Gulf Stream Locale - A Field Laboratory for Cloud Process

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Clouds associated with the Gulf Stream Locale, (Figure 1) are in general due to the cyclogenesis or redevelopments of the storms off the east coast of the United States in winters, movement along the coast of the storms that are generated over the Gulf of Mexico in the spring and fall and mesoscale convective circulations present in all seasons. During the summer and early fall ,this region is also susceptible to hurricanes moving from the south. There have been several attempts to reproduce some of the observed synoptic and mesoscale features of these systems (e.g., Kreitzberg and Perkey 1977; Holt et al. 1990; Huang and Raman 1990, 1992; Liou et al. 1990). In the winter, even when no storms are present and an arctic high-pressure system controls the weather in the region, cold air outbreaks produce convective clouds over a wide area (Wayland and Raman 1989; Grossman and Betts 1990; Chou and Zimmerman 1989). Even with clear weather conditions, mesoscale convergence induced by the horizontal surface temperature gradients produces clouds over this region (Huang and Raman 1991).

The effect of these clouds on radiation balance can be significant. Surface heat fluxes vary from about 50 W/m^2 during a summer day (Raman 1991) to values in excess of 1500 W/m^2 during an intense cold air outbreak in the winter (Raman and Riordan 1988; Akkarapuram and Raman 1988). Interestingly, large heat fluxes occur during synoptically quiescent conditions and produce multiple cloud layers over a major portion of the Atlantic ocean (Wayland 1991). With the development of synoptic scale storms, the clouds are normally of strato-cumulus type, again covering a significant area of the Gulf Stream Locale.

Scale Interactions

Effects of the cloud feedback processes in modeling global climate is currently a major concern. The Gulf Stream Locale is probably one of the important and ideal regions to tackle this problem for the following reasons. It is a region where surface forcing plays a very important role in cloud generation. It is also a region where winter storms are generated when two major forcing mechanisms act in concert: one is the surface forcing caused by the presence of the Gulf Stream and the other is the upper level forcings related to jet streaks and mid-tropospheric troughs. Another feature of this locale is that the surface forcing exists all the time with minor variations. This feature makes at least one parameter constant.

Another aspect that makes this locale interesting is the processes of scale interaction that generate and maintain clouds. For example, *micro-scale* turbulence causes surface fluxes of heat whose gradients induced by the Gulf Stream set up *mesoscale* atmospheric circulations which by themselves, produce about 25% of the clouds. When upper air support becomes available, these mesoscale circulations develop into *synoptic scale* mid-latitude cyclones, which are major generators of clouds in the region. Understanding the scale interaction is important to formulate good subgrid parameterizations for global climate models.

The Gulf Stream Locale is covered by clouds over 70% of the time. These clouds mainly consist of cumulus, stratocumulus, alto-stratus and alto-cumulus (Daum and Hadlock 1991). The challenge is to devise a method to realistically incorporate the thermodynamic processes associated with these clouds in dynamic climate models. That would require a better understanding of the physical processes of clouds of different scales produced by different processes. The Gulf Stream Locale would provide a test case for these processes since a finer resolution global climate model can resolve some of the predominant cloud features in this region. The Gulf Stream, responsible for the generation of the clouds, cannot be resolved explicitly in these models.

