NWP SAF

Plan for use of IASI data in European NWP centres

Version 2.5

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Plan for use of IASI data in European NWP centres

Version 2.4
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1. INTRODUCTION

This is a high-level end-to-end plan for processing IASI data and assimilating them into the global and regional NWP systems together with assumptions concerning the processing and distribution of IASI data by the EPS CGS (Core Ground Segment) at EUMETSAT, on which our access to the data depends.

It is a "baseline plan" in the sense that it represents a "Day 1" system which could be implemented to assure early exploitation of IASI data. It is therefore conservative, using scientific methods and processing modules already established for ATOVS and AIRS data where possible and, where not, using methods for which the development approach is clear. However it does not preclude the substitution of improved methods for Day 1, if they can be developed and demonstrated in time. Collaboration with NWP and satellite processing centres outside Europe (e.g. NESDIS, NASA/DAO, NCEP) will also provide valuable input to implementation strategies. An example of this is the AIRS project set up between NESDIS and NWP centres providing a near real time dataset for assimilation of AIRS data.

Although Section 3 of the plan was originally developed in the context of Met Office processing systems, the options and principles described in the plan are of general validity for NWP centres planning to use IASI data, and this document therefore forms (as Deliverable 3.1 of the NWP SAF) a specification of NWP interface options for European users of IASI. *Italicised text denotes optional steps in the processing*.

2. PROCESSING AND DISTRIBUTION AT EUMETSAT - ASSUMPTIONS

2.1 Iteration of user requirements

The current EPS End User Requirements Document (EPS/MIS/REQ/93001, 1997) contains generic statements of requirements for Level 1 products for all EPS instruments and for some geophysical (Level 2) products. It has not yet been developed into a statement of specific well-defined data sets and iterated with users to ensure that it **really** meets their requirements. Also, it has not addressed precise user requirements for the possible sub-levels of data, e.g. whether users would prefer Level 1B or level 1C IASI data.

The EPS Science Support Task Force (EPS-SSTF) developed a proposal for a processing system for all EPS data to meet these generic requirements, which included a proposed top-level design for the processing system showing the main processing modules and the data sets at the interfaces between them. EUMETSAT have developed this plan further in their internal preparations for the EPS CGS and the EPS product generation and data format specification documents are available for IASI and ATOVS instruments at: ftp://ftp.eumetsat.de/ISSWG/Resources/EUMETSAT_Documents/. This design contains intermediate and final data sets which are, in principle, potential products for distribution to users.

A recent survey conducted by EUMETSAT (EUM/STG-SWG/15/03/DOC/04) has revealed that at least 2 products will be required to meet the stated requirements of NWP users: a Level 1 product (probable users: UKMO, ECMWF, Météo-France, NCEP and others) and a Level 2 product (probable users: DWD, HIRLAM, NESDIS and others).

2.2 Processing at EUMETSAT

EUMETSAT/CNES plans (already presented to ISSWG) anticipate the following processing stages within the EPS CGS:

- Level 0 to Level 1C by the IASI Technical Expert Centre
- Level 1C to Level 2 by EUMETSAT

Level 1C IASI data includes statistics of AVHRR data on each IASI fov, to aid subsequent treatment of the effects of cloud on IASI data.

Level 1C data are all radiances in units of $mW/(ster.m^2.cm^{-1})$.

Level 1C data are full resolution, both in terms of horizontal sampling and spectral sampling (0.25 cm^{-1}). Level 1C spectra are apodised to a standard ISRF, where adjustments have been made to remove differences between the 4 fovs at each scan position, between scan positions and any variations in time.

Level 1C data should be processed and stored using sufficient bit resolution to preserve information that might otherwise be lost through the apodisation process (Lee, 2003a).

Methods for Level 0 to Level 1C processing have been proposed and documented by CNES (Cayla, 1996).

Level 1C to Level 2 processing is less clearly defined. Several retrieval methods are under consideration. There have been discussions within the ISSWG on this topic and a summary is available from EUMETSAT (presentation by P. Schlüssel in ISSWG-17 proceedings at ftp://ftp.eumetsat.de/ISSWG/Resources/ISSWG-17_Proceedings/ and from the EPS ground segment documentation). The error covariance matrix of the level 2 product is also planned to be distributed to users in a compressed format. For AAPP both NWP dependent (e.g.. 1DVAR) and NWP independent (e.g. ICI) retrievals have been requested by the users and it is likely a similar requirement will exist for IASI. The main dilemma is likely to concern the desired error characteristics of the products and, in particular, whether the Level 2 product is required to be wholly or mainly independent of NWP products.

