THE APPLICATION OF MSU MICROWAVE DATA TO THE STUDY OF AUSTRALIAN REGION TROPICAL CYCLONES.

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1. ABSTRACT

The Microwave Sounding Unit (MSU) on board the NOAA polar orbiting satellites has been used to determine tropical cyclone intensity by measuring the horizontal gradient of the upper warm temperature anomaly. Aircraft measurements and dropsonde data near Northern Hemisphere tropical cyclones indicate that the magnitude of the warm anomaly can reach 16 deg. C.

Velden and Smith (1983) correlated the MSU derived temperature anomalies to the intensity of Atlantic tropical cyclones. Similar studies using Australian tropical cyclones have shown a smaller MSU-derived anomaly. Anomalies were obtained from MSU raw brightness temperatures adjusted for the effects of increasing slant path and from retrieved temperatures using the TOVS physical retrieval scheme implemented in the Australian Bureau of Meteorology (Le Marshall et al., 1994).

Composite temperature profiles obtained from 20 years of radiosonde and cyclone data for the Western Australian region were obtained and synthetic radiances calculated. These were used to determine some of the reasons for the reduced MSU response and to derive adjustments to improve the correlation between the observed anomaly and cyclone intensity. The proposed Advanced Microwave Sounding Unit (AMSU) with greatly improved vertical and horizontal resolution is shown to have potential to give measurements which more closely reflect the magnitude of the upper tropospheric temperature anomaly.

2. INTRODUCTION

Tropical cyclones are intense low pressure systems with a warm core near the cyclone centre or eye. The warm temperature anomaly peaks in the upper levels of the cyclone near 300 hPa. Gray and Shea (1973) and others have inferred anomalies up to 16 K. The Microwave Sounding Unit (MSU) on board the NOAA polar orbiting satellite has four sounding channels in the 5.5 mm oxygen absorption band. MSU channel 3, with its peak response near 300 hPa is well suited to measure the associated temperature anomaly. However the scan spot size (110 km at nadir) will not fully resolve the inner warm core. The Advanced Microwave Sounding

Unit as part of the ATOVS onboard the next generation NOAA satellites has not only more sounding channels but a reduced scan spot size of 50 km at nadir.

3. COMPOSITE CYCLONE TEMPERATURE PROFILES

Radiosonde data for the period 1968 to 1988 were combined with official three hourly "best track" positions of North Western Australian cyclones to derive a composite tropical cyclone upper temperature structure. Observed temperatures beyond 15 degree radius from the cyclone centre were used as representative of the environment and averaged to obtain an indication of the anomaly closer to the core. Initial results are shown in Fig.1. The upper tropospheric warming is evident with a peak of 6 K around 300 hPa. Significant cooling is shown above 150 hPa. The radius of warming extends to at least 800 km from the cyclone centre. Holland (1983) obtained similar results for composites of oceanic cyclones in the Australian region. The data presented here, and that of Holland (1983), do not reveal the 15 K anomaly inferred by the composites published by Frank (1977) but this may be due in part to the lack of aerial reconnaissance in the Australian region. The sparseness of the radiosonde network precluded the stratification of the data into quadrants. Little data are available near cyclones in northern and western quadrants except when the cyclones are over land.

