Ocean Dielectric Constant

Heather Lawrence, Niels Bormann, Stephen English, Alan Geer

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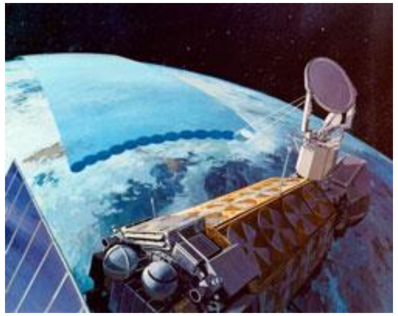
ECMWF

Background: Ocean Emissivity and Dielectric Constant

Microwave instruments sensitive to the ocean surface

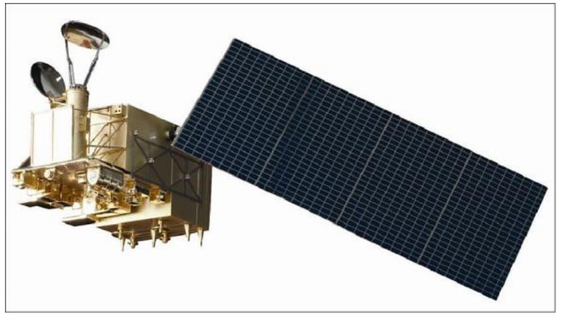
Microwave Imagers

SSMI/S

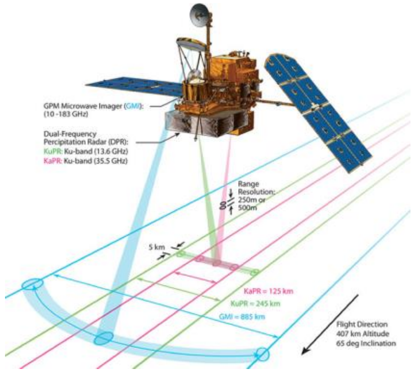


GCOM W1 AMSR-2

FY-3 MWRI



GPM GMI



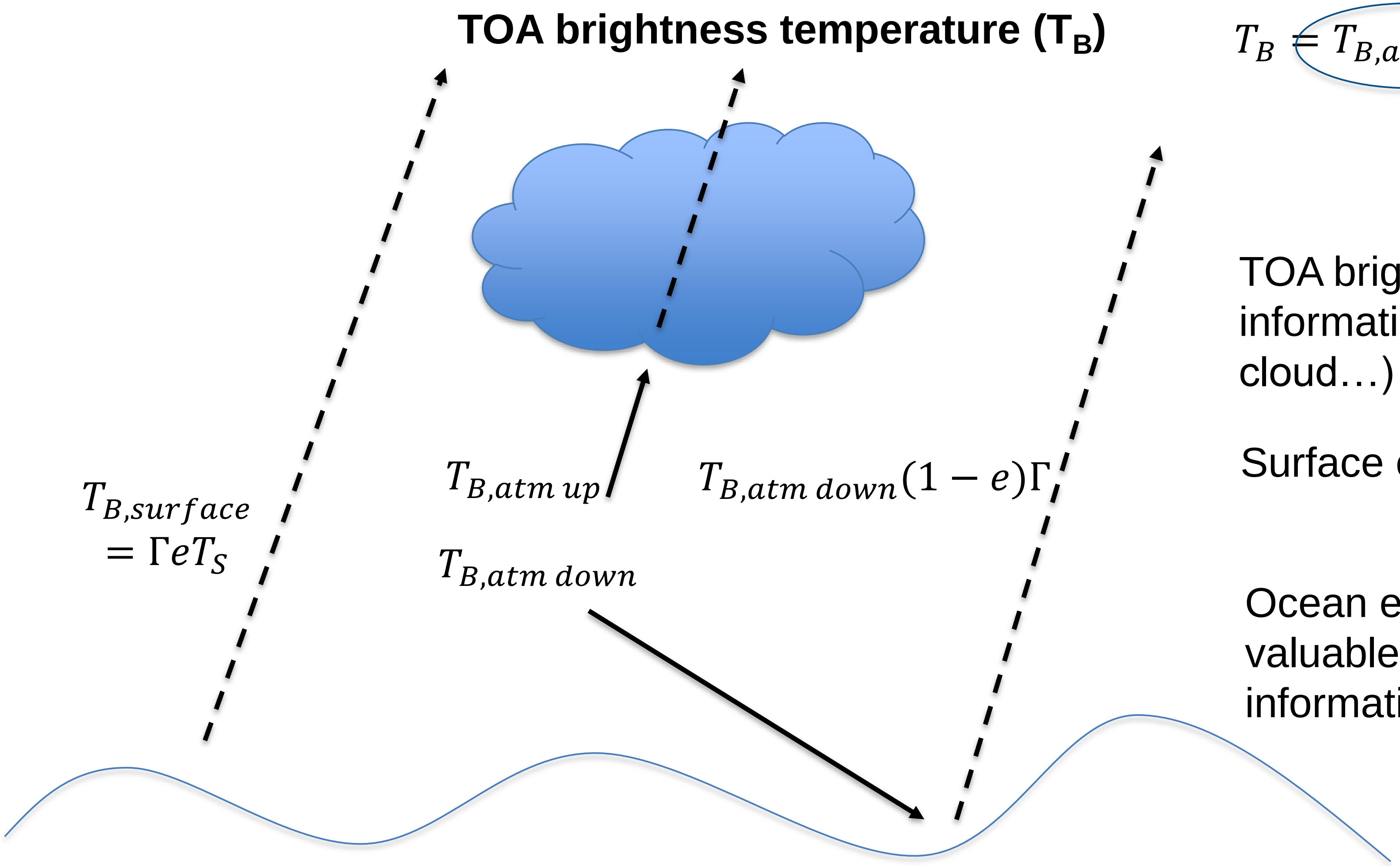
Sensitive to: ***total column water vapour, cloud/precipitation***

+ Microwave Temperature & Humidity Sounders

Currently assimilated frequencies: 18 – 90 GHz, 183 GHz

Desired frequency range for ocean emissivity: 1 – 1000 GHz

Ocean emissivity for microwave imagers/sounders



$$T_B = T_{B,atm\ up} + \Gamma e T_s + T_{B,atm\ down}(1 - e)\Gamma$$

TOA brightness temperature contains information on the atmosphere (tcwv, cloud…)