2.3 Format and Compression of IASI data for NWP users

2.3.1 Level 1 formats

Dialogue is still needed with the NWP user community to establish the details of a Level 1 product to meet their needs. It is assumed that agreement will be reached with all relevant NWP users on one product, which meets their collective needs, and that distribution will be via the EPS-NRT-UT in each NWP centre. It is assumed that UKMO will not have to pass on the data to other centres, as is currently the case for NOAA sounding data.

For the purposes of this plan, and based on discussions with EUMETSAT and other NWP users, we assume that this product is a compressed form of Level 1C data.

Distribution of Level 1C data will provide NWP users with a product at the same stage of processing as is currently used for ATOVS data, thus giving NWP centres the flexibility they require over subsequent pre-processing and assimilation issues. However, it will remove from NWP users the need to carry the processing load and detailed instrument expertise required for the Level 0 to 1C conversion. Care will be needed to reduce any loss of information in this conversion to levels acceptable to users, and continuing dialogue with EUMETSAT/CNES is needed on this issue.

Compression of Level 1 data before transmission to users in desirable to reduce telecomm costs. However it should be done in such a way that it does not increase unduly the development, maintenance and processing costs at the user end. For instance agreed WMO formats (e.g. BUFR) have been adopted for all satellite data for NWP

assimilation to standardise the archive format and NWP interface. A current baseline (for discussion with EUMETSAT and all NWP users) proposes the compression methodology suggested by NESDIS for transmission of AIRS data to Europe and that of Lee for transmission of IASI data (Lee, 2003b). This compression process should be implemented so that it is a self-contained module that will not need any significant maintenance by NWP centres.

The proposed methodology is that the 1C radiance spectra are compressed by projecting them on to the leading eigenvectors of the covariance matrix and then entropy encoding the eigenvector scores. There are two stages required to achieve this:

***Off-line**:*

- Real data (IASI Level 1C, in this case) sampled from several days of observations are used to compute the leading eigenvectors of the covariance matrix of either the BT spectrum or the radiance spectrum normalised by the expected noise. Pre-launch this could be done using simulated data. It is anticipated one centre (e.g. EPS CGS) will update the eigenvectors on a regular basis. The eigenvectors in use will always be transmitted with the data perhaps in a header record. Preliminary work at UKMO and NESDIS indicates that less than 500 eigenvectors will be sufficient for the spectrum to be reconstructed by the user without significant loss of information)

On-line:

- Each measured spectrum is projected on to these eigenvectors to calculate the associated coefficients.
- These coefficients are stored to adequate precision, entropy encoded and transmitted to users along with the corrector data which is the difference between the original and reconstructed spectrum. This allows extreme or anomalous profiles not included in the training set to be reconstructed, if required, although in practice NWP centres will probably not use the corrector data except for monitoring the difference between original and reconstructed spectra.

2.3.2 Level 2 format

It is planned to distribute the level 2 IASI+ATOVS retrievals in BUFR format over the GTS and through the EPS-NRT-UT. The definition of these formats has been defined at:
`ftp://isswg:iss642wg@ftp.eumetsat.de/ISSWG/Resources/EUMETSAT_Documents/` in the IASI level 2 format specification.

3. PROCESSING AT NWP CENTRES

3.1 Data reception

Compressed global level 1C IASI data will be received through the EPS primary near real-time user terminal (EPS-NRT-UT) located at European Met. Services. Level 1C data for other EPS instruments will also be received. (HIRS, AMSU-A and MHS data are of particular interest here, and statistics of AVHRR data on IASI fovs are assumed to be part of the IASI Level 1 data set.) Level 2 EUMETSAT retrievals will also be provided as a separate dataset available to the user terminal.

It is assumed that global level 1 data will be available with an average delay of less than 2.25 hrs of the measurement time, although a new requirement for some global and regional NWP centres is to receive the data within 30 mins if possible. In order to meet this new requirement the EUMETSAT ATOVS Retransmission Service (EARS) may be further developed to provide IASI data over a large part of the N. Hemisphere within 30 mins of measurement time. This option is currently under consideration by EUMETSAT. These data are then provided to the NWP centres through a satellite based broadcast system (EUMETCAST). It is also anticipated that raw HRPT-like data for the local area will be able to be received directly from METOP-1 in addition to the EARS data feed. Both these datasets will be processed to Level 1C using a AAPP-like package but will not be compressed. NWP

centres will have a requirement for these data where timeliness (i.e. < 1.5 hours) is critical, e.g. for regional model assimilation.

