Impacts of soil moisture initialization on the dynamical seasonal forecast in boreal summer

Myong-In Lee, Eunkyo Seo, and Jee-Hoon Jeong
Ulsan National Institute of Science and Technology
Chonnam National University

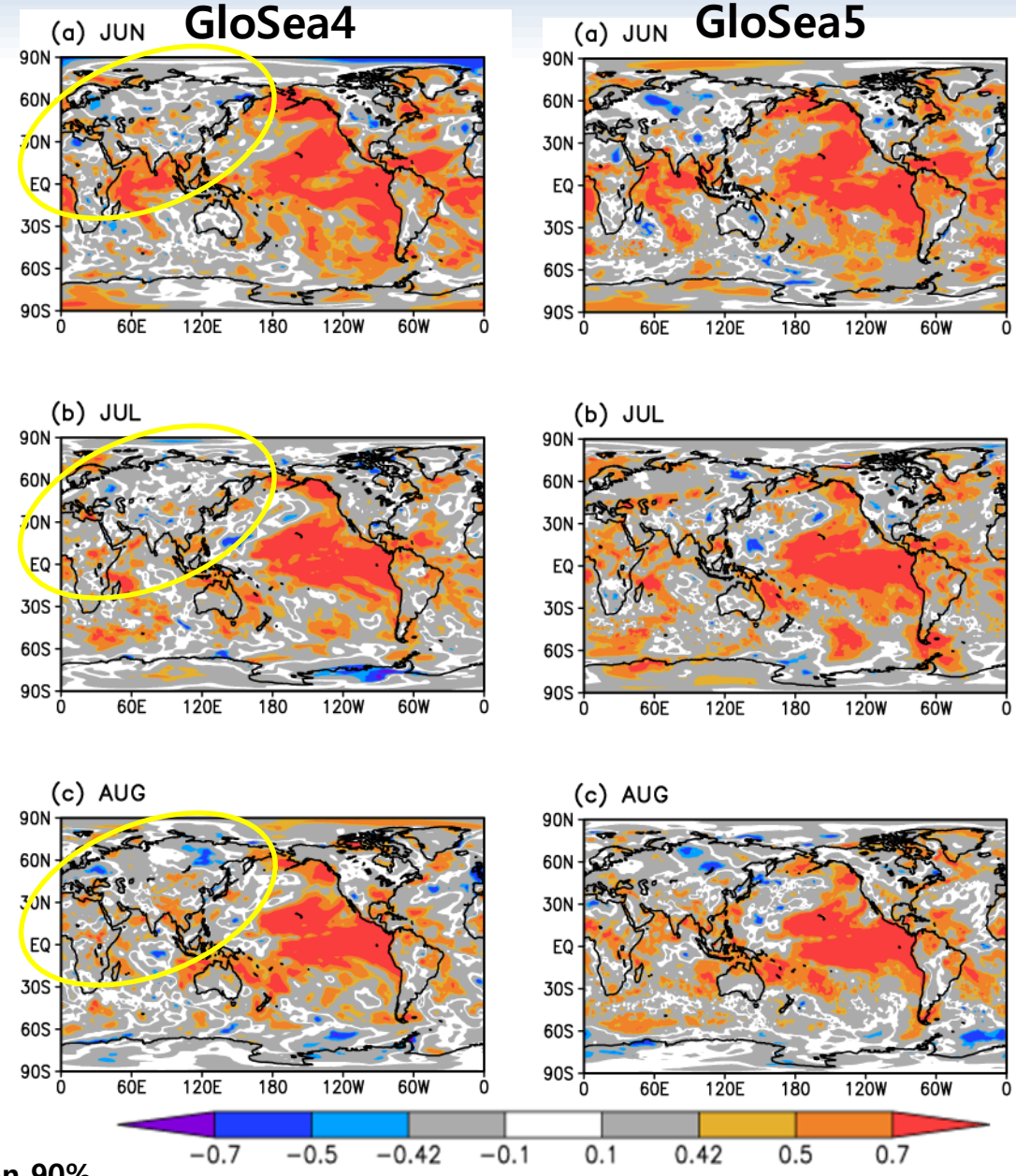
APCC seminar, APCC, Jan 20, 2016

Overview

- ✓ Motivations & Objectives
- ✓ Production of Off-line Land Surface Data
- ✓ Results from Long-term Hindcast Experiments
- ✓ Summary & Conclusions

Motivation – "Skill Cliff" in Land

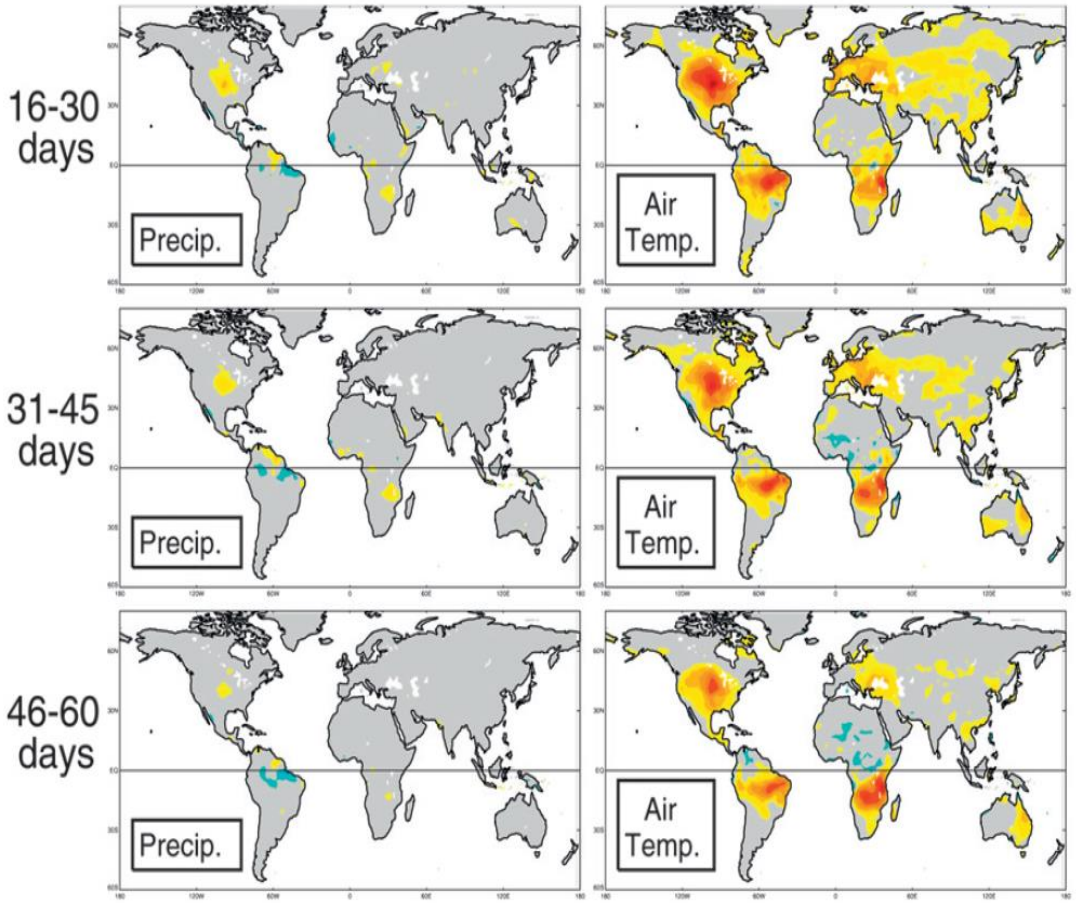
Prediction Skill (ano. corr.)
Surface Temperature
(Init @ May 1)



Prediction skill drops rapidly in midlatitude lands → impractical even in month 1

Gray color is statistically significant level less than 90%

Motivation – Land initialization



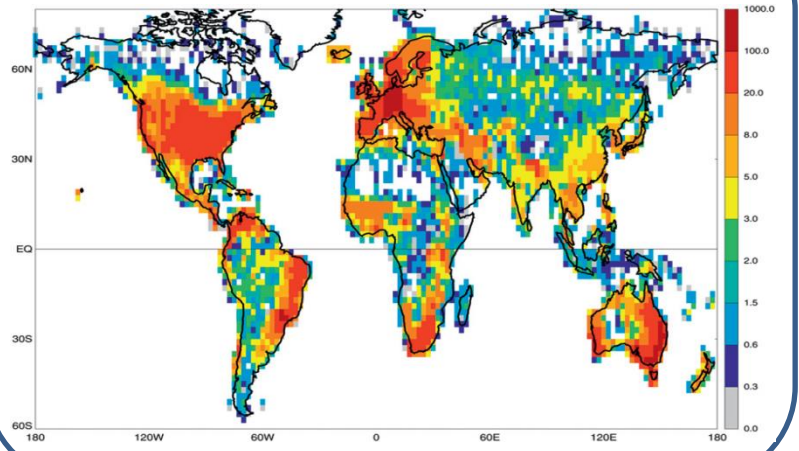
(Koster, R. D. et al. 2011, J Hydromet.)

Potential Predictability=

$$r^2(var_{nat}, var_{ens}) - r^2(var'_{nat}, var'_{ens})$$

var: with land initalization
var′: without land initalization

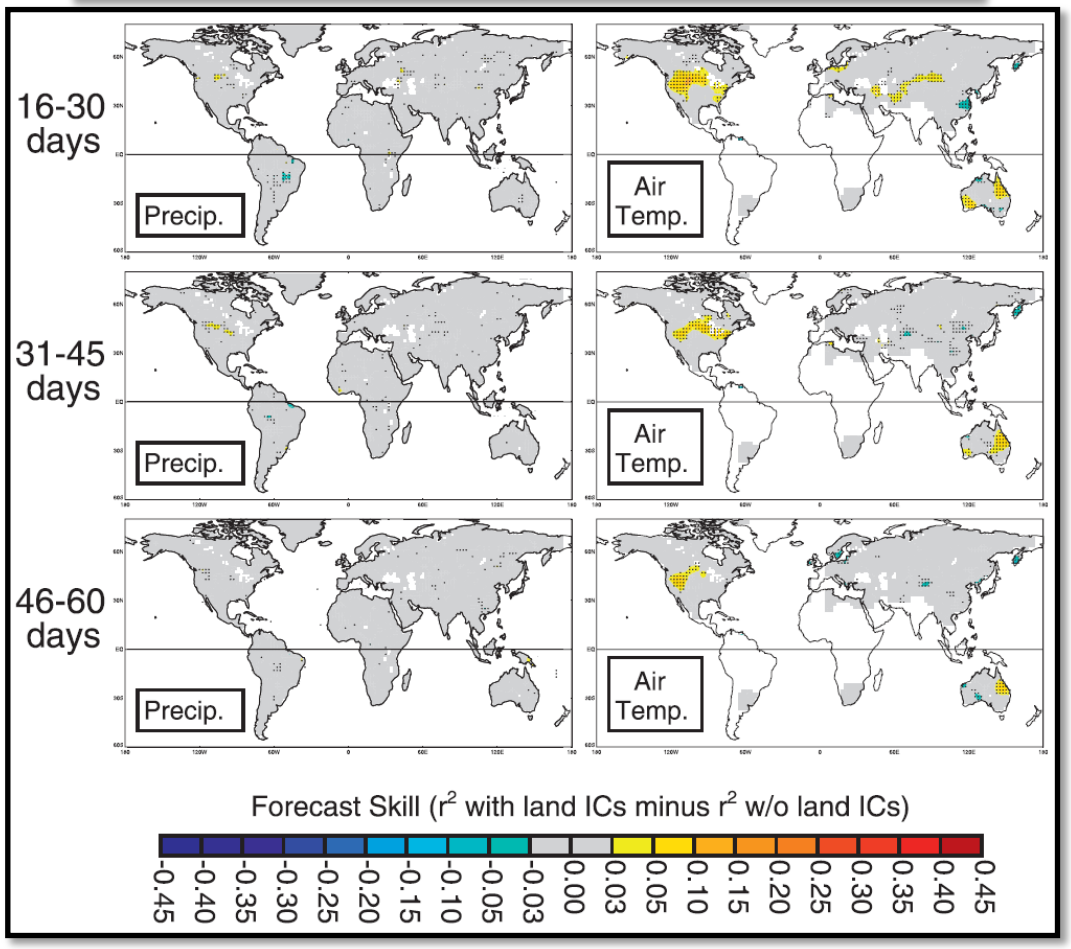
Average number of rain gauges contributing to the GSWP-2 forcing data for 1986–95.



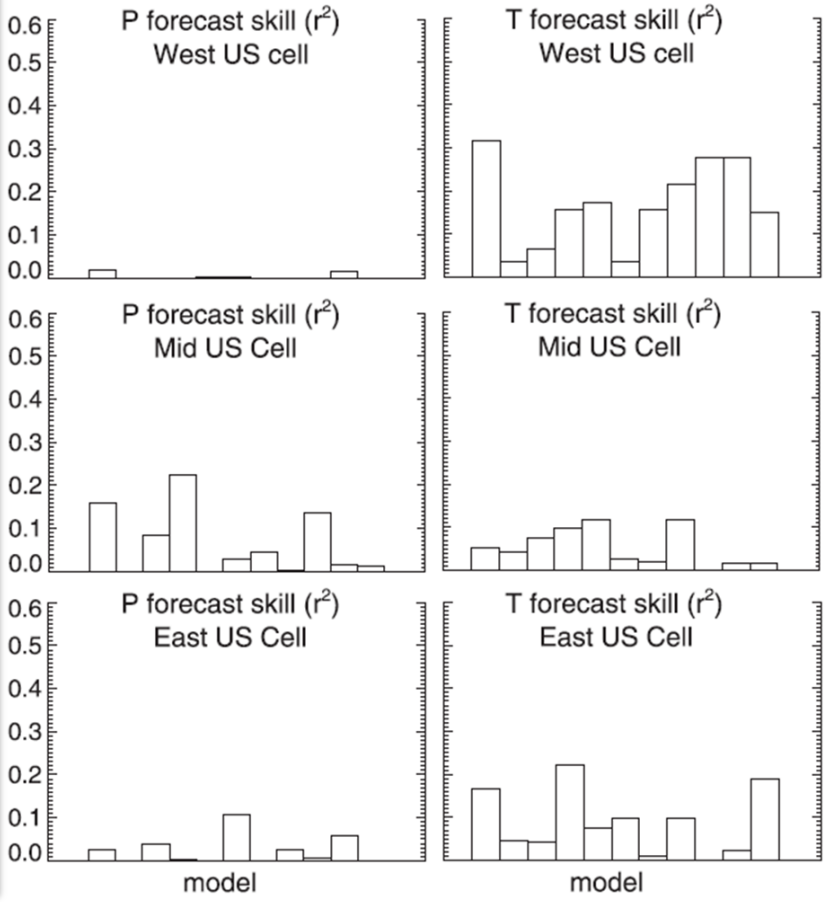
Suggesting the importance of the atmospheric forcing data (particularly precipitation)

Motivation – Land initialization

Global Land–Atmosphere Coupling Experiment (GLACE2) 1986–95



(Koster, R. D. et al. 2011, J Hydromet.)



