

# UTLS OZONE NEWSLETTER

Issue 1

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Editor: Rebecca Penkett



**Natural  
Environment  
Research  
Council**

Welcome to the first edition of the UTLS (Upper Troposphere Lower Stratosphere) OZONE Newsletter. The UTLS OZONE thematic Programme has now been running for just over a year. To date, we have had 2 funding rounds and written a Science Plan and an Exploitation Plan. A timetable of forthcoming activities can be found below.

Future activities	Date 1999
3rd Announcement of Opportunity (AO)	21 Apr
Science Meetings Cambridge: Leeds:	4 May 15/17 Dec
Implementation Plan meeting	5 May
Workshops with Potential co-funders and scientists	May - Jul
Exploitation Plan Committee meetings	May & Oct
Royal Meteorological Society UTLS OZONE meeting London:	17 Nov
3rd AO closing date	19 Nov

UTLS OZONE is a new NERC (Natural Environment Research Council) thematic programme to carry out research on the chemical composition and structure of the upper troposphere and lower stratosphere (UTLS) at middle latitudes. The broad aim of the UTLS OZONE Programme is embodied in the Programme Mission Statement

The UTLS OZONE Science Plan (see <http://nerc.utls.ac.uk>) describes the scientific issues central to UTLS OZONE scientific research, strategies for carrying out this research, and highlights areas which require special attention. In brief, the principal scientific objectives of the Programme are as follows:

1) Ozone depletion is largest in the lower stratosphere with year-round reductions in middle (and high) latitudes in both hemispheres. Understanding these changes requires quantification of *in-situ* chemical loss (due to chlorine and other halogen species) and the

## UTLS OZONE Mission Statement

The UTLS OZONE Programme aims to advance scientific knowledge about middle latitude ozone and its role in the Earth's climate system, thereby enabling authoritative statements to be made about ozone change. This will be achieved by quantifying the impact of human activity within the context of natural variability.

role of transport to/from the polar/tropical/upper stratosphere and the troposphere. Understanding ozone change in the future as well as in the past and present day requires examination of the interactions between chemistry, dynamics and radiative balance within the Earth's climate system. Related to this, the potential recovery of the ozone layer at middle latitudes as chlorine loading decreases is an important issue.

2) Trends in upper tropospheric ozone have been identified at middle latitudes showing important regional differences in magnitude and sign. Increasing trends have been reported over Europe and reductions over North America. Understanding the ozone trends over the last three decades and resolving differences in this controversial area is an important objective. This will require quantification of the different components of the ozone budget in this region - transport of ozone from the stratosphere, *in-situ* chemical production of ozone from pollutants emitted *in-situ* (e.g. aircraft) or uplifted from the surface by meteorological processes (e.g. convection, frontal systems).

3) An ultimate goal will be increased knowledge of feedbacks within the chemistry climate system, notably the impact of changing ozone on the Earth's climate system via radiative forcing in a region which is sensitive to such perturbations. The potential impact of changes in climate on ozone also needs to be addressed. Furthermore, study of the climatic effects of changes in other radiatively active gases, aerosols and clouds in the UTLS is still in its infancy. Also, the impact of human activity on chemical composition and climate needs to be studied within the context of natural variability.

The main deliverables that will be produced by the Programme are shown in the adjacent box.

The UTLS OZONE research Programme will produce a wealth of results which will have significant value to government and industry in the development of policy to protect our environment as well as their intrinsic scientific value. The development of collaborations between scientists and organisations outside UK academic institutions is strongly encouraged, given the requirement to attract £0.5M of co-funding into the Programme within the first 3 years (i.e. by March 2001).

To help facilitate collaboration between universities and outside organisations, an Exploitation Plan has been written. It identifies potential exploiters of UTLS OZONE research within government and industry and describes initiatives to realise co-funding. Co-funding can either be cash or in-kind (e.g. use of a facility free of charge). An Exploitation Plan Committee (EPC) has been set up to coordinate activities related to the exploitation of UTLS OZONE Research. The Exploitation Plan can also be found on the UTLS OZONE website (<http://utls.nerc.ac.uk>).

In this Newsletter, you will find abstracts from the first UTLS OZONE Science meeting which was held in Cambridge on 17 December 1998. Attendance was very encouraging with over 70 participants. The presentations consisted of invited talks on a number of important research topics as well as a series of talks by PIs funded in the first round of UTLS OZONE. The latter gave an overview of their projects, most of which got underway in late 1998, including plans for field experiments and scientific topics which they hope to address. In fact, many of the projects funded in the first round are collaborations with existing EU projects and make use of platforms funded by these projects. Details about projects funded in the first round can be found in the latest issue of NERC's Atmospheric Chemistry Newsletter (<http://www.nerc.ac.uk/as/achem98.htm>).

