Mapping extent, volume and carbon content of global tropical wetlands

Part 3: preliminary global results

TWINCAM/SWAMP

Thomas Gumbricht

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Data sources for wetland mapping

Wetlands can be mapped from a variety of data sources:

- Ground survey (older topographic maps)
- Aerial photos (modern topographic maps)
- Optical satellite images
- Thermal satellite images
- Radar satellite images
- Microwave satellite images
- Elevation data (e.g. from radar or lidar satellite images)
- Gravimetric data (large water bodies with volume changes)
- Combinations of 2 or more of the above

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Ground survey – too labor intense

Older topographic maps stem out of military mapping needs. Wetlands where important, and are hence usually well represented on topographic maps. But topographic maps are seldom publicly available (for free), the mapping across countries is not consistent, and updating is irregular.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Aerial photos – labor intense, not consistent

Global mapping of wetlands using aerial photo interpretation would be very labor intense. The number of interpreters involved is prohibiting. Using Landsat data instead of aerial photos, a semi-manual photo-interpretation approach has been used to map the global extent of mangroves (Giri et al., 2010). Perhaps it is possible to map all wetlands in a similar manner as well.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Optical satellite images – demands reference data, cloud contamination in the tropics

Traditional (statistical) classification methods require (local) reference sites – preferably falling in the same scene. Globally this is difficult to acquire. Cloud contamination, especially in the tropics, is a problem. Generic indexes that relate to wetlands (e.g. soil wetness or vegetation phenology), is a possible alternative, and was developed as part of the TWINCAM mapping effort.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Thermal satellite images – cloud contamination in the tropics, no unique wetland signal

Wetlands have a higher latent (and lower sensible) heat flux compared to drier land. Wetlands can be detected as (sustained) cool-spots in the landscape. Dense vegetation with shallow ground water can give similar heat fluxes as wetlands, and the same is true for moist forests (with non-histosolic soils). But thermal satellite images have a potential for wetland mapping in combination with other data.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Radar satellite images – demands reference data and time series, poor availability

Radar images are not disturbed by clouds, a great advantage. But availability of global radar images is limited. The interpretation of radar images is not trivial and demands both reference sites, as well as time series (if mapping of surface wetness conditions is required). In the TWINCAM project an attempt was made to use publicly available global radar (PALSAR) data, but the data set turned out to be inconsistent, and not useful.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Microwave Brightness Temperature – coarse spatial resolution, vegetation disturbances

Microwave Brightness Temperature images are very useful for mapping the soil surface wetness (0-5 cm), but the soil wetness is masked out if under dense and wet vegetation. Readily available microwave images are of coarse resolution (10-50 km pixel size), which is too coarse for mapping wetlands. The GIEMS data set is a global surface wetness dataset from Microwave BT and optical data, monthly time step and 25 km spatial resolution.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Elevation data – promising results in a per-basin approach

Topographic wetness can be extracted from any elevation data source as the accumulated drainage (upstream) area of each cell divided by the cell size and the cell slope and/or curvature. It demands that climate is consistent within the basin. To be used as a global index, rainfall/runoff needs to be considered, as well as the difference in soil hydraulic response in various soils. As part of TWINCAM a generic global topographic-runoff wetness index has been developed.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Gravimetric data – most wetlands too small to generate any detectable signal

Publicly available gravimetric data from the twin-satellite GRACE can be used for detecting volumetric changes in earth surface water content. Most wetlands are, however too small for any change in the gravity to be detected. Large water reservoirs can be detected. As part of the TWINCAM project GRACE data was tried out for large wetlands like e.g. the Okavango inland delta in Botswana. But no useful results could be obtained.

Data sources for wetland mapping

Advantages and disadvantages with different data sources:

- Combinations of 2 or more of the above – the most promising approach

Bwangoy et al (2010) combined optical, radar and topographic data to map the wetlands of the Central Congo Basin. Their approach is still based on local reference conditions, and would demand re-calibration for each (sub)basin. The alternative is to use generic indicators that represent similar conditions globally. This has been the aim of the wetland mapping effort within TWINCAM.

The TWINCAM mapping approach

The approach used within TWINCAM/SWAMPS, has been to combine data and information, including:

- Hydrology and topography to derive topographic wetness
- Optical multispectral satellite images for deriving a surface wetness index
- Adopt times-series satellite images at medium resolution to allow phenological analysis of surface wetness
- Geomorphological conditions related to hydrology in general and wetlands in particular (”hydromorphology”)

The TWINCAM mapping approach

The TWINCAM/SWAMPS mapping approach is more of an expert system, and not dependent on local reference data:

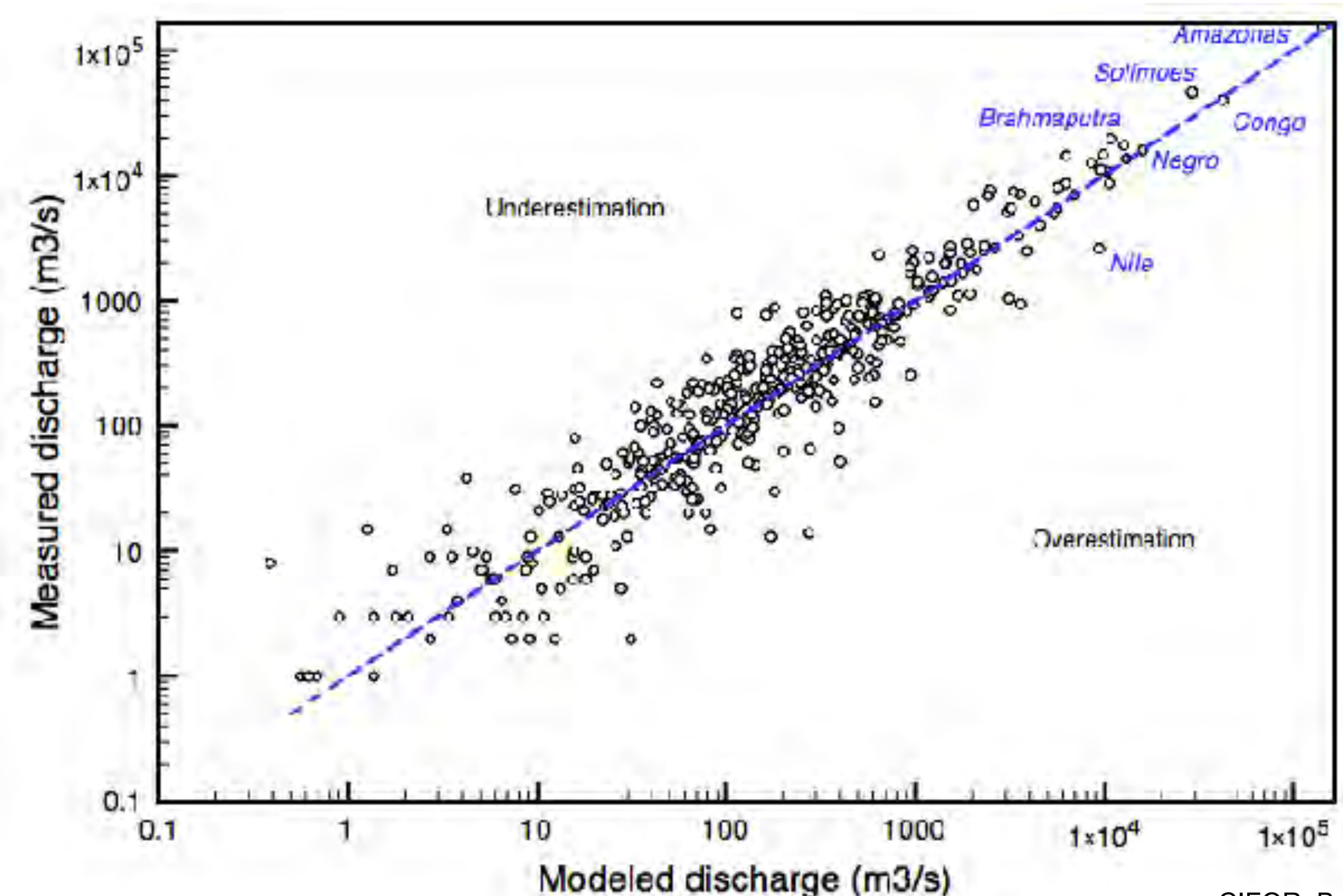
- All derived data used in the classification is intelligible,
- Most input layers are of ratio or ordinal scale, and can be thresholded as a way to calibrate the wetland map in different regions,
- Hydromorphological information is used as boolean data for identifying potential wetland areas, and for distinguishing different wetland classes

The TWINCAM mapping approach

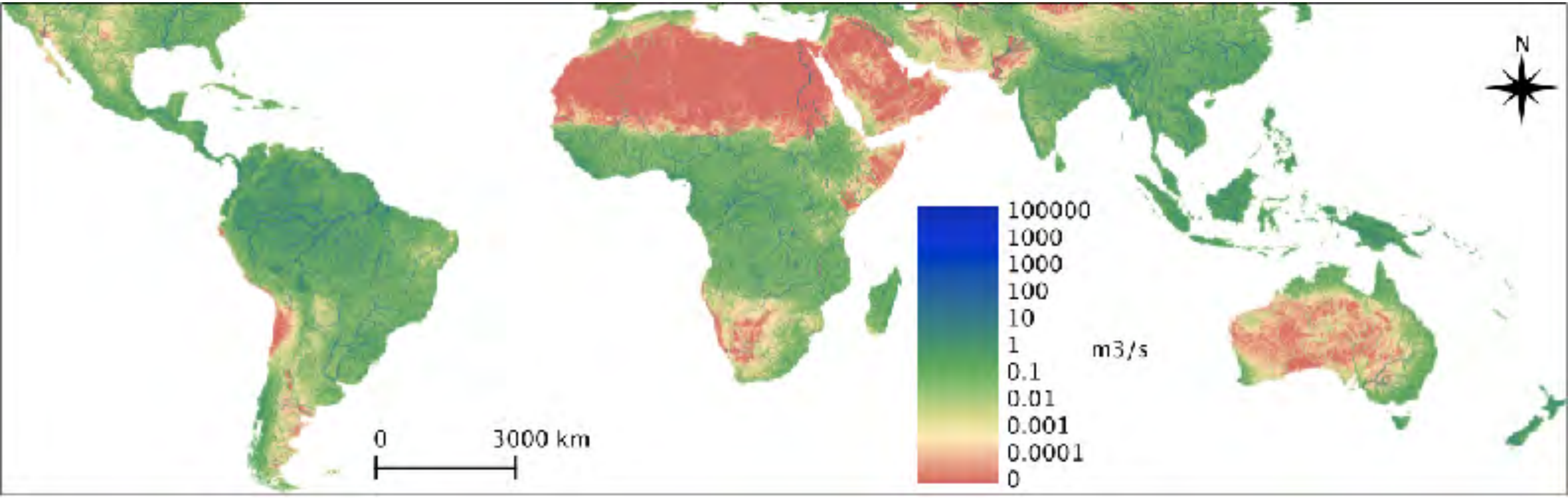
- Hydrology and topography to derive surface wetness

  - Development of a global high spatial resolution rainfall-runoff model
  - Development of global estimates of flooding and floodout volumes
  - Definition of thematic wetland topographic convergence indexes (WTCI) for describing surface wetness in cells with saturated water conditions.

- Global rainfall-runoff model at 250 m spatial resolution and annual time step - results



- Global average runoff (m3/s)



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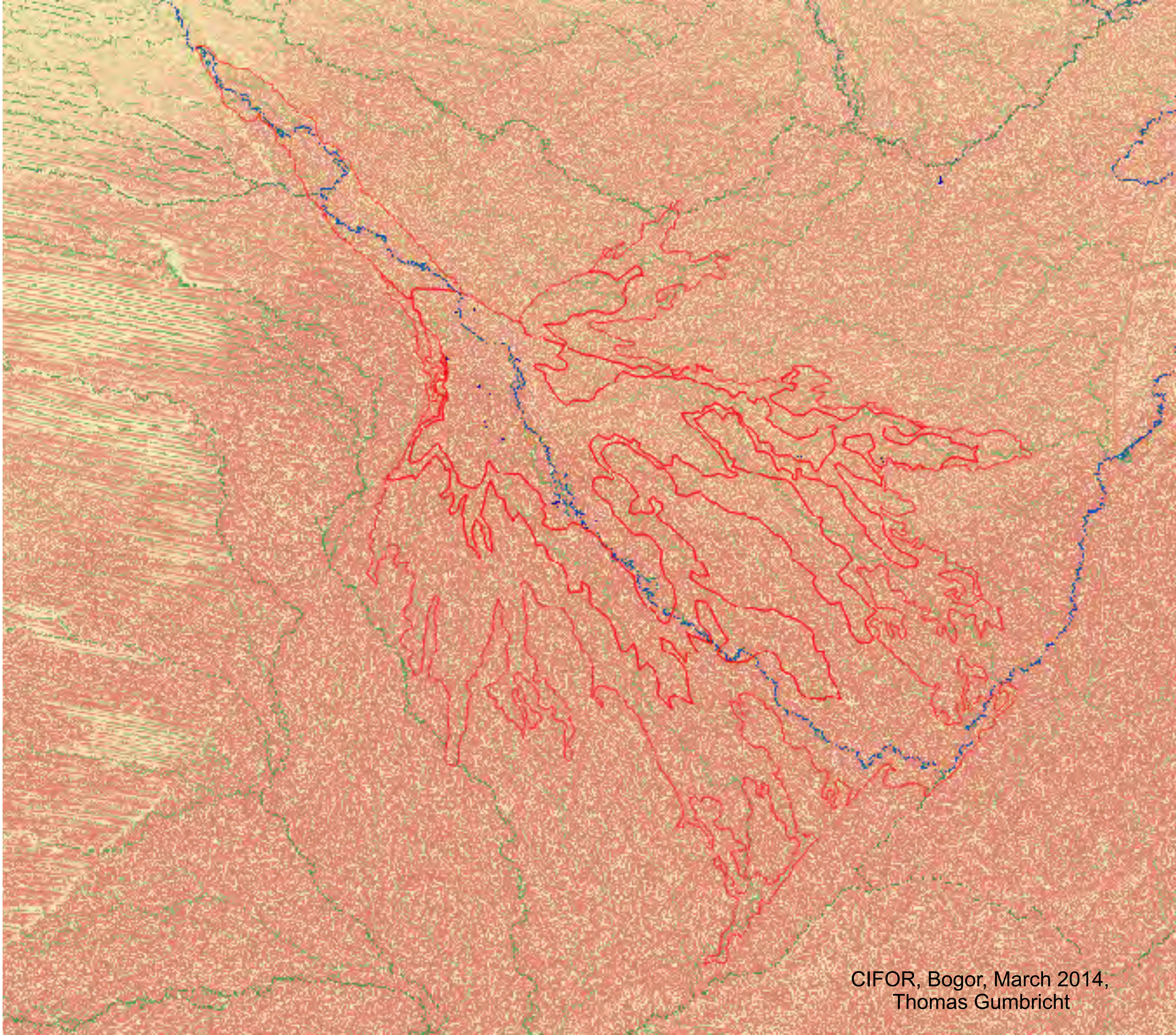
Runoff



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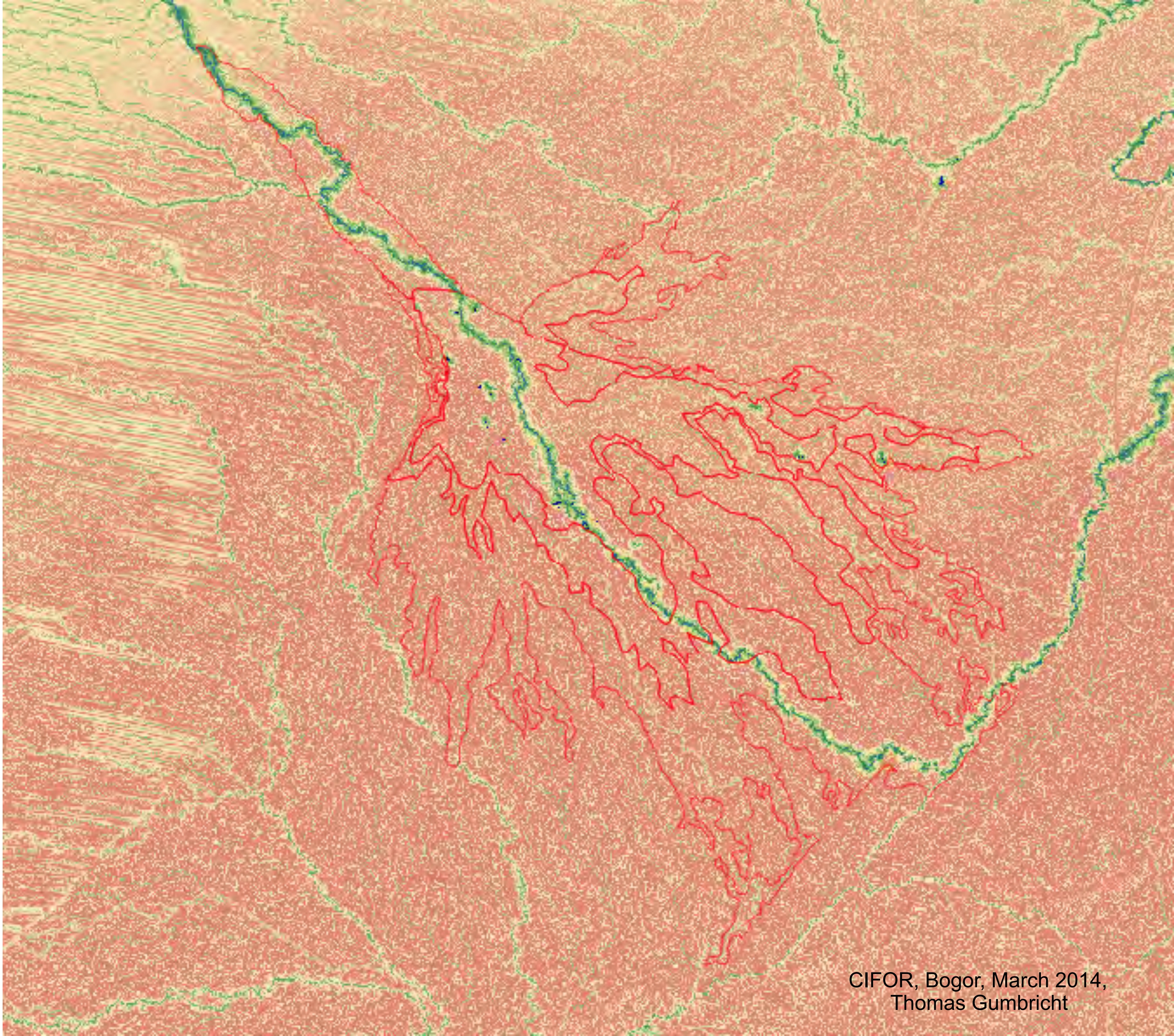
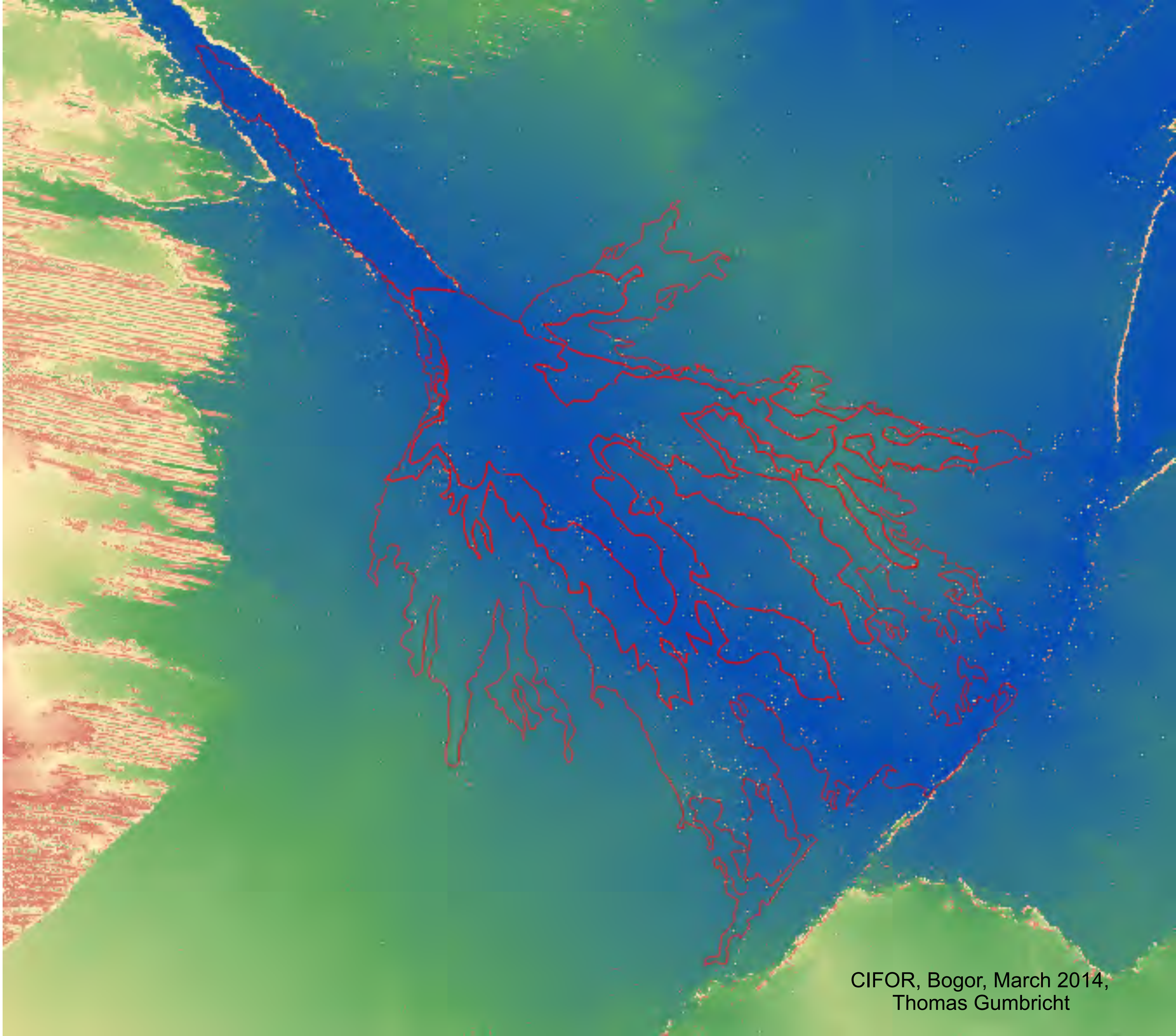
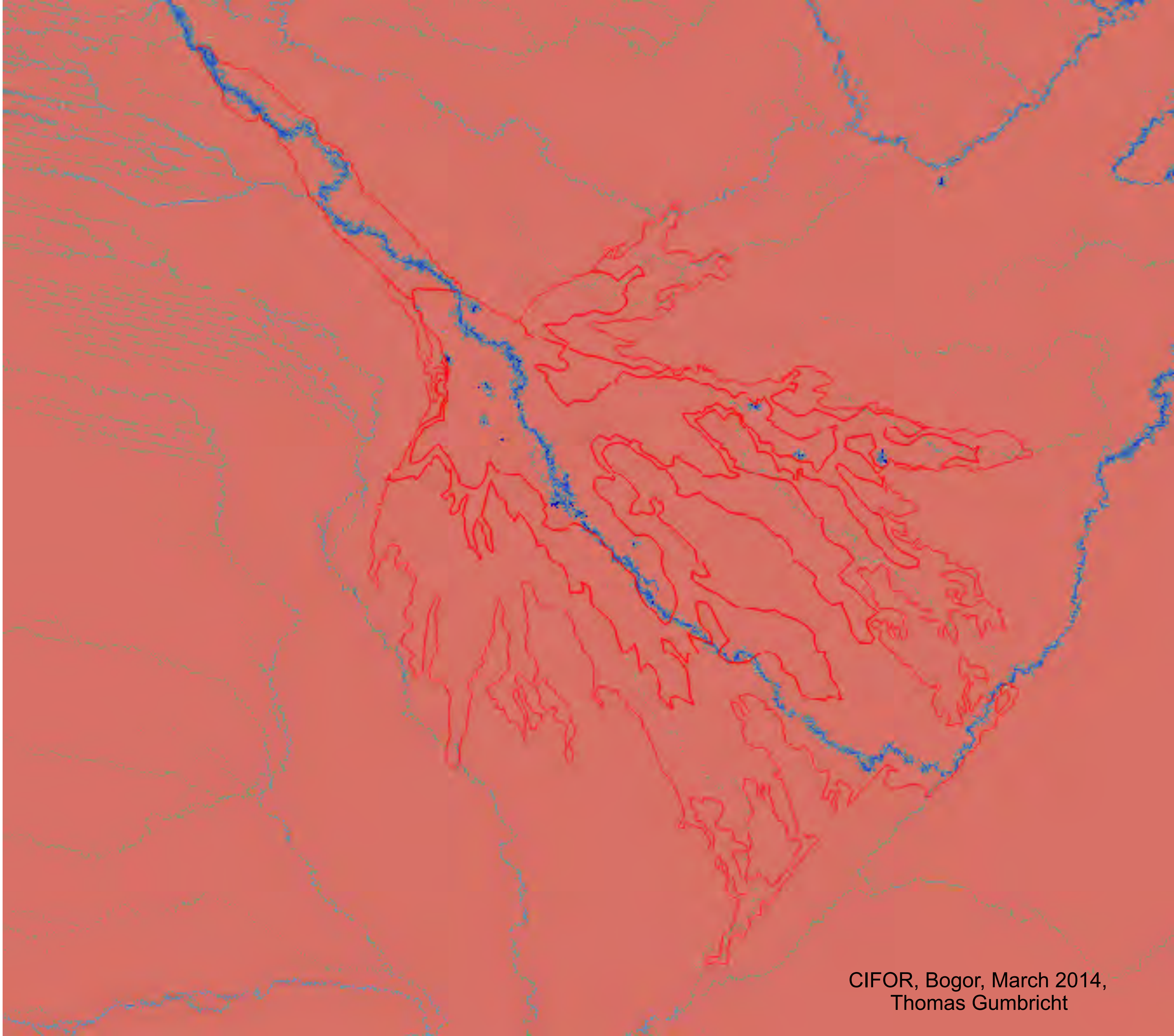
Valley-
flooding



