Evaluation of surface emissivity estimates up to 325 GHz with the ISMAR airborne instrument

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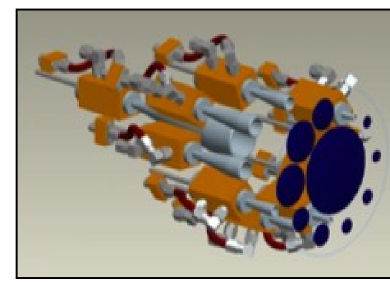
ISMAR and MARSS channel information

Instrument	Channels	Freq. Off.	BW	NetΔT	Polar.	FOV	Spectral
(GHz)	(GHz)	(GHz)	(K)				feature
MARSS (MWI)	89	±1.0	0.65	0.42	Mixed	12.0	Window
5*ISMAR (MWI)	5*118.75	±1.1	0.4	0.5	5*V	5*<3.8	5*O_2
		±1.5	0.4	0.5			
		±2.1	0.8	0.5			
		±3.0	1.0	0.5			
		±5.0	2.0	0.5			
MARSS (MWI)	157.0	±2.6	2.6	0.69	H	11.0	Window
3*MARSS (ICI)	3*183.31	±1.0	0.45	0.64	3*H	3*6.2	3*H_2O
		±3.0	1.0	0.44			
		±7.0	2.0	0.35			
ISMAR (ICI)	243.2	±2.5	3.0	0.5	V + H	<3.6	Window
3*ISMAR (ICI)	3*325.15	±1.5	1.6	1.0	3*V	3*<3.6	3*H_2O
		±3.5	2.4	1.0			
		±9.5	3.0	1.0			
3*ISMAR (ICI)	3*448.0	±1.4	1.2	1.2	3*V	3*<3.6	3*H_2O
		±3.0	2.0	1.2			
		±7.2	3.0	1.9			
ISMAR (ICI)	664.0	±4.2	3.0	1.5	V + H	<3.8	Window

ISMAR (The International Sub-Millimeter Airborne Radiometer)

- A demonstrator of ICI partially supported by ESA and UKMO
- Along track, -10° to +55°, downward and upward
- 118 (V), 243 (H+V), 325 (V), 448 (V), 664 (V+H)



MARSS (Microwave Airborne Radiometer Scanning System)

- A demonstrator of AMSU-B, already flew in several campaigns
- Along track, -40° to +40°, downward and upward
- 89 (Mixed), 157 (H), 183 (H)

ISMAR campaigns

Campaign	Location	Date
STICCS-2 (Sub-millimeter Trial in Cirrus and Clear Skies)	Out of Prestwick, Scotland	26/11/2014-15/12/2014
COSMICS (Cold-air Outbreak and Sub-Millimeter Ice could Study)	Out of Prestwick, Scotland	04/03/2015-25/03/2015

ISMAR flights

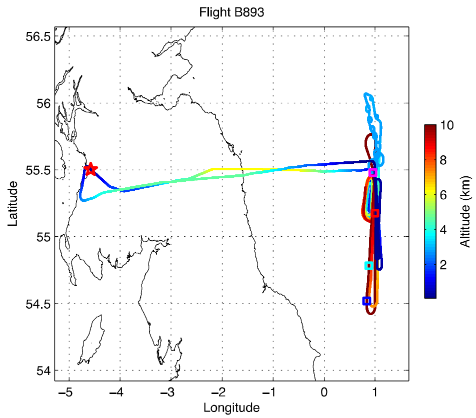
- All flights have been analyzed and simulated by radiative transfer code
- Systematic comparisons between the observed downwelling radiation and the simulations (similar results as the group in Chalmers)
- Calculation of the emissivities
- Concentrate on 4 flights, with limited

Flight	Date	Location	Comments
STICCS	2014		
B875	28/11 (5h)	North-west of Scotland (sea)	Clear sky condition. Several low-level runs for emissivity retrieval.
B878	02/12 (5h)	East coast of Scotland (sea) and east of England (land)	One part under clear sky over the sea off the east coast of Scotland at different altitudes, the other part, thin cirrus conditions over land on the eastern of England.
B879	03/12 (3h)	West of Prestwick (sea)	Stratocumulus cloud conditions with clear air above and above clouds.
B884	14/12 (5h)	North-east of Edinburgh (sea)	Cloud conditions (cirrus, cumulus, and stratocumulus). First part for wind probe calibration maneuvers, and the second part for cirrus cloud study.
COSMICS 2015			
B889	05/03 (2.6h)	Northwest of Prestwick (sea)	ISMAR measurements aborted during this flight because of problem.
B891	08/03 (1.7h)	East of Edinburgh (sea)	Test of ISMAR and analysis of the cirrus clouds. ISMAR operated normally on the ground and initially in flight, failure during climb at around FL160.
B892	09/03 (2.7h)	West coast of Scotland (sea)	ISMAR test in clear air above stratocumulus clouds.
B893	10/03 (5.3h)	East coast of Scotland (sea)	Low-level runs under clear sky conditions for surface emissivity study.
B894	11/03 (4.6h)	Northeast of Aberdeen (sea)	Intent to measure cirrus off north-east Scotland. Aborted due to aircraft science power failure.
B895	13/03 (3.7h)	North of Scotland (sea)	Cirrus study.
B896	17/03 (5.1h)	Over Greenland	Measurement over Greenland, with some clouds observed during the flight.
B897	18/03 (3.5h)	East coast of Iceland	Flight over a precipitating frontal system. Three transects across the system. Cloud varied from thin and broken cirrus clouds to full-depth precipitating clouds. Measurements mostly above the cloud tops.
B898	19/03 (4.5h)	Over Greenland	Clear sky condition mainly, with some occasional cirrus. Some low level observations over the ice cap.
B900	21/03 (2h)	Along west Scottish coastline	Measurement of cirrus from Prestwick to Iceland. Aircraft science power failed at the beginning of the science section, and redirection toward Keflavik. Observations over land along west Scottish coastline.
B901	22/03 (2.5h)	West of Reykjavik	Not designed for ISMAR. Measurements above and below supercooled liquid stratocumulus cloud.

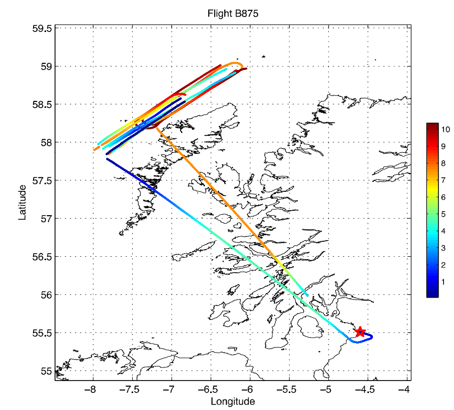
ISMAR campaigns

Flight B893 and Flight B875 **for ocean emissivity**

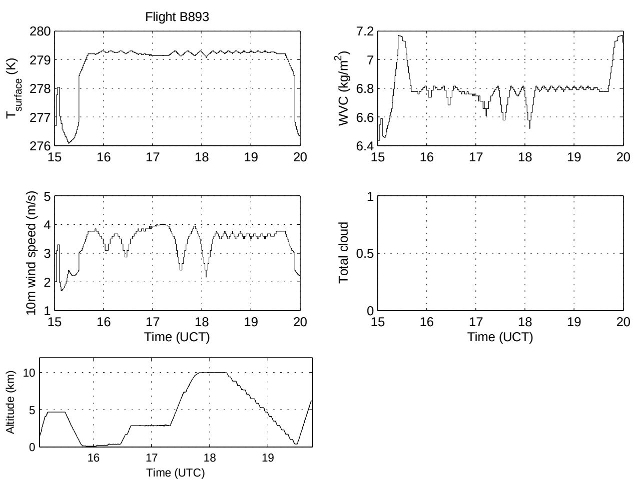
Flight off the east coast of Scotland
A number of low-level runs at 100, 500, 1000 ft for surface studies.

