Observations from the Maritime Continent : Darwin, Australia

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ABSTRACT

A major observational and research program is being undertaken in Darwin, Australia as part of the Tropical Ocean and Global Atmosphere (TOGA) and the National Aeronautics and Space Administration (NASA) Tropical Rainfall Measuring Mission (TRMM). Darwin is situated in northern Australia and experiences a monsoon environment typical of the Maritime Continent region, together with break and transition periods when continental systems are predominant. The Darwin initiative follows the recent Australian Monsoon Experiment (AMEX) and Equatorial Mesoscale Experiment (EMEX) and represents a continuing effort to gather data on the nature of convection in this strategic tropical location.

1. Introduction.

Darwin's strategic location in on the southern edge of the Maritime Continent and at the western extremity of the Pacific Walker circulation, together with its long period of established observations, has made it one of the most well known of all tropical observing sites. The SOI is based on Darwin pressure records that extend back to the last century and Darwin was the base for the recent AMEX/EMEX and Stratosphere/Troposphere Exchange Project (STEP) experiments.

The Bureau of Meteorology Research Centre has continued this tradition by promoting an extensive upgrading of the observing capacity in collaboration with NOAA, NASA, NCAR, NSF, the Northern Territory Regional Office of the Bureau of Meteorology, and a number of United States and Australian universities. We describe the observing system in section 2 and the climatological features of the region in section 3. Some recent experimental and research results are presented in sections 4-6.

2. The Darwin observing system.

The current Darwin observing system, shown in Fig. 1, covers a comprehensive array of mesoscale observations. A NOAA/TOGA Doppler radar has provided extensive Doppler coverage since 1988. This will be removed in 1990 and replaced by a Bureau of Meteorology radar in 1991. For the 1988/89 and 1989/90 wet seasons, dual Doppler observations are being taken in conjunction with the NSF funded MIT radar. MIT also have installed a network of coronal point discharge and could-to-ground lightning detectors for 1988-1990.

Full tropospheric wind and thermal soundings are taken every 12 hours and additional wind soundings are made at the intervening 6 hours. A 50 Mhz Doppler profiler is being installed this year by BMRC in collaboration with the NOAA Aeronomy Laboratory. This will contain one vertical beam for 1989/90 and then be upgraded to a three beam system. A 915 Mhz profiler also will be installed to provide detailed boundary layer observations during special observing periods.

A mesonet of 26 surface raingauges was installed in 1987 and this is being upgraded to include complete surface observations from automatic weather stations at about five sites. A surface radiation monitoring station is being installed this year.

