Ocean Permittivity: Considerations for the CRTM

Eric Bayler
NESDIS / STAR

Traceability of Sea-Surface Salinity (SSS) to Brightness Temperature (T_b)

Generic T_b:

$$Tb_p(\theta) = Tb^{\uparrow}(\theta) + \tau_{atm}\left[E_p(\theta)T_{sfc} + Tb_p^s(\theta)\right]$$

E_p(θ) is polarized surface emissivity

Generic Ocean Surface Emissivity (ϵ):

$$\epsilon_{sfc}(v,\theta,p,SST,SSS,U,\phi) = \epsilon_{flat}(v,\theta,p,SST,SSS) + \epsilon_{rough}\left(\epsilon_{flat},U,\phi\right) + \varepsilon_{foam}(U,\theta)$$

Fresnel Reflectivity (polarization):

$$E_v = \left(\frac{P_r\cos\theta - \sqrt{P_r - 1 + \cos^2\theta}}{P_r\cos\theta + \sqrt{P_r - 1 + \cos^2\theta}}\right)^2 + \left(\frac{P_i\cos\theta - \sqrt{P_i - 1 + \cos^2\theta}}{P_i\cos\theta + \sqrt{P_i - 1 + \cos^2\theta}}\right)^2 \qquad E_h = \left(\frac{\cos\theta - \sqrt{P_r - 1 + \cos^2\theta}}{\cos\theta + \sqrt{P_r - 1 + \cos^2\theta}}\right)^2 + \left(\frac{\cos\theta - \sqrt{P_i - 1 + \cos^2\theta}}{\cos\theta + \sqrt{P_i - 1 + \cos^2\theta}}\right)^2$$

P_r , P_i = ocean permittivity (real, imaginary)

Permittivity (dielectric constant):

$$P = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_1}{1 + j2\pi\nu\tau_1} + \frac{\varepsilon_1 - \varepsilon_\infty}{1 + j2\pi\nu\tau_2} - j\frac{\sigma}{2\pi\upsilon\varepsilon_0}$$

complex double Debye model

Empirical models: ε_s, ε_1, σ, τ = f(SSS)

Relevant Empirical Ocean Permittivity Models

- **Klein & Swift (1977)**
  - 1 – 10 GHz (focused at 1 - 3GHz)
  - Poor representation above 10 GHz
  - Primary reference model

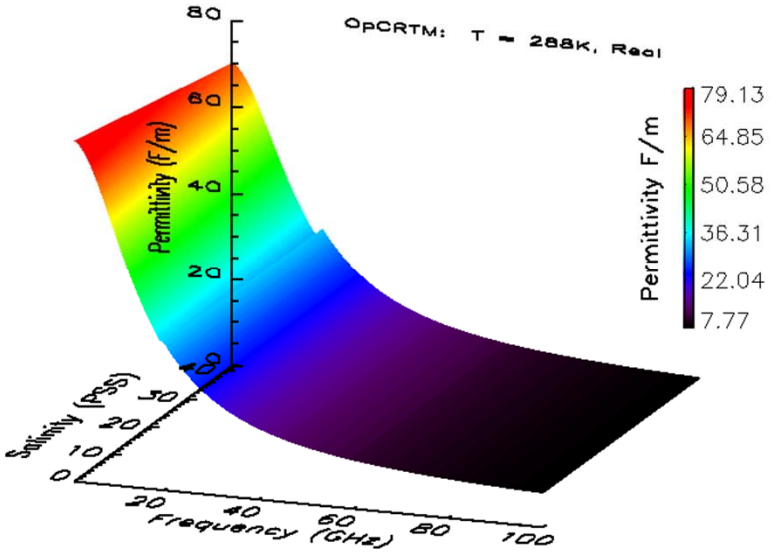
- **Guillou *et al.* (1998)**
  - 3 – 37 GHz
  - ***Current CRTM permittivity model for frequencies < 20 GHz***

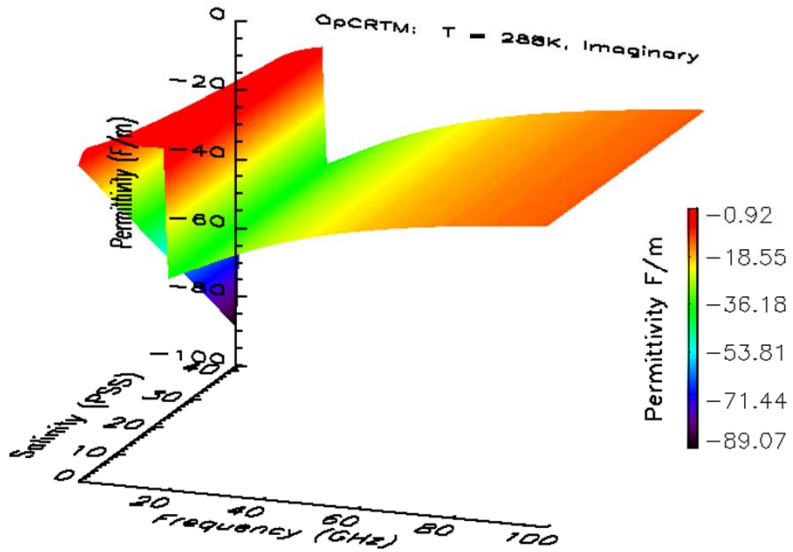
- **Ellison *et al.* (2003) = FASTEM-3**
  - 30 – 105 GHz
  - **DOES NOT INCLUDE SALINITY DEPENDENCE**
    - At higher frequencies, salinity dependence becomes negligible
  - ***Current CRTM permittivity model for frequencies ≥ 20 GHz***

- **Liu *et al.* (2010) = FASTEM-4**
  - 1 – 410 GHz
  - **Pending CRTM operational implementation**
    - Being implemented at UK Met Office and ECMWF

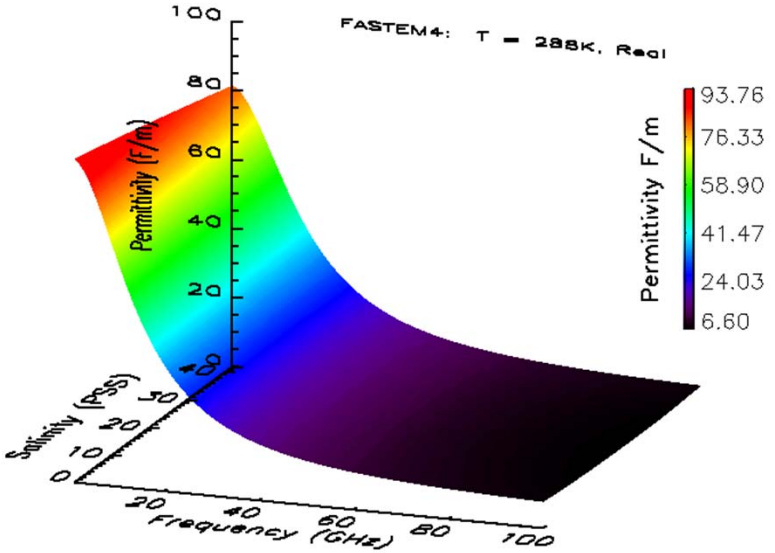
CRTM Configuration (T = 288°K)