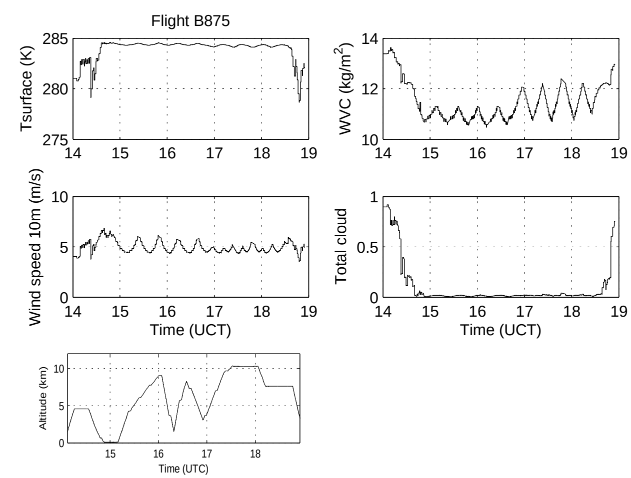


Flight off the northwest coast of Scotland
A number of low-level runs at 100 ft for surface studies.



Atmospheric variables





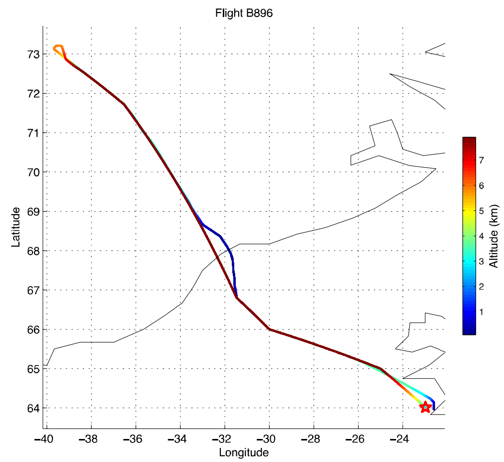
- Clear sky condition
- Wind speed is around 4 m/s
- Surface temperature is about 280 K
- Integrated water vapor content is less than 7 kg/m^2

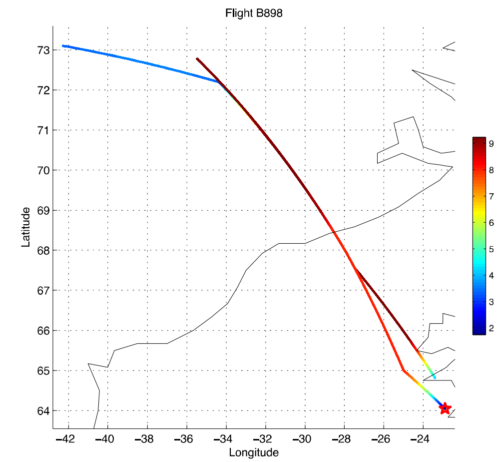
- Clear sky condition
- Wind speed is around 5 m/s
- Surface temperature is about 285 K
- Integrated water vapor content is less than 12 kg/m^2

ISMAR campaigns

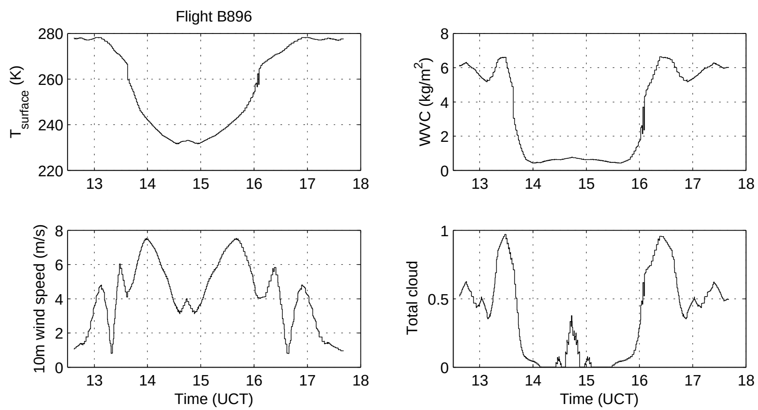
Flight B896 and B898 **for sea-ice and the continental ice emissivities**

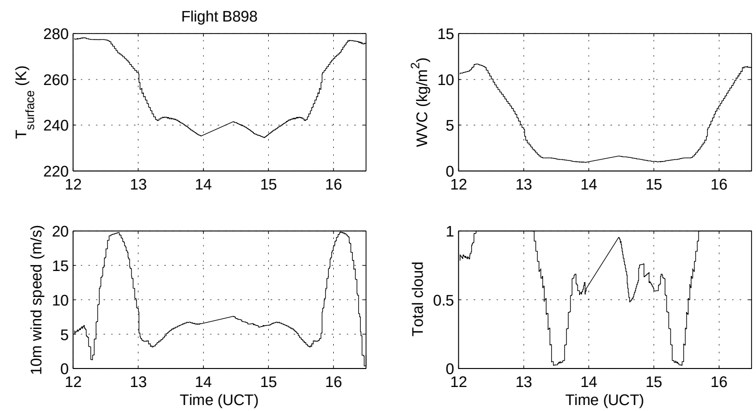
The flight track



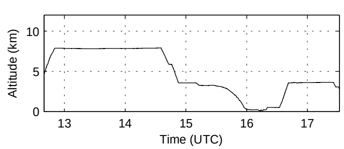


Atmospheric variables

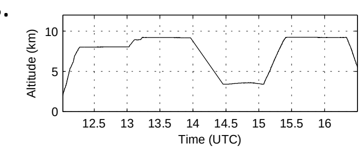




The aircraft altitude



- Main observations over Greenland.
- Low-altitude run from summit down to coast for surface studies.
- Surface temperature is about 240 K.
- Water vapor content is less than 1 kg/m^2.



Evaluation of the ISMAR and MARSS observations

- Atmospheric Radiative Transfer Simulator (***ARTS***) (Eriksson et al., 2011)
- Atmospheric profiles (i.e., pressure, temperature, water vapor profile): ***ERA-Interim*** ECMWF (0.125° on 60 model levels)
- The gas ***Rosenkranz*** absorption models are used for water vapor, oxygen, and nitrogen. The ozone absorption has been also considered.
- Note that the liquid water absorption, and the particle scattering are not considered in our simulations.
- The pitch, roll, and orientation angles of the aircraft are taken into consideration.

Evaluation of the ISMAR and MARSS observations

Flight B893
Up looking (zenith)

