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Projected change in the East Asian summer monsoon from dynamical downscaling

: Moisture budget analysis

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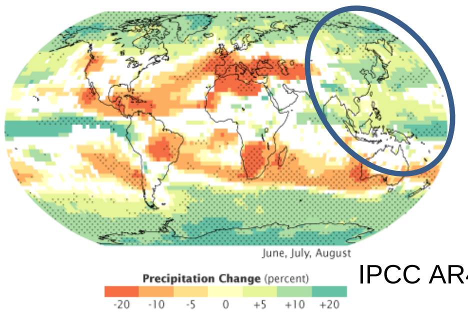
Background
– Importance of East Asian summer monsoon

- Summer monsoon characterized with heavy rainfall considerably influences on human life not only by playing as a water resource but also by causing natural hazards such as flood and drought.

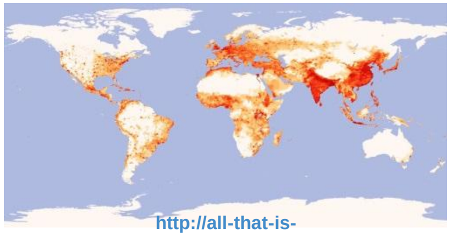
- Under the global warming during the last decades, there had been an increasing trend in summer precipitation in global monsoon areas (Hsu et al., 2013; IPCC, 2013 and references therein; Wang et al., 2012; Wang et al., 2013).



IPCC AR4

- Given the effects on water resources over East Asia, a densely populated, agricultural area, it is of considerable importance to project and understand the possible future effects of climate change on the East Asian summer monsoon (e.g., Meehl and Arblaster, 2003).

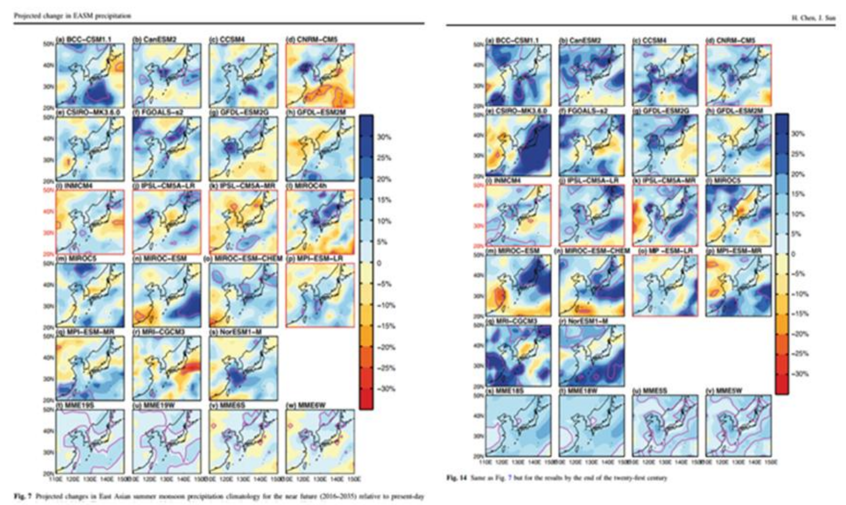
World Population in 2013



http://all-that-is-interesting.com/map-population-density

Background
- Reason for downscaling for regional climate simulation

- Social demand for detailed information of climate change and its impacts
- Limitations in computational resource
- Large inter-model difference in global climate model simulations partially caused by the incapability of simulating the regional features due to the coarse resolution and insufficient treatment of small scale processes due to relatively coarse horizontal resolution



Precipitation projected for a near-term (left) and the end of 21st century climate (right) (Fig. 14 in Chen and Sun (2013))

Purpose

- To investigate an East Asian summer monsoon change projected under a RCP4.5 global warming scenario using a pseudo global warming (PGW) method
- To understand the underlying mechanism of the change

There are several studies with dynamical downscaling on East Asian monsoon change using CMIP5 climate model projections based on RCP scenarios. Most of them analyzed the results with a qualitative approach describing the spatial and temporal changes in temperature, precipitation and monsoon circulation (e.g., Lee et al., 2013; Lee et al., 2014; Oh et al., 2013; Oh et al., 2014).