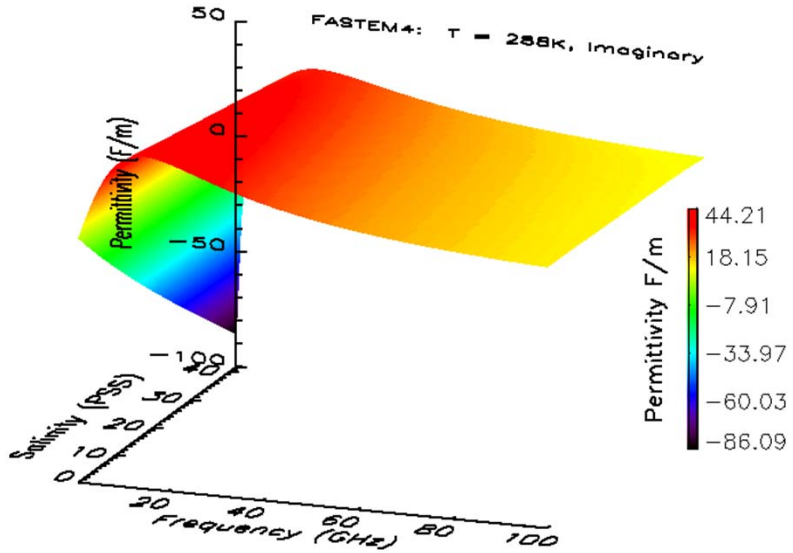
Operational Permittivity: Freq < 20 GHz, Guillou *et al.*; **Freq ≥ 20 GHz**, Ellison *et al.*





