Microrad 2008, Firenze, 11-14 March 2008

The SMOS ocean salinity retrieval algorithm

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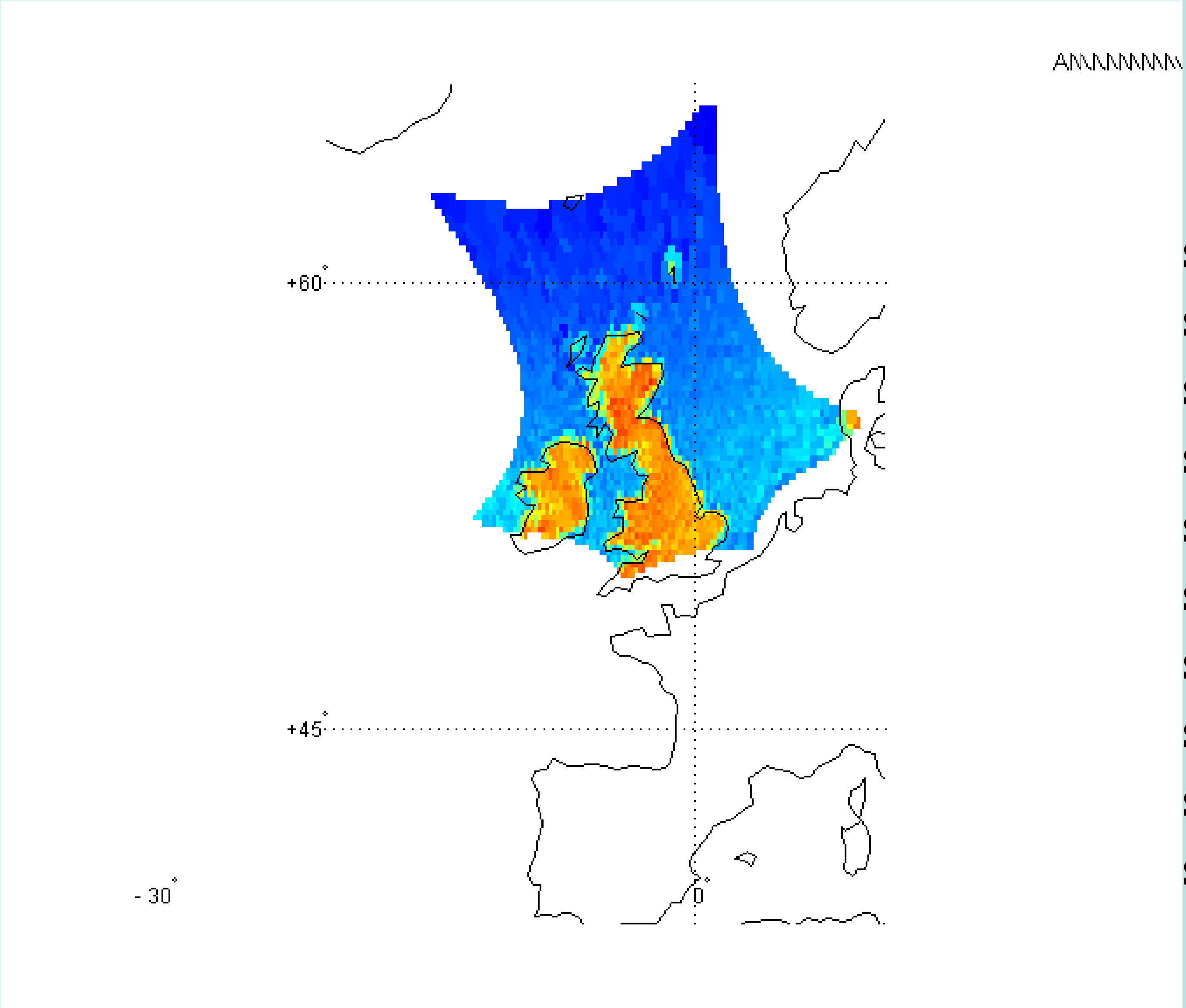
SMOS Ocean Salinity Level 2 Algorithm

Objective: to retrieve sea surface salinity along a SMOS half-orbit from brightness temperature (Level 1c product)

- Development funded by ESA (2005-2008)
- Algorithms proposed and tested by a team of Expert Support Laboratories:
    - Institut de Ciències del Mar, Barcelona
    - Laboratoire d'Océanographie et du Climat: Expérimentation et Approches Numériques, Paris
    - Institut Français de Recherche pour l'Exploitation de la Mer, Brest
- Prototype processor developed by ACRI-ST (France)
- Operational processor implemented by GMV (Spain)

SMOS 2-D Field of view (1 FOV / 10) (F. Petitcolin, ACRI-st)



SEPSv3 simulations

S90	216s
S80	192s
S70	168s
S60	144s
S50	120s
S40	96s
S30	72s
S20	48s
S10	24s
S1	T0

Satellite pass: 06 & 18 h local time (Equator)

