Sun L-band brightness temperature measurements from Soil Moisture and Ocean Salinity (SMOS) mission. Preliminary results for a potential usage of SMOS data for space weather applications

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Backgrounds

- Study performed in the framework of the “Science and Technology Space Master” Tor Vergata University Rome by E. Capolongo and supported by R. Crapolicchio and A. Bigazzi (ABSpace/Serco). The study is a 6-months project (Jun-Dec 2015).

- Additional contribution from the SMOS project team: Joe Tenerelli (Ocean Data Lab) Expert support laboratory for sea surface salinity retrieval, A. Gutierrez (Deimos E.) expert for data processing.

- Preliminary discussion of the results with Space Weather related people: Noelia Sanchez Ortiz (Deimos Space) and Thierry Dudok de Wit (Lab. de Physique et Chimie de l'Environnement et de l'Espace) has provided encouraged feedback about the outcome of the study for a potential generation of a routine, real time Space weather products from SMOS data.

- Thanks to A. Glover (ESA-SSA) we have managed to present some outcome of this study at the European Space Weather Week #12.
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What is the ESA Soil Moisture Ocean Salinity (SMOS) mission?
ESAs/CNES *Earth Explorer* Opportunity Mission - Living Planet program

*Soil Moisture Ocean Salinity (SMOS)* mission was launched on 2\textsuperscript{nd} November 2009 (6-years in orbit) and currently extended till 2017 with a possible further extension till 2020.

Direct response to the current lack of global observations of *soil moisture* and *sea surface salinity*, needed to improve our knowledge of the water cycle, and to contribute to better weather and extreme-event forecasting and seasonal-climate forecasting.

Emerging applications: *sea-ice monitoring*
The payload of **SMOS** consists of the Microwave Imaging Radiometer using Aperture Synthesis (**MIRAS**) instrument, a passive microwave **2-D interferometric full polarization radiometer**, operating at 1.413 GHz (wavelength of 21 cm) within the protected 1400-1427 MHz band. The interferometry technology provides the opportunity to remove the spatial resolution constraint in the measurements from space, mainly due to the antenna size and the wavelength.
The **MIRAS** payload comprises a central structure and three deployable arms holding the equally distributed 69 **antenna** elements.

The SMOS mission is based on a **sun-synchronous** orbit (dusk-dawn 6am/6pm) with a mean altitude of 758 km and an inclination of 98.44°.

SMOS has a **149-days** repeat cycle with a 18-days sub-cycle and a revisit time of 3 days.
SMOS Mission

The microwave interferometry technology has been developed for radio-astronomy

VLA New Mexico Socoro

Earth Observation

ESTAR (NASA) 1-D Interferometer with 7 baseline. Flew on aircraft in ‘90 to demonstrate the imaging principle

MIRAS (ESA) 2-D interferometer with 2346 baselines (69 receivers) on board SMOS satellite (launched Nov. 2009)
How SMOS “sees” the SUN
How SMOS “sees” the Sun

Due to Antenna size the Field of View is quite large and includes the full Earth and part of the Sky.

The distance amongst the antennas with a spacing of 0.875 wavelengths does not follow exactly the Nyquist criteria. For this reason part of the field of view is affected by aliasing and cannot be used. That is the reason why SMOS images has the characteristic “hexagonal” shape.

The alias free field of view (FOV) can be extended over region where the Sky alias is present by a specific processing to obtained an extended alias free FOV (EAF-FOV).

The SUN is seen as an alias in the EAF-FOV of the SMOS image.
How SMOS “sees” the Sun

- The Sun alias appears as a bright spots over the SMOS EAF-FOV image and it contaminates the radiometer measurement.
- Sun’s tails signal contaminate also the AF-FOV.
- The Sun signal is estimated and removed during the image reconstruction processing.
- The removed Sun brightness temperature (in X and Y polarization) is annotated in the SMOS L1b user product.
Solar radio burst sensed by SMOS: case of 17/05/2012
Test case 17/05/2012

- A moderate solar flare (M-class) on May 17, 2012 lit up ground stations all over the world with an unexpected and puzzling pulse of high-energy particles. It should not have happened, and scientists are now trying to figure out why it did.

- Yet either the flare or the Coronal Mass Ejection (CME) generated a Ground-Level Enhancement (GLE), a blast of high-energy particles that lit up ground stations called neutron monitors on Earth for the first time in nearly six years. Scientists don’t expect an M-class flare to create a GLE (Space.com)
1. Solar Microwave Bursts (SMB) at frequency from 2 to beyond 20 GHz, peak rapidly and last a few minutes.
2. SMBs are well correlated temporally and spatially with hard X-ray flares.
3. CMEs involve large-scale disruptions of coronal magnetic fields and plasmas, often visible in the K corona as expanding loops or sprays.
4. The most probable delay between linked CMEs and SMBs is **31 minutes**, with ejections following bursts. The rms scatter (Gaussian width) among these events is 36 minutes.