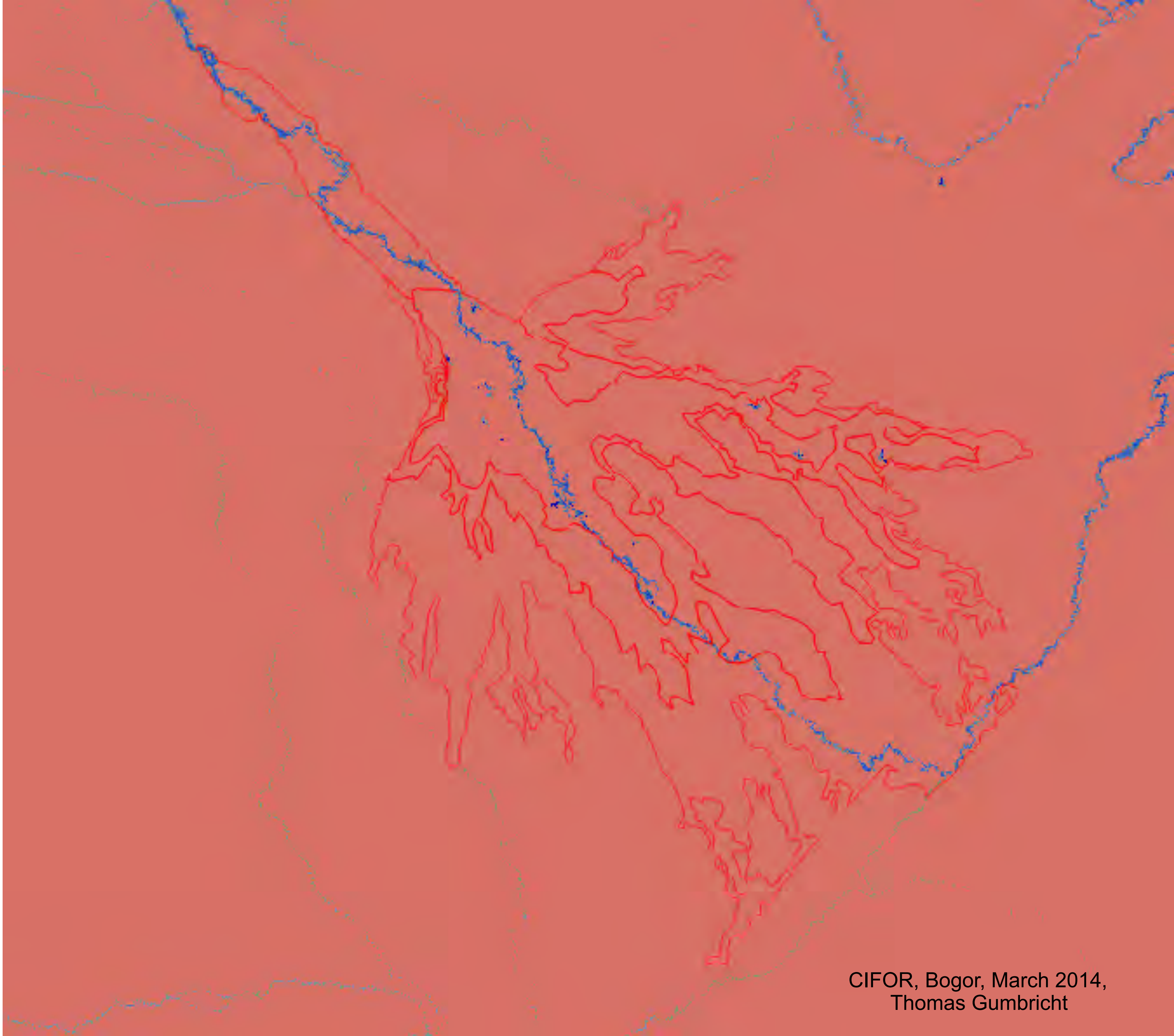
Plain-
floodout



WTCI



WTCI-
riverine



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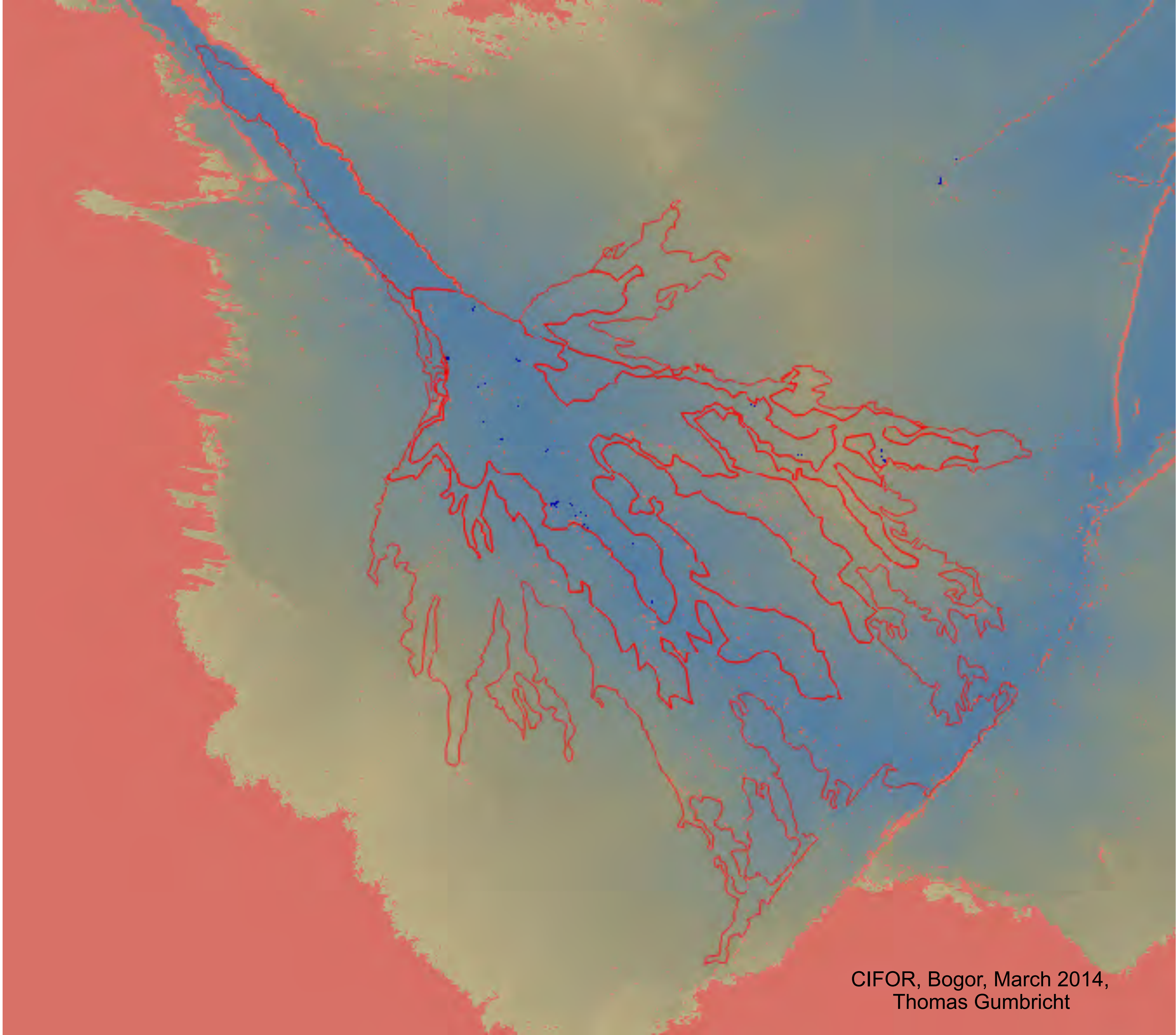
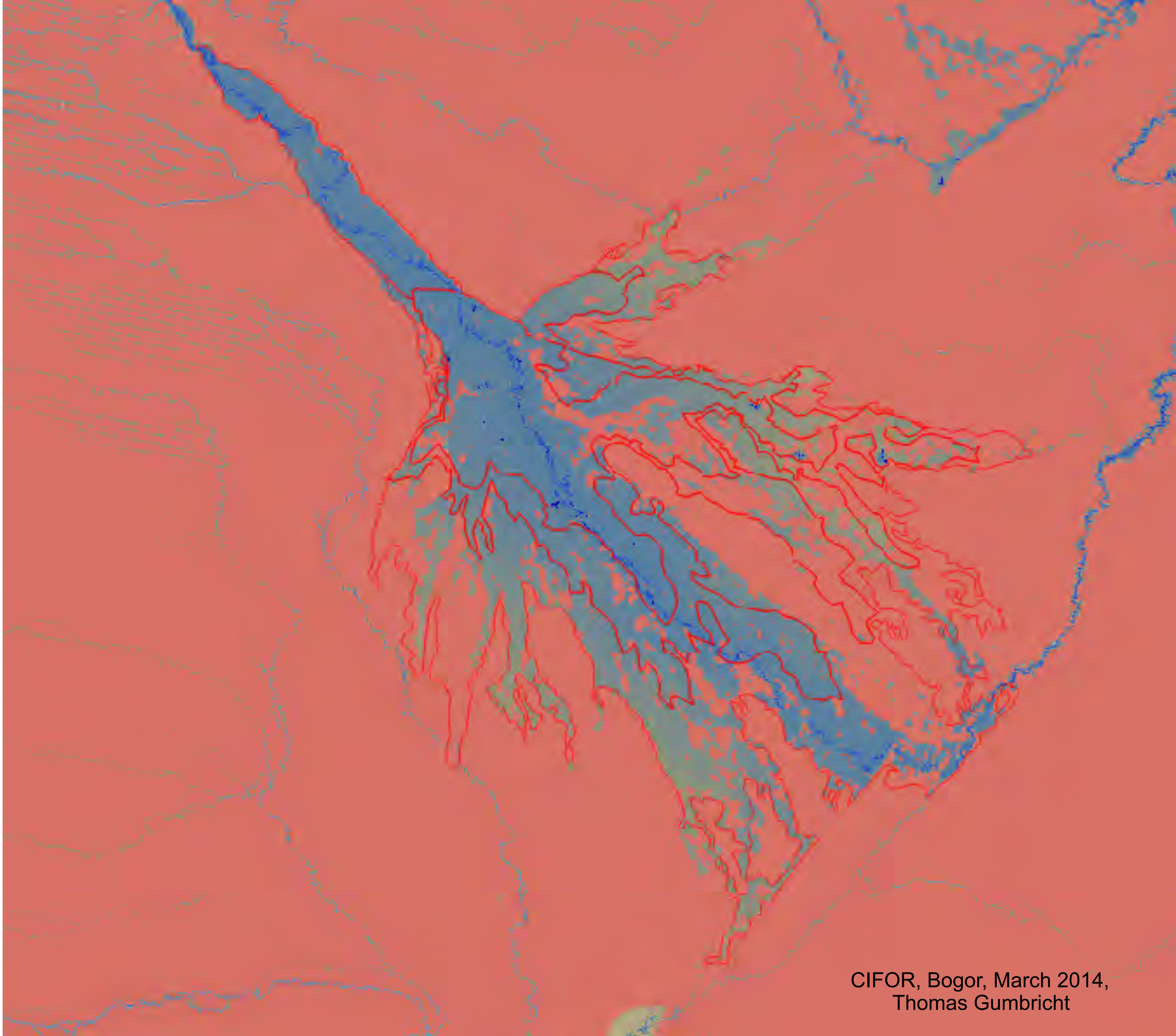
WTCI-
floodout



WTCI-
wetflood



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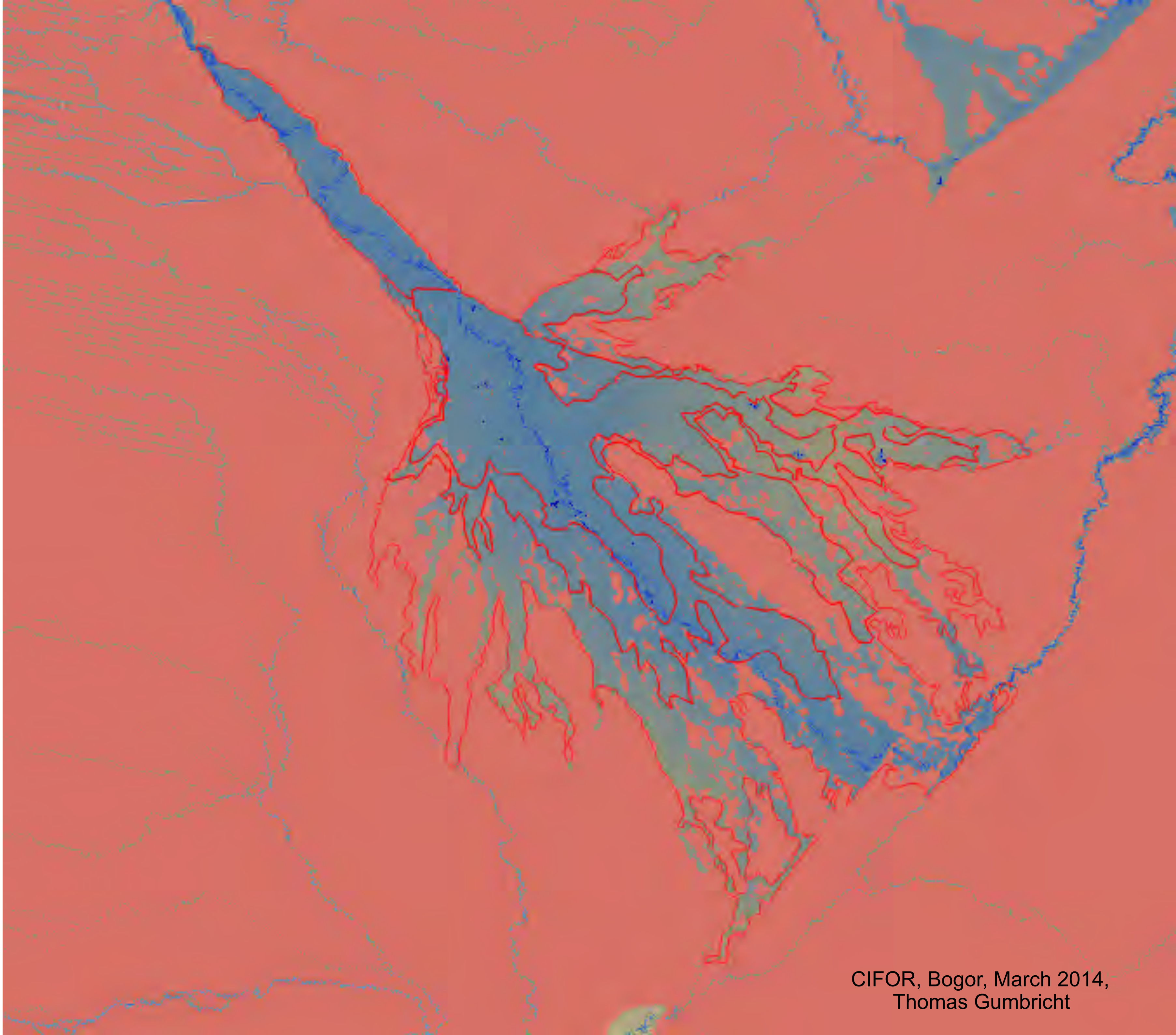
WTCI-
wetmarsh



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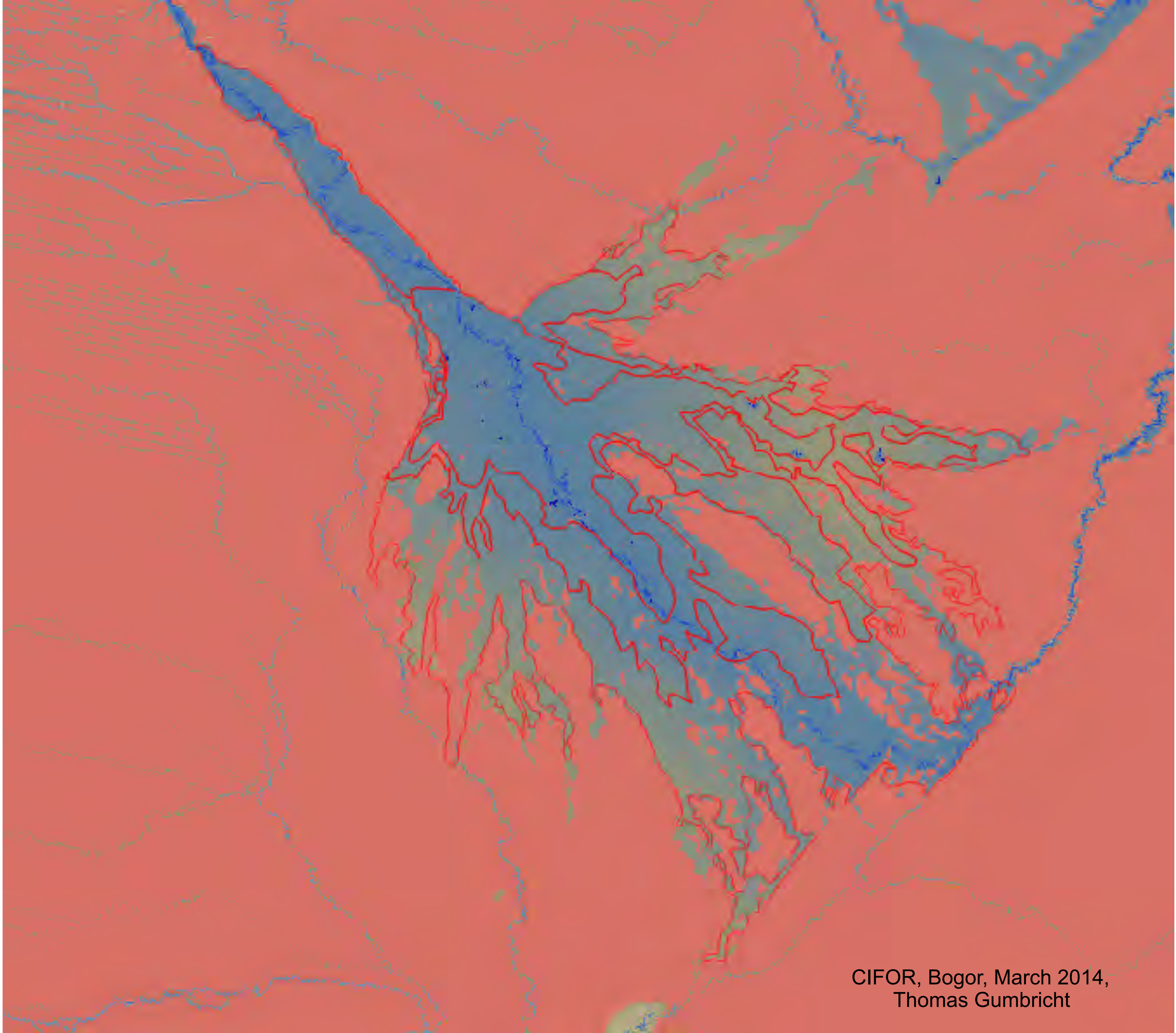
WTCI-
aridmarsh



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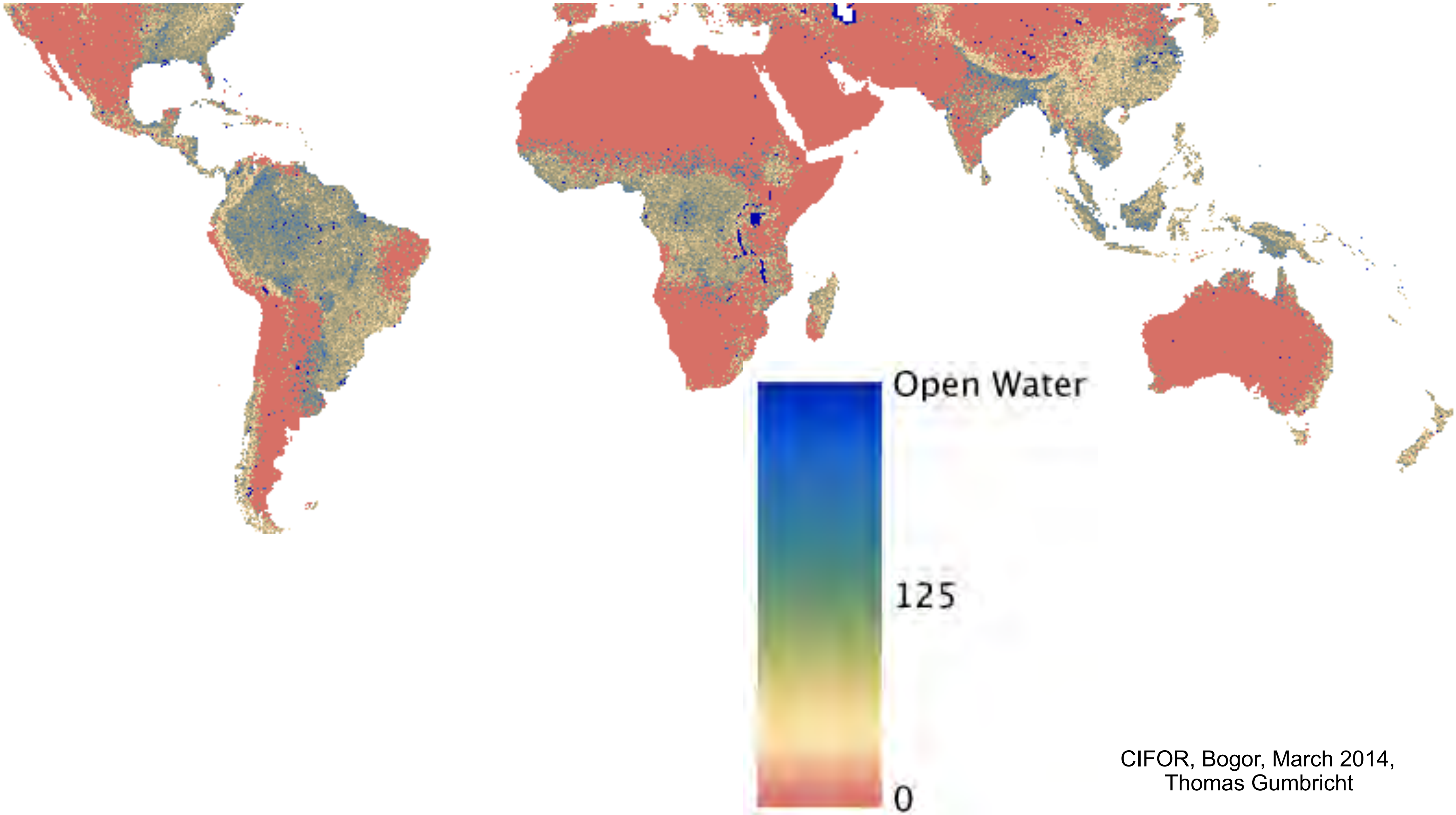
Wetland Topographic Convergence Index

