Diurnal variability in the monsoon region: Preliminary results from the CEOP Inter-Monsoon Studies (CIMS)

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1. Introduction

CIMS is a CEOP scientific initiative to assess, validate and improve the capabilities of climate models in simulating physical processes in monsoon regions around the world. CIMS will be conducted in conjunction with the two other CEOP initiatives; the Water and Energy Balance Studies and the Watershed Hydrology to demonstrate the utility of CEOP data for better understanding of the regional and global water cycle and for model physics improvement. Model validation data will be derived from CEOP global data sets, model location time series (MOLTS), as well as in-situ observations from reference sites, which include GEWEX continental scale experiments (CSE). In CIMS, numerical experiments will be designed and targeted towards simulation of fundamental physical processes that will likely lead to identification of basic errors and biases in model physics. For this purpose, a hierarchy of models including general circulation models (GCM), regional climate models (RCM) and cloud resolving models (CRM) will be used. Monsoon processes are targeted in CIMS because of their scientific values and their importance in improving weather and climate predictions in the global tropics and extratropics. Moreover, monsoon processes involve strong interactions of atmosphere, the land, the biosphere and the oceans, and constitute the basic building blocks of climate models.

CIMS should be considered not only as a research project for CEOP but also a pilot research effort, towards the broader goal of improving model physics parameterization for climate predictions and global change projections. As such, the coordination with on-going model inter-comparison projects and GEWEX and CLIVAR modeling initiatives are critically important for CIMS. For more details of CEOP and CIMS, the readers are referred to the CIMS report on http://www.ceop.net.

2. Objectives of CIMS

There are myriad physical processes governing the variability of monsoon regions ranging from supercloud cluster organization, cumulus, stratocumulus cloud formation, boundary layer processes, surface radiative and hydrologic forcings, air-sea, and air-land interactions to biosphere feedbacks, and anthropogenic impacts. From a modeling viewpoint, the most fundamental processes are those associated with the diurnal cycles, the annual cycles and monsoon intraseasonal oscillations. Identifying model errors and biases in the these fundamental processes will provide important clues for improving model physics particularly with respect to the better understanding of the water and energy cycles, and interactions of the atmosphere with land and oceanic surface processes. Realistic simulation of these processes is a pre-requisite for better climate predictions on seasonal, interannual and longer time scales. Specific objectives of CIMS are:

i) To provide better understanding of fundamental physical processes underpinning the diurnal and annual cycles, and intraseasonal oscillations in monsoon land and adjacent oceanic regions of Asia, Australia, North America, South America and Africa.
ii) To demonstrate the synergy and utility of CEOP integrated satellite data, *in situ* observations and assimilated data in providing a pathway for model physics evaluation and improvement

3. Preliminary results

All monsoon regions of the world are known to have pronounced diurnal cycle variability. According to previous studies, deep convection and associated precipitation tend to peak in the late afternoon or evening over land areas, and in mid-night to early morning over adjacent oceanic regions. However, there are large variations to this basic theme in different monsoon regions. In addition, the amplitudes of the diurnal cycle are often strongly modulated by daily and synoptic scale forcings. In the following, we provide some highlights of CIMS-related ongoing research focusing on the daily and diurnal variability over different monsoon regions.

a. Himalayas regions

The Himalayas region provides strong orographic and thermal forcings on the Asian monsoon. The daily and diurnal rainfall in this region is very complex. A preliminary analysis of precipitation variability during the EOP-1 was conducted at the CEOP Himalayas Reference Site (HRS). Surface data were collected at the Pyramid AWS (5035 m above sea level), established by a collaboration effort among Ev-K2-CNR, the Epson Meteo Centre and the Water Research Institute/CNR, and at Syangboche AWS (3833 m above sea level), established by the Glaciological Expedition of Nepal and maintained by GAME-AAN project. The two AWSs are located about 20 km apart along the Khumbu Valley, that runs from southwest to northeast reaching Mt. Everest. AWSs data were compared to TRMM 2A25 PR instantaneous observations and 3B42 daily rainfall rate gridded at 1°x1° resolution, and with NASA's Global Modeling and Assimilation Office (GMAO, formerly the Data Assimilation Office) GEOS-3 3-hr accumulated precipitation data at the HRS (27.96°N, 86.81°E, which is Pyramid AWS' location). The current analysis was limited to July 2001, when air temperature was constantly above 0°C, to avoid errors related to solid precipitation measurement.

