The COST 723 Action

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ABSTRACT: An overview is provided of the COST 723 Action, 'Data Exploitation and Modelling of the Upper Troposphere and Lower Stratosphere'. The three working groups are introduced and a summary of Action activities within them is provided. The achievements of the Action are: three international workshops; the LAUTLOS humidity measurement campaign; dedicated meetings to discuss the quality of upper troposphere/lower stratosphere ozone and humidity measurements; two journal special issues; more than 90 papers in the peer-reviewed literature; one international summer school; and a successor COST Action which builds on COST 723. The recommendations made are: for COST to continue to support the short-term scientific missions instrument, as they are perceived to be value for money; to encourage the use of COST money to increase links between COST Actions and other scientific communities; and for the COST secretariat to recommend that Actions consider a summer school instead of a final workshop or meeting. Copyright © 2007 Royal Meteorological Society

1. Introduction

COST (details of all acronyms and abbreviations are provided in an appendix) is a European instrument supporting cooperation among scientists across Europe that funds networks via Actions. One of these Actions, COST 723, 'Data Exploitation and Modelling of the Upper Troposphere and Lower Stratosphere' (http://www.cost723.org) ran for four years from September 2002 to September 2006. The scientific motivation for COST 723 was a concern that chemical, dynamical and microphysical processes in the radiatively important UTLS region were not well understood. To address this concern, COST 723 was set up, its main objective being to advance the understanding of the state of the global UTLS, and of the role played by these processes in this altitude region. The Action has contributed towards making the best use of observations, models and assimilation algorithms. In this, the Action has brought together successfully the diverse communities working in the area of the global UTLS.

The Action has contributed toward the development and provision of value-added quality-controlled datasets of geophysical parameters (e.g. ozone and water vapour) which are important for the study of radiative, dynamical, and photochemical processes in the tropopause altitude region (5 km above and below the tropopause). Hitherto, there has been little information on these geophysical parameters in this region.

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The Action has also contributed toward the definition of new strategies for future research by providing a mechanism for bringing together expertise in the various areas relevant to the scientific study of the UTLS, and by spawning a new COST Action, ES0604/WAVACS, which will run for four years from October 2007.

Seventeen countries participated in this Action: Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, and United Kingdom.

In this paper we provide an overview of the Action. In section 2 we summarize the activities of the working groups, and section 3 provides conclusions and recommendations.

2. Working groups

The Action consisted of three WGs:

- **WG1:** Data and measurement techniques
- **WG2:** An assimilated ozone and humidity dataset
- **WG3:** Assessing the state of the UTLS and understanding the relevant processes.

Because these areas are closely related, activities associated with the three WGs were linked together by common meetings and workshops.

Below we provide a summary of the activities in each WG. The work in each WG was disseminated to the wider community in peer-reviewed publications, reports,

presentations at international workshops and conferences, and contributions (as organizers and lecturers) at summer schools.

2.1. WG1: Data and measurement techniques

The activities in this WG were initiated at the WG1 meeting in Bern, Switzerland in October 2003, and consolidated at the opening workshop of the Action at ESA-ESTEC (Noordwijk, The Netherlands) in March 2004. At these meetings, evidence was presented that ozone observations in the UTLS are reasonably well covered by existing databases, e.g. the NDSC, the GAW, and the WOUDC.

The most important UTLS issue at the global scale was found to be the inconsistency and uncertain quality of the various humidity datasets available. Humidity observations have been made *in situ*, by ground-based or aircraft-based remote sensing, and from satellite platforms. Significant inconsistencies persist across different observation techniques, and even within each observation technique. This was, therefore, a focus of WG1 activities. Because of the strong dependence of RH on temperature, temperature information was found to be also crucial.

