the deadliest tropical cyclone in history?

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1. Introduction

On 12 November 1970, a severe tropical cyclone of moderate strength riding the crest of high tide lashed East Pakistan with a 20-ft storm surge and killed approximately 300,000 people. The official figures show 200,000 confirmed burials and another 50,000 to 100,000 missing. Preliminary unofficial estimates placing the death toll near one million now appear unrealistic as officials have found that many of those originally listed as missing turned up when relief supplies became available. Accurate fatality figures are difficult to determine because of the large influx of workers into the islands from the mainland at the time of the storm to harvest the rice crop.

The November cyclone ranks as one of the most deadly, if not the deadliest, storm to ever devastate a coastal area. Table 1 lists the number of deaths associated with several noteworthy tropical cyclone/typhoon/hurricane tragedies where death tolls were in excess of 5000. Prior to the November 1970 cyclone, there had been only 5 other storms where the loss of life equaled or was in excess of 100,000 and in one of these, the Japanese typhoon in 1923, most of the people perished in the earthquake and fire that occurred simultaneously with the storm.

Countries bordering the Indian Ocean are confronted with one of the most serious storm surge problems of any place on the Earth. This is particularly true in the northern Bay of Bengal where the unique combination of a large astronomical tide, a funneling coastal configuration, low flat terrain and frequent severe tropical storms occasionally produce storm surges that kill thousands of people. This is dramatically illustrated in Table 1 where it is seen that 13 of the 19 disasters listed occurred in either India or East Pakistan. In contrast, the Western Hemisphere has experienced only three storms with comparable death figures. Even in the western Pacific where the most intense typhoons in the world develop, storm related fatalities generally do not approach the extremes observed in the Bay of Bengal.

TABLE 1. Deaths associated with noteworthy tropical cyclone disasters.

Year	Location	Deaths
1970	East Pakistan	300,000
1737	India	300,000
1881	China	300,000
1923	Japan	250,000
1897	East Pakistan	175,000
1876	East Pakistan	100,000
1864	India	50,000
1833	India	50,000
1822	East Pakistan	40,000
1780	Antilles	22,000
1839	India	20,000
1789	India	20,000
1965	East Pakistan	19,279
1963	East Pakistan	11,468
1963	Cuba-Haiti	7,196
1900	Texas	6,000
1960	East Pakistan	5,149
1960	Japan	5,000

TABLE 2. Damage estimated in the 12 November 1970 cyclone

Population affected	4.7 million
Crop loss	$63 million
Loss of cattle	280,000
Loss of poultry	500,000
Houses damaged	400,000
Schools damaged	3,500
Fishing boats destroyed (marine)	9,000
Fishing boats destroyed (inland water)	90,000

Aside from the indescribable human misery associated with the horrendous loss of life, the repercussions from this cyclone offer a formidable challenge for the survivors. Table 2 lists damages suffered in several categories and losses sustained by the fishing industry can be used to emphasize the seriousness of post storm conditions. Nearly 90% of the marine fishermen suffered heavy losses including the destruction of 9000 offshore

[1] In December 1970, the World Bank asked the National Hurricane Center, Miami, Fla., for the services of a hurricane expert to evaluate deficiencies in the Pakistan Cyclone Warning Service. This paper summarizes the results of two fact-finding trips to East Pakistan by Dr. Frank.

boats. Of the estimated 77,000 inland fishermen operating in the cyclone affected region, approximately 46,000 lost their lives, and damage was severe to the surviving 40%. It is estimated that approximately 65% of the total annual fishing capacity of the coastal region of East Pakistan was destroyed by the storm. The full impact of this loss becomes evident when it is realized that 80% of the total per capita intake of animal protein by East Pakistan's 73,000,000 residents comes from fish. Prior to the November cyclone, the protein consumption was already 10% below what is normally considered minimum adequate requirements to sustain life. Unless immediate emergency measures are taken, the per capita supply of fish will drop by another 35% during the coming months.

