High Resolution Soil Moisture for Agricultural Applications and Low Frequency Passive Microwave User Requirement Consolidation Study

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• Soil Moisture for dEsert Locust earLy Survey- SMELLS project
• REC: Crop irrigation management by multi-sensor remote sensing approach
• Low Frequency Passive Microwave User Requirement Consolidation Study
SMELLS project introduces the use of Soil Moisture to preventive management of Desert Locust.

Those plagues have threatened agricultural production in Africa, the Middle East and Asia for centuries and regularly affect up to one-tenth of the world’s human population.
Scientific Justification

Preventive management aims to prevent or to limit crop damage by controlling populations before they can reach high densities and form mass migrating swarms.

Surface to be monitored is immense latitudes 0 – 40 N, longitudes 20 W – 80 E
moist sandy soil & green vegetation

rainfall
Meteosat
ARTEMIS CCD
CMORPH RFE

vegetation
GIMMS NASA GFSC
NOAA AVHRR
SPOT
LANDSAT
MODIS
SENTINEL
1. The establishment of a dialogue between developers and Desert Locust monitoring users about their requirements related to Soil Moisture Remote Sensing.

2. Assessing the capacity of Soil Moisture to predict Desert Locust presence to be used in the framework of Desert Locust preventive management.

3. The development of an innovative approach to derive High Resolution Soil Moisture products from Sentinel-1 in synergy with SMOS data.
In accordance with Requirements Baseline defined with Users, the SMELLS project has provided Soil Moisture (SM) estimations at two spatial resolutions:

- SM at a resolution of 1km for the entire AOI based on L-band passive MW every 10 days between 2010 to 2017 and
- SM at a resolution of 100m for areas where and when Sentinel-1 acquisition is available for 2015-2016.
Users Requirements
SSM (1 km, 2-3 days)

L-band Passive MW SMOS/SMAP/WCOM
- accuracy 0.04 m³/m³
- low spatial resolution 40 km
- high temporal 2 - 3 d

+ Medium Resolution O/T MODIS (1 km, 1 d)
SSM
1km / 2-3 days

L-band Passive MW SMOS/SMAP/WCOM
- accuracy 0.04 m3/m3
- low spatial resolution 40 km
- high temporal 2 - 3 d

+ Medium Resolution O/T MODIS (1 km, 1 d)

Implemented and validated in Catalonia [Merlin et al., 2013, Escorihuela et al. 2016], Central Morocco (Merlin et al. 2015), South Eastern Australia (Malbeteau et al. 2016) and USA (Molero et al. 2016)
SMELLS 1km

SMELLS 1km

SMELLS 1km201001AV2

SMELLS Soil Moisture Stations

[Map showing soil moisture stations in Morocco, Algeria, and Mauritania]
SMELLS Soil Moisture Stations

**MOROCCO**
Fam el Hisn, province of Guelmim-Es Semara
(Lat N 29°00'58.8", Lon W 8°50'29.9")

**ALGERIA**
Abalessa, province of Tamanrasset
(Lat N 22°47'33.0", Lon E 4°14'41.0")

**MAURITANIA**
42km South-east of Akjoujt, province of Adrar
(Lat N 19°38'07.4", Lon W 14°02'03.3")

**MALI**
Yélimané, province of Kayes
(Lat N 15°07'11.8", Lon W 10°33'14.8")
AMMA Sites Mali and Niger
### SMELLS Soil Moisture Stations

<table>
<thead>
<tr>
<th>SMELLS 1 km product</th>
<th>R</th>
<th>RMSE</th>
<th>bias</th>
</tr>
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<tr>
<td>Akjoujt</td>
<td>0.78</td>
<td>0.020</td>
<td>0.016</td>
</tr>
<tr>
<td>FamHisn</td>
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<td>0.020</td>
<td>-0.016</td>
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<td>Yelimane</td>
<td>0.81</td>
<td>0.045</td>
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<tr>
<td>Tamanraset</td>
<td>0.45</td>
<td>0.154</td>
<td>-0.138</td>
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## AMMA Soil Moisture Stations