We further examined the changes by conducting an atmospheric moisture budget analysis and quantitatively analyzed especially the causal attributions of precipitation change over East Asia. A similar approach with moisture budget analysis has been conducted globally (e.g., Hsu et al. 2012) and also for East Asia (e.g., Seo et al. 2013), but the analysis used global climate model data which simulated the monsoon climates under the hydrostatic balance. Our analysis with the WRF model for a non-hydrostatic and compressible air decomposed an atmospheric moisture flux into the contributions from moisture advection and also from wind divergence/convergence.

Models

Global model for future climate projection

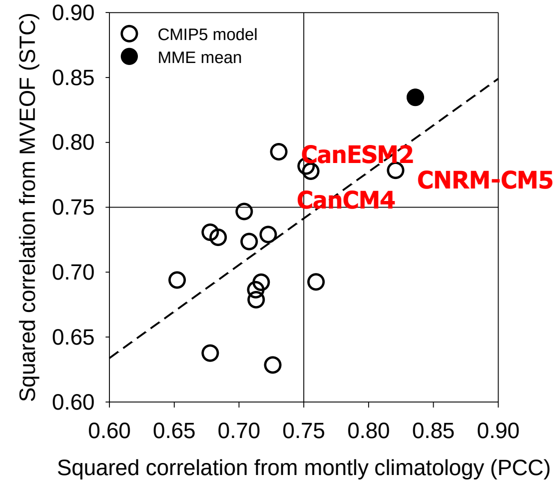
CMIP5 CanESM2

6-hourly climatology from

Historical simulation (1981-2000) - baseline

RCP4.5 simulation (2081-2100)

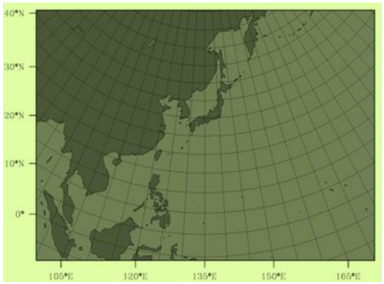
Evaluation for East Asian summer monsoon



Regional model for dynamical downscaling

WRF (Weather Research and Forecast model)