Forecast skill=

$$r^2(var_{obs}, var_{mod}) - r^2(var_{obs}, var'_{mod})$$

var: with land initalization

var′: without land initalization

→ Large region- and model-dependence

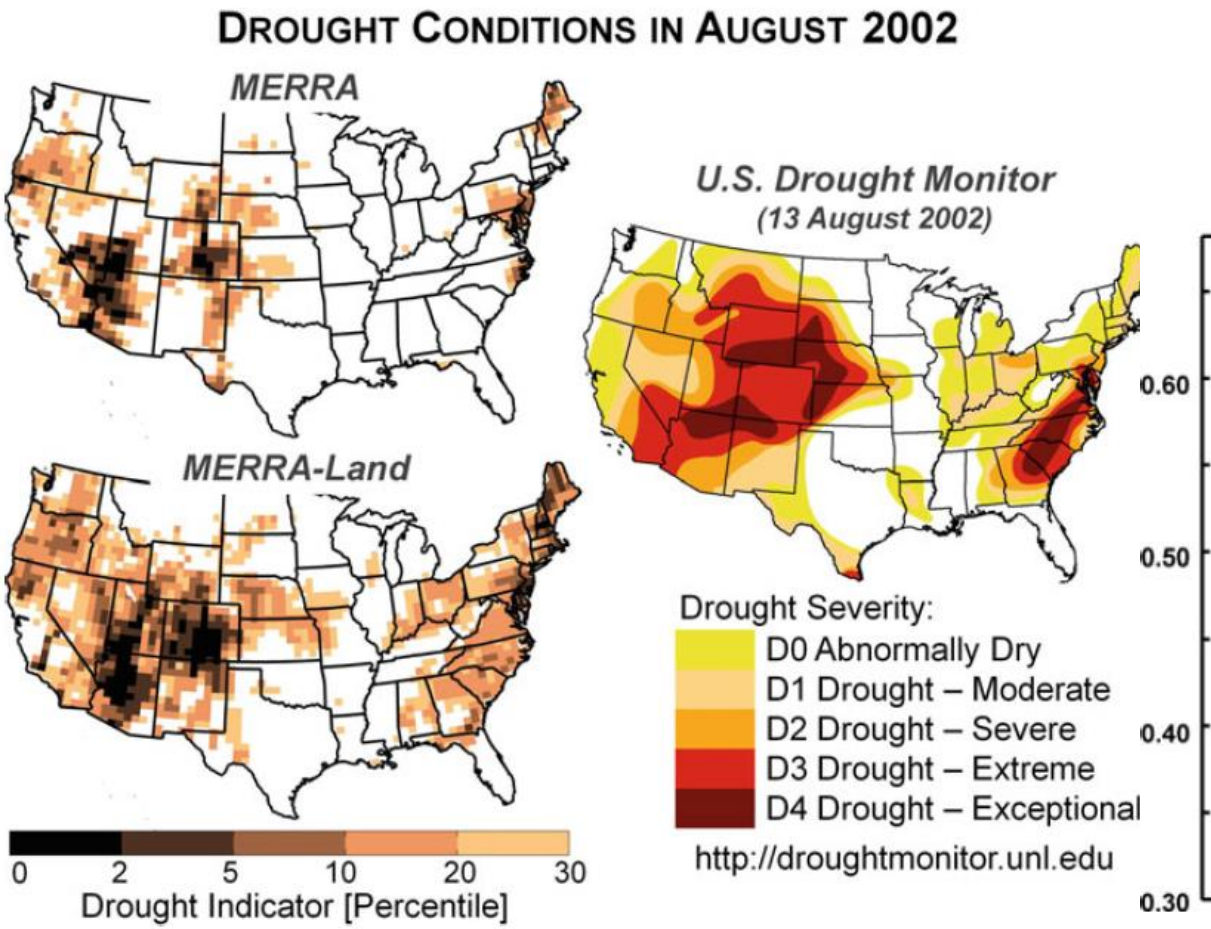
Current Status of Land Initialization

Modeling system	Atmosphere/Land	Ocean	Sea Ice
Canadian Centre for Climate Modelling and Analysis (CCCMA - CanCM4)	ERA40/Interim **Off-line CLASS** [Merryfield et al. 2013]	SST (ERSST&OISST), T&S (SODA & GODAS)	HadISST1.1
NCEP (CFSv2)	NCEP CFSR reanalysis **Off-line Noah LSM (forced by CFSR)** [Saha et al. 2010]	NCEP CFSR ocean analysis	NCEP CFSR reanalysis
EC-EARTH consortium (EC-EARTH)	ERA40/Interim [Du et al. 2012, Hazeleger et al. 2013]	Ocean assimilation (ORAS4/NEMOVAR S4)	NEMO3.2-LIM2 forced with DFS4.3
Met Office Hadley Centre (MOHC - HadCM3)	ERA40/ECMWF operational analysis **Full-field anomaly initialization** [Smith et al. 2013]	SST, T&S (Smith and Murphy, 2007)	HADISST
Global Modeling and Assimilation Office, (NASA – GEOS-5)	MERRA	T&S from ocean assimilation (GEOS iODAS)	GEOS iODAS reanalysis
Geophysical Fluid Dynamics Laboratory (GFDL - GFDL-CM2.1)	NCEP reanalysis **GFDL ensemble coupled data assimilation (ECDA)** [Yang et al. 2013]	Ocean observations of 3-D T & S & SST	No

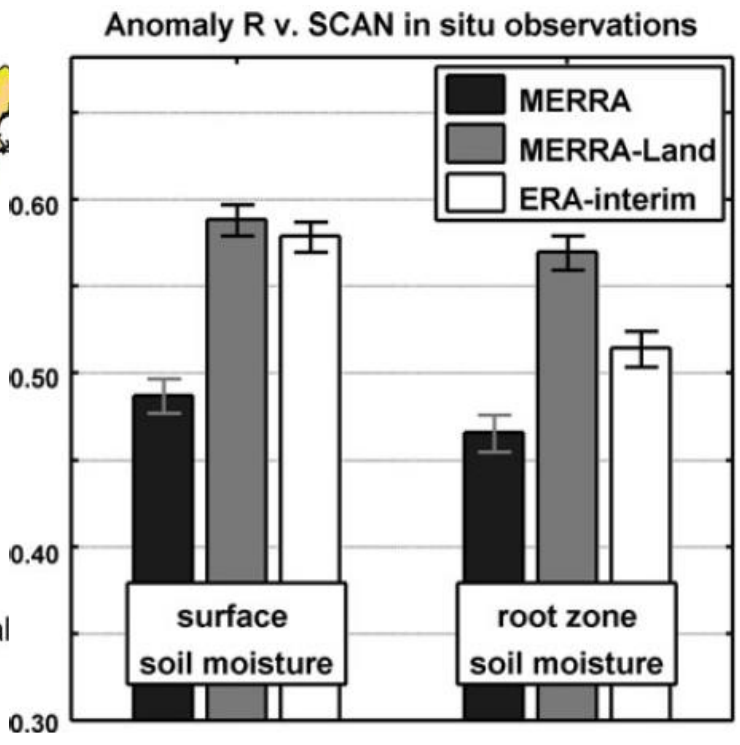
Among 16 operational centers

(IPCC 5th report, 2013)

Motivation – Soil Moisture



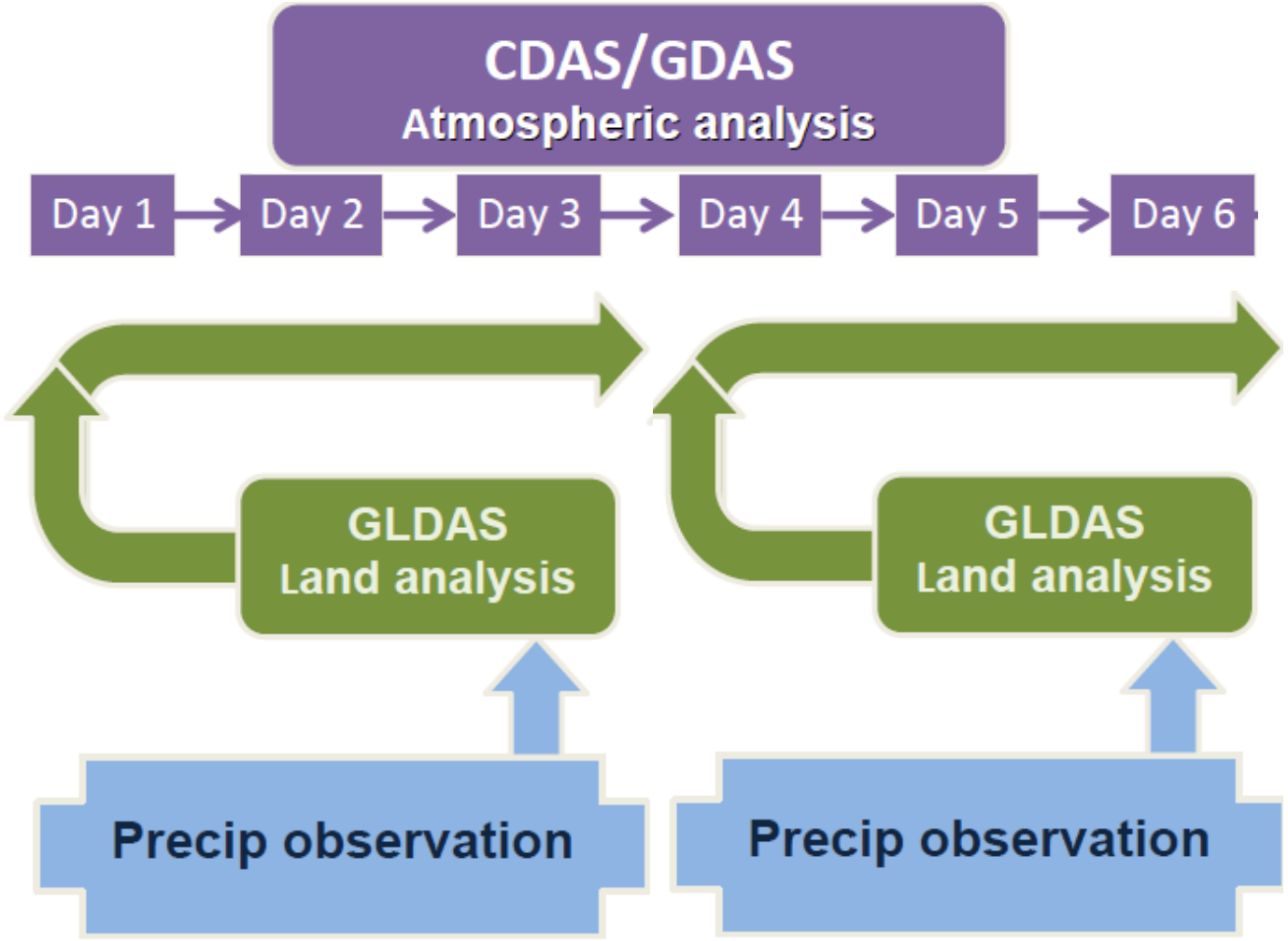
(Reichle et al. 2013)



Data assimilated forcing dataset for simulation of offline land surface model is crucial to produce realistic soil moisture

Skill (pentad anomaly R; dimensionless) estimates (2002–2009) versus SCAN in situ surface and root zone soil moisture measurements at 85 stations.

NCEP Real-time Operational land initialization



GLDAS: Noah land surface model (LSM) under NASA/Land Information System (LIS).
Precip. obs: CFSv2/GDAS atmospheric data assimilation output. (CMAP+gauge)

Research Statement

- ✓ **Land initialization** is known to be important, particularly in the **S2S time scale** (sub-seasonal to seasonal time scale ~ 60 days).

- ✓ Land initialization systems in operational centers are still in **beginning stage**, due to data limitations such as **a lack of** long-term, global, **in-situ observations** of hydrological cycle in surface and subsurface.

- ✓ An alternative, and popular choice to obtain subsurface condition is using the **off-line land surface model** with observational forcing dataset.

- ✓ Improvements by land initialization in any operational system seems quite **empirical** in that it must depends on:
  - ***Model and initialization methods***
  - ***Forcing data quality***
  - ***Potential predictability (region-dependence)***

→ This study reveals the impact of soil moisture initialization impact on the KMA/Met Office Global Seasonal Forecasting System version 5 (GloSea5)

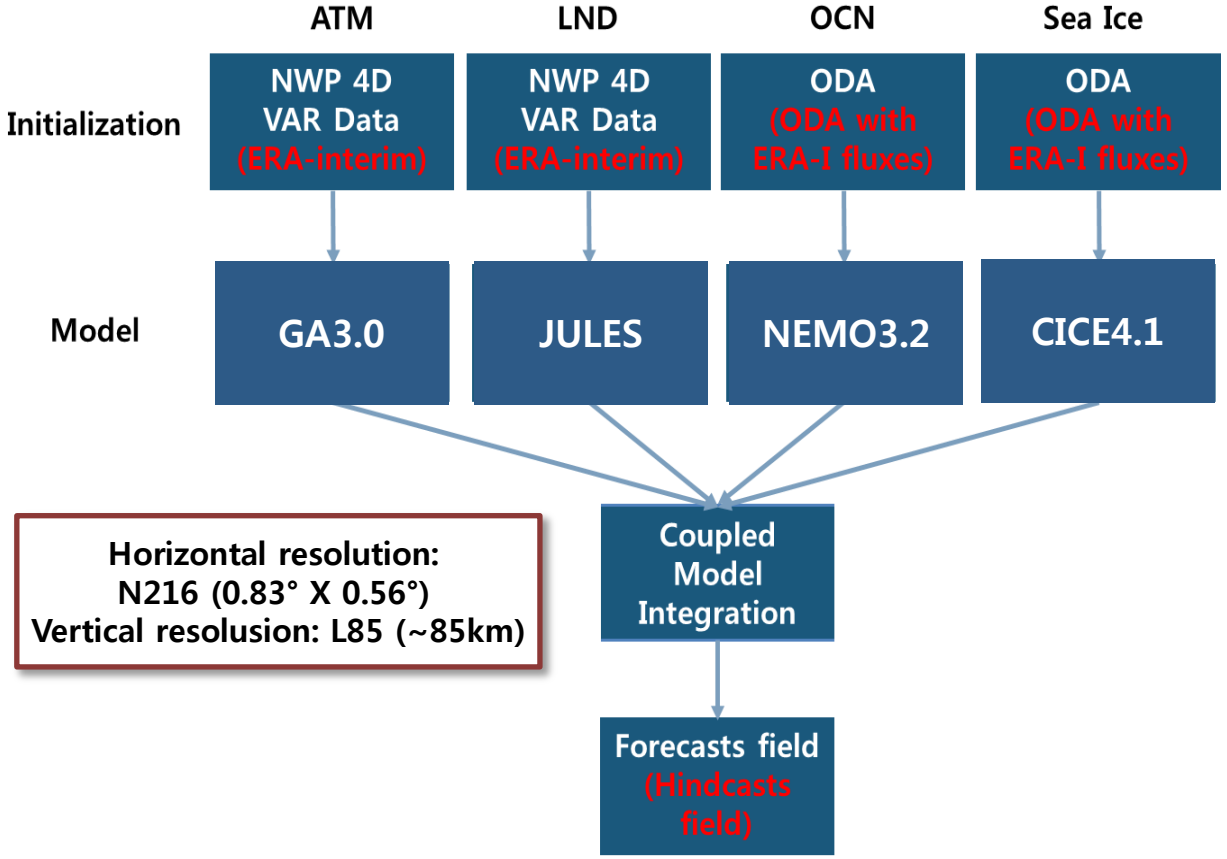
Description of GloSea5

GloSea Description

- UK Met Office Global Seasonal Forecasting System (GloSea version 4; Arribas et al. 2011), Version 5 (Maidens et al. 2013) with GA3.0 in increased resolution
- Based on the Hadley Center Global Environment Model version 3 model (HadGEM3); Coupling in 3-h interval

Flow of System Initialization and Forecasts

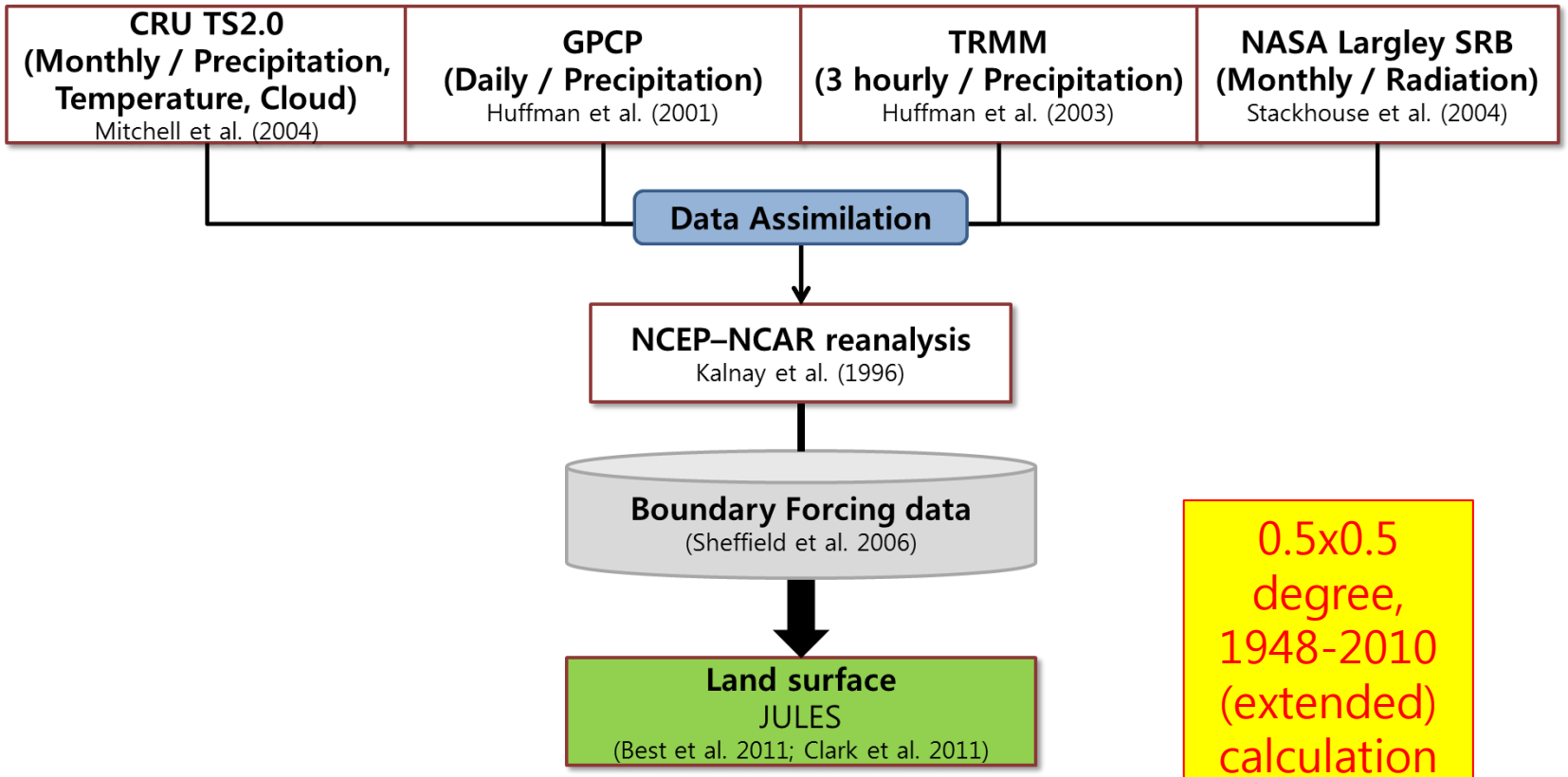
◆ Forecast (Hindcast)



