Development of Global Land & Hydrologic Modeling Framework: Physics and Data

전 지구 지면 및 수문 모델링 프레임워크의 개발:
물리과정과 데이터의 측면에서

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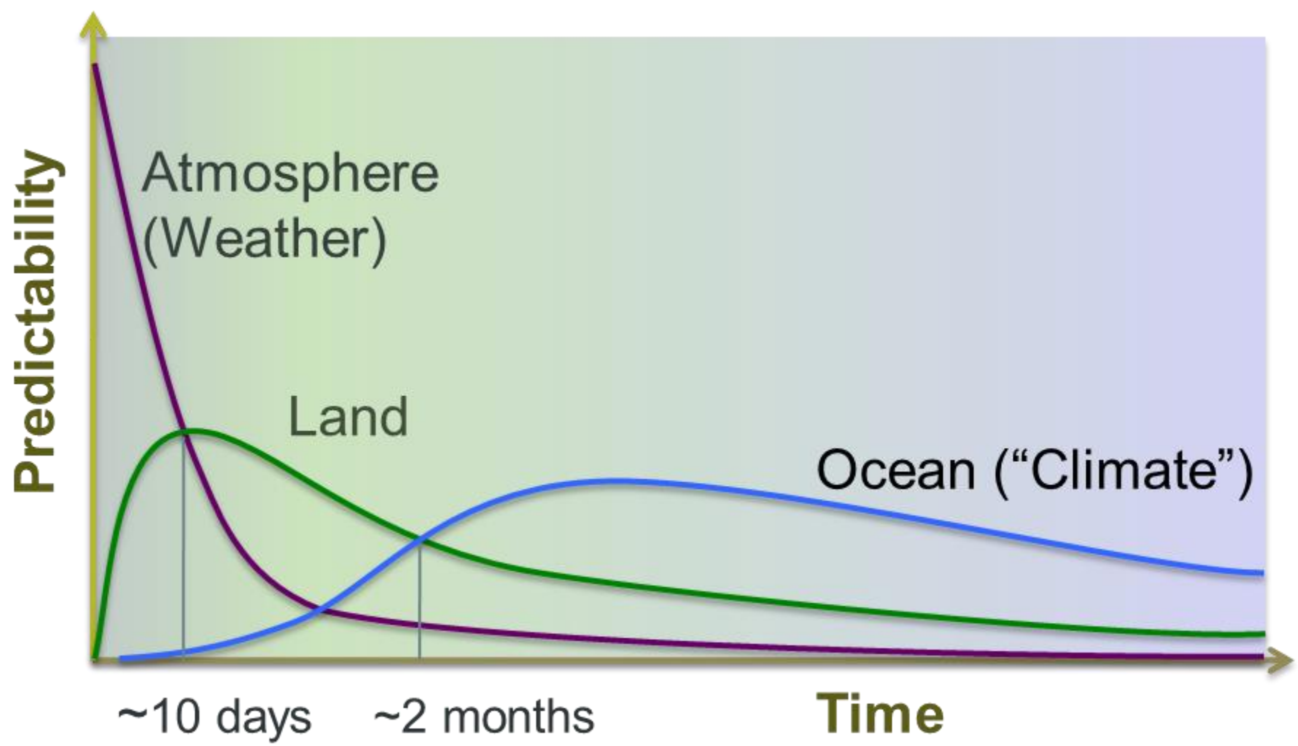
Land, Predictability and Prediction

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

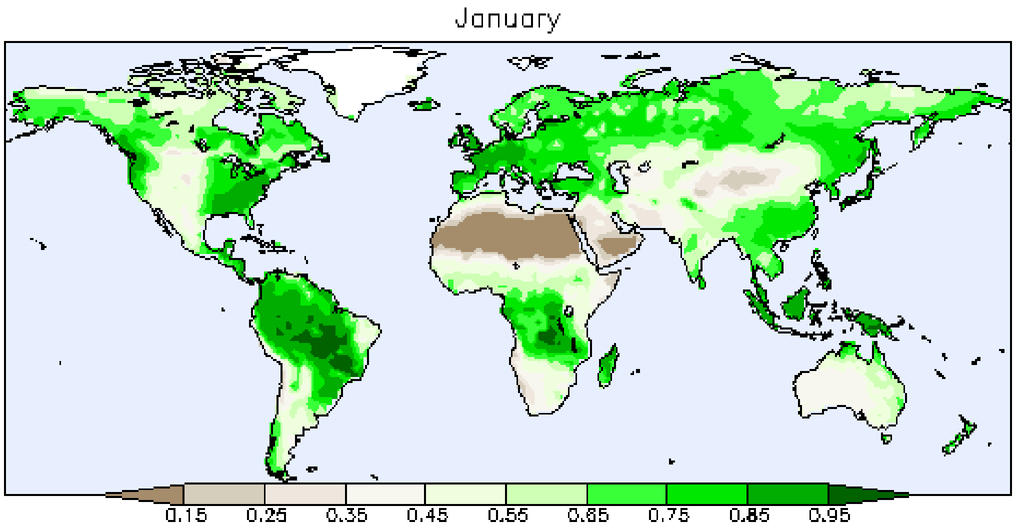
The 2-4 week “subseasonal” range is a hot topic in operational forecast centers now.

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* –

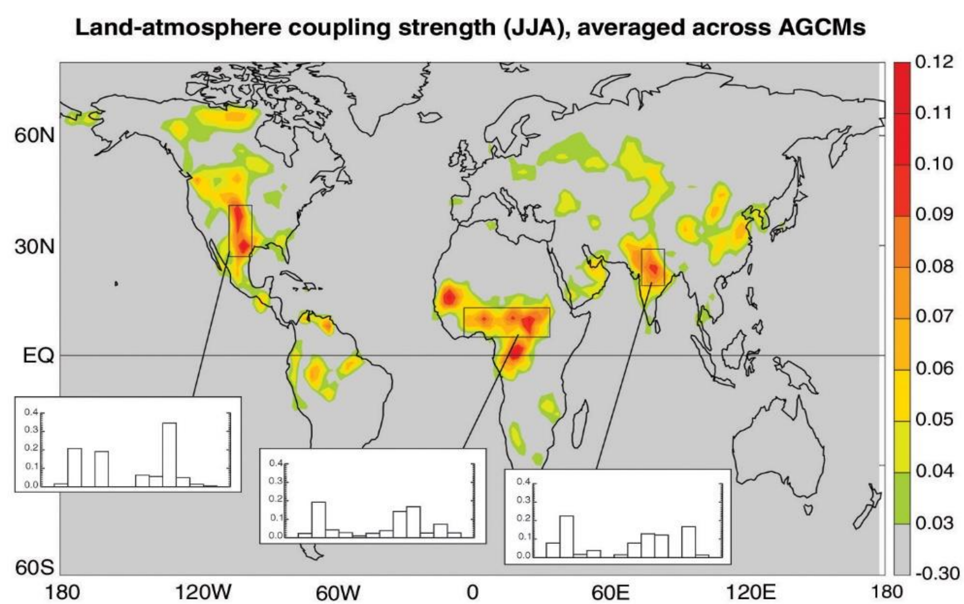


Global Soil Wetness Project is a core project of GLASS/GEWEX/WCRP which was devised to provided a surrogate 'observed', off-line simulated, land surface states which are not routinely reported unlike ocean.

– 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

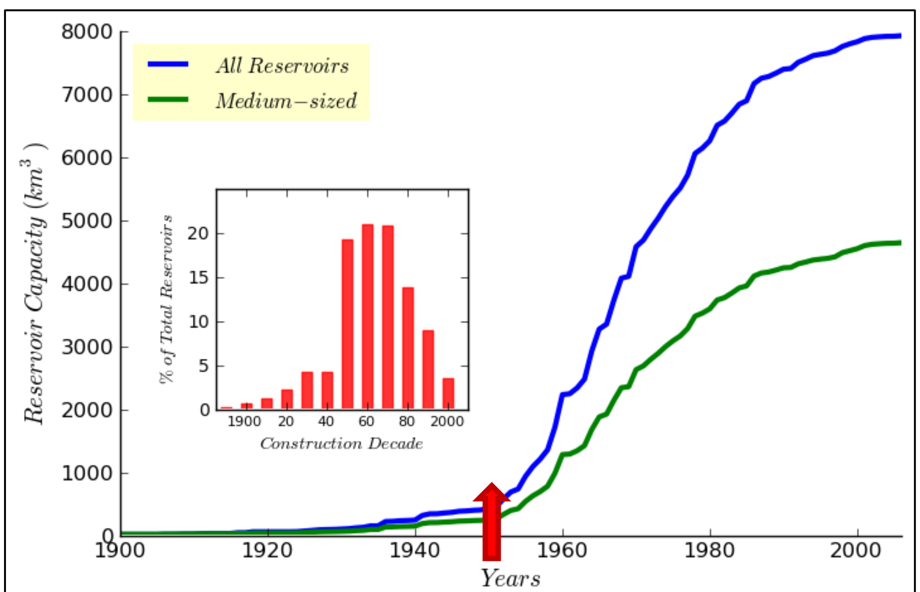


Geology of Mankind: "Anthropocene"

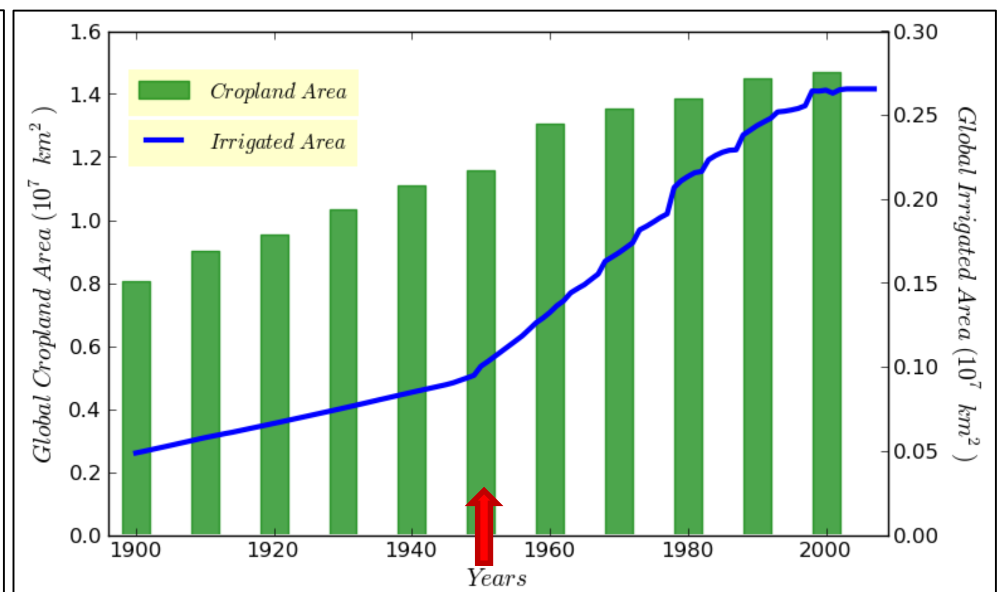
+ Human activities became the major drivers of global environmental changes

+ Real global water cycles are not natural anymore!
  : Human activities have altered water flows and storages significantly during the past century through irrigation, damming, groundwater extraction, ...

