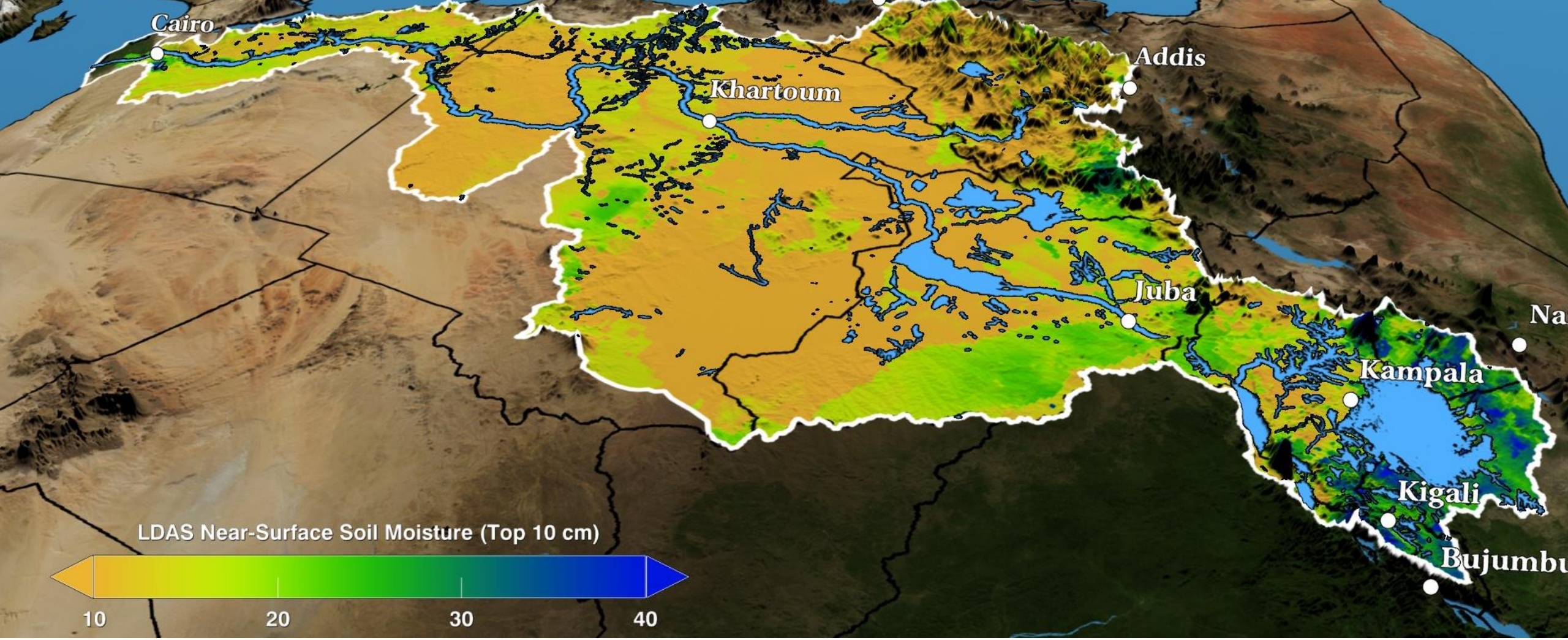


REMOTE SENSING FOR WATER BUDGET MONITORING: THE NILE RIVER BASIN

Ben Zaitchik
Johns Hopkins University

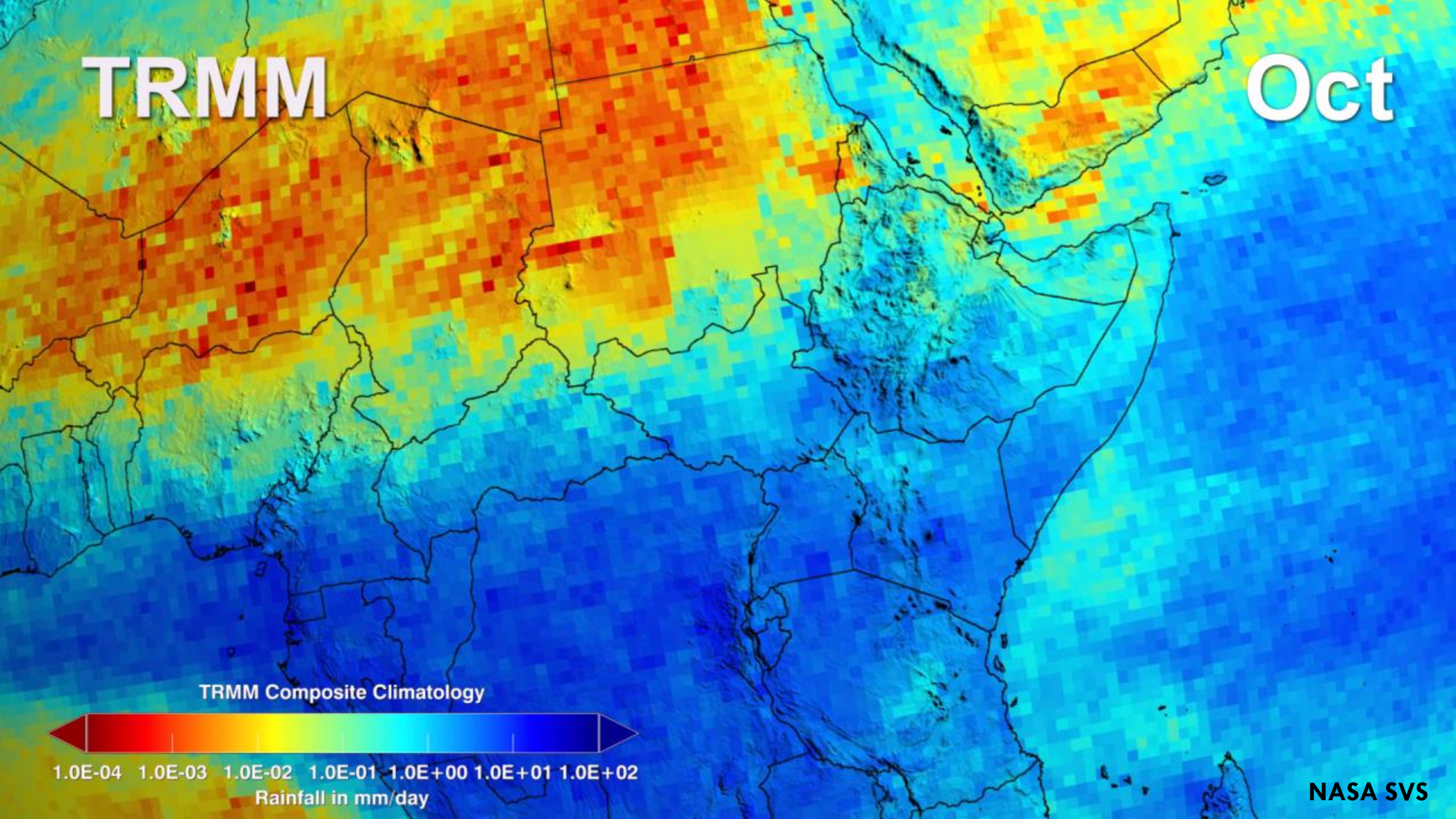
OBJECTIVES

Apply Earth Observations to:

Estimate the distributed water balance of the Nile Basin

Improve and evaluate hydrological models used in water resource analysis

Monitor and understand variability in hydrologically complex regions


TRMM
Oct
TRMM Composite Climatology
1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 1.0E+01 1.0E+02
Rainfall in mm/day
NASA SVS