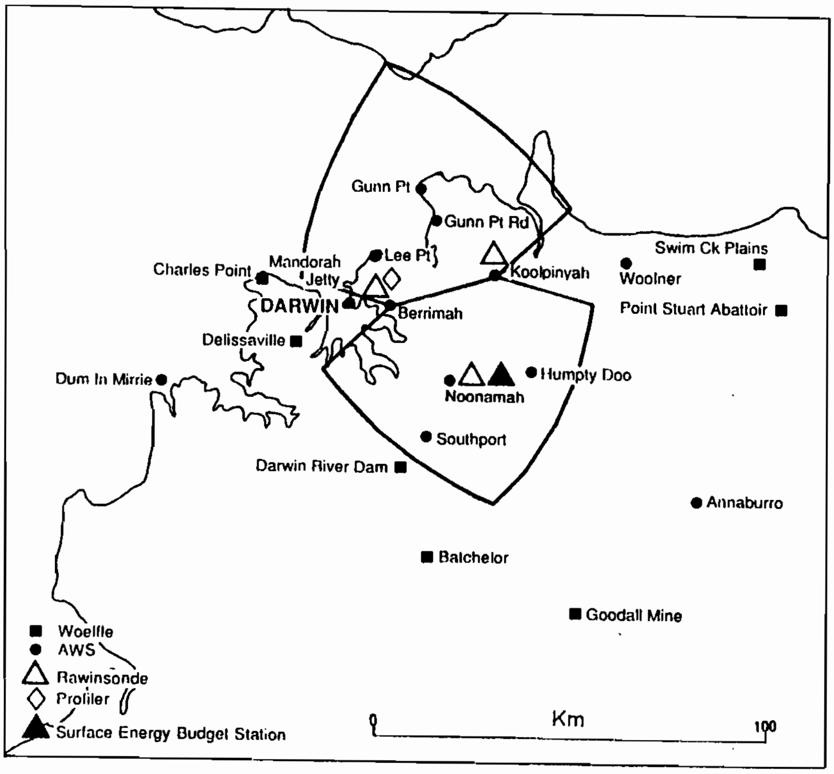

FIG.1. The Darwin observing system for the 1989/90 wet season.

3. Climatological features of the Darwin region.

Darwin lies at the southern edge of the Maritime Continent, within the world's largest source of latent heating. It experiences a classical monsoon climate described in detail by Holland (1986). The onset of the active period, when rainfall and low level equatorial westerly flow occur, is normally during late December, with the retreat to easterly flow and dry conditions usually occurring during late February or early March. Break periods, when low level subtropical esterly flow is again established, occur for around 20% of the summer monsoon season. As a result, there are two to three active westerly flow phases per season, with a mean period between active phases of 40 days. There is a close relationship between low-level westerly flow at Darwin and rainfall over northern Australia (Holland, 1986). In the Darwin region, however, thunderstom and squall line activity during the pre-monsoon October to December transition season contribute up to 30% of the total rainfall (Nicholls et al. 1982).

It is seen from Fig. 1 that within 150 km of Darwin approximately 48% of the area is oceanic, 43% is continental, and 9% is tropical islands. This diverse range of environments provides a rich variety of weather systems. The rain-producing systems during both the transition and wet season include oceanic monsoon cloud clusters and equatorial cloud bands, maritime-continent island thunderstoms, "pop-corn" cumuli and mesoscale convective complexes from the tropical continent, north Australian cloud lines and tropical squall lines, monsoon depressions and tropical cyclones. Theses continental and maritime systems have a variety of convective and mesoscale structures and undergo distinct lifecycles ranging from diurnal to those associated with synoptic scale organization. An indication of the frequency of storm occurrence, and their diurnal shift from land to ocean is shown in Fig.2.

