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Surface Emissivity Model: Development and Validation Cal/Val Activities

Thomas Meissner and Frank Wentz
Remote Sensing Systems

Aquarius Cal/Val Workshop
Surface Roughness Group
JPL, February 1- 2, 2011

Outline

- RSS ocean surface emissivity model (C- band results)
  - Dielectric constant
  - Wind induced emissivity
  - Atmospheric components
  - Absolute calibration
  - Measured minus computed TB
  - SST retrievals
- L-band dielectric models
- Cal/val plan
  - Pointing analysis
  - Measured minus computed TB
  - Absolute calibration
  - Adjustment /update of surface emissivity models
  - Adjustment/updates of handling of galactic radiation
- Work to be done

Ocean surface emissivity model

$$E = \underbrace{E_0(T,S)}_{\text{specular}} + \underbrace{\Delta E_W(W,\ldots)}_{\substack{\text{wind induced}\\ \text{(excess)}\\ \text{isotropic part}}} + \underbrace{\Delta E_\varphi(W,\varphi,\cdots)}_{\text{wind direction signal}}$$

- Emissivity model shows up in salinity retrieval algorithm in the very last step:
  - Calibration: Counts -> TA
  - remove galaxy, sun, moon radiation
  - APC: TOI TB
  - remove Faraday rotation: TOA TB ->
  - remove atmosphere: surface emissivity
  - SSS is matched to surface **emissivity model**
    - derivation of regression coefficients
    - MLE

Ocean surface emissivity: Specular E_0

- Determined by dielectric constant of sea water + Fresnel reflection law
- Debye double relaxation law:

$$\boxed{\varepsilon(T,S)=\frac{\varepsilon_S(T,S)-\varepsilon_1(T,S)}{1+i\,\nu/\nu_1(T,S)}+\frac{\varepsilon_1(T,S)-\varepsilon_\infty(T,S)}{1+i\,\nu/\nu_2(T,S)}+\varepsilon_\infty(T,S)-i\,\frac{\sigma(T,S)}{(2\pi\varepsilon_0)\nu}}$$

Debye parameters

$$\boxed{\varepsilon_S,\ \varepsilon_1,\ \varepsilon_\infty,\quad \nu_1,\ \nu_2,\quad \sigma}$$

depend on SST, SSS

- **T. Meissner and F. J. Wentz**, "The complex dielectric constant of pure and sea water from microwave satellite observations," *IEEE TGRS* , vol. 42, no. 9, pp. 1836 – 1849, 2004.
  - 2011: Small adjustment.

Ocean surface emissivity: Wind induced (excess) ΔE_W ΔE_φ

- 2-scale ocean roughness models not accurate enough
- Needs to be determined from observations
- **T. Meissner and F. J. Wentz**, "The Emissivity of the Ocean Surface Between 6 – 90 GHz Over a Large Range of Wind Speeds and Earth Incidence Angles," *submitted to IEEE TGRS* , 2011.
  - C – W band. EIA: 0^o – 65^o. Wind speed: 0 – 40 m/s.
  - Refinement and extension of previous works
  - AMSR ATBD
- L-band
  - WISE: used before 2010
  - PALS: adopted for AQUARIUS in 2010

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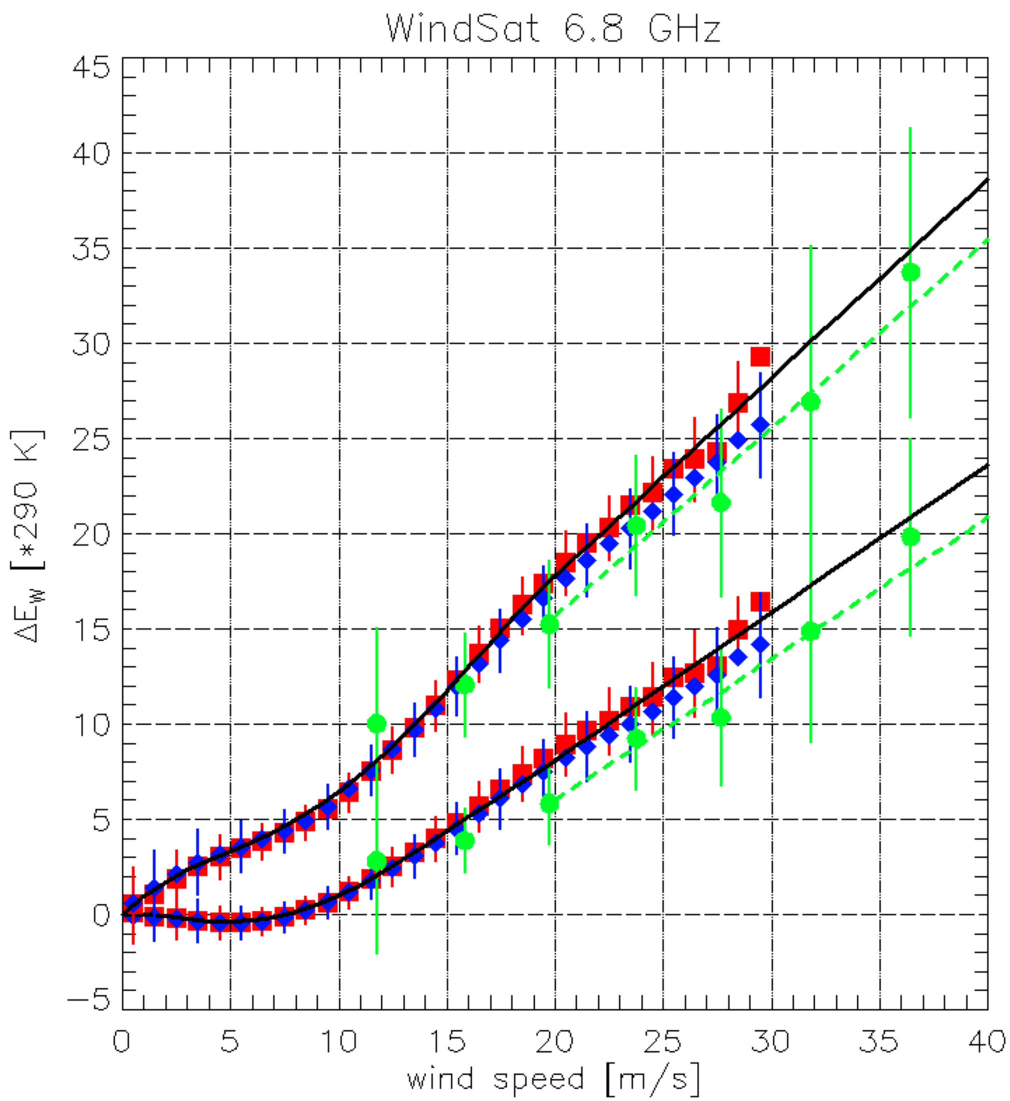
Wind induced (excess) emissivity at C-band

