Snow, ice, and sea ice microwave emissivity parameterization

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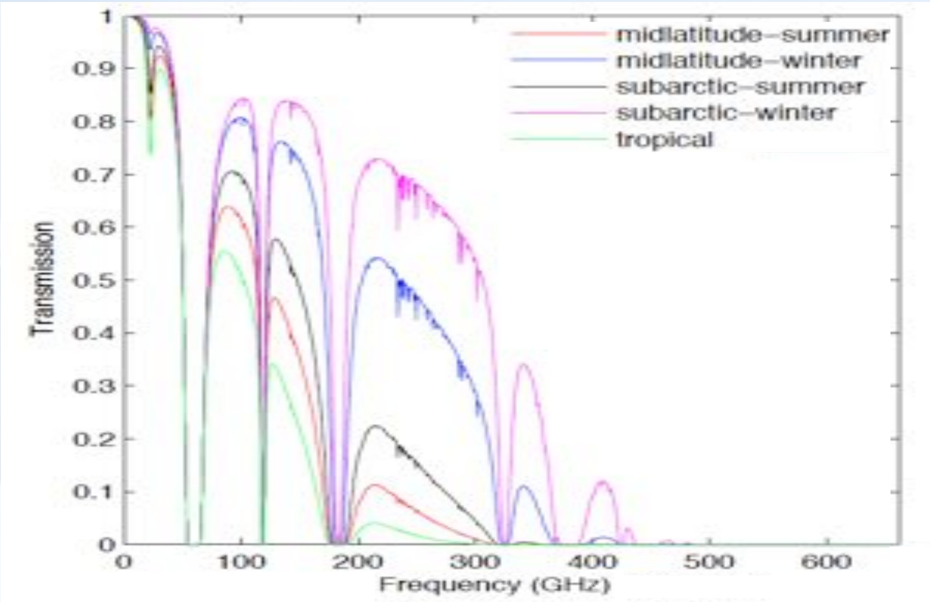
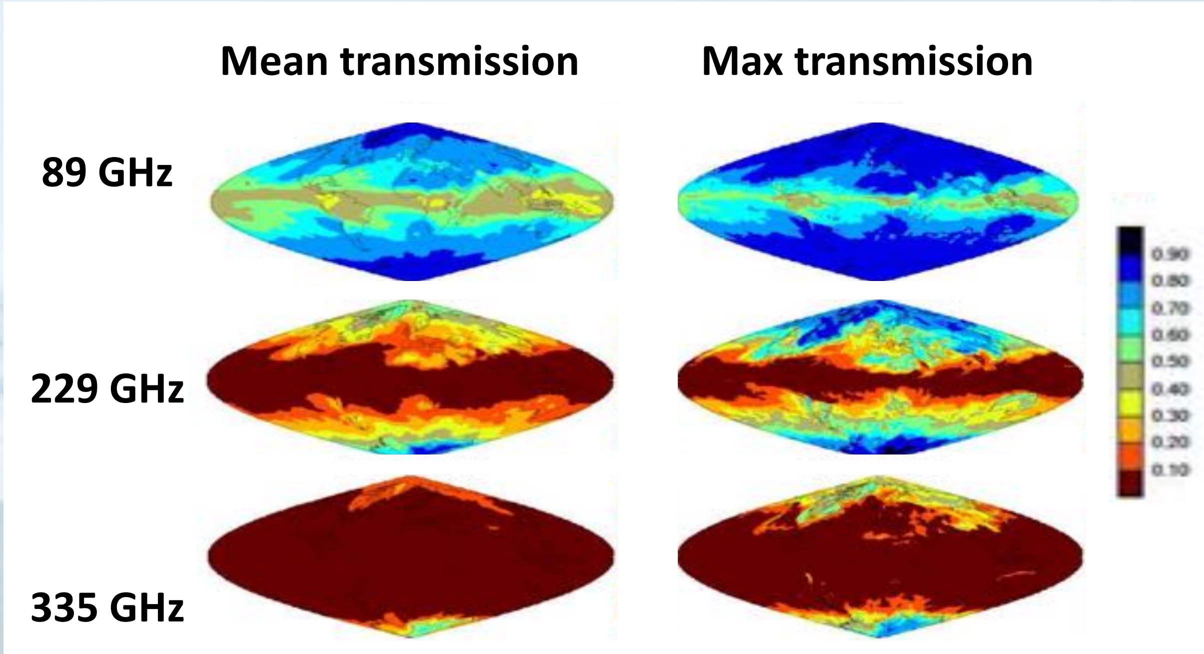
The microwave surface emission / scattering contribution to the satellite observations over polar regions

Under clear ski conditions:





CIMR

MWI

MWS

ICI

Significant contribution of the surface, especially under cold and dry conditions, even at frequencies above 200 GHz

Necessity to have microwave emissivity estimation:

- over the large frequency range covered by current and future missions
- consistent across frequencies, especially for the developments of multi-frequency sea ice and snow retrieval (e.g., from CIMR)
- including error covariance estimates
- able to handle the large temporal and spatial variability of the polar environment
- fast and practical
- ….

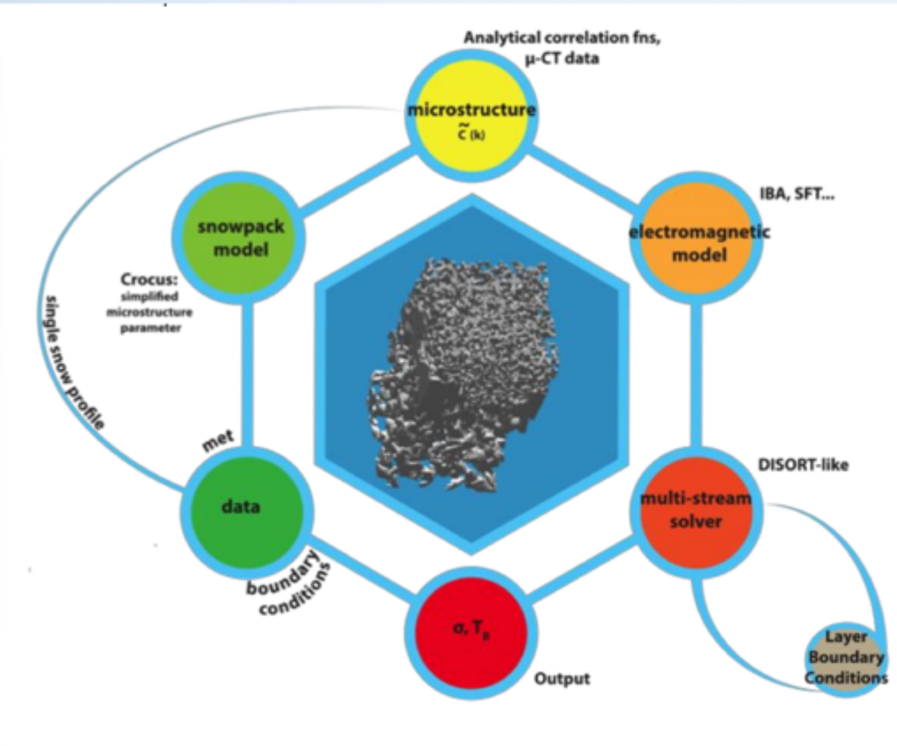
The different possibilities

- **Radiative transfer modeling**
- **Direct calculation from satellite observation**
- **Parameterization of satellite-derived estimation**

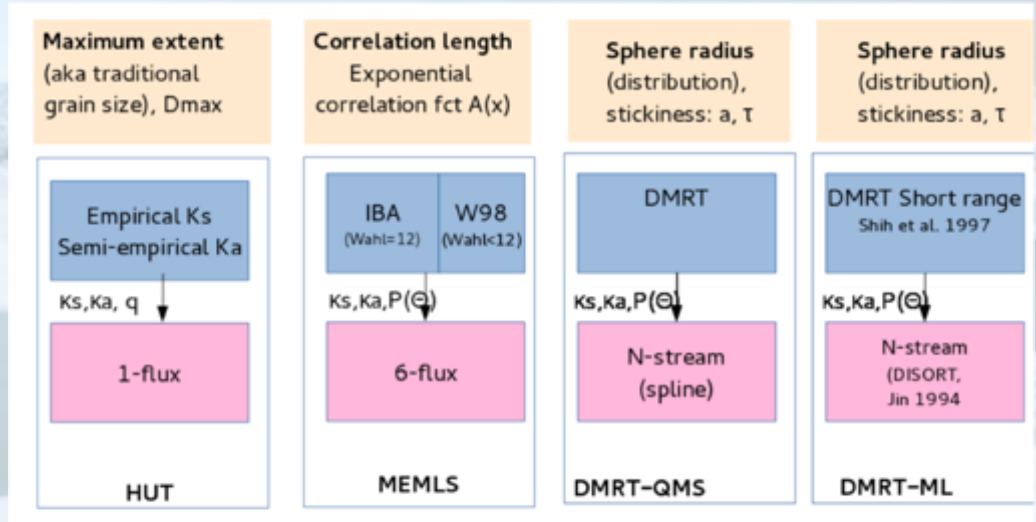
Radiative transfer modeling

Different models developed for snow and ice (HUT, MEMLS, SMRT, DMRT, SMRT…)
Rather large complexity, depending on the models, and requiring many input parameters

SMRT (Picard et al., GMD, 2018)
See https://www.smrt-model.science/documentation.html



Comparison of the different model principals
(Lowe and Picard, TC, 2015, Pan et al., TGRS, 2016)



- **Applicable to multiple frequencies, polarizations, and angles?**
- **Availability of the input parameters?**
- **Applicable at global scale under a large diversity of conditions?**

Radiative transfer modeling

Example: A recent effort to evaluate a model at large scale by Burgard et al., TC, 2020.

based on the MEMLS model

In summer, the MEMLS model not applicable and use of the Round Robin Data Package (RRDP)

At 6.GHz, V pol, 53°, for winter

Incidence angle	55°
Ocean temperature	−1.8 °C
Incoming microwave radiation from the atmosphere	0 K
Ice ocean reflectivity for V polarization	0.25
Brine pocket form	spherical
Correlation length first-year ice	0.35 mm for depth < 20 cm, 0.25 mm for depth > 20 cm
Correlation length multiyear ice	1.5 mm
Snow thickness	as computed by SAMSIM
Snow density	$300\,\mathrm{kg\,m^{-3}}$
Snow correlation length	0.15 mm
Snow salinity	$0\,\mathrm{g\,kg^{-1}}$
Snow temperature	as computed by SAMSIM

