An expert approach for identifying and mapping tropical wetlands and peatlands: areas, depths and volumes

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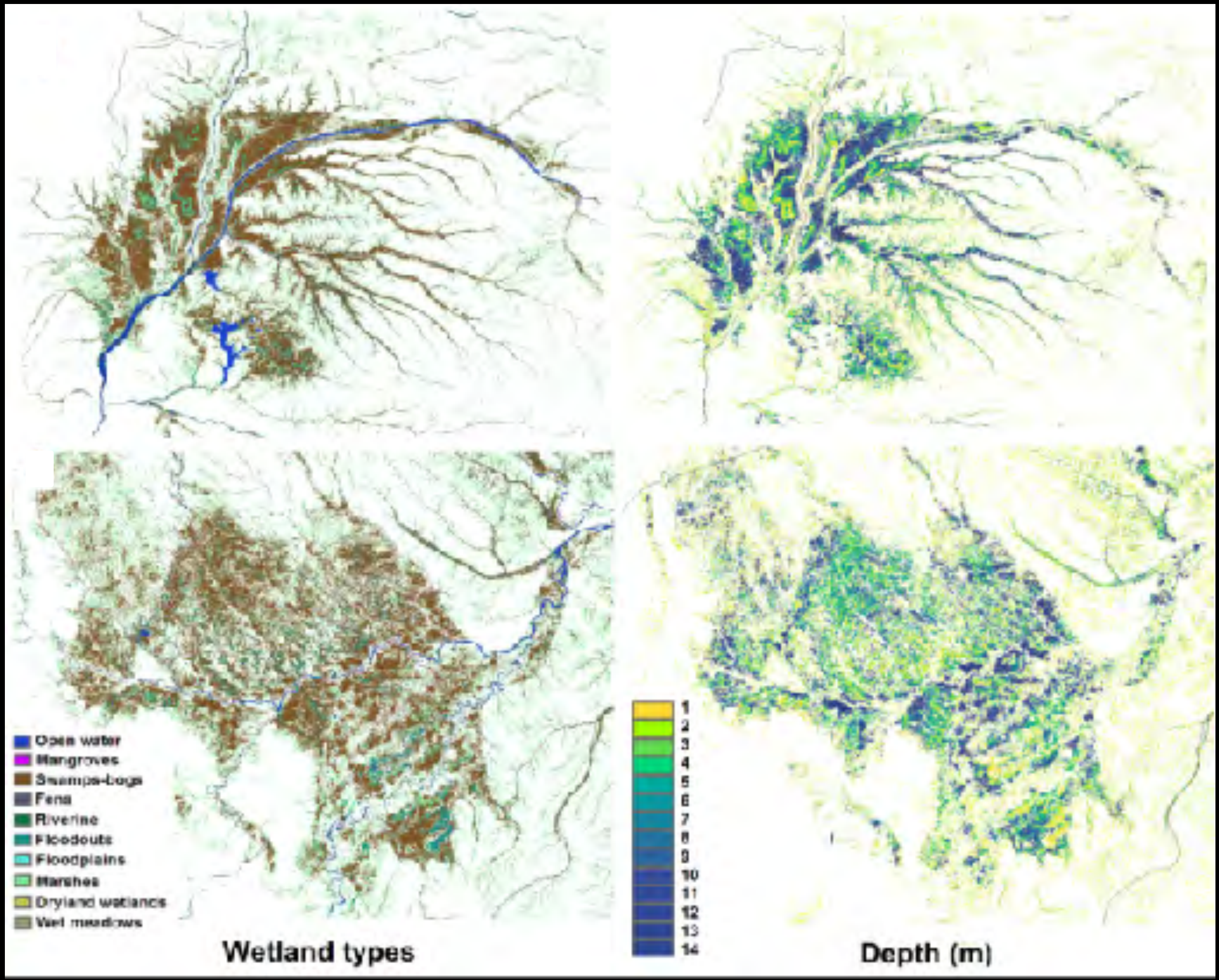

Source: Gumbricht et al. (GCB) 2017

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More methodological information and maps available at: http://www.karttur.com/
Data download at SWAMP website: http://www.cifor.org/global-wetlands/

Publications

- **Gumbricht** *et al.* **(2002)** Remote sensing to detect sub-surface peat firs and peat fire scars in the Okavango Delta, Botswana. South African Journal of Science, 98,351-358.

- **Gumbricht T (2015)** Hybrid mapping of pantropical wetlands from optical satellite images, hydrology and geomorphology. In: Remote Sensing of Wetlands: Applications and Advances. (eds Ralph W. Tiner, Megan W. Lang, Victor V. Klemas), pp 433-452. CRP Press. Taylor and Francis Group. Boca Raton, Florida.

- **Gumbricht T (2016)** Soil Moisture Dynamics Estimated from Modis Time Series Images. In: Multitemporal Remote Sensing. Remote Sensing and Digital Image Processing (ed Y Ban). Springer International Publishing, Cham, Switzerland. DOI 10.1007/978-3-319-47037-5_12.

- **Gumbricht** *et al.* **(2017)** An expert system model for mapping tropical wetlands and peatlands reveals South America as the largest Contributor. Global Change Biology. DOI: 10.1111/gcb. 13689

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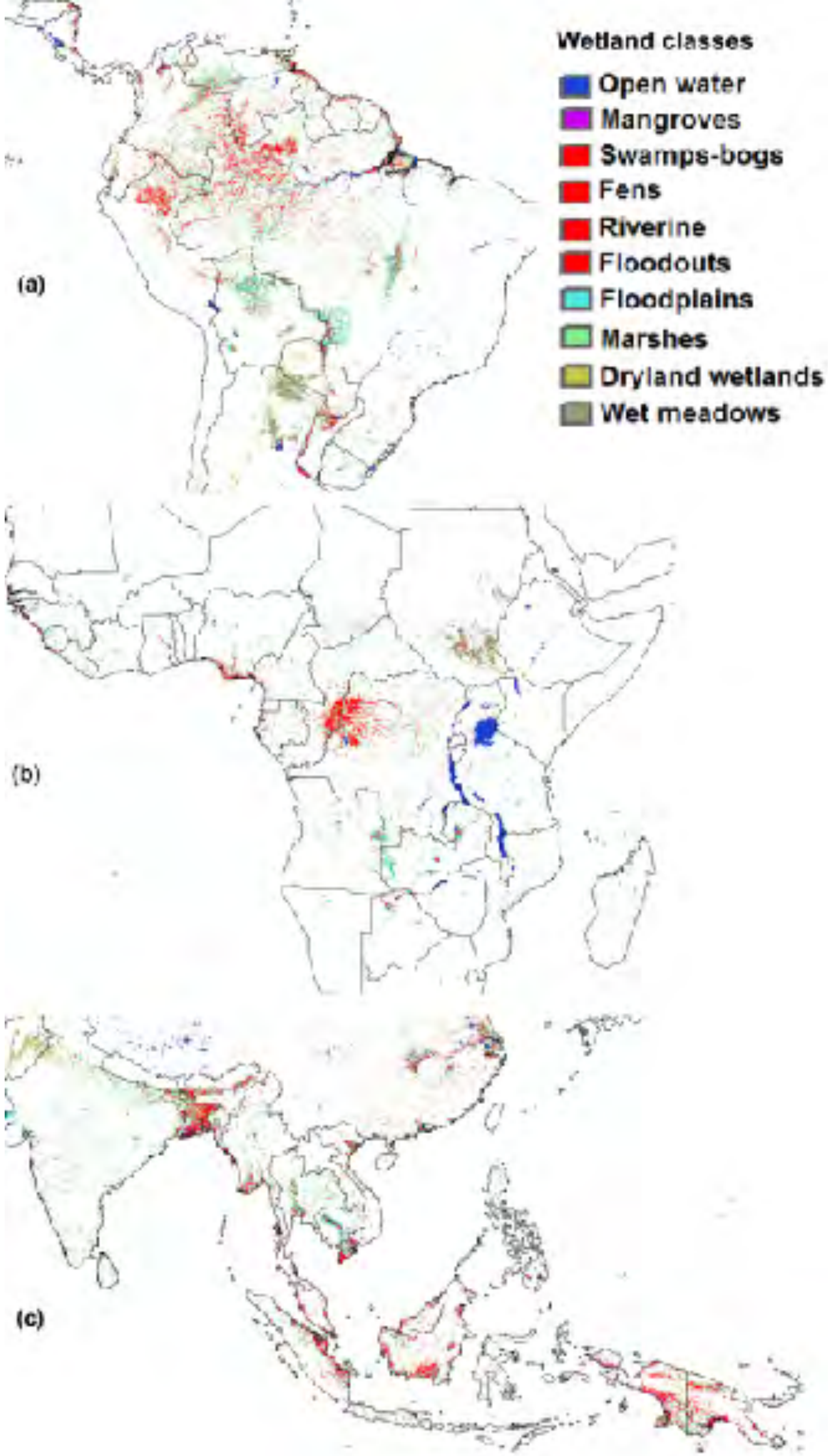
Index

- **Maps produced & validation**
- **The expert system model**
- **The biophysical indices**
- **Known errors, caveats and possible improvements**



Tropical maps of wetlands and peatlands

General characteristics:

- 3 maps: wetlands, peatlands, depths
- 9 maps for individual wetland types (1-100%)
- 236m
- 38° N to 56° S; 161° E to 117° W (tropics and subtropics), includes 146 countries but excludes small islands.

