# OPERATIONAL ASSIMILATION OF TOVS RADIANCE DATA IN THE AUSTRALIAN BUREAU OF METEOROLOGY

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## 1. ABSTRACT

**The physically-based operational TOVS retrieval system currently used to generate meteorological fields from locally received TOVS raw radiances in the Australian Region is described in this paper. These meteorological fields are used in the local Regional ASsimilation and Prognosis System (RASP) to produce operational forecasts across the Australian Region.**

**The paper summarises the cloud height and ozone determination techniques employed in the system and the radiance and transmittance tuning methodologies. The impact of these local TOVS data on operational forecasts in the Australian Region is shown. The impacts that have been recorded by adding to a data base which already includes low resolution NESDIS TOVS data and local cloud drift winds. A case study, indicating the strong impact of TOVS data, is given.**

**The synoptic application of these data, including their use for diagnosing severe weather and for estimating tropical cyclone intensity is also described. In particular, the generation of calibration curves, providing intensity of tropical cyclones versus the upper tropospheric temperature anomaly is reported. In addition, the general characteristics of the new ITPP-5 package, which incorporates AVHRR data and which is currently undergoing a real time trial, are also noted.**

## 2. INTRODUCTION

For over a decade, the Australian Bureau of Meteorology (BoM) has received by direct readout and utilised NOAA second generation sounding data from the TIROS-N NOAA/A series of satellites and visible (VIS) and infrared (IR) data and from the Geostationary Meteorological Satellite (GMS). The real time application of these data in the Australian BoM is vital for numerical weather analysis and prediction both in the Australian Region and over the Southern Hemisphere.

As a result, the regional polar orbiting satellite groundstations (Melbourne, Perth, Darwin and Casey) occupy a position of importance in the BoM. They provide high resolution TOVS data for operational regional forecasts within the stringent operational cut-off times. The importance of these data is demonstrated below, in the context of an operational data base which already includes NESDIS low resolution TOVS data (SATEMs) and GMS cloud drift winds (SATOBs), as well as locally generated cloud drift winds, which provide high density coverage (400 - 600 vectors every 6 hours) over the Australian Region (Le Marshall and Pescod, 1991). The local wind data, when assimilated into the local operational Regional Analysis and Prognosis system (RASP) (Mills and Seaman, 1990), have also been shown to improve accuracy of weather forecasting in the Australian Region (Le Marshall et al., 1992).

The assimilation experiments described in this document record the impact of these locally received and processed TOVS data on a numerical forecast system which uses the full operational data base of the National Meteorological Centre (NMC), Melbourne and image and local TOVS data based 1000 - 500 hPa bogus thickness observations.

The real time physical retrieval scheme, described in this document, has been developed and is run in the Australian Region McIDAS (ARM) environment (Le Marshall et al., 1987), which includes a fully integrated global meteorological data base. The ARM system is used for operational and developmental work in the BoM NMC and all Australian Regional Forecast Centres (RFCs) and this allows easy use of the TOVS data for synoptic applications such as updating aviation grid point winds, and diagnosing areas of potential convective activity using fields of stability indices. The direct readout TOVS data studied here are processed in real time and used in the BoM's operational regional forecast system. The retrieval system has also been implemented on a personal computer (PC-ARM) and versions of this are being used for tropical and Antarctic research, and for operational use with the Philippines Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) in Manila.

## 3. THE REAL TIME PHYSICAL RETRIEVAL SCHEME

### 3.1 The Algorithm

The TOVS physical retrieval scheme is similar to that described in Le Marshall et al., (1994). The scheme uses a simultaneous solution of the Radiative Transfer Equation (RTE) for temperature and absorbing constituent, similar to Smith et al., (1991). It employs the following perturbation form of the RTE.

$$\delta R_\nu = \beta^0_\nu(P_s)\tau^0_\nu(P_s)\delta T_s - \Sigma^N_{i=1}\int_0^{P_s}\beta^0_\nu(p)\delta T_i(p)\tau^0_\nu(p)\,d\ln\tau^0_{\nu_i}(p), \quad (1)$$

where $R_\nu$ is spectral radiance at frequency $\nu$ and includes both Microwave Sounding Unit (MSU) and High Resolution Infra-Red Sounder (HIRS) data, N is the number of optically active atmospheric constituents, $\delta$ of a variable designates the true minus initial value (where superscript 0 denotes initial value), $\tau_\nu(p)$ is the total transmittance to the top of the atmosphere above pressure level p, $\tau_{\nu i}$ is the transmittance of $i_{th}$ absorbing constituent, $T_i(p)$ is the effective temperature of the $i^{th}$ absorbing constituent, being the temperature of the gas which would give rise to the observed radiances, assuming that the initial gas concentration was correct and

$$\beta^0_\nu(p) = \partial B_\nu(T^0)/\partial T \quad (2)$$

$$\textit{and}\ \delta T_i(p) = T_i(p) - T^0(p),$$

where $B_\nu(p)$ is Planck radiance. This perturbation form of the RTE is solved using direct linear matrix inversion.

