Optimization of Physics Parameterizations

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Optimization of Physics Parameterizations

What is a parameterization?

- Small scales processes (e.g. convection, turbulence, clouds, radiation etc) are not resolved by typical grid size in climate models.
- Therefore, the statistical contribution of sub-grid processes must be expressed in terms of the large-scale parameters themselves. The mathematical procedure involved is generally called a parameterization.

Why needs an optimization?

- Regional Climate Models suffer from the large sensitivity and uncertainty of physical parameterizations that directly affect the reliability of model performance.
- The difficulty of incorporating or modifying physical schemes is the absence of any universally superior physical scheme because its performance varies according to region, season and combination with other schemes.
- Therefore, it is important to use appropriate physical parameterizations for the selected target region in order to optimize the model performance.

Key Physics Parameterizations

Convective Parameterization

- The convective parameterization scheme is the most important and the sensitive physical process associated with the simulation of the monsoon rainfall.
- Precipitation is directly affected by the cumulus convection parameterization and its interaction with other physical processes.

Land Surface Parameterization

- Chen et al. (2012) and Steiner et al. (2005) showed that Community Land Model (CLM) can improve the simulations compared to other land surface schemes within WRF and RegCM modeling system.
- In particular, soil moisture constrained by land surface scheme affects the surface energy budget by modulating the relative partitioning of latent and sensible heat fluxes, which in turn induces the change of the atmospheric stability to determine the convective activity.

Sensitivity of Convection Scheme

- Grell vs. Emanuel within RegCM3
- **Im E.-S.***, Ahn J.-B., Remedio A. R., Kwon W.-T., 2008: Sensitivity of the regional climate of East/Southeast Asia to *convective parameterizations* in the RegCM3 modelling system. Part1: Focus on the Korean peninsula. *Int. J. Climatol*., 1861-1877

Sensitivity of Land-Surface Scheme

- BATS vs. CLM within RegCM4
- Kang S.-C., **Im E.-S.***, J.-B. Ahn, 2014: The impact of two *land-surface schemes* on the characteristics of summer precipitation over East Asia from the RegCM4 simulations. *Int. J. Climatol*.,34, 3986-3997.

Precipitation Process in Climate Model

Large-scale vs. Convective Precipitation

❖ In most climate models, clouds and precipitation are represented in two forms :

- Resolvable grid-scale precipitation
- Unresolvable subgrid-scale precipitation able

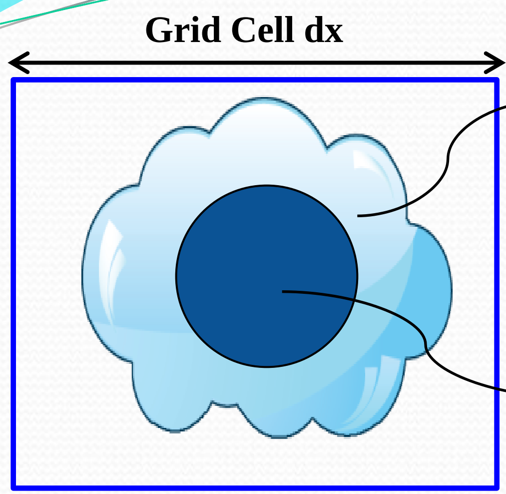
❖ The resolvable grid-scale precipitation is explicitly described by simple diagnostic schemes based on the linking the average relative humidity of a grid cell to the cloud fraction and cloud water, whereas the unresolvable precipitation is produced by a convective parameterization which describes the effects of subgrid-scale convective cloud.

Modeding Steps for the Formation of Precipitation

❖ Parameterization for the presence or absence of clouds (i.e. **cloud fraction**).

❖ Parameterization for the conversion of cloud liquid water to rainfall (i.e. **autoconversion**).

Examples of Parameterization for Cloud Fraction



FC=fractional cloud cover

$$\mu = \frac{\overline{R}}{R_{\text{clim}}} = f_r \text{FC}_{\text{cnv}}$$

$\overline{\text{R}}$: grid-average rainfall
R_{clim} : climatological rainfall intensity
f_{r} : fraction of total cloudy area that is raining

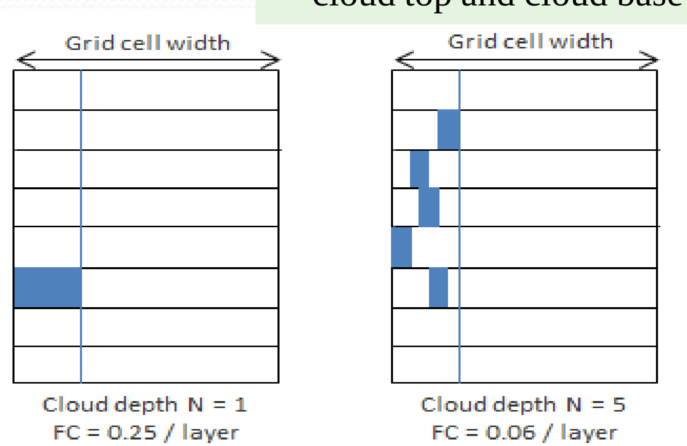
From Eltahir & Bras (1993)
Gianotti & Eltahir (2014b)

μ=fractional coverage of rainfall

Treatment In RegCM3

$$\text{FC}_{\text{cnv}} = 1 - 0.75^{1/N}$$

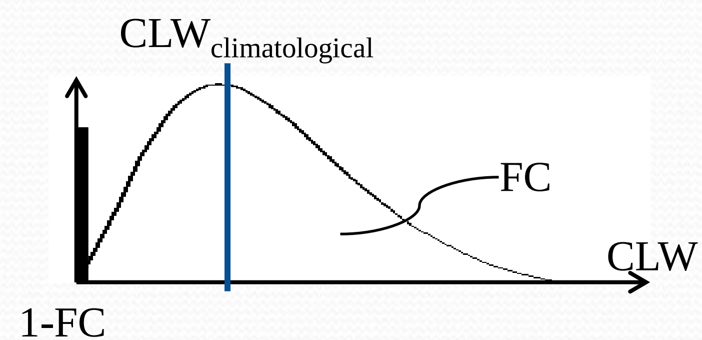
N: number of layer between cloud top and cloud base



Treatment In MIT RCM

$$\text{FC}_{\text{cnv}} = \frac{\overline{\text{CLW}}}{\text{CLW}_{\text{clim}}}$$

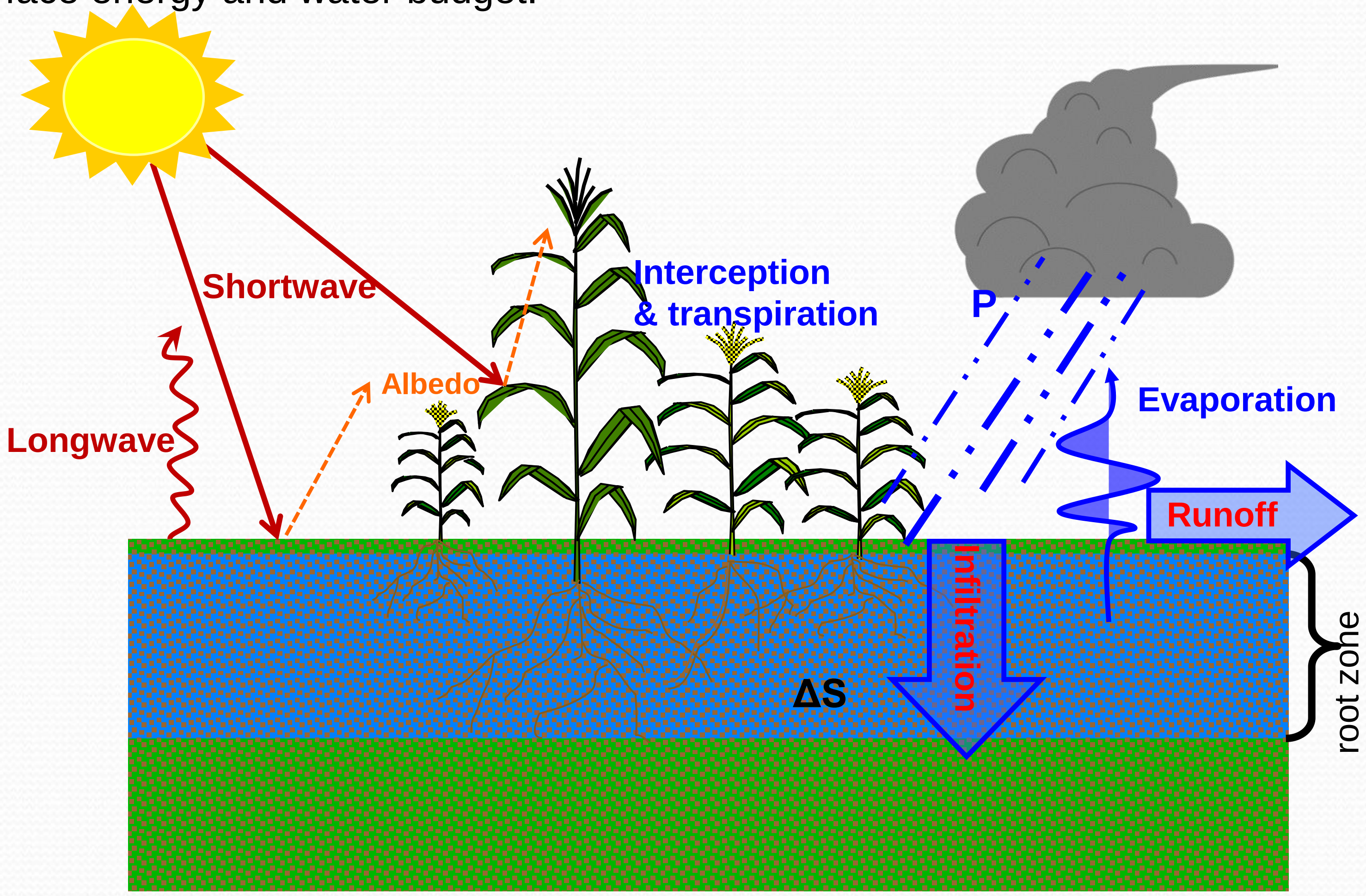
CLW : cloud liquid water



Adapted from Gianotti (2012) and Gianotti & Eltahir (2014a,b)

Schematic of Principle Components in Land-Surface Process

- Land-surface parameterization includes the land-atmosphere exchanges of energy, momentum, water, and carbon.
- Therefore, land-surface parameterization can play an important role in modulating the surface energy and water budget.