<table>
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<th>SMELLS 1 km product</th>
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<tbody>
<tr>
<td></td>
<td>R</td>
<td>RMSE</td>
<td>bias</td>
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<tr>
<td>Agoufou</td>
<td>0.93</td>
<td>0.039</td>
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<tr>
<td>Tondi</td>
<td>0.82</td>
<td>0.046</td>
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<tr>
<td>Wankama</td>
<td>0.71</td>
<td>0.040</td>
<td>0.027</td>
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<tr>
<td>Bani</td>
<td>0.79</td>
<td>0.052</td>
<td>0.038</td>
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</table>
SMELLS 1km

SMELLS1km MOR4 22 MAY 2015

Conference on Low Frequency Passive Microwaves
ECMWF, 5th December 2017 | 20
Validation with survey data

- 2010-2016
- 36700 survey points
- 34800 points with satellite data
- 32563 points after synthesis per km² and decade

6262 INPV $\rightarrow$ 17.1% of presence
2770 CNCLP $\rightarrow$ 4.2% of presence
19192 CNLA $\rightarrow$ 59.9% of presence
4339 CNLAA $\rightarrow$ 46.3% of presence
Analysis for SM 1km – which dynamics is best?

Logit[Pr(p = presence)] = \alpha_0 + \alpha_1 \cdot SM + \alpha_2 \cdot SM^2 + \alpha_3 \cdot SM.2 + \alpha_4 \cdot SM.2^2 \\
+ \alpha_5 \cdot SM.3^2 + \alpha_6 \cdot SM.5^2 + \alpha_7 \cdot SM.7 + \alpha_8 \cdot SM.7^2 \\
+ \alpha_9 \cdot SM.8 + \alpha_{10} \cdot SM.8^2 + \alpha_{11} \cdot SM.10 + \alpha_{12} \cdot SM.10^2

-7 to -8 decades

-2 & -10 decades

Optimum SM.2 \sim 0.07
SM.7 \sim 0.125
SM.8 \sim 0.125
SM.10 \sim 0.05

Conference on Low Frequency Passive Microwaves
ECMWF, 5th December 2017 | 24
RandomForest model – only with SM adjusted on 2010-2015
November 2016 outbreak in Mauritania was concentrated on areas with Soil Moisture > 0.1 seventy days before, as predicted by the analyses on 2010-2015 data.

http://www.esa.int/Our_Activities/Observing_the_Earth/Satellites_forewarn_of_locust_plagues
Long-term high-resolution Soil Moisture dataset produced for the entire users area of interest at 1km spatial resolution for the period 2010-2017 (http://smells.isardsat.com/data-portal/)

SMELLS 1km product has been thoroughly validated, its accuracy is amongst the best soil moisture products but at a better spatial resolution (1km against typically 40km)

Correlation values are good (R > 0.70) and RMSE around 0.04 m^3 m^-3 and decadal

SMELLS 100m has room for improvement, Dramatic increase of data acquisitions since October 2016 (linked to S1B launch)
Results

Soil Moisture can explain presence/absence of Desert Locust with values significant to Desert Locust biology. Soil Moisture allows to forecast locust presence 2–3 months ahead. Current methodologies based on Vegetation Indices allow to predict presence only 1 month ahead.
• The Soil Moisture products will be integrated into the national and global Desert Locust early warning systems in national locust centres and at FAO HQ, respectively.
• The Soil Moisture products should be extended to the entire Desert Locust recession area (0-40N/20W-80E).
• Integration of S3 LST in the SMELLS 1km algorithm
• Soil Moisture products at 100m and within root-zone to be investigated to provide further capacities of Desert Locust forecast.
Agriculture is an important pressure on water resources Mediterranean countries agriculture uses 80% water available. The Mediterranean region is also one of the most sensitive areas to climate change.

Sustainable water use is a growing concern worldwide. Increasing water use efficiency in agriculture has been identified as one of the key themes relating to water scarcity and drought.

Irrigation performance assessments at the field scale show a mismatch between irrigation requirements and the amount of irrigation water that is actually applied. Optimize on-farm irrigation management.

