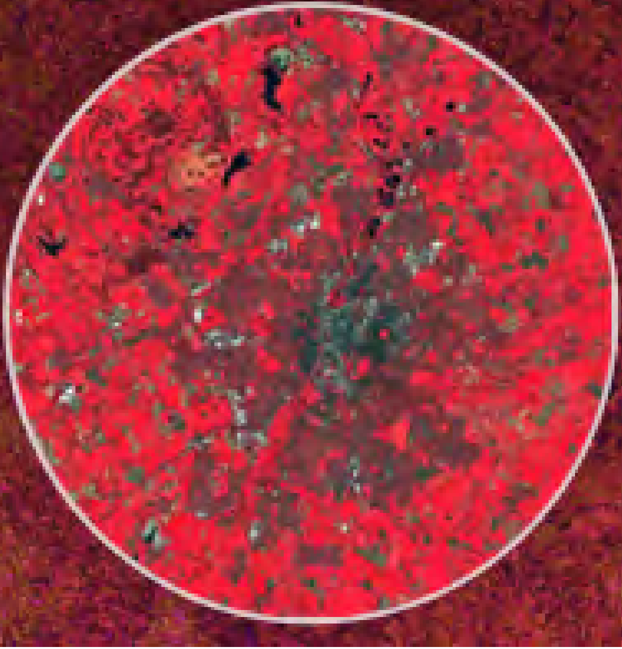
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

esa

→ 8th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

10–14 September 2018 | University of Leicester | United Kingdom



Observing the Hydrological Cycle over Land using SMOS

Ahmad Al Bitar
PhD. Ing.
Centre d’Etudes Spatiales de la Biosphère (CESBIO), Toulouse, France
Centre National de Recherche Scientifique (CNRS), Paris, France

A simple water budget

Soil moisture

Surface water

Ground water

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

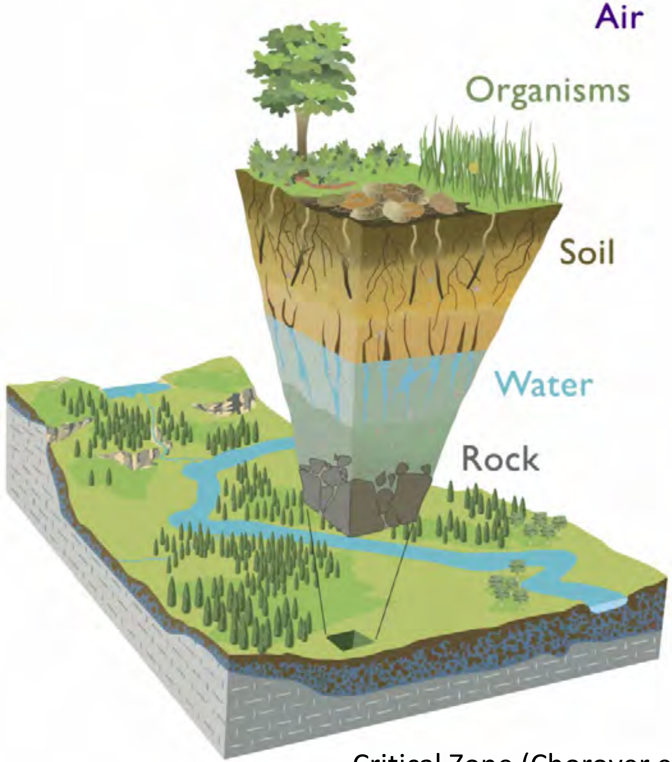
Precipitation

Evapo-transpiration

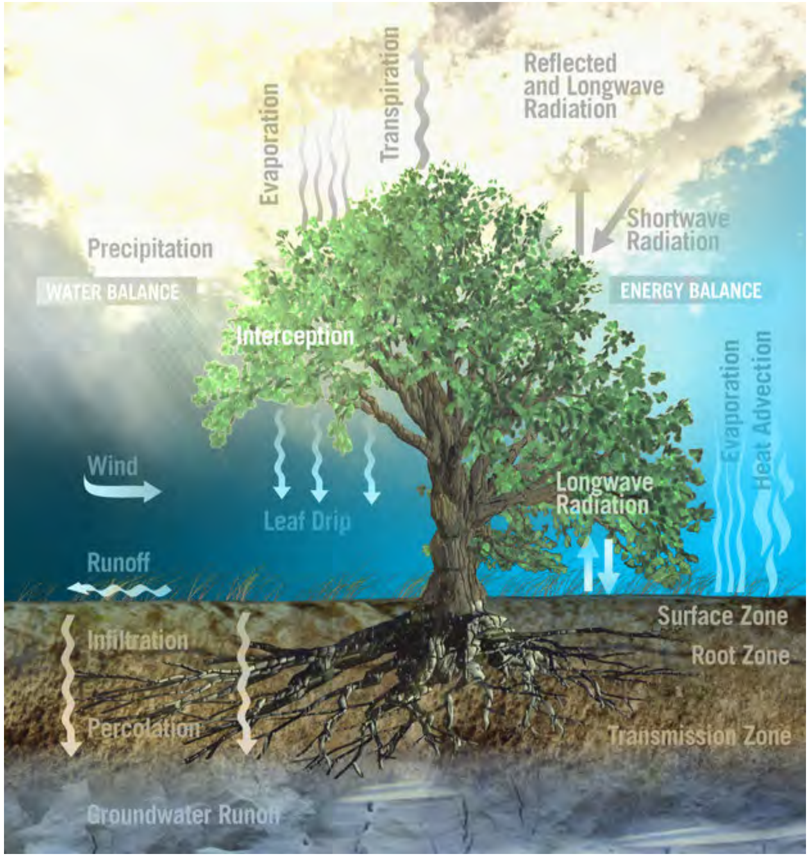
Discharge

Energy budget

The surface layer as part of the Critical zone

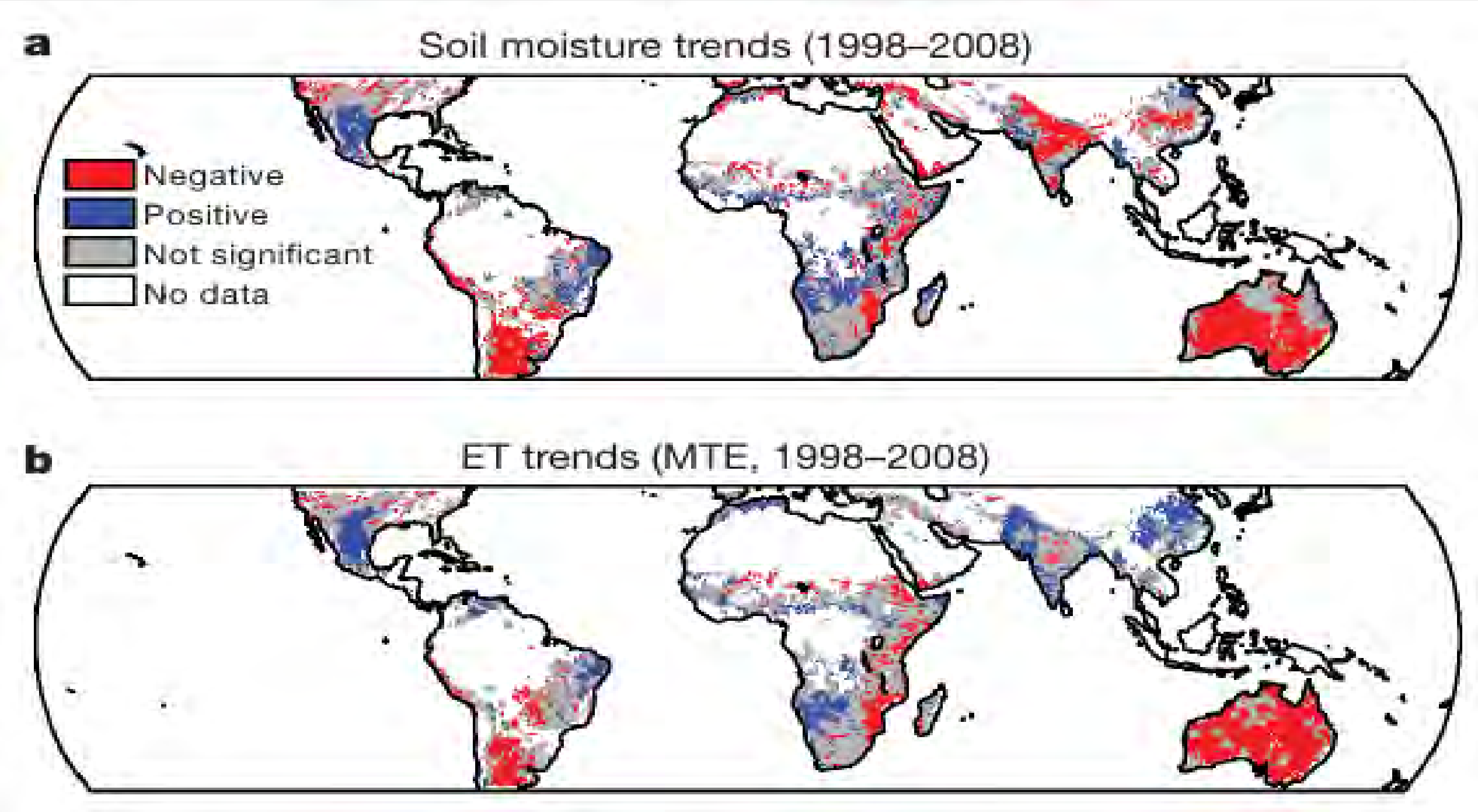


Critical Zone (Chorover et. al. 2007)



Surface Layer processes (ESA)

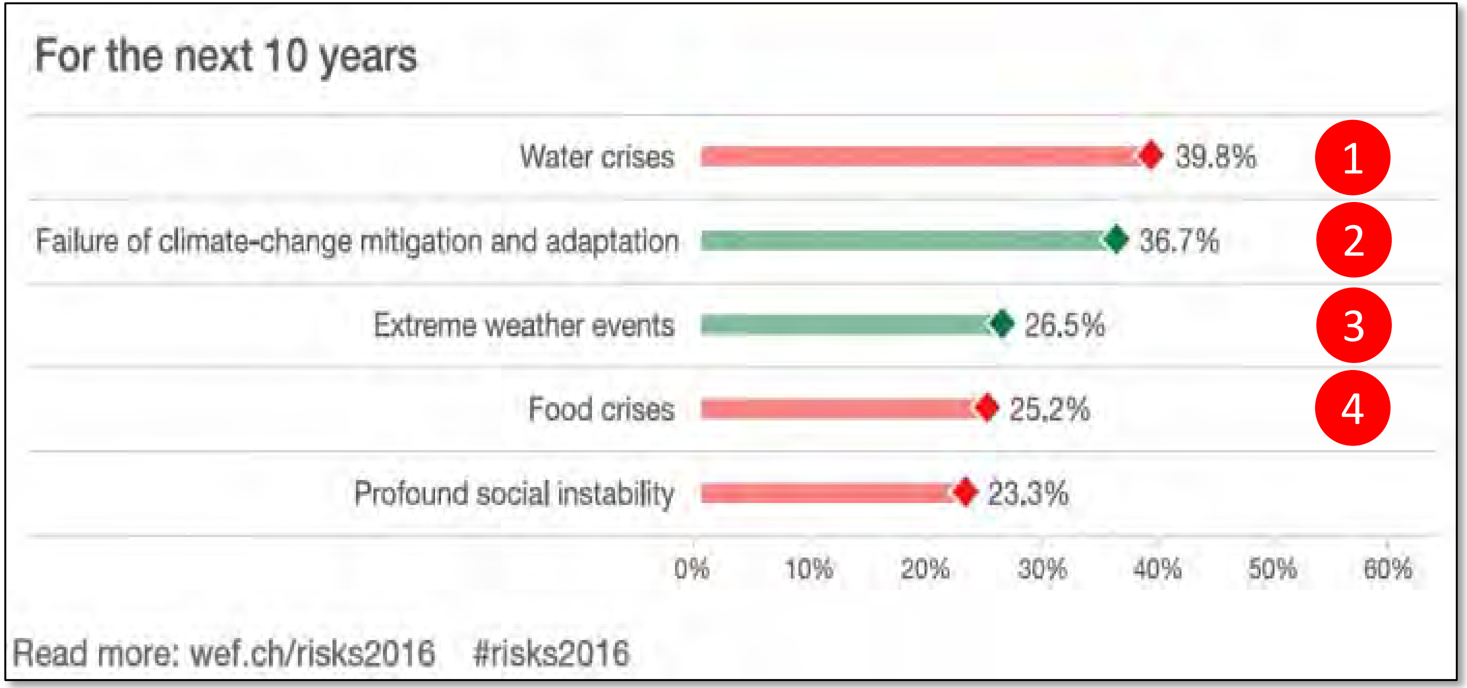
Motivation for soil moisture measurments



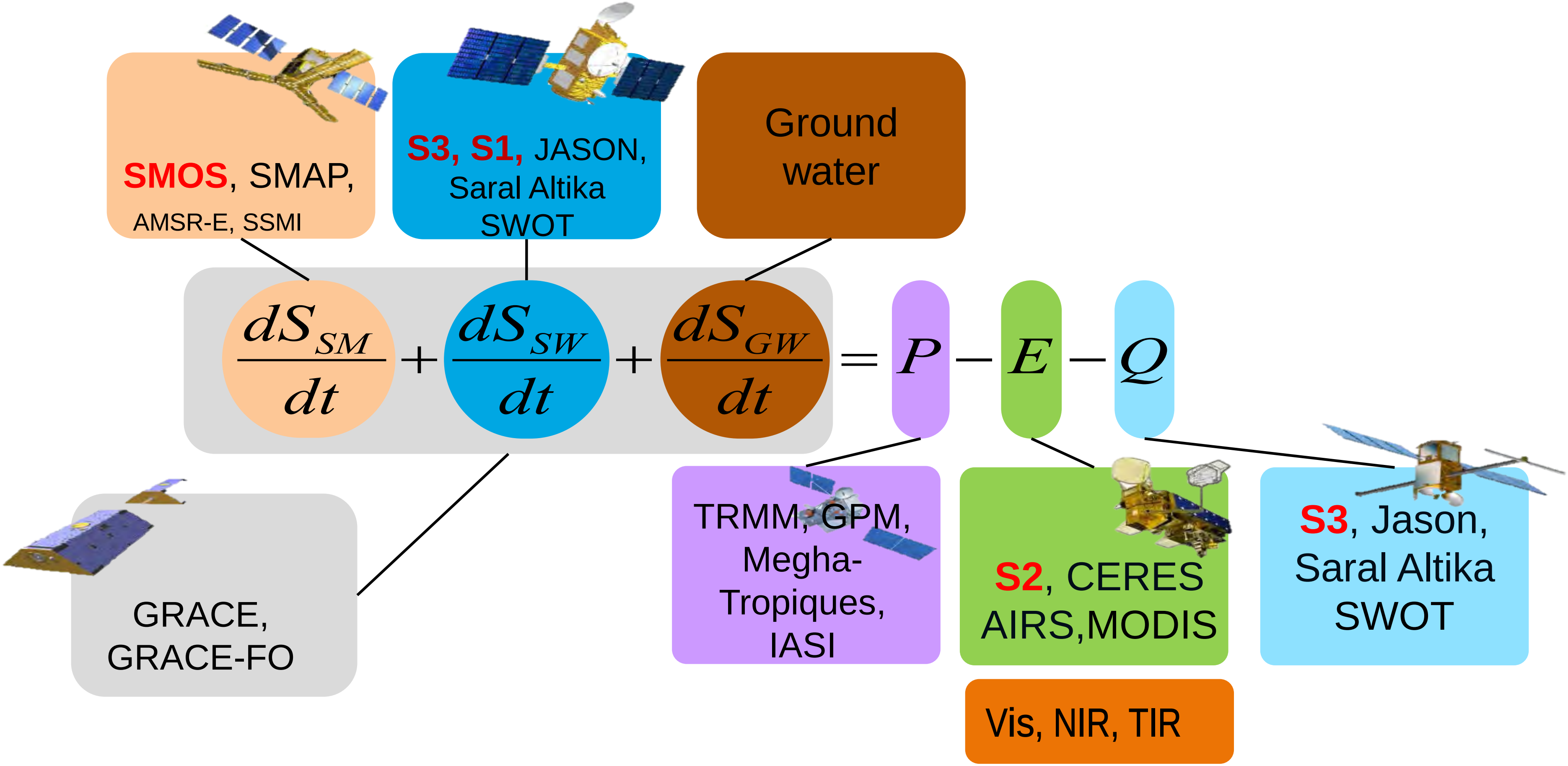
Jung et al., 2010, nature - (see also Mirales et al. 2016)

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



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

Not all components are observed at the desired resolution and accuracy

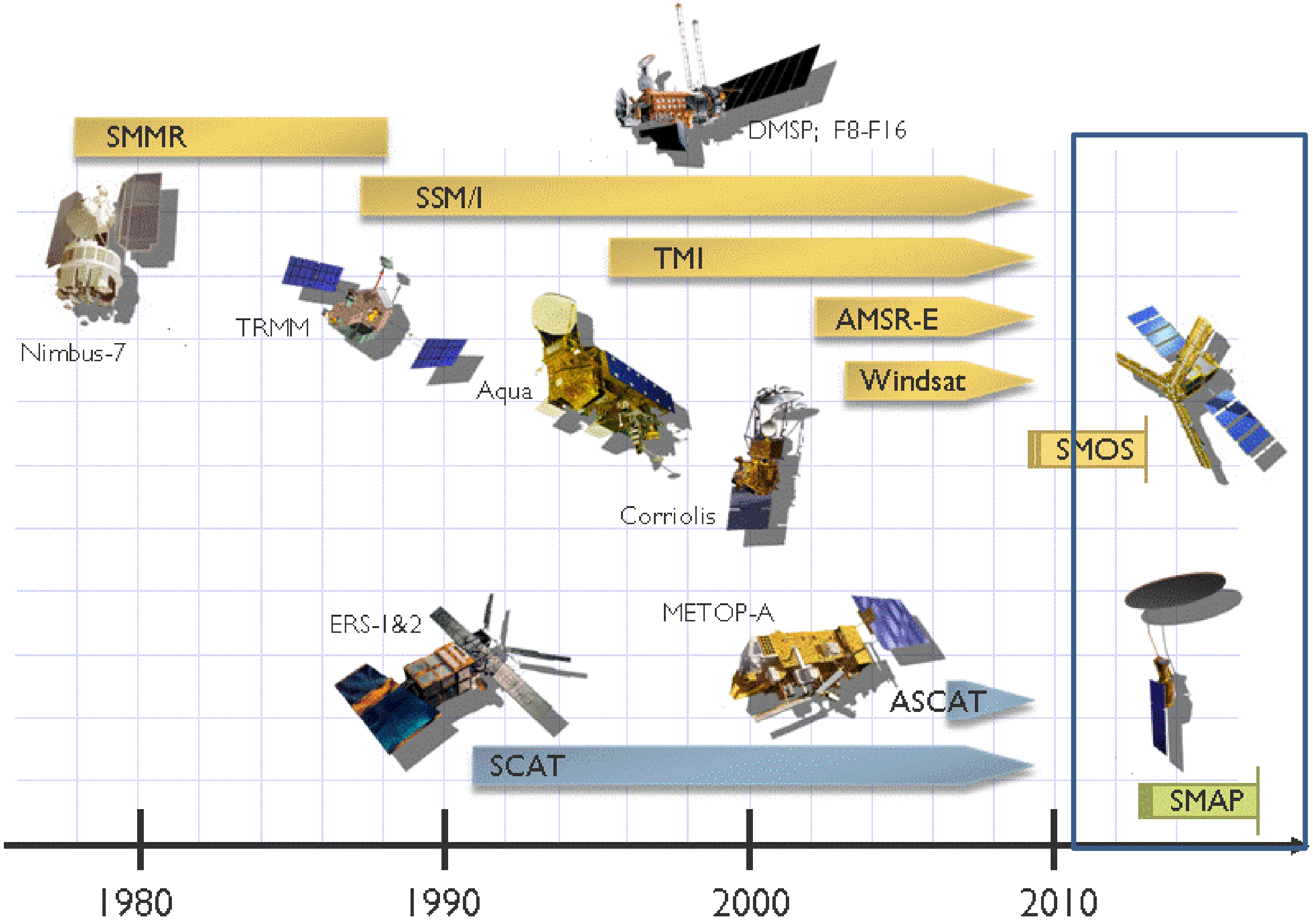
Microwave Radiometry for the hydrological Cycle

Bascis of microwave radiometry

Geophysical Products

Applications

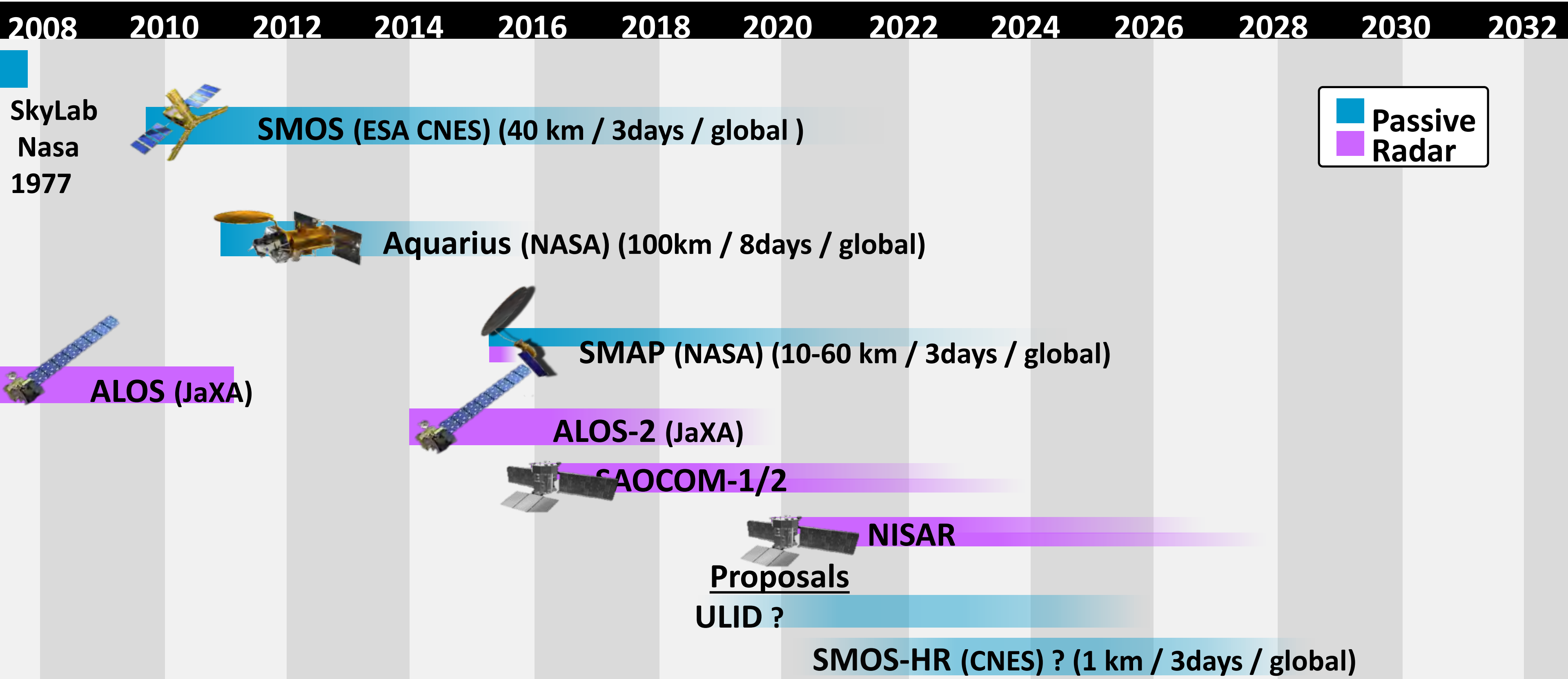
Microwave missions for global soil moisture mapping



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

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

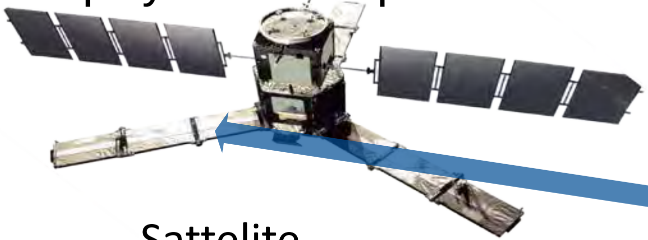
Microwave RadioMeter (MRM)?

An MRM is:

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

It measures

- Thermal radiance at a given frequency (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.



Sattelite

Airborne L-band MRM

Ground based L-band MRM

spatial scale

Signal power levels in L-Band

Example of a black body at 300 k observed between 1400 – 1427 MHz

$P = k \cdot T \cdot B$

Rayleigh-Jeans approximation of Planck's law

Emissivity = 1 (black-body)

$k = 1.380658 \cdot 10^{-23}$ JK^{-1} (Bolzmann constant)

T = 300K (Physical temperature)

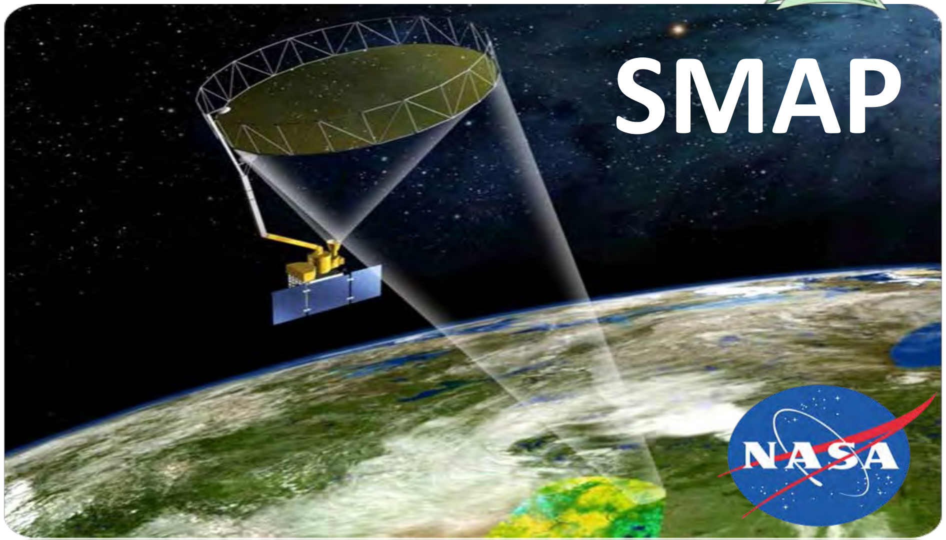
B = 27MHz (bandwidth of protected part of L-band (1400 – 1427 MHz))

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

Important features :

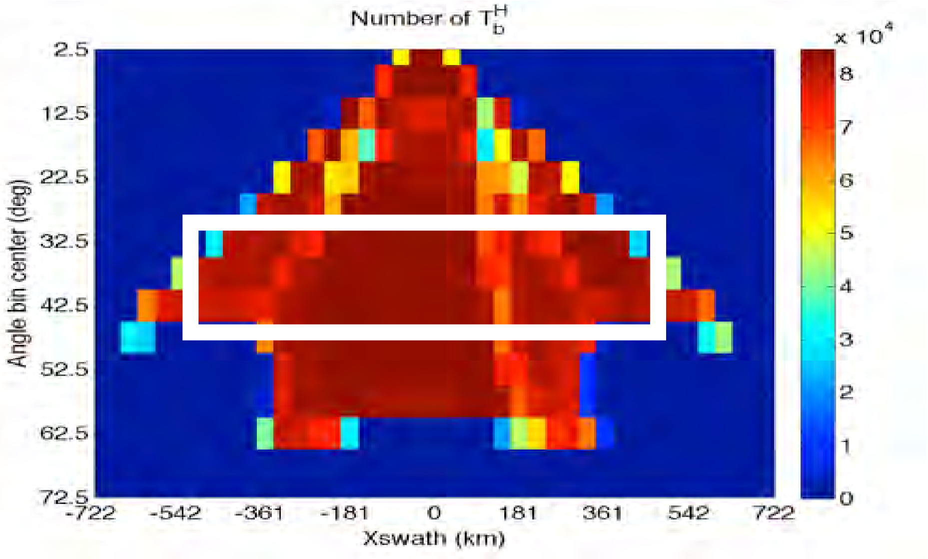
- Directed antenna with high gain
- Low-noise, narrow-band receiver
- Highly stable temperature control
- Internal and external reference (calibration) noise-sources at known noise temperatures

Same frequency but different technologies

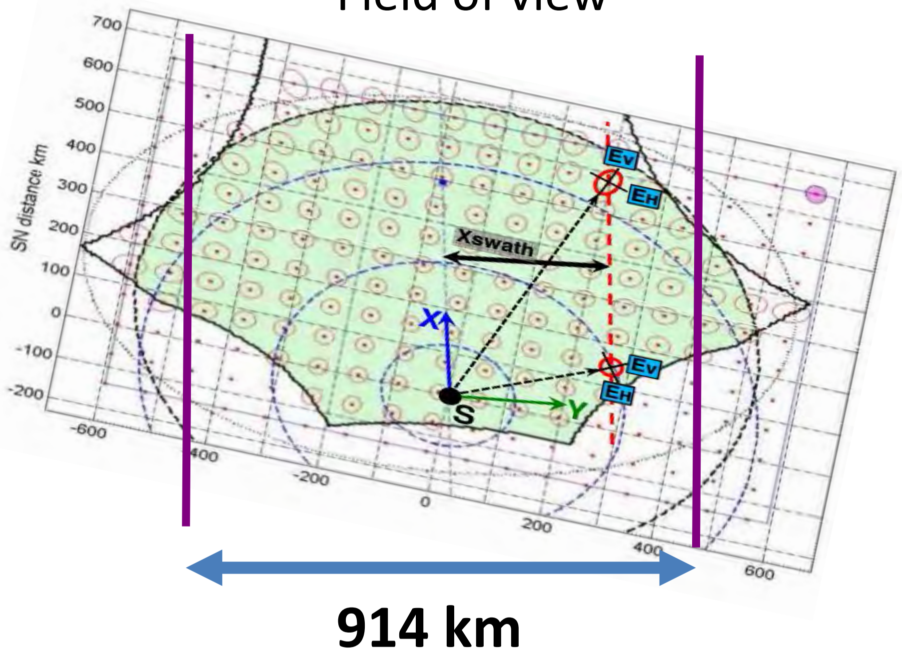


L-band Passive	**L-Band Active (3 first months) and Passive**
2D Interferometric radiometer (std: 2.4 k)	Mesh reflector antenna (std: 1.3 k)
Multi-angular acquisitions (0° - 60°+)	One fixed angle (40°)
3 days global coverage at 6 am and 6 pm	3 days global coverage at 6 am and 6 pm
Spatial resolution (27 -55 km)	Passive Spatial resolution (51 X 47km)
RFI mitigation at ground segment	Spectral filtering for RFI on board