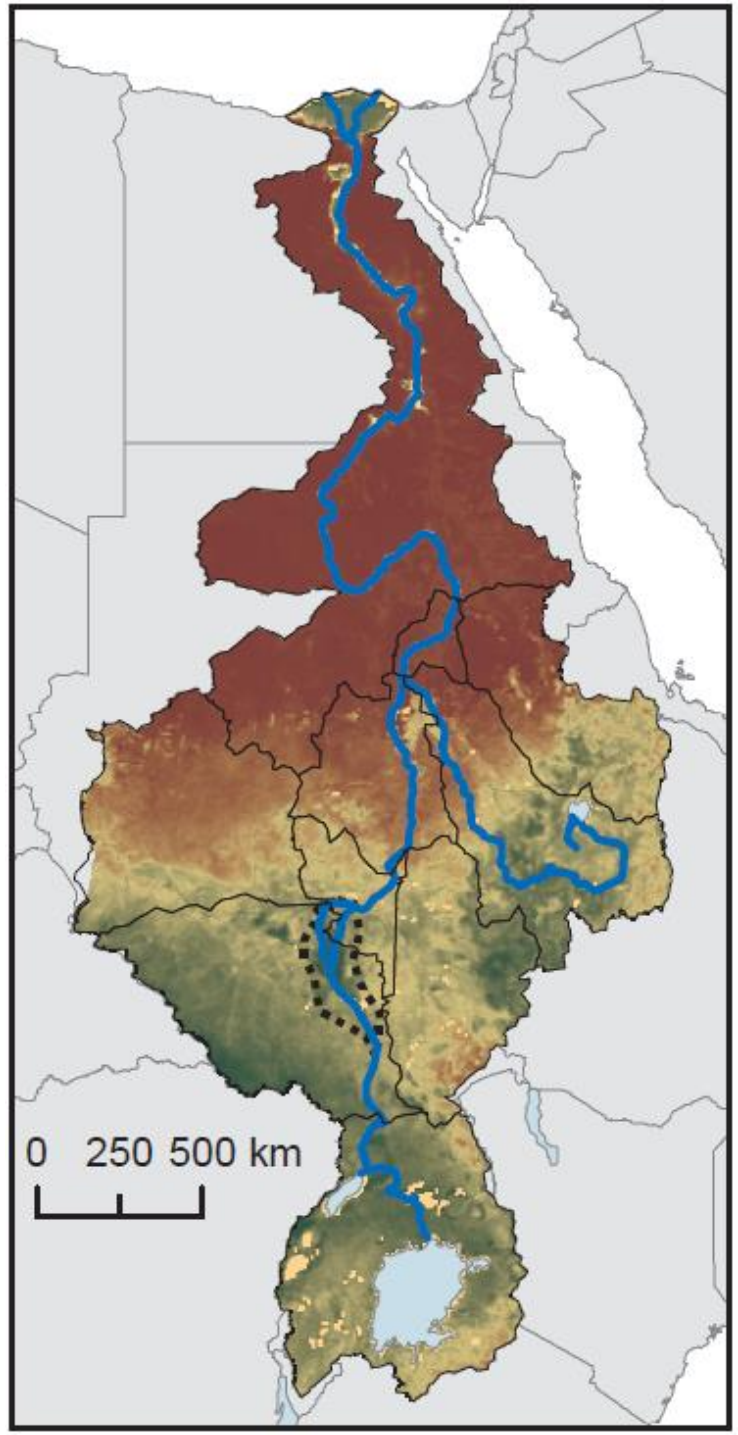
CHALLENGES

In situ data are **sparse**

In situ data are often **politically sensitive**

The basin is **evaporation dominated**

There is considerable meteorological and hydrological **complexity**



SELECTED REMOTE SENSING STUDIES OF THE NILE

Remotely sensed water balance analysis

The Nile Land Data Assimilation System

Wetland mapping and monitoring

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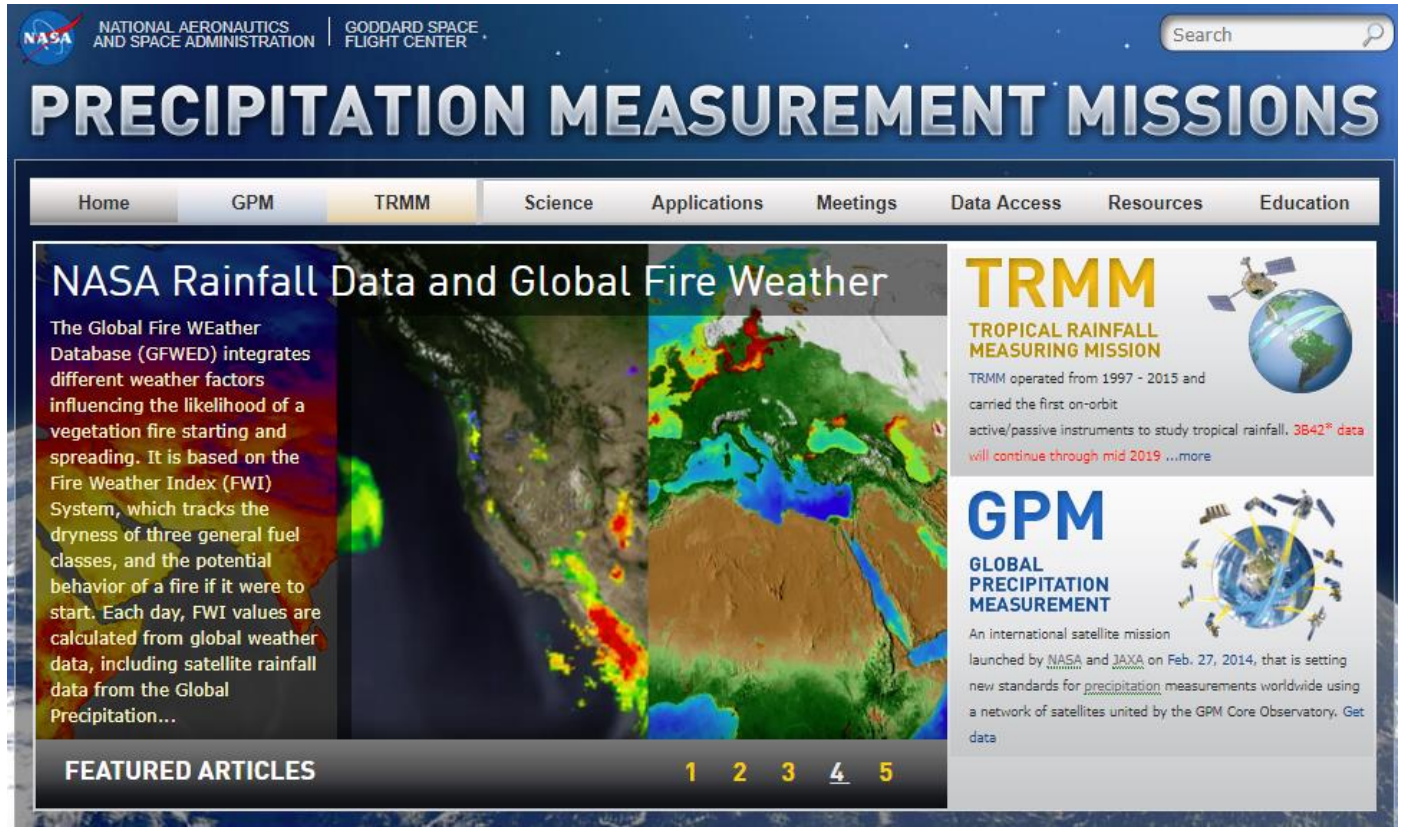
REMOTELY SENSED WATER BALANCE ANALYSIS

1st order terrestrial approach:

$$Precipitation - Evapotranspiration - Discharge = \Delta Storage$$

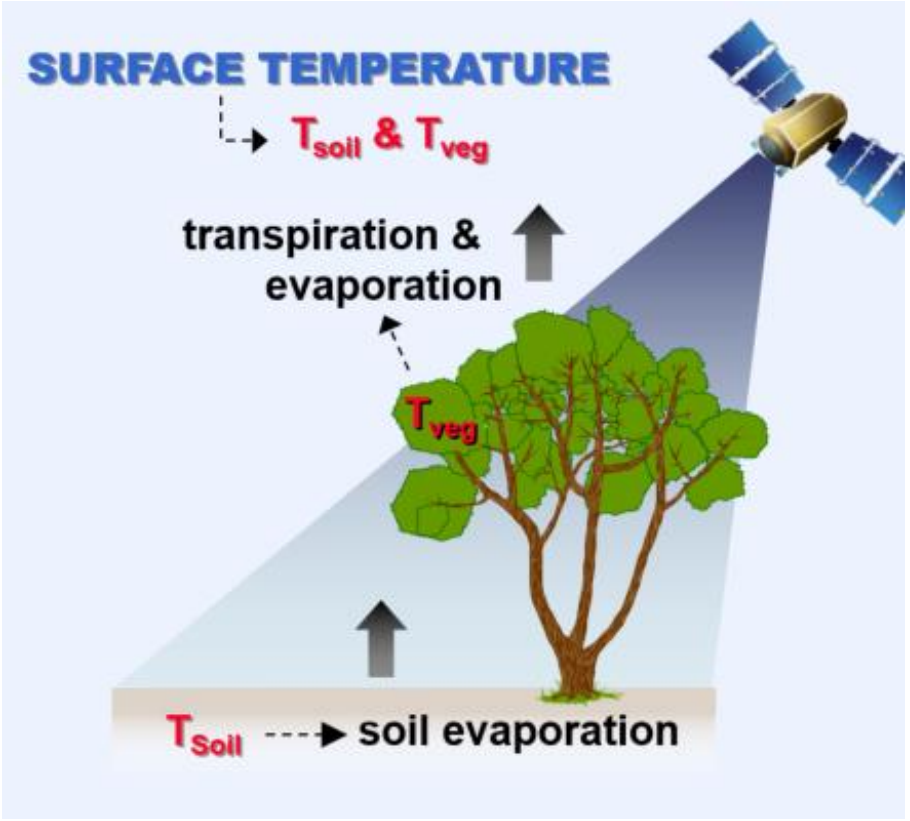
REMOTELY SENSED WATER BALANCE ANALYSIS

$$\boldsymbol{Precipitation} - Evapotranspiration - Discharge = \Delta Storage$$



REMOTELY SENSED WATER BALANCE ANALYSIS

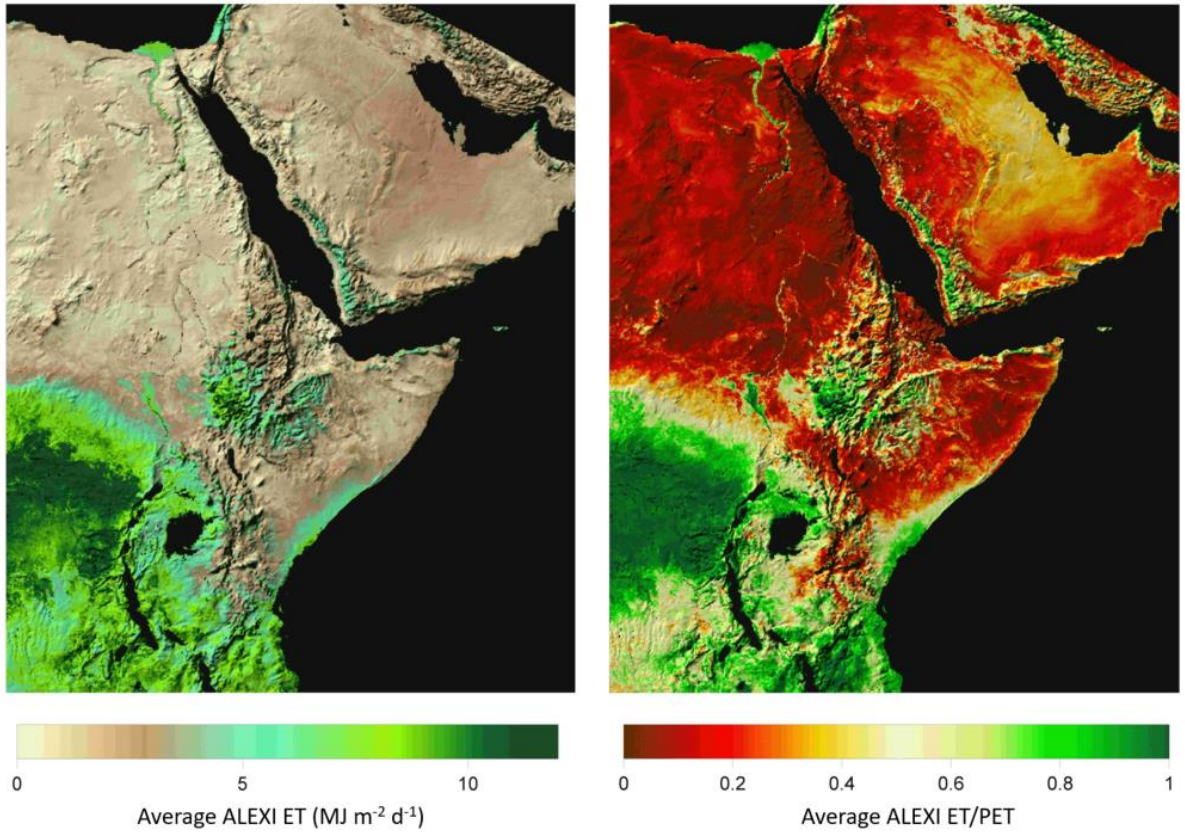
$$Precipitation - \boxed{\boldsymbol{Evapotranspiration}} - Discharge = \Delta Storage$$



Martha Anderson, USDA

REMOTELY SENSED WATER BALANCE ANALYSIS

$$Precipitation - \boxed{\boldsymbol{Evapotranspiration}} - Discharge = \Delta Storage$$