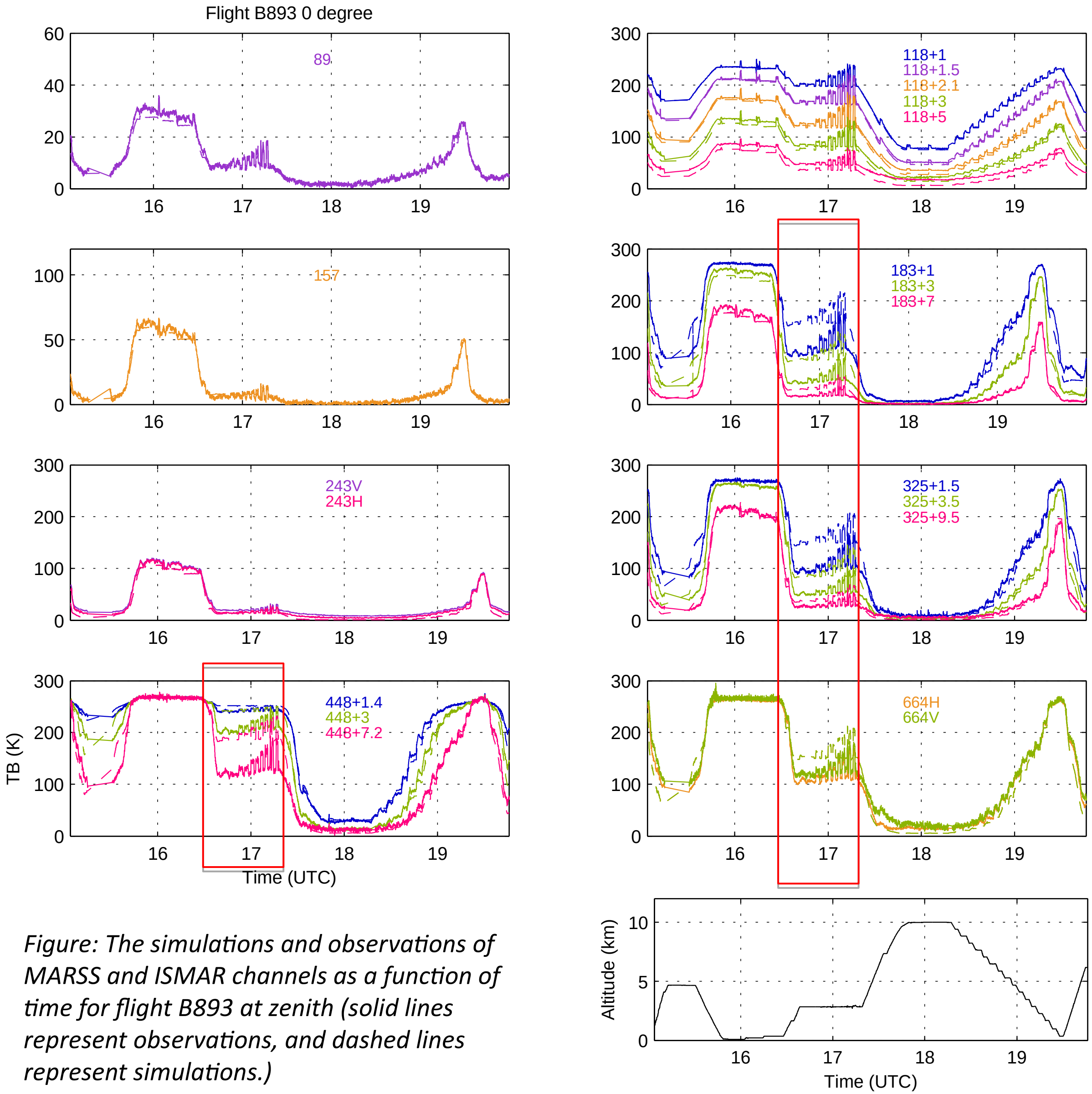
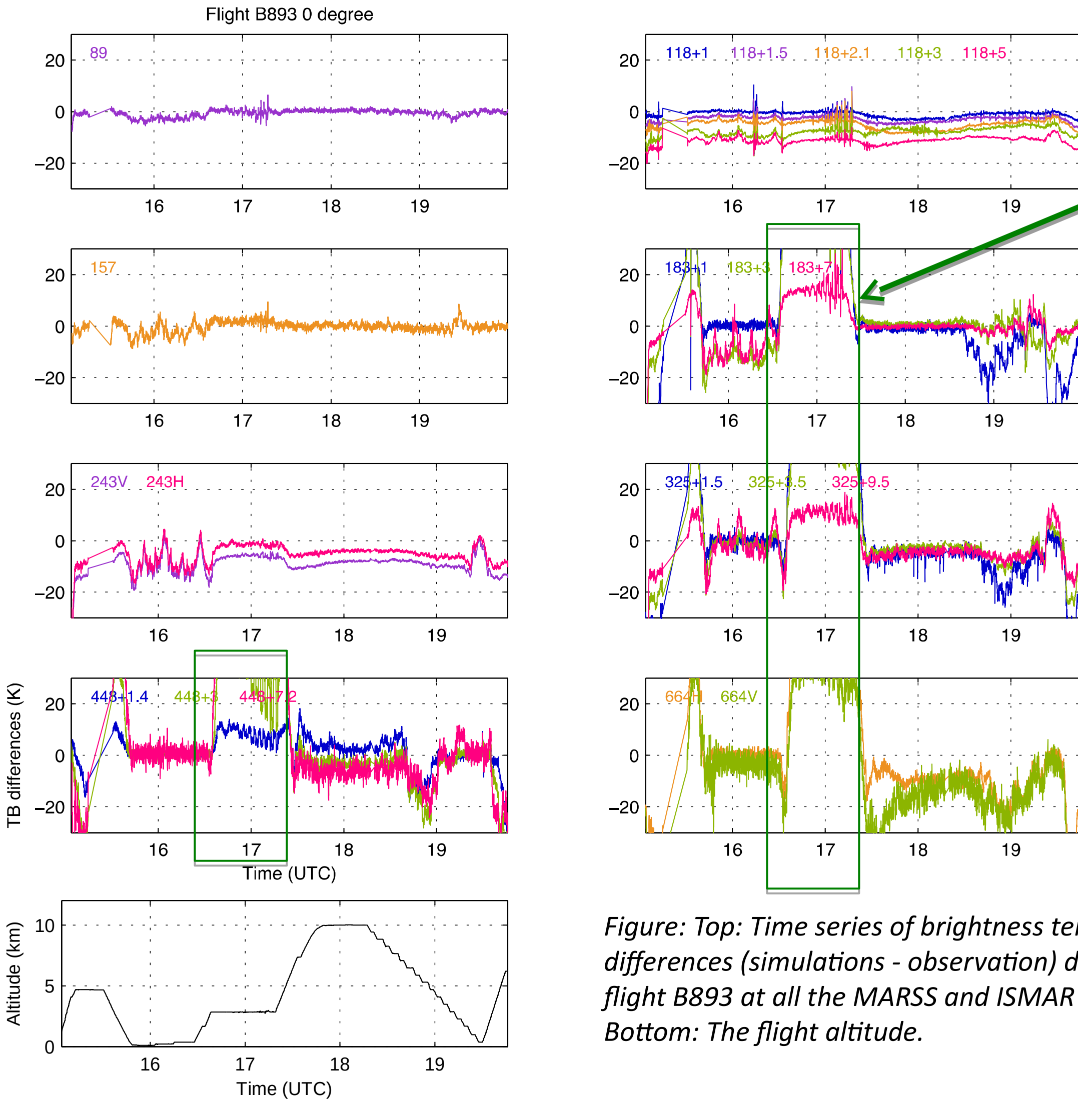


Figure: The simulations and observations of MARSS and ISMAR channels as a function of time for flight B893 at zenith (solid lines represent observations, and dashed lines represent simulations.)

Evaluation of the ISMAR and MARSS observations

***Flight B893** TB (simulations-observations)*

The flight runs and orbits at angles between 20° and 60° at 9000 ft



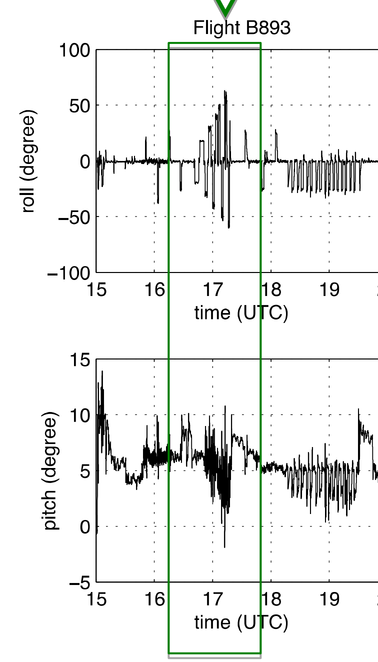


Figure: Top: Time series of brightness temperature differences (simulations - observation) during the flight B893 at all the MARSS and ISMAR channels. Bottom: The flight altitude.

Evaluation of the ISMAR and MARSS observations

Possible reason: the accuracy of the ERA-Interim atmospheric profiles (with coarse spatial and temporal resolutions)

