Introduction

The workshop was organised and sponsored by ECMWF. Following the successful launch of the AQUA satellite on 4 May 2002, a subset of radiances from the Atmospheric InfraRed Sounder (AIRS) instrument have been made available to the NWP community in near-real-time since the end of October 2002. All major NWP centres have undertaken scientific validation as well as technical preparation for the assimilation of this new class of sounder that can provide unprecedented high vertical resolution temperature and atmospheric composition information due to the multi channel nature and high spectral resolution of the instrument. AIRS is the first of a new series of advanced high spectral resolution sounders that will fly within the next 5 years (IASI on METOP, CrIS on NPP) and active preparation is underway at NWP centres to take full advantage of these future operational missions.

Significant progress has been made in the exploitation of AIRS (characterisation of biases, noise, information content) and an increasing number of centres have demonstrated a positive impact from this instrument on the quality of the numerical forecasts. However, the use of AIRS is still in its infancy: Only a small subset of the data is available (324 channels out of 2381 and 1 field-of-view out of 9), cloud detection algorithms have been designed to be extremely stringent and observation error characteristics have also been specified very conservatively. It is therefore considered timely that NWP centres share their experience of their day-1 use of AIRS data and address outstanding issues. Radiative transfer modelling, handling of clouds and systematic errors, information content extraction, monitoring and assimilation strategies were the most challenging topics considered during the workshop.

The workshop followed the usual format of invited lectures followed by discussion in working groups and it concluded with a plenary session. Ample time for discussion was also allowed at the end of each lecture session ("RT modelling", "treatment of clouds", "Assimilation", and "Information Content". This allotted time was very successful at shaping the issues to be discussed in more depth during the working groups. Two groups were then set up to consider the subjects of: "Data assimilation and information content" and "RT modelling and treatment of clouds". The recommendations of the working groups are summarised in the following two reports. The contributions of the workshop have also been posted on the ECMWF web site (http://www.ecmwf.int/publications/)

ECMWF would like to thank all the participants for contributing to a successful and stimulating workshop.

Working group 1: Data Assimilation and Information Content

Participants: J. Derber (chair), R. Engelen (sec), P. Antonelli, N. Bormann, T. Auligné, A. Collard, D. Dee, A. Dudhia, S. English, M. Goldberg, R. Hess, E. Lim, T. McNally, C. Rodgers, A. Simmons, P. Schlüssel, J.-N. Thépaut, G. Van Der Grijn

Recommendations:

Highest Priority

Use of Principal Component Analysis (PCA)

- **To ECMWF and operational DA community:** Recommend begin/continue testing the use of noise-reduced PCA based radiances in DA systems
- **To ECMWF and operational DA community:** Further study to examine feasibility of RT for PCA and for use of PCA in cloudy regions.
- **To satellite data providers:** A Flag indicating which set of PCs should accompany reconstructed radiances (this is particularly important for reanalysis).

Cloudy data

- **To ECMWF and operational DA community:** Because of the presence of clouds the use of high spectral resolution data is limited. Short-term solutions to this problem are the use of cloud-cleared radiances or the introduction of a sink variable in the data assimilation system. The complete use of the cloud information is probably a long-term project. Both short- and long-term solutions for the cloud problem should be supported.
- **To ECMWF and NESDIS:** Evaluate the use of cloud cleared radiances
- **To research community:** Study cloud detection over land/ice, especially to allow cloud detection without use of prior surface emissivity or temperature information

Data resolution

- **To ECMWF**: For reanalysis purposes need to either develop agreements (NASA, NESDIS, Eumetsat) to store and reprocess the data with external agencies or store data internally. Full resolution data needed.
- **To satellite data providers, ECMWF, and operational DA community**: Make available and use full spatial resolution AIRS data for improved hole hunting.

Handling of biases

- **To All**: Recommendation to continue to reduce need for bias correction in all components of system. It is especially important for NWP centres to use best radiative transfer (spectroscopy, LBL modelling, etc.) available.
- **To ECMWF and operational DA community:** Improve model bias and bias correction methods in relevant areas to allow better use of satellite data.