Martha Anderson, USDA

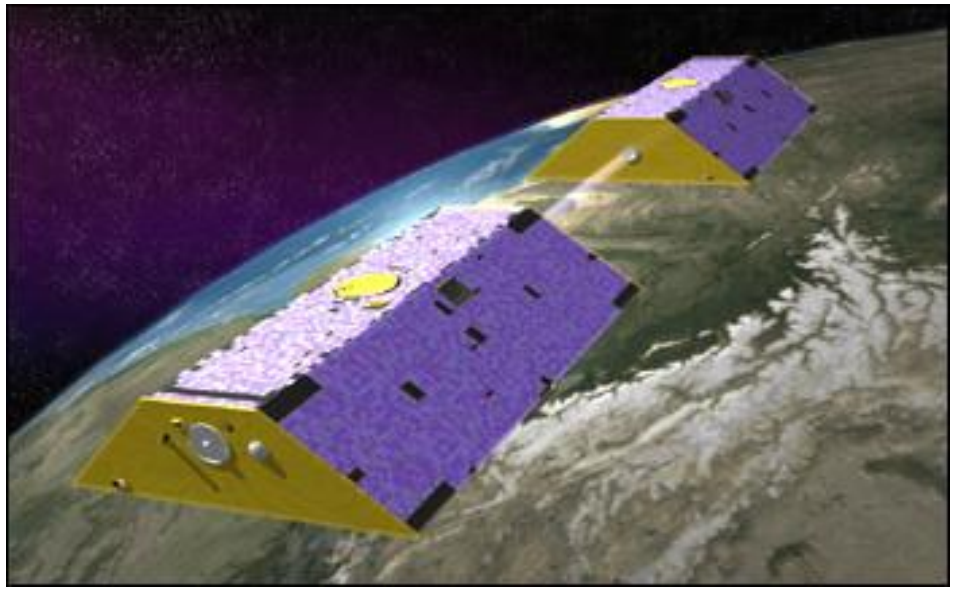
REMOTELY SENSED WATER BALANCE ANALYSIS

$$Precipitation - Evapotranspiration - \boxed{Discharge} = \Delta Storage$$

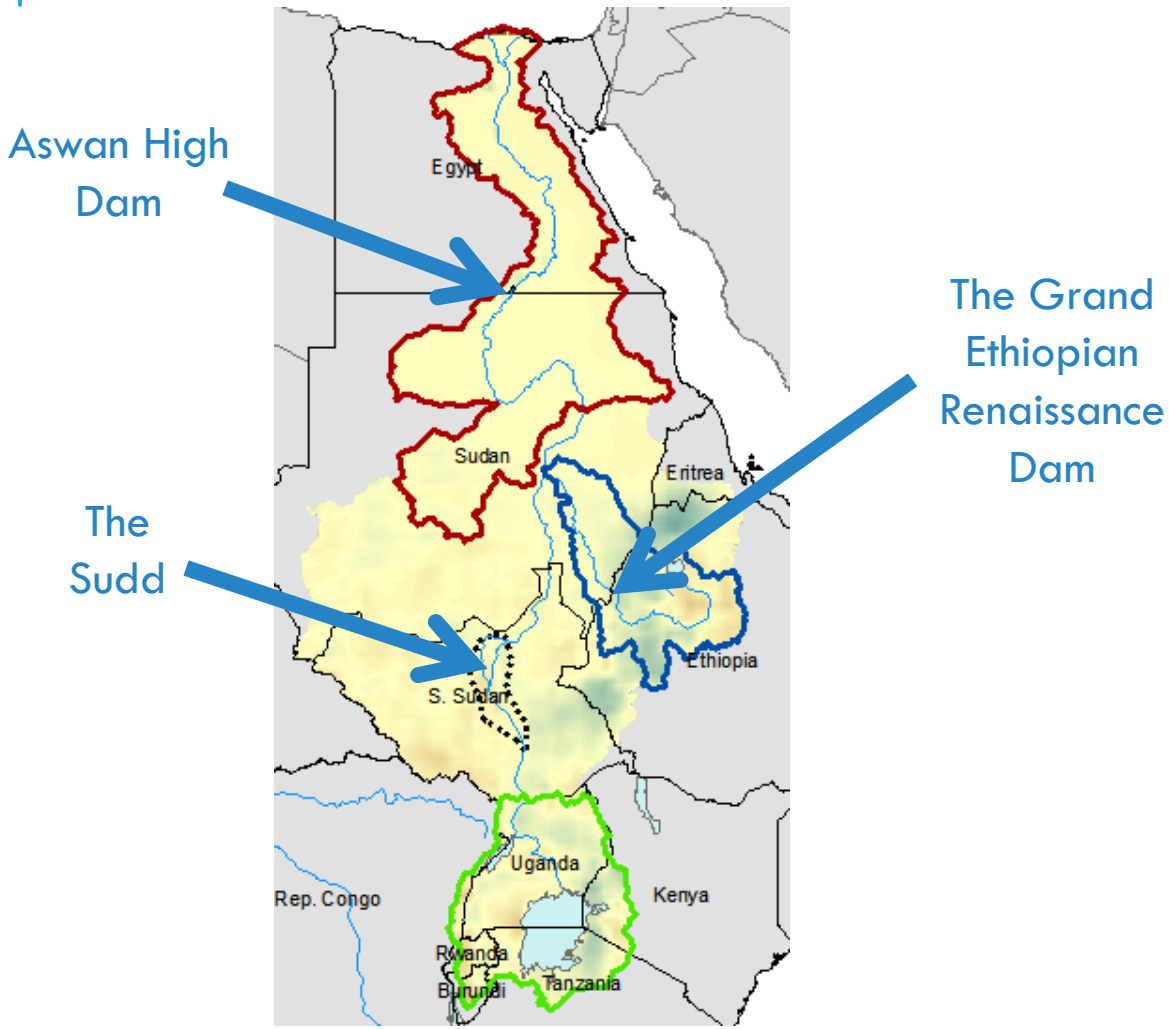
REMOTELY SENSED WATER BALANCE ANALYSIS

$$Precipitation - Evapotranspiration - Discharge = \boxed{\Delta Storage}$$

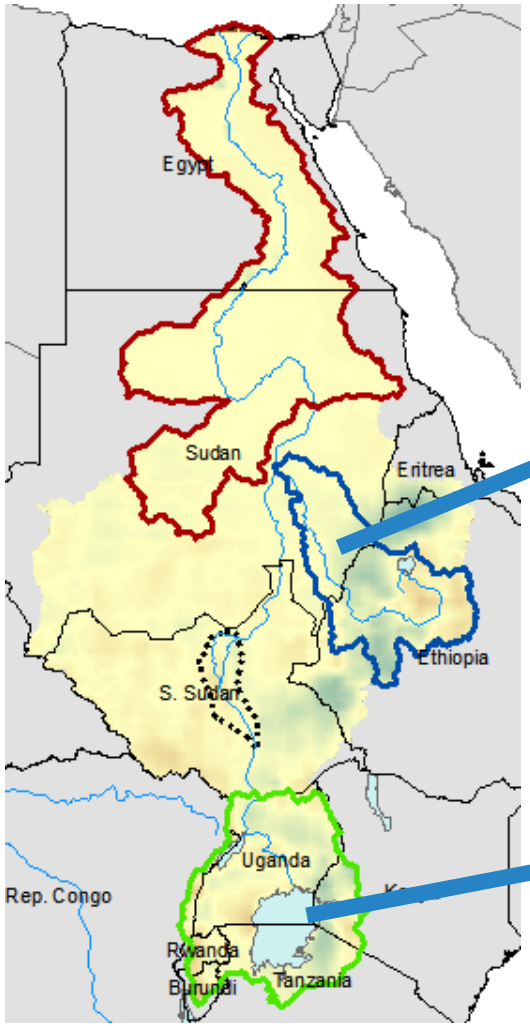
The Gravity Recovery and Climate Experiment (GRACE)

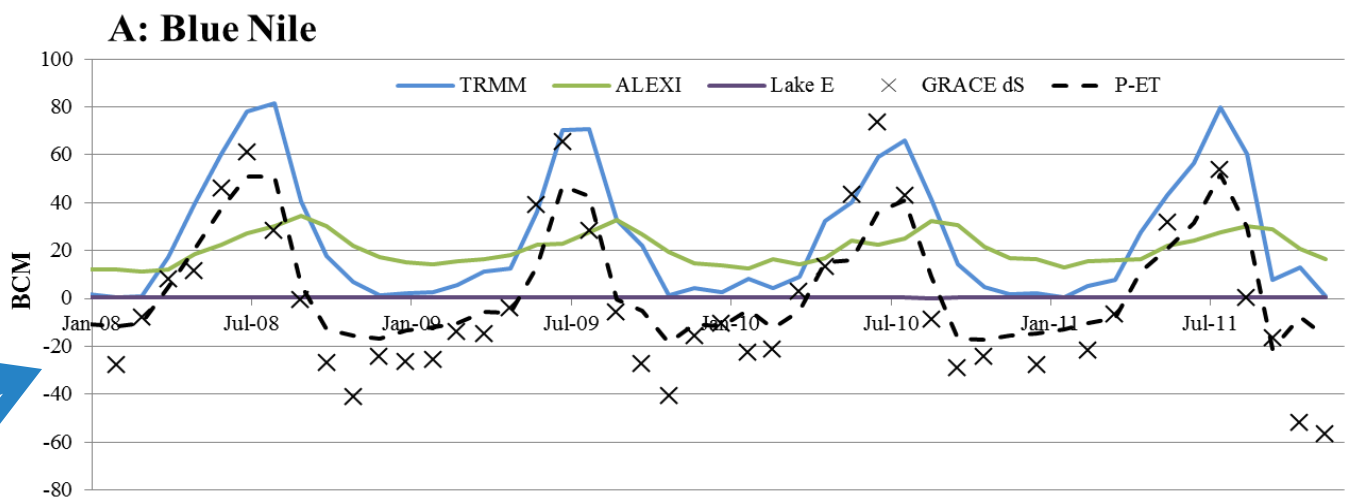


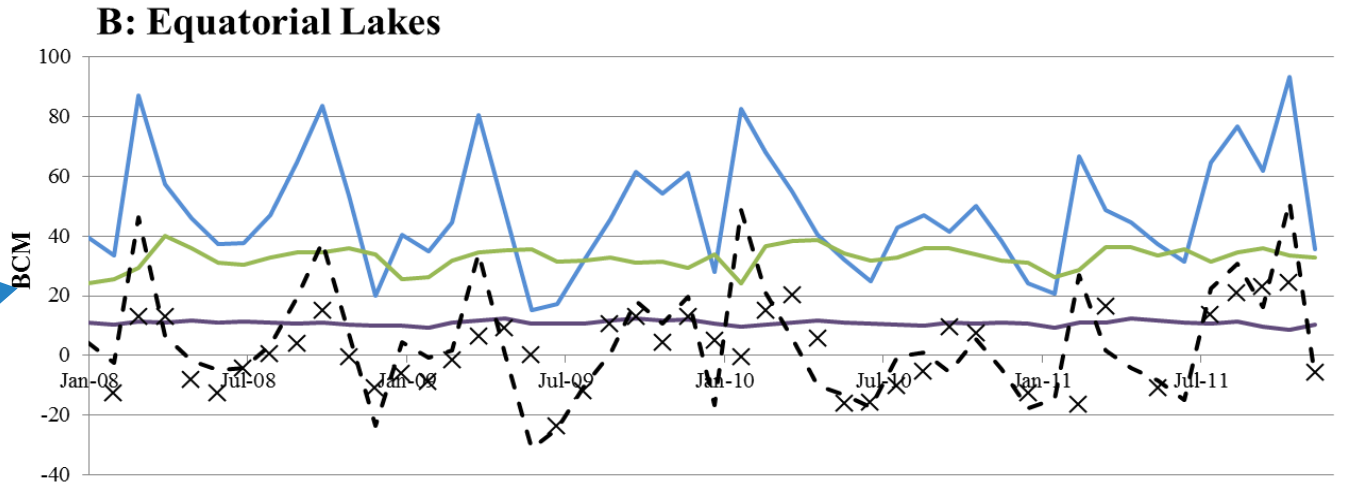
BASIN SCALE WATER BALANCE



BASIN SCALE WATER BALANCE







$P - E - \Delta S =$ RIVER DISCHARGE

	Rainfall		Land ET		dS		Lake E	Residual
Equatorial Lakes	574.8	±46.9	392.3	±19.6	-3.3	±2.8	130.4	**55.4**
Blue Nile	302.1	±20.3	247.6	±12.4	-3.0	±3.6	3.9	**53.6**
Lower Nile	40.7	±12.2	80.9	±4.0	-3.7	±2.8	11.0	**-47.5**
Sudd Wetlands	42.4	±3.4	66.4	±3.3	-	-	0.0	**-24.0**
Entire Nile basin	1939.8	±196.9	1797.3	±89.9	-20.7	±12.4	149.8	**13.5**

Units: Billion Cubic Meters per year

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Wetland mapping and monitoring

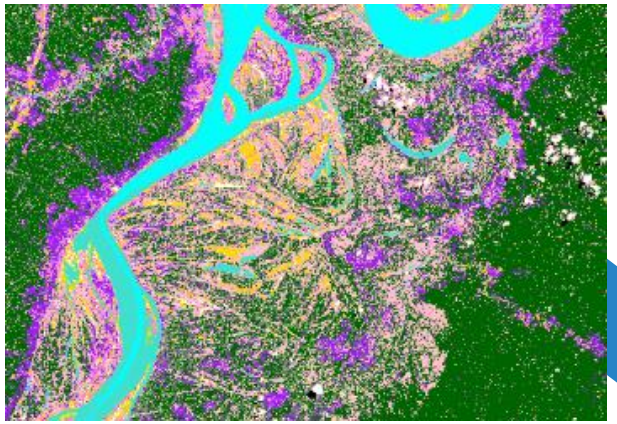
WHAT IS A LAND DATA ASSIMILATION SYSTEM?

