The assimilation of stratospheric satellite data at ECMWF

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1. Background to stratospheric satellite assimilation at ECMWF

An important milestone in the use of stratospheric satellite data was the increase in altitude of the ECMWF model top from 10hPa to 0.1hPa in 1999. Before this change stratospheric radiances were difficult to use as most channels tended to have a significant sensitivity to the atmosphere above the model top that could not be adjusted during the assimilation process. Any attempt to use these data ran the risk of aliasing signals in the radiances from above the model top to erroneous adjustments within the model domain.

Since the change extensive use has been made of stratospheric radiances from a number of different sensors, the jacobians (describing their temperature sensitivity) of which are shown in figure 1. In operations the primary source of data has been the Advanced Microwave Sounding Unit A (AMSUA) and, in the context of re-analysis, the Stratospheric Sounding Unit (SSU). A more limited use has been made of radiances from the High resolution InfraRed Sounder (HIRS) due mainly to the redundancy with AMSUA channels, but also some problems with interference based noise. All the stratospheric radiance data used comes from instruments carried by operational NOAA polar orbiting spacecraft.

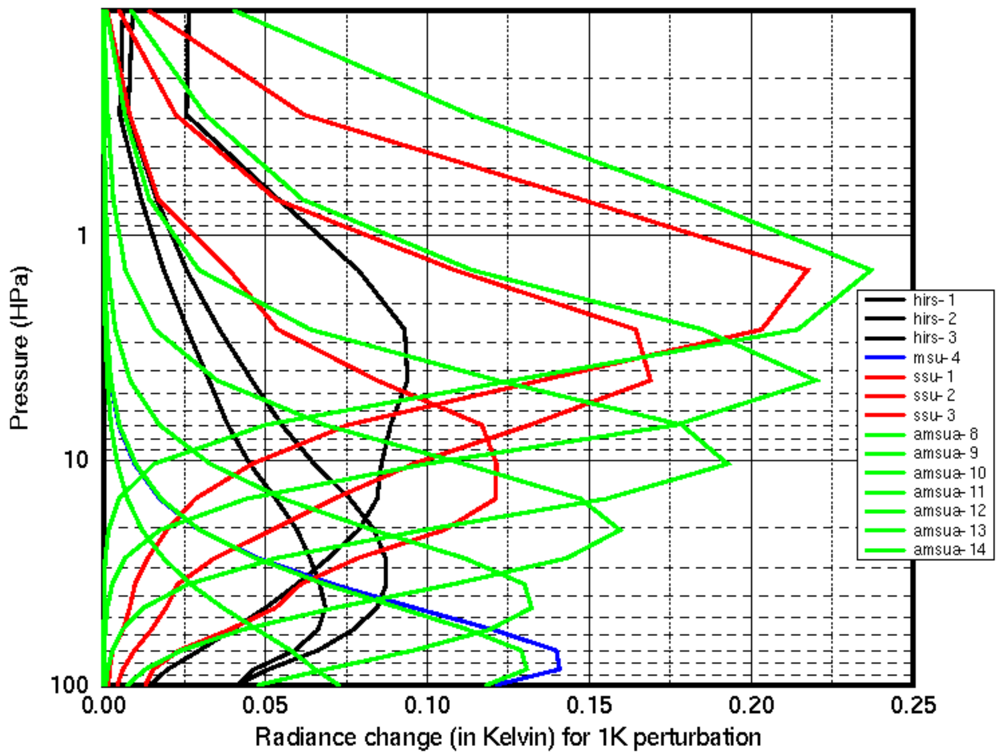

Figure 1 Jacobians of channels sensitive to the stratosphere

A key strength of the current observing system is the excellent coverage and resolution of its geographical sampling, with currently 3 AMSUA sensors providing radiances to the operational assimilation system (see figure 2). Another great advantage has been the robustness and time continuity of the AMSUA observing system, allowing detailed documentation and investigation of many interesting annual phenomena (such as the sudden warmings shown in figure 3).

