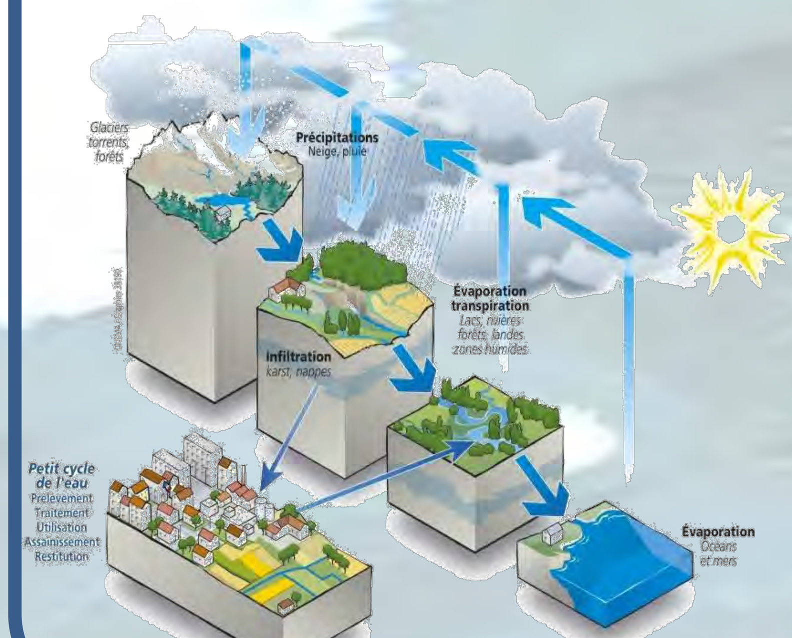
Soil moisture retrieved from space and assimilation in a hydrological model

D.J. Leroux [1,2,3], T. Pellarin [1], Y.H. Kerr [2], N. Das [3], D. Entekhabi [4]

delphine.leroux@cesbio.cnes.fr

1: LTHE, France
2: Cesbio, France
3: JPL, USA
4: MIT, USA

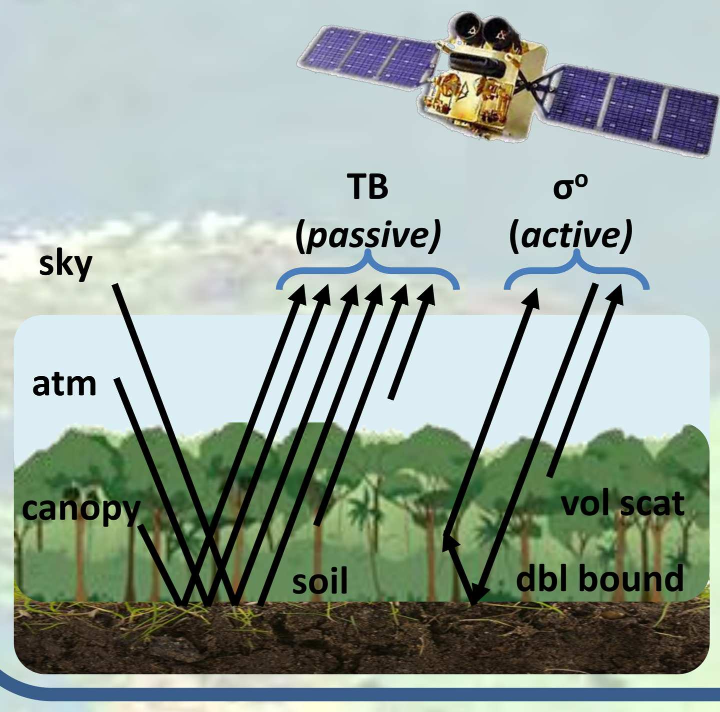
Water cycle



- Water is a **central component** in the Earth's system and is essential for life development
- Available water: 97% oceans, 1.5% ice, **1.5% land**
- **On land**: ground water, permafrost, lake, soil moisture, wetland, water vapor, river, biological water
- Human water demand: drinking water, sanitation and industrial-agricultural water (ratio ~3:4:92)
- **Agricultural water is expected to double by 2050**

- Water cycle needs to be well understood **from local to global scales** to face the future challenges in water management

