Comparison of models for sea water dielectric constant and wind (surface roughness and foam) at low microwave frequencies.

Emmanuel P. Dinnat

Goddard Space Flight Center, Greenbelt, MD, USA

Chapman University, Orange, CA, USA

Outline

- Introduction

Comparison of dielectric constant and wind (roughness + foam) models.

Validation with satellite and *in situ* data.

- Data and models

Ancillary data (ocean and atmospheric parameters) and radiative transfer model parameterizations.

Satellite and *in situ* data.

- Results

Models validation: how the models 1/ reproduce (TB) observations or 2/ retrieve accurate geophysical parameters (i.e. ocean surface salinity)

Bias assessment (global average difference between observations and model).

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Introduction

Comparisons of models for sea water dielectric constant and wind impact on ocean TB.

Results presented here are from 2 research topics:

1/ Sea Surface Salinity (SSS) Remote Sensing (Dinnat *et al.*, 2019)

2/ Inter-calibration of low Microwave radiometer for long term soil moisture record (Dinnat *et al.*, 2018)

1 => Validation uses SSS retrievals compared to *in situ* measurements.

=> L-band (1.4 GHz) only

2 => Validation uses surface Tb comparisons: satellite obs Vs radiative transfer simulations

=> frequency = L-band, C-band (6 GHz) – X-band (10 GHz), expended here to K-band (24 GHz) and Ka-band (36 GHz) .

*Is accuracy/precision requirement for 1/ (**<0.1 K**) and 2/ (~1K) relevant to our purpose ?*

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Satellite Data

	Available data	Frequency [GHz]	3dB spatial res. [km]	Temporal revisit	Incidence angle [degrees]	Orbit [A: ascending; D: descending]
AMSR-E	2002-2011	6.93 (C-band) 10.65 (X-band)	75 x 43 51 x 29	~2 days	55	sun-synchronous 1:30pm D/1:30am A
SMOS	2009-present	1.4 (L-band)	30-80*	~3 days	0-55**	sun-synchronous 6am A/6pm D
AMSR2	2012-present	6.93 (C-band 1) 7.3 (C-band 2) 10.65 (X-band)	62 x 35 62 x 35 42 x 24	~ 2 days	55	sun-synchronous 1:30pm A/1:30am D
SMAP	2015-present	1.4 (L-band)	38 x 49	~3 days	40	sun-synchronous 6am D/6pm A

** Depending on incidence angle; approximately 40 km at 40° incidence angle.*
*** We will interpolate to 40° incidence angle.*

Here we use:

- SMAP : L1B -- Version 4
- AMSR2 : L1A

-> Datasets re-gridded on (equal area) EASE Grid V2 daily at 36 km and 9 km resolutions.

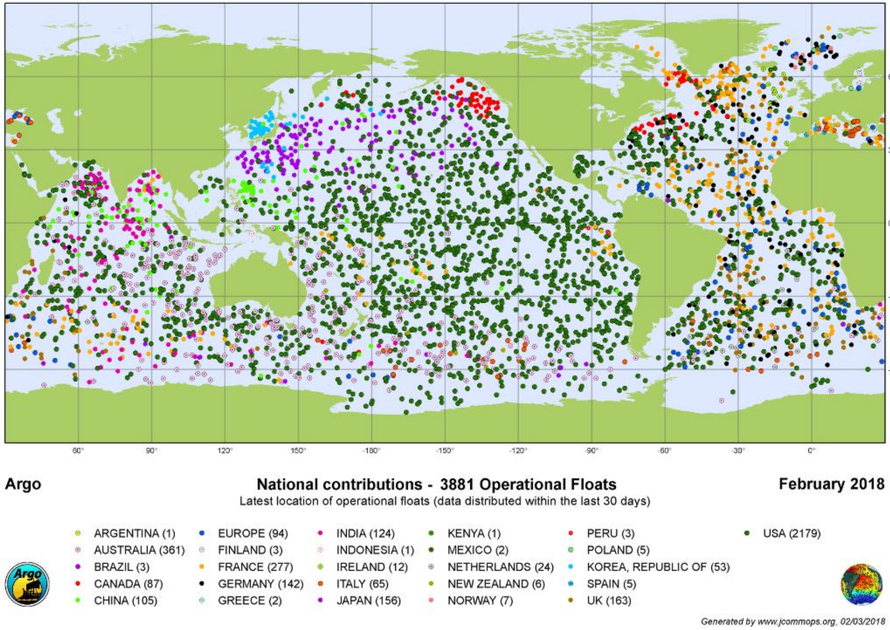
- Aquarius: L2 -- V3 (reprocessed for the study using various dielectric constant models)

In Situ Data

Sea Surface Salinity from Argo network:

~4000 active floats, vertical profiles of pressure, temperature and salinity from 2000 m deep to a few meters deep every 10 days

Source : ftp://ftp.ifremer.fr/ifremer/argo/dac/



Use measurements with:

- shallowest obs. at depth of 10 m or less
- QC value of 1 (good) or 2 (probably good) for pressure, temperature, salinity and date
- Use "adjusted" values when present and QC = 1 or 2

⇒ Gridded (drop in a bucket) and averaged at 1°x1° in lat/lon monthly.

Models and Ancillary data

- Radiative Transfer Model

  1/ Seawater TB = sum of flat and rough surface components:

$$T_{B\,water} = T_{B\,flat}(SST, SSS) + T_{B\,rough}(SST, SSS, WS, WD)$$

  Rough surface component computed using a Two-Scale model.

  2/ Surface TB = weighted sum of water and foam TB (F_{Fr} = foam fraction) :

$$T_{B\,suface} = T_{B\,water}.(1 - F_{Fr}) + T_{B\,foam}.F_{Fr}$$

  3/ Atmospheric effects: attenuation of surface emission and reflected signals and emission:

$$T_{TOA} = \left(T_{B\,surface} + \left(T_{atm}^{down} + T_{cos}.e^{-\tau_d}\right).R\right).e^{-\tau_u} + T_{atm}^{up}$$

  Atmospheric components from MPM 93 (Liebe *et al.*, 1993)

Ancillary data

- Surface:
  - Sea Surface Temperature (SST) NOAA OI2 (Reynolds *et al.*, 2007)
  - Wind speed (WS) and direction (WD) : NCEP
  - Sea Surface Salinity (SSS): HYCOM (Chassignet *et al.*, 2007)
- Atmosphere:

  Vertical profiles at 26 pressure levels:
  - Temperature
  - Geopotential height
  - Relative Humidity
  - Cloud liquid water mixing ratio

  Lat/lon 1° x 1 ° deg every 6 hours

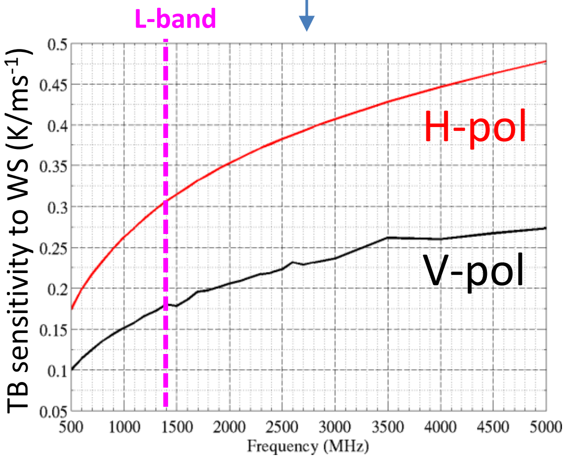
  Source: NCEP GDAS

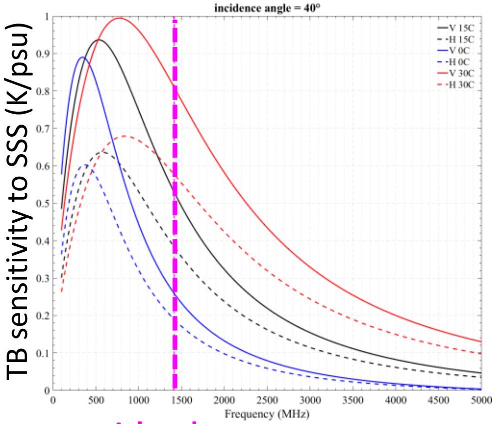
Overview differences with frequency: *Sea Surface*

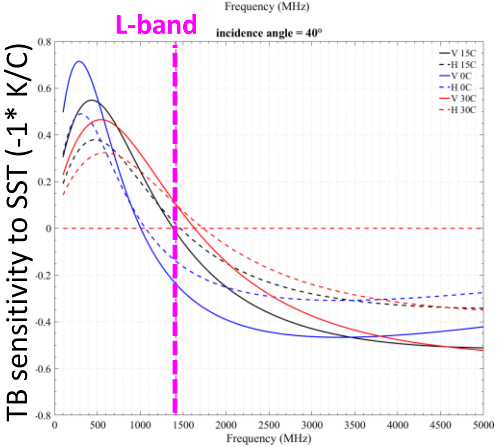
Sensitivity to **Ocean Surface** parameters:

Increase in frequency (AMSR-E/2):

