CMEM: Community Microwave Emission Model

SMOS forward operator for Numerical Weather Prediction

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I – Introduction, model presentation and recent software developments

II - Soil Dielectric Model of Mironov

III - Relative influence of vegetation data base and tiling on simulated brightness temperature

IV - Summary
CMEM: NWP model interface

- Land surface emission model developed at ECMWF for Numerical Weather Prediction (NWP) application
- To be used as the forward operator for computing TOA Brightness Temperature in the operational data assimilation scheme
  - NWP model interface
- Conceptually based on:
  - LMEB (L-Band Emission of the Biosphere), Wigneron et al., 2007,
  - LSMEM (Land Surface Microwave Emission Model), Drusch et al., 2001
- Modular: combines different parameterizations for computing surface and atmospheric emissions
- Specifically designed for L-band microwave emission for SMOS
- Also applicable for a large range of Frequency: 1 GHz to 20 GHz (suitable for RTTOV)

CMEM: Modular Model

Allows accounting for different parameterizations for each component:

- **Soil dielectric mixing model**
  
  (Wang & Schmugge / Dobson / Mironov)

- **Effective temperature model**
  
  (Choudhury / Wigneron / Holmes)

- **Soil roughness model**
  
  (None = Smooth / Choudhury / Wegmuller / Wigneron a or b or c)

- **Smooth surface emissivity model**
  
  (Fresnel / Wilheit)

- **Vegetation opacity model**
  
  (None / Kirdyashev / Wegmuller / Wigneron)

- **Atmospheric radiative transfer model**
  
  (None / Pellarin / Liebe / Ulaby)
CMEM: Modular Model

Equivalent to LMEB when corresponding options are chosen:

- Soil dielectric mixing model (Wang & Schmugge / Dobson / Mironov)
- Effective temperature model (Choudhury / Wigneron / Holmes)
- Soil roughness model (None = Smooth / Choudhury / Wegmuller / Wigneron)
- Smooth surface emissivity model (Fresnel / Wilheit)
- Vegetation opacity model (None / Kirdyashev / Wegmuller / Wigneron)
- Atmospheric radiative transfer model (None / Pellarin / Liebe / Ulaby)

CMEM updated with lastest LMEB version from Wigneron et al., 2007

Convergence CMEM-LMEB studied at the vegetation tile scale

Better than 0.01K on any surface type: water, bare soil, deciduous forest, coniferous forest, tropical forest, C3 grass, C4 grass, C3 crop, C4 crop (see poster)

Ensures that, when apropriate set of options is chosen, CMEM is in agreement with LMEB, ATBD and SMOS retrieval algorithm
CMEM: flexible portable software

CMEM is coded in Fortran90, according to NWP Centre requirements.
CMEM is flexible for:

- **Input / Output file format:**
  - Grib, Ascii (Oct 2007), Netcdf (nov 2007)

- **Input / output file size and variable dimensions**
  - Automatic detection of input size and variable allocations.

- **Portable code, for any Linux and Unix systems**
  - Requirements: Grib and Netcdf both compiled with fortran 90
  - NWP model routines and libraries are externalized (on going)

CMEM code: 6910 lines of fortran

First tagged version of CMEM (version 1.0) to be distributed in December 2007 through the ECMWF web site
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Mironov dielectric model
(Mironov et al., 2004)

- Based on the Refractive Mixing Dielectric Model for Moist soils
- Relies on separate contribution of bound water and free water to compute the soil complex dielectric constant
- Validated for a large range of soil texture
- Suitable for global scale modeling purpose
- Included in Matlab version of LMEB (J.-P. Wigneron in September 2007)
- Included in CMEM (October 2007)

Sensitivity of TB to dielectric model

- Three global scale simulations conducted for 2005 with Mironov, Dobson and Wang&Schmugge models, at T511 resolution forced by ECMWF operational products, and ECOCLIMAP vegetation data base
Sensitivity of TBH to dielectric model

Annual mean TBH Mironov – TBH Dobson: 0.8 K (2.7K sdv)

ECMWF Analysis VT: Sunday 1 May 2005 12UTC Surface: **Land-sea mask

T511 - CMEM Sensitivity to dielectric Model (Mironov - Dobson) 2005
## Sensitivity of TBH to dielectric model

<table>
<thead>
<tr>
<th>Model Comparison</th>
<th>Temperature Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wang - Mironov</td>
<td>2.4 K (2.5K sdv)</td>
</tr>
<tr>
<td>Mironov – Dobson</td>
<td>0.8 K (2.7K sdv)</td>
</tr>
<tr>
<td>Wang – Dobson</td>
<td>3.2 K (4.0K sdv)</td>
</tr>
</tbody>
</table>

Global average: Dobson leads to colder microwave emission. Wang is the warmest emission model.

Regional scale: Mironov warmer (colder) than Dobson on sandy (clay) soils

Extends to global scale the results obtained at local scale by J.-P. Wigneron on several test sites.

Better ability of Mironov to simulate higher TB on dry sandy soils

Mironov suitable for global scale
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CMEM: Subgrid scale parameterization

As in LMEB, tiles are allowed in CMEM:
- Bare soil (with / without snow)
- Low vegetation (with / without snow)
- High Vegetation (with / without snow)
- Water

Low vegetation: C3/C4 Crops/Grass
High vegetation: Deciduous/Coniferous/Rain Forests

Vegetation parameters (b',b'',tth,ttv ...) provided for each tile according to the dominant canopy type
Vegetation tiling for microwave emission modelling

At the pixel scale

Input vegetation map (ECOCLIMAP) provides for each pixel:

**Vegetation types,**

**Tiles/patches fractions:** fraction of pixels occupied by each canopy and bare soil,

**LAI:** Leaf Area index of each vegetation type

**Fcover:** within each tile, fractional area on the ground of the canopy that is occupied by vegetation. Informs on intra-tile vegetation characteristics. Provided for land surface water fluxes modelling (SVAT&LSM), tiling purpose

Tile fraction (canopy fraction within the pixel) and fcover (canopy structure within the tiles) are conceptually different.