The aim of the WG1 was thus to assess (and possibly improve) the quality of the different humidity datasets by intercomparison studies, including direct *in situ* comparisons, as well as comparisons using satellite instruments as a 'transfer standard' to interpolate between the datasets being compared. Available instruments/datasets considered were:

- Radiosonde, both for operational and research purposes (e.g. Vaughan *et al.*, 2005).
- Lidar (e.g. D'Aulerio *et al.*, 2005).
- Operational meteorological satellites (e.g. Buehler and John, 2005; Jiménez *et al.*, 2005).
- Envisat data, in particular from the MIPAS and SCIA-MACHY instruments (e.g. Lahoz *et al.*, 2007b).
- CHAMP data (e.g. Schmidt *et al.*, 2005, 2006).
- In-service aircraft from the MOZAIC project (Marenco *et al.*, 1998).
- Microwave data, both upward viewing and limb viewing (e.g. Gerber *et al.*, 2003; Buehler and John, 2005).

The results of this exercise are described in various research papers, examples of which are given below. Buehler *et al.* (2004) describe a comparison between microwave satellite humidity data and radiosondes, focusing on one radiosonde station, the reference station of the DWD in Lindenberg. Good agreement was found for radiosonde data that incorporated correction factors, but a residual dry bias of a few percent remained for extremely dry conditions. John and Buehler (2005) use the same method for a systematic comparison of European radiosonde stations and find large discrepancies between the different stations. Vaughan *et al.* (2005) describe a comparison between different types of radiosonde, the standard Vaisala RS80-A, which is used in many operational soundings, and the Snow White frostpoint hygrometer, a more sophisticated sensor. They find good agreement, provided that the correction by Miloshevich *et al.* (2001) is applied to the radiosonde data.

D'Aulerio *et al.* (2004) describe an intercomparison of water vapour retrievals between three Raman lidar stations. Feist *et al.* (2007) describe a comparison between aircraft microwave humidity data and the ECMWF analysis, demonstrating that the mesosphere and upper-stratosphere polar vortex are too dry in the ECMWF analyses, which are not based on direct observations. Feist *et al.* also provide a better understanding of the limitations of microwave observation in the UTLS region. Jiménez *et al.* (2005) compare different algorithms to process satellite humidity data, e.g. neural networks and linear regression techniques. Buehler and Courcoux (2003) discuss the impact of temperature errors on estimates of humidity supersaturation.

To improve the quality of radiosonde humidity data, a measurement campaign (LAUTLOS) was carried out in Sodankylä, Finland, during 11–25 February 2004. The results of the campaign were discussed at a dedicated expert meeting in Lindenberg, Germany, on 24–27 August 2004, hosted by Ulrich Leiterer. The scientific aims of the campaign are briefly listed below, with references to papers describing results from the campaign:

- To improve and validate research-type hygrometers and radiosondes, including: Meteolabor Snow White hygrometers, NOAA frostpoint hygrometers, CAO Flash Lyman alpha hygrometers, Lindenberg FN sondes, and Vaisala RS90 routine sondes (Vömel *et al.*, 2007b).
- To compare and cross-validate *in situ* and remote-sensing measurement methods for stratospheric humidity (Deuber *et al.*, 2005).
- To better understand humidity transport processes in the arctic lower stratosphere (Maturilli *et al.*, 2006; Karpechko *et al.*, 2007).
- To set up a 'standard water vapour mixing ratio profile' for the LAUTLOS campaign period, using *in situ* measuring hygrometers and radiosondes over the range 300–10 hPa.
- To validate and improve the solar radiation correction for the Vaisala RS90 latest version, the Vaisala RS80, and the Snow White SRS-C34 temperature sensors (Vömel *et al.*, 2007a).
- To study the influence of the balloon wake on temperature measurements, with a focus on stratospheric day and night conditions.
- To study the RH of Arctic stratus clouds under ice supersaturated conditions, including an investigation of the frequency of occurrence of the liquid and ice phase in supercooled clouds.
- To study the RH during polar stratospheric cloud (PSC) events over the range 100–30 hPa.
- To study the water vapour budget in the northern stratosphere over Europe, using data from a meridional

cross-section between Ny-Alesund (78 °N), Sodankylä (68 °N) and Lindenberg (52 °N).

