Ocean emissivity model applications: RTTOV perspective

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Met Office

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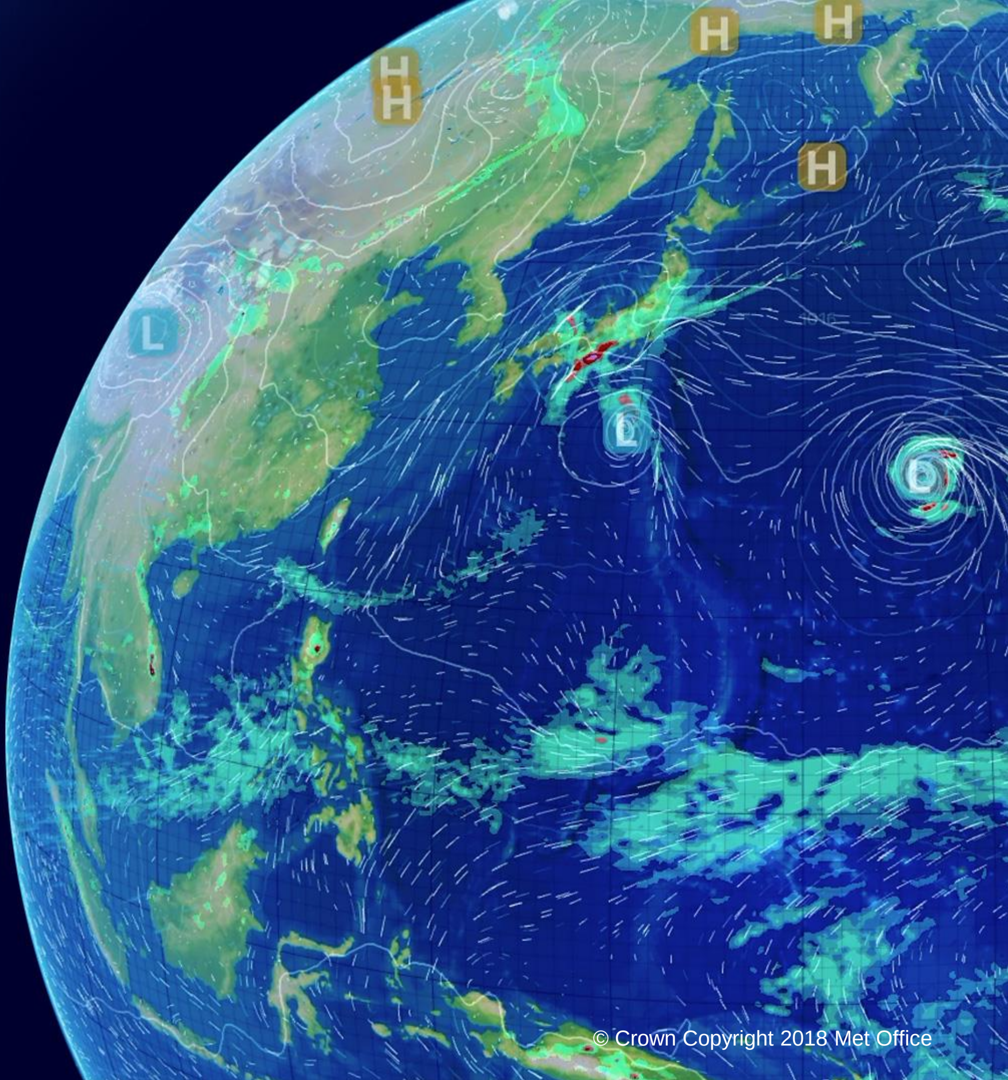
Thanks to contributions from Heather Lawrence, Fabien Carminati and James Hocking



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Application of ocean emissivity models in NWP
Talk outline

- RTTOV ocean emissivity: infrared model
- RTTOV ocean emissivity: microwave model
- Uncertainty in Earth Observation (GAIA-CLIM)
- Summary / for discussion

IR sea surface emissivity models in RTTOV

- Option 1: ISEM (Sherlock, 1999)
- Option 2: IREMIS (Saunders et al., 2017)

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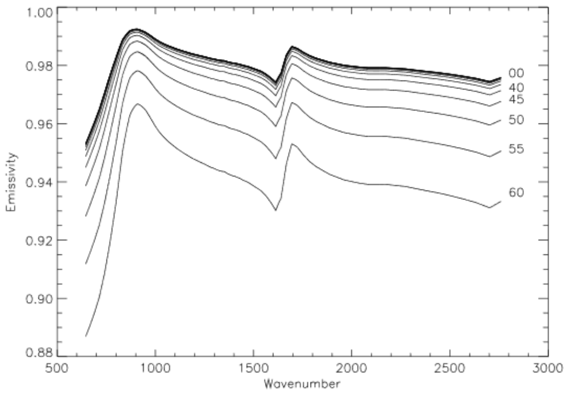
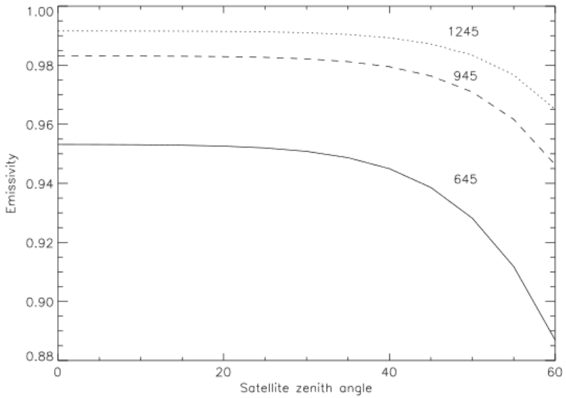
ISEM (Sherlock, 1999)



(a) Spectral and zenith angle dependence of sea surface emissivity (Masuda, $|u|=0$).



(b) Zenith angle dependence of the sea surface surface at 645, 945, and 1245 cm^{-1}.