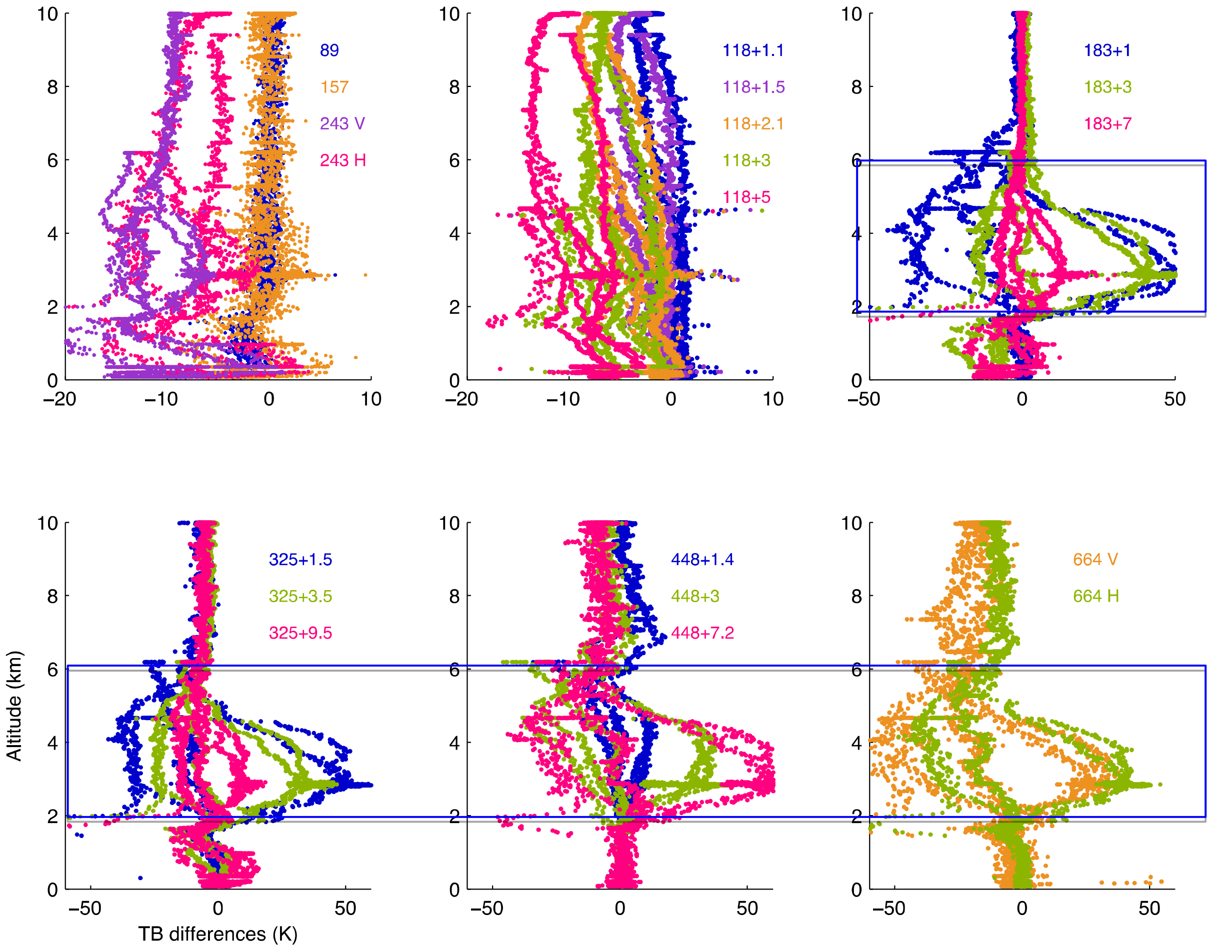
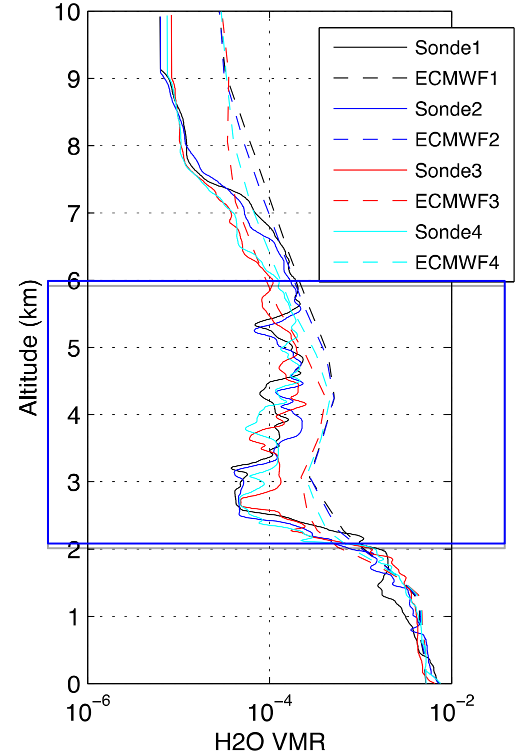


Figure: Brightness temperature differences (simulations - observations) against the aircraft altitudes during the flight B893 at all the MARSS and ISMAR channels.



ERA-Interim profiles reproduce more water vapor (between 2 and 6 km) in comparison with the dropsonde profiles (2.6 times in average).

Principles for emissivity calculation

Radiative transfer equation (clear sky, specular reflection):

$$T_{bp} = T_s \times \varepsilon_p \times e^{-\tau(0,H)/\mu} + (1-\varepsilon_p)T_d \times e^{-\tau(0,H)/\mu} + T_u \qquad (1)$$

The surface emissivity:

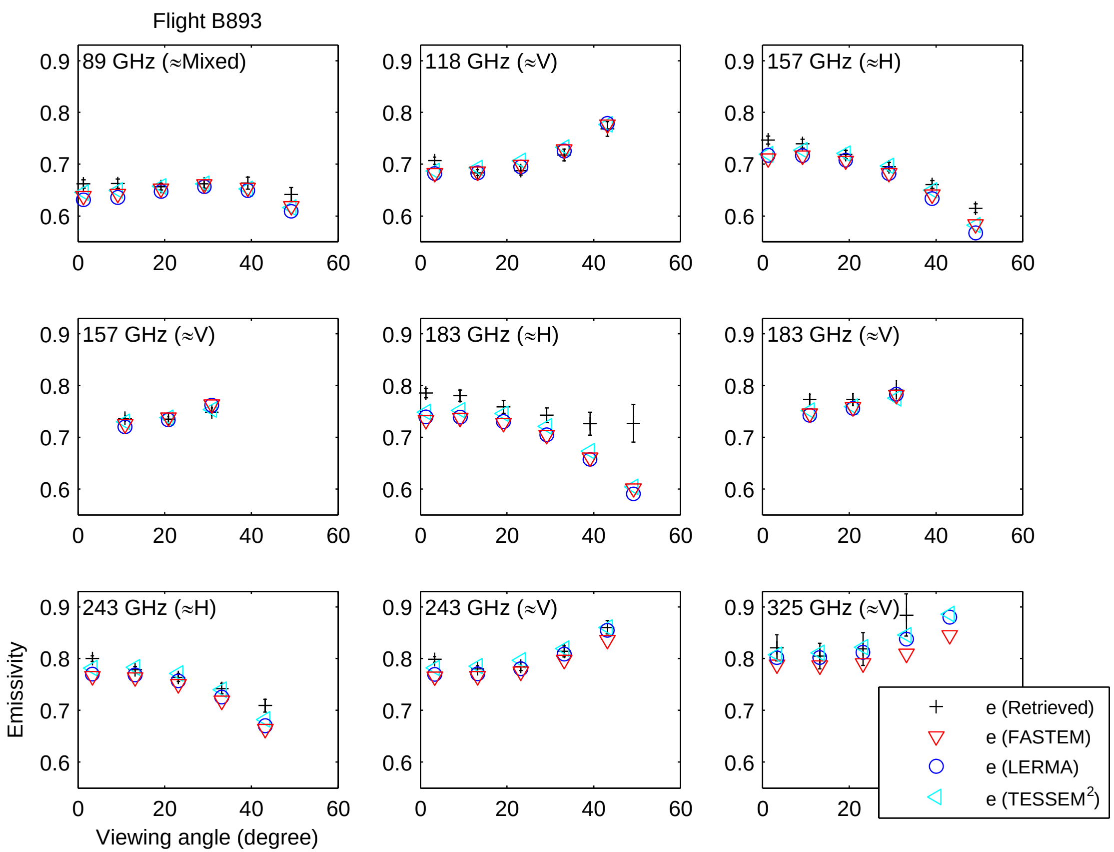
$$\varepsilon_p = \frac{T_{bp} - T_u - T_d \times e^{-\tau(0,H)/\mu}}{e^{-\tau(0,H)/\mu} \times (T_s - T_d)} \qquad (2)$$

T_{bp} is the observed brightness temperature by the ISMAR or MARSS for polarization p;
T_d is derived from the up-looking aircraft observations (down to the aircraft altitude);
T_u is the simulated upwelling brightness temperature below the aircraft;
T_s is the surface skin temperature from ERA-Interim database;

The ocean emissivity

Angular dependence

Flight B893 100 ft



- **The three sea surface emissivity models provide very similar results, with TESSEM² closer to our physical model above 200 GHz.**
- **The simulations and aircraft estimations agree rather well for the more transparent channels**
- **At 183 and 325.15±9.5 GHz, the aircraft estimates are poor, due to the strong opacity of these channels.**
- **Close to nadir, the emissivity is overestimated at lower frequencies. This is likely related to the aircraft shadow effect.**