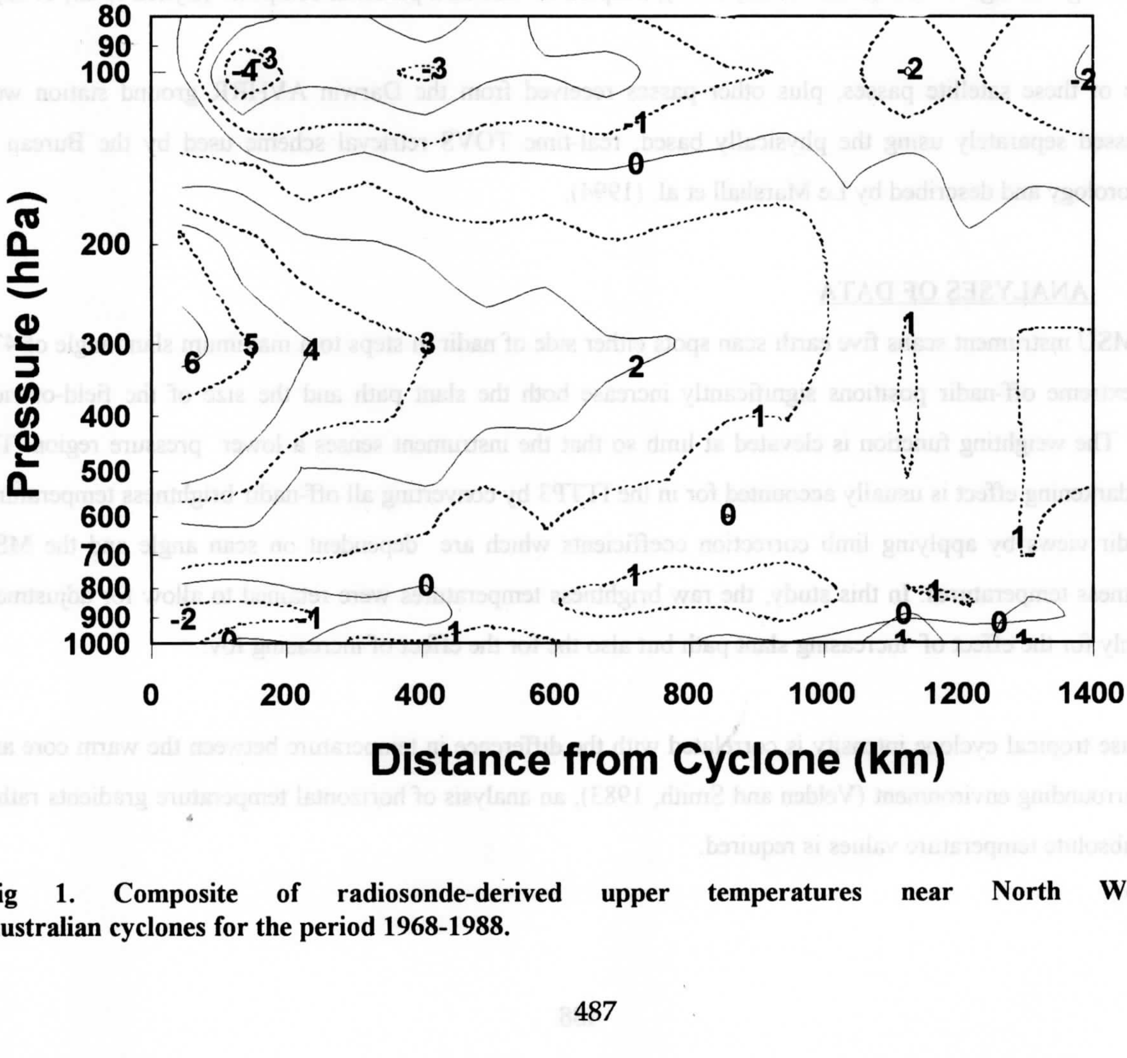

Fig 1. Composite of radiosonde-derived upper temperatures near North Western Australian cyclones for the period 1968-1988.

4. MICROWAVE SOUNDINGS.

Microwave sounding is particularly suited to tropical cyclone studies because it is little affected by cloud. Attenuation however becomes important in the case of heavy precipitation. The MSU has four channels (referred to in this paper as MSU1, MSU2, MSU3 and MSU4) with weighting functions peaking at 700 hPa, 500 hPa, 300 hPa and 100 hPa for nadir view. MSU1 also senses the earth's surface and with microwave sounding the emissivity has to be allowed for. Both MSU1 and MSU2 can be affected by scattering due to precipitation. In studying tropical cyclone anomalies, our interest is centred mainly in the region near 300 hPa and data from MSU3 which does not sense the surface, and is little affected by liquid water. Both raw radiances and 250 hPa retrieved temperatures were used to obtain anomalies near the cyclone centre.