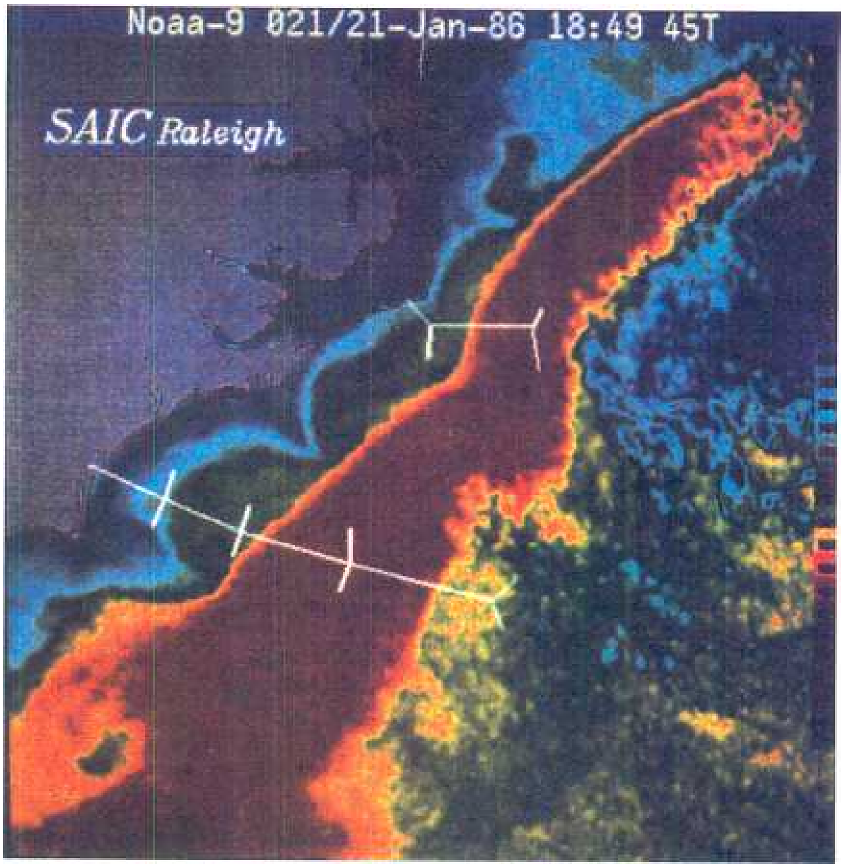

Figure 1. Typical Location of the Gulf Stream with Reference to the Coast in the Gulf Stream Locale

Hence, a combination of mesoscale and regional scale observations and modeling would be required to address this problem.

An example of the possible role of the marine boundary layer structure and circulation in the offshore redevelopment of a mid-latitude cyclone was given by Holt and Raman (1990). Data obtained from over the cold shelf waters, midshelf front near the shelf break, and the Gulf Stream separated by about 200 km, revealed the markedly different nature of the boundary layers. A strong horizontal gradient of surface turbulent heat flux existed. Total heat flux varied from about zero near the coast to about 250 W/m^2 over the Gulf Stream. This caused a low-level mesoscale convergence across the western edge of the Gulf Stream in the vicinity of the developing cyclone (Figure 2). The difluence zone near the Gulf Stream was topped by layered stratocumulus with a cloud layer about 400-m thick between 800 m and 1200 m. Satellite information indicated that a mid-latitude cyclone was developing in the region of the aircraft observations (Figure 3).

A typical visible imagery of the cloud pattern for a different storm generated off Cape Hatteras is shown in Figure 4. This storm of January 3 and 4, 1989, may have been the deepest extratropical cyclone to occur south of 40N in this century. Central pressure reached 938 millibars at 21Z January 4, 1989. A deepening rate of 24 mb/6 hr was estimated to have occurred between 09Z and 15Z on that date. Winds in the boundary layer reached at least 90 knots during the mature stage of the storm. Rapid deepening occurred when the upper air forcing reached the

