National Aeronautics and Space Administration

Monitoring and Modeling Floods using Earth Observations

Amita Mehta & Sean McCartney

Guest Speaker: Dr. Augusto Getirana, NASA-GSFC

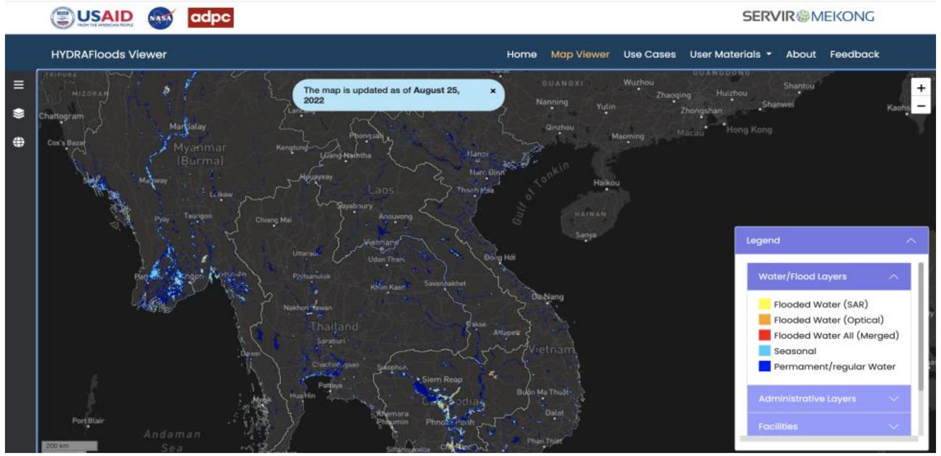
September 21, 2022

Training Outline

Two 2-hour sessions offered in English with materials available in Spanish

Part 1: September 14, 2022

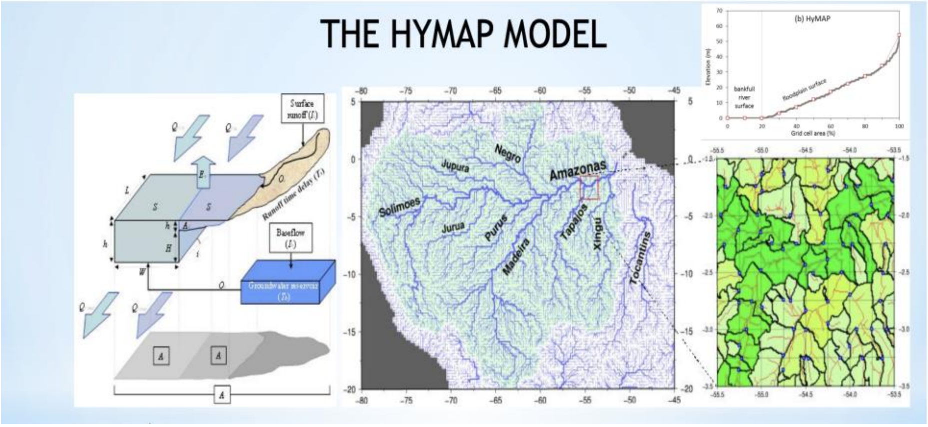
Overview: Flood Monitoring and Modeling



https://hydrafloods-servir.adpc.net/map/

Part 2: September 21, 2022

Introduction: The Hydrological Modeling and Analysis Platform (HyMAP)



https://ldas.gsfc.nasa.gov/sites/default/files/ldas/nldas/presentations/Getirana_NLDAS_HyMAP_10Nov2016.pdf

Outline for Part 2

- Review of Part 1
- Introduction to The Hydrological Modeling and Analysis Platform (HyMAP) and its applications
- Summary and Q/A

Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form accessed from the ARSET website
  - Homework will be made available on today.
  - Due date for homework: **October 7, 2022**.
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Review of Part 1

Flood Monitoring Tools

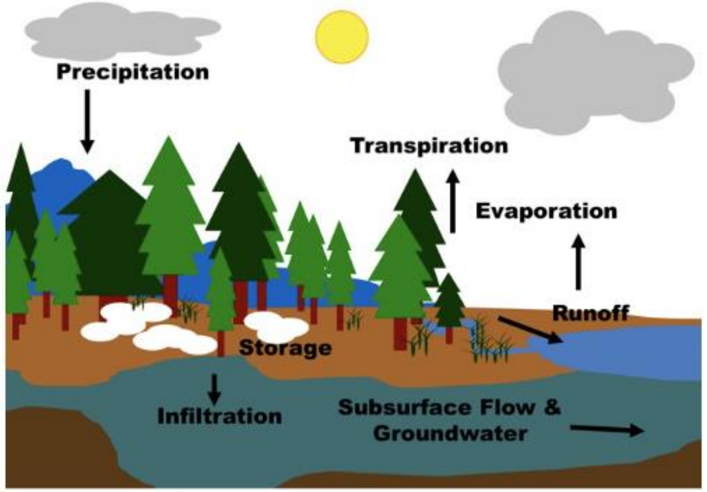
- [1]MODIS-Based Flood Mapping (NASA Worldview)
- [1]Dartmouth Flood Observatory River Watch (DFO River Watch)
- [2]Global Disaster Alert and Coordination System (GDACS)
- Advanced Rapid Imaging and Analysis (ARIA)
- **The HYDrologic Remote sensing Analysis for Floods (HYDRAFloods)**

[1]https://appliedsciences.nasa.gov/join-mission/training/satellite-remote-sensing-flood-monitoring-and-management

[2]https://appliedsciences.nasa.gov/join-mission/training/english/arset-overview-global-disaster-alert-and-coordination-system-gdacs

Hydrologic and Hydraulic Flood Modeling

- **Hydrologic Models**: Circulation of water through the hydrologic cycle and quantification of runoff flow produced by precipitation. It deals with precipitation, evaporation, infiltration, groundwater flow, surface runoff, and streamflow.



https://ncar.github.io/hydrology/projects/hydrologic_modeling

- **Hydraulics Models**: The mechanical behavior of water in open or closed channels. It provides water flow and depth as water moves from one point to the next in a channel.

boise river 2d modelling software

https://dudek.com/do-you-know-the-difference-between-hydrology-and-hydraulics/

https://www.nww.usace.army.mil/Media/Images/igphoto/2002565818/

Flood Modeling

- Remote sensing observations are routinely used for inputs:
  - Weather and precipitation data
  - Digital elevation
  - Land cover

- NASA Earth observations used for flood monitoring, mapping, and modeling from:
  - MODIS
  - Landsat
  - GPM
  - SRTM
  - SMAP
  - Sentinel-1and -2 (ESA)

Examples of Open-Source Flood Models

The following models are widely used for flood inundation mapping at the watershed/river basin scale:

- U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS)
- The Soil & Water Assessment Tool (SWAT)

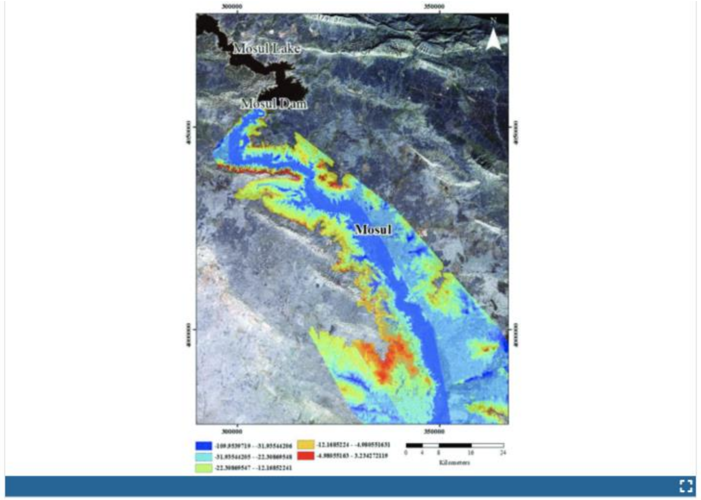


Fig. 3.
Flood map of hypothetical failure scenario for Mosul-Dam.

https://ieeexplore.ieee.org/document/8900379

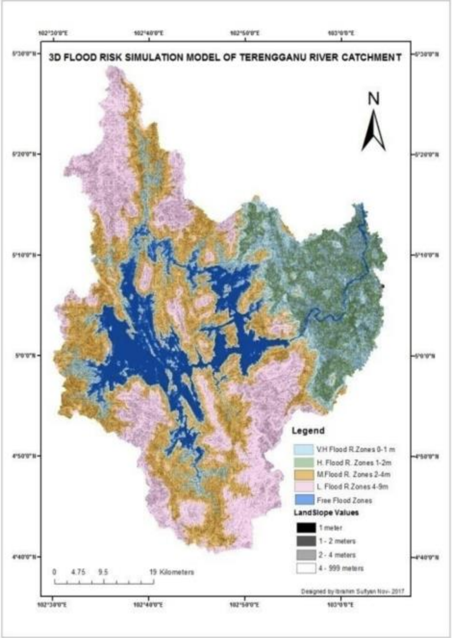
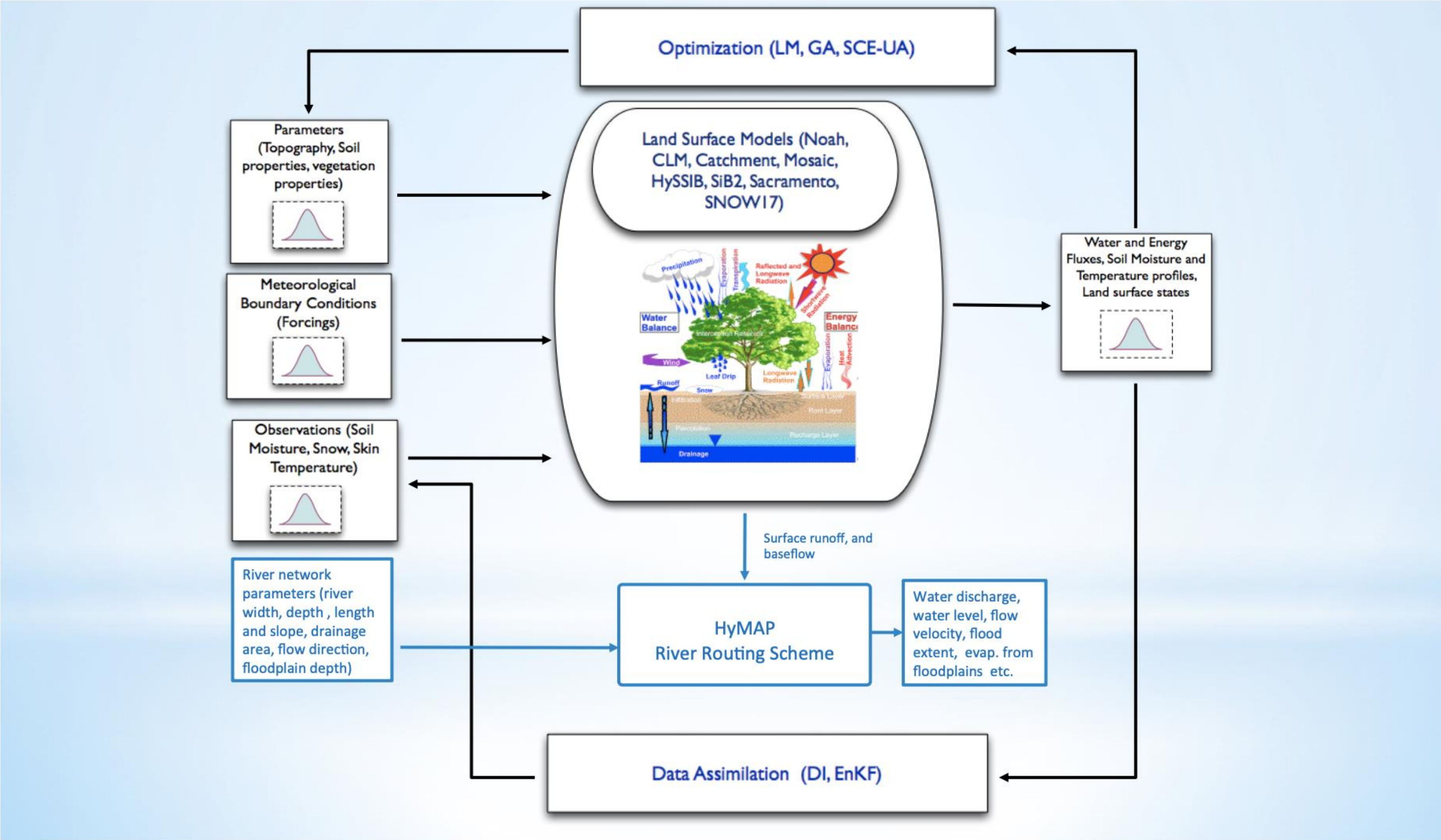


Figure 10: Flood Simulation Model of the Terengganu River Catchment

DOI : http://doi.org/10.26480/jcleanwas.02.2018.19.24

Part 2: NASA Land Information System and HyMAP Routing Model

https://lis.gsfc.nasa.gov/software/lis



https://ldas.gsfc.nasa.gov/sites/default/files/ldas/nldas/presentations/Getirana_NLDAS_HyMAP_10Nov2016.pdf

Recent progress on flood modeling at NASA Goddard:
From model development to capacity building
Focus: HyMAP Applications

Recent progress on flood modeling at NASA Goddard: From model development to capacity building

APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Dr. Augusto Getirana

Sep. 21, 2022

Why should we care about flood modeling?

Climate change and human activities have been magnifying the occurrence, intensity and impacts of extreme hydrological events

Bangladesh and India (2022)

Source: Reuters

Kentucky, USA (2022)

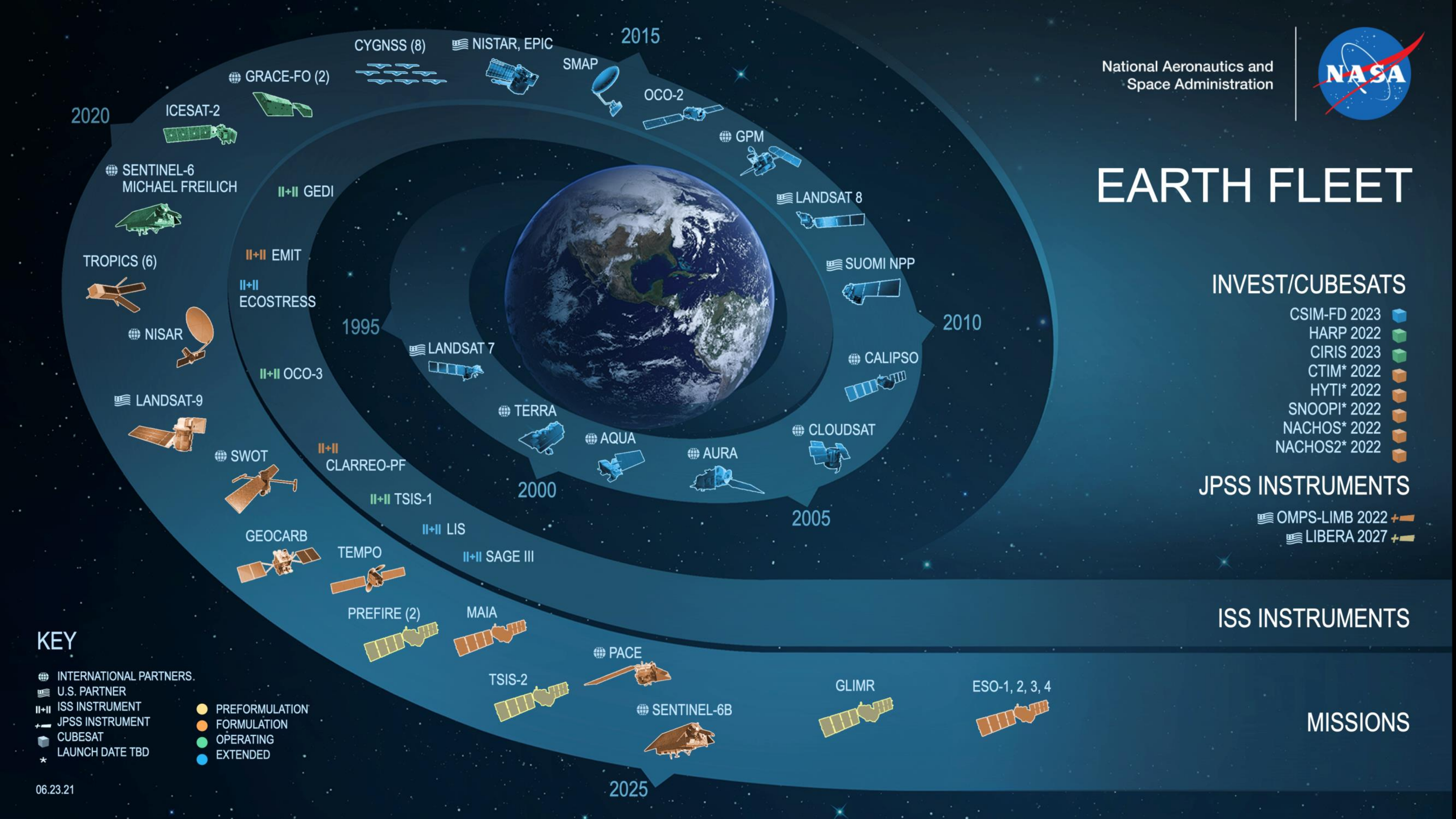
Source : USA Today

Pakistan (2022)

