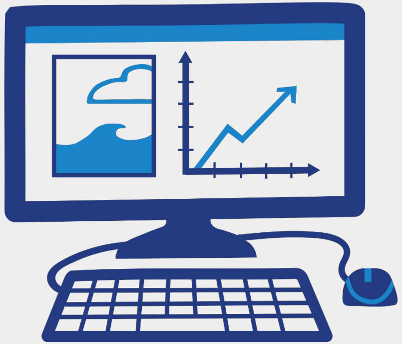
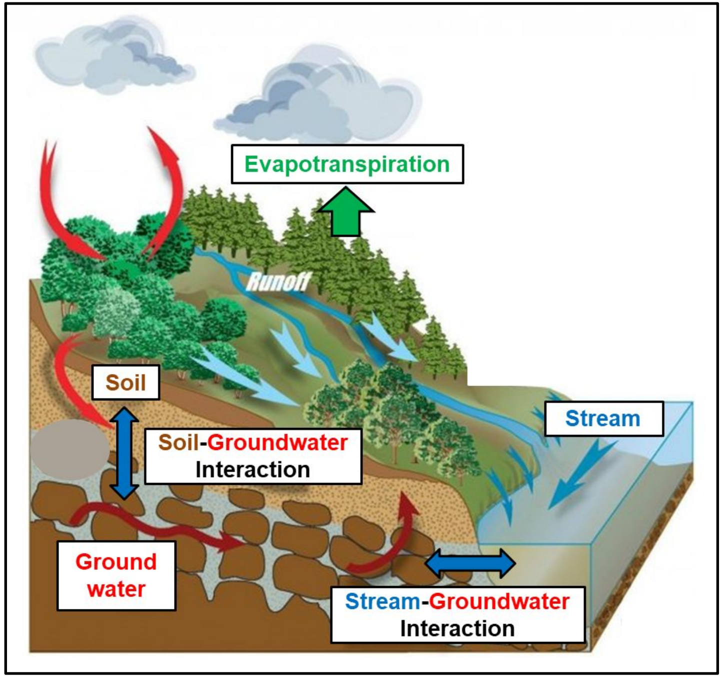


Next-Generation NOAA water modeling: Climate Risks & Interactive Sub-seasonal to Seasonal PredictabilitY (CRISSPY) in the ESM framework (BIL)

Anthony Preucil and Land Modeling Team

Q1: Concerning GFDL's core strength of building and improving models of the weather, oceans, and climate for societal benefits, how can GFDL leverage advances in science and computational capabilities to improve its key models? What are the strengths, gaps, and new frontiers?

Approach

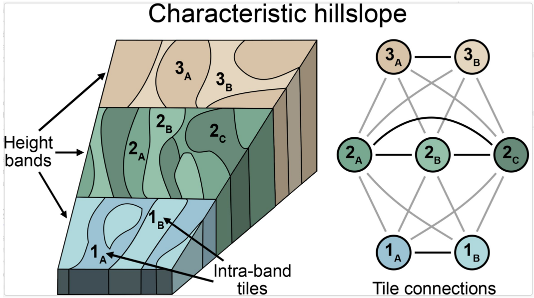


- Too much or too little water interacting with natural and managed ecosystems: predict and project hydrological & ecological droughts, fires, floods
- Orography-aware LM4.2 in the GFDL ESM framework – hydrological cycle at the stakeholder-relevant scale

Goals

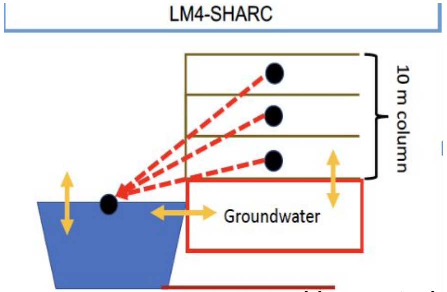
- Improve understanding of land-atmosphere interactions related to water availability and flooding under climate and direct anthropogenic change in the GFDL land and climate models
- Enhance initialization and assimilation capabilities of land components of the GFDL climate and Earth System Models, including soil moisture and vegetation state
- Develop and apply novel hydrologic capabilities to capture two-way interactions among the unsaturated soil, the groundwater, and streams/rivers
- Improve software and computational infrastructure to support land-water modeling in the Earth system framework and to deliver information about hydroclimate hazards to the user