Incidence angles and swath width



Field of view



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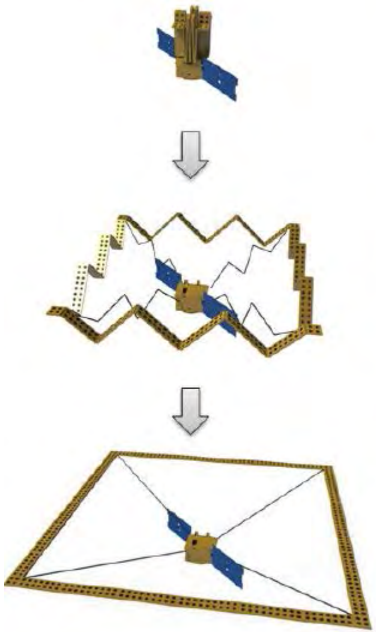
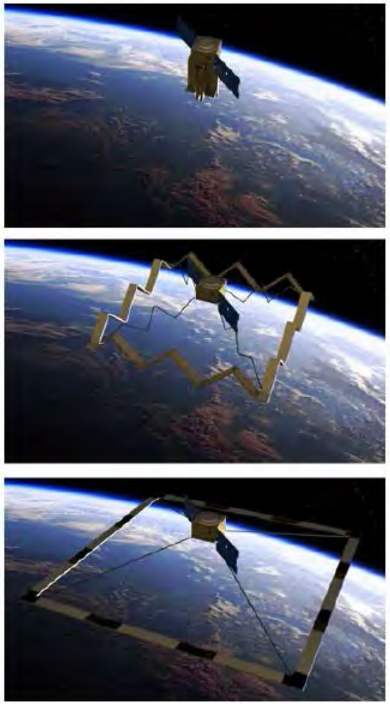
SMOS HR

- Objective
  - L Band continuation
    - Science and opertaional applications
  - Improve spatial resolution and filtering
    - 10 km, 3 day revisit, global
- Solution
  - Factor 2 through concept improvement
  - Factor 2 through signal processing
- Situation
  - R&T study underway
  - Phase 0 started
  - Programmatic context
    - Collaboration NASA, CAS, …





Copernicus Imaging Microwave Radiometer (CIMR)

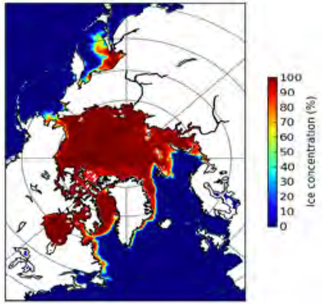
- **Mission Objective**
- Respond's directly to the ***Integrated EU Arctic Policy***
- Climate Change and Safeguarding the Arctic
- Environment Sustainable Development in and around the Arctic
- International Cooperation on Arctic Issues
- Operational Sea Ice Services and Global SST capability

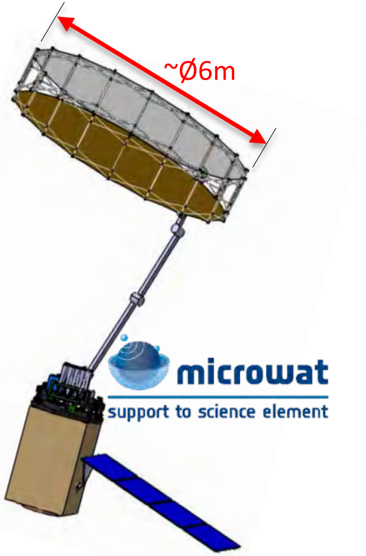
- **Characteristics (To be Confirmed)**
- Conically scanning multi-frequency microwave radiometer
- **Single satellite**, Observation Zenith angle 55±1.5°
- **Loose convoy flight with MetOp-SG(B)** <360s separation
- **~95% global coverage every day, mean 6 hourly-revisit in Arctic Areas**
- In Phase A/B1, Launch: 2025

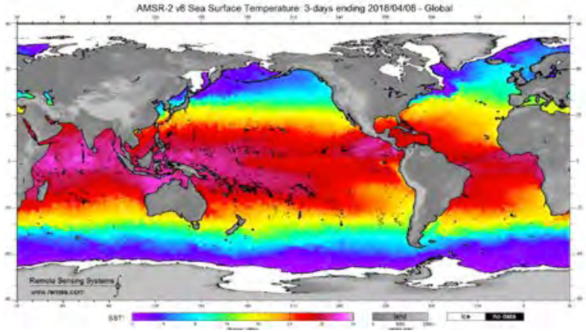
Channels (GHz, all H&V*):	1.4	**6.9**	**10.65**	**18.7**	**36.5**
Resolution (km):	≤55	**≤15**	**≤15**	**≤5**	**≤5** (g:3km)
NEΔT (K @150K):	≤0.3	**≤0.2**	**≤0.3**	**≤0.3**	**≤0.7**

*Full Pol in discussion

- **Products (Performance TBC, P=Primary, S=Secondary)**
- ***P1: Sea Ice Concentration (≤5 km, 5%)***
- ***P2: Sea Surface Temperature (10 km, ~0.2 K)***
- *S: Sea Ice Drift (≤25 km, 3 cm/s)*
- *S: Thin Sea Ice Thickness (~40 km, 10%)*
- *S: Snow on Sea Ice*
- *S: Snow Water Equivalent*
- *S: Sea Surface Salinity (~40 km)*
- *S: Ice Type (≤5 km)*
- *S: Extreme Wind*
- Additional tertiary products (eg. global soil moisture, atmospheric water load, IST, precipitation rate…)

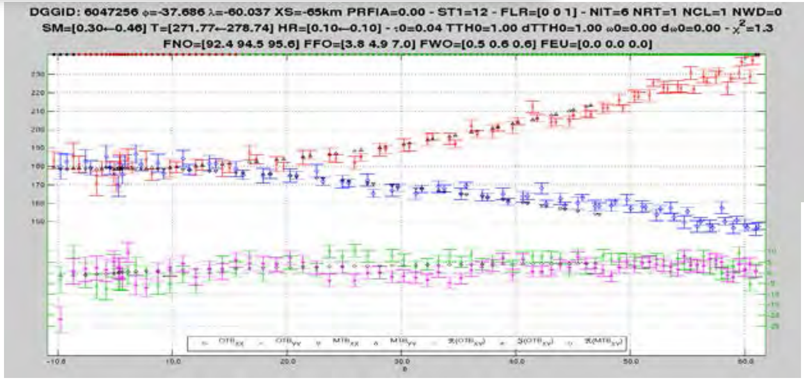




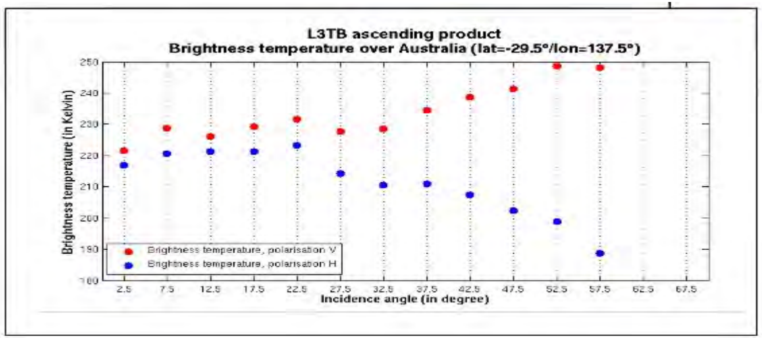


SMOS brightness temperatures

First step, computing pseudo-L3TBs from NRT Tbs



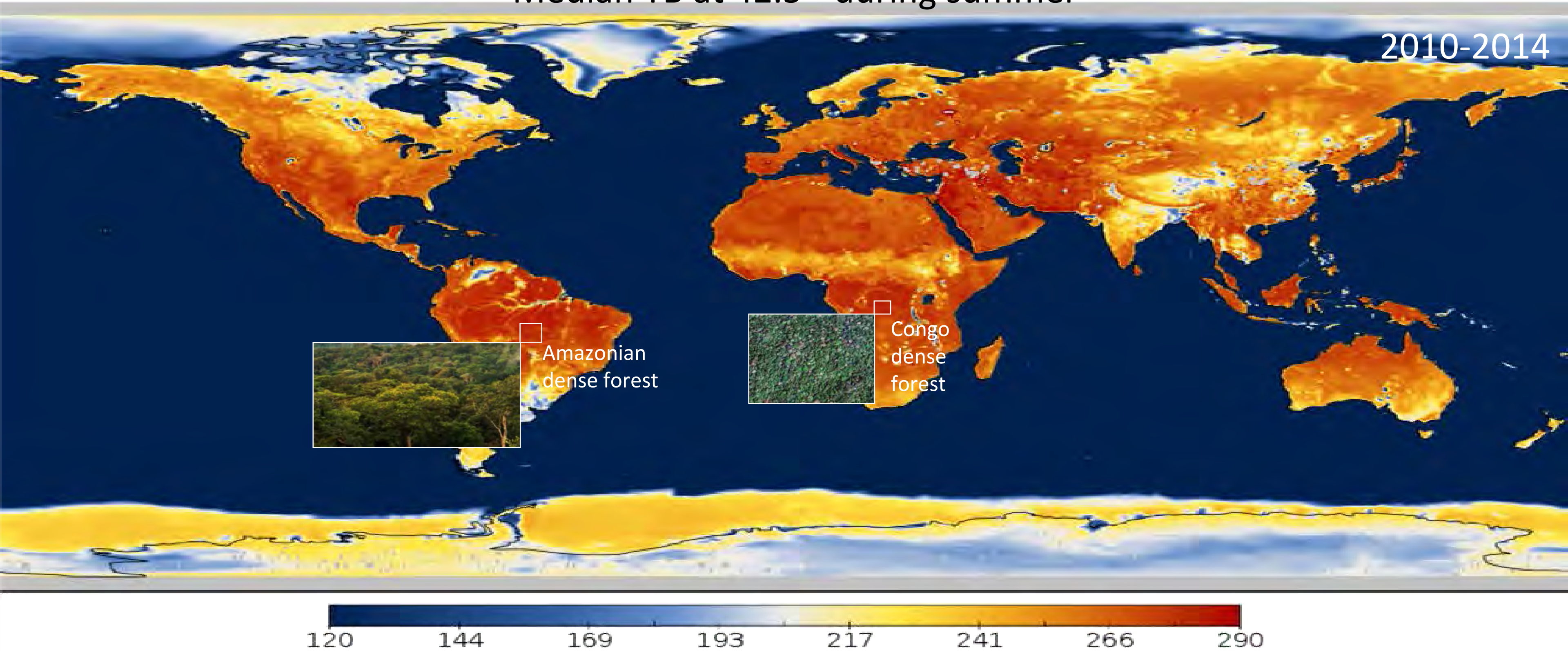
- L1C
  - No angle binning
  - XY polarization reference frame
  - ISEA g



- L3TB
  - angle bins of 5º
  - HV polarization
  - EASE grid

SMOS Brightness temperatures

Median TB at 42.5 ° during summer



SMOS Brightness temperatures

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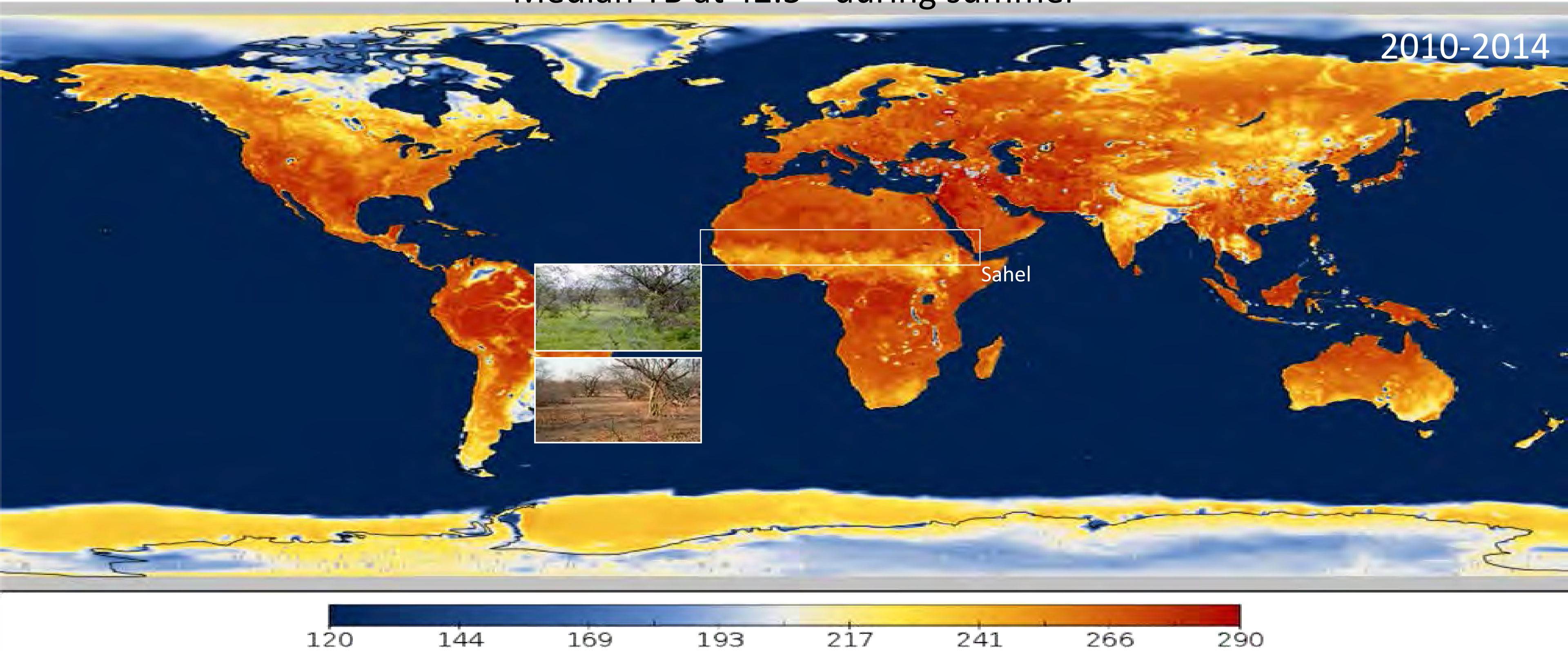
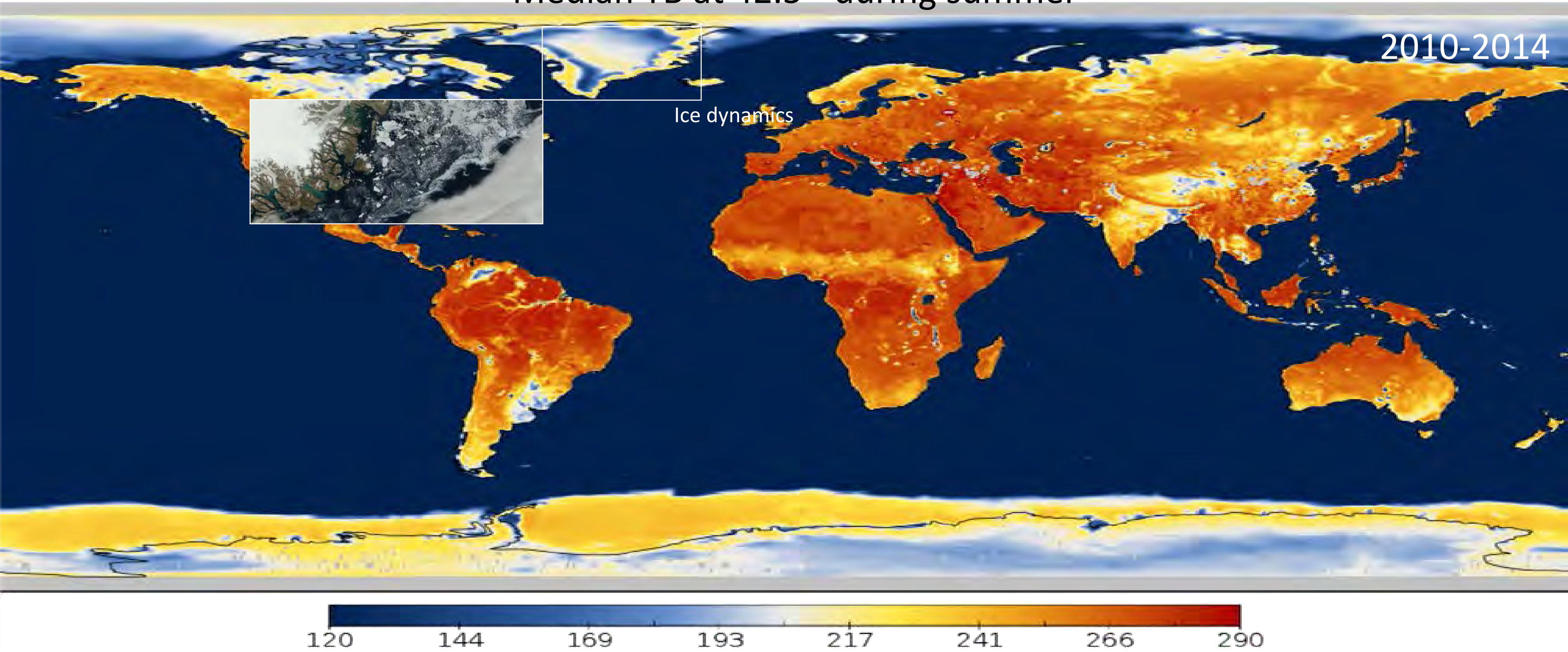


SMOS Brightness temperatures

Median TB at 42.5 ° during summer



SMOS Brightness temperatures

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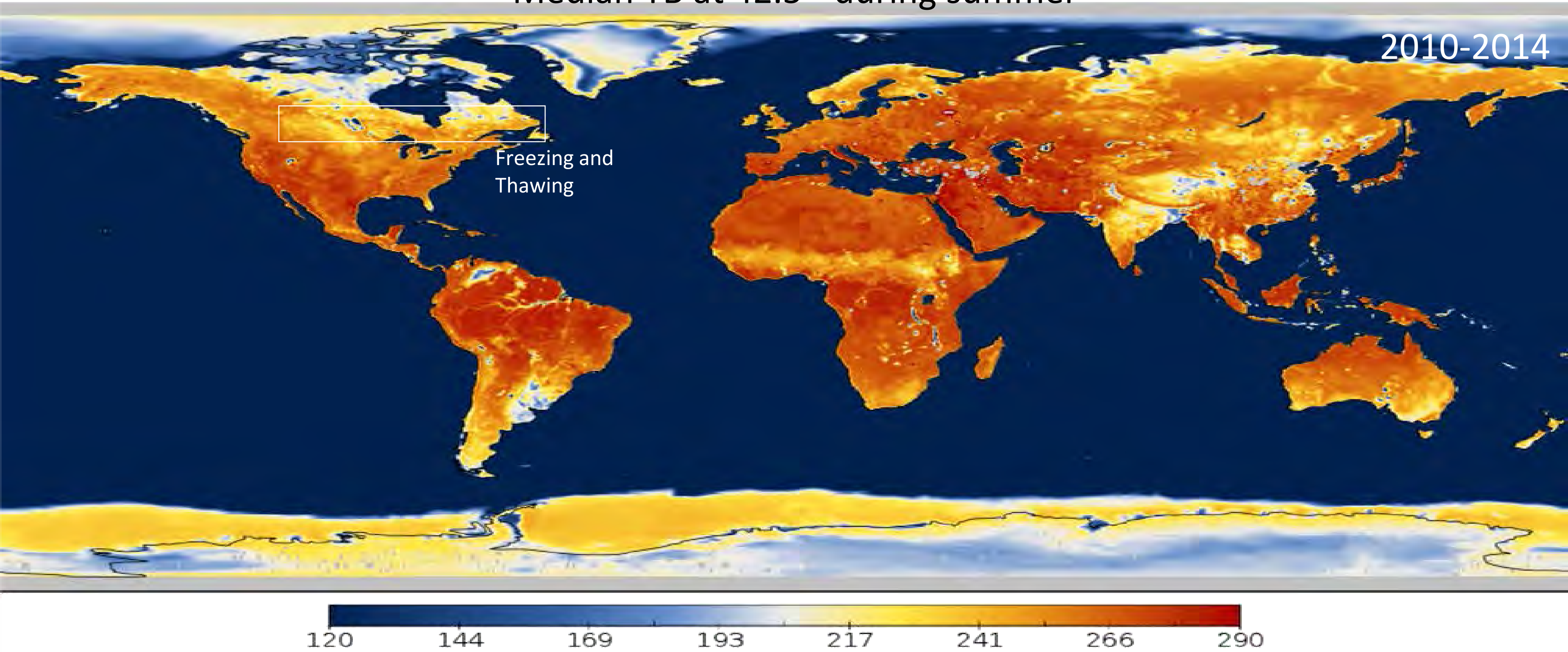

SMOS Brightness temperatures

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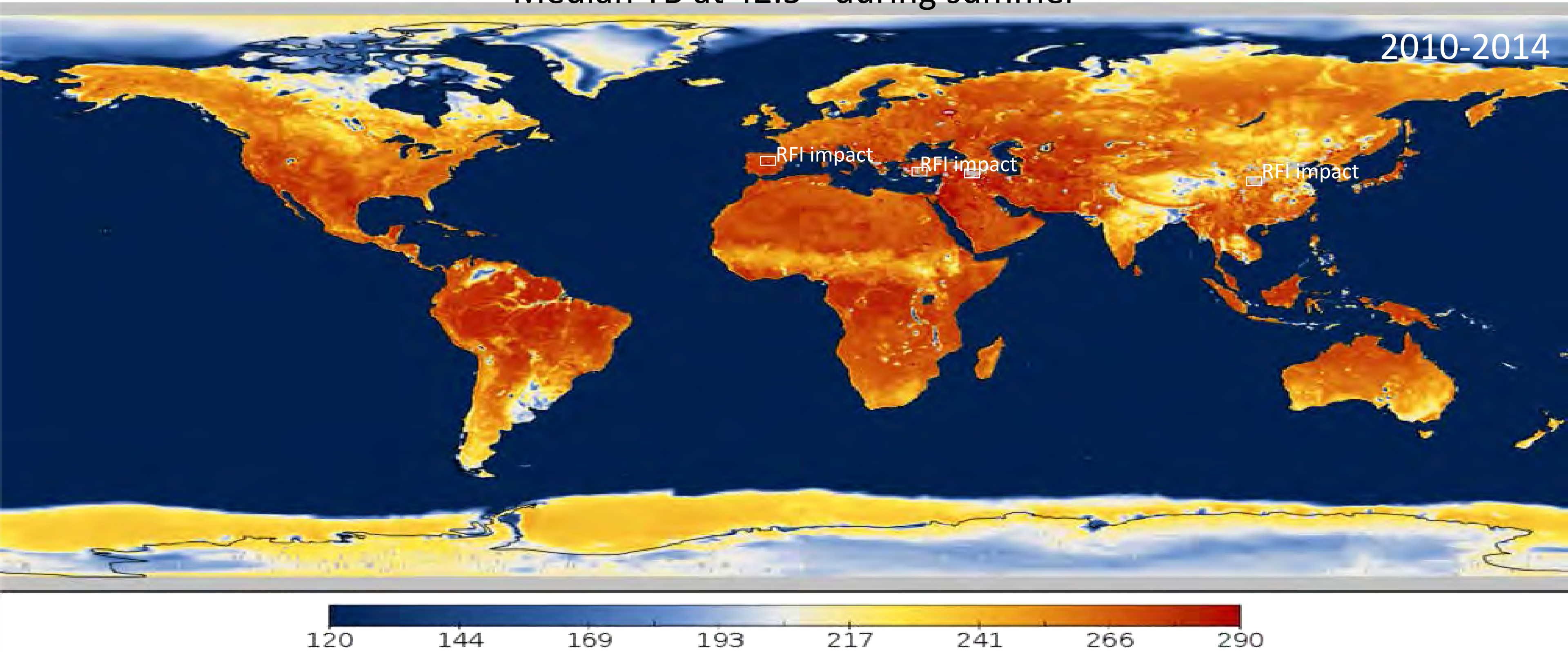
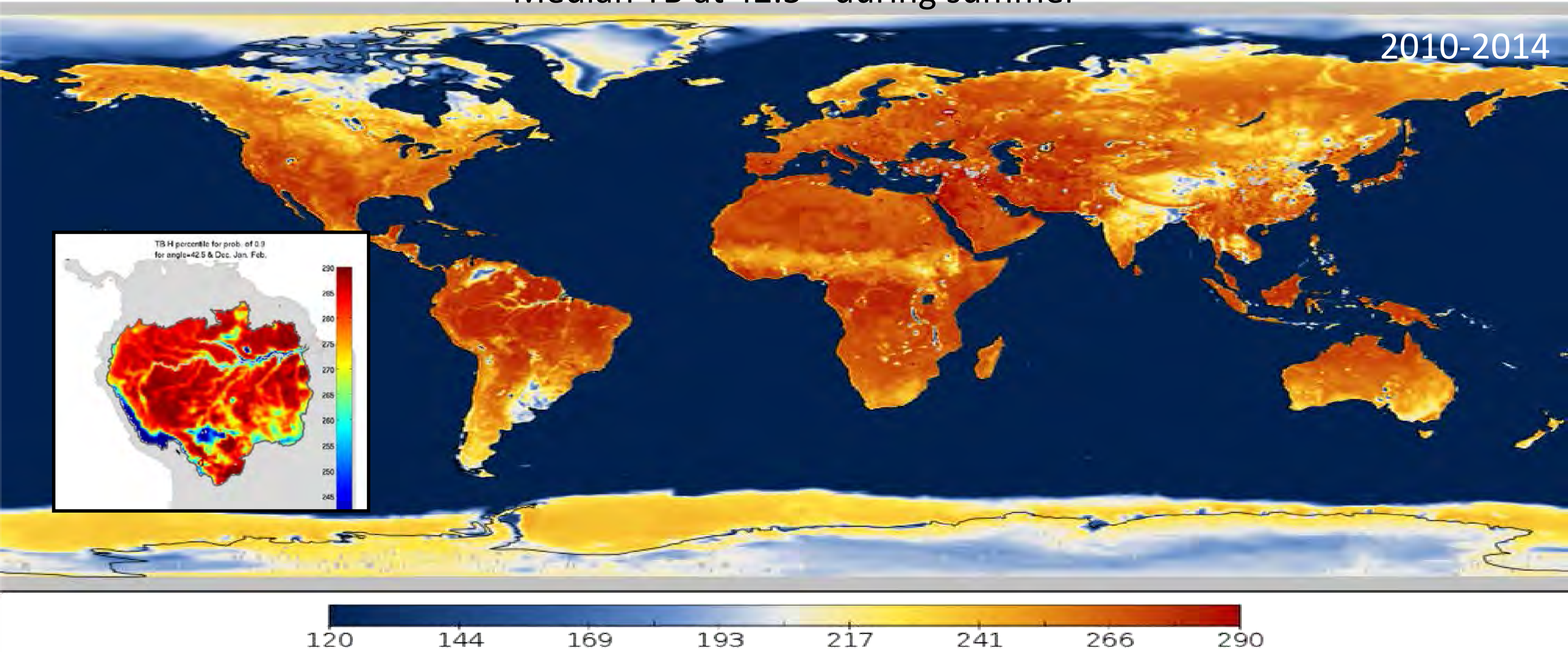


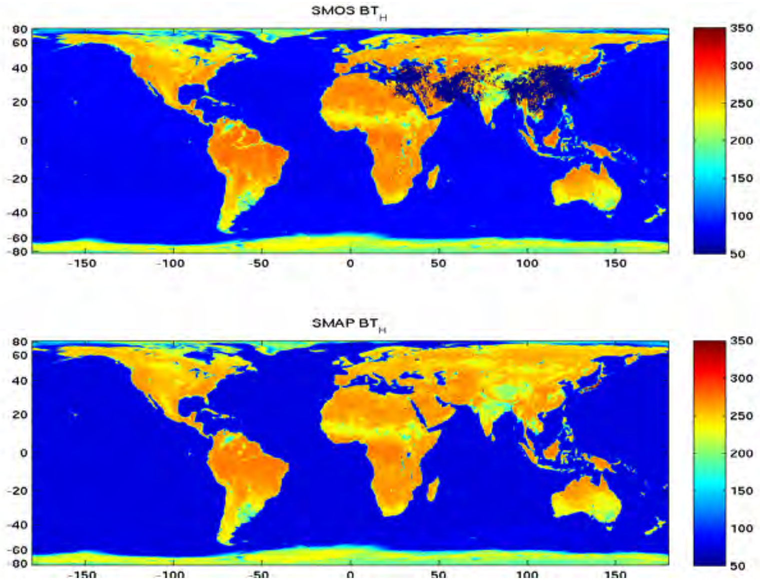
SMOS Brightness temperatures

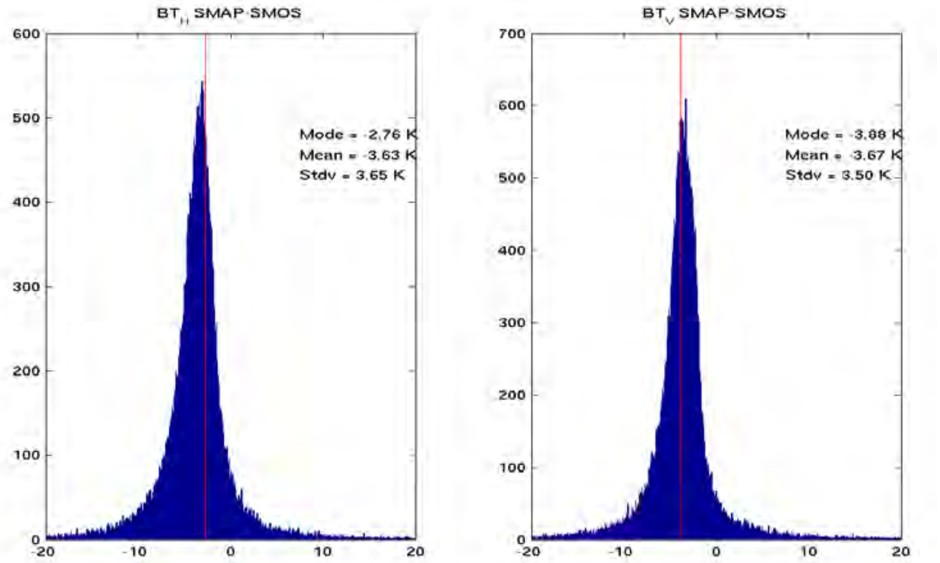
Median TB at 42.5 ° during summer



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)

Microwave Radiometry for the hydrological Cycle

Bascis of microwave radiometry

Geophysical Products

Applications

Physical model inversion approach

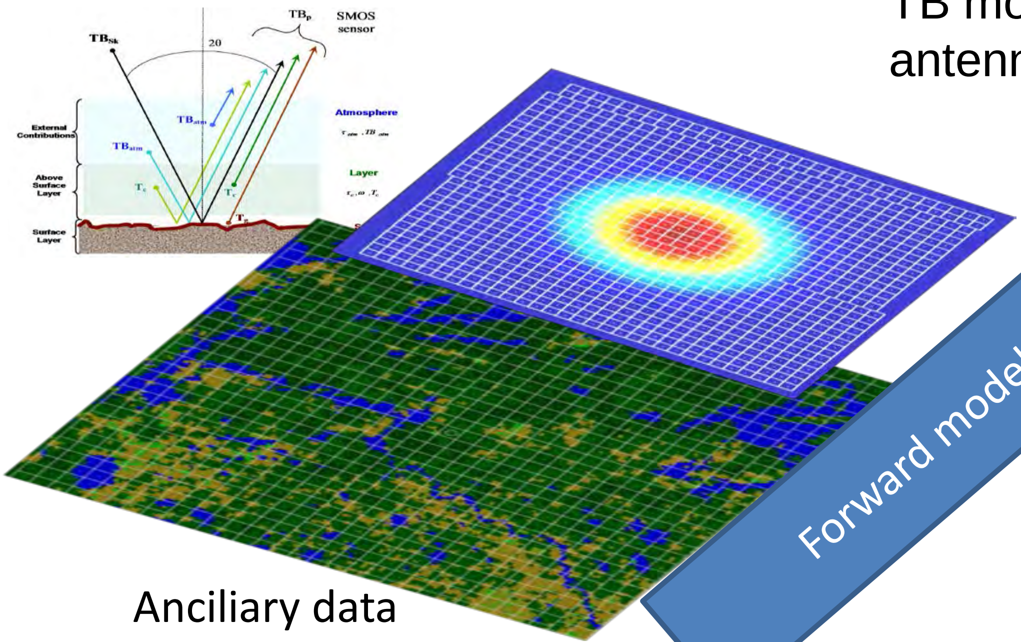
L2SM retrieval algorithm
Ref: (Kerr Y. et al.,ieee-tgrs 2012) and ATBD L2 SM

TB model at antenna level

TB observed at antenna level

Inversion algorithm

Soil moisture, Vegetation optical depth…



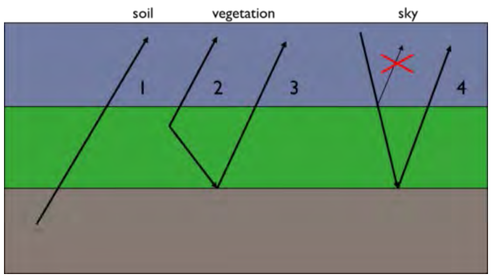
Forward model

Anciliary data

TB modeling at Top of atmosphere

$T_{B,tot}(P,\theta)$	=	$e_s T_s \gamma$	+	$(1-\omega)(1-\gamma)\,T_v$	+	$(1-\omega)(1-\gamma)T_v(1-e_s)\gamma$	+	$T_{B,sky}\gamma^2(1-e_s)$
Total		**Soil (1)**		**Vegetation (2)**		**Soil + Vegetation (3)**		**Sky (4)**

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)

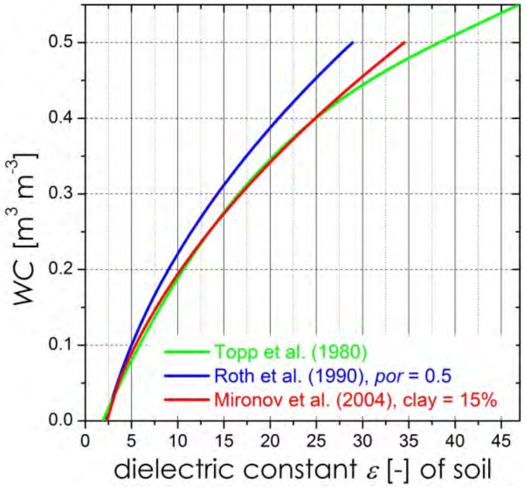
Reflectivity/ dielectric constant /Soil moisture

$e(\lambda) = 1 - r(\lambda)$

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

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

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



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

What frequency for soil moisture ?

