

Tropical Cyclone Intensity Determination Through Upper-Tropospheric Aircraft Reconnaissance

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Abstract

It is proposed that attention be given to the possibility of tropical cyclone intensity determination through upper-tropospheric jet aircraft reconnaissance. The cyclone's upper-level temperature anomaly and its gradient can be related to surface pressure and wind. This is particularly relevant to foreign countries affected by these cyclones that do not have a dedicated low altitude aircraft reconnaissance capability, but have available jet aircraft. Only the ordinary aircraft instrumentation for measuring temperature and pressure-altitude would be required. Jet flights are faster, longer ranged, and less turbulent (if echoes are avoided) than propeller flights. Many more aircraft are available for such missions.

1. Introduction

Although very significant strides have been made in the utilization of satellite picture data for cyclone intensity determination (as demonstrated by Dvorak, 1975), operational forecasters usually also desire verifying aircraft intensity information when cyclones are nearing populated coastal regions and they must make major forecasting decisions.

Despite the fact that cyclone intensity estimates from satellite picture configurations by Dvorak (1975) have been found to be generally satisfactory in the majority of cases (especially when applied by experts such as Dvorak), the relationship between cloudiness configuration and intensity is quite complex and significant difficulties in intensity determination can occur in individual situations. Arnold (1977) has documented some of these cases for West Pacific cyclones. In addition, the satellite reception and interpretation experience in many foreign countries is not adequate for cyclone intensity determination.

Even when maximum wind and central pressure are known, there is a question about the reliability of these parameters for estimation of the outer cyclone strength and damage potential. Cyclone damage will vary greatly with the horizontal size of the high wind-low pressure region and the concentrated nature of the inner-core circulation. A specified value of maximum wind or central pressure, as currently available from

the satellite intensity estimations, even if accurate, may not allow a forecaster to always make a very reliable evaluation of potential cyclone damage from storm surge, wind, and rainfall.

It is important that the outward horizontal extent of the cyclone's circulation and asymmetry are known. Such information is often not readily available from satellite picture images. Storm cirrus canopies often obscure the measurement of low-level wind vectors. Until satellite measurements can provide this information there is likely to be a continued requirement for aircraft reconnaissance in important forecast situations. This is especially true with the improvements in storm warning and evaluation procedures that allow for wiser and more orderly civilian response to cyclone alerts.

There are, nevertheless, growing financial and technical difficulties in the continuation of traditional (since mid-1940s) low- and middle-level aircraft reconnaissance by the United States and in the establishment of reconnaissance programs by countries less technically and economically advantaged than the United States. No country other than the United States has a dedicated, standby tropical cyclone reconnaissance capability. The financial and technical requirements of maintaining propeller aircraft are becoming more difficult as aviation interests focus more on jet operations. Low-level reconnaissance as currently used requires specially equipped and maintained propeller aircraft with high instrument and maintenance costs. Also, specially trained crews have to be committed for extended periods of a tropical cyclone season. This is not cost effective. Countries affected by these storms typically require only a few crucial cyclone strength determination measurements per year and sometimes none. It is only when cyclones are within 24-48 h of populated coastal areas that such measurements become so important and redundancy of intensity determination with the satellite becomes critically important. The growing expense of maintaining a traditional propeller aircraft reconnaissance capability along with the major developments in satellite technology have led to decisions causing significant reductions in United States reconnaissance flights.