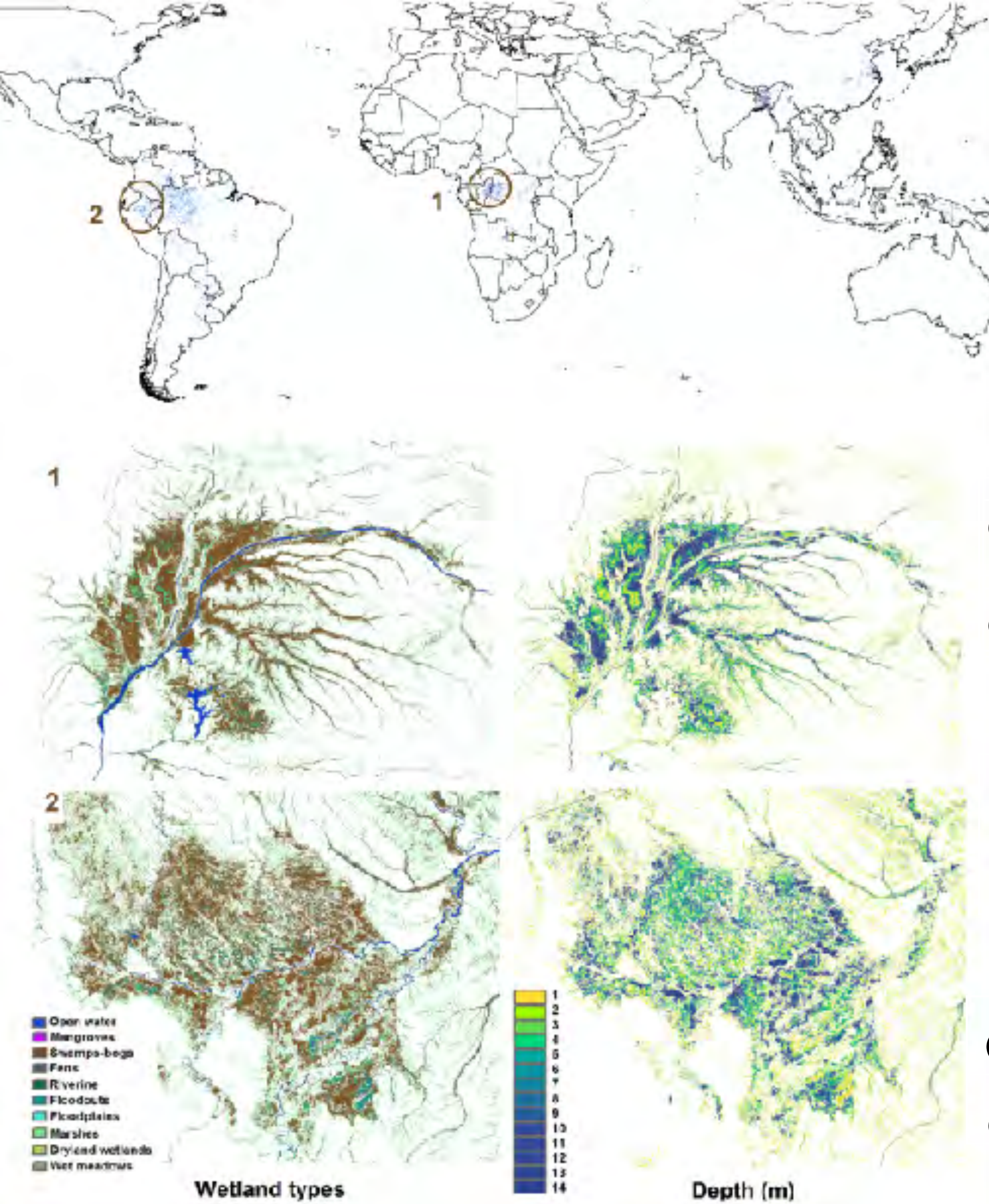
Peat: ≥50% organic matter (30% carbon content), ≥30cm thick.

Gumbricht et al. 2017 vs Page et al. 2011

Tropical peat area : 3-fold increase
Tropical peat volumes and stocks: 4-fold increase

Highest continental contribution in area and volume: South America, Brazil not SE-Asia, Indonesia

Source: Gumbricht et al. (2017)



Examples of area and depth for the two largest peat deposits in the tropics, outside Asia

Cuvette Central DRC-Congo
Pastaza-Marañón in Peru

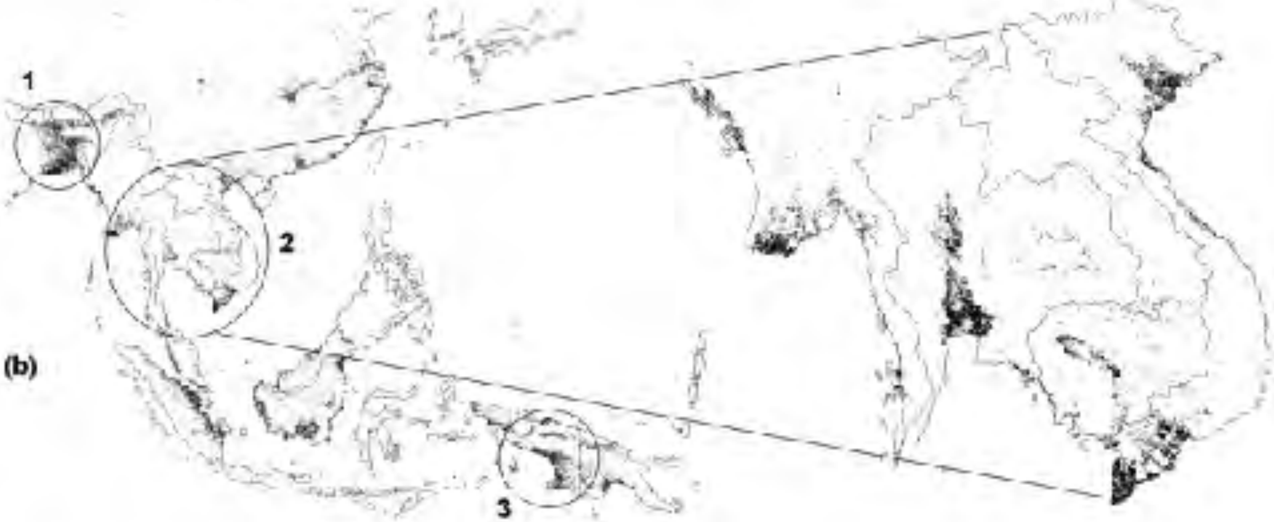
	Area (km^2) (other study)	Area (km^2) (this study)
Pastaza-Marañón (Draper et al 2015)	35,600	40,838
Congo Basin (Dargie et al 2017)	145,500	125,440

	Volume (km^3) (other study)	Volume (km^3) (this study)
Pastaza-Marañón (Draper et al 2015)	70,7	257
Congo Basin (Dargie et al 2017)	600	915

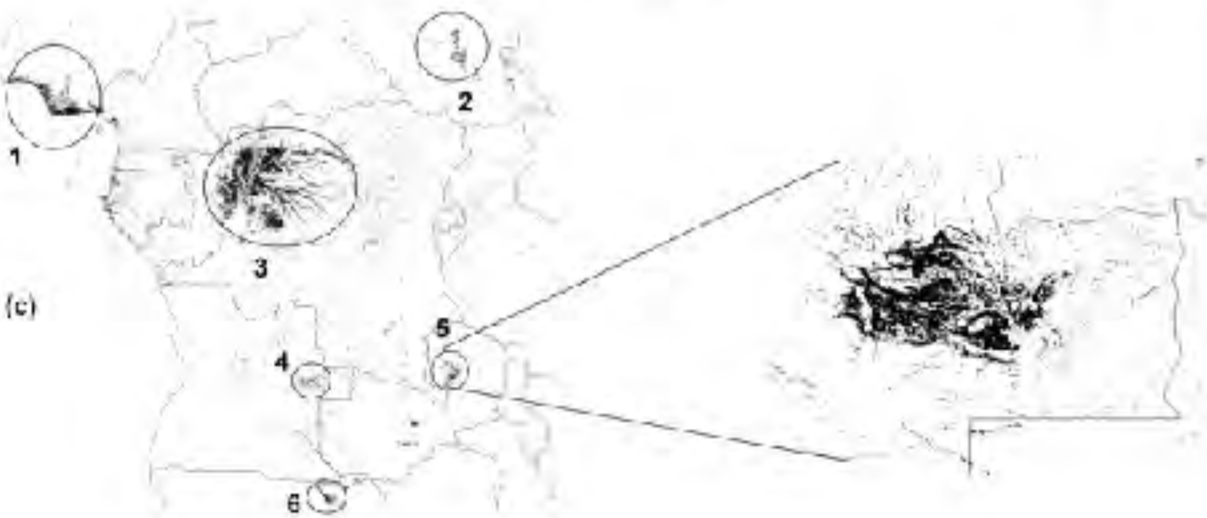
	Depth (m) (other study)	Depth (m) (this study)
Pastaza-Marañón (Draper et al 2015)	2,0	6,3
Congo Basin (Dargie et al 2017)	4.2	6.9

Some under-reported peatlands in the tropics

Latin America (Amazon Basin, Argentina Río de la Plata, Paraná River Basins)



Asia (All river deltas, Bangladesh, Indonesia Papua)

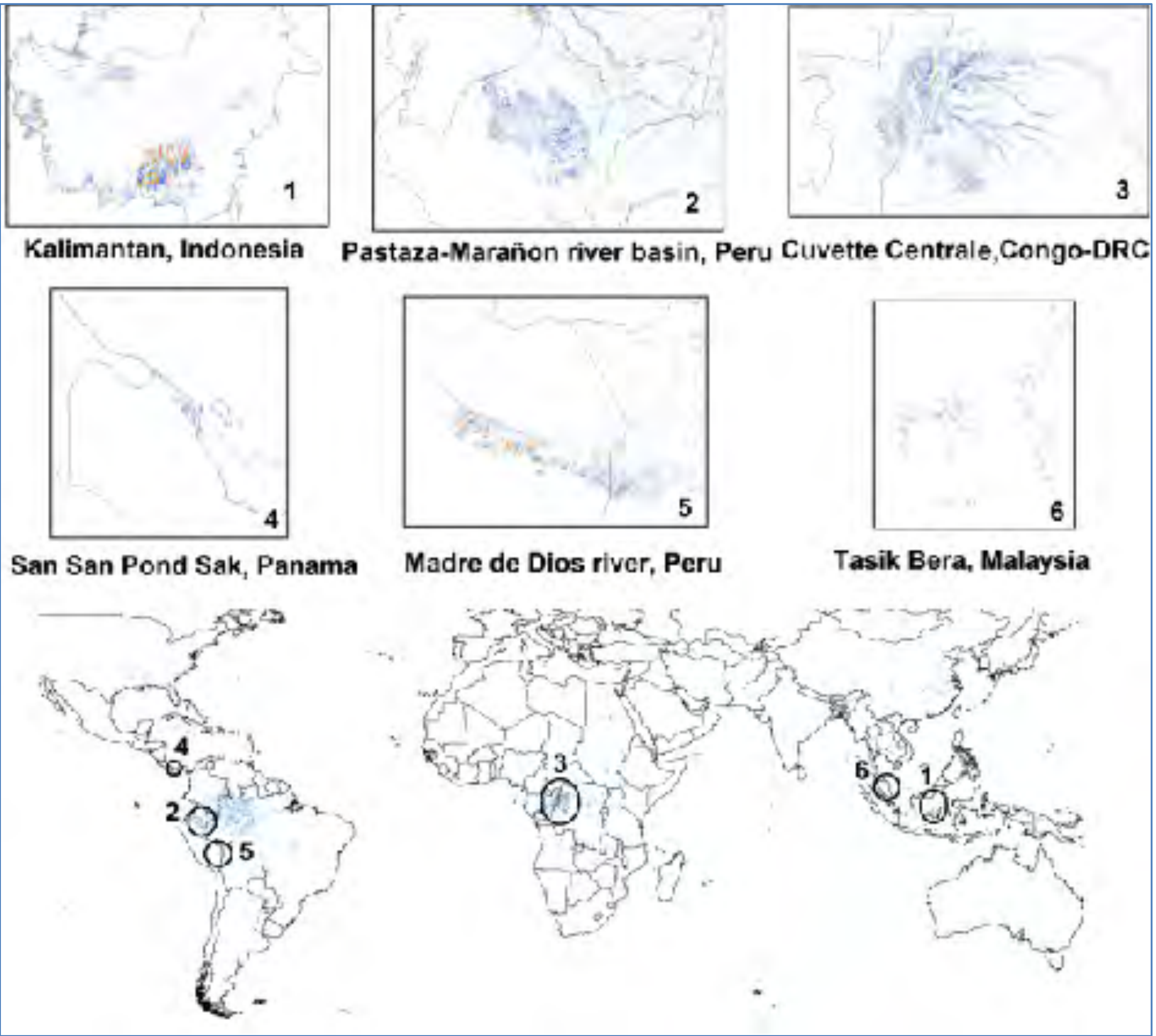


Africa (Cuvette-Central, Angola, Zambia, Botswana, Sudan)

Validation

Figure S1: Distribution of the peat points (n= 275) used to validate the peat maps produced with our expert system model.

