Effects of diurnal cycle on the Asian monsoon : Modeling study

[1]Jung-Eun Kim*, [1]Myung-Seo Koo,
[2]Masao Kanamitsu, and [1]Song-You Hong

[1]Yonsei University, Korea
[2]Scripps Institution of Oceanography, USA

Introduction

• **Observational studies for diurnal cycle of precipitation**

→ The maximum precipitation occurs in the late afternoon to early evening hours over land and at night or early morning over oceans.
→ It can be modulated by geographical (Dai 2001), and seasonal (Oki and Musiake 1994) characteristics.

• **Modeling studies for diurnal cycle of precipitation**

1) Evaluation studies
→ Dai and Trenberth (2004) / Basu (2007)
: Evaluate the diurnal cycle of precipitation in a GCM
→ Koo and Hong (2010)
: Investigate the diurnal variations of precipitation over East Asia using a RCM

2) Inevitable component
→ Neale and Slingo(2003) : critical role of the Maritime Continent over the western Pacific in a simulated global climatology
→ Sato et al. (20008) : resolution at less than 7 km in a simulated diurnal cycle of precipitation over Tibetan Plateau

Introduction

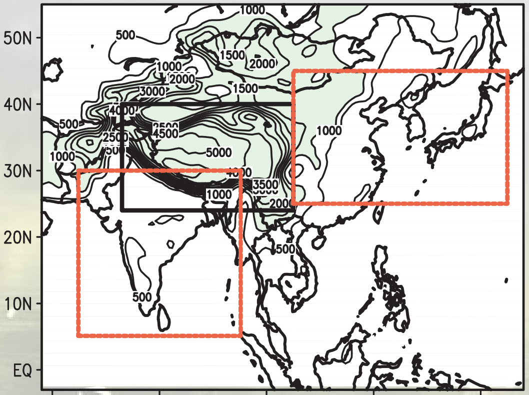
➔ **The diurnal forcing is a key factor in influencing the precipitation mechanisms over complex land-sea terrains, which in turn modulates large-scale circulations and embedded dynamics**

❖ Objective

- To examine the role of diurnal cycle on the summer monsoon circulations (precipitation) over Asia using a RCM

- Focusing on clarifying the diurnal effect of solar forcing on surface properties and upper-level features

- A dynamic influence of the Tibetan high on the monsoon climate will also be discussed.



Model setup

❖ **Model :** NCEP-RSM (*Regional Spectral Model)*

- Resolution : 151×112 (horizontal resolution : 60 km)
- Case : April to July 2004 (near normal monsoon) – MJJ for analysis
- Convective Parameterized Scheme : SAS (Park and Hong 2007)
- Planetary Boundary Layer scheme : YSU PBL (Hong et al. 2006)
- SW and LW

  : M.D. Chou short wave (Chou and Lee 1996) / long wave (Chou and Suarez 1994) radiation scheme
- I.C & B.C : NCEP/DOE Reanalysis 2 (Kanamitsu et al. 2002)

Characteristics / Experimnets	Solar forcing	SW/LW calculation interval
CTL	diurnal variation	SW=LW=1hr
NDI	Non-diurnal variation	SW=LW=24hr

Model setup

The daily-mean solar flux in NDI run is prescribed from the value integrated for a given date.

Solar zenith angle

H : a
sol

t to

$$\int_{sunrise}^{sunset} \cos \boxed{\Theta_0}(t)\ dt = \int_{-H}^{H} (\sin$$

$$\boxed{\omega}$$

A function of solar declaration angle and latitudes, but not the zenith angle

Angular velocity of the earth

$$\rightarrow \frac{1}{\pi}(\sin\varphi \sin\delta H + \cos\varphi\cos\delta\sin H)$$

$$*\cos H = -\tan\varphi\tan\delta$$

$$H = \cos^{-1}(-\tan\varphi\tan\delta) = \cos^{-1}(-\frac{\sin\varphi\sin\delta}{\cos\varphi\cos\delta})$$

Model setup

Characteristics / Experimnets	Solar routine	SW/LW calculation interval
CTL	diurnal variation	SW=LW=1hr
NDI	Non-diurnal variation	SW=LW=24hr

The radiation fluxes are computed every 24 hr when the R2 data are updated.

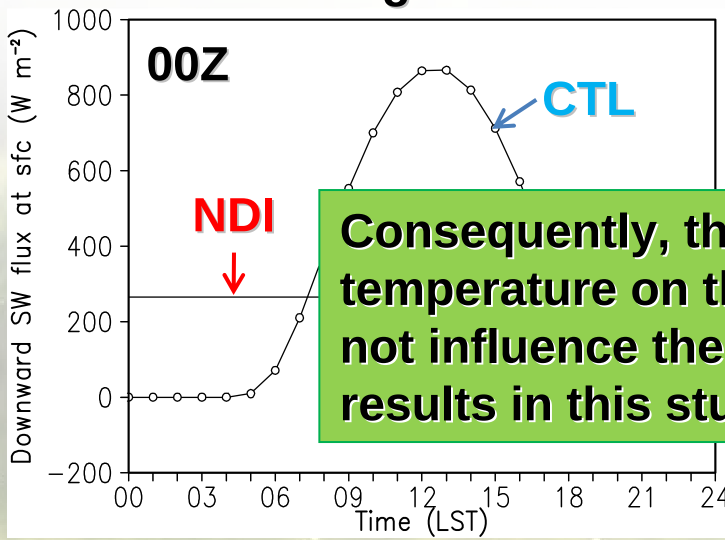
::: Remarks

1)The analyzed data from the R-2 are updated every 24 hr to remove the diurnal variation of large-scale forcing at the lateral boundaries.

