

# GSWP3 and LS3MIP &

## Development of Global Land Surface Modeling/Validation/Benchmarking Framework

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& Thanks to : Paul Dirmeyer, Aaron Boone, Bart van den Hurk, Gerhard Krinner, Sonia Seneviratne, Chris Derksen, Gill Compo, David Lawrence, Jim Randerson, Forrest Hoffman, Eun-chul Chang, Satoshi Watanabe, Tomoko Nitta, Misako Hatono, Tomohito Yamada, Kei Yoshimura, Yukiko Hirabayashi, Taikan Oki, ...

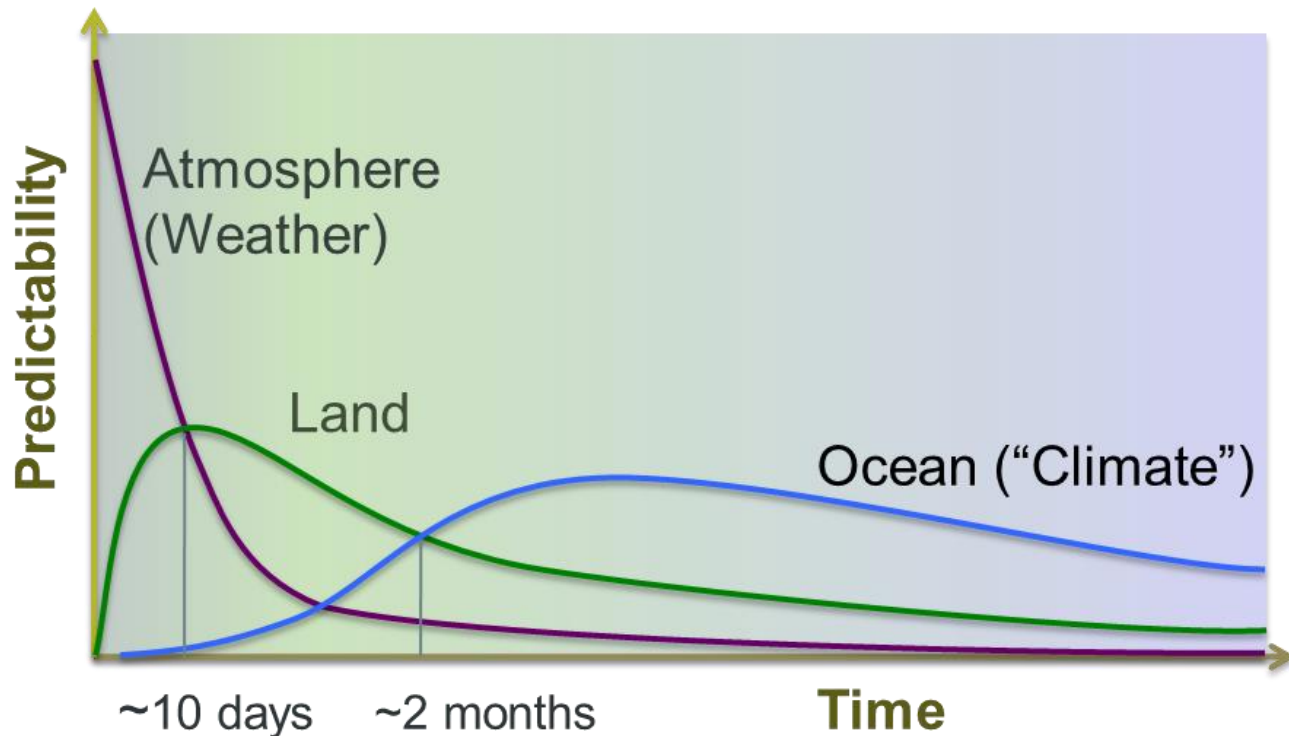
# Land, Predictability and Prediction

Land states (namely soil moisture, snow and vegetation) can provide predictability in the window between deterministic (weather) and climate (O-A) time scales.

The 2-4 week “subseasonal” range is a hot topic in operational forecast centers now.

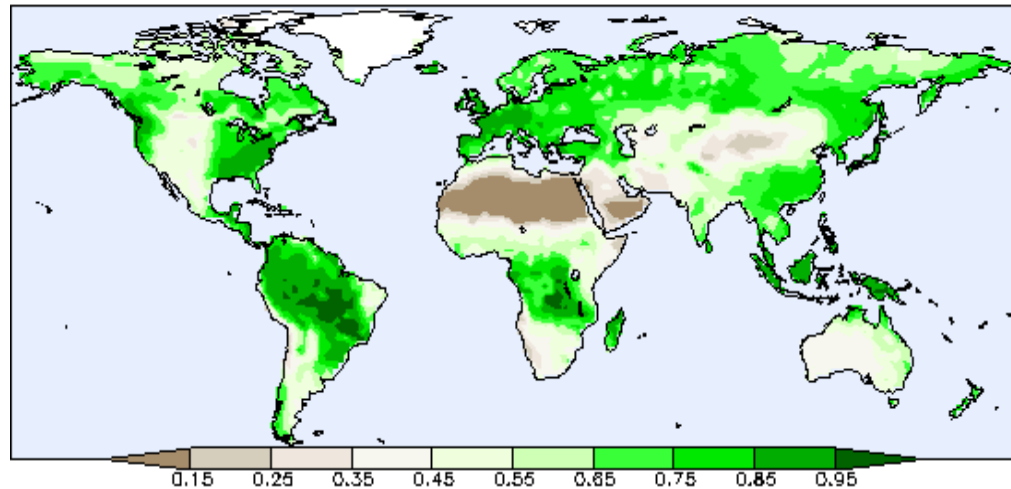
Active where we have **sensitivity**, **variability** and **memory**.

Slide courtesy of Dirmeyer (personal comm.)



# GSWP and GLACE – international initiatives for land-atmosphere interaction and model diagnosis –

January



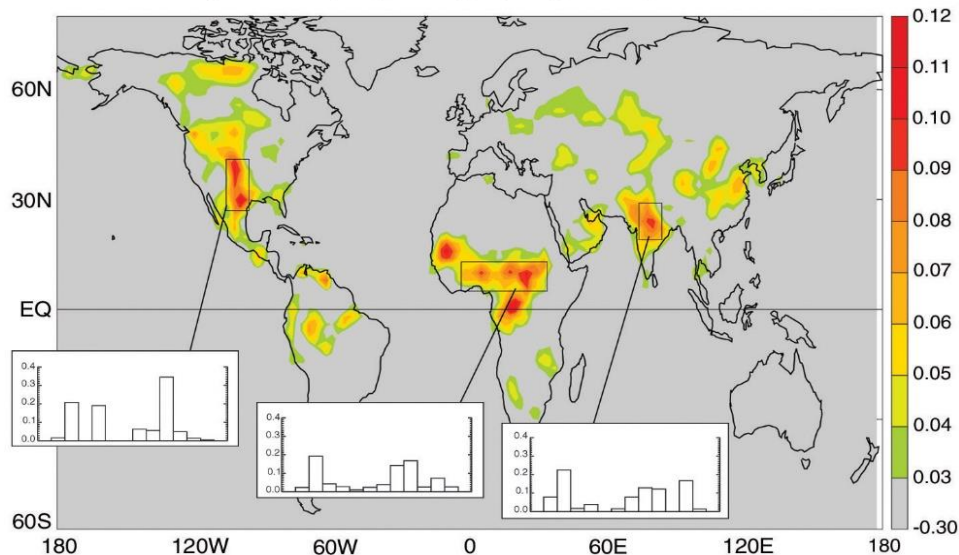
Global Soil Wetness Project is a core project of GLASS/GEWEX/WCRP which was devised to provide a surrogate 'observed', off-line simulated, land surface states which are not routinely reported unlike ocean.

– Dirmeyer et al., 1998, 2006

Global Land-Atmosphere Coupling Experiment is another core project of GLASS/GEWEX/WCRP which explored the global distribution of land-atmosphere coupling (i.e., Hot spots) and the soil-moisture memory impact on seasonal predictabilities.

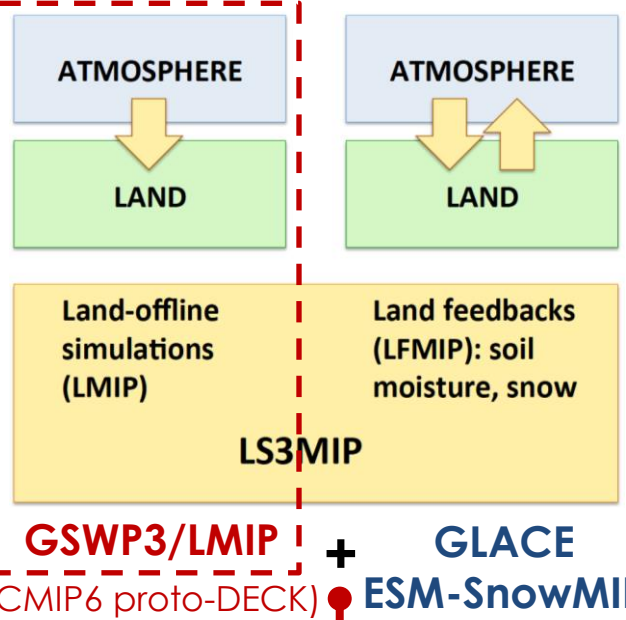
– Koster et al., 2006, 2010

Land-atmosphere coupling strength (JJA), averaged across AGCMs



# Global Soil Wetness Project Phase 3

Super-ensemble **land reanalysis** for 20 and 21<sup>st</sup> Century as inter-community service



## WCRP + GEWEX Grand Challenges

- Cloud, Circulation & Climate Sensitivity
- Water Availability
- Climate Extremes
- Regional Climate Information
- Regional Sea-level Rise
- Changes in Cryosphere
- Precipitation Variability
- E/W Exchanges
- Uncertainty

Land Surface, Snow, Soil moisture  
**LS<sub>now</sub>3MIP** Model Intercomparison Project  
 Land processes, forcings, and feedbacks in CMIP6 climate change simulations

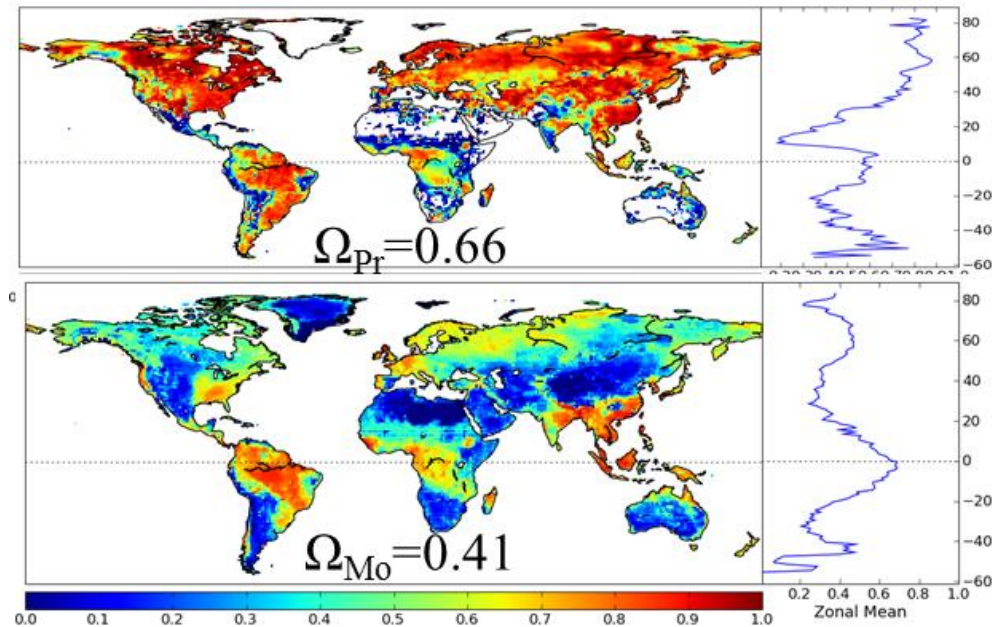
to quantify the associated uncertainties and better constrain climate change projections for earth system models in CMIP6.

# Gaps to be Filled by LS3MIP

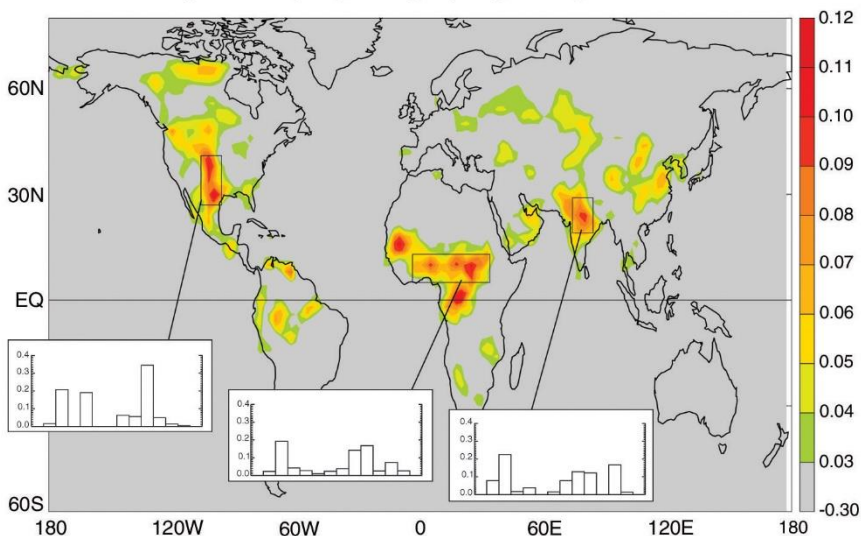
+ Map (uncertainty of) water resources over the 20th century (and beyond)

Kim (2010) showing that disparity in simulated runoff from uncertainty in ensemble precipitation is much less than model uncertainty :