Linear combination

$$TB = \sum f_i \cdot T_{Bi}$$

and energy not for

![Diagram showing vegetation types and fractions](image-url)
At the tile and field scale

Based on field experiments knowledge, at the canopy scale, vegetation parameters calibrated at the canopy scale implicitly account for intra canopy heterogeneities. Link optical thickness to LAI (or WVC) at canopy scale.

For each land cover type, calibrated parameters: \( \omega_h, \omega_v, \theta, \theta_v, b', b'', \ldots \)

\[
\tau_{\text{nadir}} = b' \text{LAI} + b'' \\
\tau_{\text{SV}} = \tau_{\text{nadir}} \left( \sin^2 \theta \text{th} + \cos^2 \theta \right) \\
\tau_{\text{SH}} = \tau_{\text{nadir}} \left( \sin^2 \theta \text{th} + \cos^2 \theta \right)
\]
Vegetation tiling for microwave emission modelling

From the canopy scale to the pixel scale:
Vegetation parameters calibrated at the canopy scale to be applied at the tile scale to ensure consistency between measurements & microwave modelling.

But when considering vegetation heterogeneities, some microwave codes make use of fcover to recompute the vegetation fractions. This is inconsistent with the vegetation parameters calibrated on sites, at the canopy scale, where tiling nor fcover are considered in the calibration.

Modellers must take care of making an appropriate use of vegetation parameters provided at canopy scale in tiled emission models.

As done in SMOS BB and SMOS Level 2 algorithm, ECOCLIMAP (or other vegetation DB) tiling must be used as it (no fcover) in microwave emission models.
Sensitivity of brightness temperature to vegetation

What is the influence of vegetation re-tiling on simulated brightness temperature?

What are the relative role of tiling, vegetation characteristics and LAI in the obtained sensitivity of TB to vegetation?

Four global scale simulations conducted with CMEM at T511 resolution, with operational ECMWF products for 2005 with two vegetation data bases used in input:

EXP1 ECOCLIMAP LAI (monthly), type, fractions weighed with fcover

EXP2 ECOCLIMAP LAI (monthly), type, fractions (consistent with field measurements of parameters and consistent with SMOS L2 algorithm)

CTRL TESSEL LSM LAI (cst), type, fractions

EXP3 ECOCLIMAP LAI (monthly), TESSEL type and fractions
Sensitivity of brightness temperature to vegetation

Previous studies

ANNUAL MEAN TBH(K): EXP1 - CTRL

Mean value -3K (sdv 10.9K)

-> TB colder with ECOCLIMAP data base

Includes effects of different:
- types
- LAI
- fractions
+ fcover
re-tiling
Sensitivity of brightness temperature to vegetation

Sensitivity of global annual mean TBH (K) to vegetation:

**EXP1 - CTRL**  
-3.0K (sdv 10.9K)  (due to types, LAI, fractions, fcover)

Part of this cold sensitivity might be due to an overestimation of bare soil fraction caused by the use of fcover in inconsistensity with microwave parameters definition/calibration

**EXP2 – CTRL**  
-1.7K (sdv 10.0K)  (due to types, LAI, fractions)

-> proper sensitivity on vegetation data base when ECOCLIMAP tiling is used as it, in agreement with field approaches for which parameters were calibrated, and in agreement with SMOS L2 algorithm

**EXP2 – EXP3**  
-0.6K (sdv 10.0K)  (due to types and fractions only)

The difference (-1.1K) is the sensitivity of TBH to the vegetation LAI annual cycle
Summary (1/2)

- CMEM, portable fortran90 software to compute SMOS microwave emission of land surfaces in NWP models. Flexible to I/O grid-size and format.
- Modularity: various soil and vegetation and atmosphere parameterizations.
- Updated with LMEB lastest dvpts (Wigneron 2007) and Mironov (2004); and numerical convergence ensured between LMEB and CMEM.
- Mironov parameterization of soil dielectric constant included in CMEM and global simulation performed for 1 year.
- Results show Mironov is intermediate between Dobson and Wang in global mean average. Compared to Dobson, Mironov allows representing warmer/ colder TB for sand/clay surfaces, in agreement with J.-P. Wigneron inter-comparison at field scale. Sensitivity of TBH to dielectric model is 0.8 K (sdv 2.7K) when comparing Mironov to Dobson in global mean average. It is 2.4 K (sdv 2.5K) between Wang and Mironov. Mironov is shown to be suitable for SMOS global scale modelling.
Summary (2/2)

- Sensitivity of simulated TB investigated to separate the effect of different component of vegetation inputs in the sensitivity.

- Modellers must take care of making an appropriate use of vegetation parameters provided at canopy scale in tiled emission models As done in SMOS BB and SMOS Level 2 algorithm, ECOCLIMAP (or other vegetation DB) tiling must be used as it (no fcover) in microwave emission models.

- Important for SRVT on land surfaces to be consistent with this approach

- Proper sensitivity (LAI, type, fractions) to vegetation data base is -1.7 K when comparing TESSEL and ECOCLIMAP data bases, of which -1.1 is due to LAI annual cycle.

- Averaged relative sensitivity to dielectric model is as important as that to vegetation map. But scatter is more important for vegetation sensitivity (10K) than for dielectric model (4K for Wang - Dobson)