The results from the second UTLS OZONE funding round were decided in February 1999. The successful proposals are listed at the end of this Newsletter.

I am also pleased to announce the THIRD UTLS OZONE funding round. The announcement of opportunity can be found on the UTLS website. Note that the closing date is 19 November 1999 and that funds are available for co-funding initiatives which tackle the issues described in the Science and Exploitation Plans.

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- Increased knowledge about ozone change, climate change, global atmospheric pollution and consequent risks to the environment.
- A quantitative basis for predicting future changes in ozone and climate resulting from human activity and natural events.
- High quality data on atmospheric composition and physico-chemical processes in the UTLS region, to be stored and made available to all interested parties.
- Rapid dissemination of important findings to policy makers and other stakeholders through national and international assessment reports, newsletters, the world wide web, meetings with users and when appropriate, press releases.
- Rapid dissemination of results to the scientific community, and others, via presentation at scientific meetings and conferences and publication in recognised journals.

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## Abstracts from the first UTLS OZONE Science Meeting - Cambridge, December 1998

### Aircraft Data – What Can It Tell Us?

Recently, several airborne measurement campaigns have collected data over the North Atlantic to investigate mechanisms for ozone production in the free troposphere from surface pollutants, lightning and aircraft emissions. Whilst this data is extremely valuable, there is still a distinct lack of data in the UTLS region between 9km and 16km.

During the NERC ACSOE (Atmospheric Chemistry Studies of the Oceanic Environment) campaign in summer 1997, several flights were made with the MRF C-130 from the Azores in the central Atlantic. The O<sub>3</sub> and CO data have been examined as a means of understanding the contribution of surface pollutants to photochemical ozone production in the troposphere.

Previous analyses of surface and aircraft O<sub>3</sub> and CO data have shown correlations in the range of 0.25 to 0.4 in summertime air [e.g. Parrish et al., 1993]. In the ACSOE data, correlations in this range were found in clean, moist airmasses generally originating from the tropical lower troposphere. In several flights, higher correlations were found. These airmasses were polluted with higher concentrations of, for example, CN, compared to air sampled at lower levels, suggesting a continental origin. They were also drier than air at lower levels.

Trajectories and analysis of the meteorological fields showed

that this air had undergone uplift by frontal systems over North America in the preceding few days. Reasons for the differing O<sub>3</sub>:CO ratios, such as changing water vapour, are being investigated. This also includes looking at the effects from dilution by mixing (e.g. with upper tropospheric/lower stratospheric air) on the polluted air.

One of the striking features of all profiles collected during the ACSOE 1997 flights was the presence above the boundary layer of many layers of polluted air of different origin. Analysis of the composite profiles for all flights showed that all flights made both in spring and summer showed a high correlation between ozone, NO<sub>y</sub>, CO and CN with over twice as much ozone present at 7 km (60-80 ppbv) than at the surface (20-40 ppbv). This suggests that large-scale intercontinental transport of pollution is occurring in the mid troposphere throughout the year. In the spring there is sometimes enough nitric oxide available (greater than 40 pptv) for ozone production to be occurring in the polluted layers remote from their source.

Direct comparisons between results from the Cambridge global 3-D chemistry transport model, TOMCAT and observations along C-130 flight tracks were also shown. TOMCAT is capable of producing the general features seen in the data, i.e. transport of pollutants away from continental regions and production of O<sub>3</sub> in these airmasses. However, the model tends to underestimate the concentrations of major pollutants (e.g. CO) and O<sub>3</sub> in the polluted layers which were observed. This may be due to the horizontal resolution or the lack of fast hydrocarbon chemistry (e.g. isoprene) in the model.

#### Acknowledgements:

The following people are thanked for their data: S. Schmitgen, D. Kley (CO, FZ Julich); MRF including K. Dewey, J. Kent, H. Richer (O<sub>3</sub>, CN, met. data); UEA (S. Bauguitte, G. Mills, B. Bandy). The Cambridge model runs were performed by M. Cahill with assistance from P. Plantevin, H. Rogers, D. Shallcross and J. Pyle. Trajectories were calculated by M. Evans.