**LMIP/GSWP3**



Land-atmosphere coupling strength (JJA), averaged across AGCMs



+ Explore model-dependent land-atmospheric coupling

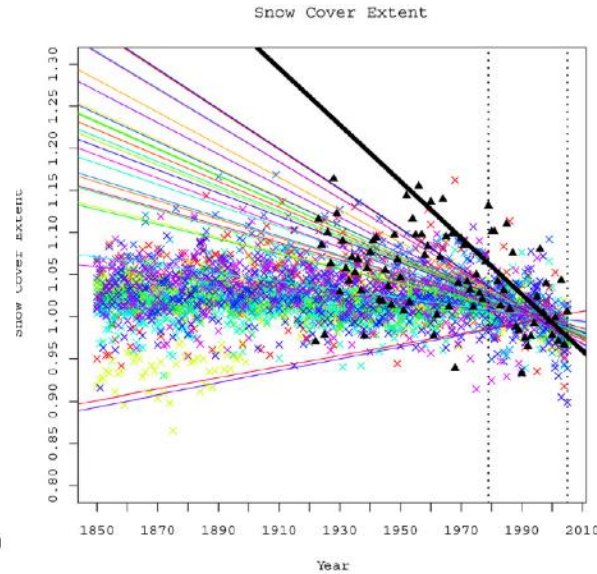
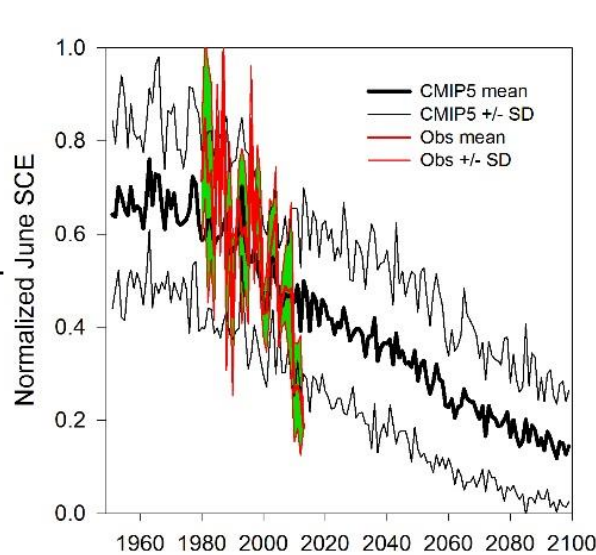
Koster et al (2006): GLACE result showing model-specific land-atmospheric coupling strength :

**LFMIP**

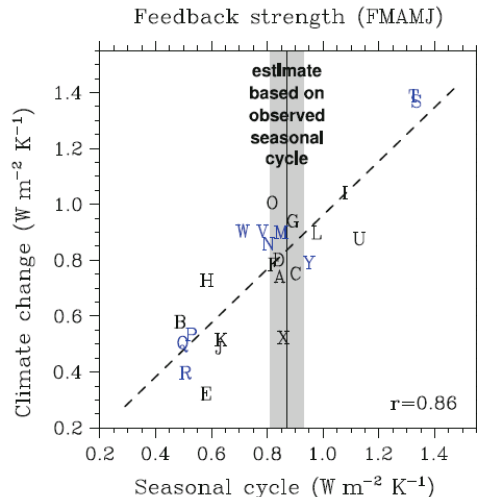
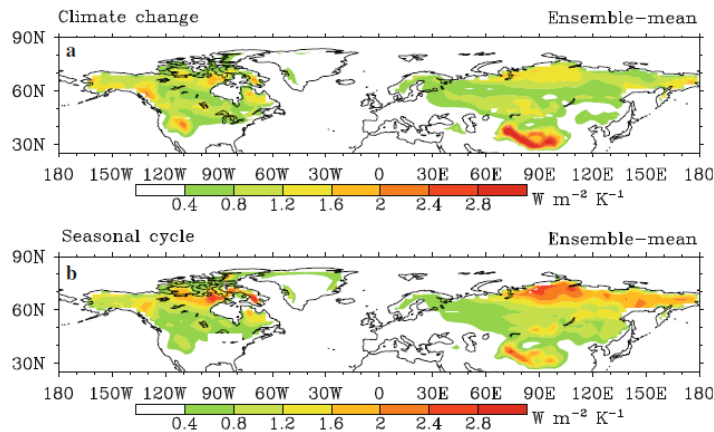
# Gaps to be Filled by LS3MIP

+ Ability of climate models to capture observed rates of spring snow cover reductions

Brutel-Vuilmet et al. (2012);  
 Derksen and Brown (2012):  
 CMIP5 models underestimate the significant reductions in spring snow cover extent observed during the satellite era :  
**ESM-SnowMIP**



+ Linkage between snow-albedo feedback and 21st century warming

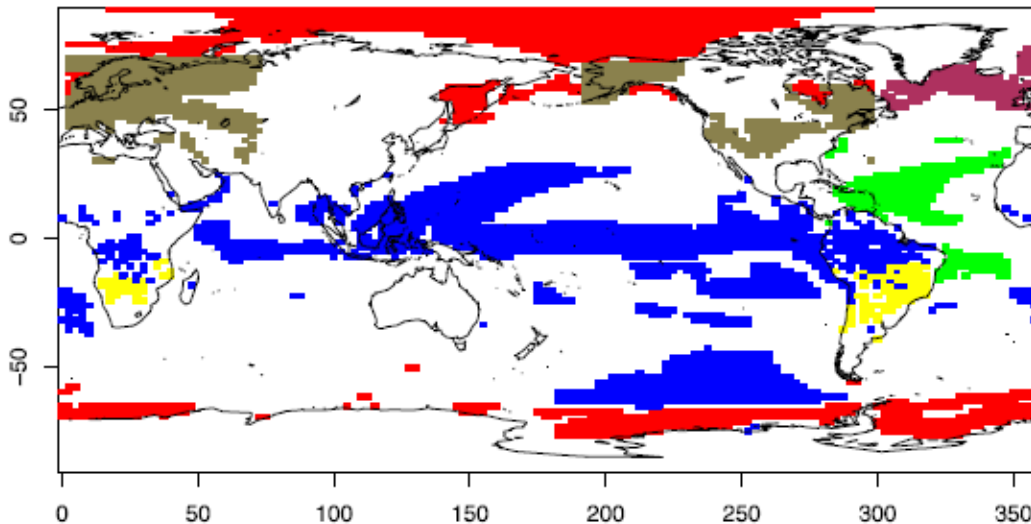
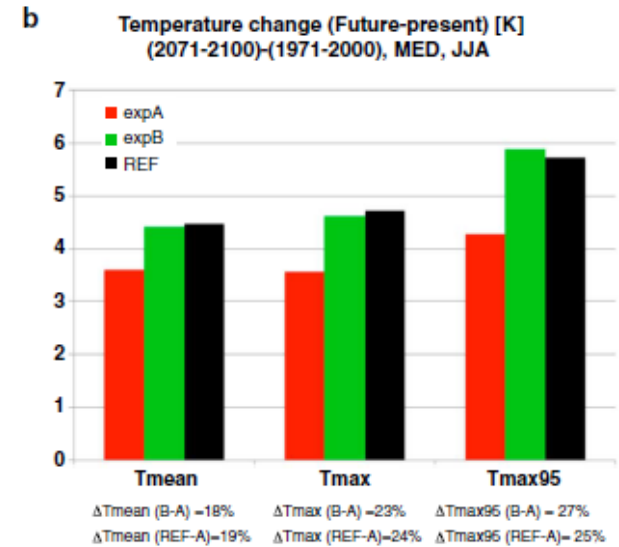
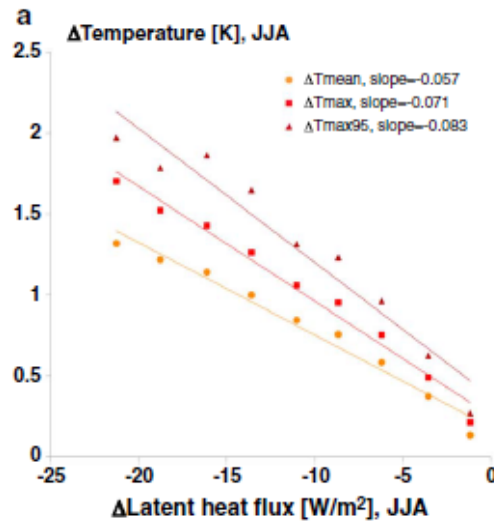


Qu and Hall (2013): The spread in snow albedo feedback accounts for much of the CMIP5 spread in the 21st century warming of Northern Hemisphere land masses :  
**ESM-SnowMIP**

# Gaps to be Filled by LS3MIP

+ Soil moisture affecting the climate change signal

Seneviratne et al (2014):  
GLACE-CMIP5 result  
showing effect of  
prescribing 20th century  
soil moisture climatology :  
**LFMIP**

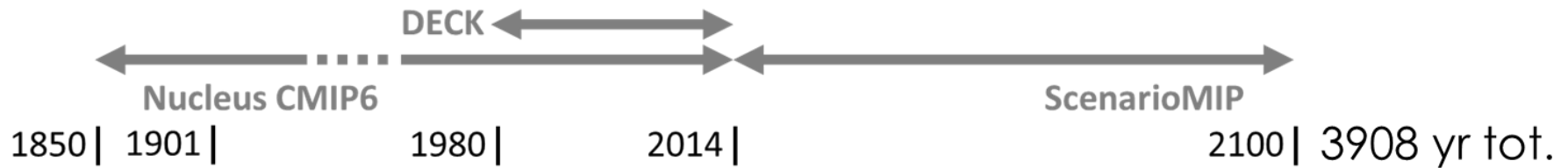


+ (Seasonal) Predictability can alter in a warmer climate

Del Sole et al (2014): Changes in seasonal predictability as a result of a trade-off between more signal and more noise in a warmer world :

**LFMIP**

# Experiment Structure of LS3MIP/CMIP6



Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-72, 2016

Manuscript under review for journal Geosci. Model Dev.

Published: 11 April 2016

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Geoscientific  
Model Development  
Discussions

Open Access



## 1 The Land Surface, Snow and Soil moisture Model Intercomparison Program (LS3MIP):

2 aims, set-up and expected outcome

3

4 Bart van den Hurk<sup>1</sup>, Hyungjun Kim<sup>2</sup>, Gerhard Krinner<sup>3</sup>, Sonia I. Seneviratne<sup>4</sup>, Chris Derksen<sup>5</sup>,

5 Taikan Oki<sup>2</sup>, Hervé Douville<sup>6</sup>, Jeanne Colin<sup>6</sup>, Agnès Ducharne<sup>7</sup>, Frederique Cheruy<sup>7</sup>, Nicholas

6 Viovy<sup>8</sup>, Michael Puma<sup>9</sup>, Yoshihide Wada<sup>10</sup>, Weiping Li<sup>11</sup>, Binghao Jia<sup>12</sup>, Andrea Alessandri<sup>13</sup>,

7 Dave Lawrence<sup>14</sup>, Graham P. Weedon<sup>15</sup>, Richard Ellis<sup>16</sup>, Stefan Hagemann<sup>17</sup>, Jiafu Mao<sup>18</sup>,

8 Mark G Flanner<sup>19</sup>, Matteo Zampieri<sup>20</sup>, Rachel Law<sup>21</sup>, and Justin Sheffield<sup>22,23</sup>

an evaluation of the  
land processes  
representation

long-term terrestrial  
energy/water/carb  
on cycles **LMIP**

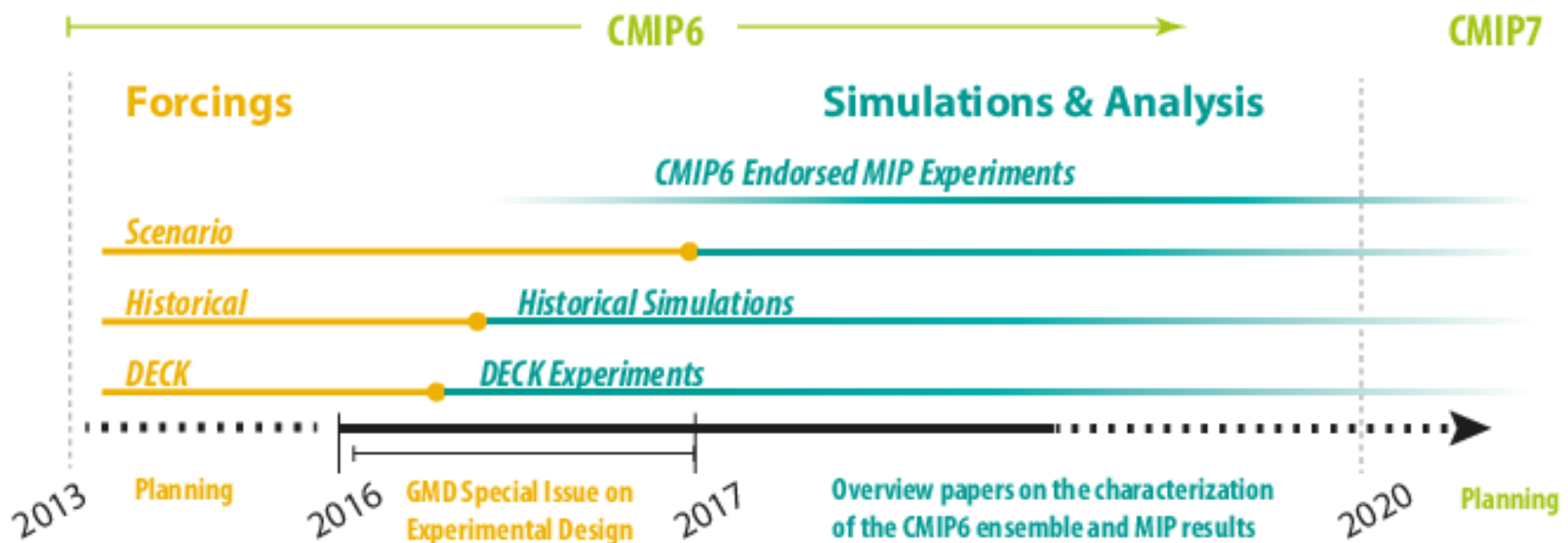
role of snow and soil  
moisture feedbacks  
to climate forcing

contribution of land  
processes to the  
predictability **LFMIP**

# MIPs: Model Intercomparison Projects

## Coupled Model Intercomparison Project (CMIP)

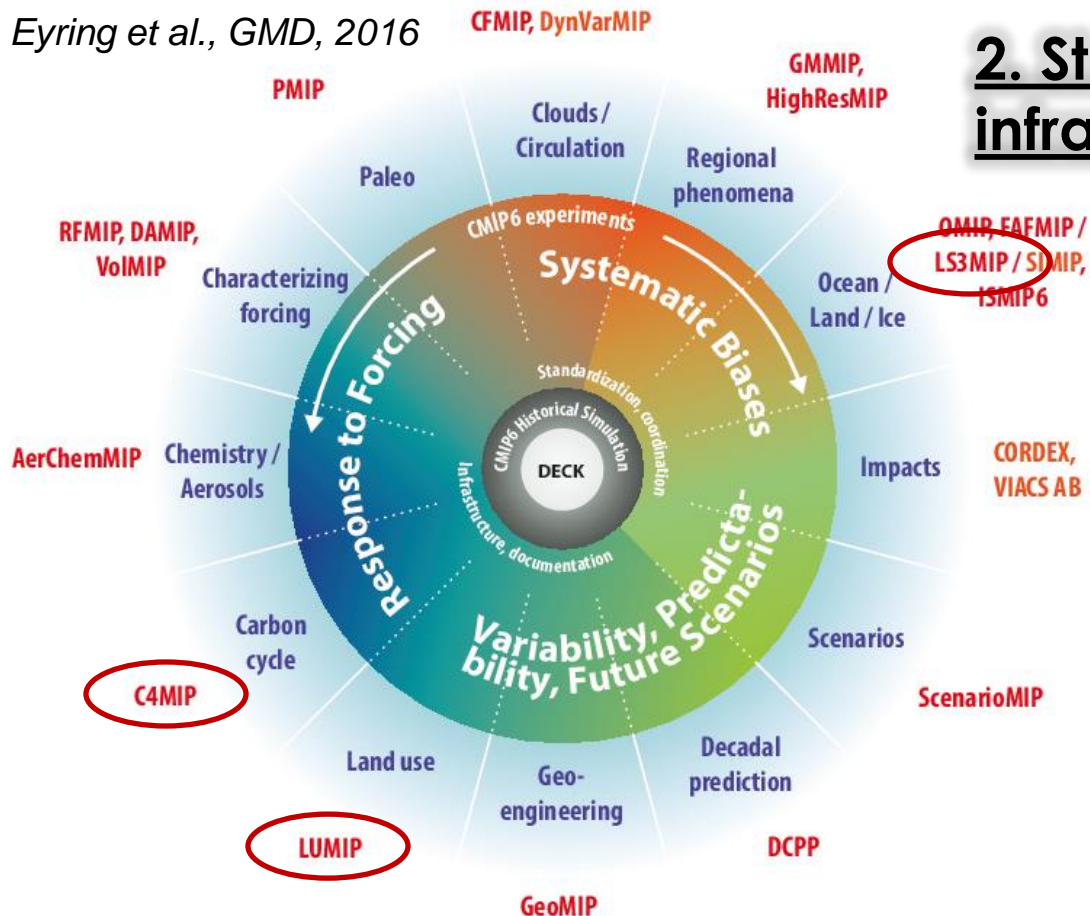
- \* CMIP is a project of the WGCM/WCRP.
- \* CMIP has coordinated climate model experiment since 1995.
- \* CMIP's central goal is to advance scientific understanding of the Earth system.
- \* CMIP model simulations have also been regularly assessed as part of the IPCC Climate Assessments Reports and various national assessments.



