

Humidity observing system experiments within the ECMWF assimilation system



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1 Abstract

The global analysis and forecast of observed humidity has been studied by means of observing system experiments with the ECMWF 4D-Var data assimilation scheme. Data from Microwave Imagers (SSMIS, TMI, AMSRE), Microwave Sounders (MHS) and Infrared Sounders (HIRS, AIRS, GEOS) instruments have been used in order to evaluate the impact of each observing system on the humidity and total column water vapour analysis and forecast. The results show that each tested data type contributes to the humidity analysis, but significant impact has been observed by the assimilation of microwave imagers observations in the all-sky approach (clear/cloudy situations) over ocean (Bauer et al. 2010, Geer et al. 2010).

The large information content coming from the Microwave Imagers in the all-sky approach encourage additional studies and a potential further step is to prove that this data can also be used over land (all-sky assimilation has, to date, been limited to ocean cases only). In order to explore the use of Microwave observations over land under clear/cloudy situations, some feasibility studies on the land emissivity retrieval have been performed within the ECMWF assimilation system as preliminary step. Results show that land surface emissivities calculated using SSMIS, TMI and AMSRE observations have been found in very good agreement in both clear and cloudy sky conditions.

References

- Aires, F., C. Prigent, F. Bernado, C. Jiménez, R. Saunders, and P. Brunel, 2010. A tool to estimate Land Surface-Emissivities at Microwaves frequencies (TELEM) for use in numerical weather prediction. *Q. J. R. Meteorol. Soc.*, **137**, 690–699
- Bauer, P., A. J. Geer, P. Lopez, D. Salmond, 2010. Direct 4D-Var assimilation of all-sky radiances. Part I: Implementation. *Q. J. R. Meteorol. Soc.*, **136**, 1868–1885
- Geer, A. J., P. Bauer, and C. W. O'Dell, 2009. A revised cloud overlap scheme for fast microwave radiative transfer in rain and cloud. *J. Applied Meteorology*, **48**, 2257–2270
- Geer, A. J., P. Bauer, P. Lopez, 2010. Direct 4D-Var assimilation of all-sky radiances: Part II. Assessment. *Q. J. R. Meteorol. Soc.*, **136**, 1886–1905
- Karbou, F., C. Prigent, L. Eyraud and J. Pardo, 2005. Microwave land emissivity calculations using AMSU-A and AMSU-B measurements. *IEEE Trans. on Geoscience and Remote Sensing*, **43**, 5, 948–959
- Karbou, F., N. Bormann and J.-N. Thépaut, 2007. Towards the assimilation of satellite microwave observations over land: feasibility studies using SSMIS, AMSU-A and AMSU-B. *NWPSAF Tech. Rep.*, 37pp
- Prigent, C., W. B. Rossow and E. Matthews, 1997. Microwave land surface emissivities estimated from SSM/I observations. *J. Geophys. Res.*, **102**, 21867–21890
- Prigent, C., F. Chevallier, F. Karbou, P. Bauer and G. Kelly, 2005. AMSU-A surface emissivities for numerical weather prediction assimilation schemes. *J. Applied Meteorology*, **44**, 416–426
- RTTOV v10, Users' guide v1.5, Updated 2012-01-17, available at: http://research.metoffice.gov.uk/research/interproj/nwpsaf/rtm/rtm_rttov10.html

2 Humidity observing system experiments within the ECMWF assimilation system

The impact of humidity observations within the ECMWF assimilation system has been studied by means of observing system experiments. Six different observing system experiments have been run for 1–31 August 2011, using the incremental 4D-Var assimilation system at T255 horizontal resolution (~78 km).

A Control assimilation experiment that uses all the available observations of the operational system has been set up and used as reference to investigate the impact of each observing system. The impact of humidity observations has been assessed by means of 4 additional experiments, same as the Control, but in each experiment a specific data type has been withheld. In order to estimate the impact of humidity observations from satellite sensors, the experiments have been set up as follows:

Exp1: MW Imagers data withheld from Control (SSMIS, TMI, AMSRE)

Exp2: MW Sounders data withheld from Control (MHS)

Exp3: IR Sounders withheld from Control (HIRS, IASI, AIRS, GEOS)

Exp4: Baseline: All data above remove (satellite humidity observation system is withheld from Control)

Table 1 summarizes the channels that have been selected and removed by each sensor/satellite within each experiment.

In order to better understand which differences are significant among the satellite observations, a further experiment has been set up. The 6th experiment (Control*) is identical to the Control, but different initial conditions for the first cycle (31 07 2011, 00 UTC) have been used.

The impact of each satellite observing system (MW Imagers; MW Sounders; IR Sounders; Baseline), in all comparison in the following, has been estimated in terms of the root mean square (RMS) of analysis differences:

$$RMS_{observing_system} = RMS(AN_{Control} - AN_{Exp}) - RMS(AN_{Control} - AN_{Control*}) \quad (1)$$

where AN is the humidity analysis produced twice daily (00 or 12 UTC) by the variational assimilation system. The second term on the right side of the equation can be interpreted as an estimation of the humidity analysis uncertainty coming from the full assimilation system.