What is seen from space

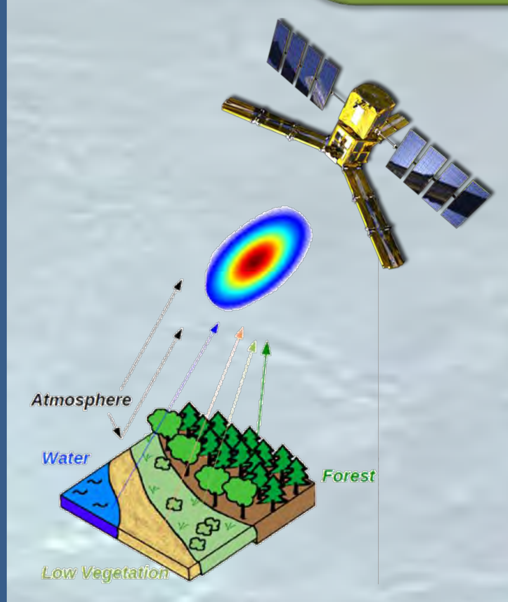


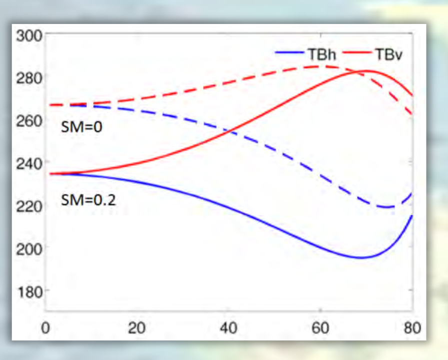
- **Soil moisture (SM)** is involved in all the steps of the water cycle: evapotranspiration, surface runoff, soil infiltration
- Best frequency to monitor SM: **L-band (1.4 GHz)**
- 2 technologies of instruments: **passive** (natural emission of the Earth), **active** (observation of a backscattered emission)
- 3 main layers are involved and need to be quantified in the signal: atmosphere, vegetation, soil

- **Global scale by satellite observations assimilated in hydrological models for local scales**

SMOS

Kerr et al., 2001

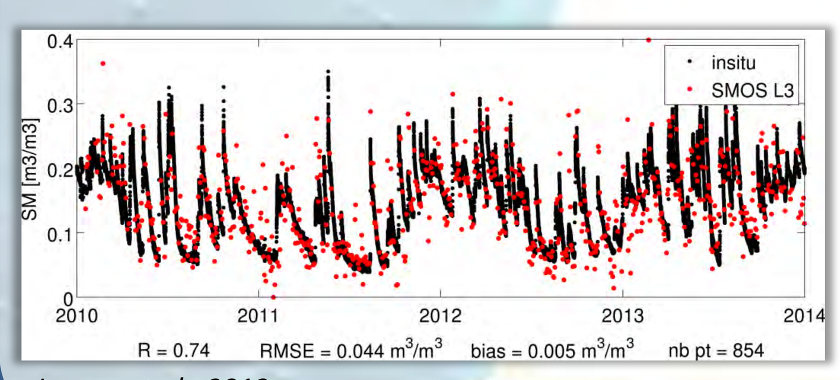




Science requirements:
-Retrieve SM with an accuracy of 0.04 m^3/m^3 and a resolution better than 50 km at least every 3 days at global scale
- Retrieve OS with an accuracy of 0.1 psu and a resolution of 200 km every 10 days at global scale

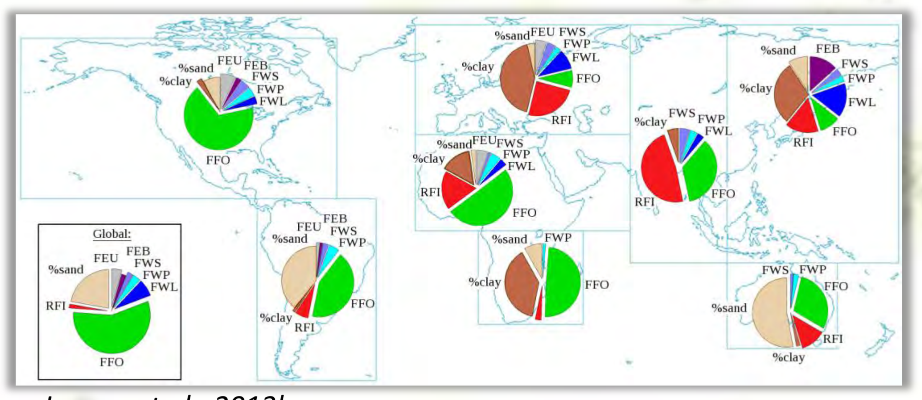
- **Soil Moisture Ocean Salinity**: launched in November 2009, 6am/6pm, 3 arms of 4 m, covers the globe every 3 days (1000 km swath)
- **Radiometer**: interferometer, L-band, multi-angular from 0 to 60°, resolution of ~ 40km
- **Retrieve SM** using L-MEB (L-band microwave emission of the biosphere) model, by taking into account both polarizations and all the available angles (also retrieves vegetation parameter τ)