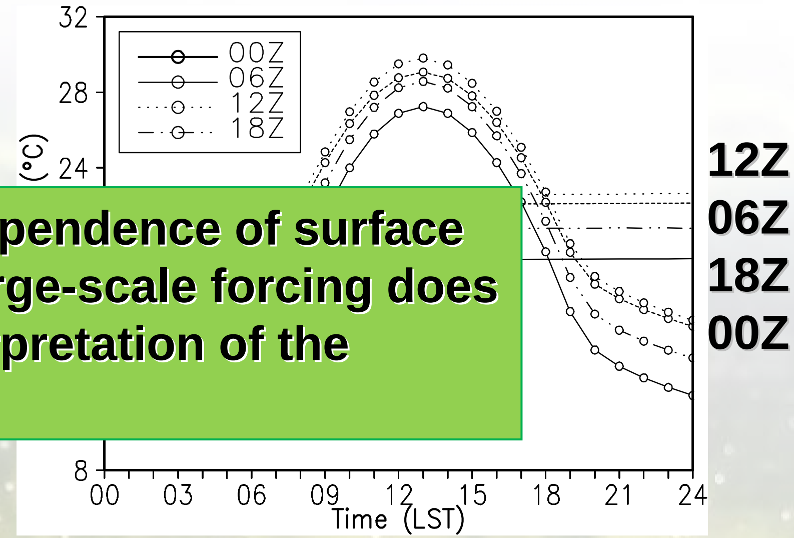
2) Four sets of exp. with different initial time starting at 06 12 18 (31 March) and 00 UTC (1 April) are performed.

Model setup Validation

Downward SW at the ground



SFC temperature



Consequently, this dependence of surface temperature on the large-scale forcing does not influence the interpretation of the results in this study !

Despite the same solar forcing used for both runs, the averaged solar flux from the CTL is greater than that from the NDI experiment.

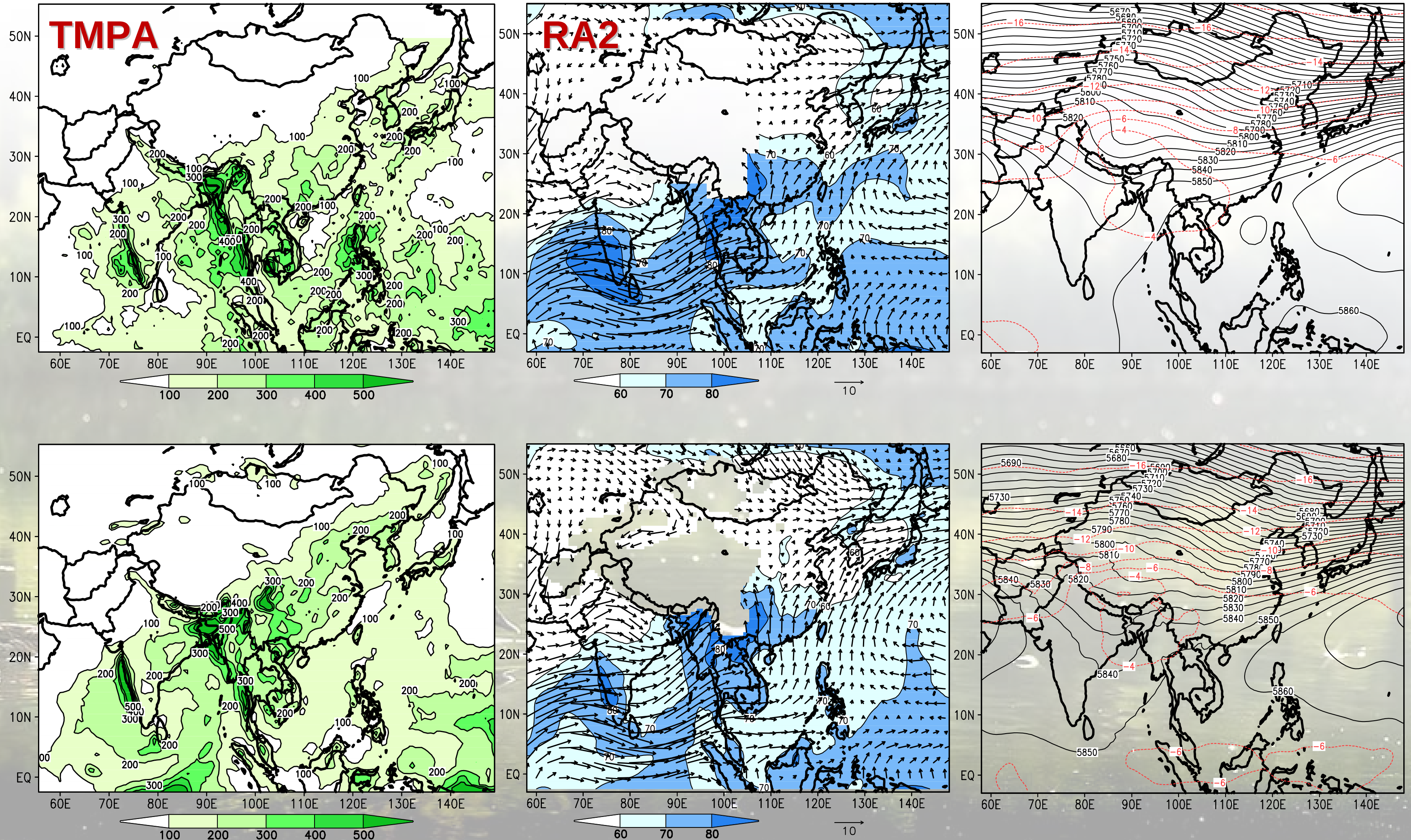
Simulation results depend upon the external large-scale.
However, the differences between CTL and NDI show the same direction for each set.