SMOS multi-look capability

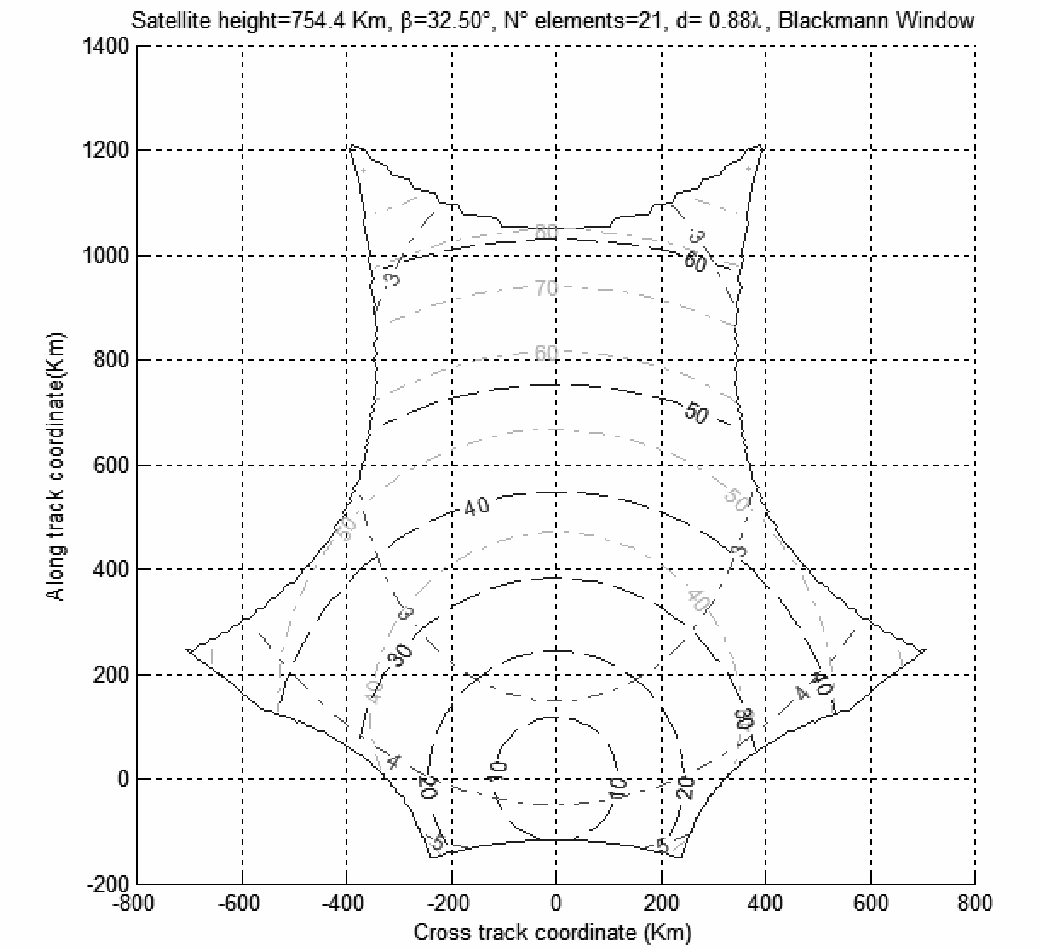
- A single spot in the ocean is observed in consecutive snapshots, alternatively horizontal and vertical polarisations (dual/pol mode)

- Variable number of observations depending on its distance to satellite sub-track (maximum 78 horizontal + 78 vertical)

- Many measurements of Tb corresponding to a single SSS under different incidence angle ➔ overdetermination

- The overdetermination can be used during the inversion process to retrieve different parameters that influence Tb

Measurements variability within FOV



Multi-angular and spatially variable nature of the measurements:

• incidence angle (dashed lines) ranges from 0 to 65º

• spatial resolution (dash-dotted lines) from 32 to 100 km

• radiometric sensitivity (dash-dotted) from 1.8 K at boresight to 5 K.

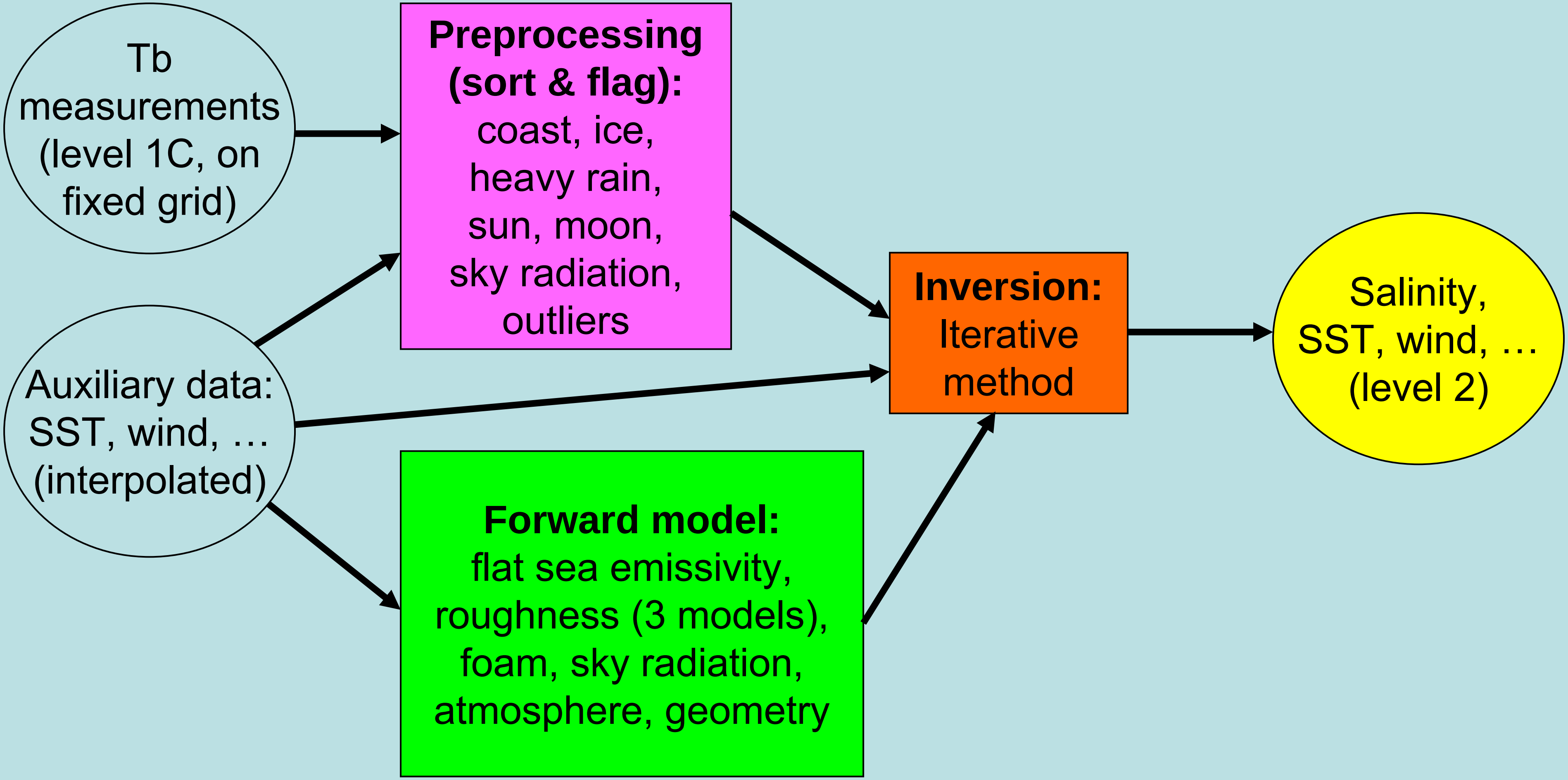
• data interpolated into an ISEA grid (approx. 15 km spacing)