Surface emissivity must be modelled

Ocean emissivity also contains valuable near-surface wind information

Ocean emissivity

Flat Ocean

Fresnel Emissivity depends only on the dielectric constant

(assuming absolutely flat surface)

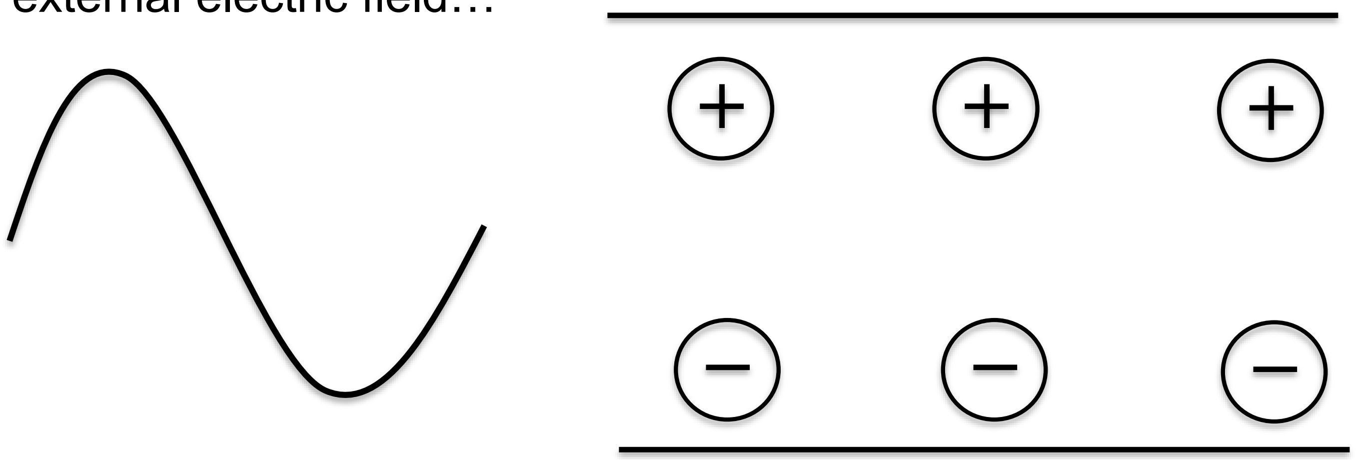
Rough Ocean

Surface roughness and foam increase emissivity

Linked to 10-m wind-speed over ocean (correlation)

Dielectric Constant of sea-water

Apply an oscillating external electric field…



Degree of Polarisation is determined by ε

$$\varepsilon(\upsilon) = \varepsilon'(\upsilon) + i\varepsilon''(\upsilon)$$

Debye Model

ε_S Value for a static field

ε_∞ Value for a field of infinite frequency

$$\boldsymbol{\varepsilon(\upsilon) = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon(\infty)}{1 + i\omega\tau} - i\frac{\sigma}{2\pi\varepsilon_0\nu}}$$

Double-Debye Model

ε_1 Intermediate value

$$\boldsymbol{\varepsilon(\upsilon) = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_1}{1 + i\omega\tau_1} + \frac{\varepsilon_S - \varepsilon_\infty}{1 + i\omega\tau_2} - i\frac{\sigma}{2\pi\varepsilon_0\nu}}$$

FASTEM dielectric constant model

Double-Debye

$$\varepsilon(v) = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_1}{1 + i\omega\tau_1} + \frac{\varepsilon_S - \varepsilon_\infty}{1 + i\omega\tau_2} - i\frac{\sigma}{2\pi\varepsilon_0 \nu}$$

Liu, Weng & English (2011):

$$\varepsilon_\infty = a_0 + a_1 T \quad (4a)$$

$$\varepsilon_s = (a_2 + a_3 T + a_4 T^2 + a_5 T^3) \times (1 + a_6 S + a_7 S^2 + a_8 TS) \quad (4b)$$

$$\varepsilon_1 = (a_9 + a_{10} T + a_{11} T^3) \times (1 + a_{12} S + a_{13} S^2 + a_{14} TS) \quad (4c)$$

$$\varepsilon_0 = 8.8429 \times 10^{-12}\ [\mathrm{F/m}] \quad (4d)$$

$$\tau_1 = (a_{15} + a_{16} T + a_{17} T^2 + a_{18} T^3) \times (1 + a_{19} S + a_{20} ST + a_{21} ST^2) \quad (4e)$$

$$\tau_2 = (a_{22} + a_{23} T + a_{24} T^2 + a_{25} T^3) \times (1 + a_{26} S + a_{27} ST + a_{28} S^3) \quad (4f)$$

$$\alpha = \alpha_{25} \exp(-\beta\delta) \quad (4g)$$

- Express constants as polynomial functions of sea surface temperature and salinity
- Fit to laboratory measurements

Study: investigating uncertainties in the ocean dielectric constant

What are the uncertainties in modelling surface emissivity?

Background: GAIA-CLIM project

- Identified as a gap in performing cal/val of satellite data to reference standards
- Useful in determining observation errors

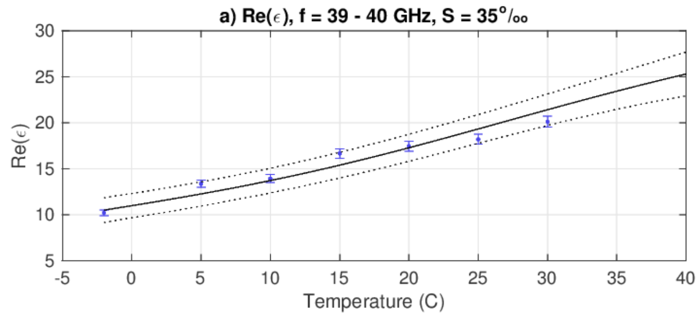
Uncertainty in the dielectric constant model requires:

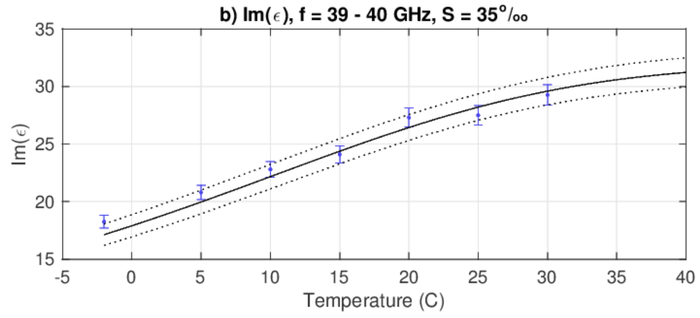
- Laboratory measurements with good uncertainty estimates

$$\sigma_{\varepsilon'}{}^2 = \left(\frac{\partial \varepsilon'}{\partial x_1}\sigma_{x_1}\right)^2 + \left(\frac{\partial \varepsilon'}{\partial x_2}\sigma_{x_2}\right)^2 + \ldots$$

- Compared to reference liquids

e.g. Gregory & Clarke (2009)





What do current laboratory measurements tell us about the uncertainty?

- Perform a literature review to identify available laboratory seawater & water measurements with uncertainties

- Compare dielectric constant measurements to FASTEM

- Transform measurements and uncertainties into brightness temperatures and compare to FASTEM

- Main focus: 10 – 90 GHz (also 1.4, 6.8 GHz)

Dielectric Constant measurements available in the literature with uncertainties

Pure water measurements can be used as a substitute at f > 20 GHz

Ellison et al (1996) tabulates all water measurements with uncertainties, up to 1996:

ELSEVIER

Journal of Molecular Liquids 68 (1996) 171–279

journal of MOLECULAR LIQUIDS

Water: A dielectric reference

W. J. Ellison, K. Lamkaouchi[1], J.-M. Moreau

Laboratoire de Physique des Interactions Ondes-Matière,
Ecole Nationale Supérieure de Chimie et Physique de Bordeaux
Université Bordeaux 1, B.P. 108, 33402 Talence, France

(1) Equipe de Spectronomie,
Dept. de Physique, Faculté des Sciences de Meknès, Maroc

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Appendix A

The data is presented in chronological order. For each author the data is first ordered by increasing frequency and for a given frequency by increasing temperature. The year of publication and the first author refer to the reference in the general bibliography.

The two columns % ε' and % ε" represent the percentage error estimates given by the authors or the estimates that we could deduce from information in the article.

1948 COLLIE

GHz	°C	ε'	ε"	% ε'	% ε"
3.000	0.00	79.66	24.70	1.00	1.00
3.000	10.00	78.07	17.50	1.00	1.00
3.000	20.00	77.42	13.10	1.00	1.00
3.000	30.00	76.78	9.80	1.00	1.00
3.000	40.00	72.56	7.54	1.00	1.00
3.000	50.00	68.44	5.80	1.00	1.00
3.000	60.00	65.37	4.55	1.00	1.00
3.000	75.00	60.49	3.30	1.00	1.00
9.345	0.00	44.82	41.60	1.00	1.00
9.345	10.00	53.85	37.60	1.00	1.00
9.345	20.00	61.41	31.80	1.00	1.00
9.345	30.00	63.31	25.50	1.00	1.00
9.345	40.00	65.58	21.20	1.00	1.00

Dielectric Constant measurements available in the literature:10 – 90 GHz

Used in FASTEM?

Seawater measurements:

Ellison et al (1996) seawater measurements ***6.8, 10.65, 18, 24, 90 GHz, -2 – 30 C***

✓ Ellison et al (1998, 2003) seawater measurements ***7 – 90 GHz, -2 – 30 C***

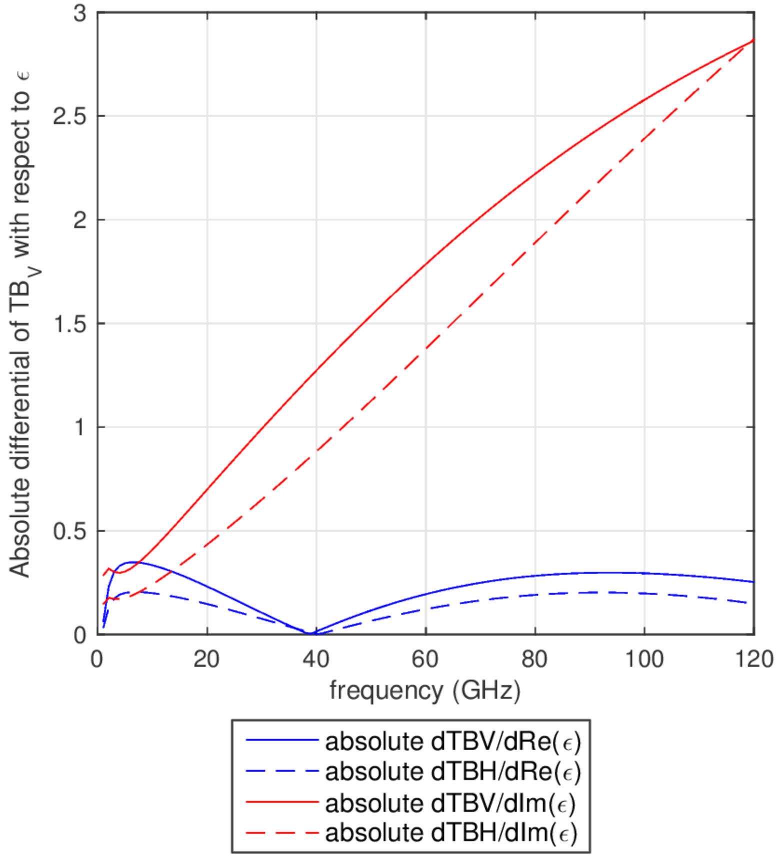
Water measurements:

✓ Kaatze (1981) pseudo water measurements ***5 – 70 GHz, 0 – 30 C***

+ Richards & Sheppard (1991), Kaatze (1989), Pottel at al (1980)

What are the uncertainties in the FASTEM dielectric constant model?