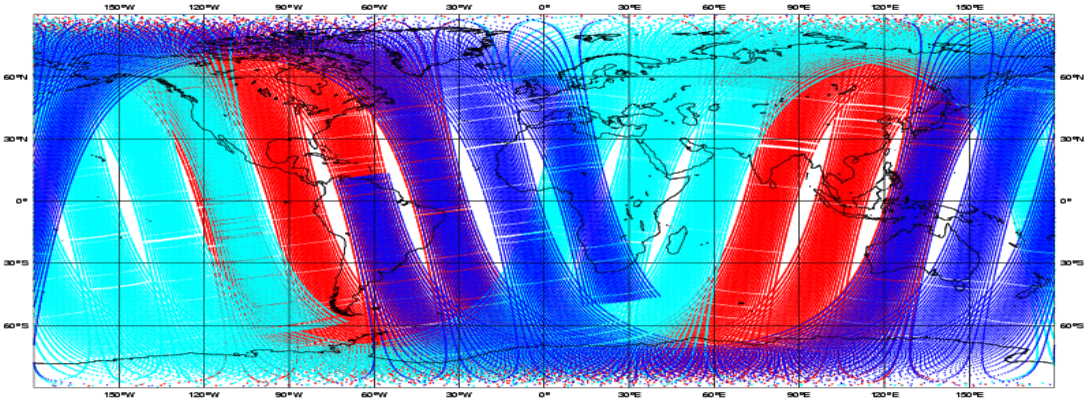

Figure 2 Coverage of AMSUA data on NOAA polar orbiters

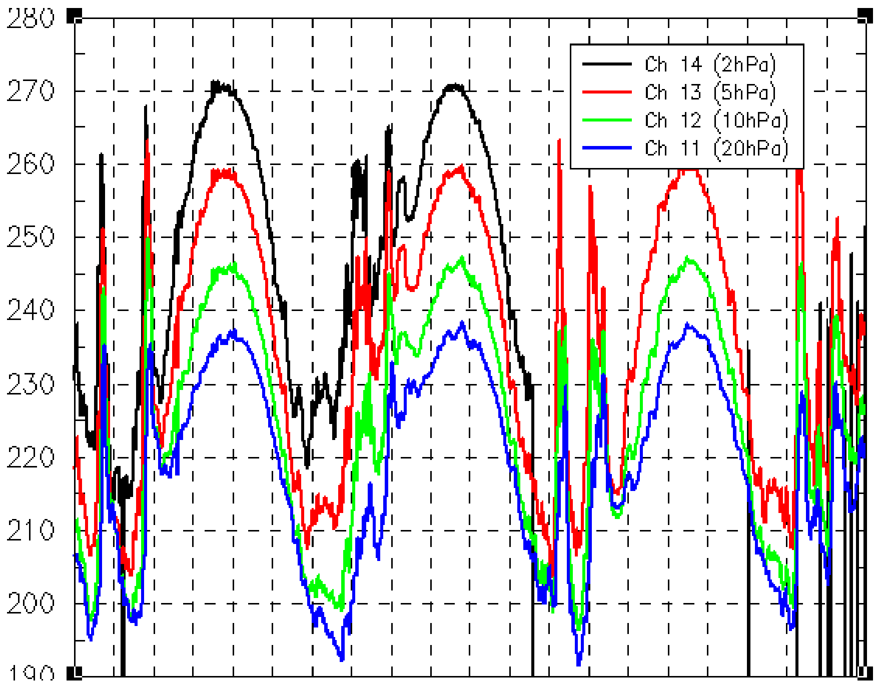

Figure 3 Mean (North) polar AMSUA brightness temperatures for 2 years showing sudden warmings interrupting the normal cold winter temperatures

The main weaknesses of the current observing system are related to the poor vertical resolution of passive nadir sounding instruments and systematic error. These are discussed in the following two sections.

2. Systematic error

Systematic errors in satellite radiance data (or the radiative transfer models used in their assimilation) are a particular problem as they tend to have a global influence. The monitoring of satellite instruments has reached a very mature stage in recent years and has exploited the ability of NWP systems to expose problems in individual instruments and cross-check against other instruments. However, there is obviously a limit below which it is difficult to determine if a source of data systematically wrong or if it is actually exposing a problem in the "standard" against which the monitoring is performed (i.e. the NWP system). Currently we can detect (and generally correct rather well) systematic errors down to a few tenths of a Kelvin, but it is known that even small residual biases can cause significant adjustments to the assimilation system over long periods. A particular problem with the stratosphere is that the NWP model tends to have its largest systematic temperature errors at high altitudes, invalidating the traditional approach of diagnosing data and RT errors using the NWP model. This is illustrated very well by the time series of AMSUA channel 14 radiance departures shown in figure 4. The large seasonal variation of the bias (together with the anti-correlated hemispheres) suggested that the bias was a feature of the NWP model and not the AMSUA. This was subsequently confirmed by cross checking with data from the Halogen Occultation Experiment (HALOE). A less obvious consequence of systematic errors in the NWP model is that they can give rise to apparent scan dependent biases being diagnosed in the data. It can be shown that a systematic error in the model lapse rate gives a systematic under or over estimation of the limb effect, and thus a scan dependent bias that is not due to the data or RT model.