Source : Al Jazeera

Petropolis, Brazil (2022)

Source : NBC


National Aeronautics and Space Administration
NASA
EARTH FLEET
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CALIPSO
SUOMI NPP
LANDSAT 8
GPM
OCO-2
SMAP
NISTAR, EPIC
CYGNSS (8)
GRACE-FO (2)
ICESAT-2
SENTINEL-6 MICHAEL FREILICH
TROPICS (6)
NISAR
LANDSAT-9
SWOT
GEOCARB
TEMPO
PREFIRE (2)
MAIA
TSIS-2
PACE
SENTINEL-6B
GLIMR
ESO-1, 2, 3, 4
GEDI
EMIT
ECOSTRESS
OCO-3
CLARREO-PF
TSIS-1
LIS
SAGE III
INVEST/CUBESATS
CSIM-FD 2023
HARP 2022
CIRIS 2023
CTIM* 2022
HYTI* 2022
SNOOPI* 2022
NACHOS* 2022
NACHOS2* 2022
JPSS INSTRUMENTS
OMPS-LIMB 2022
LIBERA 2027
ISS INSTRUMENTS
MISSIONS
KEY
INTERNATIONAL PARTNERS
U.S. PARTNER
ISS INSTRUMENT
JPSS INSTRUMENT
CUBESAT
* LAUNCH DATE TBD
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EXTENDED
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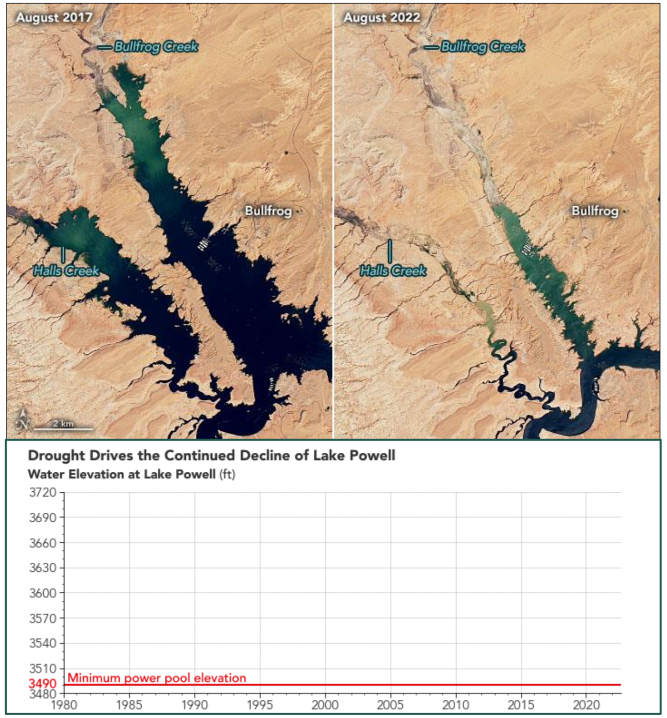
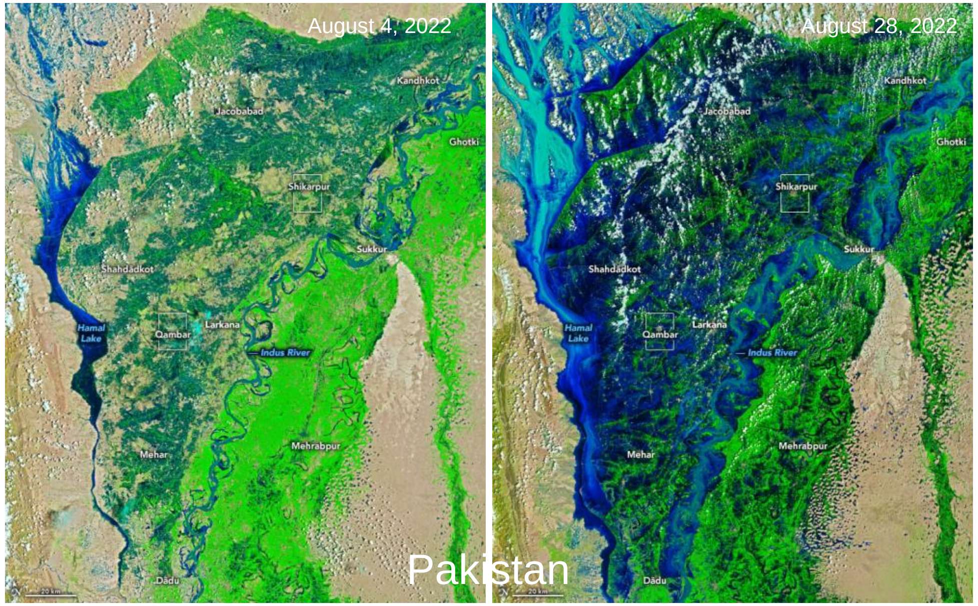
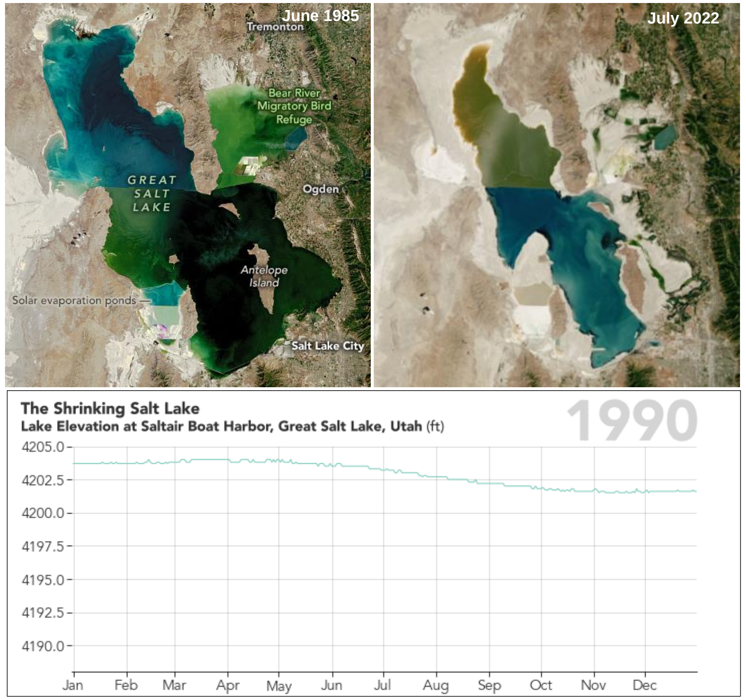
Satellites help us monitoring extreme events and quantifying their socioeconomic impacts







Source: NASA's Earth Observatory

Remote sensing of surface hydrology

Advantages

- Monitoring of remote regions;
- Spatial distribution;
- Open access.

Disadvantages

- Temporal resolution;
- Limited physical processes;
- Relatively short time series;
- Past events only.

Integration with computational models

- Evaluation;
- Calibration;
- Data assimilation.

Result

- Estimates of unobserved physical processes;
- Refined spatial and temporal resolutions;
- Scenarios;
- Forecasts.

Flood models and river routing schemes

Main characteristics

- Spatial and temporal scales;
- Discretization;
- Complexity of physical processes.

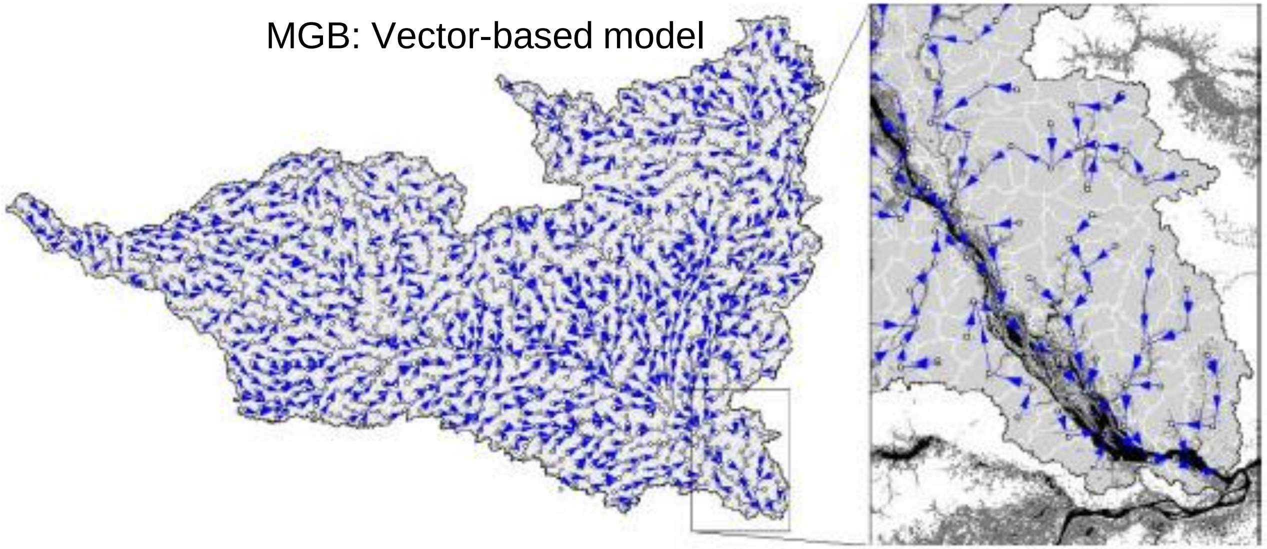
Global scale

TRIP (Oki et al., 1999)
WaterGAP (Doll et al., 2003)
CTRIP (Decharme et al., 2011)
CaMa-Flood (Yamazaki et al., 2011)
HyMAP (Getirana et al., 2012)
MOSART (Li et al., 2013)
DRTR (Wu et al., 2013)

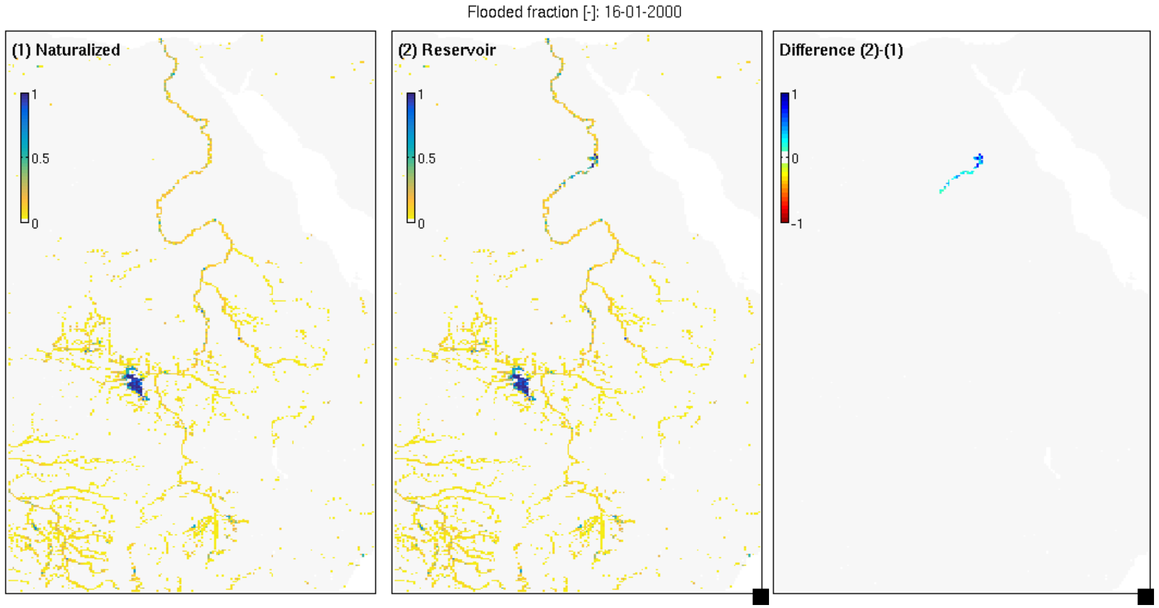
Continental/meso scale

LISFLOOD-FP (Bates and De Roo, 2000)
MGB (Collischonn et al., 2007)
LEAF-Hydro-Flood (Miguez-Macho et al., 2007)
THMB (Coe et al., 2008)
RAPID (David et al., 2011)

MGB: Vector-based model



HyMAP: Grid-based model



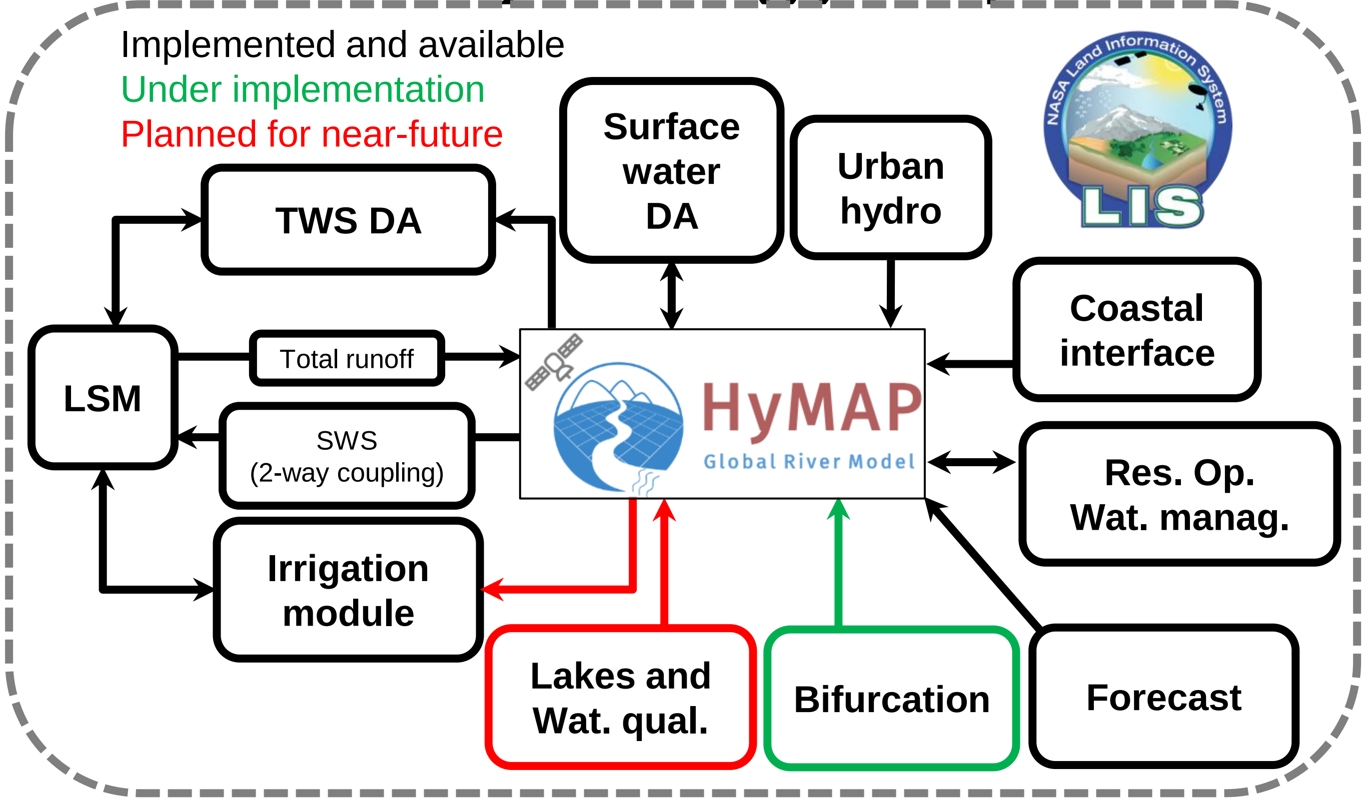
LIS surface hydrology capabilities

HyMAP Features

Implemented:
- Local inertia formulation
- Adaptive time step
- Backwater effects
- Floodplain dynamics
- 2-way coupling
- Reservoir operation
- Water management
- GRACE-DA correction for SWS
- Surface water DA (water level, discharge and extent)
- Urban flood and drainage
- Coastal interface