Global Reservoir Capacity

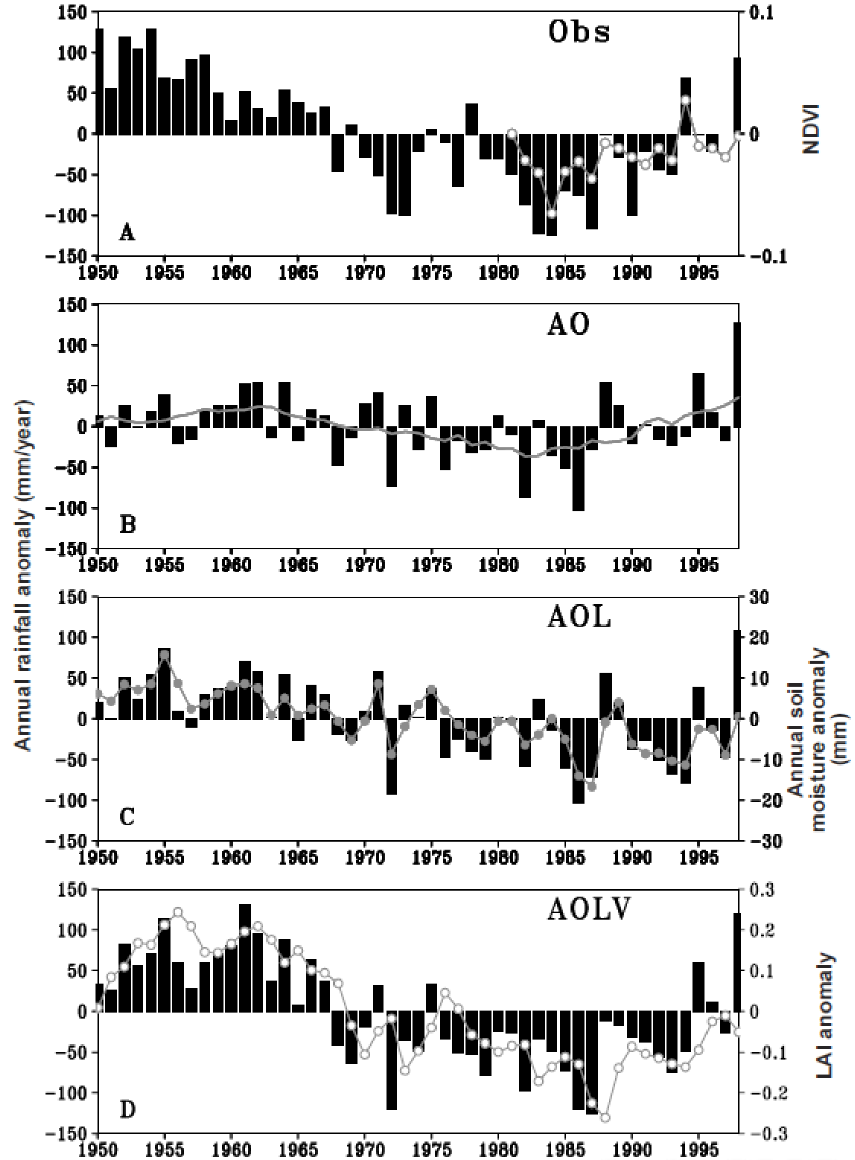


Global Cropland Area



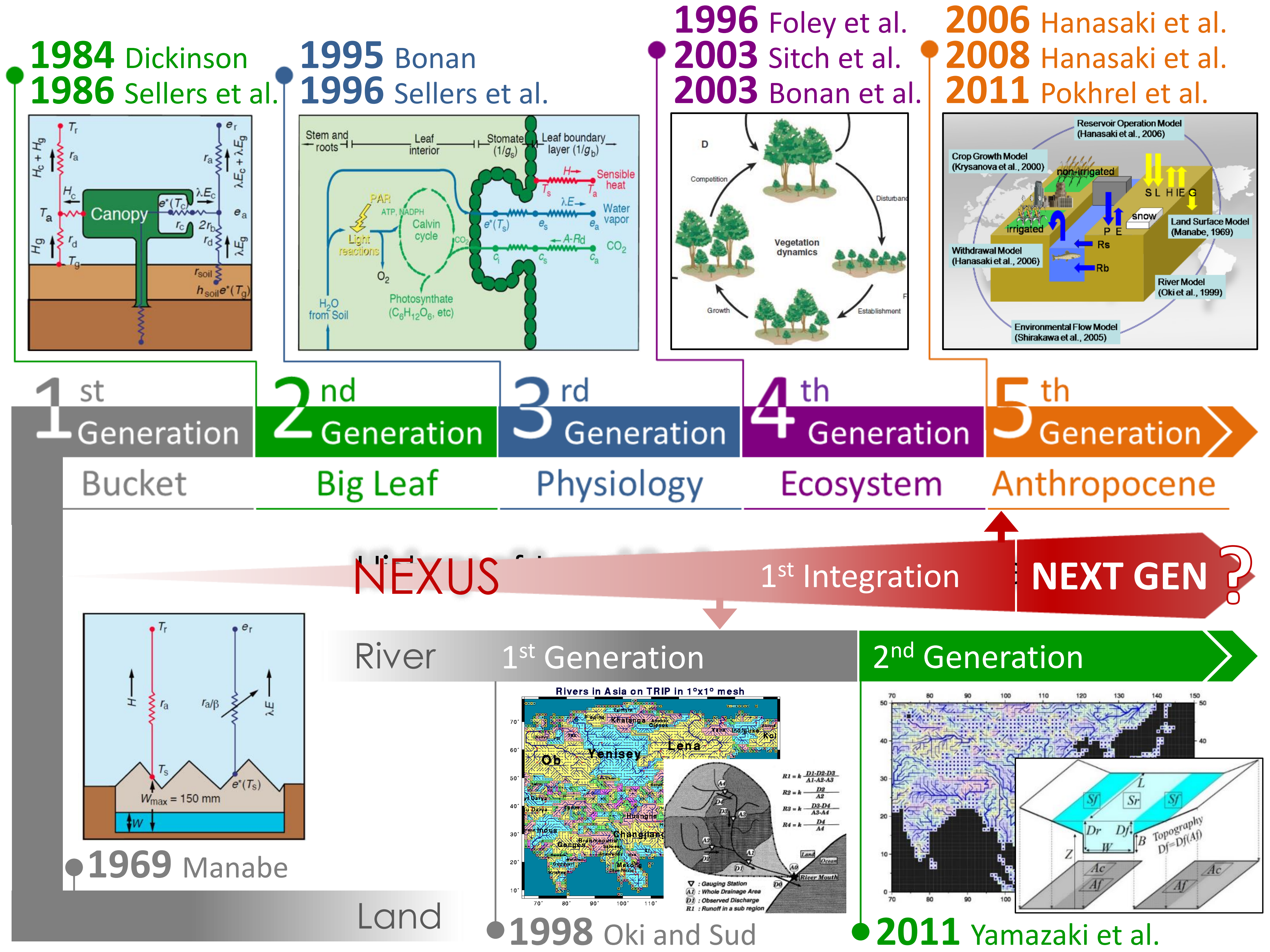
Representation of Interdecadal Climate Variability

& Human Impact?



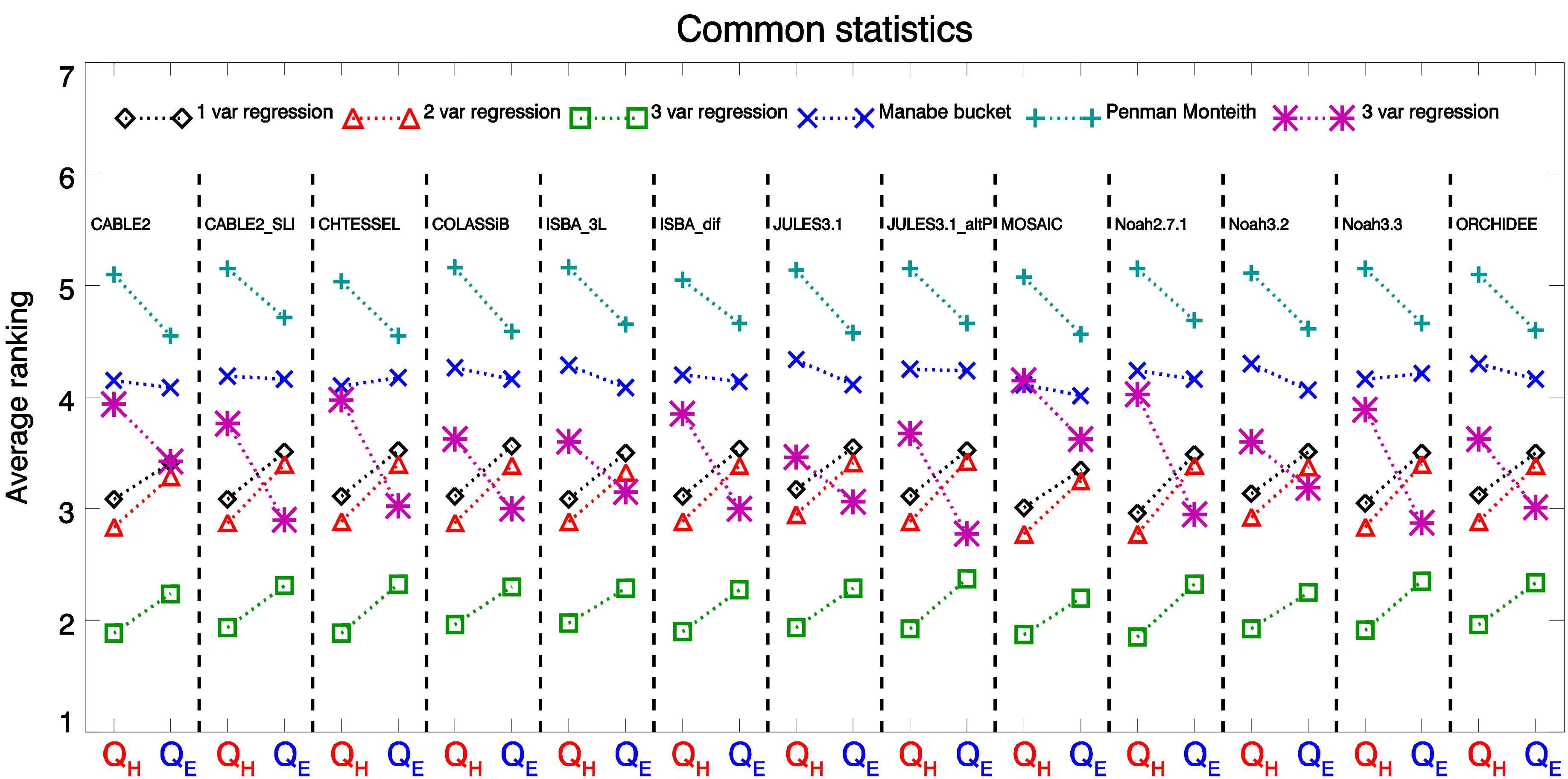
Better representation of precipitation anomaly with **Atmosphere** + **Ocean** + **Soil Moisture** + **Vegetation Interaction**

Zeng et al., 1999



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.
1st Generation
Bucket
2nd Generation
Big Leaf
3rd Generation
Physiology
4th Generation
Ecosystem
5th Generation
Anthropocene
NEXUS
1st Integration
NEXT GEN ?
River 1st Generation
2nd Generation
Rivers in Asia on TRIP in 1°x1° mesh
1969 Manabe
Land
1998 Oki and Sud
2011 Yamazaki et al.
Canopy
Stem and roots
Leaf interior
Stomate
Leaf boundary layer
Sensible heat
Water vapor
Calvin cycle
Light reactions
Photosynthate
Vegetation dynamics
Competition
Growth
Establishment
Reservoir Operation Model (Hanasaki et al., 2006)
Crop Growth Model (Krysanova et al., 2000)
Land Surface Model (Manabe, 1969)
Withdrawal Model (Hanasaki et al., 2006)
River Model (Oki et al., 1999)
Environmental Flow Model (Shirakawa et al., 2005)
non-irrigated
irrigated
snow
W_{max} = 150 mm

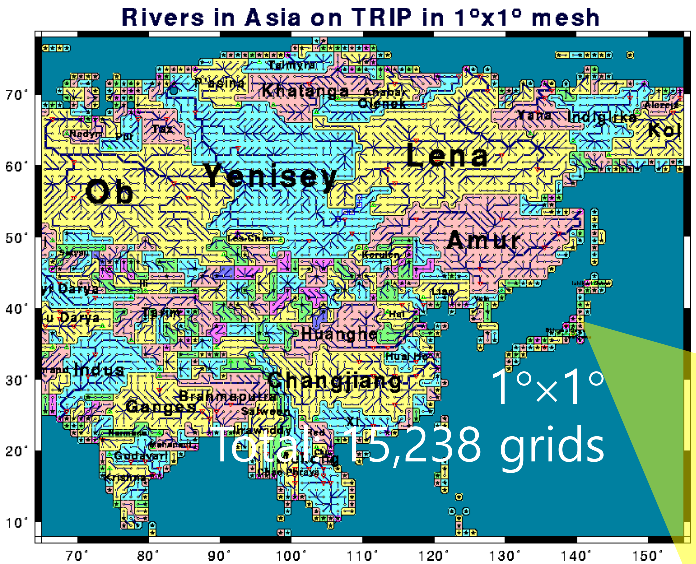
PLUMBER: PALS Land sUrface Model Benchmarking Evaluation pRoject

