ASSIMILATION OF TOVS DATA AT THE UK MET OFFICE

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Summary: This paper describes the processing of TOVS data for assimilation into NWP models at the Meteorological Office at Bracknell as at August 1993. After an introduction to the use of satellite soundings in the NWP system, some historical background is given. Then the current satellite soundings systems (global and local) are described, and the target system which has guided the current designs is outlined. Finally, some comments are made about expected future developments in applications, in instruments and in assimilation techniques.

1 Satellite Soundings in NWP at Bracknell

1.1 The Met Office operational NWP system

The operational NWP system at the Met Office in Bracknell includes three atmospheric forecast models: the global model, the limited area model (LAM) and the mesoscale model. Each of these is an implementation of the unified forecast/climate model (Cullen, 1993).

1.2 Data assimilation

Data assimilation is part of the unified model framework, and all three operational NWP models use the analysis correction scheme described by Lorenc et al (1991). This uses a repeated insertion of observations during assimilating integrations of the model, with observation weights recalculated each time-step.

There is a vertical-horizontal splitting of the three-dimensional analysis. Conceptually, the vertical analysis of satellite soundings involves the inference of profiles Δx_η of increments to model variables (eg temperatures) at model levels from vectors y^m of observed variables (eg radiances) for instrument channels. This vertical analysis has been further split into inversion of radiances to profiles x_p at specified isobaric levels (the retrieval levels) and interpolation of increments from retrieval levels to model levels. The retrieval levels are determined by the available radiative transfer models. In the Bracknell systems to date the inversion takes place (either at NESDIS in Washington or locally at Bracknell) before data are presented to the assimilation whilst the interpolation is embedded in the assimilation itself.

As is well known the inversion of satellite radiances is an underdetermined problem and solution requires the provision of prior information. A key topic of this paper is the change from inversion at NESDIS to local inversion using prior information from the assimilating NWP model.

There is an expectation that future developments will allow the inversion also to be embedded in the assimilation, with possibly the need for the interpolation eliminated, and the splitting into horizontal and vertical analysis to be avoided.

1.3 Categories of satellite soundings available

Four categories of satellite sounding data are currently available to the NWP assimilations at Bracknell.

1. Global Soundings System (GLOSS) retrievals at 120km resolution obtained by inversion of TOVS radiance data (HIRS, MSU and SSU) received from NESDIS, using global model or LAM background profiles as appropriate. Note that '120km resolution' is an approximate term, implying selection of 1 in 3x3 HIRS fields of view (FoV).

2. Local Area Soundings System (LASS) retrievals at 120km resolution obtained by inversion of TOVS data (HIRS and MSU) received by direct read-out, using LAM background profiles.

3. NESDIS TOVS retrievals at 120km resolution.

4. NESDIS TOVS retrievals at 500km resolution.

[In addition, DMSP retrievals at 175km resolution are received, but are not processed. Following an earlier period of monitoring and evaluation it was decided that further study of DMSP soundings should await the availability of radiance data.]

1.4 Use of satellite soundings

1.4.1 Status of the four categories

GLOSS retrievals, currently based on NESDIS clear radiances, are being used in parallel trials prior to operational introduction in both the global and the limited-area NWP assimilations as a replacement for NESDIS 120km retrievals.

LASS retrievals have been assimilated for extended periods in the past. At present a revised formulation is awaiting testing for reintroduction into the limited area assimilation. LASS is seen primarily as an earlier delivery of the local subset of GLOSS (though currently there are also certain processing advantages relative to GLOSS). The earlier delivery is important for the LAM but can have little effect in the global model which is run later in each cycle.

NESDIS 120km retrievals and NESDIS 500km retrievals are currently used operationally in both the global and the limited-area NWP assimilations.

1.4.2 Selection of sounding data for assimilation

Within each 3 degree by 3 degree latitude-longitude box, at most one category of sounding data is selected for presentation to the assimilation in the order LASS, GLOSS or NESDIS 120km, NESDIS 500km.

Humidity data in TOVS retrievals are not assimilated at present.

Over land, soundings are not used below 100hPa, and 120km soundings are not used north of 60S.

North of 30S, NESDIS soundings are not used below 850 hPa.

