LERMA activities directly related to ISMAR

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- *Evaluation of the ISMAR observations with radiative transfer simulations (clear sky)*

- *Instrument noise evaluation*

- *Surface emissivity calculation*

Evaluation of the ISMAR observations with radiative transfer simulations (clear sky)

- All flights analyzed
- Concentrate on 3 flights, with clear sky and low flying altitudes

Flight # Campaign	*Date*	*Dur. (h)*	*Target*	*Surf.*	*Comments*
B875 STICCS	28/11/14	5	Clear-sky conditions	S / I	Mainly observations over sea, north-west of Scotland Transit mainly over sea, over some islands
B878 STICCS	02/12/14	5	Clear-sky conditions over the sea off the east coast of Scotland, followed by thin cirrus cloud over the eastern part of England	S / L	First part of the flight over sea, east of Edinburgh at different flight levels Second part over land but with cirrus Transit mainly over land In cloud conditions and above clouds at the end of the flight
B879 STICCS	03/12/14	3	Stratocumulus cloud over the sea with clear air above, although there were a few contrails in the operating area	S / I	Mainly flight over sea, west of Prestwick at different flight levels Few minutes over land during the transit after take off and before landing Flight in cloud conditions and above clouds
B884 STICCS	14/12/14	5	First part of the flight for wind probe calibration maneuvers, and the second part for cirrus cloud	S / L	Mainly flight over sea, north-east of Edinburgh Transit over land on both ways Flight in cloud conditions and above clouds
B889 COSMICS	05/03/15	2.6	ISMAR Test and Cirrus Evolution [aborted]	S / I	Mainly flight over sea, northwest of Prestwick. Very little observations over land Problem with ISMAR (flight aborted)
B891 COSMICS	08/03/15	1. 7	ISMAR Test and Cirrus Evolution [aborted]	S / L	Flight over the sea, east of Edinburgh. Transit over land (reliability of the ISMAR data to check for flight leg on way to the zone of interest). Problem with ISMAR (operated normally on the ground and initially in flight, failed during climb at around FL160).
B892 COSMICS	09/03/15	2.7	ISMAR test flight in clear air above stratocumulus clouds	S / I	Mainly flight over sea, northwest of Prestwick. Very little observations over land
B893 COSMICS	10/03/15	5.3	Clear-sky & ISMAR instrument performance characterization	S / L	Flight over the sea, east of Sunderland (along the 1°E meridian). Transit over land.
B894 COSMICS	11/03/15	4.6	Cirrus evolution with an A-train overpass [aborted because of aircraft science power failure]	S / L	Flight over the sea Northeast of Aberdeen. Transit over land
B895 COSMICS	13/03/15	3.7	Cirrus Evolution	S / L	Flight over sea, north of Scotland. Transit over land
B896 COSMICS	17/03/15	5.1	Clear sky over Greenland Summit overpass in conjunction with an overpass of NPP	S / L	Take-off from Reykjavik (Island). Main observations over Greenland. Transit over the water.
B897 COSMICS	18/03/15	3.5	Iceland Frontal Precip	S / I	North-south flight, west of Island over water. Transit over the water with little observations over land Aircraft mostly above the top of the clouds although it was sometimes just below cloud top. Along the transect, the cloud varied from thin, broken cirrus to full-depth precipitating cloud.
B898 COSMICS	19/03/15	*NK*	Greenland Summit Overpass in conjunction with an overpass of NPP	S / L	Take-off from Reykjavik (Island). Main observations over Greenland. Transit over the water. NASA ER-2 also made measurements in the same area just after the FAAM BAe-146 began its return transit
B900 COSMICS	21/03/15	*NK*	Cirrus Evolution [aborted]	S / I	Main flight over water. Observation over land along West Scottish coastline.
B901 COSMICS	22/03/15	*NK*	Supercooled liquid stratocumulus	S	Main flight over water west of Reykjavik (Island).
B902 COSMICS	24/03/15	*NK*	Transit between Reykjavik to Prestwick	S	ISMAR was operated during the transit.

- Atmospheric Radiative Transfer Simulator (***ARTS***) (Eriksson et al., 2011)

- Atmospheric profiles (i.e., pressure, temperature, water vapor profile): ***ERA-Interim*** ECMWF (0.125° on 37 pressure layers)

- The gas ***Rosenkranz*** absorption models are used for water vapor, oxygen, and nitrogen.

- Note that the ozone absorption, 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.

Flight B893

Up looking (zenith)

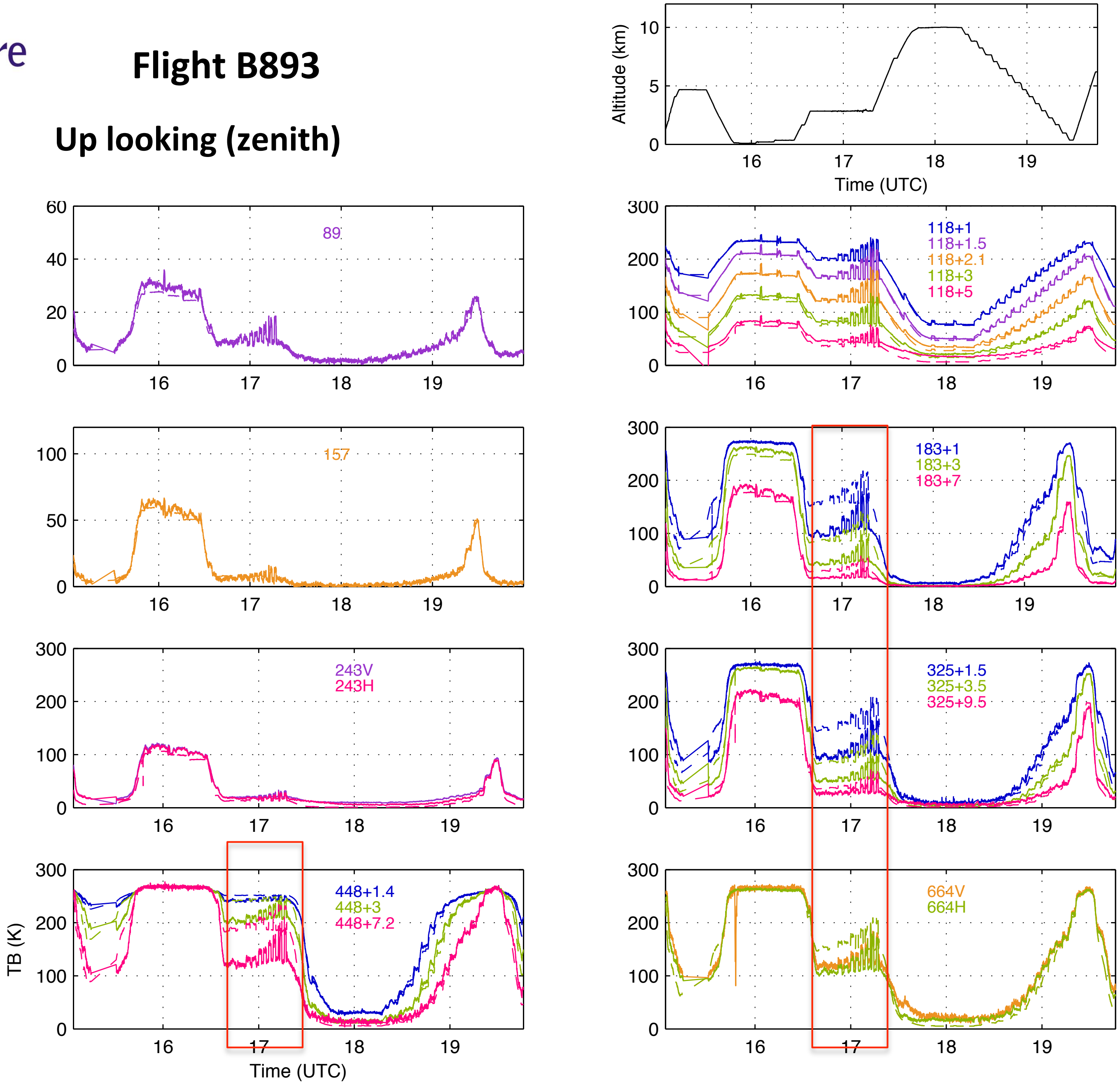


Figure: The simulations and observations of MARSS and ISMAR channels as a function of time for flight B893 at zenith (solid lines represent observations, and dashed lines represent simulations.)