Numeric 65% agreement in the tropics
74% agreement in Indonesia



There is not enough ground data available to properly validate tropical peatland maps

Figure S2: Visual validation of our map against six major tropical peat deposits as reported in Lawson *et al., (*2014)

Visual

The expert system model (knowledge-based predictive approach)

Considers three basic requirements for wetland/peatland development:

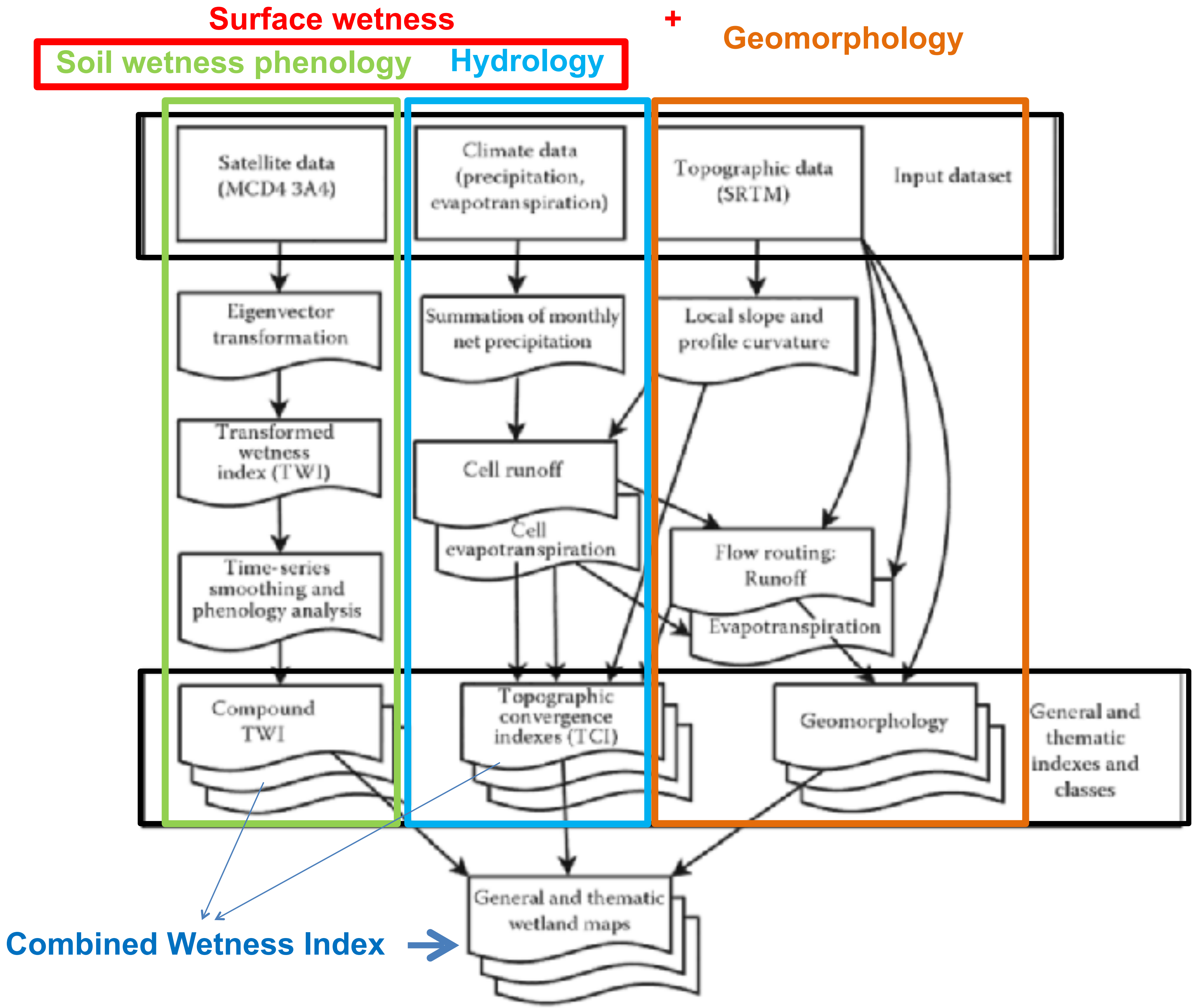
1. Water input exceeds the atmospheric water demand (potential evapotransp.)
2. The surface is wet or inundated for prolonged periods
3. The geomorphology allows surface water accumulation

Requires data on:

1. Regional and local water balances:
   - Mean Monthly precipitation1950-2000 from WorldClim global dataset
   - Evapotranspiration from CRU- East Anglia
2. Soil moisture (surface wetness phenology):
   - 16-day BRDF–corrected MODIS (MCD43A4) for mapping the duration of wet and inundated soil conditions (236m) year **2011** (2010-2012)
3. Geomorphology:
   - Version 4 of the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM), prepared by CIAT (250m)

Develops and parameterizes three biophysical indices per pixel, at 236m:

1. Wetland Topographic Convergence Index (wTCI) (monthly) topographic wetness
2. Transformed Wetness Index (TWI) (bi-weekly): soil moisture/
3. Geomorphological Index

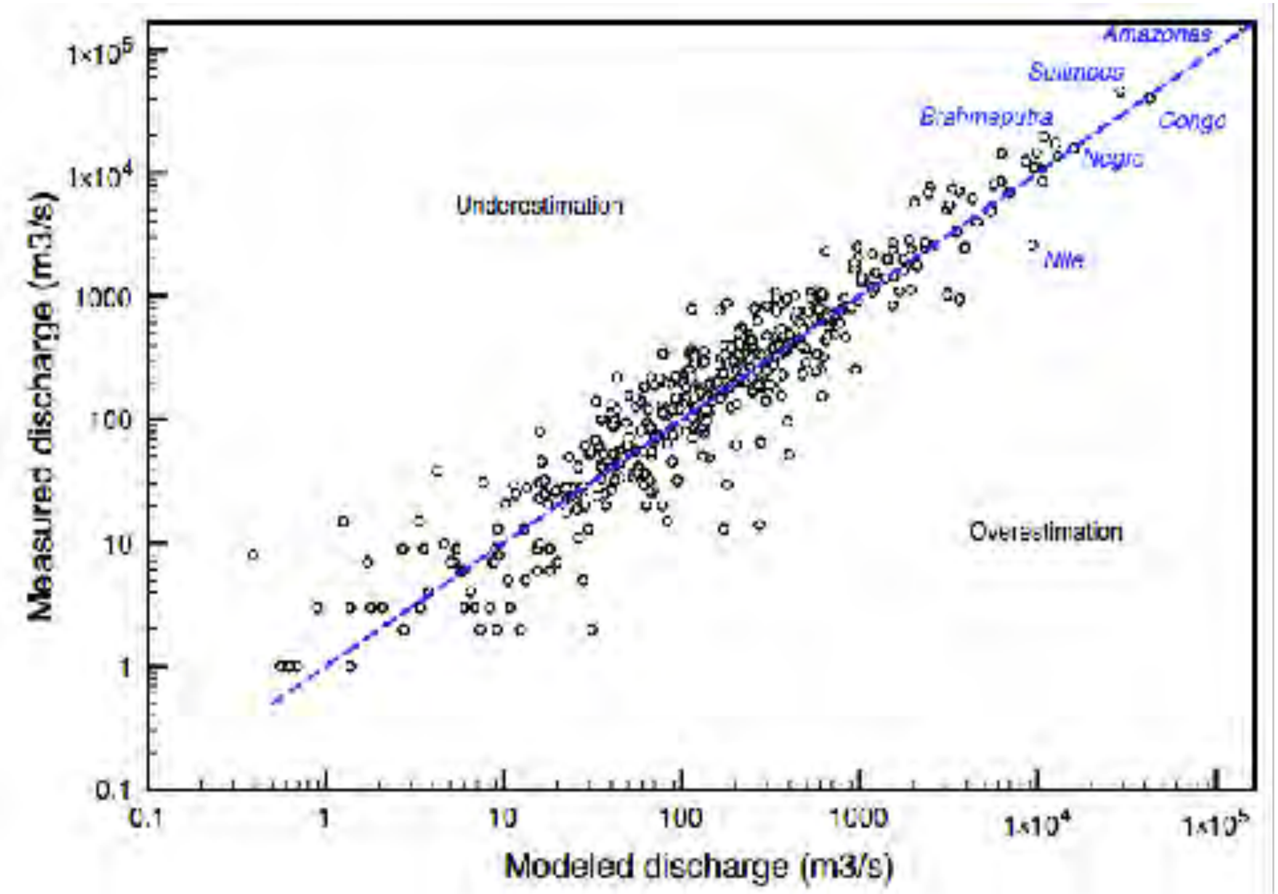


Surface wetness
+
Geomorphology
Soil wetness phenology
Hydrology
Satellite data (MCD4 3A4)
Climate data (precipitation, evapotranspiration)
Topographic data (SRTM)
Input dataset
Eigenvector transformation
Summation of monthly net precipitation
Local slope and profile curvature
Transformed wetness index (TWI)
Cell runoff
Cell evapotranspiration
Flow routing: Runoff
Evapotranspiration
Time-series smoothing and phenology analysis
Compound TWI
Topographic convergence indexes (TCI)
Geomorphology
General and thematic indexes and classes
General and thematic wetland maps
Combined Wetness Index

Hydrological modeling: Wetland Topographic Convergence Index (wTCI)

Modification of the TCI (Beven and Kirby 1979) to account for tropical conditions