2. November 1970 cyclone

The origin of the November cyclone can be traced back to the remnant of a tropical storm that moved westward across Malaya on 5 November. This system spawned a depression over the south central Bay of Bengal on 8 November. The depression strengthened and probably attained storm intensity on 9 November, while drifting very slowly northward. The center of the cyclone was never probed by standard meteorological instruments; therefore, it is impossible to reconstruct an accurate time profile of intensity. Satellite pictures received in Dacca suggest the cyclone steadily strengthened while accelerating north, then northeastward towards the coast. Sustained winds were probably near hurricane force on 11 November and may have reached 100 kt by the time the cyclone moved inland. At the meteorological office in Chittagong, 50 mi southeast of the point where the eye made landfall, the anenometer blew down at 2200Z on 12 November, just after a wind speed of 78 kt had been recorded. A ship anchored in Chittagong Port reported a maximum gust of 120 kt at 2245Z. The track of the cyclone is shown in Fig. 1 and daily satellite views are shown in Fig. 2.

Empirical relationships between the maximum wind and the central pressure in tropical cyclones have been determined by several scientists for hurricanes in the Atlantic and for Pacific typhoons (see Fletcher, 1955; Myers, 1957; and Kraft, 1961). Since we have no reason to believe that cyclones differ dynamically from hurricanes or typhoons, these same relationships should be valid for storms in the Bay of Bengal. Thus, the esti-

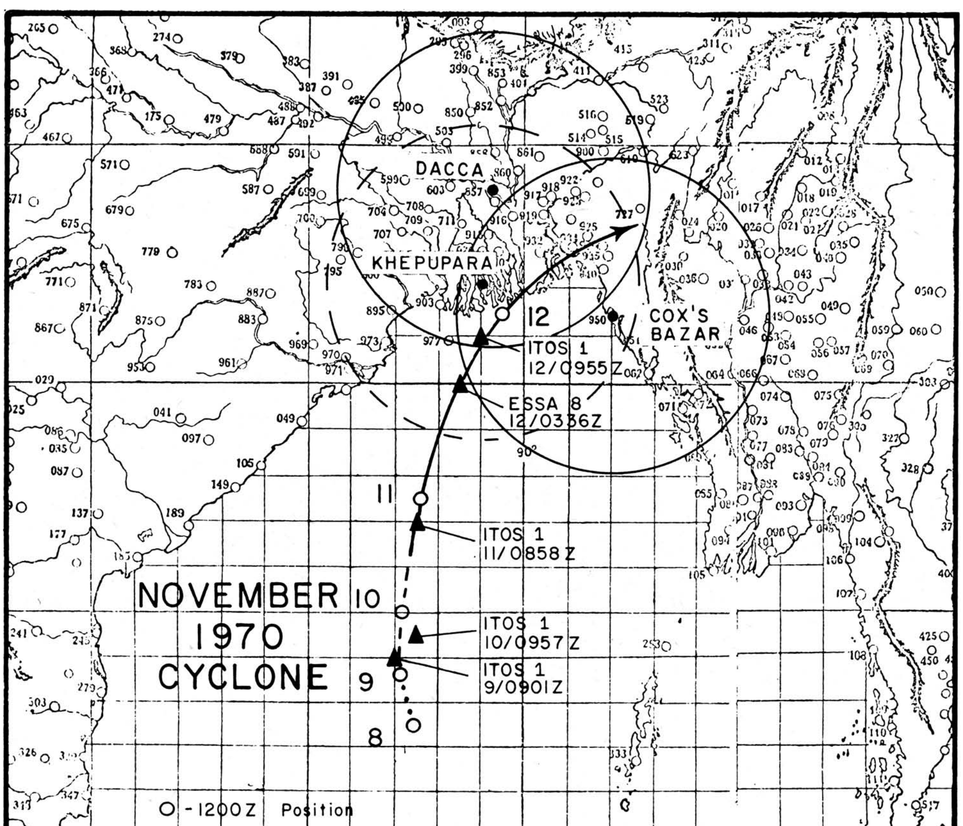

FIG. 1. Track of the November 1970 cyclone. The dotted line indicates depression strength, dashed storm and solid hurricane. Open circles show the 1200Z position. Triangles show the cyclone positions obtained from satellite pictures.