The first guess temperature and moisture fields can be provided by climatology, a statistical retrieval or, more usually, a forecast from the Regional or Global Numerical Weather Prediction scheme. First guess surface temperature and moisture fields may be provided by the regional optimum interpolation scheme of Keenan et al., (1986). The retrieval scheme also produces estimates of cloud amount and height, skin temperature and total ozone. The retrieved temperatures and moistures are quality controlled using analysis and forecast fields from the operational global or regional forecast systems. The retrieval scheme is also able to use a local radiance bias and transmittance correction scheme.

In the *operational processing system*, the orbits are automatically scheduled. Initially, drifting buoy data are extracted from the TIROS Information Processor (TIP) stream and then the preprocessor generates, calibrates and navigates the HIRS and MSU data. The second step interpolates the operational global analysis and prognosis output to provide first guess fields at the satellite orbit time. The retrieval program then colocates the HIRS and MSU data and performs a full physical retrieval for every HIRS 3 x 3 field of view array, using the forecast model first guess. The output fields are automatically quality controlled, again using data from the operational analysis/prognosis system. In operational mode, filtering and manual editing are not performed. Wind vectors based on gradient balance are generated for operational purposes in the NMC and routine archiving programs are run, to allow for transmittance and radiance bias correction.

Features of the scheme related to ozone estimation, cloud height estimation and radiance and transmittance tuning are summarised below.

3.2 Total Ozone Estimation

The method to calculate total ozone has been developed from the algorithm of Ma et al., 1984, which is the basis of that used in the International TOVS Processing Package (ITPP). The method employs the RTE and uses statistical relationships among HIRS channels 1 to 4 radiances and ozone amount to establish a first guess profile as in Ma et al., 1984. Several enhancements have been made to the algorithm of Ma et al. to improve the accuracy of the estimated total ozone and these are described in Wu and Le Marshall, (1992). The algorithm now has the form

$$\delta u / \mu = \{\delta R \ln 10\} / \{\int_0^{P_s} \tau_{H_2O} * d\tau_{O_3} / dq * dB\}$$

where u (p) is the ozone path length to the satellite and q* is "a transmittance scaling factor" (see Ma et al., 1984 for details). This provides quicker convergence to a final ozone profile and an iteration step is included for the final part of the algorithm. Results from the new algorithm have been compared with those from the original scheme and with surface-based Dobson spectrophotometer observations, and these indicate an increase in accuracy (Wu and Le Marshall, 1992).

3.3 Cloud Estimation

Channels 5 and 7 of the HIRS are used to estimate cloud height and amount, using $CO_2$ slicing as described in Le Marshall et al., (1989), namely, via the relationship

$$(R_{\nu_5} - R_{C_{\nu_5}}) / (R_{\nu_7} - R_{C_{\nu_7}}) = \{\int_{P_c}^{P_0} \tau_{\nu_5} \, \partial B_{\nu_5} / \partial p \, dp\} / \{\int_{P_c}^{P_0} \tau_{\nu_7} \, \partial(B_{\nu_7}) / \partial p) dp\}$$

where $R_C$ is the clear column radiance and $P_C$ is the cloud top pressure. Once cloud height and amount are calculated, a full physical retrieval is performed, accounting for cloud in the field of view.

3.4 Radiance and Transmittance Tuning

The retrieval scheme has been established with three radiance bias and transmittance correction schemes. These are necessary to remove systematic errors which arise from radiance calibration errors and errors in the forward calculation. It is important to remove such errors since they may be of similar magnitude to the signal (i.e. the difference between the first guess radiances and the observed radiances).

Systematic errors in radiances are corrected by adding a bias term, Δ, which varies with channel and with some measure of the air mass type. Systematic errors in the transmittance are corrected by raising the transmittance τ to the power γ. This is equivalent to assuming that the optical depth is adjusted by a constant factor. One scheme provides radiance tuning similar to that described in Le Marshall et al., (1989) and is based on a data set of collocated, near contemporaneous radiosonde and TOVS soundings. The tuning employs limb corrected MSU data, which are used to separate the radiance sample into 8 synoptically distinct groups, using discriminant analysis. Subsequent to this, an estimate of radiance bias by class can be made and, using the probabilities of being in one of the 8 classes, a bias correction for each channel can be calculated. The second scheme uses simple regression to relate the bias correction for each channel to the limb corrected MSU brightness temperatures for MSU channels 2 to 4. This is the form now used for the ITPP, which has been developed at the Co-operative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin, Madison, and has been the form used prior to May, 1993 in the retrieval scheme. After May, 1993, however, it was replaced by a scheme which more correctly adjusts transmittances and bias in the one step. Presently, first guess bias (Δ) and the transmittance exponent (γ) are selected, based on the forecast derived 500 hPa temperatures. The Δ and γ values are calculated, noting that if

$$\tau = \tilde{\tau}^{\gamma} \text{ and } R_m = R(\gamma) + \Delta,$$

where $\tau$ is the atmospheric transmittance, $\tilde{\tau}$ is the untuned theoretical estimate of transmittance, $R_m$ is the measured radiance and $R(\gamma)$ is the radiance computed using $\gamma$, then, noting that subscript 0 denotes the initial estimate, to first order in $\gamma$:

$$R_m - R(\gamma_0) \approx \Delta + (\gamma - \gamma_0)\, \partial R(\gamma_0) / \partial \gamma \qquad (5)$$

Hence, using matches between radiosonde and satellite to give $(R_m - R(\gamma_0))$ and to estimate $\partial R(\gamma_0)/\partial\gamma$, $\gamma$ and $\Delta$ may be estimated from a least squares fit to the data. This technique is presently being extended to allow a choice of Δ and γ using MSU channels 2, 3 and 4 radiances.