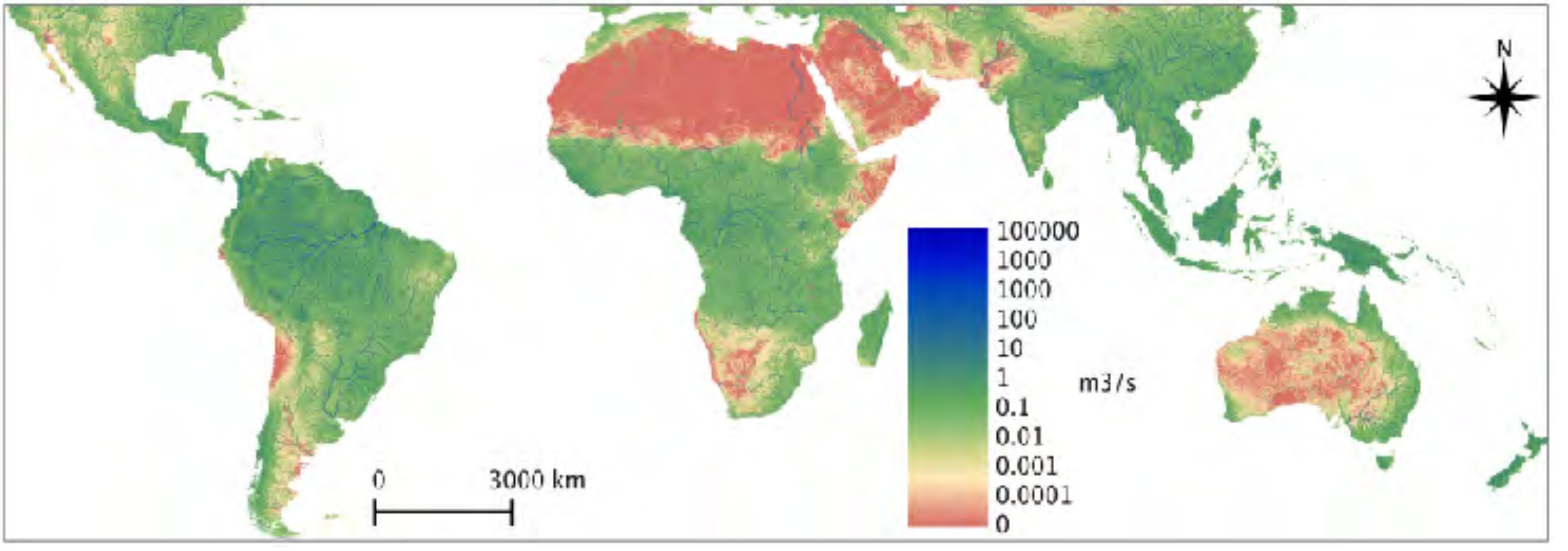
Outputs: Surface runoff, ground water flow, flooding volumes



The figure shows modeled versus measured discharge for 435 globally distributed runoff stations (log scale).

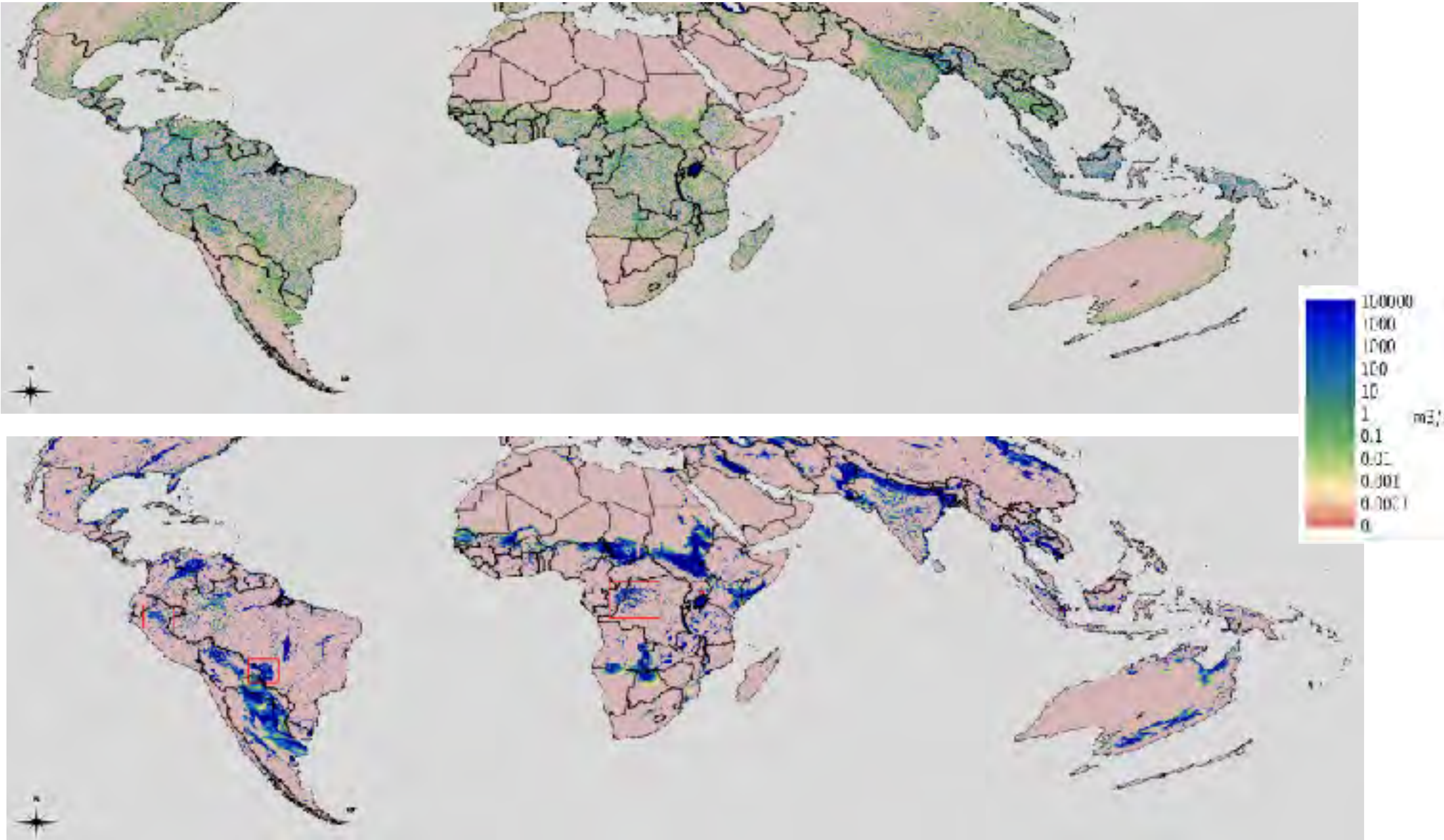
Basic model concept:
1. Monthly vertical water balance from precipitation and reference evapotransp. (rET)
2. Routing of surplus water while allowing rET to fill up while considering local slope and curvature, and soil water conditions.

Hydrological modeling: global runoff



Estimated mean global runoff for the period 1950-2000.

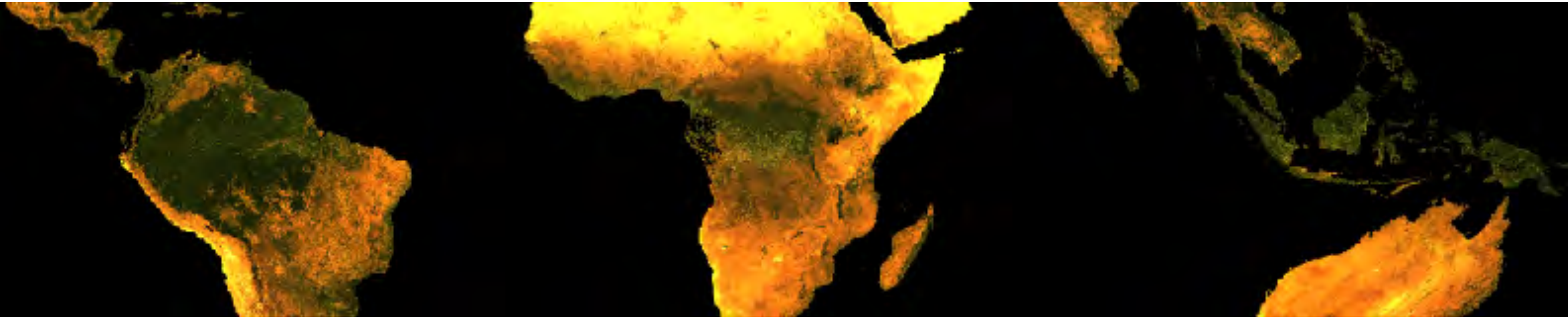
Hydrological modeling: flood volumes

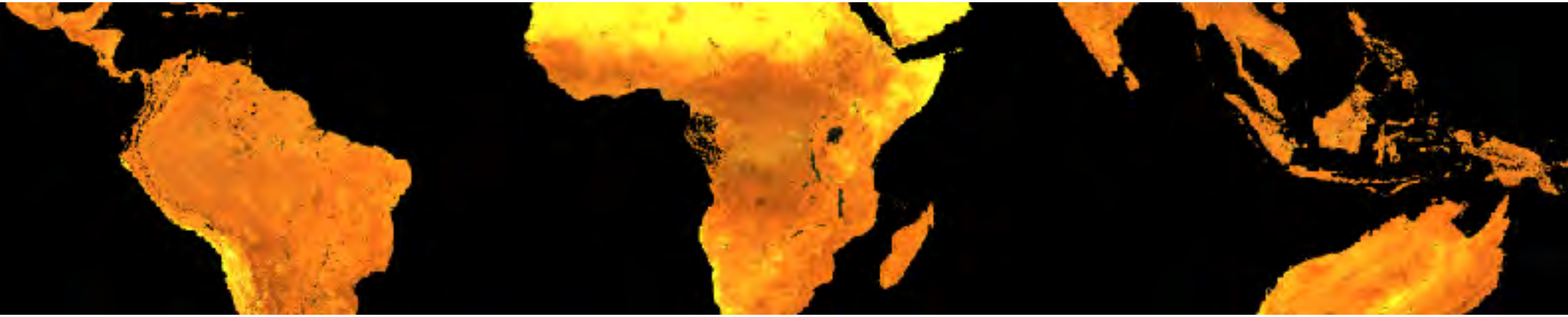


Estimated flood volumes for confined valleys (top) and alluvial plains (bottom)

Soil moisture: Transformed Wetness Index (TWI)

Vegetation unmixing: Photosynthetic Vegetation (PV), NPV, Soil brightness and water





The two MODIS composites are made with the same algorithm and the same data, but with the vegetation signal from photosynthetic vegetation (PV) and non-PV removed from the lower panel using a unitary matrix transformation.

