REPORT ON THE SECOND INTERNATIONAL IASI CONFERENCE

SEVRIER, FRANCE

25 TO 29 JANUARY 2010

CNES – CENTRE NATIONAL D'ÉTUDES SPATIALES

EUMETSAT

SUMMARY REPORT ON

THE SECOND IASI INTERNATIONAL CONFERENCE

SEVRIER, FRANCE

25-29 JANUARY 2010

CONFERENCE ORGANIZED BY: **CENTRE NATIONAL D'ETUDES SPATIALES (CNES)**

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With the participation of CNRS/INSU

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and the contribution for the status reports of all the Chairs of the sessions

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EXECUTIVE SUMMARY

The second International IASI Conference took place about three years after launch of the IASI instrument on the MetOp-A platform and only 30 months after the first data were distributed to users (beginning with NWP centres).

The conference confirmed the good performance of the instrument and system, maintained by CNES and EUMETSAT. The data availability is very good (more than 95%). The performance of IASI has been continuously assessed by the IASI TEC and is routinely validated against NWP model output. This monitoring shows that the spectra are of a very good quality: very well calibrated radiometrically (bias below 0.3 K) and remarkably stable. As a consequence, the use of IASI data allows very good results to be achieved, and the creation of products which were unexpected at the time the instrument was designed.

A key role of IASI is in support of numerical weather prediction (NWP). A large number of centres now assimilate IASI data. They all showed a significant impact on global NWP – the largest single impact of any instrument even on top of existing systems. No centre has reported any problems in the real-time availability of IASI data, which is a significant endorsement of the EUMETSAT EUMETcast distribution service. There are differences in the way the data are used between centres, in the number and set of channels used, and the regions and conditions where they are used. The impact obtained by the various centres suggests that a wider usage of IASI data over e.g. clouds, polar regions and land surfaces will lead to further impact. The IASI data are used in limited area (regional) models as well, where good benefit can be demonstrated, even to variables which are not closely related to the measurements themselves, like wind and precipitation. The move to assimilate more IASI data in regional models is very encouraging but raises its own challenges. Since most regional models have large land fractions the challenges of utilising IASI data over land become even more worthy of study. The conference presented several results showing the development of emissivity atlases and the retrieval of surface temperature and emissivity using IASI data. The challenges of utilising IASI data near the surface remain significant, particularly where the thermal contrast between the surface and the lowest layers of the atmosphere is small, but it is encouraging to see growth in research in this area. Additionally, the assimilation of IASI ozone channels by ECMWF gives very good results verified against MLS, comparable to those obtained with the more established UV spectrometers.

The campaign experiments set up for the validation of level 1 or L1 (Joint Airborne IASI Validation Experiment (JAIVEx)) or level 2 or L2 (Lindenberg and Sodankylä) are now used extensively to inter-compare the inversion methods or assimilation products with *in situ* measurements, which gives an opportunity to investigate the limitations of the methods and of the data.

The high spectral resolution of IASI and its very high stability are extremely beneficial for atmospheric composition analysis. Yearly emissions of minor trace gases like NH_3 estimated from IASI are demonstrated to be consistent with models, but IASI retrievals have allowed the identification of some plumes not yet accounted for in the models. In case of events like biomass burning, dust storms or volcanic eruptions, many trace gases and aerosols can be detected. This is very useful for emerging operational applications like air quality monitoring and for the activities of the operational Volcanic

Ash Advisory centres. The retrieval of ozone profiles are of a very good quality, including for the first time tropospheric partial columns, providing information on air quality. Carbon monoxide retrievals have been validated with MOPITT, but IASI provides a much more complete coverage of information permitting the provision of daily maps which are routinely assimilated by ECMWF for the GMES MACC project. Very encouraging results were also shown for carbon dioxide concentration in the upper troposphere and total column methane retrievals.

Work has also been undertaken to develop schemes using IASI information for the retrieval of surface and cloud properties – paving the way for even greater use of IASI data. Some results were presented on the use of principal components (PC), and in particular PC radiative transfer, showing innovative ways of dealing with and utilising the high volume of data from satellite-borne interferometers – giving promise for the enhanced use of IASI

Other sessions during the conference focused on retrieval techniques and spectroscopy. Progress has been good, but some work remains to improve water vapour profile retrieval. This will require improvements in the spectroscopy. Further work is also needed on cloud and aerosol properties where an inter-comparison of products has been started, and on climate monitoring where IASI will play a critical role owing to its long lifetime and good instrument performance which allows it to be used as a reference for calibrating other infrared sensors.

In summary, the IASI instrument has proven itself to be well calibrated and stable and the results showed confirm its significant contribution to NWP and Climate Studies.

1. INTRODUCTION

The second IASI International Conference was held at the hotel “Les balcons du lac”, in Sévrier, France, from 25 to 29 January 2010. This event took place three years after the launch of MetOp-A (and with it IASI) on the 19 October 2006 and two years after the 1st IASI International Conference in Anglet. This conference was jointly organized by the CNES and EUMETSAT with the participation of CNRS/INSU.

The objectives of this second conference were:

- To give an update on the instrument performance and availability,
- To discuss the methods for data handing,
- To show the results of assimilation of IASI in numerical weather prediction models and its benefits for meteorology,
- To present the results of the continuing validation,
- To review the current level 2 operational products and compare them and their current quality with products from other agencies or laboratories.
- To recommend further level 2 algorithm developments where needed.
- To start to prepare IASI–B (what is needed for validation?)
- Drawing from the lessons learnt with IASI to feed the requirements of IASI-NG
- To promote IASI and broaden the user community and applications.

Around 150 participants attended the conference and provided either technical or scientific contributions. A list of participants is given in Annex 1. Twelve countries were represented plus two international agencies (ECMWF and EUMETSAT), several space agencies (CNES, NASA, DLR, SRON, etc.), several national meteorological services, and few industrial companies, including ThalesAleniaSpace, who manufactured the instrument.

The presentations were gathered on a range of issues which included:

- Instrument availability, performance and monitoring
- Data Handling : Processing, Compression, Distribution, Archiving
- Applications :
  - Weather forecasting (global or regional NWP)
  - Clouds and aerosols
  - Surface
  - Retrievals
  - Trace gases

- Spectroscopy and radiative transfer (RT) for IASI
- Product validation
- Next Fourier transform infrared (FTIR) atmospheric sounders

There were a total of 55 oral and 45 poster presentations. The oral presentations were 20 minutes long including questions. One special keynote on NWP was 30 minutes long. All posters were presented orally in five poster presentations: there were 3 minute-presentations for each poster. All posters were visible for the whole week but there were two special poster sessions to enable discussions with the authors. A special prize was awarded to the best poster. The programme was established by a scientific committee, the composition of which is given in Annex II. The conference programme can be found in Annex III.

At the end of the conference, the concluding session provided status reports, where the session chairs summarised the activities of each session by topic, as listed above. These reports, given in section 2, include for each topic a summary of the state of the art showing the highlights, the open issues and some suggestions of work to address these issues.

The scientific committee which held a meeting during the conference recommended maintaining a frequency of two years between two successive conferences in view of the number of new results and the wide perspectives of IASI use. The committee also decided to prepare a review paper of the major results to be published in the Bulletin of American Meteorological Society, and possibly an article which could be targeted at a more general scientific magazine such as the “New Scientist”.

2. STATUS REPORTS

2.1. INSTRUMENT AVAILABILITY, PERFORMANCES, MONITORING

by J. Taylor (Met Office) and C. Camy-Peyret (LPMAA)

2.1.1. HIGHLIGHTS

IASI continues to perform extremely well. It is working well within its specifications, is stable and providing a very high level of availability. The interaction between the EPS CGS (EUMETSAT) and the TEC (CNES) is working well allowing improvements to the level 1C data to be realised e.g. separate flags for the 3 bands and actual cloud fraction information for the 4 fields of view. The near real time monitoring of radiances works well and gives a clear indication of changes in the instrument or more often the NWP system. Presentations comparing the IASI instrument with AIRS and AATSR showed the stability and absolute radiometric accuracy. The comparisons with AATSR have indicated potential problems with the filter response of the 12 μm AATSR channel which will be investigated.

Ice contamination of IASI optics is well understood and an appropriate strategy is in place to further reduce down time. Other strategies to reduce down time have been implemented for Moon avoidance and recovery from single event upsets. Some of these strategies remain to be tested as EUMETSAT/CNES await events to test the new processes.

IASI continues to be a very successful mission and is fast being established as a reference standard for other satellites as part of the GSICS project. Its impact on NWP continues to expand and the growth in utilisation for atmospheric chemistry continues with a rapid expansion of the range of species being identified in IASI spectra.

2.1.2. ISSUES AND FUTURE ACTIVITIES

Some minor issues remain for the level 1C product where slight interpixel differences are manifesting themselves in some user processed parameters. This is potentially due to the Gibbs effect and this is being studied by EUMETSAT/CNES. There may also be some scope for an optimisation of the bit trimming applied to the IASI data in order to avoid the few data overflows that occur in the rare, but potentially important for climate, cases of major stratospheric warming.

