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G-SWAF a 10 years dataset of global water dynamics from L-Band microwave: from concept to applications

Al Bitar Ahmad, Marie Parrens, Jeremy Guilhen, Ayan Fleischmann, Sabine Sauvage, Christophe Fatras, José Miguel Sánchez-Pérez, Columba Martínez-Espinosa, Yann Kerr, Santiago Pena Luque, et al.

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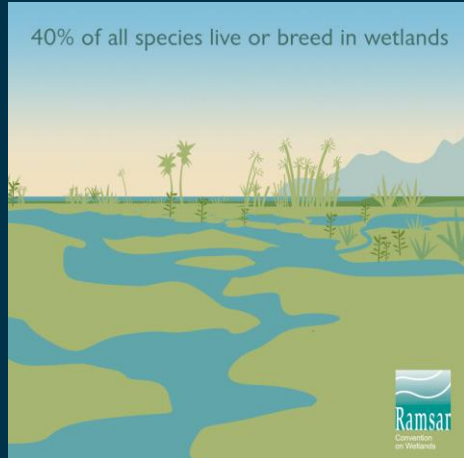
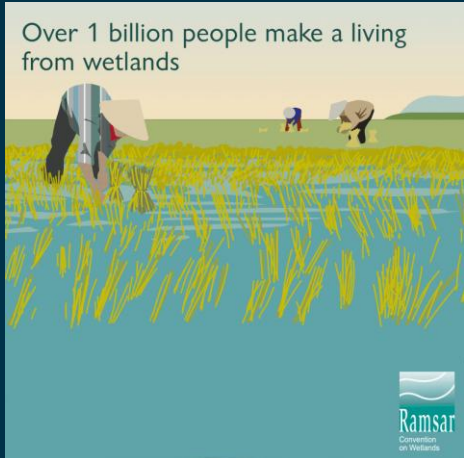
G-SWAF

A 10 Years Dataset of Global Inland Water Dynamics from L-Band Microwave:
from Concept to Applications

Ahmad Al Bitar

Parrens M., Guilhen J., Fleischmann A., Sauvage S., Fatras C., Sánchez-Pérez J-M, Martínez-Espinosa C., Kerr Y., Pena-Luque S.,
Picot N., Cherchali S.

Wetlands



Importance of mapping water surfaces in tropical regions to understand the underlying processes
(Alsdorf et al., 2007 ; Bakker, 2012 ; Finlayson et al., 1999 Vorosmarty et al., 2015; Costanza et al., 2014)

“wetlands and riparian areas as significantly important nitrogen traps” (Martinez-Espinosa et al. Sci. Tot. 2020, Vitousek et al. 1997)

Global Climate Change and rice food security
(N.V. Nguyen FAO, 2002)

<https://www.worldwetlandsday.org/en/>



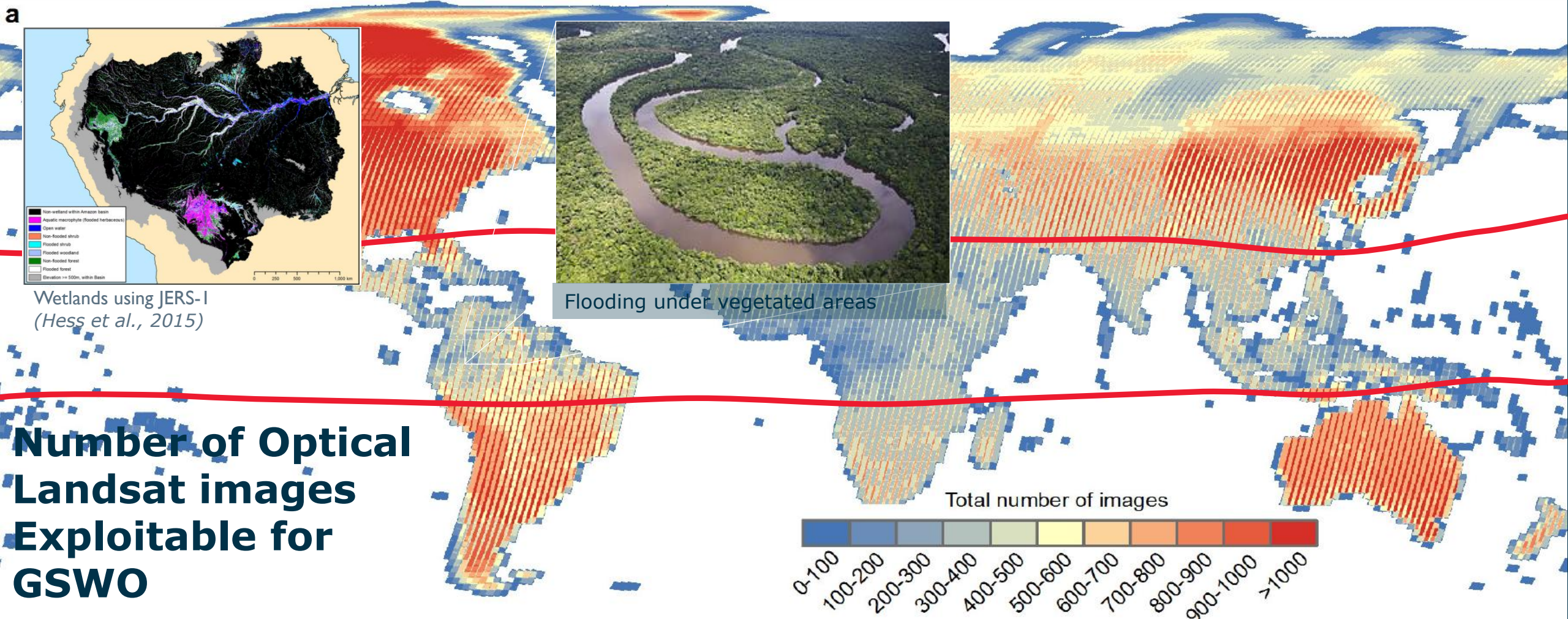
Afrixalus dorsalis Brian Gratwicke CC



Sound: Afrixalus Frog - British Library

Photos: Odzala National Park, Congo © Scott Ramsay

Monitoring of wetlands from space



**Number of Optical
Landsat images
Exploitable for
GSWO**

from Pekel et al. Nature, 2016

➔ Motivation for L-Band based water surfaces

What is the potential of SMOS data for wetlands monitoring ?

SMOS
(ESA Earth explorer)
data since Jan 2010

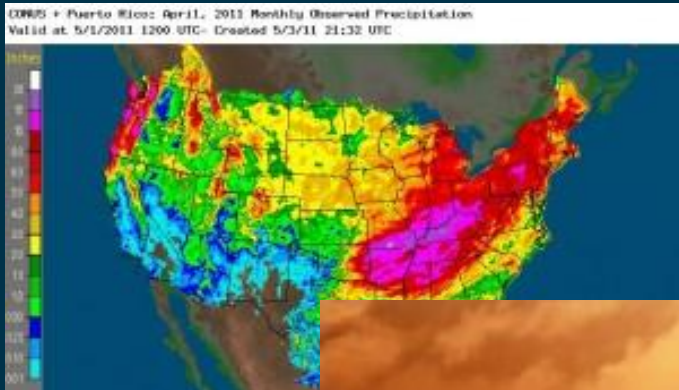
L-Band

2D interferometric
radiometer
Multi-angular & full-
polarization

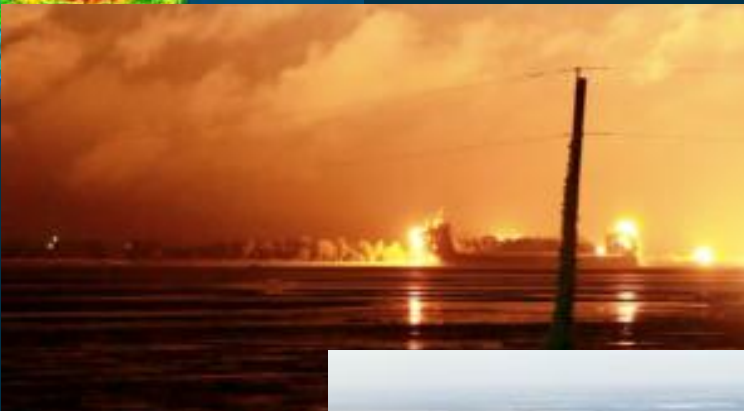
40 km resolution with 3 days
global coverage



