Addressing biases in cloudy situations using the all-sky assimilation of microwave radiances

by Katrin Lonitz, Alan Geer, Richard Forbes, Peter Bechtold

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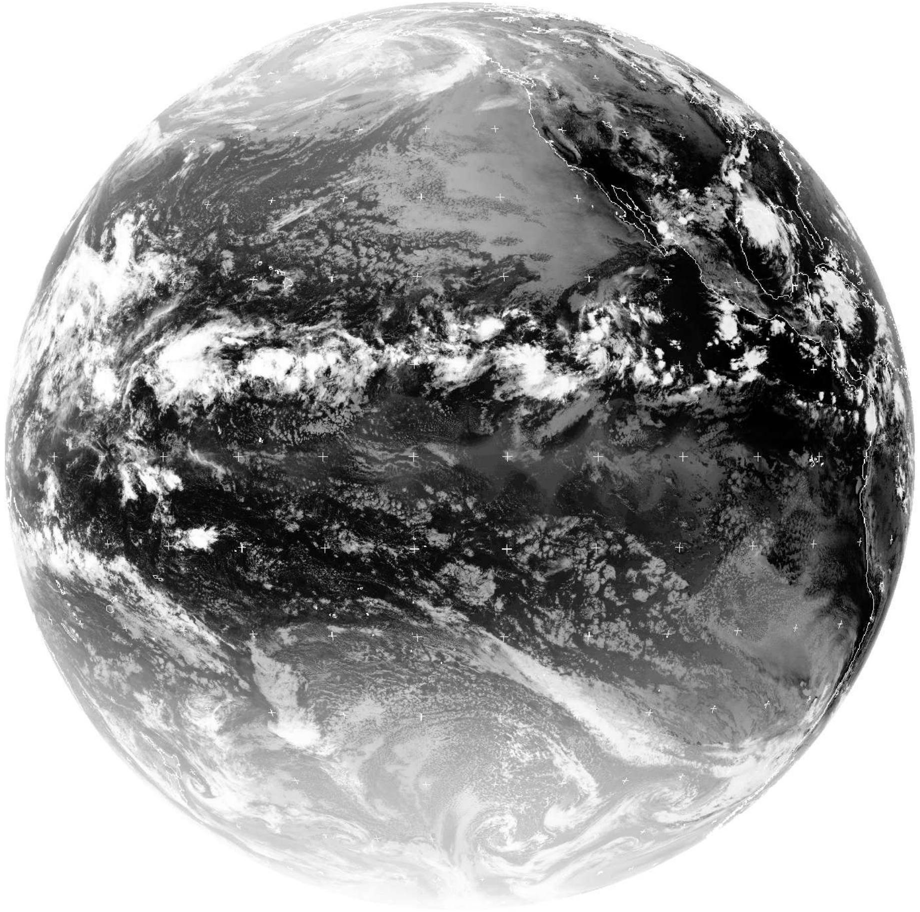
Use of all-sky microwave data

13 August 2016

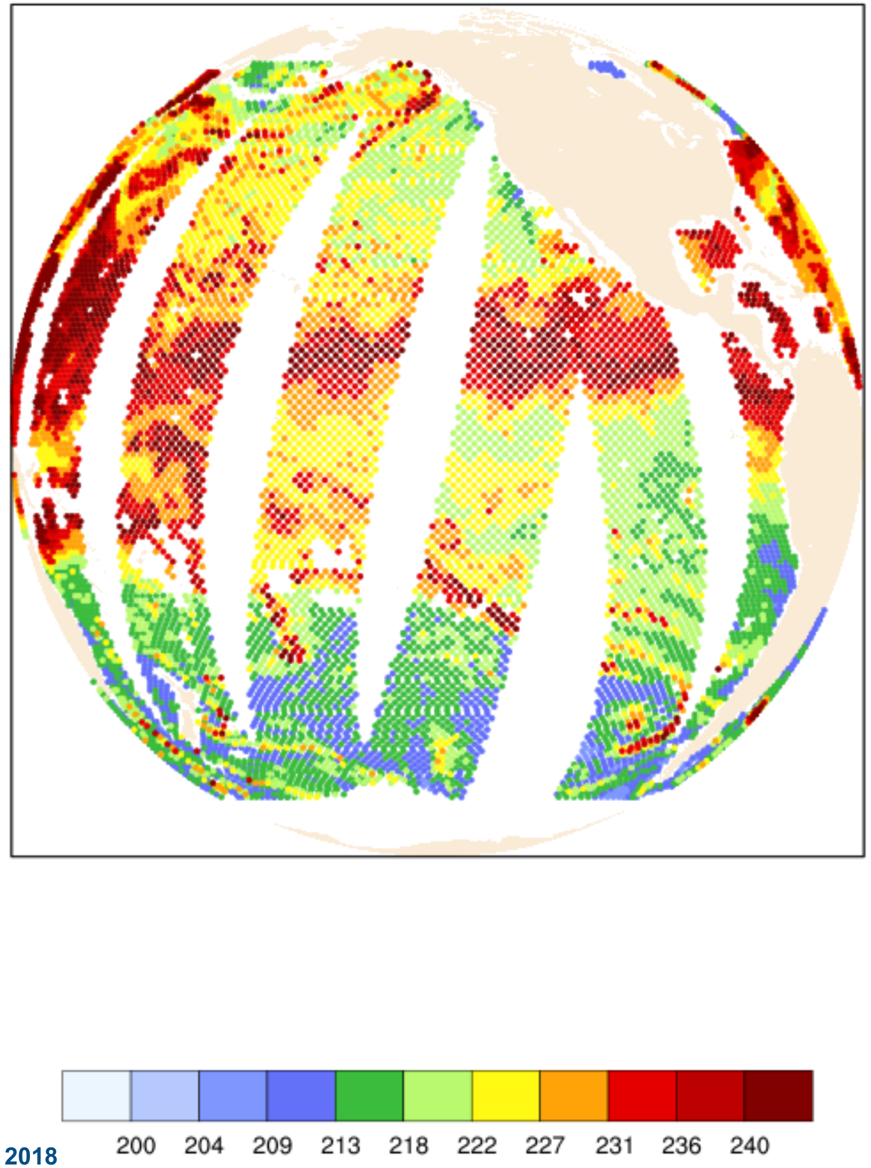
GOES mid-infrared – 15UTC

Dundee receiving station / NOAA / EUMETSAT



Microwave - 9-21UTCZ

AMSR2 37 GHz, v-polarised



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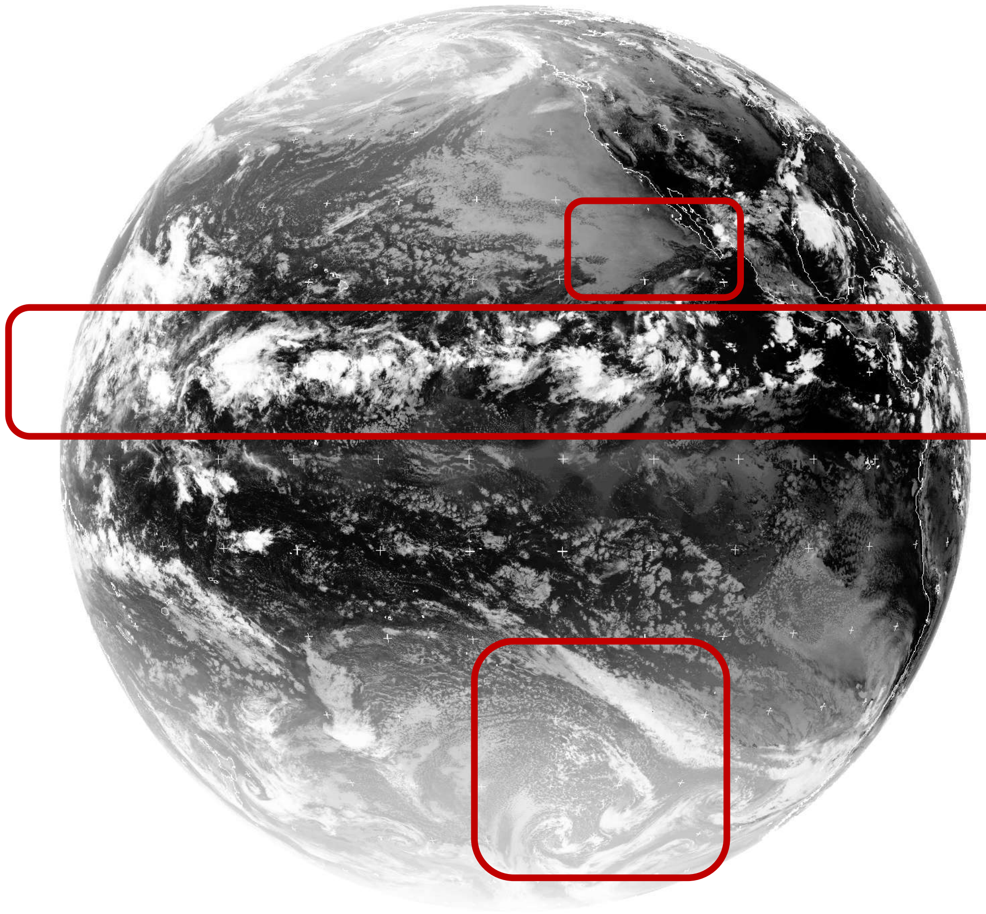

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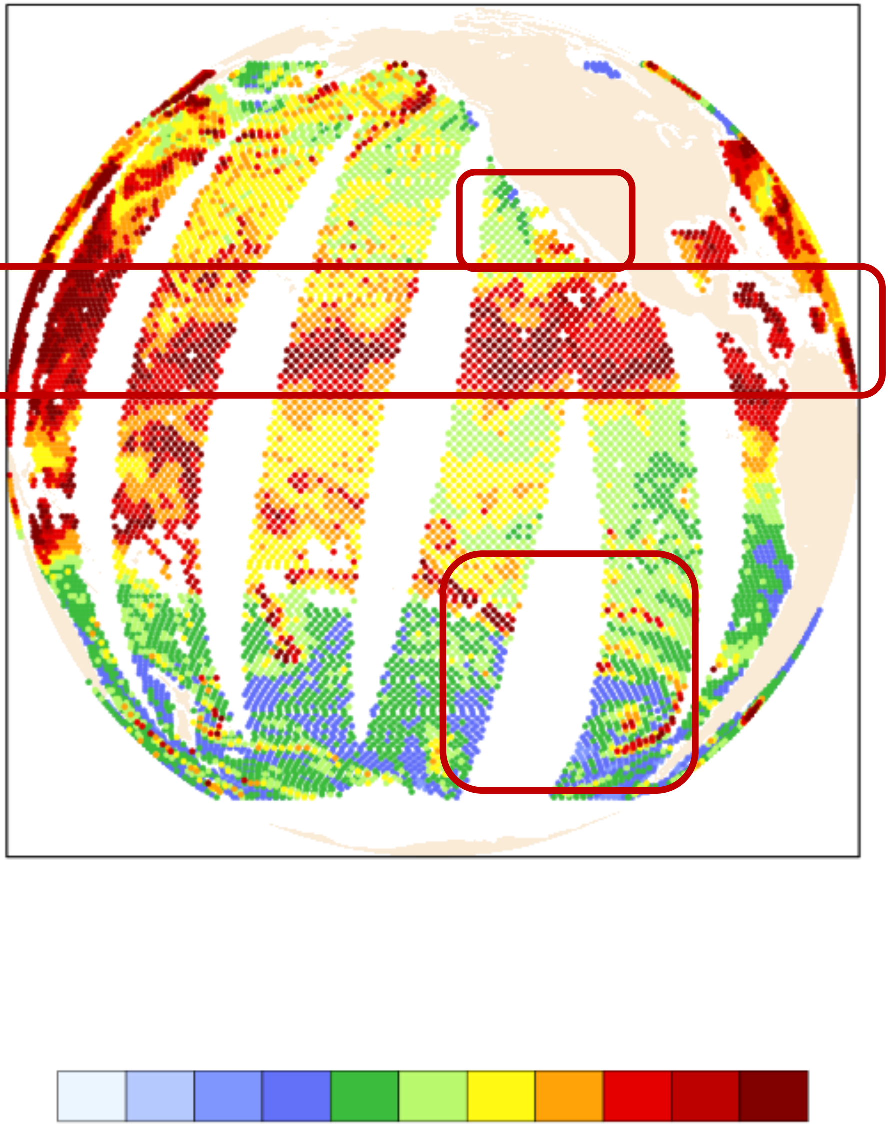

Variational bias correction

VarBC predictors

Imager channels	Sounding channels
Constant	Constant
	1000-300hPa thickness
	200-50hPa thickness
	10-1hPa thickness
	50-5hPa thickness
Tskin	
TCWV	
Surface windspeed	
nadir view angle^(1..4)	nadir view angle^(1..4)
	(ascending/descending bias)

VarBC predictors

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TCWV	
Surface windspeed	
nadir view angle^(1..4)	nadir view angle^(1..4)
	(ascending/descending bias)

