Short Term Scientific Mission to the Data Assimilation Research Centre at the University of Reading

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1 Introduction

As yet there is no available long-term dataset of assimilated stratospheric water vapour, though many groups are working with shorter periods of research satellite data, such as from MIPAS on Envisat and UARS/MLS. Neither ECMWF operational analyses nor ERA-40 incorporate observations of stratospheric water vapour. Stratospheric water vapour distributions depend on the ECMWF model's cross-tropopause transport, stratospheric tracer transport and mixing, and the parameterisation of methane oxidation. However, since transport is controlled by winds that benefit from the assimilation of observed temperatures and winds, the model is capable of producing approximate distributions of stratospheric water vapour and especially, structures of planetary scale advection and mixing, including for example streamers of moist and dry air around the polar vortex (e.g. Simmons et al., Q.J.R. Meteorol. Soc. (1999), 125, pp. 353-386.) There are, however, known problems such as excessive upward transport of water vapour, the lack of a QBO and a tropical tape recorder that is too fast.

2 Purpose of the visit

The Institute of Applied Physics at the University of Bern, Switzerland, has measured equator-to-pole vertical cross-sections of water vapour (from roughly 15 km to 70 km) with an airborne microwave radiometer. Cross sections were made roughly once per year (see Figure 1). We planned to compare these cross-sections with water vapour from ECMWF operational analyses corresponding to the same location and date.

The idea behind this study was to validate both the microwave retrievals and the ECMWF analyses. Since the comparisons were for specific dates, it was hoped that they will highlight aspects of day-to-day stratospheric variability, such as mixing features. Independent humidity observations from HALOE and SAGE-II were to be used to help attribute the causes of any discrepancies between the two datasets. We also planned to investigate the possibility of using the analyses as a transfer standard to perform a cross-validation and take a close look at the upper tropical tropopause which shows up in the microwave measurements and would be of particular interest to COST-723. So far, there has been little work published on the validation or intercomparison of mid- and upper-stratospheric water vapour in the ECMWF analyses. This study would be a useful contribution.

On the personal level the idea was to allow Dietrich Feist to learn about data assimilation in a research group that is actively developing its own stratospheric water vapour analyses. The Reading group would gain experience of a new type of independent validation data and an understanding of the characteristics of another

