THE ASSIMILATION OF SSM/I HUMIDITY AND WIND SPEED INFORMATION

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1. Introduction

The Special Sensor Microwave Imager (SSM/I) was first flown on the Defense Meteorological Satellite (DMSP) F8 polar orbiting spacecraft in 1987. Since then it has been carried on all subsequent DMSP platforms, the most recent being F15 launched in 1999. The instrument measures horizontally and vertically polarized radiation at 3 frequencies (19, 37 and 85GHz) and vertically polarized radiation at 22GHz. The instrument has a conical scanning action (rather than the cross-track scan adopted by microwave instruments on the NOAA polar orbiting spacecraft) that maintains a constant angle to the Earth's surface of about 53 degrees. The intention of such an approach is to simplify the contribution to the measurements of surface emission and reflection by only having to consider the surface emissivity at a single angle.

The region of the electromagnetic spectrum measured by SSM/I is shown in figure 1. The lower frequency channels are essentially window channels (where the atmosphere is almost transparent) and measure radiation from the surface. However, they also sample a rather weak water vapour line which results in significant absorption in very moist atmospheres. The higher frequency measurement at 85GHz is also essentially a window channel, but is in a part of the spectrum where water vapour continuum effects can result in significant absorption (indeed stronger than the line at 22GHz). It can also be seen that cloud absorption becomes more significant at 85GHz compared to the lower frequencies.

Observed SSM/I brightness temperatures at 19GHz are shown in figure 2 to illustrate some of the spectral characteristics of the measurements. The most obvious feature is that radiation measured over land and ice is much larger than that from the sea. This is because the emissivity of the sea surface is rather low (0.4 to 0.6 depending on polarization) compared to that of land (typically near 1.0). Over the dark background of the sea surface emission it is possible to see variations in atmospheric water vapour, areas of high humidity showing up as bright emission. It is this feature that allows information on total column water vapour (TCWV)to be extracted from SSM/I data. Over land the surface emission is so bright that it is difficult to detect any signal due to water vapour variations.

In addition to being intrinsically low, the emissivity of the sea surface is strongly modified by surface wind due to its roughening effect. This is illustrated in figure 3 where a number of different theoretical emissivity models are used to predict the vertically (V) and horizontally (H) polarized emission (at 37 and 85GHz) from a sea surface at 288K. It can be seen that all the models predict a significant increase in the H component compared to that of the V component with increasing wind speed. It is this strong dependence of the sea surface emission (or rather the difference between the V and H components) on surface roughness that allows the extraction of surface wind speed (Ws) information from SSM/I.

