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→ 7th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

4–9 September 2017 | Szent István University | Gödöllő, Hungary

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OBSERVING THE HYDROLOGICAL CYCLE OVER LAND USING SMOS

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A simple water budget

Soil moisture

Surface water

Ground water

$$\frac{dS_{SM}}{dt} + \frac{dS_{SW}}{dt} + \frac{dS_{GW}}{dt} = P - E - Q$$

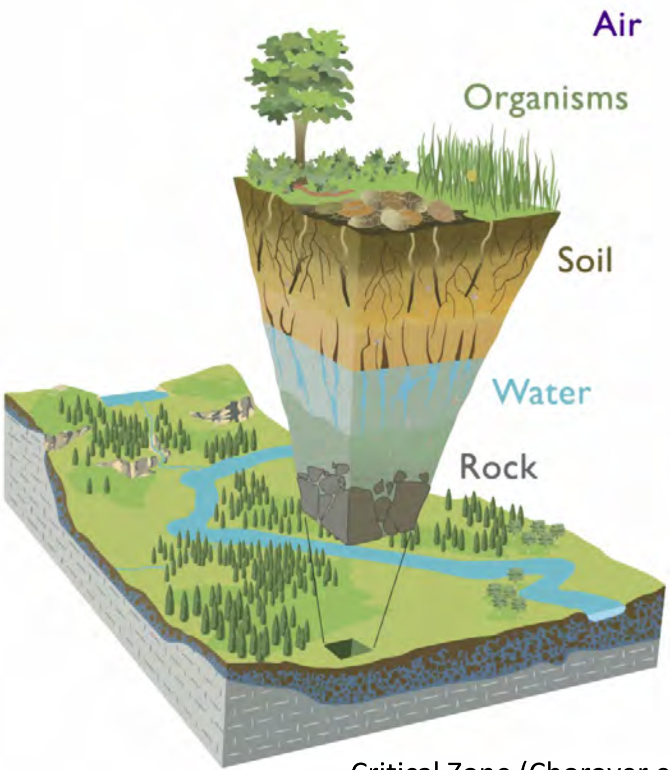
Precipitation

Evapo-transpiration

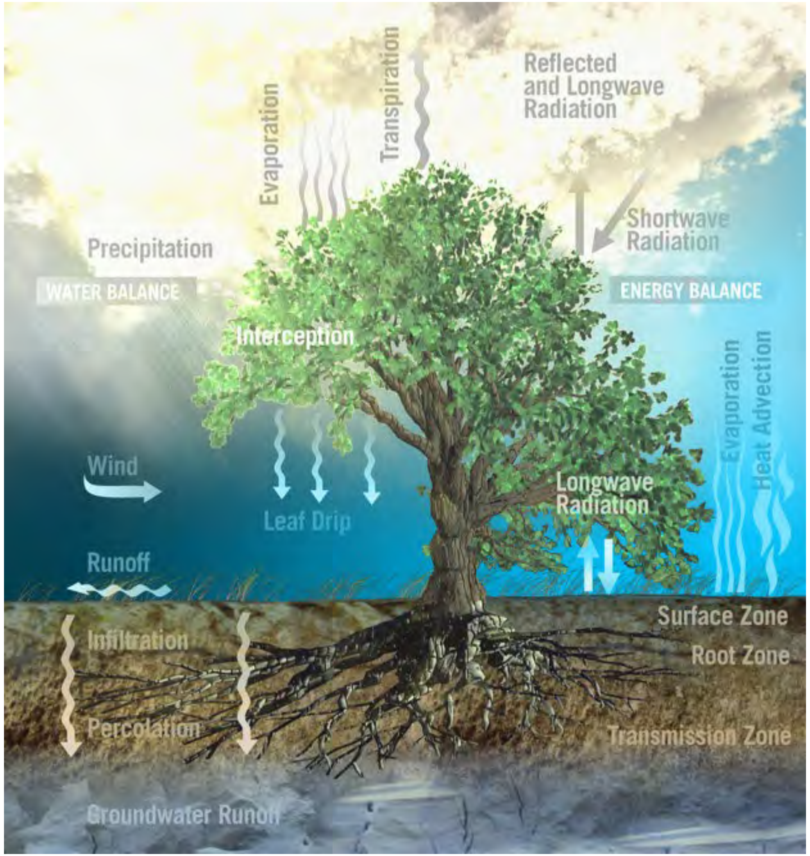
Discharge

Energy budget

The surface layer as part of the Critical zone

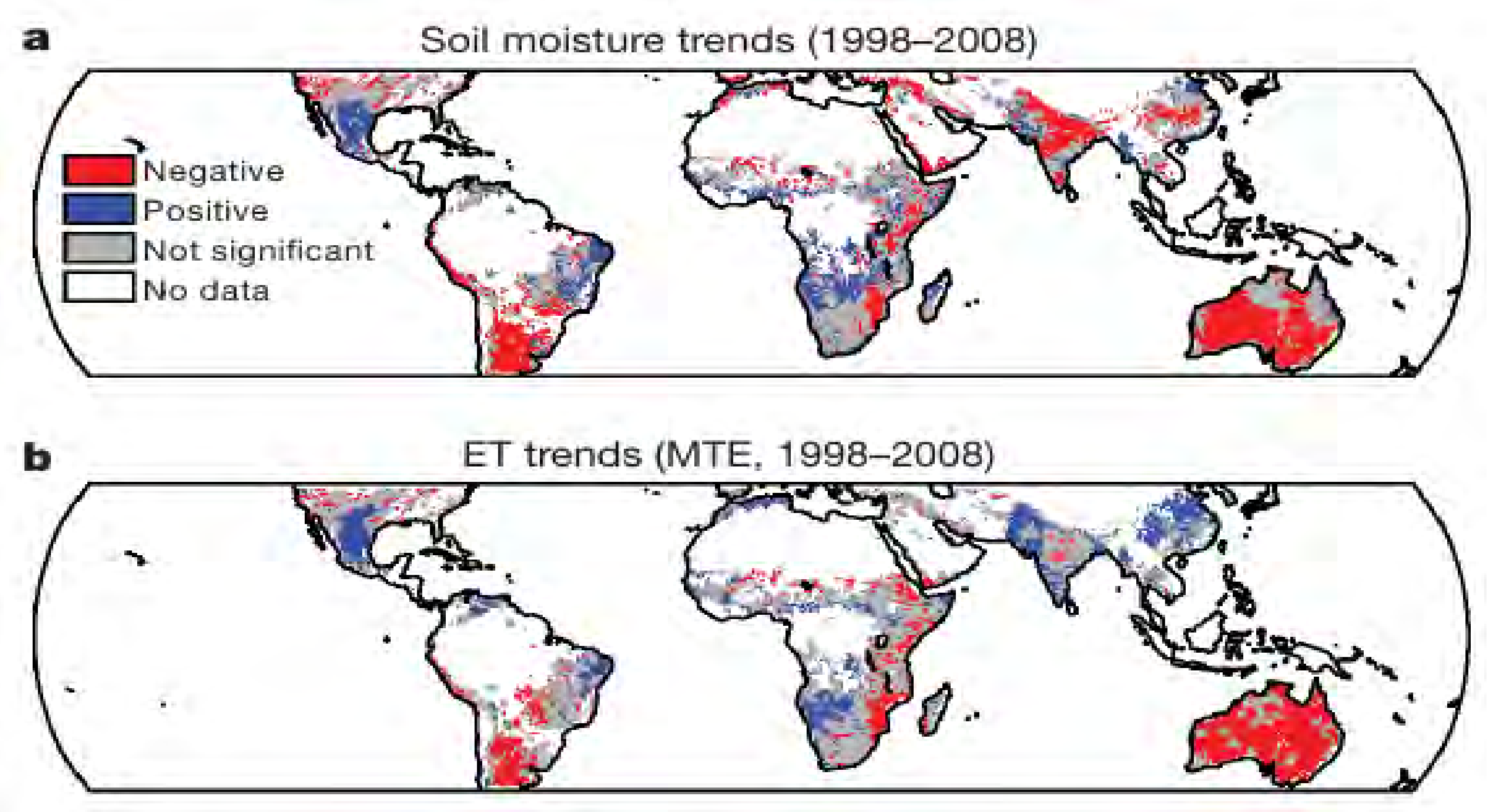


Critical Zone (Chorover et. al. 2007)



Surface Layer processes (ESA)

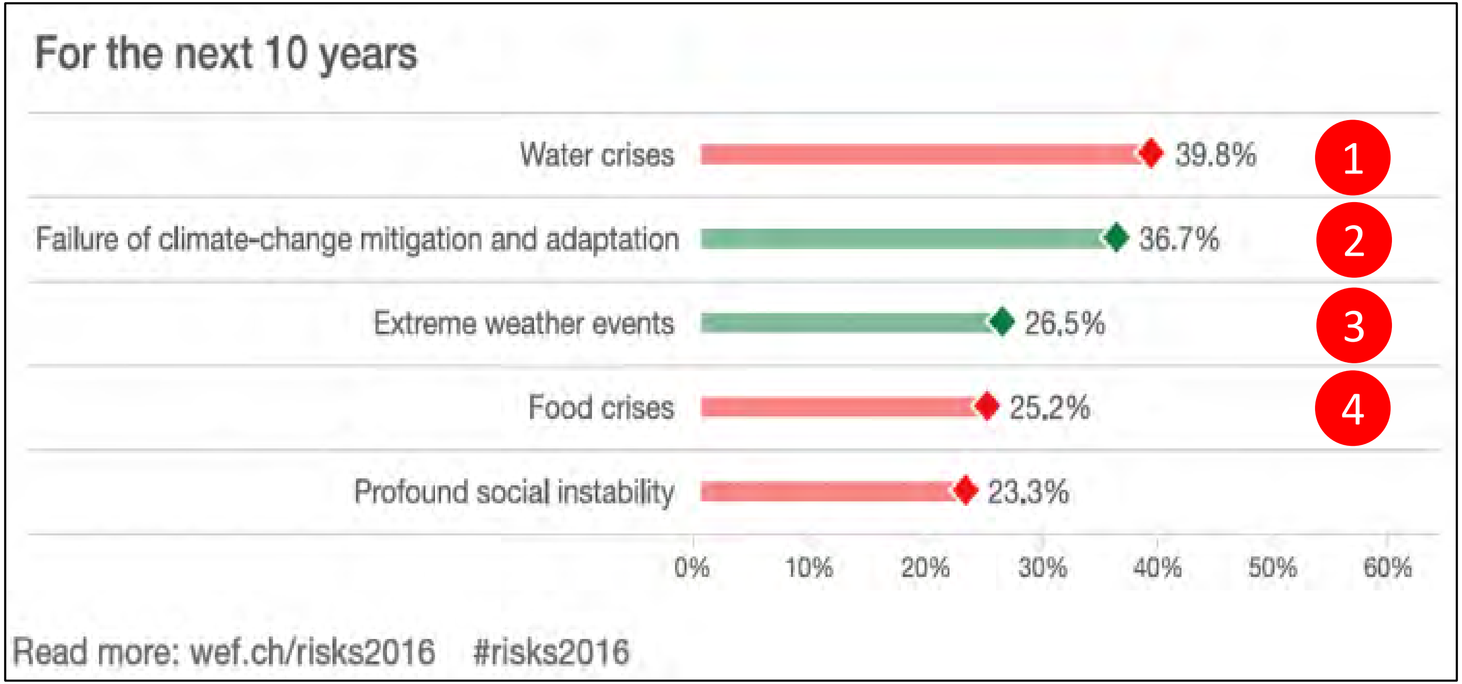
Motivation for soil moisture measurments



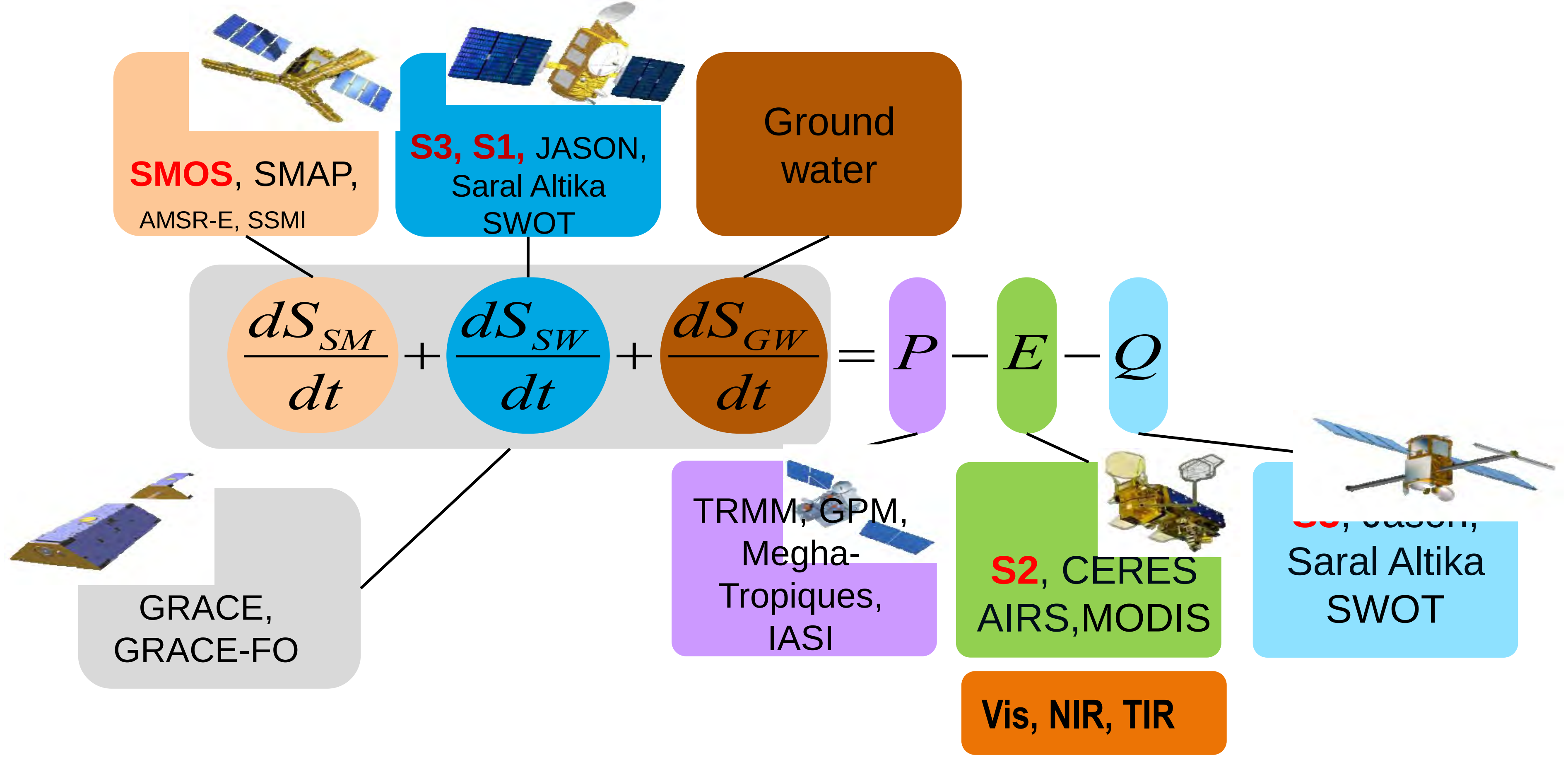
Jung et al., 2010, nature - (see also Mirales et al. 2016)

Is it a priority to observe the hydrological cycle ?

The Global Risks Perception Survey from the World Economic Forum

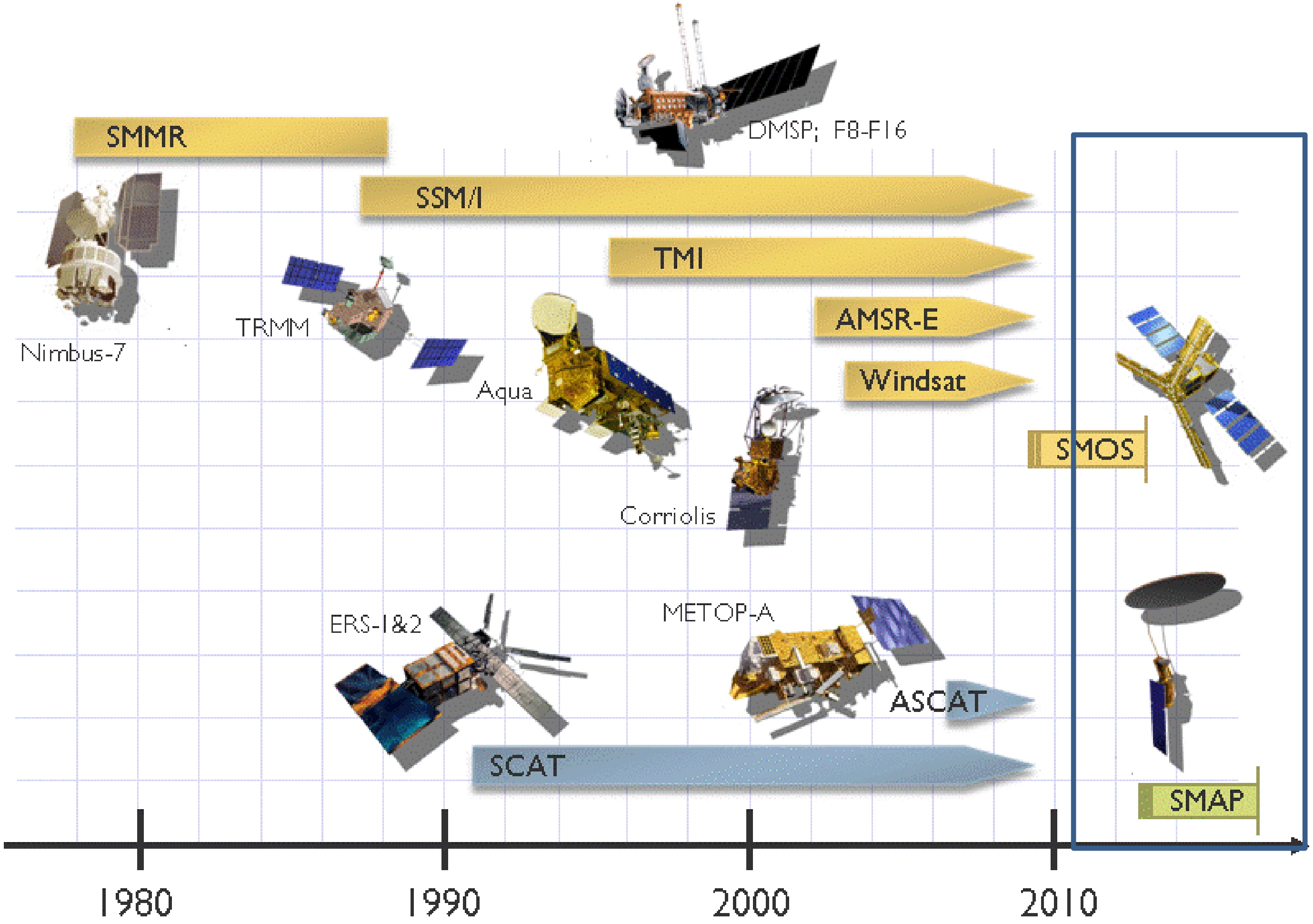


Space measurements for the water cycle



Not all components are observed at the desired resolution and accuracy

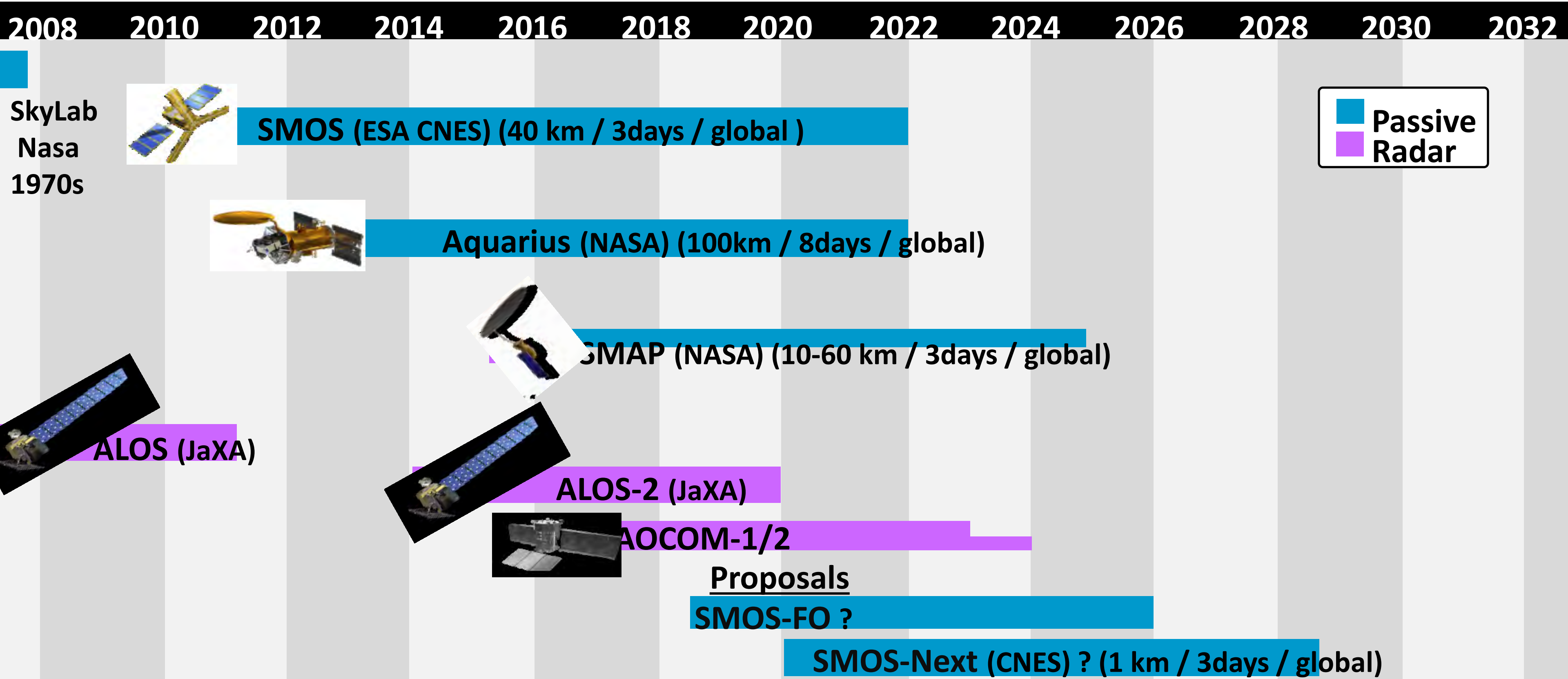
Microwave missions for global soil moisture mapping



Dedicated
SM
Missions
L-Band

Sentinel 1

L-Band missions



Soil moisture products are also available from C-Band sensors (AMRSE1/2, ASCAT, RadarSat)

Al Bitar, Cesbio

Microwave Radiometry for the hydrological Cycle

- Bascis of microwave radiometry
- Geophysical Products
- Applications

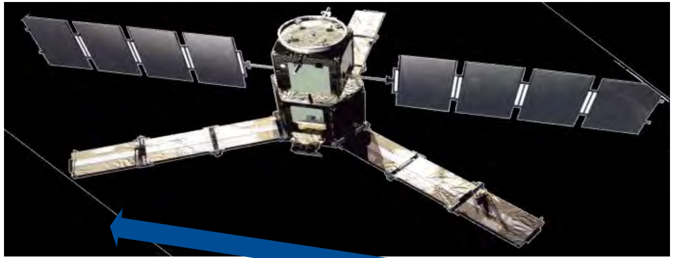
What is a Microwave RadioMeter (MRM)?

An MRM is:

- A passive remote sensing device (in contrast to an active radar).
- A highly sensitive receiver for thermal radiation.

What is measured?

- Thermal radiance (called brightness temperature) T_B^p (p = H, V)
- Thermal radiation is electromagnetic radiation generated by charged particles in matter that move due to kinetic energies associated with physical temperature T.



Airborne L-band MRM

Ground based L-band MRM

spatial scale

Signal Power

Very low power levels P are measured:

$$P = k\,T\,B \approx 1.1 \cdot 10^{-13}\ \mathrm{W}$$

Rayleigh-Jeans approximation of Planck's law
Emissivity = 1 (black-body)
$k = 1.380658 \cdot 10^{-23}\ \mathrm{JK}^{-1}$ (Bolzmann constant)
$T = 300\mathrm{K}$
$B = 27\mathrm{MHz}$ (bandwidth of protected part of L-band (1400 – 1427 MHz))

Important features:

$$P \approx 1.1 \cdot 10^{-13}\ \mathrm{W}$$

- Directed antenna with high gain.
- Low-noise, narrow-band receiver.
- Highly stable temperature control.
- Internal and external reference (calibration) noise-sources at known noise temperatures.

Brightness Temperature modeling

$$T_{B,tot}(P,\theta) = e_s T_s \gamma + (1-\omega)(1-\gamma)T_v + (1-\omega)(1-\gamma)T_v(1-e_s)\gamma + T_{B,sky}\gamma^2(1-e_s)$$

1. soil 2. vegetation 3. vegetation-soil 4. sky

e_s soil emissivity; linked to soil moisture through dielectric constant

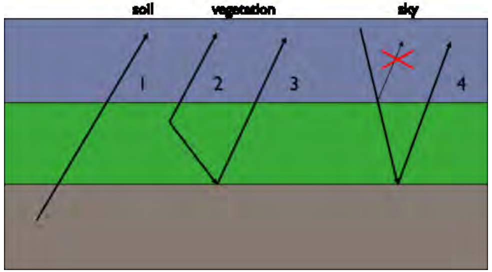
T_s physical temperature of soil

T_v physical temperature of vegetation

ω **single scattering albedo of vegetation (omega)**

γ **canopy transmissivity; vegetation optical depth τ (tau)**

T_{Bsky} sky brightness temperature



P polarisation (H or V)

θ incidence angle

Jennifer Gant SMOS Training Course 2017
for a recent review see (Wigneron et al. 2017, RSE)

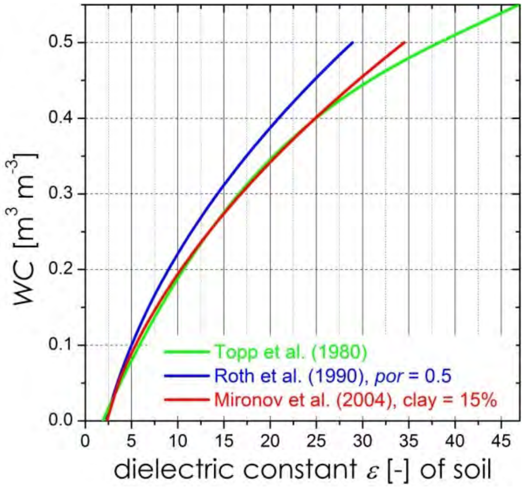
Reflectivity/ dielectric constant /Soil moisture

e(λ) = 1 - r(λ)

- ‘Fresnel equations’: Dielectric constant ($\varepsilon = \varepsilon' + i \cdot \varepsilon''$) determines smooth surface reflectivity R, depending on incidence angle θ:

$$R_{\mathrm{H}} = \left[\frac{\cos\theta - \sqrt{\left(\varepsilon - \sin^2\theta\right)}}{\cos\theta + \sqrt{\left(\varepsilon - \sin^2\theta\right)}} \right]^2$$

$$R_{\mathrm{V}} = \left[\frac{\varepsilon\cos\theta - \sqrt{\left(\varepsilon - \sin^2\theta\right)}}{\varepsilon\cos\theta + \sqrt{\left(\varepsilon - \sin^2\theta\right)}} \right]^2$$



(Jennifer Grant, Wigneron et al. RSE L-MEB)

What frequency for soil moisture ?

L-Band – 1.4 GHz

SMOS

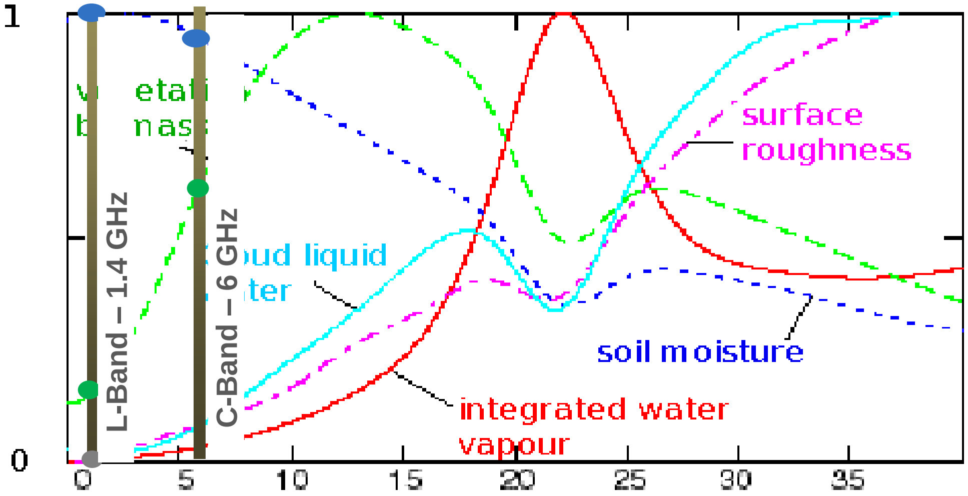
AQUARIUS

SMAP(2015)

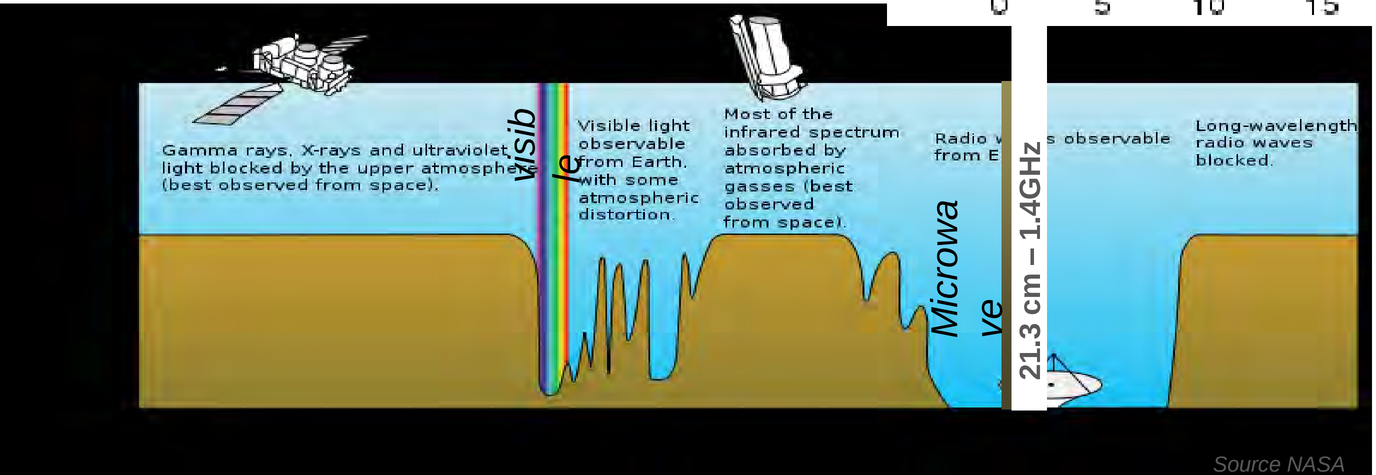
C-Band – 6 GHz

AMSR-E

ASCAT (Active)

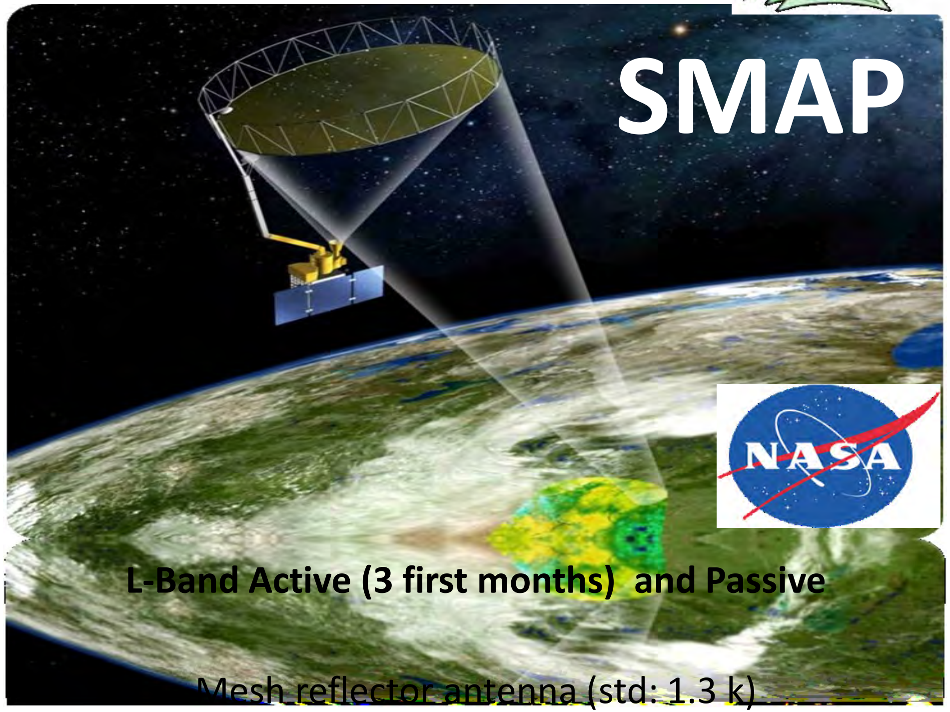


Source CESBIO



Source NASA

Same frequency but different technologies

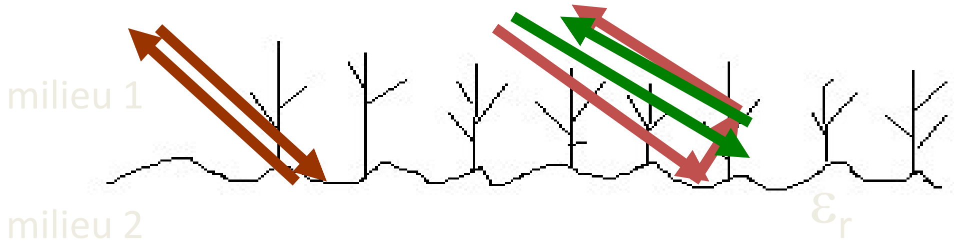


and Passive	L-Band Active (3 first months) and Passive
fer diometer (std: 2.4 k)	Mesh reflector antenna (std: 1.3 k)
Multi-angular acquisitions (0° - 60°+)	One fixed angle (40°)
3 days global coverage at 6 am and 6 pm	3 days global coverage at 6 am and 6 pm
Spatial resolution (27 -55 km)	Passive Spatial resolution (51 X 47km)
RFI mitigation at ground segment	Spectral filtering for RFI on board

An apparte on Radar backscattered signal

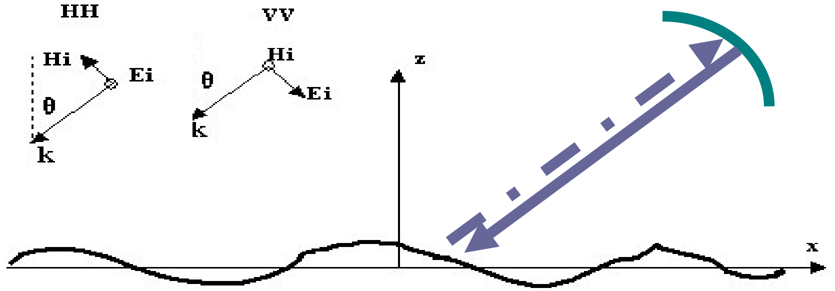
Modélisation de la rétrodiffusion d’un sol couvert:

$$\sigma^0_{total} = \sigma^0_{veg} + \gamma^2 \sigma^0_{sol} + \sigma^0_{veg-sol}$$



Modélisation de la rétrodiffusion du sol

$$\sigma^\circ_{pp} = \frac{k^2}{2}\exp[-2k_z^2 s^2]\sum_{n=1}^{\infty}\left|I^n_{pp}\right|^2 \frac{w^n(-2k_x,0)}{n!}$$



From M. Zribi 2015, CESBIO

Inversion algorithms to estimate surface soil moisture

References	Frequency & pol	Parameters retieval	Ancillary data	Surface type	Algorithm base
Dubois et al, 95, Oh et al., 92, Zribi et al., 03, Zribi et al., 08, Baghdadi et al., 11, 2012, Balenzo et al., 09	L, C band/ HH, VV, HV	Mv, R/ Mv/ R	-	Bare soil/ sparse veg	Regression
Wagner et al, 99, Wagner et al., 08, Kim&VanZyl, 09, Van Doninck et al., 12, Zribi et al., 14, Kumar et al., 15, Gorrab et al., 15	C band/ HH, VV	Mv	-/Optical data	Bare soil/ veg surfaces	Change detection
Paloscia et al., 08, Baghdadi et al., 10, El-Hajj et al. 15	C band/ HH, VV, HV	Mv/ Mv, VWC	-/Optical data	Bare soil/ veg surfaces	ANN
Kim et al., 12, Kim et al., 14	L band/ HH, VV	Mv, R/ Mv, R, VWC	-	Bare soil/ sparse veg	Numerical scattering model
Shi et al., 97, Joseph et al., 08, Pierdicca et al., 2010,	L, C band/ HH, VV, HV	Mv/ Mv, R	-	Bare soils	IEM