- Real-time Ensemble Forecast and Hindcast
- Anomaly initialization for land surface (Hindcast)

Off-line JULES Land Surface Model

- Jules-vn3.4: developed from MOSES (GloSea's LSM)
- Parallelized version(after v3.2)
- Multiple soil layers (4 layers: 0.1, 0.25, 0.65, 2m)
- Global 0.5° x 0.5° resolution (can be adjusted to GLoSea res.)
- Multiple snow layers (3 layers)



0.5x0.5 degree, 1948-2010 (extended) calculation

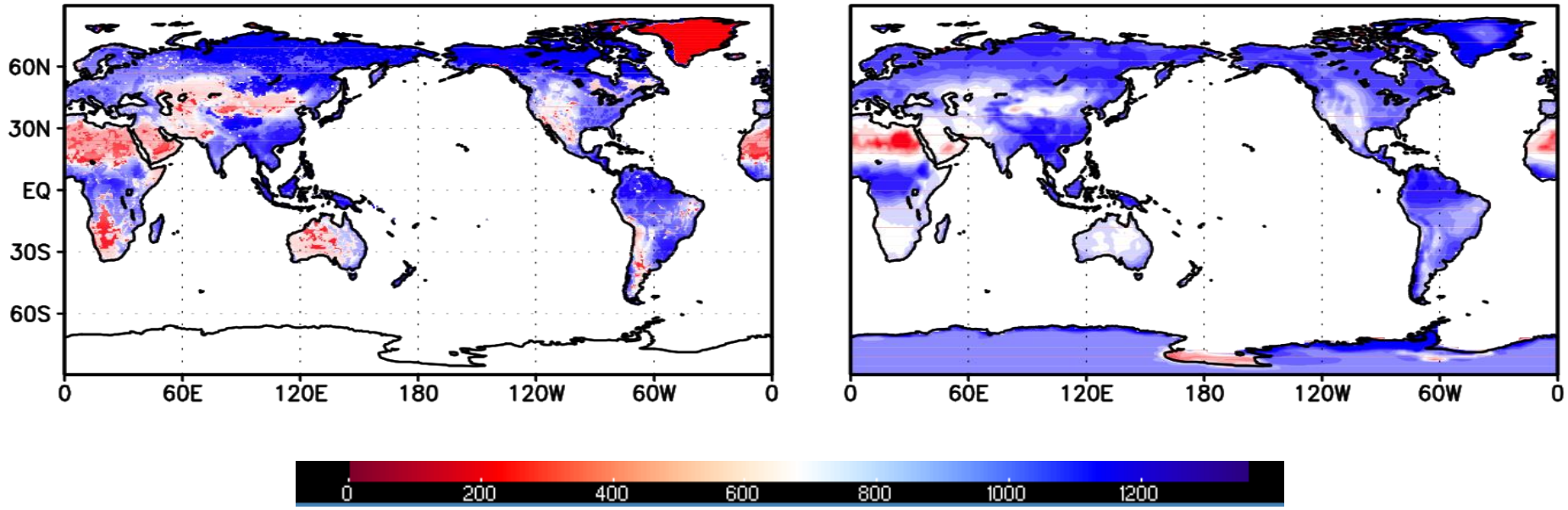
Comparison of Soil Moisture Climatology (kg/m^2)

August

0~2 meter soil moisture

JULES

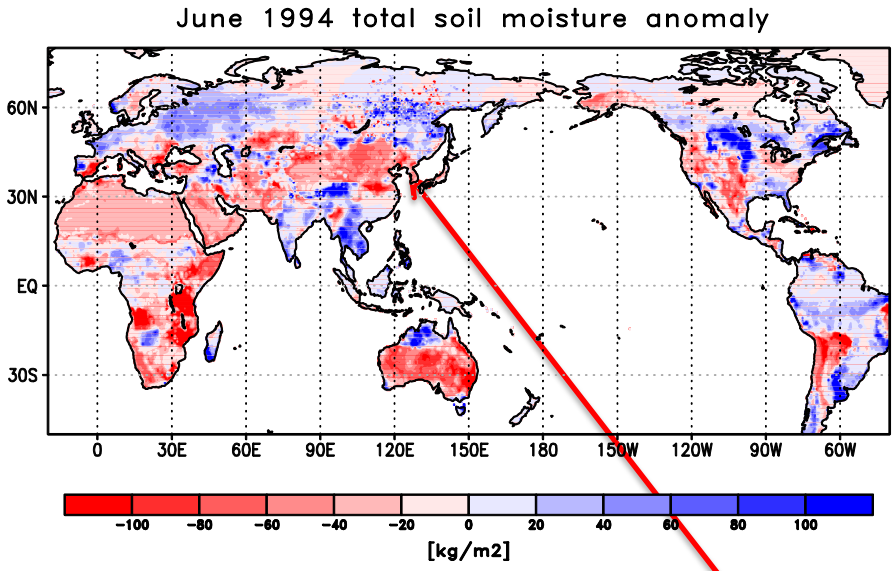
ERA-interim



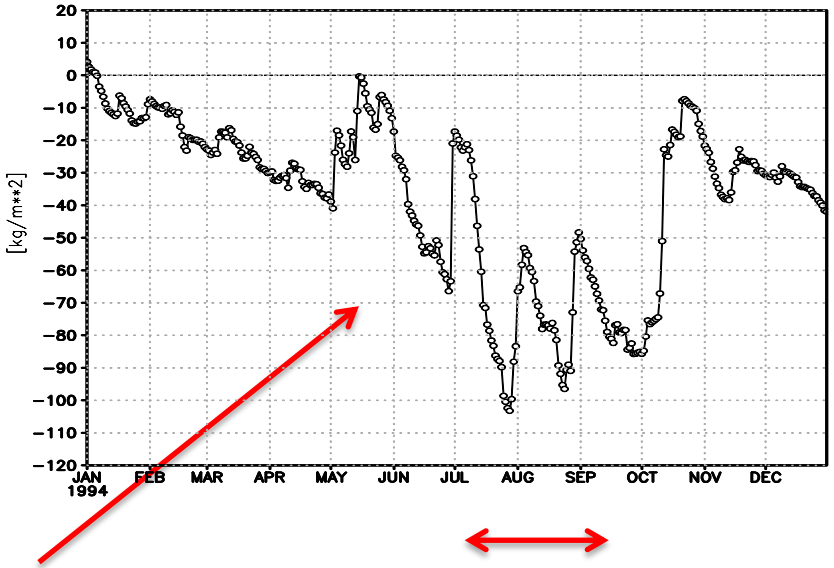
→ Larger spatial changes in JULES

JULES simulation
1994 drought & heat wave case

SM anomaly (1986-1995 climate)



Total soil moisture averaged over South Korean grid-point s for 1 Jan ~ 31Dec 1994



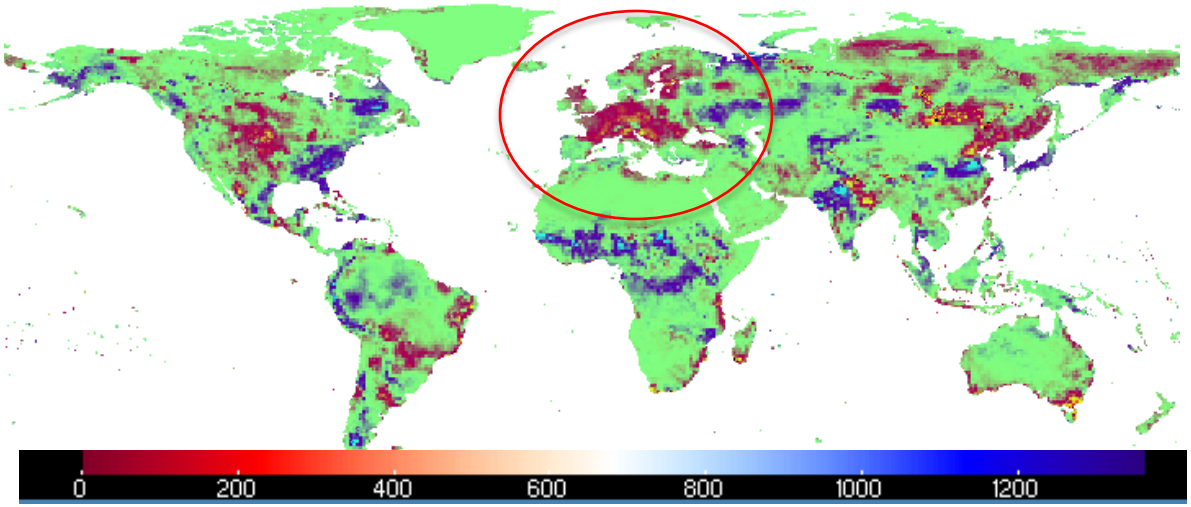
Precursory signal by soil moisture

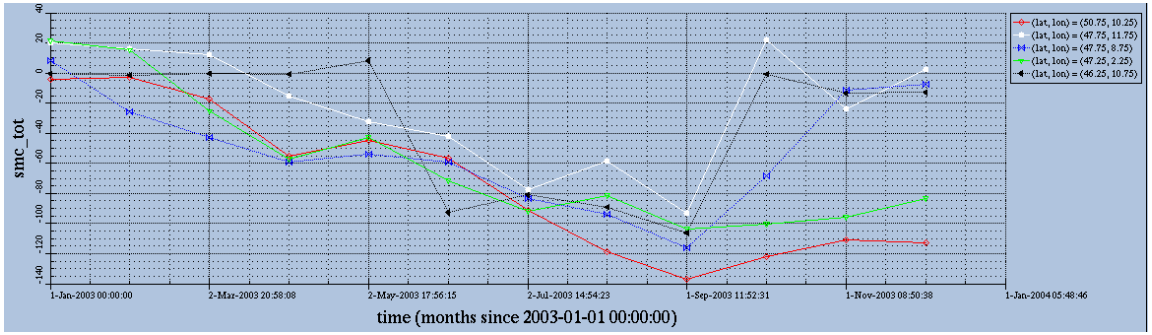
South Korea Heat wave period

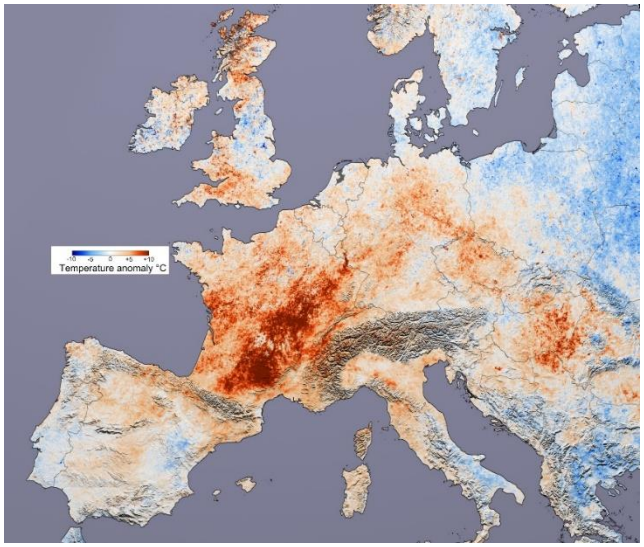
1994 heat wave is associated with drought signal. JULES simulation shows that negative soil moisture anomaly is spatially consistent with the recordable heat wave (June) over the Northeast Asia. Moreover, the simulation also reproduces Australian drought signal.

JULES simulation
2003 European drought & heat wave case

Simulated SM anomalies for May 2003



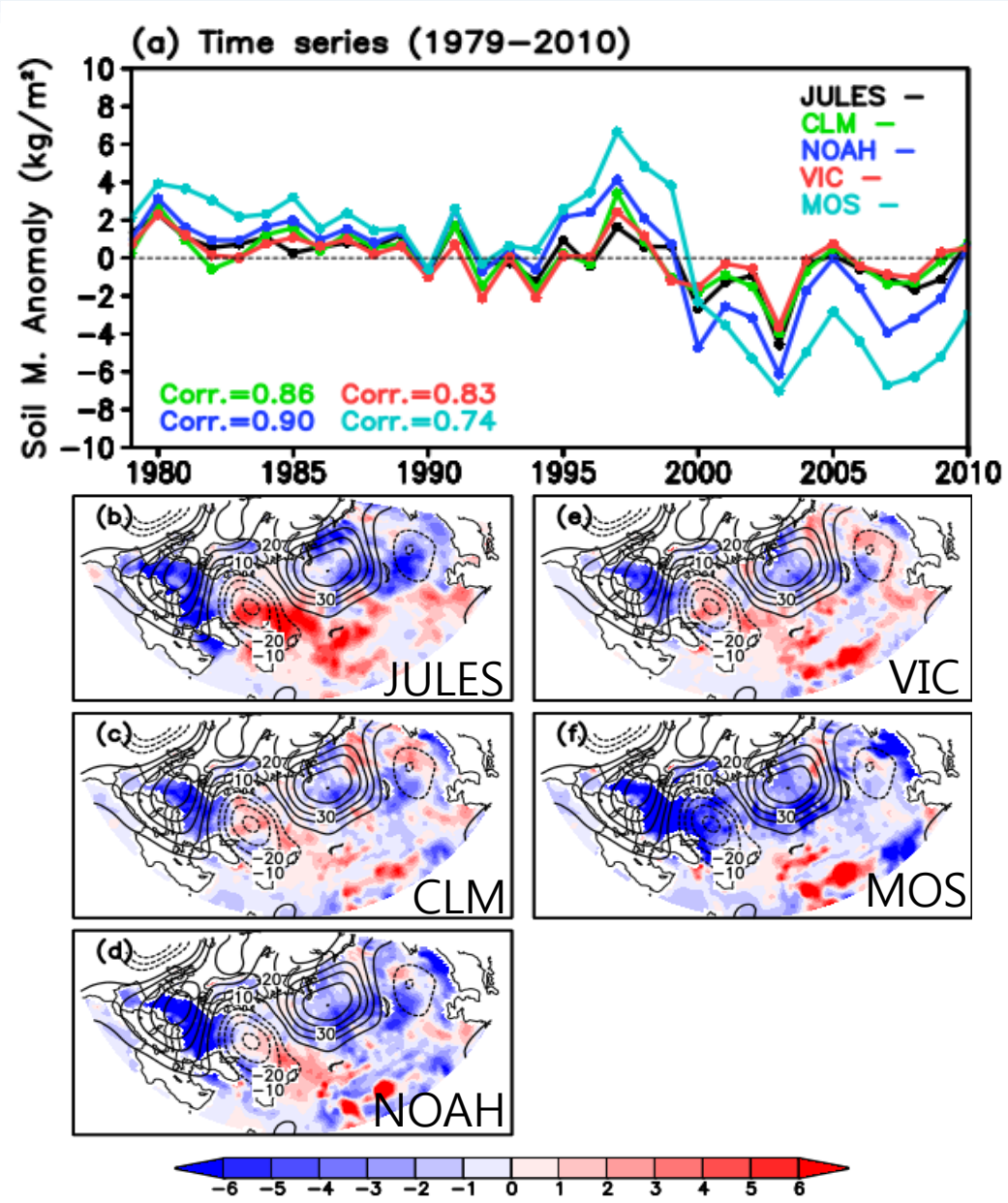




European heat wave
Anomalous SAT

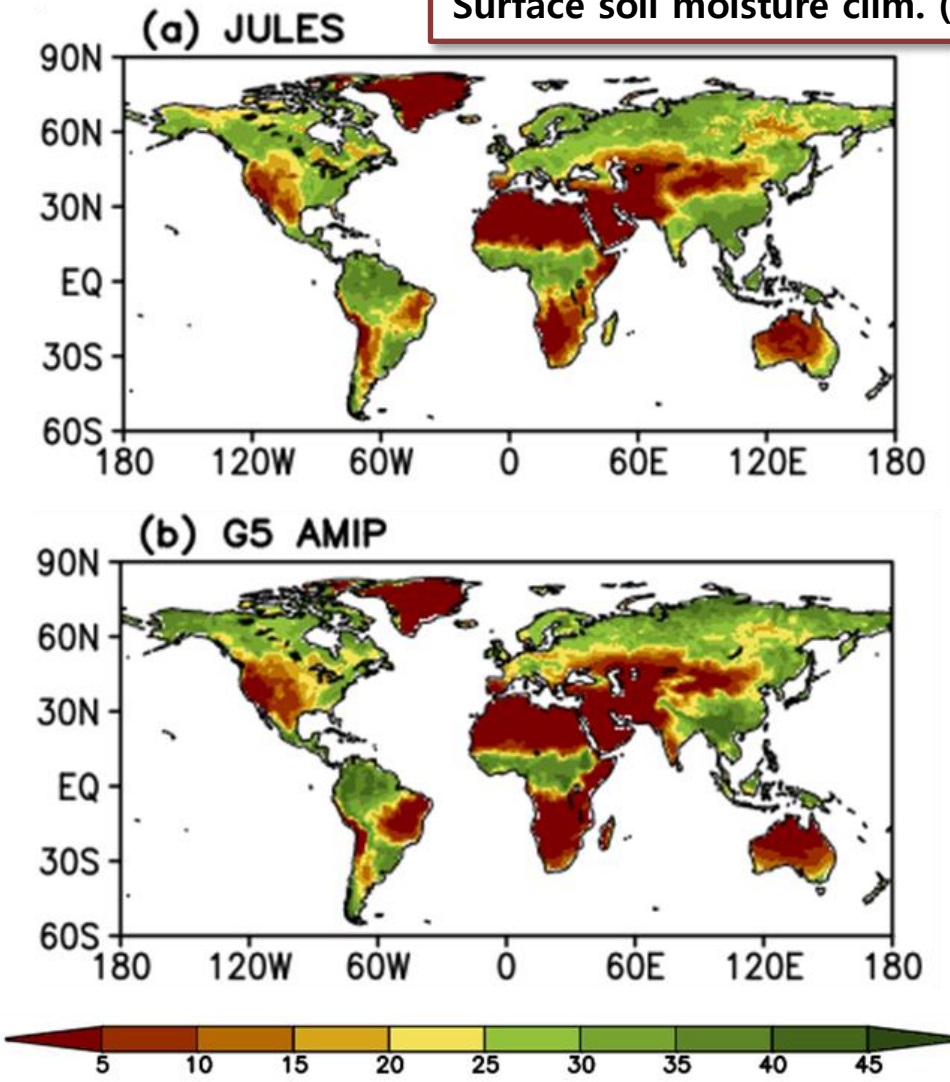
- 2003 European heat wave is related with land-atmosphere interaction over the Western Europe dry condition (drought) during spring season.
- Overall, JULES off-line run precisely simulates the drought pattern.

