Assessing the impact of different liquid water permittivity models on the assimilation of microwave radiances

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doi.org/10.5194/amt-12-405-2019

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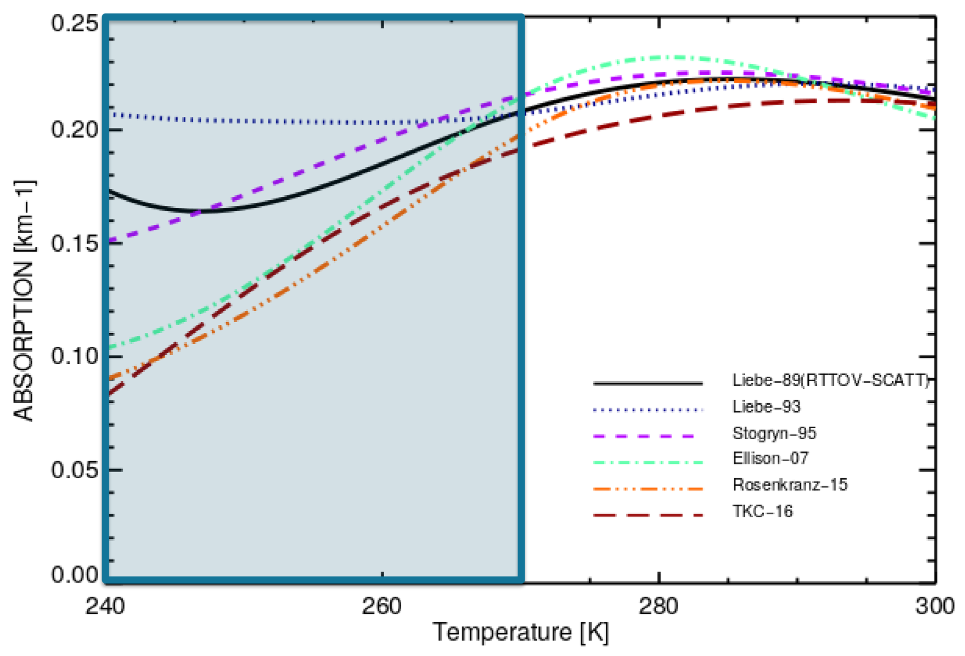
1. Motivation

The occurrence of liquid water for temperatures below 0ºC (supercooled liquid water) is typical for clouds in the higher latitudes (e.g. in frontal systems and cold-air outbreak regions). Due to a lack of laboratory experiments and observations the constraint on absorption properties of supercooled liquid water is poor. More precisely, the **permittivity of liquid water**, which is one of the key factors determining the absorption in the microwave band, is poorly known for these low temperatures and, hence, **existing liquid water permittivity models differ substantially** (right Fig.). Differences are largest for low temperatures and high frequencies.

In this study **we quantify impacts of the different permittivity models for pure liquid water** in the context of the **assimilation of microwave observations** that are sensitive to clouds, humidity and precipitation using the Integrated Forecast System (IFS) of the ECMWF.



Absorption as a function of temperature for liquid water clouds with 0.1 gm^{-3} water content for 150 GHz.

2. Essential ingredients to undertake this study:

- ✓ Assimilation system, which allows microwave observations under cloudy conditions: all-sky assimilation
- ✓ High-quality forecast model with reasonable skill in representing areas which are of most interest when it comes to studying the effect of absorption properties of liquid water, i.e. supercooled liquid water in cold-air outbreak regions: IFS
- ✓ Good observation operator for the all-sky assimilation of microwave radiances: RTTOV-SCATT
- ✓ Various liquid water permittivity model (imbedded in observation operator):
  - Liebe (1989): default until IFS Cycle 46R1
  - Liebe et al. (1993)
  - Stogryn et al. (1995)
  - Ellison (2007)
  - Rosenkranz (2015)
  - Turner et al. (2016)
- ✓ Running monitor experiments, to monitor a **change in first guess brightness temperature** which is solely due to a change in observation operator/ permittivity model for **SSMIS-F17** frequencies between **19GHz to 183GHz**.

