DIURNAL CYCLE OF CLOUD AND PRECIPITATION ASSOCIATED WITH THE NORTH AMERICA MONSOON SYSTEM: A CASE STUDY FOR 2003 AND 2004

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1. INTRODUCTION

Despite its importance, diurnal cycle of cloud and precipitation over the globe has not been examined thoroughly, due primarily to the lack of observation data with appropriate temporal and spatial resolution. Recently, new systems have been established at the NOAA Climate Prediction Center (CPC) to produce high-resolution gridded fields of satellite-based cloud and precipitation data sets on a quasi real-time basis over the globe.

In this work, we examine the diurnal cycle of cloud and precipitation associated with the North American Monsoon System [NAMS] for summers of 2003 and 2004 using these newly available high-resolution satellite data sets.

2. CLOUD AND PRECIPITATION DATA

Three satellite-based data sets are used in this study to examine the diurnal cycle of cloud and precipitation over Mexico and Southwest United States.

The global full-resolution infrared (IR) data set of Janowiak et al. 2001] are constructed by inter-calibrating and merging observations from several geostationary satellites. Gridded fields of surface / cloud top temperatures are generated on a 4km x 4km resolution over the global domain [60^{o}S-60^{o}N] in 30-min intervals since February 2000.

The high-resolution precipitation data are created by a new method called CPC Morphing technique (CMORPH, Joyce et al. 2004). The CMORPH technique defines precipitation estimates by temporal-spatially interpolating precipitation estimates based on satellite microwave observations through cloud advection vectors computed from consecutive cloud images. Gridded fields of precipitation are produced on an 8km x 8km grid over the global domain [60^{o}S-60^{o}N] since December 2002.

In addition, the TRMM Precipitation Radar (PR) observation data (2A25) are used to examine the three-dimensional structure of the NAMS precipitation. Covering a period from December 1997, the TRMM product 2A25 includes estimates of instantaneous rainrates on a 4km x 4 km horizontal and 250 m vertical resolution over a span of ~450km across the satellite orbits over the global tropical belt [37.5^{o}S-37.5^{o}N].

The above-described IR, precipitation and TRMM PR data over Mexico, Southwest United States and their adjacent oceanic areas [120^{o}W-90^{o}W; 22^{o}N-32^{o}N, figure 1] are extracted from the global fields. Three-hourly values of cloudiness, surface precipitation and 3-D precipitation rates are calculated on a 0.25^{o}lat/lon grid for the summers [May – October] of 2003 and 2004. For the IR data, fractional coverages of clouds colder than 215^{o}K, 235^{o}K and 255^{o}K are calculated to represent high, middle and low clouds, respectively.

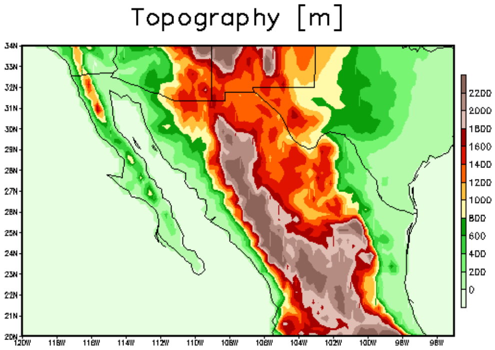

Fig.1: Topography [m] of the target area of this study.

3. DIURNAL CYCLE

As a first step, we examined the spatial distribution of mean cloudiness and surface precipitation over the 6-month period from May to October of 2003 (figure 2).

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Cloud and precipitation associated with the North American Monsoon System [NAMS] appear as extended bands over both the west and east coasts of Mexico along the mountain ranges. Cloudiness is more frequent and precipitation is heavier over the west coast than those over the east coast.

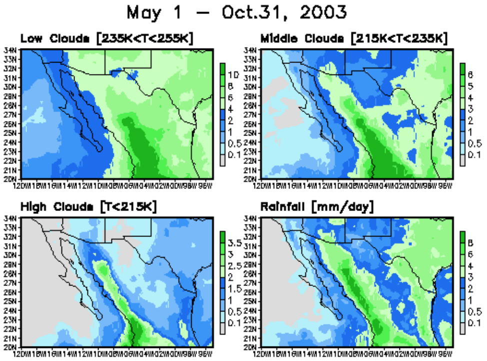

Fig.2: Distribution of the 6-month mean cloudiness (%) for low (top left), middle (top right), and high (bottom left) clouds, and precipitation (mm/day) over the target domain.

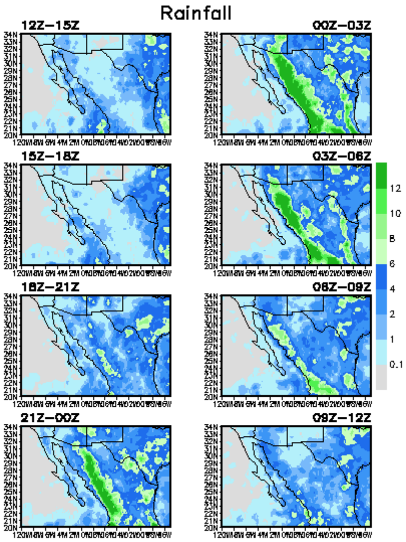

Fig. 3: Distribution of 3-hourly mean precipitation (mm/day) over the 6-month period from May to October, 2003.