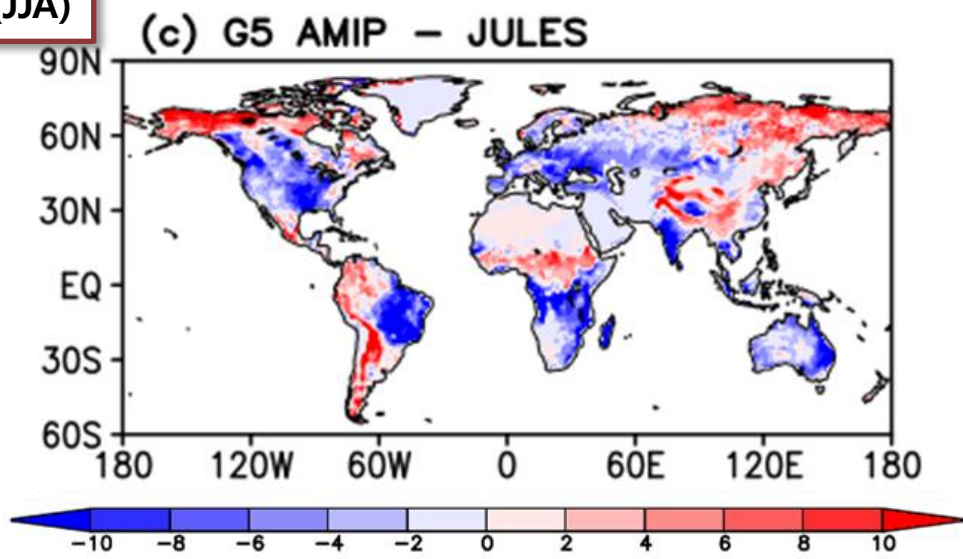
Comparison between land surface reanalysis



Climatology Difference by coupling with atm

Surface soil moisture clim. (JJA)





- **Overall AMIP soil moisture global distribution resemble offline LSM calculation.**
- **However, the model has negative anomaly, especially, in the middle latitude**

Drift of the Model Climatology

(Dirmeyer et al. 2000, JC)

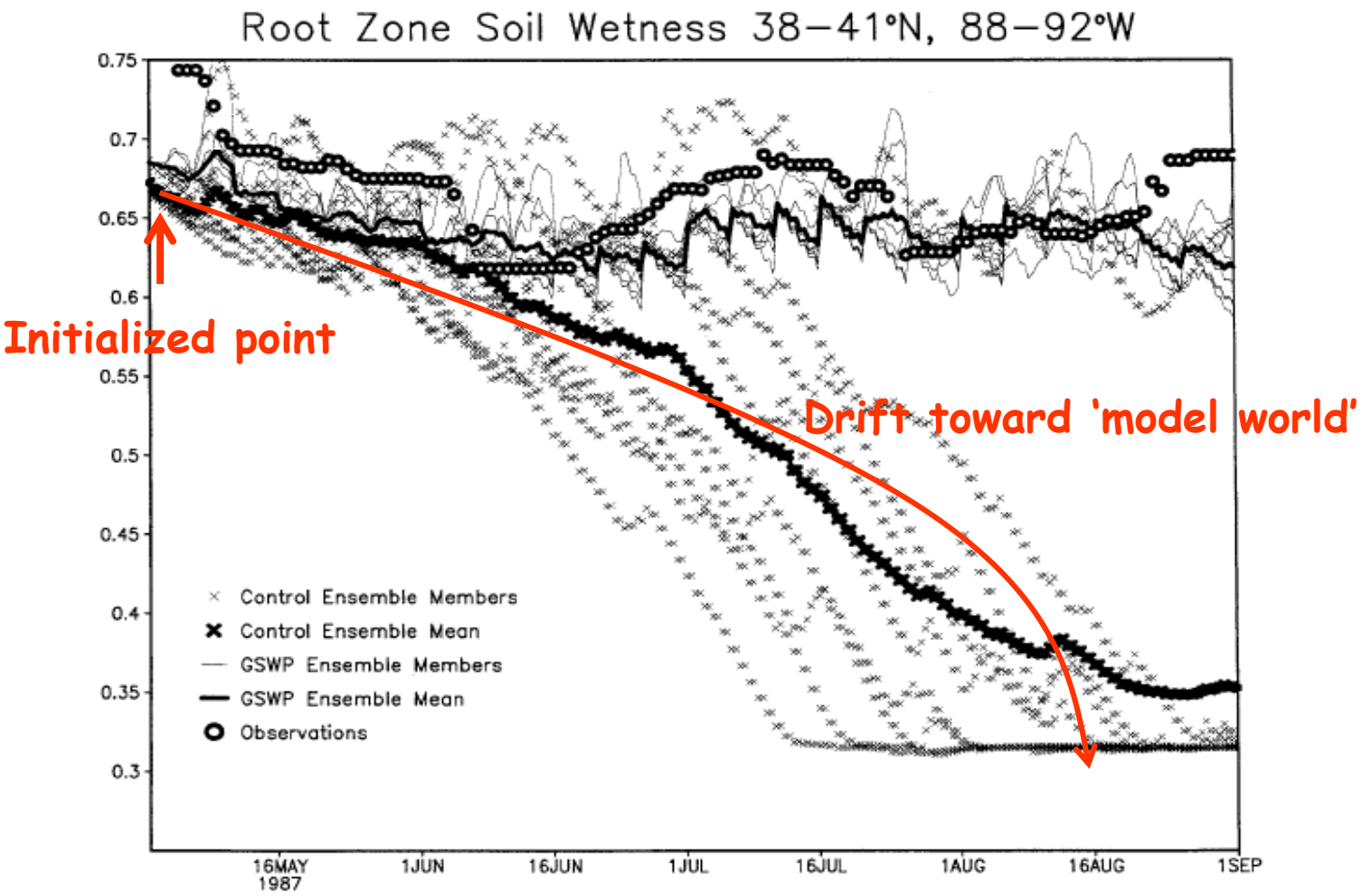
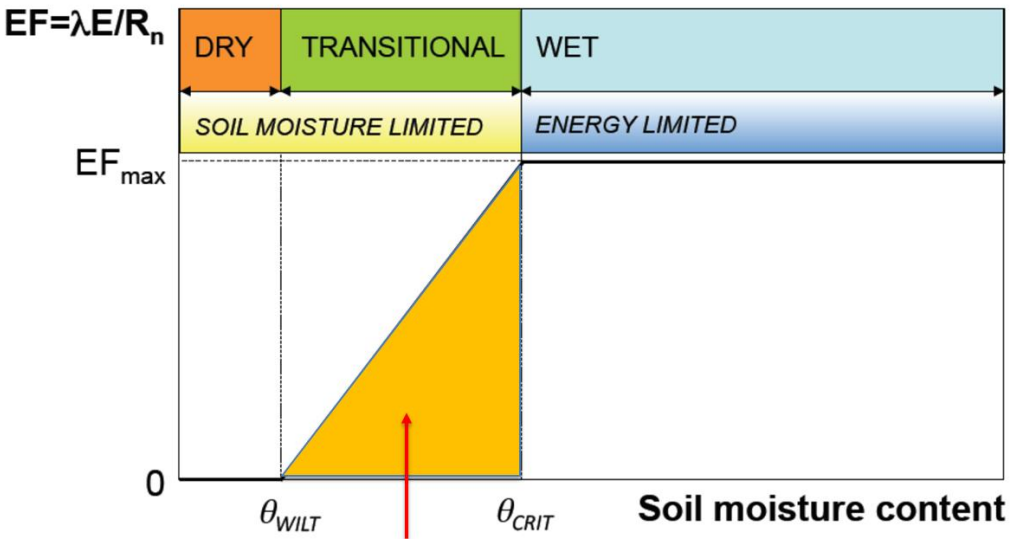


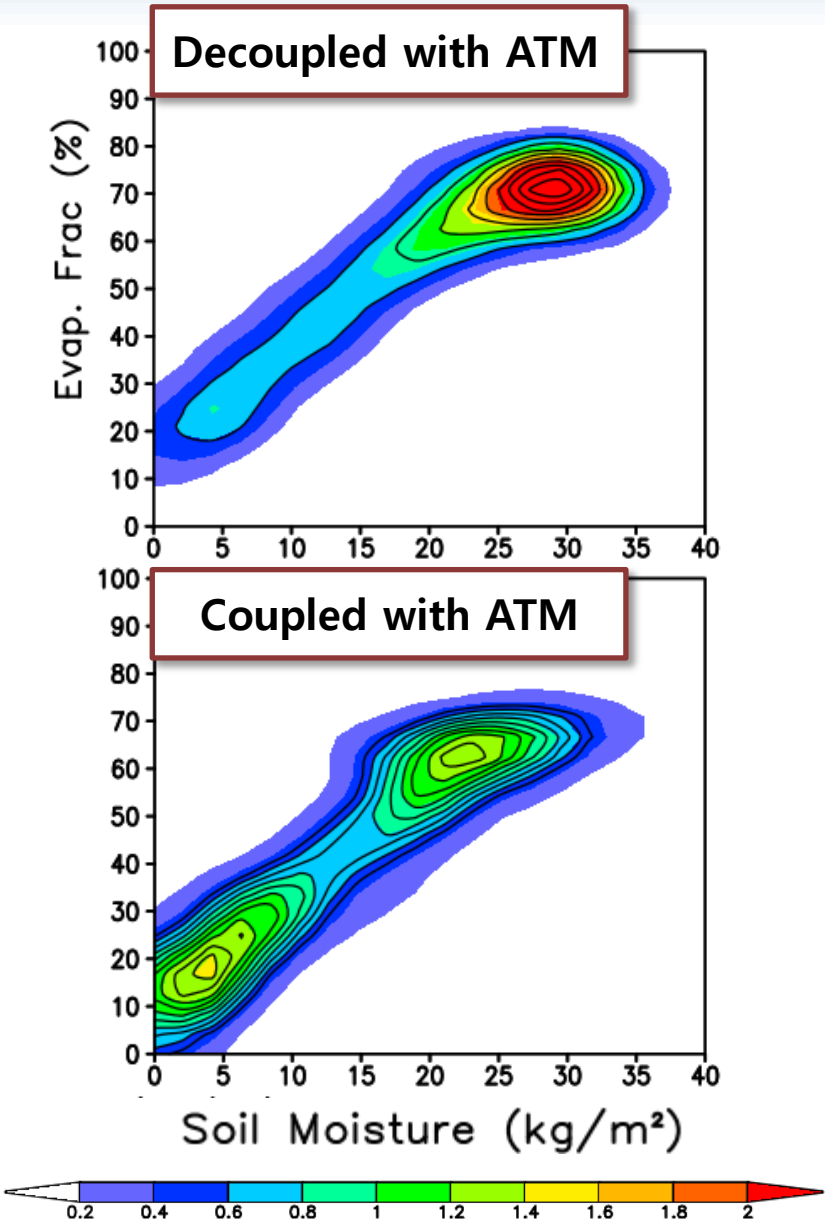
FIG. 4. Comparison of the evolution of root zone soil wetness for individual ensemble members (light) and the ensemble mean (bold) for the control and GSWP cases during May–Aug 1987 at a grid cell over Illinois. Also shown is the top 1-m soil wetness averaged for 12 Illinois Soil Moisture Network stations. Units are fraction of saturation.

Climatology Difference by coupling with atm

(Seneviratne et al. 2010, Earth-Science Reviews)



Regime where evaporation is sensitive to soil-moisture



Evapo. Fraction vs Soil Moisture diagram

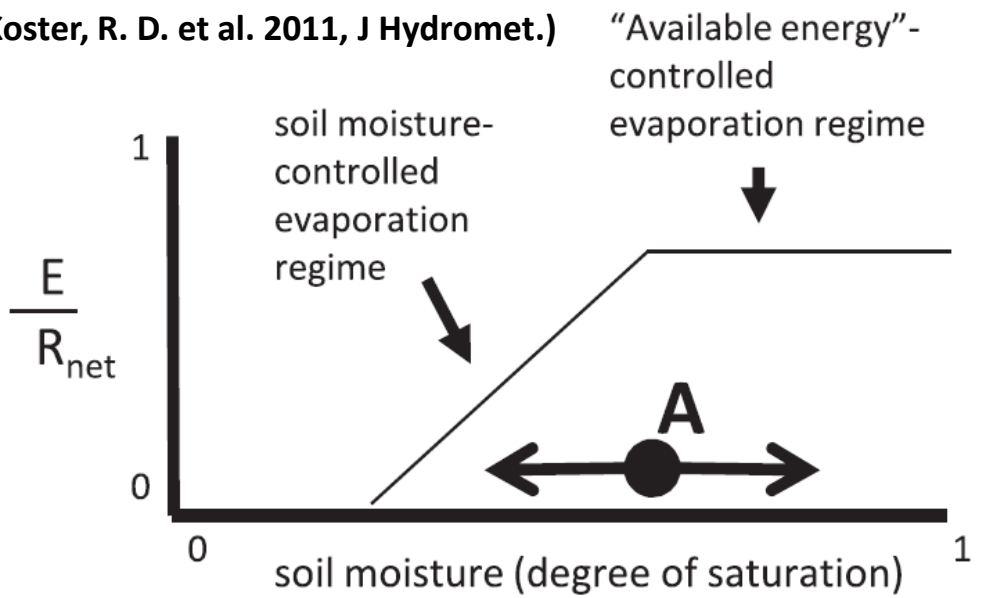
Relative Wet climate

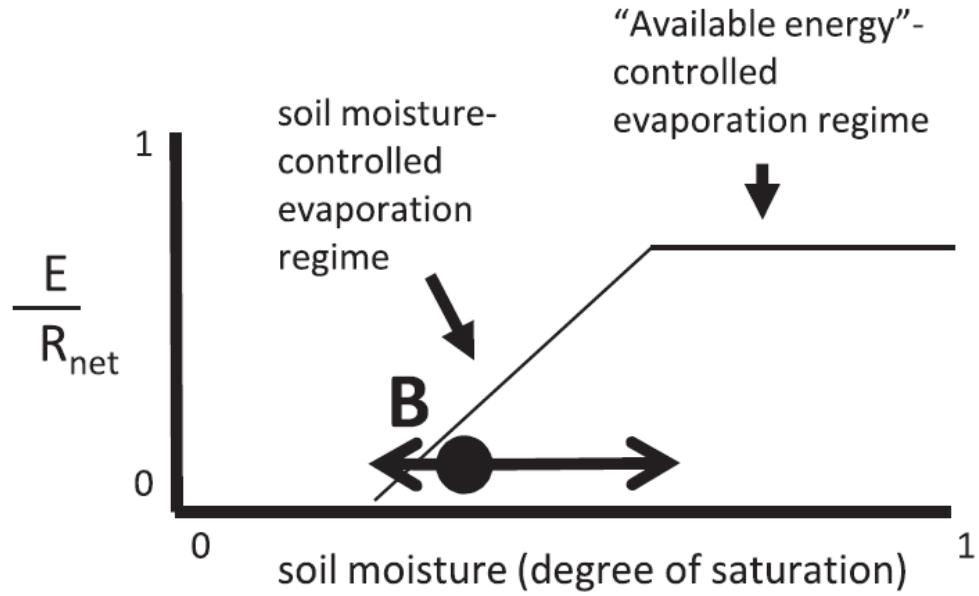
Only the drier than-average years showing sensitivity of evaporation to soil moisture.