The raw radiances were obtained from satellite passes obtained from the data archives held by the Western Australian Satellite Technology and Applications Centre (WASTAC) and at Curtin University. For each pass the TOVS data were extracted and preprocessed and calibrated using part of the International TOVS Processing Package ITTP3 (Smith et al., 1985), adapted for use on a personal computer (Lynch et al., 1988).

Some of these satellite passes, plus other passes received from the Darwin AVHRR ground station were processed separately using the physically based, real-time TOVS retrieval scheme used by the Bureau of Meteorology and described by Le Marshall et al. (1994).

5. ANALYSES OF DATA

The MSU instrument scans five earth scan spots either side of nadir in steps to a maximum slant angle of 47°. The extreme off-nadir positions significantly increase both the slant path and the size of the field-of-view (fov). The weighting function is elevated at limb so that the instrument senses a lower pressure region. The limb darkening effect is usually accounted for in the ITTP3 by converting all off-nadir brightness temperatures to nadir views by applying limb correction coefficients which are dependent on scan angle and the MSU brightness temperatures. In this study, the raw brightness temperatures were retained to allow for adjustment not only for the effect of increasing slant path but also the for the effect of increasing fov.

Because tropical cyclone intensity is correlated with the difference in temperature between the warm core and the surrounding environment (Velden and Smith, 1983), an analysis of horizontal temperature gradients rather than absolute temperature values is required.

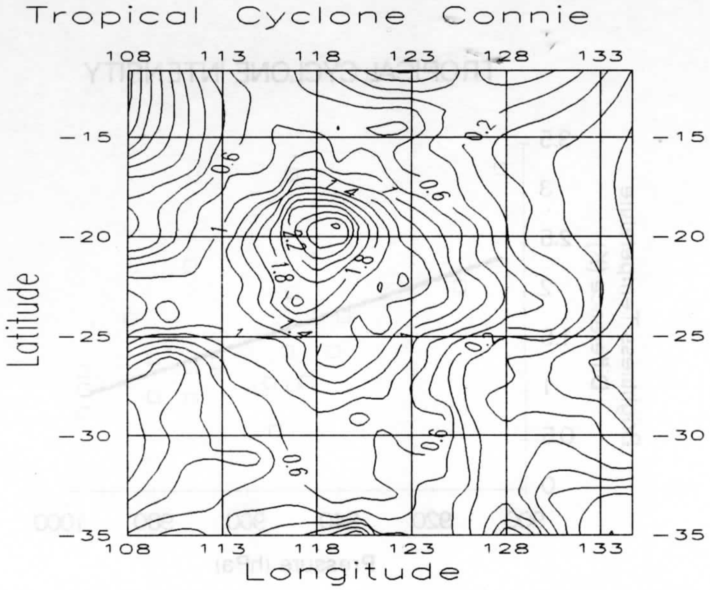

Fig. 2 Anomaly plot of MSU3-derived brightness temperatures around tropical cyclone Connie. The cyclone is centred near 19.9 S, 118.5 E.

The method used to remove limb effects is similar to that described by Purdom et al., (1986). An anomaly field was obtained by averaging the brightness temperatures of the same scan spot for a particular channel and a latitude range over a large number of passes. These average values were then subtracted from the raw brightness temperatures for the cyclone affected passes to obtain an anomaly field. Fig. 2 shows an anomaly plot of MSU3-derived brightness temperatures for an orbit over tropical cyclone Connie, January 19th, 1987. The cyclone was estimated to be centred near 19.9 S, 118.5 E with a central pressure of 950 hPa. The maximum anomaly observed is 3.2 K. Using the above method for limb correction, combined with the Bureau of Meteorology 'best track' cyclone positions, the warm temperature anomaly for MSU3 brightness temperatures was obtained for a number of cyclones. The anomalies were plotted against cyclone intensity and a regression line fitted. Fig 3 shows the results.