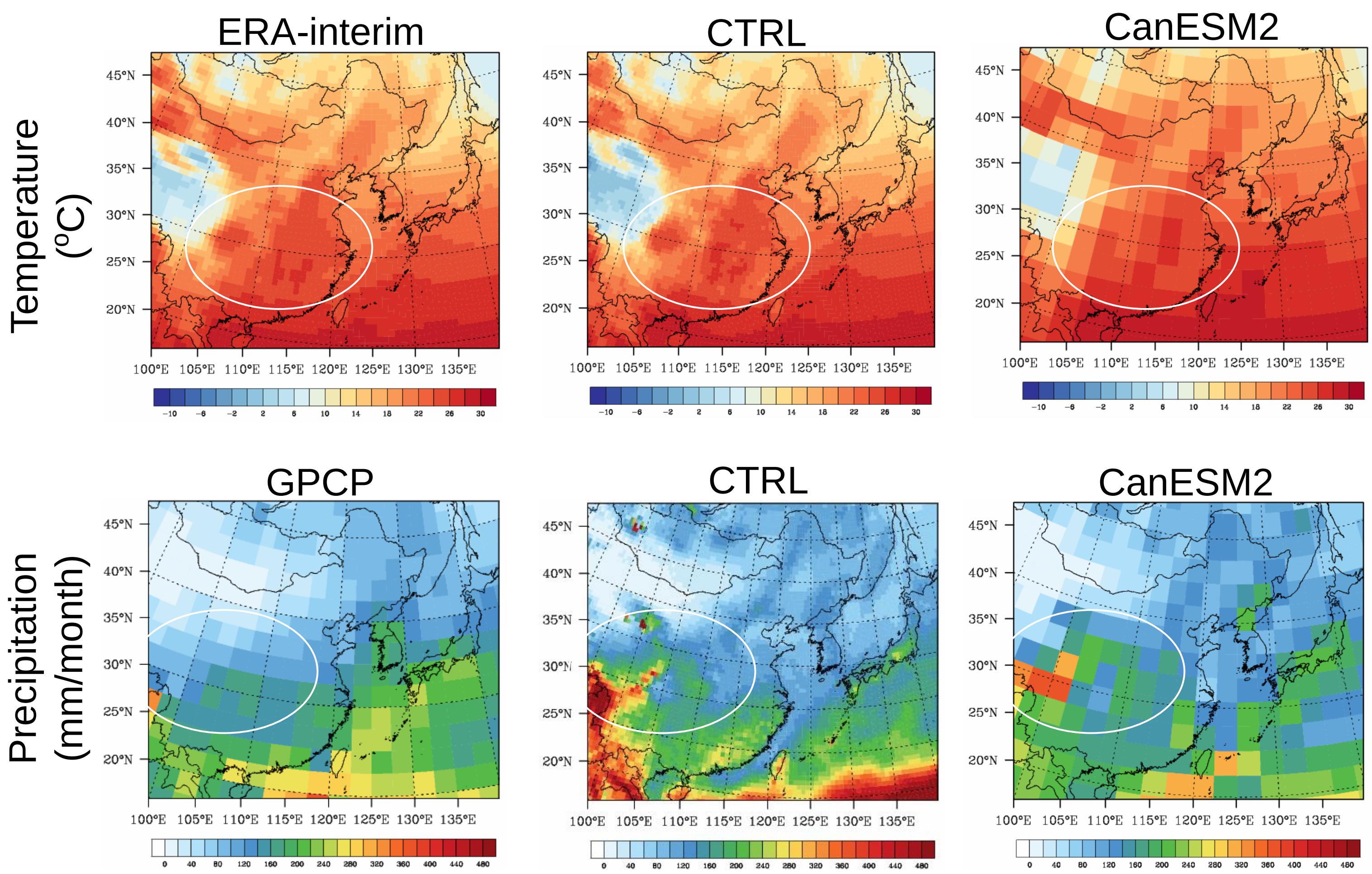
Configuration	
Map projection	Lambert-conformal
Integration period	20 April ~ 31 August from 1981 to 1990
Horizontal resolution	50 km
Number of grids	215×155×27
Domain	
Physical parameterization	
Moist convection	Kain-Fritsch (Kain, 2004)
Microphysics	WSM6 (Hong and Lim, 2006)
Boundary layer	YSU (Hong et al., 2006)
Land surface model	Unified Noah
Shortwave radiation	Dudhia
Longwave radiation	RRTM (Mlawer et al., 1997)



Pseudo Global Warming (PGW) Experiment

Dynamical downscaling	Boundary condition
CTRL Present climate	NCEP/DOE reanalysis time-series → Transient simulation
PGW Future climate	NCEP/DOE reanalysis time-series + CanESM2 climate change (RCP4.5 – Historical) 6hourly climatology difference → Quasi-equilibrium simulation

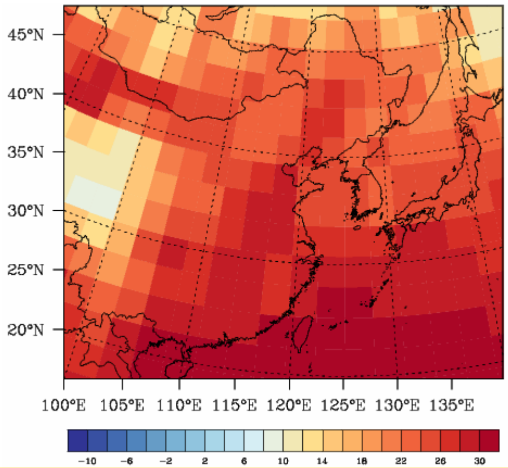
CTRL results for summer surface air temperature and precipitation



PGW results – Surface air temperature (ºC)

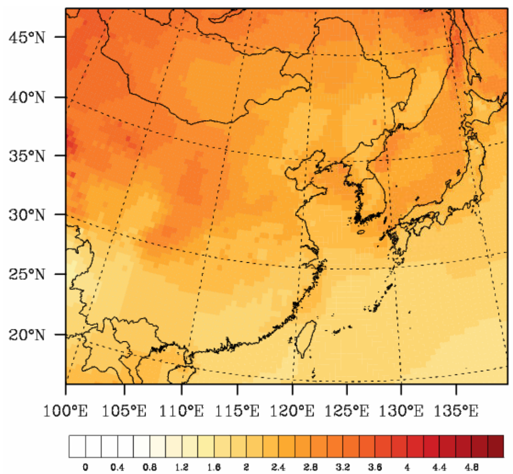
Future climate (2081-2100)