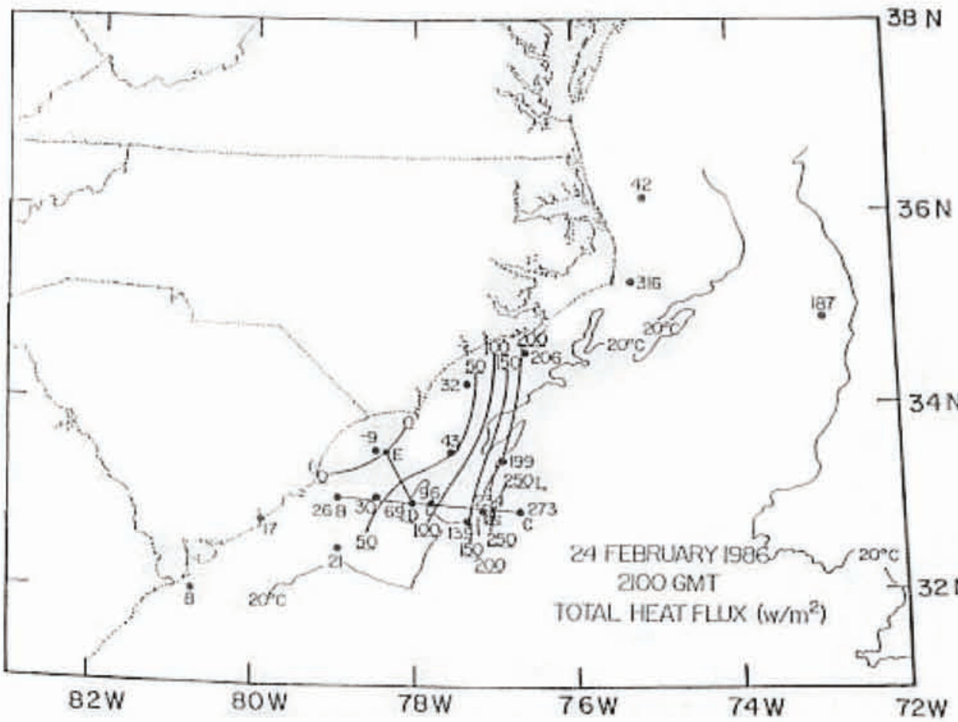

Figure 2. A Strong Gradient of Surface Heat Fluxes Leads to a Mesoscale Circulation Near the Western Edge of the Gulf Stream.

coastline at about 00Z on January 4, and the cyclone appeared to take the form of a trough containing several centers rather than a single area of low pressure.

The tight cloud band surrounding a small clear "eye" in the visible image marks the spot of lowest pressure at this time and appears to have been the result of a strong mesoscale development in the interior of the cyclone during the period of rapid deepening. Through the use of satellite imagery, the development is deduced to have begun in the northwest quadrant of the cyclone, which contained several circulation centers of about equal strength during the period of rapid cyclogenesis.

Intense rain bands were observed over the Gulf Stream region at the onset of rapid cyclogenesis via the Special Sensor Microwave/Imager (SSM/I) on board a Defense Meteorological Satellite Program (DMSP) polar orbiting satellite. The strong sea surface temperature gradients near the Gulf Stream may have played a role in the development of these rain bands in that strong surface latent and sensible heating lowered the static stability and allowed moist unstable air to penetrate deep into the troposphere. Another interesting feature is that the storm track paralleled the west wall of the Gulf Stream from just off Cape Hatteras, east into the open Atlantic. This path could be due to a low pressure region over the Gulf Stream coinciding with the preferred track of the east coast storms. This process has the effect of producing increased cloudiness over the Gulf Stream Locale.

ARM Scientific Objectives Pertinent to The Gulf Stream Locale

One of the main ARM scientific issues to be addressed in this locale is the process of cloud formation, maintenance, and dissipation. It is important to parameterize the cloud processes properly so that the correct type of clouds with appropriate radiative properties are generated in a climate model. Parameterization is necessary because the