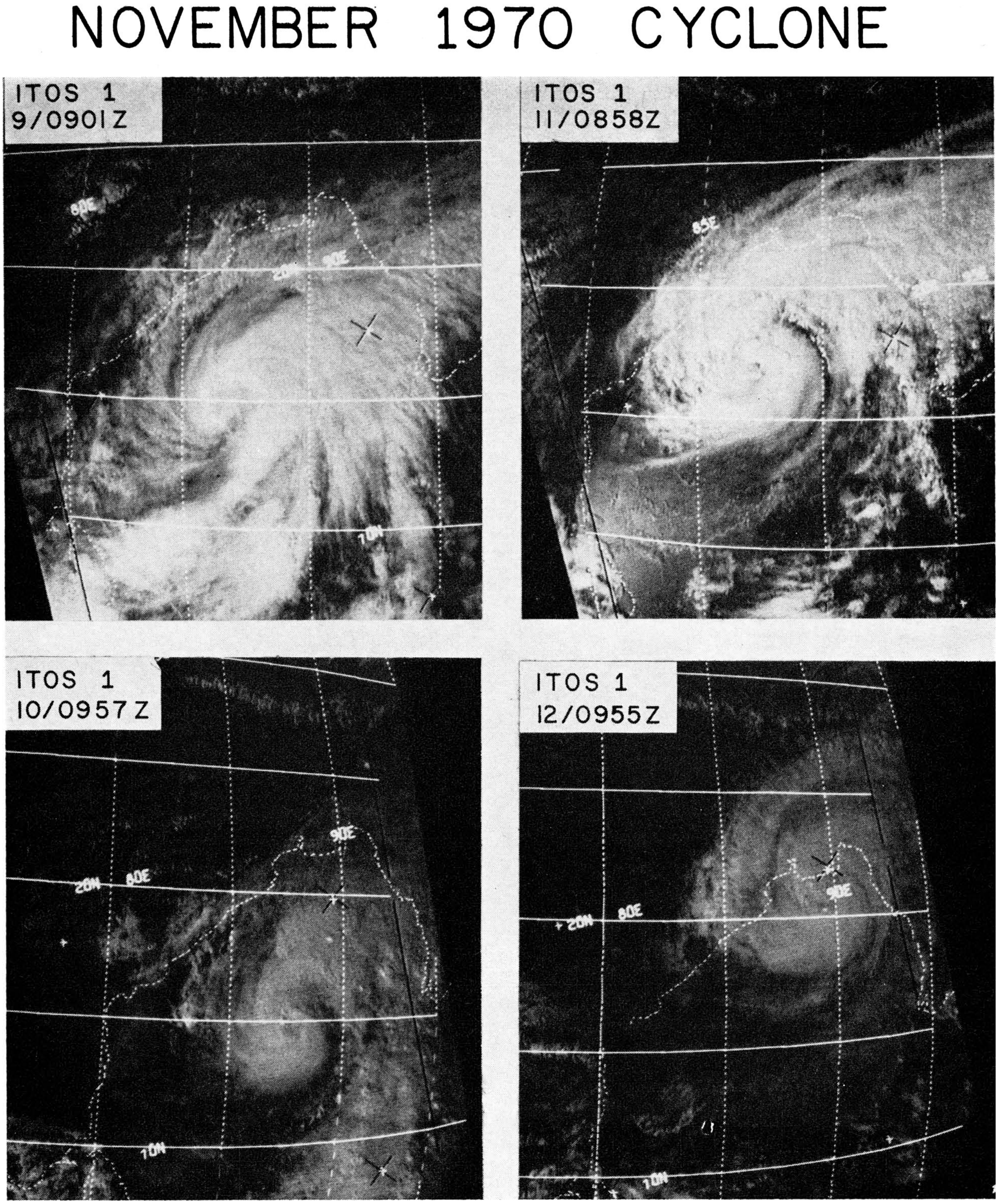

Fig. 2. ITOS 1 satellite views of the November 1970 cyclone.

mated maximum wind of 100 kt in the November 1970 cyclone corresponds to a central pressure between 950 and 960 mb. If this is true, it is important to note that the November cyclone was not the most intense storm to ever afflict East Pakistan. In 1876, the "Bakerganj" cyclone devastated the coast with an estimated 40-ft storm surge and killed between 100,000 and 400,000 people. A ship within the eye of that storm recorded a pressure of 930 mb. Dunn (1961) emphasized the seriousness of this type of storm by predicting that over 1 million lives will be lost if another "Bakerganj" cyclone occurs.