2.2. DATA HANDLING: PROCESSING, COMPRESSION, DISTRIBUTION, ARCHIVING

By C. Clerbaux (LATMOS/ULB) and D. Klaes (EUMETSAT)

2.2.1. HIGHLIGHTS

A. Gambacorta *et al.* discussed the effects of scene inhomogeneities on the IASI instrument line shape (ILS) in order to assess the spectral characteristics and the order of magnitude of the error induced in the radiance spectrum. This error was found on average to be several orders of magnitude below the instrument noise across all bands.
More specifically, the error starts to become significant (i.e. comparable with the instrument noise) only for radiometric offsets of the order of 3σ values for band 1, 1σ value for band 2 and 2σ values for band 3, where σ (the standard deviation of the distribution of the radiometric offsets), is found of the order of 10^{-4} radians.
The centroid shifts also do not show any spatial correlation across the four fields of view. No significant correlation could be found between the NOAA algorithm retrieval biases and the shift in the radiometric centroid. It was concluded that other sources of errors are playing a more important role in determining the uncertainties of the retrievals.

P. Prunet *et al.* addressed in a poster the synergy between IASI sounding and AVHRR imagery for the processing of IASI data in inhomogeneous scenes, suggesting the use of the AVHRR radiance clusters in the IASI FOV in order to disaggregate the spectra and retrieve the spectra of the various components. The proposed method has increased the number of pixels which can be processed. The noise structure remains the same and the noise amplitude is not strongly increased. The inversion of the cloud cleared spectra yields consistent products like total columnar CO and ozone profiles in cloudy situations.

Significant progress has been made in the processing of IASI radiances for the monitoring of atmospheric composition, as shown by J. Hadji-Lazaro *et al.* in a poster contribution. The “near-real time” treatment of IASI level 1C data at LATMOS and ULB using the ULB algorithms at a different level of maturity are used to retrieve of total columns and/or profiles of reactive species like CO, CH_4, O_3, HNO_3, NH_3 and VOCs. The results allow also the tracking of pollution plumes and NRT alerts in cases of volcanic eruptions.

D. Klaes *et al.* summarised in a poster the current EPS/MetOp data processing and applications indicating that most EPS/MetOp products are now in routine operations. Exception is the trace gas products from IASI, which are still under validation. CO and ozone columnar amount products are currently being validated – CO is addressed in a specific presentation in Session 8. Applications from several instruments on the same platform provide possibilities for synergy applications, e.g. from IASI and GOME-2 for ozone and trace gas retrievals.

Synergetic use of MetOp/IASI and ENVISAT/MIPAS data was discussed in a poster by S. Del Bianco *et al.* Data fusion techniques were used to combine retrieved quantities. The problem of biases can be overcome using the measurement space solution (MSS) method for the representation of the retrieval products and for the subsequent data fusion. The MSS method was applied to the data fusion ozone profiles derived from MIPAS and IASI and their quality demonstrated by comparing the fused ozone profiles with those from individual retrieval products.

T. Labrot presented a web-site at Météo-France for real-time visualisation of atmospheric fields from MetOp. These can be combined with "conventional" data and model output. This web-site is hence an efficient tool for now casting, but also for the validation of products. The web site can be visited at http://retmetop.meteo-spatiale.fr/

A. Huang proposed a way to perform radiative transfer in a fast and efficient way on a huge amount of data like IASI spectra by using the Graphics Processing Unit (GPU) of computer graphic cards. This represents a low cost possibility to accelerate an IASI RTM by factor of 1523 using massive parallel processing on a GPU compared to a conventional system. This provides perspectives for the even huger amount of data to be processed from future instruments.

Compression

P. Prunet *et al.* discussed the progress of principal component compression (PCC) of IASI data and the exploitation of trace gases information for atmospheric chemistry. Results obtained through Principal Component Analysis (PCA) suggest some powerful properties of noise filtering but also highlight that specific events such as biomass burning could be missed, if spectra with similar features are not included in the training set. Such events are easily identified by the reconstruction scores, which will be disseminated together with the compressed spectra.

T. Hultberg showed in a complementary poster presentation that including outliers in the basis for the calculation of the eigenvectors allows the capture of a large set of atmospheric situations and, in particular, the retention of information on trace gases and pollution (e.g. ammonia) in the spectra.

Distribution

All MetOp products are disseminated in near real time via EUMETCast. ULB/LATMOS is also distributing CO chemistry products derived from IASI in near real-time, using the L1C data and level 2 temperature data (so called TWT directory) received via EUMETCast by the ETHER French facility.

Locally received IASI products are planned to be disseminated via the EUMETSAT Advanced Retransmission Service (EARS). This was discussed in a poster by C. Ponsard. A new EARS service, called EARS-IASI, is being established by EUMETSAT to complement the existing EARS-ATOVS, EARS-AVHRR and EARS-ASCAT services. A copy of the IASI level 1 processor (OPS-LRS) will be run at each participating reception station, together with an enhanced version of the AAPP processor. EARS-IASI dissemination will comprise 366 IASI channels, used by ECMWF (L1C, BUFR) and also PC Scores processed at EUMETSAT.

F. Montagner showed in a poster the upcoming modification of the IASI L1C product and the services for MetOp-B. A new level 1C format will begin trial dissemination in March (15 March 2010). It comprises some additional information:

- boolean quality flag
- detailed quality flag
- co-located IIS/AVHRR images for each IASI FOV
- cloud fraction from AVHRR

In the 2nd quarter of 2010 the parallel trial dissemination of PC score spectra is planned. The residuals will be available off-line.
MetOp-B launch is planned in the second quarter of 2012. Once it becomes the operational satellite, it is planned to disseminate the full spectra from MetOp-B and in parallel PCC spectra from MetOp-A through EUMETCast.

Archiving

All MetOp products are archived in the EUMETSAT Data Centre (formerly known as the Unified Meteorological Archive and Retrieval Facility UMARF). PCA products will be an addition, the original spectra will always be archived and kept. All MetOp products are also available in the NOAA CLASS archive. IASI level 1C products are also available in the French CNES ETHER archive.

2.2.2. ISSUES AND FUTURE ACTIVITIES

Near real time chemistry products from IASI are available for further scientific applications. Note that the lack of half the L2 temperature and humidity products. EUMETCast distributed data limits the current L2 trace gas products (Action EUMETSAT to provide L2 TWT products for all 4 pixels. Note: The full resolution L2 profiles will be available on EUMETCast from March).

Work on principal component scores has progressed well and we can expect the availability of compressed spectra which minimize the loss of relevant information on trace gases and species. It is welcomed that such spectra will be disseminated in parallel soon. This will allow them to be tested in assimilation and applications and to see how robust and accurate the method really is. Attention has to be taken to verify that the information on relevant species is kept. It will be also important to see whether for some applications, such as chemistry monitoring, there will be a user need to receive the full IASI spectra (in case the PC scores do not keep all the information), or whether the trace gas retrievals are able to benefit from the increased signal to noise ratio in the reconstructed radiances.

Further investigation will be required into the assessment of non-homogenous scenes in order to find the origin of uncertainties in the retrievals.

It was noted with satisfaction that the dissemination of locally processed data in the framework of the EARS service is planned, and that the basis of it is the IASI OPS software. This underlines the need to watch closely in order that the consistency of the local and the global processing software is ensured.

It was noted that data are fully archived. It was also noted that re-processing of the full data record after spectral re-calibration would be necessary.

An application including the use of the Graphics Processing Units (GPU) for massive parallel processing was noted with interest, having in mind the high amount of data and the interest in achieving the fast processing of full spectra. This was noted also with regard to the even higher amount of data from future instruments and this is an activity to follow further.

2.3. WEATHER FORECASTING (GLOBAL AND REGIONAL NWP)

By A. McNally (ECMWF) and V. Guidard (Meteo France)

Following the launch of MetOp-A in October 2006, NWP centres quickly started to assimilate IASI radiances and there were examples of the data being used operationally as early as mid-2007. Even with a fairly conservative setting to the assimilation parameters (e.g. data selection, cloud detection and channel selection) the clear positive impact of IASI was demonstrated in systems that were already using data from many other sensors (e.g. multiple ATOVS sensors, SSM/I and SSM/IS and AIRS). At the time of the 2^{nd} International IASI Conference (i.e. 3 years later) the majority of NWP centres now assimilate IASI data in their operational global model. Evaluations of the impact of IASI have been consolidated with some exhaustive experimentation. Recent results from a 1 year test period confirm the strong forecast impact of IASI (and AIRS), but also show a clear benefit of having two hyper-spectral sounders compared to one.

While channel usage has increased slightly compared to day-1 systems, the limit is still about 200 channels - most of these located in the long-wave CO_2 band and providing information on temperature. Some data in the IASI water vapour band are now assimilated, but this is currently restricted to a few tens of channels. Difficulties related to the modeling of observation error correlations, ambiguities with temperature, non-linearity of Jacobians and biases in the assimilating NWP model have been suggested as reasons for the continued under-exploitation of the IASI water vapour band. NWP centres identify this area as a priority in which progress has to be made. One advance towards using more of the full IASI spectrum for NWP is in the ozone band. Preliminary results were shown that demonstrate that constraining the assimilation with IASI ozone channels produces analyses of comparable or better quality than those based upon the more established ultra violet ozone observations.