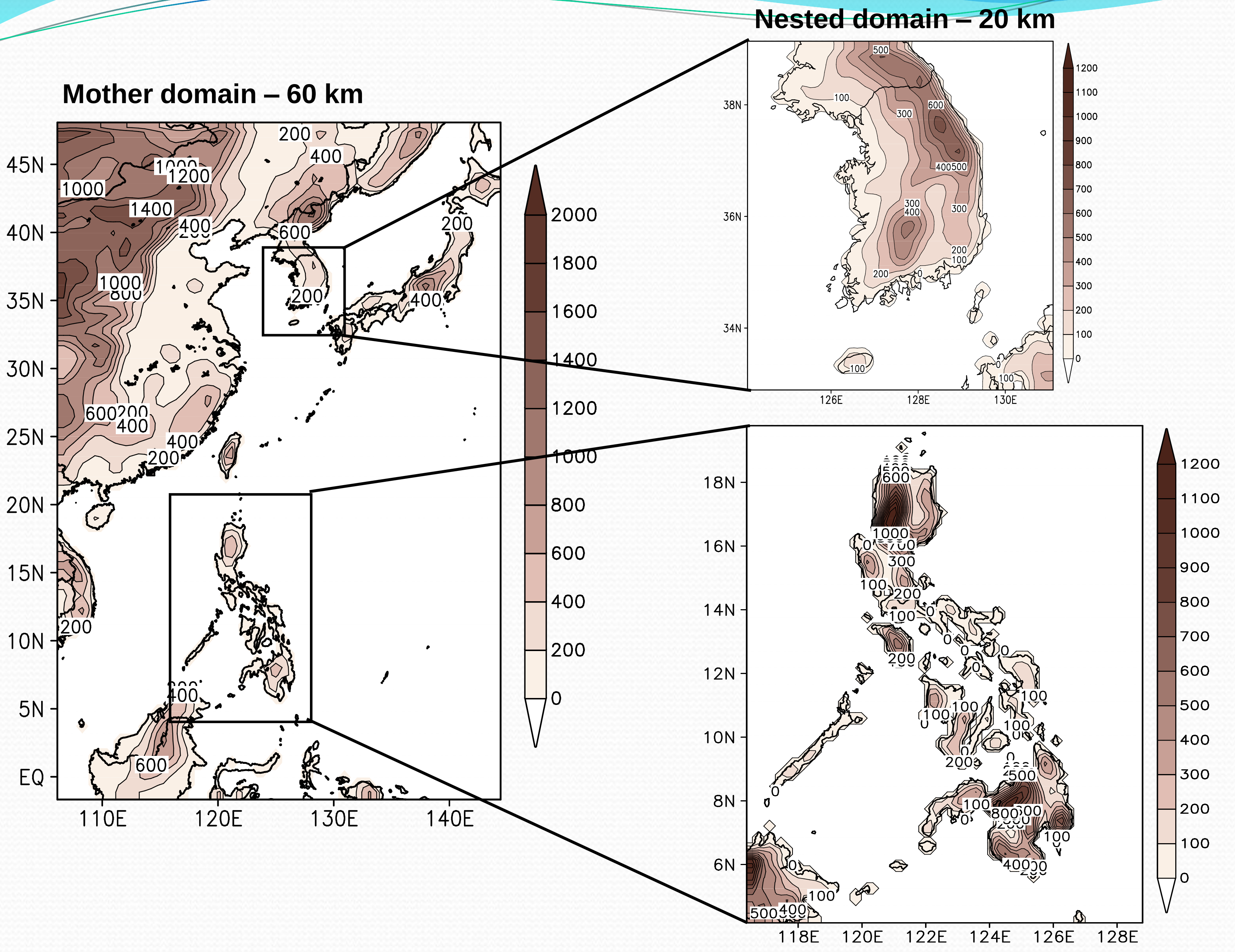
Modified Fig.1 from Marcella & Eltahir (2014)

Sensitivity of Convection Scheme

Grell vs. Emanuel

- **Im E.-S.***, Ahn J.-B., Remedio A. R., Kwon W.-T., 2008: Sensitivity of the regional climate of East/Southeast Asia to *convective parameterizations* in the RegCM3 modelling system. Part1: Focus on the Korean peninsula. *Int. J. Climatol*., 28, 1861-1877.

RegCM3 Double-Nesting System



RegCM3 Configuration

❖ Resolution

- Mother domain – 60 km
- Nested domain – 20 km

❖ Integration Period

- 1 Nov. 1999 – 31. Dec. 2004
- One month: Spin-up
- Five year: Analysis period

❖ Initial & Boundary Condition

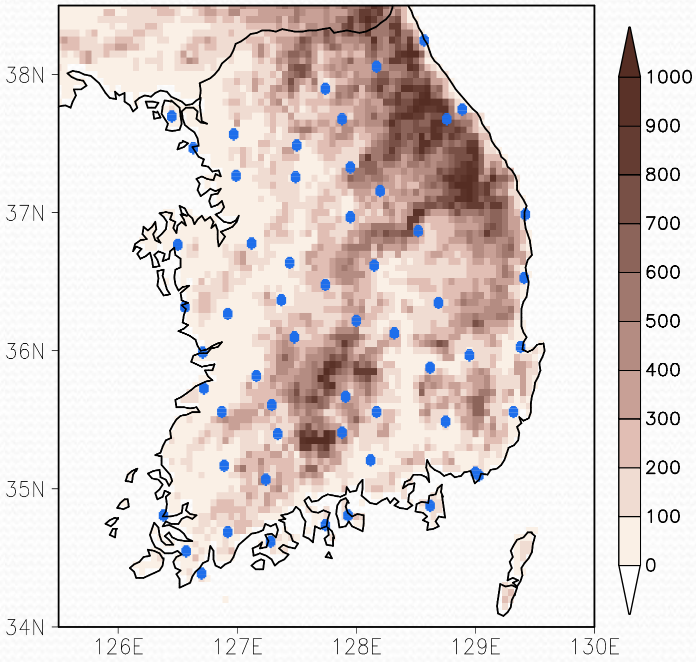
- NCEP/NCAR Reanalysis data (2.5X2.5 degree)

❖ Convection Scheme

- **Grell with Fritsch-Chappell closures**
- **MIT Emanuel**

❖ Verification strategy

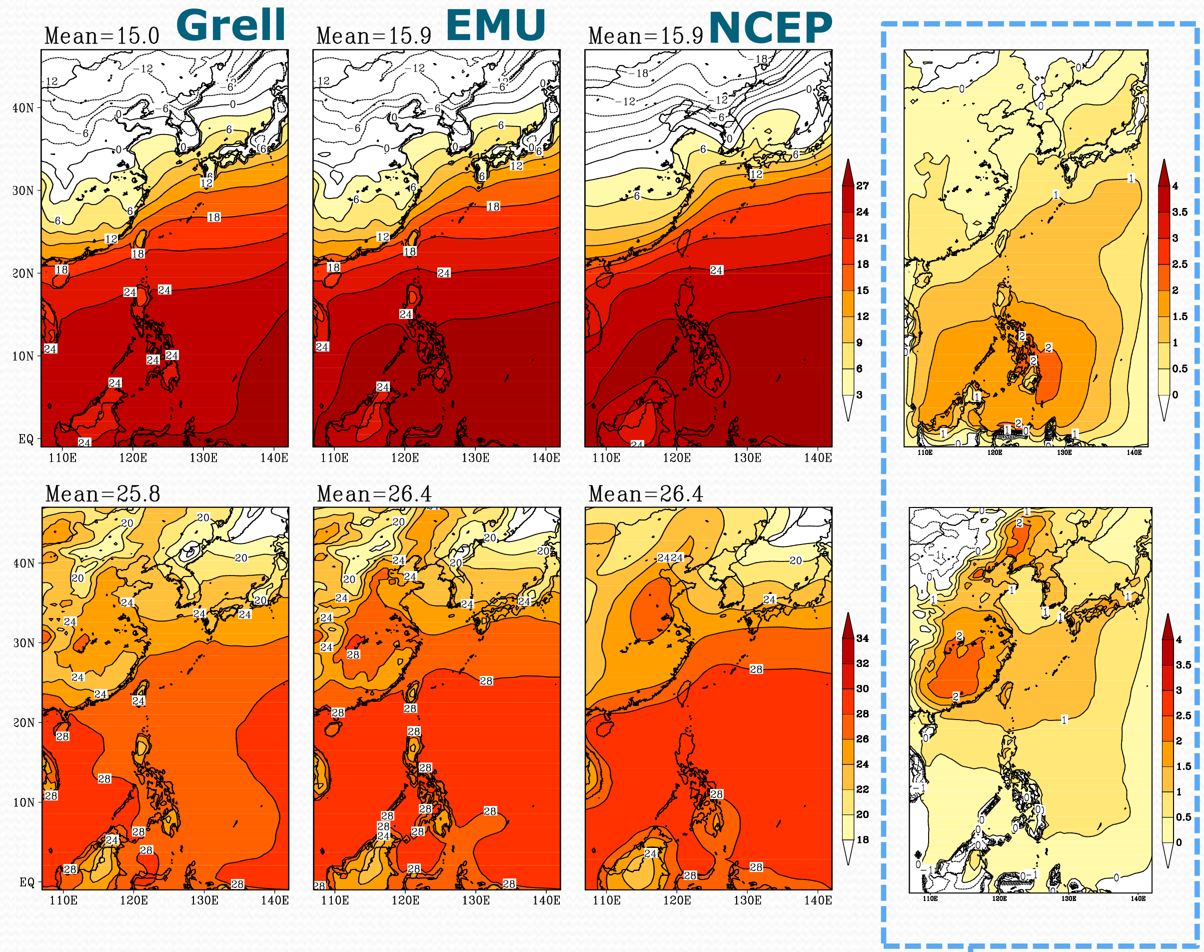
- Mother domain: GPCP, NCEP/NCAR
- Nested domain: 60 station data maintained by KMA



Seasonal Mean Surface Air Temperature

Winter
[DJF]

Summer
[JJA]

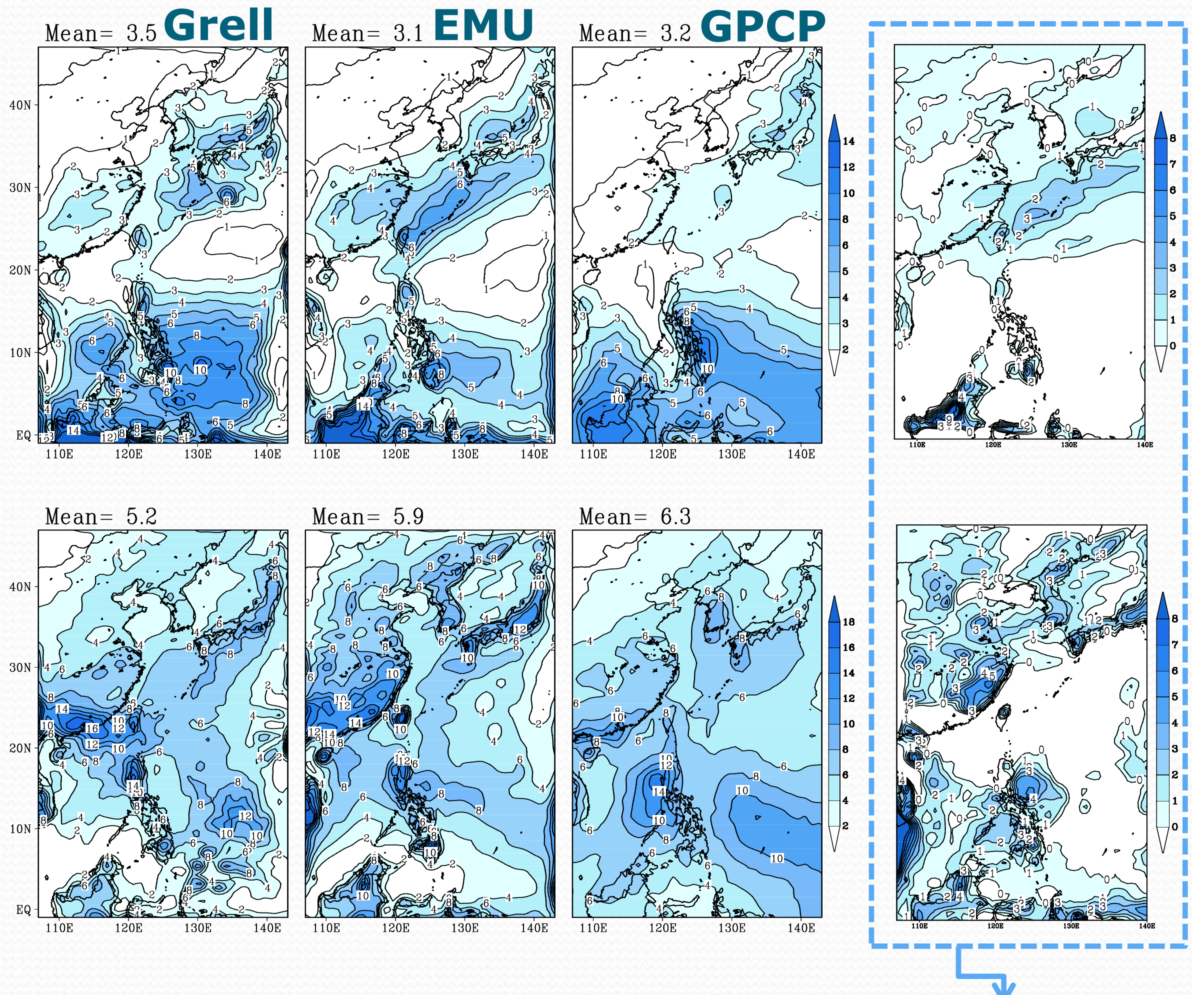


Difference (EMU-Grell)