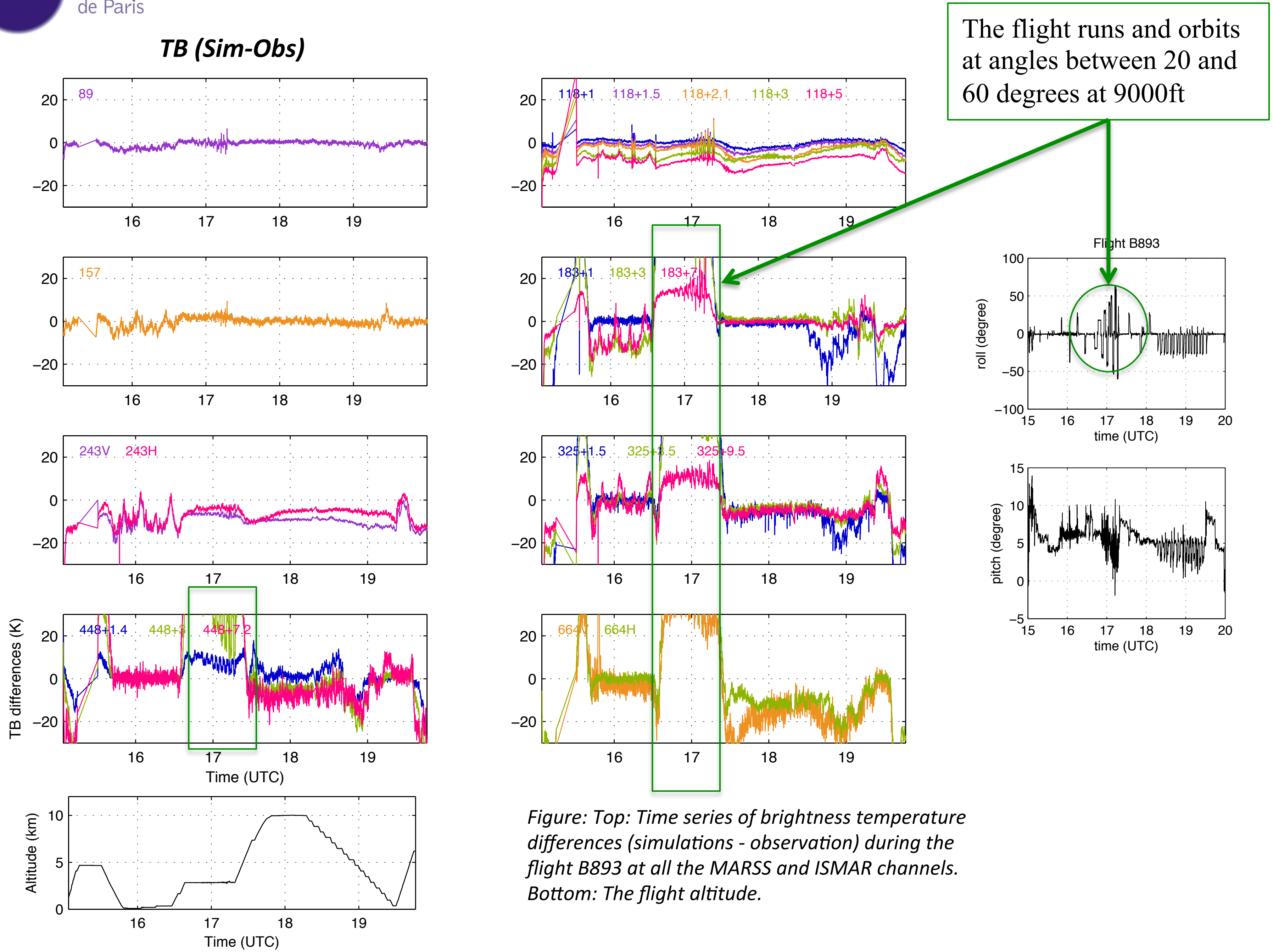


Figure: Top: Time series of brightness temperature differences (simulations - observation) during the flight B893 at all the MARSS and ISMAR channels. Bottom: The flight altitude.

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

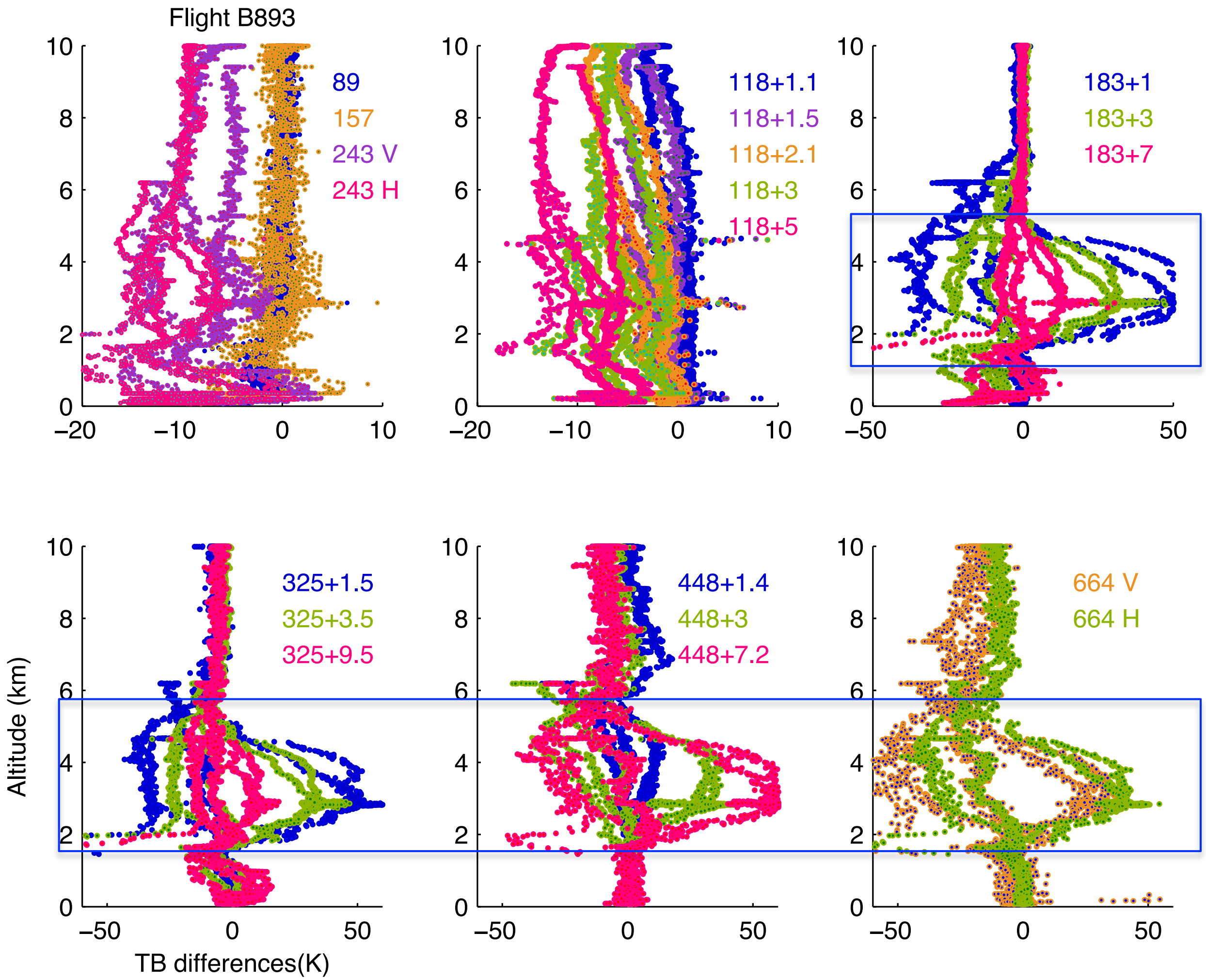


Figure: Brightness temperature differences (simulations - observations) against the aircraft altitudes during the flight B893 at all the MARSS and ISMAR channels.

