Working Group I:Radiative Transfer and Instrument Validation

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1. Instrument validation

It is recognized that the success of AIRS and IASI is due primarily to the quality of the instruments. It is then important that detailed pre-launch characterization be properly resourced. Also, validation methodologies for instruments based on new technologies requires the establishment of new dedicated protocols. These considerations have lead to the following recommendations.

Recommendation to satellite agencies: Detailed pre-launch characterization requires adequate support to science and industrial teams to ensure that instruments fully meet all specifications. Provision should therefore be made for financial support dedicated to activities that might require funding in excess of what originally planned.

Recommendation to the IASI calibration team: Issue unclassified material pertaining to calibration and maintenance based on the experience gained with IASI. This will be very useful for other current and planned missions involving hyper-spectral infrared radiances.

AIRS and IASI post-launch calibration campaigns like JAIVEX (see http://cimss.ssec.wisc.edu/jaivex/) have been very successful, confirming the excellent quality of the IASI and AIRS spectra. The agreement between AIRS, IASI and aircraft based instrument spectra was remarkable. The following recommendations emerged from the discussions.

Recommendation for the organization of future campaigns: Take full advantage of aircraft observations to validate both new instruments and forward RT models. For RT model validation, special attention should be paid to very moist air masses. It is crucial for the validation of RT models that the in situ data are of the highest quality.

Recommendation to NWP modelers: Take advantage of AIRS and IASI for model validation of radiances and derived products such as cloud parameters. A long list of Level 2 products is available. Retrievals can also be used to evaluate biases associated with other instruments (e.g. mid/high troposphere humidity observations from radiosondes).

Recommendation related to bias correction in NWP: Use AIRS/IASI to evaluate radiance biases associated with other IR sensors such as HIRS or those on geostationary satellites, thereby providing independent bias estimates from those operationally used in NWP. In good part, this work is being done through the intercalibration mandate of GSICS (see http://www.star.nesdis.noaa.gov/smcd/spb/calibration/icvs/GSICS/index.php).

Recommendation to GSICS and reanalysis community. A high degree of collaboration is encouraged to identify and resolve current and historical satellite instrument biases.

2. Radiative transfer

NWP centers rely on fast RTMs which are based on accurate computations of transmittances/radiances performed using line-by-line (LBL) RTMs. It is then crucial that a long term commitment to the development and maintenance of LBL models used in NWP (e.g. LBLRTM) be secured. This is all the more important in light of the fact that NWP centres are currently not responsible of the development/maintenance of LBL models.

Recommendation to NWP-SAF and JCSDA: Explore the possibility of securing continuous funding for research work in the area of LBL modeling. Integrate findings obtained in parallel development work.

The accuracy of the forward model is one of the main limiting factor in using AIRS and IASI radiances. The use of IASI radiances can be very valuable in detecting errors related to the quality of either the line parameters or the forward model (e.g. errors in the line shape). Spectroscopic errors (i.e. line parameters and line shape) are still an outstanding issue and it is important that research in these fields continues. Although a better spectroscopy should be the driving factor in the improvement of LBL models, it is also important that alternative approaches to the improvement of forward models are explored like the tuning of the optical depths using well calibrated radiances and good in situ information. Finally, the interaction between the NWP and spectroscopy communities should be improved.

Recommendation to NWP centres: Support activities aimed at identifying and reducing/eliminating errors in fundamental spectroscopy. Update fast RTM's coefficients in a timely fashion with the release of new spectroscopic line parameters.

The issue of the computational efficiency of fast RTMs remains a concern. The availability of high spectral resolution radiances from instruments on board geostationary platforms, as planned for MTG and other missions, will require even faster RTMs. It is noted that PC-based models are currently about 15 times faster than RTMs currently used in NWP. The development of PC-based models should therefore be encouraged and pursued. In association with the availability of PC-based fast models it is deemed important to explore the possibility of the direct assimilation of PC scores and/or reconstructed radiances in NWP to asses whether either approach can lead to results that are superior to the direct assimilation of radiances. For instance, the noise reduction property of PC scores could be exploited for the assimilation of IASI radiances in the noisy short wave region (IASI band 3).