TAKE HOME Messages

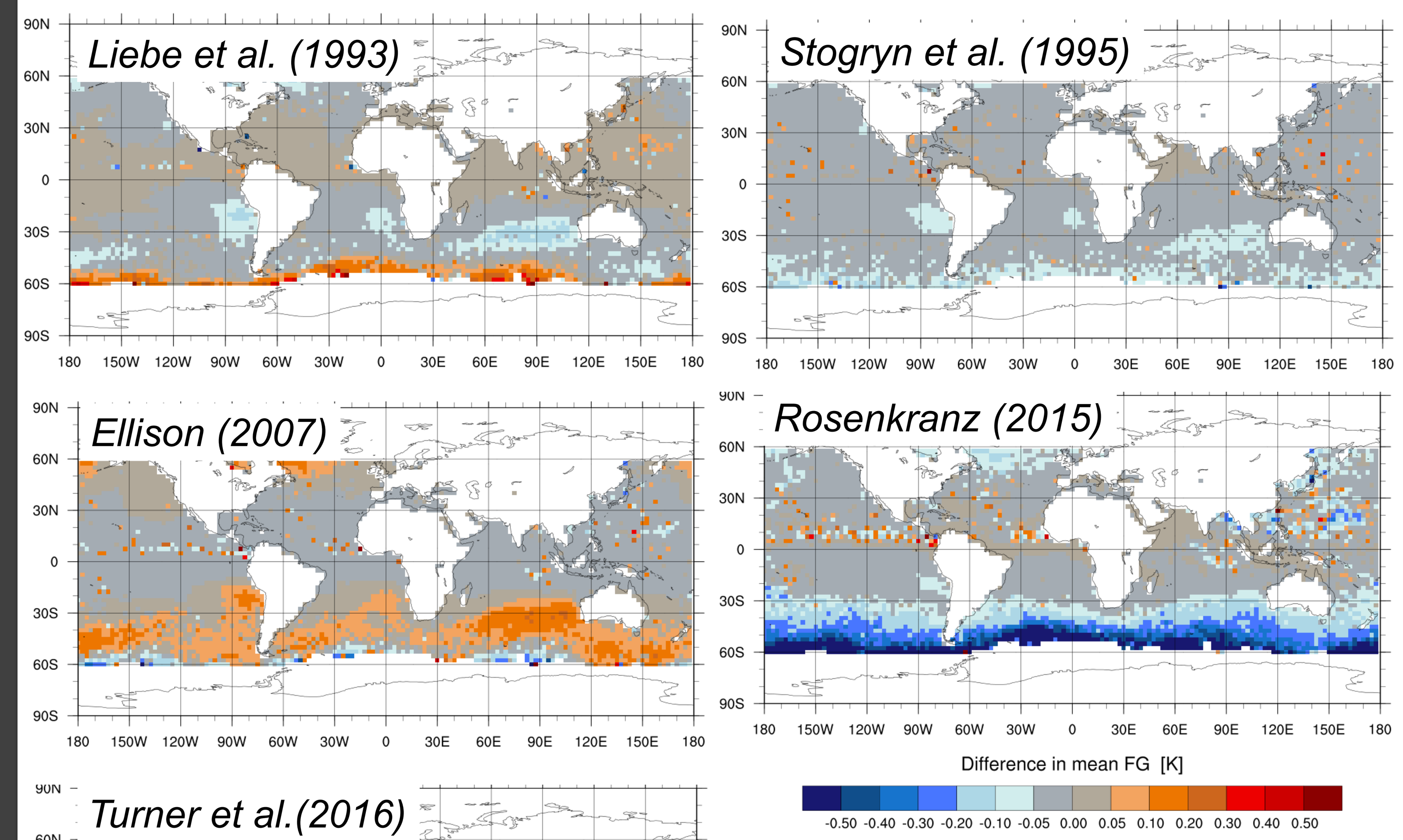
I. The **largest reduction in simulated brightness temperatures** is observed in areas with supercooled liquid water, such as cold-air outbreaks for **Rosenkranz (2015) and Turner et al. (2016).**