Daily total precipitation is represented in Fig.1a, together with estimated values from NASA's GMAO MOLTS and TRMM (average over the mesh 27°-28°N; 86°-87°E, which encloses the two AWSs). Both measured precipitation series exhibit a strong and similar intra-seasonal cycle. The only discrepancy around 10-11 July was checked by the snapshot of TRMM/PR at 1230 UTC, when the satellite passed just over the Khumbu Valley showing isolated meso-scale convection prevailing only over Syangboche AWS. Such convective cells with sub-regional fine structure may cause large discrepancy even at points only 20 km apart.

A large precipitation event on 19-20 July is evident in all of the series. The agreement of GMAO with observations is good; however, GMAO tends to underestimate precipitation during the most intense events, even if the monthly total is close to observations (about 91% of what is observed at the Pyramid). TRMM estimates reproduce observations very well. Daily variations of precipitation are strongly correlated with synoptic scale forcings associated with the fluctuations of the Tibetan High. The synoptic scale forcings strongly modify the amplitude, and possibly the phases of the diurnal cycle (e.g., Ueno et al., 2001a; Bollasina et al., 2002).

Figure 1b shows the diurnal variation of 3-hourly precipitation at the two AWSs, in comparison with NASA's GMAO MOLTS. At higher altitude (Pyramid), precipitation has two distinct peaks, one in the (local) early afternoon, and the other at midnight. At lower altitude (Syangboche), precipitation is more concentrated from the evening to the early morning. Differences in precipitation as a function of elevation is very important for surface hydrology, and its mechanisms have been discussed based on thermally induced local circulation under the condition of constant large scale monsoon upslope flow (e.g., Ueno et al., 2001b; Barros and Lang, 2003). For instance, strong daytime precipitation may be caused around the ridges, and local scale convergence or radiative cooling may cause night time precipitation at lower elevation. The MOLTS data show comparable magnitude, with a single peak about 3 hours (6 hours) advance of Pyramid (Syangboche).

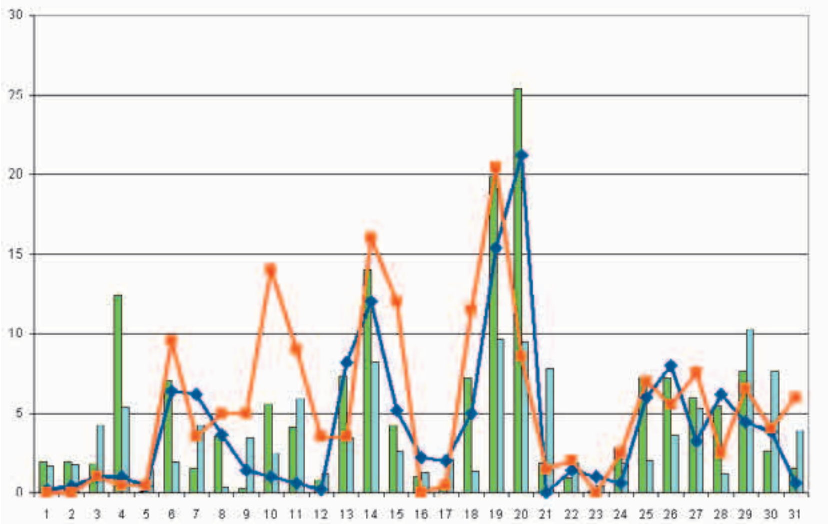

Figure 1a Time series of daily total precipitation (mm) observed at Pyramid (dark blue line) and at Syangboche (red line), estimated by GMAO MOLTS (light blue rectangles) and TRMM data (green rectangles) during July 2001.