- smaller SSS dependence
- larger SST dependence
- larger wind speed dependence







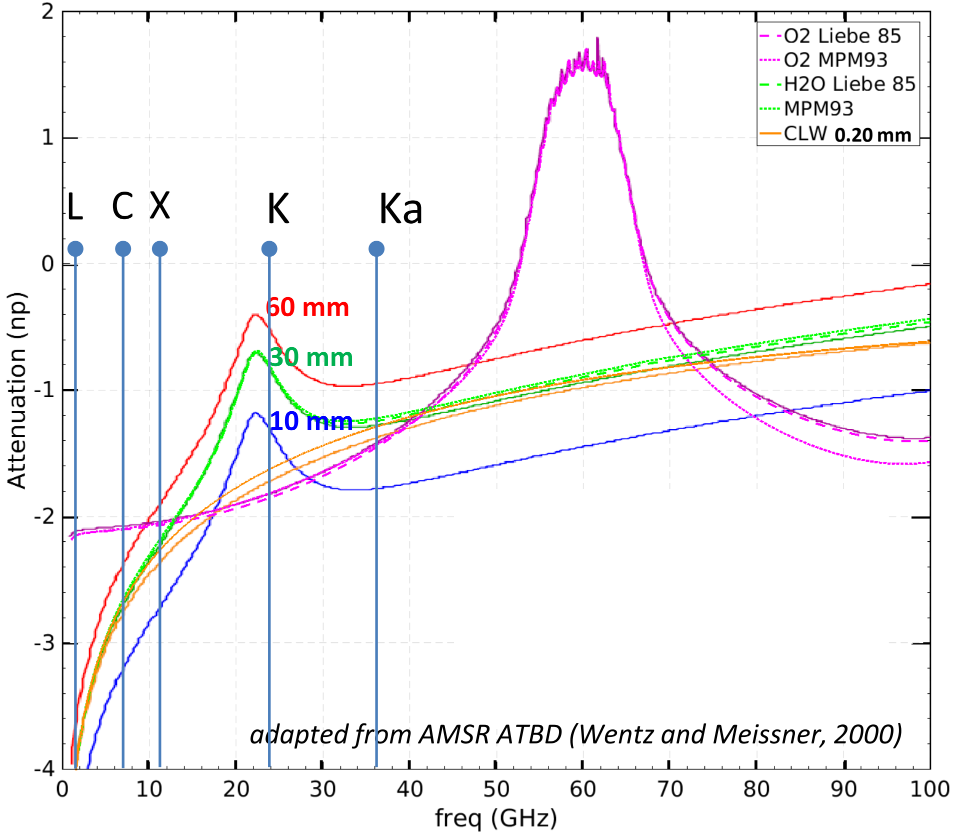
Overview differences with frequency: *Atmosphere*

Atmospheric attenuation and emission:

At L-band, atmospheric effect almost independent of water vapor (WV) and cloud liquid water (CLW)

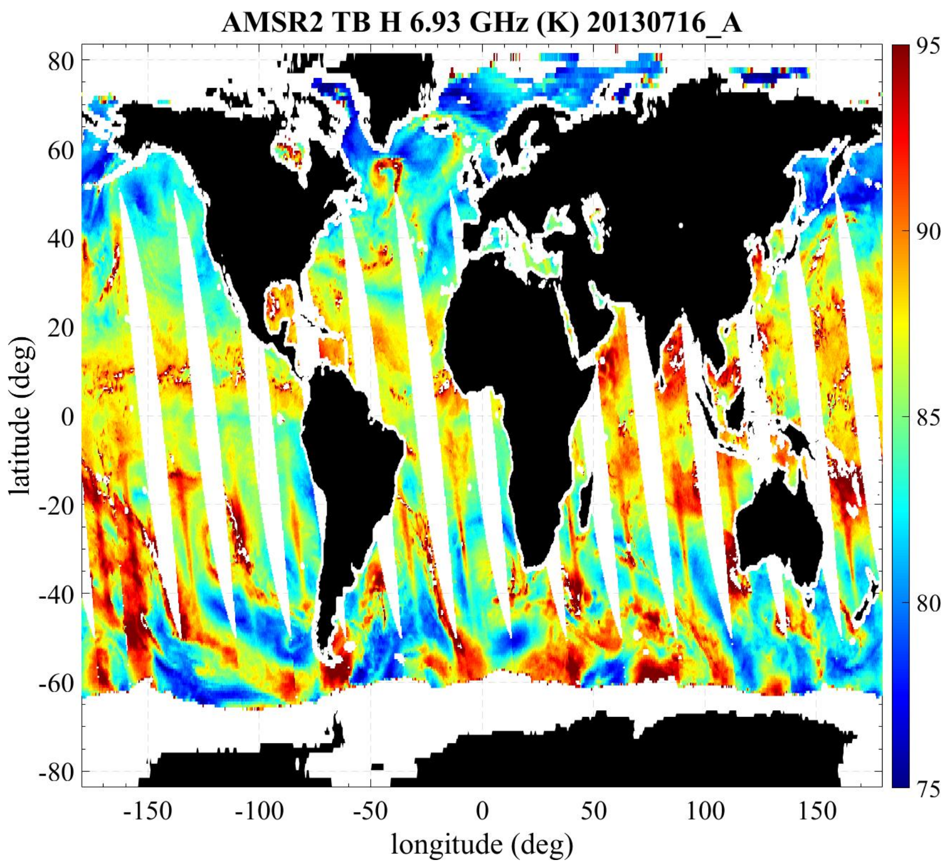
At higher frequencies, impact of CLW and WV increase, become very significant at X-band and above.

At L-band, impact of Faraday rotation in ionosphere => polarization mixing.



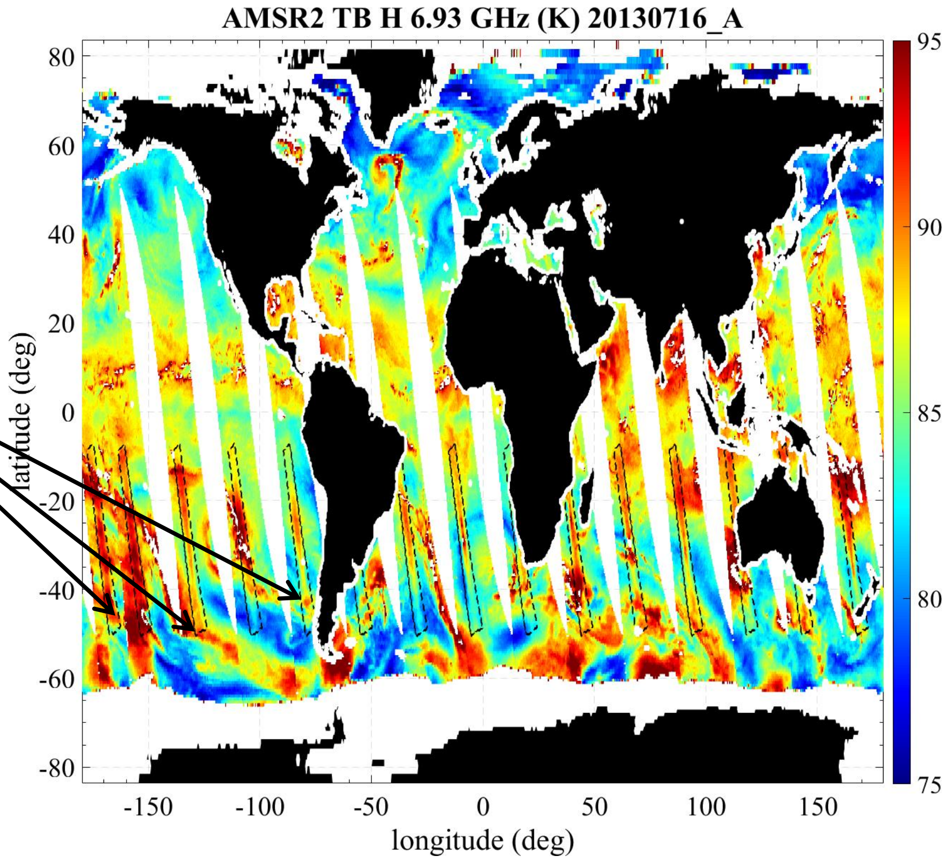
Overview differences with frequency: *Reflected Solar Radiation*

- Sun Reflection
  - Sun TB decrease when *f* increases
    - 75,000 K at L-band
    - 15,000 K at C-band
    - 12,000 K at X-band
  - SMAP, SMOS, Aquarius ride the terminator
  - ⇒ Sun reflection comes from side, 'edge' of FOV
  - AMSR-E, AMSR2 have mid-day orbits
  - ⇒ Sun image in middle of FOV



Overview differences with frequency: *Reflected Solar Radiation*

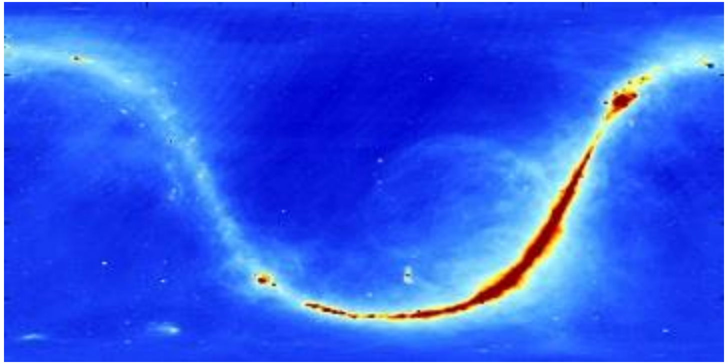
Solar filter limits
(based on Sun azimuth
and elevation angles)



Overview differences with frequency: *Celestial Sky*

- Reflected galaxy
  - Major issue at L-band: introduces regional and seasonal biases, difficult to model
  - Sky emissivity Increases below L-band (is P-band [500 MHz] in the near future?)
  - Lesser impact at higher frequencies: same CMB, less galactic contributions