For the first time in history, the November 1970 cyclone offers an opportunity to document a cyclone induced storm surge in East Pakistan. Three years ago, the East Pakistan Water and Power Development Authority installed an excellent network of tide gages along the coast. The locations of these instruments are shown in Fig. 3: stars indicate maximum water level; gages and automatic recorders are identified by encircled stars. Water levels observed during the November 1970 cyclone have been presented in two different forms in Fig. 3. First, the encircled numbers indicate water heights above that expected with the normal astronomical high tide, and second, isolines have been drawn for water depths above the ground. It is recognized that the water depth analysis is grossly oversimplified since it is based entirely on readings taken at coastal locations. Water depths over the interior regions were considerably less than on the beaches, depending on the size of the island and the distance inland. The highest water mark above high tide shown in Fig. 3 is 12.5 ft on the northern coast of Bohla Island. At this place the normal diurnal tidal range is between 12 and 14 ft; thus, the maximum water depth was around 20 ft above mean sea level. The authors are indebted to M. R. Tarafder, East Pakistan Water and Power Development Authority for sharing with us the water level data shown in Fig. 3.

One of the factors mentioned above that makes East Pakistan subject to one of the most severe storm surge problems in the world is the large diurnal variation in the astronomical tide. The normal tidal range varies from around 10 ft near the Pakistan/India border, to nearly 18 ft on Sandwip Island: the easternmost large island located 15 mi northwest of Chittagong. An example of this unusually large tidal range is shown in Fig. 4 which presents a water level trace from a coastal gage outside Chittagong harbor recorded during the November 1970 cyclone. The predicted trace is indicated by a dashed line on the 12th and 13th; therefore, at this location (50 mi southeast of landfall) the portion of the storm surge induced by the cyclone was a little

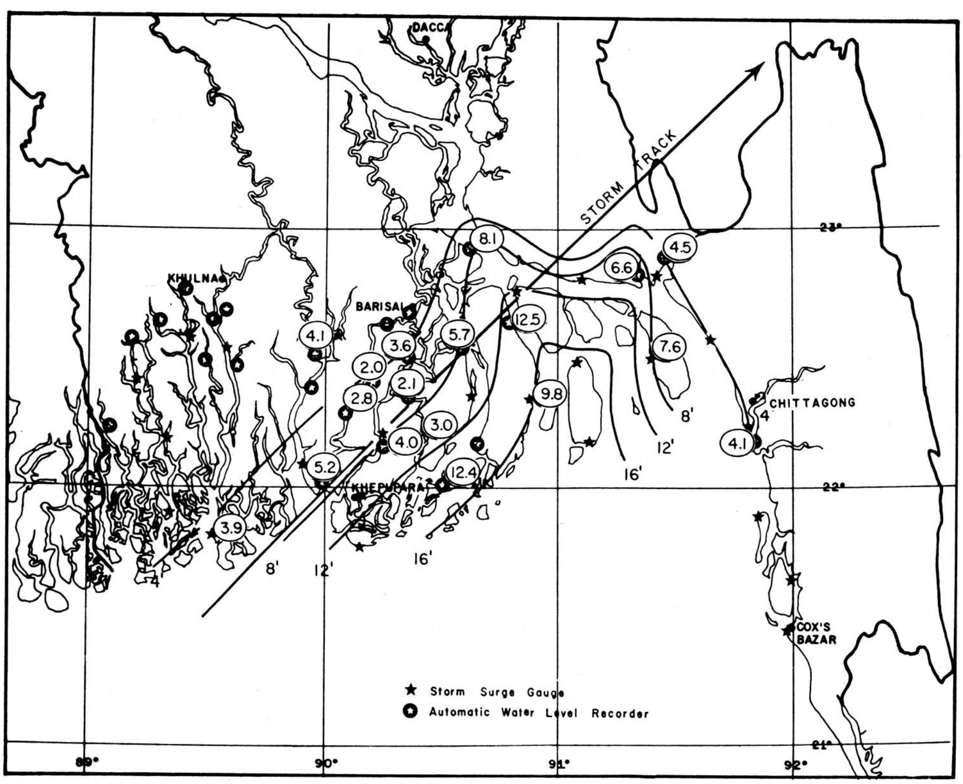

FIG. 3. Storm surge data for the November 1970 cyclone. Encircled numbers are the height of the water above that expected with high tide, and isolines show the water depths above the ground. (Data courtesy of M. R. Tarafder, East Pakistan Water and Power Development Authority)

