NOAA Technical Memorandum NWS WR-110

COOL INFLOW AS A WEAKENING INFLUENCE ON EASTERN PACIFIC TROPICAL CYCLONES

William J. Denney
Weather Service Forecast Office
Redwood City, California

December 1976

UNITED STATES
DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary /

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator /

NATIONAL WEATHER
SERVICE
George P. Cressman, Director

CONTENTS

COOL INFLOW AS A WEAKENING INFLUENCE ON EASTERN PACIFIC TROPICAL CYCLONES

William J. Denney
Weather Service Forecast Office, National Weather Service
Western Region, NOAA, Redwood City, California

ABSTRACT. Relevant research reports are reviewed briefly. They are the basis for concluding that the possibility of cool inflow should be considered regularly in making Eastern Pacific hurricane intensity forecasts. Greater inflow into the right side of a moving storm has special significance for Eastern Pacific hurricane intensity changes. The areal extent of the storm's circulation is another important factor in determining the amount of cool inflow. Satellite pictures reveal much about the volume of air rising in a hurricane's central chimney and, therefore, of the cyclone's intensity. Further application of satellite information and a computer program could be the way to improved intensity forecasts.

I. THESIS

Forecasters dealing with Eastern Pacific hurricanes have long been faced with an apparent difference of opinion as to the importance of inflow of cool air as a dissipating influence. At the National Weather Service (NWS) Eastern Pacific Hurricane Center, the problem has traditionally been dealt with in a qualitative way using trajectory techniques to anticipate weakening and satellite pictures or other indications of current intensity for confirmation and comparison. This approach was first questioned on the record by Sadler (1963), who concluded, incidental to a Television Infrared Observation Satellite (TIROS) study of 1962 hurricanes, that the outer storm circulation usually acts as a barrier keeping cold air to the north from entering directly into the inner storm circulation.

Sadler's conclusion was discounted by forecasters as contrary to the equations of motion, which require friction-induced cross-isobar flow with streamlines toward lower pressure in the inflow layer. Also, later high-resolution satellite pictures seemed to explain Sadler's observation as having originated from a breaking up of trade-wind stratocumulus when approached by the hurricane. This breakup was a result of turbulence from stronger low-level winds, heating from below and vertical stretching of the cool layer as this air moved along a cyclonic trajectory into the hurricane circulation.

Operational application of the weakening effect due to cool air inflow continued into the 1970s (Denney 1969, 1971, 1972), with seeming support from indications of satellite pictures and from data received from air-reconnaissance flights. However, Hansen (1972) disputed claims as to the importance of cool inflow. He stated that dissipation from the effects of cold water would be limited to contact of the cyclone's circulation (radius about 100 n.m.) with water as cold as 77.5° F. (25.3° C.). Hansen's paper is self-contradictory, however, in that it later says in listing evidences of dissipation: "Cyclonic deformation of the stratocumulus cloud bank north of the storm indicates incorporation of cooler air from below the inversion level north of the cyclone into the peripheral cyclone circulation". Hansen's principal objection to the importance of cool inflow was that the response of the atmosphere to a warmer sea is quite rapid, so one would expect air that had traveled more than 200 miles south of the 80° F. isotherm to be capable of sustaining any ongoing intensity of a hurricane, whatever initial properties of the air may have been, or however direct to the center the trajectory might be.

It is theoretically possible to formulate an equation giving the modification of air along a trajectory into a hurricane; unfortunately, no such equation or other objective approach to the problem is available to the forecaster just now. There is substantial expert opinion supporting the concept of cool inflow as a hurricane dissipating influence (Riehl 1954, p. 339), (Simpson 1971). Also it has been shown that equivalent potential temperature (θ_E) determines the minimum pressure possible in the rain area of a tropical cyclone. No lower than 1000 mb seems possible from normal tropical air (θ_E about 350° A) which reaches the base of the eye wall (Malkus and Riehl 1959). From the same hydrostatic considerations, for each degree the inflow air is warmer or cooler than normal, a 2.5 mb lower or higher possible pressure results.