Figure generated by the SMOS End-to-end Performance Simulator (UPC, 2004)

SMOS SSS retrieval approach

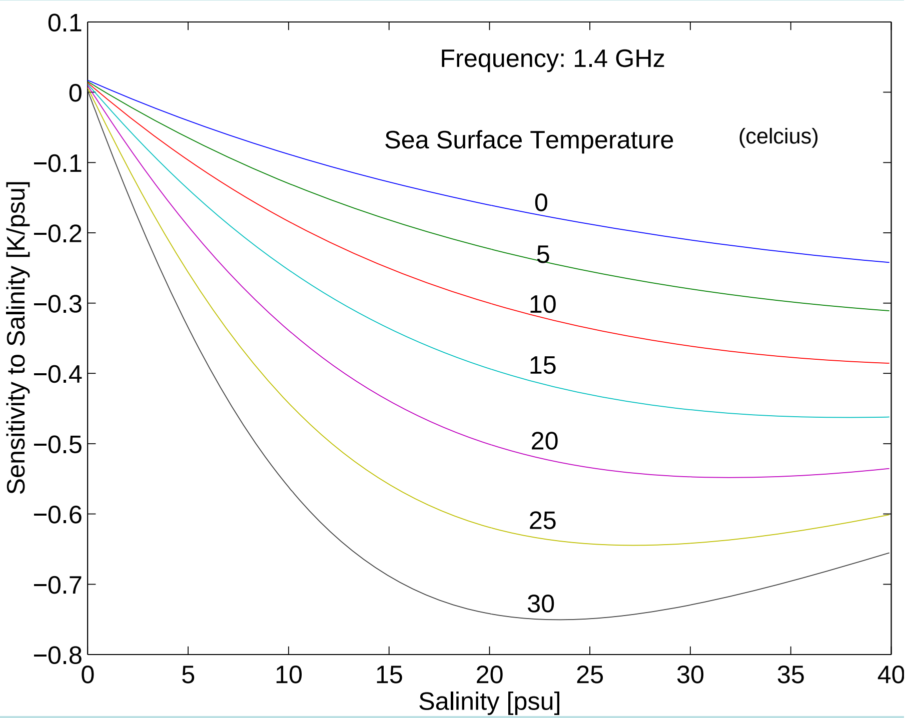
- To model the polarised L-band emission of the ocean surface using a guessed SSS value
- Auxiliary data needed to describe the environmental conditions
- Compare modelled Tb with SMOS measurements for all available angles
- Reach the best fit through iterative modifications of guessed values

