All-sky assimilation in the tropics: improving cloud and precipitation forecasts

Alan Geer[1], Katrin Befort[1] and Philippe Chambon[2]

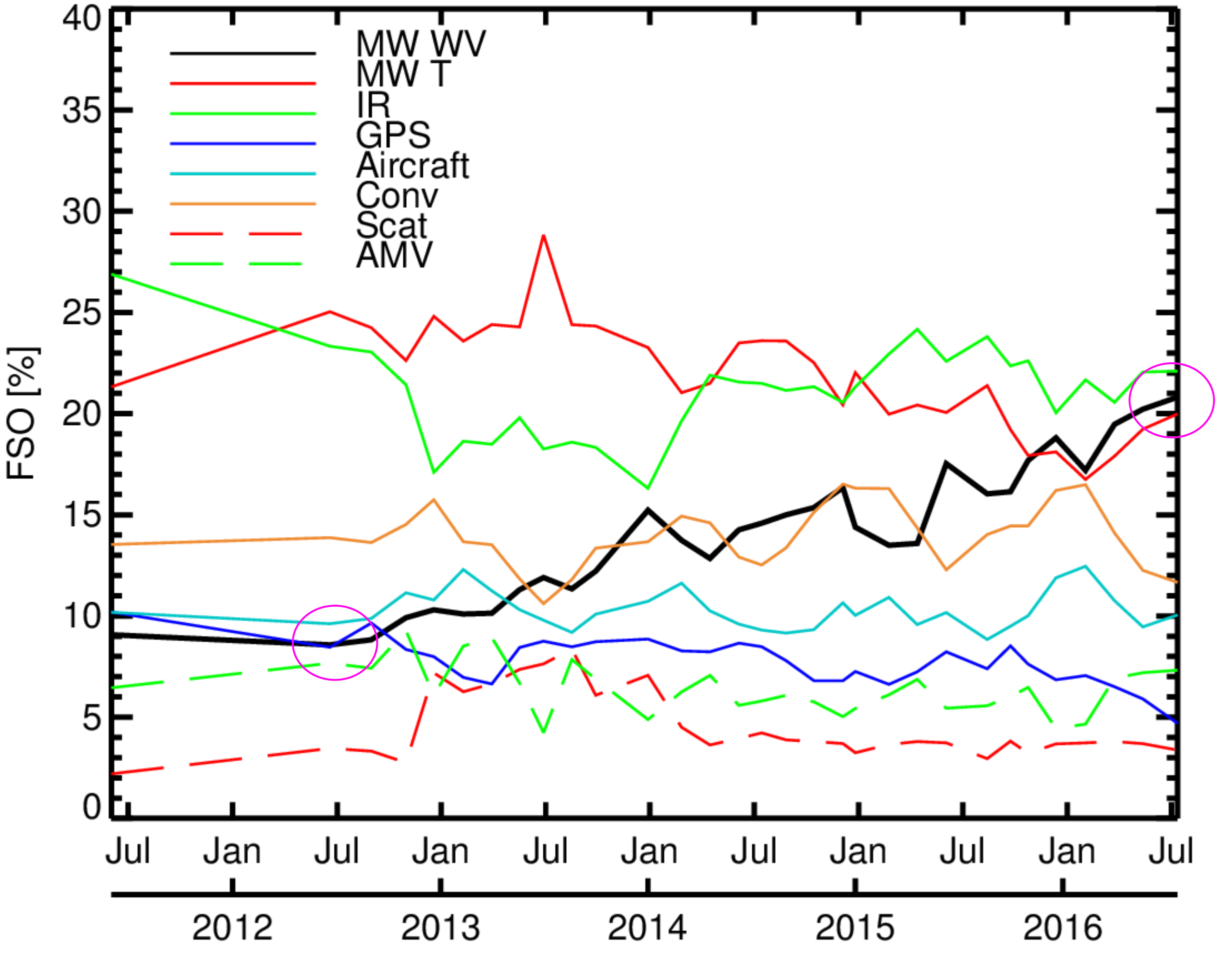
1. ECMWF
2. Météo France

ECMWF

Forecast sensitivity (FSO) of major observing systems in ECMWF operations

Summer 2006
(from Cardinali, 2009)