L-Band – 1.4 GHz

SMOS

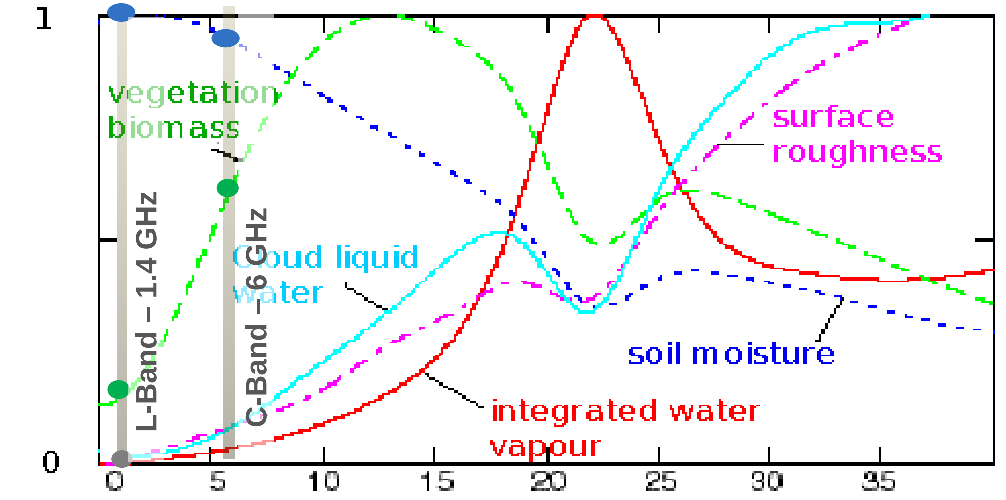
AQUARIUS

SMAP(2015)

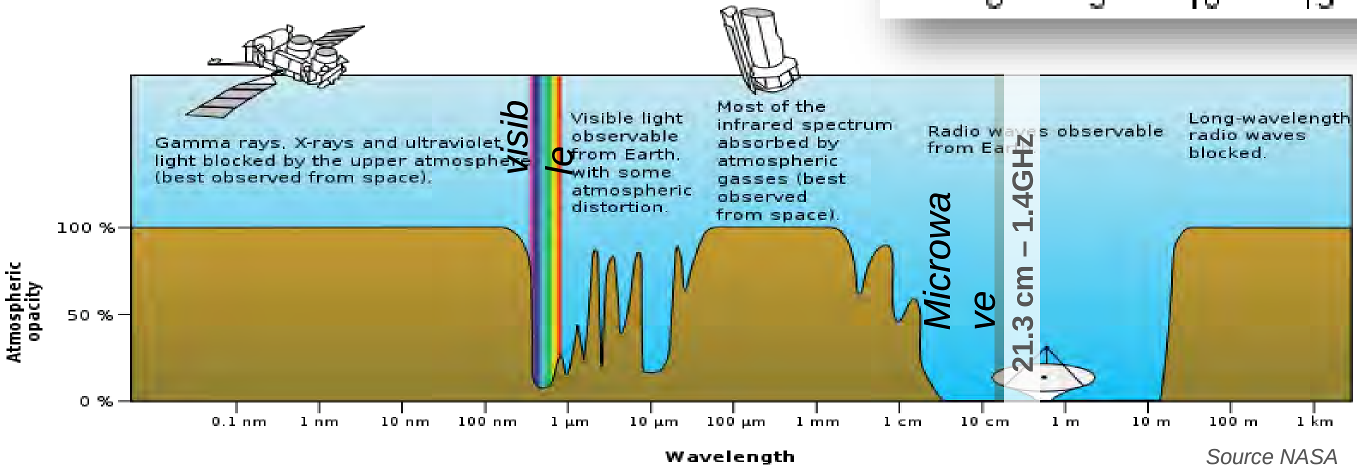
C-Band – 6 GHz

AMSR-E

ASCAT (Active)

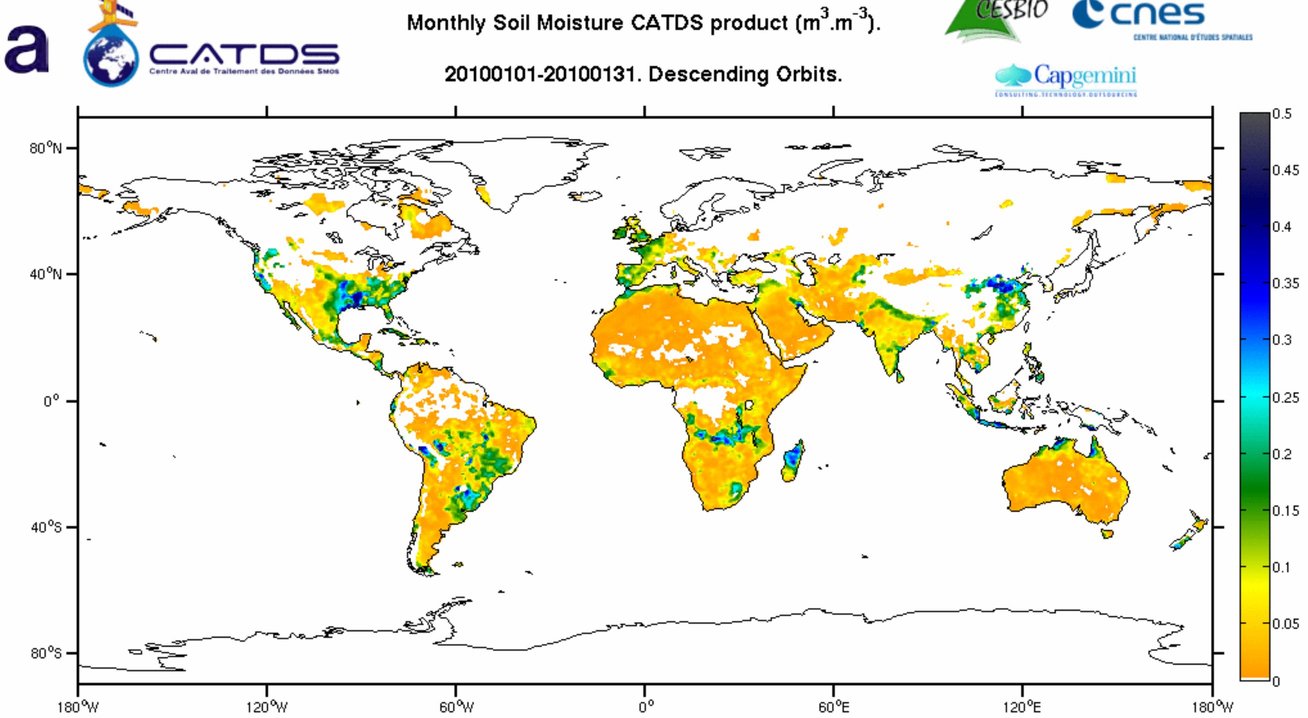


Source CESBIO



Source NASA

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) (Al Bitar et al., ESSD 2017)
- 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

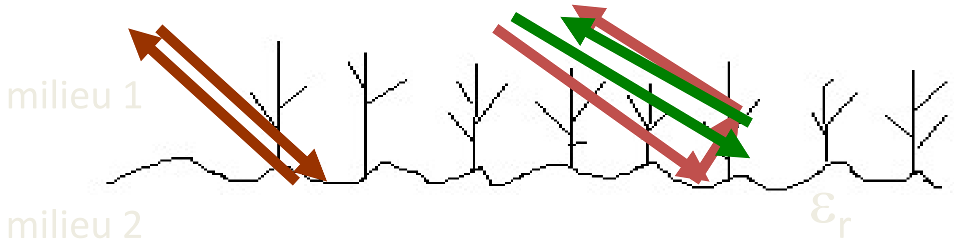
- Impact of Roughness (Mialon et al. 2012, Parrens et al. in review)
- Enhancing vegetation parametrisation (Rahmoune et al., 2014, Wigneron et al. 2012)
- Enhancing snow and ice representation (Mike Schwank, Gamma RS)
- Enhancing retrievals over organic soil (SMOS HiLat – Bircher et al.)

An “aparté” on Soil moisture from SAR

About Radar backscattered signal

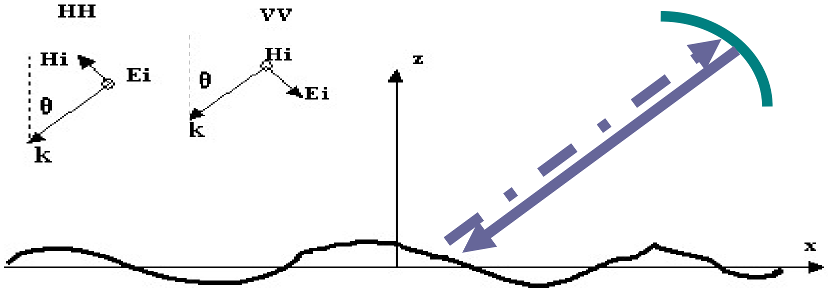
Modeling the vegetated soil backscatter

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



Modeling of the soil backscatter

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



From M. Zribi 2015, CESBIO

Inversion algorithms to estimate surface soil moisture

CESBIO

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 model
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	Neural Networks
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	Physical modeling

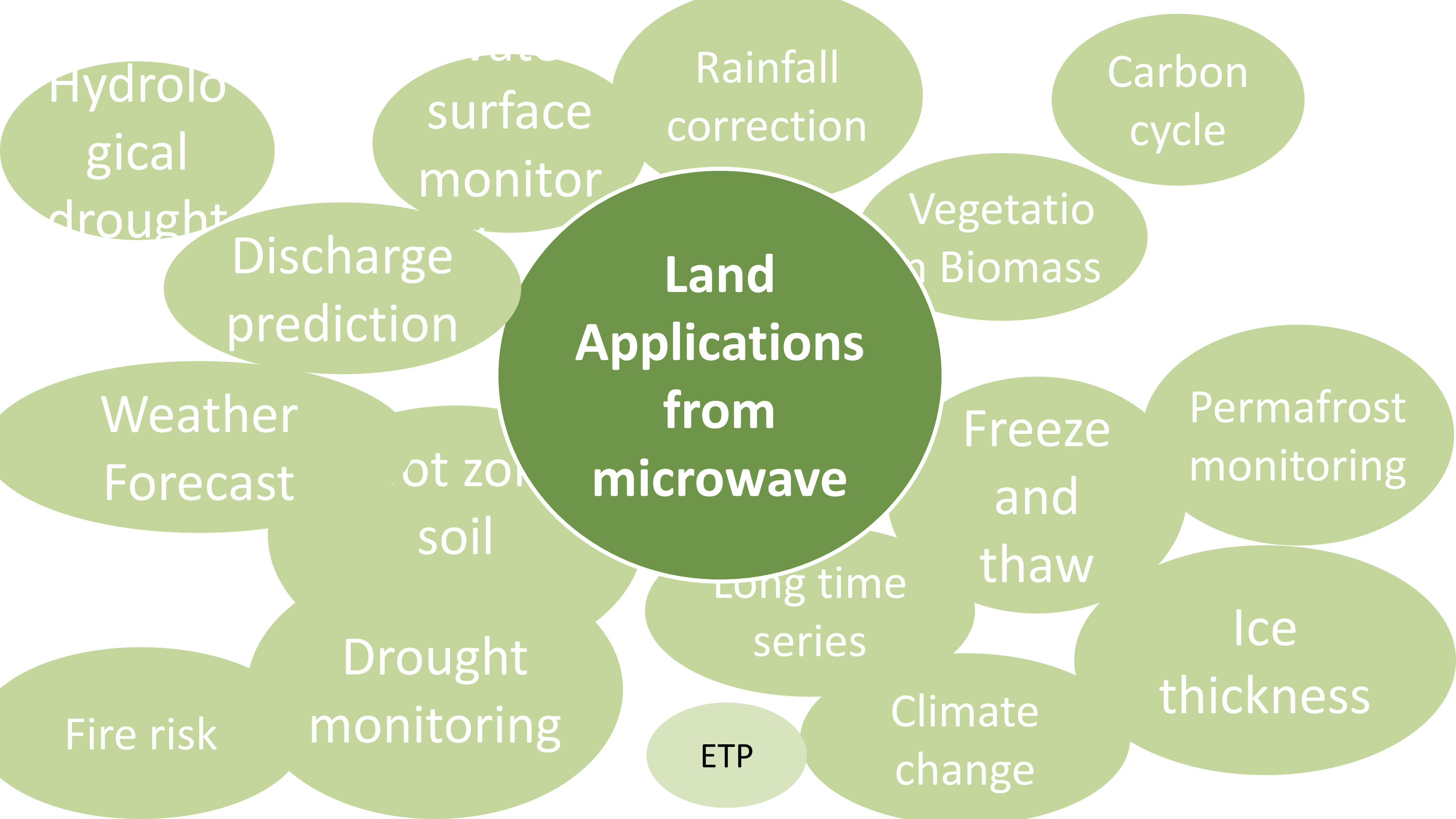
From M. Zribi 2015, CESBIO

Microwave Radiometry for the hydrological Cycle

Bascis of microwave radiometry

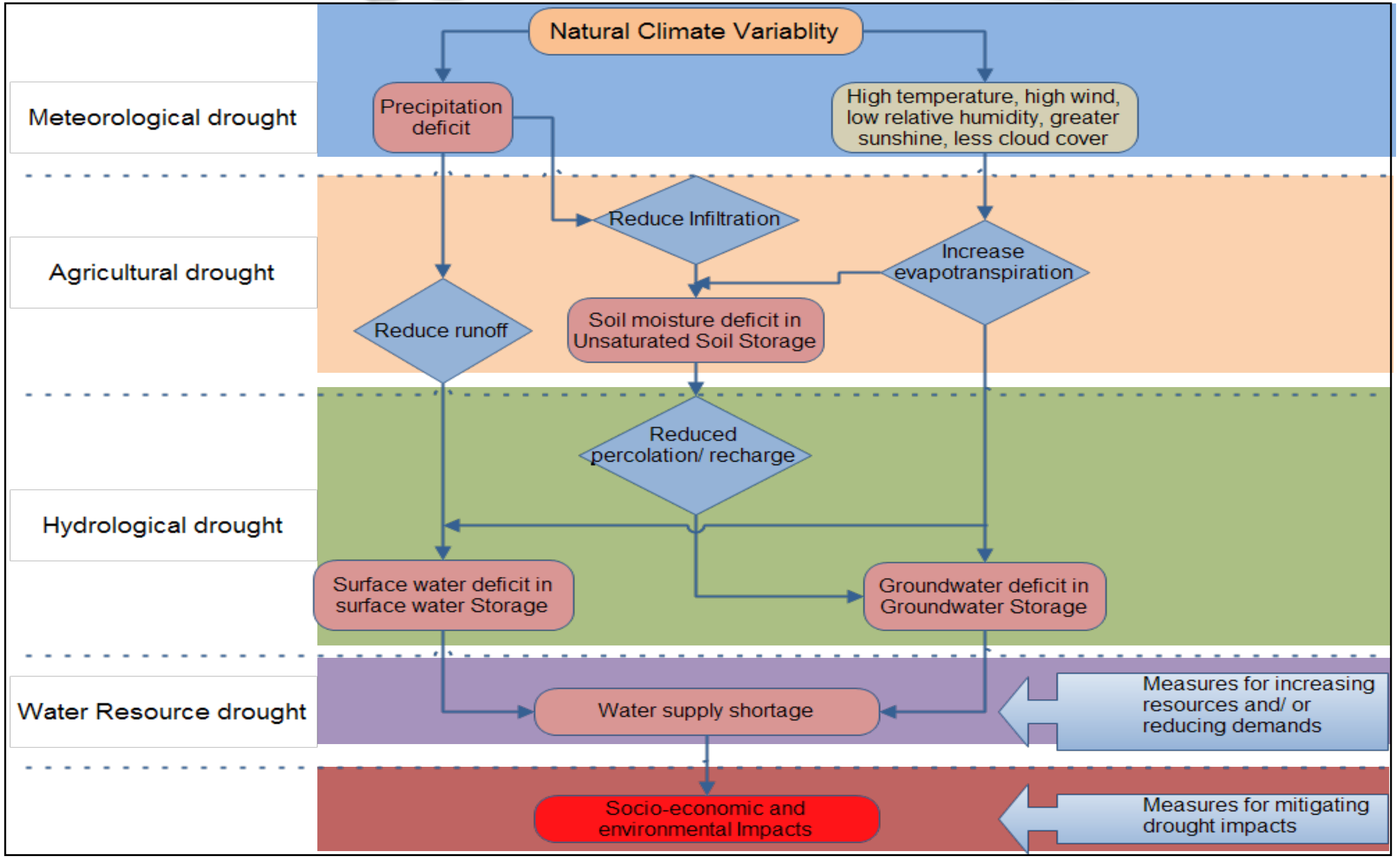
Geophysical Products

Applications



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

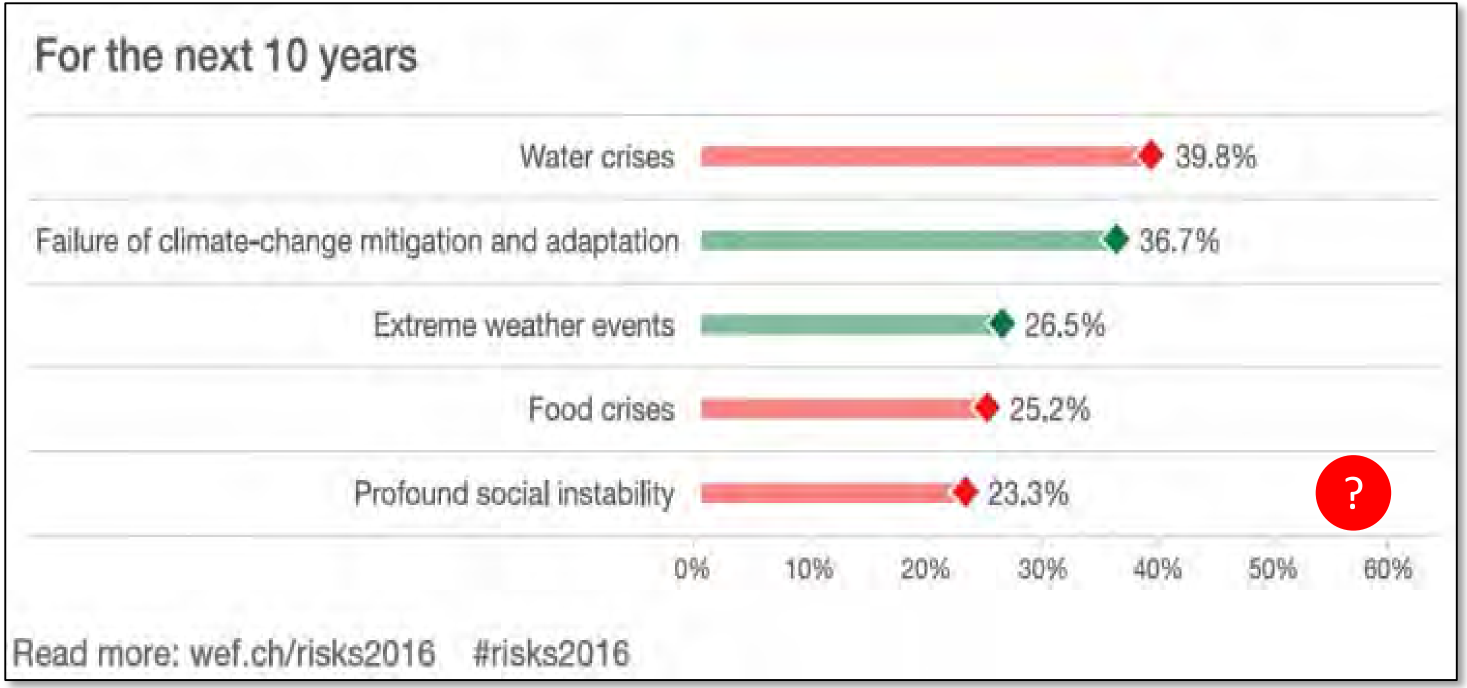
Types of drought



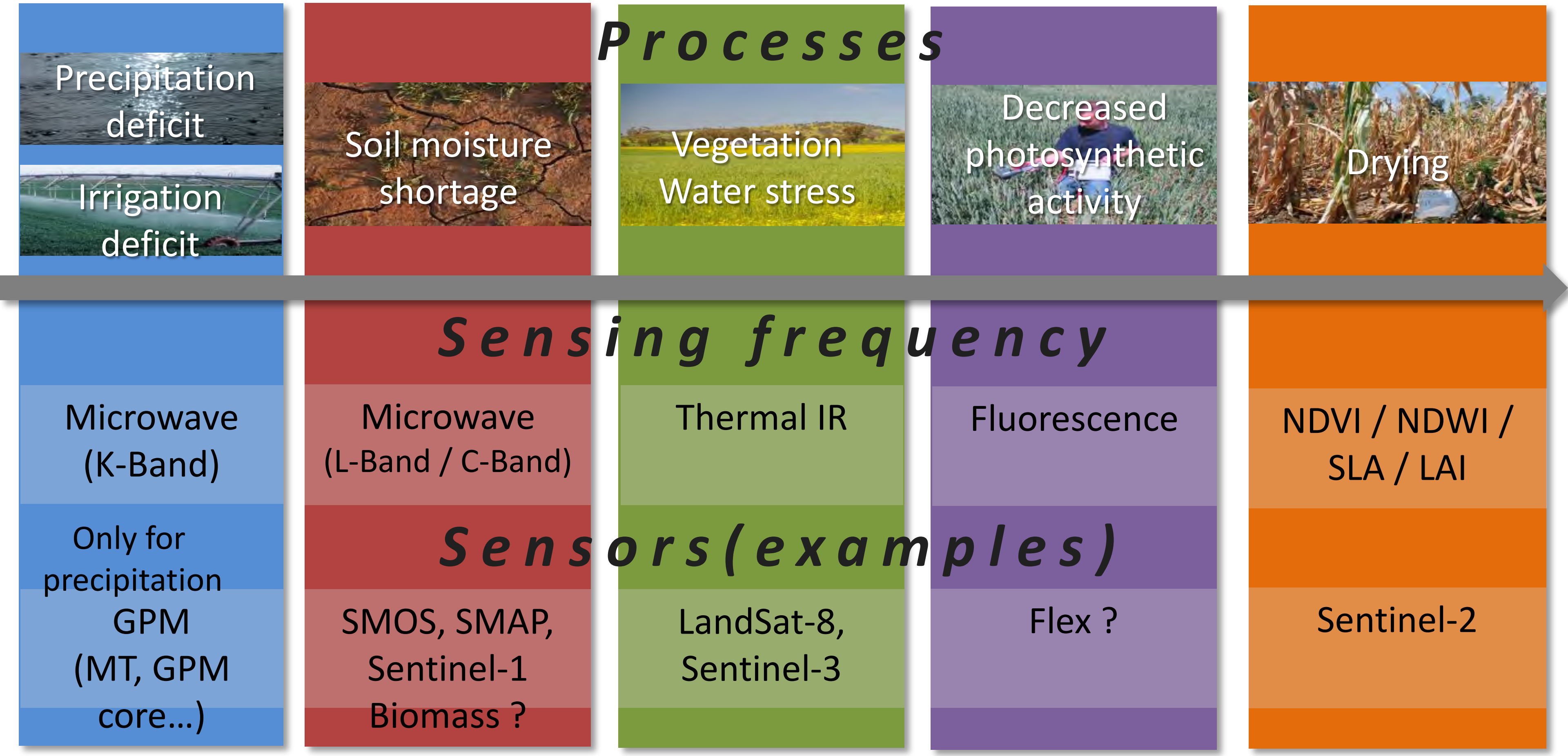
Source: National Drought Mitigation Centre, and G. Rossi, B. Bonaccorso, A. Cancelliere, (2003)

Is it a priority to observe the hydrological cycle ?