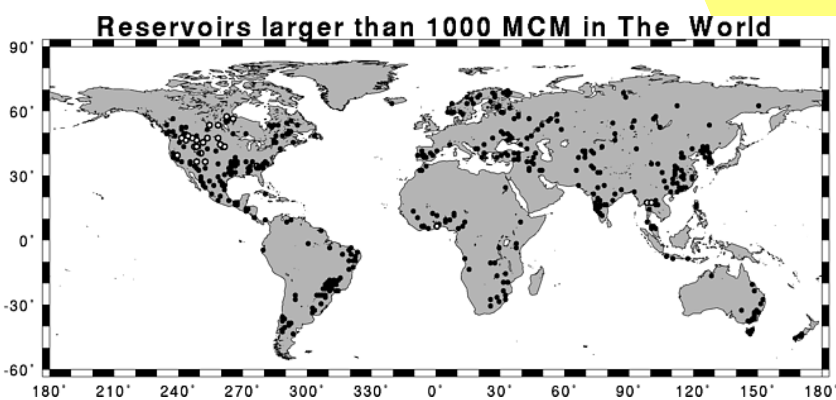


Best et al., (2015) JHM

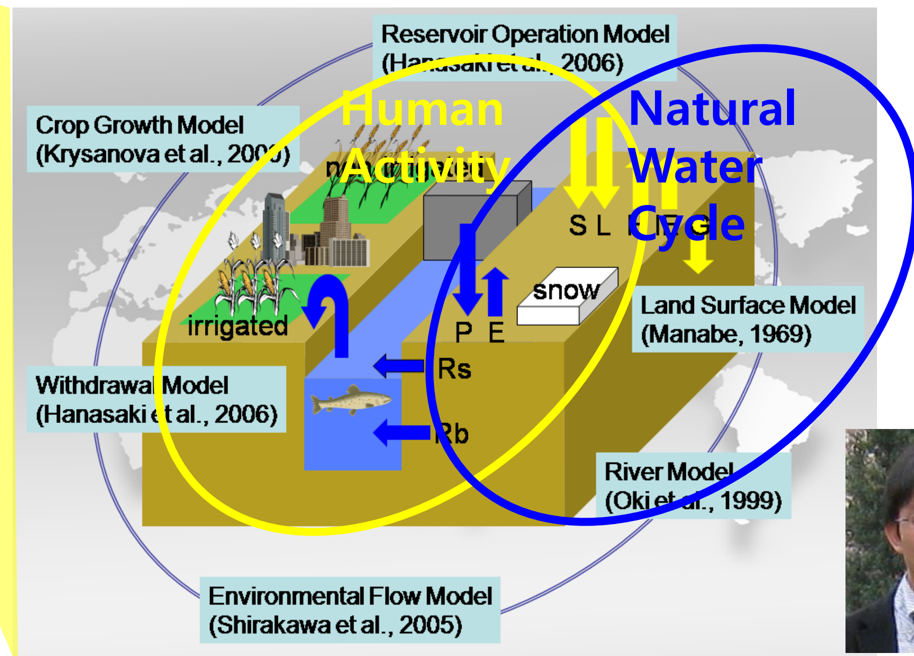
Representation of Anthropogenic Impact

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





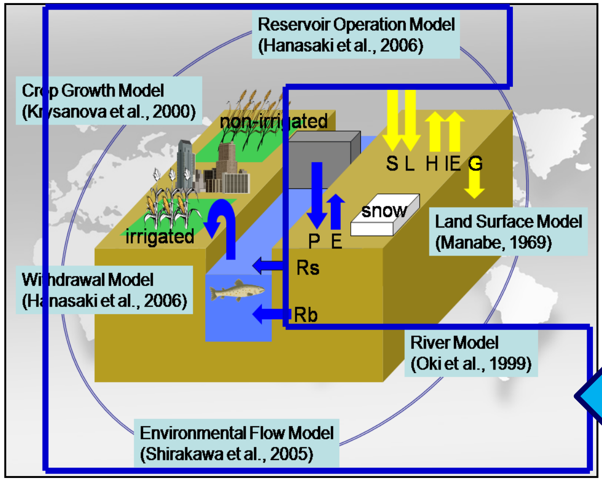
452 reservoirs, 4140 km^3

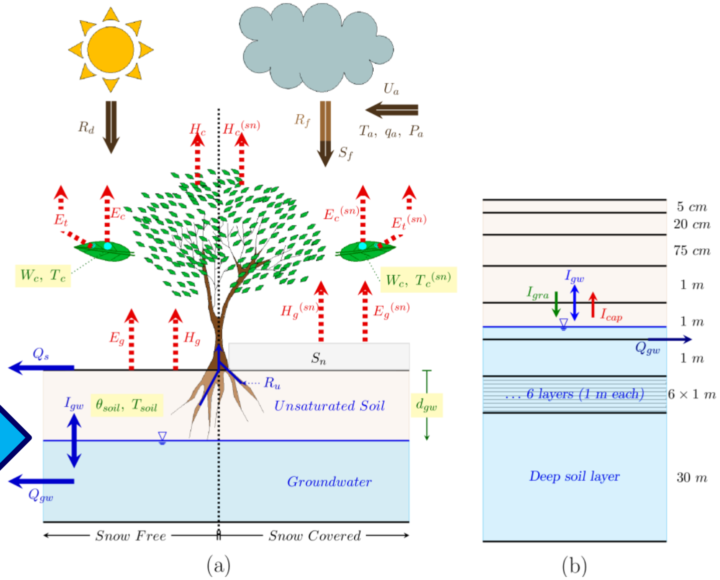


Hanasaki et al., 2006, 2008

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.

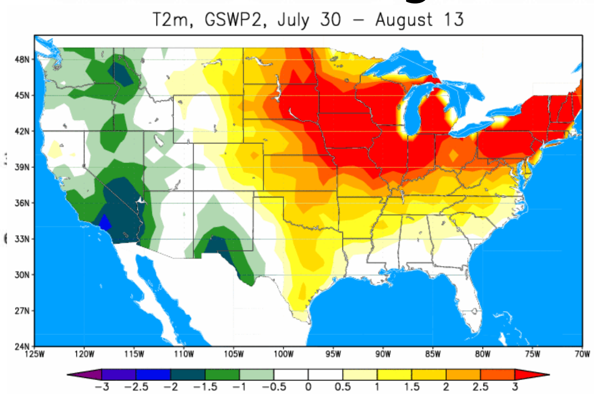
- ✓ Land surface hydrology scheme is a simple **Bucket Model**
- ✓ **Vegetation** : accounted implicitly

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

Pokhrel, Kim et al., 2012

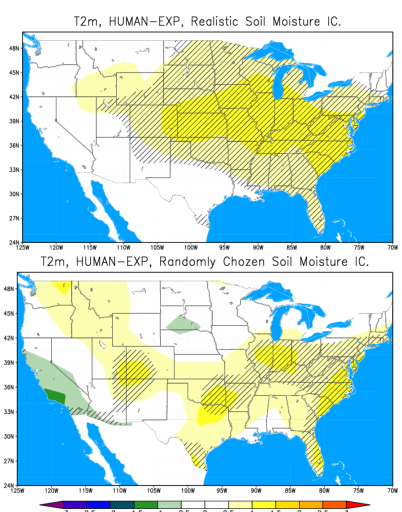
Land-atmosphere Interaction in a Global Climate Model in Association with Human Activities

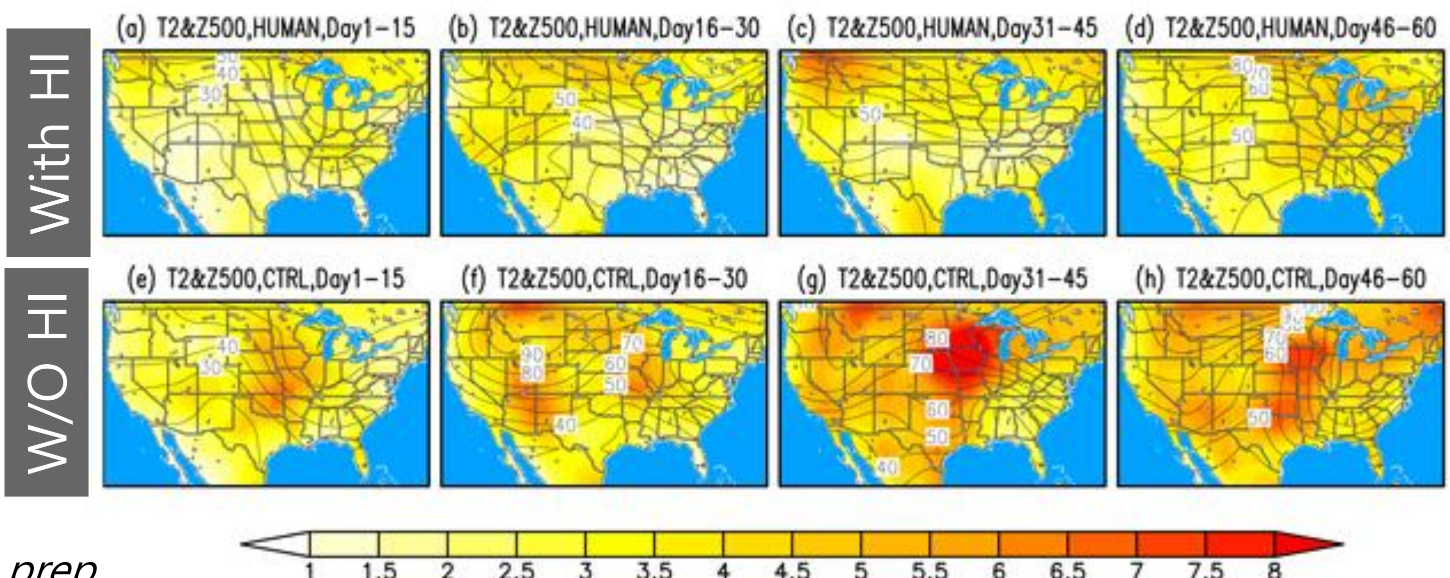
+ Spread of near surface temperature (2m Tair) among ensemble members becomes smaller by incorporating surface water-groundwater-human models in the AGCM.



+ 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.