No cloud predictor yet for all-sky assimilation

Addition of cloudy VarBC predictor for microwave imager channels

Addition of cloudy predictor: For C37 > 0.05 , Predictor = 1

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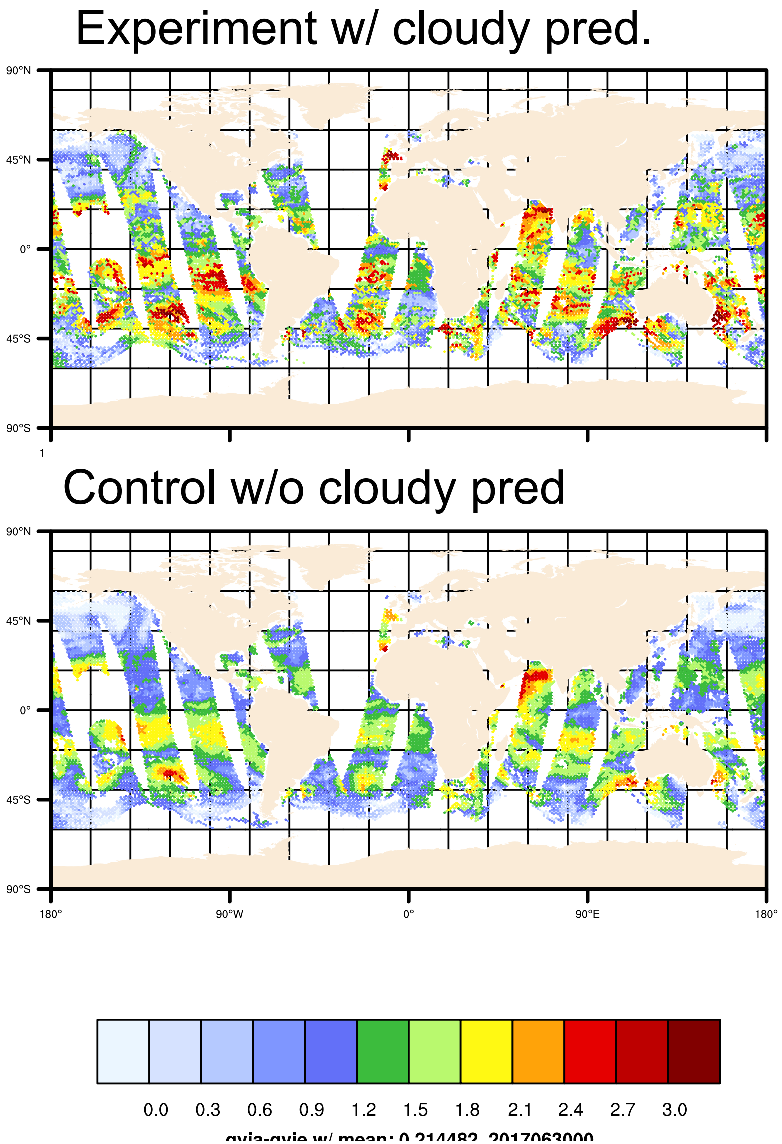
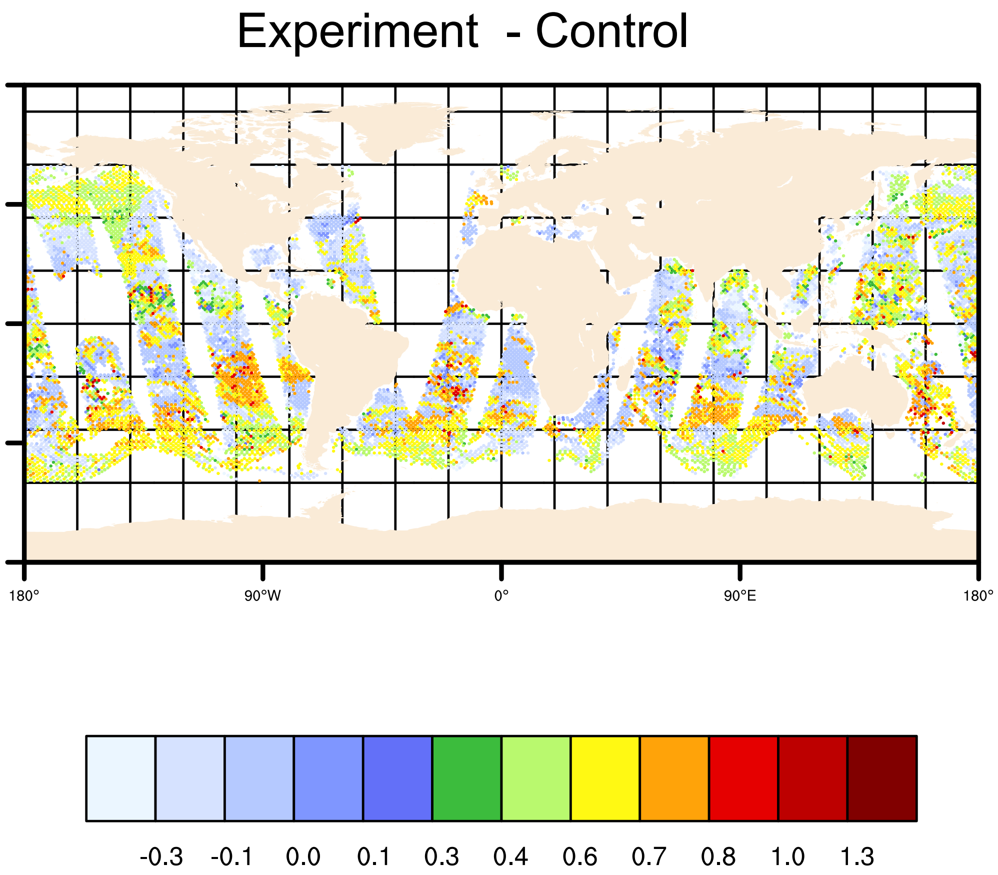
Addition of cloudy predictor: For C37 > 0.05 , Predictor = 1



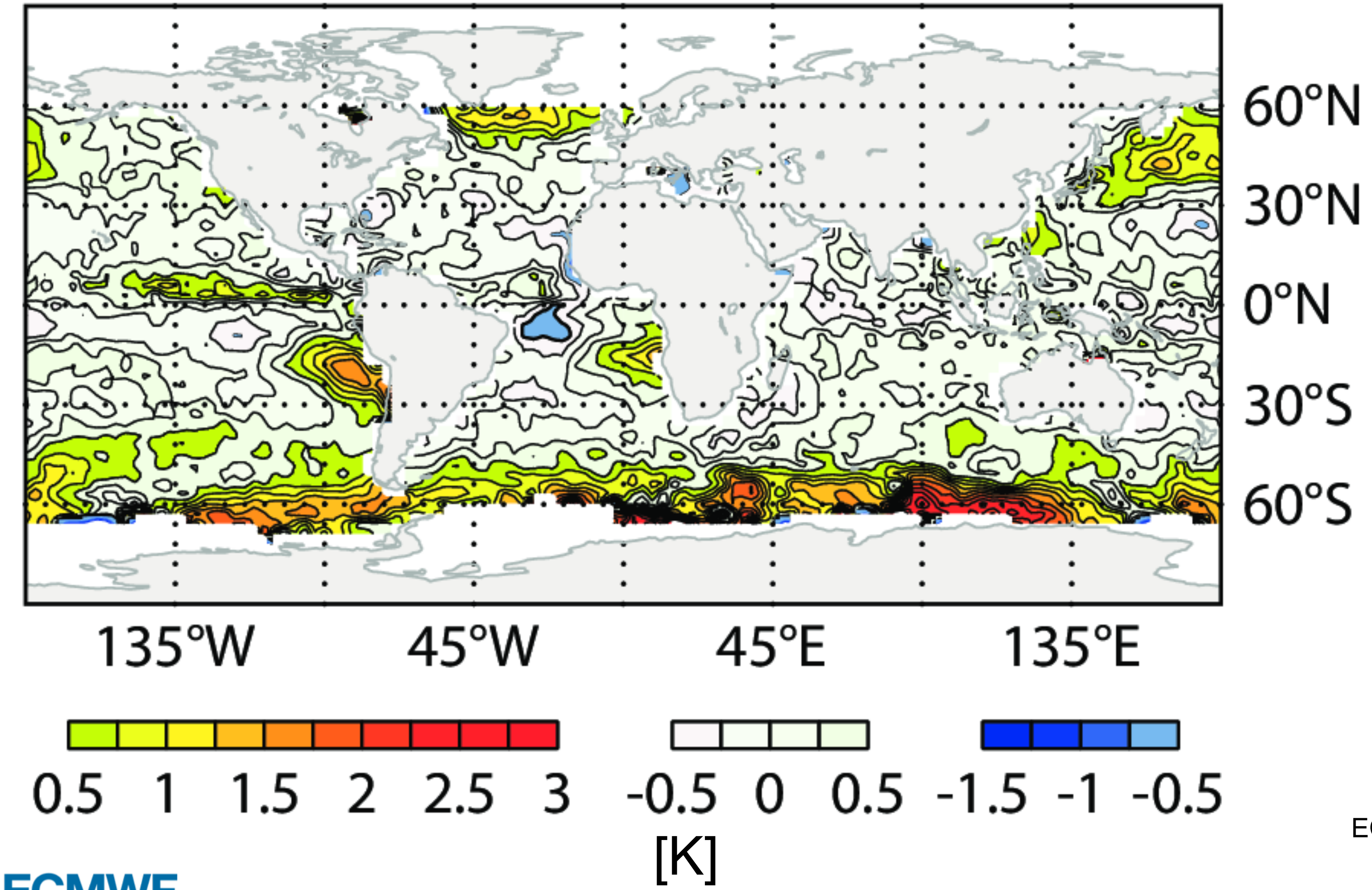
Bias correction [K] for 37 v SSMIS-F17
30 June 2017



Systematic model biases

Brightness temperature bias between observations and first guess (FG departure)

- Data from SSMI/S, 92 GHz, IFS Ops (HRES), May 2014 – April 2015



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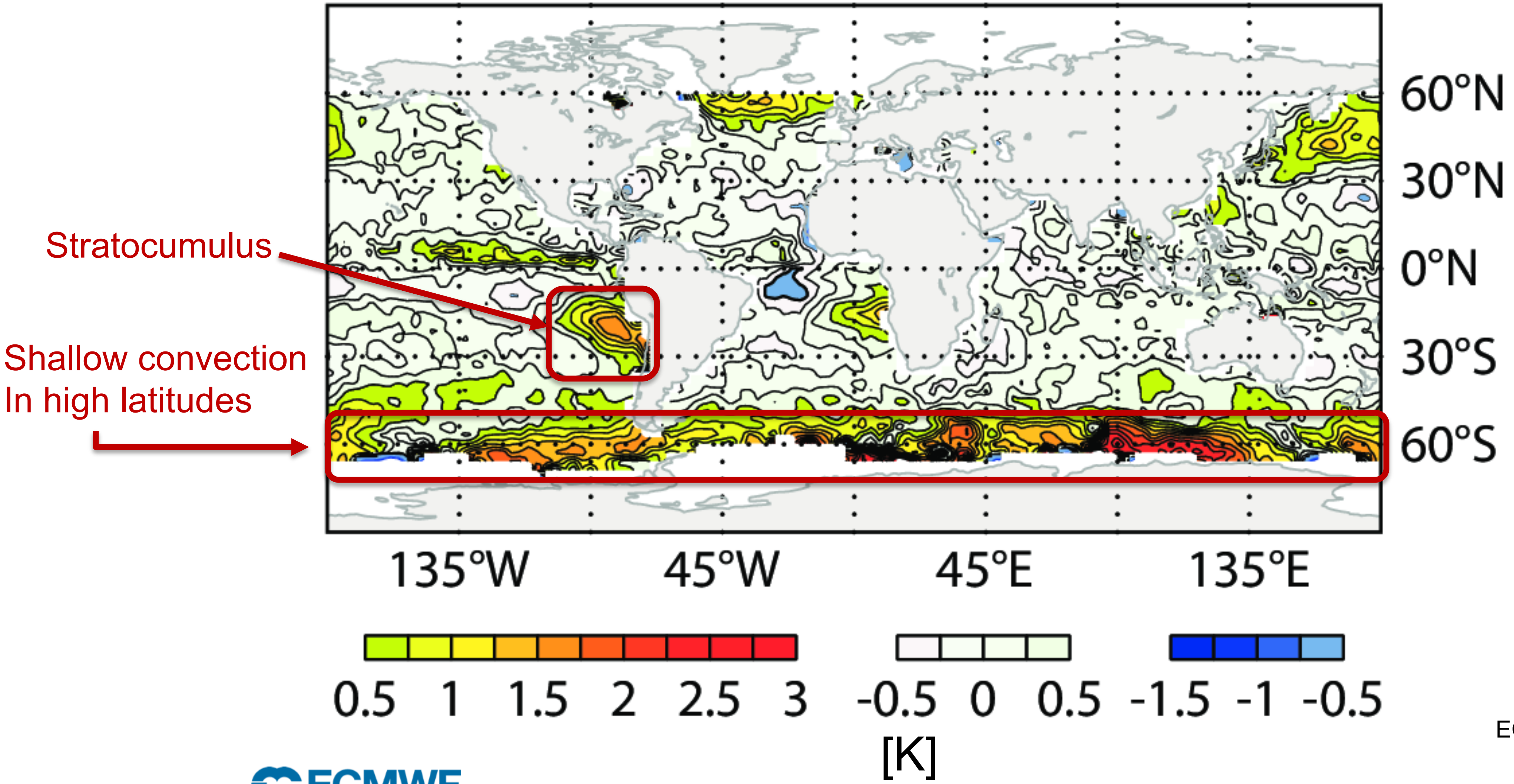

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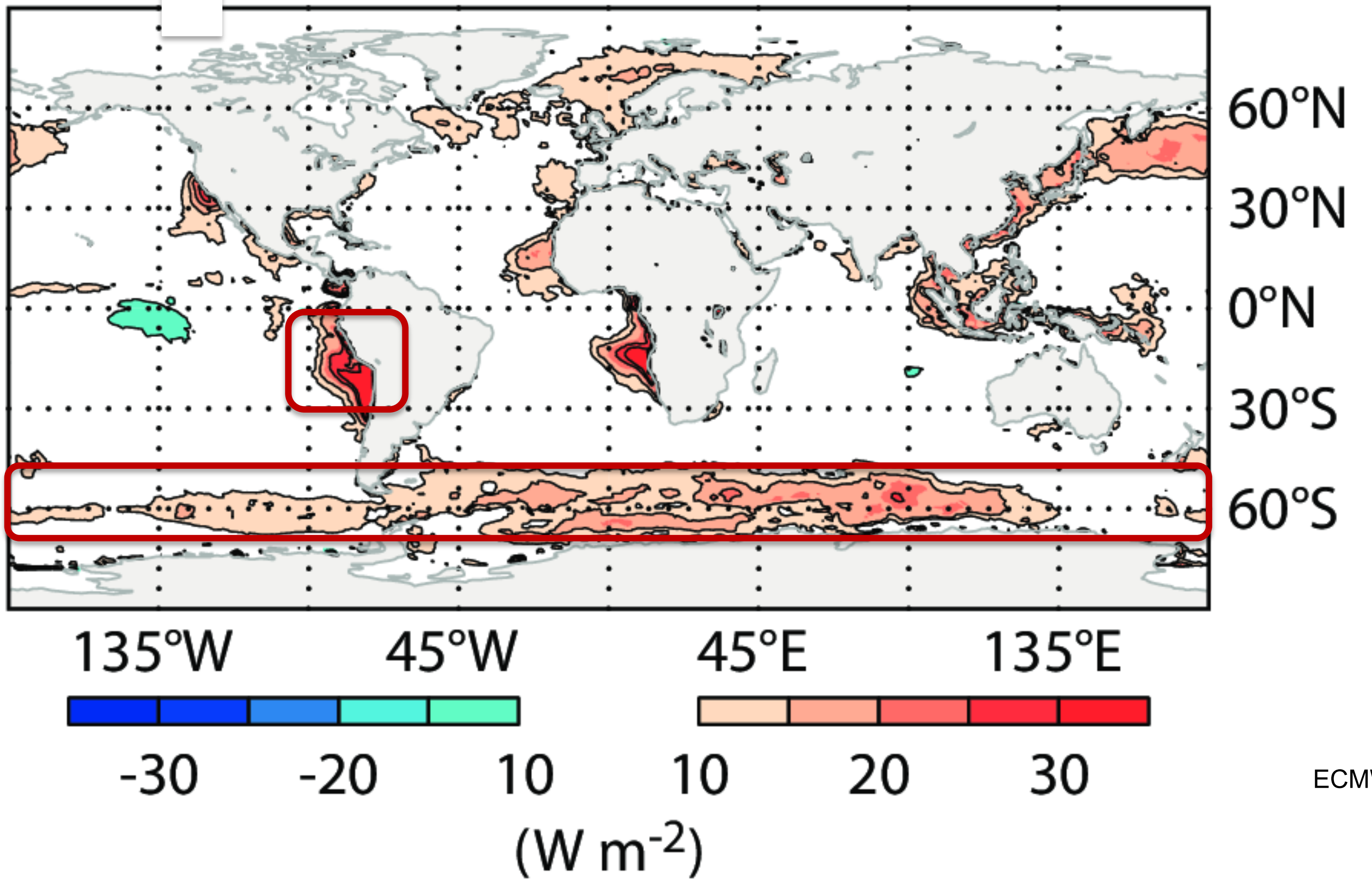
Net shortwave radiation difference (model – obs)

- Data CERES, 24 hour forecast top-of-atmosphere, IFS Ops (HRES), May 2014 – April 2015