L-band sky map (3 K – 18 K)



https://podaac.jpl.nasa.gov/dataset/AQUARIUS_ANCILLARY_CELESTIALSKY_V1

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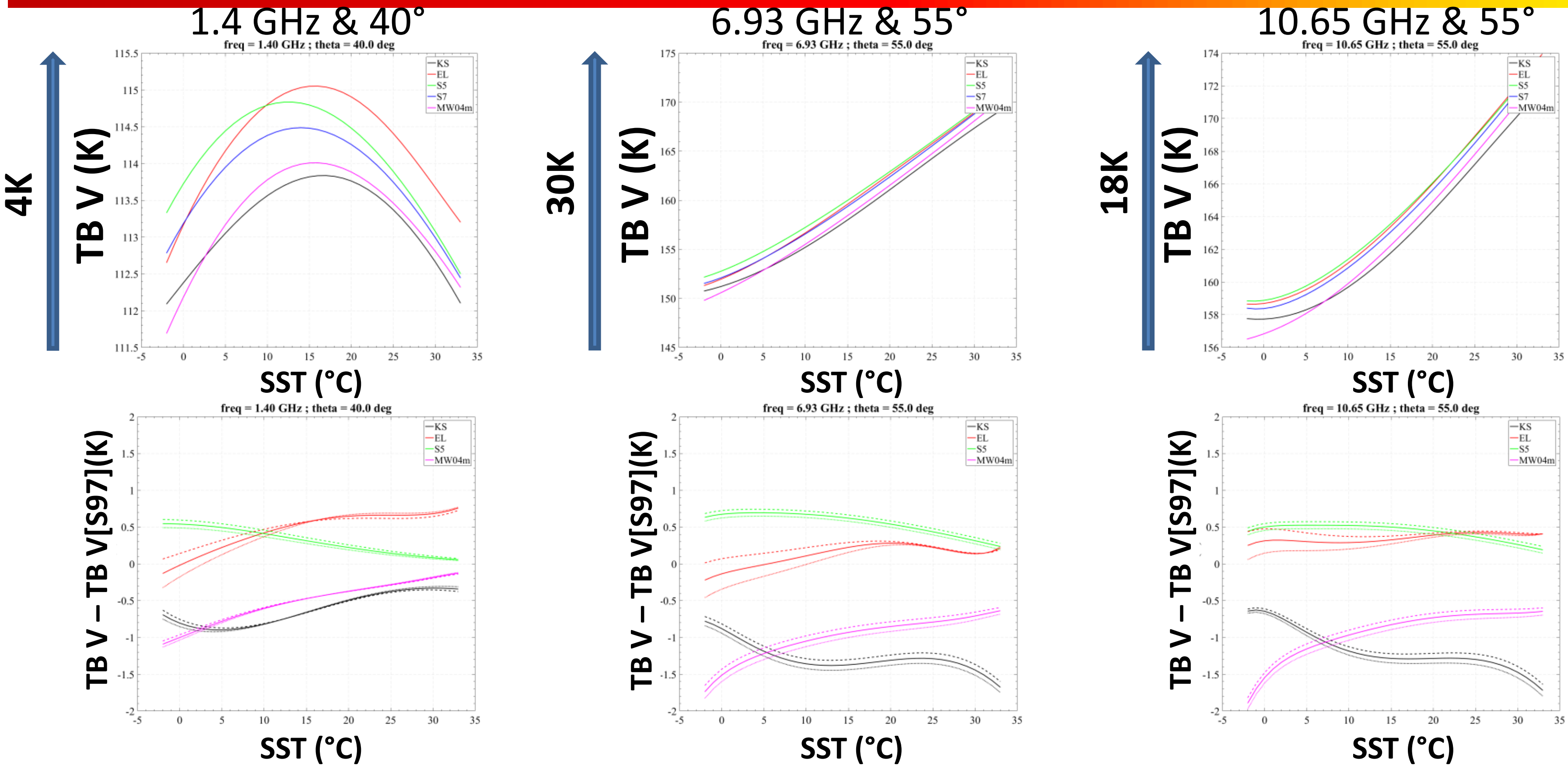
Models: sea water dielectric constant

- Dielectric constant models assessed:

Klein et Swift (KS)	**1977**	**1.4 GHz et 2.65 GHz**
Stogryn (ST95)	**1995**	**7 GHz → 14 GHz**
Ellison et al. (EL)	**1998**	**3 → 20 GHz, 23.8 GHz, 36.6 GHz et 89 GHz**
Stogryn (ST97)	**1997**	**(ST95 + EL)**
Meissner and Wentz	**2004 (Rev 2012,2014)**	**1.4 GHz – 90 GHz (empirical)**
Zhou et al	**2017**	**1.4 GHz (still being developed)**

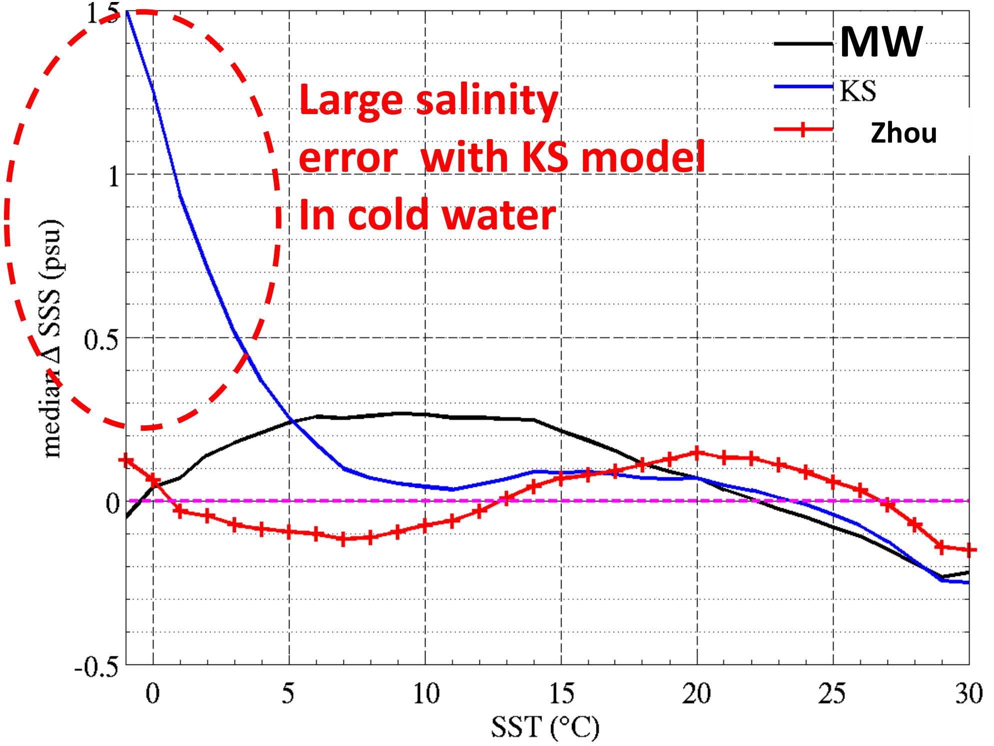
Dielectric constant: TB comparisons at various frequencies



Dielectric constant model: Validation at L-band

- Aquarius L2 V3 reprocessed using various dielectric constant models:
  - Klein and Swift 1977 has large biases in cold waters at L-band (and more SST dependent biases observed at higher frequencies)
  - Zhou 2019 offers good performances at L-band but based on 1 freq measurements and not validated at higher frequencies (& SSS dependence issue … solved in upcoming version)
  - Meissner and Wentz is validated over large range of frequencies, and has good performances at L-band.

Aquarius SSS retrievals with various ε models

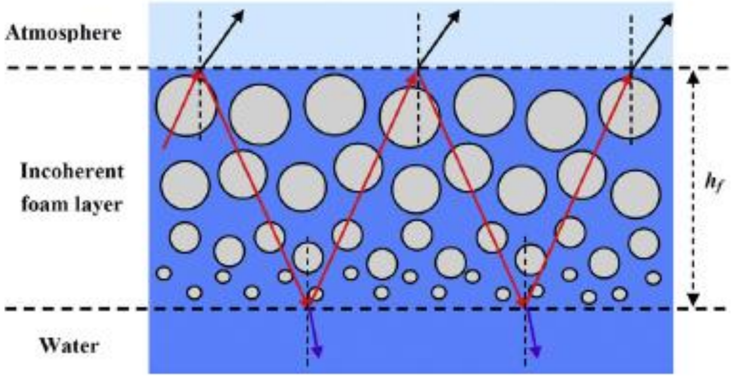


WIND MODELS

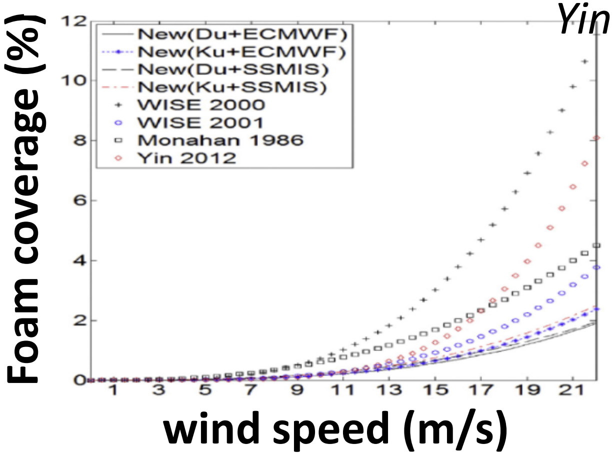
Wind Models: sea surface roughness and foam

Sea spectrum Durden and Vesecky (1985) ["semi-empirical" model]:

- Yueh 1997 modified (x2) to match slope variance measurements, showed good match with SSMI dTB/dWS at 19 & 37 GHz
- Used for SMOS pre-launch studies and first years of operations
- Yin et al. 2016 revisited model to better match SMOS observations at multiple incidence angles (0 – 55 deg):
  - Adjust spectrum amplitude to x1.25
  - Foam emissivity from (Anguelova & Gaiser 2013)
    - Void fraction air foam interface $V_{af} = 0.97$
    - *Effective* thickness (~2 cm)
  - Fit foam fraction function as $F_{frac} = a.W^b$ (smaller fractions than previous models)