A **Land Data Assimilation System (LDAS)** is a tool that merges models and observation.

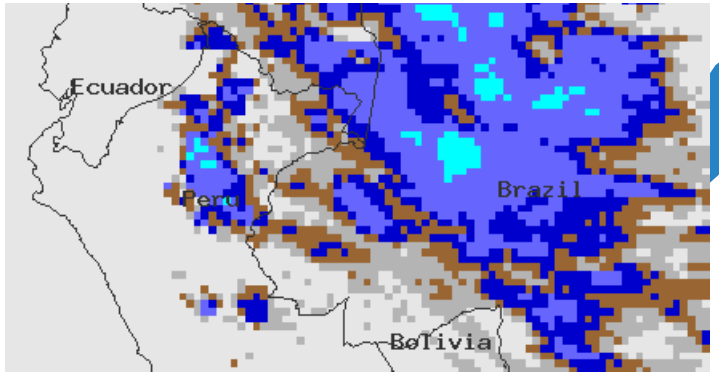
Principle: integrated analysis yields more **reliable** and more **meaningful** information.

LDAS

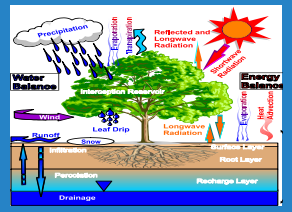
Landscape Information



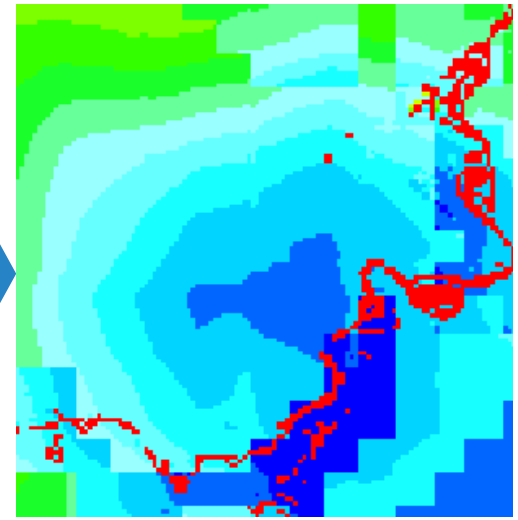
Meteorological Data



Land Surface Model

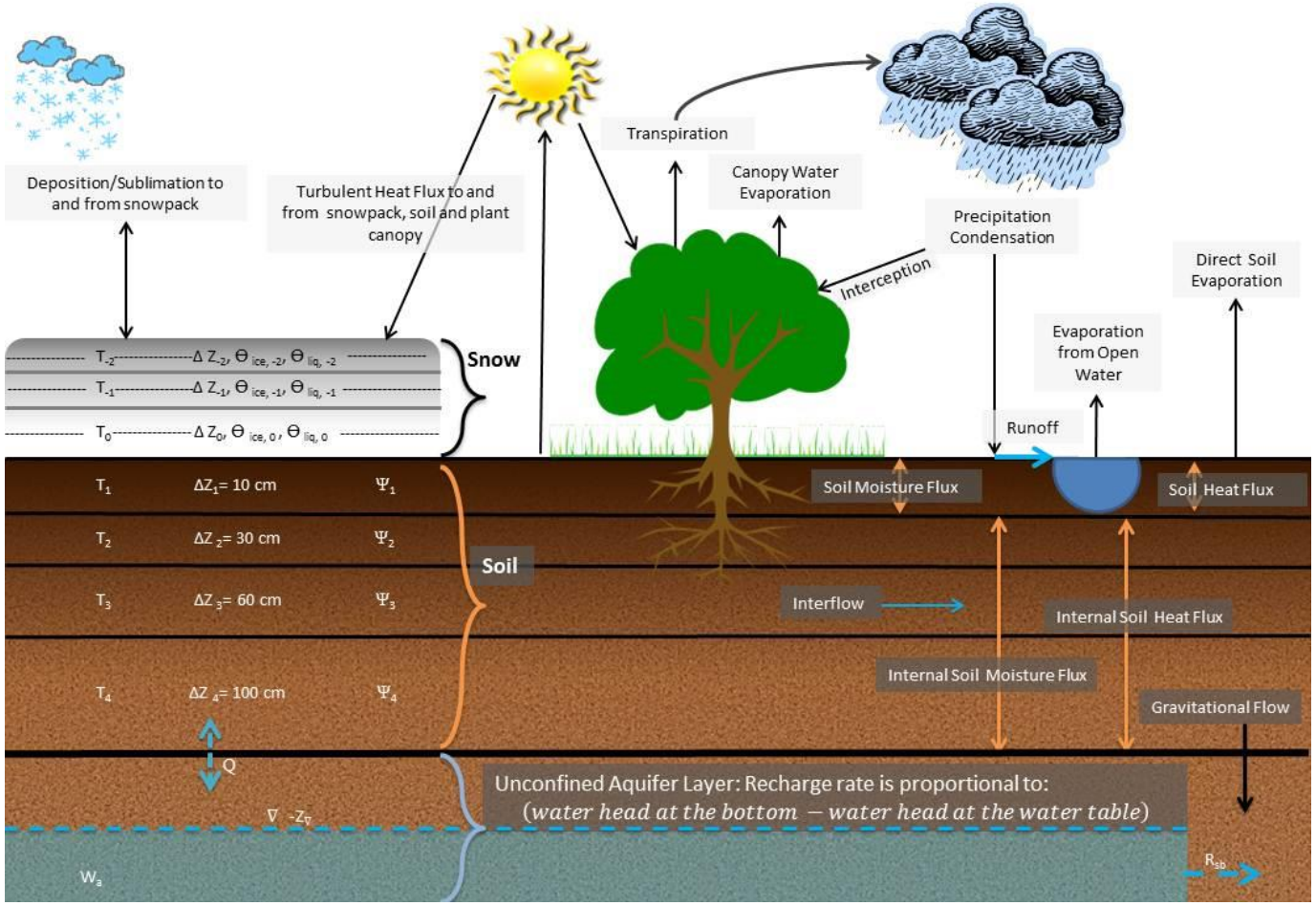


LDAS Output



- Hydrological fluxes and storage
- Localized meteorology
- Vegetation status

LAND SURFACE MODEL

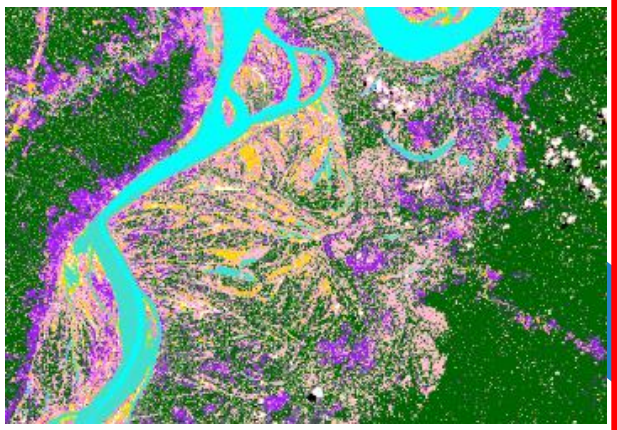


http://www.jsg.utexas.edu/noah-mp

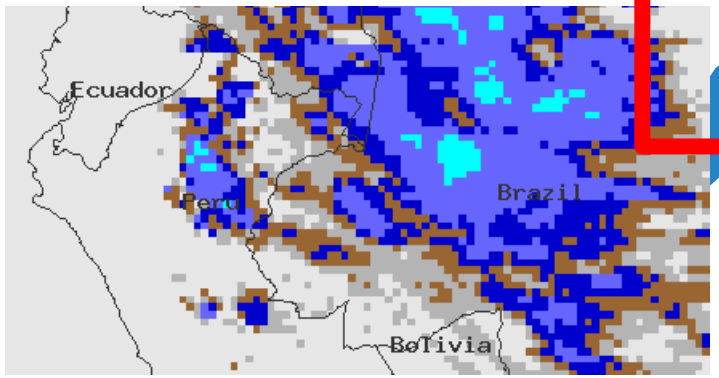
LDAS

Data Assimilation

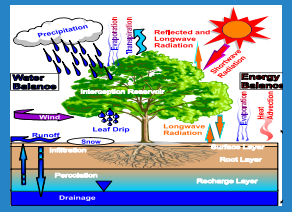
Landscape Information



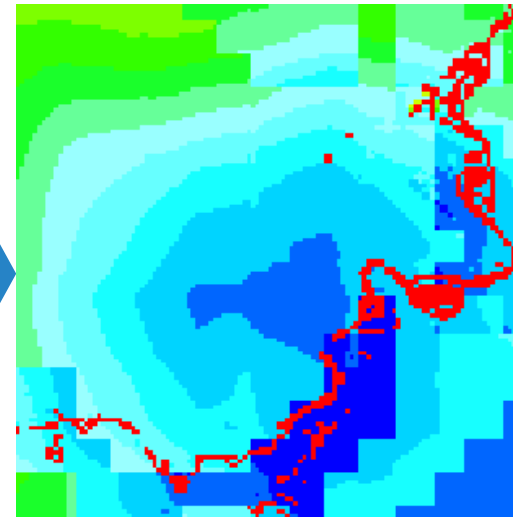
Meteorological Data



Land Surface Model



LDAS Output



- Hydrological fluxes and storage
- Localized meteorology
- Surface energy balance

LDAS AROUND THE WORLD

The Global LDAS (**GLDAS**)

The North American LDAS (**NLDAS**)

The South American LDAS (**SALDAS**)

The South Asia LDAS (**South Asia LDAS**)

The Famine Early Warning System LDAS (**FLDAS**)

And more . . . .

THE NASA LAND INFORMATION SYSTEM

The NASA Land Information System is a **software framework** to support flexible use of advanced **land surface models** and **land data assimilation**.