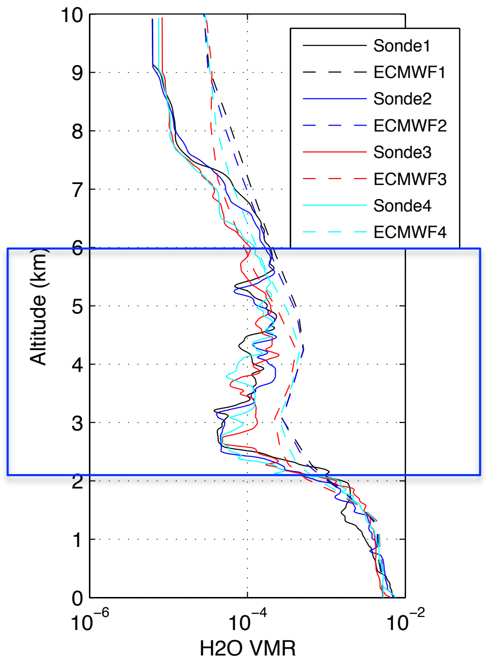


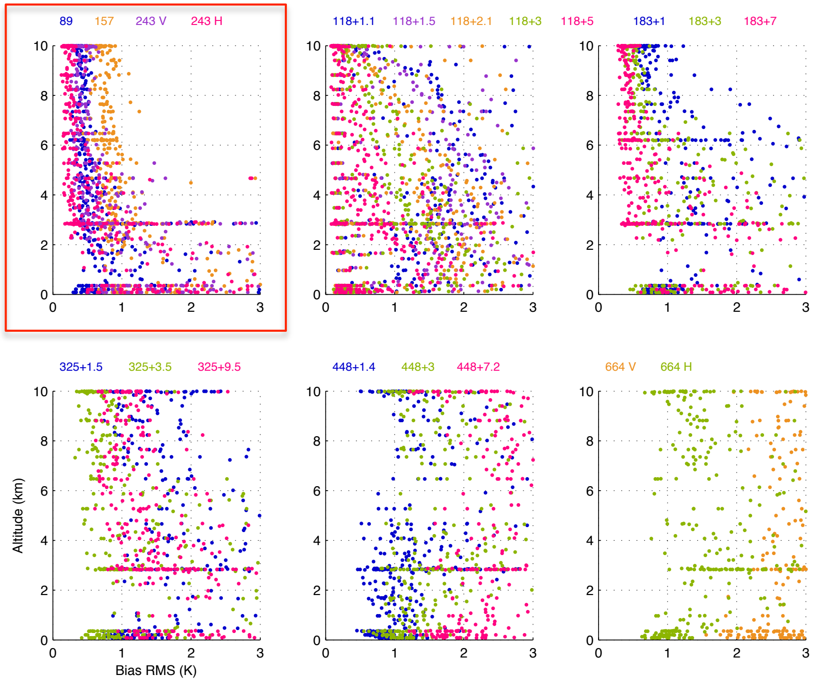
Figure: The water vapor volume mixing ratio profiles from the four radiosondes released at 17:54, 17:57, 18:06, and 18:09, respectively, and the ERA-Interim at 18:00 during the flight B893.

ERA-Interim profiles reproduce more water vapor (between 2000 and 6000 m) in comparison with the radiosonde profiles (2.6 times in average).

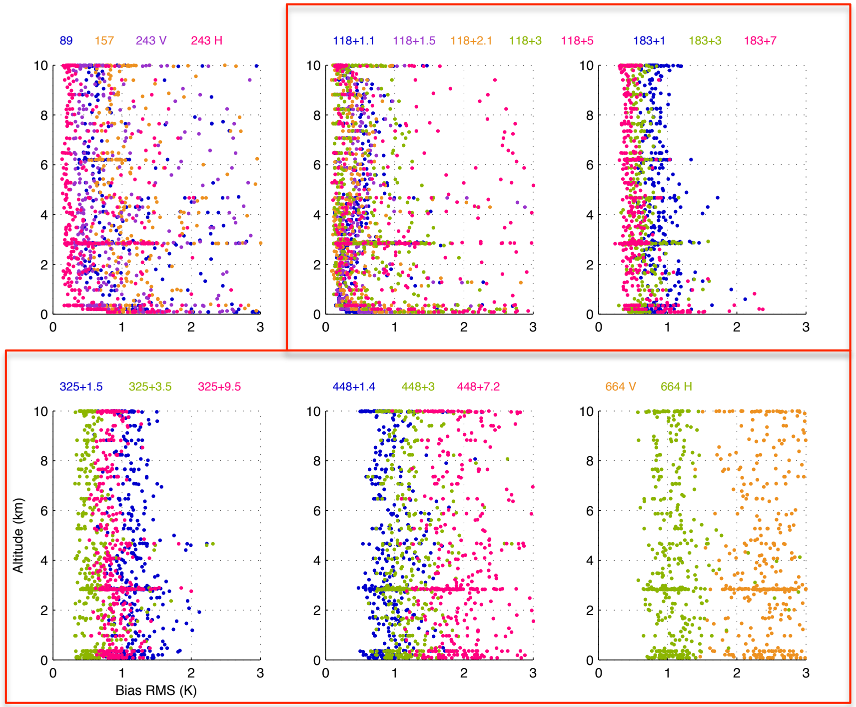
Instrument noise evaluation

The brightness temperature moving window std (K) are calculated for each 30 seconds.

Up looking (0°)



Down looking (130°)

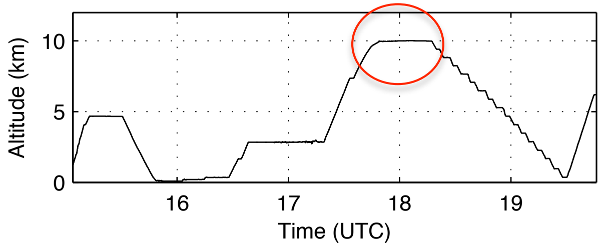


Due to different sensitivities to the water vapor and the surface, the channel noises are estimated using the up looking observations for window channels 89, 157, 243V, 243H GHz, and the down looking observations for the sounding channels 118, 183, 325, 448, 664 GHz.

Table: Summary of observed brightness temperature std (K) at MARSS and ISMAR channels for flight B893. Note that the std presented here are the median value of the std for the high level (10 km) running periods.

Frequency (GHz)	std (B893 up looking)	std (B893 downlooking)	Channel noise (K)
89	0.41	0.82	0.23
118.7503+/-1.1	0.31	0.23	0.5
118.7503+/-1.5	0.27	0.21	0.5
118.7503+/-2.1	0.21	0.16	0.5
118.7503+/-3.0	0.54	0.58	0.5
118.7503+/-5.0	0.17	0.24	0.5
157	0.66	0.97	0.72
183.248+/-0.75	0.66	0.84	0.62
183.248+/-2.5	0.51	0.55	0.42
183.248+/-6	0.41	0.44	0.33
243.2 V	0.37	0.58	0.5
243.2 H	0.23	0.27	0.5
325.15+/-1.5	1.35	0.97	1.0
325.15+/-3.5	0.60	0.52	1.0
325.15+/-9.5	0.94	0.85	1.0
448+/-1.4	1.06	0.82	1.2
448+/-3.0	1.26	1.14	1.2
448+/-7.2	2.30	1.89	1.9
664 V	3.24	2.62	1.5
664 H	1.09	0.84	1.5

We consider the median values of the std for the high level (10 km) running periods as representation of the 'noise' for each channel.



- The calculated std is in the range of the given channel noise.
- Similar results are obtained from other flights

Surface emissivity calculation from ISMAR measurements

Background on the estimation of microwave surface emissivities

Based on models over ocean:

Over the past decades, many surface emissivity models have been developed, including:

- **Full emissivity models** (Stogryn, 1967, Wilheit, 1979, Wentz, 1983, Prigent and Abba, 1990, Guissard et al., 1992) : accurate but expensive in computation for the operational requirement.
- **Fast models** : FASTEM (Fast Microwave Ocean Emissivity Model), a semi-empirical emissivity model. It improves calculation speed but is developed only for frequencies from 6 to 200 GHz.

Based on the observations over land:

- Land and ice surface emissivity at low frequencies have been well analyzed based on the observations from satellites and airborne and aircraft (e.g., Prigent et al., 1997, 2006, 2015; Karbou et al. 2005; Harlow et al. 2011).
- However, few emissivity studies are performed at frequencies higher than 157 GHz.

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Principles for emissivity calculation from ISMAR

Radiative transfer equation (clear sky, specular reflection):

$$T_{bp} = T_{surf} \times \varepsilon_p \times e^{-\frac{\tau(0,H)}{\mu}} + (1-\varepsilon_p)\int_0^H T(z)\alpha(z)e^{-\frac{\tau(0,z)}{\mu}}dz + \int_0^H T(z)\alpha(z)e^{-\frac{\tau(z,H)}{\mu}}dz$$

T_{bp} is the brightness temperature in polarization p;
T_{surf} is the surface skin temperature;
ε_p is the surface emissivity in polarization p;
τ is the atmospheric opacity;
μ is the cos(θ), where θ is the incidence angle;
H is the orbiter height;
$T(z)$ is the atmospheric temperature at altitude z;
$\alpha(z)$ is the atmospheric absorption coefficient at altitude z;

The surface emissivity:

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

$\mathbf{T_{bp}}$ observed upwelling brightness temperature below the aircraft for the given angle for polarization p; $\mathbf{T_u}$ measured upwelling atmospheric contribution below the aircraft (ignored for very low flying conditions); $\mathbf{T_d}$ measured downwelling atmospheric contribution by the radiometer above the aircraft in the opposite direction; $\mathbf{T_{surf}}$ sea surface temperature from ERA-interim.

