

Physics-based runoff production: From land-surface modeling to river model forcing

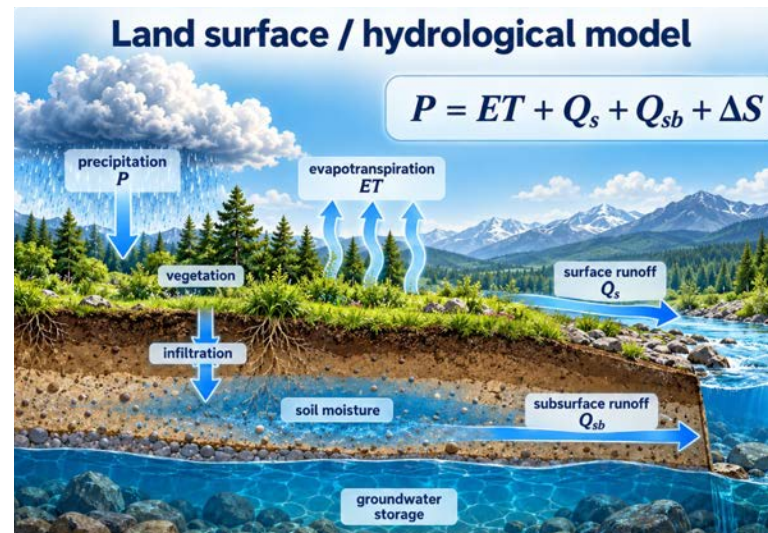
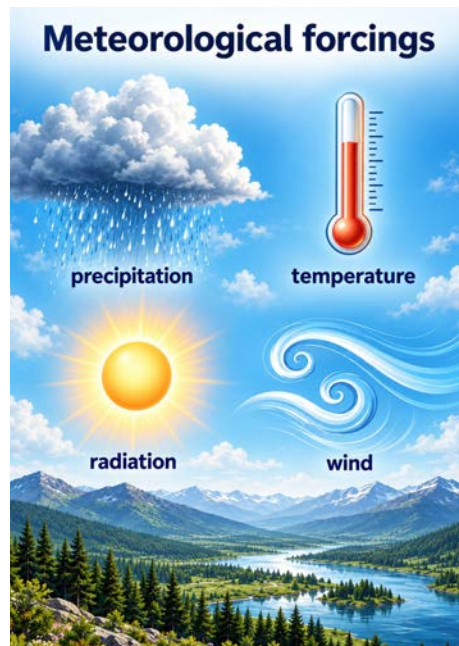
Augusto Getirana
NASA Godard Space Flight Center, SSAI

With contributions from: David Mocko, Hiroko Beaudoin, Jessica E. Lahmers, Elyssa Collins

Runoff is the link between land and river models

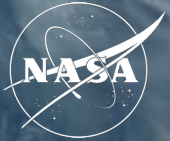


Physics-based runoff is generated by the land model – streamflow emerges after lateral routing and storage

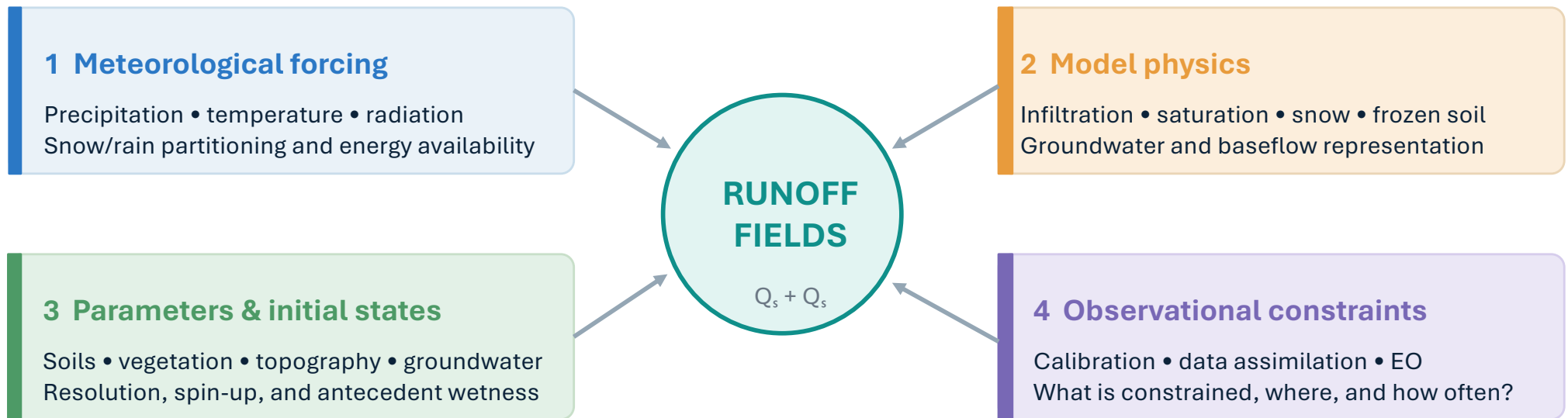


River routing / flood modeling → streamflow • water level • flooding

Why physics-based runoff estimates disagree



Runoff uncertainty reflects forcing, model structure, parameters, states, and observational constraints



There is no unique physics-based runoff estimate

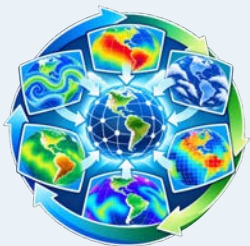
The runoff-product landscape



Different systems are designed for different questions—and produce different runoff fields.