1.4.3 Quality control of soundings

All satellite soundings are quality controlled on a level-by-level basis against NWP background fields using a Bayesian algorithm in an iterative calculation of the probability of gross error. Data are rejected if the final probability of gross error exceeds 50%. In addition there is a multilevel check whereby a complete set of levels is rejected once several levels within the set have failed the quality control check.

Soundings are also subjected to a check on the static stability departure from background.

In the LASS and GLOSS processing there are additional quality checks that may result in a retrieval being flagged.

2 Historical Perspective

TOVS temperature retrievals supplied by NESDIS have been assimilated since the early days of TIROS-N (launched in 1978). Over the years the NESDIS retrievals have become available at higher horizontal resolutions: first 500km, then 250km, and now 120km. The quality of NESDIS retrievals has also improved, especially in the most recent years.

Beginning in the early 1980s, locally produced TOVS retrievals also became available. The following sections trace the development of TOVS processing at Bracknell.

2.1 Origins of LASS

The early development of the Local Area Soundings System at Bracknell, based on direct read-out TOVS data received at Lasham, is described by Eyre and Jerrett (1982). The first version, implemented routinely in 1983, was essentially the International TOVS Processing Package (ITPP) imported from the CIMSS at Madison, Wisconsin. The emphasis was on the provision of soundings for the local area of a similar nature to those available from NESDIS but in a more timely fashion and at higher horizontal resolution.

2.2 Synoptic use by CFO

From an early stage products from the LASS were made available to forecasters in the Central Forecasting Office at Bracknell. For this it was necessary to provide conventional data such as 1000-500hPa thicknesses, by vertically integrating the retrieved temperature and humidity profiles. Additional assistance was given to the forecasters by calculating the thermal wind vectors implied by the thicknesses for groups of soundings. Later it was found useful to provide charts showing differences between retrievals and the forecast backgrounds on which they were based.

2.3 Local climatological prior information

The first significant local development of the ITPP was the use in the linear retrieval algorithm of climatological information specific to the LASS area.

2.4 New cloud clearing scheme

Early study of the LASS results suggested that cloud clearing was one of the main sources of error. This stimulated research that culminated in a new cloud clearing scheme (Eyre and Watts, 1987). This method not only includes revised cloud detection algorithms; it goes on to calculate a complete field of estimated HIRS clear-column radiances, using the N* method where possible and, if all else fails, relying on simulated values based on regression from MSU measurements. Finally, sequential estimation operators are used to improve the horizontal consistency of the fields. The cloud detection aspects of the scheme were favourably validated again more recently by Rizzi et al (1992), though the same study revealed some possible defects in the clear-column estimates themselves.

2.5 Forecast model background profiles

A primary aim in the establishment of LASS had always been the provision of useful data for the NWP system. LASS data were in fact assimilated for a period beginning in September 1984, but misgivings persisted about the impact of the climatological component entering the retrievals as prior information (Lorenc et al, 1985). It became recognised that the accuracy of NWP results in the LASS area is such that more accurate retrievals can be obtained if NWP profiles are used to provide the necessary prior information for the inversion (Eyre et al, 1986). The linear inversion can then be written as follows.

$$x - x^b = W.[y^{cm} - y(x^b)] \tag{1}$$

where x is the retrieved profile vector, x^b is its NWP background value, y^{cm} is the vector of cloud-cleared measured radiances, and $y(x)$ is the forward radiative transfer model enabling background radiances $y(x^b)$ to be calculated from the background profile x^b. The inverse matrix, W, defined as

$$W = B.K^T.(K.B.K^T + O + F)^{-1} \tag{2}$$

is that giving the most probable solution on the assumption of Gaussian errors with the expected covariance matrices B for errors in the background profiles, O for errors in the measurements and F for errors in the forward model. K, which represents the matrix of partial derivatives of $y(x)$ with respect to the elements of x, is assumed independent of x for the linear algorithm.

This approach was adopted operationally using the then current LAM background profiles in May 1988, and LASS data were assimilated operationally from that date for more than four years. Their impact was studied by Bell and Hammon (1989) who found it to be small and positive and a definite improvement relative to NESDIS soundings which gave a negative impact at that time.