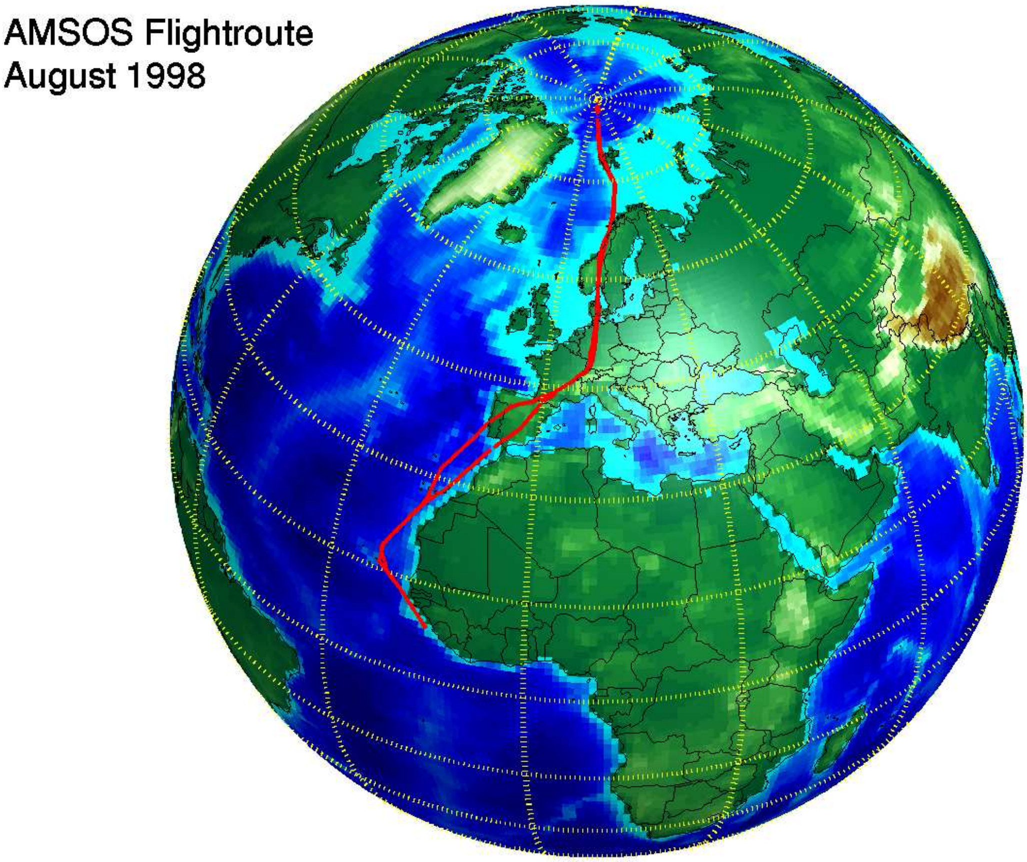

Figure 1: Flight route of AMSOS during 1998 mission. The Learjet first flew from Switzerland via the Canary Islands to Cape Verde and the African West Coast and back to Switzerland. The second part of the campaign went from Switzerland to Norway and via Spitzbergen to the North Pole.

assimilation system. The study with ECMWF data was to be a prototype for a similar study when the University of Reading's own stratospheric water vapour analyses would be ready for validation.

3 Work carried out during the visit

As expected, a number of practical problems had to be solved before the intercomparison could even begin. The main tasks that had to be solved were to

1. find and retrieve the ECMWF data files matching the aircraft measurements

2. find software to read the ECMWF GRIB files into Matlab
3. convert ECMWF data on model levels to the geometric altitude grid used for the aircraft profiles
4. convert ECMWF data and aircraft measurements to consistent units
5. find the closest matching ECMWF profiles for each aircraft profile

All the software for the above tasks had to be written from scratch. Some of the conversions were quite difficult and required active support from the ECMWF helpdesk (including a visit to ECMWF). In some cases the source code of the ECMWF model had to be consulted to find out how to proceed. It proved very useful that Dietrich Feist had acquired a user account to the ECMWF's archive server MARS a few weeks before the visit. Another problem was handling the large amounts of data produced by the ECMWF model which amounted to several hundred megabytes per intercomparison day.

Even though the time schedule for the visit was very tight with only six working days, all the practical tasks above were solved in time to produce a complete intercomparison of the first aircraft mission of August 1998 with the corresponding ECMWF data.

4 The AMSOS data set

During this STSM, only data from the first AMSOS mission in August 1998 (see also Figure 1) was compared to the corresponding ERA-40 water vapor profiles that were closest in time and space. That mission was chosen mainly for two reasons:

1. it has the largest latitude coverage of all AMSOS missions (see Figure 2)
2. it took place during the summer when the atmospheric situation was relatively quiet. In such a situation, one would expect mostly large-scale structures in the water vapor distribution so that the exact match of time and space is not so important for the intercomparison.

The profiles were compared one-by-one in the order that they were retrieved from the AMSOS data. A total of 148 AMSOS profiles were available for this intercomparison. Their number (from 1 to 148) is the index on the x-axis for most plots in this report. This index was only chosen as a practical parameter to provide compact intercomparison plots. As one can see from Figure 3, this index corresponds roughly to time but with large intermittent gaps when the aircraft