CNTL Evaluation

Precipitation | **850 hPa** | **500 hPa**

OBS

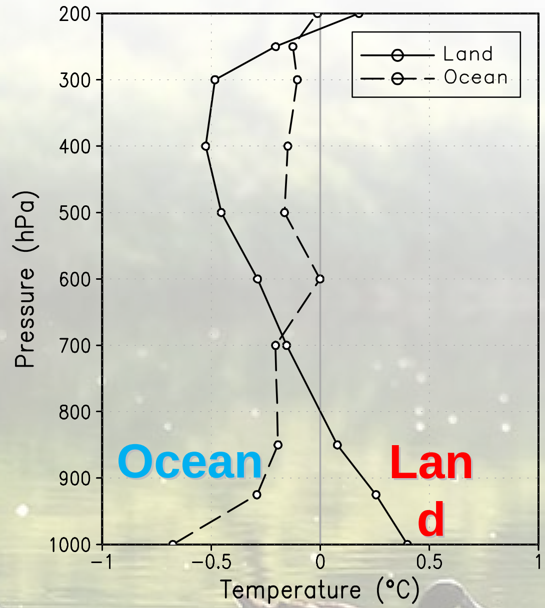
CNTL



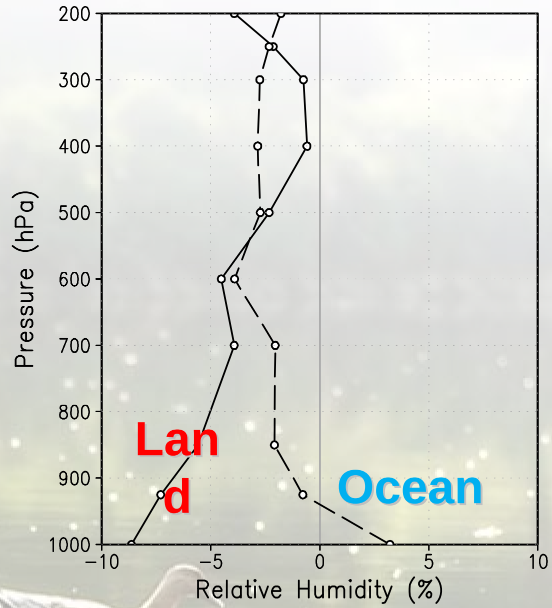
CNTL Evaluation

CTL-RA2

Temperature



Relative Humidity

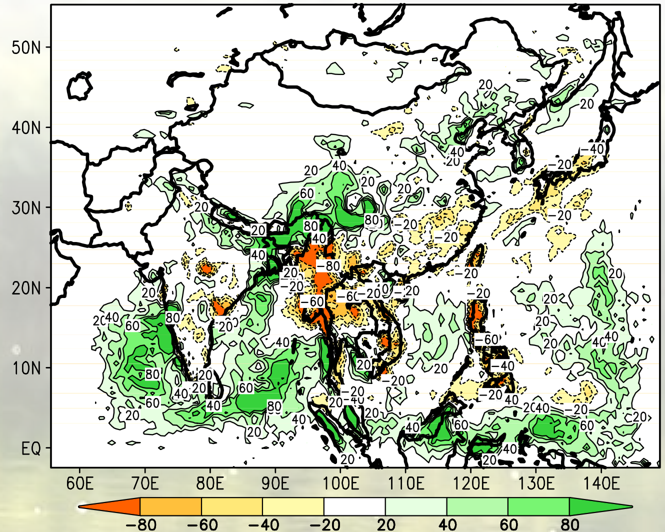


Even though the CTL shows unstable structure over land, and cold bias over oceans, the amount is not distinct.
→ It provides confidence in this sensitivity results

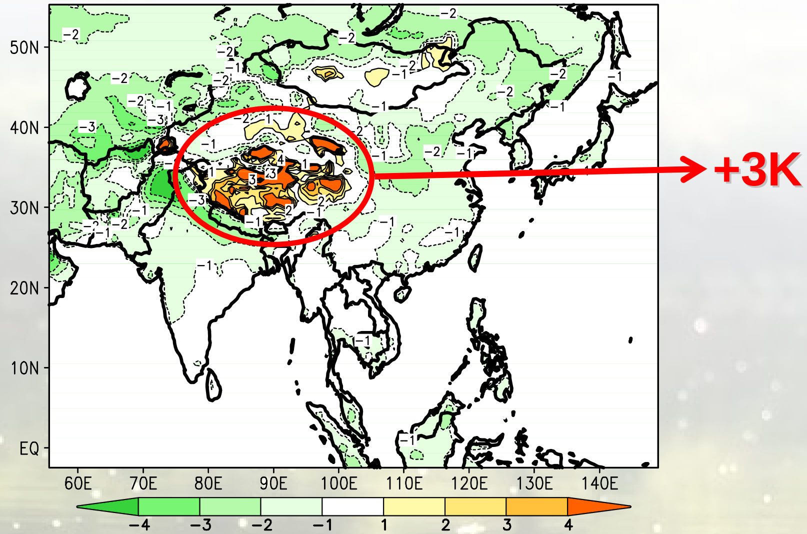
Effects of diurnal cycle
: CTL *vs.* NDI