Ice-free ocean emissivity

Flight B893

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

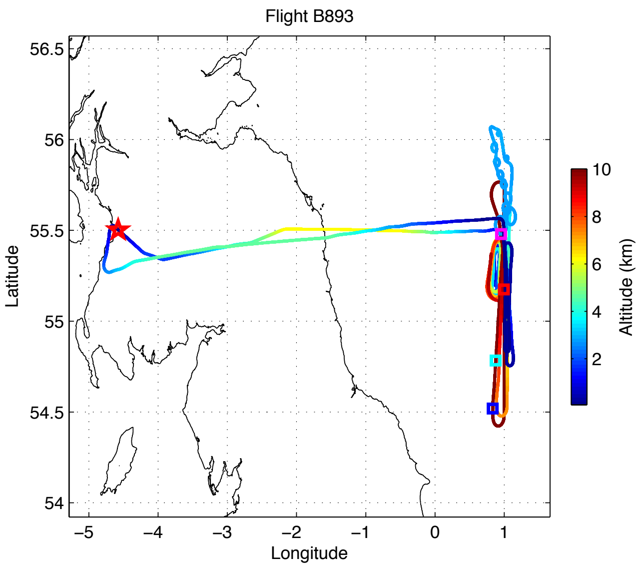


Figure: The flight track of B893 with the flight altitude in color. The red star is the place for taking off and the four squares in blue, light blue, read, and purple show the observed point of the first, second, third, and fourth radiosonde, respectively.

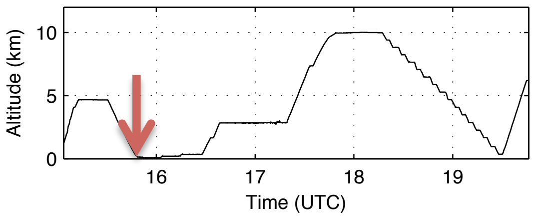


Figure: The aircraft altitude.

Atmospheric variables

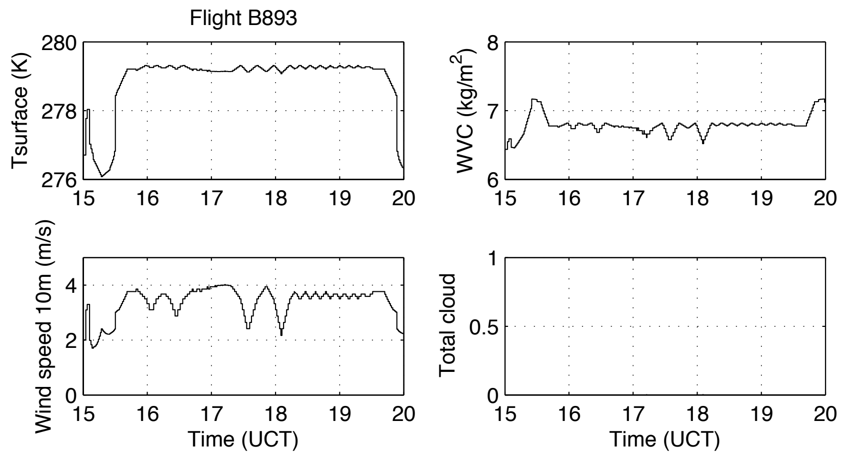
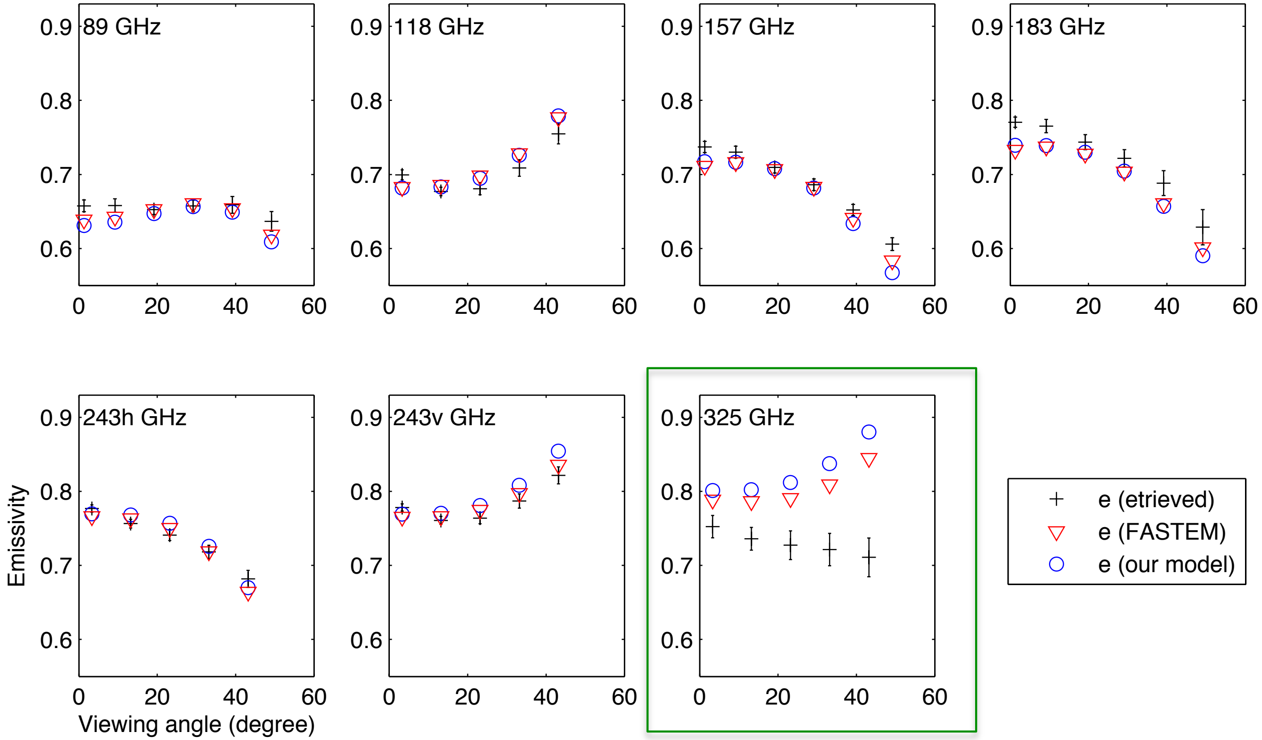


Figure: The surface skin temperature, integrated water vapor content, 10-m wind speed, and the fraction of total cloud against the observation times during flight B893 (from ERA-Interim database).

- Clear sky condition
- Wind speed is around 3 m/s
- Surface temperature is about 280 K
- Integrated water vapor content is less than 7 kg/m^2

Angular dependence of the emissivities



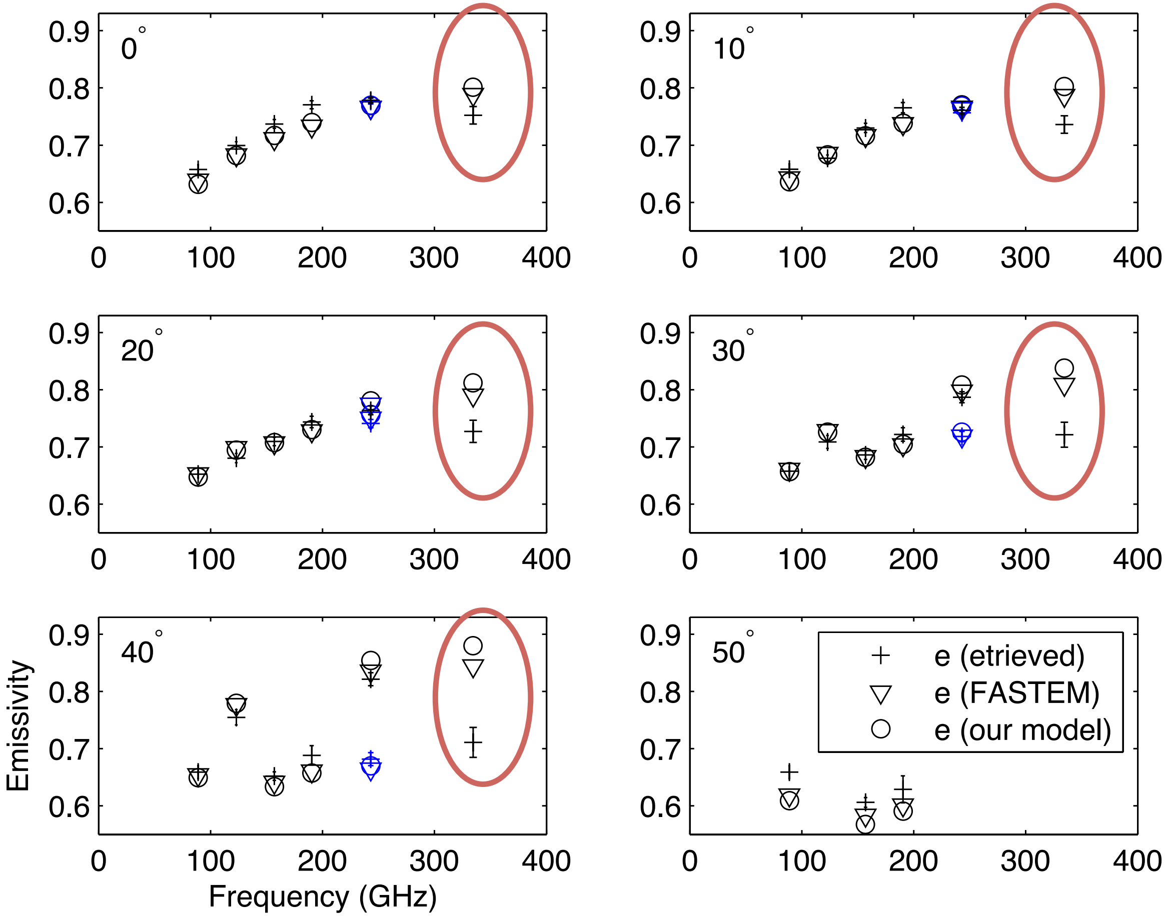
FASTEM (Fast Microwave Ocean Emissivity Model, English and Hewison, 1998), a semi-empirical emissivity model used broadly for surface-sensitive frequencies between 6 and 200 GHz.