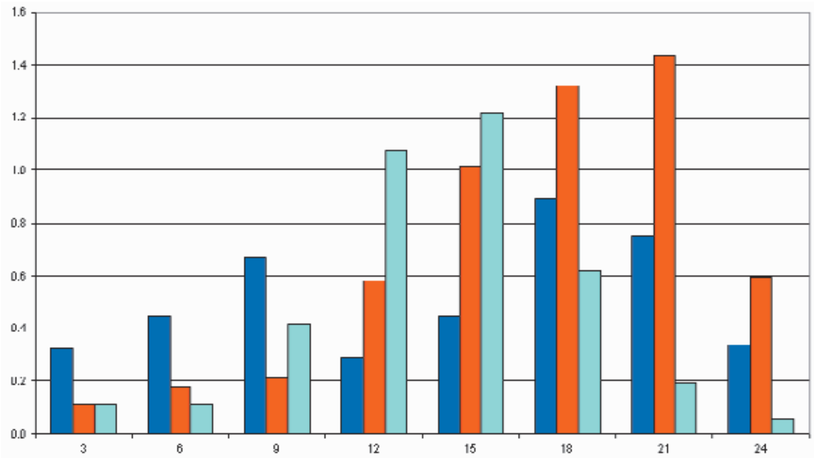

Figure 1b Diurnal cycle of average 3-hourly total precipitation (mm) at Pyramid (dark blue) , Syangboche (red) and estimated by GMAO MOLTS (light blue) during July 2001. Time is in UTC (Nepal LT – 6-hr).

b. Other monsoon regions

Diurnal convection generated locally in monsoon regions may propagate systematically away from its source. Satomura (2000) simulated the diurnal variation of convective activity along east-west cross-sections of Indochina using 2-dimensional cloud resolving model (RAMS). Diurnal convection excited by topography in the afternoon propagates eastward during the nighttime, with an estimated speed of 7 ms-1. These results were consistent with radar observations from the GAME-tropics project. However, other more complex features such as early morning peak of convection in northeastern Thailand have not been simulated realistically. Thee-dimensional cloud resolving models is strongly recommended in CIMS.

In the equatorial region over the Sumatera Island, with the mountain range above 3000m, interesting diurnal movement of convective activity has been noted, based on analysis of GMS IR1 data by Sakurai et al. (2003). They found a diurnal cycle of convective activities which became active in mountainous region in the afternoon and migrated westward and/or eastward at a distance of several hundreds kilometers from midnight to morning (Fig. 2). The westward migration of cloud systems occurred in all areas almost throughout a year except in August. An area of eastward migration was observed in/near the ITCZ around 100oE. The area appeared to shift northward and southward with annual cycle. The reasons for the preferred eastward or westward propagations of diurnal oscillations are unknown, and should be clarified in future. Interaction between the diurnal cycle and seasonally varying monsoonal circulation will be a focus for CIMS.

In the American monsoon region, diurnal variability manifests itself not only in convection but also in low-level jet (LLJ). The LLJ's are generally found flowing parallel to north-south oriented mountain ranges such as the Andes for the South American monsoon (SAM), and the Sierra Madre for the North American monsoon (NAM) (e.g., Douglas 1995; Berbery 2001; Berbery and Fox-Rabinovitz 2003). The SAM LLJ is important in transporting moisture from tropical South America towards the subtropical monsoon region of southern Brazil and the La Plata Basin. Its diurnal cycle is not well known, with modeling studies suggesting a nighttime maximum that is consistent with the predominantly nighttime precipitation over La Plata basin (Berbery and Collini 2000), while other studies suggest that the strongest wind in the afternoon and its core maximum wind is located between 1600-2000 m (Marengo et al. 2002).

For the NAM, the Gulf of California (GC) LLJ is most pronounced in the early morning, along the coast of Mexico reaching the southwestern Arizona. This can be seen in Fig.3, which shows the 3-hourly moisture flux at 925 hPa, simulated by the ETA model and satellite estimated precipitation that includes TRMM. As the inland heats up during the afternoon, the LLJ gives way to a predominantly eastward flow, transporting moisture from the GC, which in terms leads to strong moisture convergence and peak diurnal precipitation along the coastal region of Mexico. Synoptic scale fluctuations of the LLJ of the GC are responsible for moisture surges, which may lead to the onset the monsoon rain in southwestern United States.