The TWI- wetness estimates are done from the data illustrated in the lower panel

Soil moisture: Transformed Wetness Index (TWI)

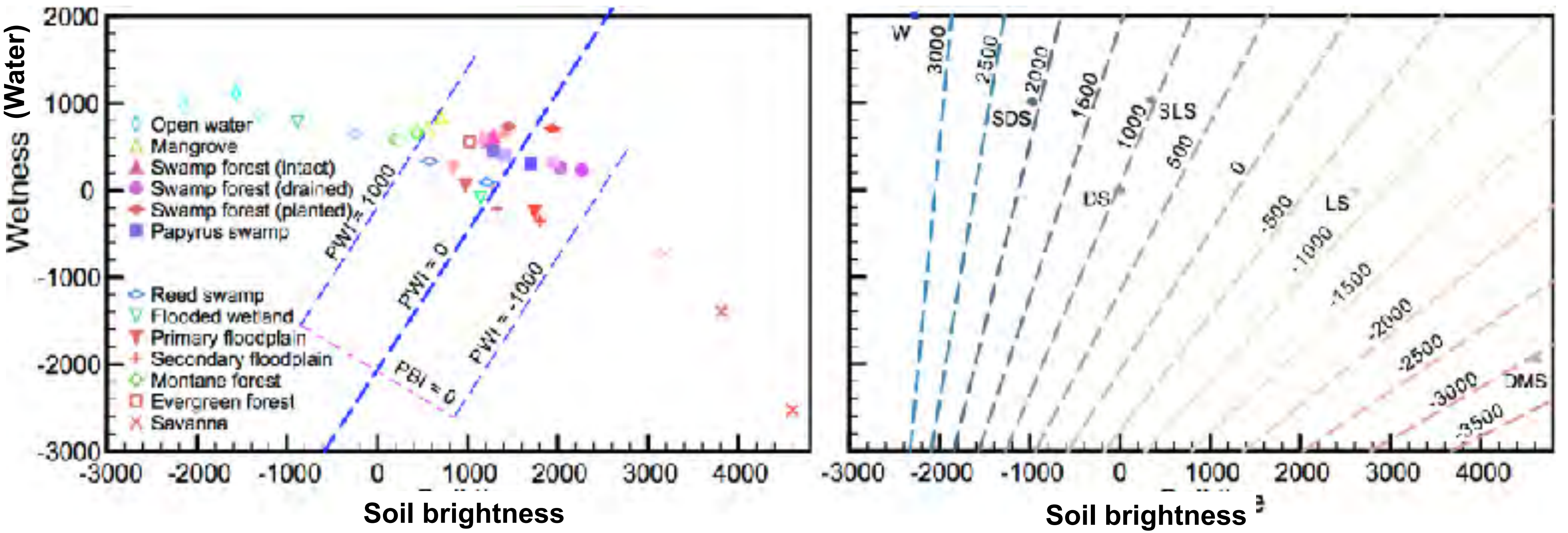


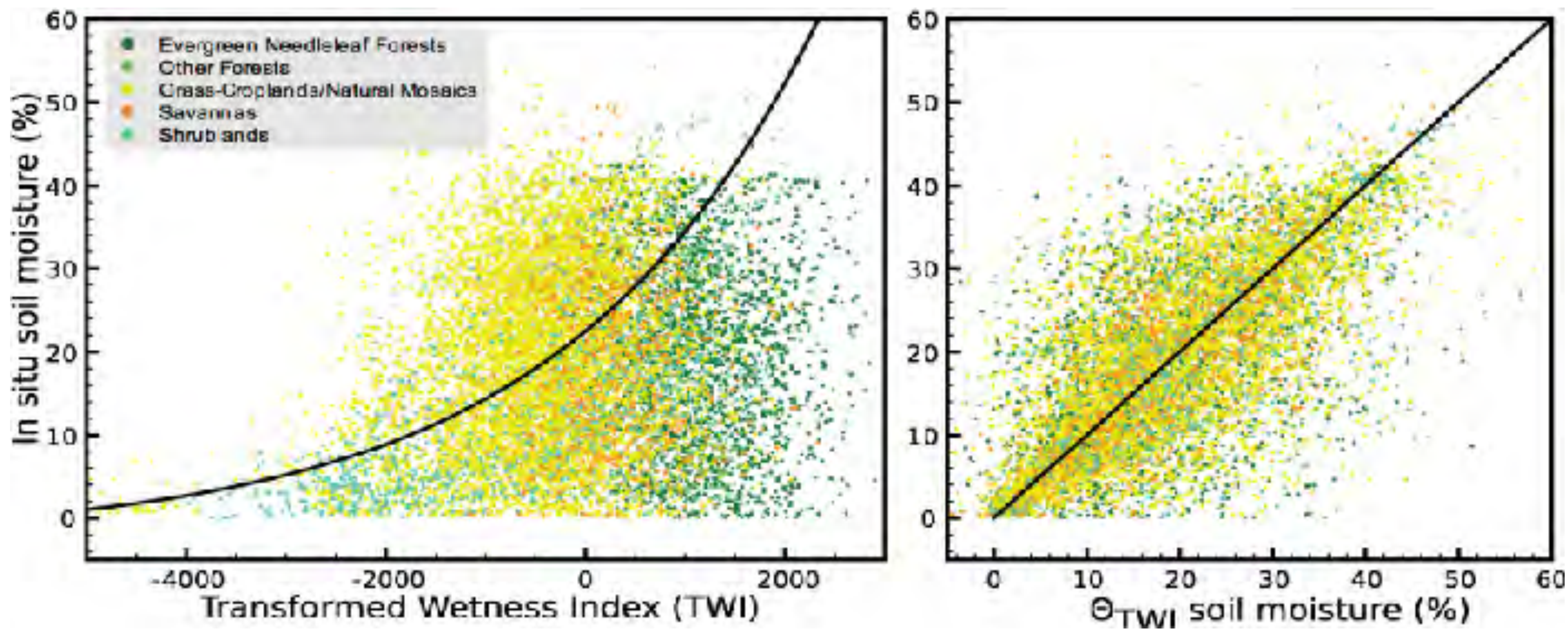
Illustration of the construction of TWI: Surface wetness estimation by an optimized non-linear differentiation using soil-brightness and water.

- The axis are the same in both illustrations, represeting soil brightness (x) and water (y) derived from the unitary matrix transformation of the original MODIS data.
- The PWI = 0 is the soil iso-wetness line, a perpendicular wetness index, helps estimate:
  - ➢ wetness for different types of landcover
  - ➢ the differenciated TWI for different hydrological conditions (right panel)
- The colors of the right panel corresponds to the colors in the TWI map (next slide).

Transformed Wetness Index to SOIL MOISTURE

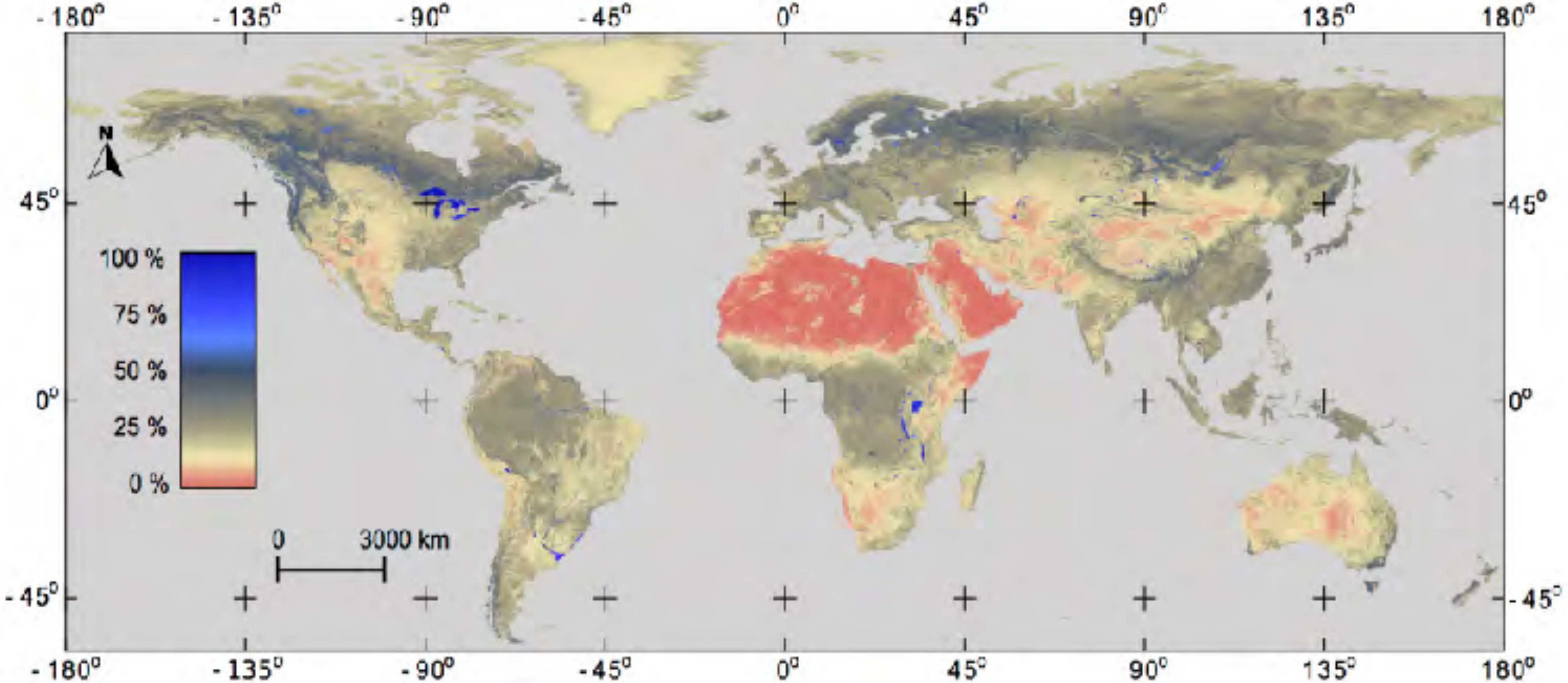
Basic model concept:

1. Unitary matrix transformation (spectral un-mixing) of multispectral image data to eigen vectors representing soil brightness, photosythetic vegetation (PV), non-PV and water.
2. Surface wetness estimation by an optimized non-linear differenciation using soil-brightness and water.
3. Calibration using soil moisture measurements from the the International Soil Moisture Network (ISMN)



The figure shows modeled versus measured soil moisture: left original TWI, right converted to soil moisture and assimilated to mean and STD of measured time-series from ISMN.