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### **Halocarbon Measurements and the UTLS Contribution to CARIBIC (Civil Aircraft Remote Sensing and In-situ Measurements in Troposphere and Lower Stratosphere based on the Instrumentation Container concept)**

There is a distinct lack of trace gas and aerosol concentration data in the UTLS region, due partly to a lack of suitable platforms for making observations. The EU CARIBIC

project aims to investigate the spatial and temporal distribution of a wide-range of compounds by making regular measurements from a commercial airliner (Boeing 767) flying twice-monthly between Germany (50°N) and the Maldives (4°N). CARIBIC is a multi-laboratory programme instigated primarily by the Max-Planck Institute for Chemistry (MPI-Mainz, Germany) and LTU International Airways. The current instrument package includes *in-situ* ozone, aerosol and CO measurements, as well as a large volume whole air sampler (WAS), collecting 12 samples during the return flight. Compounds measured in WAS include hydrocarbons, halocarbons and SF<sub>6</sub>, as well as the concentration and isotope ratios of CO, CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. The altitude range (up to 12 km) and flight route allows for sampling of mid-upper tropospheric air in tropical regions and lower stratospheric air in mid-latitudes. The UEA (University of East Anglia) contribution to CARIBIC will be to make measurements of a suite of halocarbon trace gases, using a small, bench-top GC-MS (HP 6890/5973), which will be purchased with funds provided by NERC UTLS OZONE. The instrument will be coupled to a fully-automated, pre-concentration and sample analysis inlet, capable of analysing a large number of air samples on a 24-hour cycle. Approximately 40 halocarbons will be measured, which will account for virtually 100% of organic chlorine, bromine and iodine in the UTLS region. Since halocarbons are excellent tracers of air mass origin (pollution, biomass burning, stratospheric air, oceanic air, etc), the data will also be used to investigate the age and origin of air in the tropopause region. Details of the CARIBIC project were presented, together with preliminary data from a flight carried out in June 1998.

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### **Organics by Airborne Real-time Chromatograph (ORAC).**

The monitoring of non-methane hydrocarbons (NMHC) can provide valuable insight into many aspects of atmospheric processes. Inspection of specific hydrocarbon pairs can allow a reasonable estimate of the degree of photochemical ageing which a particular air mass has undergone. Such an ability should allow the analysis of vertical structure within the atmosphere since the different layers present will have undergone a range of photochemical processing. Thus, the use of the so-called 'chemical clock' measurement afforded by such an instrument will allow a greater understanding of the mixing and transport processes occurring in the troposphere.

An instrument has been designed and constructed at the University of Leeds which will allow such measurements to be made. The instrument continuously samples ambient air by simply diverting air from the standard forward sampling pipe on the MRF C-130 aircraft and pumping it through one

of three traps. The traps are cycled every 3-4 minutes allowing, at any one time, one trap to be acquiring, one being analysed and the third being purged in preparation for the subsequent sample. Acquisition is carried out sub-ambiently using a graphite based adsorbent. The sample injection is accomplished by ballistically heating the sample trap, this has been shown to provide a suitably fast injection. The compounds selected initially are benzene, toluene and acetone, although other compound ranges may also be targeted, such as acetylene and iso-/n-pentane.

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## **Mixing around Frontal Zones - the DCFZ (Dynamics and Chemistry of Frontal Zones) Project.**

Frontal systems transport air over large horizontal and vertical distances, bringing differing airmasses into close proximity. The dynamical structure of fronts makes it likely that mixing will occur within and across the frontal surface, and this has consequences for both the dynamics and the chemistry in these regions. The aim of the UTLS OZONE DCFZ project is to obtain data that leads to an understanding of the chemical structure of frontal systems, and the extent and effect of mixing on this structure. There are three sources of data that will be used in the project. The Met. Research Flight C-130 aircraft will obtain *in-situ* measurements of a wide range of chemical species (especially during the period of overlap with an EU funded field campaign, MAXOX (Maximum Oxidation Rates in the Troposphere) when extra instrumentation will be available) as well as thermodynamic and turbulence data. The MST radar at Aberystwyth, which has a fixed vertical beam, will provide vertical profiles of the wind field, turbulence and static stability as fronts pass overhead. The Chilbolton radar, in southern England, which can scan in azimuth and elevation, will provide high-resolution vertical and nearly-horizontal cross-sections of reflectivity and radial velocity. Previous work with this radar has indicated that it will be possible to determine in real time locations where mixing is occurring over large vertical depths, making it possible to guide the aircraft into these regions even though they may not be apparent at the time to scientists on the aircraft.