- Refractive indices are from Hale and Querry (1973) with the Friedman (1969) salinity correction
- Based on the Masuda (1988) model which calculates the emissivity for a rough sea surface with the Cox and Munk (1954) isotropic wave slope statistics

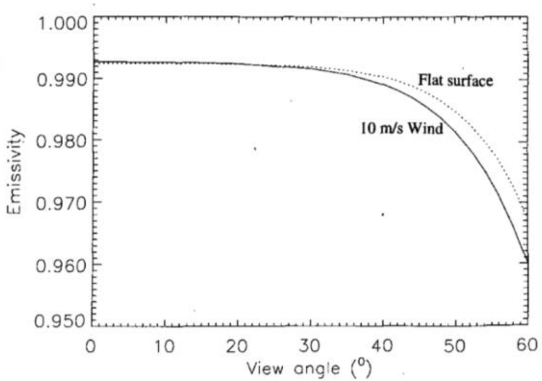


FIG. 1. The direct emissivity of a water surface at 11 μm as a function of viewing angle. The dotted line is for a plane surface and the solid line is for a rough surface resulting from a wind speed of 10 m s^{-1}.

Watts et al. (1996)

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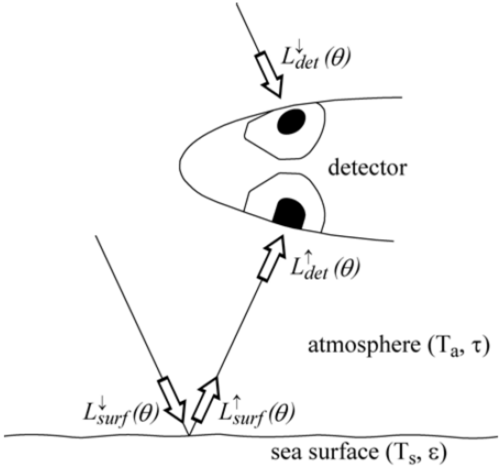
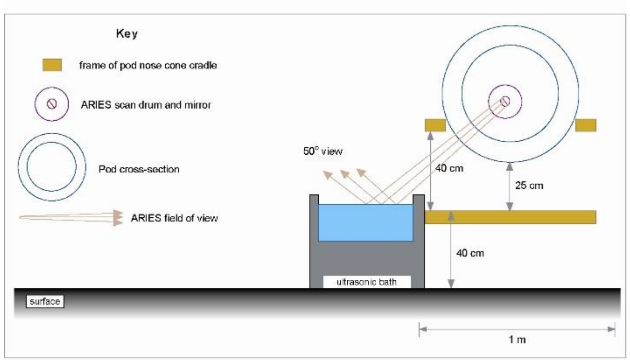
Airborne data (ARIES interferometer)

