Parameterization of the surface emissivity at microwaves to submillimeter waves

Catherine Prigent, Filipe Aires, Observatoire de Paris and Estellus
Lise Kilic, Die Wang, Observatoire de Paris

with contributions from
Fatima Karbou (Météo-France) and Chris Grassotti (NOAA/AER)

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Outline

- Why calculating surface emissivities up to 700 GHz?
- The sea surface emissivity parameterization: **TESSEM²**
  (Tool to Estimate the Sea Surface Emissivity at Microwaves to Millimeter waves)
- The land surface emissivity parameterization: **TELSEM²**
  (Tool to Estimate the Land Surface Emissivity at Microwaves to Millimeter waves)
- Evaluation of the emissivity parameterization with ISMAR (talk by D. Wang)
- Conclusions

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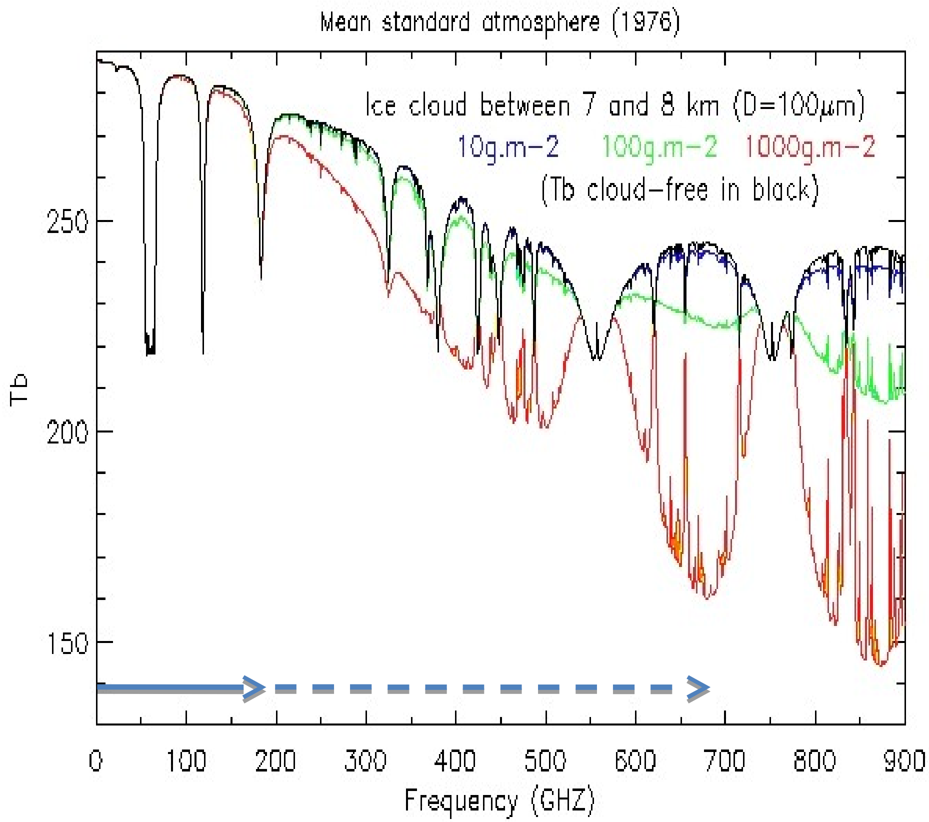
Exploration of a new range of frequencies with MetOp-SG (~2020):

The Ice Cloud Imager (ICI) with frequencies up to 664 GHz



Channel	Frequency (GHz)	Bandwidth (MHz)	NEΔT (K)	Polarisation	Footprint Size at 3dB (km)
ICI-1	183.31±7.0	2x2000	0.7	V	15
ICI-2	183.31±3.4	2x1500	0.7	V	15
ICI-3	183.31±2.0	2x1500	0.7	V	15
ICI-4	243.2±2.5	2x3000	0.6	V, H	15
ICI-5	325.15±9.5	2x3000	1.1	V	15
ICI-6	325.15±3.5	2x2400	1.2	V	15
ICI-7	325.15±1.5	2x1600	1.4	V	15
ICI-8	448±7.2	2x3000	1.3	V	15
ICI-9	448±3.0	2x2000	1.5	V	15
ICI-10	448±1.4	2x1200	1.9	V	15
ICI-11	664±4.2	2x5000	1.5	V, H	15

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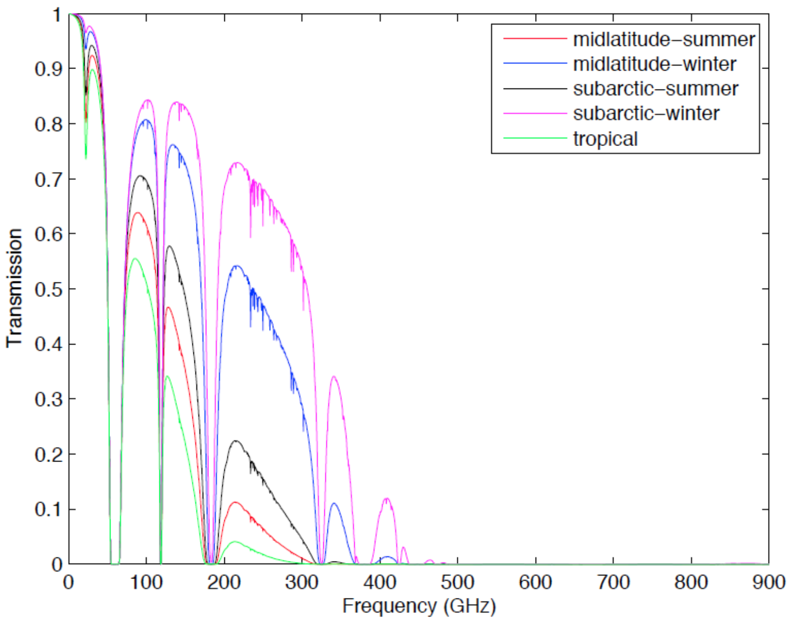
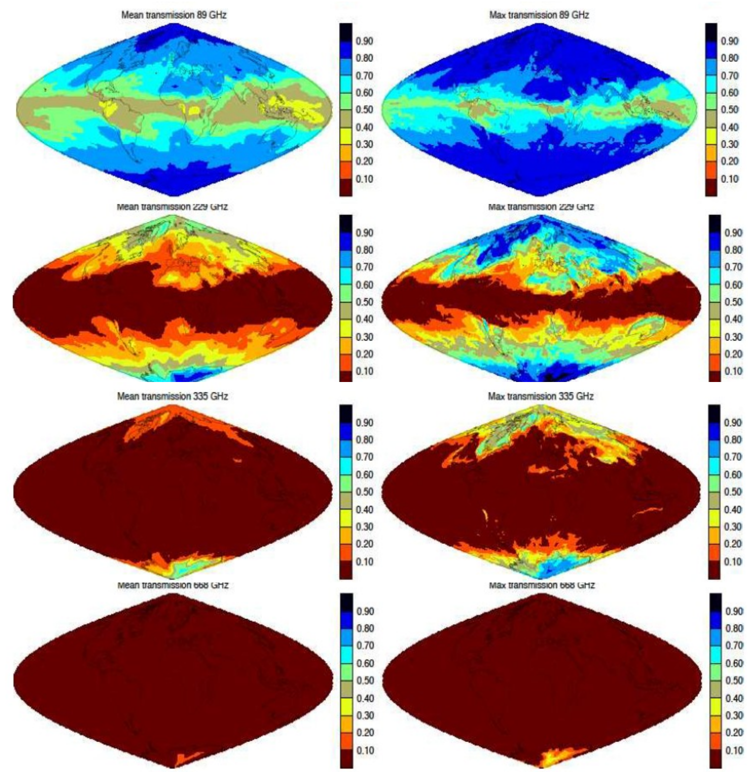
The surface impact at microwaves to millimeter waves



Mean transmission

Max transmission

53° incidence



89 GHz

229 GHz

335 GHz

668 GHz

Decreasing contribution from the surface with increasing frequencies, but still significant impact above 200 GHz, under cold and dry conditions

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The objective

To provide the community with realistic parameterization / modeling of the surface emissivities up to 700 GHz

- **Globally (ocean, land, including snow and ice)**
- **Based on the experience gained so far**
- **Codes that can be easily interfaced with community radiative transfer**

Very little or no emissivity modeling efforts above 200 GHz (most work below 100 GHz)
Some work around 150 GHz for AMSU-B / MHS / SSMI / ATMS, but not consolidated
No observations above 200 GHz (except ISMAR).

Over open ocean, rather low emissivity and models exist relating emissivity to wind speed.

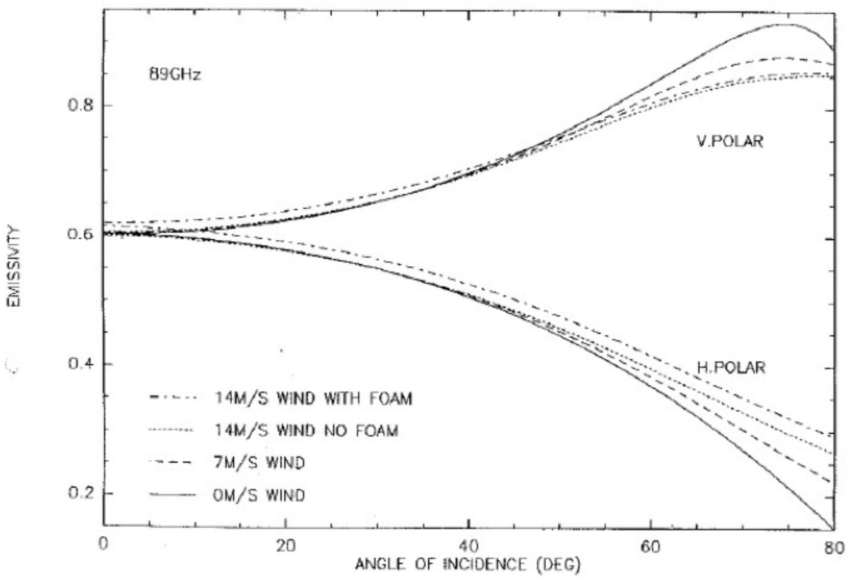
Over snow and ice, modeling very challenging. Large variability as well as large number of parameters influencing the signal. Frequency dependence expected.

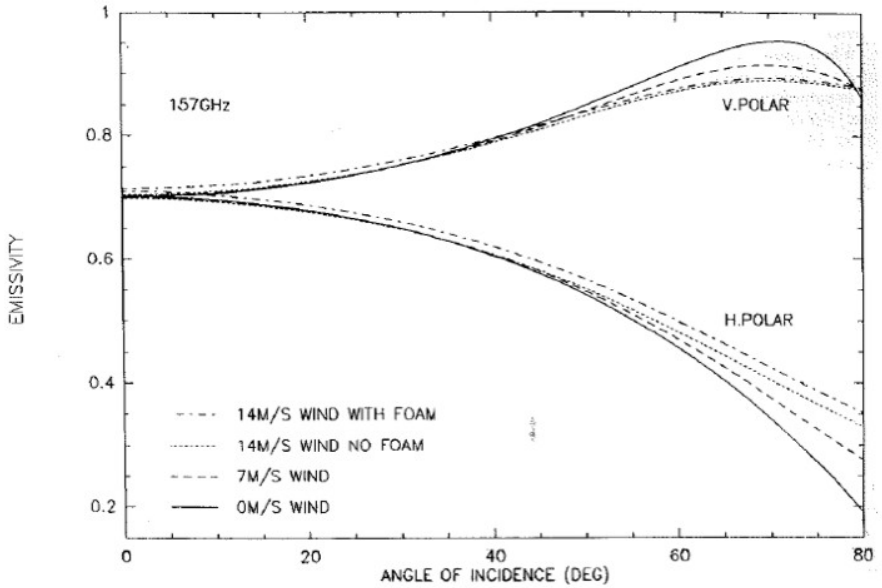
Over land, high emissivity and modeling challenging (large number of parameters influencing the signal such as vegetation, soil moisture, roughness, topography….). However, frequency dependence rather limited for most surface types.