From M. Zribi 2015, CESBIO

Microwave Radiometry for the hydrological Cycle

Bascis of microwave radiometry

Geophysical Products

Applications

How is data organised (case of SMOS)

L0 Correlation, Telemetry

L1c Brightness temperatures

L2 Physical variables
(soil moisture, optical thickness…)

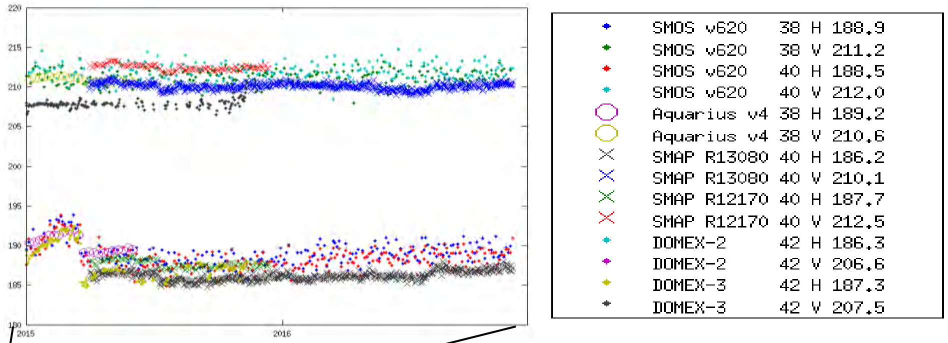
L3SM (time synthesis soil moisture)

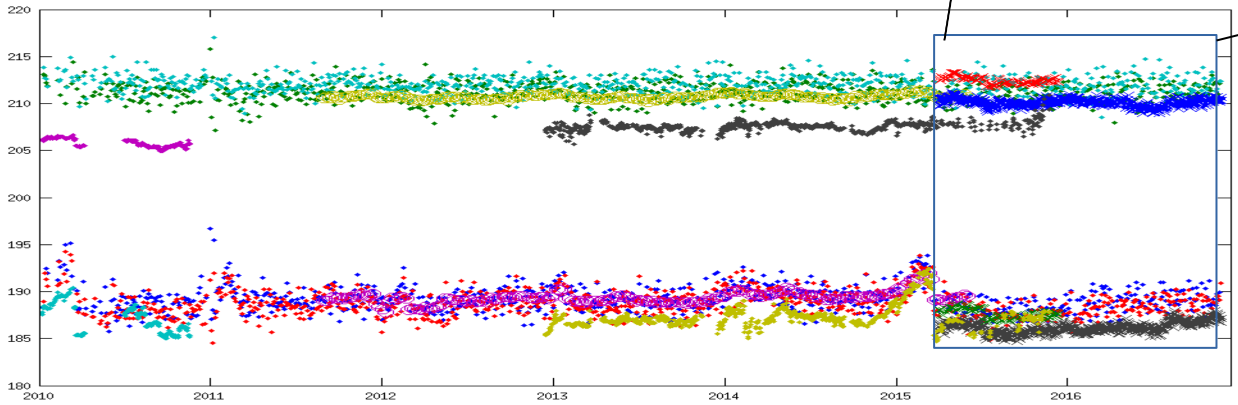
L3TB (time synthesis angle binned TB)

L4 High-end product obtained from models and other sensors

Dome Concordia Antarctica for long term monitoring

- Long term stability
- Overall good agreement
- Incidence induced bias between SMAP and Aquarius



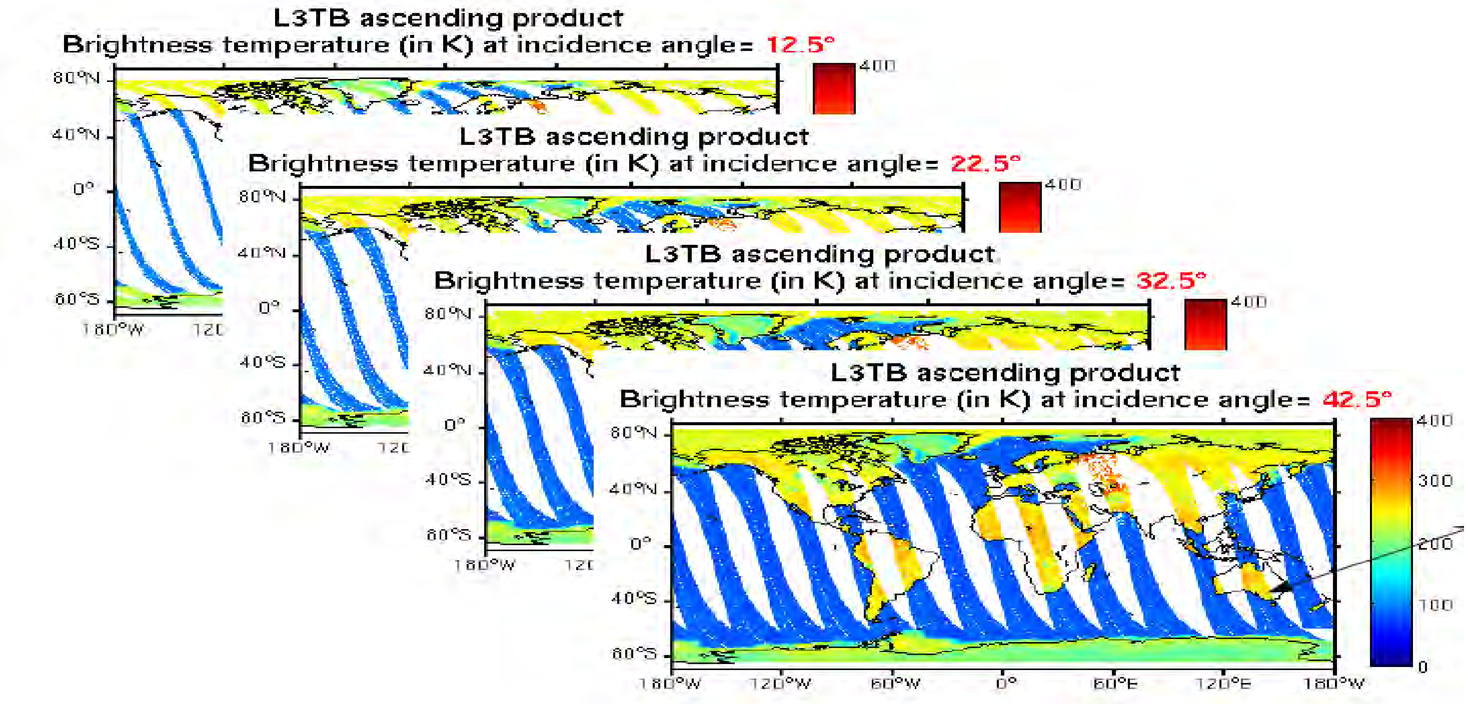


Sensor	Version	Inc	TBH	TBV	DTBH	DTBV
Aquarius	v4	28	192.90	206.19	0.59	1.16
Aquarius	v4	38	189.23	210.61	0.33	-0.62
Aquarius	v4	45	185.03	213.40	1.01	-0.98
SMAP	R12170	40	187.67	212.46	-0.88	0.41
SMAP	R13080	40	186.17	210.08	-2.38	-1.97
SMOS	v620	38	188.90	211.23		
SMOS	v620	40	188.55	212.05		
SMOS	v620	28	192.31	205.03		
SMOS	v620	45	184.02	214.38		
DOMEX-2		42	186.27	206.57	-0.015	-6.645
DOMEX-3		42	187.34	207.54	1.055	-5.675

F. Cabot (CESBIO)

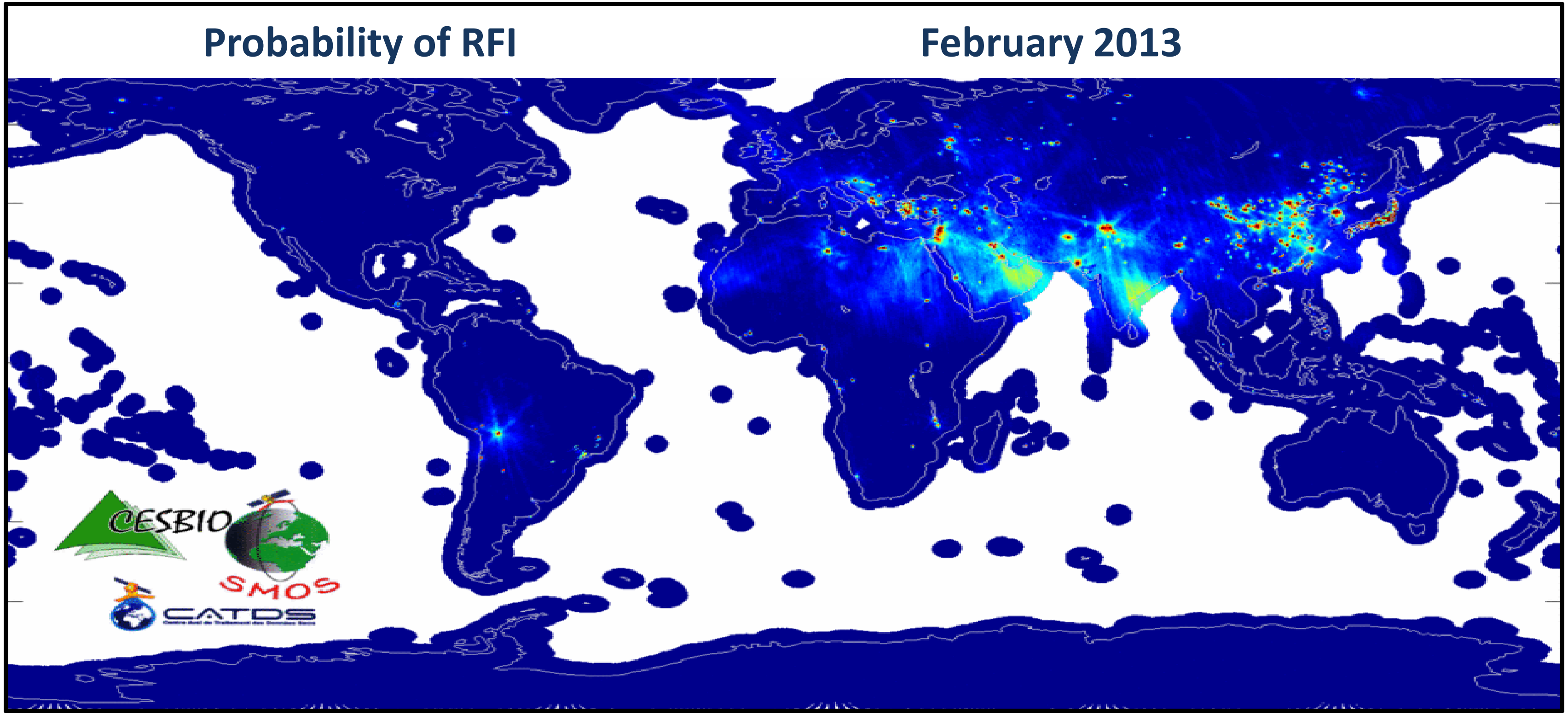
L3TB

Angle binned Brightness Temperatures **H/V/HV At Surface Level**



Al Bitar et al. 2017 ESSD

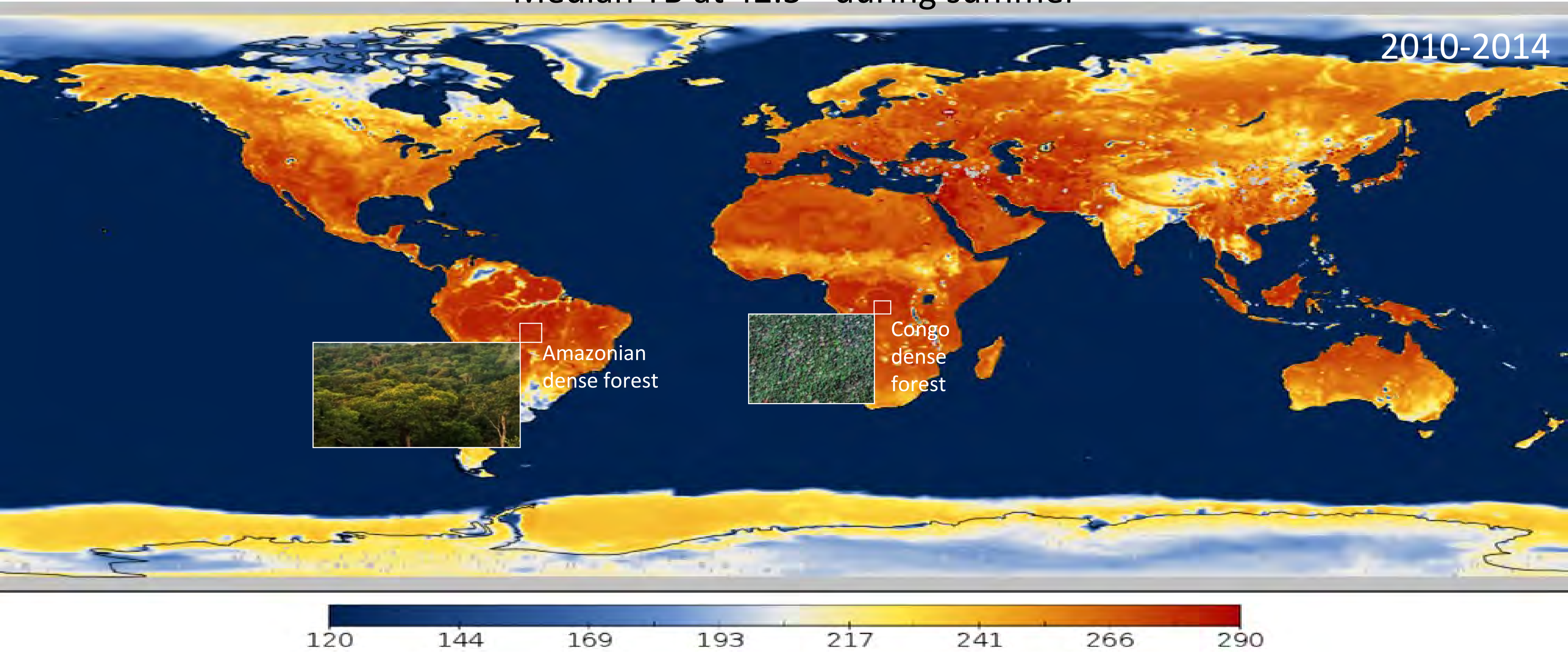
Reducing Radio Frequency Interference



Richaume et al., IGARSS, 2014
see also : Oliva R. et al. 2012 ,Anterrieu et al. , Khazaal et al. Soldo et al.

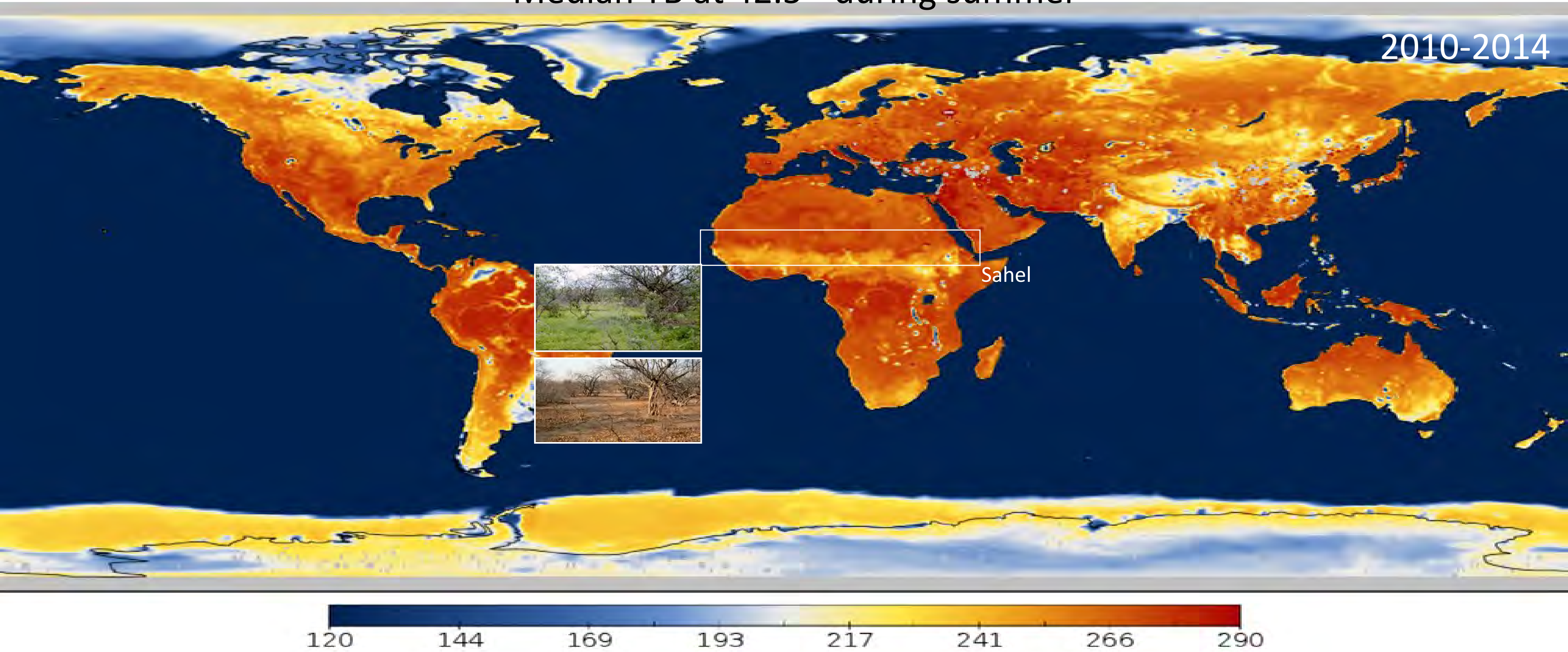
SMOS Brightness temperatures

Median TB at 42.5 ° during summer



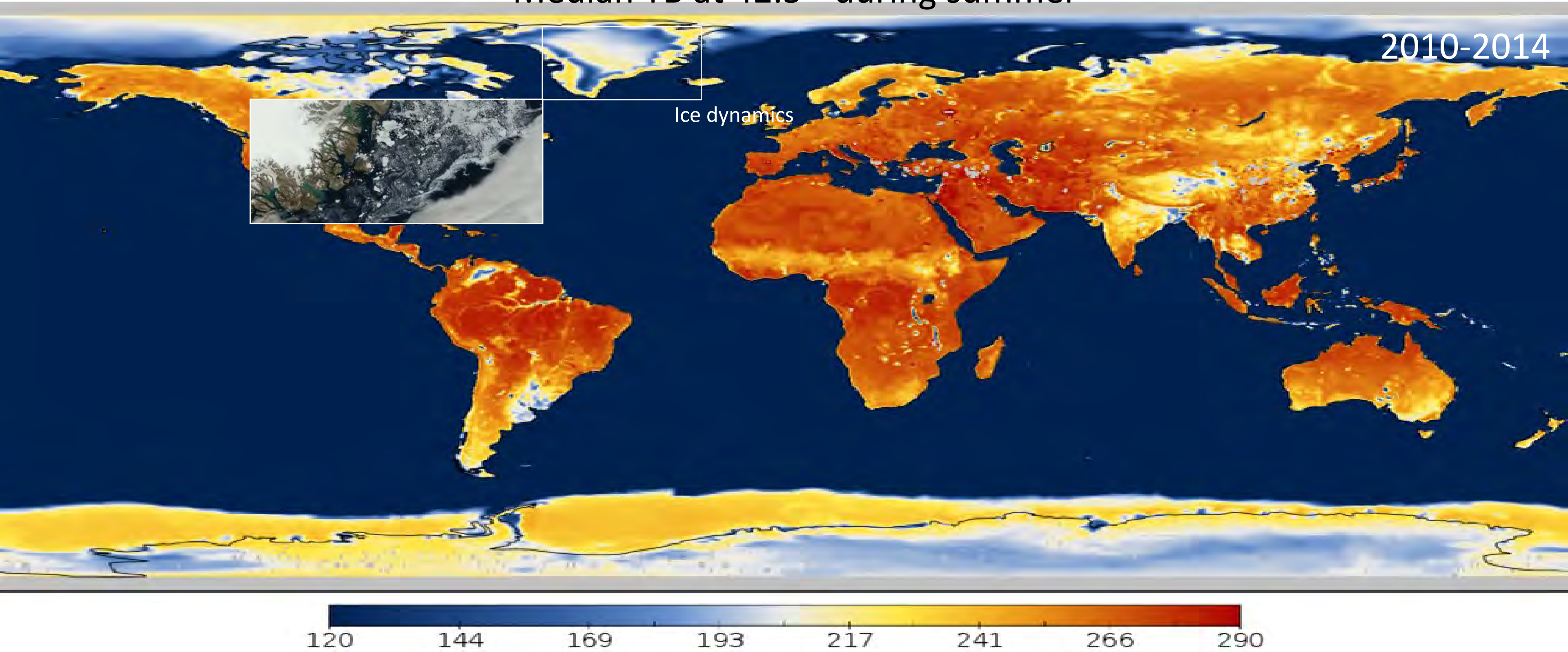
SMOS Brightness temperatures

Median TB at 42.5 ° during summer



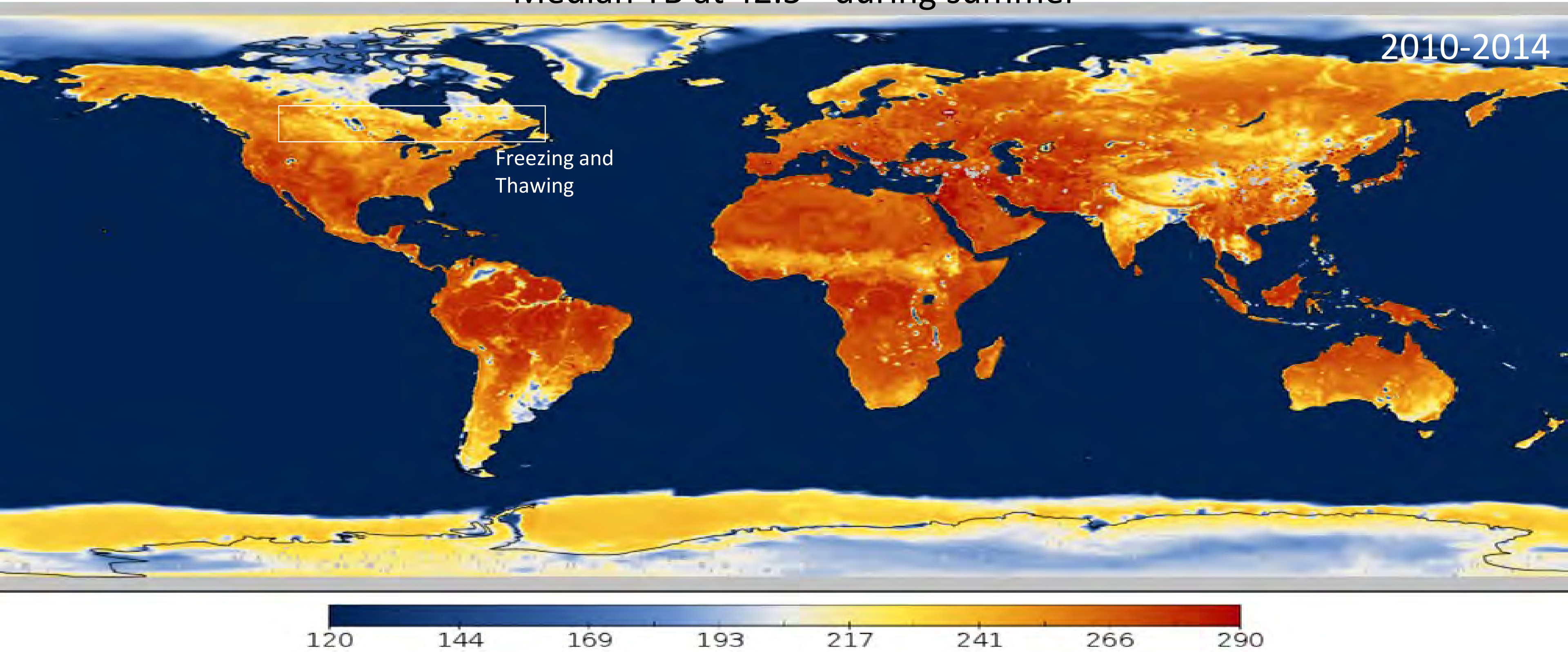
SMOS Brightness temperatures

Median TB at 42.5 ° during summer



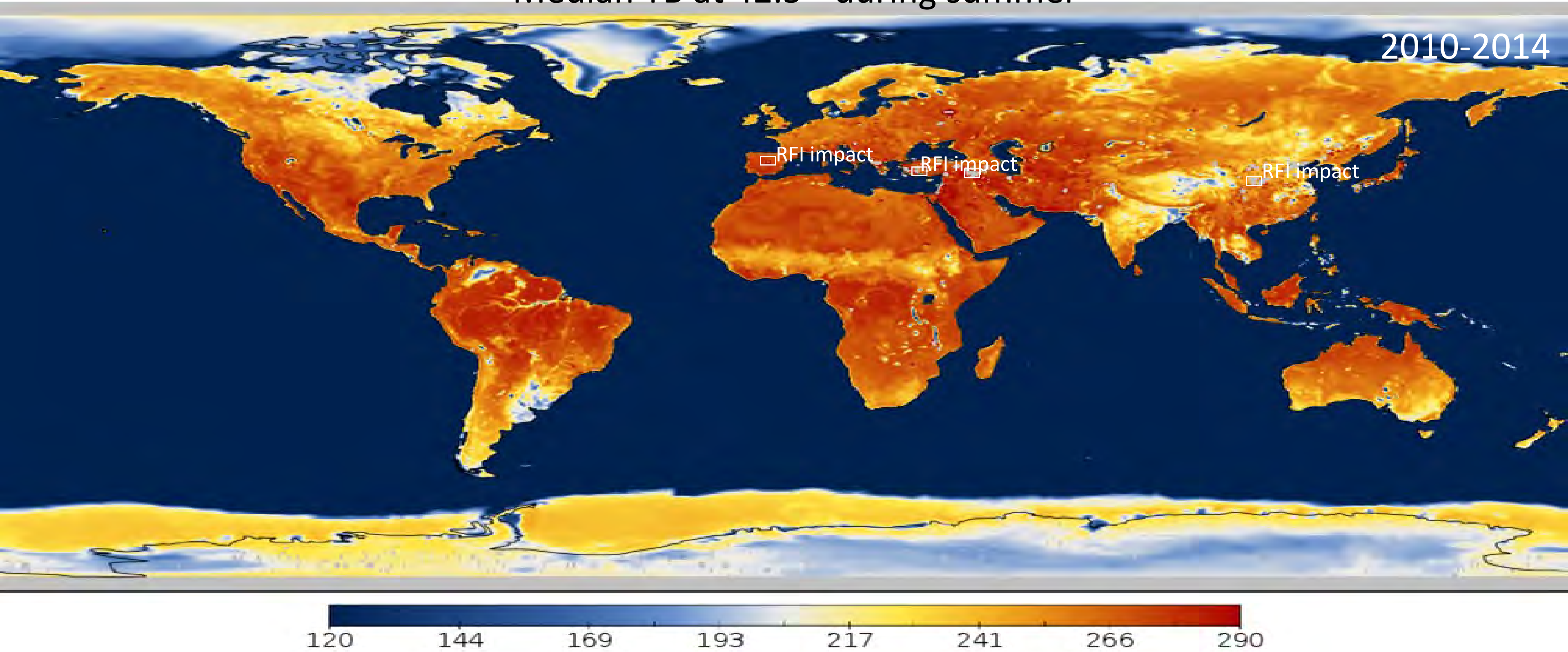
SMOS Brightness temperatures

Median TB at 42.5 ° during summer



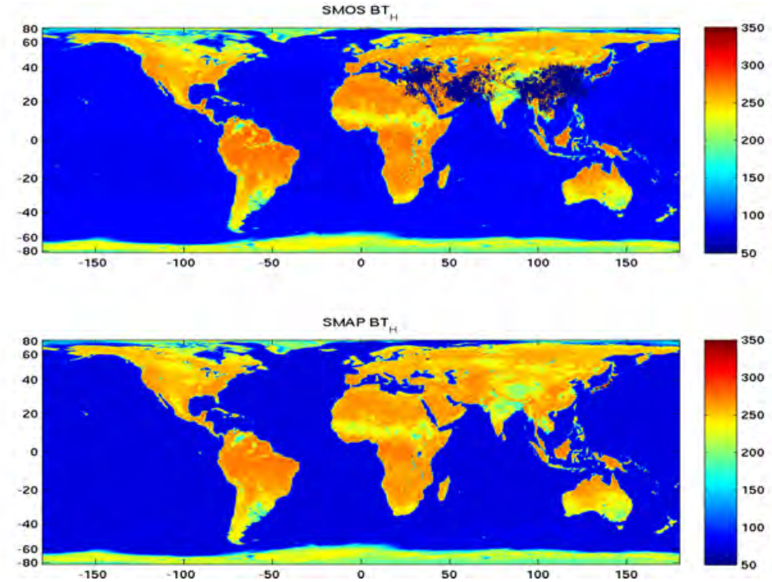
SMOS Brightness temperatures

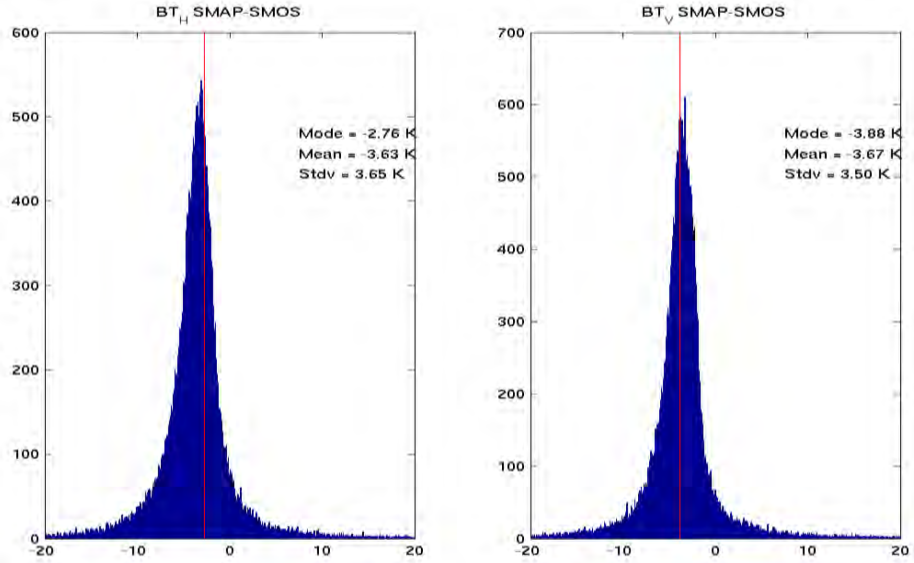
Median TB at 42.5 ° during summer



Higher level comparison

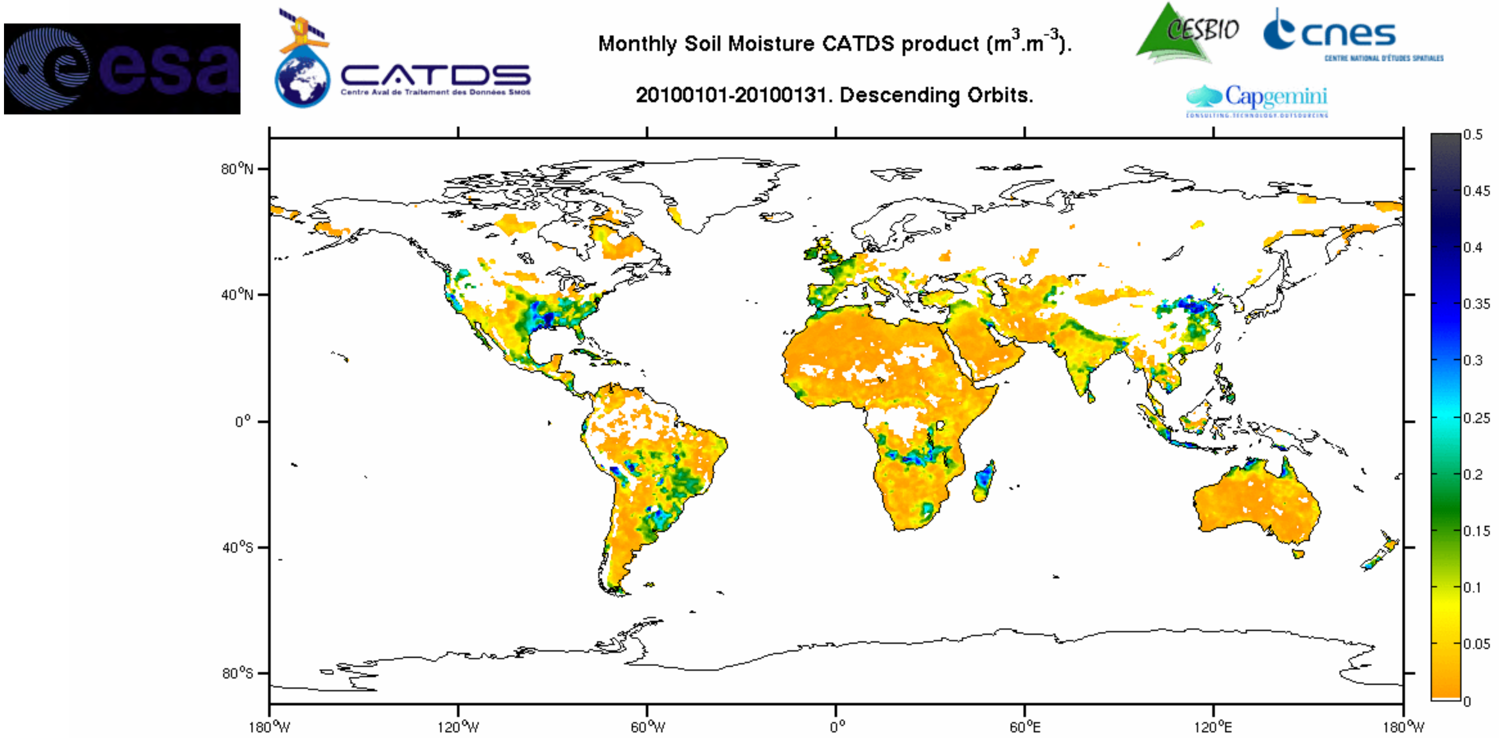
- Global maps of brightness temperatures are averaged over 3 months periods and compared
- Need for careful selection of acquisition to remove potential contamination
- Compared at top of atmosphere
- Overall consistent with previous results





(Al Bitar et al. ESSD 2017)

Soil moisture products



SMOS Soil moisture retrievals

Retrieval methodology

- Physically based retrieval (Wigneron et al. RSE, Kerr et al. 2012 IEEE TGRS, Lievens et al. 2014)
- Multi orbit retrieval (L3) (Jacquette et al., SPIE, 2010) (Al Bitar et al., IGARSS 2010)
- Single channel algorithm (Jackson et al., Maciej et al. 2014, Delannoy et al. 2012)
- Neural Network retrievals (Rodriguez et al., 2017)

Validation

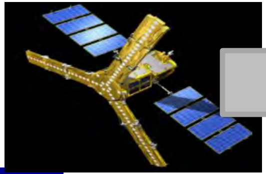
- Comparison with global data (Alyaari et al. 2014a, Alyaari et al. 2014b,…)
- …
- Validation with in-situ networks (Wigneron et al. 2012, Bircher et al. 2012, Leroux et al. 2014, Al Bitar et al. 2012, Albergel et al. 2012 …)
- Downscaling and validating (Merlin et al. 2010,2012, Piles et al.)

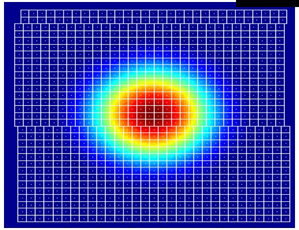
Enhancing retrievals

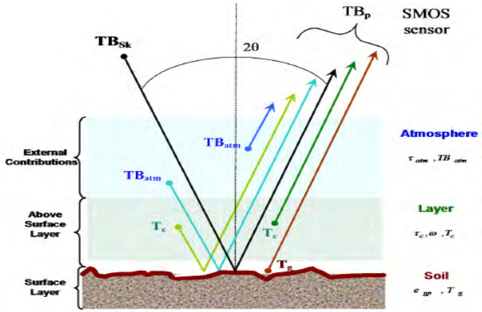
- Impact of Roughness (Mialon et al. 2012, Parrens et al. in review)
- Enhancing vegetation parametrisation (Rahmoune et al., 2014, Wigneron et al. 2012)
- Enhancing snow and ice representation (Mike Schwank, Gamma RS)
- Enhancing retrievals over organic soil (SMOS HiLat – Bircher et al.)