WindSat wind speeds
use 18.7 GHz and above

QuikSCAT wind speeds

HRD wind speeds
(high winds)

RSS emissivity model



Absolute calibration

- Count to TA. External calibration targets T_{hot} and T_{cold}

$$T_{A,p} = T_{hot} + \lambda\left(C_{Earth,p}\right)\cdot\left(T_{cold} - T_{hot}\right), \quad p = v,h \quad \lambda(C) \equiv \frac{C - C_{hot}}{C_{cold} - C_{hot}}$$

- Antenna pattern correction (APC)

$$\begin{pmatrix} T_{B,v} \\ T_{B,h} \end{pmatrix} = \mathbf{A}^{-1}\cdot\begin{pmatrix} T_{B,v} \\ T_{B,h} \end{pmatrix} = \begin{pmatrix} 1-a & a \\ a & 1-a \end{pmatrix}^{-1}\cdot\begin{pmatrix} \tilde{T}_{A,v} \\ \tilde{T}_{A,h} \end{pmatrix} \quad \text{cross-pol}$$

$$T_A = \eta\cdot\tilde{T}_A + (1-\eta)\cdot T_{cold} \quad \text{spillover}$$

- Absolute calibration = The calibration parameters **a** and **Thot / η** are determined on-orbit
  - Pre-launch values for $\mathbf{T_{hot}}$ **η** **a** are not accurate enough
  - Calibration to ocean RTM
  - Average over large ensemble (> 3 months)

$$T_{B,p} \approx \frac{T_{hot}}{\eta} + \lambda\left(C_{Earth,p}\right)\cdot\left[T_{cold} - \frac{T_{hot}}{\eta}\right] + a\cdot\frac{T_{hot}}{\eta}\cdot\left[\lambda\left(C_{Earth,p}\right) - \lambda\left(C_{Earth,x}\right)\right] + \ldots$$

$$p, x = \text{co/cross-pol}$$

Determination of wind induced emissivity

- RTM $$T_B = T_{BU} + \tau \cdot E \cdot T_S + \tau \cdot R \cdot \left[T_{BD} + \tau \cdot T_{cold} \right] + \tau \cdot T_{B,\,scat}$$
- TB: measured by radiometer
- Atmospheric parameters T_{BU}, T_{BD}, τ from auxiliary field (NCEP)
- SST, wind speed + direction from **independent** source
  - auxiliary field (NCEP, Reynolds)
  - In situ (buoys)
  - radiometer
    - WindSat , SSM/I, SSMIS, AMSR
    - Must not use the channel whose emissivity is to be determined
  - scatterometer
    - need accurate geophysical model function
- Scattering correction $T_{B,scat}$ negligible at L-band
- Solve RTM equation for E
- Subtract specular part E_0
- Stratify as function of SST, wind speed + direction

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Wind induced (excess) emissivity at C-band