The ocean emissivity

The ocean emissivity

- A function of surface wind speed, surface temperature, salinity
- Foam produced when the wind increases
- Large scale geometric optic (wave slope distribution) + small scale roughness (ripples)
- A fast model derived from a two-scale model (FASTEM)





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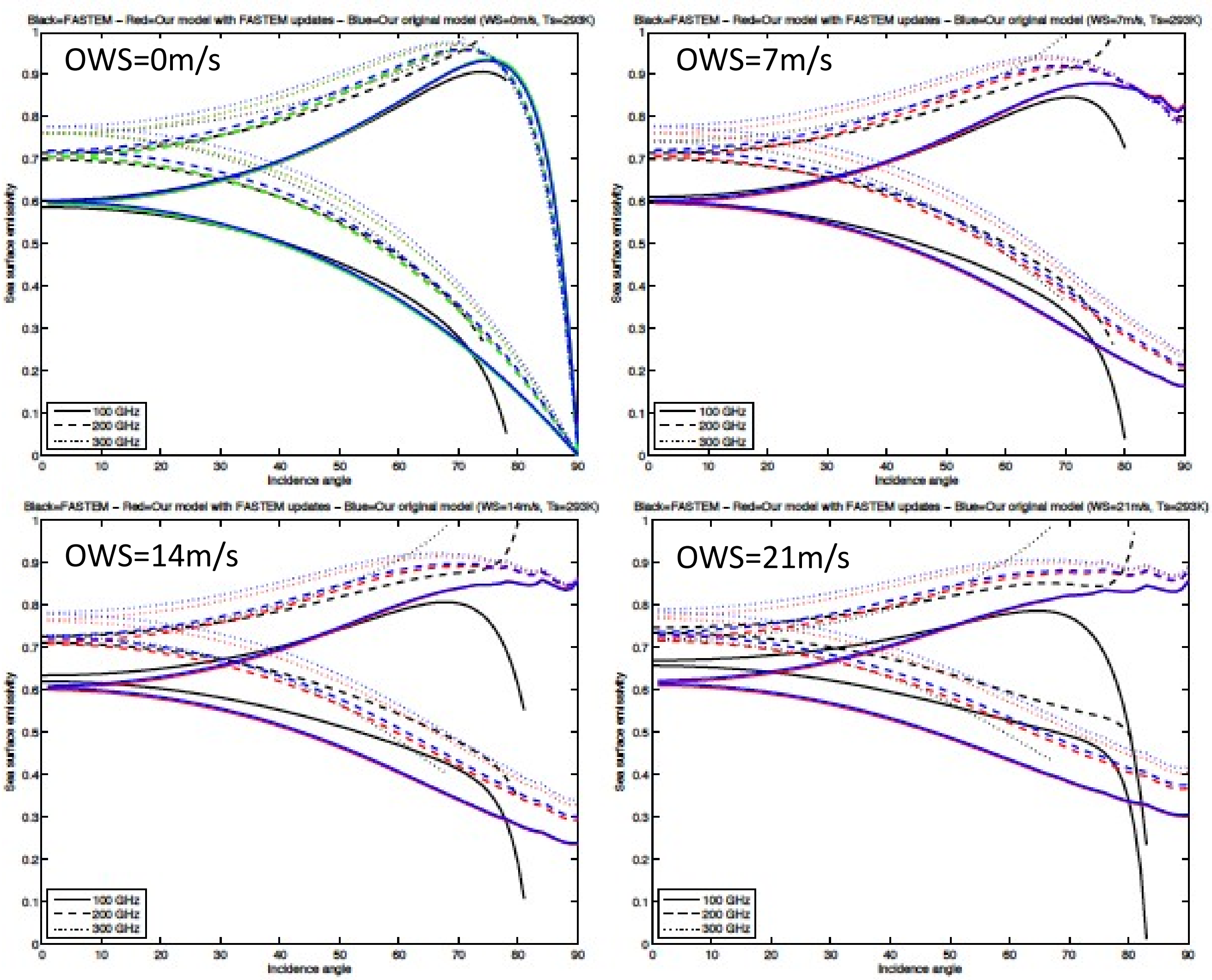
The ocean emissivity

- FASTEM has been thoroughly validated up to 100 GHz.
- FASTEM corresponds to a parameterization of a 'slow' physical model, optimized for frequencies below 200 GHz. The 'slow' model is not available at this stage.
- In-house emissivity code based on the same initial physical hypothesis (Prigent and Abba, 1989). It has been updated with the latest developments as in FASTEM (dielectric properties, foam cover and foam emissivity)

The proposed parameterization: to mimic FASTEM as much as possible up to 200 GHz with a smooth transition to our model for higher frequencies.

1) Comparison of the two models (FASTEM and our model)
2) Development and evaluation of the parameterization

The ocean emissivity: angle dependence



FASTEM
Our updated model
Our original model
Fresnel model

293K

Very similar behavior of the two models for medium wind speeds. Discrepancies at higher wind speeds.
Non physical behavior of FASTEM for large angles (as expected) and departure from the Fresnel laws for 0m/s wind speed.

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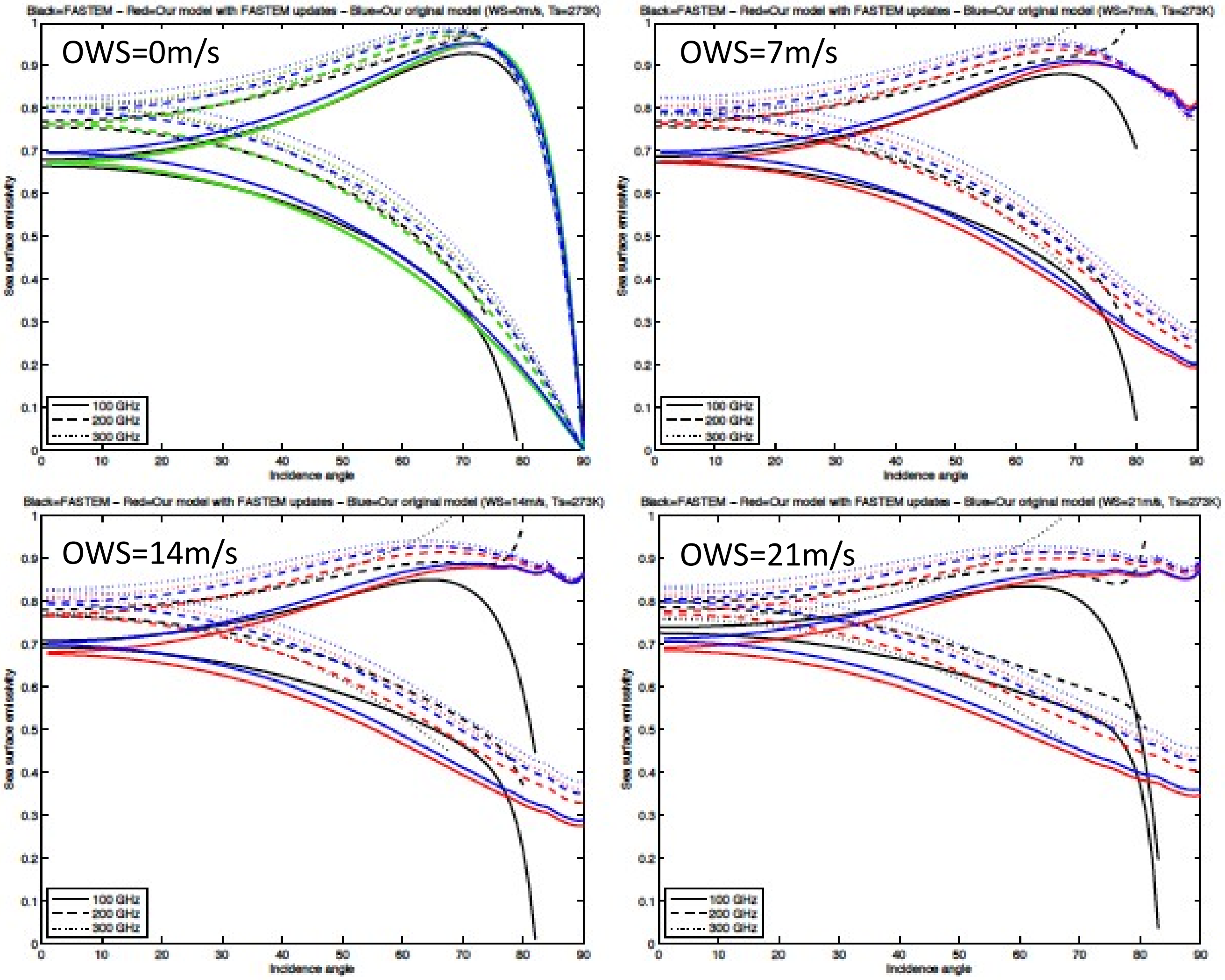
The ocean emissivity: angle dependence



FASTEM
Our updated model
Our original model
Fresnel model

273K

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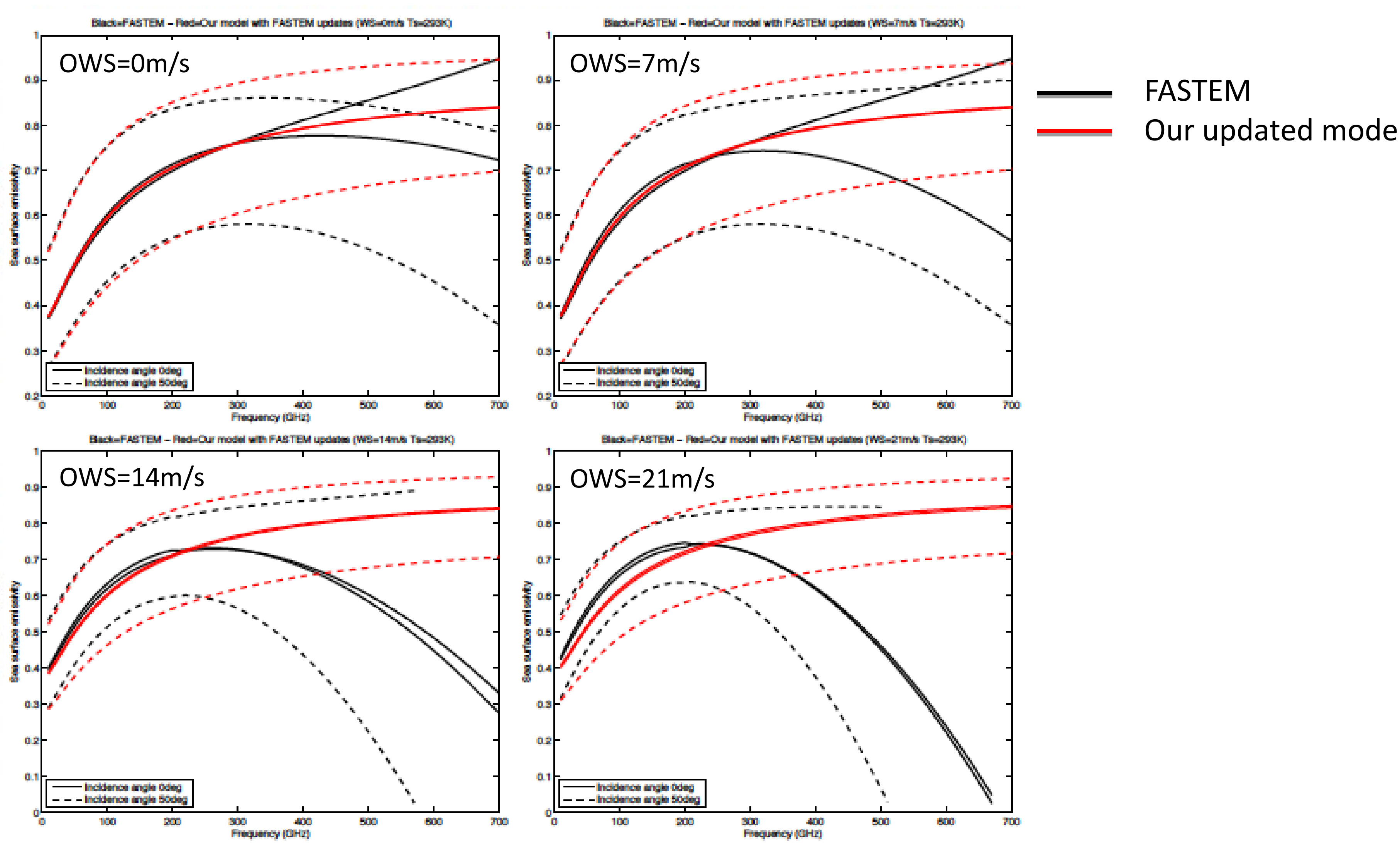
The ocean emissivity: frequency dependence