Time series of SM over Little Washita



Leroux et al., 2013a

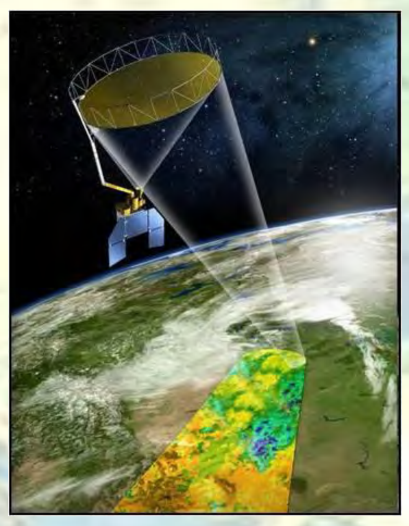
Source of error in the SM retrievals (triple collocation and ANOVA)

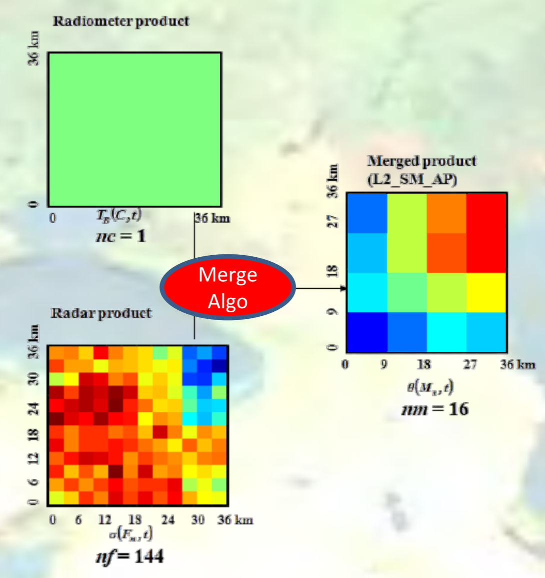


Leroux et al., 2013b

SMAP

Entekhabi et al., 2010

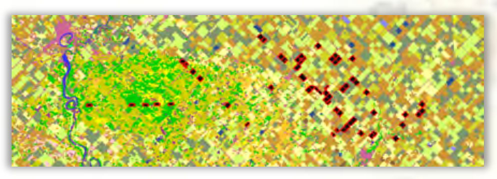




Science requirements:
-Retrieve SM with an accuracy of 0.04 m^3/m^3 at a resolution of 10 km at least every 3 days at global scale
- Retrieve freeze/thaw state with 80% of accuracy in the region north of 45N latitude at 3 km resolution every 2 days

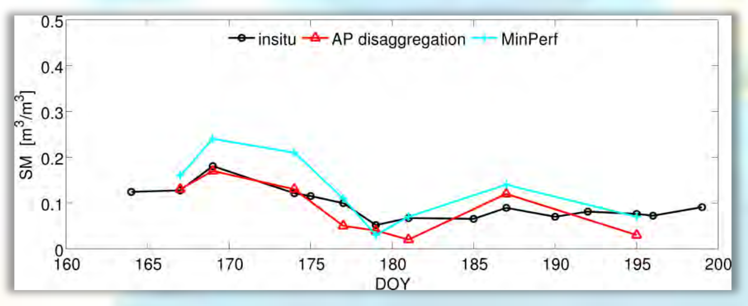
- **Soil Moisture Active Passive**: will be launched in November 2014, 6am/6pm, rotating antenna of 6 m, covers the globe every 3 days (1000 km swath)
- **Radiometer**: L-band, 40°, resolution of ~ 40km + **Radar**: L-band, 40°, resolution of ~ 3km
- **Disaggregate TB** from 36 km to 9 km using radar information at 3 km **and retrieve SM** using SCA (Single Channel Algorithm) at H polarization