LAND REANALYSIS

*Atmospheric reanalysis → offline
land model*



ERA5-Land

MERRA-2

Consistent, long-term
land-state reconstruction

LAND DATA ASSIMILATION SYSTEMS

Forcing + LSMs + observations



NLDAS

GLDAS

Multi-model / DA framework
for land hydrology

GLOBAL HYDROLOGICAL MODELS

Hydrology + water resources



WaterGAP

PCR-GLOBWB

Broader water cycle and
human-water processes

MULTI-MODEL EXPERIMENTS

Common forcing / protocols



PILPS

ALMIP-2

Structural uncertainty and
intercomparison



Physics-based runoff comes from a broad model ecosystem

NASA Goddard LDAS evolution: Toward finer-scale, observation-constrained hydrology



ESTABLISHED

NEXT GENERATION

REGIONAL

NLDAS-2

regional benchmark

Multi-model land simulations
Noah • VIC • Mosaic • SAC

Common forcing exposes structural model spread

NLDAS-3

in development

1-km • North + Central America
Reduced latency • Noah-MP • remote-sensing DA

*Toward higher-resolution, observation-constrained runoff →
HyMAP hydrodynamic model*

GLOBAL

GLDAS

Global LDAS

Global land-surface simulations
Multiple LSM / product generations

Long-term global hydrologic context

HydroGlobe

In development

Noah-MP • global • close to real time
SMAP/ESA CCI • MODIS • GRACE/GRACE-FO • snow DA

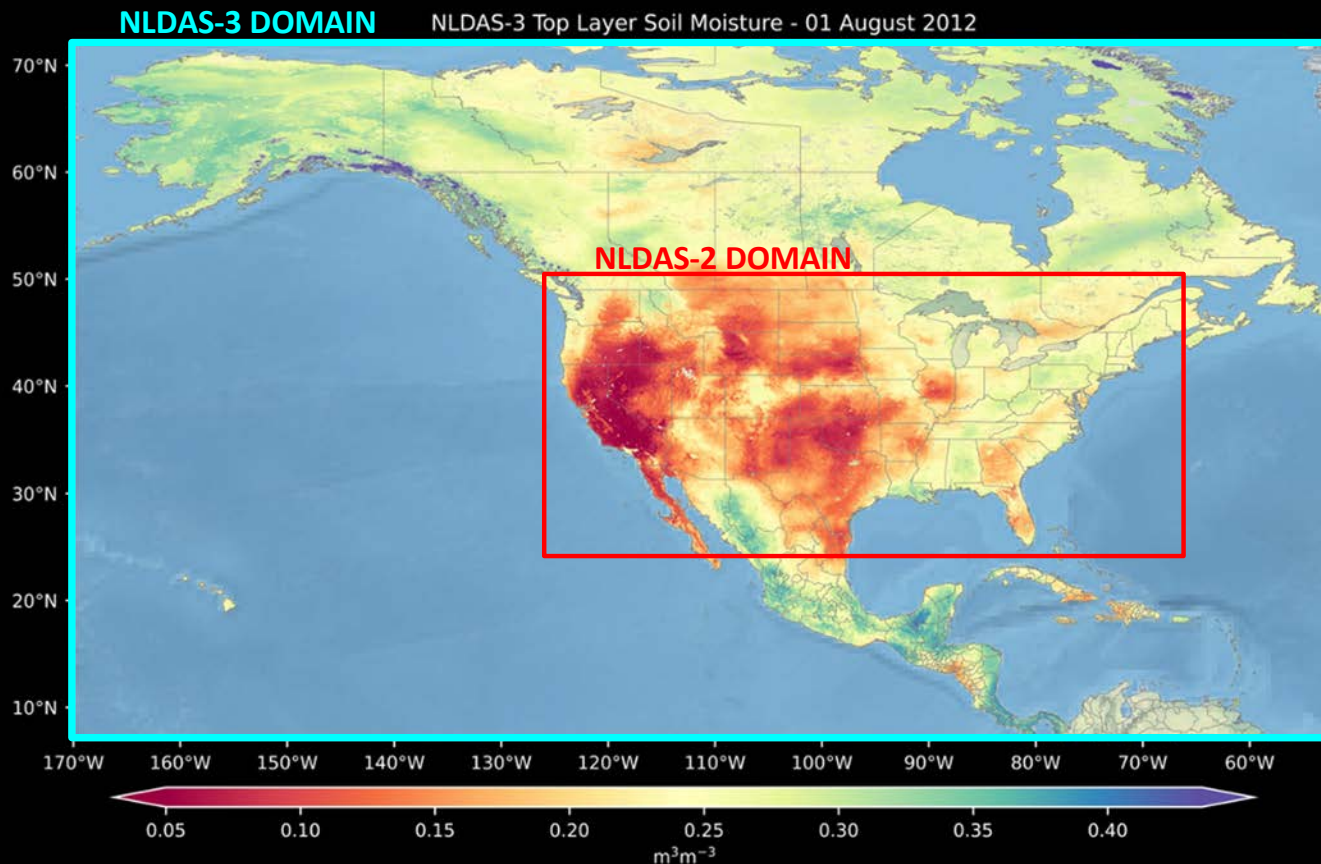
Surface + subsurface runoff → HyMAP hydrodynamic model

higher spatial detail

lower latency

stronger Earth-observation constraints

NLDAS Phase 3: A 1-km surface meteorological and land-surface dataset over North America



Domain over North America, Central America, & Caribbean (NLDAS-2 domain in red box), including AK, HI, PR, and USVI.

1-km for the entire domain

Land and water variables over North America in near real-time

Improved satellite data assimilation for better estimates of soil moisture, snow, water storage, ET, runoff, etc.

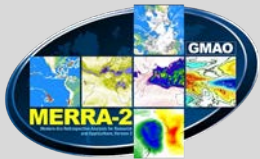
Credit: David Mocko

NLDAS-3 System Setup and Capabilities

Improvements
in red



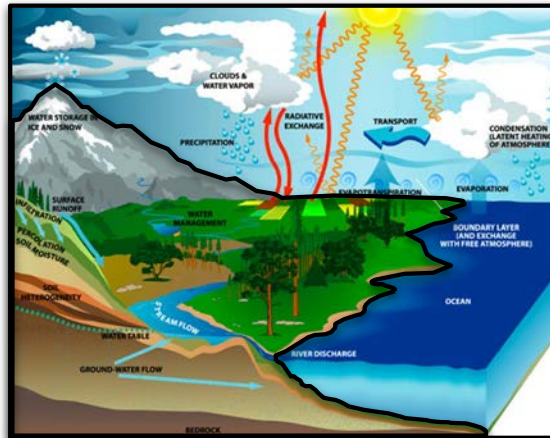
Satellite Data Assimilation
(soil moisture, snow,
terrestrial water, vegetation)