Non physical behavior of FASTEM for large frequencies as expected

The ocean emissivity

Statistical parameterization designed to minimize differences:

1) with FASTEM over its validity range (frequencies below 190 GHz, angles below 60°)
2) with our physical model else where (frequencies above 300 GHz and angles above 70° for a smooth transition with FASTEM)

RMS= 0.007 over the full minimization range
RMS=0.009 over FASTEM

Inputs to the model (same as FASTEM):

- Frequency (GHz)
- Incidence angle form nadir (deg)
- Wind speed at 10m (m/s)
- Skin temperature (K)
- Salinity (psu)

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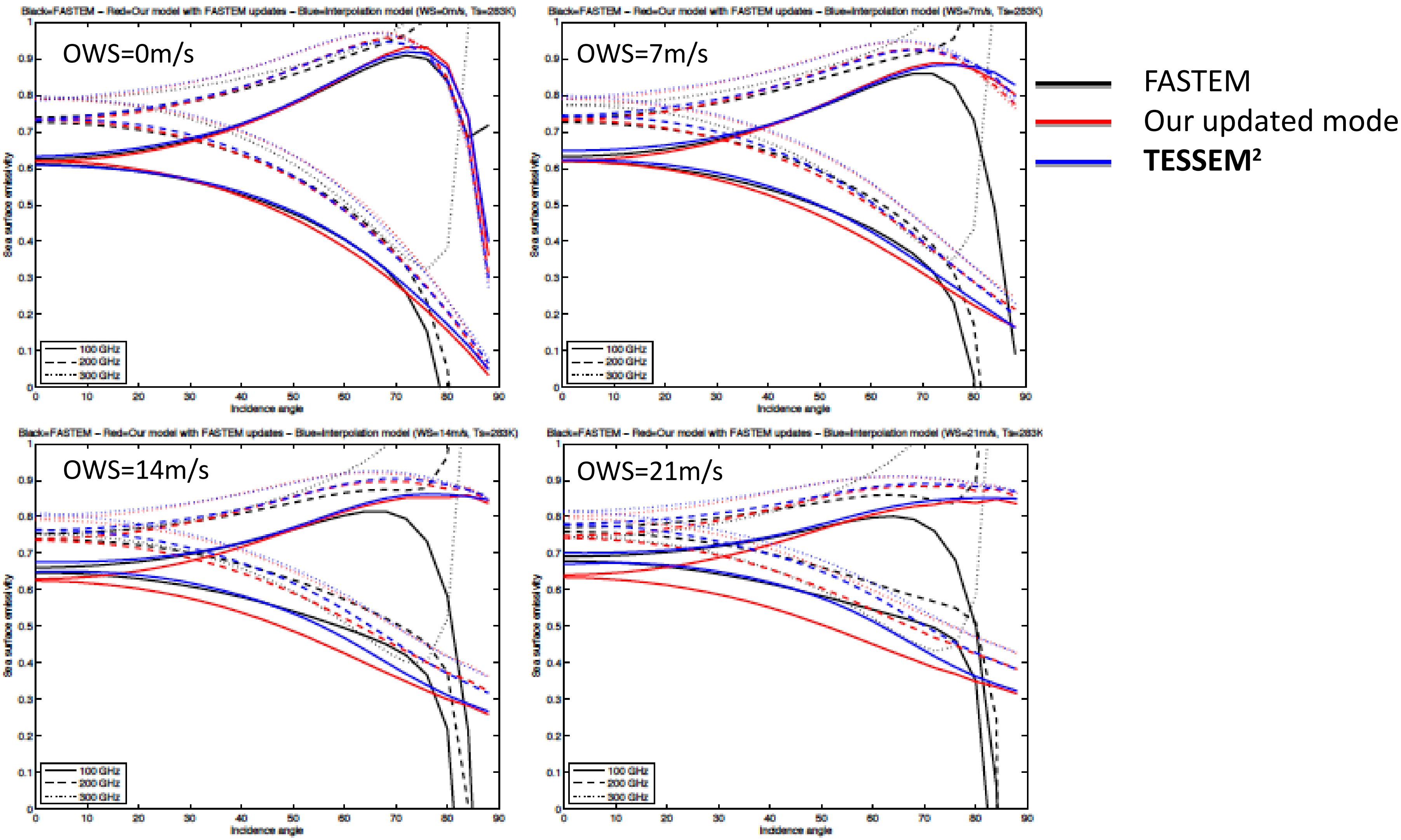
The ocean emissivity: angular dependence



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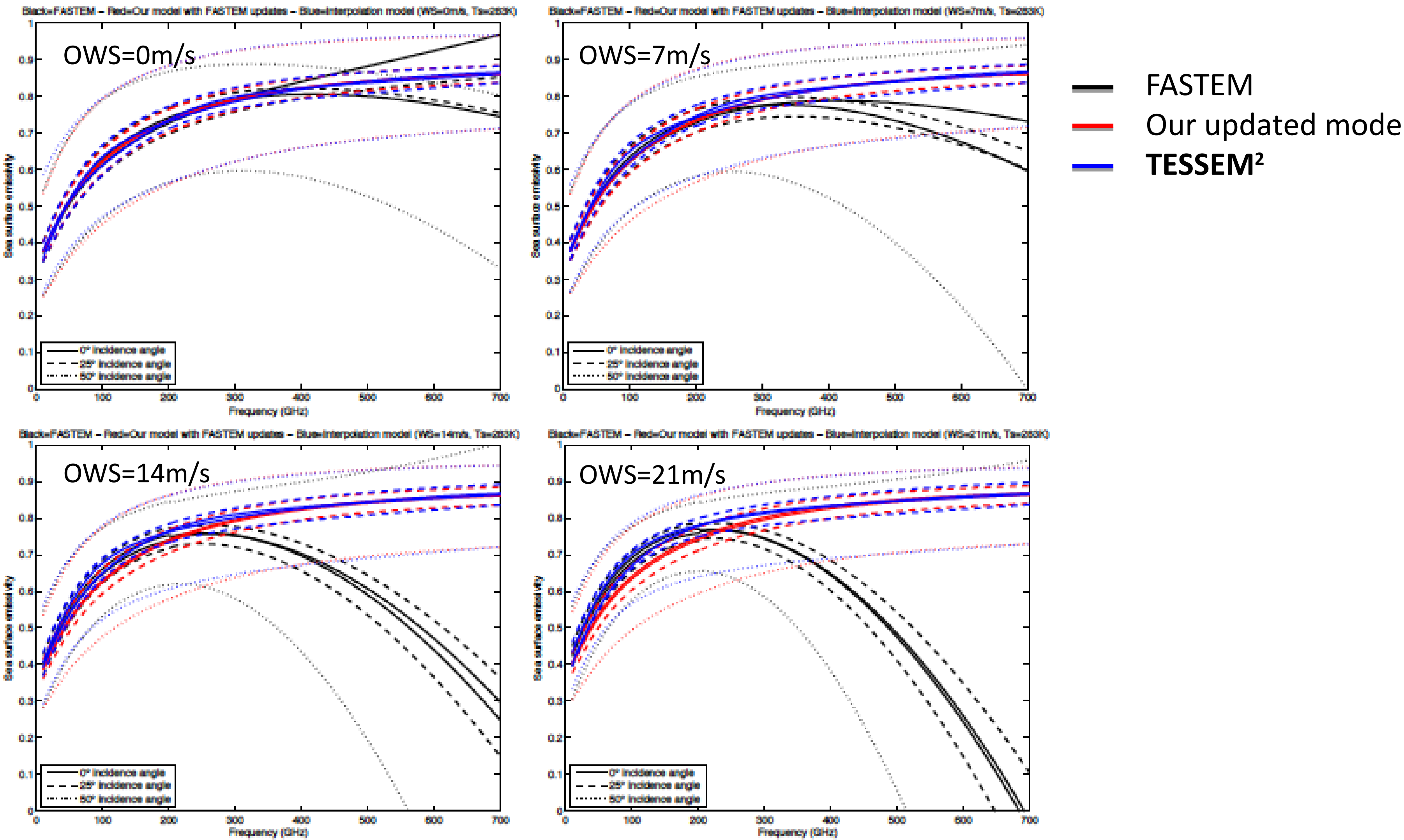
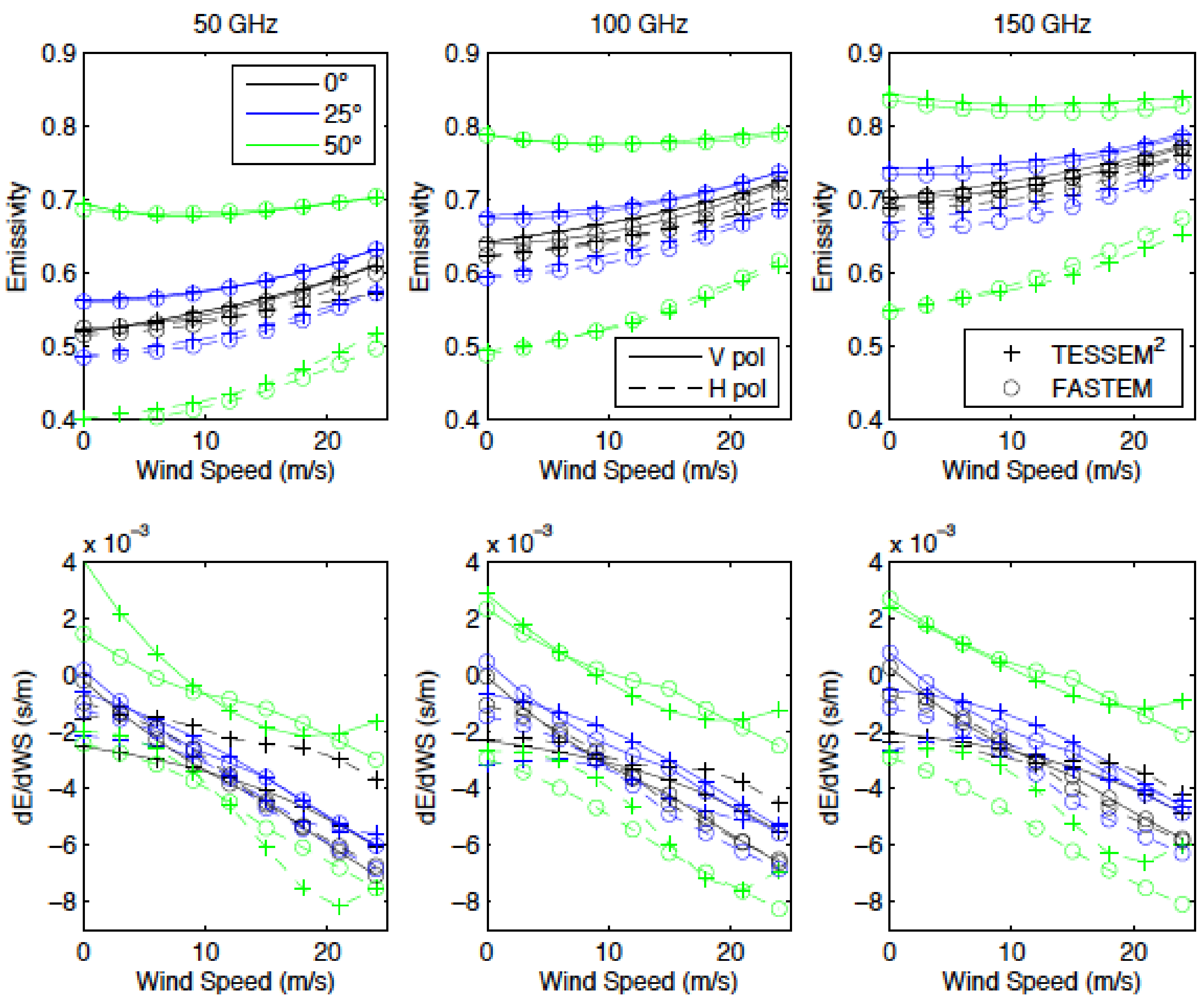
The ocean emissivity: frequency dependence