From Fig 3 it is evident that the warm temperature anomaly found from MSU data correlates poorly with the intensity of North West Australian tropical cyclones. Prata et al., (1986) attributed the poor sensitivity to the MSU's large fov (109 km at nadir and 323 km at limb) relative to the spatial extent of the warming, the poor vertical resolution and the spatial misalignment of the tropical cyclone centre with the MSU fov. Van Burgel et al. (1994) showed results for 5 passes over tropical cyclone Elsie where the anomaly varied from 1.0 K to 1.4 K whilst the central pressure varied between 950 hPa and 975 hPa. From a best-fit track it appeared the maximum anomaly was on average 100 km distant from the MSU fov centre.

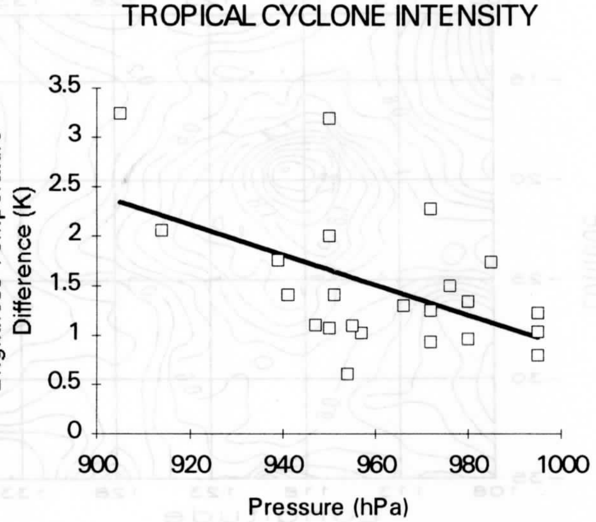

Fig 3. MSU3 brightness temperature anomalies versus tropical cyclone central pressure for NorthWestern Australian tropical cyclones.

6. FORWARD CALCULATION

The ITPP3 package contains routines to enable a forward calculation of MSU radiances to be performed using a radiosonde temperature profile. The profile used was similar in structure to the composite previously obtained, with the magnitude of the anomaly near the core adjusted to include similar values reported from aerial reconnaissance near Typhoon "Inez" and other cyclones.

To allow for the varying scene temperature across the MSU antenna field of view, calculations were made across the entire instrument's earth fov at 1 degree steps. The increased slant path was calculated by multiplying the transmittances by sec (ϕ). The derived radiances were then adjusted to incorporate the antenna gain pattern as provided with the ITTP software. The half-power beamwidth (-3 dB) for MSU is 7.5 degrees but significant radiation is received outside this beamwidth, aided by the antenna sidelobes. Figs 4 and 5 indicate the MSU response for the input cyclone anomaly at various scan angles. Fig. 4 is for a clear atmosphere whilst fig. 5 is for an atmosphere with cloud between 700 hPa and 400 hPa with a liquid water content of 0.7 gm/m^3. The cloud represents a total liquid water content of about 3 mm. Calculations presented here are for two cases: 1) sea surface with minimum foam and a clear atmosphere and 2) sea surface with .16 foam (produced by a wind velocity of 20 m/sec) and a cloudy atmosphere.

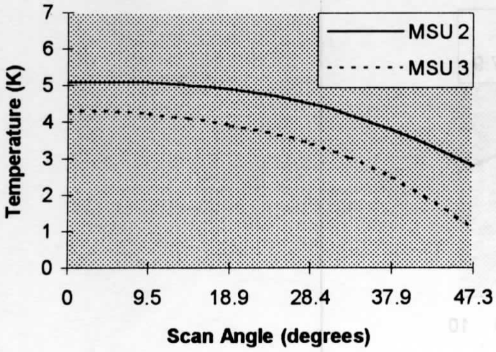

Fig 4. Temperature anomaly response for MSU2 (solid line) and MSU3 (dashed line) for a clear atmosphere obtained from forward calculations using the synthetic profile.

