TYPHOON MONITORING AND TRAJECTORY PREDICTION IN THE PHILIPPINE REGION USING A PC-BASED NOAA DIRECT READOUT SYSTEM AND AN INTEGRATED DATA BASE

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1. ABSTRACT

In 1991 a NOAA S-band reception station and integrated data processing system were commissioned at the Philippines Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) in Manila. During 1991 and 1992 these provided support to weather forecasting operations, in particular, they were used for monitoring the intensity and positions of typhoons during the 1991 and 1992 typhoon seasons and to provide some regional sounding capability.

This paper briefly details the personal computer-based ground station. It also describes the local TOVS sounding and deep layer mean forecast systems, developed for the National Forecast Centre of PAGASA for estimating cyclone intensity and track. The paper shows the TOVS data retrieval system when analysing cyclone data in the Philippines Region has delineated upper tropospheric temperature anomaly fields which can be related to analysed storm intensity, central pressure and maximum wind speed. The ground truth data used in this study were, generally, operational estimates of storm intensity but have still allowed useful computation of the coefficients relating temperature anomaly to storm intensity and have resulted in callibration curves which may be used for operational purposes. The deep layer mean forecast system described in the paper is used operationally.

2. INTRODUCTION

While high temporal resolution GMS Stretched VISSR data form a prime data base for the monitoring and forecasting of severe weather (particularly typhoons) in the tropical Pacific, NOAA TOVS and AVHRR radiances also provide important fields. These include high resolution visible and infrared imagery, sea surface temperatures, temperature and moisture soundings, cloud height and amount and total ozone measurements. These are available, twice daily, from each of the polar orbiting satellites. Of particular interest, in the tropical cyclone season, is the orbiters' ability to monitor the upper tropospheric temperature anomalies associated with tropical disturbances, such as typhoons and, also, its general sounding capability, given the sparse conventional sounding network in the region.

This paper briefly describes the PC-based ground station and the data analysis system, installed at PAGASA, for the reception and real time processing of AVHRR and TOVS data. This system provides an integrated real time meteorological data base and related meteorological applications which allow tropical cyclone intensity monitoring, using both image analysis (via the Dvorak technique) and TOVS data, and the use of the deep layer mean data for track forecasting.

Kidder et al., in 1978, related typhoon upper tropospheric temperature anomalies from the SCAnning Microwave Spectrometer (SCAMS) on NIMBUS-6 to surface pressure anomalies, providing evidence to support the relationship between intensity and temperature anomaly. Kidder et al., 1979 demonstrated that, if the storm is assumed to be in hydrostatic equilibrium, a linear relationship exists between the magnitude of this upper air temperature anomaly, the surface pressure anomaly and the maximum windspeed. Later results, illustrating this relationship, have been subsequently published (see, e.g., Velden and Smith, 1983, Velden et al., 1984, Velden, 1989 and Velden et al., 1991).

The research, delineated in this paper, was based on 34 observations of typhoons, which moved within the field of view of the Manila ground station in 1991 and 1992. The ground truth data for the study were operational estimates of wind speed and surface intensity, derived using conventional data, Dvorak's technique (Dvorak, 1984) and from other sources of information. The data were examined in relation to tropical cyclone characteristics, such as eye, cloud, rainfall and storm maturity.

Another area of study in this paper was cyclone trajectory forecasts based on deep layer mean winds. Earlier evidence for the utility of this approach may be seen, for example, in Velden at al., 1984 and the present study shows evidence of the utility of this approach in the Central Western Pacific.

3. THE NOAA RECEPTION SYSTEM

The PAGASA NOAA HRPT satellite data reception, ingestion, processing and analysis station has three main components. The first is an enclosed, tracking 2.4 m antenna. The second is an ingest workstation, which is responsible for scheduling, tracking, data acquisition, data storage and the archival of the NOAA HRPT data. It both drives the antenna and receives NOAA HRPT data via a SCSI interface. The third component is the processing, display and analysis, P.C. Australian Region McIDAS workstation (Le Marshall et al., 1987). A block diagram, describing the system is seen in Fig. 1.