The Global Risks Perception Survey from the World Economic Forum



Stages of agricultural drought

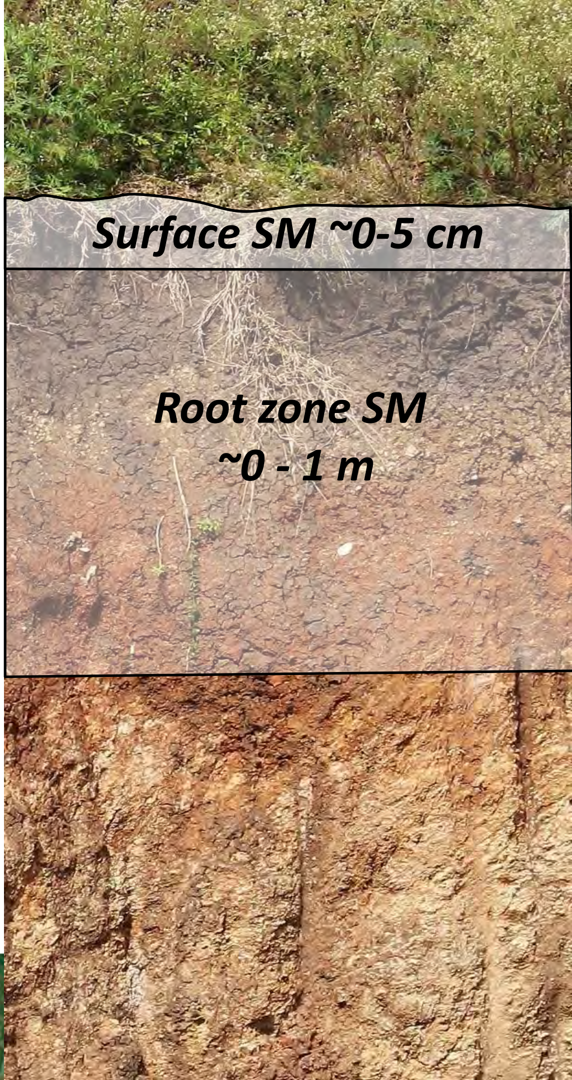


Root zone soil moisture

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

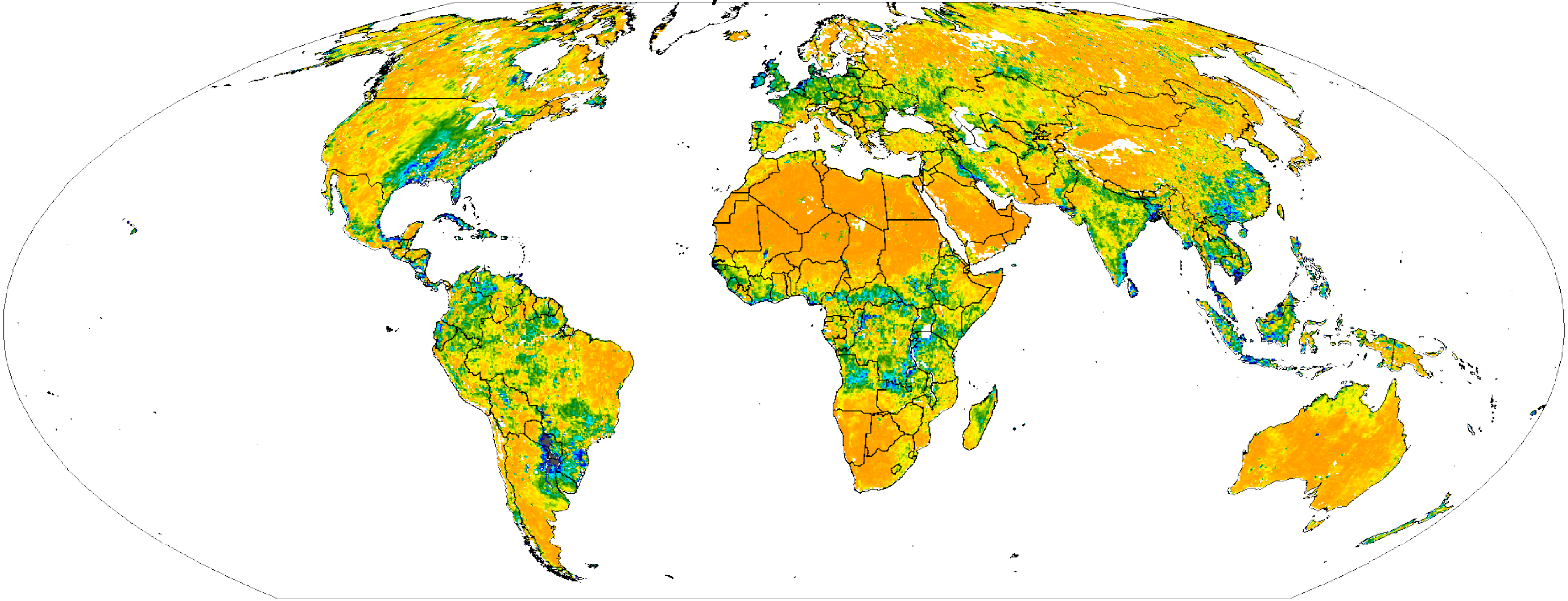
SMOS measures surface soil moisture, root zone soil moisture need to be modeled

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)



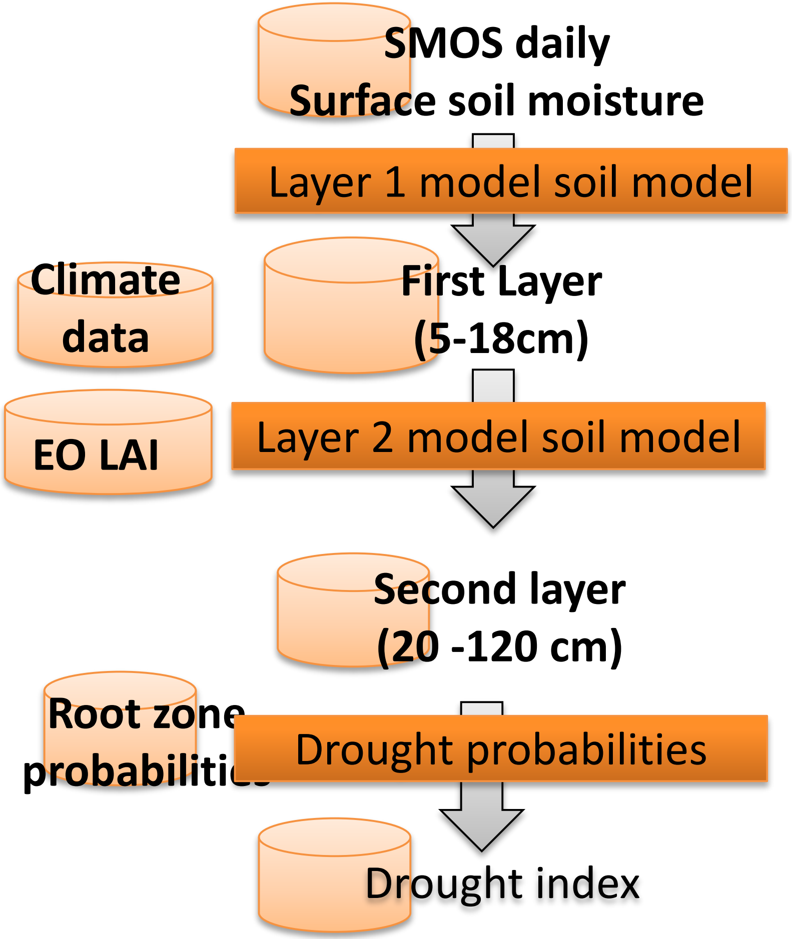
SMOS Global root zone soil moisture maps

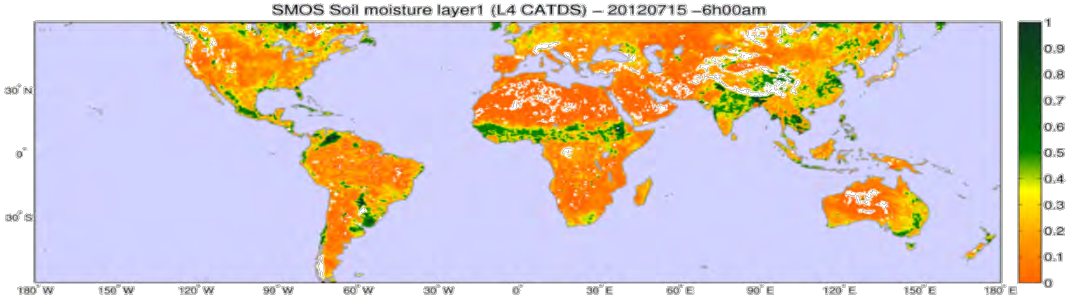
May 2016

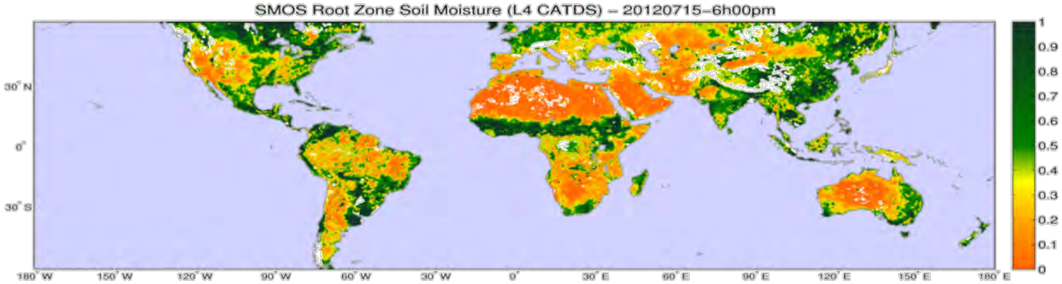


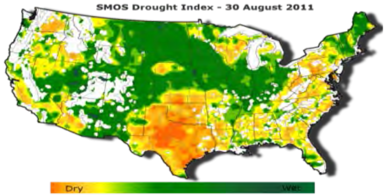
Al Bitar et al., 2013, Kerr et al. 2016

available on www.catds.fr





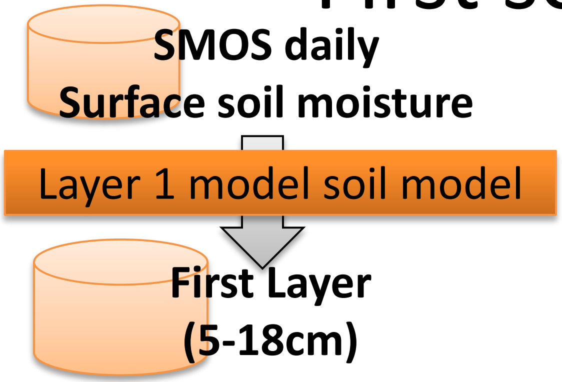


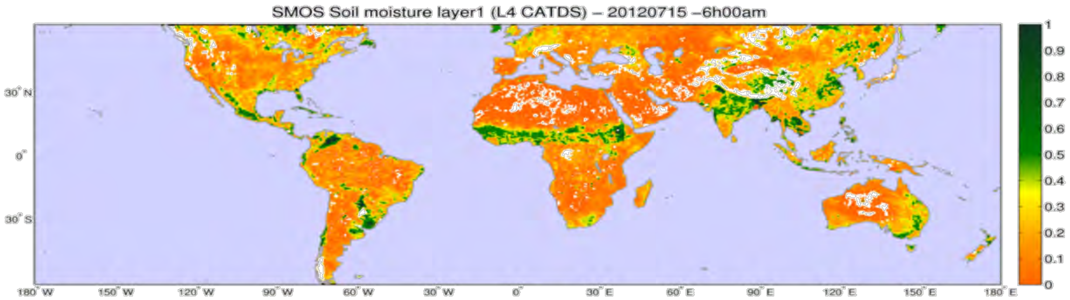


web application
+
Netcdf products :
EASE grid 25km

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 ($m^3/m^3/s$)

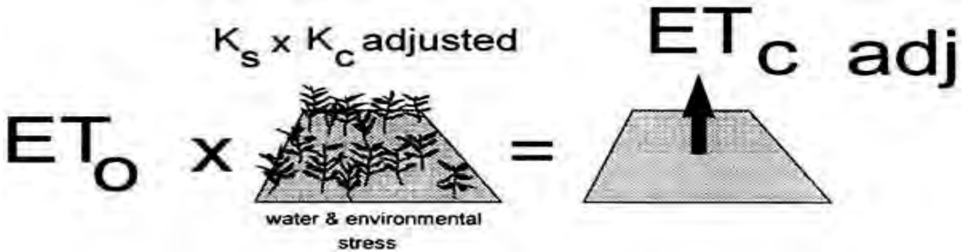
A linearized (force restore) formulation is used

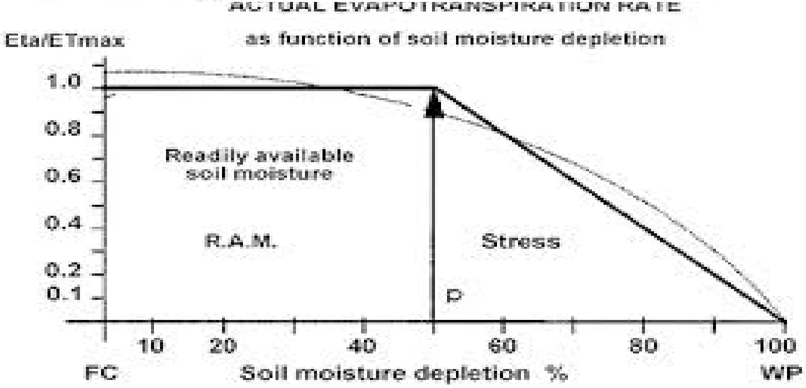
Vegetation transpiration model (T)

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

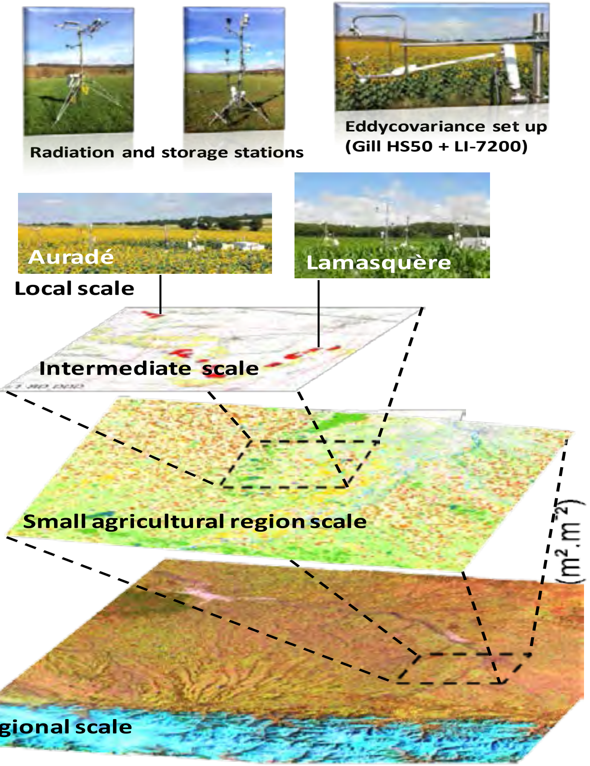
computed using FAO-56 method forced by NDVI and air temperature

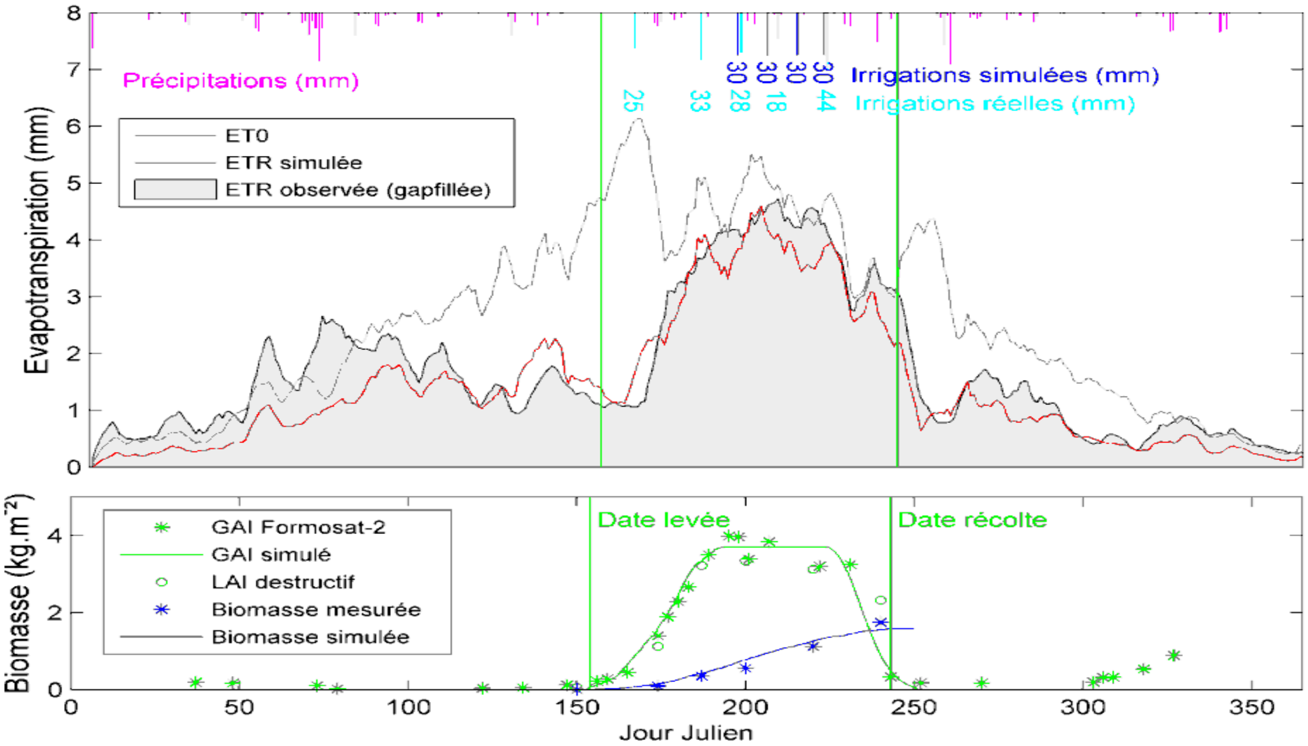
Kcb=a exp (b. NDVI)
adapted from Er-Raki et al. (2010)





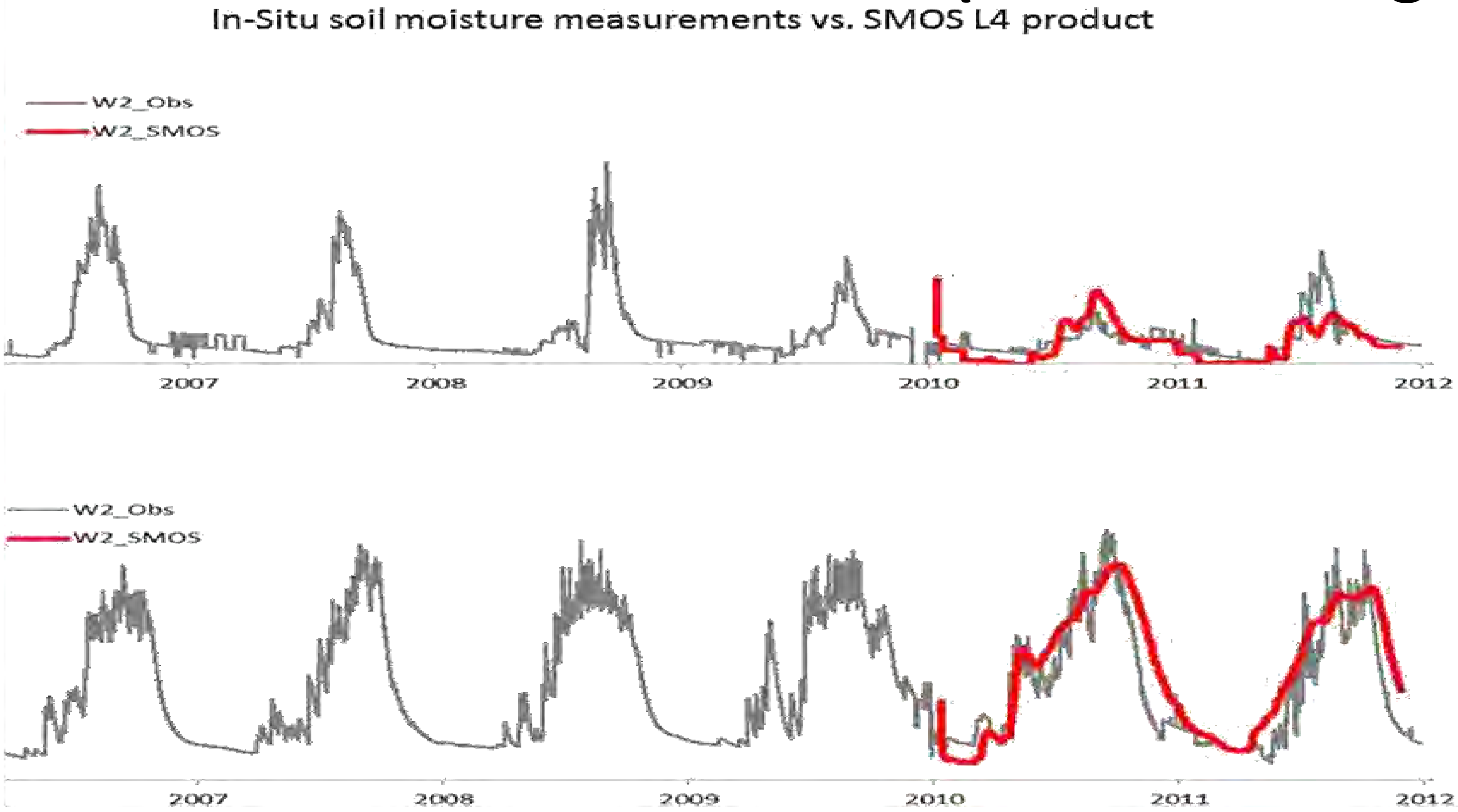
Why are we using the remote sensing driven FAO approach ?





(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

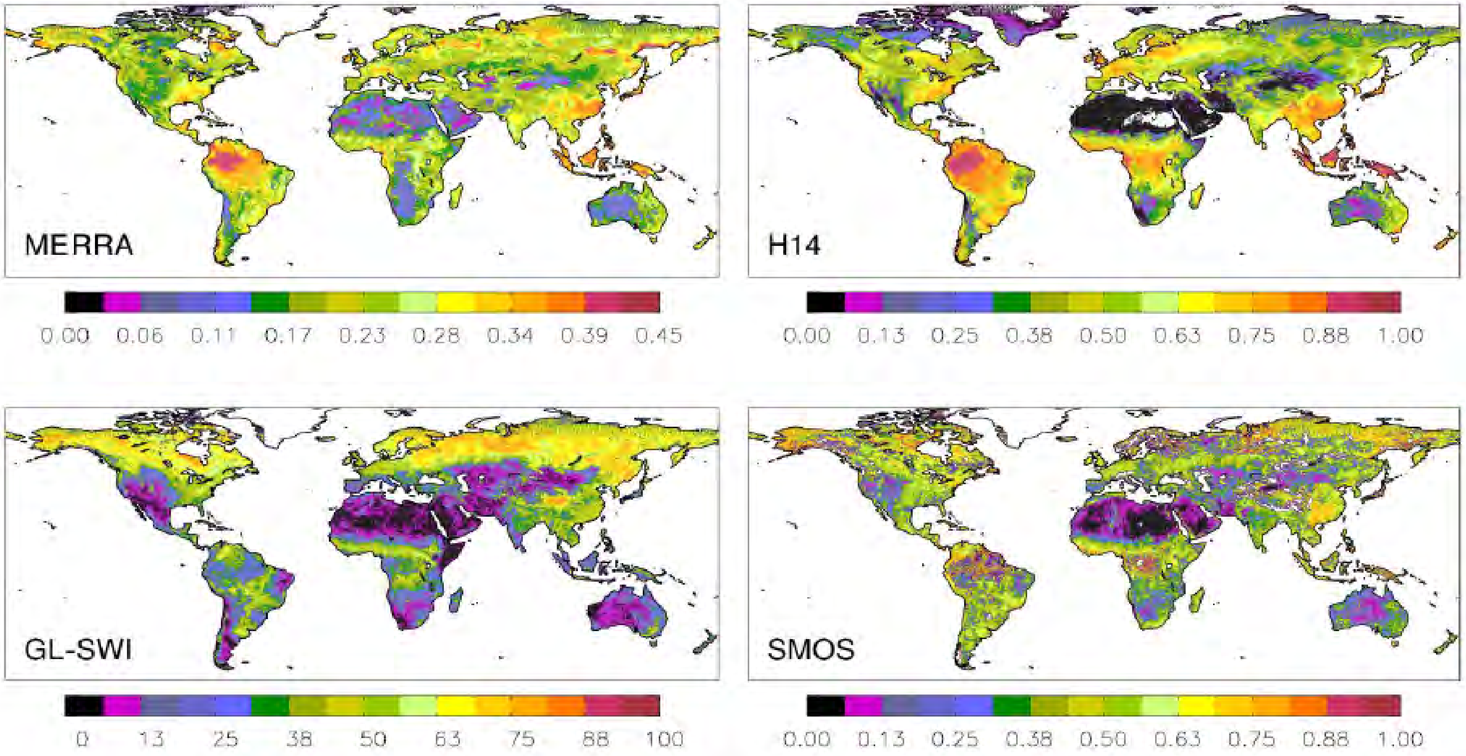
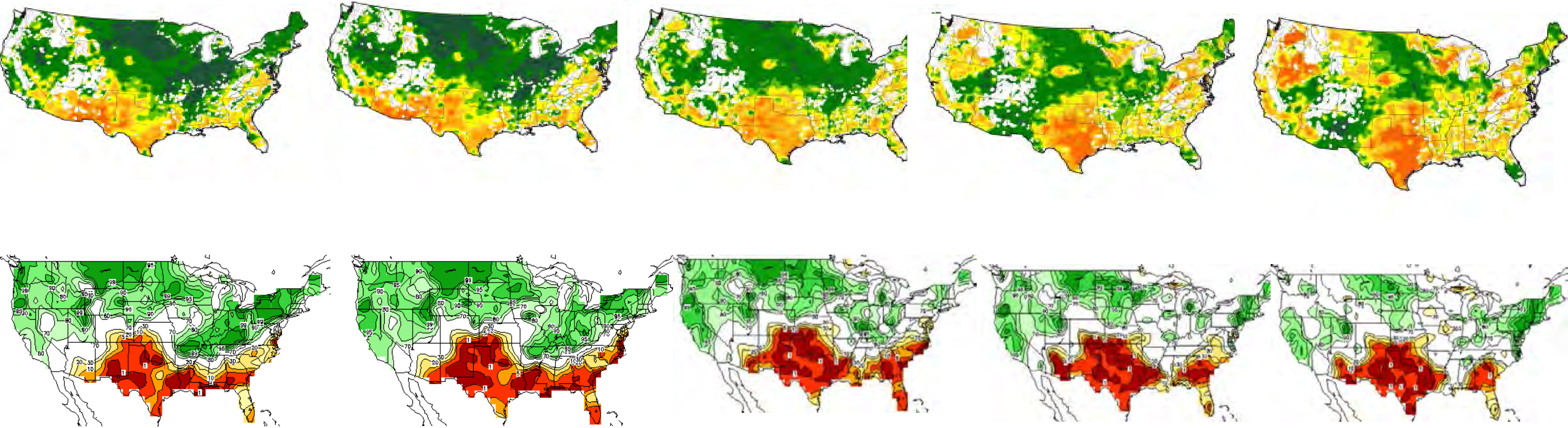


Figure 1: Annual mean root-zone soil moisture maps for MERRA, H14, GL-SWI and SMOS.

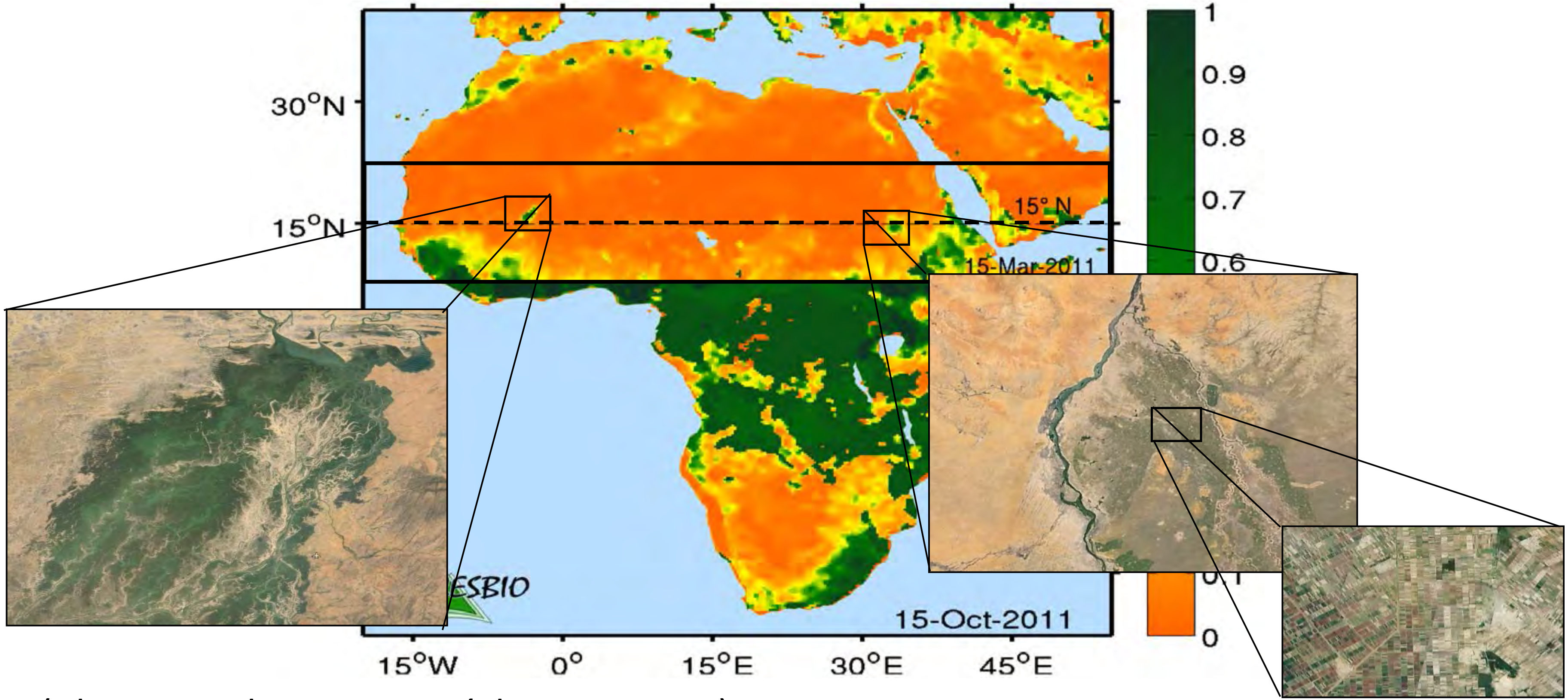
Pellarin, T., de Rosnay, P., Albergel, C., Abdalla, S., & Al Bitar, A. H-SAF Visiting Scientist Program HSAF_CDOP2_VS12_02, 2013.

RZ soil moisture vs NOAA NCEP Bucket model

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



Drought in the horn of Affrica

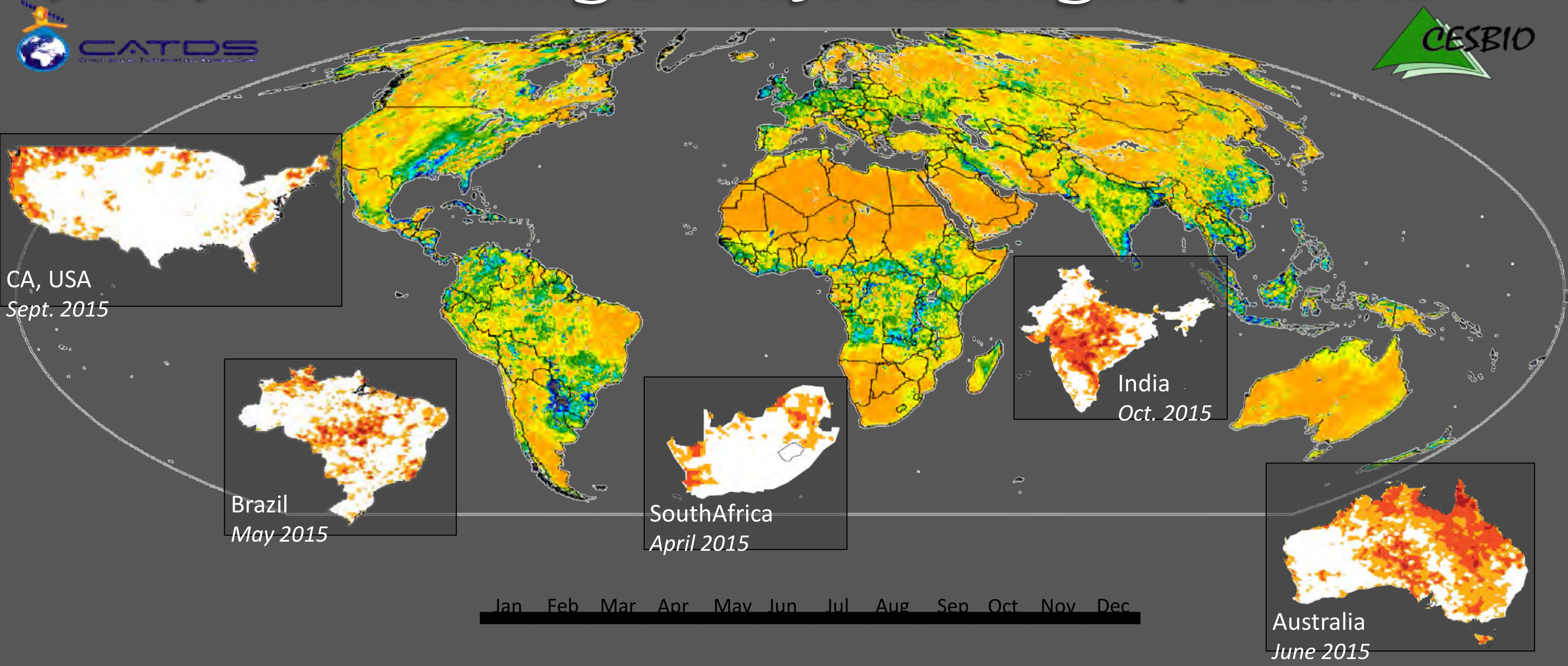


(Al Bitar et al. , in revue sécheresse 2016)

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

We found the missing link between SMOS sandwich & SMOS sat !