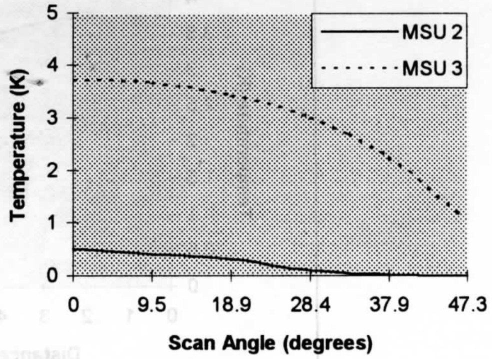

Fig. 5 As for Fig. 4 for a cloudy atmosphere.

For non- cloudy conditions, the MSU2 response is of greater magnitude than that of MSU3. This is due to the broad MSU weighting functions. MSU3 is sensing the stratospheric cooling evident above 150 hPa. However, fig. 5, which is more realistic for conditions near tropical cyclones, shows significant attenuation in MSU2 due to liquid water whilst MSU3 retains a significant response. For clear atmospheres the increase in scan angle has a lesser impact on MSU2 because of the lifting of the weighting function as the slant angle increases. The response shown in Fig. 5 is for non-precipitating clouds. MSU2 in particular is also affected by scattering by precipitation.

Using similar forward calculations, the effect of horizontal misalignment can be modelled by offsetting the cyclone centre from the fov centre in 1 degree intervals across track. Fig. 6 shows the results for the anomaly profile used previously. For the MSU, the half power point is 3.75^0 from the centre of the beam whilst the centre of the next scan spot is at 9.47^0. There is also a misalignment possible in the along track direction. Thus, at worst, the response is across track misalignment of 4.7^0 plus a possible 5.5^0 (84 km) along track misalignment. From fig. 6 we see this would reduce the MSU response by about half.

These factors of misalignment of the cyclone centre from the scan spot centre and scan angle dependence can be included in the forward calculation to derive coefficients to enable adjustments to be applied to the MSU-derived parameters for the above effects of spot size, misalignment and tropical cyclone structure.

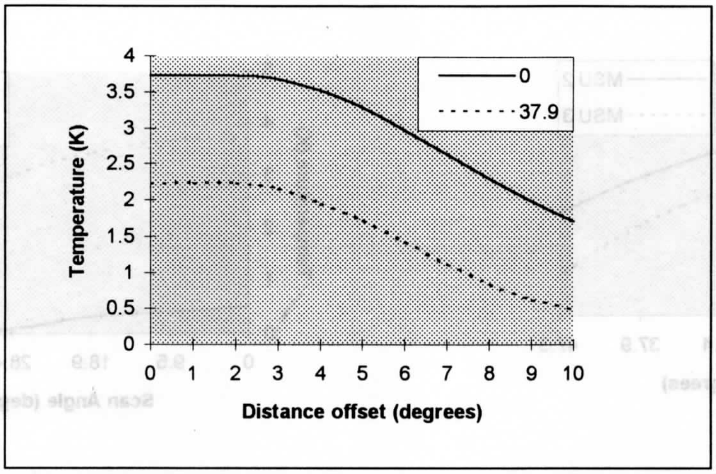

Fig 6. Results of modelling the MSU3 anomaly response when the cyclone is offset from centre of scan spot. Two cases are shown: 0^0 scan angle and 37.9^0 scan angle.

7. RETRIEVED TEMPERATURES

The use of the raw MSU-derived brightness temperatures allows adjustments to be made to the observed MSU-derived values to compensate for offset, varying fov and cloud according to model output as discussed in the previous section. However, the peak of the weighting function for an MSU channel is not always located at the level of maximum warming. As the forward modelling shows, the increased elevation of the weighting function maximum at off-nadir scan position results in MSU3 sensing more of the stratospheric cooling evident at levels above Australian tropical cyclones. Also this increased elevation means the limb correction technique employed does not compare anomalies at the same level. NOAA satellite data for a number of cyclones in the West Australian and Coral Sea basins were processed to obtain temperature anomalies from retrieved temperatures using the physical retrieval scheme described by Le Marshall et al. (1994). Information from MSU channels 2, 3 and 4 plus HIRS channels 1, 2 and 3 are used to obtain the retrieved 250 hPa temperature anomalies. The results are shown in Figs 7a and 7b for temperature anomaly verses maximum wind speed and verses pressure anomaly. Fig. 8 shows the contours of 250 hPa retrieved temperatures superimposed on a GMS IR satellite image of tropical cyclone Orson.