Satellite humidity observing system (Channels withheld from Control experiment)

MW Imagers (Exp1)			IR Sounders (Exp3)		
Sensor	Satellite	Channels (GHz)	Sensor	Satellite	Channels
SSMIS	SMSP17	19V&H; 22V; 37V; 91V	HIRS	NOAA17	7.33; 6.52 (µm)
TMI	TRMM	19V&H; 22V; 37V; 85V	NOAA19	7.33; 6.52	
AMSRE	AQUA	19V&H; 24V&H; 37V	METOPA	7.33; 6.52	
MW Sounders (Exp2)			IASI	METOPA	1367.05; 1384.27; 1392.95; 1395.28; 1407.06; 1421.06; 1422.27; 1990.04; 1994.41; 2014.91 (cm ⁻¹)
Sensor	Satellite	Channels (GHz)	AIRS	AQUA	1251.40; 1316.10; 1339.70; 1342.30; 1367.80; 1392.20; 1514.0 (cm ⁻¹)
MHS	NOAA18	183.3 ± 1.0; ± 3.0; ± 7.0	GOES 11	6.7 (µm)	
MHS	NOAA19	183.3 ± 3.0; ± 7.0	GOES 13	6.7	
MHS	METOPA	183.3 ± 1.0; ± 3.0; ± 7.0	METEOSAT 7	6.2; 7.3	
			METSAT-2	6.8	
			Baseline (Exp4)		
All satellite data above withheld from Control					

Table 1 Summary of the observations withheld from Control experiment

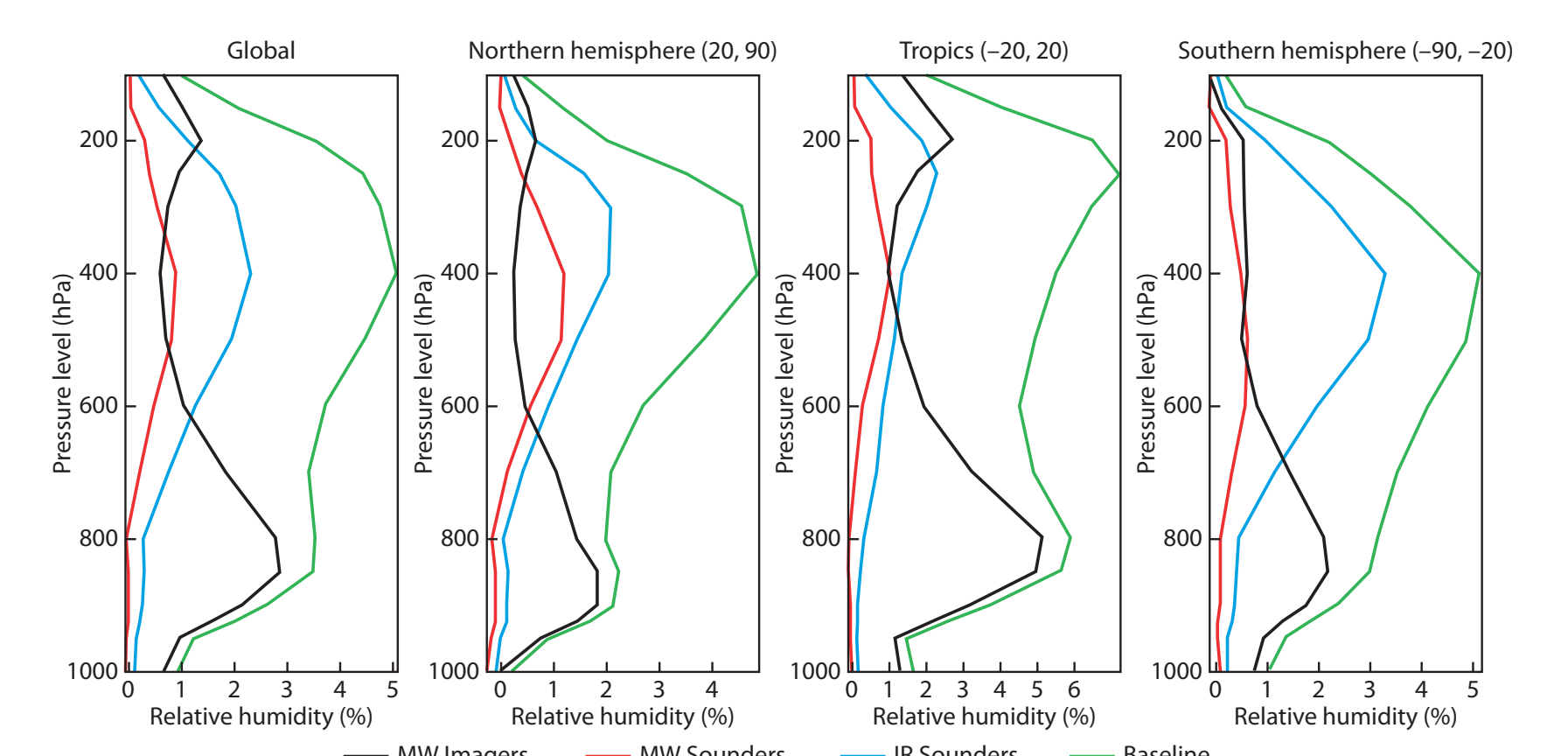


Figure 1 Impact of each satellite observing system (MW Imagers; MW Sounders; IR Sounders; Baseline) on the vertical profile of relative humidity, computed over 5–31 August 2011, for all the Globe, Northern Hemisphere, Tropics and Southern Hemisphere. Calculations are performed according to equation 1 considering the humidity analysis produced at 12 UTC