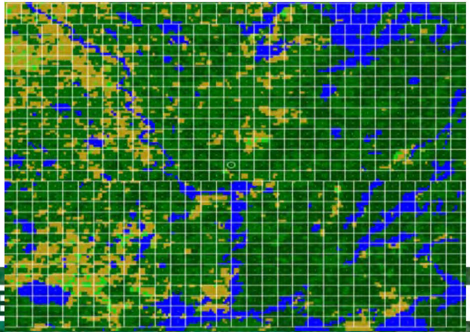
Soil moisture retrieval algorithm

L2SM retrieval algorithm
Ref: (Kerr Y. et al.,ieee-tgrs 2012) and ATBD L2









TB1

Std(TAU)

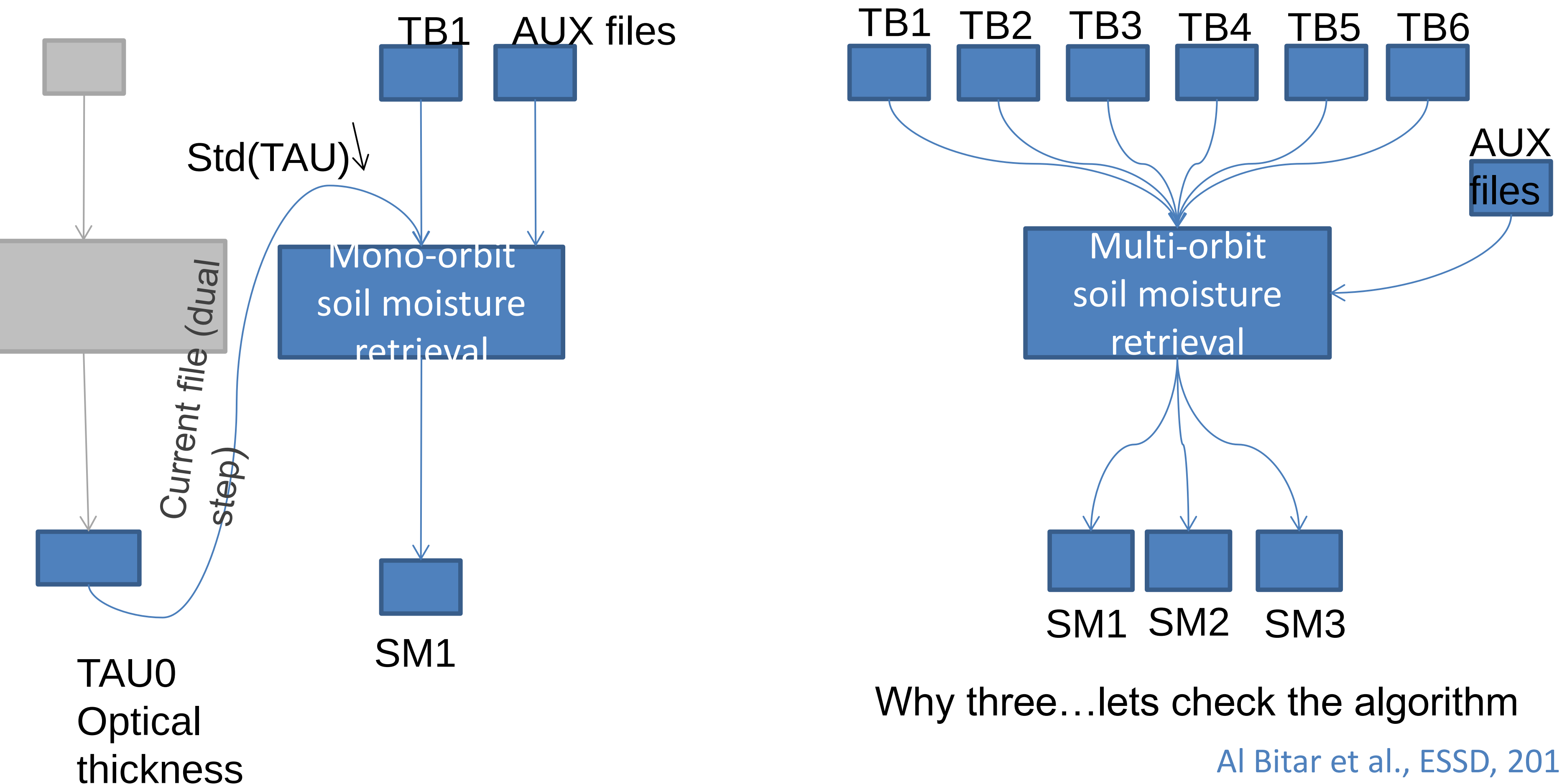
Mono-orbit soil moisture retrieval

Current file (dual step)

TAU0
Optical thickness

SM1

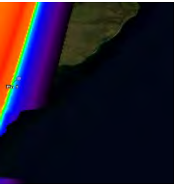
L3 Multi-orbit retrievals



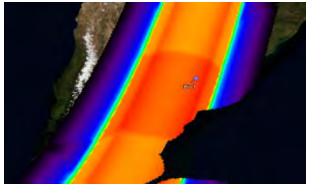
Why three…lets check the algorithm

Al Bitar et al., ESSD, 2017

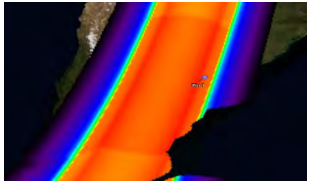
Revisits and Angular Sampling



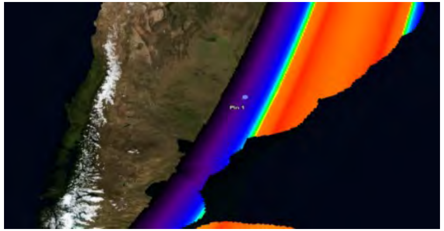
0-05-15



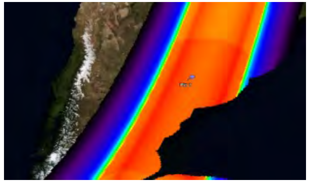
2010-05-18



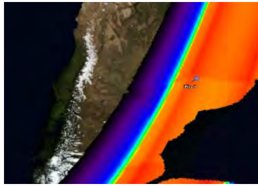
2010-05-20



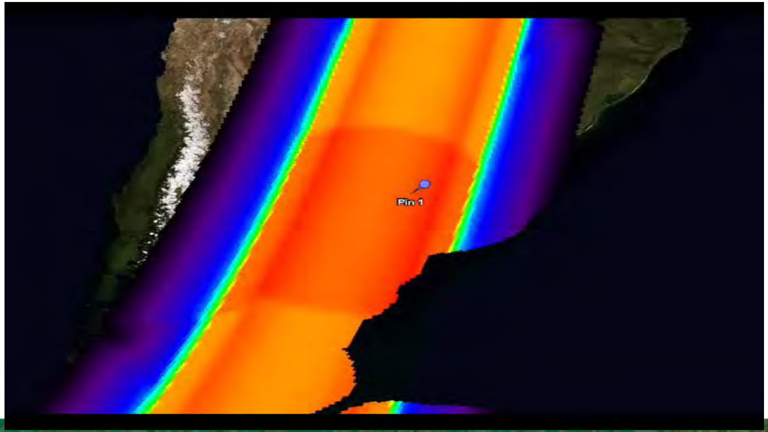
2010-05-21



2010-05-23



2010-05-25



Motivation: Using information from preceding and succeeding revisits angular sampling can be enhanced

Optical Thickness Correlation

Vegetation Optical thickness

is a function of

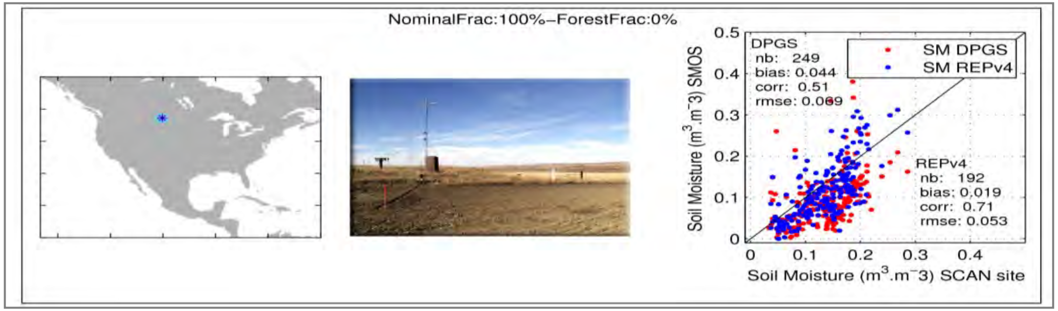
Vegetation water content

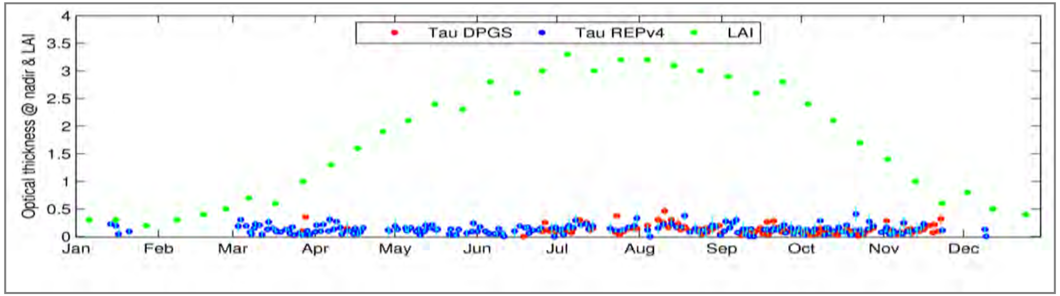
which can be related to

Leaf Area Index

which is

Generaly Highly correlated over a periode of several days





Motivation: Using correlation of optical thickness in a multi-orbit retrieval algorihm can enhance the robustness of the retrieval and reduce the number of degrees of freedom of the retrieval.

Al Bitar et al. – Workshop SMOS 2011- Arles – France

Cost function

Mono-orbit :
SML2PP,
emission models (LMEB …)

$$\mathrm{Cost} = (\mathbf{TB}_{\mathrm{obs}} - \mathbf{TB}_{\mathrm{mod}})^t\, \mathbf{Cov}_{\mathrm{TB}}^{-1}\, (\mathbf{TB}_{\mathrm{obs}} - \mathbf{TB}_{\mathrm{mod}}) + \sum \frac{(P - P_0)^2}{\sigma_p^2}$$

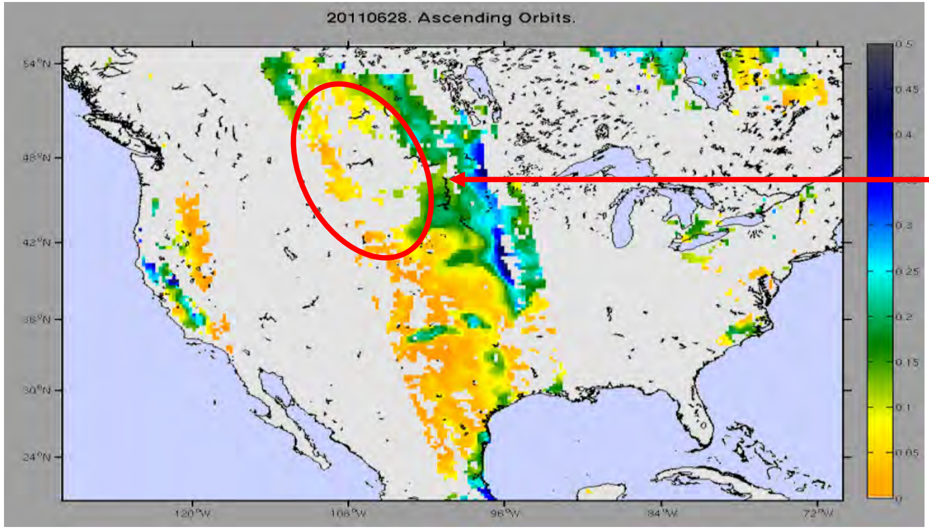
Multi-orbit:
CTL3OPT,
same emission models
(LMEB …)

$$\mathrm{Cost} = (\mathbf{TB}_{\mathrm{obs}} - \mathbf{TB}_{\mathrm{mod}})^t\, \mathbf{Cov}_{\mathrm{TB}}^{-1}\, (\mathbf{TB}_{\mathrm{obs}} - \mathbf{TB}_{\mathrm{mod}}) + \sum_{P \neq \mathrm{Tau}} \frac{(P - P_0)^2}{\sigma_p^2} + (\mathbf{Tau} - \mathbf{Tau_0})^t\, \mathbf{Cov}_{\mathrm{Tau}}^{-1}\, (\mathbf{Tau} - \mathbf{Tau_0})$$

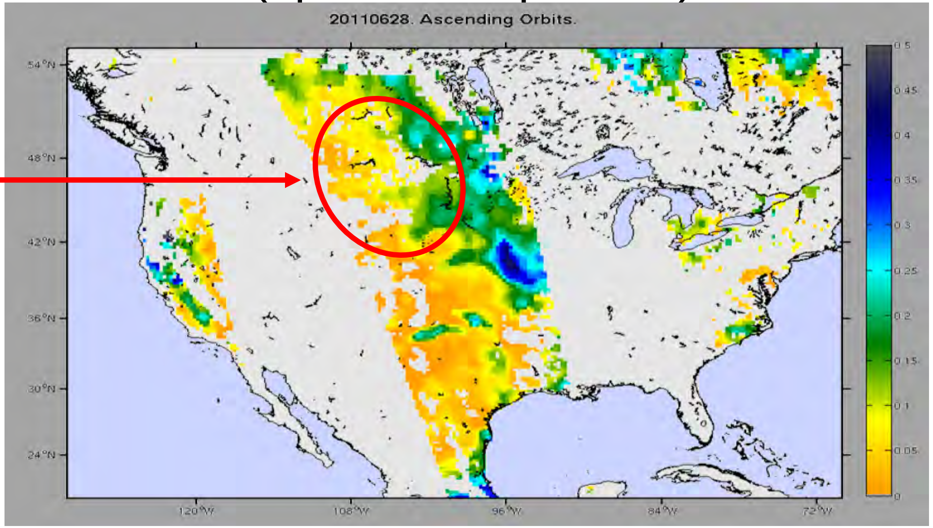
$$\mathrm{TB} = \begin{vmatrix} \mathrm{TB}_1 \\ \mathrm{TB}_2 \\ \mathrm{TB}_3 \end{vmatrix} \qquad \mathbf{Cov}_{\mathrm{Tau}} = \sigma_{\mathrm{Tau}}^2 \begin{bmatrix} 1 & \rho_{21} & \rho_{31} \\ . & 1 & \rho_{23} \\ . & . & 1 \end{bmatrix}$$

Soil Moisture comparision

Mono-orbite retrieval



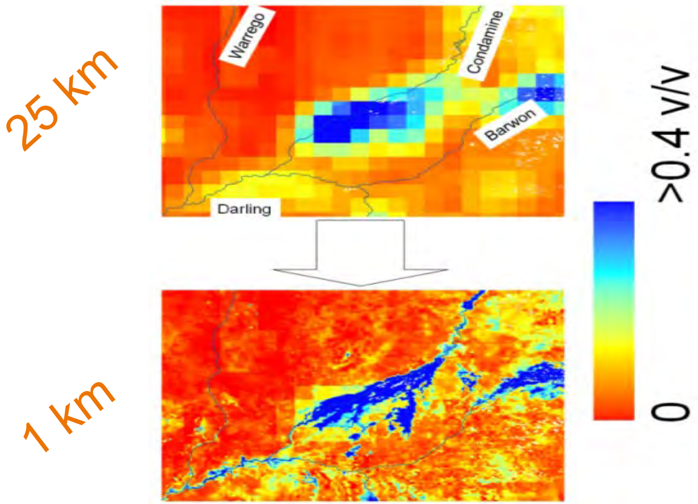
Multi-orbite retrieval
(operational product)



Al Bitar et al. – Workshop SMOS 2011- Arles – France

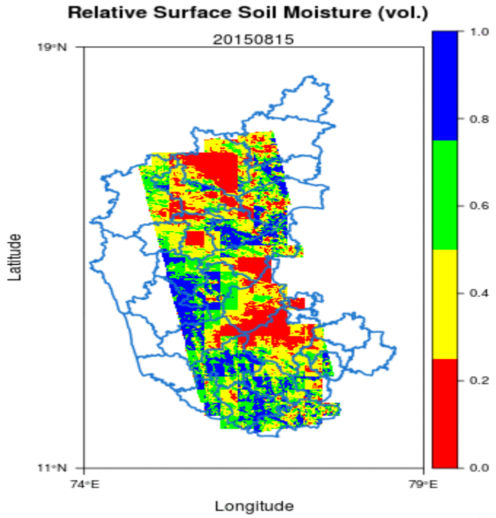
L4 High resolution SM product

SMOS & optical sensors



(Merlin et al. 2012) (Molero et al., RSE, 2016)

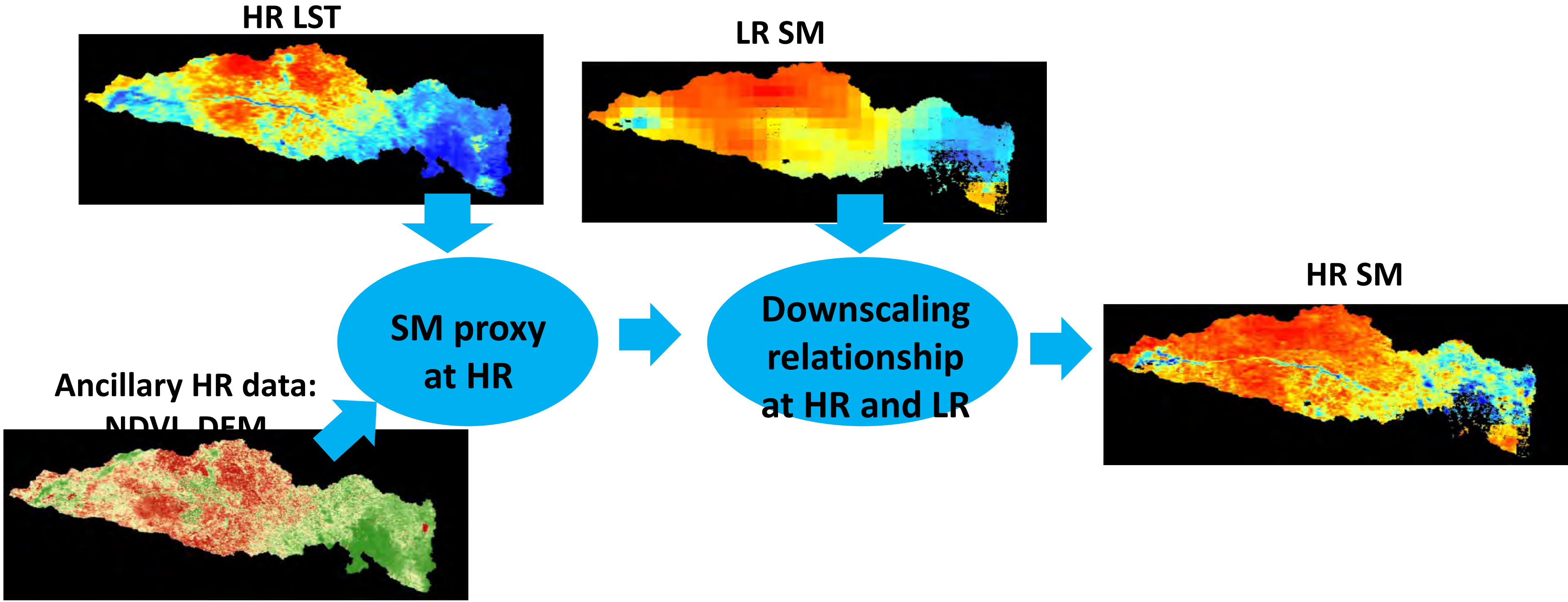
SMOS & C-Band radar



(Tomer et al., RS, 2015, 2016)
sat@aapahinnovations.com

Rationale for evaporation-based SM downscaling

Generic scheme



Merlin et al.

DISPATCH method

DISaggregation based on Physical And Theoretical scale CHange

1) SEE = Soil Evaporative Efficiency = LEs/LEp,s
= (Ts,dry - Ts)/(Ts,dry – Ts,wet)

Normalizes LST for

Vegetation
Cover = fc

d

Meteo
forcing

2) Semi-physical SEEmod(

SM

3) Downscaling relationship

$$SM_{HR} = SM_{LR} + \left(\frac{\partial SEE_{\text{mod}}}{\partial SM} \right)_{LR}^{-1} \times (SEE_{HR} - SEE_{LR})$$

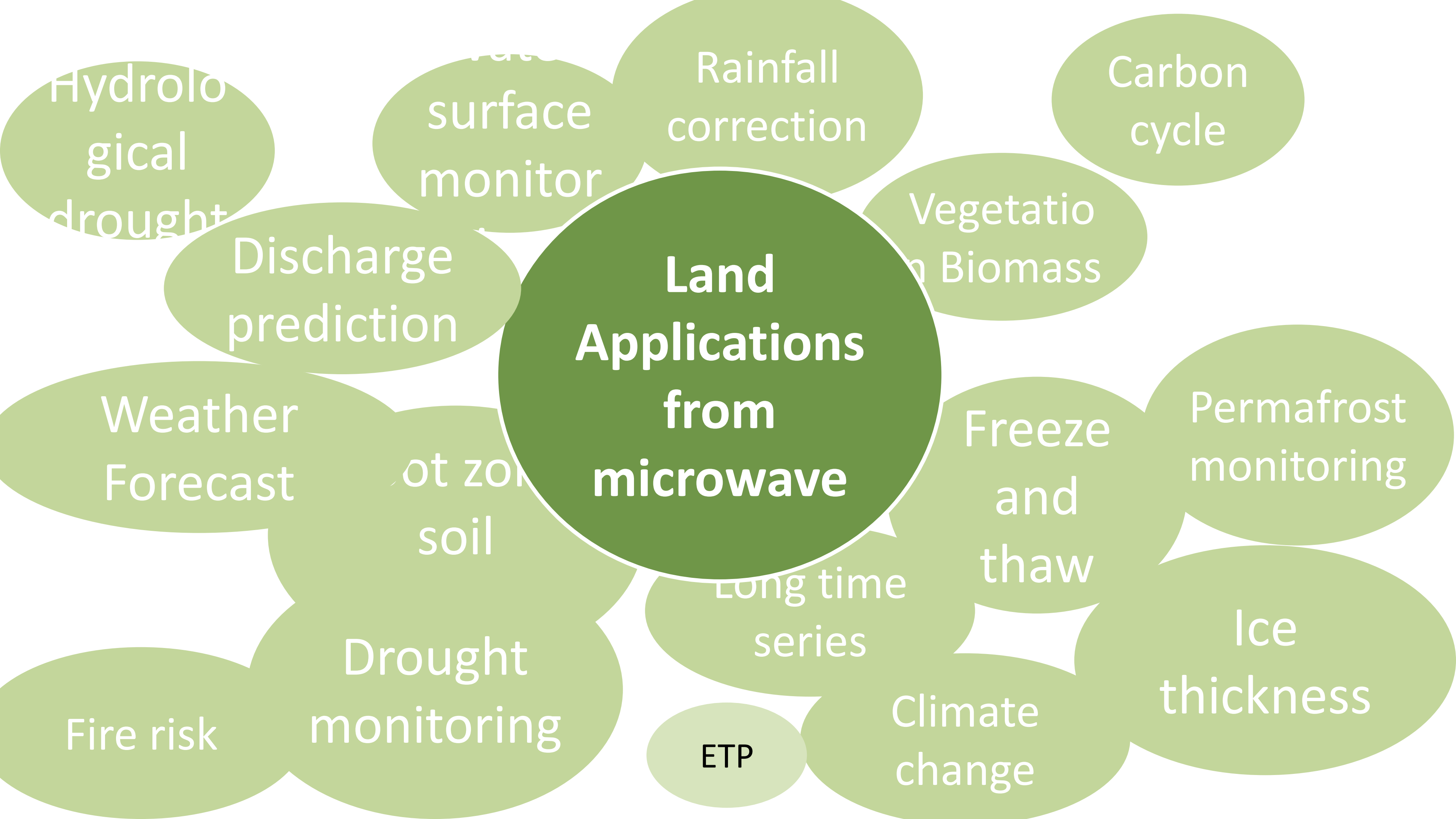
Merlin et al. RSE 2008; TGRS 2012; RSE 2013

Microwave Radiometry for the hydrological Cycle

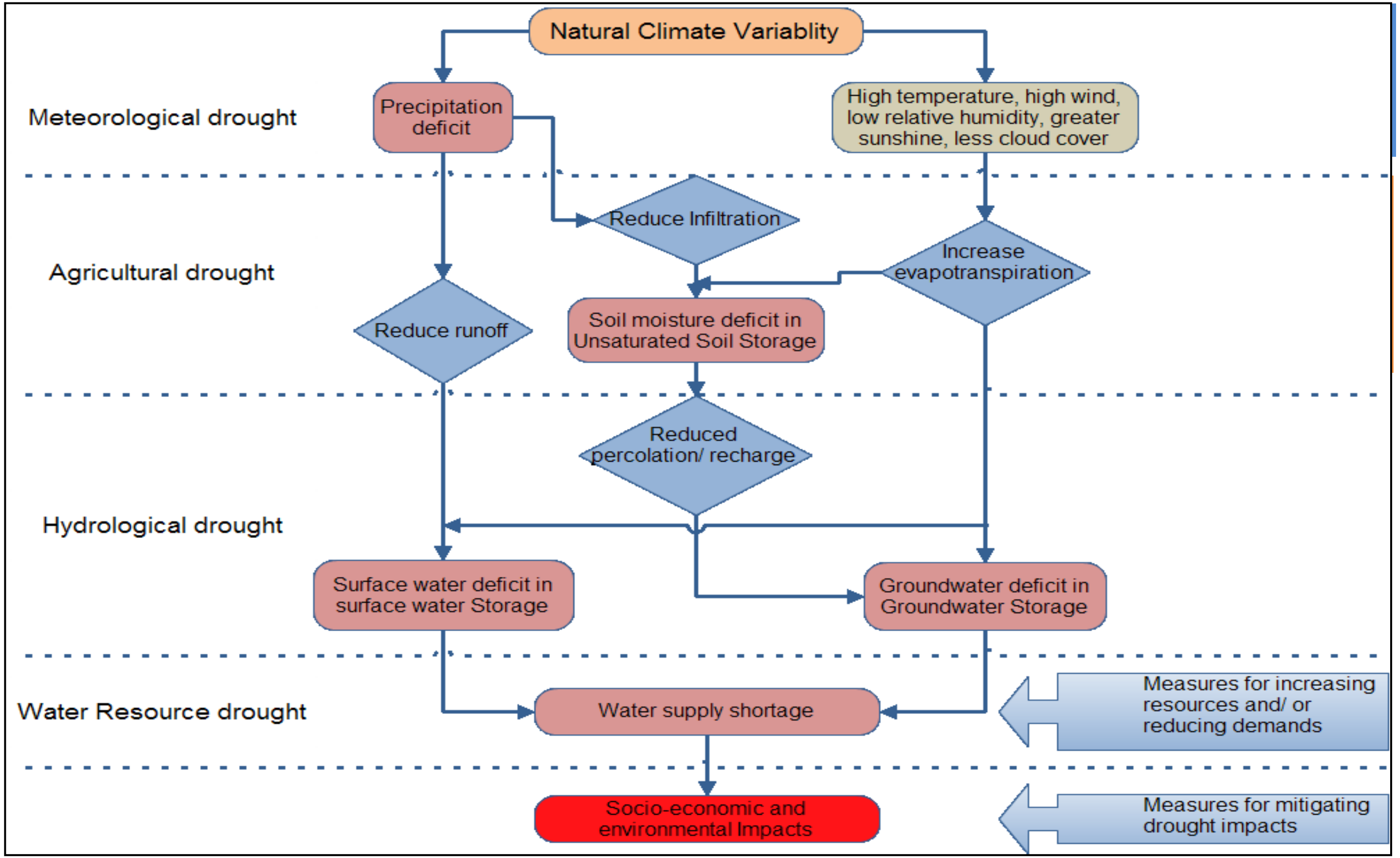
Bascis of microwave radiometry

Geophysical Products

Applications


Hydrolo
gical
drought
surface
monitor
Rainfall
correction
Carbon
cycle
Vegetatio
Biomass
Discharge
prediction
Land
Applications
from
microwave
Weather
Forecast
soil
Freeze
and
thaw
Permafrost
monitoring
time
series
Ice
thickness
Drought
monitoring
Fire risk
ETP
Climate
change

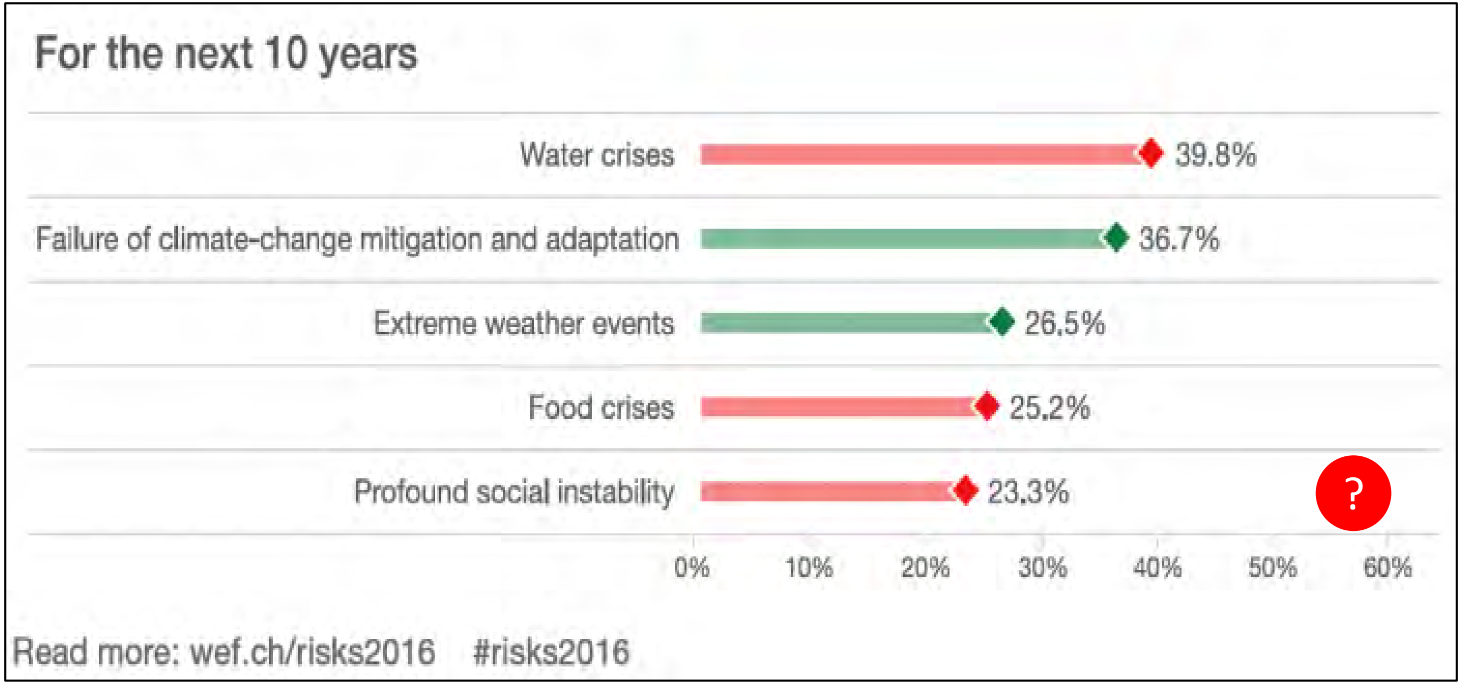
Types of drought



Source: National Drought Mitigation Centre, and G. Rossi, B. Bonaccorso, A. Cancelliere, (2003)

Is it a priority to observe the hydrological cycle ?

The Global Risks Perception Survey from the World Economic Forum



Stages of agricultural drought

Processes

Sensing frequency

Microwave (K-Band)	Microwave (L-Band / C-Band)	Thermal IR	Fluorescence	NDVI / NDWI / SLA / LAI

Sensors(examples)

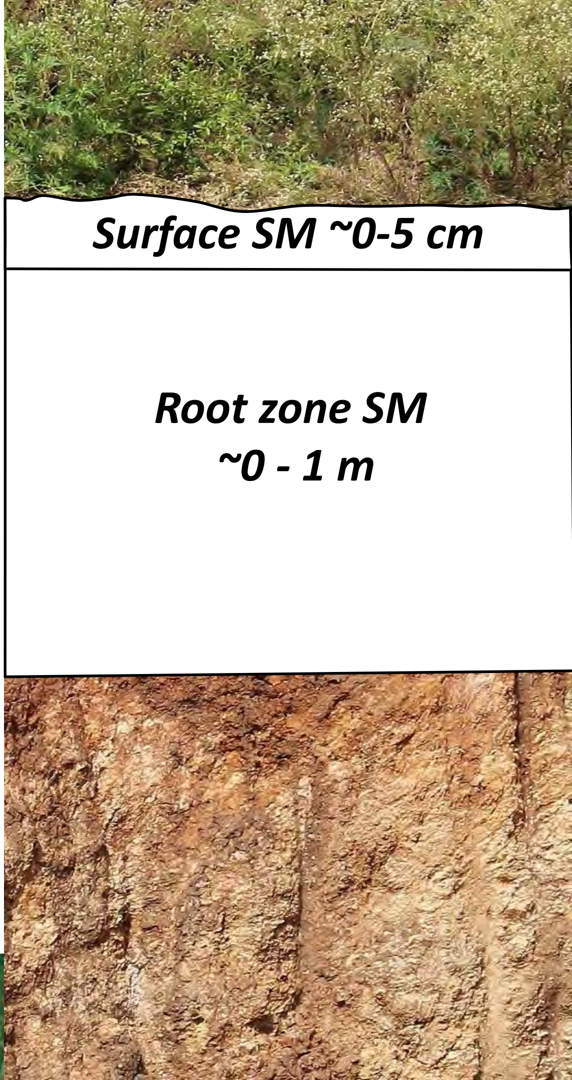
Only for precipitation GPM (MT, GPM core…)	SMOS, SMAP, Sentinel-1 Biomass ?	LandSat-8, Sentinel-3	Flex ?	Sentinel-2

Root zone soil moisture

Root zone soil moisture is a very usefull information to access agricultural drought in an **early warning system**

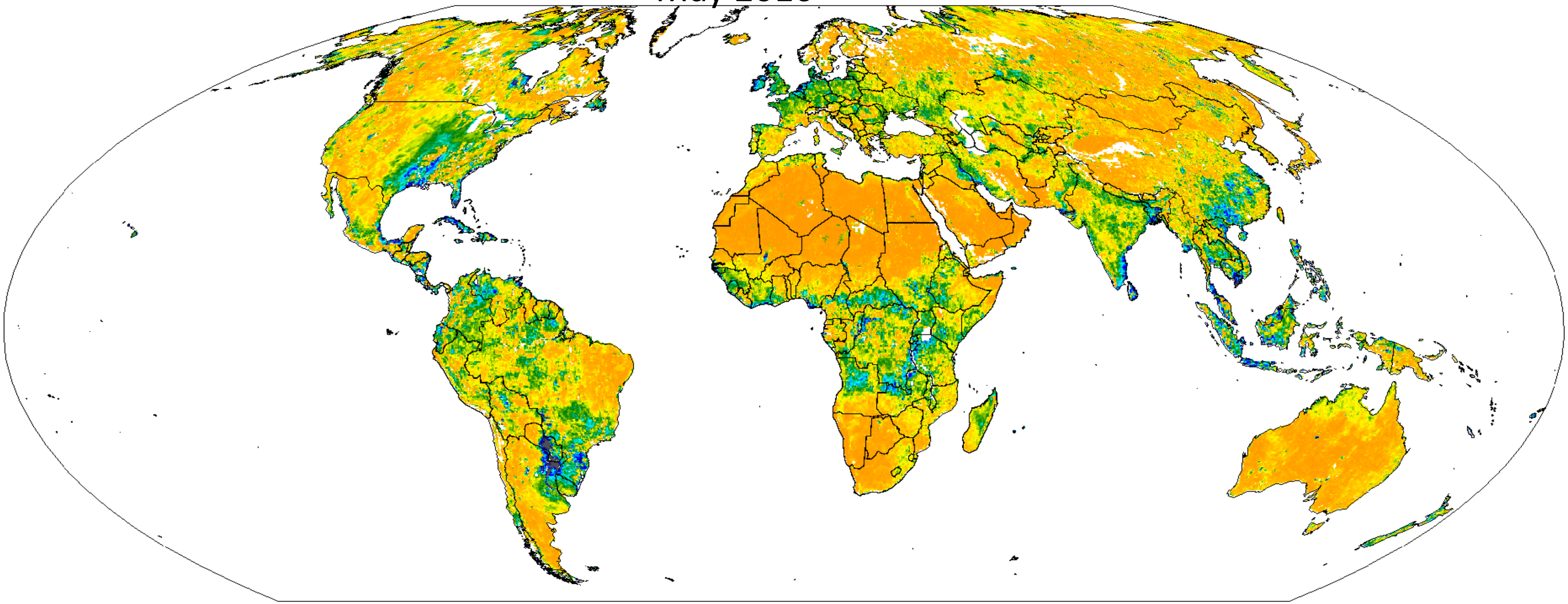
SMOS measures surface soil moisture, root zone soil moisture need to be modeled

At CESBIO **SMOS surface soil moisture** and MODIS LAI are assimilated into a double bucket model to compute **root zone soil moisture**.
(Al Bitar et al. 2013, Kerr et al. 2016)