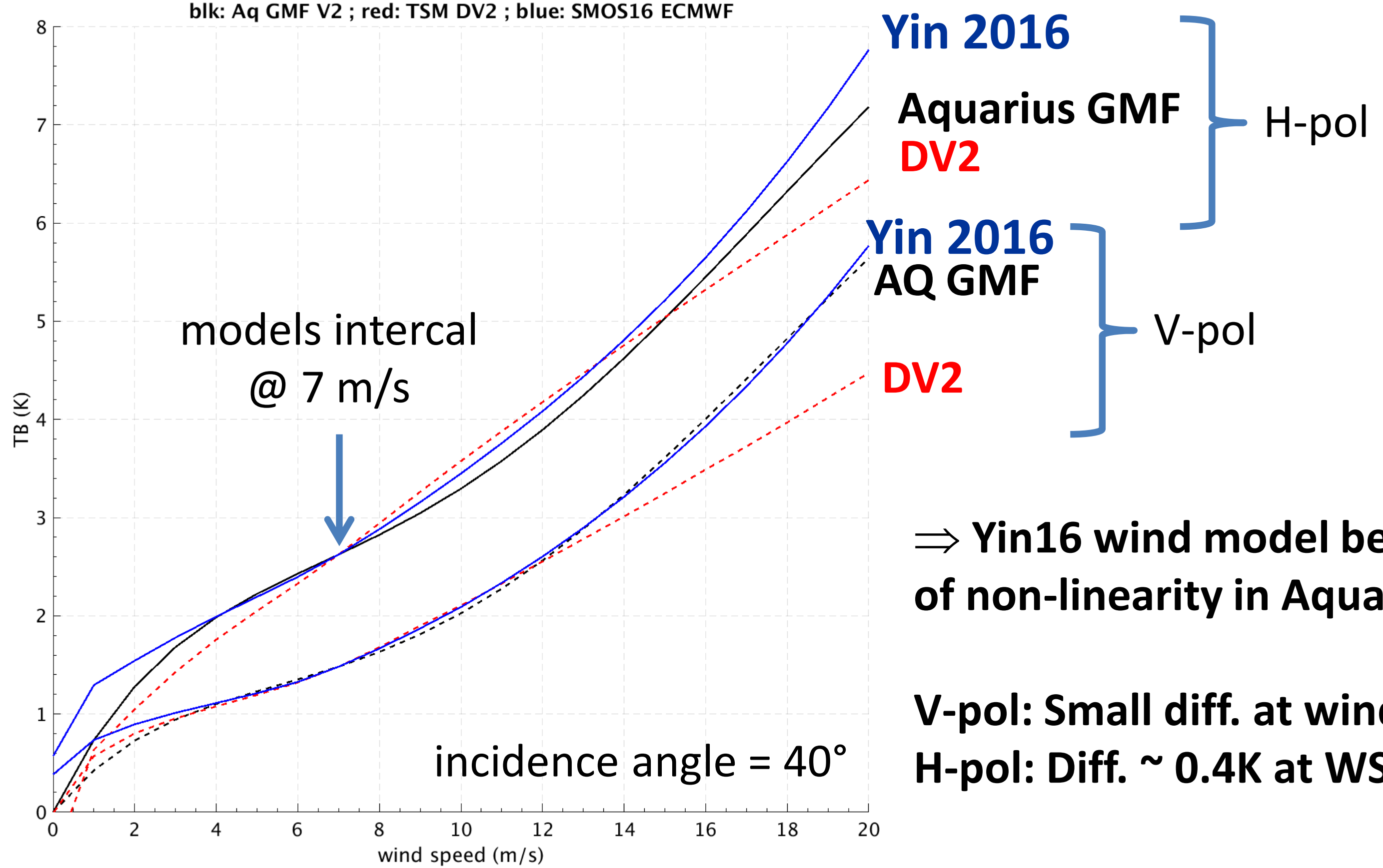


Yin et al., 2016



new model = less foam

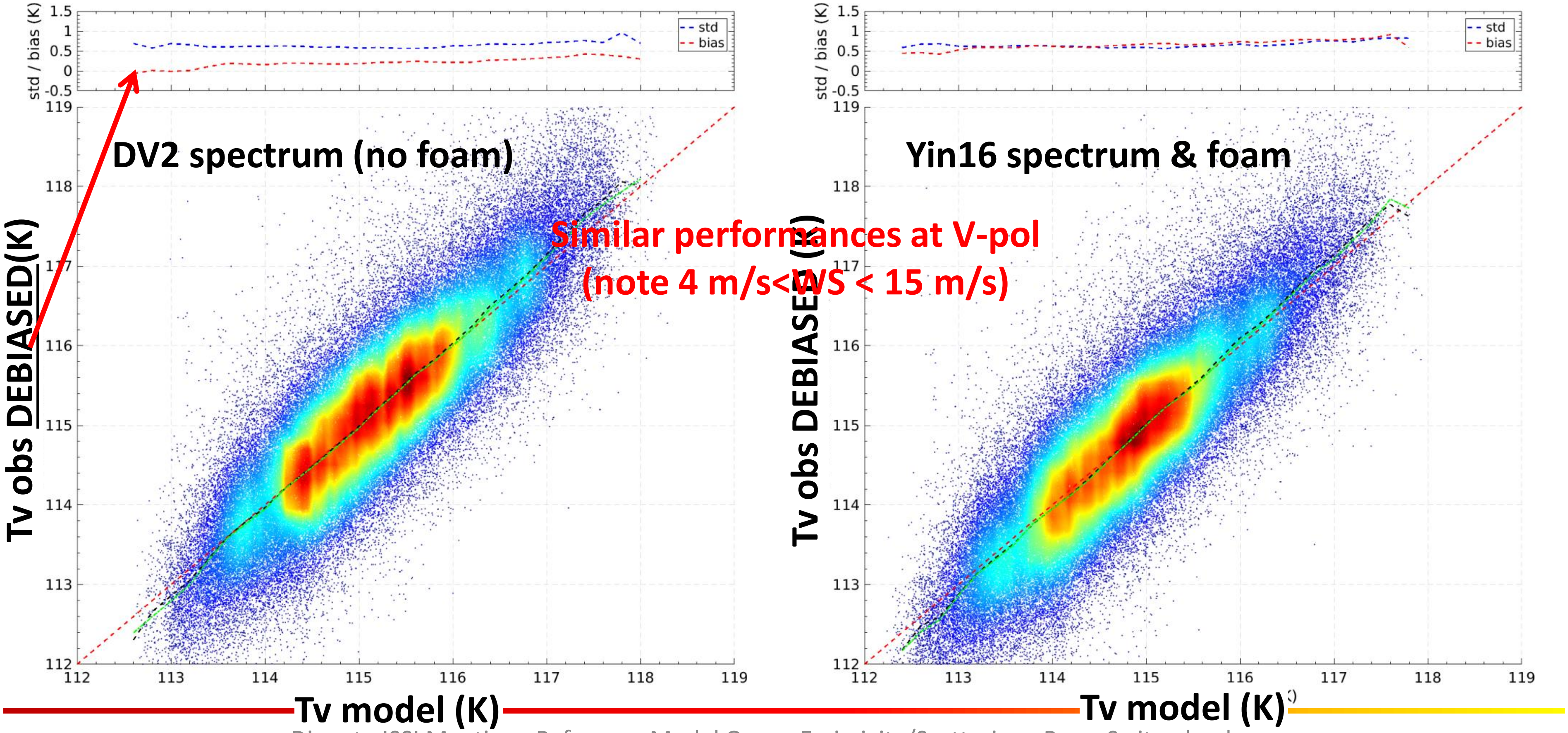
Wind Model validation at 1.4 GHz



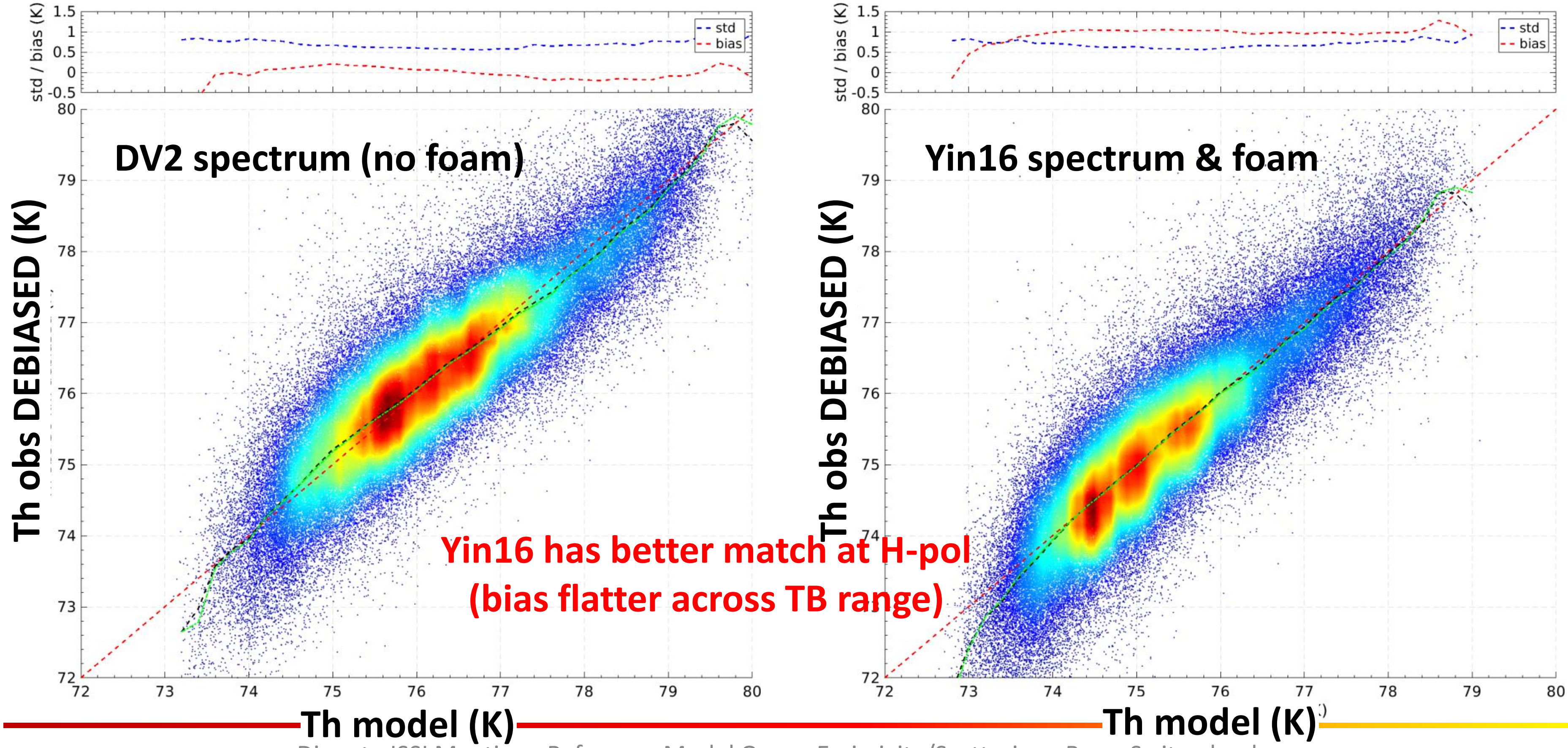
⇒ **Yin16 wind model better match of non-linearity in Aquarius observations**

