Remote Sensing Of The Atmosphere Using Microwave Radiometers

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ABSTRACT

The Advanced Microwave Sounding Unit has had a large positive impact on the accuracy of numerical weather forecasts through the direct assimilation of the measured radiances. This has been independently reported by many weather forecast centres. This requires fast and accurate radiative transfer models and a good understanding of instrument and radiative transfer model errors. Various issues relating to the effective use of such data in data assimilation systems will be discussed. Possible future developments will also be considered.

INTRODUCTION

The use of observations made by microwave radiometers in the application of numerical weather prediction has increased in recent years. This, combined with other improvements such as direct radiance assimilation, has led to a situation where satellite observations have as much impact on height forecast accuracy as conventional observations even in well-observed areas of the northern hemisphere. This is in contrast to earlier use of satellite data where their use gave neutral or even negative impact in the more well-observed portions of the globe (Bouttier and Kelly 2001). This paper will give a summary of what data is being used, both microwave and infra-red, and how it is being processed.

PASSIVE MICROWAVE SOUNDERS

At present most Numerical Weather Prediction (NWP) centres are using data from the Advanced Microwave Sounding Unit (AMSU) or its predecessor (MSU) either as temperature retrieval or in the form of radiances. AMSU measures brightness temperatures at 23.8, 31, 89 and 150 GHz as well as 12 channels between 50 and 58 GHz and 3 channels centred on the water vapour line at 183.3 GHz. The channels between 50 and 58 GHz provide temperature information for the troposphere and stratosphere. Passive microwave radiometers for temperature sounding have developed rapidly in the last 30 years. The requirement of NWP models for temperature and humidity information has also become more demanding during this period for many reasons, including their resolving power and ability to simulate the real atmosphere. Table 1 gives some of the key instruments launched since 1972. Note that only MSU and AMSU have fully operational status and real-time distribution through the global telecommunication system.

Instrument	Year of launch	Frequencies	Nadir field of view
NEMS	1972	53.6, 54.9, 58.8	200 km
SCAMS	1975	52.8, 53.8, 54.4	150 km
SSM/T	1978	50.5, 53.2, 54.3, 54.9, 58.4, 58.8, 59.0	175 km
MSU	1978	50.3, 53.7, 55.0, 57.9	110 km
AMSU	1998	12 channels 50.3-57.293	48 km

Table 1: The main nadir microwave radiometers for temperature sounding 1972-1998

The vertical resolution of the temperature information is poor, with only two to three pieces of independent information on temperature in the troposphere. This has not prevented the data being very important for the analysis of large scale flow in NWP models, and having a large impact on the accuracy of NWP forecasts. Those centres using the AMSU radiances have all reported substantial improvements in forecast accuracy compared with use of the older MSU instrument, which had only four channels between 50 and 58 GHz, no clean window channels (transmission loss due to oxygen absorption in the most transparent channel, 50.3 GHz, is around 30%) and no channels at frequencies above 58 GHz. Similar developments have occurred for humidity information, with early instruments like the Special Sensor Microwave Imager (SSM/I) providing total column water vapour information which is also assimilated at several NWP centres. Since 1998 AMSU-B has provided some limited vertical profile information for water vapour. At the Met Office AMSU radiances are assimilated directly, both from the temperature sounder (AMSU-A) and the humidity sounder (AMSU-B). As well as the use of the sounding information microwave instruments also provide information on the surface. This is also widely exploited in NWP models, in particular windspeed and sea ice. Snow analyses used at some NWP centres also make use of microwave measurements. Other surface fields may become important in the future (e.g. sea surface temperature, although the accuracy requirement for climate studies is far more demanding than for NWP). Another area of significant current and future development is in precipitation and cloud assimilation where microwave measurements are an information-rich source of data.

RADIATIVE TRANSFER MODELS

The radiative transfer model used at the Met Office is called RTTOV [2]. RTTOV has the capability to simulate many different instruments including microwave imagers and sounders (AMSU, SSM/I, SSMIS). RTTOV is a fast model using coefficients derived from a line-by-line model (the Millimeter-wave Propagation Model of Liebe [3]). RTTOV has recently been enhanced to improve the handling of cloudy microwave observations, and to model the surface emissivity more accurately for oceans [4]. It also has a limited capability for other surfaces.