SFC variables (1) CTL-NDI

Precipitation



SFC temperature

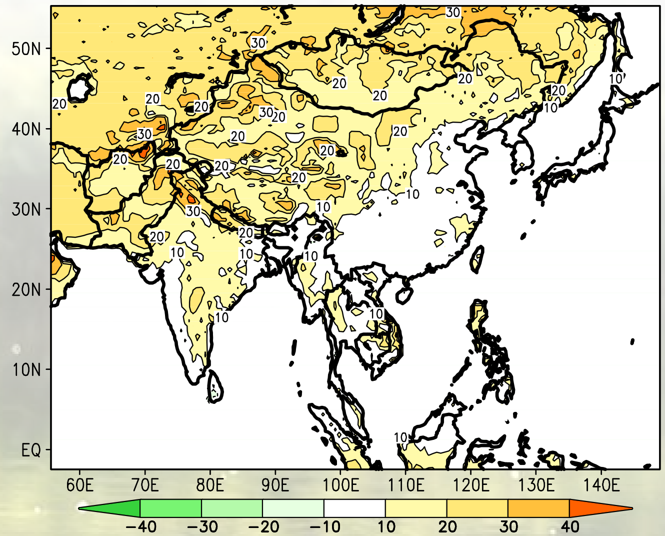


Land
+10.89 %

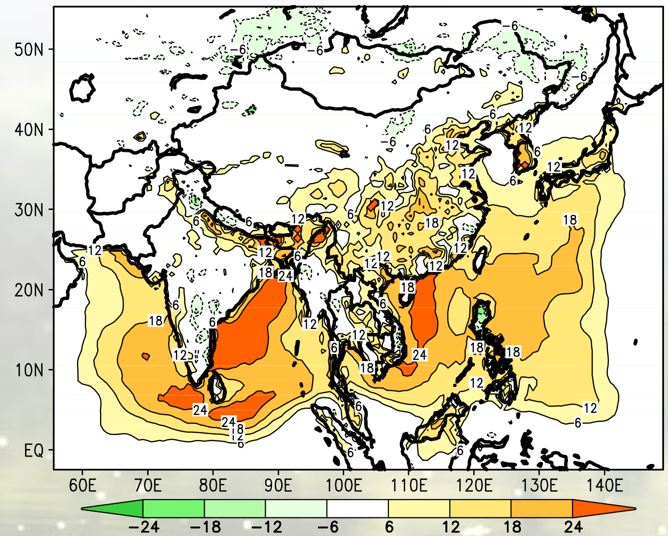
Ocean
+3.09 %

SFC variables (2) CTL-NDI

SH

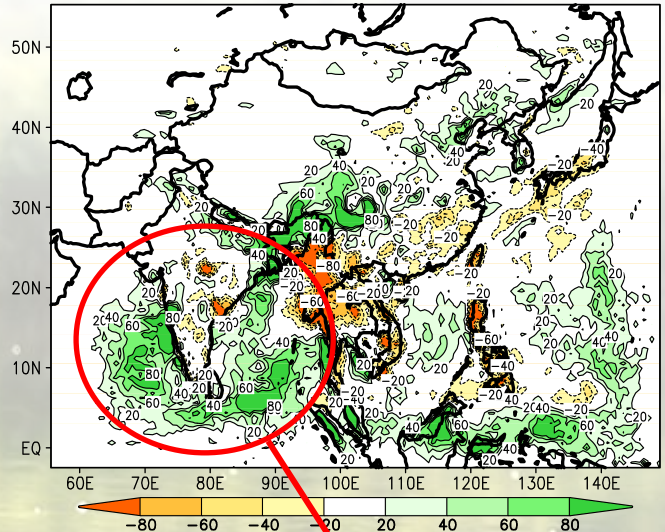


LH

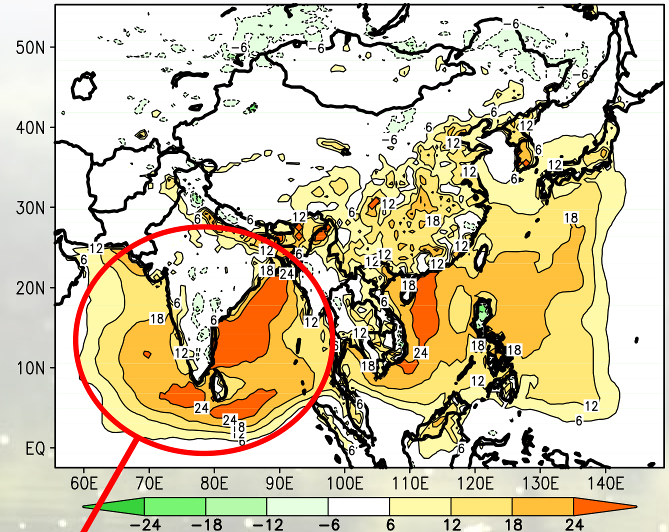


SFC variables (2) CTL-NDI

Precipitation



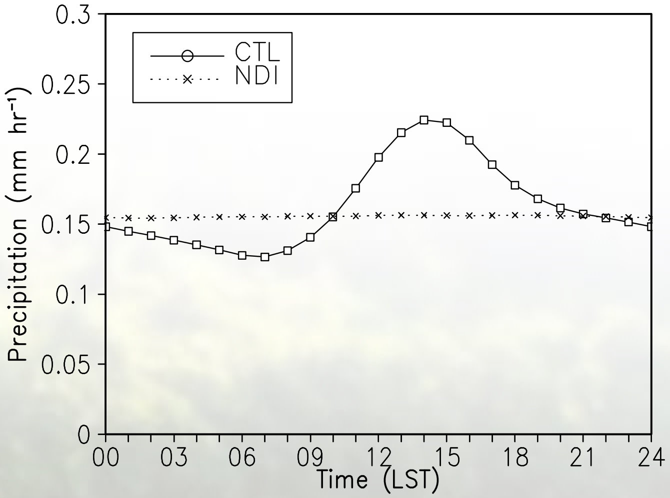
LH



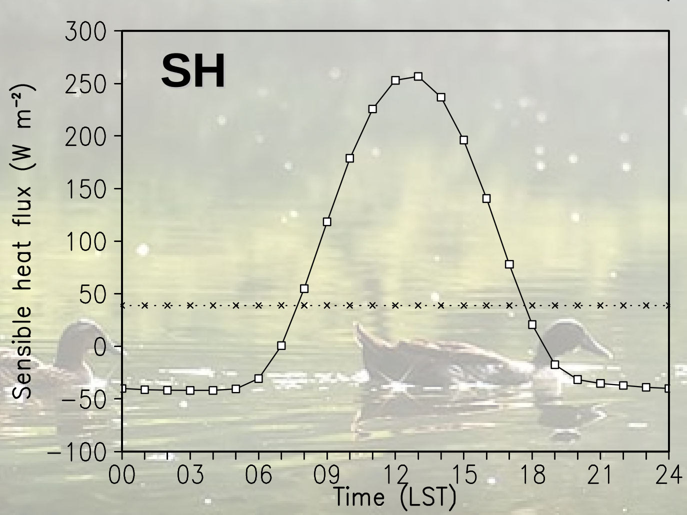
The areas of enhanced LH and precipitation are overlapped over the Indian oceans, but not in elsewhere.

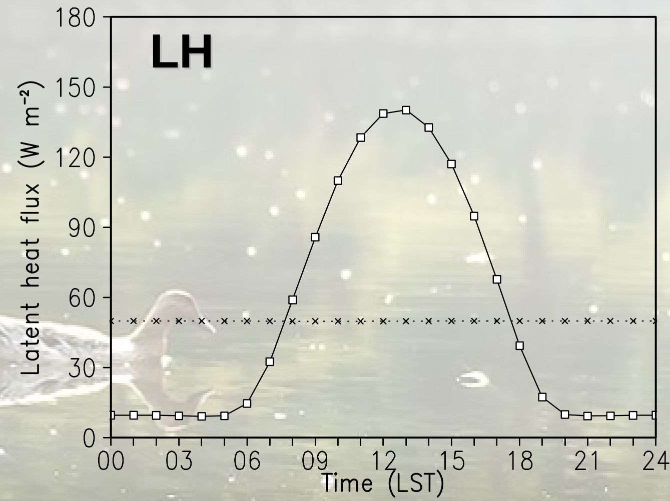
Diurnal variation over land

Precipitation



Precipitation from the CTL demonstrates a typical diurnal evolution having an afternoon peak and a lax suppression pattern at nighttime, whereas the corresponding simulation from the NDI shows a constant intensity.