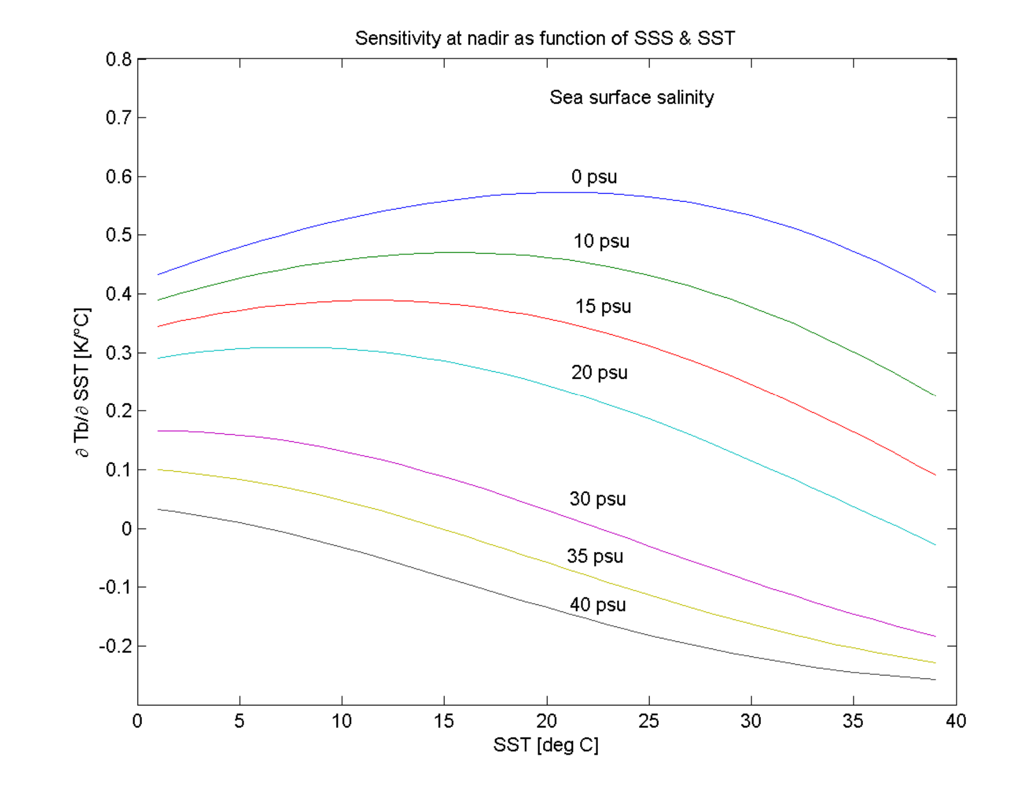
The SMOS Salinity Prototype Processor



Sea surface emission at L-band

At 0° incidence and flat sea



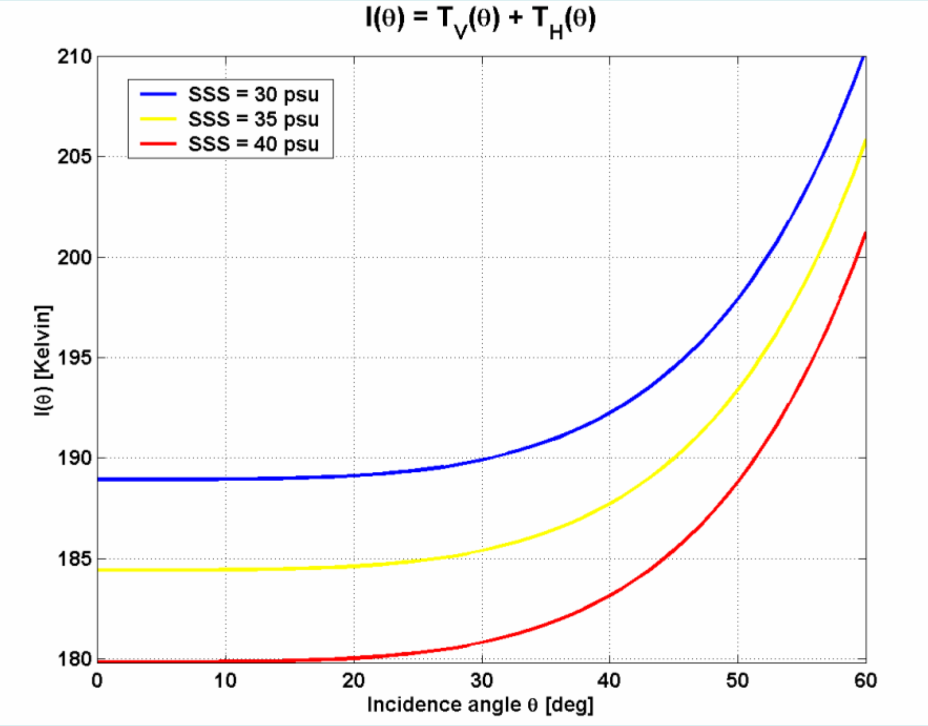


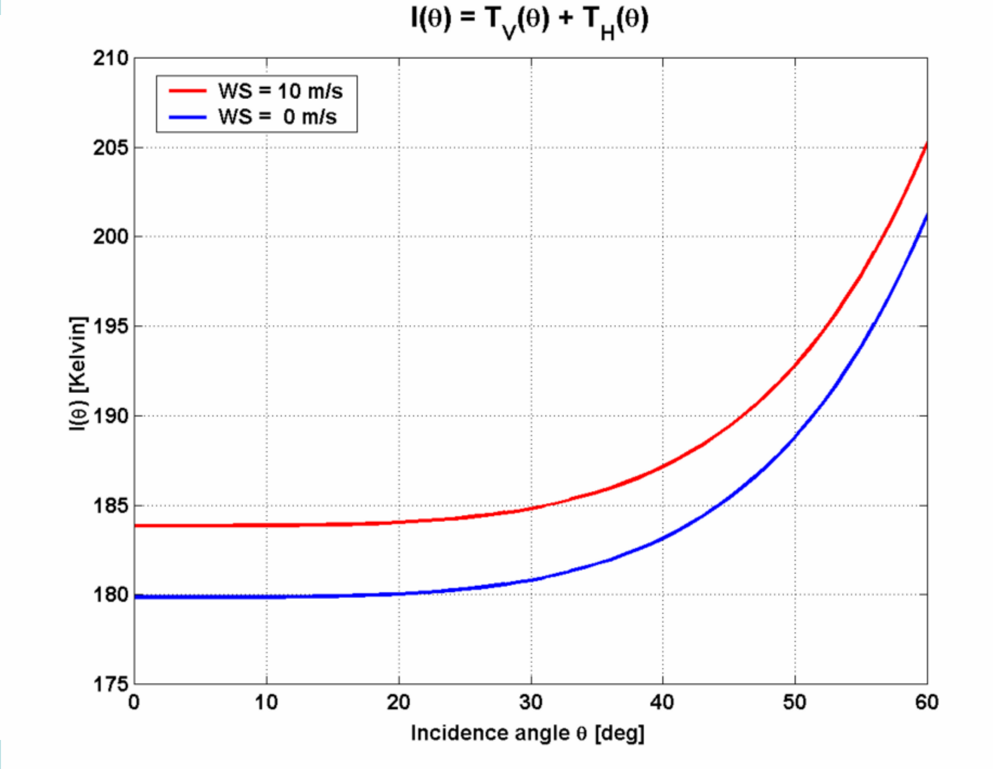
Sensitivity of T_b to S over a smooth surface is **0.2 to 0.8 K/psu** depending on ocean temperature, incidence angle and polarization

SSS retrieval more difficult at high latitudes

Emitting surface geometry

Influence of incidence angle and surface roughness on emissivity





at 0 wind

at 40 psu (Camps et al., 2001)