A monthly emissivity atlas based on MODIS (5 km resolution) is available from the University of Wisconsin. Using a principle component technique, emissivity spectra can be readily reconstructed using only 8 emissivity values as input. This atlas can be used at NWP centers and will soon be available in RTTOV. Although this is a good start, this emissivity atlas requires further validation and improvements. More importantly, a methodology to dynamically update the emissivity fields has to be implemented.

NWP centers have agreed to make available online their radiance monitoring sites. Specifically for IASI, there is an agreement to post detailed statistics for a selected list of 15 channels. Beyond that initial step, there should be an action to formally compare the monitoring statistics. Coordinated efforts between the RT and assimilation communities will lead to a better mutual understanding of the nature of the biases in radiance observations. Sometimes, more than one fast RTM coefficient file is available for the same instrument (e.g Kcarta or LBLRTM based coefficients for RTTOV). Fast RTM modelers should detail the limitations associated with the use of any of these files and possibly recommend which one to utilize.

It was noted that inhomogeneous scenes viewed by IASI result in a spectral shift of the response function. In the worst case (partly cloudy scenes), this effect may lead to errors reaching 1.5 K. Assimilation in coastline areas is subject to errors of the order of 0.3 K. It is recommended that these effects be documented.

Another issue is the introduction of non LTE effects in fast models used operationally in NWP. In particular, this capability is crucial for the daytime assimilation in the shortwave domain. This should allow in principle the improvement of the NWP analyses in the stratosphere.

This workshop reported on recent progress in the assimilation of cloudy infrared radiances. One of the implications is that the accuracy of the forward model computation in presence of cloudy scenes should be properly assessed. Consequently, a validation strategy is required for RTMs in cloudy situations. This issue is being addressed in the ITSC RT subgroup. The use of A-Train data represents a major asset for this investigation. It is important that also when using a simplified treatment of the cloudy radiative transfer assuming single cloud layers, the spectral variation of cloud emissivity should be properly accounted for.

Recommendation to NWP centres: To pursue the exploitation of cloudy infrared radiance assimilation. To develop fast RTMs of increasing complexity/realism for that purpose.

In relation to climate and model validation, it was suggested that the development of an OLR product from hyperspectral sounders would be useful. Indeed, there is a long commitment for IASI and CrIS, while this is not the case for the various broadband radiometers available today (e,g. on Terra, Aqua). The latter require much care for calibration and the various instruments do not have identical characteristics (field of view, spectral limits, etc.). A methodology was developed by NOAA to normalize radiances to nadir, allowing direct comparisons with model output of OLR.

3. Future instruments

The IASI instrument is considered to have quasi ideal characteristics for the METOP orbit for the purpose of atmospheric sounding and assimilation into NWP analyses. In particular the trade-off between pixel size and spectral resolution could hardly be improved upon. Having secured the continuity of IASI for the next two decades (IASI-2 and 3 are already built), it would be desirable that the characteristics of future IR hyperspectral instruments will include:

- Lighter, less expensive design
- Improved techniques for maintenance of calibration and monitoring
- Adaptability to other orbits: geostationary, highly elliptical
- Collocation with medium resolution imager characterized by a few more channels than AVHRR (13-14 μm CO_2, 6-7 μm H_2O)
- Improved spectral resolution, focusing on the sensitivity to low level temperature and humidity and to specific GHG or chemical species (e.g GOSAT)
- Reduction of noise in the shortwave region
- Exploit synergies/complementarities between NWP, environmental monitoring and climate applications

Working Group II: Assimilation

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1. Use over land and ice surfaces

At most NWP centres use of IASI and AIRS data over land is limited to channels that have negligible contribution from the surface.

NCEP uses CRTM along with a database of IR emissivity spectra. This allows assimilation over land in principle but in practice most observations are still rejected by quality control. Studies at ECMWF have shown positive impact using a simple fixed surface emissivity over land where the cloud detection serves as a very tight quality control on the surface sensitive channels.

It was noted that use of channels with contributions from the surface over Antarctica is problematic. It was suggested that this is due to a combination of poorly specified surface emissivities, poor a priori knowledge of the surface temperature and strong near-surface inversions over Antarctica which can cause strong disagreement with model. The complex topography over mountainous areas can also be problematic.

NCEP are the only centre to have tried IR emissivity retrieval but results so far have been too noisy. The algorithm needed hundreds of channels to reduce the noise to an acceptable level.