The ocean emissivity

Aircraft shadow effect

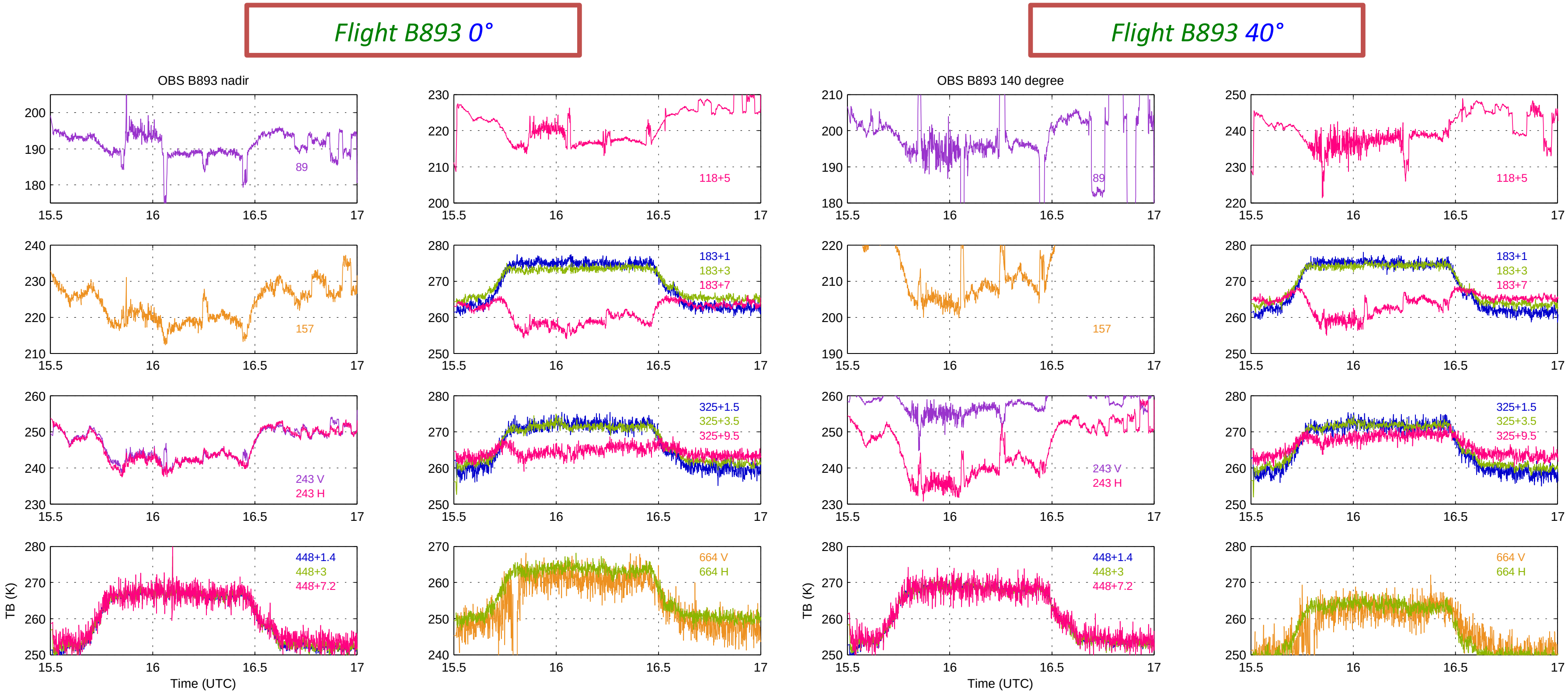
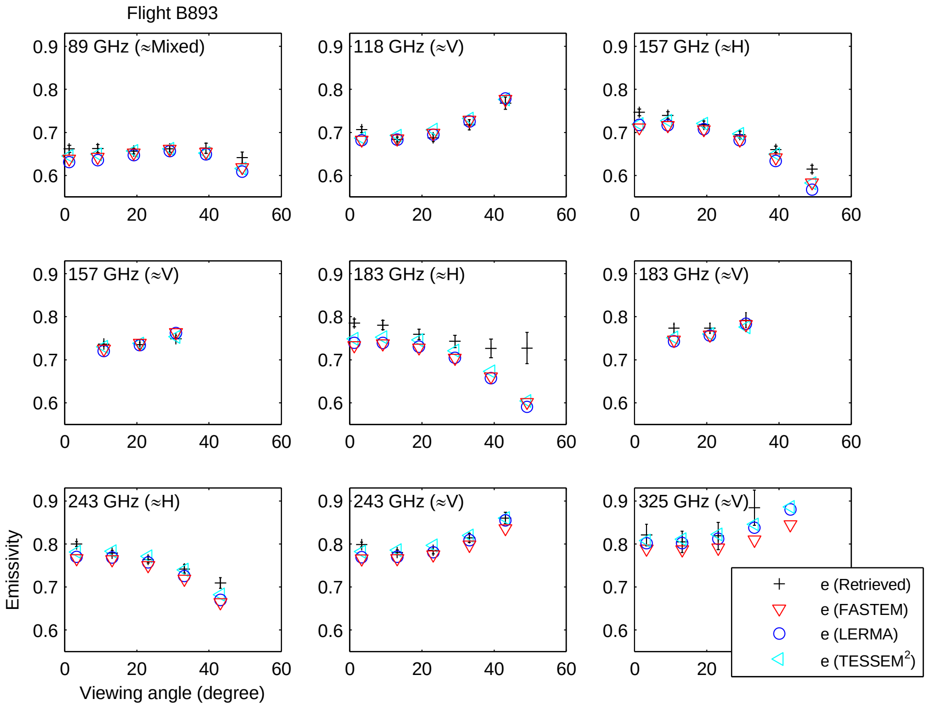


Figure: Zoom on ISMAR and MARSS observations for the low level runs during flight B893.

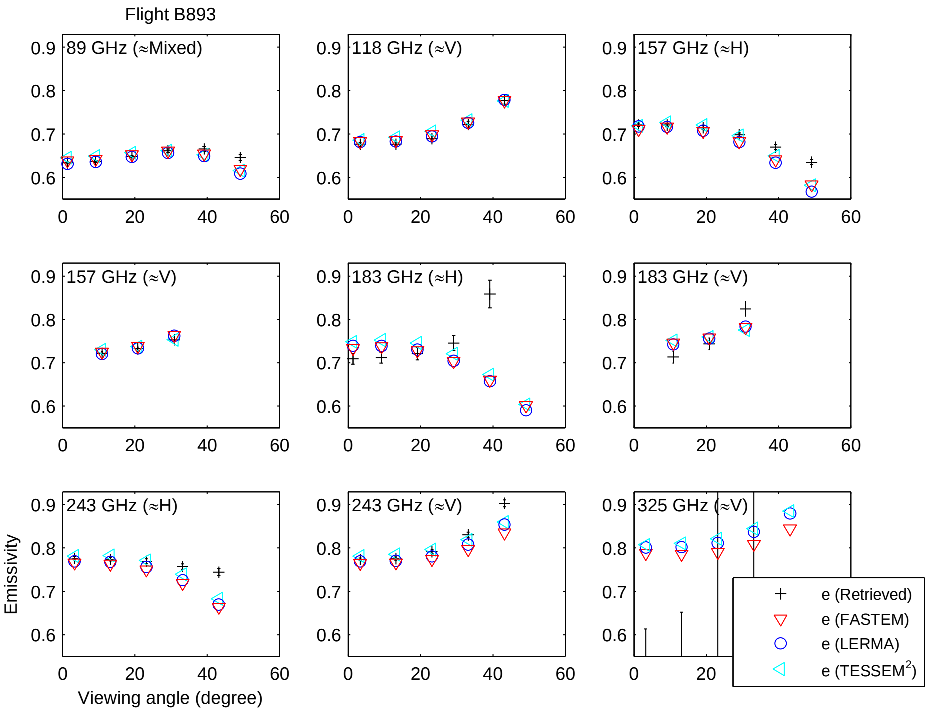
The reflection of the aircraft at the surface warms the Tbs at window channels close to nadir.