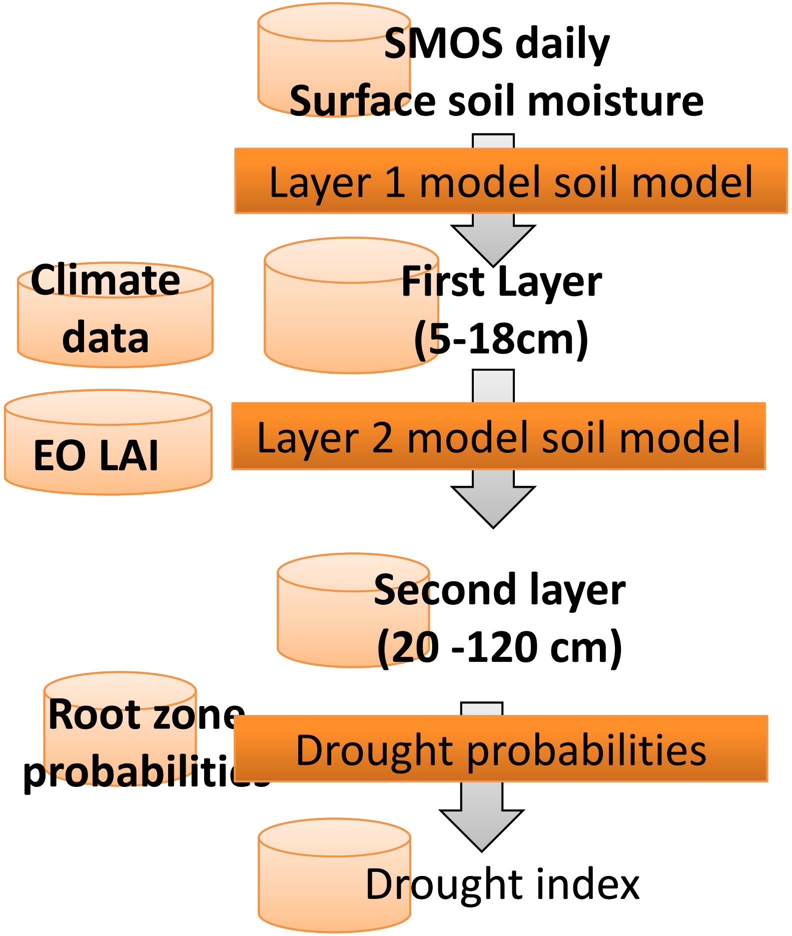
SMOS Global root zone soil moisture maps

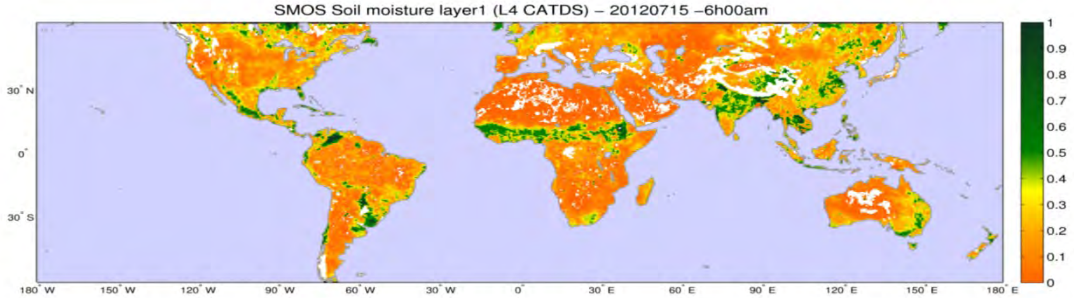
May 2016

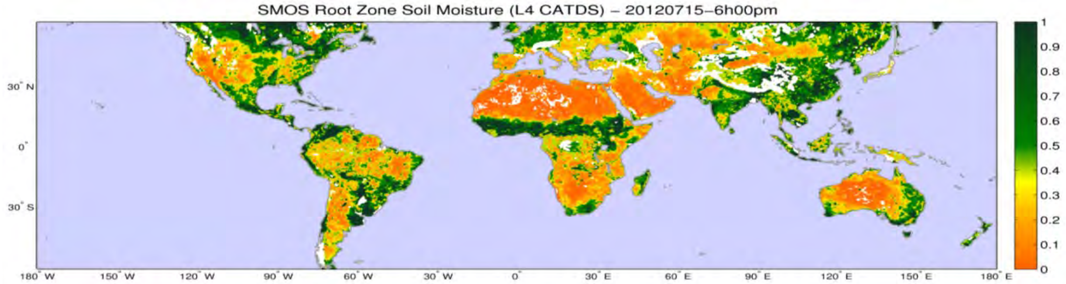


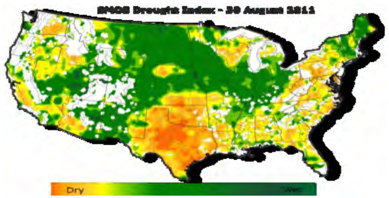
Al Bitar et al., 2013, Kerr et al. 2016

available on www.catds.fr





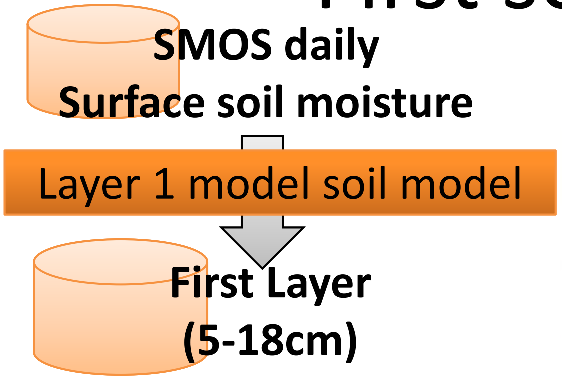


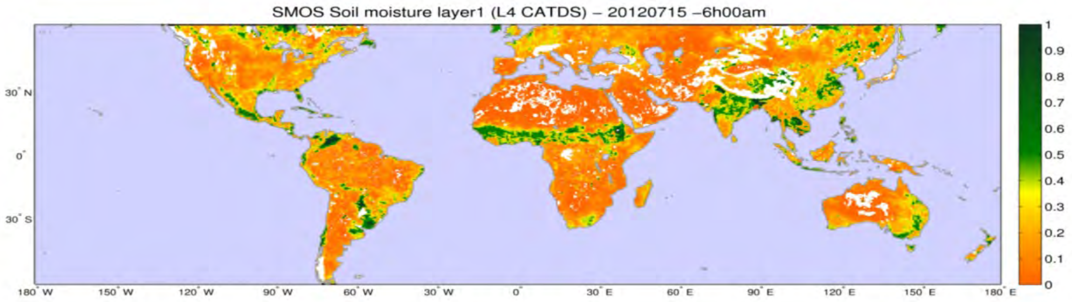


web application
+
Netcdf products :
EASE grid 25km

Al Bitar et al., 2013

First soil layer model





(Al Bitar et al. 2017 ESSD)

from surface to ~20 cm

sequential formulation of the exponential filter

Based on Albergel et al. (2006)

But doesn't take into account the capillary effect (interaction between the different layers) and vegetation transpiration

Al Bitar et al., 2013

Second layer model: 20cm – 1.5 m

Theta based Richards Equation

$$\frac{\partial\theta(h,\mathbf{x})}{\partial t} - T = \nabla.[\mathbf{K}\ \nabla h] - \nabla.[\mathbf{K}\ \mathbf{g}_B]$$

h : capilary pressure in (m)

Θ : water content (m3/m-3

K : hydraulique conductivity (m/s)

g : unit gravity vertor

T : vegetation transpiration ($m^3/m^3/s$)

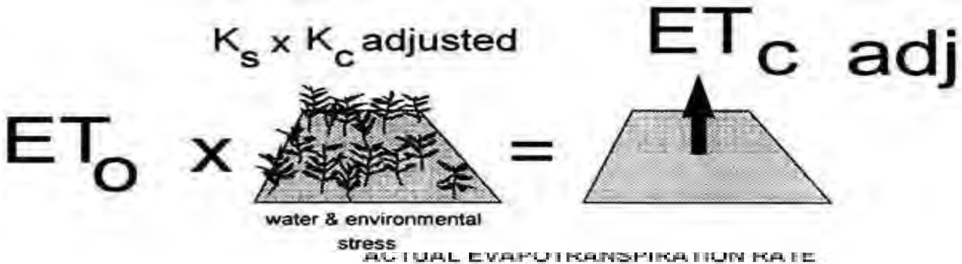
A linearized (force restore) formulation is used

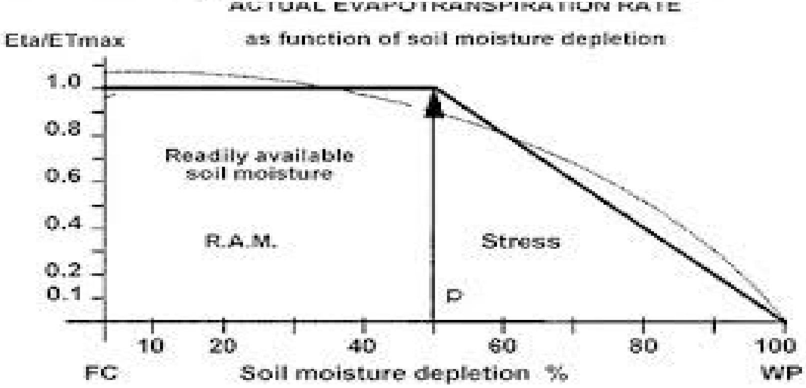
Vegetation transpiration model (T)

T : Transpiration of the vegetation (m^3/j)

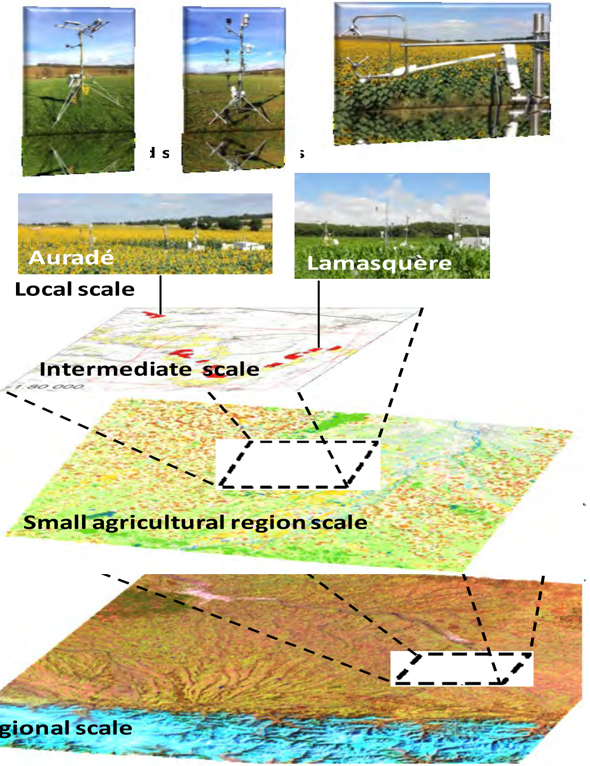
computed using FAO-56 method forced by NDVI and air temperature

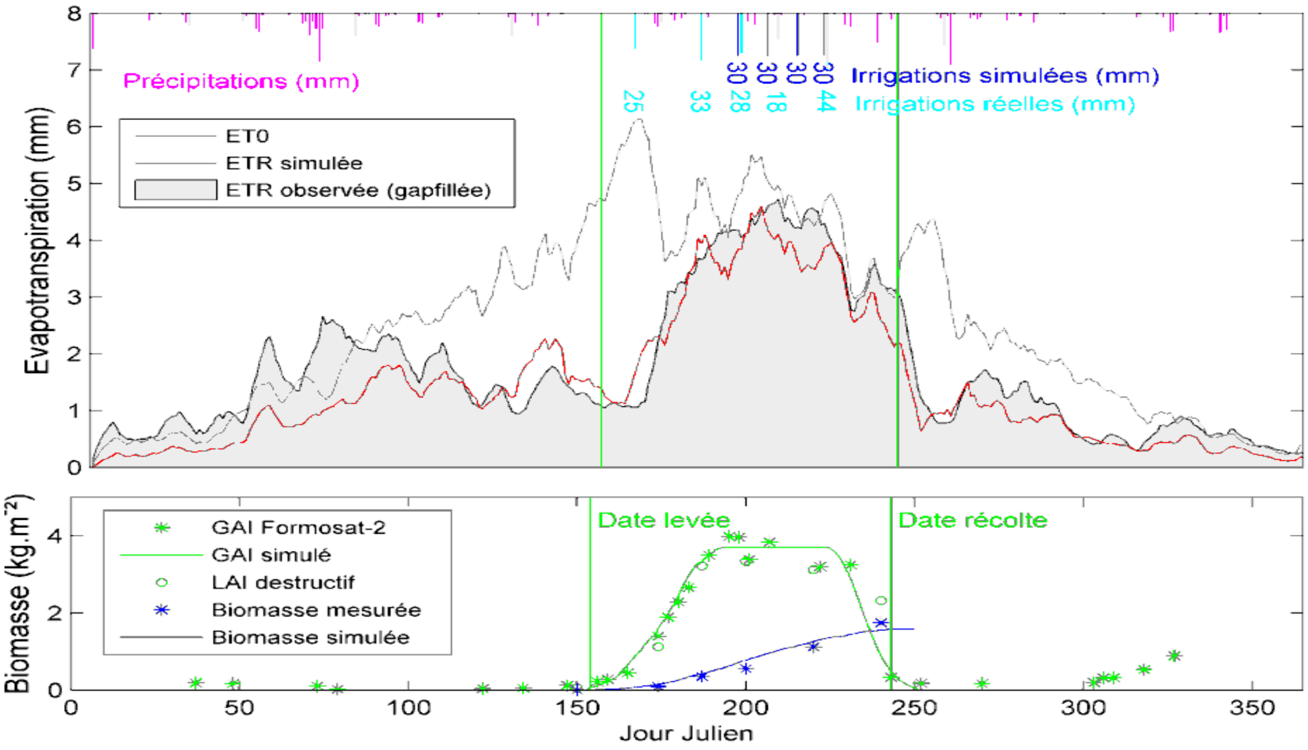
Kcb=a exp (b. NDVI)
adapted from Er-Raki et al. (2010)





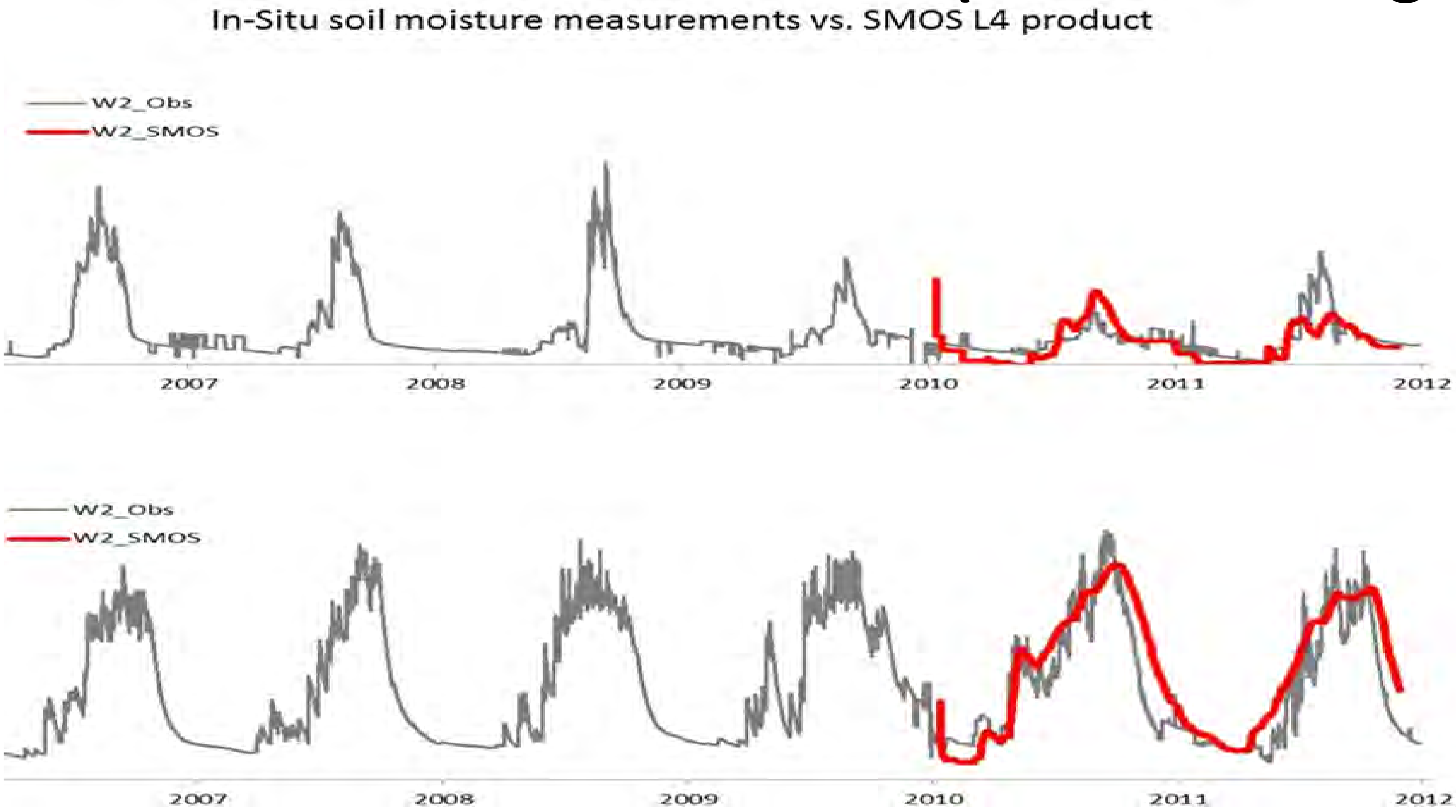
Why are we using the remote sensing driven FAO approach ?





(Battude et al. RSE 2016, AWM 2017)

Validation over AMMA sites (Benin and Niger)



Pellarin, T., de Rosnay, P., Albergel, C., Abdalla, S., & Al Bitar, A. H-SAF Visiting Scientist Program HSAF_CDOP2_VS12_02, 2013.

Comparision to root zone products

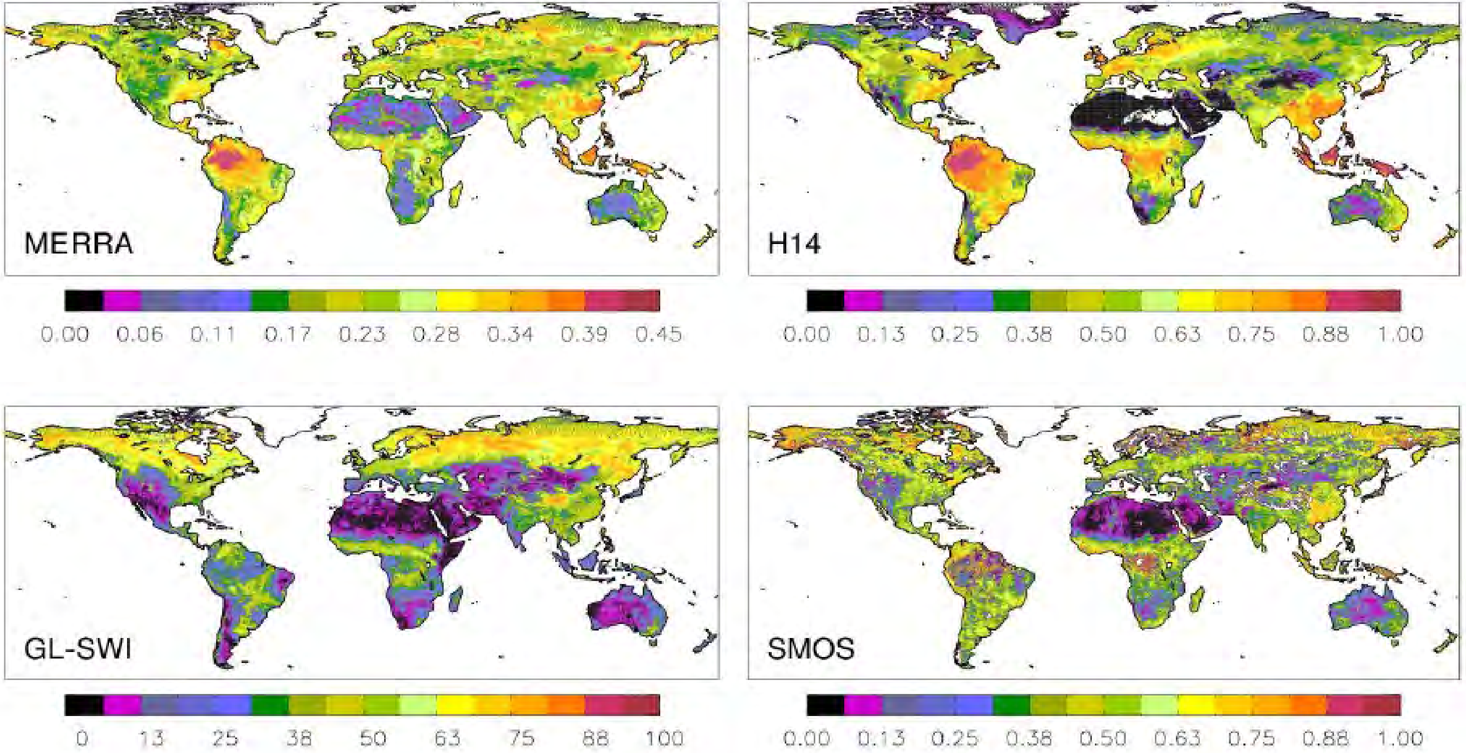
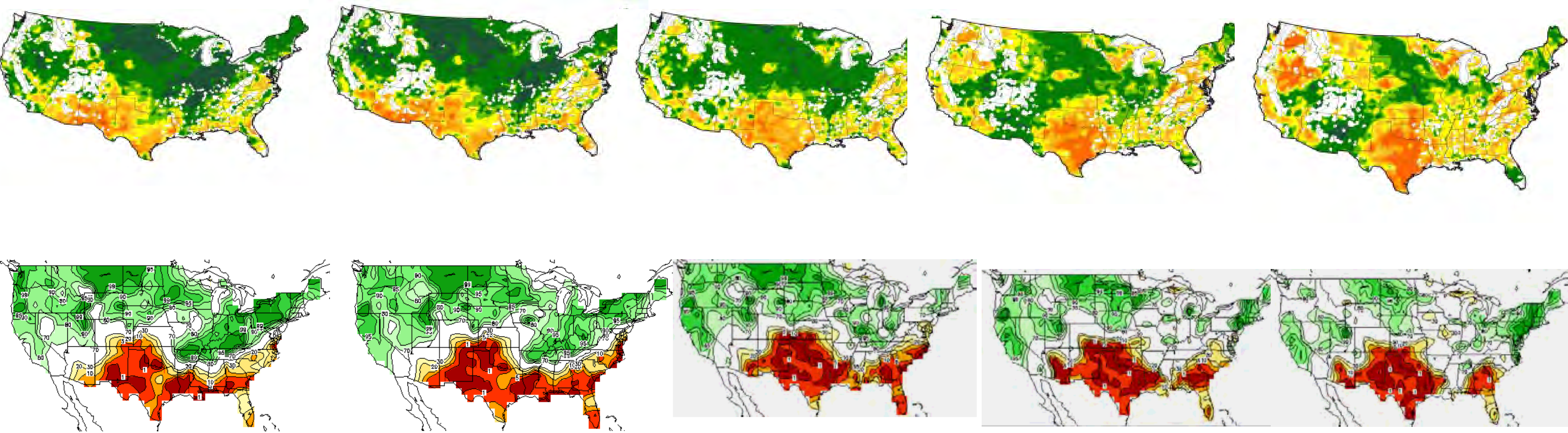


Figure 1: Annual mean root-zone soil moisture maps for MERRA, H14, GL-SWI and SMOS.

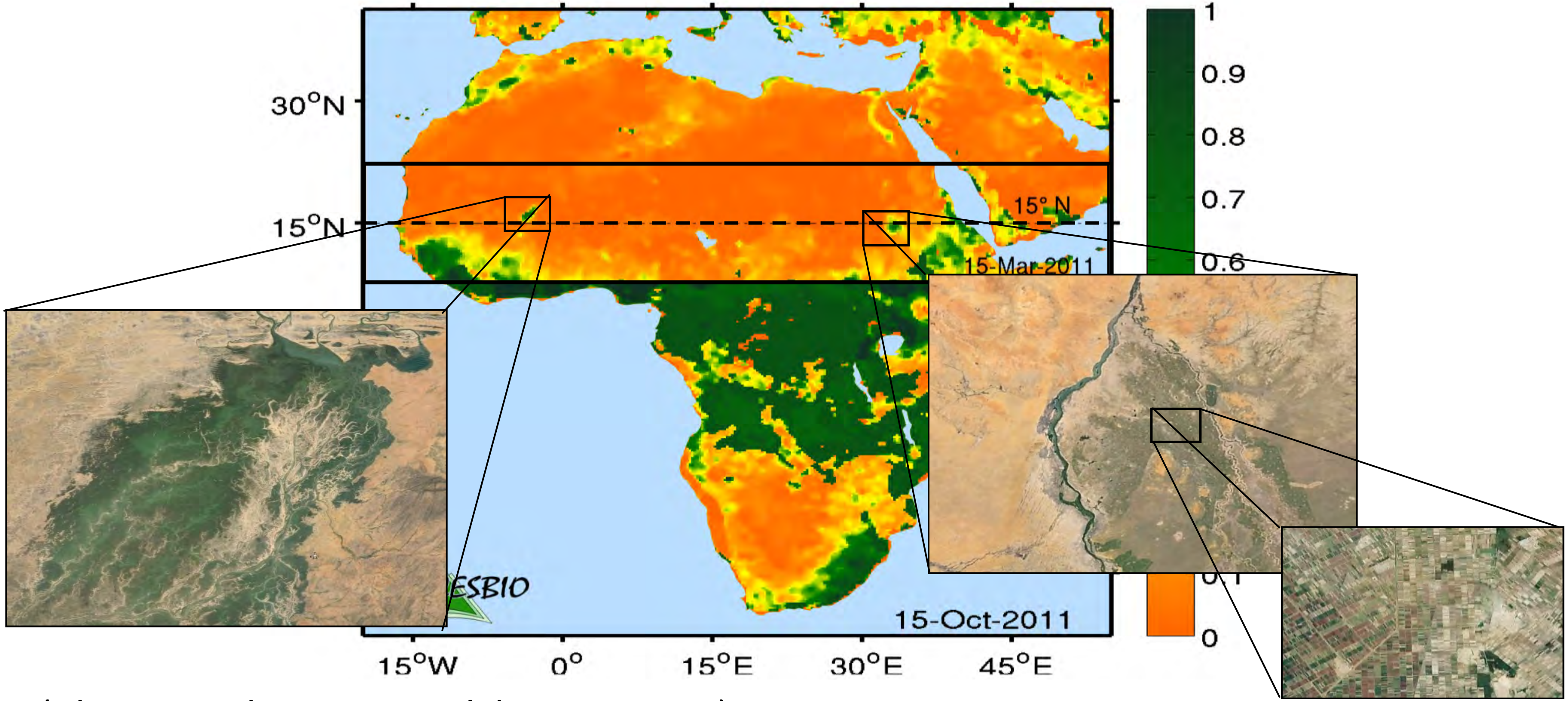
Pellarin, T., de Rosnay, P., Albergel, C., Abdalla, S., & Al Bitar, A. H-SAF Visiting Scientist Program HSAF_CDOP2_VS12_02, 2013.

RZ soil moisture vs NOAA NCEP Bucket model

May 2011 | June 2011 | July 2011 | August2011 | September 2011



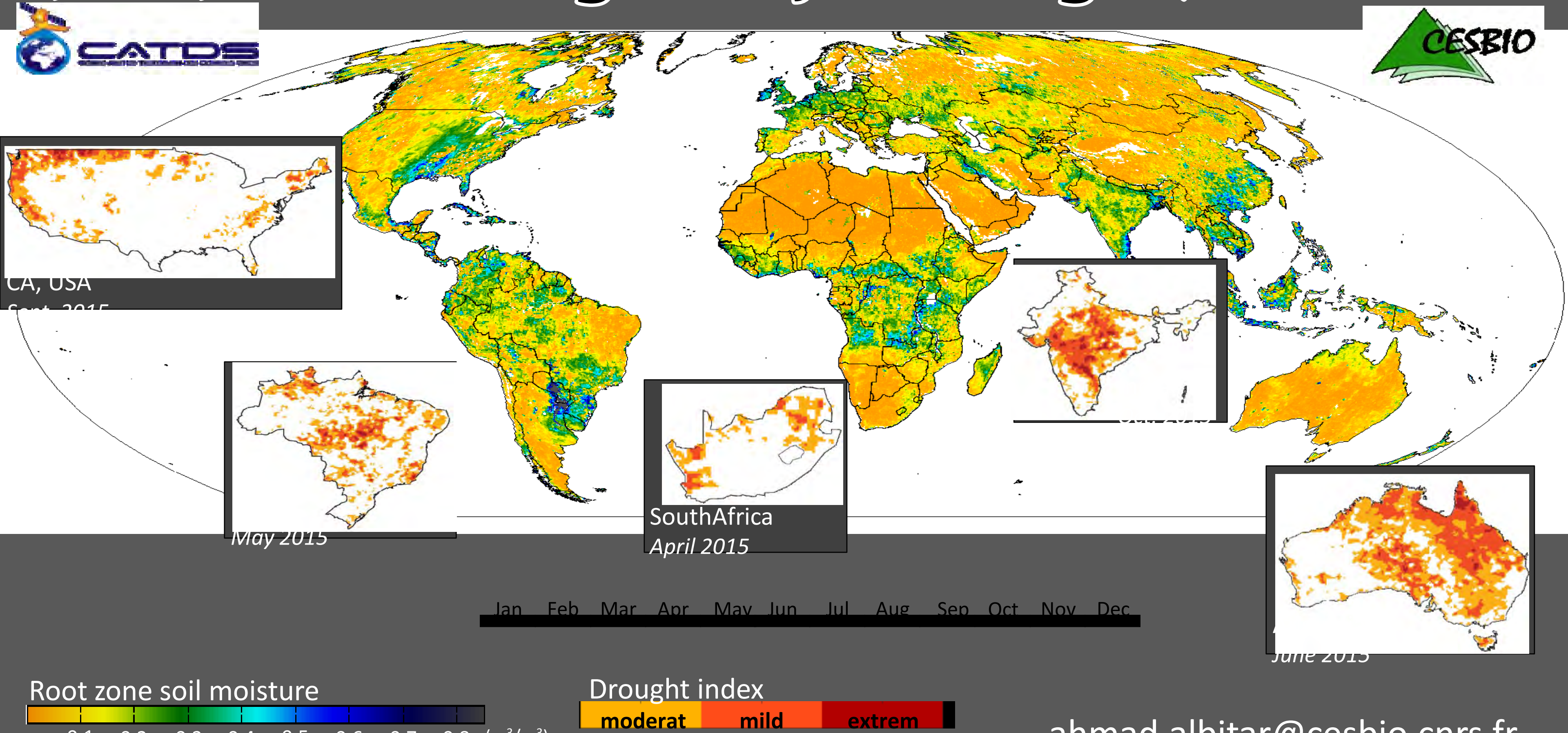
Drought in the horn of Affrica



(Al Bitar et al. , in revue sécheresse 2016)

Al Bitar, R. Escadafald, Kerr Y. Revue Sécheresse , 2014

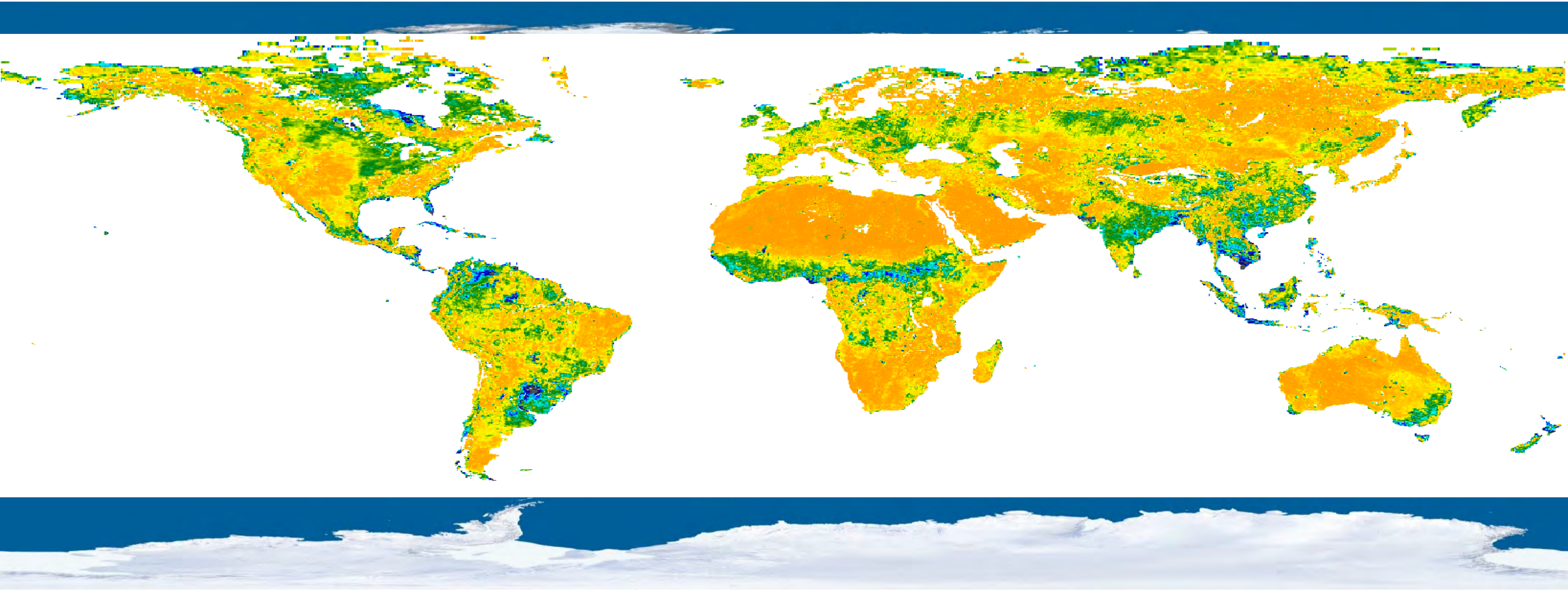
SMOS monitoring 5 major droughts in 2015



ahmad.albitar@cesbio.cnrs.fr

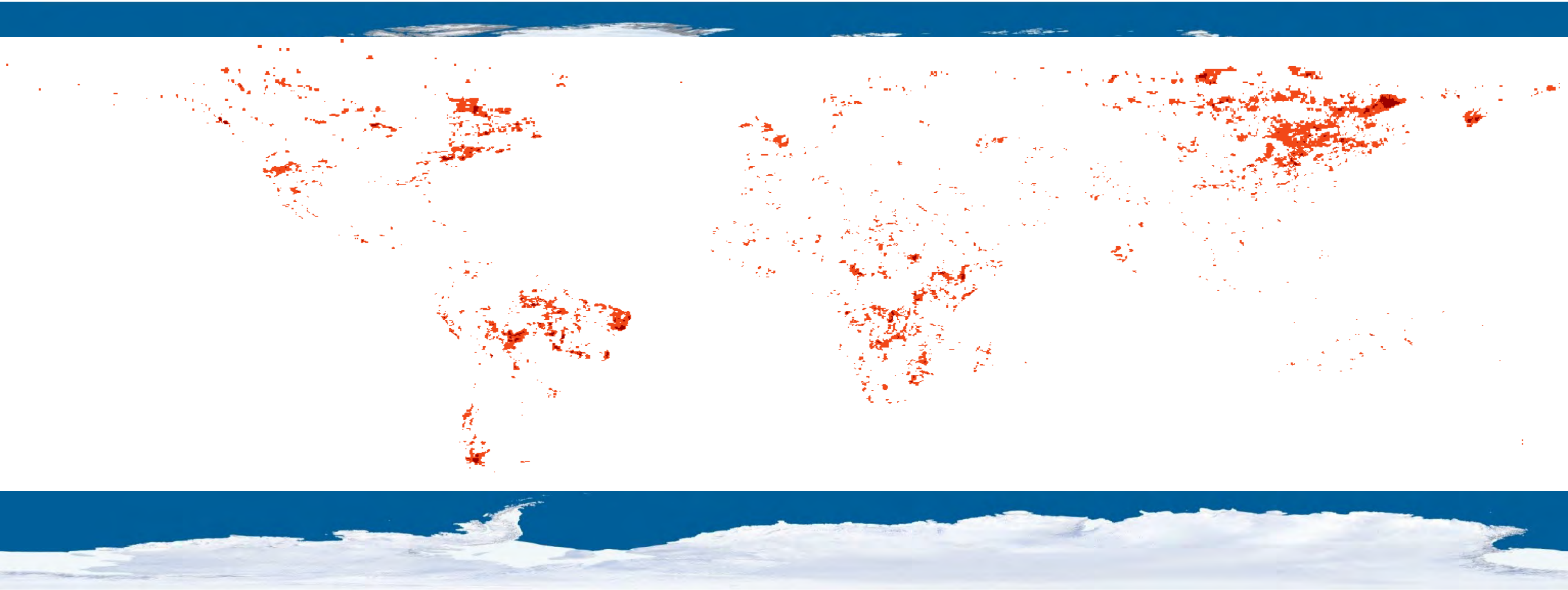
Root zone soil moisture in 2016

Feb. / May / Aug. / Nov/ 2016



Droughts from Root zone soil moisture anomalies 2016

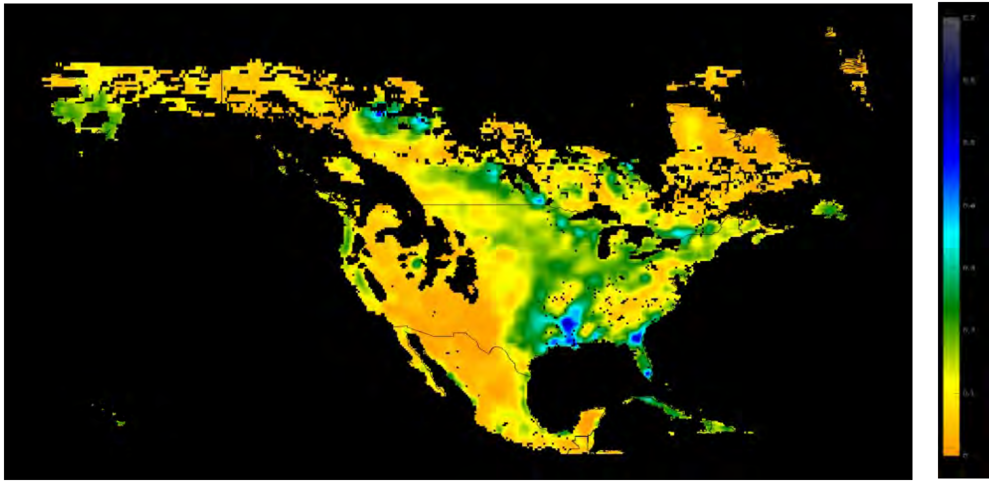
Feb. / May / Aug. / Nov/ 2016

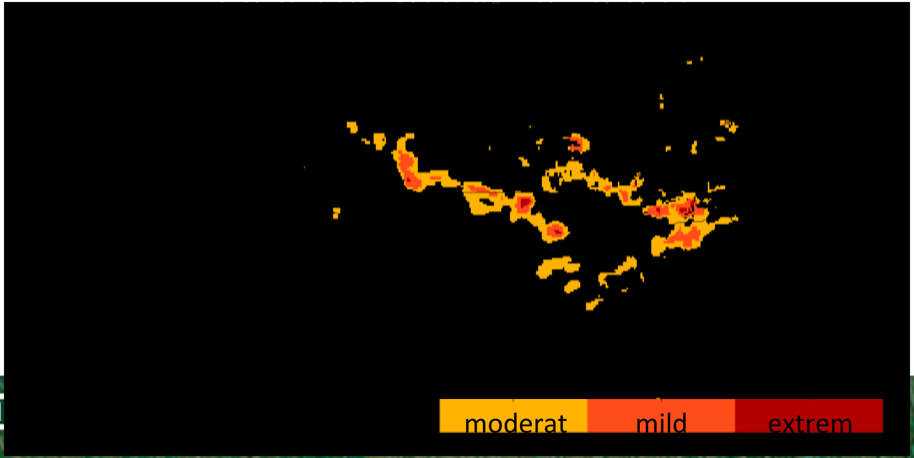


What is looming a world food crises because of prolonged drought conditions, that can be driven from socio-climatique situations.