2.6 Closer coupling with NWP system

When the LASS first began using NWP background profiles, the organisation of the processing was such that forecasts for up to 15 hours ahead were used as backgrounds. In February 1990 a closer coupling between LASS and the NWP system was introduced (Gadd, 1990) which reduced this maximum to around 8 hours. Time interpolation of NWP backgrounds was also introduced at this stage.

2.7 Problems with NWP backgrounds

In October 1992 assimilation of LASS was discontinued due to disquiet about interaction with NWP background biasses. Study of this problem has highlighted two features. Firstly, given the present interface between satellite soundings and NWP, it is important that NWP output algorithms for standard level temperatures do not produce large biases. Secondly, it is essential to ensure strict consistency in all transformations and interpolations from model data x_η to pressure level data x_p throughout the NWP and satellite sounding systems; otherwise marked artificial biases can easily be introduced. Introduction of operational NWP changes to deal with these points was completed in May 1992. By that time however, additional considerations delayed a reintroduction of LASS to the assimilations, as explained below.

2.8 Non-linear inversion of radiances

Eyre (1989a) developed a non-linear algorithm for the inversion of cloudy TOVS radiances. This is an iterative algorithm based on the minimization of a penalty function, J.

$$J(x) = (x - x^b)^T.B^{-1}.(x - x^b) + [y^m - y(x)]^T.(O + F)^{-1}.[y^m - y(x)] \tag{3}$$

The nth iteration may be written as follows.

$$x_{n+1} - x^b = W_n.[y^m - y(x_n)] + W_n.K_n.(x_n - x^b) \tag{4}$$

W_n is as defined in Eq 2 but with K replaced with K_n. In Eyre's application of this algorithm, y^m are the measured radiances (cloudy, uncorrected, ie level 1b) whilst the profile vector x includes not only temperatures (T) and humidities - held as log of mixing ratio (q) - but also fractional cloud amount (n), cloud top pressure (p_t) and microwave surface emmissivity (ϵ_s). Preliminary values of n and p_t are retrieved using HIRS channels 7 and 8 before the iterations using all channels.

A number of refinements of Eyre's method have been developed and tested by P.D.Watts and P.C.Dibben (personal communication). Perhaps most important among these has been the use of a horizontal constraint on p_t, which has helped to reduce errors arising from an inherent ambiguity in the response of HIRS radiances to changes in n and changes in p_t.

Even though the inversion of cloudy radiances has still not been established as an operational method, the non-linear variational algorithm itself has great generality and is used in the current systems outlined below. Note for example that, when applied to clear radiances, and with $x_1 = x^b$, the first iteration yields the linear solution given in Eq 1 above, but with the advantage that K is a function of the background profile x^b. Even when restricted to clear radiances, the non-linear algorithm offers significant advantages compared with the linear as regards humidity retrievals (Gadd, 1993).

3 Current Systems: GLOSS

3.1 Origins of GLOSS

The evolution of TOVS processing within LASS raised questions about the policy for global soundings. The availability of cloud-cleared radiances with global coverage from NESDIS (col-located with the 120km retrievals) opened the possibility of developing a Global Soundings

System (GLOSS) which uses background profiles derived from the relevant NWP model. The first version of GLOSS, using global model background profiles, was implemented for evaluation purposes in August 1992.

3.2 Outline of GLOSS processing

The Global Soundings System (GLOSS) is the processing system designed to provide satellite sounding data with global coverage for assimilation into the NWP models at Bracknell. GLOSS depends on the transmission to Bracknell of global TOVS data from NESDIS in Washington, and has the same basis as the ECMWF 1DVAR scheme (Eyre et al, 1993) though there also are many differences. An outline of the processing in GLOSS is given in the following subsections.

3.2.1 Data selection

Data records are set up on the Cray containing NESDIS clear brightness temperatures (BTs), at present for NOAA-11 and NOAA-12, in 6-hour time intervals (global model) or 3-hour intervals (LAM), along with collocated background profiles valid at the middle of the interval, horizontally interpolated from NWP data. (The NWP background temperatures are provided at 18 levels from 1000hPa to 10hPa and the background humidities at 7 levels from 1000hPa to 300hPa. In addition, NWP background values of skin temperature, screen temperature, screen humidity and surface pressure are provided.)