A strong diurnal cycle of cloudiness and precipitation is observed during the summers of 2003 and 2004. Precipitation and high clouds (not shown) have a minimum in the morning [12Z-15Z], develop their extension and strength in the afternoon and reach the maximum in late afternoon [00Z-03Z, Fig.3]. The frequency of the low clouds [Fig. 4] exhibits a diurnal cycle similar to that of the precipitation and high clouds but with the maximum delayed for ~3 hours.

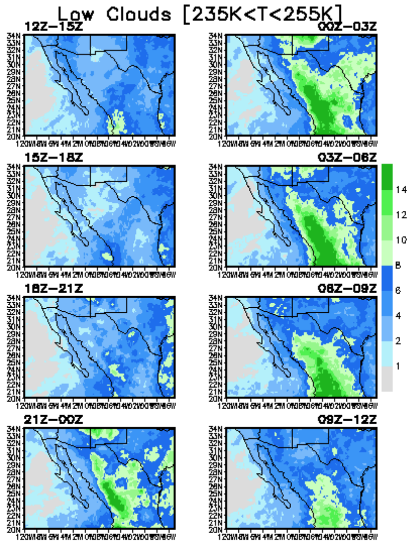

Fig. 4: Same as in fig.3, except for low clouds (%).

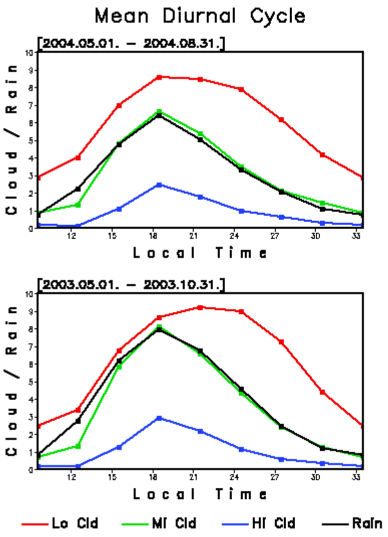

Fig. 5: Diurnal cycle of precipitation (black) and cloudiness for high (blue), middle (green) and low clouds (red) averaged over a spatial domain from 22^{o}N-32^{o}N, 5^{o} west and east to the crests of the Sierra Madre Occidental mountain range for summers of 2003 (bottom) and 2004 (top).

To further quantify the diurnal cycle of clouds and precipitation associated with the NAMS, mean values of cloudiness and precipitation are calculated over a spatial domain from 22^{o}N-32^{o}N and 5^{o} west and east to the crests of the Sierra Madre Occidental mountain range (figure 5). On average, clouds / precipitation starts at ~09LST, reach maximum at ~18LST and then diminish during evening time. A flat tail is observed in the amount of low clouds after they reach the maximum, a reflection of the existence of canopy of cirrus, which has similar TBB as the low clouds, after the peak of convection.

A brief examination of the time series of the mean precipitation over the spatial domain (Fig. 6) shows that the phase of the diurnal cycle is relatively stable throughout the period, while its magnitude presents changes of synoptic and intraseasonal time scales, indicating that the diurnal cycle is modulated by the large-scale circulation and moisture fields.

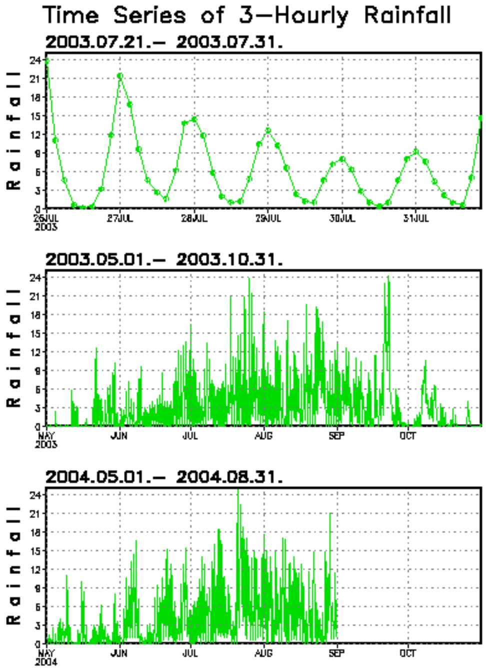

Fig. 6: Time series of precipitation (mm/day) averaged over a spatial domain from 22^{o}N-32^{o}N, 5^o west and east to the crests of he Sierra Madre Occidental mountain range for summers of 2003 (middle) and 2004 (bottom). The top panel shows the results for a sub-period of 6 days, while the bottom panel presents time series for the entire period.