Non physical behavior of FASTEM for large frequencies as expected

The ocean emissivity: wind speed Jacobians



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The ocean emissivity: conclusion

TESSEM²

Tool to Estimate Sea Surface Emissivities in Microwave and Millimeter waves

- It capitalizes on the realism of FASTEM at lower frequency where FASTEM has been thoroughly evaluated
- It exploits the physical model where FASTEM is not valid
- It is a fast parameterization that can easily complement FASTEM in community radiative transfer codes (e.g., RTTOV, CRTM, ARTS)
- The Jacobians can be estimated analytically, with respect to the environmental variables (wind speed, surface temperature, and salinity) for the forth coming assimilation
- The parameterization could be easily updated to integrate any new development in the physical model, any new version of FASTEM, or any new observations to calibrate the parameterization.

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The land and sea-ice emissivity

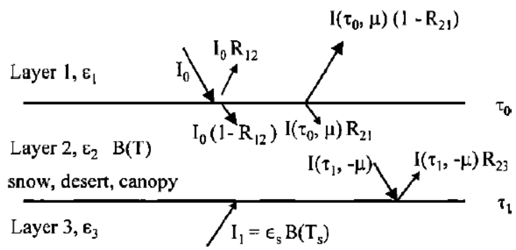
The land and sea-ice emissivity

Two community models:

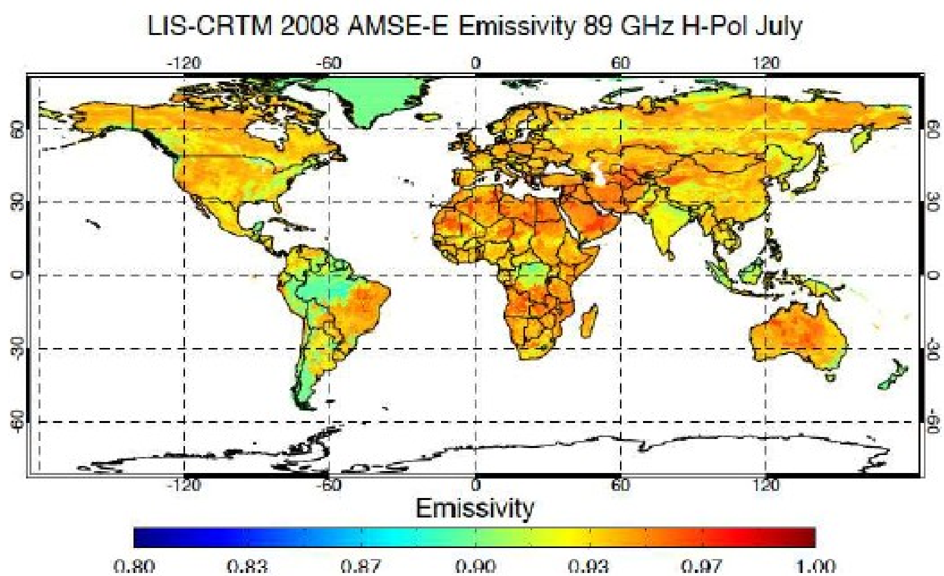
CMEM (ECMWF) (Holmes et al., 2008), but essentially for low frequencies

CRTM (NOAA) (Weng et al., 2001)

Two stream radiative transfer model. Requires a large number of inputs…



Weng et al., 2001



Exemple of emissivity at 89 GHz, simulated with CRTM, with inputs from NASA / LIS

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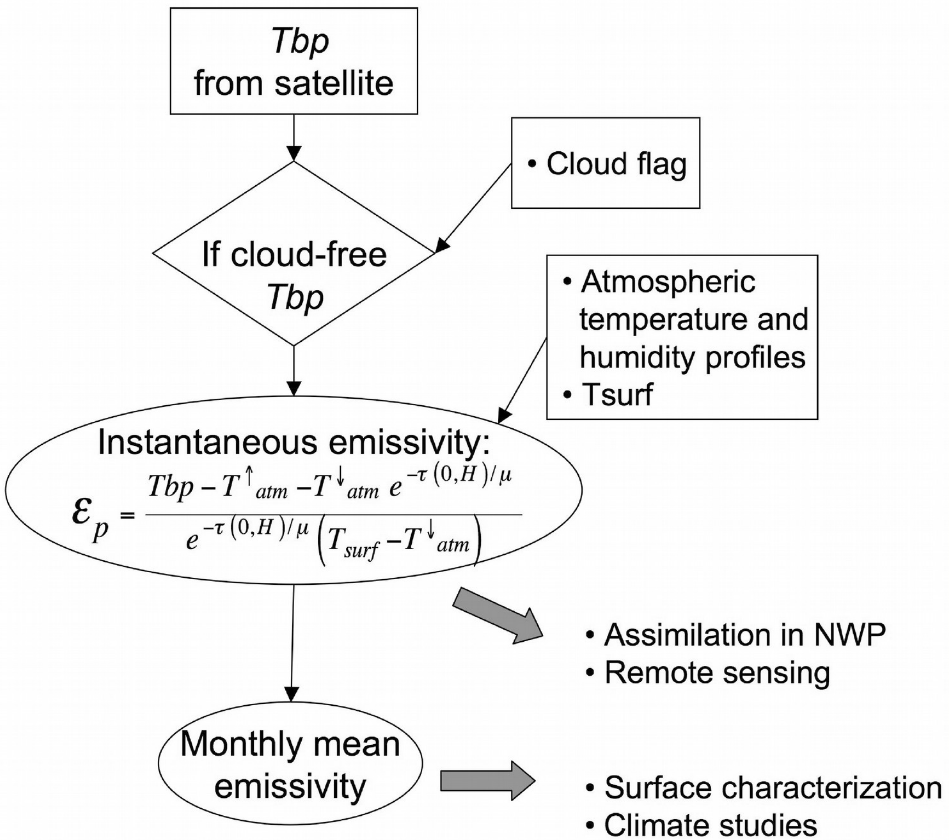
The land and sea-ice emissivity

The satellite-derived emissivity

A generic method to derive land surface emissivity from satellite that can be applied to microwave imager and sounder window channels

$$Tb_p = \varepsilon_p . Ts . \tau + (1-\varepsilon_p) . Tdown . \tau + Tup$$



$$\varepsilon_p = \frac{Tb_p - Tup - Tdown . \tau}{\tau . (Ts - Tdown)}$$

Assumptions:

- Specular approximation

- Ts is the IR surface skin temperature

=>Retrieval of an 'effective' emissivity

Std of the order of 0.015 over a month

For the SSM/I processing:

ISCCP cloud flag and Tsurf

NCEP reanalysis

(Prigent et al., JGR, 1997; BAMS, 2006)

A methodology often used since for other instruments: AMSU (Prigent et al., 2005; Karbou et al., 2005), AMSR-E (Moncet et al. , 2008)

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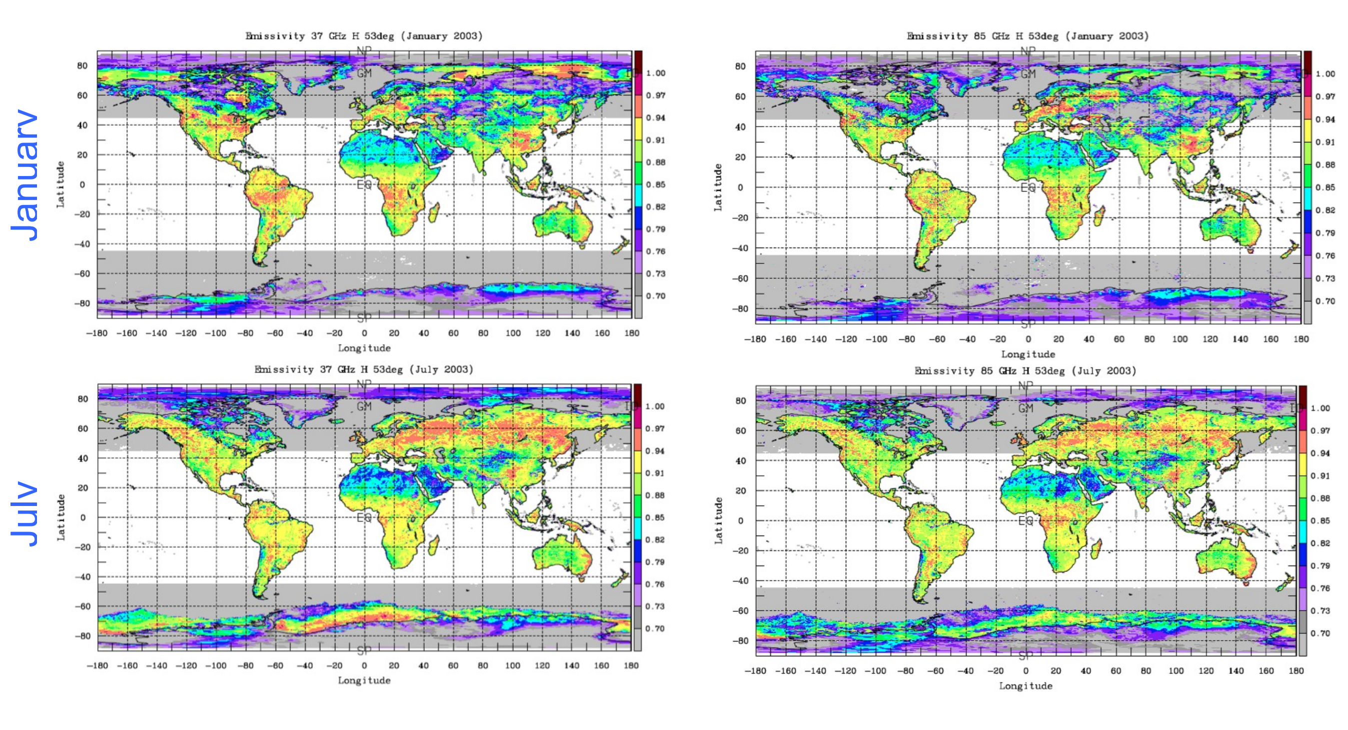
The land and sea-ice emissivity