Long-standing bias in SW



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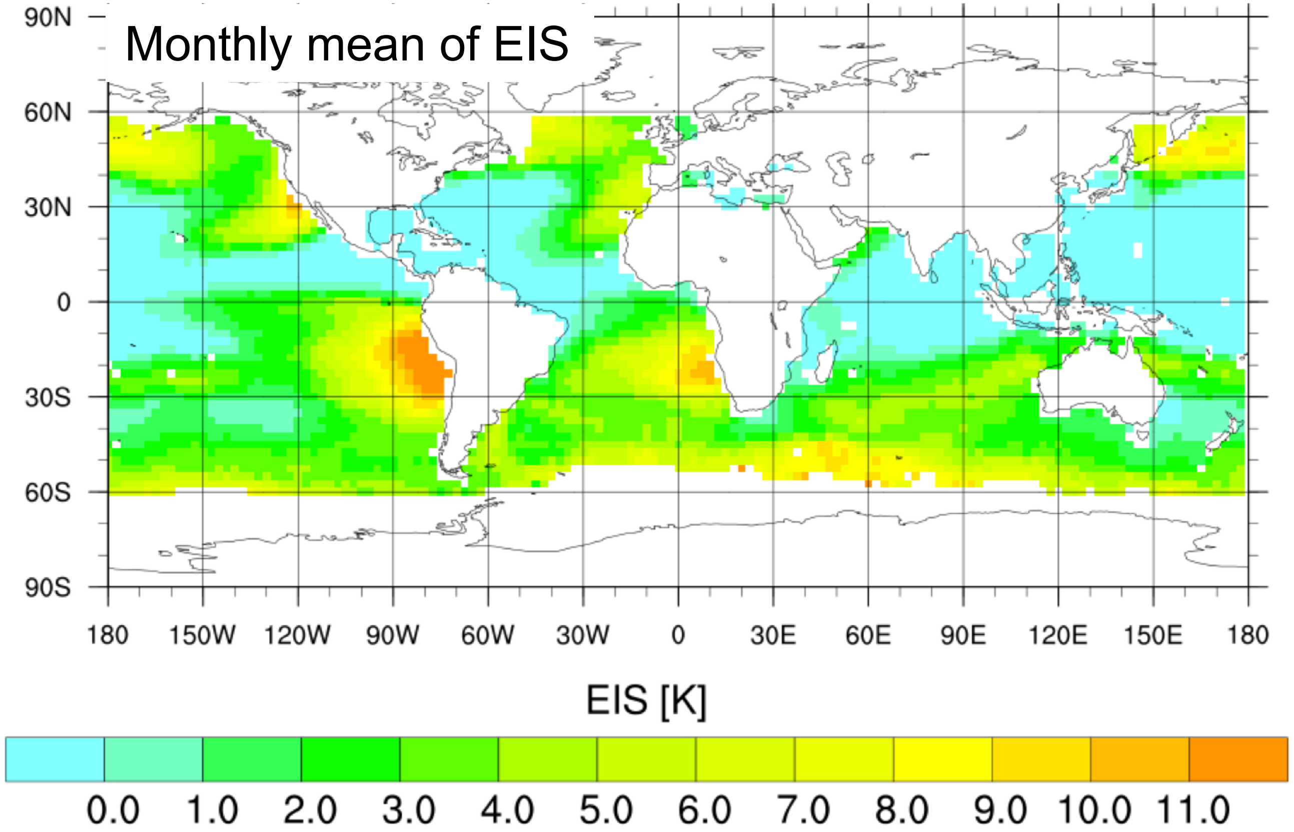
Systematic biases in Stratocumulus regions*

*EUMETSAT/ECMWF Fellowship Programme, Research Report No. 44

Using Estimated Inversion Strength (EIS) to detect Stratocumulus



$$EIS = LTS - \Gamma_{850}\,(Z_{700} - LCL)^{*}$$

Γ_{850}…adiabatic potential temperature gradient at 850 hPa [K m^{-1}]

Z_{700}…height of the p = 700 hPa surface [m]

LCL…lifting condensation level [m]

LTS…lower-tropospheric stability [K]

* Wood and Bretherton, 2006

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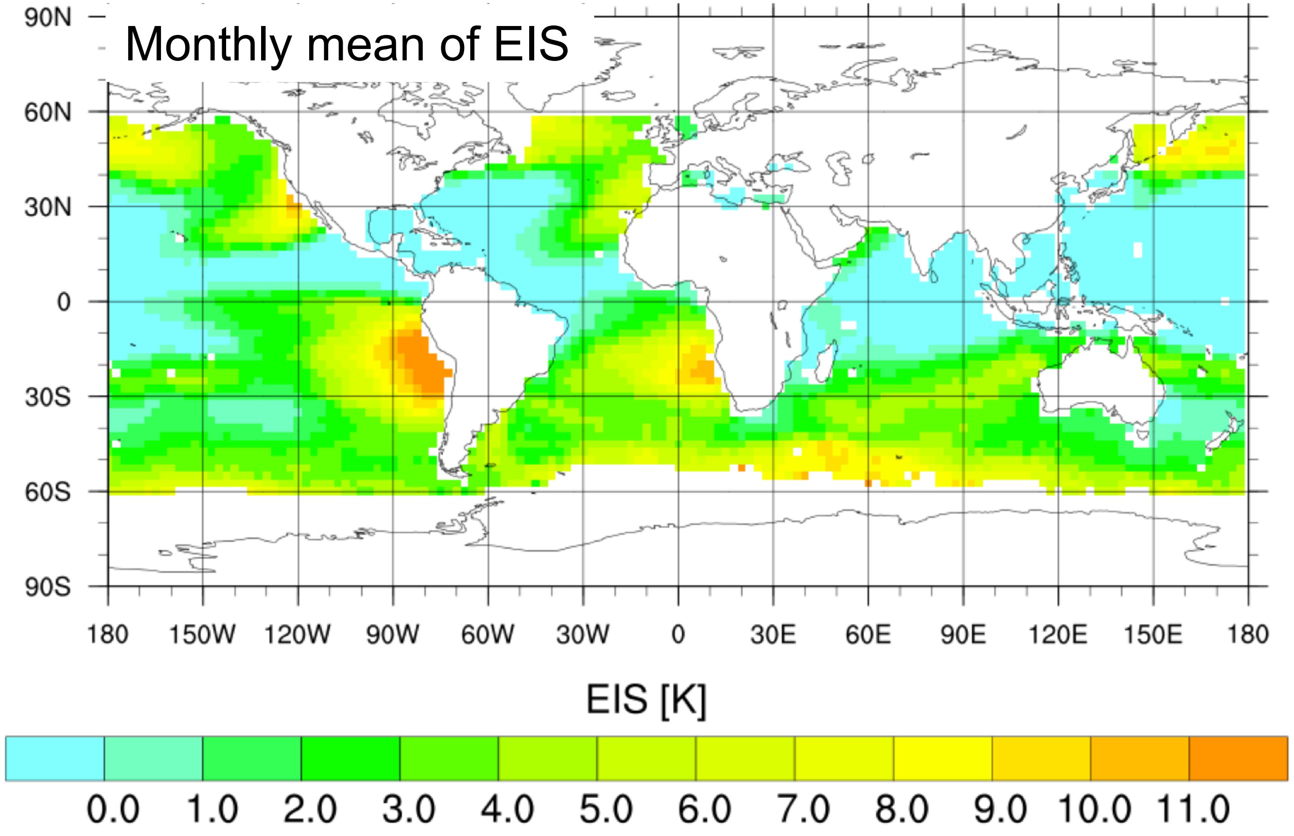

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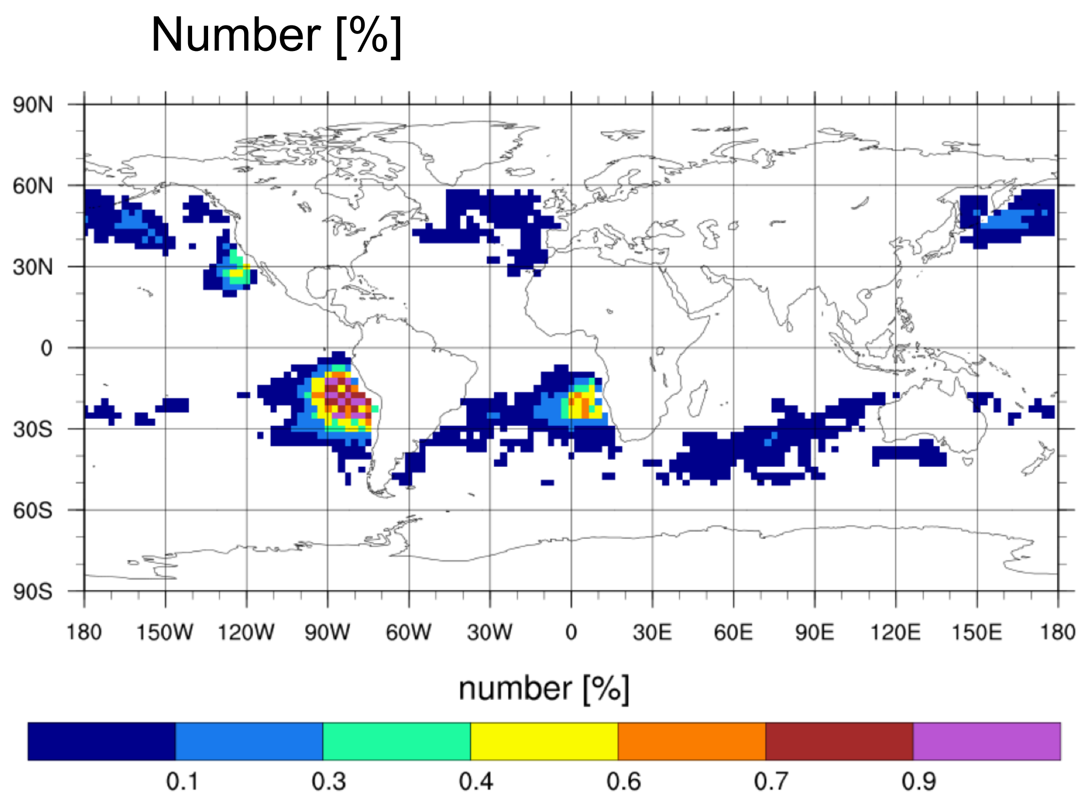
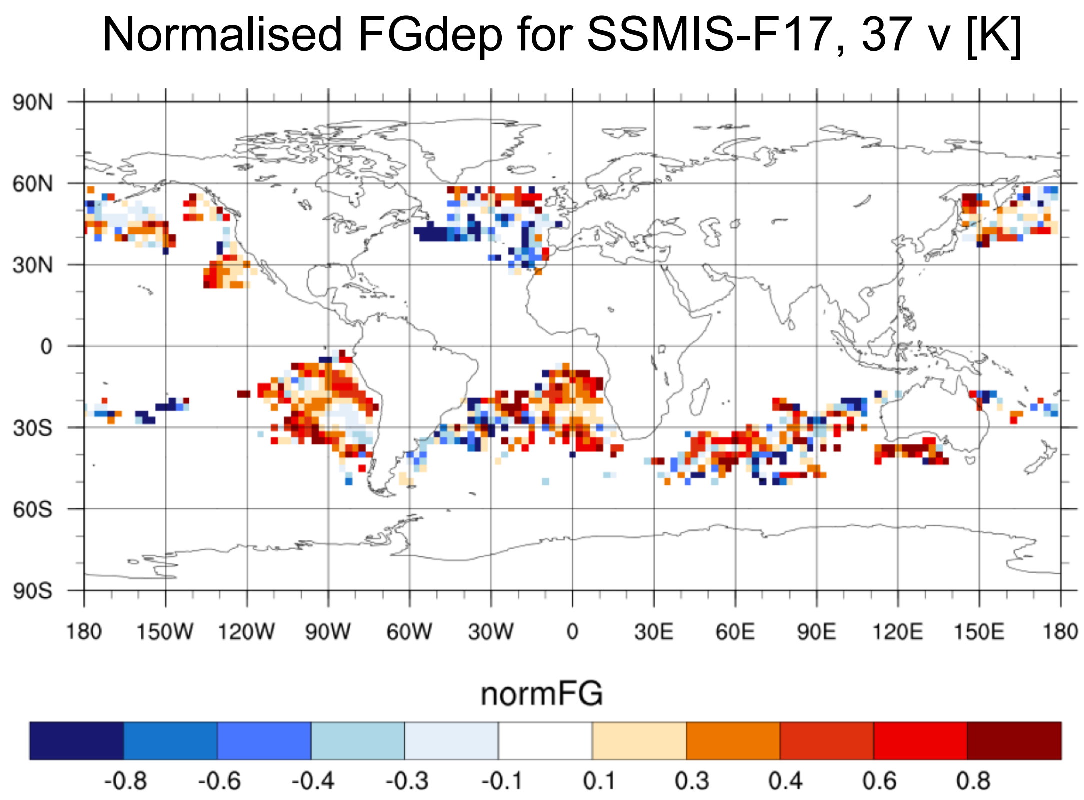
Identifying Stratocumuls regions:

$$EIS > 9K,$$
$$IWP + SWP < 10^{-12} kg\, m^{-2}$$

Using Estimated Inversion Strength (EIS) to detect Stratocumulus





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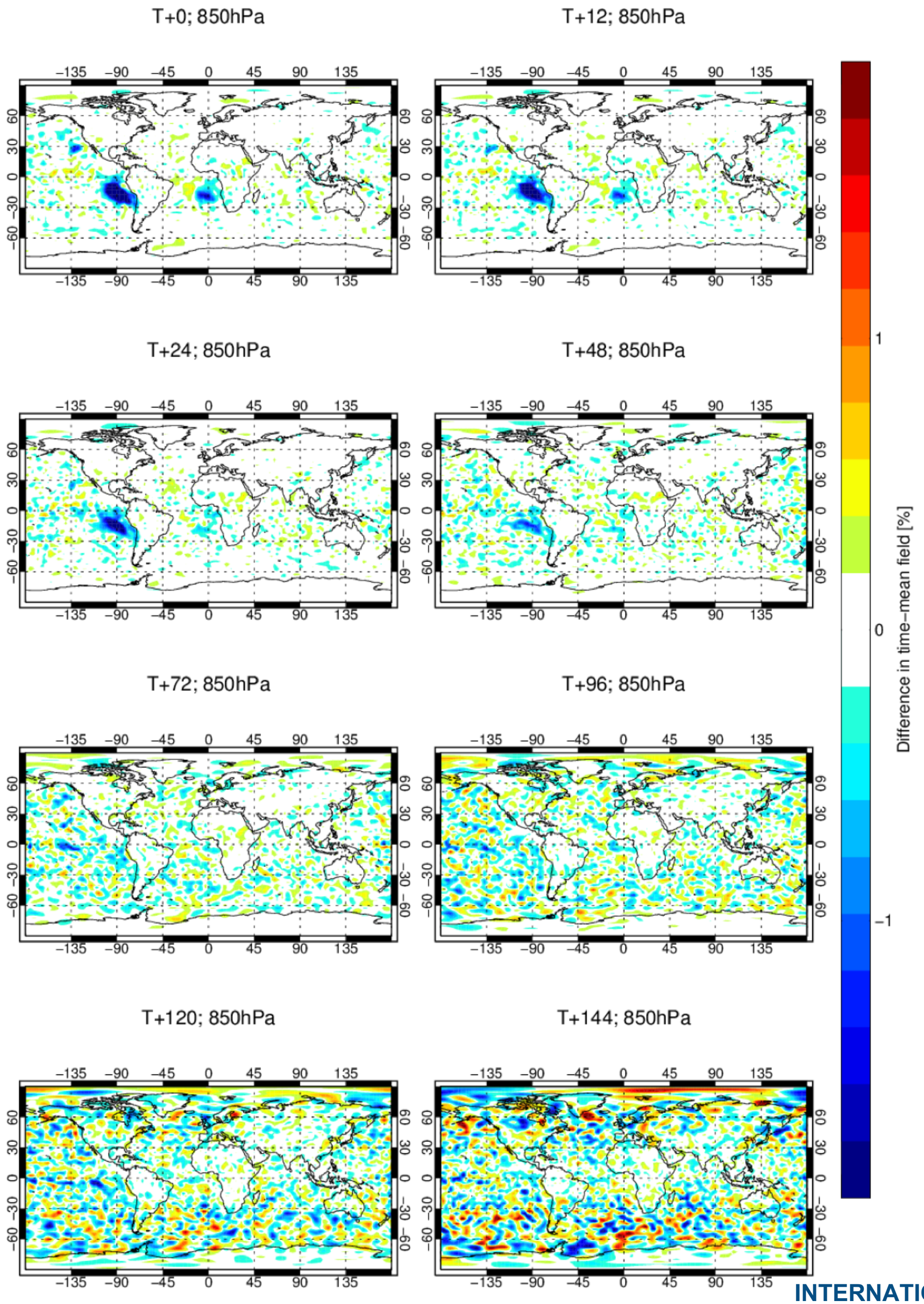
Difference in mean humidity (Sc off – ctrl)