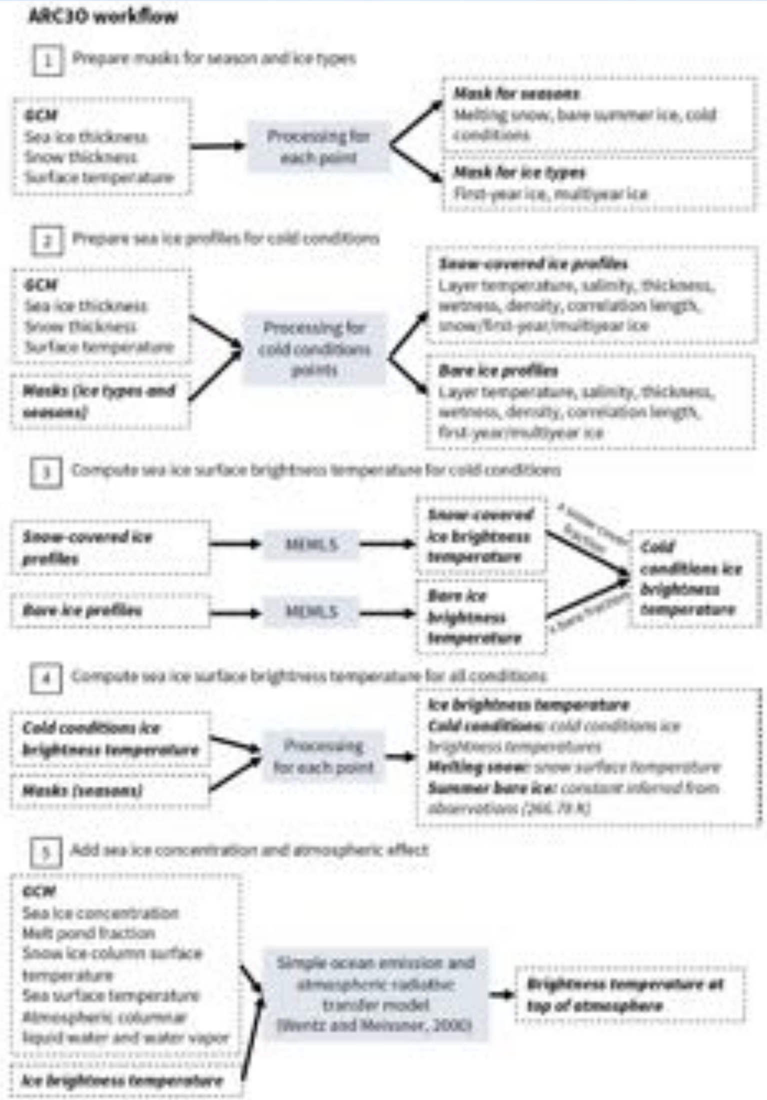


Figure 1. Workflow of the Arctic Ocean Observation Operator ARC3O.

Radiative transfer modeling

Example: A recent effort to evaluate a model at large scale by Burgard et al., TC, 2020.

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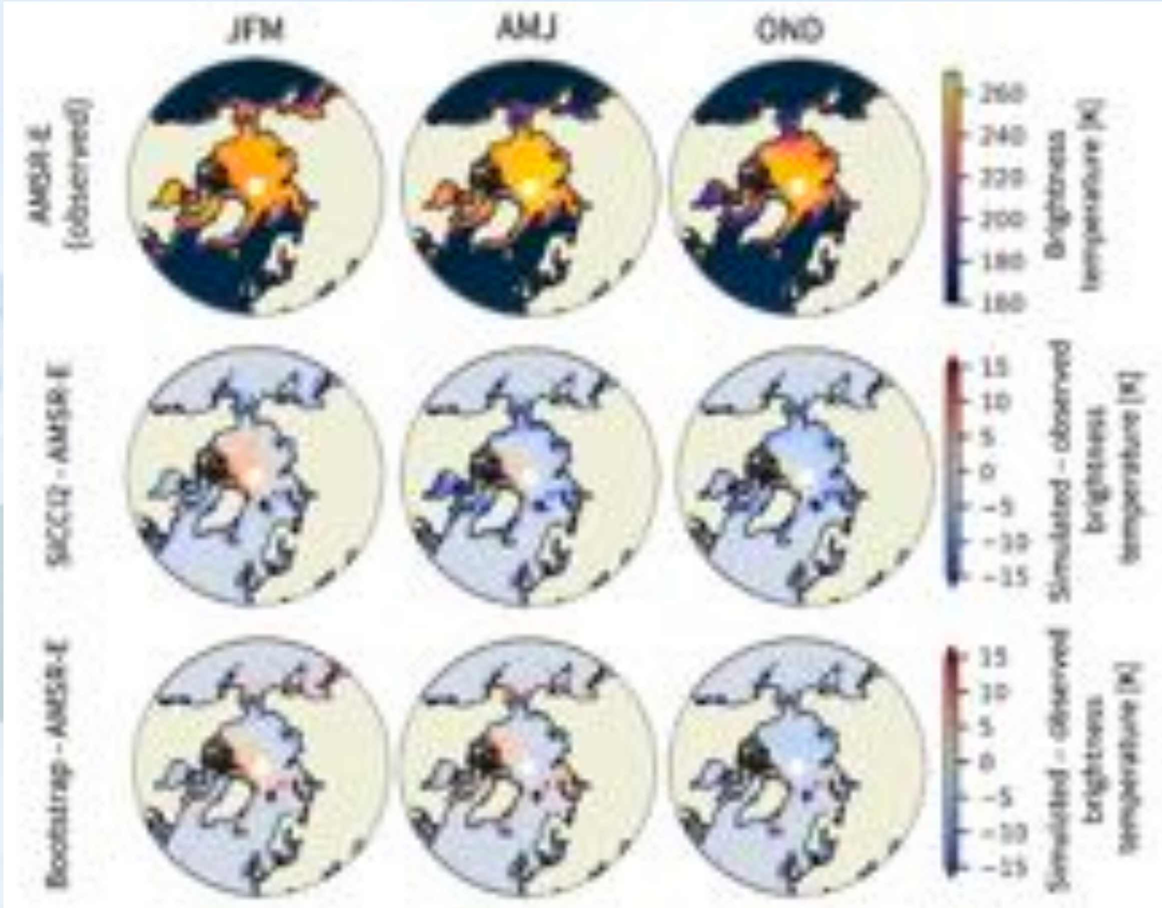
At 6.GHz, V pol, 53°, for winter

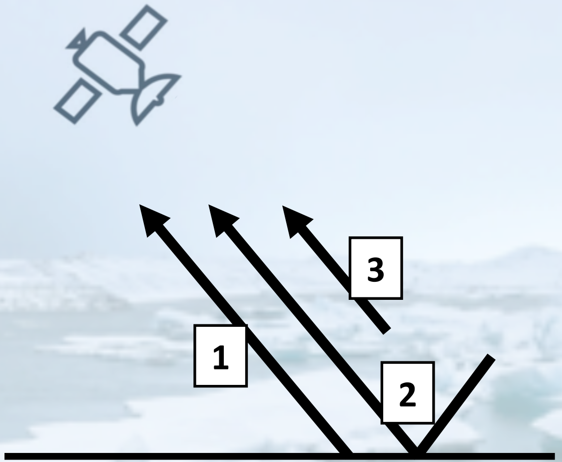
What about H polarization?
What about the other AMSR frequnecies?



(after debaising)

Satellite-derived microwave emissivity datasets

The basis:



$$Tb_p = \underbrace{T_{surf} \times \epsilon_p \times e^{-\tau(0,H)/\mu}}_{\boxed{1}} + \underbrace{T_{atm}^{\downarrow} \times (1 - \epsilon_p) \times e^{-\tau(0,H)/\mu}}_{\boxed{2}} + \underbrace{T_{atm}^{\uparrow}}_{\boxed{3}}$$

$$\boxed{\epsilon_p = \frac{Tb_p - T_{atm}^{\uparrow} - T_{atm}^{\downarrow} \times e^{-\tau(0,H)/\mu}}{e^{-\tau(0,H)/\mu} \times (T_{surf} - T_{atm}^{\downarrow})}}$$

First applied globaly to SSM/I observations

Prigent et al., JGR, 1997; BAMS, 2006…

Often used since for other instruments

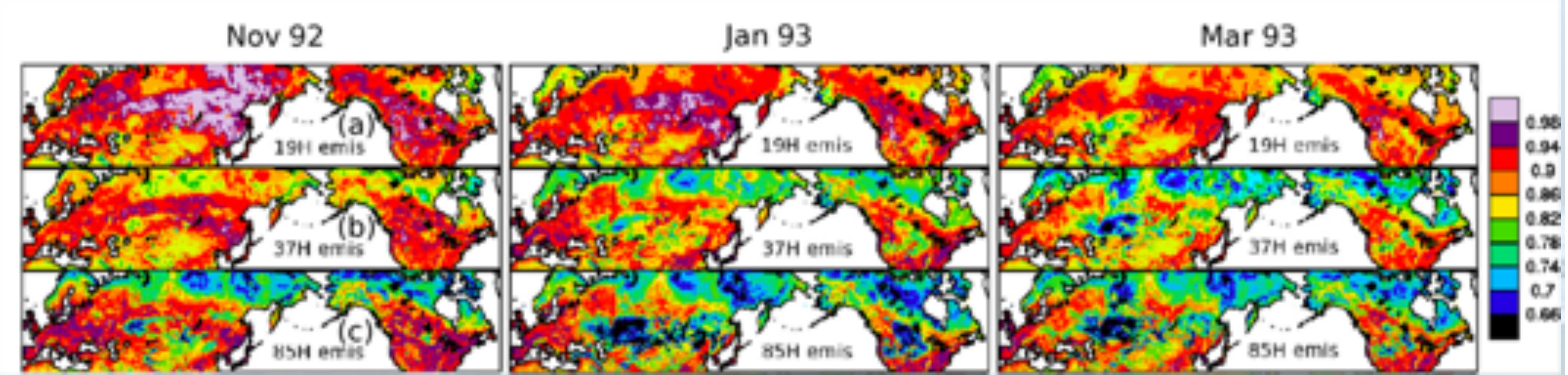
AMSU (Prigent et al., 2004; Karbou et al., 2005…), AMSR (Moncet et al. , 2011; Norouzi et al., 2015…)