Capturing Sub-Grid Heterogeneity in LM4-HydroBlocks



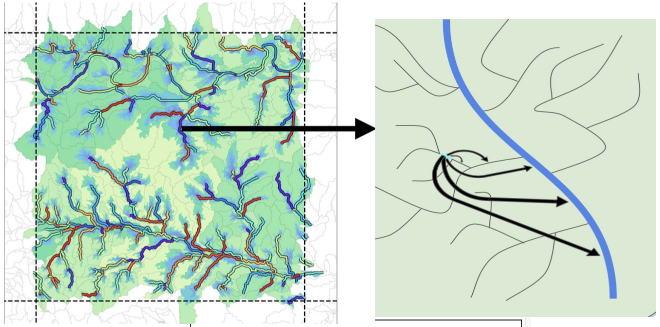
Subin et al 2014, Chaney et al 2018

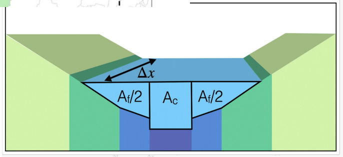
Land model resolving Soil, Hillslope Aquifer, and River Continuum



Hong et al (2024)

NEW subgrid stream/river routing, Two-way coupling with soil column and ground water





LM4 has a unique ML capability to formally upscale land heterogeneity into ESM/climate model and translate back model output about ecosystems, hydrology, and hazards at a forest plot or a farm scale!

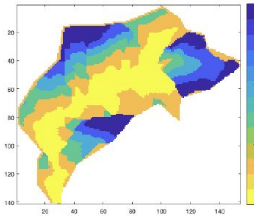
LM4.2 -SHARC

Providence Creek, Sierra Nevada (NV)

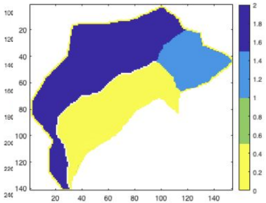
❖ **Soil, Hillslope Aquifer, and River Continuum (SHARC)**

- **Unsaturated soil–groundwater vertical interaction concerning water table depth**
- **Water transport**

