National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

esa

→ 8th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

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Vegetation Products from L-Band measurements

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Team
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Level 1 TB : algo, calibration.
ESA level 2 : Soil Moisture / VOD retrieval algorithm from SMOS
CATDS level 3 and 4

CATDS
Centre Aval de Traitement des Donnees Smos

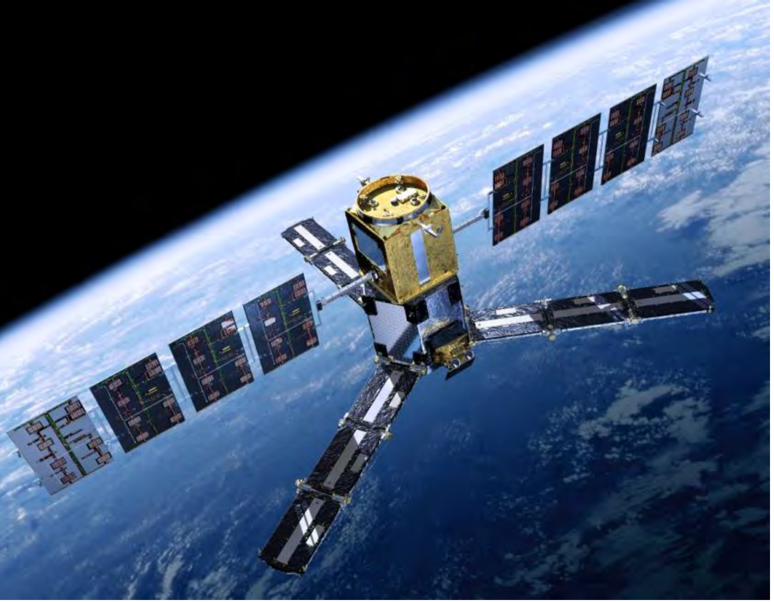
http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS

http://www.cesbio.ups-tlse.fr/SMOS_blog/

http://www.catds.fr/

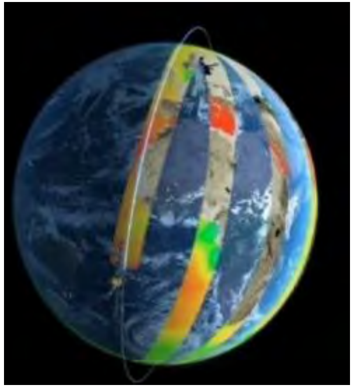
Objectives

- ✓ Present VOD (Vegetation Optical Depth) derived from SMOS
- ✓ Read SMOS Data using Matlab



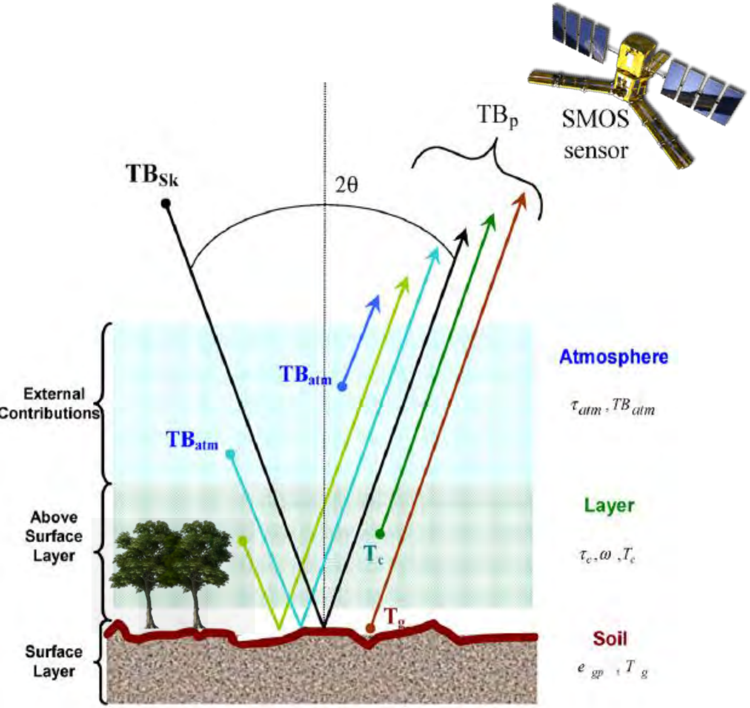
SMOS (Soil Moisture and Ocean Salinity)