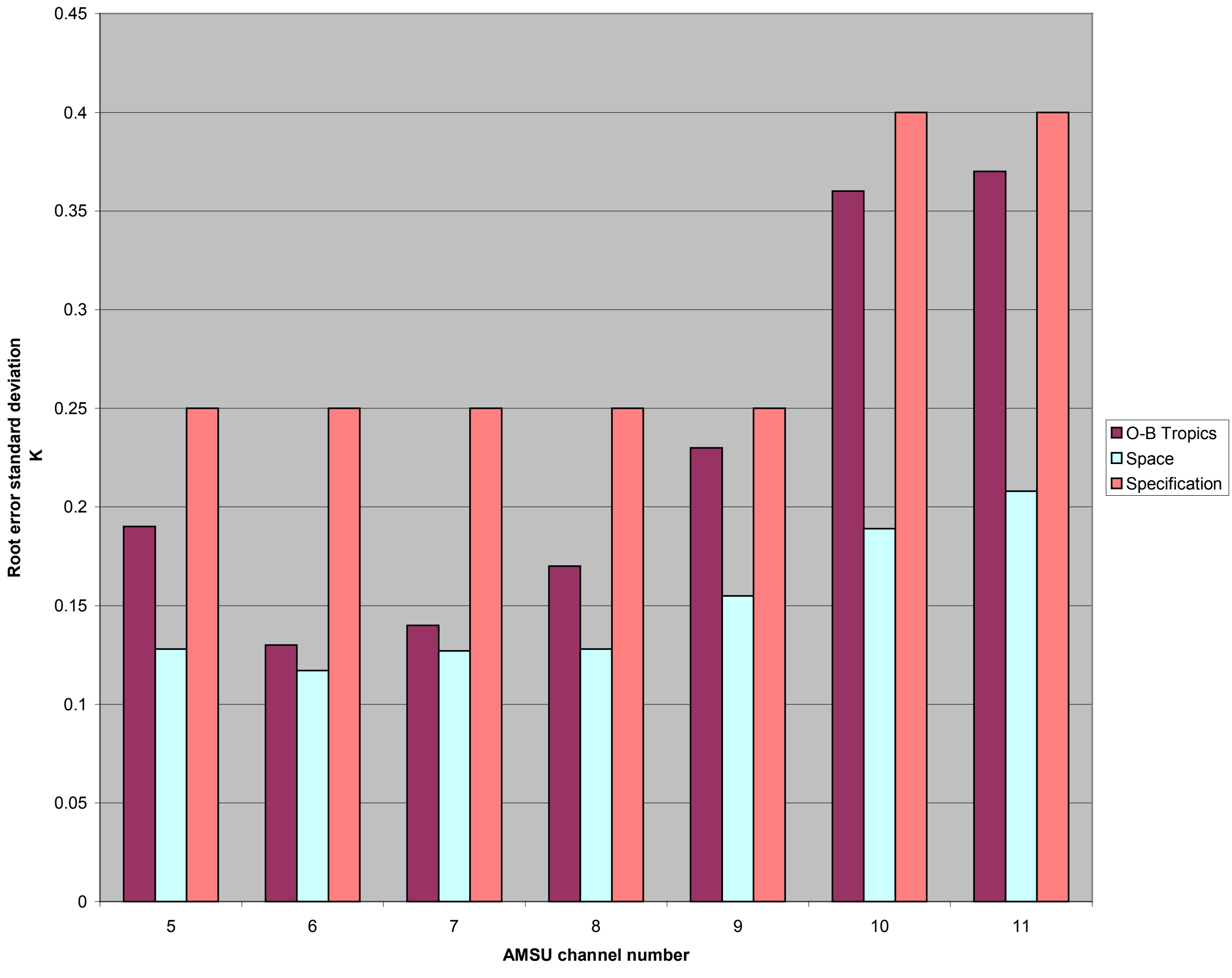

Fig. 1 AMSU instrument noise variance in space compared to observation minus model differences in the tropics, instrument noise measured in-flight and the original AMSU-A specification.

The radiative transfer models used for assimilation of radiances must be both fast and accurate. Figure 1 shows how accurately the temperature sounding channels of AMSU are modelled using a short range (six hour) forecast from an NWP model. This is found to be of order 0.15 K for channels 6 and 7 whose peak contribution comes from 400 hPa and 250 hPa respectively. This underlines the accuracy of both the short range forecast, the observations and the radiative transfer model used to simulate them. Channels whose peak contribution comes from nearer the surface have poorer fit because the emissivity of the surface is less well known than the absorption by oxygen molecules and also because the short range forecast is less accurate for surface fields (e.g. windspeed) than for atmospheric temperature. Here accuracy is considered in terms of the impact on radiance measurements such that different parameters (windspeed, temperature) can be compared with each other.

DATA ASSIMILATION

Many NWP centres now assimilate microwave radiances directly, especially from AMSU [5]. At the Met Office radiances are assimilated directly using a 3D-var assimilation system. When assimilating radiances directly, quality control is important and different methods are used to detect cloud and precipitation in microwave observations at different operational centres.

The impact of ATOVS data on the accuracy of NWP was large and positive [6]. More recently experiments have been run [1] which have shown the impact of removing different observation types from the data assimilation system. The impact of removing ATOVS was comparable with removing radiosondes in the northern hemisphere and much larger than any other observation type in the southern hemisphere. These results, first achieved at ECMWF [1] have been repeated at the Met Office (Dumelow, pers. comm.).

Both centres (Met Office and ECMWF) reporting this exceptionally large impact of ATOVS on forecast accuracy are assimilating radiances directly in variational assimilation systems. No centre assimilating retrievals generated from the measured radiances has yet reported a positive impact in the northern hemisphere which is comparable with that achieved using radiosondes. As many centres have been assimilating retrievals since the early 1990s whereas radiance assimilation only began in the mid to late 1990s this is a notable success for direct radiance assimilation.

