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STUDIES OF EXTRATROPICAL CYCLONIC STORMS (THE CYCLES PROJECT).(U)
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The organization of mesoscale rainbands with respect to synoptic fronts in extratropical cyclones is described. Airflow patterns, microphysical structures and precipitation producing mechanisms in various rainbands have been documented.

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FINAL TECHNICAL REPORT FOR AFOSR CONTRACT F49620-77-C-0057

STUDIES OF EXTRATROPICAL CYCLONIC STORMS (THE CYCLES PROJECT)

1. Research Objectives

The principal objectives of the CYCLES PROJECT during the past three years have been to explore the mesostructures and microstructures of extratropical cyclonic storms and the mechanisms responsible for the formation and organization of clouds and precipitation in these large storm systems.

Field studies have been caried out over and just off the Pacific Coast of Washington State using combined radar, airborne and ground observations and measurements.

2. Status of Research Effort*

The principal findings of the CYCLES PROJECT may be summarized as follows†:

- The heaviest precipitation in cyclonic storms is organized on the large mesoscale into rainbands.[6,10,11,12] CYCLES data show that the rainbands can be classified into six distinct types: warm-frontal, warm-sector, narrow cold-frontal, wide cold-frontal, post-frontal and wave-like. The motions of the rainbands, with respect to the synoptic-scale features, have been established. For example, the wide cold-frontal rainbands move with the winds in the vicinity of 600 mb and therefore move faster than the surface cold front. The narrow cold-frontal rainband, on the other hand, moves with the surface cold front.

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* For full details of results obtained to date in the CYCLES PROJECT the reader is referred to the publications listed in §3.

† Superscript numbers refer to CYCLES publications listed in §3(a).

- Stream flow and convergence patterns in several of the different types of rainbands have been deduced from Doppler radar measurements.[10,11,12] For example, narrow cold-frontal rainbands are associated with strong updrafts (~5 km wide) that originate in a region of strong convergence in the boundary layer. Warm-frontal rainbands associated with a "feeder-seeder" mechanism in which ice crystals from upper-level clouds seed and scavenge water that has condensed in a lower-level "feeder" cloud.

- Using values of condensation rates (derived from the Doppler windflow measurements) and precipitation rates, the precipitation efficiencies of several different types of rainbands have been deduced. For example, in one case study the precipitation efficiencies of warm-sector, wide cold-frontal and narrow cold-frontal rainbands have been found to be ~45%, ~80% and ~40%, respectively.[11]

- The heaviest precipitation within the rainbands is comprised, on the small mesoscale, of numerous precipitation cores that occupy areas ranging from ~10% - 100 km^2. Precipitation cores have lifetimes of up to 1 hr; they are themselves composed of cells[5].

- In the case of warm-frontal (and probably wide cold-frontal) rainbands, the precipitation cores originate in generating cells aloft.[5,10,11,12]

- The precipitation cores in narrow cold-frontal rainbands are elliptical in shape and are oriented at such an angle to the cold front that the convergence of warm, moist air in the boundary layer into the cores is maximized.[8] This finding, which is completely different from the old view which pictured cold fronts as consisting of continuous lines of convection, has important practical implications. For example, the characteristics associated with the passage of a cold front (a sharp drop in temperature, windshift, pressure check) are only experienced when a precipitation core passes over a station, otherwise, the changes are much more gradual.

- The microphysical characteristics of several regions of cyclonic storms have been documented through airborne measurements.[5,6,10,11,12,15] Clouds within the warm-frontal rainbands contain high ($\sim 10\ \ell^{-1}$) ice particle concentrations, whereas, the regions between them do not. This is due to the fact that these rainbands are fed by particles from upper-level generating cells. Those rainbands that originate in strong updrafts from the boundary layer (e.g. young warm-sector and narrow cold-frontal rainbands) contain relatively high levels of supercooled water and few ice particles. Wide cold-frontal rainbands contain a mixture of supercooled water and ice.

- In those rainbands in which a "seeder-feeder" mechanism operates, the precipitation efficiencies approach 100%, whereas, those rainbands fed by strong boundary-layer flow have precipitation efficiencies of ~50%.[11]

- Airborne measurements have shown that the precipitation particles in the rainbands associated with cyclonic storms tend to follow an exponential size distribution and that the particle-size distribution parameters vary in a systematic manner with temperature.[9] This result may be important in making tractable the detailed modeling of precipitation particles in frontal systems.

  The extent to which the particle-size distributions deviate from an exponential distribution can provide information on particle-growth mechanisms in the rainbands.