Ongoing:
- Bifurcation

Future:
- Sediment dynamics
- Irrigation coupling
- Lake module

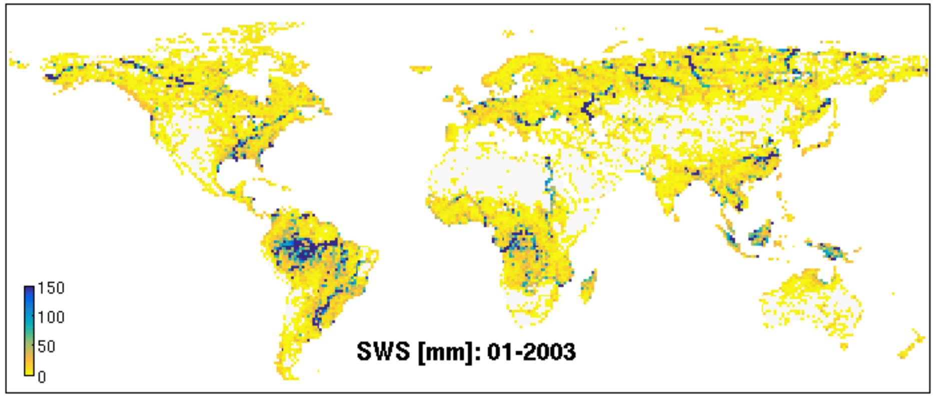


Outputs

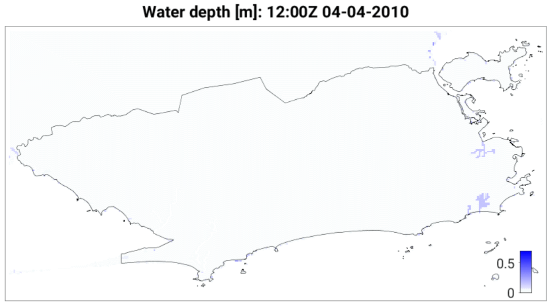
- Water discharge
- Water depth
- Water storage
- Flow velocity
- Floodplain extent
- River slope

Flexible spatial scale

1º global surface water storage variability



200-m streamflow over Rio de Janeiro city



Content of this seminar

- Rivers and floodplains as key components of terrestrial water storage variability
- Climate and human impacts on hydrology and flood risk in Southern Louisiana
- Impacts of dam operation on Lake Victoria, in Eastern Africa
- Development of a flood model for the city of Rio de Janeiro, Brazil
- **Final considerations and prospects**

Content of this seminar

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Rivers and floodplains as key components of terrestrial water storage variability

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL074684

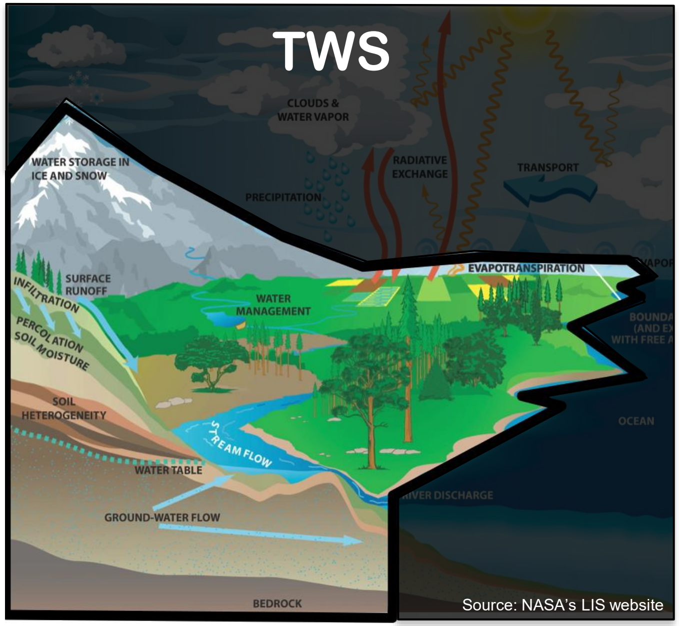
Rivers and Floodplains as Key Components of Global Terrestrial Water Storage Variability

Augusto Getirana[1,2], Sujay Kumar[1], Manuela Girotto[3,4], and Matthew Rodell[1]

Scientific questions

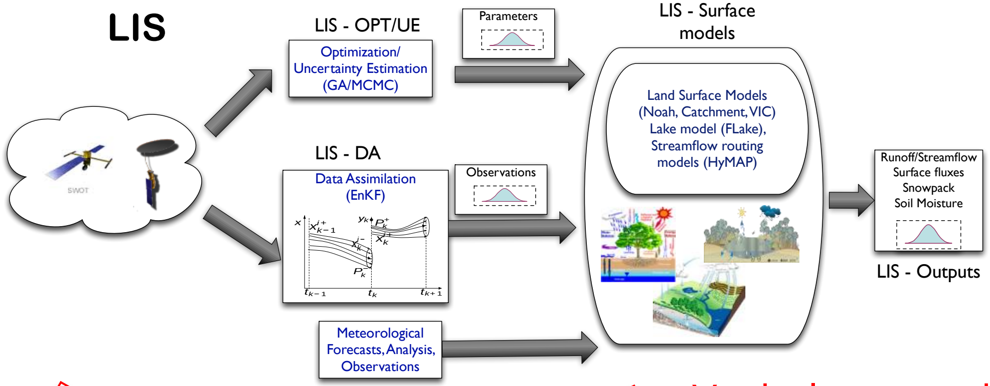
1. What is the global impact of surface water storage on TWS?
2. How does that impact vary spatially?

Modeling Framework



Source: NASA's LIS website

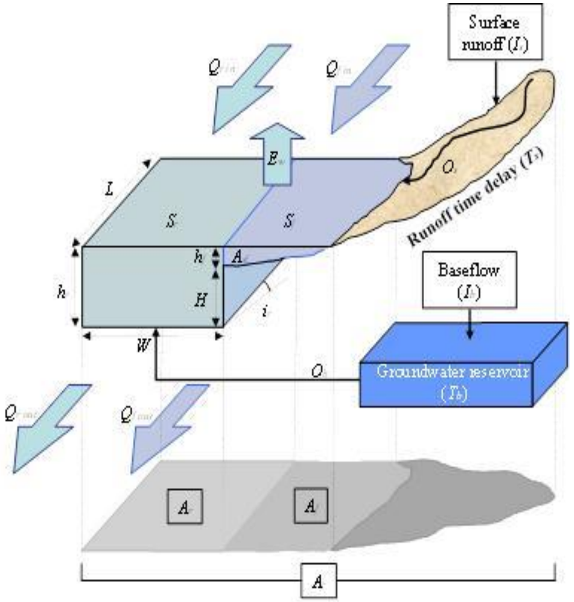
LIS

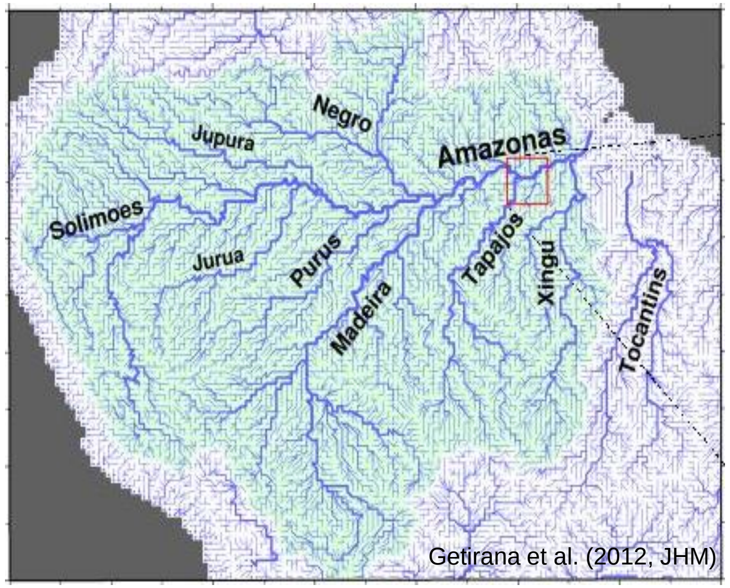


Surface water dynamics;
Surface water storage (SWS)

Vertical water and energy balance;
Land water storage (LWS)

HyMAP



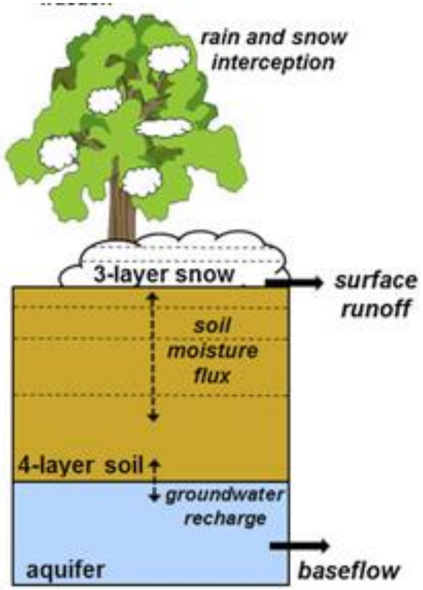


Getirana et al. (2012, JHM)

Surface runoff

Baseflow

Noah-MP



Mendoza et al. (2015, JHM)

Experimental design

Four meteorological forcings and two precipitation datasets, totaling 12 runs;

Meteorological forcings:

- MERRA2 (1979-present)
- GDAS (2000-present)
- Princeton (1948-2014)
- ECMWF (2003-present)

Precipitation datasets:

- TRMM (1998-2016)
- TRMM-RT (1998-2016)

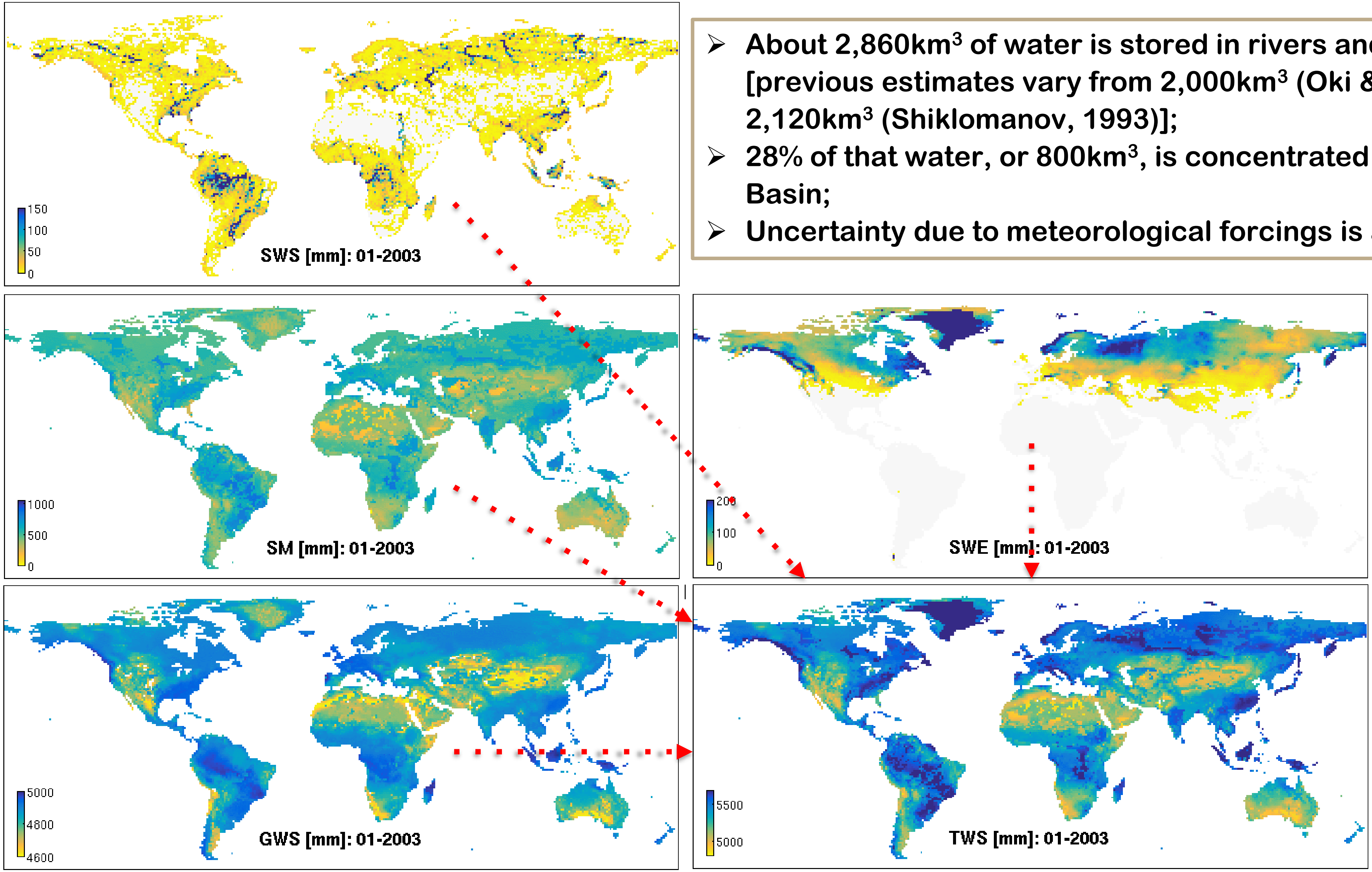
Modeling protocol:

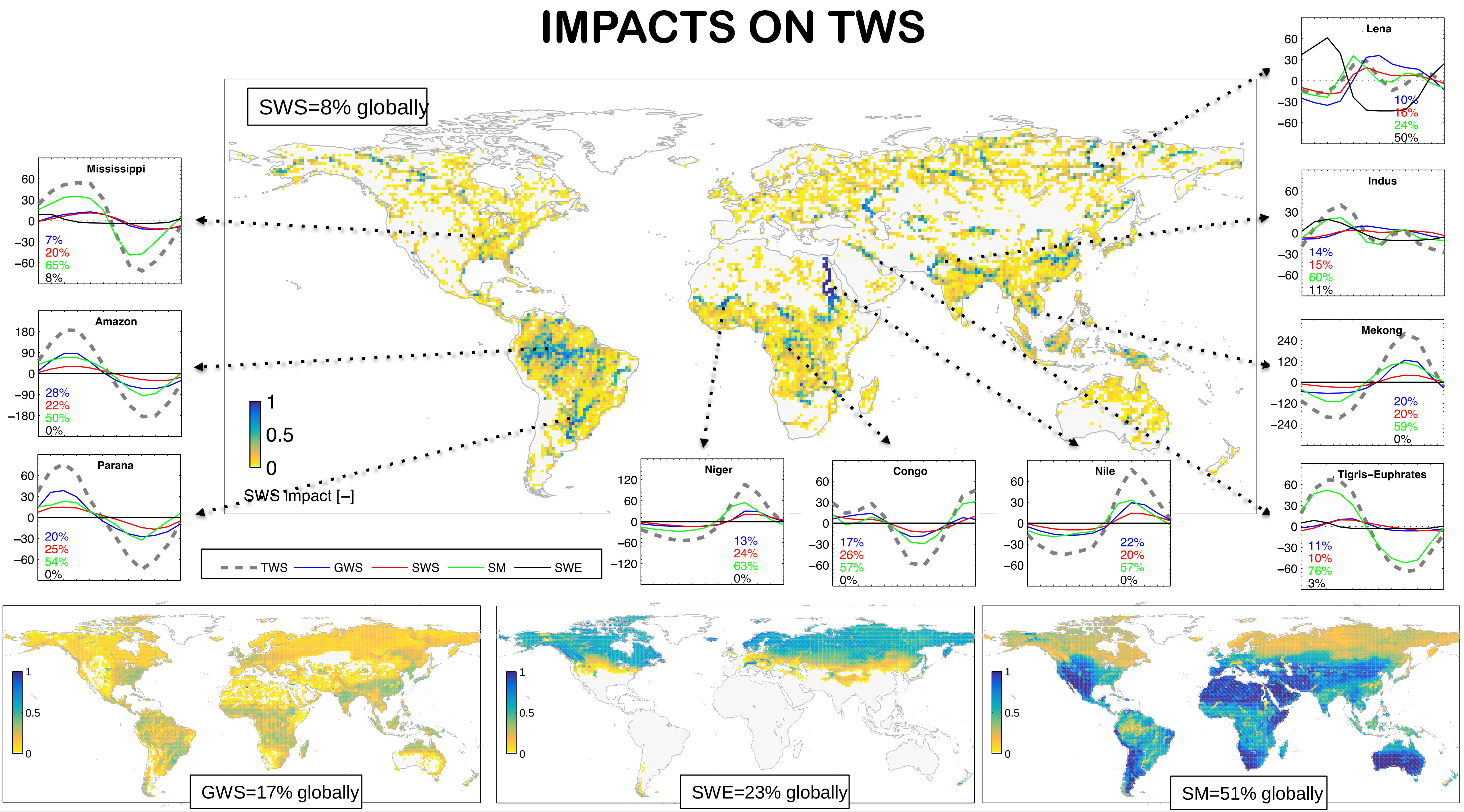
- 50-year spin up;
- 1-degree spatial resolution;
- 1-hour time step;
- 2003-2014 period.

