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# CONVECTIVE CLOUDS OVER THE BAY OF BENGAL

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## 1. INTRODUCTION

The Bay of Bengal in the northern summer is the site of the highest mean precipitation of the entire Asian monsoon region and perhaps of the global oceans. Despite its importance to both weather and climate, the region remains poorly sampled and modeled (Webster et al., 2002). Many independent datasets document the high degree of convective activity within the Bay of Bengal, yet a comprehensive survey of convective activity using frequent infrared satellite imagery has not been done. In part, this reflects the paucity of geostationary satellite data for this region. Thus, one surprise of the recent JASMINE[1] experiment was large, long-lived, diurnally-repeating, southward-propagating squall lines occurring within the middle of the Bay.

This study documents the convection occurring within the Bay of Bengal more completely, using geostationary satellite data possessing high viewing angles. In 1999, the geostationary Meteosat-5 satellite was moved to 63°E in support of INDOEX[2] and JASMINE. Meteosat-5 provided high-quality, 3-hourly coverage of the Bay of Bengal during the entire 1999 monsoon season, creating, among other things, a larger context for the convection observed during JASMINE. Additional 3-hourly infrared data for the 1988 monsoon season increases the representativeness of the findings. These data come from the INSAT geostationary satellite.

A pixel-grouping algorithm is used to identify a cloud cluster, which can then be tracked from image to image to characterize the temporal progression of convective events. Results are broken down by cloud size and location.

This work has been recently submitted (Zuidema, 2002); the submitted journal article is available at http://www.etl.noaa.gov/˜ pzuidema/jasmine.pdf.

## 2. DATA AND METHOD

The Meteosat-5 infrared mean count at a 0.25° resolution were converted to brightness temperatures ($T_b$). Similarly-derived INSAT infrared brightness temperatures were interpolated to the same 0.25° spatial resolution. We used two infrared temperature thresholds, 235 K and 210 K, to document the behavior of all clouds thought to be rain-bearing, and the behavior of the most heavily precipitating individual clouds. A cloud tracking procedure was also implementated but will not be discussed here. This method was previously developed and applied to characterize the Australian monsoon and the tropical western Pacific (Chen et al., 1996)(and references therein).

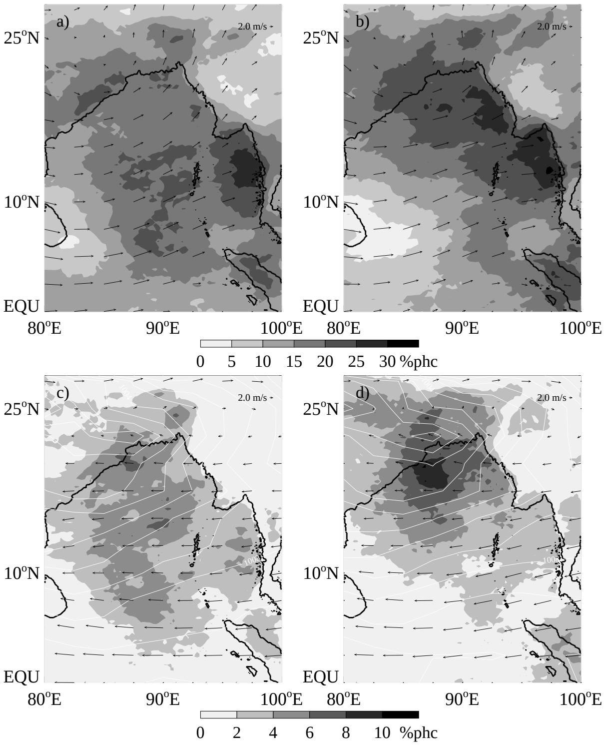

FIG. 1: Monsoonal-mean (May 1-September 30) percent high cloudiness maps for (a) 1988 PHC$_{235}$, (b) 1999 PHC$_{235}$, (c) 1988 PHC$_{210}$, (d) 1999 PHC$_{210}$. Superimposed in (a) and (b) are the NCEP Reanalysis May-September mean 850-mb winds (arrows) for the respective years. Panels (c) and (d) include the NCEP Reanalysis May-September mean 300-mb winds (arrows) and sea level pressure (white line; 1-mb contour levels).

## 3. SELECTED RESULTS

Striking differences occurred between the convection of 1988 and of 1999, and, between convective activity as measured by a 235 K and 210 K threshold. This is shown in the percent high cloudiness plots of Figure 1. Percent high cloudiness is defined as the percent of pixels with brightness temperatures less than 235 K or 210 K (PHC$_{235}$ and PHC$_{210}$ respectively).