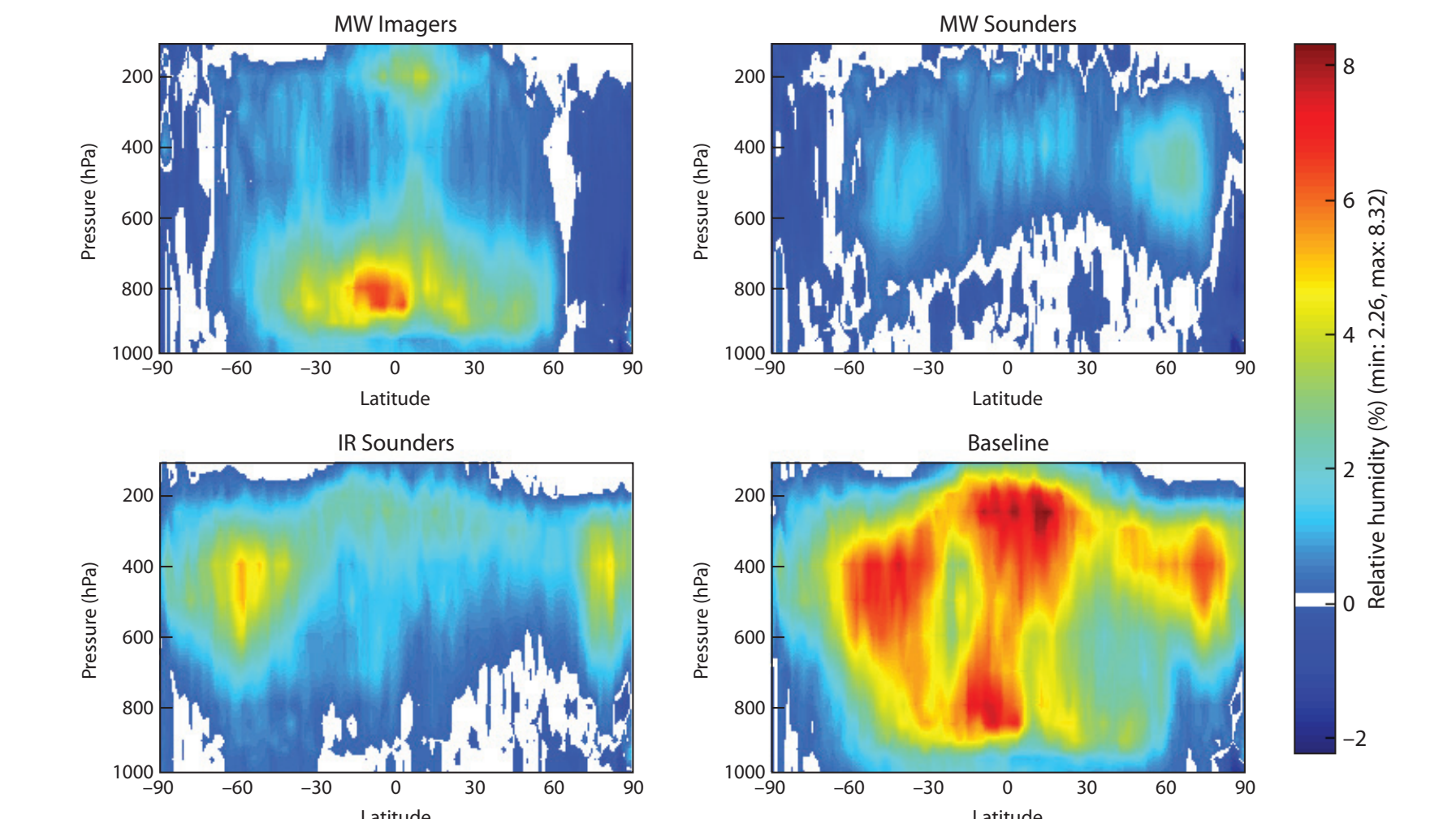


Figure 2 As in Figure 1, but along zonal cross-sections

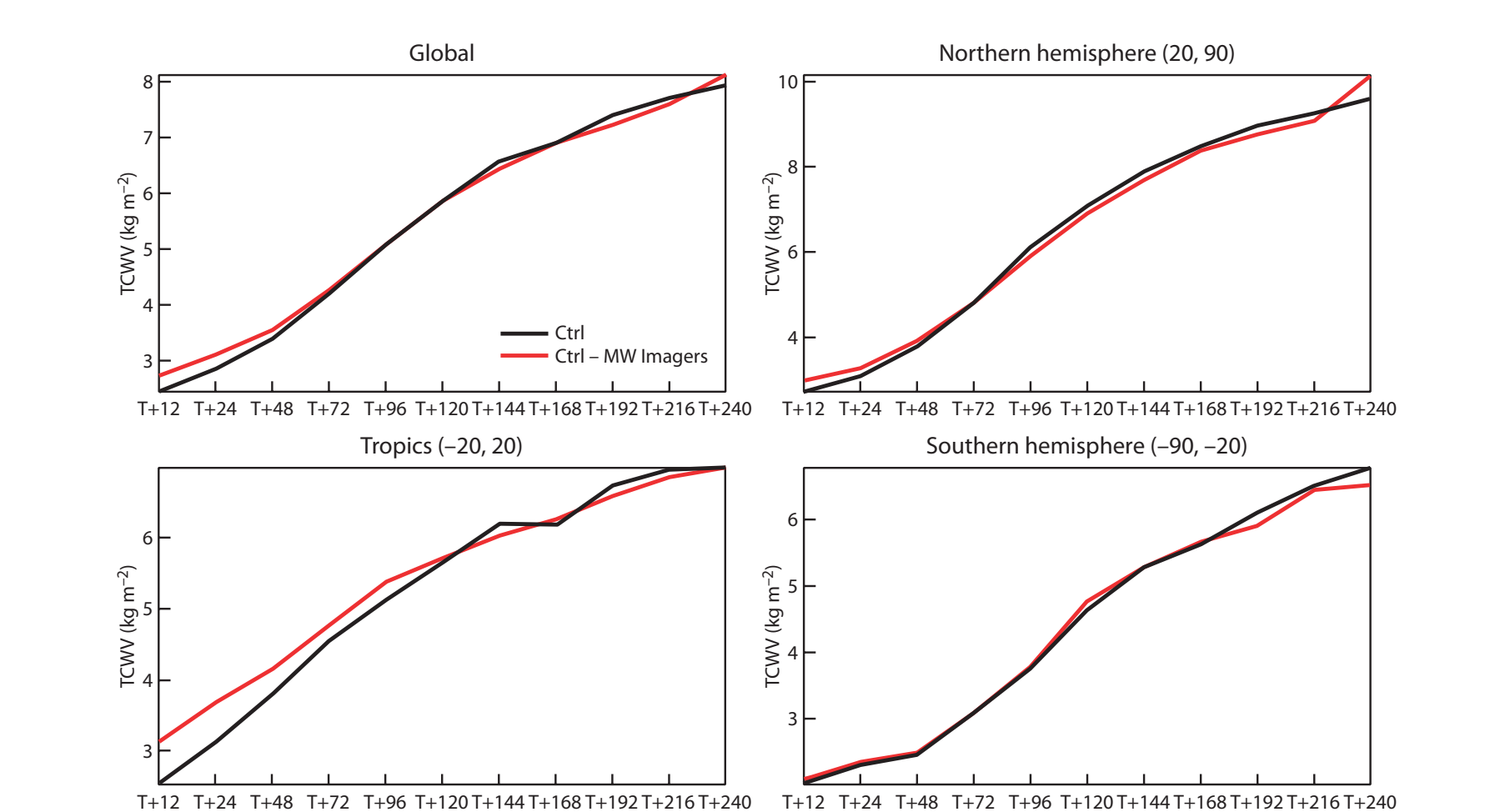


Figure 3 TCWV forecast time series verified against independent observations from Envisat Microwave Radiometer (MWR). RMS differences between observations and forecast have been computed over 5–31 August 2011. 10 days TCWV forecast have been produced each hour from 00 UTC analysis. Black line: Control experiment verified against MWR observations, red line: Exp1 (MW Imagers withheld from Control) verified against MWR observations

3 Preliminary results of land emissivity retrievals using MW imager data in clear/cloudy situations

The large information content coming from the Microwave Imagers in the all-sky approach encourage additional studies in order to explore the use of microwave data over land. In this context, inter-sensor land surface emissivity retrieval comparisons (SSMIS, TMI, AMSRE) have been performed as well as some evaluations with independent emissivity data. In particular, emissivities retrieved using SSMIS, TMI and AMSRE observations have been compared with:

- land surface emissivities provided by TELEM atlas (Aires et al. 2010) available within the RTTOV package (RTTOV v10);
- dynamic emissivity retrievals obtained from AMSUA Channel 3 (50.3 GHz) and assigned to Channel 5 (53.6 GHz), where clear sky observations over land are operationally assimilated within the ECMWF system.

Land surface emissivity estimations have been already investigated by many authors (Karbou et al. 2005, 2007, Prigent et al. 1997, 2005, among many others). However, in this work, the emissivity retrieval has been implemented for the first time within the all-sky approach context (Geer et al. 2009). RTTOV-SCATT cloud overlap schemes have two sub columns and, the all-sky brightness temperature, which depends on the average cloud fraction over the whole profile (c), is computed as follow:

$$T_{allsky} = cT_{Cld} + (1-c)T_{Clr} \quad (2)$$

where T_{Clr} and T_{Cld} are respectively the brightness temperature of the clear sub column (taking into account only gaseous absorption) and of the cloudy sub column (taking into account cloud, precipitation and scattering). For a given zenith angle (θ) and frequency (ν), the land surface emissivity (ϵ) has been estimated as:

$$\epsilon(\nu, \theta) = \frac{T_B(\nu, \theta) - cT_{Cld}^\uparrow(\nu, \theta) - (1-c)T_{Clr}^\uparrow(\nu, \theta) - cT_{Cld}^\downarrow(\nu, \theta)T_{Cld} - (1-c)T_{Clr}^\downarrow(\nu, \theta)T_{Clr}}{(c\tau_{Cld} - (1-c)\tau_{Clr})T_s - cT_{Cld}^\downarrow(\nu, \theta)\tau_{Cld} - (1-c)T_{Clr}^\downarrow(\nu, \theta)\tau_{Clr}} \quad (3)$$

where T_B is the observed brightness temperature, T_{Clr}^\uparrow , T_{Clr}^\downarrow , τ_{Clr} are the up-welling and down-welling radiation and the atmospheric opacity of the clear sub column, and T_{Cld}^\uparrow , T_{Cld}^\downarrow , τ_{Cld} are the same quantities but for the cloudy sub column. T_s , instead, is the surface skin temperature taken from the short-range forecasts. Observed brightness temperature have been selected within the latitude range of [-60, +60] degree. Where c is greater than 0.05 observations have been considered as cloudy, otherwise they are classified as clear (emissivity is estimated from equation 3 with c = 0).

4 Summary

Each observation type investigated has an impact on the humidity analysis. However, the results show that the all-sky approach (MW Imagers) dominates the humidity analysis much more than the other two observing systems, and in particular, marked impact is observed in the lower troposphere (1000–600 hPa) and in the deep convection area (250–100 hPa). MW Sounders and IR Sounders, instead, dominate the humidity analysis in the middle troposphere (600–200 hPa), specially in the Northern and Southern hemisphere (figures 1 & 2). In addition, TCWV forecast time series verified against independent observations from MWR (figure 3) show deterioration in RMS up to 4 days (T+96) in the Tropics, when MW Imagers are removed from the Control experiment.

Land surface emissivity retrievals using SSMIS, TMI and AMSRE observations have been found in very good agreement in both clear and cloudy sky conditions (figures 4, 8 & 9). The results show also reasonable and good match with land surface emissivities provided by TELEM atlas available within the RTTOV package as well as with dynamic emissivity retrievals obtained from AMSUA window channels (figures 4, 5, 6 & 7). These results are very promising and encourage additional investigations on the possibility to assimilate microwave imagers observations over land within the all-sky approach.

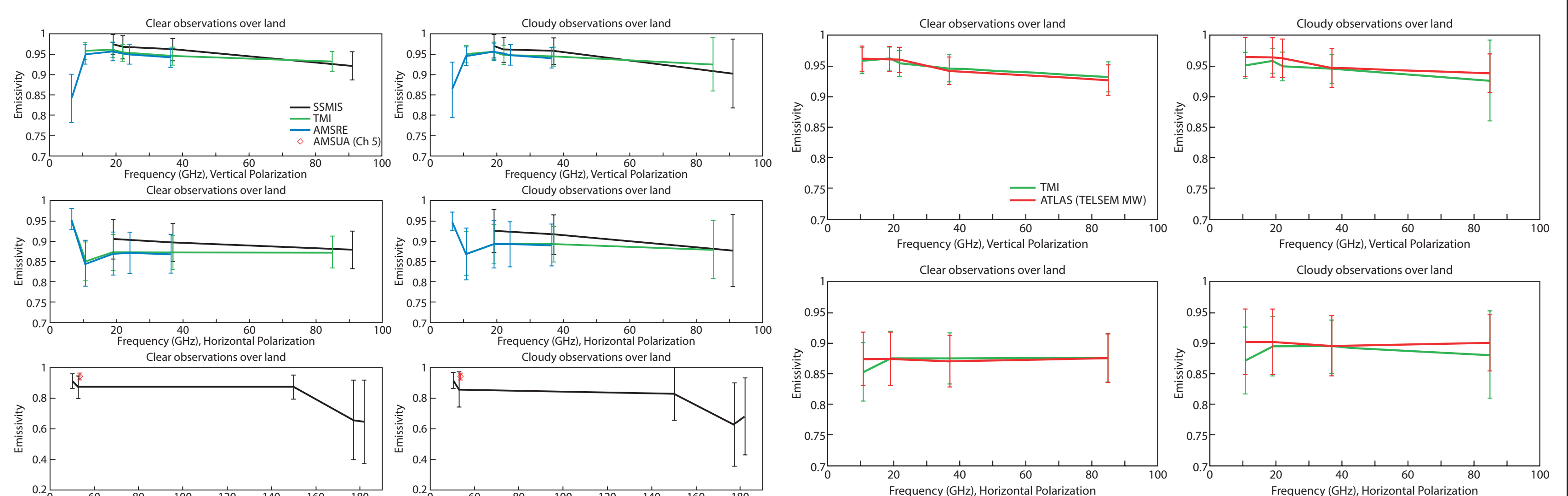


Figure 4 Mean and standard deviation of land surface emissivity variation with frequency over a 3 week period (1–21 August 2011) for SSMIS, TMI, AMSRE. Left panels are for clear observations, right panels for cloudy/rainy observations instead. SSMI-like frequencies with vertical polarisation (top panel) have been separated from frequencies with horizontal polarisation (middle panel). Bottom panel is for the other investigated SSMIS frequencies (50.3, 52.8, 150, 183 ± 3 GHz). In addition, as reference in the bottom panel, the red diamond is the mean and standard deviation of AMSUA dynamic emissivity retrievals