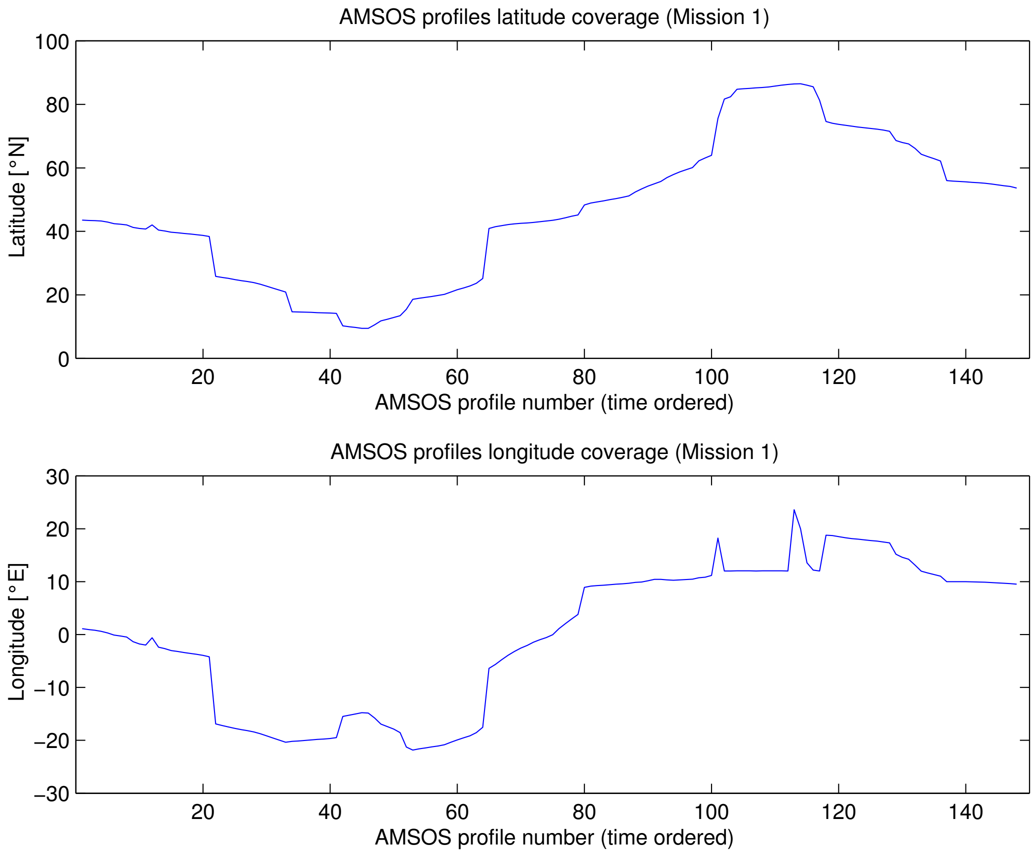

Figure 2: Latitude and longitude of AMSOS profiles.

was on the ground. Unfortunately, there was no obvious physical or geographical parameter that could be used to replace this. Latitude and longitude (see Figure 2 were both ambiguous.

5 Main results obtained

The first intercomparison of single profiles (see Figure 4) showed a surprisingly good match between ECMWF's ERA-40 data and the aircraft measurements with the microwave radiometer. The profiles are almost identical between roughly 20-40 km altitude, where the microwave retrieval has the highest sensitivity and the smallest a-priori contribution. That was most encouraging since the microwave retrieval was completely independent of ECMWF data and even used temperature from a different source.