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## **Analysis of Chemical Airmass Differences near Warm Fronts**

Measurements were made using ozonesondes and the UKMO (UK Meteorological Office) C-130 aircraft in the region of

warm fronts. Seven ozonesondes, launched from Aberystwyth and intercepting warm fronts, all show warm conveyor belts (WCBs) identified by layers above the front containing higher relative humidity values and lower ozone concentrations. In three cases, layers containing near-zero ozone concentrations were observed below the tropopause. The other sondes sampled intrusions of upper-tropospheric/stratospheric air overrunning the warm fronts - indeed one case showed both characteristics. The aircraft intercepted the WCB and free tropospheric air behind a warm front. Three airmasses were identified by changes in ozone and CO concentrations and in relative humidity. The WCB was composed of air from various sources: clean, moist boundary layer and lower free-tropospheric air lifted up as the warm front crossed the Atlantic, and cleaner air from lower free troposphere over the USA.

*Wendy Davies, Geraint Vaughan,  
University of Wales, Aberystwyth.*

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## **Transport and Chemistry at the Tropopause**

The tropopause is naturally regarded as a boundary between two airmasses with contrasting chemical characteristics. It is difficult to explain this contrast unless the tropopause acts as some kind of barrier to transport, in particular to transport along isentropic surfaces. Advection studies using isentropic winds obtained from large-scale meteorological datasets have been used to show the existence of a tropopause transport barrier, exploiting a hybrid Eulerian-Lagrangian diagnostic known as 'effective diffusivity' (Haynes and Shuckburgh 1999). This diagnostic clearly shows the differing strength of the transport barrier on different isentropic surfaces and how the strength varies with season. In particular, it highlights the weakness of the tropopause transport barrier in Northern Hemisphere summer, due in part to the flow associated with the Asian summer monsoon, that has been noted by others on the basis of descriptive synoptic studies.

The transport properties of the isentropic flow near the tropopause have implications for, and must be consistent with, the dynamics in that region. The dynamics are determined in part by the distribution of potential vorticity (PV) which is, to good approximation, a conserved tracer. The presence of a tropopause transport barrier is consistent with the strong isentropic gradients of PV that are associated with the tropopause. It is still an open question in geophysical fluid dynamics as to whether the strong PV gradients are best regarded as a consequence of the transport properties of the larger scale flow, or whether they are crucial in determining those transport properties. Nonetheless, this combination of transport barrier plus strong PV gradients has been observed in other contexts, such as the stratospheric polar vortex. Recent numerical simulations (Haynes and Scinocca, 1999) have shown that flow in a simple model atmosphere that is thermally relaxed towards a baroclinically unstable state, naturally organises itself to give a tropopause-like structure with a mid-latitude sharp PV gradient at upper levels, but no mid-latitude sharp PV gradient at lower levels.

The strong chemical contrast across the tropopause may allow interesting and potentially important chemical effects when tropospheric and stratospheric air mix. These effects have been studied using chemical box model experiments with two boxes, one initialised with stratospheric chemical characteristics and the other with tropospheric chemical characteristics. The rate of mixing between the boxes is specified and the chemical concentrations in the boxes allowed to evolve. The results predict that the mixing results in a substantial increase in reactive species such as OH and destruction of some of the ozone originating in the stratospheric box (Tan et al 1999). The implications for modelling the chemical distributions in the upper tropospheric and lower stratospheric regions need to be examined further.

*Peter Haynes, DAMTP, University of Cambridge.  
<http://www.atm.damtp.cam.ac.uk/people/phh/>*

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## The Polar Stratosphere seen from Long Duration Balloons

Ozone depletion is the result of a sequence of events - cooling, PSCs (polar stratospheric clouds), chlorine activation and then ozone photochemical destruction - occurring along the trajectory of an air mass during its motion in the vortex winter stratosphere. Therefore, ideally, it could be studied by Lagrangian measurements of appropriate meteorological, micro-physical and chemical parameters carried out on long duration balloons. Such Lagrangian approach is now feasible using Infra-Red Montgolfier (MIR) operated by CNES (Centre National d'Etudes Spatiales).

Two first flights in the Arctic were attempted first in the late vortex of February-April 1997. The balloons were carrying a relatively light payload of 45kg made of a meteorological package and a SAOZ (Système d'Analyse par Observation Zenitale) UV-visible spectrometer for measuring the vertical profiles of ozone and NO<sub>2</sub>. They lasted in flight for respectively 12 and 22 days until their automatic cut down for recovery.

