Next Generation Spaceborne Instrument for Monitoring Ocean Salinity with Application to the Coastal Zone and Cryosphere

Emmanuel Dinnat, *Chapman University & NASA/GSFC*
Giovanni de Amici, *NASA/GSFC*
David Le Vine, *NASA/GSFC*
Jeffrey Piepmeier, *NASA/GSFC*

Outline

- Scientific Objectives and Requirements
  - SSS continuity
  - Enhanced capabilities :
    - SSS in Cold waters/high latitudes with increased accuracy
    - SSS closer to coast and sea ice
    - Cryosphere (e.g. sea ice thickness)
- Simulation Tool

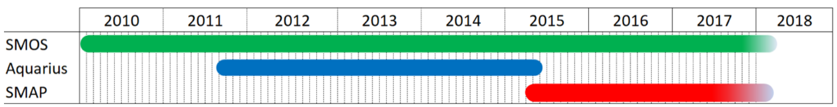
  Forward model & retrieval algorithm

  $\Rightarrow$ Assess retrieval performance given instruments parameters and geophysical uncertainty
- Instrument Design Study
- Summary

SCIENTIFIC OBJECTIVES AND REQUIREMENTS

Scientific Objectives

Continuity of sea surface salinity monitoring



+ SMOS 8+ years
+ Aquarius (dedicated to SSS) died ~ 3 years ago
+ SMAP going strong but lacking features for SSS (e.g. SMOS multi angle or Aquarius scatterometer)

⇒ Need the next SSS monitoring mission

Enhanced of SSS observation capabilities

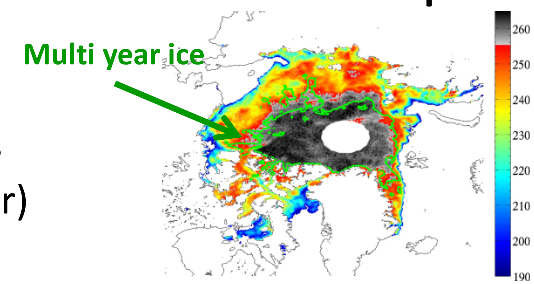
Current limitations:
e.g.

- limited spatial resolution (e.g. coastal, sea ice melt)
- increased errors in cold waters / high latitudes

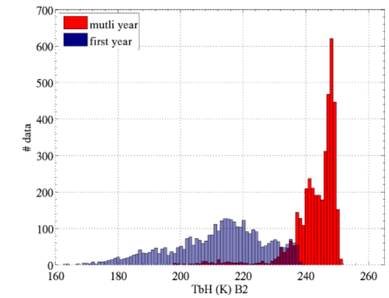
Cryosphere Applications: sea ice age, thickness and snow layer thickness

L-band sensitive to sea ice age

SMAP TB map

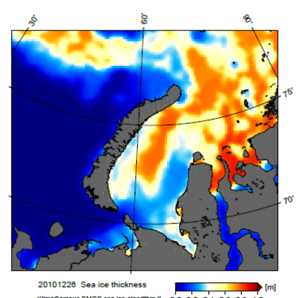


Aquarius TB histogram



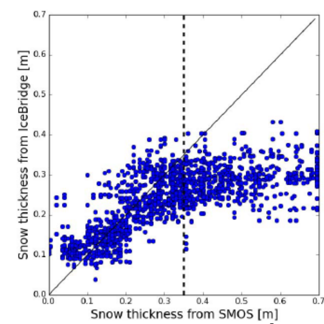
Dinnat and Brucker (2017)

L-band sensitive to thin sea ice (<0.5 – 1 m) and snow thickness over thick ice



SMOS SI thickness

Tian-Kunze et al., 2014



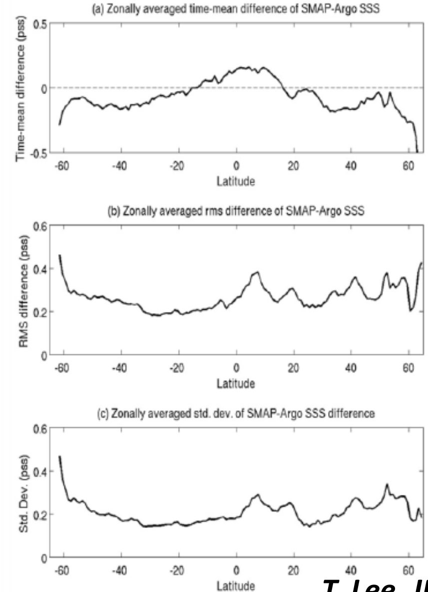
SMOS Snow thickness

Maaß et al 2013

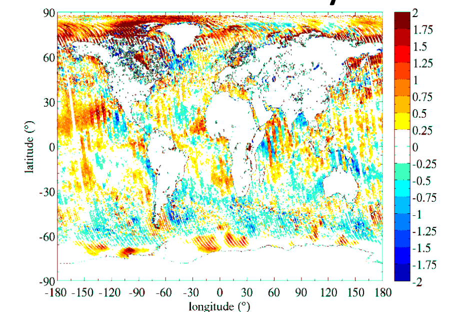
Limitations of current technology

- Increased error in cold waters:
  - – Loss of sensitivity TB vs SSS
  - **⇒ Add low freq channels (P-band)**
  - – Uncertainty in SST and roughness
  - **⇒ Use multiple frequencies (P-/L-/S-/C-bands) for multi-parameter retrievals**

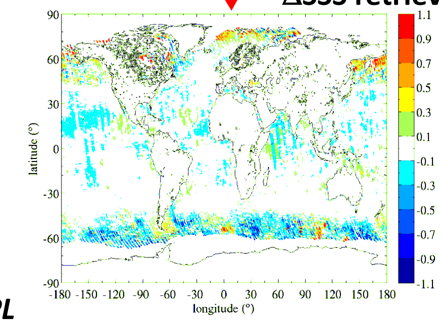
SMAP SSS – in situ vs latitude



ΔSST ancillary



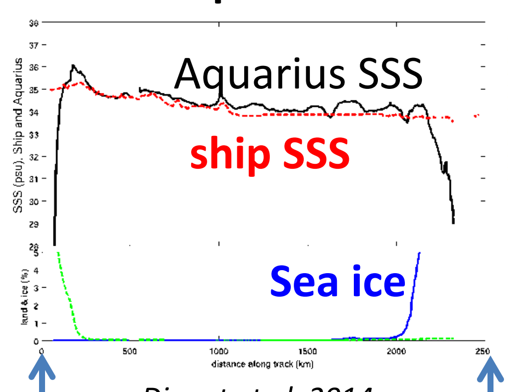
ΔSSS retrieved



T. Lee, JPL

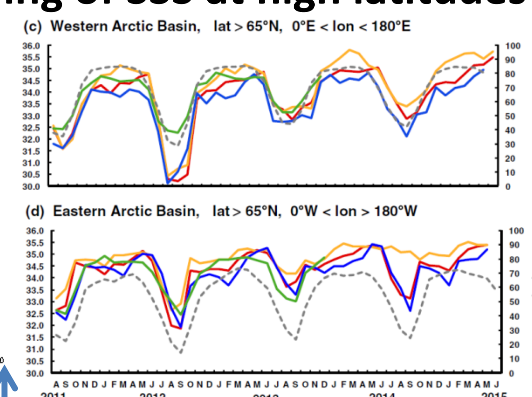
- Increased errors/missing retrievals near coasts/ice
  - – Due to large footprint & side lobes
  - **⇒ Large 15-m class reflector for resolution of 10 km – 20 km**

Sea ice impacts monitoring of SSS at high latitudes



Dinnat et al. 2014

Tazmania Antarctica



Garcia-Eidell et al., JGR, 2017

Requirements for SSS monitoring high latitudes and coastal regions

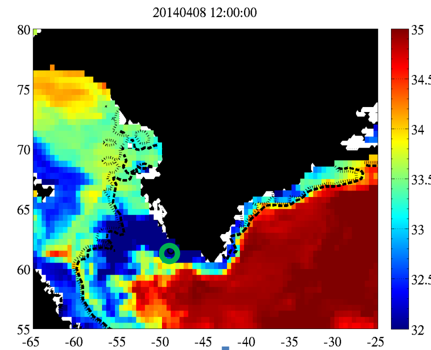
- We used in situ SSS observations and ocean model simulations from NASA GMAO (Global Modeling and Assimilation Office) to derive space/time and accuracy requirements, esp. in coastal regions (Greenland, Congo, Ganges)

- Coastal current (Congo river mouth, East and West Greenland Currents) as narrow as ~ 40 km
  - Spatial resolution 10 km - 20 km

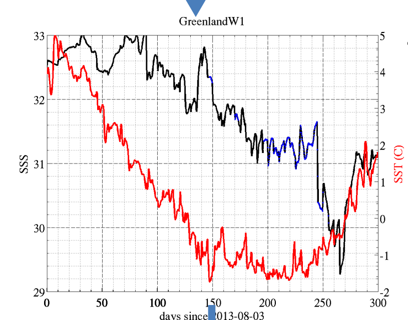
- Most challenging accuracy need:
  0.35 psu over < 20 days at 6°C

  ⇒ **ΔTB < 0.13 K at L-band**

e.g. West Greenland current

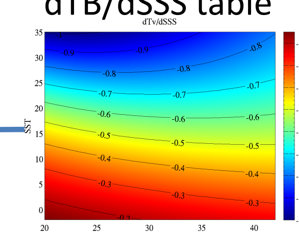


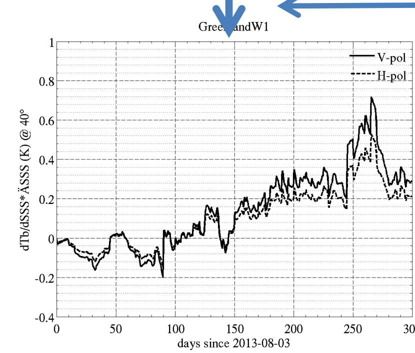
GMAO SST & SSS Fields (credits: G. Vernières, GMAO now NOAA)



Temporal variability of SSS and SST

dTB/dSSS table





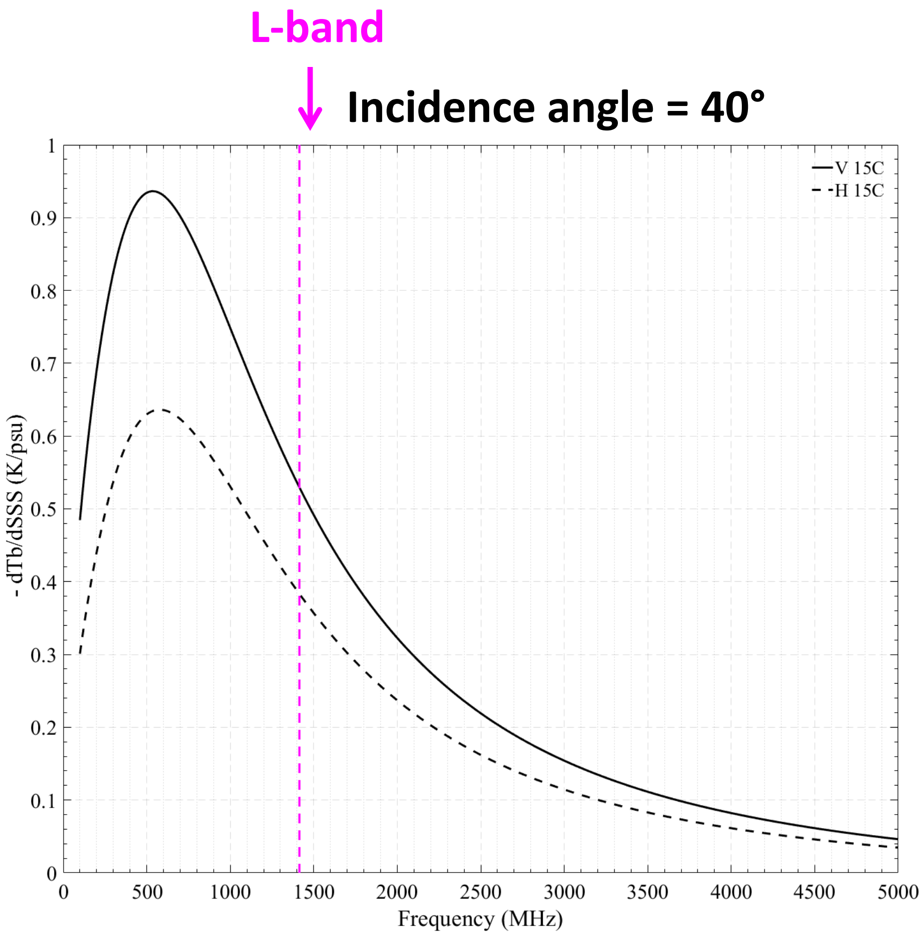
Temporal variability of TB (due to SSS only)

SIMULATION TOOL

Radiometric sensitivity to SSS

Low frequencies (~500 MHz):

- increased sensitivity compared to L-band (x3 in cold waters)



Flat surface Tb, ε from [Klein and Swift, 1977]
(similar results with [Meissner and Wentz, 2004])
Incidence angle = 40°

