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THE TROPICAL CYCLONE AS A HEAT ENGINE CAN BE MODIFIED

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Dr R.C. Gentry, as the Director of the National Hurricane Laboratory, Miami USA, commenced by giving an outline of the integrated research facility at Miami. The Laboratory is on the campus of the University of Miami, and in the same building as the National Hurricane Centre (NHC) under Dr R.H. Simpson. The NHC is the forecast centre for tropical meteorology in the USA and has three permanent staff engaged on research and development work on tropical cyclones - mainly on synoptoclimatological movement prediction. There are also six specialist meteorologists, who are fully engaged in forecasting during the cyclone season (June to October) and who do development work for the remainder of the year. Also on the campus is the University of Miami Radar Meteorological Laboratory, the Miami Institute of Atmospheric Science under Professor M.A. Estoque and the Experimental Meteorological Laboratory under Drs J. Simpson and W. Cotton.

The scope of research at the National Hurricane Laboratory covers all fields of tropical meteorology, but tends to projects requiring a long period of development. The main sections are the theoretical modelling, case studies, cloud physics and numerical studies. It is the operational headquarters for project "Stormfury", a joint project between the National Oceanic and Atmospheric Administration and the Department of Defence designed to test the practicability of hurricane modification projects.

The two compelling reasons for hurricane modification projects are the upward trend in the amount of damage caused by tropical cyclones and that our knowledge of the physical processes fundamental to the maintenance of tropical cyclones suggest promising avenues of experimentation. Deaths attributed to tropical cyclones in the USA have shown a decrease this century, evidence we hope of better warnings and increased community preparedness.

The basic hypothesis, for current tropical seeding, is for the seeding of supercooled clouds outside the radius of maximum winds with the object of causing them to grow larger, as the latent heat released increases the local bouyancy and to form a new eye wall outside the existing one. If this can be accomplished, it seems reasonable from angular momentum considerations that the maximum winds in the storm will be less than in the old eye wall. Thus the energy of the storm will be spread over a larger area. An earlier hypothesis expected that the latent heat released would so change the thermal structure, that the pressure field and thus the wind field would be flattened out. Measurements of actual amounts of supercooled water vapour (in updrafts, up to 2 gm m^{-3} at levels between -5 and -10^{o}C) would not be sufficient alone to achieve this change, but numerical models indicate that a natural heating mechanism is triggered.

Results for the seeding of Tropical Cyclone "Debbie" in 1969 were presented. This cyclone was seeded on two days by five seeding aircraft. After the first seeding run on 18 August outside the inner eye wall and across a second outer eye wall, the maximum wind speed at 10,000 ft (3,050 m) decreased from 98 to 68 kn (181 to 126 km/h) five hours after the last seeding - a 31% reduction. On 20 August after a similar seeding program and within six hours after the final seeding the maximum wind speed had dropped from 99 to 84 kn (183 to 156 km/h) - 15% reduction. After the first seeding on each day, there was an initial increase in wind speeds outside the eye wall, consistent with the expected formation at that radius of a new eye wall. There has been a large number of simulations of modifications with the symmetrical tropical

cyclone model. These indicate that the best area for seeding is between 20 and 35 km radii, which was just outside the radius of maximum wind speed, and that either a sudden dose of large heating or a long dose of moderate heating is necessary to cause modification.

The only tropical cyclone seeded in 1972 was "Ginger", but at the time of seeding it was twenty days old and had a flat broad profile. It was not considered that the seeding had much overall effect although much information was gained from seeding individual clouds. The tropical cyclones seeded are not random, partly because they are restricted to ones well away from land areas, so that experiment evaluation is difficult. The Laboratory has compiled extensive statistics on frequency of specified wind speed changes for tropical cyclones as a basis for judging modification success.

A second area of potential modification tested has been the use of polymer films to reduce evaporation from the ocean. A recent product tested lasted three to four hours in 5 kn (9 km/h) winds and aircraft measurements of wave spectra indicated a reduction of 50% in the kinetic energy of the waves. This product was biodegradable and could also inhibit spray. The lack of sufficient wind and seas did not allow a full test of the film although the fact that it was short lived was not encouraging. Recent measurements of sea temperature profiles have indicated the extent of mixing and upwelling in the ocean below the tropical cyclone. There have been recorded instants when the subsequent cooling of the sea surface temperature caused by upwelling, below a slow moving tropical cyclone, has been followed by a weakening.

The present plans at the National Hurricane Laboratory are (i) to improve the current theoretical models, (ii) to investigate further the natural variability in tropical cyclones, (iii) to investigate further on cloud physics and scale interaction, (iv) to increase the seeding area by including Northern Pacific tropical cyclones, (v) to test other methods and materials for seeding potential and (vi) to develop and test procedures to maximize results in field experiments.

Dr K.T. Spillane asked about the magnitude of the effect of changes in sea surface temperatures and ocean evaporation and Dr Gentry said that from the numerical model experiments either a four degree temperature drop or total evaporation suppression reduced the tropical cyclone energy by 50%. He also said that because of land fall restrictions, they had not gathered any quantitative data on rainfall, so that the effect of seeding or evaporation suppression could only be guessed at. To a question from Mr T. Gibson, a list of modification techniques which were currently uneconomic was given. It included pumping up deep water, towing icebergs into the area, injecting dry ice and adding a nitrogen compound which extracts heat. The seeding with silver iodide had proved the best logistically. One canister contained 160 gm of silver iodide and on explosion gave an estimated 10^{12} to 10^{14} nucleating particles. In the experiments five planes were used each with 200 canisters, and the seeding was considered to act as a trigger in a natural mechanism for self destruction. Dr W.J. Gibbs asked about aircraft navigation problems, and Dr Gentry said that while the Doppler navigation used had errors between 2 and 20 n mi (3.7 and 37 km), all radar photographs were corrected to a common tropical cyclone eye.

S.C.A.