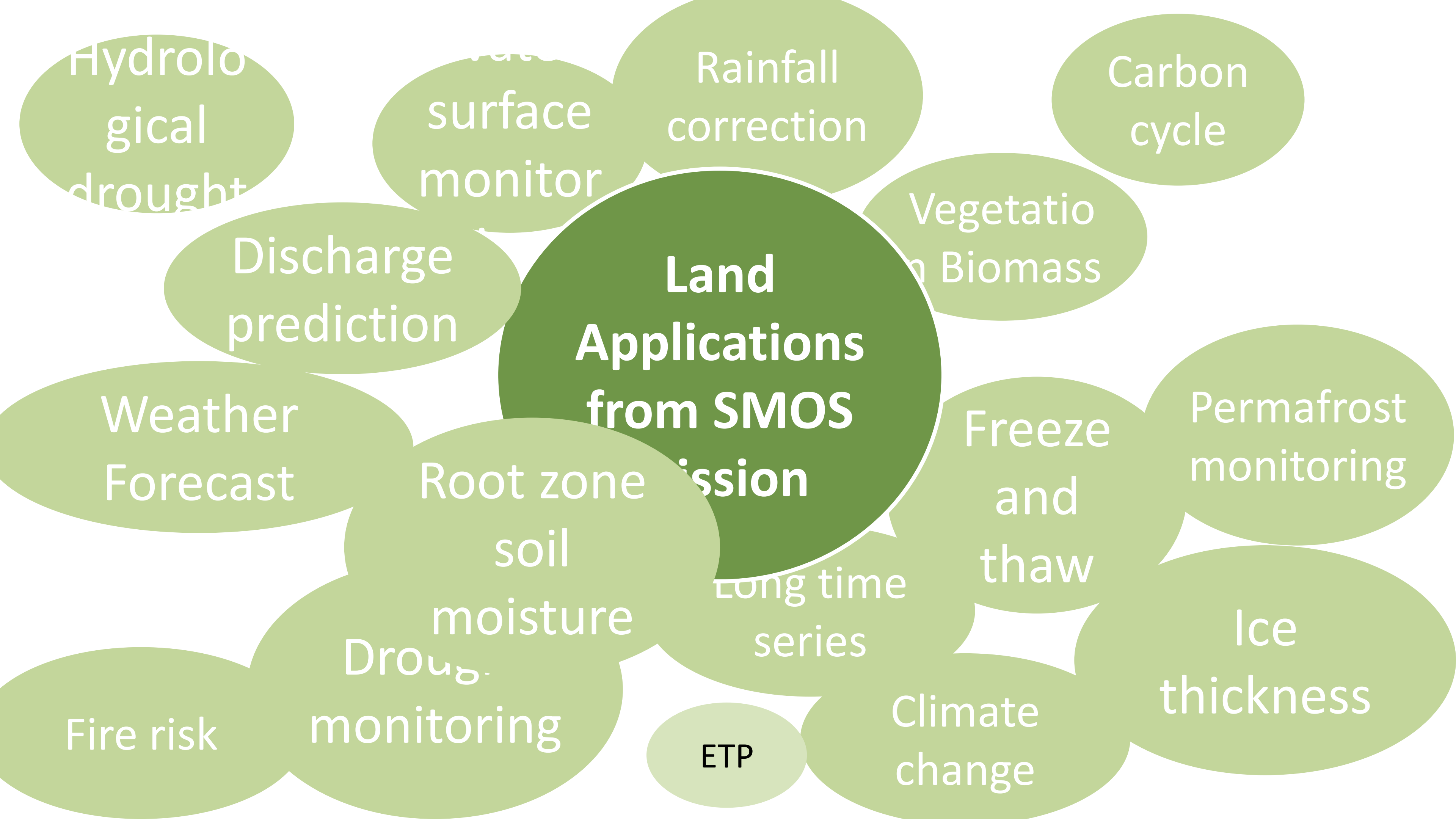
ght before Canada Fires in 2016

Proof of the adequacy of the SMOS root zone soil moisture as a index into an early drought and fire risk warning system.





Communication over ESA web portal



Land Applications from SMOS
ission
Hydrolo
gical
drought
surface
monitor
Rainfall correction
Carbon cycle
Vegetatio
Biomass
Discharge prediction
Weather Forecast
Root zone soil moisture
Freeze and thaw
Permafrost monitoring
time series
Ice thickness
Climate change
ETP
Fire risk
monitoring

AGU Fall Meeting 2016

Hydrology session H51P

How are the wetlands over tropical basins impacted by the extreme hydrological events ?

Ahmad Al Bitar[1,2], Marie Parrens[1,3],

F. Frappart[4], F. Papa[5], J.-F. Cretaux[3,4], Y.H. Kerr[1,3], J.-P. Wigneron[6]

[1] CESBIO, [2] CNRS, [3] CNES, [4] LEGOS, [5] IRD, [6] ISPA

France

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How are the wetlands over tropical basins impacted by the extreme hydrological events ?

Why monitor wetlands
and
How can we achieve this ?

How are the wetlands over tropical basins impacted by the extreme hydrological events ?

Why monitor wetlands
and
How can we achieve this ?

What does it tell us
about Droughts and
ENSO dynamics ?

Why, monitor Tropical wetlands ?

Case of the Amazon

Water budget

The Amazon River contributes to **18%** of the global river discharge to the ocean and almost 5% of all the continental masses.

So It is important to map the 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)

CO2 budget

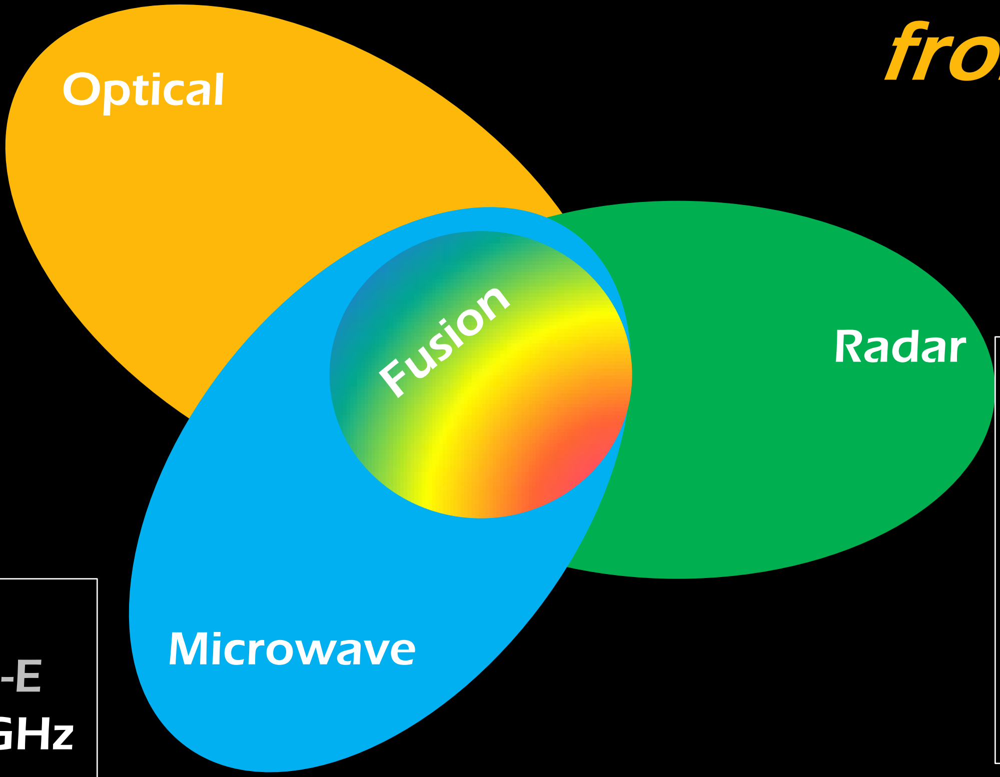
"Outgassing of CO_2 from rivers and wetlands constitut a carbon loss of 1.2 Mg C ha^{-1} yr^{-1}. Overall carbon budget of rainforests, summed across terrestrial and aquatic environments closer to being in balance " (*Richey et al. Nature 2002*)

"…a sediment load of 3 million tons near its mouth" (Molinier et al.,IAHS 1996)

How can we monitor wetlands surfaces ?

from space

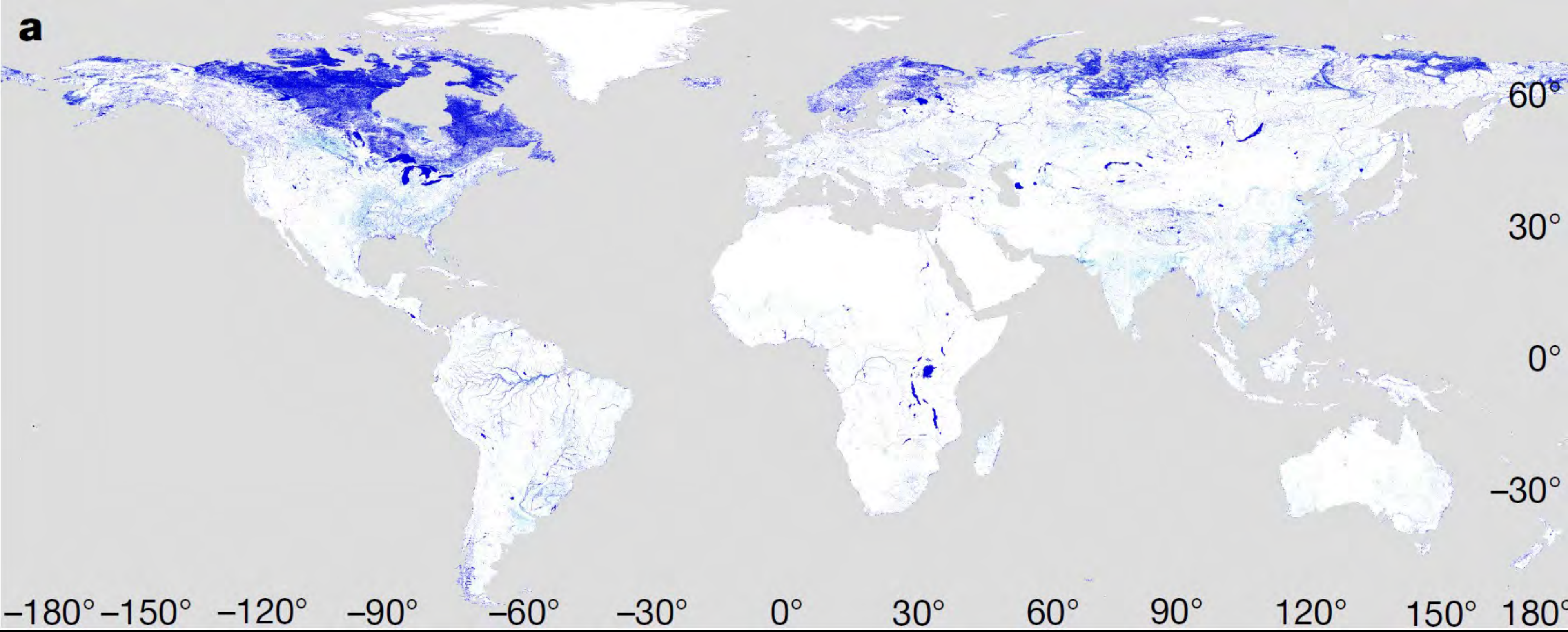
- Visible
  - *Sentinel-2*
  - *MODIS*
  - *LANDSAT*
- NIR
  - *LANDSAT*



- C-band
  - *Sentinel 1*
  - *RadarSAT*
- L-band
  - *PALSAR*
- X-band
  - *TERRASAR*

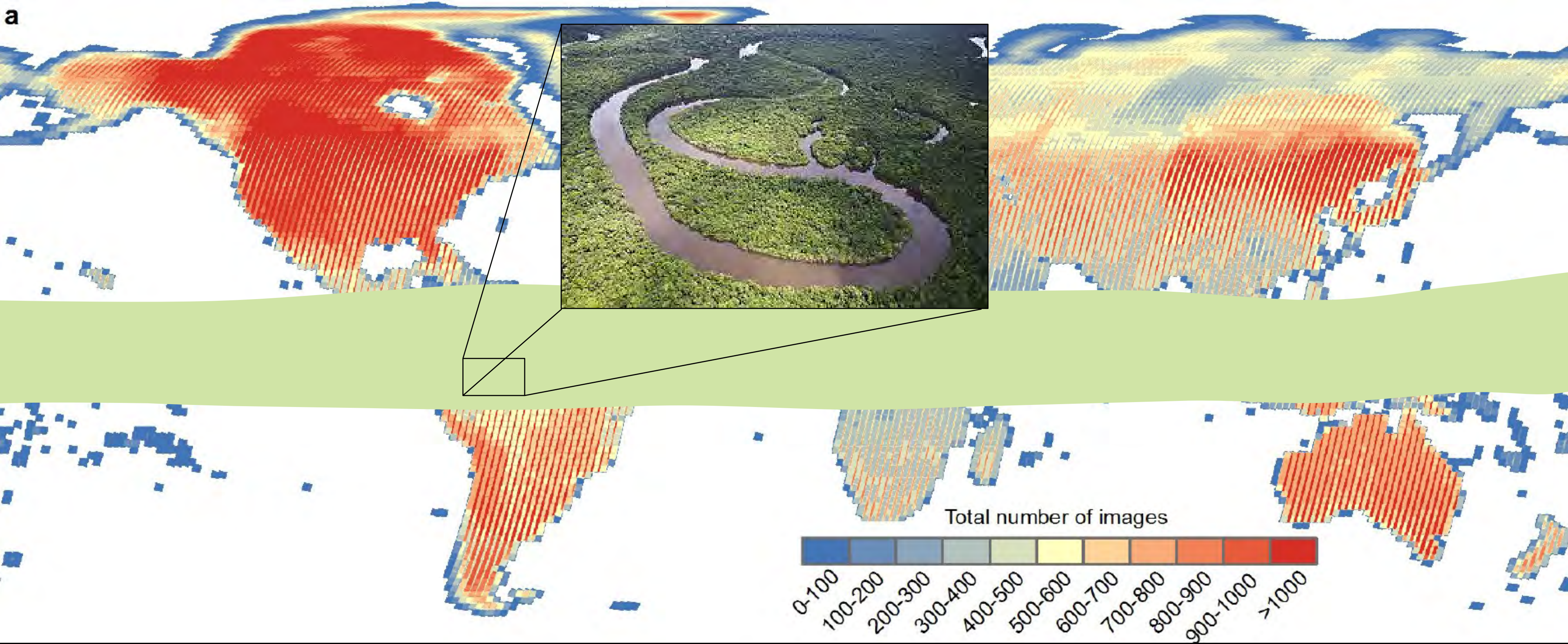
-C-band
  - AMSR-E
- K - ka GHz
- SSMI

State of the art, *and astonishing*



from Pekel et al. Nature, 2016

State of the art, yet



from Pekel et al. Nature, 2016

image from wwf

Advantage of Microwave RS

- Microwave has all weather capabilities.
- Sensors have a high revisit frequency (1-3 days).
- The Can provide signal underneath the vegetation (depending on frequency).
- Proof of concept and products exist since more than a decade.

<u>But :</u>

- Microwave sensors have a low spatial resolution : ~0.25° .

<u>So :</u>

- Synergistic approached need to be privielaged (Prigent et al., 2008).

Advantage of Microwave RS

L-band

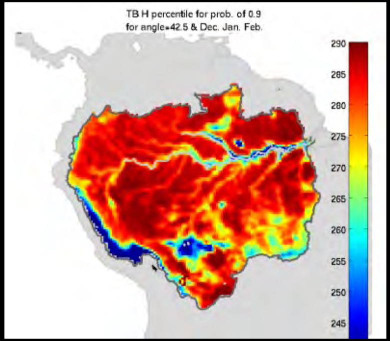
- The impact of vegetation is lower in L-band.
- The impact of heavy rainfall is also lower than C-band.
- Multi angular and full polarisation acquisitions are available

<u>But :</u>

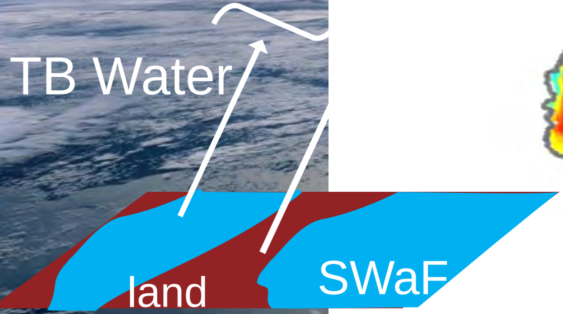
- *At which vegetation density it is still an open question*

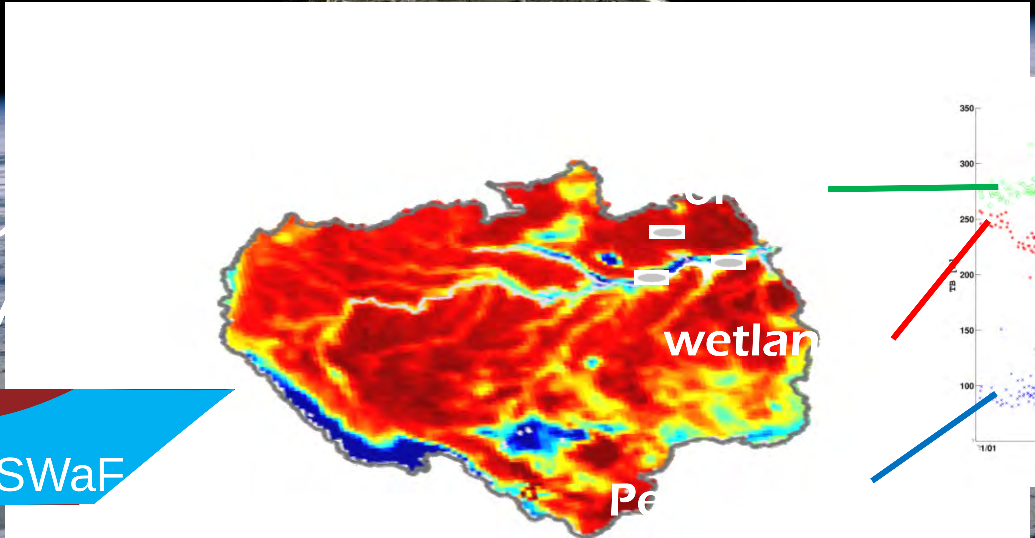
(Rahmoun et al. 2015, Parrens et al. 2015).

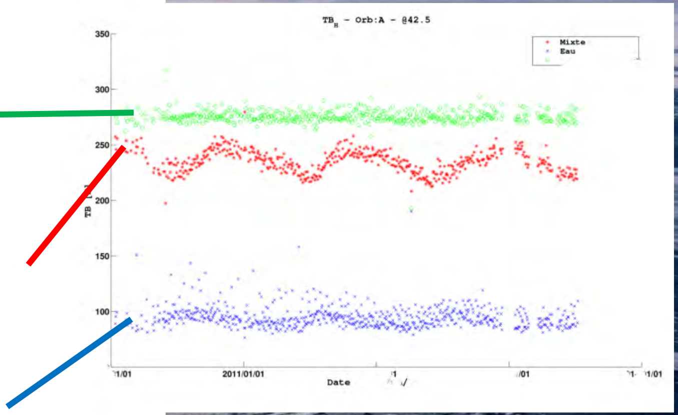
SWAF - Water fraction using SMOS data



Al Bitar et al., in review

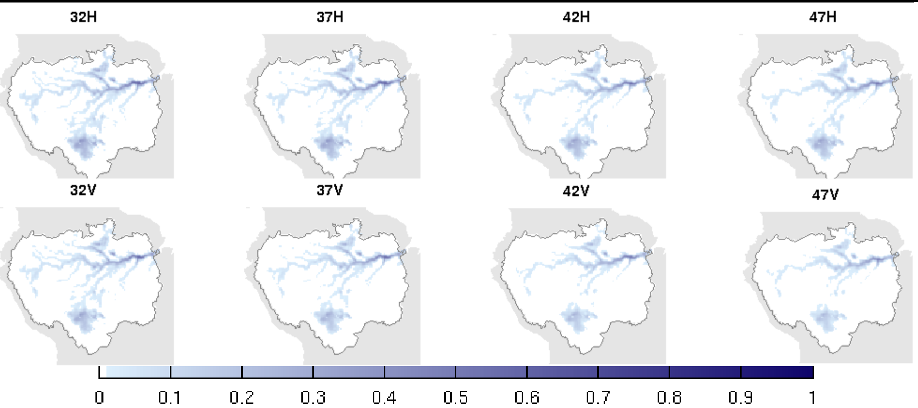




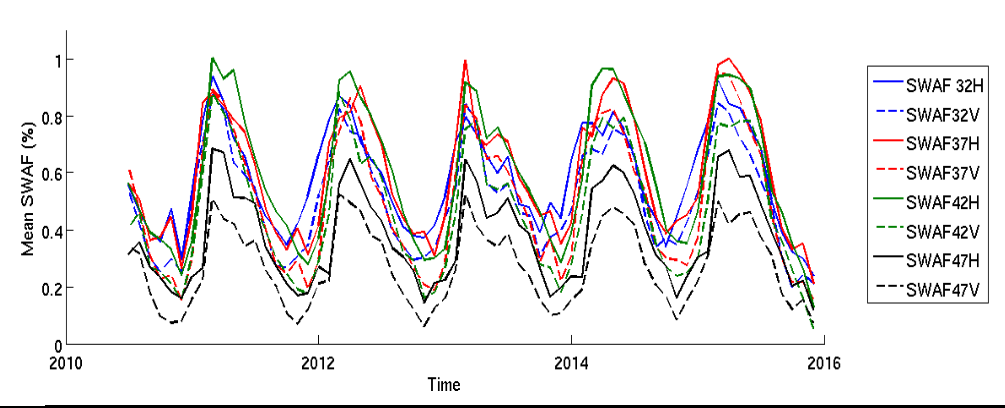


Impact of polarisation and incidence angle

Mean SWAF for 2010 - 2016



Timeseries over entire basin



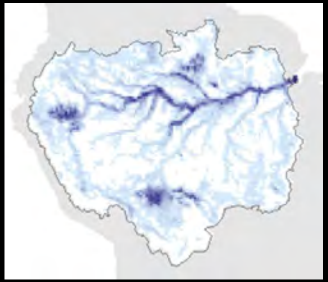
Parrens et al. Waters 2017

Validation of the SMOS Water fraction

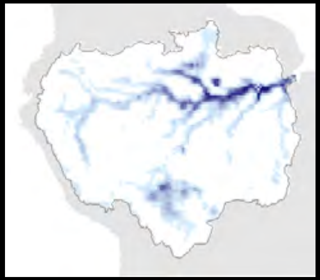
Against static maps

IGBP

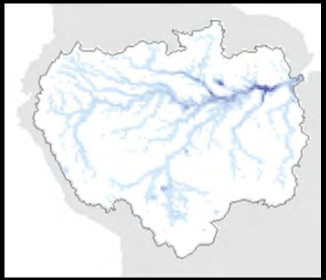
GlobCover



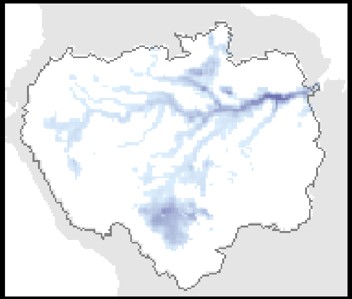
GIEMS

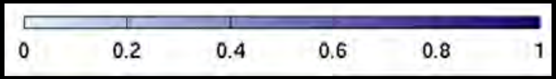


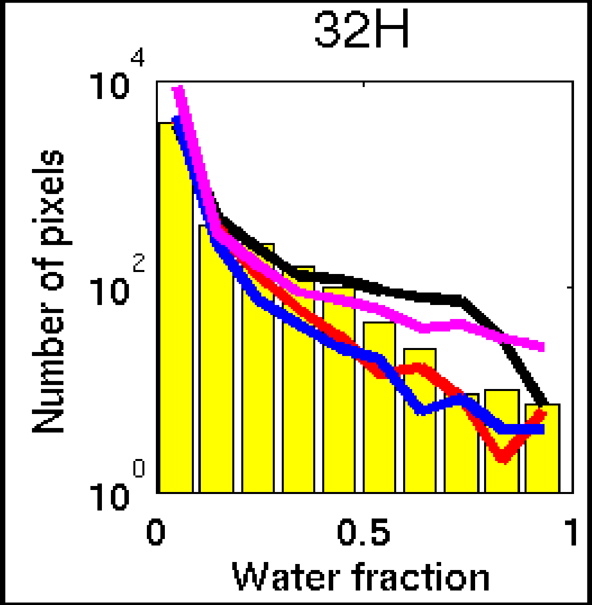
ESA CCI



SWAF



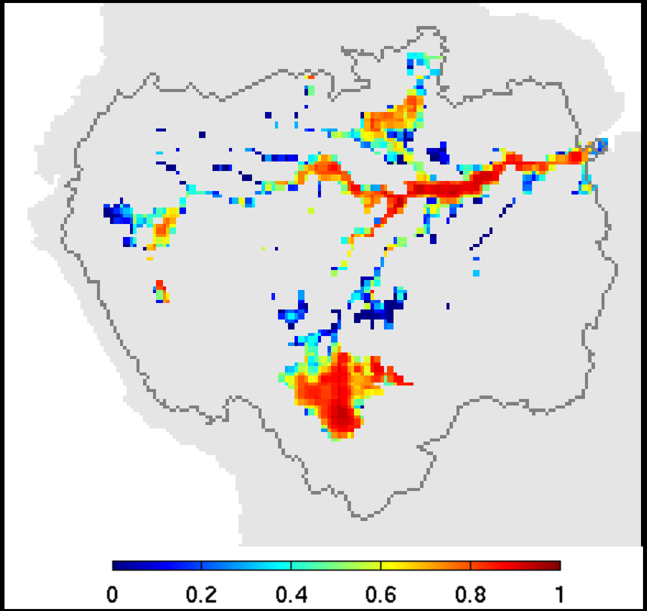




Validation of the SMOS Water fraction

Against dynamic maps

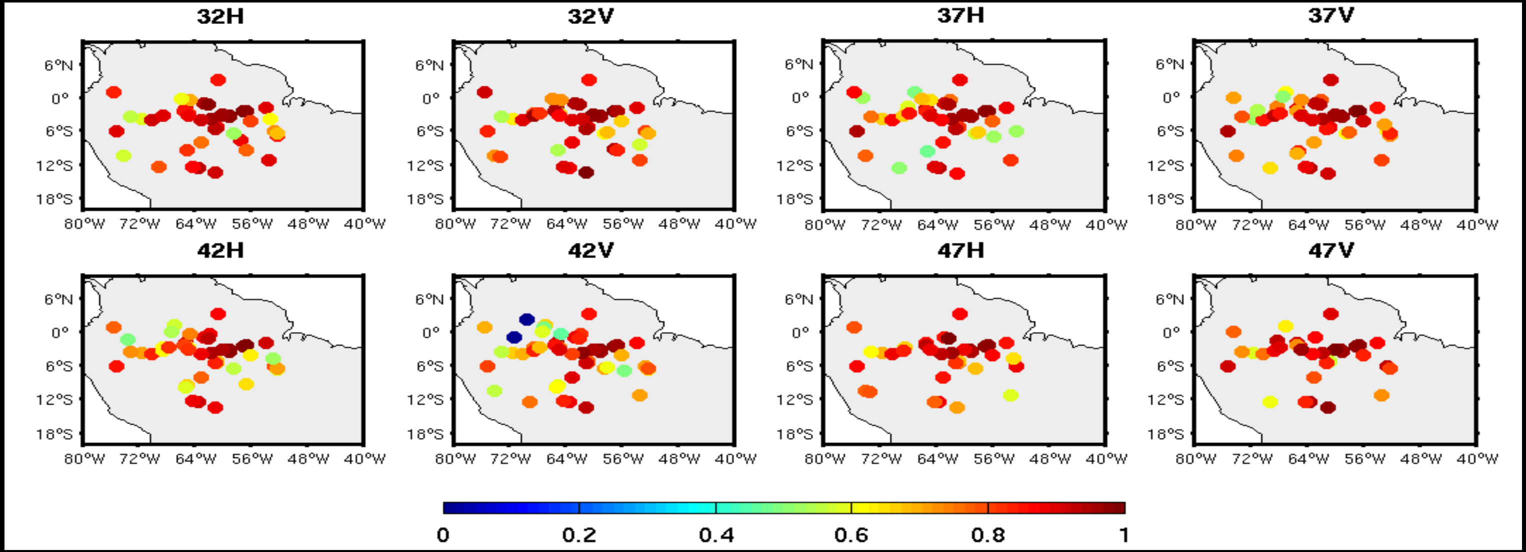
Temporal correlation between SWAMPS and SWAF products



Validation of the SMOS Water fraction

Against heights from altimetry

Correlation between Jason-2 water heights and SWAF



Nodes with high topography are excluded

How are the wetlands over tropical basins impacted by the extreme hydrological events ?