Compare FASTEM to laboratory measurements, in terms of **dielectric constant values** and **brightness temperatures**



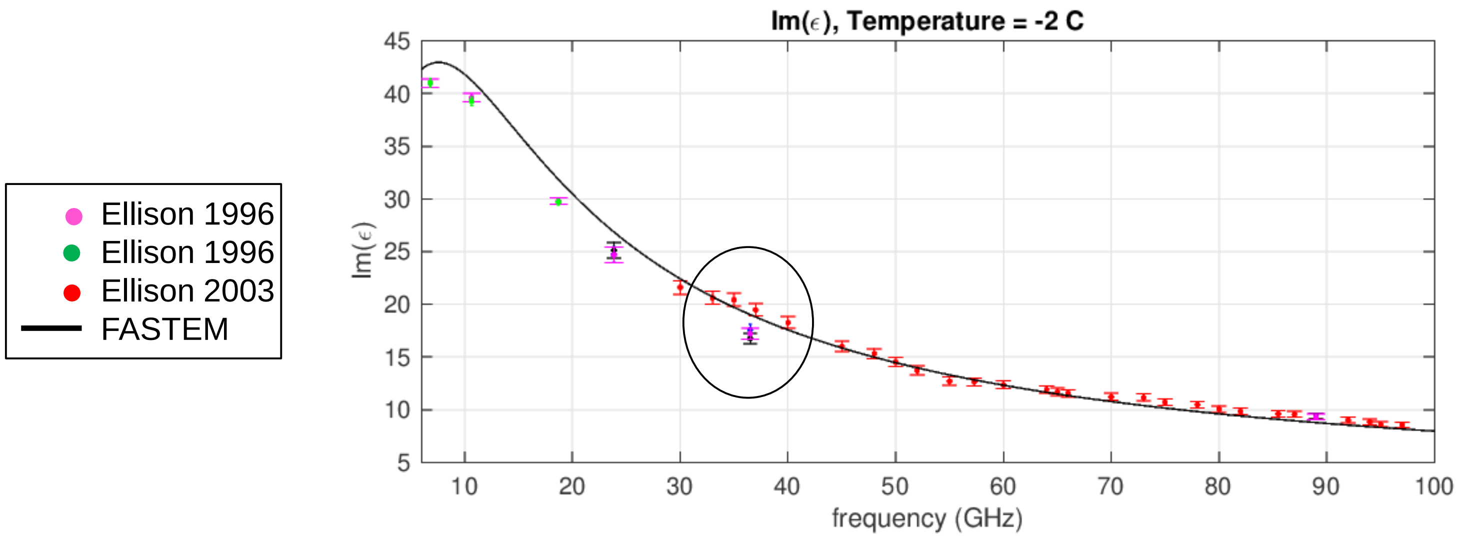
Uncertainty in brightness temperature space:

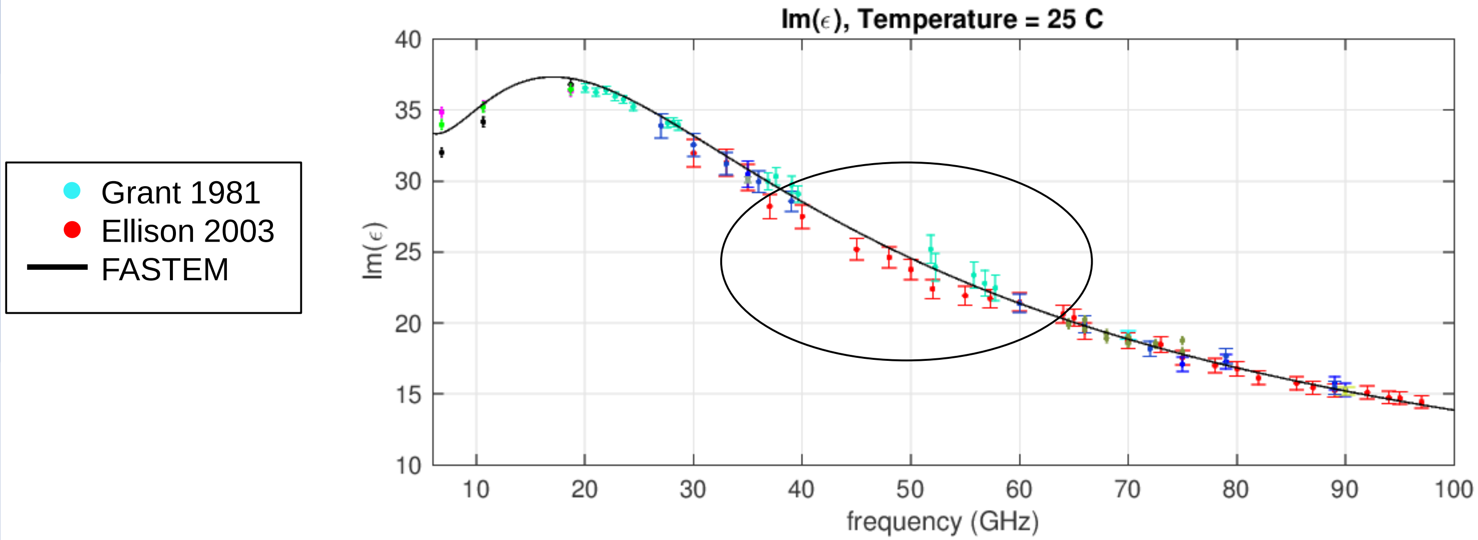
$$\sigma_{TB}{}^2 = \left(\frac{\partial T_B}{\partial \varepsilon'}\sigma_{\varepsilon'}\right)^2 + \left(\frac{\partial T_B}{\partial \varepsilon''}\sigma_{\varepsilon''}\right)^2$$

At frequencies greater than 10-15 GHz, only the imaginary term matters…

1 – 3 % uncertainty in Ɛ leads to **0.3 – 1.0 K** uncertainty in brightness temperatures