Two statistical studies of the components of motion in hurricanes (Hughes 1952 and Miller 1959) revealed the radial component of low-level motion toward the center much greater on the right side than on the left. Those results were not related to the speed of the cyclone. Malkin and Myers (1961) did relate the imbalance of inflow to the speed of the cyclone center through wind fields simulated by a trajectory technique and found a direct relationship. Their simulated hurricane moving 30 mph had radial motion inward at 75 mph from the right rear quadrant 25 miles out, while on the left front quadrant at the same distance there was outflow at 25 mph.

Snellman (1962) applied low-level (2000-ft) trajectories in relating the speed of hurricanes Diane of 1955 and Carol of 1954 to weakening produced by entry of relatively cool air from the U. S. land mass to the left of their tracks. Diane's relatively slow movement allowed penetration of the cool air and dissipation followed. Carol moved rapidly north-northeast to Long Island and New England as a disastrous hurricane, with the rapid movement precluding entry of cool air into the hurricane's circulation.

II. CONCLUSIONS

The possibility of cool inflow should be considered regularly when making forecasts of intensity of tropical cyclones in the Eastern Pacific. Evaluation of the problem will be difficult in many instances because the forecaster will have much less than full knowledge of the distribution of sea-surface temperatures and of distribution of atmospheric winds, moisture, and temperature. Also, the complex relationships involved in modification of the inflow moving over progressively warmer water, with downward mixing of dry air a factor in some cases, could be handled by a computer program.

Lack of information or a technique for direct application of the cool inflow concept does not preclude use of the idea. An attempt should be made to recognize onset of cool inflow possibilities at any stage of the 72-hour period regularly covered in the forecasts, and to take account of them in the forecast intensities. Ship routing is usually done on the basis of the 48- and 72-hour forecast positions and intensities; thus if forecast winds are routinely too high in certain areas, the forecasts will come to be disregarded.

The greater flow from the right side to the center in a cyclone circulation is one reason why, on a climatological basis, westward-moving Eastern Pacific tropical cyclones tend to weaken shortly after they pass the longitude of Cape San Lucas, Baja California (110°W.), since cooler sea-surface temperatures exist to the right of the storm. It is also a reason why recurring cyclones in the same area are less likely to weaken as they move rapidly northeast toward Mexico since, climatologically, warmer sea-surface temperatures exist to the right of the storm center. Further, west-northwestward moving cyclones are typically impinging on the periphery of a subtropical high-pressure cell to the north with its low-level cool outflow at the same time that increasing distance from the ITCZ is reducing equatorial inflow.

Size of a tropical cyclone is a factor affecting inflow. The large cyclone draws in low-level air from great distances, and thereby can take in cool air from areas that a smaller one could not reach. Thus, the normal growth with maturity is a self-limiting feature for many Eastern Pacific cyclones, leading to their weakening and dissipation. It contributes to the average smaller size of cyclones in the area (Hansen 1972), although all factors that reduce average cyclone life span also contribute.

Satellite pictures are a means of indirect analysis of properties of inflow to a hurricane, and can be even more useful than a direct analysis. For example, the cessation of cirrus production by the central chimney of a hurricane as revealed by satellite pictures may be a clear indication that the equivalent potential temperature of inflow air reaching the base of the eye-wall is so low that the inflow will no longer rise to the cirrus level despite continuing low-level convergence. In such a situation eye-wall conversion of latent heat to kinetic energy has been almost totally disrupted, and low-level convergence is building a surface stable layer of increasing depth under the central area of the cyclone. Obviously, central pressure is increasing rapidly, and eye-wall winds have already decreased considerably because of loss of the source of kinetic energy together with accumulation of relatively dense low-level air under the eye-wall. Rapid dissipation normally continues. Other less-dramatic information is regularly apparent and should be put to full use. For example, techniques for determining cloud temperatures and movements could be given wider application, as could lapse rates determined through satellite sensors such as VTPR.

All forecasters dealing with Eastern Pacific tropical cyclones would benefit from careful study of each item of literature cited, developing insights into processes of energy exchange and knowledge of typical cyclone behavior. Such insights and knowledge might be a basis for more accurate analyses and forecasts of tropical cyclones.