Irrigation and fertilizer management improvements can help closing the crop yield gaps globally.
Scientific Objectives

REC aims at develop an operational remote sensing algorithm dedicated to root zone soil moisture monitoring at the parcel scale.

REC will allow for the first time to:

1) to map root zone soil moisture on a daily basis at the field scale and
2) to quantitatively evaluate the different components of the water budget at the field scale from readily available remote sensing data.

These estimates will be integrated in an irrigation management system that will be used to trigger irrigation.
The approach is being implemented and validated in two sites in collaboration with their respective irrigation agencies:

- the modern irrigated area of Segarra-Garrigues in Lleida, Catalonia, Spain managed by ASG
- the irrigated perimeter of the Haouz Plain in the Tensift watershed, Morocco managed by the ORMVAH
L-band Passive MW (40 km, 2/3 d)  
+ Medium Resolution OT (1 km, 1 d)  
+ High Resolution OT (100 m, 16 d)

SSM (1 km, 2/3 d)  
SSM (100 m, 16 d)

+ SAR S1 (20 m, 5/6 d)

SSM (100 m, 5/6 d)
Disaggregation of passive MW derived soil moisture with DISPATCH: current status and developments. *Vivien Stefan.*

Downscaling the SMOS soil moisture data at 1 km and 100 m resolution using MODIS and Landsat optical/thermal data. *Nitu Ojha.*

Disaggregation of SMOS soil moisture to 100 m resolution using MODIS optical/thermal and Sentinel-1 radar data: evaluation over a bare soil site in Morocco. *Omar Ali Eweys.*

Synergetic Use of Sentinel-1 and Sentinel-2 Data for Soil Moisture Mapping at 100 m Resolution. *Qi Gao.*

Soil moisture retrieval from a synergy between Sentinel-1 radar and Landsat-7/8 thermal data. *Abdelhakim Amazirh.*

Sensitivity of Sentinel-1 radar data to biophysical parameters over irrigated crops. *Soufiane Sersif.*
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Downscaling the SMOS soil moisture data at 1 km and higher resolution using MODIS and Landsat optical/thermal data. *Nitu Ojha.*

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Soil moisture retrieval from a synergy between Sentinel-1 radar and Landsat-7/8 thermal data. *Kim Amazirh.*

Sensitivity of Sentinel-1 radar data to biophysical parameters over irrigated crops. *Soufiane Sersif.*
Task 2: Establish a list of the different products (L1 to L4) supported by L-Band measurements together with their accuracies and feasibility/maturity (Science Readiness Level SRL). The products will also be evaluated in terms of ARL(application Readiness Level).

For each product, the following features are reported when available:
- Product accuracy in physical units
- Temporal and spatial resolution requirements
- Scientific Readiness Level (SRL)
- Application Readiness Level (ARL)
- L-band uniqueness / options
Science Readiness Level

Phase F  9  Science Impact Quantification
Phase E2  8  Validated and Matured Science
Phase E1  7  Demonstrated Science
Phase B, C, D  6  Consolidated Science and Products
Phase A  5  End-to-End Performance Simulations
Phase 0  4  Proof of Concept
(Pre-) Phase 0  3  Scientific and Observation Requirements
Pre - Phase 0  2  Consolidation of Scientific Ideas
Pre - Phase 0  1  Initial Scientific Idea