Comparison between FASTEM and dielectric constant measurements

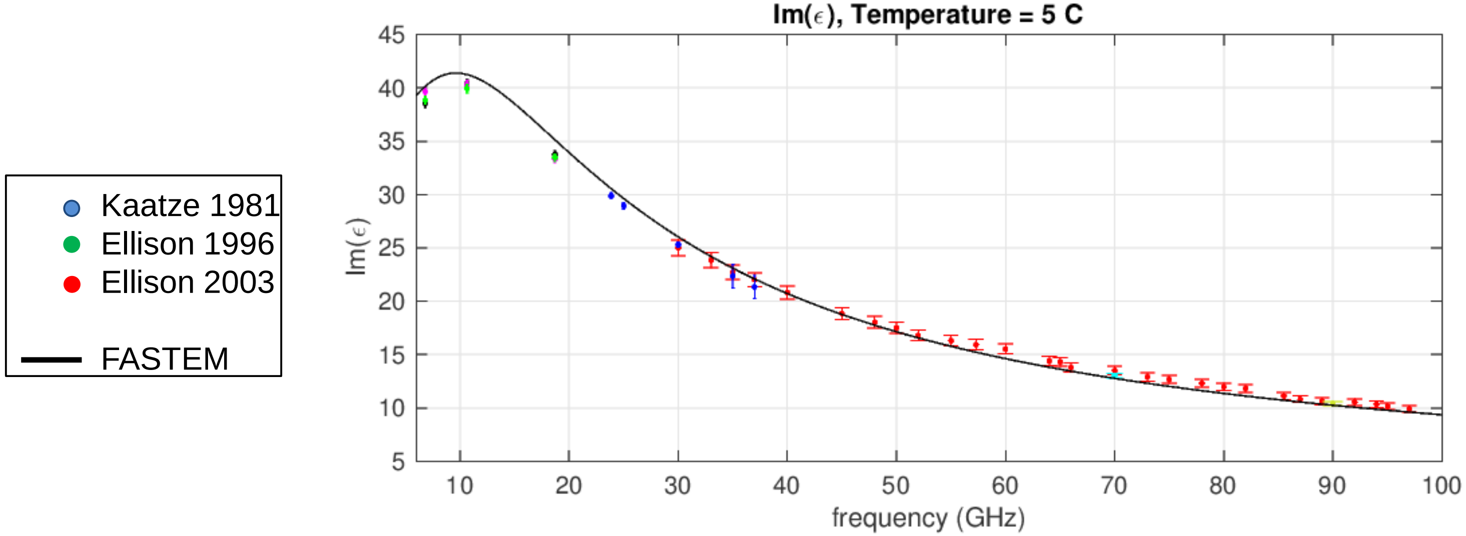


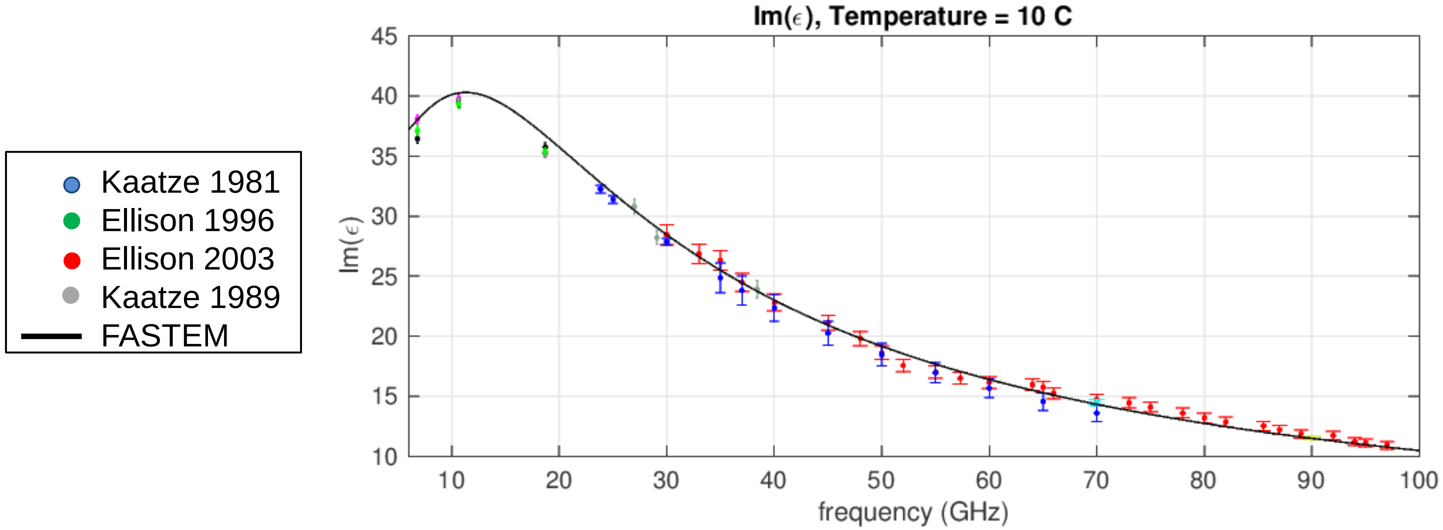


Do measurements agree with each other?

- Generally good agreement between measurements
- Some inconsistencies between different laboratory measurements

Comparison between FASTEM and dielectric constant measurements





Do measurements agree with FASTEM?

- Good agreement between FASTEM and measurements at **higher frequencies (30 – 90 GHz)** and higher temperatures (**15 – 30 C**)