WindSat wind speeds
use 18.7 GHz and above

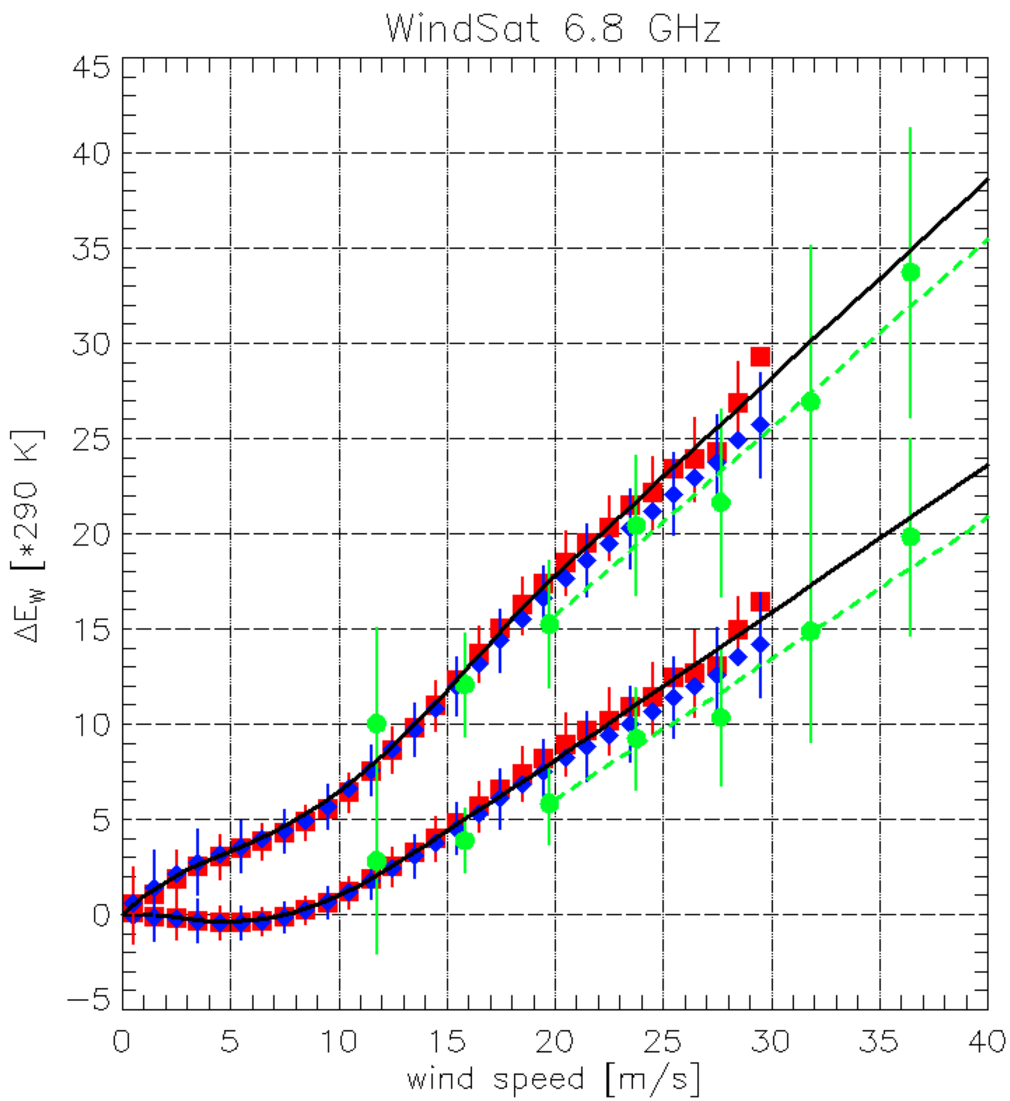
QuikSCAT wind speeds

HRD wind speeds
(high winds)

RSS emissivity model

Consistency between results from different ground truth

HRD winds little too high



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SST dependence of ΔE_W

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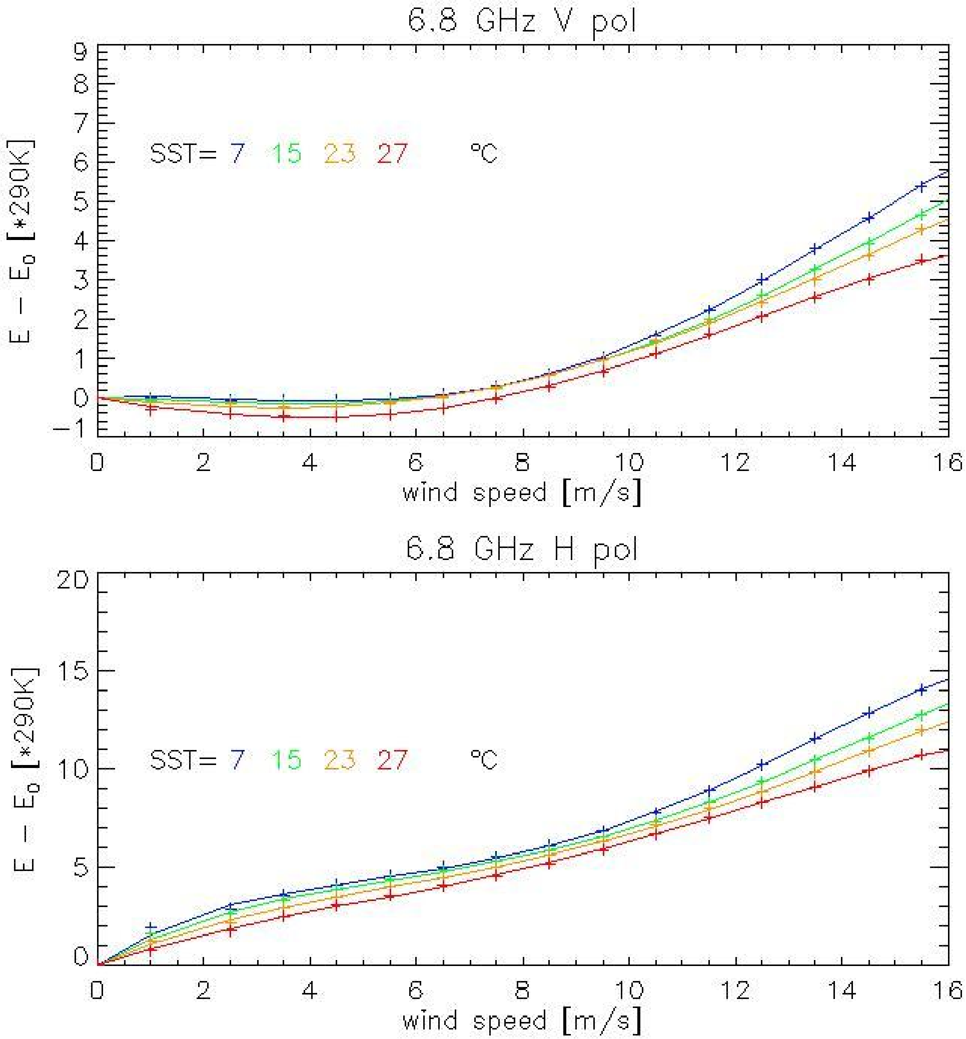
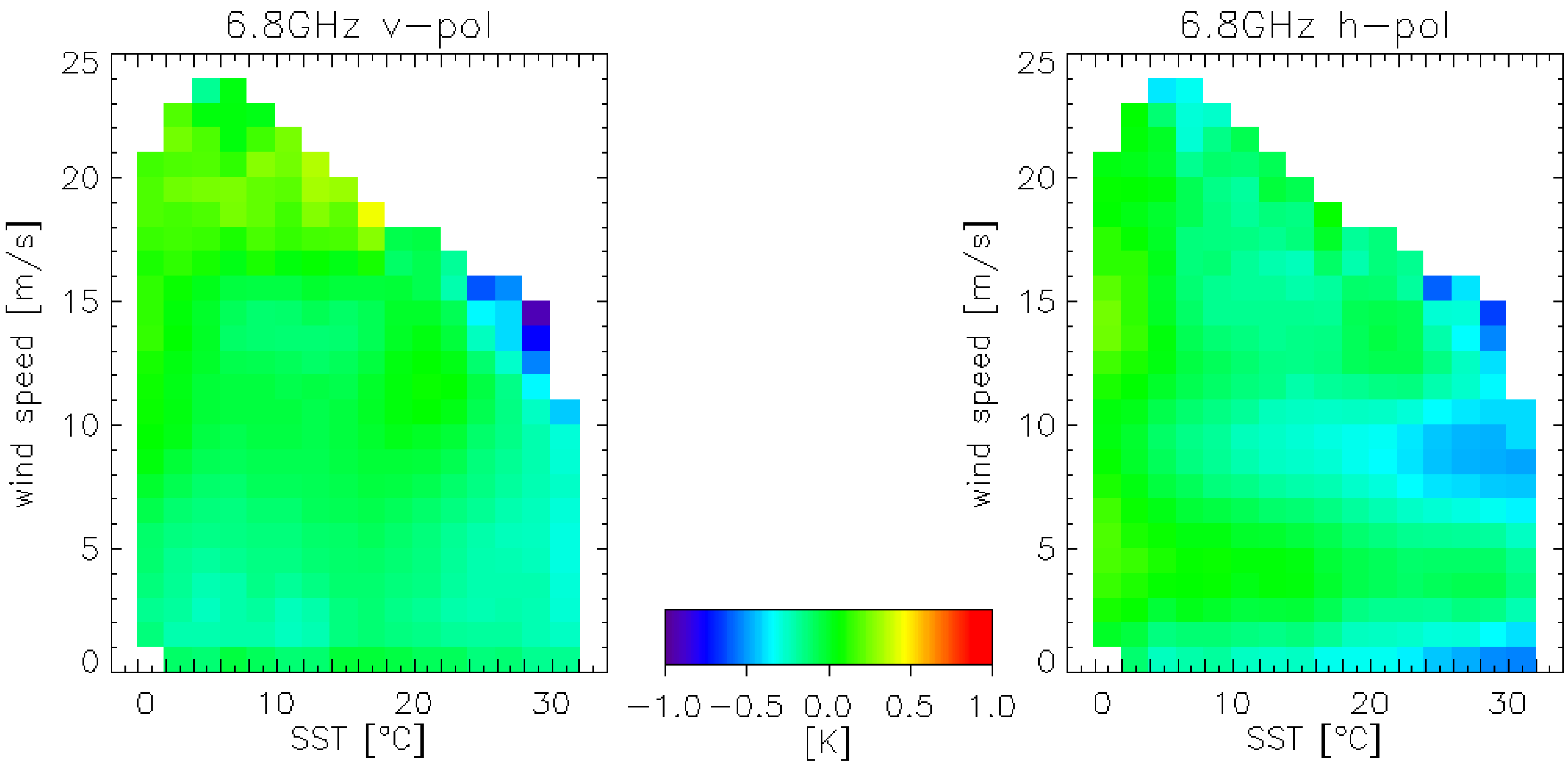
- Data suggest that $\Delta E_W\,(W, T_S) \approx f(W) \cdot E_0(T_S)$