The sea surface emissivity model of LERMA (Prigent and Abba, 1990), marine radiometric response at microwave, based on geometric-optics approach.

Figure: The angular dependence of the mean retrieved emissivities by using MARSS and ISMAR observations of flight B893 and simulated emissivities by FASTEM and the emissivity model of LERMA at 89, 118.7503+/-5, 157, 183.248+/-6, 243.2, and 325.15+/-9.5 GHz. The standard deviations are indicated for each mean retrieved emissivity (error bars).

- The retrieved surface emissivities correspond well to the simulated ones with FASTEM and the emissivity model of LERMA, up to 243 GHz
- The retrieved emissivities are noisier at larger incidence angles, especially in the water vapor sounding channels.

Frequency dependence of the emissivities



- At 89, 157, and 243 GHz window channels, the agreement between the retrieved and simulated emissivities is much higher than at sounding channels.
- The emissivities retrieved at 325.15+/-9.5 GHz are questionable (too much atmospheric opacity).

Figure: The frequency dependence of the mean retrieved emissivities by using MARSS and ISMAR observations of flight B893 and simulated emissivities by FASTEM and the emissivity model of LERMA at 10°, 20°, 30°, 40°, 50° scan angles. The squares stand for the FASTEM results, the triangles stand for the LERMA model results, and the transverse lines indicates the error bars.

Tests of the models on other channels (325, 448, and 664 GHz)

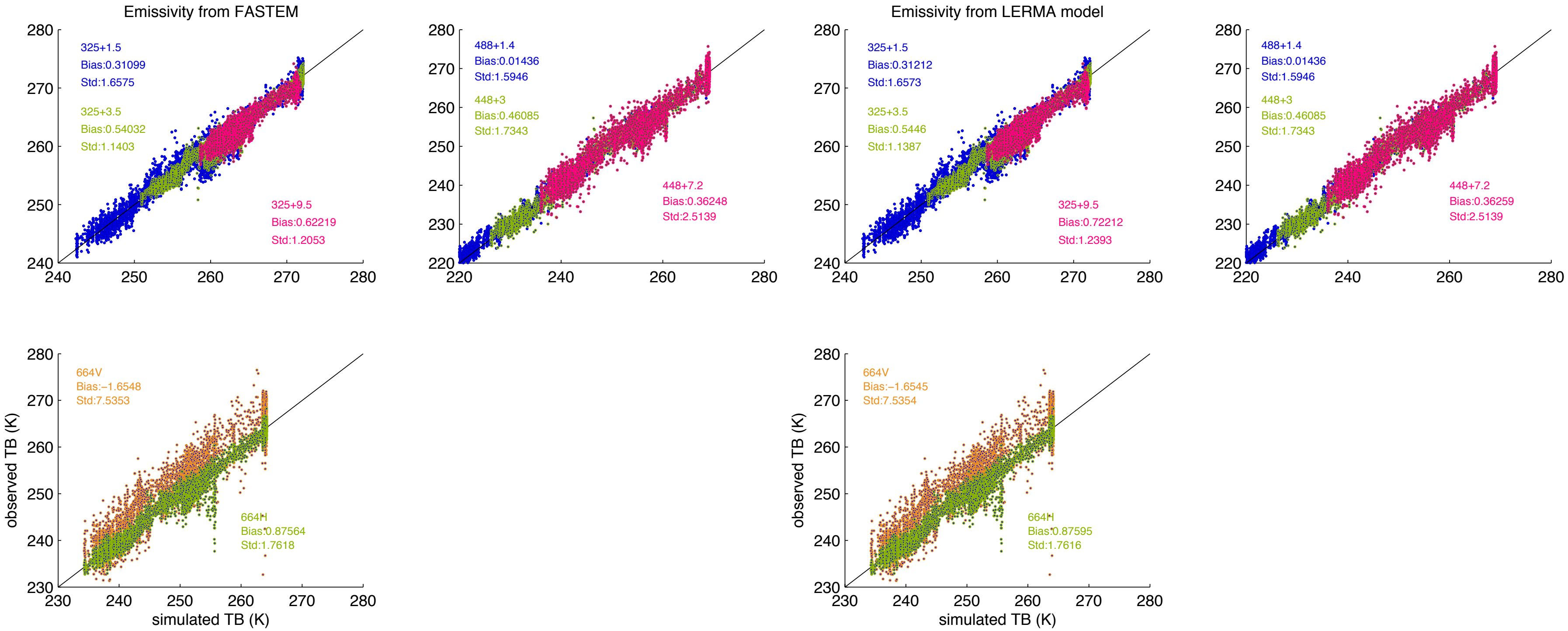


Figure: Scatter plot of simulated and observed brightness temperatures from some ISMAR channels, like 325.15 +/- (1.5, 3.5, 9.5), 448 +/- (1.4, 3, 7.2), and 664 GHz in both vertical and horizontal polarizations at scan angle around 50°. In the simulations, the surface emissivities are both provided by the FASTEM and LERMA model under the same atmospheric condition. The biases and std of measured and simulated data are given in the upper left and the lower right corners. The black solid line represents the 1:1 line.

- The atmosphere is quite opaque at these higher frequencies (very limited impact of the surface).

Flight B875

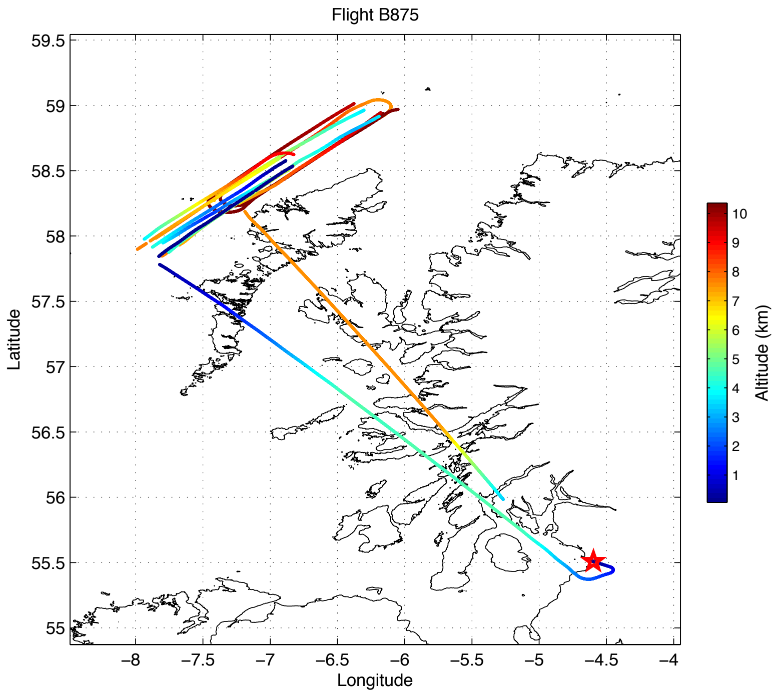


Figure: The flight track of B875 with the flight altitude in color. The red star indicates the departure airport.

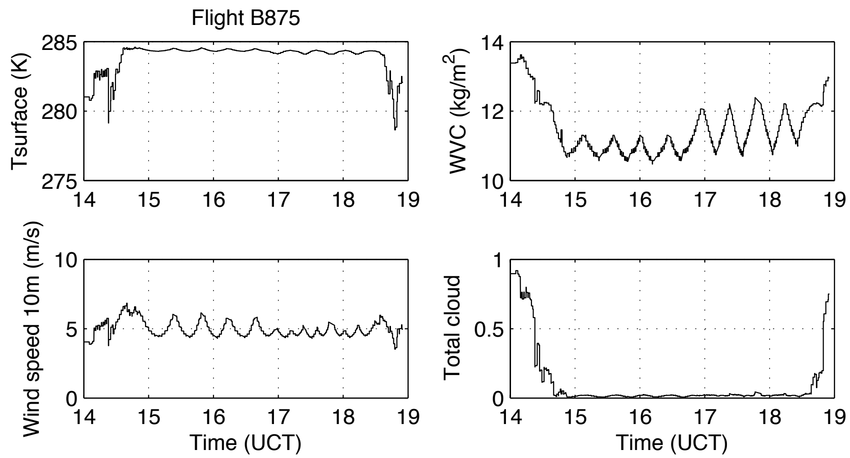


Figure: The surface skin temperature, integrated water vapor content, 10-m wind speed, and the fraction of total cloud against the observation times during flight B875.