First detection of large scale floods with SMOS – Mississippi 2011



Snow melt
+
heavy rainfall

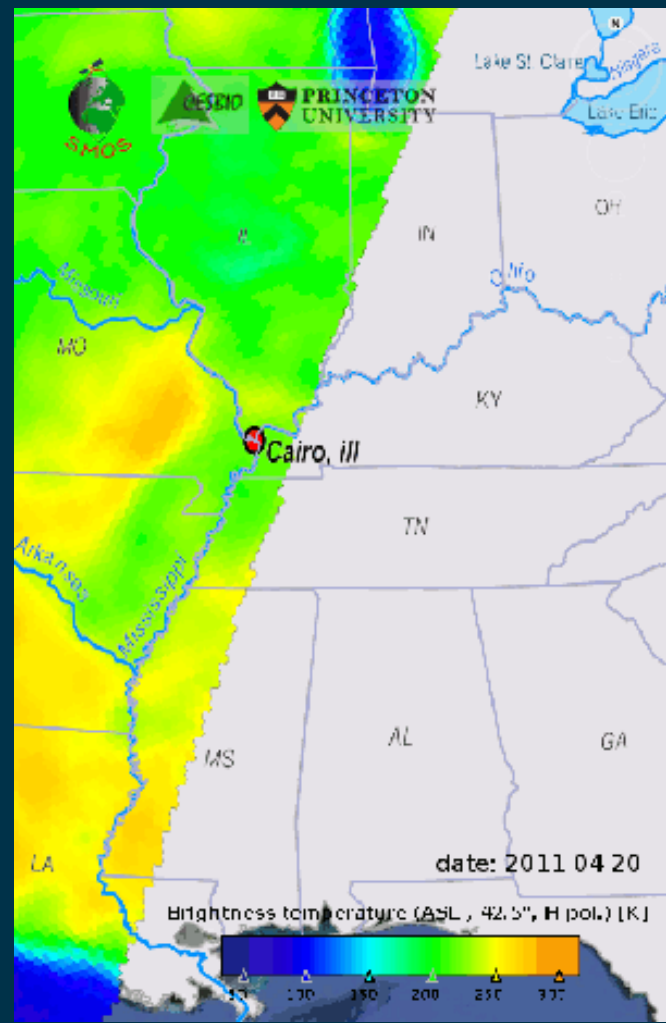


Levee destruction



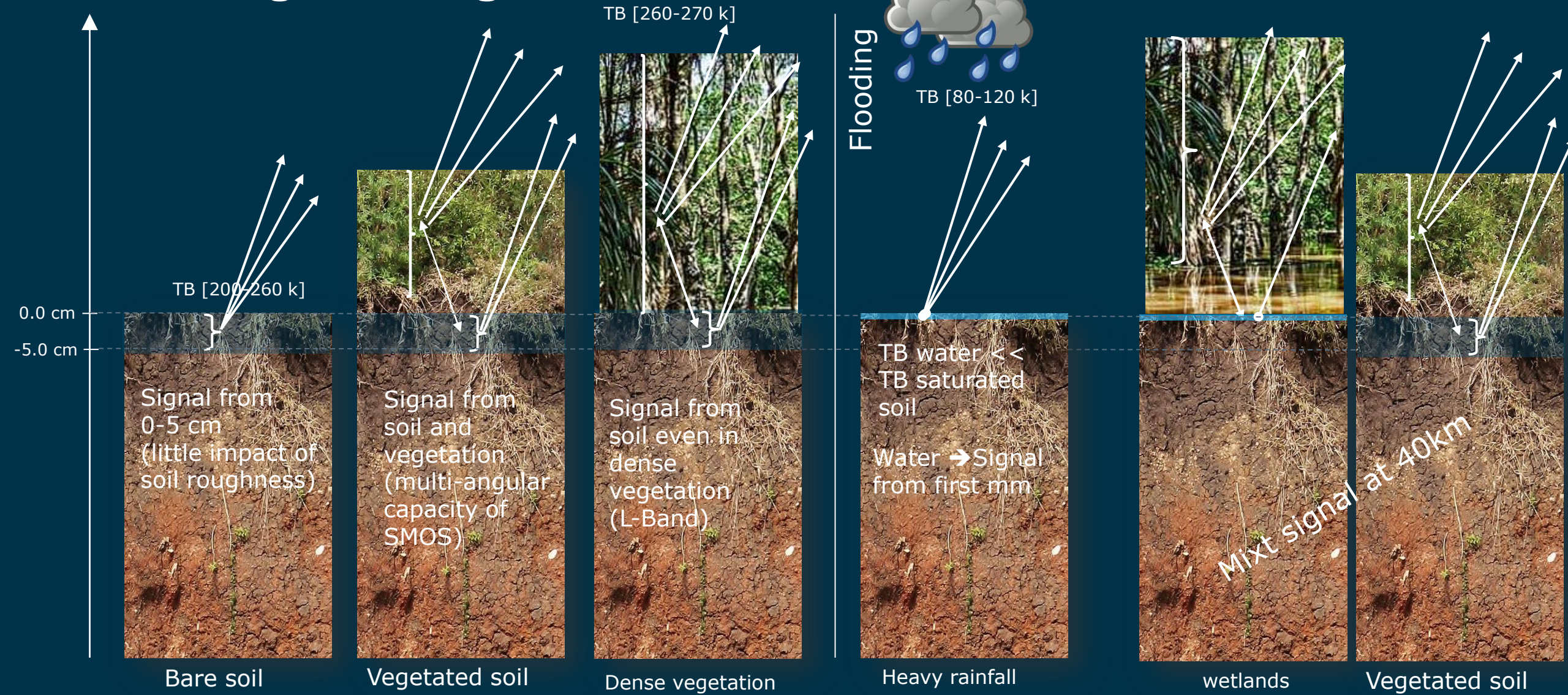
Floods

SMOS TB@42.5 H



Al Bitar et al. SMOS 1st Workshop, Arles, 2011

L-Band signal during floods

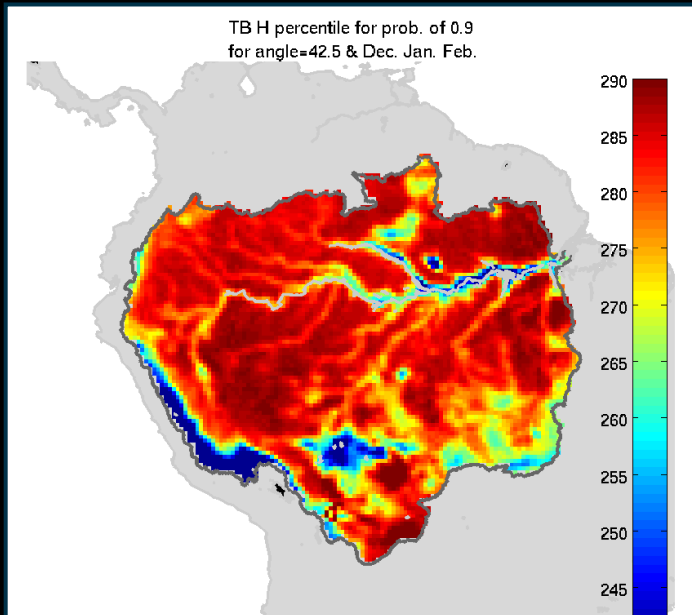
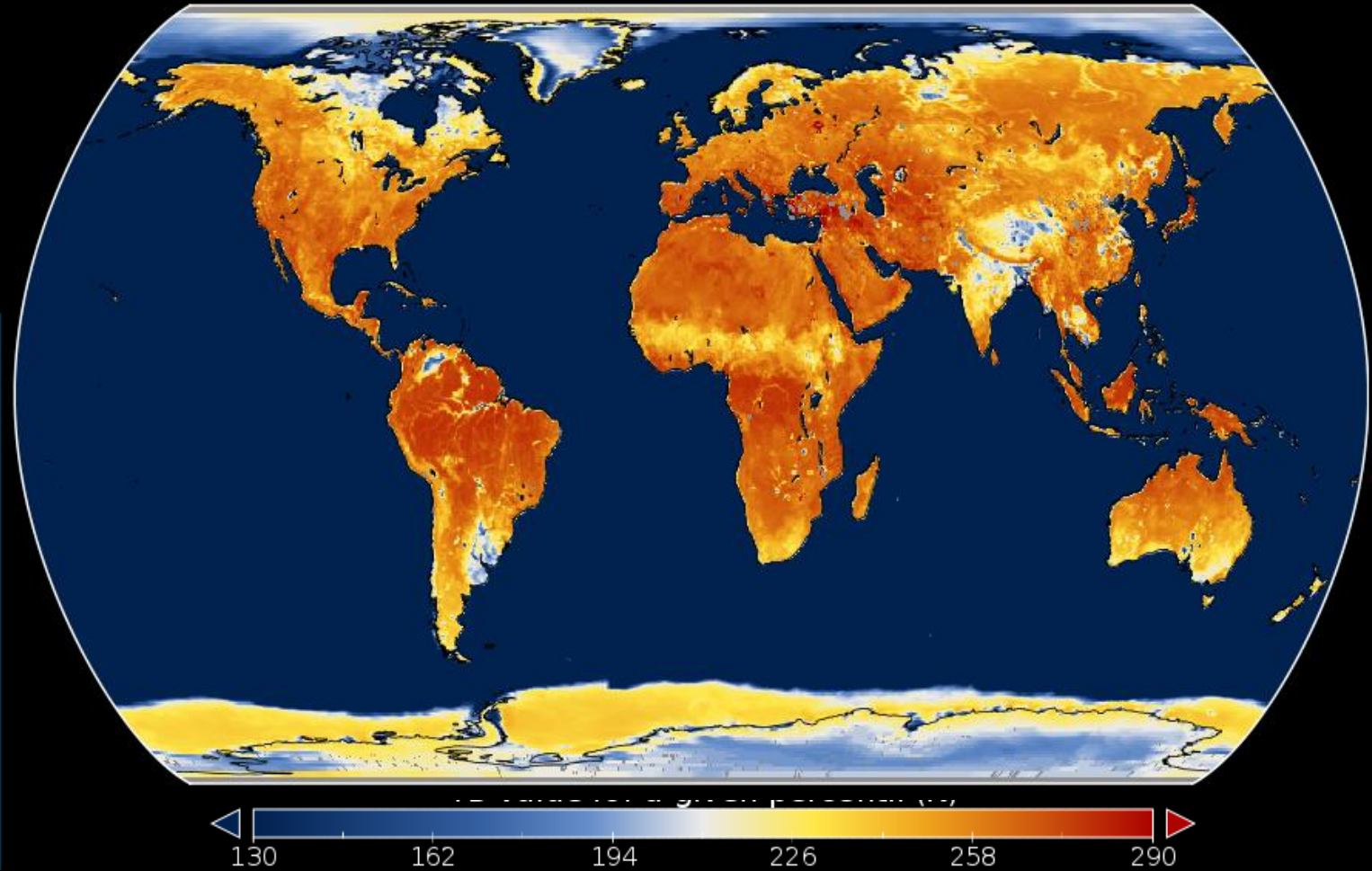


Ponding effect during rainfall
 (Al Bitar et al., IEEE 2012,
 Jackson et al. 2012)

SMOS CATDS L3 TB – Angle binned at TOA

Median TB H @ 42.5°

Seasonal floods visible from SMOS TB

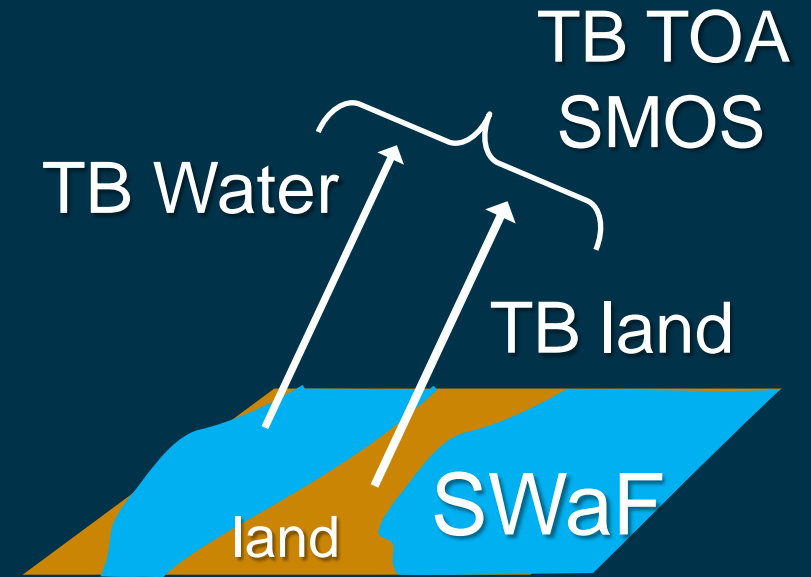
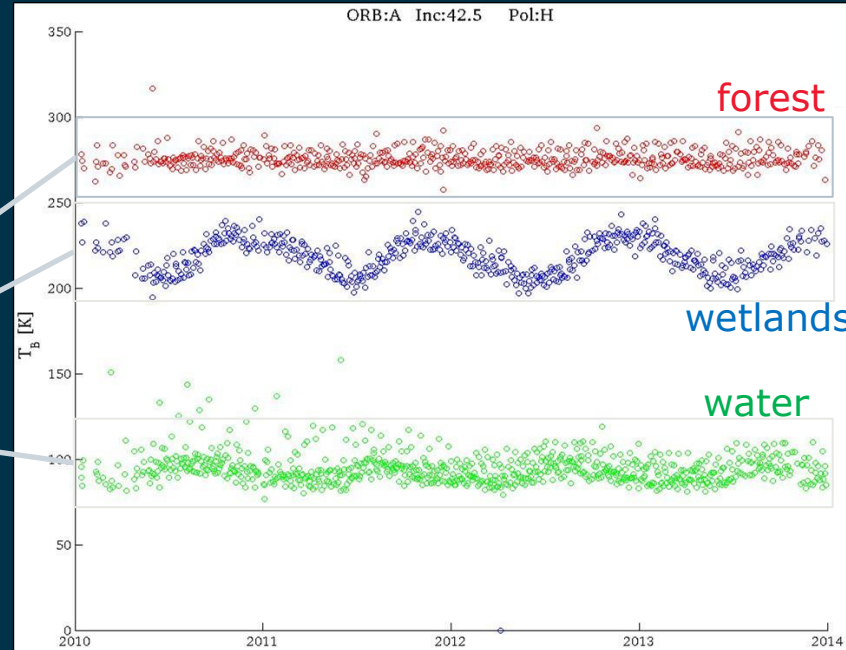
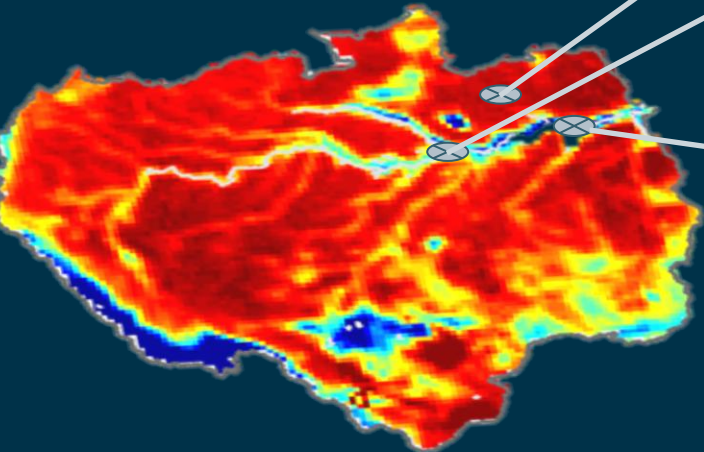