Wetland Topographic Convergence Index

General Wetlands



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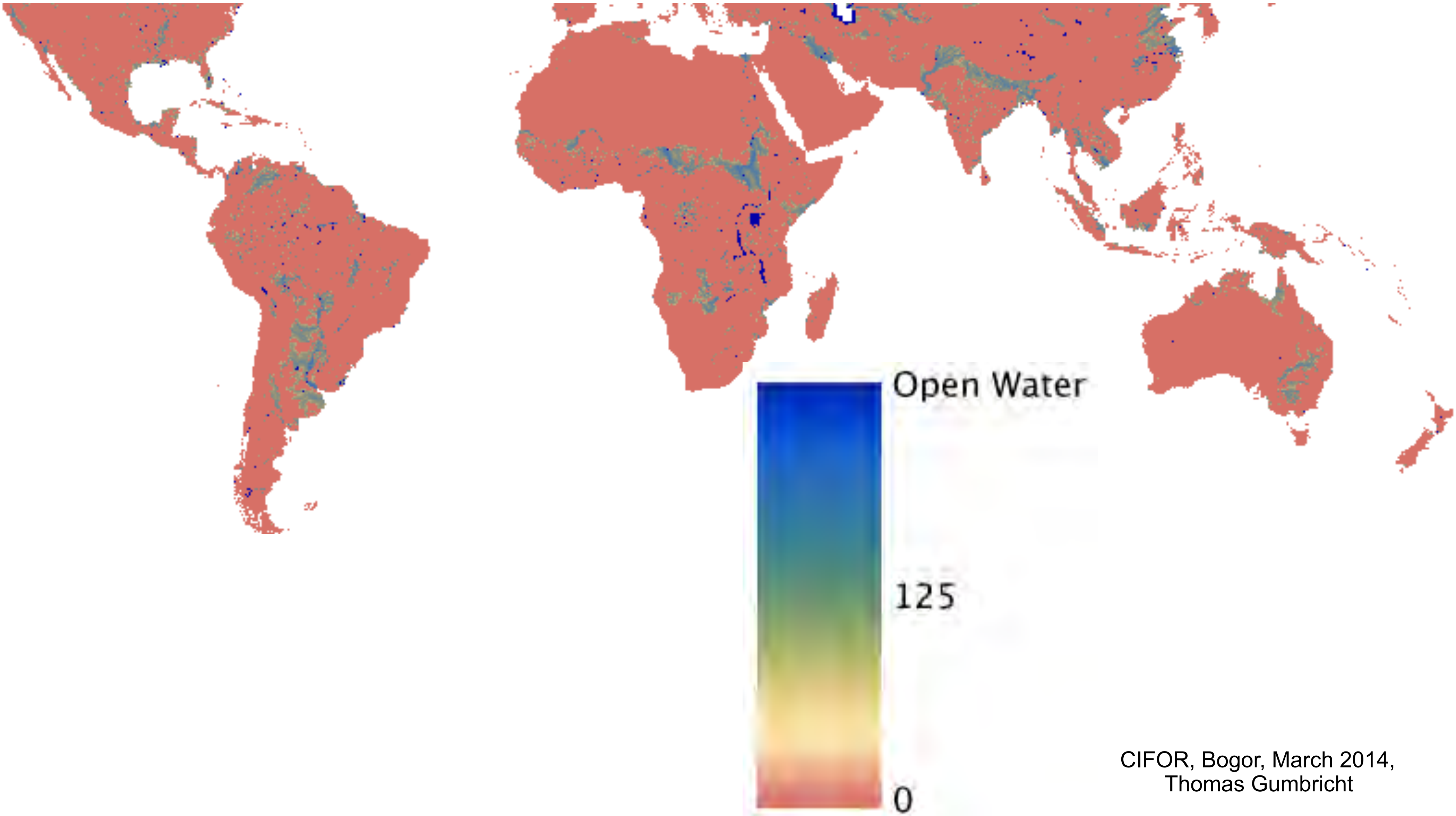
Wetland Topographic Convergence Index

Floodout Wetlands



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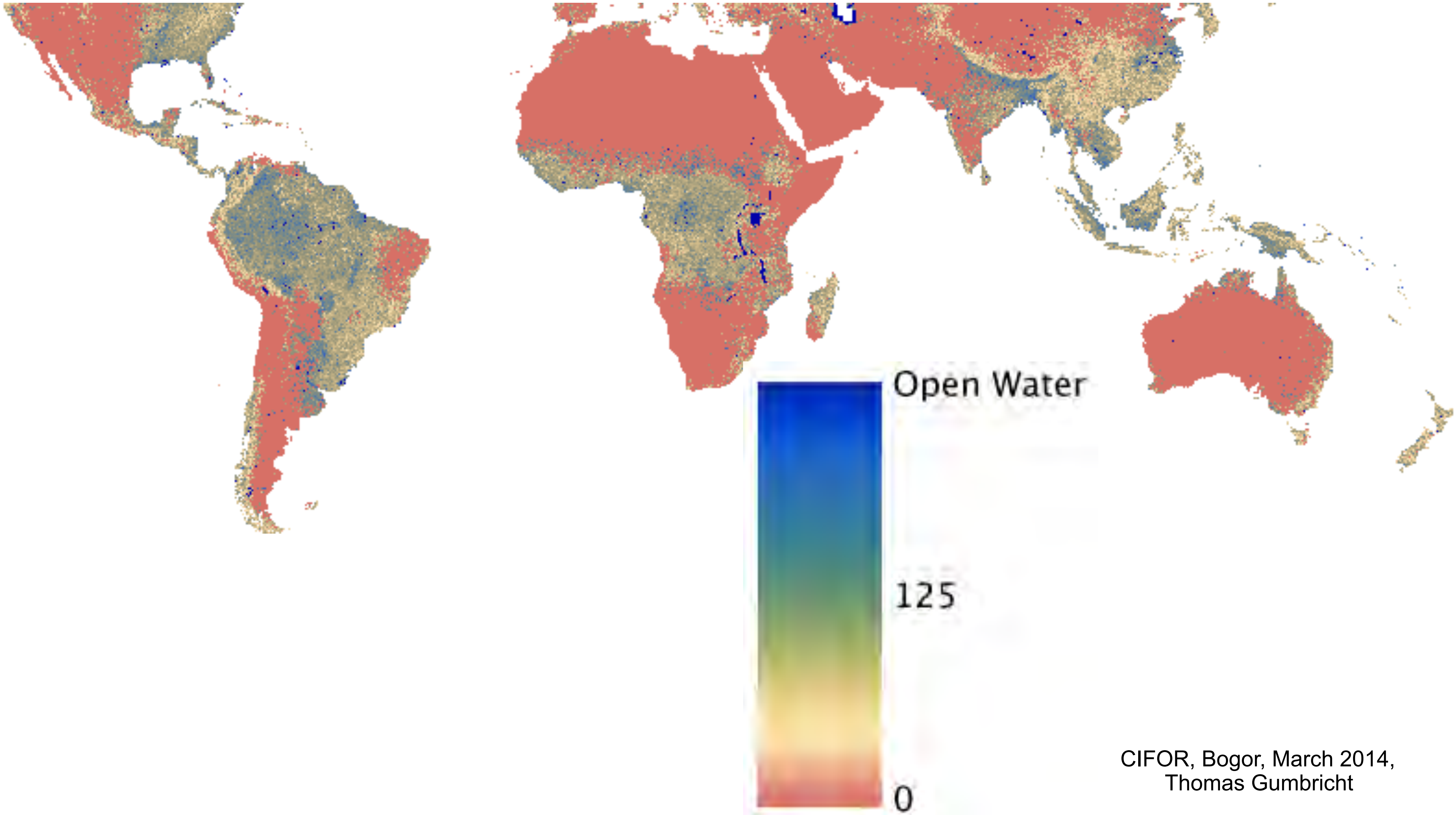
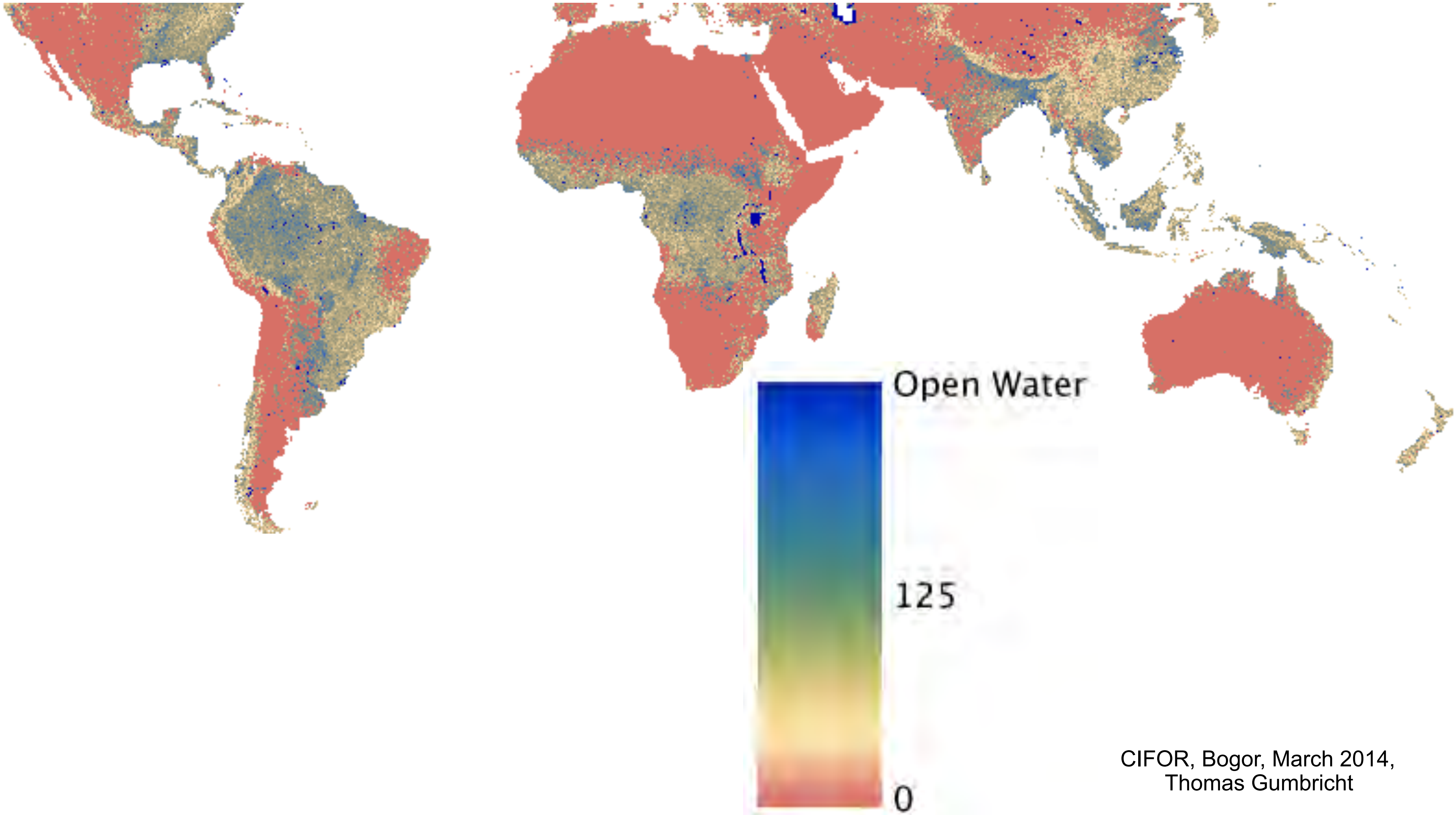
Wetland Topographic Convergence Index

General + Floodout Wetlands



Wetland Topographic Convergence Index

Wet Marsh Wetlands



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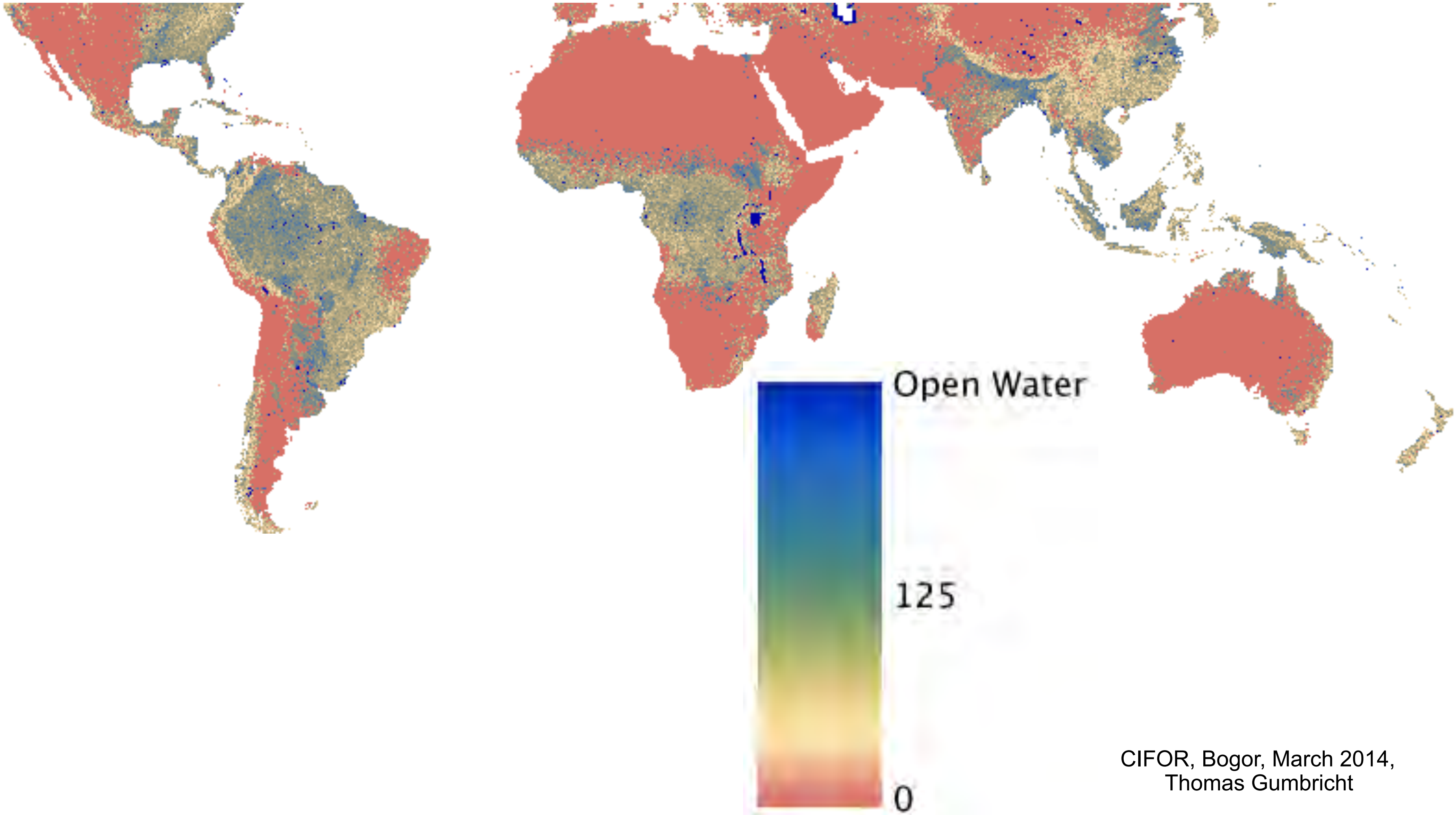
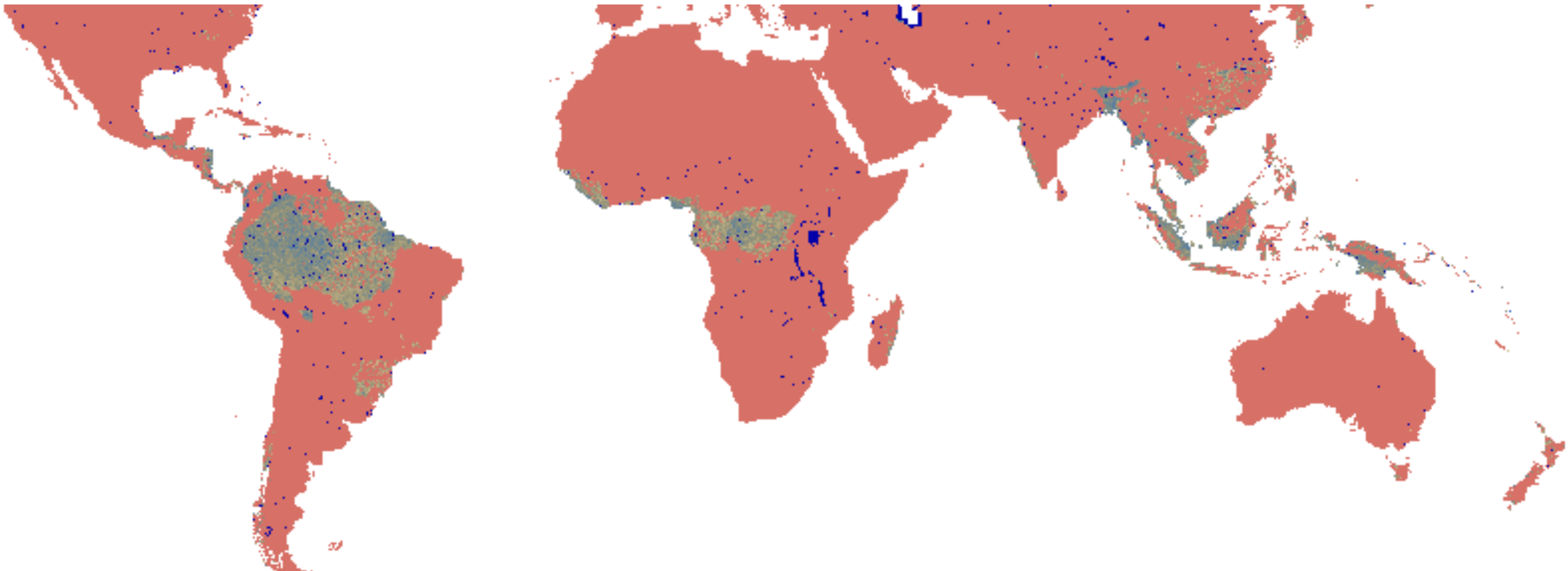
Wetland Topographic Convergence Index