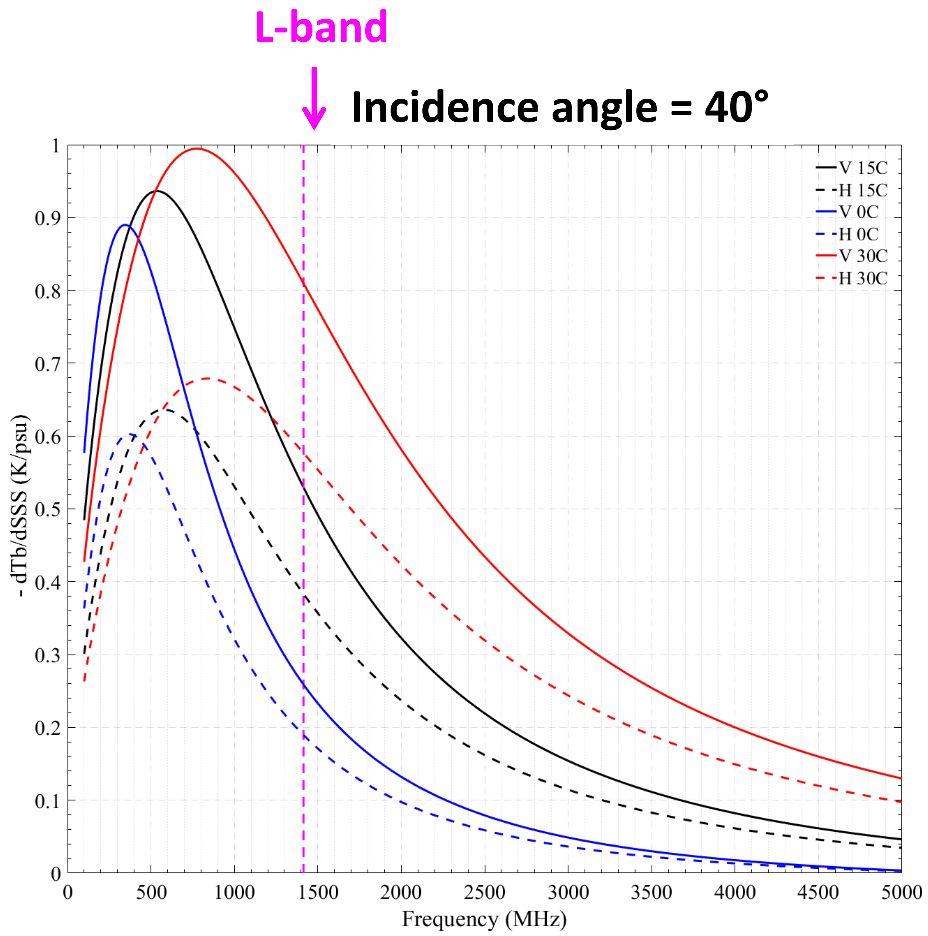
Radiometric sensitivity to SSS

Low frequencies (~500 MHz):

- increased sensitivity compared to L-band (x3 in cold waters)
- uniform sensitivity across temperatures

L-band : sensitivity loss is 2/3 at 0°C vs 30°C

500 MHz: sensitivity loss is 11% at 0°C vs 30°C



Flat surface Tb, ε from [Klein and Swift, 1977]
(similar results with [Meissner and Wentz, 2004])
Incidence angle = 40°

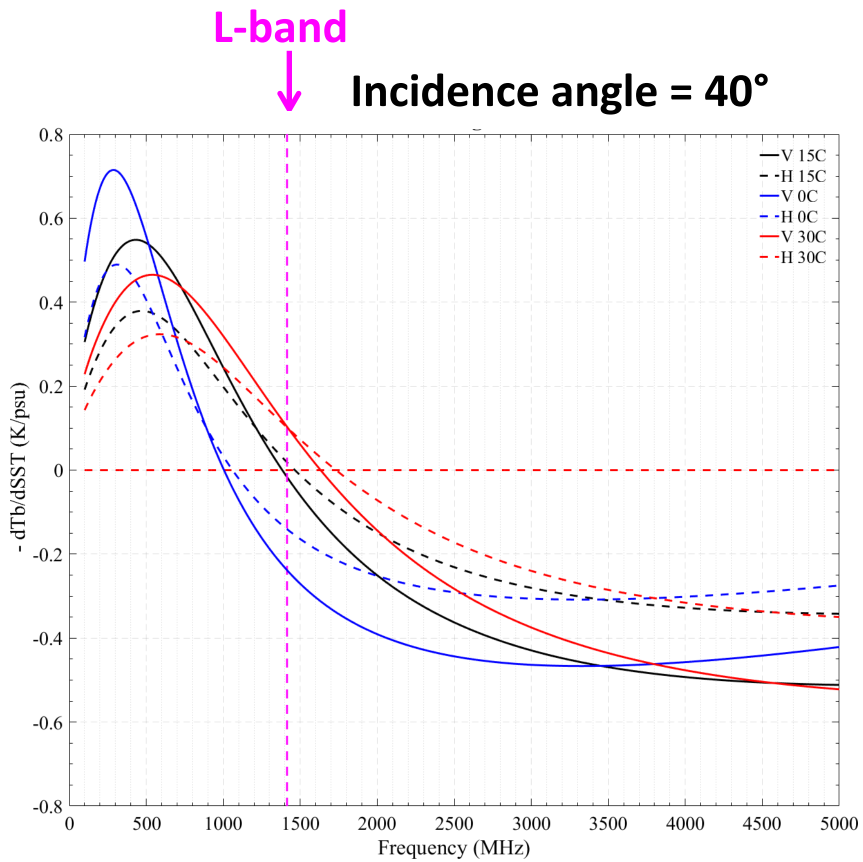
Radiometric sensitivity to SST

Lower Frequencies *tend(*)* to increase sensitivity to SST

(*) **<u>For cold waters, 1000 MHz offer very small sensitivity</u>**

High freq offer similar sensitivity to low freq (opposite sign)

⇒ Use high freq. to improve and correct SST



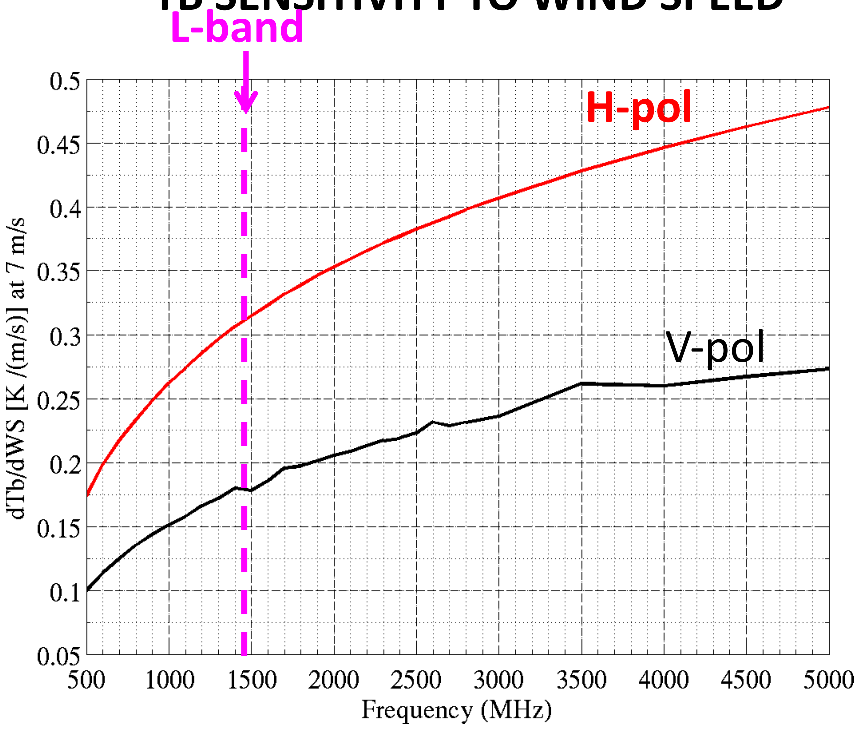
Flat surface Tb, ε from [Klein and Swift, 1977] (small difference at high freq & cold water with [Meissner and Wentz, 2004]) Incidence angle = 40°

Wind speed impact on TB as function of frequency

- Sensitivity computed as dTB/dWS, in K/MS at WS = 7 m/s:
  - most WS over global ocean are 'close' to 7 m/s
  - foam impact is limited
  - Tb vs WS is fairly linear

  (SST = 18°C, SSS = 35 psu)
- Two-scale model
- Durden & Vesecky (1985) sea spectrum multiplied by 2

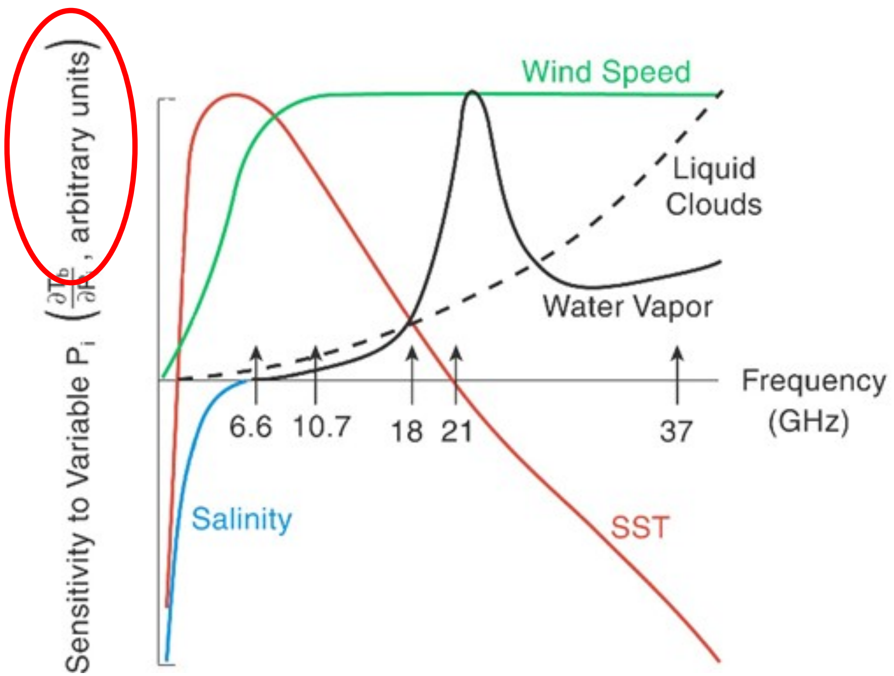
TB SENSITIVITY TO WIND SPEED



TB sensitivity to wind speed as a function of frequency for (black) V-pol and (red) H-pol. The incidence angle is 40°, the SST is 16°C and the SSS is 35 psu.

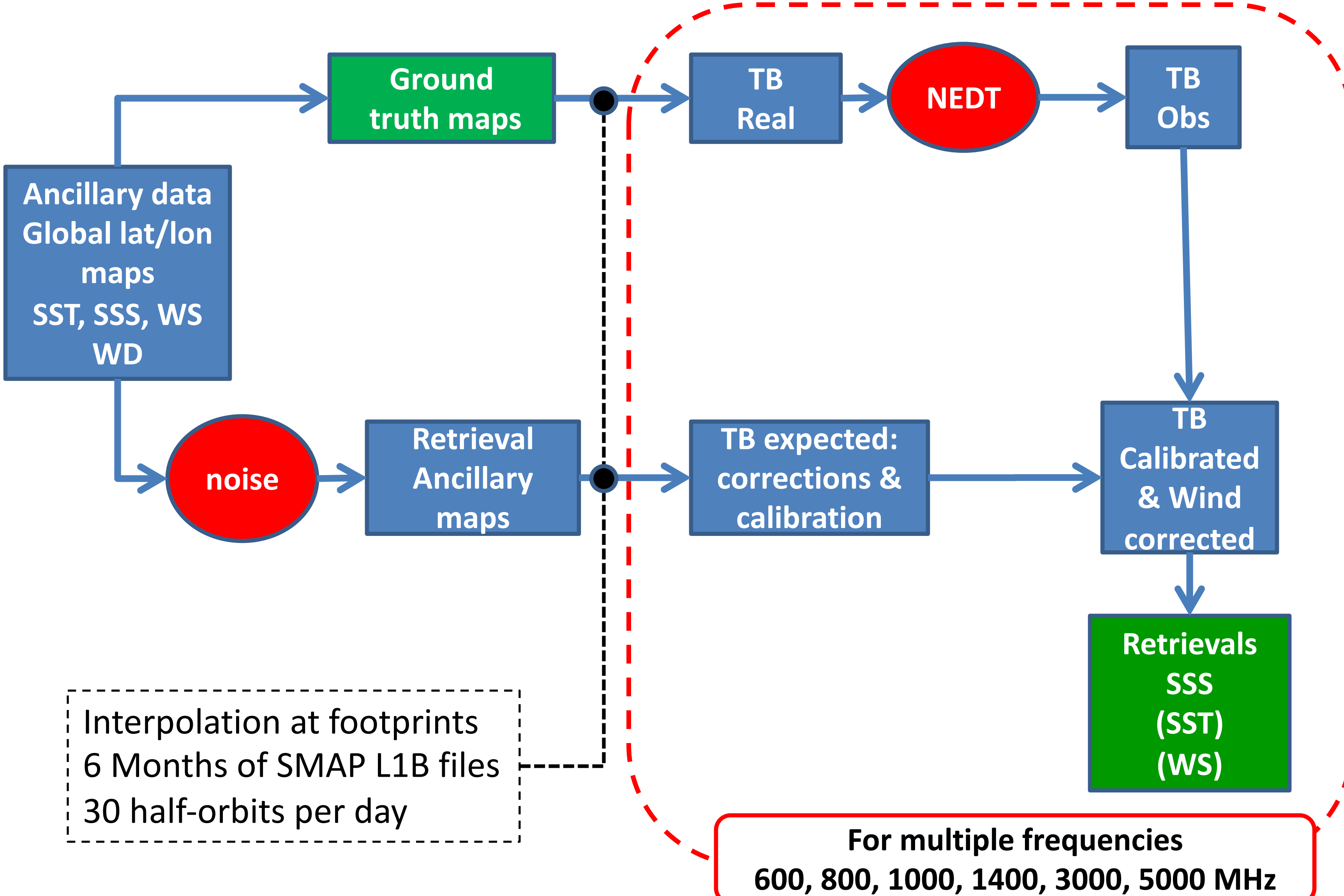
<u>Dependent on model.</u>

Simulations Tool: assess impact of parameters over 500 MHz – 5000 MHz



- Retrieval performance will depend on
  - Sensitivity curves
  - Ancillary parameters errors (random & systematic)
  - Radiometric noise
    - Freq bandwidth
    - Integration time
    - …
  - Model error
- We developed a forward model & retrieval simulator to assess the impact of ancillary and radiometric errors, choice of frequencies and bandwidth, gridding resolutions etc …

