Estimating the Primary Analysis Variables, Temperature, Moisture and Wind from Space – Science and Cooperation

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1. INTRODUCTION

Errors in the estimation of wind, temperature and moisture from space-based observations have been reduced, particularly for regional applications, as the spatial, temporal and spectral resolution of the observations, data assimilation methods and computer power have improved. This paper describes progress, illustrating the advances with results derived from the use of recent, current and next generation operational sounding and image data. It presents examples of both the improvements in the estimation of the primary analysis variables and the resultant benefits to numerical weather prediction (NWP) from these improved data.

In particular, the importance of satellite direct readout is noted for providing timely data for regional applications where short data cut-off times are present. It also records the important role which shared community software plays in the utilisation of data from these operational satellite systems for both operations and research. It notes the important roles played by international collaboration, by the ITWG and by members of the wind community who attend the IWWs (International Wind Workshops). These two communities have been vital in the effective use of the operational satellite systems. The software they have produced and shared has been central in the use of satellite observations for operations and research on both global and regional scales.

2. BACKGROUND

Ever increasing improvements have been made in the observational capacity of earth observing satellites. Almost continuous improvements in the spatial, spectral and temporal resolution of the observations from these satellites have led to greater utility of the data. This paper provides evidence of the increasing benefits being derived from greater observational- power.

It concentrates on use of passive observations in the visible, infrared (IR) and microwave parts of the spectrum and examples are given of their increasing utility in particular for NWP. It also notes the impending availability of very high spatial, temporal and spectral resolution data, their ability to provide enhanced information about atmospheric state, and the anticipated benefit of this information in applications such as NWP. Examples used in this paper are drawn from the Southern hemisphere.

3. BENEFITS FROM INCREASING SPATIAL, TEMPORAL AND SPECTRAL RESOLUTION OBSERVATIONS

Improvements seen in operational forecasting capability, have been derived to a significant extent, from improved numerical modelling capability, improved data assimilation techniques, improved computing capacity and to a very significant extent improvements in the data base, particularly the remotely sensed data base. From the early 1970s, when images were used to provide the analyses for NWP, through the 1970s, with the introduction of first generation sounders and geostationary observations, and, later, through the 1980s, with the introduction of second generation sounders, increasing forecast accuracy has been recorded.

Imagery

Improvements due to imagery in the data base are not demonstrated here. Suffice it to say, weather systems over the southern oceans and other parts of the southern hemisphere, can go unnoticed in analysis (because of the sparsity of conventional data) if satellite imagery is not used.

Sounding Data

Improvements to regional and global forecast systems with the use of second generation sounding (TIROS Operational Vertical Sounder - TOVS) data are now well documented (eg. Bourke et al. 1982, Le Marshall et al. 1994) and these data have assumed an ever increasing role in the numerical analysis and prognosis. Improvements to the Australian Region forecast system are seen in Table 1.

Table 1: S1 Skill Score for local physical TOVS data assimilation forecasts (TOVS/RASP) and the matching control (NMOC) forecasts during the period 23UTC 17-12-92 to 11UTC 30-1-93.

System	Level	+12hr.	+24hr.	+36hr.
RASP	MSLP	32.2	41.0	49.5
TOVS/RASP	MSLP	30.3	37.8	45.1
RASP	500Hpa	15.4	21.2	28.7
TOVS/RASP	500Hpa	14.1	19.3	25.5
RASP	300Hpa	12.9	17.9	24.9
TOVS/RASP	300Hpa	12.2	16.9	23.0

This shows the S1 skill scores (Teweles and Wobus 1954) for a real time data impact experiment in December 1989 - January 1990. The experiment examined the benefits to the operational Australian Region forecast model resulting from the use of full resolution TOVS raw radiances, directly readout from satellite, via a physical retrieval scheme. This full physical retrieval scheme was subsequently implemented operationally. In the experiment the operational NMOC system was used as the control with the with the experimental system being identical but having TOVS radiances added to its data base. The 3 and 4 point S1 skill score gain seen in Table 1 with the use of TOVS is significant but expected given the lack of conventional data over the southern hemisphere.