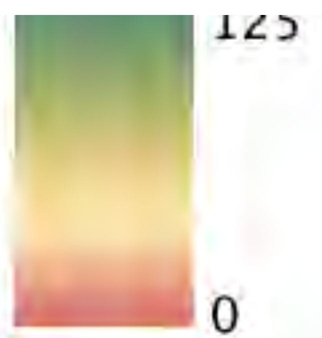
Arid Marsh Wetlands



Wetland Topographic Convergence Index

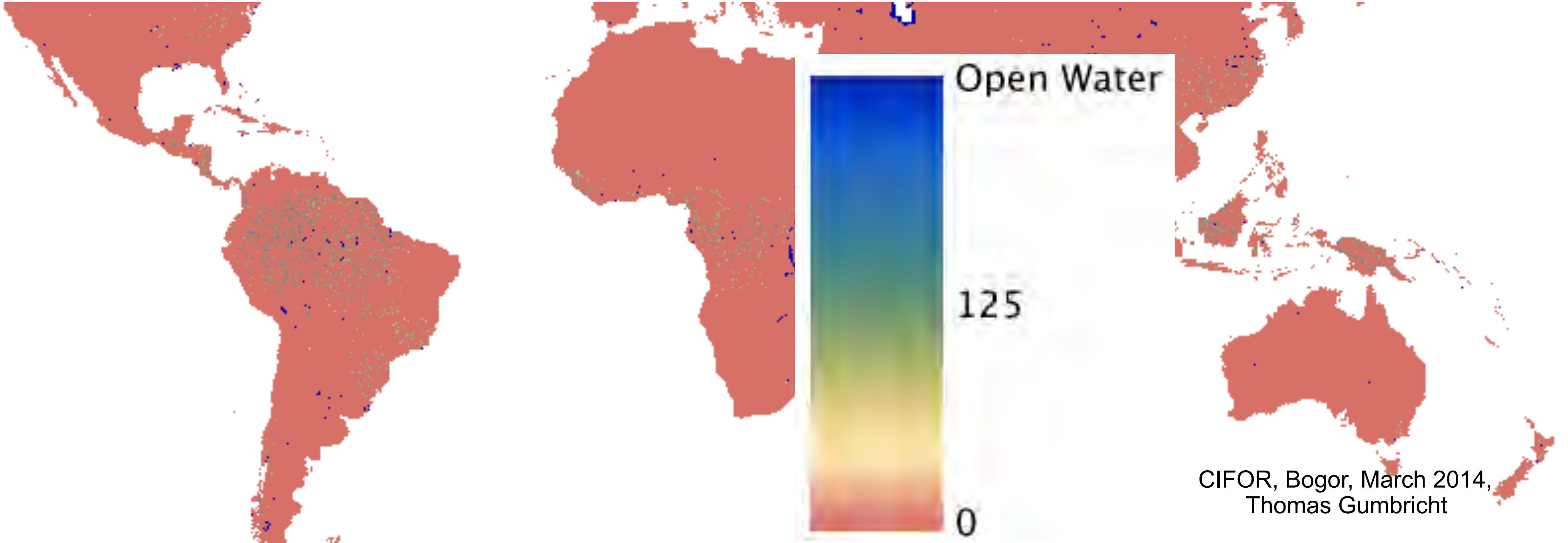
Ombrotrophic bogs





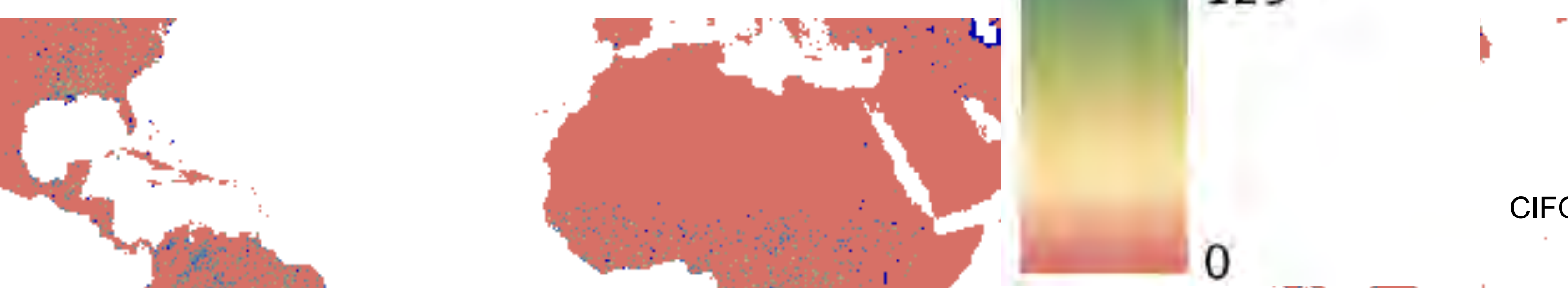
Wetland Topographic Convergence Index

Minerotrophic fens



Wetland Topographic Convergence Index

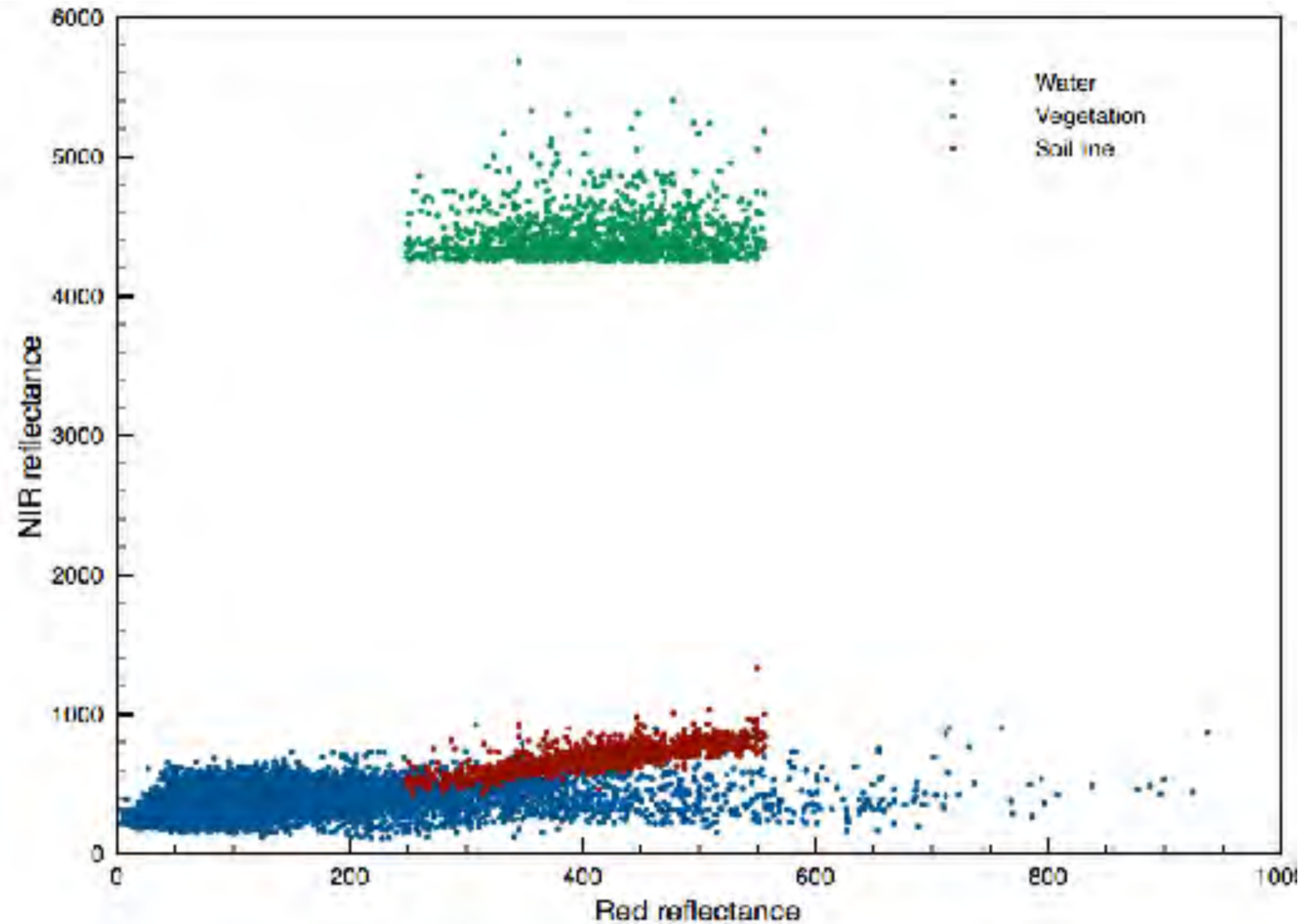
Riverine Wetla



The TWINCAM mapping approach

- Optical multispectral satellite images for deriving a surface wetness index
  - Definition of global tropical spectral end-members
  - Optimized eigen-vector transformation (= Principal Component Analysis, PCA) for converting band reflectance to soil and surface wetness features (Sometimes called Tasseled Cap in image processing)
  - Definition of the Transformed Wetness Index (TWI), an optimized normalized difference algorithm using the soil and wetness features to capture surface wetness

- Optical multispectral satellite images for deriving a surface wetness index



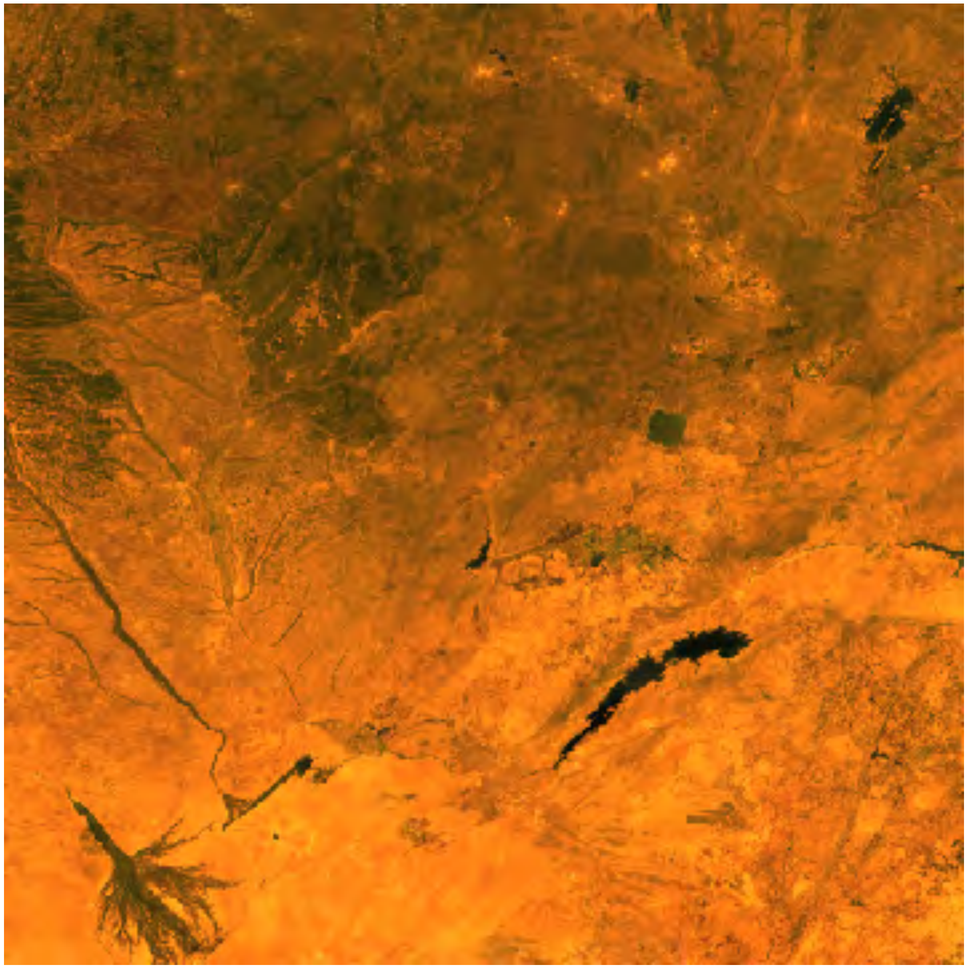
Spectral end-members for parts of Indonesia and Malaysia

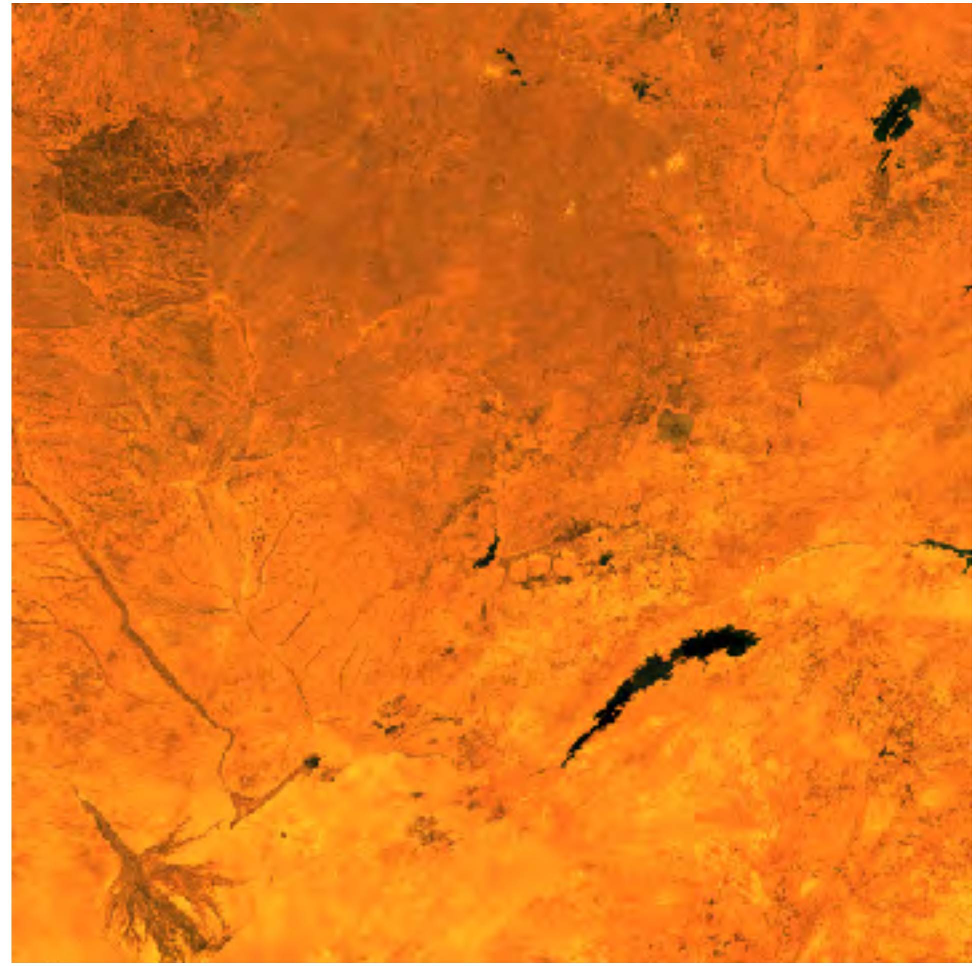
- Optical multispectral satellite images for deriving a surface wetness index

Material	R	NIR	B	G	MIRa	MIRb	MIRc
Dark soil (offset)	0.0563	0.1008	0.0147	0.0507	0.1531	0.1836	0.1699
Brightness	0.314812	0.320970	0.359456	0.336364	0.249772	0.657334	0.247078
PV	-0.193666	0.798701	-0.140345	-0.094762	0.390175	-0.199024	-0.322562
NPV	0.482520	0.134057	-0.025535	0.347607	0.071952	-0.653813	0.441669
Wetness	0.188177	0.038364	0.493917	0.350060	-0.358132	-0.173122	-0.662112

Optimized eigen vectors for surface wetness mapping

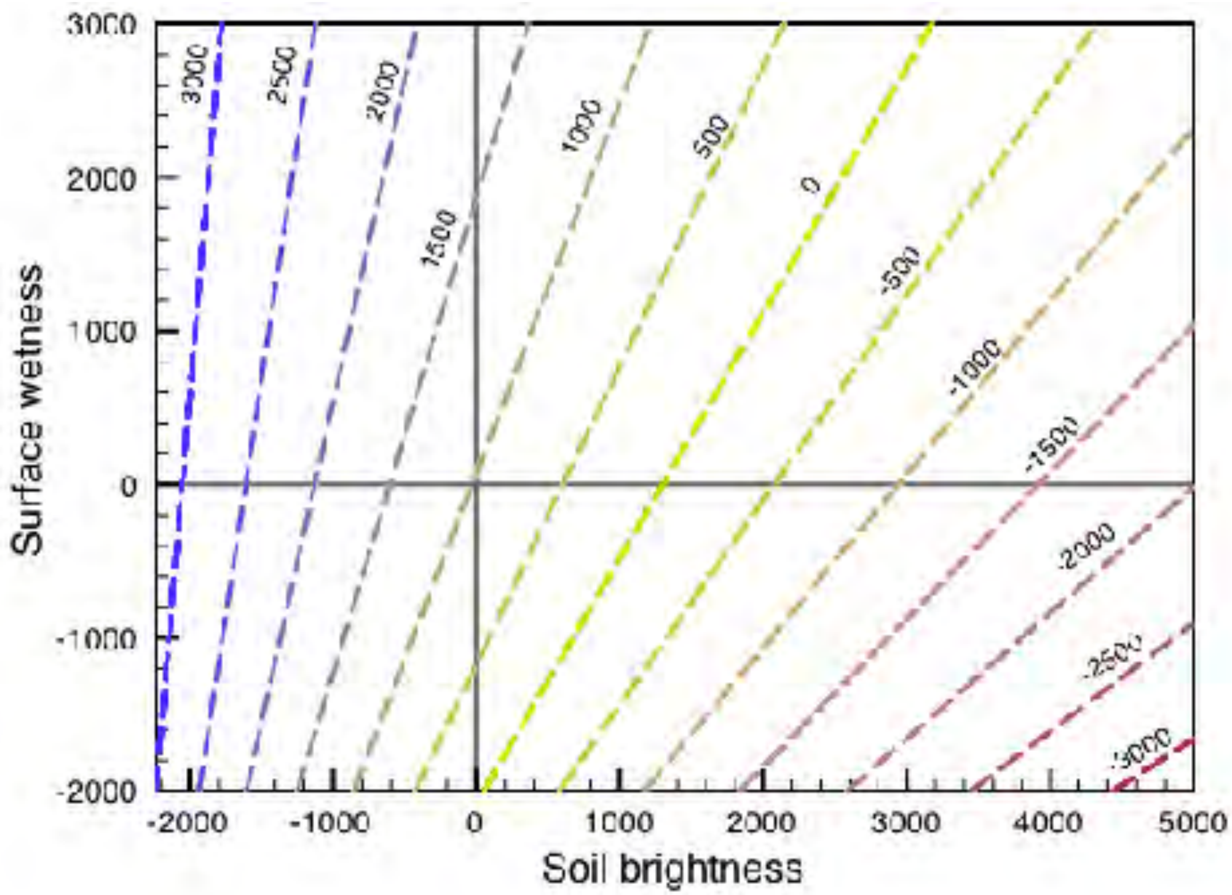
- Optical multispectral satellite images for deriving a surface wetness index





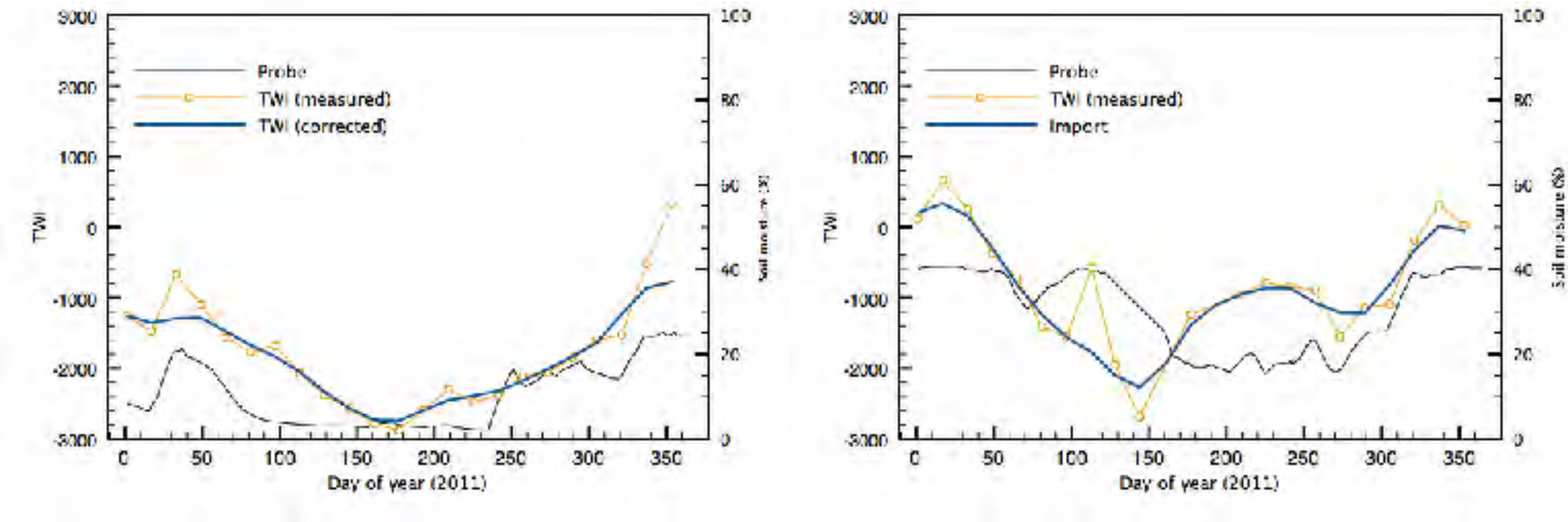
The adoption of PCA can be regarded as a kind of pixel-unmixing, where the vegetation parts of the optical VIS/NIR reflectance is removed. The soil wetness index is based on the image to the right (recomposed from the PCs, excluding vegetation components).

- Optical multispectral satellite images for deriving a surface wetness index



Isolines of soil wetness as defined by soil brightness (PC1) and surface wetness (PC4)

- Optical multispectral satellite images for deriving a surface wetness index

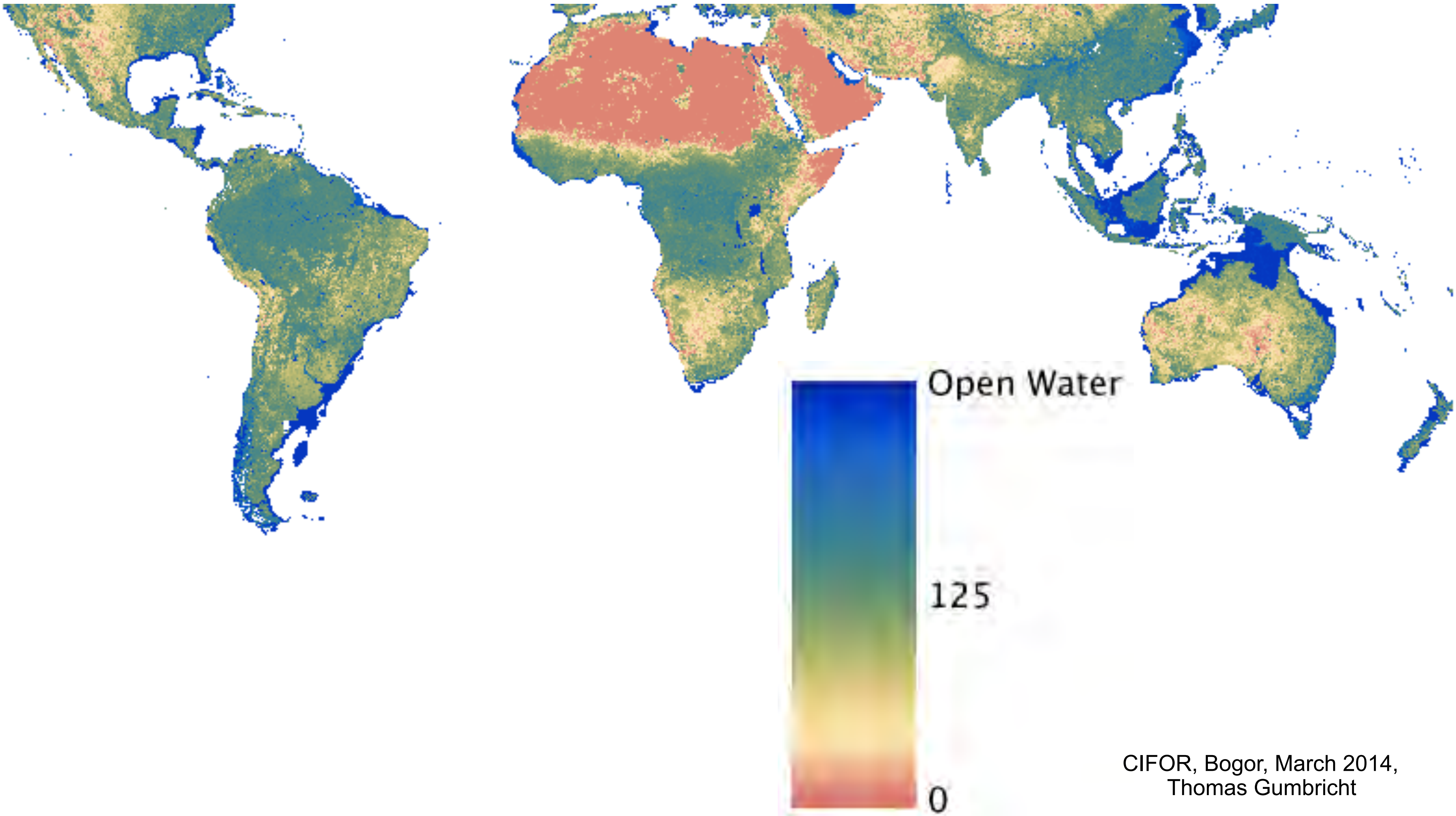


Comparison of the TWI for two US sites (NRCS 2006 and NRCS 2046) for the calendar year 2011. Probe represents in-situ soil moisture measurements and TWI the MODIS derived soil wetness. The corrected TWI is smoothed using a local regression. The probe represent a sub m2 area whereas the MODIS data represent 250000 m2.