Associated with the BTs are the NESDIS classifications of soundings as clear, partly cloudy or cloudy. The following channels are used.

1 - 8, 10 -15 (HIRS), 22 - 24 (MSU) and 25 - 27 (SSU) if classified 'clear'

1 - 3 (HIRS), 22 - 24 (MSU) and 25 - 27 (SSU) if 'cloudy' or 'partly cloudy'

3.2.2 Preprocessing

In the GLOSS processing, channel 8 is 'decorrected' if necessary to remove an atmospheric attenuation correction applied by NESDIS. The decorrection code (M Uddstrom, personal communication) uses separate coefficients for NOAA-11 and NOAA-12. NESDIS do not apply the correction if the column is judged to be very dry according to certain criteria, and the decorrection is not applied in such cases. (It is understood that attenuation correction of channel 8 will be discontinued with the introduction of NESDIS's RTOVS processing system, scheduled for later in 1993.)

After this decorrection of channel 8, the BTs listed above are assumed to satisfy the following specifications (and to be free from other NESDIS preprocessing).

- The HIRS brightness temperatures have been corrected for scan angle.

- The MSU brightness temperatures have been corrected for scan angle (including asymmetry), antenna gain pattern, and surface emissivity and have been mapped to HIRS locations.

- The SSU brightness temperatures have been corrected for scan angle and mapped to HIRS locations. (Note that the SSU mapping includes provision of values at wider scan locations and values for satellites that do not carry the SSU instrument.)

These are referred to below as the input BTs.

The NWP background temperature profiles are interpolated to other levels and extrapolated upwards from 10mb. (Note that RTTOV - see below - performs an internal extrapolation of humidity upwards from 300mb).

Background clear BTs are calculated using the forward radiative transfer model RTTOV (Eyre, 1991) modified to use the NESDIS retrieved total column ozone where available. (The ozone value is not available for a small subset of the soundings and in these cases a regression method is used to estimate total ozone from the 70hPa background temperature.)

A modified version of the air-mass dependent bias correction algorithm (Eyre,1992) is applied. Channels 22-24 (MSU) and HIRS channel 1 are used as predictors of bias corrections to the differences between the input BTs and the background clear BTs for all the channels listed above. The coefficients required to obtain the bias corrections are calculated off-line and updated each month.

3.2.3 Inversion

The inversion is carried out using the non-linear algorithm given at Eq 3 above.

The NESDIS-classified 'clear' soundings are treated as potentially cloudy and the full inversion algorithm is applied to 20 channels at nadir. This includes the preliminary calculation of cloud amount and cloud top pressure using channels 7 and 8. For the NESDIS-classified 'cloudy' and 'partly cloudy' soundings the non-linear algorithm is applied to the 9 channels that are assumed unaffected by cloud.

The matrix of measurement + forward model error covariances $(O+F)$ is diagonal. The diagonal elements are calculated using standard values of the radiometric errors and the value of 0.4K for the expected rms forward model errors in each channel.

The matrix of background error covariances (the B matrix) was determined empirically, using radiosonde observations up to 50hPa in the LASS area as truth, and then extrapolated to higher levels using regression relationships.

3.2.4 Quality control

Following Eyre (1989b), a retrieval is flagged (for rejection by the NWP data assimilation) if the bias-corrected difference between the input BT and the BT corresponding to the retrieved profile in any channel exceeds 4 times the expected rms BT error (ie the square root of the appropriate diagonal element from the $O + F$ matrix).

3.2.5 Monitoring

The retrieved profiles, the BTs corresponding to them, and quality control flags are stored in the data records for subsequent access by the NWP system (for assimilation) and by the GLOSS monitoring facilities using NWP data (B.R.Barwell and S.J.Cox, personal communication) and monitoring using radiosonde observations (P.C.Dibben and D.E.Chapman, personal communication).

