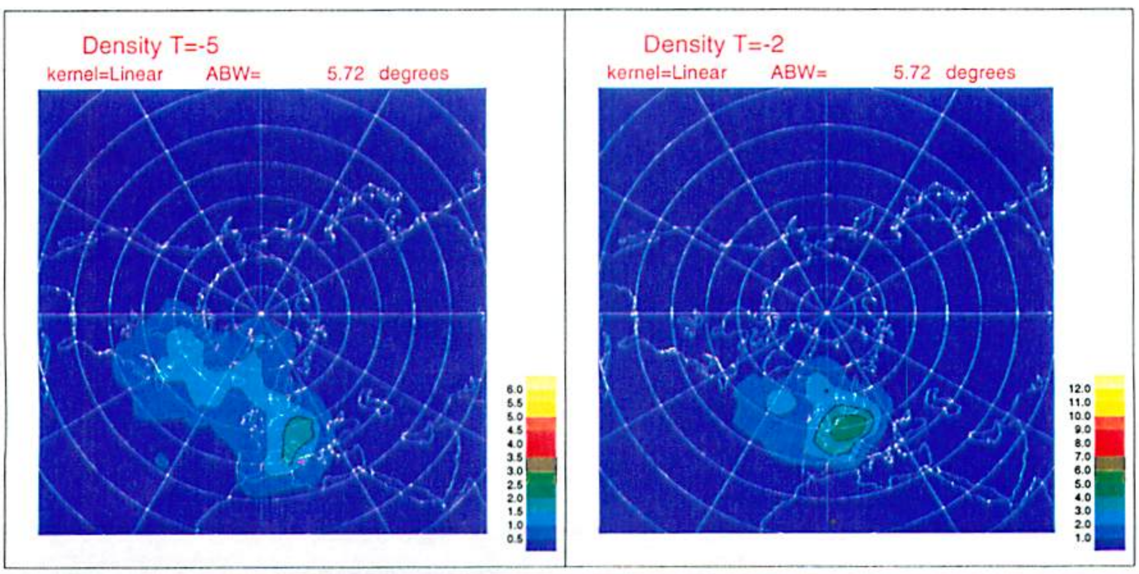


Figure 42. (left) Seasonal mean (June-Sept.) All India Rainfall anomalies, normalized in terms of standard deviation. Coloured bars represent each ensemble member; hooked red bar is ERA. The figure shows the ensemble spread for each year as well as the skill of the ensembles in predicting the actual AIR anomaly, shown here from ERA.

Figure 43. (middle) The 15 model mean of the surface temperature and precipitation anomalies between the 6ka and PD simulations in JJA and the corresponding inter-model standard deviations.

Figure 44. (bottom) the probability densities for air origin at 2 days and 5 days before arriving over Western Europe.