Seasonal Mean Precipitation

Winter
[DJF]

Summer
[JJA]



Difference (EMU-Grell)

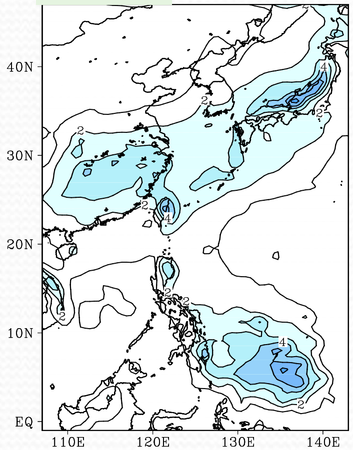
Convective & Large-scale Precipitation

Large-scale Precipitation

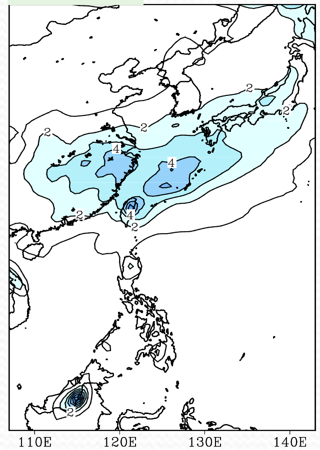
Convective Precipitation

Winter [DJF]

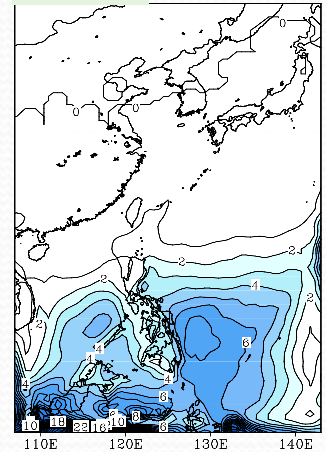
Grell



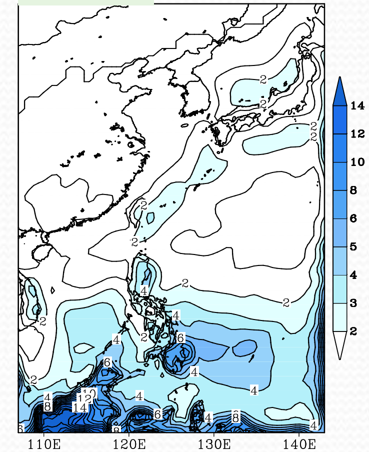
EMU



Grell

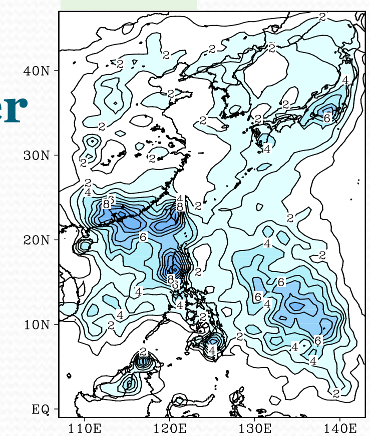


EMU

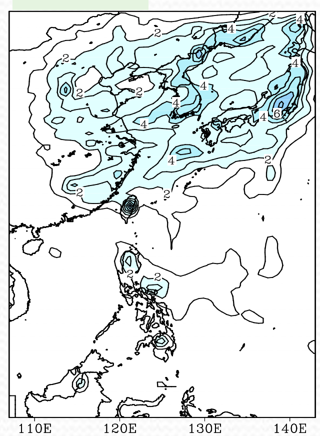


Summer [JJA]

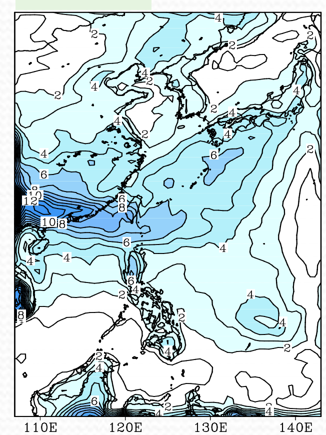
Grell



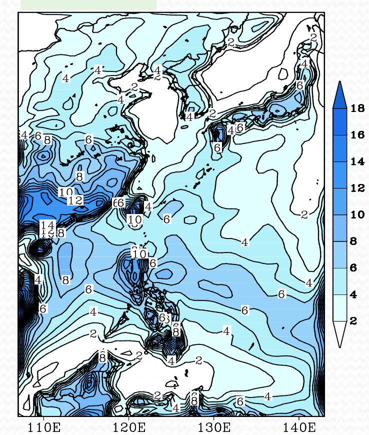
EMU



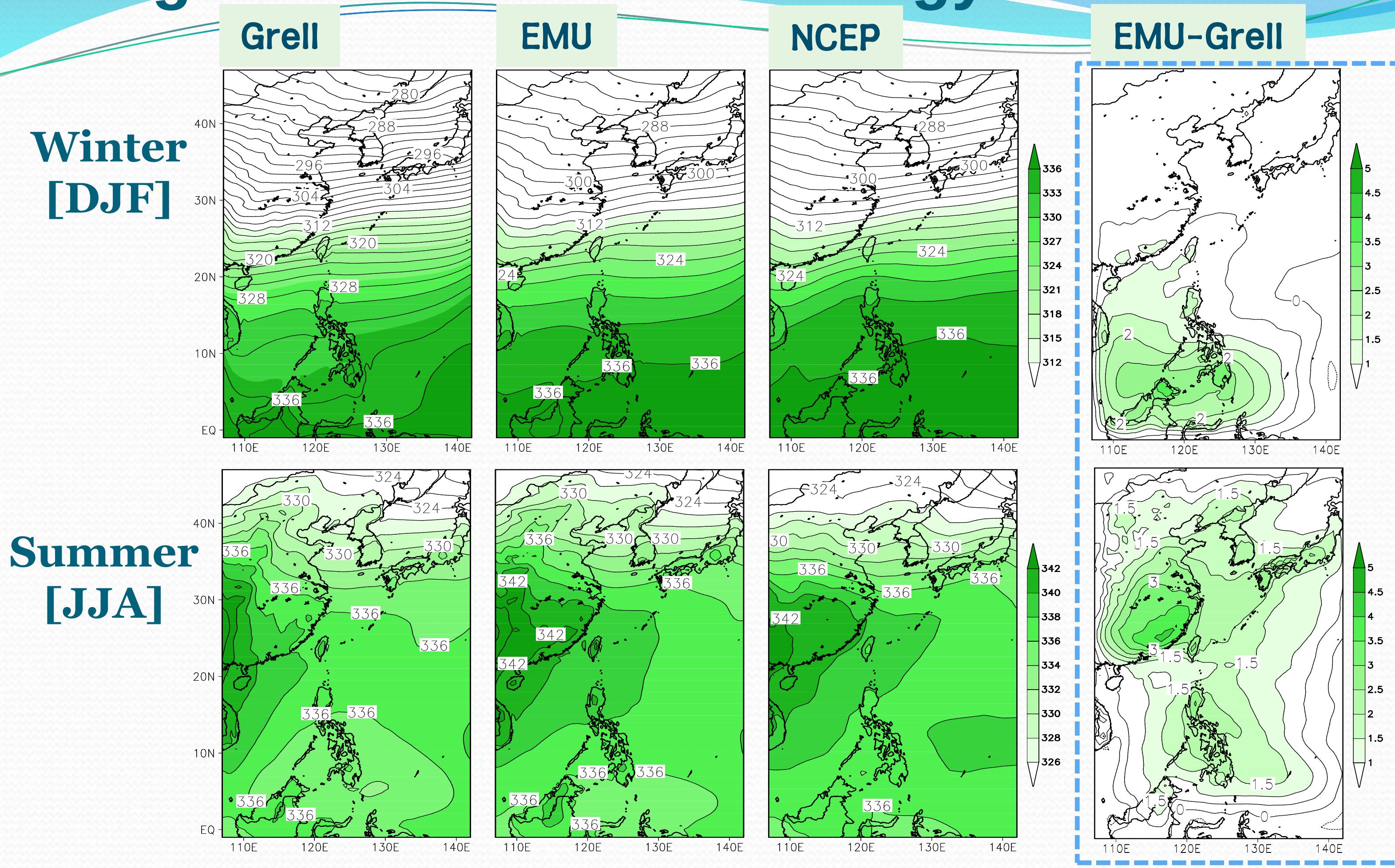
Grell



EMU



Integrated Moist Static Energy



MSE=CpT+Lq+gZ : Sum of the sensible, latent, geopotential energy

✓ Vertically integrated MSE could be a good description of the state of the atmosphere.

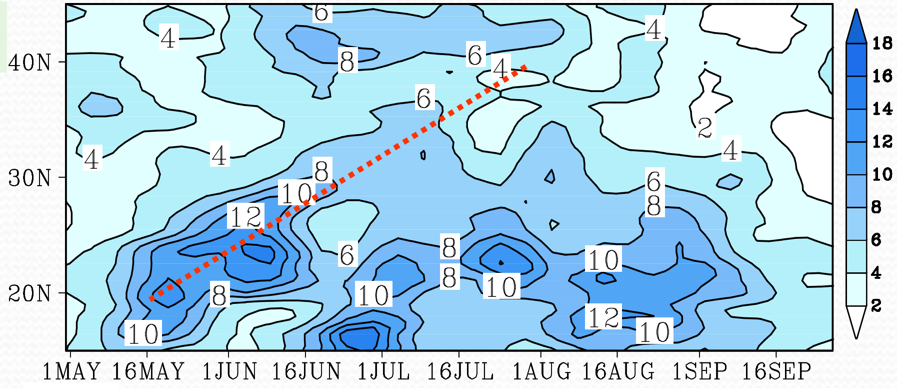
✓ Precipitation in the tropics depends on the MSE of the troposphere from 1000 to 400 hPa.