Flights at low levels by propeller aircraft are slow (by jet standards) and are usually quite turbulent. Center penetration occasionally cannot be made when

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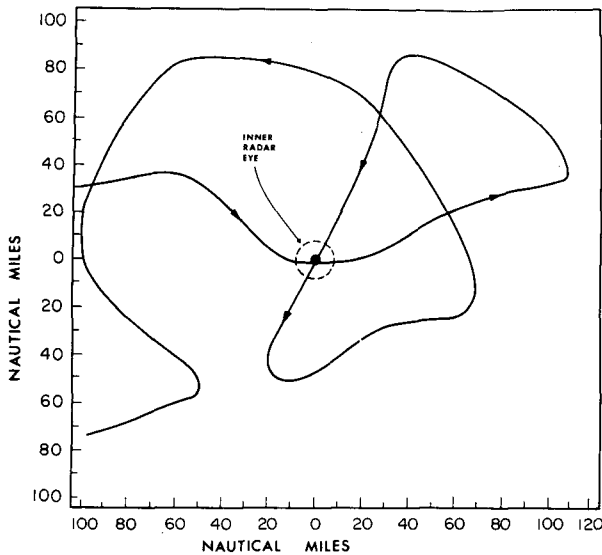


FIG. 1. Flight track flown at 250 mb into Helene on 26 September 1958 by a National Hurricane Research Laboratory B-47 aircraft.

cyclones are very intense and extreme turbulence occurs, such as with Hurricane Camille (1969). This situation can occur during critical forecast periods just prior to landfall. By contrast, jet aircraft reconnaissance accomplished in the upper troposphere encounters significantly weaker winds, generally less intensity of turbulence (if echoes are avoided), and flight missions can be conducted in half to a third of the time required for conventional propeller missions. Nearly all countries have jet aircraft that could be made available on short notice for such upper-tropospheric reconnaissance. No special crew training would be required if the flights are conducted with a few trained meteorologists who are temporarily deployed for such flights.

This paper is written to suggest the examination of a new tropical cyclone reconnaissance technique. It is particularly directed to foreign countries who do not have a tropical cyclone reconnaissance capability—countries such as Japan, Taiwan, Hong Kong, Philippines, Burma, China, Bangladesh, India, Australia, Mexico, etc.—that are affected by tropical cyclones and at the same time have national airlines but not a standby capability for low-level aircraft reconnaissance. For emergency situations caused by the approach of a tropical cyclone it is suggested that a foreign government could command one of its national jet aircraft on an emergency basis for 6–8 h to make a flight at 250 mb through the center of a threatening cyclone. A determination of the magnitude and areal extent of the approaching cyclone's upper-tropospheric temperature structure could be readily made. Previously prepared monographs and information could be available to translate this upper-level temperature information into estimates of low-level pressure and wind and the horizontal extent of the strong winds.

Only the measurement of temperature on a constant pressure surface would be made. Such measurements are routine on jet aircraft. Most commercial jet airliners have weather radar for echo avoidance, and satellite information would likely be available at the takeoff point (major national airports) for flight planning. No extra aircraft crew personnel would be required, and only one or possibly two passes through the upper cyclone would be required. The aircraft would fly at a constant pressure level and record temperature at specified intervals of 10–20 km. The execution of this flight track might be approximately as indicated in Fig. 1.

2. Determination of cyclone intensity

Tropical cyclones are warm-core systems. Their intensity is proportional to the magnitude of upper-tropospheric temperature anomaly at the cyclone's center. A cyclone's intensity might be directly determined by the measurement of this temperature anomaly. Aircraft flights between 200–300 mb—optimum level for jet aircraft flying—may likely give a very accurate measurement of the cyclone's overall intensity and damage potential.

Figures 2 and 3 portray temperature anomaly in typhoons and hurricanes as obtained from composited rawinsonde data in the Western Pacific and Western Atlantic. Note that the maximum temperature anomaly occurs in the upper troposphere and that significant