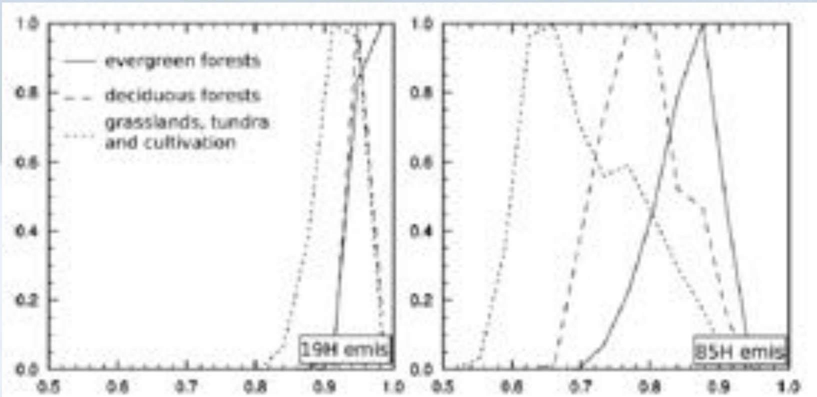
Or imbedded in surface-atmosphere retrievals

SSMI (Aires et al., JGR, 2001), multiple-instruments (Boukabara et al., RS, 2018), GMI (Munchack et al., IEEE TGRS, 2020)

Satellite-derived microwave emissivity datasets

Derived from **SSM/I** (Paris Observatory)
(Cordisco et al., JGR, 2005)





Satellite-derived microwave emissivity datasets

For instance derived from the **Microwave Integrated Retrieval System (MIRS) at NOAA**
(Boukabara et al., RS, 2018)

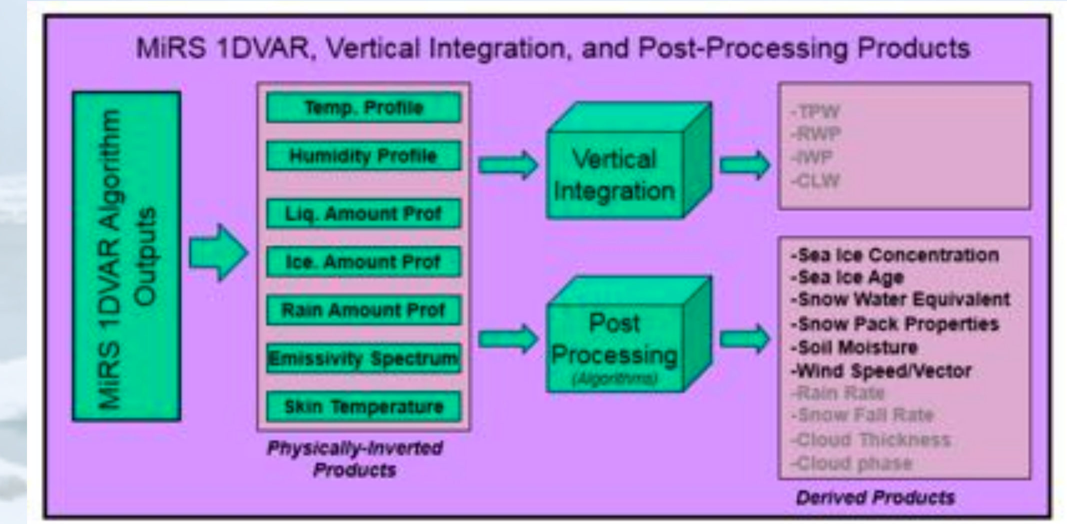
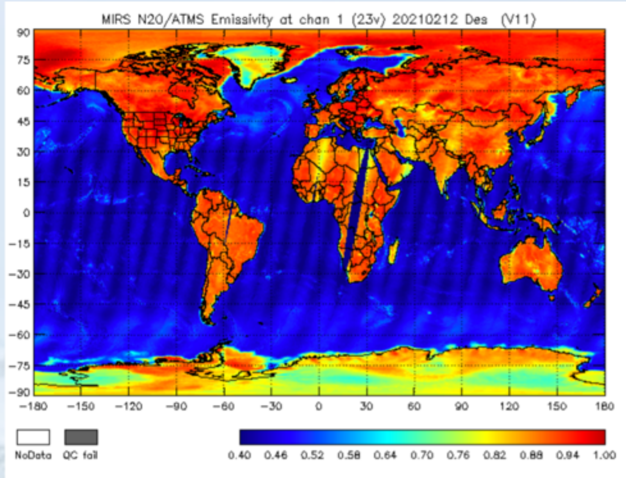
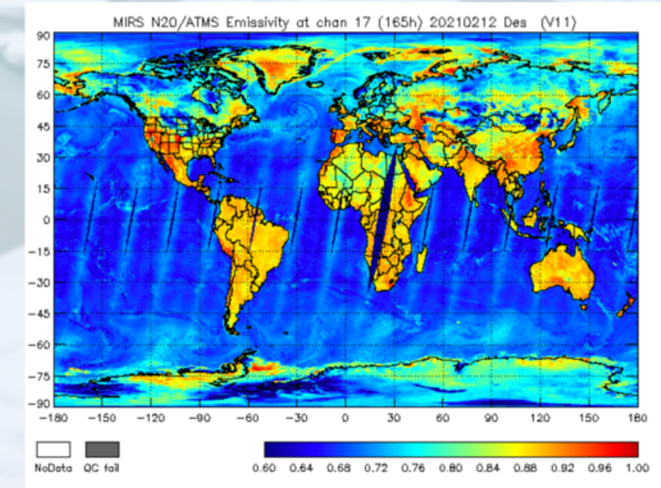


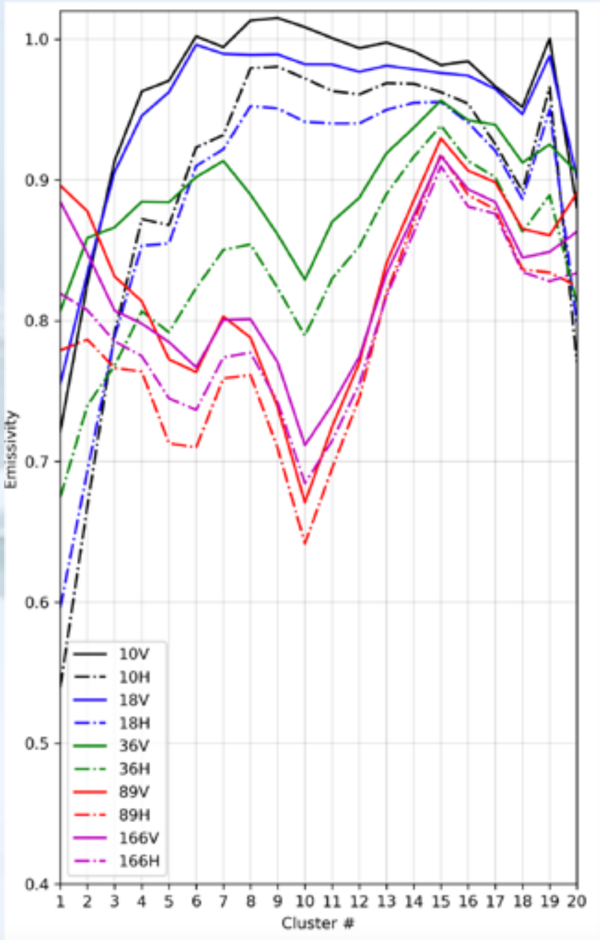
Figure 1. Products from the Microwave Integrated Retrieval System (MiRS) two-steps retrieval process. Products listed in bold under "Derived Products" are generated from the emissivity spectrum. Soil moisture and wind speed/vector are not current operational products. 1DVAR: one-dimensional, variational-based physical approach.



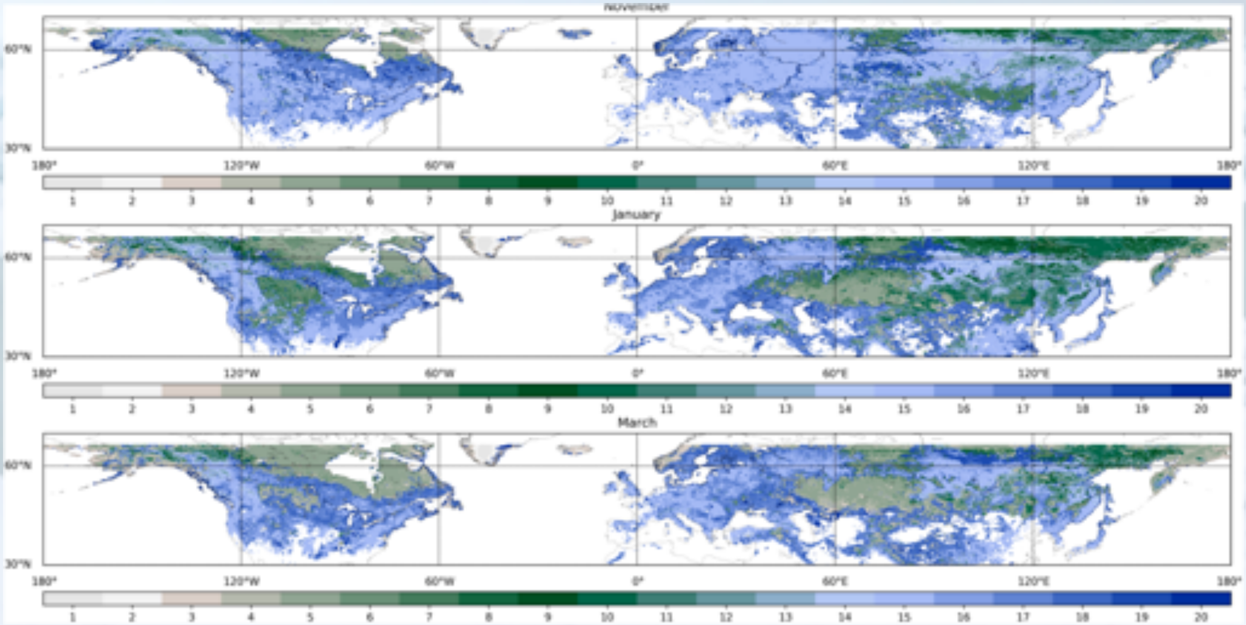


Satellite-derived microwave emissivity datasets

Derived from the **GPM Microwave Imager (GMI), along with the σ_0 from the GPM DPR**
(Munchack et al., IEEE TGRS, 2020)



Systematique calculation of the surface emissivity at GMI frequencies between 10 and 166 GHz, using optimal estimation method (simultaneous retrieval of atmosphere and surface parameters).



