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 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.)
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
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, ...
Representation of Interdecadal Climate Variability & Human Impact?

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

Zeng et al., 1999
History of Land Surface Model Development

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

1st Integration
- NEXUS

NEXT GEN

Rivers

1st Generation
- 1969 Manabe

2nd Generation
- 1998 Oki and Sud

- 2011 Yamazaki et al.
Common statistics

Best et al., (2015) JHM
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

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.

✓ 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**

Water table dynamics
(Yeh and Eltahir, 2005)
Pumping scheme
Koirala et al.

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.
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** (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)
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]

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 \[W\]  
\[= \text{Heat capacity \}[J/\text{kg}^\circ\text{C}] \times \text{Density \}[\text{kg/m}^3] \times \text{Discharge \}[\text{m}^3/\text{s}] \times \text{Temperature \}[\circ\text{C}]\]

Meridional pattern is different from that of the ocean

- \(60^\circ\text{N}:\) Arctic Rivers from South to North
- \(25^\circ\text{N}:\) 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 $\propto$ T. dif. $\times$ Discharge
  - vertical: vertical heat budget in SODA3-JRA55 [Carton et al., 2018]
Temperature Rise Due to TPP Cooling: $T_{PP} - T_{noPP}$

Temperature rise due to power plants ($°C$)

Number of grids

+ Temp. increases due to TPP cooling travels to downstream area.
+ Such impacts are piled up within river basin networks.
Status quo of Future Projection

- Population
- Economy
- Agriculture
- Technology Development
- ... (omitted)

- Urbanization
- Equality

- Renewable Energy
- Deforestation
- ... (omitted)

Integrated Assessment Model

- Socioeconomic Development
- Energy & Land Use

Earth System Model

- Emissions
- Climate Change

Impact Model

- Climate Impacts
Integrated Framework for “Adaptive Pathways”

- Population
- Economy
- Agriculture
- Technology Development
- Governance
- Urbanization
- Equality
- Water Management
- Renewable Energy
- Wildfire

Integrated Assessment Model
- Socioeconomic Development
- Energy & Land Use
- Emissions
- Earth System Model
  - Climate Change
  - Impact Model
    - Climate Impacts

SUSTAINABLE DEVELOPMENT GOALS
Off-line Framework for Large-scale Land Simulation

Atmospheric Reanalysis

Land Surface Model

River Model

Observations

Atmos. Forcing Data

Bias Corr. +

Evaluation / Benchmarking System for Model Simulations and Input Data
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.

Kim, 2010
Preliminary Results and Known Problems

+ Relatively small bias of solar radiation
ORCHIDEE-MICT (v8.4.1), a land surface model for the high latitudes: model description and validation

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

Integrates 25 variables in 4 categories from ~60 datasets
Thank you