It is recognised that one requirement for land surface emissivity retrievals is to be able to detect cloud in the field of view. In the absence of auxiliary information, to do this good a priori knowledge of the surface emission is needed. The use of an emissivity atlas is suggested. One also needs good knowledge of the surface temperature.

It was suggested to look for surfaces where emissivity is high enough that the reflection term can be ignored and thus emission rather than emissivity/skin temperature can be retrieved.

Recommendation to NWP Centres: Try to use more channels which are less affected by the surface over land.

Recommendation to NWP Centres: Use atlases to derive first guess emissivities and then investigate the use of analysing the emissivity and skin temperature from the observations. For initial studies independent information on whether the FOV is clear is needed (e.g., AVHRR+model surface temperature or from SEVIRI). One should also focus on surfaces that are likely to be homogeneous within the FOV and well characterised.

Recommendation to NWP Centres: Improve analysis of land surface temperature towards current sea surface temperature accuracy (~1K) through improvement of the models and the use of auxiliary observations (e.g., SEVIRI) to tune parameters of models (e.g., soil parameters).

2. Cloud / aerosol detection / rejection

Most centres are satisfied with their current cloud detection schemes although the admission of some radiances contaminated with undetected cloud into the assimilation scheme is acknowledged. Most centres have bias corrections in the window region of the order of a few tenths of a Kelvin which is most likely due to this.

It is suggested that use is made of auxiliary data to verify and enhance the cloud detection schemes. For CrIS it is important to include VIIRS data, if possible.

Recommendation to NWP Centres: Make better use of AVHRR clusters to validate cloud detection schemes.

Recommendation to NOAA/NESDIS: Investigate the inclusion into the CrIS BUFR files of information equivalent to the AVHRR clusters or at least the standard deviation and mean radiances within the CrIS FOV. Also investigate the addition of VIIRS cloud height and amount. Suggest liaison with EUMETSAT on this.

Recommendation to NWPSAF: Consider the mapping of VIIRS radiances to CrIS FOVs within AAPP for direct readout applications.

3. Improving description of observational error covariance matrix

While there is evidence that there are significant off-diagonal elements to the (observational+forward model+representivity) error covariance matrix for IASI and AIRS, it is not clear that this matrix can be estimated with sufficient accuracy or that the specification of spectrally correlated errors is important.

Attempts at using correlated error covariances (either estimated from first principles or via the Hollingsworth-Lonnberg approach) at ECMWF for AIRS produced neutral or negative impact on the system. Similar studies which included simple models of correlated errors in GPSRO assimilation similarly were either neutral or negative.

A well constructed OSSE could be used to illustrate the importance (or otherwise) of correlated errors.

Correlated observation errors are not currently being used at any NWP centre primarily because no-one is sure of their exact form.

In addition to spectral correlation, it was noted that spatial correlation of errors is also ignored in current assimilation systems (except for thinning) and this may also be significant.

4. Water band assimilation

It should be noted that problems with the assimilation of water vapour information (and particularly fine vertical structures) is a feature of the data assimilation as a whole and is not limited to IASI and AIRS observations. Furthermore, as many more channels are typically used for IASI and AIRS compared to other instruments the total weight given to these humidity channels is as large as or greater than the other satellite instruments.

There are a number of possible issues that affect water vapour assimilation:

- There is ambiguity in the humidity Jacobians in that the channels are not only sensitive to humidity but have a strong temperature sensitivity.
- The humidity Jacobians are themselves non-linear i.e, the Jacobians are themselves function of the humidity field.
- The assimilation of humidity information is hampered by the relatively large bias in the water band which is removed via bias correction. This appears to be systematic NWP model error but RT errors

may also be important. For variational bias correction the upper tropospheric humidity channels are not strongly anchored by independent uncorrected observations (e.g. radiosondes).

- Information in the humidity fields tends to be lost in the forecast fields after 1 or 2 days.

The approach pursued at NCEP where humidity channels are not assimilated if the departure exceeds 1.5K but which may be reintroduced in later iterations appears a promising solution to the first two issues.

The high vertical resolution of retrieved humidity fields was one of the major expectations from the IASI instruments. We need a better understanding of what the vertical structure information available in the IASI observations is and what is achievable on assimilating IASI humidity channels.

Recommendation to NWP centres: The use of field campaigns to rigorously validate IASI retrievals will provide information on what can be achieved. Support the ISSWG retrieval inter-comparison exercise.