**Blended
meteorological
inputs**

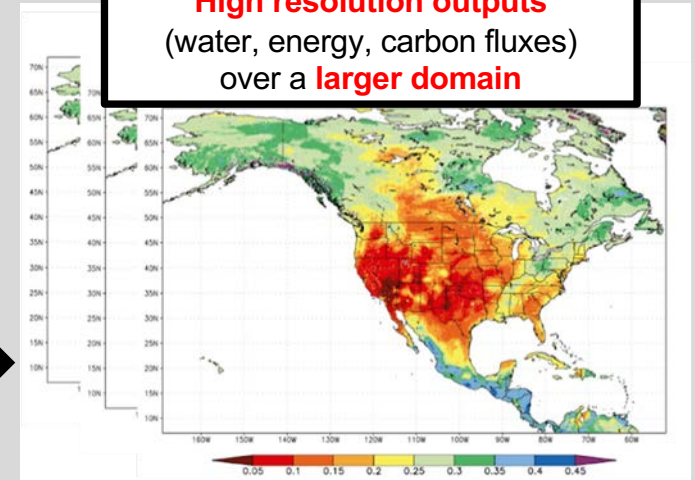


**Land Information System
Running Noah-MP and HyMAP-3**



Credit: David Mocko

High resolution outputs
(water, energy, carbon fluxes)
over a **larger domain**



Providing **real-time** cloud-based **outputs**
(with **more variables**) & **analysis** platforms

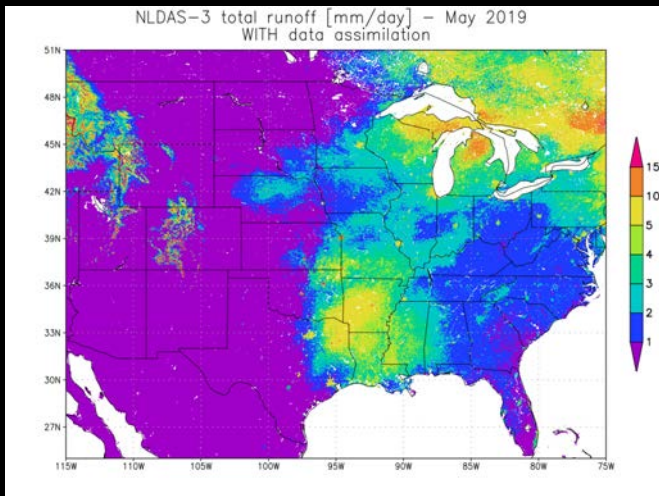


EARTHDATA
VEDA **BETA**

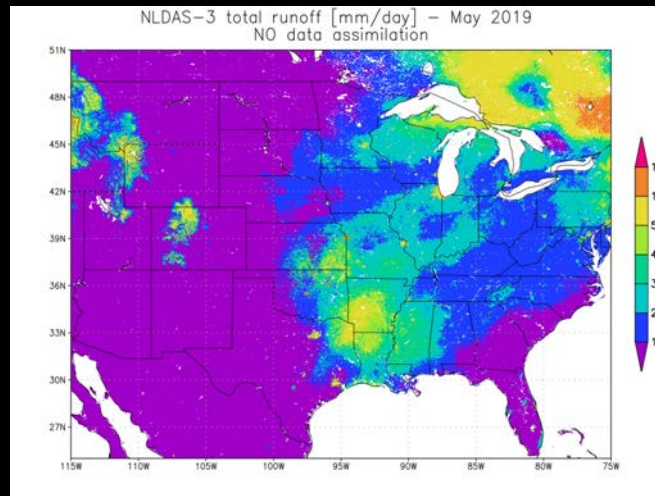


NLDAS-3 total runoff for May 2019

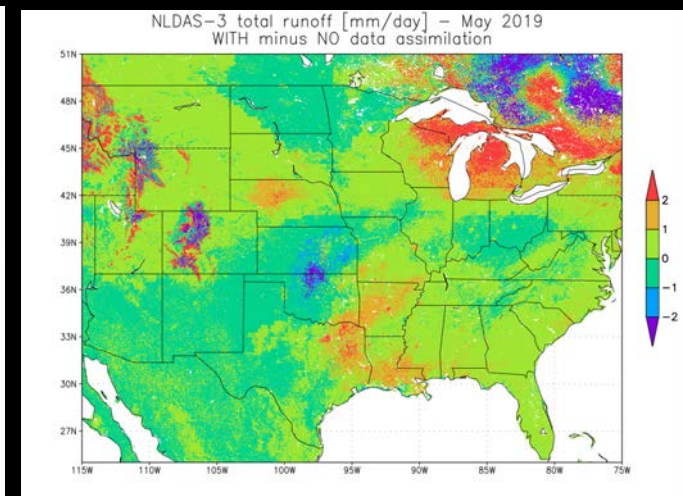
WITH data assimilation



NO data assimilation



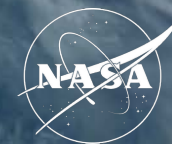
WITH minus NO DA



- Data assimilation (DA) increased total runoff in TX/AK/LA
- Total runoff also increased by DA in MI/WI
- DA decreased total runoff in OK/KS
- Both increases and decreases in snowmelt areas (Ontario/Quebec and Rockies)

Credit: David Mocko

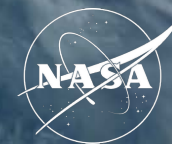
GLDAS Datasets



- Global Land Data Assimilation System (GLDAS) generates land surface fluxes estimates from multiple land surface models by integrating multiple model- and observation-based inputs within the Land Information System modeling software.
- GLDAS-2 comprises three sub-versions, each having different meteorological forcing data.
- HYMAP-3 routing coupled with four LSMs at 1°, daily for 1948-2014.