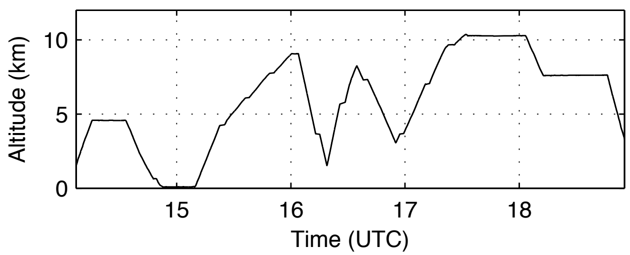


Figure: The aircraft altitude.

- Clear sky condition
- Wind speed is around 5 m/s
- Surface temperature is about 283 K
- Integrated water vapor content is less than 9 kg/m^2

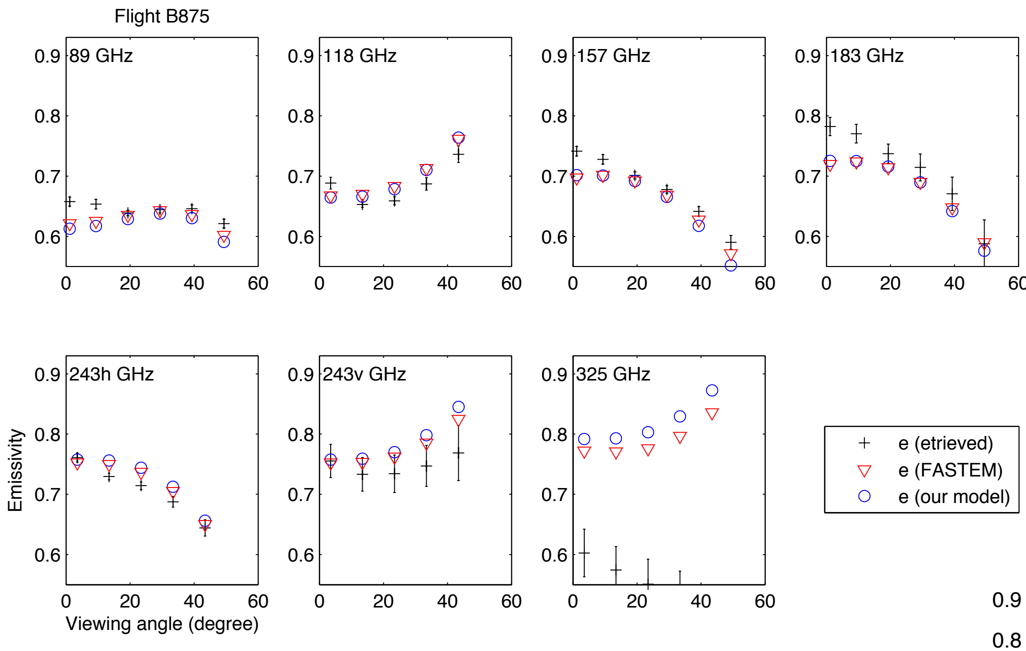


Figure: The angular dependence of the mean retrieved emissivities by using MARSS and ISMAR observations of flight B875 and simulated emissivities by FASTEM and the emissivity model of LERMA at 89, 118.7503+/-5, 157, 183.248+/-6, 243.2, and 325.15+/-9.5 GHz. The standard deviations are indicated for each mean retrieved emissivity (error bars).

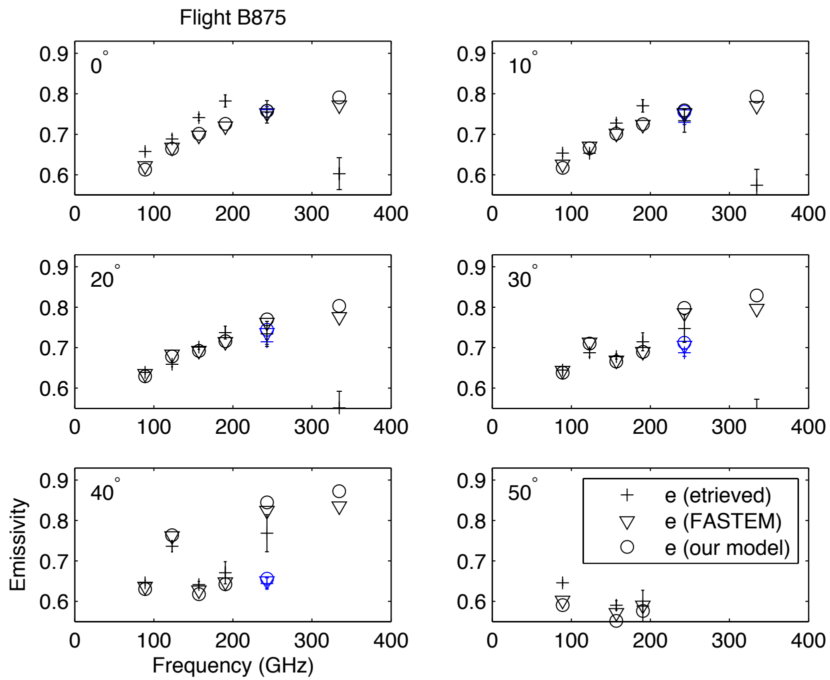
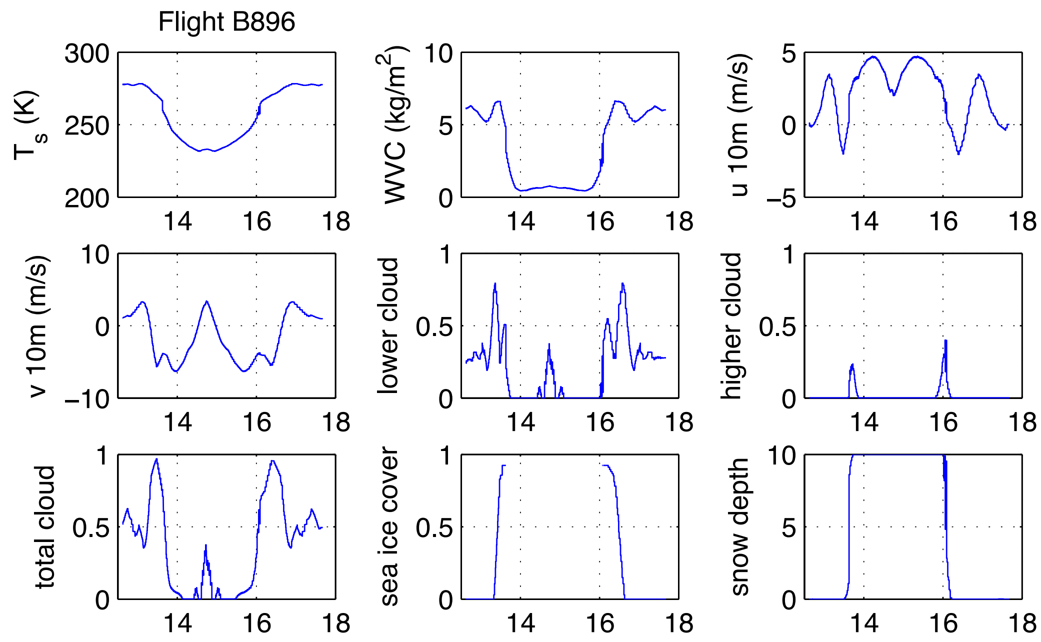


Figure: The frequency dependence of the mean retrieved emissivities by using MARSS and ISMAR observations of flight B875 and simulated emissivities by FASTEM and the emissivity model of LERMA at 10°, 20°, 30°, 40°, 50° scan angles. The squares stand for the FASTEM results, the triangles stand for the LERMA model results, and the transverse lines indicate the error bars.