III. REFERENCES

Denney, William J., 1969: Eastern Pacific Hurricane Season of 1968. Monthly Weather Review, Vol. 97, No. 3, 207-224.

Denney, William J., 1971: Eastern Pacific Hurricane Season of 1970. Monthly Weather Review, Vol. 99, No. 4, 286-301.

Denney, William J., 1972: Eastern Pacific Hurricane Season of 1971. Monthly Weather Review, Vol. 100, No. 4, 276-293.

Hansen, Herbert Loye, 1972: The Climatology and Nature of Tropical Cyclones of the Eastern North Pacific Ocean. Master's Thesis, Naval Postgraduate School, Monterey, California, 174 pp.

Hughes, L. A., 1952: On the Low-Level Wind Structure of Tropical Storms. Journal of Meteorology, Vol. 9, No. 6, 442-428.

Malkus, J. S., and Riehl, R., 1959: On the Dynamics and Energy Transformations in Steady-State Hurricanes. National Hurricane Research Project Report No. 31, U. S. Department of Commerce, Weather Bureau, 31 pp.

Miller, Banner I., 1958: The Three-Dimensional Wind Structure Around a Tropical Cyclone. National Hurricane Research Project Report No. 15, U. S. Department of Commerce, Weather Bureau, 41 pp.

Myers, Vance A., and Malkin, William, 1961: Some Properties of Hurricane Wind Fields as Deduced from Trajectories. National Hurricane Research Project Report No. 49, U. S. Department of Commerce, Weather Bureau, 45 pp.

Riehl, Herbert, 1954: Tropical Meteorology. McGraw-Hill Book Company, Inc., New York, 281-357.

Sadler, J. C., 1963: Tropical Cyclones of the Eastern North Pacific as Revealed by TIROS Observations. Scientific Report No. 4, Meteorology Division, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, 39 pp.

Simpson, R. H., 1971: The Decision Process in Hurricane Forecasting. NOAA Technical Memorandum NWS SR 53, U. S. Department of Commerce, National Weather Service, Southern Region Headquarters, Fort Worth, Texas, 35 pp.

Snellman, Leonard W., 1962: On the Relationship Between Intensity and Speed of Hurricanes after Recurvature. Proceedings of the Second Technical Conference on Hurricanes, June 27-30, 1961, Miami Beach, Florida. National Hurricane Research Project Report No. 50, U. S. Department of Commerce, Weather Bureau, 27-33.

Western Region Technical Memoranda: (Continued)

No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis, January 1970. (Out of print.) (PB-189434)

No. 45/3 Precipitation Probabilities in the Western Region Associated with Summer 500-mb Map Types. Richard P. Augulis, January 1970. (Out of print.) (PB-189414)

No. 45/4 Precipitation Probabilities in the Western Region Associated with Fall 500-mb Map Types. Richard P. Augulis, January 1970. (Out of print.) (PB-189435)

No. 46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates, December 1969. (PB-190476)

No. 47 Statistical Analysis as a Flood Routing Tool. Robert J. C. Burnash, December 1969. (PB-188744)

No. 48 Tsunami. Richard P. Augulis, February 1970. (PB-190157)

No. 49 Predicting Precipitation Type. Robert J. C. Burnash and Floyd E. Hug, March 1970. (PB-190962)

No. 50 Statistical Report on Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona, 1969. Wayne S. Johnson, April 1970. (PB-191743)

No. 51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell, July 1970. (PB-193102)

No. 52 Sacramento Weather Radar Climatology. R. G. Pappas and C. M. Veliquette, July 1970. (PB-193347)

No. 53 Experimental Air Quality Forecasts in the Sacramento Valley. Norman S. Benes, August 1970. (Out of print.) (PB-194128)

No. 54 A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation. Barry B. Aronovitch, August 1970.