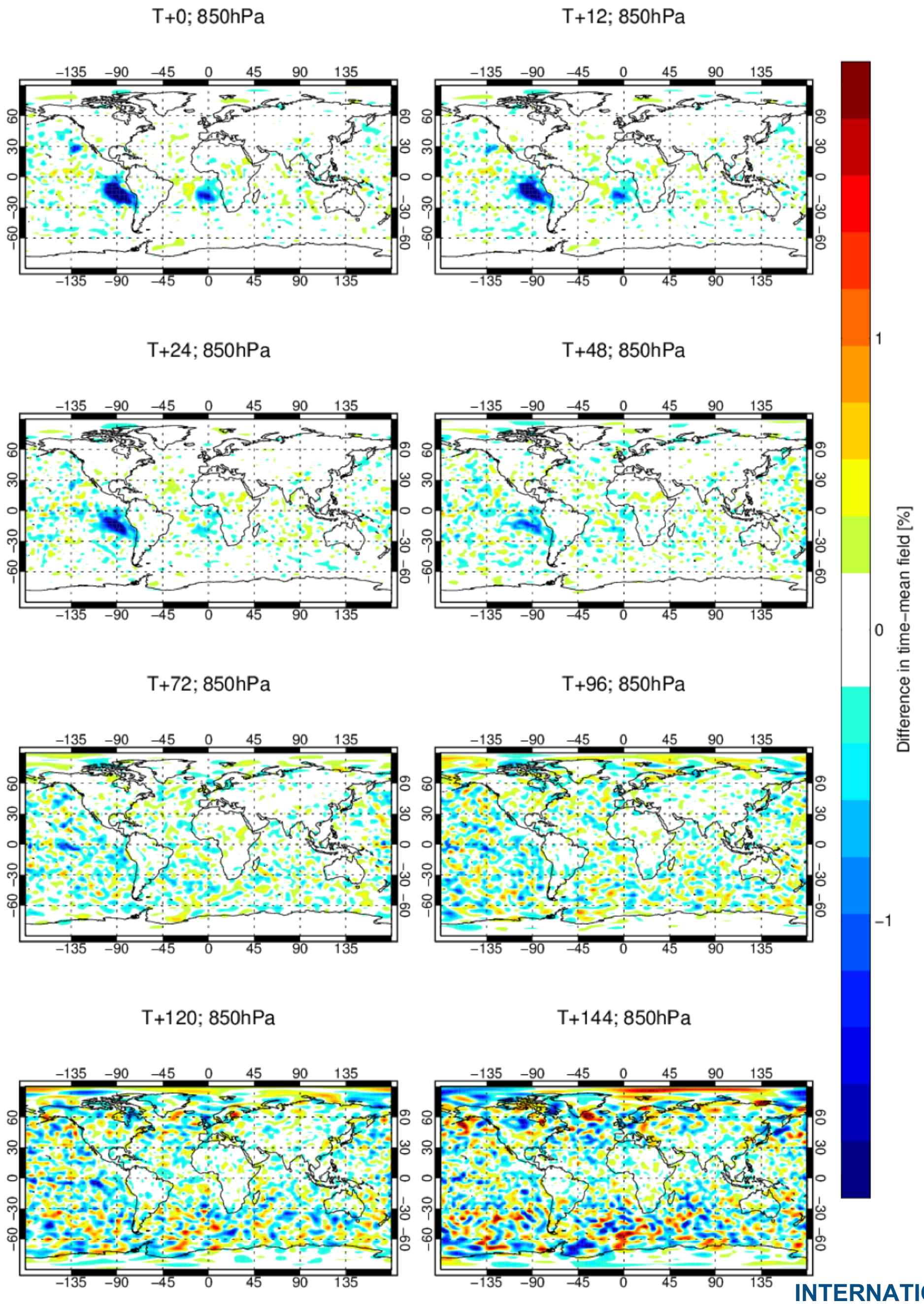


Increase

Changes in forecast scores for humidity at 850hPa

decrease

Difference in mean humidity (Sc off – ctrl)

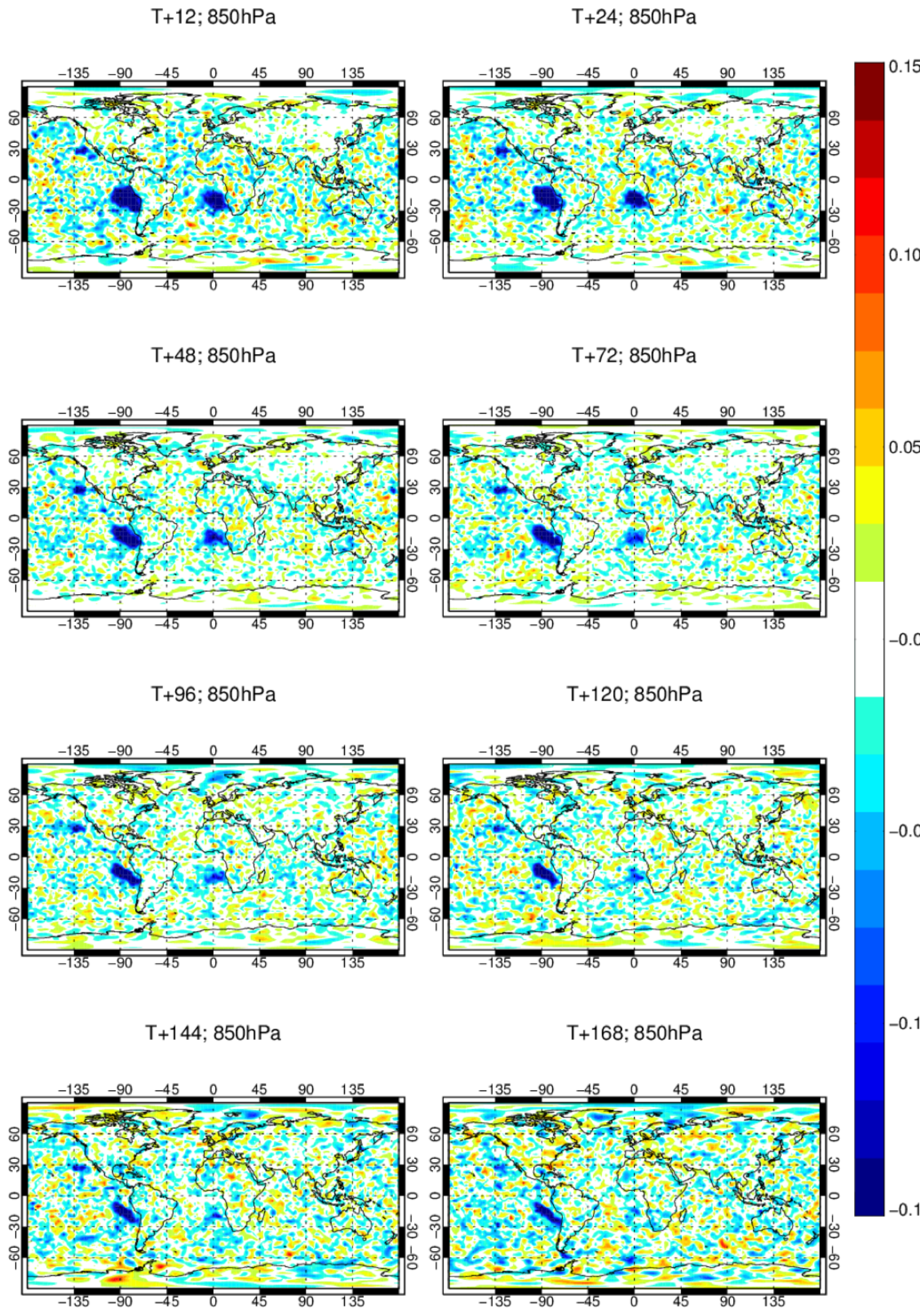


Increase

Changes in forecast scores for humidity at 850hPa

decrease

Change in humidity error (Sc off – ctrl)



Summary: Systematic biases in Stratocumulus regions

- Biases in Stratocumulus fields are believed to be caused by too little drizzle or cloud water.
- The estimated inversion strength (EIS) is a fair indicator to detect regions of stratocumulus but is not able to distinguish well enough the areas of bias from those areas unaffected, i.e EIS is not recommend to be used as a predictor.
- Screening Stratocumulus fields does not alter medium-range forecast, it only changes the analysis and short-range forecast in very localised stratocumulus areas.
- Observations in stratocumulus areas are probably useful for the assimilation system and should, therefore not be screened.