The analysis was performed using the 12-member ensemble mean as the reference.

GLOBAL TERRESTRIAL WATER STORAGE

- About 2,860km^3 of water is stored in rivers and floodplains [previous estimates vary from 2,000km^3 (Oki & Kanae, 2006) to 2,120km^3 (Shiklomanov, 1993)];
- 28% of that water, or 800km^3, is concentrated in the Amazon Basin;
- Uncertainty due to meteorological forcings is about 6% globally.




IMPACTS ON TWS
SWS=8% globally
SWS impact [–]
Mississippi
7%
20%
65%
8%
Amazon
28%
22%
50%
0%
Parana
20%
25%
54%
0%
Lena
10%
16%
24%
50%
Indus
14%
15%
60%
11%
Mekong
20%
20%
59%
0%
Tigris–Euphrates
11%
10%
76%
3%
Niger
13%
24%
63%
0%
Congo
17%
26%
57%
0%
Nile
22%
20%
57%
0%
TWS
GWS
SWS
SM
SWE
GWS=17% globally
SWE=23% globally
SM=51% globally

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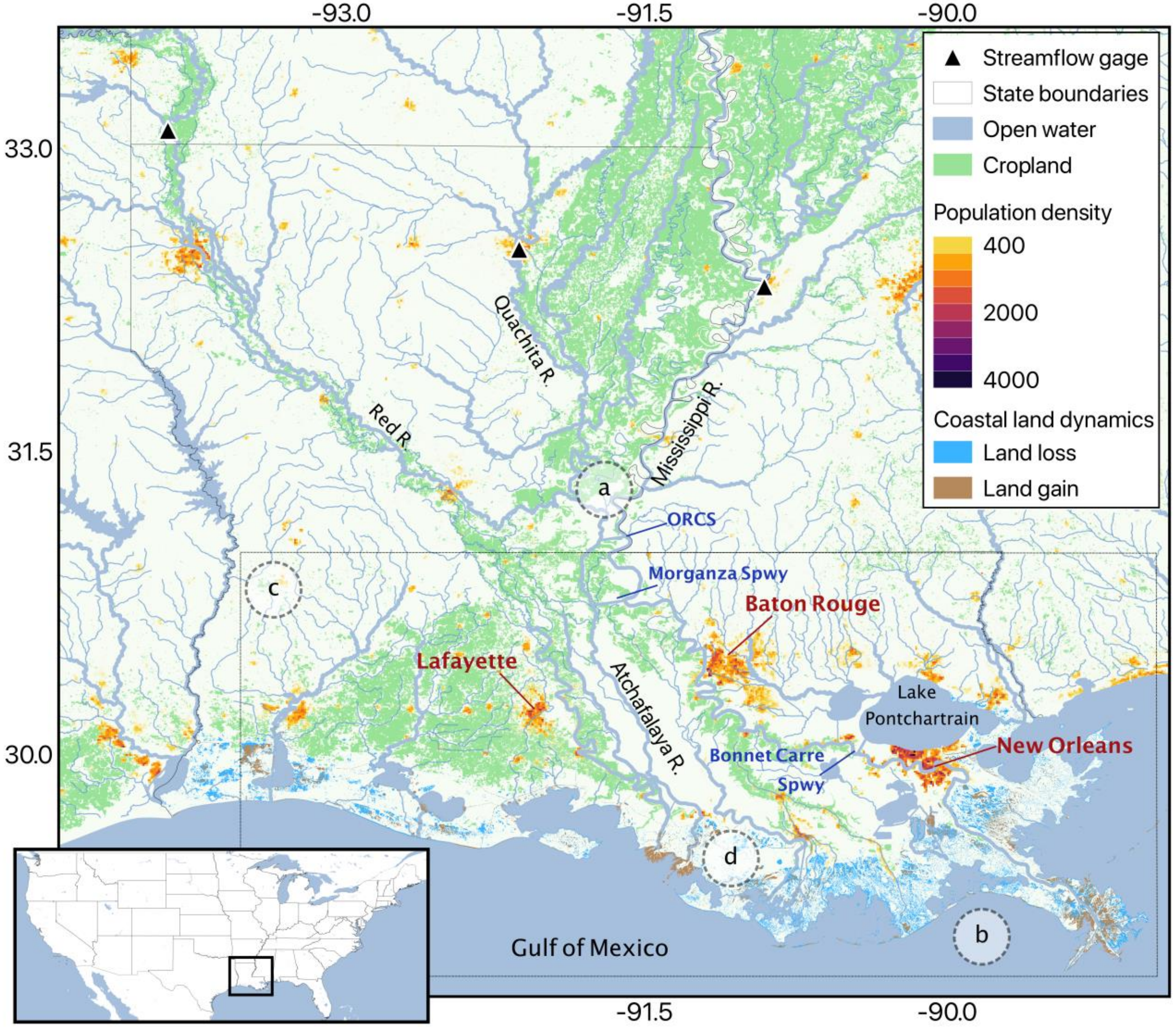
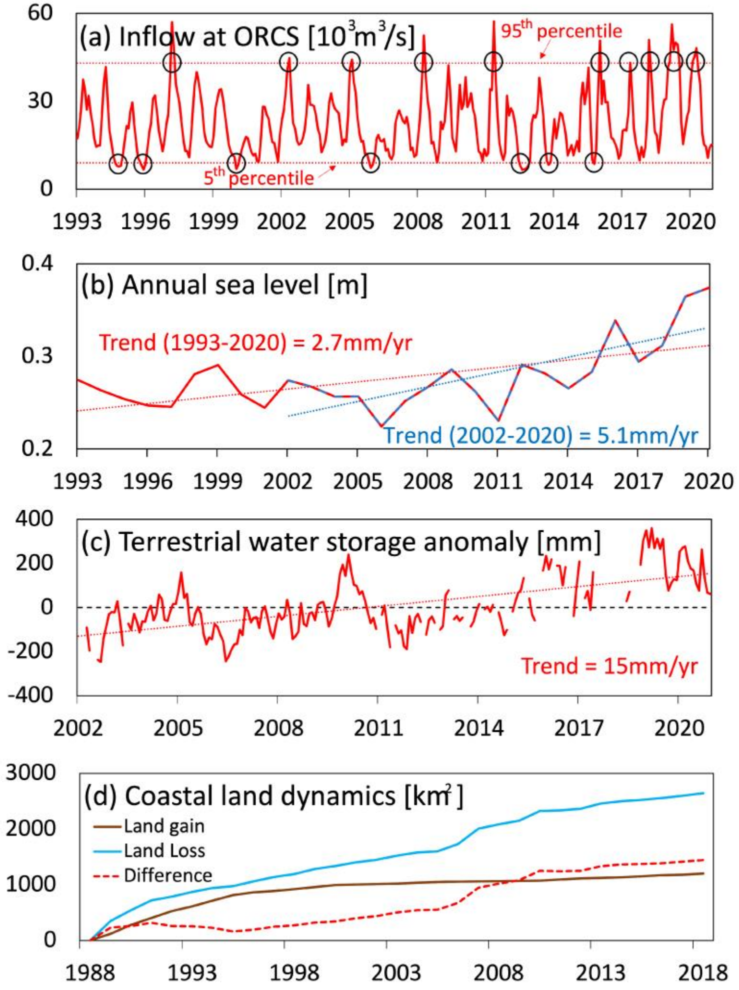
Climate and human impacts on hydrology and flood risk in Southern Louisiana

Observation-based evidence of hydrological change, sea level rise, increased terrestrial water storage and land loss



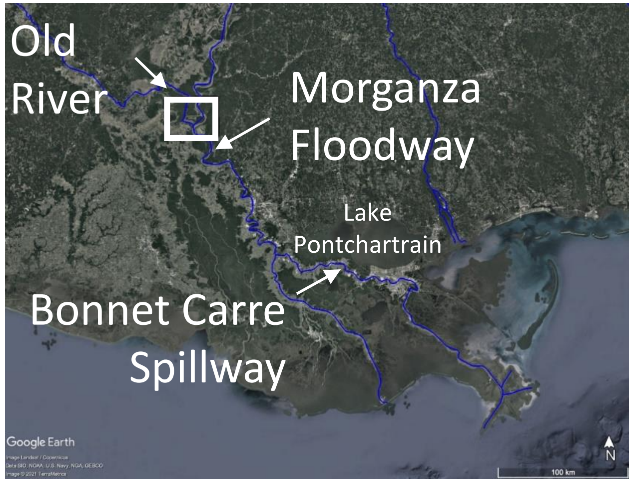


MRD model configuration

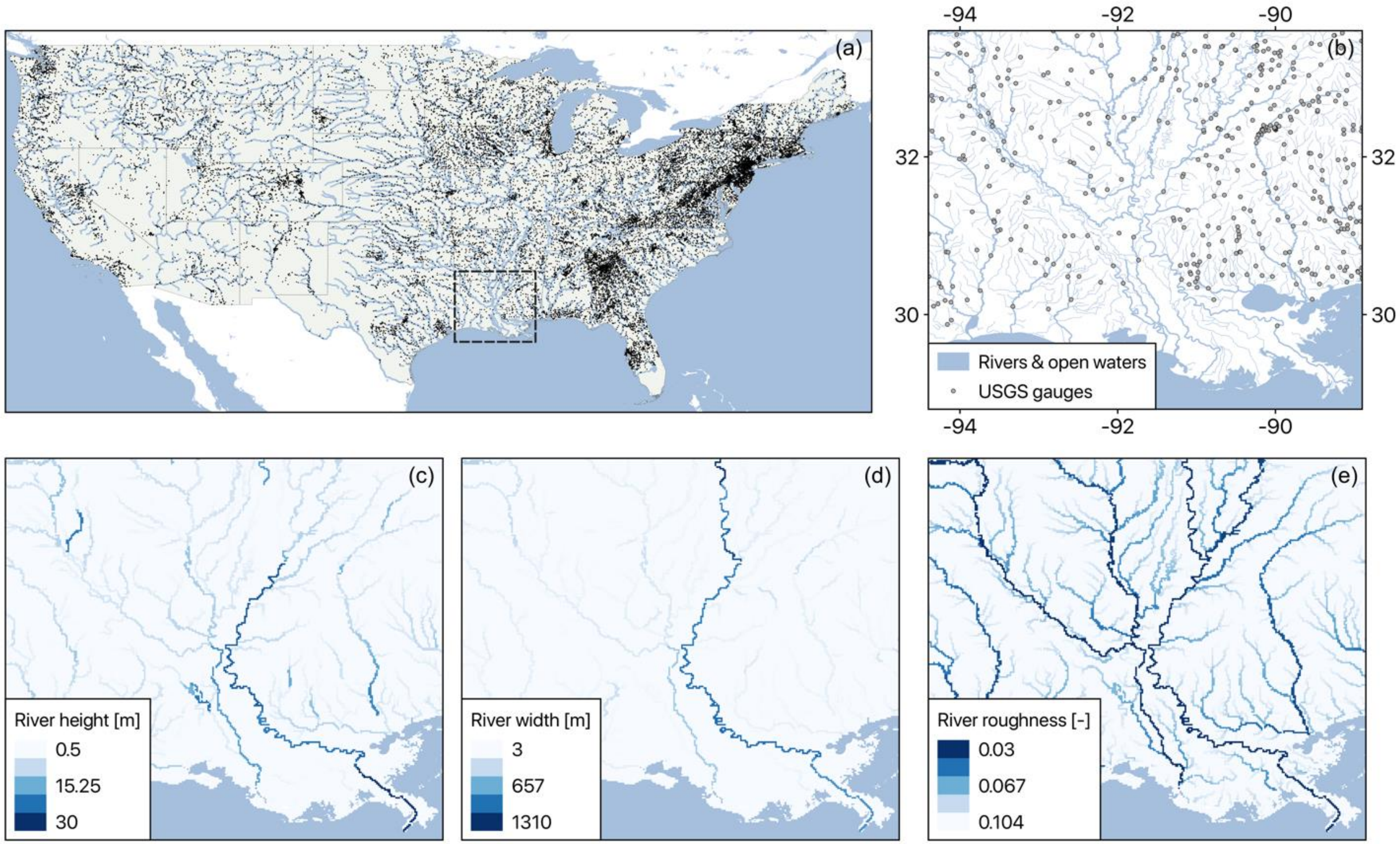
- 1993-2020 period;
- 2km spatial resolution;
- MERRA-2;
- Streamflow obs used as upstream boundary condition at 3 locations;
- Radar altimetry used as downstream boundary condition;
- 4 experiments;

Scenario	Hydrology	Sea level	Water management
1	Yes	7-day	Yes
2	Yes	7-day	No
3	Yes	Climatology	No
4	Yes	Constant	No