Spatially, the IASI data are still underused. Observations are typically thinned to a resolution of 120-180 km and only one of the four available pixels is assimilated. Data usage over land and sea-ice has generally increased. Nevertheless the channel selection is still conservative because the modelling of surface emission (from surface temperature and surface emissivity) is not sufficiently accurate. Promising results from explicit surface temperature estimation using the IASI data were presented in the framework of the ConcordIASI project. As the modelling and estimation of surface parameters is key to the further exploitation of sounding data over land and ice surfaces, research activity in this area is a priority.

The detection of clouds in the IASI data is achieved through a variety of methods and most NWP centres assimilate clear channels above the cloud top. A significant step forward since the 1st IASI Conference has been made with the assimilation of cloud-affected radiances (3 oral presentations). Strategies differ from one centre to another, but a common feature is the use of a simplified single cloud layer representation. It is acknowledged that in the future this is likely to be superseded by a more realistic description of the cloud conditions. In a significantly more complex framework the interplay between cloud variables (e.g. cloud water and ice profiles) and other geophysical variables (e.g. temperature and humidity) will be constrained by, and fully interact with, the NWP model physics and dynamics during the minimization process.

Since the 1st Conference, centres have begun to assimilate IASI in limited-area models (LAMs), from mesoscale to convective scale (2 oral and 1 poster presentations). Progress has been accelerated by incorporating the experience gained in global systems and positive impact of IASI has been demonstrated (even on precipitation forecasts). The density of radiance data used in finer mesh models is higher (up to 80 km), but with most of the model domains covering land areas, even more emphasis is placed on the accurate modelling of surface emission.

2.4. APPLICATIONS: CLOUDS AND AEROSOLS

by L. Lavanant (Meteo France) and P. Schlüssel (EUMETSAT)

2.4.1. HIGHLIGHTS

The detection of cloud and dust/aerosols is a key pre-processing step of the IASI data before any retrieval of atmospheric/surface parameters.

Mineral dust aerosols play an important role in climate by altering the radiation budget. Their direct radiative effect can modify the general circulation on climate timescales, but also at shorter time scales. A key issue of IR remote sensing is its ability to retrieve aerosol optical depth (AOD) as well as mean dust layer altitude, a variable required for measuring the impact of aerosols on climate. Moreover, since hyperspectral atmospheric sounders like IASI have a large sensitivity to dust spectral signatures, dust must be incorporated into profile retrievals for accurate results.

Three oral presentations and one poster on this topic were given at the conference. Notice that the number of studies with IASI has increased since the last conference (only one presentation at the first conference). New techniques taking full advantage of the high spectral resolution of the IASI sounder have been developed. The higher spectral resolution of IASI compared to AIRS should allow a better characterization of aerosol properties by avoiding the spectral regions covering main water vapour lines.

L. Clarisse presented a simultaneous retrieval scheme for gases and aerosols, capable of distinguishing different classes of aerosol and deriving particle radii and concentration. The tool works with any type of aerosol and is suited to the study of pollution events. However this tool is not fit for operational use yet as it takes about half an hour processing time per spectrum.

L. Klueser introduced a fast retrieval scheme for dust aerosol optical depth based on brightness temperature departures of several channels centred at 11 μm with a reference channel at 12 μm. Indeed, mineral dust is characterized by high extinction around 10.5 μm and significantly smaller extinction around 12 μm. This scheme is used to determine the most likely dust type, surface emissivity and dust layer temperature using pre-calculated AOD spectra for 5 different dust mixtures. Validation is still preliminary.

S. Peyridieu presented an inversion method based on a look-up table approach which allows simultaneous retrieval of the AOD and dust altitude. The method was developed for AIRS and gives a very good agreement of AOD between AIRS and MODIS and of dust altitudes with CALIOP. It is now applied to IASI observations with encouraging preliminary results.

The poster by H.-T. Lee presented simulations of IASI spectra for different dust characteristics used to define a retrieval scheme. A set of IASI data covering Asian dust situations has been compiled. An initial analysis shows encouraging results.

Dealing with cloud-affected radiance spectra is also a critical issue for accurate atmospheric profiles and trace gas retrievals. At the first IASI conference it was recognized that there is a need for additional cloud information inside the IASI product. This has been taken into account and the future operational L1C products will include the cloud flag and fractional coverage.

Two oral presentations and one poster were given during the session on this topic.

F. Faijan compared two inversion methods with observed cloud-affected radiances and with cloud-cleared spectra. He showed the impact of both methods by comparing their degrees of freedom in the retrieved fields for a 24 hr period.

C. Stubenrauch provided effective cloud emissivity, pressure and bulk microphysical properties of semi-transparent cirrus. The scheme is based on a χ^2 minimization and has been used for long-term climatology with TOVS and AIRS. It shows good agreement with CALIOP data and has been recently adapted to IASI.

M. Ridal presented a poster on the CO_2-slicing cloud product validation done in the context of the NWCSAF. This method is very similar to the one implemented at EUMETSAT. The poster shows good agreement with CALIOP data.

Several presentations given in different sessions were also largely related to cloud detection and processing that shows the importance of cloud characterization for different applications. Three oral presentations on the assimilation of cloud-affected channels (N. Fourrié, A. McNally, E. Pavelin) and a poster dealing with the inter-comparison of cloud products for cloud-affected channel assimilation (L. Lavanant) were presented.

2.4.2. ISSUES AND FUTURE ACTIVITIES

It has been recognized that IASI has a large sensitivity to dust spectral signatures and the presence of dust should largely affect the atmospheric retrieval accuracy. We encourage further activities on this topic.

Users that are not necessarily experts in dust detection express the need for a dust and aerosol type detection scheme to be used in a pre-processing step, as dust is one of the main ‘outliers’. This could be achieved by making available a simple dust pre-processing package including the dust AOD and altitude retrieval.

Many cloud characterization schemes are based on the CO_2-slicing method. This method has limitations with respect to low-level clouds and we recommend more work on coupling AVHRR and IASI data. We remind users that the AVHRR radiance analysis information provided in the IASI level 1C products easily allows this coupling. EUMETSAT CLP cloud product will take into account the coupling of both instruments with improved results and will be available soon.

Situations with multi-layer cloud formations are not taken into account by many schemes which only retrieve one cloud layer even in complex situations. When using such a product, the multi-layer situations should be flagged and we encourage the use of the AVHRR radiance analysis for detecting the heterogeneity in the IASI field of view.

Operational meteorological centres have started to handle cloud-affected IASI data. First inter-comparisons of cloud products show large differences mainly for small effective cloud amounts and low-level clouds. To understand the differences and possibly flag doubtful results, we encourage continued inter-comparison exercises to assess the quality of the operational cloud products. Performing the exercise where correlative measurements are available would help to evaluate the absolute quality of products (suggest high latitude comparison with CALIOP at orbit intersection).

Validation of retrieved cloud/dust products or of retrieved atmospheric profiles in cloudy conditions through field campaigns is important for their use in NWP/MESO-NH and NWC applications. We encourage the use of available data, such as those of the Lindenberg and Sodankylä campaigns, which are available on the EUMETSAT ftp server and which provide data of cloud-radar systems and ground-based temperature and water vapour profilers. Also of interest are other campaigns such as the ConcordIASI campaign near the Seychelles Islands, which will be available on the ConcordIASI web site and which should provide a set of marine dropsonde profiles in cloudy conditions. The necessity for co-registration of the campaign data with IASI spectra, AVHRR data, and NWP fields before their distribution is important for easy and efficient use by the community. Concerning the cloud detection itself, a EUMETSAT AVHRR/IASI cloud detection dataset covering more than 24000 globally distributed and visually analysed situations is available for the community.

2.5. APPLICATIONS : SURFACE

By C. Crevoisier (LMD)

Skin temperature and emissivity spectra are essential variables for climate studies, including the computation of total radiative budget, as well as the study of land-atmosphere interactions, and their parameterization in climate and (agro) meteorological models. Also, the retrieval of meteorological profiles, trace gas concentration profiles, and cloud and aerosol characteristics is strongly sensitive to getting emissivity and skin temperature correct. In particular, for NWP applications, a better description of the land surface emissivity and a consistent surface skin temperature will enable the use of more IASI tropospheric sounding channels over land.

2.5.1. HIGHLIGHTS

2.5.1.1. LAND SURFACE TEMPERATURE AND EMISSIVITY

Generally, in data assimilation or physical retrieval procedures, the emissivity and/or skin temperature are either:

1) kept constant, leading to significant errors on retrieved products, especially over regions where emissivity varies (e.g. vegetation, agricultural regions, snow);

2) taken from climatologies, usually established from other instruments (e.g. MODIS) or from catalogues (lab measurements);

3) included in the state vector (sometimes as a by-product) and thus retrieved simultaneously with temperature, water vapour, and gas profiles. In this case, the main problem is the correlation between the retrieved “emissivity”/“skin temperature” and the temperature of the first layers above ground. The retrieved surface emissivity and skin temperature do not necessarily have to be the truth but have to be consistent to ensure a successful retrieval. Possibilities for the decorrelation of surface characteristics from atmospheric temperature in data assimilation schemes are under investigation (for instance, using PC analysis).