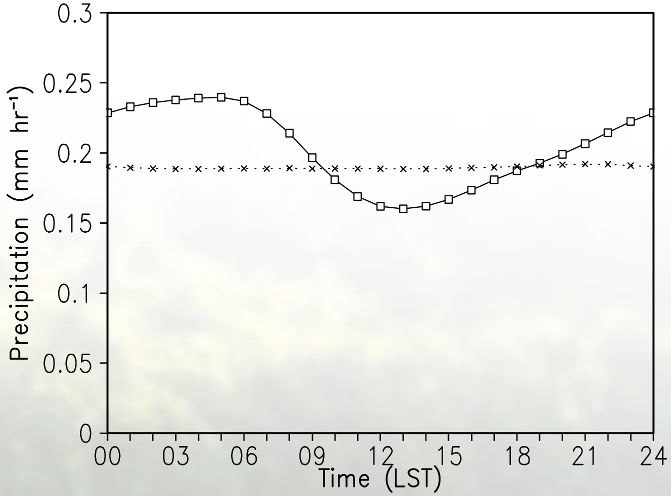




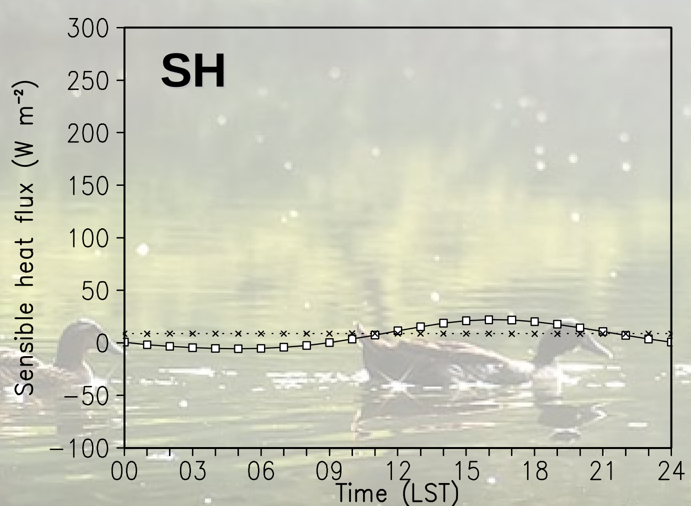
The averaged flux from the CTL run overwhelms the amount from the NDI run.

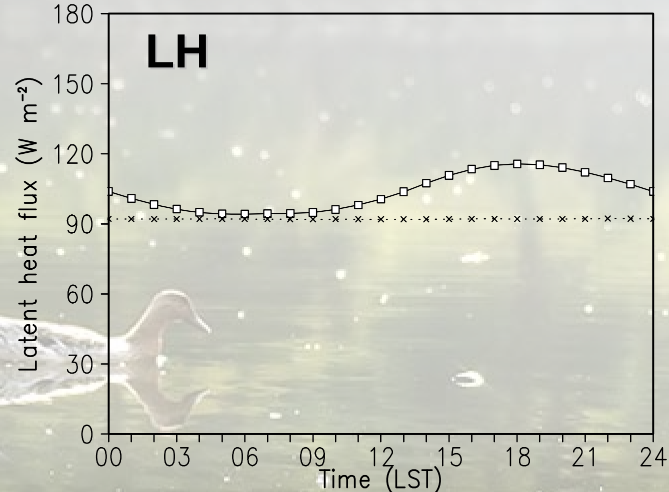
Diurnal variation over ocean

Precipitation



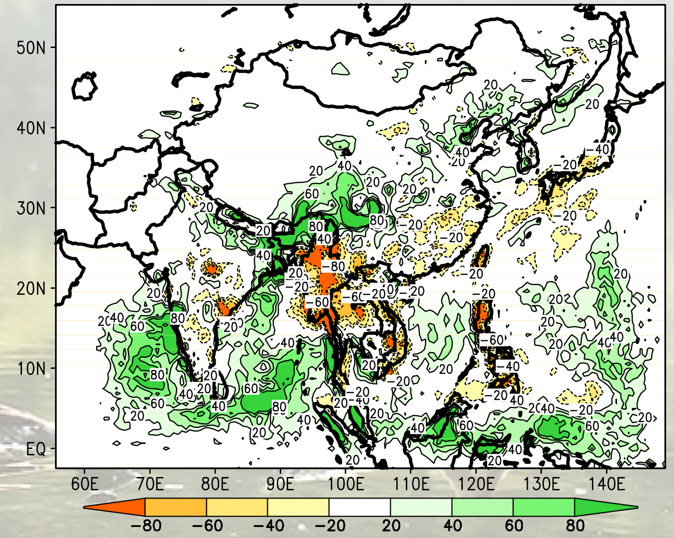
Over the ocean, precipitation is intense in nighttime than in daytime when the diurnal cycle is taken into account.
(← It is induced by the increase of RH due to cooler temperature.)





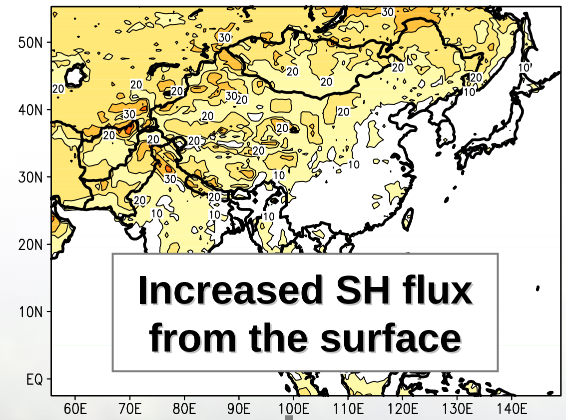
What is the physical link of increased precipitation in the presence of diurnal forcing effect?

Precipitation (CTL-NDI)