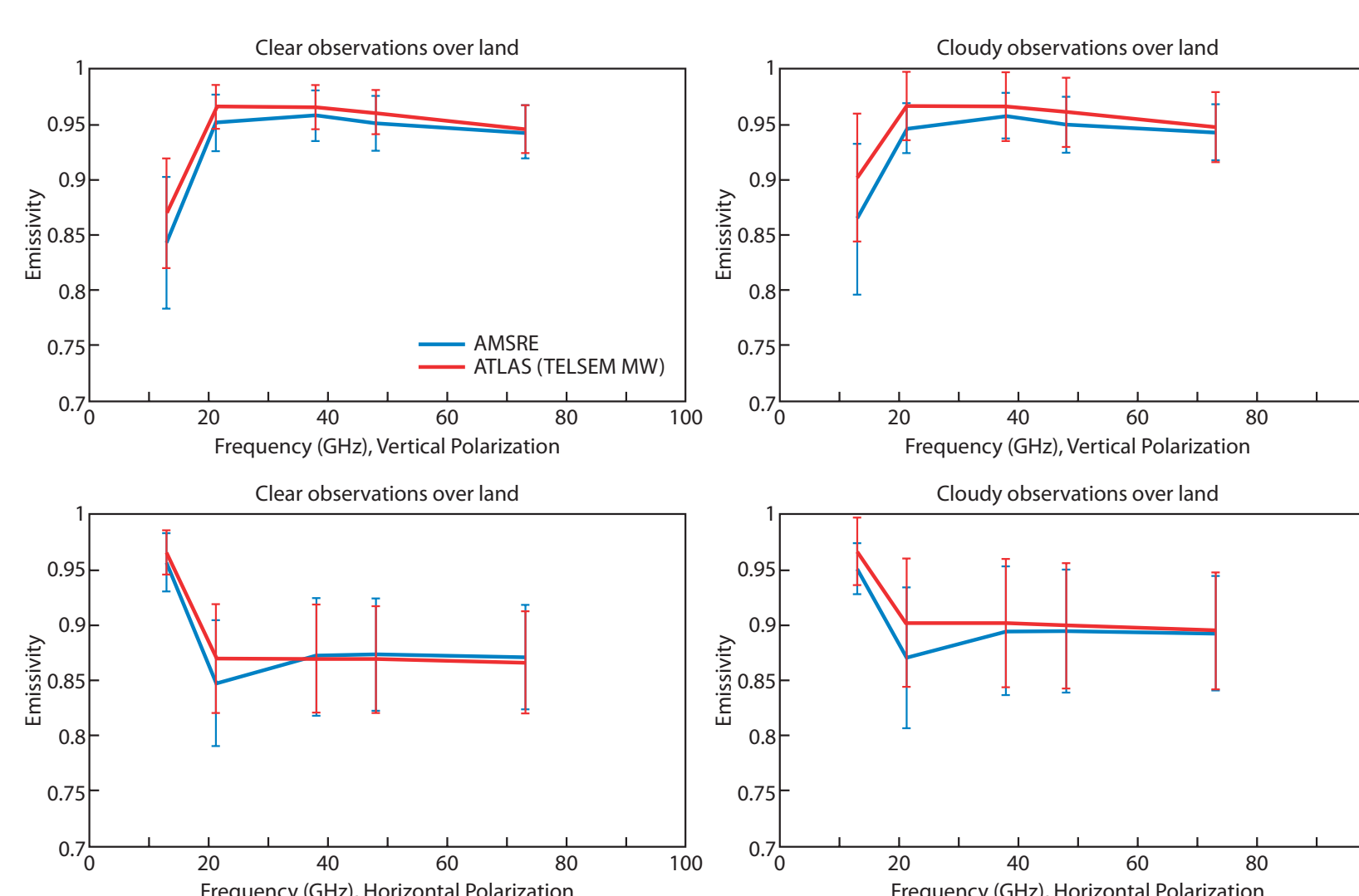


Figure 5 Mean and standard deviation of land surface emissivity variation with frequency over a 3 week period (1–21 August 2011) for AMSRE compared with mean and standard deviation computed used emissivities from TELEM atlas. Left panels are for clear observations, right panels for cloudy/rainy observations instead. SSMI-like frequencies with vertical polarisation (top panel) have been separated from frequencies with horizontal polarisation (bottom panel)