- ESA Earth Explorer Mission
- Launched in Nov.2009, data available since May 2010
- Passive microwave L-Band (λ= 21 cm, f=1.4 GHz)
- Main Objectives
  - Surface Soil Moisture (m3 of water/m3 of soil)
  - Sea Surface Salinity
- Resolution
  - ✓ Orbit ~polar, Sun synchronous
    - Ascending orbits = 6am solar local time
    - Descending orbits = 6 pm solar local time
  - ✓ Level 2 : 15km Soil moiture and Vegetation
  - ✓Spatial : covers the Earth Surface in ~3 days

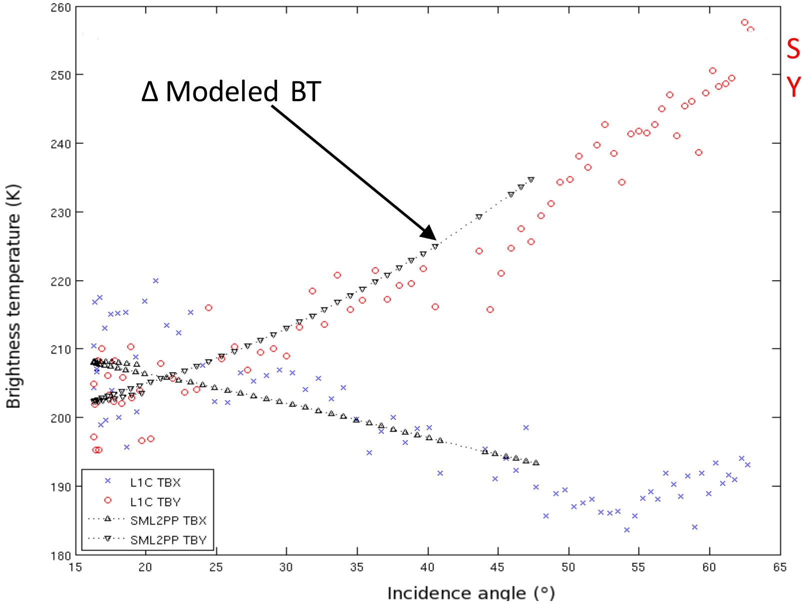


Passive microwave L-Band (λ= 21 cm, f=1.4 GHz)

- Passive ⇒ measure the Emission of the Earth Surface



- Microwave ⇒ Brightness Temperatures TB at Horizontal and Vertical Polarisation



SMOS BT
Y polarization

SMOS BT
X polarization

From SMOS T_B observations to soil / vegetation at Surface level

‘L-MEB’ model: L-band Microwave Emission of the Biosphere

Simple radiative transfer (RT) model for a soil-vegetation system

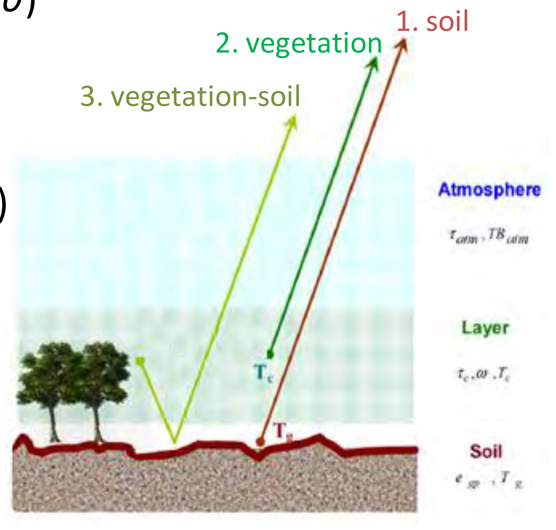
References: Wigneron et al., RSE, 2007 ; Kerr et al. 2012