Relative Dry climate

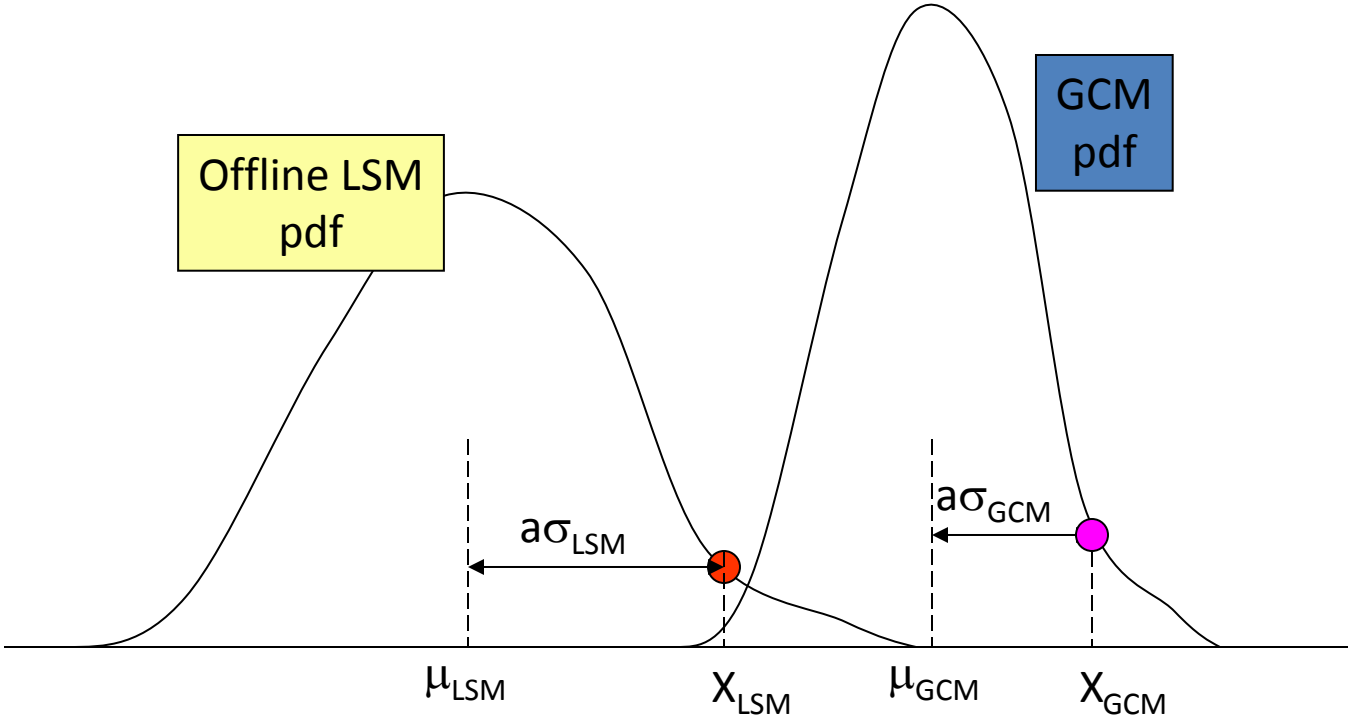
Drier-than-average years cannot get too dry, whereas **wetter-than-average years could get quite wet**.

(Koster, R. D. et al. 2011, J Hydromet.)





Anomaly Initialization of Soil Moisture



Standard normal deviate scaling

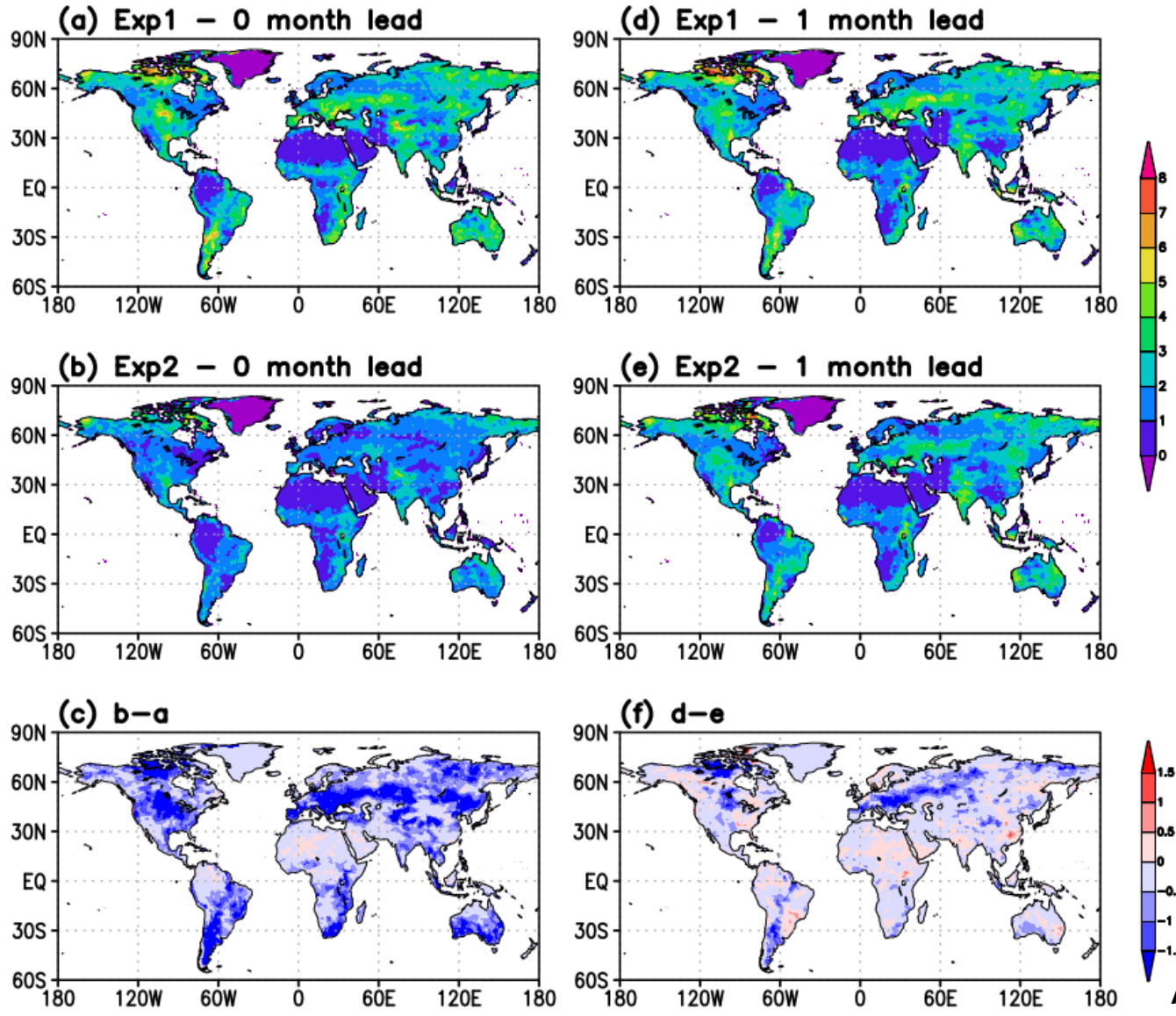
$$\frac{X_{\text{mod}} - \overline{X_{\text{mod}}}}{\sigma_{\text{mod}}} = \frac{X_{\text{obs}} - \overline{X_{\text{obs}}}}{\sigma_{\text{obs}}}$$

Avoiding **climate drift, initial shock**

GLACE-2 type Experiments

	Exp1	Exp2
Atmosphere	Initialized from the ERA-interim data of same date as in Exp0 but different year chosen randomly	
Land	Initialized with the AMIP simulation	Soil moisture anomaly initialization with JULES offline simulation and long-term AMIP runs
Ocean / Sea Ice	Monthly prescribed by observations **(AMIP simulation)**	
Number of Ensemble Member	10	
Ensemble generation	Arbitrary chosen atmospheric initial condition	
Integration period	1996~2010	

Surface Soil Moisture RMSE



Root Mean Square Error

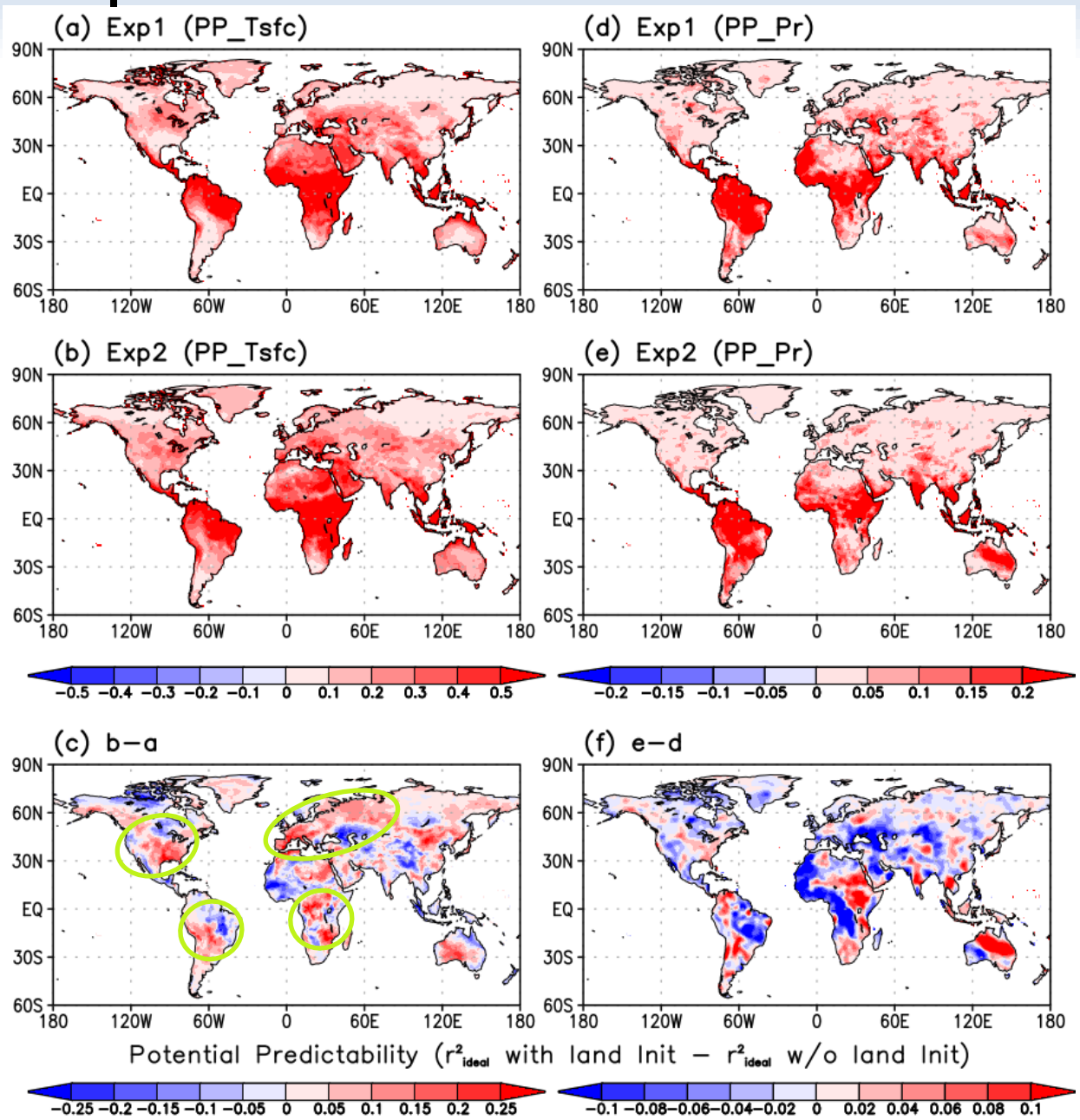
$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(f_i - o_i)^2}$$

N = # Forecast / observation pairs
f = Forecast
o = Observation

The region where RMSE get decreased is in mid-latitude

Anomaly map:
RMSE(with init) – RMSE(without init)

Spatial distribution of potential predictability



Step1
Verify predictability

$$Potential\ Predictability = r^2(var_{nat}, var_{ens}) - r^2(var'_{nat}, var'_{ens})$$

var: *with land initalization*

var': *without land initalization*

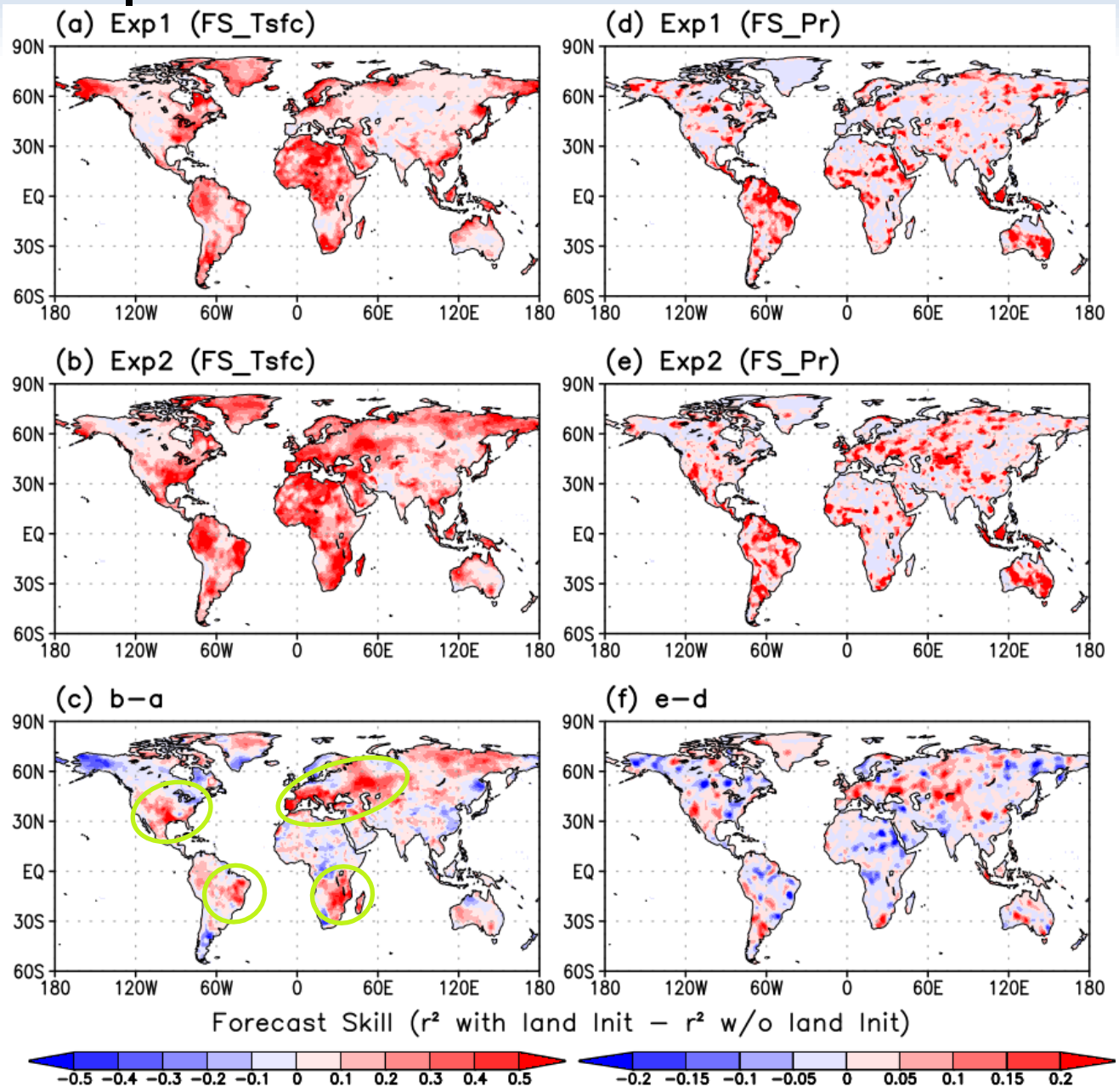
Step2
forecast skill

$$Forecast\ skill = r^2(var_{obs}, var_{mod}) - r^2(var_{obs}, var'_{mod})$$

var: *with land initalization*

var': *without land initalization*

Spatial distribution of forecast skill



Step1
Verify predictability

$$Potential\ Predictability = r^2(var_{nat}, var_{ens}) - r^2(var'_{nat}, var'_{ens})$$