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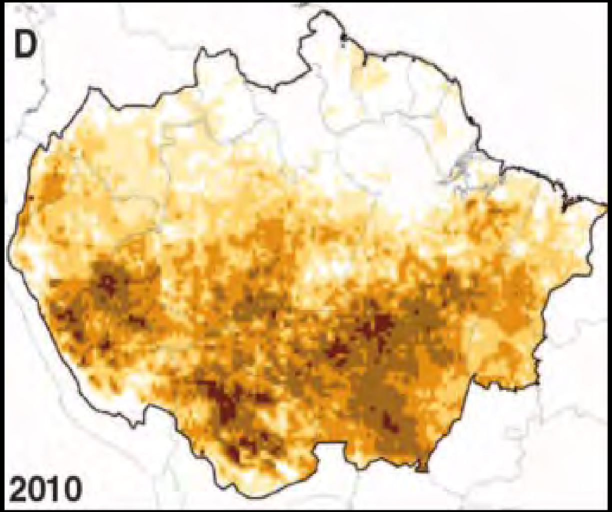
Droughts of 2010

Clim. Water. Index

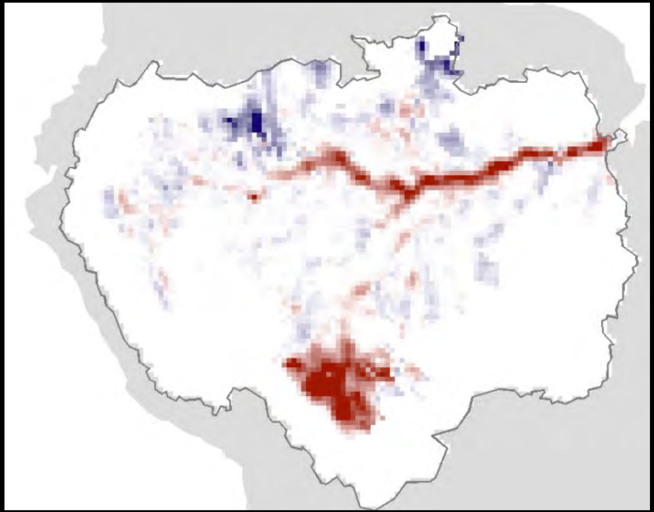


water deficit

(Lewis et al., Science 2011)

Anomaly of water fraction

Jul. – Sept. 2010



anomaly of SMOS water fraction

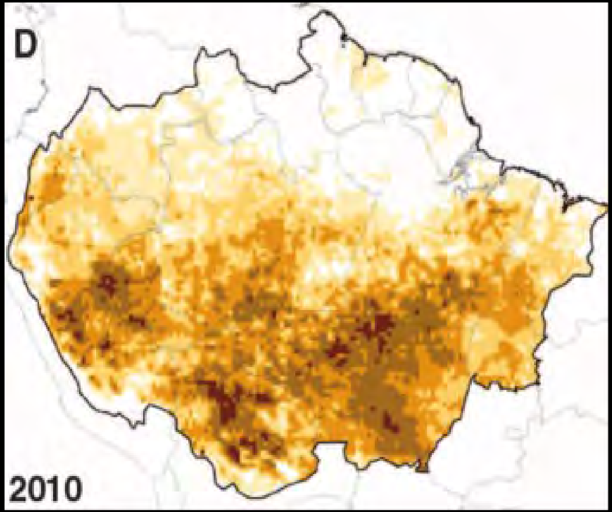
abnormaly dry *abnormaly wet*

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

Reuters ©

Droughts of 2010 vs 2015

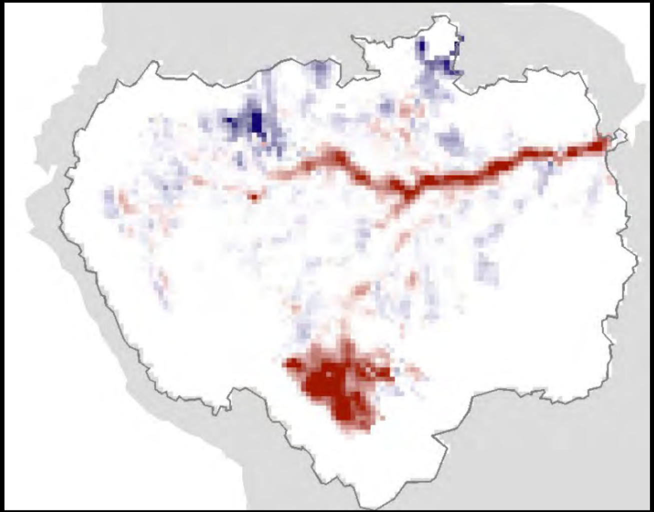
Clim. Water. Index



water deficit

(Lewis et al., Science 2011)

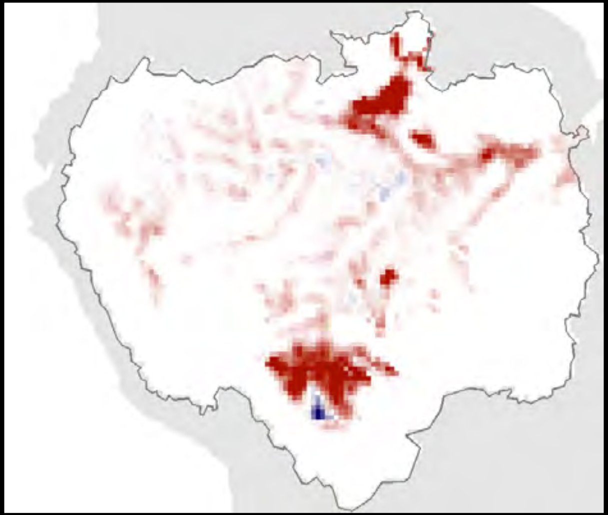
Anomaly of water fraction
Jul. – Sept. 2010



anomaly of SMOS water fraction

abnormaly dry *abnormaly wet*

Anomaly of water fraction
Oct. – Dec. 2015

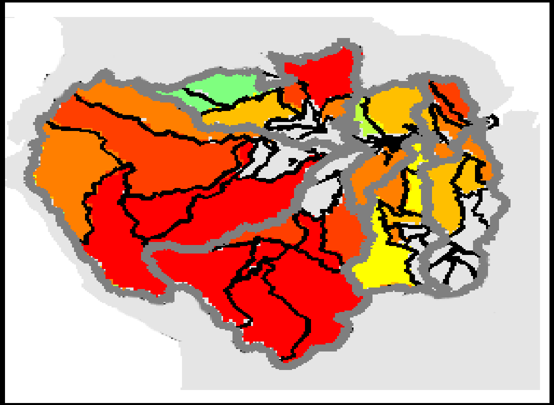


anomaly of SMOS water fraction

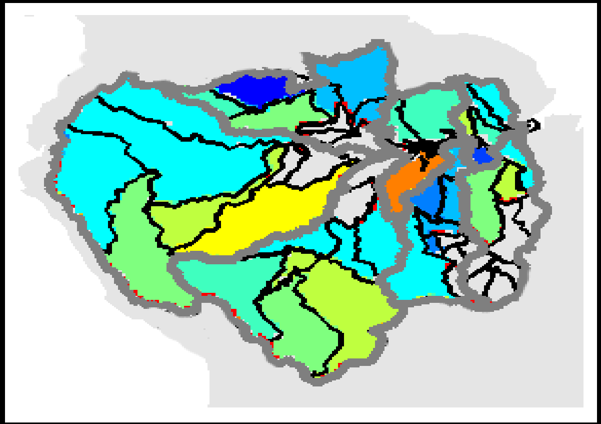
abnormaly dry *abnormaly wet*

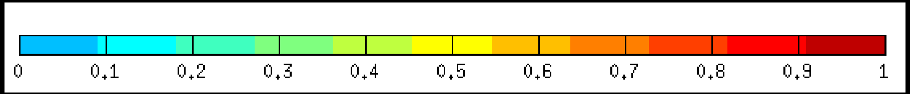
Link between Precipitation and SWAF

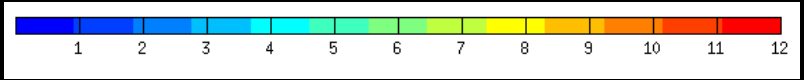
Correlation value (r)



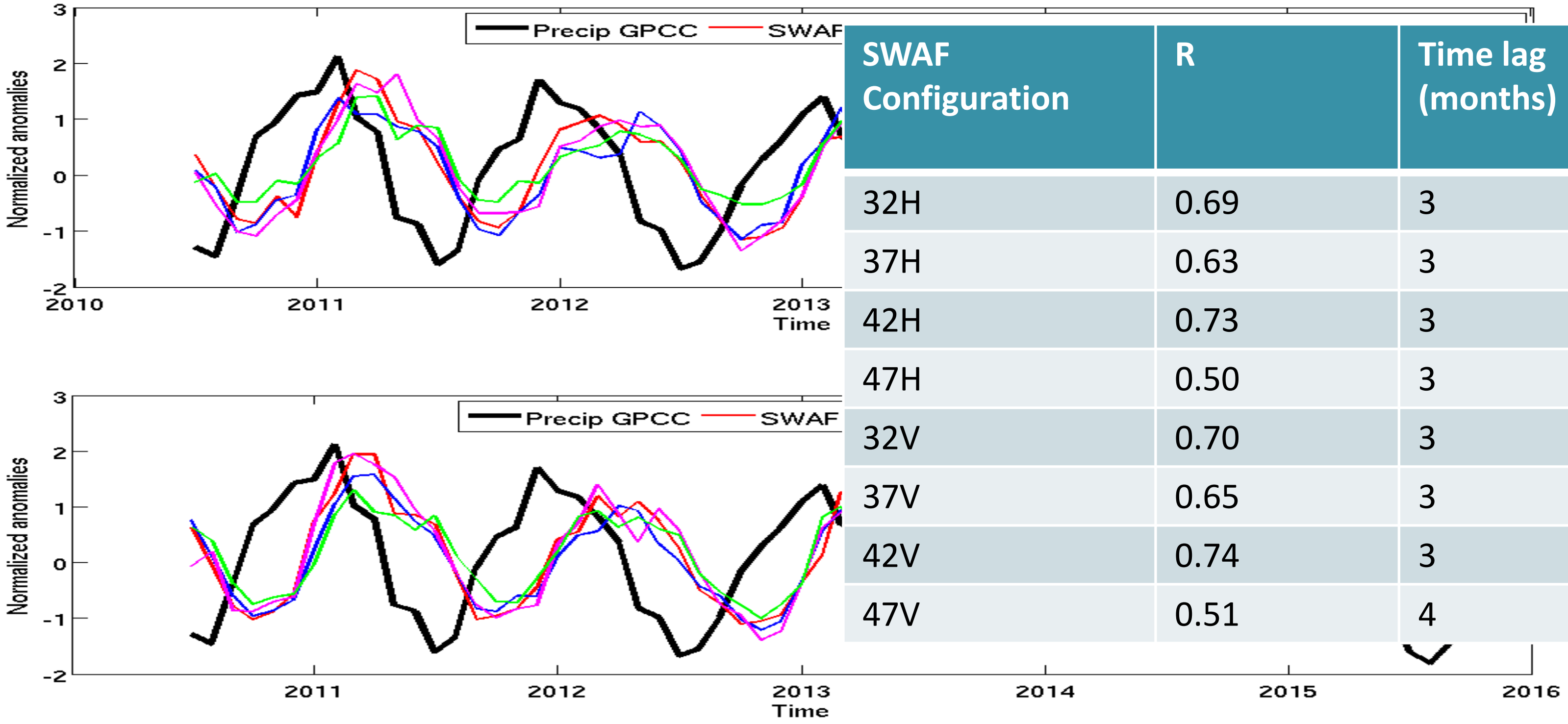
Time lag (weeks)





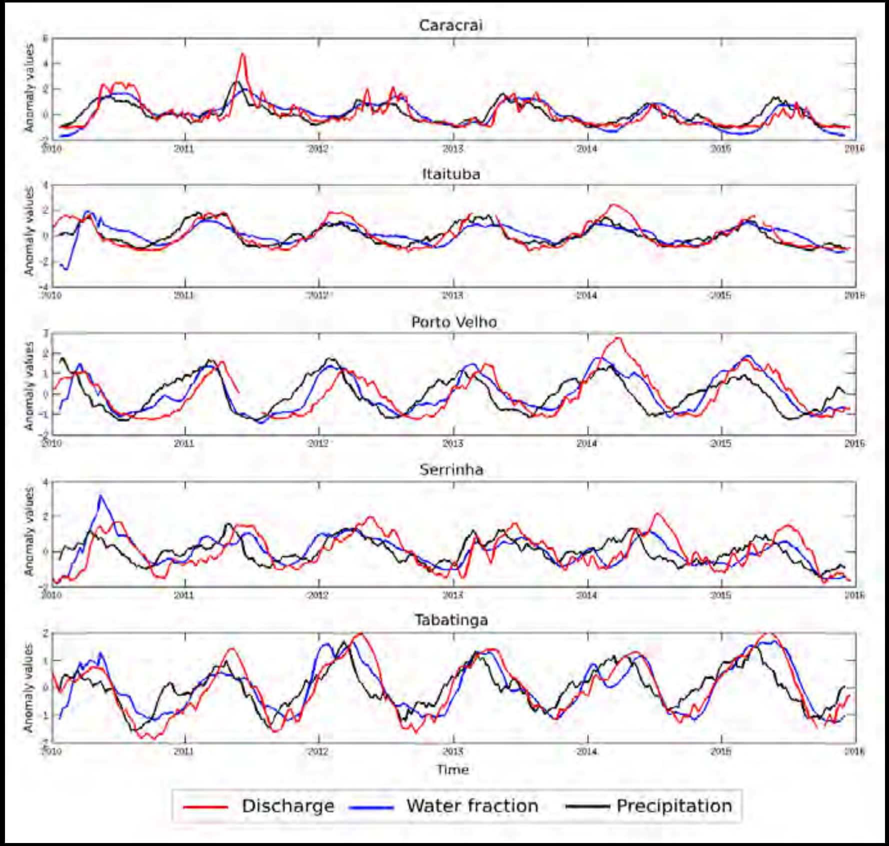


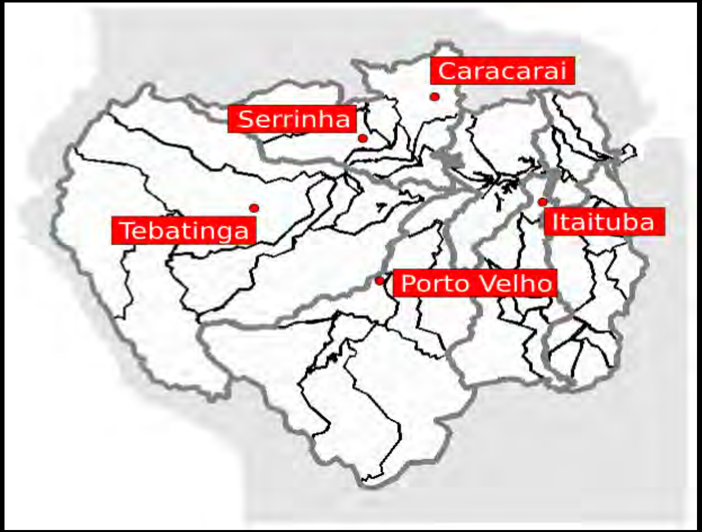
Comparison of the SMOS water fraction
With precipitation data (GPCC – monthly products)



SWAF Configuration	R	Time lag (months)
32H	0.69	3
37H	0.63	3
42H	0.73	3
47H	0.50	3
32V	0.70	3
37V	0.65	3
42V	0.74	3
47V	0.51	4

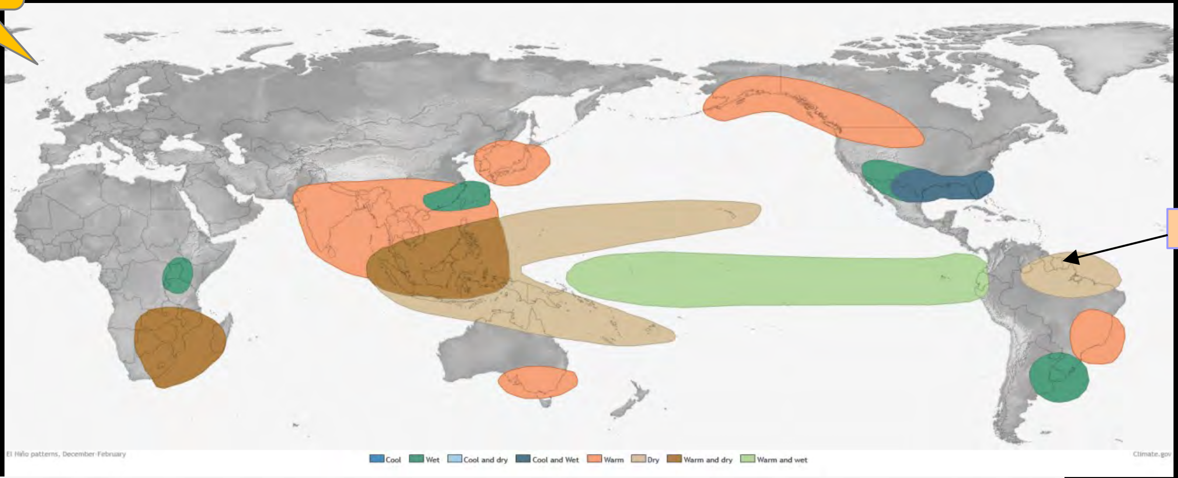
Link between Discharge and SWAF





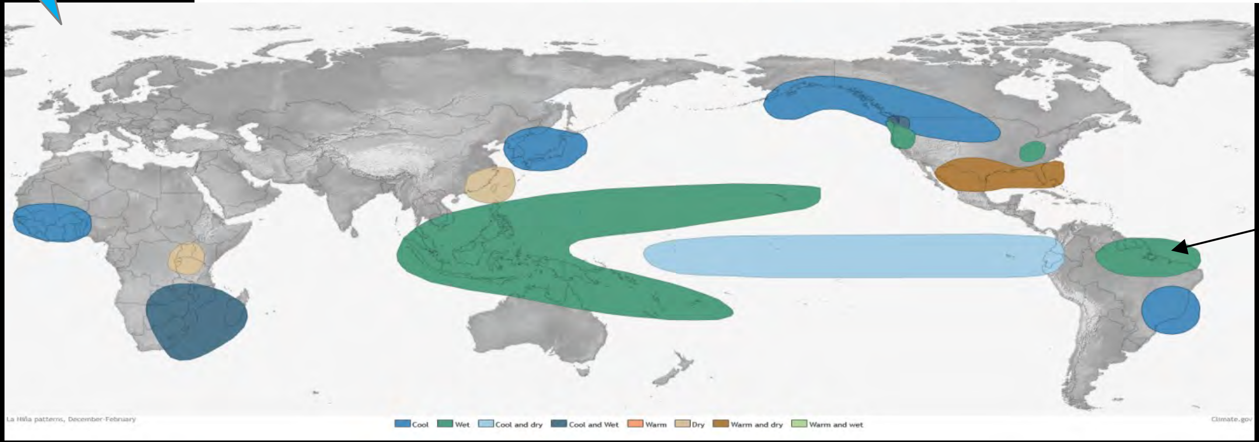
What are the changes during ENSO years ?

El Nino



Dry

La Nina

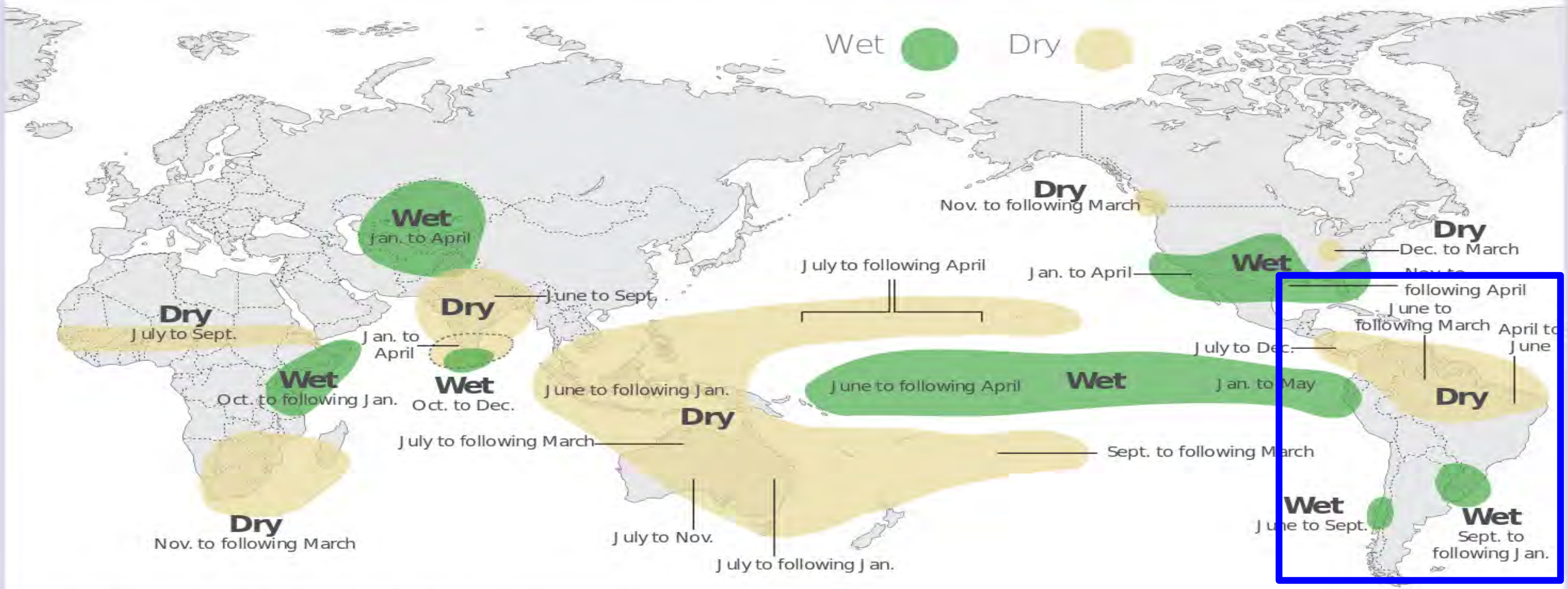


Wet

What are the changes during ENSO years ?

El Niño and Rainfall

El Niño conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although they vary somewhat from one El Niño to the next, the strongest shifts remain fairly consistent in the regions and seasons shown on the map below.

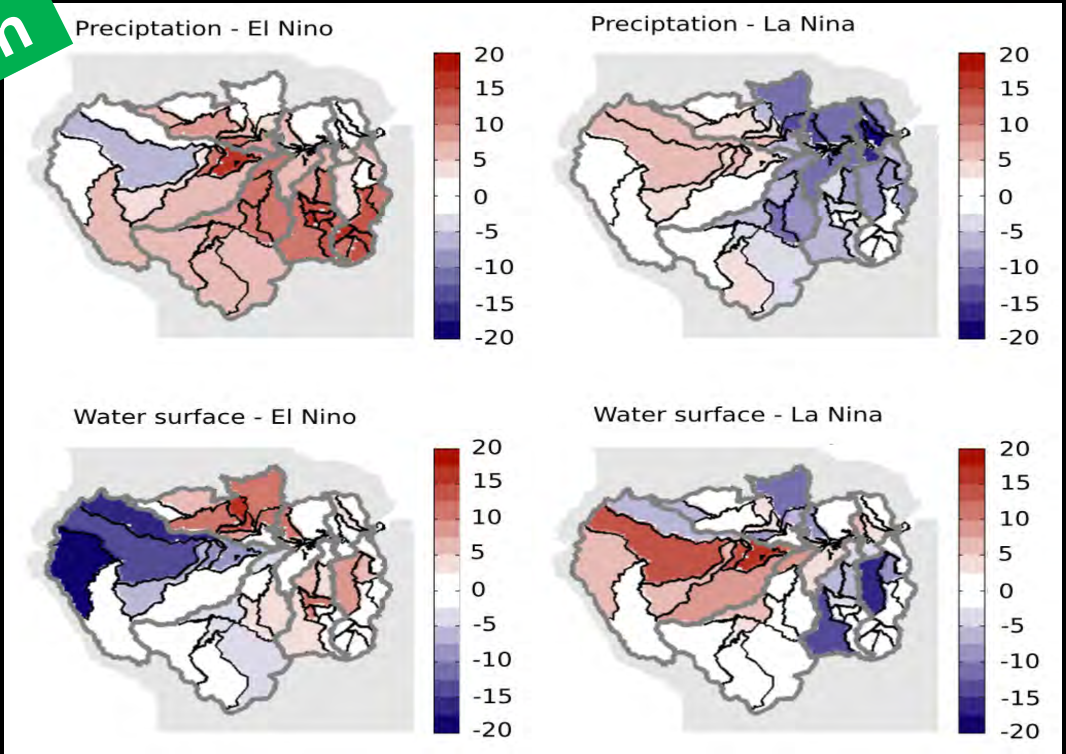


For more information on El Niño and La Niña, go to: http://iri.columbia.edu/ENSO

Sources: Ropelewski, C. F. and M. S. Halpert. 1989: Precipitation patterns associated with the high index phase of the Southern Oscillation. J. Climate, 2, 268-284.
Mason and Goddard, 2001: Probabilistic precipitation anomalies associated with ENSO. Bull. Am. Meteorol. Soc. 82, 619-638.

Difference of anomaly of integrated water surfaces

rainy season



Dryer

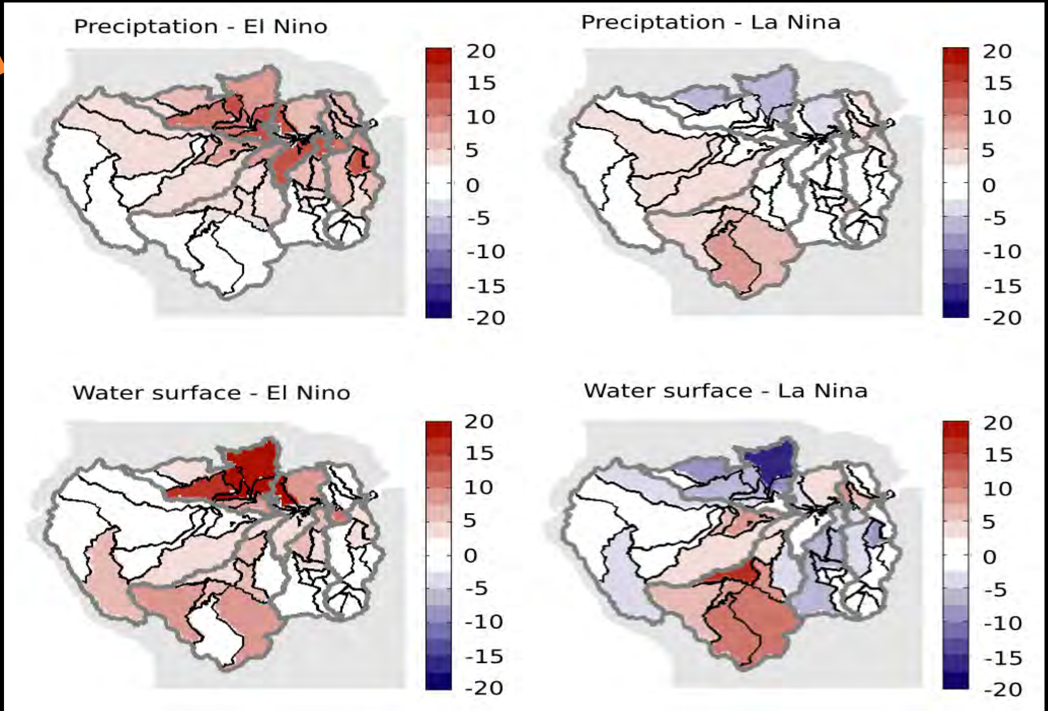
Wetter

Dryer

Wetter

Difference of anomaly of integrated water surfaces

dry season



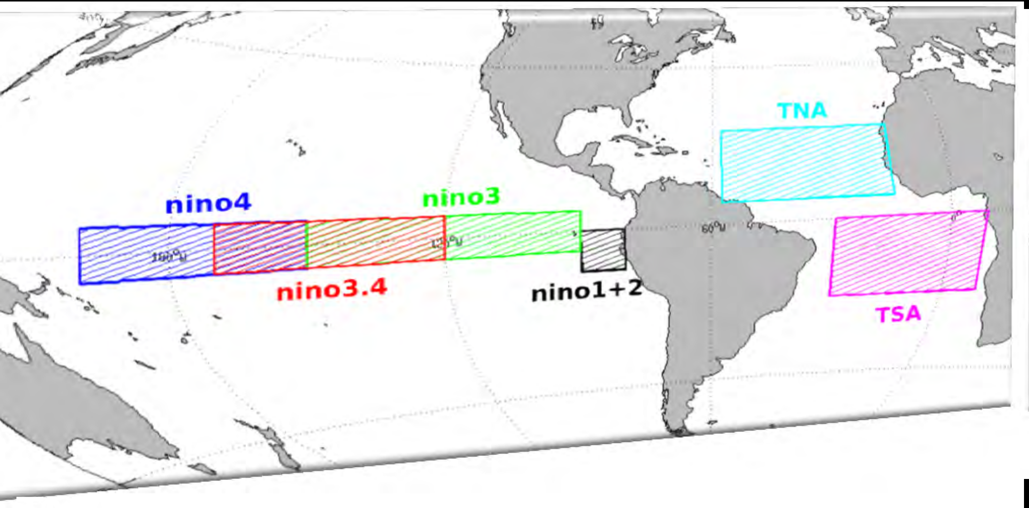
Dryer

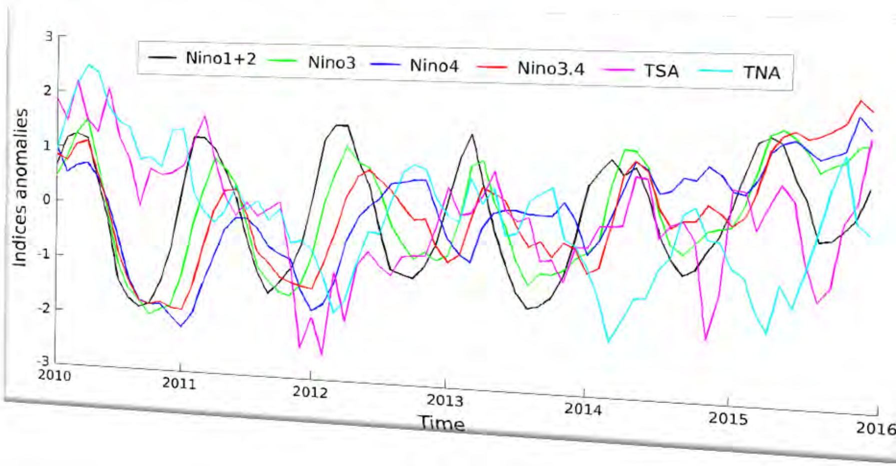
Wetter

Dryer

Wetter

Localisation of the SST indices





TNA: Tropical Northern Atlantic Index
TSA: Tropical South Atlantic Index

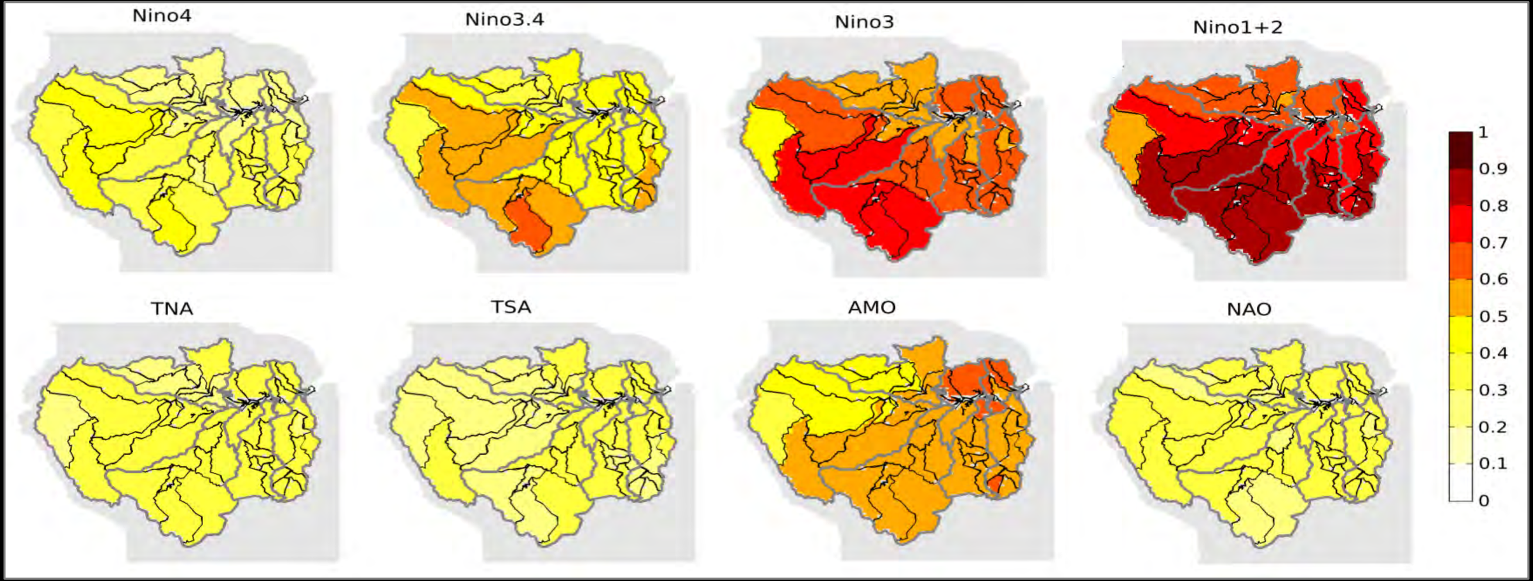
Normal years : 2012, 2013, 2014
El nino year : 2015
La nina year : 2011

ONI : Oceanic Nino Index

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2010	1.3	1.2	0.9	0.5	0.0	-0.4	-0.9	-1.2	-1.4	-1.5	-1.4	-1.4
2011	-1.3	-1.0	-0.7	-0.5	-0.4	-0.3	-0.3	-0.6	-0.8	-0.9	-1.0	-0.9
2012	-0.7	-0.5	-0.4	-0.4	-0.3	-0.1	0.1	0.3	0.3	0.3	0.1	-0.2
2013	-0.4	-0.4	-0.3	-0.2	-0.2	-0.2	-0.3	-0.3	-0.2	-0.3	-0.3	-0.3
2014	-0.5	-0.5	-0.4	-0.2	-0.1	0.0	-0.1	0.0	0.1	0.4	0.5	0.6
2015	0.6	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.7	2.0	2.2	2.3
2016	2.2	2.0	1.6	1.1	0.6	0.1	-0.3	-0.6	-0.7			

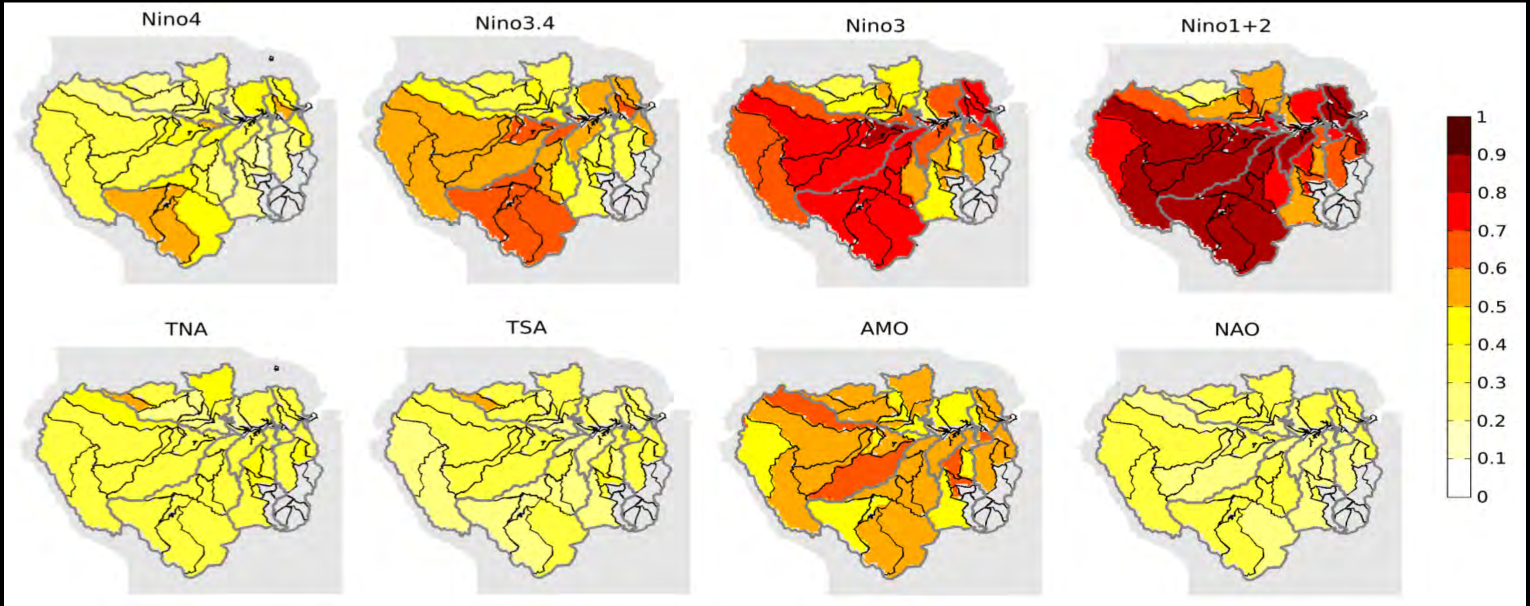
Teleconnexion

Lagged correlation between SST indices and TRMM precipitation data



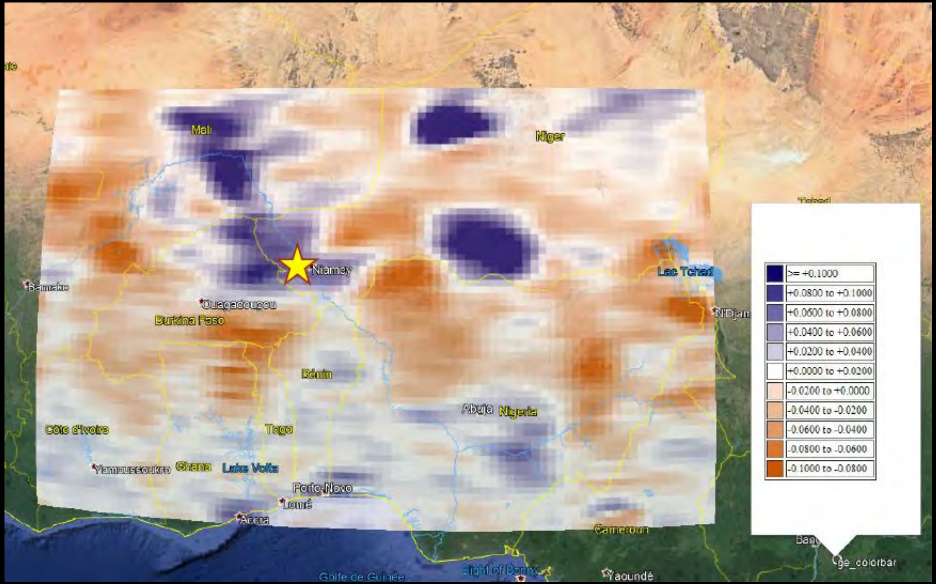
Teleconnexion

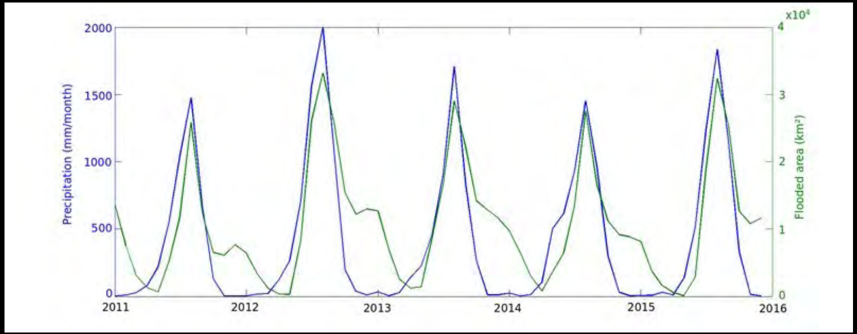
Lagged correlation between SST indices and SWAF surface water fraction data

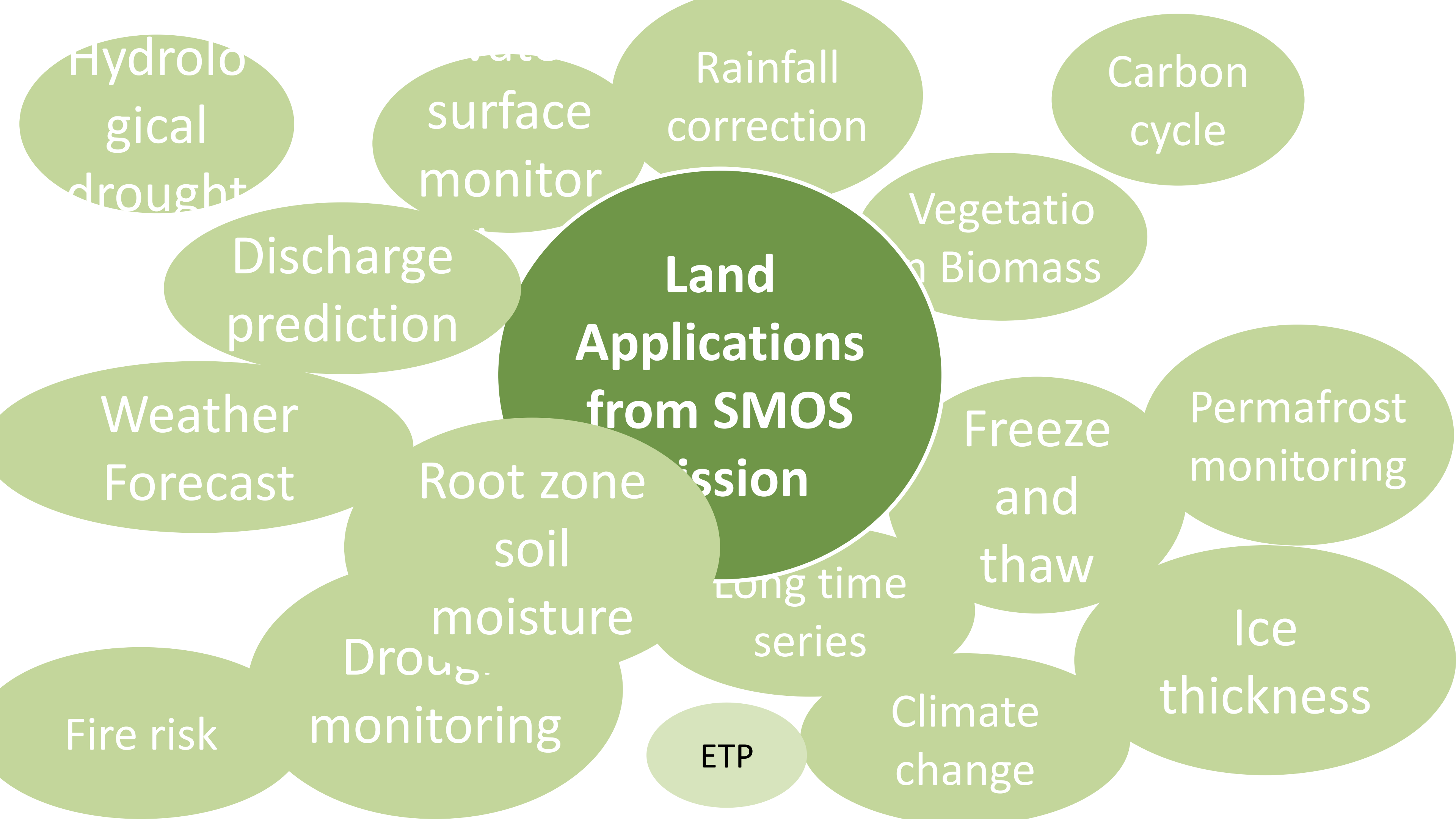


Can we see the current flods in Niger ?