L-MEB algorithm

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

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

e_s	soil emissivity; linked to soil moisture through dielectric constant (P,ϑ)
T_s	physical temperature of soil
T_v	physical temperature of vegetation
ω	single scattering albedo of vegetation (omega) (P,ϑ)
γ	canopy transmissivity; linked to vegetation optical depth τ (tau) (P,ϑ)
T_{Bsky}	sky brightness temperature (P,ϑ)
P	polarisation (H or V)
θ	incidence angle



Vegetation emission terms ("tau-omega model")

Thermal Equilibrium: Kirchhoff's Law (valid for MWs): $e(\lambda) = a(\lambda)$

- **ω** scattering loss $\Rightarrow$ $(1- \omega)$ not scattered/lost = absorbed radiation
  - Fixed in SMOS algorithm
  - Assumed independent of incidence angle
  - Assumed independent of polarisation in many cases i.e. $\omega_V = \omega_H$
  - Forest = 0.06

- **γ** transmissivity $\Rightarrow$ $(1- \gamma)$ not transmitted = fraction of the vegetation that is non-transparent, i.e. part of vegetation layer that emits radiation

- Veg. emission direct

$= (1 - \omega) \cdot (1 - \gamma) \cdot T_{veg}$

- Veg. emission reflected by soil $(1 - e_{soil})$ and transmitted (γ) back up through canopy

$= (1 - \omega) \cdot (1 - \gamma) \cdot T_{veg} \cdot (1 - e_{soil}) \cdot \gamma$

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

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
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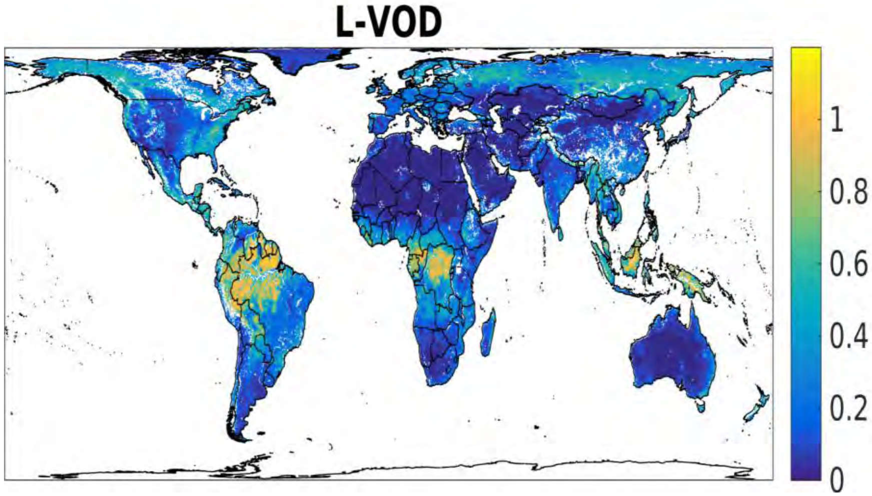
P	polarisation (H or V)
θ	incidence angle

Vegetation Optical Depth (τ)

$$\gamma = e^{\frac{-\tau}{\cos\theta}}$$

- τ : at Nadir
- Depends on :
  - biomass density
  - structure
  - vegetation water content



- Vegetation « seen » at various wavelengths

X band
λ= 3 cm

L band
λ= 21 cm

P band
λ= 70 cm

VHF
λ>3 m

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SMOS Data

- **ESA (European Space Agency)**
  - Level 1:
    - L1a: Visibilities
    - L1b: Fourier Coefficients
    - L1c: Brightness Temperatures , polarization X/Y (antenna frame)
  - Level 2 :
    - Surface Soil Moisture, salinity

- **Centre Aval de Traitement des Données SMOS CATDS**
  - Level 3: Brightness temperatures, polarization H/V
  - Level 3: Soil moisture & VOD, dielectric constant
  - Level 4: SMOS + model hydro (Root Zone Soil Moisture ; Drought Index ; desaggregation ...)