Regarding the difference between surface temperature and the first atmospheric layers above ground, T. Phulpin presented the impact that temperature inversions have on the accuracy of the retrieved profiles in the lower atmospheric layers, and on the ability to retrieve profiles. In particular, even if the first guess of skin temperature from NWP models is reasonably accurate over some surface types and at certain times of day, in some situations errors are well above expectation. A few encouraging studies have shown that, when the thermal contrast is high enough (positive or negative), information on the boundary layer composition can be retrieved from IASI.

2.5.1.2. CLIMATOLOGIES

Two climatologies of emissivity and skin temperature are now available from IASI.

V. Capelle (LMD) presented a monthly climatology at a spatial resolution of 1° × 1° of skin temperature and emissivity spectra derived at LMD for the period July 2007 to now, based on the work described in Péquignot *et al.* (2008). The emissivity spectra are given between 3.7 to 14 µm, with a resolution of 0.05µm. The climatology will be available in the coming months at http://ara.lmd.polytechnique.fr.

D. Zhou (NASA) presented a monthly climatology obtained at NASA for the year 2008 at a spatial resolution of 0.5° × 0.5° based on EOF retrieval where the whole atmospheric state (T, H_2O, O_3, CO, cloud and surface parameters) is retrieved at once. The climatology is available upon request (contact: daniel.k.zhou@nasa.gov).

The precision for both emissivity climatologies is about 1-3 %, with a lower precision near the short waves because of the higher radiometric noise of IASI in band 3. The solar radiation might also impact the retrieval of surface temperature during day, and hence the retrieved spectral emissivity spectra (when both are performed simultaneously) leading to a daytime/nighttime difference in the emissivity spectra.

Seasonal variation of emissivity is clear in both climatologies.

2.5.2. RECOMMENDATIONS

Concerning the land surface temperature and emissivity:

- Retrieved surface characteristics should be compared to vegetation indicators such as NDVI, precipitation fields, etc.
- The retrieval of sea surface temperature (SST) from IASI should be investigated (or presented if studies already performed).
- It is important to correctly model the downwelling reflected component in RT models used for retrievals and assimilation.
- Identification of cases with high thermal contrast should be more systematically performed and the possibility of IASI to detect temperature inversions and to give information on the boundary layer composition should be further investigated.
- The correlations between available surface products and the temperature of the first layers above ground should be studied and characterized when both are retrieved at the same time. In particular, what exactly is called “emissivity” and “skin temperature”?
- When emissivity is not retrieved, use should be made of climatologies.
- Studies on emissivity/skin temperature should be tightly linked to study on clouds/aerosols, in particular in the context of non-homogeneous scenes to avoid possible misinterpretation.

2.6. APPLICATIONS: RETRIEVALS

By C. Serio (U. Basilicata) and P. Schlüssel (EUMETSAT)

2.6.1. HIGHLIGHTS

Session 6 included five oral talks and five poster presentations. The five oral presentations described different retrieval methods and showed applications of IASI data for the retrieval of temperature, humidity, O_3, CO_2, and surface emissivity.

P. Antonelli discussed physically based retrievals from IASI during the JAIVEx field campaign. The simultaneous retrieval of land surface emissivity is considered important. An open issue seems to be the proper characterisation of the background covariance. The use of reconstructed radiances from principal components seems to give superior results compared to the use of original spectral samples.

L. Lavanant discussed the way towards a better retrieval of fine structures in atmospheric water-vapour profiles. It was stressed that the simultaneous retrieval is very sensitive to the choice of the background covariance. A dynamic in-line selection of channels and a sequential retrieval helps to obtain water-vapour structures, but generally it was found that IASI is rather insensitive to low-level humidity, which is an inherent problem for infrared retrievals over surfaces that are of similar brightness temperature as the lower atmosphere.

G. Masiello summarised the inter-comparison of different statistical retrievals for the initialisation of an iterative retrieval for temperature, water vapour, and ozone. The so-called functional sliced inverse regression leads to a better resolution in the water vapour profile, while a simple EOF-based regression generally provides rather smooth profiles. Using ECMWF analyses at altitudes above 30 km for the initialisation of the iterative retrieval leads to biased results.

W.L Smith reported on results from a dual regression sounding algorithm for rapid extraction of cloud, surface and atmospheric sounding parameters. The dual regression handles IASI measurements under all cloud conditions and provides profiles either above the cloud top, or in case of thin clouds or cloud-free situations down to the surface. Generally, the retrievals from IASI data provide more humidity structure than respective NWP fields.

J. Taylor discussed results obtained from a 1D-var retrieval utilizing a principal component-based radiative transfer, which makes use of the full IASI spectrum and is still economic with computing time. Data from the JAIVEx campaign were used to study the retrievals in detail. Moisture structures are well captured in the free troposphere, while results closer to the surface suffer from lack of detail. The importance of correct error covariances in simultaneous retrievals is stressed. The retrieval works well over ocean and land.

A paradigm for these five talks is the JAIVEx experiment, which has been used as case study to assess retrieval accuracy and IASI consistency itself. Despite the different schemes, all presenters showed very good results for temperature. On the other hand, water vapour is still an issue and the presentations seemed to agree that a physical inversion step is important to improve H_2O final accuracy, in comparison to linear statistical regression.

Considering that for water vapour the inverse problem is not linear, some presentations explored the effect of different strategies. Some new results have been shown which exploit

- Proper time-space co-location of radiosonde observations,
- Proper training (which includes cloudy situations) of EOF regression
- New statistical approaches with an improved skill to reduce the dimensionality of the inverse problem, such the Functional Sliced Inverse Regression.

The recent improvement and advances in spectroscopy of some important atmospheric gas species, such as CO_2, have proven to be beneficial for the retrieval of temperature in the upper troposphere. The presentations have shown that a proper formulation of the background covariance is still an important issue to be addressed in future IASI studies. Furthermore, retrievals must account for the surface emissivity.

Presentations also showed that the utilisation of PC scores in retrievals is progressing well, thus focusing on using full IASI spectra instead of picking a few spectral samples.

Finally, some presentations focused on the analysis of spectral residuals and it was shown that systematic biases still exist, which call for improved forward modelling and spectroscopy.

The five posters have addressed further points concerning IASI applications, which covered:

- information content analysis
- synergy of IASI with other instruments (such as SEVIRI)
- fast forward modelling for IASI
- schemes to estimate OLR from IASI data
- temperature sounding in IASI band 3, exploiting N_2O channels

S. Clough discussed the importance of an information-centered representation of retrievals with limited degrees of freedom, such as retrievals of columnar amounts of trace gases. A post-processing step is proposed to transform full profile retrievals to the right degree of vertical resolution, commensurate with the information content.

K. Hungershöfer summarized a project to synergize the high vertical sampling and high accuracy of IASI water vapour profiles with the high temporal resolution but less accurate water vapour measurements of SEVIRI aiming at an optimal representation of water vapour fields. Such combined fields would be of benefit for NWP, nowcasting, and climate monitoring.

E. Le Flochmoën described a software package for the fast 1D-var retrieval of chemical constituents from IASI data. The package includes a pre-processing step to allow for spatio-temporal sub-sampling of the data, merging with *a priori* information from NWP and chemical transport models, and cloud detection. Examples of ozone retrievals are presented.

H.-T. Lee described development efforts towards a retrieval of outgoing longwave radiation from IASI data. The retrieval scheme is based on a regression model, set up with simulations from line-by-line calculations. This work follows up the climate data records derived from HIRS since 1979. Validation is ongoing using CERES data.

C. Pierangelo presented a novel approach of temperature retrievals in the shortwave N_2O absorption band with the aim of improving the sounding in the lower troposphere. The new retrieval technique has been applied to the JAIVEx data and shows promising performance. Retrieval of CO_2 from IASI could benefit from this retrieval technique which allows temperature information to be separated from the CO_2 signal.

Based on the oral and poster presentations, it is possible to conclude that

- The stability and accuracy of IASI data has been assessed and definitively proven
- IASI is beneficial to temperature sounding for the lower-to-upper atmosphere, and the accuracy provided in the free troposphere is within the IASI mission objective of 1 K in 1 km layers.

2.6.2. ISSUES AND FUTURE WORK

The same presentations lead us to conclude that there are still open issues, which are listed here:

- Boundary layer temperature and water vapour retrievals have to be assessed with more extensive case studies
- It seems that the 10% goal accuracy for water vapour cannot be reached everywhere in the troposphere, and there are parts in the lower troposphere, where the goal accuracy should be relaxed to a more realistic 15-20%. However, this point has to be addressed further with analysis of IASI data.
- Retrieval of lower-to-middle tropospheric water vapour fine structures is still an open issue.
- Some more spectroscopic and forward modelling effort is still needed to improve the calculations for synthetic IASI radiances and reduce the spectral residual within the IASI radiometric noise.

2.7. SPECTROSCOPY AND RADIATIVE TRANSFER FOR IASI

By N. Jacquinet-Husson (LMD) and L. Strow (U. of Maryland)

2.7.1. HIGHLIGHTS

This session included four oral presentations and one poster, covering two main topics: forward Radiative Transfer Modelling (RTM) and spectroscopic data for RTM's.