Satellite-derived microwave emissivity datasets

$$\epsilon_p = \frac{Tb_p - T_{atm}^{\uparrow} - T_{atm}^{\downarrow} \times e^{-\tau(0,H)/\mu}}{e^{-\tau(0,H)/\mu} \times (T_{surf} - T_{atm}^{\downarrow})}$$

Sources of potential errors:

The surface temperature T_{surf}

- Tsurf=Tskin? Tskin from NWP model, from IR (under clear sky conditions) ?
- Sub-surface contribution? Tsurf=Teff

The atmospheric contribution

- especially at high frequency
- depends on atmospheric profiles and atmospheric absorption model
- adjusted when calculation within a full surface / atmosphere inversion model (as in MIRS or in Aires et al., 2001)

Specular approximation

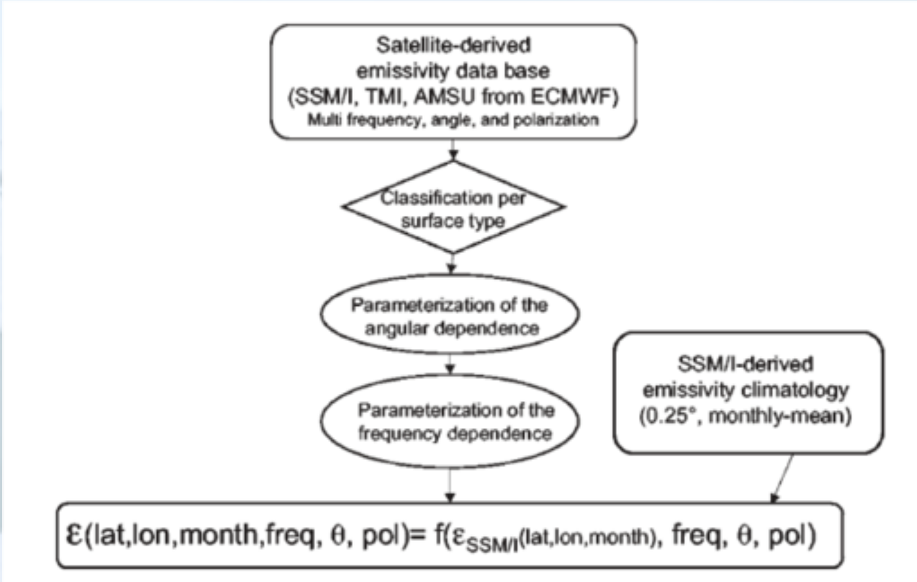
- always valid? Lambertian contribution close to nadir and at high frequency? Especially over snow and ice? (Matzler, GRSL, 2005; Karbou et al., GRSL, 2005; Harlow, TGRS, 2009)

Satellite-derived microwave emissivity datasets

From one satellite, observations of a limited range of frequency, angle, polarization
How to derive general emissivity parameterization from satellite-derived emissivities?

⇒ An analysis of emissivities derived from multiple satellites, to parameterize the emissivity frequency, angle, and polarization dependence

TELSEM²
Tool to Estimate Land Surface Emissivities in the Microwaves and Millimeter waves
(Prigent et al., IEEE TGRS, 2008; Aires et al., QJRMS, 2011; Wang et al.,JAOT, 2017)



Differences in the assumptions for the emissivity calculation for the diverse instruments (Tsurf, atmospheric profiles or atmospheric absorption model) or satellite inter-calibration issues can lead to inconsistencies / difficulties.

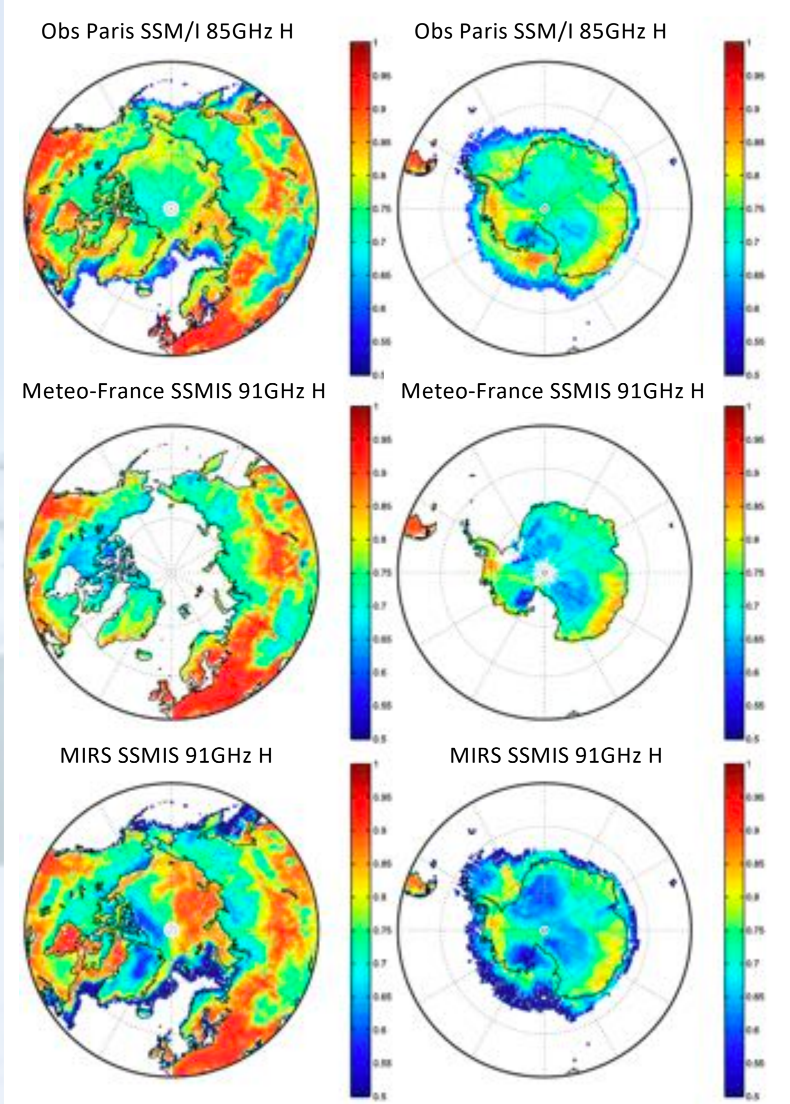
Satellite-derived microwave emissivity datasets

TELSEM[2] over the poles (Wang et al., JAOT, 2017)

- **Merging of several emissivity estimates from different instruments and institutes**

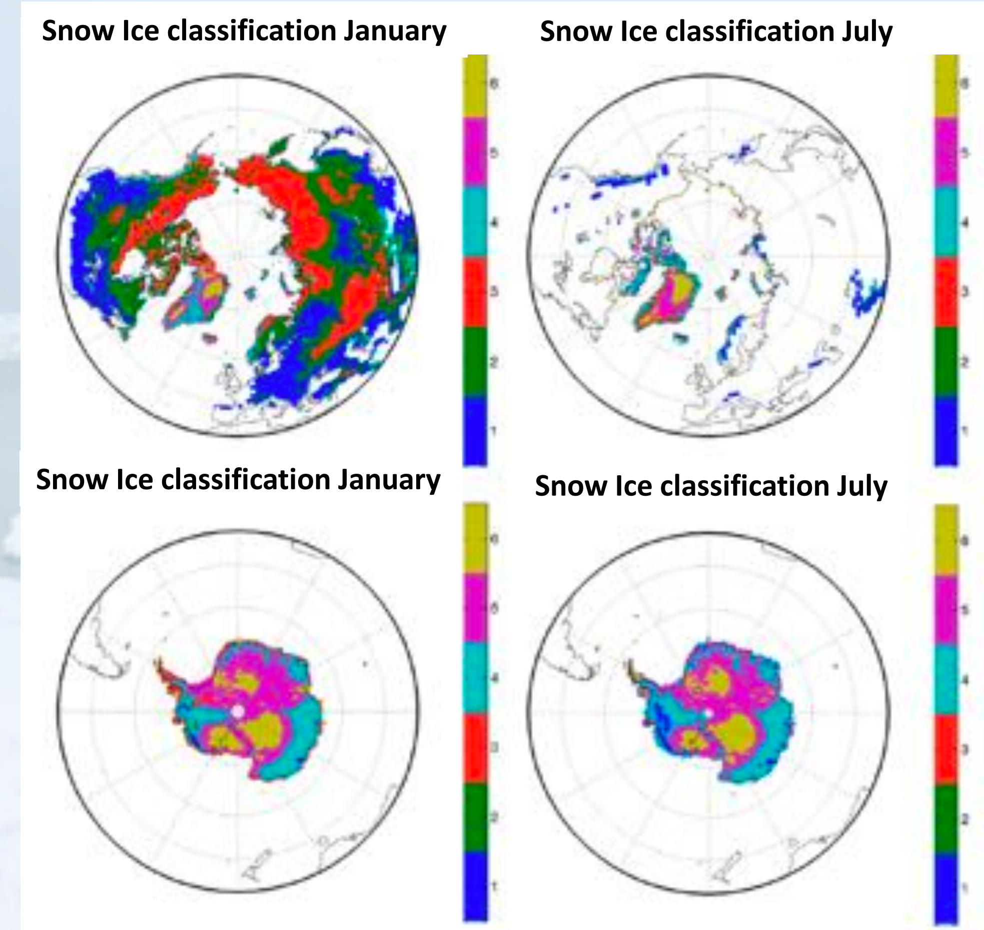
TABLE 1. Characteristics of the satellite-derived emissivity datasets used in this analysis. Note that the NOAA/MIRS retrieves the first five EOPs with SSMIS observations. Freq. is frequency; spatial res. is spatial resolution.