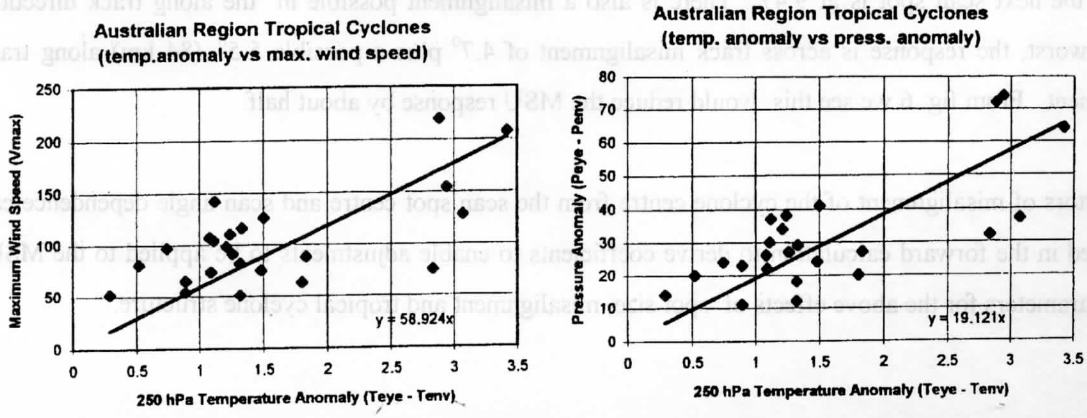

Fig. 7a. 250 hPa temperature anomaly versus maximum wind speed and Fig. 7b 250 hPa anomaly versus tropical cyclone pressure anomaly. Temperature anomaly obtained from the physical retrieval scheme.

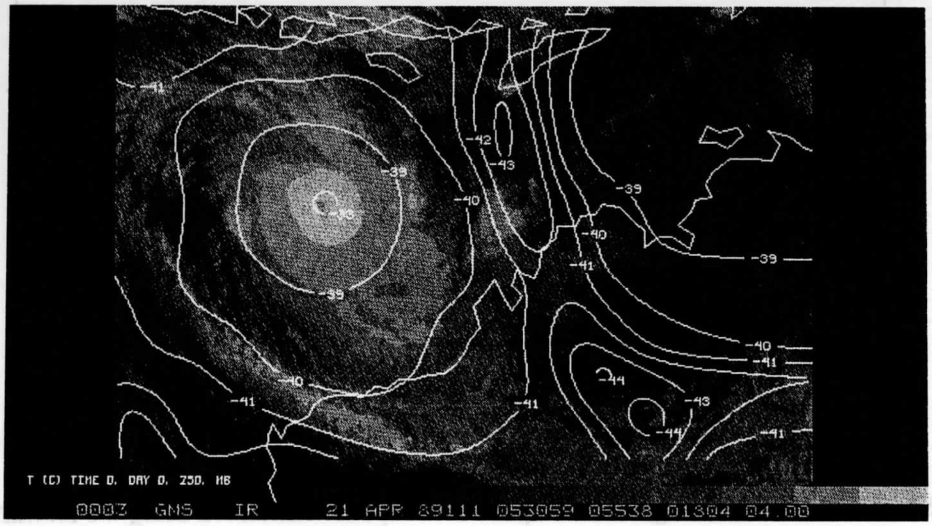

Fig 8. Contours of the 250 hPa retrieved temperatures superimposed on infrared GMS satellite image of tropical cyclone Orson on April 21st, 1989.

8. ADVANCED MICROWAVE SOUNDING UNIT

The improved resolution from the Advanced Microwave Sounding Unit (AMSU) is expected to improve the response to the cyclone temperature anomaly. The AMSU has a half power beam width of 3.3 degrees and the distance between adjacent scan spots is 3.3 degrees. There are 15 scan spots for a cross-track scan of +/- 48.33 degrees from nadir with 30 earth fields of view per line (Mo et al., 1993).