- The use and development of modern systems and techniques for acquiring measurements and making them available in real-time for decision-making have contributed greatly to the success of the CYCLES PROJECT. For example, the demonstration that color-display Doppler radar data can, through simple pattern recognition schemes, provide real-time information on mesoscale features (e.g. warm- and cold-air advection, jets, fronts, etc.) was first achieved in the CYCLES PROJECT.[3,7] Techniques have also been developed for obtaining information on particle types and growth mechanisms in clouds from a vertically-pointing Doppler radar.[1,7] The utility of simultaneous measurements in the X-band (3.2-cm wavelength) and K_a-band (0.85-cm wavelength) radars in revealing both clouds and precipitation in cyclones has also been demonstrated.[13]

3. PUBLICATIONS AND THESES (1977-80)

(a) Refereed Scientific Journals

1) "Deduction of Ice Particle Types in the Vicinity of the Melting Layer from Doppler Radar Measurements." R. R. Weiss, J. D. Locatelli and P. V. Hobbs, J. Appl. Met., 16, 314-316, 1977.

2) "A Theoretical Study of the Evolution of Mixed Phase Cumulus Clouds." B. C.Scott and P.V. Hobbs, J. Atmos. Sci., 34, 812-826.

3) "Real-Time Wind Measurement in Extratropical Cyclones by Means of Doppler Radar." H. W. Baynton, R. J. Serafin, C. L. Frush, G. R. Gray, P. V. Hobbs, R. A. Houze, Jr., and J. D. Locatelli, J. Appl. Meteor., 16, 1022-1028, 1977.

4) "Natural Cloud Seeding with Accompanying Release of Precipitation." L. F. Radke and P. H. Herzegh, Beit. Physic. Atmos., 50, 448-495, 1977.

5) "Rainbands, Precipitation Cores and Generating Cells in a Cyclonic Storm." P. V. Hobbs and J. D. Locatelli, J. Atmos. Sci., 35, 230-241, 1978.

6) "Organization and Structure of Clouds and Precipitation on the Mesoscale and Microscale in Cyclonic Storms." P. V. Hobbs, Review of Geophysics and Space Physics, 16, 741-775, 1978.

7) "A Technique for Obtaining Detailed Wind Fields in a Frontal System from a Single-Doppler Radar." J. D. Locatelli and P. V. Hobbs, J. Appl. Meteor., 17, 1076-1079, 1978.

8) "The Cellular Structure of Narrow Cold-Frontal Rainbands." P. V. Hobbs and K. R. Biswas, Quart. J. Roy. Meteor. Soc., 105, 723-727, 1979.

9) "Size Distribution of Precipitation Particles in Frontal Clouds." R. A. Houze, Jr., P. V. Hobbs, P. H. Herzegh and D. B. Parsons, J. Atmos. Sci., 36, 156-162, 1979.

10) "Microphysics and Dynamics of Clouds Associated with Mesoscale Rainbands in Extratropical Cyclones." T. J. Matejka, R. A. Houze, Jr., and P.V.Hobbs, Quart. J. Roy. Meteor. Soc., 106, 29-56, 1980.

11) "The Mesoscale and Microscale Structure and Organization of Clouds and Precipitation in Mid-Latitude Cyclones, I: A Case Study of a Cold Front." P. V. Hobbs, T. J. Matejka, P. H. Herzegh, J. D. Locatelli, and R. A. Houze, Jr., J. Atmos. Sci., 37, 568-596, 1980.

12) "The Mesoscale and Microscale Structure and Organization of Clouds and precipitation in Mid-Latitude Cyclones, II: Warm Fronts." P. H. Herzegh and P. V. Hobbs, J. Atmos. Sci., 37, 597-611, 1980.

13) "Simultaneous Observations of Cloud and Precipitation Particles with Vertically-Pointing X- and K_a-Band Radars." R. R. Weiss, Sr., J. D. Locatelli and P. V. Hobbs, IEEE Trans. on Geoscience Elecronics, (special issue on Radio Meteorology), G-17, 151-153, 1979.

14) "Reply to 'Comments on Size Distribtutions of Precipitation Particles in Frontal Clouds'." J. Atmos. Sci., 37, 697-700, 1980.

15) "The Mesoscale and Microscale Structure and Organization of Clouds and Precipitation in Mid-Latitude Cyclones, III. Air Motions and Precipitation growth in a Warm-Frontal Rainband." R. A. Houze, Jr., S. A. Rutledge, T. T. Majetka and P.V. Hobbs. J. Atmos. Sci. (in press).

4. List of Professional Personnel Associated with Research Effort

(a) Teaching Faculty
Prof. Peter V. Hobbs
Prof. Robert A. Houze, Jr.