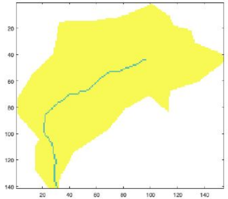
- Soil tiles

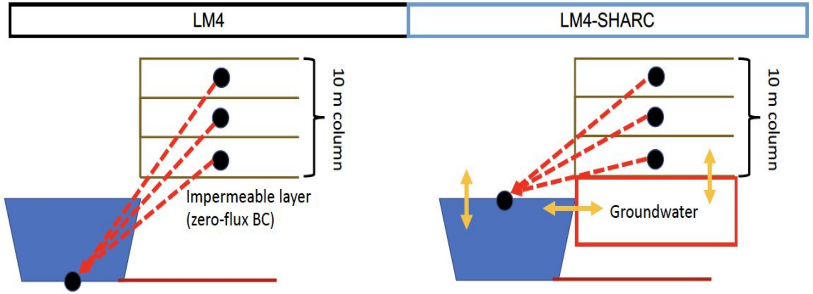


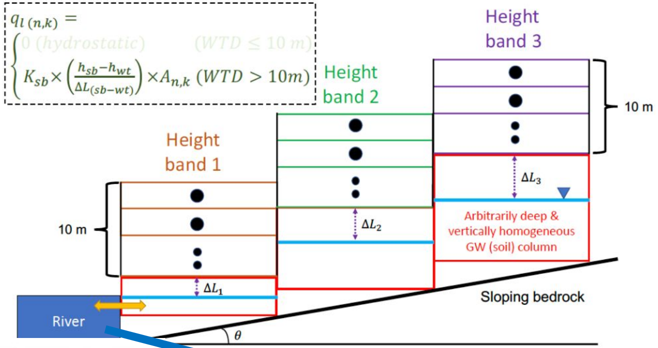
- Hillslopes

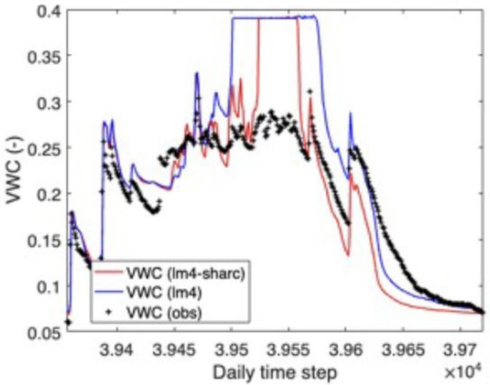


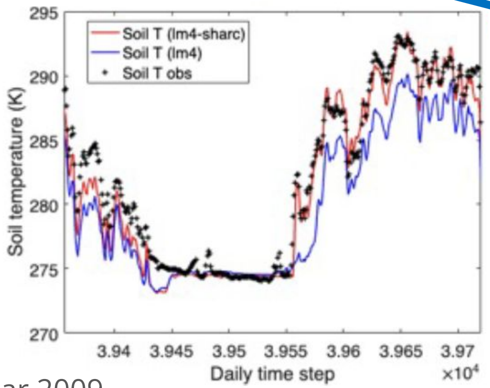
- Stream flowline











Year 2009

NEW RIVER ROUTING

- Two-way coupling with tiles
- Reach-based subgrid
- Inlet-outlet reaches form continental networks
- kinematic wave approach

Chaney et al 2021

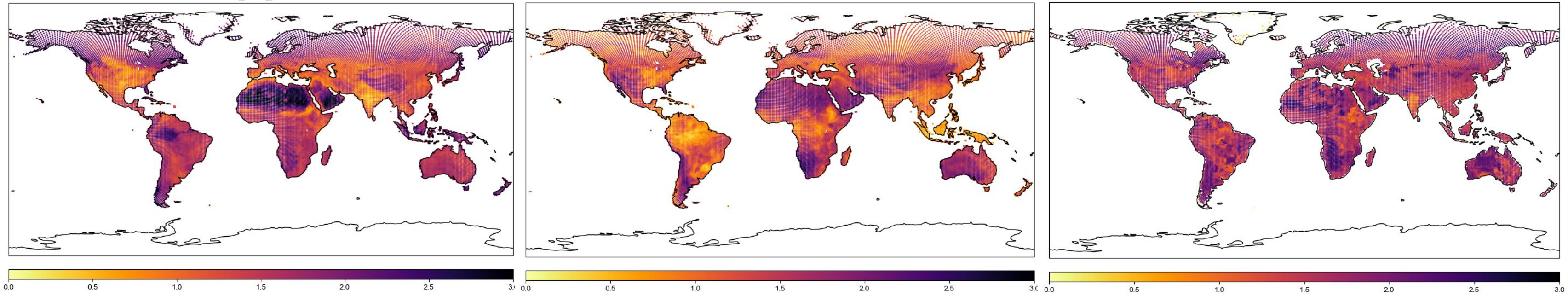
Hong et al, 2024 in review

Capture Uncertainty in Global Dataset of Soil Hydraulic Parameters

Soil parameters global map	Resolution	PTF / soil data	Water retention model
Rosetta 3-global (RST)	30-arc-second (1km)	ROSETTA 3 (ANN) / SoilGrids	van Genuchten
HiHydroSoil v2.0 (HHD)	30-arc-second (1km)	Toth et al (2014) / SoilGrids	van Genuchten
Dai et al (2019) (DAI)	30-arc-second (1km)	Ensemble PTF / GSDE	van Genuchten