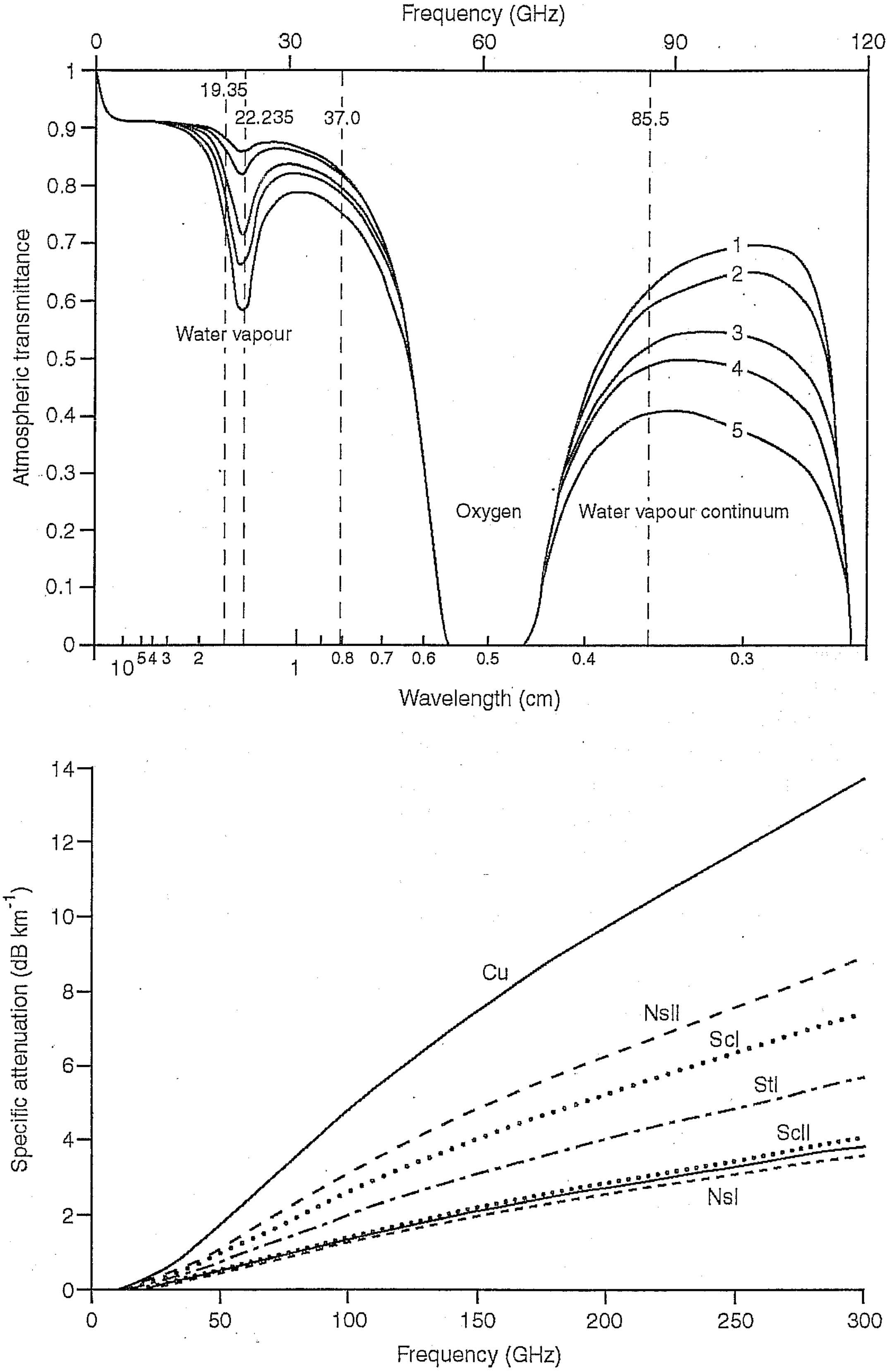

Figure 1. Absorption in the microwave region of the spectrum measured by SSM/I.

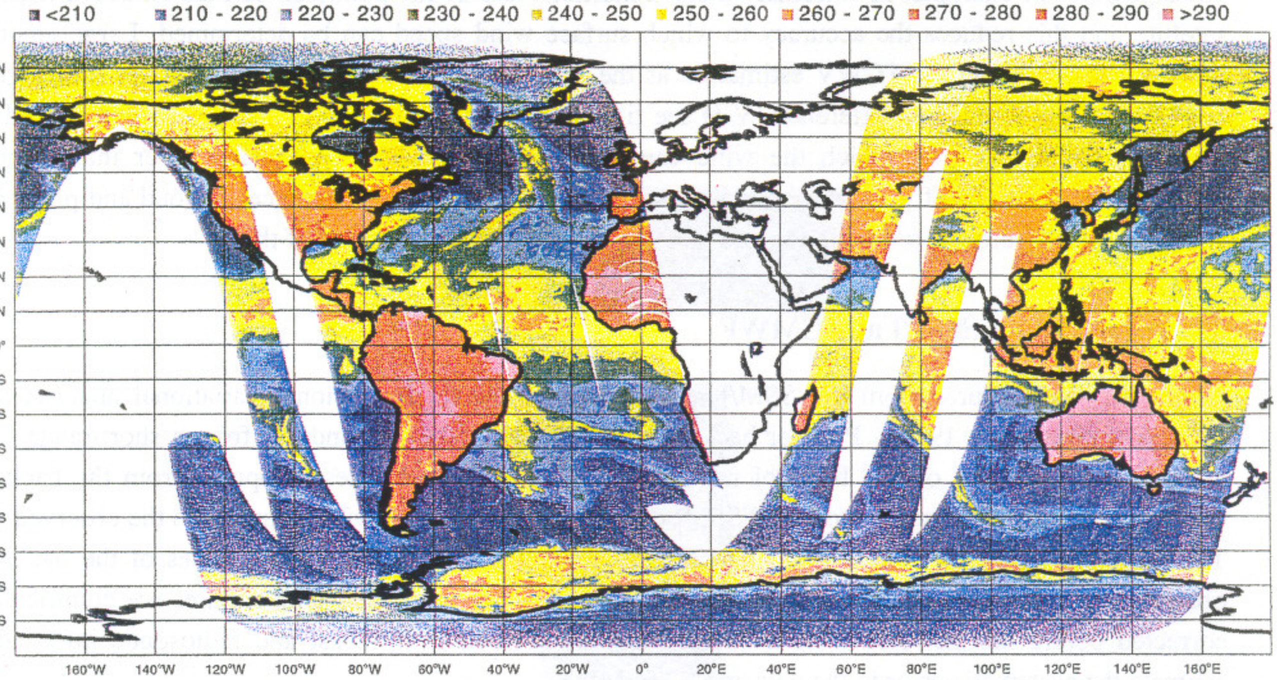

Figure 2. Observed SSM/I brightness temperatures in the 19GHz (H) channel showing the high emission over land / ice and changes in emission over sea due to humidity variations.