V-pol: Small diff. at wind speed > 3 m/s
H-pol: Diff. ~ 0.4K at WS > 9 m/s

SMAP observation and simulation consistency



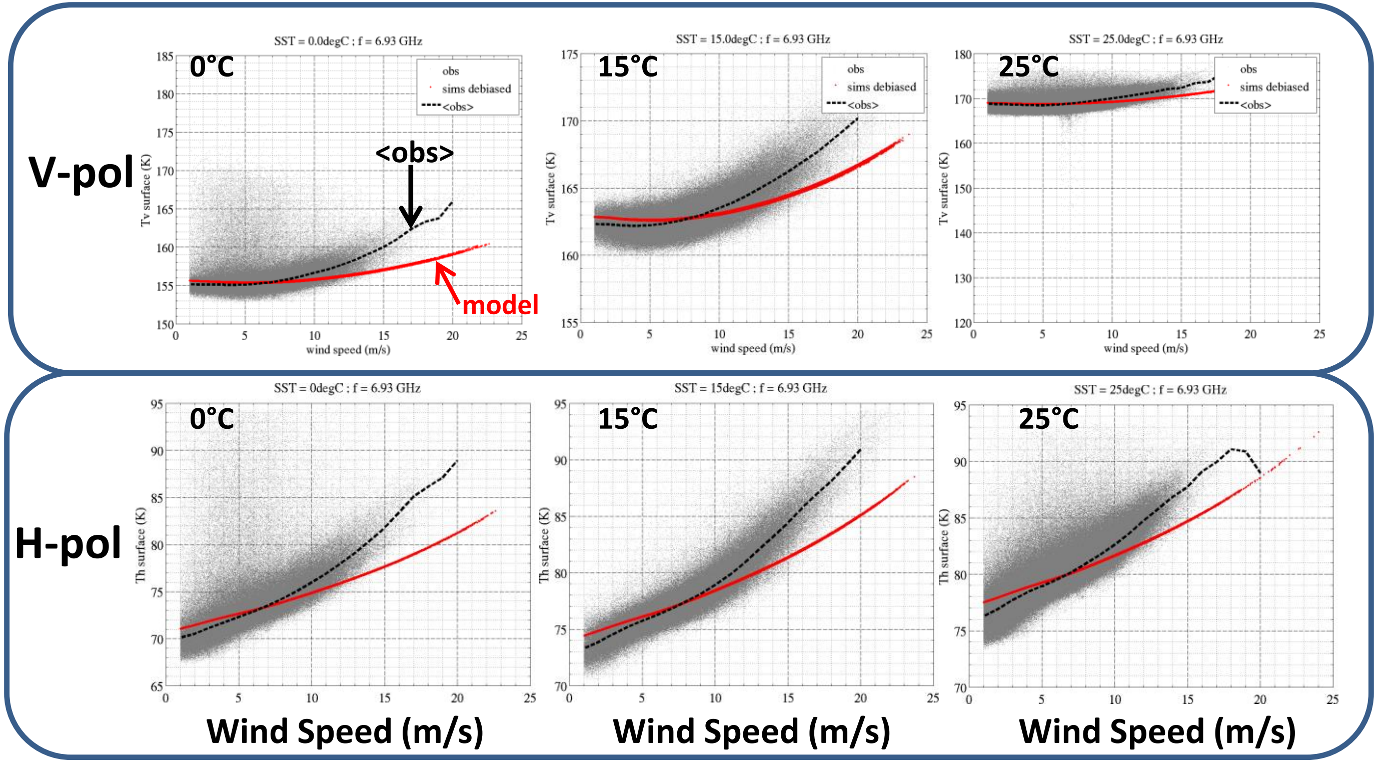
Results: SMAP observation and simulation consistency



Yin16 has better match at H-pol (bias flatter across TB range)

AMSR2 wind model validation – **6.93 GHz**

3 months of AMSR2 data / simulations (01/2017 – 03/2017)



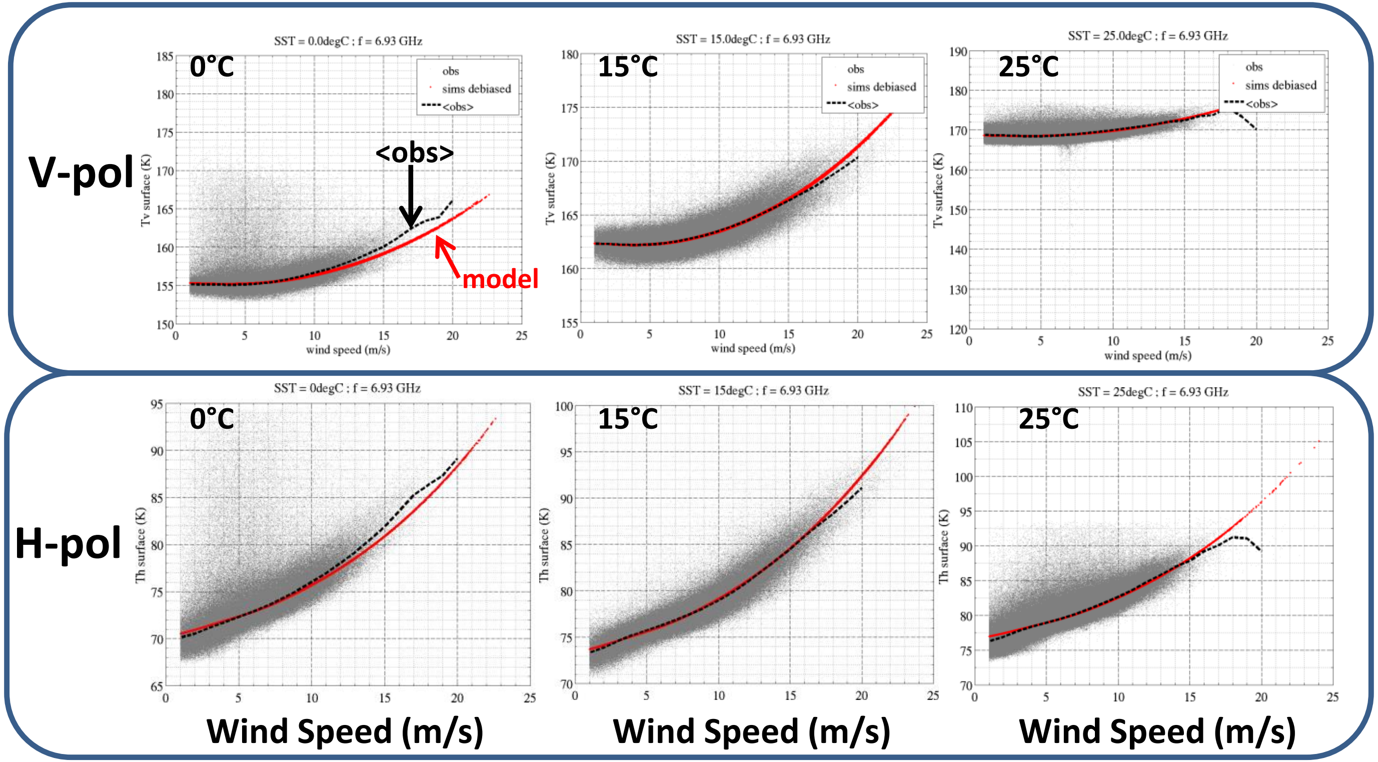
Spectrum: DVx1.25
Foam emissivity: Yin et al. 2016
Foam fraction: Yin et al. 2016

⇒ not enough curvature in TB vs wind speed, in both polarizations

⇒ Error 1K or more at low wind speed and WS > 10 m/s

AMSR2 wind model validation – **6.93 GHz**

3 months of AMSR2 data / simulations (01/2017 – 03/2017)