A particular example, showing the impact of these TOVS data on the forecast track of tropical cyclone Bobby in February 1995 can be seen in Le Marshall and Mills (1995). Forecasts using the then operational Australian Region forecast model, the current operational model (LAPS), and the current operational model with TOVS, show that the track of Tropical Cyclone Bobby through Western Australia is only well-predicted through use of direct readout sounding data. Currently, real time TOVS data are not available operationally to the regional forecast system unless they are derived from direct readout, as a result of short cutoff times (about 1.5 hours).

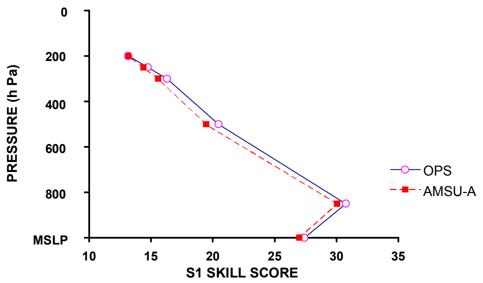

Figure 1. The S1 skill scores of 24 hour forecasts for Operations (OPS) and Operations using AMSU-A data (AMSU-A) in the Australian Region

The TOVS instrument used in the study above has been recently improved by the addition of spectral channels in the microwave. The new instrument, the Advanced TOVS, has greater spectral and spatial resolution and now carries a 20-channel HIRS,(High resolution InfraRed Sounder) and a 20-channel Advanced Microwave Sounding Unit (AMSU). The effect of addition of NOAA-15 ATOVS data to the operational Australian Region forecast scheme is seen in Fig. 1. In this experiment the operational NMOC system was used as the control, with the with the experimental system being identical, but having NOAA-15 ATOVS AMSU-A radiances added to its data base. A gain in S1 skill score is seen throughout the troposphere, even though NOAA-15 direct readout at this stage was providing poor coverage due to data transmission problems from the satellite.

Atmospheric Motion Vectors

From the 1970s winds generated from tracking features in sequential geostationary satellite images have been used in NWP. Sequential imagery from the geostationary satellite, GMS-5, has been used to provide near-continuous wind observations over the Australian Region.

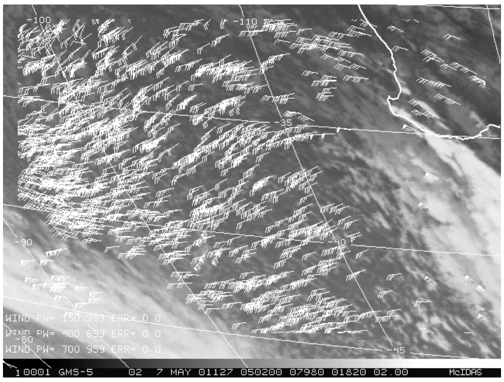

Figure 2. Atmospheric Motion Vectors 05UTC 7 May 2001

These data have been generated from observations in the high-resolution visible, visible, 11 µm infrared and 6.7 µm water vapour absorption bands as a result of the increased temporal and spectral resolution of GMS imagery available in the 1990s. The method for deriving these vectors is in Le Marshall et al.(1998b). An example of Cloud and water vapour motion vectors generated in real time South-west of Australia at 05UTC on 7 May 2001 is seen in Fig. 2.

The impact of these data on operational forecasts using intermittent assimilation techniques is well documented with the improvement in operational forecasts from using infrared, hourly and water vapour motion vectors being found in Le Marshall et al. 1998b,c.These works show increasing accuracy of the operational Australian Region forecast system with the incorporation of 11µm, hourly, visible and 6.7 µm image based winds. Recently another impact study has been completed illustrating the impact of using all winds simultaneously, with appropriate quality control.

The benefits of using these wind data with improving data assimilation techniques, namely continuous assimilation techniques such as 4-D variational assimilation have also been demonstrated. In a series of studies examining tropical cyclone track and intensity predictions significant gains in forecast track accuracy (Le Marshall and Leslie 1988) and a beneficial influence on intensity prediction (Le Marshall and Leslie 1999) have been found to result from use of the high resolution wind data. In the case of track forecasts it can be seen that by comparison with operational forecasts in general (Gordon et al., 1998), these forecasts illustrate the potential for greatly improved operational prediction.