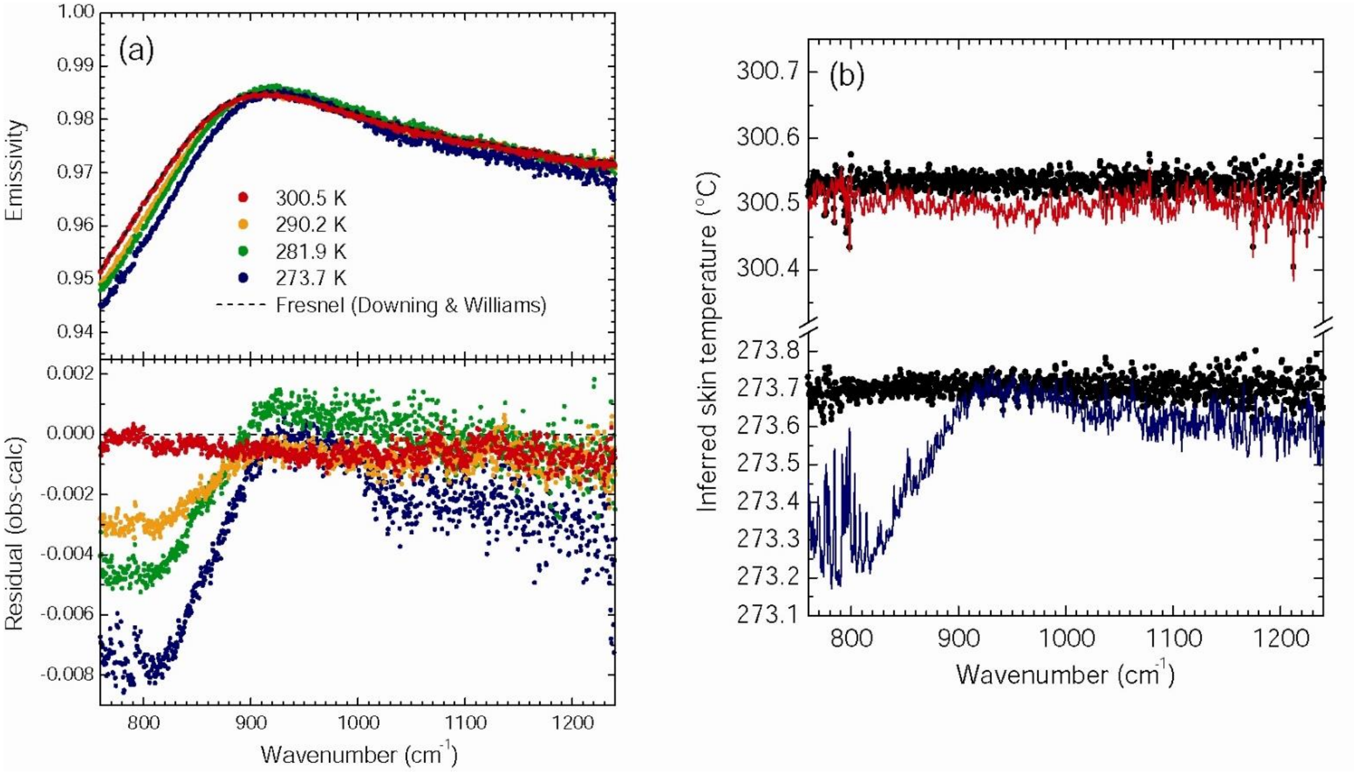


Ground-based data



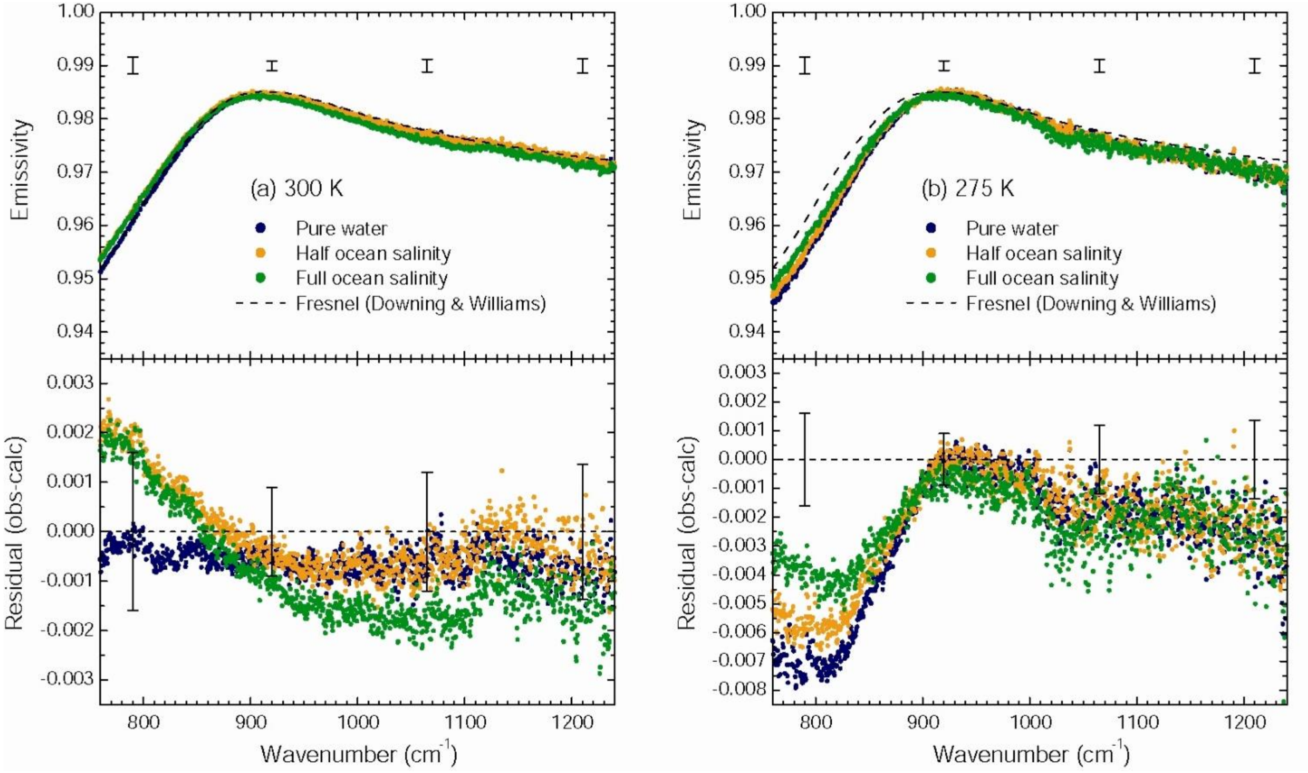
- ARIES interferometer flew on Hercules C-130 research aircraft (now on FAAM BAe-146)
- Upwelling and downwelling IR radiance measurements to test ocean emissivity models
- Associated ground-based tests 760-1240 cm^{-1}

Met Office experiments



- Experimentally retrieved emissivity for pure water departs from room temperature (300 K) laboratory data with decreasing temperature near 800 cm^{-1}

Met Office experiments



- Impact of varying salinity less than temperature dependence in mid-IR range (magnitude consistent with Friedman 1969 data)

IREMIS (Saunders et al., 2017)

- Refractive indices are from Hale and Querry (1973) with the Pinkley and Williams (1976*) salinity correction
- In the 10-12 μm window the Newman et al. (2005) linear dependence of refractive index on skin temperature is used
- The wave slope model is based on Masuda (2006) which is a development of the Masuda (1988) model (incorporates surface-emitted surface-reflected radiation)
- The wave slope statistics are taken from Ebuchi and Kizu (2002) rather than Cox and Munk (1954)
- Presence of foam for windspeeds 7-10 m/s or greater is neglected (assumed high emissivity)

* Transposed from graphs in manuscript

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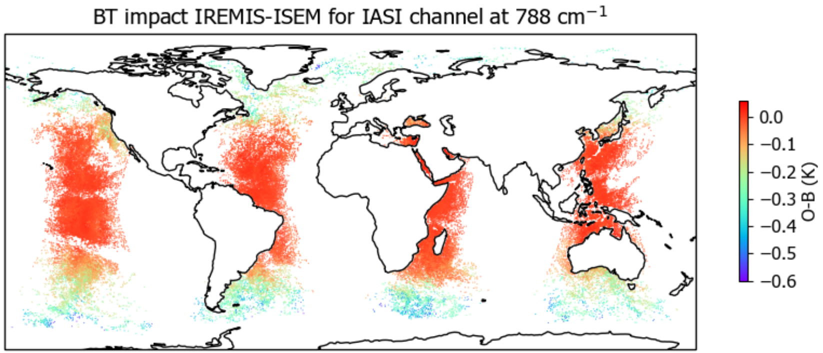
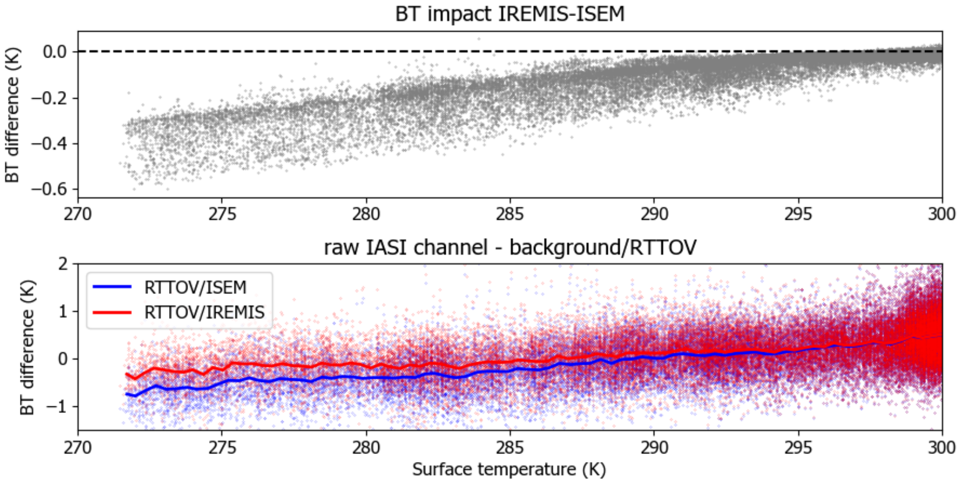
IREMIS vs. ISEM

- Impact is greatest for low sea surface temperatures
- Replacing ISEM with IREMIS results in difference up to ~0.5 K for IASI channel at 788 cm^{-1}