Simulations Tool: assess impact of parameters over 500 MHz – 5000 MHz



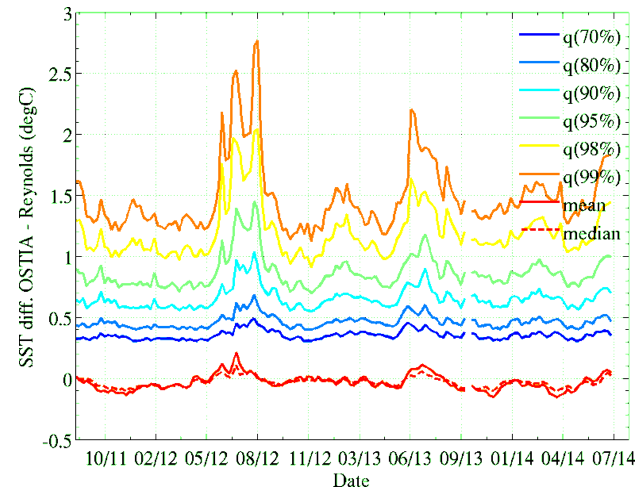
Ancillary parameters Uncertainty

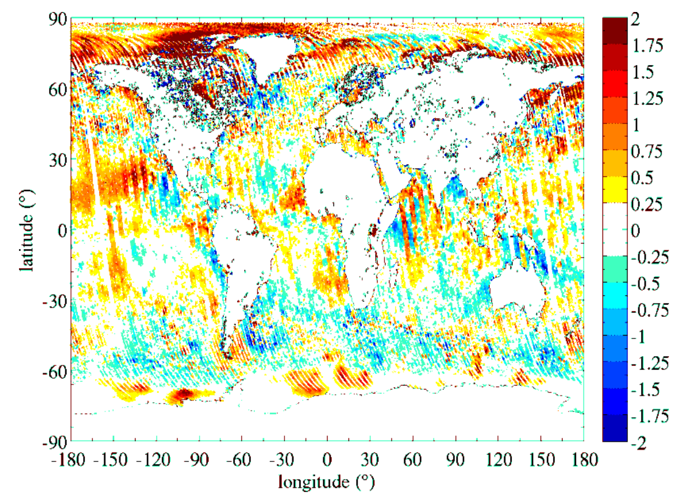
- Sea Surface Temperature
  - σ_{SST} = 0.7°C
  - Bias = 0°
- Salinity
  - σ_{SSS} = 1 psu
  - Bias = 0 psu
- Wind Speed
  - σ_{WS} = 1 m/s
  - Bias = 0 m/s
- Wind Direction
  - σ_{WD} = 30°
  - Bias = 0°

Additional errors to be added:

- Biases (e.g. regional, seasonal)
- Varying random error: e.g. SST errors increase with clouds & aerosols (IR), high winds (MW), close to land ~ 100 km (MW), due to water vapor (MW)

SST OSTIA – NOAA OI V2





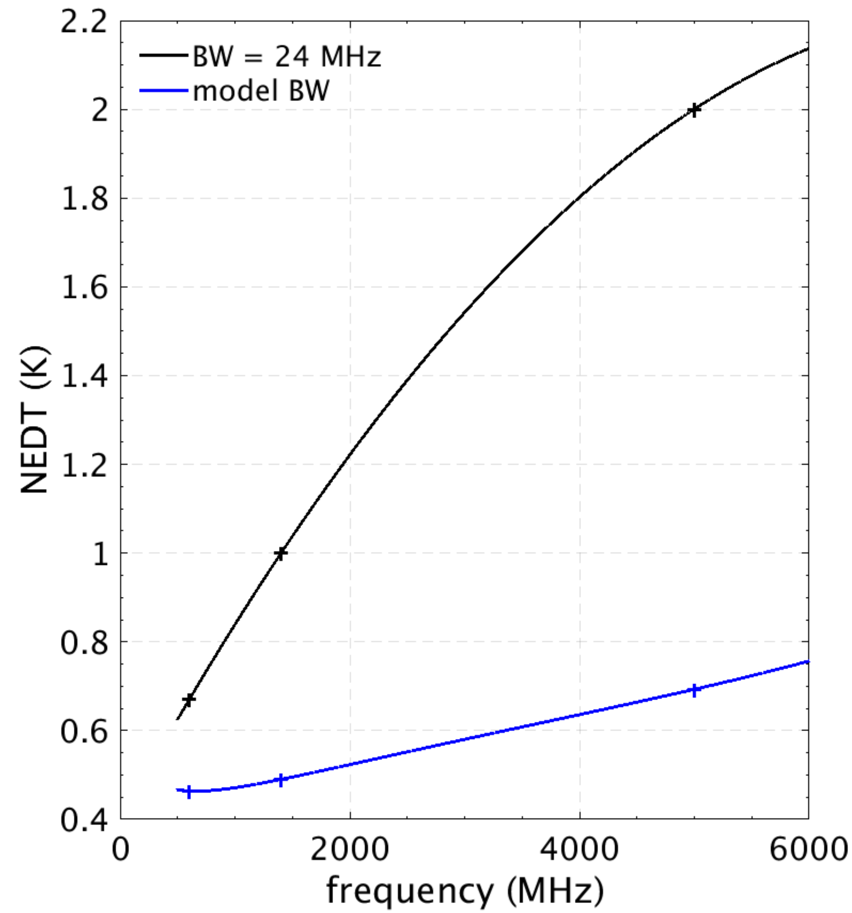
Radiometer NEDT model

- Based on SMAP footprint NEDT @ BW = 24 MHz ; t = 15 ms

- Scaled with frequency (receiver) by
  x 0.66 at P-band
  x 2.00 at C-band
  (BW = 24 MHz)

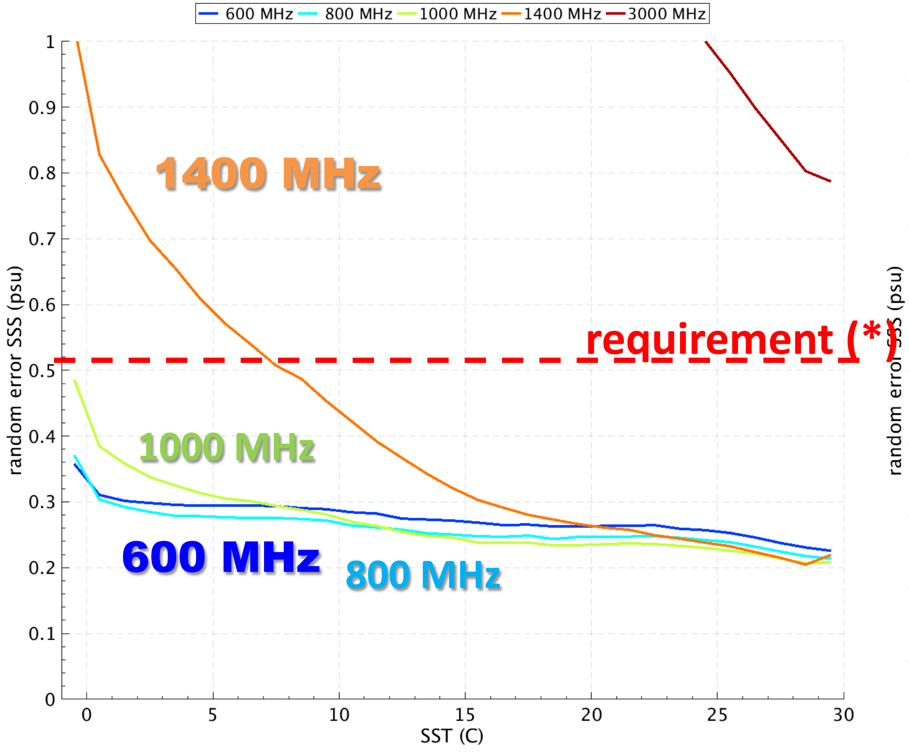
- Scaled with following BW:
  600 MHz BW = 50 MHz
  1400 MHz BW = 100 MHz
  5000 MHz BW = 200 MHz

(10% center frequency – RFI penalty)