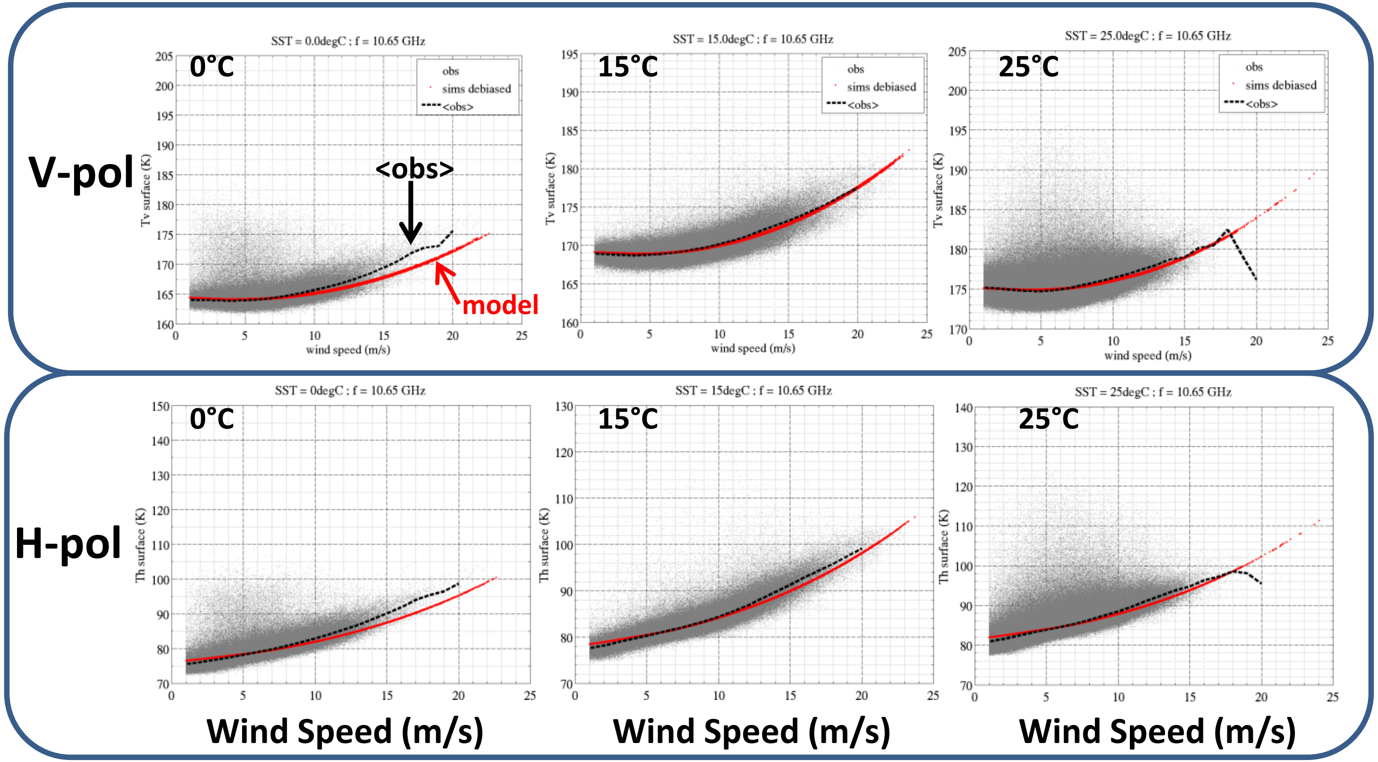


Spectrum: DVx1.25
Foam emissivity: Yin et al. 2016
Foam fraction: MO1986

⇒ Very good match at all SST and most WS
⇒ Error increases at 0degC and WS > 12 m/s

AMSR2 wind model validation – 10.65 GHz

3 months of AMSR2 data / simulations (01/2017 – 03/2017)

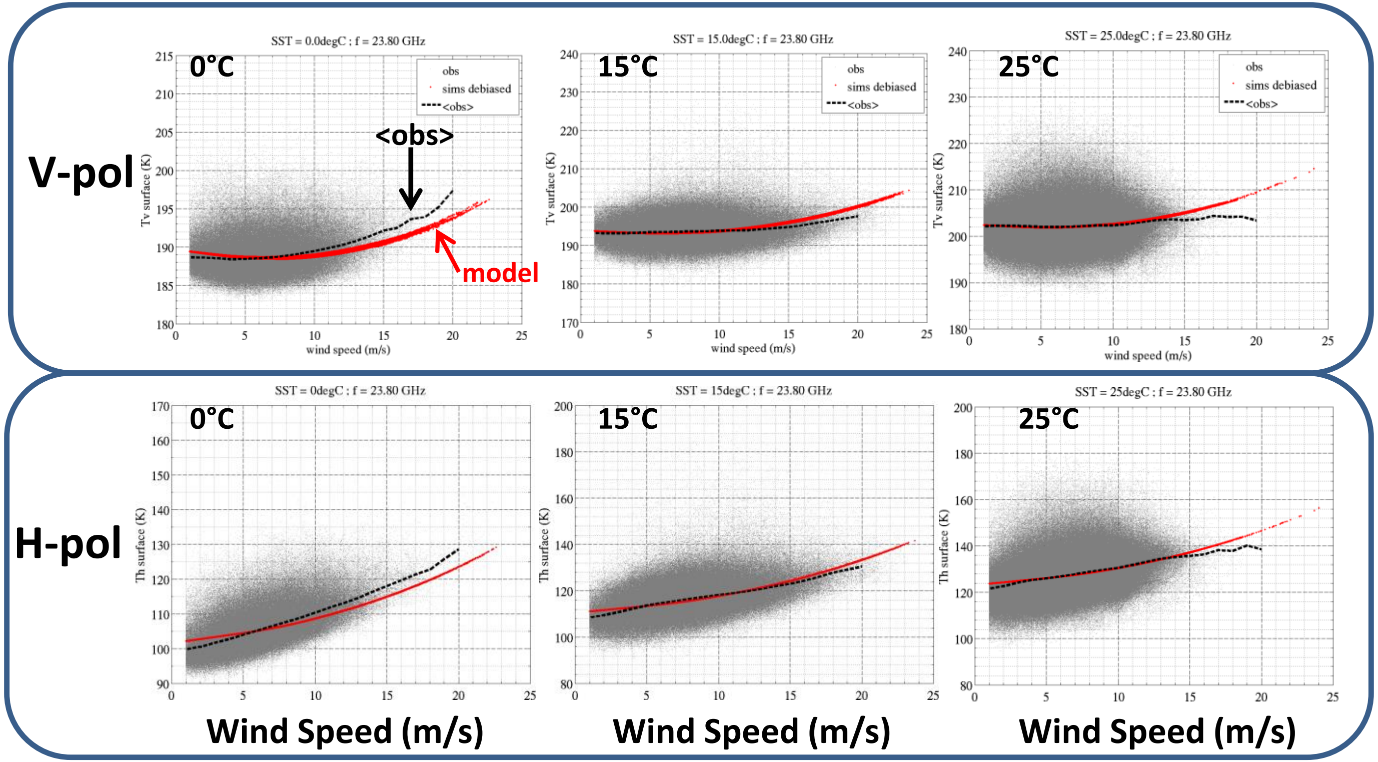


Spectrum: DVx1.25
Foam emissivity: Yin et al. 2016
Foam fraction: MO1986

⇒ Performance degrade slightly
⇒ Good match overall

AMSR2 wind model validation – 23.8 GHz

3 months of AMSR2 data / simulations (01/2017 – 03/2017)



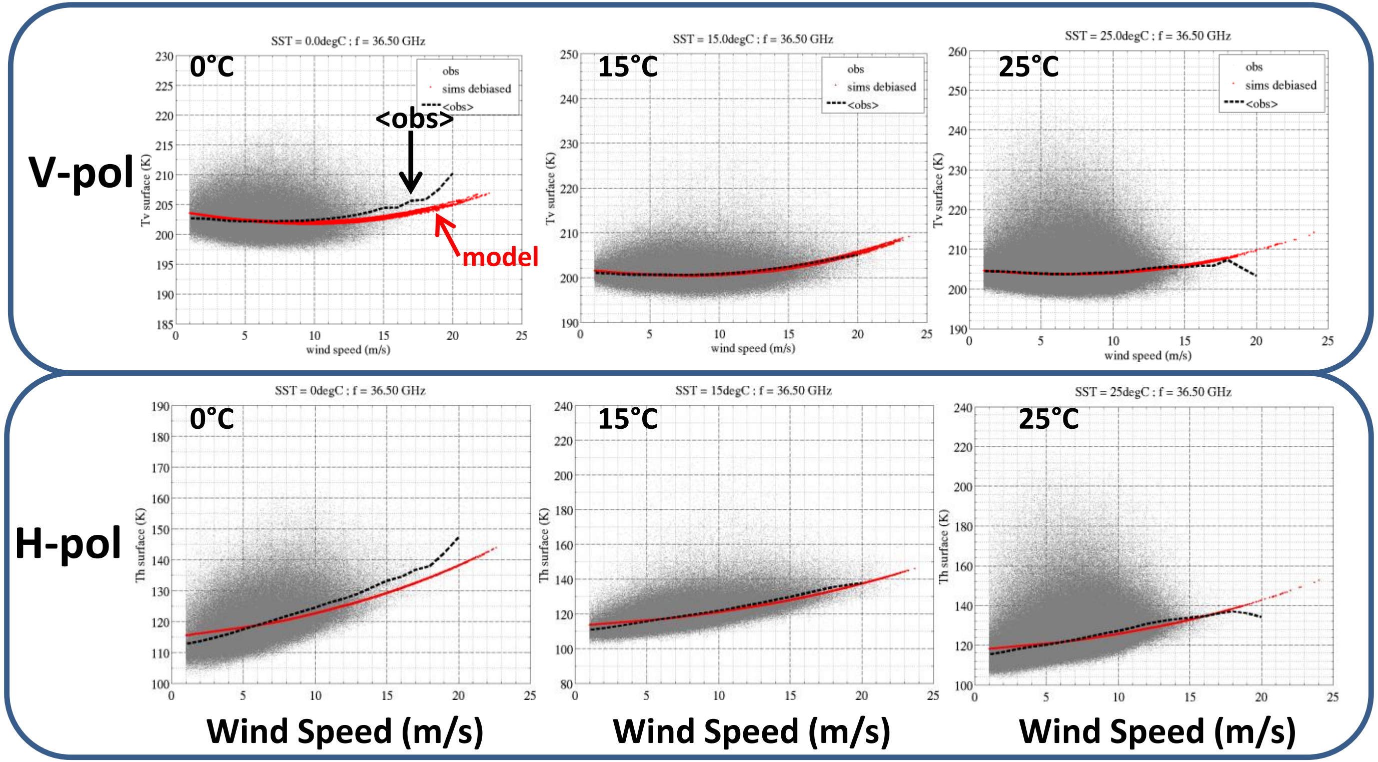
Spectrum: DVx1.25
Foam emissivity: Yin et al. 2016
Foam fraction: MO1986

⇒ Performance degrade
⇒ Scatter in observations increases

Atmo correction issue ?

