Synergetic Aspects and Auxiliary Data Concepts for Sea Surface Salinity Measurements from Space

AO/1-4505/03/NL/CB

An ESA study
Kicked-off 1st April 2004
Objectives of the study

The present project has two primary objectives:

1) - The first is to **develop schemes** for **processing the auxiliary data** which will be used to characterize both:
   - the **sea surface temperature** and,
   - the **roughness state**, within the SMOS-observed ocean scenes.

   These processing will be developed **in view of maximizing the quality of the Sea Surface Salinity retrievals from Level 1C brightness temperature products**.

   => At the end, the development of these processings schemes **shall serve the SMOS ground segment implementation**.

2) – The second objective is to **quantify the benefits** of the future **combined sea surface salinity measurements from SMOS and AQUARIUS/SAC-D missions**.


Activity description

Task 1: Auxiliary Data Processing schemes

Task 2: Characteristics of SMOS vs Aquarius Level-3 SSS products

Task 3: Impact of combined SMOS/Aquarius SSS data for OGCM
WP-1100: A Review on practical issues for SSS remote-sensing

Participants: UPC, ICM-CSIC, CLS

1-Review SSS Retrieval Algorithms for SMOS in terms of auxiliary data requirements (direct modeling and inversion method issues)

2-Review of the Main Constraints on auxiliary SST and Roughness data for SMOS (emissivity sensitivities, identification of the more useful auxiliary parameters, their required accuracy, the impact of SMOS spatio-temporal sampling at Level 1 C on surface State estimation with regard to its natural variability)

3-Review of SMOS Level 1C product geo-referenced prototype grid features (shall be used as a reference data collection grid for auxiliary data processings)
WP1200: Auxiliary Sea Surface Temperature Data Processing Schemes

N. Reul (IFREMER) and Meric Srokosz (SOC)
Objective

1) Identify and characterize potential auxiliary SST data for SMOS,

2) Provide definition for the adequate SST data product for SMOS,

3) Provide expected spatio-temporal lags between SSS and SST observations,

4) Analyze benefit of IR and microwave SST measurements for high-latitude cold and tropical warm ocean area,

5) Develop collection/selection SST data processing schemes for the SMOS level 1C products
Review of SST product definitions

Figure 1.1. Schematic diagram showing (a) idealised night-time vertical temperature deviations from SST_fnd and (b) idealised day-time vertical temperature deviations from SST_fnd in the upper ocean.
Identification and characteristics of auxiliary SST products

We distinguish two types of SST data:

- the "direct" spaceborne L2 SST data products:
  - From Infra-Red (IR) sensors (Polar LE orbiting and Geostationnary satellites)
  - From Microwave (MW) sensors

and,

- the so-called « consolidated » and « analyzed » SST products from the GHRSSST-PP.
SST Level 2 products from IR sensors

The following satellite sensors are considered

1) NOAA/AVHRR
2) AATSR
3) MODIS,
4) MSG and GOES.
Summary on Infra-Red SST data

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Space Coverage (latitudes range)</th>
<th>Spatial Resolution</th>
<th>Type of SST measured</th>
<th>Local Time of measurements</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA/AVHRR</td>
<td>Global (Daily)</td>
<td>1.1 km-4 km</td>
<td>SST&lt;sub&gt;skin&lt;/sub&gt;</td>
<td>02:24 pm (N-16) 10:24 pm (N-17)</td>
<td>±0.5 K</td>
</tr>
<tr>
<td>AATSR</td>
<td>Global (6 days)</td>
<td>1 km</td>
<td>SST&lt;sub&gt;skin&lt;/sub&gt;</td>
<td>10:00 am</td>
<td>±0.25 K</td>
</tr>
<tr>
<td>MODIS</td>
<td>Global</td>
<td>1 km</td>
<td>SST&lt;sub&gt;skin&lt;/sub&gt;</td>
<td>10:30 am (Terra) 1:30 pm (Aqua)</td>
<td>±0.3 K</td>
</tr>
<tr>
<td>MSG</td>
<td>Limited coverage</td>
<td>3 km</td>
<td>SST&lt;sub&gt;skin&lt;/sub&gt;</td>
<td>twice daily</td>
<td>±0.6 K</td>
</tr>
<tr>
<td>GOES</td>
<td>Limited coverage (see table 1.2)</td>
<td>6 km</td>
<td>SST&lt;sub&gt;skin&lt;/sub&gt;</td>
<td>every 3 h</td>
<td>±0.7 K</td>
</tr>
</tbody>
</table>