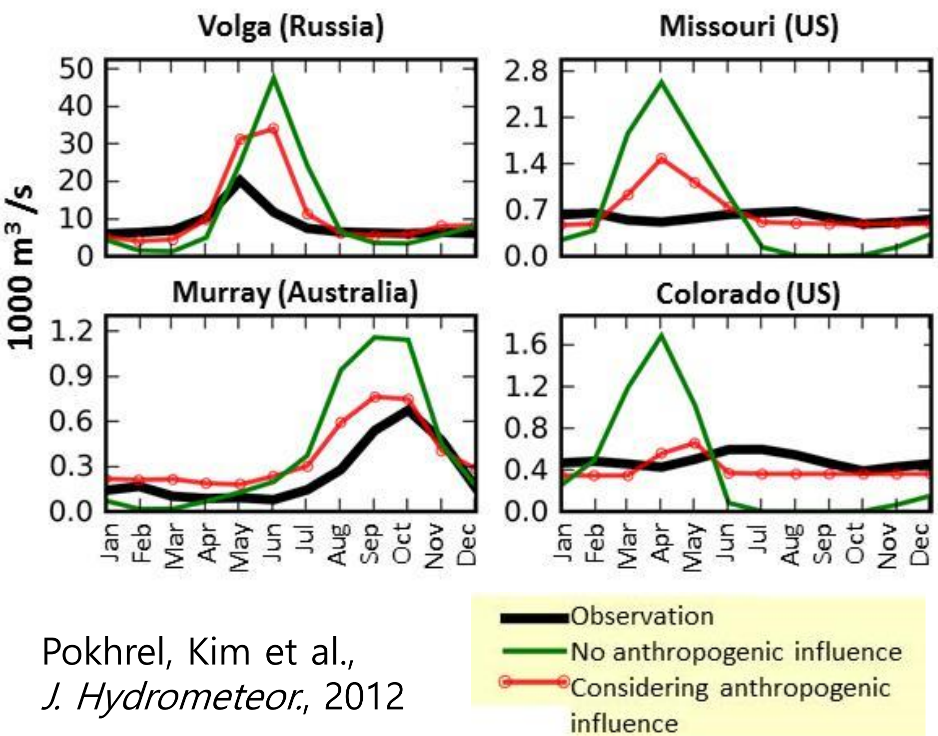
HiGW-MAT – Pokhrel et al., JHM, 2011



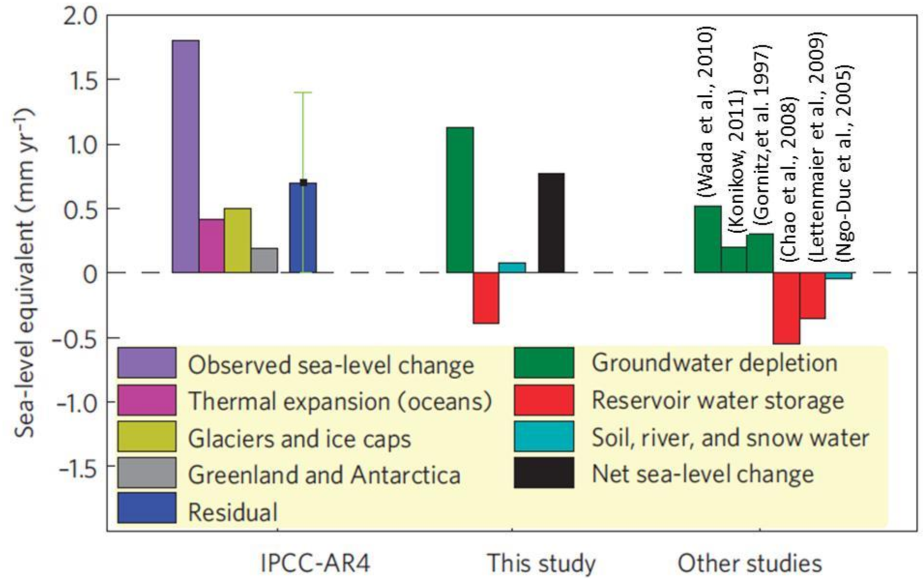


Yamada et al., in prep.

Representation of Anthropogenic Impact



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



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

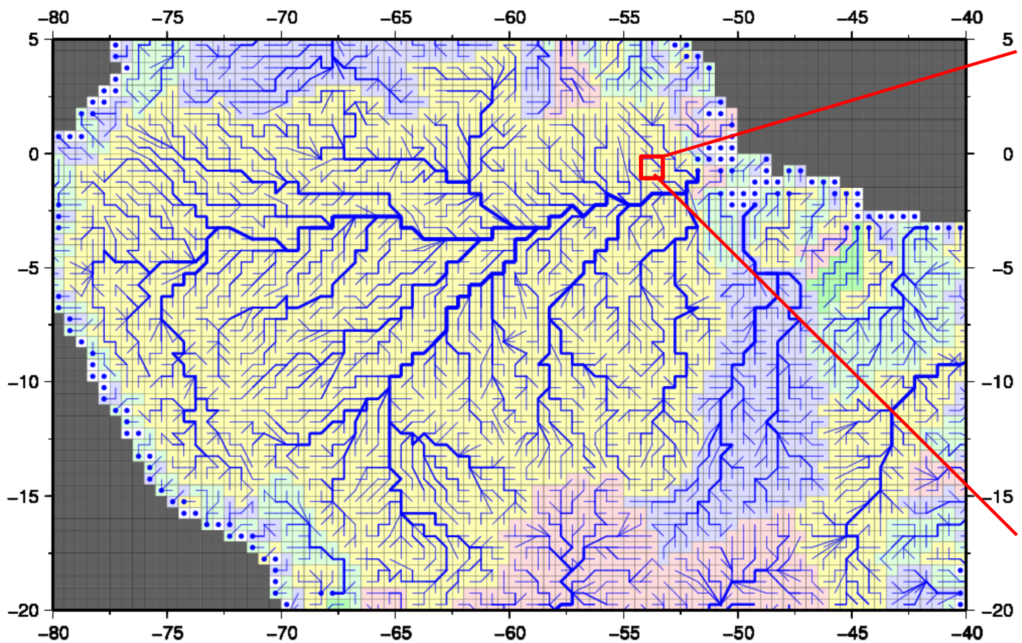
Anthropogenic influence on natural water cycles is better reflected with additional model components reproducing human-induced alterations, which lead the improved simulation of river discharge by the models.

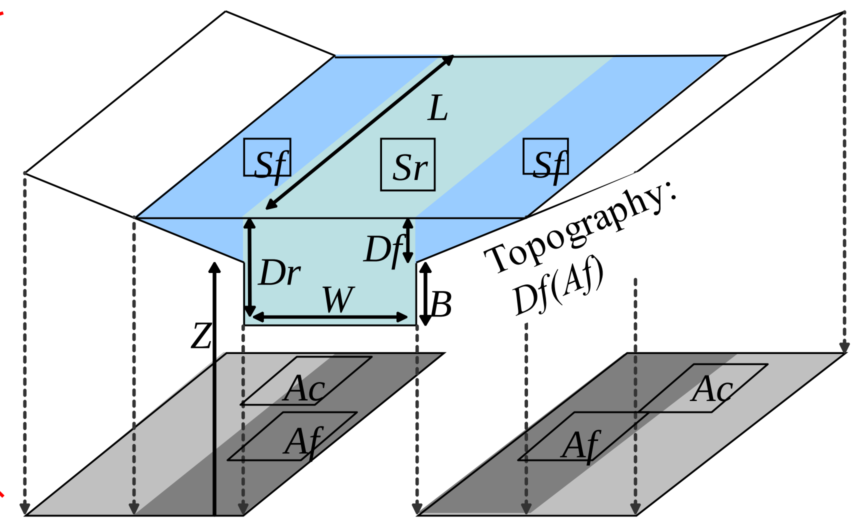
Estimated terrestrial water storage changes (1961-2003) indicate the largest contribution of the unsustainable groundwater use to net sea-level change.

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

CaMa-Flood (**Ca**tchment-based **Ma**cro-scale **Flood**plain 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)





Yamazaki, Kim et al, 2011

T-CHOIR

Tightly Coupling framework for Hydrology of Open water Interactions in River–lake network

[Tokuda, Kim, Yamazaki, and Oki, GMD, 2021]

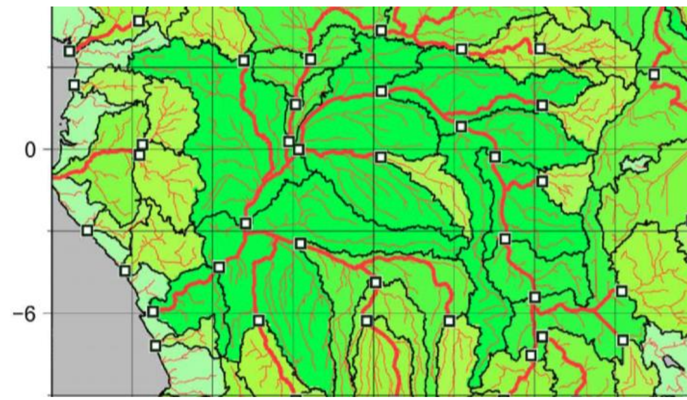
Global river water temperature model

HEAT-LINK (Heat Exchange and AdvecTion with fLood and Ice NumeriKs)

[Tokuda, Kim et al., 2019]

River routing model, CaMa-Flood [Yamazaki et al., 2011; 2013]

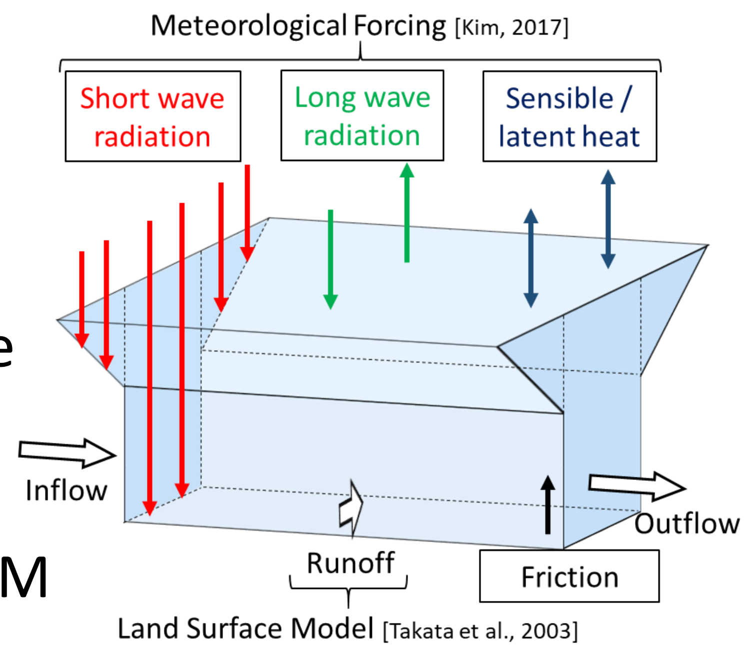
- Land area is divided into unit-catchments
- Calculate discharge [Bates et al., 2010]
- Represent floodplain inundation
- Input data: runoff [Kim et al. 2009]



[Yamazaki, Kim et al., 2011]

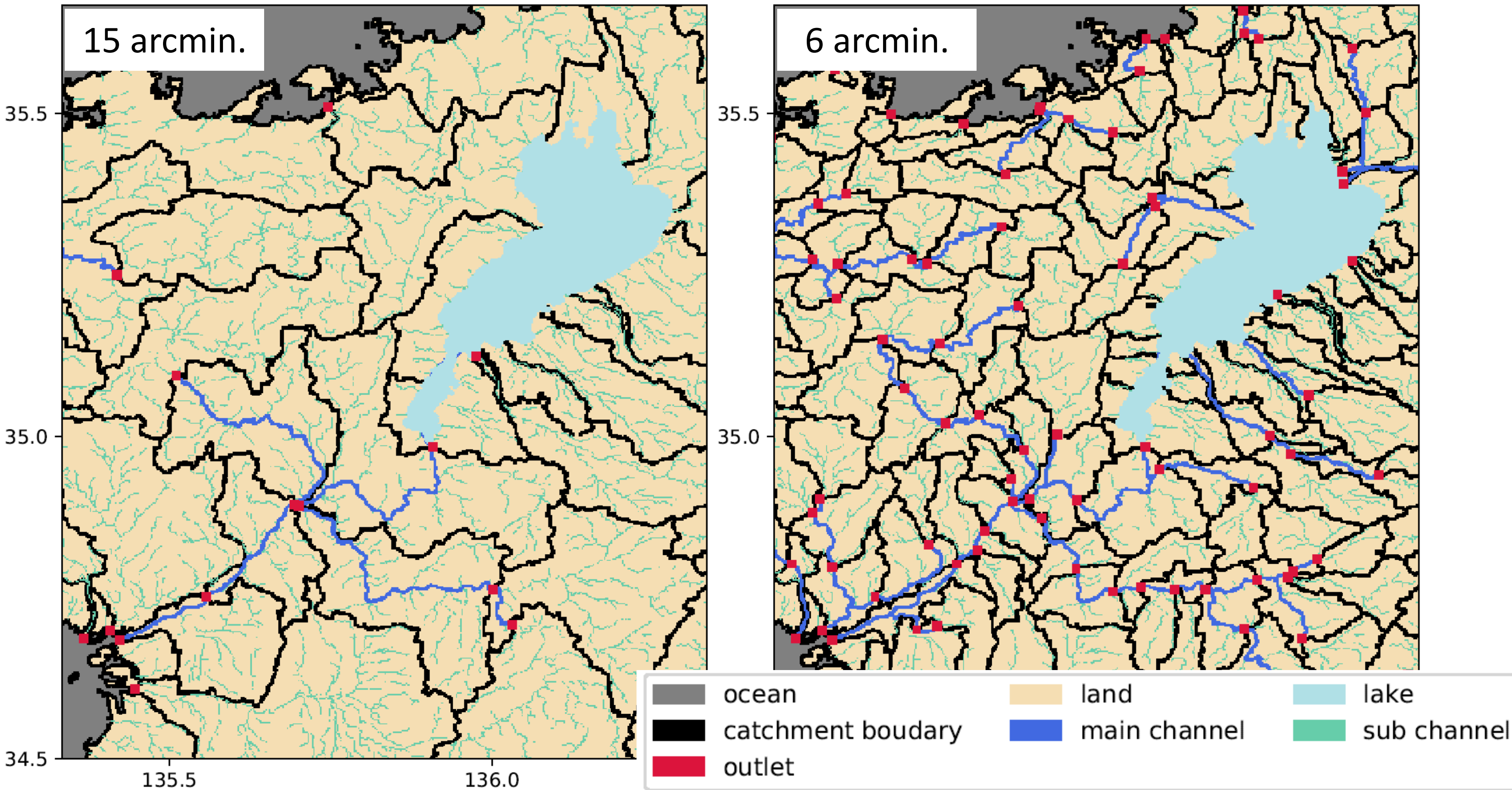
Heat budget

- Advective heat/ice transport
- Local (vertical) energy budget
  - heat fluxes, runoff
  - Mass & energy budget of water & ice
- Input data
  - Meteorological forcing data
  - Runoff temperature calculated by LSM [Takata et al., 2003]



