1. INTRODUCTION

ECMWF is currently developing a system to generate retrieved products from TOVS measurements intended for routine assimilation into the operational forecast model. The method of retrieval uses a one dimensional variational analysis (1-D VAR) of (initially) NESDIS cloud cleared radiances and is intended to operate on raw (cloud contaminated) measurements in the near future. The 1-D VAR retrieval scheme is so called within the context of ECMWF’s plan to adopt a three and ultimately four dimensional variational analysis of all observations in the operational forecast suite. Though the explicit retrieval step may be regarded as a temporary interface to the current OI analysis, the problems which must be addressed in the 1-D case are directly relevant to the future integration of satellite data within the 3 and 4 dimensional systems.

2. THEORETICAL BACKGROUND

In any variational analysis scheme we are faced with minimising a cost function \( J(X) \) which is equivalent to searching for the most probable atmospheric state \( X \), conditional upon a set of observations having occurred and some background estimate of the state \( X_b \). For the 1-D analysis of a multi-channel satellite measurement \( Y_m \) the cost function minimised becomes

\[
J(X) = (X-X_b)^T B^{-1} (X-X_b) + (Y_m-Y)^T E^{-1} (Y_m-Y)
\]

where the matrices \( B \) and \( E \) represent the background and measurement/forward model error covariances respectively, these errors being assumed unbiased (and therefore must have been previously corrected). The cost function is minimised using an iterative algorithm based upon Newton’s method. Following a scheme developed at the U.K. Meteorological Office (Eyre 1989), convergence is reached when further iterations produce no significant adjustment of the profile \( X \). It is expected that convergence will be reached quickly (i.e. in one or two adjustments of the profile) at least when analysing cloud cleared radiances and this is supported by the test runs carried out to date. The extra computational expense required to operate 1-D VAR on cloudy radiances should not be excessive.

The success of the analysis (i.e. its ability to produce a better estimate of the atmospheric state than the background) may be considered as dependent upon three factors.

1. Our ability to perform fast accurate forward calculations to obtain \( Y_X \) from the state \( X \) (including any extrapolation or assumptions which relate \( X \) to the atmospheric parameters required for radiative transfer calculations, e.g. ozone amount). A fast adjoint of the forward calculation is also required in the
minimisation process (i.e. to evaluate the gradient of the cost function).

2. Our ability to model accurately errors in the background profile $x_b$ and any subtle inter-level correlations of the error.

3. Our ability to model accurately errors in the satellite measurements, the processing stages they undergo (e.g. cloud clearing, corrections for limb and emissivity effects) and the calculated radiances $y_x$ (i.e. forward model errors). Both the random and bias component of these errors are required.

Although 2 is very important (Watts and McNally 1988, McNally 1990) it will not be discussed in this paper and may even be considered a problem best addressed by the data assimilation community as a whole. The following section describes the system recently set up at ECMWF to address the problem of estimating forward model and measurement errors.

3. THE ECMWF RADIANCE MONITORING SYSTEM

An important part of the present ECMWF data assimilation system is the quality control of NESDIS "120 km" TOVS retrieved products (15 mean layer virtual temperatures and 3 precipitable water values) before their use in the OI analysis. One of the checks currently applied is based upon comparing radiances calculated from the forecast background field with the measured values. Apart from its operational quality control applications, the system (known as PRESAT) has recently been adapted to generate a routine archive of measured and forecast radiances for use in tuning the 1-D VAR retrieval scheme. The data coverage processed in a typical 6 hour period (around 12Z) is shown in Figure 1.

Running in parallel to PRESAT is a matching system called COLOC which is designed to generate a complementary archive data base of TOVS measurements with synthetic values calculated from coincident radiosonde ascents. The coverage of these data is obviously more sparse than forecast radiance comparisons and that for the same 6 hour period is shown in Figure 2.

4. USE OF THE SYSTEM AND STRATEGY

How the data bases will be used to tune 1-D VAR is not yet clear as neither the PRESAT (forecast radiance) nor the COLOC statistical output provide exactly what is required. The former is obviously subject to forecast error contamination and will tend to overestimate the true combined measurement and forward model radiance errors. The COLOC system will also tend to suggest a tuning in excess of that required due the inevitable presence of intrinsic radiosonde errors and those associated with poor temporal and spatial coincidence.

It is expected that the two systems will have to be used in a complementary way, utilising the most useful aspects of each. Radiance tuning against the forecast obviously provides a greater volume of data and statistics which are more spatially representative than radiosonde matching. However, radiosondes are currently the best available measure of the atmospheric state viewed by the satellite and on a local scale represent a very stringent check upon any global tuning derived from forecast comparisons.
5. PRELIMINARY INVESTIGATIONS

As a preliminary test the radiance monitoring system was run over a ten day period from February 1989 and statistics of measured-forecast radiances were collected. A simple filtering and horizontal analysis of the mean radiance differences produced the fields shown in Figures 3 and 4. Though the radiance differences will certainly contain a component of forecast error, the results do suggest that a rather complicated system of bias correction will be required to run 1-D VAR successfully, possibly using corrections based upon a number of air-mass predictors. A stringent quality control to remove residual cloud effects will also be necessary in the bias correction scheme. It must be stressed that these results are very preliminary and it is impossible to draw any firm conclusions until PRESAT and COLOC have built up a more substantial data base on which to operate.

6. SUMMARY

It is hoped that in the near future the radiance monitoring systems will generate a statistical data base from which an accurate tuning and correction procedure can be developed. The importance of this is recognised at ECMWF not only for the successful implementation of 1-D VAR within the operational forecast system, but as necessary requirement of the planned 3 and 4 dimensional variational assimilation in which the same radiance errors will have to be modelled.

7. REFERENCES


Figure 2. Data coverage of measured-sonde radiance comparisons in the same 6 hour period.
Figure 3. Filtered field of measured-forecast radiance differences averaged over a 10 day period for IIIRS channel 7

Rad Dev ch 7 noaa 11
Time: 43200 GMT, Date: 890212, no obs: 103767
Gaussian Grid
Analysis of raddev

[Diagram of radiance differences with contour lines and grid]
Figure 4. 
Filtered field of in situ-forecast reliability differences averaged over a 10 day period for HIRS channel 4.

Time: 4:32:00 GMT
Date: 890212
Gaussian Grid
Analysis of raddev

No obs: 103767
TECHNICAL PROCEEDINGS OF THE
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