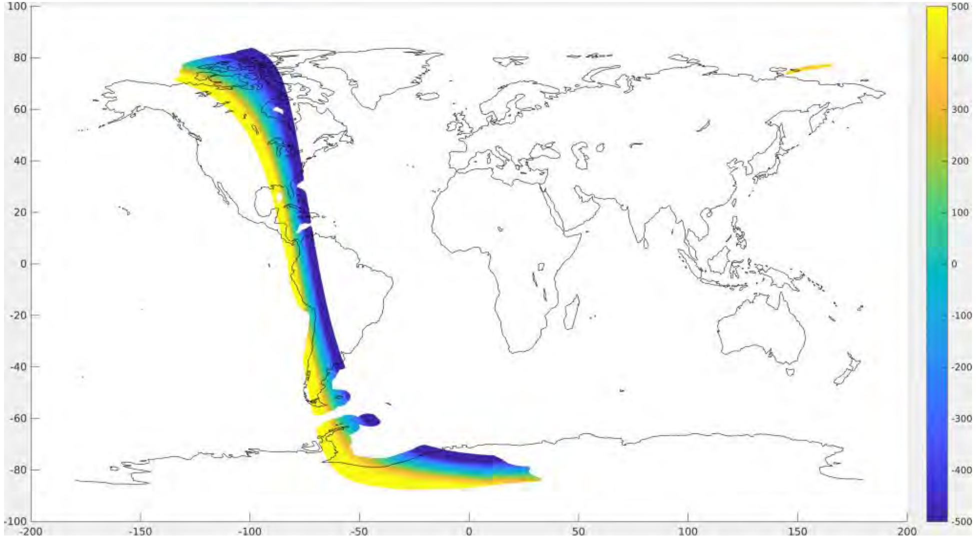
- BEC Spain : Barcelona Expert Center
  - Level 3 et 4

    Aggregation of ESA products

	Swath Product	**Aggregated Product**
Known as	ESA Level 2	CATDS Level 3
Algorithm	Use of 1 overpass	• Use of 3 consecutive overpasses • Correlation of the vegetation optical depth
Derived soil moisture	• One per ½ orbit	• 1 day • 3-day • 10-day • monthly products
Format	BinX ; Netcdf	Netcdf
Grid	Isea4h9 ~15 km	EASE Grid ~25x25km

Level 3 : Al Bitar et al. 2017, ESSD

SMOS Level 2 land products

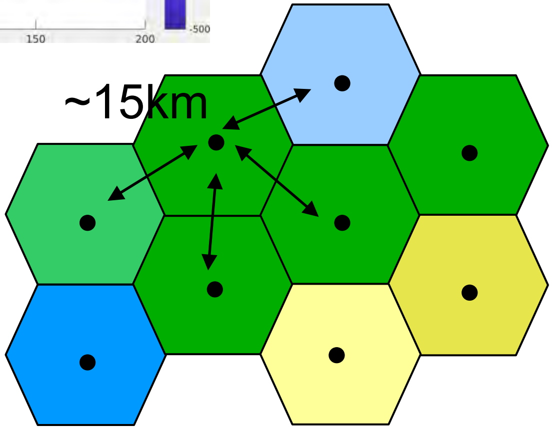


- per ½ orbit
    - Ascending
    - Descending

UDP : User Data Product

- 2 files:
    - .HDR Header
    - .DBL Datablock, BINARY file containing the data

- L2 soil moisture Grid
    - ISEA4h9
    - spatial resolution ~15 km



SMOS Level 2 land products

UDP -User Data Product-

Parameters of the model

SM
TAU
DQX = index, quality of the retrieval NOT an error compared to in-situ
Dielectric constant
TB @ 42.5° from models!
RFI_Prob
CHI2

Successful retrieval = value
Failed retrieval = -999

- **Science flags**
  Information about the conditions: forest, topography, rain, snow...
- **Confidence flags**
  Evaluation of the retrieval:
    - *retrieval failed (FL_NO_PROD)*
    - *is retrieved soil moisture within an expected range? its DQX ?*
    - *quality of the models*
    - *RFI contaminations*
- **Processing Flags**
  Conditions of the retrieval: model used, initial conditions.…