var: *with land initalization*

var': *without land initalization*

Step2
forecast skill

$$Forecast\ skill = r^2(var_{obs}, var_{mod}) - r^2(var_{obs}, var'_{mod})$$

var: *with land initalization*

var': *without land initalization*

Gain spatial distribution

With/Without Land initialization

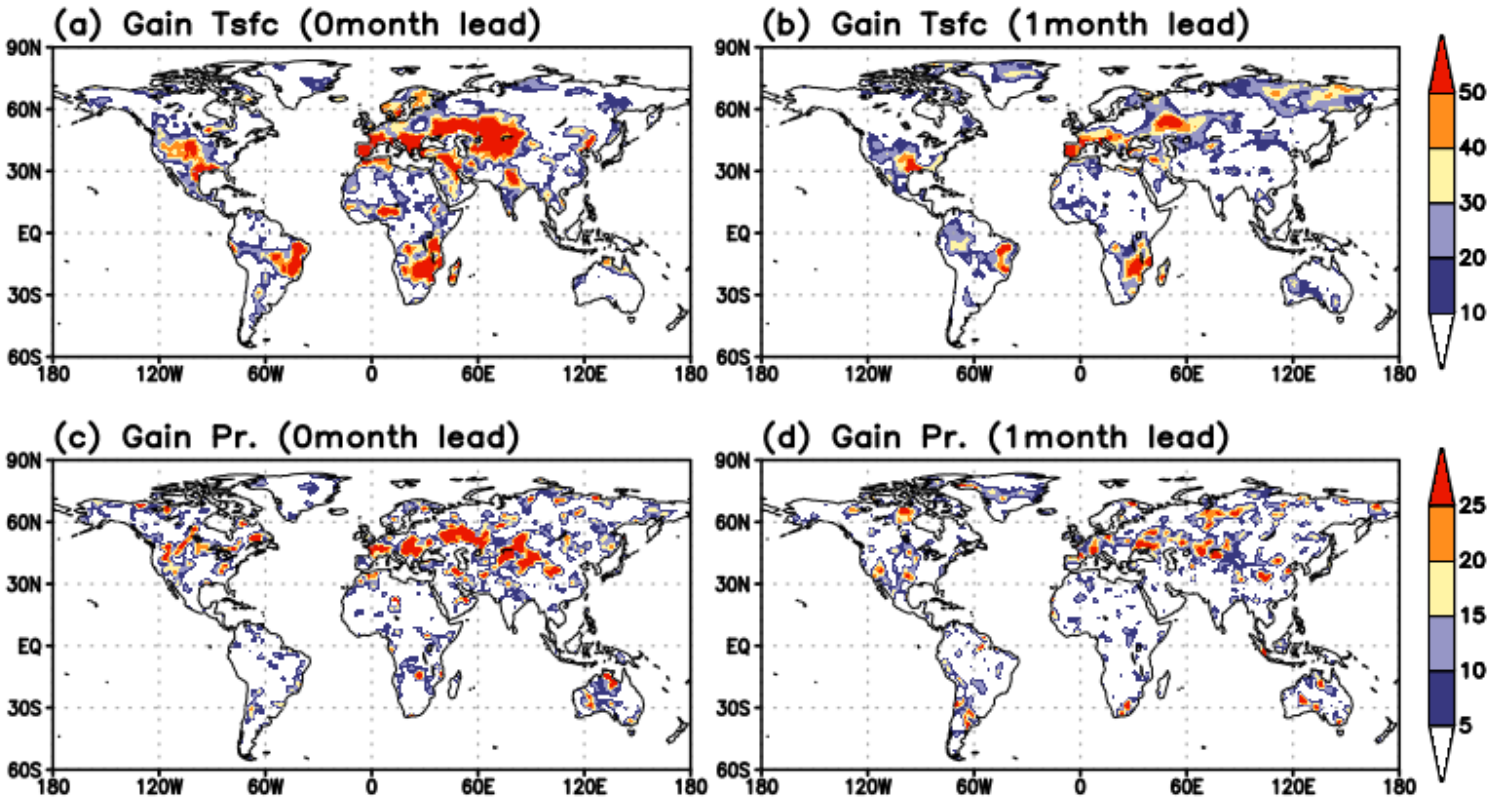
$$R_{CTL} = r_{CTL}|r_{CTL}|$$

$$R_{LIC} = r_{LIC}|r_{LIC}|$$

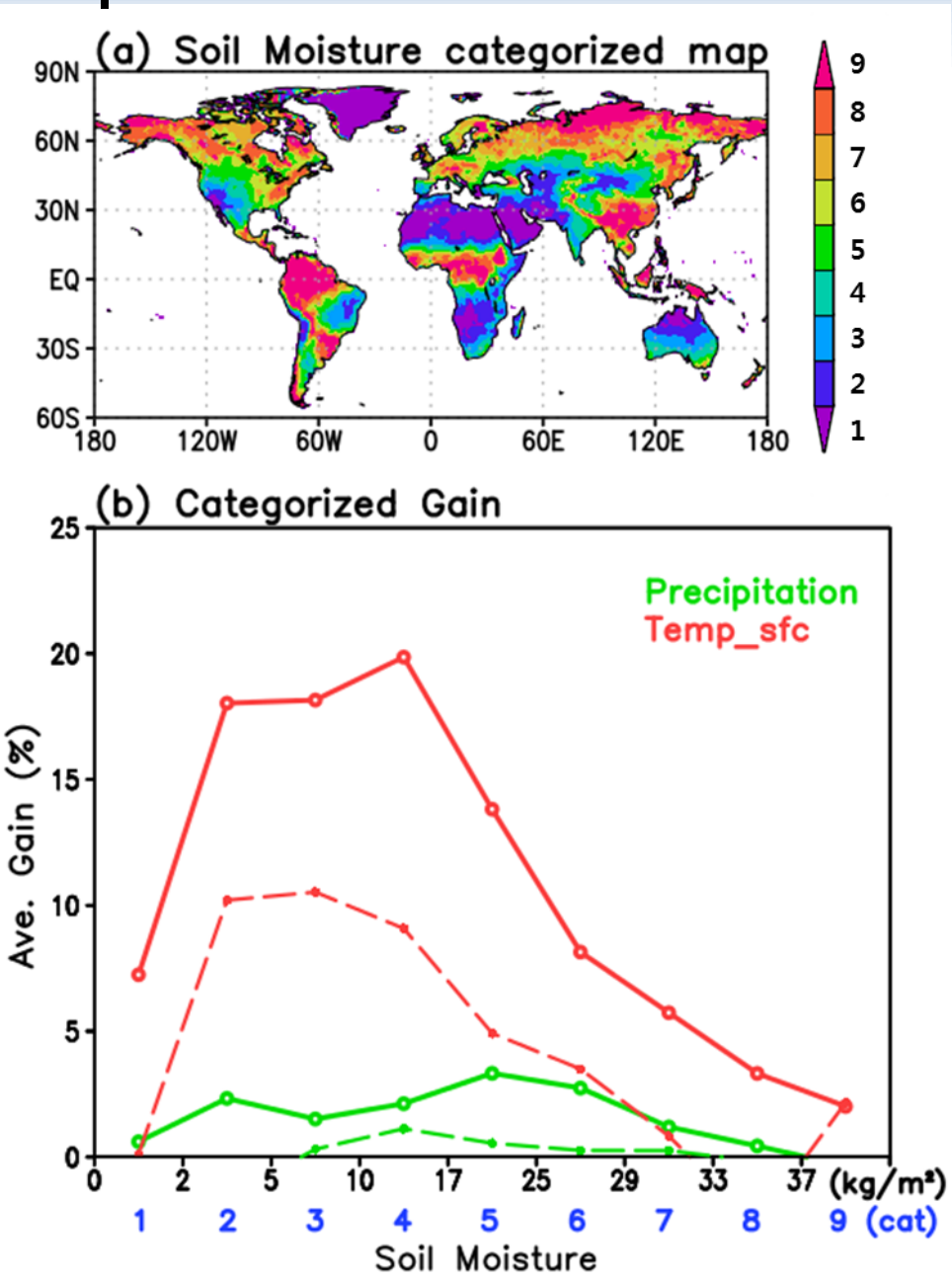
(Dirmeyer et al. 2005, J Hydromet.)

$$G_{LIC} = \frac{R_{LIC} - R_{CTL}}{1 - R_{CTL}} \times 100$$

% increase of the skill by Land Initialization

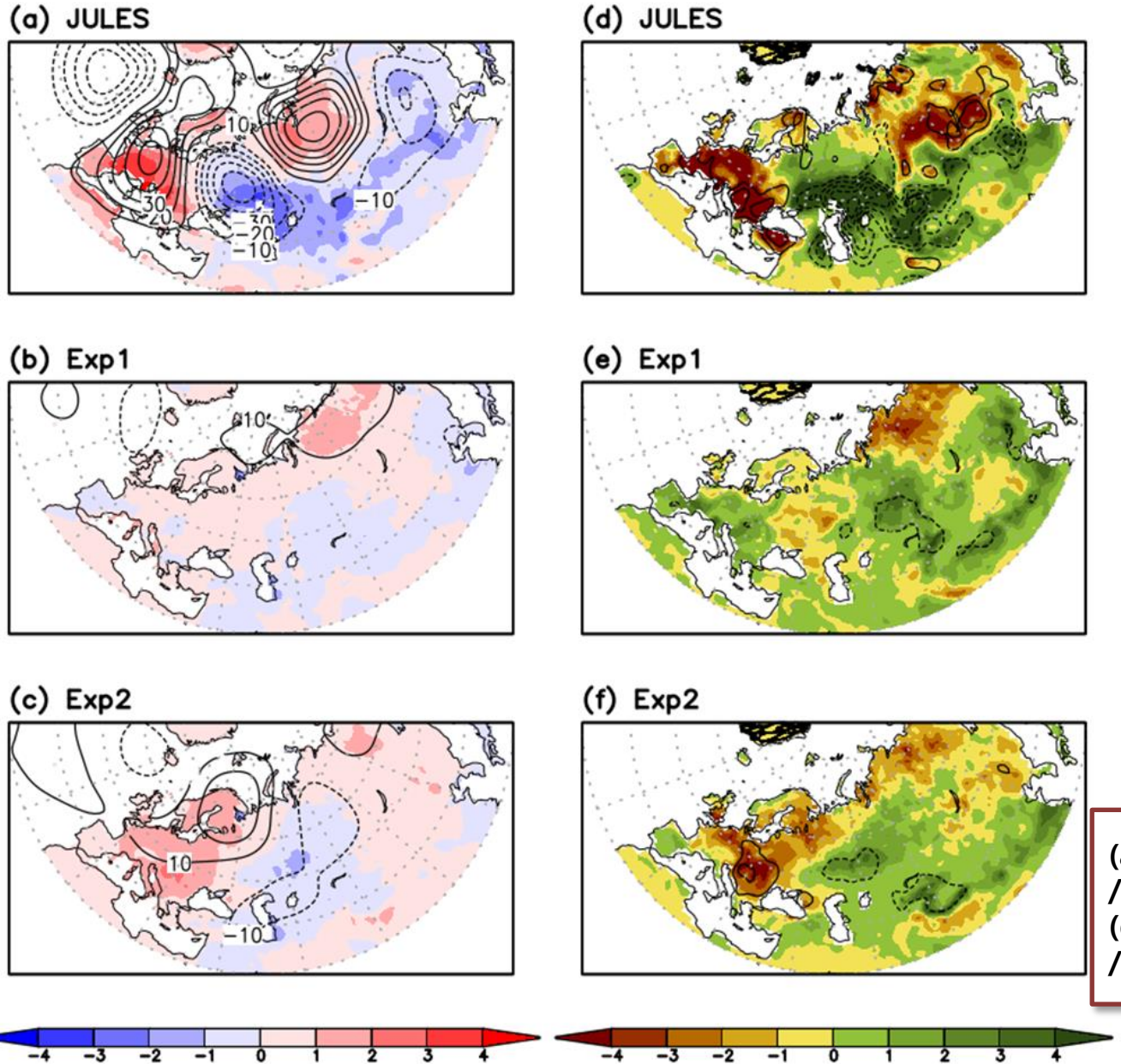


Gain categorized by soil moisture



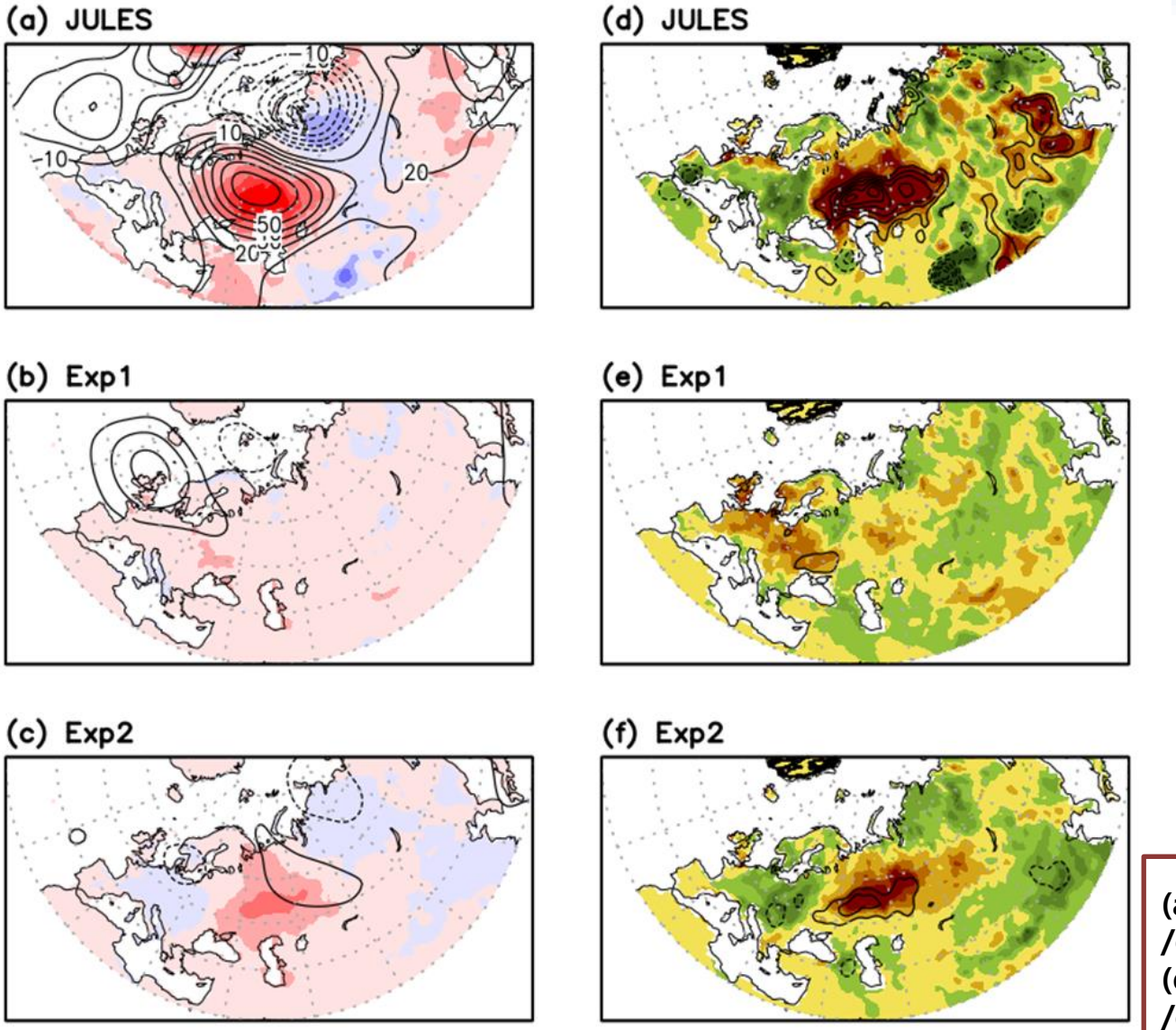
-> Soil moisture initialization impact into seasonal forecast scores is dominant over the relatively drier region rather than wet region.

2003 European heat wave



(a)~(c):shading(Tsfc anom.)
/contour(500GPH anom.)
(d)~(f):shading(Soil Moist. anom.)
/contour(SH/Rad anom.)