No. 55 Application of the SSARR Model to a Basin Without Discharge Record. Vail Schermerhorn and Donald W. Kuehl, August 1970. (PB-194394)

No. 56 Areal Coverage of Precipitation in Northwestern Utah. Philip Williams, Jr., and Werner J. Heck, September 1970. (PB-194389)

No. 57 Preliminary Report on Agricultural Field Burning vs. Atmospheric Visibility in the Willamette Valley of Oregon. Earl M. Bates and David O. Chilcote, September 1970. (PB-194710)

No. 58 Air Pollution by Jet Aircraft at Seattle-Tacoma Airport. Wallace R. Donaldson, October 1970. (COM-71-00017)

No. 59 Application of P.E. Model Forecast Parameters to Local-Area Forecasting. Leonard W. Snellman, October 1970. (COM-71-00016)

NOAA Technical Memoranda NWS

No. 60 An Aid for Forecasting the Minimum Temperature at Medford, Oregon. Arthur W. Fritz, October 1970. (COM-71-00120)

No. 61 Relationship of Wind Velocity and Stability to SO_2 Concentrations at Salt Lake City, Utah. Werner J. Heck, January 1971. (COM-71-00232)

No. 62 Forecasting the Catalina Eddy. Arthur L. Eichelberger, February 1971. (COM-71-00223)

No. 63 700-mb Warm Air Advection as a Forecasting Tool for Montana and Northern Idaho. Norris E. Woerner, February 1971. (COM-71-00349)

No. 64 Wind and Weather Regimes at Great Falls, Montana. Warren B. Price, March 1971.

No. 65 Climate of Sacramento, California. Wilbur E. Figgins, June 1971. (COM-71-00764)

No. 66 A Preliminary Report on Correlation of ARTCC Radar Echoes and Precipitation. Wilbur K. Hall, June 1971. (COM-71-00829)

No. 67 Precipitation Detection Probabilities by Los Angeles ARTC Radars. Dennis E. Ronne, July 1971. (Out of print.) (COM-71-00925)

No. 68 A Survey of Marine Weather Requirements. Herbert P. Benner, July 1971. (Out of print.) (COM-71-00889)

No. 69 National Weather Service Support to Soaring Activities. Ellis Burton, August 1971. (Out of print.) (COM-71-00956)

No. 70 Predicting Inversion Depths and Temperature Influences in the Helena Valley. David E. Olsen, October 1971. (Out of print.) (COM-71-01037)

No. 71 Western Region Synoptic Analysis-Problems and Methods. Philip Williams, Jr., February 1972. (COM-72-10433)

No. 72 A Paradox Principle in the Prediction of Precipitation Type. Thomas J. Weitz, February 1972. (Out of print.) (COM-72-10432)

No. 73 A Synoptic Climatology for Snowstorms in Northwestern Nevada. Bert L. Nelson, Paul M. Fransioli, and Clarence M. Sakamoto, February 1972. (Out of print.) (COM-72-10338)

No. 74 Thunderstorms and Hail Days Probabilities in Nevada. Clarence M. Sakamoto, April 1972. (COM-72-10554)

No. 75 A Study of the Low Level Jet Stream of the San Joaquin Valley. Ronald A. Willis and Philip Williams, Jr., May 1972. (COM-72-10707)

No. 76 Monthly Climatological Charts of the Behavior of Fog and Low Stratus at Los Angeles International Airport. Donald M. Gales, July 1972. (COM-72-11140)

No. 77 A Study of Radar Echo Distribution in Arizona During July and August. John E. Hales, Jr., July 1972. (COM-72-11136)

No. 78 Forecasting Precipitation at Bakersfield, California, Using Pressure Gradient Vectors. Earl T. Riddiough, July 1972. (COM-72-11146)

No. 79 Climate of Stockton, California. Robert C. Nelson, July 1972. (COM-72-10920)

No. 80 Estimation of Number of Days Above or Below Selected Temperatures. Clarence M. Sakamoto, October 1972. (COM-72-10021)

No. 81 An Aid for Forecasting Summer Maximum Temperatures at Seattle, Washington. Edgar G. Johnson, November 1972. (COM-73-10150)

No. 82 Flash Flood Forecasting and Warning Program in the Western Region. Philip Williams, Jr., Chester L. Glenn, and Roland L. Raetz, December 1972. (COM-73-10251)