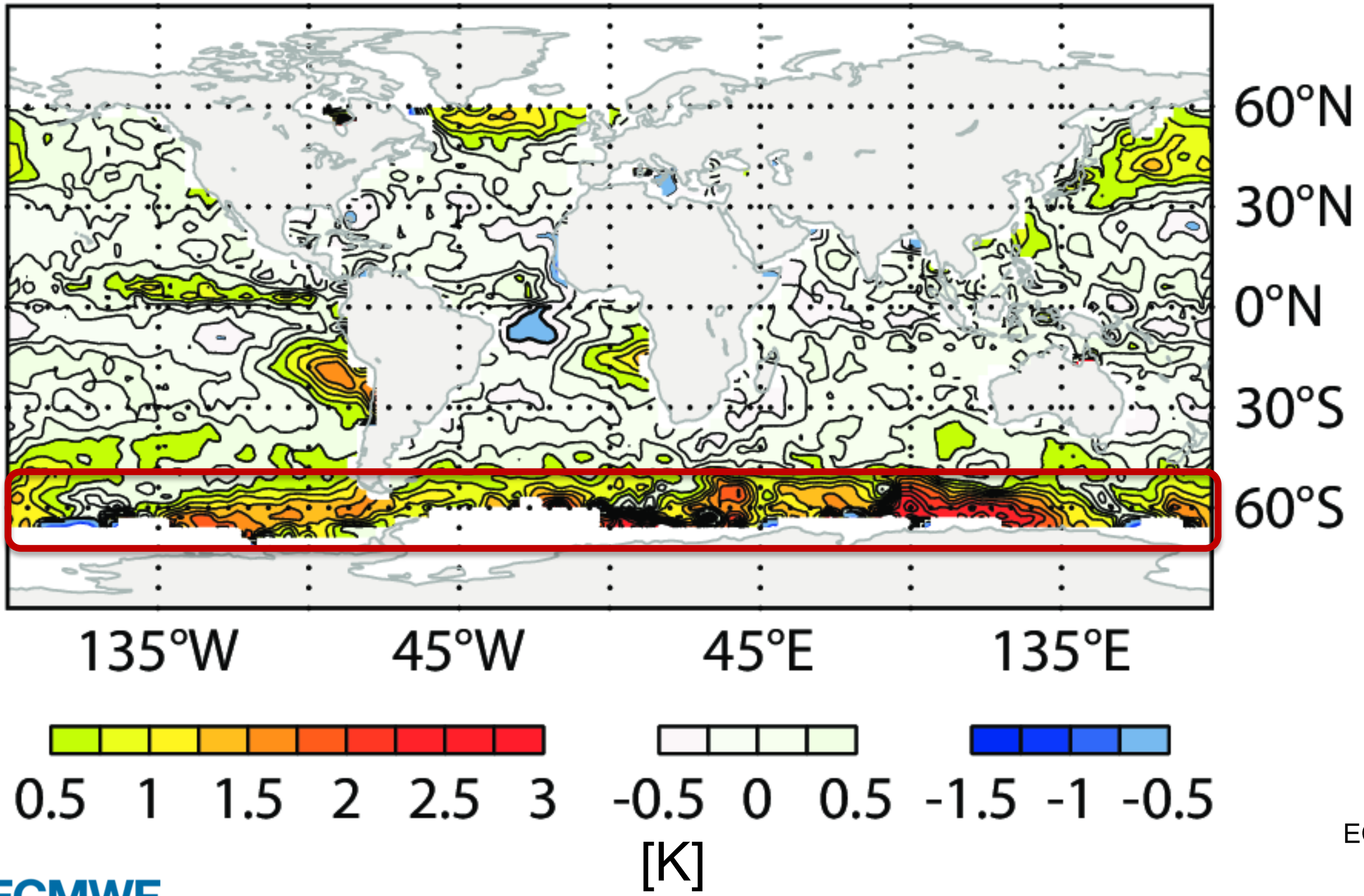
Systematic biases in higher latitudes*

*ECMWF Newsletter No. 146

Shallow convection in high latitudes

- Data from SSMI/S-F17, 92 GHz, IFS Ops (HRES), May 2014 – April 2015

Shallow convection
In high latitudes



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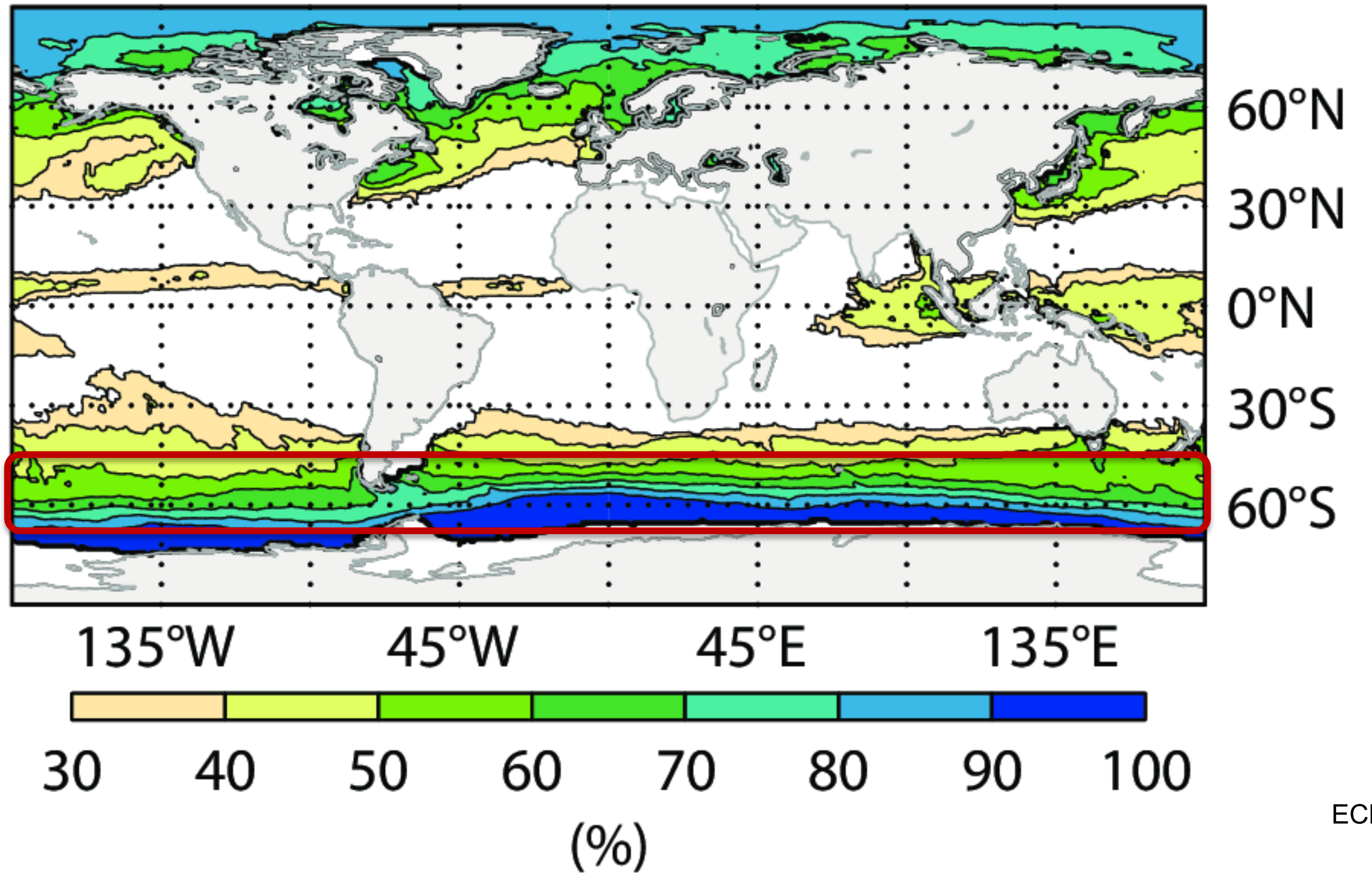
Shallow convection in high latitudes

- Percentage of total vertically integrated supercooled cloud liquid



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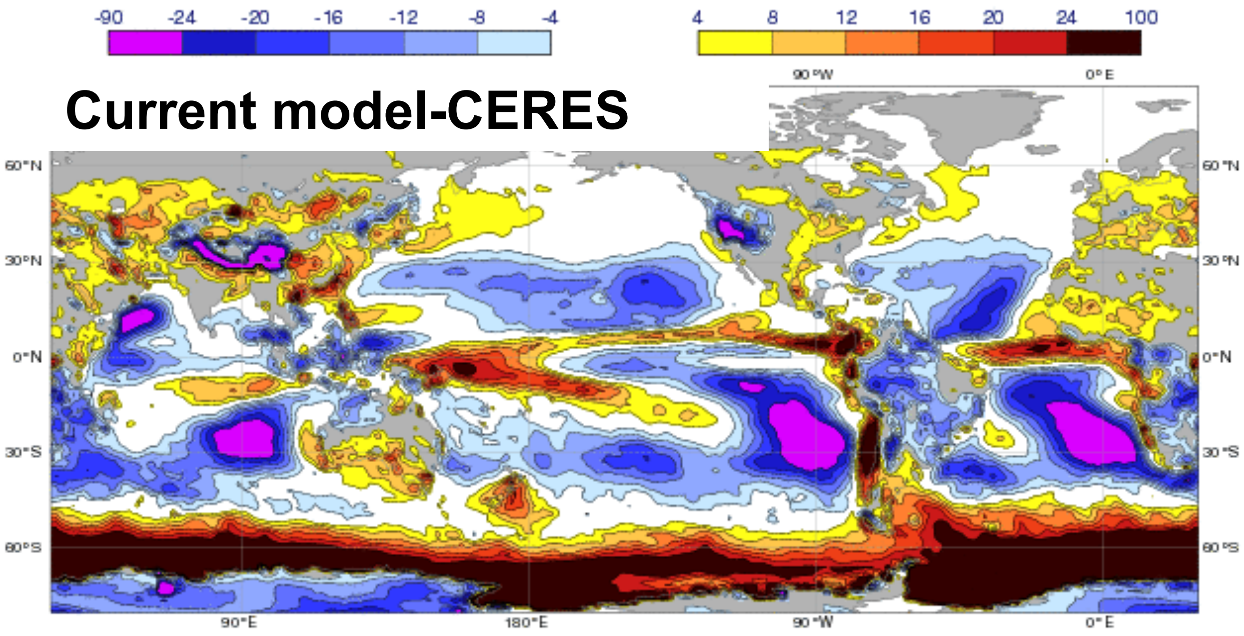
Shortwave bias between model and CERES

- Coupled integrations for **new** and **current IFS model cycle**, 1981 -2010, DJF

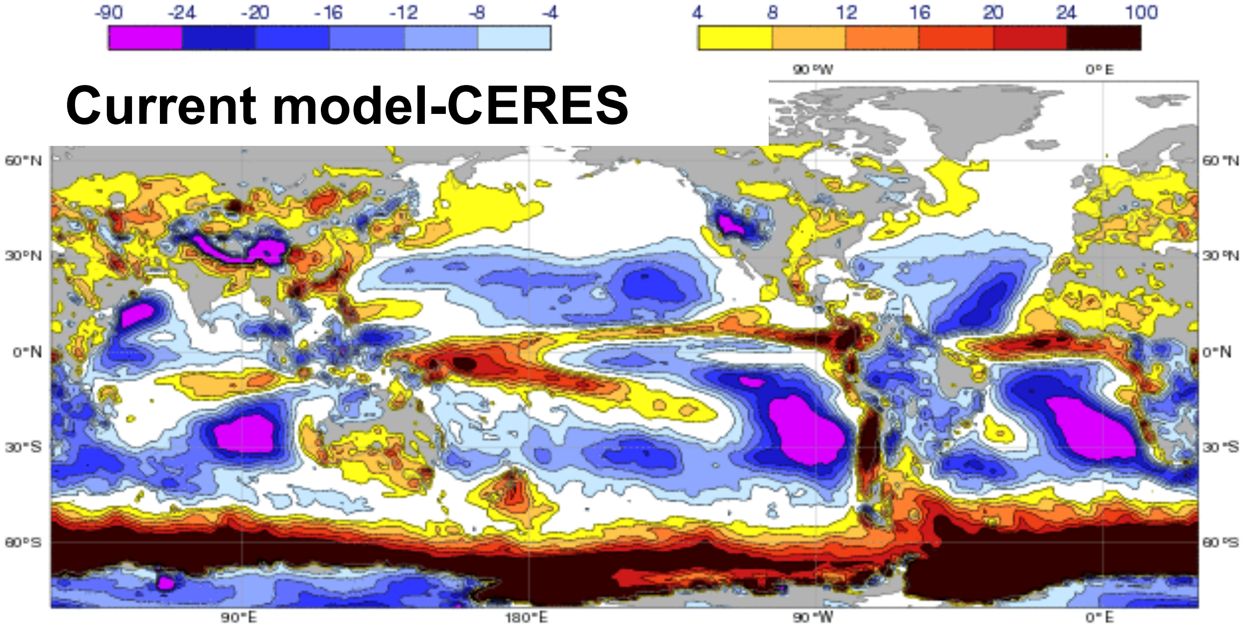
[W m^{-2}]

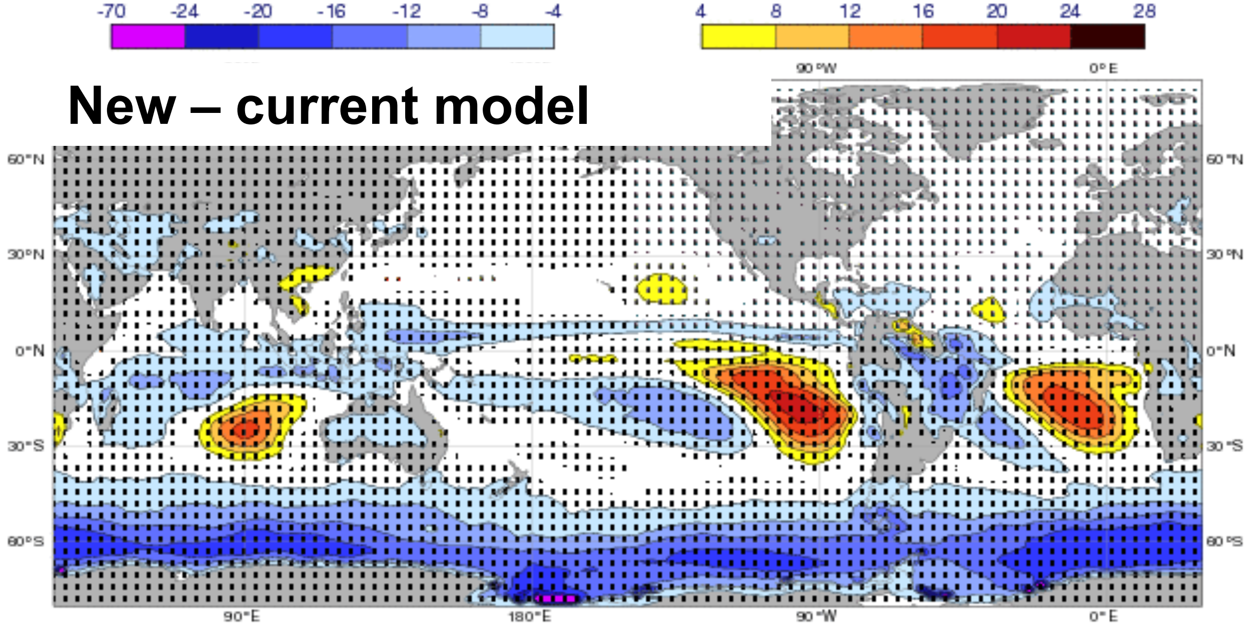
Current model-CERES



Shortwave bias between model and CERES

- Coupled integrations for **new** and **current IFS model cycle**, 1981 -2010, DJF





- **New model**: enables the production of only liquid for shallow clouds for temperatures down to -38 °C (Richard Forbes, Peter Bechtold)
  → corrects SW radiation error in SH by around 20 W/m2 or 15%

Summary: Systematic biases in higher latitudes

- IFS like many other NWP and climate models underestimate amount of supercooled liquid water in higher latitudes(Forbes et al 2016 ,Bodas Salcedo et al 2016)
- Bias understood through study of systematic underestimation of MW brightness temperatures in cold-air outbreak regions
- New IFS cycle improved to allow existence of surface driven shallow cumulus clouds which consists of supercooled liquid water only, (down to -38°C)

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Summary
-
Different options of dealing with biases

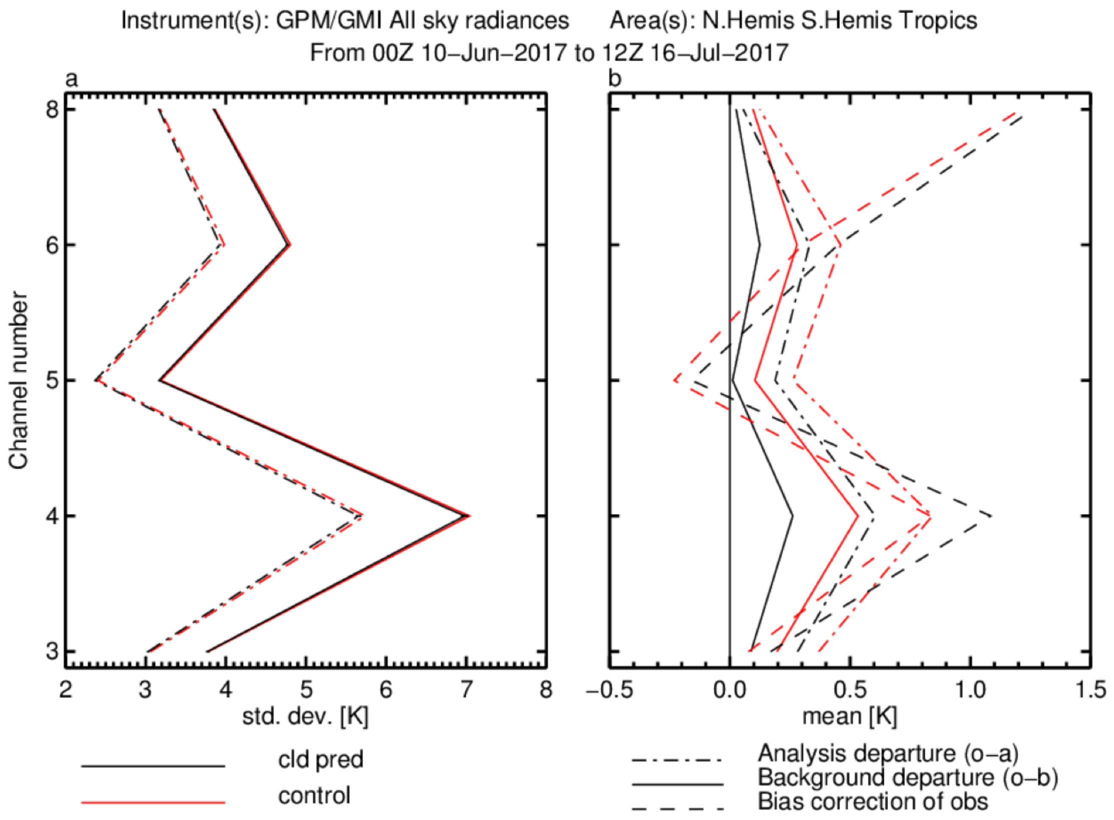
Bias correction	(No) Screening	Improving forecast model
Test of using cloudy predictor for all-sky assimilation of microwave imagers	Bias in Stratocumulus fields (no screen) Bias in cold-air outbreaks	Representation of supercooled liquid water in higher latitudes