# CMIP6: a More Continuous and Distributed Organization

## 3. CMIP-Endorsed Model Intercomparison Projects (21 MIPs)

Eyring et al., GMD, 2016



## 2. Standardization, coordination, infrastructure, documentation

### 1. Common Experiments

**DECK (entry card for CMIP)**

- AMIP simulation (~1979-2014)
- Pre-industrial control simulation
- 1%/yr CO<sub>2</sub> increase
- Abrupt 4xCO<sub>2</sub> run

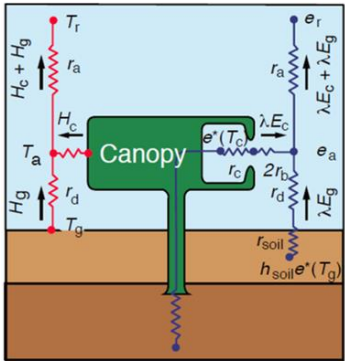
**CMIP6 Historical Simulation (entry card for CMIP6)**

- Historical simulation using CMIP6 forcings (1850-2014)

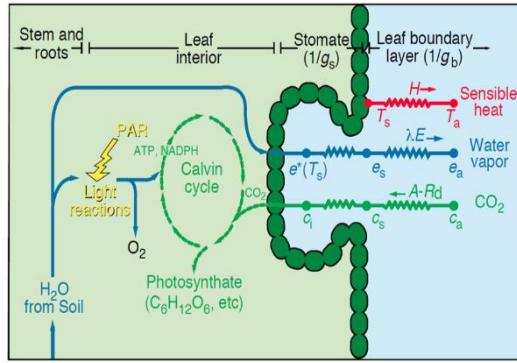
*DECK (Diagnosis, Evaluation, and Characterization of Klima)*

*& CMIP6 Historical Simulation to be run for each model configuration used in CMIP6-Endorsed MIPs*

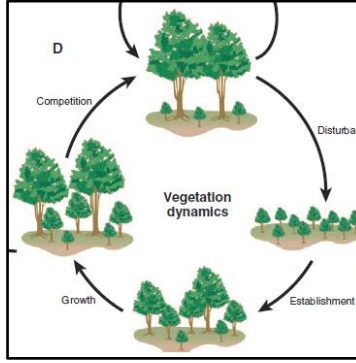
**1984** Dickinson  
**1986** Sellers et al.



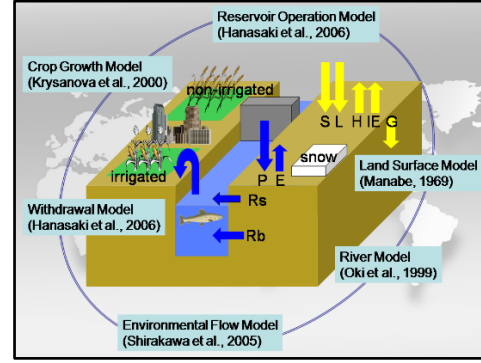
**1995** Bonan  
**1996** Sellers et al.



**1996** Foley et al.  
**2003** Sitch et al.  
**2003** Bonan et al.



**2006** Hanasaki et al.  
**2008** Hanasaki et al.  
**2011** Pokhrel et al.



**1**st Generation

**2**nd Generation

**3**rd Generation

**4**th Generation

**5**th Generation

Bucket

Big Leaf

Physiology

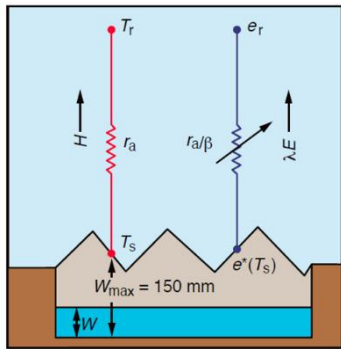
Ecosystem

Anthropocene

**NEXUS**

1<sup>st</sup> Integration

**NEXT GEN ?**



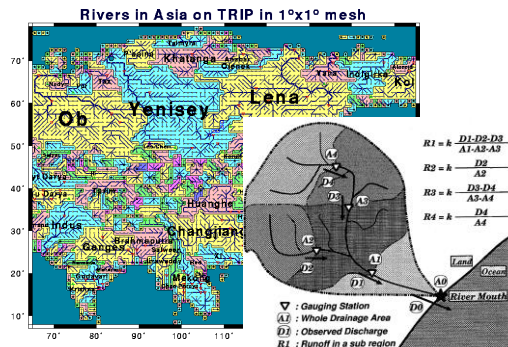
**1969** Manabe

River

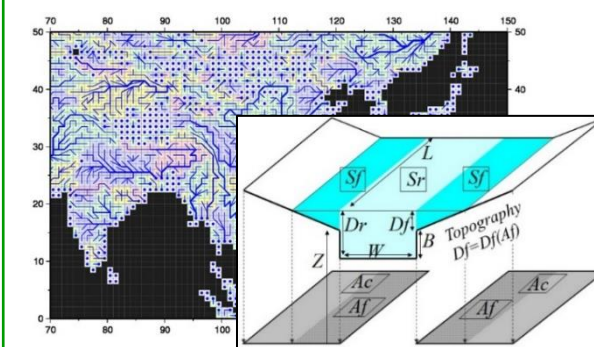
1<sup>st</sup> Generation

2<sup>nd</sup> Generation

Land



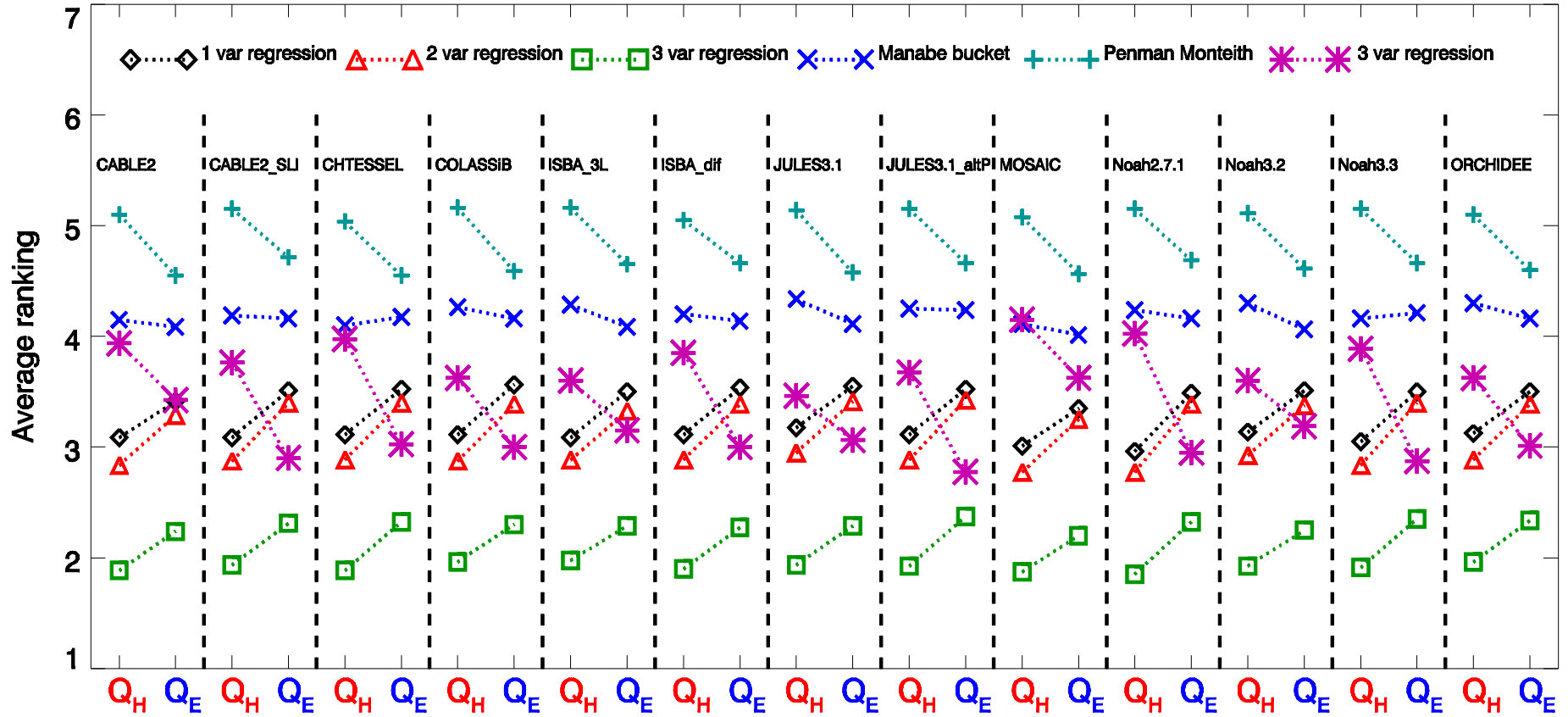
**1998** Oki and Sud



**2011** Yamazaki et al.

# PLUMBER: PALS Land sUrface Model Benchmarking Evaluation pRoject

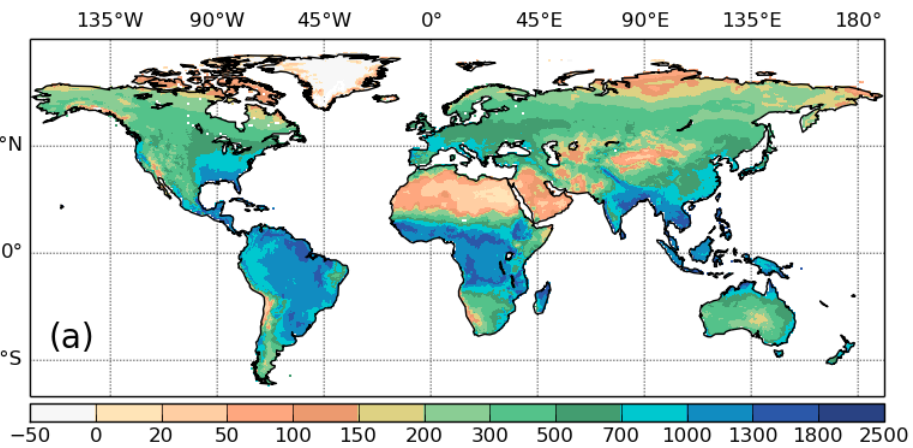
## Common statistics



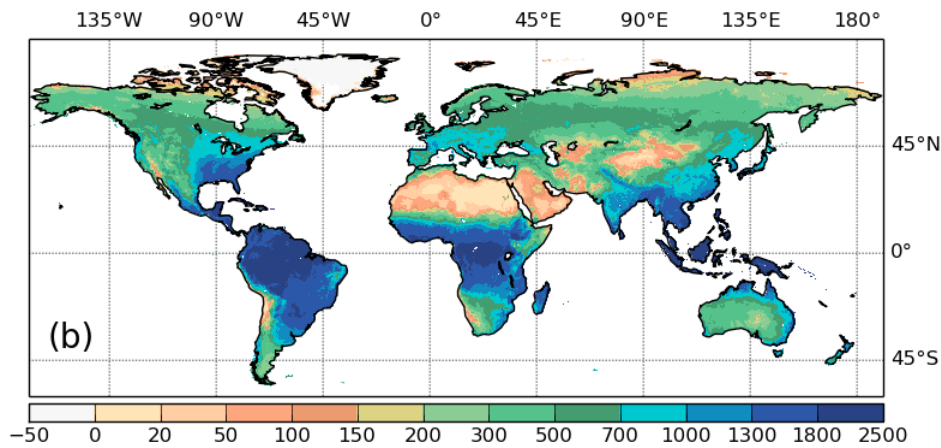
Best et al., (2015) JHM

# Preliminary Results and Known Problems

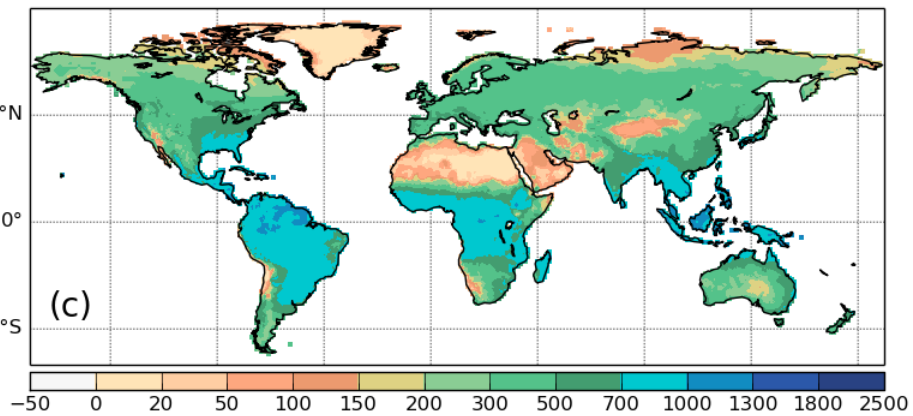
+ Significant discrepancy of spatial distributions found between models but no apparent changes or shifts in temporal variability (Here, Evapotranspiration in 20<sup>th</sup> Century)