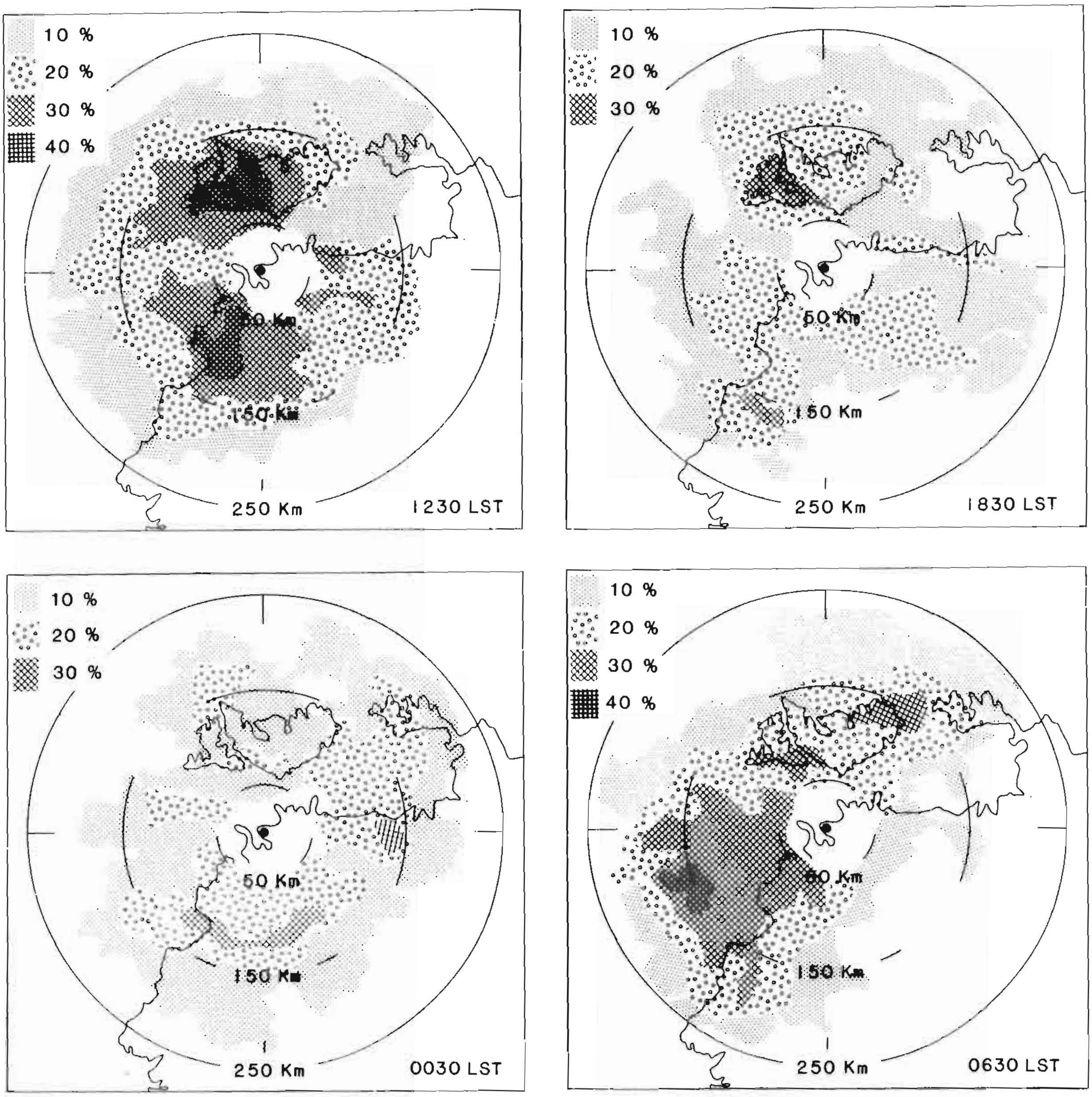

FIG.2. Percentage occurrence of radar echoes greater than 15 dBz at darwin during Phase II of AMEX at 1230, 1830, 0030 and 0630 LST.

Considerable interannual variability is observed in the strenght and duration of the summer monsoon at Darwin. The average daily rainfall is related to the SOI, but the length of the monsoon season is not (Holland, 1986). This may be because the length of the heavy rain and westerly monsoon bursts are very sensitive to the phase of the 30-50 day oscillation (Holland, 1986). There also is considerable variability in the occurrence of the different types of weather system from season to season. During a weak summer monsoon year, squall-lines and island thunderstoms are predominant. During a very active summer monsoon, the rain tends to fall from large-scale upslope flow associated with the well-developed monsoon through. Although tropical cyclones rarely pass over Darwin, rainbands from these systems and from monsoon depressions often occur. Interactions with subtropical flow appear to be particularly important in determining the scale and nature of the convection at Darwin (Keenan and Brody, 1988).

3. The Tropical Rainfall Measuring Mission (TRMM).

TRMM is a US and Japanese program to obtain a minimum three-year data set of 500x500 km^2 scale monthly averaged estimated rainfall rate probabilities in tropical regions (Thiele, 1987). The satellite based instrument package is planned for launching in the mid 1990s. The program involves development of new rainfall measuring techniques using both satellite and ground-based approaches and gathering of data sets suitable for diabatic initialization of weather forecast models. The program is being supported by comprehensive ground-truth observations taken in collaboration with TOGA.