Recommendation to RT modellers: Work to improve RT models in the humidity band.

Recommendation to ECMWF: Investigate the use of IASI as an absolute standard to constrain UTH by using IASI radiances as uncorrected anchoring observations for VarBC.

5. Strategy for cloud affected radiances

Current implementations for the assimilation of cloud affected radiances are superficially similar but are quite difference in detail:

Met Office: Cloud top pressure (CTP) and cloud fraction is retrieved in 1DVar and fixed in 4DVar. This is operational for AIRS, and soon to be operational for IASI. 90% of the clear sky Jacobian has to be above the cloud top for assimilation in 4DVar. The number of fields of view used is increased by a factor of four over hole hunting for IASI.

Meteo-France uses CO2 slicing to infer CTP and cloud fraction. These are fixed in 4DVar and only channels that peak above the clouds are assimilated.

ECMWF uses a least-squares scheme to derive CTP and cloud fraction and then only assimilates data in overcast scenes. CTP varies during the main 4DVar analysis. The same set of channels that would be assimilated if the field of view were deemed clear are used in overcast conditions.

No centre attempts to initialise model variables from the cloud information itself, i.e., following route used with microwave observations where cloud properties are used to modify the temperature and humidity fields.

Microwave instruments are important for filling in information below the cloud top which are not observable from IR instruments.

Recommendation to NWP Centres: Continue research into the use of cloud-affected radiances in NWP. The use of the cloud observations themselves to initialise model fields should be pursued.

6. Interface to the assimilation (R/RR/PC/L2)

Reconstructed radiances or Principal Components compress the information contained in the IASI spectrum into a subset of channels. The diagonal of the error covariance is reduced but at the expense of increased correlations.

Principal components are non-local and are therefore difficult to use if one only wants to use channels insensitive to cloud located at a particular level. One is limited to “hole-hunting” (i.e. completely clear scenes) or to including the cloud properties explicitly in the assimilation scheme.

If the cloud issue is ignored, the question of whether the non-locality of the Jacobians is an issue was raised. Would a data assimilation scheme benefit from the fact that principal components are orthogonal? The question of whether non-locality is an issue may be linked to how well the background error covariance is specified – this should be investigated further. It was also questioned whether the bias correction of principal components (which would all have contributions from the entire atmosphere) would be problematic.

Studies into the assimilation of reconstructed radiances are to focus on the possibility of making use of the noisy band 3 radiances of IASI. Otherwise further research in this area is not a top priority.

Logistics of data transfer (PCA / lossless)

There is a danger that if spectra are compressed with PCA that the correlations that are introduced will compromise the ability to derive trace gas abundances.

Recommendation to Data Providers: It is recommended that if observations are to be compressed for communication, this compression scheme should not introduce cross-correlation between the channels. Ideally this process should be lossless.

Recommendation to EUMETSAT: Studies into the use of truly lossless compression of IASI data should be pursued.

7. Bias

It was noted that as the standard deviation of the innovations decreases, the relative effect of uncorrected biases may become more important.

VarBC is used to automate the previously sporadic updates to the bias correction coefficients. As this is done every model cycle, there is a tendency for the bias model to drift where there are no independent uncorrected observations to anchor the system (current anchoring observations are the radiosonde network (tropospheric temperature and lower tropospheric humidity); GPSRO (upper tropospheric and stratospheric temperature) and AMSU channel-14 (temperature around the stratopause). Upper tropospheric humidity is an example of a model field which is not well anchored by uncorrected observations. Other constraints may also be put on the bias correction system, for example through the choice of bias correction predictors.

Studies have been done in the past where VarBC has only been allowed to evolve in locality of radiosondes. Results were inconclusive.

It is suggested that some IASI and/or AIRS channels may be assimilated without bias correction to anchor the upper-tropospheric humidity. The Met Office have made an initial attempt at this but the results were negative. A knowledge of the quality of the radiative transfer might allow one to choose a small number of high quality IASI/AIRS channels to be used as anchoring points (possibly with an independently-derived derived bias-correction).

It was noted that handling systematic NWP model errors with a bias correction (wrongly) applied to the radiance observations can improve forecast skill. For example, the JMA model has a known dry bias, the assimilations of uncorrected AIRS data improves this bias in the analysis, but the forecast is worse. Introduction of TCWV as a bias-correction predictor produced a more biased analysis but the forecast was improved.