Table 1.3. Main features of IR SST products

To summarized, IR Sensors provide SST products with the following strengths:

- High Accuracy
- High Resolution
- Long Heritage (20 years)

but with following weaknesses:

- Obscured by Clouds
- Atmospheric Corrections Required
SST Level 2 products from MW sensors

The following satellite sensors are considered

1) AMSR-E
2) TMI

The important feature of microwave retrievals is that SST can be measured through clouds, which are nearly transparent at 10.7 and 6.9 GHz. This is a distinct advantage over the traditional infrared SST observations that require a cloud-free field of view. Ocean areas with persistent cloud coverage can now be viewed on a daily basis. Furthermore, microwave retrievals are not affected by aerosols and are insensitive to atmospheric water vapor. However, the microwave retrievals are sensitive to sea-surface roughness, while the infrared retrievals are not. A primary function of the TRMM SST and Aqua AMSR-E SST retrieval algorithm is the removal of surface roughness effects.
- **Summary on microwave SST data**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>TMI</th>
<th>AMSR-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Coverage (latitudes range)</td>
<td>40° S to 40° N</td>
<td>89.24°N and 89.24°S</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>0.25 deg (~25 km)</td>
<td>0.25 deg (~25 km)</td>
</tr>
<tr>
<td>Type of SST measured</td>
<td>SST\textsubscript{subskin}</td>
<td>SST\textsubscript{subskin}</td>
</tr>
<tr>
<td>Local Time of measurements</td>
<td>changing local times</td>
<td>1h30 ±15mn p.m (asc) or 1h30±15mn a.m (desc)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.52°C rms</td>
<td>0.6°C rms</td>
</tr>
<tr>
<td>Data provider</td>
<td>REMSS</td>
<td>REMSS</td>
</tr>
<tr>
<td>Data transport</td>
<td>ftp from REMSS (ftp.ssmi.com)</td>
<td>ftp from REMSS (ftp.ssmi.com)</td>
</tr>
<tr>
<td>Missing data causes</td>
<td>high wind speed (&gt; 17 m/s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>coastal regions (&lt; 100 km from coastlines)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sun-glitter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>land</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sea ice</td>
<td></td>
</tr>
</tbody>
</table>

To summarized, microwave Sensors provide SST products with the following strengths:

- Clouds Transparent
- Relatively Inensitive to Atmospheric Effects

but compared to IR products, they exhibit the following weaknesses:

- Sensitive to Surface Roughness,
- Poorer Accuracy
- Poorer Resolution
“Consolidated” and “ ANALYZED” SST products

The second main type of data considered as potentially adapted SST products for SMOS are the consolidated and analyzed global SST products, such as the one that will be generated by the GHRSSST-PP (see GHRSSST-PP report, Donlon, C.J. et al, 2003). The emphasis of the project is to use complementary satellite Level 2 satellite SST (IR and microwave) and in situ data products together to deliver a new generation of SST data products. Satellite data from the sensors previously listed shall thus be used as input to the GHRSSST-PP processing software (see GDS-v1.0-rev1.5). Complementarily, moored buoy, drifting buoy and ship SST observations obtained from the CORIOLIS and several identified data center data shall be also used as in situ input to the processing.