Transformed Wetness Index



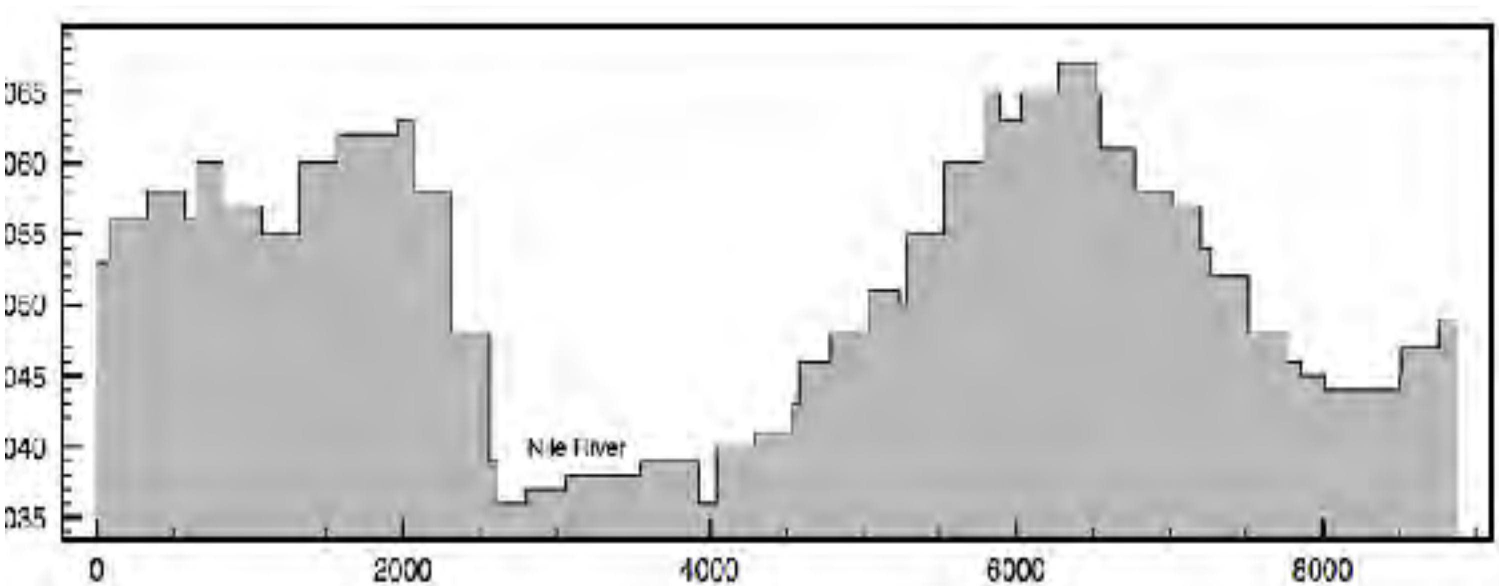
Estimated global soil surface wetness for 2011 using the Transformed Wetness Index. The conversion from the TWI raw index to soil moisture content (%) was done using data from the International Soil Moisture Network (ISMN) illustrated in the next slide.

Geomorphology

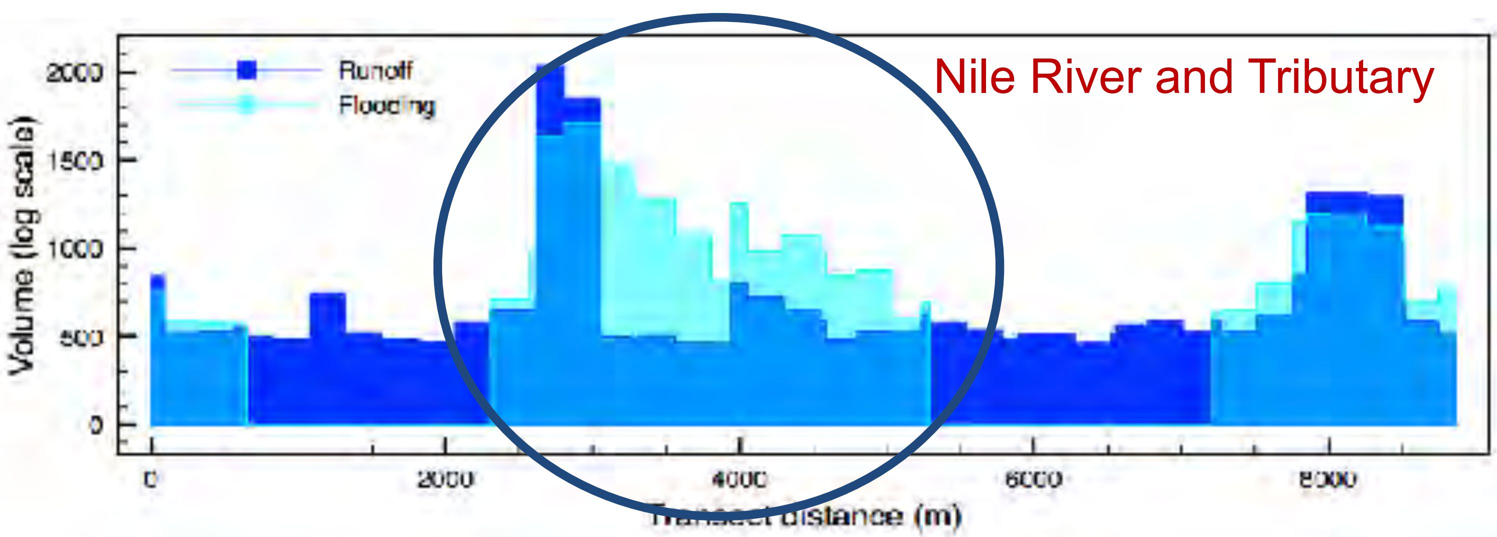
Final Outputs: geohydromorphologies + depth

1. Topography + Hydrology

Case example of a topographic transect with the Nile River



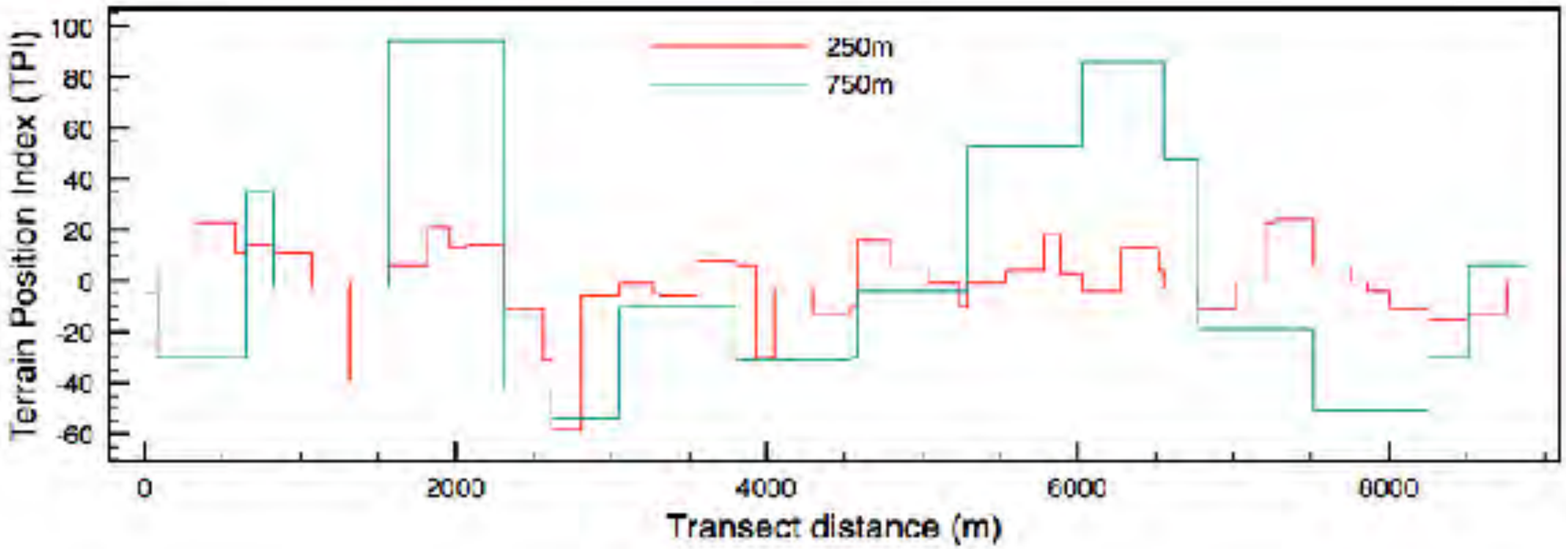
Digital elevation model (SRTM)



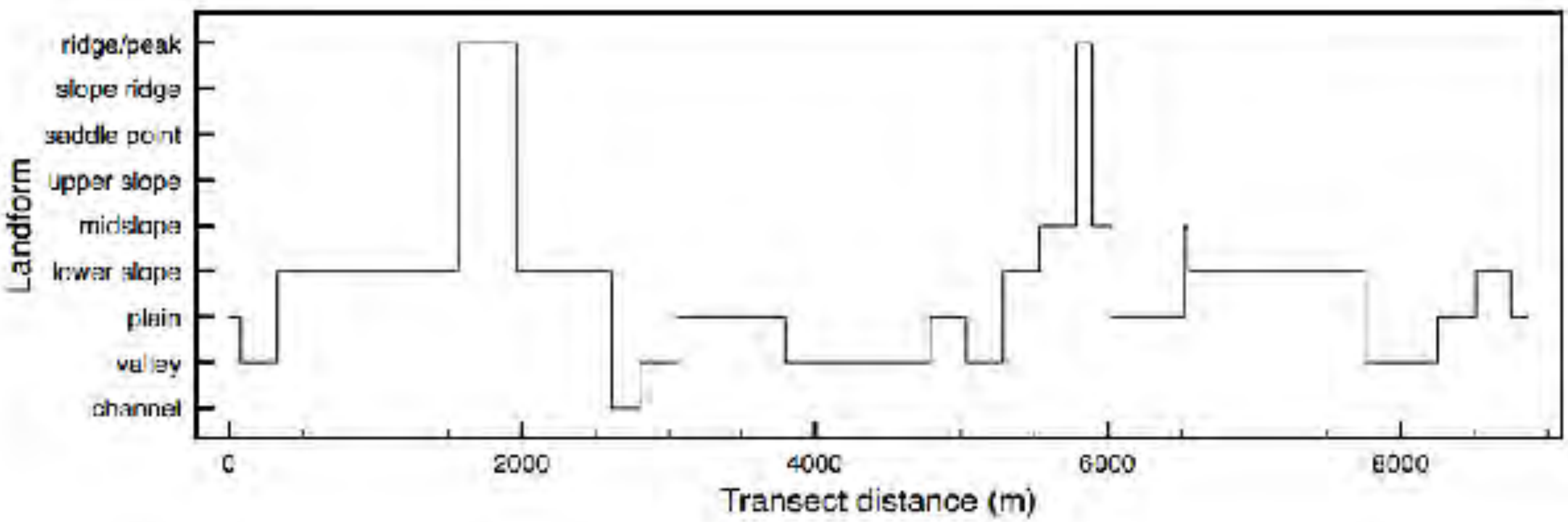
Runoff and flooding volumes (note the Log-scale)