Below 20 km, the microwave retrieval increasingly depends on a-priori in-

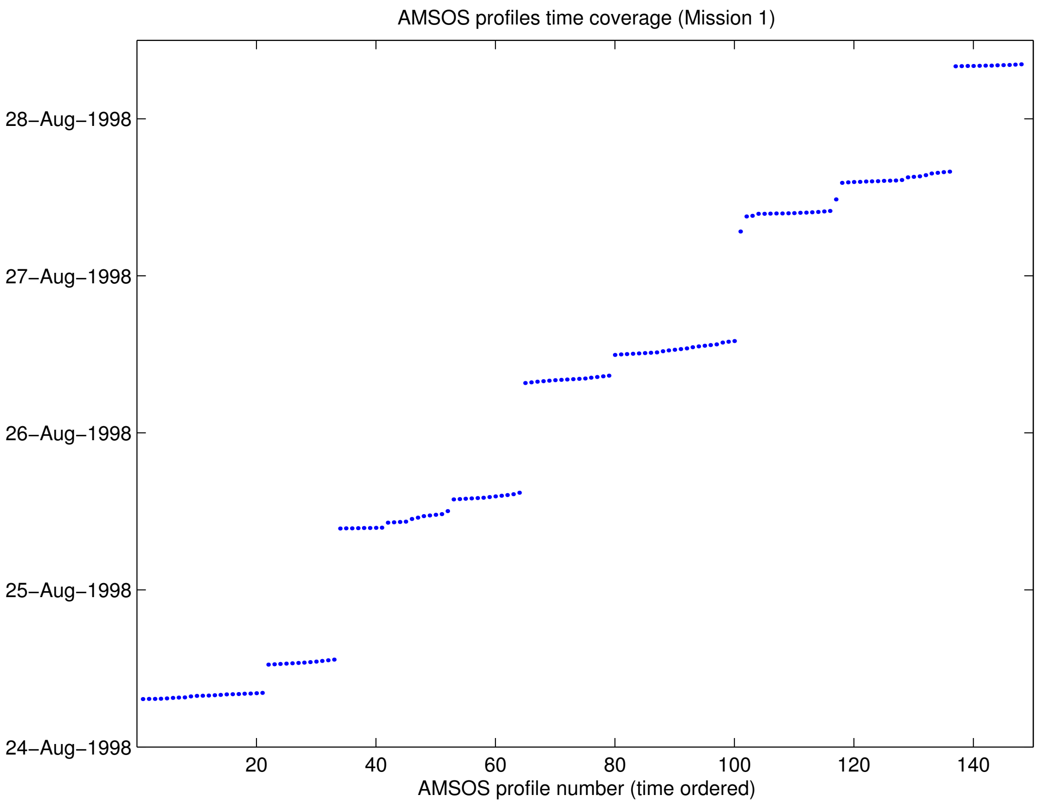

Figure 3: Time coverage of the AMSOS profiles.

formation with decreasing altitude. This is illustrated in Figure 5 which shows a typical averaging kernel of the AMSOS retrieval. The peaks of the averaging kernel are a measure of the retrieval's vertical resolution and sensitivity to the observed parameters. Below 15 km, the retrieved microwave profile basically falls back to the a-priori profile that was used as part of the retrieval process. Since that a-priori profile was taken form the US-Standard atmosphere and had nothing to do with ECMWF data, one would not expect any match between the two.

Above 40 km the two profiles start to diverge with increasing altitude. That was expected since ECMWF only takes CH_4 oxidation into account but not photolysis of H_2O. Therefore the ECMWF profile approaches a constant H_2O volume mixing ratio at the top layers. However, in the real atmosphere water vapor photolsysis reduces H_2O above 40-50 km with increasing altitude. This leads to a peak that is typically found near 50 km when the H_2O-distribution is mainly governed by large-scale transport.

A comparison of all microwave profiles from the aircraft mission of 1998 showed that not all profiles compare as well as the first example (see Figure 6). It