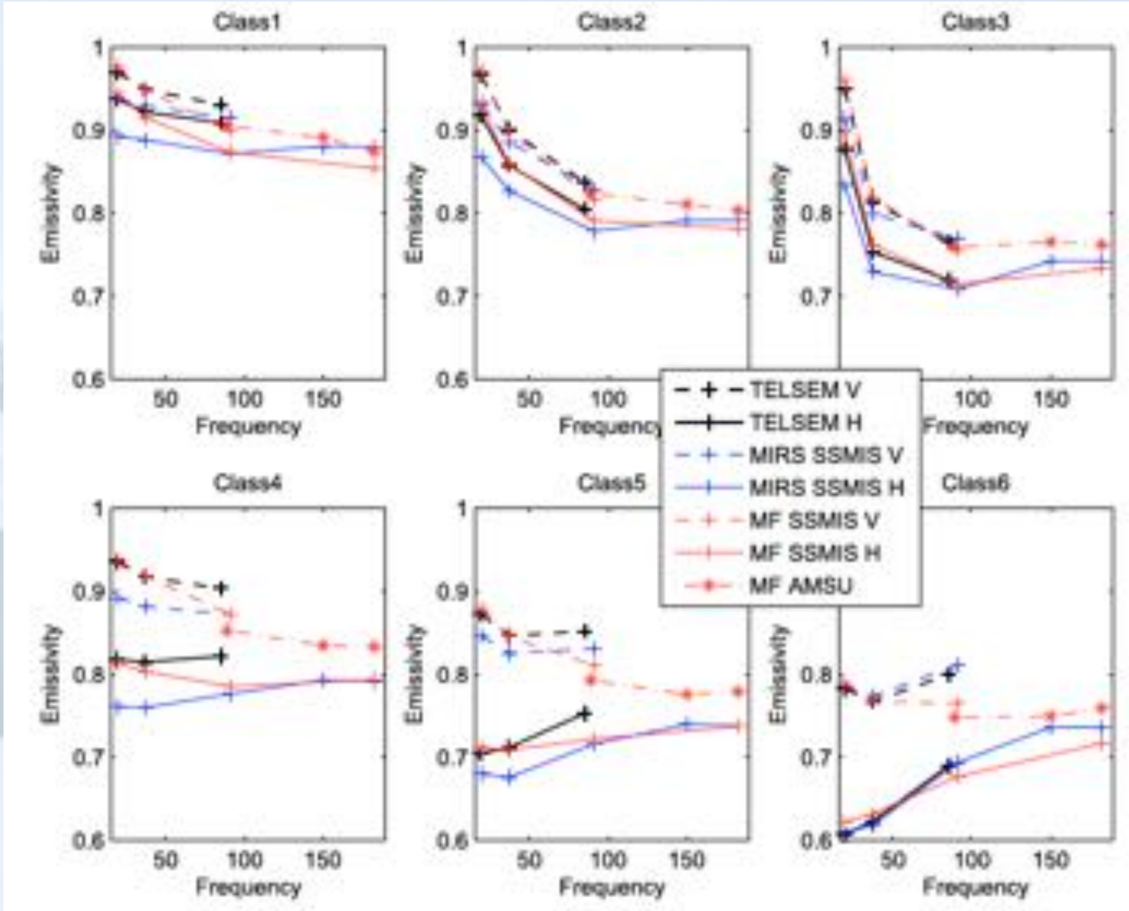
Dataset	Sensor	Surface type	Freq. (GHz)	Angle, polarization	Spatial res.	Temporal sampling	Temporal cover
TELSEM	SSM/I	Continents + sea ice	19, 37, 85	53°, V + H	0.25° × 25°	Monthly mean	Climatology
Emissivity NOAA/MIRS	SSMIS	All surfaces	19, 37, 91, 150, 183	53°, V + H (<100 GHz), H (>100 GHz)	0.25° × 25°	Each satellite overpass	March + October 2014
Emissivity Météo-France	AMSU-B	Continents	89, 150, 183	Small and large angles separately, with mixed polar.	0.25° × 25°	Monthly mean	2014
Emissivity Météo-France	SSMIS	Continents	19, 37, 91, 183	53°, V + H (<100 GHz), H (>100 GHz)	0.25° × 25°	Monthly mean	2014



Satellite-derived microwave emissivity datasets

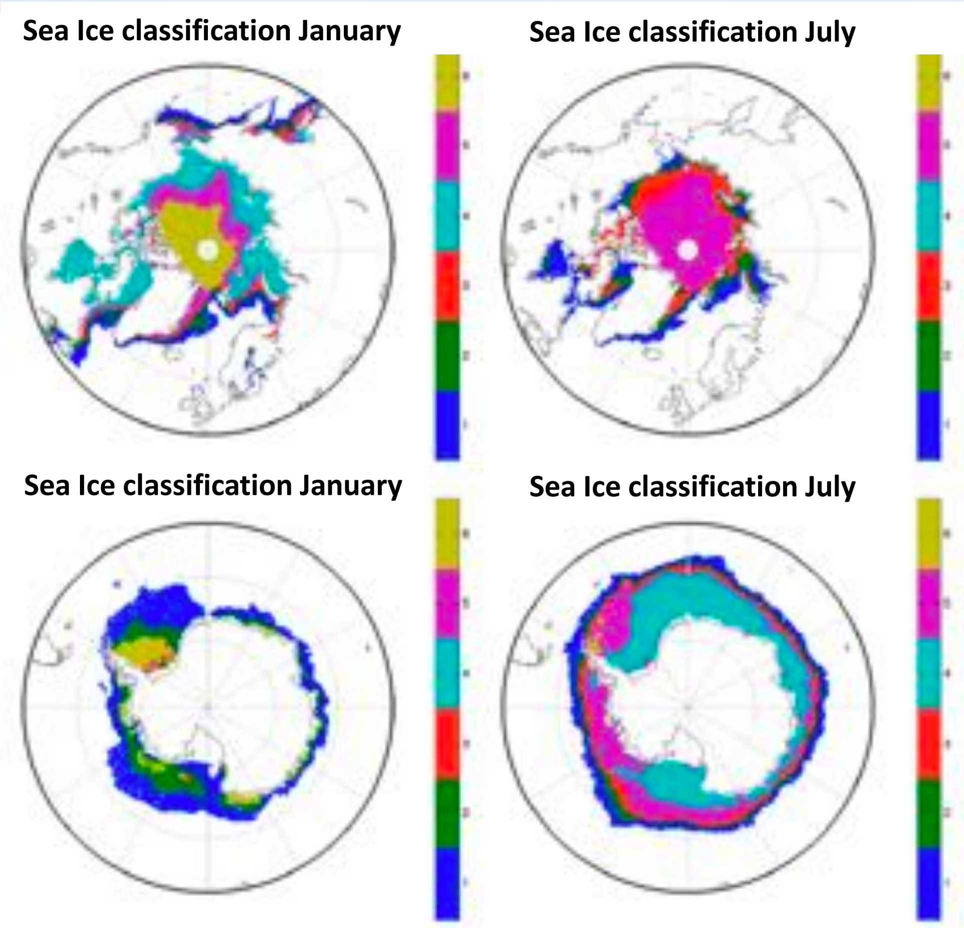
TELSEM² for CONTINENTAL SNOW AND ICE (Wang et al., JAOT, 2017)

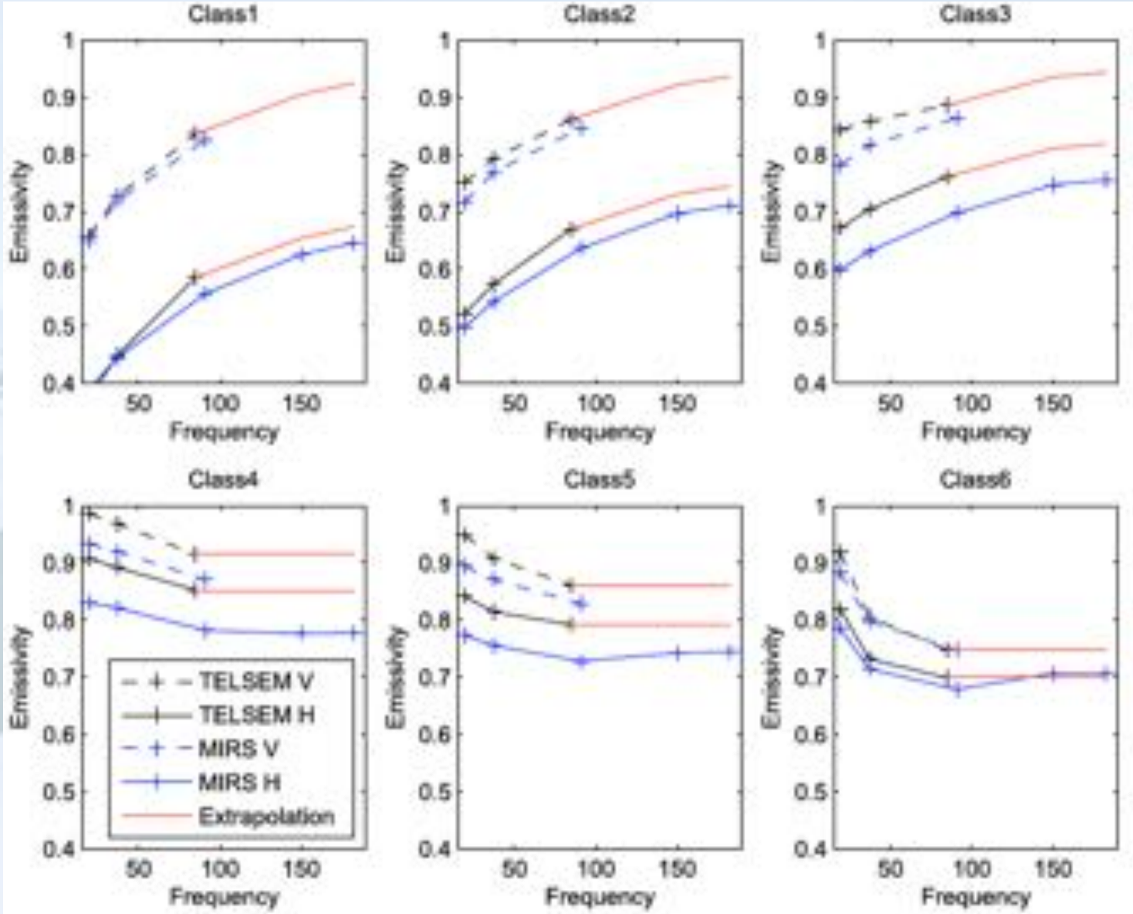




Satellite-derived microwave emissivity datasets

TELSEM² for SEA ICE (Wang et al., JAOT, 2017)