River-lake network

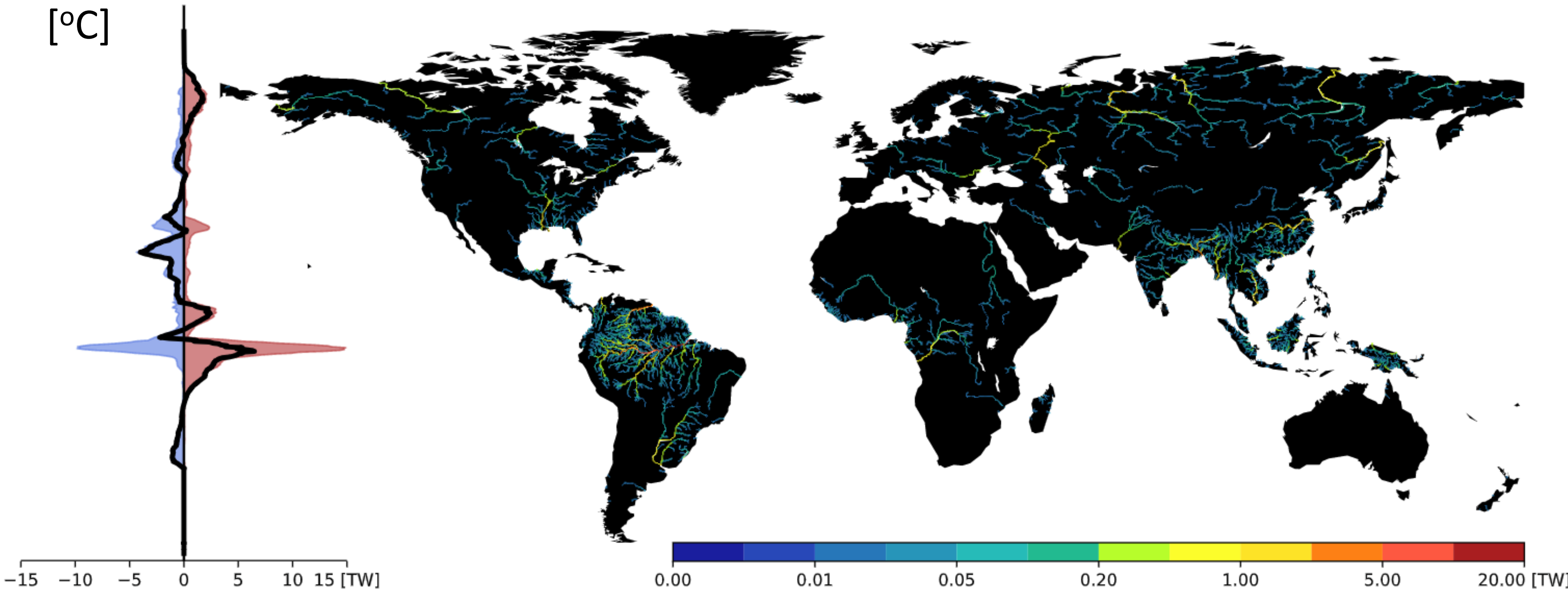
Example (Lake Biwa & Yodo River basin)



- Validated with reported upstream area of reservoirs (Correlation = .9992)
- Grid boundary matches with lake outlet
  => easy to couple with reservoir operation model

Riverine energy transport [Tokuda, Kim et al., in rev.]

Thermal discharge [W]
＝Heat capacity [J/kg°C] × Density [kg/m³] × Discharge [m³/s] × Temperature [°C]

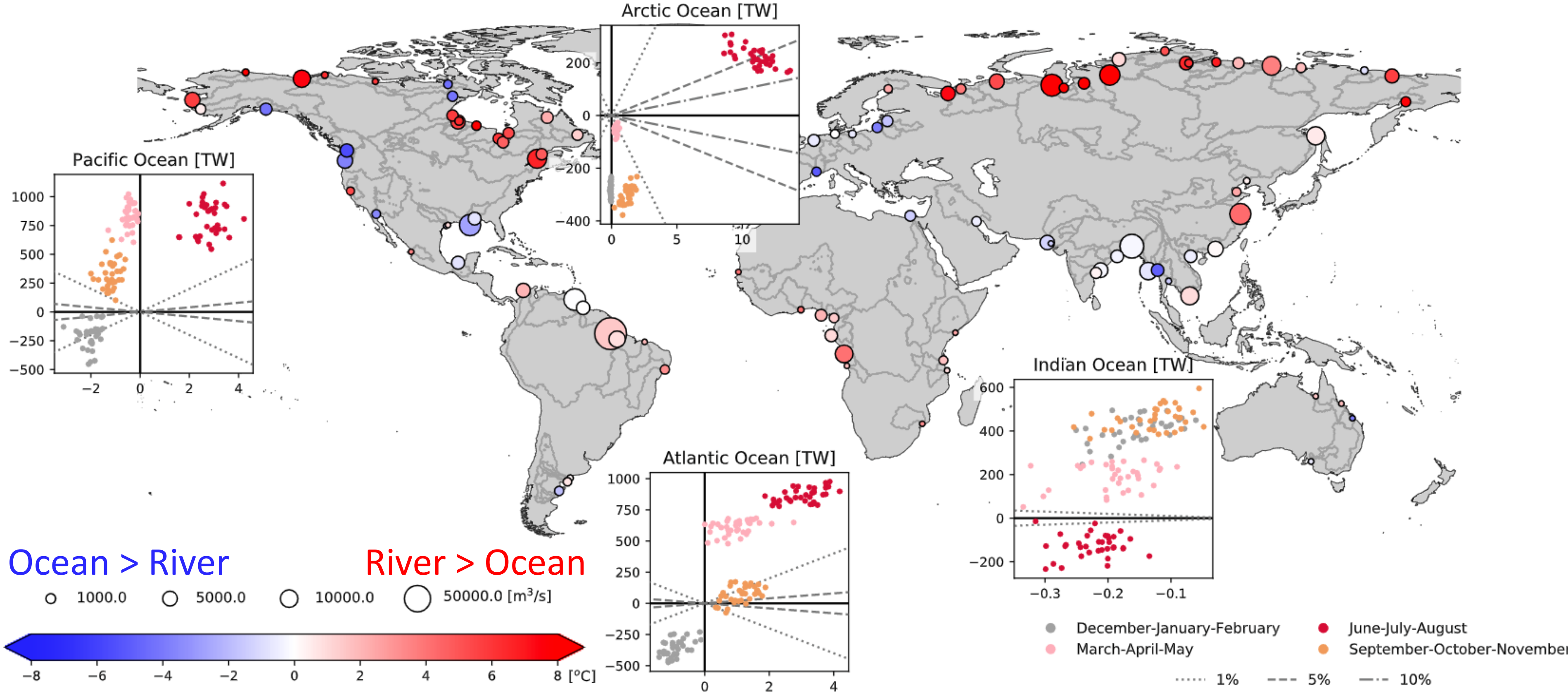


Meridional pattern is different from that of the ocean

- 60°N: Arctic Rivers from South to North
- 25°N: Ganges-Brahmaputra-Meghna and Mekong rivers
- Equator: Amazon River

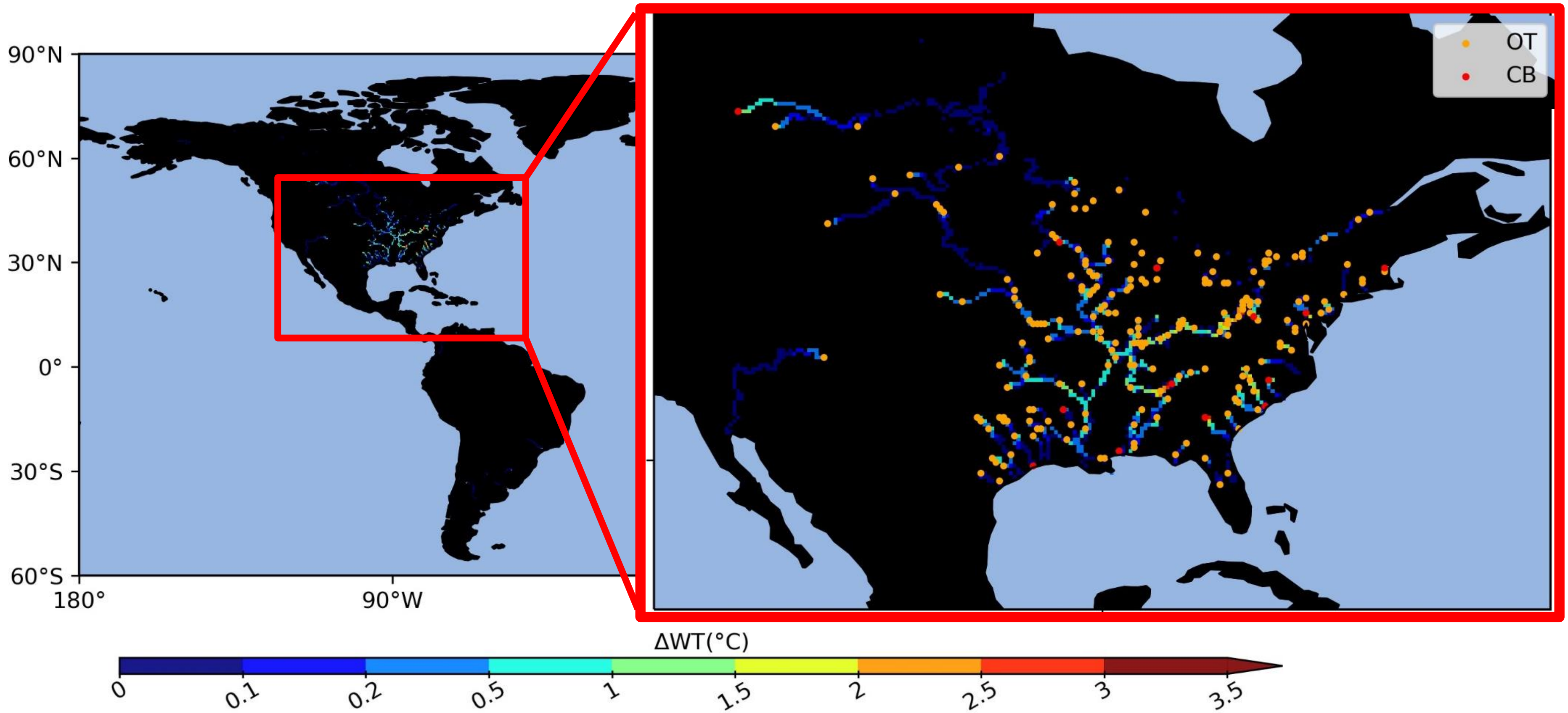
Riverine energy transport [Tokuda, Kim et al., in rev.]