Geomorphology

2. Topographic Position Index (TPI) and Landform classes



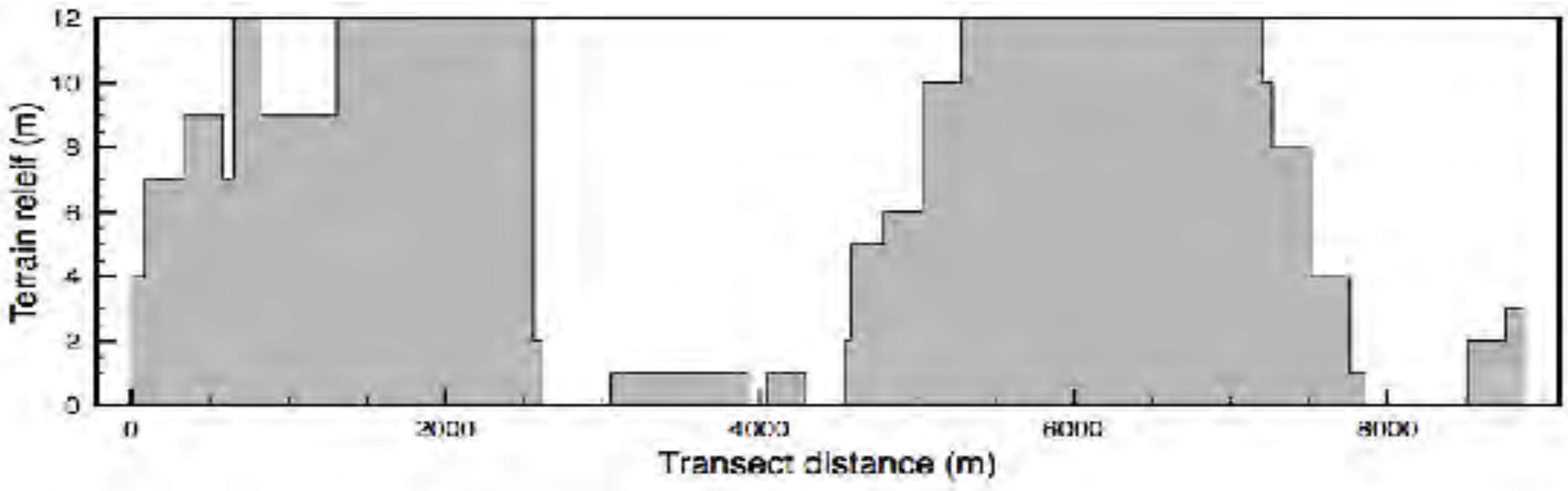
Topographic Position Index (TPI) at 250 and 750m along the transect



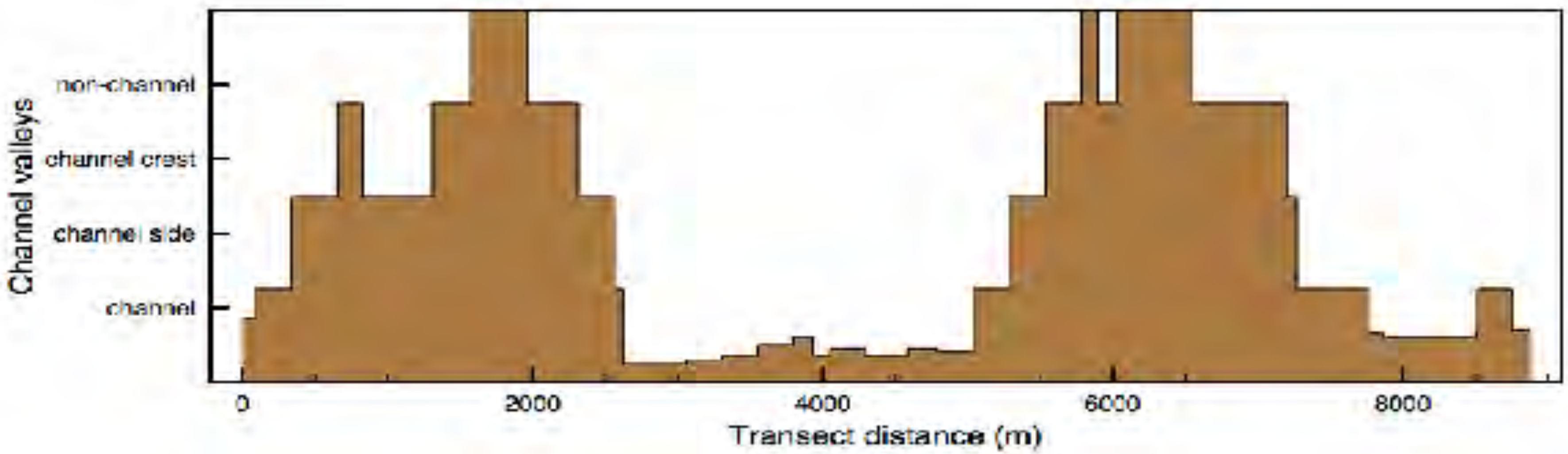
Landform classes derived from multiscale analysis (250 and 750 m pixel scale) using The Topographic Position Index (TPI)

Geomorphology

3. Terrain relief and geohydromorphologies

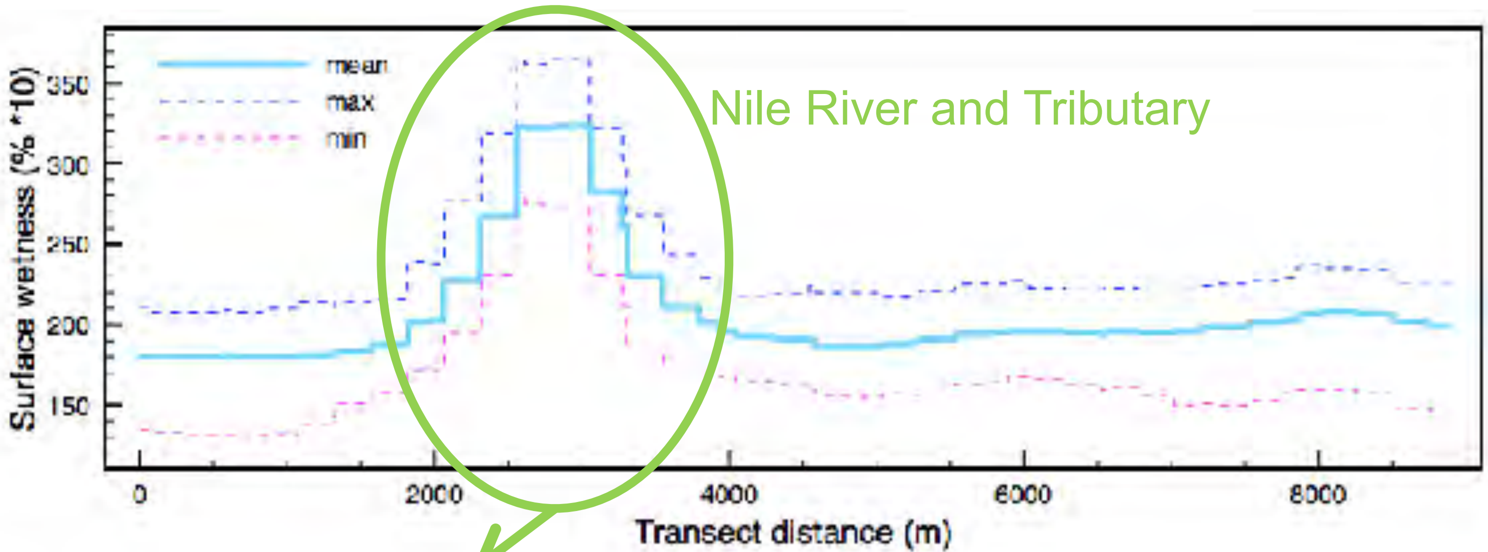


The **terrain relief** is the **drop in elevation between the DEM and the nearest drainage point**, with the latter identified from a combination of the landform map and the runoff map



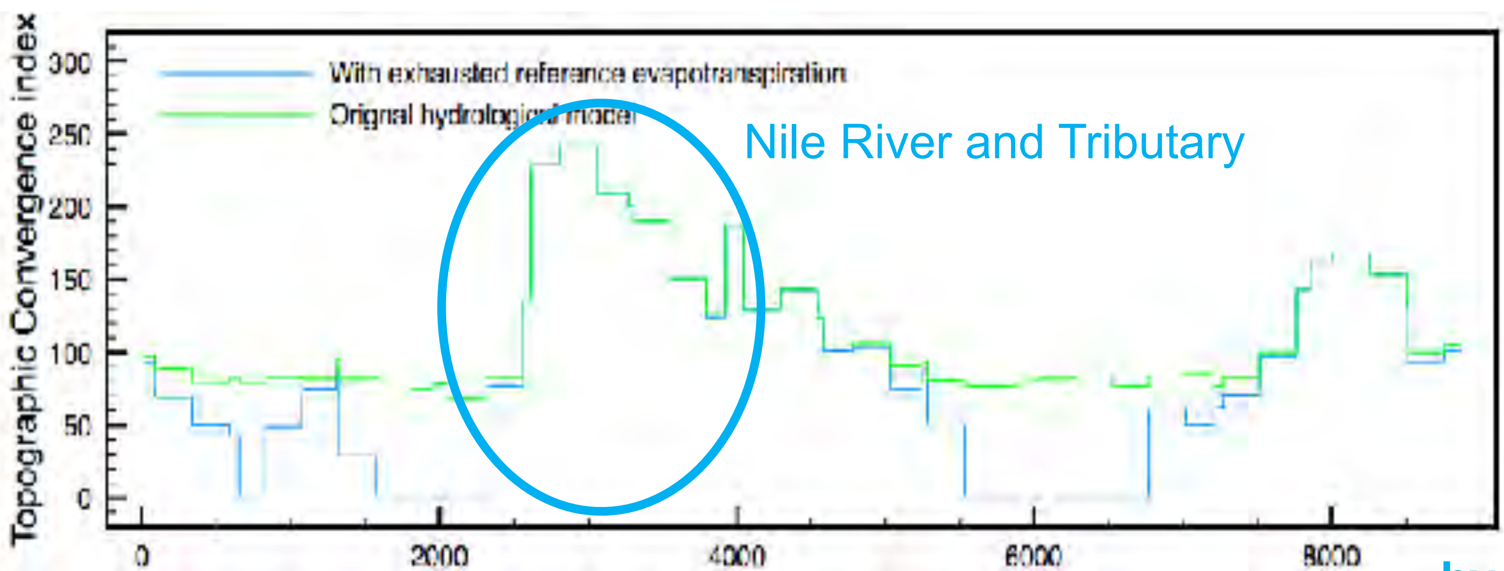
Combining the runoff map and the DEM map, we classify **geohydromorphologies** (i.e. **confined valleys with a feeding channel** with channel components (sides and crests)). These geohydromorphologies threshold wetland occurrence and assist in wetland categorization.