✓ The spatial distribution of the integrated MSE directly reflect the general characteristics, as shown in the convective precipitation .

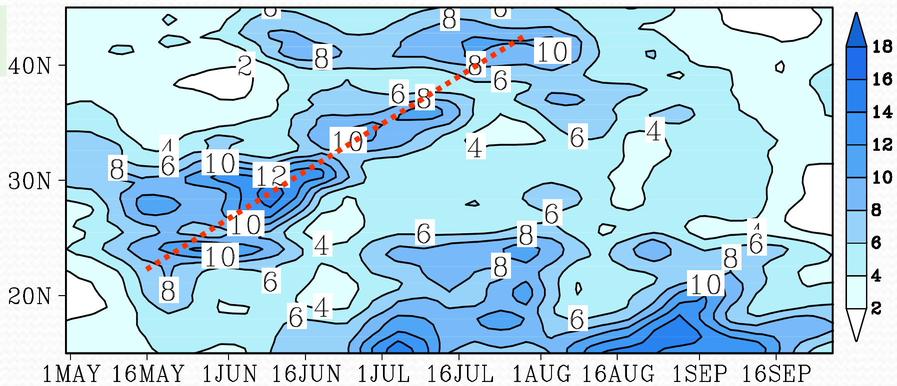
✓ The atmospheric condition simulated by EMU is more favourable for activating the convection during the summer.

Propagation of Monsoon Rain Band

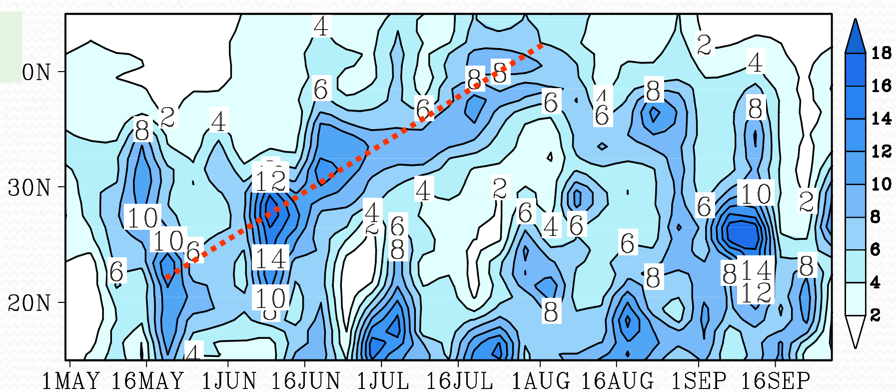
Grell



EMU



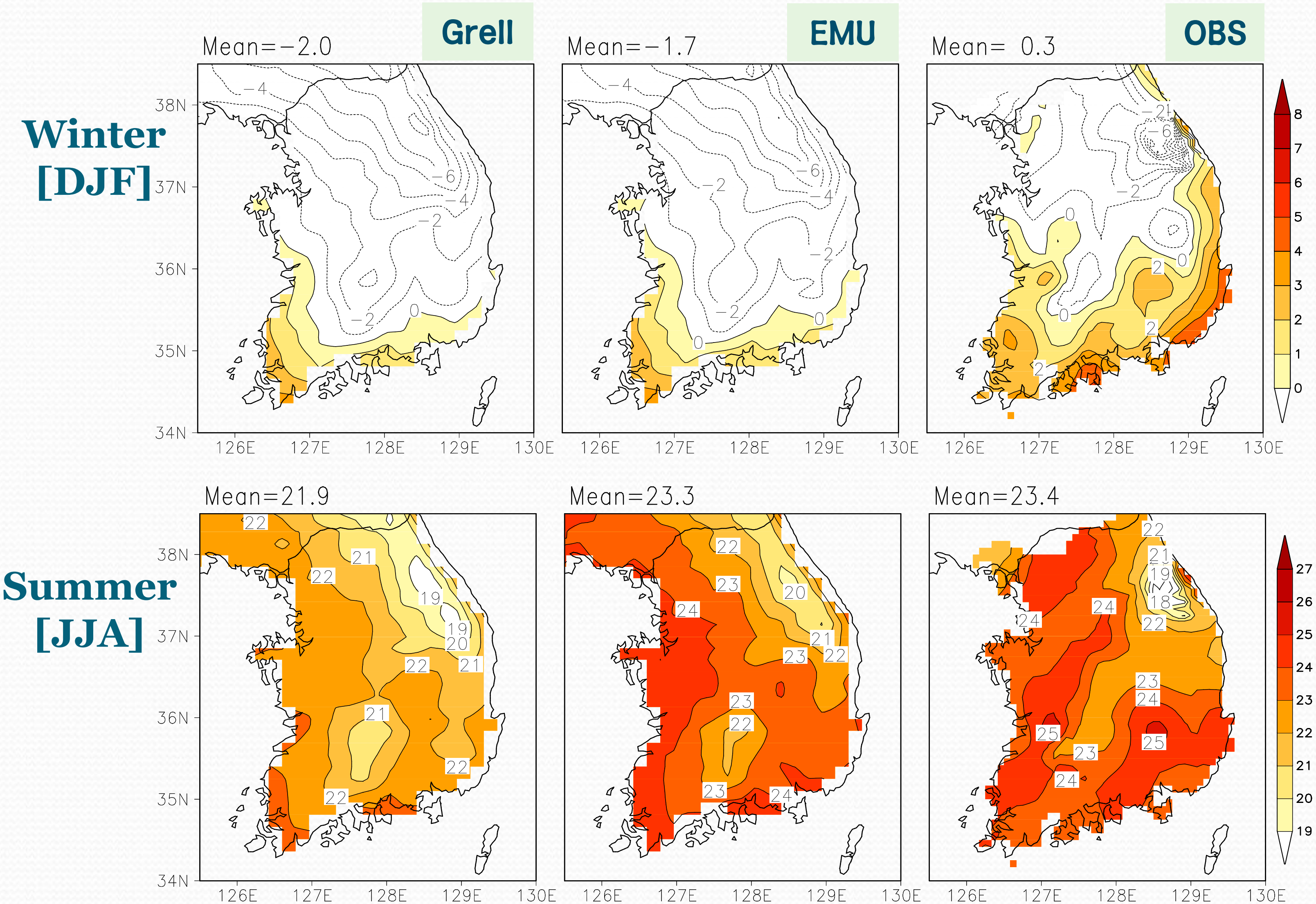
GPCP



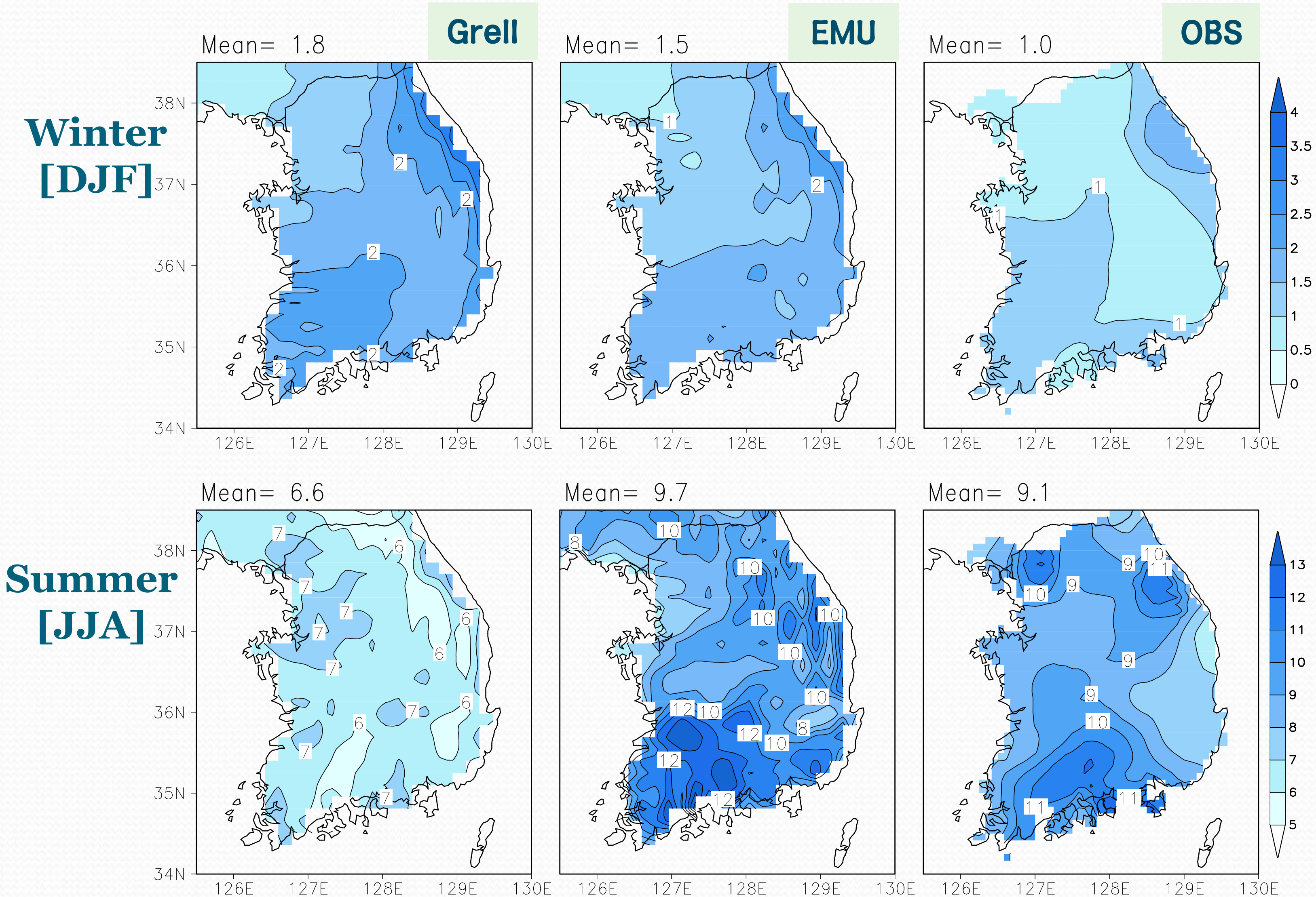
- ✓ Time-latitude cross-section of the zonal average 5-day rainfall amount along the band, 120–130˚E.
- ✓ The development of the monsoon is characterized by the northward propagation of the rain band.
- ✓ It is observed that in comparison with the Grell simulation, the EMU simulation produces a substantial improvement in the timing and amplitude of the rain band.

- ✓ The EMU simulation realistically reproduces the maximum position and the propagation speed.
- ✓ However, in the Grell simulation, the position of stationary phase from early June to mid June appears to be displaced somewhat southward and the simulation fails to capture the northward propagation. The northward expansion of the rain band is weak or does not even occur, resulting in estimates drier than those of the GPCP.
- ✓ In early September, another maximum takes place in the lower part around 30 ˚N, which should be linked to the rainfall caused by typhoons. The biggest weakness of the EMU simulation occurs at this time. Despite considerable improvement, the EMU simulation has limitations in realistically capturing the effect of typhoons.