- To initiate climatological long-term studies based on improved and corrected upper-air humidity measuring techniques used at the stations of Ny-Alesund, Sodankylä and Lindenberg.

Another dedicated expert meeting, convened to improve lidar water vapour measurements, was held in Matera, Italy, on 13 July 2004. This meeting was hosted by Gelsomina Pappalardo, and chaired by Philippe Keckhut. The goal of this workshop was to bring together the main teams involved in water vapour Raman lidar measurements, and discuss current issues. Water vapour Raman lidar is a promising technique for probing the upper troposphere and the tropopause region. However, this relatively new technique has strong calibration requirements. Results of the workshop are described in Keckhut *et al.* (2004) and Cornacchia *et al.* (2004). Among other things, a positive outcome of the workshop was that it allowed participating lidar instrument teams to be involved in satellite H_2O validation. Furthermore, it helped the organization of a follow-on international workshop about water vapour measurements in the UTLS within the NDACC, and helped pave the way for the inclusion of water vapour lidar observations in the NDACC. Finally, within WG1, the Service d'Aéronomie developed a tool to facilitate the comparison of high-resolution water vapour fields with cirrus and water vapour lidar observations, which will be of interest for future campaigns.

During 2005, the WG1 radiosonde validation and calibration efforts continued. An expert meeting held in Helsinki in August 2005 was used to discuss the results of the LAUTLOS campaign and to plan publication of the results. (For more information on the results themselves, see the list above.)

Finally, during 2006, two STSMs were used to bring young scientists from Finland and Poland to Lindenberg (Germany), in order to familiarize them with the radiosonde humidity correction algorithms developed there. It is planned to apply the same corrections to the Polish and Finnish data. This is one of the various examples of the transfer of expertise between European institutions that took place during COST 723, chiefly via the mechanism of STSMs.

The overview given here focuses on publications that directly deal with UTLS data quality, particularly for humidity measurements. But WG1 also gave rise to several publications that deal with more general UTLS measurements and data applications. Overall, more than 30 peer-reviewed articles were published by participants in WG1. A full list can be found at http://www.cost723.org/publications/#no1.

2.2. WG2: An assimilated ozone and humidity dataset

In the 1990s, following years of development of meteorological data assimilation by the NWP community, the data assimilation methodology (e.g. Kalnay, 2003) began to be applied to constituents, with a strong focus on stratospheric ozone (Rood, 2005). Although constituent data assimilation is less mature than assimilation in the NWP community, there has been substantial progress over the last 15 years, with the field evolving from initial efforts to test the methodology to later efforts focusing on products for monitoring ozone and other constituents (e.g. Lahoz *et al.*, 2007a). More recently, the production of ozone forecasts by a number of operational centres (e.g. ECMWF: Dethof, 2003) has become routine. A notable feature of the application of the data assimilation methodology to stratospheric constituents has been the strong interaction between the NWP and research communities, for example, in the EU-funded ASSET project (http://darc.nerc.ac.uk/asset; Lahoz *et al.*, 2007b), in which the WG2 participants were strongly involved.

Building on these efforts in constituent data assimilation, COST 723 set itself two objectives concerning the UTLS region: (i) to develop algorithms to assimilate an increasing variety of UTLS datasets into NWP-based GCMs and CTMs, and (ii) to use the developed algorithms to provide a quality-controlled assimilated UTLS ozone and water vapour dataset for the use of the scientific community.

To address these objectives, data assimilation was used to incorporate novel observations (e.g. ozone and stratospheric water vapour from Envisat atmospheric chemistry instruments) into systems based on NWP models and CTMs, and to evaluate research satellite data and the models. Details of the use of assimilation techniques to evaluate Envisat atmospheric chemistry data (MIPAS, SCIAMACHY and GOMOS) are provided in Geer *et al.* (2006a) and Lahoz *et al.* (2007a, b).