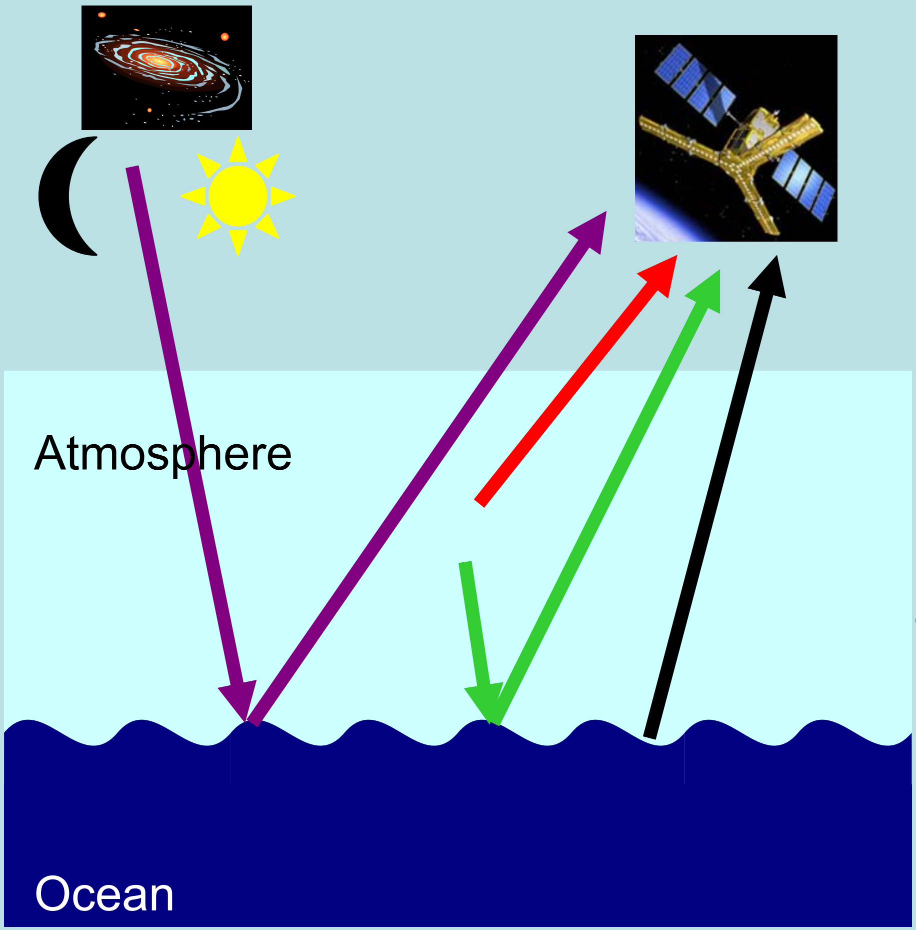
$\Rightarrow$ effect of 5 psu ~ 10 m/s

Observation geometry to be carefully controled

The sea surface L-band emission

- Polarised emission quite well modelled for a flat sea at L-band (dielectric constant + geometric optics)
- Roughness effects, the main issue (surface geometry)
- T_b,p = T_b,p *flat* (θ, SST, SSS) + ΔT_b,p *rough* (θ, Φ, wind waves, swell, other wave characteristics, foam coverage, foam emissivity, rain)
- Consider L-band emission from other sources that reach the radiometer
- Modification of emitted radiation along its path to the antenna

Modular Forward Model



- **Sea surface emissivity models**
  - **Dielectric constant** of sea water (Klein and Swift, 1977)
  - 3 **roughness** models

    Model 1: Dinnat et al., 2002 (2-scale, Durden and Vesecky spectrum×2)

    Model 2: Johnson and Zhang, 1999 (SSA, Kudryavtsev spectrum)

    Model 3: Gabarró et al., 2004 (empirical)
  - **Foam** (Reul and Chapron, 2003)
- **Other contributions**
  - **Atmosphere**

    Tropospheric (from Liebe, 1993)

    Faraday rotation (Waldteufel et al, 2004)
  - **Sky radiation** (reflected / scattered), **sun glint** (Reul et al., 2007)

Surface roughness effects

Three different roughness model options:

-Two theoretical models (Two-scale, small slope approximation): statistical description of the sea surface + asymptotic solution for electromagnetic scattering

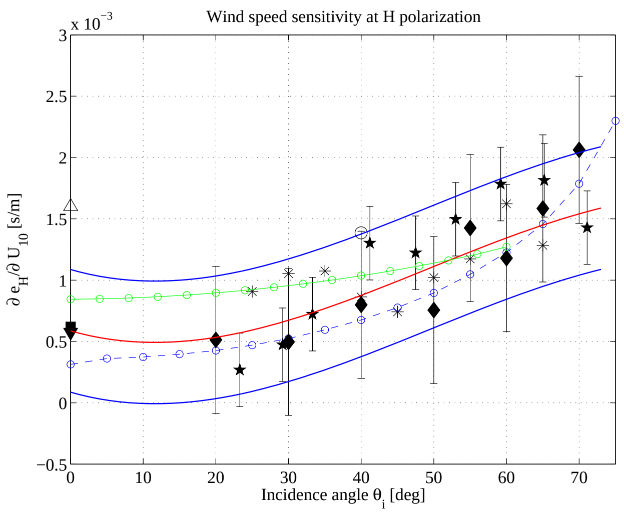
- A semi-empirical formulation derived from the WISE campaign data set. measured polarized Tb fitted to different combinations of available roughness descriptors

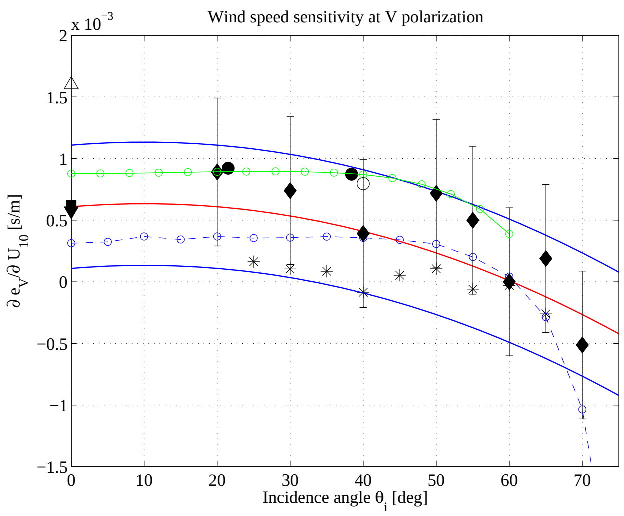
Additional specific model to account for the effect of foam on the sea surface emissivity (thickness and coverage)

During SMOS commissioning phase (and beyond, if necessary) the different options, and suboptions, will be tested until identifying the best one. This may not be the same for different ocean regions or seasonal conditions

Surface roughness effects

Sensitivity of L-band sea surface emissivity to wind speed as function of incidence angle. Over measured Th and Tv data we plot predictions from SSA (blue) and two-scale (green) models at SST=15°C and SSS=35 psu. The red curve shows a best-fit through the observations.