SMOS Level 2 land products

- FORMAT : BinX or netcdf
- Transform to netcdf
  - ✓ use ESA toolbox http://step.esa.int/main/download/
  - ✓ unzip smos-ee-to-netcdf-standalone.zip
  - ✓ document : SMOS-BOX-FormatConversionUserGuide-5.4.0-final.pdf

Linux shell command :

```
./smos-ee-to-nc.sh SM_OPER_MIR_SMUDP2_20180801T103640_20180801T112959_650_001_1/
SM_OPER_MIR_SMUDP2_20180801T103640_20180801T112959_650_001_1.DBL
```

Objectives

- ✓ Present VOD (Vegetation Optical Depth) derived from SMOS
- ✓ **Access the data using Matlab**

General information

- File content
- Attributes of field
  - Field Values
  - Offset
  - Scale Factor …

```
>> p='SM_OPER_MIR_SMUDP2_20180801T121643_20180801T131004_650_001_1.nc'

p =

SM_OPER_MIR_SMUDP2_20180801T121643_20180801T131004_650_001_1.nc

>> info=ncinfo(p)

info =

      Filename: [1x120 char]
          Name: '/'
    Dimensions: [1x1 struct]
     Variables: [1x72 struct]
    Attributes: [1x370 struct]
        Groups: []
        Format: 'netcdf4'

>> info.Variables.Name
>> info.Variables. Attributes
```

- Get the VOD from the product

```
>> vod=ncread(p,'Optical_Thickness_Nad');
```

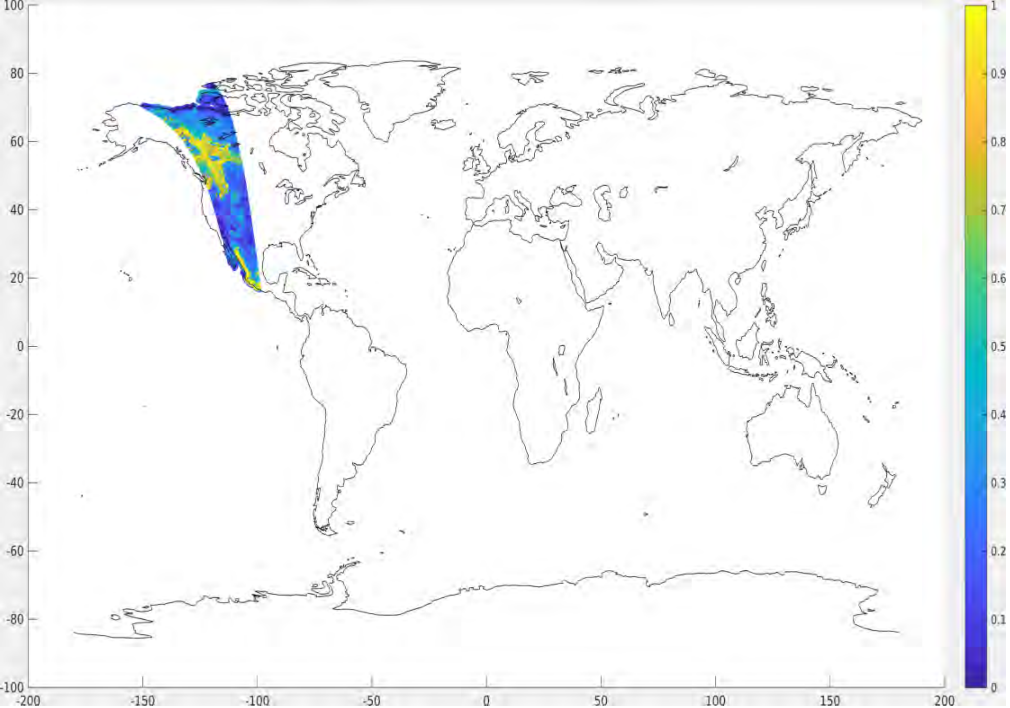
- Get Latitudes and Longitudes of all nodes