- Representation of water management

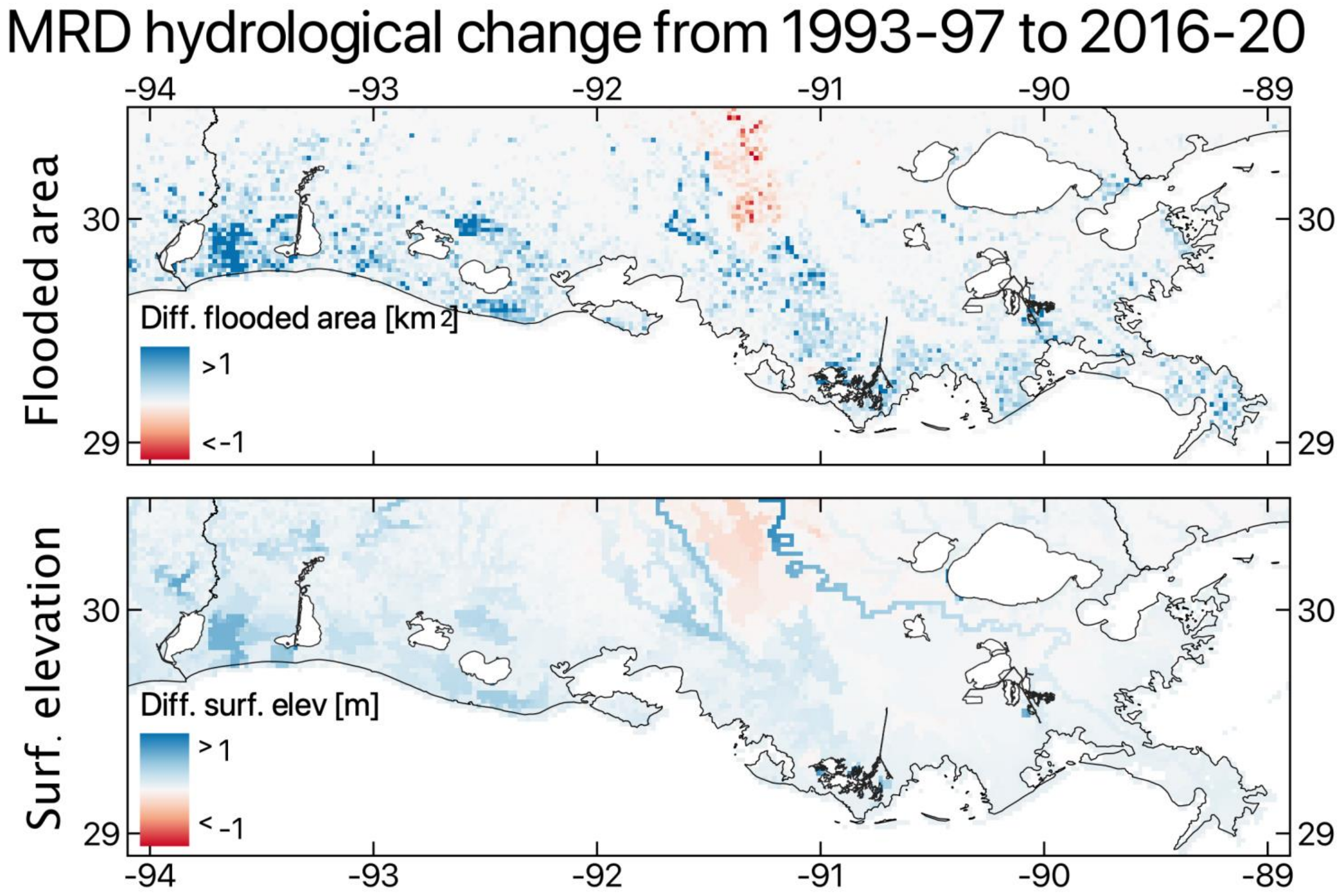


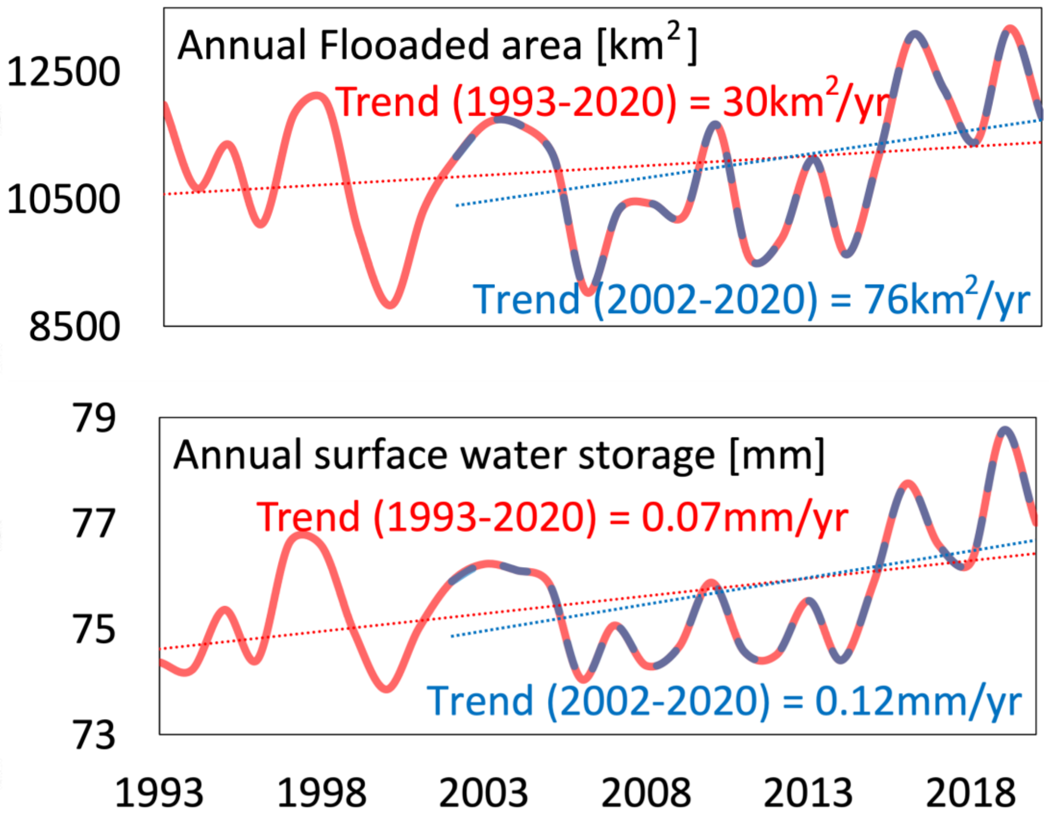
River geometry parameterization



Model-based MRD hydrological changes

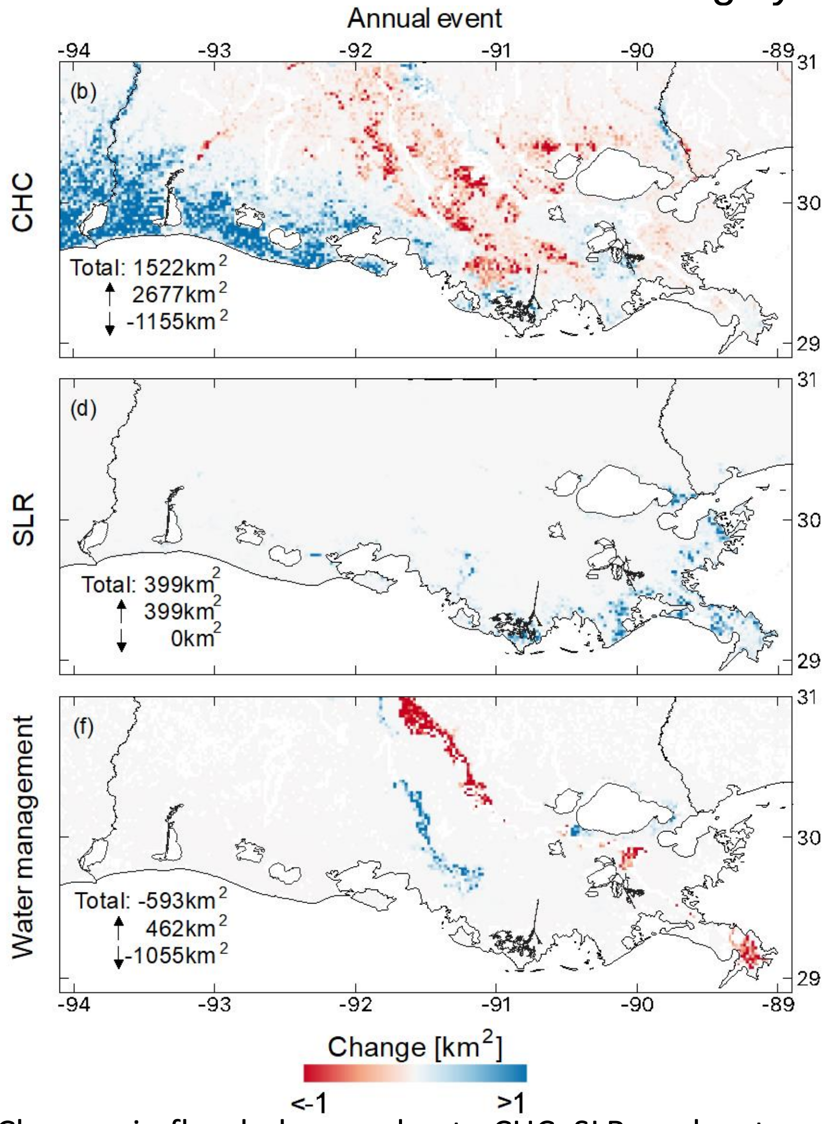
Based on Scenario 1 (i.e., all factors considered), surface elevation and flooded area generally increase over the domain from 1993-97 to 2016-20



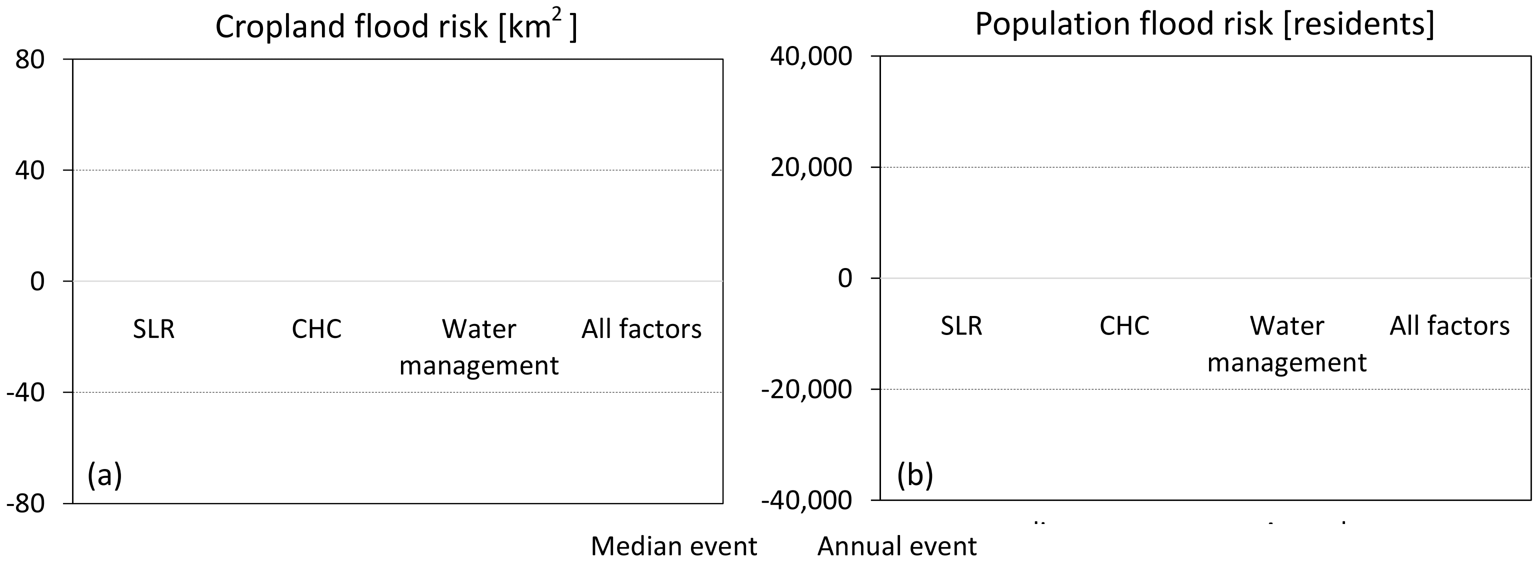


Coastal interface & water management

3 factors considered in our modeling system: Climate-induced hydrological changes (CHC), sea level rise (SLR) and water management



Changes in flooded areas due to CHC, SLR, and water management over coastal Louisiana for annual events



Flood risk over coastal Louisiana as a function of return period (median and annual events) due to SLR, CHC, water management and all factors combined (all factors).

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Impacts of dam operation on Lake Victoria, in Eastern Africa

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Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

Hydropower dam operation strongly controls Lake Victoria's freshwater storage variability

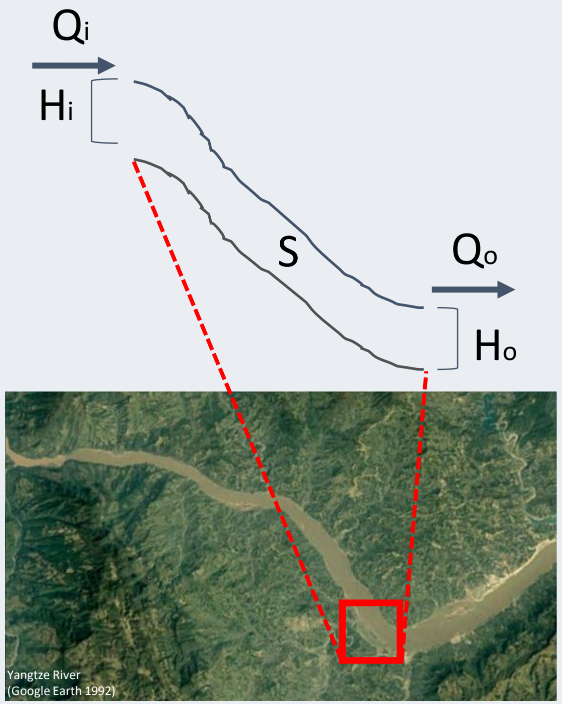
Augusto Getirana [a,b,*], Hahn Chul Jung [a,c], Jamon Van Den Hoek [d], Christopher E. Ndehedehe [e]

Objectives

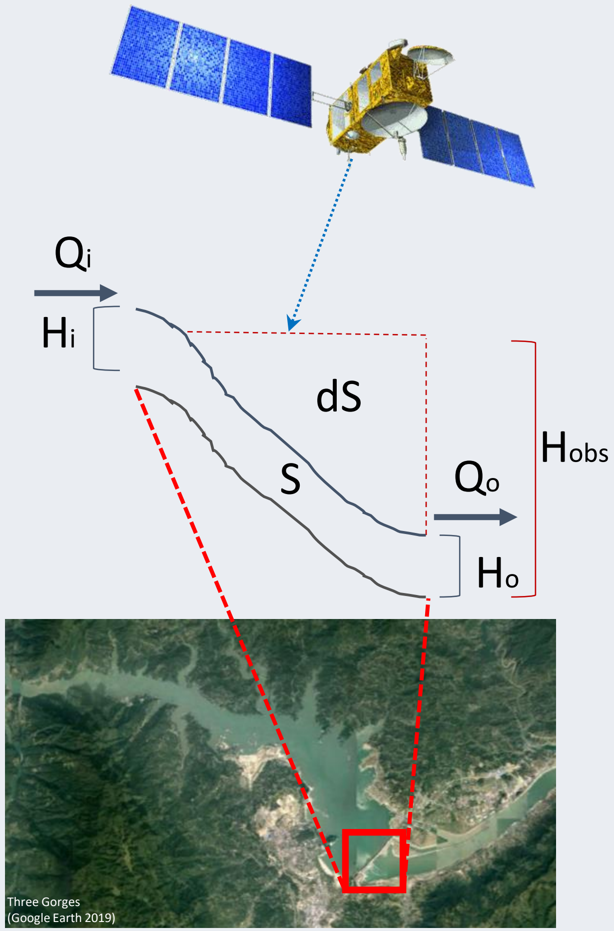
1. **Propose and implement a satellite-based reservoir operation scheme in HyMAP;**

2. **Evaluate impacts of such a scheme on the representation of:**
   i. **surface water dynamics (water elevation and extent);**
   ii. **terrestrial water storage variability.**

Implementation of a satellite-based reservoir operation scheme

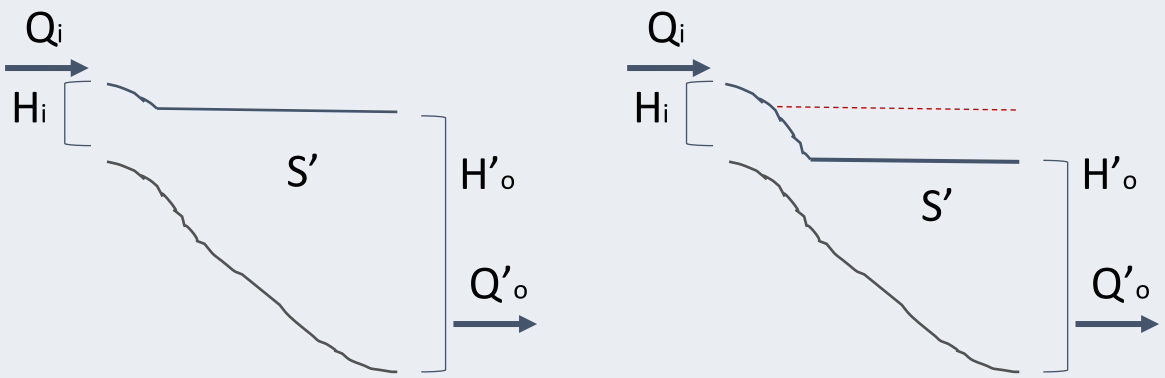


Grid cell
(naturalized system)



Grid cell
(Reservoir operation)

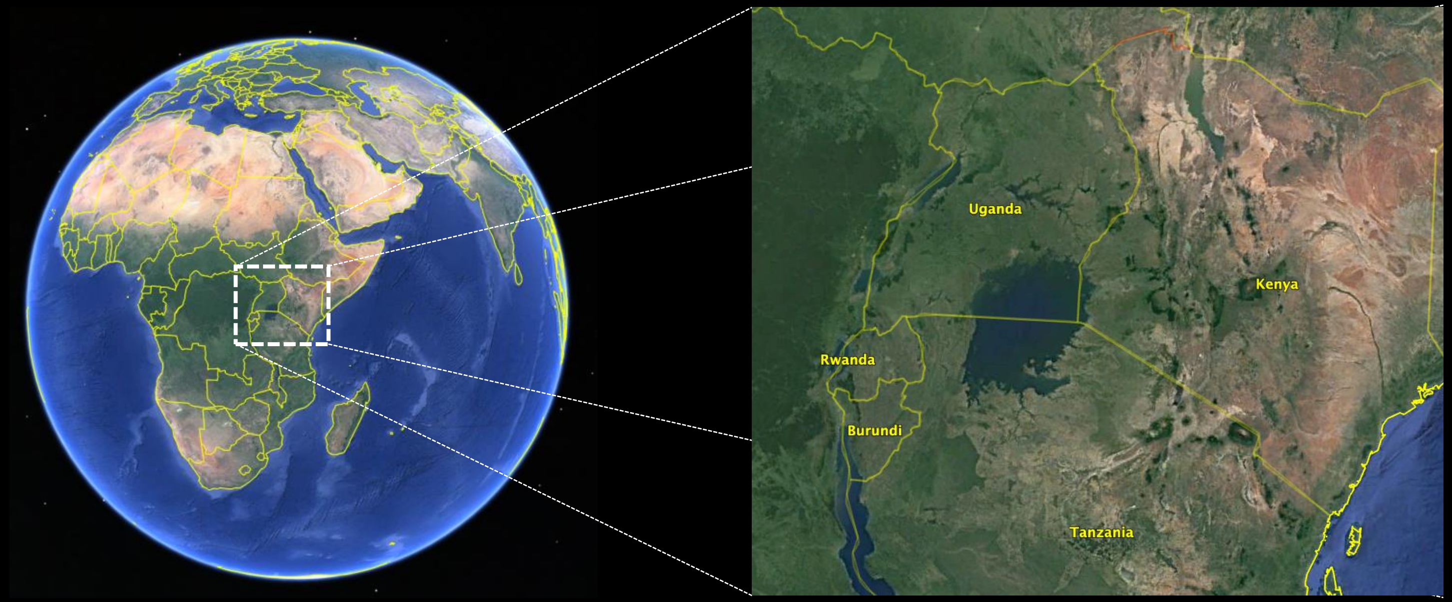
Satellite-based reservoir operation scheme



