SMOS-derived Soil Moisture at 1 km Spatial Resolution and First Results of its Application in Identifying Fire Outbreaks

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Outline

1. Introduction

2. SMOS soil moisture downscaling approach (research product at SMOS-BEC)

3. Use of 1 km SMOS-derived soil moisture into identifying fire outbreaks: early results

4. Conclusions
Why do we care about soil moisture?

**Accurate** measurements of the Earth’s surface soil moisture are needed to (~50 km, 3-days):

- Improve our **understanding** of water and energy fluxes between atmosphere, surface & subsurface
- **Climate** studies → changes to water availability?

Regional applications require higher spatial resolution (1-10 km)

- Better **land & water resources** management
- Improve **agricultural productivity**
- Enhance **weather and climate** forecast skills
- More effective **flood/drought/landslides** mitigation

Adapted from Chen et al. [2001]
Remote sensing of soil moisture

L-band radiometry is **optimal** for soil moisture measurement

- Protected band (1.400 – 1.427 GHz)
- Direct relationship of soil emissivity with soil water content
- Atmosphere nearly transparent
- Sensitive to $s_m$ in presence of vegetation (up to $\sim$5 kg/m$^2$)

**Radiometer**: measures the thermal noise emitted by bodies at $T > 0$ K

**Technique known since the ‘70s, but not applied due to the large (> 20 m) antennas required to achieve a decent (~30-50 km) spatial resolution**

3 main approaches for adequate coverage: 3 days & 50/1-10 km spatial

1. **ESA SMOS** mission: synthetic aperture radiometry
   - ~ 50 km

2. **NASA SMAP** mission: large lightweight antenna
   - 40 km (radiometer)
   - 10 km (radar + radiometer)

3. **Pixel disaggregation techniques** → 1-10 km
Soil Moisture and Ocean Salinity Mission

- ESA’s 2nd Earth Explorer Opportunity mission
- Global maps of SM and OS
- MIRAS: first 2D synthetic aperture radiometer for Earth observation (69 antennas, 3.5 m per arm)

- Multi-angular (from 0 - 65º)
- Full polarimetric (H, V, T3, T4)
- Spatial resolution: ~30 to ~90 km
- Radiometric sensitivity: 2.6 K to 5 K
- Pixel variability depends on its position in the FOV

Launched on November 2, 2009
Two steps:

1. A linking model, which is an extension of the “universal triangle” concept is used to relate 40 km SMOS observations to 1 km MODIS NDVI and $T_s$ aggregated to 40 km → set up a system of linear equations for all pixels in the scene → $a_{ijk}$

2. 1 km soil moisture maps are obtained by applying the linking model using $a_{ijk}$ (from step 1), $T_s$ and NDVI data at 1 km and TB re-sampled at 1km.

**Linking model**

General expression:

$$s_m = \sum_i \sum_j \sum_k a_{ijk} \cdot \text{NDVI}_i \cdot T_s^j \cdot T_B^k$$

Second order approximation:

$$s_m = a_{000} + a_{001} T_{BN} + a_{010} T_N + a_{100} F_r + a_{002} T_B^2 + a_{020} T_N^2 + a_{200} F_r^2 + a_{011} T_N T_{BN} + a_{101} F_r T_{BN} + a_{110} F_r T_N$$

$$T_N = (T_s - T_{s,\text{min}})/(T_{s,\text{max}} - T_{s,\text{min}})$$  

$$T_{BN} = (T_B - T_{B,\text{min}})/(T_{B,\text{max}} - T_{B,\text{min}})$$  

$$F_r = (\text{NDVI} - \text{NDVI}_{\text{min}})/(\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}})$$
Validation over OZnet (SE Australia)

- Downscaling algorithm applied to a set of 20 SMOS images acquired during SMOS commissioning phase (Jan-Feb 2010)

- Soil moisture variability is captured at 10 and 1 km spatial scales, without a significant degradation of RMSE

Validation studies

Further validation of the downscaling algorithm is underway
First maps of 1 km soil moisture over the Iberian Peninsula

- Soil moisture maps over Spain at 1 km spatial resolution are available at the SMOS-BEC homepage: [http://www.smos-bec.icm.csic.es](http://www.smos-bec.icm.csic.es)
- Validation of experimental data is underway
How to access SMOS-BEC data?

- NetCDF versions of data files at http://www.smos-bec.icm.csic.es
- Send an e-mail to smos-bec@icm.csic.es to become a registered user and download data
Use of 1km $s_m$ in identifying fire outbreaks

Naive approach: higher probability of fires when soil is “hot” and “dry” and there is vegetation

- **Selection of fires** from the National database of forest fires 2010 with coincident SMOS data (up to 3 days before the fire outbreak)

- Use of the MODIS MCD45A1 product to delineate burned area (pixels affected, on risk of fire)

- **Selection of random areas**, same burned area and date as the selected fires.

- Comparison of **SMOS-derived 1 km soil moisture**, 1 km daily MODIS Ts and 1km 15-day MODIS NDVI data in Fire and Random areas.
Use of 1km $s_m$ in identifying fire outbreaks

- Error bars show Random and Fire pixel distributions have distinct values of $S_m$ and $T_s$
- A different indicator for vegetation state should be used (daily NDVI, LAI...)

Mann-Whitney U-test was used to confirm that Random and Fire samples are independent
Use of 1km $s_m$ in identifying fire outbreaks

**red: fires**  Blue: random areas

Fire risk pre-conditions:

$S_m \leq 0.039 \text{ m}^3/\text{m}^3$

$T_s \geq 33^\circ\text{C}$
First results

Results indicate that SMOS-derived $s_m$ could be a variable worth including in fire risk maps, but still a lot of work needs to be done.

Fire risk pre-conditions:

$S_m \leq 0.039 \text{ m}^3/\text{m}^3$

$T_s \geq 33^\circ \text{C}$

Fire risk map 05/09/10 (64 % fires in risk zone)

- Detected fires
- Non-detected fires
- Low fire risk
- High fire risk

Fire risk map 21/08/10 (46% fires in risk zone)

Fire risk map 25/07/10 (85% fires in risk zone)
Conclusions

- A downscaling algorithm is used to provide 1 km maps of the Earth’s surface soil moisture (distribution through SMOS-BEC homepage) → path opener to new applications

- **First results** of the prospect use of 1 km SMOS-derived soil moisture data into identifying fire risk areas have been presented.

- Work in progress:
  - Data collection for a 2-year study (2010-2011)
  - Explore the added value of introducing 1km SMOS soil moisture data into a fire risk index (e.g. Canadian, Australian index)
Thanks for your attention!
1 km soil moisture maps over the Iberian Peninsula

http://www.smos-bec.icm.csic.es/
Use of $1km\ s_m$ in identifying fire outbreaks

- **Selection of fires** from the National database of forest fires 2010 with coincident SMOS data (up to 3 days before the fire outbreak)
- **Selection of random areas**, same burned area and date
- Comparison of soil moisture, MODIS $T_s$ and NDVI data in Fire and Random areas.

**Fire risk map 25/07/10**

- $S_m \leq 0.039\ m^3/m^3$
- $T_s \geq 33^\circ C$

**Detected fires**
**Non-detected fires**

- Low fire risk
- High fire risk

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**MODIS 1km NDVI**

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**MODIS 1km $T_s$**

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**1km soil moisture**

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