European Space Agency
Application Readiness Level

**APPLICATION READINESS LEVEL (ARL)**

- **ARL 9**: Approved, Operational Deployment and Use in Decision Making (Sustained Use)
- **ARL 8**: Application Completed and Qualified (Functionality Proven)
- **ARL 7**: Application Prototype in Partner’s Decision Making (Functionality Demonstrated)
- **ARL 6**: Demonstration in Relevant Environment (Potential Demonstrated)
- **ARL 5**: Validation in Relevant Environment (Potential Determined)
- **ARL 4**: Initial Integration and Verification (Prototype/Plan)
- **ARL 3**: Proof of Application Concept (Viability Established)
- **ARL 2**: Application Concept (Invention)
- **ARL 1**: Basic Research (Baseline Ideas)
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<thead>
<tr>
<th>Application Area</th>
<th>Required</th>
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<td></td>
<td>Spatial</td>
<td>Temporal</td>
<td>Accuracy</td>
<td>SRL</td>
<td>ARL</td>
<td>Latency</td>
<td>Uniqueness</td>
</tr>
<tr>
<td>SSM</td>
<td>10 km</td>
<td>1d</td>
<td>0.020</td>
<td>9</td>
<td>8</td>
<td>NRT</td>
<td></td>
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<tr>
<td>RZSM</td>
<td>10 km</td>
<td>1d</td>
<td></td>
<td>9</td>
<td>7</td>
<td>1d</td>
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<tr>
<td>Inland Surface Water Extent</td>
<td>10 km</td>
<td>3d</td>
<td>2,5K</td>
<td>7</td>
<td>5</td>
<td>1w</td>
<td></td>
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<tr>
<td>Enhanced Stream Flow</td>
<td>10 km</td>
<td>3d</td>
<td>1K</td>
<td>6</td>
<td>5</td>
<td>1w</td>
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<tr>
<td>Enhanced Rainfall</td>
<td>10 km</td>
<td>3d</td>
<td>0.04</td>
<td>8</td>
<td>6</td>
<td>1d</td>
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Hydrology

NRT

1d

1 w

1 m

1 y

100 km 10 km 1 km 100 m 10 m 1 m

Surf. water extent rain stream flow
# Land: Carbon Cycle and Agriculture

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<tr>
<th>Application Area</th>
<th>Required</th>
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<th>ARL</th>
<th>Latency</th>
<th>Uniqueness</th>
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<tr>
<td>Carbon cycle: tree biomass</td>
<td>25 km</td>
<td>7</td>
<td>4</td>
<td>1 w</td>
<td>Active radar also useful</td>
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<tr>
<td>Large scale carbon exchange fluxes (L4) and phenology</td>
<td>100 km</td>
<td>5</td>
<td>6</td>
<td>3 m</td>
<td>Active radar also useful</td>
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<tr>
<td>Agriculture: Crop Yield</td>
<td>30 m</td>
<td>8</td>
<td>4</td>
<td></td>
<td>O/T limited by clouds</td>
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<tr>
<td>Agriculture: Irrigation</td>
<td>30 m</td>
<td>8</td>
<td>5</td>
<td></td>
<td>O/T limited by clouds</td>
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<tr>
<td>Forestry: Yield</td>
<td>10 m</td>
<td>7</td>
<td>6</td>
<td></td>
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</table>

**Table:**

- **Application Area:** Carbon cycle: tree biomass, Large scale carbon exchange fluxes (L4) and phenology, Agriculture: Crop Yield, Agriculture: Irrigation, Forestry: Yield
- **Required:** Spatiow Temporal Accuracy
- **SRL:** 7
- **ARL:** 4
- **Latency:** 1 w
- **Uniqueness:** Active radar also useful, O/T limited by clouds
## Land: Hazards

<table>
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<tr>
<th>Application Area</th>
<th>Required Spatial</th>
<th>Required Temporal</th>
<th>Accuracy</th>
<th>SRL</th>
<th>ARL</th>
<th>Latency</th>
<th>Uniqueness</th>
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</thead>
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<tr>
<td>Flash Flood forecasting</td>
<td>10 km</td>
<td>1d</td>
<td>0.04</td>
<td>7</td>
<td>6</td>
<td>NRT</td>
<td>Need real SM measurements</td>
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<tr>
<td>Drought Early Warning</td>
<td>10 km</td>
<td>10d</td>
<td>0.04</td>
<td>4</td>
<td>4</td>
<td>24 h</td>
<td>Needs real SSM measurements</td>
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<td>Fire risk assessment</td>
<td>1km</td>
<td>NRT</td>
<td>0.04</td>
<td>4</td>
<td>3</td>
<td>NRT</td>
<td>Needs real SM measurements</td>
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<td>Food Security: Yield</td>
<td>10km</td>
<td>1d</td>
<td>0.04</td>
<td>6</td>
<td>4</td>
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<td>Desert Locust Management</td>
<td>100m</td>
<td>10d</td>
<td>0.04</td>
<td>7</td>
<td>6</td>
<td>3 d</td>
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<tr>
<td>Epidemiology: malaria, Vector Born Diseases</td>
<td>100m</td>
<td>10d</td>
<td>0.04</td>
<td>2</td>
<td>2</td>
<td>3 d</td>
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Land: Hazards