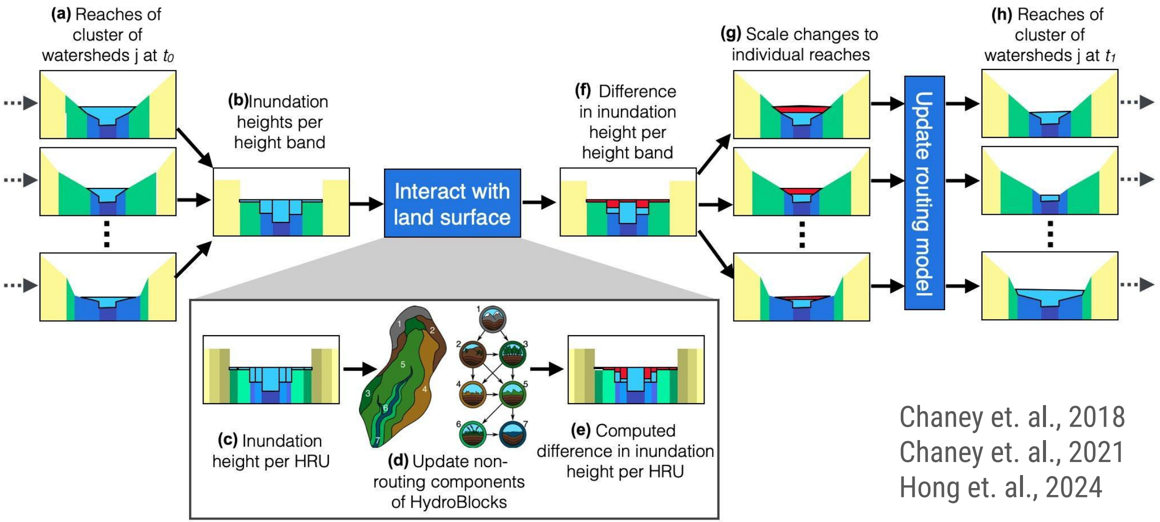
HMC-based soil properties aggregating at macro-scale (1 deg)

Saturated hydraulic conductivity (in unit of $\log_{10}(K_{sat})$ (cm/d))



Hong et al, 2024

Implementing HydroBlocks sub-grid river routing scheme in LM4.2



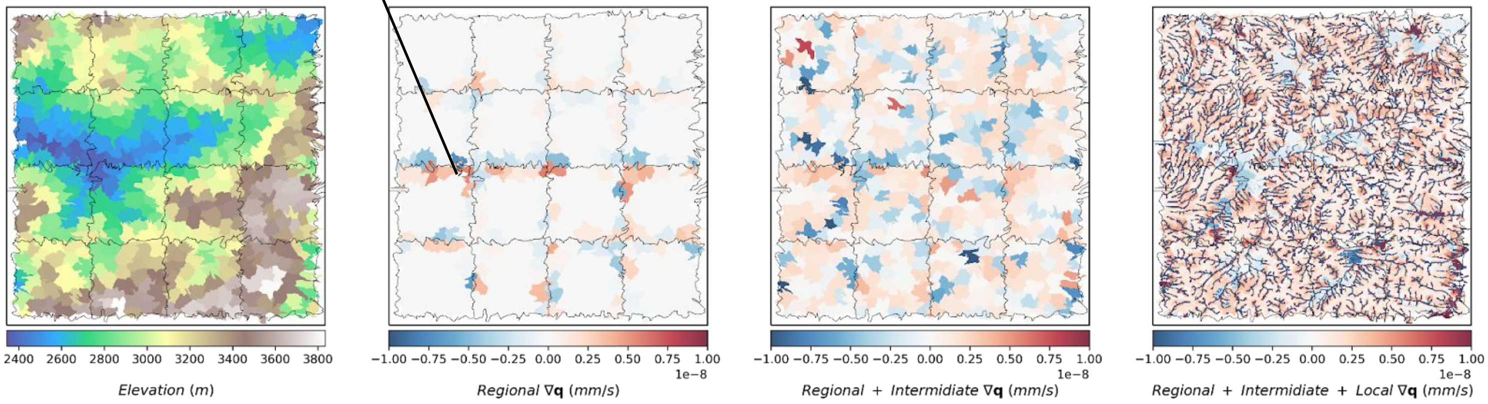
Chaney et. al., 2018
Chaney et. al., 2021
Hong et. al., 2024

- **HydroBlocks** routing: Kinematic wave (explicit solver & particle tracker)
- **Limitations routing:** i) Channel features depend heavily on clustering of hillslopes, ii) requires simplification for large number of reaches, iii) constant velocity, iv) kinematic wave approximation (no backwater effects).