It appears that all available data is not enough to discriminate the best adapted correction between these three models of the roughness impact.

Galactic noise correction

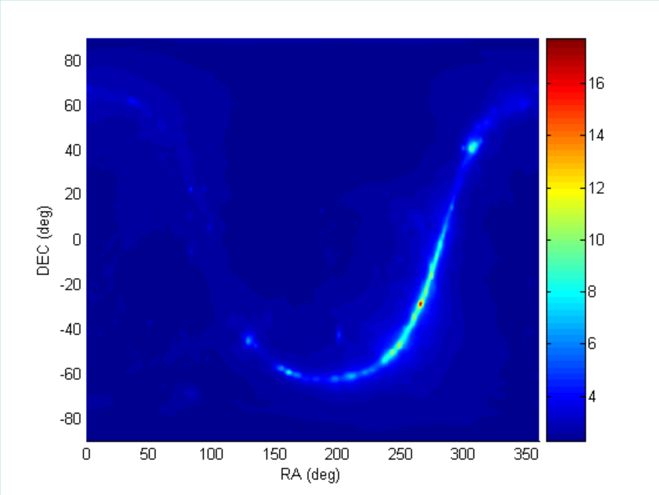
Three models are implemented in the L2 OS processor:

- GN0 model: constant incidence galactic noise of 3.7 K multiplied by specular reflection coefficients

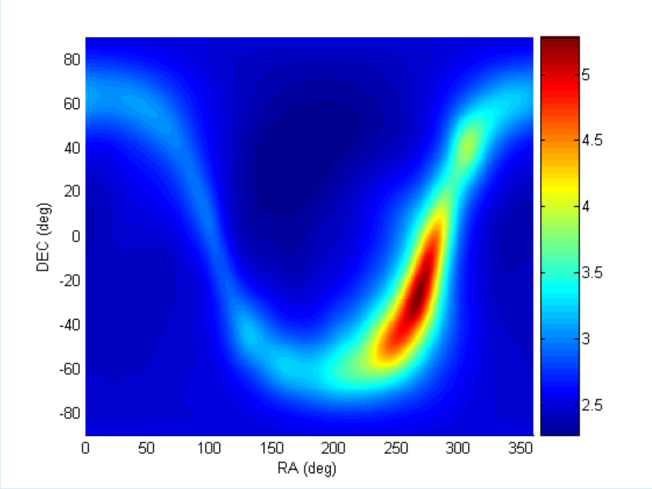
- GN1 model: incidence galactic noise obtained from Reich & Reich map convoluted by the mean WEF and multiplied by specular reflection coefficients

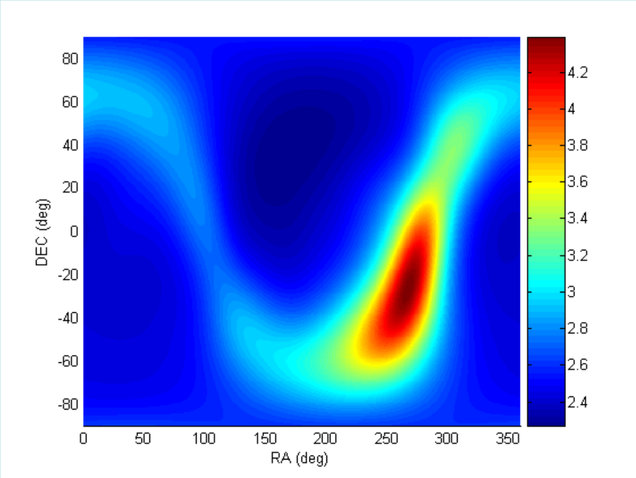
- GN2 model: reflected galactic noise obtained from Reich & Reich map convoluted by bistatic coefficients according to the measurement geometry and the wind speed