PGW

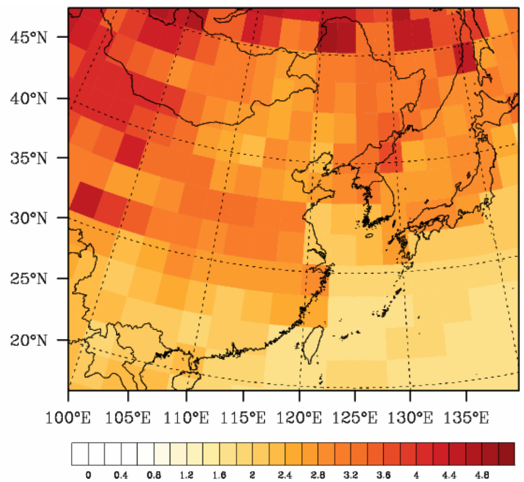


Climate change

PGW



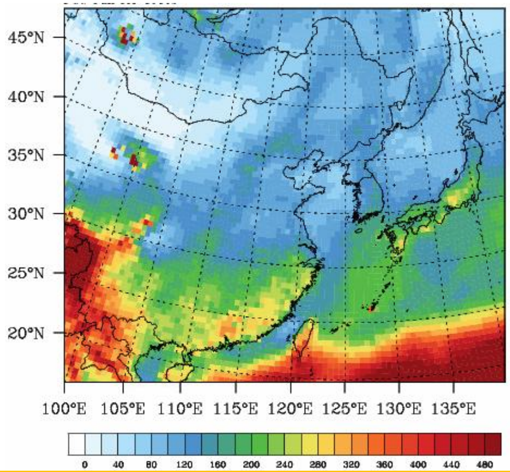
CanESM2



PGW results – Precipitation (mm/month)

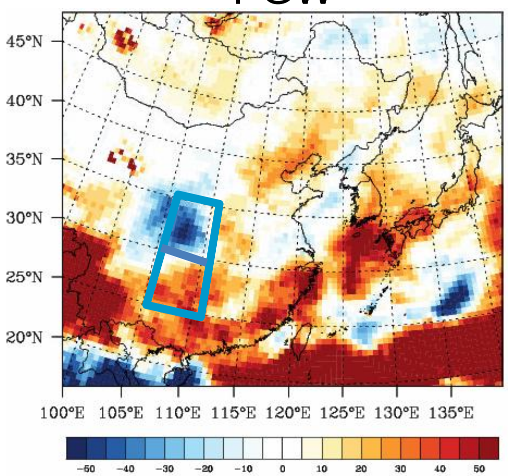
Future climate (2081-2100)