SMAPVEX12 field campaign Canada, June-July 2012

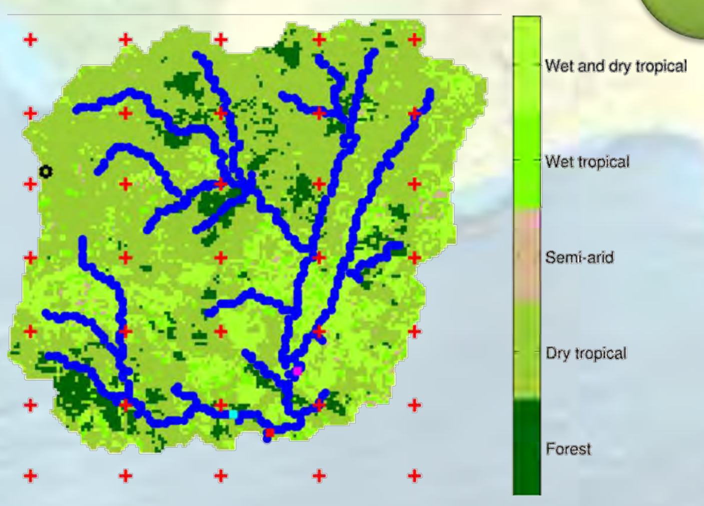


TB disaggregation from 30 to 6km

SM time series for a corn field disaggregation improves SM



Data assimilation



- **West Africa**: severe droughts and floods affecting the population, infrastructures with consequences on food and health security ⇒ hydrological model
- **Ouémé catchment in Benin**: 14,600 km^2, 1200 mm/yr (rainy season Apr-Oct), savannah and cultures, 20-35°C (ET is the major component of the water balance)
- Instrumentation: meteo stations, raingauges, streamflow stations, SM stations, …
- **DHSVM** (Distributed Hydrology Soils and Vegetation Model): physically based model that represents the effects of topography, soil and vegetation; solves the **energy and water balance** at each grid cell and time step

- **Assimilation of SMOS soil moisture product using a simple sequential Kalman filter with 4 state variables:**

$$\begin{bmatrix} sm1_k^+ \\ sm2_k^+ \\ sm3_k^+ \\ sm4_k^+ \end{bmatrix} = \begin{bmatrix} sm1_k^- \\ sm2_k^- \\ sm3_k^- \\ sm4_k^- \end{bmatrix} + K_k\left[y_k^{obs} - \hat{y}_k^-\right]$$

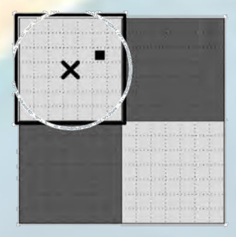
$$K_k = BH_k^T\left[H_k B H_k^T + R_k\right]^{-1}$$

- k : model scale grid cell
- K : Kalman filter *[4xm]*
- y^{obs} : observations *[m]*
- $\hat{y}^-$: observation predictions *[m]*
- B : background error cov. matrix *[4x4]*
- H : observation operator *[4xm]*
- R : observation error cov. matrix *[mxm]*
  (m observations)

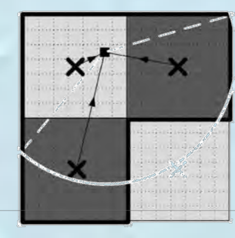
- 2 options are tested:
  - **3D-C1**: state variables are updated using a **single** SMOS observation
  - **3D-Cm**: state variables are updated using **multiple** SMOS observations