The TRMM ground truth project (Thiele, 1987) includes the objective of determining the three-dimensional structure of tropical precipitation and rainfall amounts from spatial scales less than 1 km up to a 100,000 km^2 area for a one month time period. To date, ground truth data on tropical rainfall have been limited to short period field experiments, e.g. GATE and AMEX/EMEX. In addition, these data have not been collected at locations representative of the entire global regime. NASA, NOAA and BMRC therefore have established a TRMM ground truth station at Darwin to obtain a climatology of convection and total rainfall indicative of the monsoon climate and the maritime continent.

The data collected in Darwin are being used initially in support of pre-TRMM studies. The aim of these pre-TRMM ground measurement studies are to :

1) Undertake rainfall measurement comparisons relevant to spaceborne radar/radiometer techniques, and

2) Undertake rainfall measurements on the scales relevant to the satellite mission.

The mode of operation is to mix a long-term climatological monitoring of the rainfall in the vicinity of Darwin with data obtained during intensive special observing periods. The operation has fulfilled the following objectives:

1) Quantitative estimation of precipitation rates using the high accuracy, 5 minute base scan data available on pseudo constant altitude surfaces,

2) Monitoring of the convective components of precipitation for echo tracking (5 minute base scan data),

3) Three dimensional structure of the precipitating systems from the convective to mesoscale using the 5-15 minute interval volumetric scan data,

4) Monitoring of the stratiform component of precipitation at 15-60 minute hourly intervals using the Extended Velocity Azimuth Display (EVAD) method of Srivastaval et al. (1986).

5) Deriving statistics of vertical motion using EVAD and vertical sounding data.

Further information on the TRMM ground truth mission at Darwin may be found in Keenan et al. (1988).

4. The Island Thunderstorm Experiment (ITEX).

Tropical convective activity within the maritime continent region is dominated by local thunderstorms generated on a diurnal basis over the many tropical islands. Examination of satellite data by Holland and Keenan (1980) showed that this deep, geographically fixed, tropical convection is the basic source of convection within the so called "boiler-box" of the tropics. Disturbances often exist and can be associated with widespread convective activity but these local ephemeral thunderstorms emerge as the basic convective element of the maritime continent.

Houze et al. (1981), Williams and Houze (1987) and Keenan et al. (1989b) have documented some diurnal variations that occur over the maritime continent region. And several experiments (EMEX, WMONEX) have examined the structure of convective disturbances over the ocean. The ITEX objective (Keenan et al. 1989a) was to complement these studies by gathering detailed information on the thunderstorm complexes that regurlarly form over Bathurst and Melville Islands to the north of Australia (Fig.1). The observing system shown in Fig.1 was complemented by additional rawinsonde stations on Melville Island and at Cape Don, and by an array of surface anemometers which were established on the islands together with a radiation budget and surface flux station. An instrumented aircraft was used to obtain photographic and thermal data in the vicinity of the developing storms.

ITEX was a collaborative effort between BMRC, the Centre for Dynamical Meteorology at Monash University, and NASA. The aims were to obtain the first comprehensive data set of these Maritime Continent thunderstorms and to carry out physical and numerical studies on their structure, generation and evolution. Particular attention was given to the mechanisms of generation, to the evolution, to the structure, the quasi-steady location over the islands and to the causes of decay. Studies are underway that focus on the surface energy budget, the role of sea breeze circulations and their interaction with thunderstorm scale circulations, the role of the large-scale environment and the larger-scale modification by the thunderstorms. Future studies are planned on analytic and numerical examination of tropical cumulus convection and on comparative tests of existing convective cloud models.

Further information on this experiment and on the climatology of thunderstorms over the islands may be found in Keenan et al., (1988, 1989a).