The work in WG2 aimed at incorporating stratospheric constituent data although some work in ASSET concerned the assimilation of tropospheric constituent data (e.g. Nieradzik and Elbern, 2006; Lahoz *et al.*, 2007b). Recent reviews of constituent data assimilation have been provided by Lary (1999), Khattatov (2003) and Rood (2005). Lahoz *et al.* (2007b) provide an overview of data assimilation work performed as part of the ASSET project; Lahoz *et al.* (2007a) provide a review of stratospheric constituent data assimilation which builds on the Rood review and describes recent results, including those achieved within the ASSET project.

Three modelling approaches can be identified in the assimilation of stratospheric constituent data:

2.2.1. Assimilation into a NWP model based on a GCM

In this approach, the standard operational observations are assimilated, plus research satellite observations (e.g. GOME, Envisat). The models generally incorporate a simple linear parametrization of the chemical sources and sinks of ozone (e.g. the Cariolle scheme; Cariolle and Déqué, 1986). An advantage of this approach is that it allows for radiation/chemistry/dynamics feedbacks. Another advantage is that it is relatively cheap to add

simple chemistry to a tried and tested operational NWP system. A disadvantage of this approach is that the representation of chemistry often tends to be simple. Another disadvantage is that GCMs are complex and generally expensive in terms of computer resources (e.g. Lahoz *et al.*, 2007a).

The assimilation schemes used tend to be variational (3D-variational; 4D-variational). Kalman filter (KF) schemes tend not to be used due to their high computing requirements, although a number of operational centres are investigating the combination of variational and KF notions in their assimilation set-up (e.g. Buehner, 2005).

Examples (not exhaustive) of this assimilation approach are provided by the Met Office/DARC (Jackson and Saunders, 2002; Struthers *et al.*, 2002; Jackson, 2004, 2007; Lahoz *et al.*, 2005, 2007a,b; Geer *et al.*, 2006a, 2006b, 2007) and ECMWF (Dethof, 2003; Dethof and Hólm, 2004).

2.2.2. *Assimilation into a chemical model*

In this approach, a chemical model (a photochemical box model or a CTM) is forced by winds and temperatures from an external source (typically a GCM or analyses derived from a GCM-based assimilation system). The chemical scheme used by CTMs varies in complexity and depends on the final application. If the assimilation system focuses on long-lived species (e.g. methane), chemistry can be neglected. If the assimilation system focuses on ozone, a parametrized chemical scheme can be sufficient (see above). If the assimilation system focuses on reactive species, i.e. short-lived species (e.g. NO_2), then explicit calculation of the chemical interactions is generally necessary. The first two cases are cheaper in computer time than the third one. An advantage of this approach is that it tends to be cheaper than GCMs, and thus allows greater flexibility in the set-up of the chemical model. A disadvantage of this approach is that it does not allow for radiation/dynamics/chemistry feedbacks. The assimilation schemes used are variational or simplifications of the KF.

Examples (not exhaustive) of this approach are provided by KNMI (Eskes *et al.*, 2002, 2003; Segers *et al.*, 2005), BIRA-IASB (Errera and Fonteyn, 2001), GMAO (Štajner *et al.*, 2001), Service d'Aeronomie (Marchand *et al.*, 2004), NCAR (Khattatov *et al.*, 1999, 2000), DLR (Baier *et al.*, 2005), and the University of Köln (Nieradzik and Elbern, 2006).

2.2.3. *Assimilation into a coupled GCM/CTM model*

In this approach, a GCM and a CTM are combined by coupling. The coupling can involve a CTM external to the GCM, or a chemistry subroutine embedded in the GCM. This approach is still in its early stages of development, but early results appear promising.