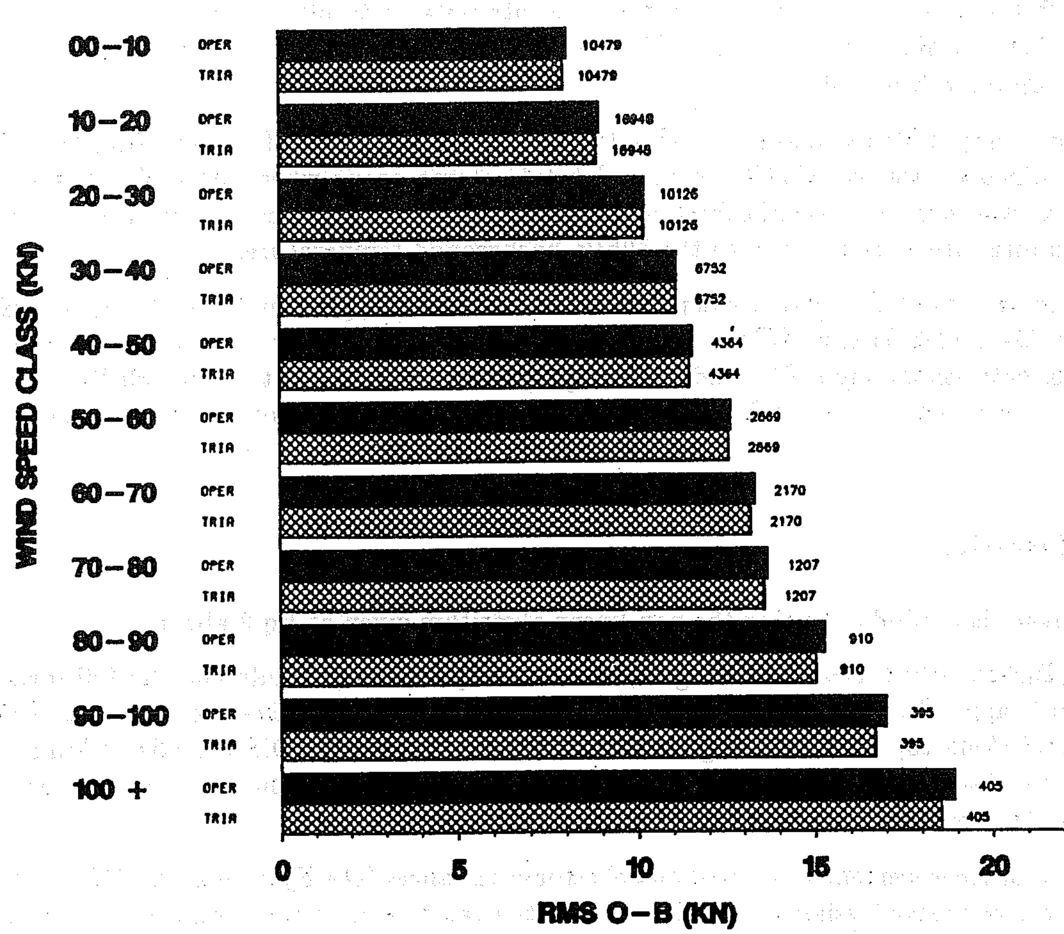

Figure 1: RMS fit of background (B) winds to radiosonde observations (O) in 45N-15N, 22-30 June 1993

3.3 NWP impact studies

The impact of GLOSS is being studied by experimental runs of the NWP suite in parallel with the operational suite. In the experiments, the NESDIS 120km temperature retrievals are replaced globally with the GLOSS 120km data. As explained previously, these 120 km soundings are assimilated over the sea.

In two experiments to date, an independent data assimilation cycle has been run using GLOSS in place of NESDIS 120km soundings.

The first experiment was run in February 1993, and the results were used to refine the GLOSS processing. A second experiment was then run from 22 June until 15 July 1993.

The second experiment has been assessed by statistics of the fit of NWP background fields (6 hour forecasts) to radiosonde observations. Results for winds have been studied in 5 latitude bands (90-45N, 45-15N, 15N-15S, 15-45S, and 45-90S). Particular importance is attached to errors when the observed wind is in excess of 100kn. The latitude band with the largest number (405) of such cases was 45-15N, and the results for this band are shown in Figure 1. Similarly encouraging results were obtained for the other latitude bands.

A third trial is now planned, in which 3 day forecasts will also be assessed.

4 Current Systems: LASS

4.1 The roles of GLOSS and LASS

GLOSS and LASS represent two routes by which the same TOVS measurements can be processed for use in NWP. LASS is viewed essentially as providing the local subset of the GLOSS data in a more timely fashion. Note that the terms GLOSS and LASS refer to the global and local sources of the TOVS radiances, and thus that, when GLOSS data are assimilated in the LAM, it is the LAM background that is used in the inversion.