The ocean emissivity

Flight B893 100 ft



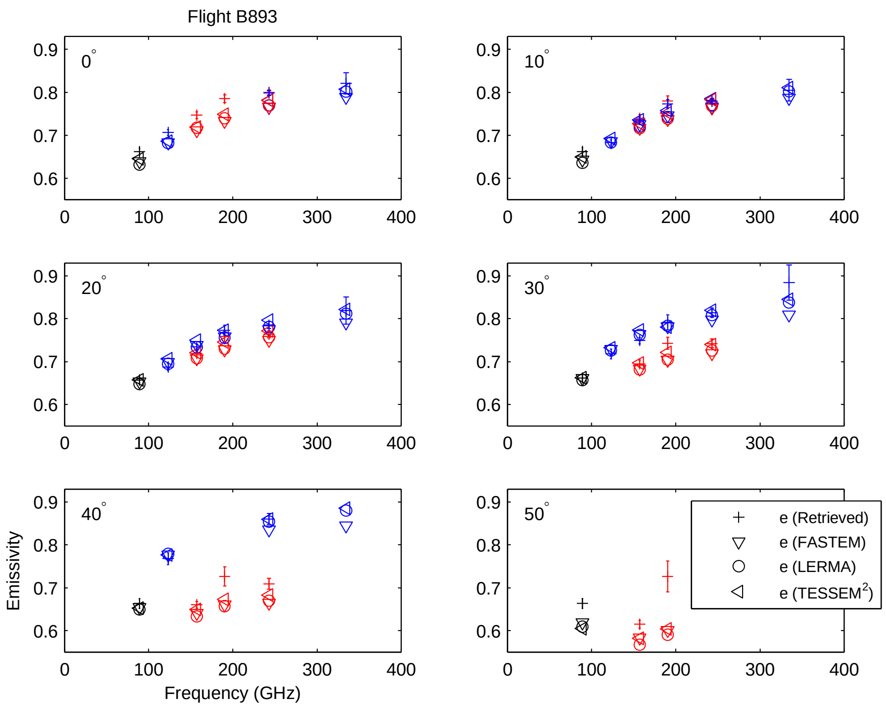
Flight B893 500 ft



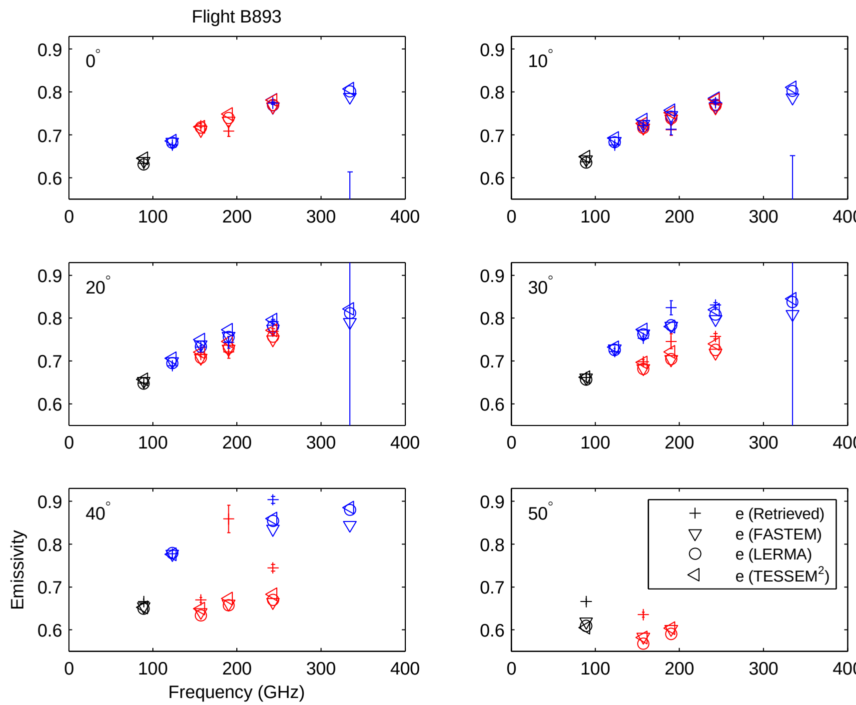
The ocean emissivity

Frequency dependence of the emissivity

Flight B893 100 ft



Flight B893 500 ft



- **At 89, 157, and 243 GHz window channels, the agreement between the retrieved and simulated emissivities is much higher than at sounding channels.**
- **At 183 and 325.15±9.5 GHz, the estimates are poor, due to the strong opacity of these channels.**

The sea-ice and continental ice emissivities

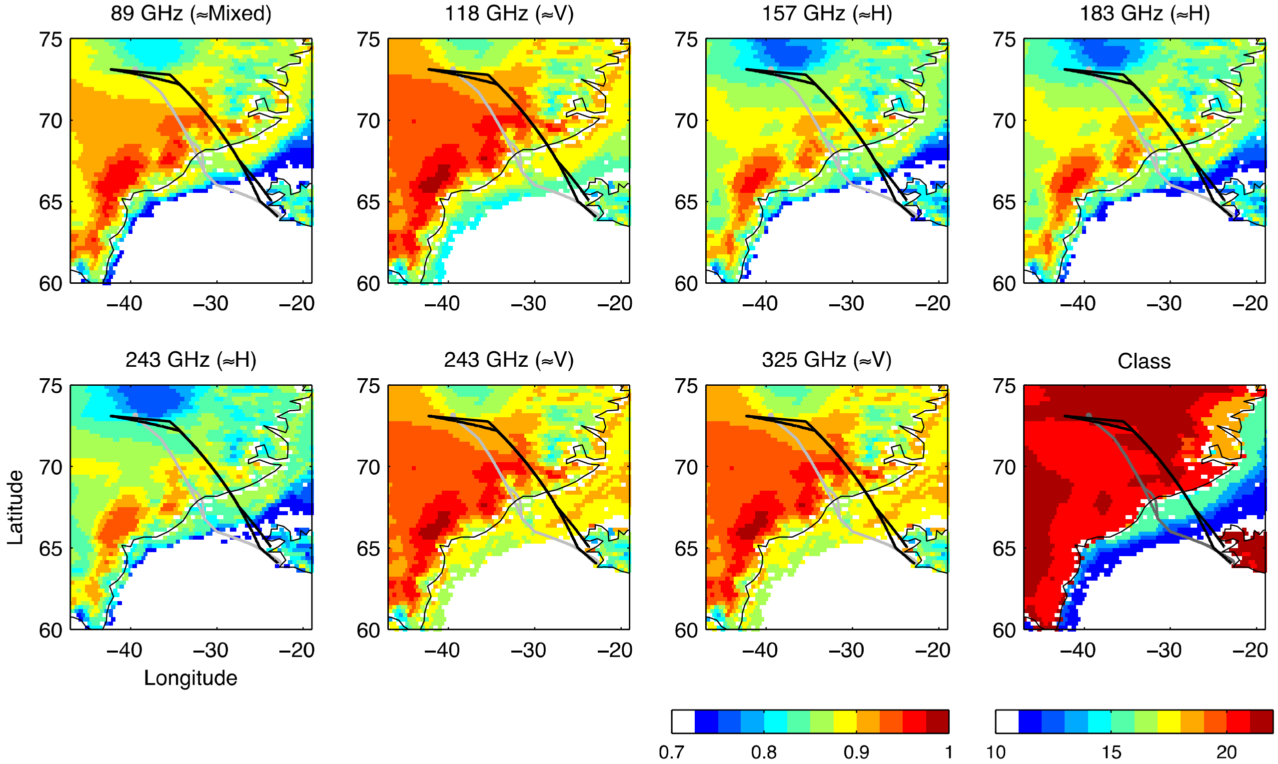


Figure: B896 and B898 flight patterns, superposed on the TELSEM² emissivities estimated at 40° for each ISMAR and MARSS frequencies up to 325 GHz, at 40° incidence angle.