PGW

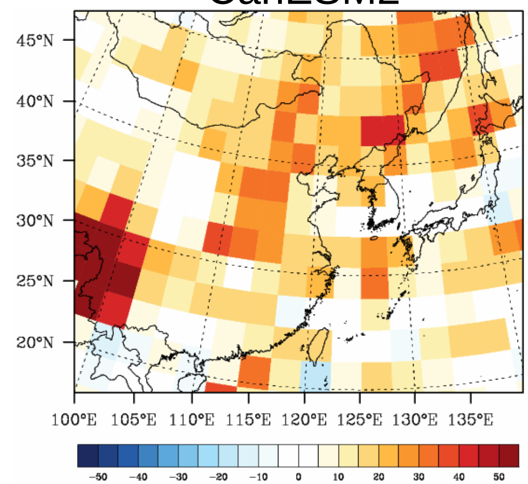


Climate change

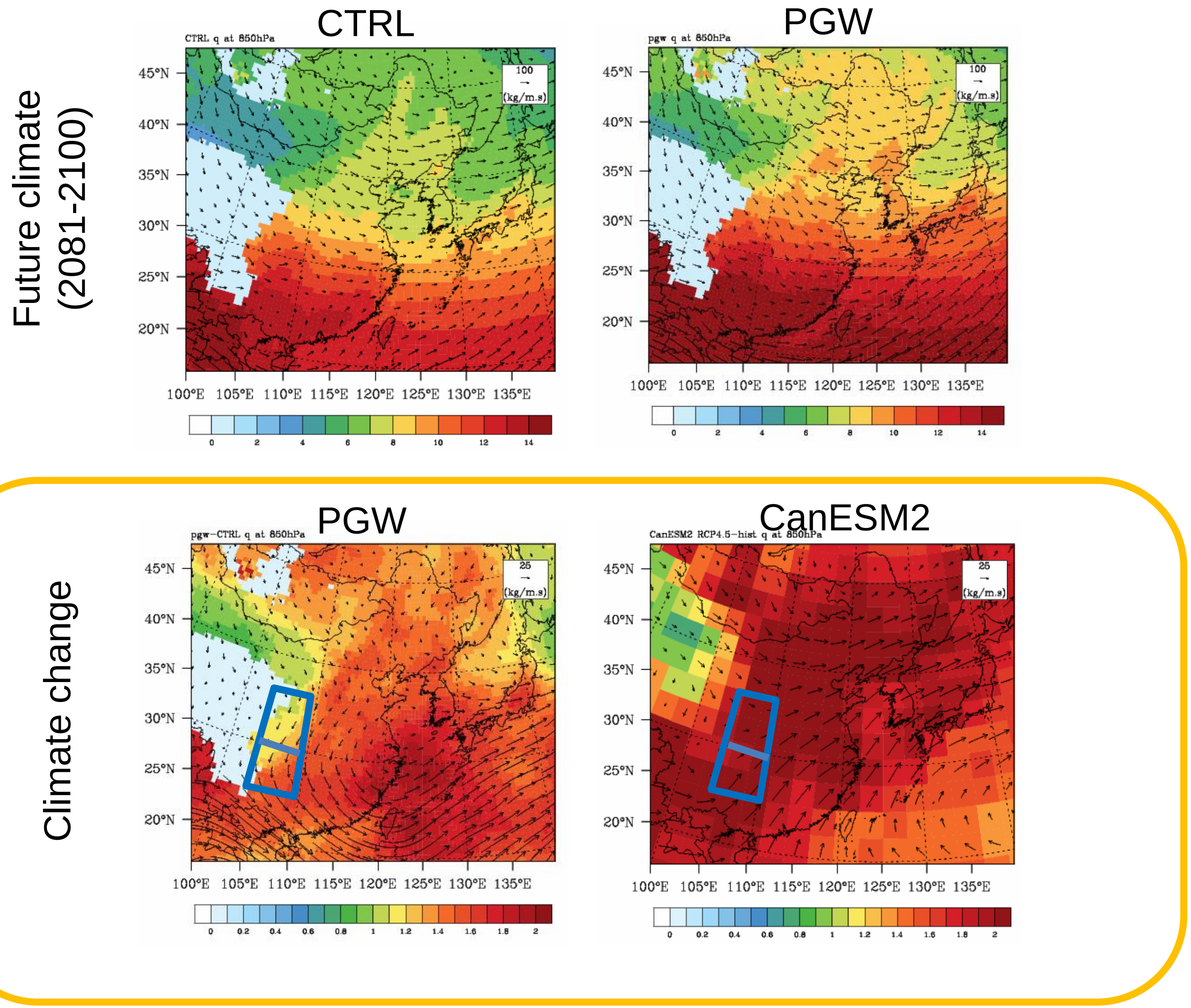
PGW



CanESM2



Specific humidity (kg/kg) and vertically integrated moisture flux (kg/m/s)