SMOS monitoring 5 major droughts in 2015



Root zone soil moisture

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 (m^3/m^3)

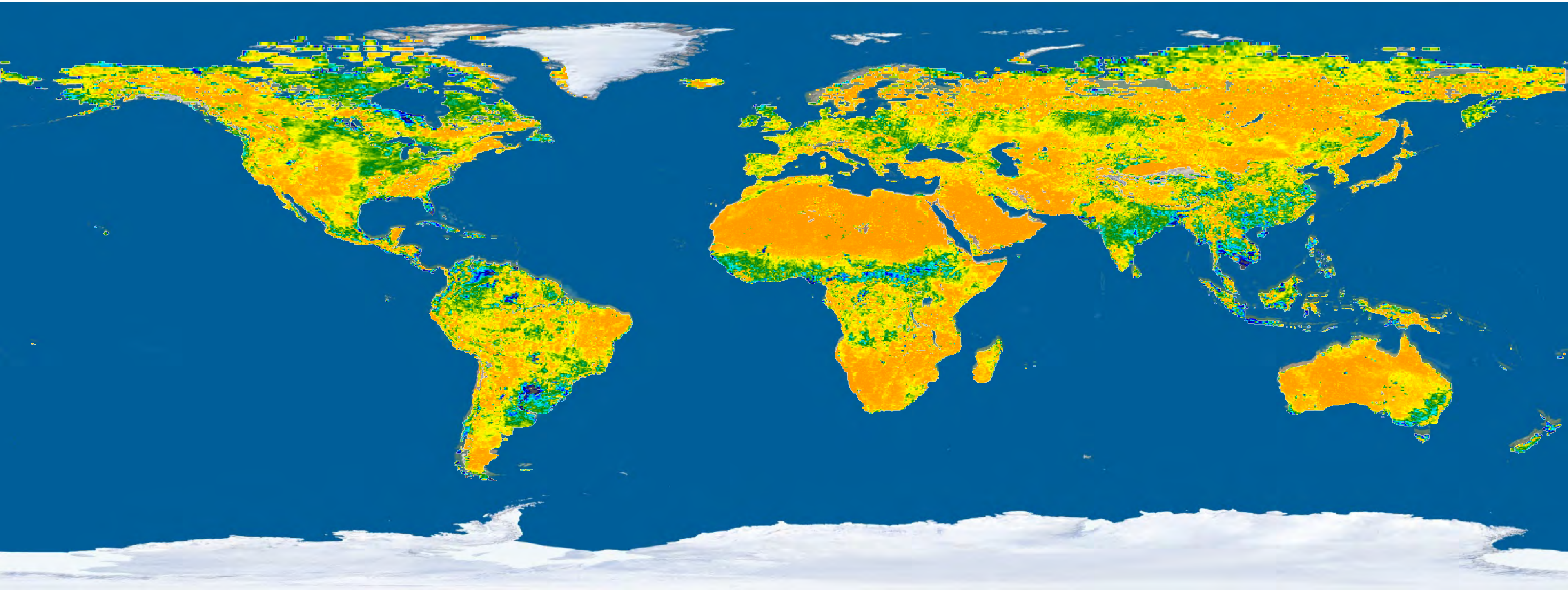
Drought index

moderat mild extrem

ahmad.albitar@cesbio.cnrs.fr

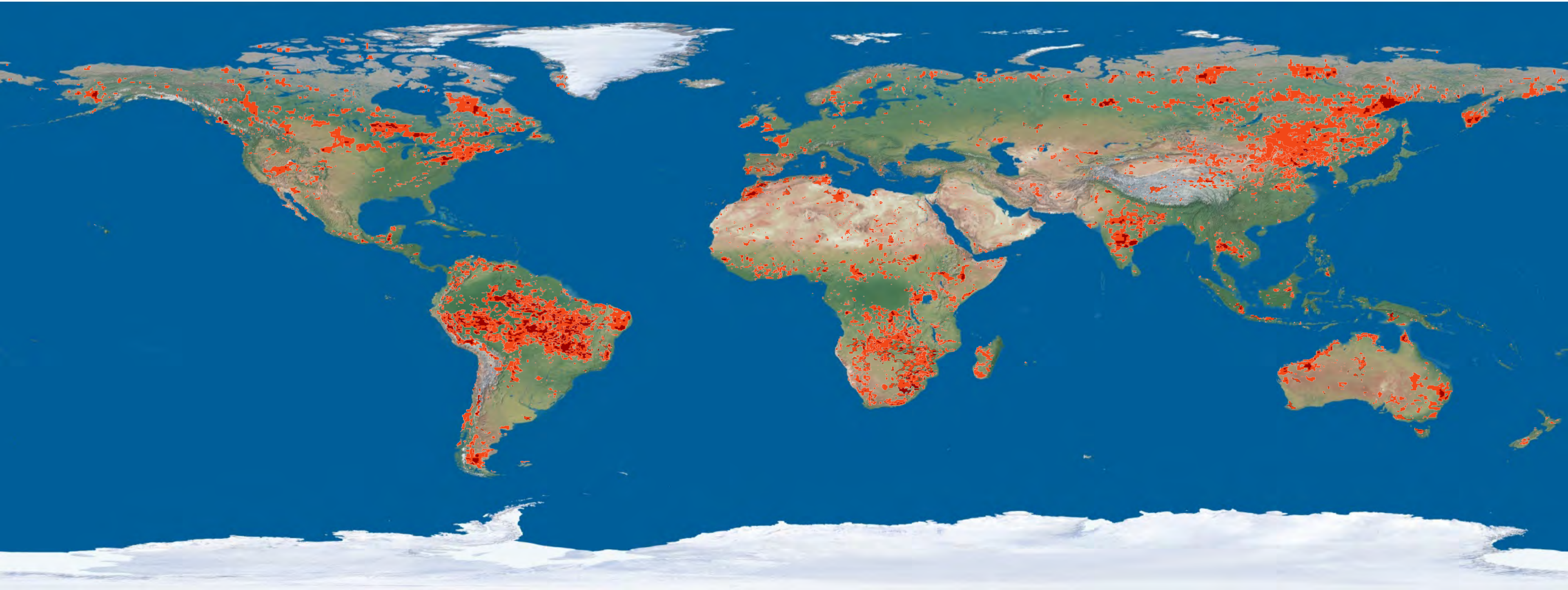
Root zone soil moisture in 2016

Feb. / May / Aug. / Nov/ 2016



Droughts from Root zone soil moisture anomalies 2016

Feb. / May / Aug. / Nov/ 2016

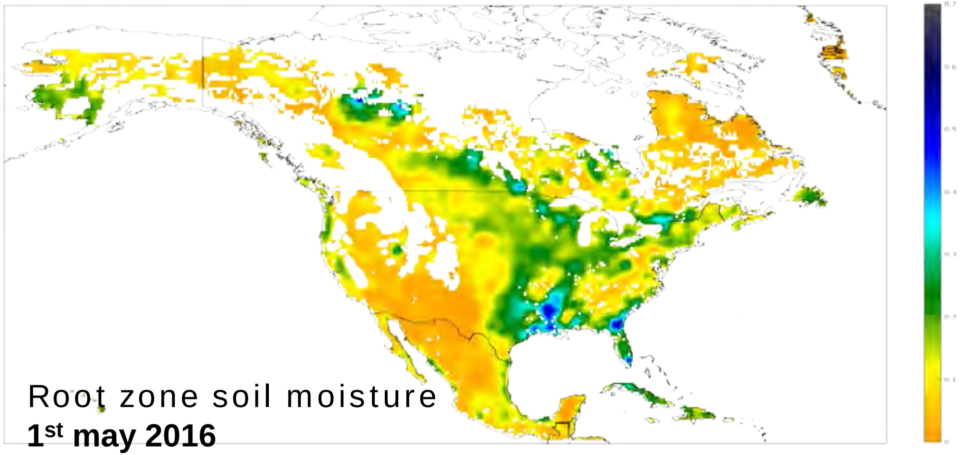


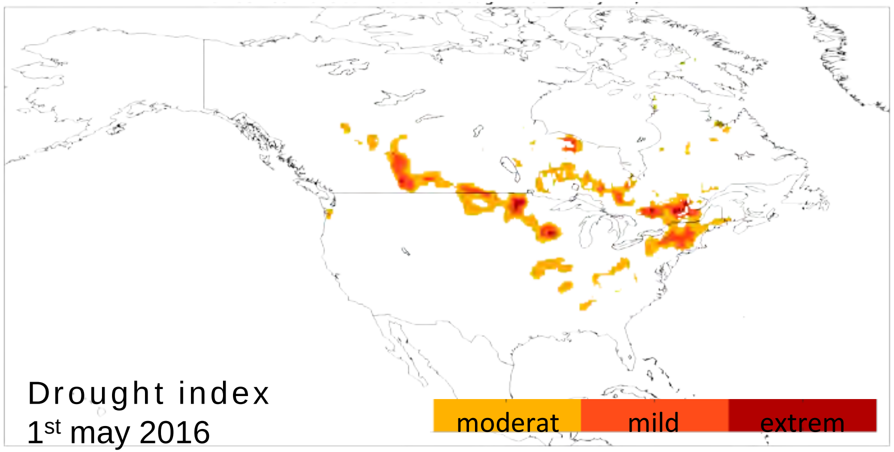
What is looming a world food crises because of prolonged drought conditions, that can be driven from socio-climatique situations.

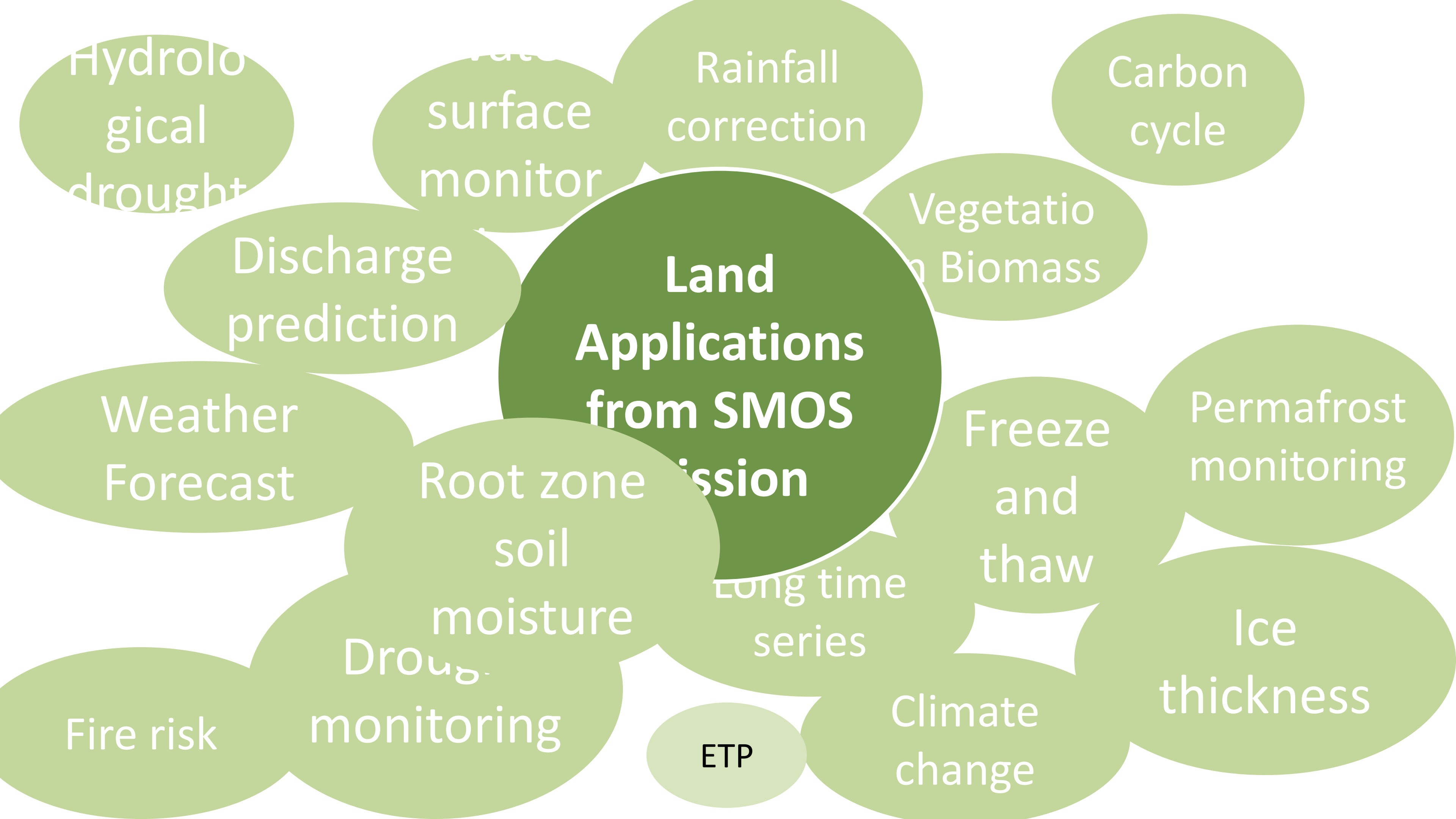
Drought before Canada Fires in 2016

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

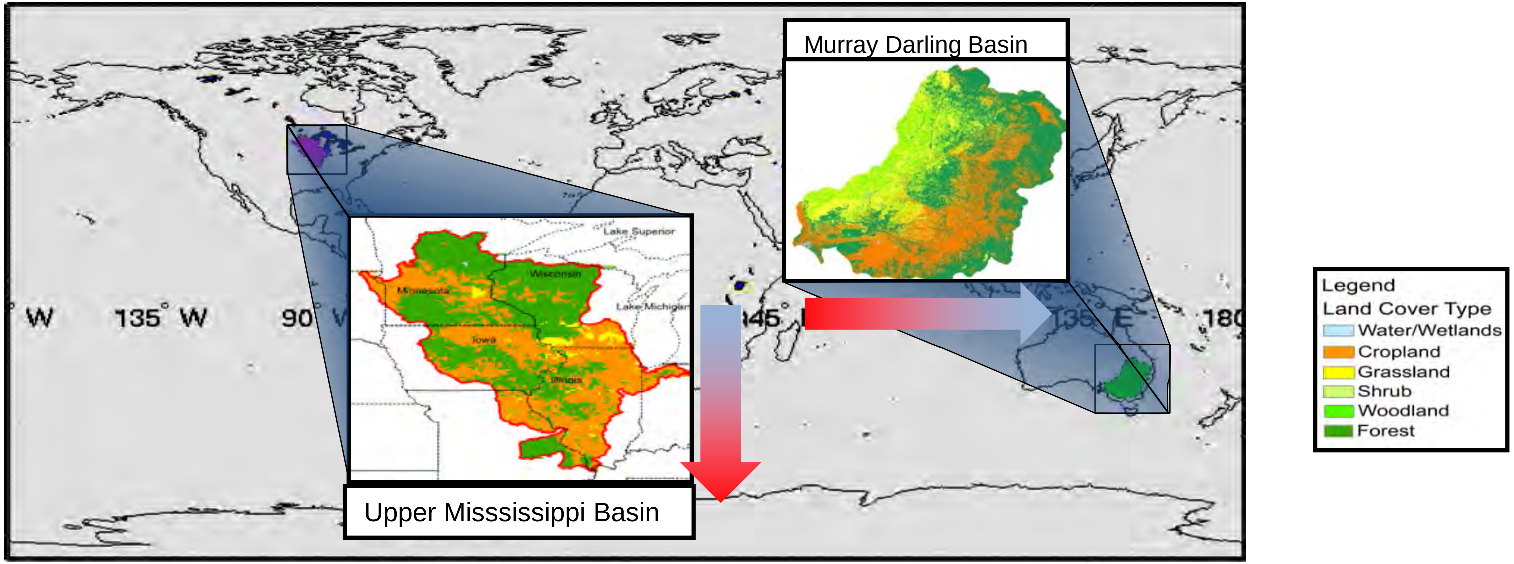
Communication over ESA web portal



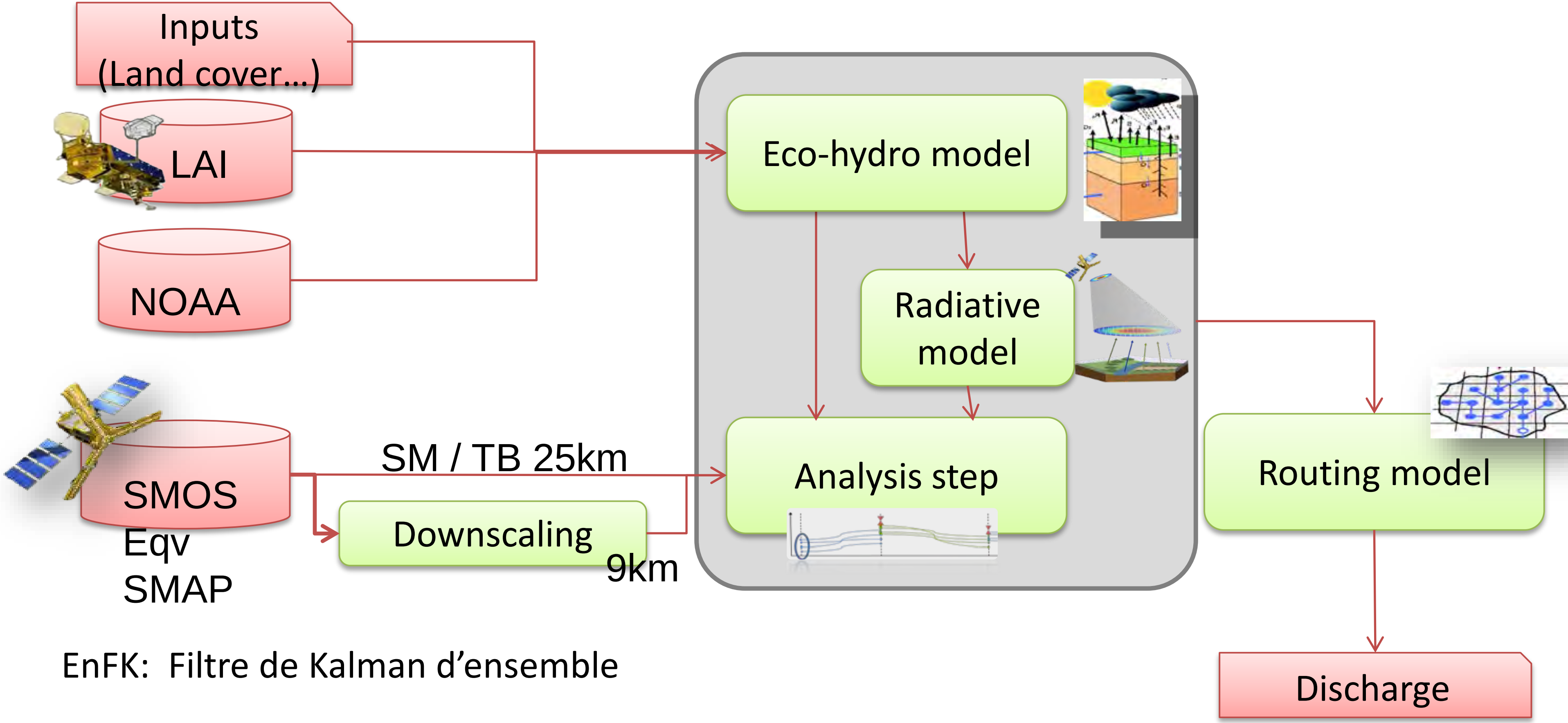



Hydrolo
gical
drought
surface
monitor
Rainfall
correction
Carbon
cycle
Vegetatio
Biomass
Discharge
prediction
Land
Applications
from SMOS
ission
Weather
Forecast
Root zone
soil
moisture
time
series
Freeze
and
thaw
Permafrost
monitoring
Droug
monitoring
Fire risk
ETP
Climate
change
Ice
thickness

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

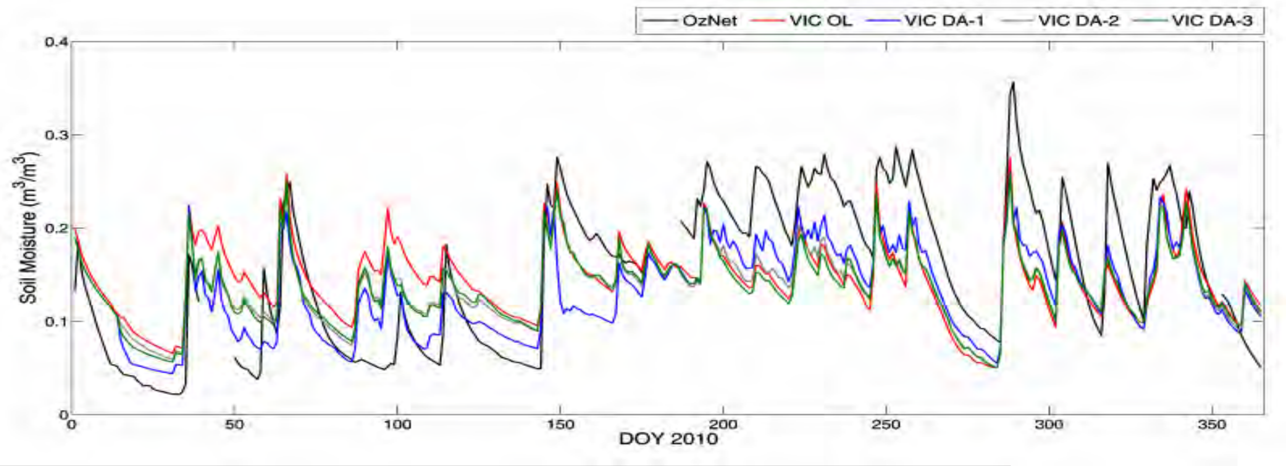


Land Data Assimilation System - LDAS



EnFK: Filtre de Kalman d'ensemble

Surface soil moisture - Murray Darling Basin



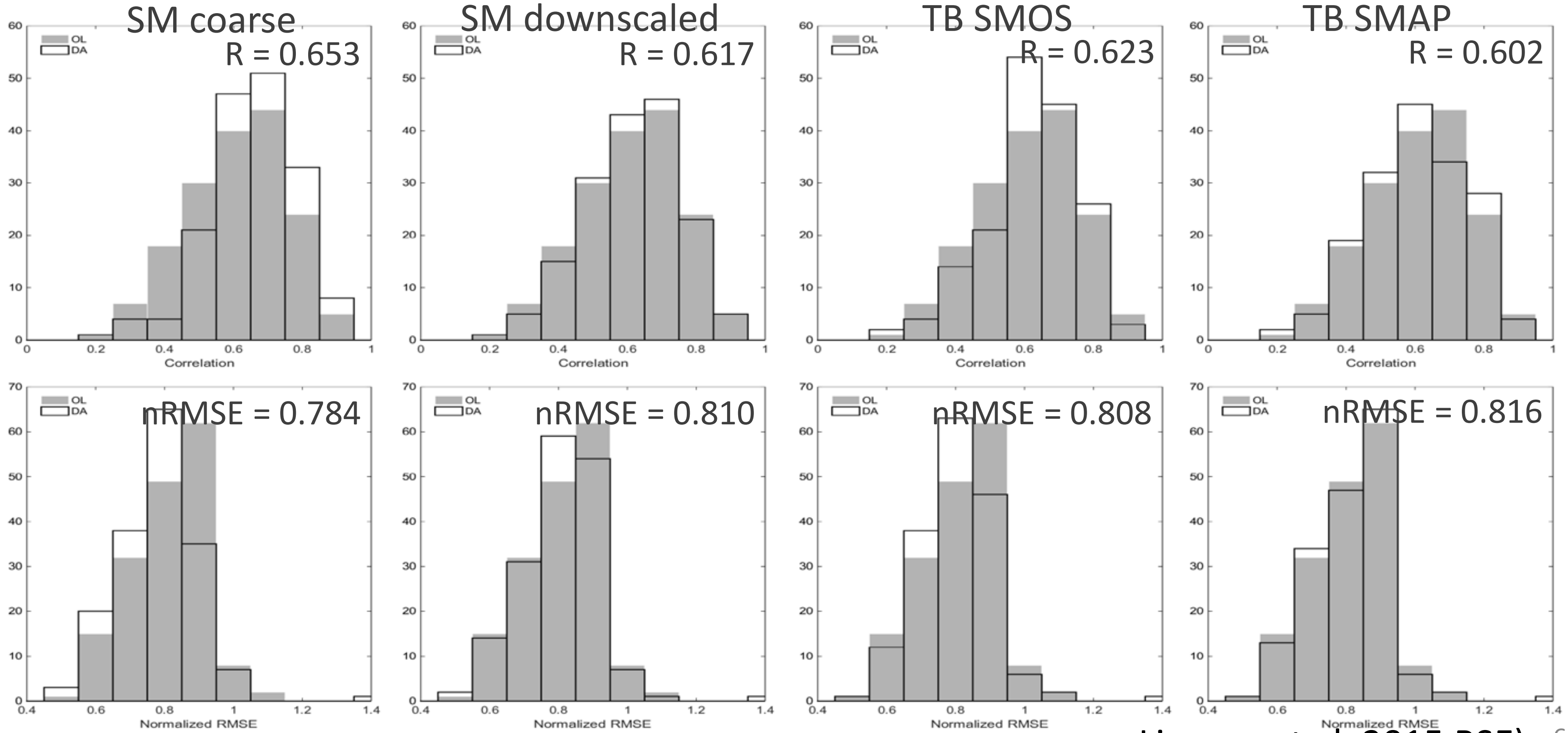
SM record	RMSE m^3/m^3	R (-)
SMOS	0.045	0.726
VIC open loop	0.058	0.549
DA SM coarse	0.045	0.713
DA SM downscaled	0.047	0.727
DA TB SMOS	0.050	0.661
DA TB SMOS(SMAP)	0.046	0.700

(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

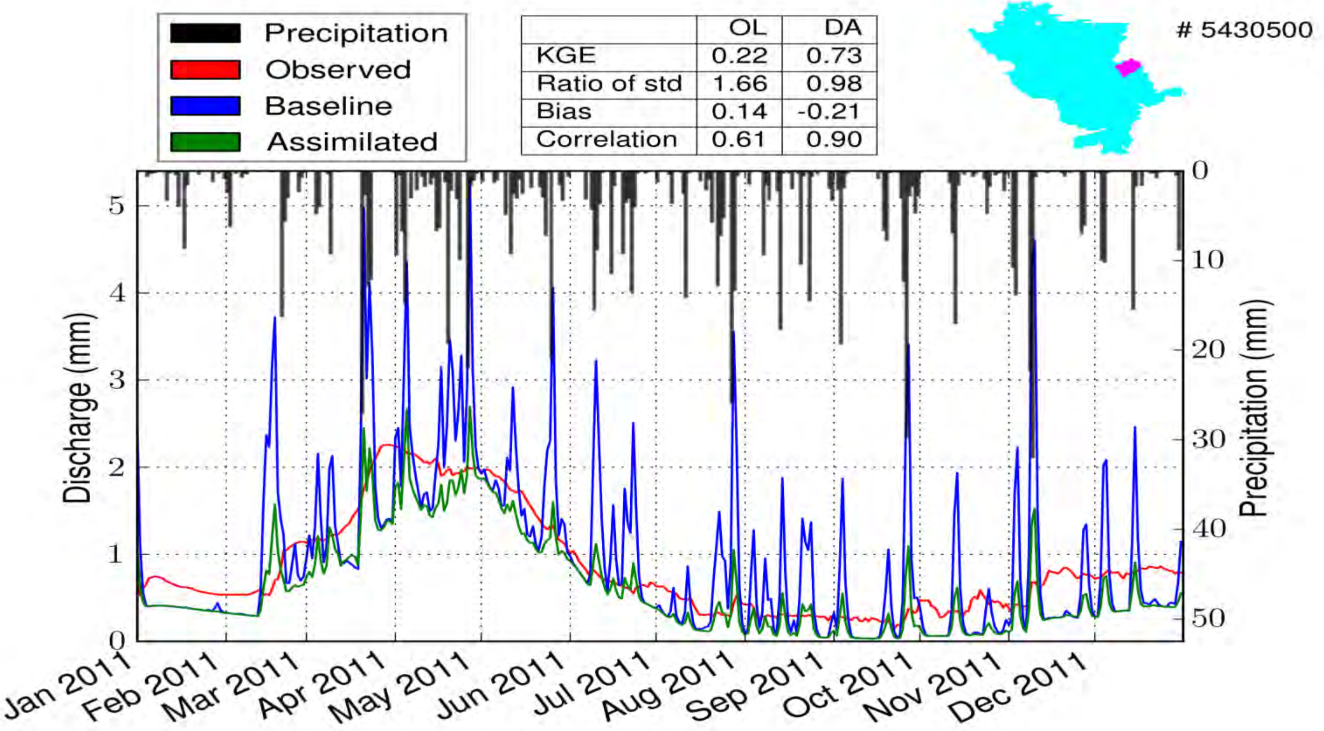
Comparison of DA experiments

Open loop: R = 0.608 / nRMSE = 0.812

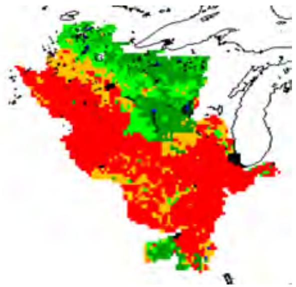


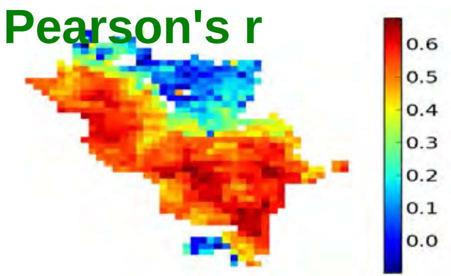
Lievens et al. 2015 RSE)