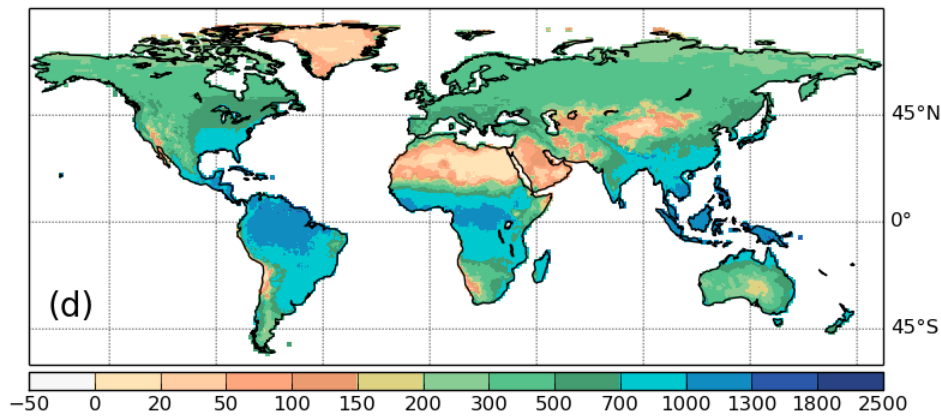
MATSIRO



CLM4.5



ETH with Rnet<sub>MATSIRO</sub>

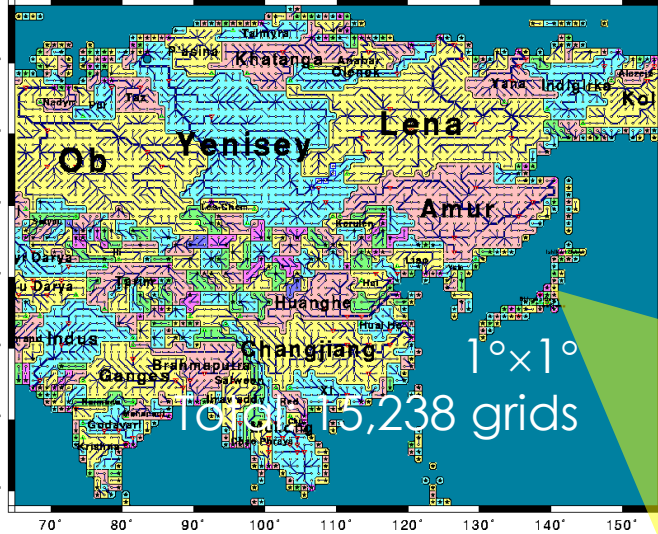


ETH with Rnet<sub>SRB</sub>

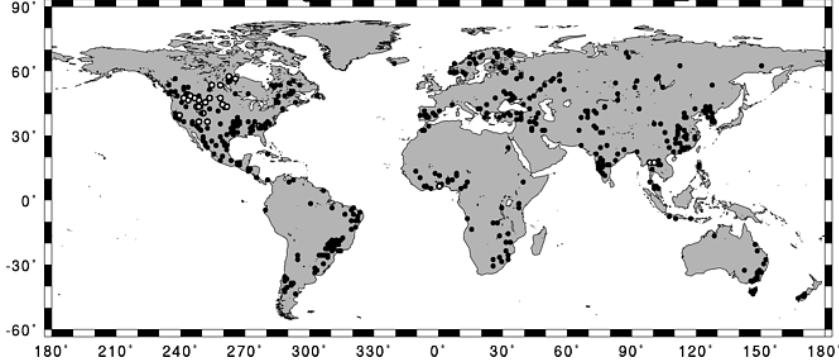
# Representation of Anthropogenic Impact

1. Simulate both water availability (streamflow) and water use **at daily-basis**
2. Deal with interaction between **natural hydrological cycle** and **anthropogenic activities**
3. **Applicable** for future climate change simulation

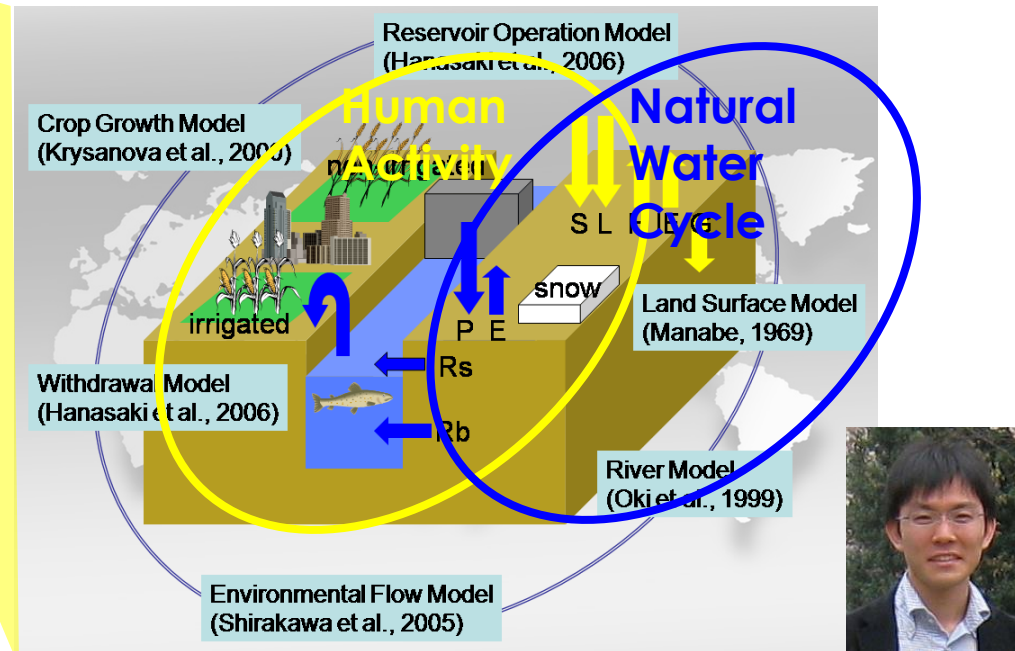
Rivers in Asia on TRIP in 1°x1° mesh



Reservoirs larger than 1000 MCM in The World



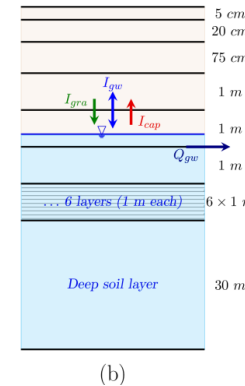
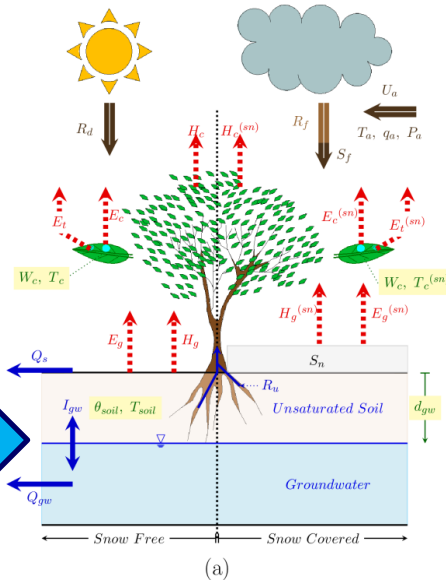
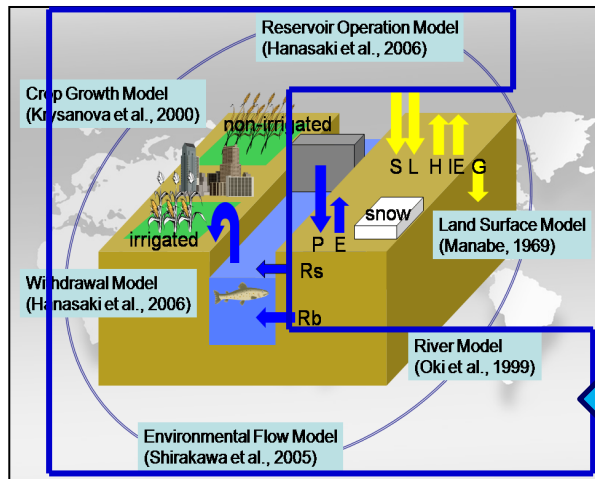
452 reservoirs, 4140 km<sup>3</sup>



Hanasaki et al., 2006, 2008

# Representation of Anthropogenic Impact

- Land Surface Models (LSMs) are designed to be coupled with GCMs
  - **No Human Impacts (HI) representation**
- Numerous Global Hydrological Models (GHMs) with HI representation exist, but
  - Mostly designed for **offline simulations**
  - Simple ET parameterizations (**energy balance not considered**)
  - Vegetation dynamics/Carbon cycles are not accounted.



**Water table dynamics**  
(Yeh and Eltahir, 2005)

**Pumping scheme**  
Koirala et al.

- ✓ Land surface hydrology scheme is a simple **Bucket Model**
- ✓ **Vegetation** : accounted implicitly

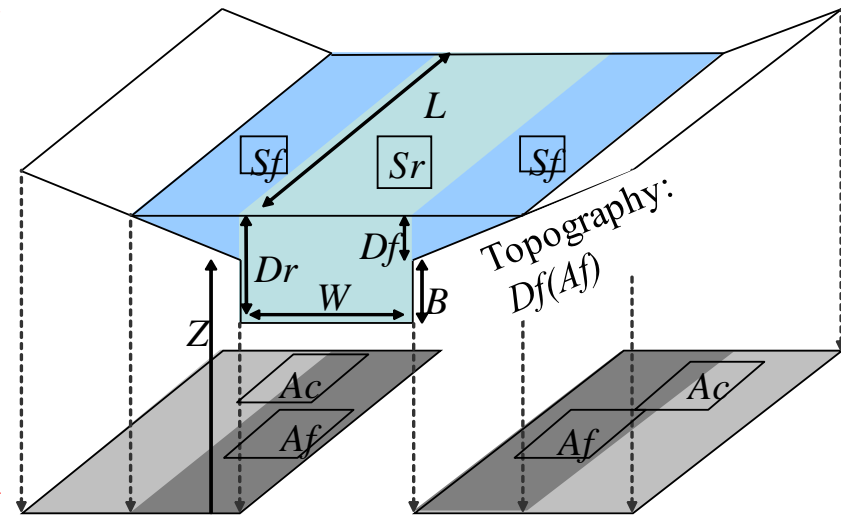
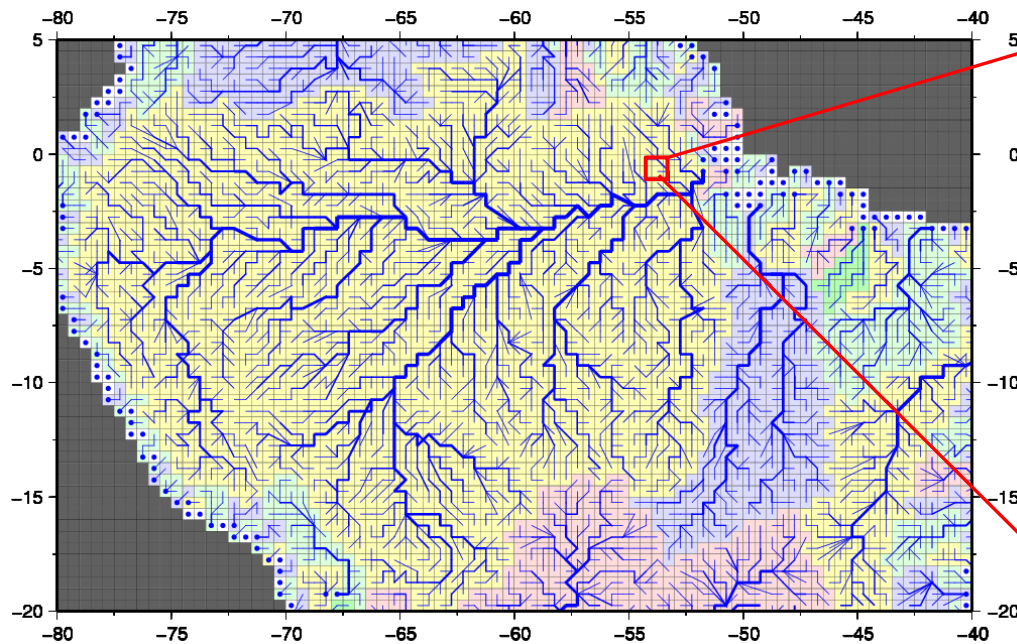
- ✓ Further, **new irrigation scheme** for MATSIRO LSM is developed
- ✓ **Water table dynamics and a newly developed pumping scheme**

Pokhrel, Kim et al., 2012

# A physically based description of floodplain inundation dynamics in a global river routing model

## CaMa-Flood (Catchment-based Macro-scale Floodplain model)

- Distributed river routing model using River Network Map
- **Input:** LSM Runoff, **Output:** Water storage (Prognostic)  
River discharge, Water level, Inundated area (Diagnosed)
- River and floodplain storage with sub-grid topographic parameters.
  - > Explicit representation of water stage in a single grid-box (25km size)

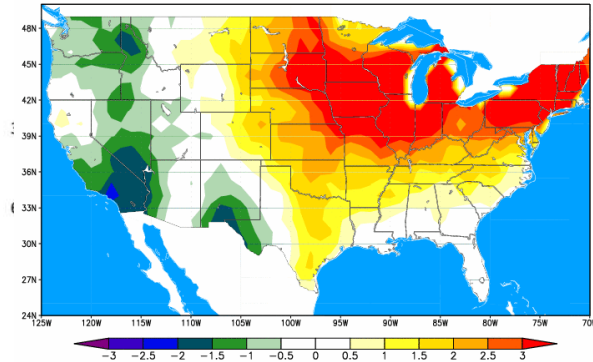


# Land-atmosphere Interaction in a Global Climate Model in Association with Human Activities

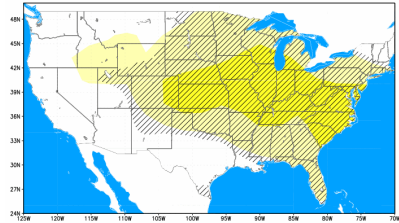
+ Spread of near surface temperature (2m Tair) among ensemble members becomes smaller by incorporating surface water-groundwater-human models in the AGCM.

+ Sub-seasonal forecast skill for near surface air temperature (Day16-30) was improved by using realistic land initializations in the fully coupled AGCM with surface-groundwater-human models.

T2m, GSWP2, July 30 – August 13



T2m, HUMAN-EXP, Realistic Soil Moisture IC.