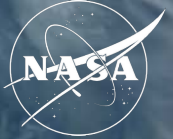
	GLDAS-2.0	GLDAS-2.1	GLDAS-2.2
Models	Catchment, Noah, VIC, HyMAP	Catchment, Noah, VIC	Catchment
Forcing	Princeton Meteorological Forcing Data	GDAS, downscaled GPCP precipitation, U.S. Air Force downward radiation	ECMWF IFC Analysis
Spatial Resolutions	0.25°, 1.0°	0.25°, 1.0°	0.25°
Temporal Resolutions	3-hourly, monthly	3-hourly, monthly	daily
Period	1948 - 2014	2000 - present	2003 - present
Assimilated Variables	none	none	Terrestrial Water Storage

GLDAS Model configurations

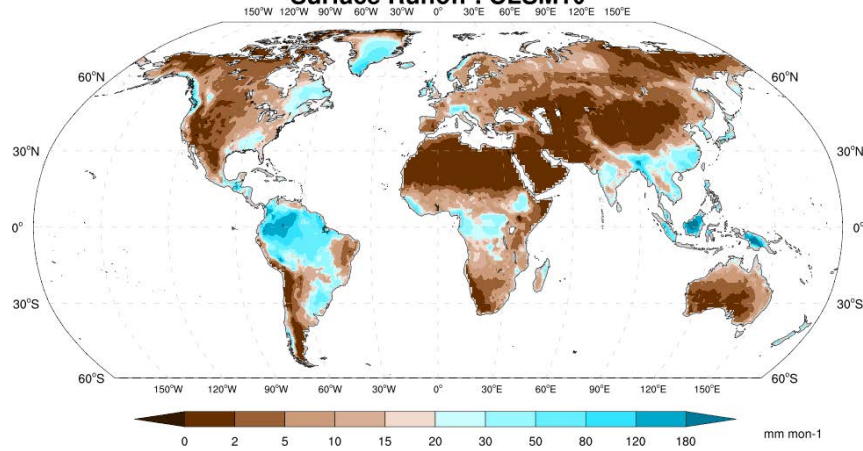


	Noah	VIC	CLSM	Noah-MP
Version	3.6	4.1.2	F2.5	4.0.1
Land Cover	Modified IGBP 20 classes	UMD 14 classes	Mosaic 7 classes	Modified IGBP 20 classes
Soil Texture	STATSGO/FAO	STATSGO/FAO	FAO	STATSGO/FAO
Vegetation	Monthly climatology GRFC	Monthly LAI from vegetation table	Monthly climatology LAI	Monthly climatology GRFC
Elevation	GTOPO30	GTOPO30	GTOPO30	GTOPO30
Snow	1 snow layer	2 snow layers	3 snow layers	3 snow layers
Soil/subsurface	4 fixed soil layers: 0-10, 10-40, 40-100, and 100-200 cm	3 soil layers (upper 0-10 cm; deeper layers spatially variable)	Catchment-based moisture states; no fixed soil layers	4 fixed soil layers: same as Noah; dynamic aquifer below soil column
Groundwater treatment	none	none	Diagnosed subsurface/GWS from catchment storage	Prognostic unconfined aquifer