5. Squall-line and continental convection.

Tropical convection in the vicinity of Darwin has been shown by Keenan and Carbone (1989) to exist in a surprisingly large variety of modes. Bulk Richardson number classification and radar derived structure indicated the existence of storm conditions ranging from the high shear, moderate buoyancy range of tornadic type disturbances to the low stability moderate shear of hurricane rainbands. Darwin squalls encompassed the dynamic regime of severe squalls found in the US to the low stability/shear encountered in the oceanic and monsoon regimes. Important differences in the propagation mechanisms on the squalls were evident and recent observational data collected at Darwin have indicated the frequent occurrence of microbursts in association with this deep convective activity.

Tropical squalls during transition and break periods of the Darwin wet season result primarily from storms generated along the sea breeze front, from continental type squalls generated over the escarpment region 250 km to the east, or from continental storms to the east and south-east. A preliminary climatology indicates that during the 1500-0200 LST period, sea breeze front storms occur on 77% of days and major squalls from the east on 60% of days.

Oceanic convection occurs during monsoon conditions. The maritime systems are different in structure from the continental storms with generally weaker convective activity and a greater proportion of stratiform precipitation. However, very large CAPE is observed prior to the development of rainbands. In addition, squall-like lines develop within the massive stratiform decks.

An intensive examination of these tropical squalls, deep convection and monsoon convection will be carried out in the 1989/90 season by collaboration between the following institutions: Bureau of Meteorology Research Centre, Monash University Centre for Dynamical Meteorology, NASA Goddard Space Flight Center, Colorado State University, Massachusetts Institute of Technology, National Center for Atmospheric Research, NOAA Aeronomy Laboratory and the Northern Territory Regional Office, Bureau of Meteorology.

The aims are to investigate :

1. **The convective to mesoscale structure, motion and evolution of storms affecting Darwin and their interaction with environment.** Attention will be directed to comparisons with midlatitude systems, the generation and maintenance of the stratiform precipitation, the coupling between the horizontal and vertical flow within the trailing anvils and differences between oceanic and continental systems.

2. **The relationship between planetary boundary layer flow and the initiation, maintenance and propagation of tropical convection.** Convergent boundaries caused by the interaction between the sea breeze front, storm outflow and variations in surface heating will be investigated in relation to the propagation and initiation of the convective systems. Recent work by Rotunno et al. (1988) suggests that the structure and longevity of squalls is determined by the interaction between the environmental low level shear and the cold pool outlow from the convective cells. In addition, propagation of the squalls seems to be related to the speed of cold pool outflow.

3. **The development of microbursts in a tropical environment.** Previous observational data from the NOAA/TOGA radar has indicated that microbursts occur 4-5 times per day between 1230 and 1930 LST within 60 km of Darwin during break or transition season flow. The evolution of these tropical microbursts will be investigated in a contrasting regime to that of the dry continental sub cloud air; an environment in which most microbursts have been studied.

4. **The investigation of the lightning characteristics of continental and monsoon convection.** Preliminary investigations by E. Williams (MIT) and S. Rutledge (CSU) during the last two wet seasons in Darwin indicate that convective clouds in the vicinity of Darwin are indeed electrified highly with lightning rates in some clouds (those in an environment of large CAPE) equalling that observed at mid-latitudes. Observations indicate that in-cloud lightning (IC) rates dominate cloud-to-ground (CG) rates with ratios about 30 to 1. Investigations will continue on the electrical properties of both continental and monsoon convection with emphasis on relating electrical characteristics to cloud dynamics and cloud vertical development.

5. **Mesoscale Forecasting Experiments.** An intensive, mesoscale forecasting program will be mounted to evaluate the use of Doppler radar in aviation forecasting and to develop a climatology of gust fronts and convective downbursts in a tropical environment.

The observational network will be based on the NOAA/TOGA and MIT Doppler radars for convective scale data, an associated mesoscale network of surface weather stations, three rawinsonde stations, a surface energy budget station, a wind profiler and a tipping bucket raingauge network. The enhanced network will be concentrated about the dual Doppler lobes of the two radars, as shown in Fig. 1. These lobes are in a favourable location for observation of both squalls initiated along the sea-breeze front and continental squalls propagating to the west from the escarpment. Smaller sea breeze front and locally generated squalls can be found in either or both lobes whereas escarpment squalls typically encompass both lobes.