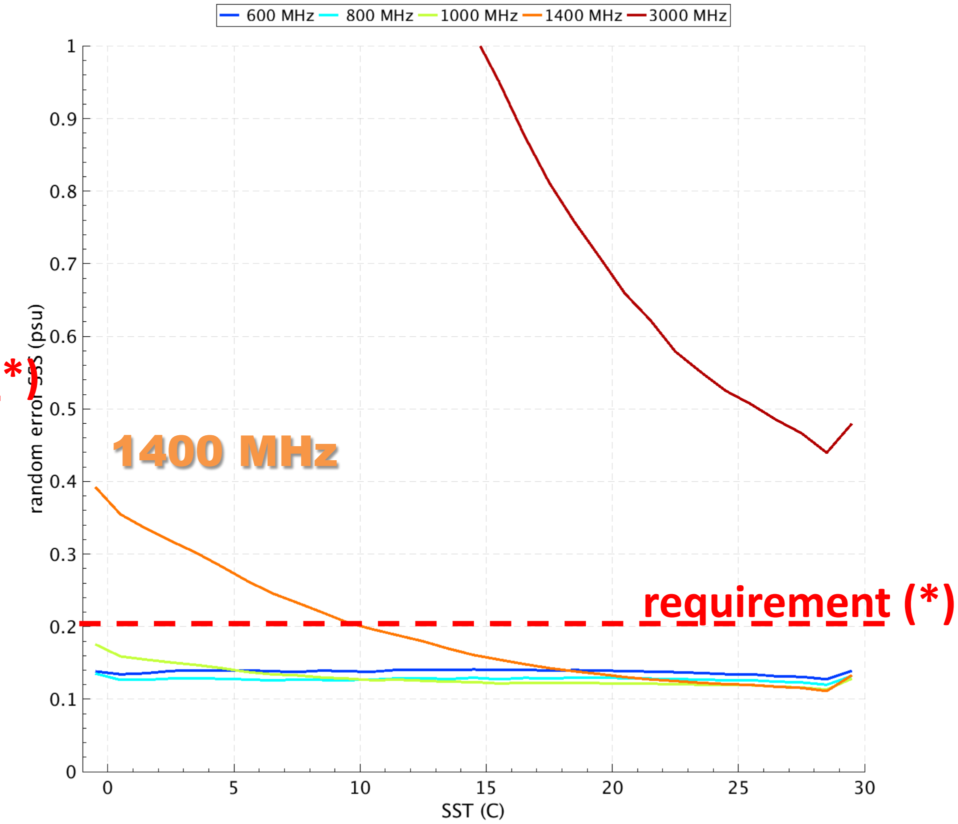


SSS random error vs SST

Daily maps at 0.5°x0.5° lat/lon over 6 months



Weekly maps at 0.5°x0.5° lat/lon



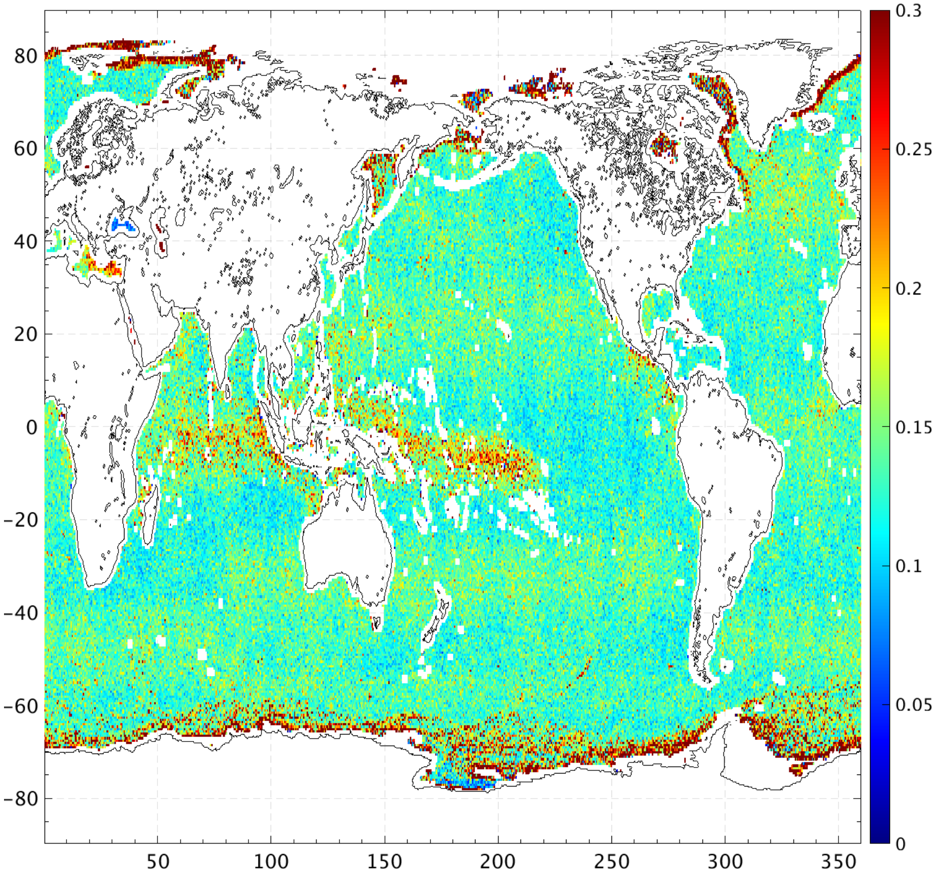
L-band alone has good performances in warm waters (4 x BW) but fails in cold waters

800 MHz optimum compromise between SST & SSS sensitivities

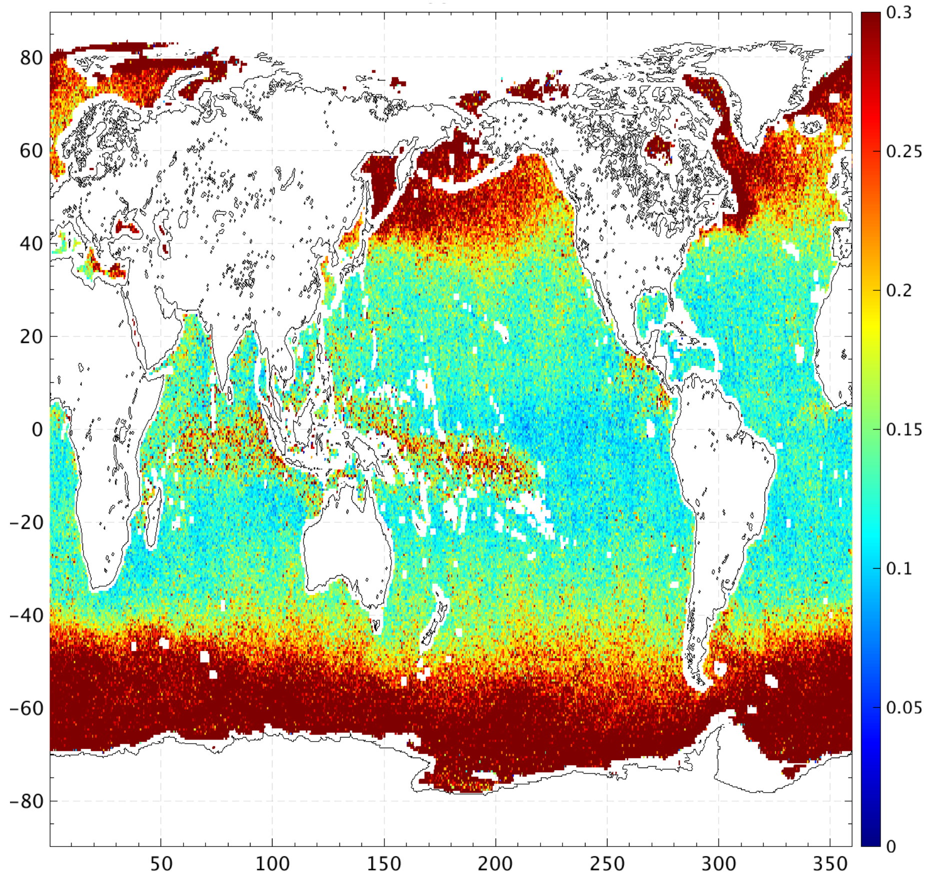
(*) *0.35 psu/20d/20 km*

SSS retrieval random error maps
Weekly products

800 MHz

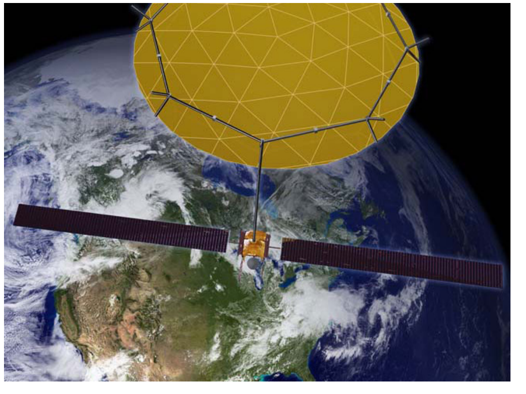


1400 MHz



Instrument Design Study

- Req: Increased spatial resolution (≤ 20 km) & low frequency
  - large 15-meter class reflector
  - tradeoff between revisit time, sensitivity and swath coverage suggest the use of multiple simultaneous footprints.
  - single-dish-multiple-feed interferometer in order to synthesize high resolution electronically steerable beams.

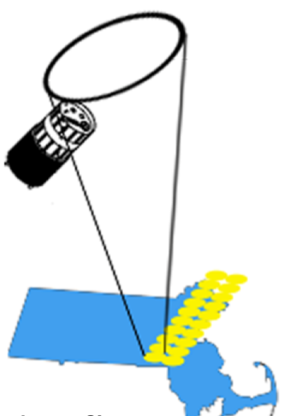


SkyTerra 1 (22 m reflector)

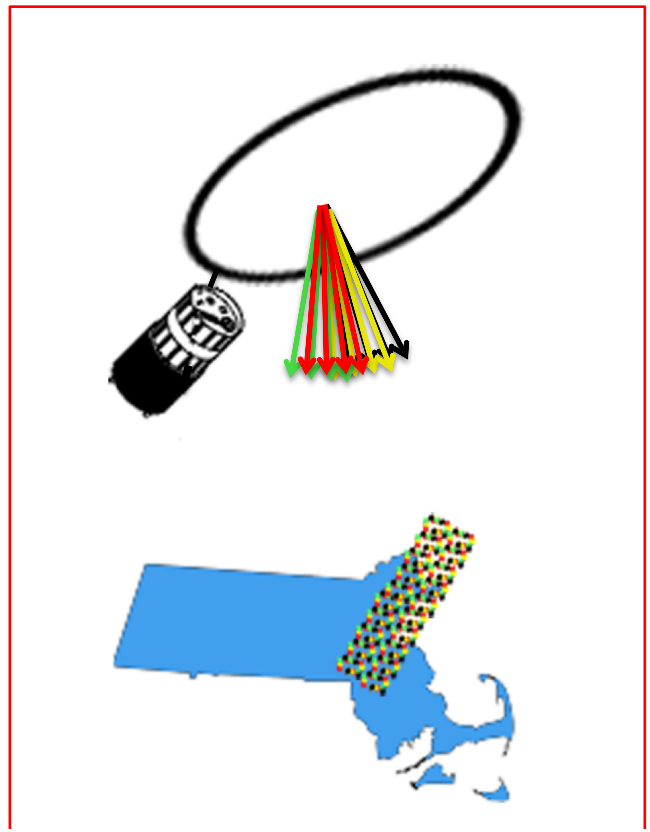
Large reflectors improve spatial resolution, but reduce coverage (for a given spin rate and integration time)

Recovery of full spatial coverage requires novel feed arrangements

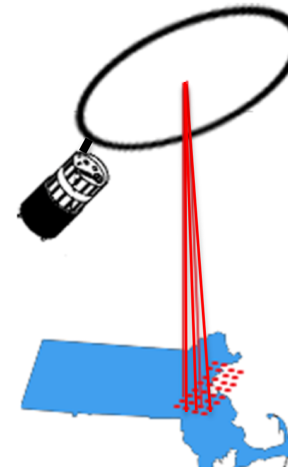
Small reflector, single feed: Nyquist-sampled full spatial coverage.



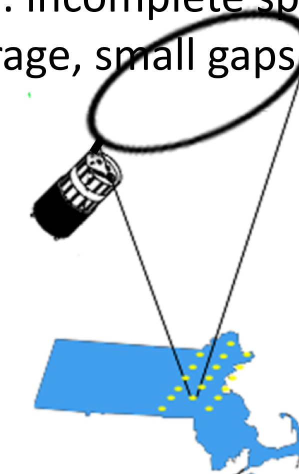
Mid-sized reflector, single feed: almost Nyquist-sampled full spatial coverage.



Instantaneous illumination shown in red; other footprints (green, yellow, black) are synthetized via phased array techniques.



Large reflector, multiple feeds: incomplete spatial coverage, small gaps



Large reflector, single feed: incomplete spatial coverage, large gaps.

Instrument Design Study

- Req: Increased spatial resolution (≤20 km) & low frequency
  - ➢ large 15-meter class reflector
  - ➢ tradeoff between revisit time, sensitivity and swath coverage suggest the use of multiple simultaneous footprints.
  - ➢ single-dish-multiple-feed interferometer in order to synthesize high resolution electronically steerable beams.

- RFI likely over parts of the bandwidth (esp. coastal areas)

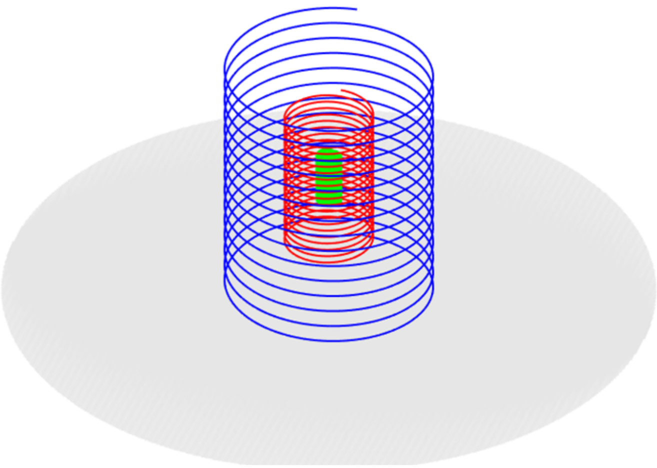
  ⇒ RFI mitigation techniques from the SMAP

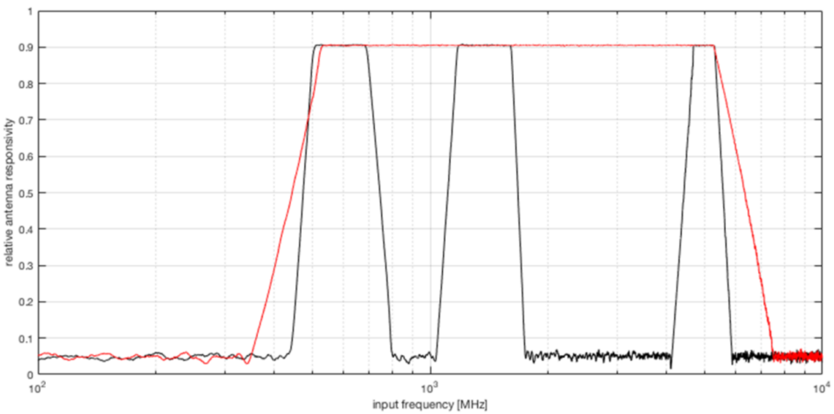
  e.g. high spectral resolution with about 4x4096 channels 275 kHz wide over ~ 500 MHz – 5000 MHz.