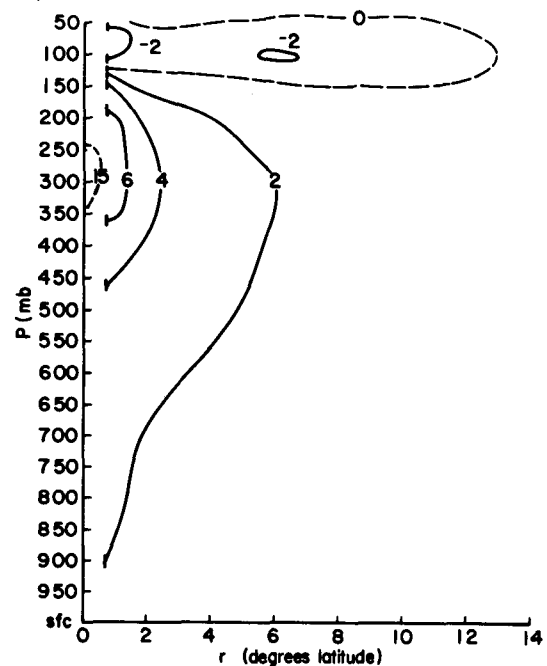


FIG. 2. Rawinsonde composited mean temperature anomaly ($^{\circ}\text{C}$) for West Pacific (from Frank, 1977). The dashed inner isotherms have been inferred from NHRL aircraft data.

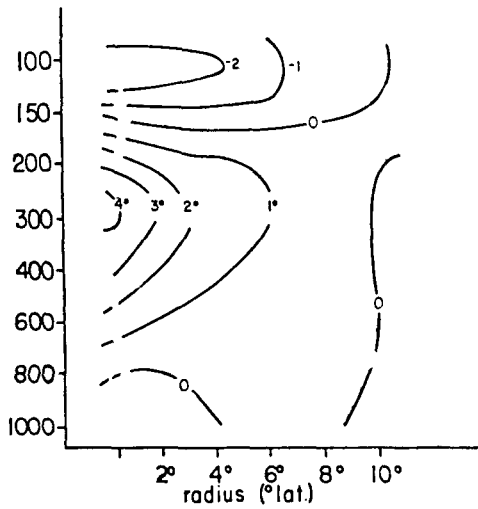


FIG. 3. Rawinsonde composited mean temperature anomaly (°C) for West Atlantic hurricanes. (From Núñez and Gray, 1977.)

temperature anomaly extends 2-4° latitude radius outward from the cyclone's center. Large positive temperature anomaly is not present in the lower layers. At inner radii these upper-tropospheric temperature anomalies can be as large as 10-15°C (Figs. 4 and 5).

Figure 6 portrays the inner-core (5-50 n mi) radial distribution of upper-tropospheric temperature anomaly from the mean summertime tropical atmosphere, which had been measured by the National Hurricane Research Laboratory upper-tropospheric research flight missions during the late 1950s and 1960s. Note the large inner-core gradient of upper-tropospheric temperature anomaly that is portrayed. Figure 7 portrays a mean inner cyclone region (0-3° latitude radius) temperature excess over the temperature at 3-7° latitude radius for five progressively more intense classes of West Pacific cyclones as determined by Arnold (1977) from composited West Pacific rawinsonde data. (Table 1 de-

TABLE 1. Five West Pacific tropical cyclone intensity classes (from Arnold, 1977).

Stage	Name	Estimated mean central pressure mb	Estimated average maximum sustained surface winds m/s (kt)
I	Developing cluster	1005	8 (15)
II	Tropical depression	1002	13 (25)
III	Tropical storm	990	26 (50)
IV	Typhoon	965	41 (80)
STY	Super-typhoon	935	59 (115)