Basic validation tool:
Measured minus computed TB



Check deviation from ideal case = green

Validation of model components

- Measured minus computed TB analyzed as function of SST and wind speed (+ direction).
- Assume that ground truth data are unbiased (on average).
- Absolute offset (bias) has been calibrated away.
- Dielectric model
  - shows up as SST dependent crosstalk
- Non resonant continuum of oxygen absorption
  - from Liebe et al. 1992
  - shows up as SST dependent crosstalk
  - Dielectric model: $\Delta T_{B\ v,pol} : \Delta T_{B\ h,pol} \approx 3 : 2$
  - O_2 absorption: $\Delta T_{B\ v,pol} : \Delta T_{B\ h,pol} \approx 1 : 2$
- SST dependence: $\Delta E_W = f(W) \cdot E_0(T_S)$
  - shows up as SST dependent crosstalk
  - grows with wind speed
- Wind speed dependence of ΔE_W
  - shows up as wind speed dependent crosstalk

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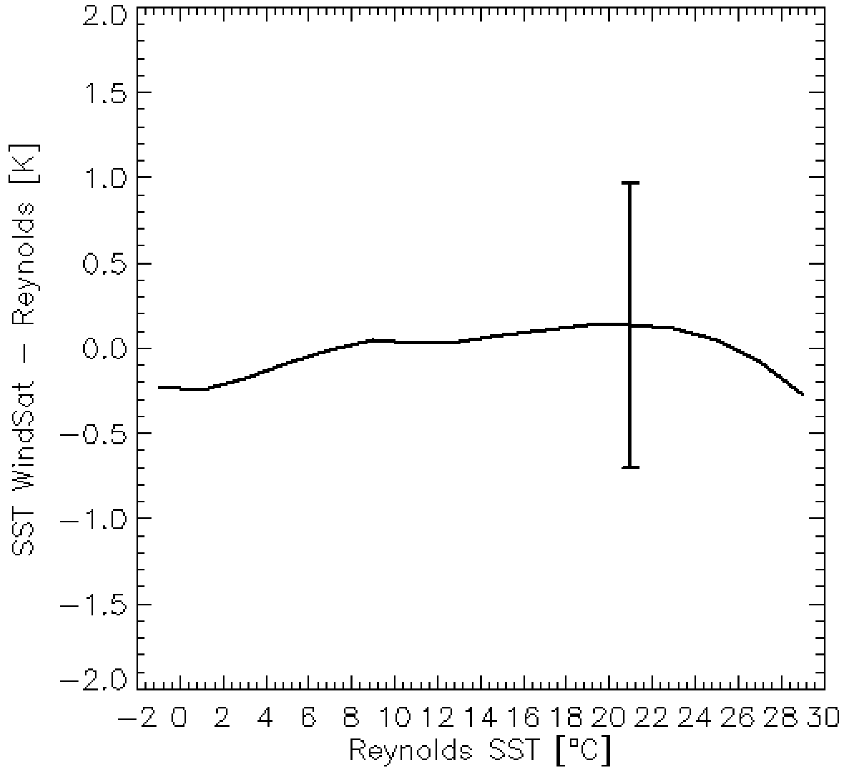
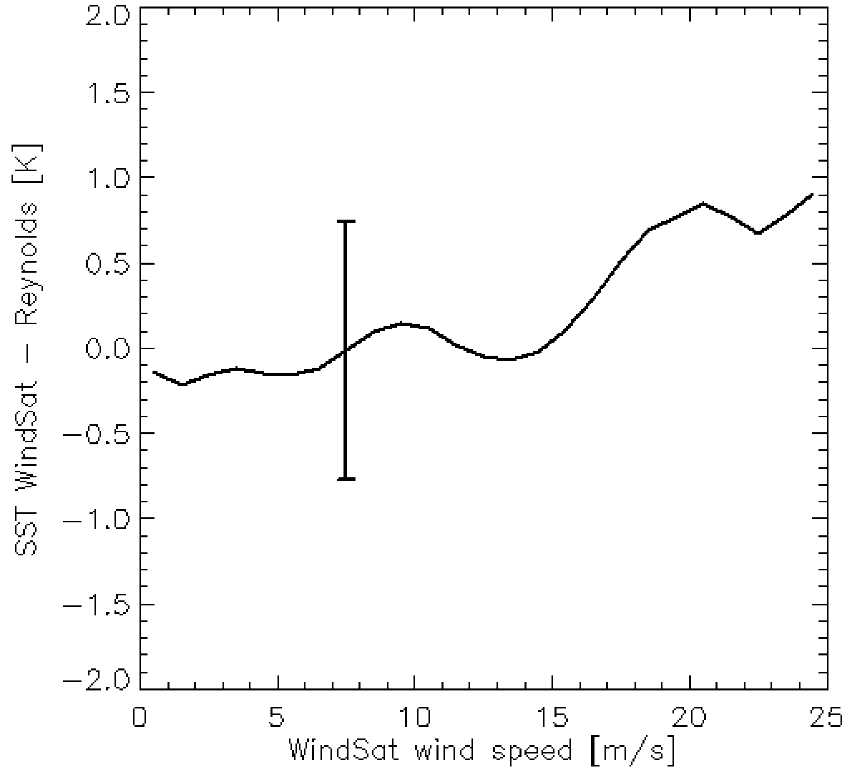
Retrieved SST versus *ground truth*