(Al Bitar et al., ESSD, 2017)

SWAF - SMOS Water Fraction over Amazon

Time series of TB H 42.5°

Median TB H @ 42.5



$$TB\ TOA\ SMOS = TB\ Land \times (1 - SWAF) + TB\ water \times SWAF$$

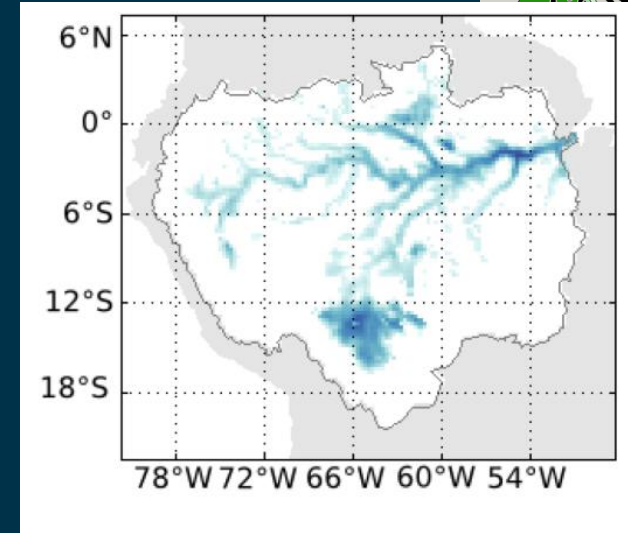
- TB water is modeled using the Klein & Swift (1977) model based on the parameterisation in Ulaby (1983)
- TB Land & Forest is forced based on non-flooded nodes.
- SWAF (the fraction of water surface) is retrieved.

(Parrens et al. Water, 2017)
(Al Bitar et al. 2015, SMOS 2nd Science Workshop)

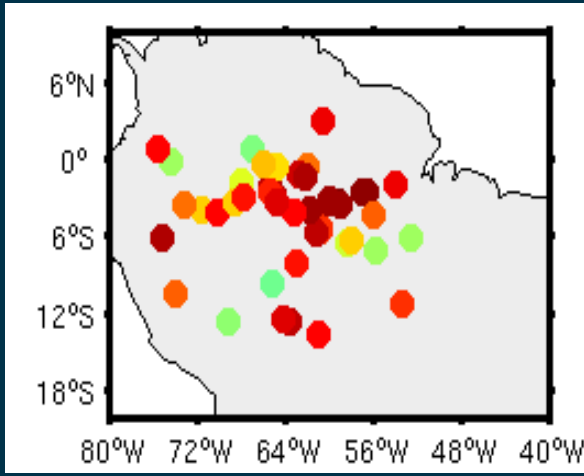
Mapping Dynamic Water Fraction under the Tropical Rain Forests of the Amazonian Basin from SMOS Brightness Temperatures

Marie Parrens ^{1,*}, Ahmad Al Bitar ¹, Frédéric Frappart ^{2,3}, Fabrice Papa ^{2,4}, Stéphane Calmant ², Jean-François Crétaux ², Jean-Pierre Wigneron ⁵ and Yann Kerr ¹

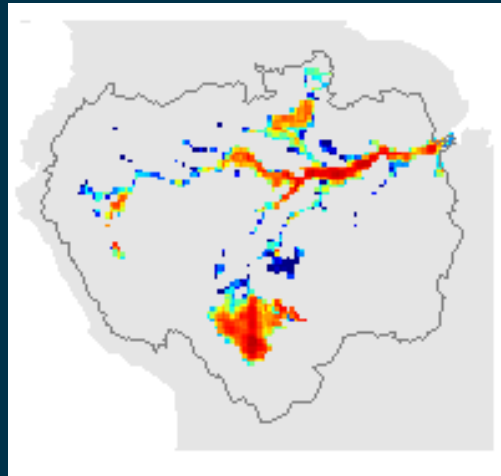
Validation and comparison SWAF :



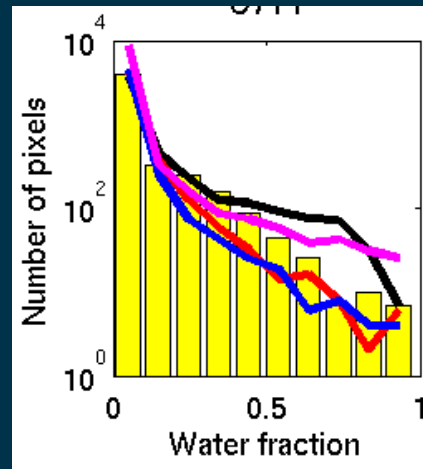
Altimetry Jason2



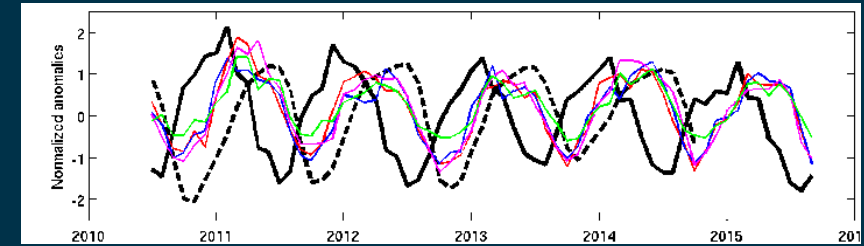
SWAMPS



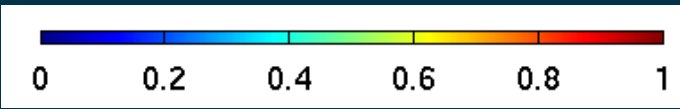
Static maps



Rainfall / Discharge



— Precip GPCP
 - - - Discharge
 — SWAF 32H
 — SWAF 37H
 — SWAF 42H
 — SWAF 47H



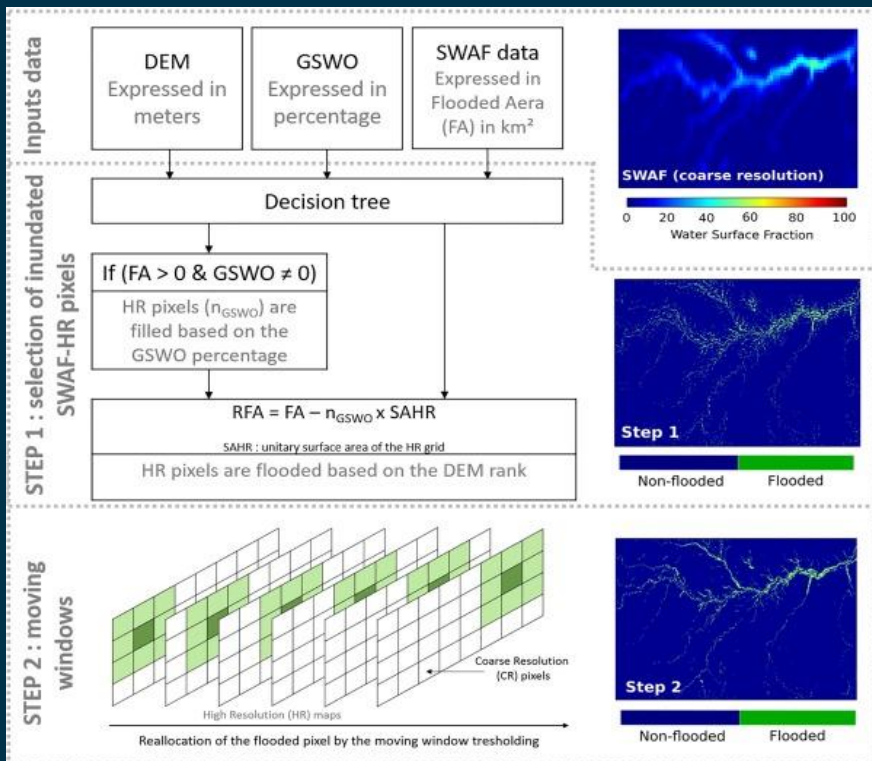
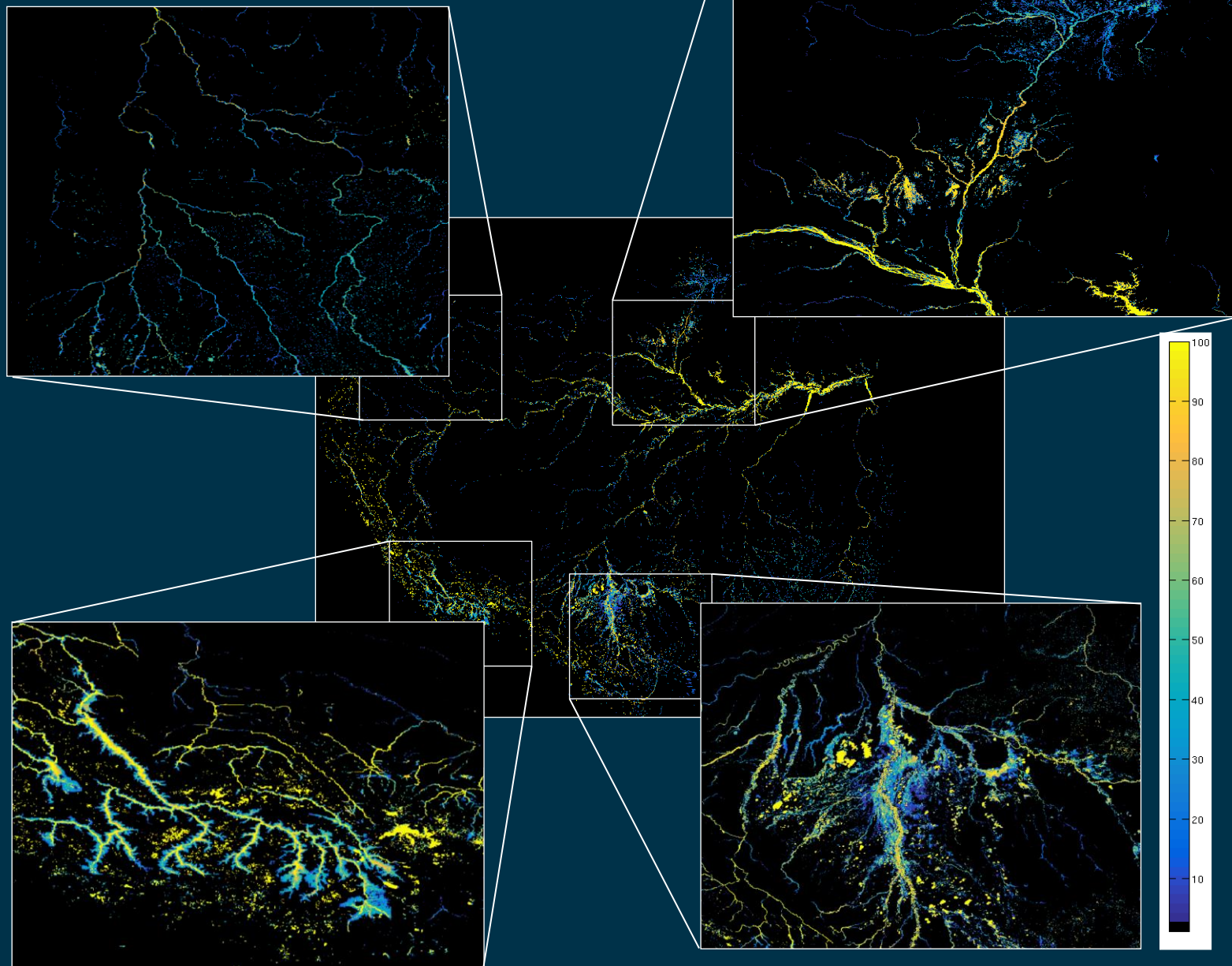
Lag Consistent with previous studies