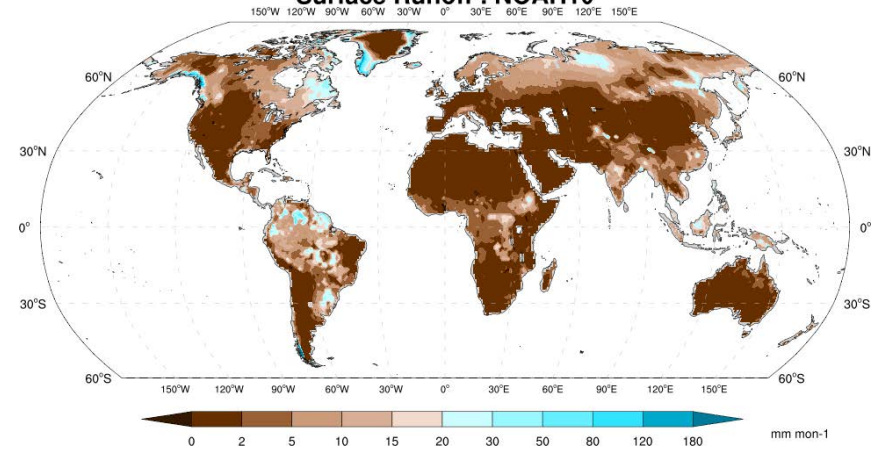
GLDAS Surface Runoff



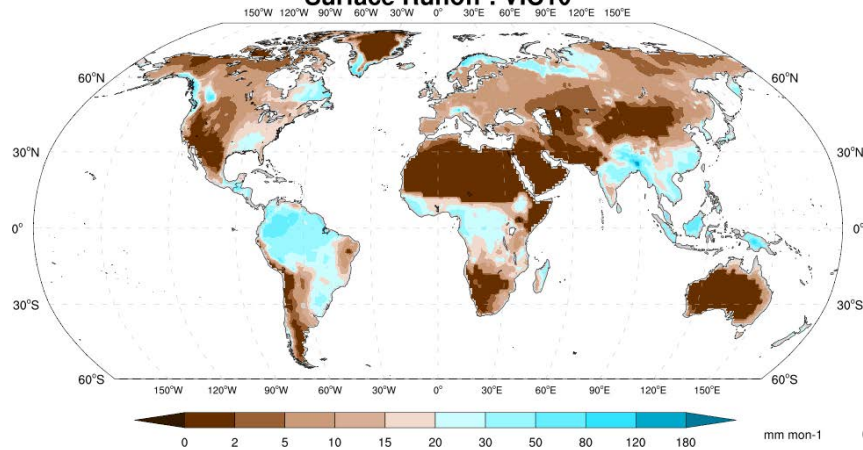
Surface Runoff : CLSM10



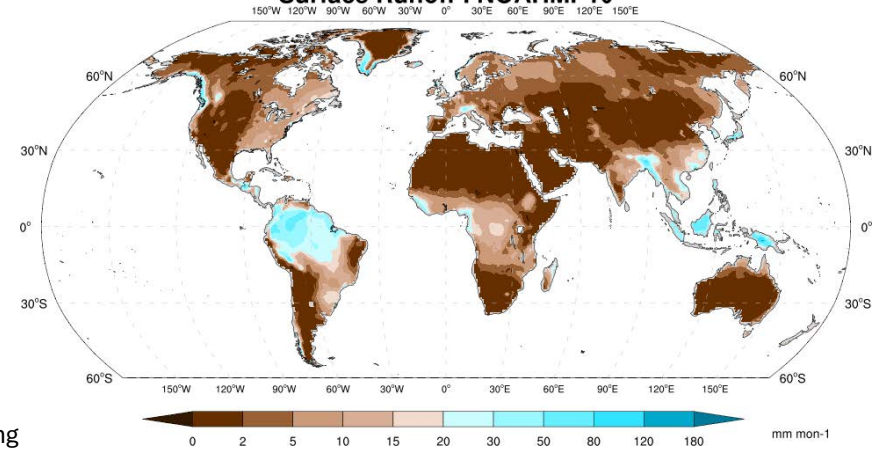
Surface Runoff : NOAH10



Surface Runoff : VIC10

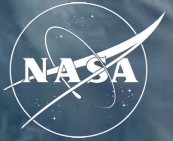


Surface Runoff : NOAHMP10

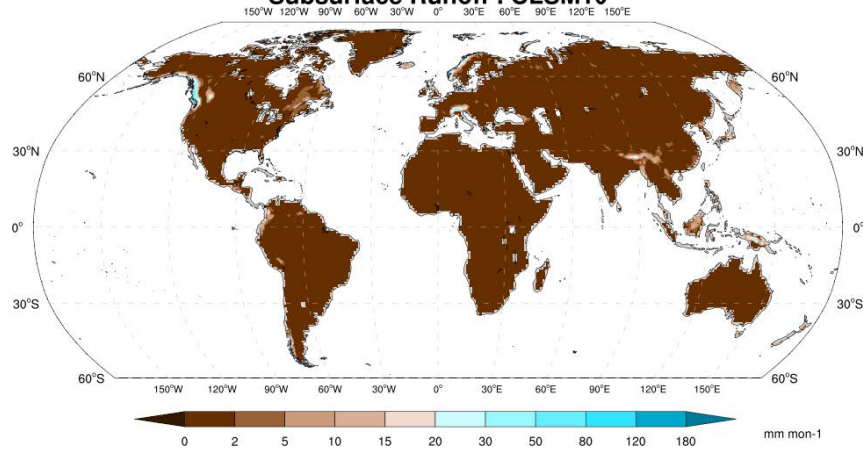


Credit: Hiroko Beaudoin

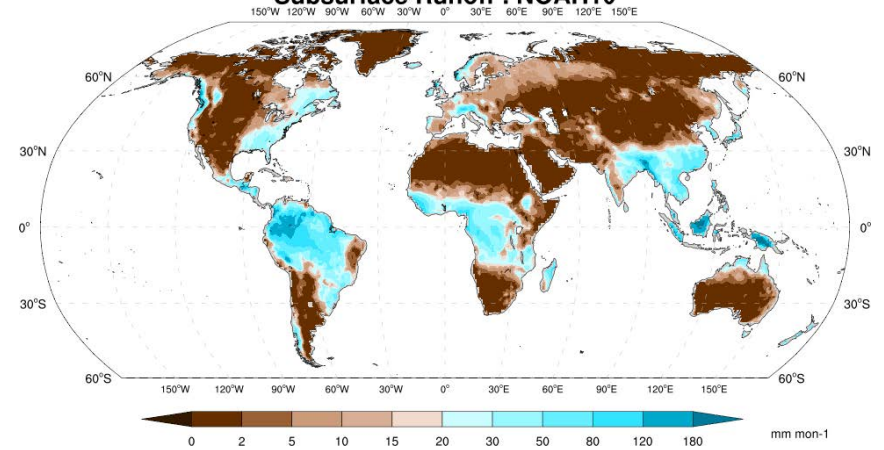
GLDAS Baseflow Runoff



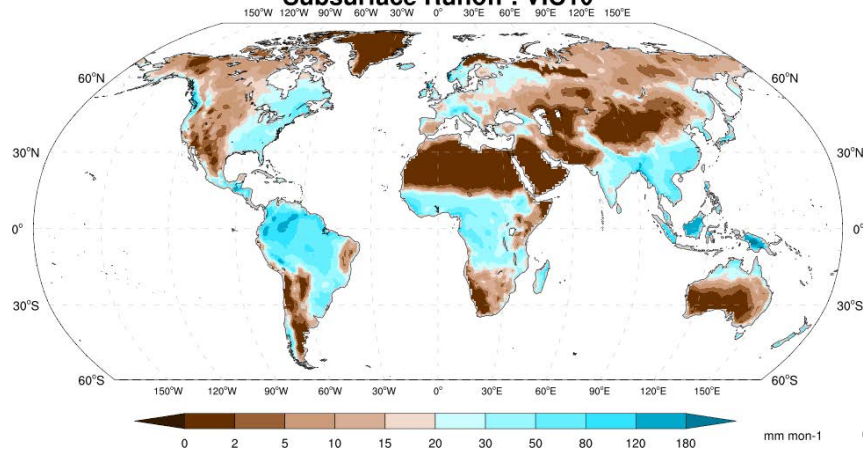
Subsurface Runoff : CLSM10