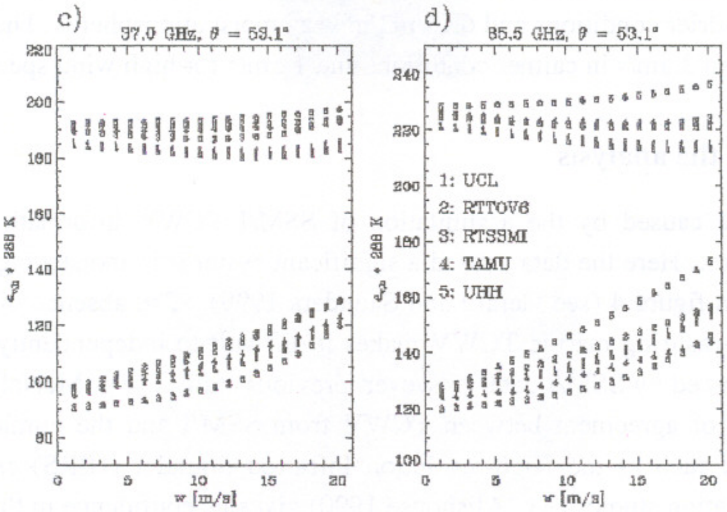

Figure 3. Various emissivity models predicting the surface emission over sea as a function of wind speed.

Our ability to extract information about humidity and surface wind speed depends on the state of the atmosphere. For example, in extremely moist conditions less of the polarized surface emission reaches the satellite and this reduces the accuracy to which surface wind speed can be determined. Large amounts of moisture also degrade the TCWV estimation as the brightness temperature signal saturates. For high wind conditions the polarization difference (V-H see figure 3) is more sensitive to changes in wind speed which improves the accuracy to which the wind can be determined. There are many other interactions that influence the accuracy of wind and humidity estimates, in particular the presence of cloud and precipitation, and the reader is referred to Phalippou and Gerard 1996 for a full discussion of these.

2. The use of SSM/I at ECMWF

Brightness temperatures from the SSM/I are supplied to a one dimensional variational analysis scheme (1DVAR) (Phalippou 1995). Prior or background estimates of TCWV and Ws from a short-range forecast are optimally adjusted on the basis of how well brightness temperatures computed from the background (using a fast radiative transfer model RTSSMI described in Phalippou 1993) compare to the observed values. The adjustment process is optimal in that it takes in to account the error covariances of the background, observed data and the radiative transfer model. The observed brightness temperatures are empirically bias corrected before the 1DVAR using a combination of short-range forecast and radiosonde information to estimate the systematic error in the data and RTSSMI.

The 1DVAR adjusted background estimates of TCWV and Ws are then supplied as pseudo-observations to the main data assimilation system which is a four dimensional variational analysis (Rabier et al. 2000). The errors assigned to these pseudo-observations were empirically determined and reflect the varying accuracy of the TCWV and WS estimates under different atmospheric conditions. For TCWV the error varies linearly between 2Kg/m2 in drier conditions and 6Kg/m2 in very moist atmospheres. The error assigned to Ws varies quadratically between 3.5m/s in calmer conditions and 1.5m/s for high wind speeds.

3. Impact on the analysis

The largest changes caused by the assimilation of SSM/I TCWV information were in the Tropics and Southern Hemisphere. Here the data caused a significant systematic moistening of the analysis in excess of 1Kg/m2 as shown in figure 4 (see Gerard and Saunders 1999). The absence of any extensive conventional observing system measuring marine TCWV makes it difficult to independently verify the validity of these humidity changes forced by SSM/I data. However, previous studies (e.g. McNally and Vesperini 1996) have shown a high level of agreement between TCWV from SSM/I and the humidity information from other satellite instruments such as the High-resolution Infra-red Sounder (HIRS) carried on NOAA platforms. This and other validation studies (e.g. Alishouse 1990) gives us confidence in the use of the SSM/I humidity information.

The main impact of SSM/I Ws information was to systematically increase the surface wind speed in the extra-tropics (up to 0.5 m/s in some cases). Independent validation with ERS altimeter data and conventional wind speed observations from ships and drifting buoys all show better agreement with the higher wind speeds forced by SSM/I data assimilation.

