Vegetation Products from L-Band measurements

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

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 ($\lambda = 21$ cm, $f=1.4$ GHz)

• Main Objectives
  Surface Soil Moisture (m$^3$ of water/m$^3$ 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 moisture and Vegetation
  ✓ Spatial : covers the Earth Surface in ~3 days
Passive microwave L-Band ($\lambda = 21$ cm, $f=1.4$ GHz)

- Passive $\Rightarrow$ measure the Emission of the Earth Surface

- Microwave $\Rightarrow$ Brightness Temperatures TB at Horizontal and Vertical Polarisation
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
$T_{B,\text{tot}}(P,\theta) = e_s T_s \gamma + (1 - \omega) (1 - \gamma) T_v + (1 - \omega) (1 - \gamma) T_v (1 - e_s) \gamma + T_{B,\text{sky}} \gamma^2 (1 - e_s)$

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

- $e_s$: soil emissivity; linked to soil moisture through dielectric constant $(P,\theta)$
- $T_s$: physical temperature of soil
- $T_v$: physical temperature of vegetation
- $\omega$: single scattering albedo of vegetation (omega) $(P,\theta)$
- $\gamma$: canopy transmissivity; linked to vegetation optical depth $\tau$ (tau) $(P,\theta)$
- $T_{B,\text{sky}}$: sky brightness temperature $(P,\theta)$

- $P$: polarisation (H or V)
- $\theta$: incidence angle
Vegetation emission terms ("tau-omega model")

**Thermal Equilibrium: Kirchhoff’s Law (valid for MWs):**

\[ e(\lambda) = a(\lambda) \]

- **\( \omega \) scattering loss** ⇒ \((1 - \omega)\) 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

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

- **Veg. emission direct**
  \[ = (1 - \omega) \cdot (1 - \gamma) \cdot T_{\text{veg}} \]

- **Veg. emission reflected by soil** \((1 - e_{\text{soil}})\) and transmitted \((\gamma)\) back up through canopy
  \[ = (1 - \omega) \cdot (1 - \gamma) \cdot T_{\text{veg}} \cdot (1 - e_{\text{soil}}) \cdot \gamma \]
\[
T_{B,\text{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,\text{sky}} \gamma^2 (1 - e_s)
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\(\theta\): incidence angle
Vegetation Optical Depth ($\tau$)

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

- $\tau$: at Nadir
- Depends on:
  - biomass density
  - structure
  - vegetation water content
• Vegetation « seen » at various wavelengths

- X band \( \lambda = 3 \) cm
- L band \( \lambda = 21 \) cm
- P band \( \lambda = 70 \) cm
- VHF \( \lambda > 3 \) m

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

*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

~15km

8th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING
10–14 September 2018 | University of Leicester | United Kingdom
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

- **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....

Successful retrieval = value
Failed retrieval = -999
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

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 ...

```matlab
>> 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

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

• Get Latitudes and Longitudes of all nodes

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

*Rq:*

- *data are vectors*
- *Nb of points varies from a product to another*

• Display the VOD

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

```matlab
>> 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

```matlab
>> 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

```matlab
>> 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

```matlab
>> rfi = nread(p,'RFI_Prob');
```
Strategy to start with the SMOS data

- **SM**: ≠ -999 and within the range [0 - 0.7] m³/m³
- **SM_DQX**: ≠ -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

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


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