## 4. THE SOUNDINGS

The simultaneous retrieval scheme described above is currently run routinely in real time, for all NOAA 11 and 12 traverses of the Australian region. Some verification statistics are provided in

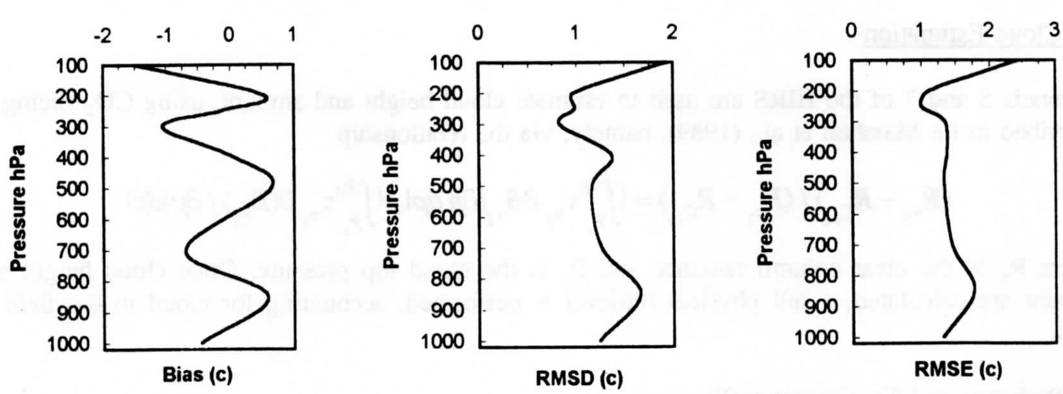



Figure 1 NOAA-11 temperature retrieval statistics compared to Australian Region radiosondes (within 40 km and 1 hour), 23 - 27 February, 1995

Fig. 1, in which early 1995 Australian Region NOAA 11 TOVS retrievals have been compared to BoM point radiosonde data within 40 km and 1 hour in space and time. The RMS differences in comparison to the radiosonde values can be seen to generaly lie between 1 and 2 Kelvin through most of the troposphere. The sounding data have demonstrated their utility in several ways. They have beeen shown to be useful in synoptic applications as well as beneficial to numerical weather prediction (NWP) in the Australian region.

### 4.1 Synoptic Applications

The local high resolution TOVS data can provide estimates of sub-synoptic scale fields such as total ozone, cloud height and cloud amount. It also can provide wind shears for use in updating aviation grid point winds and the manual drawing of upper air charts. The utility of satellite soundings to position the jetstream, which is related to thermal gradients in the troposphere, was shown by Blechman (1981). In Fig. 2, gradient winds at 250 hPa, derived from real time TOVS retrievals are shown overlying an *independent* BoM NMC isotach analysis for 12 UTC, 23 August, 1993. The depiction of jet intensity and direction in these products, particularly in data-sparse areas, indicate their significant advantages for real time aviation forecasting.

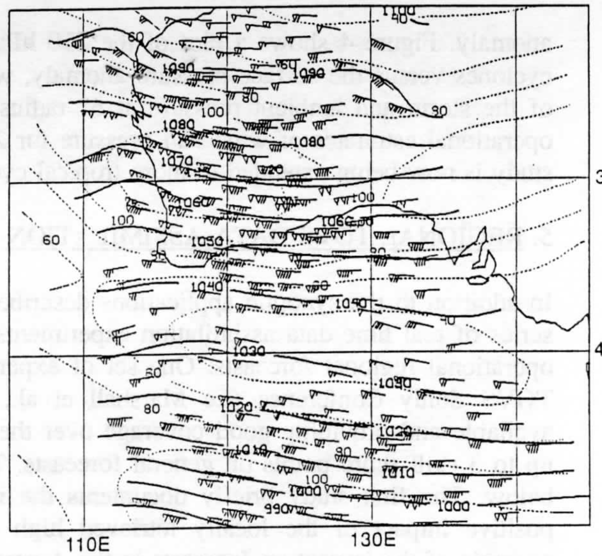



**Figure 2** NOAA 12 TOVS 250 hPa geopotential height and gradient wind (knots) soundings over the BoM NMC isotach analysis 23 August, 1993

The system also provides fields of stability indices. The utility of satellite-derived stability indices for forecasting severe weather has been demonstrated in previous studies (Keller and Smith, 1983).

Another example of the synoptic application of the physical retrieval scheme estimation of tropical cyclone intensity in the Australian Region. In this application, the upper tropospheric temperature anomalies at 250 hPa, estimated from raw TOVS radiances, have been related to cyclone intensity by examining Western Australian and Coral Sea cyclones. A typical example from this study is presented in Figure 3, which shows the TOVS 250 hPa estimates of temperature in °C analysed over an image of tropical cyclone Orson.