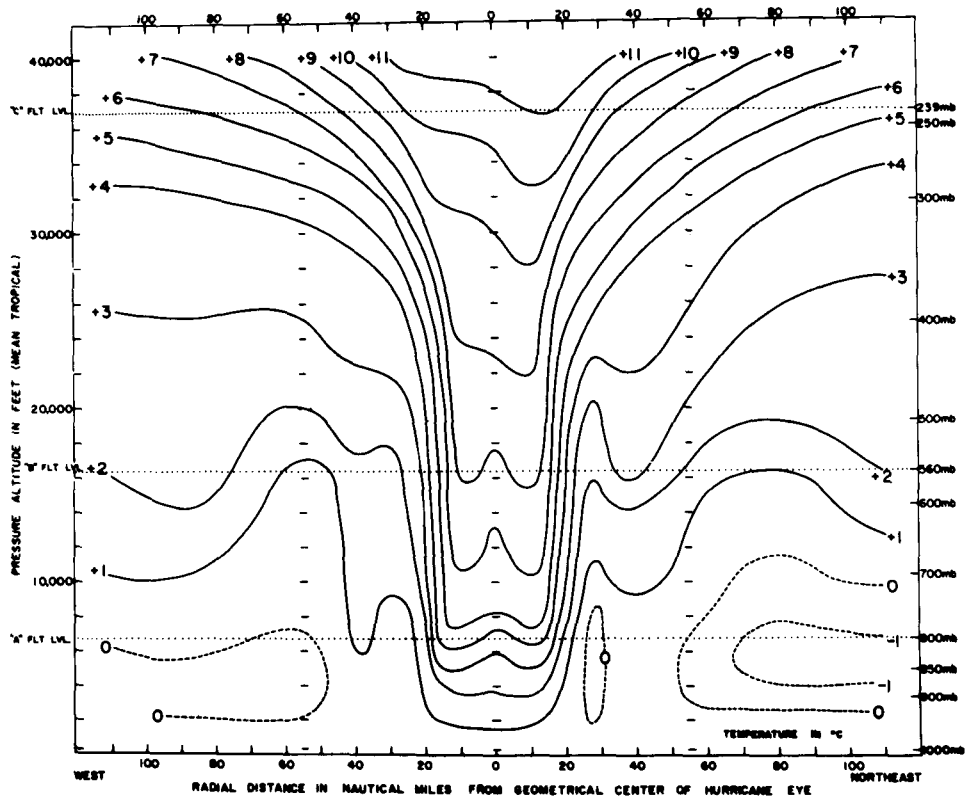


FIG. 4. Vertical cross section of temperature anomaly (°C) from mean tropical atmosphere along radial traverse of hurricane Cleo, 1958. (From LaSeur and Hawkins, 1963.)

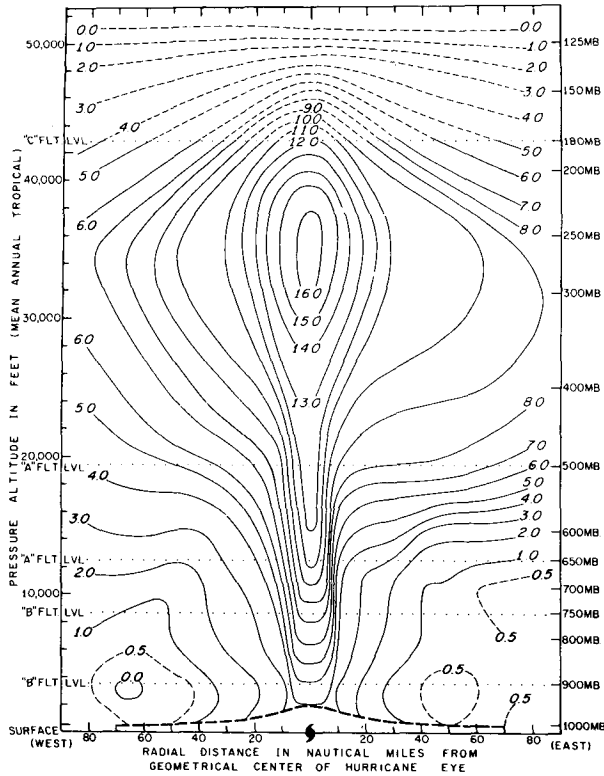


FIG. 5. Vertical cross section of temperature anomaly ($^{\circ}\text{C}$) from mean summertime tropical atmosphere for Hurricane Hilda on 1 October 1964. (From Hawkins and Rubsam, 1968.)

scribes these intensity classes.) Note the direct correlation of average upper-level temperature anomaly with intensity class.