LIS is an **integration tool** that can be used to exchange and enhance information across projects

CUSTOMIZING LDAS FOR THE NILE BASIN

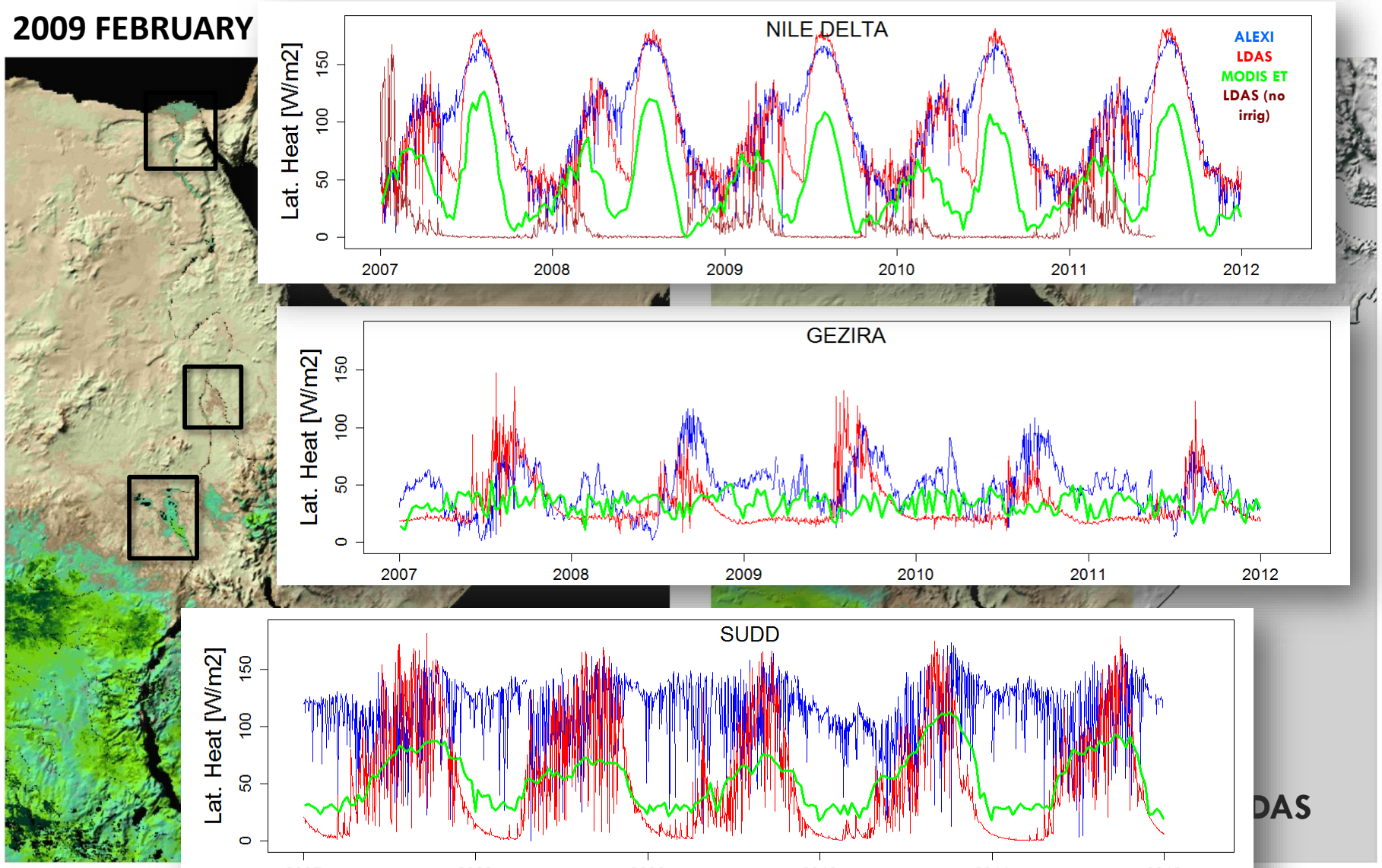
What **meteorological products** should we use?

How will we account for **irrigation**?

What information is available on **land cover, soils, etc.**?

How will we **evaluate the system**?

EVALUATION: EVAPOTRANSPIRATION



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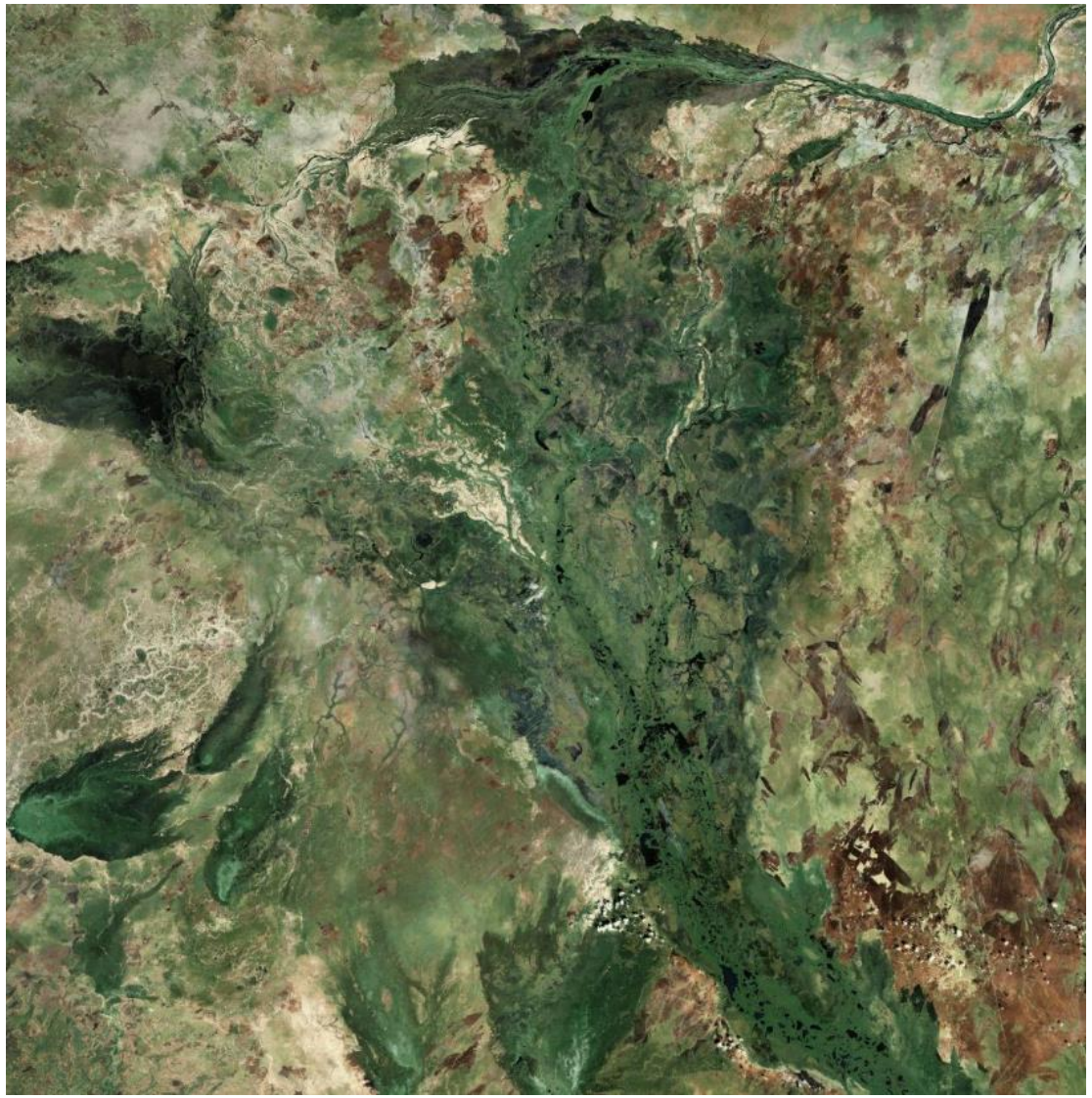
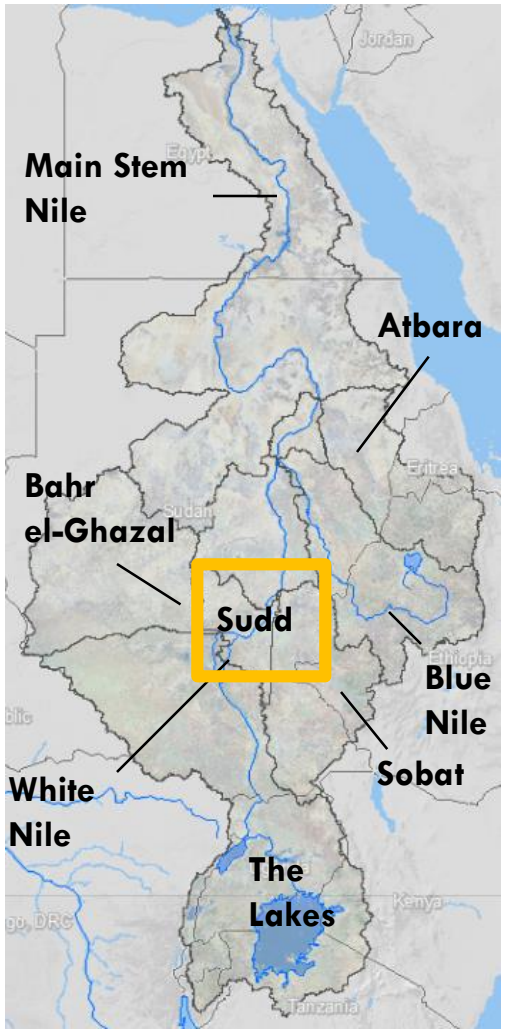
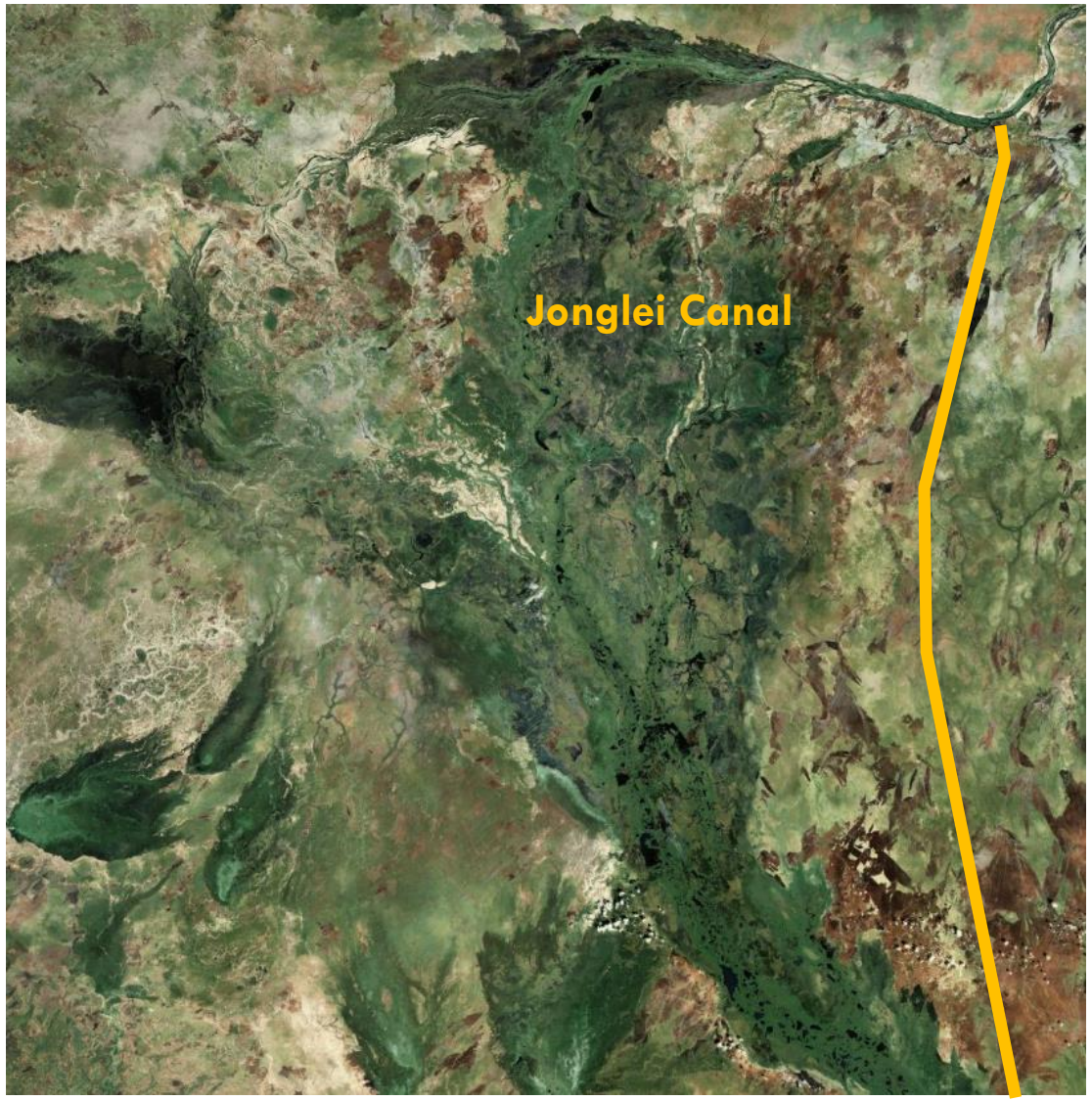
THE SUDD