FUTURE DEVELOPMENTS

In the near future interferometers and grating spectrometers will be launched which will provide temperature and humidity information from infra-red measurements with vertical resolution several times better than that achievable from microwave systems. However microwave systems will remain the only source of temperature and humidity information under unbroken cloud. Furthermore it is not yet demonstrated that positive impact can be achieved by assimilation of cloudy infra-red data, although some encouraging results have been reported (Joiner, pers. comm.). It appears unlikely that the NWP user requirement for temperature and humidity can be met by infra-red radiances alone. Therefore the requirement for systems like AMSU will continue.

The NWP user requirement for cloud and precpitation information is not currently met by the global observing system and the increasingly sophisticated data assimilation systems make direct assimilation of microwave radiances in areas of cloud and precipitation a realistic goal. The development of fast and accurate radiative transfer models for precipitation in support of this goal is a high priority [7]. Furthermore a better understanding of the error characteristics of all stages of processing of cloudy radiances is required in order to allow effective assimilation of such data. It is possible that assimilation of retrievals may provide some short term benefit ahead of a capability to handle radiances directly.

A 1D-var approach to analysing cloud-affected SSM/I brightness temperatures prior to assimilation has been in place for several years at both the ECMWF [8] and the Met Office [9]. This 1D-var uses the logarithm of specific humidity profile and vertically integrated liquid water path as separate control variables, with the cloud's vertical distribution fixed based on the a priori information. This 1D-var has been successfully extended [10] to give 1D-var more freedom to analyse the cloud profile, by using total water as a control variable. Vertical profiles of water vapour and cloud can then be retrieved simultaneously without the need to define the error correlations between cloud and water vapour. This approach could be extended to include other variables in the total water control variable (e.g. ice profile, precipitation).

In the shorter term microwave cloud and precipitation imagery has a high potential as an imagery product for operational weather forecasters and an example for AMSU is shown in Fig. 2 using a simple maximum likelihood approach [11].

CONCLUSIONS

Microwave radiometry is providing important information to NWP. The impact has recently been shown to be as large as that from radiosondes in the northern hemisphere at two independent NWP centres. Both the observations themselves and the models used to simulate them are remarkably accurate with the random component of error less than 0.2 K for most tropospheric channels, and even less in the mid to upper troposphere. At present precipitation, cloud and, to a lesser extent, surface information is under-exploited. More development of fast models for precipitation and surface emissivity are required.

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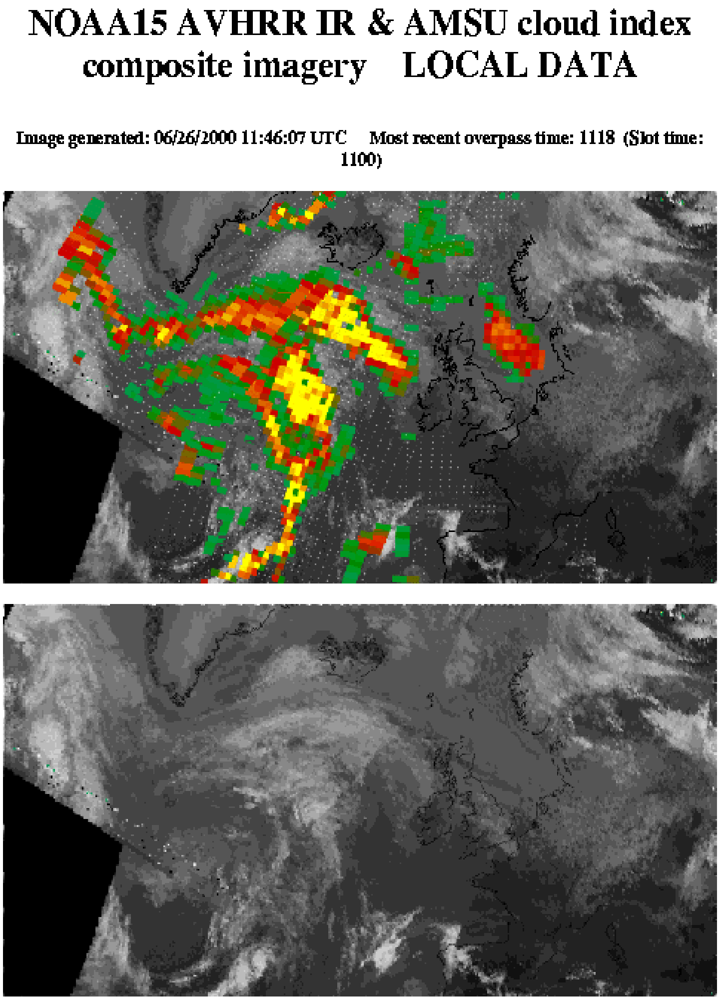

Fig. 2: Microwave cloud information superimposed on infra-red imagery from AVHRR on NOAA-15

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