The satellite-derived emissivity: TELSEM

Large variability in space, time and frequencies, especially under snow and ice conditions



- A robust database of global daily emissivities over 15 years derived from all the available **SSMI** instruments, along with a few months of other satellite-derived maps.
- A monthly-mean product available to the community with a spatial resolution of 0.25° x 0.25° at the equator from 1993 to 2007 (53° incidence)
- With the help of AMSU and TMI observations, extrapolation of the emissivities in angle, frequency, and polarization: **TELSEM (Tool to Estimate Land Surface Emissivity at Microwaves)**

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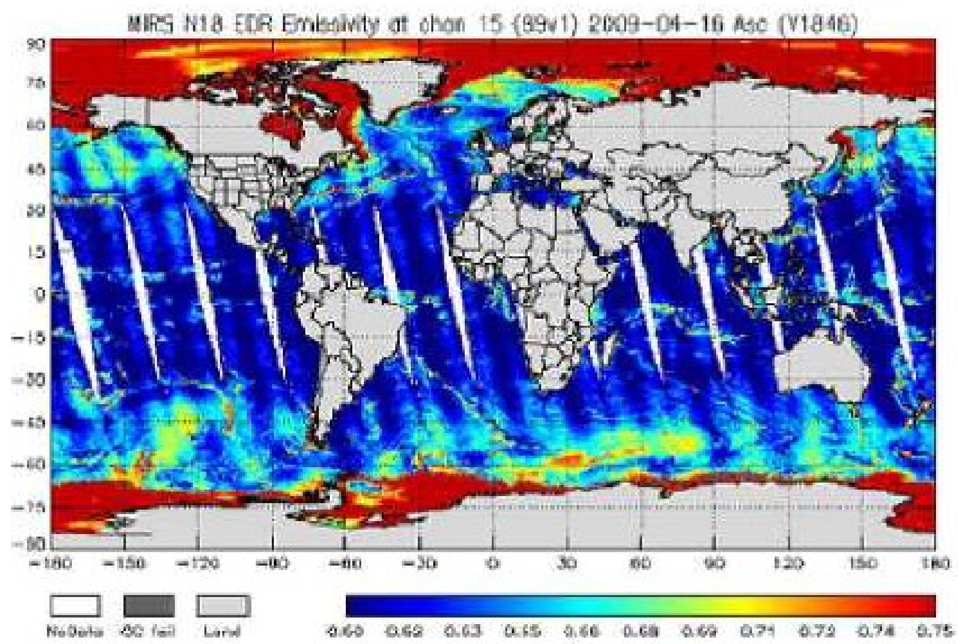
The land and sea-ice emissivity

The satellite-derived emissivity

The Microwave Integrated Retrieval System (MIRS) at NOAA

A 1D VAR retrieval that estimates the emissivity (along with many other atmospheric and surface parameters) from the current operational microwave instruments.

Due to the lack of independent information, not the direct emissivities but Empirical Orthogonal Function (EOF) of the emissivities are retrieved (original EOF basis computed off-line).

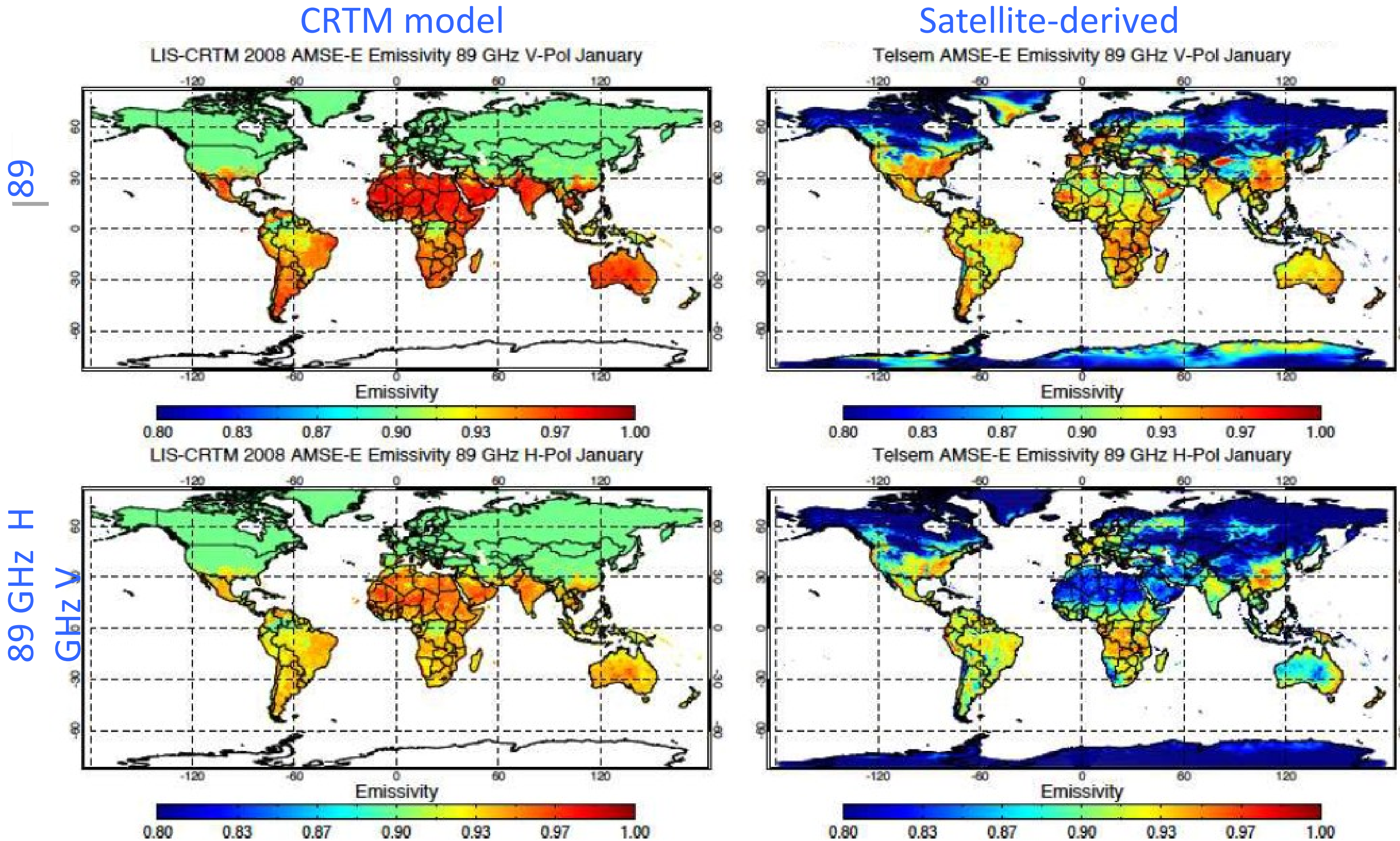


NOAA 18 MHS at 89 GHz
16/04/2009

Kongoli et al., 2010

The land and sea-ice emissivity

Comparison model and satellite-derived land surface emissivity



The land and sea-ice emissivity

The parameterization will be based on the **satellite-derived emissivities**

Processing steps to performed:

- Extrapolate the dataset to higher frequency
- Parameterize the angular and polarization diversity at high frequency

- For frequency interpolation, satellite-derived emissivities available up to 190 GHz.
  - *Methodology*: classification of the surfaces per types according to the TELSEM data base, and analysis of the frequency dependence per surface types from the different data sources

- For angular and polarization parameterization, very limited information available

The land and sea-ice emissivity

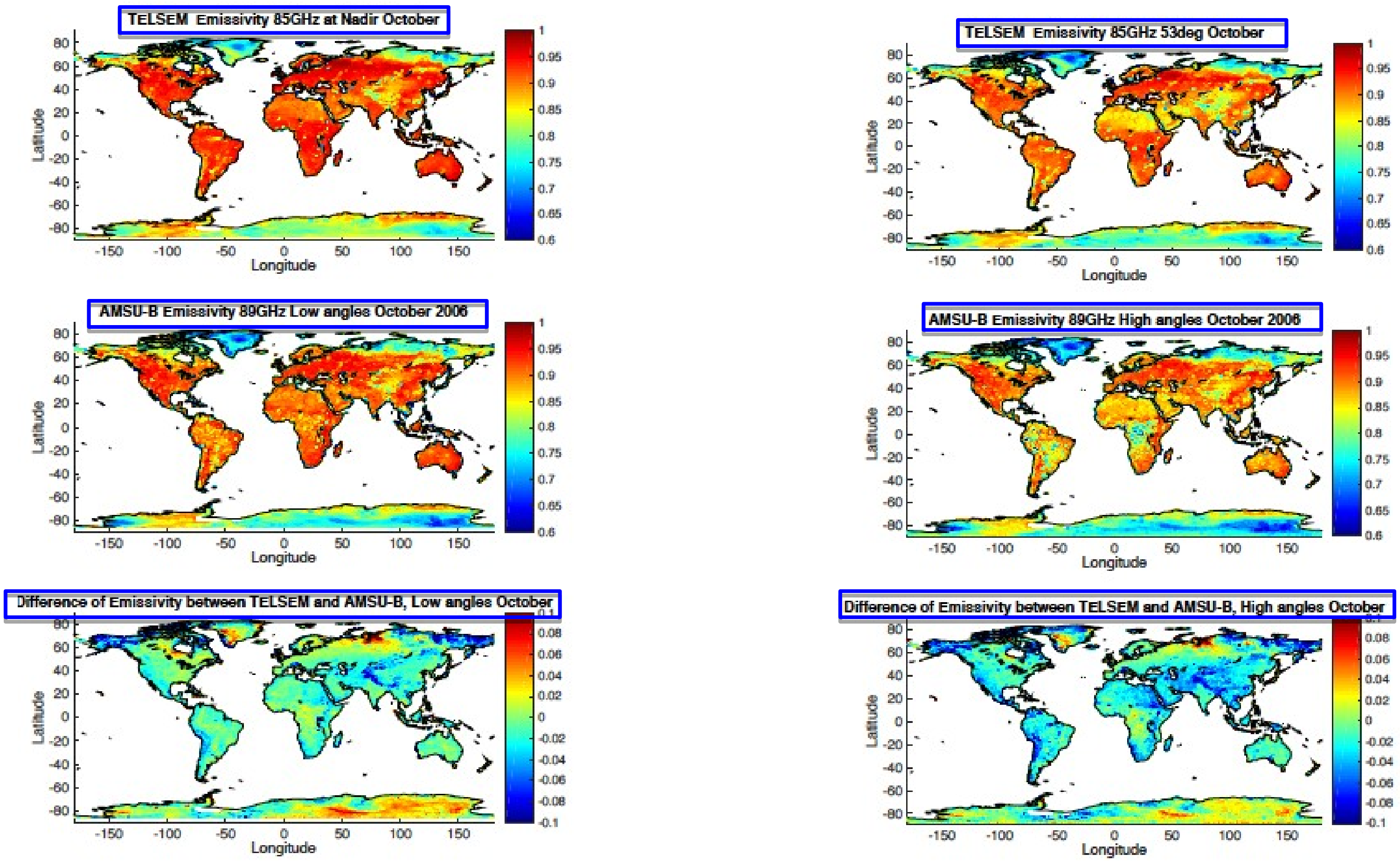
The datasets used in this study:

Dataset	Satellite	Surface type	Freq. (GHz)	Angle, polar.	Spatial res.	Temporal sampl.	Temporal cover	Note
TELSEM	SSM/I	Continents + sea ice	19, 37, 85	53°, V and H polar	.25°x.25°	Monthly mean	Climatology	
Emissivity MIRS NOAA	SSMI/S	All surfaces	19, 37, 91, 150, 183	53°, V + H if F<100GHz H if F >100GHz	.25°x.25°	Each satellite overpass	Mar. + Oct. 2014	Emissivity EOF
Emissivity Météo-France	AMSU-B	Continents	89, 150, 183	Low and high angles separately, with mixed polar	.25°x.25°	Monthly mean	2014	
Emissivity Météo-France	SSMI/S	Continents	19, 37, 91, 183	53° V + H if F<100GHz H if F >100GHz	.25°x.25°	Monthly mean	2014	

The land and sea-ice emissivity

Evaluation of the consistency of the various satellite estimates

Ex: TELSEM and MF AMSU-B in October



- Limited differences for most surface types, except snow and ice
- Over the Tropics, cloud contamination in the AMSU-B emissivity estimates

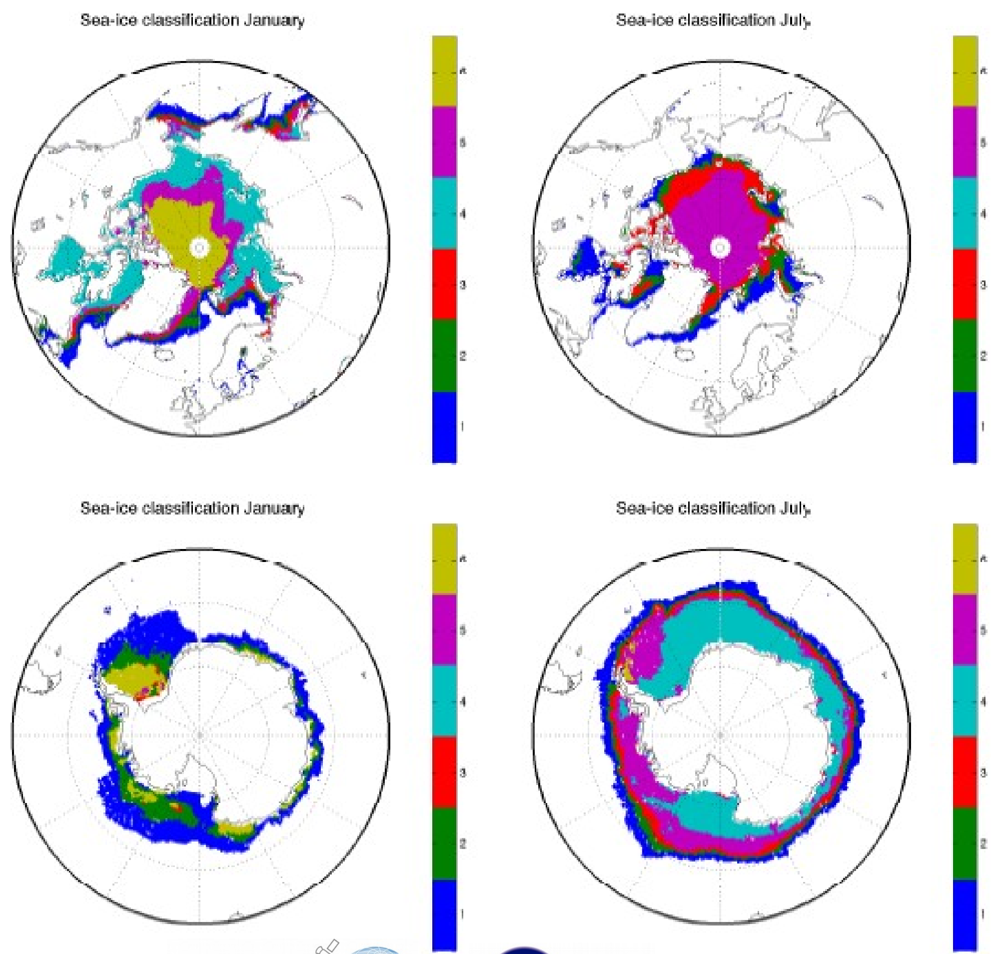
The emissivity of sea-ice

Classification of the SSM/I emissivities (K-mean)

January **July**

North pole

South pole



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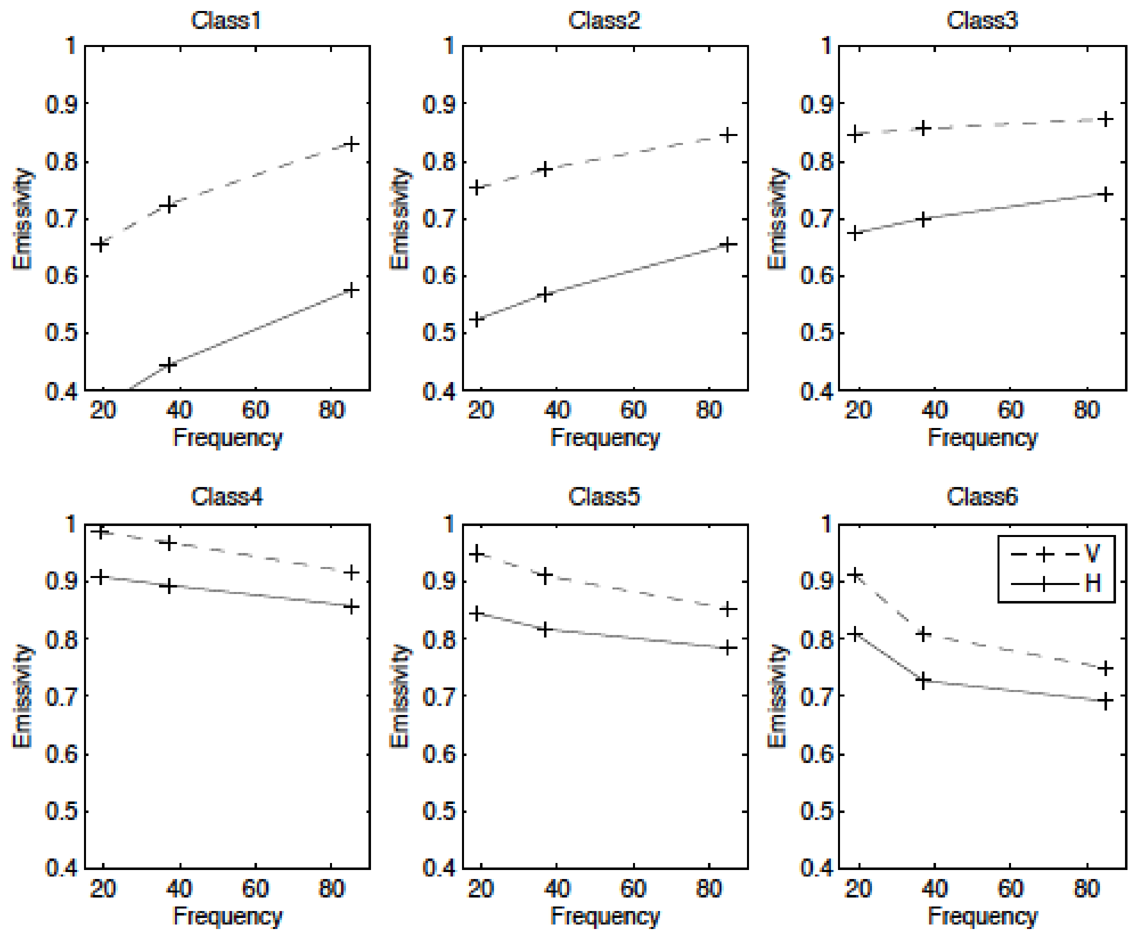
The emissivity of continental snow and ice

Classification of the SSM/I emissivities (K-mean)

Increasing emissivity from classes 1 to 3 (sea-ice margin)

Decrease of the emissivities from 37 to 85 GHz for classes 4 to 6.



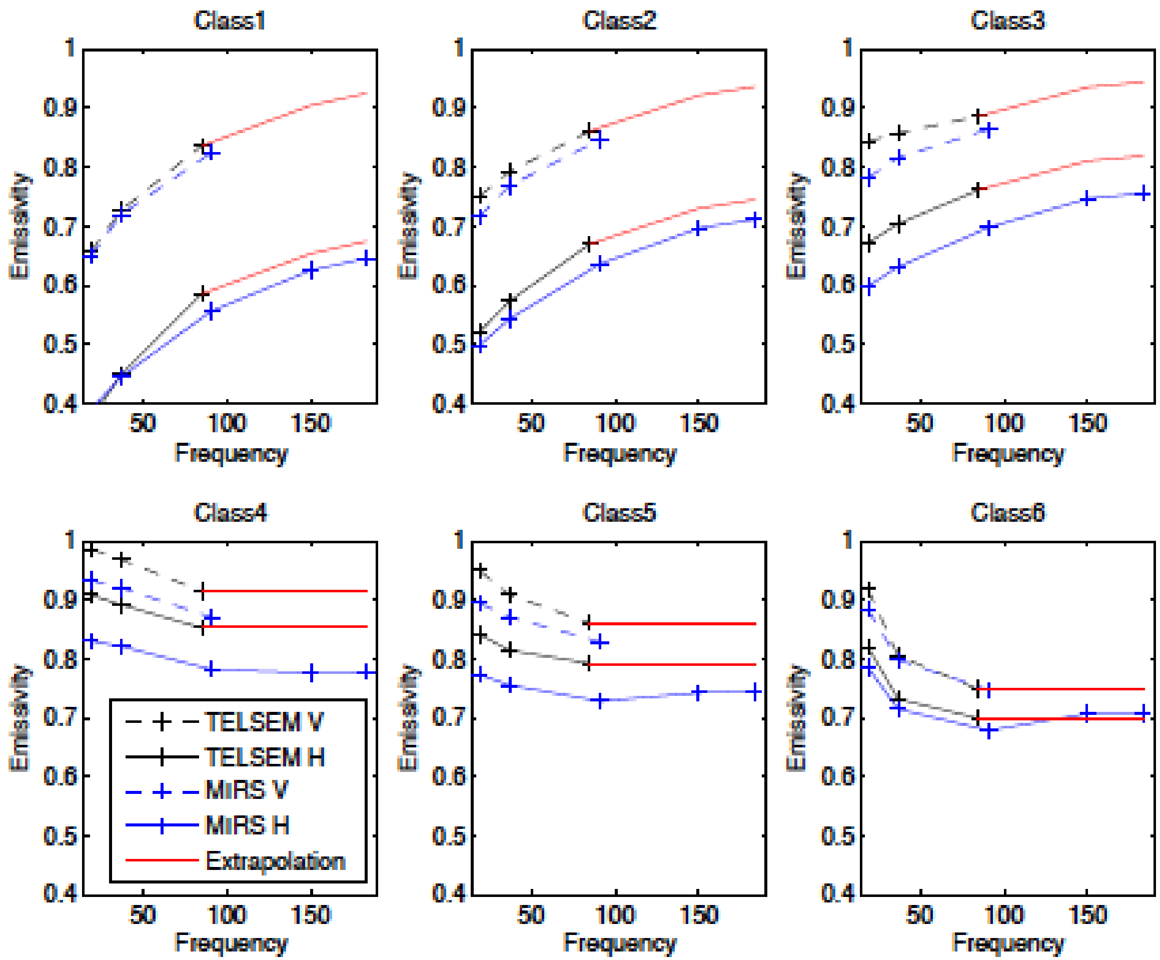
The emissivity of sea-ice

The frequency dependence as seen from TELSEM and MIRS

Significant bias between MIRS and TELSEM for several classes, but similar frequency dependence up to 90 GHz

⇒ For classes 1 to 3, assume similar frequency dependence as MIRS, for both polarization, taking into account the biais.