From SWAF to SWAF-HR 1km

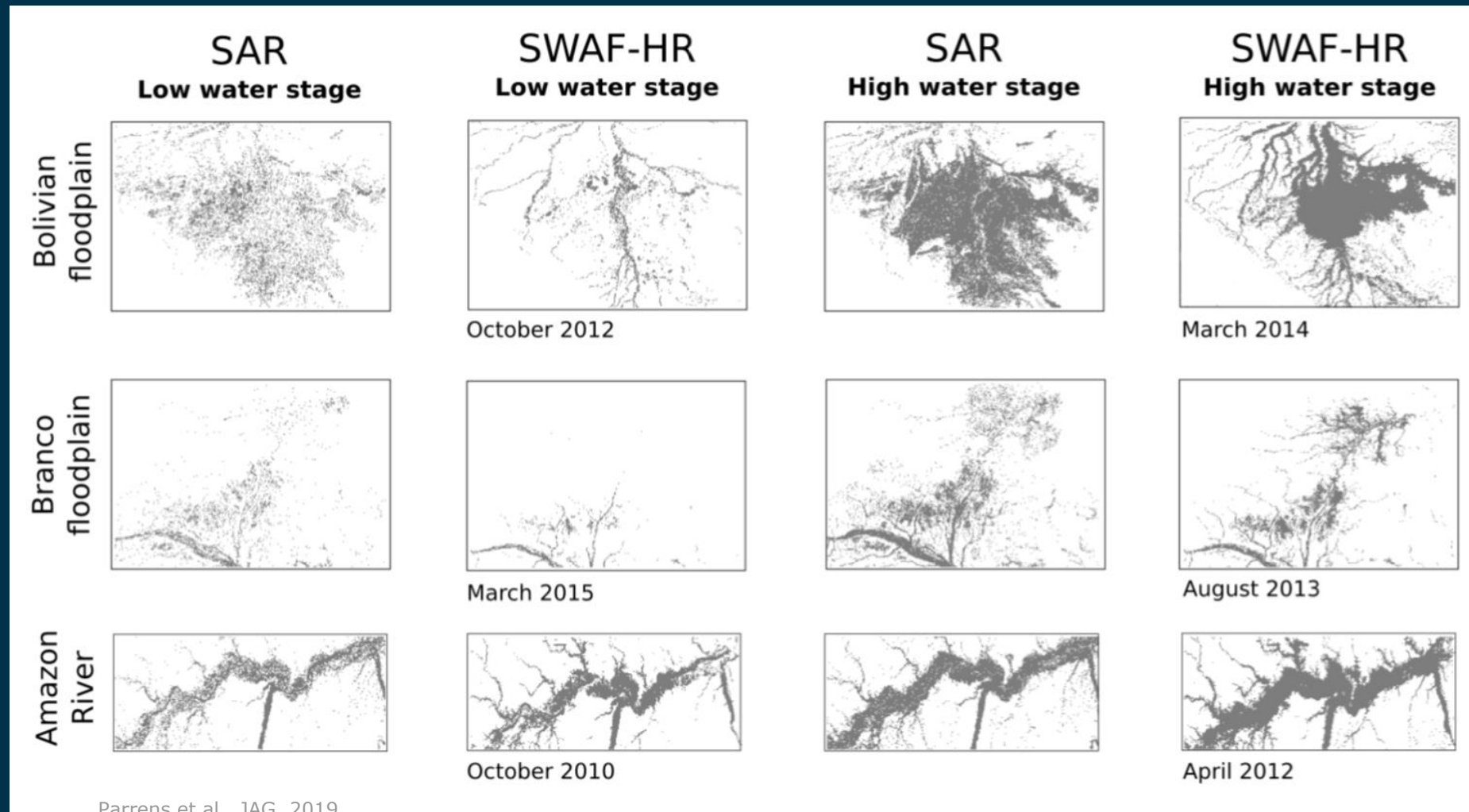


High resolution mapping of inundation area in the Amazon basin from a combination of L-band passive microwave, optical and radar datasets

Marie Parrens ^{a, b, c, d, e}, Ahmad Al Bitar ^a, Frédéric Frappart ^c, Rodrigo Paiva ^d, Sly Wongchuig ^d, Fabrice Papa ^c, Dai Yamasaki ^e, Yann Kerr ^a



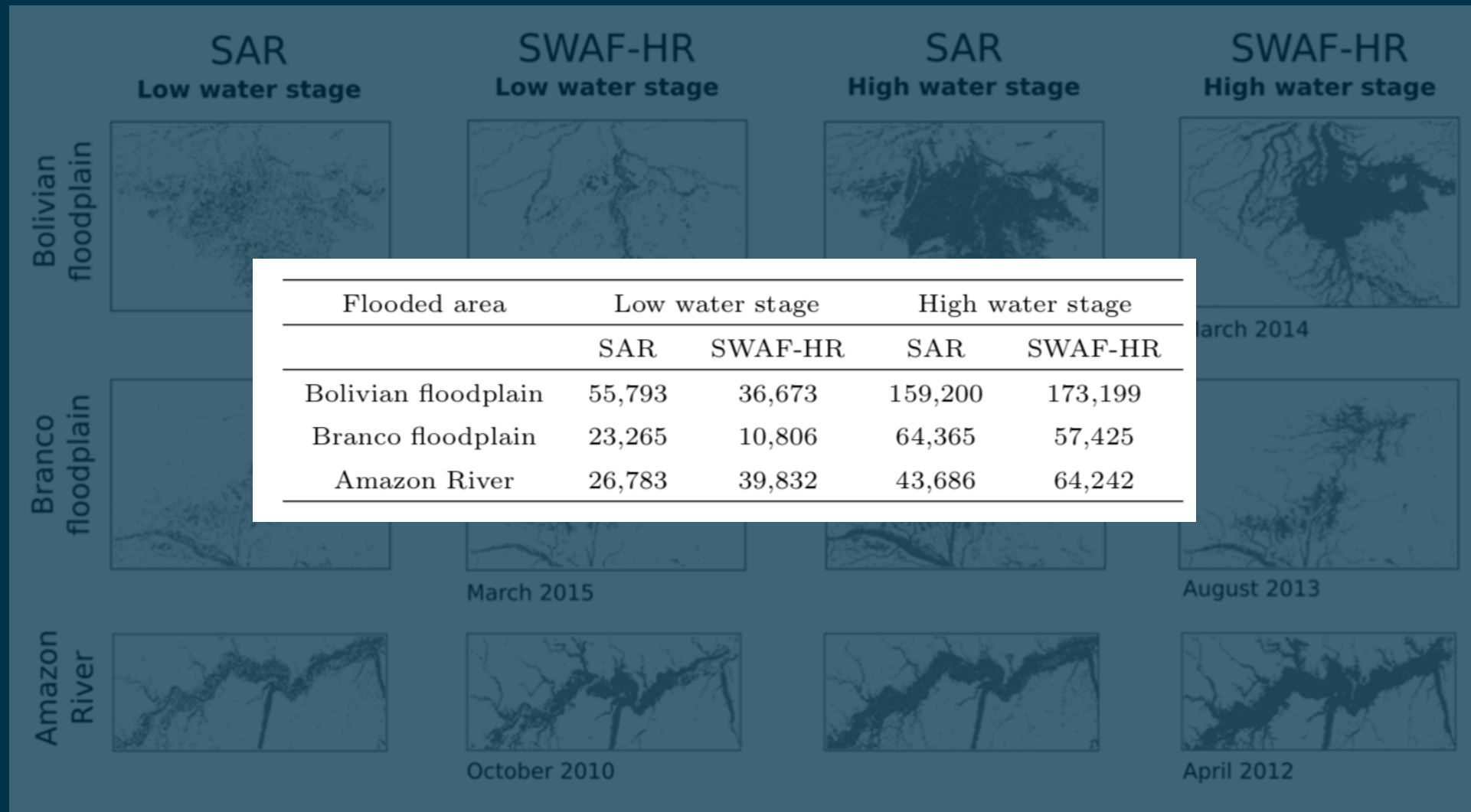
SWAF-HR vs SAR data



Parrens et al., JAG, 2019

(Parrens et al., JAG, 2019)

SWAF-HR vs SAR data



(Parrens et al., JAG, 2019)

G-SWAF - Global SWAF - (J' soif)

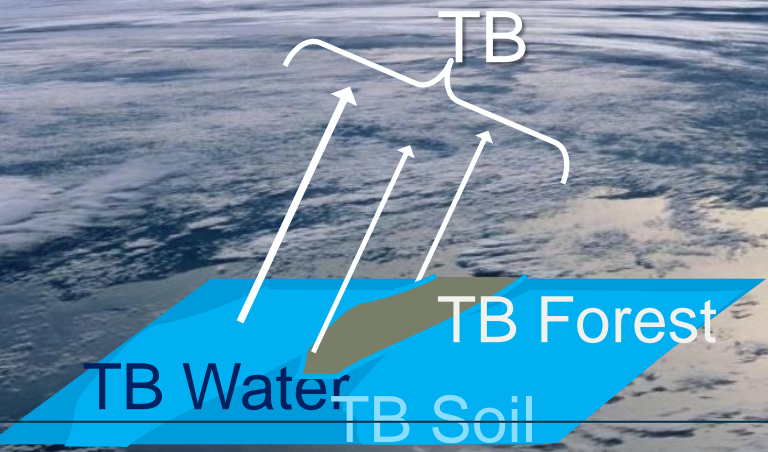
Multiple elementary surface contributions, exploitation of polarisation and multi-angular acquisitions