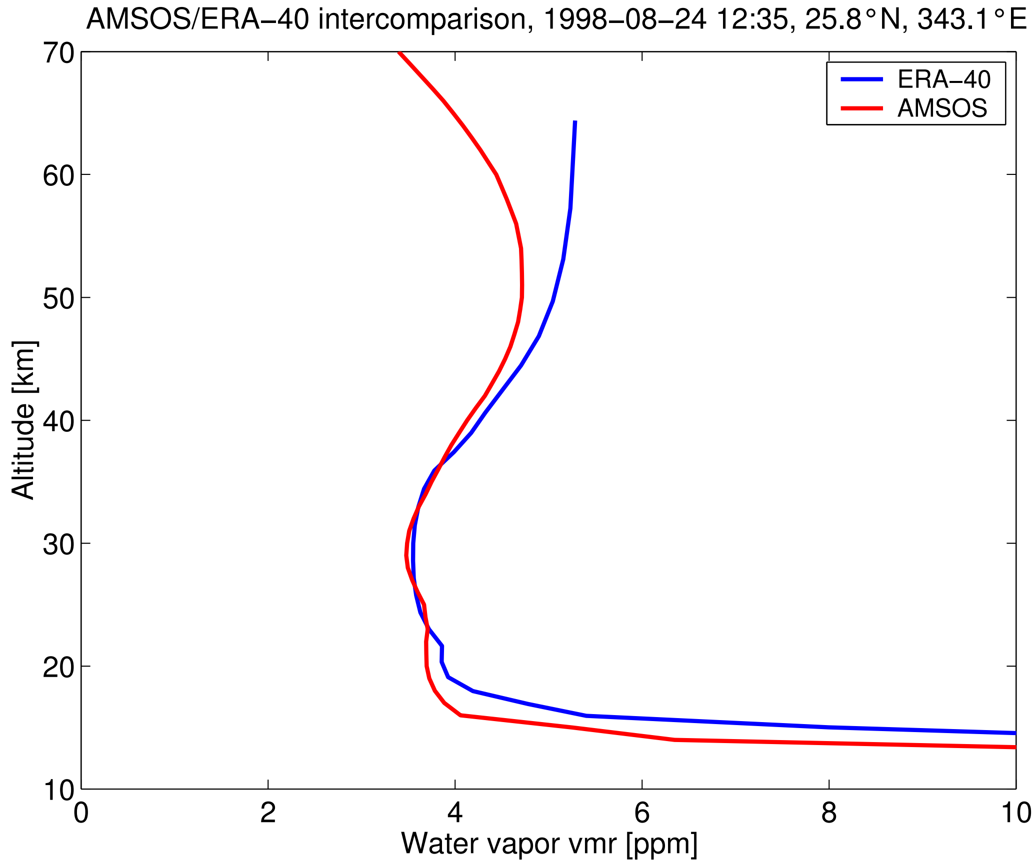

Figure 4: Single profile intercomparison AMSOS vs. ERA-40

is not clear yet if the large discrepancy aound profiles no. 30-45 is a small-scale atmospheric feature that was not captured by ECMWF or an artifact in the microwave profiles. However, all profiles beyond profile no. 70 agree very well with their ECMWF counterparts and even reproduce very fine details like the steep increase of H_2O around 25 km from profile no. 75-85. In general, the difference between the two data sets is usually smaller than 1 ppm with slightly higher values for the ERA-40 profiles.

6 Personal summary

For personal reasons on my side as well as Alan Geer, this STSM had to be shorter than originally planned. Not counting the traveling days and the weekend in between, only six full working days remained. During this limited time, it was not

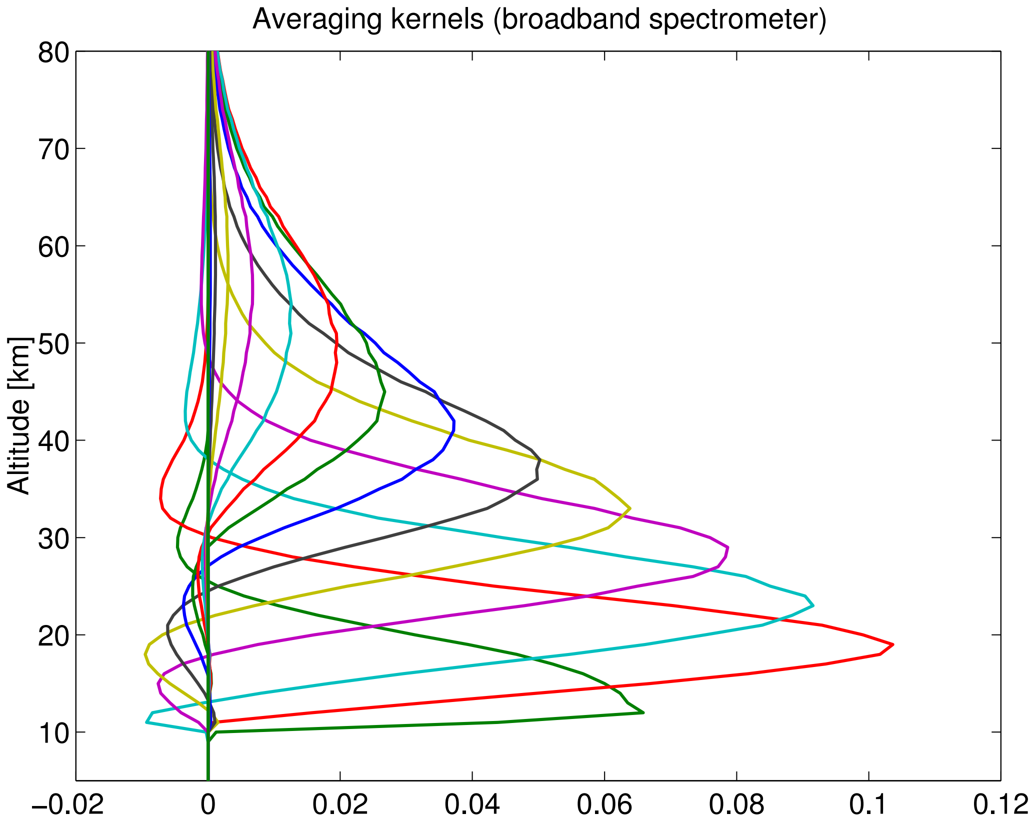

Figure 5: Example averaging kernel for the AMSOS retrievals in mission 1.

possible for me to pick up a lot on data assimilation. Since the water vapor assimilation scheme for the Metoffice model had been delayed, it would have been a waste of time to dive too far into the theory of data assimilation.