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[1] Joint Air-Sea Monsoon Interaction Experiment

[2] Indian Ocean Experiment

In 1999, much of the high cloudiness occurred near shore, seen in panels b) and d). In 1988, the high cloudiness was less localized and extended further south (panels a) and c)). 1988 is considered a strong monsoon year and 1999 a slightly weak monsoon year according to the All-India Rainfall Index (AIRI), an average of station rain gauge within India. Yet, averaged over the Bay of Bengal, (80°E-100°E, 5°N-25°N), slightly more high cloudiness occurred in 1999 than in 1988 for both $T_b$ thresholds. One implication is that perhaps AIRI is more indicative of the spatial pattern of convection over the Bay, than of the mean amount.

The other interesting aspect of Figure 1 is that the very-high cloudiness maps (PHC$_{210}$; panels a) and b)) show quite different cloud maxima than the PHC$_{235}$ maps. Most of the lower-level high cloudiness is found near the eastern side of the Bay, particularly within the Gulf of Martaban (located at about 97°E and 16°N). In contrast, most of the very-high high cloudiness occurs at the northwest or west side of the Bay.

The differing distributions of cold and very-cold high cloudiness is reflected in other data as well. There is a good spatial match between Figure 1b and the 1999 TRMM mean rainfall estimate for the same period. The north-northwest side of Bay, where the coldest clouds occur, in turn corresponds well with the cyclone distribution reported by the Joint Typhoon Warning Center in Guam, thus is the site of the most extreme weather phenomena for this region.

A remarkable result of the cloud cluster analysis is a distinct spatial grouping by size, shown here in Fig. 2. The four size groups are defined from quartiles constructed from the size distribution summed over both years. The smallest cloud clusters occur either at the east side of the Bay near shore, or over land. As the cloud clusters increase in size, they are less likely to occur over land and more likely to occur in the middle and northwest side of the Bay.

We find that it is the smaller, less-cold, shorter-lived cloud systems close to the eastern shore that contribute most of the rainfall in the Bay of Bengal. This contrasts with other, similar studies, for example the tropical western Pacific, that determine that it is large cloud systems that are responsible for most of the tropical precipitation. At the east side of the Bay, seasonal-mean low-level onshore winds come upon onto a coastal mountain range. The diurnal cycle is typical of that of other coastline regions around the world (not shown). This consistent local-scale cycle occurring within a monsoonal context is then responsible for some of the heaviest rainfall in the world.

At the northwest side of the, Bay the dynamics are very different and much more influenced by the larger-scale circulation. The monsoonal-mean sea level pressure minimum occurs here (Figure 1c and d). The maximum in the mean 850 mb relative vorticity, an indicator of the occurrence of circulation centers, occurs slightly south of the surface low for both 1988 and 1999.

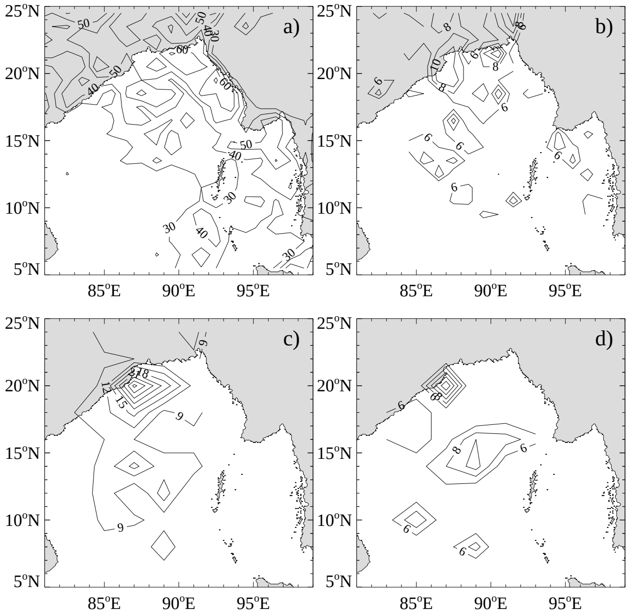

FIG. 2: Locations of the cloud clusters of both years within the a) lowest ($r < 85$ km), b) 2nd ($85 < r < 140$ km), c) 3rd ($140 < r < 210$ km) and d) top quartile ($r > 210$ km), expressed as countours of the number of clusters. Panels a) and b) are at a 1° resolution and panels c) and d) at a 2° resolution.

A secondary maximum in large cloud clusters occurs near the location of the JASMINE IOP, or about 89°E and 11°N (Fig. 2d). The nocturnal rainfall, large cloud cover, and southward propagation of the experienced JASMINE IOP convection are consistent with climatology. The JASMINE convective intensity was unusual, however, and is speculated to be an influence of the preceeding, dry middle-tropospheric conditions.

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