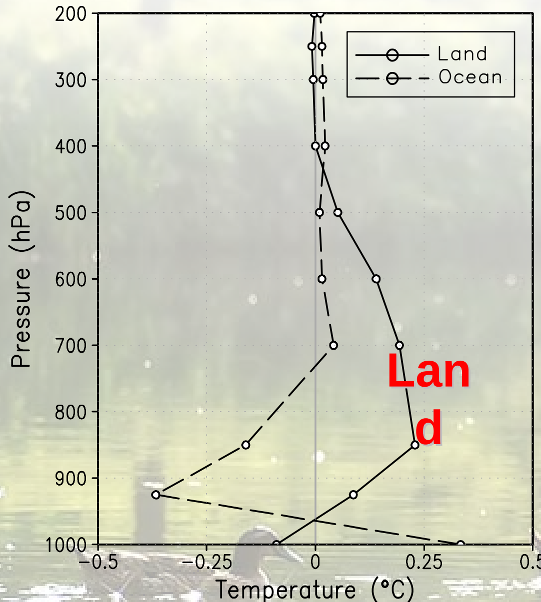
Vertical profile over Land

CTL-NDI

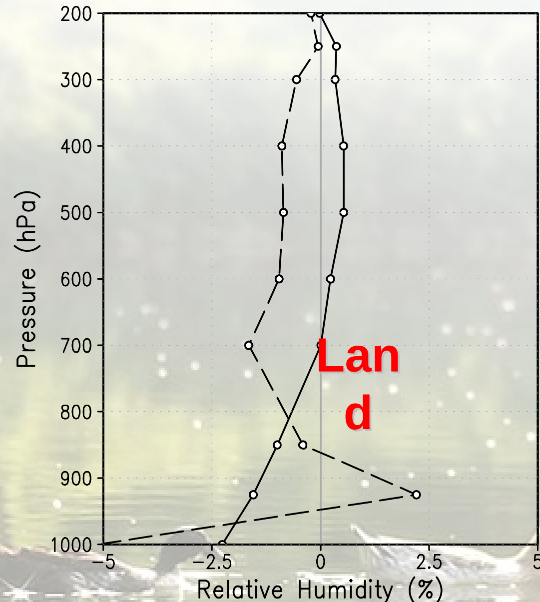


Increased SH flux from the surface

Temperature



Relative Humidity



Enhanced boundary layer mixing (PBL height is increased by 9.5%)

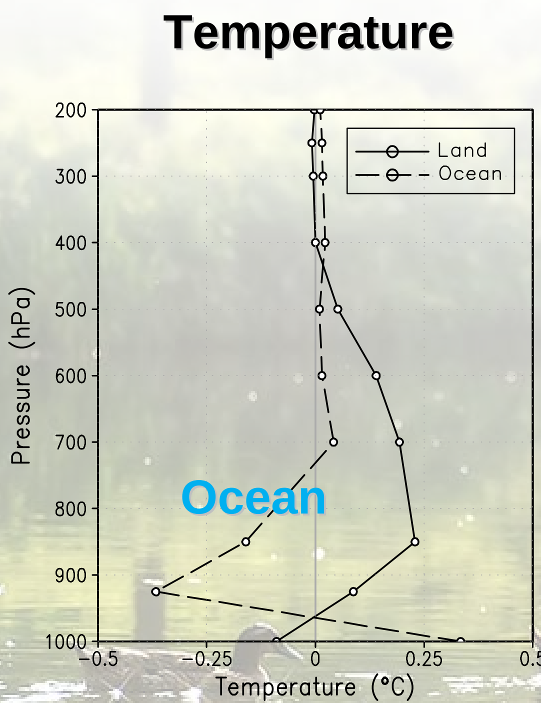
Warming in lower-troposphere

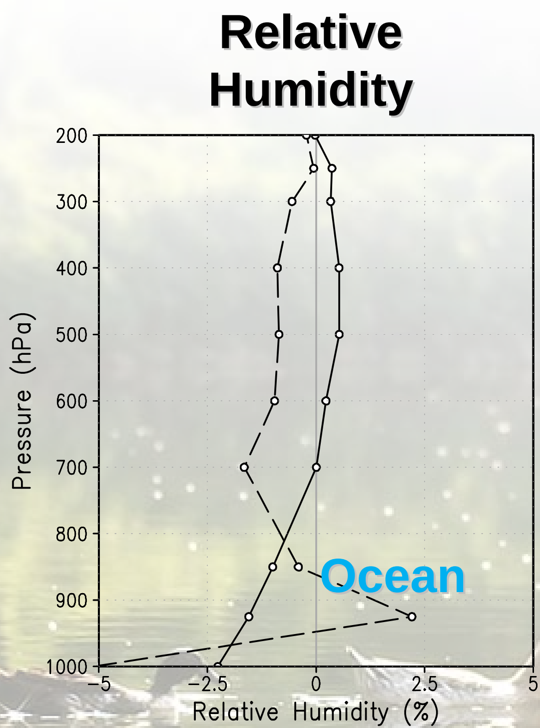
Reduction of moisture and temperature near the sfc

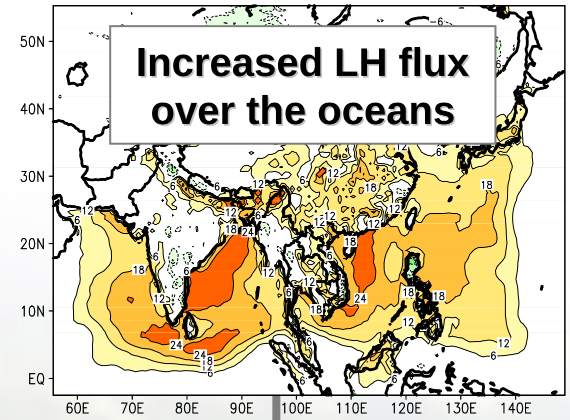
*** The positive heat fluxes due to the diurnal cycle transports heat and moisture upward. → It plays a role in enhancing the convective initiating, resulting in the increased precipitation.**

Vertical Profile over Oceans

CTL-NDI







Warming in the near surface & Cooling at 900 hPa

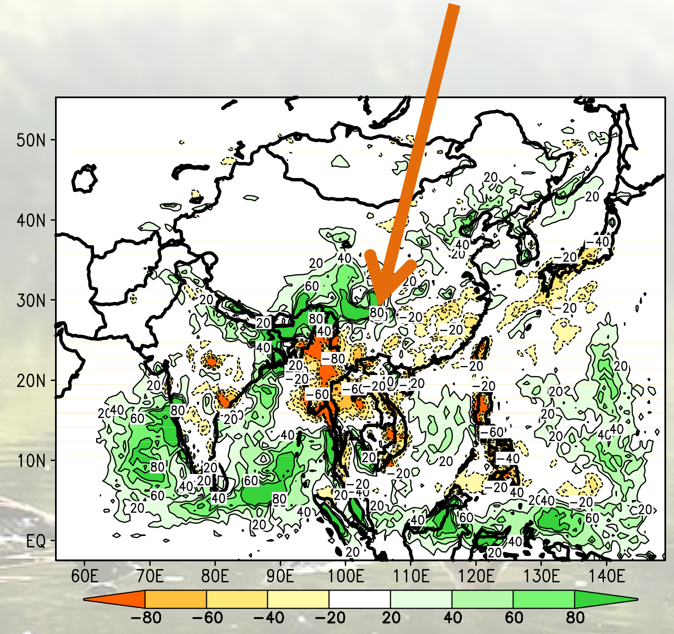
Enhanced boundary layer mixing (PBL height is increased by 65.3%) *cf.* Land : 9.5%