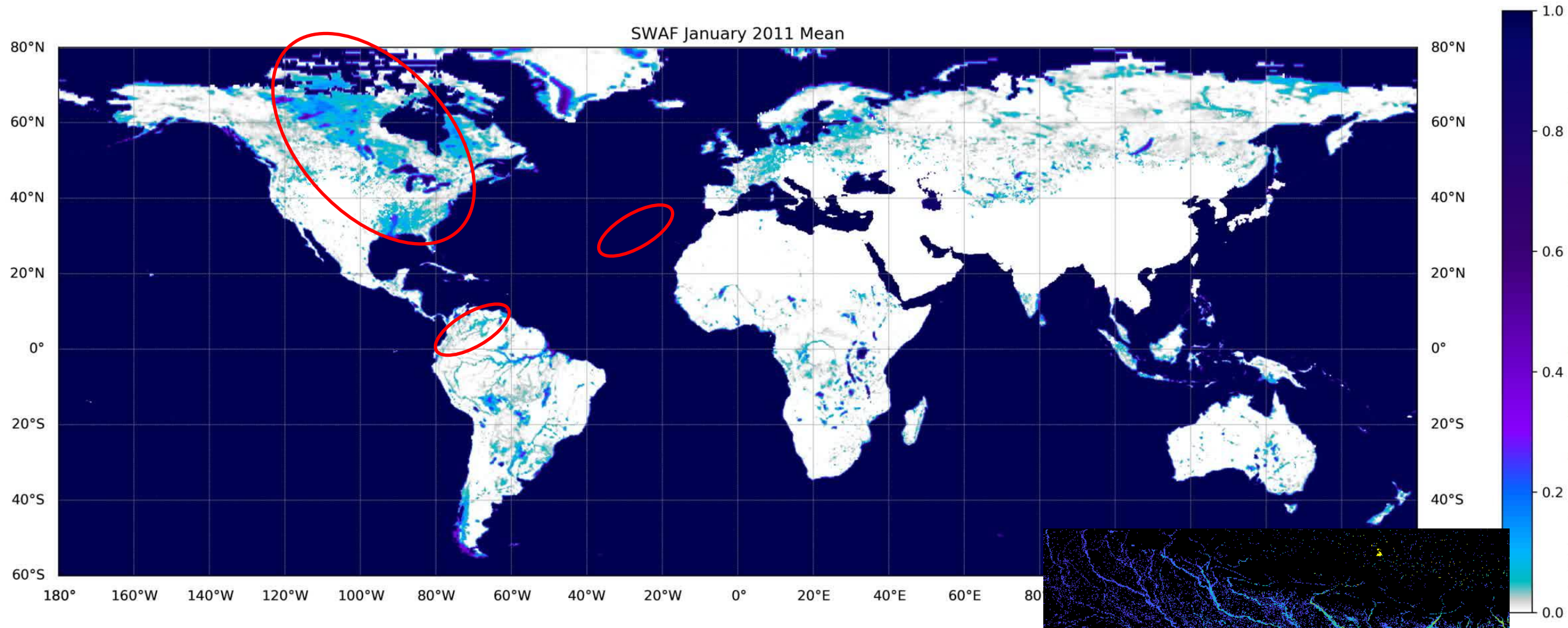
$$TB(\theta_i, P_i) = TB_w(\theta_i, P_i) * F_w + TB_f(\theta_i, P_i) * F_f + TB_s(\theta_i, P_i) * F_s$$

- Surface fractions (Fw, Fs and Ff) are retrieved
- TB water is modeled.
- TB forest and TB soil are forced based on spatio-temporal constraints.
- An iterative inversion is applied.

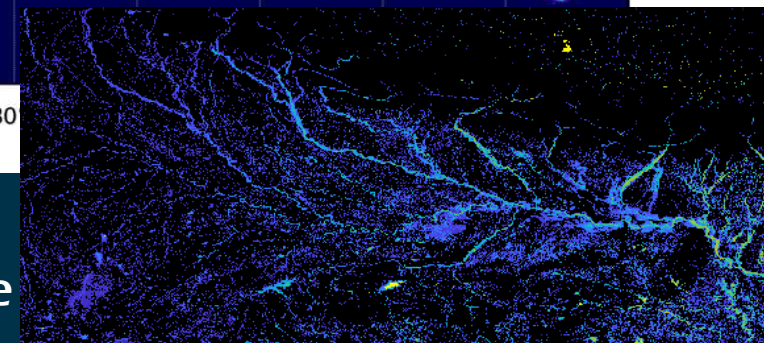
Al Bitar et al., IGARSS, 2020



G-SWAF maps – 2010 – 2020 – Weekly @ 25 km

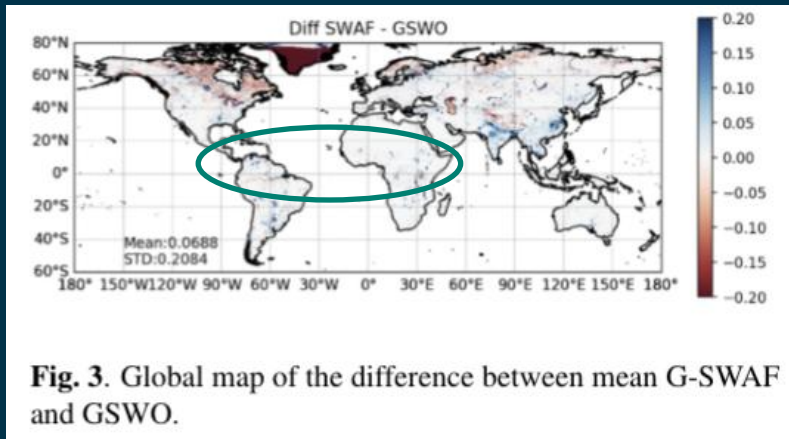


G-SWAF-HR over Gange-Brahmapoutre

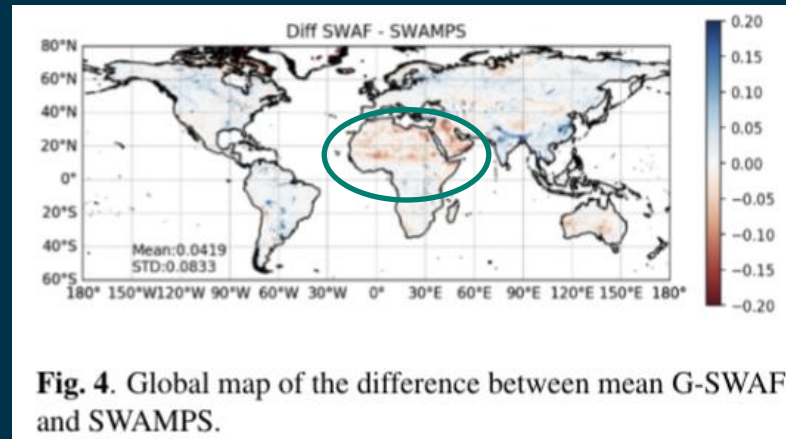


Comparing G-SWAF to existing products

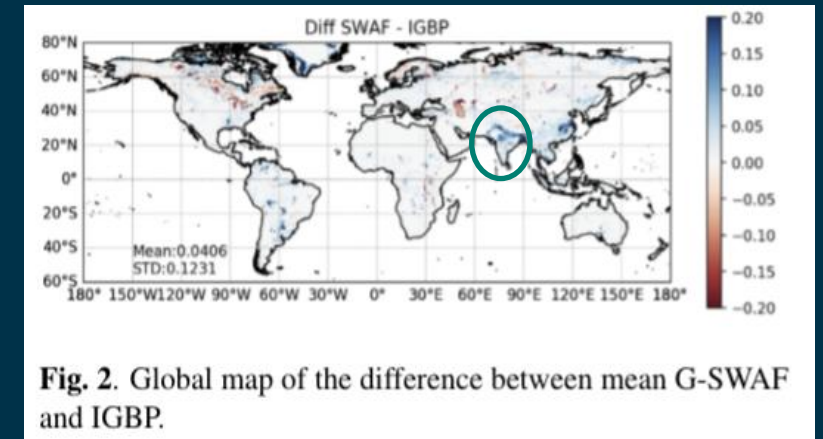
G-SWAF-GSWO



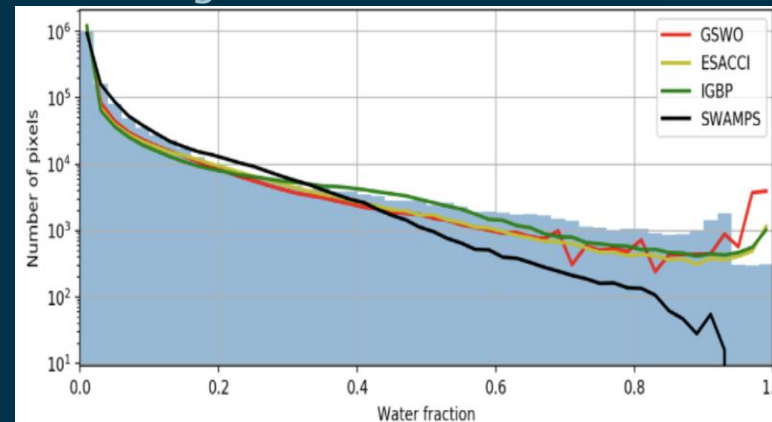
G-SWAF-SWAPS



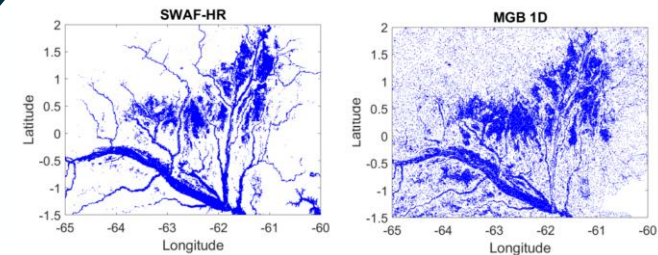
G-SWAF-IGBP



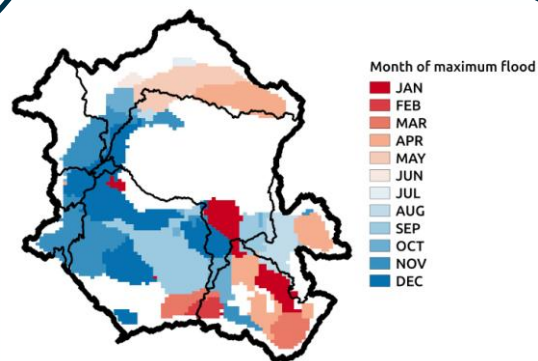
Histograms of water fractions



G-SWAF applications



1D-2D hydrodynamic modeling
(Fleischmann et al., WRR, 2020)

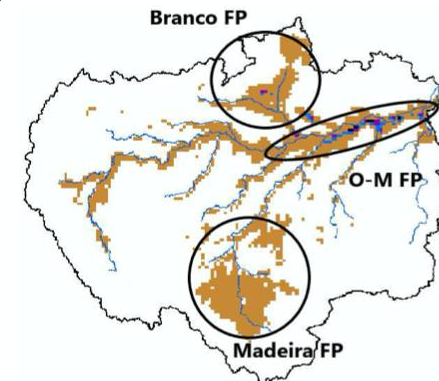


Congo River Basin hydrology
(Favras et al. WRR in review)

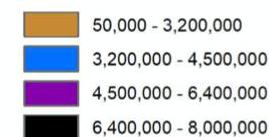
Droughts



(Lopez et al. 2020)



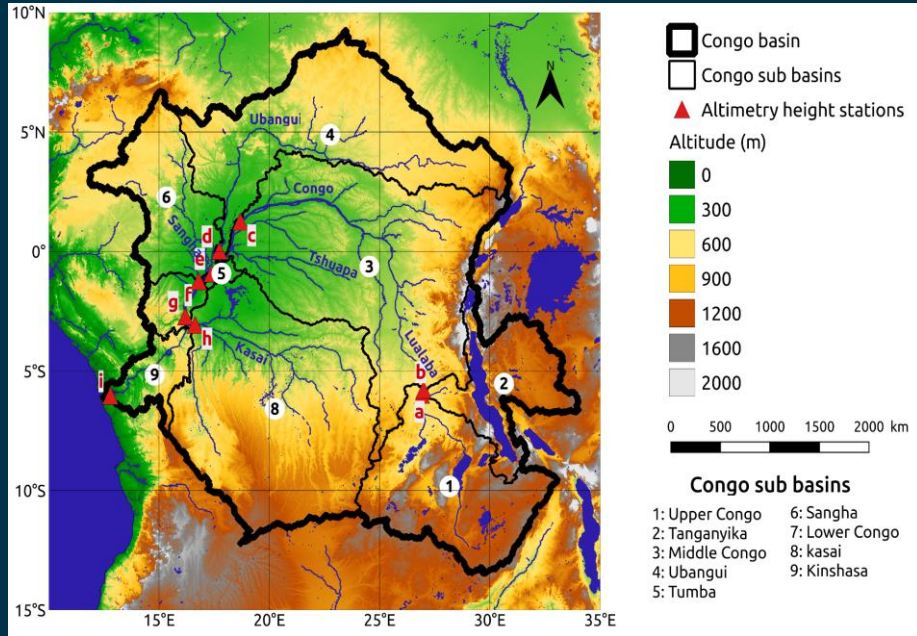
Denitrification (mol of NO₃-)