⇒ For classes 4 to 6, assume constant emissivity



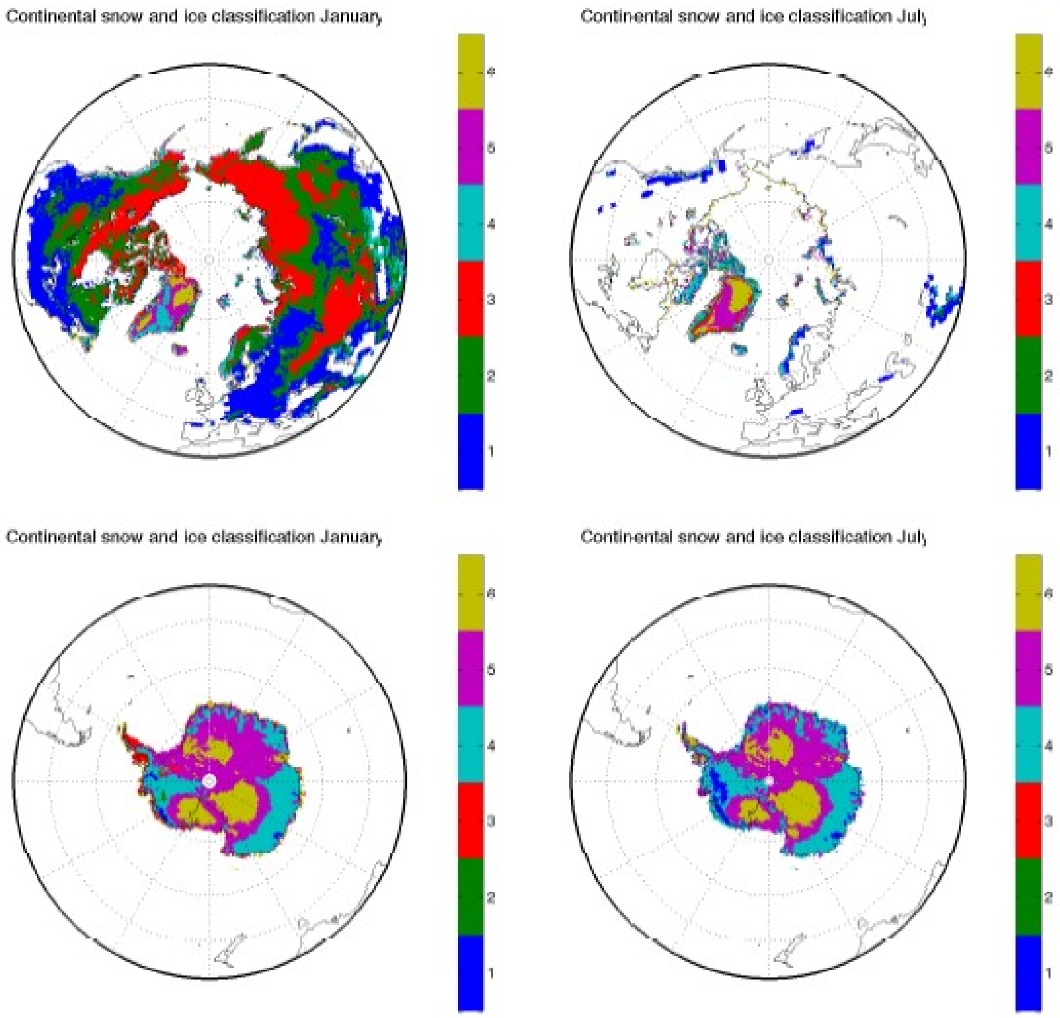
Results in red

The emissivity of continental snow and ice

Classification of the SSM/I emissivities (K-mean)

North pole

South pole

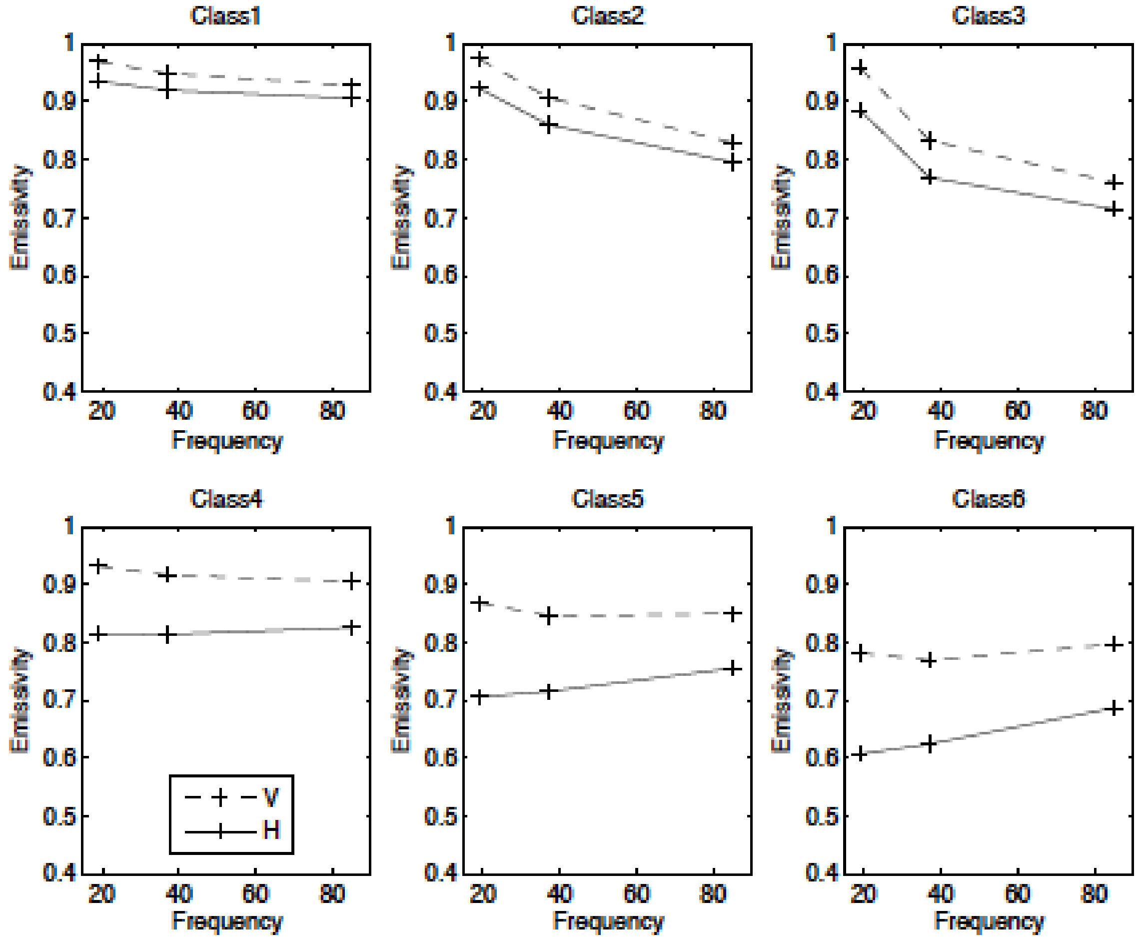


The emissivity of continental snow and ice

Classification of the SSM/I emissivities (K-mean)

Decreasing emissivity from class 1 to class 3.

Slight increase of the emissivities from 37 to 85 GHz for classes 5 and 6 (continental ice).



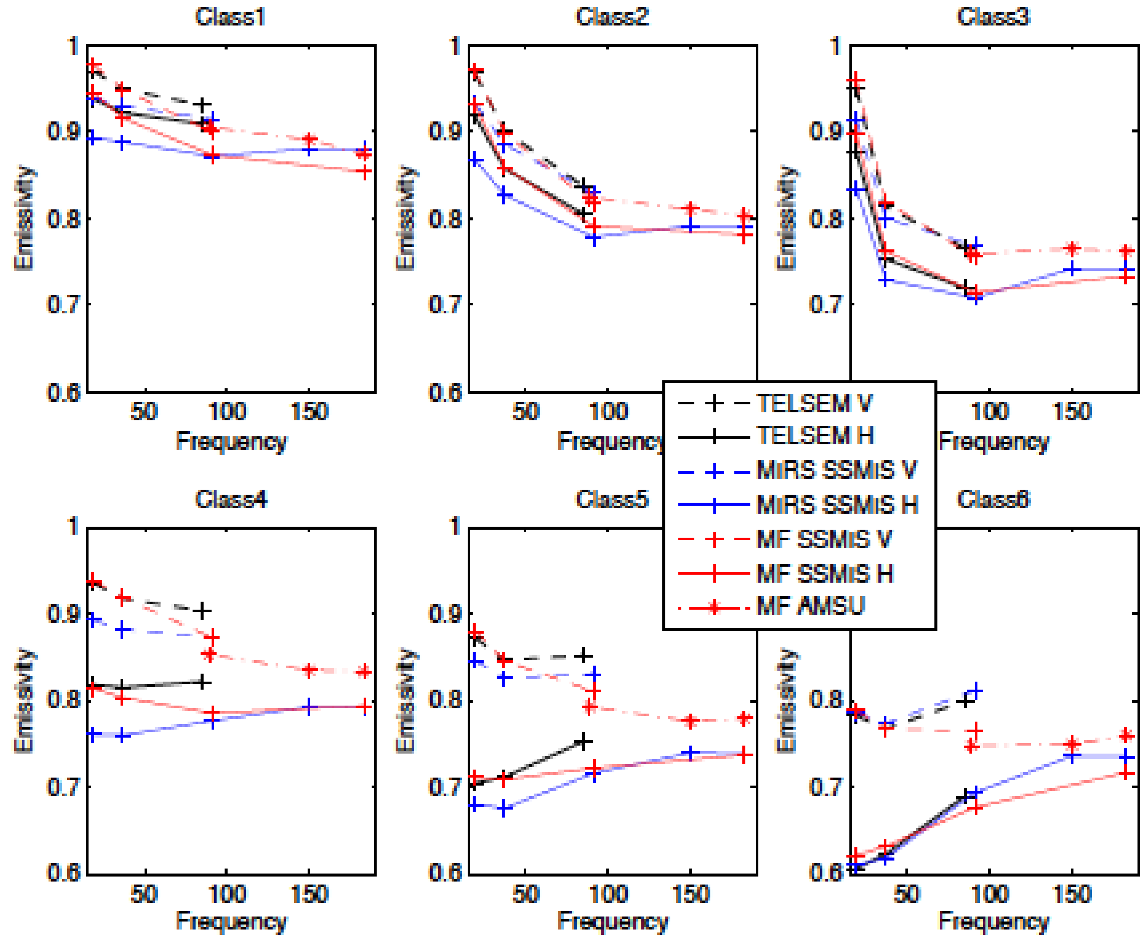
The emissivity of continental snow and ice

The frequency dependence as seen from TELSEM, MF, and MIRS

Significant differences can be observed, even for the same instrument.