4. OROGRAPHIC EFFECTS

Topography plays an important role in driving the regional circulation and thereby the evolution of cloud and precipitation systems. To examine the relationship between orography and clouds / precipitation, composite maps of the east-west section of mean cloudiness and precipitation are constructed for each of the 3-hourly box and relative to the position of mountain crest [Fig.7]. Cloud and precipitation systems start from higher elevation in the morning, move toward the coast as they reach the maximum in late afternoon.

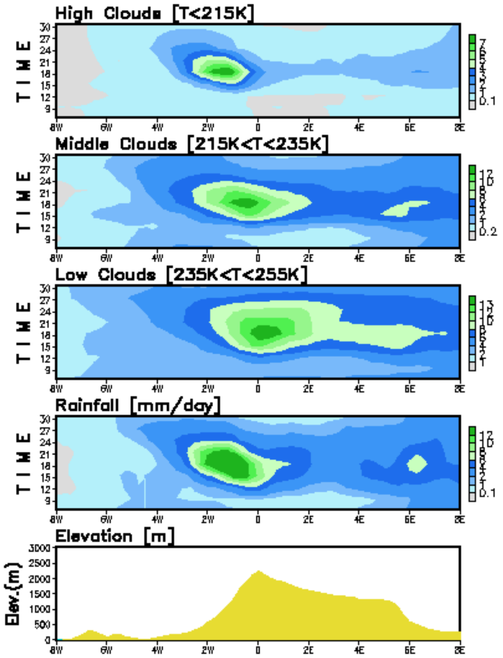

Fig. 7: East-west section of 3-hourly mean cloudiness averaged from 22^{o}N to 32^{o}N relative to the crests of the Sierra Madre Occidental mountain range, together with the mean elevation (bottom).

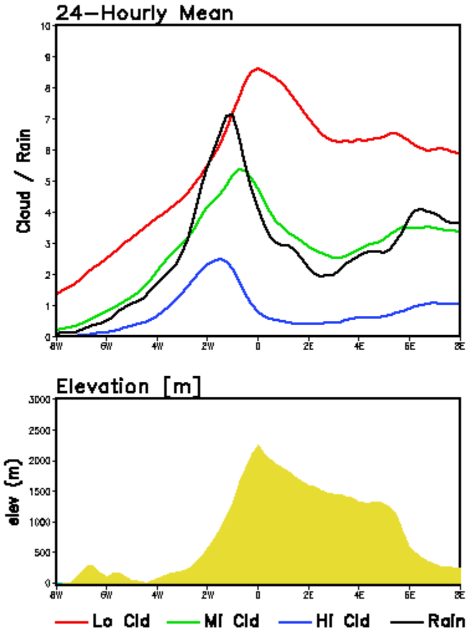

Fig. 8: East-west section of 24-hourly mean cloudiness averaged from 22^{o}N to 32^{o}N relative to the crests of the Sierra Madre Occidental mountain range, together with the mean elevation (bottom).

An east-west section of the 24-hourly mean cloudiness [Fig. 8], meanwhile, shows that position of maximum cloudiness for higher clouds is west to that for warmer clouds, with the center of deep convection and precipitation located ~100km west to the mountain crest.

This westward tilt of the maximum convection can be confirmed from the three-dimensional observations of the TRMM Precipitation Radar (PR). The east-west section of the mean PR precipitation (figure 9) shows that the strongest and deepest convection, reaching as high as 15km, is ~100km to the west of the mountain crest.

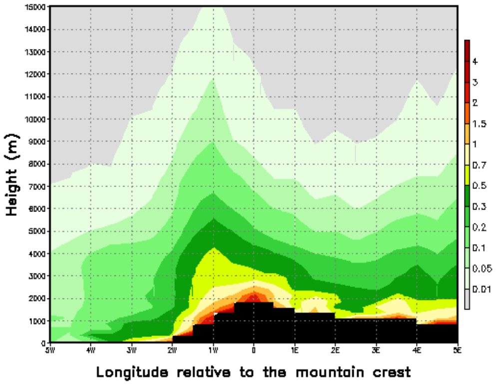

Fig. 9: Height-longitude section of mean precipitation observed by the TRMM PR for a 6-month period from May to October 2003. Precipitation is averaged from 22^{o}N to 32^{o}N relative to the crests of the Sierra Madre Occidental mountain range.

5. SUMMARY

A comprehensive diagnostic study has been performed to describe the temporal-spatial structure of the mean state and diurnal cycle of the NAMS cloud and precipitation systems for the summers of 2003 and 2004. Our results showed the following:

1) Variations of cloudiness and precipitation associated with the North American Monsoon System (NAMS) are dominated by the diurnal cycle;

2) Clouds / precipitation start from higher elevation in the morning, move toward the coast as they reach the maximum in late afternoon;

3) The phase of the diurnal cycle is relatively stable, while the magnitude presents changes of synoptic and intraseasonal time scales; and

4) Maximum of deep convection appear ~100km west to the mountain crests.

Further work is underway to extend the examination for other years and to investigate the relationship between changes in diurnal cycle and large-scale circulation and moisture fields.

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