Approach to fit multiple low freq feeds

- Nested-helix feed assembly
- Center-of-phases of the three (600, 1410, and 5000 MHz) frequency-optimized units collocated at the focus of a shared parabolic reflector by offsetting the helices along the Z-axis
- Limits bandwidth (black line)

  ⇒ **Increases RFI survivability (?)**





Acceptance bandwidth for a nested-helix (black) vs log-periodic spiral antenna (in red)

Conclusion

- SSS observations and simulations from ocean model used to derive spatial and temporal requirements for next generation salinity

  $\Rightarrow$ 'weighted' towards coastal currents in cold waters (< 20 km, ~ 0.35 psu* over 20 days)

  * ppt, psu, pss, N/A, …

- A simulation tool was developed to assess instrument design impact on retrievals (NEDT, center frequency(/ies), bandwidth)

- Instrument study:
  - 15 m class reflector (spectral resolution)
  - Multiple frequencies over 500 MHz - 5000 MHz (cold water sensitivity & ancillary parameters uncertainty)
  - High spectral resolution (RFI)

- Ongoing study to define feeds that satisfy high spatial resolution (10 - 20 km), revisit time of 3 – 8 days, full spatial coverage and high gain efficiency

Future Work

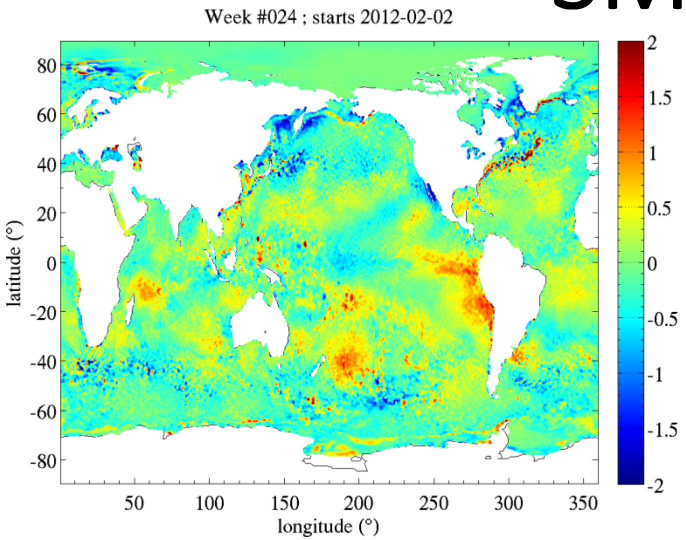
- Simulator tool improvements:
  - Add bias and varying random errors to ancillary data
  - Assess impact of model uncertainty (esp. roughness)
  - Assess atmospheric / Ionospheric effects
  - Celestial sky
  - Add multi-parameter retrieval to take advantage of whole frequency range (e.g. roughness at high freq)

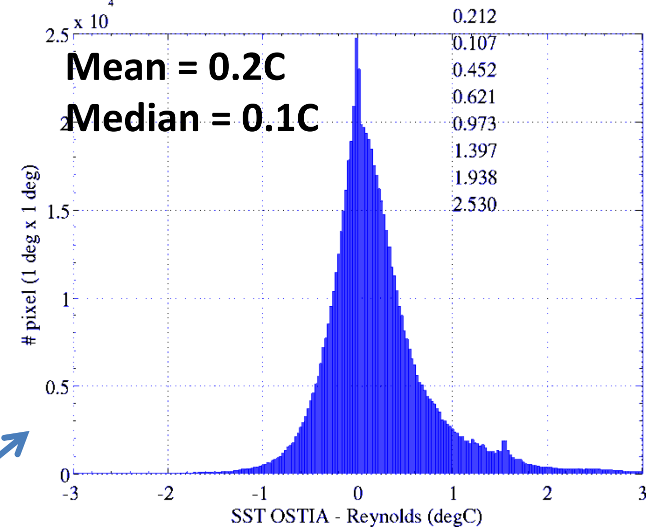
  $\Rightarrow$ Mission with wide ocean applications ? (SSS, SST, WS)
- Continue instrument design study (...)
- Open issue: RFI impact on bandwidth and instrument design in general (RFI environment unknown at low frequencies)

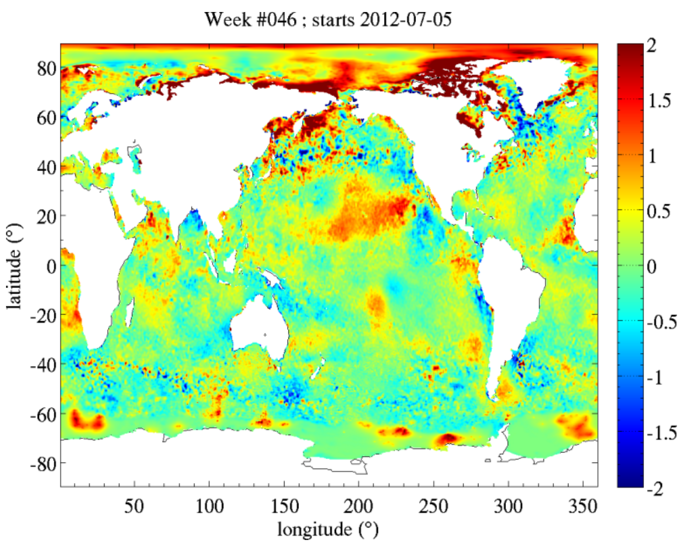
Thank you for your attention !

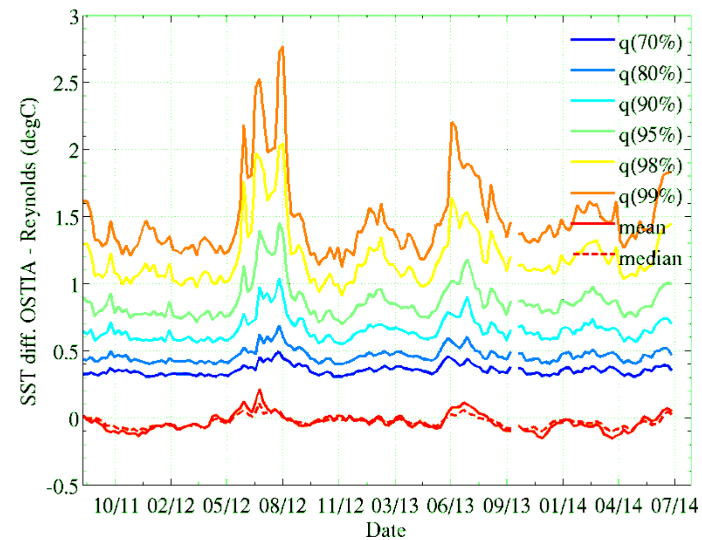
Backup

SST differences OSTIA – Reynolds OI (i.e. SMOS – Aq)



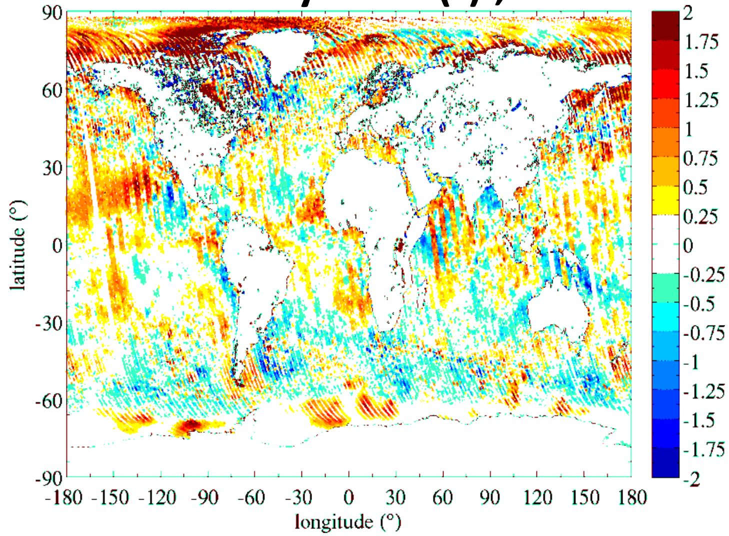




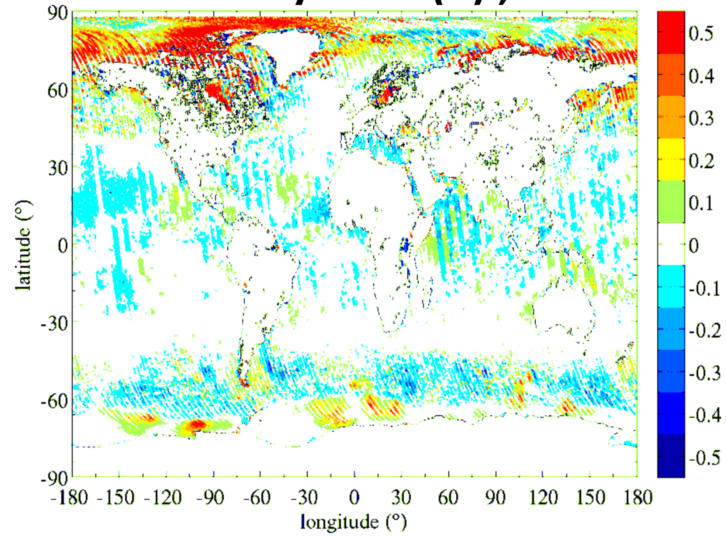


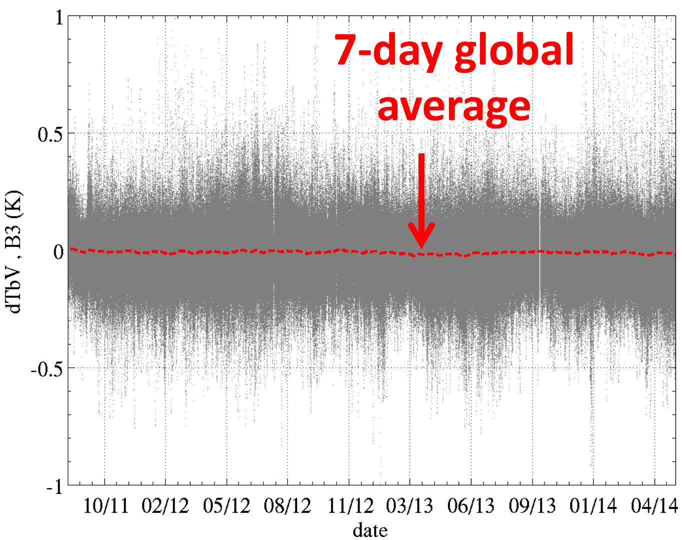
SST interpolated at Aquarius footprints

ΔSST OSTIA – Reynolds (°) ; Week 46

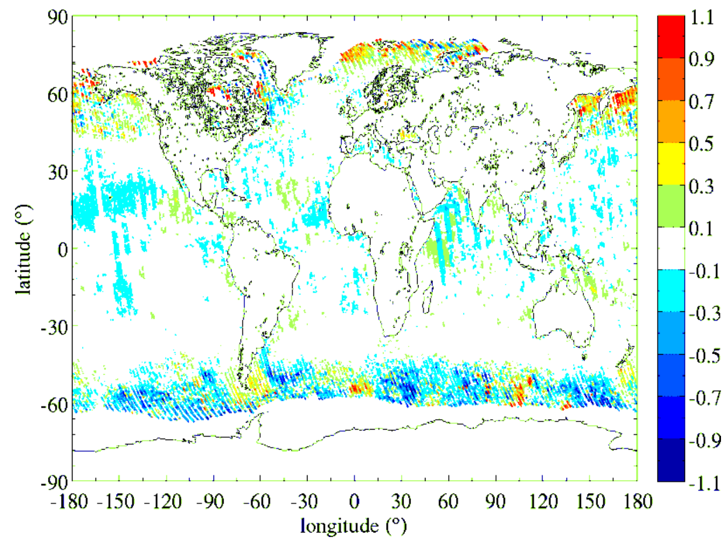


ΔTbV OSTIA – Reynolds (K) ; Week 46





ΔTbV OSTIA – Reynolds (K)
~ 3years of data



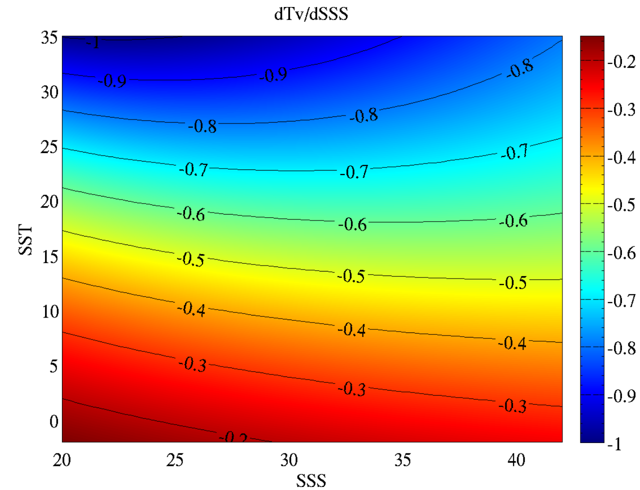
ΔSSS OSTIA – Reynolds (K)
Week 46

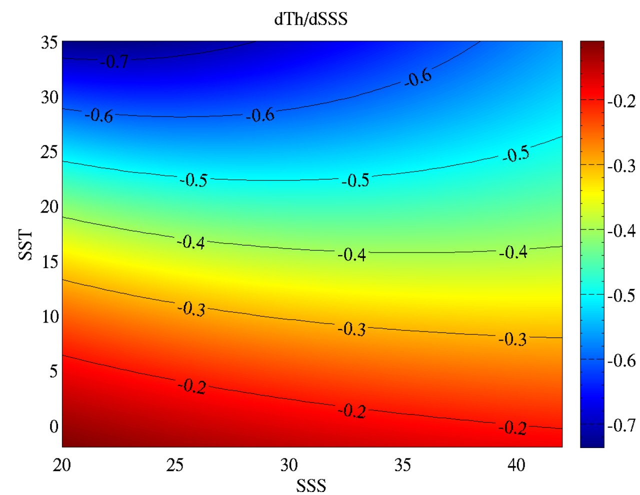
Changes in Tb from changes in SSS

dTb is computed from cumulative sum of δTb computed from changes in SSS (δSSS) for consecutive GMAO 6h fields