Note that the GHRSSST-PP products shall be delivered operationally by identified GDAC on a global scale in 2007, so that they should be available during SMOS mission, if funded.
Skin, subskin or bulk SST products for SMOS?

Figure 1.37. Schematic of the diurnal SST cycle.
In order to study the effects of diurnal heating, we have adapted the OCCAM experiments used in Drange et al. (1999) and Boutin et al. (2002). Data from the OCCAM model were used previously to investigate the effects of different averaging regimes and noise to the potential retrieval accuracy of the SMOS sensor.

The SSS retrieval accuracy was estimated using the brightness temperature model by Yueh (1997) applied to OCCAM sea surface salinity (SSS) and temperature (SST) fields. Hence, L-band brightness temperatures were first forward-modelled using the OCCAM temperature and salinity, as a function of wind speed and direction, then SSS was retrieved from the brightness temperatures and the OCCAM SST and wind, all modified by random noise.

A range of experiments were carried out to investigate:

- possible errors introduced by using ‘bulk’ or foundation temperature values, rather than sub-skin temperatures, when calculating the SSS at the nominal SMOS overpass-times of 6am and 6pm.
- possible errors introduced by using sub-skin temperatures obtained before, or after, the time of the SMOS retrieval for the inversion.

The experiments were carried out for retrievals at two incidence angles (0° and 5°), at vertical (Tv) and horizontal (Th) polarisations separately, and for the combined Tv and Th (denoted TvTh) and for the 1st Stokes parameter (denoted 1Stk).

The sub-skin diurnal heating effect ($\Delta T$) has been estimated from the time of day in hours ($t$), wind-speed in m s$^{-1}$ ($u$) and insolation in W m$^{-2}$ ($Q$) using the formula of Gentemann et al. (2003):

$$ \Delta T = a \cdot f(t) \left[ (Q - Q_0) - b(Q - Q_0)^2 \right] e^{-0.1u} $$

(1.2)
Recommendations

- Whenever possible coincident SST data should be used, from any available source, reduced to a sub-skin or foundation temperature.

- Where coincident data are not available, the satellite SST data used for salinity retrievals are limited to nighttime values. The closest nighttime value should be used, i.e. the preceding night for 6am or following night for 6pm, but if this is not possible then the following nighttime value (for 6am) or preceding nighttime value (for 6pm) is preferable to a temporally closer daytime value, i.e. a time separation of 18 hours is preferable to using a daytime temperature with a time separation of 6 hours.

- if the GHRSS-PP level 4 products are to be used for the SST fields, then the diurnal variation field in the product could be used as an indicator of the expected quality of the daytime SST field if no other alternative were available.
Spatio-temporal lags between SMOS and auxiliary SST products

SMOS Level 1C products space-time features

Following recommendations from the study on Level 1 product processing (see RD SMOS-DMS-TN-5200), we have implemented an ISEA (Icosahedron Snyder Equal Area) hexagonal grid of aperture 4 and resolution 9 to simulate the Level 1C SMOS brightness temperature data sampling grid.

*Figure 1.18. Illustration of ISEA4H9 level 1C grid space sampling. Left: SMOS field of view in Bay of Biscay. Right: zoom on the Level1C ISEA4H9 grid.*

mean distance between nodes of 15.072 km
Figure 1.19. Local time of data acquisition for the future SMOS satellite. The couple of acquisition is 06:00/18:00 LT (ascending/descending) and is in the range of latitudes between 40°S-40°N. For higher latitudes between 40° and 70°N, the observation is at 05:00 and 19:00 LT for this orbit.