Backup

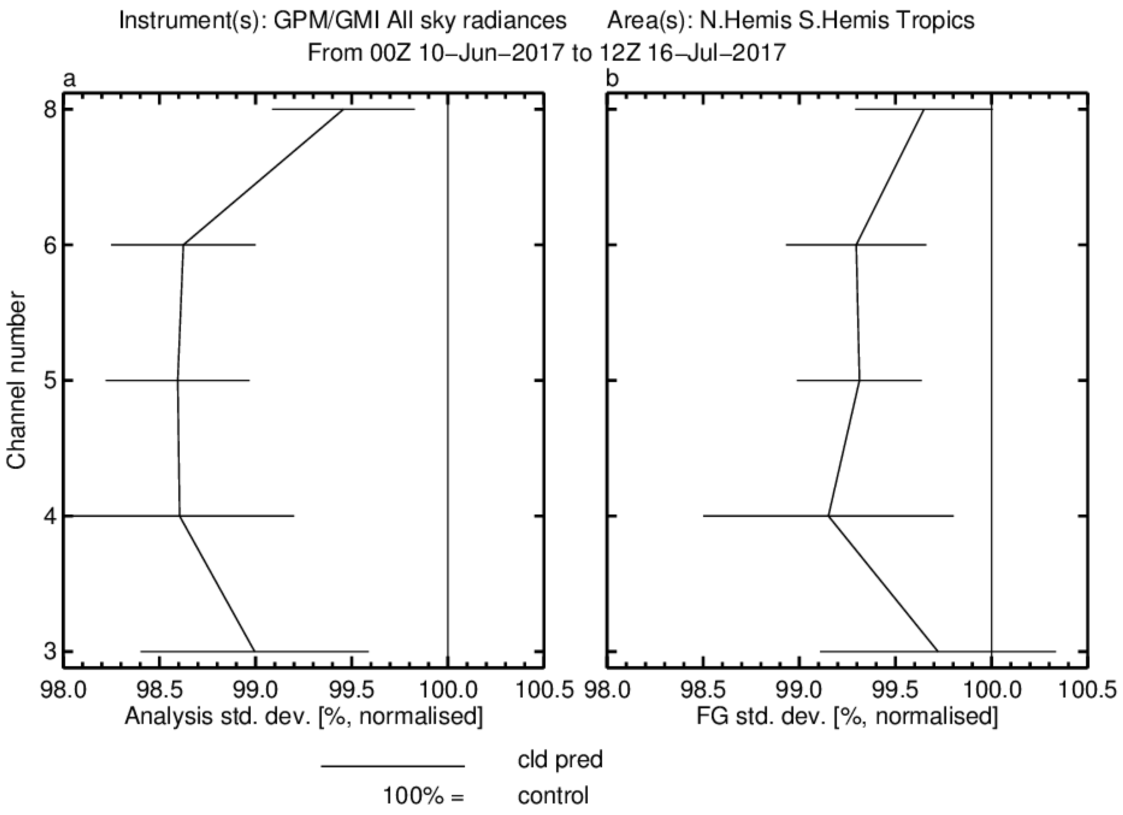
Addition of cloudy VarBC predictor for microwave imager channels

Addition of cloudy predictor: For C37 > 0.05 , Predictor = 1

GMI obstat fits



GMI normalised obstat fits



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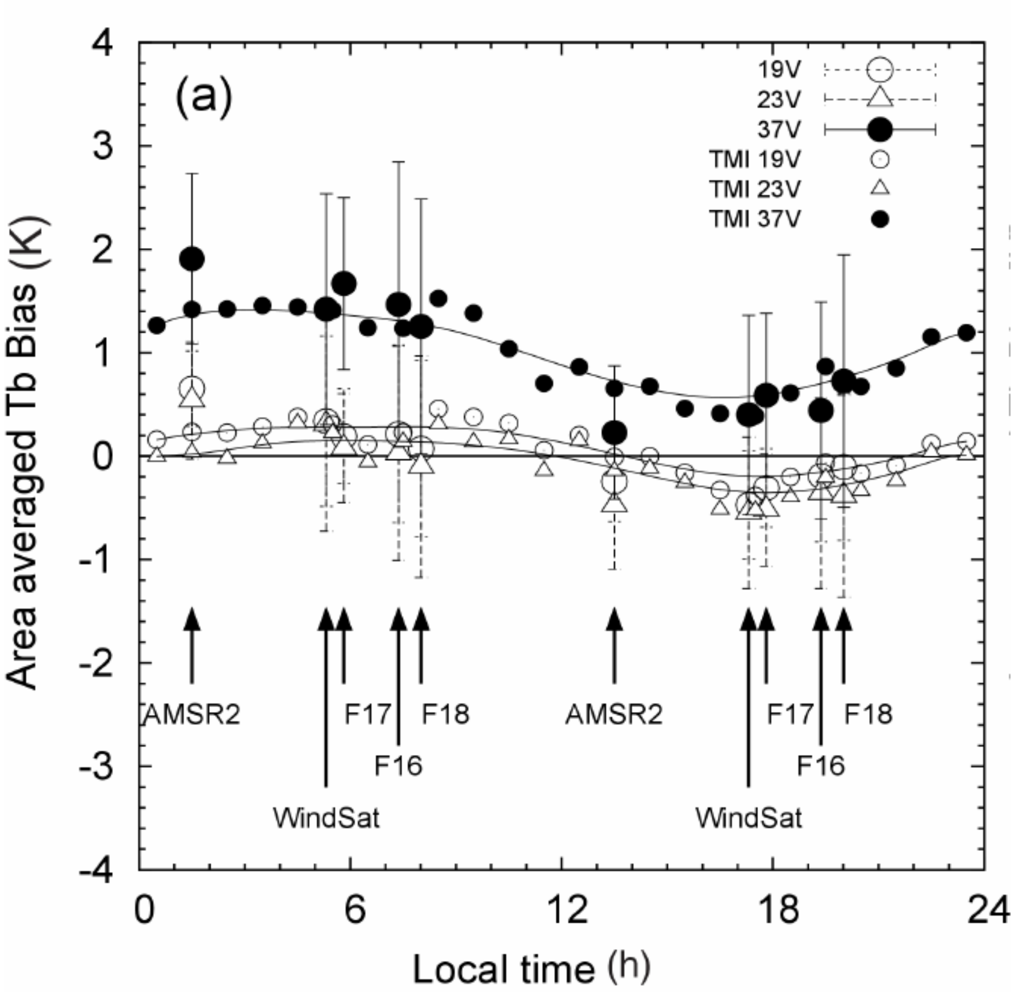
Biases in Stratocumulus fields

Daily cycle in brightness temperature in Stratocumulus area

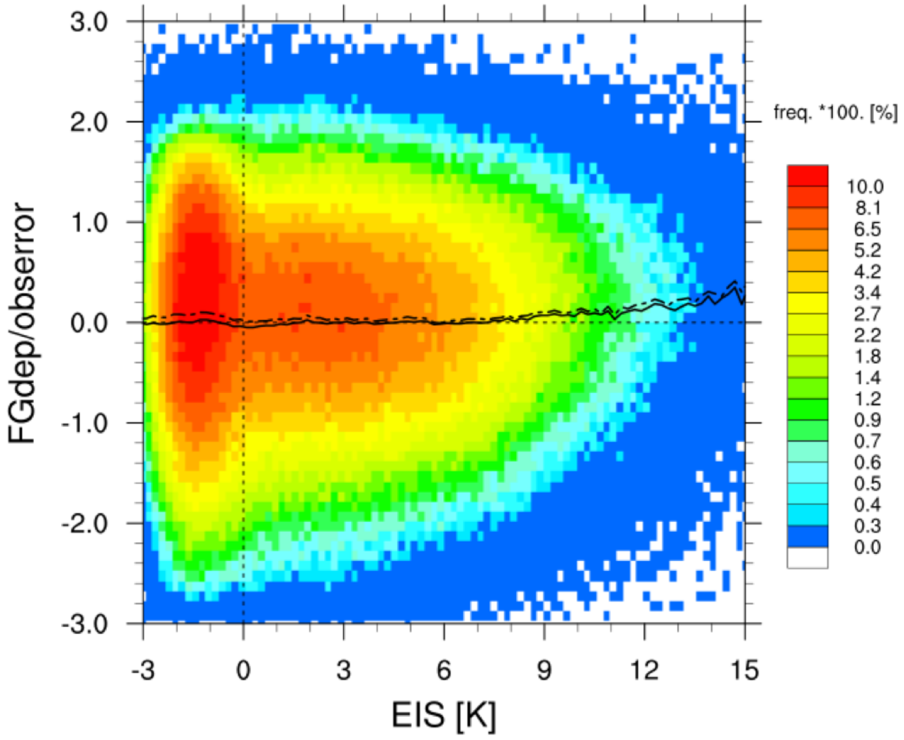


- Daily cycle in bias seen through all alll-sky assimilation of MWI
- Larger bias in the morning compared to the evening
- Physical Processes Team in working on reducing/removing bias

Fig.: Biases as functions of observation local time of microwave imagers (AMSR2, SSMIS F16, F17, F18, WindSat, and TMI) for 15 June to 15 October 2013 from selected Sc area off the west coast of South America.

Kazumori et al 2016, QJRMS

Using Estimated Inversion Strength (EIS) to detect Stratocumulus



- Test if EIS can be used as VarBC predictor
  → not good enough

- Use EIS for liquid clouds to screen microwave imager observations in Stratocumulus fields.
  → 42R1 experiments: control & Sc off
  → 6 months of testing: 1 July- 31 Dec. 2013

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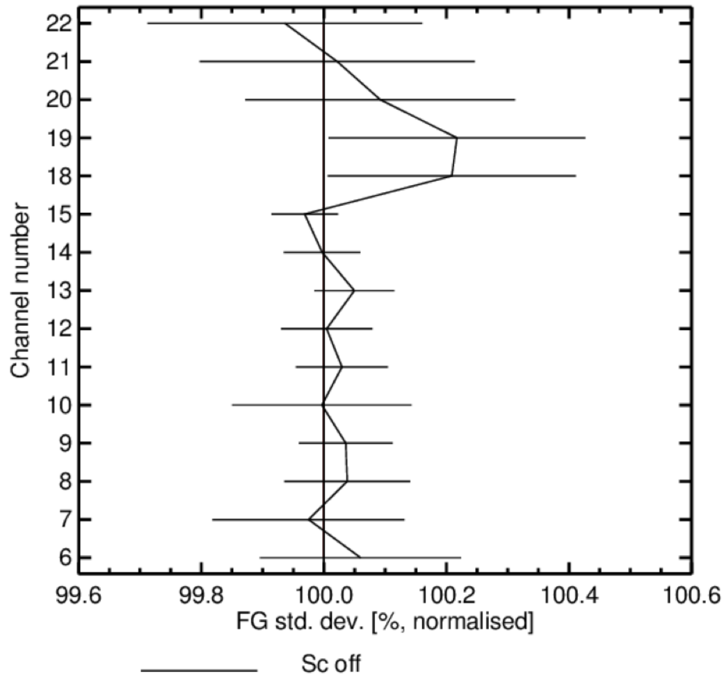
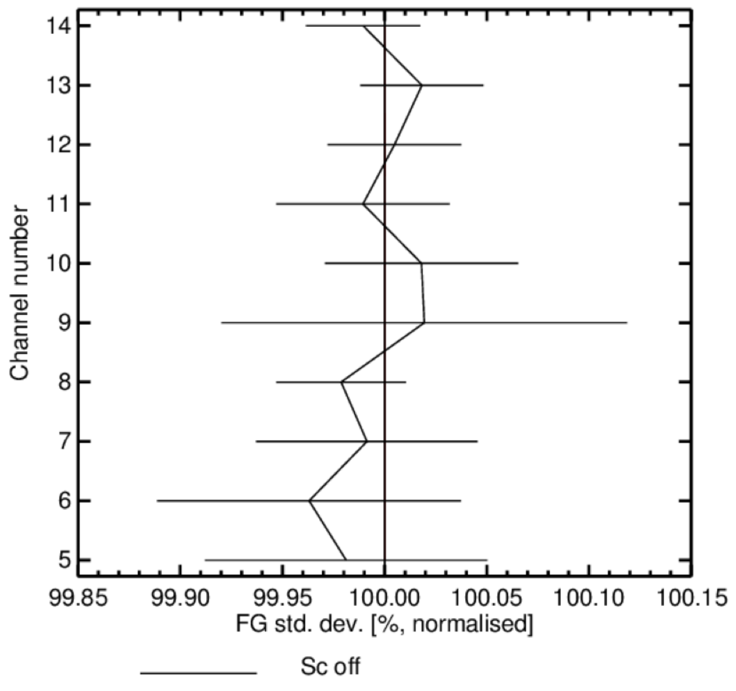
Observational verification - Tropics

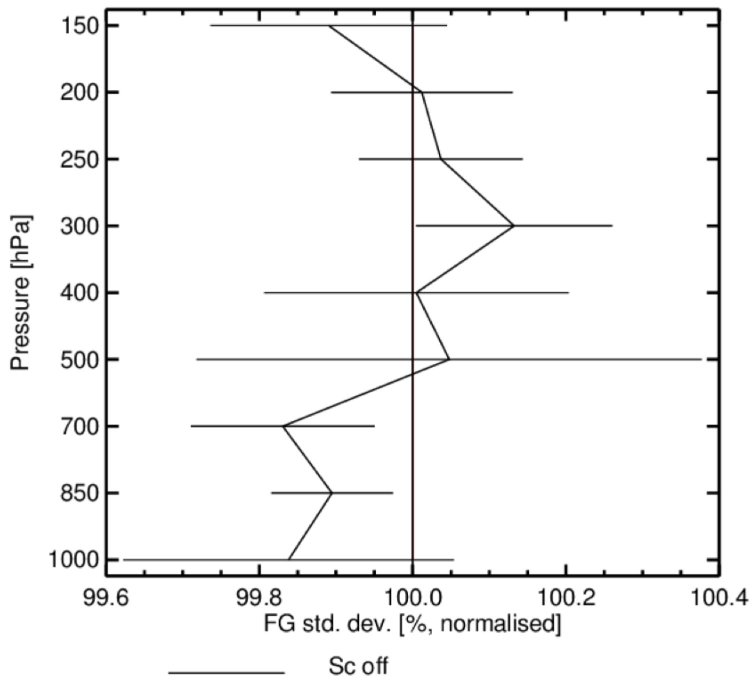
ATMS



AMSUA



AMVs



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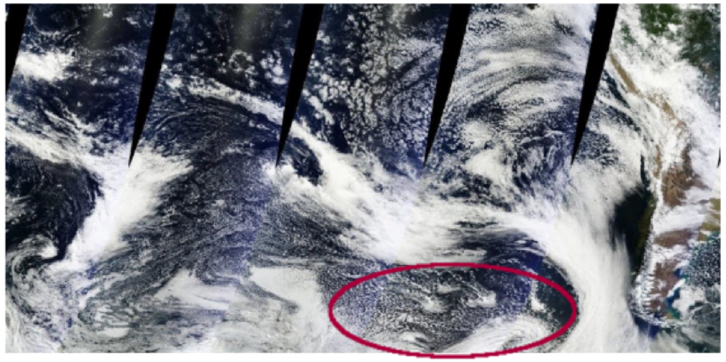
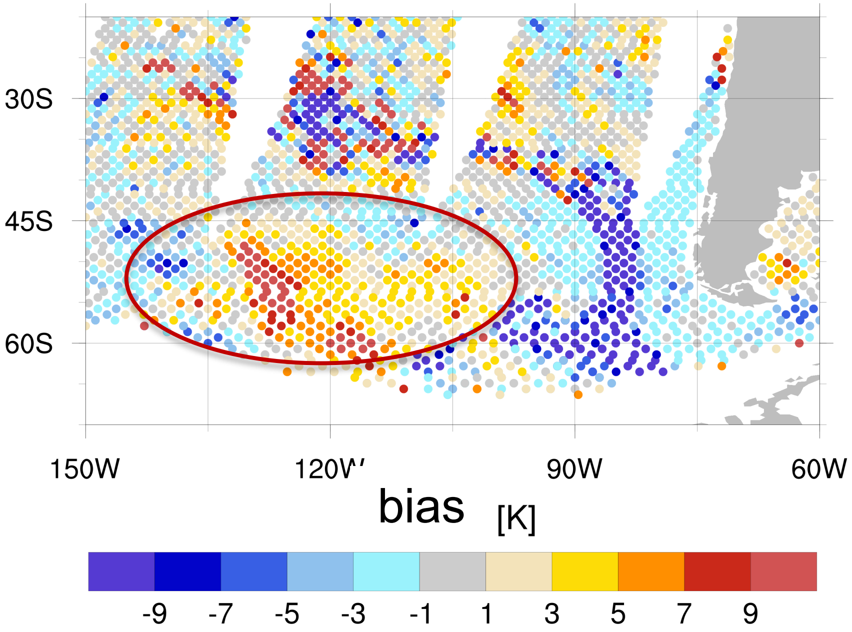
Case study of shallow convection in high latitudes

- 24 August 2013

MODIS Picture



Bias in 37GHz

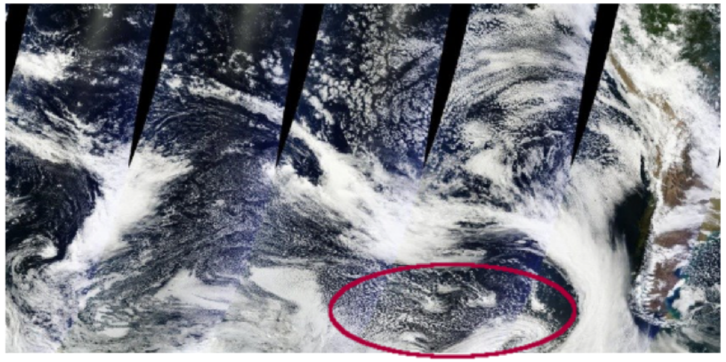


- Areas with positive bias have been identified as cold-air outbreaks.
- Unstable boundary layer creating low-level cumulus clouds.
- Often in liquid phase even though the temperatures are well below 0ºC.