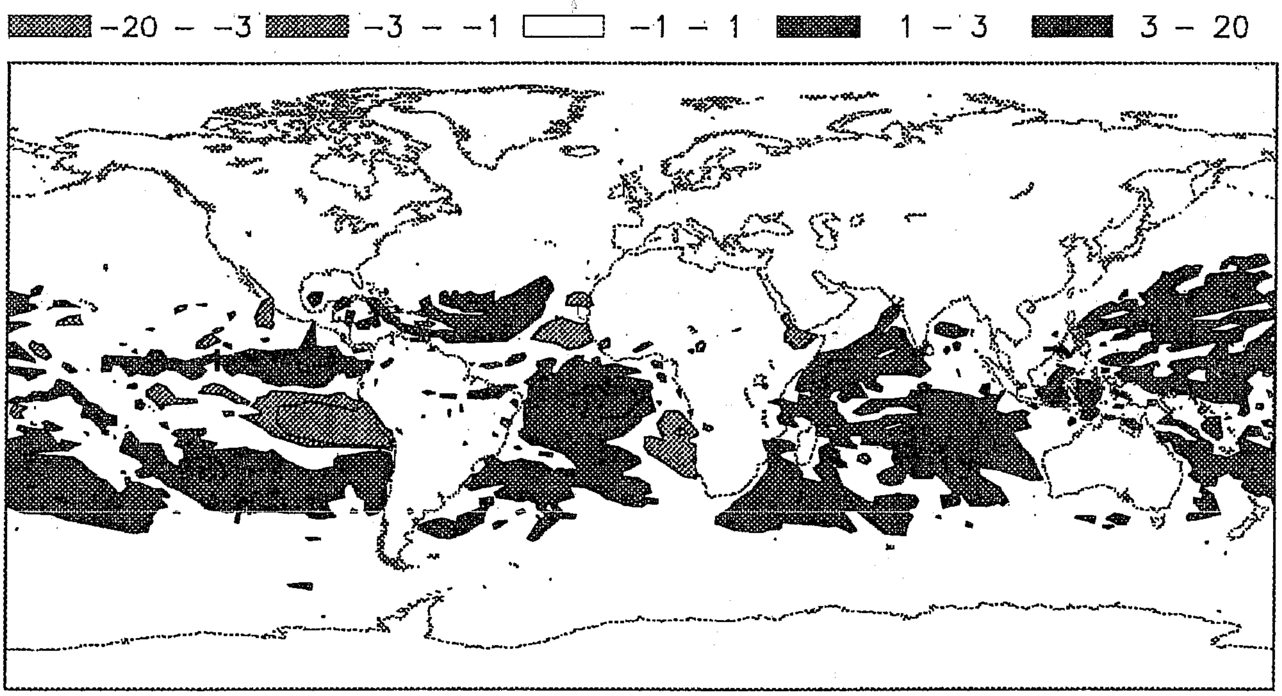

Figure 4. Mean TCWV analysis changes (in Kg/m2) due to the assimilation of SSM/I data in December 1997.

4. Impact upon forecasts

The humidity analysis changes in the Tropics caused by the SSM/I TCWV information are not retained by the forecast. Indeed it is difficult to detect differences between forecasts run from the analyses with and without SSM/I after 3 days, the extra humidity introduced by SSM/I being removed by precipitation. The humidity changes in the southern extra-tropics are retained slightly longer by the forecast (e.g. 4 to 5 days).

In the periods that have been tested the use of SSM/I wind speed information improved the quality of 850HPa wind forecasts in the short and medium range (i.e. out to day 6). In some individual cases (particularly in winter) it has been found that the improvements to the surface wind speed analysis have also translated in to significantly improved forecasts of important synoptic features.

5. Summary and further research

It is clear that the SSM/I instrument provides very useful information and some very positive results have been obtained when the data are assimilated. However, there is a need to further validate and understand the changes to the analysis caused by the use of SSM/I TCWV and Ws.

For humidity the main effort is being concentrated on understanding the interaction between the data and forecast model. We know from simulations that the ability of the forecast to retain the SSM/I humidity information depends strongly on how the TCWV is distributed in the vertical. At the moment this is controlled by an average statistical covariance model of background humidity errors (in both the 1DVAR and subsequent 4DVAR analyses of the data). The largest adjustment takes place at levels where the background is considered least accurate (in practice around 750HPa). Experiments have shown that varying the covariance model (in particular the implied vertical correlations) can have a dramatic effect on the activation of convective precipitation.

For wind information the main effort is being directed towards harmonizing the use of SSM/I in the presence of other observing systems that provide marine surface wind speed (primarily scatterometer data from QuickScat and ERS platforms). This includes establishing an optimal weight to assign to the observations and eliminating any systematic disagreement between different observing systems.

References

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