Transformed Wetness Index (TWI)

Transformed Wetness Index (TWI)

Mean TWI 2011



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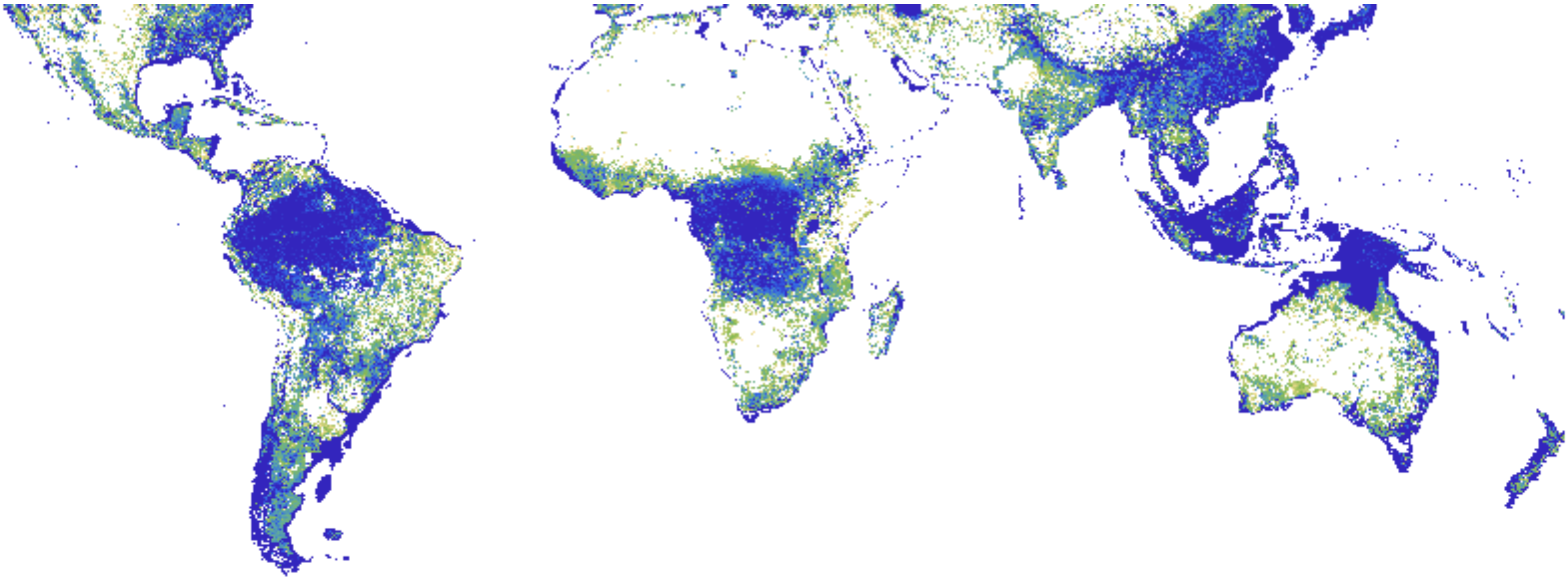
Mapping global tropical wetlands

Transformed Wetness Index (TWI)

Length Wet Season (TWI > 0) 2011



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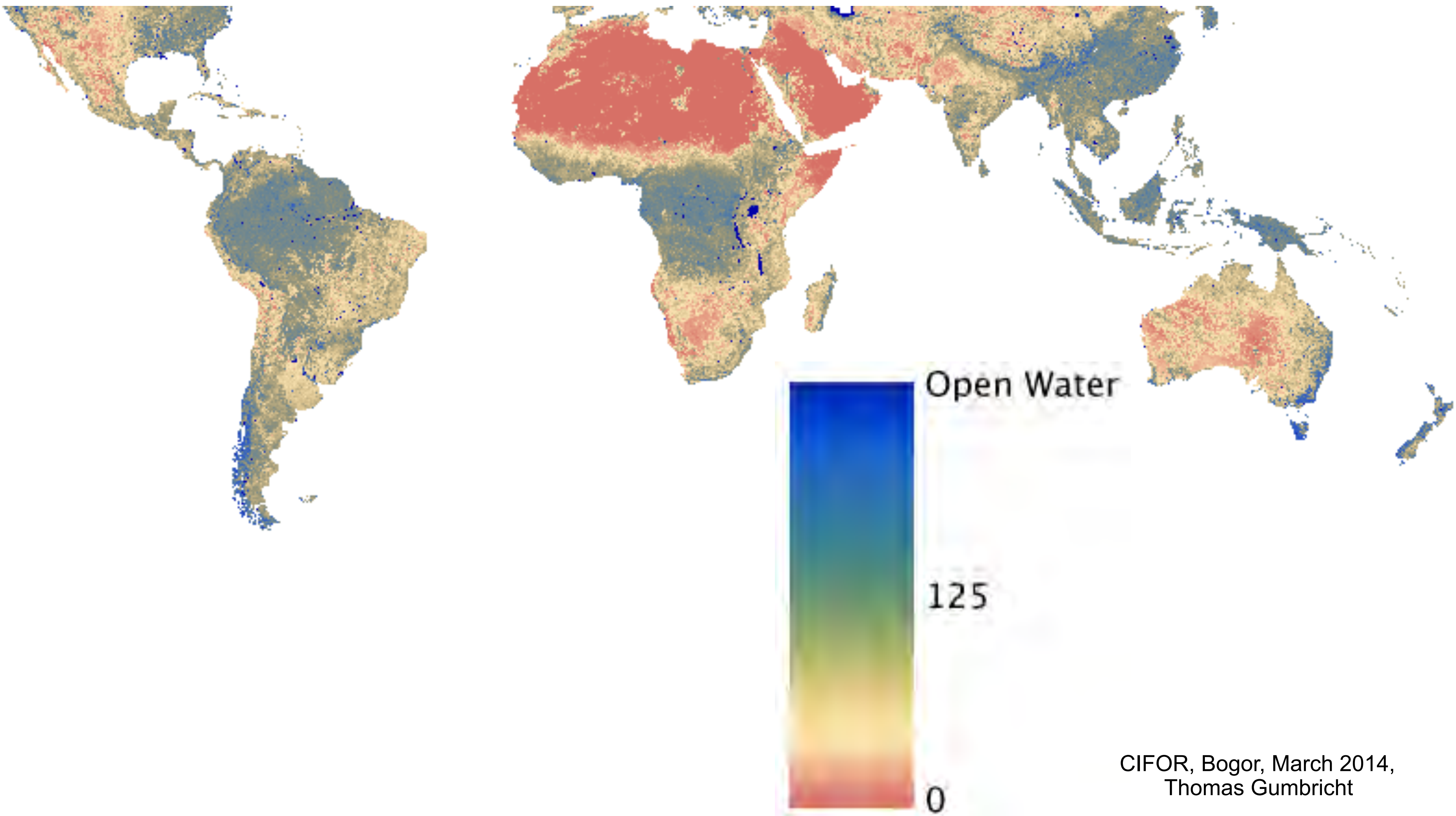
compounded Transformed Wetness Index (cTWI)

compounded Transformed Wetness Index (cTWI)

General Wetlands



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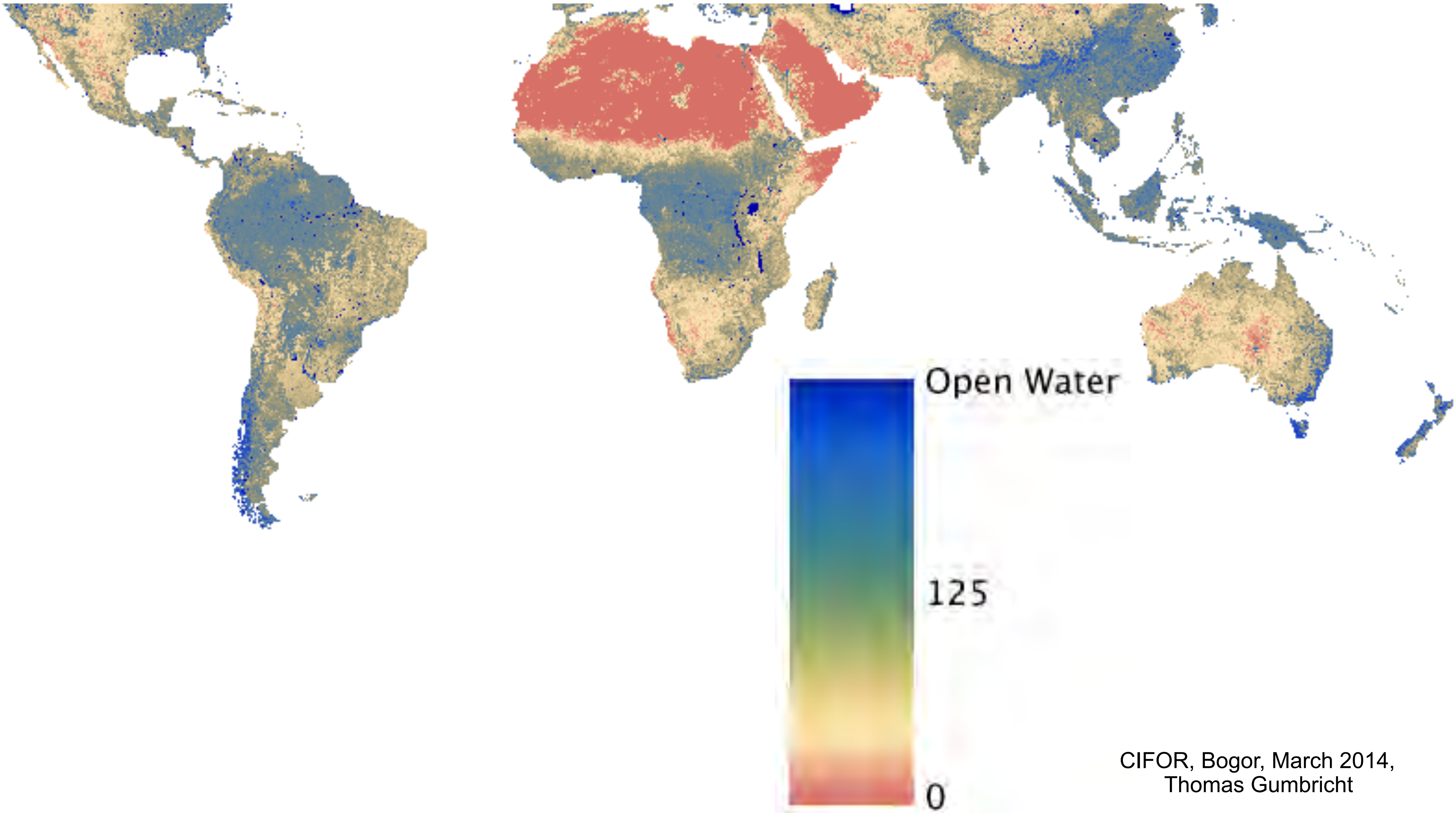
compounded Transformed Wetness Index (cTWI)

Flooded Wetlands



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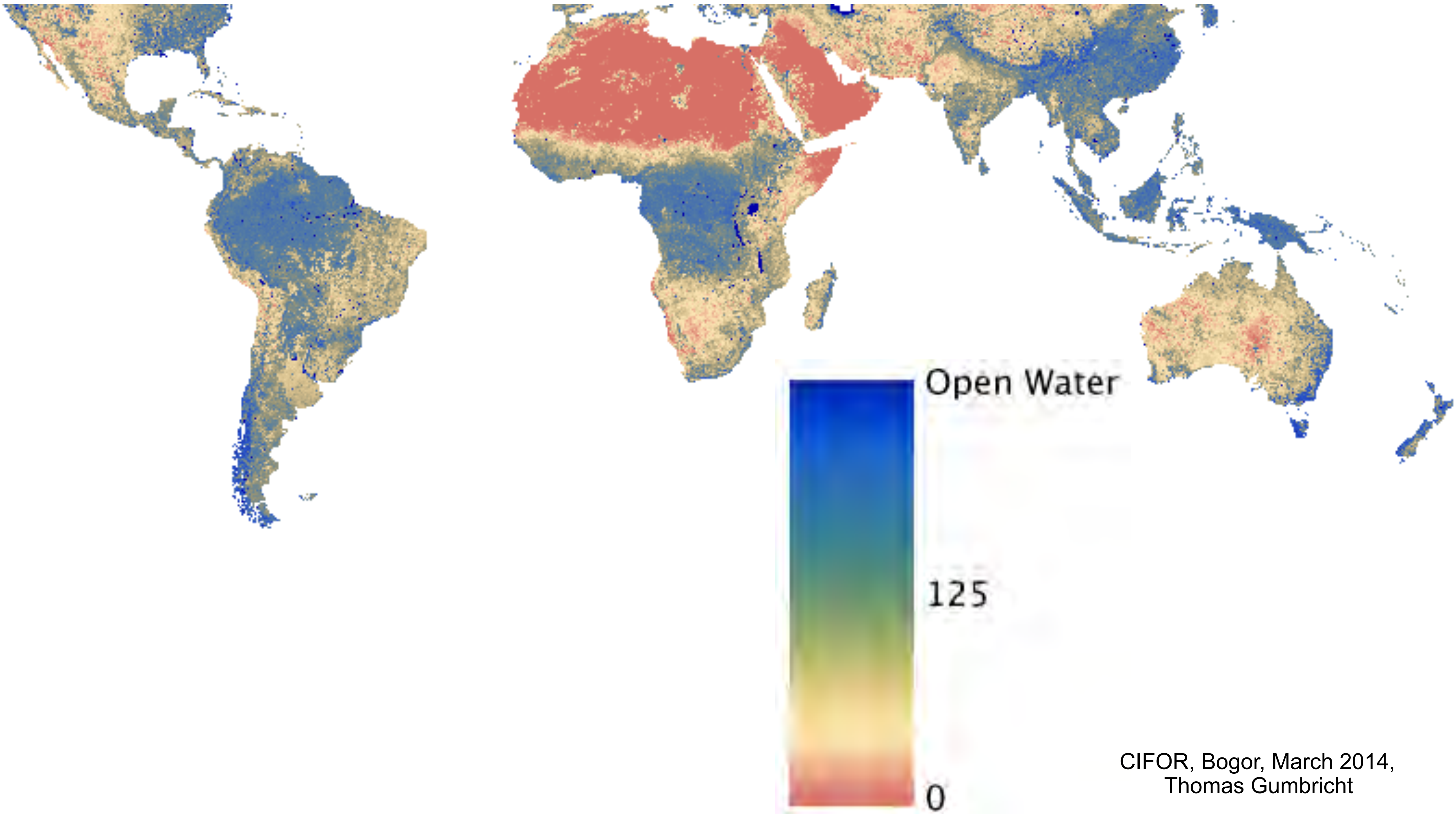
compounded Transformed Wetness Index (cTWI)

Wet Marsh Wetlands



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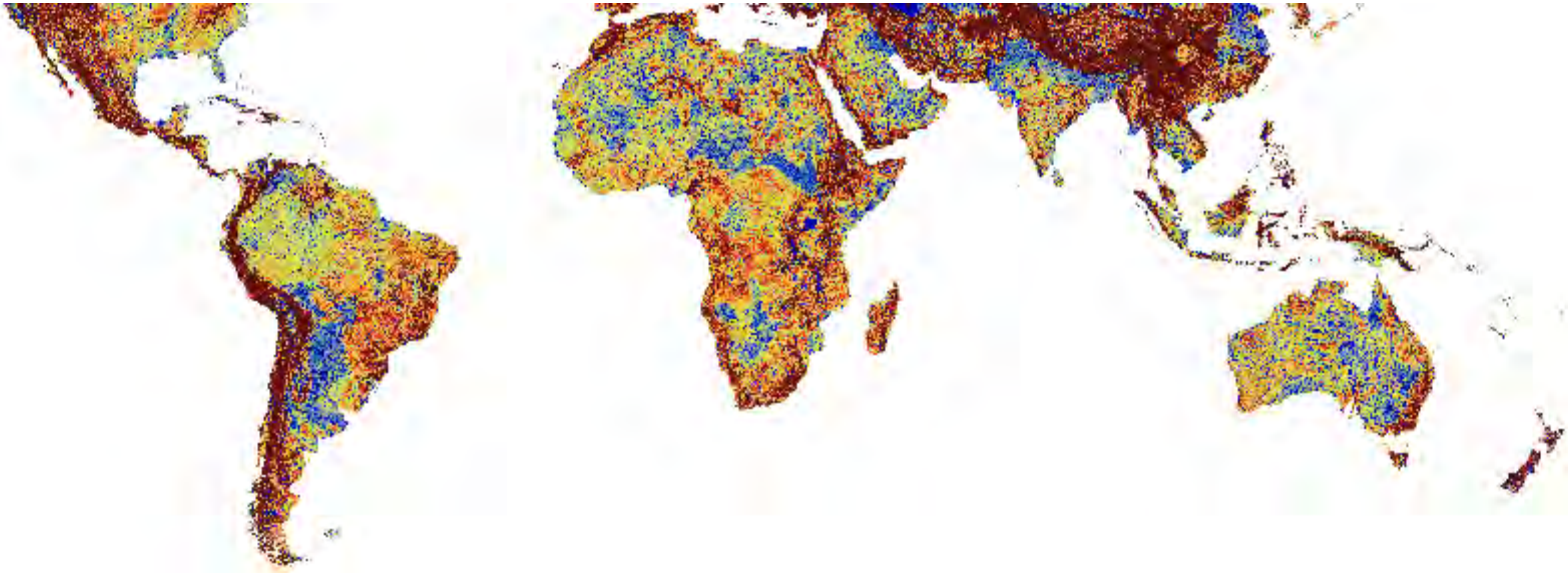
The TWINCAM mapping approach

- Hydromorphological maps
  - Hydraulic terrain relief
  - Channel valleys
  - Small and Large valleys (with or without flowing channels)
  - General geomorphology
  - Plain and valley geomorphology
  - Dome shaped features
  - Valley shaped featured
  - Plains and valleys

Hydromorphology

Hydromorphology

Hydraulic terrain relief (floodouts and floodplains)

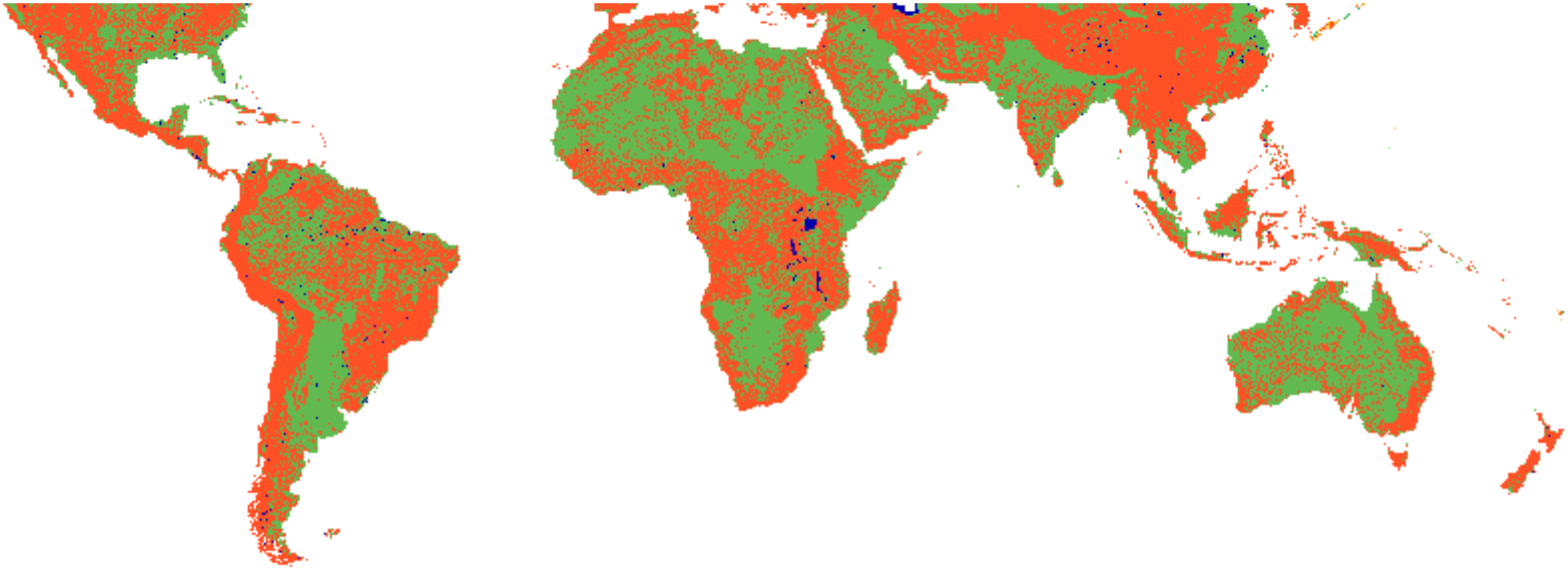


Hydromorphology

Geomorphology

Hydromorphology

Plains and Valleys



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The TWINCAM mapping approach

- Hybrid mapping, combine
  - Thematic or generic WTCI, and
  - Thematic or generic cTWI, with
  - Hydromorphological constraints.
  - Set a threshold for defining (thematic) wetlands or peatlands

e.g. ”Find all areas where WTCI from precipitation alone is > 150 and the period of annual inundation is longer than 60 days, and that is either a plain or dome-shaped. Classify index values above 50 as ombrotrophic bogs”

Mapping global tropical wetlands

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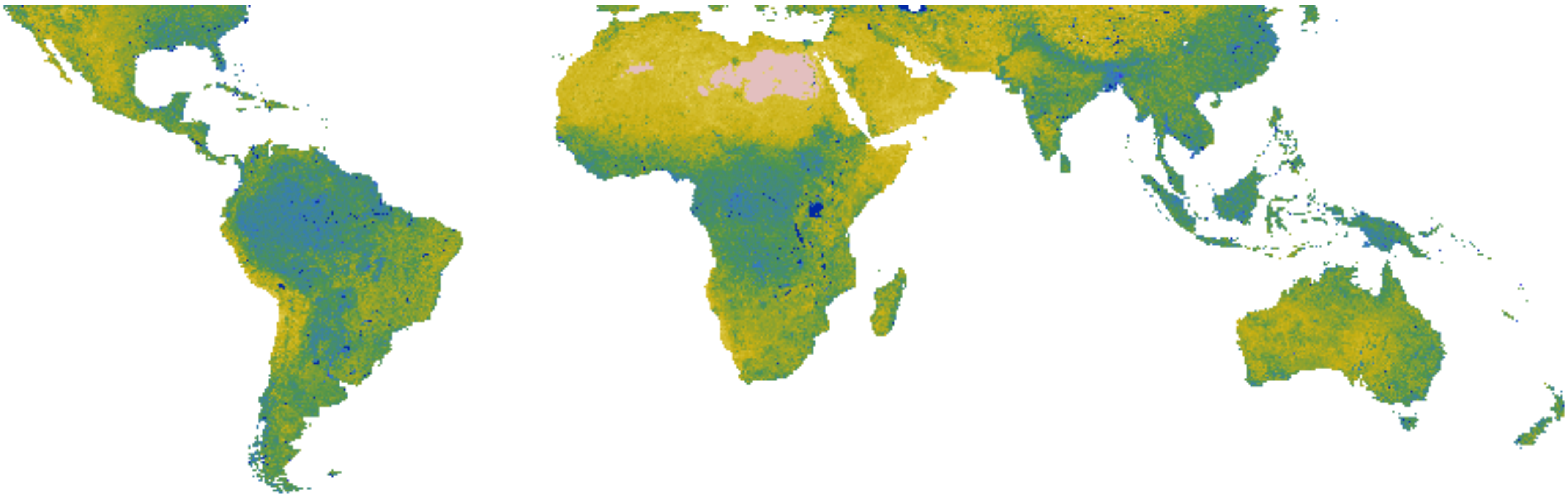
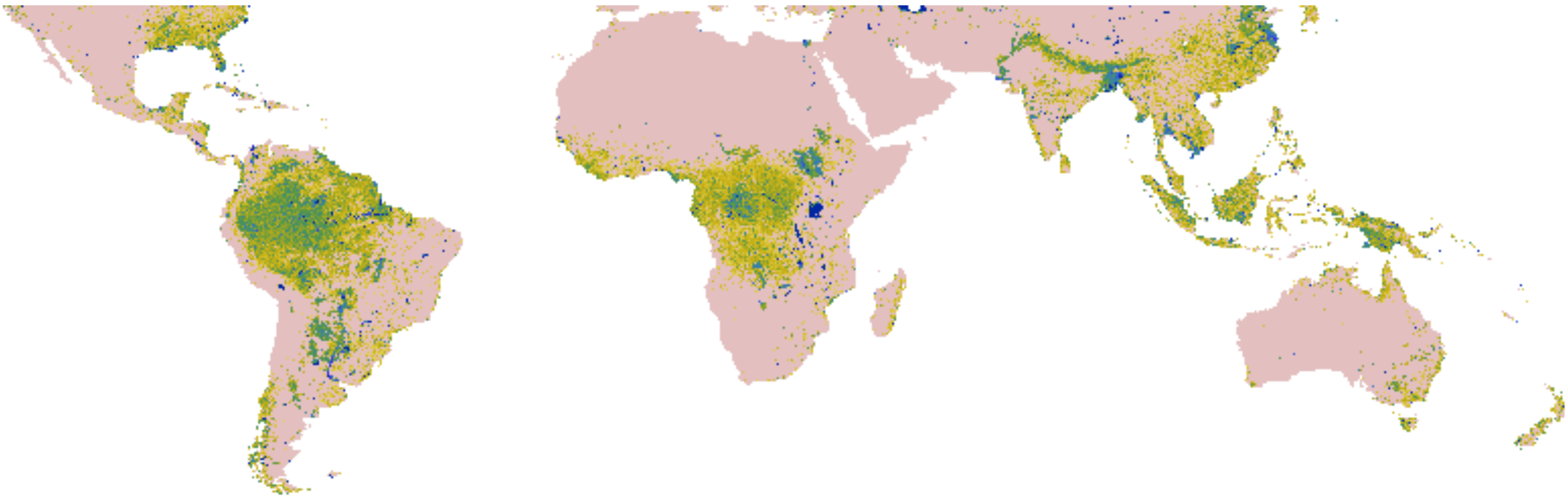
Mapping global tropical wetlands

Global soil wetness, for all areas (not only wetlands)



Mapping global tropical wetlands

Global wetland wetness (areas with positive water balance)