Hydrostatic considerations dictate that surface pressure anomaly (p'_{sfc}) be very closely related to upper-tropospheric temperature anomaly (T'). Thus,

$$p'_{sfc} = K_1 T' \quad (1)$$

where K_1 is a correction coefficient that will vary with T' , pressure level, and radius. K_1 can be empirically specified from aircraft and composited rawinsonde data.

The cyclone's lower-tropospheric wind speed (V) will be related to the radial gradient of T' , radius (r), and some correction coefficient K_2 related to T' , r , pressure level, cyclone azimuth, and latitude. It can also be empirically determined. Thus,

$$V = K_2 \frac{1}{r} \frac{\partial T'}{\partial r} \quad (2)$$

Through a combination of rawinsonde and National Hurricane Research Laboratory research flight information a reliable determination of the K_1 and K_2 correction factors should be obtainable.

Figures 8 and 9 illustrate how (in a statistical sense) upper-tropospheric temperature anomaly for different West Pacific cyclone intensity groups is related to lower-tropospheric height and wind speed for the

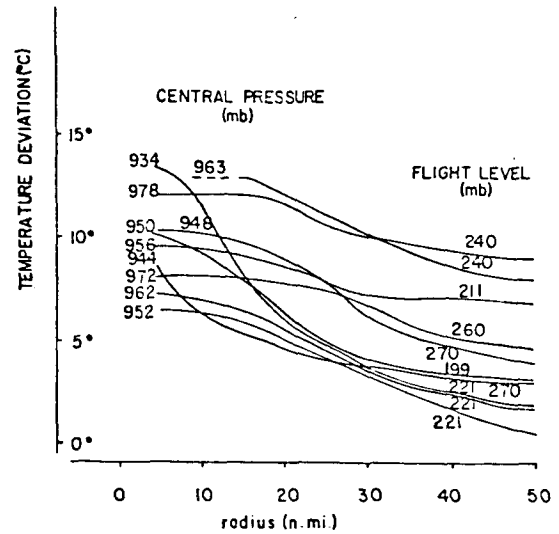


FIG. 6. Inner core upper-tropospheric temperature anomaly from the mean summertime tropical atmosphere as measured by NHRL upper-level flights (data from Gray and Shea, 1976).

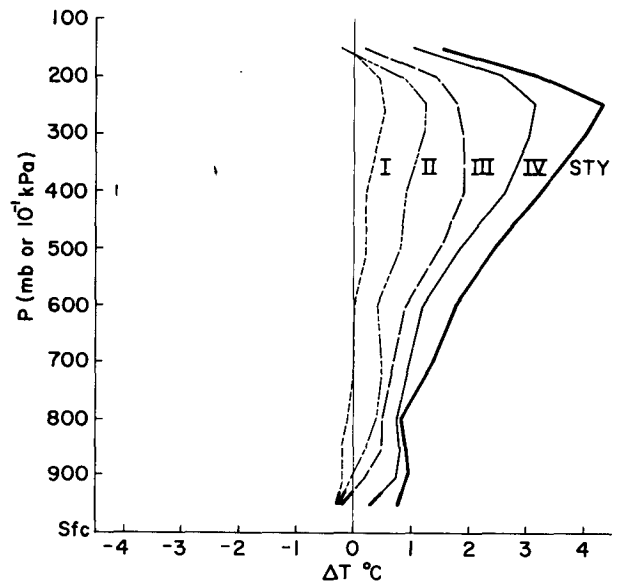


FIG. 7. Mean $0-3^{\circ}$ latitude radius mean temperature anomaly (ΔT) profiles for five progressively more intense tropical storm stages I, II, III, IV, and STY. $\Delta T = \bar{T}_{(0-3^{\circ})} - \bar{T}_{(3-7^{\circ})}$ for stages I, II, and III; $\Delta T = \bar{T}_{(0-3^{\circ})} - \bar{T}_{8^{\circ}}$ for stages IV and STY. See Table 1 for a description of these classes of cyclone intensity (from Arnold, 1977).

different intensity cyclones defined in Table 1. These are only statistical relationships and, for application in individual situations, more specific knowledge of the T' and wind relationship must be obtained. If research were focused on this subject, very useful individual case relationships could likely be obtained.