As shown in the aforementioned examples, diurnal variability in the monsoon regions represent a complex interplay of responses of convection, moisture and circulation to solar heating, thermal and mechanical effects from topography, latent heating from precipitation, and surface heating. As the first step for model physics improvement, climate models should be validated against their ability to reproduce the diurnal cycle.

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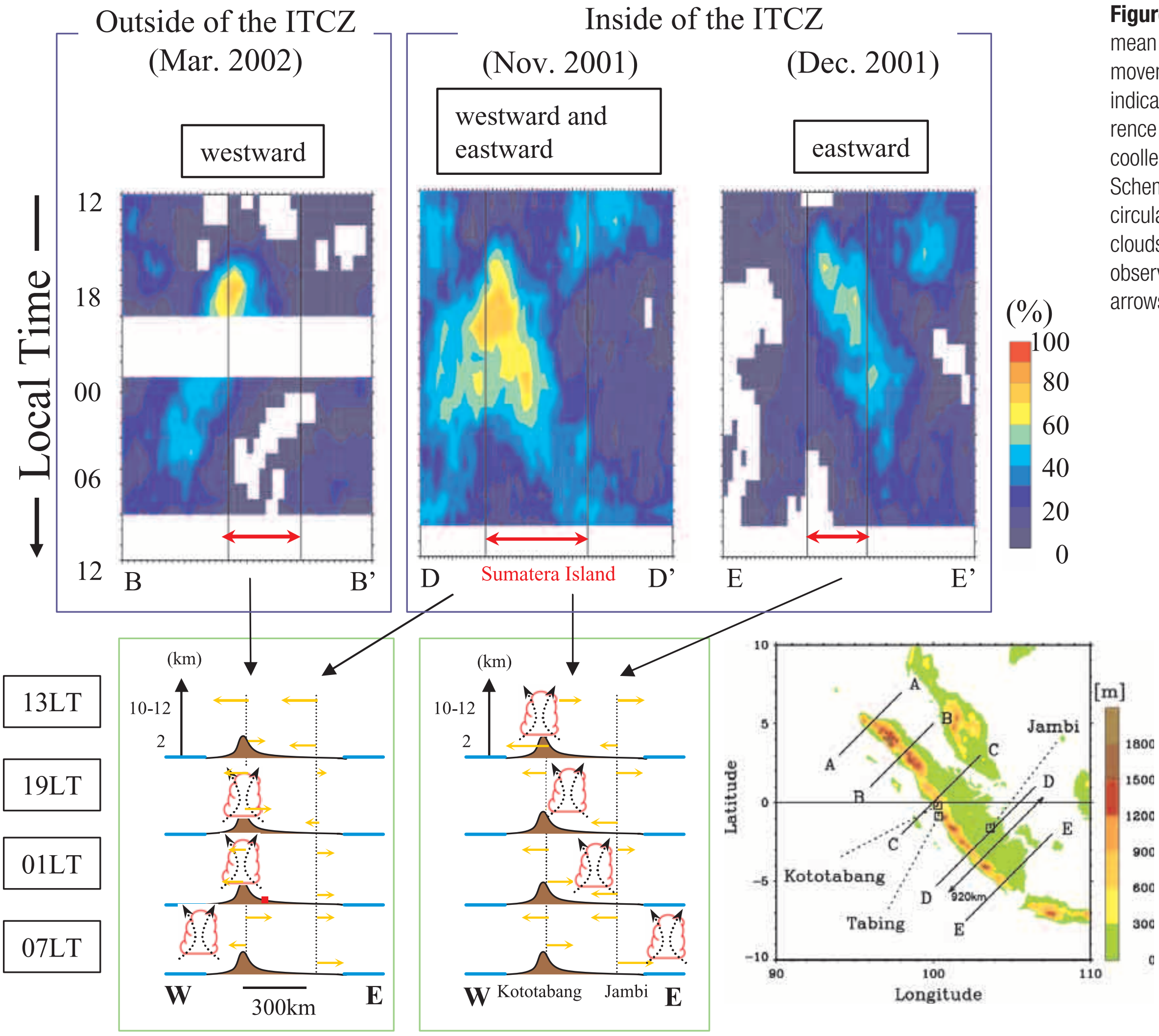

Figure 2 Upper panels: Monthly mean diurnal cycles of cloud movement over Sumatra Island, indicated by frequency of occurrence of cloud top temperature cooller tan 230K. Lower panels: Schematic showing structures of circulation around convective clouds based on rawinsonde observations indicated by yellow arrows (Sakurai et al., 2003).