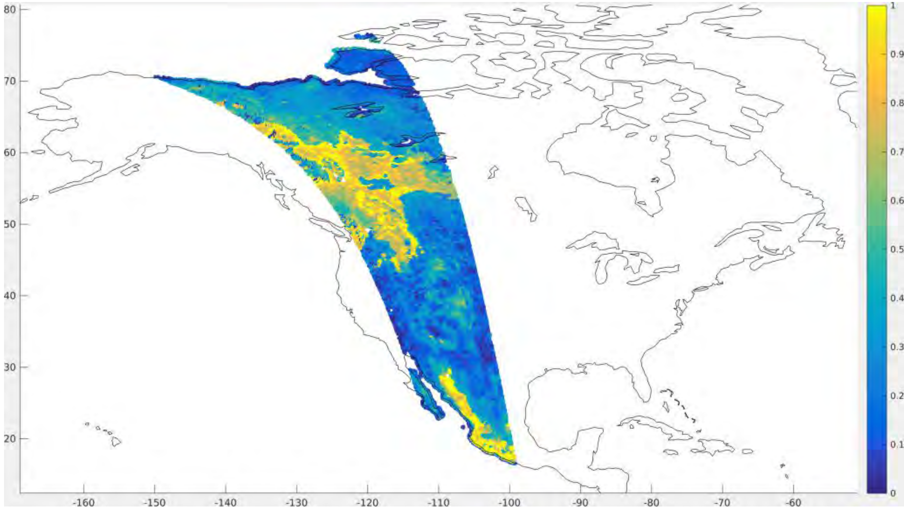
```
>> lat_smos=ncread(p,'Latitude') ;
>> lon_smos=ncread(p,'Longitude') ;
```

Rq :
$\Rightarrow$ *data are vectors*
$\Rightarrow$ *Nb of points varies from a product to another*

- Display the VOD

```
>> load coast ;
>> figure
>> scatter(lon_smos,lat_smos,15,vod,'filled')
>> hold on ;
>> plot(long,lat,'-k') ;
```


100
80
60
40
20
0
-20
-40
-60
-80
-100
-200
-150
-100
-50
0
50
100
150
200
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


80
70
60
50
40
30
20
-160
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

- Extract the time

```
>> days = ncread(p,'Days') ;
>> sec  = ncread(p,'Seconds') ;
>> microsec = ncread(p,'Microseconds') ;

>> dayref_smos = datenum(2000,01,01) ;
>> time_smos = dayref_smos + days + sec* 1/86400 + (microsec)*1e-6* 1/86400 ;
>> time_smos(isnan(time_smos)) = [] ; % Remove nan values
>> datestr(time_smos)
```

- DGG ID

One Node = one id

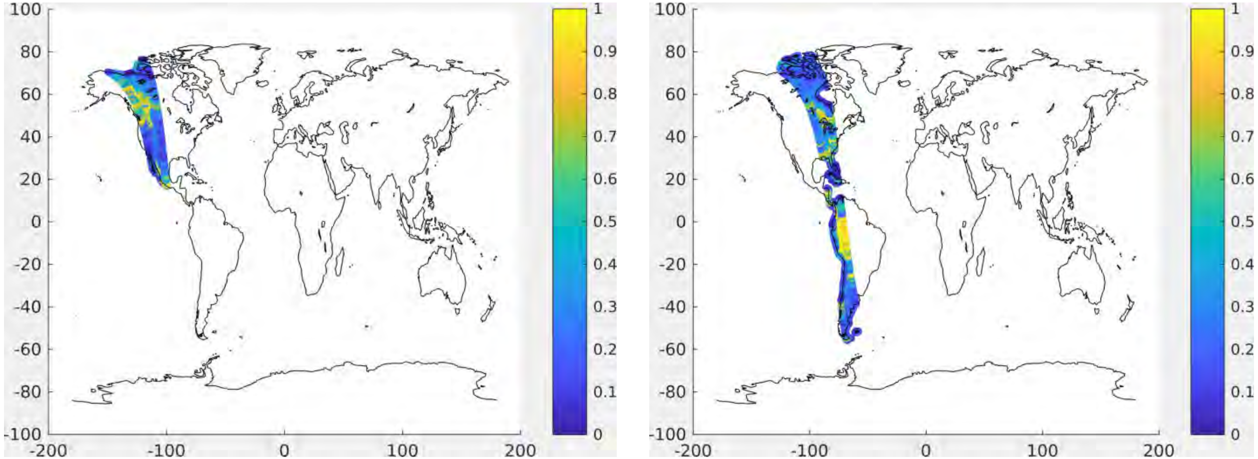
```
>> dgg=ncread(p,'Grid_Point_ID') ;

>> figure
>> scatter(lon_smos,lat_smos,15,dgg,'filled') ;
>> hold on ;
>> plot(long,lat,'-k')
```