GLOSS data are intended for assimilation in both the global model and the LAM. LASS data are intended for assimilation only in the LAM at present since their earlier availability will not normally be necessary for the present global model schedule. As explained in section 1.4.2, there is a hierarchical selection of sounding data such that GLOSS data will not be used in those parts of the LAM area where LASS data are available.

4.2 Options for LASS processing

Three distinct approaches to TOVS processing have now been used at various stages at Bracknell.

4.2.1 Linear inversion of cloud-cleared radiances (LCC)

This is the method used operationally in LASS until October 1992. 'Cloud-cleared' implies estimated clear-column limb-corrected HIRS values everywhere.

4.2.2 Non-linear inversion of level 1b radiances (N1b)

This is the method used experimentally for the inversion of cloudy radiances. 'Level 1b' implies calibration, earth-location, and possibly some quality control but no other pre-processing. Mapping of MSU to HIRS FoVs is also required.

4.2.3 Non-linear inversion of cloud-free radiances (NCF)

This is the method currently being used in GLOSS trials. 'Cloud-free' is a term adopted to distinguish from 'cloud-cleared' as used in LCC above, and includes both 'it is believed there is no cloud' and 'the channel is unaffected by cloud'. Thus 'cloud-free' implies all HIRS plus mapped MSU when the HIRS FoV is believed to be clear but HIRS 1, 2 and 3 only plus mapped MSU otherwise. When resolution is reduced to 1 in 3x3, clear FoVs are selected preferentially. Note that the inversion remains free to retrieve cloud at the FoVs believed to be clear.

4.2.4 Status of the three methods

• LCC retrievals have not been assimilated since October 1992 due to background bias problems. It has been an objective for some time to replace LCC with N1b.

• N1b is the target method for both LASS and GLOSS and is the basis for all longer-term research. It cannot yet be used for GLOSS because the global 1b data is not received from Washington. For LASS, versions of N1b are run regularly and generally achieve similar radiosonde collocation scores to LCC. However N1b requires considerably more computing resources than LCC without any evidence of commensurate benefits for temperature soundings. (There are, of course, other benefits, notably the cloud information retrieved.)

• NCF is used for GLOSS. The results of a parallel run in which GLOSS replaced NESDIS retrievals (see above) are encouraging.

4.2.5 NCF method for LASS

After having been withdrawn from the assimilation LASS (whichever version) requires parallel forecast runs to check its impact before reintroduction. To expend this effort on LCC is not attractive given that it is not seen it as a long-term option. N1b at present (judged by collocation statistics) would provide no benefit to the current NWP system despite increased cost in computing resources.

A third option is to set up NCF for LASS and this has now been done. NCF LASS differs from previous versions in that it follows closely the methods that have been developed for GLOSS. The main differences from GLOSS are

(i) Local rather than NESDIS cloud detection.

(ii) Measurements used without correction to nadir.

(iii) Microwave surface emissivity is retrieved using MSU channel 1.

(iv) Time interpolation of NWP background profiles.

(v) SSU data are not processed in LASS.

There are several advantages in using NCF for LASS. It is step towards N1b, which remains the goal. It brings a closer consistency of LASS and GLOSS. Benefits may come from the combined GLOSS/LASS monitoring and tuning effort.

5 Short-Term Development of Current Systems

The following developments are envisaged in the short-term.

1. Assimilation of TOVS humidity data. The usefulness of HIRS channels 11 and 12 in monitoring changes in NWP humidity fields has already been demonstrated (Renshaw, 1993).

2. Revision of error covariance matrices.

3. Modification of increments and weights in the assimilation to take approximate account of correlated errors of retrievals and NWP backgrounds.

4. More sophisticated quality control, following up the approach of Barwell and Young (1993) that was implemented in linear LASS.

6 Target System

Recent work leading to the current systems outlined above has been guided by a target TOVS system. This has four important features.