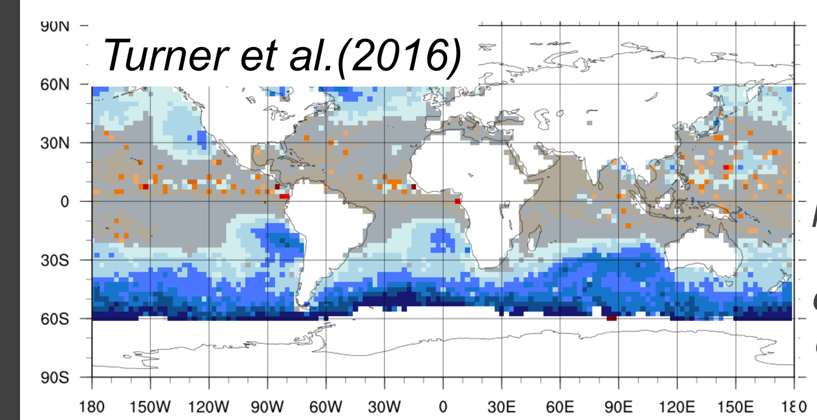
II. On a global scale, the **differences between the permittivity models are small** and cannot explain the main discrepancy between the model and observations**. Forecast scores are mostly neutral.**

III. However, the **biggest improvements** in terms of observational fits to microwave imagers could be seen for **Turner et al. (2016) and Rosenkranz (2015)** for frequencies below 183 GHz.

IV. **Rosenkranz (2015)** is now the default liquid water permittivity model for RTTOV-SCATT 12.2.

3. Change in simulated brightness temperature compared to Liebe (1989)





Maps of differences in simulated brightness temperatures [K] between the newer liquid water permittivity models and Liebe (1989) for 150 GHz, h-polarised, brightness temperatures co-located to corresponding SSMIS-F17 observations. Means are over August 2016. White indicates areas where data is not included due to the presence of, among other things, land surfaces and sea-ice.

Reduced absorption decreases the simulated brightness temperatures for some frequencies.

Significant discrepancies between models are found mainly **below 0ºC at lower frequencies** but at higher frequencies they are present across the temperature range.

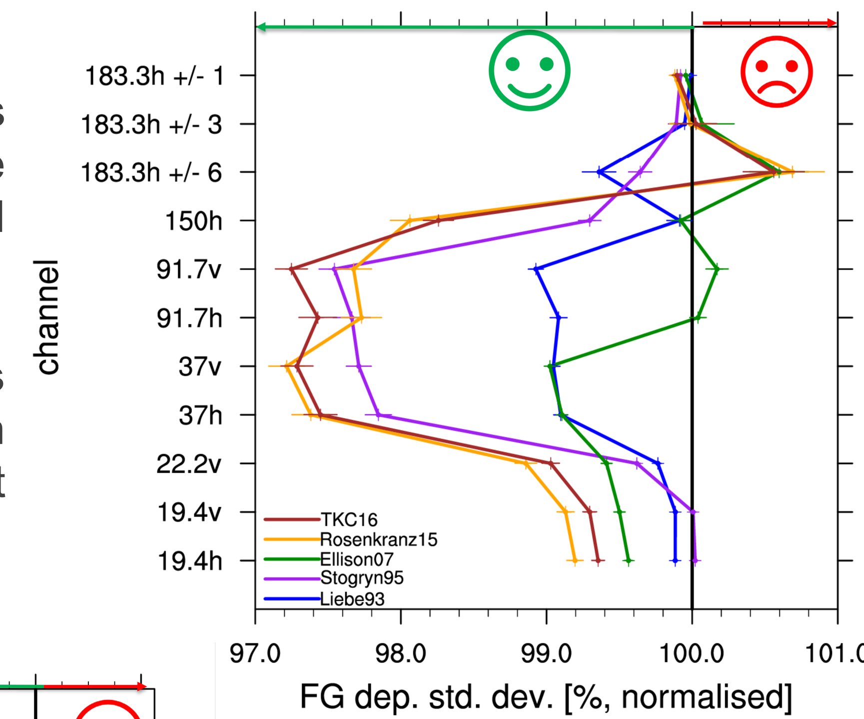
Largest differences occur mostly where **supercooled liquid water** prevails - in the midlatitudes (fronts, **cold-air outbreak areas**) and to a minor extent around the ITCZ (deep convective clouds) for frequencies up to 150 GHz (left Fig.).