Rq :

For time series

- find the DGG of interest, get its position in the product



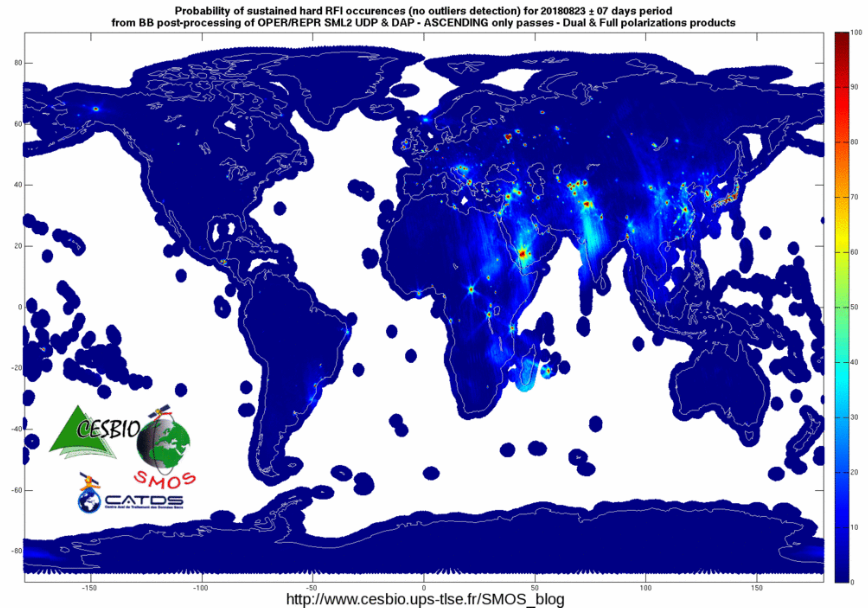
- DGG ID

```
>> p='SM_OPER_MIR_SMUDP2_20180801T121643_20180801T131004_650_001_1.nc‘ ;
>> vod=ncread(p,'Optical_Thickness_Nad') ;
>> size(vod)
ans =
      66635          1
>> p='SM_OPER_MIR_SMUDP2_20180801T103640_20180801T112959_650_001_1.nc‘ ;
>> vod=ncread(p,'Optical_Thickness_Nad') ;
>> size(vod)
ans =
     116384
```

- RFI (Radio frequencies Interferences)

  - Sources emitting at L-band…but should not
  - Affect SMOS TB and so the derived SM-VOD

```
>> rfi = ncread(p,'RFI_Prob') ;
```



Probability of sustained hard RFI occurences (no outliers detection) for 20180823 ± 07 days period
from BB post-processing of OPER/REPR SML2 UDP & DAP - ASCENDING only passes - Dual & Full polarizations products

http://www.cesbio.ups-tlse.fr/SMOS_blog

Strategy to start with the SMOS data

- SM $\neq$ -999 and within the range [0 - 0.7] m3/m3

- SM_DQX $\neq$ -999 & SM_DQX < 0.1 m3/m3
  < 0.07 (L2SM SMOS Report)
  < 0.099 (Bircher et al.)
  < 0.06 (dall Alamico et al. 2012)

- N_RFIX + N_RFIY / M_AVA0 : *RFI of the day !*
  <0.05/0.1 ;
  <0.04 (Bircher et al. 2013) tested at the Danish site with a lot of RFI

- P_RFI < 10 %
  RFI over a long period: if one source switched on, then affects the P_RFI for a long time period