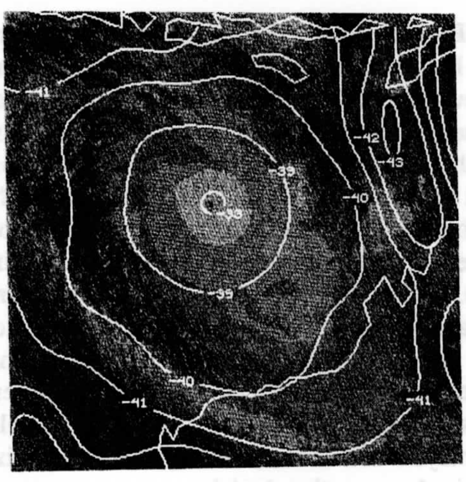


**Figure 3** Tropical cyclone Orson, with TOVS 250 hPa temperatures (°C)

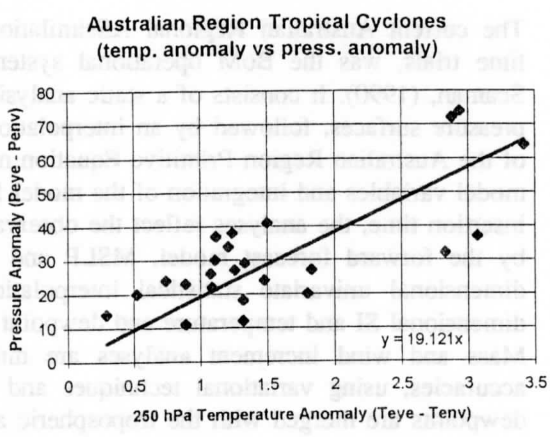



**Figure 4** The TOVS-derived 250 hPa temperature anomaly (°C) versus surface pressure anomaly (hPa) for 24 tropical cyclones over the Australian Region

The temperature anomalies at 250 hPa over these tropical cyclones have been related to surface pressure anomaly and wind speed to produce calibration plots which may be used for operational application. These plots have been produced using the operational system, running in a mode where retrievals were obtained using the MSU and stratospheric HIRS channels to calculate the upper air temperature anomalies. In these cases, the difference between temperature over the storm and the mean ambient temperature 6 degrees great circle distance from the storm constitutes the anomaly. Figure 4 shows a plot of the 250 hPa temperature anomaly associated with the tropical cyclones versus the surface pressure anomaly, which is the difference between the central pressure of the storm and ambient pressure at 6° radius from the centre. This plot was constructed using operational estimates of wind and pressure for 24 tropical cyclones in the Australian Region. This study is now being extended to more tropical cyclone cases.

## 5. REGIONAL TOVS DATA ASSIMILATION

In addition to the synoptic applications described above, the TOVS data have also been used in a series of real time data assimilation experiments in the Australian region to gauge their impact on operational regional forecasts. One set of experiments was described in the Seventh International TOVS Study Conference (Le Marshall et al., 1993) and indicates that the TOVS data, when available and providing good coverage over the Australian Region, can have a positive impact of up to 3 skill score points on general forecasts. Two further examples of data impact are presented below. The first study briefly documents the results from an operational trial which shows the positive impact of the locally retrieved high resolution TOVS data. The second is a graphic example of the impact on forecasts in the Australian Region which can result from the omission of the operational TOVS data in a particular case.

All impacts gained in these data assimilation examples have been obtained against the full NMC data base. This includes all local and GTS data available at the regional cut-off time (T + 7.5 hrs. for the 0600 UTC and 1800 UTC analyses and T + 1.5 hrs. for the 0000 UTC and 1200 UTC analyses). It should be noted that the short (1.5 hr.) data cut-off for the primary forecast times of 0000 and 1200 UTC results in limited NESDIS TOVS data being available for these analyses.

### 5.1 The Current and Next Generation Regional Forecast Systems

The current Australian **R**egional **AS**similation and **P**rognosis (**RASP**) System, used for the real time trials, was the BoM operational system and has been described, in detail, by Mills and Seaman, (1990). It consists of a static analysis of deviations of data from a short-term forecast on pressure surfaces, followed by an interpolation of these analysis increments to the sigma surfaces of the Australian Region Primitive Equation model, the addition of these increments to the forecast model variables and integration of the model forward to the next analysis time. Hence, at each data insertion time, the analyses reflect the observations, but have a strong dynamic constraint provided by the forward forecast model. MSLP and geopotential layer thickness are analysed, using 2-dimensional univariate statistical interpolation (SI). Wind components are analysed using 3-dimensional SI and temperature and dewpoint are analysed using the successive correction method. Mass and wind increment analyses are mutually adjusted to reflect their respective analysis accuracies, using variational techniques and separate analyses of screen level temperatures and dewpoints are merged with the tropospheric analyses. Data are analysed at 11 pressure levels and the forecast model has 15 sigma levels. Both the analysis and forecast models have a horizontal grid spacing of 150 km. The RASP system was used in the operational trial.