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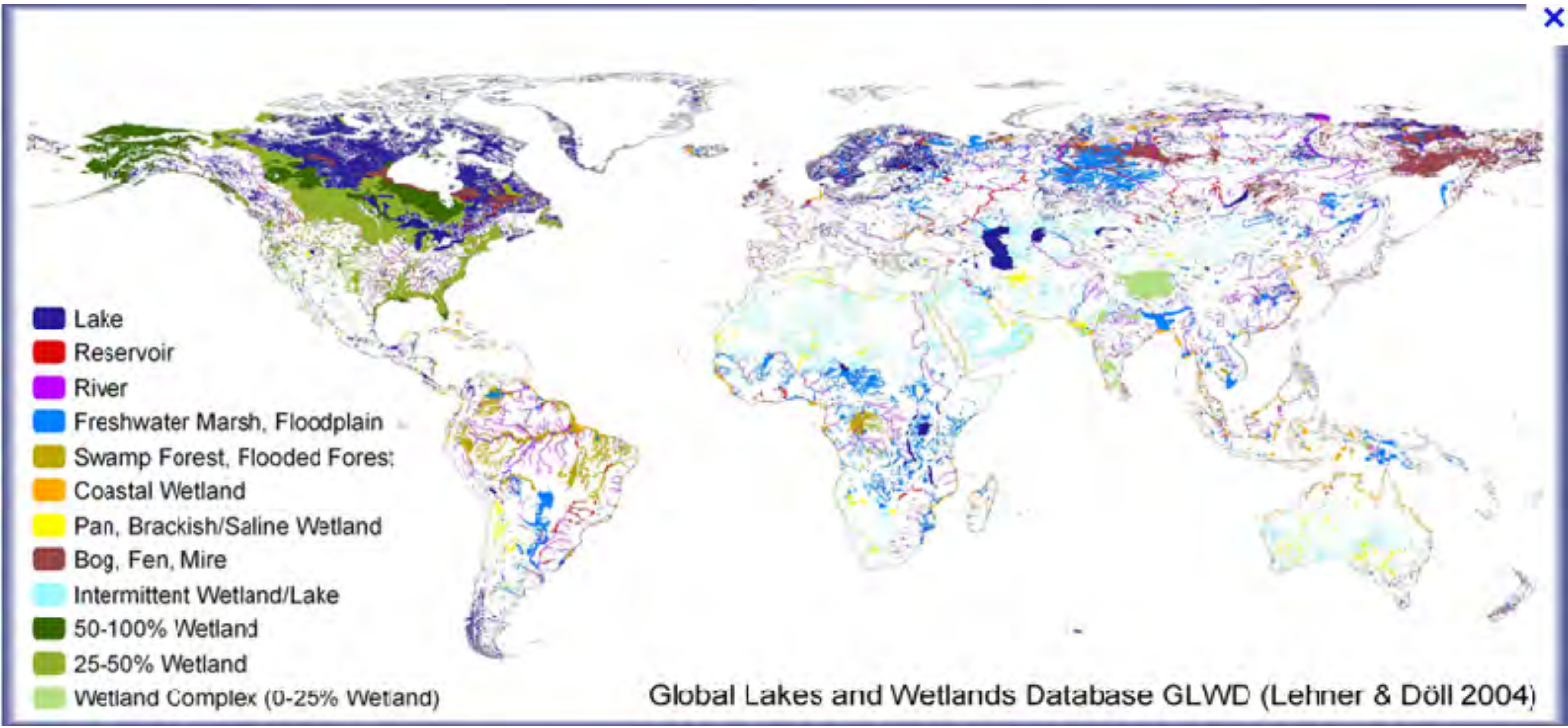
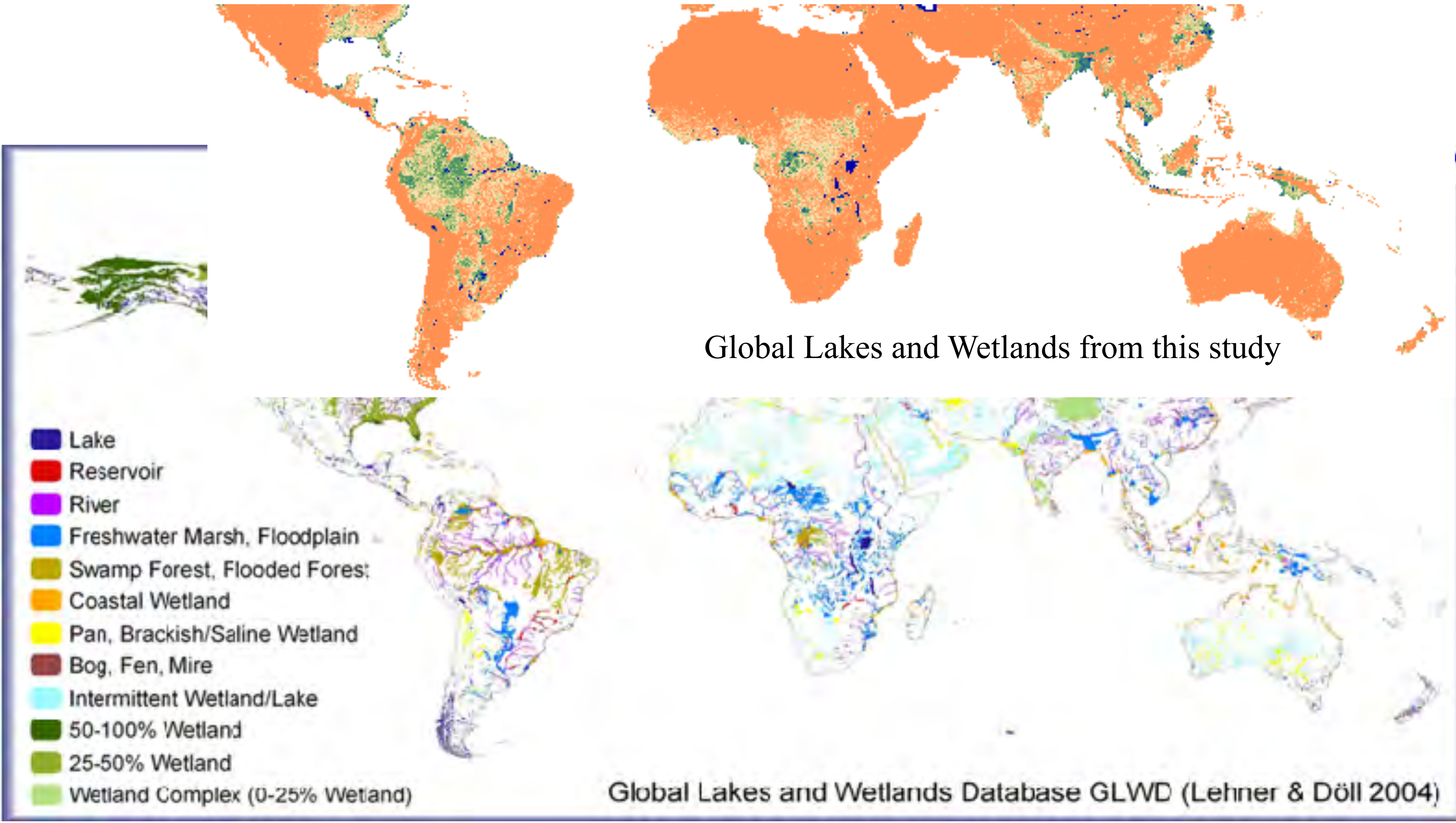
Mapping global tropical wetlands



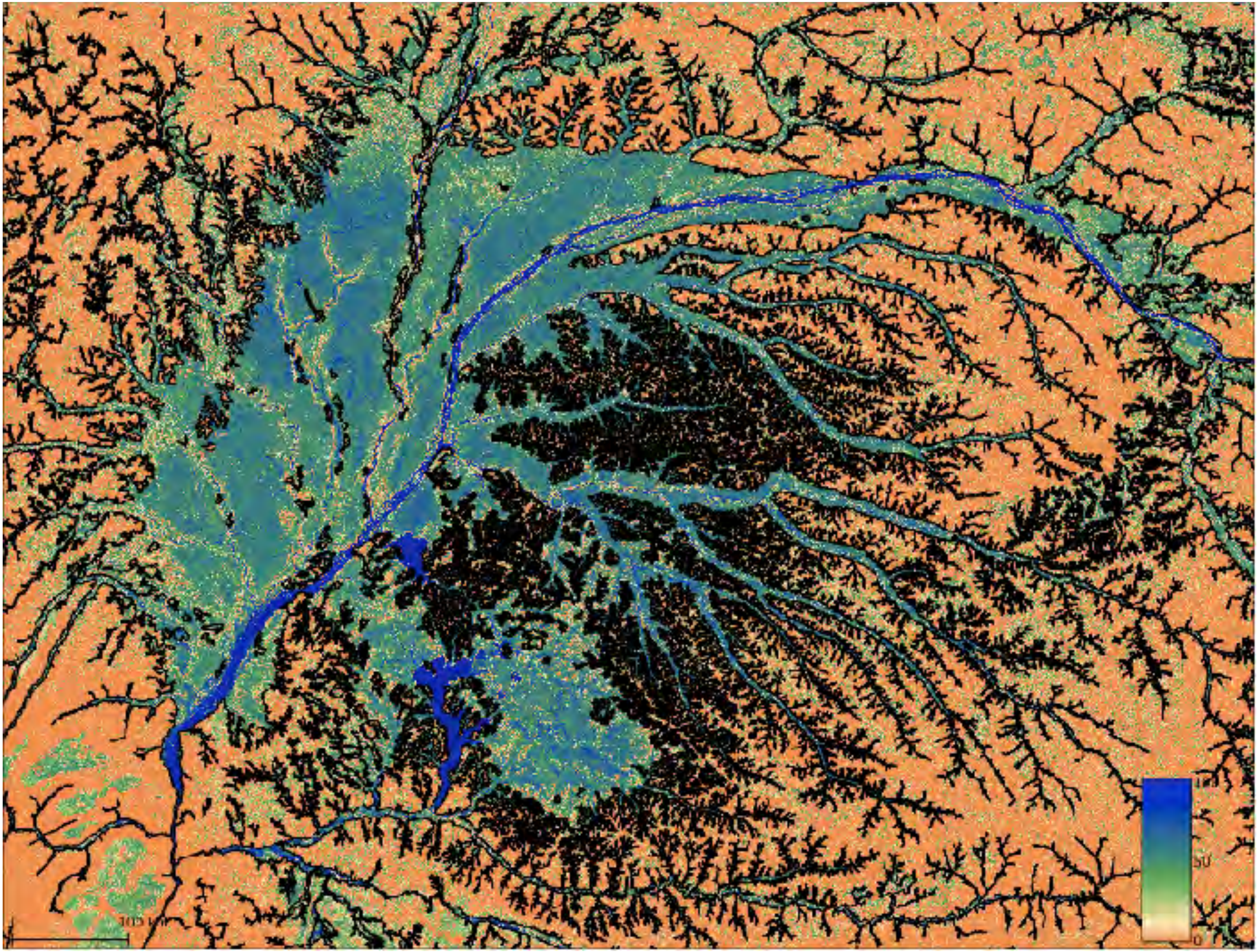
Mapping global tropical wetlands



Global Lakes and Wetlands from this study

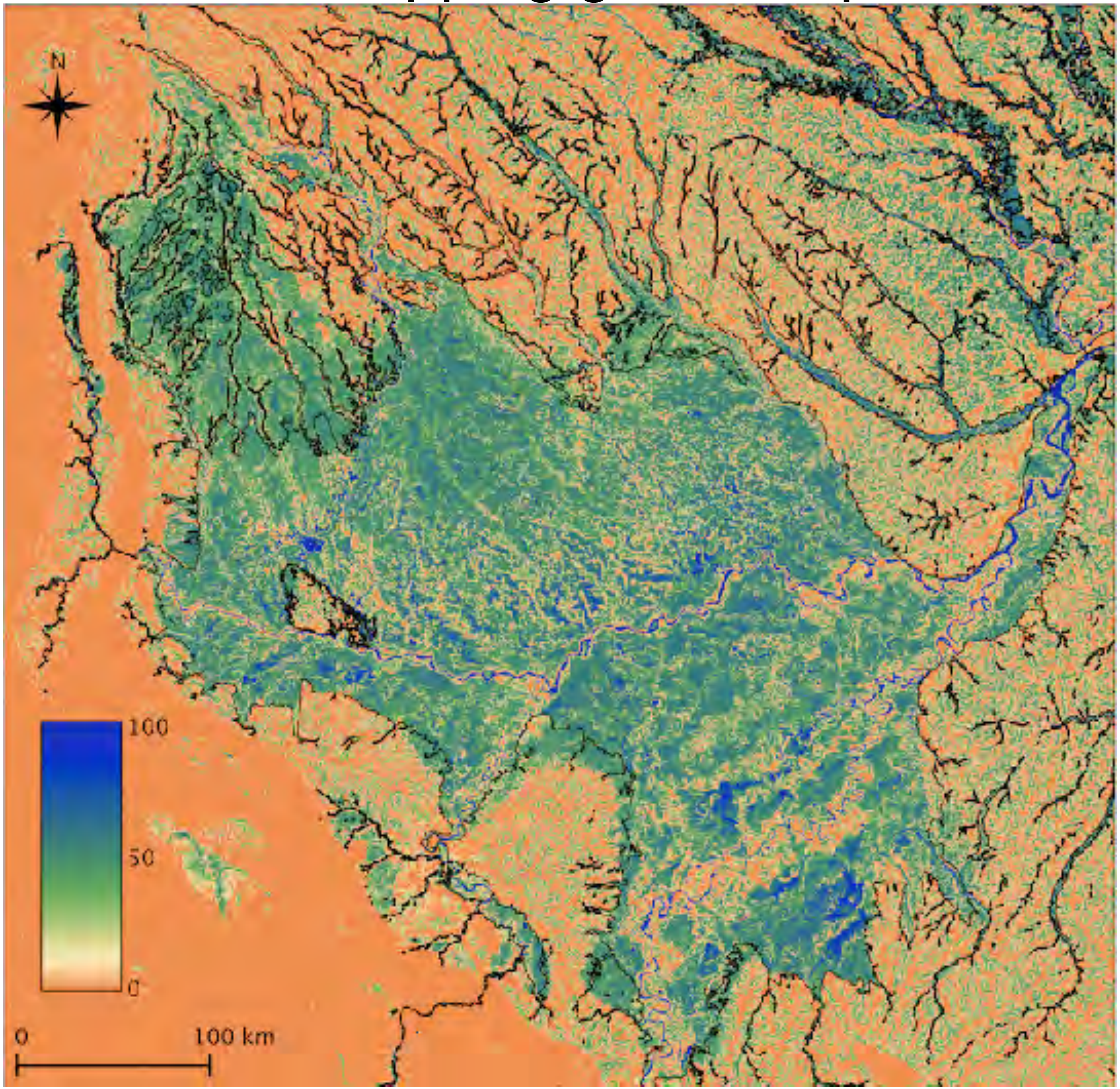
Global Lakes and Wetlands Database GLWD (Lehner & Döll 2004)

Mapping global tropical wetlands



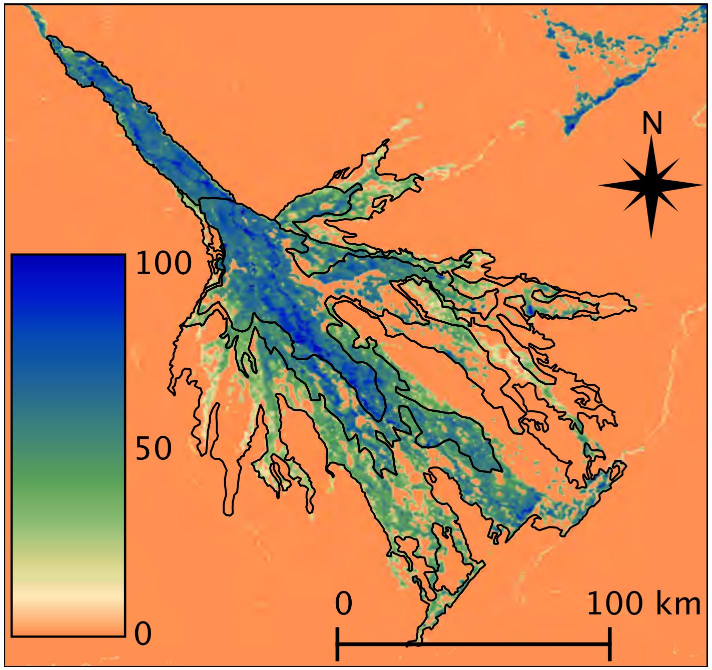
Wetland map from Bwangoy et al (2010) over the central Congo basin (black).

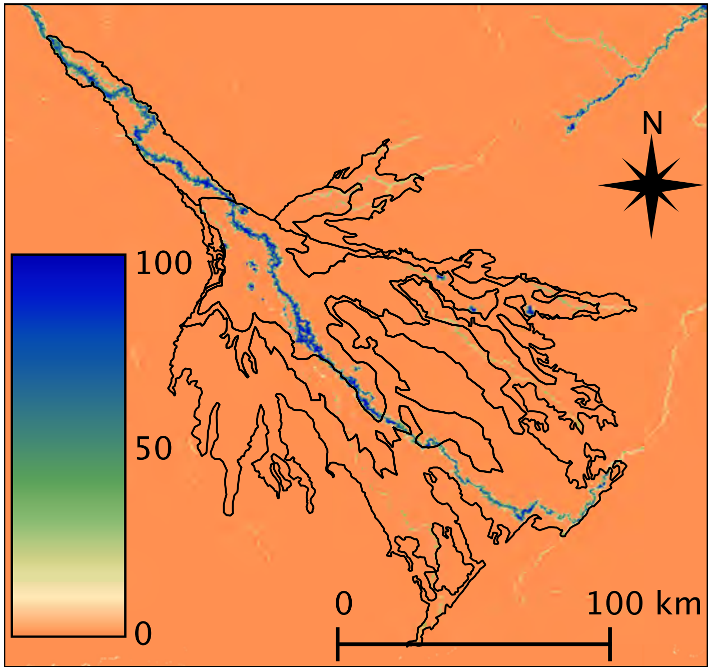
Mapping global tropical wetlands



Wetland map from Hess et al (2012) over the Peruvian Amazon (black).

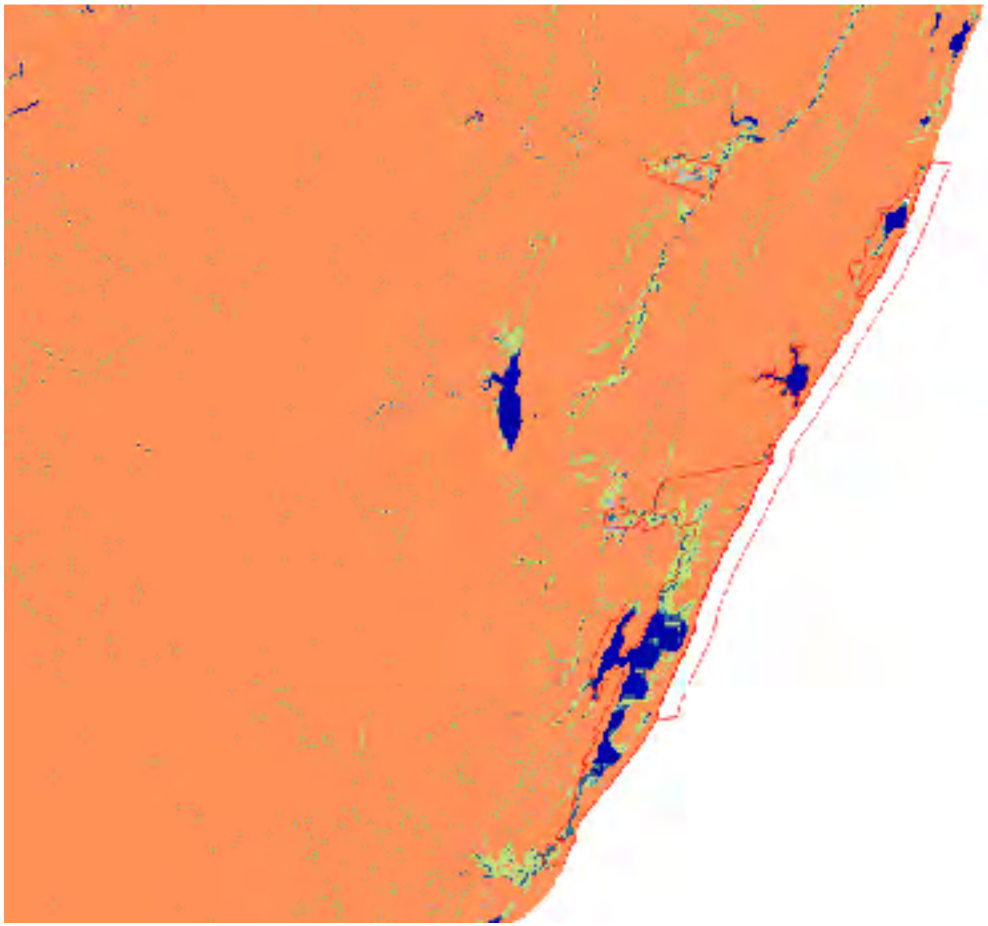
Mapping global tropical wetlands





Wetland map from McCarthy et al (2002) over the Okavango (black).
Left map calculated using **river floodout;**
Right map calculated using **channel flooding**

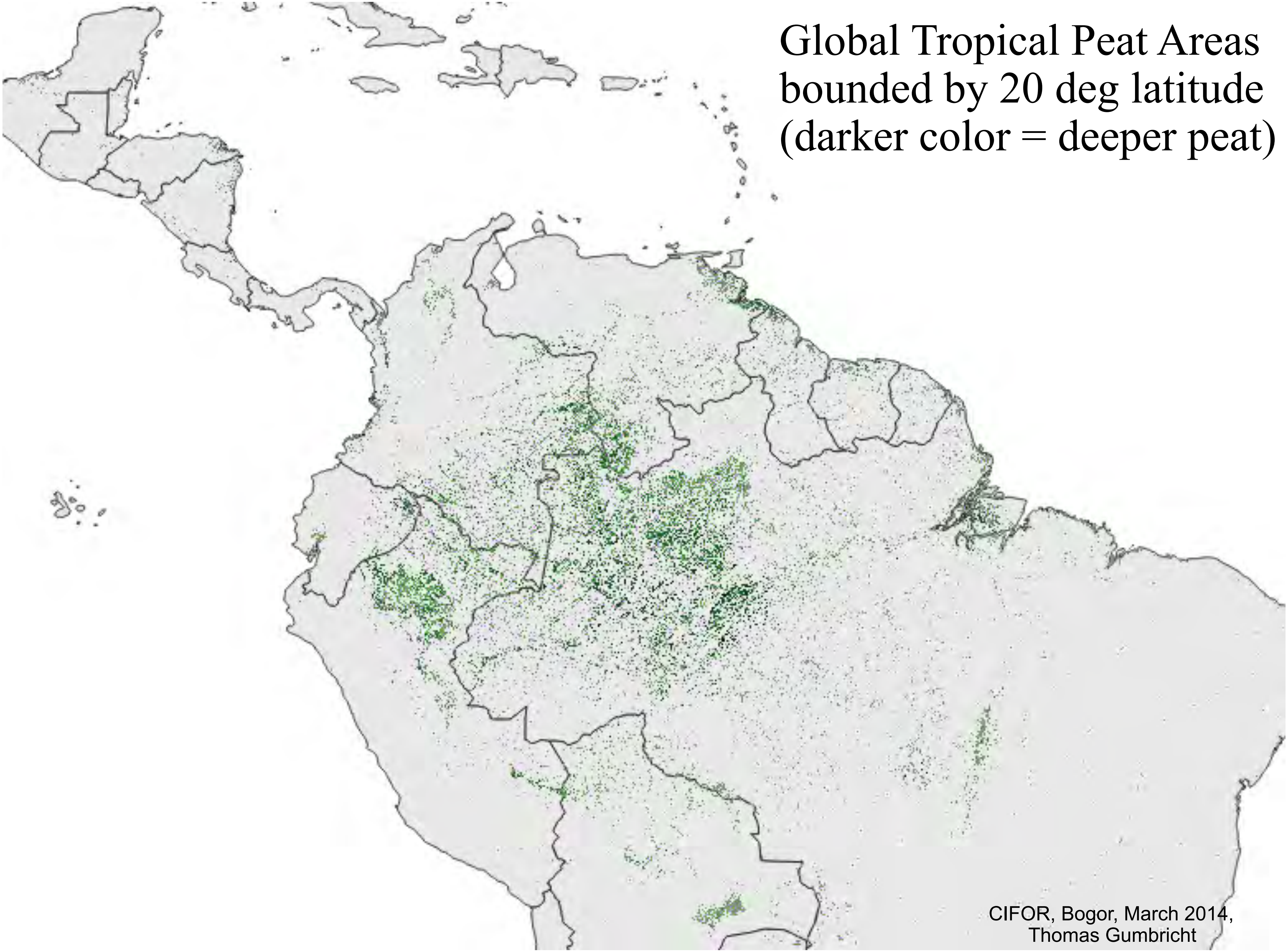
Mapping global tropical wetlands



Ramsar sites on the South African East coast (St Lucia, Lake Sibya, Kosi Bay and Ndumo Game reserve)