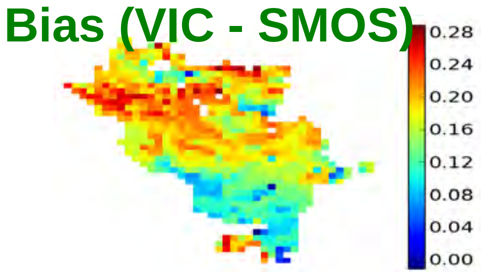
Débit sous bassin – Upper Mississippi Bassin



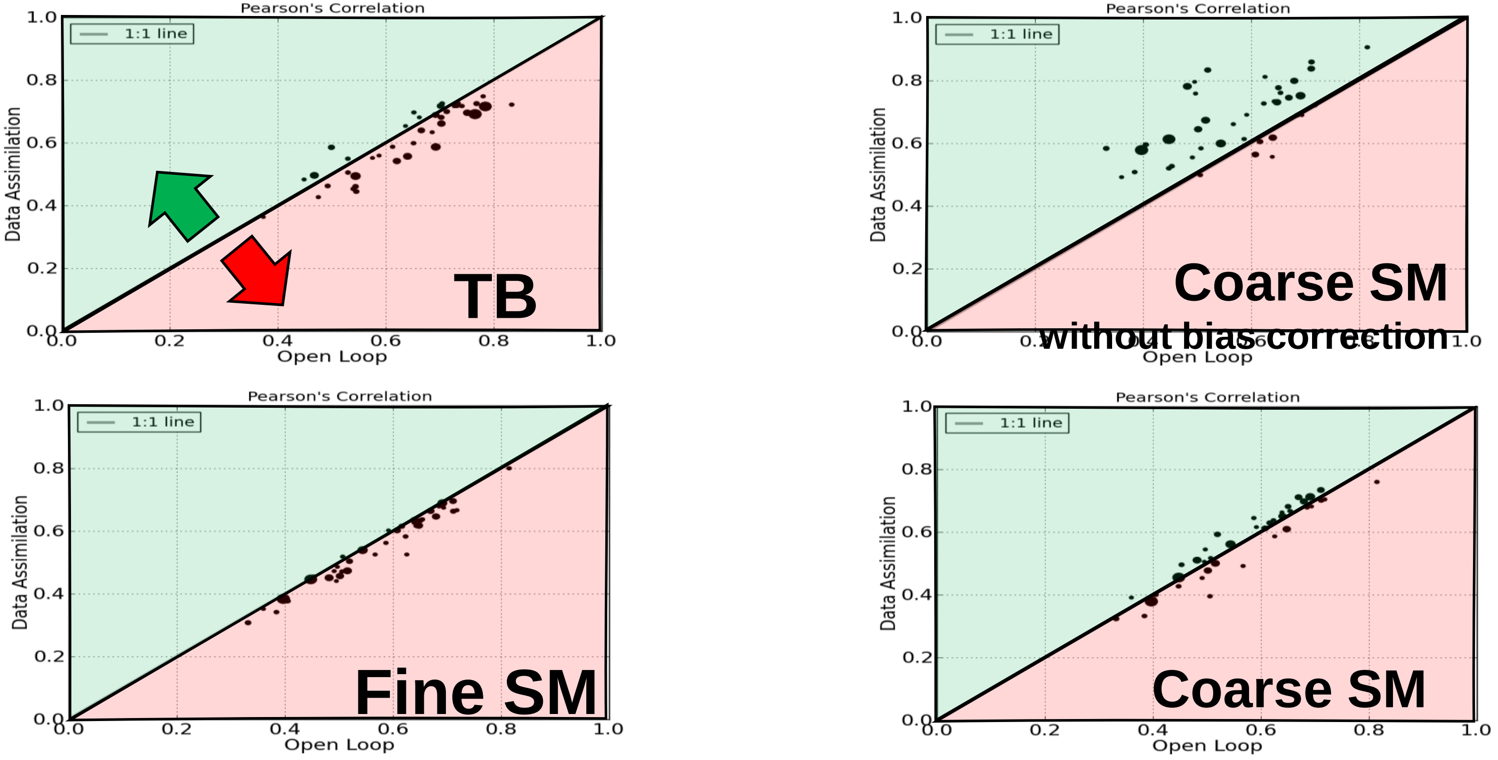
	OL	DA
KGE	0.22	0.73
Ratio of std	1.66	0.98
Bias	0.14	-0.21
Correlation	0.61	0.90





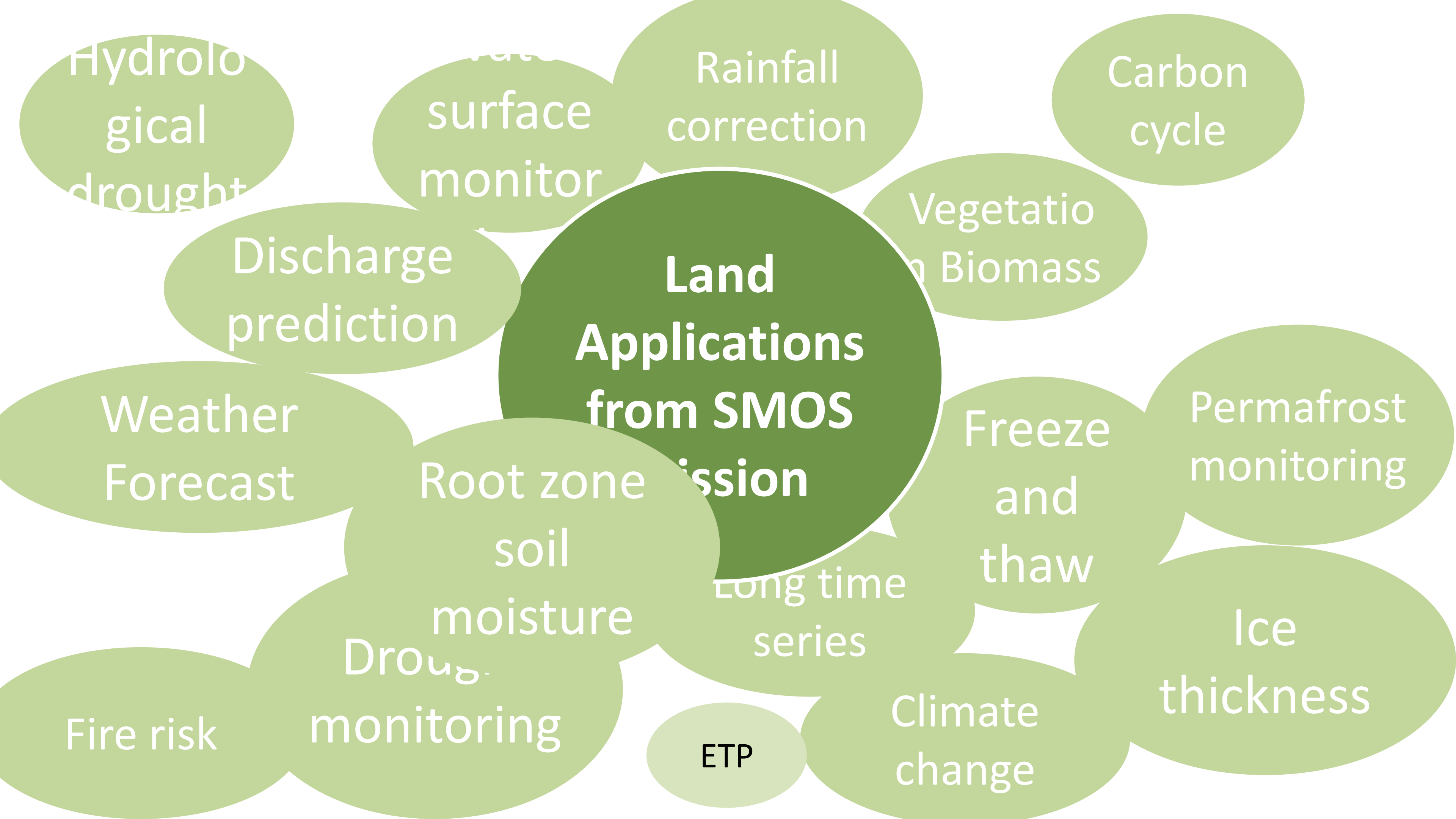


Débit sous bassin – Upper Mississippi Bassin



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 from SMOS
Hydrolo gical
surface monitor
Rainfall correction
Carbon cycle
Vegetatio Biomass
Discharge prediction
Weather Forecast
Root zone soil moisture
Freeze and thaw
Permafrost monitoring
Long time series
Ice thickness
Drou monitoring
Fire risk
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 Forecast

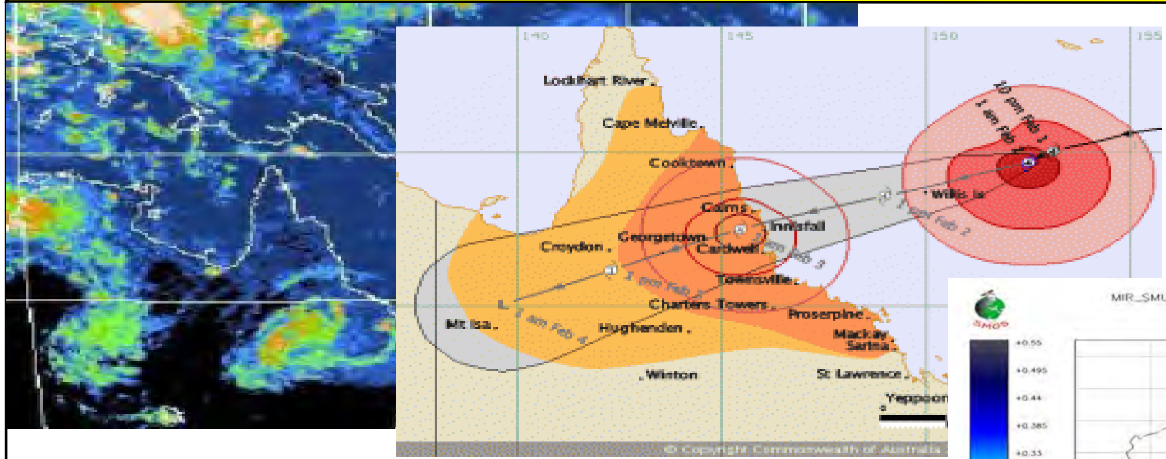
Start

End

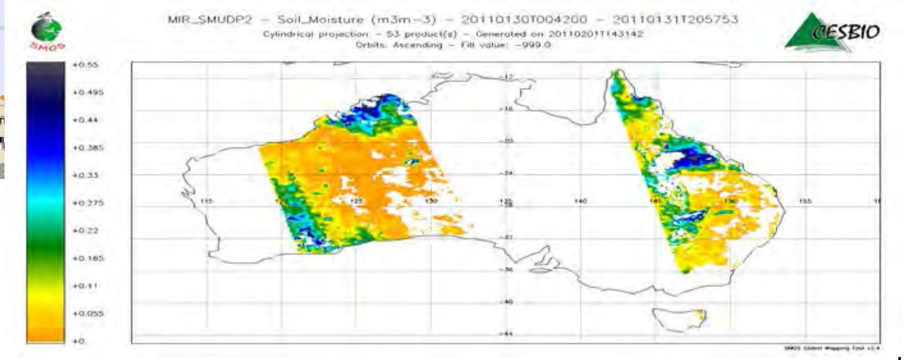
Prediction / Early alert

Monitoring

Post / damage analysis



Cyclone YASI, 2011



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

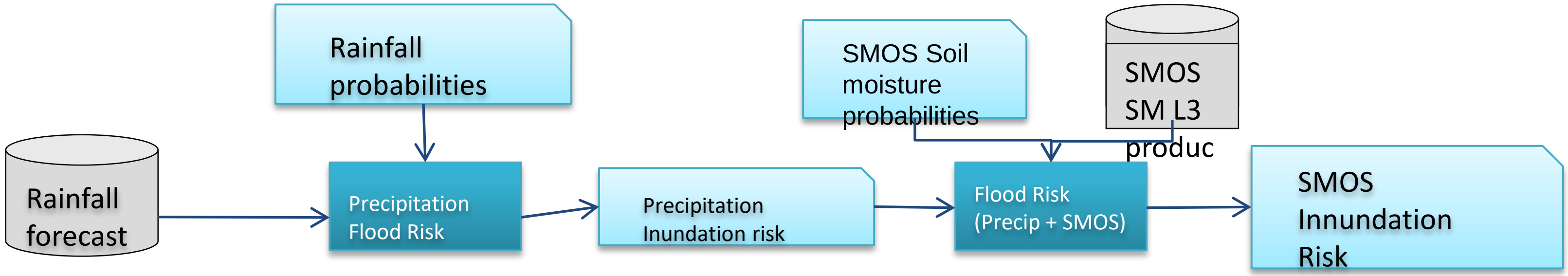
Flood Risk Forecast

- 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

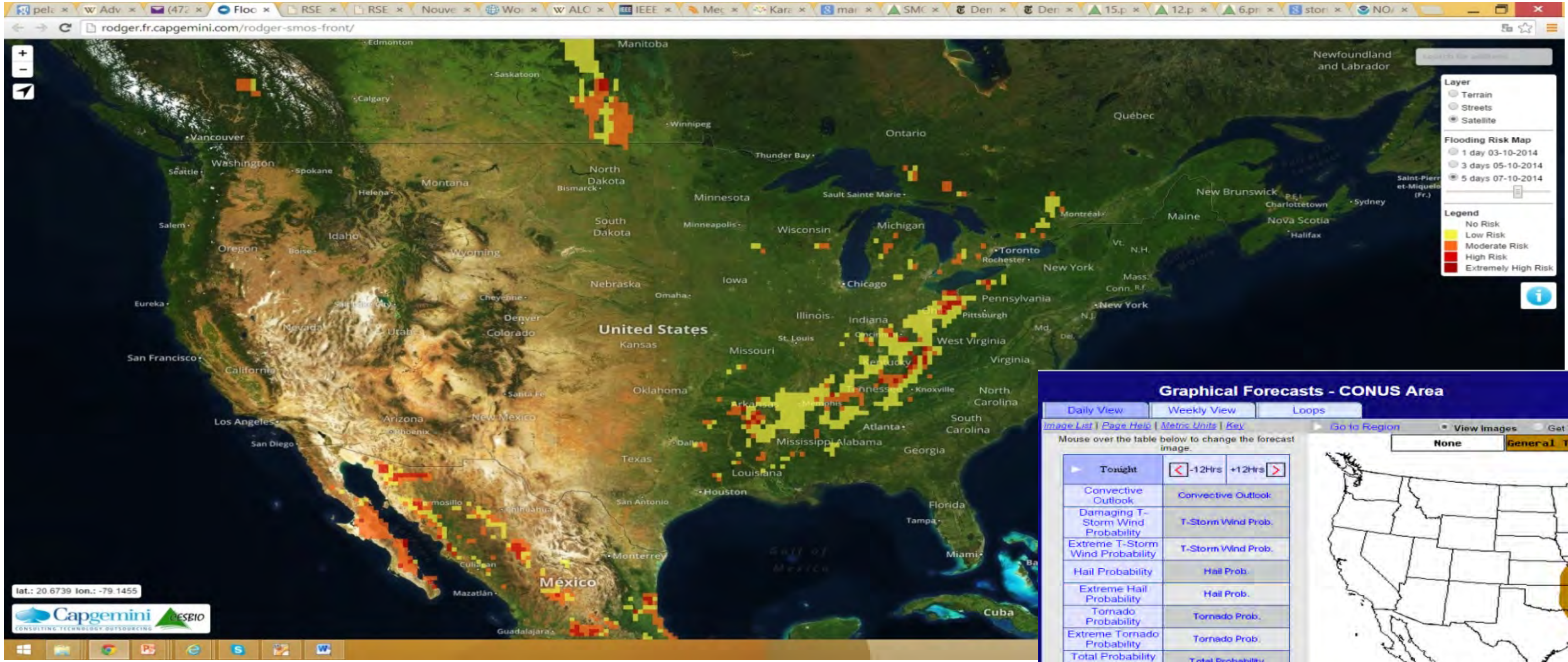
Methodology

Leveraging inundation risk based on SMOS soil moisture prior knowledge

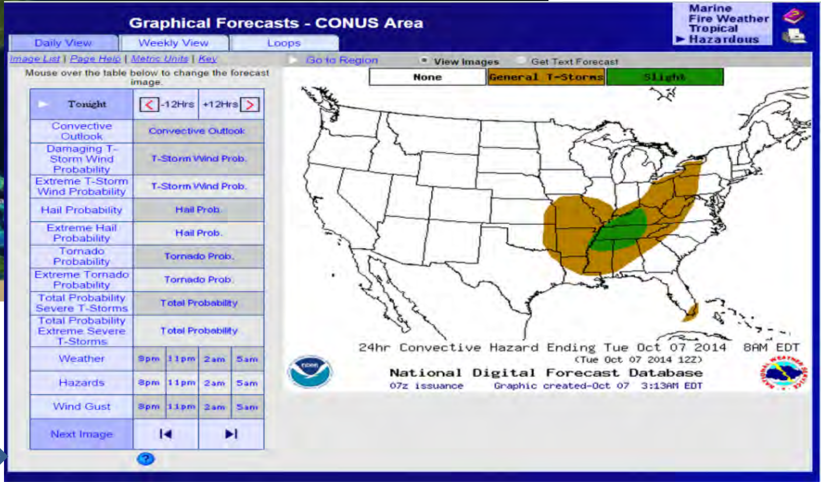


SM vs SM_perc	None /0	Low /1	Moderate /2	High /3
0.8	None /0	None /0	Low / 1	Moderate /2
0.8 - 0.9	None /0	Low / 1	Moderate /2	High / 3
0.9 +	None /0	Moderate /2	High / 3	Ext High / 4

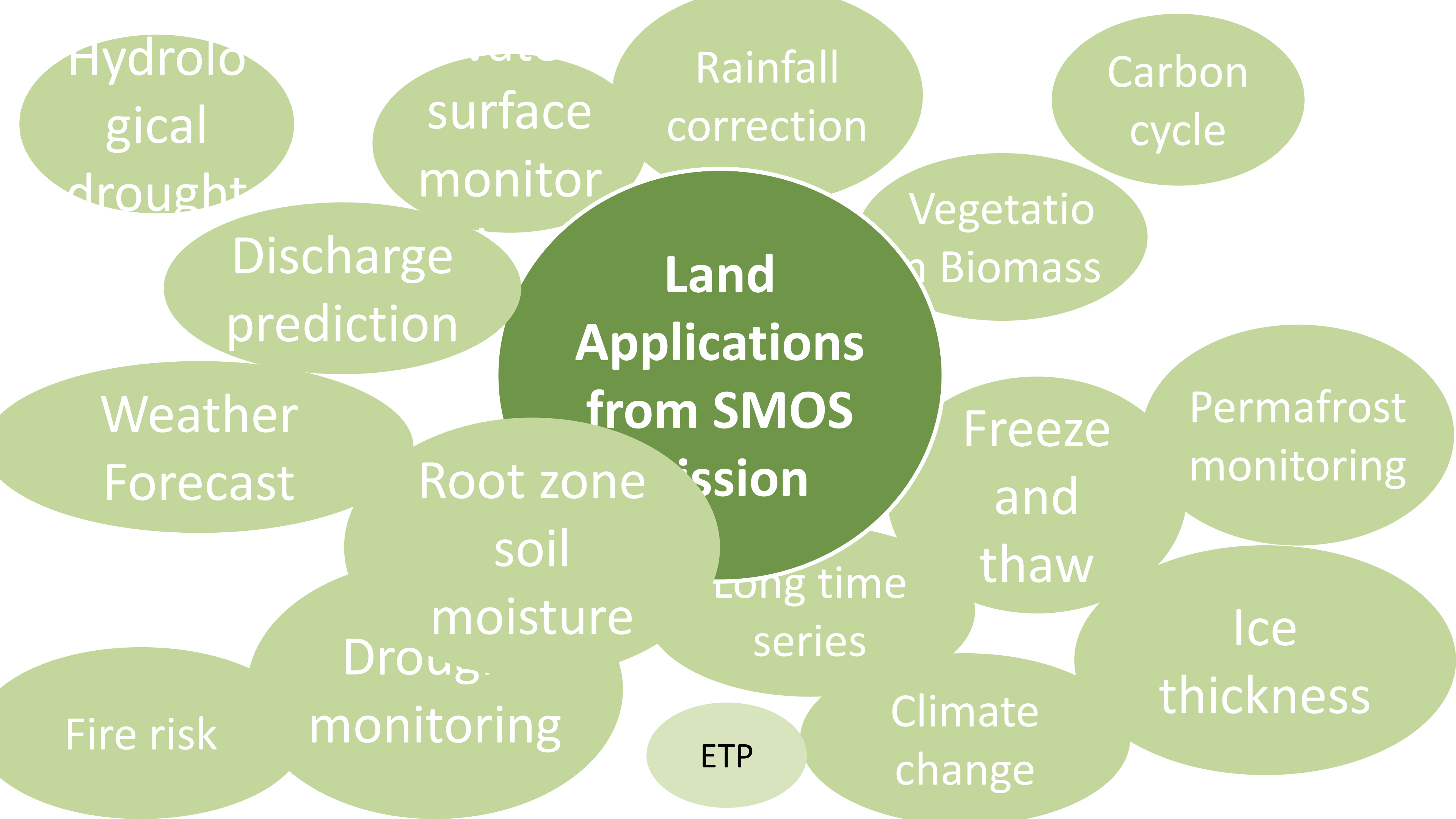
Operational implementation by CapGemini and CESBIO



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



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



Land Applications from SMOS
ission
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Vegetatio
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Weather
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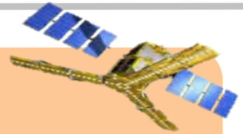
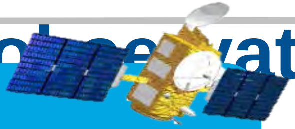
soil
moisture
Freeze
and
thaw
Permafrost
monitoring
Long time
series
Ice
thickness
Droug
monitoring
Fire risk
ETP
Climate
change

Hydrology in the context of Earth System observation approach



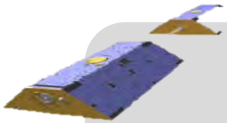
SMOS, SMAP,
AMSR-E, SSMI



Jason, **S3**
Saral Altika
SWOT, S1

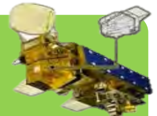
Ground water

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



GRACE,
GRACE-FO

TRMM, GPM,
Megha-Tropiques,
IASI



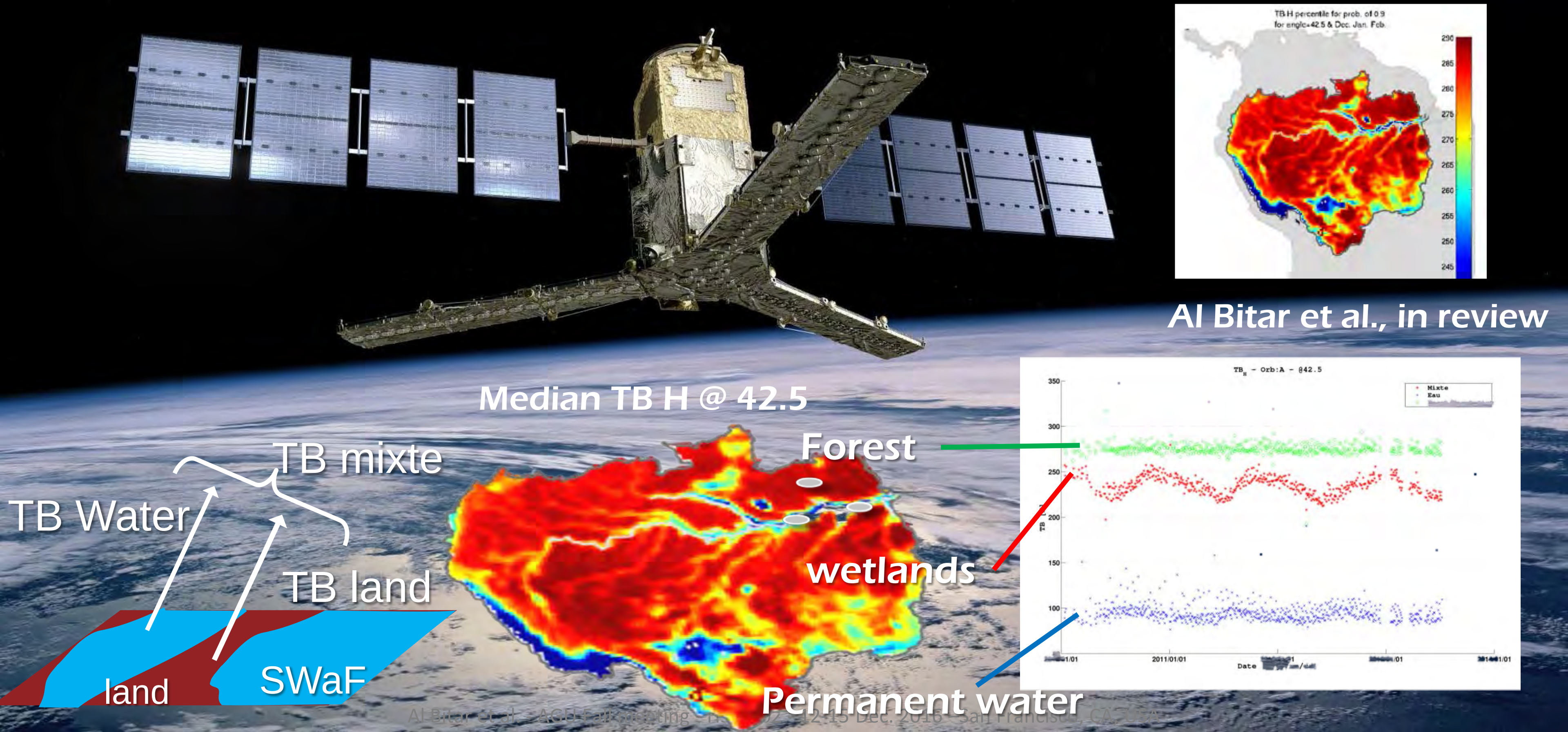
CERES, S2
AIRS, MODIS
SPOT, Pléiades

Vis, NIR, TIR

Jason, **S3**
Saral Altika
SWOT

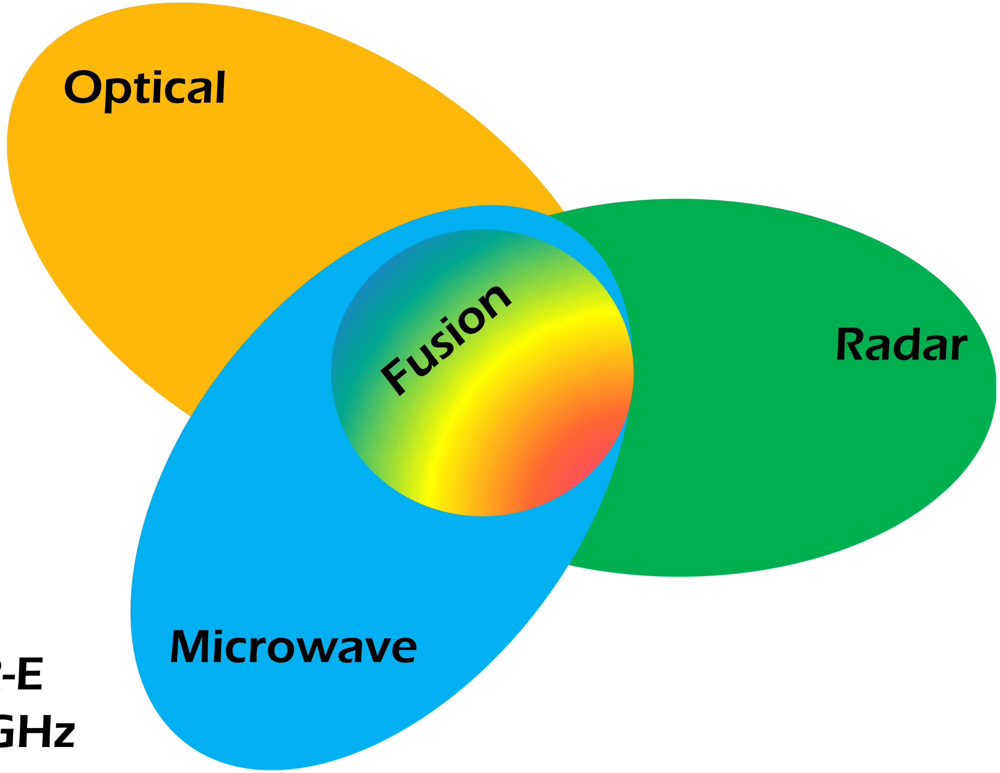
Not all components are observed at the desired resolution and accuracy

SWAF - Water fraction using SMOS data



Monitoring of water surfaces *from space*

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



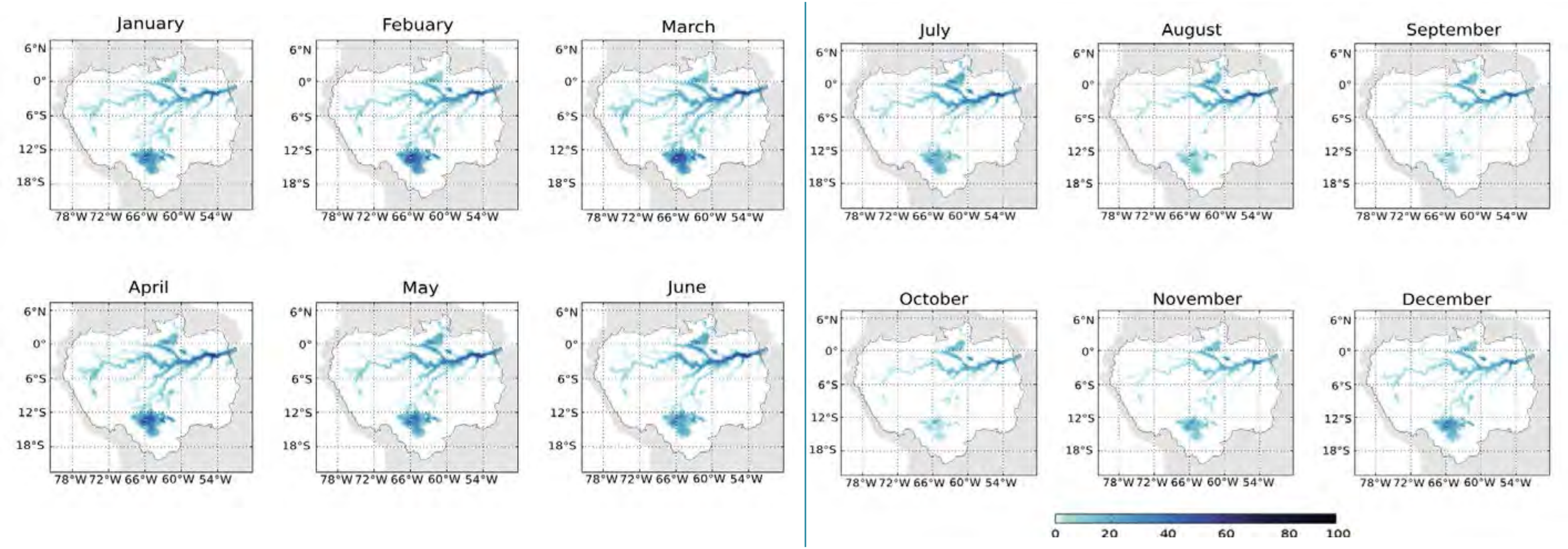
- C-band
  - *Sentinel 1*
  - *RadarSAT*
- L-band
  - *PALSAR*
- X-band
  - *TERRASAR*