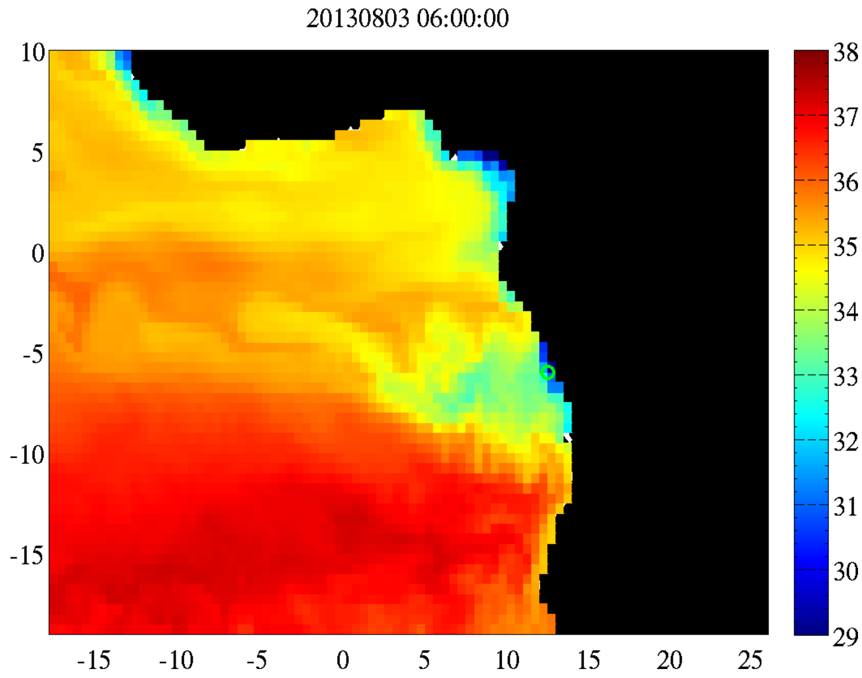
$\delta Tb = \partial Tb/\partial SSS * \delta SSS$

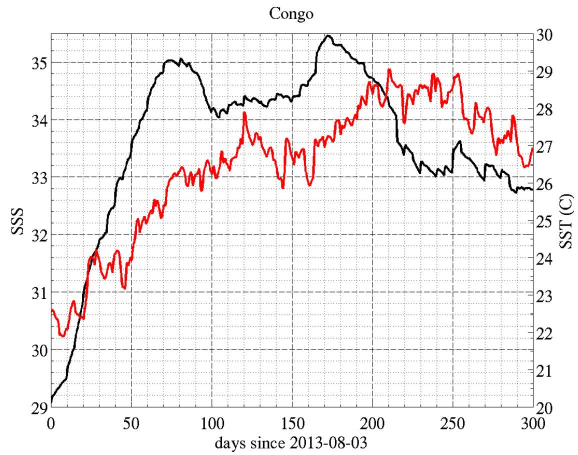
Tb sensitivity to SSS ($\partial Tb/\partial SSS$) is computed for current SST and SSS from lookup tables to the right =>