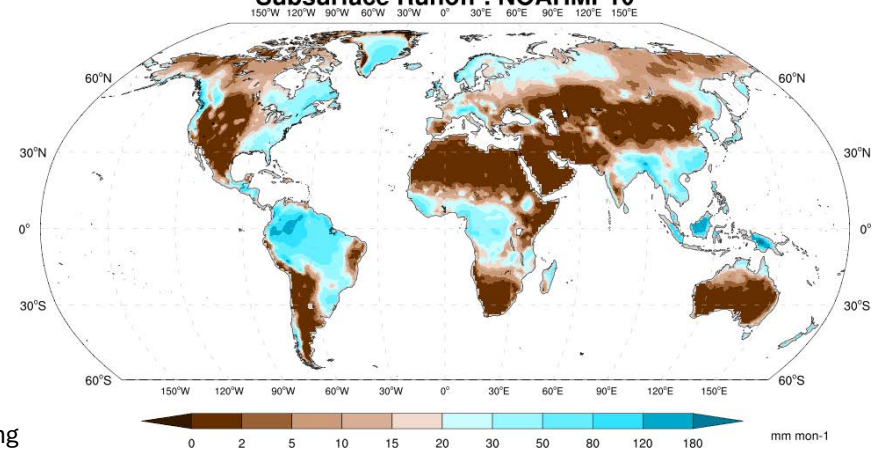
Subsurface Runoff : NOAH10



Subsurface Runoff : VIC10



Subsurface Runoff : NOAHMP10

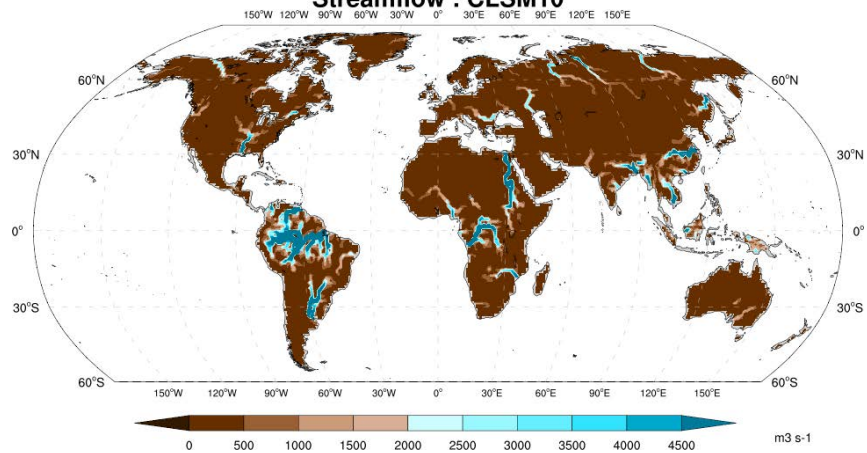


Credit: Hiroko Beaudoin

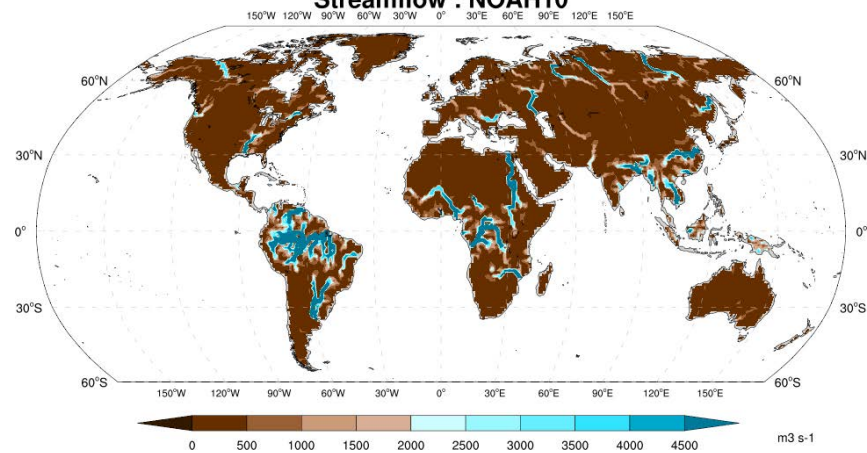
GLDAS Streamflow



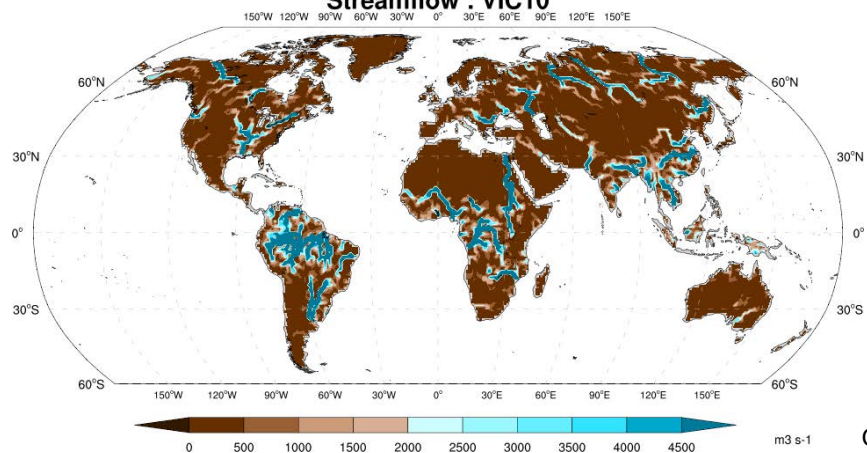
Streamflow : CLSM10



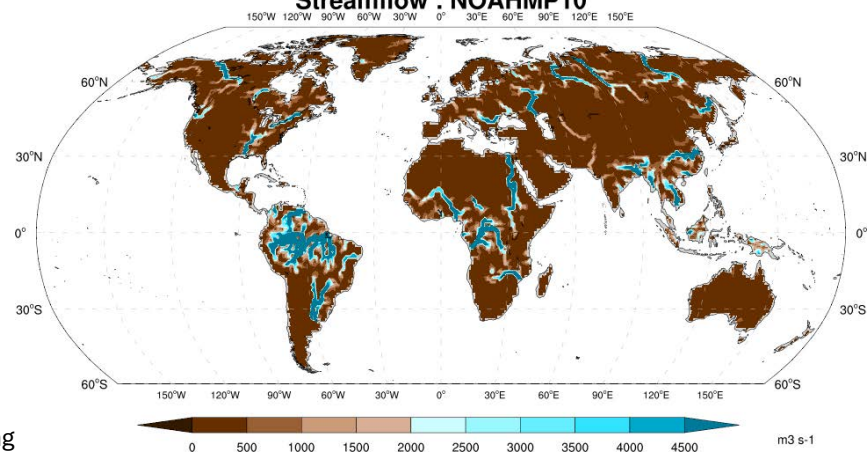
Streamflow : NOAH10



Streamflow : VIC10



Streamflow : NOAHMP10

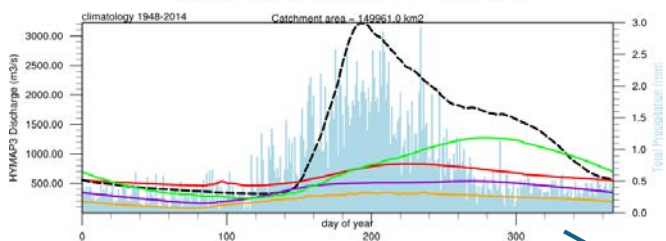


Credit: Hiroko Beaudoin