Microwave sea surface emissivity models in RTTOV

- FASTEM: versions 1-6. Dependence on 10m wind speed, skin temperature, salinity, zenith angle and azimuth angle; ocean surface foam fraction. Optimized < 200 GHz (Steve's talk)
- TESSEM^2 (Prigent et al., 2016). Based on FASTEM but applicable to 10-700 GHz (e.g. MetOp-SG ICI application)
- At the Met Office the default for microwave sounders/imagers is FASTEM version 2 – planned upgrade to FASTEM-6

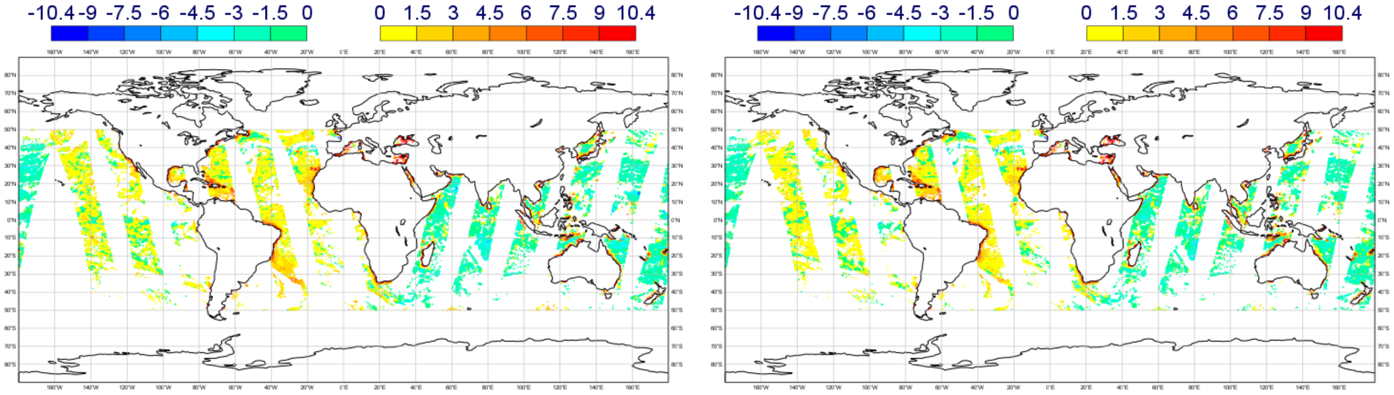
GAIA-CLIM

- GAIA-CLIM (Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring) aimed to establish sound methods for the characterisation of satellite-based Earth Observation (EO) data using reference non-satellite data
- We (Met Office, ECMWF) explored using NWP as a framework for cal/val of new satellite missions: AMSR2 on GCOM-W1, MWHS-2 and MWRI on FY-3C, MTVZA-GY on Meteor-M N2 and GPM GMI

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 640276.

Satellite cal/val in NWP

ECMWF O – B (minus global average) | **Met Office O – B (minus global average)**



FY-3C MWRI 10.65 GHz H-pol channel (Heather Lawrence, ECMWF for GAIA-CLIM)

- Every new satellite measurement must be evaluated before use in NWP
- “O-B” (observation minus NWP background model brightness temperature) is a key diagnostic
- NWP fields offer advantages for satellite validation – they are spatially continuous, constrained by large numbers of observations and physically consistent – and tend to exhibit small biases (tenths of K for temperature fields)
- However, surface sensitivity can complicate the picture…

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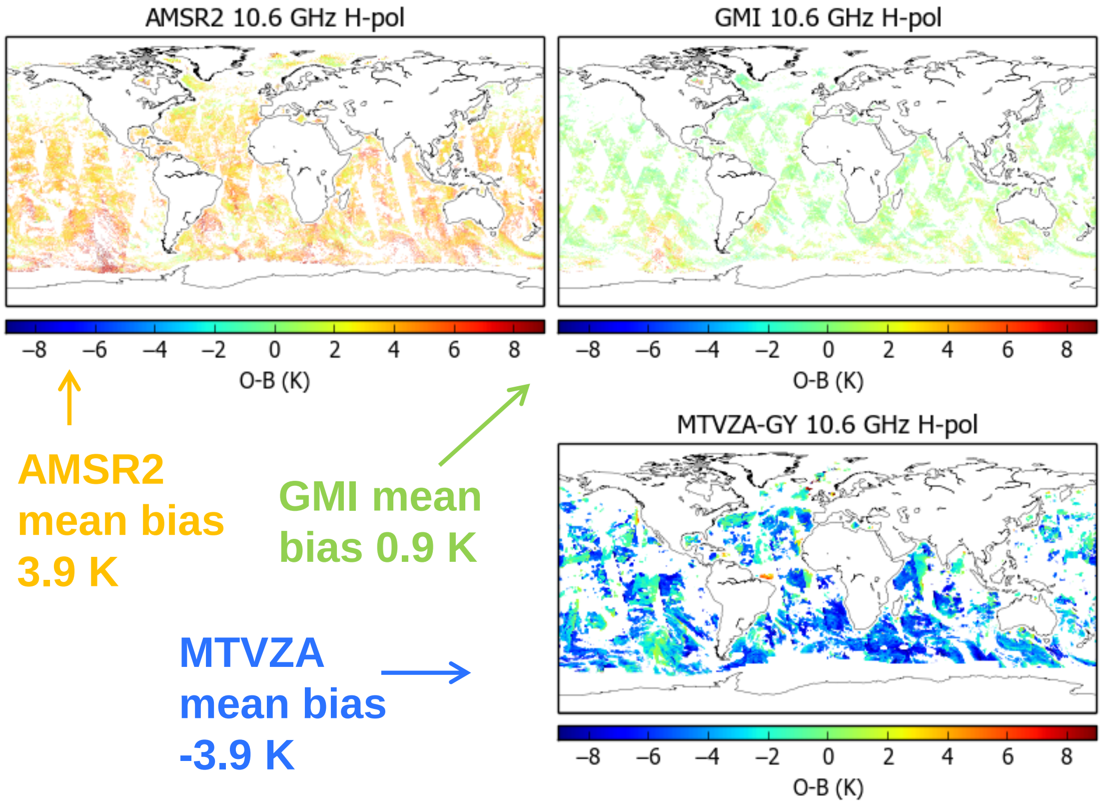
Satellite cal/val in NWP