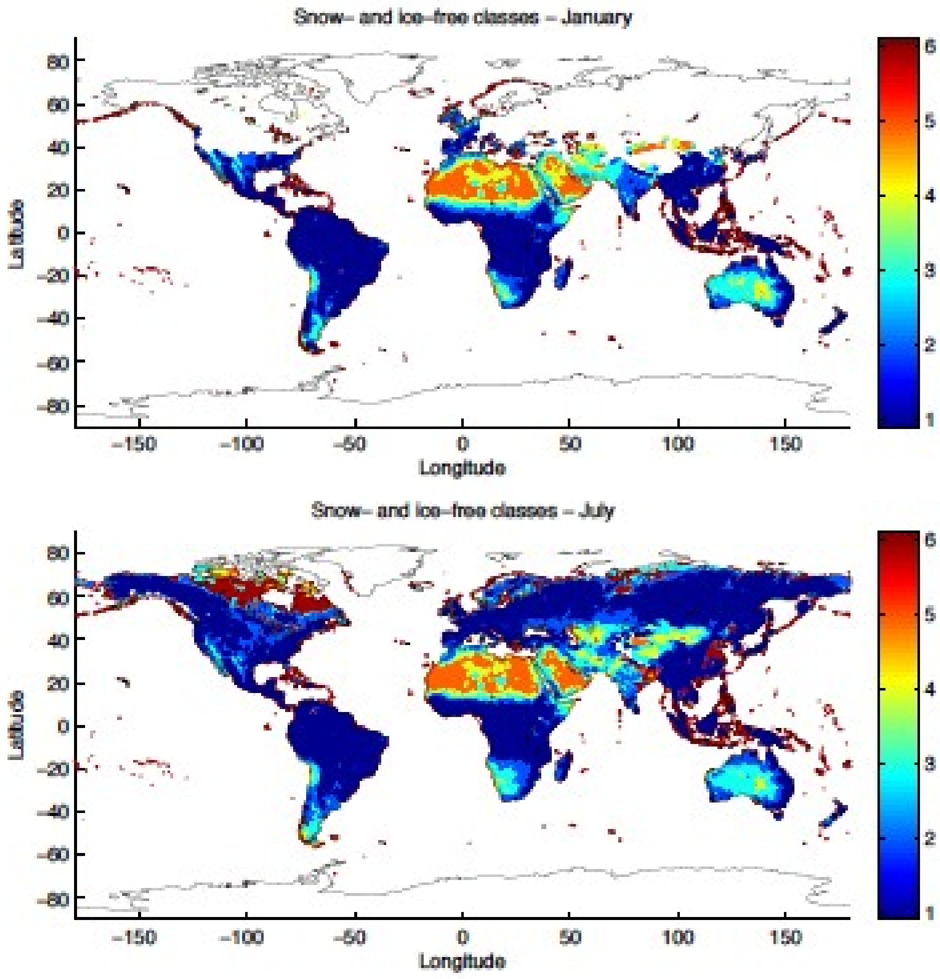
From the same group, inconsistencies between estimates (SSMI/S and AMSU-B): instrument calibration?

All estimates considered, constant extrapolation is suggested.



The land emissivity (snow and ice free)

Classification of the SSM/I emissivities (K-mean)

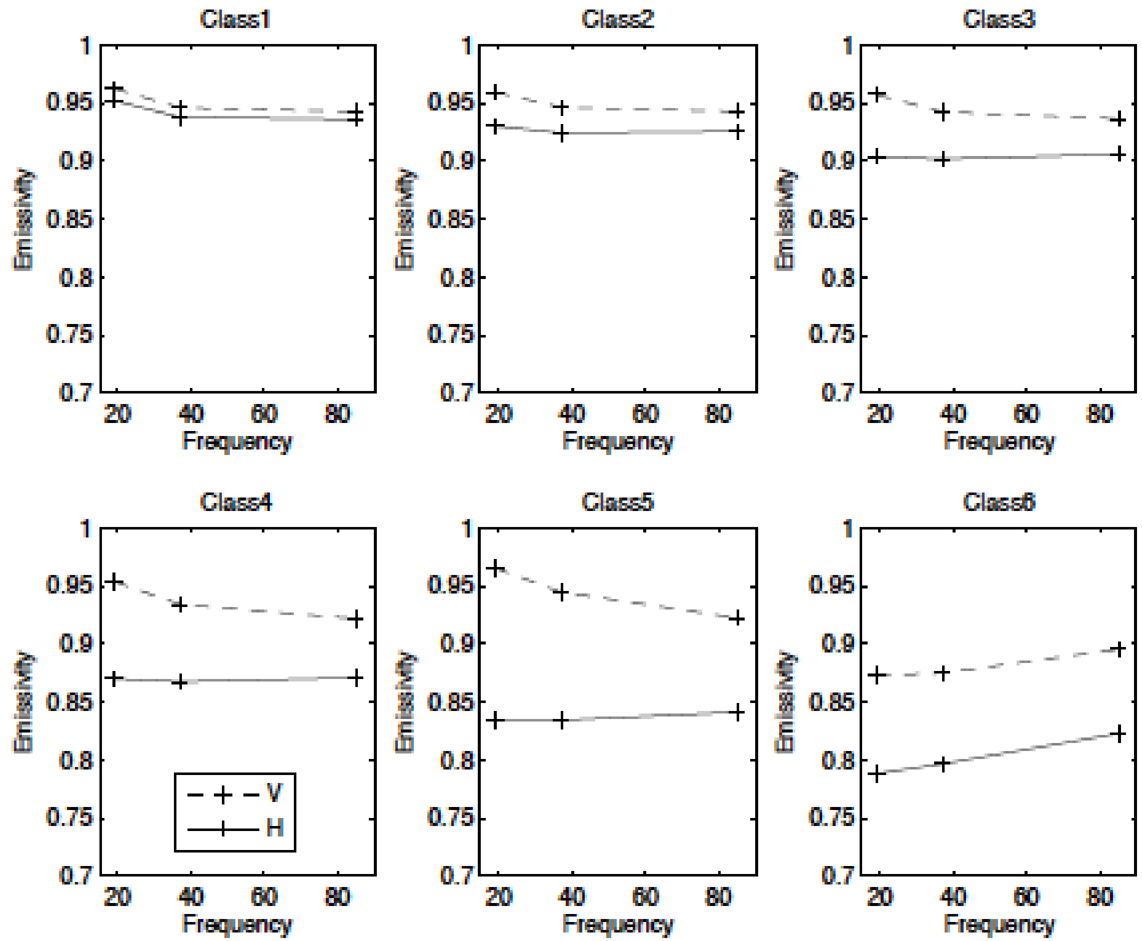


The land emissivity (snow and ice free)

Classification of the SSM/I emissivities (K-mean)

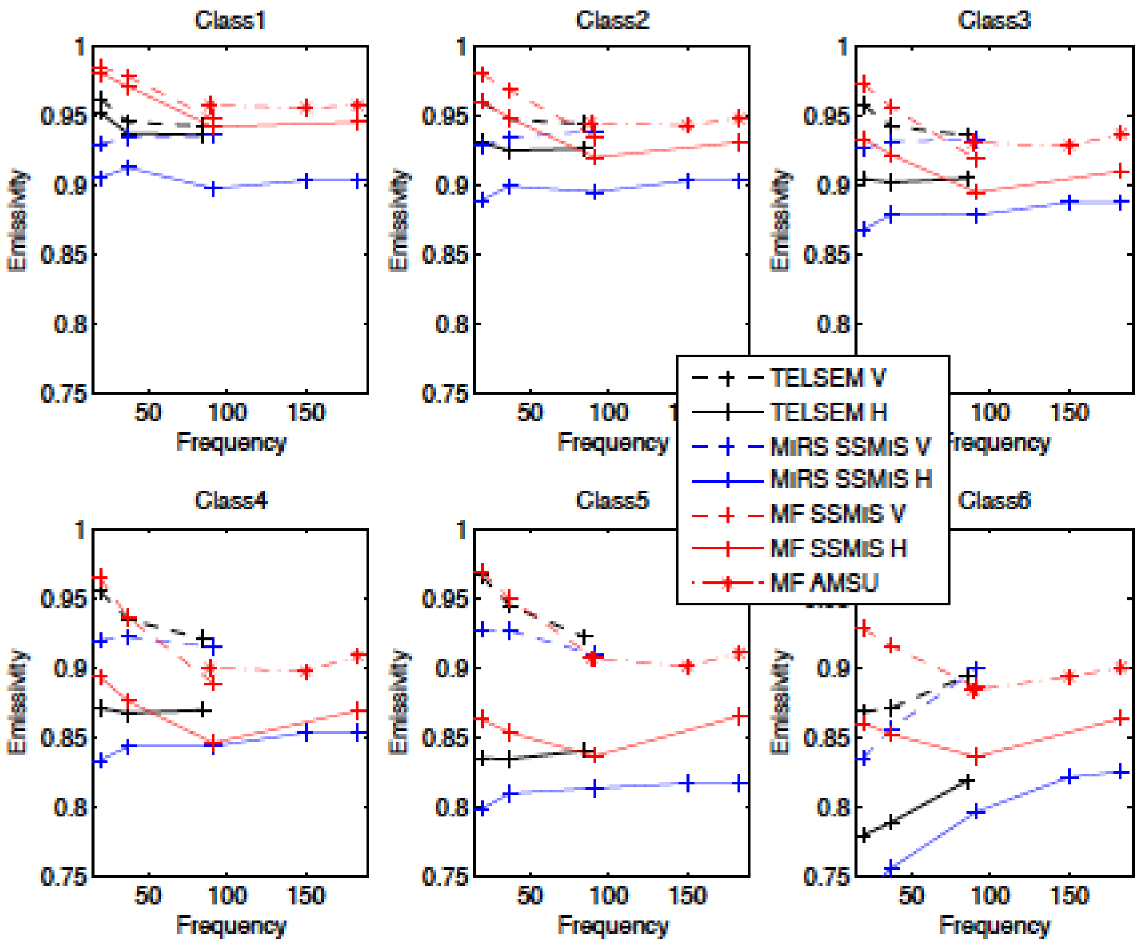
Decreasing vegetation density.

Class 6: presence of water



The land emissivity (snow and ice free)

The frequency dependence as seen from TELSEM, MF, and MIRS



The land and sea-ice emissivities: conclusion

TELSEM²

Tool to Estimate Land Surface Emissivities in Microwave and Millimeter waves

- It provides global realistic estimates of the emissivity for all continental and sea-ice surfaces, up to 700 GHz, monthly mean, at 25 km resolution.
- Inputs are the lat, lon, month, frequency, and incidence angle. Outputs are the emissivities in V and H polarizations.
- It is anchored to the SSMI-derived TELSEM
- It benefits from satellite-derived emissivities calculated at Météo-France and NOAA up to 190 GHz
- Parameterization of the frequency dependence could be updated if new emissivity estimates were available at global scale above 100 GHz.
- Handeling of the angular and polarization dependence suffers from the lack of available information
- Error estimates from TELSEM are propagated at higher frequencies

Conclusions

TESSEM^2 and **TELSEM^2** codes are available to the community

They are fully compatible with RT community codes

- Same language as their ancestors
- Same inputs as their ancestors
- Same outputs as their ancestors

Partly evaluated with ISMAR! See next presentation