Pending Operational Permittivity: Freq 1 – 410 GHz, FASTEM4



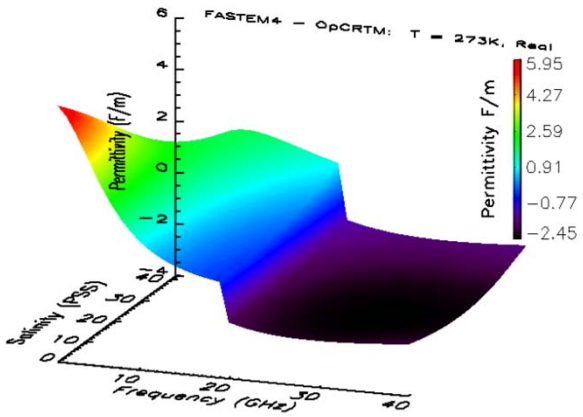


Temperature Implications

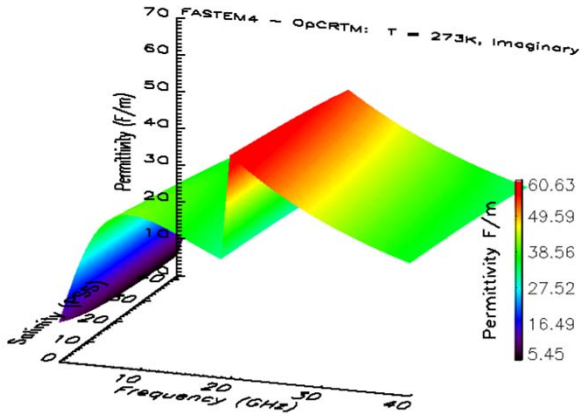
FASTEM4 - OpCRTM

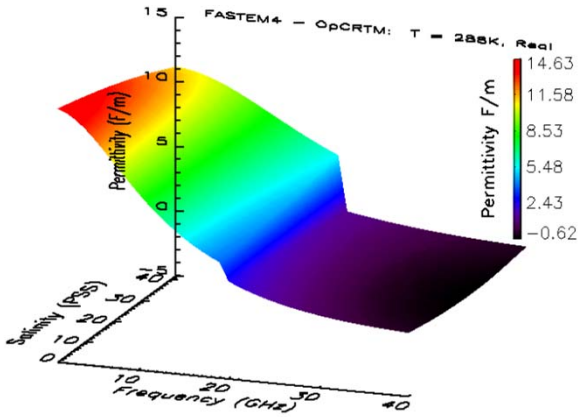
Real Component

Imaginary Component

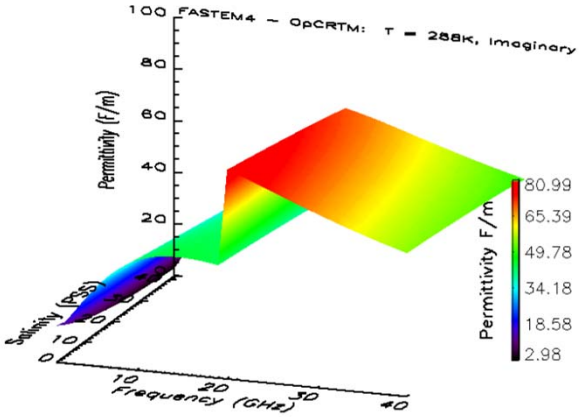


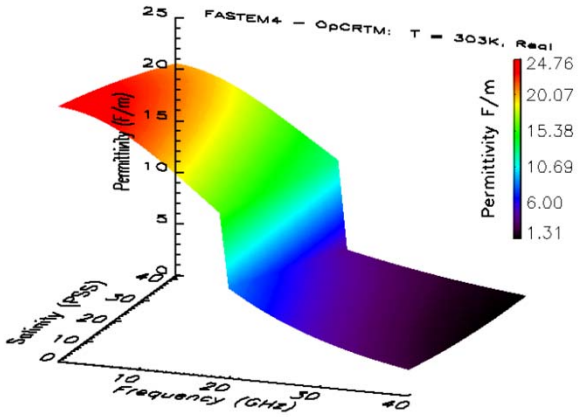
T = 273°K = 0°C



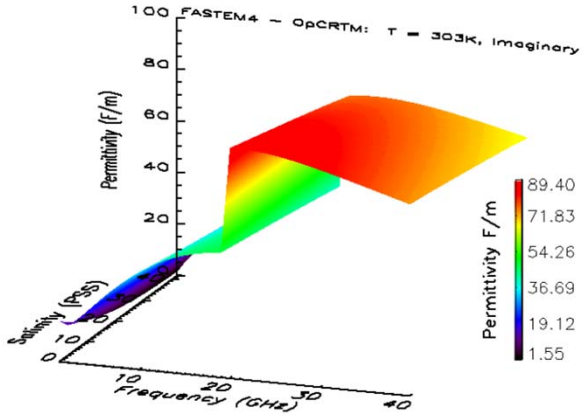


T = 288°K = 15°C





T = 303°K = 30°C



Permittivity: Salinity Implications

at 288^{0}K relative to 35 PSS