The data assimilation set-up in MSC (Met Service Canada), described in Polavarapu *et al.* (2005a, 2005b), is built on a GCM (the CMAM), but arguably is best described as a coupled system as it uses full chemistry rather than the simplified chemistry approach commonly used in NWP systems based on GCMs (see above). Environment Canada is also using this approach with another GCM, GEM-strato, coupled with full chemistry from BIRA-IASB (Q. Errera 2007, personal communication).

2.2.4. *Results from WG2: Ozone and humidity analyses*

The assimilation of ozone data using various techniques (GCMs and chemical models – but no coupled GCM/CTM models; variational and KF assimilation schemes) was assessed in the ASSET ozone intercomparison project (Geer *et al.*, 2006b). This paper discusses in detail the quality of the resulting ozone analyses. To summarize, this first intercomparison of ozone analyses, demonstrated that for current ozone data assimilation systems, in general, in regions of good data quality and coverage, similarly good results are obtained regardless of the assimilation method, or the assimilation system. Furthermore, this intercomparison showed that, in general, the first priority for improving ozone data assimilation systems is improved modelling of chemistry and transport.

A particular challenge that WG2 addressed is the assimilation of water vapour in the troposphere and stratosphere. The operational assimilation of water vapour data in the stratosphere by NWP centres is limited by the availability of suitable data (Simmons *et al.* 1999). The reduction in specific humidity by four to five orders of magnitude from the surface to the stratosphere also makes the assimilation problem considerably more difficult. Due to assimilation problems, both the Met Office (D. Jackson 2007, personal communication) and ECMWF (Hólm *et al.*, 2002) have made to date *ad hoc* fixes to constrain the stratospheric humidity field.

Besides problems arising from this large variation of water vapour, there is an issue concerning what is the best way of assimilating water vapour, i.e. whether to use RH or specific humidity as the control variable (Bouttier and Courtier 1999). In the troposphere, RH provides a better representation of clouds and precipitation; in the stratosphere, RH has very low values, which makes specific humidity better suited. The choice of water vapour control variable is being discussed in the literature (Hólm *et al.* 2002; Dee and da Silva 2003; Lahoz *et al.* 2007b). Lahoz *et al.* (2007b) also discusses the quality of humidity analyses. The DARC/Met Office and ECMWF (among others) are working on developing the assimilation of water vapour in the troposphere and stratosphere.

Overall, several-month ozone analyses were provided within WG2 and used to evaluate a number of ozone assimilation systems and Envisat data (Geer *et al.*, 2006a). By contrast, only about two months of stratospheric humidity analyses were provided within WG2 (Lahoz *et al.*, 2007b). This is chiefly due to the difficulties in providing analyses using a troposphere–stratosphere model (see above). Despite these problems in deriving stratospheric humidity analyses, the ASSET work

provided one of the first evaluations of the impact of assimilation of height-resolved humidity data into NWP and CTM systems, demonstrating a positive impact of assimilation of stratospheric humidity data (Lahoz *et al.*, 2007b).

2.3. WG3: Assessing the state of the UTLS and understanding the relevant processes

Two areas concerning the UTLS have benefited from the work in the COST 723 WG3: (i) the study of cirrus in the tropopause region, and (ii) the quantitative understanding of transport in the tropopause region. We discuss these in turn.

2.3.1. Cirrus clouds

Cirrus clouds are important in a number of ways. They play an important role in modulating the radiative energy flow through the Earth's atmosphere, and are able to both heat or cool the atmosphere, depending on their micro-physical and radiative properties, their geographical location and altitude, and the time of day. They are part of the hydrological cycle and affect the humidity field in the upper troposphere. They allow heterogeneous chemistry to occur and hence play a role in the regulation of stratospheric ozone. Finally, they are part of weather systems.