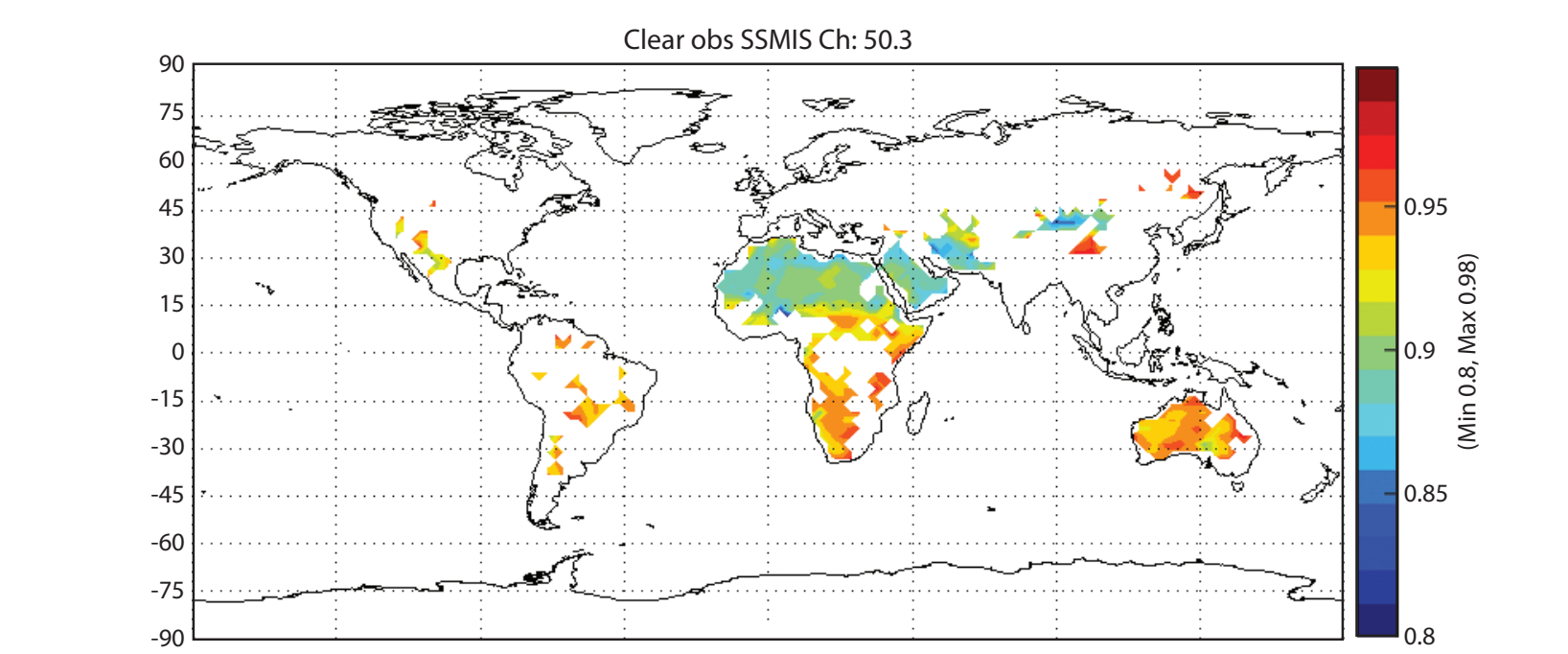


Figure 8 Mean land surface emissivity retrievals from SSMIS channel 1 (50.3 GHz) for clear observations, binned in 2.5° by 2.5° boxes over a 3 week period (1–21 August 2011)