As shown in Fig. (1.19), the local time for SMOS data acquisition will depend on the latitude belt. Two distinct latitude belts should be considered for analysis: between 40°S and 40°N where the morning and evening local time for observation are approximately identical (e.g., 06:00-18:00 ±1/2 hour), and between 46° and 90°N (and S), where the ascending and descending local time are nonsymmetric (e.g., 06:00-24:00).
Therefore, when co-locating SMOS data with auxiliary SST data from other wide-swath sensors (e.g. AMSR-E, TMI, AVHRR, MSG, etc), it is expected to observe significant variations of the local time difference between SST data and the same Level 1C product, even in mid-latitude seas.
Simulations

Selection of 5 representative ocean zones

Figure 1.17. Geographical Zones Selected for auxiliary SST-data analysis
The methodology used to determine the space-time lags between SMOS Level 1C data and the four previously described key auxiliary SST data sets was the following:

1. SMOS orbit propagator was ran for a complete orbit cycle (about 22.9 days) for one selected month when cloud coverage is one of the densest of the year on north atlantic (January 2007).

2. for this period, the latitude/longitude coordinates of the borders of each FOV was determined along orbit, with a sampling rate of about 20 minutes to simulate (approximately) the time required to generate Level1 C data. At such sampling rate, there is no gap in SMOS swath spatial coverage along the orbit earth track (see left plot in figure 1.21).

3. each time a FOV border intercept the selected geographical zones, UTC time of SMOS passage was stored and the latitude/longitude coordinates on the ISEA4H9 grid of each points intercepting the FOV and the geographical zone, were calculated (see right plot in figure 1.21), and stored. For instance, calculations in Bay of Biscay zone for the SMOS orbit cycle during the month of January yields to 199 FOVs intercepting the area (the average number of pixels within each FOV is about 5000).

4. Once the previous steps of computation were realized, a FOV by FOV analysis was performed to compute space and time distances between given sets of auxiliary data and the stored space-time SMOS parameter. Auxiliary SST Data availability was also determined.
Processing windows: ~15 km from a SMOS pixel and ±12 h from SMOS time of acquisition

First case: Auxiliary SST data with coarser resolution than SMOS

Output from processing: $\Delta x$, $\Delta t$, and availability
Second case: Auxiliary SST data with finer resolution than SMOS

Output from processing: $\Delta t$, availability and if available: number of SST data/pixel SMOS
Example 1: AMSR-E/SMOS

Figure 1.30. Space lag distribution between L1C SMOS data and AMSR-E data. East Mediterranean Sea (left plot) and Equatorial ocean zone (right plot).
Figure 1.31. Time lag distribution between L1C SMOS data and AMSR-E data. Norway Sea (left plot) and Bay of Biscay (right plot).

Coincidence: very rare!
Example 2:

GOES-MSG/SMOS
IR sensors will not always provide SST products for SMOS. Data availability is particularly critical in high-latitude ocean area due mainly to cloud coverage.

Coincident IR data shall be rare except in cloud free conditions from geostationary sensors. However, for average available IR data, nighttime estimates of the SST can very often be estimated.

A spatial averaging processing is required for IR data as several values can be affected to a single SMOS level 1C pixel.
Microwave SST products are much more often available, especially in high-latitude seas and are likely candidates to characterize SST for SMOS in mid and high-latitudes seas.

Main drawback is poorer accuracy then IR data, wind-dependence and inability to probe the coastal zones.

Coincident microwave data with SMOS products shall be as well rare but nighttime estimates of the SST can very often be provided.

Results MW data

<table>
<thead>
<tr>
<th>Zone</th>
<th>Data Availability</th>
<th>Time lags $\tau$ [hours]</th>
<th>space lags [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway Sea</td>
<td>70.1%</td>
<td>(-7,-2)</td>
<td>8 ± 0.4</td>
</tr>
<tr>
<td>Bay of Biscay</td>
<td>88 %</td>
<td>(-6,-3,+7)</td>
<td>8.8 ± 0.4</td>
</tr>
<tr>
<td>Canarian Area</td>
<td>86.4%</td>
<td>(-5,+8)</td>
<td>8.6 ± 0.2</td>
</tr>
<tr>
<td>East Mediterranean</td>
<td>64.1%</td>
<td>(-5,+7)</td>
<td>9.7 ± 0.3</td>
</tr>
<tr>
<td>Equatorial Area</td>
<td>93.5%</td>
<td>(-5,-4,+7)</td>
<td>11 ± 0.03</td>
</tr>
</tbody>
</table>