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

Pecklet al. 2017, Aires et al. 2017, Ferrant et al. 2017, Parrens et al. 2017

Impact of polarisation and incidence angle

Mean SWAF for 2010 - 2016



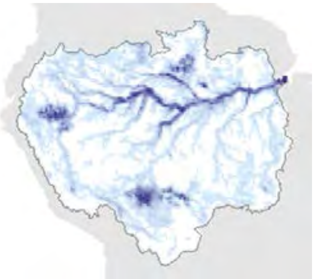
Parrens et al. Waters 2017

Validation of the SMOS Water fraction

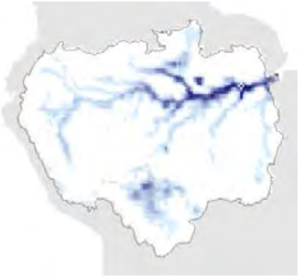
Against static maps

IGBP

GlobCover

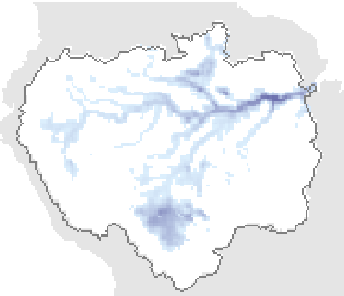


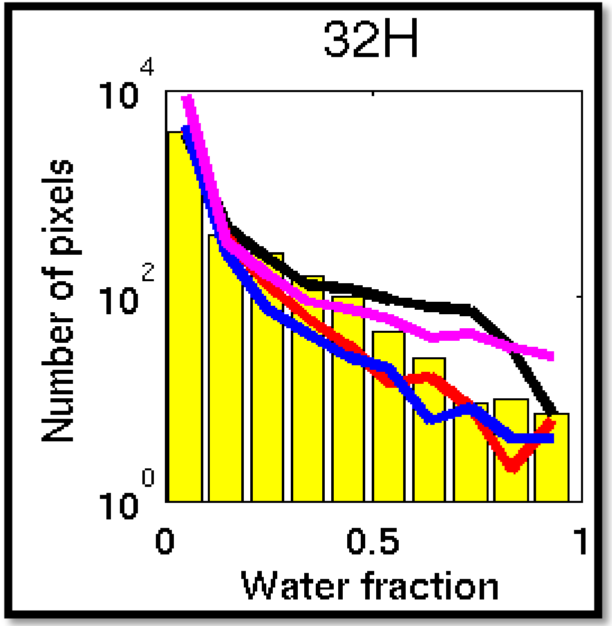
GIEMS



ESA CCI

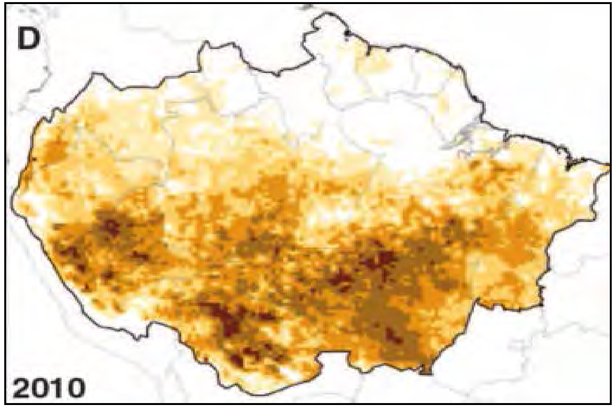
SWAF





Droughts of 2010

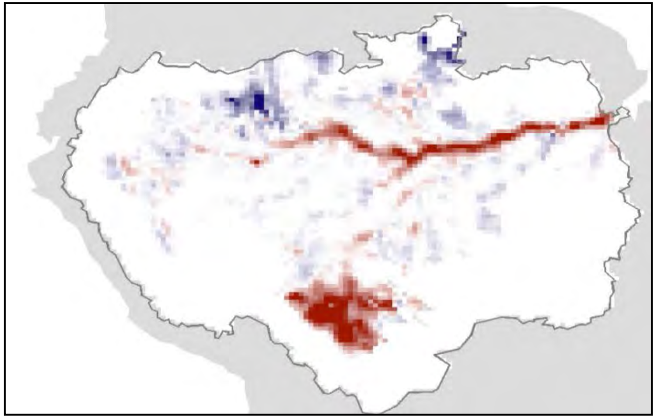
Clim. Water. Index



water deficit

(Lewis et al., Science 2011)

Anomaly of water fraction
Jul. – Sept. 2010



anomaly of SMOS water fraction

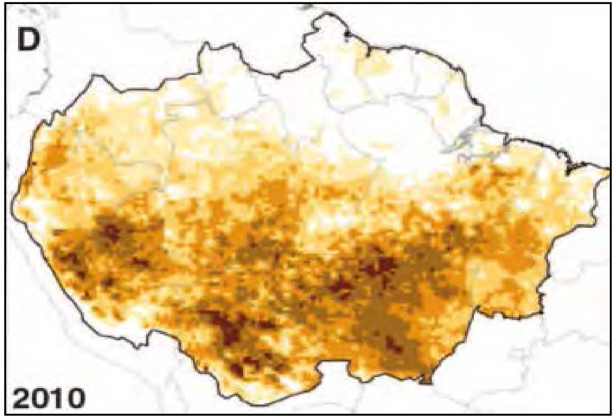
abnormaly dry *abnormaly wet*

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.

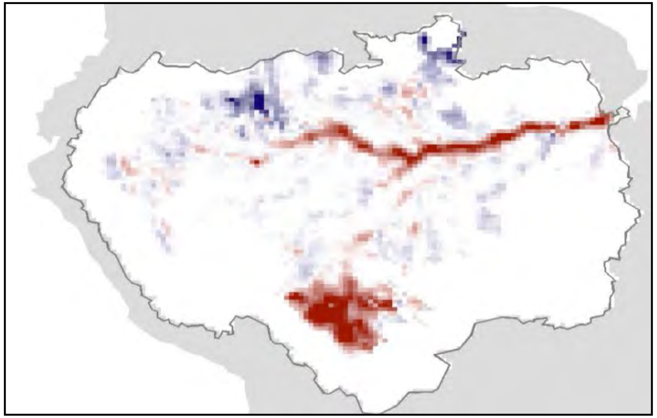
Reuters ©

Droughts of 2010 vs 2015

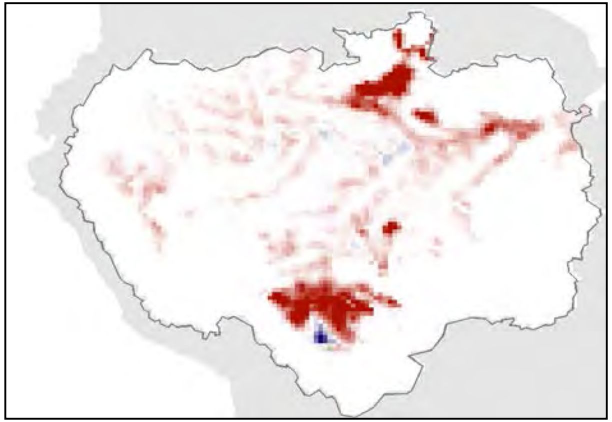
Clim. Water. Index



Anomaly of water fraction
Jul. – Sept. 2010



Anomaly of water fraction
Oct. – Dec. 2015



water deficit

(Lewis et al., Science 2011)

anomaly of SMOS water fraction

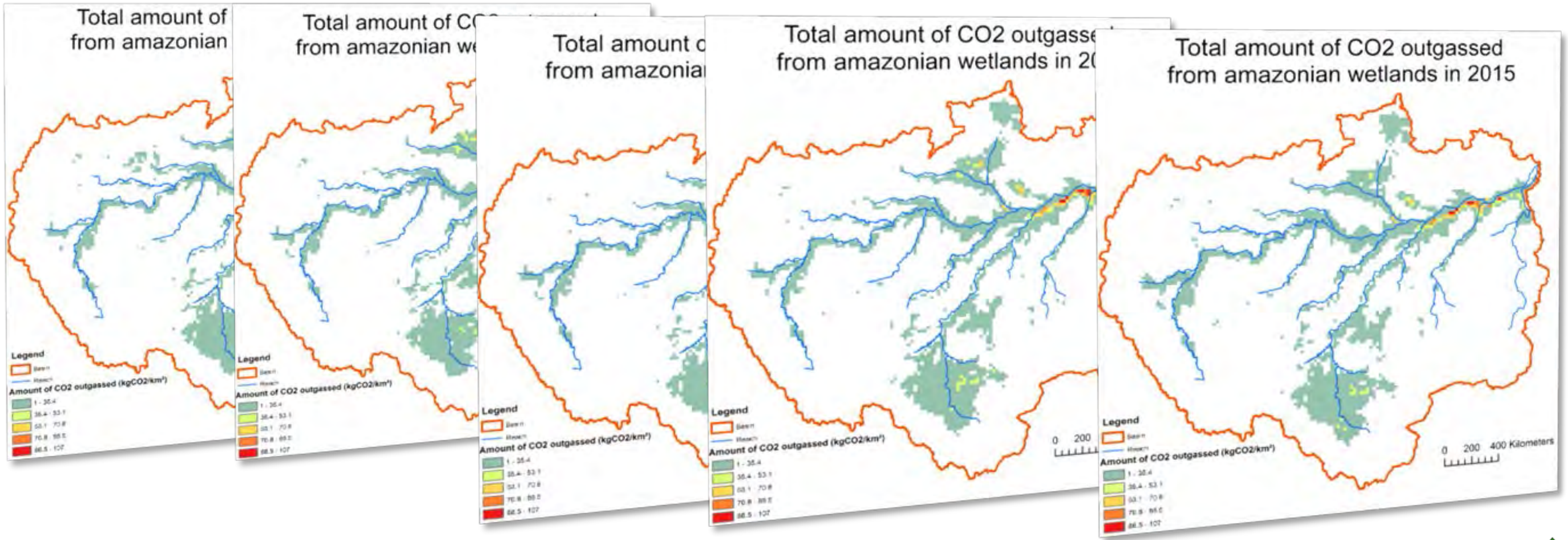
abnormaly dry *abnormaly wet*

anomaly of SMOS water fraction

abnormaly dry *abnormaly wet*

Nitrogen and Carbon fluxes of inland water surfaces

Denitrification rate was estimated as following (Peyrard et al. 2011): $\boldsymbol{R_{NO_3} = -0.8\left(\rho.\frac{1-\varphi}{\varphi} \cdot k_{POC}[POC] \cdot \frac{10^6}{M_C}\right.} +$



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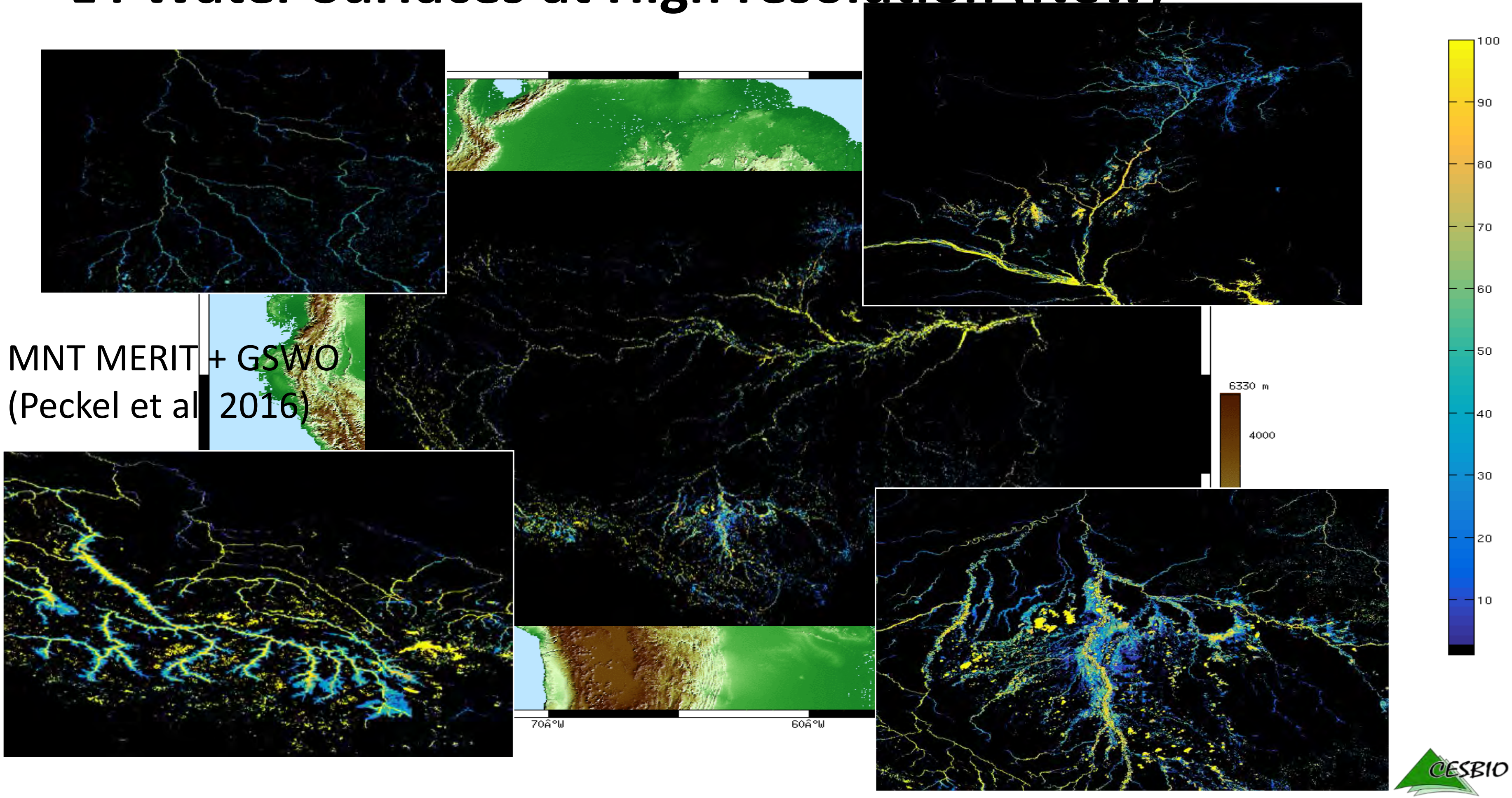
L4 Water Surfaces at High resolution (New)



MNT MERIT + GSWO
(Peckel et al. 2016)

Land Applications from SMOS …ission

Hydrolo gical drought

surface monitor

Rainfall correction

Carbon cycle

Vegetatio n Biomass

Discharge prediction

Weather Forecast

Root zone soil moisture

Freeze and thaw

Permafrost monitoring

…ong time series

Ice thickness

Drou… monitoring

Fire risk

ETP

Climate change

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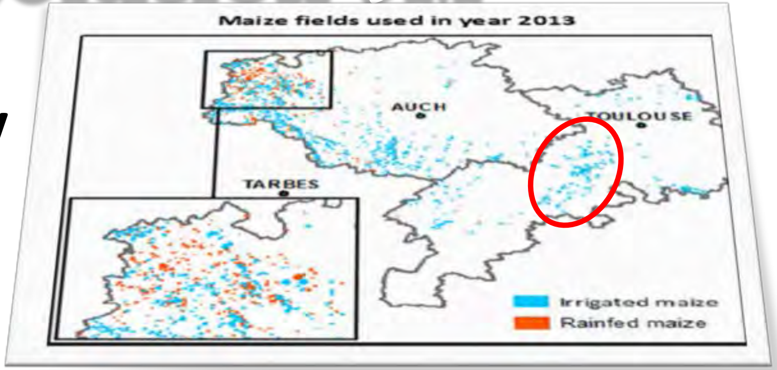
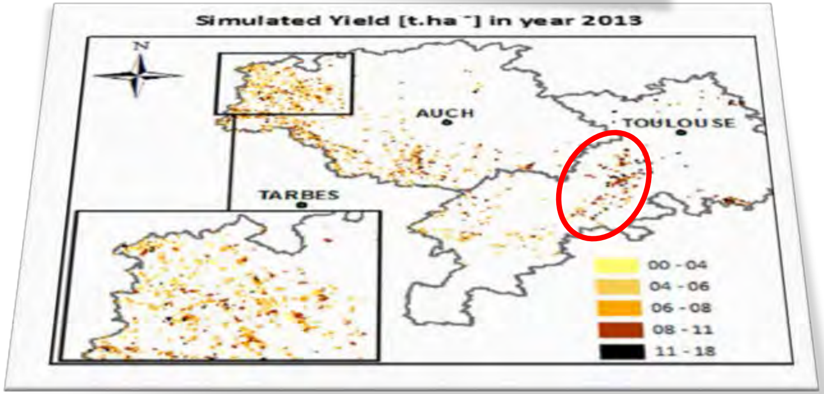
The need for high resolution SM

Yield and soil moisture availability are highly correlated.

Irrigation accounts for about 70% of water ressources uses.

Gravitary irrigation in South India



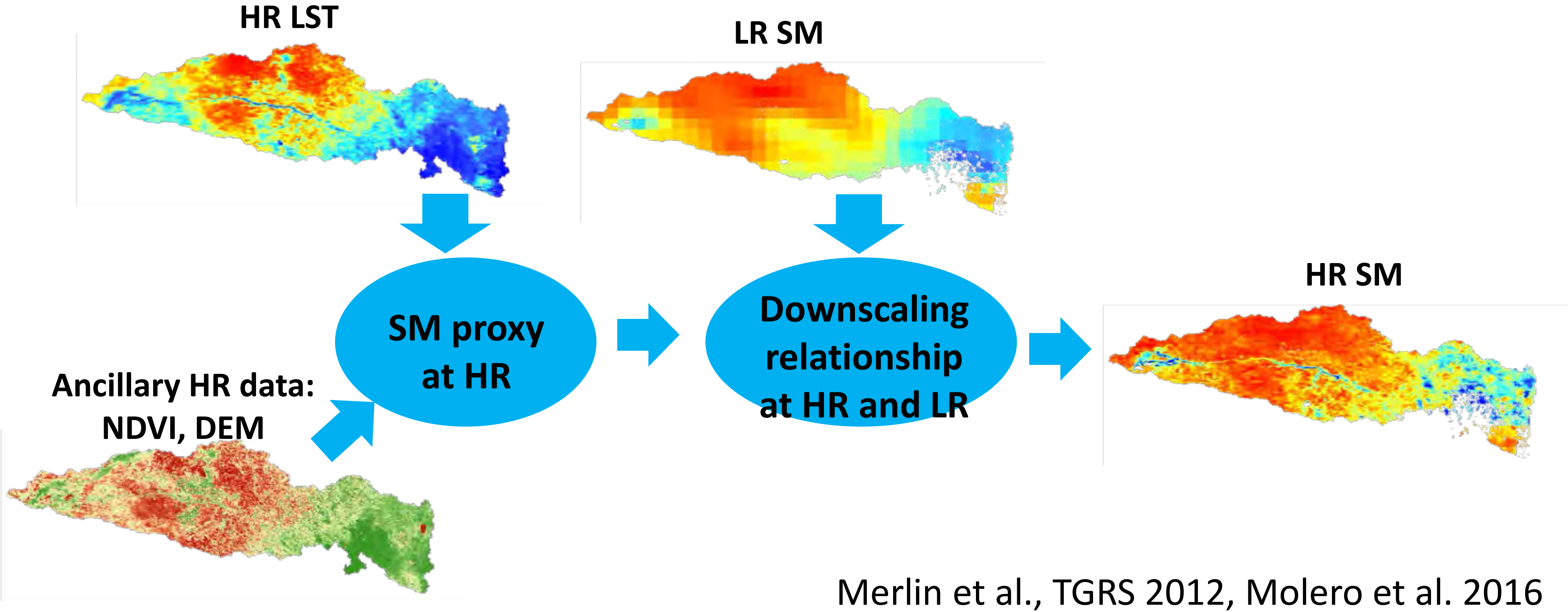


(Battude, Al Bitar et al. RSE 2016, AWM 2017)

➔ But Irrigation and yield applications will need high resolution (sub kilometric products while conserving revisit).

Rationale for evaporation-based SM downscaling

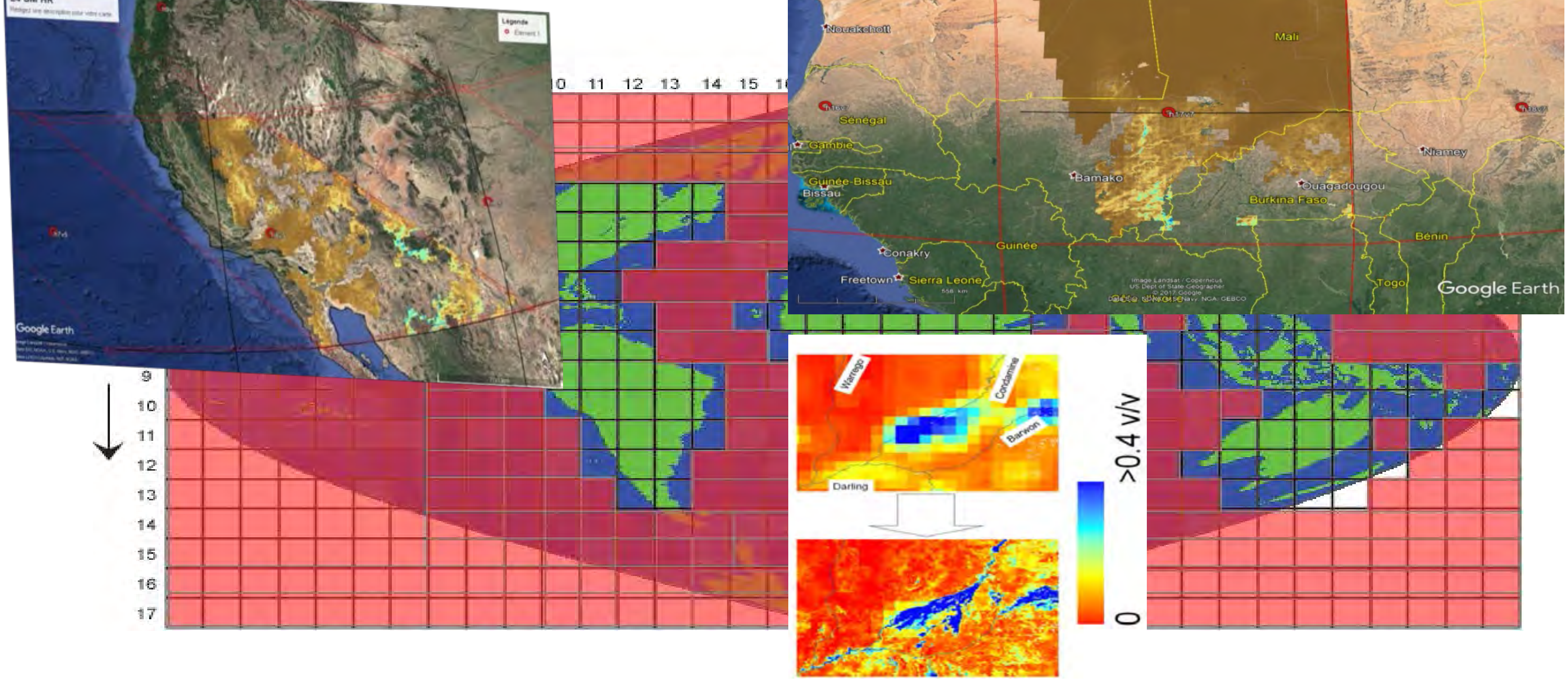
Generic scheme



Merlin et al., TGRS 2012, Molero et al. 2016

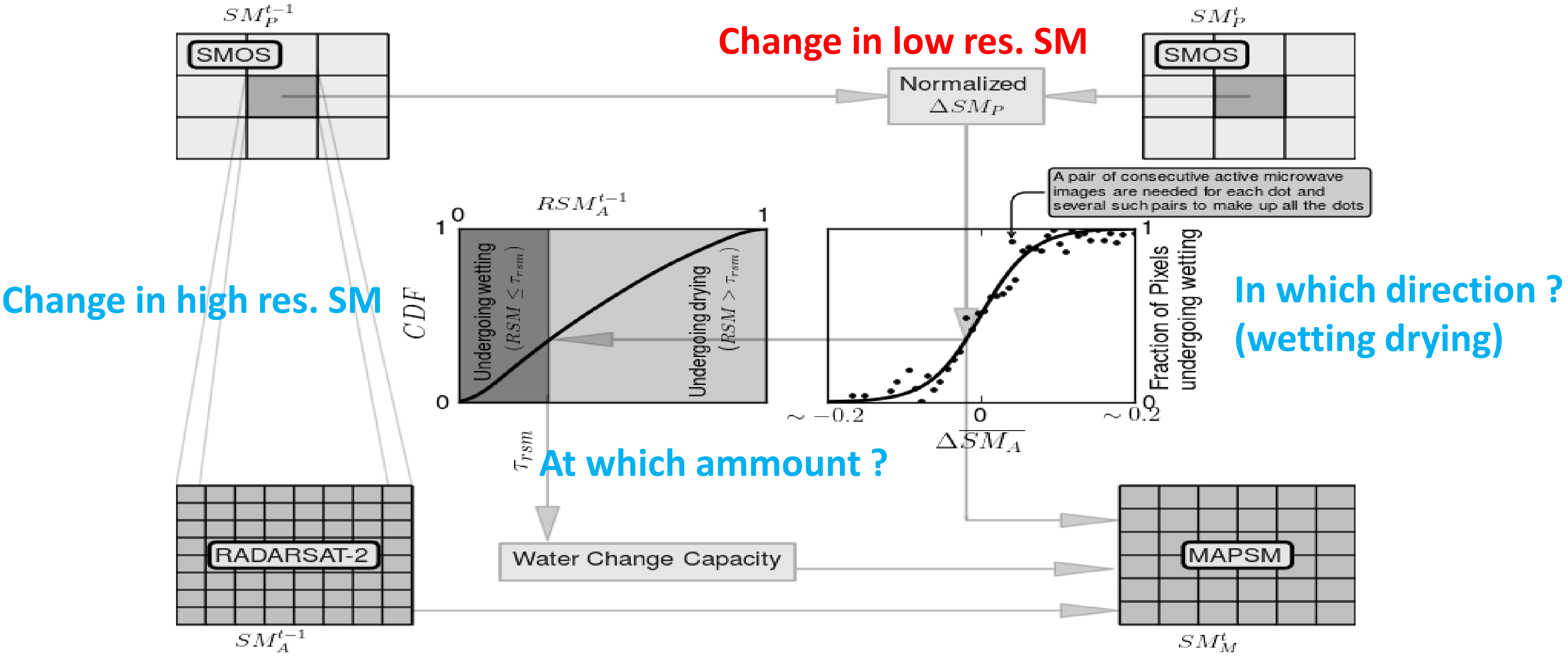
C4DIS - L4 high resolution soil moisture

Now runing operationaly !



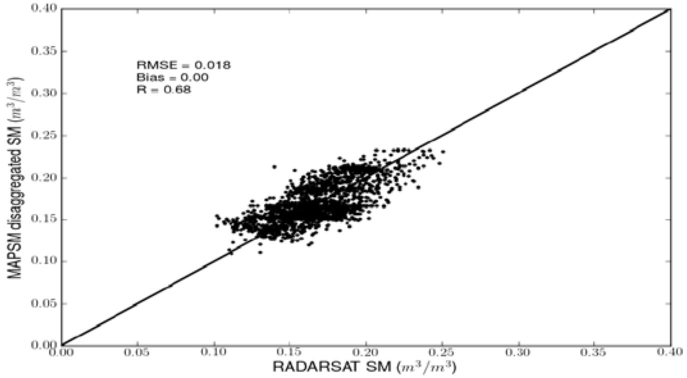
Dispatch is a disaggregation algorithm using microwave + optical (visible & thermal) remote sensing (Merlin et al. 2012) (Molero et al., RSE, 2016)

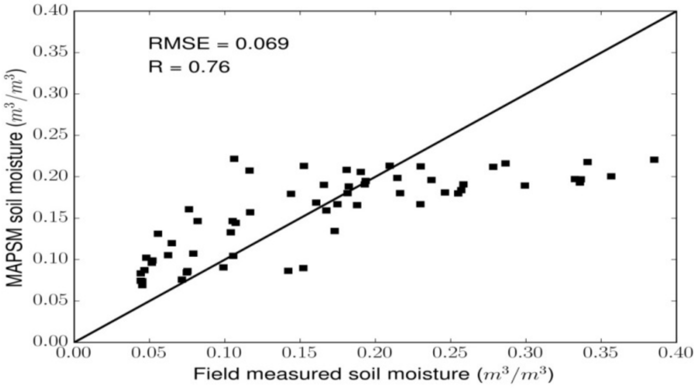
MAPSM: Active-Passive fusion



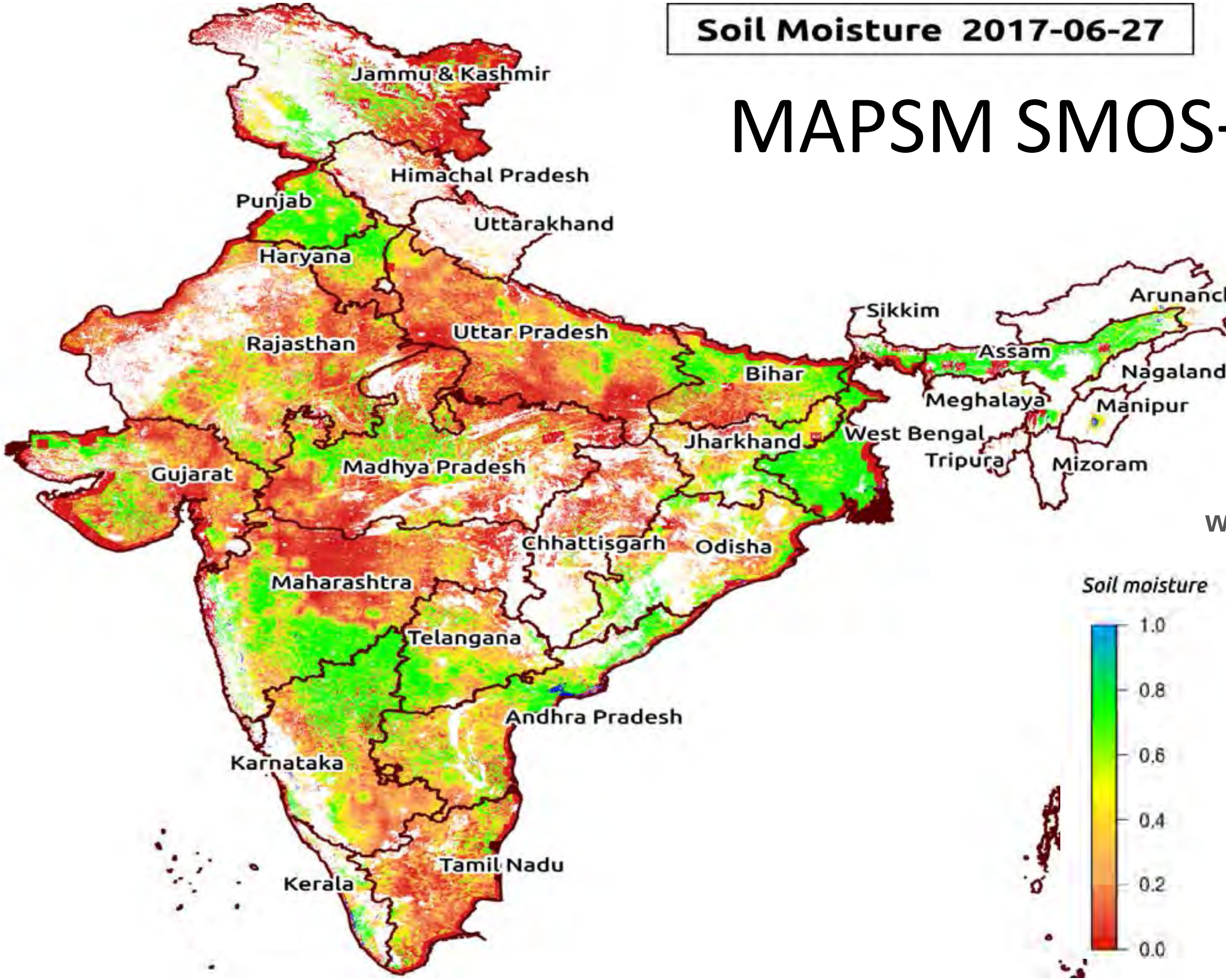
- Tomer, S. K., Al Bitar, A., Sekhar, M., Zribi, M., Bandyopadhyay, S., & Kerr, Y. (2016). MAPSM: A spatio-temporal algorithm for merging soil moisture from active and passive microwave remote sensing. Remote Sensing, 8(12), 990.
- Tomer, S. K., Al Bitar, A., Sekhar, M., Zribi, M., Bandyopadhyay, S., Sreelash, K., ... & Kerr, Y. (2015). Retrieval and multi-scale validation of soil moisture from multi-temporal SAR data in a semi-arid tropical region. Remote Sensing, 7(6), 8128-8153.