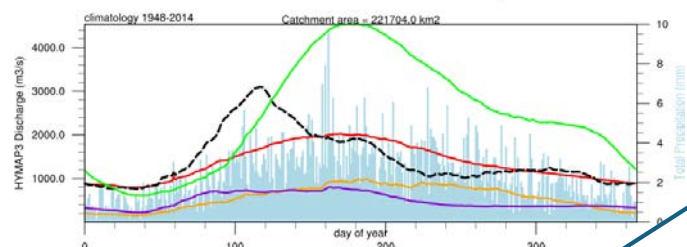
GLDAS Streamflow



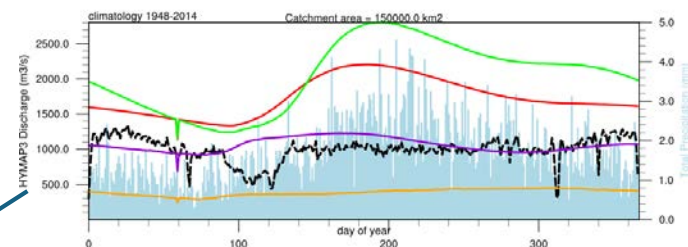
YUKON RIVER: ABOVE WHITE RIVER



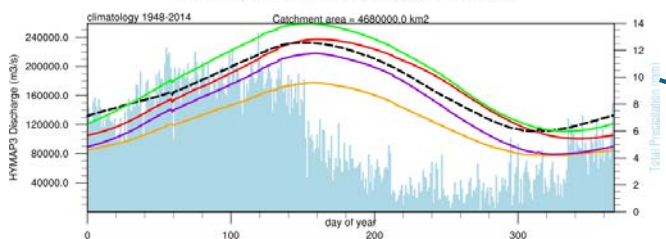
MISSISSIPPI RIVER: CLINTON, IA



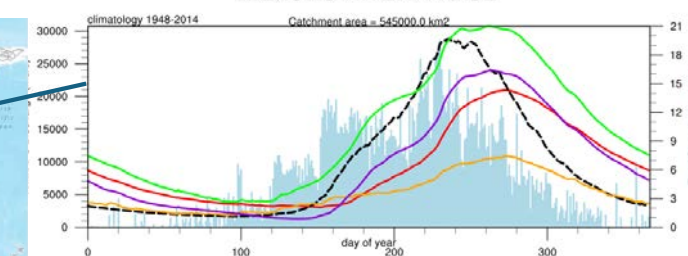
VOLGA: RYBINSKAYA GES



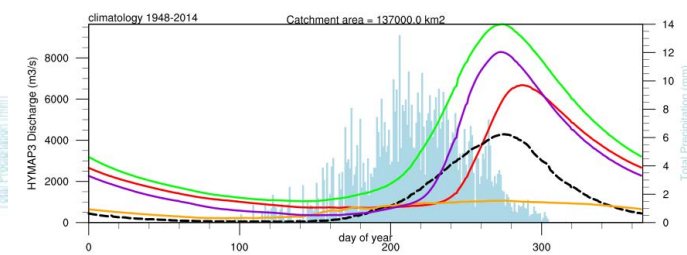
AMAZON RIVER: OBIDOS - PORTO



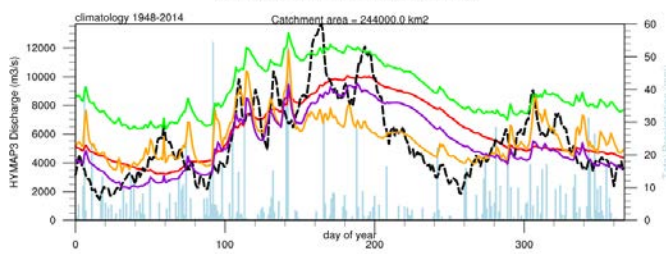
MEKONG RIVER: PAKSE



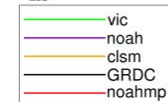
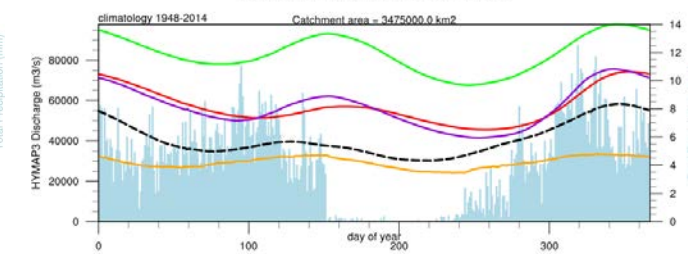
RIVER NIGER: KIRANGO AVAL