However, I did pick up a lot on the practical issues of using and interpreting data from models like ECMWF. Even though I managed to get access to the ECMWF archive server MARS some weeks before my trip to Reading, I hardly understood how the huge selection of data products on this system could be used. Through the many discussions with my colleague Alan Geer and through a visit to ECMWF I learned many different things:

- which of the many data products on ECMWF's archive server MARS are the ones that I need?
- on what coordinates does a spectral model like ECMWF's IFS run internally and how can they be converted to my own favorite coordinates to get a much higher vertical and horizontal resolution than the ECMWF standard

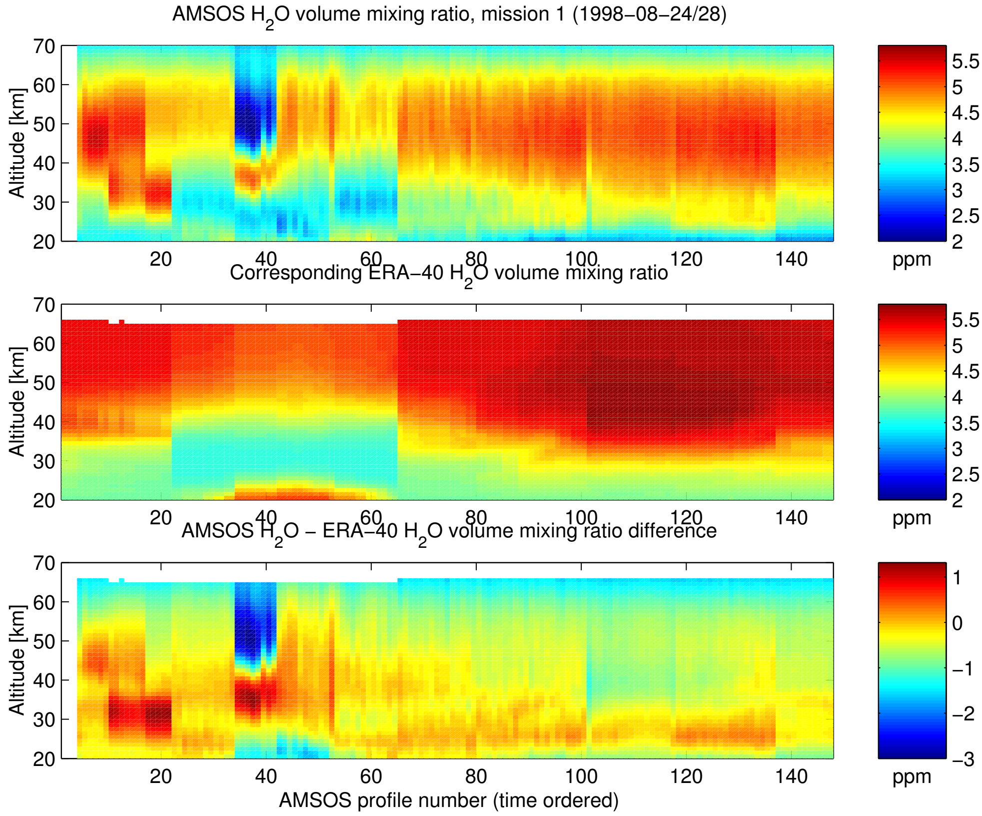

Figure 6: Intercomparison for the whole 1998 mission. The top plot shows H_2O profiles retrieved by AMSOS. The center plot show the corresponding ERA-40 profiles that were closest in time and space on the same color scale. The bottom plot shows the difference of the two data sets.

products?

- what are the differences between the different versions of the IFS model?
- how can I find important internal parameters of the ECMWF model in the IFS source code?
- how can I handle the huge amounts of data that ECMWF puts out every day?
- how can I read the ECMWF data files and use them with my own software?
- where can I trust the ECMWF model output and where not?

Even though many of the points above may seem trivial for someone from the modelling community they were not at all obvious to me. In fact, I would guess that only a few people from the experimental community really understand how to use this model output. Therefore, I did profit a lot from this visit. If I had known all these things before, it would have been much easier for me to interpret my own data in the past.

7 Outlook

It was clear from the beginning that the whole study could not be finished during the visit to Reading. The plan was to find out if such an intercomparison between AMSOS and ECMWF data would be feasible and how much could be expected from it. Since the comparisons that were carried out during the visit looked very promising, the plan is to reproduce them for all five aircraft missions from 1998 to 2002. This work should be carried out between January and February 2005. There is also an option to repeat the microwave retrievals with spectra that have undergone an improved calibration and quality-control. Those spectra were not available when the H_2O profiles were first retrieved.

The interpretation of the results will be continued when Alan Geer from Reading University returns from a two-month trip in February/March 2005. The mid-term goal is to extend the study into a journal article in Geophysical Research Letters or a comparable journal. The long-term goal remains to do a similiar comparison with the water vapor product for the Metoffice model that is currently being developed at the University of Reading.