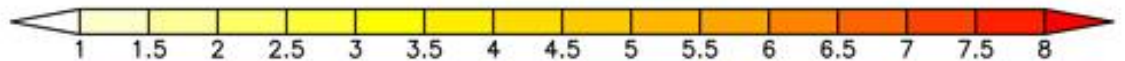
With HI

(a) T2&Z500,HUMAN,Day1-15 (b) T2&Z500,HUMAN,Day16-30 (c) T2&Z500,HUMAN,Day31-45 (d) T2&Z500,HUMAN,Day46-60

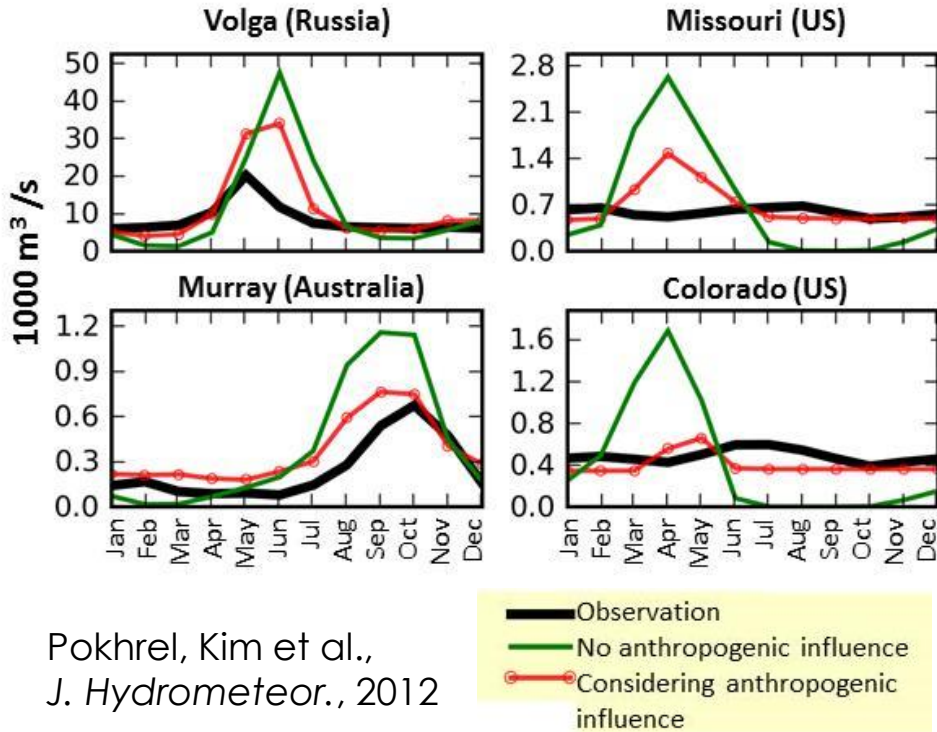


W/O HI

(e) T2&Z500,CTRL,Day1-15 (f) T2&Z500,CTRL,Day16-30 (g) T2&Z500,CTRL,Day31-45 (h) T2&Z500,CTRL,Day46-60

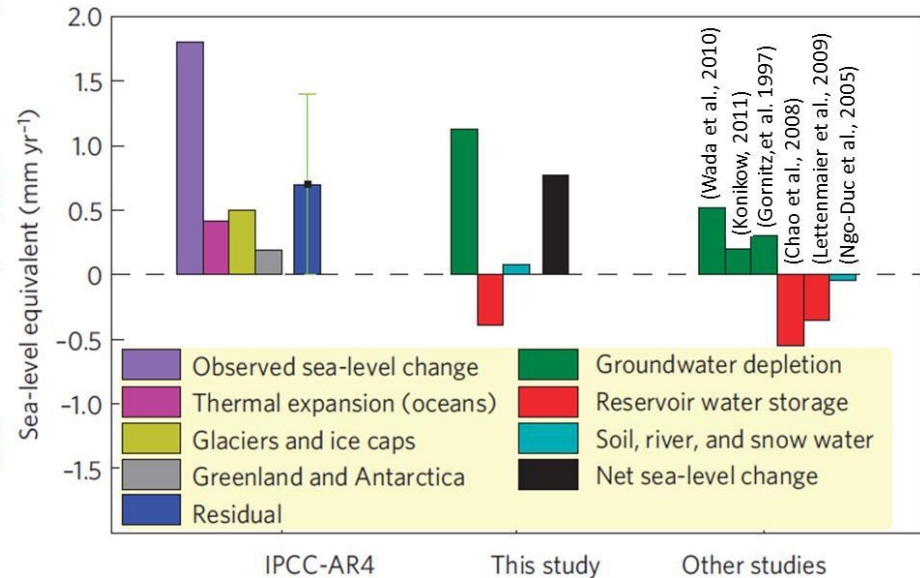


# Representation of Anthropogenic Impact



Pokhrel, Kim et al.,  
*J. Hydrometeorol.*, 2012

Anthropogenic influence on natural water cycles is better reflected with additional model components reproducing human-induced alterations, which lead the improved simulation of river discharge by the models.

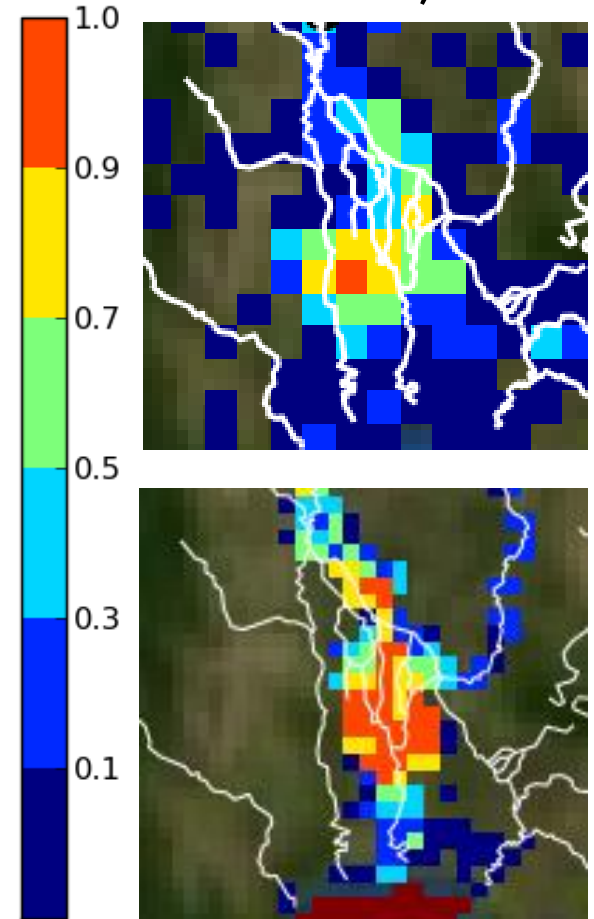
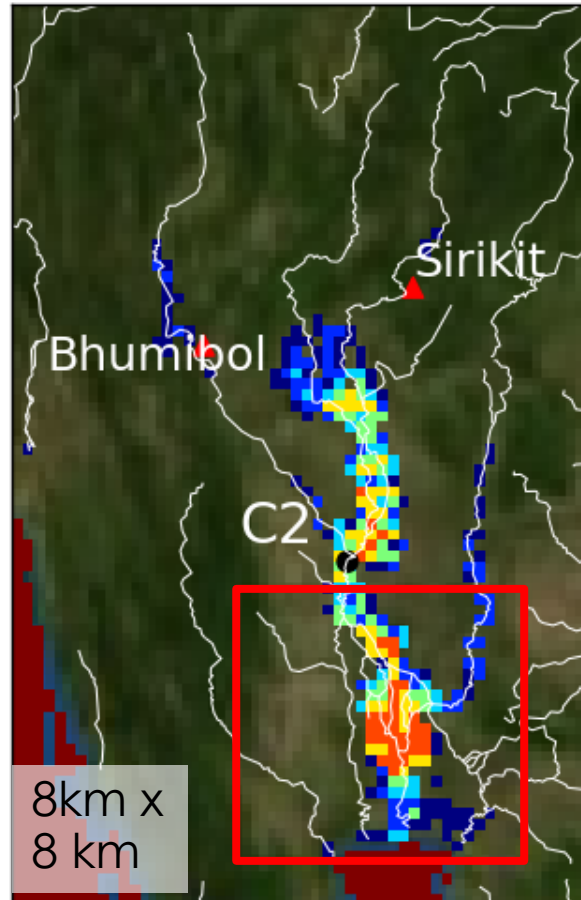
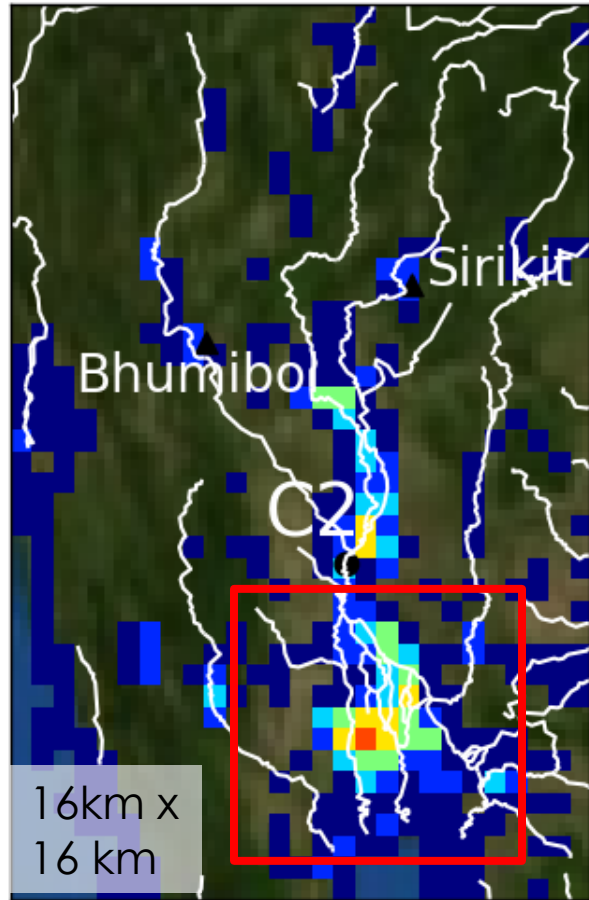


Pokhrel, et al., *Nature Geoscience*,  
 2012

Estimated terrestrial water storage changes (1961-2003) indicate the largest contribution of the unsustainable groundwater use to net sea-level change.

# Thai Flood 2011

Percent of area that is inundated (October 15, 2011)



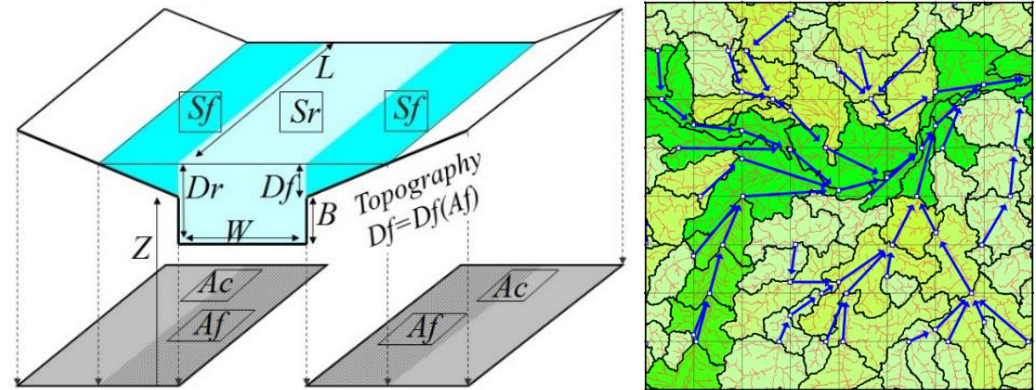
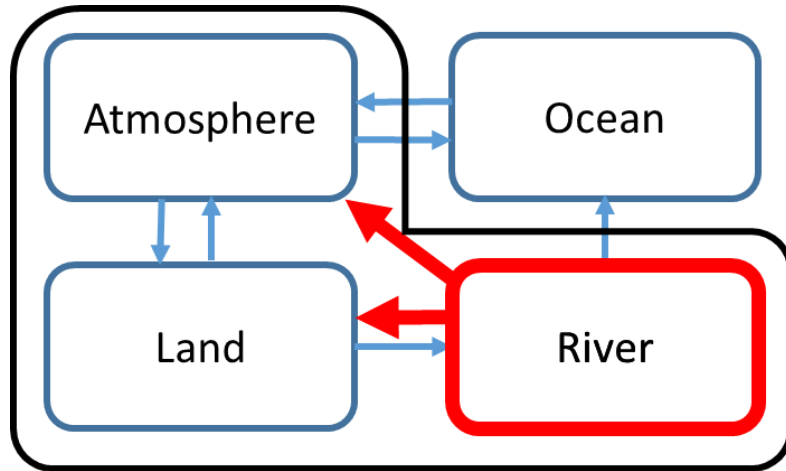
MODIS & AMSR-E Obs.

**Simulation H08-CaMa**

Zoomed in images

Takeuchi, K. Oki, H. Kim, 2012, In Preperation

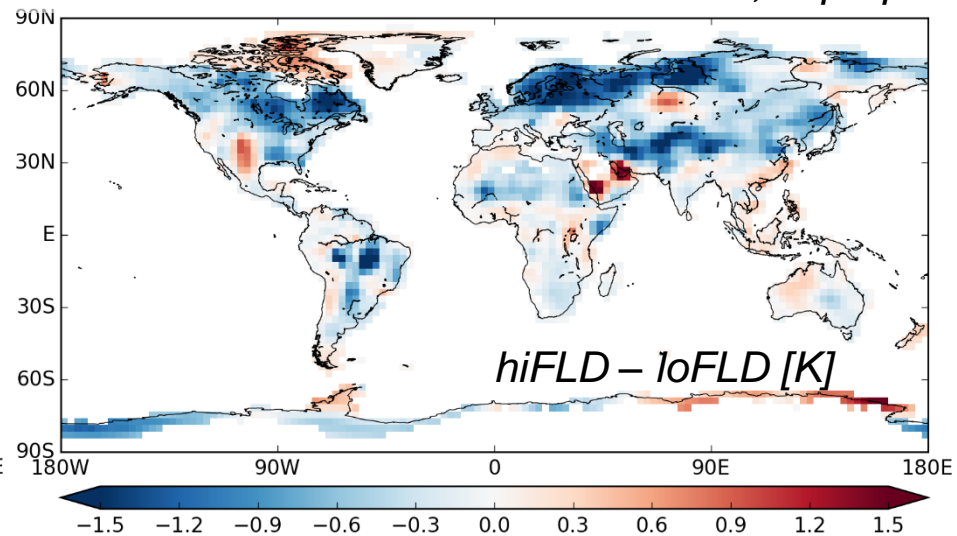
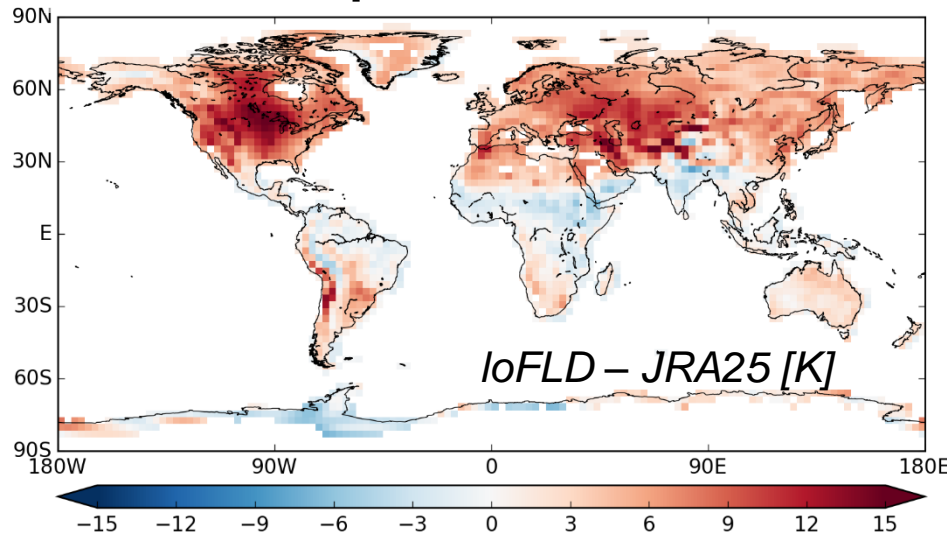
# River Inundation Process in a Climate Model