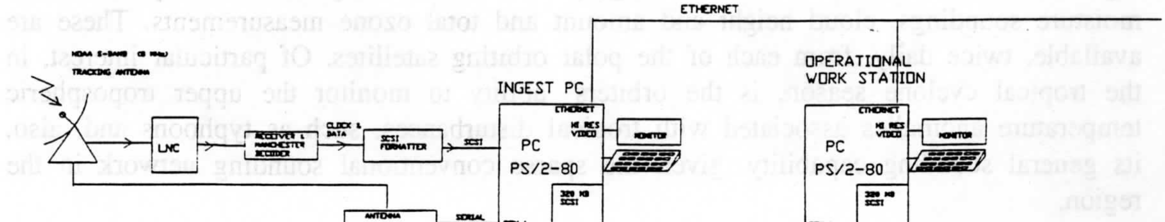

Fig. 1 A block diagram of the PAGASA NOAA ground station

Once ingested, the data are transferred to the second workstation for formatting, calibration, navigation and image processing of the HRPT data. This data analysis workstation also derives temperature and moisture profiles, skin temperature, cloud height, cloud amount and total ozone from the TOVS data in the received signal and produces from the HRPT data fields such as sea surface temperature. The system also has additional workstations, allowing analysis and use of application programs in areas such as the National Forecasting Centre.

4. THE DATA BASE

Satellite data used in this study consisted of NOAA orbits, received at PAGASA, during 1991 and 1992, when 14 tropical cyclones passed within the field of view of the system. The cyclones, related dates and durations are shown in Table 1.

Name of Tropical Cyclone	Date	No. of Cases
Asiang	June 24 - 29, 1992	6
Ditang	July 17 - 21, 1992	2
Lusing	Aug. 31 - Sept. 5, 1992	6
Maring	Sept. 18 - 23, 1992	4
Paring	Oct. 18 - 27, 1992	4
Seniang	Nov. 25 - 30, 1992	6
Trining	Oct. 24 - 31, 1991	1
Uring	Nov. 02 - 7, 1991	2
Warling	Nov. 08 - 14, 1991	1
Yayang	Nov. 14 - 19, 1991	2

Table 1 The tropical cyclones, quantitatively analysed to relate temperature anomaly and storm intensity.

The conventional data related in this study to the upper tropospheric temperature anomalies, were taken from the seasonal typhoon review performed routinely by PAGASA at the end of each typhoon season. The wind intensity and surface pressure estimates for the cyclones were mainly derived using the Dvorak technique, available surface pressure or wind speed observations and other information such as that available from Tropical Cyclone Warning Centres. These data were generally those available in real time and did not represent a "special observation" data set.

5. THE TOVS DATA PROCESSING SYSTEM

The TOVS data retrieval scheme used for this study is similar to that described in Le Marshall et al., 1994. The scheme employs a simultaneous linear solution of the Radiative Transfer Equation for temperature and absorbing constituent similar to Smith et al., 1991. It uses the perturbation form of the Radiative Transfer Equation

$$\delta R_\nu = \beta_\nu^0(P_s)\tau_\nu^0(P_s)\delta T_s - \Sigma_{i=1}^{N}\int_0^{P_s}\beta_\nu^0(p)\delta T_i(p)\tau_\nu^0(p)\, d\ln\tau_{\nu_i}^0(p) \quad (1)$$

where R_ν is the spectral radiance, N is the number of optically active atmospheric constituents, δ is the true minus initial value, $\tau_\nu(p)$ is the total transmittance above p, τ_i is the transmittance of the i^{th} absorbing constituent, μ_i is the concentration of the i^{th} absorbing constituent, $T_i(p)$ is the effective temperature of the i^{th} absorbing constituent, and

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

$$\delta T_i(p) = \delta T_i(p) - T^0(p) \quad (3)$$

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

The first guess options available to the system are forecast model or regression generated fields and climatology. In this study, the first guess was a climatology, specifically developed to provide an appropriate first guess for the Philippines Region. The first guess surface air temperature and moisture fields were, again, climatological but accounted for diurnal variation and elevation. The scheme was carefully quality controlled and also produced estimates of cloud amount and height, skin temperature and total ozone.