Case study of shallow convection in high latitudes

- 24 August 2013

MODIS Picture



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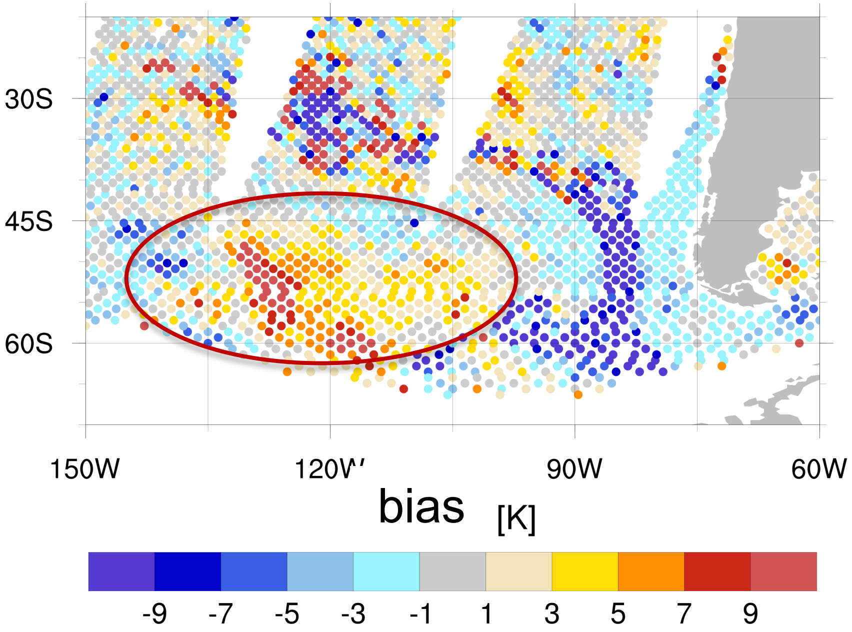
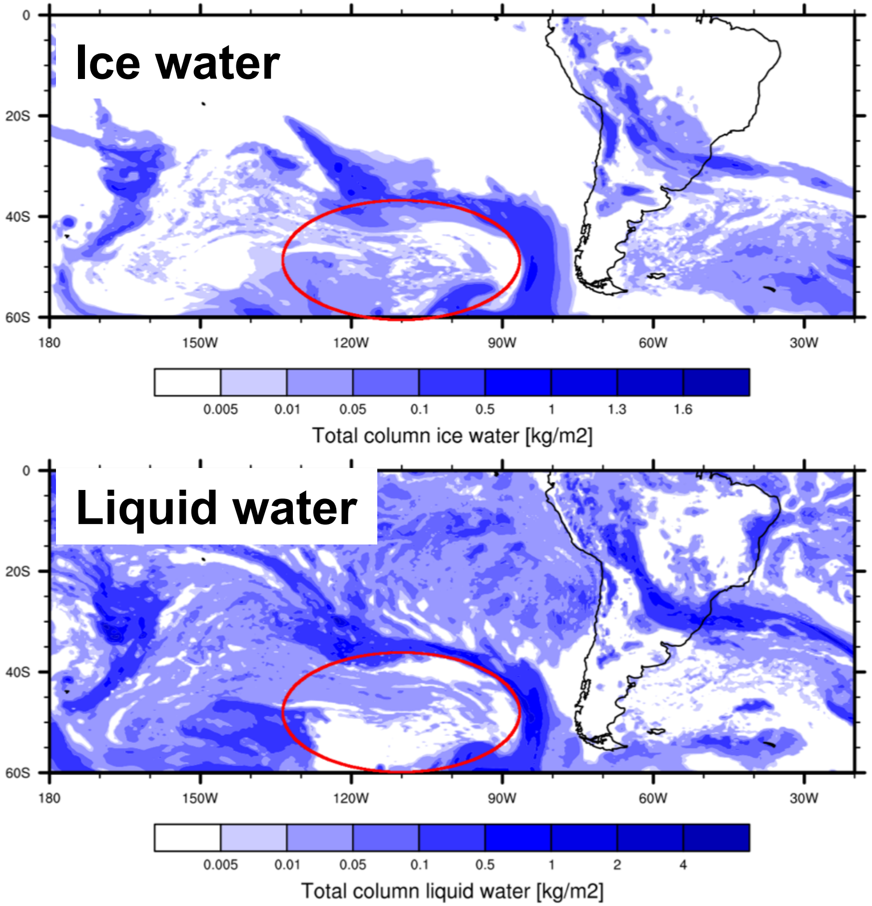


- Areas with positive bias have been identified as cold-air outbreaks.
- Unstable boundary layer creating low-level cumulus clouds.
- Often in liquid phase even though the temperatures are well below 0ºC.
- **Model creates ice-phased clouds in those areas.**

Model fields



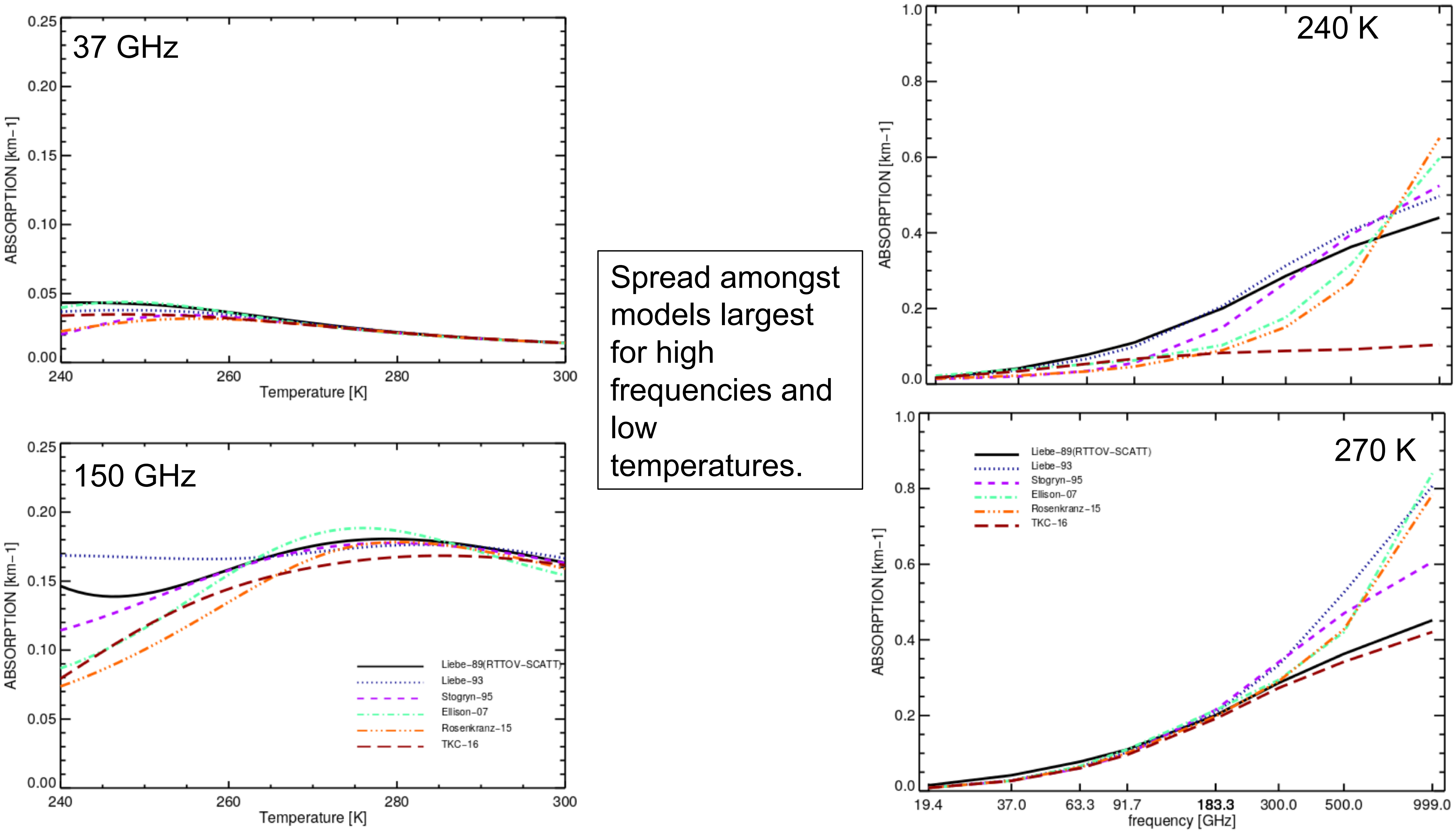
Liquid water absorption model*

*AMT paper in preparation

Different liquid water absorption models

reference	Absorption model
Liebe89 (current)	Liebe 1989
Liebe93	Liebe et al 1993
Stogryn95	Stogryn et al 1995
Ellison07	Ellison 2007
Rosenkranz15	Rosenkranz 2015
TKC16	Turner et al 2016

Absorption coefficient for liquid water cloud w/ 0.1 gm3

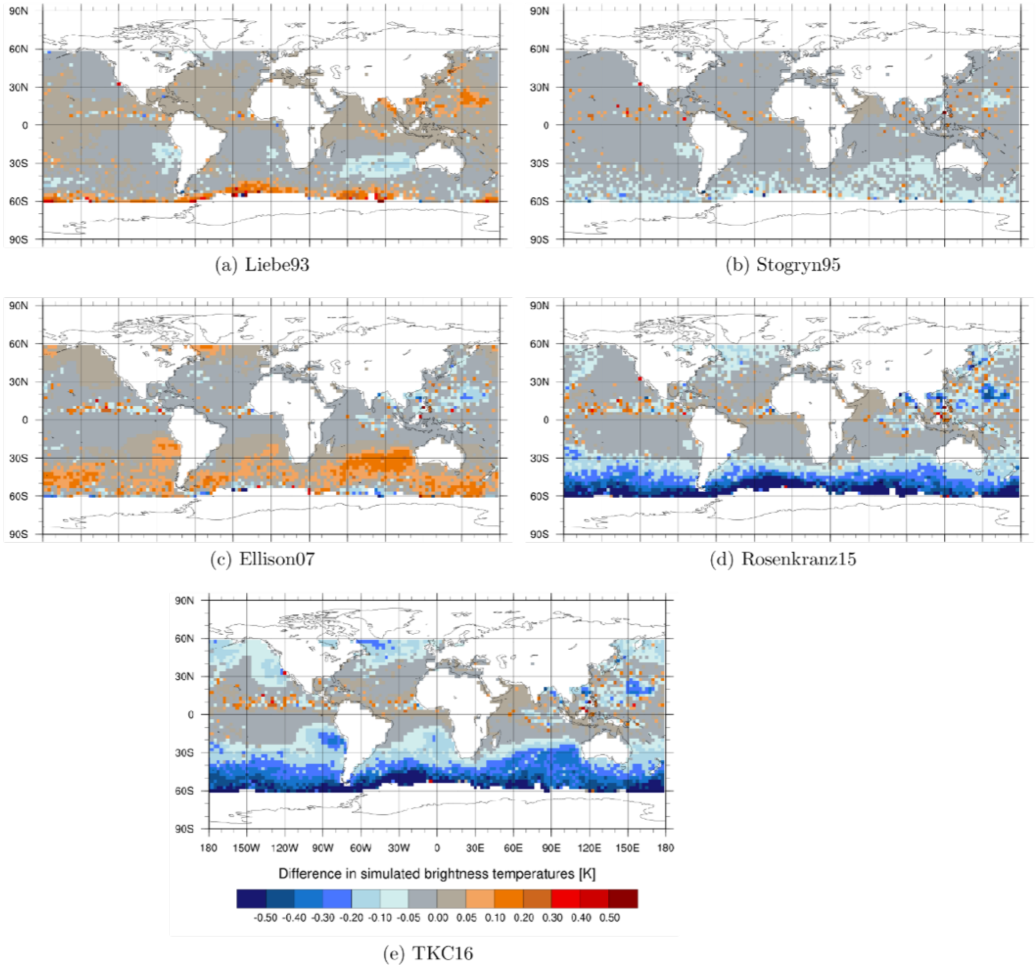


Spread amongst models largest for high frequencies and low temperatures.