I. Forward Radiative Transfer Modelling (RTM):

1. Spectroscopy-based RTMs

X. Calbet *et al.* gave a presentation describing the most appropriate method for the validation of the OSS (Optimal Spectral Sampling) RTM used in the retrieval of the future level 2 products (moisture and temperature profiles), from the MTG-IRS instrument. Special emphasis was given to water vapour retrievals in the upper troposphere and lower stratosphere. The retrieval method, based on the use of real data from IASI, for MTG-IRS which is a similar instrument, has been described. As a first conclusion: RTMs reproduce IASI observations within 1σ instrument noise in the 1500-1570 cm^{-1} and 1615-1800 cm^{-1} spectral regions. Bias in these regions is less than 2% in absolute RH (representing an average of 0.06σ IASI noise, corresponding to 0.03 $mW/[m^2\ sr^{-1}\ cm^{-1}]$), but could not be measured exactly due to uncertainty in the bias correction of sondes, and variations in different RTMs.

S. Clough gave a keynote talk on the spectroscopic issues for the forward model for IASI. The approach presented, for the validation and refinement of the forward RTM modelling, relied on an evaluation of spectroscopic residuals in the context of temperature and species retrievals from IASI data themselves. The issues already resolved have been documented, including: line coupling for 667 cm^{-1} CO_2 Q-Branch (Niro *et al.*); CO_2 band head at 2385 cm^{-1} for low water vapour cases by an adjustment of the CO_2 continuum; CH_4 residuals with the introduction of Tran *et al.* line coupling scaled by a factor of 1.5,. The following remaining issues have been noticed: CF_4 needs to be included in calculations; N_2O appears to be variable requiring profile scale factors ranging from 1.00 to 1.04; widths of selected water vapour lines have to be changed by a factor of up 0.5 in the H_2O P-branch; the water vapour continuum has to be modified by up to –5% to +5%.

L. Chaumat *et al.* presented 4A/OP: A fast and accurate operational forward radiative transfer Model. 4A (Automatized Atmospheric Absorption Atlas)/OP (Operational) a user-friendly, fast and accurate, line-by-line RTM for the computation of transmittances, radiances and Jacobians, particularly efficient in terms of accuracy and computation time, was presented on a poster with associated possible computer capability illustration demos. It has been co-developed by LMD (Laboratoire de Météorologie Dynamique) and NOVELTIS, which has created the "operational" version and is in charge of its industrialization and distribution, with the official support of CNES: 4A/OP is the reference RTM for IASI level 1 Cal/Val and level 1 operational processing. The associated website http://www.noveltis.fr/4AOP/ includes an on-line registration form for its new version distribution consisting of: scattering for aerosol contribution (coupled with DISORT -Discrete Ordinates Radiative Transfer- RTM); an updated line-mixing for CO_2; the new GEISA 2009 Spectroscopy and the pressure shift for H_2O.

2. PC (Principal Components)-based RTMs

X. Liu *et al.* in their presentation on a radiative transfer model under cloudy sky conditions, recalled that IASI, an ultra-spectral satellite sensor with 8461 spectral channels, presents a challenge for processing in a physical retrieval system or in a Numerical Weather Prediction (NWP) data assimilation system. Modelling clouds is even more computationally demanding since it involves multiple scattering calculations. A Principal Component-based Radiative Transfer Model (PCRTM), which can efficiently calculate the IASI radiances under both clear and cloudy sky conditions has been presented. It has been shown that for up to six modelled layers of clouds, the results compared well with DISORT. Results of retrieving cloud properties have been presented as well.

M. Matricardi described a Principal Component Based Version of the RTTOV fast Radiative Transfer Model. The PC version of RTTOV (PC_RTTOV), based on the computation of a database of line-by-line spectra for a large number of diverse atmospheric situations, has been presented. It is a more accurate and computationally efficient version of RTTOV for IASI and AIRS developed by exploiting principal component (PC) analysis. In PC_RTTOV the profile dependent predictors consist of a selected set of IASI and AIRS radiances simulated using the standard RTTOV fast transmittance model. It has been shown that: the simulation of an IASI spectrum is typically 12 times faster than the simulation performed using the standard RTTOV model; the root-mean-square of the difference between fast model and line-by-line IASI radiances shows a significant and universal improvement when the PC_RTTOV model is used; for a consistent number of channels a ten-fold reduction of the rms error has been achieved compared to the standard RTTOV model. It has been emphasized that the availability of PC_RTTOV will also enable ECMWF to investigate the merit of the assimilation of PC scores to exploit the noise reduction capability of PC analysis (e.g. IASI band 3).

II. Spectroscopy data for RTM's

N. Jacquinet *et al.* described the evaluation and evolution of the GEISA/IASI Spectroscopic Database. The content of the 2009 edition of the GEISA (Gestion et Etude des Informations Spectroscopiques Atmosphériques: Management and Study of Atmospheric Spectroscopic Information)/IASI) spectroscopic database has been described. This IASI specific spectroscopic database has been initiated within the framework of the IASI Science Sounding Working Group (ISSWG). It is a sub-set, within the 599-3001 cm^{-1} IASI spectral range, of the whole GEISA database (10^{-6} to 35877.031 cm^{-1} spectral region; 50 molecules archived representing 110 isotopes; total of 3807997 entries). GEISA/IASI is a system organized similarly to GEISA, comprising three independent sub-databases devoted respectively to: line transition parameters of 20 molecular species, i.e.: H_2O, CO_2, O_3, N_2O, CO, CH_4, O_2, NO, SO_2, NO_2, HNO_3, OCS, C_2H_2, N_2, NH_3, C_2H_4, HCN, HCOOH, CH_3OH, H_2CO; infrared selected absorption cross-sections; atmospheric aerosol microphysical and optical properties. GEISA/IASI is the reference spectroscopic database for the validation of the level 1 IASI data, using the 4A RTM (4A/LMD http://ara.lmd.polytechnique.fr) and associated 4A/OP (see I-1 c). Results of "calc-obs" comparisons based on IASI observations have been presented. GEISA/IASI is implemented on the CNES/CNRS "Ether" Products and Services Centre WEB site http://ether.ipsl.jussieu.fr, where all archived spectroscopic data can be handled through general and user friendly associated management software facilities. More than 350 researchers are freely registered for on line use of GEISA.

A. Perrin *et al.* presented some recent results concerning quantitative spectroscopy of several tropospheric or stratospheric molecules: recent updates performed in the GEISA database. She showed, in particular, recent results for formic acid and formaldehyde for which recent updates were performed in the GEISA/IASI database. Regarding formic acid (trans-HCOOH): the 9 µm and 5.6 µm infrared regions are associated with the strong ν_6 and ν_3 bands, respectively. Located in an atmospheric window, the sharp Q-branch structure of the ν_6 band near 1105 cm^{-1} is commonly used to probe tropospheric formic acid by infrared remote sensing techniques. However, retrievals of HCOOH concentrations are also possible in the 5.6 µm region. The present update is the first inclusion of HCOOH parameters in the 5.6 µm region, and an intensity update at 9 µm. Indeed, at 9 µm the intensities were about 2 lower than laboratory measurements.
For formaldehyde (H_2CO), the major update in the infrared region for the line positions and line parameters involves the complete replacement of the line list at 3.6 µm and the addition of a list at 5.7 µm. The 5.7 µm corresponds to the ν_2 band together with three dark bands. In the 3.6 µm region the lines belong to the ν_1 and ν_5 bands together with nine dark bands.

2.7.2. ISSUES AND FUTURE ACTIVITIES

I SPECTROSCOPY SPECIFIC ISSUES

IASI related RTM spectroscopy problems still to be solved have been pointed out during the presentations. High priority areas to investigate are mainly related to H_2O, CO_2 and CH_4 and can be summarised as the following:

1. **H_2O: Highest priority**

a) Review the accuracy of water vapour line widths. This might be more important than the intensities

b) Review the water vapour continuum in the short wave window region (i.e. band 3)

c) Width and shift measurements of water vapour should be made (with temperature dependence if possible). Every spectral line relevant for IASI should be measured. Calculations are not proving sufficiently accurate.

d) Laboratory measurements should be performed to resolve the large spectral residuals in the R-branch.

e) The line shape of water vapour transitions requires assessment e.g. velocity dependent Voigt? The band centre spectral region of the ν_2 band is a prime candidate.

2. **CO_2**

Resolve the inconsistency between CO_2 ν_2 and CO_2 ν_3 bias by improving the CO_2 spectroscopy in the ν_3 band.

3. **CH_4**

Improve the methane spectroscopy, introducing line mixing

II GENERAL SPECTROSCOPIC REQUIREMENT TO ACHIEVE FORWARD MODEL ACCURACIES REQUIRED FOR RETRIEVALS FROM IASI AND FUTURE SOUNDERS.