The TELSEM² emissivity shows a significant spatial variability, especially close to the coast both over sea and continental ices

The sea-ice and continental ice emissivities

Flight B896

On the way to Greenland On the way back

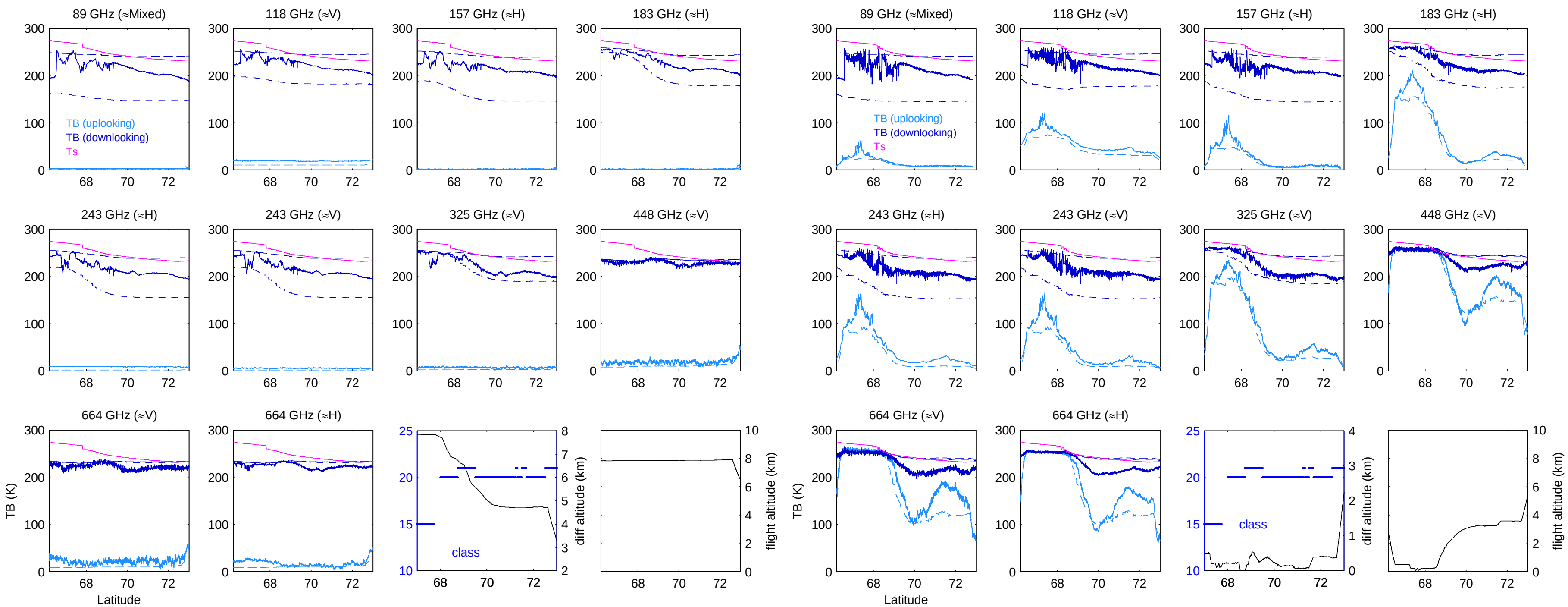


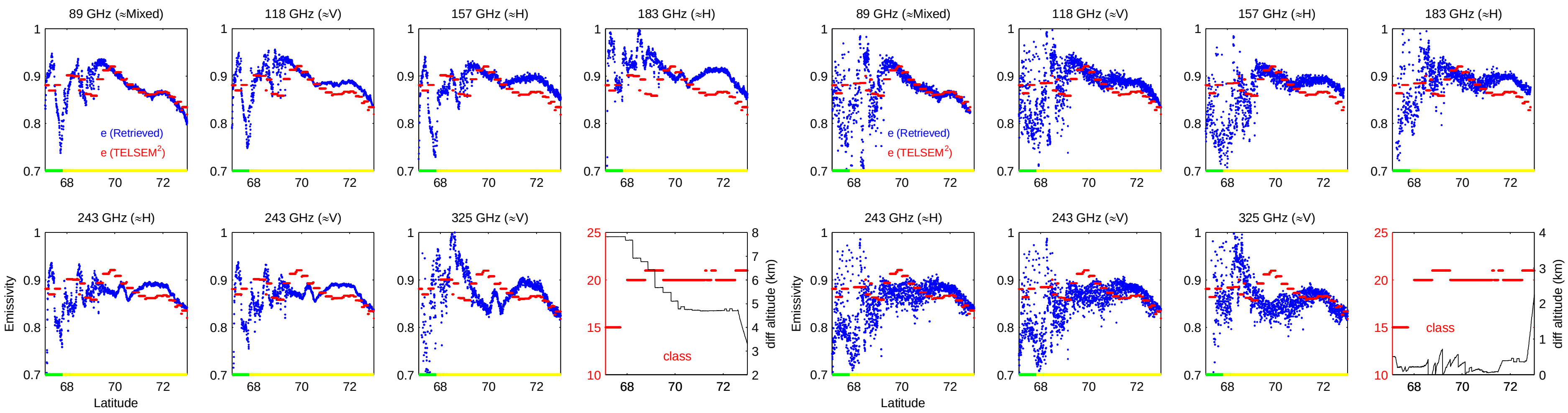
Figure: For flight B896, the uplooking and downlooking observed Tbs at 0◦ for most channels, as a function of the latitude, along with radiative transfer simulation. Corresponding radiative transfer simulations are also presented (dashed lines).

- **The significant discrepancies between 67°- 68°, at low frequencies, likely due to cloud presence.**
- **The discrepancies, between 71°-73°, at high frequencies, due to thin ice clouds that reflect rather warm radiation from the surface upward**
- **Southern of 69.5°, the flight was over the coastal regions with large spatial variability (sea ice, fjord, mountains)**
- **At 448 GHz and above, there is no sensitivity to the emissivity**

The sea-ice and continental ice emissivities

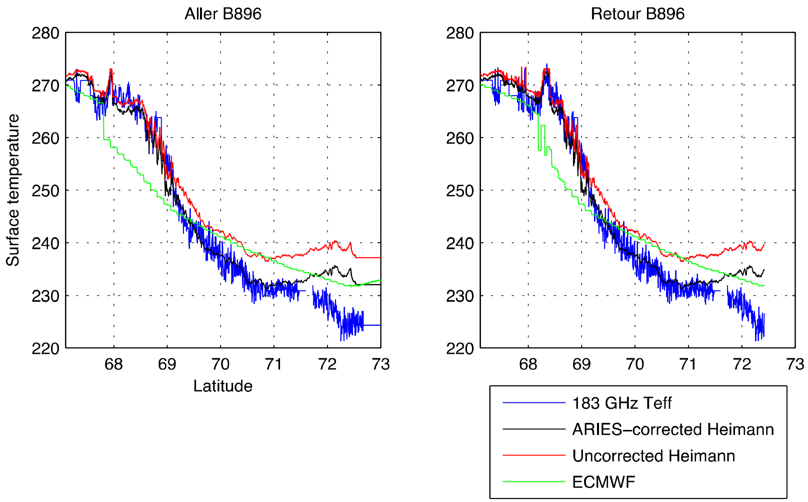
B896 0° scan angle

On the way to Greenland | On the way back



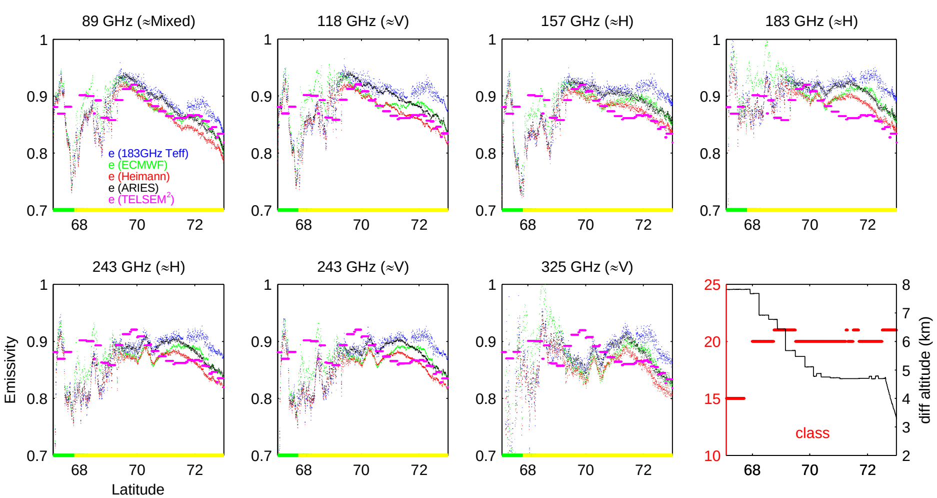
- **Over the continent ice, the agreement between the modeled and retrieved emissivity is very good at 89 GHz and very satisfactory at 118 and 157 GHz.**
- **At high frequencies, around 70°, the retrieved emissivities do not match with the simulations. It is likely due to an atmospheric problem.**
- **For the sea-ice emissivity, the aircraft retrieved emissivities show a very large variability.**