- Temperature> 0°

Deeper analysis

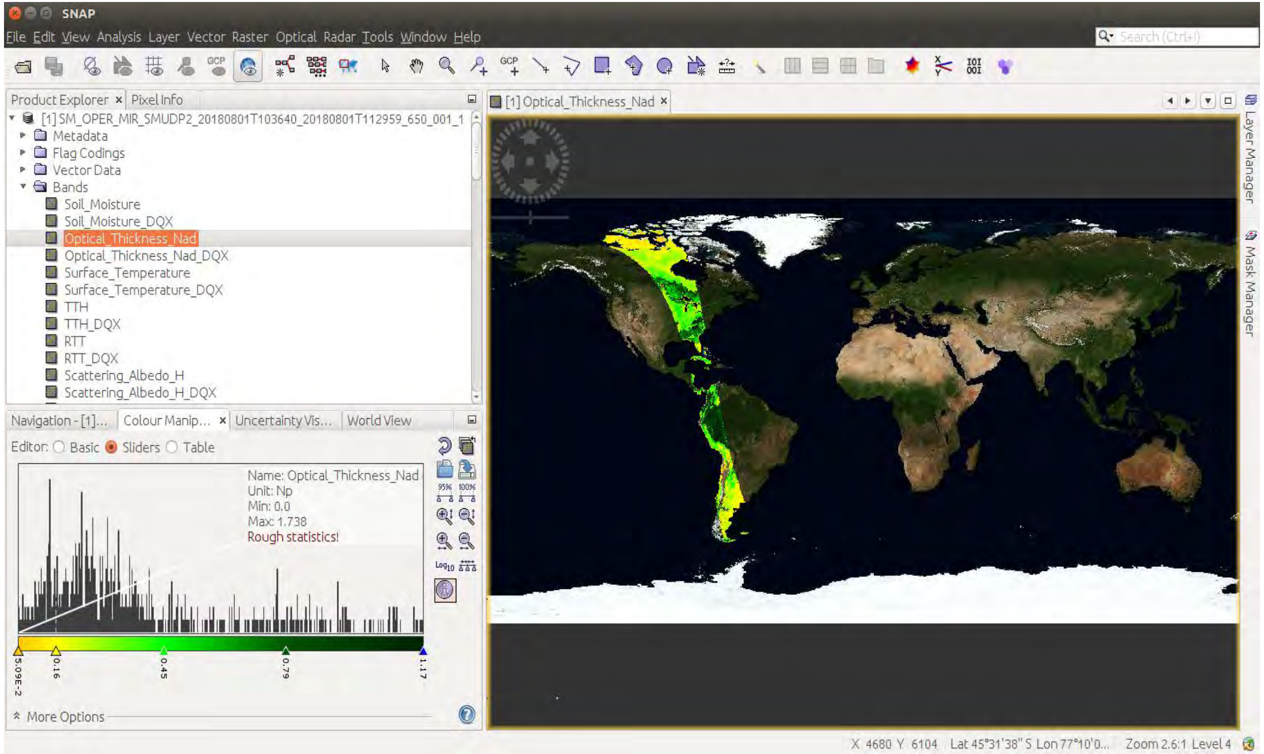
- Flags: *Understand the retrieval conditions (rain …)*
- Fraction : FM0 (for instance forest => *FM0_FO> 90%)*

NOTE: Thresholds can be adjusted to your site

Other Tools

- NCO : nco.sourceforge.net
- Python
- GDAL
- Panoply (Nasa, Netcdf grib viewer)
- ESA toolbox

SNAP + SMOS toolbox



Name: Optical_Thickness_Nad
Unit: Np
Min: 0.0
Max: 1.738
Rough statistics!

X 4680 Y 6104 Lat 45°31'38" S Lon 77°10'0... Zoom 2.6:1 Level 4

https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/smos/content/-/asset_publisher/t5Py/content/data-reader-software-7633

References

*) Rahmoune et al. 2013
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Vol 6, n. 3, June 2013

*) Vittucci et al. 2016, Remote Sensing of Environment, 180, 115–127

*) Vittucci et al. 2017, IEEE Geoscience and Remote Sensing Letters, vol. 14, n. 12

*) Parrens et al. 2017, IEEE Geoscience And Remote Sensing Letters

*) Rodríguez-Fernández et al. 2018 Biogeosciences, 15, 4627–4645, 2018