In terms of outstanding spectroscopy issues, the following specific actions—which are already underway—must be reinforced and maintained:

a) Necessary validation: Assessment in GEISA/IASI of:
   - spectroscopic molecular species related to IASI trace gas retrievals, i.e: HCN, NH_3, HCOOH, C_2H_4, CH_3OH, H_2CO, added to already implemented ones more related to operational meteorology, i.e.: H_2O, CO_2, O_3, N_2O,CO, CH_4, O_2, NO, SO_2, NO_2, HNO_3, OCS, C_2H_2, N_2.-
   - cross-sections already implemented: i.e.: CFC-11, CFC-12, CFC-14, CCl_4, N_2O_5, HCFC-22. Consider complementary ones to be added (such as PAN).

b) The still outstanding general spectroscopy-related conclusions for public databases, from ISSWG -30 June-2 July 2008, CNES, Paris, France-, have to be remembered, i.e.: line coupling/mixing modelling, (which should be used in conjunction with the molecular parameters of the data base from which they have been derived) and non-LTE (Local Thermodynamic Equilibrium) effects are areas to be urgently investigated.

c) Recent results from S. Newman («Report on the impact of use of different spectroscopic databases on forward modelling of IASI and ARIES spectra and associated 1d-var retrievals » by *S. Newman OBR, Met Office, Exeter, UK (Version 1.1 21 January 2010)* and J.-M. Hartmann (a very new issue of CO_2

Line–mixing database, including line shifts and H_2O line broadening for humid atmospheres) will bring useful contributions.

2.7.3. CONCLUSIONS AND RECOMMENDATIONS FOR RTM'S

Making the assumption that the spectroscopic requirements to achieve forward model accuracies required for retrievals from IASI and future sounders, as quoted above, are satisfied, the following conclusions and recommendations for RTM's have been listed for RTMs' present status and future follow-up:

a) The use of principal component RTMs is increasing, for both clear sky and scattering atmospheres. 1D-var retrievals are successfully using this approach. However, the rather unconventional form of the PC Jacobians raises some concern on the use of the PC RTMs in NWP radiance assimilation.

b) The use of common RTMs among NWP groups is continuing. However, IASI chemistry applications use a wide variety of different RTMs and line-by-line algorithms. This does not appear to be a significant problem for most applications as long as the availability of updated spectroscopy databases continues.

c) Detailed inter-comparisons of various RTMs with *in situ* observations continue, but often different groups use different *in situ* data, sometimes with very limited statistics. A possible recommendation is to encourage users to evaluate a common, well documented, set of *in situ* atmospheric measurements taken coincident with IASI overpasses. We encourage EUMETSAT to collect, document, and distribute a common dataset of *in situ* profiles measured coincident with IASI overpasses in order to allow better validation of different RTMs against ground truth.

2.8. APPLICATION: TRACE GAS

By P.-F. Coheur and D. Edwards (NCAR)

Since launch, IASI has demonstrated excellent and stable performance, both spectral and radiometric, that are of evident benefit for the monitoring of atmospheric trace gases and for studying processes in relation to climate and the chemistry of the lower atmosphere. It was shown that the IASI spectra contain signatures of a dozen species with a range of lifetimes, from long-lived climate gases to short-lived boundary layer pollutants. In fire plumes, several unusual compounds are also detected, enhancing the potential of IASI to contribute to the monitoring of atmospheric composition change. Among the longer-lived species in the lower atmosphere, it is worth pointing out that several have been paid little if any attention until now (CFCs, N_2O, OCS).

The analysis of the IASI spectra for trace gases requires using radiative transfer and retrieval models, with near-real-time requirements for global applications. There has been a wealth of developments in the scientific community since the previous conference. Many different codes are now available for specific scientific studies besides the operational processing chain of EUMETSAT. All perform reasonably well and the reference spectroscopy has proved adequate in most unsaturated parts of the spectrum. Several important issues were, however, raised for the trace gas retrievals: these concern in particular the optimal treatment of surface properties (emissivity and surface temperature) and the accuracy of the temperature profile in the first layers, which have a crucial impact on the retrievals of near-surface concentrations. Also, the importance of a proper characterization of the retrieved products to benefit the atmospheric community in general was explicitly stated. This is currently an issue for the operational processing chain, which is under extensive development and has already been recently improved for carbon monoxide. The issue of data compression through PCA was briefly discussed and the problem of potentially missing extreme events and/or exotic species was raised.

In addition to its ability to probe simultaneously the signatures of many pollutants, IASI has demonstrated profiling capabilities for CO and O_3, which are likely superior to those of previous instruments. This may prove to be extremely important for the decade to come especially considering that, outside of Europe, dedicated chemistry missions are only in the very early planning stages. Furthermore, the expected 15-year dataset of IASI trace gases will allow the long term chemical records of interannual variability and possibly trends started with instruments such as MOPITT and AIRS to continue. It will also add the crucial infrared information to the complementary UV-visible passive nadir sounders in operation in the same timeframe.

The results presented during the conference have revealed the first applications of IASI for climate monitoring: IASI was shown to improve on the thermal infrared CO_2 retrieval accuracy of other instruments, and is therefore likely to make a significant contribution to carbon budget studies in the future. Clear seasonal and inter-hemispheric variations, and in addition information on vertical transport, were highlighted for CO_2 and CH_4. These current results only use the thermal infrared part of the spectrum, and although challenging, there are indications that the surface concentration of methane can be obtained locally by exploiting the IASI short-wave channels. Further applications on the ozone monitoring side have been demonstrated. Global-scale ozone profiles separating troposphere, UTLS and stratospheric partial columns have been acquired, allowing the development of the ozone hole to be followed (complemented by HNO_3 concentration fields) along with stratospheric intrusions into the troposphere. Lower tropospheric retrievals of ozone remain a challenge, but the first steps were made in identifying an anthropogenic chemical production near large cities. Similarly, global-scale CO distributions have been obtained and analyzed (locally and globally), to reveal the sources, transport and seasonality of hemispheric pollution. For both species, the first steps in data assimilation were made, showing great promise with regard to air quality forecasts (e.g. assimilation of CO in MACC, and of O_3-radiances at ECMWF).

The IASI achievements in monitoring the tropospheric and stratospheric distributions of several important pollutants simultaneously, with unprecedented sampling, additionally make it possible to perform focused process studies. For instance, the unexpected exploitation of IASI for monitoring strong sources and for differentiating these by sectors (industry/urban, agriculture, and biogenic) was demonstrated with the measurements of CO, NH_3, CH_3OH and HCOOH, respectively. Moreover, work on inversions of the retrieved fields to constrain these chemical emissions is beginning and shows promise. IASI has also demonstrated its potential as a pollution tracker, identifying the emission, and then following the chemistry and transport of biomass burning or volcanic plumes. The correlations between IASI species were looked at to some extent (e.g. CO_2/CH_4 for climate and C-budgets, O_3/HNO_3 in the stratosphere), but could be exploited further (CO_2/CO, O_3/CO in the troposphere), along with the synergy with other sounders (e.g. NO_2/HNO_3 to improve on the N-budget, IASI/limb sounders to study vertical transport patterns).

For all species, validation activities have started (see next summary), showing the overall good performance of IASI for trace gas retrievals. These should be extended on all scales, using cross-validation with other satellite data globally and precise ground-based or airborne instrumentation locally. For some species (e.g. NH_3) correlative data for a validation of IASI columns are virtually nonexistent.

2.9. PRODUCT VALIDATION

By F. Hilton (Met Office) and H. Revercomb (CIMSS)

Since IASI data were released operationally in July 2007, a vast number of products have been developed for meteorological variables, air quality and atmospheric chemistry applications. The community is increasingly aware that, in order to ensure that products are useful for operational purposes or understanding atmospheric components, products should be well characterised and validated.

The products developed from IASI data are hugely diverse, including temperature and water vapour profiles, cloud products, and chemical species. The process of product validation depends strongly on the type of product and available validation data for that product. Results presented at the conference showed that a wide range of validation data is in use, and in many cases products are being validated against multiple data sources. These include dedicated radiosonde campaigns coincident with overpasses, ground-based infrared and microwave instrumentation, IASI balloon flights and intercomparisons with other satellite data products, other centres' IASI products, and model data.

The conference highlighted the importance of understanding the nature and sensitivity of both the IASI product and the validation data, regardless of its source. Errors in the validation data should be well characterised; even in the case of a direct measurement of the product species, care should be taken to understand instrumental measurement errors, temporal and spatial non-coincidence errors, and differences in the vertical resolution or sensitivity between IASI and the validation data. Where different satellite-derived products are being compared, an understanding of the *a priori* constraints influencing the products and the product averaging kernels is crucial before a meaningful comparison can be performed. The papers presented demonstrated various methods for dealing with the different sensitivities of product and validation data, including smoothing the high-resolution data with the averaging kernels of the lower-resolution data, and using data assimilation into a model as a system for product intercomparison.

For products from IASI to be incorporated into operational systems, in particular through data assimilation for numerical weather prediction or chemical transport modelling, the products need to be presented with their error covariances, and ideally with their *a priori* assumptions and averaging kernels. The analysis of the averaging kernels and information content of a given retrieval is commonplace in the atmospheric chemistry community, but it was good to see meteorological parameters being assessed in the same way at this conference. This practice should certainly continue to allow assessment of whether individual products are fit for a given purpose to which they may be put by the user.

2.9.1. RECOMMENDATIONS

A recommendation to the community would be to ensure that as many different sources of validation data are used as possible. Whilst a wealth of data sources has already been used, there are new datasets and other products which should be considered. Papers in this session included presentations on radiosonde datasets from Sodankylä and Lindenberg, which are available for meteorological product validation, while elsewhere in the conference, the ongoing ConcordIASI campaign was discussed. For trace gas product validation, satellite-derived products from TES are available and should be added to validation procedures in conjunction with the MOPITT retrievals, which seem to be more widely in use among the IASI community.