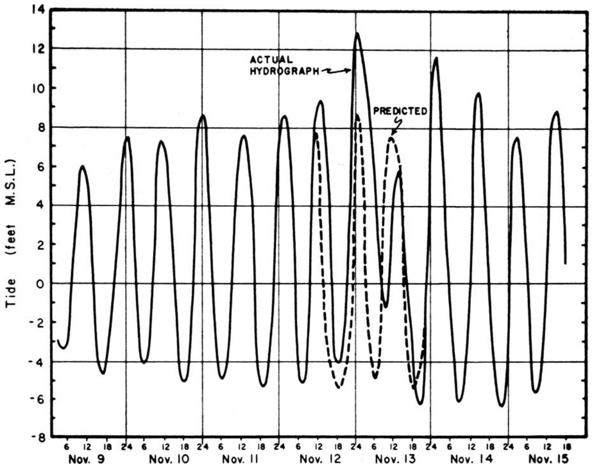

FIG. 4. Water level record from a coastal gage outside Chittagong harbor. The dashed line is the predicted trace.

over 4 ft. This trace reveals a tidal range of nearly 15 ft and stresses the importance of timing in formulating a cyclone warning. The impact of this fact is vividly revealed by comparing the November 1970 cyclone with the October 1960 storm that claimed over 5,000 lives (Dunn, 1962). Both cyclones were about the same strength. The tremendous difference in fatalities is attributed to the fact that the November 1970 cyclone crossed the coast at high tide while the October 1960 storm moved onshore at low tide.

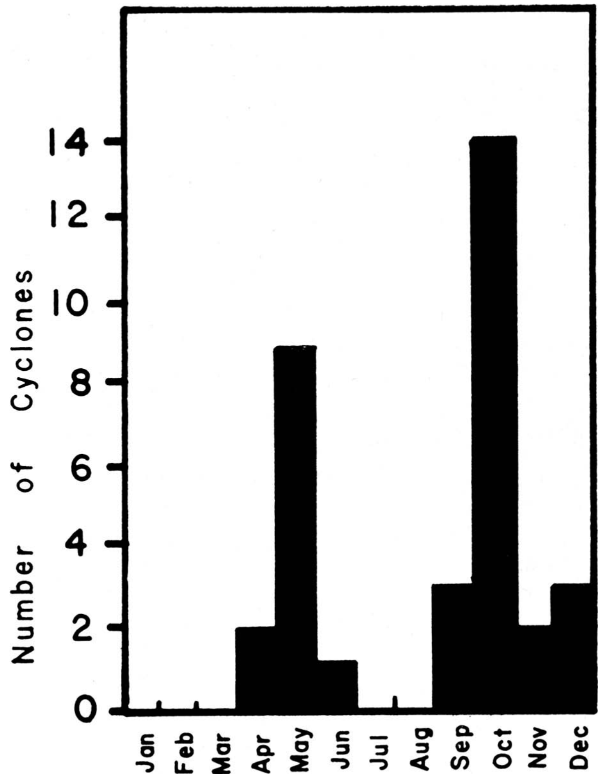

FIG. 5. Monthly distribution of 34 severe cyclones that have affected East Pakistan during the last 190 years.

3. The cyclone problem in East Pakistan

The average annual frequency of tropical depressions (winds less than 39 mph) in the Bay of Bengal is between 12 and 13, of which 5 strengthen and become cyclonic storms with winds equal to or greater than 39 mph (Rao, 1964). Even though nearly 50% of the depressions form during the summer months of July, August and September, most of these remain weak and offer no serious threat. The severe killer cyclones develop mainly during the spring and fall, with over 75% occurring during the 5 months of 15 April to 15 June and 15 September to 15 December. Husain (1966) found that East Pakistan has experienced the fury of 34 severe cyclones with winds in excess of 54 mph during the past 190 years. Fig. 5 shows the monthly distribution of these 34 storms and clearly reveals a double maximum of activity with the primary maximum occurring in October and a secondary peak in May.