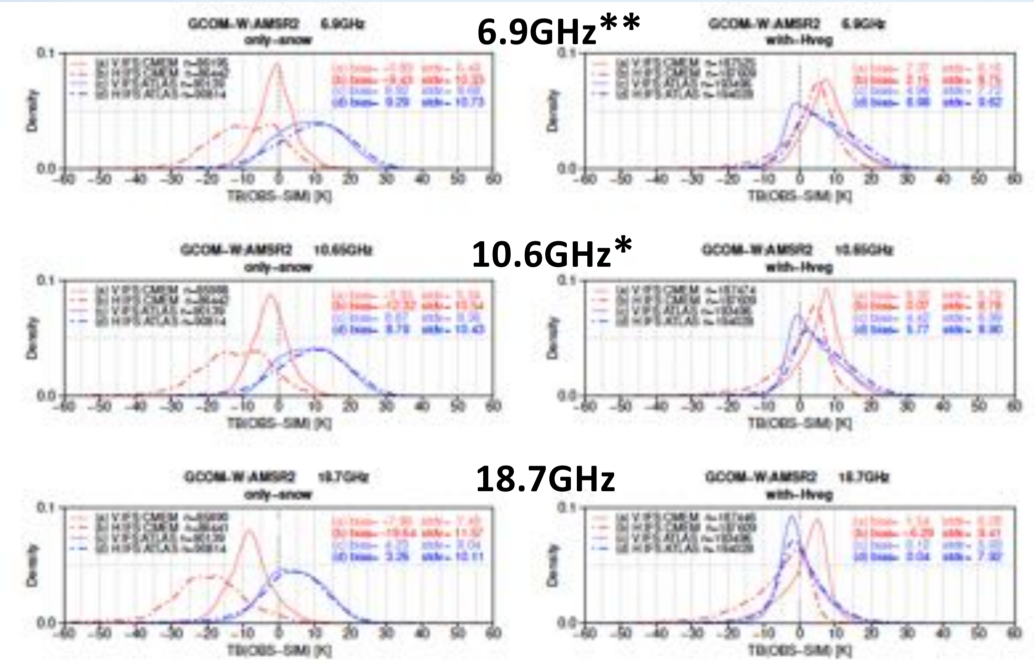


Comparison between modeled and satellite-derived emissivities

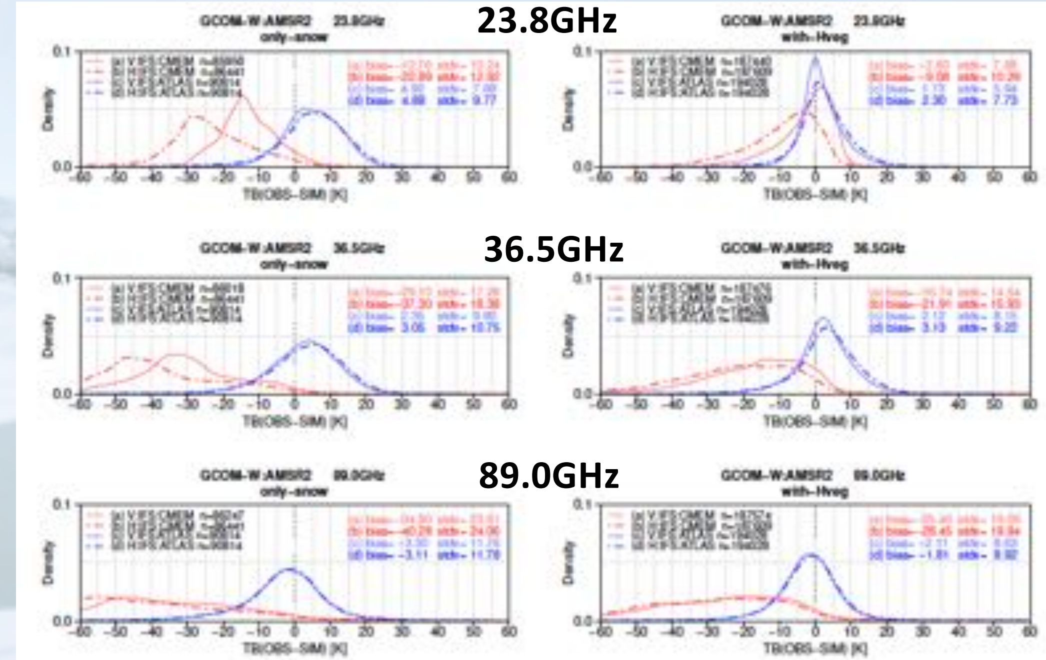
Snow modeled emissivity (CMEM) and satellite-derived emissivity (TELSEM²) at ECMWF

compared to AMSR observations from 6.9 to 90 GHz

Only snow | **Snow with vegetation**



Only snow | **Snow with vegetation**



Satellite-derived emisivity

Snow radiative transfer model

* **Outside the interpolation range for TELSEM²**

———— V pol

\- - - - - - H pol

Hirahara et al., RS, 2020

Satellite-derived microwave emissivity

TELSEM^2

Tool to Estimate Land Surface Emissivities at Microwaves and Millimeter waves
(**distributed with RTTOV and CRTM)**

- It provides global realistic estimates of the emissivity for all continental and sea-ice surfaces, from 18 to 700 GHz, monthly mean, at 25 km resolution.

- **Inputs:** **lat, lon, month, frequency, and incidence angle.**
- **Outputs:** **emissivities in V and H polarizations, along with error correlations.**

- It is anchored to the SSMI-derived microwave emissivities

- It benefits from satellite-derived emissivities calculated in different institutes

- Realistic **FIRST GUESS** estimates, along with error covariances

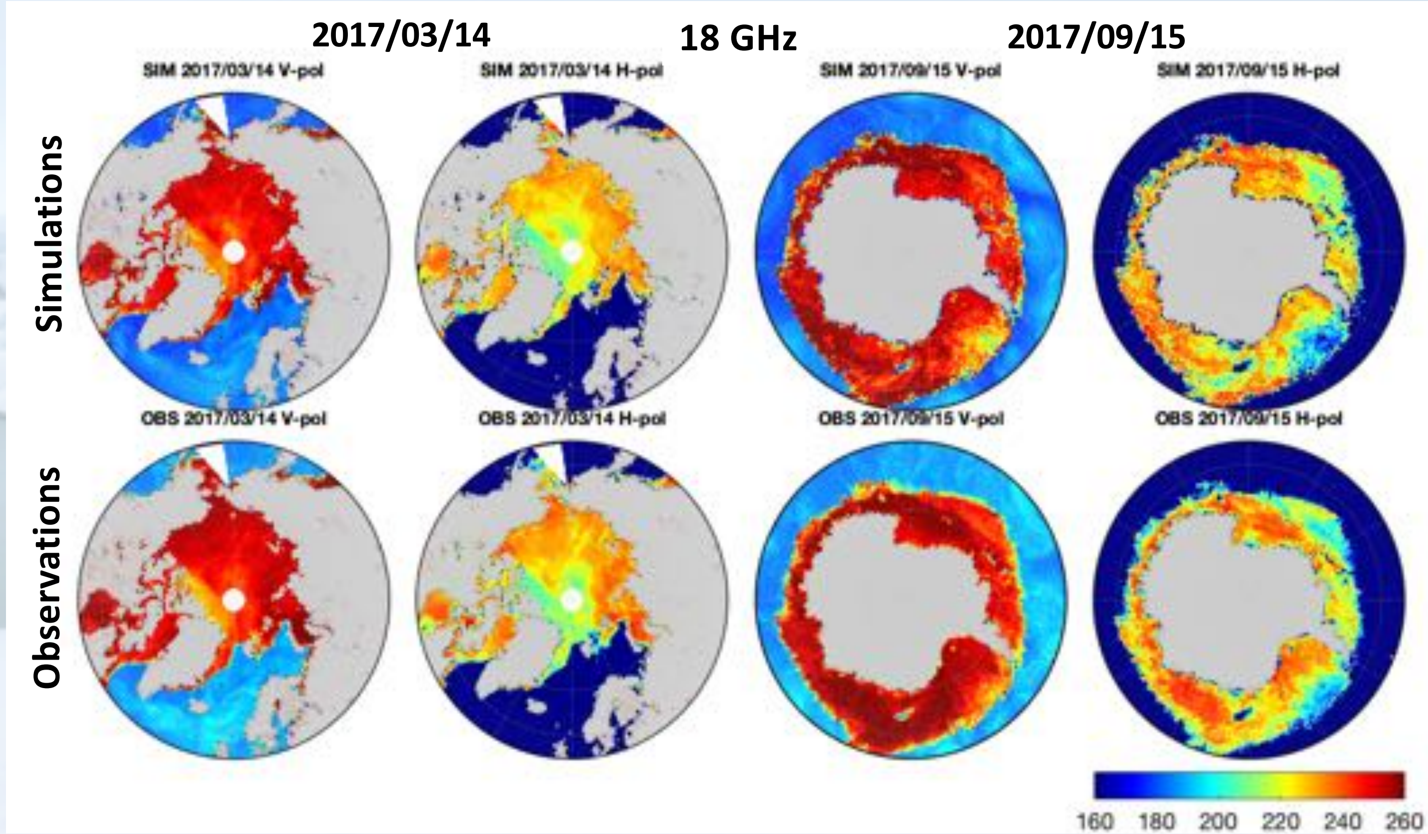
To be updated with new emissivity estimates, especially below 18 GHz (AMSR + SMAP + SMOS)

For a better consistency in NWP applications, use of the NWP framework of interest for the emissivity estimations (Tsurf, atmospheric profiles and radiative transfer model…), for all the instruments.

Satellite-derived microwave emissivity

On the same principal, developing a parameterization of the sea ice emissivities based on the **ESA Sea Ice Round Robin Data Package** (Pedersen and Saldo, 2016) at SMOS/SMAP and AMSR frequencies and observing conditions.

- First systematic estimation of the emissivities, directly from the RRDP information.
- Emissivity parameterized as function of the the 2-meter air temperature, the ice age (first year or multi-year), and the snow depth.
- Reasonable comparisons with AMSR2 observations, for both poles and seasons, and for all frequencies and polarizations.