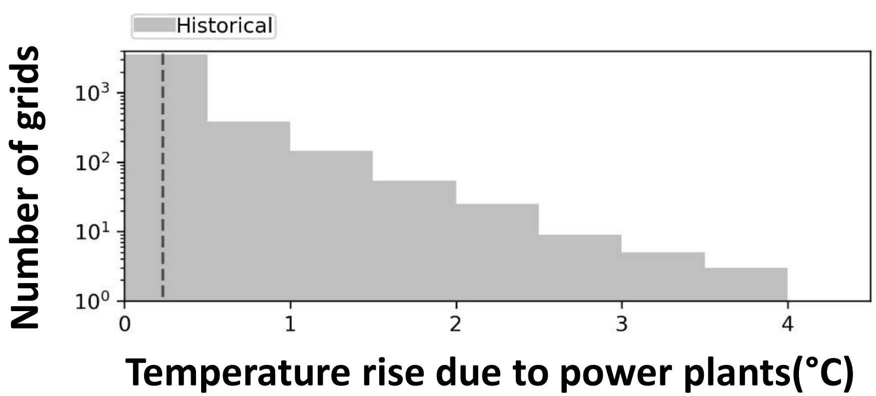
Temperature difference between river and coastal waters at mouths



- Part of the energy reaches to Arctic Ocean
- Scatter: heat budget of coastal waters (~200km)
  - horizontal: net contribution of rivers = T. dif. × Discharge
  - vertical: vertical heat budget in SODA3-JRA55 [Carton et al., 2018]

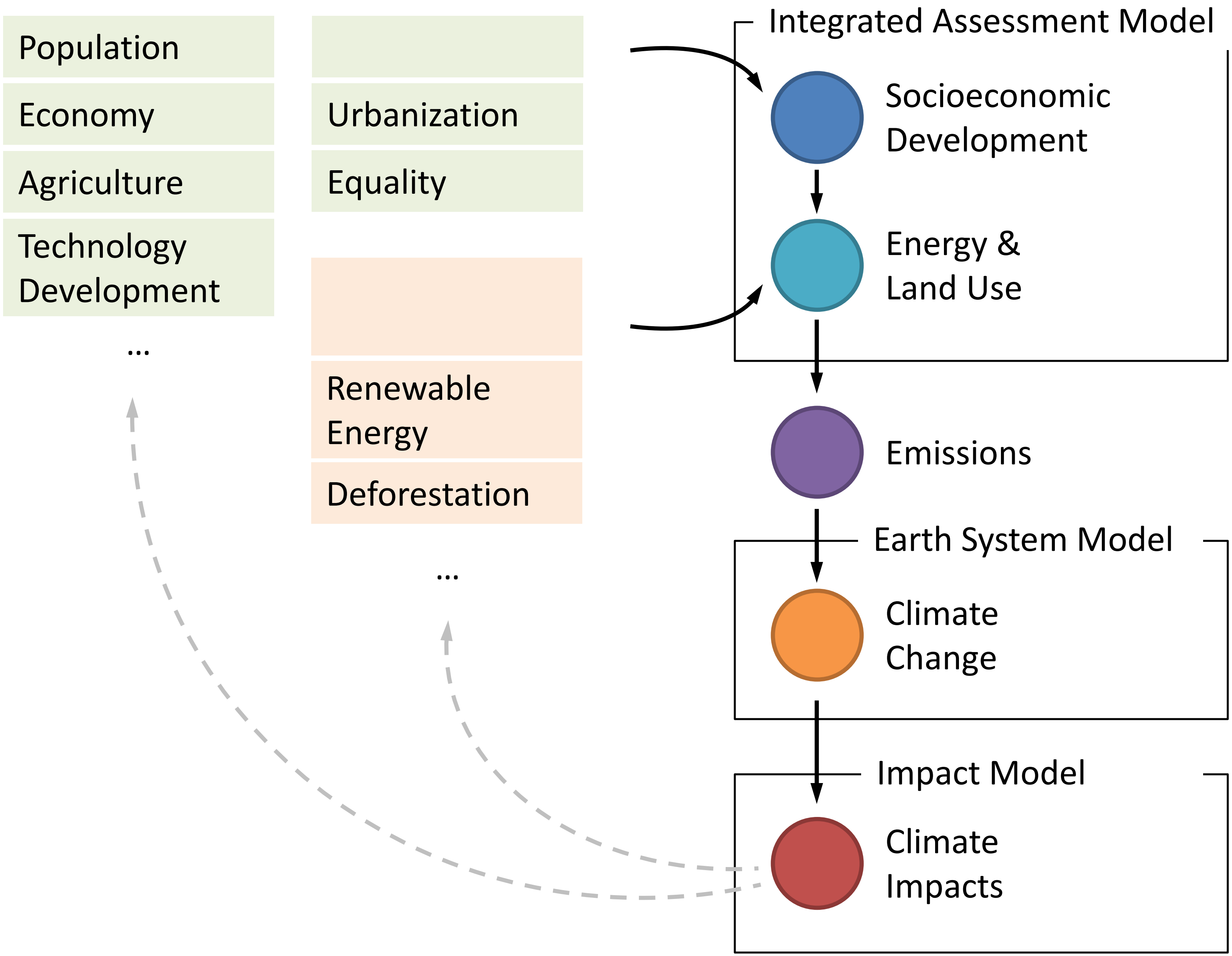
Temperature Rise Due to TPP Cooling: T_{PP}-T_{noPP}



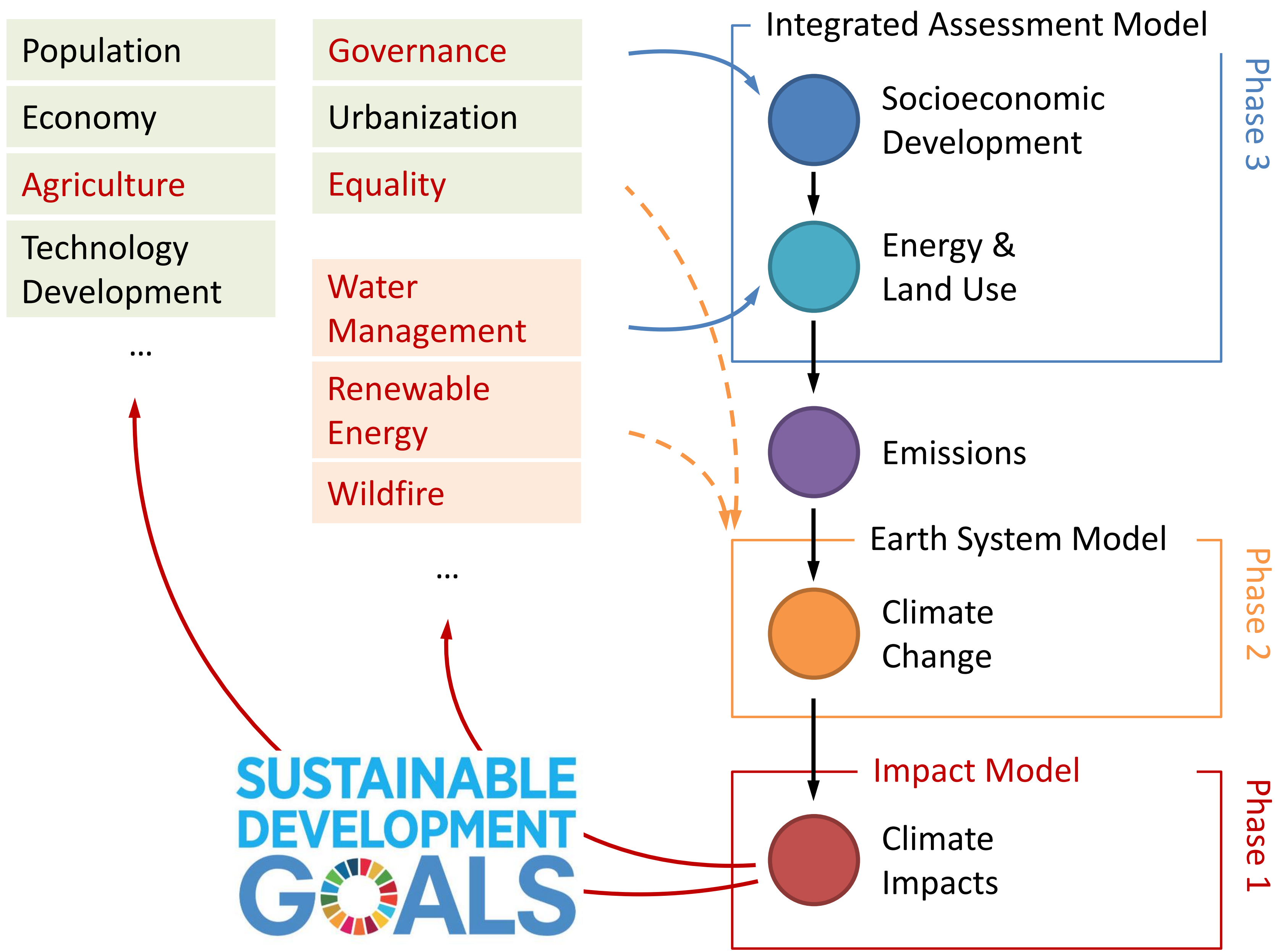


+ Temp. increases due to TPP cooling travels to downstream area.
+ Such impacts are piled up within river basin networs.

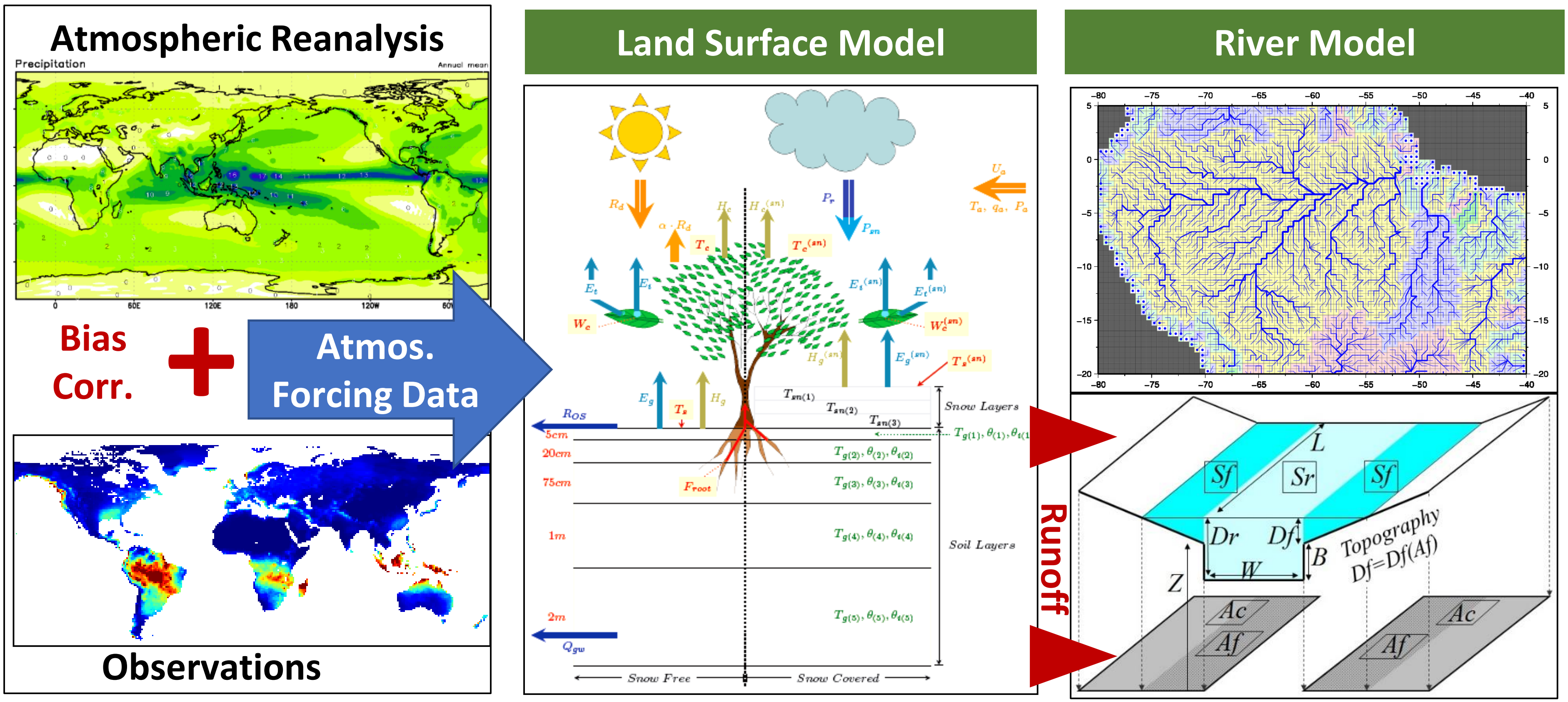
Status quo of Future Projection



Integrated Framework for “Adaptive Pathways”