(b) Research Faculty
Dr. Lawrence F. Radke
Dr. Richard W. Weiss, Sr.
Mr. John D. Locatelli

(c) Graduate Students and Degrees

1)	Thomas J. Matejka:	"Mesoscale Organization of Cloud Processes in Extratropical Cyclones." (Ph.D-1980)
2)	Paul H. Herzegh:	"Studies of Stratiform Cloud Systems Associated with Cyclonic Storms" (Ph.D. Thesis being written).
3)	David Parsons:	Ph.D. thesis in progress (concerned with orograhic effects).
4)	Steven A. Rutledge:	Ph. D thesis in progress (concerned with modeling studies).
5)	Ola Persson:	"The Structure of Some Small Mesoscale Features in Cyclonic Storms" (M.S.-1980).
6)	Melanie Kruidenier:	"Mesoscale Organization of a Stratiform Cloud System Observed in Satellite Imagery" (M.S.-1980)

5. Interactions

(a) Presentations at Conferences

1) "Doppler Radar Measurements of the Airflow within a Mesoscale Cold-Frontal Band.:" T. J. Matejka and R. A. Houze, Jr., Preprints 18th Radar Meteorology Conf., Atlanta, GA 17-2, 1978.

2) "Air Motions and Precipitation Growth in a Mesoscale Precipitation Band Associated with a Warm front." P. H. Herzegh and P.V. Hobbs, loc. cit., 23-28.

3) "The University of Washington's CYCLES PROJECT: An Overview." P. V. Hobbs, Preprint Volume AMS Conf. on Cloud Physics and Atmospheric Electricity, Issaquah, WA, 271-276, 1978.

4) "Air Motions, Mesoscale Structure and Cloud Microphysics Associated with a Cold Front." P. V. Hobbs, J. D. Locatelli, T.J. Matejka and R. A. Houze, Jr., loc. cit., 277-283.

5) "Generating Cells and Precipitation Growth in Mesoscale Rainbands." P. H. Herzegh and P. V. Hobbs, loc. cit., 284-291.

6) "Microphysical and Dynamical Structure of Mesoscale Cloud Features in Extratropical Cyclones." T. J. Matejka, R. A. Houze, Jr., and P. V. Hobbs, loc. cit., 292-299.

7) "Airborne Measurements of the Size Distributions of Precipitation Particles in Frontal Clouds." R. A. Houze, Jr., P. V. Hobbs, P. H. Herzegh and D. B. Parsons, loc. cit., 169-172.

8) "Doppler Radar Study of a Warm-Frontal Rainband." R. A. Houze, Jr., S. A. Rutledge, T. J. Matejka and P. V. Hobbs. 19th AMS Conf. on Radar Meteorology, April 1980, Miami, FL.

9) "Observed Structures of Atmospheric Precipitation Systems - A Global View." R. A. Houze, Jr. Int'l Symposium on Effects of the Lower Atmosphere on Radio Propagation at Frequencies above 1 GHz, Lennoxville, Quebec, Canada, May 1980.

10) "Observations of Snow Size Distributions in Frontal Clouds: Deviations from the Marshall-Palmer Form." P. H. Herzegh and P. V. Hobbs, Int'l Conf. on Cloud Physics, Clermont-Ferrand, France, July 1980.

11) "The Mesostructure and Microstructure of Extratropical Cyclones." P. V. Hobbs, loc. cit.

12) "Precipitation Efficiencies and the Potential for Artificially Modifying extratropical Cyclones." P. V. Hobbs. WMO Weather Modification Conference, Clermont-Ferrand, France, July 1980 (Invited Paper).

(b) Presentations at Colloquia

1) AMS Workshop on Mesoscale Interactions with Cloud Processes, NCAR, October 24-25, 1977 - P.V. Hobbs (Talk).

2) Atmospheric Sciences Dept., University of Washington, Seattle, WA, March 9, 1978 - by P. V.Hobbs (Dept. Colloquium).

3) Workshop on Limited Area Mesoscale Prediction System, NCAR, May 3, 1978 - by P. V. Hobbs (Talk).

4) Air Force Geophysical Laboratories, Hanscombe Field, MA, September 28, 1978 - by P. V. Hobbs (Dept. Colloquium).

5) Meteorolgoy Dept., Pennsylvania State University, State Park, PA, September 28, 1978 - by P. V. Hobbs (Dept. Colloquium).

6) Atmospheric Sciences Dept., University of Wyoming, Laramie, WY, November 6, 1978 - by P. V. Hobbs (Dept. Colloquium).

7) NOAA's Goephysical Fluid Dynamics Laboratory, Princeton, September 24, 1979 - by P. V. Hobbs (GFDL Colloquium Series).

8) Meteorology Dept., University of Maryland, September 28, 1979 - by P. V. Hobbs (Dept. Colloquium).

9) Minisymposium on Mesoscale Phenomena and their Interactions, September 29 - October 1, 1980, GFDL/NOAA, Princeton, N. Y. - two talks by P.V. Hobbs.

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