More refined evaluation of the cyclones' temperature and resulting low-level pressure-wind could be obtained

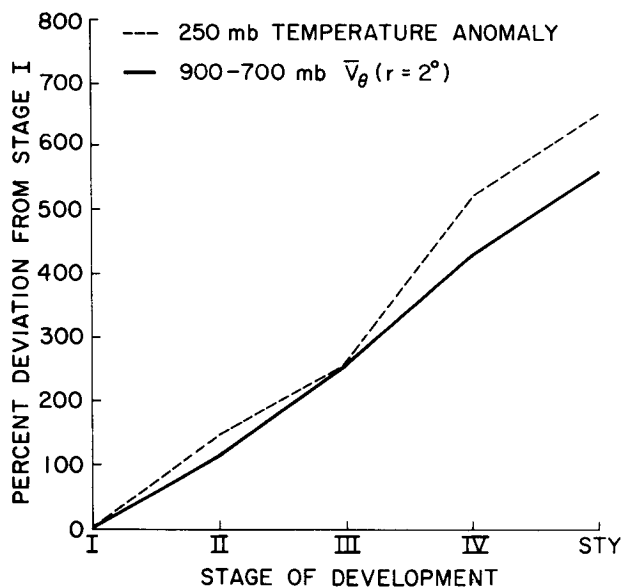


FIG. 8. The 250 mb temperature anomaly and 900-700 mb tangential wind at $r = 2^\circ$ latitude, each expressed as a percent deviation from the corresponding developing cluster (Stage I) values (from Arnold, 1977).

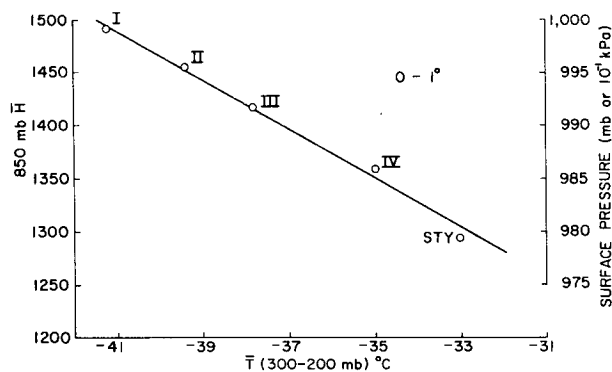


FIG. 9. The mean 300-200 mb temperature from $0-1^\circ$ latitude vs. mean 850 mb height from $0-1^\circ$ latitude (from Arnold, 1977).

if a downward pointing microwave spectrometer similar to that flown on the Nimbus VI satellite was also made a part of the jet aircraft instrument package. As discussed by Rosenkranz and Staelin (1977) and Kidder *et al.* (1978), such microwave measurements (see following discussion) allow the determination of temperature through a deep tropospheric layer and would be more reliable than measurements taken at a single level. It might be possible to temporarily install such an instrument on a jet aircraft just prior to a mission if some prior aircraft modification has been accomplished. A mean surface to 250 mb temperature determination would have a very high correlation with

surface pressure. Although highly desirable for the most accurate intensity determination, such additional instrumentation is not strictly required. Individual level values may prove to be quite sufficient.