- During GAIA-CLIM we assessed instrument data quality for imagers AMSR2, GMI and MTVZA
- The O-B biases are different – but what is the absolute uncertainty in the comparison?
- Uncertainty in modelled surface emission is not well determined

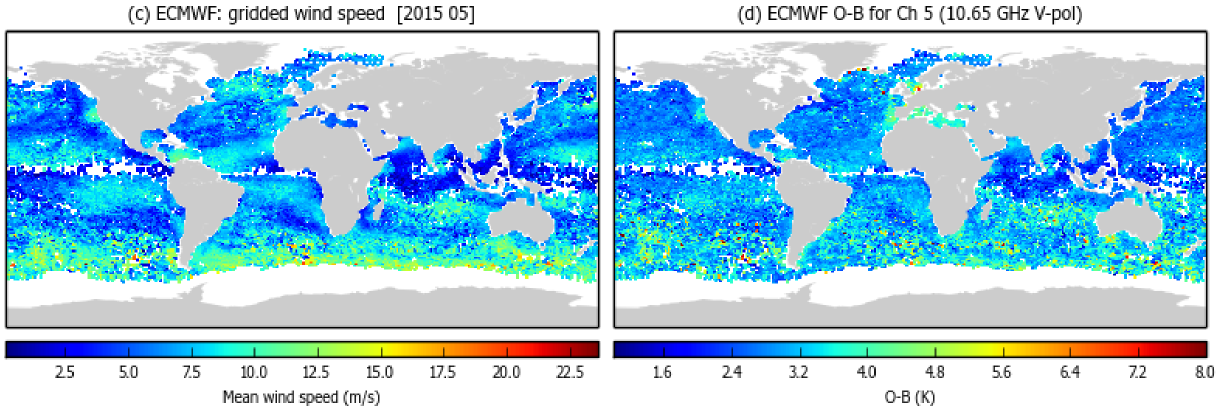


Data selection

$$P_{37} = (T_v - T_h) / (T_{v\_clear} - T_{h\_clear})$$

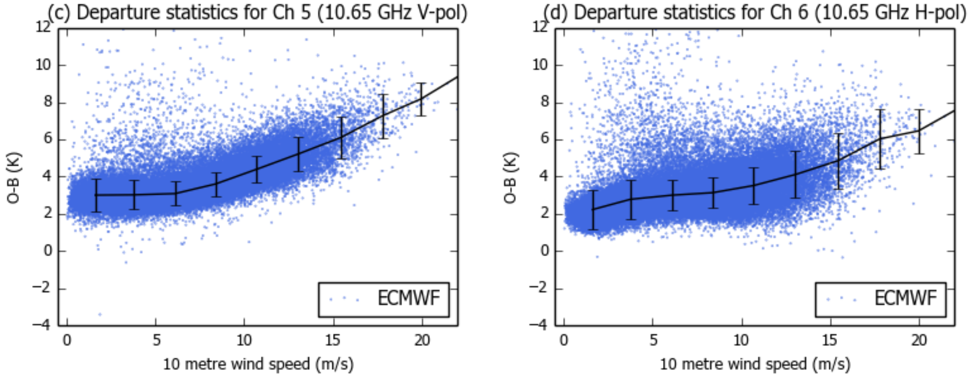
$$C_{37} = 1 - P_{37}$$

Petty and Katsaros (1990)



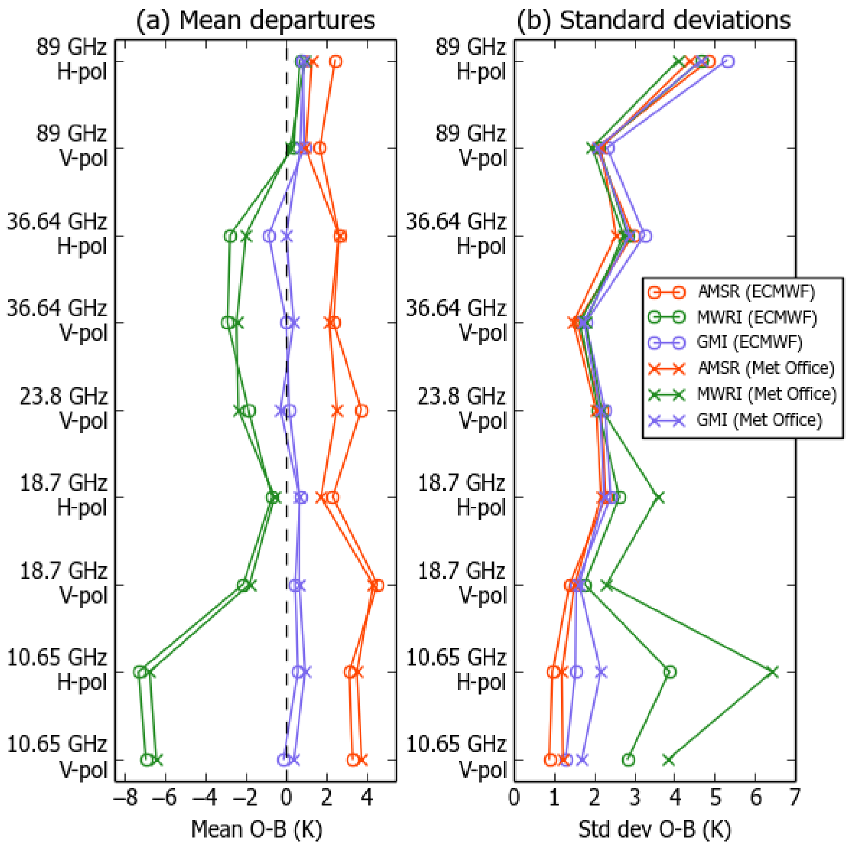
AMSR2

- O-B statistics depend on QC applied
- For GAIA-CLIM we used depolarisation signature at 37 GHz to screen out cloudy scenes where there is less confidence in RT
- We also limited data set to scenes with surface wind speed < 7 m/s