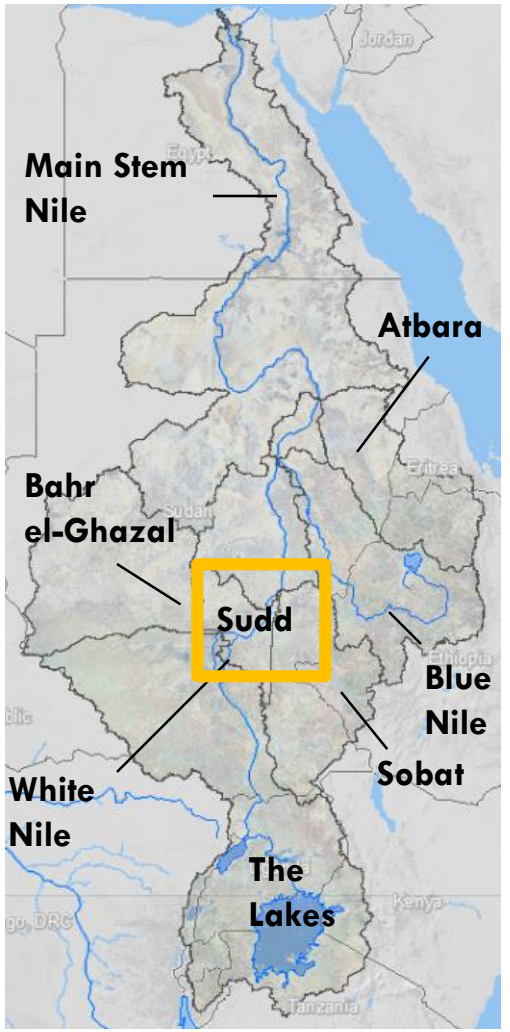



Main Stem Nile
Atbara
Bahr el-Ghazal
Sudd
Blue Nile
Sobat
White Nile
The Lakes

THE SUDD

THE SUDD


Jonglei Canal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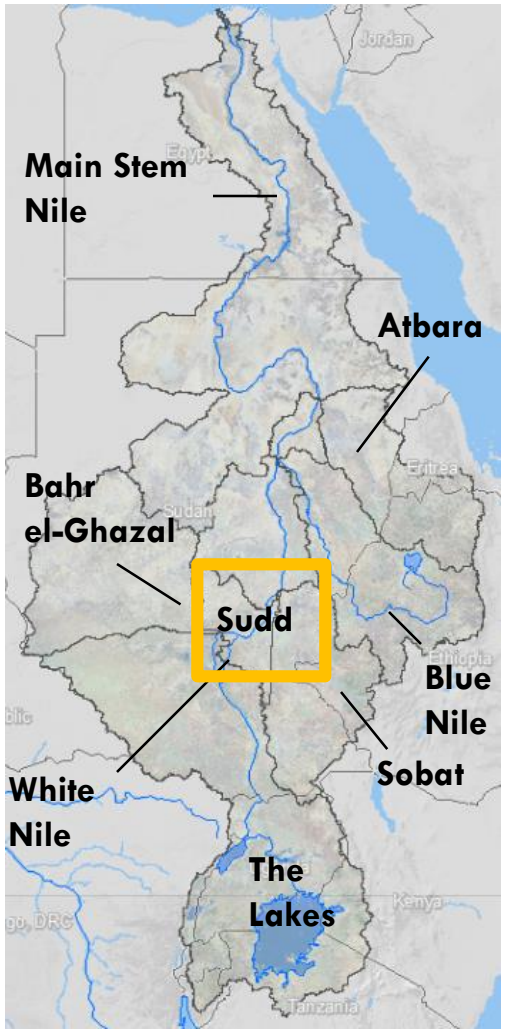
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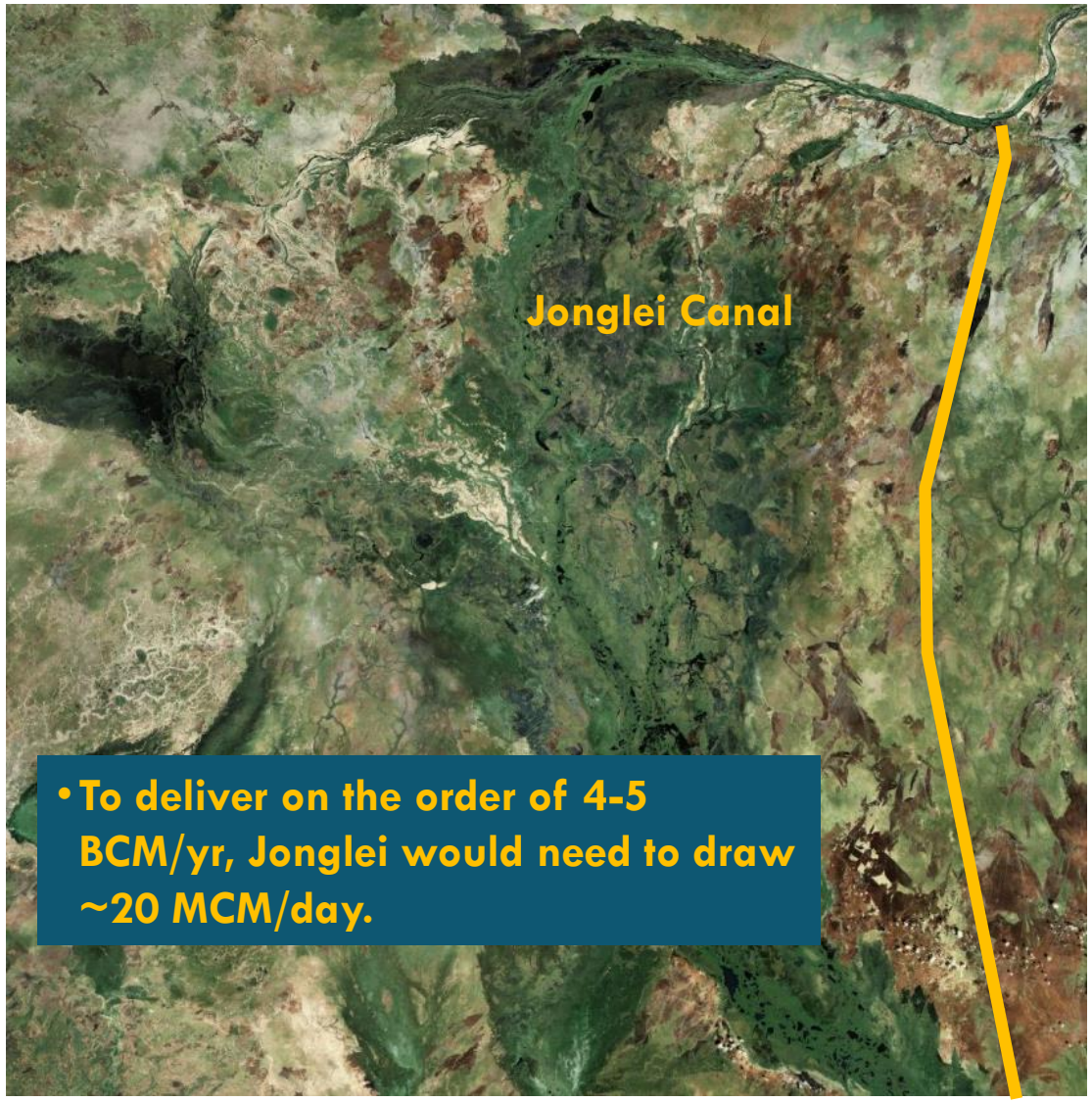
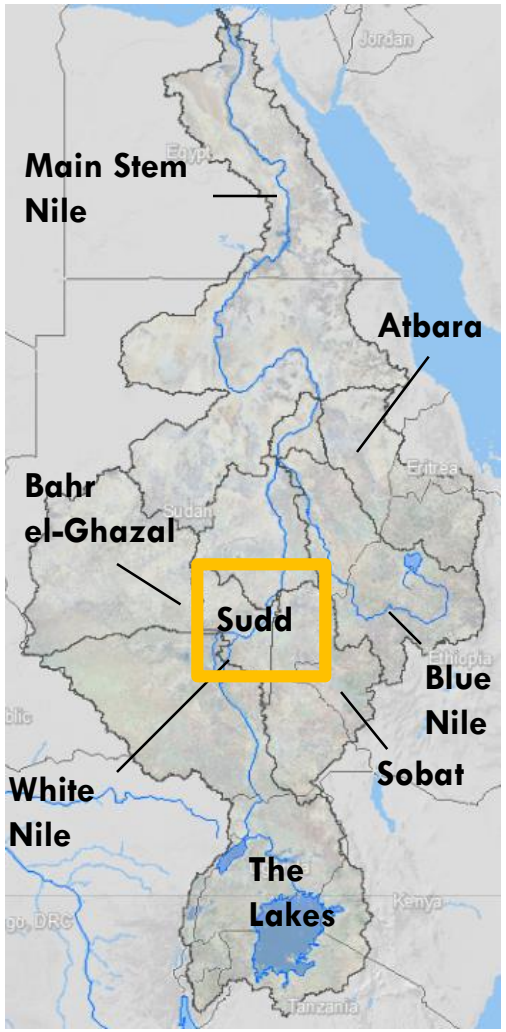

Jonglei Canal
• To deliver on the order of 4-5 BCM/yr, Jonglei would need to draw ~20 MCM/day.