Sea-ice emissivity

Atmospheric transmission can be large at high frequencies, under very dry atmospheres. Over snow, ice, and sea-ice transmission higher than 30% in 50% of the cases

Atmospheric variables



Flight B896

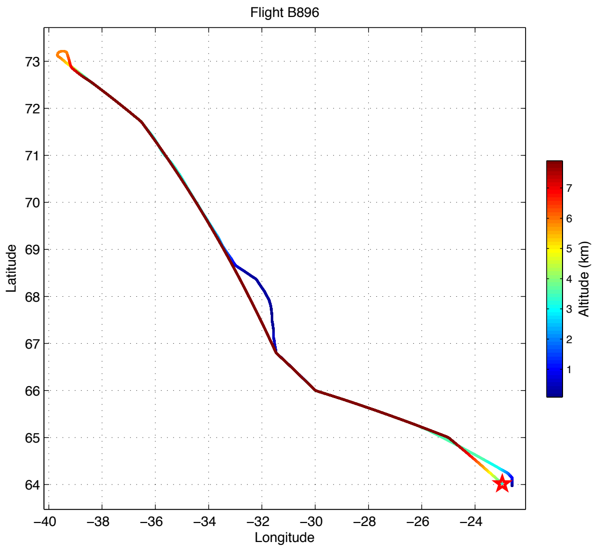


Figure: The flight track of B896 with the flight altitude in color. The red star is the place for taking

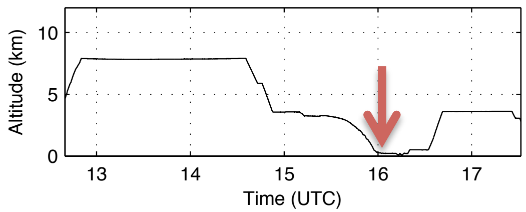


Figure: The aircraft altitude.

- Main observations over Greenland.
- Low-altitude run from summit down to coast for surface studies.
- Surface temperature is about 267 K
- Wind speed is around 4 m/s
- Water vapor content is less than 1 kg/m^2.

Angular dependence of the sea-ice emissivities

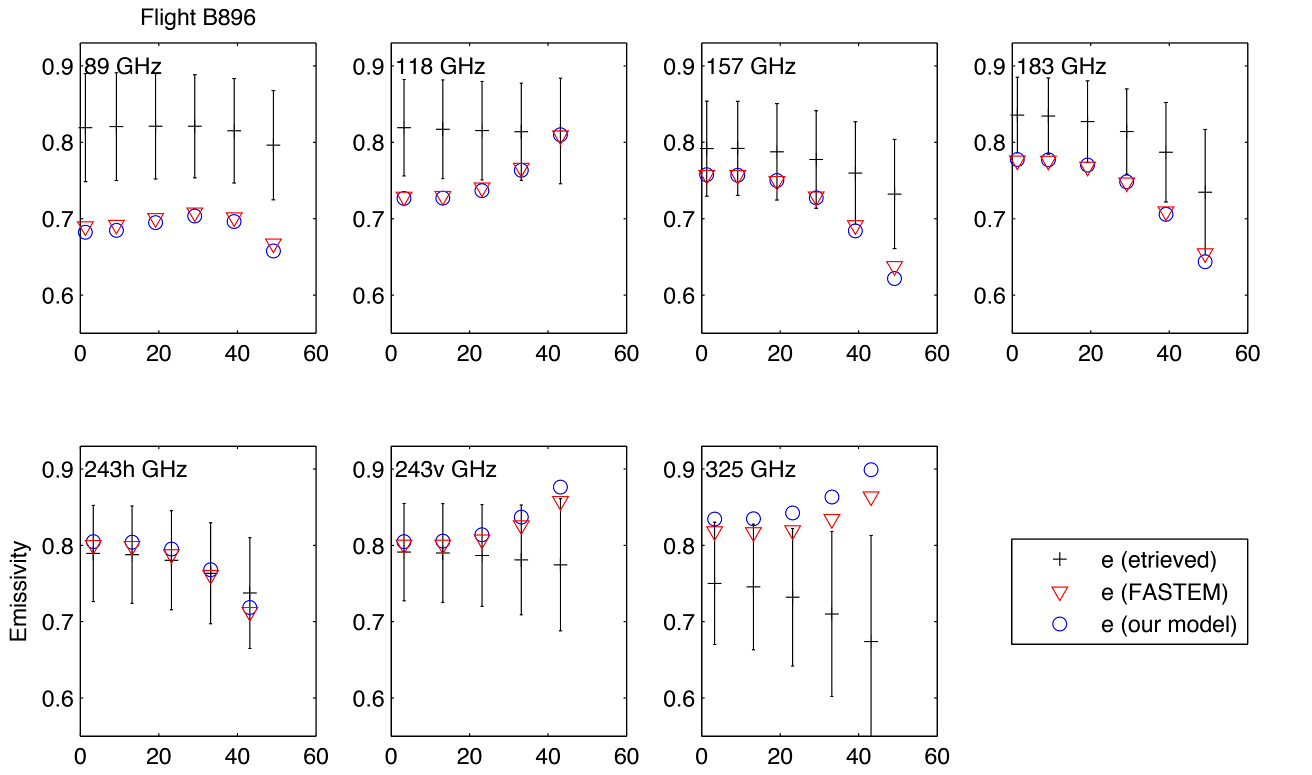
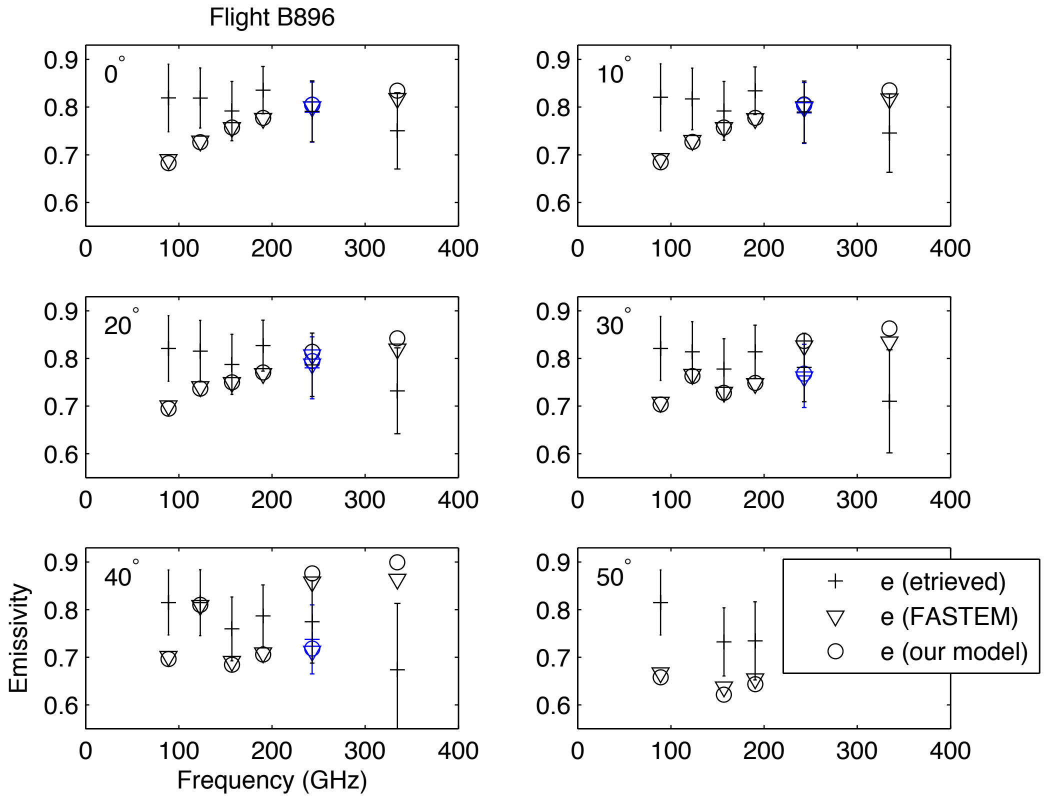
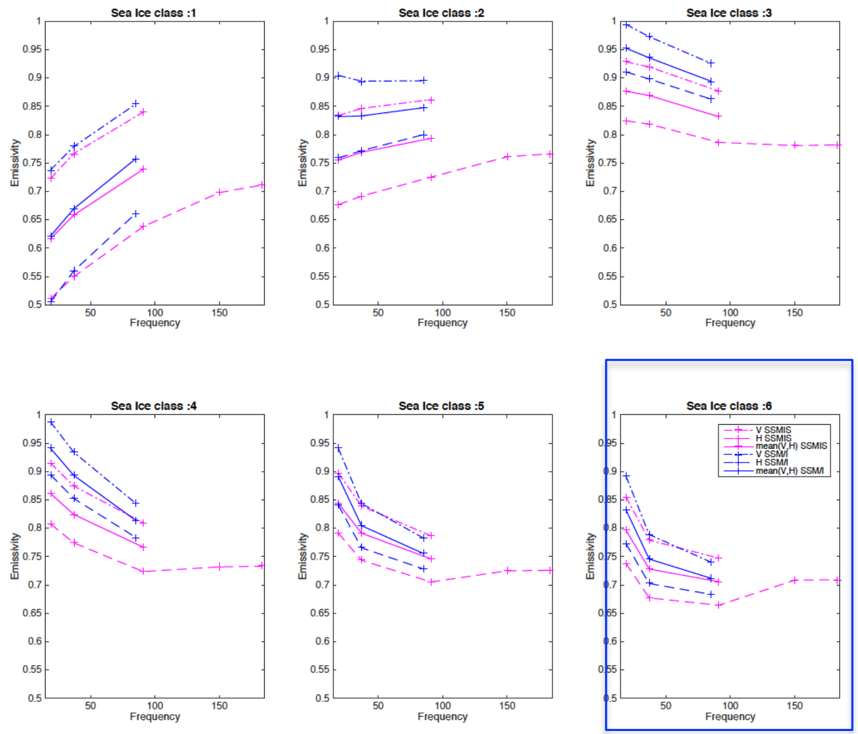