Using the same synthetic cyclone anomaly as input and calculating brightness temperatures across the scan, the AMSU response for tropical cyclones can be modelled. The antenna gain function used was that determined from theoretical calculations as described by Ulaby et al. (1983). Results are shown in figures 9 and 10. When compared with the modelled results for MSU3, it is apparent that AMSU channels 6 and 7 will resolve more of the warm temperature anomaly and be less affected by increasing scan angle or cyclone centre misalignment.

9. CONCLUSIONS

The coarse horizontal and vertical resolution of the Microwave Sounding Unit reduces the warm temperature anomaly signal from soundings near North Western Australian cyclones. The sensitivity could be improved by making adjustments using the coefficients obtained from the forward model. The proposed Advanced Microwave Sounding Unit (AMSU) with greatly improved vertical and horizontal resolution, will result in measurements which more closely reflect the magnitude of the upper tropospheric temperature anomaly near cyclones and thereby allow estimates of tropical cyclone intensity to be made.

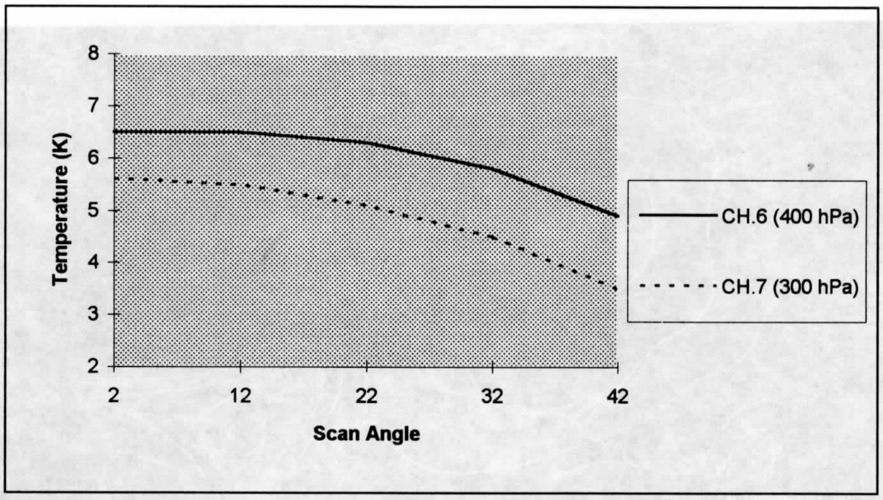

Fig 9. AMSU channel 6 and 7 brightness temperature response calculated using the forward model.

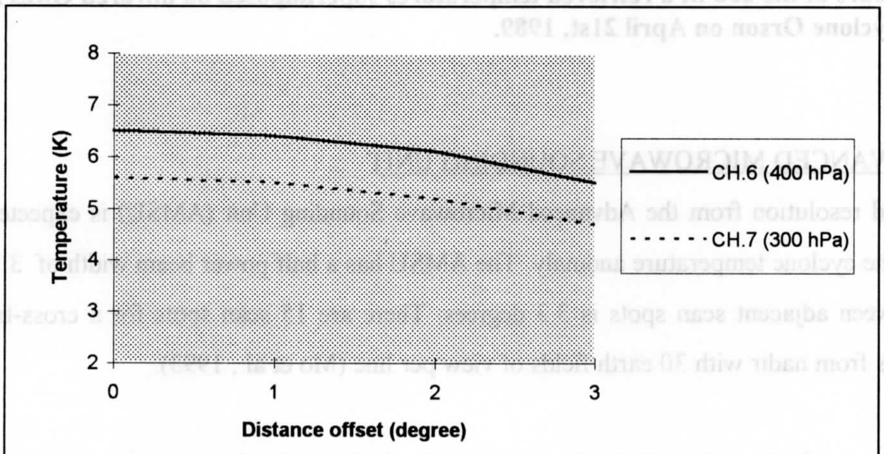

Fig 10. AMSU brightness temperature response versus distance from centre of scan spot for nadir view calculated using the forward model.

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