Flood area difference between 2016 and 2017

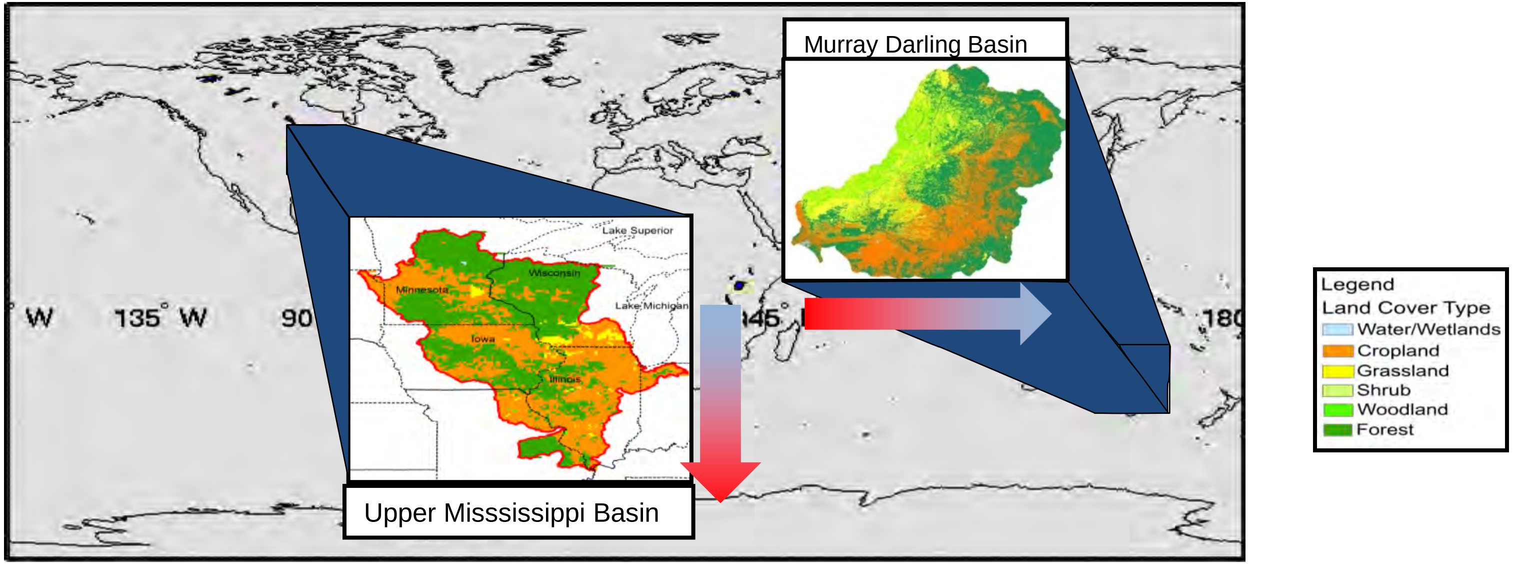




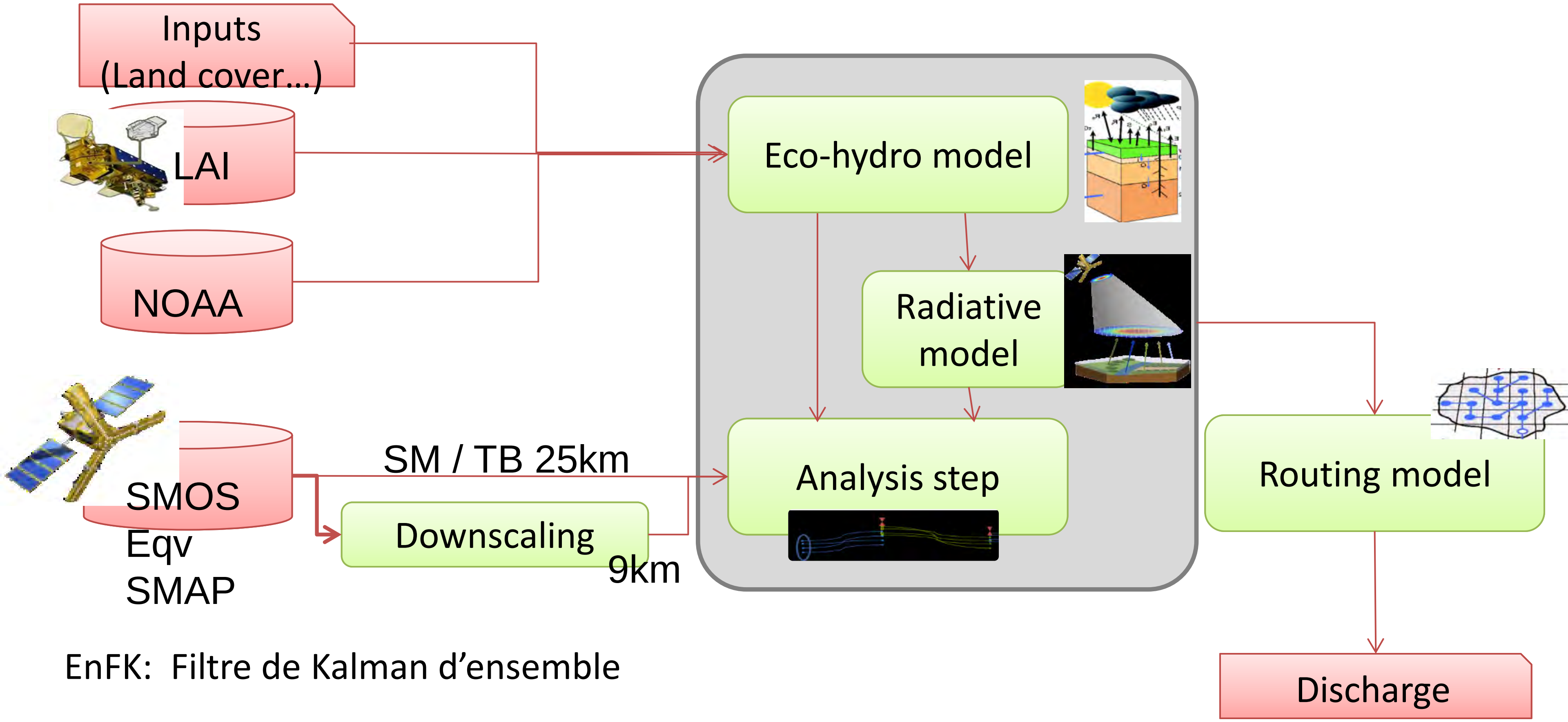


Land Applications from SMOS ission
Hydrolo gical drought
surface monitor
Rainfall correction
Carbon cycle
Vegetatio Biomass
Discharge prediction
Weather Forecast
Root zone soil moisture
Freeze and thaw
Permafrost monitoring
ong time series
Ice thickness
Droug monitoring
Fire risk
ETP
Climate change

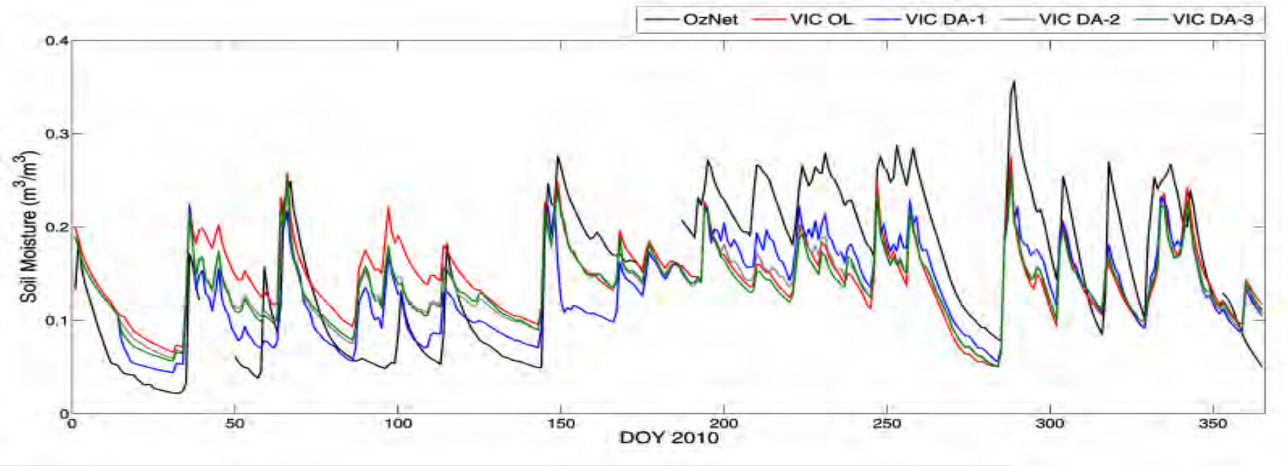
Apport de l'humidité du sol SMOS dans la prévision du débit.



Land Data Assimilation System - LDAS



Surface soil moisture - Murray Darling Basin



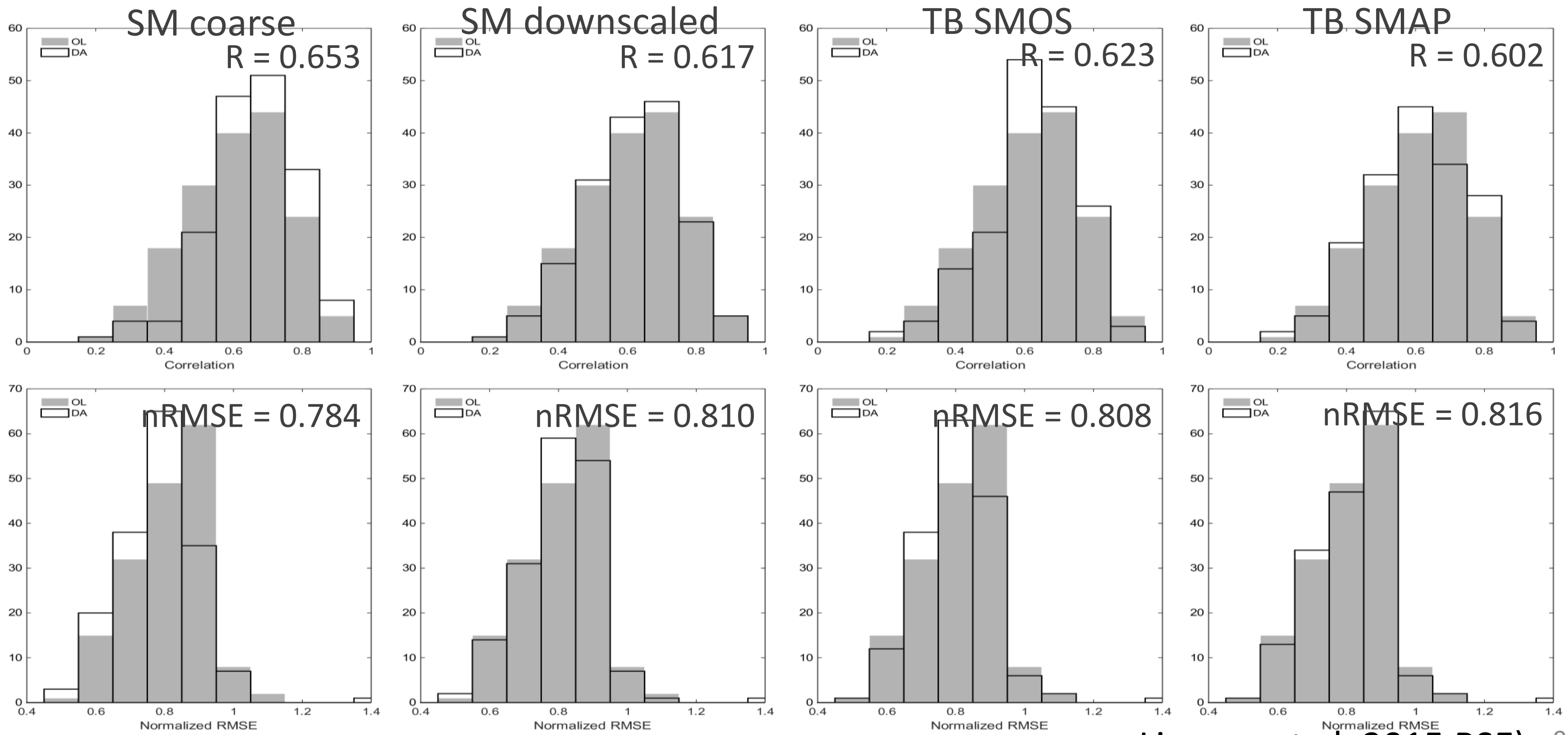
SM record	RMSE m³/m³	R (-)
SMOS	0.045	0.726
VIC open loop	0.058	0.549
DA SM coarse	0.045	0.713
DA SM downscaled	0.047	0.727
DA TB SMOS	0.050	0.661
DA TB SMOS(SMAP)	0.046	0.700

(Lievens et al. 2015 RSE)
(Lievens et al. 2016 RSE)
(Lievens, Al Bitar et al. 2015 JHM)
(Verhoest et al. 2014)

Discharge – Murray Darling Basin

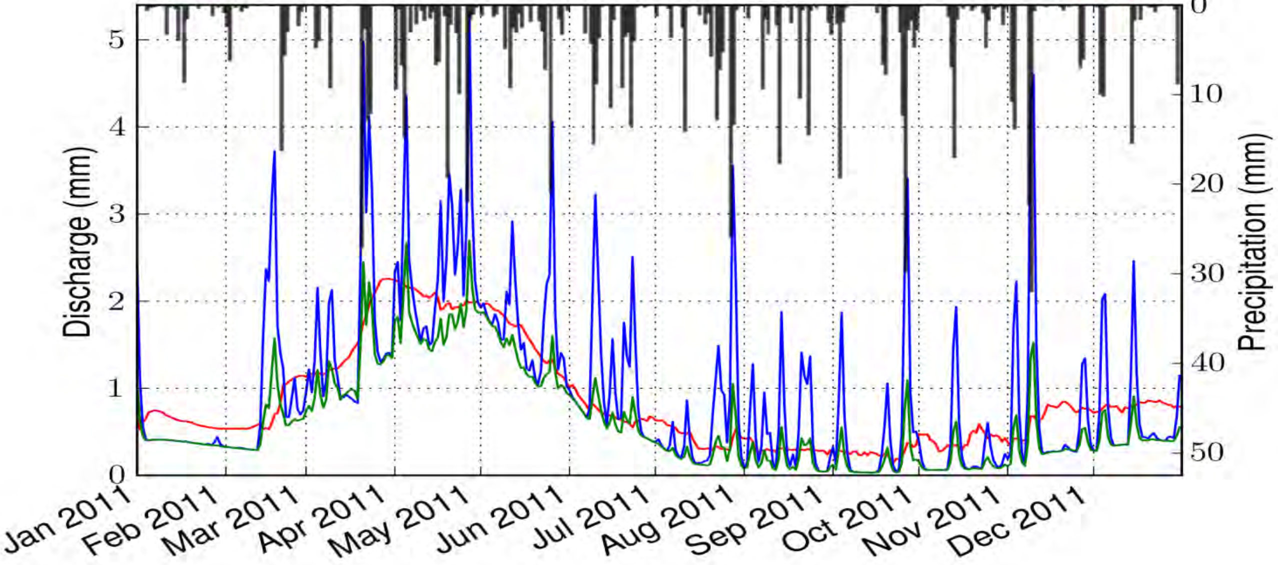
Comparison of DA experiments

Open loop: R = 0.608 / nRMSE = 0.812

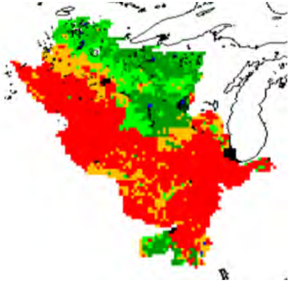


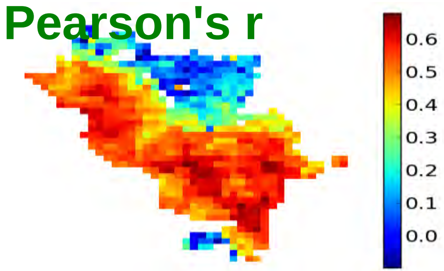
Lievens et al. 2015 RSE)

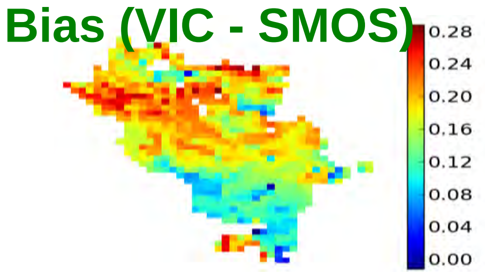
Débit sous bassin – Upper Mississippi Bassin



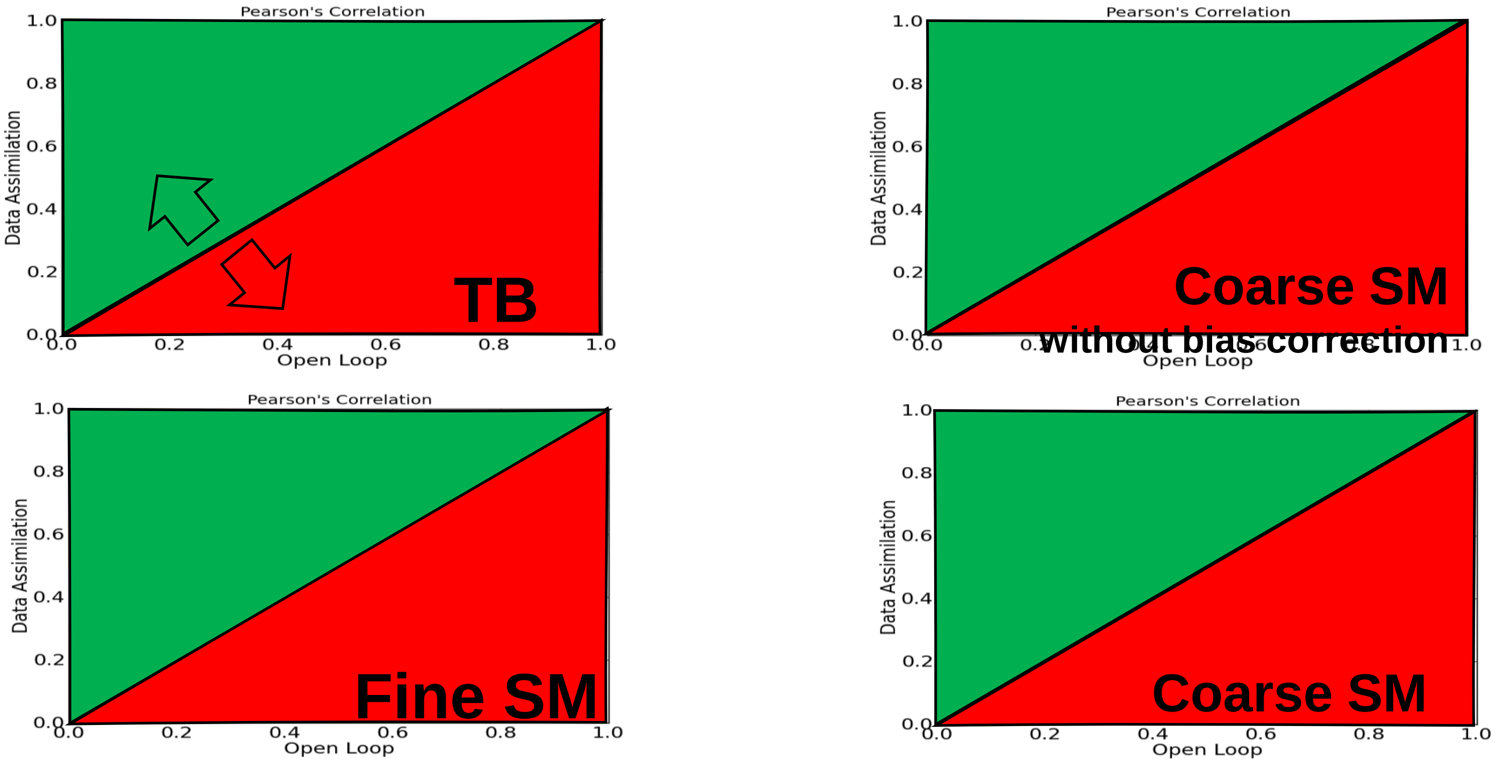
	OL	DA
KGE	0.22	0.73
Ratio of std	1.66	0.98
Bias	0.14	-0.21
Correlation	0.61	0.90





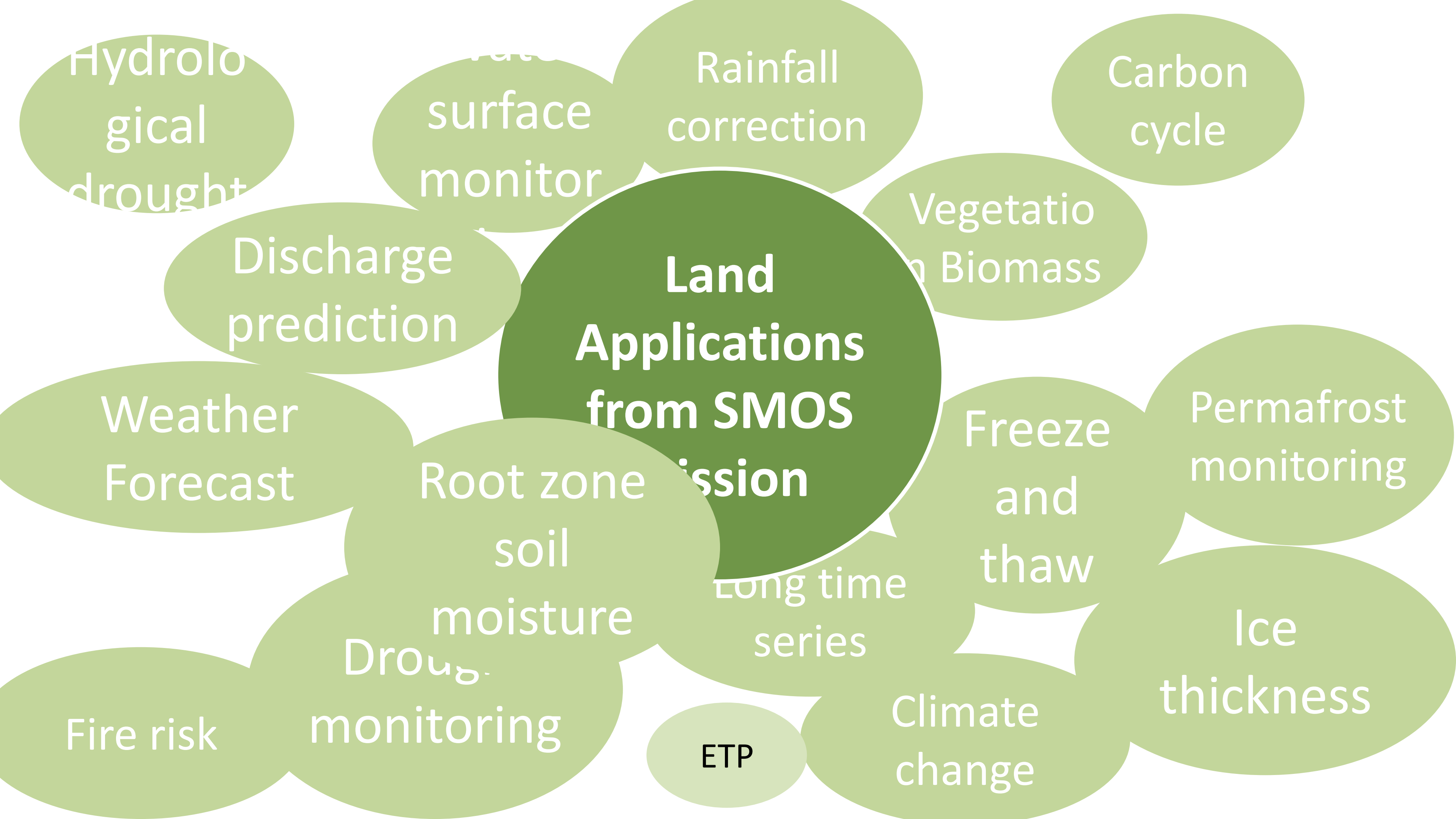


Débit sous bassin – Upper Mississippi Bassin



Size of the dot represents the relative area of the basin.
TB is for May-Nov, 2011, others are for Jan, 2010 – Dec, 2011

S. K. Tomer et al. 2014


Land
Applications
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Hydrolo
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surface
monitor
Rainfall
correction
Carbon
cycle
Vegetatio
Biomass
Discharge
prediction
Weather
Forecast
Root zone
soil
moisture
Freeze
and
thaw
Permafrost
monitoring
ong time
series
Ice
thickness
Fire risk
Drou
monitoring
ETP
Climate
change

SMOS

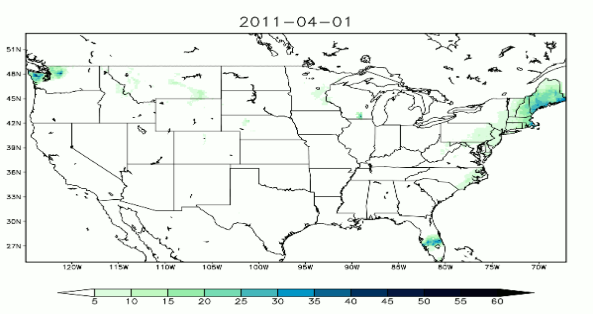
L4 – Flood risk Forecast

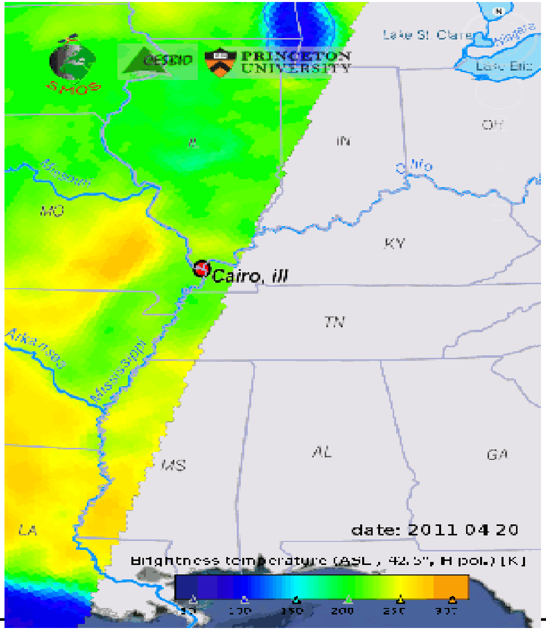
Al Bitar A., Chone A., Tomer S. K., Joyeux J., Villard P. , Bodnar R., Kerr Y.

Flood Risk Mapping

End

Prediction / Early alert | **Monitoring** | Post / damage analysis

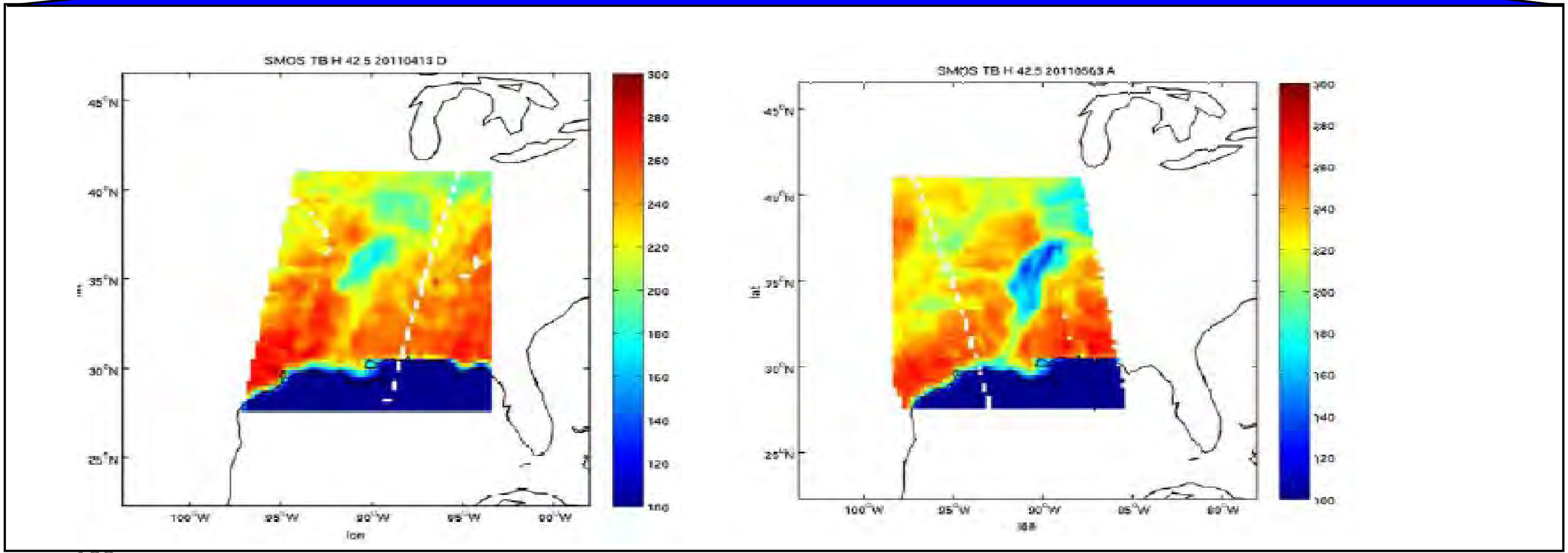




Flood Risk Mapping

End

Prediction / Early alert | **Monitoring** | Post / damage analysis



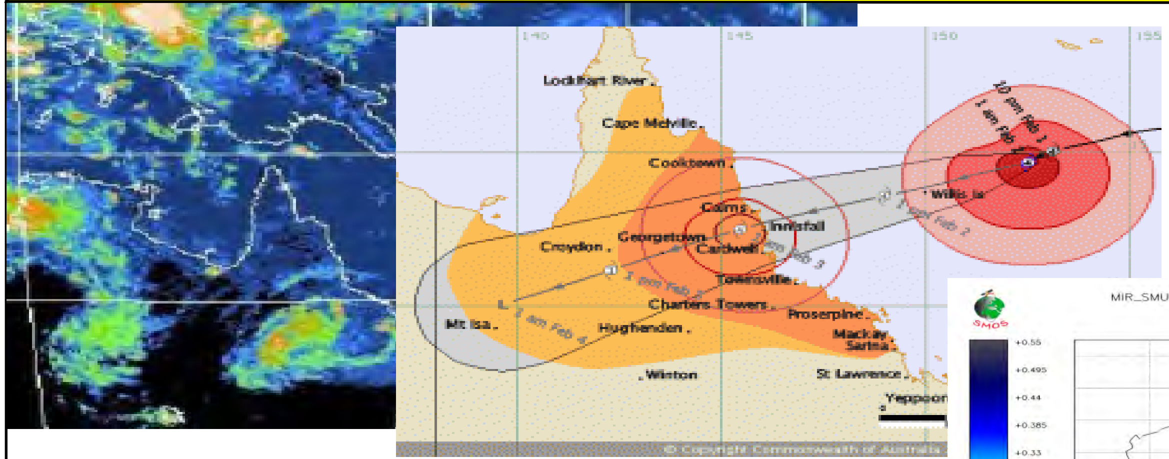
Flood Risk Mapping

- The use of SMOS for mapping floods is hampered by the resolution.
- Eventhough SMOS has the advantage of frequent revisit and all weather capabilities. This is likely to be less interesting with the recent launch of the ESA Sentinel 1 mission and futur frequente rivisits radar.

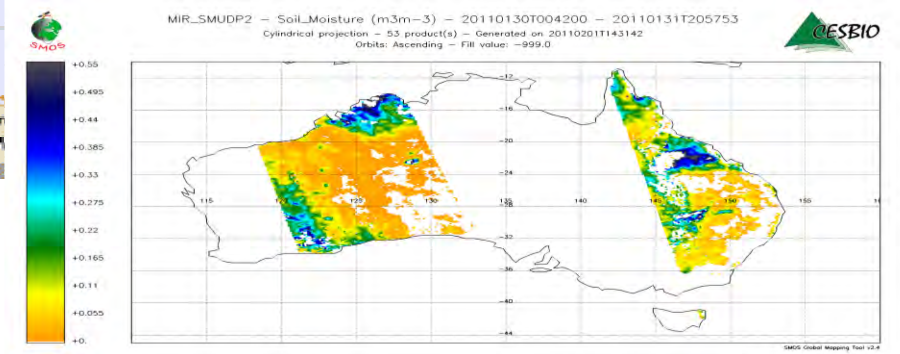
Flood Risk Forecast

Start | End

Prediction / Early alert | **Monitoring** | Post / damage analysis



Cyclone YASI, 2011



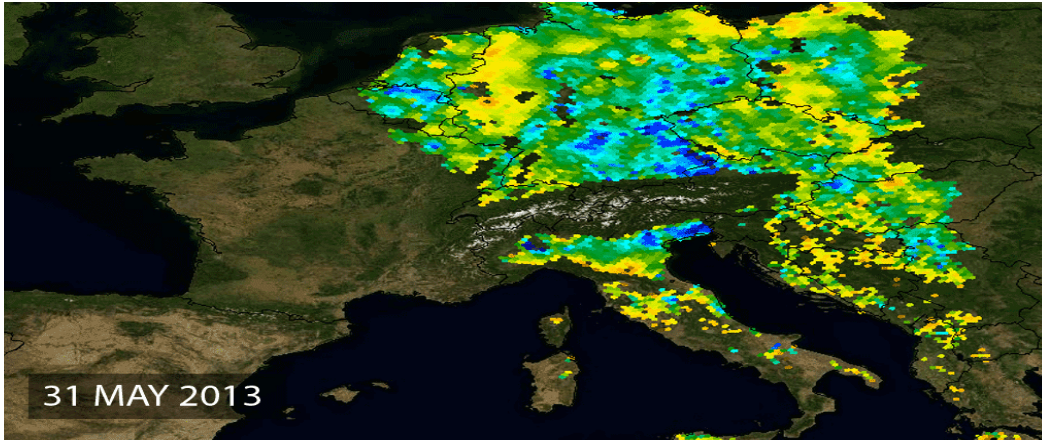
SMOS Blog, Gruhier C., Kerr Y., BoM

Flood Risk Mapping

End

Prediction / Early alert | **Monitoring** | Post / damage analysis

Germany, 2013



ESA portal, Drusch M.