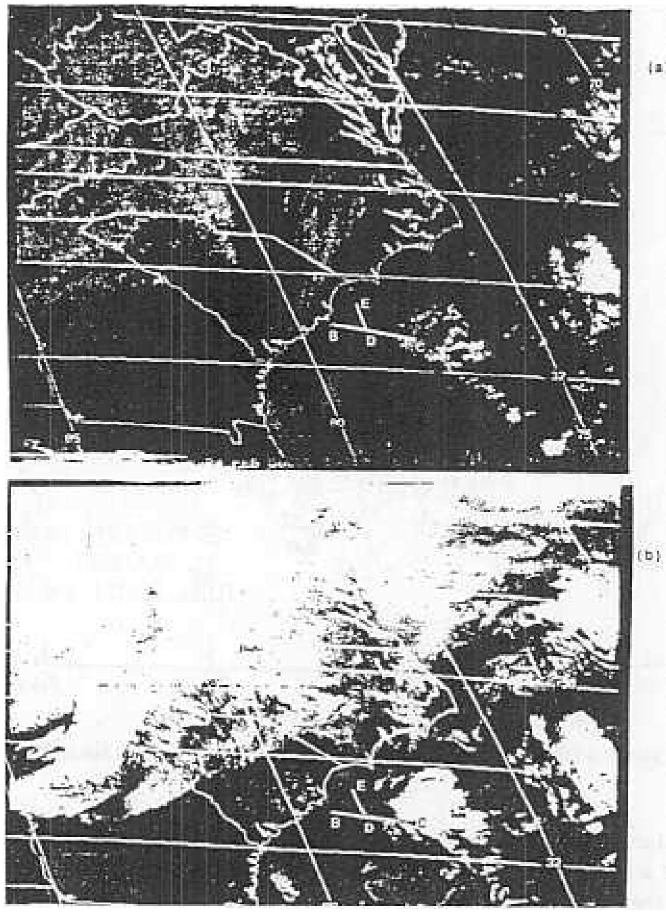

Figure 3. Visible Satellite Pictures from GOES-6 for February 24, 1986, at (a) 1600Z (b) 1800Z. The offshore redevelopment of the cyclone is evident.

processes responsible for the generation of the clouds are micro and mesoscale. Other ARM scientific issues of relevance are surface turbulent fluxes of sensible and latent heat, surface inhomogeneity (in roughness, hydrology and heating), diurnal variations in surface energy budget, and the representation of the planetary boundary layer in large scale models.

Acknowledgments

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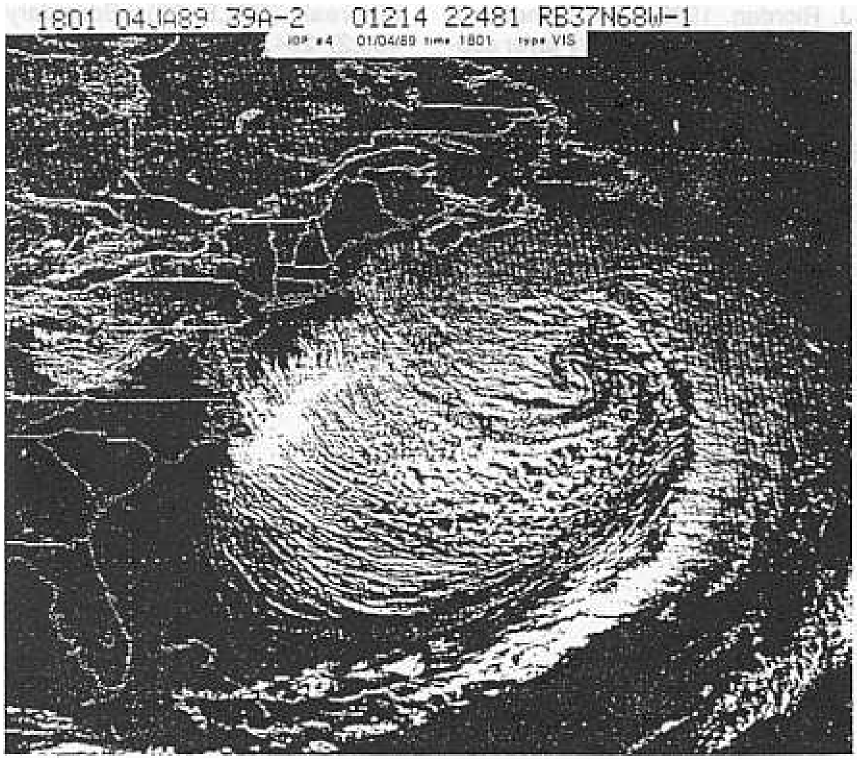

Figure 4. The ERICA Storm of January 3 and 4, 1989, the Deepest Extra-Tropical Cyclone South of 40N in This Century. The track was along the Gulf Stream.

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