2.10. NEXT FTIR ATMOSPHERIC SOUNDERS

By J. Taylor (Met Office) and C. Camy-Peyret (LPMAA)

With IASI performing so well a key question on everyone's mind is "What is happening next?" This short session tried to answer some of the questions and give the community a brief glimpse into the future.

A key element of this conference was the growth in the number of chemical species being observed in IASI spectrum. C. Clerbaux gave a summary of IASI's ability to detect global distributions of CO_2, CH_4, O_3, CO, HNO_3, methanol, formic acid, ammonia, dust and volcanic SO_2. She reported on the Global Monitoring for Environment and Security initiative which is looking at the requirements for NWP, climate and pollution monitoring. EUMETSAT is preparing for the next polar orbiter to be launched after the MetOp program. The first of these Post-EPS satellites will be launched around 2019. As part of this process CNES are looking at potential designs for IASI Next Generation (IASI-NG) which may have a factor of 2 gain in terms of spectral resolution and signal to noise ratio. Such an instrument will represent a marked improvement in the detection of many chemical species.

T. Maciaszek (CNES) presented the results of their Phase 0 study for IASI-NG and highlighted the improved spectral resolution and noise performance whilst maintaining a continuous spectrum from 645 to 2760 cm^{-1}. The proposed instrument will have four detectors instead of three and will have a cluster of 3×3 fields of view. Active cooling will be applied to lower the detector temperatures down to <65 K, having the dual benefit of reducing noise and increasing the speed of recovery from outages. The maximum optical path difference (OPD) will be increased to 4 cm, to reduce self-apodisation, which is basically truncation of the interferogram by not sampling it out far enough. This reduces the spectral resolution. Two possible practical solutions to improve the spectral resolution were studied, and the chosen one involves introducing a mechanism to work in synchronisation with the corner cube mechanism to correct the optical path difference for each pixel to improve the contrast so that all pixels behave similarly.

S. Tjemkes (Eumetsat) presented ideas for a hyperspectral infrared sounder (MTG-IRS) on the Meteosat Third Generation. A decision on this will be made at EUMETSAT council in 2010. A brief overview of the instrument was given and the issues associated with data volumes were aired. Clearly the proposal has great interest for the future but the optimum way of using the data is still to be resolved.

3. RECOMMENDATIONS

Regarding the conference, considering the progress of studies, the growing community and the need for exchange among scientists and users, the scientific committee recommended maintaining a frequency of two years. In terms of the format of the conference, the “residential form” has be unanimously acknowledged, as it permits many and intense discussions on methods and results, and also to elaborate plans for future projects. A number of scientific issues emerged from the conference and there are clearly some areas of work which are promising to improve on the current quality of results: Work will be required to improve the retrieval of humidity profiles, surface emissivity and surface temperature; on the assimilation of cloudy radiances and the retrieval of cloud properties; and in the area of spectroscopy where some coordination is needed.

As for validation, methodology is now well established and ready to be applied to IASI on MetOp-B and –C.

4. CONCLUSIONS AND FUTURE PLANS

IASI was once again recognised to be an excellent instrument with high levels of performance and remarkable stability. Major scientific results have been obtained from IASI.

There has been a lot of progress in the two years since the last conference and there are many ideas for improving the current products, to expand the conditions in which IASI data are used, and to develop new products. They will have to be explored. Some will need some time, but the 15 year lifetime of the programme permits us to envisage full exploitation of IASI’s potential.

First lessons have been learnt and reflected upon, resulting in statements of requirement for Post-EPS. The new concept of IASI-NG, to be flown from 2020 onwards is expected to meet these numerous and ambitious requirements.

ANNEX 1

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ANNEX 2

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Larrabee Strow, University of Maryland
Antony McNally, ECMWF
Nicole Jacquinet-Husson, LMD
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<u>Topics / Co-Chairs</u>

1. Instrument availability, performances, monitoring. J. Taylor and C. Camy-Peyret
2. Data Handling : Processing, compression, Distribution, Archiving C. Clerbaux and D. Klaes
3. Applications : Weather forecasting (global or regional NWP) T McNally and V. Guidard
4. Applications : Clouds and aerosols L. Lavanant and P. Schlüssel
5. Applications : Surface C. Crevoiser and H. Revercomb
6. Retrievals C. Serio and P. Schlüssel
7. Spectroscopy and radiative transfer for IASI L. Strow and N. Jacquinet-Husson

8. Products validation — F. Hilton and H. Revercomb
9. Applications : Trace gas — P.-F Coheur and D. Edwards
10. Next FTIR Atmospheric sounders — J. Taylor and C. Camy-Peyret

Summary reports : T. Phulpin and D. Klaes

Conclusions

ANNEX 3

FINAL AGENDA

Monday January 25	
08 :00 – 14 :00 REGISTRATION	
12:30	***LUNCH***
14:00	**OPENING SESSION** - CNES: Philippe GOUDY / EUMETSAT: Marc COHEN / ORGANISATION
Session 1: Instrument Availability, Performances, Monitoring ***Chairpersons: Jonathan Taylor & Claude Camy-Peyret***	
14:45	The EPS/MetOp System - *M. Cohen*
15:05	Status of IASI instruments : FM2 after 3 years in orbit, PFM-R and FM3 on ground - *L. Buffet*
15:25	IASI performances - *E. Pequignot*
15:50	***COFFEE BREAK***
Session 1: Instrument Availability, Performances, Monitoring ***Chairpersons: Jonathan Taylor & Claude Camy-Peyret***	
16:20	IASI L0/L1 NRT Monitoring at EUMETSAT: Results from 2.5 years of Operations - *L. Fiedler*
16:40	Radiometric Intercomparisons of AIRS and IASI for Climate Monitoring Applications - *L. Strow*
17:00	Evaluation of IASI and airs spectral radiances using simultaneous nadir Overpasses - *D. Tobin*
17:20	Demonstration of the radiometric accuracy of IASI for climate monitoring using coincident data from the Advanced Along-Track Scanning Radiometer. – *J. Remedios*
17:40	**POSTER PRESENTATION 1 : Sessions 1 & 2**
18:30	***ICE BREAKER & DINNER AT THE HOTEL***
Tuesday January 26	
Session 2: Data Handling: Processing, Compression, Distribution, Archiving ***Chaipersons: Cathy Clerbaux & Dieter Klaes***	
08:30	Evaluating scene in-homogeneity effects on the IASI instrument line shape - *A. Gambacorta*
	Principal Component Compression of IASI data: impact on the exploitation of trace gases information for atmospheric chemistry - *P. Prunet*

08:50	
Session 3: Applications: Weather Forecasting (global or regional NWP) ***Chaipersons: Vincent Guidard &Tony McNally***	
09:10	An overview of the assimilation of IASI radiances at operational NWP centres - *F. Hilton*
09:40	Toward a better assimilation of IASI data over polar area, in the framework of the ConcordIASI campaign. - *A. Bouchard*
10:00	Assimilation of IASI Data into the Regional NWP Model COSMO-EU: Setup and Results - *M.Schwaerz*
10:20	**POSTER PRESENTATION : Sessions 3, 4 & 7**
10:45	***COFFEE BREAK***
Session 3: Applications: Weather Forecasting (global or regional NWP) *Chaipersons: Vincent Guidard &Tony McNally*	
11:10	Impact of IASI assimilation in convective scale model AROME - *V. Guidard*
11:35	Improved assimilation of IASI radiances at the UK Met Office - *E. Pavelin*
11:55	Assimilation of IASI cloudy radiances in global numerical weather prediction model. - *N. Fourrié*
12:15	The direct assimilation of cloud affected IASI radiances - *A. McNally*
12:35	*LUNCH*
Session 4: Applications: Cloud and Aerosol *Chairpersons: Lydie Lavanant & Peter Schlüssel*	
14:00	Sounding of aerosols with IASI - observations, retrievals and open questions - *L. Clarisse*
14:20	Processing of IASI cloudy heterogeneous scenes using the AVHRR radiances analysis in an operational context. - *F. Faijan*
14:40	Remote Sensing of Mineral Dust with IASI - *L. Klueser*
15:00	**POSTER PRESENTATION 3 : Session 6**
15 :20	*COFFEE BREAK*
Session 4: Applications: Cloud and Aerosol *Chairpersons: Lydie Lavanant & Peter Schlüssel*	
15:50	Dust aerosol optical depth and altitude retrieved from hyperspectral infrared observations (AIRS to IASI) and comparison with other aerosol datasets (MODIS, CALIOP, PARASOL) - *S. Peyridieu*
16:10	Global Cloud Climatologies from satellite-based InfraRed Sounders (TOVS, AIRS and IASI) - *C. Stubenrauch*
Session 5: Applications: Surface	

	Chairpersons: Cyril Crevoisier
16:30	Infrared continental surface emissivity spectra and skin temperature retrieved from IASI observations - *V. Capelle*
16:50	Influence of emissivity and temperature inversion on the IASI products - *T. Phulpin*
17:10	POSTER SESSION
20:00	*DINNER AT THE HOTEL*