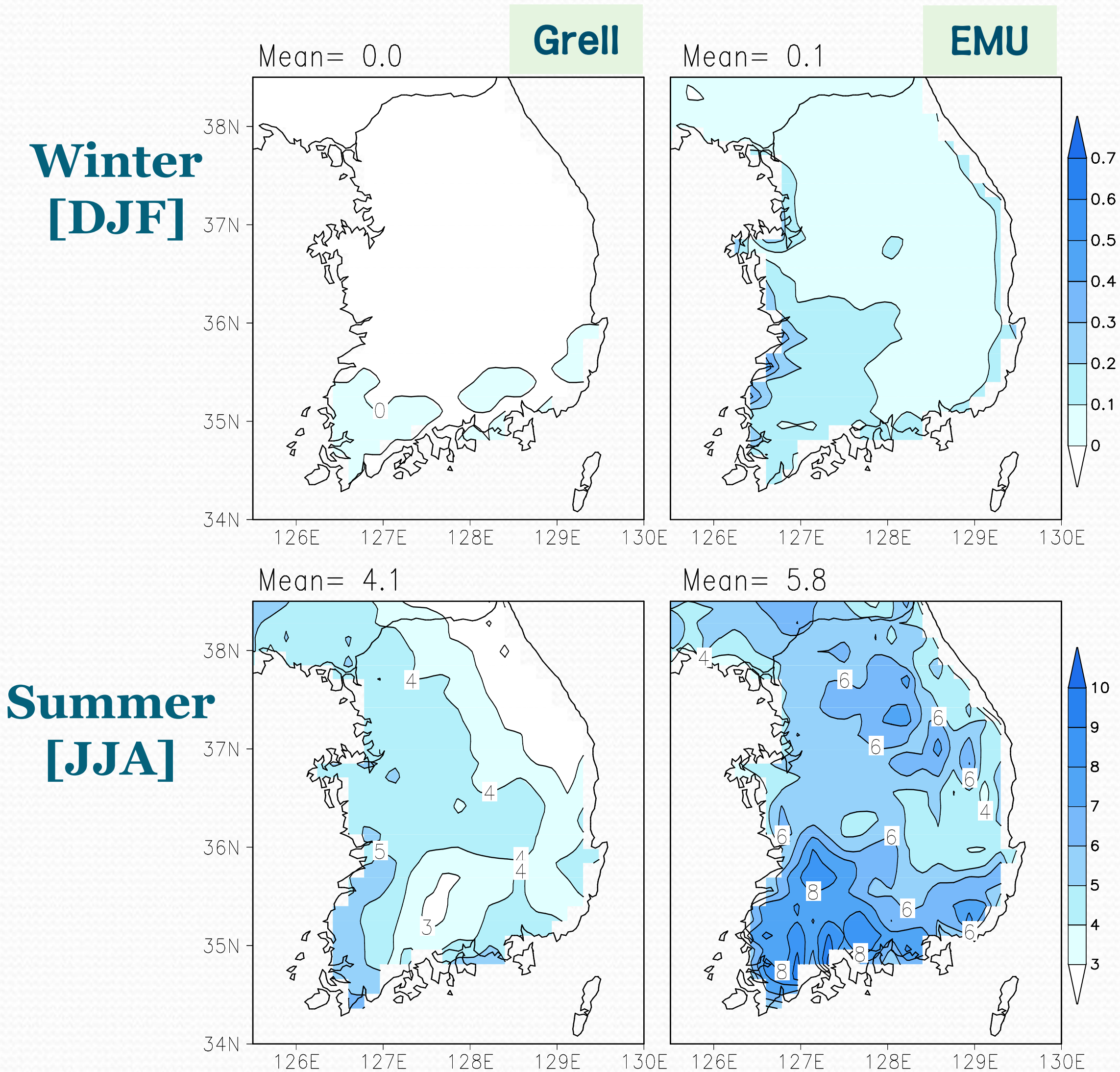
Seasonal Mean Surface Air Temperature



Seasonal Mean Surface Air Temperature

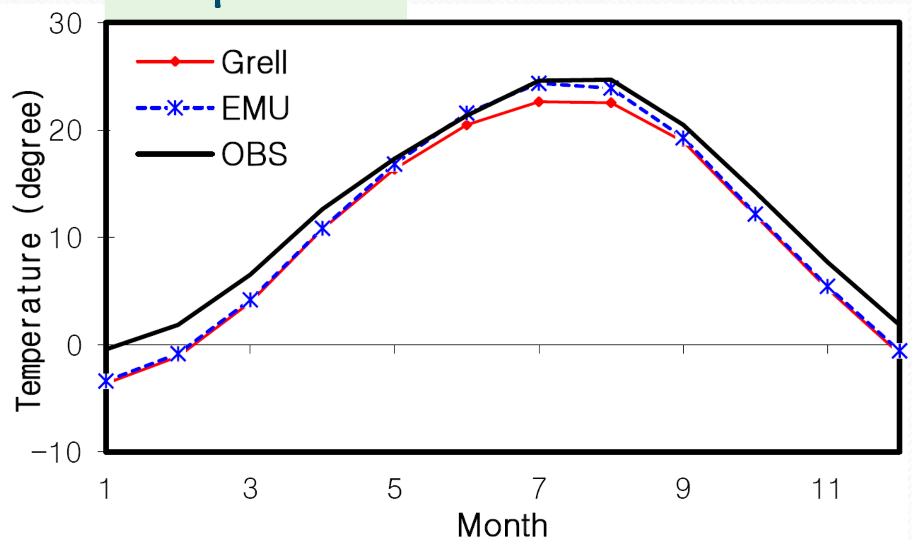


Convective Precipitation

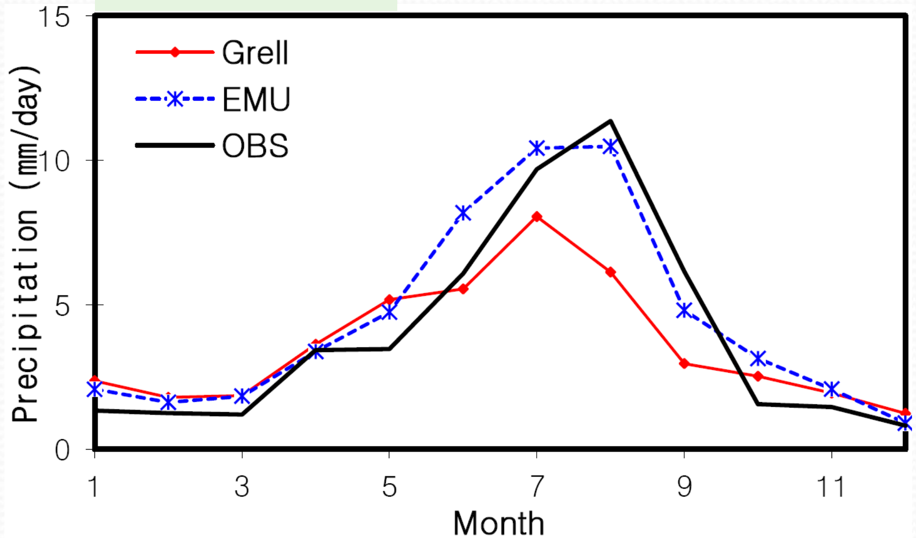


Monthly Variation

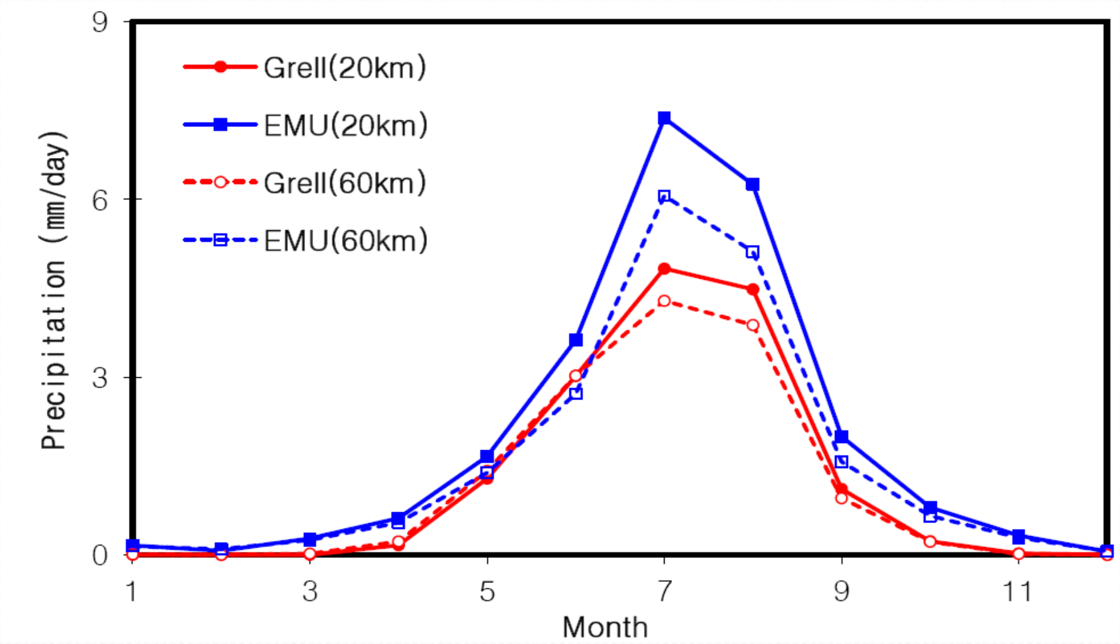
Temperature



Precipitation

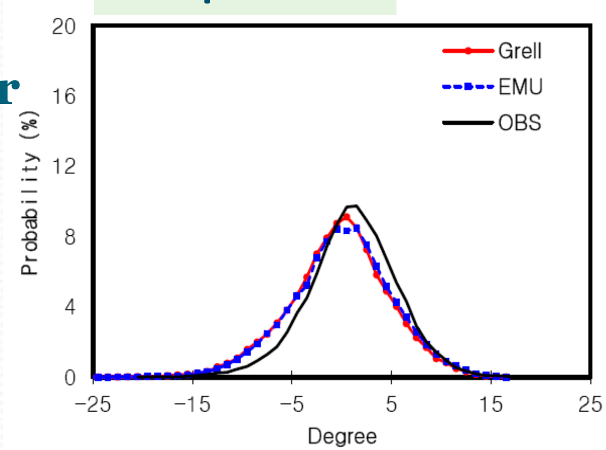
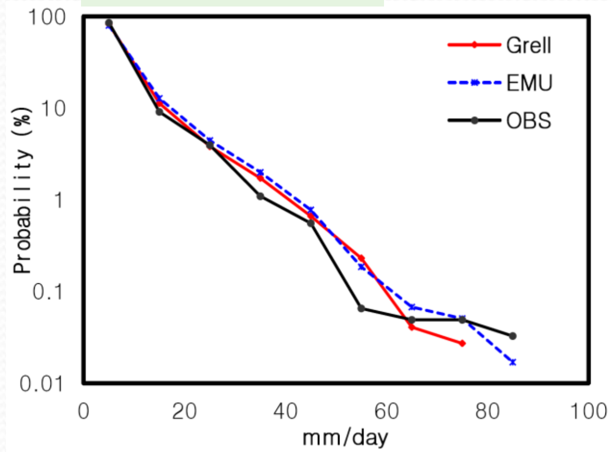
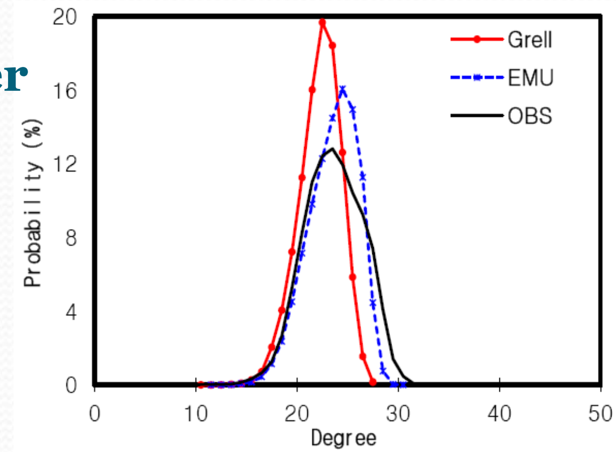
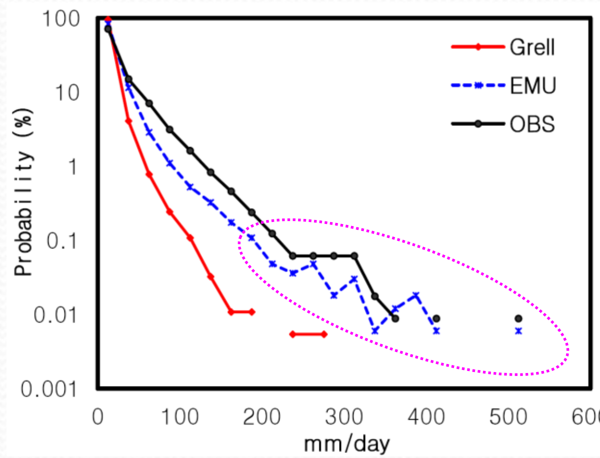