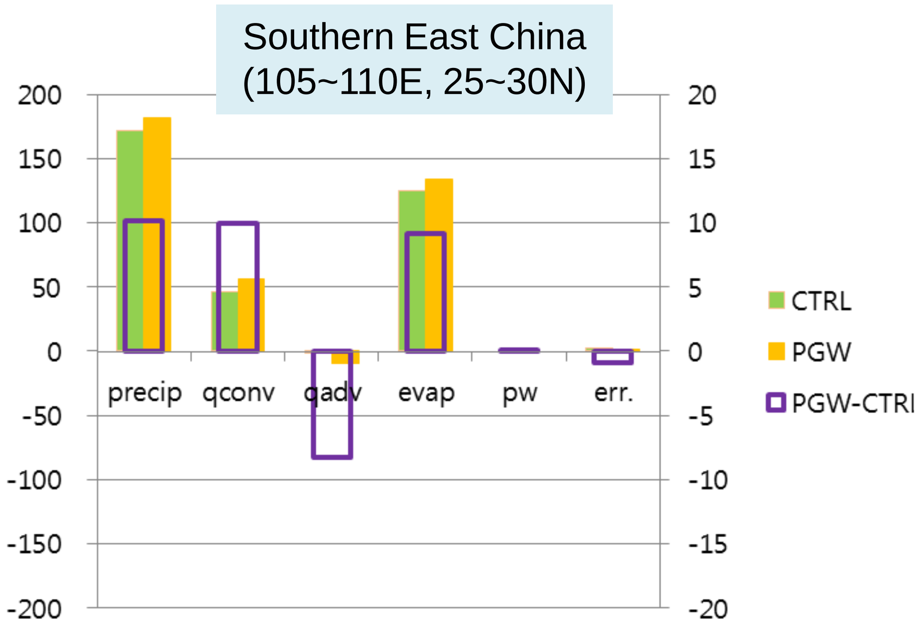


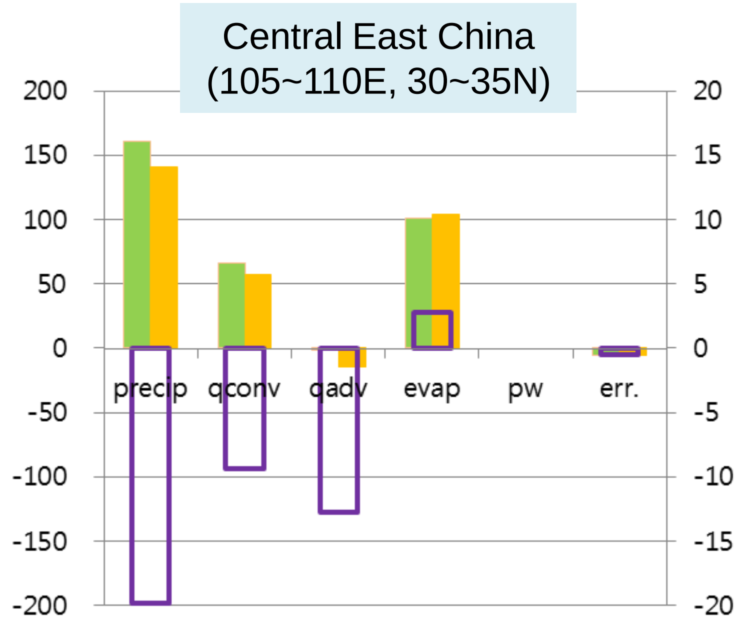
$$\frac{\partial W_A}{\partial t} + \vec{\nabla} \cdot \frac{1}{g} \int_{p_s}^{0} q\vec{V}\, dp = E - P$$

$$\frac{\partial W_A}{\partial t} + \langle \vec{V_H} \cdot \vec{\nabla} q \rangle + \langle q \vec{\nabla} \cdot \vec{V_H} \rangle = E - P + \varepsilon$$

$$\Delta P = \Delta E - \Delta \langle \vec{V_H} \cdot \vec{\nabla} q \rangle - \Delta \langle q \vec{\nabla} \cdot \vec{V_H} \rangle - \Delta \frac{\partial W_A}{\partial t} + \Delta \varepsilon$$

precip = evap + qadv + qconv + pw + err





Conclusion

- Focused on the East China region around the Yangtze river that displayed a high contrast in the precipitation change, the local moisture budget analysis for the contrasting areas indicated that an increase in surface evaporation and horizontally convergent flow led to the precipitation increase over the central East China while a horizontal advection of dry air from the northern continental area and horizontally divergent flow led to the precipitation decrease over the southern East China.
- These results suggest that the causes of future changes in precipitation due to global warming could be different depending on region.
- By using multiple models, it is important to assess the uncertainty as well as to provide the significance of the projected results.

Thank you!