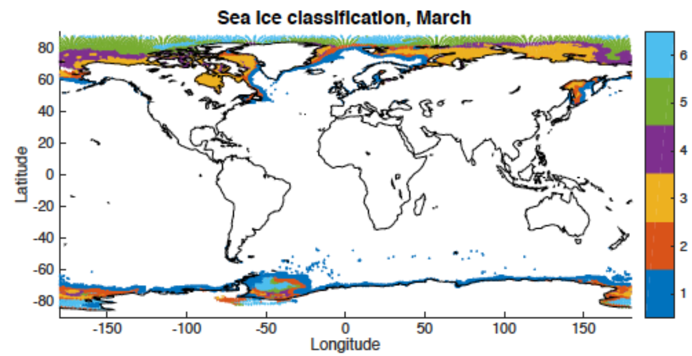
Figure: The angular dependence of the mean retrieved emissivities by using MARSS and ISMAR observations of flight B896 and simulated emissivities by FASTEM and the emissivity model of LERMA at 89, 118.7503+/-5, 157, 183.248+/-6, 243.2, and 325.15+/-9.5 GHz. The standard deviations are indicated for each mean retrieved emissivity (error bars).

Here the sea surface model results are just an indicator (not for direct comparison!)
The retrieved emissivities decrease with scan angle in both polarisations.

Frequency dependence of the sea-ice emissivities







The retrieved sea-ice emissivities are consistent with satellite-derived ones

Conclusion

- Under clear sky conditions, the upward looking observations agree well with the ARTS simulations.
- ISMAR and MARSS signals are stable and provide high quality measurements during the two campaigns.
- In the window channels at 89, 157, and 243.2 GHz, the ice-free ocean surface emissivity has been estimated, during low level transects. The agreement between the retrieved and simulated emissivities is reasonable.
- At higher frequencies (325.15, 448, and 664 GHz), larger atmospheric opacity limits the surface contribution to the received brightness temperature, and the surface emissivity could not be estimated, even when flying at low levels.
- The frequency dependence of the retrieved sea-ice emissivities is consistent with satellite-derived ones, up to 200 GHz.

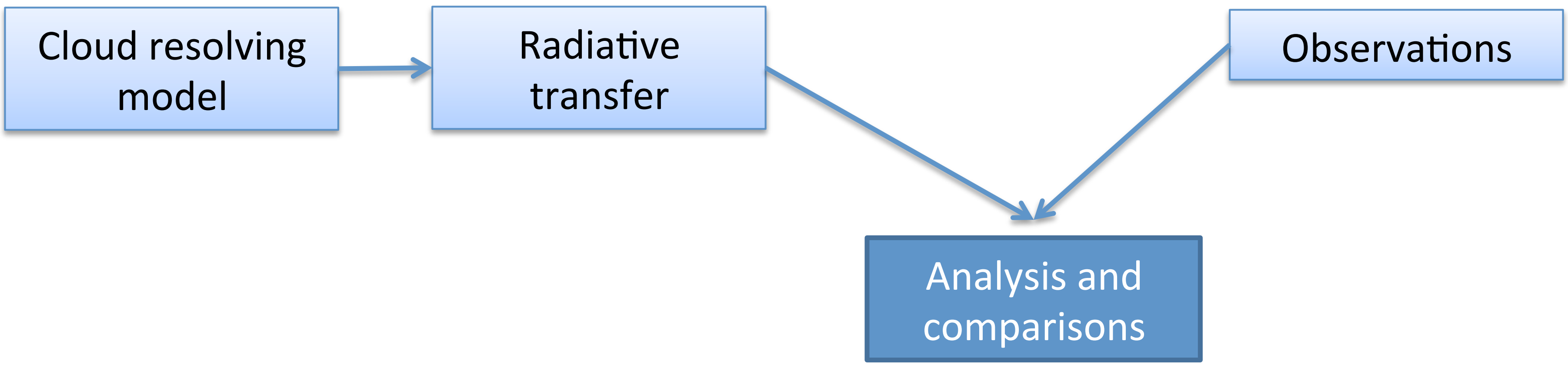
LERMA activities to prepare ICI (but not strickly related to ISMAR)

- Preparation of realistic radiative transfer simulations up to 700 GHz to form a training database for statistical retrieval.
- Evaluation of the simulations up to 200 GHz with existing satellite observations and above 200 GHz with ISMAR.
- Development of statistical retrievals (NN or Baysien).

LERMA activities to prepare ICI (but not strickly related to ISMAR)

Preparation of realistic radiative transfer simulations up to 700 GHz to form a training database for statistical retrieval.

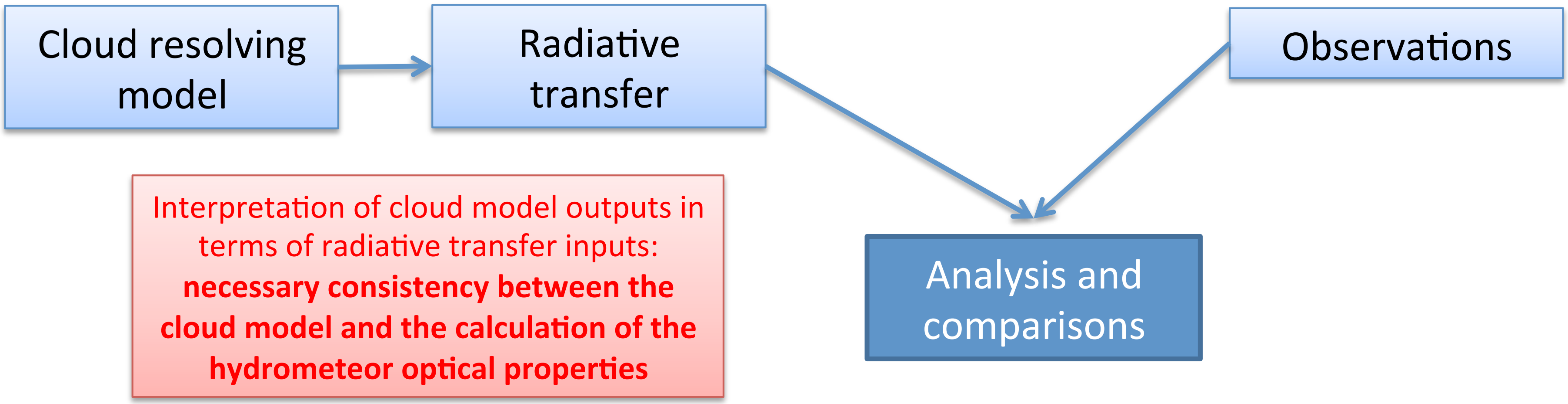
- A cloud resolving model to provide realistic descriptions of the atmospheric columns (e.g. **WRF**, Meso-NH)
- A radiative transfer model that handles scattering accurately and efficiently (e.g. **ARTS, RTTOV**)
- Evaluation with satellite observations up to 200 GHz (**SSMI/S, MHS, Cloudsat**…)



LERMA activities to prepare ICI (but not strickly related to ISMAR)

Preparation of realistic radiative transfer simulations up to 700 GHz to form a training database for statistical retrieval.

- Very high sensitivity of the simulations to the microphysics of the frozen particles
- Cloud models do not provide all the necessary information for the calculation of the optical properties of the frozen particles
- Some hypotheses have to be made, with necessary consistency between the assumptions in the cloud model and the radiative transfer.



LERMA activities to prepare ICI (but not strickly related to ISMAR)

Preparation of realistic radiative transfer simulations up to 700 GHz to form a training database for statistical retrieval.

Two areas of special interest:

- Simulations of snow clouds (key contributors to the scattering effects)
- Polarized scattering (with the recent analysis of the MADRAS data at 157 GHz, V and H)

Thank you for your attention!

Discussion ?

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.

About the ARTS simulations:

- Our TBs are a little higher than the results of Patrick for flight B893 between 16.6 and 17.2 h when the flight runs and orbits at bank angles between 20 and 60 degrees.
- The differences come from different configuration of ARTS? or different resolution of the input database?