On the average, residents of East Pakistan have been lashed by a severe cyclone one out of every 5 years; however, the distribution is certainly not evenly spaced in time. Fig. 6 shows the number of storms by 10 year periods. Records in the 18th and 19th centuries are not complete and the increase noted since 1890 may not be real. The significant points to note are the active period during the first part of this century, the lull extending from 1930 to 1960 when only 3 severe storms occurred and, most important, the sharp increase during the sixties with an average of one storm per year. Table 3 lists the severe storms that have occurred in East Pakistan since 1960 along with fatality estimates and information on the storm surge. The November 1970 cyclone culminated an unusually active period of

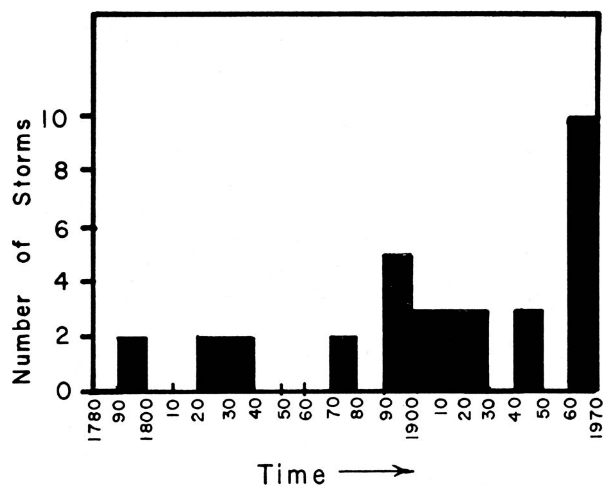

FIG. 6. The number of severe cyclones that have affected East Pakistan by 10-year periods.

TABLE 3. Severe cyclones affecting East Pakistan since 1960.

Date	Deaths	Tide
9 Oct. 1960	3,000	10
31 Oct. 1960	5,149	15–20
9 May 1961	11,468	8–10
28 May 1963	11.520	14–17
11 Apr. 1964	196	—
11 May 1965	19,279	12
14 Dec. 1965	873	
1 Oct. 1966	850	15
17 Apr. 1969	75	
23 Oct. 1970	300	
12 Nov. 1970	300,000	18–20

tropical storm activity in East Pakistan where cyclones have killed an average of over 5000 people per year during the last decade.

4. Meteorological facilities in East Pakistan

Following the disastrous tropical cyclones in October 1960, the Government of Pakistan decided to take immediate steps to improve the Cyclone Warning Service. They solicited the advice of Dr. Gordon E. Dunn, former director of the National Hurricane Center in Miami, Fla., who went to East Pakistan and reviewed the warning system, making a number of recommendations. As a result of Dunn's visit, a number of important changes were initiated, including the installation of several critical meteorological instruments, and the Government of Pakistan is to be commended for its effort.

The Storm Warning Center that was recently transferred from Chittagong to Dacca has the following facilities to support its work. Through the offices of East Pakistan Red Cross, a 10-cm radar was given by the Swedish Save the Children Fund and has been in operation at Cox's Bazar since the middle of 1969. Another weather radar purchased from Pakistan's own resources has been installed at Dacca. A third radar given as aid by the U. K. Government is due to arrive in Dacca early this year for installation at Khepupara. These three radars will provide the ability to monitor the progress of any storm that moves within 200 mi of the coast. The locations of these radars are shown in Fig. 1.

Satellite pictures are received at an APT ground station that was constructed by the Pakistan Space and Upper Atmosphere Research Committee (SUPARCO) for the Meteorological Department in April 1968. Pictures received on this equipment provide information on the location and development of all disturbances that pose a threat to East Pakistan and that are located beyond the range of the coastal radars. The APT receiver was assembled by rigging component parts from several different manufacturers in order to reduce costs. The coastal radars and pictures from satellites form the cornerstone of the East Pakistan storm surveillance system.