Jimenez et al., under review JGR, 2021

Satellite-derived microwave emissivity

From **ESA Sea Ice Round Robin Data Package**

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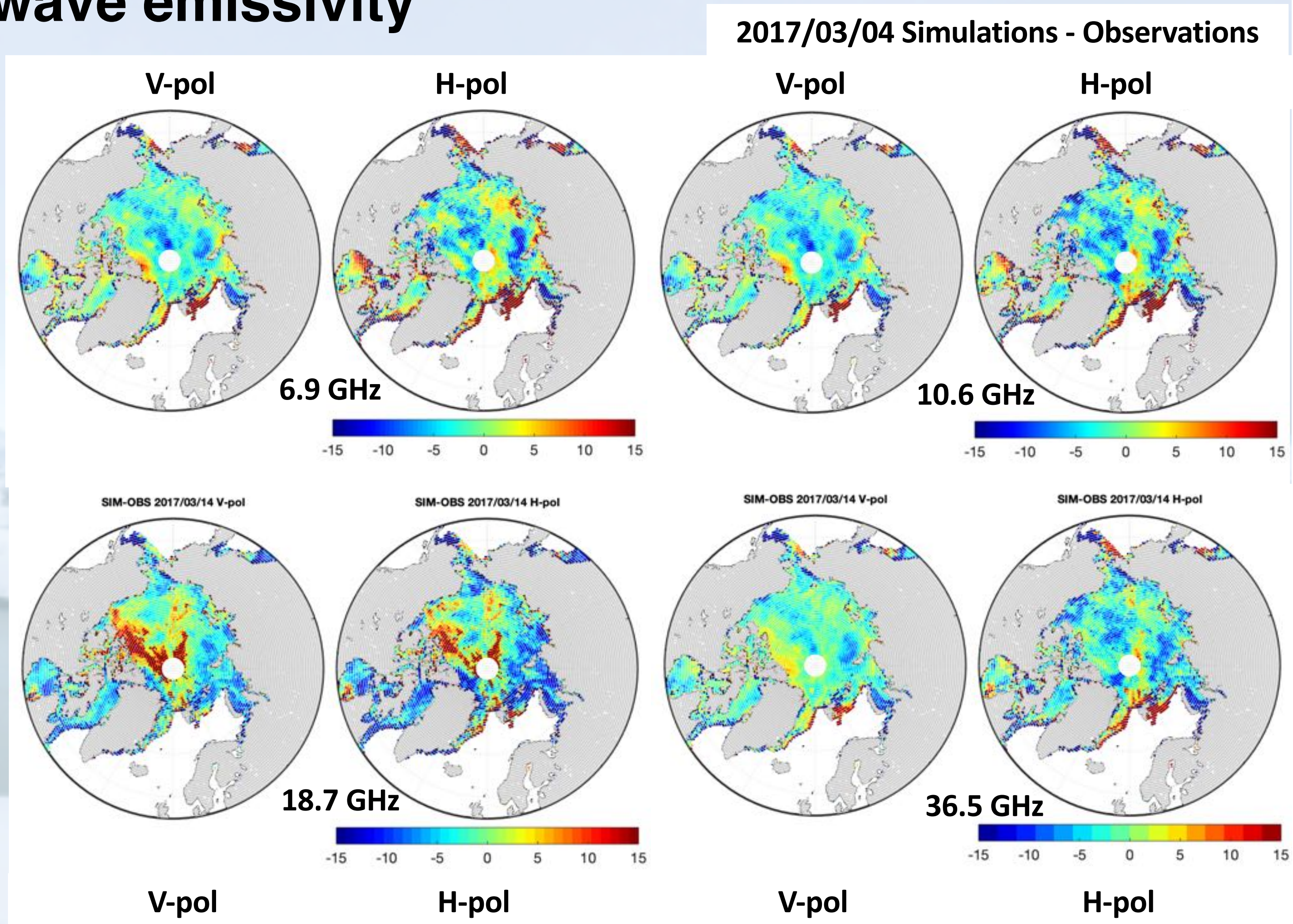
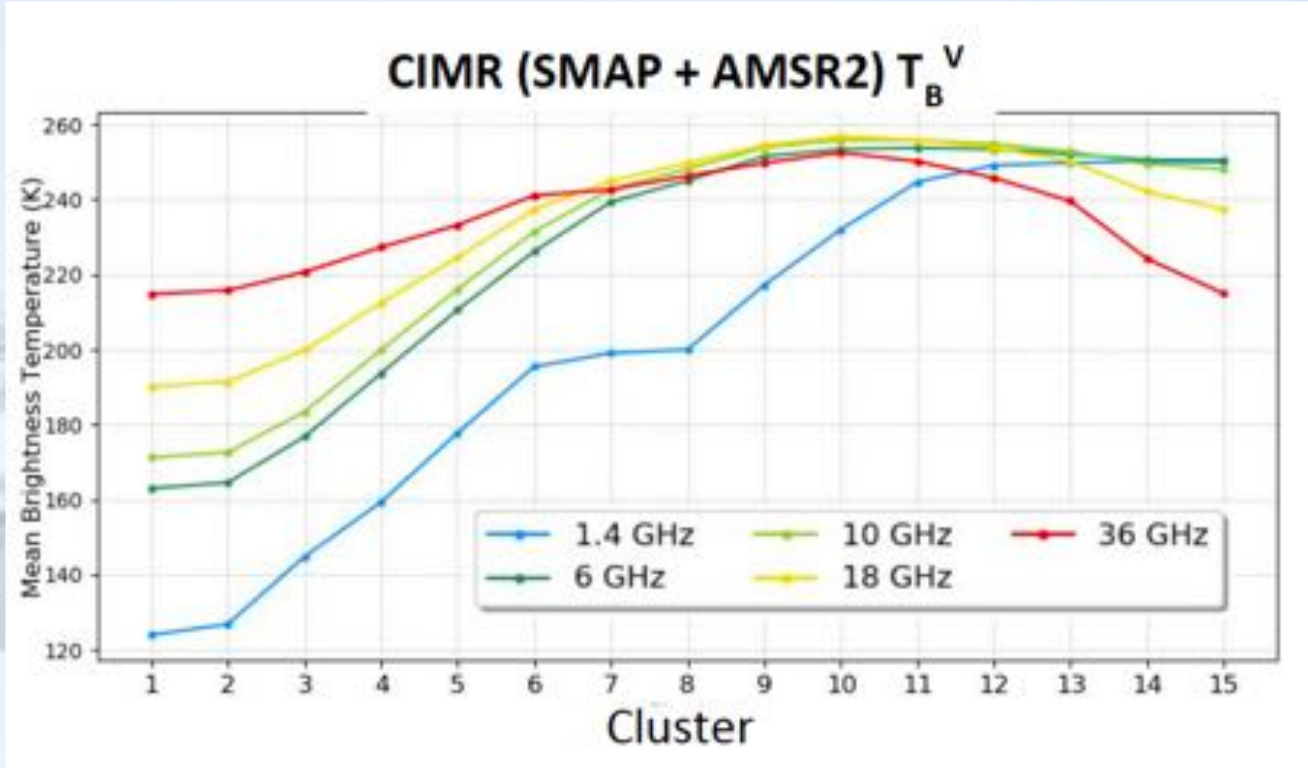


Jimenez et al., submitted JGR, 2021

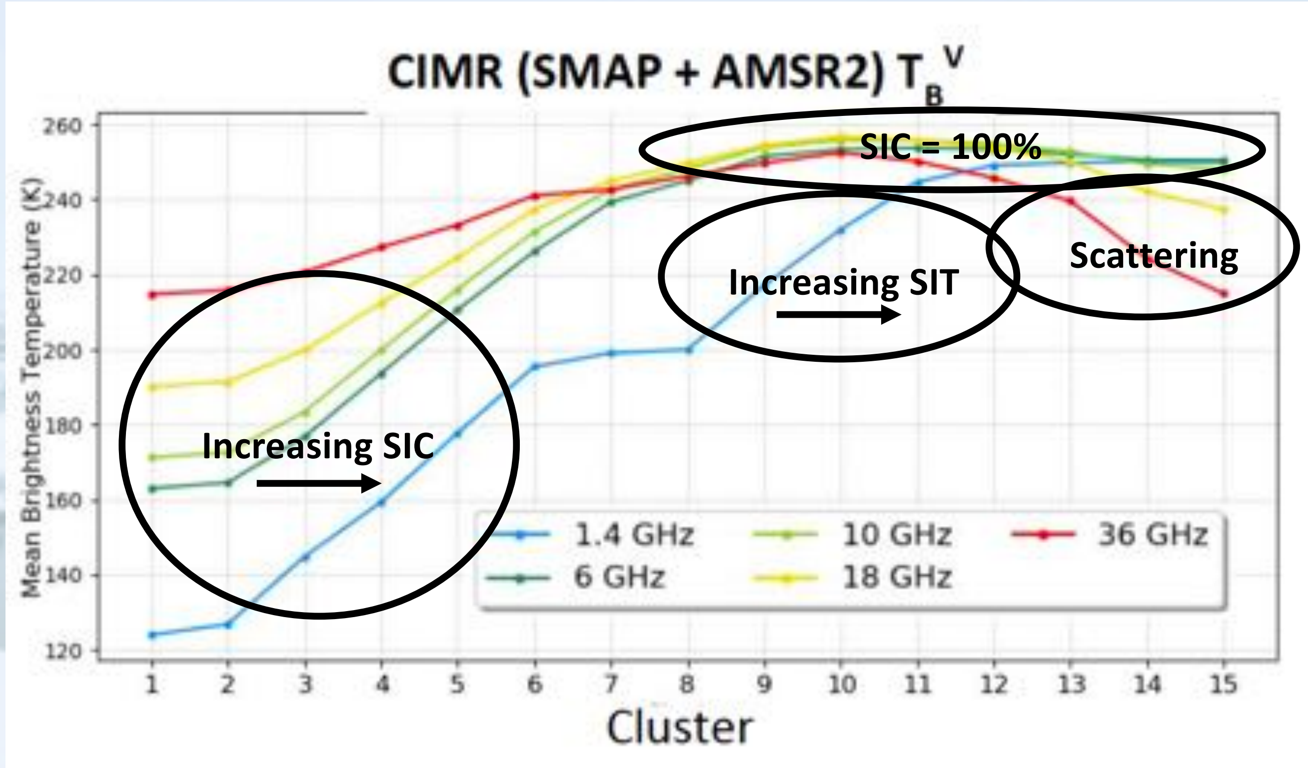
Satellite-derived microwave emissivity



Classification of one year of SMAP and AMSR2 data over the Arctic, to extract the dominant T_B patterns and their co-variabilities