Main Stem Nile
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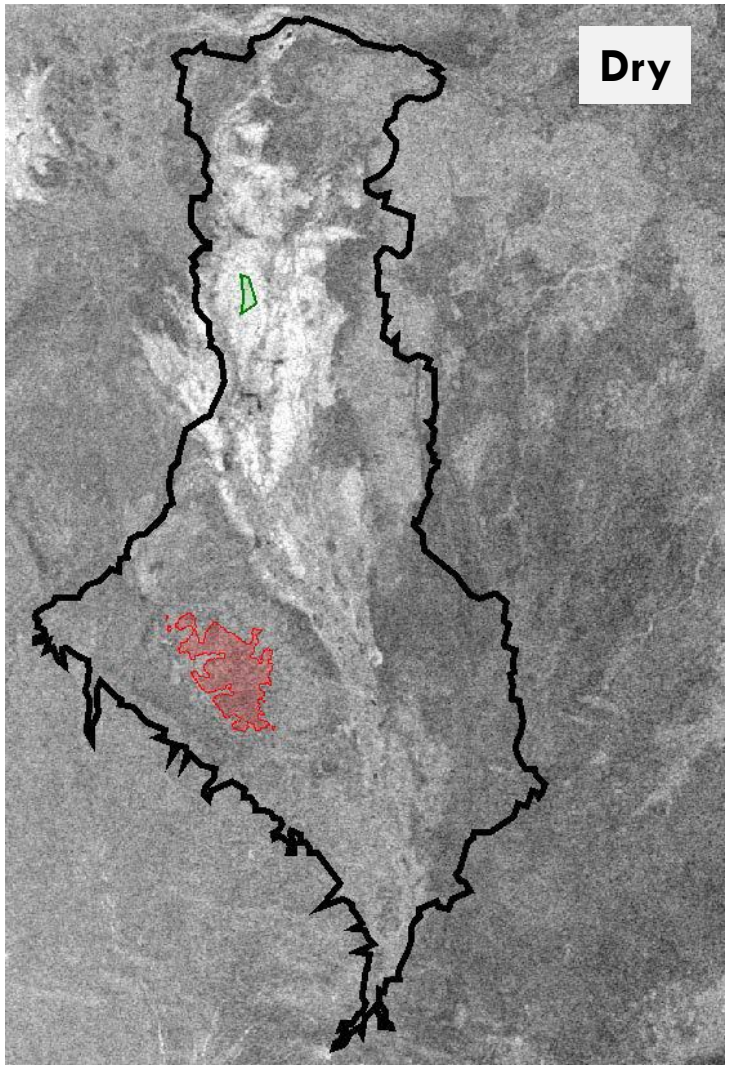
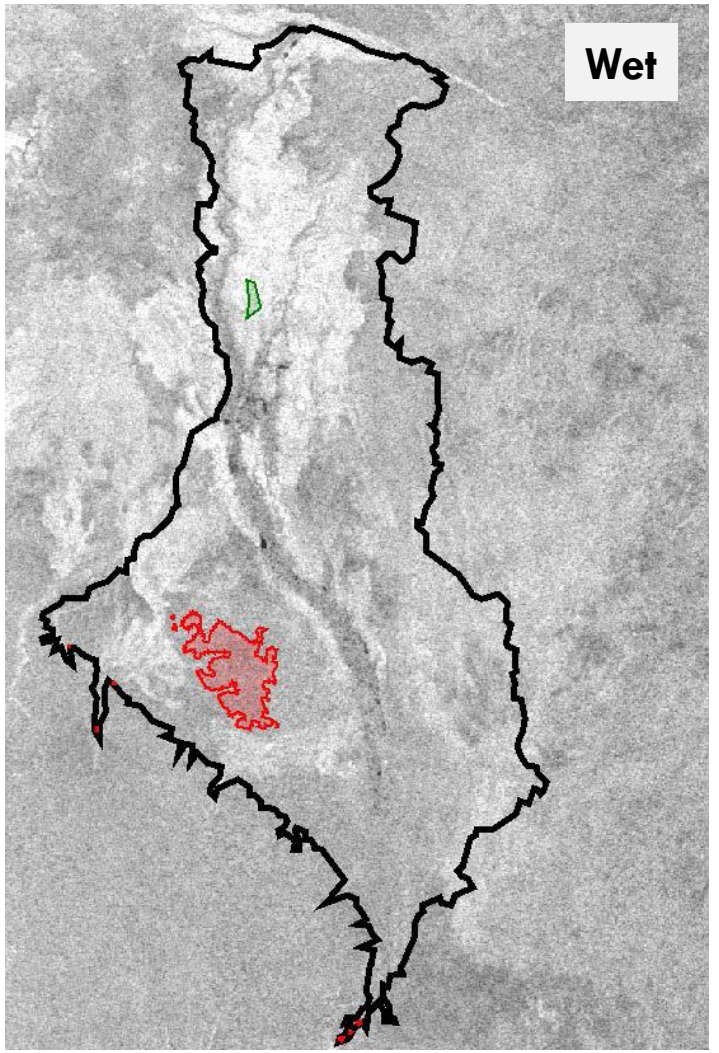
FLOODED AREA: SYNTHETIC APERTURE RADAR

Brightness indicates intensity of radar backscatter





Red and green areas are locations of known land cover

ASAR imagery

SAR AND FLOODED VEGETATION

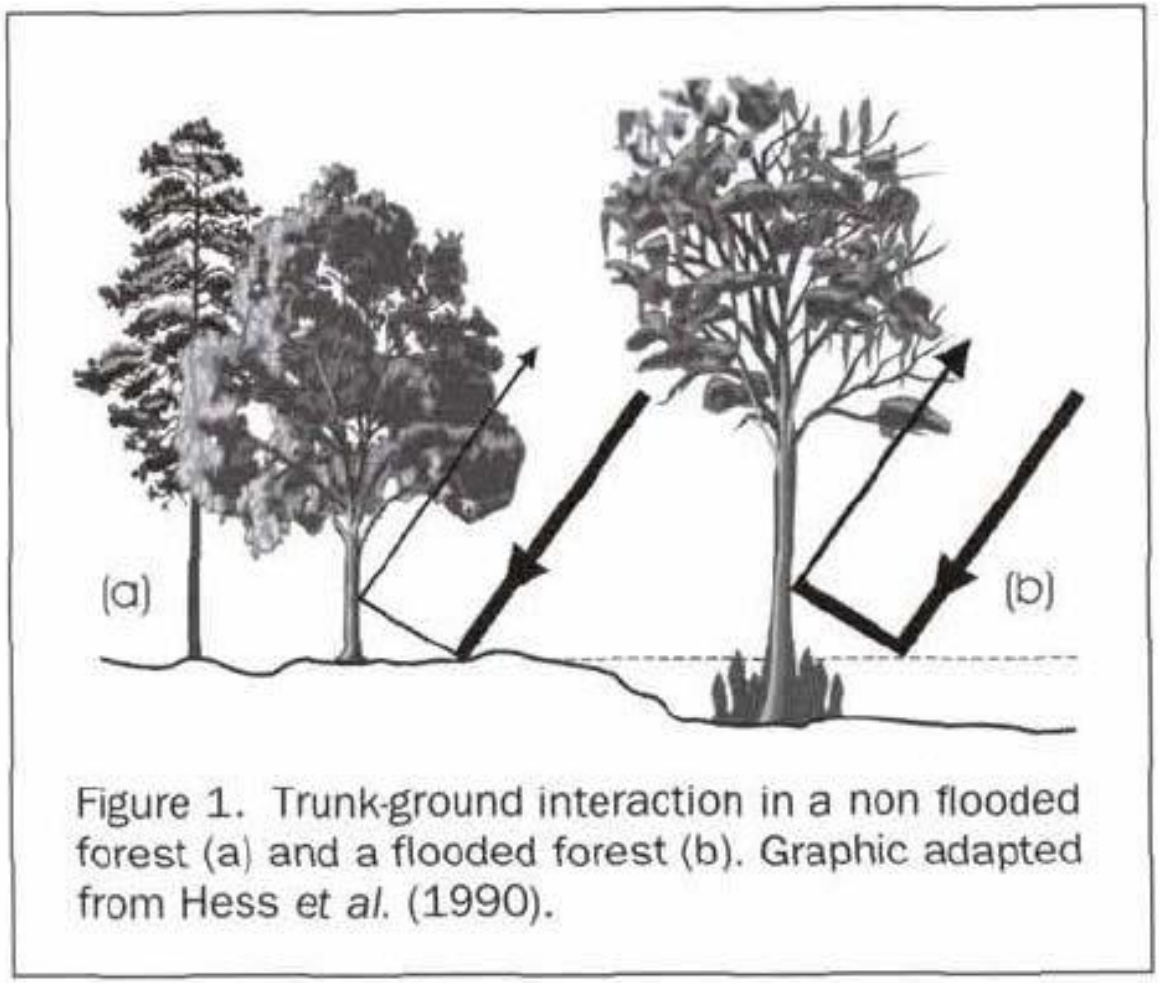


Figure 1. Trunk-ground interaction in a non flooded forest (a) and a flooded forest (b). Graphic adapted from Hess *et al.* (1990).

Bright:
Flooded Vegetation

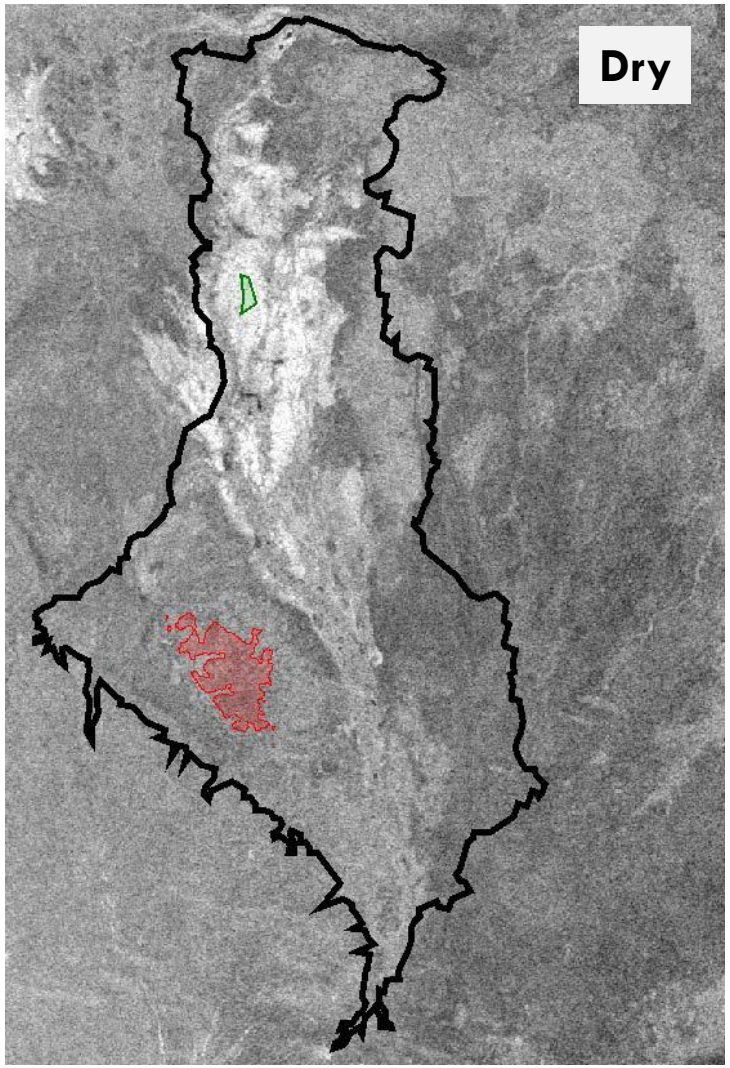
Medium:
Dry Land

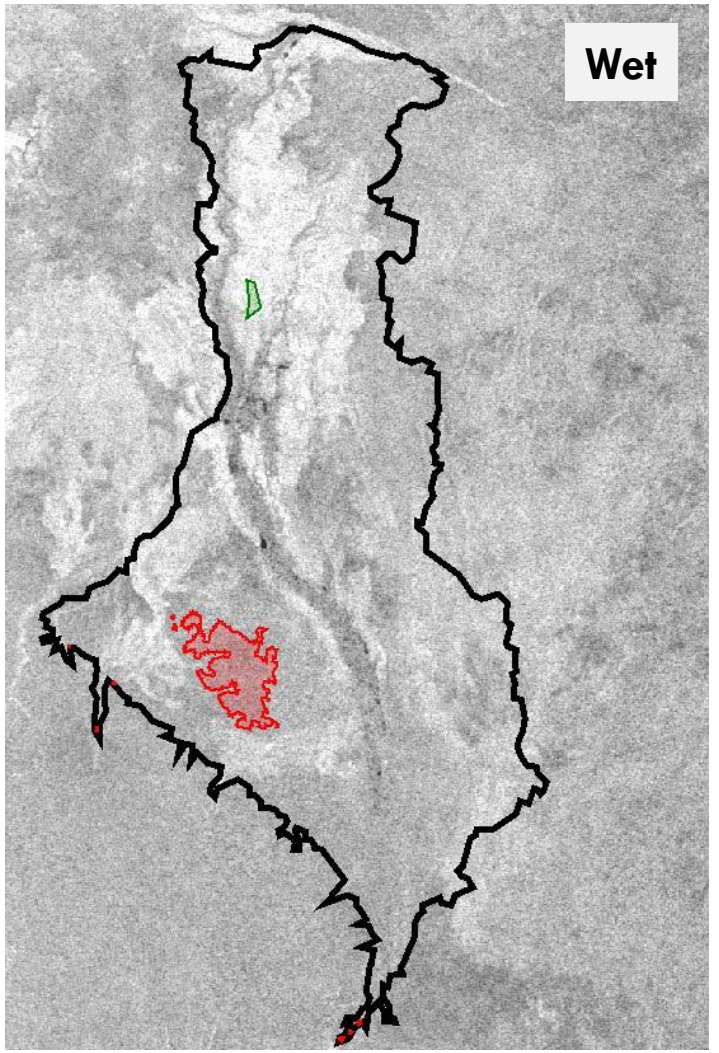
Dark:
Open Water

Townsend (2001)