No. 83 A Comparison of Manual and Semiautomatic Methods of Digitizing Analog Wind Records. Glenn E. Rasch, March 1973. (COM-73-10669)

No. 84 Southwestern United States Summer Monsoon Source--Gulf of Mexico or Pacific Ocean? John E. Hales, Jr., March 1973. (COM-73-10769)

No. 85 Range of Radar Detection Associated with Precipitation Echoes of Given Heights by the WSR-57 at Missoula, Montana. Raymond Granger, April 1973. (COM-73-11030)

No. 86 Conditional Probabilities for Sequences of Wet Days at Phoenix, Arizona. Paul C. Kangieser, June 1973. (COM-73-11264)

No. 87 A Refinement of the Use of K-Values in Forecasting Thunderstorms in Washington and Oregon. Robert Y. G. Lee, June 1973. (COM-73-11276)

No. 88 A Surge of Maritime Tropical Air--Gulf of California to the Southwestern United States. Ira S. Brenner, July 1973.

No. 89 Objective Forecast of Precipitation Over the Western Region of the United States. Julia N. Paegle and Larry P. Kierulff, September 1973. (COM-73-11946/3AS)

No. 90 A Thunderstorm "Warm Wake" at Midland, Texas. Richard A. Wood, September 1973. (COM-73-11845/AS)

No. 91 Arizona "Eddy" Tornadoes. Robert S. Ingram, October 1973. (COM-74-10465)

NOAA Technical Memoranda NWSWR: (Continued)

No. 92 Smoke Management in the Willamette Valley. Earl M. Bates, May 1974. (COM-74-11277/AS)

No. 93 An Operational Evaluation of 500-mb Type Stratified Regression Equations. Alexander E. MacDonald, June 1974. (COM-74-11407/AS)

No. 94 Conditional Probability of Visibility Less than One-half Mile in Radiation Fog at Fresno, California. John D. Thomas, August 1974. (COM-74-11555/AS)

No. 95 Climate of Flagstaff, Arizona. Paul W. Sorenson, August 1974. (COM-74-11678/AS)

No. 96 Map Type Precipitation Probabilities for the Western Region. Glenn E. Rasch and Alexander E. MacDonald, February 1975. (COM-75-10428/AS)

No. 97 Eastern Pacific Cut-off Low of April 21-28, 1974. William J. Alder and George R. Miller, January 1976. (PB-250-711/AS)

No. 98 Study on a Significant Precipitation Episode in the Western United States. Ira S. Brenner, April 1975. (COM-75-10719/AS)

No. 99 A Study of Flash Flood Susceptibility--A Basin in Southern Arizona. Gerald Williams, August 1975. (COM-75-11360/AS)

No. 100 A Study of Flash-flood Occurrences at a Site versus Over a Forecast Zone. Gerald Williams, August 1975. (COM-75-11404/AS)

No. 101 Digitized Eastern Pacific Tropical Cyclone Tracks. Robert A. Baum and Glenn E. Rasch, September 1975. (COM-75-11479/AS)

No. 102 A Set of Rules for Forecasting Temperatures in Napa and Sonoma Counties. Wesley L. Tuft, October 1975. (PB-246-902/AS)

No. 103 Application of the National Weather Service Flash-flood Program in the Western Region. Gerald Williams, January 1976. (PB-253-053/AS)

No. 104 Objective Aids for Forecasting Minimum Temperatures at Reno, Nevada, During the Summer Months. Christopher D. Hill, January 1976. (PB252866/AS)

No. 105 Forecasting the Mono Wind. Charles P. Ruscha, Jr., February 1976. (PB254650)

No. 106 Use of MOS Forecast Parameters in Temperature Forecasting. John C. Plankinton, Jr., March 1976. (PB254649)

No. 107 Map Types as Aid in Using MOS PoPs in Western U. S. Ira S. Brenner, August 1976. (PB259594)

No. 108 Other Kinds of Wind Shear. Christopher D. Hill, August 1976. (PB260437/AS)

No. 109 Forecasting North Winds in the Upper Sacramento Valley and Adjoining Forests. Christopher E. Fontana, September 1976.