The next Limited Area Prediction System to be used in the Bureau is the **LAPS** and is currently undergoing final trials before handover to NMC. The main features of the system are 0.75° lat./long. resolution, 19 levels and a domain from 15° N to 65° S and 65° E to 185° E. It uses high order numerics and detailed parameterisation of physical processes, including cumulus convection, large scale rain, shallow convection, radiative transfer, diagnostic clouds, stability-dependent flux layer and iterative soil moisture.

The analysis scheme is multi-variate, statistical interpolation, formulated in $\varsigma$ co-ordinates on the model latitude/longitude grid. MVSI is applied to influence the MSLP geopotential, thickness and wind. Prediction error statistics are used with mass and wind statistics adjusted for geostrophic consistency. An error growth algorithm is also implemented. Divergent wind increments are analysed and gross error checking is followed by a comprehensive cross-validation.

In this system, super-obbing of closely spaced observations is implemented and data is manipulated in large volumes of the order of an octant of the globe. Another important feature is that significant and mandatory level wind and moisture data are used. This model was used in the Tropical Cyclone Bobby case study.

5.2 The Imapct of the Local TOVS Retrievals

Two examples are cited here, indicating the importance of high resolution TOVS retrievals in the Australian Region. The first case involves a longer-term (121 forecasts) study of the general impact of the TOVS data on skill scores in the Australian Region. The second involves an important tropical cyclone motion forecast.

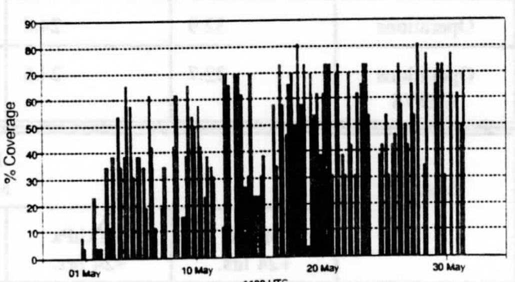
5.2.1 The Operational Trial

A series of real time data assimilation cycles, using local TOVS data has been completed. From 1 April 1993 to 31 May 1993, the TOVS system was provided with a first guess from the Australian Global Assimilation and Prognosis System (GASP) and remained unchanged for 2 months.

In this experiment, the local TOVS data have been added to the data used in the operational RASP Scheme, which is run routinely in the NMC and which provides operational regional forecasts. The analyses resulting from the addition of these locally retrieved TOVS data have been used to produce 24-hour and 36-hour forecasts, using the operational RASP forecast model in real time. The output from these forecasts has then been compared to the operational forecasts, which act as the control to produce the S1 skill score table shown below.

In Table 1, 121 forecasts, generated in real time, using the BoM NMC data plus local TOVS data (Operations + TOVS) have been compared to forecasts produced in BoM NMC (Operations). Verifications were performed using both analyses from the experimental system (Operations + TOVS) and the BoM NMC system (Operations). Regardless of the comparison standard (Operational + TOVS, or Operational Analyses), for the forecast intervals +24 and +36 hours and for all verified levels, namely, MSLP, 500 hPa and 300 hPa, the system using the high resolution TOVS data has not been outperformed, in any category, by the Operational system. The experimental system was superior for sixteen out of eighteen categories and the same for two out of eighteen categories presented.

**Figure 5**Local TOVS data coverage during May 1993. Each bar gives the average TOVS coverage for the 6 hr. analysis cycle.




Local TOVS data coverage, during this experiment, was less than optimal. An examination of the data coverage for May (Fig. 5) shows that the mean coverage is less than 50%. Coverage has been defined as that fraction of the areas south of 20° S and west of 140° E, for which high resolution data were available. This definition was chosen because of the importance of (TOVS) data coverage to regional analysis and forecasting in the data sparse region to the south west of Australia.

**TABLE 1 : S1 skill scores for 24 and 36 hour forecasts generated using the operational Regional Assimilation Prediction Scheme, with and without local TOVS in the analysis step.**

(1 April 1100 UTC to 31 May 2300 UTC 1993 121 cases Average coverage 43.1%)

| System | Verifying Anal | +24 hr. | | | +36 hr. | | |
|---|---|---|---|---|---|---|---|
| | | MSLP | 500 hPa | 300 hPa | MSLP | 500 hPa | 300 hPa |
| Operations | Operations | 33.6 | 23.8 | 22.4 | 39.8 | 30.8 | 29.2 |
| Operations + TOVS | Operations TOVS | 33.4 | 23.5 | 21.9 | 39.5 | 30.3 | 28.7 |

| System | Verifying Anal | +24 hr. | | | +36 hr. | | |
|---|---|---|---|---|---|---|---|
| | | MSLP | 500 hPa | 300 hPa | MSLP | 500 hPa | 300 hPa |
| Operations | Operations + TOVS | 33.5 | 23.8 | 22.1 | 39.7 | 30.5 | 29.0 |
| Operations + TOVS | Operations + TOVS | 33.4 | 23.5 | 21.9 | 39.5 | 30.3 | 28.7 |

| System | Verifying Anal | +24 hr. | | | +36 hr. | | |
|---|---|---|---|---|---|---|---|
| | | MSLP | 500 hPa | 300 hPa | MSLP | 500 hPa | 300 hPa |
| Operations | Operations | 33.6 | 23.8 | 22.4 | 39.8 | 30.8 | 29.2 |
| Operations + TOVS | Operations | 33.5 | 23.8 | 22.4 | 39.6 | 30.5 | 28.9 |