CaMa-Flood – Yamazaki et al., WRR, 2011

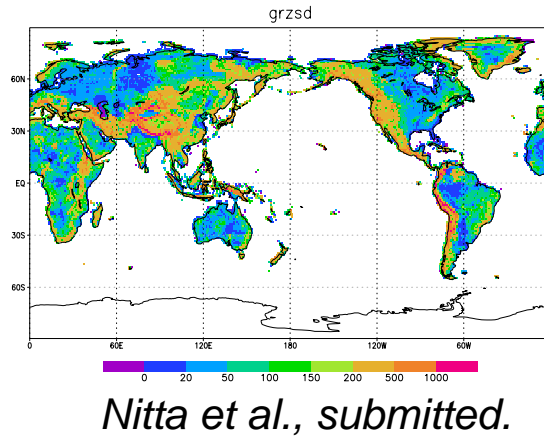
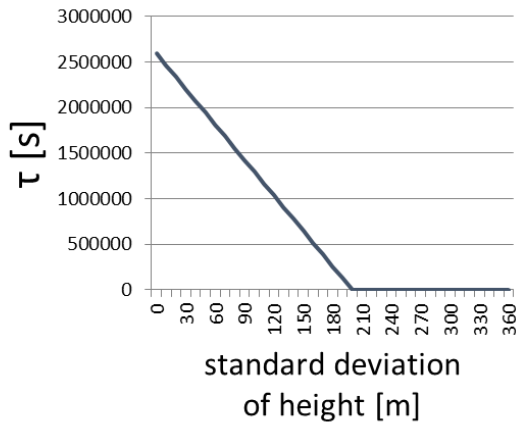
## 2m Air Temperature

Hatono et al., in prep.



+ Warm bias at high latitudes is slightly (~10%) alleviated.

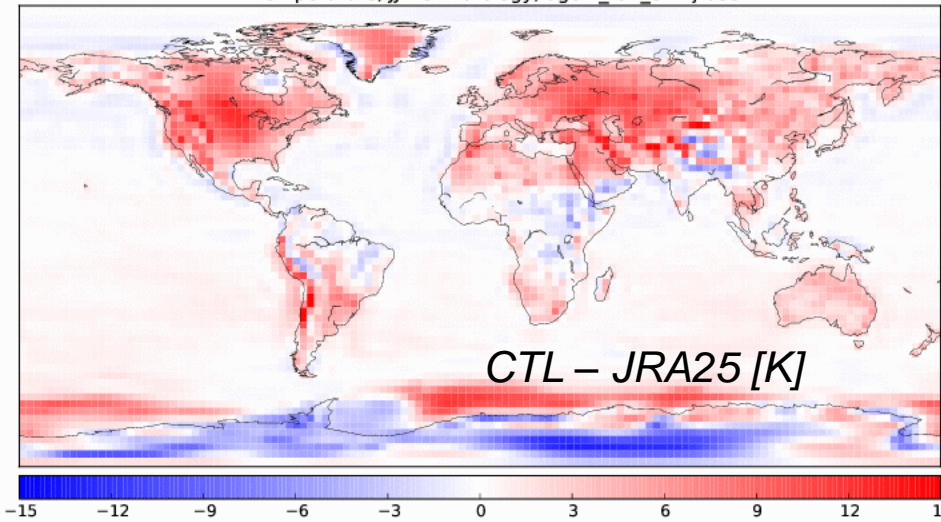
# Impact of Arctic Wetlands on Climate System



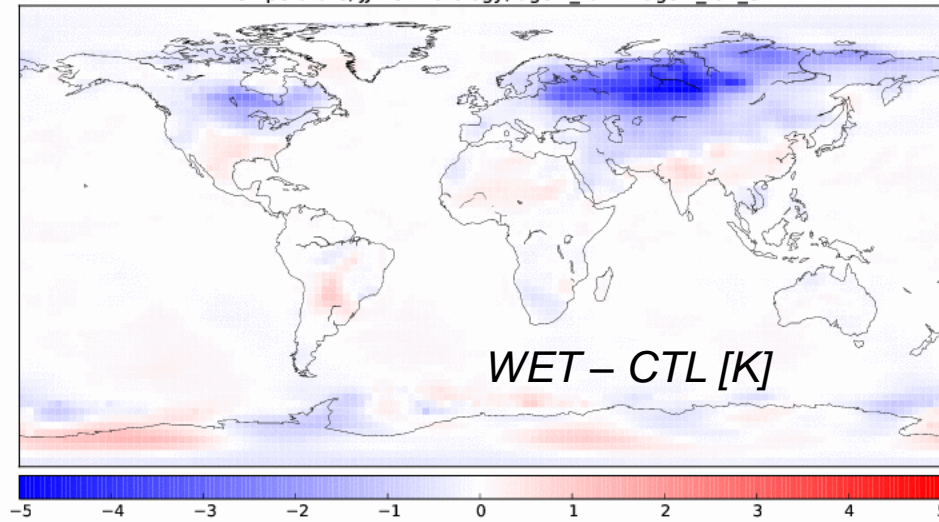
+ Add a surface tank that stores part of (1-a) snowmelt surface runoff  
 + Topography dependent time constant ( $\tau$ )

$$S_t = S_{t-1} - (S_{t-1}/\tau + (1 - \alpha)R_s)dt$$

2m temperature, JJA Climatology, agcm\_run\_ctl - jra55



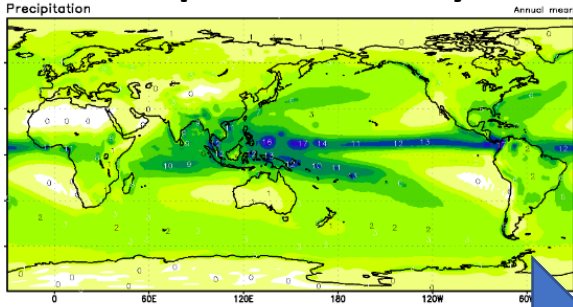
2m temperature, JJA Climatology, agcm\_run1 - agcm\_run\_ctl



+ Warm bias at high latitudes is considerably (up to ~30%) alleviated.

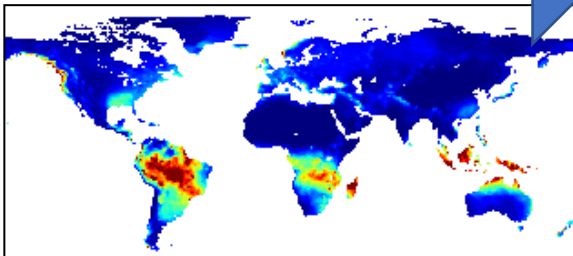
# Off-line Framework for Large-scale Land Simulation

## Atmospheric Reanalysis



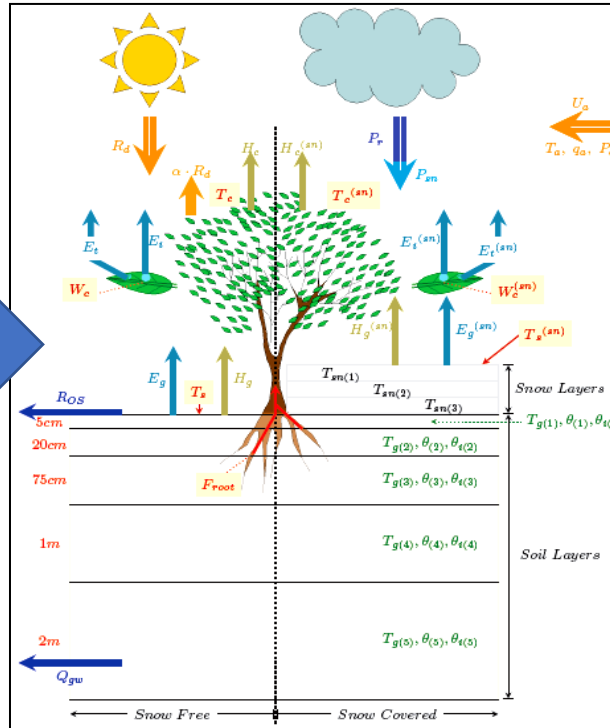
Bias  
Corr. +

Atmos.  
Forcing Data

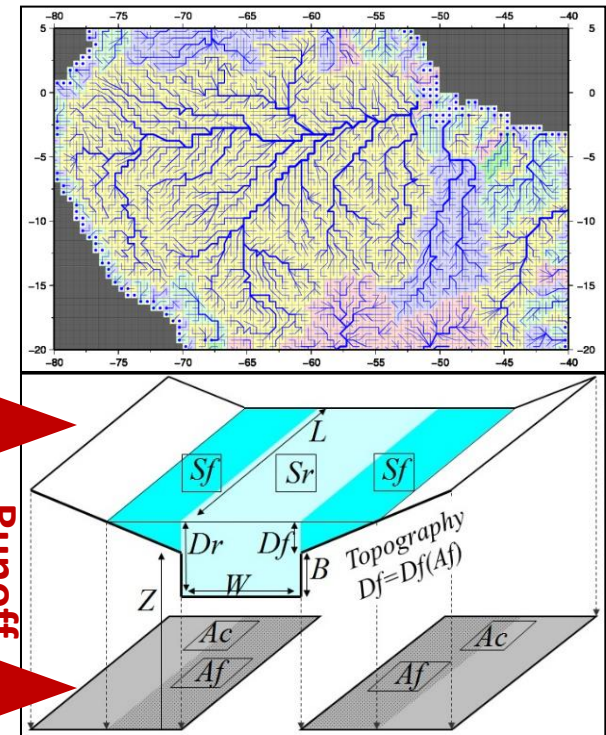


Observations

## Land Surface Model



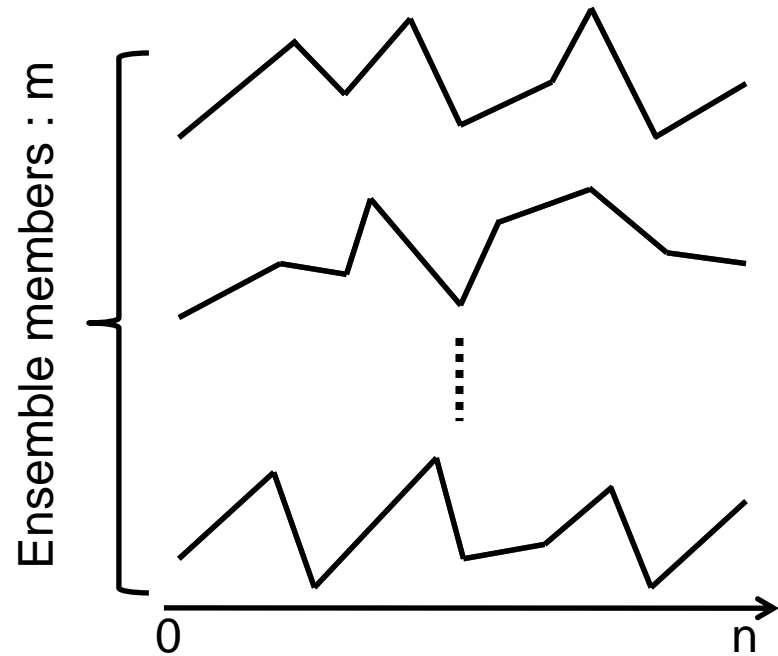
## River Model



Evaluation / Benchmarking System for  
Model Simulations and Input Data

# Similarity Index: $\Omega$

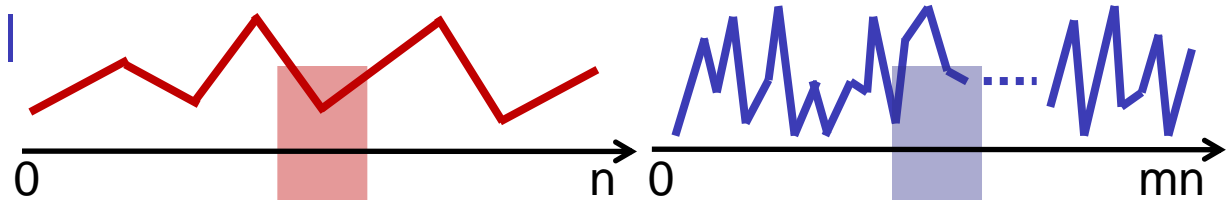
$\Omega$  : Index to measure the **similarity** of individual time series of ensemble members [Koster et al., 2000]



Very different

$-0 \sim 1$

Identical



$$\Omega_a = \frac{m\sigma_{\hat{a}}^2 - \sigma_a^2}{(m-1)\sigma_a^2}$$

$$\sigma_{\hat{a}}^2 = \text{Var}\left[\frac{1}{m} \sum_{i=1}^m a_{ij}\right]$$

Mean Variability

$$\sigma_a^2 = \text{Var}[a_{ij}]$$

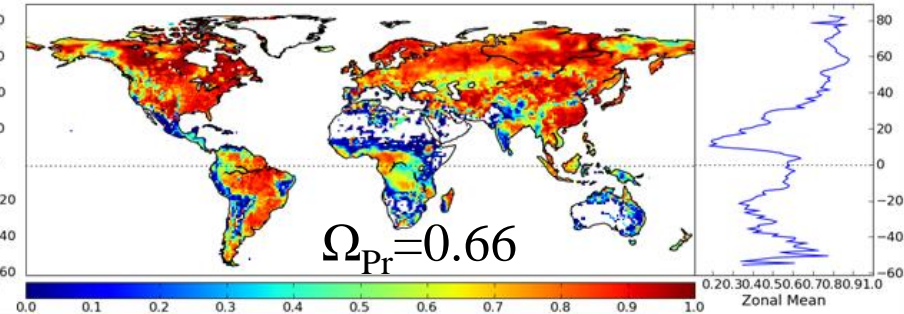
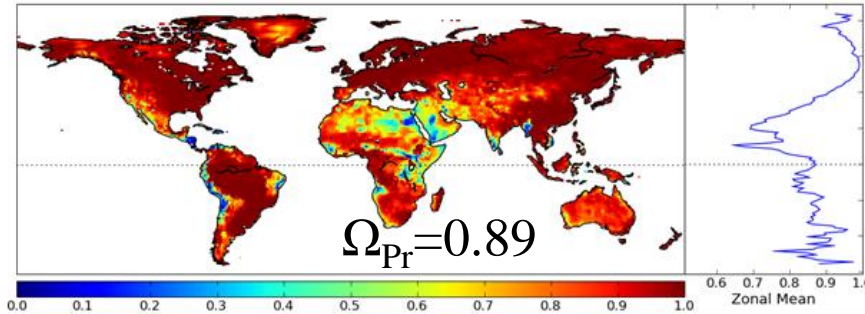
Total Variability