Resolution vs. Convective Scheme



- ➢ In an attempt to verify the contribution to resolutions (60 km vs. 20 km) and the effect of CPS (Grell vs. EMU), we comprehensively compared the monthly variation in the convective precipitation obtained by both the EMU and Grell simulations for the mother domain (60 km) and nested domain (20 km) over Korea.
- ✓ The convective precipitation increases with the horizontal resolution. The precipitation produced by the EMU simulation is generally greater than that produced by the Grell simulation, particularly in the summer season. Therefore, the nested domain simulation with the EMU shows the maximum precipitation intensity.
- ✓ An important result derived from this figure is that the impact of the enhanced horizontal resolution is not as large as that of the CPS. Convective precipitation derived from different CPSs is the major contributor to the performance of the simulated precipitation in terms of magnitude and location.

Frequency Distribution of Daily Temp. & Precip.

	Temperature	Precipitation
Winter [DJF]		
Summer [JJA]		

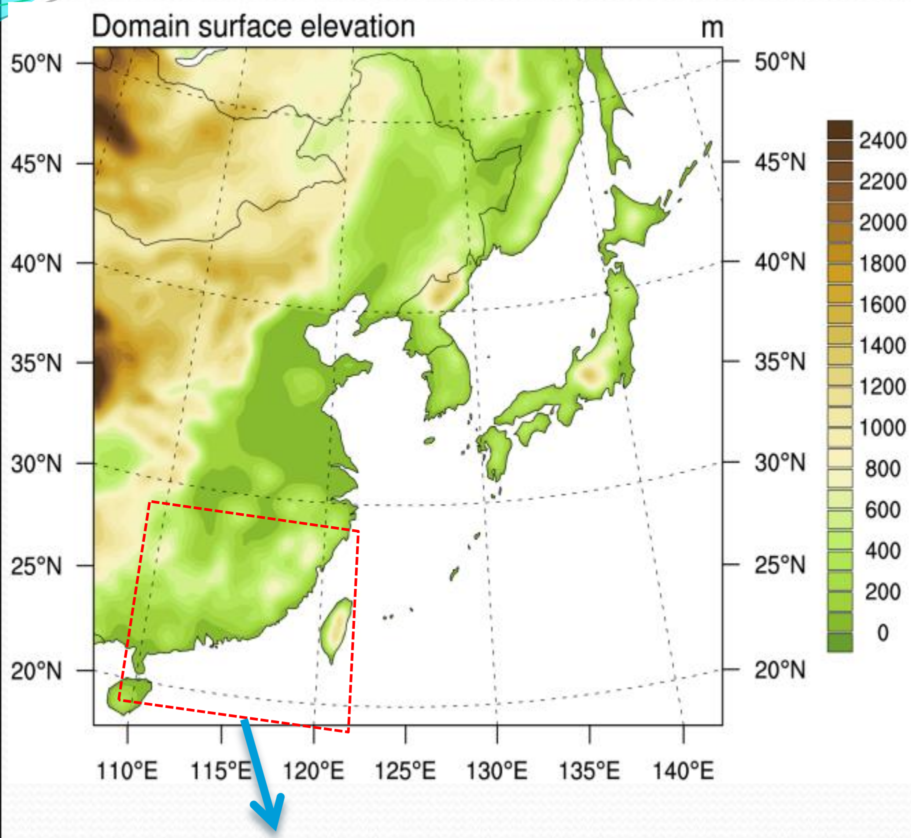
- ➢ The improvement seen in the distribution of summer precipitation is particularly important in terms of the performance to capture the extreme event
- ➢ This result suggests that the EMU is capable of producing extreme precipitation events closer to observation.

Sensitivity of Land Surface Scheme

BATS vs. CLM

- Kang S.-C., **Im E.-S.***, J.-B. Ahn, 2014: The impact of two *land-surface schemes* on the characteristics of summer precipitation over East Asia from the RegCM4 simulations. *Int. J. Climatol*.,34, 3986-3997.

RegCM4 Configuration & Domain



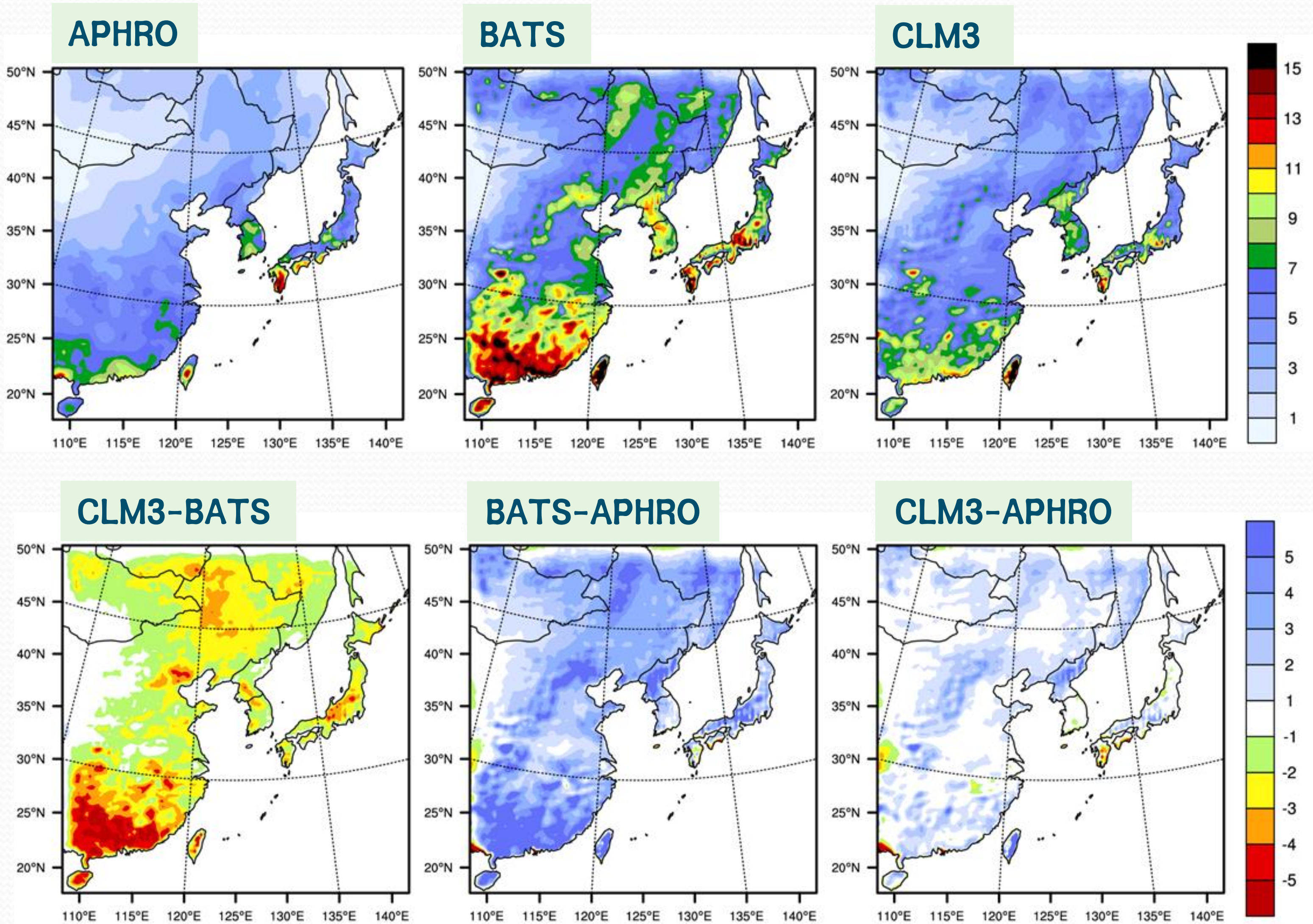
South China
Latitude: 20°N ~ 30°N
Longitude: 108°E ~ 122°E

Vertical Layers (top)	23 sigma layers (50 hPa)
Horizontal Resolution	30 km (127 X 127)
Cumulus convection	MIT - Emanuel
Radiation	Modified CCM3
PBL	Modified Hotslag
itial & Boundary Condition	ERA-Interim (1.5deg)
SST	ERSST, APCC/CCSM3
Simulation Period	1989-2007 (19-year)
LSM	BATS or CLM3