6. OBSERVING TROPICAL CYCLONES WITH THE TOVS

Radiances from MSU channels 2, 3 and 4, as well as radiances from the stratospheric HIRS channels were used to depict the thermal structure of the upper troposphere and stratosphere, in the region of tropical cyclones. TOVS 250 hPa temperature data, such as is seen in Fig. 2 for tropical cyclone Seniang, show the presence of a warm thermal anomaly, associated with tropical cyclones. This temperature anomaly usually is large around 250 hPa and a number of authors, (Kidder et al., 1978; Velden and Smith, 1983) have related this temperature anomaly to tropical cyclone intensity, in particular, the maximum wind speed, and the surface pressure anomaly.

When determining and using these anomalies, however, several factors need to be considered. The horizontal resolution of the MSU is near 113 km sub-satellite and approximately 250 km at the limb and hence the MSU may not fully capture the smaller localised warming patterns associated with less intense or developing storms. The effects of limb resolution may also lead to a reduction of the apparent intensity of the storm.

In addition to these considerations, other factors to be borne in mind include the possibility that the footprint may not be centred on the storm anomaly centre and there may be rainfall contamination associated with the observations. The effect of precipitation, to an extent, can be gauged by viewing of sequential passes, by examination of the infrared imagery (where, for example, a very low 11 μm (Channel 8) temperature commonly means rain contamination), the retrieval fields and by an examination of the manner in which limb-corrected microwave MSU-2 or MSU-3 varies across the track through the storm centre.

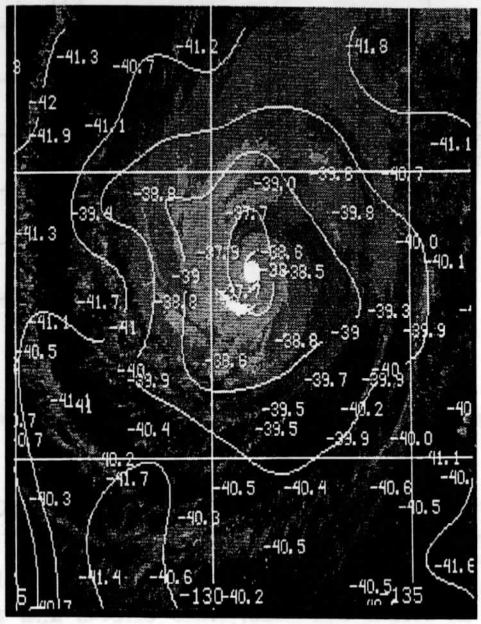

Figure 2 Tropical cyclone Seniang with TOVS 250 hPa temperatures and analysis at 0600 UTC on 27 October 1992

6.1 Estimation of Surface Intensity Tropical cyclones from two seasons, (Table 1), have been examined in detail and the TOVS-determined upper tropospheric temperature anomalies related to the analysed surface pressure departure from ambient conditions. Here, the 250 hPa temperature anomaly between the storm centre and a radius of 6° is related to the surface pressure difference between the cyclone centre and the pressure at 6° radius. Where possible, sequential imagery, raw radiance data and soundings from sequential orbits, passing close to the tropical cyclone, (within 6°), based on three microwave channels (2, 3 and 4) and the stratospheric HIRS channels have been examined, to provide an estimate of the temperature anomaly associated with the warm cores relative to the average temperature at 6° radius from the anomaly centre.

Using 34 suitable orbits taken at Manila during the 1991 and 1992 cyclone seasons, linear regression was used to formulate the relationship between surface pressure anomaly, Δp, and the 250 hPa temperature anomaly ΔT_{250}. The least squares regression relationship, assuming no intercept, is

$$\Delta p = 13.8 \Delta T \tag{1}$$

The RMS error associated with this relationship is 12.3 hPa. This relationship is displayed in Fig. 3 (a). If one allows an intercept for this relationship, one finds that the regression relationship is changed to

$$\Delta p = 17.1 \Delta T - 12.0 \tag{2}$$

This relationship has an RMS error of 7.6 hPa. Relationship (1) is not dissimilar to that found by Velden, 1991 for Atlantic typhoon cases and has similar errors.