# Simulation Uncertainty – model vs input data –

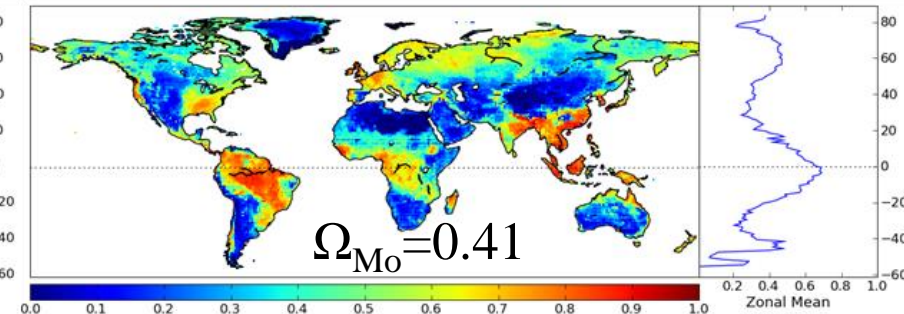
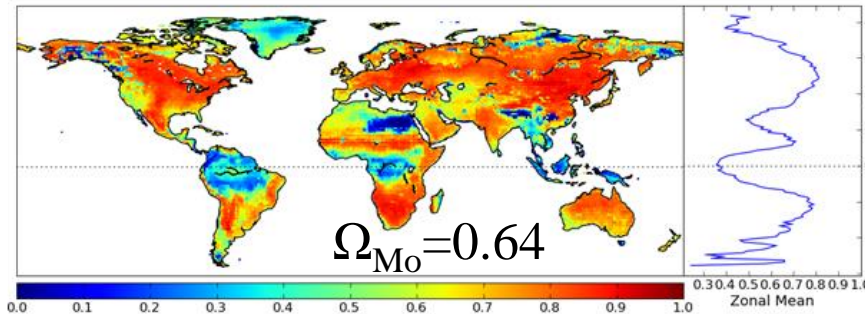
## Evapotranspiration

## Runoff

Ens. Prcp.



Ens. Mod.



*Kim, 2010*

Uncertainty in simulated evapotranspiration and runoff introduced by different land surface schemes in GSWP2 are larger than precipitation uncertainty-induced uncertainty by 28% and 40% in the similarity index ( $\Omega$ ) globally.

# Generation Atmospheric Boundary Conditions

## Model Input Data for EXP1 (long-term retrospective)

### Dynamical Global Downscaling

- \* Spectral Nudging using GSM (Yoshimura and Kanamitsu, 2008)
- \* Single Ensemble Correction (Yoshimura And Kanamitsu, 2013)
- \* Vertically Weighted Damping (Hong and Chang, 2012)

### Two-pass Bias Correction

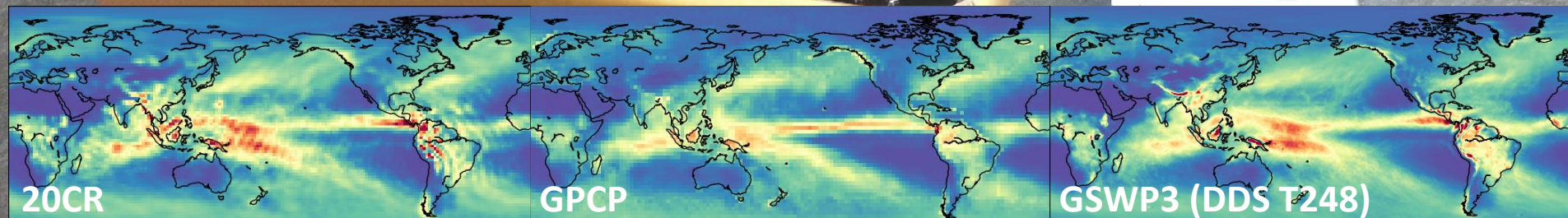
- \* LDMF Daily Correction (Kim et al., in prep.)
- \* Parametric Monthly Correction (Watanabe et al., 2012)

**GSWP3  
LS3MIP  
Forcing**

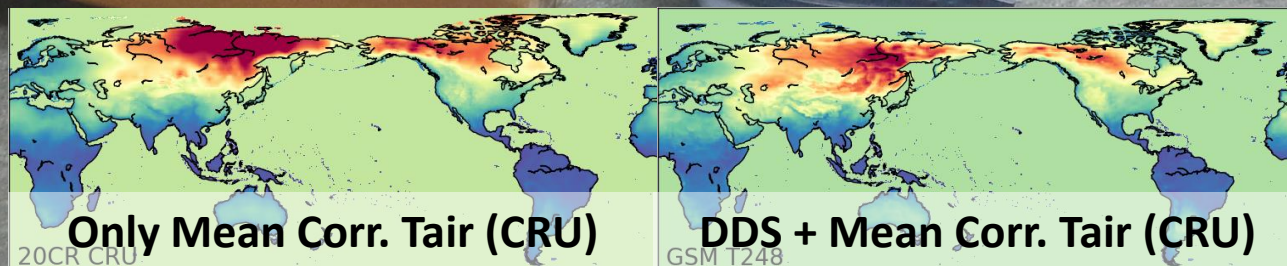
20CR (Compo et al., 2011)  
1871-2010 6hr / 2°x2°(91x180)

Observations (Prcp: GPCC, CPC-  
Unified; Tair: CRU; Rad.: SRB)

0.5°x0.5°  
1901-2010 3hr



Better representation  
of mean and  
**variability** in high-  
frequency domain



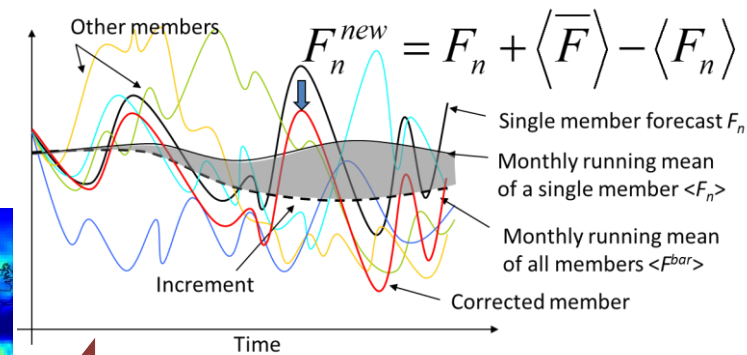
**Only Mean Corr. Tair (CRU)**

**DDS + Mean Corr. Tair (CRU)**

# Comparison Table for Existing Forcing Data

	NCC	GSWP2	Princeton	ELSE	WATCH	GSWP3
Reference	Ngo Duc et al., 2005	Dirmeyer et al., 2006	Sheffield et al., 2006	Kim et al., 2009	Weedon et al., 2011	Kim et al., in prep.
Temporal Coverage	1948-2000 53 years	1982-1995 14 years	1948-2008 61 years	1979-2010 32 years	1901-2001 101 years	<b>1851-2011</b> <b>161 years</b>
Spa./Temp. Resolution	1 deg. 6 hours	1 deg. 3 hours	1 deg. 3 hours	1 deg. 6 hours	0.5 deg. 3 or 6 hours	0.5 deg. 3 hours
Base Reanalysis	NCEP/NCAR 1948 - now T62 / 6hr	NCEP/NCAR 1948 - now T62 / 6hr	NCEP/NCAR 1948 - now T62 / 6hr	JRA25 1948 - now T106 / 6hr	ERA-40 1957 - 2002 TL159 / 6hr	<b>20CRv2c</b> <b>1851 - 2011</b> 2 deg. / 6hr
Spa. Dis-aggregation	Bi-linear	Bi-linear	Bi-linear, Bayesian	Bi-linear	Bi-linear	<b>Dynamical Downscale</b>
Temp. Dis-aggregation	N/A	Variability from Obs.	Variability from Obs.	N/A	Variability from Obs.	<b>Dynamical Downscale</b>
Bias Correction	Only monthly (Add/Ratio)	Only monthly (Add/Ratio)	Only monthly (Add/Ratio)	Only monthly (Add/Ratio)	Only monthly (Add/Ratio)	Monthly (Add/Ratio) & <b>Daily</b> <b>(Non-para.)</b>

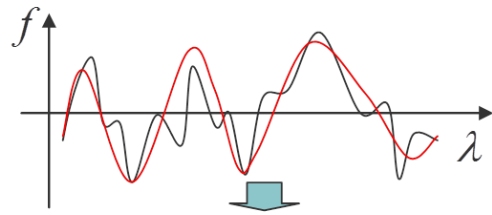
# Spectral Nudging for Global Dynamical Downscaling



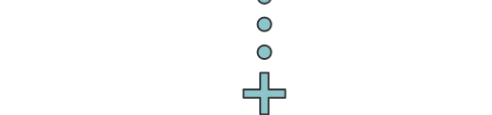
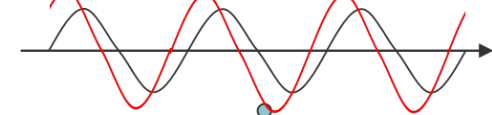
**Incremental Correction of Single Member**

*Yoshimura and Kanamitsu 2013*

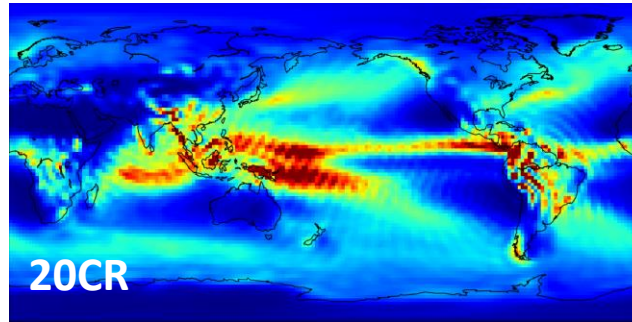
Fourier series



Nudge scale:  $\bullet$  Forecast < 1000km



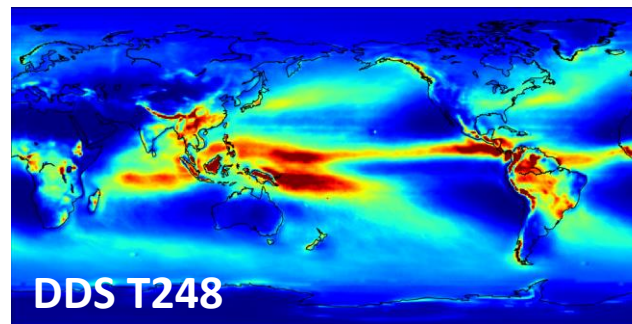
*Yoshimura and Kanamitsu 2008*



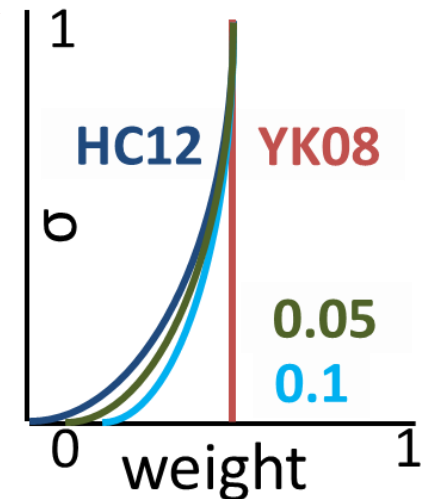
**Nudging**  
U, V, T, P

$$f_{(\lambda, \phi)} = \sum_{m=-M}^{m=M} A_{(m, \phi)} e^{im\lambda}, \text{ with}$$

$$A_{(m, \phi)} = \begin{cases} A_{f(m, \phi)} & \left( |m| > \frac{2\pi R_E \cos \phi}{L} \right) \\ \frac{1}{\alpha + 1} [A_{f(m, \phi)} + \alpha A_{a(m, \phi)}] & \left( |m| \leq \frac{2\pi R_E \cos \phi}{L} \right) \end{cases}$$



**Vertically Weighted Damping Coef.**



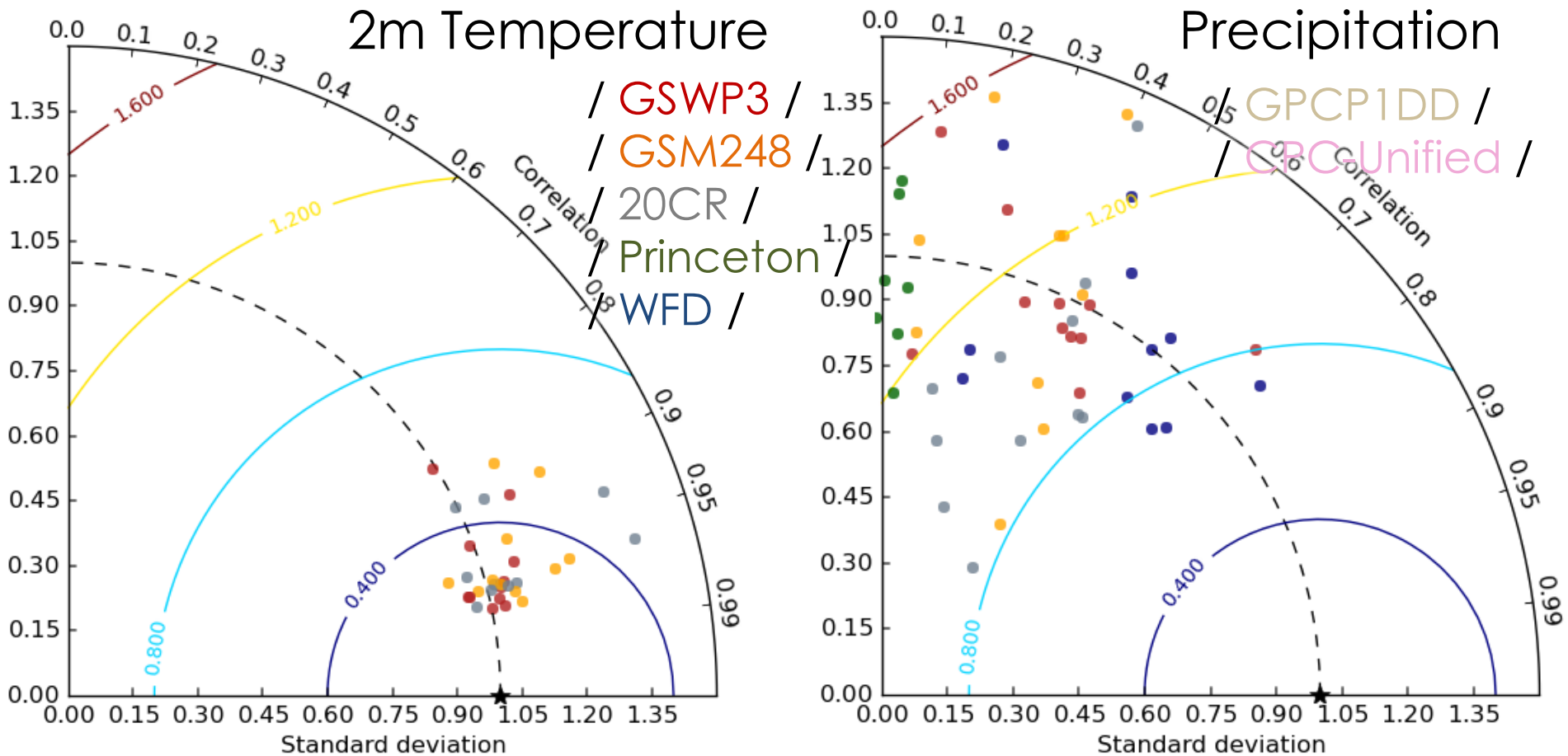
*Hong and Chang 2012*

Successfully generate high frequency signals preserving low frequency background.