It should be noted that with the order of magnitude increase in data volume for IASI reception equipment, processing power and archive storage will all need to be significantly upgraded from the current ATOVS computer hardware requirements. It is anticipated that by 2005 continued improvements in computer hardware will facilitate this without significantly higher costs.

3.2 Pre-processing

The compressed global level 1C data will be transferred from the EPS-NRT-UT to the system to be used for pre-processing IASI data prior to its storage in an archive (note the decompression could be done on the EPS-NRT UT but this has not been confirmed and may not be desirable). Locally received and/or EARS data will also need to be transferred to the same or another pre-processor. The baseline is a system of similar functionality to the current systems used for ATOVS data pre-processing with AAPP. (Note: The initial operational use of METOP data for NWP is likely to be ATOVS data, i.e. HIRS + AMSU-A + MHS data, acquired via the EPS-NRT-UT and transferred to the AAPP processor. IASI, being a new instrument, is likely to take a little longer to bring into operational use.) If both global *and* local data are to be processed and assimilated it is important that the origin of the data is retained within the observations.

Pre-processing software could be based on the current ATOVS pre-processor, AAPP, with modifications to reflect the different requirements of HIRS and IASI. The pre-processor would only perform operations that do not require access to NWP fields. The pre-processor should:

- pre-process IASI 1C data, including:
  - de-compress the data to recover the complete spectrum
  - IASI only and IASI + AVHRR/imager cloud tests
- pre-process AMSU-A 1C data (e.g. identify precip. effects, etc. not included in subsequent RT model)
- pre-process MHS 1C data (e.g. identify precip. effects, etc. not included in subsequent RT model)
- *optionally map AMSU-A data to the IASI grid*
- *optionally map MHS data to IASI grid*
- perform data selection as follows:
  - selected IASI fovs and selected IASI channels (<500) for possible assimilation
  - more heavily filtered fovs, but all channels, for monitoring and development work requiring the full spectrum. For this purpose, eigenvector coefficients could be stored rather than the full spectrum.
- perform data reformatting (convert data to an efficient storage format e.g. BUFR encoded EOFs before storing in NWP centre archive)

Note in addition EUMETSAT level 2 retrieval products could undergo a data selection here before being stored in the archive although data volumes are so small this is not expected to be necessary.

Pre-processed IASI+AMSU-A+MHS radiances either on their original fovs (level 1C radiances) or with AMSU-A+MHS data remapped to the IASI fovs, sometimes called level 1D radiances, and/or EUMETSAT retrievals will be stored in the archive.

3.3 Processing within the NWP system

3.3.1 Fast RT model

The RT model for IASI radiance assimilation must have similar properties to that currently used for ATOVS (i.e. RTTOV). Forward, tangent linear, adjoint and K matrix (Jacobian) versions of the model are all required. Several options exist:

- RTTOV-8 - This already exists in beta test form as RTIASI-3 from ECMWF. The technical solution currently being implemented is to combine with RTTOV-7 to provide a unified model for all satellite radiances, RTTOV-8. This new model is planned for release in early 2004.
- RTIASI-4 – This is an updated version of RTIASI-3 described by (Matricardi, 2003) which includes reflected solar radiation and variable trace gases.
- PFAAST- This model also exists in beta test form at University Maryland Baltimore County (Hannon *et al*, 1996) and has been compared with RTIASI (V. Sherlock, Comparison of IASI fast model radiance simulations, Met. Office NWP Tech. Rep. **287** 2000 link at `http://www.metoffice.com/research/interproj/nwpsaf/rtm/papers/shell.pdf`)
- Modify OPTRAN, (McMillin *et. al.* 1995) the model used at NOAA/NCEP for AIRS.

3.3.2 Observation Processing

The initial processing should be performed before the data is presented to 3/4DVAR. This could include a 1DVAR retrieval step or just a background check. The bias correction (see 3.3.3 below) is normally applied at this stage although it may also be applied separately at the 3/4DVAR stage. For the 1DVAR step the basic framework can be taken from the NWP SAF Met Office 1DVAR which was designed with IASI in mind.