- Δ SST : ΔT_B(6.8 GHz v-pol) ≈ 2 : 1
- Accuracy of C- band dielectric model 0.1 – 0.2 Kelvin
  - Should apply to L-band if Debye law holds
- Post-hoc adjustment to retrieved SST
  - Static ΔSST correction table

Error bars

- Relevant errors in the emissivity model show up as **deviation from green** in 2-dimensional ΔT_B (T_S, W) plot
  - Deviation from flat curve in 1-dimesnional plot
- Vertical error bars in ΔE_W curves or in ΔT_B plots
  - Standard deviations
  - Not of primary interest
  - Largely dominated by random errors in the ground truth
    - Reynolds SST in ΔE_W plot (0.8 K error)
    - Atmospheric parameters (can be large, 2 K or more for higher frequencies)
  - Contain possible dependence of emissivity on other parameters (wave height), that have not been included in the emissivity model.
  - Possible improvement of emissivity model
    - Take the residuum ΔT_B in each wind speed bin and see if there is a correlation with respect to that parameter.
    - If yes, then this correlation can be parameterized as additional degree of freedom in the emissivity model.
    - Need reliable measurement for that parameter.
    - So far we have not found any necessity to do that.

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L-band dielectric models

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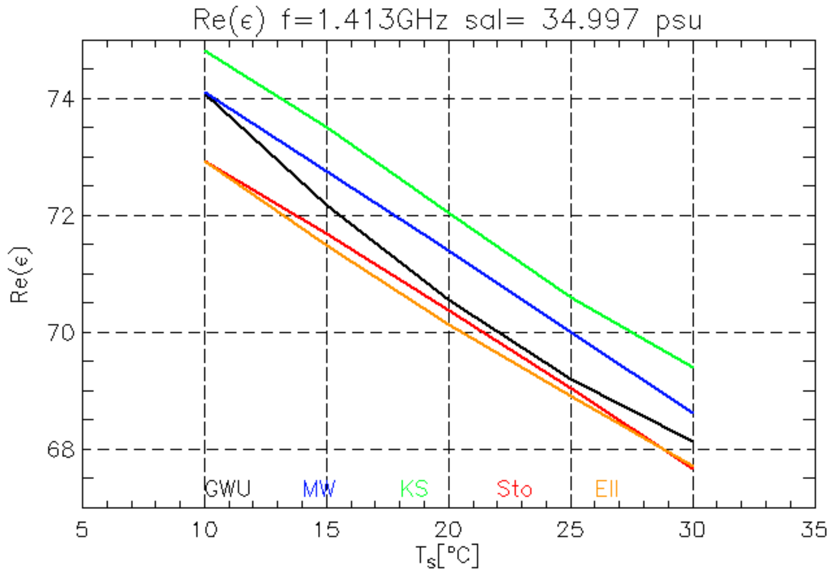

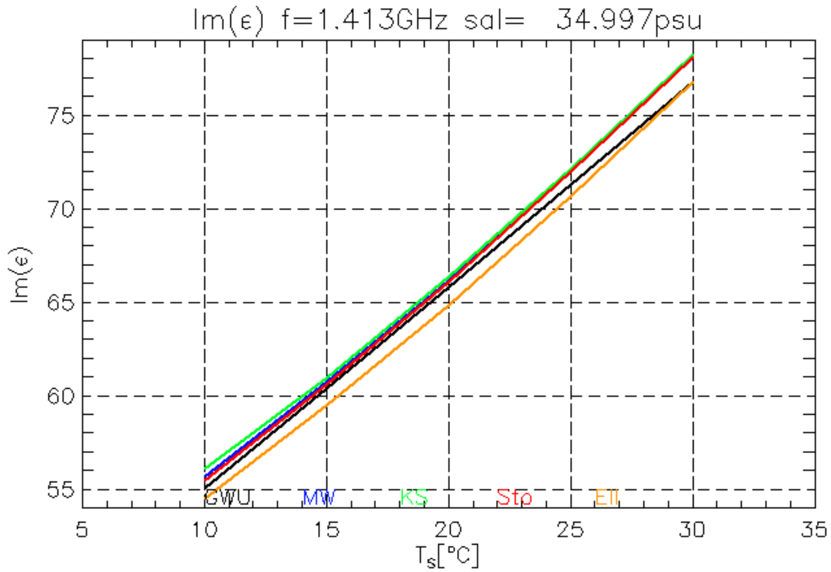

[**GWU**]: **R. Lang et al.:** A New Model Function for the Permittivity of Sea Water at 1.413 GHz, *Proc. Of the 11th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment, 1 -4 March 2010, Washington DC, USA.*

[**MW**]: **T. Meissner + F. Wentz**, "The Complex Dielectric Constant of Pure and Sea Water From Microwave Satellite Observations", *IEEE TGRS* vol. 42(9), 2004, pp. 1836 – 1849. + small adjustment 2011.