De Lannoy et al., 2010

Assim. 3D-C1

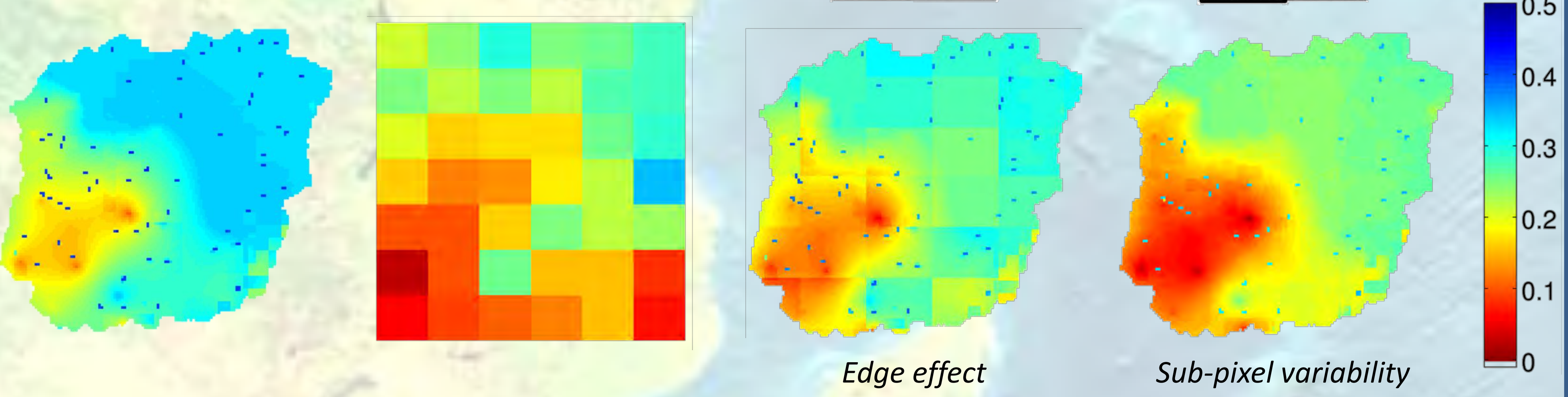


Assim. 3D-Cm



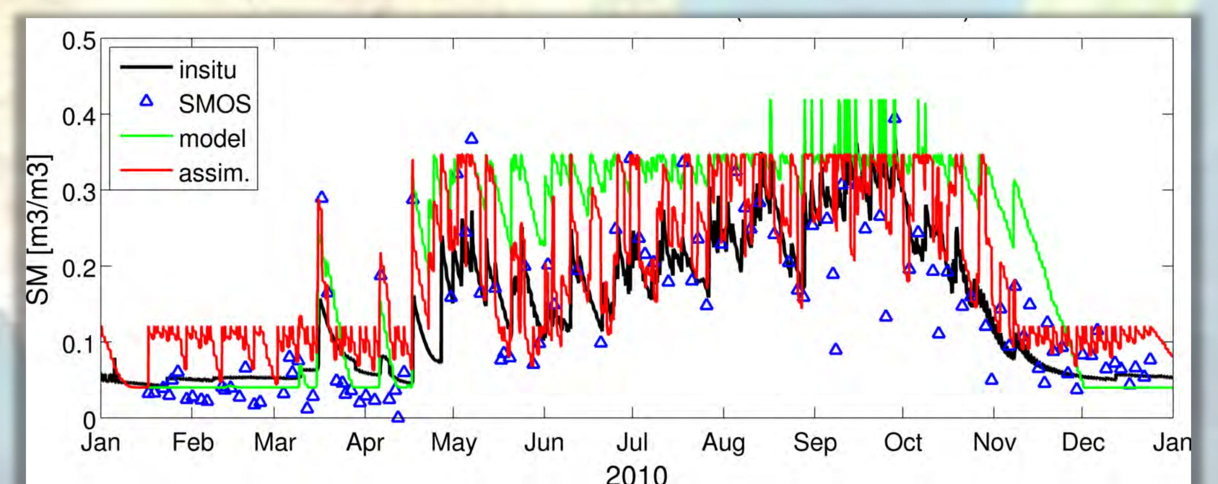
Model forecast
(June 2, 2010 @ 6am)

SMOS soil moisture
Level 3 product



Edge effect *Sub-pixel variability*

- Time series of simulated soil moisture for 2010 with in situ measurements



	Model DHSVM	Assim. (3DCm)	*SMOS*
R	0.86	0.86	*0.82*
uRMSE	0.073	**0.050**	*0.057*
bias	0.072	**0.044**	*0.002*

m^3/m^3

Perspectives

- Assimilation: implement **ensemble Kalman filter**, bias correction, **variational** approach (to avoid gaps), take into account SMOS observation errors (fixed value now)
- Investigate the **stream flow** output and the complete water/energy balance
- Improve the model calibration (upper saturation for example)
- Assess the **impact of finer satellite observations** in the assimilation process (SMOS vs. SMAP)

Bibliography

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