Their meteorological data have been used for testing several aspects of the models. The average bias between ECMWF (European Centre for Medium-Range Weather Forecasts) and measured temperature was found to be smaller than 0.5°C, but accompanied by a relatively large scatter of 4°C, mainly due to a long wavelength modulation of wave number one. The model was found to overpredict the amplitude of the temperature change: colder than the measurements in cold areas and warmer where the atmosphere was warm. Another surprise was the small scatter (less than 0.75°C) of the difference in temperature at wavelength scale shorter than 1500 km. Since this figure includes the scatter due to interpolation between ECMWF levels, it means that the contribution of orographic and gravity waves was very small,

on average. Indeed, orographic coolings have been unambiguously detected, for example, above the Ural or Siberian mountains east of the Yenissei river. But, although the surface wind was blowing from the west at relatively fast speed (20 m/s), the amplitude of the coolings remained small: 2°C compared to 6°C predicted by a meso-scale model. It is therefore not clear whether orographic PSCs could contribute significantly to the chemical activation of the stratosphere.

Another aspect of the results was the evolution of ozone and NO<sub>2</sub> in the vortex between 24 February when the first balloon was launched and 8 April 1997 when the second went down. In agreement with other studies, a large reduction of about 25% was observed to take place in ozone concentration in the lower stratosphere during the first three weeks while that of NO<sub>2</sub> was remaining small. But as soon as first signs of warming were reported, the NO<sub>2</sub> concentration was observed to grow rapidly and the ozone loss to stop. However, an intriguing point is the rapid growth of NO<sub>x</sub>, faster than that expected from photochemical models. It would require some process or photochemical rate for recovering NO<sub>x</sub> from HNO<sub>3</sub>, not well captured at the moment.

This first attempt at long duration balloon flights in the Arctic will be followed by a new experiment, the EC supported Lagrangian Experiment during the winter of 1999, as part of THESEO (Third European Stratospheric Experiment on Ozone), which is to use three MIRs as well as four superpressure balloons of 10 m diameter flying at constant level around 60 hPa. These balloons are to carry a variety of instruments including three developed in the frame of UTLS: the semi-conductor ozone and the surface acoustic wave (SAW) in-situ detectors of the University of Cambridge and the CH<sub>4</sub> tuneable diode laser of the National Physical Laboratory and Cambridge.

If successful, it is planned to extend this experiment in the future for promising studies of a variety of processes in the UTLS at other latitudes including tropics.

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du Centre National de la Recherche Scientifique,  
Paris, France.*

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## Modelling of Ozone in the Arctic Lower Stratosphere

Observations of column ozone in the Arctic region have revealed large reductions during the 1990s. Although this downward trend is in some ways similar to the onset of the Antarctic ozone hole in the mid 1980s, there are important differences. The balance of chemistry and dynamics in determining average ozone levels in the Arctic is significantly different to the Antarctic. In the strong, cold Antarctic polar vortex, rapid springtime chemical ozone loss, initiated by heterogeneous reactions on polar stratospheric clouds (PSCs)

occurs throughout a large region of the lower stratosphere. Chemical ozone depletion has been observed in the Arctic, but this vortex is generally much smaller, weaker and more dynamically active.

Using a state-of-the-art three-dimensional (3-D) stratospheric model we have investigated the relative importance of dynamics and chemistry in causing the Arctic ozone trend in the 1990s. In the region averaged poleward of 63N, dynamical variations dominate the interannual variability, indicating that, over this area, the low average column values of the late 1990s are not indicative themselves of a trend towards more chemical depletion. The model results do show, however, that halogen increases since the early 1970s are responsible for a large reduction in the average March column ozone amounts, which includes a significant contribution to ozone depletion outside of the polar vortex, due to non-PSC related halogen chemistry. Future changes to average Arctic ozone amounts due to climate change may be more dependent on possible circulation changes than an increase in chemical loss within the smaller vortex area. This UTLS OZONE project will address these issues as well as analysing data collected as part of the THESEO Arctic field campaign in winter 1998/99.

*Martyn Chipperfield, The Environment Centre,  
University of Leeds.*

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## Balloon-Borne Measurements of Trace Gases

Balloon-borne measurements of tracers such as long-lived halocarbons, CH<sub>4</sub> and water vapour are being made at mid- and high northern latitudes throughout the 1998/99 winter as part of THESEO. These measurements are being used to test the transport and dynamics in the 3-D CTMs (chemical transport models) which are diagnosing chemical ozone loss; to investigate the descent in the Arctic vortex; and to give information about the amount of inorganic chlorine and bromine.