Soil moisture (TWI) + Hydrology (wTCI) + Geomorphology



Soil moisture TWI derived from MODIS time-series

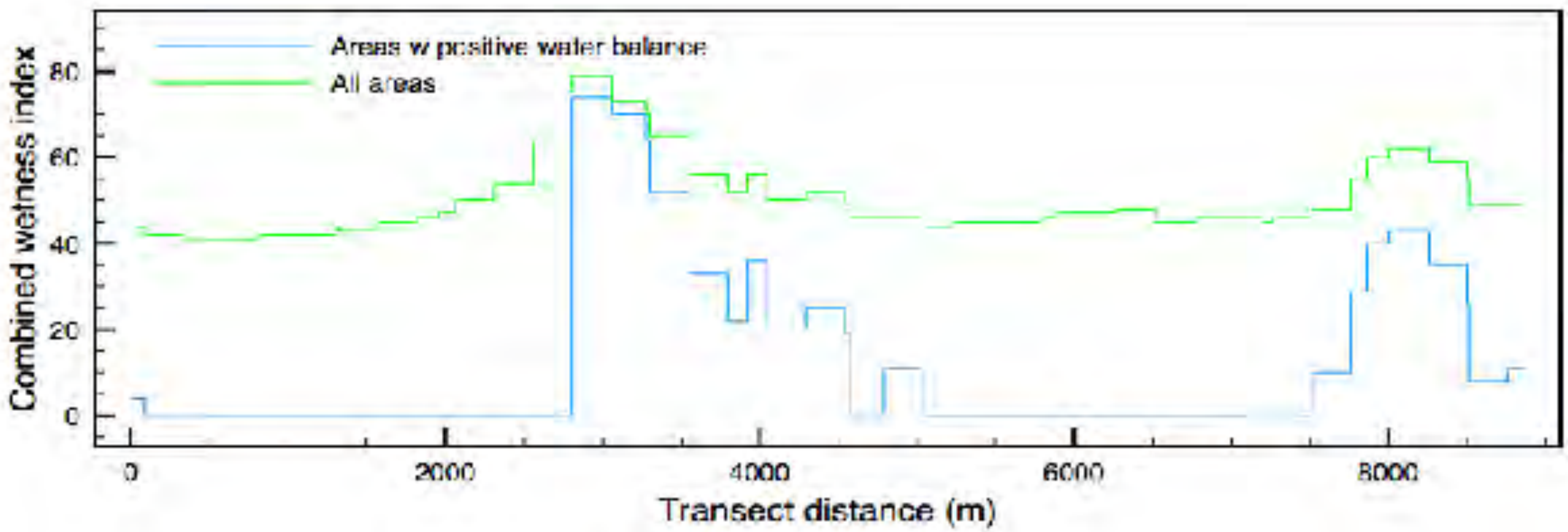
Response by reeds and Papyrus vegetation along time, depending on flooding and soil surface water



Topographic Convergence Index (wTCI)
(runoff and flooding)
+
local slope and profile curvatures

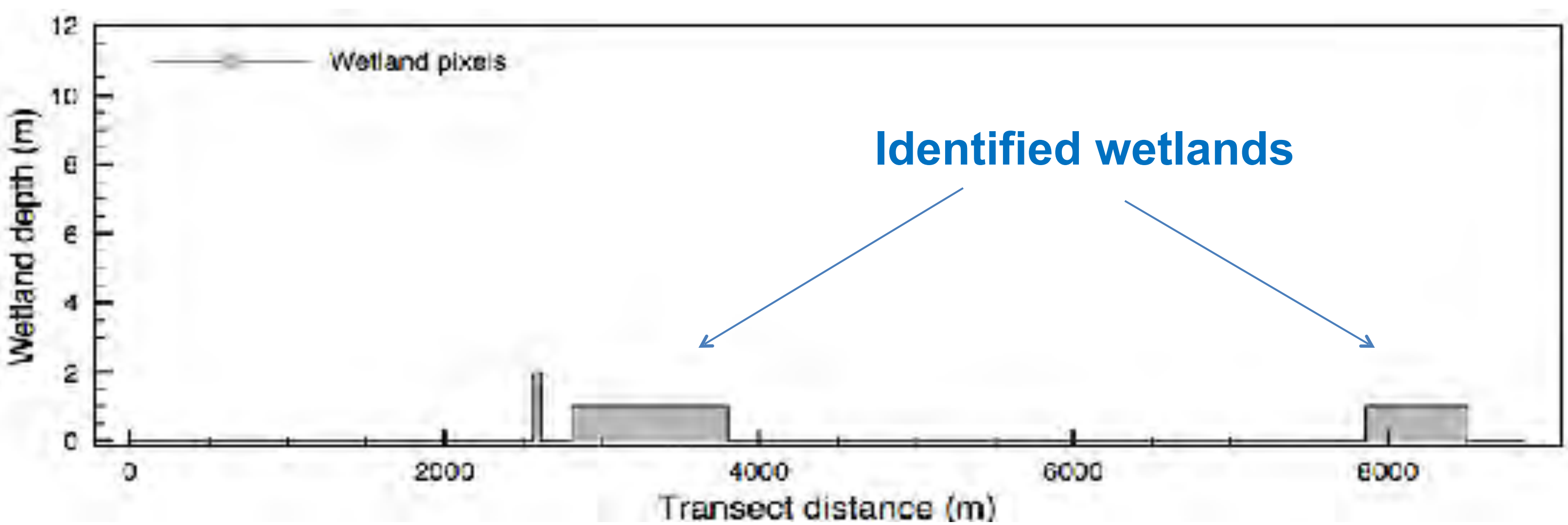
hydrological wetness

Combined Wetness Index: wTCI + TWI



Combined Wetness Index

The green line shows the combined wetness for all regions, whereas the blue line is restricted to areas that can host wetlands related to landform, terrain relief, and water blance. The index is arbitrarily scaled

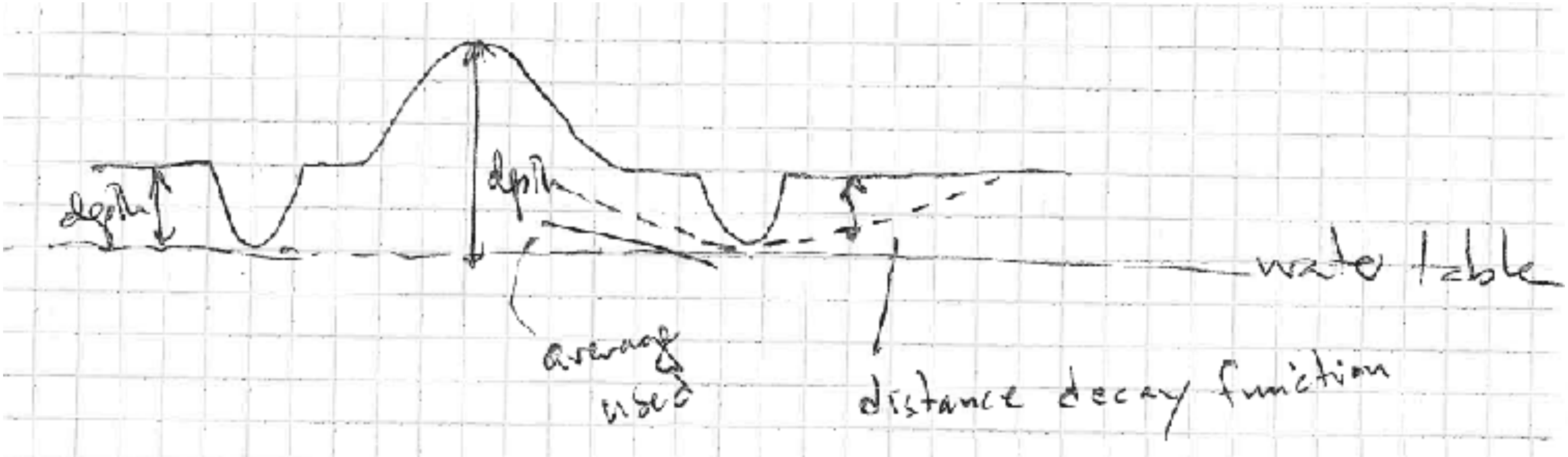


Depth (m)

Identified wetlands along the transect, **illustrated by showing the assigned depth**. The assigned depth is maximized for different wetland categories and can never exceed the terrain relief.

Depths

1. Depth has been derived from a combination of:
   - geomorphological data
   - hydrological wetness data
   - distance decay functions



2. Depth thresholds max-min are assigned to each wetland class

Wetland class	Wetland depth	Peatland depth	Max Depth
Bog	Domerelief	Domerelief	45
Fen	Valleyrelief	Valleyrelief	7
Riverine	Valleyrelief	Valleyrelief	4
Flood-plain	Valleyrelief	Valleyrelief	4
Flood-out	Plainrelief	Plainrelief	4
Marsh (valley)	Valleyrelief	omitted	4
Marsh (plain)	omitted	omitted	0

Questions?

Statistics of tropical peatlands

	Total area (Mkm²)	Volume (km³)	Depth (m)	Stocks** (GtC)
Tropics Page et al. (2011)	0.44 (0.39-0.66)	1,758 (1,585-1,822)	2.3	89
Tropics Gumbricht et al. (2017)*	1.5 x3	6,991 x4 (5,765-7,079)	2.5	352 x4
Indonesia Page et al. (2011)	206,950 (206,950-270,630)	1,138 (1,138-1,157)	5.5	57
Indonesia Gumbricht et al. (2017)	225,420	1,388 (1,089-1,396)	4.9-6.2	70
Brazil Page et al. (2011)	25,00 (15,000-55,000)	50 (3-59)	2.0	3
Brazil Gumbricht et al. (2017)	312,250	1,489 x30 (1,218-1,512)	3.9-4.8	75

Table 1: Estimates of tropical peat variables. **Source**: Gumbricht et al. (GCB) 2017.
* Same study area of Page et al., (2011)
** Using standard values for bulk density and carbon content

Highest peat area (km²): Brazil, Indonesia, DRC, China, Colombia, Peru, USA, Bangladesh, India, Venezuela, PNG, Congo
Highest peat volume (km³): Brazil, Indonesia, DRC, Peru, Congo, Colombia, Venezuela, PNG, Bangladesh, China, Malaysia, India
Highest peat area Page: Indonesia, Peru, Malaysia, Brazil, Zambia, PNG, Venezuela, Sudan, Guayana, Panama, Uganda.