Cirrus clouds cover on average 20%–30% of the Earth, and even much more when sub-visible cirrus are included (Gayet *et al.*, 2004; Keckhut *et al.*, 2006) Hitherto, cirrus clouds have been generally perceived as isolated objects, identified by their microphysical and radiative properties. However, they exist in an environment that allows ice crystals to form and persist for some time (a few hours at midlatitudes and up to several days in the Tropics). In general, the properties of the environment in which cirrus clouds are embedded have received much less attention than the cirrus clouds themselves. The COST 723 Action sponsored work that remedied this shortcoming.

An important result obtained during recent years has been the observation that supersaturation over ice outside and, more surprisingly, inside cirrus clouds, is ubiquitous at all latitudes (Comstock *et al.*, 2004; Gayet *et al.*, 2004; Gierens *et al.*, 2004; Spichtinger *et al.*, 2004; Gettelman *et al.*, 2006). COST 723 provided a platform to discuss this work by organizing a workshop on cirrus clouds and their supersaturated environment on 11–12 October 2004, at Oberpfaffenhofen, Germany. At this workshop, observations, microphysical studies (Cantrel and Heymsfield, 2005) and modelling studies were discussed, with strong emphasis on the development of cirrus clouds parametrizations for GCMs and their impact on model performance (Gierens, 2003; Kärcher and Haag, 2004; Gettelman and Kinnison, 2007). A parametrization of ice supersaturation has been incorporated into the ECMWF IFS (Tompkins *et al.*, 2007). One of the conclusions of the meeting was that whereas synoptic cold pools define the overall thermodynamic conditions in which the formation of ice clouds takes place, cloud properties are determined by mesoscale processes (e.g. Garrett *et al.*, 2004; Spichtinger *et al.*, 2005a).

2.3.2. Transport

Many important gases, including ozone, are long-lived species in the UTLS and their distribution depends strongly on the transport and mixing properties of the atmospheric flow. Water vapour, although it may experience condensation below the cold point, can also be considered as a long-lived species. A simplified but useful point of view is to consider the UTLS as a region consisting of a number of fairly well-mixed reservoirs separated by transport or mixing barriers. For a long time, the main issue has been to estimate the fluxes between these reservoirs, but results show large variation in these estimates (Gettelman and Sobel, 2000), due to the lack of a unique and unambiguous definition of the tropopause and other separating surfaces. It has been the goal of COST 723 and other recent work to focus instead on the basic mechanisms generating barriers and mixing in the UTLS. We summarize these contributions below.

The subtropical jets located at about 30 °S and 30°N in latitude, and at roughly 200 hPa or $\theta = 350$ K in the vertical, divide the extratropical lowermost stratosphere from the upper tropical troposphere (Holton *et al.*, 1995; Highwood and Hoskins, 1998). This barrier provided by the subtropical jets, which coincides with large isentropic gradients in all trace gases and potential vorticity is, however, permeable to intrusions between the tropics and the extratropics, mainly through breaking Rossby waves, particularly at the site of active baroclinic regions (Waugh and Polvani, 2000). Although mixing is three-dimensional, and mostly occurs in the vertical, tracer gradients are first generated by layer-wise isentropic motion combined with vertical shear and can be diagnosed efficiently by Lagrangian methods (e.g. Haynes and Shuckburgh, 2000a, 2000b; Legras *et al.*, 2005; F. d'Ovidio 2007, personal communication).

Another barrier divides the extratropics from the tropics, forming a 'tropical pipe' in the mid-stratosphere (Plumb, 2002). This barrier is separated from the one mentioned above (associated with the subtropical jets) by a region extending from $\theta = 370$ K to about $\theta = 450$ K, centred at $\theta = 400$ K, and in which meridional exchange is favoured (Waugh, 1996). These exchanges are important for determining the distribution of long-lived species in the lowermost extratropical stratosphere (Hoor *et al.*, 2004).