- Floods
- Droughts
- Food Security
- Fire
- Epidemiology

NRT
1d
1w
1m
1y

100 km 10 km 1 km 100 m 10 m 1 m
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<tr>
<th>Application Area</th>
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<th>ARL</th>
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<tr>
<td></td>
<td>Accuracy</td>
<td></td>
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<tr>
<td>Air-sea interaction/Climat change: SSS long term change (&gt;10 years)</td>
<td>5°</td>
<td>1y</td>
<td>0.005 psu</td>
<td>4</td>
<td>3</td>
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<td>8d</td>
<td>0.2</td>
<td>7</td>
<td>6</td>
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<td>Application Area</td>
<td>Required</td>
<td>SRL</td>
<td>ARL</td>
<td>Latency</td>
<td>Uniqueness</td>
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<tr>
<td>Ocean circulation: mesoscale/eddy propagation</td>
<td>50km</td>
<td>1w</td>
<td>0.1</td>
<td>4</td>
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<td>Ocean circulation: AMOC</td>
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<td>ARL</td>
<td>Latency</td>
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<td>Freshwater Fluxes: River plumes</td>
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<td>5 3 NRT</td>
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<td>4 3 6m</td>
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<td>No/In situ (Argo)</td>
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<td>ARL</td>
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<td>Extreme events/Air-sea interactions:</td>
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<td>Cyclones</td>
<td>10km</td>
<td>8</td>
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<tr>
<td></td>
<td>&lt;4h</td>
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<td>5m/s</td>
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<td>Extreme events: Flooding</td>
<td>50km</td>
<td>7</td>
<td>6</td>
<td>6m</td>
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</tr>
<tr>
<td></td>
<td>1w</td>
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<tr>
<td>Application Area</td>
<td>Required Spatial</td>
<td>Temporal</td>
<td>Accuracy</td>
<td>SRL</td>
<td>ARL</td>
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<tr>
<td>Sea ice and climate</td>
<td>25km</td>
<td>1w</td>
<td>5%</td>
<td>3</td>
<td>6</td>
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<tr>
<td>Sea ice thickness and ship routing</td>
<td>100m</td>
<td>NRT</td>
<td>10%</td>
<td>4</td>
<td>3</td>
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<td>Application Area</td>
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<td>Required Temporal</td>
<td>Accuracy</td>
<td>SRL</td>
<td>ARL</td>
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<td>F/T: inversion modelling (methane fluxes)</td>
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<td>F/T: process studies (carbon exchange)</td>
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<td>F/T: operational hydrology</td>
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<td>ARL</td>
<td>Latency</td>
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<td>Snow density: inversion modelling (methane fluxes)</td>
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<td>50 kg/m³</td>
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<td>50 kg/m³</td>
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<td>Permafrost: (active layer dynamics) for inversion modelling (methane fluxes)</td>
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Snow Permafrost

NRT

1d

1 w

1 m

1 y

100 km 10 km 1 km 100 m 10 m 1 m

Perm afrost snow D

SWE
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</table>
NWP

- Surf. Wind
- SSS Sealce

Dimensions:
- NRT
- 1d
- 1w
- 1m
- 1y

Distances:
- 100 km
- 10 km
- 1 km
- 100 m
- 10 m
- 1 m
Conclusions and Further Work

- Large number of unique applications based on low frequency MW (most need L-band)
- Required T/S/A technologically feasible for a large number of unique applications

The outcome is two fold:
- Produce a white paper summarizing the findings. This document is a living one regularly updated and complemented. To be the basic reference document describing where L band radiometry stands.
- Build up a working group of international stature that consolidates the requirements.
- -> you are welcome to participate! send an email:

mj.escorihuela@isardSAT.cat