If $(Q_o - Q_{min}) \times dt \geq dS$

If $(Q_o - Q_{min}) \times dt < dS$

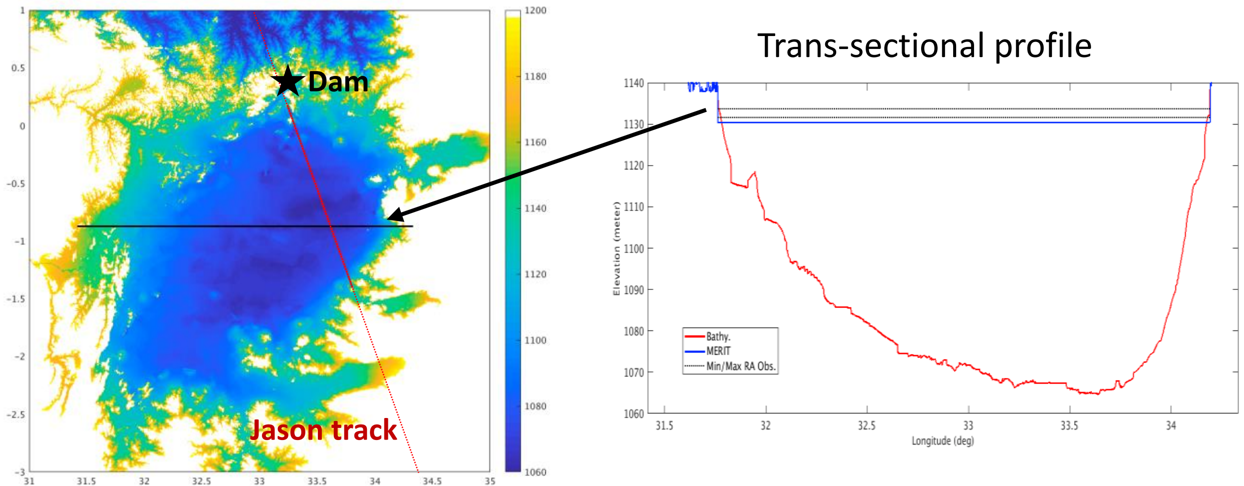
Lake Victoria



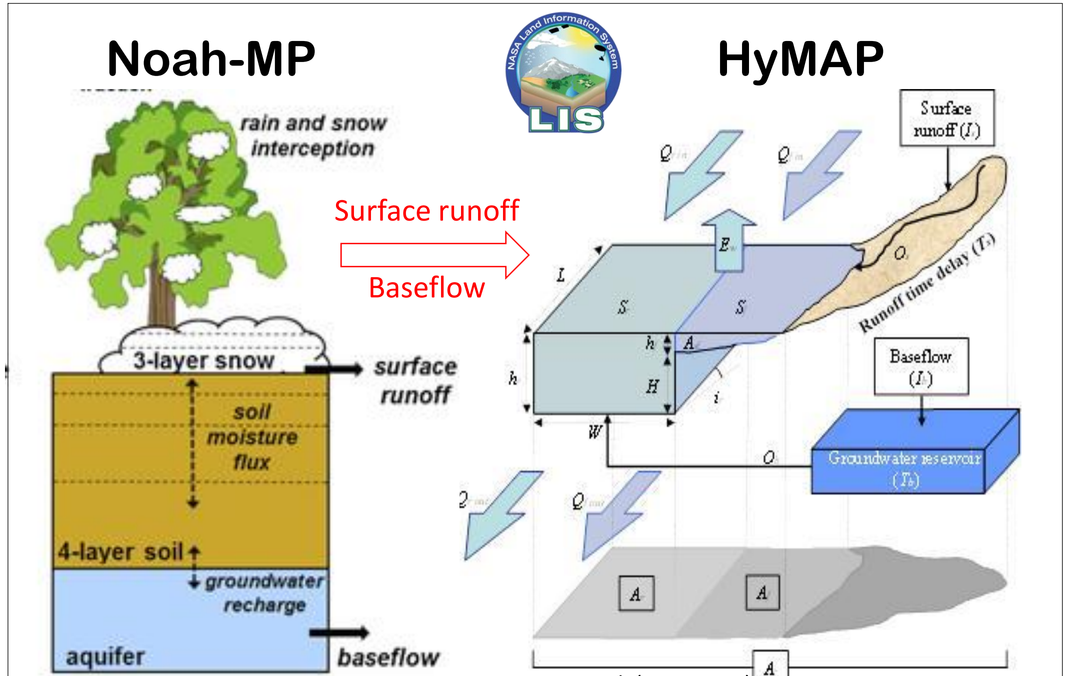
- Located in Eastern Africa;
- Shared by Uganda, Tanzania and Kenya;
- World's second largest freshwater lake after Lake Superior in the US.;
- Water extent: ~66,500km^{2};
- Water volume: ~2,750km^{2};
- Drainage area: ~252,000km^{2};
- White Nile River headwaters;
- Directly supports the livelihood of more than 42 million people;
- Controlled since 1954 (Nalubaale dam).

Parameterization

- 3-arcsec MERIT Hydro (Yamazaki et al., 2017): DEM, flow direction, drainage area;
- 3-arcsec bathymetry (Hamilton et al., 2016);
- Hydroweb's radar altimetry time series (Cretaux et al., 2011).



Experimental design



Mendoza et al. (2015, JHM)

Getirana et al. (2012, JHM)

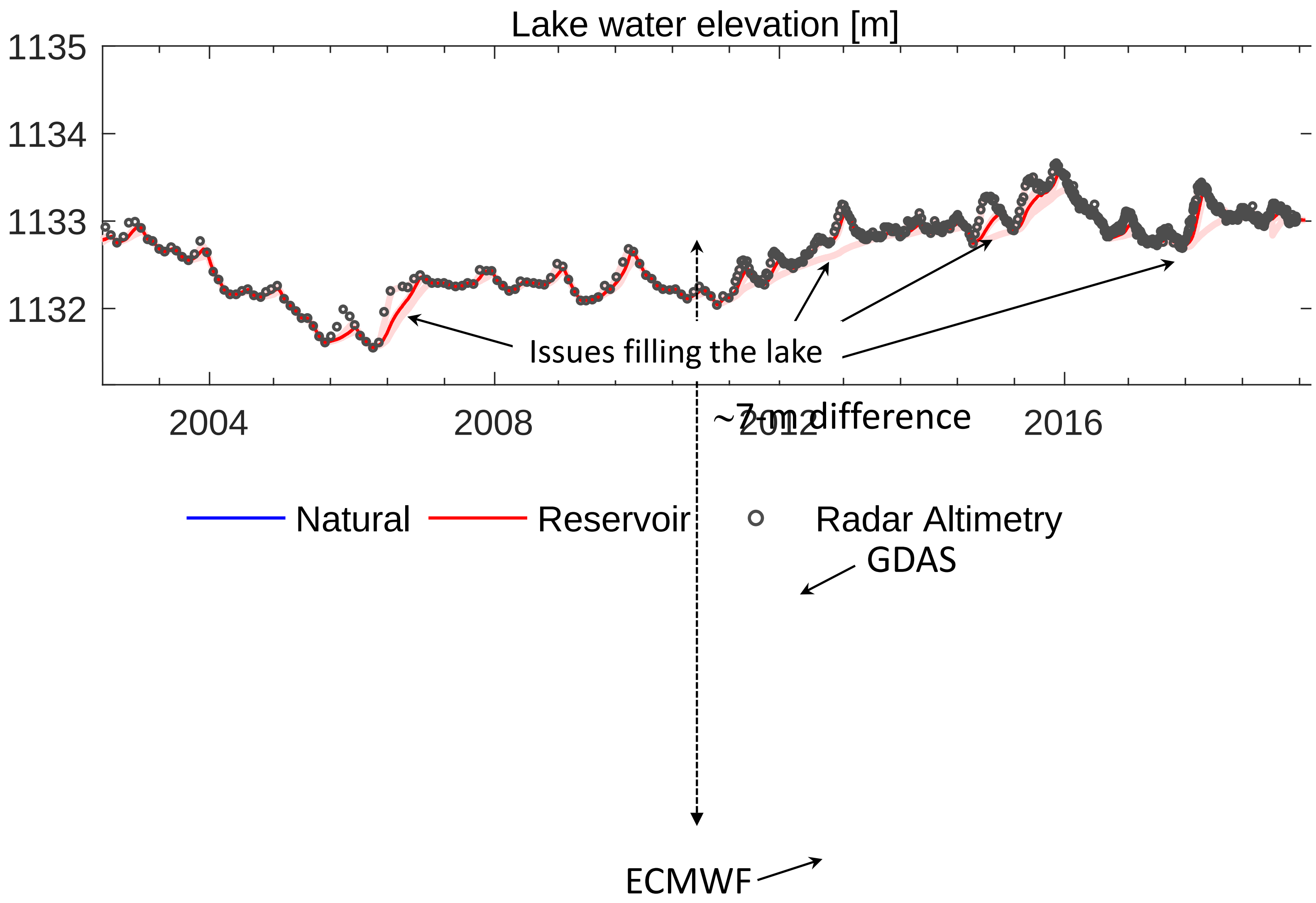
- ❑ Hydrological models:
- Noah-MP land surface model;
- Representation of groundwater;

- HyMAP global flood model;
- Local inertia formulation;
- Adaptive time step.

- ❑ Experiments:
- Naturalized system;
- Reservoir operation;
- Q_{min}=0;
- 0.1-degree spatial resolution;
- 15-min time step;
- 2003-present.

- ❑ Meteorological forcings:
- **MERRA-2** (**M2**; 1979-present) ;
- **CHIRPS** (**M2C**; 1981-present);
- **ECMWF** (2003-present);
- **GDAS** (2000-present).

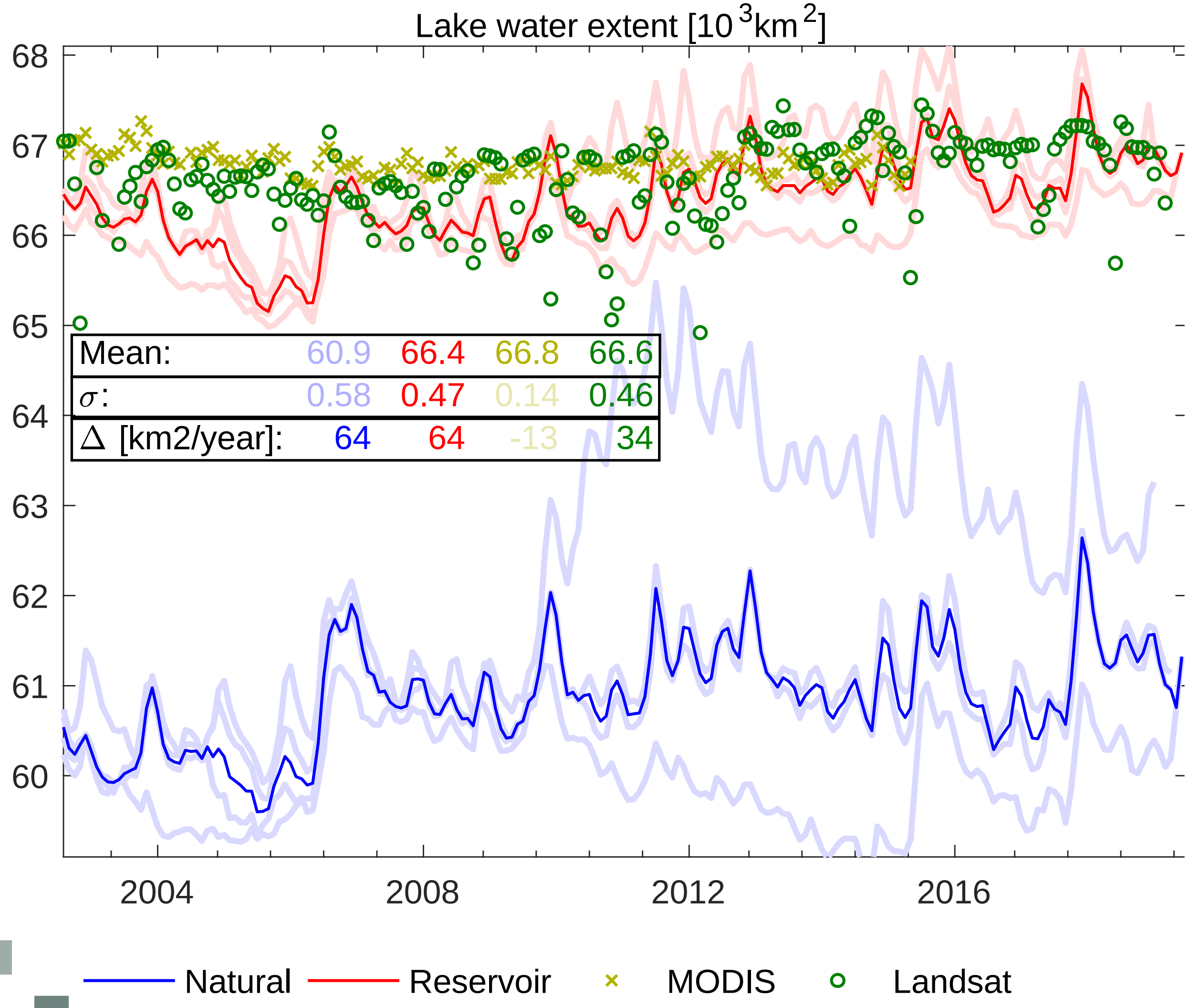
RESULTS

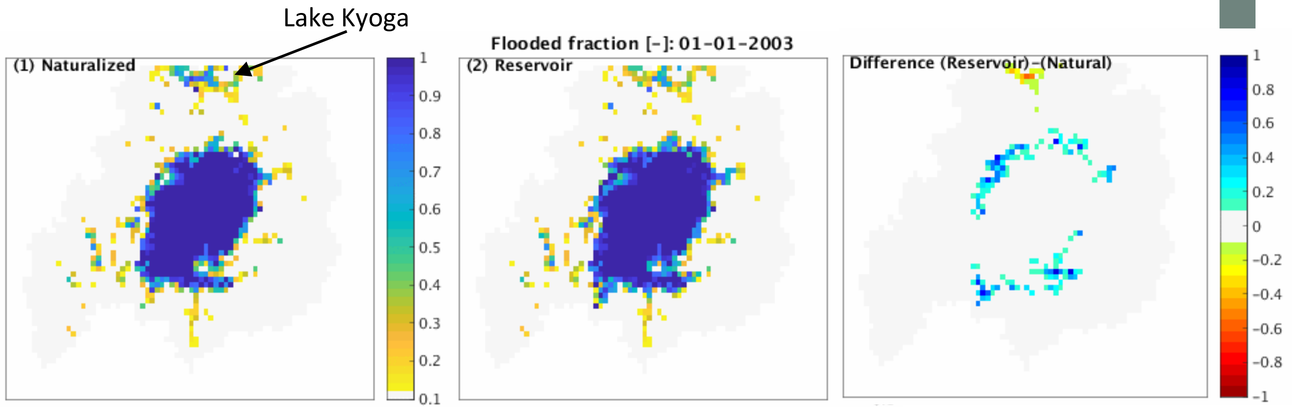


	M2	M2C	ECMWF	GDAS
RMSE	0.08	0.10	0.17	0.05
NS	0.95	0.93	0.79	0.99
r	0.98	0.97	0.94	0.99
γ	0.99	0.97	0.93	1.00

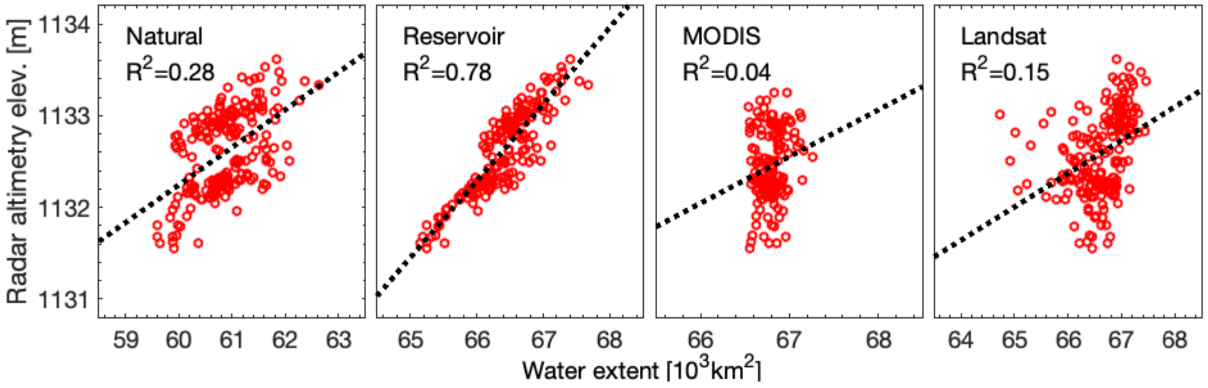
- All forcings present good metrics for water elevation;
- GDAS shows the best overall result;
- There are issues filling the lake, in particular, ECMWF;
- There is about 7-m difference between experiments with reservoir and naturalized system;
- GDAS has too much water and ECMWF has too little;
- Ensemble median is used for comparison;
- All metrics are significantly improved with the reservoir operation scheme.