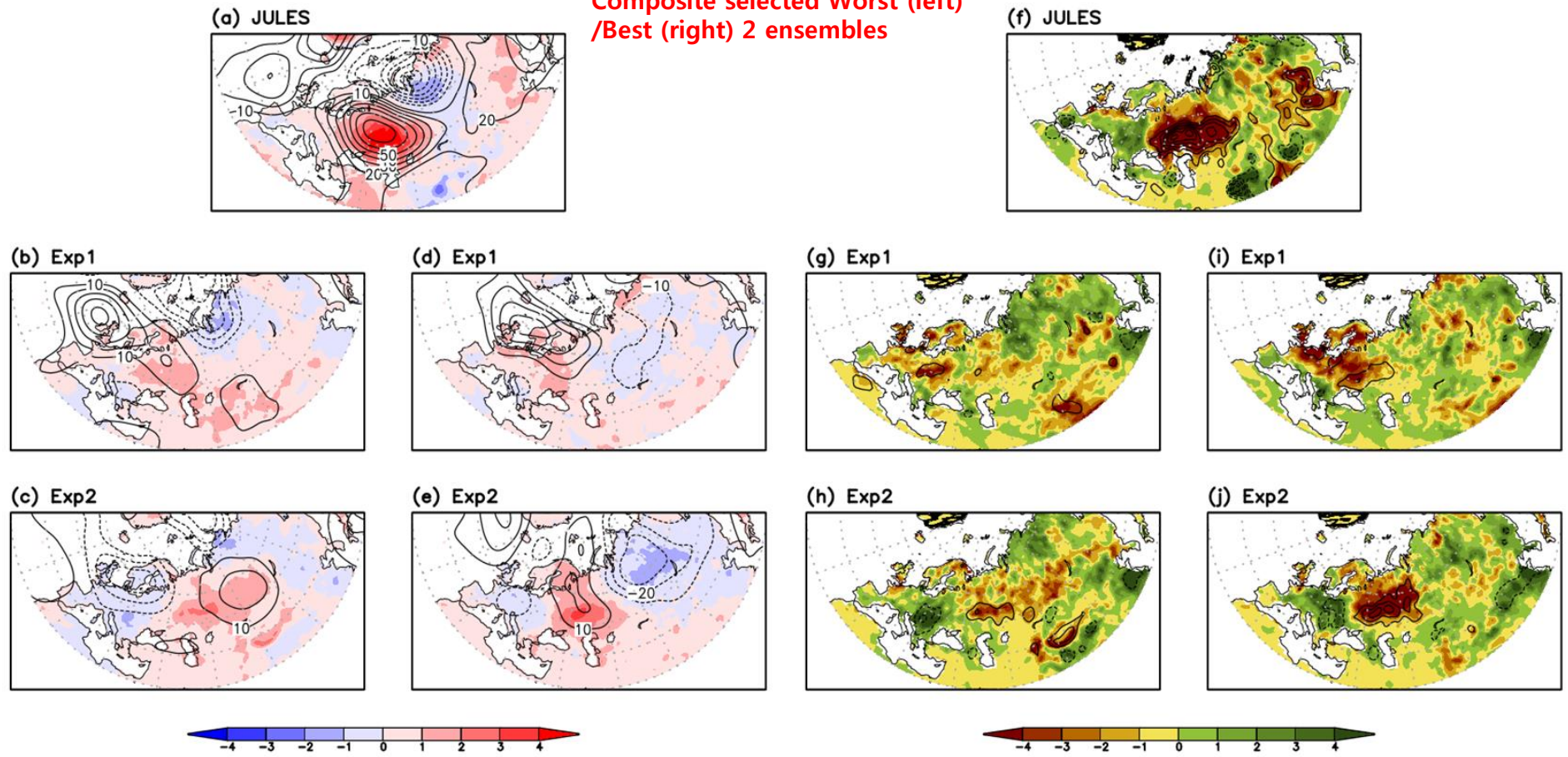
2010 Russian heat wave



(a)~(c):shading(Tsfc anom.)
/contour(500GPH anom.)
(d)~(f):shading(Soil Moist. anom.)
/contour(SH/Rad anom.)

Importance of land-atmosphere coupled initialization

Composite selected Worst (left) /Best (right) 2 ensembles



-> To Emphasize atmospheric extreme phenomenon soil moisture initial condition is important to be balanced with atmosphere initial condition.

(a)~(c):shading(Tsfc anom.) /contour(500GPH anom.)
(d)~(f):shading(Soil Moist. anom.) /contour(SH/Rad anom.)

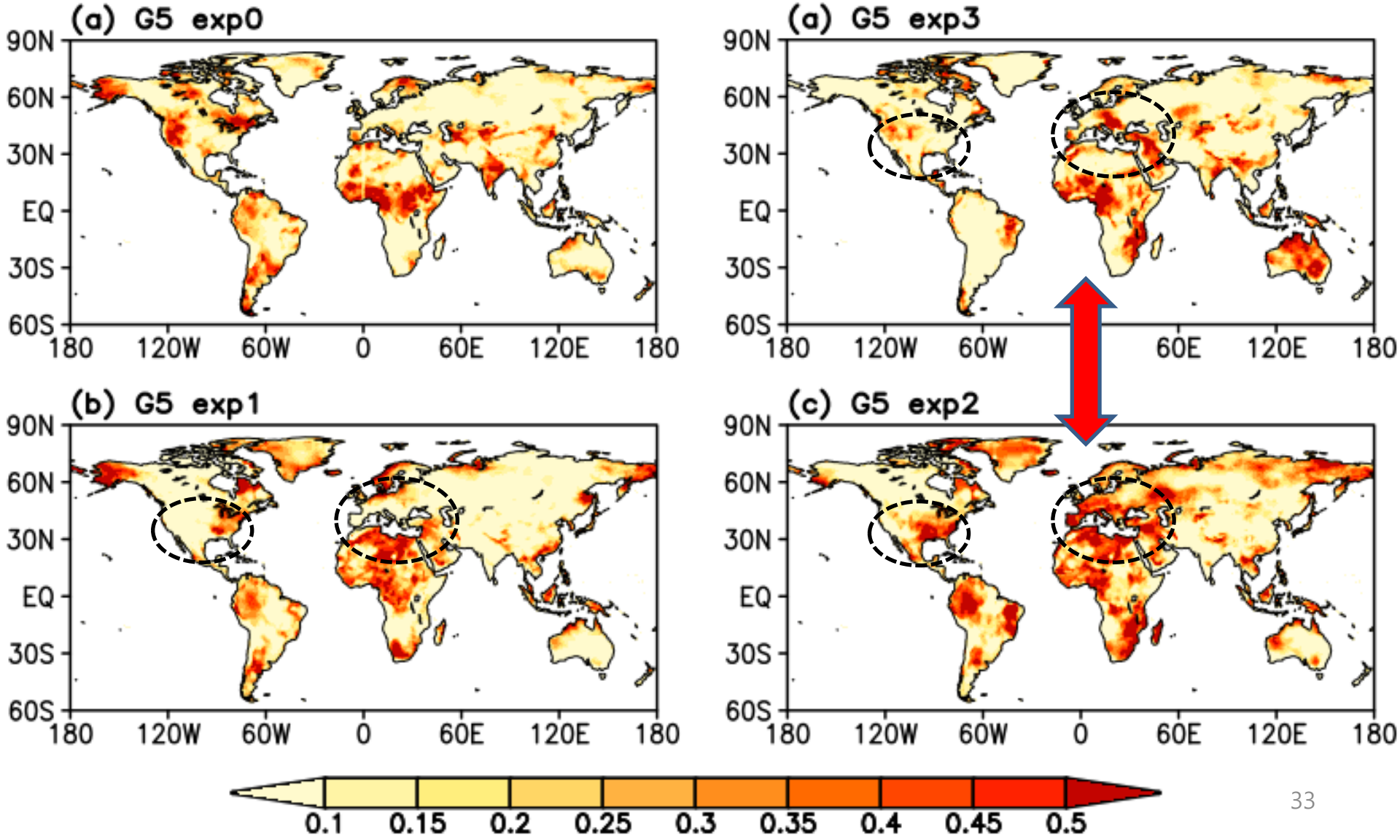
Further Issues/Discussions

GLACE-2 type Experiments

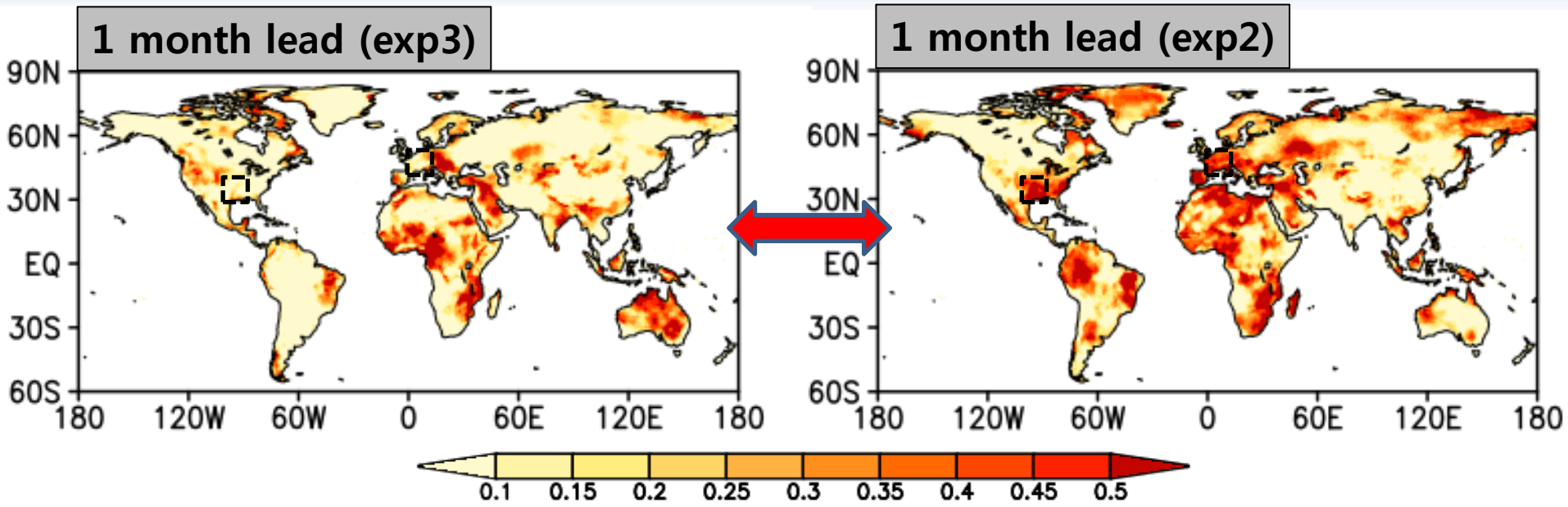
	Exp0	Exp3	Exp1	Exp2
Atmosphere	Initialized from ERA-interim		Initialized from the ERA-interim data of same date as in Exp0 but different year chosen randomly	
Land	Initialized with 10 year-average monthly climatology (no yearly variation)	Soil moisture anomaly initialization with JULES offline simulation and long-term CMIP runs	Initialized with the AMIP simulation	Soil moisture anomaly initialization with JULES offline simulation and long-term AMIP runs
Ocean / Sea Ice	Initialized from Seasonal ODA reanalysis **(Coupled simulation)**		Monthly prescribed by observations **(AMIP simulation)**	
Number of Ensemble Member	3		10	
Ensemble generation	Stochastic Kinetic Energy Backscattering (SKEB2; Bowler et al., 2009)		Arbitrary chosen atmospheric initial condition	
Integration period	1996~2009		1996~2010	

Comparison of FS with GloSea5 hindcast exp0~3

1 month lead JJA forecast



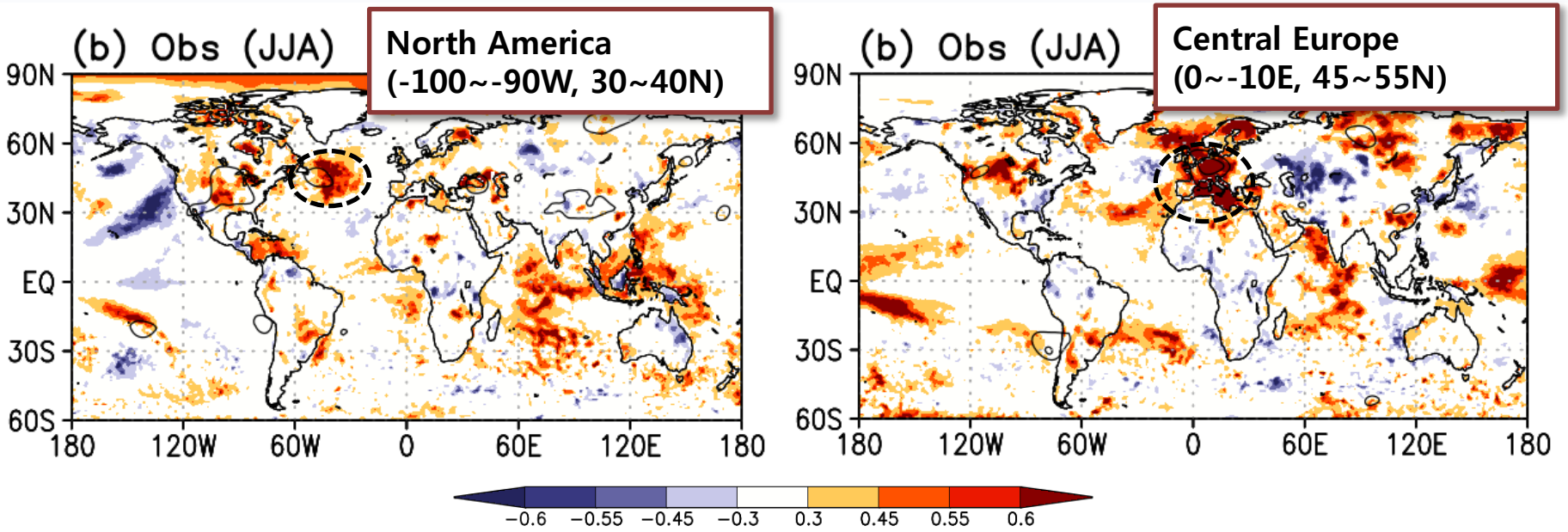
What's wrong?



Possible reasons

1. ~~Initial condition problem (ATM)~~
   -> Negligible after 2 weeks
2. ~~Initial condition problem (Land)~~
   -> JULES based initialization
3. Number of ensembles
4. Boundary condition problem (Ocean)
   -> Negative effect

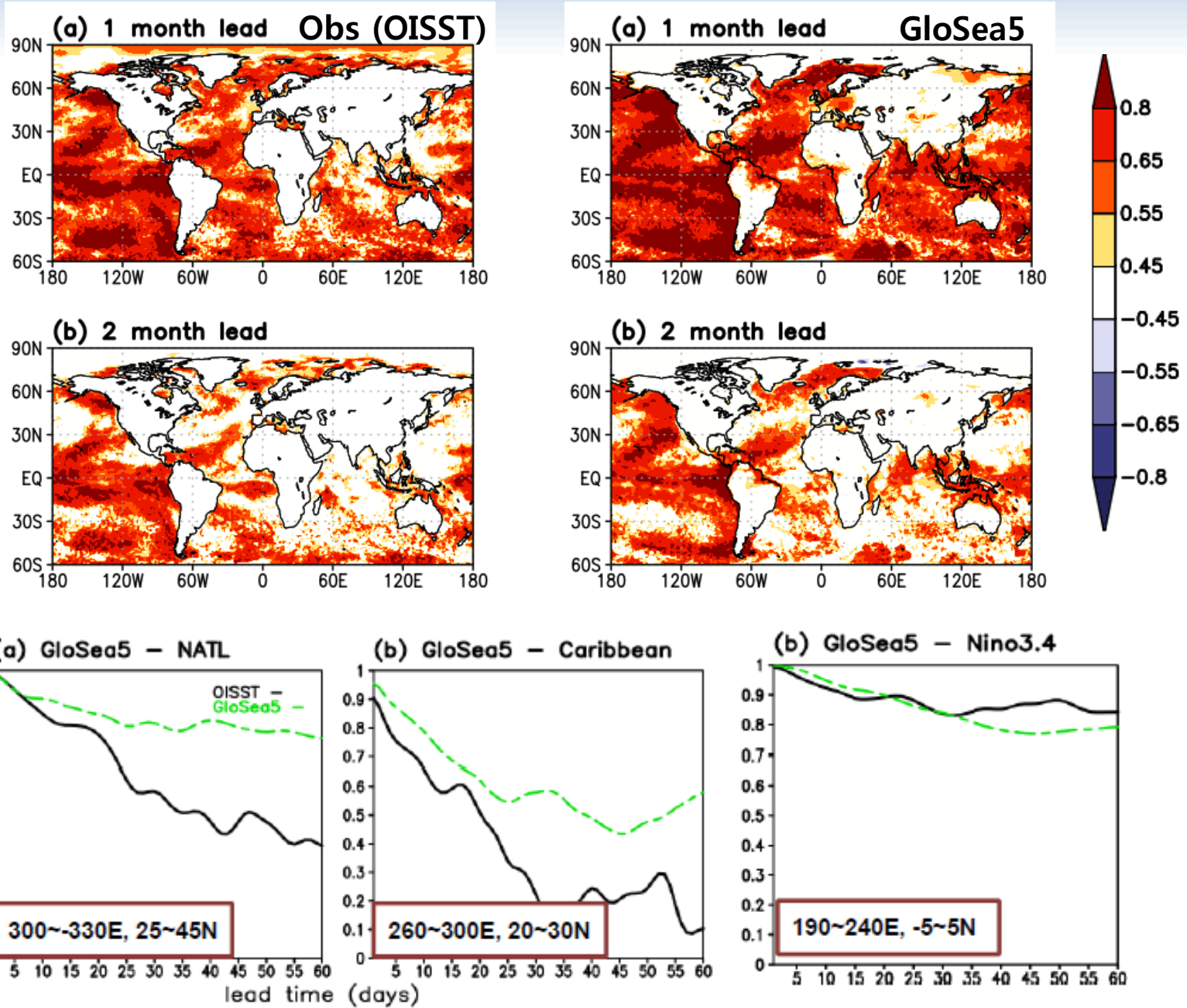
Diagnosis of some problems



Shading: temporal correlation btw. Tsfc and OISST SST(ocean)/ JULES Soil Moist.(land)