Small changes in brightness temperature **for 183+/-6GHz** because radiative transfer effects are dominated by scattering from frozen hydrometeors.

4. Observational fits to SSMIS-F17

To find the best choice in liquid water permittivity model we look at how the fits between simulation and observations change. Typically, a reduction in the standard deviation in FG departure (difference in observed and simulated brightness temperature) can be interpreted as a better fit.

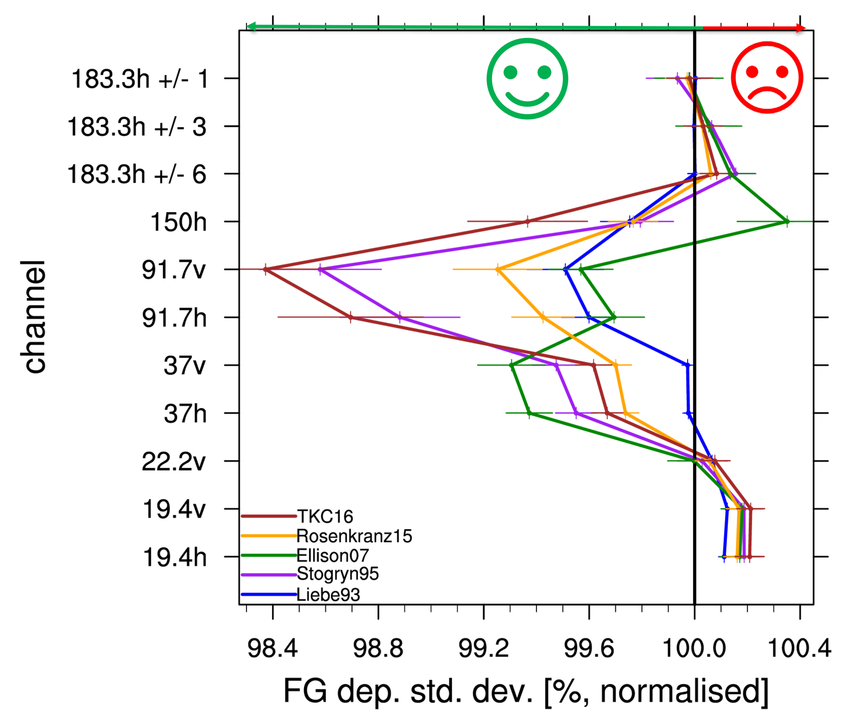
For most permittivity models the **standard deviation in FG departure is reduced compared to Liebe (1989)**, as shown for the southern hemisphere in the right Fig. The largest reduction occurs at 92 GHz, v-polarised for Turner et al. (2016) of about 2.7 %.



A larger standard deviation in FG departure (degradation) exists at 183 ± 6 GHz for Turner et al. (2016), Rosenkranz (2015) and Ellison (2007) compared to Liebe (1989).

This **degradation vanishes** for samples with **only liquid hydrometeors** and a large cloud amount (left Fig.).

Here, **compensating biases in the scattering** model and in the absorption model most likely play a major part.



Standard deviation in FG departure from SSMIS-F17 normalised by the standard deviation of results from Liebe (1989). The horizontal bars indicate a 95 % confidence range. Results cover the time period for August 2016 between 20ºS & 90ºS.

Top: for all samples.
Bottom: for samples with no frozen hydrometeors but containing some cloud