Soriot et al., IGARSS, 2021

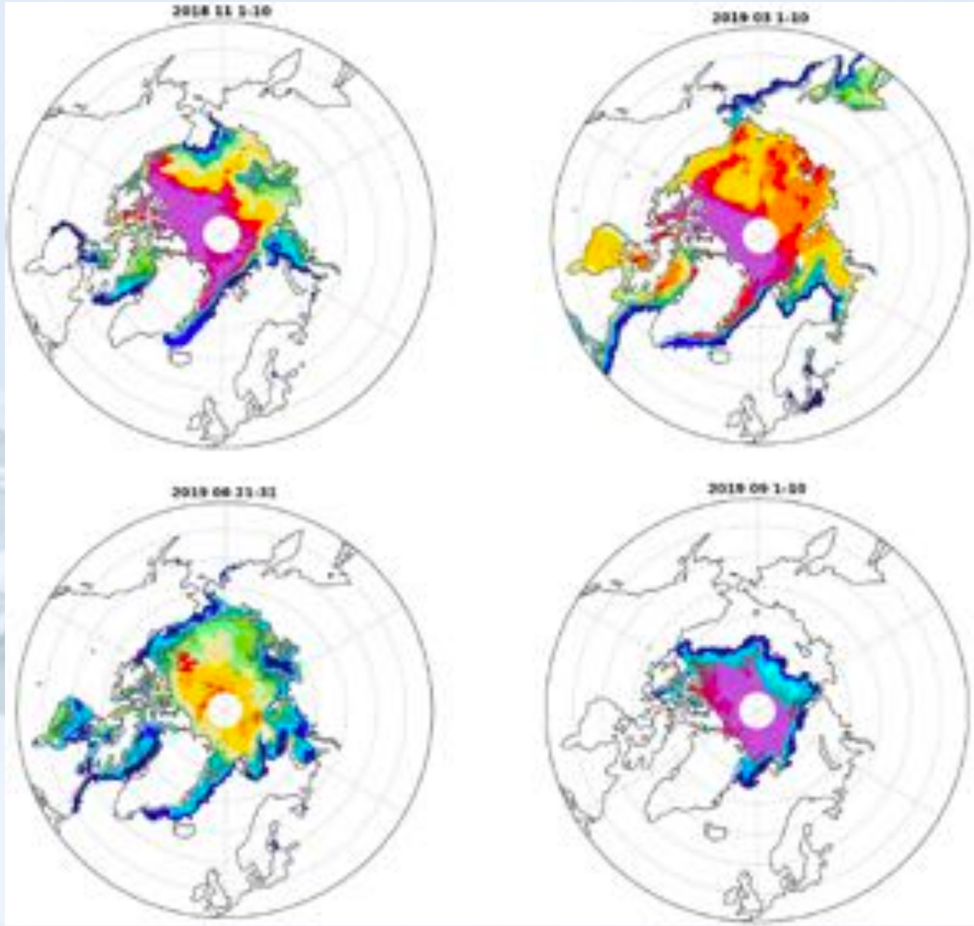
Satellite-derived microwave emissivity

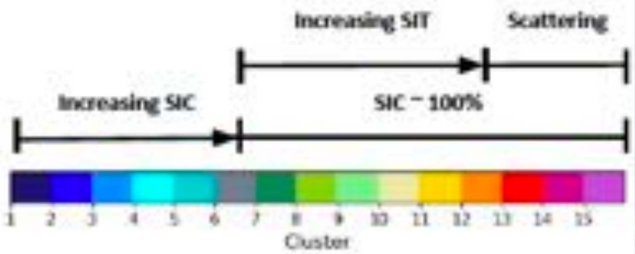


Interpretation of the signatures, in terms of geophysical parameters

Soriot et al., IGARSS, 2021

Satellite-derived microwave emissivity

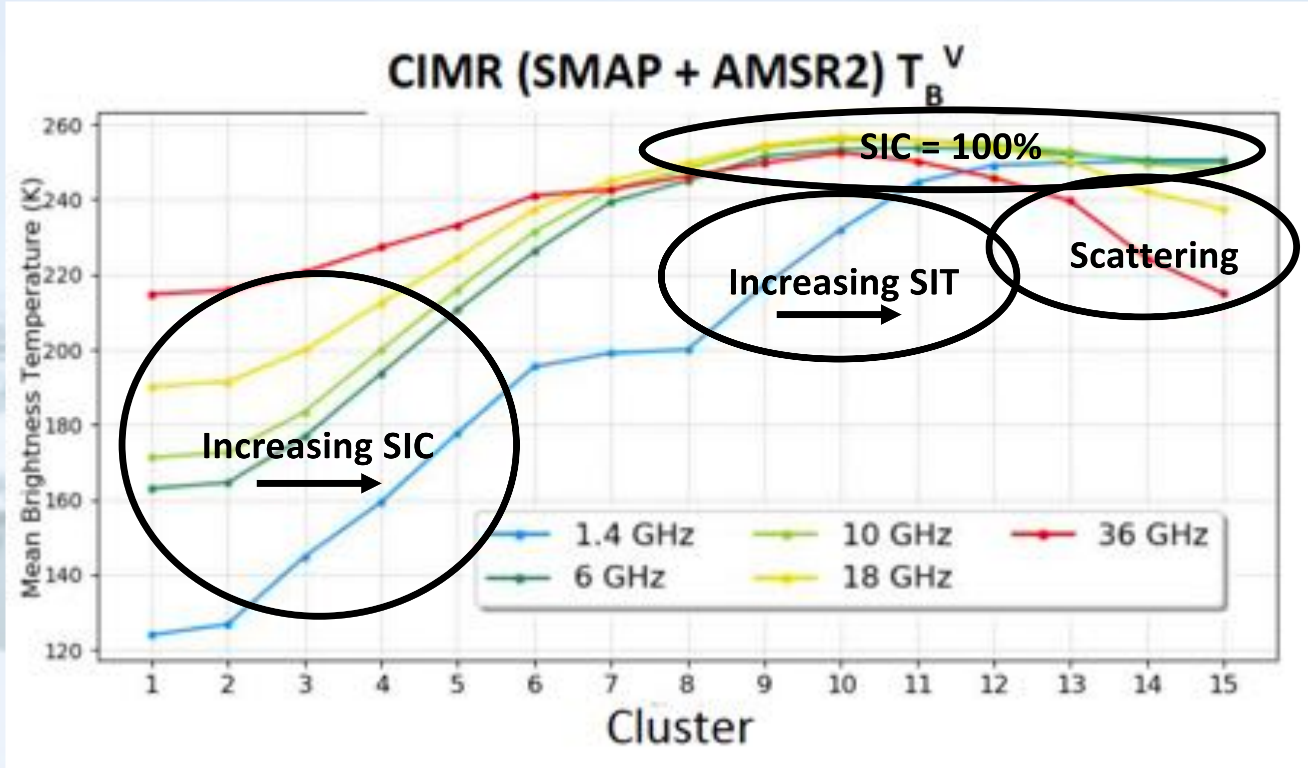




Spatialy and temporaly consistent clustering results (despite the fact that no temporal or spatial information is provided to the clustering)

Soriot et al., IGARSS, 2021

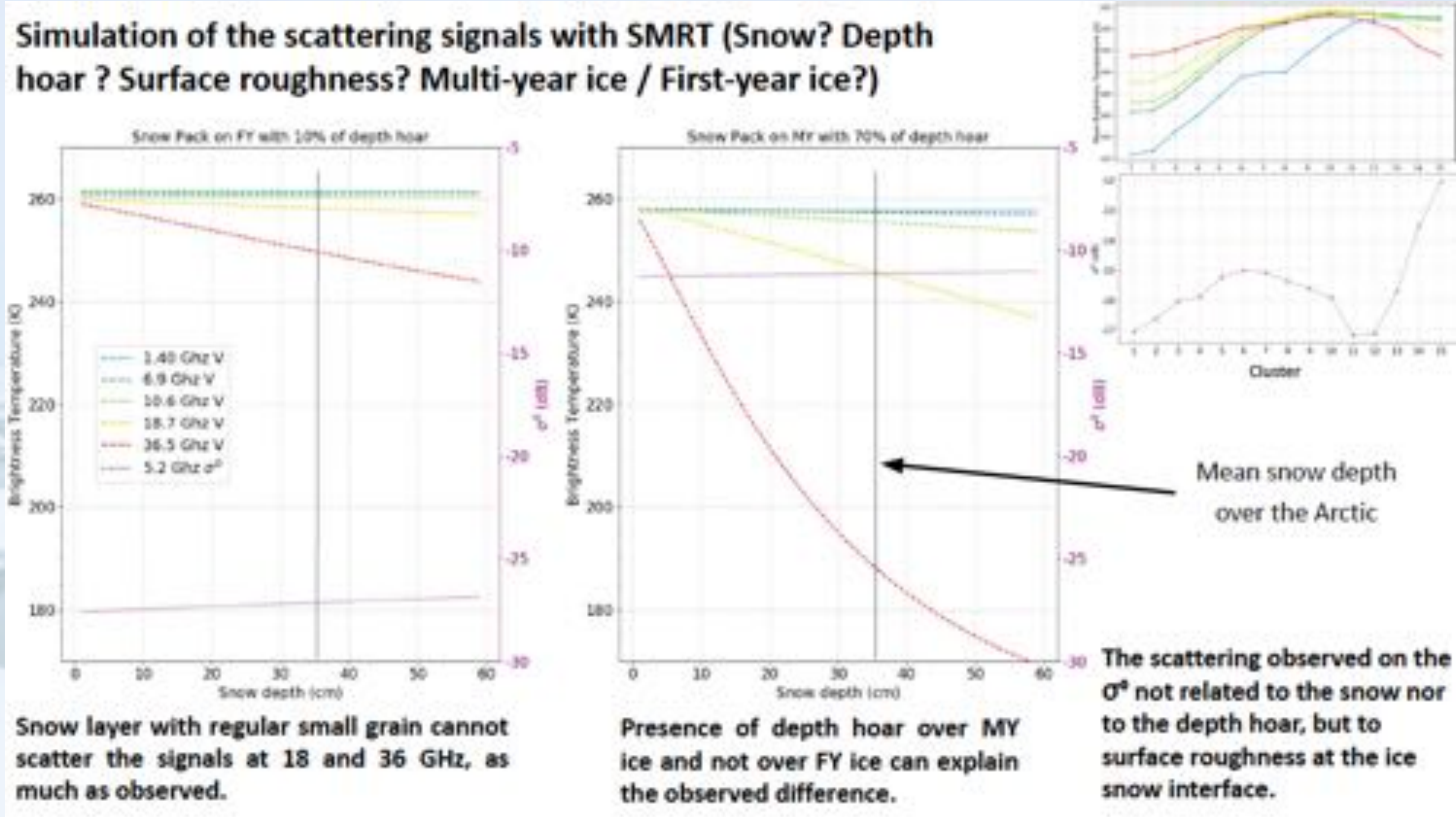
Satellite-derived microwave emissivity



Soriot et al., IGARSS, 2021

Can we reproduce it with radiative transfer modeling to better understand the key parameters that drive these variabilities?

Satellite-derived microwave emissivity



Can we reproduce it with radiative transfer modeling to better understand the key parameters that drive these variabilities?

Soriot et al., IGARSS, 2021

Conclusion

- **Accurate quantification of snow, ice, sea ice microwave emissivity required, for sounders and imagers.**

- **It has to be consistent**:
  - For a large range of frequencies (1 to ~ 300 GHz?!)
  - For multiple angles and both orthogonal polarizations
  - At continental scale
  - Over the full annual cycle

- **Radiative transfer models still very challenging** for large scale applications, under multiple instrument conditions and diverse environements.

- **Satellite-derived emissivity** estimates and associated parameterization can provide reasonable first guess estimates with **realistic multi-frequency co-variabilities, spatial patterns and temporal behaviors**. Error covariances can be calculated.

- **Interest of radiative transfer models to understand the general behavior and help the selection of the key parameters for emissivity parameterization**. These radiative transfer models have to be flexible enough to cover a large frequency range, dual polarization, and angle dependence.

Conclusion

Physics-aware statistical parameterization of the snow, ice, sea ice emission / scattering?

1) Estimation of the satellite-derived emissivities from multiple satellites (large range of frequencies and incidence angle, dual polarizations). For NWP applications, use of the NWP framework of interest for the multiple satellite emissivity estimations, for a better consistency.

2) Understanding the key geophysical parameters that drive the emissivity variabilities and co-variabilities (consistently at multiple frequencies and observing conditions), with the help of the physics (possibly with radiative transfer modeling) and of statistical analyses.

3) Based on this physical understanding of the variability, parameterization of the emissivities as a function of observing conditions (frequency, incidence angle, polarization) and geophysical information (location, time of the year, ice and snow properties), using statistical methods.