5. Limitations of the Cyclone Warning Center

Even though the Government of Pakistan has taken some vital steps to improve the Cyclone Warning Service, there are still some critical deficiencies. People intimately acquainted with the cyclone problem in the Bay of Bengal are convinced that a significant number of lives can be saved if warnings can be improved. At the present time, there is a limitation on the effectiveness of warnings involving storms with a severe surge potential because meteorologists in this part of the world do not have the proper observing facilities to distinguish between killer and nonkiller cyclones. As a result, people have been drastically overwarned and this breeds apathy—which is the greatest enemy to a storm warning service. Time after time, coastal residents have been warned of "Great Danger" (the highest degree of danger), then found that conditions were not nearly as bad as expected. Without question, apathy was one of the main reasons for the lack of emergency action prior to the November cyclone in East Pakistan. It is estimated that over 90% of the people in the disaster area knew about the storm; yet, less than 1% sought refuge in more substantial buildings, and most of those who did *were not land or home owners.* Residents had never experienced a storm surge like the one that devastated the coast in November and felt no urgency to leave their homes.

The most critical need of the cyclone warning center is a method for determining the strength of a cyclone before it reaches the coast. Without this information, forecasters can not identify those infrequent cyclones that have a killer potential and thereby reserve the "Great Danger Warnings" for the most threatening situations. The only practical way of obtaining this information is with aircraft reconnaissance; however, this is an expensive program. There is an urgent humanitarian need for some international agency to establish a flight group that would provide data for all nations around the Indian Ocean faced with the cyclone problem. This is the only way that cyclone warnings can be made more effective.

One point needs to be clarified in regards to the warnings. The foreign press unjustly criticized the meteorological department. Part of their criticism stems from an improper interpretation of the satellite bulletins issued by NESC (National Environmental Satellite Center) in Washington, D. C. The press claimed that NESC issued emergency bulletins which were ignored by the Pakistan meteorologists. This was not true. The bulletins issued by NESC were routine in accordance with procedures that have been in existence for several years. As a matter of fact, communications delays caused the messages from NESC to arrive in East Pakistan as much as 23 hr after the picture time and were of little value to the Storm Warning Center. Excellent pictures were received in East Pakistan on their own APT equipment from both ESSA 8 and ITOS.

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References

Dunn, G. E., 1961: Tropical Cyclone Early Warning System for East Pakistan. Report prepared for the United States Operations Mission to Pakistan, 44 pp.

——, 1962: The tropical cyclone problem in East Pakistan. *Mon. Wea. Rev.*, **91**, 83–86.

Fletcher, R., 1955: Computation of maximum surface winds in hurricanes. *Bull. Amer. Meteor. Soc.*, **36**, 247–250.

Husain, S. A., 1966: Tropical cyclones of the Bay of Bengal affecting Pakistan. Paper presented to the Working Group of Experts on Cyclones held in Dacca, Pakistan, in December 1966, 15 pp.

Kraft, R. H., 1961: The hurricane's central pressure and highest wind. *Mariners Weather Log*, **5**, No. 5.

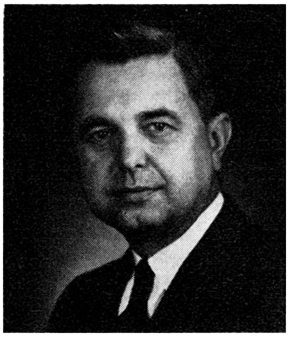
Myers, V., 1957: Maximum hurricane winds. *Bull. Amer. Meteor. Soc.*, **38**, 227–228.

Rao, P. R., 1964: Tracks of storms and depressions in the Bay of Bengal and the Arabian Sea. India Meteorological Department, 201 pp.

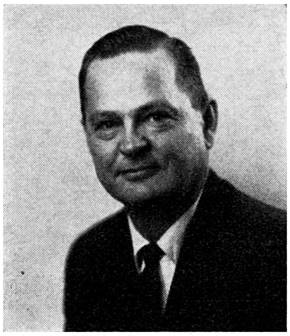
news and notes

Elections to the National Academy of Engineering

Two AMS members are among the 29 American engineers recognized for their important contributions to engineering theory or their pioneering accomplishment in technological development by election to the National Academy of Engineering. Both Dr. Michael Ference, Jr., and Dr. John H. Ludwig have been involved in varying aspects of air pollution technology and control.



Dr. Ference is vice-president-scientific research staff of the Ford Motor Company, Dearborn, Mich., and serves on the President's Air Quality Advisory Board and the Governor's Science Advisory Board of the State of Michigan. He was cited for his accomplishments in physics and electronics for government and industry. He holds the B.S., M.S., and Ph.D. degrees, all in physics, from the University of Chicago. He is the recipient of the U. S. Army Exceptional Civilian Service Award and the honorary Sc.D. degree from Kenyon College.