It is important to interact with the NWP modelling community to give feedback on the performance of the upper-tropospheric humidity field.

Met Office see seasonal drifts in the bias which are related to carbon dioxide and ozone. The use of climatological ozone to correct the ozone signal in the 15micron band is insufficient.

Are we using the correct predictors in our VarBC scheme? Analytic studies can me made, but results will be system dependent. Too many predictors will absorb more model bias and will result in a smoother but more biased analysis.

Recommendation to NWP centres: For those centres using adaptive bias correction schemes, attempt to identify observations that can be assimilated without bias correction to anchor model fields that are currently not well constrained.

8. Impact of IASI on NWP

Most NWP centres have demonstrated significant increase in forecast skill due to IASI assimilation (on top of a full forecast system that already includes AIRS). In some cases, the impact from IASI assimilation was as large as any other single sensor implementation.

Experience gained from AIRS assimilation was essential for rapid and effective implementation of IASI.

IASI and AIRS have roughly equivalent impact as most NWP centres.

We are happy with the high data quality, especially the availability of the entire spectrum in near-real-time and its availability soon after launch.

Working Group III: IASI for environmental studies

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9. Recommendations

- There is a request to EUMETSAT to provide L2 retrievals on all pixels in near-real-time. (EUMETSAT)
- There is a request to EUMETSAT to provide a summary cloud flag for the L1 products in near-real-time. (EUMETSAT)
- Investigations of future improvements in terms of spectral resolution and noise characteristics for a IASI follow-on (post-EPS framework) is supported. It is also recommended to investigate the possibility of flying such an instrument in an afternoon orbit (13:30), because of the better thermal contrast and more active chemistry. (EUMETSAT, NOAA)
- There is a recommendation to have full spectral resolution data available in near-real-time from CrIS in order to measure CO. (NOAA)
- It is recommended to investigate the effect of using reconstructed radiances on the trace gas retrievals/assimilation in view of future band width limitations for parallel dissemination of METOP-A/B. Does it work better (reduced noise), does it alias unwanted information into the trace gases, does it compromise the retrieval of weak absorbers? (EUMETSAT, NWP-SAF in collaboration with retrieval community)
- There is a strong request from MACC and retrieval community to make in-situ atmospheric composition data available for validation purposes and bias correction anchoring sooner than current practice (several weeks to months now >> a few days to a few weeks needed). The AERONET data provision is a good example how it could work. This request should be brought forward to both the WMO WIGOS initiative and the EEA activities within GMES. (WMO, EEA, data providers)
- It is noted that the operational bias correction of IASI radiances is not always well-suited for the atmospheric composition assimilation. More work needs to be done to find improved bias correction models. (ECMWF)
- MACC will assimilate radiances in the thermal infrared. For all other parts of the spectrum retrievals are the default, but work will be carried out to see if radiance assimilation is feasible (e.g., MODIS aerosol, GOSAT CO2). For the retrievals MACC will need to define what information is needed for optimal assimilation. (MACC)
- It is recommended that data providers provide averaging kernels as well as prior values with their retrieval products for optimal assimilation of these retrievals. More work is needed on the use of full retrieval error covariance matrices in the assimilation. (ECMWF/MACC and data providers)
- There is a recommendation to investigate which weak absorbers could be useful for the MACC system and which of these weak absorbers can be measured with IASI to sufficient accuracy. (MACC/air quality modeling community and retrieval community)

- Good prior knowledge of surface emissivity would allow the use of more IASI channels over land. A new emissivity model will be available through the NWP-SAF. We recommend investigating the use of these surface emissivities as either prescribed values or a priori values to see if this gives a positive impact on the trace gas retrieval and assimilation over land. (ECMWF/MACC, NWP and retrieval community)
- MACC would like to see if it is possible to retrieve optical depth for desert dust over land from IASI radiances. This would be very complementary to the MODIS aerosol products. (MACC and retrieval groups)
- There is a recommendation to improve the spectroscopy in the thermal infrared. Gases where issues remain are H2O, CH4, and O3. Also, good spectroscopic data is lacking for some of the weak absorbers in the spectrum. (science community)
- ECMWF appreciates the work on inter-calibration of AIRS, IASI, and other sensor radiances as is for instance done by GSICS.