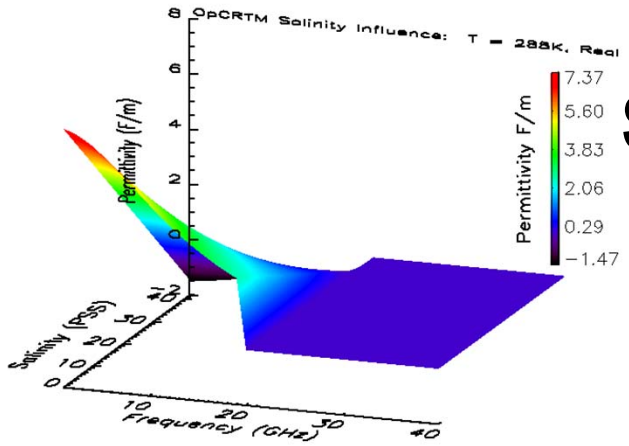
Real Component

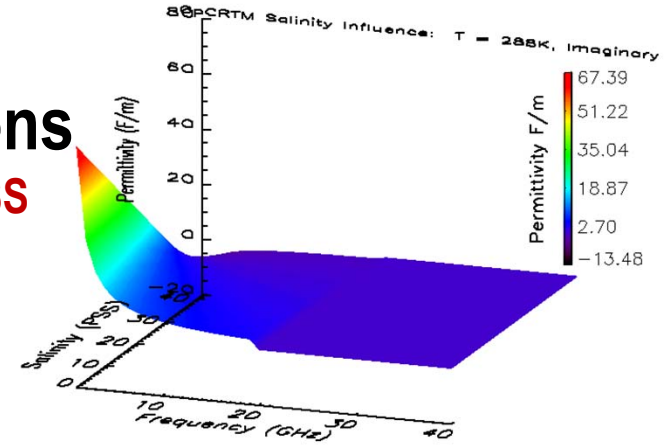
Imaginary Component

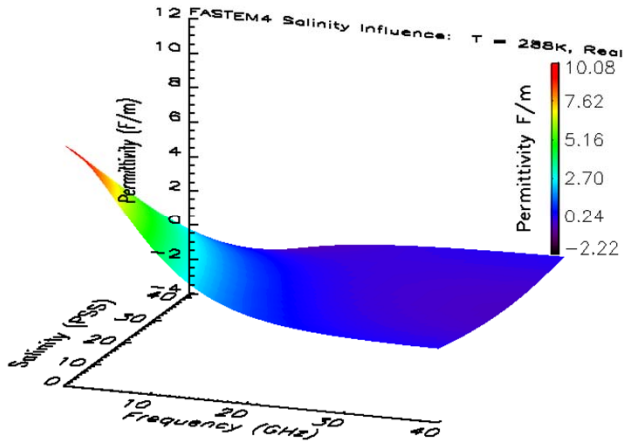
OpCRTM

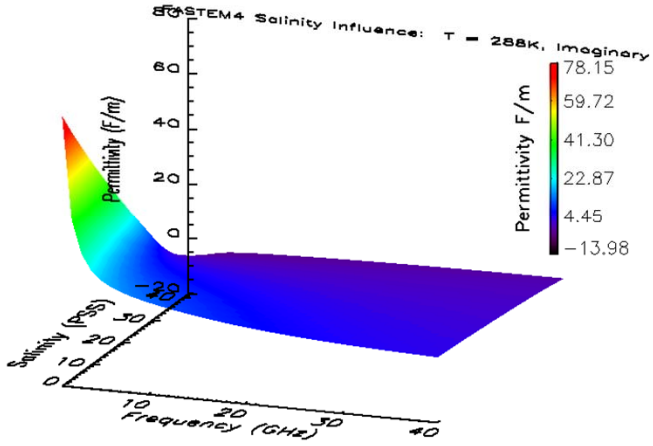
FASTEM4

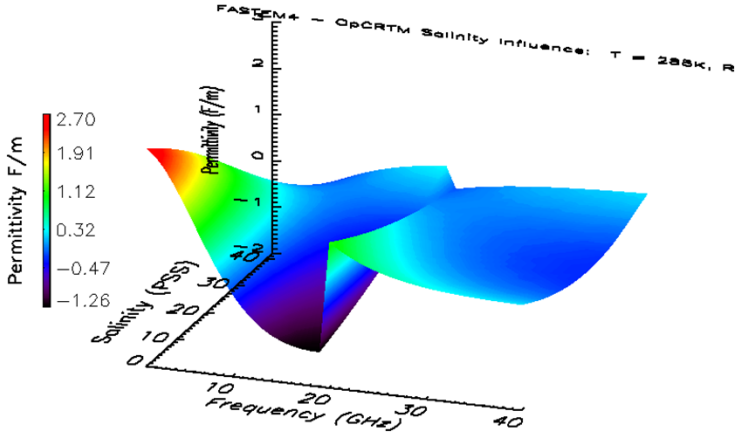
FASTEM4 - OpCRTM

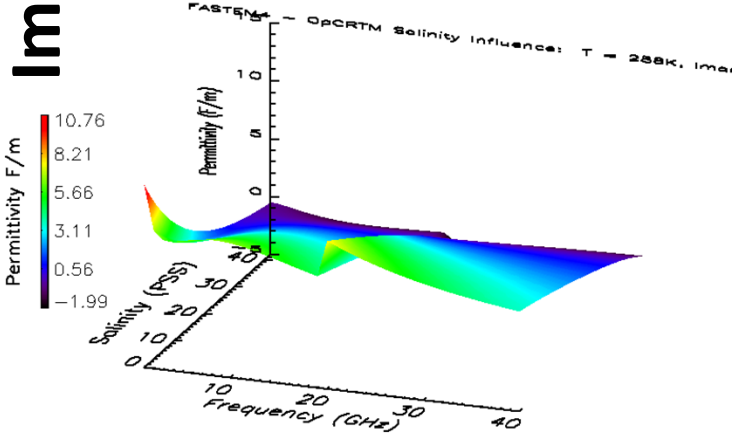








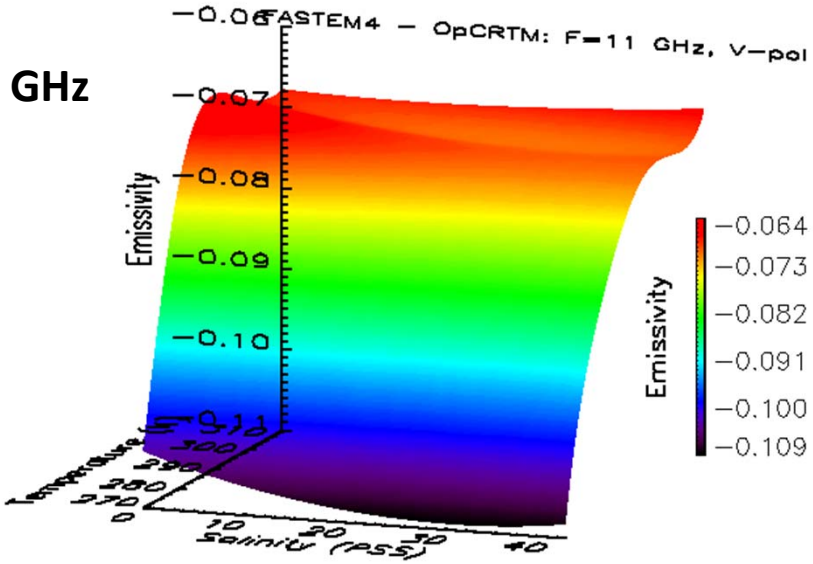




Emissivity Implications: FASTEM4 - OpCRTM

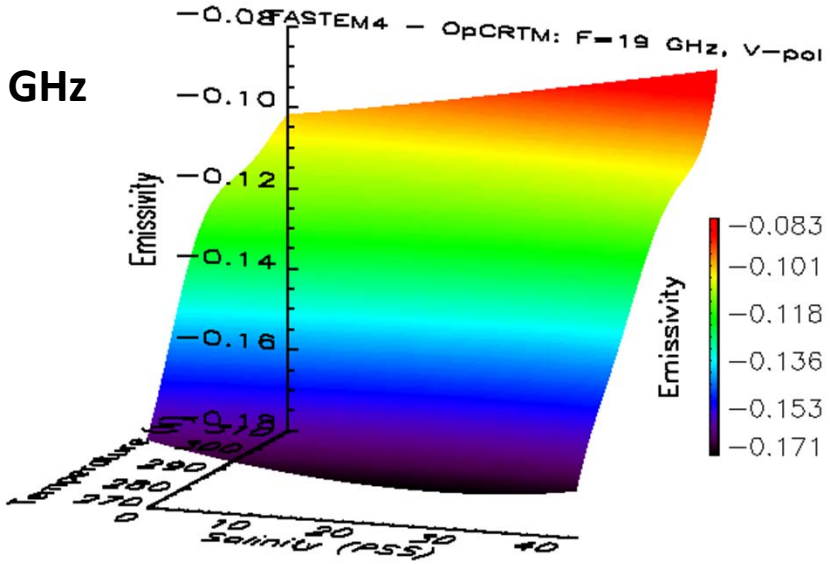
Case: Nadir view; Flat sea; No wind; Vertical polarization