Relating Sub-grid Hydro-Heterogeneity to regional scales via Rivers and Groundwater

Regional Units

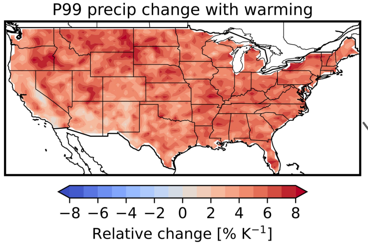
Inter-cell **Intra-cell** **Hillslope**

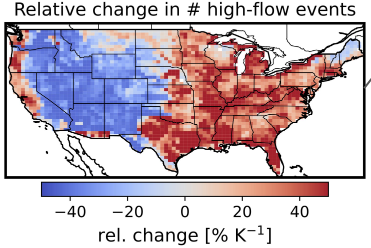


The combination of the regional, intermediate, local divergences constitute the multi-scale groundwater flow

Linking Atmospheric and Streamflow Extremes

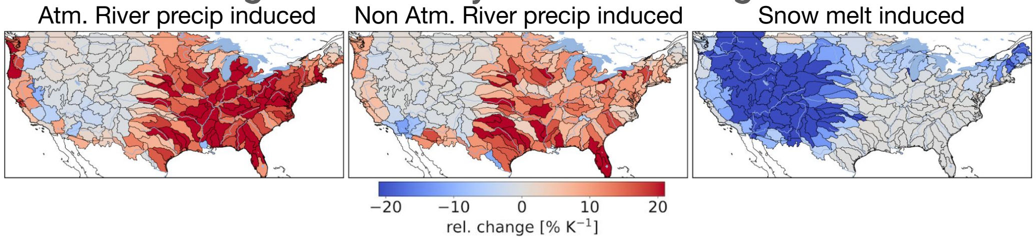
Extreme precipitation and high river streamflows change differently with warming:





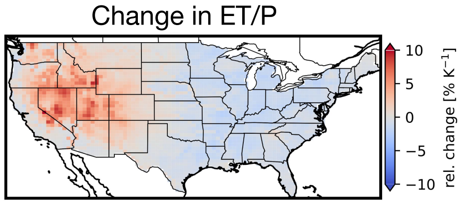
Why?

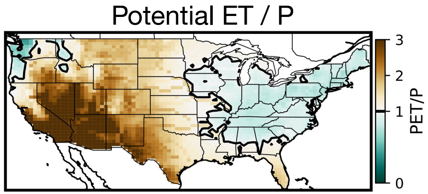
Changes in drivers of high flows



→ Increase of precipitation driven high-flows in the East, particularly by Atm. Rivers.
→ Reduction of spring-time melt reduces high-flows over mountainous West.

Changes in surface water balance





→ Evapotranspiration (ET) increases more than precipitation (P) in the West, yielding reduced streamflows.
→ This is because ET is water limited in the West and energy limited in the East.