Denitrification fluxes over
Amazon
(Guilhem et al., BG 2020)

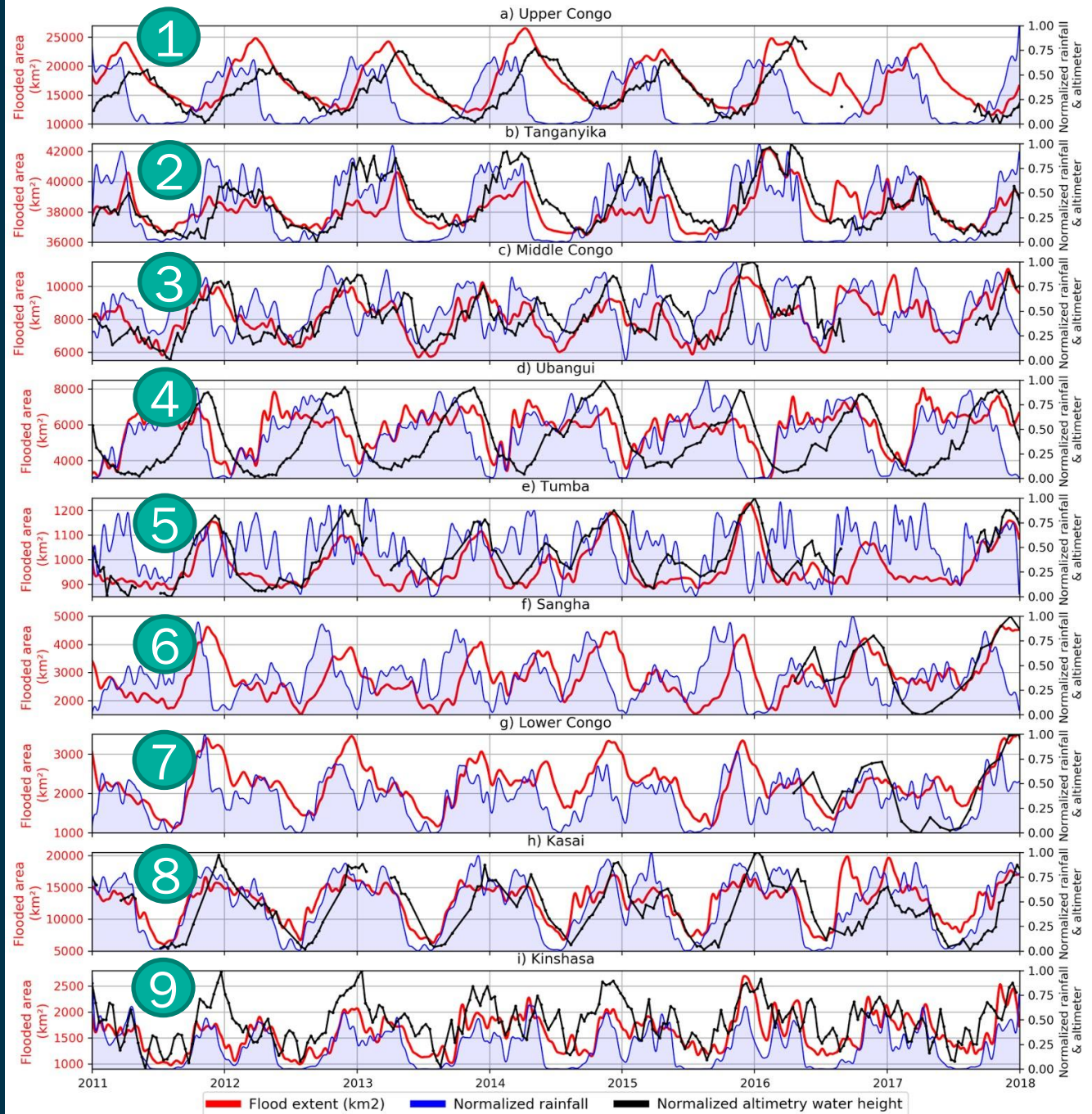
Check www.catds.fr for the dataset release

Congo River Bassin floods



SMOS G-SWAF flooded area

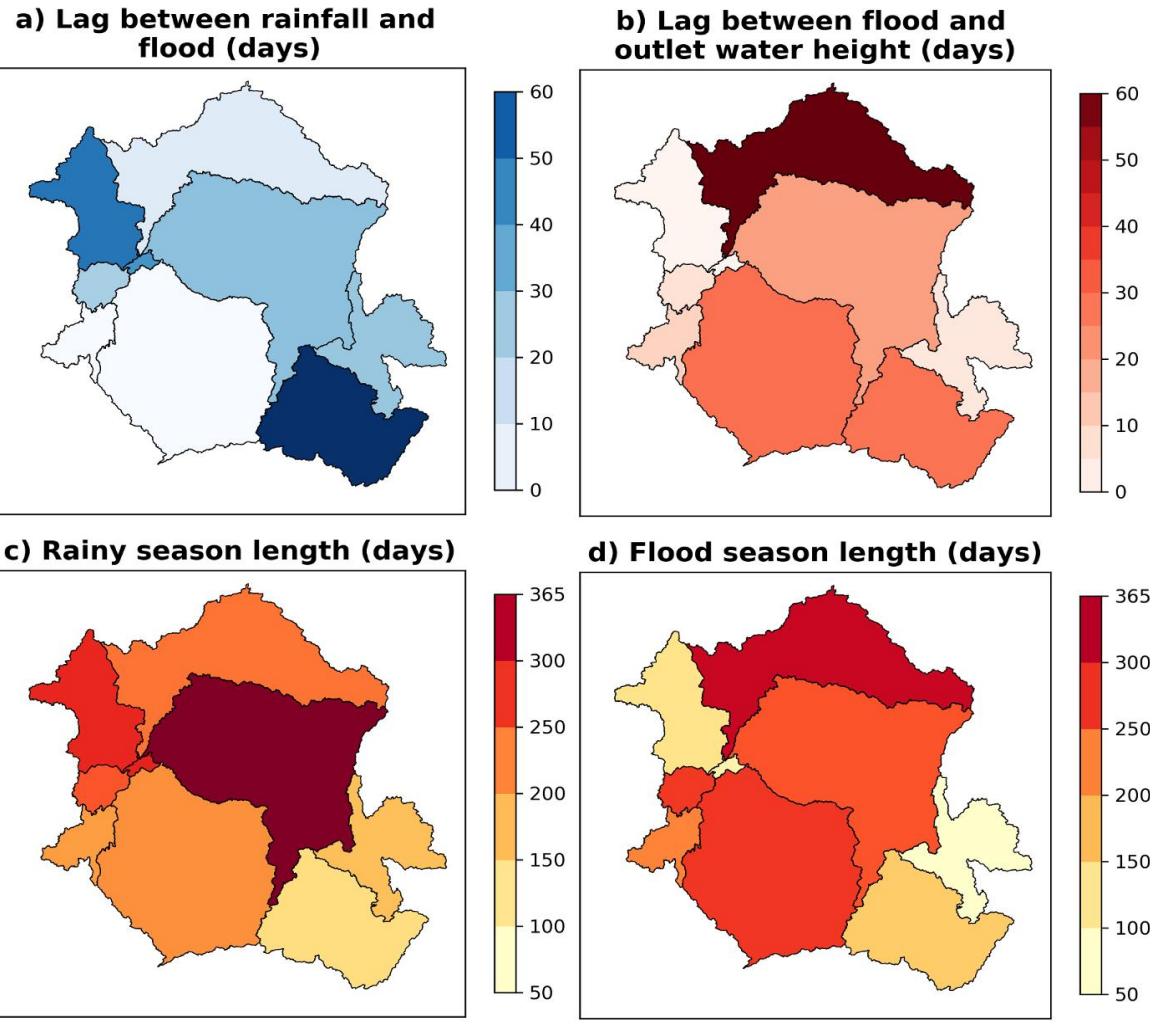
Sub basin	Rainfall and flood extent		Flood extent and sub-basin outlet water height		Proportion of flooded area for 2011-2017	
	Time lag (days)	Lagged correlation	Time lag (days)	Lagged correlation	Min (%)	Max (%)
Upper Congo	67	0.89	28	0.90	2.55	5.86
Tanganyika	26	0.70	5	0.68	13.69	15.81
Middle Congo	28	0.53	20	0.77	0.58	1.14
Ubangui	8	0.73	60	0.56	0.42	1.24
Tumba	41	0.34	1	0.91	6.19	8.73
Sangha	49	0.68	1	0.80	0.53	1.64
Lower Congo	23	0.76	7	0.68	1.65	5.31
Kasai	0	0.86	29	0.76	0.68	2.22
Kinshasa	0	0.83	10	0.56	0.95	2.63



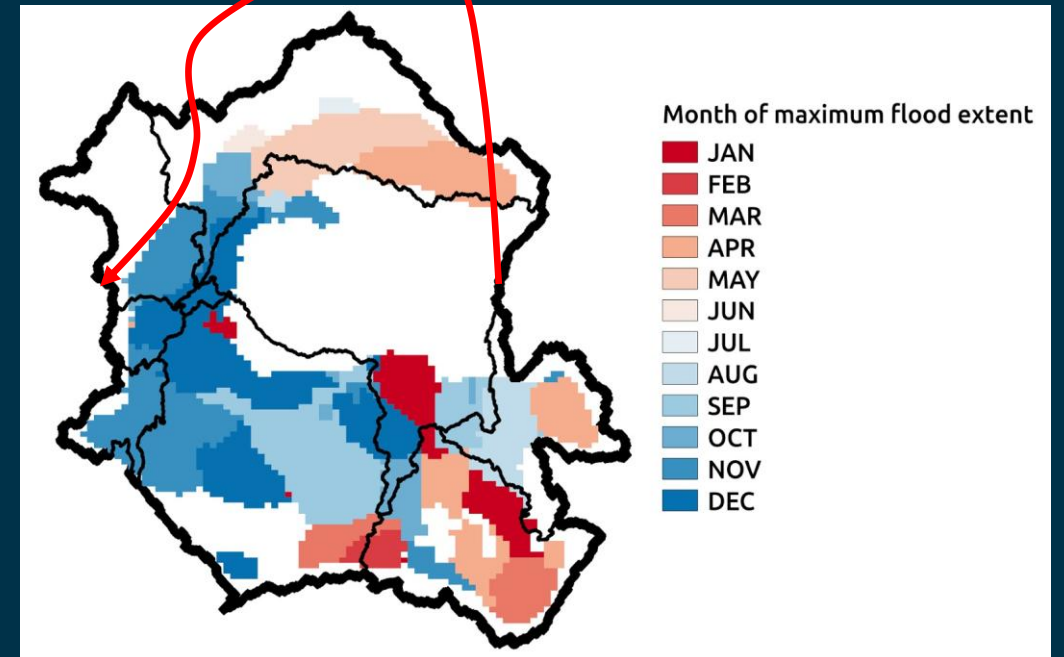
TRMM precipitation
Jason-2 Sentinel 3 Altimetry (hydroweb)

CRB - Congo River Basin floods

Hydrological indicators over the CR



Map of the month corresponding to the maximum flooded areas over the CRB after the application of a majority filter of size 9.



Denitrification rate of Amazonian wetlands

In wetlands, during inundation periods denitrification processes nitrates (NO_3^-) into atmospheric dinitrogen (N_2).