For radiances:

- Apply O-B checks on radiances; reject if greater than a certain threshold
- Perform additional cloudy radiance processing using NWP background as a constraint for example:
  - McNally and Watts (2003) cloud tests to identify cloudfree channels
  - Variational method (e.g. English *et. al.* 1999) to identify cloudfree fovs
  - 1DVAR retrievals of cloud parameters which can be used in 3/4DVAR
- *Optionally perform 1DVAR retrieval on IASI selected channels including remapped AMSU-A+MHS+AVHRR to identify inconsistent radiances and/or provide a retrieved profile above the model top*
- Differences from current ATOVS processing:
  - § New or enhanced RT model (e.g. RTTOV-8).
  - § Potentially a variable number of channels (< 500) defined from results of information content studies
  - § Possible non-diagonal O+F matrix, contributions from instrument noise, residual cloud, forward modelling (i.e. spectroscopy, fast model parameterisation errors) and "non-linearity error"
  - § Minimisation routines optimised for no. obs > profile vector elements
  - § Possible additional cost functions (e.g. for super-saturation or super-adiabatic lapse rates)

For retrievals

- O-B checks for EUMETSAT retrievals and thinning before assimilation
- Check for unrealistic profiles (e.g. super-adiabatic or super-saturated)

3.3.3 Bias correction

Experience with ATOVS and METEOSAT has shown that any mean bias between the observed and simulated radiances has to be removed by an empirical tuning before assimilation. These biases can be introduced by instrument calibration, pre-processing, RT model errors and NWP model forecast errors (though it is debatable whether you should remove biases from the last). The current plans suggest that a method outlined by Harris and Kelly (2001) can be effective for reducing the mean bias in the computed radiances. Experience with AIRS (Cameron, 2003) has shown that only a few predictors for scan position and upper level thickness (200-50hPa) and lower level thickness (850-300hPa) are required to be effective in reducing biases. An important assumption in this is that the biases only change slowly with time (i.e.> 1 week) which was the case for AIRS but will need to be investigated through the monitoring statistics for IASI. Note that different bias correction files may be required for regional and global models.

3.3.4 Data Monitoring

To provide statistics on the observed minus background radiances and retrievals for IASI a monitoring system similar to AIRS should be provided. The link to the AIRS monitoring web pages for the Met Office can be found at: http://www.metoffice.com/research/nwp/satellite/infrared/sounders/
This is required to alert users to any potential problems with the AIRS radiances/retrievals. It is also important to produce plots in the same format as other NWP centres to facilitate easy comparisons. A separate METOP ATOVS monitoring system (very similar to the current NOAA one) which will provide monitoring for ATOVS+AVHRR will also be required for METOP. Note that HIRS radiances should continue to be monitored even after they have been replaced by IASI radiances as they will provide a useful independent source of radiance data to monitor the NWP system. For IASI it is envisaged the following monitoring plots will need to be provided on a routine basis throughout the lifetime of each METOP satellite and many of these are already provided for AIRS (see link above for example plots):

- Monitor number of soundings for each satellite at various stages of processing:
  - § received from EUMETSAT on EPS-NRT-UT or EARS or local HRPT.
  - § passed quality control (separate into clear and cloudy + qc flags)
  - § assimilated in 3/4DVAR (separate into clear and cloudy +qc flags)
- IASI 1C radiance O-B stats before and after any bias correction in the form:
  - § Time series for a selection of channels or combination of channels (option to separate in latitude bands: 20S-20N; 20-70; 70-90, land, sea, ice)
  - § Global radiance monitoring statistics separated into day/night for each 6hr assimilation window for all channels
  - § 'Tartan' plots for all channels monitoring time series of radiances and radiance biases and st. deviation of observed minus background and retrieved minus background both for 6 hour time period and for past 3 months (see above link for example plots where they are referred to as DNA plots).
  - § Monthly histograms for all channels assimilated for a selection of different latitude bands for O-B and O-A
  - § Biases and number of observations plotted as a function of scan angle for a few channels
  - § Global monthly mean maps for a selection of channels
- Time series of 1DVAR qc flags and cloud stats
- Time series of 3/4DVAR qc flags
- *O-B and O-A stats for 1DVAR retrievals (optional)*
- *Optionally if users are interested in collocation statistics with other observations (i.e. within 50km and 1 hr of IASI sounding) for IASI radiances or 1DVAR retrievals:*
  - *Radiosonde/profiler temperatures and relative humidity*
  - *GPS temperature (from space) and water vapour (from space and surface) soundings*
  - *SSM/I(S) 1DVAR temperature and water vapour retrievals*
  - *AATSR sea surface temperatures*
  - *Ground based total column ozone and ozonesondes*
  - *GOME retrievals*
- *Optionally O-B, O-A and collocation stats as above for EUMETSAT retrievals*