Table 1.12. Statistics for AMSR-E/SMOS co-localisation features. Hours in bold face indicate main peak of distributions. Secondary peaks are indicated as well.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Data Availability</th>
<th>Time lags $\tau$ [hours]</th>
<th>space lags [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway Sea</td>
<td>0 %</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bay of Biscay</td>
<td>0.2%</td>
<td>(-6,+4)</td>
<td>8.8 ± 0.4</td>
</tr>
<tr>
<td>Canarian Area</td>
<td>81.2%</td>
<td>(-7,+4,+5)</td>
<td>8.6 ± 0.2</td>
</tr>
<tr>
<td>East Mediterranean</td>
<td>60.2%</td>
<td>(-4,+7)</td>
<td>9.7 ± 0.3</td>
</tr>
<tr>
<td>Equatorial Area</td>
<td>75.45%</td>
<td>(-8,+4)</td>
<td>11 ± 0.03</td>
</tr>
</tbody>
</table>

Table 1.13. Statistics for TMI/SMOS co-localisation features. Hours in bold face indicate main peak of distributions. Secondary peaks are indicated as well.
SST Auxiliary Data Processing schemes for SMOS (SST-ADPS)

Requirements:

- Whenever possible coincident SST data should be used, from any available source, reduced to a sub-skin or foundation temperature.

- Where coincident data are not available, the satellite SST data used for salinity retrievals are limited to nighttime values. The closest nighttime value should be used, i.e. the preceding night for 6am or following night for 6pm, but if this is not possible then the following nighttime value (for 6am) or preceding nighttime value (for 6pm) is preferable to a temporally closer daytime value, i.e. a time separation of 18 hours is preferable to using a daytime temperature with a time separation of 6 hours.

- If the GHRsst-PP level 4 products are to be used for the SST fields, then the diurnal variation field in the product could be used as an indicator of the expected quality of the daytime SST field if no other alternative were available.

The SST-ADPS that is proposed here is based on consolidated satellite SST products as well as analyzed SST data, namely the so-called L2P and L4 SST products that shall be delivered globally by the GHRsst-PP, since:

⇒ L2P data products will provide the highest quality data obtained from a single sensor for a given SMOS L1C processing window,

⇒ the analyzed foundation SST L4 products which will be delivered daily with a grid resolution of 1/12 results from a merging and statistical are free of diurnal warming effects and the products shall be always available for SMOS L1C.
The SST-ADPS data processing flow is designed to:

(a) Ingest and define input SST data sets.

(b) Collocate L2P and L4 data records with SMOS level1C measurements.

(c) Provide tests for L2P data availability.

(d) Assign L4 SST data in case of non availability of L2P data.

(e) In case of L2P data availability, extract the best IR and MW product as function of SMOS local time (mainly around 6 am or 6 pm).

(f) Select best SST product from best Spaceborne SST product and best analyzed product.

(g) Consolidate the choice by comparison of the output SST product with the one used for previous SMOS measurement on the same pixel.

(h) For each output SST data, provide a temporal coincidence test. If required, diurnal variation correction might be applied. But a non corrected product shall as well be kept as output.

Figure 1.36. General overview of the SST auxiliary data processing for SMOS (SST-ADPS). Input data sources and output parameters are shown in color, processing steps with a further breakdown are indicated as well.
1-Auxiliary roughness data Identification

Four types of auxiliary roughness parameters were considered as inputs to the processings:

- **Wind speed vector** $\mathbf{U}$, from numerical models and satellite sensors
- **Significant wave height** $H_s$, from models and altimeters
- **Mean wave period** $T_p$, and, from models and altimeters
- **Available NRCS** $\sigma_o$ and **Brightness temperature** $T_b$ data
  (Aquarius, Metop/Ascat, SSM/I, WindSat...)