This process is not well quantified. A method utilizing SWAF is applied to derive denitrification.

$$D_{\text{NO}_3} = R_{\text{NO}_3} \cdot \text{SWAF} \cdot Q_{\text{wa}}, \quad (2)$$

where D_{NO_3} is the net denitrification in moles per month, R_{NO_3} is the denitrification rate in moles per month per litre, SWAF is the fraction of land covered with open waters and Q_{wa} is the water storage capacity for each type of soil (L) retrieved from the FAO soil database.

$$R_{\text{NO}_3} = -0.8 \cdot \alpha \cdot \left(\rho \cdot \frac{1 - \phi}{\phi} \cdot k_{\text{POC}} \cdot [\text{POC}] \cdot \frac{10^6}{M_C} + k_{\text{DOC}} \cdot [\text{DOC}] \right) \cdot \frac{[\text{NO}_3^-]}{[k_{\text{NO}_3} + \text{NO}_3^-]}, \quad (1)$$

where R_{NO_3} is the denitrification rate ($\mu\text{mol L}^{-1} \text{d}^{-1}$), $0.8 \cdot \alpha$ represents the stoichiometric proportion of NO_3^- consumed in denitrification compared to the organic matter used with $\alpha = 5$ as mentioned in Peyrard et al. (2010), ρ is the dry sediment density (kg dm^{-3}), ϕ is the sediment porosity, k_{POC} is the mineralization rate constant of POC (d^{-1}), POC refers to the POC in the soil and the aquifer sediment (%), M_C is the carbon molar mass (g mol^{-1}), DOC refers to the DOC in the aquifer water ($\mu\text{mol L}^{-1}$), k_{DOC} is the mineralization rate constant of DOC (d^{-1}), k_{NO_3} is the half-saturation constant for NO_3^- limitation ($\mu\text{mol L}^{-1}$), and NO_3^- is the nitrate concentration in the aquifer ($\mu\text{mol L}^{-1}$).

(Guilhen et al., Biogeosciences, 2020)

First estimates of Denitrification over Wetlands from satellite observation

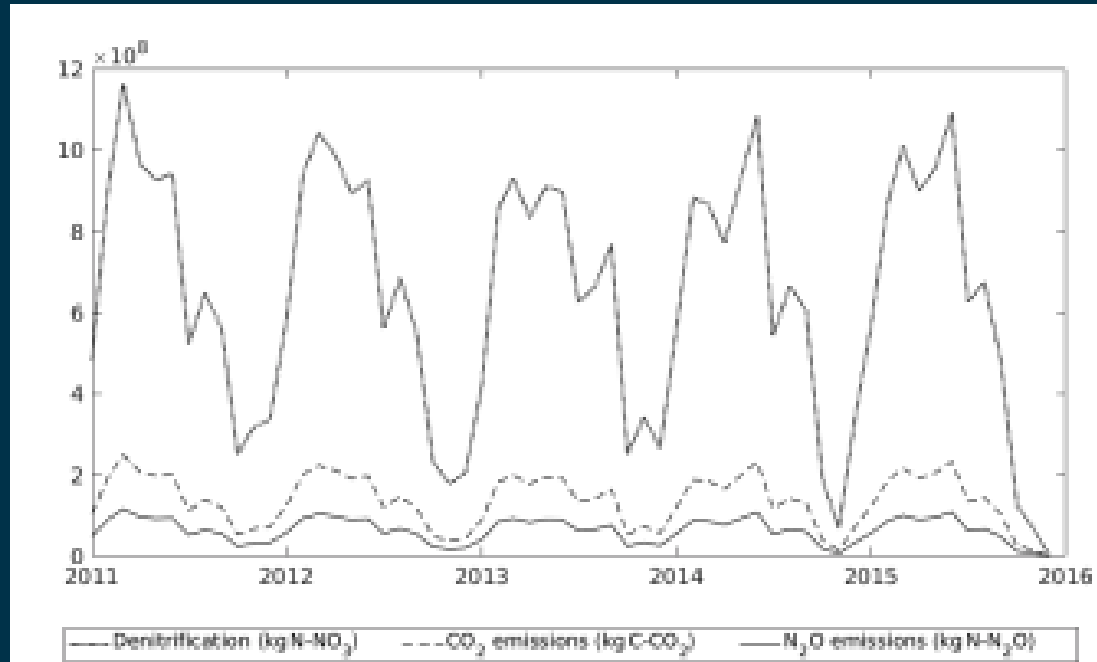


Figure 5. Monthly denitrification (kgN-NO₃) and CO₂ (kgC-CO₂) and N₂O (kgN-N₂O) emissions over the entire Amazon watershed for the period 2011–2015.

(Guilhen et al., Biogeosciences, 2020)

Towards global estimates (Martinez-Espinoza et al., Sci. Tot., 2020)

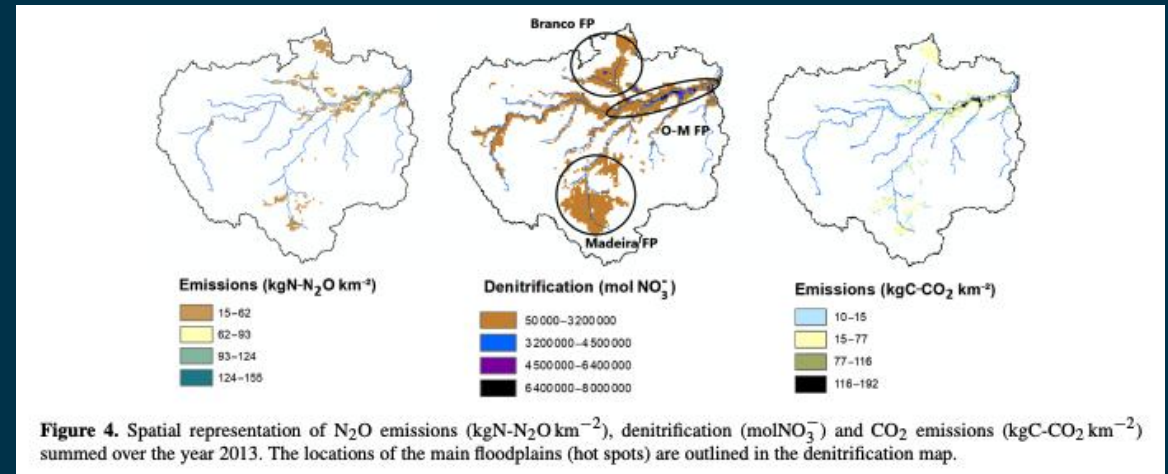


Figure 4. Spatial representation of N₂O emissions (kgN-N₂O km⁻²), denitrification (molNO₃⁻) and CO₂ emissions (kgC-CO₂ km⁻²) summed over the year 2013. The locations of the main floodplains (hot spots) are outlined in the denitrification map.

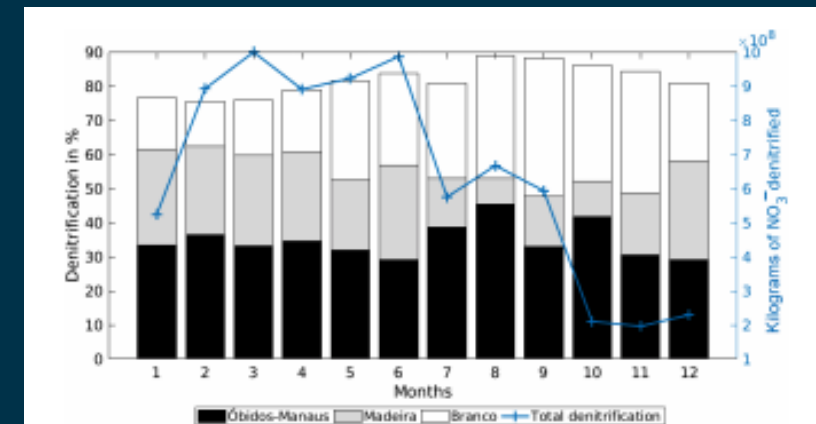
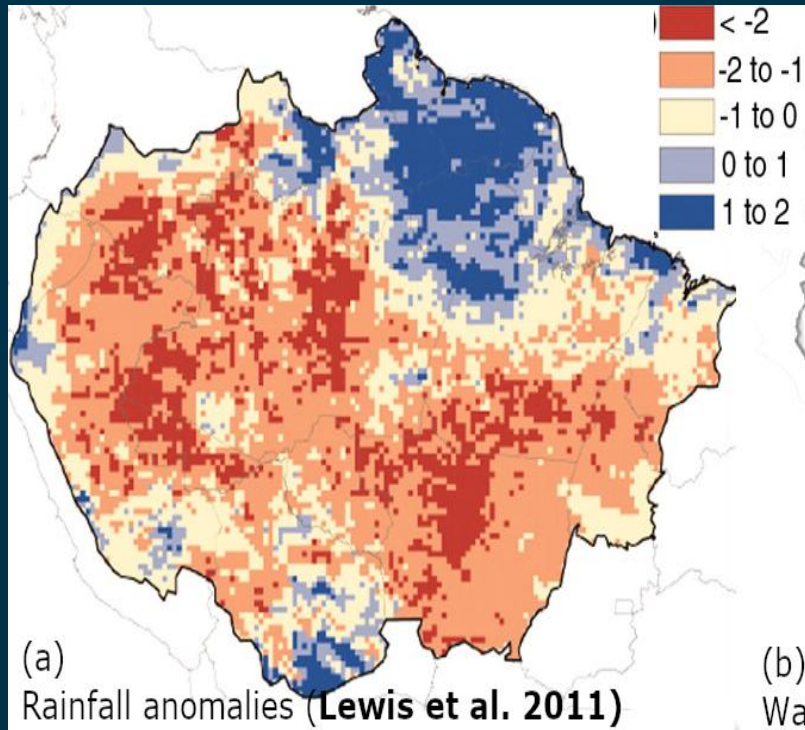


Figure 7. Average monthly contribution of each floodplain – the O-M FP (black), the Madeira FP (grey) and Branco FP (white) – to the Amazon total denitrification. The residual contribution to make up 100 % is associated with the other wetlands in the basin. The blue line represents the average monthly denitrification for the period of the study, and it shows the main trend observed over the Amazonian watershed.

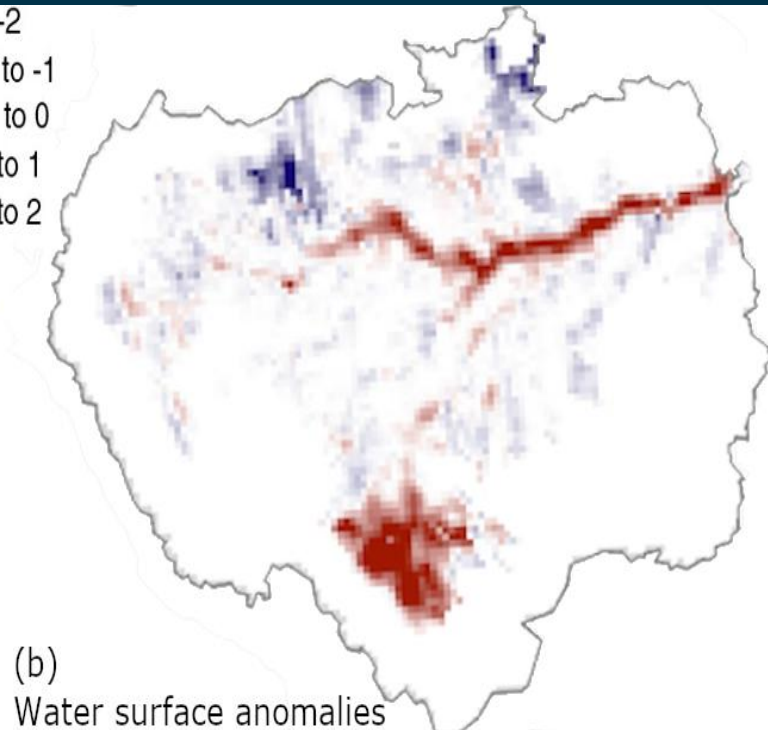
Hydrological Drought in 2010

Rainfall Anomalies



Anomaly of water fraction

Jul. – Sept. 2010



Drought depicted for the South amazon but also for the innundation plains, which can not be detected using the Clim. Water Index which is based on optical data.