AMSR2 wind model validation – 36.5 GHz

3 months of AMSR2 data / simulations (01/2017 – 03/2017)

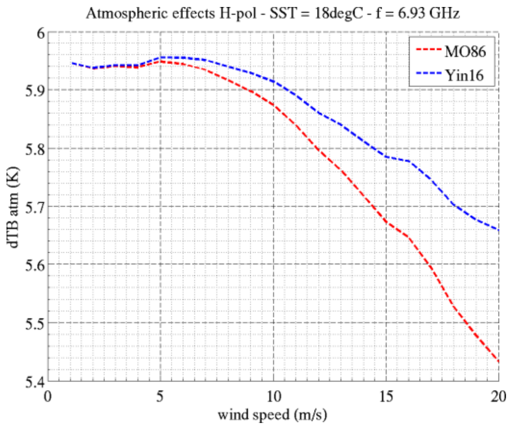


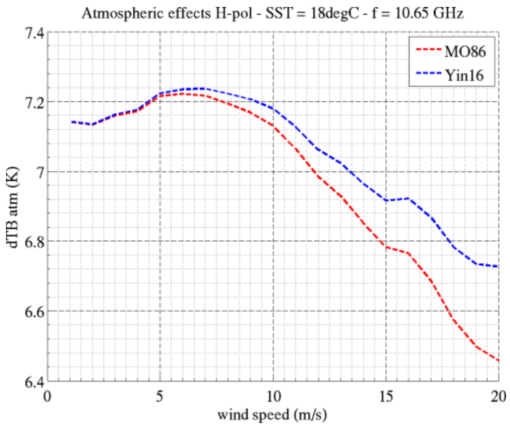
Spectrum: DVx1.25
Foam emissivity: Yin et al. 2016
Foam fraction: MO1986

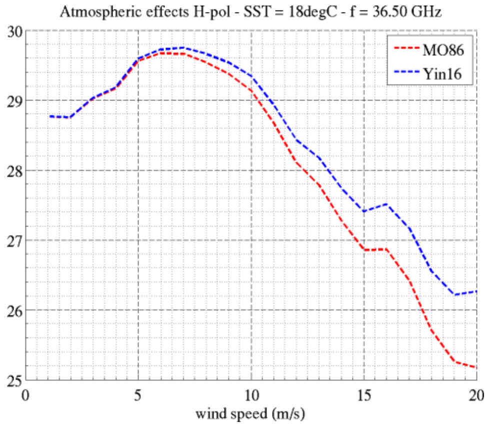
⇒ Performance degrade
⇒ Scatter in observations increases

Atmo correction issue ?

Atmospheric correction dependence on wind model







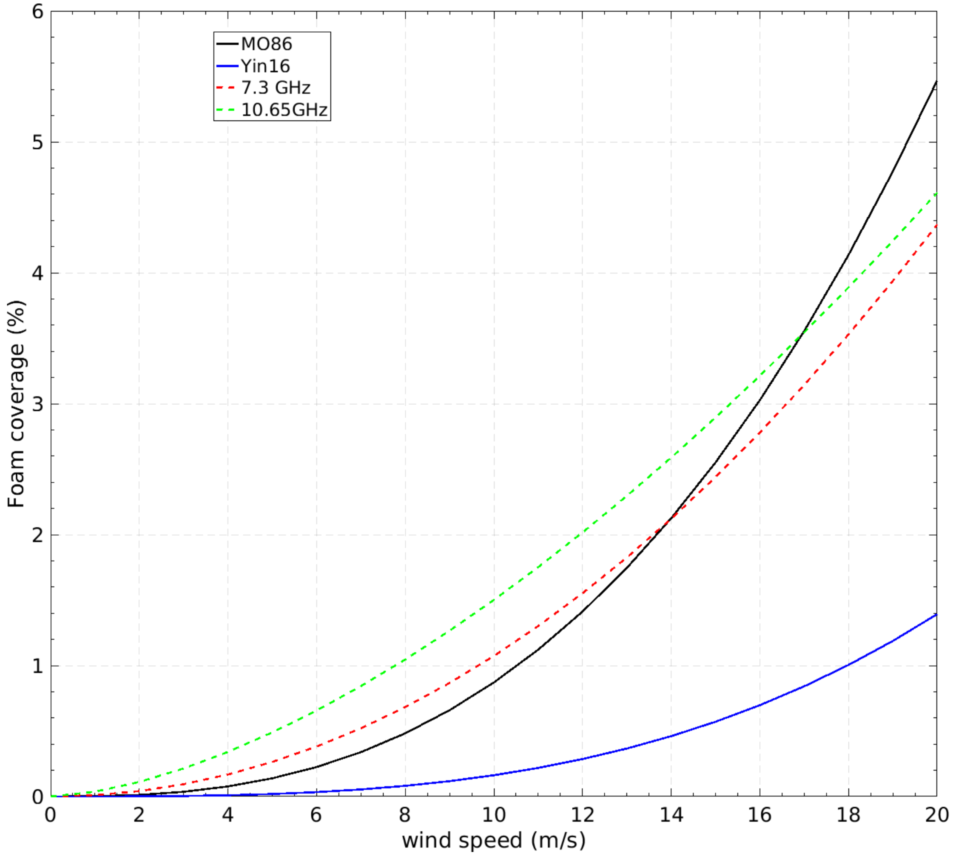
There is a small impact of wind model on atmospheric corrections, up to 0.5K -> 1K at 36 GHz.

Foam fraction retrieved from AMSR2 observations

Foam fraction model

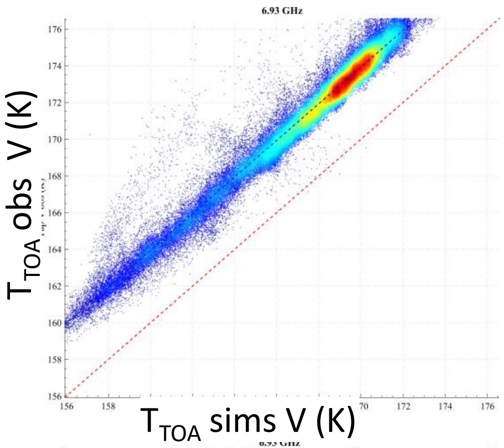
$$F_{frac} = a.W^b$$

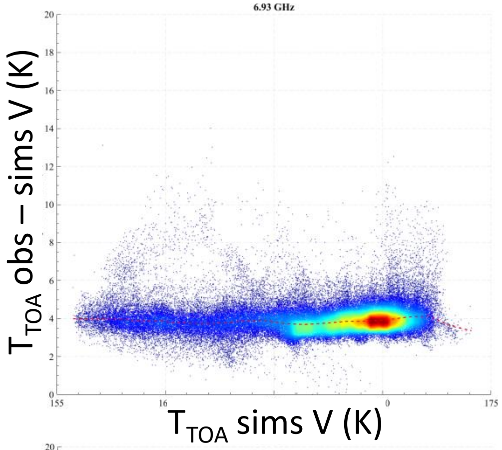
(a,b) adjusted to minimize differences between AMSR2 apparent temperatures (i.e Tsurf + dTatm) and simulations at H-pol

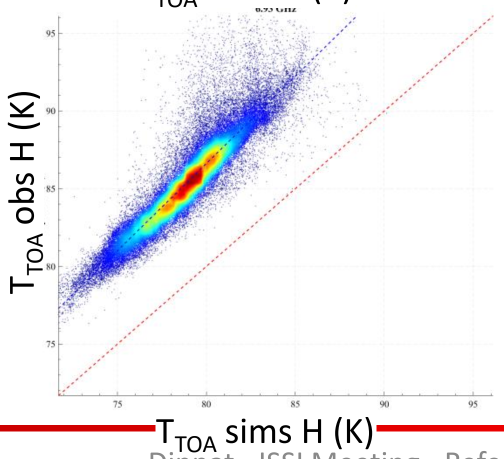


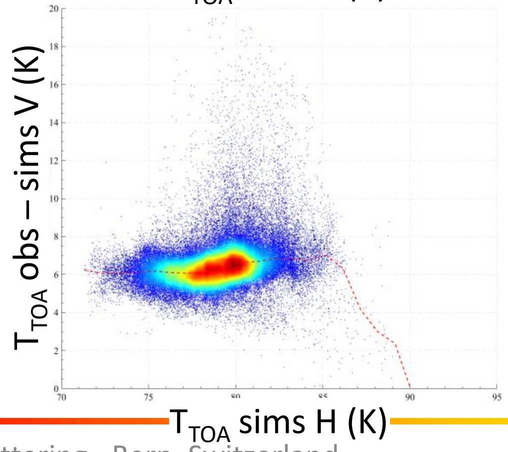
Results: AMSR2 observation and simulation consistency