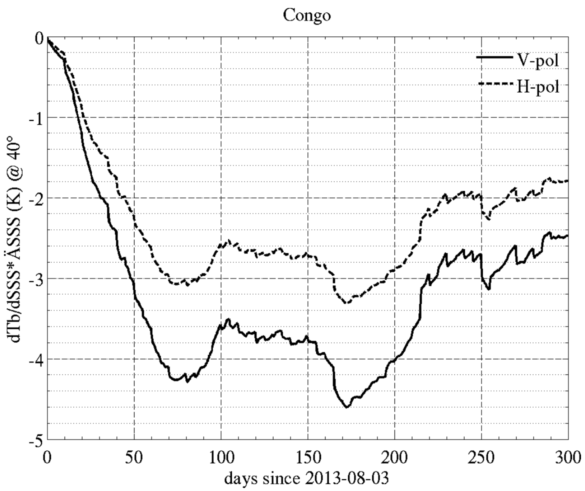




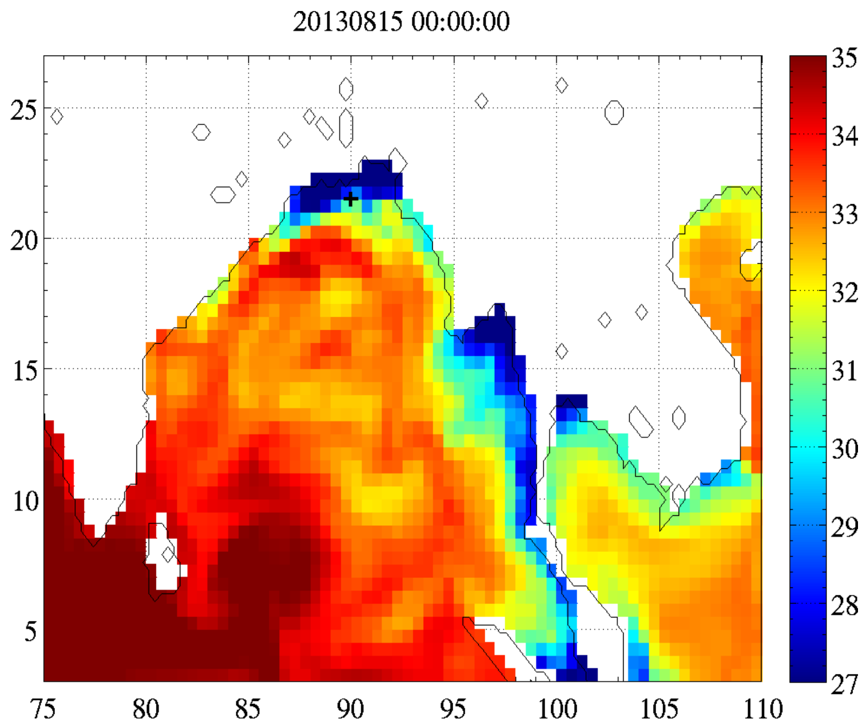
Congo river mouth

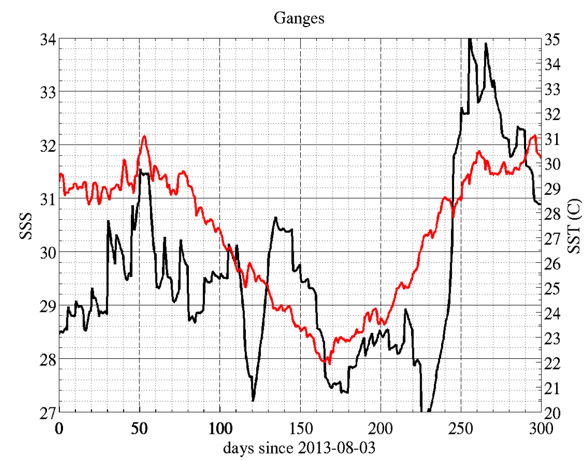


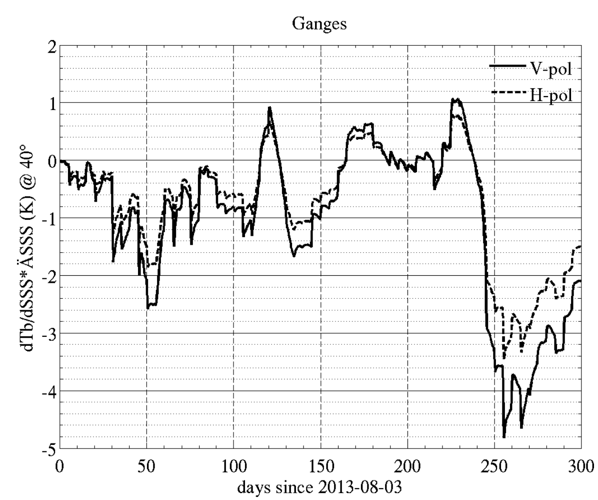




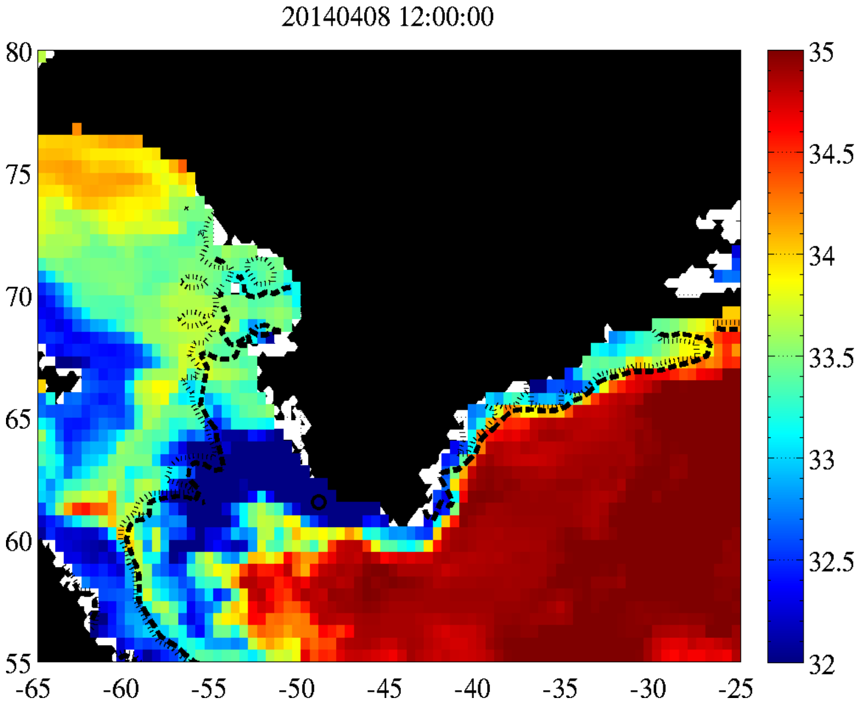
Ganges mouth

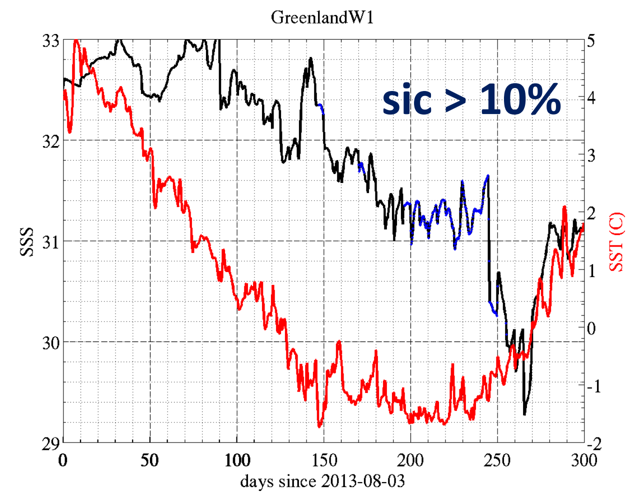


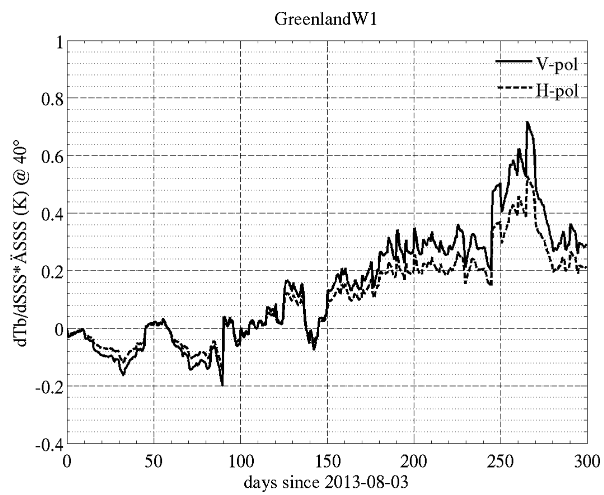




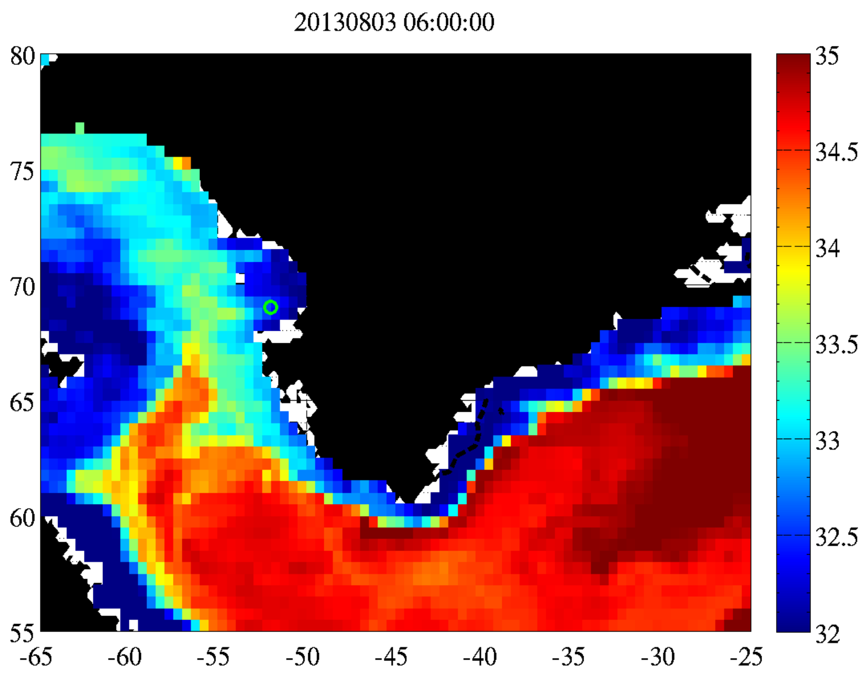
Greenland West 1

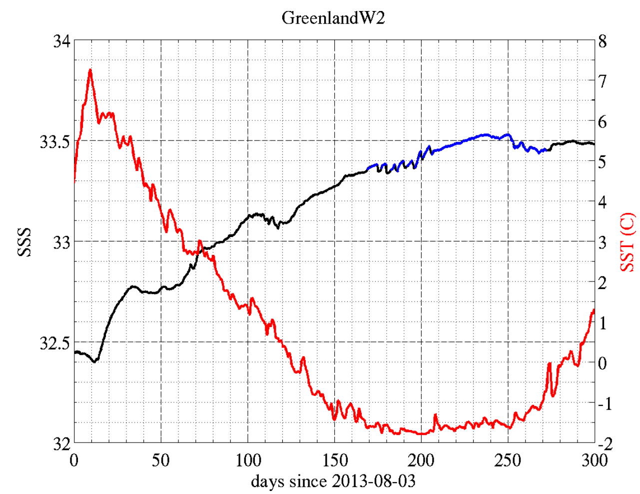


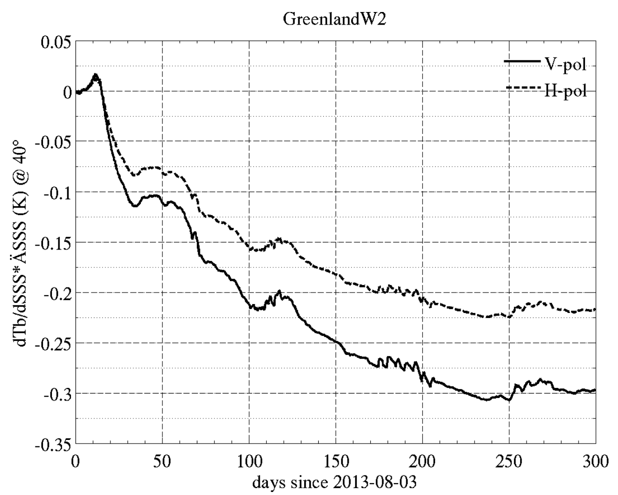




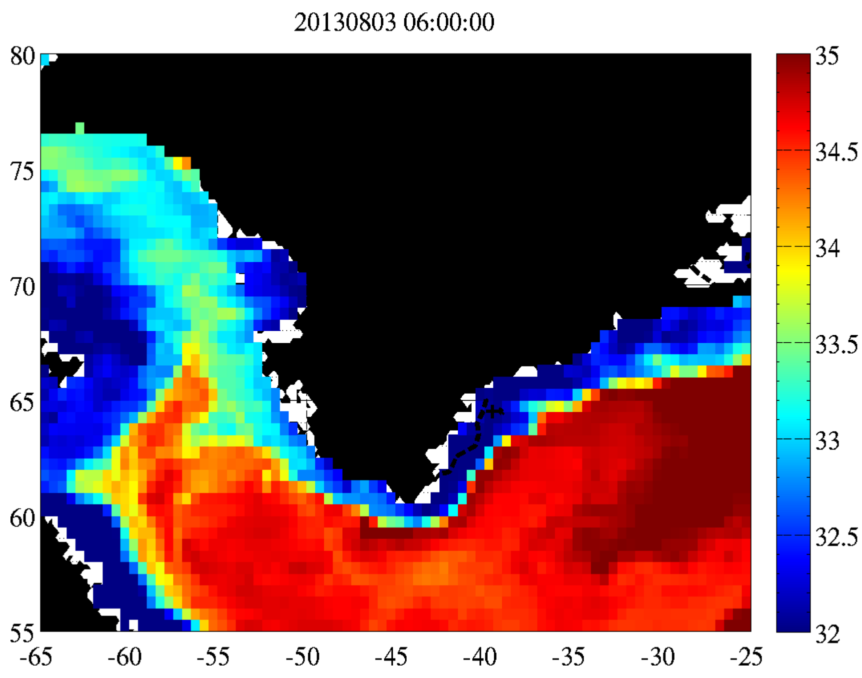
Greenland West 2
Jakobshavn Glacier

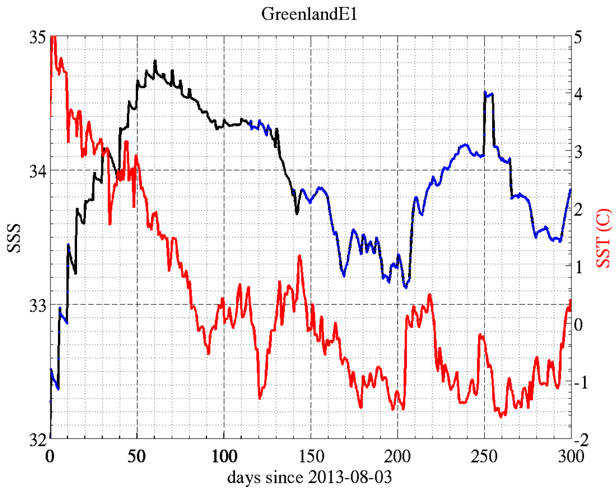


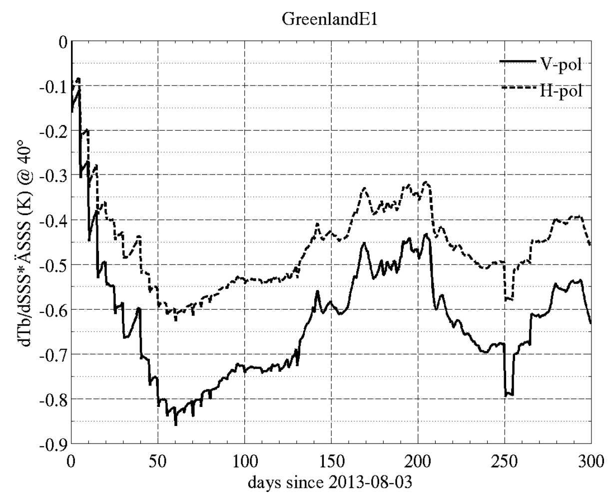




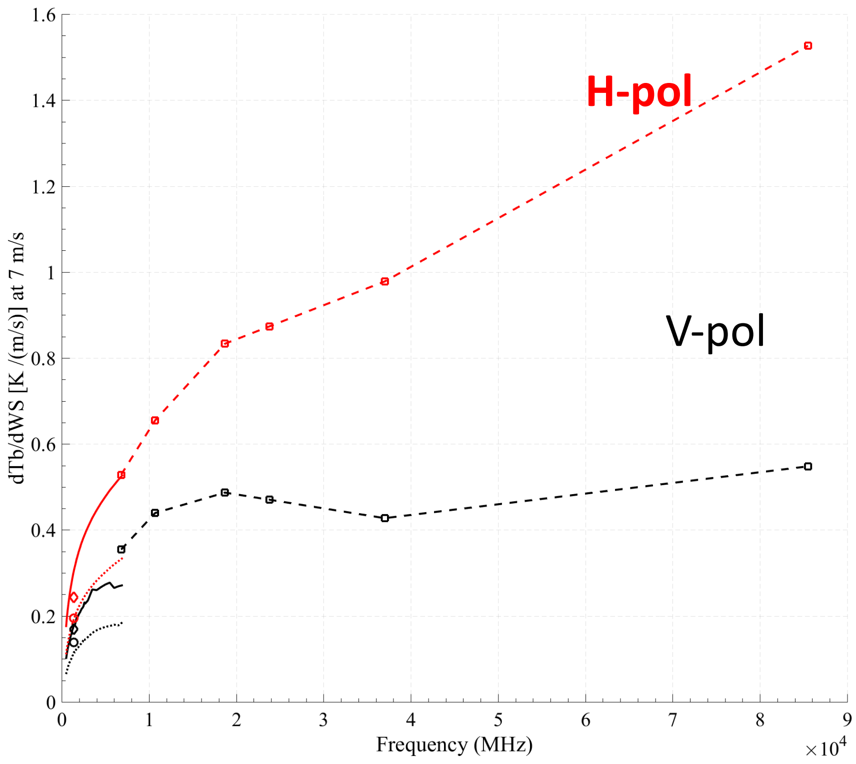
Greenland East







Uncertainty on wind impact dependence with frequency



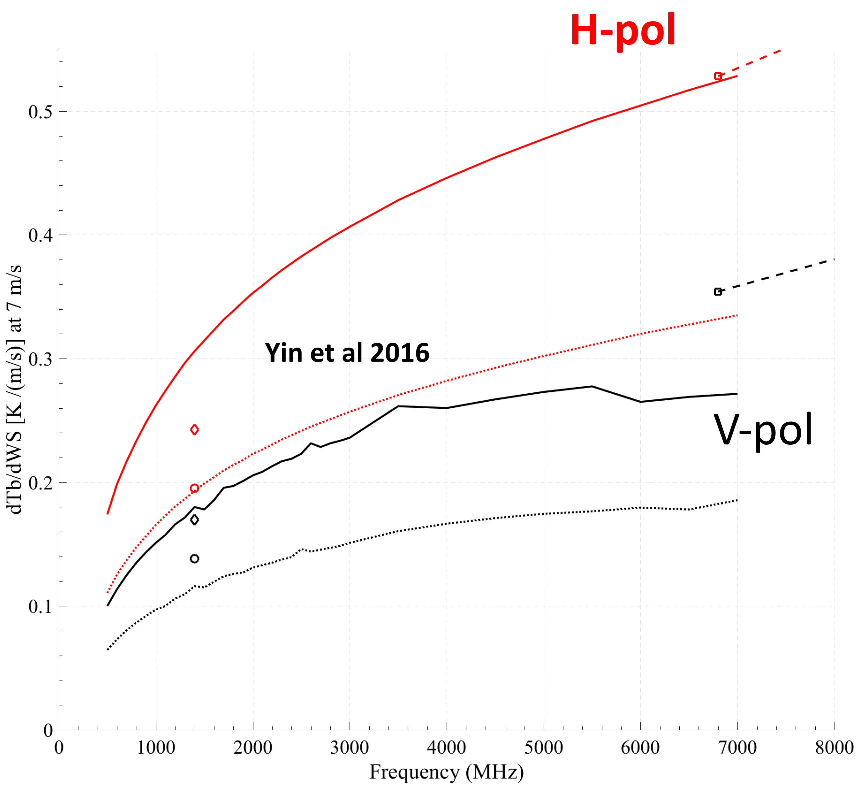
Uncertainty on wind impact dependence with frequency

- Wind impact vs frequency still uncertain at low end
  - Yin et al (2016): revised TSM with sea spectrum and foam model adjusted with SMOS TB

  -> Durden and Vesecky (1985) * 1.25

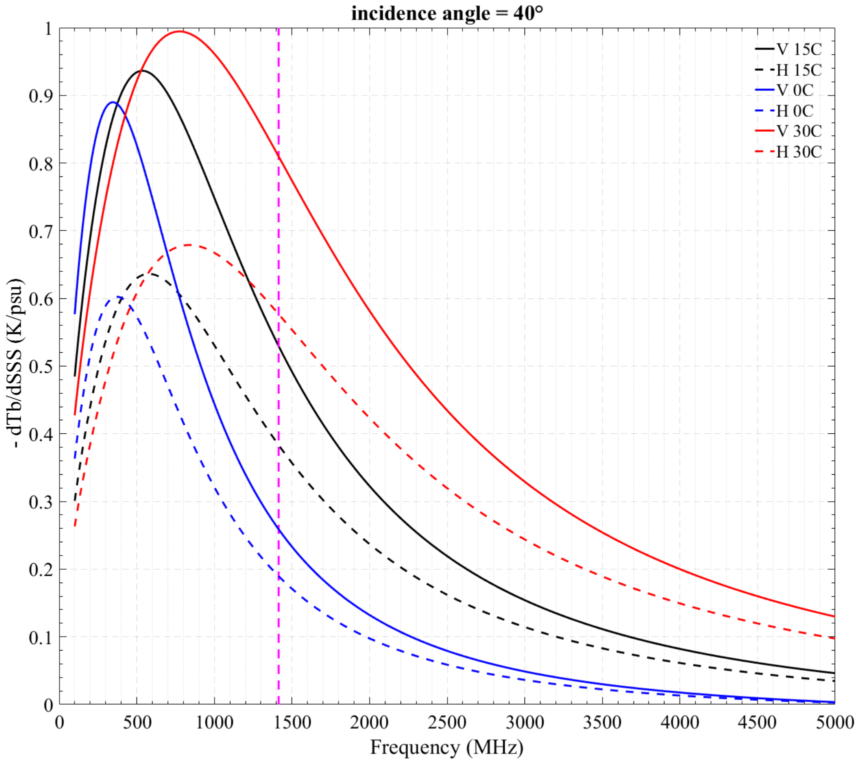
  -> foam XXX
  - Aquarius GMF (Meissner et al., 2014)