The first part of the study focused on the identification on the potential sea-surface roughness parameters from satellite-based measurements. Scatterometers, radiometers, altimeters data can be used to this purpose. At resolution comparable to SMOS pixel size, the wind speed vector can be provided with a 2 m/s precision in amplitude and 20° in direction. Significant wave height and peak wave period $T_p$ can be obtained with a 50 cm and 20% precision, respectively.
1-Auxiliary roughness data Identification

2 types of data sources were considered:

**Satellite Data** (e.g. QuickSCAT wind speed)

**Numerical Weather Center products**
2-Co-location analysis

Figure 16: Left: Example of SMOS L1c data (blue dots) together with QUIKSCAT gridded data (red dots). Right: Zoom.
Time and Space scales of wind & wave variability

(e.g. see Tournadre, JGR, 1993)

Study of temporal and spatial variability of Hs (in situ + Geosat altimeter data) for 2 regions:
- North Sea (Frigg), and,
- Equatorial Atlantic (Palanca).

Mean Duration and length of stationarity for Hs signals are twice as large for the Equatorial Atlantic as for the North Sea:

<table>
<thead>
<tr>
<th>Ocean region</th>
<th>Duration of stationnarity</th>
<th>Length of homogeneity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equatorial areas:</td>
<td>7 hours, 20 min</td>
<td>189 km</td>
</tr>
<tr>
<td>High and Mid latitudes:</td>
<td>2 hours, 50 mn</td>
<td>63 km</td>
</tr>
</tbody>
</table>

Average Hs value over the globe oceans: <Hs>~2m => old and young swells!
2-Co-location results

Requirement for auxiliary wind and wave data collection is to find data within a processing window of <50 km and <3 hours from SMOS data.

<table>
<thead>
<tr>
<th>Sources</th>
<th>&lt; 25 km and &lt; 1 hour [%]</th>
<th>&lt; 25 km and &lt; 3 hours [%]</th>
<th>&lt; 50 km and &lt; 3 hours [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMWF</td>
<td>20.1</td>
<td>63.5</td>
<td>100</td>
</tr>
<tr>
<td>TOPEX</td>
<td>0</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>SSMI</td>
<td>0</td>
<td>1.5</td>
<td>1.9</td>
</tr>
<tr>
<td>QUIKSCAT</td>
<td>48.0</td>
<td>48.0</td>
<td>50.8</td>
</tr>
</tbody>
</table>

Table 20: Summary of SMOS collocation with ECMWF, TOPEX, SSMI and QUIKSCAT at the equatorial region.

<table>
<thead>
<tr>
<th>Sources</th>
<th>&lt; 25 km and &lt; 1 hour [%]</th>
<th>&lt; 25 km and &lt; 3 hours [%]</th>
<th>&lt; 50 km and &lt; 3 hours [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMWF</td>
<td>29.4</td>
<td>85.0</td>
<td>100</td>
</tr>
<tr>
<td>TOPEX</td>
<td>0.6</td>
<td>1.8</td>
<td>3.6</td>
</tr>
<tr>
<td>SSMI</td>
<td>2.9</td>
<td>22.2</td>
<td>24.2</td>
</tr>
<tr>
<td>QUIKSCAT</td>
<td>25.6</td>
<td>30.5</td>
<td>33.3</td>
</tr>
</tbody>
</table>

Table 21: Summary of SMOS collocation with ECMWF, TOPEX, SSMI and QUIKSCAT at 60° North latitude.