Transport moisture from the ocean into the atmosphere

*** The additional moisture that is accumulated near the surface in daytime brings about the cloud formation in the nighttime when the temperature is cooled.**

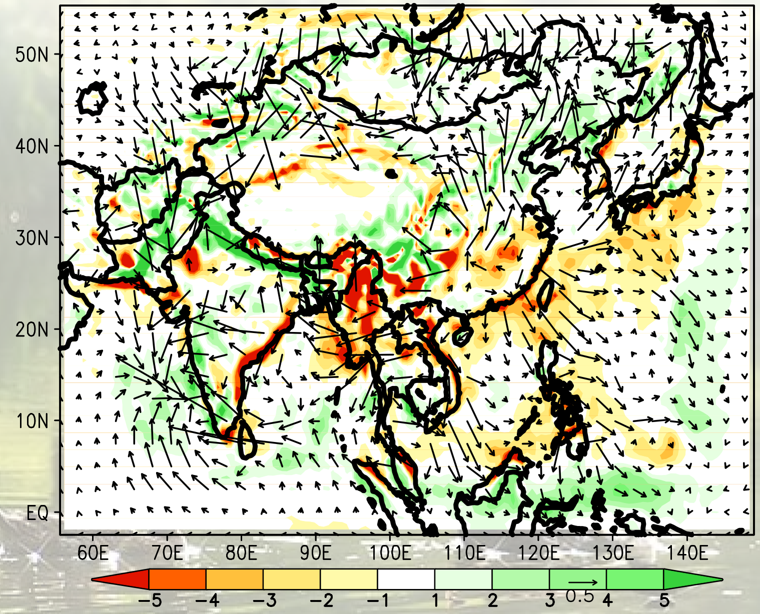
What is the reason for the reduction of precipitation over some areas centered in the Indo-China peninsula and south China?

Precipitation



Dynamic circulations CTL-NDI

850 hPa Wind (arrow)
Vertically integrated moisture convergence (shading)

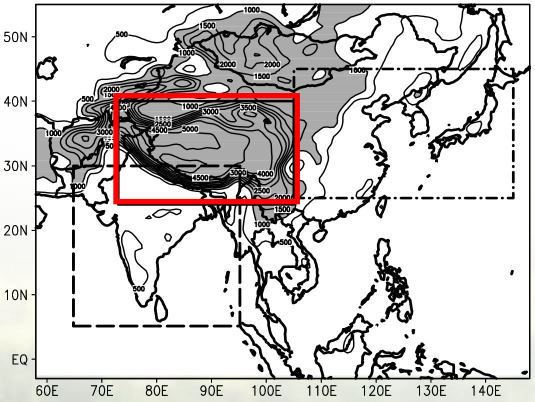


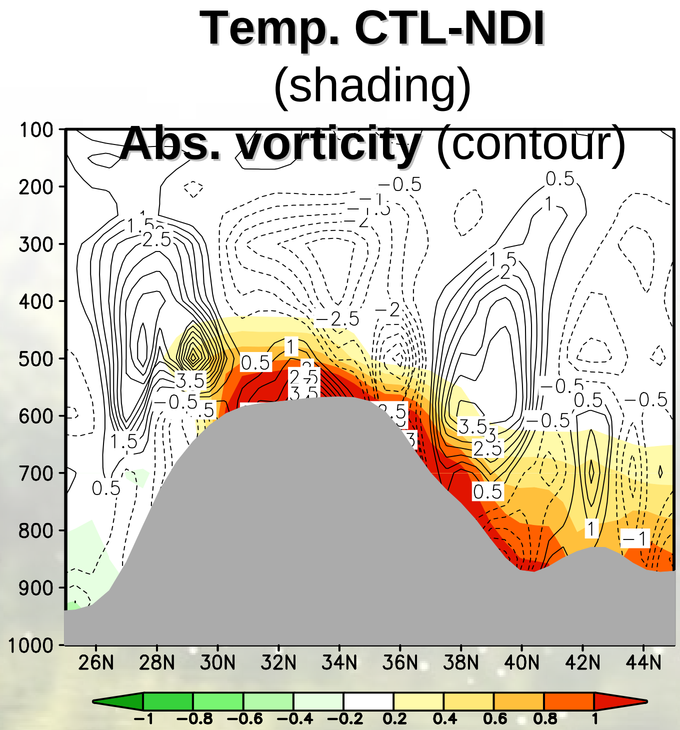
The Areas of enhanced precipitation over the oceans largely coincide with the convergence area.

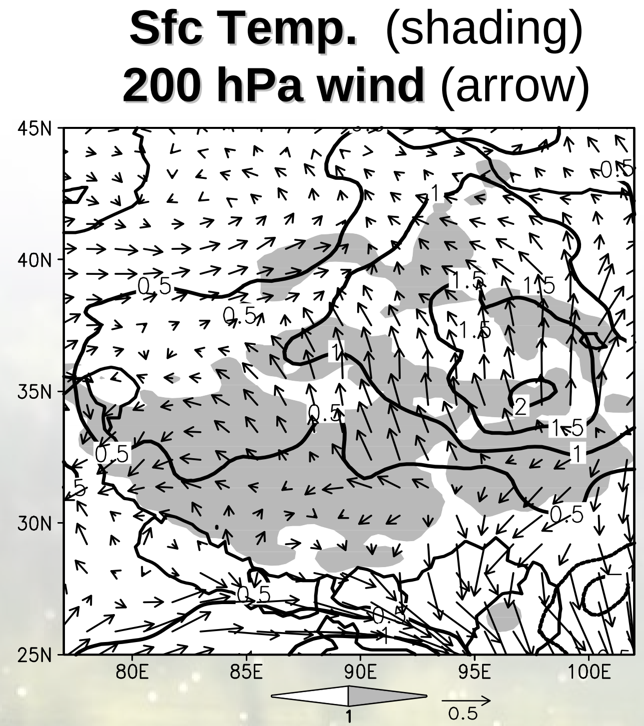
→ Enhanced daytime PBL mixing due to the inclusion of diurnal cycle may lead to a subsequent feedback due to changes in large-scale circulation increasing the moisture.

→ The monsoonal precipitation band in east Asia is shifted northward.