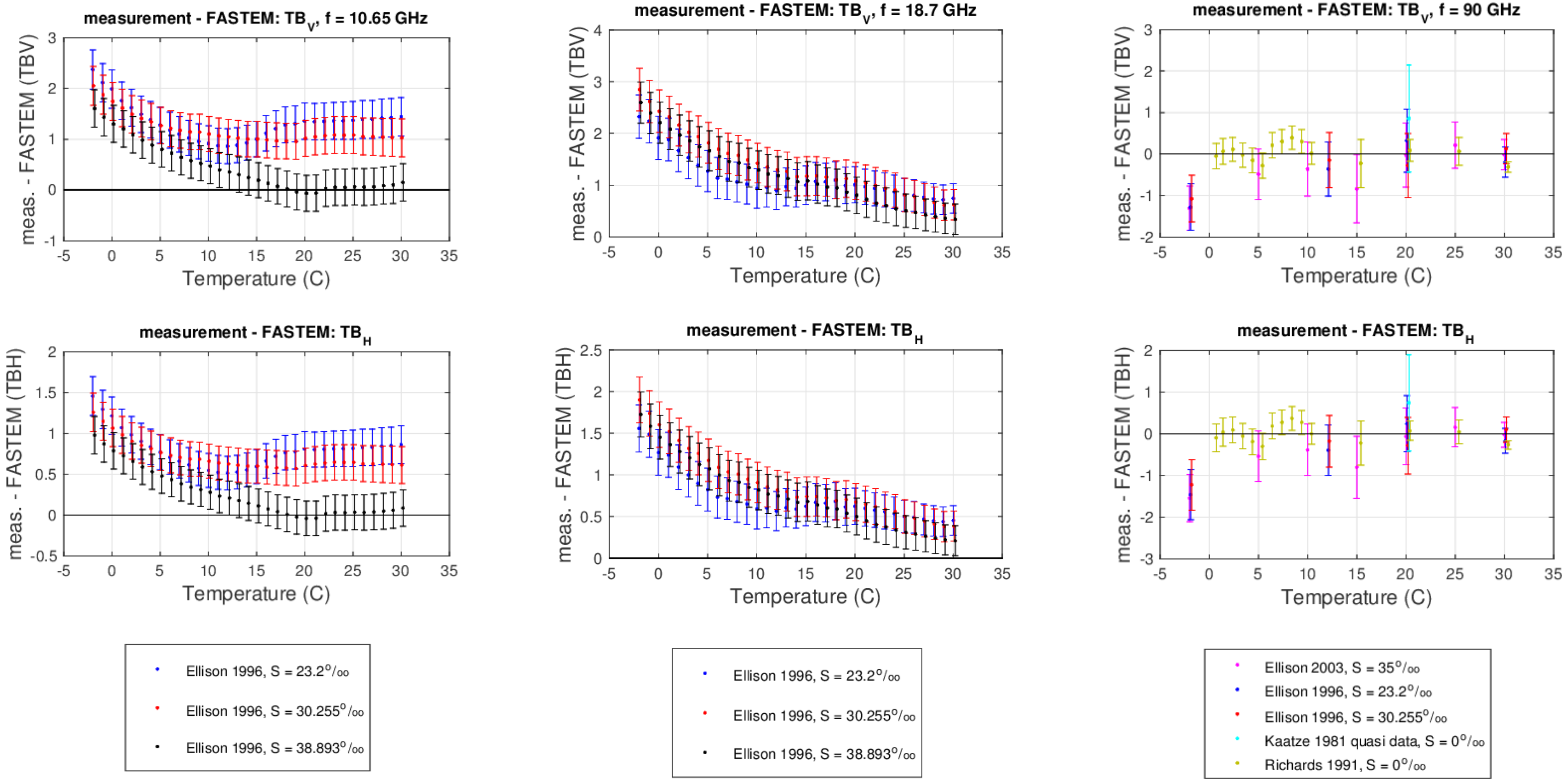
- Inconsistencies between FASTEM and low temperature measurements at low frequencies
  - Ellison et al (1996, 1998)
  - Kaatze (1981)