Wednesday January 27

	Session 6: Applications: Retrievals - *Chairpersons: Carmine Serio & Peter Schlüssel*
08:30	Physically based retrievals obtained from IASI observations collected during the JAIVEx field experiments - *P. Antonelli*
08:50	Towards a better retrieval of fine water vapour atmospheric structures using IASI data. - *L. Lavanant*
09:10	Intercomparison of two different statistical approaches to the initialization of the physical inversion of IASI radiances for temperature, water vapour and ozone. - *G. Masiello*
09:30	A Dual-Regression Hyperspectral Atmospheric Sounding Algorithm - *W. Smith*
09:50	Application of a 1d-var retrieval scheme on IASI data gathered during JAIVEX - *J. Taylor*
10:20	**POSTER PRESENTATION 4 : Sessions 5 & 9**
10:35	*COFFEE BREAK*
	Session 7: Spectroscopy for IASI and Radiative Transfer Models for IASI *Chairpersons: Nicole Jacquinet & Larrabee Strow*
11:05	Validation of radiative transfer models in the highly absorbing water vapour band for hyperspectral infrared sounders - *X. Calbet*
11:25	The Forward Model for IASI: Spectroscopic Issues - *S. Clough*
11:45	The GEISA/IASI Spectroscopic Database: Description, Evaluation, Evolution - *N. Jacquinet*
12:05	**POSTER PRESENTATION : Session 10 & 8**
12:45	*LUNCH*
14:15	**GUIDED TOUR OF ANNECY**
	COFFEE BREAK
	Session 7: Spectroscopy for IASI and Radiative Transfer Models for IASI *Chairpersons: Nicole Jacquinet & Larrabee Strow*
17:15	Radiative Transfer Model Under Cloudy Sky Conditions - *X. Liu*
17:35	A Principal Component Based Version of the RTTOV fast Radiative Tranfer Model - *M. Matricardi*

17:55	Quantitative spectroscopy of several tropospheric or stratospheric molecules: recent updates performed in the GEISA database - *A. Perrin*
18:15	POSTER SESSION
19 :45	***COCKTAIL AT THE HOTEL***
21:00	*DINNER AT THE HOTEL*

Thurday January 28

Session 8: Applications: Trace Gas : *Chairpersons: Pierre Coheur / David Edwards*

08:30	Trace gas retrievals in the operational IASI L2 product processor - *T. August*
08:50	Retrievals of ozone profiles from IASI: latest results and validation with MOZAIC and sonde data - *B. Barret*
09:10	Global to local observations of atmospheric ammonia with IASI – *P.-F. Coheur*
09:30	First results of the assimilation of ozone tropospheric columns provided by the IASI instrument to assess air quality with a chemical transport model - CHIMERE at a continental scale - *A. Coman*
09:50	Carbon dioxide retrieval from IASI measurements using the KLIMA inversion algorithm - *M. Gai*
10:10	CO_2 and CH_4 in the tropics: 2,5 years from MetOp/IASI - C. *Crevoisier*
10:30	IASI measurements of tropospheric ozone over megacities - *G. Dufour*
10 :50	*COFFEE BREAK*

Session 8: Applications: Trace Gas

Chairpersons: Pierre Coheur / David Edwards

11:10	Using IASI Retrieved CO Measurements to Characterise CO Emissions from Local African Fires - *S. Illingworth*
11:30	First global observation of formic acid from the IASI infrared sounder - *A. Razavi*
11:50	Global and local ozone measurements from the thermal infrared IASI sounder for the monitoring of atmospheric composition - *C. Scannell*
12:10	Using IASI trace gas retrievals to analyze the impact of fire emissions on air quality *S. Turquety*
12:30	*LUNCH*

Session 9: Products Validation : *Chairpersons: Fiona Hilton & Hank Revercomb*

14:00	An examination of the impact of *a priori* constraint assumptions on the retrieval of carbon monoxide from IASI and MOPITT - *D. Edwards*
14:20	Validation of HNO_3, CO and CH_4 column amounts from IASI using ground-based FTIR data - *T. Kerzenmacher*
14:40	An Assessment of the Absolute Accuracy of IASI Retrieved Precipitable Water Vapor at Tropical, Mid-Latitude, and Arctic Ground-Truth Sites - *H. Revercomb*

15:00	Validation of IASI ozone columns using data assimilation - *S. Massart*
15:20	*COFFEE BREAK*
	Session 9: Products Validation : *Chairpersons: Fiona Hilton & Hank Revercomb*
15:40	IASI carbon monoxide validation over the Arctic - *M. Pommier*
16:00	Information content and error assessment for IASI and AIRS temperature and water vapor retrievals - *N. Pougatchev*
17:30	***CONFERENCE EVENING***

Friday January 29

	Session 10: Next FTIR Atmospheric Sounders : *Chairpersons: Jonathan Taylor & Claude Camy-Peyret*
09:00	What's next after IASI? : IASI-new generation onboard postEPS - *C. Clerbaux*
09:20	Studies on IASI Follow-on at CNES : IASI Next Generation - *T. Maciaszeck*
09:40	Towards a consolidated L2 processor for MTG-IRS - *S. Tjemkes*
10:00	Advanced developments for infrared sounding applications - *D. Simeoni*
10:20	*COFFEE BREAK*
10:50	*SESSION SUMMARY*
10:50	*CLOSING SESSION (Thierry Phulpin)*
12:30	*LUNCH BUFFET*

POSTER PRESENTATION

Session 1: Instrument Availability, Performances, Monitoring

Of chessboards and ghosts: Signatures of micro-vibrations from IASI monitoring in NWP?
A. McNally

IASI Technical Expertise Center
J. Chinaud

Assessing IASI radiance accuracy via a LEO/LEO intercalibration and a stand-alone validation approaches
N.A. Scott

Radiometric and spectral validation of Infrared Atmospheric Sounding Interferometer (IASI) observations with the aircraft-based Scanning High-Resolution Interferometer Sounder
J. Taylor

Session 2: Data Handling: Processing, Compression, Distribution, Archiving

MIPAS-ENVISAT and IASI-MetOp data fusion using the Measurement Space Solution method
M. Gai

Near-real time processing of IASI radiances for the monitoring of the atmospheric composition
J. Hadji-Lazaro

Development of a GPU-based High-Performance Radiative Transfer Model for the High-spectral Resolution Infrared Sounders
H.L.A. Huang

IASI Principal Component Compression (PCC) - first experiences.
T. Hultberg

EPS/MetOp Data Processing and Applications
D. Klaes

A Web site for MetOp Real-Time atmospheric fields visualisation for NowCasting applications. Poster and Desktop presentations.
T. Labrot

Evolution of IASI products and dissemination
F. Montagner

EARS-IASI Pilot Service: Description and Status
C. Ponsard

Synergy between IASI sounding and AVHRR imagery for the processing of IASI data in non-uniform scenes
P. Prunet

Session 3: Applications: Weather Forecasting (global or regional NWP)

The vertical resolution of the information content of the IASI assimilation system
F. Hilton

Observation Impact of IASI on the US Navy's Atmospheric Analyses and Forecasts
B. Ruston

The sensitivity of the harmonie/norway forecasts to the IASI Data
R. Randriamampianina

Session 4: Applications: Cloud & Aerosol

Aerosol and cloud remote sensing from high resolution infrared sounders. Application to IASI observations.
H. Herbin

Cloud top retrievals using the CO_2 slicing method on IASI data
M. Ridal

Comparison of Observed and Simulated Infrared Hyper-Spectral Characteristics of Asian Dust
B.I. Lee

Session 5: Applications: Surface

Global land surface climatology data retrieved from IASI measurements
D.K. Zhou

Session 6: Applications: Retrievals

Information-centered representation of retrievals with limited degrees of freedom for signal: Application to methane from the Tropospheric Emission Spectrometer
S. Clough

ESA WACMOS IASI-SEVIRI merged water vapour product
K. Hungershöfer

SOFRID : SOftware for Fast Retrievals of IASI Data
E. Le Flochmöen

Development of IASI Outgoing Longwave Radiation
H.-T. Lee

Temperature sounding from IASI using N2O channels : theoretical study and validation with JAIVEx observations.
C. Pierangelo

Session 7: Spectroscopy for IASI and Radiative Transfer Models for IASI

4A/OP: A fast & accurate operational forward radiative transfer model
L. Chaumat

Session 8: Applications: Trace Gas

Sensitivity of IASI measurements to boundary layer pollution: theoretical analyses and case studies from IASI operation
P.-F. Coheur

Methane and methanol measurements from the IASI sounder
A. Razavi

Mid- to lower-tropospheric global measurements of CO_2 with AIRS and IASI
L. Strow

Channel selection for trace gas detection
J. Walker

IASI thermal infrared ozone profile retrieval using a regularization method
A. Wassmann

Retrieval of ozone profiles from MetOp
A. Waterfall

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J.L. Lacour

Session 9: Products Validation

Validation of IASI-derived water vapour profiles using COPS data
T. Deleporte

Carbon monoxide distributions from the IASI/MetOp mission: evaluation with other space-borne sensors
M. George

Tropospheric ozone from IASI: comparison of different inversion algorithms and validation with ozone sondes
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Examining the quality of IASI and AIRS temperature and moisture retrievals over East Asia using radiosonde observations and numerical model outputs
E.H. Kwon

Measurements of water isotopologues from IASI and ground-based FTIR at a subtropical site in the southern hemisphere
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High variable humidity profiles in troposphere - a challenge in observation and validation
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A. Larar

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