Reuters ©

anomaly of SMOS water fraction



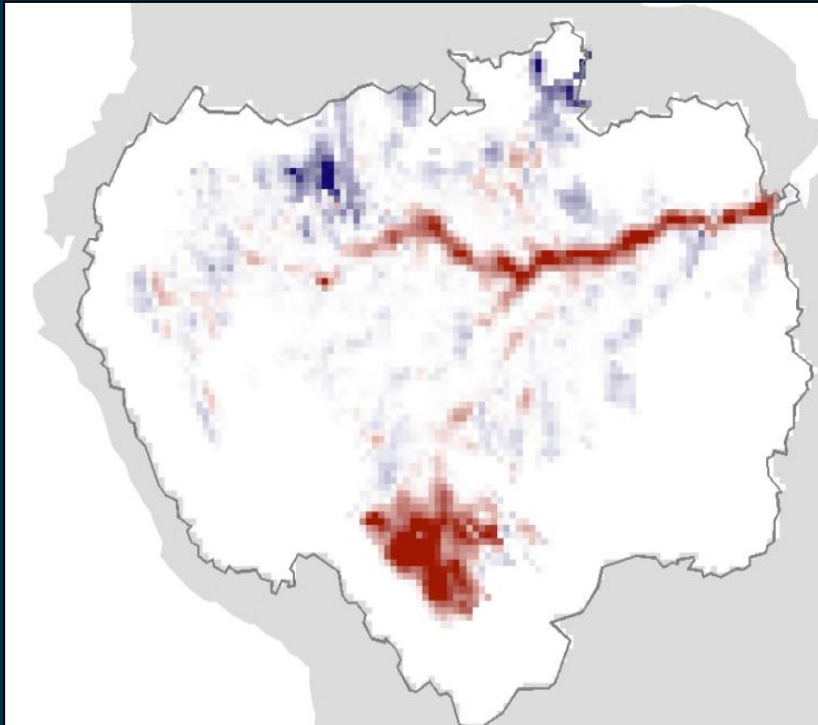
abnormally dry

abnormally wet

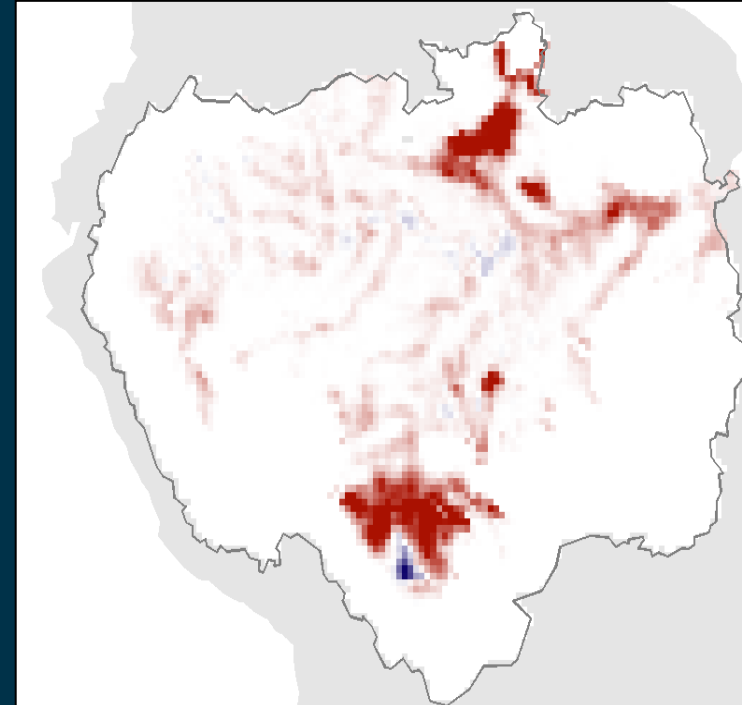
(Parrens et al., *Water*, 2017)
(Lopez et al., *Geo. Surveys*, 2020)

Hydrological Droughts in 2015

Anomaly of water fraction
Jul. – Sept. 2010



Anomaly of water fraction
Oct. – Dec. 2015



anomaly of SMOS water fraction

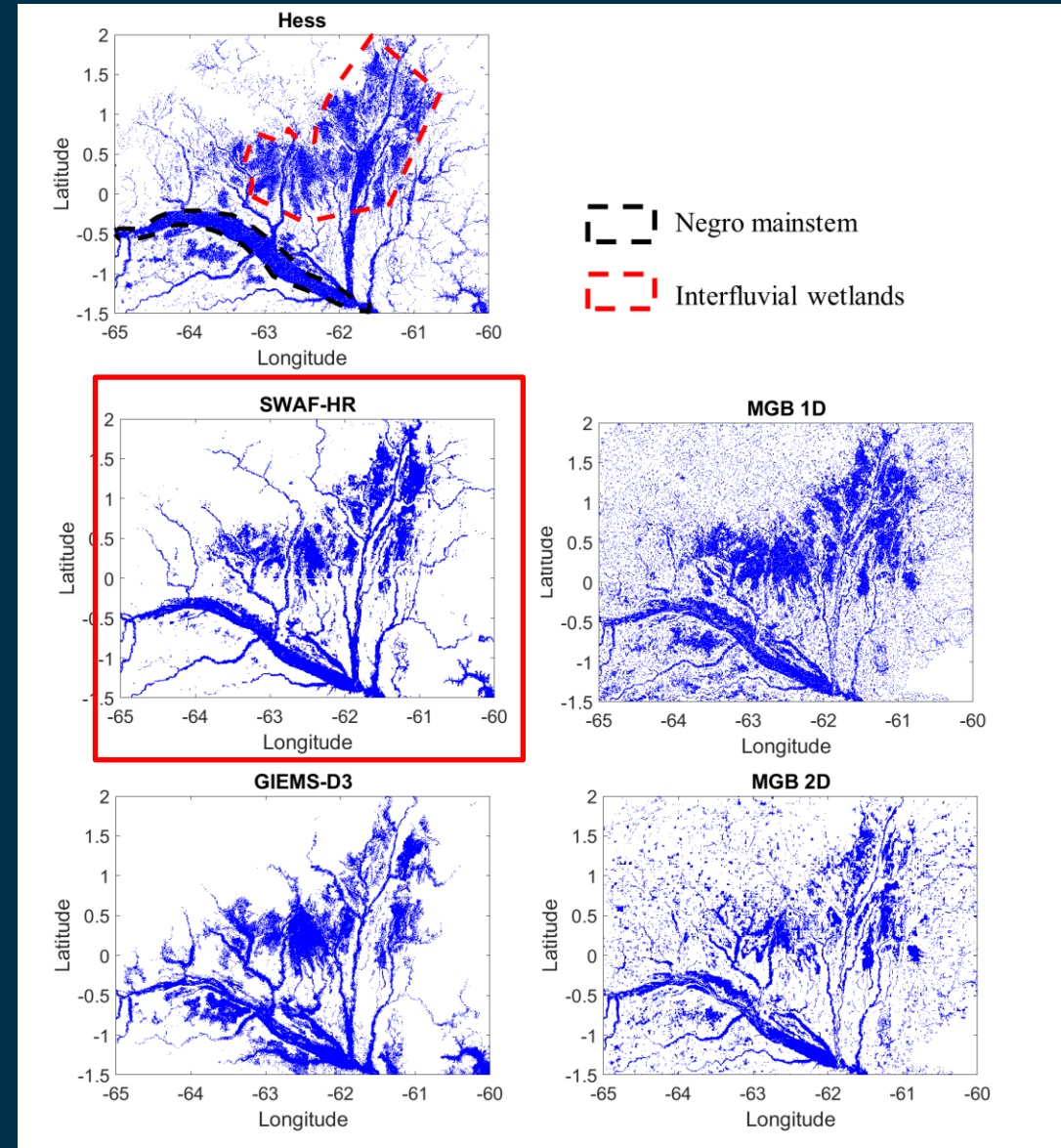


1D vs 2D hydrodynamic modeling

Performance metrics between simulated and observed flood extent time series (RMSE and r) and between 1D and 2D estimates (RMSD and r).

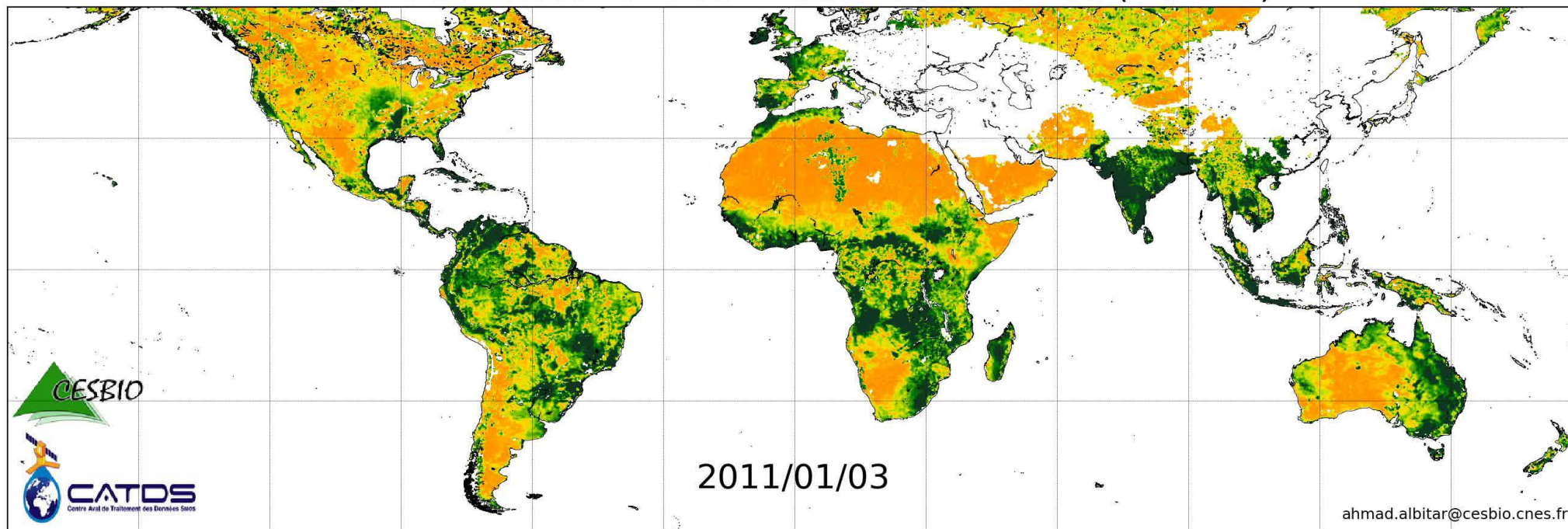
	Interfluvial wetlands				
	1D x GIEMS	2D x GIEMS	1D x SWAF	2D x SWAF	1D x 2D
RMSE or RMSD (%)	59%	46%	24%	31%	27%
r	0.58	0.65	0.82	0.87	0.89
Negro Mainstem					
RMSE or RMSD (%)	27%	17%	14%	21%	25%
r	0.59	0.74	0.79	0.75	0.75

(Fleischmann et al. WRR, 2020)



Thank you !

CATDS L4 - Root Zone Soil Moisture from SMOS (m³.m⁻³)



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 CNES TOSCA SWOT SOLE, CNES TOSCA SMOS, CNES SWOT_AVAL,
 CNES Post-doctorial program, CNES/Ifremer CATDS

Application of SWAF: Impact of extreme events on Amazonian water bodies