Comparison to laboratory measurements in brightness temperature space

10.65 GHz | 18.7 GHz | 90 GHz

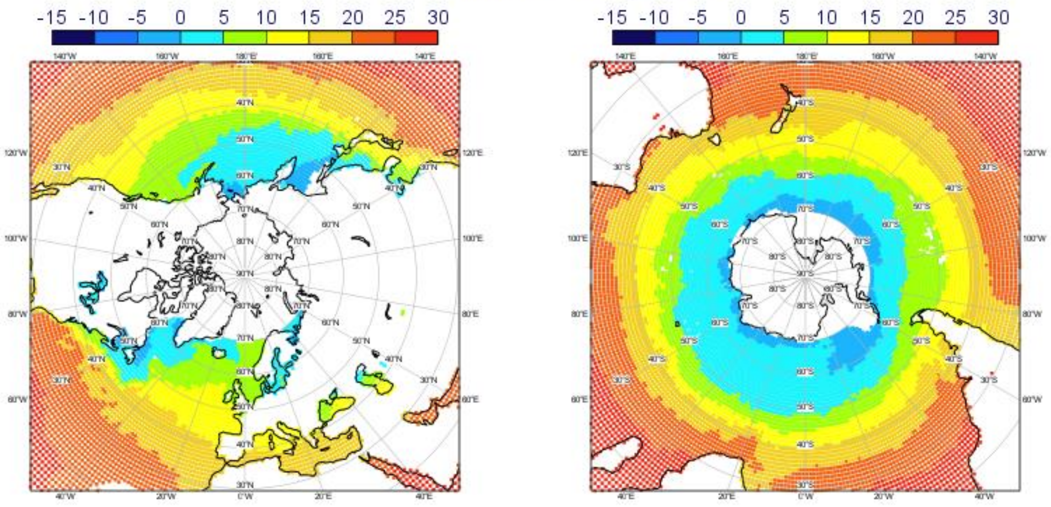
V pol

H pol

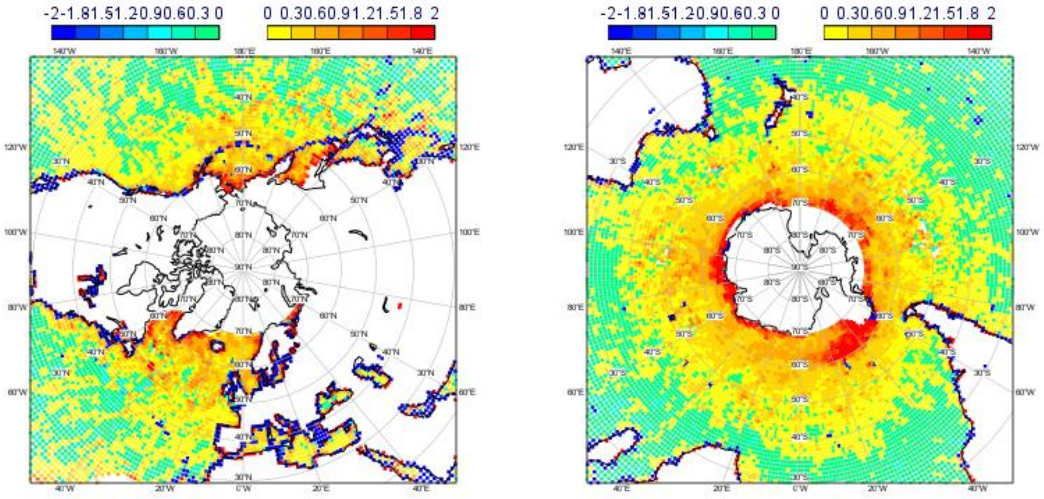


Skin-temperature dependent biases for GMI, January 2018

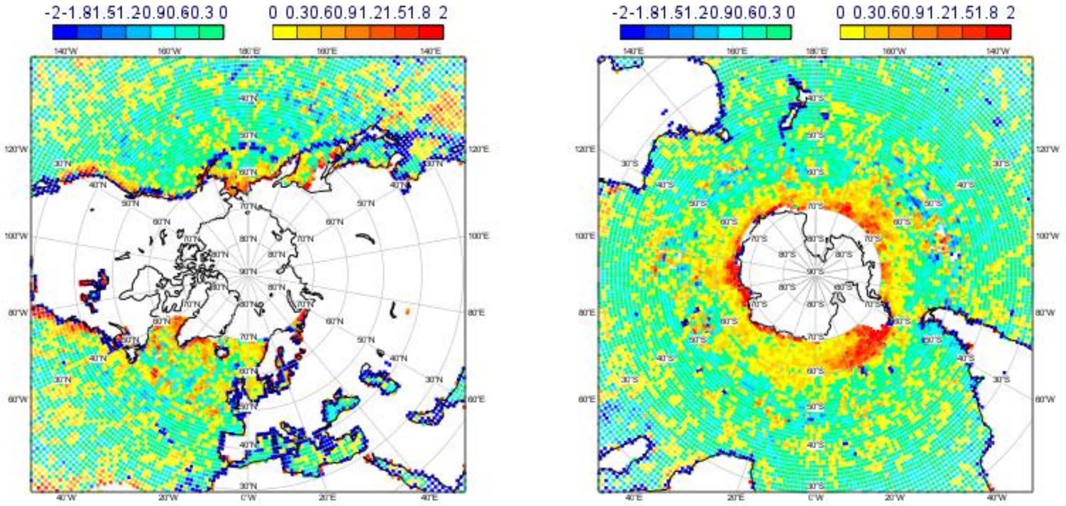
Mean skin temperature



GMI channel 10V mean O - B minus mean (-1.34276202085K)



GMI channel 18V mean O - B minus mean (-0.607337735021K)

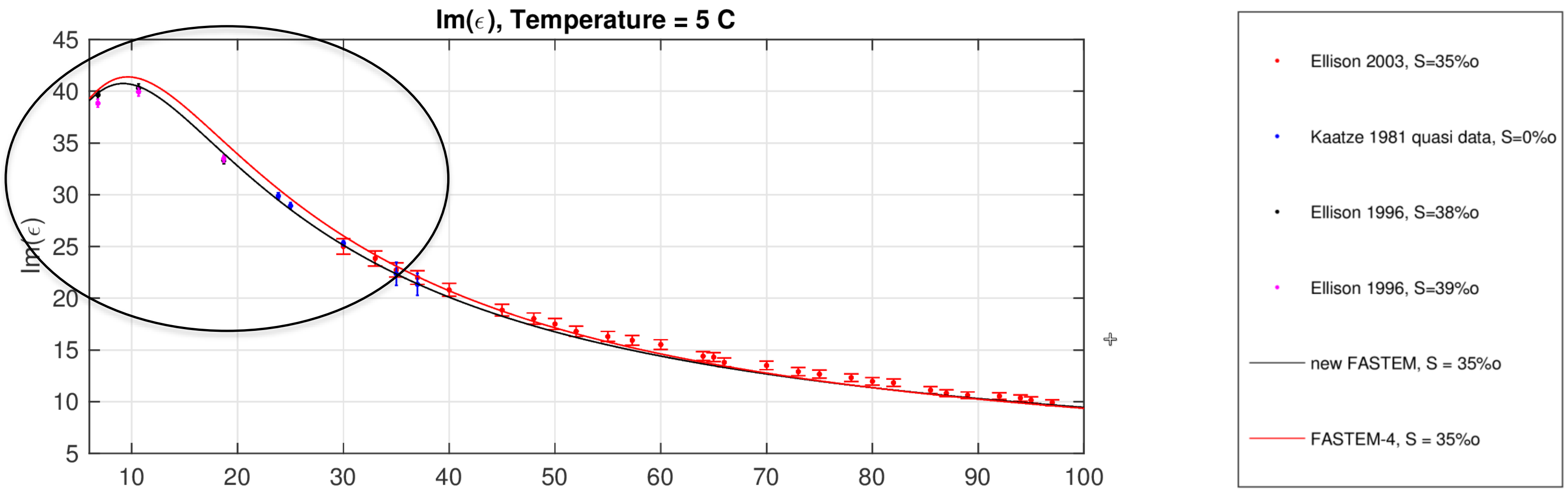


Observations filtered for cloud and wind

10V Bias ~ 0.3 – 0.6 K

No clear bias at 18 GHz

What happens if we perform a better fit to low temperature – low frequency measurements?