11 GHz



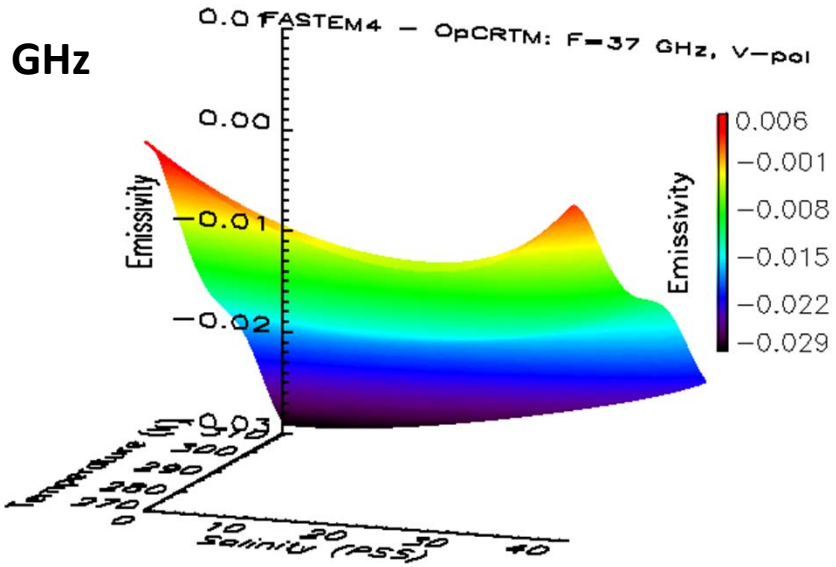
AMSR-E, WindSat, TMI

19 GHz



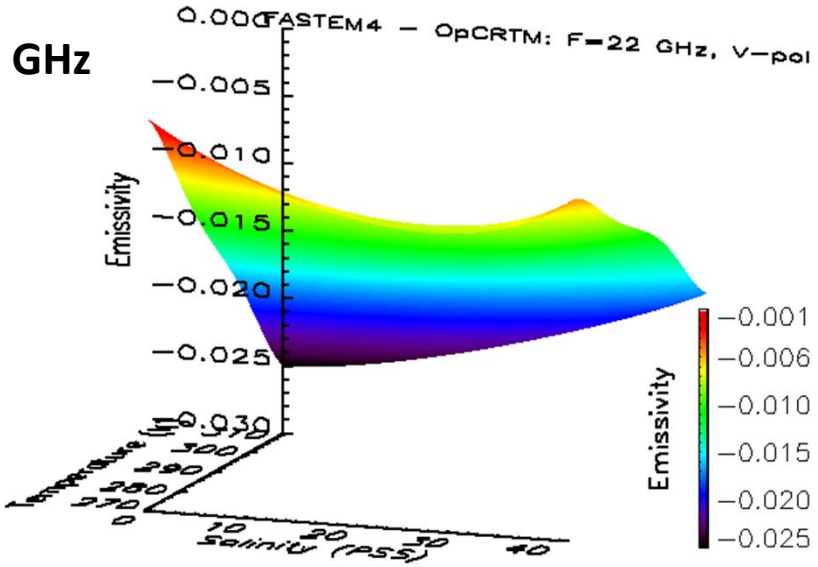
AMSR-E, WindSat, SSMIS, Jason MWR, TMI

22 GHz



AMSR-E, WindSat, SSMIS, AMSU-A2, ATMS, Jason MWR, TMI

37 GHz

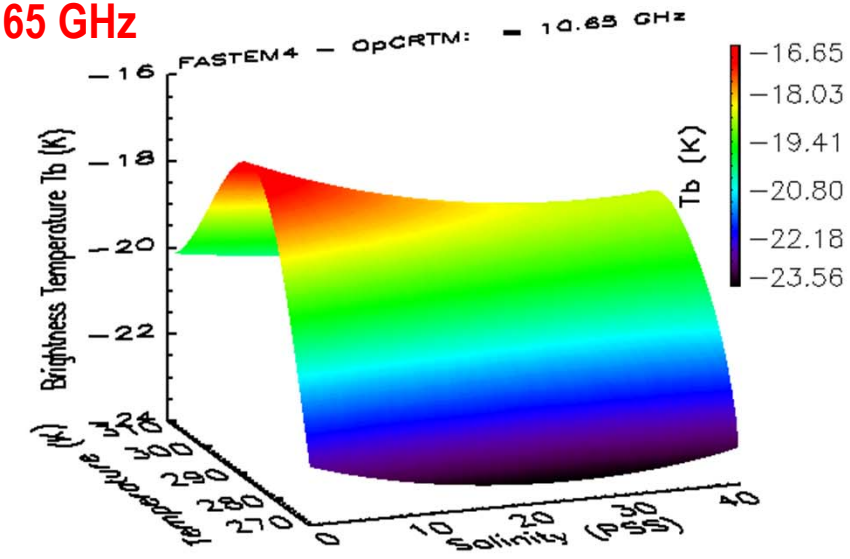


AMSR-E, WindSat, SSMIS, AMSU-A2, ATMS, Jason MWR, and TMI

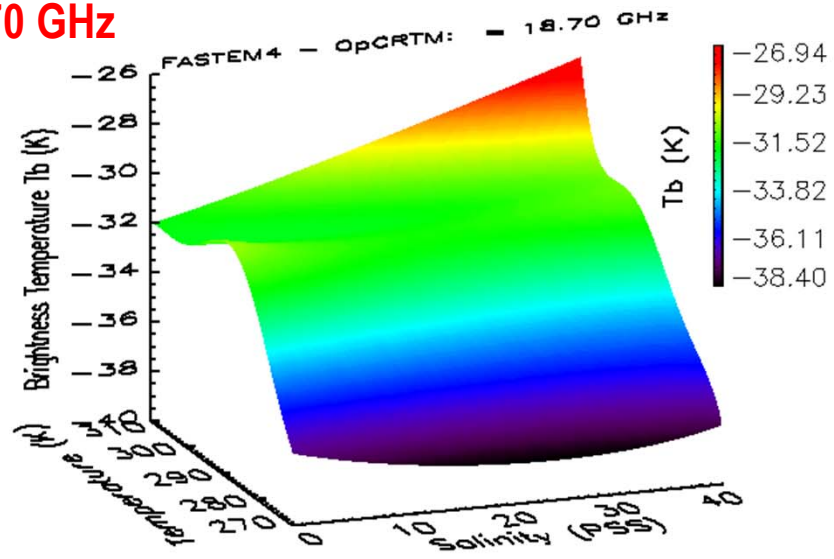
Brightness Temperature Implications: AMSR-E

FASTEM4 – OpCRTM Case: Nadir view; Flat sea; No wind; Vertical polarization

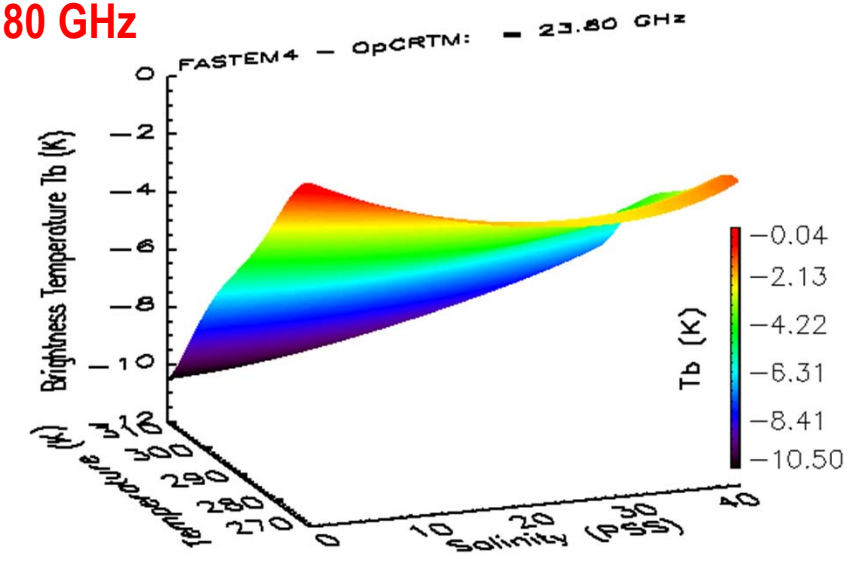
10.65 GHz



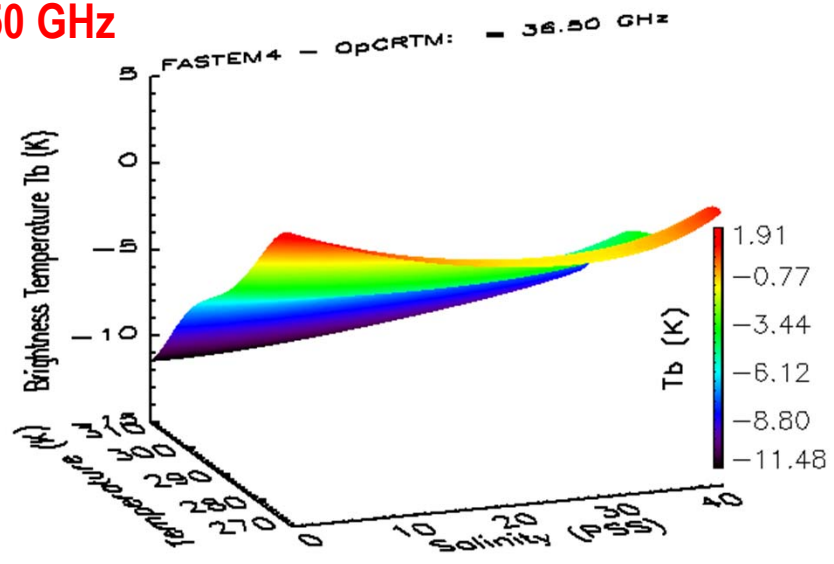
18.70 GHz



23.80 GHz



36.50 GHz

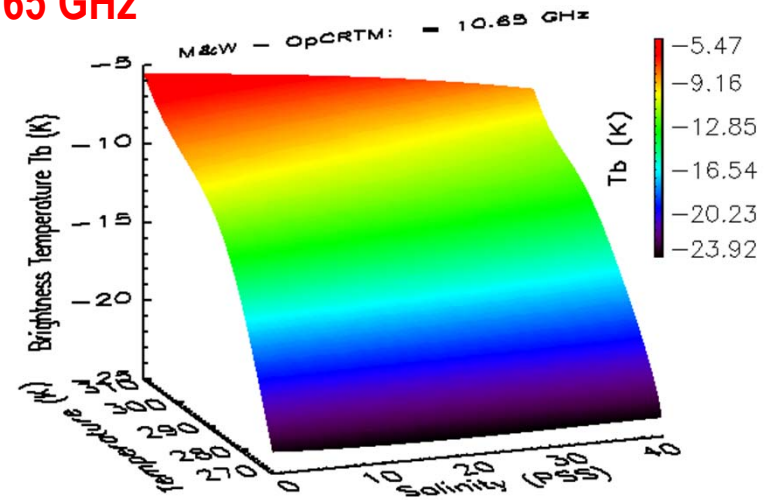


NOAA operational AMSR-E SST: (Meissner & Wentz, 2004)