The extratropical tropopause is now recognized as a region where tropospheric and stratospheric air mix and, in doing so, gives rise to a transition layer of about 1 to 2 km, or 30 K in potential temperature, above the thermal tropopause (Hoor *et al.*, 2002, 2004; Sprenger and Wernli 2003; Pan *et al.*, 2004; Hegglin *et al.*, 2005). Deep exchanges across the tropopause occur due to tropopause folds combined with convection (Stohl *et al.*, 2003; Reid and Vaughan, 2004; Brioude *et al.*, 2006) and are most intense in the occluded region of cyclonic

perturbations. The warm conveyor belt transports air directly from the boundary layer to the UTLS (Eckhardt *et al.*, 2004), a mechanism which can also contribute to the generation of cirrus clouds (Spichtinger *et al.*, 2005b). Similarly, tropopause folds can transport ozone-rich air from the stratosphere down to the ground (Gerasopoulos *et al.*, 2006).

One of the difficulties in defining fluxes across the tropopause is the frequent observation of a double tropopause structure in the thermal profiles (Añel *et al.*, 2007; Randel *et al.*, 2007), with a much broader vertical distribution than tropopause folds diagnosed from the analyses provided by weather services (Wernli and Bourqui, 2002; Sprenger and Wernli, 2003). The origin of this discrepancy that may impact considerably on flux calculations is possibly the limited resolution of the analyses. Note that Wernli and Bourqui (2002) introduced a method to calculate fluxes that accounts for mixing delays and thus allows air that crosses (e.g. from the troposphere to the stratosphere), to mix irreversibly within the stratospheric air.

Water vapour mixing ratios do not exceed a few parts per million by volume (ppmv) in the stratosphere, setting the chemical conditions required for ozone to be a long-lived tracer. The factor limiting water vapour stratospheric concentrations is that tropospheric air mainly enters the stratosphere in the tropics, where it has to cross a very cold tropopause, causing very strong dehydration. It has become clear over recent years that this process cannot be readily explained as a simple vertical effect from convection, but that horizontal transport plays an important role in carrying air across the cold point (Holton and Gettelman, 2001; Fueglistaler *et al.*, 2005). During northern winter, most of the transport is concentrated over the maritime continent (Indonesia) where air crosses the tropopause near its coldest point, resulting in a 'dry fountain' (water vapour values about 2.5 ppmv). During northern summer, most of the transport is shifted towards India where the steering of parcel trajectories by the monsoon anticyclone is such that those parcels trapped in the anticyclone at the tropopause avoid the coldest point and enter the stratosphere with more than 4 ppmv of water vapour. This is manifested in a 'wet fountain', observed from EOS MLS on the NASA Aura platform (Randel and Park, 2006) and reproduced by Lagrangian models (M. Bonazzola and P. James 2007, personal communication). The representation of clouds is the weak point of large-scale Lagrangian calculations, which thus cannot take account of the role of overshooting convection which can inject water several kilometres above the tropopause (Dessler *et al.*, 2006; Chaboureau *et al.*, 2007; Grosvenor *et al.*, 2007; Pommereau *et al.*, 2007). However, it is still highly uncertain whether such effects are non-negligible when physical effects are averaged over large spatial scales (A. Gettelman and T. Birner 2007, personal communication; T. Peter 2007, personal communication).

The main contribution of COST 723 has been to promote successfully the use of ECMWF reanalyses and Lagrangian trajectories to study transport and mixing properties in the UTLS. The availability of a new intermediate reanalysis (Simmons *et al.*, 2007) with much improved transport properties opens new avenues for further studies.