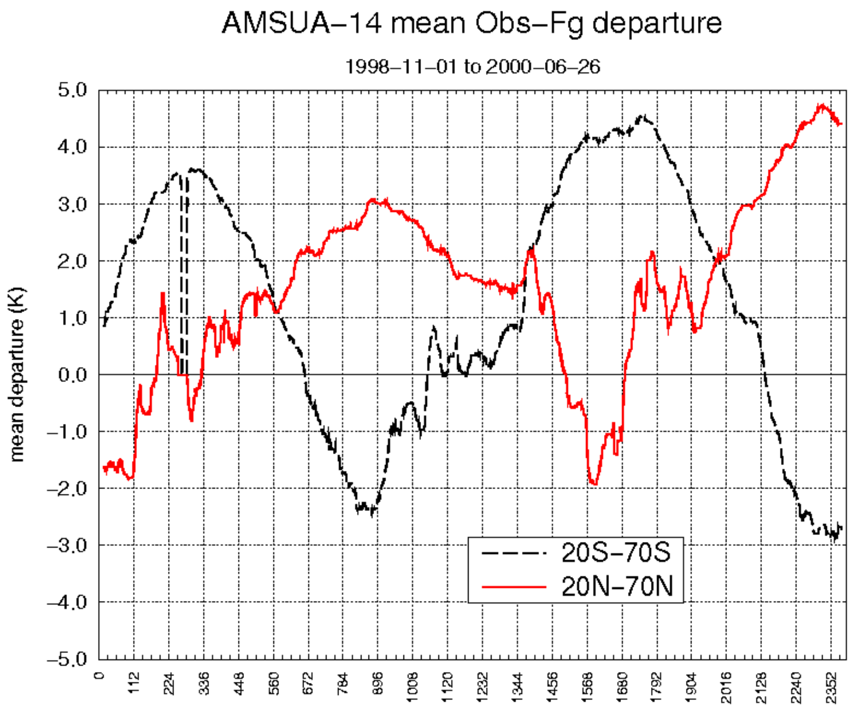

Figure 4 Time series of AMSUA-14 systematic radiance departures

3. Vertical resolution and J_b

Due the physics of passive nadir sounding, the radiance data from the current operational instruments provide a limited amount of information about the detailed vertical distribution of temperature in the atmosphere. Instead they offer information about rather deep vertical layers. This limitation puts a huge emphasis upon the ability of the analysis system to correctly distribute the temperature increments in the vertical. This vertical distribution of increments is controlled by the background error covariance combined with any other constraints imposed upon the system. Figure 5 shows how well (in 1-dimensional analysis) a large hypothetical perturbation (or error) can be recovered (or corrected) by the assimilation of radiance data (in this particular case simulated radiances from the AIRS instrument). It can be seen that the smooth perturbation is not recovered very well, with an under adjustment near the top of the model accompanied by vertical oscillations (or ringing below). This is a direct consequence of the background errors being too small at the top of the model, but also the fact that in the ECMWF analysis system temperature errors are assumed to be anti-correlated over very short vertical scales (essentially encouraging oscilliatory solutions). While the perturbation simulated is large, it is not unrealistic considering the nature of stratospheric errors we wish the satellite data to correct.

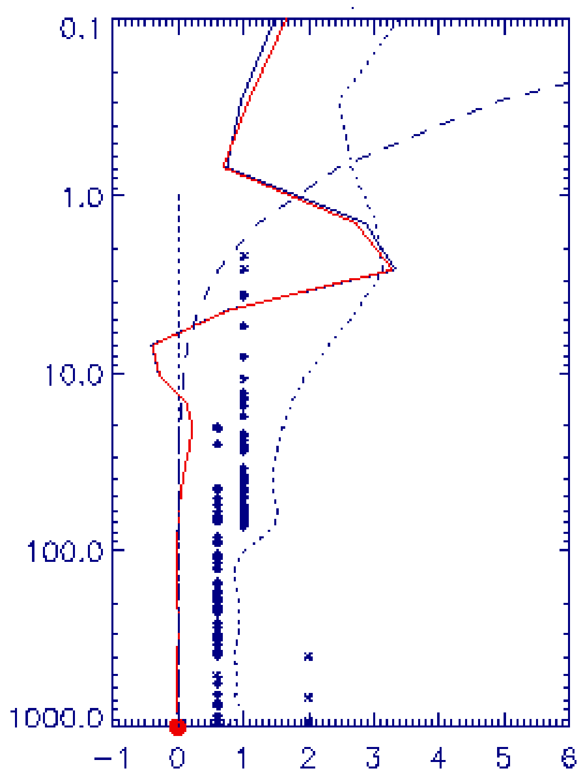

Figure 5 The recovery of a smooth temperature perturbation (dashed line) using a 1DVAR analysis (red line) .

4. Future perspectives

New satellite data from the Atmospheric InfraRed Sounder (AIRS) with many thousands of channels and the Special Sensor Microwave Imager/Sounder (SSM/IS) will provide more detailed (in the case of AIRS) and higher (in the case of SSM/IS) information on stratospheric temperature structures. However, they will still be limited and rely on a skillful assimilation system to constrain fine vertical structure and deal with systematic errors. Some of the problems related to poor vertical resolution will certainly be reduced with the introduction of limb sounding data to operational assimilation systems. New data from instruments on board the ENVISAT platform are an exciting prospect and are already showing great promise. Indeed exploiting the synergy between the very high vertical resolution of limb sounding instruments and the strengths of the current nadir sounding sensors may be the key to successful stratospheric radiance assimilation for the future.