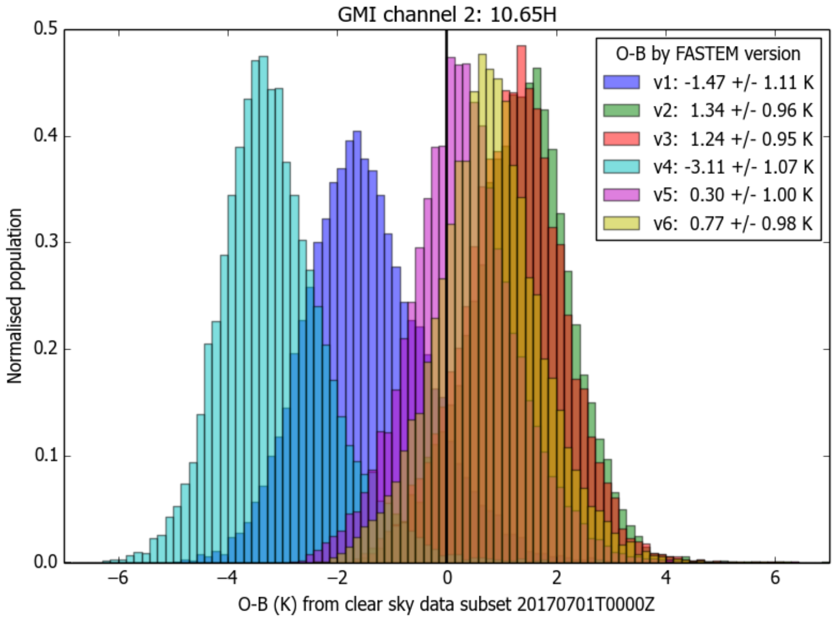
Satellite cal/val in NWP

- Common channels on AMSR2, MWRI, GMI
- Mean biases per instrument/channel for ECMWF and the Met Office are very similar (both using RTTOV and FASTEM-6)



Satellite cal/val in NWP

- GMI is considered to be a well designed instrument with small calibration biases
- Compare O-B statistics with the different FASTEM versions – with FASTEM-5/6 biases are small but we cannot be sure about contributions to the bias (instrument and emission model biases might cancel)



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GAIA-CLIM recommendations

GAIA-CLIM documented unfulfilled user needs (“gaps”) in the availability of truly reference quality data to support ECV monitoring

Thematic recommendation 8. Improve quantification of the effects of surface properties to reduce uncertainties in satellite data assimilation, retrieval and satellite to non-satellite data comparisons

“Surface emissivity and its uncertainty can be the dominant source of uncertainty in the analysis and utilisation of the satellite measurements… a reference ocean emissivity model should be developed [for the spectral region of 1 –200 GHz] supported by reference-quality laboratory measurements of the seawater dielectric constant”

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GAIA-CLIM recommendations

Treatment of uncertainty and traceability

- Identify the specific elements that make up the product chain for this combination of parameters
- Identify the inputs, the process, the uncertainties and sensitivities of the element to these parameters
- Characterise the form of the uncertainty, is it random, quasi-systematic or systematic?
- Combine the individual elements and associated uncertainty information to create the overall traceability chain

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Summary

- In RTTOV the models for MW and IR ocean emissivity have been developed separately
- Are there any barriers to a model spanning MW-IR frequencies?
- NWP plays an increasingly important role in cal/val of new missions, but interpretation of observation-model differences is hampered by unknown errors in surface emission models
- GAIA-CLIM recommended a community effort to establish a reference ocean emissivity model to address this gap
- Traceable uncertainty estimates are a key goal for a reference quality model

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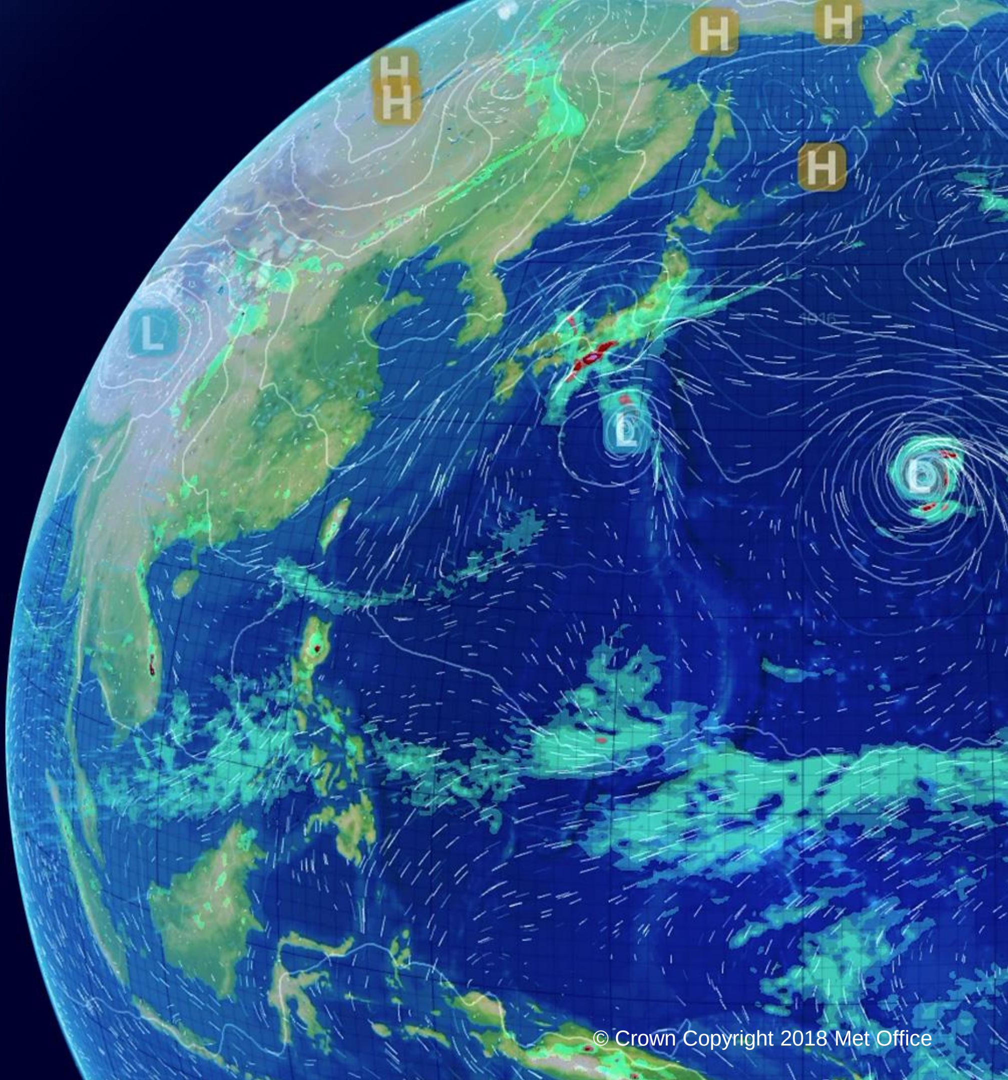
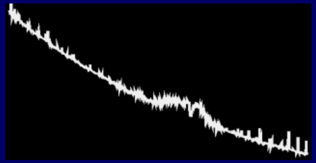
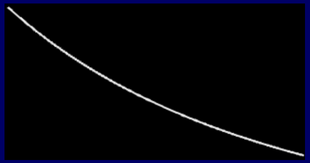
Thank you