- Simulation using smaller wind impact model to be performed

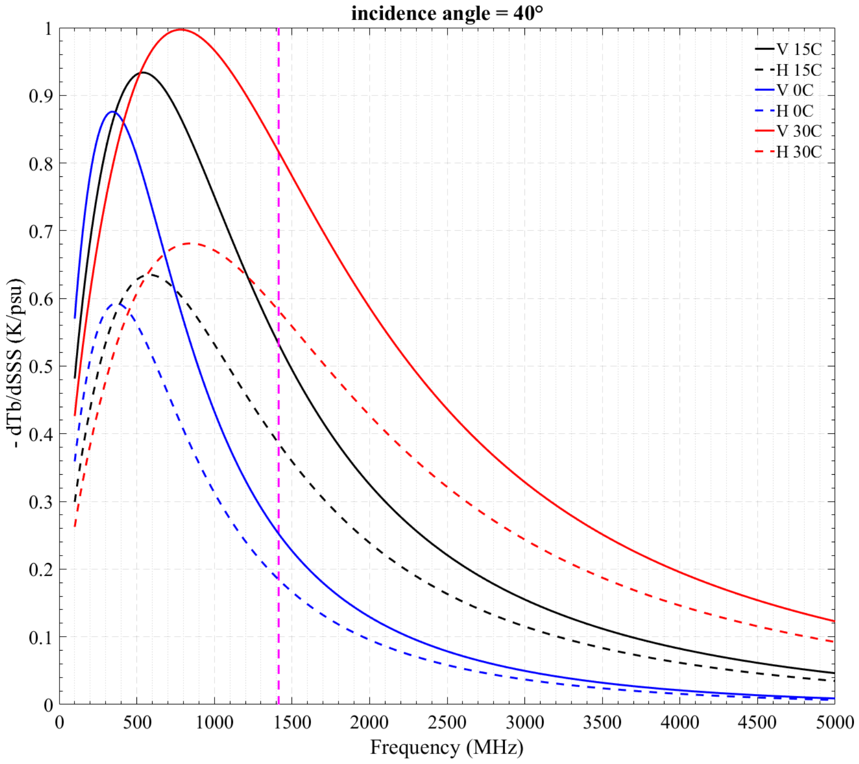


Difference in models
Sensitivity to salinity

Klein and Swift (1977)

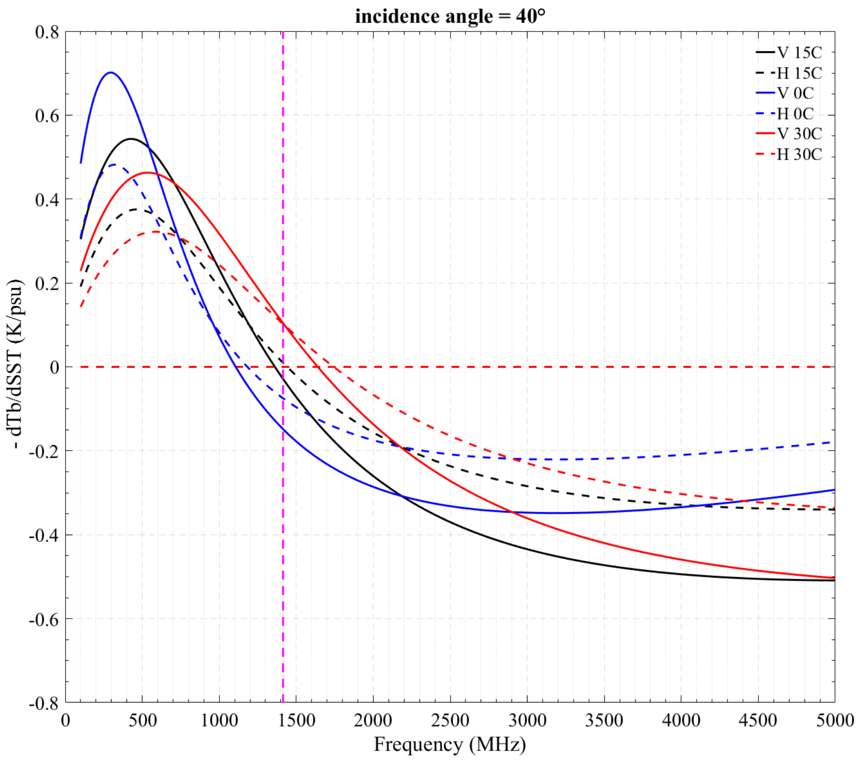


Meissner and Wentz (2004, 2012)

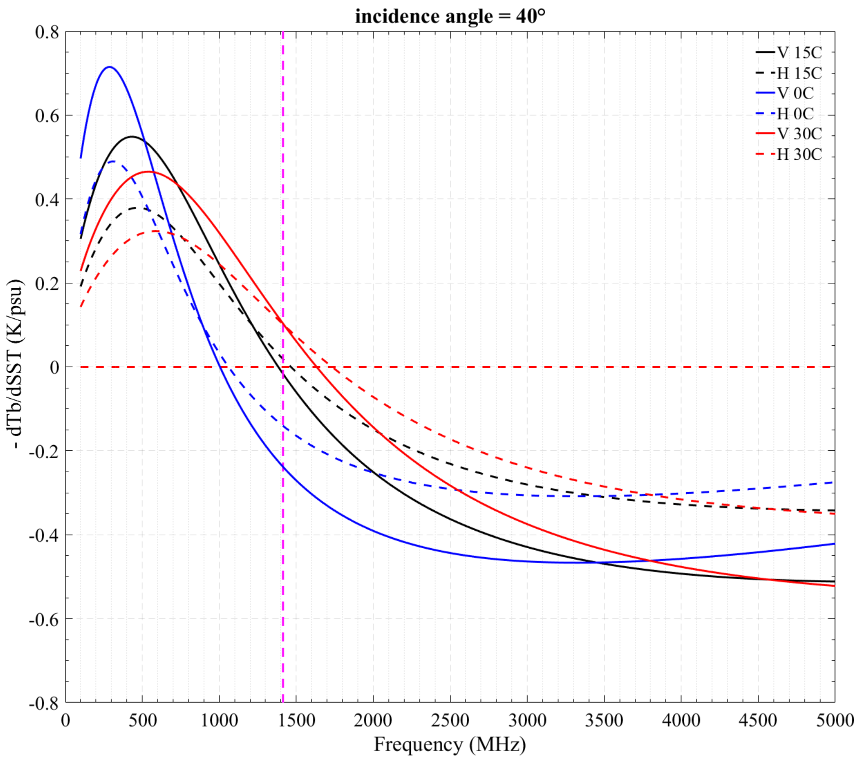


Difference in models
Sensitivity to temperature

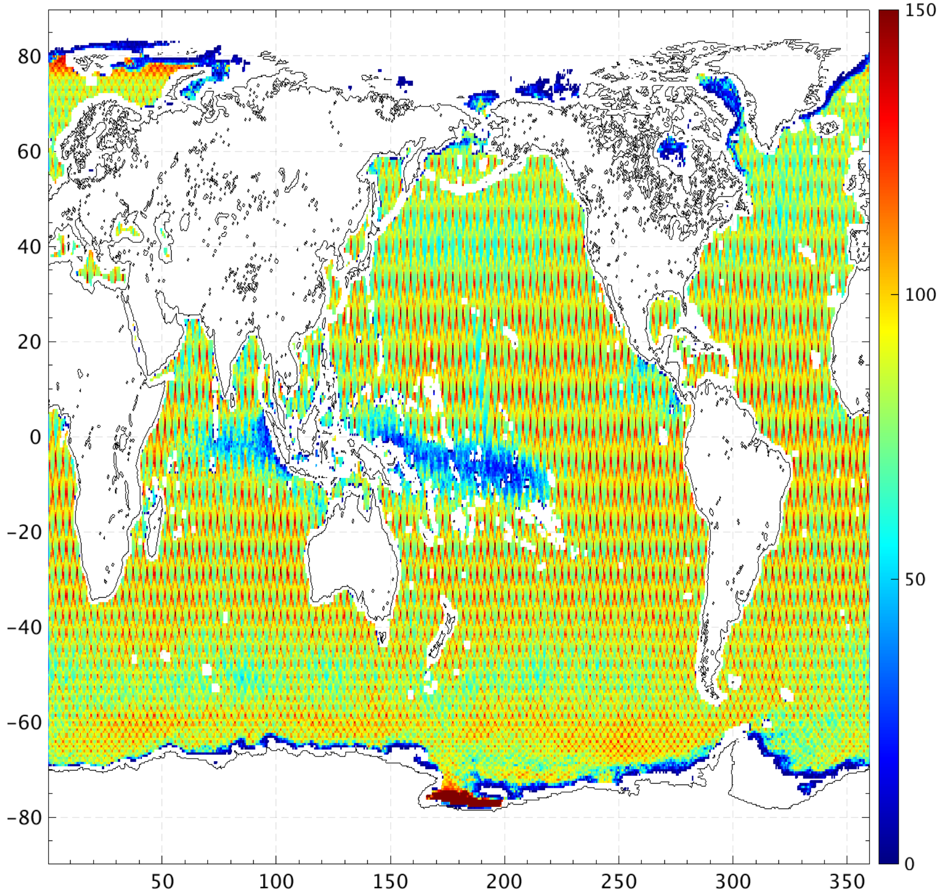
Klein and Swift (1977)

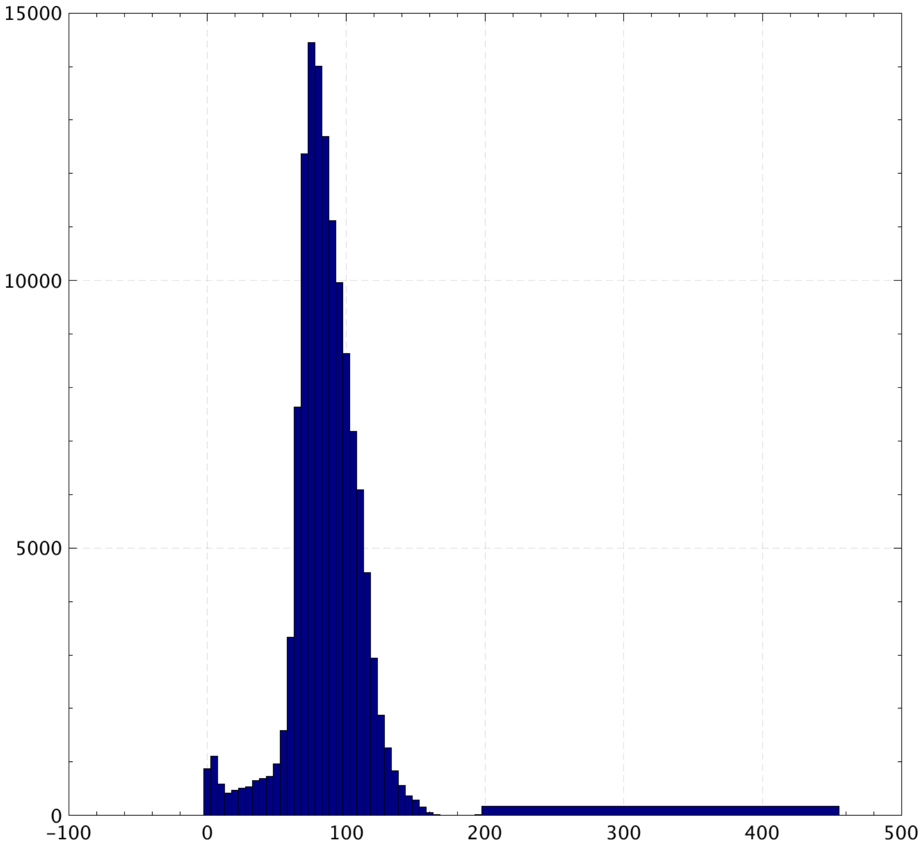


Meissner and Wentz (2004, 2012)



Number of obs per grid cell (0.5°x0.5° weekly)





- 0.70 at 0.125 deg, Daily
- 0.66 at 0.625 deg, Daily (Ricciardulli and Wentz 2004)