Thermal effect of the TP







Diurnal forcing melts snow of 79%

Yanai and Wu (2006)

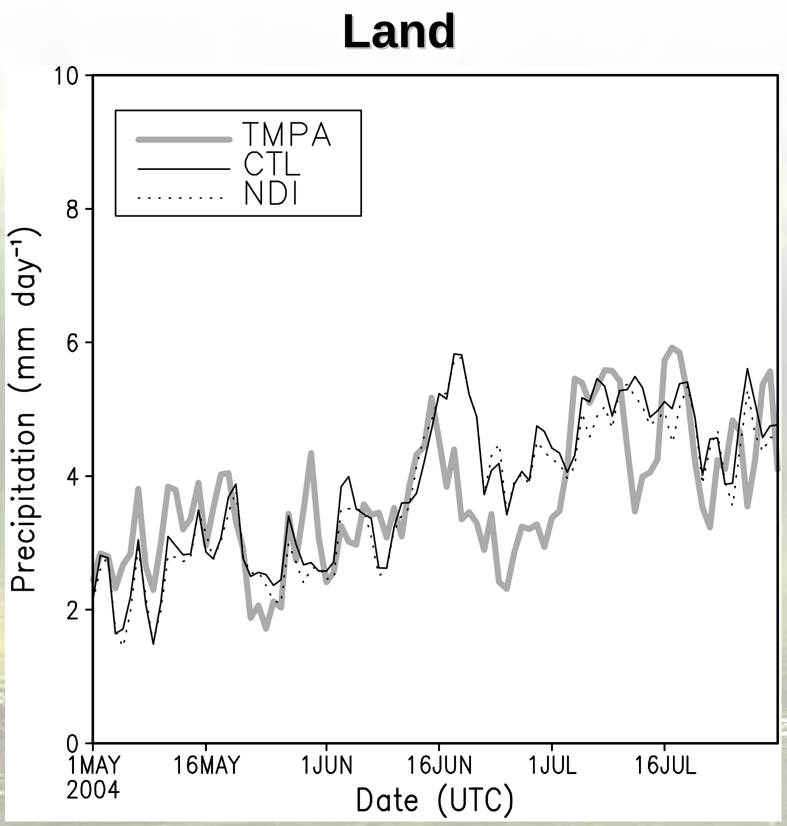
Decrease in the albedo over the TP

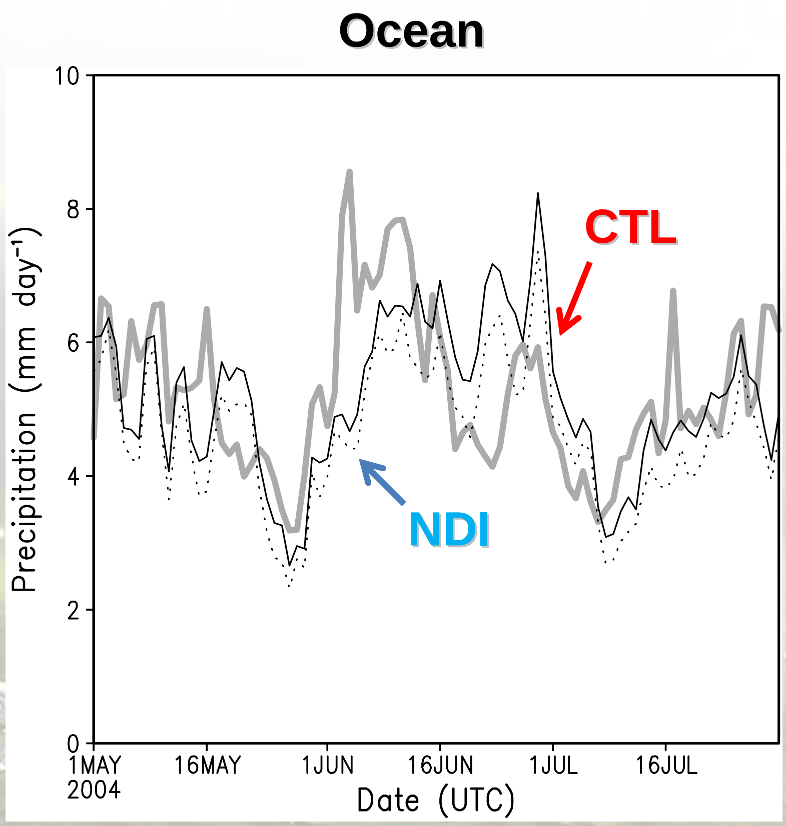
The diurnal forcing presence shows a prevailing sfc heating over the TP.

Formation of the thermal low near the sfc and the Tibetan high in the upper troposphere

Intraseasonal evolution

CTL-NDI





Summary

* Effects of diurnal cycle of solar forcing on the Asian monsoon circulations are examined on the platform of the regional climate modeling forced by analyzed forcing.

* From the comparisons of the simulations with (CTL) and without (NDI) diurnal solar forcing experiments, About 10 % increase over land and 3 % increase over the oceans of seasonal precipitation can be attributed to the effects of diurnal cycle.

• Over land, surface hydroclimate is strongly influenced by the interaction between land and atmosphere, resulting in cooler surface temperature except for the TP region.
• Over oceans, the increase of precipitation is robust by the enhanced planetary boundary layer mixing.

* The diurnal cycle is also found to contribute to the formation of the Tibetan high in the upper troposphere, which consequently influences the east Asian monsoon as well as Indian monsoon climate.

Thank you !

Concept & Modification

$$\boxed{F = F_e \cos\Theta_0} \quad \Rightarrow \quad Q = \int_t F(t)dt$$

Solar zenith angle

H : a half-day (from sunrise or sunset to solar noon. Units of radians)

$$\int_{sunrise}^{sunset} \cos \boxed{\Theta_0}(t)\, \mathrm{dt} = \int_{-H}^{H} (\sin\varphi \sin\delta + \cos\varphi\cos\delta\cos h)\frac{dh}{\boxed{\omega}}$$

Angular velocity of the earth

$$\rightarrow \frac{1}{\pi}(\sin\varphi\sin\delta H + \cos\varphi\cos\delta\sin H)$$

$$*\cos H = -\tan\varphi\tan\delta$$

$$H = \cos^{-1}(-\tan\varphi\tan\delta) = \cos^{-1}(-\frac{\sin\varphi\sin\delta}{\cos\varphi\cos\delta})$$

In the code, hday means H (a half-day radian)
Xmu means “cos (solar zenith angle)”