COLOUR FIGURES

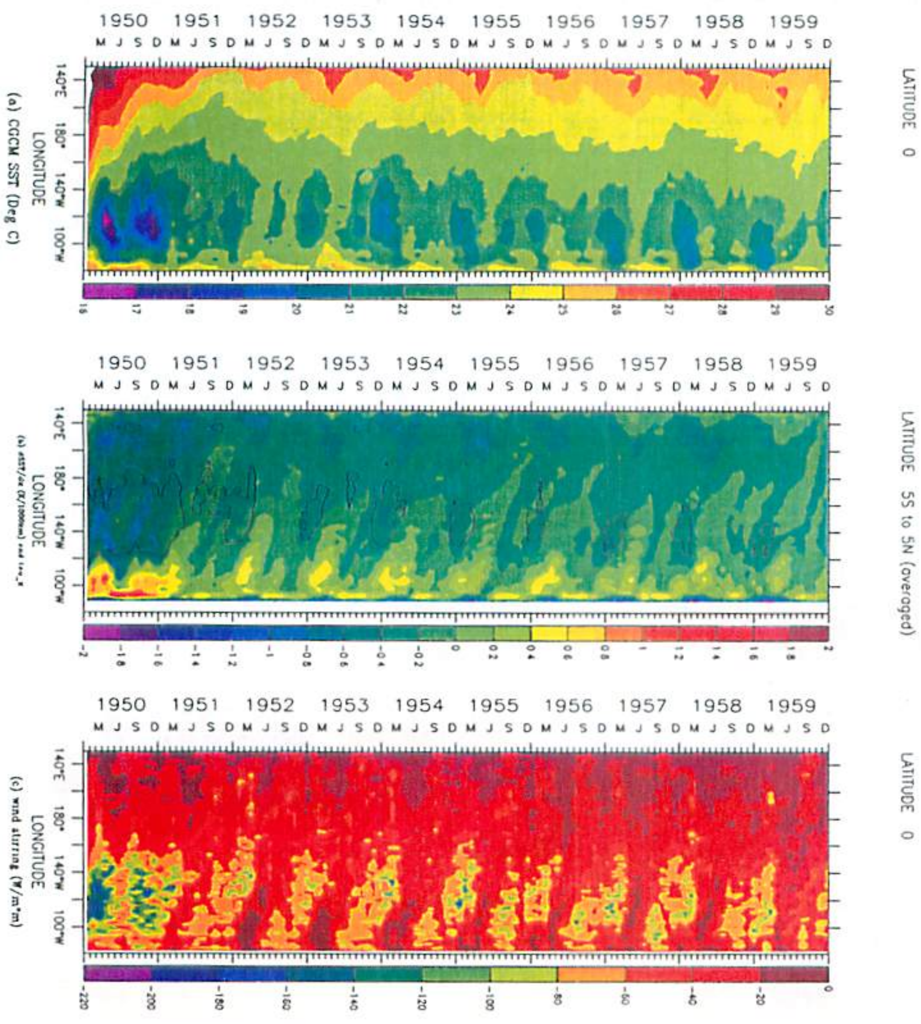


Figure 45. (left)

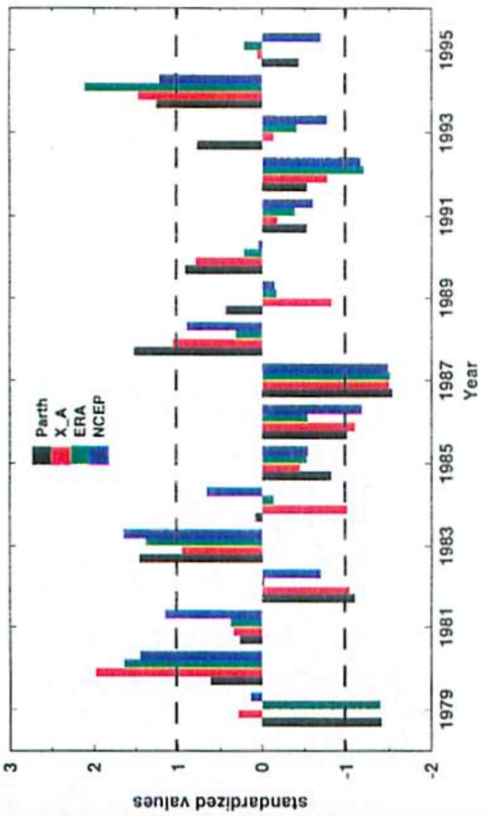


Figure 46. (bottom,left) Comparison of seasonal mean (June-Sept.) All India Rainfall anomalies (normalized in terms of standard deviation) from (i) observed station rain gauge record of Parthasarathy et al. (1995), (ii) satellite and surface data derived climatology of Xie and Arkin (1996). (iii) reanalysis data from ERA and NCEP/NCAR. The dashed lines represent ±1 standard deviation, typical of strong/weak monsoons.

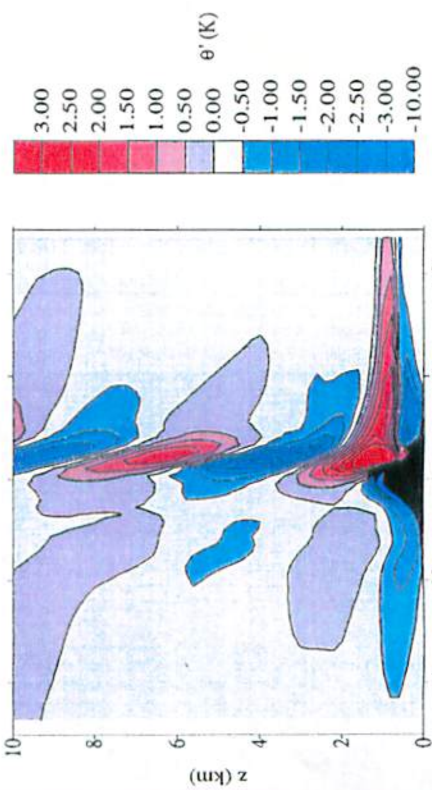


Figure 47. (bottom right) An example of the potential temperature perturbations when directionally sheared flow passes over an isolated circular mountain.