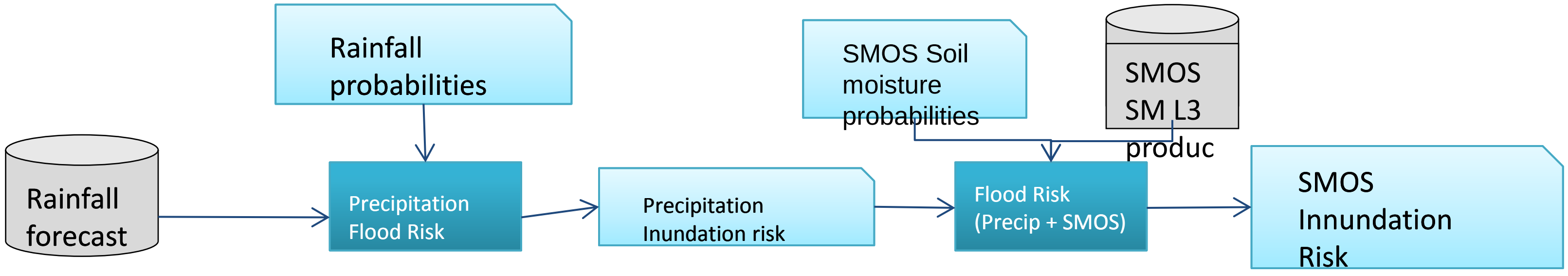
Flood Risk Forecast

- Flood can be classified into several types : Hurricanes, storm surge, heavy rainfall…
- Soil moisture is expected to play a role for heavy rainfall driven floods, but there are still many ways of implementing this information in hydrological modeling.
- Here we consider that soil moisture conditions prior to the flooding will influence the projected flood risk in a 1-5 days for the following reasons :
  - saturated soils increase risks of flooding
  - Soil moisture is a proxy for rainfall
  - Land surface / atmospheric coupling (Koster et al. 2010)

SMOS Flood Risk Forecast

Methodology

Leveraging inundation risk based on SMOS soil moisture prior knowledge

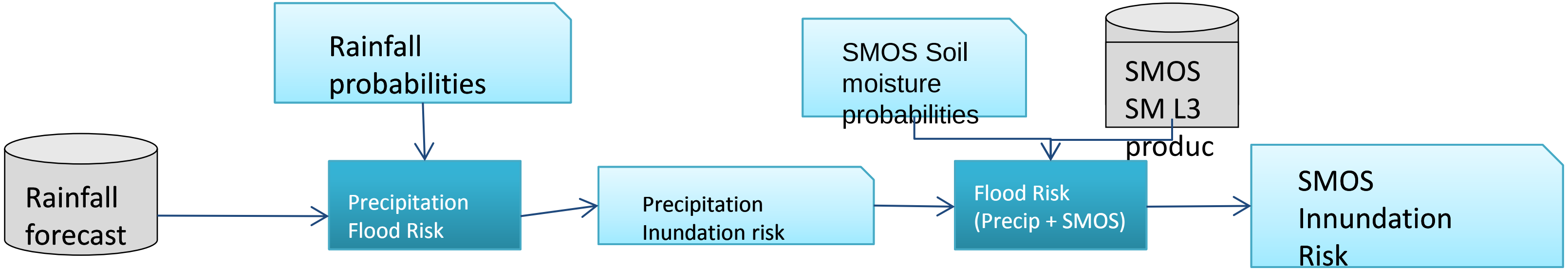


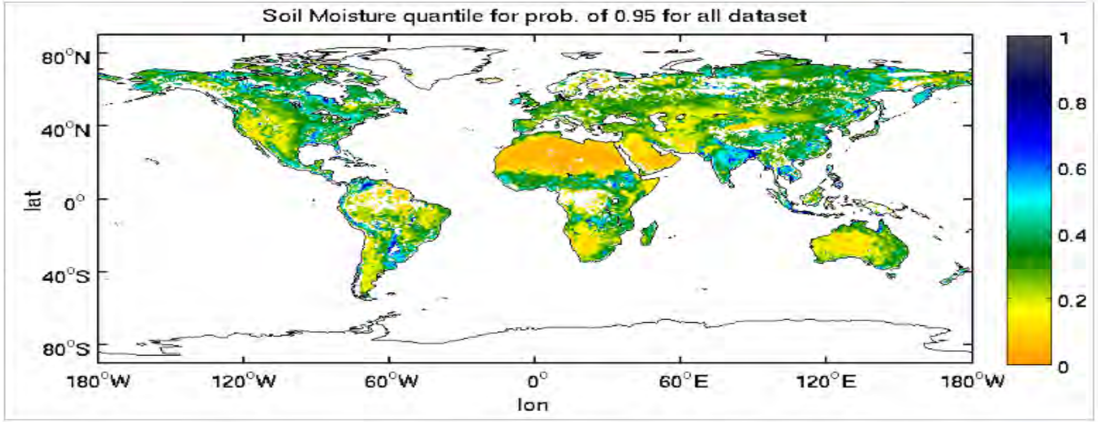
Prate	Risk
Prate < Perc(0.7)	None / 0
Prate_Perc(0.7) < Prate < Perc(0.8)	Low /1
Prate_Perc(0.8) < Prate < Perc(0.9)	Moderate / 2
Prate_Perc(0.9) < Prate	High / 3

SMOS Flood Risk Forecast

Methodology

Leveraging inundation risk based on SMOS soil moisture prior knowledge

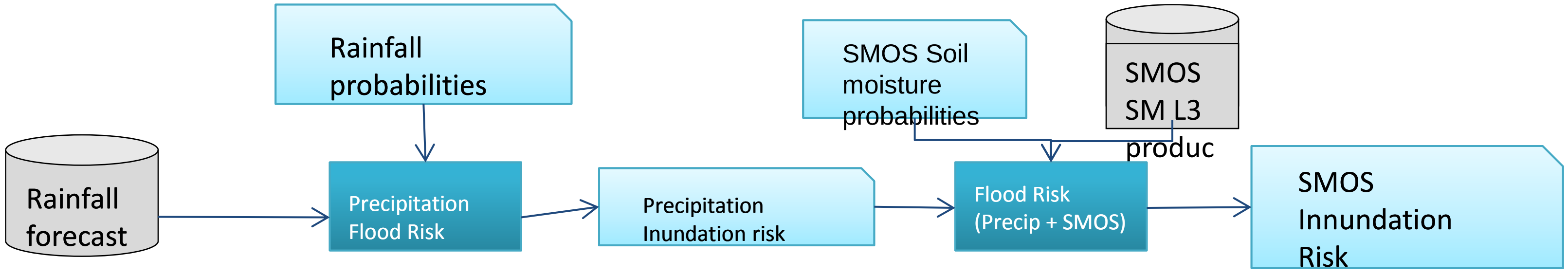




SMOS Flood Risk Forecast

Methodology

Leveraging inundation risk based on SMOS soil moisture prior knowledge

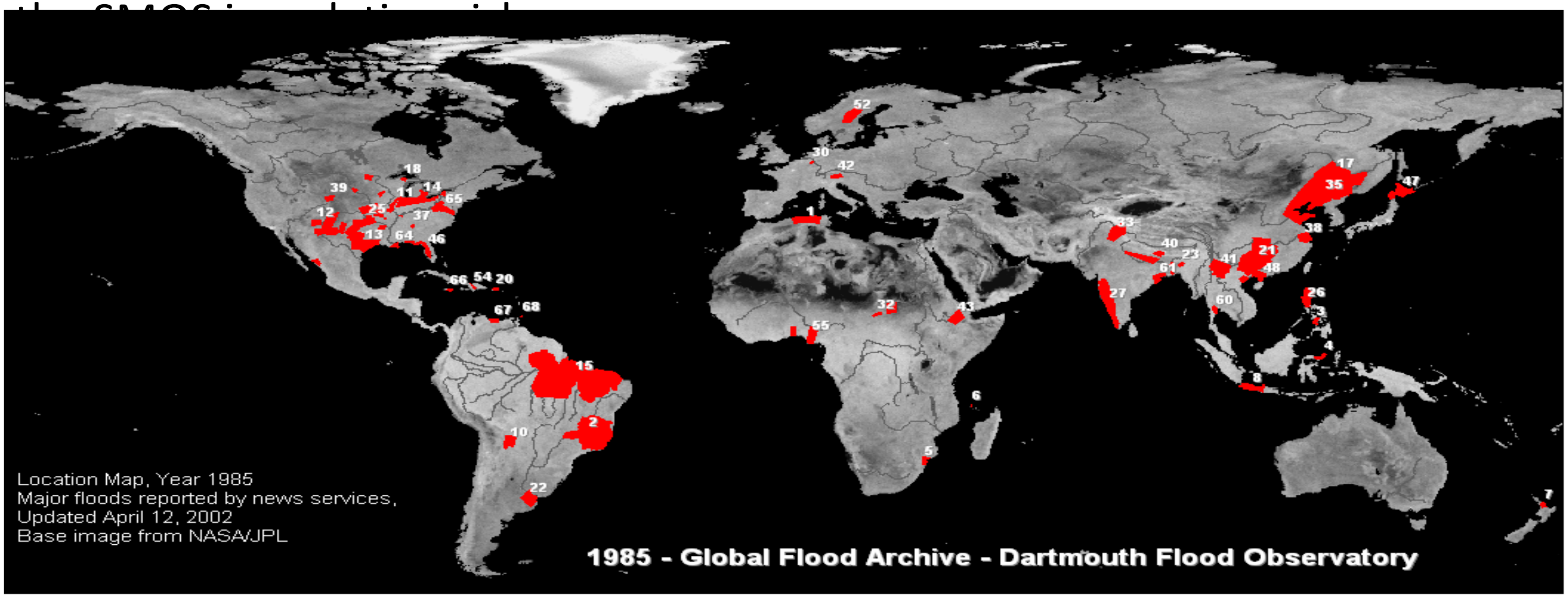


SM vs SM_perc	None /0	Low /1	Moderate /2	High /3
0.8	None /0	None /0	Low / 1	Moderate /2
0.8 - 0.9	None /0	Low / 1	Moderate /2	High / 3
0.9 +	None /0	Moderate /2	High / 3	Ext High / 4

SMOS Flood Risk Forecast

Results

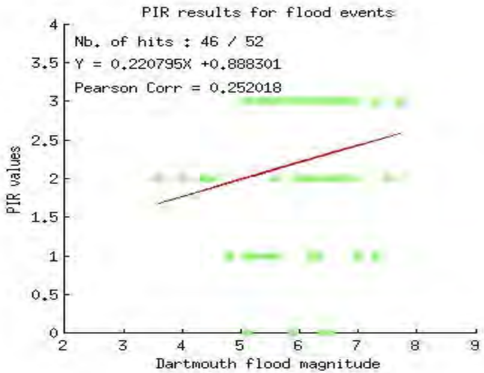
- Compare with the Dartmouth Flood Observatory
- Dartmouth magnitude of the flood against the Precipitation inundation risk and the SMOS inundation risk

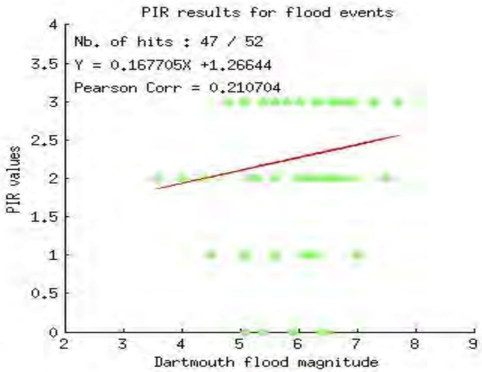


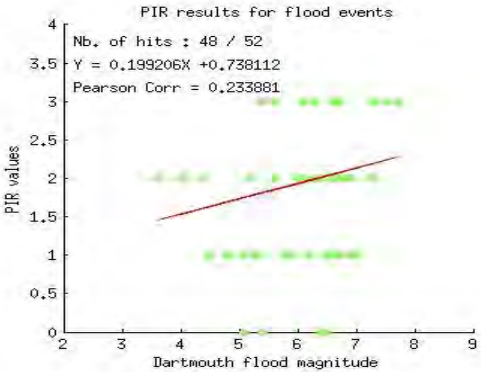
Comparision over Africa

1 day | 3 days | 5 days

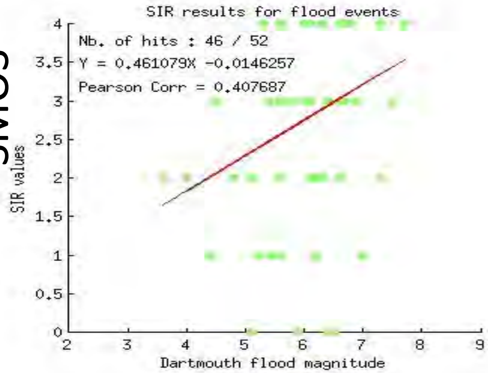
Precipitation

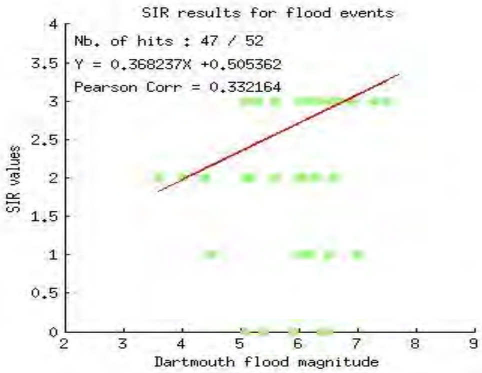


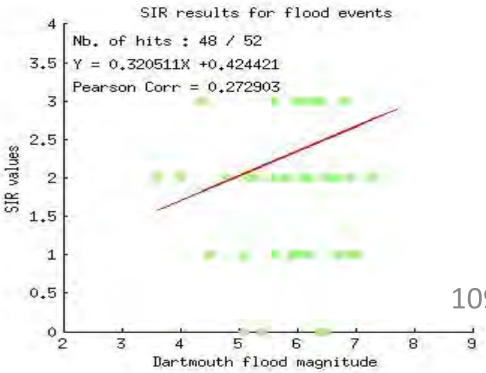




Precipitation + SMOS



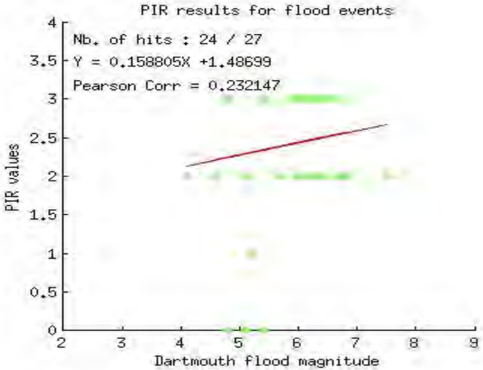


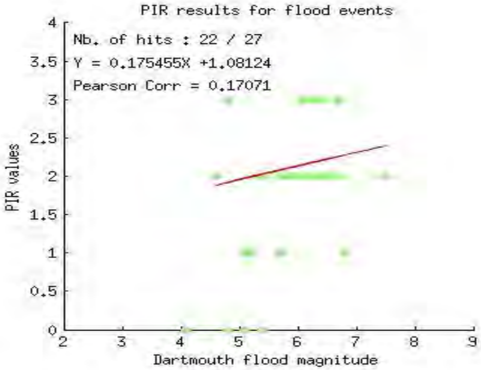


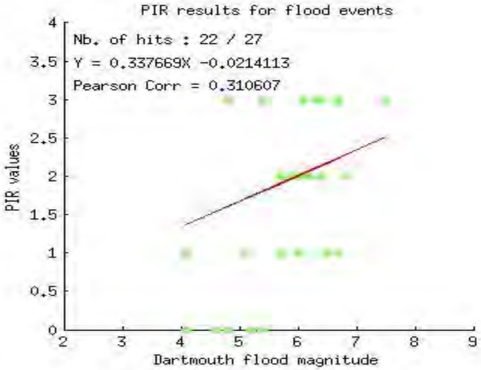
Comparision over North America

1 day | 3 days | 5 days

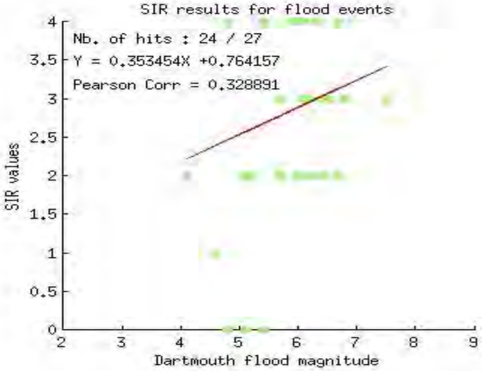
Precipitation

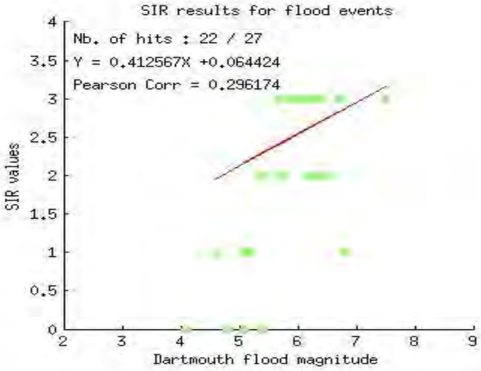


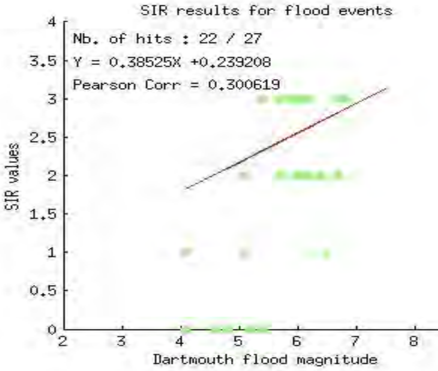




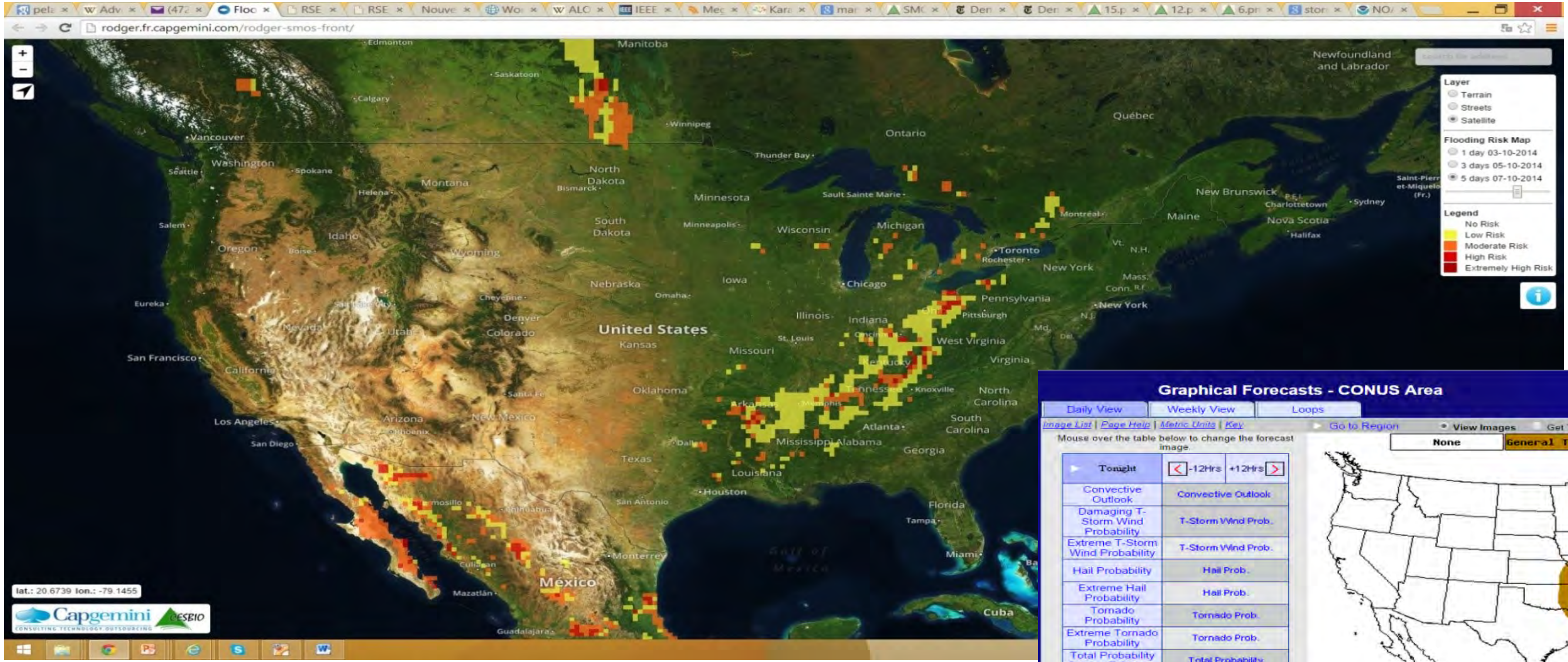
Precipitation + SMOS

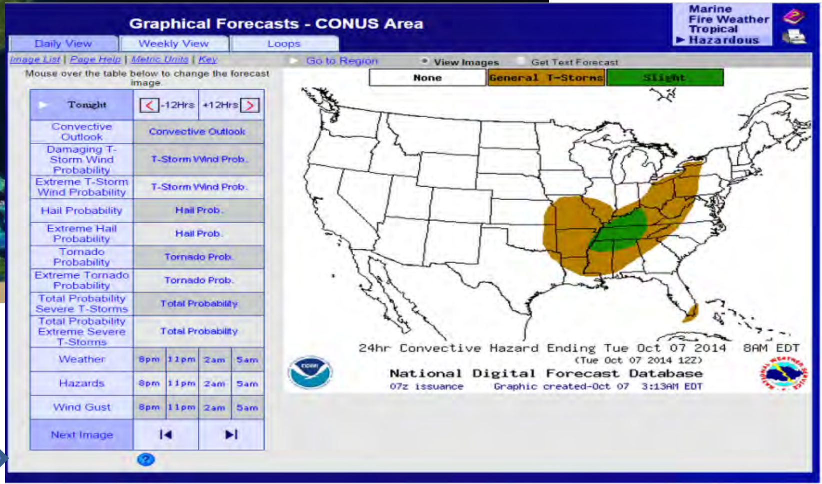






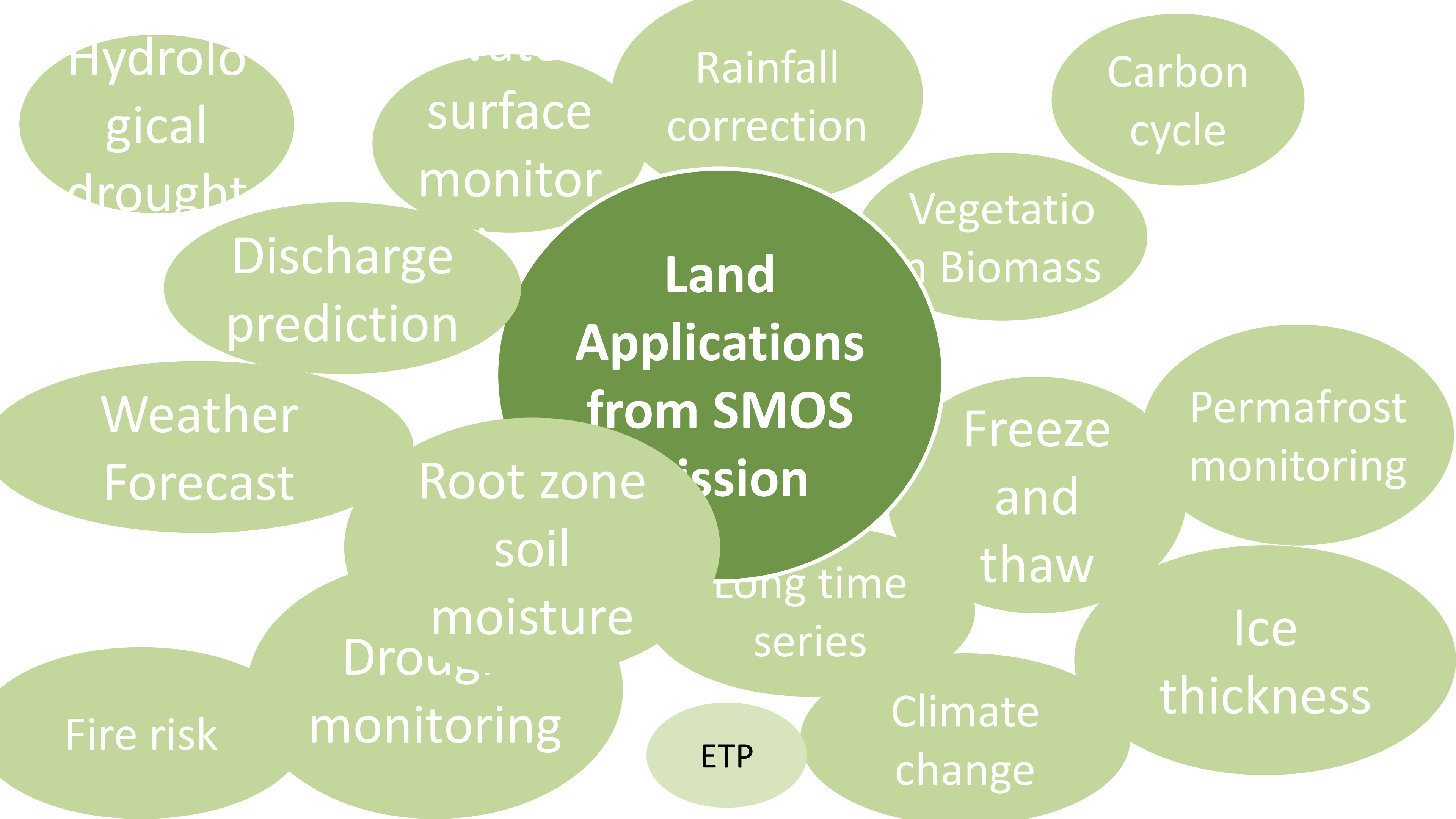
Operational implementation by CapGemini and CESBIO





SMOS flood risk on 07 Oct. 2014 at 12h45 for the next 5 days

Storm risk by NOAA on 07 Oct. 2014 at 12h45


Hydrolo
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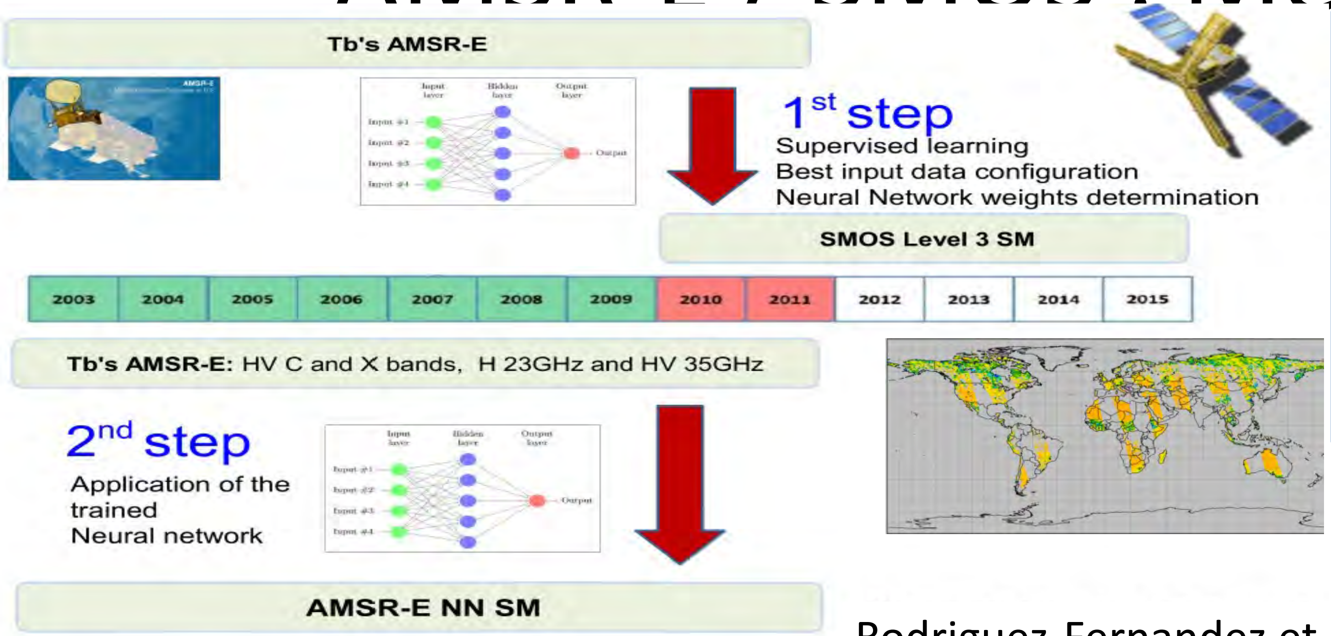
drought
surface
monitor
Rainfall
correction
Carbon
cycle
Vegetatio
n Biomass
Discharge
prediction
Land
Applications
from SMOS
ission
Weather
Forecast
Root zone
soil
moisture
Freeze
and
thaw
Permafrost
monitoring
Long time
series
monitoring
Ice
thickness
Fire risk
ETP
Climate
change

AMSR-E / SMOS : Method



SMOS L3 SM:

- Global remote sensing dataset
- Multi-orbit retrieval with constrains on the optical depth variability
- Well validated against other global datasets and in situ measurements (Albergel et al. 2012, Jackson et al. 2010, Albitar et al. 2012, Al Yaari et al. 2014, Leroux et al. 2012…)

Rodriguez-Fernandez et al. (2016, Remote Sensing)

3^{rd} step

Local evaluation

In situ ISMN

Global evaluation

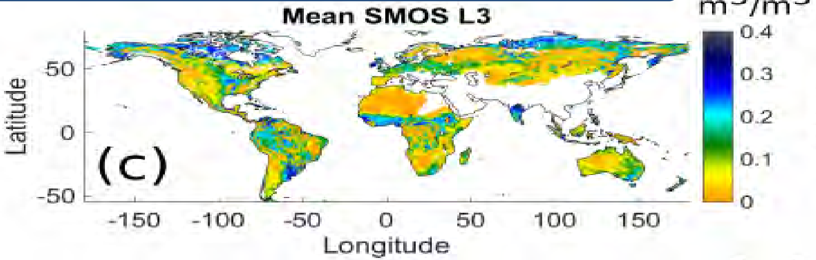
A-Land

Interim Land

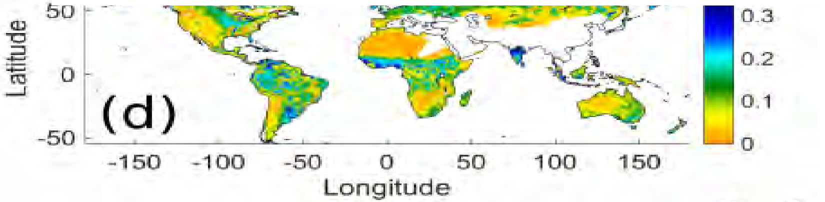
E LPRM

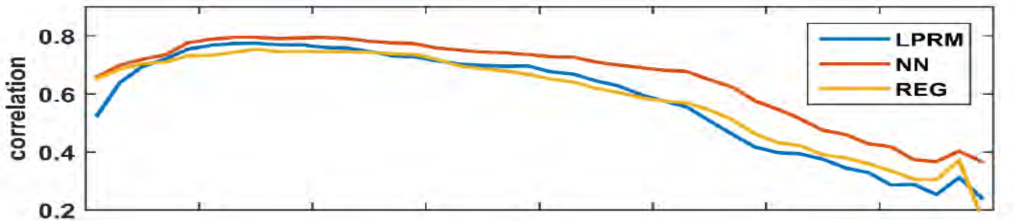
AMSR-E NN SM vs SMOS L3 SM:
consistent datasets !

Average from June 2010 to October 2011

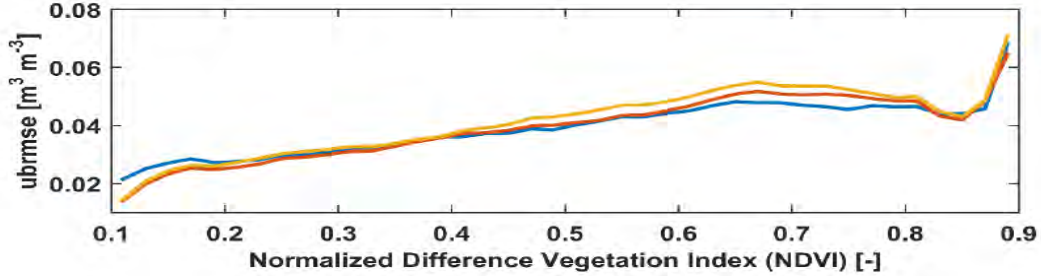


Rodriguez-Fernandez et al. (2016, Remote Sensing)

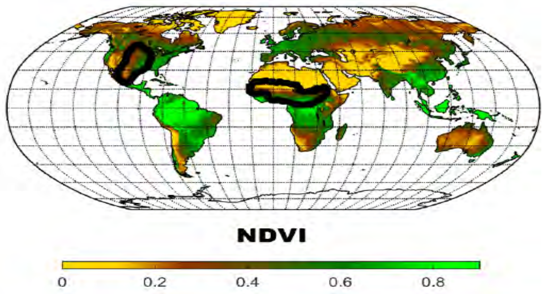




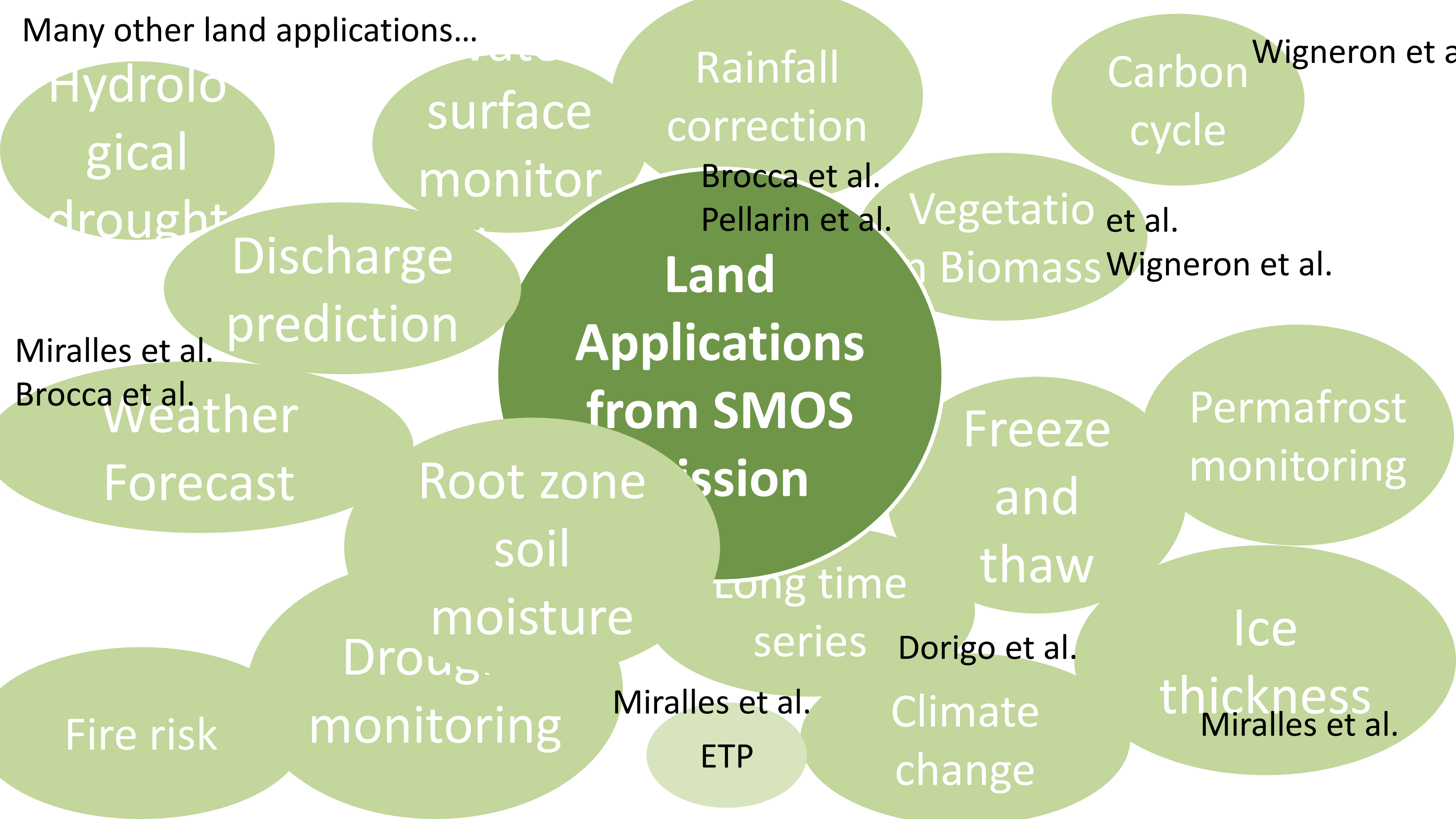
Van der Schalie, De Jeu, Rodriguez-Fernandez. Al Yaari, Kerr et al. (2017, Submitted to *Journal of Climate*)



Stats with respect to SMOS SM



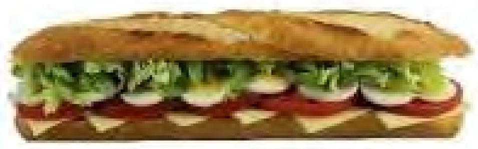
Many other land applications…



Lessons learnt

SMOS is not about…

It is not about the Belguim sandwich SMOS



Or the more famous Single Malt Of Scotland

it is more about food security

Lessons learnt from SMOS

1 - L-Band is a low energy signal..but very rich in information.

2- Soil Moisture monitoring is key to many processes but we didn’t grasp yet it’s full potential.

3 – Validation of soil moisture at low resolution remains a challenge

General Lessons learnt, beyond SMOS

- One should leave space for imagination and innovation…don’t limit your applications to mission objectives.

- Synergie is the key to advancing knowledge and reducing equifinality.

- Information is in the data awainting…even when at low resolution…

What next...

an operational L-Band mission ?

...maybe our **practical session** on a shorter timescale