**TABLE 2 : S1 skill scores for May, 1993, for 24 and 36 hour forecasts generated using the operational Regional Assimilation Prediction Scheme, with and without local TOVS in the analysis step, for cases with good data coverage (≥ 50 %)**

| System | BMRC/NMC REAL TIME TRIAL May 1993 (All data) | | | | | |
|---|---|---|---|---|---|---|
| | MSLP +24 hrs. | 500 hPa +24 hrs. | 300 hPa +24 hrs. | MSLP +36 hrs. | 500 hPa +36 hrs. | 300 hPa +36 hrs. |
| Operations | 32.9 | 24.8 | 23.2 | 39.5 | 32.0 | 30.7 |
| Operations +TOVS | 32.7 | 24.6 | 22.8 | 39.0 | 31.7 | 30.0 |

| System | BMRC/NMC REAL TIME TRIAL May 1993 (50% or greater coverage) | | | | | |
|---|---|---|---|---|---|---|
| | MSLP +24 hrs. | 500 hPa +24 hrs. | 300 hPa +24 hrs. | MSLP +36 hrs. | 500 hPa +36 hrs. | 300 hPa +36 hrs. |
| NMC | 32.7 | 25.2 | 23.1 | 37.9 | 31.5 | 30.6 |
| Operations +TOVS | 32.5 | 24.0 | 22.4 | 37.2 | 30.6 | 29.1 |

If the verification for May is repeated, as it had quite poor coverage at the start of the month, and examine the S1 skill scores for those forecasts for which the initial analysis field had 50% or better data coverage, compared to those for all forecasts, one sees that, on average, the forecast skill has improved (Table 2).

This increase in skill is also illustrated in Fig. 6 (a) and Fig. 6 (b), which show forecast skill scores for Operations and Operations + TOVS, plotted for the 300 hPa, +36 hr. forecasts. Forecasts shown above the diagonal line indicate that a better forecast resulted from the use of TOVS data. It is clear that the inclusion of TOVS data has, in general, increased forecast skill and shown positive impact in the Australian region.

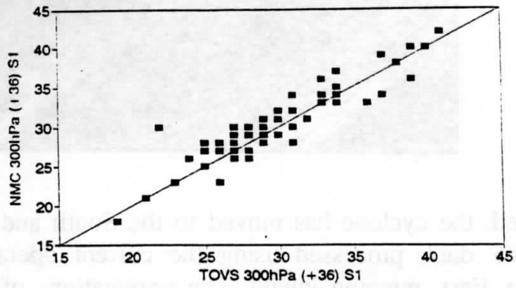



**Fig. 6 (a)** Operational plus TOVS forecast skill scores plotted against NMC operational skill scores for May 1993 in the Australian Region

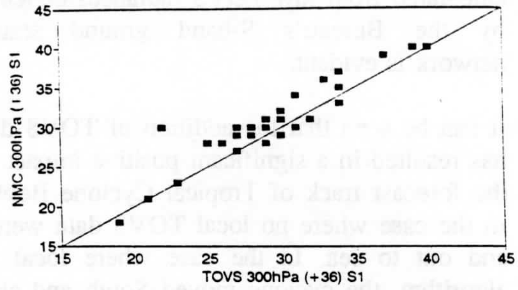



**Fig. 6 (b)** As in (a) but for greater than 50 per cent TOVS data coverage

5.2.2 <u>Tropical Cyclone Bobby : A strong example of the impact of operational local TOVS data</u>

Early on the morning of 25 February, 1995, Tropical Cyclone Bobby crossed the Western Australian coast, near Onslow.

The operational regional forecast after landfall predicted that the cyclone would move west of south in the first 24 hours, over the coast near Shark Bay and then, subsequently, off the coast. This proved to be a significant forecast error, for the operational regional system (the RASP) and the next generation regional system (the LAPS) which was then undergoing real time trials and the Bureau's Tropical Analysis and Prognosis system.

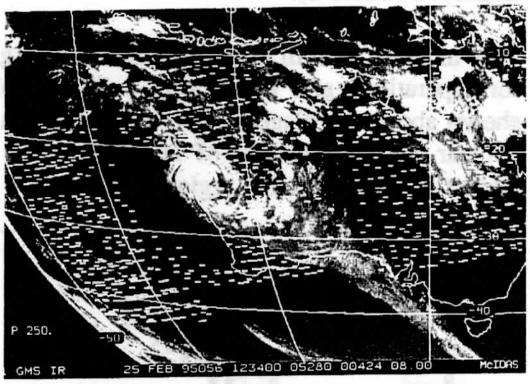
As it transpired, logisitic problems, including an extremely heavy load on the the communications network between Perth and Melbourne resulted in the loss of operational local TOVS sounding data from the input stream into the operational forecast model on 25 February, 1995.