4.THE HYPERSPECTRAL FUTURE

In early 2001, the launch of the first hyperspectral instrument to provide operational data (the AIRS) will be undertaken. To date this type of hyperspectral data has been available only from limited sources. Two instruments to provide such data from high altitude flights on NASA ER2 aircraft are the High resolution Interferometer Sounder (HIS) and the NAST-I (NPOESS Aircraft Sounding Testbed - Interferometer) instrument. These instruments are airborne interferometers, capable of taking full interferograms every few seconds and the related power spectra from these instruments have been used to produce temperature and moisture profiles (see eg. Smith et al. 1999). The temperature profiles have accuracies greater than 1 K with moisture accuracies of the order of 10%.

These interferometer data have been used in a series of 4-dimensional variational assimilation experiments, which, for the first time, are using hyperspectral data in high resolution studies. The first study (Le Marshall et al. 2001) involved the use of HIS data, taken over the Chesapeake Bay region in the United States in 1995 and using 1 km resolution, has involved documenting the impact of these data on initialisation using 4-D variational assimilation. A second study (Leslie et al. 2001) has been completed using NAST-I data around Andros Island on 13 September 1998, where the influence of these high resolution sounding data on initialised wind fields has been noted. Several new instruments providing remotely sensed data at higher spatial, temporal and spectral resolution will be flying in the near future, these include IASI, CrIS and GIFTS.

5. SCIENCE AND CO-OPERATION

There is little doubt that the science of satellite meteorology has progressed significantly as a result of international co-operation. Both research and operational atmospheric sounding from space have benefited from the International (A)TOVS Working Group (ITWG) which was formed in 1983 and has fostered free exchange of scientific information and software throughout the international sounding community. There not a single agency or group working in this area that has not benefited greatly from this exchange, which has addressed areas including radiative transfer, operational procedures and education and training The establishment of this group by the International Radiation Commission was certainly an excellent initiative.

In relation to sounding the atmosphere from space for wind, the International Wind Workshops have become fora for similar exchange of science and software. They are also fostering international co-operation and, as a result, are hastening the advance of this field.

The very worthwhile activities of these two groups have been supported principally by the WMO, the satellite operators and meteorological agencies. These important activities will continue because of their utility, efficiency and economy.

6. SUMMARY AND CONCLUSIONS

From the time of the launch of the first weather satellite on 1 April 1960, improving spatial, temporal and spectral resolution have led to improved characterisation of atmospheric state and improved predictions. The first weather satellites provided television images in the visible and IR (11 μm), allowing cloud picture interpretation to provide quantitative analyses in areas where there was otherwise no data.

Analyses and forecasts were substantially improved by the provision of sounding data in the thermal IR and microwave (eg. Smith et al. 1970, Le Marshall et al. 1994). Further improvements have been made through increases in the spatial and spectral resolutions associated with the ATOVS instrument on NOAA-15. These improvements in temperature and moisture sounding have been accompanied by the use of sequential imagery with increasing spatial, temporal and spectral resolutions to produce high resolution wind vectors (Le Marshall, 1996) which have also contributed to increased forecast accuracy. The increase in accuracy has been documented in terms of the improved data base. It should be noted that the timeliness of direct readout data processed here has allowed their use in operational NWP.

The improvement in observational capacity will be continued, early next year, with the launch of the Advanced Infrared Sounder (AIRS). This will be followed by the Infrared Atmospheric Sounding Interferometer (IASI), the Geostationary

Imaging Fourier Transform Spectrometer (GIFTS) and the Cross-track Infrared Scanner (CrIS). The benefits of this improved observational capacity will be enhanced by improving data assimilation methods such as 4-D variational assimilation and the availability of burgeoning computer power. These benefits will of course continue to be dependent on international cooperation and the sharing of ideas and software as fostered by groups such as the ITWG and IWW.

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