Dr. Ludwig is assistant commissioner for science and technology, Air Pollution Control Office of the Environmental Protection Agency. He was cited for his contributions as a uniquely qualified engineer-scientist, organizer, and director of technological resources to the solution of rapidly changing environmental challenges. Associated with the Air Pollution Control Office since 1955, Dr. Ludwig assumed his present position in 1968. He is the recipient of the Commendation Medal of the U. S. Public Health Service and the Superior Service Award of the Department of Health, Education, and Welfare. He holds the B.S. degree in civil engineering from the University of California at Berkeley, the M.S. degree in civil engineering from the University of Colorado, the M.S. degree in industrial hygiene and Sc.D. degree in air pollution from Harvard University.

Photon absorption studies

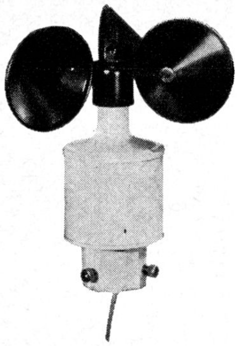
The effect of certain wavelengths of ultraviolet sunlight on the atoms and molecules of the Earth's upper atmosphere are being simulated at a special facility of the University of Wisconsin. Dr. Darrell L. Judge, Dr. Masaru Ogawa and Robert W. Carlson of the University of Southern California, Los Angeles, are using the Storage Ring at Madison under a grant from the National Science Foundation.

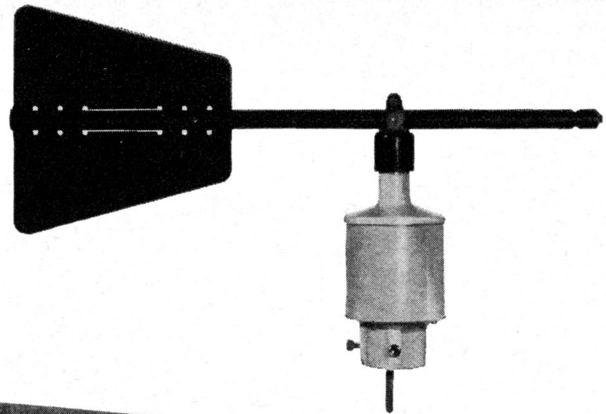
The Storage Ring is one of the few facilities that can provide a continuum of ultraviolet light throughout a broad range of this portion of the spectrum, and is thus ideal for the study of photon absorption processes. The Storage Ring is actually designed to enable nuclear physicists to study the effect of electron collisions with positrons; the ultraviolet light radiated from the electrons is a by-product of the facility.

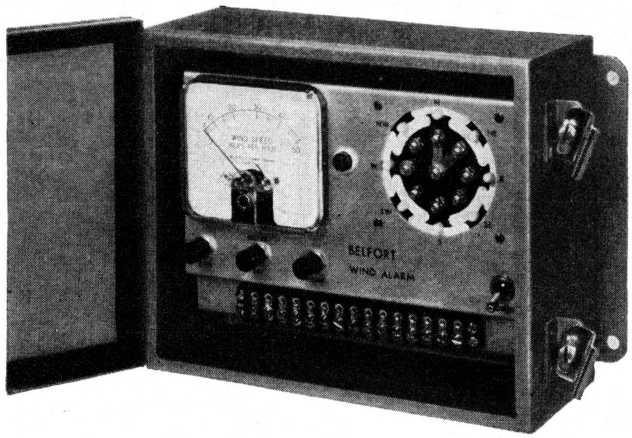
Using an monochrometer, which works something like a prism, to separate the colors of the ultraviolet light, the researchers can then observe which wavelengths affect atoms and molecules of common atmospheric gases such as oxygen, carbon dioxide, hydrogen, ozone and others.

"We are engaged in a study of primary processes," explained USC physicist Judge, whose specialty is the physical properties of gases found in planetary atmospheres. "The importance of our study, we believe, is that hopefully it will help fill in some of the information gaps about the basic processes of the upper atmosphere."

(More **news and notes** on page 449)



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