6.2 Estimation of Maximum Wind Speed The same data base associated with Pacific Ocean typhoons in 1991 and 1992, was used to define a relationship for maximum surface wind speed in terms of the 250 hPa temperature anomaly. Using 34 cases with linear regression and assuming no intercept, the relationship shown below was derived.

$$V_{max} = 42.1 \Delta T_{250} \tag{3}$$

This relationship results in a RMS error of 22.8 km/hr. This relationship is plotted in Fig. 3 (b). Again, using linear regression, and allowing an intercept, the relationship becomes

$$V_{max} = 37.0 \Delta T + 16.9 \tag{4}$$

This relationship has an RMS error of 10.5 km/hr. This relationship indicates a smaller coefficient of ΔT in the V_{max} estimate than for North Atlantic hurricanes but a larger coefficient than that reported for the North West Pacific, in Velden et al., 1991.

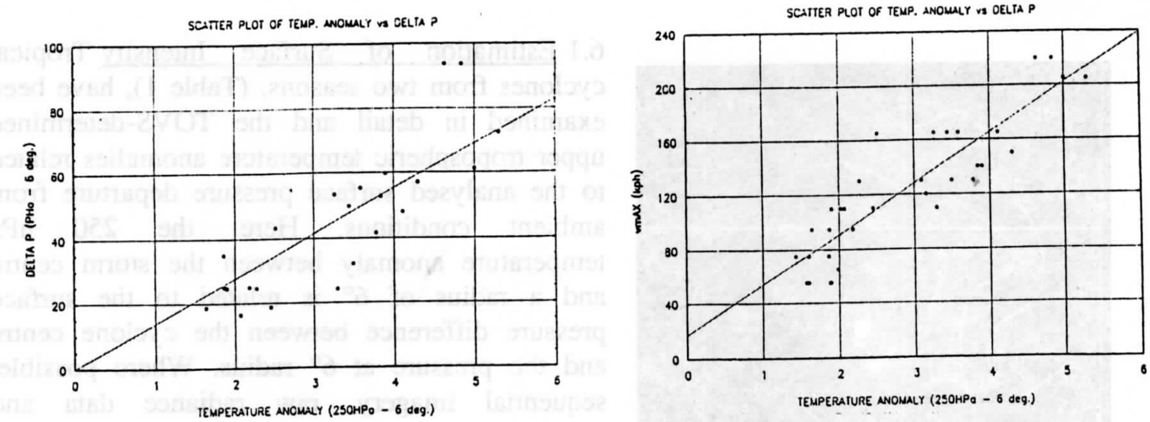

Fig. 3. Surface pressure anomaly (a) and maximum wind speed (b) versus upper tropospheric temperature anomaly, assuming no intercept (data points plotted).

The accuracy of the relationships are difficult to determine but errors may be ascribed to several sources. Non-centring of the storm in the MSU footprint, radiometric noise, the influence of clouds and precipitation, vertical position of the maximum temperature anomaly varying from storm to storm, variation in storm eye size, limb effects and also the use of operational surface pressure and wind speed data in establishing the relationships. Despite these problems, the relationships between the upper tropospheric temperature anomaly, storm intensity and surface pressure anomaly appear well founded and consistent with results found in earlier studies.

7. CYCLONE TRAJECTORY PREDICTION

Another key component of the data processing and analysis system, used in the monitoring and forecasting of tropical cyclone position, is the Deep Layer Mean (DLM) model. This model is a filtered Barotropic model set on a 2.5° x 2.5° Mercator grid with a domain of 90° E to 180° E and 45° N to 20° S (de las Alas, Adug and Bucoy, 1984). It has been initialised, using grid point wind data from the JMA global spectral model available via the Global Telecommunication System (GTS). These data are provided at 850, 500 and 200 hPa, and, from these, a deep layer mean wind (V_{DLM}) has been computed, using the relationship $V_{DLM} = 0.27V_{850} + 0.54V_{500} + 0.49V_{200}$. Use of the Deep Layer Mean Wind, which is a 3-layer, weighted mean, in preference to 500 hPa level wind data, has provided good forecast guidance, during the 1992 tropical cyclone season and the PC-based system is now used operationally.