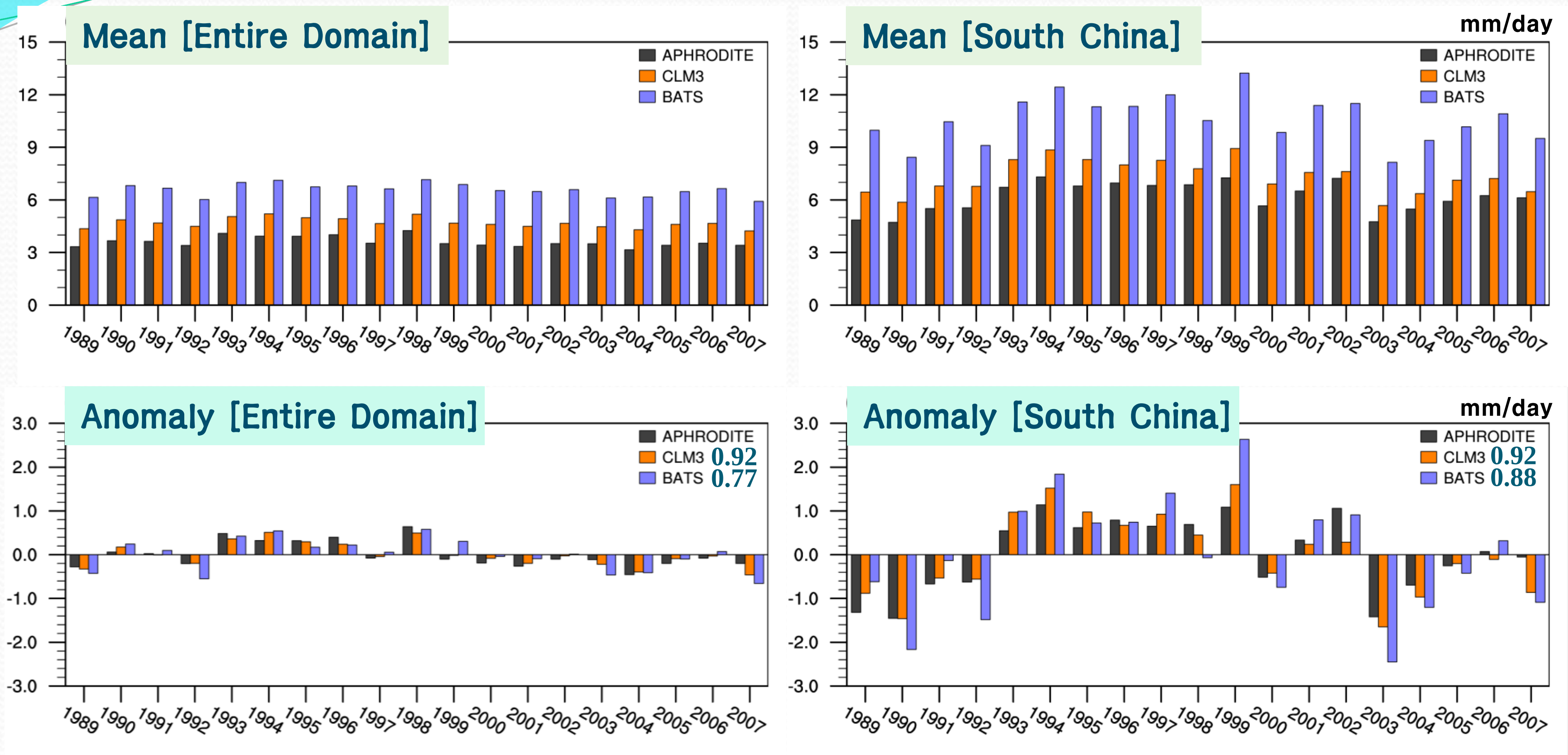
- Biosphere-Atmosphere Transfer Scheme(BATS)
- Community Land Model (CLM3)

- Observation : APHRODITE (daily precipitation with 0.25° × 0.25° grid)
- Reanalysis : ERA-Interim (daily and monthly data with 1.5° × 1.5° grid)

Spatial Distribution of JJA Precipitation

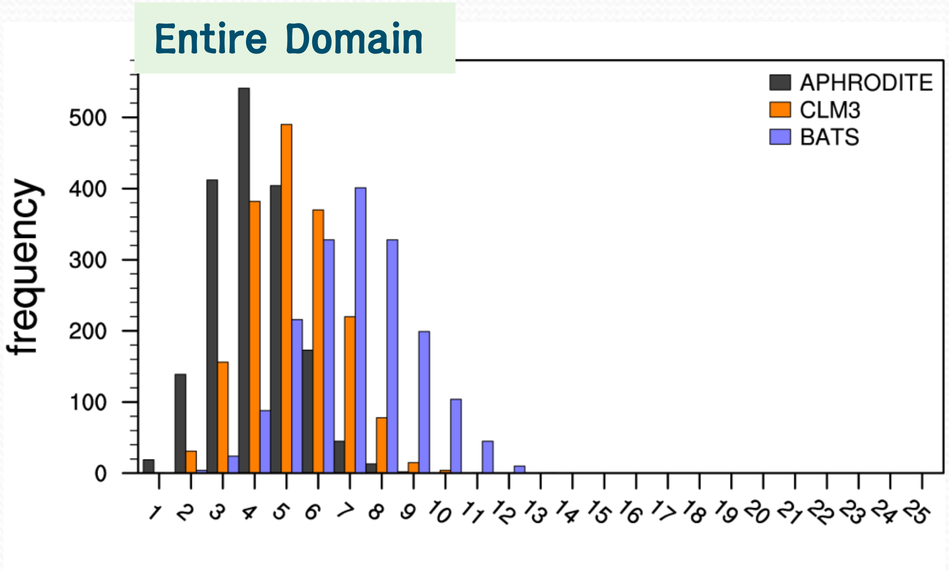


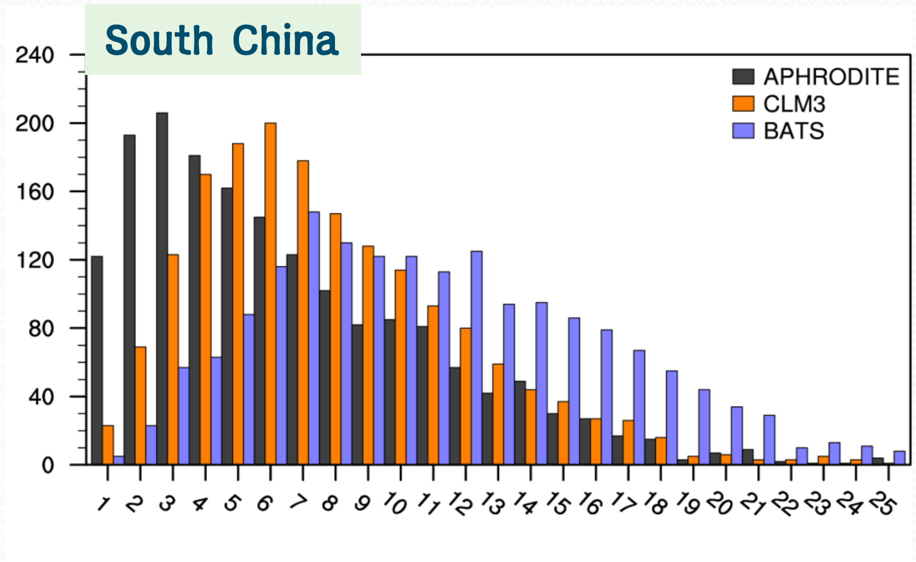
Interannual Variation of JJA Precipitation



- The overestimated error of the BATS simulation is probably not a random feature of specific year, but a rather consistent pattern in different years throughout whole period. The CLM3 simulation also shows some positive bias, but its magnitude is fairly reduced.
- The correlation coefficients in the temporal evolution of CLM3 and BATS with observation are 0.92 and 0.77 over the entire domain, and 0.92 and 0.88 over South China, respectively. Therefore, the CLM3 simulation shows more skillful performance not only in quantitative aspect but also in its evolutionary feature compared to BATS.

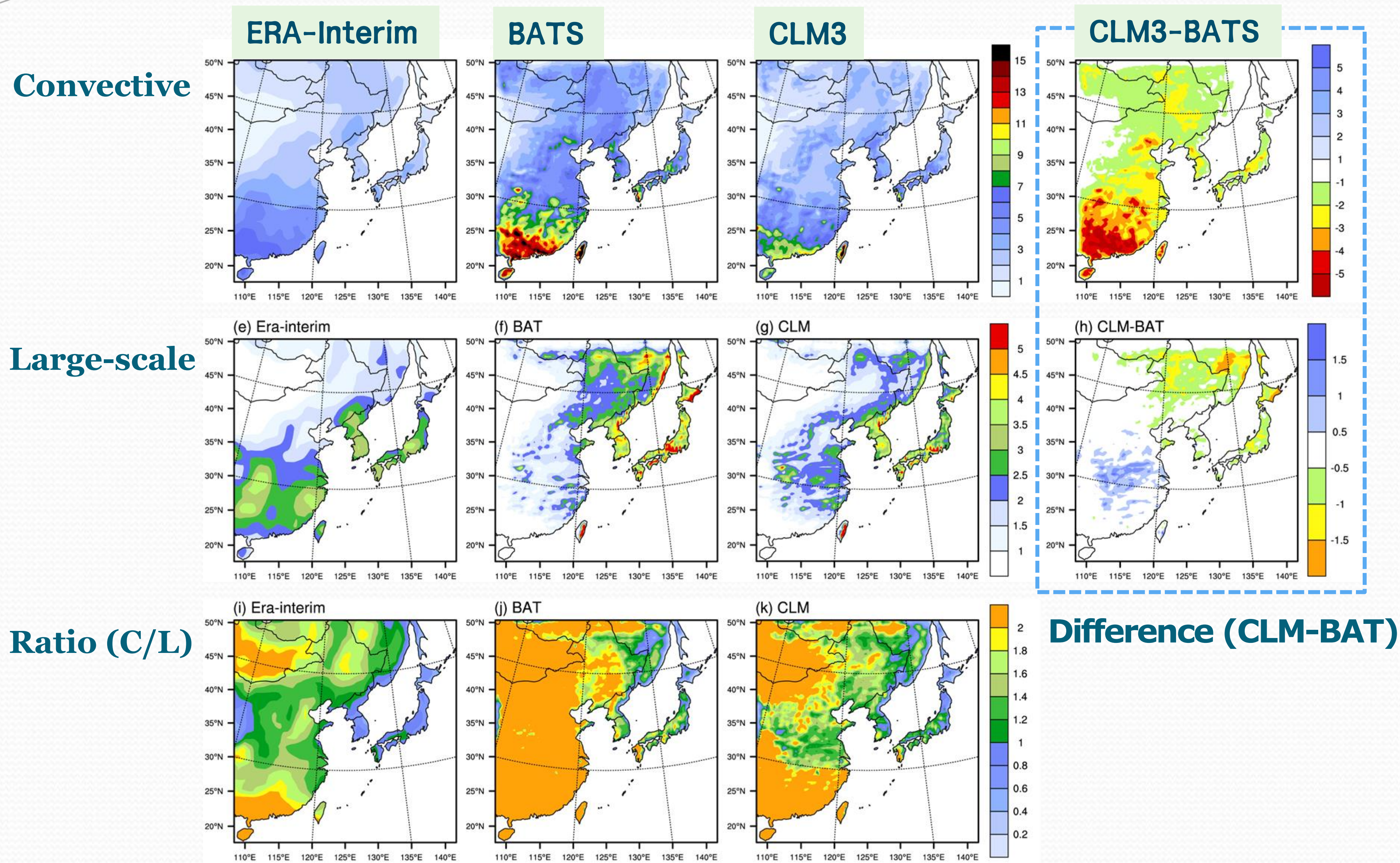
Frequency Distribution of Daily Precipitation