Concern with these forecast errors *generated in the absence of local sounding data* from the operational and next generation models, and a knowledge that longer term studies had demonstrated the utility of these data, led to a reanalysis of the starting analysis for 1200 UTC on 25 February, 1995, using the operational first guess and boundary conditions, operational data used by the National Meteorological Centre with the addition of TOVS soundings, generated using the operational retrieval scheme.

These forecasts were subsequently repeated using the next generation LAPS and the operational data base plus local TOVS data from the BoM's S-band antennae for three orbits near 1200 UTC on 25 February, 1995. The data coverage can be seen in Figure 7.

The inclusion of TOVS data resulted in quite distinct forecasts. Figures 8 (a), (b), (c) and (d) show the resulting 24- and 36-hour MSLP forecasts using the operational data base. While figures 8 (e) and (f) show the 24- and 36-hour forecasts from the reanalysis using the operational data base plus local TOVS data.

Figure 7 The coverage of TOVS data used in the analysis at 1200 UTC on 25 February 1995, shown over the GMS image for that time




Figures 8 (g) and (h) show the verifying MSLP analyses over Australia.

Clear improvement of the forecast from the inclusion of high resolution soundings calculated from raw TOVS radiances collected by the Bureau's S-band ground station network is evident.

It can be seen that the addition of TOVS data has resulted in a significant positive impact on the forecast track of Tropical Cyclone Bobby. In the case where no local TOVS data were used, the cyclone has moved to the South and West and out to sea. In the case where local TOVS data, processed using the current operational algorithm, the cyclone moved South and slightly East, remaing inland. The implications of these differences in operational guidance material could be significant. The return of a tropical cyclone over the ocean can often result in significant differences in subsequent intensity and trajectory forecasts.

## 6. FUTURE - TOVS, AVHRR

A new system, which uses AVHRR data in conjunction with a 1-dimensional variational retrieval scheme, similar to that in the new ITPP-5, has been undergoing real time trials in the BoM. Results to date indicate a superior ability to discriminate cloud and cloud characteristics and hence to determine the retrieval path. The use of spatial coherence and other physical tests has allowed an improved estimate of N*, which is now only performed in the appropriate cloud regime.

Eight months of real time testing has resulted in a stable, robust system which is being used for NWP trials. It is intended that this system will be followed by a system which will use a 3-dimensional variational approach to the retrieval problem as part of the regional analysis.

## 7. CONCLUSIONS

The Bureau of Meteorology has implemented and is now routinely using for operations a physical retrieval scheme, which uses non-limb-corrected, cloudy, raw TOVS radiances. The synoptic application of these data to generate total ozone, gradient winds, stability indices and tropical cyclone intensity estimates has been noted. It has been demonstrated that temperature and moisture data from the scheme have a positive impact on operational regional numerical forecasts. A recent study of 121 forecasts has shown that, in general, these TOVS data improve the accuracy of regional forecasts at all levels over the Australain Region. It has also been shown that the impact of the data increases with better data coverage within the region. A particular example involving Tropical Cyclone Bobby has clearly indicated the importance of the data to particular and in this case, significant, forecasts.

**Acknowledgments**

Many thanks are due to Terry Adair who helped prepare this manuscript.

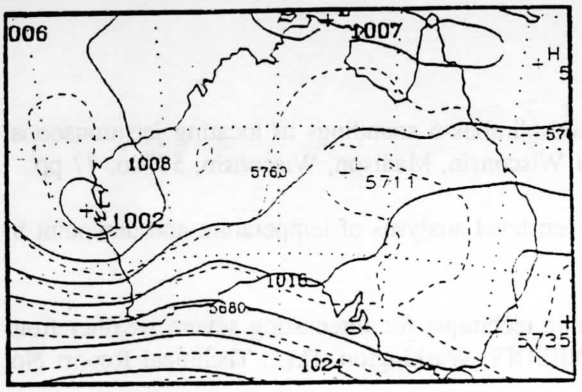



Fig. 8 (a) The 24-hour MSLP forecast from the current operational RASP, valid 1200 UTC on 26 February, 1995

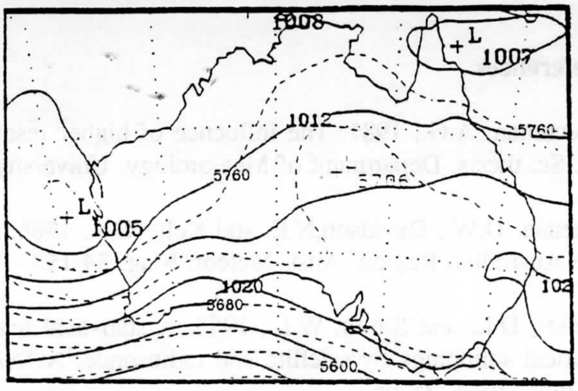



Fig. 8 (b) The 36-hour MSLP forecast from the current operational RASP, valid 0000 UTC on 27 February, 1995