[**KS**]: **L. A. Klein + C. T. Swift**, "An improved model for the dielectric constant of sea water at microwave frequencies", *IEEE J. Oceanic. Eng.* vol. OE-2, 1977, pp. 104 – 111.

[**Sto**]: **A. Stogryn et. al.**, "The Microwave Permittivity of Sea and Fresh Water", Azusa, CA: GenCorp Aerojet, 1995.

[**Ell**]: **W. Ellison et al.**, "New permittivity measurements of seawater", *Radio Sci.* vol. 33(3), 1998, pp.639 – 648.

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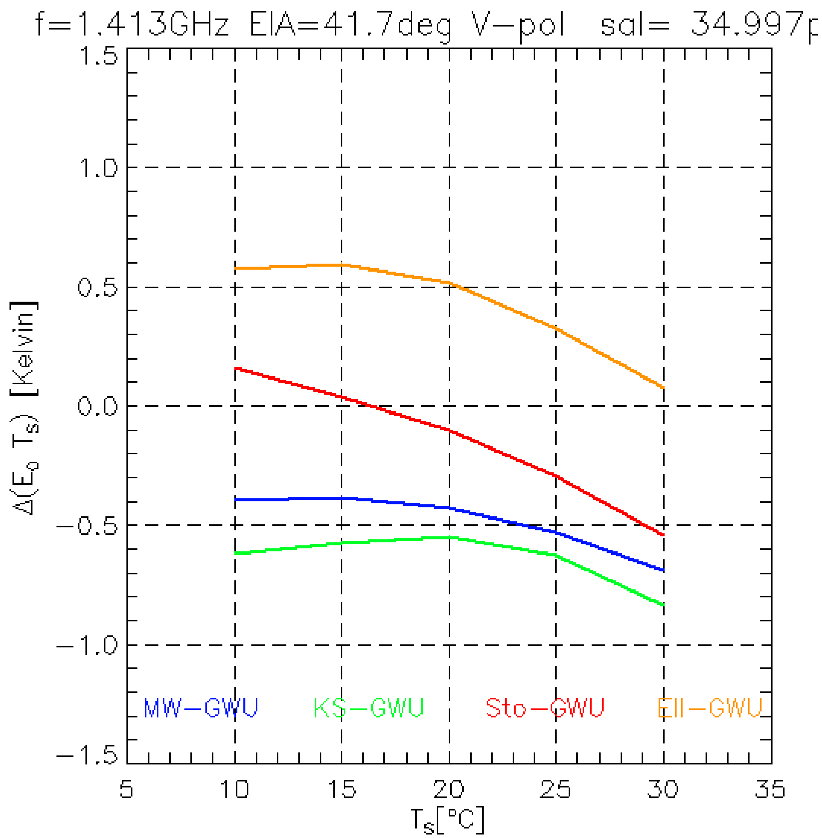
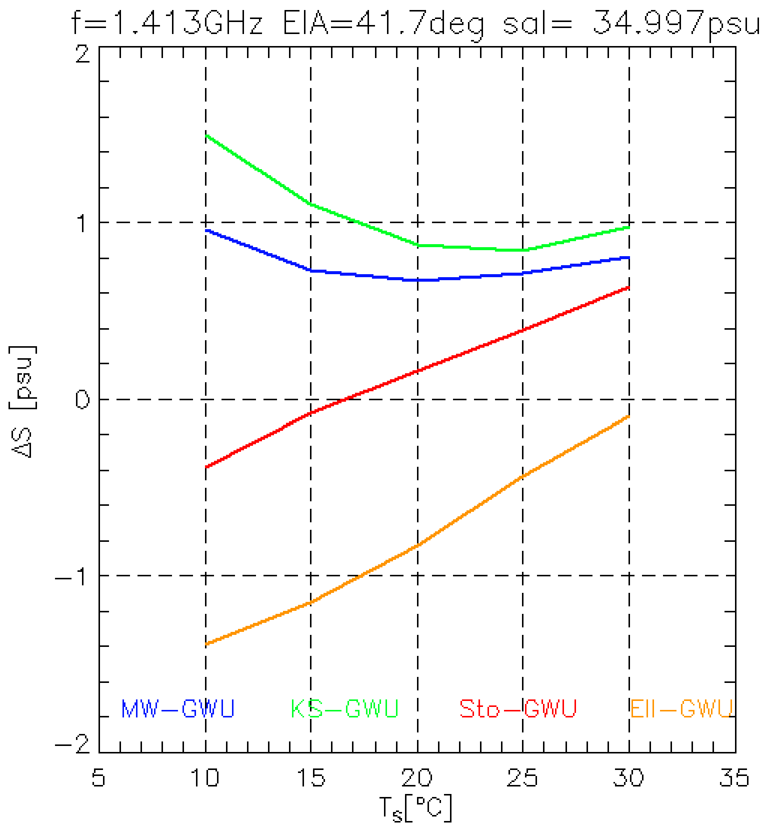
L-band dielectric models (cont.)

Effect on surface emitted TB relative to GWU versus SST



Effect on retrieved salinity relative to GWU versus SST



L-band dielectric models (cont.)