URUGUAY RIVER: SALTO

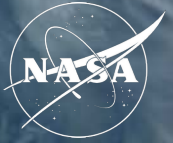


CONGO RIVER: KINSHASA



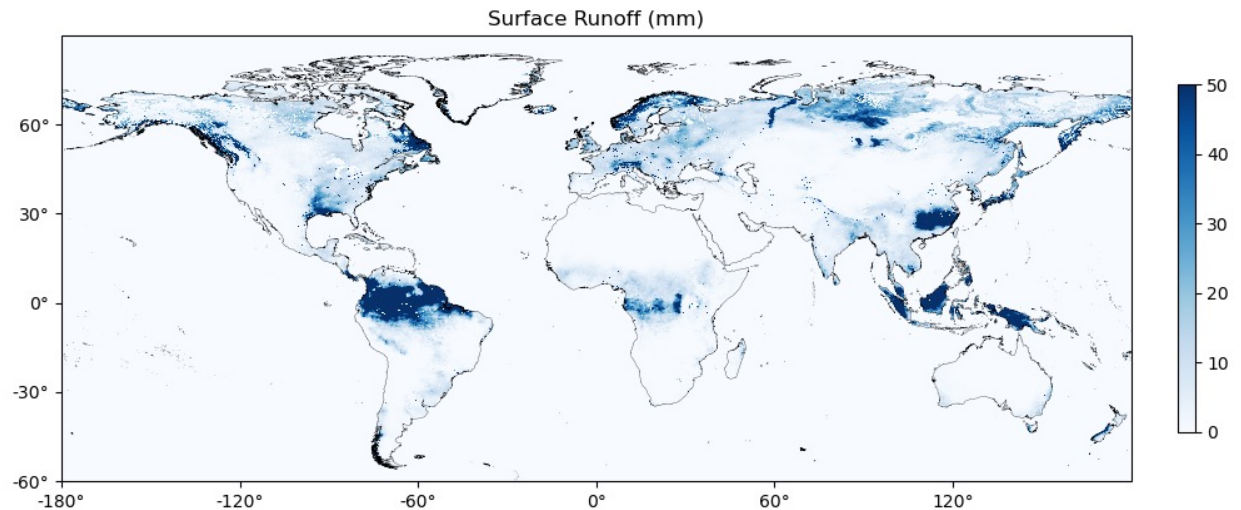
Credit: Hiroko Beaudoin

HydroGlobe



Daily 5km estimates of water, energy, and carbon fluxes 2002-2025

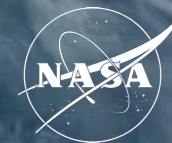
- Forcing
 - HydroSCS
- Multivariate Data Assimilation
 - Soil Moisture: ESA CCI and SMAP
 - Snow Mass: MODIS/AMSR
 - Leaf Area Index: MODIS/VIIRS
 - Terrestrial Water Storage: GRACE/GRACE-FO
- Land Surface Model: Noah-MP
- River dynamics: HyMAP-3
- Domain: 60S – 90N
- Status: Open loop production runs complete



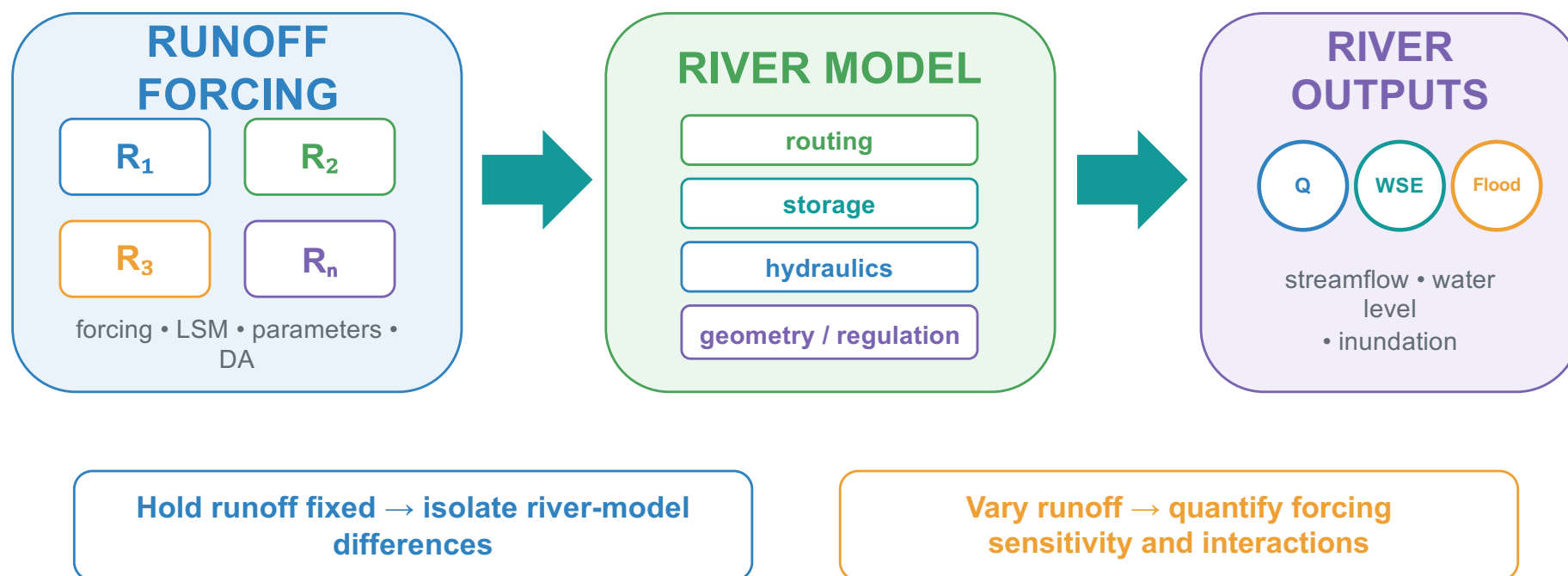
Surface runoff (mm) for May 2021.

Credit: Jessica E. Lahmers

For RivEx, runoff is an uncertain boundary condition

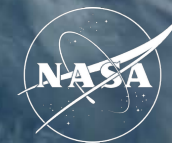


Discharge evaluation mixes uncertainty from runoff production with uncertainty from river routing and hydraulics



A single discharge score cannot tell us where the error came from.

A RivEx experiment hierarchy can separate uncertainty sources



Move from controlled experiments to end-to-end system evaluation

EXPERIMENT	RUNOFF FORCING	RIVER MODELS	WHAT IT TELLS US
1 Common runoff	One prescribed runoff field	All RivEx models	Routing, storage, hydraulics, geometry differences
2 Runoff ensemble	Multiple runoff products	Each model × each runoff field	Sensitivity to runoff uncertainty + runoff–routing interaction
3 Native systems	Each group's native runoff	Native routing / hydraulics	End-to-end performance + compensating errors

CONTROLLED



REAL-WORLD

Recommended sequence: common runoff → ensemble
→ native systems