3. Conclusions

The achievements of COST 723 are as follows:

- Two international COST 723 workshops: (i) 11–13 March 2004, ESTEC, The Netherlands; (ii) 17–19 May, Sofia, Bulgaria.
- The LAUTLOS measurement campaign.
- Dedicated meetings to discuss the quality of UTLS ozone and humidity measurements.
- One international cirrus cloud workshop (Oberpfaffenhofen, Germany, October 2004).
- Two journal special issues: (i) Atmospheric Chemistry Physics (http://www.atmos-chem-phys.net/special_issue17.html); (ii) the Quarterly Journal of the Royal Meteorological Society (this issue).
- More than 90 papers in the peer-reviewed literature.
- One international summer school: 3–15 October 2005, Cargese, Corsica, France. Informal feedback from students suggests the summer school was a great success. Details of the programme and lectures can be found at http://www.cost723.org/school.
- Thirteen STSMs, which have led to papers in the peer-reviewed literature, and increased collaboration between Western European (pre EU-25 countries) and Eastern European (new EU-25 countries) scientists. Of these 13 STSMs, 11 involved young scientists (less than 35 years of age) and 4 involved women.
- Involvement of young scientists and women in COST 723 activities (specifically workshops, summer school, and STSMs).
- A successful proposal for a COST Action (WAVACS, ES0604), which builds on COST 723. WAVACS will start in October 2007 and will last for four years.

The recommendations from the COST 723 Action are as follows:

- To continue the support of STSMs, as they are perceived to be value for money.
- To encourage the use of COST money to increase links between COST Actions and other scientific communities by (e.g.) supporting workshops and visits.
- For the COST Secretariat to recommend that Actions consider a summer school instead of a final workshop/meeting. Based on the COST 723 experience, summer schools are an effective way of bringing together young scientists and experts.

The remainder of the COST 723 special issue will focus on scientific results from the Action. (Buehler *et al.*, 2007; Del Bianco *et al.*, 2007; Jiménez *et al.*, 2007;

Rydberg *et al.*, 2007; Semane *et al.*, 2007; Vaughan and Worthington, 2007)

Acknowledgements

Appendix

Acronyms and abbreviations

ASSET	ASSimilation of Envisat daTa
BIRA-IASB	Belgisch Instituut voor Rüimte Aeronomie – Institut d'Aéronomie Spatiale de Belgique (Belgian Institute of Space Aeronomy)
CHAMP	CHAllenging Minisatellite Payload
CMAM	Canadian Middle Atmosphere Model
COST	COoperation in the field of Scientific and Technical research
CTM	Chemistry-Transport Model
DARC	Data Assimilation Research Centre (UK)
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre)
DWD	Deutsche Wetterdienst (German Weather Service)
ECMWF	European Centre for Medium-range Weather Forecasts
EOS	Earth Observing System
ESTEC	European Space Research and Technology Centre (part of the European Space Agency)
GAW	Global Atmosphere Watch
GCM	General Circulation Model
GEM	Global Environmental Multiscale
GMAO	Global Modeling Assimilation Office (NASA, USA)
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
IFS	Integrated Forecast System
KF	Kalman filter
KNMI	Koninklijk Nederlaands Meteorologisch Instituut (Royal Dutch Meteorological Institute)
LAPBIAT	LAPland Atmosphere-Biosphere facility

LAUTLOS	LAPBIAT Upper Troposphere/LOwer Stratosphere water vapour validation
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MLS	Microwave Limb Sounder
MOZAIC	Measurement of OZone and water vapour by Airbus In-service airCraft
MSC	Met Service Canada
NASA	National Aeronautics and Space Administration (USA)
NCAR	National Center for Atmospheric Research (USA)
NDACC	Network for the Detection of Atmospheric Composition Changes
NDSC	Network for the Detection of Stratospheric Change
NOAA	National Oceanic and Atmospheric Administration (USA)
NWP	Numerical weather prediction
PSC	Polar Stratospheric Cloud
RH	Relative humidity
SCIAMACHY	Scanning Imaging Absorption spectroMeter for Atmospheric CartograpHY
STSM	Short-Term Scientific Mission
TTL	Tropical Tropopause Layer
UTLS	Upper Troposphere/Lower Stratosphere
WAVACS	atmospheric WAter VApour in the Climate System
WG	Working Group
WOUDC	World Ozone and Ultraviolet Radiation Data Centre

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