- Absolute calibration
  - Absolute offsets/biases are not significant
  - What matters are slope with respect to SSS and SST
- Uncertainties within the different dielectric models are large
  - MW/GWU about 0.3 psu between 10ºC – 30ºC
  - Ellison/GWU more than 1.0 psu between 10ºC – 30ºC
- Observed some inherent uncertainties/variability in the GWU measurements
  - 2009 versus 2010 report: Im(ε) changed by almost 1.0
  - Translates into 0.5 Kelvin TB difference and 1.0 psu SSS difference

Post Launch Cal/Val: IOC

- 20 days worth of data
- First rough look at absolute calibration: **DTB analysis**
  - Do observed and calculated TB/TA match
  - TB or TA level
  - RTM: Use auxiliary fields from NCEP (SST, wind speed and direction, atmosphere).
  - Later: Match-up with more accurate ground truth (e.g. WindSat, SSMIS wind speeds rather than NCEP wind speeds).
  - **Independent** salinity observation.
    - NOT from AUQUARIUS
    - ARGOS
    - Chao salinity maps
  - Assume that RTM (MW dielectric model + PALS wind emissivity model + atmospheric model) are correct.
  - Large source of uncertainty: noise diode injection temperature TND
    - 4 K error
- Pointing analysis
  - Coast lines in ascending minus descending maps

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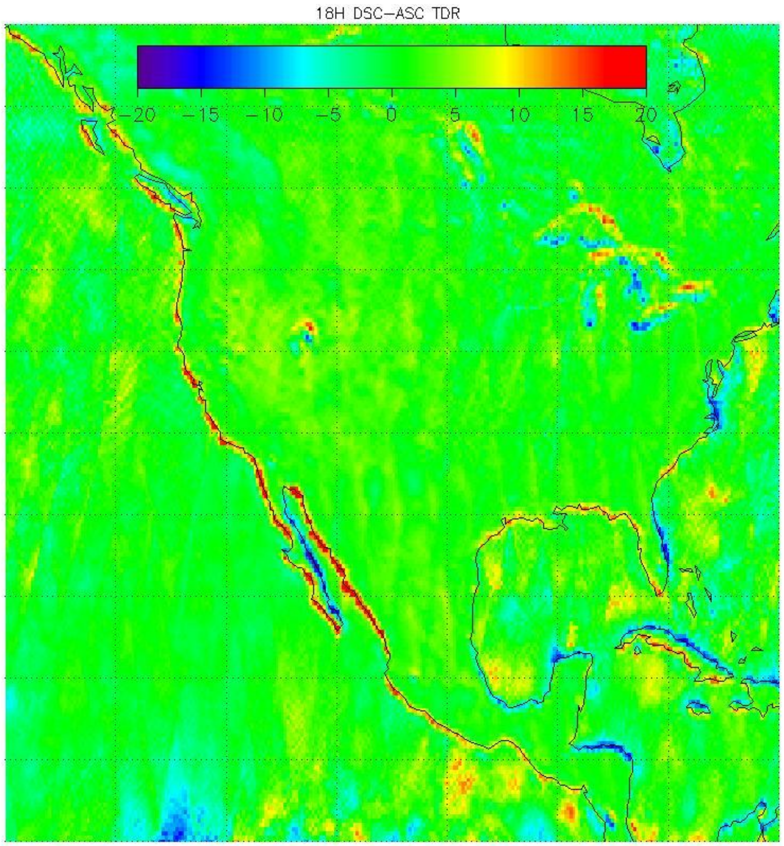
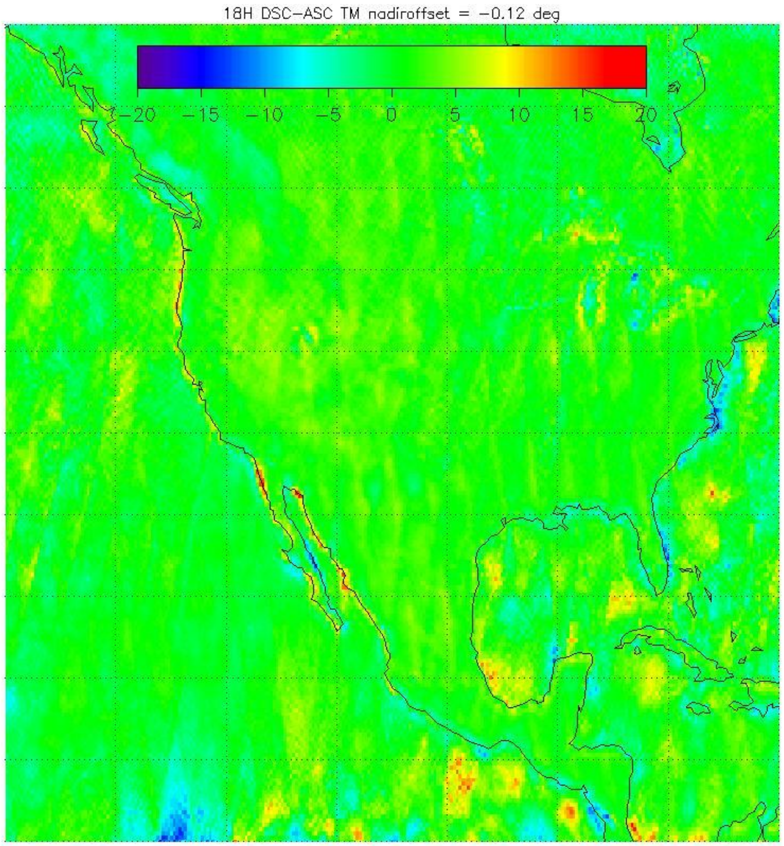
Pointing analysis

SSMIS F16



after 0.1º adjustment of cone angle (4 km location)



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Full Cal/Val plan

- Need 6 month – 1 year worth of data
  - depends how much/big calibration errors we have to deal with
  - high level of accuracy required for AQUARIUS
- Basic tool: **DTB analysis**
  - various ways to visualize DTA reveals different issues
- Absolute calibration
  - Noise diode injection temperature
  - Spillover
  - Smaller effects: x-pol
  - Might be difficult to disentangle
    - Spillover same effect on v-pol and h-pol and likely also same effect on different horns.
    - Noise diode effects different channels differently.
    - Try to find optimal solution by minimizing DTB as function of several parameters
- DTB as function of PRT readings
  - Loss factors (L2A, L2B, ...)
  - Temperature coefficients dTND/dT

Full Cal/Val plan (cont.)