3.3.5 Assimilation in 3/4DVAR

There are several different options all of which need to be investigated in terms of cost/benefit. AIRS data will provide a useful testbed for this. Thinning of the data (radiances or retrievals) will be performed on input to the 3/4DVAR. The options are to assimilate:

i. Level 2 EUMETSAT temperature, humidity *and ozone* retrieved profiles
ii. 1DVAR retrieved temperature, humidity *and ozone* profiles with level 1D IASI, AMSU-A and MHS radiances mapped to the IASI field of view.
iii. Level 1C IASI and remapped AMSU-A+MHS selected channel radiances after a 1DVAR qc step
iv. Level 1C IASI radiances only with AMSU-A and MHS assimilated separately (e.g. with HIRS 1D radiances)
v. Level 1C IASI, AMSU-A and MHS selected channel radiances independently on their original fovs
vi. Reconstructed Level 1C IASI radiances in any of the above combinations.
vii. A compressed form of the IASI radiance spectrum + AMSU-A+MHS

There can be an additional variational quality control step during the minimisation of 3/4DVAR that can reject observations (of any type) which are inconsistent with neighbouring ones.

3.4 Storage and archiving

On receipt from EUMETSAT via the EPS-NRT-UT or direct from the spacecraft the data should be pre-processed (section 3.2) to provide IASI level 1C and optionally level 2 data in a suitable format (e.g. EOFs). It is foreseen that a short term rolling archive for 1C data received on the EPS-NRT-UT could be required for research and development of the pre-processing at NWP centres. This should be for a period of at least 2 weeks. Similarly IASI level 2 retrievals from EUMETSAT should also be kept in an archive and in this case the data volumes should allow all the data to be kept. Older data can be obtained from the EUMETSAT EPS archive in Darmstadt where all products (levels 0, 1C and 2) will be permanently stored in the archive.

The level 1C and level 2 data selected for NWP assimilation will be stored in the Met Data archive for subsequent use by the assimilation which will enable re-runs of NWP experiments to be performed at any time. During the assimilation process the initial departures, quality control flags and radiance analysis departures (O-A) could all be stored along with the qc flags. The media for archive should be decided close to the launch of METOP as technology is changing rapidly. In addition to the 1C radiances additional files such as data selection files (to define which channels are assimilated and where), bias correction files, monitoring files, and collocation files will also have to be archived. The first two are necessary for re-running data assimilation experiments. These data will be kept for many years and if required for reanalyses should be kept permanently.

4. OTHER IASI PRODUCTS

The main ‘product’ from IASI is through the adjustment of the NWP model analysed fields, primarily temperature, water vapour *and ozone* and as such this is not a defined output however it must be emphasised that the NWP model fields themselves are the best description of the atmospheric and surface state at any given time. The ECMWF re-analyses which assimilated TOVS radiances are an example of this.

IASI however could potentially provide retrieved profiles of temperature, water vapour, ozone, sea surface and land surface temperature, estimates of broad-band longwave fluxes and a selection of cloud parameters (e.g. cloud top pressure, phase, drop/crystal size, etc). These can be useful for model validation and comparison with other different types of observations or for long term climate ‘signature’ datasets. These could be model independent or dependent (i.e. 1DVAR) and add very little cost to the overall processing. Alternatively the EUMETSAT and/or SAF products may meet all requirements. IASI derived image products (e.g. water vapour channel imagery) may also be of interest for dissemination to forecasters on the global scale (cf. AMSU-B imagery).

The production, dissemination and storage of these products will all need to be taken into account if any of these products are to be made available to the users.

5. NWP SAF IASI software products

The NWP SAF is developing software and reports relevant to IASI processing. The current list of IASI specific reports and software can be accessed at: http://www.metoffice.com/research/interproj/nwpsaf/iasi/index.html and the AAPP page which will include IASI ingest capability in version 5 is at: http://www.metoffice.com/research/interproj/nwpsaf/atovs/index.html . This list will continue to evolve as new developments in the NWP-SAF institutes become available.

6. SUMMARY

The purpose of this document is to provide an outline of the current thinking within NWP Centres of the various steps necessary in order to exploit IASI data from METOP. As indicated there are still some 'grey' areas where more research is needed to define the exact methodology but the overall scope of the separate tasks which need to be implemented are outlined.

Critical areas for more detailed definition are:

- methodology for data compression
- channel selection
- validation and adoption of fast RT model
- treatment of cloudy fields of view
- definition, format and dissemination of any products required

Critical areas for detailed definition within EUMETSAT/CNES are:

- form of 1C data (radiance or brightness temperature, what is apodising function)
- methodology for data compression and guidelines for decompression by users

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