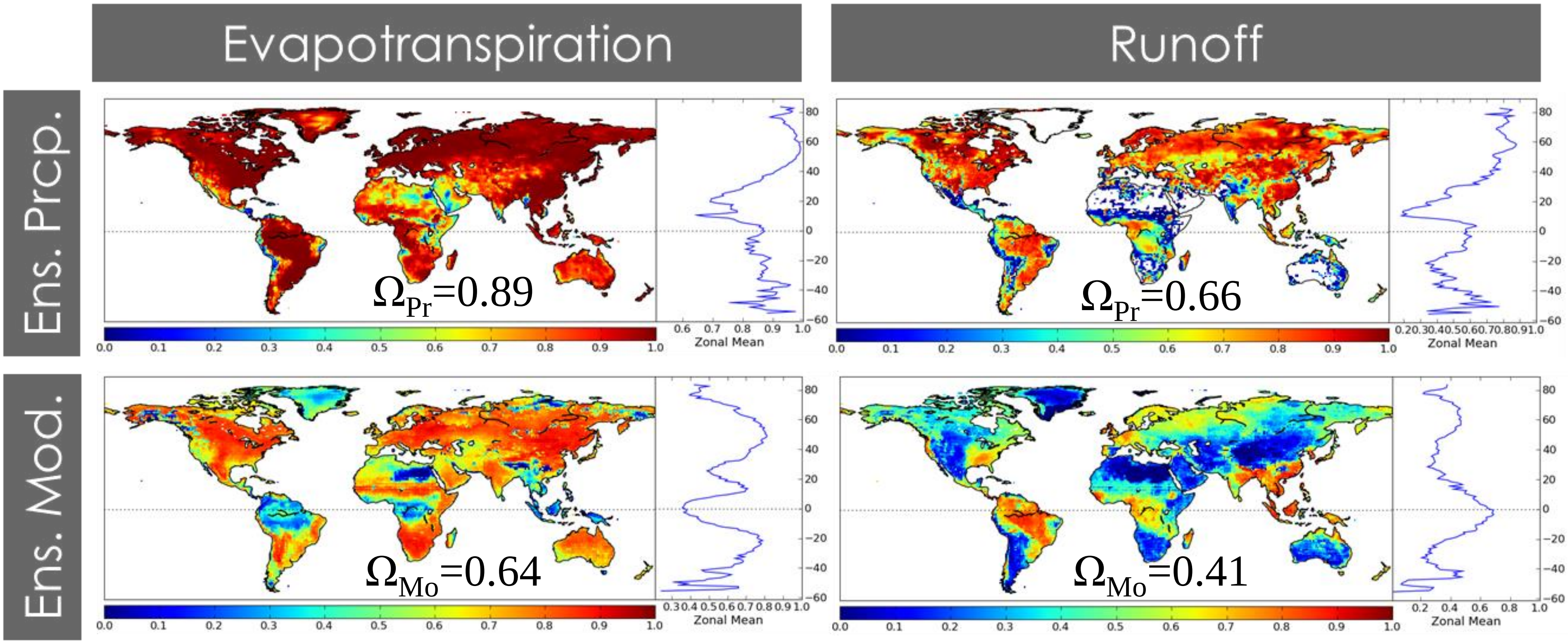


Off-line Framework for Large-scale Land Simulation



Evaluation / Benchmarking System for Model Simulations and Input Data

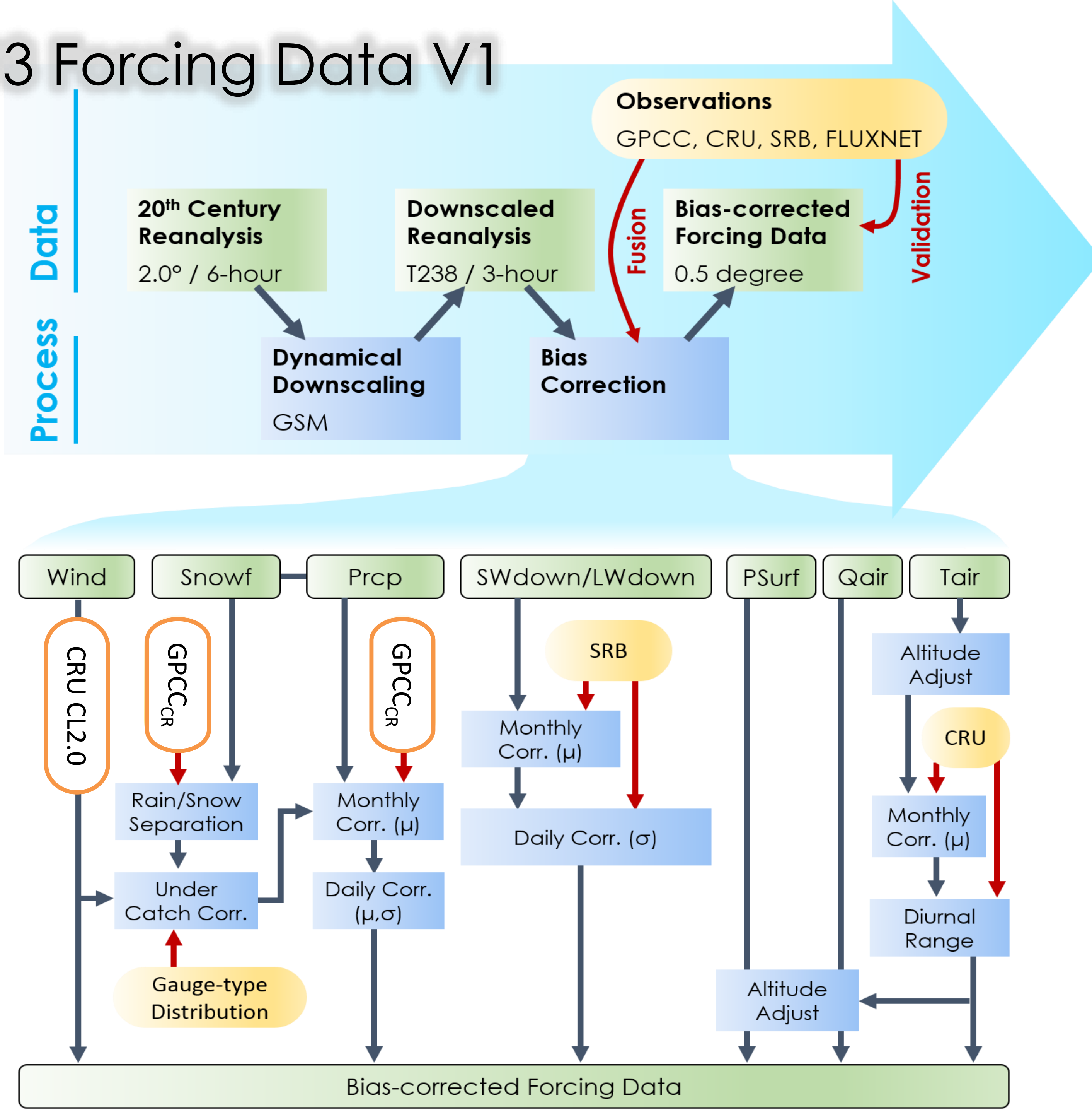
Simulation Uncertainty – model vs input data –



Kim, 2010

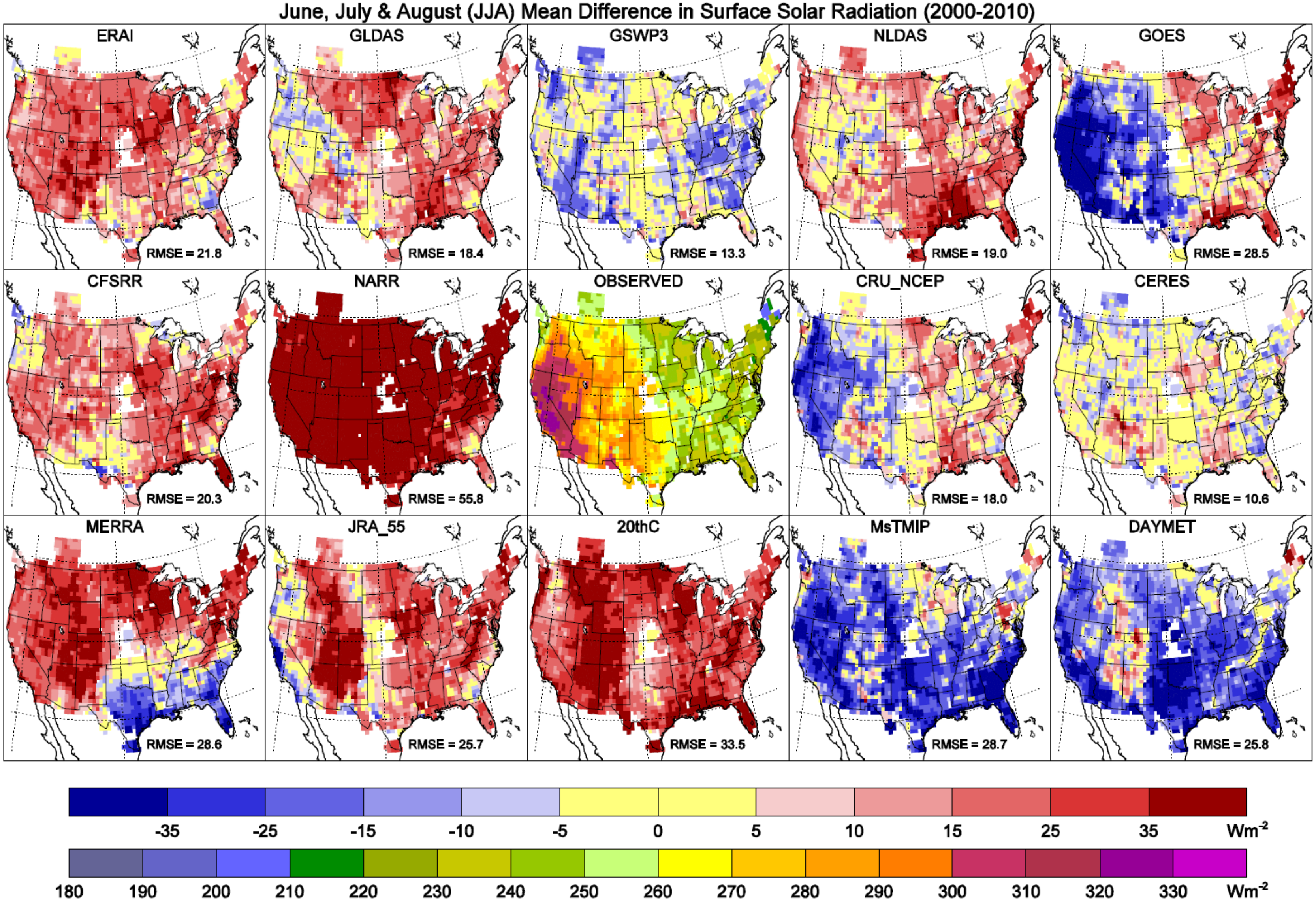
Uncertainty in simulated evapotranspiration and runoff introduced by different land surface schemes in GSWP2 are larger than precipitation uncertainty-induced uncertainty by 28% and 40% in the similarity index (Ω) globally.