Galactic noise correction



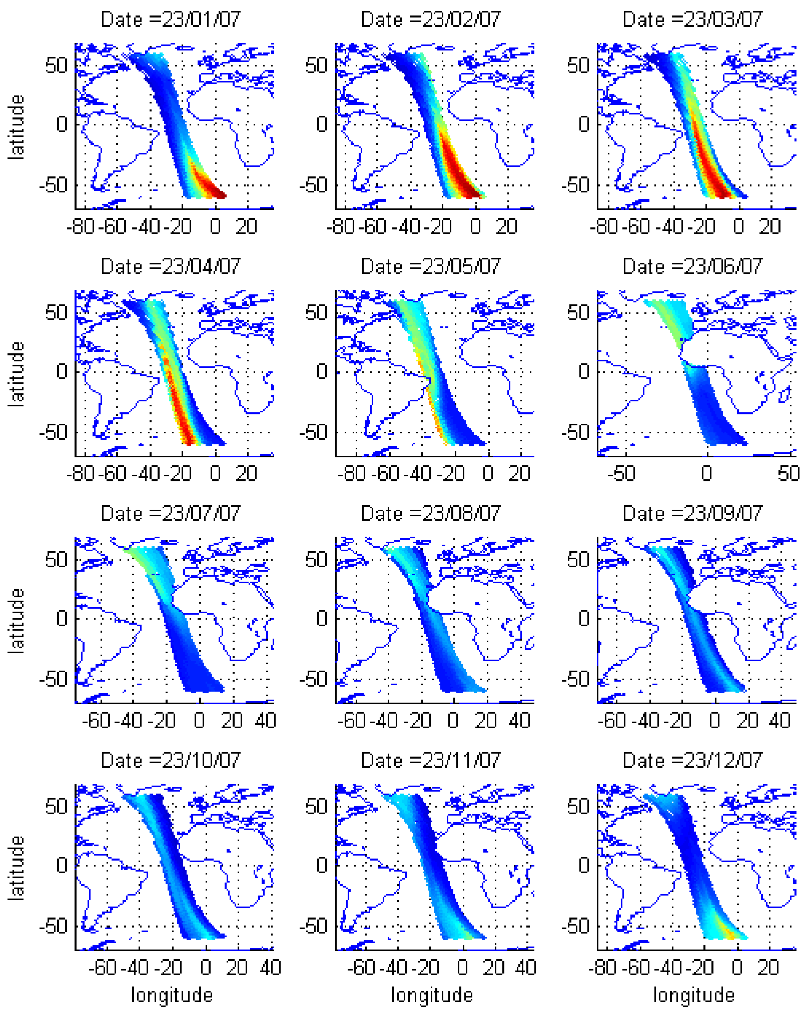
Galactic Noise model 1

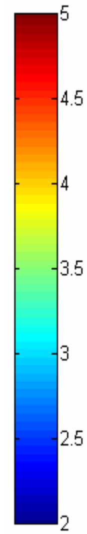


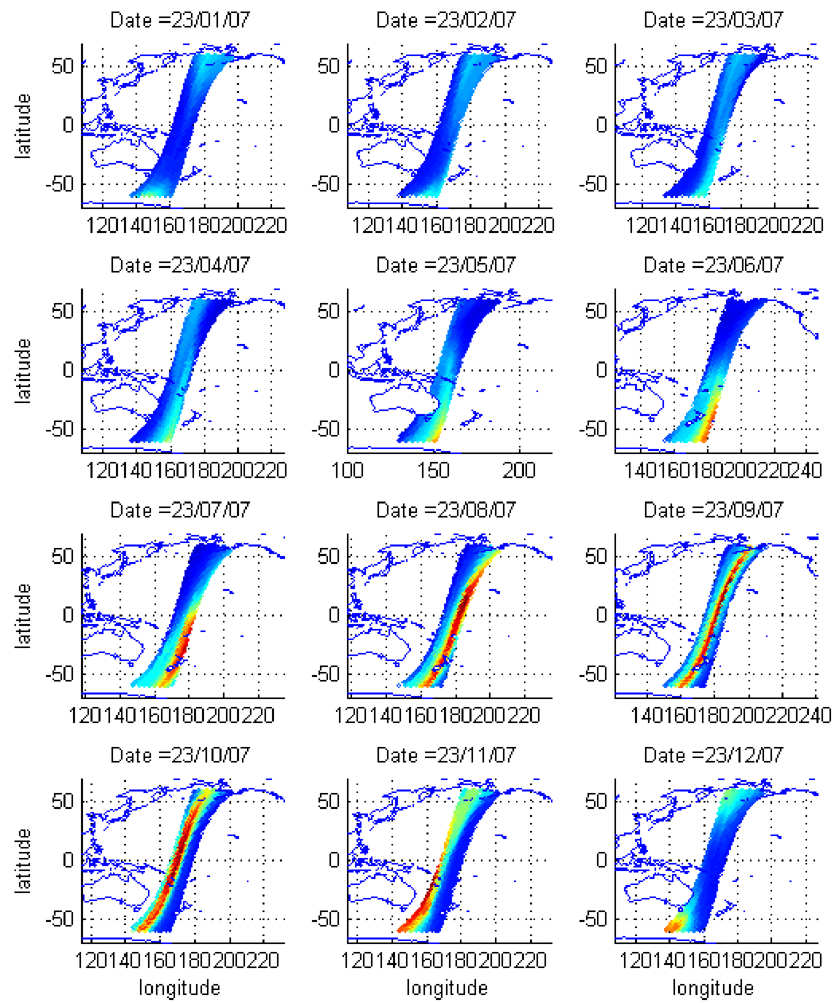


Galactic Noise model 2 with WS = 3 and 10 m/s, at 0º

Galactic noise correction



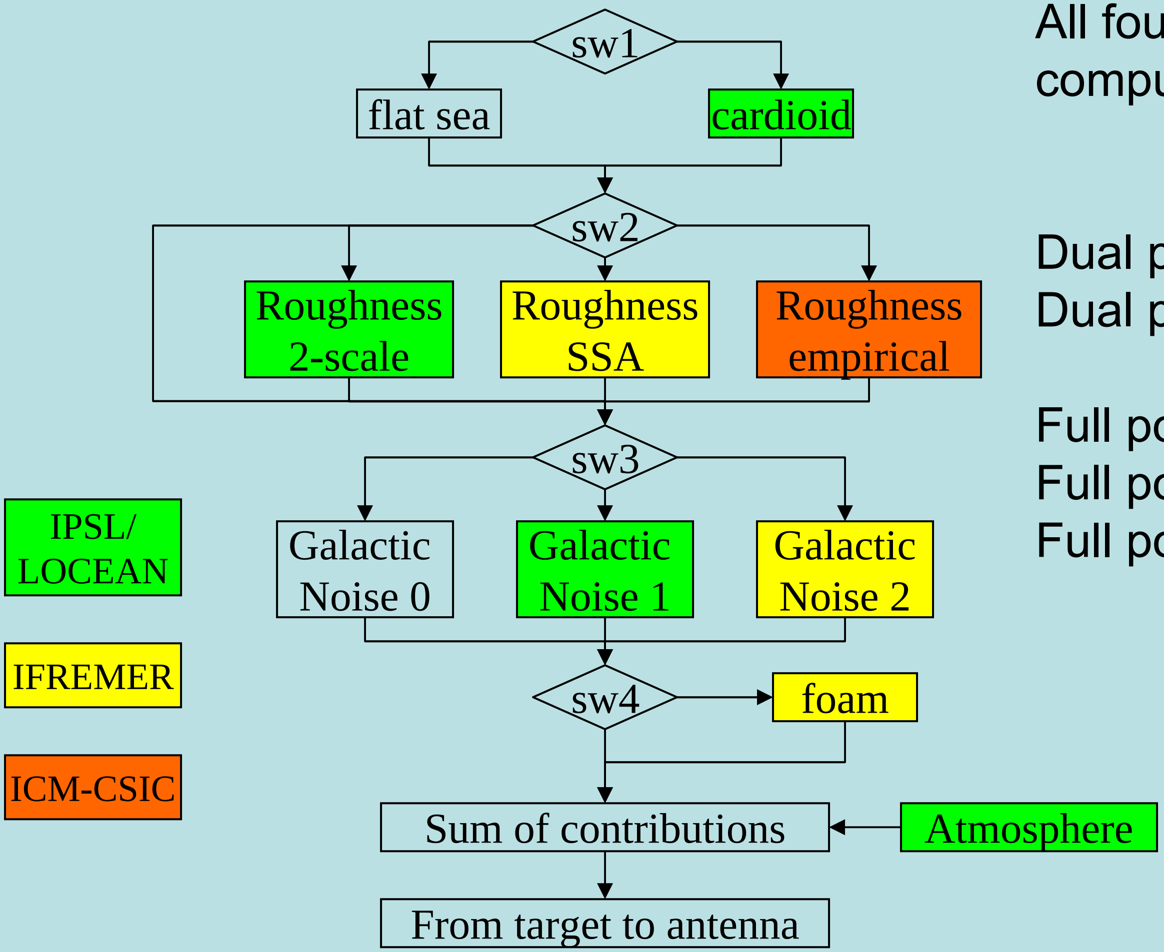




Ascending orbits

Descending orbits

Full forward model



All four Stokes parameters computed

Dual pol. => Tx / Ty
Dual pol. => pseudo Stokes 1

Full pol. => Tx / Ty / St3 / St4
Full pol. => Tx / Ty
Full pol. => pseudo Stokes 1

Iterative retrieval algorithm

Cost Function to be minimized:

$$\chi^2 = \sum_{i=1}^{N} \left[\frac{Tb_i^{meas} - Tb_i^{\mathrm{mod}}}{\sigma_i} \right]^2 + \sum_{k=1}^{K} \left[\frac{P_k - P_{k0}}{\sigma_k} \right]^2$$

Tb^{meas}: Tb measured
Tb^{mod}: Tb from a direct forward model
} in the antenna reference frame

N: number of Tb observations

P: geophysical parameters driving Tb variations (depend on forward model)

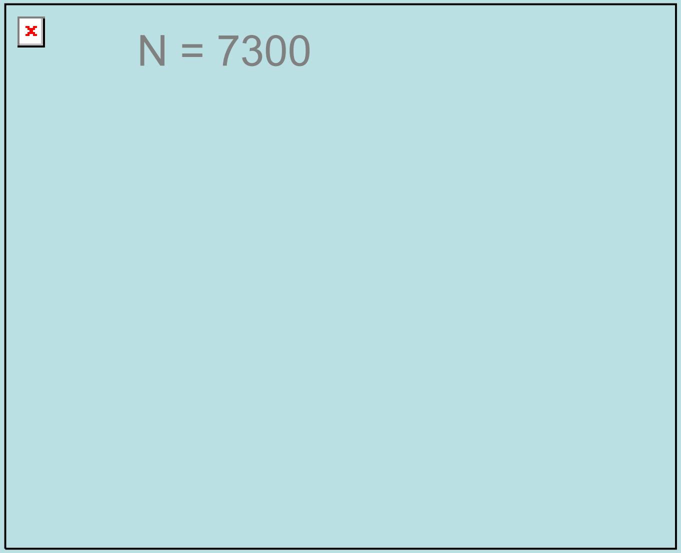
σ_i: errors on Tb^{meas}
σ_k: prescribed errors on auxiliary parameters
} Gaussian assumption