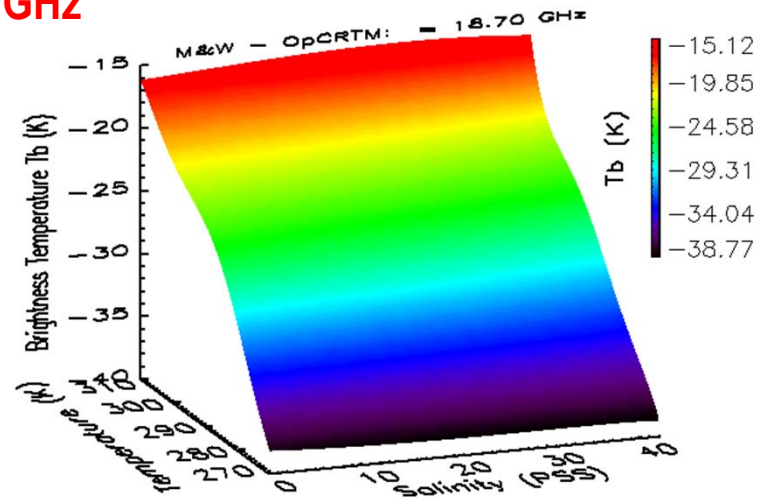
AMSR-E T_b Difference: M&W – OpCRTM

Case: Nadir view; Flat sea; No wind; Vertical polarization

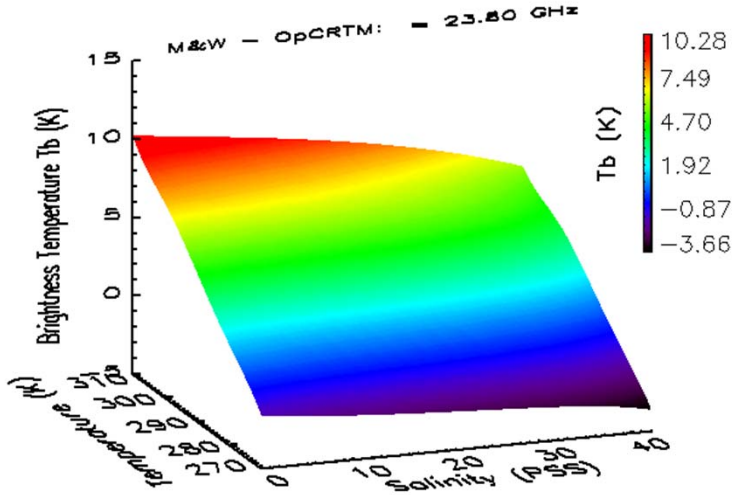
10.65 GHz



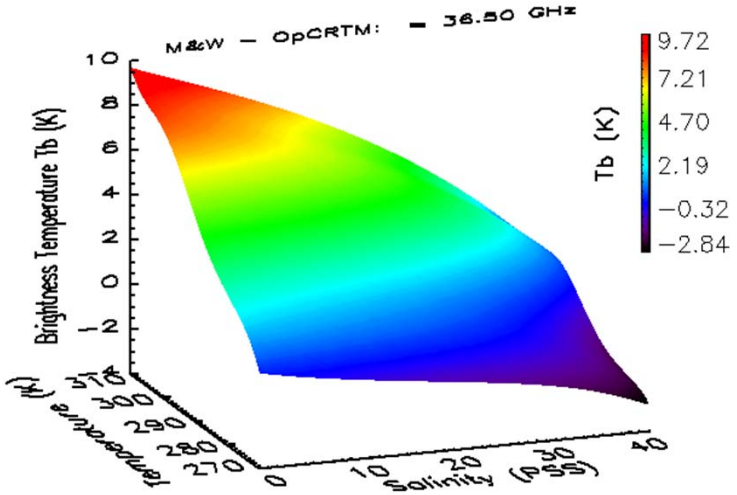
18.70 GHz



23.80 GHz



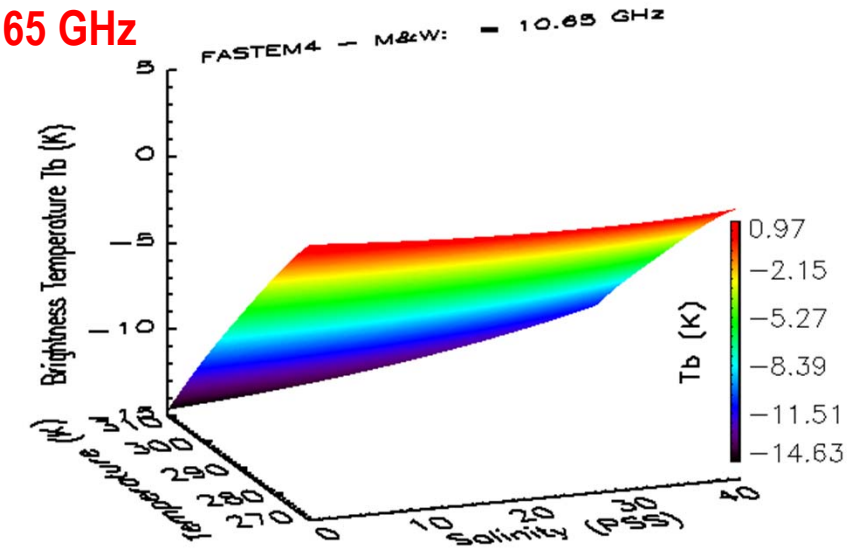
36.50 GHz



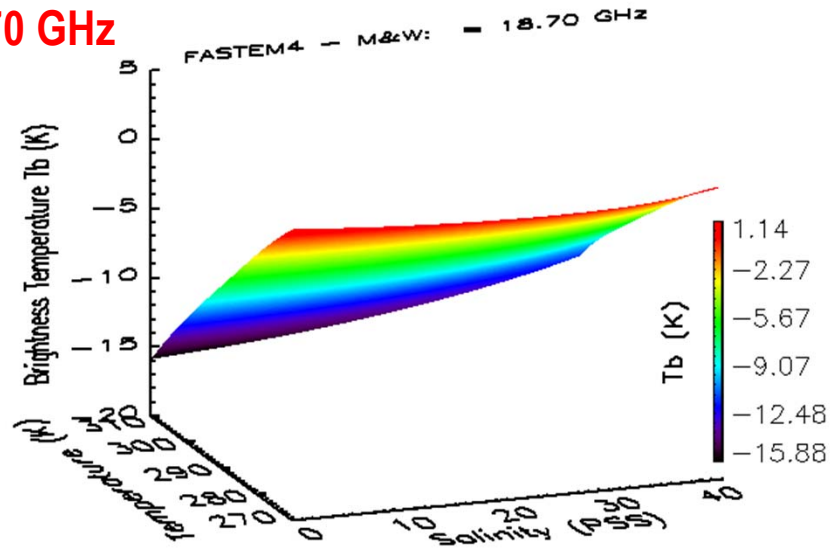
T_b Difference: FASTEM4 – M&W

Case: Nadir view; Flat sea; No wind; Vertical polarization

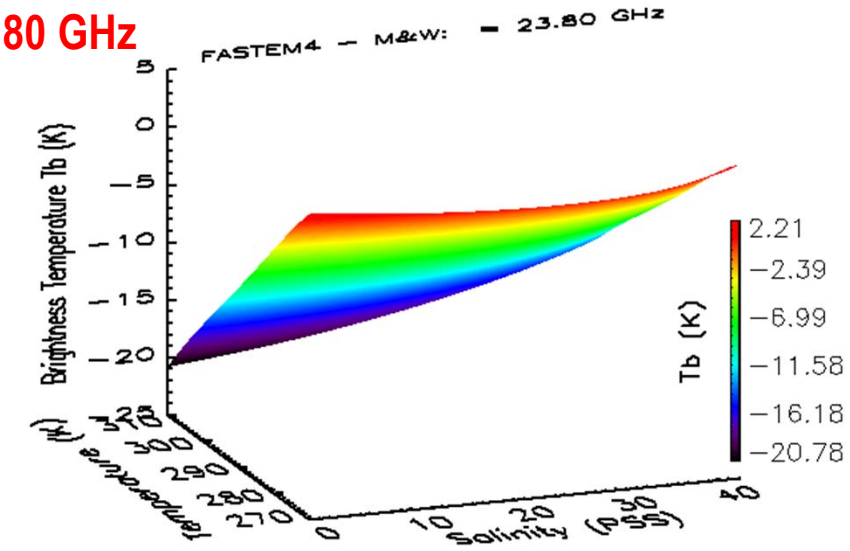
10.65 GHz



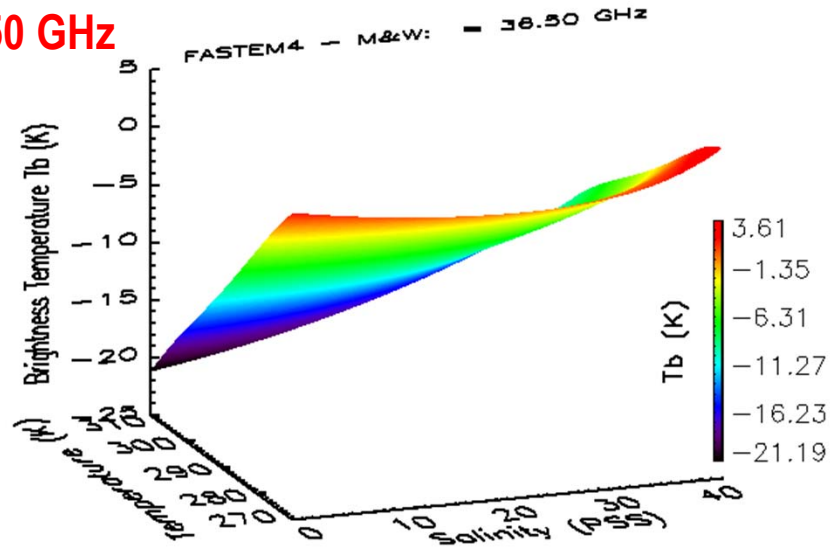
18.70 GHz