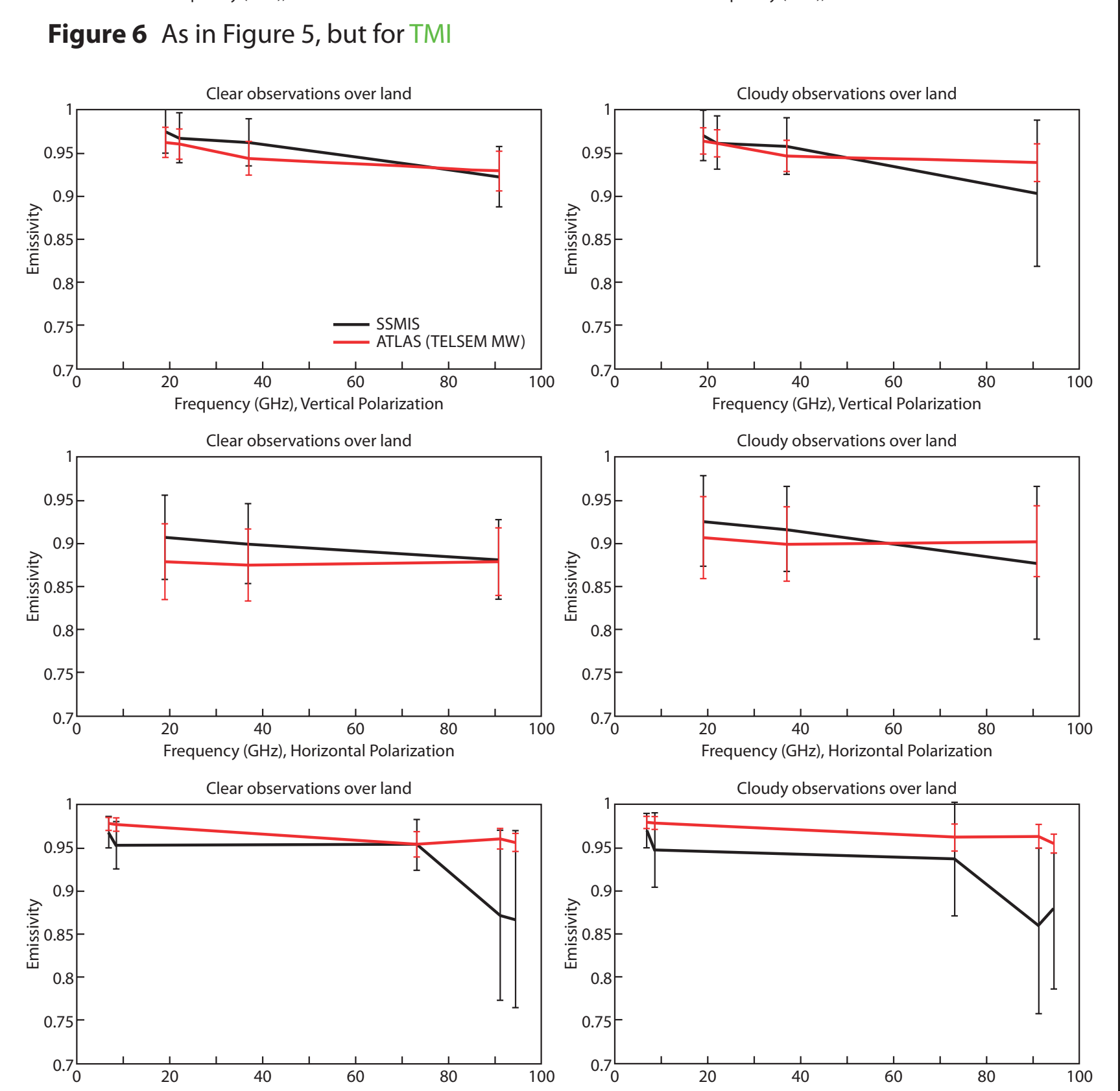


Figure 6 As in Figure 5, but for TMI

Figure 7 As in Figure 5, but for SSMIS

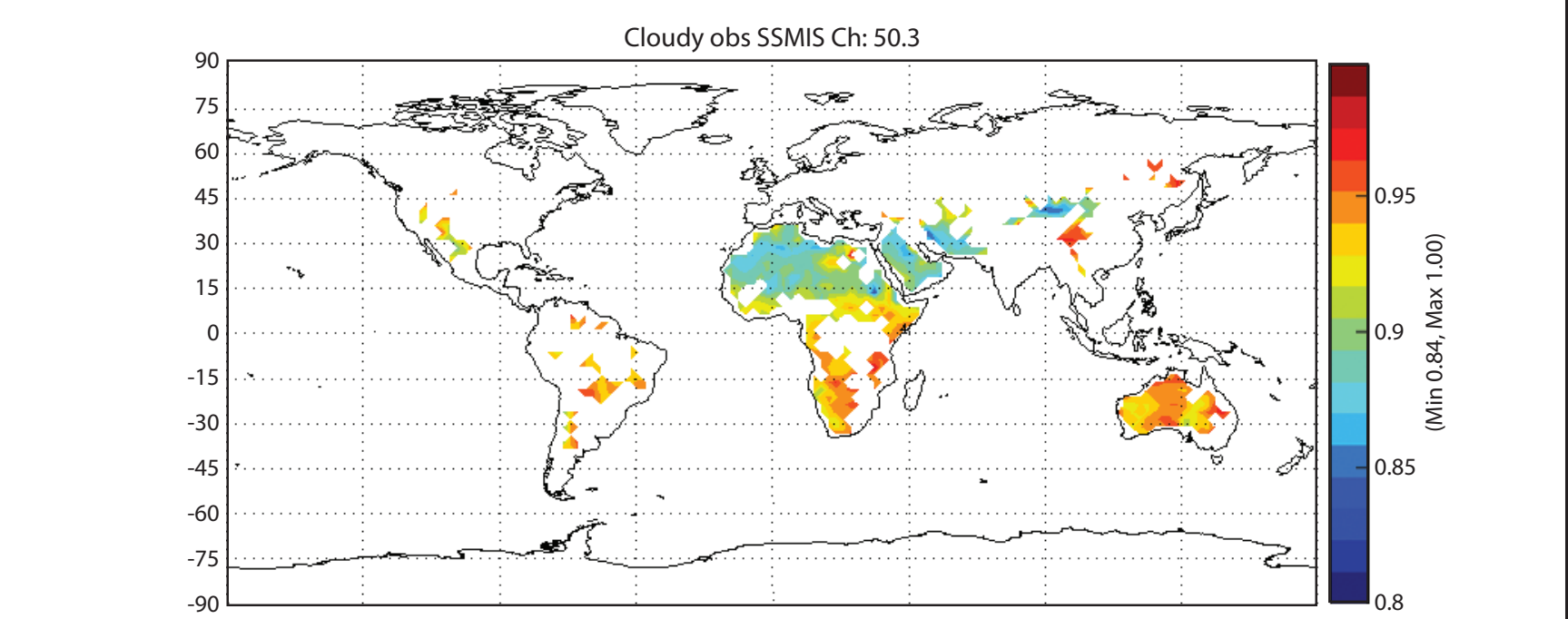


Figure 9 As in Figure 8, but for SSMIS cloudy/rainy observations