ECMWF products shall serve as the base wind speed auxiliary data.
Currently expanding the analysis to Metop/Ascat
Using satellite data when available and when not: numerical weather center products

<table>
<thead>
<tr>
<th>Latitude range [deg]</th>
<th>&lt; 25 km and &lt; 1 hour [%]</th>
<th>&lt; 25 km and &lt; 3 hours [%]</th>
<th>&lt; 50 km and &lt; 1 hour [%]</th>
<th>&lt; 50 km and &lt; 3 hours [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>58.6</td>
<td>81.0</td>
<td>65.7</td>
<td>100</td>
</tr>
<tr>
<td>10-12</td>
<td>61.8</td>
<td>82.2</td>
<td>70.5</td>
<td>100</td>
</tr>
<tr>
<td>20-22</td>
<td>62.7</td>
<td>82.7</td>
<td>69.7</td>
<td>100</td>
</tr>
<tr>
<td>30-32</td>
<td>58.8</td>
<td>84.4</td>
<td>67.2</td>
<td>100</td>
</tr>
<tr>
<td>40-42</td>
<td>57.0</td>
<td>87.1</td>
<td>63.9</td>
<td>100</td>
</tr>
<tr>
<td>50-52</td>
<td>54.2</td>
<td>88.8</td>
<td>60.0</td>
<td>100</td>
</tr>
<tr>
<td>60-62</td>
<td>43.4</td>
<td>88.8</td>
<td>48.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 22: Percentage of SMOS L1e data with joint QUIKSCAT and ECMWF data sets fitting the 25 or 50 km spatial distance constraint at less than 1 or 3 hours of the SMOS measurement.
3-Blending stage

=>While ECMWF products are well suited in terms of space/time sampling, they have a strong drawback:

HF variability is inexistant:
The main problem:

- the relatively low spatial resolution of the 6-hourly ECMWF or NCEP winds impacts the quality of the simulated sea-state.

- Compared to satellite winds:
  
  Small spatial scale (< 500 km) Variability is missing in ECMWF wind

  E.g. Quickscatt winds
  Vs ECMWF winds

Figure: Power spectra of spatial wind data from ECMWF, NCEP and Quickscatt
From Pinardy and Millif (MFSTEP report 2004).
V.2.1 Blending method

Satellite sensors will provide high-wavenumber, but temporally intermittent data. For example, QUIKSCAT revolution takes 101 min and covers a 1800 km wide swath at 25 km resolution. The ECMWF/NCEP fields are ubiquitous, but low-wavenumber: each global field is available every 6 hours on a T62 Gaussian grid (1.8° grid), but the true spatial resolution is coarser than T62. Considering a given SMOS Level 1c prototype grid cell, the blending scheme creates global fields at a maximized spatio-temporal resolution by retaining several sensor wind retrievals in swath regions, and by augmenting in the unsampled regions the low-wavenumber ECMWF and/or NCEP fields with a high-wavenumber component that is based on regional statistics. These statistics may be derived from 4°x4° bin averages and preserve the observed power-law relation between wind product power-spectral densities.

The blending shall create global fields of surface winds by retaining wind retrievals in swath regions, and in the unsampled regions (between swaths and in data gaps) augmenting the low-wavenumber NCEP fields with a high-wavenumber component that obeys observed power law relations:

\[ \text{PSD} \sim k^p, \]

where PSD is the power-spectral density, k the wavenumber, and the exponent p characterizes the power-law behaviour. For instance, QUIKSCAT data show that p takes values between -2 at high latitudes and -5/3 at the equator.

This shall improve our understanding of the average dependence of Tb with roughness.
4-Annotation stage

⇒Roughness impact is not only wind-dependent:
⇒Effects of swell and wave aging (inverse wave age=U/Cp)
⇒Idea is to annotate wind products collected with Wave prediction model
Parameters to perform further corrections: Hs, Tp⇒Cp (linear dispersion relationship)

Figure 23: Effective wind processing example. Only H-polarization ΔTb signals are used here for illustration.
Skeleton of the auxiliary roughness data processing