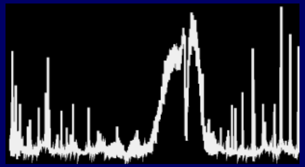


Surface Emissivity (IR retrieval method)

$$L_{surf}^{\uparrow}(\theta) = \varepsilon(\theta)B(T_s) + \left(1 - \varepsilon(\theta)\right)L_{surf}^{\downarrow}(\theta)$$



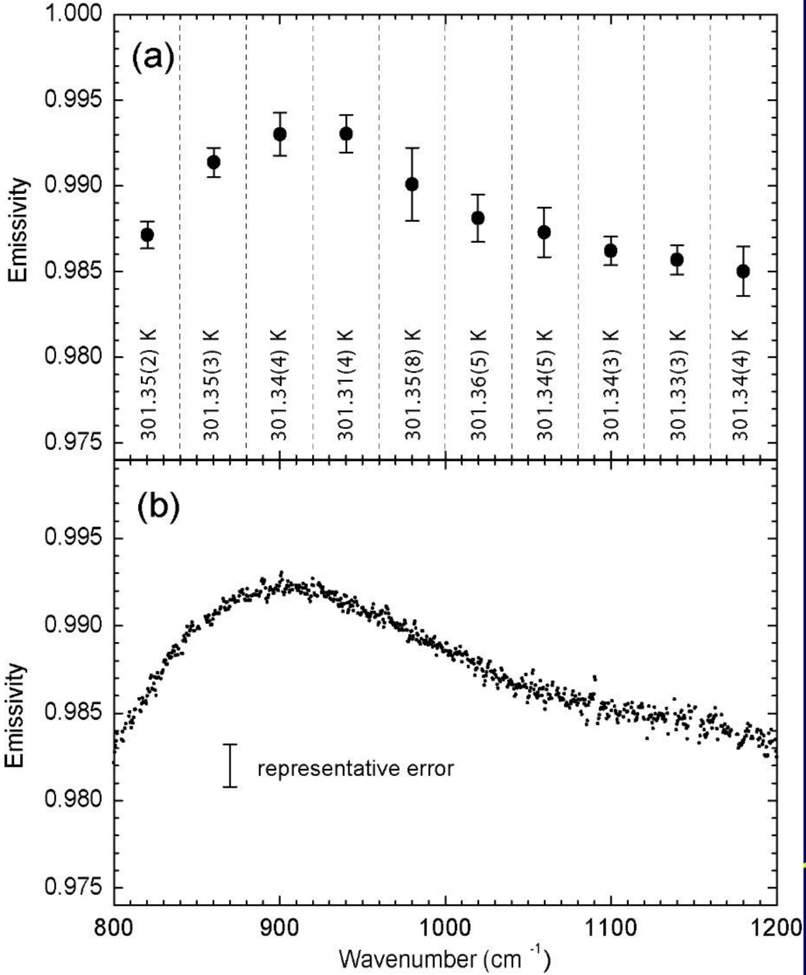




Given that the surface emission term is expected to be spectrally smooth we should be able to find the fraction r such that:

$$L_{surf}^{\uparrow} - r \cdot L_{surf}^{\downarrow} = \varepsilon B(T_s)$$

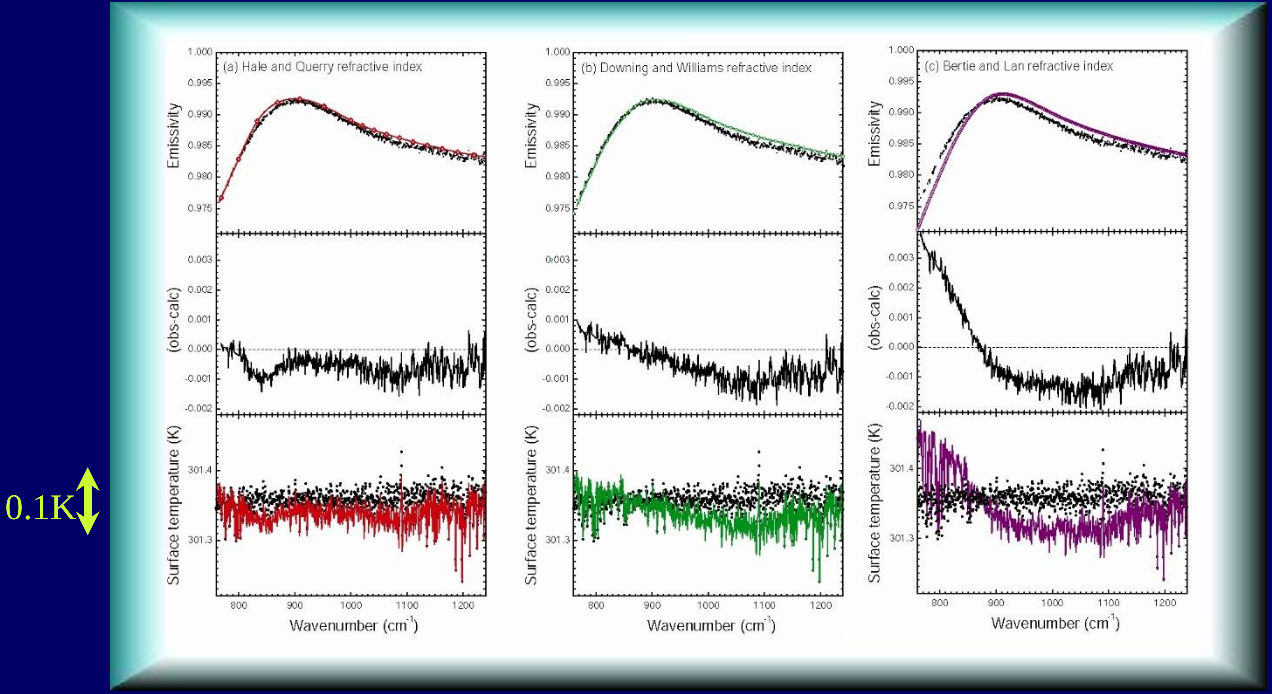
Coarse resolution retrieval from flight A670 in the tropics