Validation MAPSM: SMOS+Radarsat2





MAPSM SMOS+S1 (500m)



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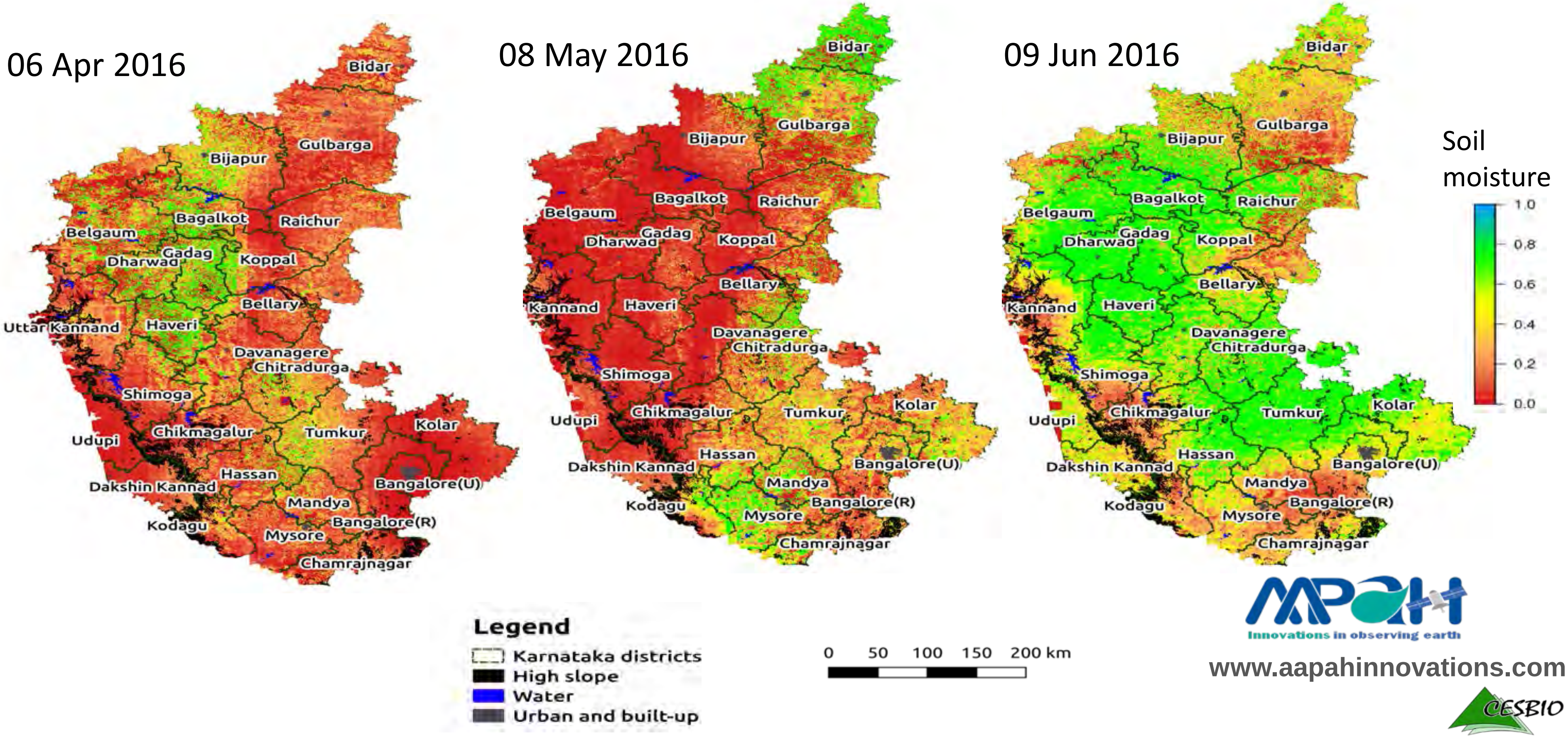
Remote Sensed high resolution relative soil moisture for Karnataka

Spatial resolution: 500 m; Temporal resolution: 1 day



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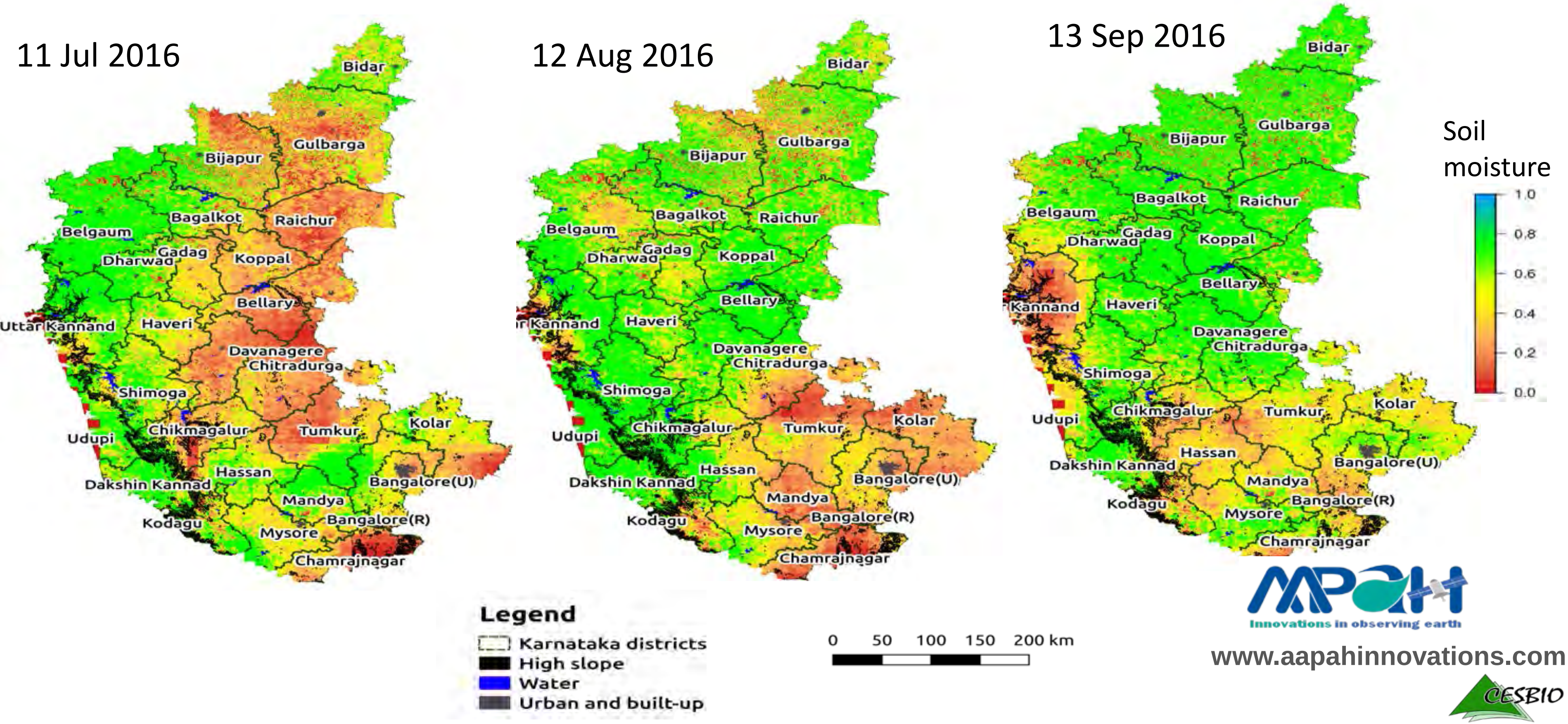

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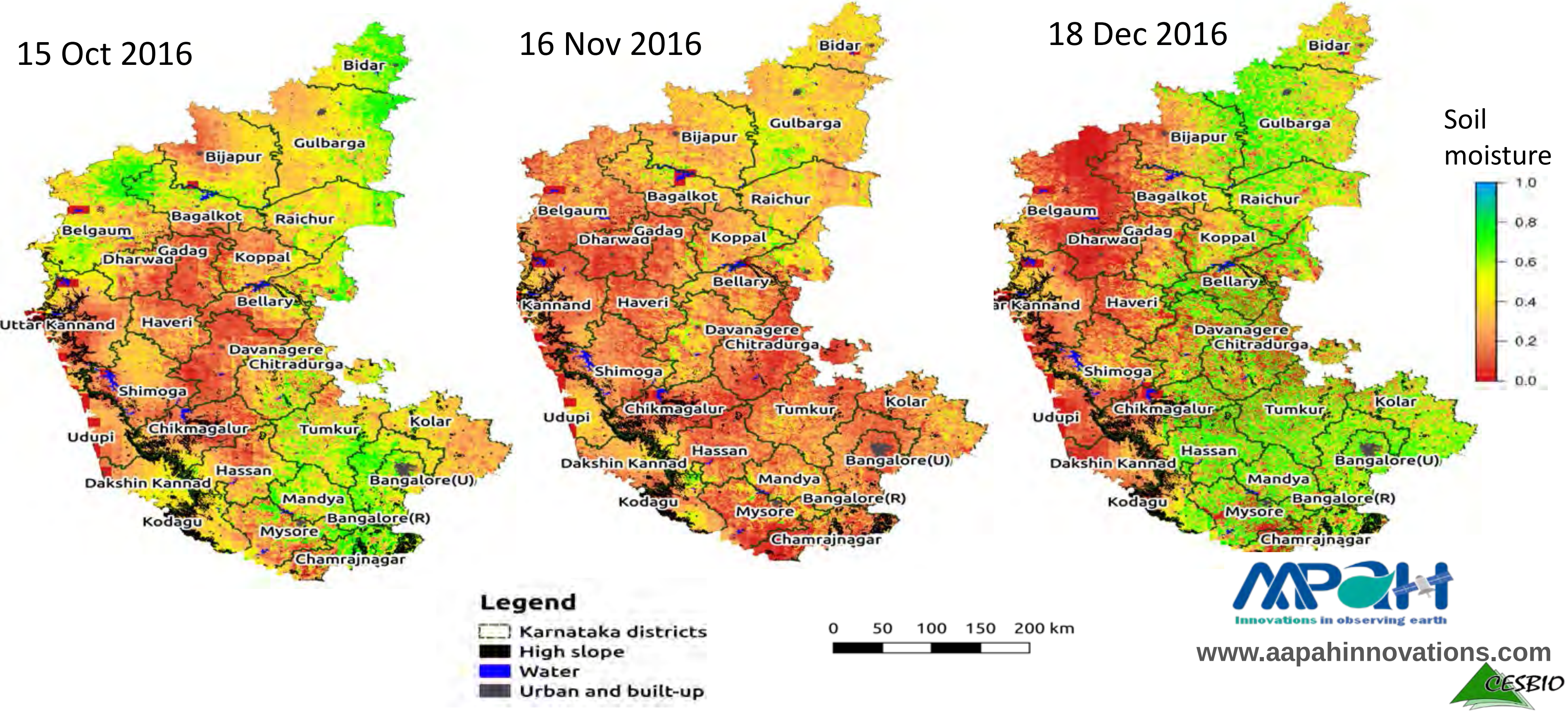

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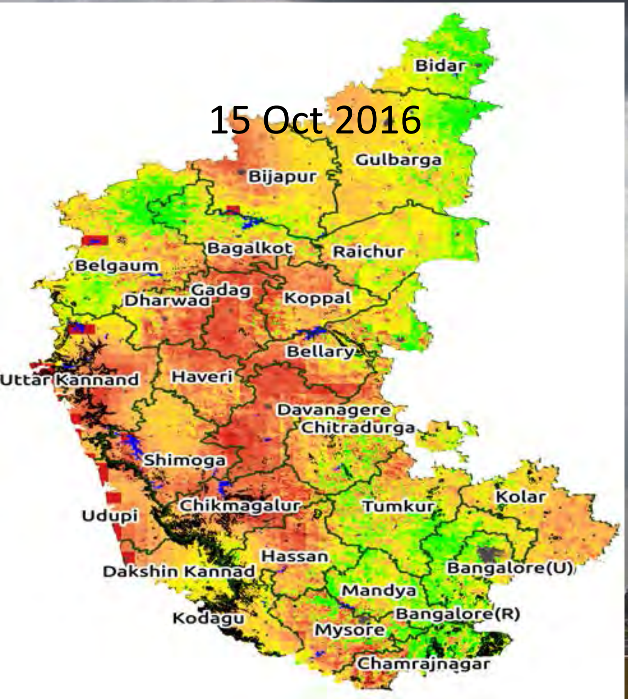
Determining optimal Cloud seeding pogramatic



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Cloud seeding aircraft -Blomberg ®

Interstate water management – The case of Cauvery Basin south india

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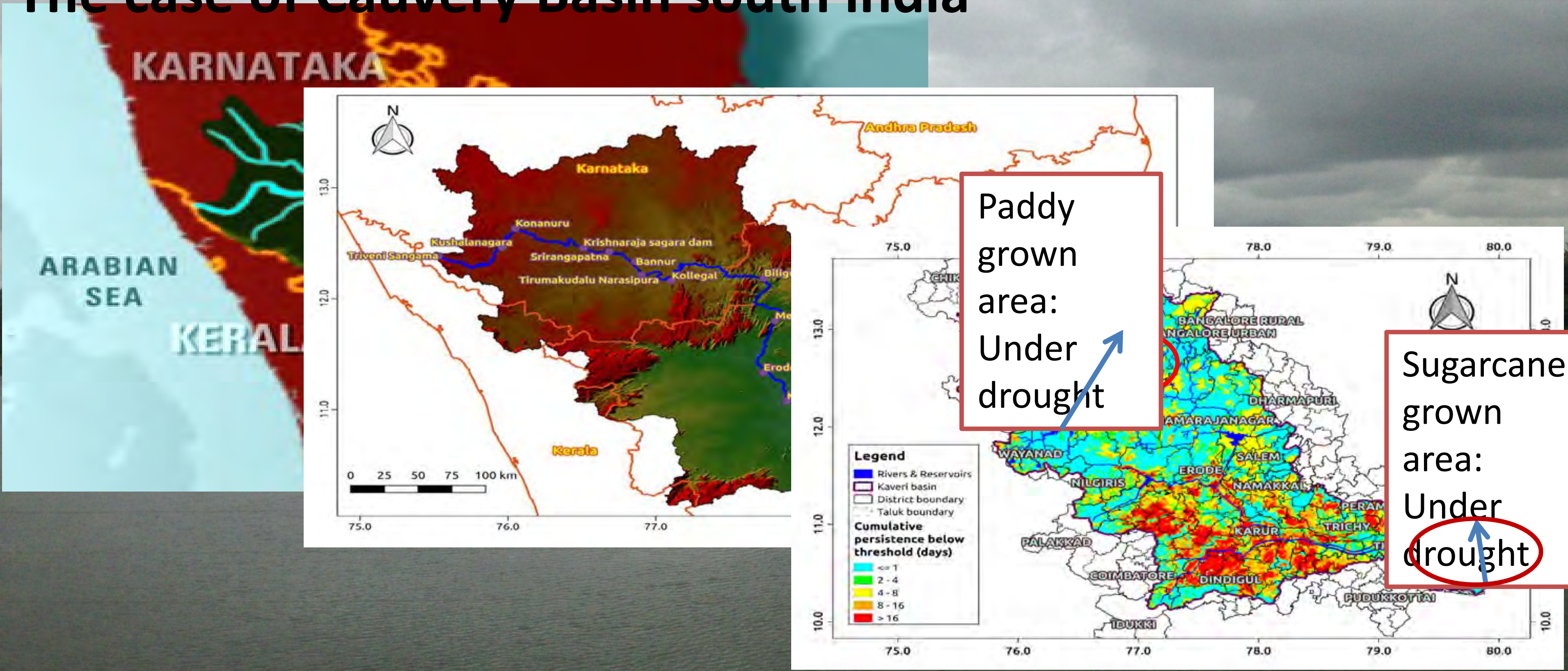
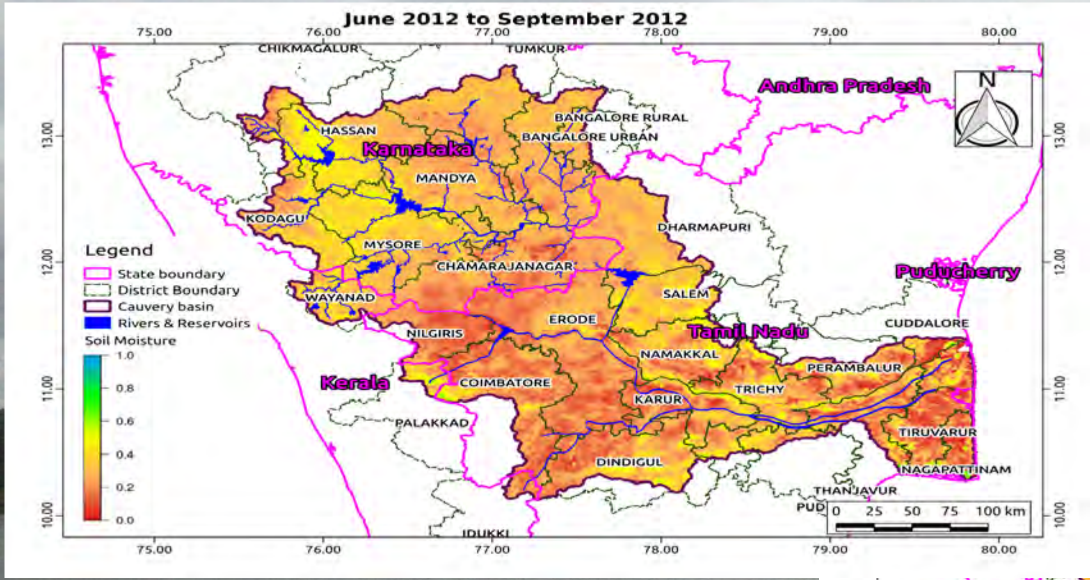
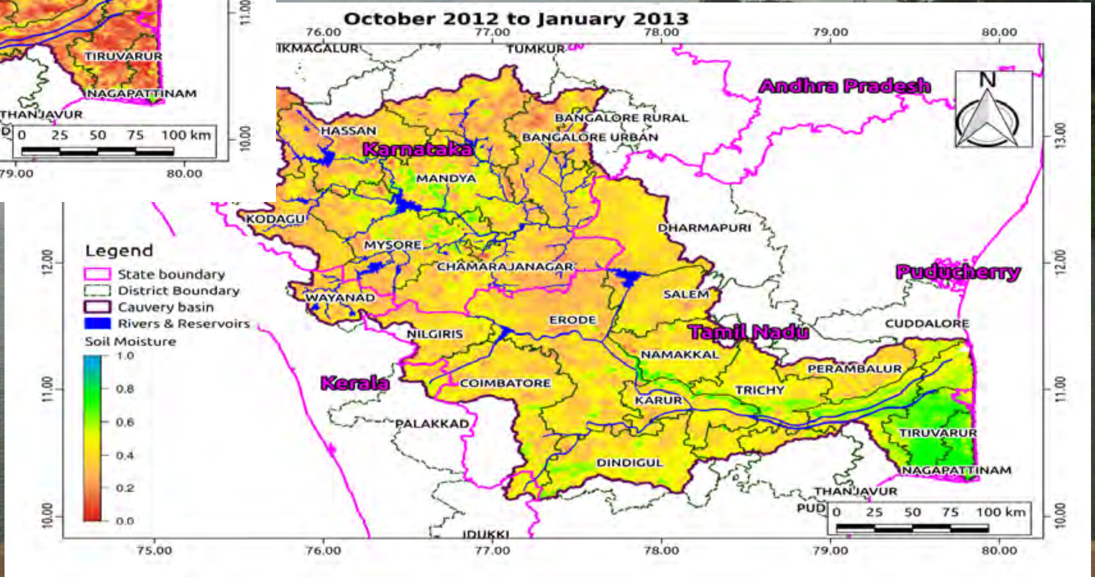


Paddy grown area: Under drought

Sugarcane grown area: Under drought

Cauvery river basin





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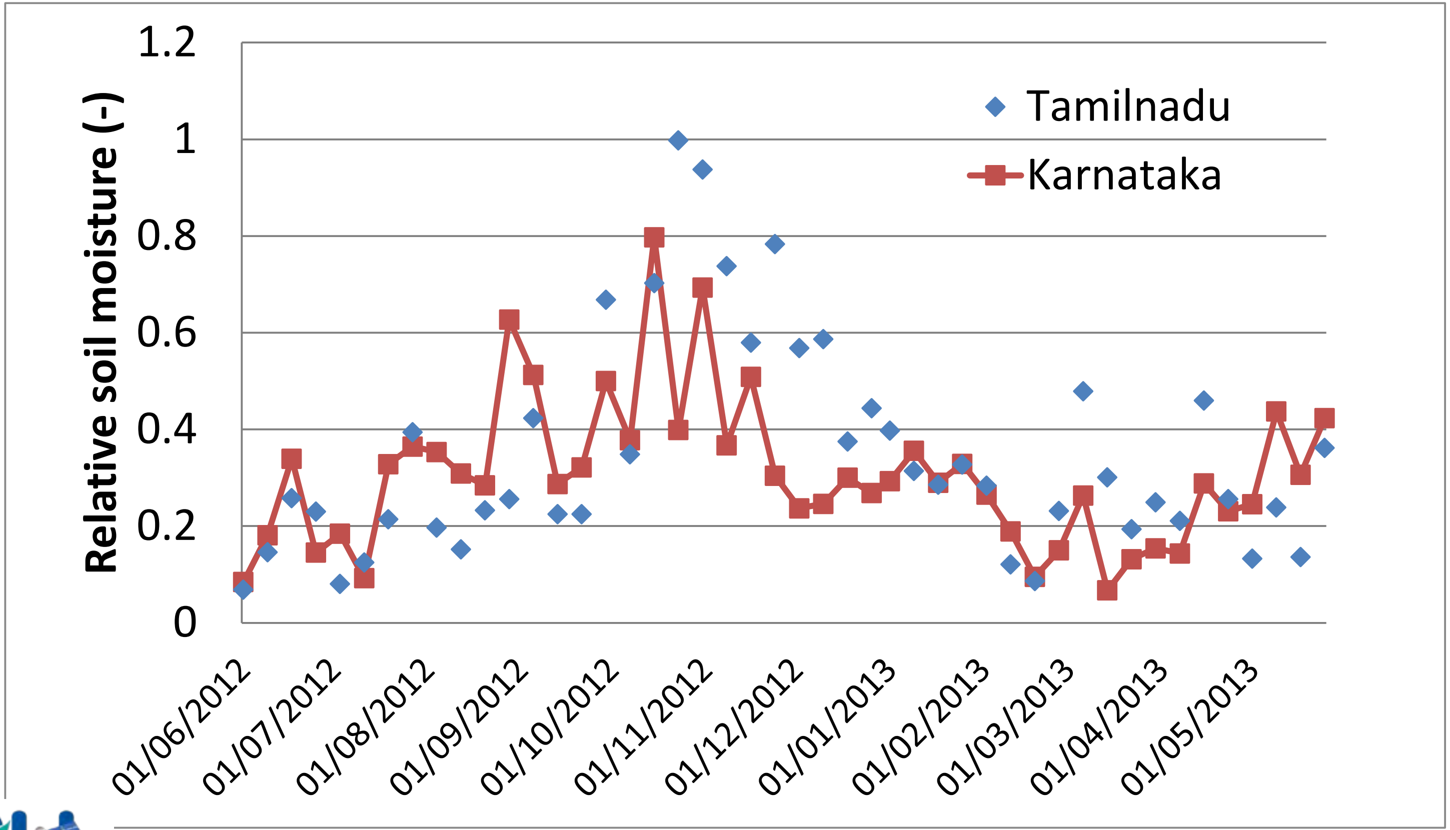
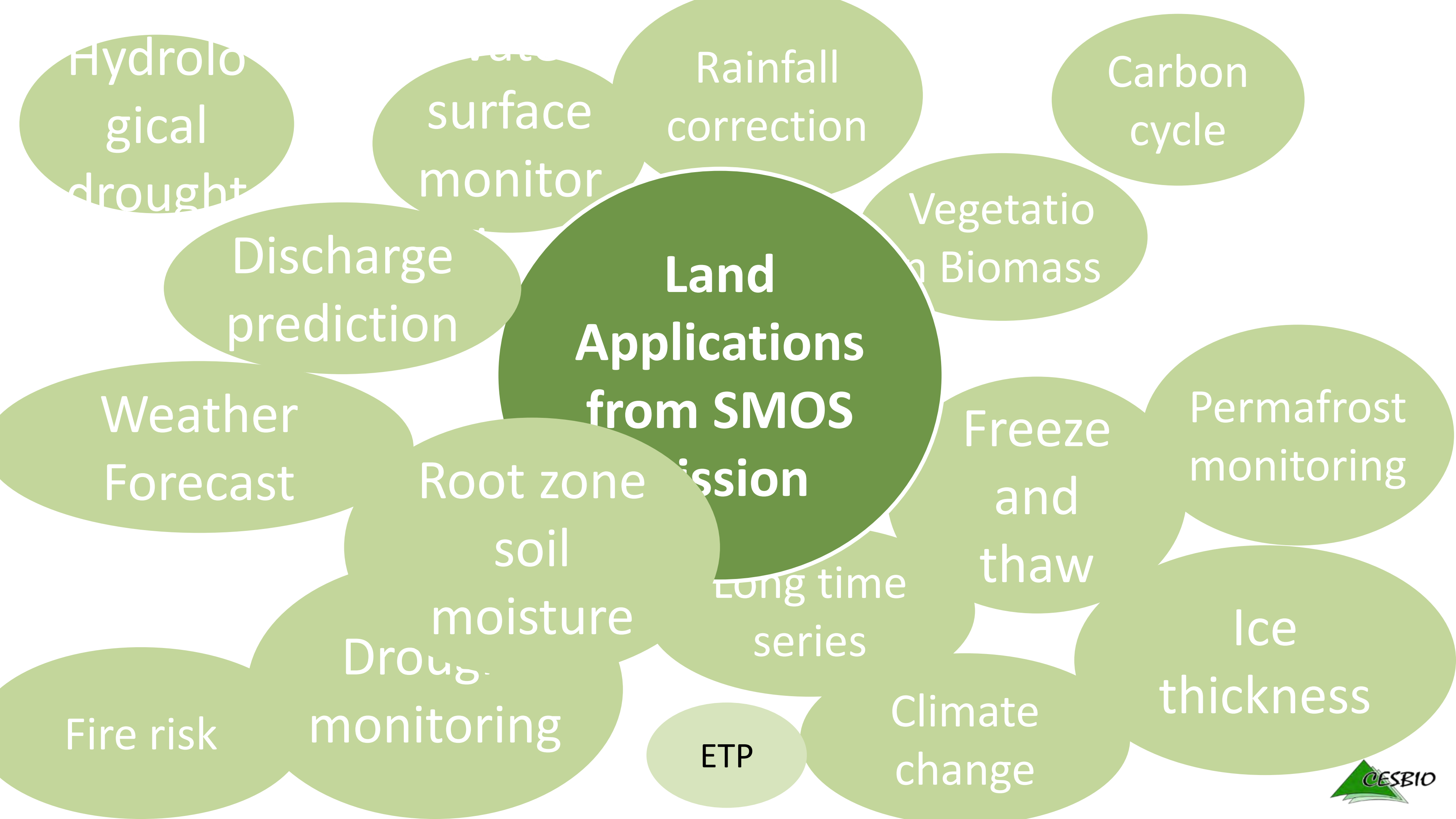
Cauvery river basin





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
series
Ice thickness
Fire risk
monitoring
ETP
Climate change
CESBIO

Many other land applications…

Hydrolo
gical
drought

surface
monitor

Rainfall
correction

Carbon
cycle

Wigneron et a

Brocca et al.
Pellarin et al.

Vegetatio
n Biomass

et al.
Wigneron et al.

Discharge
prediction

Land
Applications
from SMOS
ission

Miralles et al.
Brocca et al.

Weather
Forecast

Root zone
soil
moisture

Freeze
and
thaw

Permafrost
monitoring

Long time
series

Dorigo et al.

Ice
thickness

Miralles et al.

Drou
monitoring

Fire risk

Miralles et al.

ETP

Climate
change

CESBIO

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