The average forecast errors for 30 cases during the 1991 and 1992 typhoon seasons for 24, 48 amd 72 hour forecasts based on the DLM initialisation are 220, 422 and 505 km, respectively, a distinct improvement on those based on single level (500 hPa) winds (328, 559 and 779 km respectively).

8. SUMMARY AND CONCLUSIONS

A NOAA AVHRR ground station and TOVS and AVHRR data processing and analysis system have been installed in Manila and both TOVS and AVHRR data are being routinely processed to produce soundings, skin temperatures and other data sets for personal computer technology, is robust and is comparatively simple to maintain. It has an Australian Region McIDAS type data analysis capability (Le Marshall et al., 1987). It has been used operationally since 1991.

Supporting research has been undertaken to allow full usage of the ground station TOVS and AVHRR data and has been summarised in this paper. The TOVS component of this research is an extension of previous studies, in particular, those of Velden and Smith, 1983; Velden, 1989 and Velden et al., 1991. It looks at an area of the Central Western Pacific, not previously examined and, by use of 34 suitable observations of typhoons by satellite, has developed relationships between upper troposphere temperature anomaly, maximum wind speed and surface pressure anomaly.

As a result, the TOVS data now not only provide a basic sounding capacity which can be used to provide fields of temperature, moisture and the horizontal variation of stability suitable for shorter term forecasts, but TOVS data monitoring of tropical cyclone intensity can also be considered as an important adjunct to the usual operational method of image interpretation, (using, for example, Dvorak's technique), to guage tropical cyclone intensity. The surface pressure anomaly and wind speed algorithms reported in this paper are now able to be used, within PAGASA, as aids to estimating tropical cyclone intensity.

The relationships found between temperature anomaly, wind speed and surface pressure anomaly, in this study, are not dissimilar to those discussed in Velden, 1989 and Velden et al., 1991 for tropical cyclones in the North American region. The uncertainty associated with these relationships may be a little higher than those of Velden, 1991 because the data base consisted mainly of operational data and the limited study has not benefitted from the use of reconnaisance reports and related "special observations". These relationships will be further enhanced by observations taken over future seasons.

While further development work is necessary before a fuller exploitation of this technique can be achieved, the present results indicate the utility of TOVS data processing in real time for estimating the intensity of tropical cyclones. It has been noted that it is important, while estimating cyclone intensity, to ensure, as far as is possible, that the temperature anomaly is not rain affected, is close to the centre of the orbit, is well centred in the MSU field of view and is consistent with consecutive orbits.

In conclusion, the utility of the NOAA data, particularly in monitoring tropical cyclones, is evident, given the clear correlations found between tropical cyclone temperature anomalies, intensity and surface pressure anomaly.

This paper has also described the use of the applications associated with the ground station, to produce deep layer mean based forecasts of tropical cyclone movement, which now provides guidance for operational forecasts of cyclone motion.

Overall, it is clear that the PC based groundstation, in combination with NOAA data and an integrated data base is a powerful tool for monitoring and predicting typhoon motion and is well suited for application in the Pacific region. The utility of such systems will also increase with the availability of Advanced Microwave Sounding Unit data in 1996.

9. Acknowledgements The authors would like to thank Mr. Terry Adair for the preparation of this manuscript.

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TECHNICAL PROCEEDINGS OF

THE EIGHTH INTERNATIONAL TOVS STUDY CONFERENCE

Queenstown, New Zealand

5-11 April 1995

Edited by

J R Eyre

Meteorological Office, Bracknell, U.K.

Published by

European Centre for Medium-range Weather Forecasts
Shinfield Park, Reading, RG2 9AX, U.K.

July 1995