Effectively relieves ripple-like pattern (an artifact of 20CR due to high-res. topography mismatch)

# Data Quality Evaluation

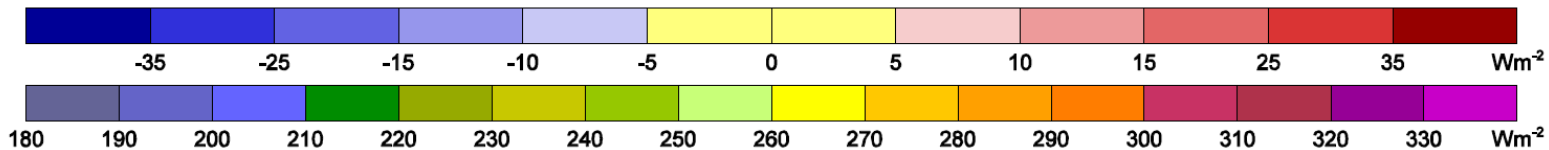
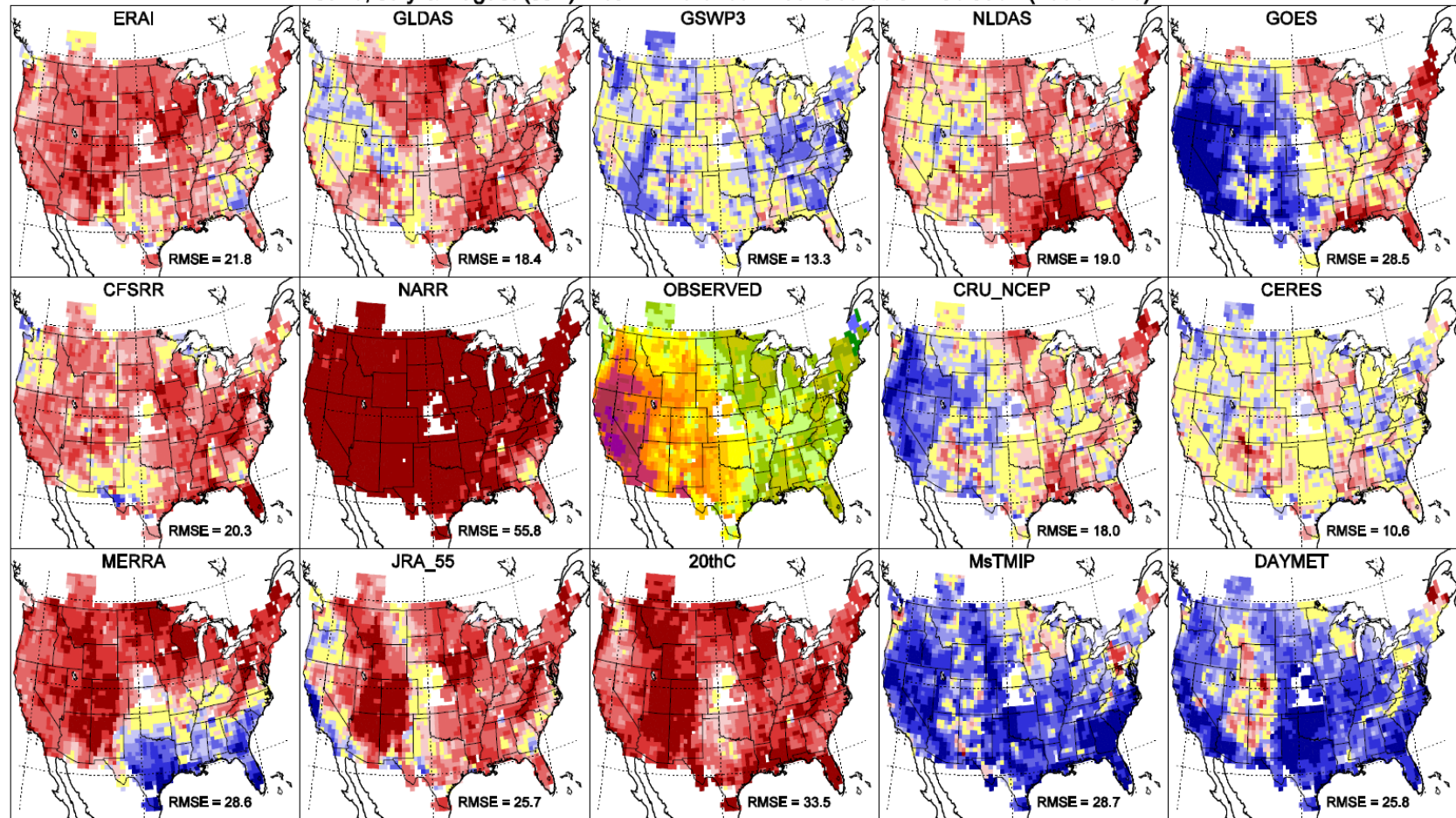
- + Beta-version of Land Surface Forcing Data Ready
- + Being used as a standard off-line climate driver of GSWP3, ISIMIP2, LS3MIP/LUMIP/CMIP6, and modeling groups.



# Preliminary Results and Known Problems

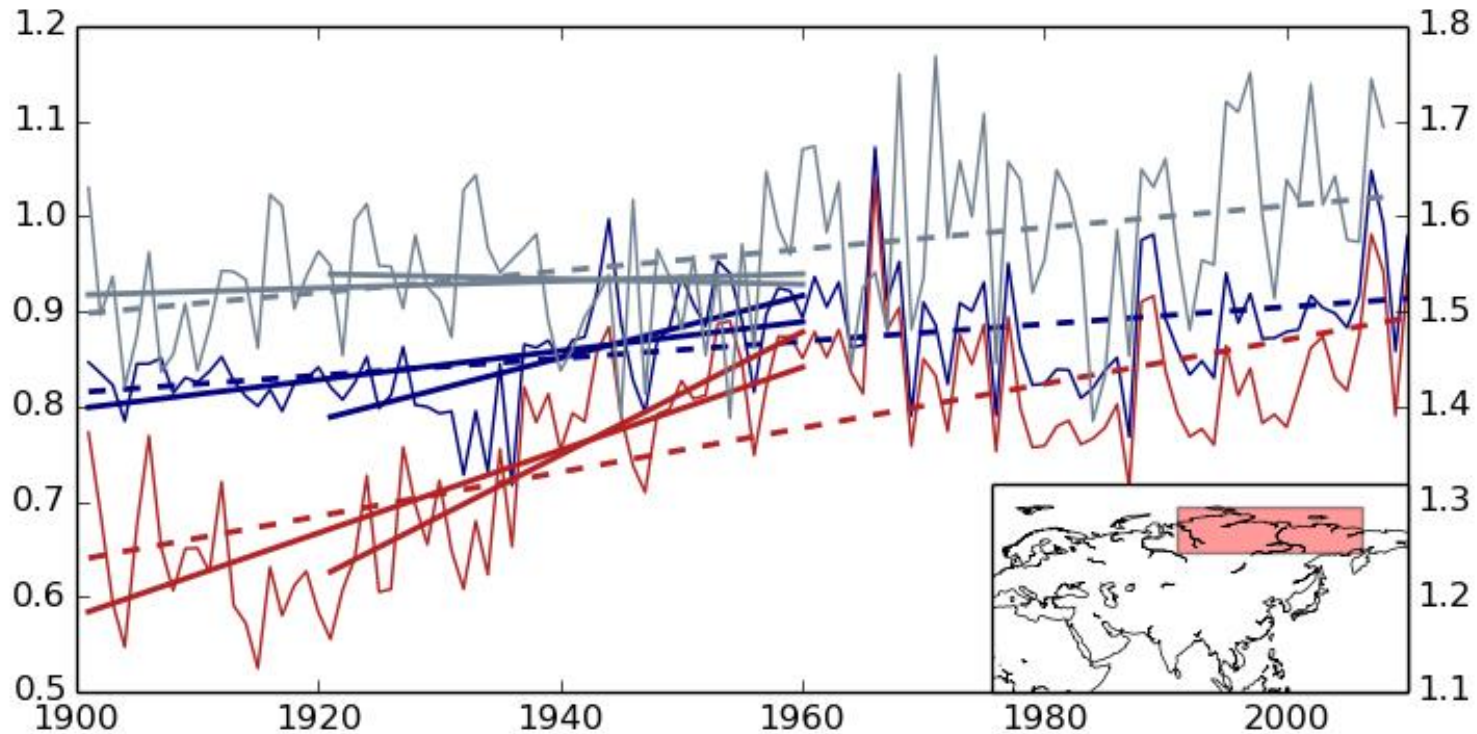
+ Relatively small bias of solar radiation

June, July & August (JJA) Mean Difference in Surface Solar Radiation (2000-2010)



# Preliminary Results and Known Problems

+ Spurious(?) trend at high latitude in early 20<sup>th</sup> Century



	Mean	1920-1960	1901-1960	1901-2010
<b>20CR</b>	1.56	-0.0003	0.0004	0.0011
<b>GPCP</b>	0.77	0.0064	0.0044	0.0023
<b>CRU</b>	0.86	0.0033	0.0015	0.0009

# ILAMB: International Land Model Benchmark

A tool for model development and assessment providing quick and comprehensive comparison against growing set of observations and metrics

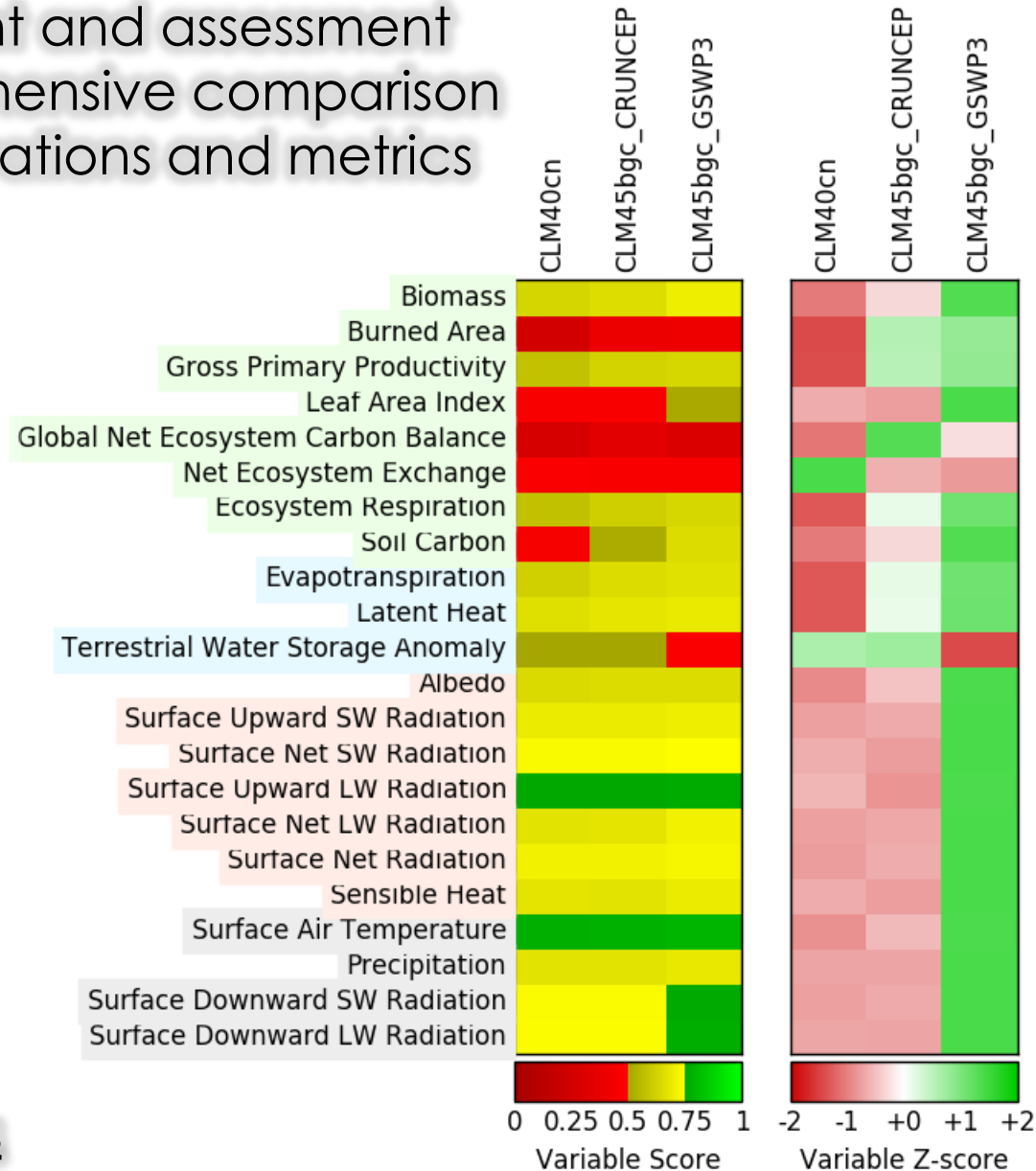
\* C-cycle (8): Above ground live biomass, burned area, CO<sub>2</sub>, GPP, LAI, global net ecosystem carbon balance, NEE, ER, soil carbon

\* W-cycle (6): ET, LE, S, R, evaporative fraction, TWSA

\* E-cycle (6): albedo, SW<sub>up</sub>, SW<sub>net</sub>, LW<sub>up</sub>, LW<sub>net</sub>, R<sub>net</sub>

\* Forcing (5): T<sub>air</sub>, precipitation, RH, SW<sub>down</sub>, LW<sub>down</sub>

**Integrates 25 variables in 4 categories from ~60 datasets**



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ILAMB/ORNL, PALS/GEWEX, HAPPI

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<http://www.gewex.org/events/hess4/>

[hess4.tokyo@gmail.com](mailto:hess4.tokyo@gmail.com)

Thank you

A black and white photograph of a beach. The foreground shows a dark, pebbly or sandy beach with some debris. The middle ground features waves with white foam crashing onto the shore. The background is a dark, low-lying landmass or city skyline under a vast, dramatic sky filled with heavy, layered clouds. The text "Thank you" is centered in the middle of the image in a simple, black, sans-serif font.