FLOODED AREA: SYNTHETIC APERTURE RADAR

Brightness indicates intensity of radar backscatter

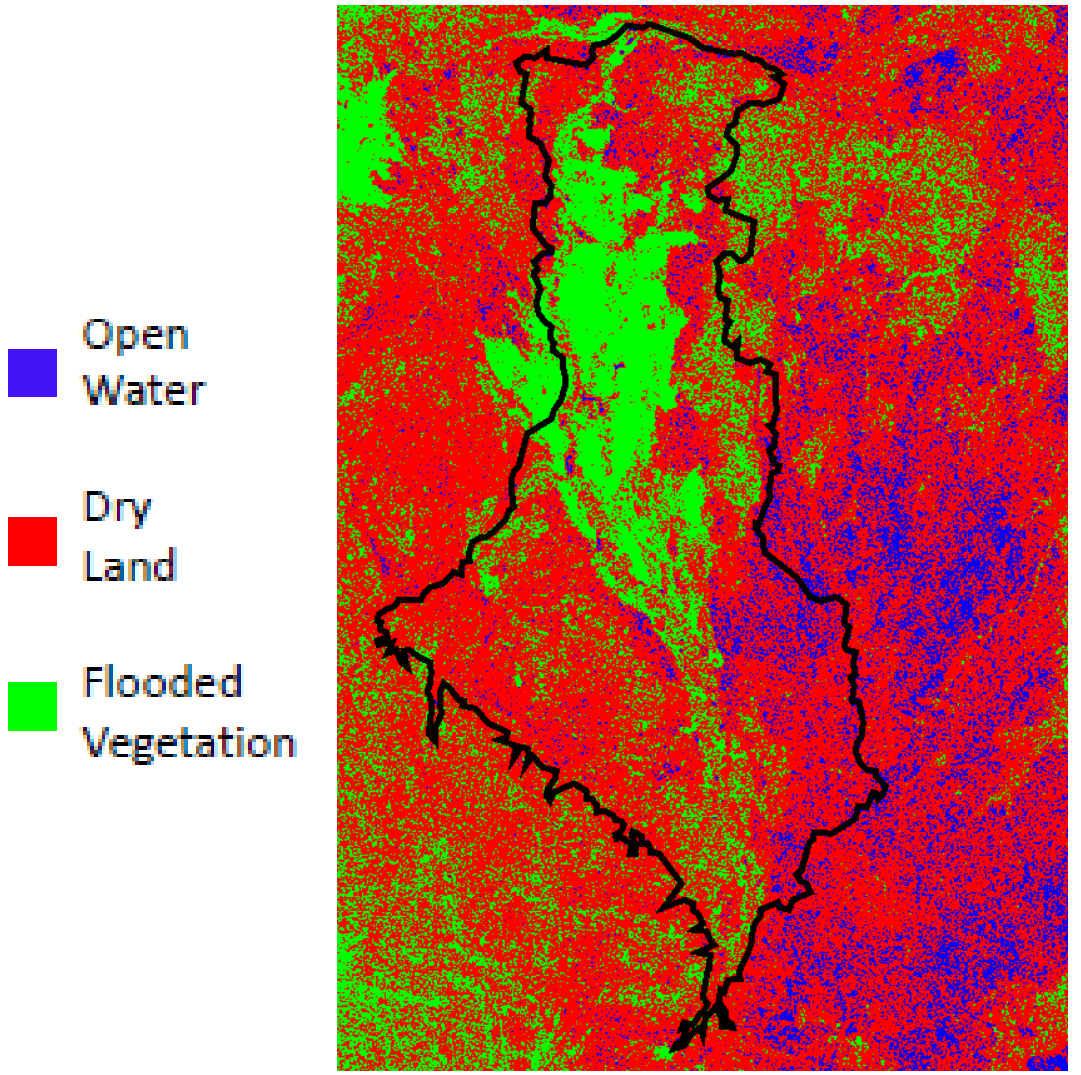




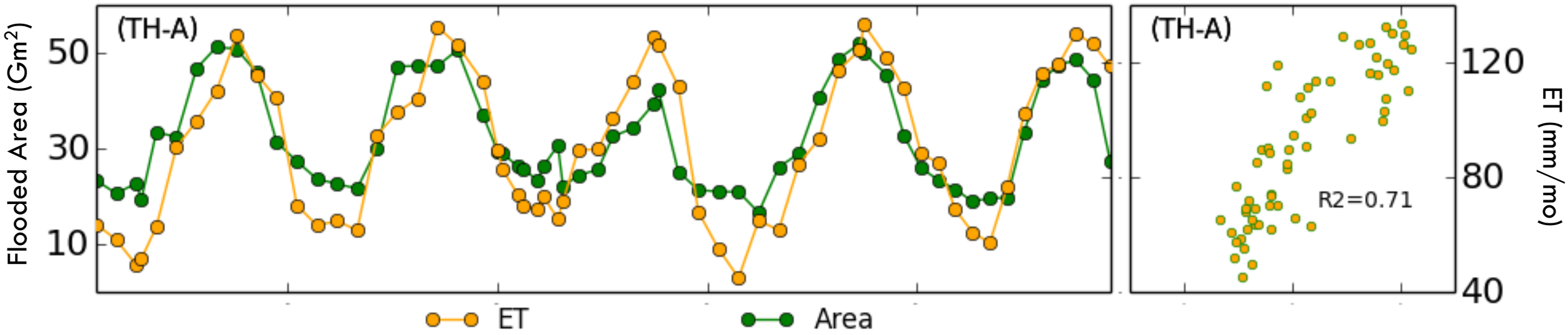
Red and green areas are locations of known land cover

CLASSIFICATION OF SAR IMAGERY

Based on backscatter thresholds we can classify open water, dry land and flooded vegetation for every date when SAR imagery is available.



MONITORING SUDD AREA & EVAPOTRANSPIRATION



Correlation between Evapotranspiration and Area allows us to link wetland area and the water balance

Wilusz et al. (2017)

PREDICTING AREA

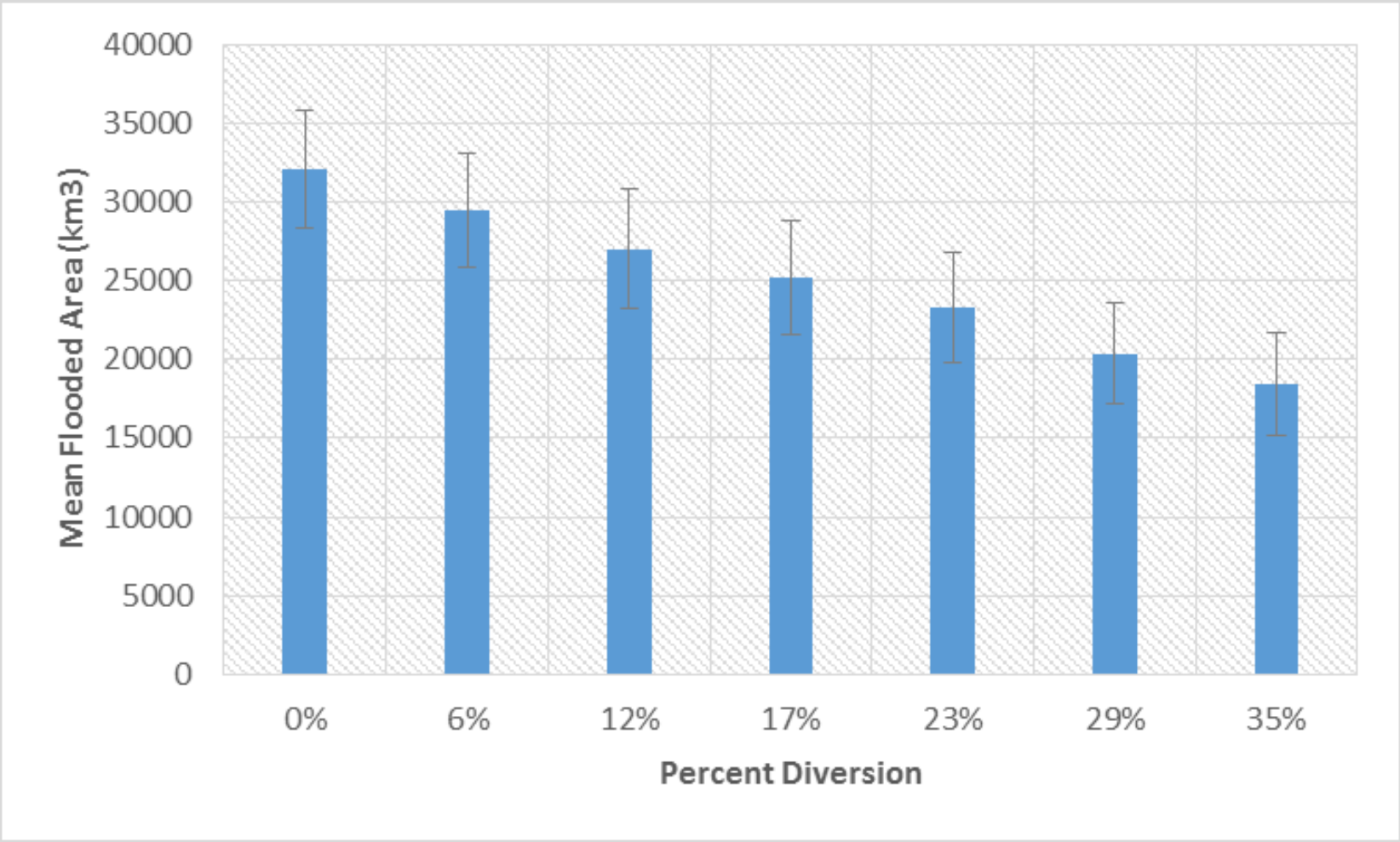
1. Define Water Balance Equation $$Q_{in} - Q_{out} + P - E = \frac{dS}{dt}$$

2. Use Area vs. ET relationship $$Q_{in} - Q_{out} + P - (k_e A + C) = k_s \frac{dA}{dt}$$

3. Solve $$Q_{in,i} - Q_{out,i} + P_i - (.001385A - .869) = .0003988 \frac{dA}{dt}$$

Based on Sutcliffe & Park 1987

THE JONGLEI CANAL



Use these equations to estimate impacts that the Jonglei Canal would have on Sudd Area

Wilusz et al. (*2017*)

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IN SUMMARY . . .

Remote sensing can contribute to **understanding**, **monitoring**, and **predicting** the water balance of large, poorly instrumented basins.

There is power in **merging data streams**, both through multi-sensor approaches and data assimilation.

Uncertainties are substantial and should not be understated.

Collaborative analysis can, sometimes, overcome skepticism of remotely sensed products.

THANK YOU