Error bars show std deviation from range of spectra

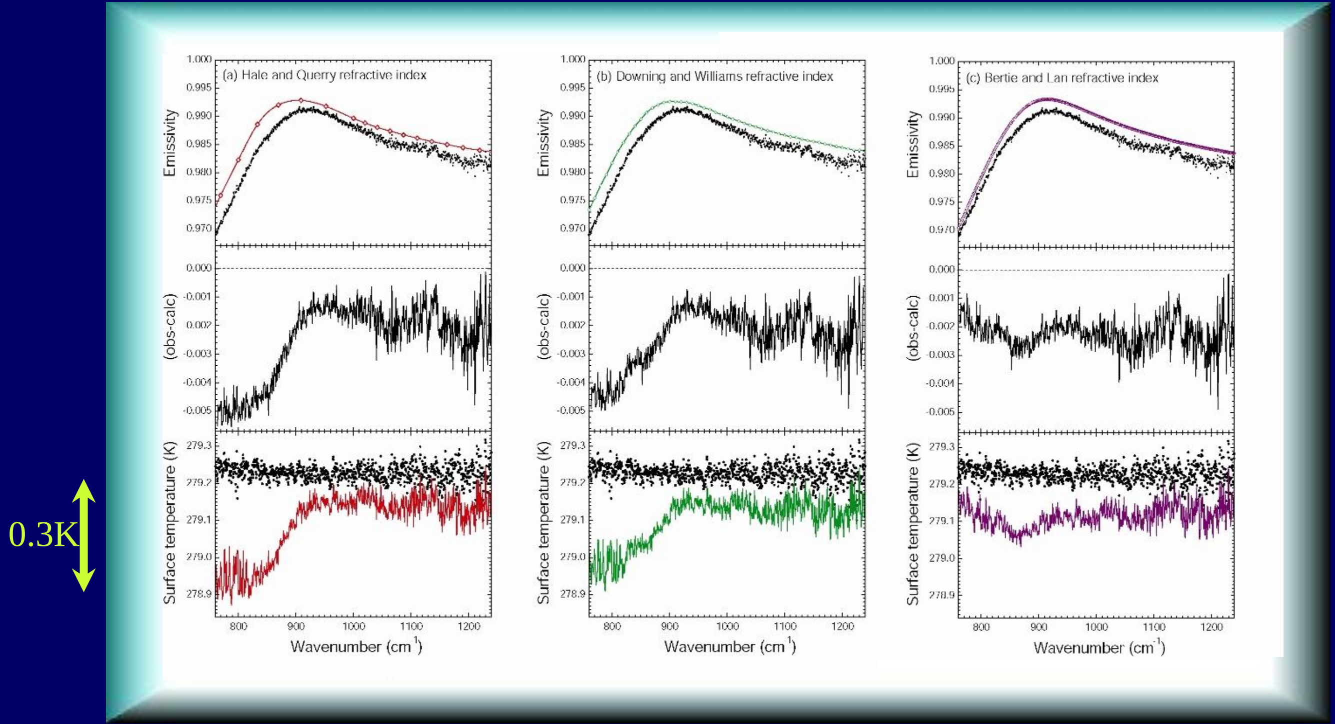
Skin temp derived for each 40cm^{-1} bin with std deviation of last digit in brackets.

Average skin temp (301.34K) used to infer high resolution emissivity, representative error approx. +/- 0.001



Hale and Querry Downing and Williams Bertie and Lan

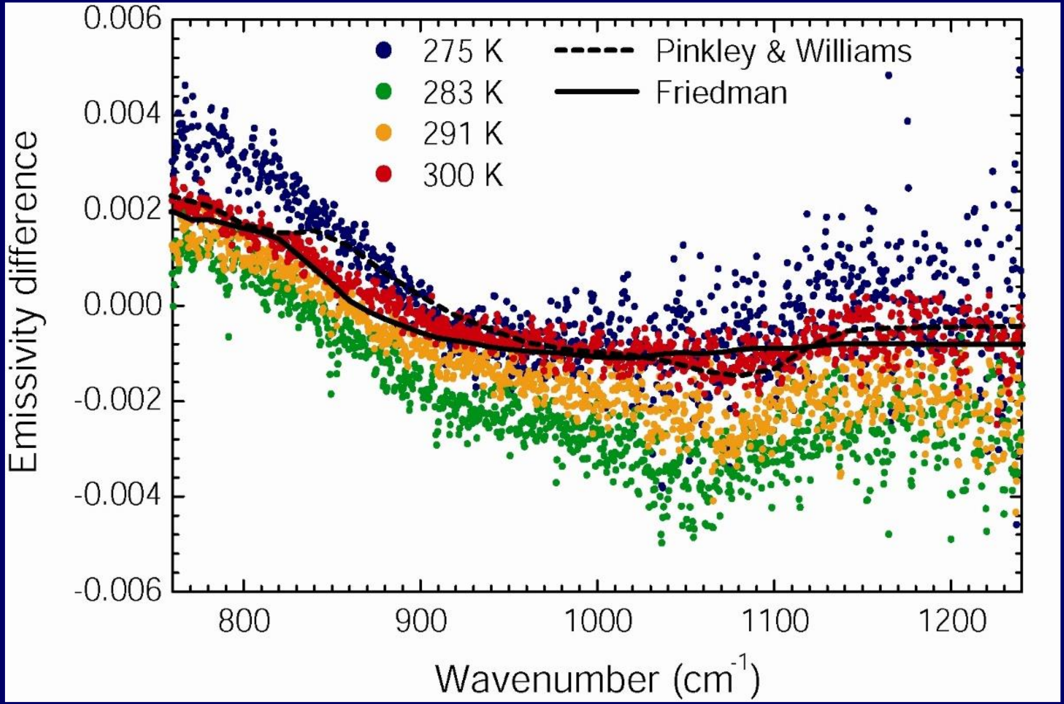
Emissivity retrieval for A670 in tropics compared to theory using three different sets of refractive indices



Hale and Querry   Downing and Williams   Bertie and Lan

Emissivity retrieval in Baltic Sea compared to theory using three different sets of refractive indices

Emissivity difference saline – pure water



We adopt widely used Friedman formulation for salinity correction as it performs well.