Evaluation of global models for East Asian monsoon (1/3)

- CMIP5 models for historical simulation: 41 in total
- CMIP5 models without offset over high terrains: 25
  - No zonal wind data available at 850 hPa

16 models

Designation	nz	nt	start year	t196101	t200012	resolution
1. BCC-CSM1-1	17	1956	1850	1333	1812	2.8° x 2.8°
2. BCC-CSM1-1-M	17	1956	1850	1333	1812	2.8° x 2.8°
3. BNU-ESM	17	1872	1850	1333	1812	2.8° x 2.8°
4. CMCC-CESM	33	1872	1850	1333	1812	3.75° x 3.75°
5. CMCC-CM	17	1872	1850	1333	1812	0.75° x 0.75°
6. CMCC-CMS	33	1872	1850	1333	1812	1.9° x 1.9°
7. CNRM-CM5	17	1872	1850	1333	1812	1.4° x 1.4°
8. CanCM4	22	540	1961	1	480	0.9° x 1.3°
9. CanESM2	22	1872	1850	1333	1812	2.8° x 2.8°
10. FIO-ESM	17	1872	1850	1333	1812	2.8° x 2.8°
11. HadCM3	17	1753	Dec 1859	1214	1693	1.3° x 1.9°
12. MPI-ESM-LR	25	1872	1850	1333	1812	1.9° x 1.9°
13. MPI-ESM-MR	25	1872	1850	1333	1812	1.9° x 1.9°
14. MPI-ESM-P	25	1872	1850	1333	1812	1.9° x 1.9°
15. NorESM1-M	17	1872	1850	1333	1812	1.9°x 2.5°
16. NorESM1-ME	17	1872	1850	1333	1812	1.9°x 2.5°

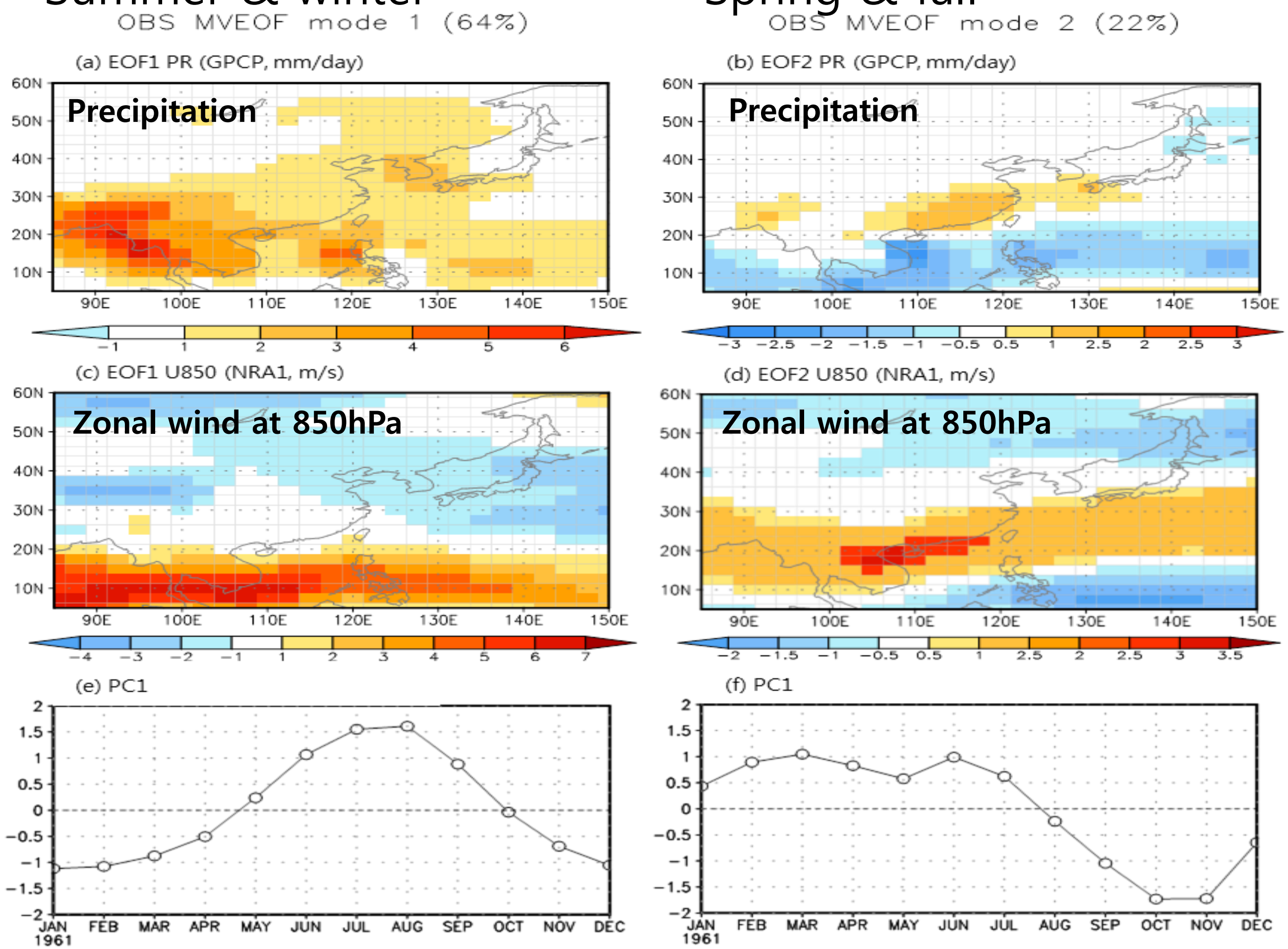
Models with different vertical resolution and starting year of integration are in red.