GSWP3 Forcing Data V1



Preliminary Results and Known Problems

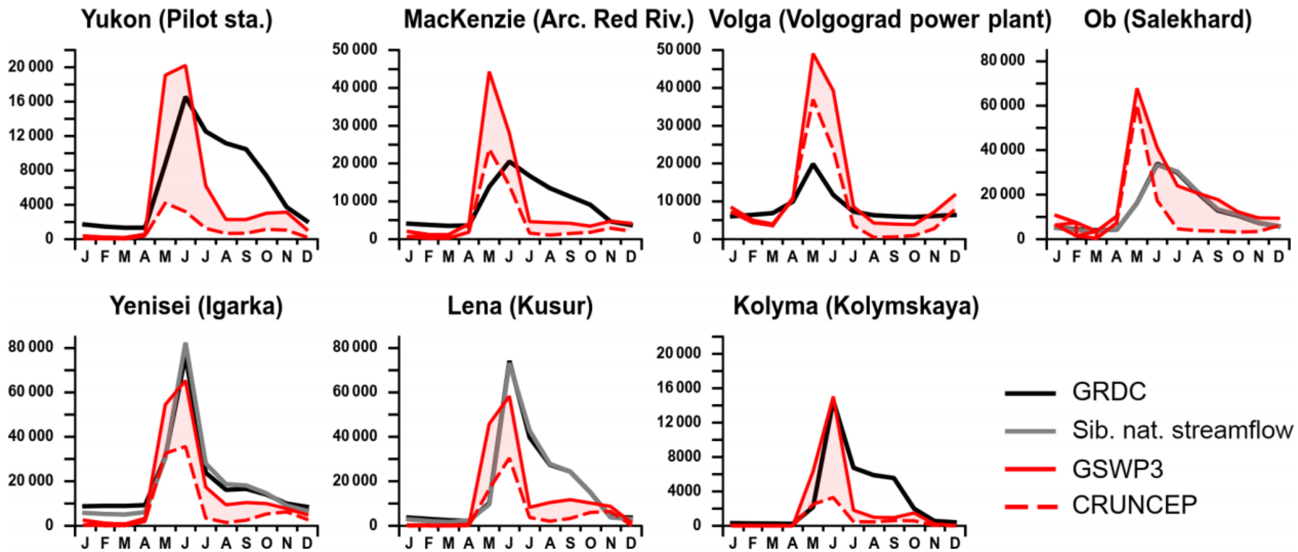
+ Relatively small bias of solar radiation

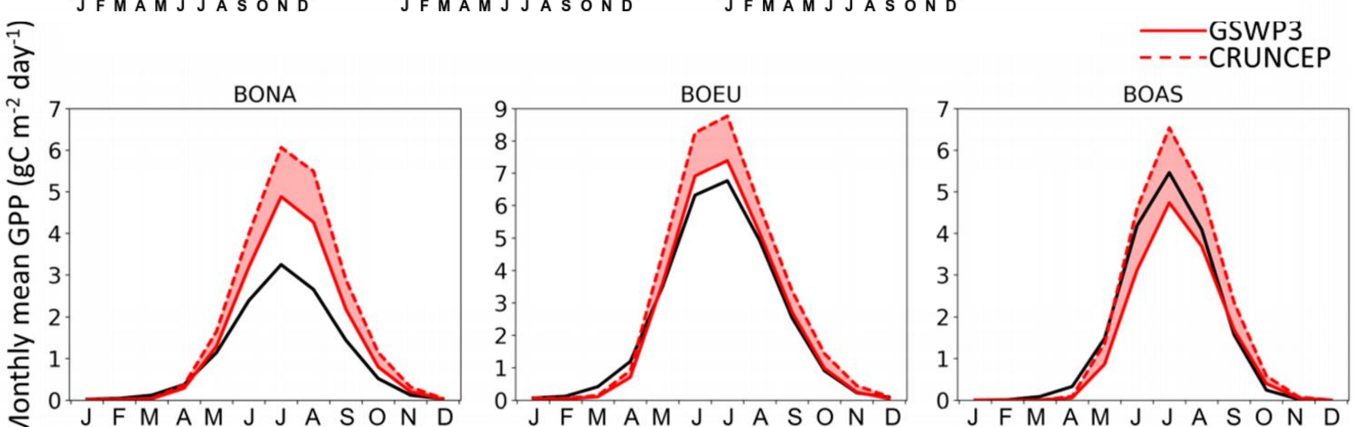


Slater, 2015

ORCHIDEE-MICT (v8.4.1), a land surface model for the high latitudes: model description and validation

Matthieu Guimberteau[1,*], Dan Zhu[1,*], Fabienne Maignan[1], Ye Huang[1], Chao Yue[1], Sarah Dantec-Nédélec[1], Catherine Ottlé[1], Albert Jornet-Puig[1], Ana Bastos[1], Pierre Laurent[1], Daniel Goll[1], Simon Bowring[1], Jinfeng Chang[2], Bertrand Guenet[1], Marwa Tifafi[1], Shushi Peng[3], Gerhard Krinner[4], Agnès Ducharne[5], Fuxing Wang[6], Tao Wang[7,8], Xuhui Wang[1,9], Yilong Wang[1], Zun Yin[1], Ronny Lauerwald[10,1,11], Emilie Joetzjer[1,12], Chunjing Qiu[1], Hyungjun Kim[13], and Philippe Ciais[1]





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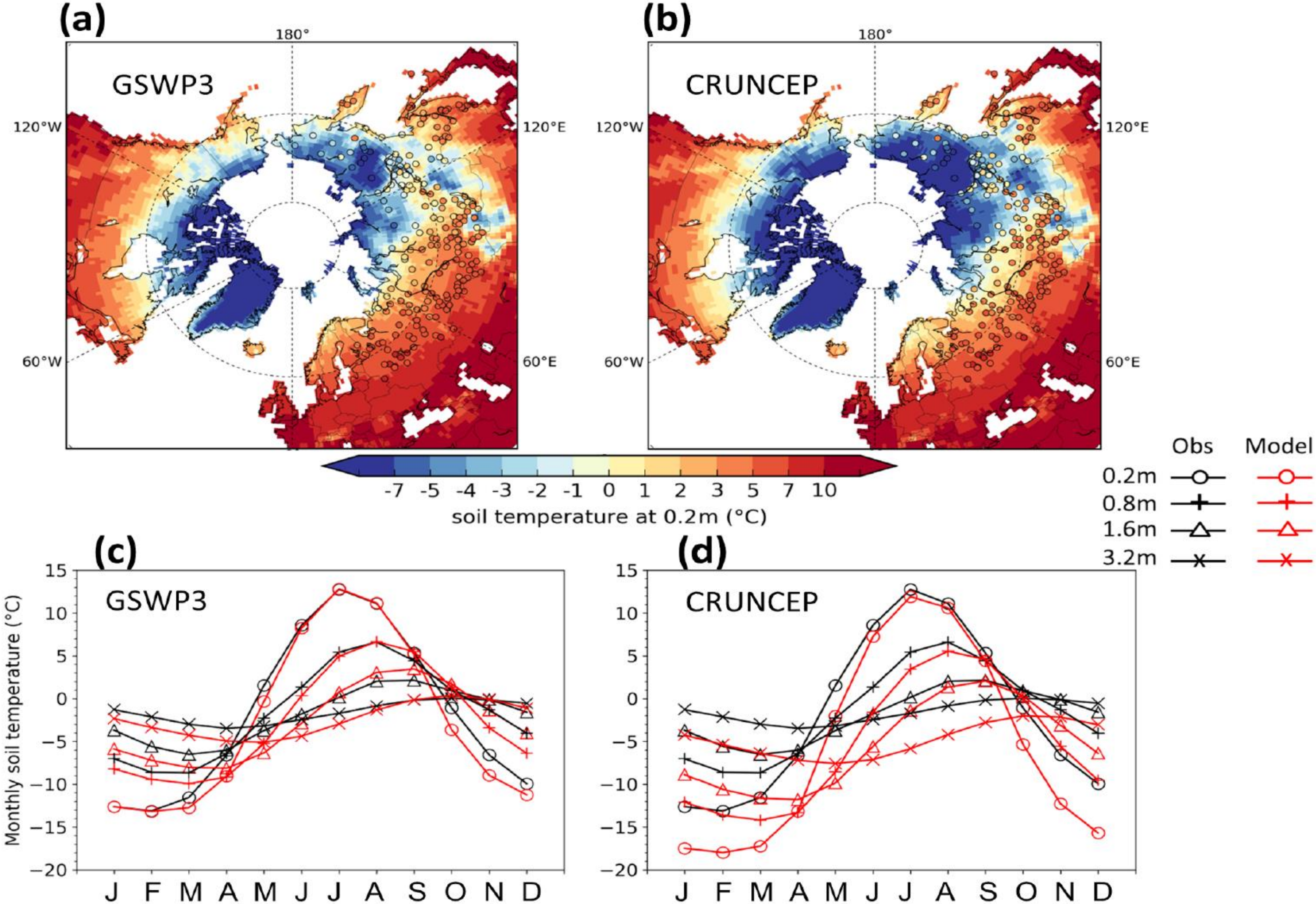


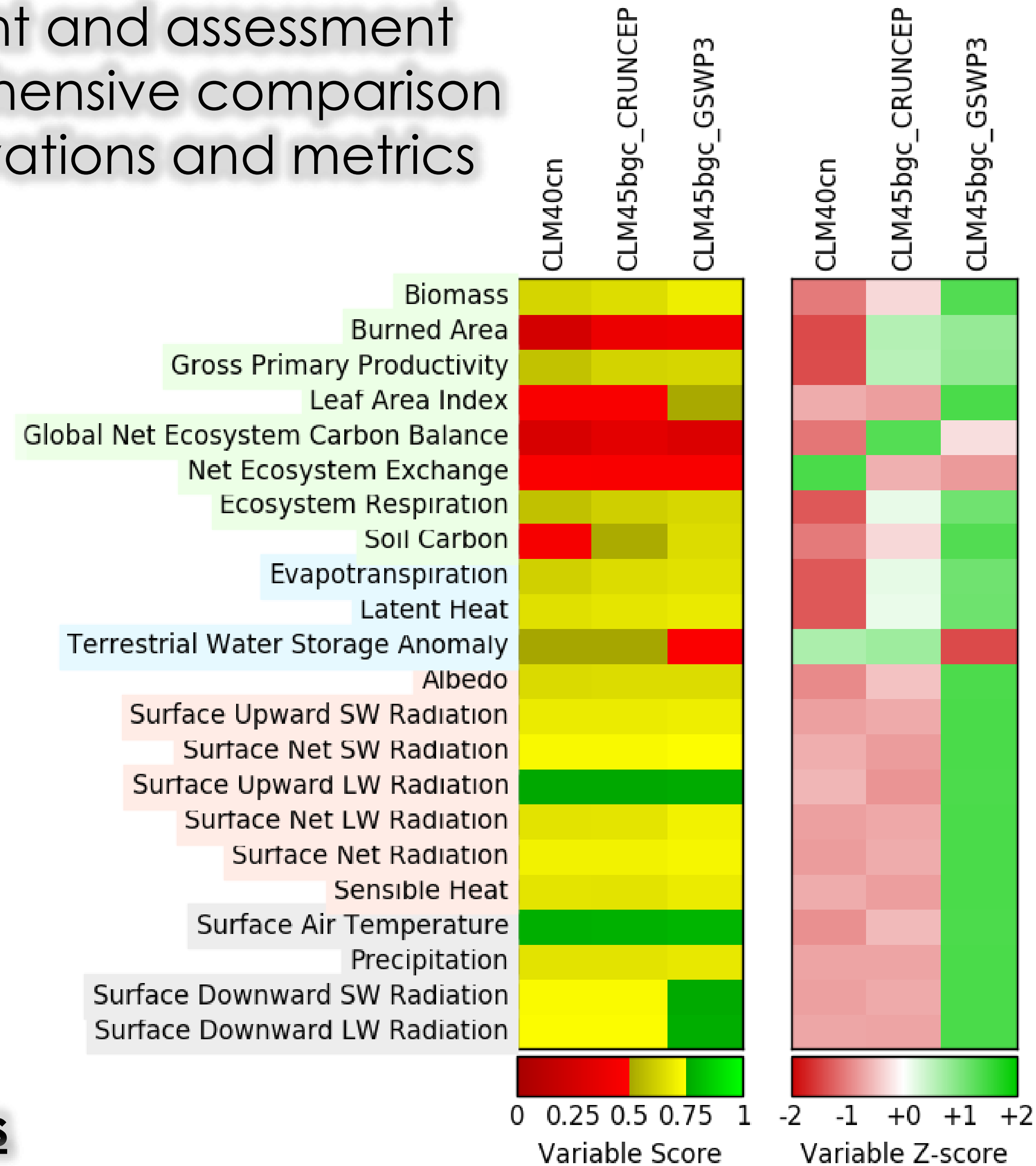
Guimberteau et al. 2015

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, CO2, 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, SWup, SWnet, LWup, LWnet, Rnet
* Forcing (5): Tair, precipitation, RH, SWdown, LWdown

<ins>**Integrates 25 variables in 4 categories from ~60 datasets**</ins>




Thank you