F= 6.93 GHz



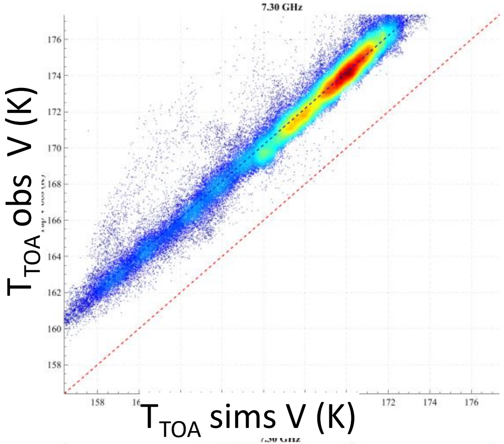


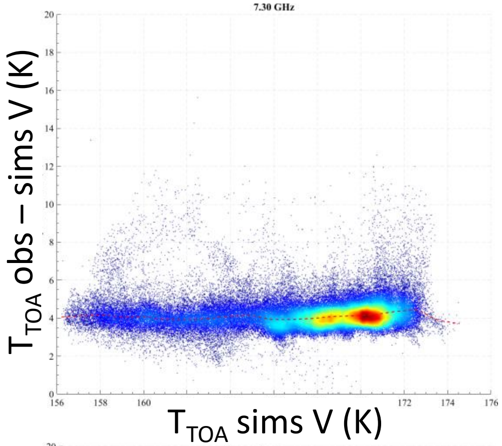


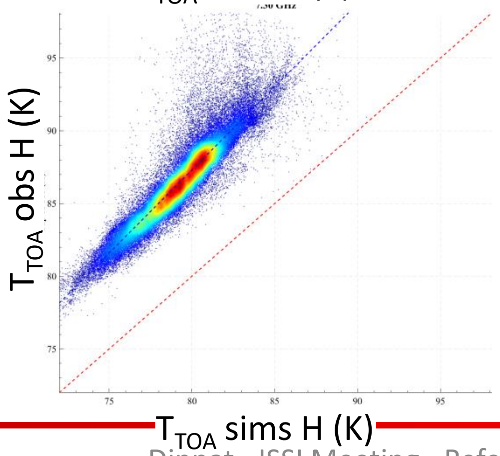


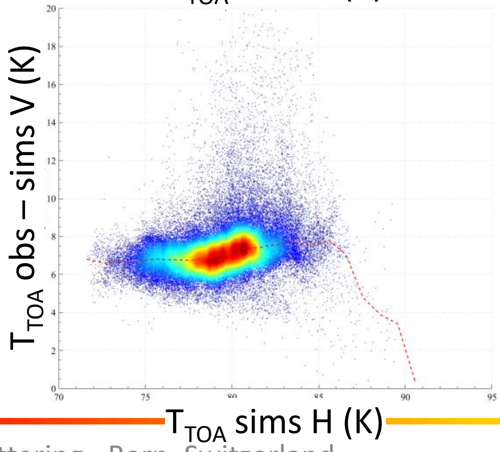
Results: AMSR2 observation and simulation consistency

F= 7.3 GHz



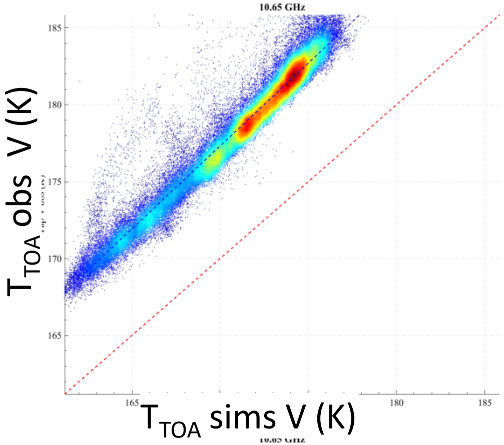


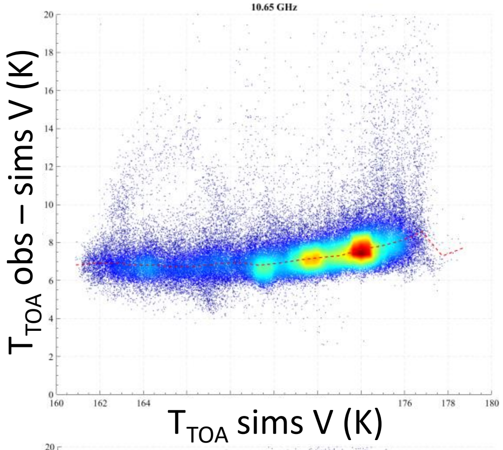


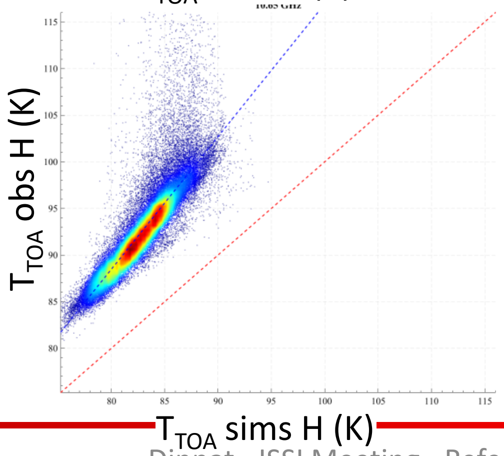


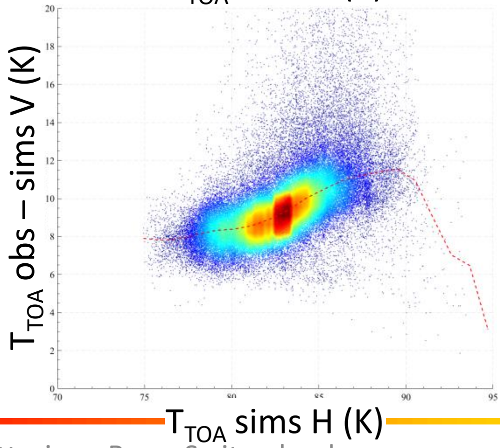
Results: AMSR2 observation and simulation consistency

F= 10.65 GHz



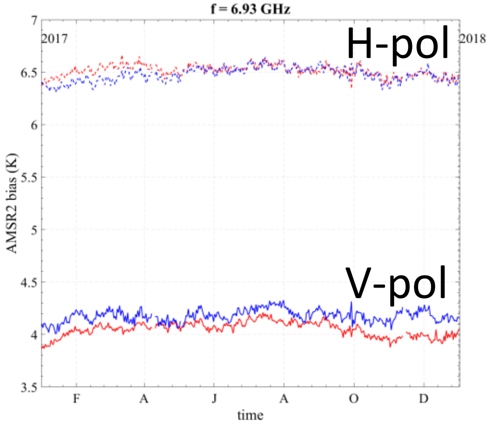




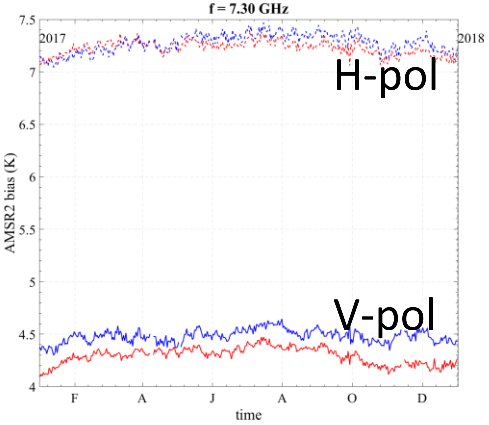


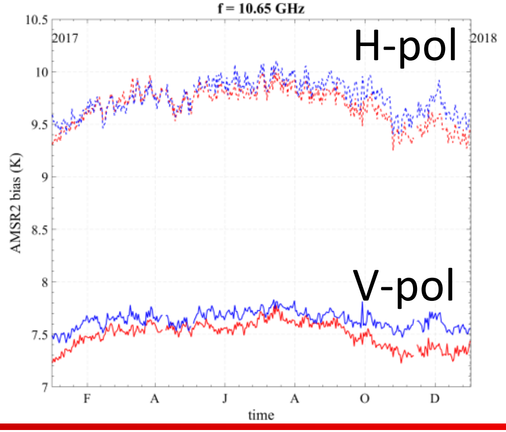
CONSISTENCY SATELLITE VS MODELS & TEMPORAL VARIATIONS

AMSR2 bias and temporal drift



ascending
descending





Bias:

	6.93 GHz	7.3 GHz	10.65 GHz
V	4 K	4.4 K	7.6 K
H	6.5 K	7.25 K	9.75 K

Conclusions

- Semi-<u>empirical</u> model possible for multi-frequency (multi-angular?) TB
  - > Some <u>parameters</u> will need to be adjusted across frequencies
  - > Acceptability will depend on required precision (0.1K?) and application range (i.e. WS > 20 m/s ?)
- Salinity remote sensing provides high precision validation for dielectric constant models at L-band
  - Zhou et al. 2017 (ΔSSS = [-0.15 psu, +0.15 psu]) and MW2012 (ΔSSS = [-0.25,+0.25]) provide accurate models for SSS retrievals
  - But only MW2012 is valid over wide range of frequencies (and Zhou has SSS dependence issue, under revision)
- Wind model has good performances over 1.4 GHz -> 10 GHz range with limited number of parameter adjustments (Using Anguelova and Gaiser 2013 emissivity)
  - Amplitude factor to sea spectrum (i.e. DV times 1.25)
  - Foam coverage coefficients in power law
- Other [equivalent?/superior?] adjustments could be made, i.e. adjust foam thickness instead of coverage or void fraction at air/foam interface. (=> the physics is unknown to some extent)
- Higher frequencies exhibit an increased scatter of TB vs WS that needs more investigation.

  (atmospheric effect, impact of atmospheric stability)

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