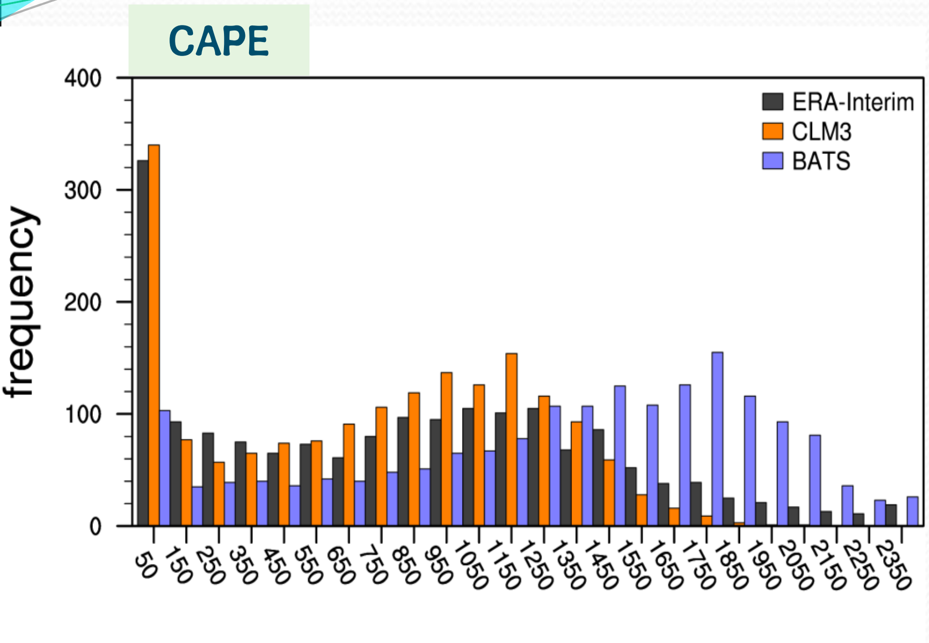


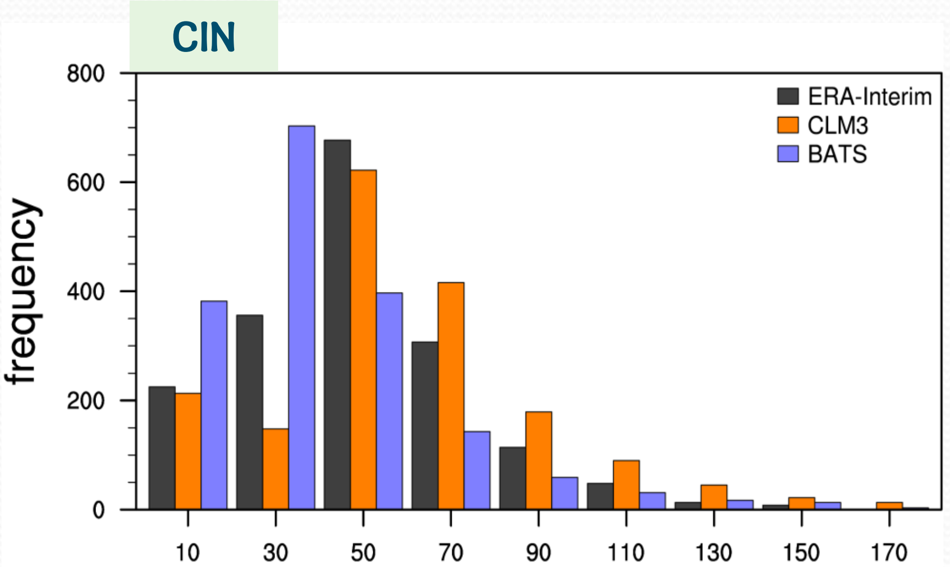
- The frequency distribution of daily precipitation again clearly reveals the different behaviour of the BATS and CLM3 simulations.
- Consistent with mean spatial pattern, the distribution of BATS simulation tends to be skewed to right side in both regions, being spread out toward longer tails.
- This behaviour indicates the more frequent occurrence of higher intensity precipitation compared to APHRODITE observation.
- Daily precipitation from CLM3 simulation is also distributed slightly shifted to the right side against APHRODITE, but its general shape and its relative ratio of the frequency corresponding to each column are much closer to those of APHRODITE.

Convective & Large-scale Precipitation



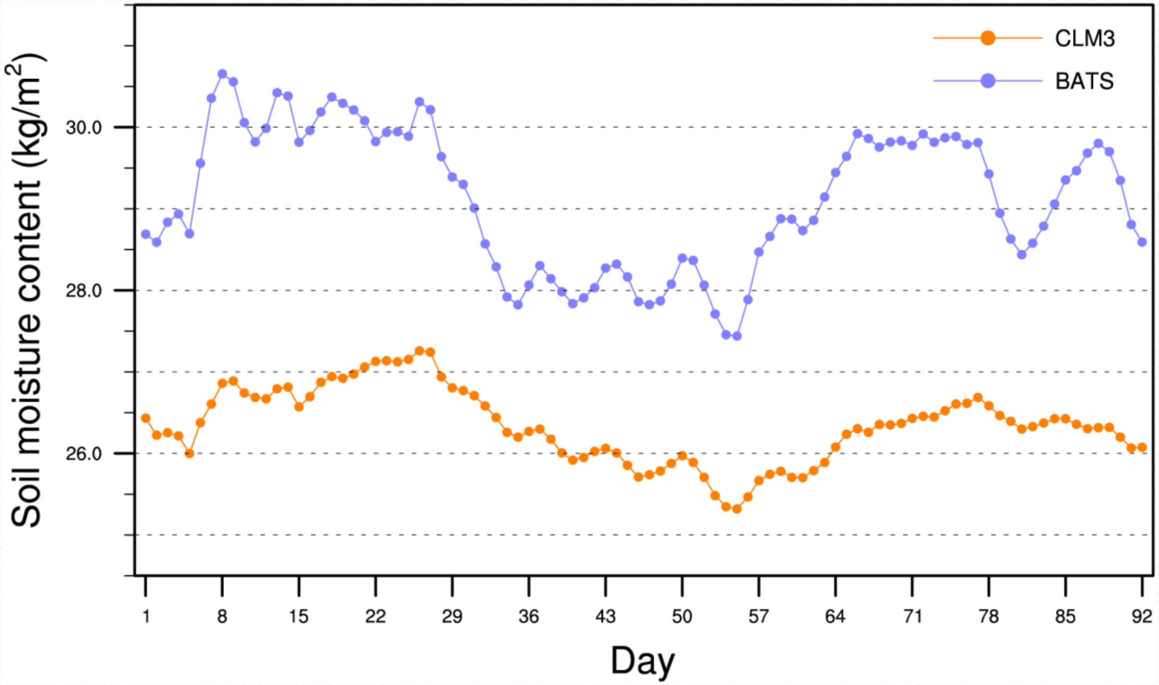
Frequency Distribution of CAPE & CIN





- Convective Available Potential Energy (CAPE) is a positive buoyancy of a rising air parcel while Convective inhibition (CIN) indicates a negative buoyant energy needed to overcome the free ascent of an air parcel.
- A larger CAPE (CIN) value corresponds to more promotion (suppression) of the triggering of convection.
- Higher θe could be an indication of potential instability responsible for a convectively favourable environment, which would increase CAPE.
- The CLM3 simulation shows considerable improvement in both the general shape of distribution and the relative ratio of each column for all the indices.
- The relatively larger CAPE and smaller CIN imply a BATS deficiency in both the intensity and the frequency of convective precipitation, which supports the assumption that deep convection intensity is modulated by CAPE while the occurrence frequency is more controlled by CIN.

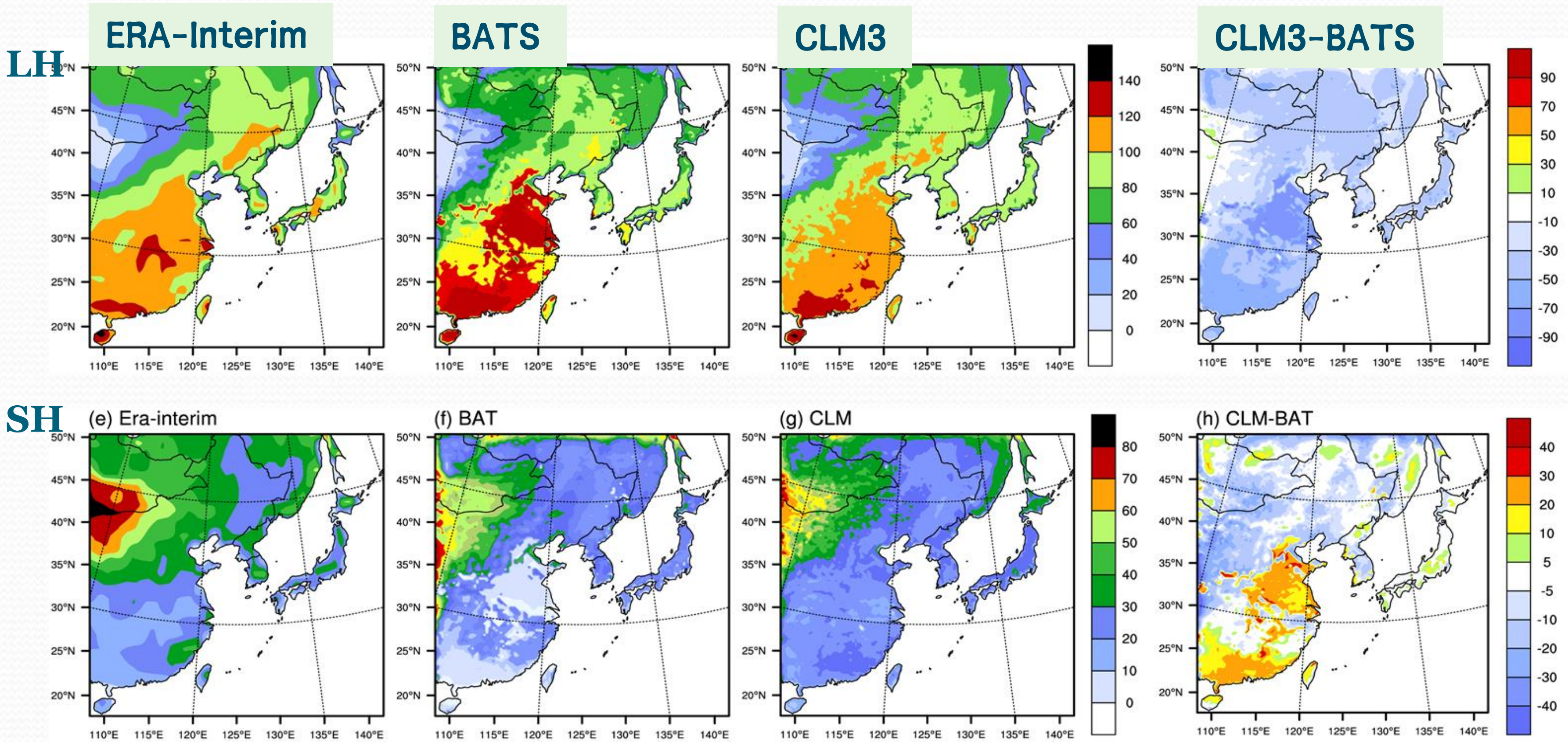
Soil Moisture averaged over South China



- The processes regulating this divergence of behaviour between CLM3 and BATS simulations are complex and it is very difficult to separately measure the impacts of the land-surface scheme because multiple processes are complicatedly interrelated. Nevertheless, a possible mechanism can be postulated by the soil moisture influence on convective precipitation. The relevant difference of both land-surface schemes is the soil moisture.

- The BATS simulation produces an excessively wet soil condition compared to that of CLM3. The wetter soil moisture is expected to lead to the higher moist static energy due to the increase of the total flux of heat(LHF and SHF) from the land surface. Therefore, the BATS simulation produces a more dominant distribution with larger CAPE and smaller CIN.

Latent & Sensible Heat Flux



- The soil moisture affects the surface energy budget by modulating the relative partitioning of latent and sensible heat fluxes.
- Wetter soil induces not only overestimation of latent heat flux but also underestimation of sensible heat flux because strong cooling simultaneously occurs with moistening of the lower atmosphere.
- Overall, CLM demonstrates better performance in terms of adequate spatial distribution and proper magnitude of the latent and sensible heat fluxes.

Thank You for Your Attention !!