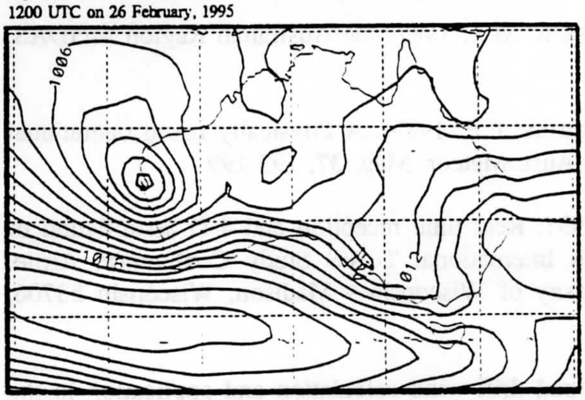


Fig. 8 (c) A 24-hour MSLP forecast from the next generation regional model (LAPS), valid 1200 UTC on 26 February, 1995

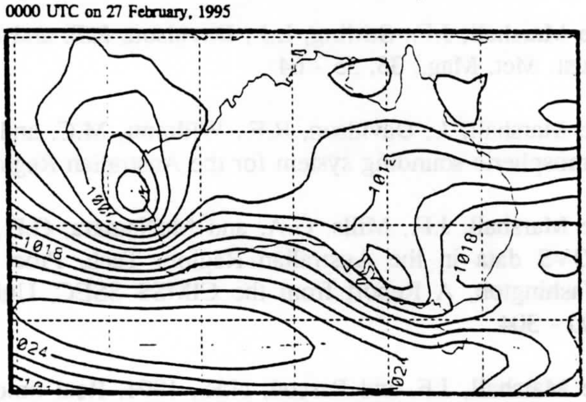


Fig. 8 (d) A 36-hour MSLP forecast from the next generation regional model (LAPS), valid 0000 UTC on 27 February, 1995

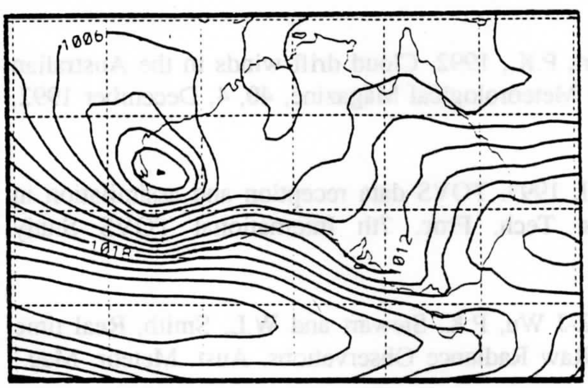


Fig. 8 (e) The 24-hour MSLP forecast from the next generation regional model (LAPS), using local TOVS data, valid 1200 UTC on 26 February, 1995

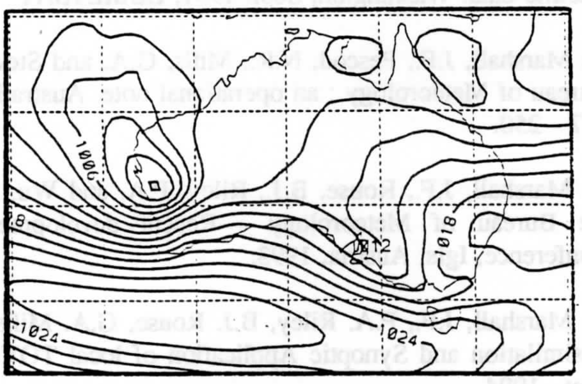


Fig. 8 (f) The 36-hour MSLP forecast from the next generation regional model (LAPS), using local TOVS data, valid 0000 UTC on 27 February, 1995

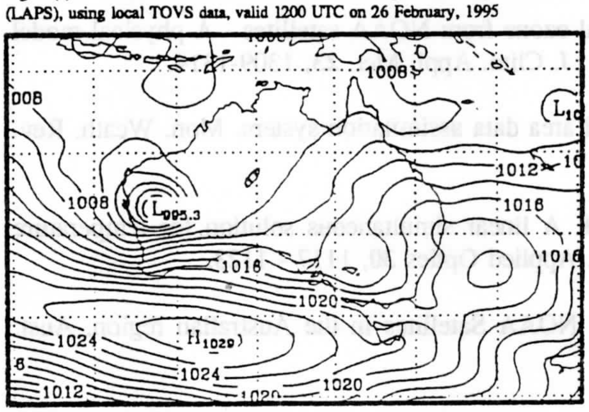


Fig. 8 (g) The Mean Sea Level Pressure Analysis, valid 1200 UTC on 26 February, 1995

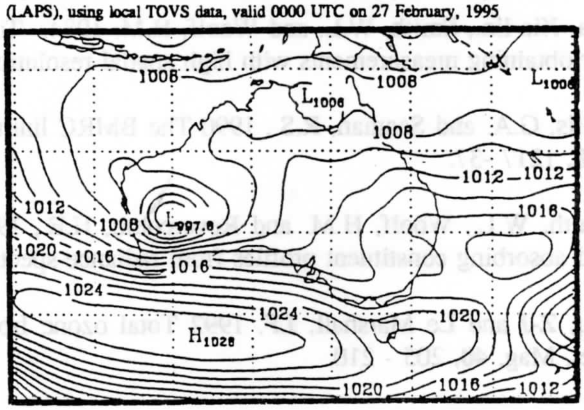


Fig. 8 (h) The Mean Sea Level Pressure Analysis, valid 0000 UTC on 27 February, 1995

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