Evaluation of global models for East Asian monsoon (2/3)

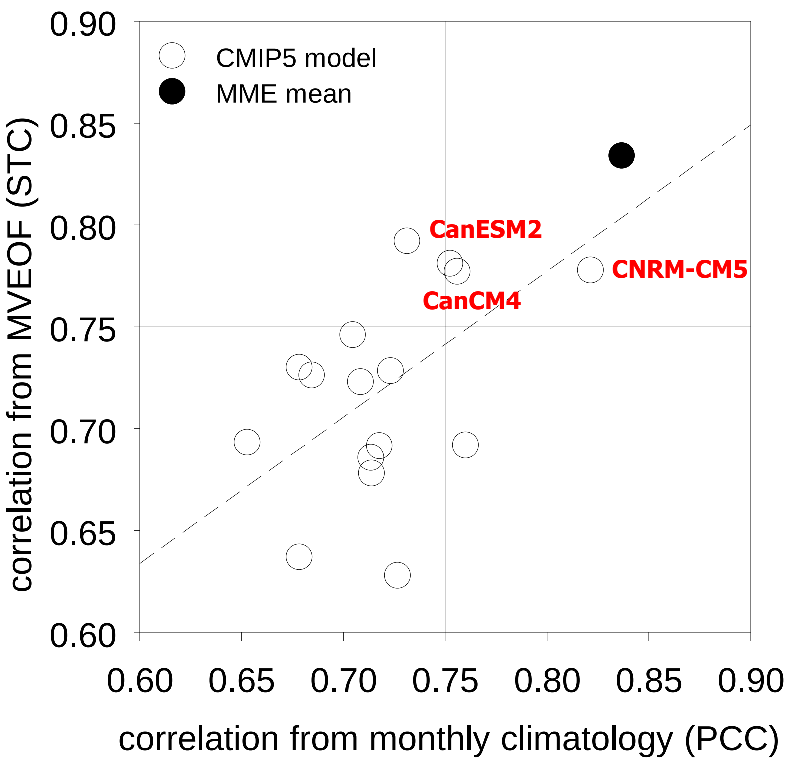
MVEOF with 850hPa wind velocity & precipitation

1st mode
Summer & winter

2nd mode
Spring & fall



Evaluation of global models for East Asian monsoon (3/3)



- Choice of CMIP5 models
  - MVEOF: **Seasonal contrast**

$$SC = \frac{0.64 * \left(\frac{PREOF1 + U850EOF1}{2} \right) + 0.22 * \left(\frac{PREOF2 + U850EOF2}{2} \right)}{0.64 + 0.22}$$

$$TC = \frac{0.64 * PC1 + 0.22 * PC2}{0.64 + 0.22}$$

$$STC = \frac{SC * DOFS + TC * DOFT}{DOFS + DOFT}$$

  - Climatological monthly mean: **Seasonal evolution**
    (a) Average of monthly pattern correlation coefficients for rainfall (PCCPR)
    (b) Average of monthly pattern correlation coefficient for U850 (PCCU850)
    (c) Average of PCCPR and PPCU850 (PCC)