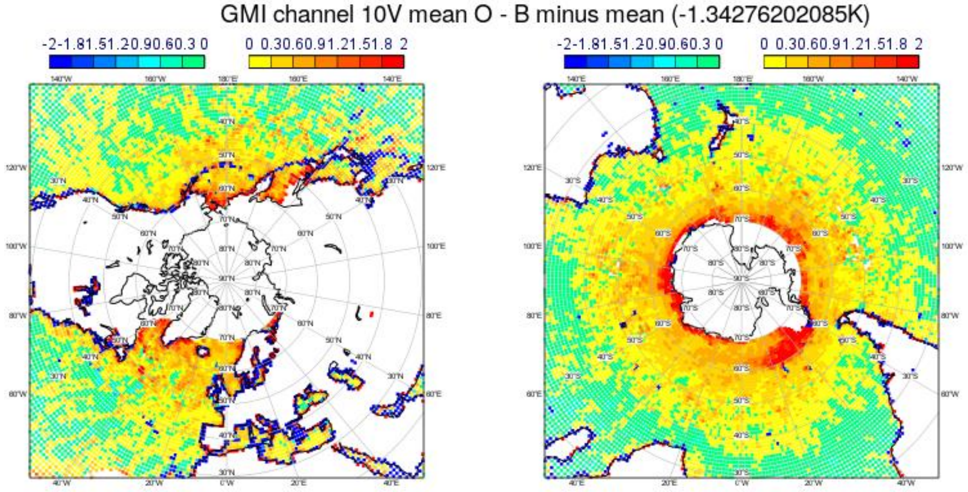


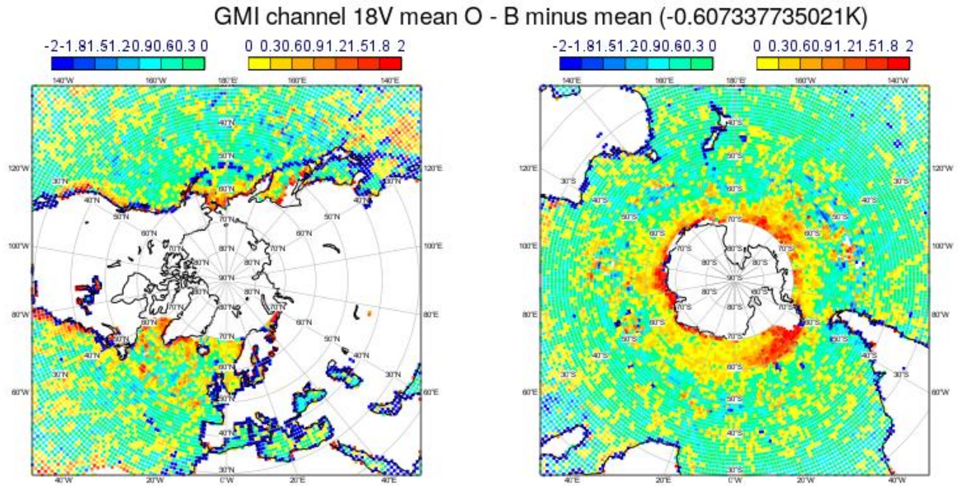
Best fit with previous FASTEM data +

- Include Ellison 1996 data at 6.8 GHz, 10 GHz
- Include more water data (Richards 1991, Kaatze 1989, Pottel 1980, etc.)
- Duplicate water/saline data at higher frequencies – to fit water data at 90 GHz

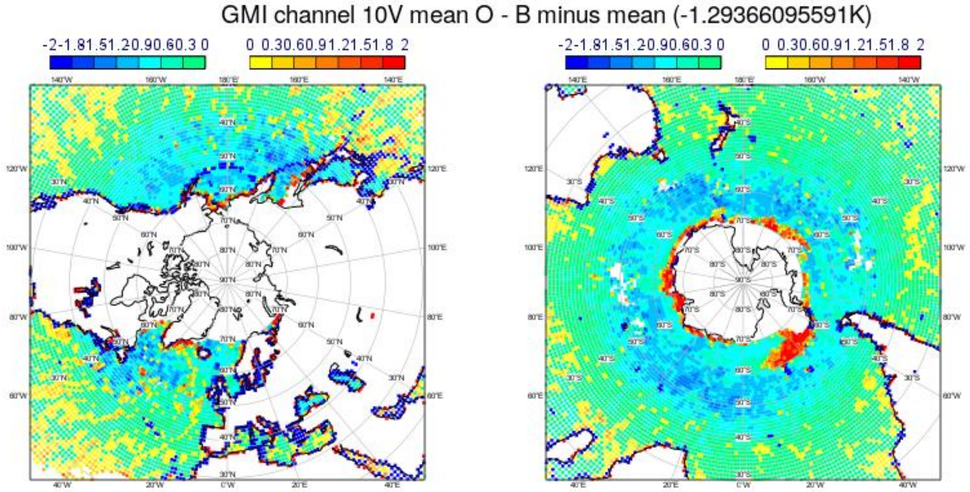
Biases compared to satellite data get worse!

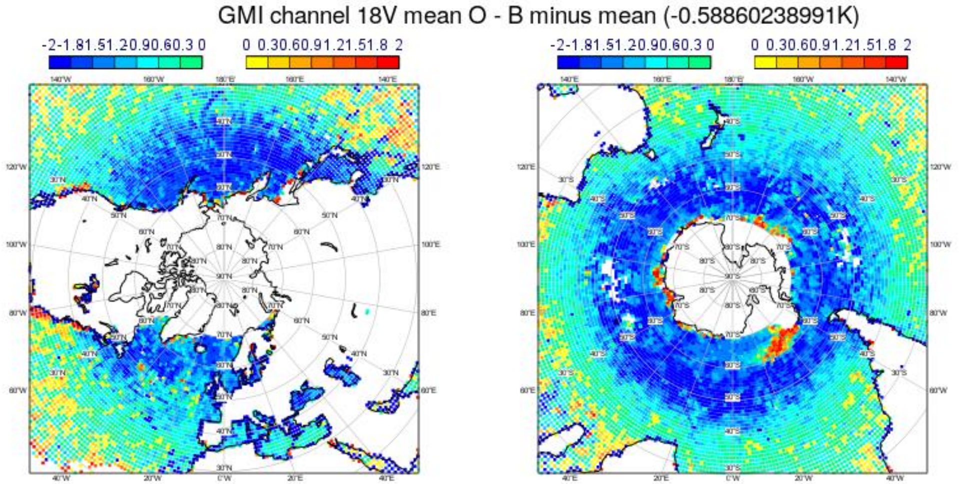
GMI January 2018, FASTEM:





GMI January 2018, new FASTEM fit:





new tskin-dependant bias:
~ 1.5 – 2.5 K

St.Dev.(O – B):
~ 2 K

Conclusions

- Traceable reference measurements are needed at all frequencies to give us confidence in the ocean emissivity model and to more accurately estimate the uncertainty

- FASTEM does not agree with low-frequency (10 - 20 GHz) low-temperature laboratory measurements but does agree well with satellite data…

- There may be biases in laboratory measurements or biases in other aspects of the forward model – ***new laboratory data is needed at 10 – 20 GHz, 0 – 15C***

- As satellite calibration improves we need more and more accurate forward models, 1 – 3 % (0.3 – 1.0 K) uncertainties may soon be too high…

See also: ITSC proceedings paper