23.80 GHz



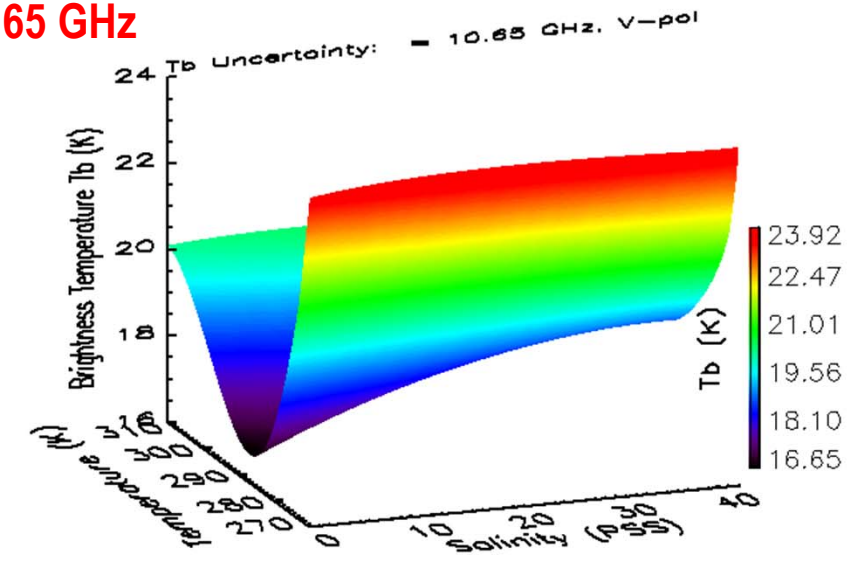
36.50 GHz



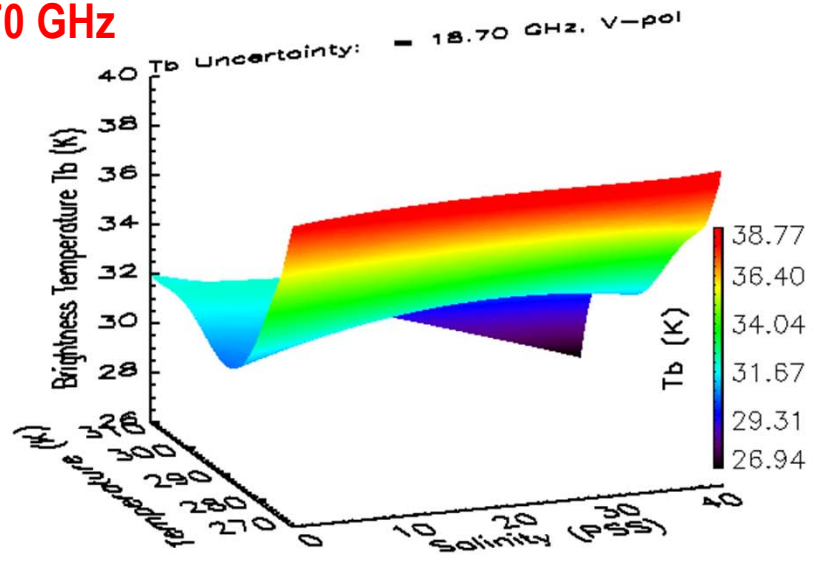
T_b Uncertainty: AMSR-E

Case: Nadir view; Flat sea; No wind; Vertical polarization

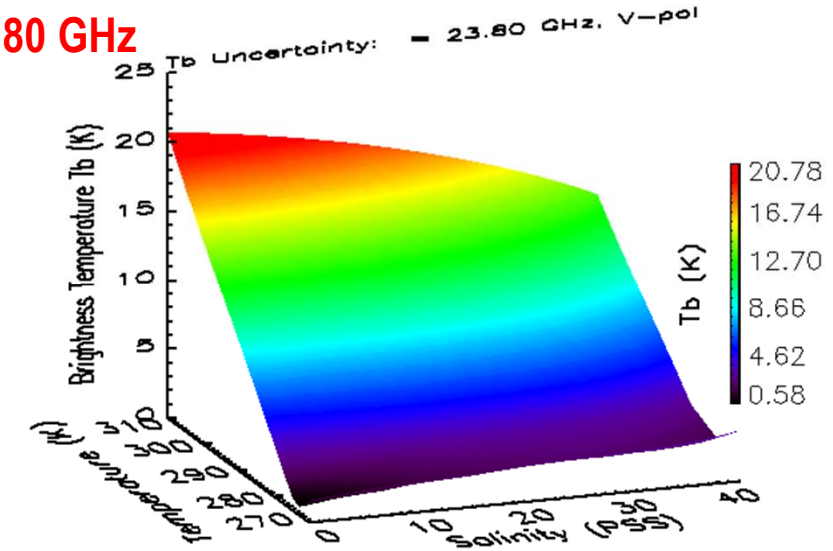
10.65 GHz



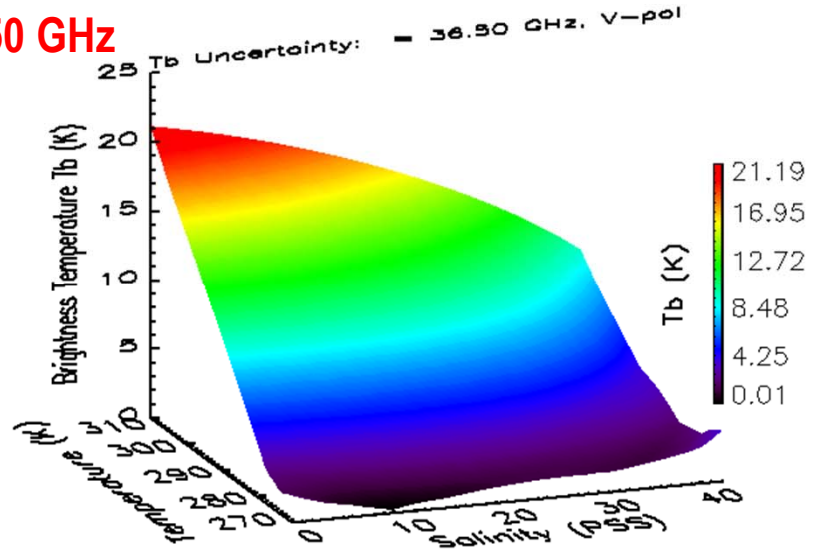
18.70 GHz



23.80 GHz



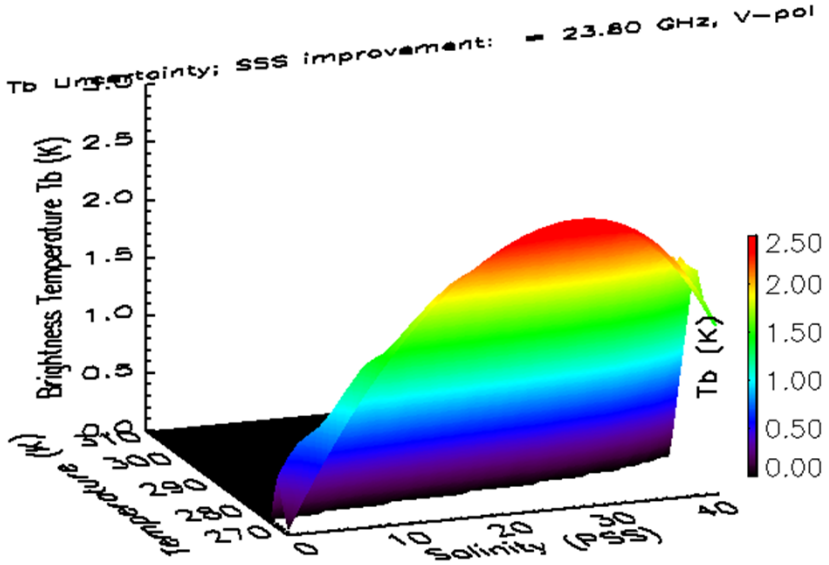
36.50 GHz



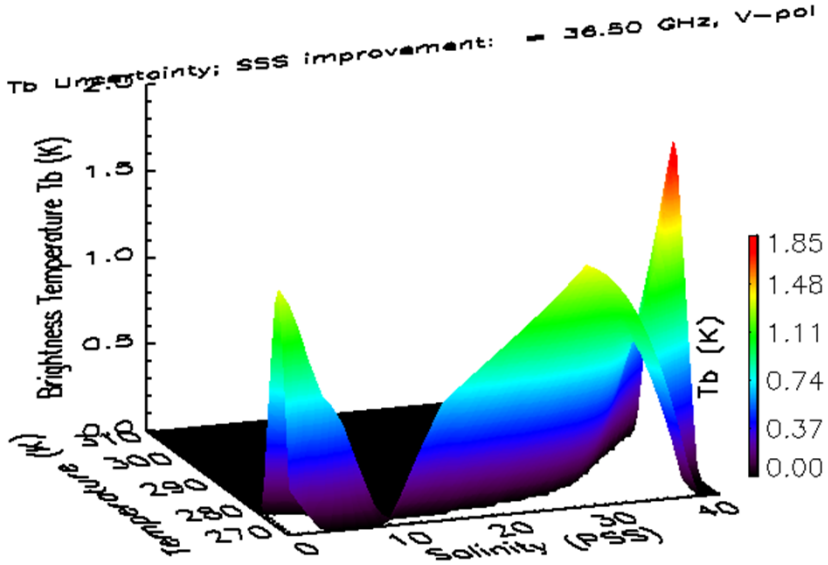
Estimated SSS Reduction in Tb Uncertainty

Case: Nadir view; Flat sea; No wind; Vertical polarization

23.80 GHz



36.50 GHz



On the Horizon

- **Consistent modeled T_b for SSS retrievals?**
  - Initial SMOS retrievals use Klein & Swift (1977)
  - Initial Aquarius retrievals will use Meissner & Wentz (2004)
  - CRTM plans to employ FASTEM4 (Liu *et al.*, 2010)

- **How will SSS observations be operationally employed to reduce T_b uncertainty?**

- **How will the T_b uncertainty introduced by choice of permittivity model be quantified and incorporated?**

- **How will convergence to a community permittivity model be achieved for consistency and comparison of results?**