WATER EXTENT





- Long-term average modeled water extents match satellite observations; (μ = mean)
- Reservoir operation and Landsat-based variability (standard deviation) are similar;
- Except for MODIS, all trends are positive (both model experiments show steeper trends);
- Water extent derived from reservoir operation shows the best agreement with radar altimetry.



- Rivers and floodplains as key components of terrestrial water storage variability
- Climate and human impacts on hydrology and flood risk in Southern Louisiana
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- **Final considerations and prospects**

NASA-Rio de Janeiro Partnership

- Better understand, anticipate, and monitor **environmental hazards** in Rio de Janeiro
- **Pioneer applications** of NASA Earth Observations at the urban scale
- Conduct **joint activities** that leverage NASA's remote sensing products and Rio de Janeiro's monitoring and crisis management capabilities
- Bring NASA Earth science to **Brazilian educators** and students

NASA-Rio Disaster Preparedness Cooperative Effort

In Dec. 2015, NASA and the City of Rio de Janeiro signed an agreement to support innovative efforts to better understand, anticipate, and monitor hazards, including heavy rainfall, sea level rise, and landslides, in and around the city. This collaboration will leverage the unique attributes of NASA's satellite data and Rio de Janeiro's management and monitoring capabilities to improve awareness of how the city of Rio may be impacted by hazards and affected by climate change.

NASA's Earth-observing satellites provide valuable information to diagnose how our environment and climate is around the world. The City of Rio de Janeiro collects important data from the ground to connect with what can be viewed from space for improving the monitoring of hazards and climate impacts, making decisions, and taking action.

This collaboration will focus on integrating, visualizing, and sharing relevant data, as well as providing detailed information about the hazards and how they are being studied with the general public. NASA seeks to develop a scientific understanding of Earth's water and energy systems and how they

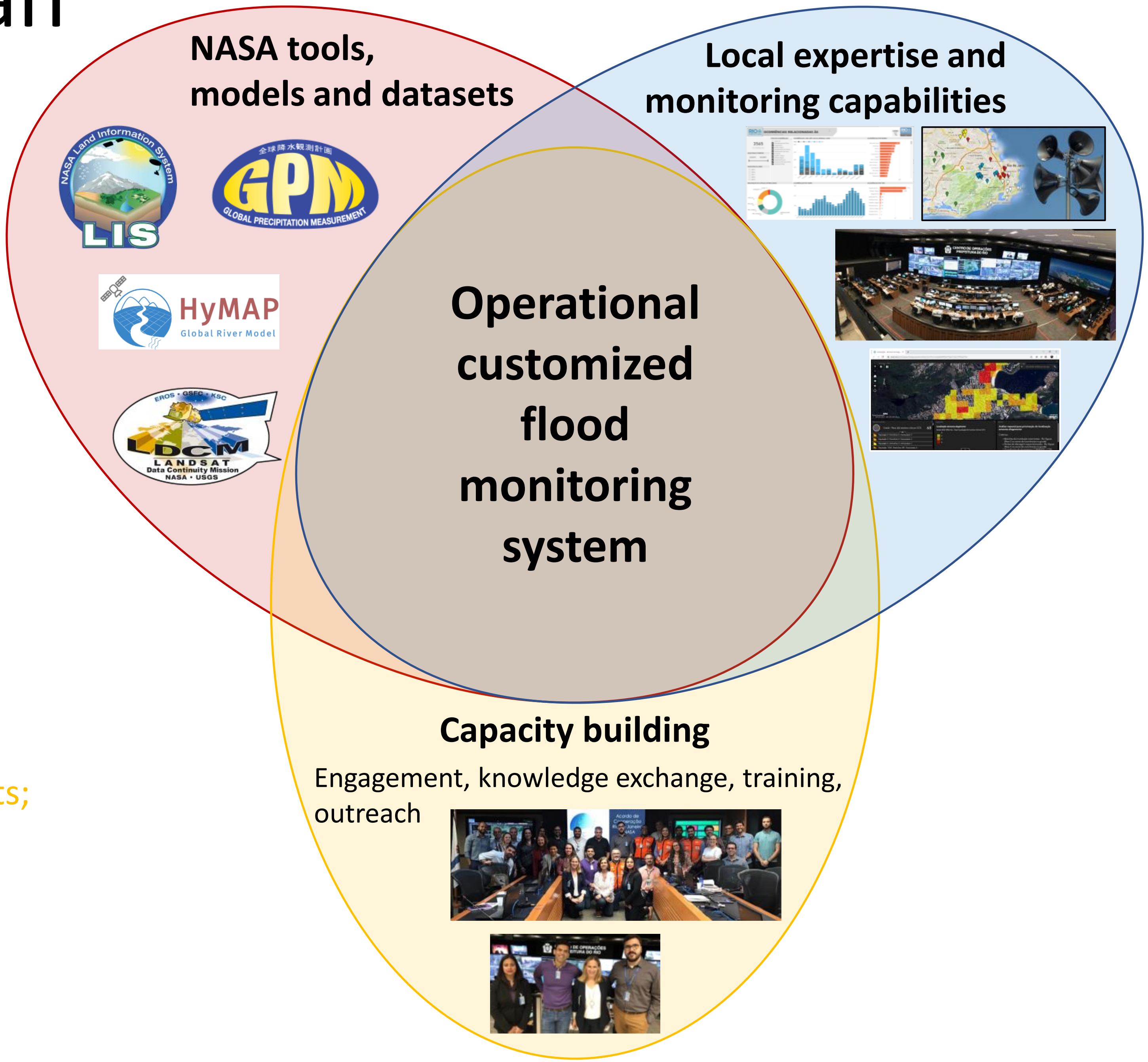
Courtesy: D. Kirschbaum

Goal and proposed plan

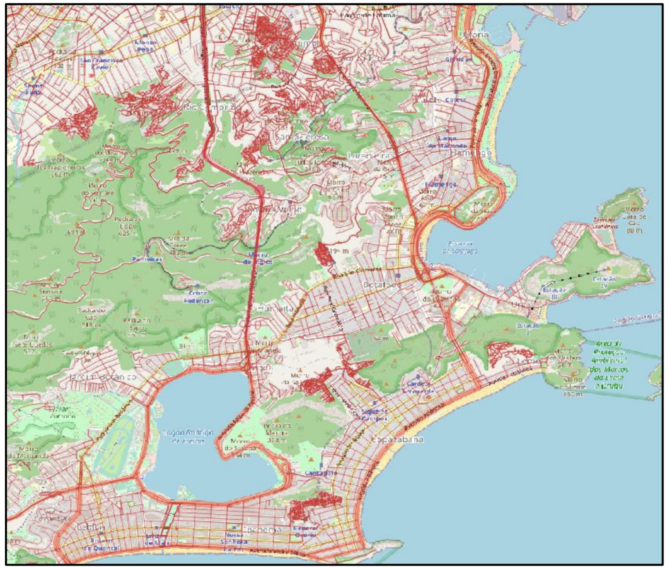
- Land Information System (LIS);
- Land surface Data Toolkit (LDT);
- GPM;
- Landsat;
- Modeling and satellite expertise.

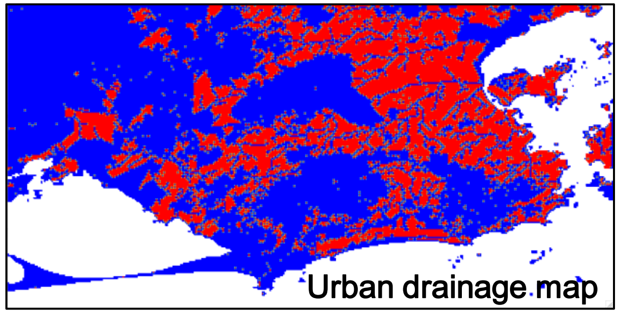
- Real-time hydrometeorological monitoring;
- Local land use and soil type distribution;
- Lidar-based DEM;
- River network and geometry;
- Flood mapping;
- Urban drainage system, etc.

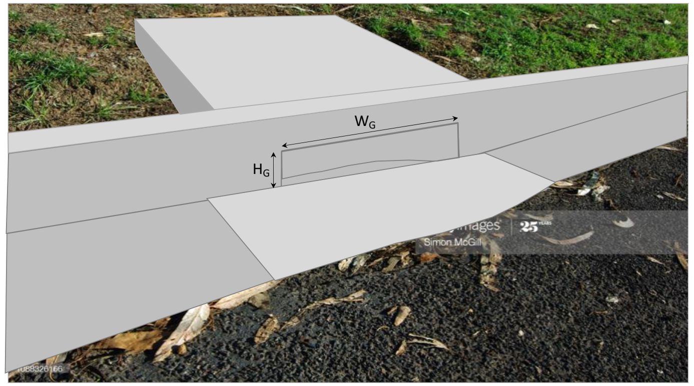
- Frequent phone calls, emails;
- Updates on results, challenges and requirements;
- Annual in person meetings and workshops;
- Strong local interest and technical expertise;
- Easy and immediate access to information, etc.

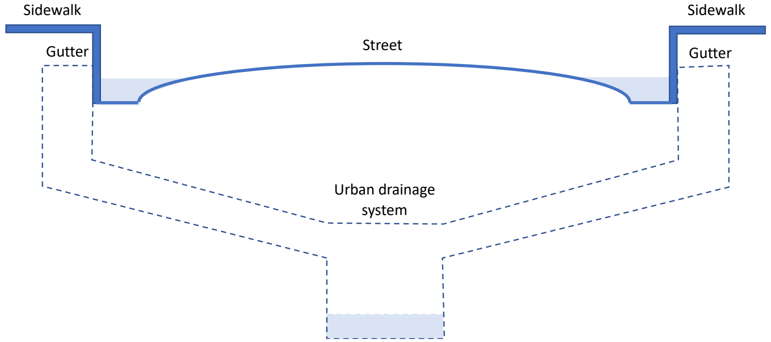


HyMAP's urban drainage module





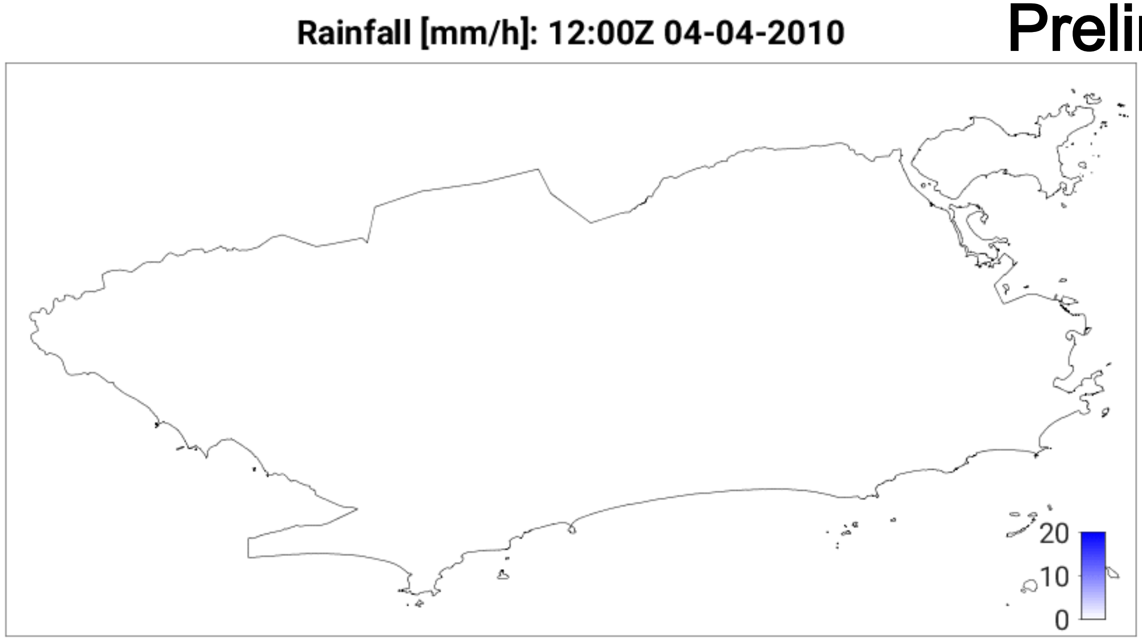


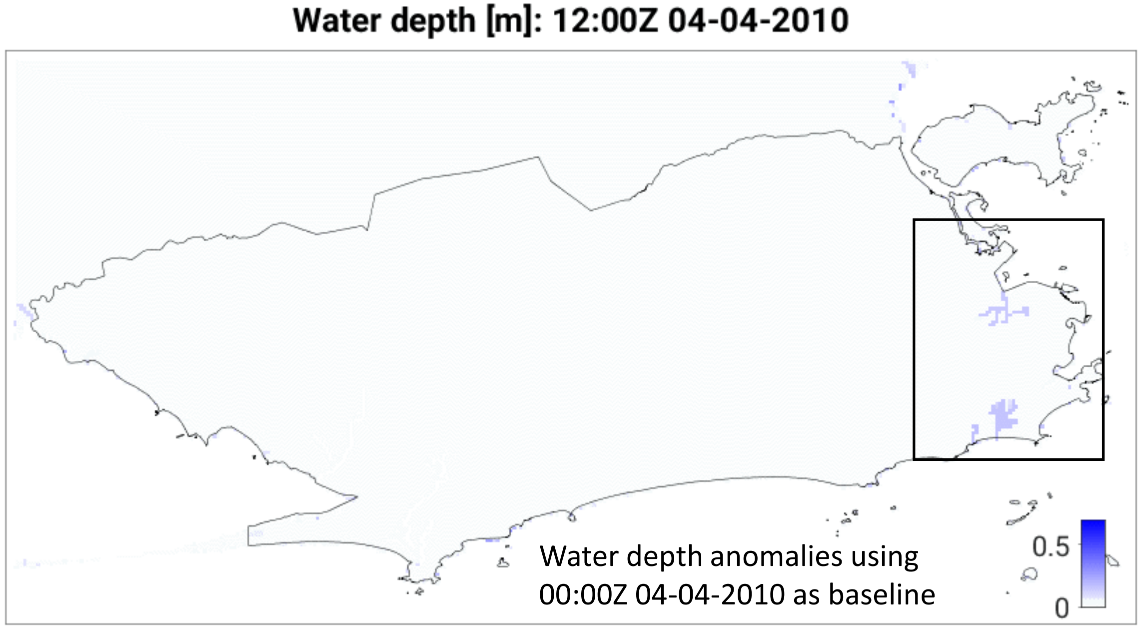


Drainage network parameters	
Street block length [m]	100
Underground squared pipe width [m]	1
Drainage length density [m/m^2]	0.02
Roughness coefficient for cement pipes [-]	0.012
Drainage system slope [m/m]	0.003