Error covariances

- **To ECMWF:** Improve background error covariance to allow inclusion of smaller scale vertical and horizontal information in the advanced satellite data (esp. moisture).
- **To ECMWF and operational DA community:** Immediate effort to define and include off-diagonal observational/representativeness error covariance elements

Monitoring and data stream

- **To satellite data providers:** Release new data to NWP centres as soon as data are available at ground stations to provide critical monitoring and feedback to satellite data providers and development of data assimilation capabilities
- **To ECMWF and operational DA community:** Development of coordinated automated monitoring systems to handle large volumes of data essential
- **To All:** Recommendation to agree in advance among NWP and satellite data providers about data comms, formats, etc. for new instruments

Longer-term priority

- To ECMWF, operational DA community, and satellite data providers: Produce and examine use of PCA of cloud-cleared radiances
- To ECMWF, operational DA community, and satellite data providers: Monitoring in PCA space is possible and should be begun
- To ECMWF and operational DA community: Produce limited set of standardized monitoring statistics and plots.
- To ECMWF and operational DA community: Recommend collaboration between various efforts (GEMS, JCSDA, etc.) for trace gas assimilation
- To ECMWF and operational DA community: Recommend investigating radiance assimilation vs. brightness temperature assimilation
- To research community: Need to further investigate info content of AIRS data with respect to moisture.
- To all: Evaluate the cost/benefit for high spectral resolution infrared sounders with higher spatial resolution.

Working group 2: Radiative Transfer Modelling and treatment of clouds

Participants: J. Eyre (chair), P. Watts (sec), F. Chevallier, W. Graesle, S. Heilliette, A. Huang, G. Kelly, L. Lavanant, M. Matricardi, R. Saunders, J. Smith, W. Smith, M. Szyndel

Recommendations:

RT modelling

Quantisation of training data sets

It is established that 100 vertical levels is adequate for RT models for foreseeable future.

For transmittance modelling trend is towards NWP model sets with good sampling and consistent treatment of water profile to high levels.

Surface parameters, e.g. spectrum of emissivity are needed for ~ 20 surface types.

Recommend more work in land surface spectral characterisation and validation. To Space Agencies

Short term aims are consolidating atmospheric and surface data sets individually. In longer term there may be a need to combine the two.

Spectral Response Functions

There is some uncertainty about the accuracy of SRFs for AIRS (Spectrometer).

Recommendation: to NOAA/NASA, provide information.

For interferometers (IASI/CrIS) no special problems are anticipated.

Apodisation (Interferometers)

It is noted that apodisation leads to an attenuation of interferogram information close to maximum Optical Path Difference. Careful attention in the data processing is needed to avoid the loss of this information.

Apodisation problems are expected to be less serious for IASI than CrIS, and particular care is required for the CrIS longwave band.

Although there are theoretical advantages in using unapodised data for retrieval/assimilation, there are technical problems in the forward modelling of such data.

Recommendation to consider whether fast models for un-apodised data are required. To NWP centres.

Spectral resolution for CrIS

When CrIS was designed, it was decided to truncate the observed interferogram by a factor of 2 in the midwave band and a factor of 4 in the shortwave band in order to minimise the telemetry requirement. However, since then, the telemetry bandwidth has been defined such that the full CrIS data stream can be

transmited to the ground and it has been determined that the full resolution data is needed to optimise the water vapour profile accuracy and to produce CO concentration from the CrIS data.

It is strongly recommended that the full CrIS data stream be transmitted to the ground. TO: Space Agencies

Spectroscopy

Spectroscopy constitutes the main limitation to RT modelling (in clear air over sea).

The MIPAS community has quantified the effects of spectroscopic and other systematic errors on the overall error budget and this approach is also encouraged for nadir sounders.

Recommendation that the approach of MIPAS community to mapping spectroscopic errors is investigated.

Handling more than 1000 channels

The Principal component radiative transfer method, PCRTM, is very promising as it offers a way of modelling radiances in thousands of channels with very many fewer RT calculations. It has been demonstrated for the clear air case. It needs careful training to cover all atmospheric cases of interest, and the extension to the cloudy case has yet to demonstrated.

Recommend to support further development on the PCRTM methodology for the NWP application.