The sea-ice and continental ice emissivities

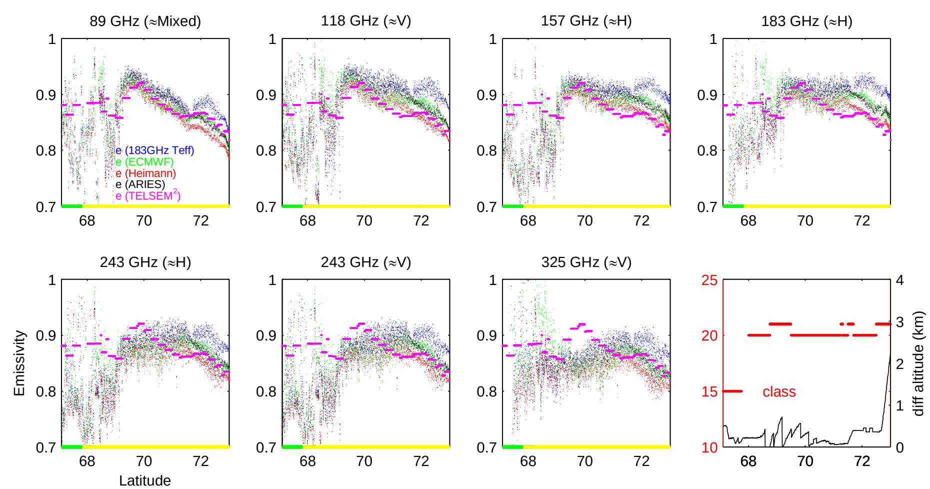


- A large Ts gradient between 68°N and 70°N, along with the large difference between the aircraft estimates and the ECMWF Ts.
- The Ts differences can be large between the Ts estimates, up to 10 K even between in situ estimates

On the way to Greenland



On the way back



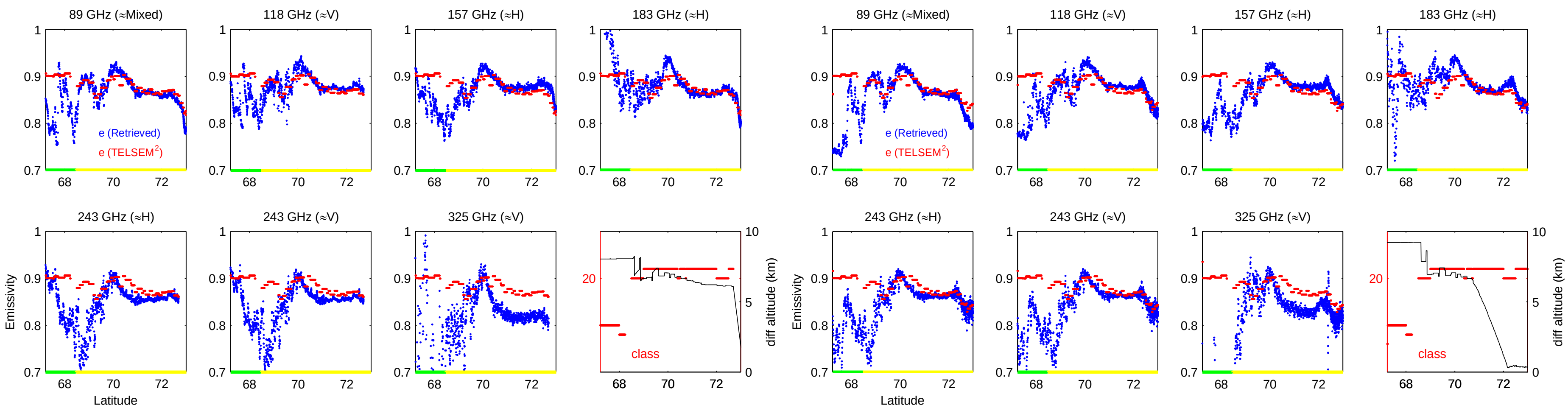
The changes in Ts estimates have a significant impact on the emissivity retrieval, as expected, but no Ts estimate does systematically improve the agreement with TELSEM².

The sea-ice and continental ice emissivities

Flight B898 0° scan angle

On the way to Greenland

On the way back



- **The agreement is very reasonable over continental ice.**
- **The increase of the emissivities around 70° simulated by TELSEM² is also observed by the aircraft retrieval.**

Conclusion

- The quality of the ISMAR and MARSS observations are within the requirements or close to it for most channels.
- Over the ocean, the agreement between the parameterized emissivity and the aircraft retrieved emissivity is very encouraging up to 325 GHz, for all angles and polarizations. At 118 and 325 GHz, the aircraft emissivity estimates are poor, due to the strong opacity of these channels.
- Above continental ice, the agreement is even exceptional at 89 and 157 GHz and is reasonable up to 243 GHz.
- Over sea-ice, the aircraft estimates are very variable spatially and temporally, and comparisons with the TELSEM^2 model were not conclusive.
- More flights under a larger variety of surface and atmospheric conditions will have to be performed.

Thank you for your attention!

About the polarisation:

- For MARSS, at 89 GHz:

$$e_m = \cos(\vartheta_s)^2 e_v + \sin(\vartheta_s)^2 e_h$$

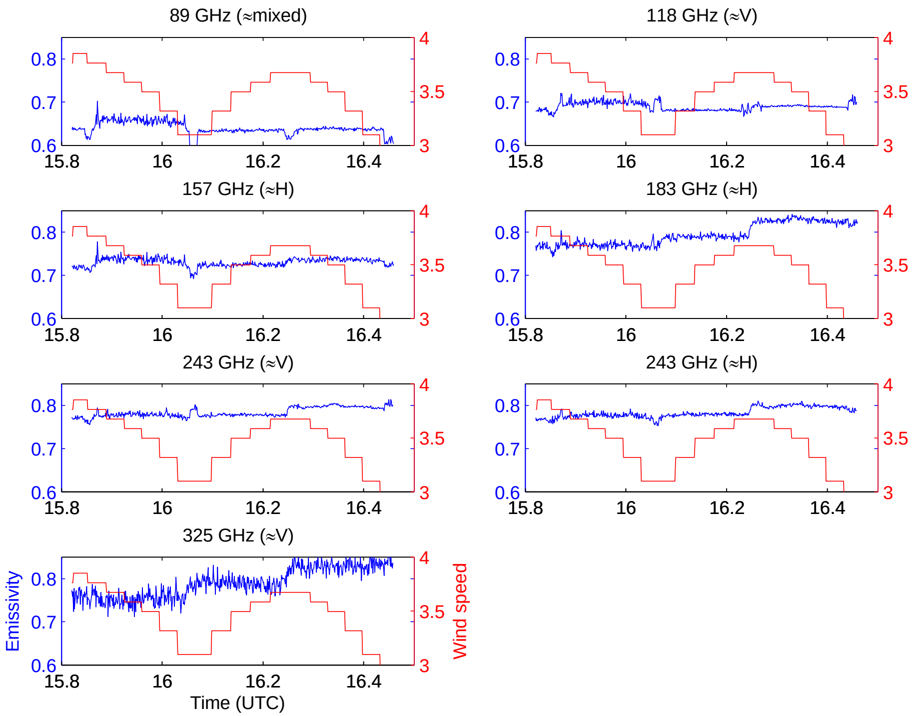
where e_v and e_h are the two orthogonal polarized surface emissivities at θ_s scan angle.

- For the rest channels of MARSS and ISMAR:

$$e_m = \cos(\vartheta_p)^2 e_h + \sin(\vartheta_p)^2 e_v$$

where θ_p is the polarization angle which is converted and calculated by the scan angle.

Flight B893 0°



Flight B893 40°