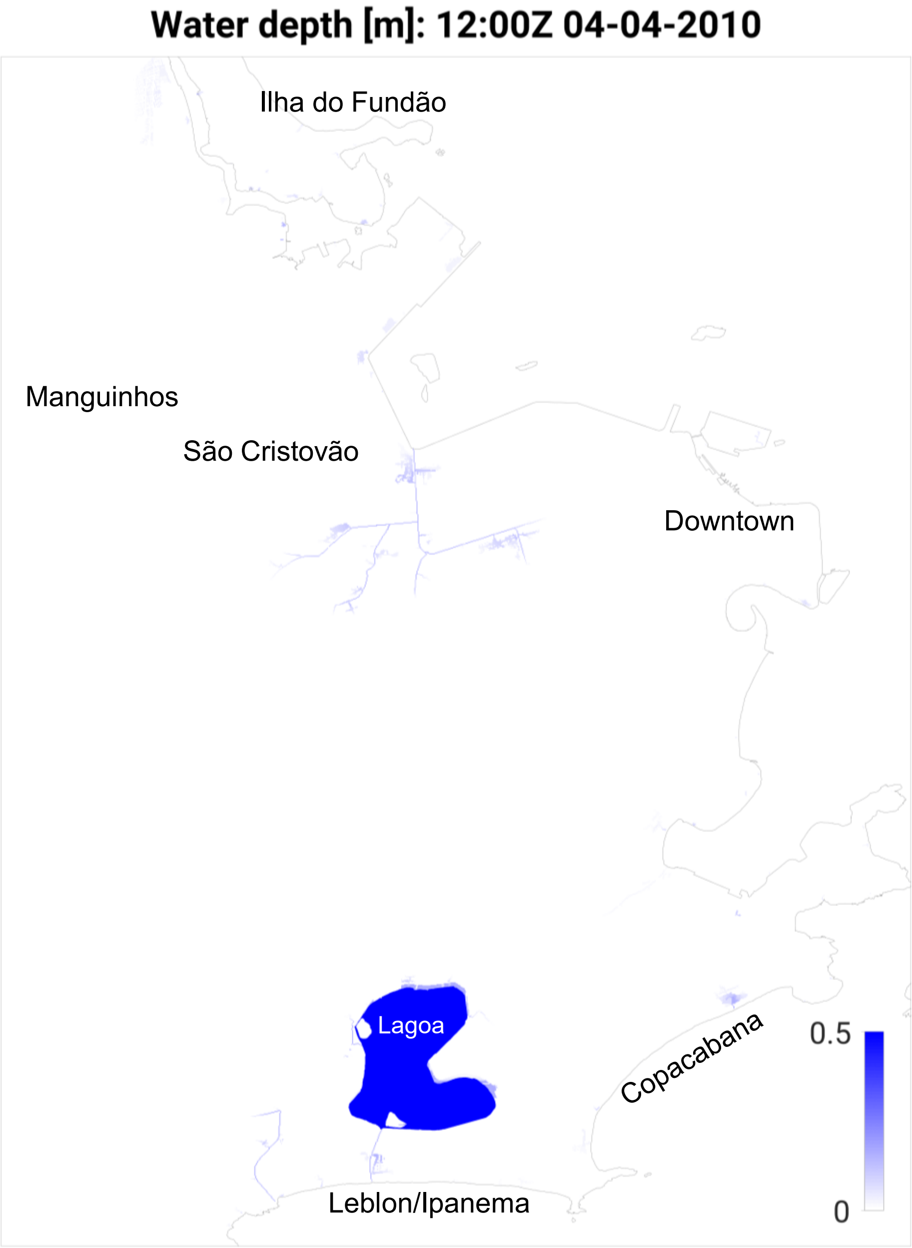
Gutter parameters	
Gutter width [m]	1
Gutter height [m]	0.15
Gutter density [units/m^2]	0.0008
Gutter water intake velocity [m/s]	2

Preliminary results





Downscaled water depth anomalies at 10-meter spatial resolution during major flood occurred in April 2010



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Final considerations & prospects

- HyMAP has been significantly improved in the past 11 years, since its initial implementation in LIS;

- The combination of all capabilities currently available in HyMAP puts it as one of the most advanced global flood models available;

- Ongoing and future developments:
  - Bifurcation;
  - Improved reservoir operation scheme;
  - Inclusion of natural lakes and a water quality module.

- HyMAP is freely available in LIS through GitHub (https://github.com/NASA-LIS/LISF);

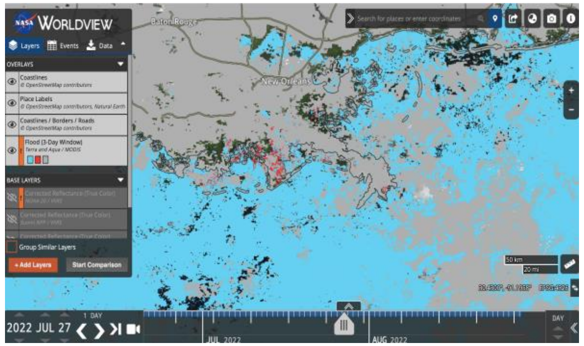
- HyMAP outputs are available from FLDAS, NCA-LDAS, and soon from GLDAS (https://ldas.gsfc.nasa.gov/);

- New collaborations for either new developments and applications are always welcome!

Summary

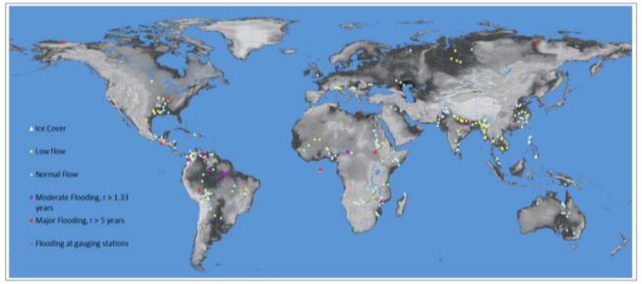
Flood Monitoring and Mapping

MODIS Flood Map



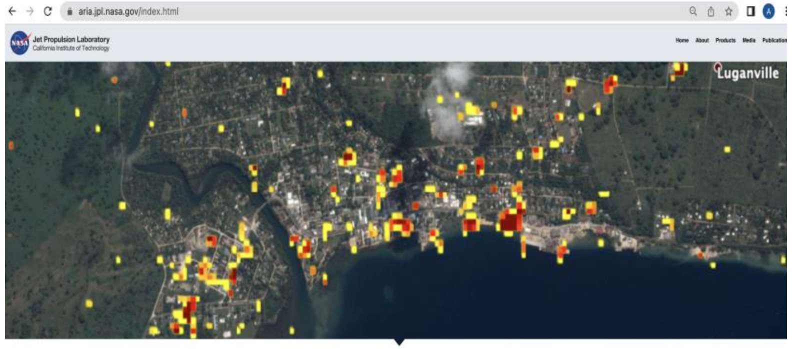
https://worldview.earthdata.nasa.gov/

Passive Microwave Observations-based River Discharge



https://floodobservatory.colorado.edu/DischargeAccess.html

Sentinel-1 SAR-based flood Mapping
ARIA



https://aria.jpl.nasa.gov/index.html

Multiple Data Sources
GDACS

https://gdacs.org/

HYDrologic Remote Sensing Analysis for Floods (HYDRAFloods)

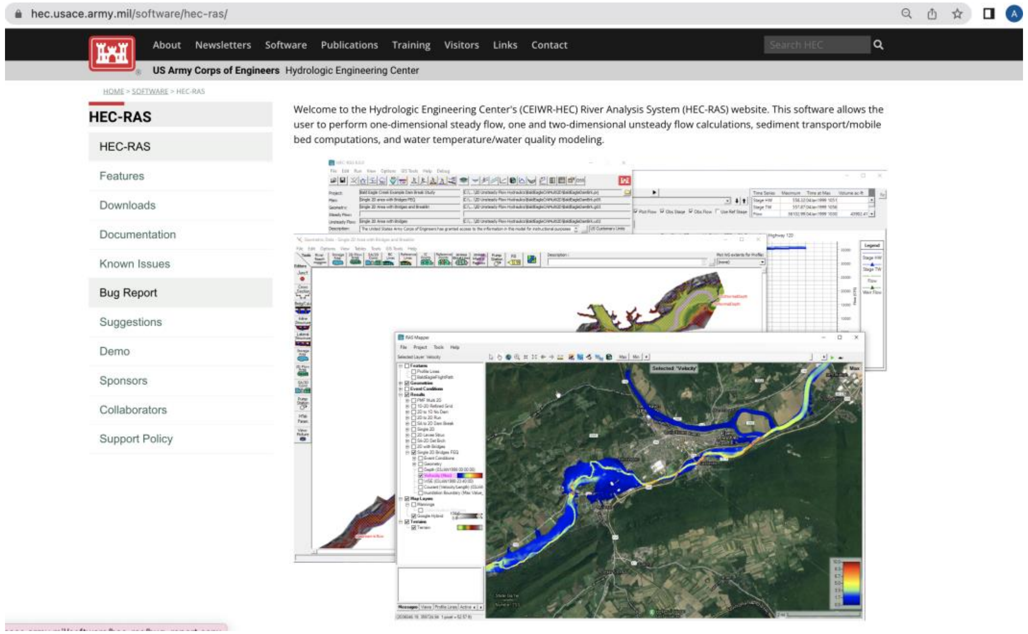
https://servir-mekong.github.io/hydra-floods/algorithms/

- HYDRAFloods uses the following remote sensing inputs:
  - Sentinel-1 C-band SAR data
  - Sentinel-2 optical data
  - Landsat 7 & 8 optical data
  - VIIRS and MODIS optical data
- A publicly available, web-based, near real-time flood monitoring tool
- Developed using Google Earth Engine and Google Cloud Platform with Python API.

- HYDRAFloods allows access to high-quality, cloud-based surface water mapping algorithms:
  - SAR Speckle Filtering Algorithms
  - Correction Algorithms
  - Applying Illumination Correction on Optical Imagery
  - Applying Slope Correction on SAR Imagery
  - Generic Water Mapping Algorithms

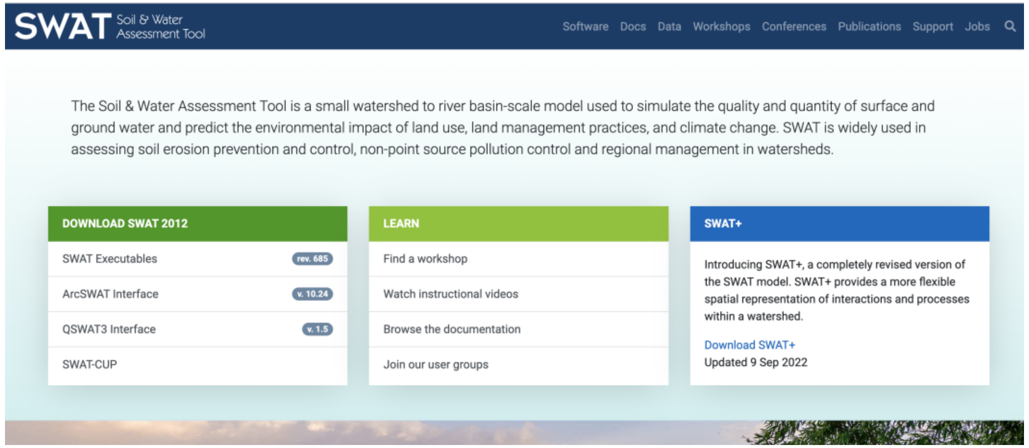
Examples of Flood Models

HEC-RAS



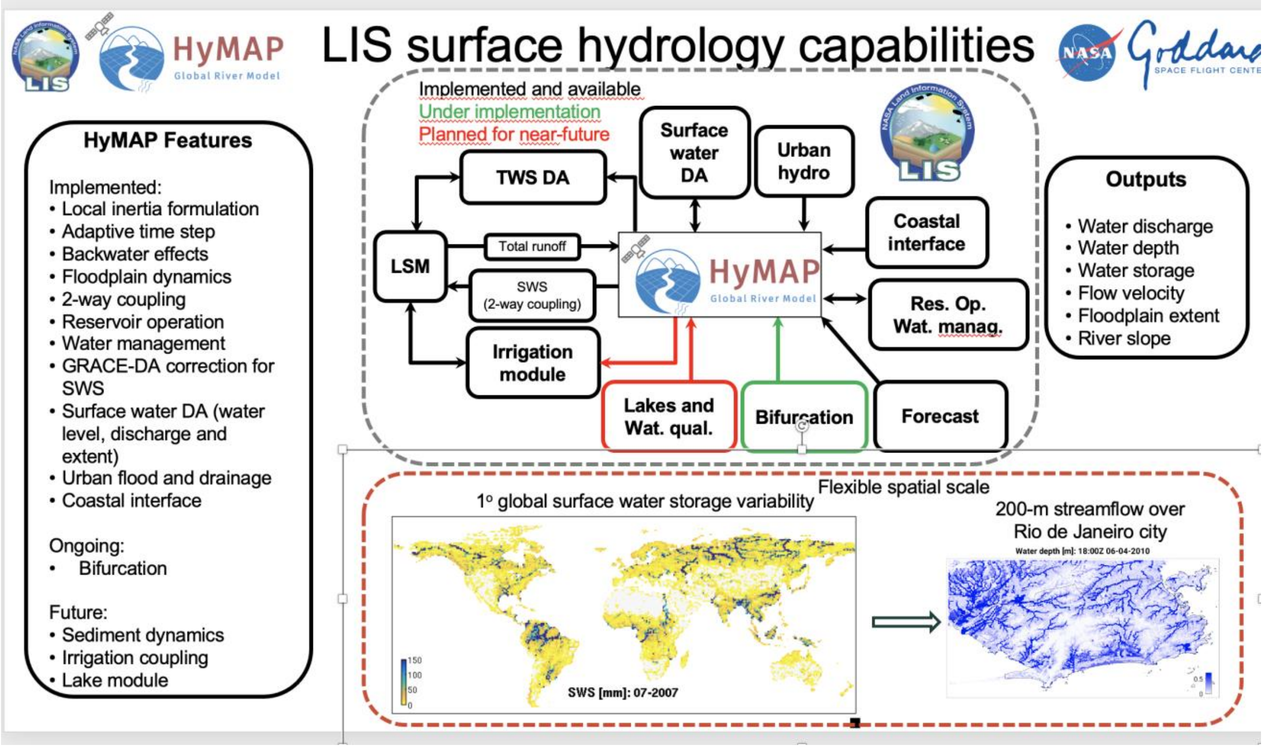
https://www.hec.usace.army.mil/software/hec-ras/

SWAT



https://swat.tamu.edu/

Flood Modeling System (LIS-HyMAP)



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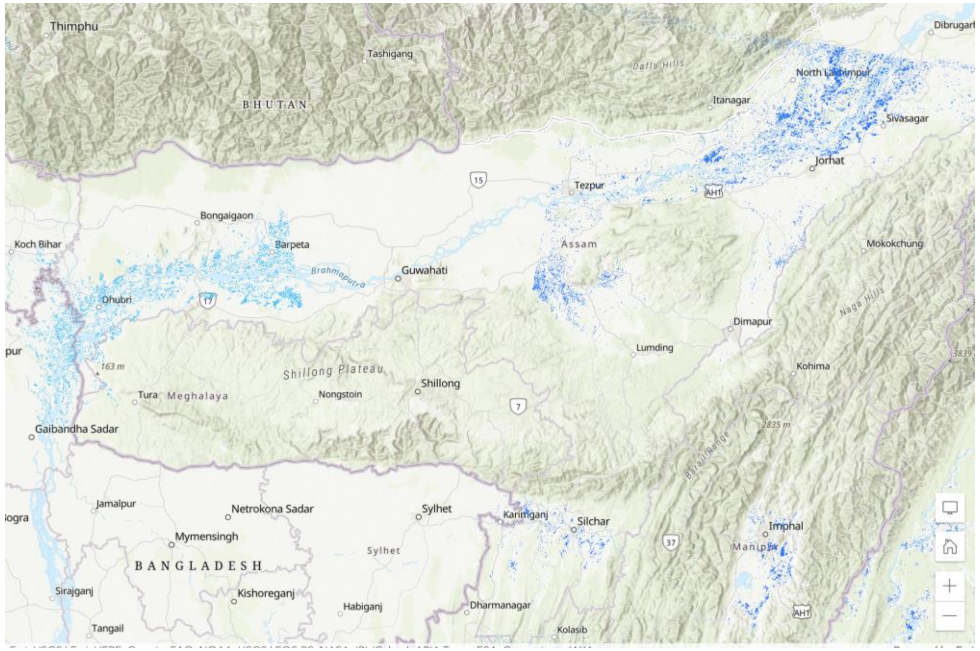
From: A. Getrirana

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.

Bangladesh Floods – June 2022



https://maps.disasters.nasa.gov/arcgis/home/item.html?id=9e49f039612741878e7f560a67f2d4e5

Contacts

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- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-monitoring-and-modeling-floods-using-earth-observations
- ARSET Website:
  - https://appliedsciences.nasa.gov/arset
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Thank You!