Setup

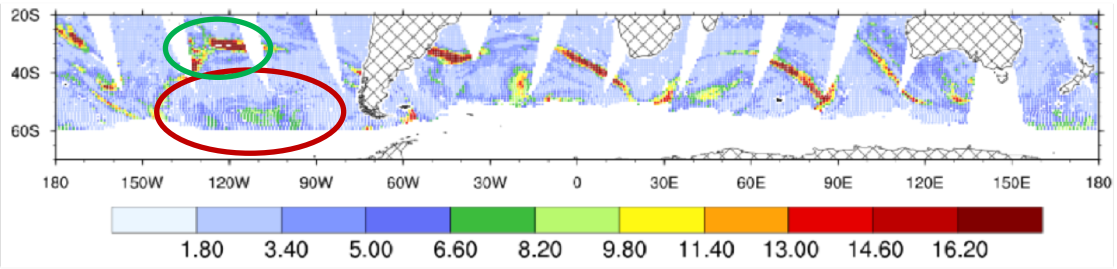
<table>
<tr><th></th><th colspan="2">description</th></tr>
<tr><td>Forecast model</td><td colspan="2">IFS CY43R3 + 45R1 model physics allowing the existence of surface driven shallow clouds containing supercooled liquid water only down to -38°C</td></tr>
<tr><td>Observation Operator for MWI (RTTOV-SCATT)</td><td colspan="2">Includes choices of the different liquid water absorption models</td></tr>
<tr><td>Experiments</td><td>1. Monitoring</td><td>2. Assimilation
a) screen
b) plusSLW</td></tr>
<tr><td>Observations</td><td>No screening of cold-air outbreak areas (supercooled liquid water) + no thinning</td><td>a) screen: default
b) plusSLW: No screening of cold-air outbreak areas (supercooled liquid water) + no thinning</td></tr>
</table>

Mean changes in simulated brightness temperatures

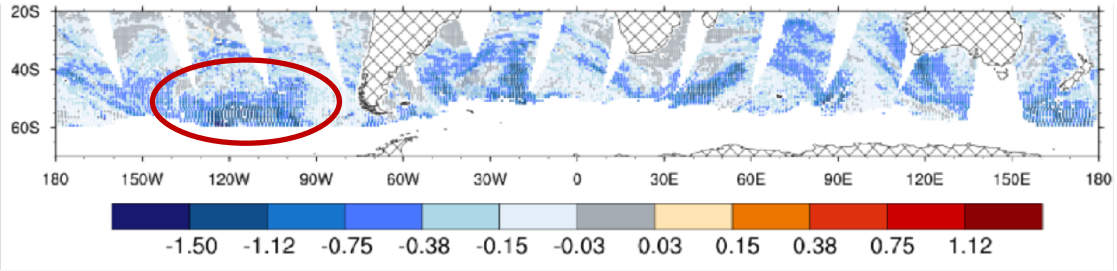


Maps of difference in simulated brightness temperatures [K] between the newer newer liquid water absorption models and the current Liebe89 for 150 h brightness temperatures co-located to corresponding SSMIS-F17 observations. Means are computed in each 2.5 ◦ lat x 2.5 ◦ lon bin and over the time period 1 to 31 August 2016. White coloured areas correspond to areas where data is not assimilated.

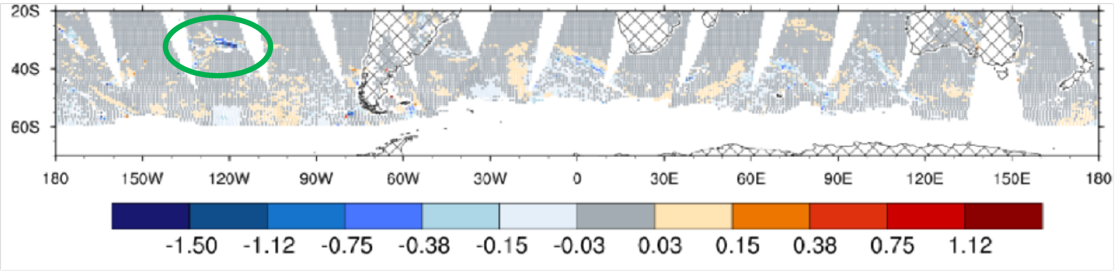
Case study: cold-air outbreak



(c) Observation error (K)



(d) Difference in simulated brightness temperature (K) between TKC16 and Liebe89 at 92 v GHz.

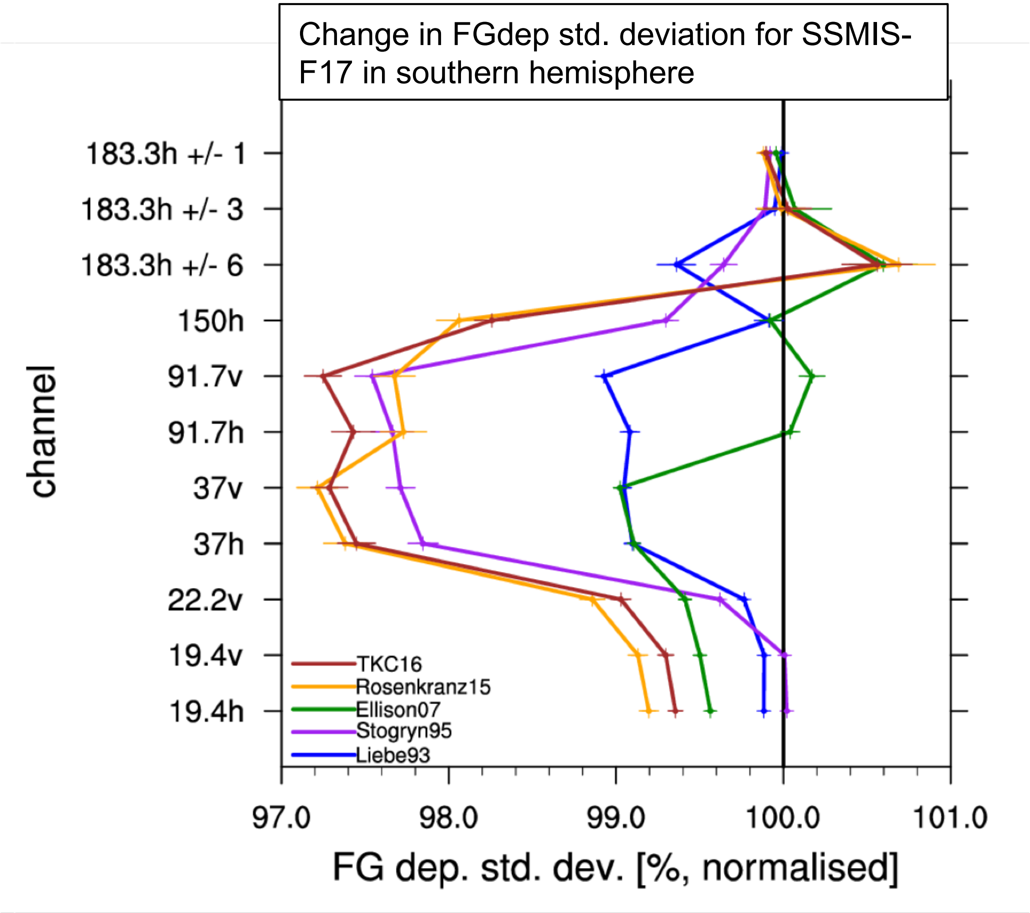


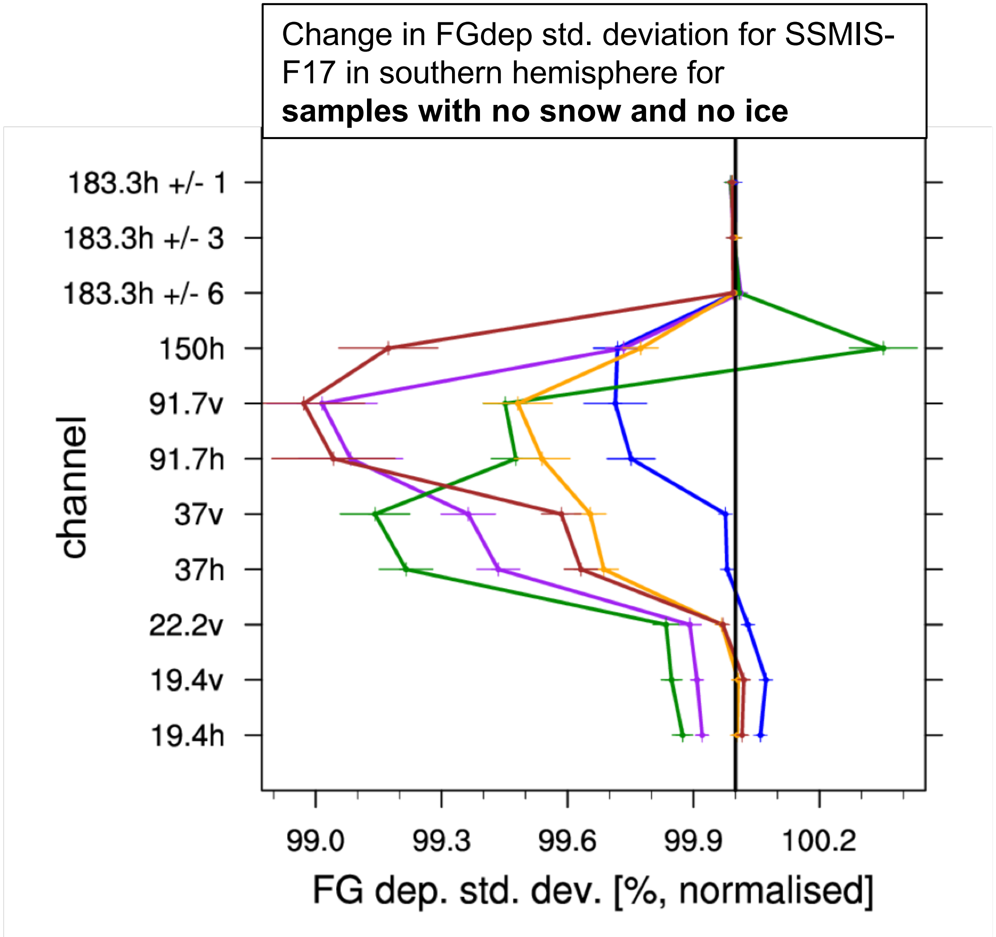
(e) Difference in simulated brightness temperature (K) between TKC16 and Liebe89 at 183±6 GHz.

Maps for c) observation error of Liebe89, d) difference in FG at 92 v GHz between TKC16 and Liebe89 and e) difference in FG at 183 ± 6 GHz between TKC16 and Liebe89 for areas of the southern high latitudes excluding land and sea ice **for 30 August 2016 00 UTC**, co-located to SSMIS-F17 observations.

- Regions where supercooled liquid water clouds prevail are more prone to large differences in simulated brightness temperature due to a different liquid water permittivity formulation.
- The FG at 92 v simulated at SSMIS-F17 locations for TKC16 is reduced compared to Liebe89 by 0.5 K to 1.5 K.
  → clouds have little liquid water < 0.1 kgm-2 or temperatures are higher than -9°C (Cadeddu and Turner 2011)
- The observed change in FG at 92 v of about 1 K is much smaller than the typical observation error of about 4 K to 10 K in these regions
  → Using a different permittivity formulation than Liebe89 might only have a small impact on the analysis in a state of art NWP system.

Results from monitoring experiments





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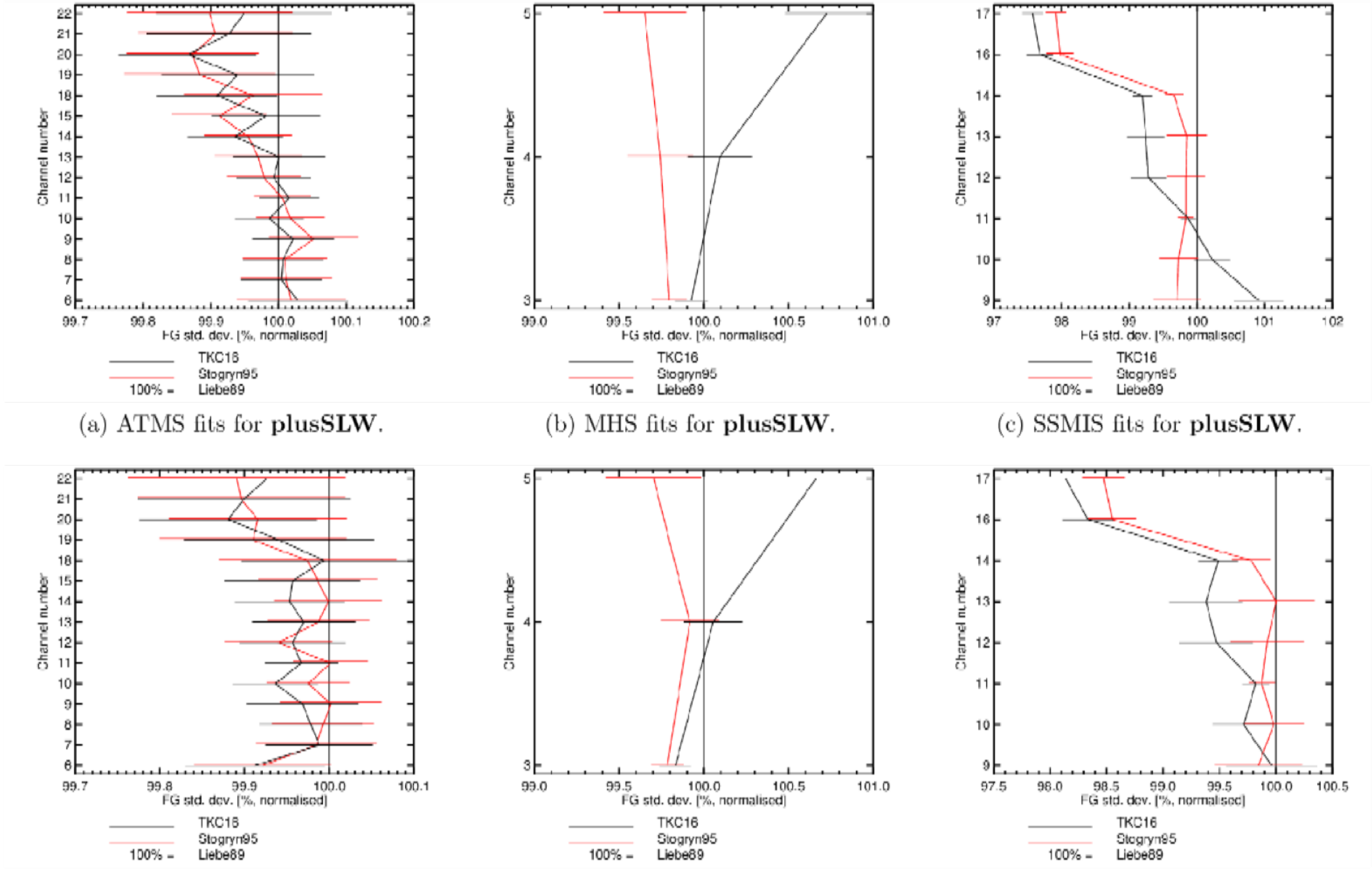
Results from assimilation experiments



(a) ATMS fits for **plusSLW**. (b) MHS fits for **plusSLW**. (c) SSMIS fits for **plusSLW**.

(d) ATMS fits for **screen**. (e) MHS fits for **screen**. (f) SSMIS fits for **screen**.

Standard deviation in FG departures in the southern hemisphere of data for TKC16 and Stogryn95 normalised by Liebe89 for **plusSLW** and for **screen**. Different colours refer to different liquid water absorption models, as shown in the figure. The horizontal bars indicate 95% confidence range. Results cover the time period from 1 June to 30 September 2016.

- Using different formulations of permittivity shows a neutral impact on forecast scores in terms of a change in root-mean-square error in humidity, temperature and wind in the long- and short-term.
- Improved observational fits to humidity sensitive channels of ATMS (ch18-22)
- Small degradation for MHS ch.5 (183+/- 7 GHz)
- Mostly improved fits for SSMIS, except forch. 9 (183 +/- 6 GHz) for plusSLW

Summary: Liquid water absorption models

- New liquid water absorption models (TKC16 and Rosenkranz15) are based on new observation under supercooled liquid water conditions
- Using them inside RTTOV-SCATT gives better fits for frequencies up to 150 GHz
- Degradation seen in 183 +/- 6 GHz related to compensating biases in scattering and absorption model
- Neutral impact on forecast scores, but improved observational fits to independent observations