6. Summary.

The enhanced observing system at Darwin is providing valuable data to support a wide variety of studies into convective and mesoscale phenomena in the Maritime Continent regime. These studies include : (i) provision of ground truth information for the Tropical Rainfall Measuring Mission; (ii) the first comprehensive examination of the island thunderstorms that comprise the bulk of the "boiler box" convection; (iii) a detailed examination of the structure of tropical squall-lines from a wide range of dynamical regimes; and, (iv) experiments on mesoscale forecasting in a tropical environment.

A number of these studies are TOGA process studies are all are contributing valuable data and understanding of the tropical heat engine.

REFERENCES

Holland, G.J., 1986: Interannual Variability of the Australian summer Monsoon at Darwin : 1952-82. *Mon. Wea. Rev.,* **114**, 594-604.

Holland, G.J. and T.D. Keenan, 1980: Diurnal Variations of Convection over the "Maritime Continent". *Mon. Wea. Rev.,* **108**, 223-225.

Houze, R.A. Jr., S.G. Geotis, F.D. Marks and A.K. West, 1981: Winter monsoon convection in the vicinity of North Borneo. Part I: Structure and Time Variation of the clouds and precipitation. *Mon. Wea. Rev.,* **108**, 1595-1614.

Keenan, T.D. and L.R. Brody, 1988: Synoptic Scale Modulation of Convection during the Australian Summer Monsoon. *Mon. Wea. Rev.,* **116**, 71-85.

Keenan, T..D., G.J. Holland, M.J. Manton and J. Simpson, 1988: TRMM Ground Truth in a Monsoon Environment : Darwin, Australia. *Aust. Meteor. Mag.*, **36**, 91-90.

Keenan, T.D. and R. Carbone, 1989: A preliminary morphology of convective systems in tropical northern Australia. Paper presented at 24th Conference on Radar Meteorology, Tallahassee, Florida, March 27-31.

Keenan, T.D., B.R. Morton, M.J. Manton, G.J. Holland 1989a: The Island Thunderstorm Experiment (ITEX) - A study of Tropical Thunderstorms in the Maritime Continent. *Bull. Amer. Met. Soc.*, **70**, 152-159.

Keenan, T.D., J. McBride, G.J; Holland, N. Davidson, B. Gunn, 1989b: Diurnal variations during the Australian Monsoon Experiment (AMEX) Phase II. *Mon. Wea. Rev.,* (to appear).

Nicholls, N., J.L. McBride and R.J. Ormerod, 1982: On predicting the onset of the Australian wet season at Darwin. *Mon. Wea. Rev.,* **110**, 14-17.

Rotunno, R., J.B. Klemp, M.L. Weissman, 1988: A Theory for Strong, Long-Lived Squall Lines. *J. Atmos. Sci.*, **45**, 463-485.

Srivastava, R.C., T.J. Matejka and T.J. Lorello, 1986: Doppler radar Study of the Trailing Anvil Region Associated with a Squall Line. *J. Atmos. Res.,* **43**, 356-377.

Thiele, O.W., 1987: On Requirements for a Satellite Mission to Measure Tropical Rainfall. *NASA Reference Publication,* **1183**, 49 pp.

Williams, M. and R.A. Houze, Jr., 1987: Satellite-Observed Characteristics of Winter Monsoon Cloud Clusters. *Mon. Wea. Rev.,***115**, 505-519.

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TABLE OF CONTENTS

MEETING COLLECTED PAPERS

WATER MASSES, SEA SURFACE TOPOGRAPHY, AND CIRCULATION

EL NINO/SOUTHERN OSCILLATION 1986-87

MOMENTUM, HEAT, AND MOISTURE FLUXES BETWEEN ATMOSPHERE AND OCEAN

EMPIRICAL STUDIES OF ENSO AND SHORT-TERM CLIMATE VARIABILITY

MISCELLANEOUS