Four retrievals: 3 salinities (3 roughness models) + Pseudo-dielec. const.

Retrieved parameters: SSS/A_card, SST, roughness parameters, TEC in dual pol mode

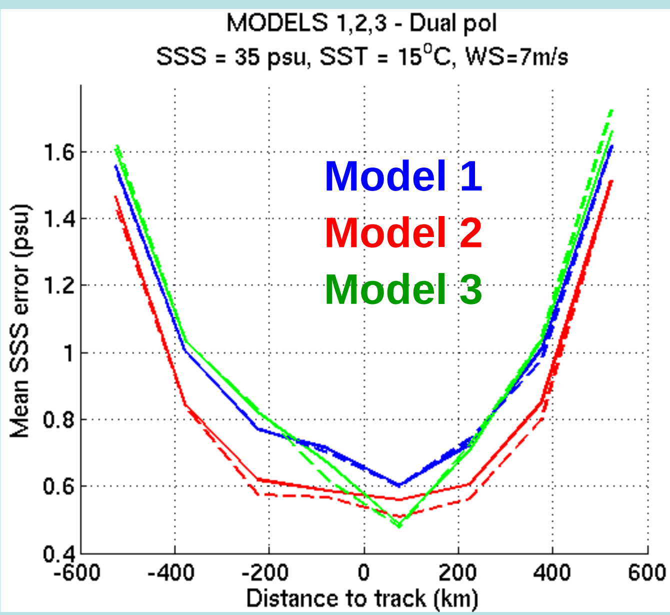
Minimization: Levenberg-Marquardt algorithm + convergence criteria

SSS retrieval behavior for the 3 models



SSS = 35 psu — σ_{SSS} = 100 psu
SST = 15°C — σ_{SST} = 1°C
WS = 7 m/s — σ_{WS} = 1.5 m/s
TEC = 10 TECu — σ_{TEC} = 5 TECu

- **Good behaviour of the retrieval**
  - distribution close to Gaussian
  - theoretical error given by the retrieval = rms error of $SSS_{retrieved} - SSS_{true}$
- **Higher errors at the edge of the swath**
  - → decreasing number of measurements per gridpoint
  - → increasing radiometric noise



——— theoretical error given by the retrieval
– – – rms error of $SSS_{retrieved} - SSS_{true}$

Present status

- Algorithm implemented in SMOS OS L2 processor
- Verification/validation almost completed
- Parameters tuning and options selection to be tested during SMOS commissioning phase
- Neural network salinity retrieval approach under development for a future implementation