- DTB time series
  - long term stability
- DTB geographical maps
  - RFI , land, sea ice contamination
  - Possible problems with emissivity model (SST)
- DTB inter/intra orbital maps
  - x-axis: time (inter-orbital), y-axis: latitude
  - revealed solar intrusion into hot load at AMSR, WindSat, SSMIS
- Bin DTB as function of SST, SSS, wind speed, wind direction
  - Reveals problems with emissivity model
  - Equivalent: retrieved minus ground truth SSS
- DTB correlation with galactic radiation
  - Significant error source: error in model for galactic radiation
    - surface roughness model: can fold back into wind emissivity model
  - Compare DTB lat/lon maps with maps of galactic TA
  - Wind emissivity model analysis should be done during times with low galactic radiation.

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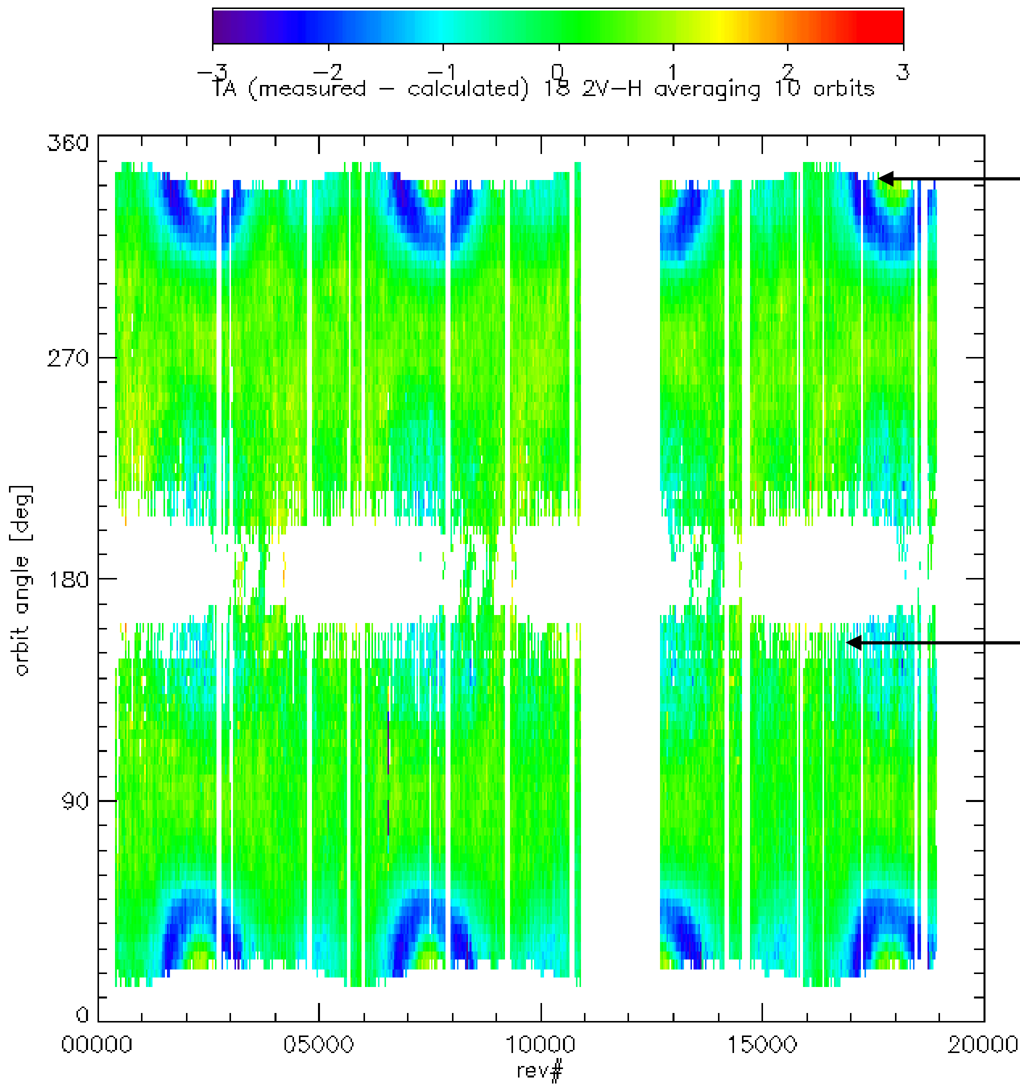
Inter/intra orbital maps: WindSat 18 GHz



Intrusion of reflected sun light

Direct Sun Intrusion

Post Cal/Val actions

- Adjustment of calibration parameters
  - Noise diode injection temperature
  - Spillover, x-pol
  - Loss factors
  - Temperature coefficients
- Adjustment/change of emissivity model component(s)
  - Cal/val can test emissivity model (MW dielectric + PALS wind) or other emissivity models (e.g.: GWU dielectric, WISE wind)
  - If we find *large* crosstalk errors, the emissivity model will need to be updated/changed.
    - Wind emissivity parameterized with polynomial rather than simple linear fit
    - High wind speeds: Big uncertainty. Probably should not retrieve SSS.
  - Need to redo absolute calibration.
  - Need to rederive regression coefficients in SSS algorithm.
- Post-hoc SSS adjustments
  - If we find *small* crosstalk errors (order of requirement level: 0.2 psu) we add static ΔSSS correction table to retrieved SSS
    - Similar than SST algorithm
    - Can depend on SST, wind speed, SSS

Work to be done pre-launch

- Not much: emissivity model is finalized
  - Any possible updates need real data and therefore be done post-launch
- Consistency checks
  - Use simulated data and *derive* emissivity model
  - Should get the input model back aside from noise
  - Tests that RTM and calibration equations were programmed correctly
  - This is a consistency check and only that. It does not give any information about quality of emissivity model.
  - Be aware of change in model that has been used for simulation
    - WISE model before 2010
    - PALS model for latest simulations
  - Creating matchups
    - Only checks quality of matchups versus current auxiliary fields
    - Does not provide any valuable information about the SSS algorithm or the emissivity model

Work to be done pre-launch (cont.)

- Improving model for reflected galactic radiation.
- Wind direction emissivity signal ΔE_{φ} at L-band.
- Check of RFI detection.
  - False alarms near geographical boundaries.