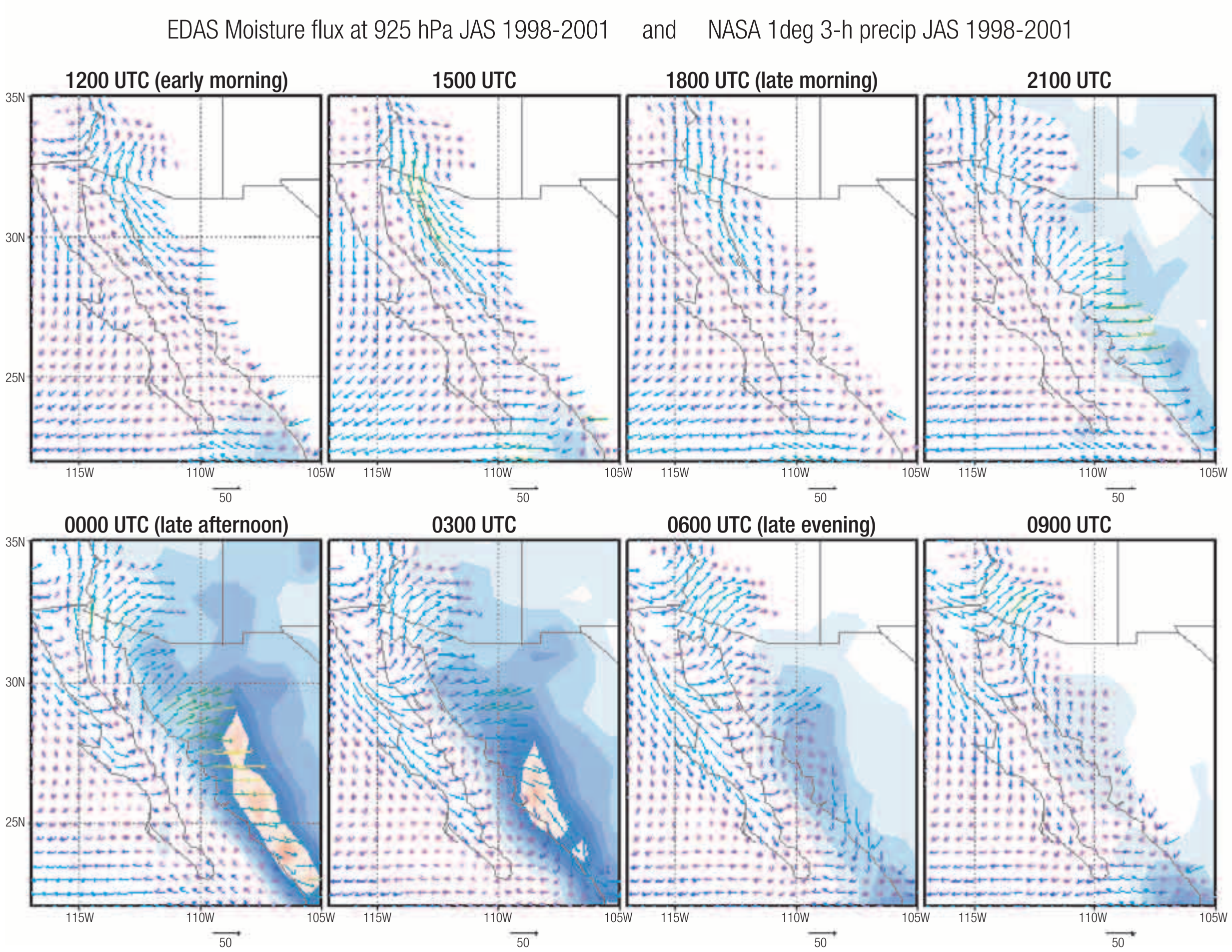

Figure 3 Diurnal cycle of vertically integrated moisture flux (gm Kg^{-1}ms^{-1}), and precipitation (mm/day) for the North American monsoon.