Global Tropical Peat Areas bounded by 20 deg latitude (darker color = deeper peat)

Global Tropical Peat Areas bounded by 20 deg latitude (darker color = deeper peat)



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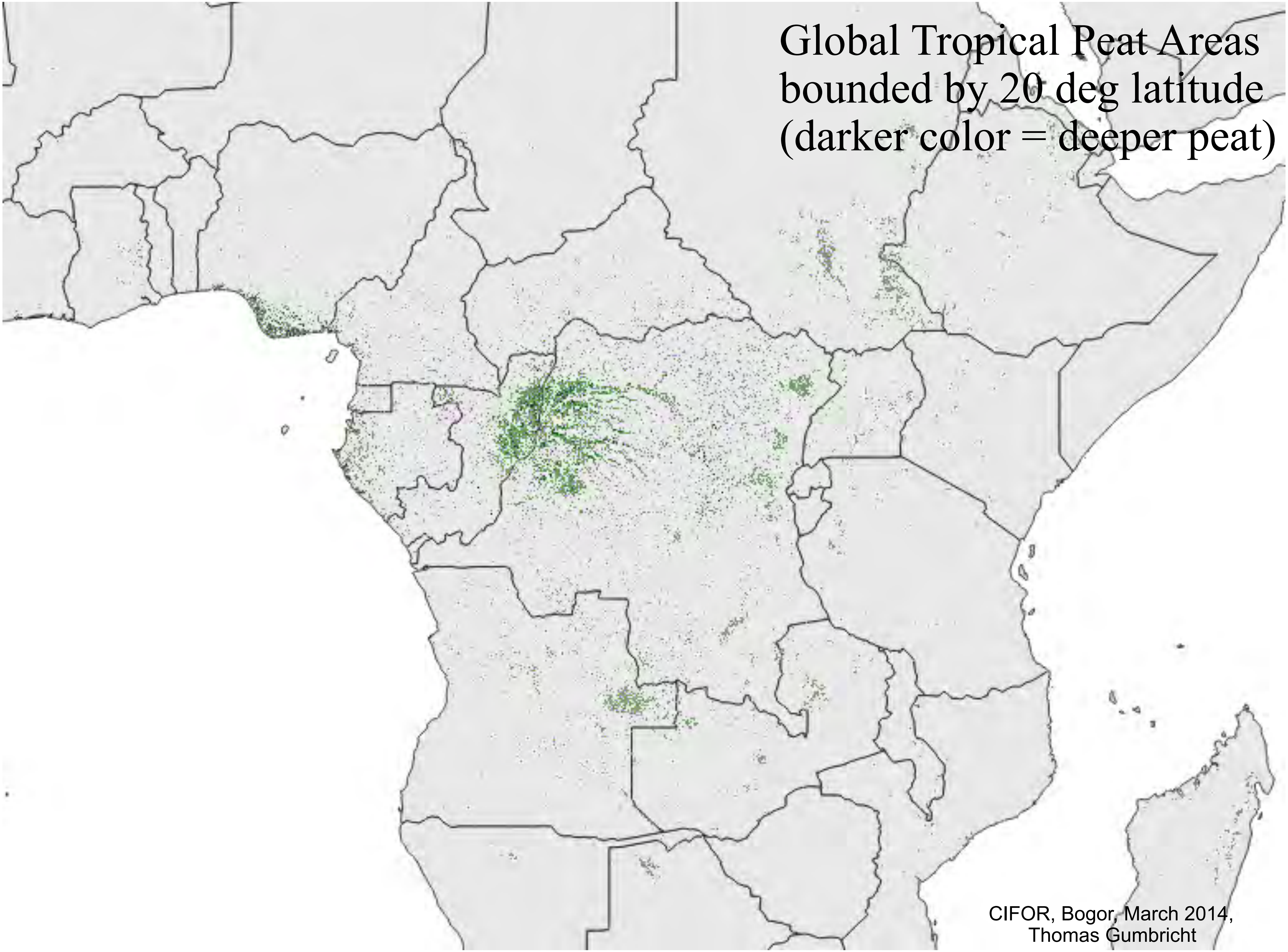
Global Tropical Peat Areas
bounded by 20 deg latitude
(darker color = deeper peat)
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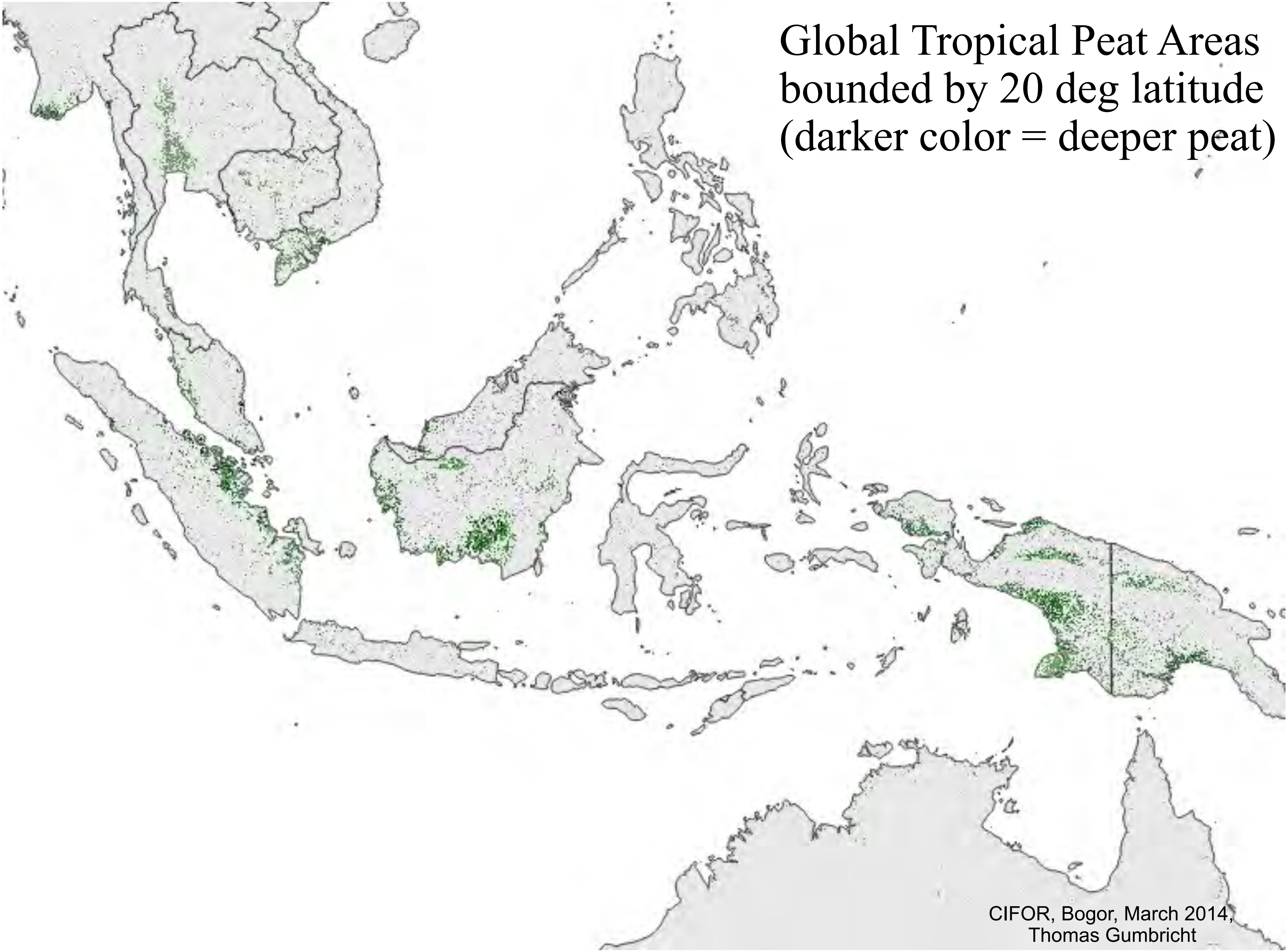

Global Tropical Peat Areas
bounded by 20 deg latitude
(darker color = deeper peat)
CIFOR, Bogor, March 2014,
Thomas Gumbricht

Mapping global tropical wetlands

Estimates of tropical wetlands and peatlands (bounded by 20º latitude)

	Total area	Volumetric area*	Total volume
	km^2	km^2	km^3
Open Water	540,000	--	--
Wetlands	4,100,000	2,700,000	10,000
Peatlands	2,100,000	1,500,000	7,100

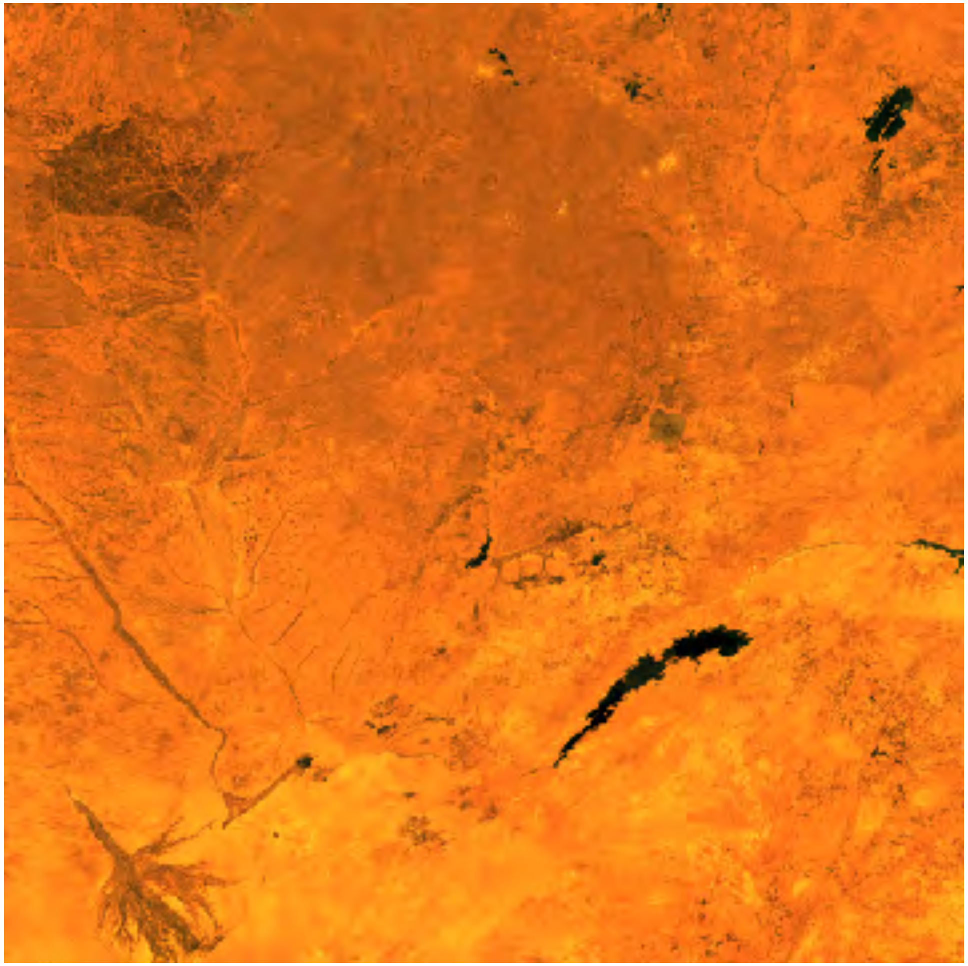
*The volumetric area excludes all cells with a recorded wetland or peatland depth equal to zero.

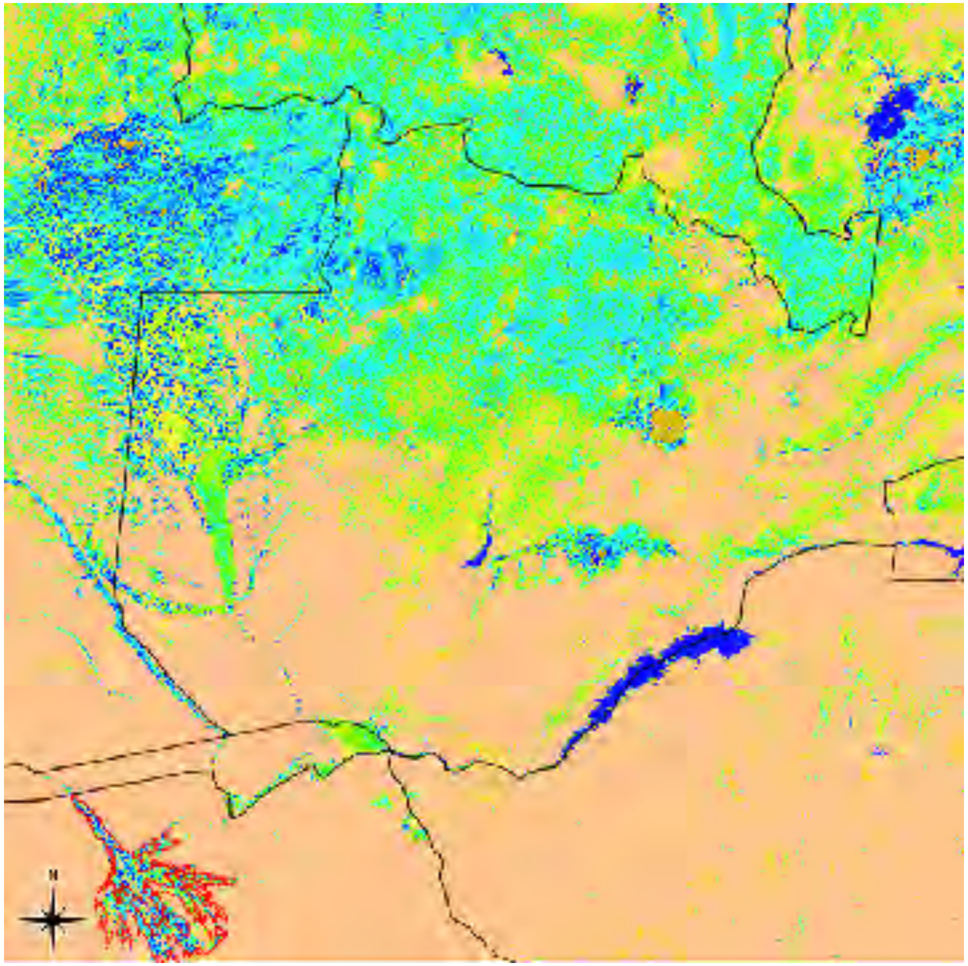
The GIEMS dataset estimate of wetlands bounded by 30 deg latitude varies between 3.8 and 6.0 million km2 (compared to 4.1 to the tropics bounded by 20 deg latitude in here).

Mapping global tropical wetlands

	Area (km2)	Open water (km2)	Wetland (km2)	Open water (%)	Wetland (%)
Bangladesh	139962	4517	114836	3,2	82,1
Cambodia	182047	3500	72668	1,9	39,9
South-Sudan	634474	553	234683	0,1	37,0
Congo	343186	2334	119287	0,7	34,8
Guyana	210663	215	64413	0,1	30,6
Colombia	1141474	8133	348435	0,7	30,5
Suriname	147068	1399	43634	1,0	29,7
Indonesia	1897836	11779	507772	0,6	26,8
Paraguay	400540	2588	106888	0,7	26,7
Bolivia	1087023	7921	288920	0,7	26,6
Venezuela	916023	8158	239034	0,9	26,1
Belize	22052	474	5623	2,2	25,5
Sri-Lanka	66114	518	16494	0,8	25,0
Liberia	96332	176	23506	0,2	24,4
Sierra-Leone	72905	251	17495	0,3	24,0
Congo-(DRC)	2338373	35491	554238	1,5	23,7
Vietnam	329453	4049	77002	1,2	23,4
Guinea-Bissau	33936	342	7841	1,0	23,1
Papua-New-Guinea	465790	3272	100531	0,7	21,6
Cuba	110986	1668	23846	1,5	21,5
French-Guiana	83669	295	17748	0,4	21,2
Peru	1297886	8595	273235	0,7	21,1

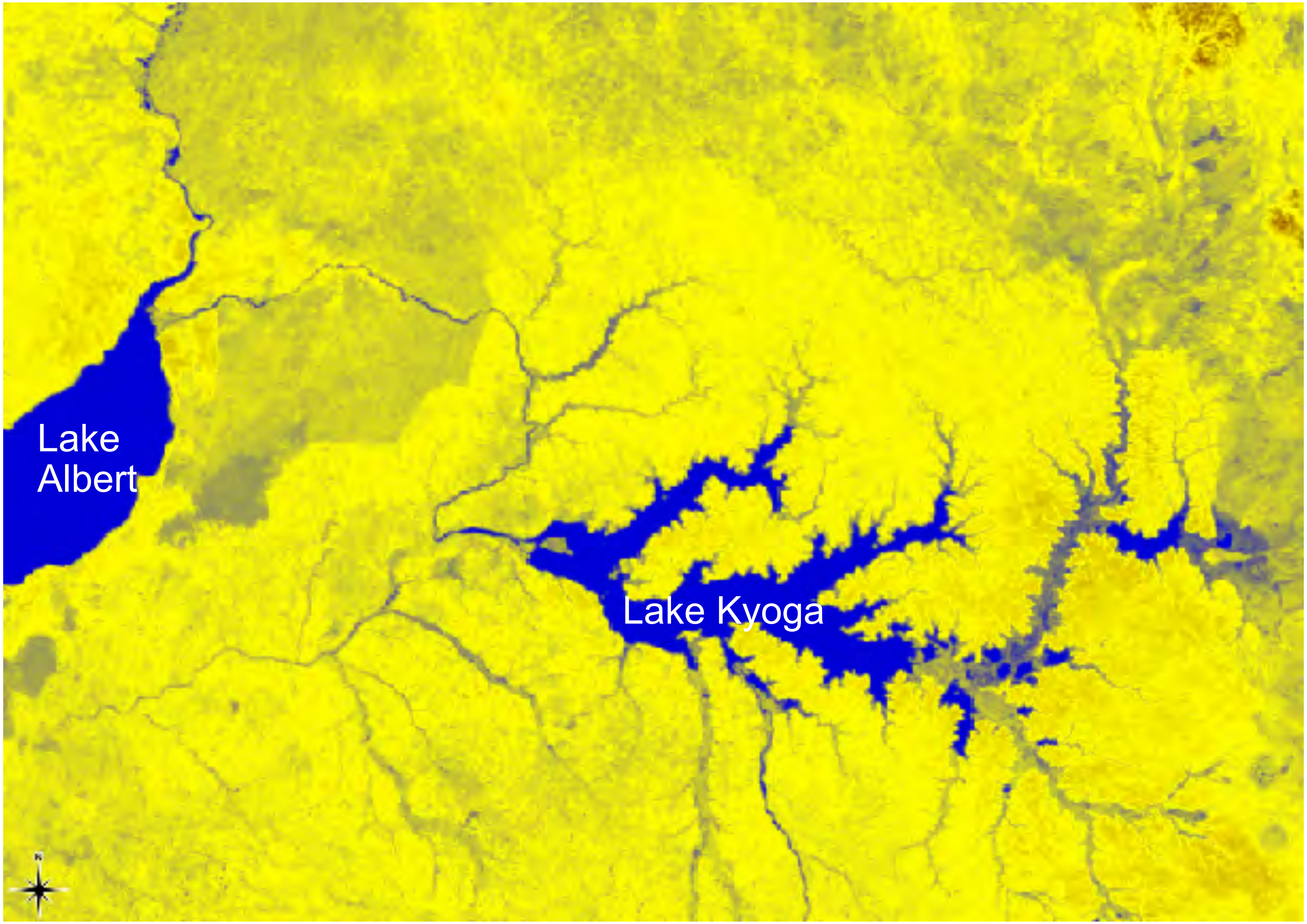
VIS/NIR soil wetness mapping





Wetness volume for 2011, tile h20v10 (Angola, Botswana, Namibia, Zambia and Zimbabwe), the Okavango Delta (Botswana) is outlined in red (lower left corner). The Okavango Delta is captured as a wet environment midst the dry Kalahari Desert..

VIS/NIR soil wetness mapping



Soil wetness (maximum wetness, 2011) for central Uganda
(Lakes Kyoga and Albert)

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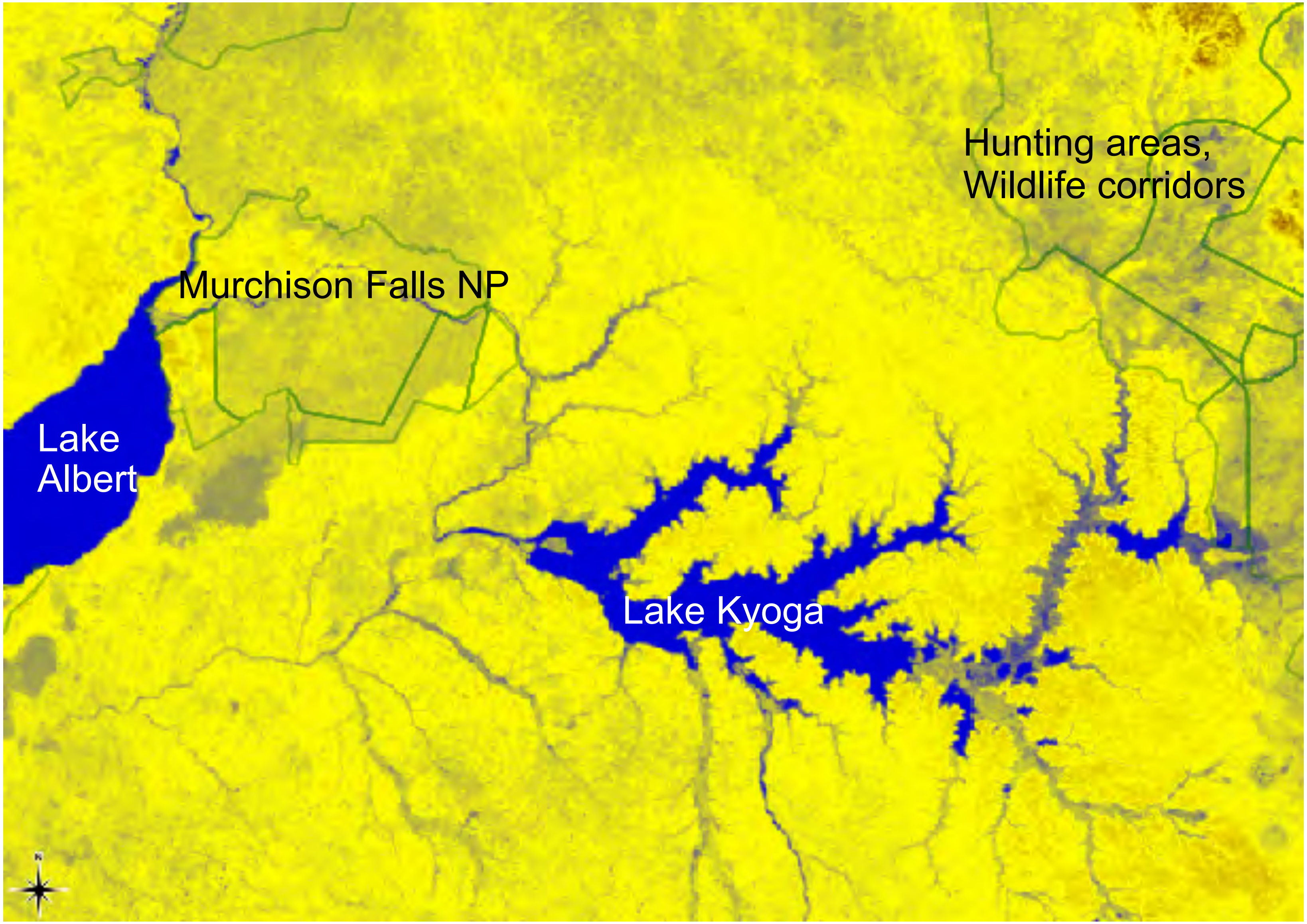
VIS/NIR soil wetness mapping