3. Satellite determination of upper-troposphere temperature

A similar approach to tropical cyclone intensity determination has been proposed by Rosenkranz and Staelin (1977) and Kidder *et al.* (1978). They suggest using satellite measurements of the cyclone's upper-tropospheric temperature to infer its strength. Research accomplished so far using Nimbus VI Scanning Microwave Spectrometer (SCAMS) satellite data appears promising. Kidder (1979) has recently analyzed temperature data over tropical cyclones retrieved with the SCAMS on Nimbus VI. The SCAMS has a field of view or spatial resolution of approximately a 145 km diameter circle. Temperature values are considerably smoothed. Even allowing for such large smoothing, Kidder has observed SCAMS 250-100 mb determined temperature differences between storm and environment as large as $4-5^\circ\text{C}$. He has also observed that the anomaly increases as the storm intensifies from a cluster to a typhoon. The future potential for cyclone monitoring from this type of measurement (if increased horizontal and vertical satellite sensor resolution can be obtained) appears promising. This is an encouraging avenue to gain increased knowledge of tropical cyclone intensity. It is especially relevant because there appears to be a limit to cyclone intensity knowledge that may be obtained from further and more refined analysis of satellite cloud configurations.

4. Summary

It is suggested that consideration be given by foreign governments and the United States to tropical cyclone intensity determinations from jet aircraft. Measurements of the cyclone's upper-tropospheric temperature anomaly and horizontal configuration may prove as reliable a measure of the cyclone's intensity as low-level propeller aircraft reconnaissance. Such measurements would likely be a more reliable source of cyclone intensity than that of satellite-observed cloud configuration and quite desirable to have when cyclones approach populated areas.

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Directory for natural hazards films

A *Directory of Sources for Films and Other Visual Materials on Natural Hazards and Their Mitigation*, by David Morton, has been made available from the Natural Hazards Research and Applications Information Center, University of Colorado. The *Directory* lists sources for the production and distribution of films, filmstrips, and other visual materials, with complete information on how they may be obtained. Citations include a brief description of the materials. The *Directory* lists a number of sources, such as NOAA, NASA, and NWS, for films on varied aspects of weather related hazards, including floods, hurricanes, tornadoes, extreme winds, and drought. The *Directory* is available for \$1.00 from: Natural Hazards Research and Applications Information Center, Institute of Behavioral Science #6, University of Colorado, Campus Box 482, Boulder Colo. 80309 (tel.: 303-492-6818).

NWS tornado film and slide series

The NWS Disaster Preparedness Staff, in cooperation with the Defense Civil Preparedness Agency, has prepared a shortened version of the 16 mm, color, sound film, *Day of the Killer Tornadoes*. This 14½ min version is comprised of footage of the actual tornadoes that hit 11 states, killed 307 people, and contained 147 twisters on 3-4 April 1974. It illustrates how the warnings, preparedness planning, and coordination of Emergency Operating Centers were effective in saving lives. The film is available from the NOAA film library at: Motion Picture Service, NOAA, 12231 Wilkens Ave., Rockville, Md. 20852.

The Disaster Preparedness Staff will also distribute a new slide series, *Tornado Safety in Residences*, prepared by James

Abernethy of the Lawrence Institute of Technology. The series costs \$36 and includes 130 slides, a 33 min cassette tape, and a commentary. This lecture depicts the effects of tornadoes on residential structures by excessive winds, missile damage, and building displacement. It identifies the safest locations in many types of residences, including mobile homes. It can be obtained from: National Audiovisual Center, Order Section, GSA, Washington, D.C. 20409. Refer to order # A00796.

Information about other disaster preparedness publications and audiovisuals can be obtained from: NWS Disaster Preparedness Staff (OA/Wx5), 8060 13th St., Silver Spring, Md. 20910.

Deadlines Calendar

Fellowships, grants, etc.

15 July 1980 **Macelwane Annual Award**
(this issue, p. 1128)

15 July 1980 **Hanks and Orville Scholarships**
(this issue, p. 1128)

Call for papers—Abstracts due

30 September 1979 **Symposium on atmospheric pollution**
(June 1979 BULLETIN, p. 661)

Call for nominations

31 December 1979 **Alan T. Waterman Award**
(August 1979 BULLETIN, p. 979) ●