Brian L. Dougherty, Harold Zirin, and Kathryn Hsu

**STATISTICAL CORRELATIONS BETWEEN SOLAR MICROWAVE BURSTS AND CORONA,**
Test case 17/05/2012

- The Coronal Mass Ejections (CME) occurred between 17-05-2012 01.37 – 02.12 utc. Full developed flare at about 02:00 utc
- Expected SMB peak around 01:40 utc
- Comparison with SMOS data acquired (REPR V620) on 17/05

(credit NASA/SOHO)
Test case 17/05/2012

17 May 2012 01.48 UTC

17 May 2012 01.37 UTC
SUN BT peak around 19 deg. South

17 May 2012 01:42:36 UTC
SUN BT: about 2.3 MK

17 May 2012 01:37 UTC

17 May 2012 01:48 UTC
Brightness Temperature (SMOS L1c) acquired at 17 May 2012 01:42:36

Colour scale [0 – 200] K. Residual Sun signal during solar microwave burst
SMOS Sun observation vs RSTN observation
SMOS observation vs RSTN

17 May 2012
SUN BT:
about 2.3 MK
09 Aug 2011
SUN BT: about 6 MK
SMOS observation vs RSTN

15 Feb 2011

SUN BT:
about 10 MK
Compute daily solar flux from SMOS by averaging sun Tbs for which Sun angle from boresight does not exceed 85 deg (from J. Tenerelli)
SMOS observation vs RSTN

Reference: EOP-GMQ-TN-003-15
Status: N/A
ESA UNCLASSIFIED - For Official Use
SMOS observation vs RSTN

Reference: EOP-GMQ-TN-003-15
Status: N/A
ESA UNCLASSIFIED - For Official Use
Why a space weather products from SMOS?
Space Weather product from SMOS?

- It is better to measure several centimetric wavelengths, since these then give access to different solar processes, which also have different atmospheric impacts (and thus space weather applications), among these wavelengths, the 20-40 cm range is of particular interest for it is a better proxy than 10.7 cm for UV radiation between, say, 200-300 nm.

- The homogeneity of the SMOS data set which does not require cross-calibration among different on Earth observatories. Present day observations are collected by various stations, with differing characteristics, and quality. This makes it very difficult to establish some worldwide monitoring.

- An independent source of information for the interpretation of the on-ground observatories measurement that from time to time can be affected by Radio Frequency Interference (RFI).
Space Weather product from SMOS?

Data can be available in near real time, every 1.2 sec. and with permanent coverage (in the period Nov-Jan Sun partially eclipsed by Earth for few minutes)

“availability of all possible real time data is an asset to analyse flight radars anomalies” (see key note H. Opgenoorth Thu. 26)

Unique opportunity to exploit full polarization data set to fill the gap in solar radio observation

“availability of solar radio in circular polarization is a must in solar observation due to its impact in GPS signal” (see M. Messeroti, solar cycle 24 working meeting Thu. 26)

Polarimetric measurements can be used to derive Faraday rotation and related **Vertical Electron Content** (VTEC) in the atmospheric as additional proxy for Sun activity.
Caveats to use **SMOS** data (as is)
Caveats

- SMOS current data is not (yet) a SW product!
- Calibration has to be improved, differences were found for ascending and descending passes

Joe Tenerelli Ocean Data Lab, France
Data availability does not cover full 24h (in the current algorithm version 620 the Sun is estimated only when it is in front of the antenna plane but potentially can be also estimated when it is in the backlobe)
Caveats

SUN in the front is cancelled!

30 deg. South

SUN in the back is still visible!

30 deg. South
Caveats

- Image with strong contrast (i.e. Land-Sea transition) could impact the estimated Sun brightness temperature (1)
- Non linearity due to antenna pattern should be re-considered (2)
RFI also impacts SMOS measurements and consequentially the estimated SUN brightens temperature (RFI flag should be used, and further improved)

RFI probability map derived from SMOS data
Conclusion

- There is a **definite interest** for exploiting in the context of space weather the L-band data from SMOS mission.
- Most of the caveats can be mitigated / removed by a tailored SMOS data processing focused on a **dedicated SW product**. The most hard being RFI.
- Many instruments can serve more than one purpose provided that this is recognized early enough, so that their operating mode and data processing can deliver data product for many different applications. SMOS could be a very nice example of **cross-fertilization between EO and SW community**.
Many Thanks for your attention!