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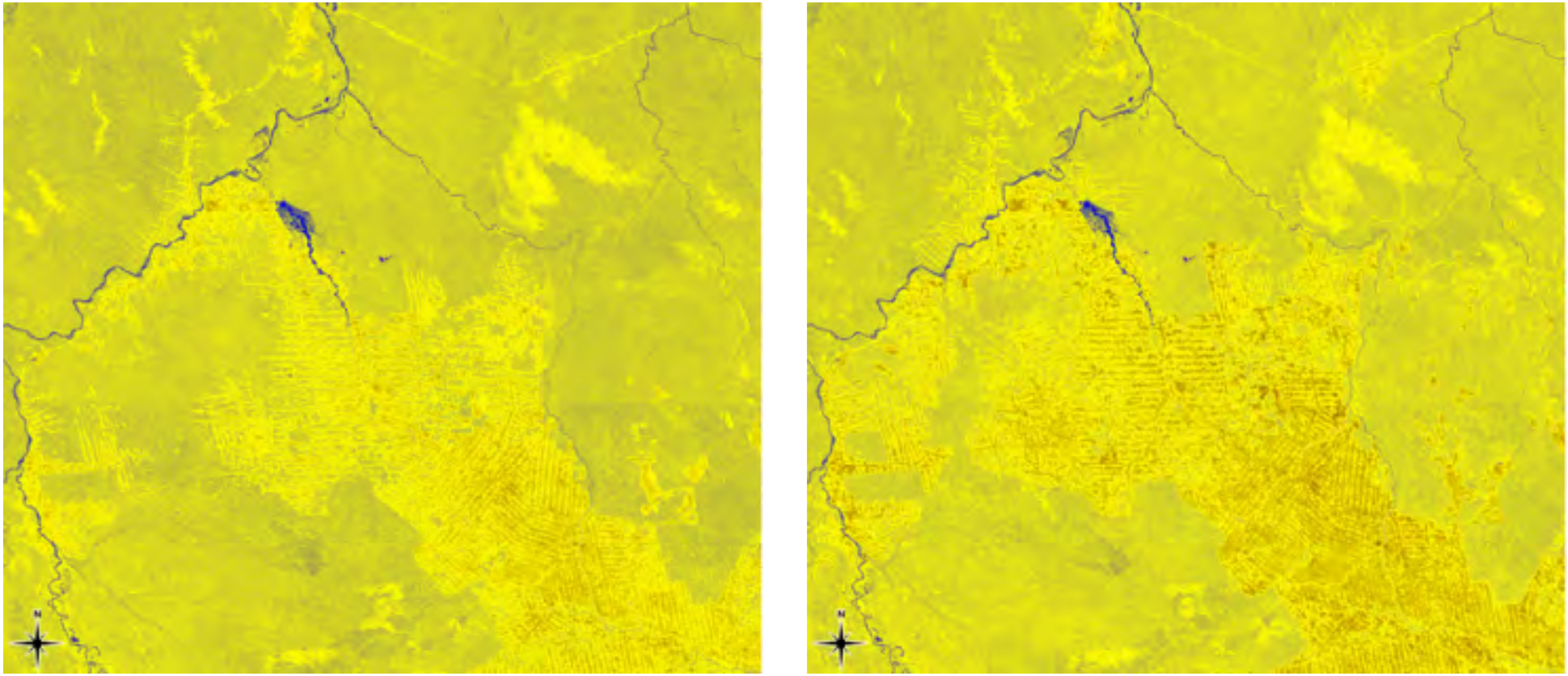
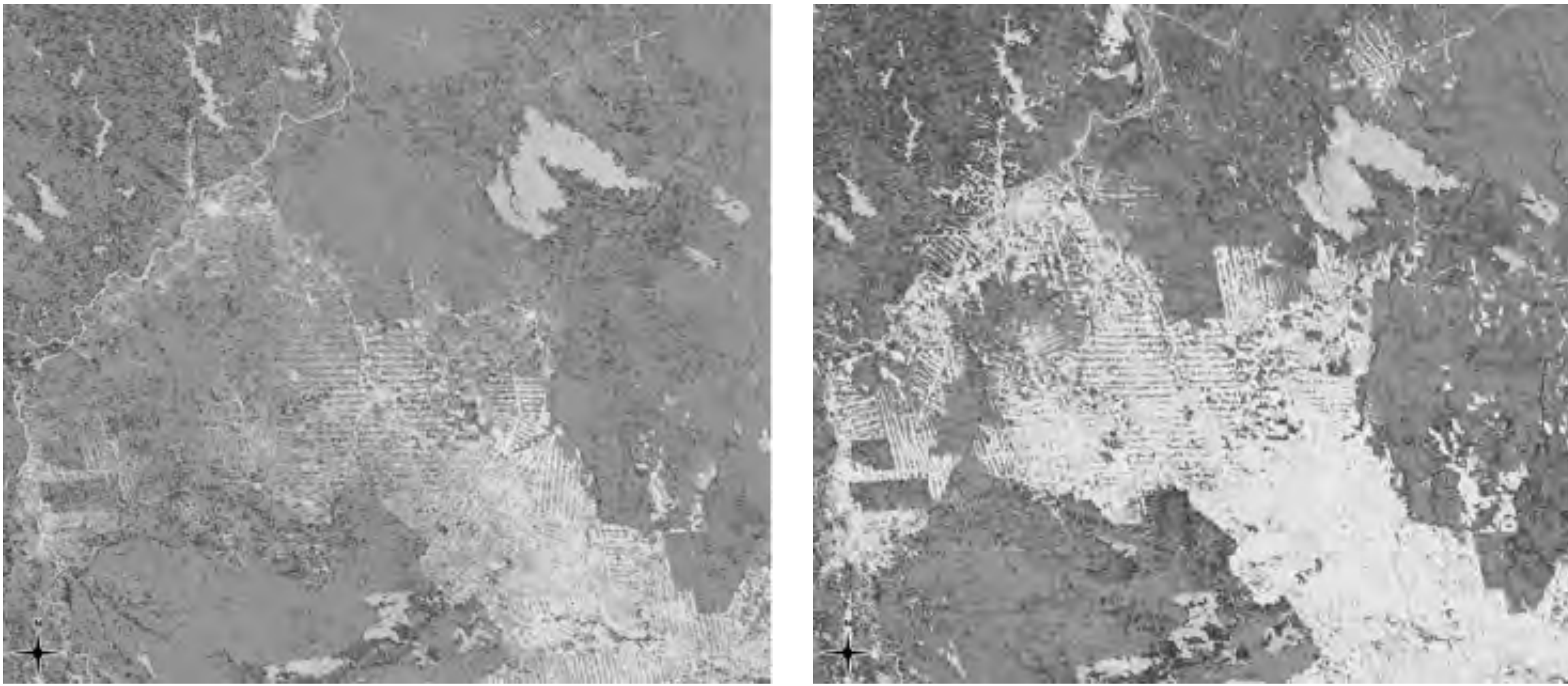


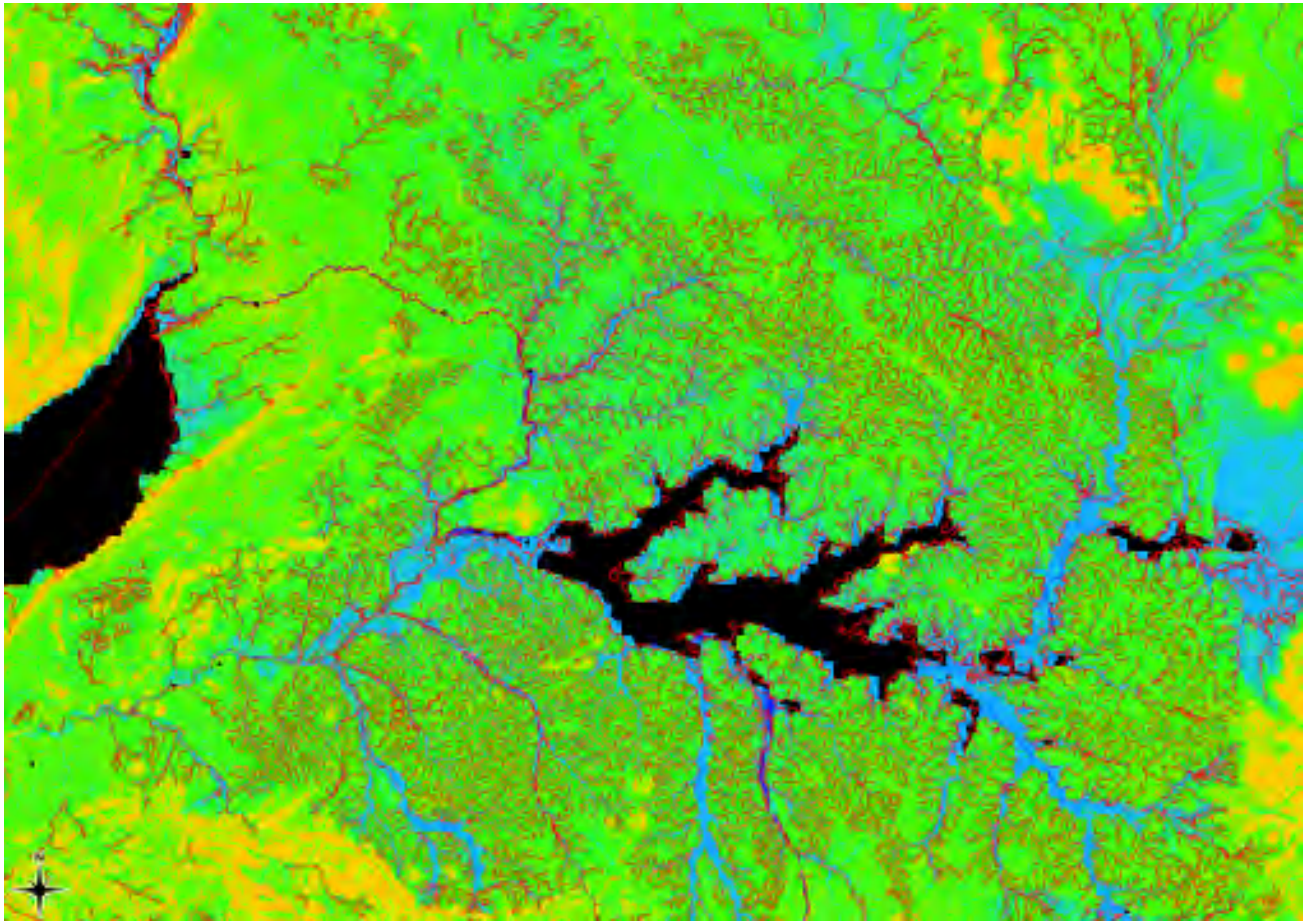
Change in soil wetness between 2001 (left) and 2011 (right)
for an area in the Central Amazon Basin

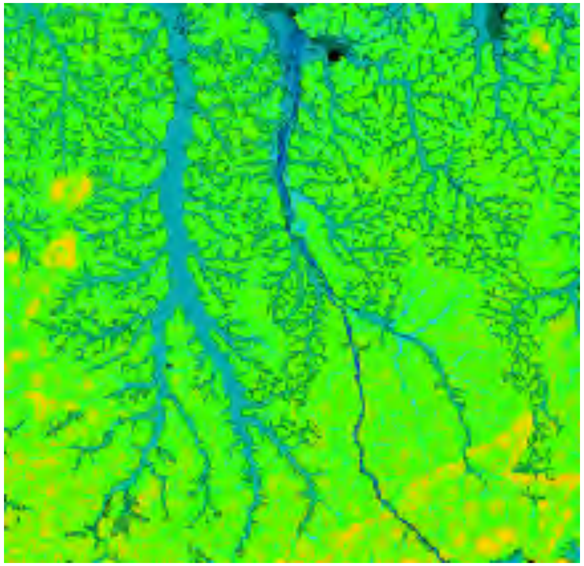
Mapping SOC from VIS/NIR spectra



Soil Organic Carbon content 2001 (left) and 2011 (right), mapped from the VIS/NIR reflectance data using a decision tree approach calibrated with data from AfSIS. Image courtesy of Tor-Gunnar Vågen, ICRAF, Kenya.

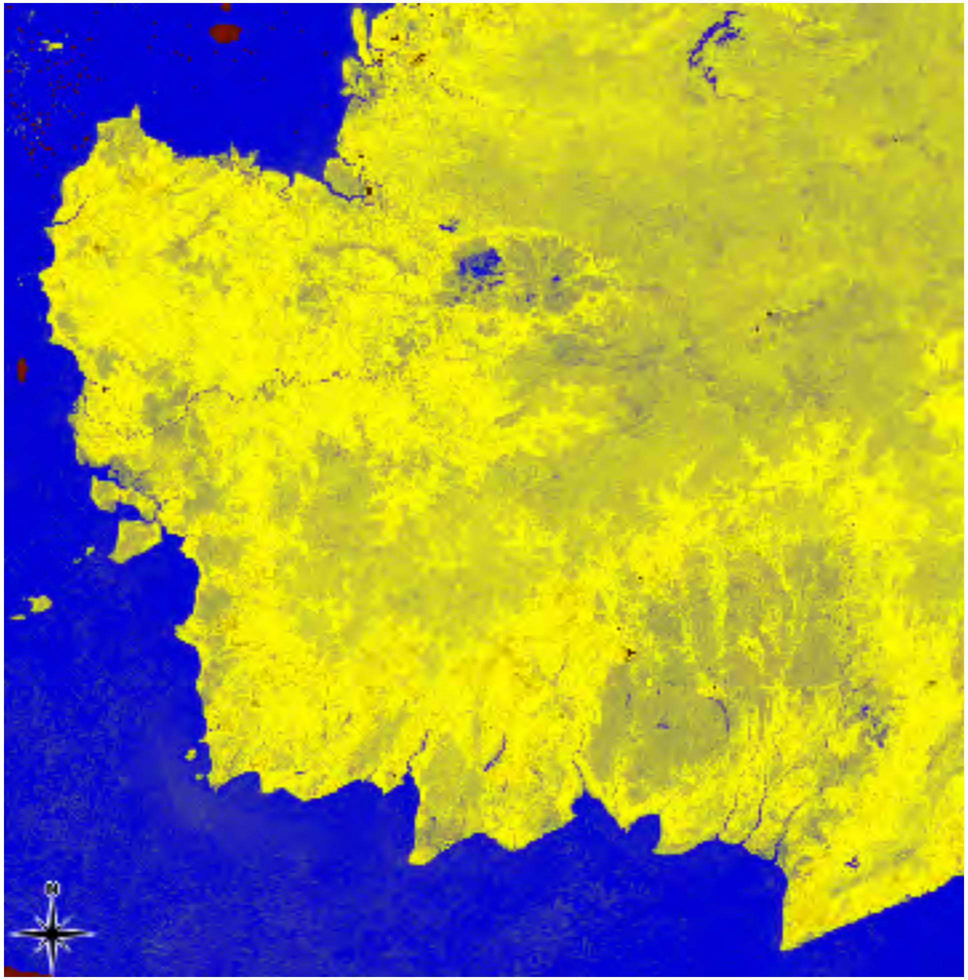
Climate-Topographic wetness

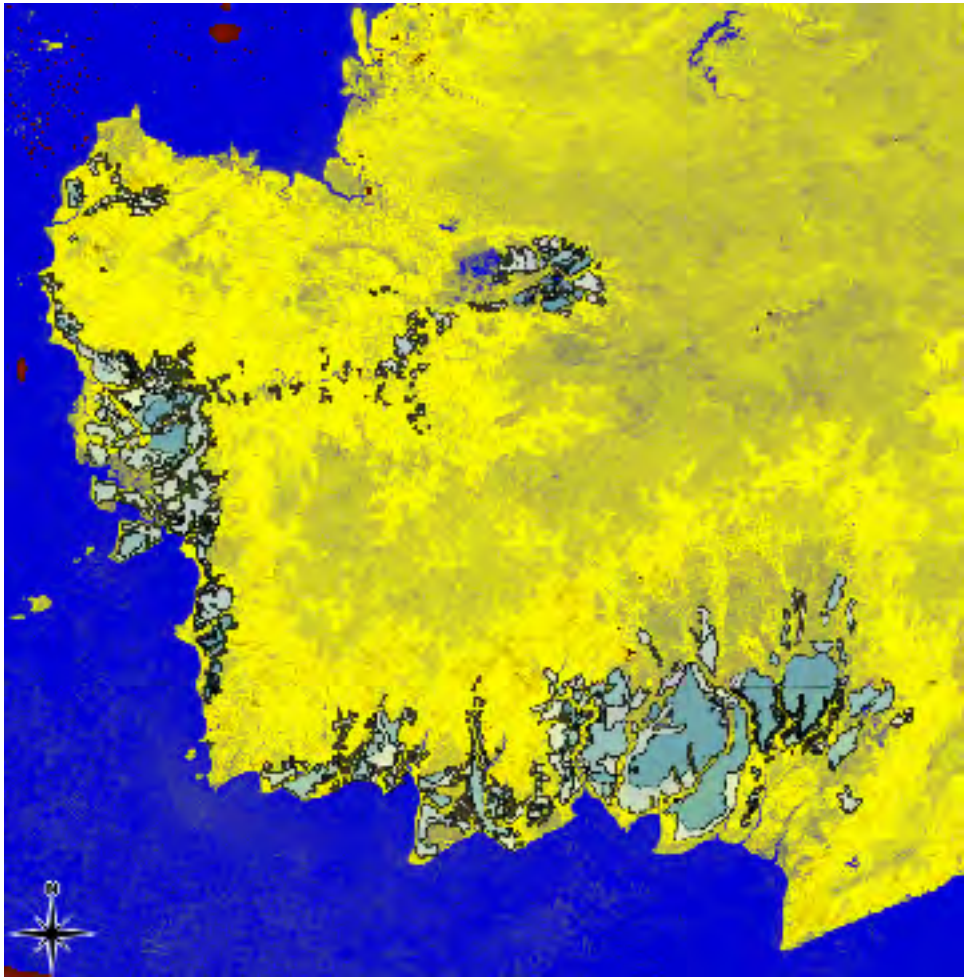




Climate-topographic wetness index for central Uganda (Lakes Albert and Kyoga). Overlay is the wetland class from the FAO Africover dataset. Detail to the right.

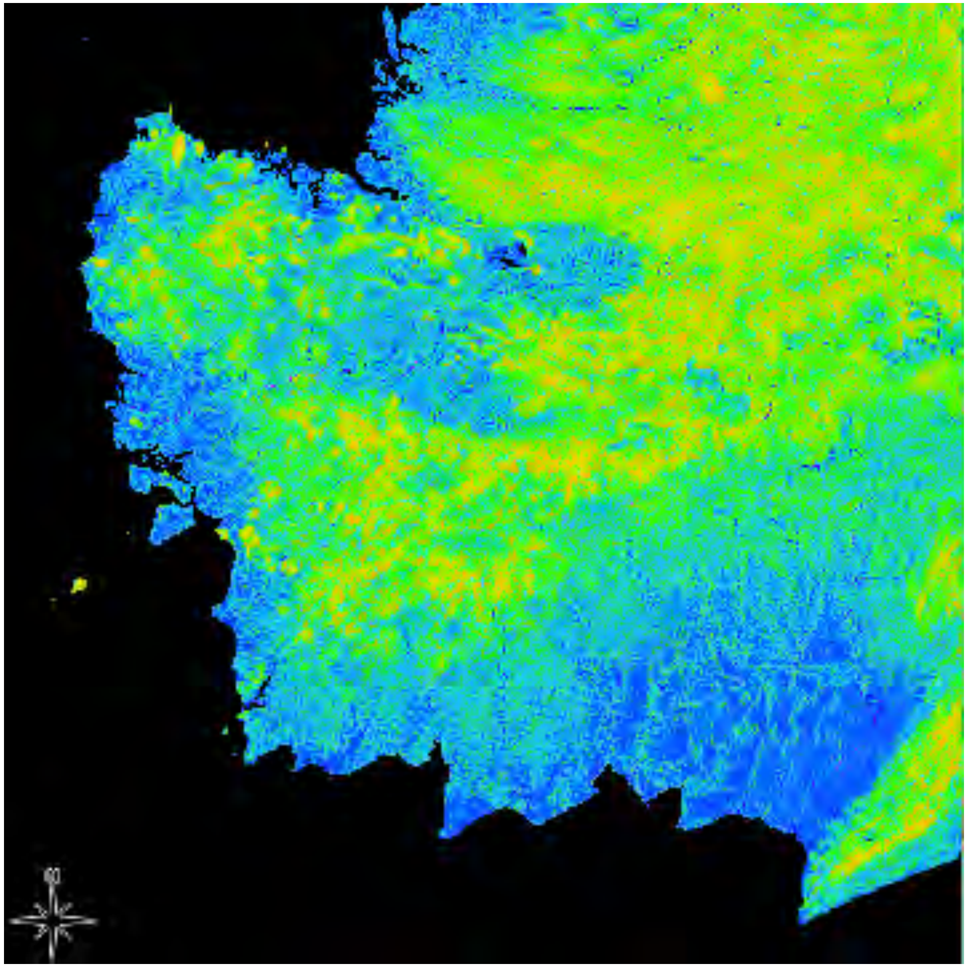
VIS/NIR soil wetness mapping

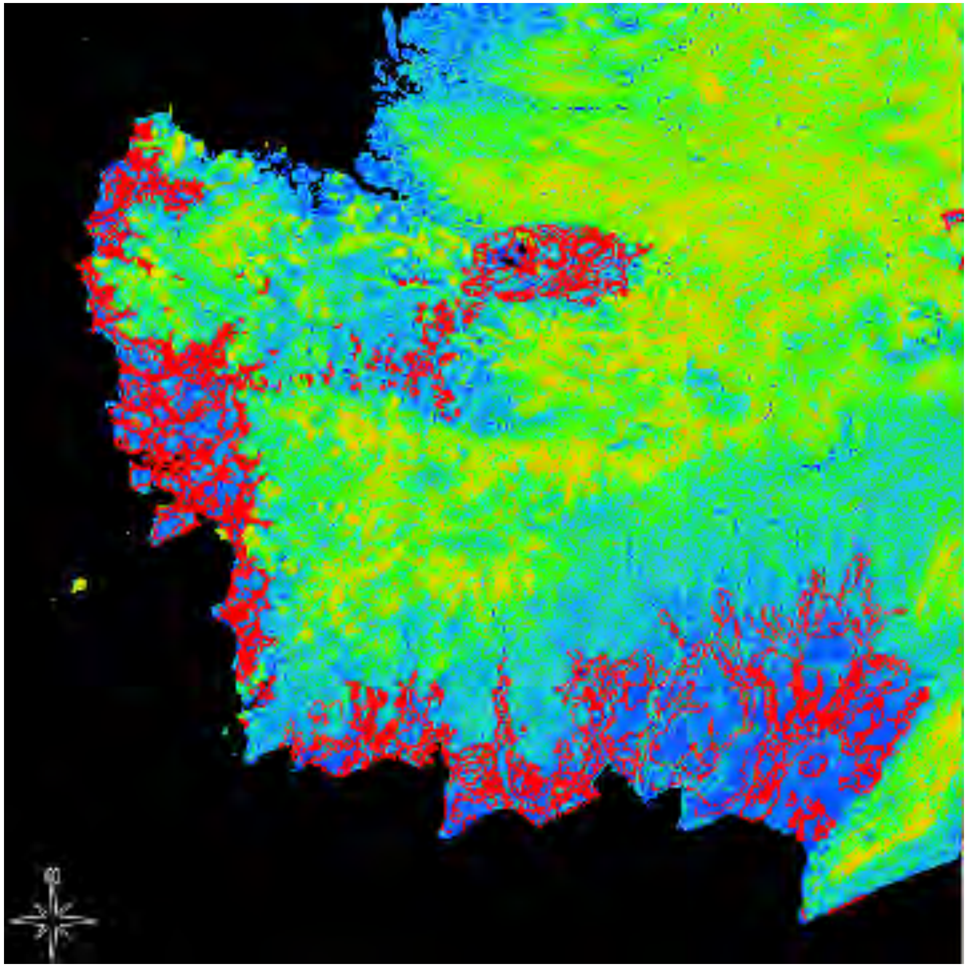




Soil wetness index for parts of Kalimantan, Indonesia (2011). Image to the right shows peatlands from the Ministry of Agriculture.

Climate-Topographic wetness





Climate topographic index for parts of Kalimantan, Indonesia (2011). Image to the right shows peatlands from the Ministry of Agriculture.