The measurements, which will be made within the UTLS OZONE tracer project, will extend the mid-latitude time series into the 1999 spring and beyond. In addition to the aims listed above, the extra tracer measurements in spring will be used to study the breakdown of the polar vortex and its mixing with mid-latitude air by looking for departures from the observed curved correlations between long-lived tracers with different stratospheric lifetimes (e.g., CFC-11 and CH<sub>4</sub>).

Three lightweight instruments which have been recently developed will be flown on small balloons. An in situ gas chromatograph weighing less than 25kg, will measure CFC-12, -11 and -113; a tunable diode laser weighing less than 10 kg will measure CH<sub>4</sub>; and a novel frost point hygrometer based on surface acoustic wave technology and weighing well

under 5 kg will measure water vapour. These will be flown with the SAOZ UV visible spectrometer and other lightweight instruments.

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Peter Woods, Tom Gardiner,  
National Physical Laboratory.*

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## Planned *In-situ* Measurements at the Tropical Tropopause

APE-THESEO is the Airborne Platform for Earth Observation (APE) contribution to THESEO. APE is the facility that manages scientific missions of the Russian high-altitude aircraft, the *M-55 Geophysica*. The *Geophysica* is an exciting new platform, well suited to the study of mesoscale processes occurring from the tropopause to 21km altitude. During APE-THESEO, the *Geophysica* will fly in tandem with the German DLR *Falcon*, which will use an on-board lidar to lead the *Geophysica* to small-scale, and short-lived, regions of interest.

APE-THESEO will probe cloud, aerosol, and trace gas distributions close to, and above, intense tropical convection, in order to understand the processes governing stratospheric dehydration, aerosol formation, and upper tropospheric-lower stratospheric transport. Mesoscale processes have been implicated in all of these processes. An important additional aspect of APE-THESEO is the collaboration with the Indian Ocean Experiment (INDOEX), which aims to investigate the effect of aerosols on climate in the Indian Ocean.

Lancaster University is providing the mission management and modelling support for the APE-THESEO mission. The UTLS OZONE Programme has provided funds to increase the participation of the theory team during the mission. It has also provided funds to cover the field costs of the meteorological forecast support team from the UK Meteorological Office.

*Robert MacKenzie, Environmental Science Department,  
Lancaster University.*

## Round 2 Funded Projects

Principal Investigator *	Project Title	Amount Awarded
Jones (Cambridge)	Development of scientific instrumentation for commercial aircraft	£67k
Heard (Leeds)	Laboratory Studies of OH productions and removal rates for the upper troposphere	£90k
O'Neill (Reading)	Evaluation of the ozone and water vapour datasets of the 40 year European re-analysis of the global atmosphere	£78k
Harwood (Edinburgh)	Studies of the tropopause region using version 5 data from MLS	£124k
Rowley (UCL)	Laboratory, theoretical and modelling studies of gas phase peroxy radical reactions affecting the UTLS HO <sub>x</sub> budget	£111k
Haigh (Imperial Coll.)	The response of lower stratosphere ozone to solar variability and its impact on radiative forcing and climate	£128k
Carslaw (Leeds)	Forecast and analysis of polar stratospheric clouds and cirrus for the NASA SOLVE arctic ozone campaign	£84k
Penkett (UEA)	Atmospheric chemistry and transport of ozone in the UTLS (ACTO)	£1M
Choularton (UMIST)	Development of a microphysical and chemical model of cirrus clouds	£40k
Chipperfield (Leeds)	Campaign participation and modelling studies for APE-GAIA	£77k
Whiteway (Aberystwyth)	An experiment to investigate gravity waves, mixing and filamentation in the tropopause	£245k
Parker (Leeds)	Gas phase and aerosol composition of air entering the upper troposphere through convective clouds	£108k
Cox (Cambridge)	Laboratory studies of the heterogeneous interaction of pollutants from aircraft - of HNO <sub>3</sub> , H <sub>2</sub> O and soot aerosols	£145k
Shine (Reading)	A general circulation model study of ozone/temperature interactions	£130k
Jones (Cambridge)	Airborne measurements of atmospheric tracers in the upper troposphere and lower stratosphere for studies of atmospheric transport and chemistry	£170k

\* Only First-named PIs given.

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Chilbolton Radar. RCRU/RAL



MIR launch preparation in Kiruna, Sweden. CNRS, Paris



Ozonesonde launch. UWA Physics Dept.



MIR launch preparation in Kiruna, Sweden. CNRS, Paris

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