Bias correction

Bias correction schemes should as simple as possible and oriented towards physical correction methods. Results from the gamma correction method were considered very promising.

Recommendation to consider operational use of this method to NWP centres.

Variational bias correction potentially offers technical advantages for operational NWP systems. However, standalone bias correction schemes may still be more appropriate for studying bias problems.

It was noted that improvements in bias correction also helped in reducing horizontally correlated observation error.

Error modelling

Spectrally correlated errors, in the observations and/or the forward model, are important; their neglect leads to sub-optimal use of the observations.

Recommendation more research is needed on how to characterize and allow for correlated observation errors in data assimilation. To NWP Centres

Monitoring

Recommendation to standardise monitoring plots between NWP centres for AIRS and other advance sounders. to NWP centres and NWP SAF.

Fast unified model

In developing more sophisticated fast models, it is desirable to retain a fast modelling framework which is unified across all satellite instruments.

Jacobian robustness

There is strong evidence that fast model jacobians can be unstable (e.g. RTTOV-7).

Recommendation that priority be given to improving the robustness of jacobians in fast models. To NWP centres

Aerosols

Nadir sounders: The inclusion of aerosols in fast RT models will be required in the medium term for air quality and other applications.

Limb sounders do not seem to present additional challenges from this point of view.

RT modelling Speed

For NWP RT is a major load on operations and so improvements in efficiency in this area would have direct advantages.

Some centres save time by storing the Jacobian matrix in the inner loop of the 3/4Dvar minimisation.

Recommendation to consider this approach.
To: ECMWF

Limb RT

The importance of the impact of horizontal gradients in the limb RT model (RTMIPAS) should be characterized. The value of a 2D operator for assimilation should also be investigated. **Recommendation to consider these issues. To ECMWF.**

Treatment of clouds

Assimilation of clear radiances and cloud detection

At present the evidence is that AIRS cloud detection is currently quite effective but conservative. The focus in this area should be on studying cloud detection performance in marginal cases.

Two approaches offer promise for improved cloud detection for advanced sounders:

- through the spectral signatures of cloud (PCAs)
- through use of colocated imagery

Also use of noise reduction methods is likely to improve cloud detection.

We support the NESDIS plan to supply MODIS cloud information collocated with AIRS data.

There is an urgent problem concerning the pre-processing of IASI data at NWP centres. At day-1 significant data reduction will be required ahead of the NWP system. It is desirable that this should include intelligent NWP-independent cloud detection. This is scientifically the least mature aspect of plans for IASI data processing.

Recommendation that NWP centres give high priority to a detailed definition of the pre-processing of IASI data prior to their NWP systems.

Assimilation of cloud-cleared radiances

NESDIS cloud cleared AIRS data is available in easily usable form. Of the order of 50% of AIRS data would then be available to assimilation (compared to 5% for completely clear data).

Recommendation to ECMWF to perform trial assimilations of the NESDIS data.

Initial experiments should focus on data over the sea.

To assist in this work information on the error characteristics of this data would be useful.

Recommendation to NESDIS to characterise the errors of the product.

Because of concerns about the propagation of AMSU information through the cloud-clearing algorithm, the working group encouraged the use of MODIS for cloud-clearing.

Assimilation of cloudy radiances

Some benefit is to be expected from continuing the 'linear channel' assimilation work started by F. Chevallier but the limitations of this approach are clear; it is not expected to work for channels strongly affected by cloud, e.g. IR channels peaking in the low troposphere.

Recommend to continue to exploit 'linear' channels in 4Dvar.

Because of the limitations, alternative approaches are needed.

There is good evidence that tropospheric temperature/humidity information is available in more strongly cloud affected cloudy radiances and to exploit this there is a requirement for an accurate cloudy RT model. Accuracy implies that it must be able to reproduce measurements in critical sounding channels to an accuracy comparable to the radiance increment equivalent to a typical NWP background error.

Recommend we start to assess how well this can be met using e.g. 1Dvar solver using a fast cloudy RT model and a simple parametric representation of cloud.

Recent work at the Centre has already provided the fast RT modelling capability. The parameterisation needs to be defined.