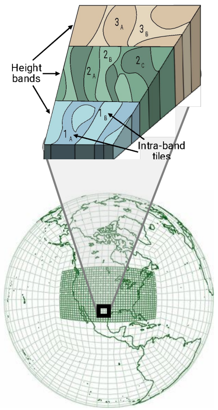
Manuscript in preparation for Nature Climate Change

Leveraging Artificial Intelligence for Satellite Soil Moisture Data Assimilation and Initialization in the GFDL ESMs and climate models

GFDL Land Data Assimilation System

GFDL Land Model

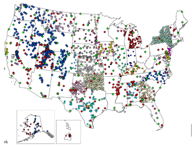
HydroBlocks



Soil Moisture DA

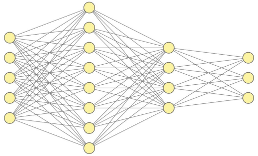
Satellite & In-situ Data

SMAP Soil Moisture Mapping



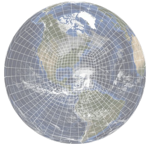
Mesoscale Network of Soil Moisture

Artificial Intelligence

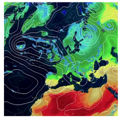


Coupled ESM

(SPEAR / FV3)



United States Unified Forecast System (UFS)



Traditional Land Data Assimilation provides limited improvements

- Ensemble **Kalman Filter**-like approaches
- Too long **memory** for fast processes
- **Coarse** spatial resolution
- Does not correct for SM **biases**
- Only 4% improvement in SM accuracy
- 1-2 deg K improvement in air temperature

GFDL AI-powered Land Data Assimilation

Maxwell Pike (GFDL) & Noemi Vergopolan (Princeton/Rice)

- Novel **Artificial Intelligence** approach
- Handles short and long **memory** processes
- HydroBlocks Hillslopes – **spatial detail**
- Train on **in-situ observations** corrects biases
- ~30% **improvement** (NOAH, Vergopolan 2021)
- Opportunity to improve **S2S predictions**

Publications and Presentations

[Poster] Hong, M., Chaney, N., Malyshev, S., Shevliakova, E., 2023. Resolving the Catchment-Scale Soil-Groundwater-River Interactions for an Earth System Modeling Framework, American Geophysical Union Fall Meeting, San Francisco, California, USA

[Oral] Hong, M., Malyshev, S., Chaney, N., Shevliakova, E., & Preucil, A. 2024. On the use of pedotransfer function for global surface simulation, American Geophysical Union Fall Meeting, Washington D.C., USA

[Poster] Hong, M., Chaney, N., Malyshev, S., Shevliakova, E., & Preucil, A. 2024. Implications of floodplain dynamics for terrestrial water-energy-carbon cycle, WaterSciCon24 (AGU), St. Paul, Minnesota, USA

[Publication, in review] Hong, M., Chaney, N. , Malyshev, S., Zorzetto, E., Preucil A., Shevliakova, E., 2024. LM4-SHARC v1.0: Resolving the Catchment-scale Soil-Hillslope Aquifer-River Continuum for the GFDL Earth System Modeling Framework, 2024. Geoscientific Model Development (GMD)

[Poster] Pike, M., Zorzetto, E., Malyshev, S., Preucil, A., Shevliakova, E. 2024. Implications of interactive changes in snow cover and land use land cover change on the radiative balance in the NOAA/GFDL coupled Atmosphere - Land model (AM4P2/LM4P2), American Geophysical Union Fall Meeting, Washington D.C., USA

[Poster] Prange, M., Zhao, M., Shevliakova, E., Malyshev, S., 2024. Using a high-resolution GCM for studying regional Atmospheric River driven hydrology, European Geophysical Union (EGU) Annual Meeting, Vienna, Austria

[Oral] Prange, M., Zhao, M., Shevliakova, E., Hong, M., Malyshev, S., 2024. Coupling the warming response of Atmospheric River precipitation to floods using a high-resolution climate model, NOAA Precipitation Prediction Grand Challenge (PPGC) Workshop, College Park, Maryland, USA

[Poster] Prange, M., Zhao, M., Shevliakova, E., Hong, M., Malyshev, S., 2024. Atmospheric Rivers as dominant driver for floods across the US in a warmer climate, American Geophysical Union Fall Meeting, Washington D.C., USA

[Poster, Oral] Preucil, A., Malyshev, S., Shevliakova, E., 2024. Characterizing the Implications of Irrigation for Historical and Future Hydroclimate in the NOAA/GFDL Climate Models, American Geophysical Union Fall Meeting, Washington D.C., USA