- Inversion of cloudy radiances.
- Use of AVHRR data for soundings.
- Complete integration of LASS and GLOSS at full HIRS resolution.
- Inversion embedded in the assimilation

6.1 Inversion of cloudy radiances

As indicated above, inversion of cloudy TOVS radiances remains the objective both for LASS and for GLOSS. The principle underlying this is that the fullest possible use should be made of the HIRS measurements. This can be achieved only with the N1b method above. Both LCC and NCF require considerable portions of the HIRS data to be discarded.

A further motivation for the inversion of cloudy radiances, of course, is the retrieval of cloud information along with the temperature and humidity information. Cloud information is likely to be increasingly useful as input to NWP systems.

6.2 Use of AVHRR data

Although designed for the provision of satellite imagery, data from the AVHRR instrument could very usefully complement TOVS in soundings work. The best approach will be to map the AVHRR pixels to each HIRS FoV. Advantage can be taken of AVHRR algorithms that classify the pixels as clear, cloudy or mixed. Thus by processing the set of AVHRR pixels for each HIRS FoV it will be possible to obtain estimates of clear and cloudy radiances for each AVHRR channel.

These AVHRR data, used along with TOVS, should be very helpful in improving the retrieval of cloud information. In this way the cloud amount/top ambiguity that features in the N1b results may be controlled more closely, with benefits for temperature and humidity information.

6.3 Global level 1b data

The developments noted in this section require the availability of level 1b TOVS data and associated AVHRR data. For LASS it is straightforward in principle to calculate the required level 1b data from the direct read-out data. For GLOSS these developments depend on arrangements to receive global level 1b TOVS data (with associated AVHRR data) from NESDIS.

In the target system the role of LASS in providing an earlier delivery of local data will remain, but will be fulfilled simply by the calculation of the local 1b data and its storage in a global 1b database. Full HIRS resolution globally is the target.

6.4 Inversion embedded in the assimilation

An attrative possibility in the current assimilation environment would be to repeat the inversion with the latest background profiles at each time step of the assimilating integration. However this development may be overtaken by a move towards four dimensional variational assimilation.

7 Further Developments

7.1 Climate data applications

Certain further developments in TOVS processing are primarily motivated by climate data applications, but may have benefits also for NWP. They may well be incorporated into the target system, and certainly if it is used in special data assimilations for climate research purposes.

7.1.1 Extensions to modelling of cloud

The modelling of cloud radiative properties for use in the non-linear inversion has already been extended in experiments described by Watts and Baran (1992) and Watts (1993). The cloud drop effective radius is now being retrieved, essentially from the previously unused HIRS channel 19, and cloud radiative properties are being modelled more completely in an extended version of the forward model RTTOV. Further research is aimed at improvement of the treatment of ice cloud and retrieval of cloud optical depth (using HIRS channel 20). This use of reflected solar radiation in channels 19 and 20 requires improved modelling also of the radiative characteristics of the physical surface.

7.1.2 Other aspects of atmospheric composition

As well as water vapour and cloud, other information on atmospheric composition can be extracted from TOVS data. Two important examples are total column ozone (obtained using HIRS channel 9) and sulphuric acid aerosol from volcanic eruptions (obtained using the differing channel 10s on NOAA 11 and 12 - see Baran et al, 1993).

7.2 Instrument developments

7.2.1 DMSP instruments

Although beyond the title of this lecture, it must be noted that the SSM/T, SSM/T-2 and SSM/I instruments on the DMSP satellites provide potentally useful sounding data. The methods described here for TOVS could be adapted for DMSP radiances if these should become operationally available in real-time.

7.2.2 ATOVS

It is believed that the methods outlined here for TOVS data can be successfully applied to ATOVS data after the launch of NOAA-K. The HIRS and AVHRR instruments will change only slightly whilst MSU and SSU will be replaced by AMSU-A and AMSU-B.

7.2.3 Advanced IR instruments

The complete information about the infrared spectrum from advanced infrared instruments such as IASI is an exciting prospect for the next century. As well as providing a basis for much higher vertical resolution in the temperature and humidity soundings, it seems likely that a much more detailed picture of surface characteristics and atmospheric composition will be obtainable.

7.3 Four dimensional variational data assimilation

Early work with four dimensional data assimilation has shown great promise. Current thinking is that the systems discussed in this paper will then find their role in the preprocessing of satellite sounding data before it is assimilated.

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