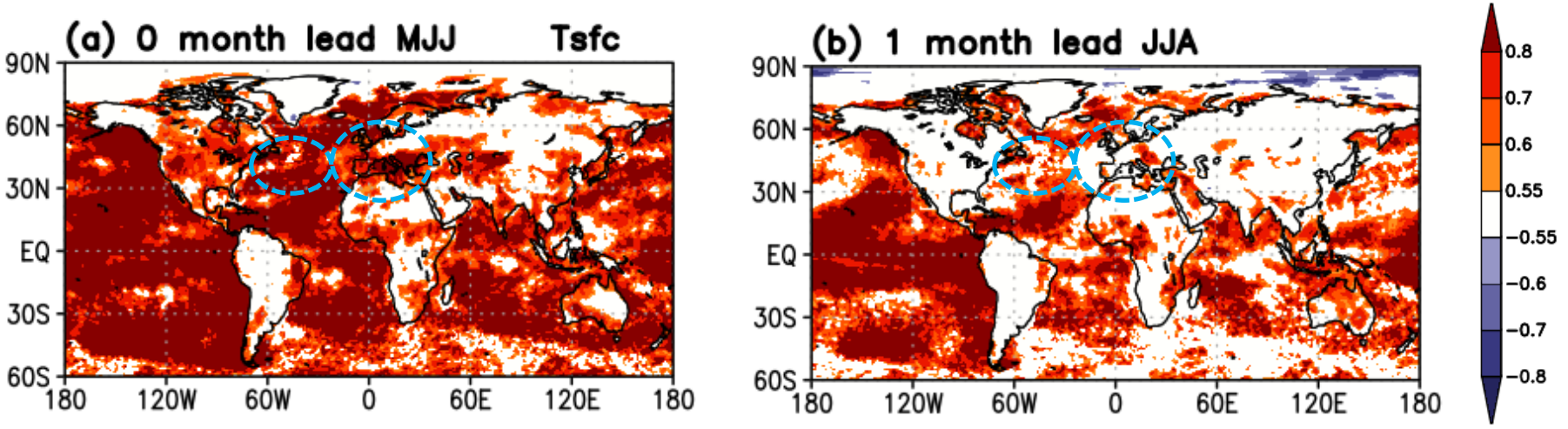
Contour: temporal correlation btw. Tsfc and MERRA 500hPa GPH

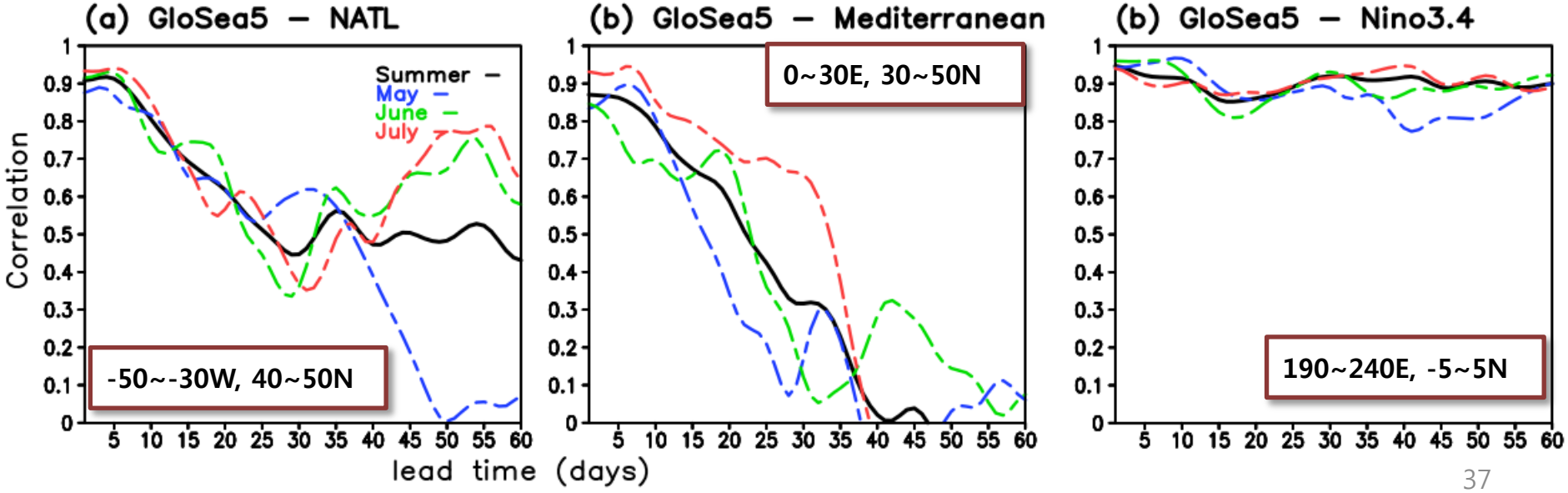
Persistence of SST (Auto correlation)



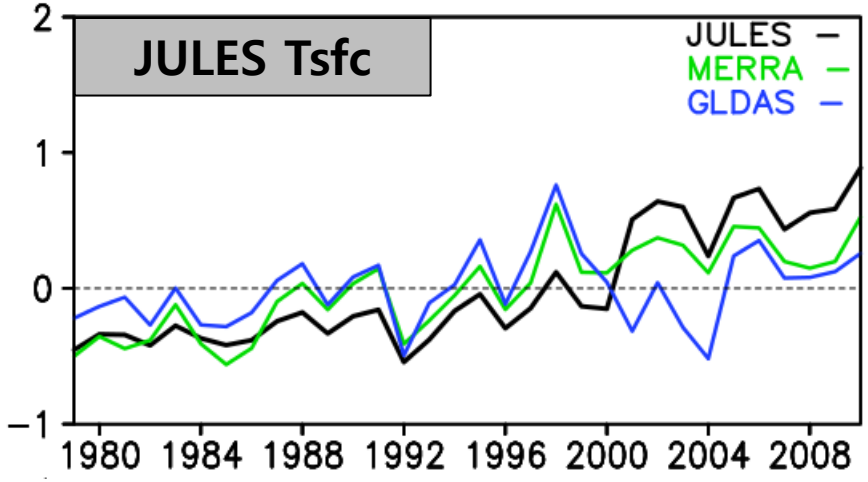
Rapid Decrease of SST prediction in midlatitudes

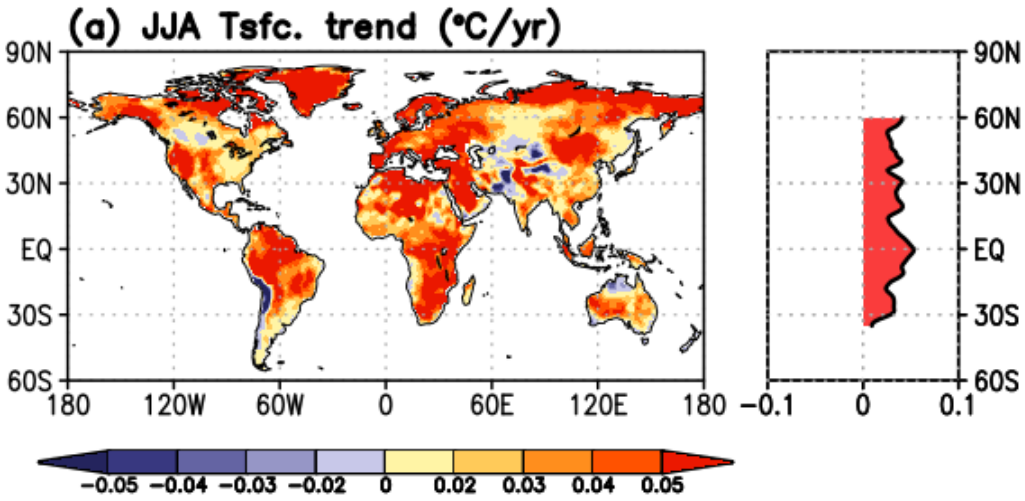
Forecast skill Tsfc

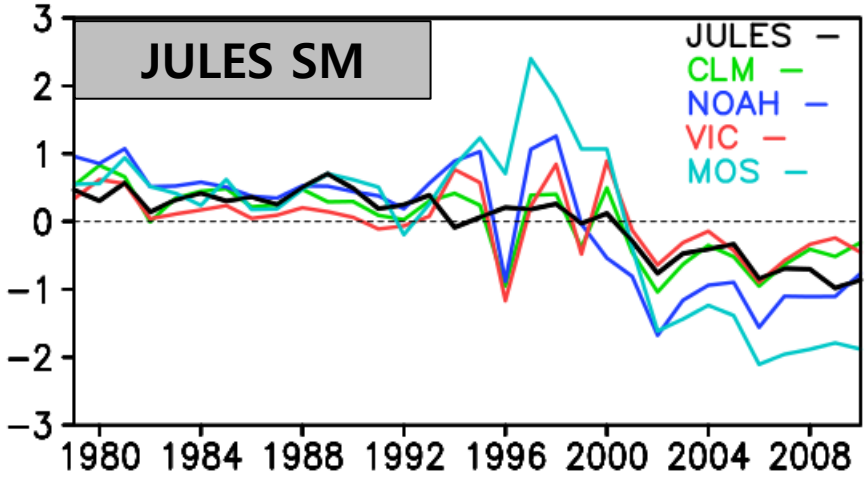


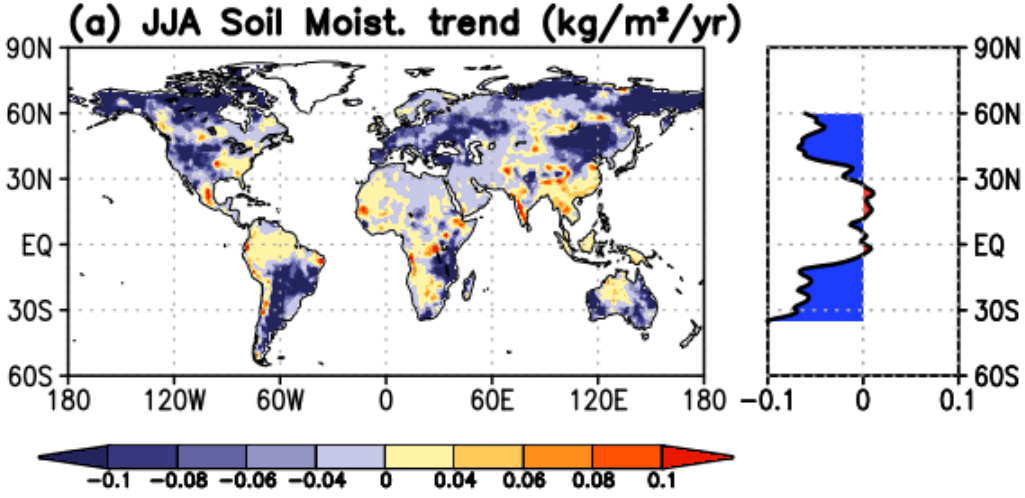


Global warming trend by reanalysis (1979~2010)



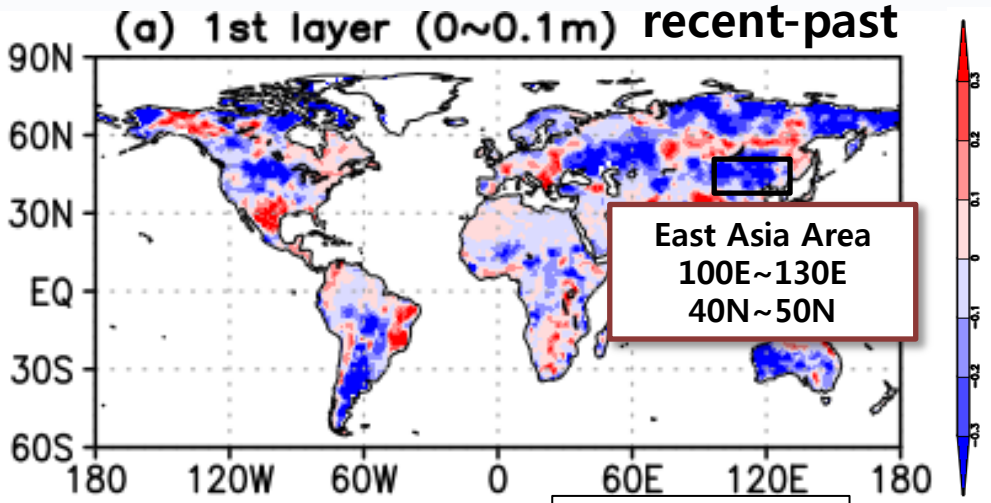




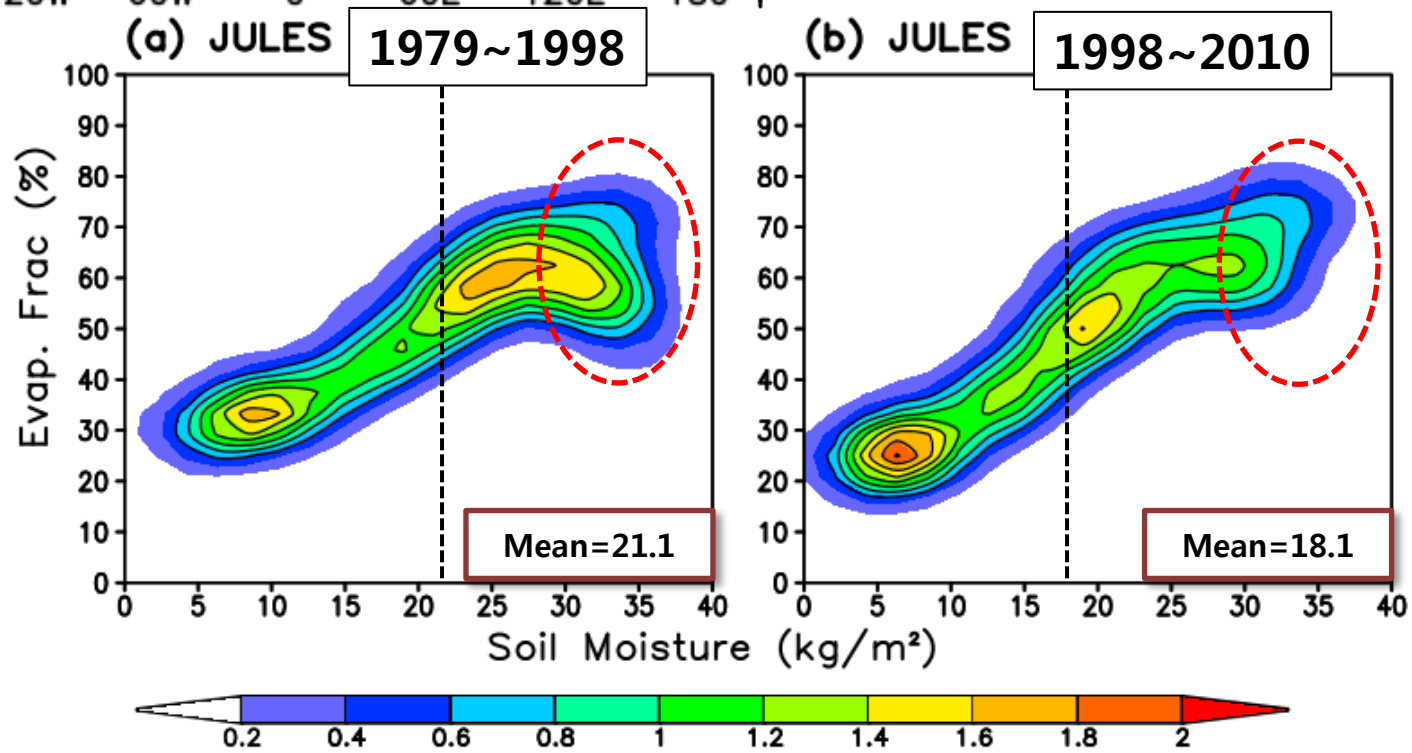


JJA Land-Atmosphere feedback change

JULES



- In the recent decade, **land-atmosphere feedback is increased** by the exchanging energy trough soil moisture sensitivity



Summary & Conclusions

- ✓ **This study investigates the impact of soil moisture initialization in KMA/Met Office GloSea5** where the seasonal forecast system significantly reveals the improvement to simulate only surface temperature, but precipitation.

- ✓ **The sensitivity is predominant for surface temperature on dry region since Land-Atmosphere coupled behaviors strongly influence on the near surface condition** through transporting latent and sensible heat flux.

- ✓ By the initialization processes, **the balance between land and atmosphere conditions is important** to emphasize the extreme atmospheric events, and **SST predictability** at the region where oceanic condition influences on the land area **is crucial in coupled forecast system**.

- ✓ Long-term change in the potential predictability is being explored in the context of global warming.

Thank you very much!

To see our research, visit our website at

http://climate.unist.ac.kr