Microwave WV	6.2 %
Microwave T	35.5 %
Infrared	28.0 %



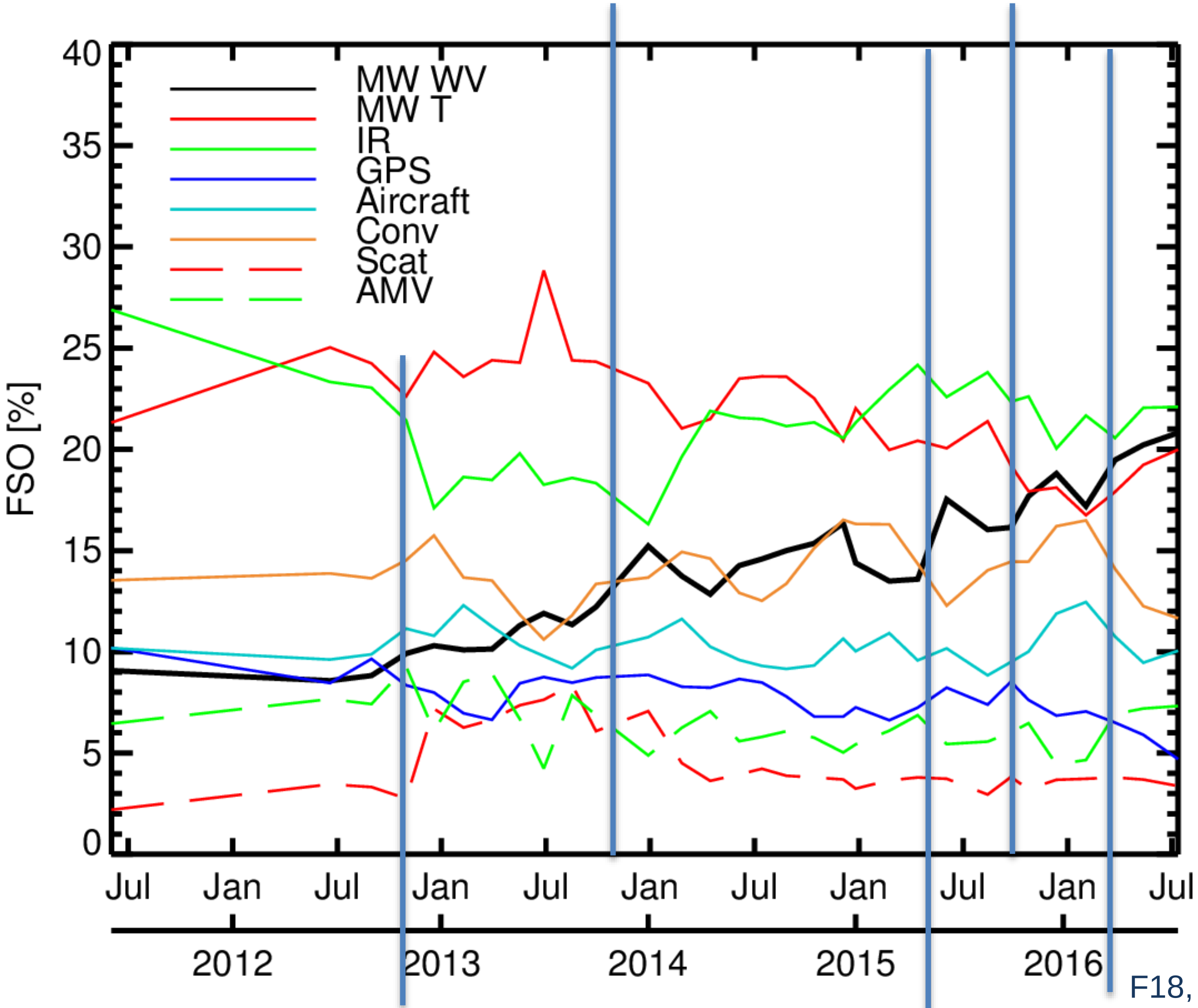
August 2016

Microwave WV	20.4%
Microwave T	20.1 %
Infrared	21.9 %

What’s happened recently?

All-sky assimilation of humidity sounding channels on SSMIS

GMI and AMSR-2 added in all-sky



F18, all-sky over snow, MWHS-2

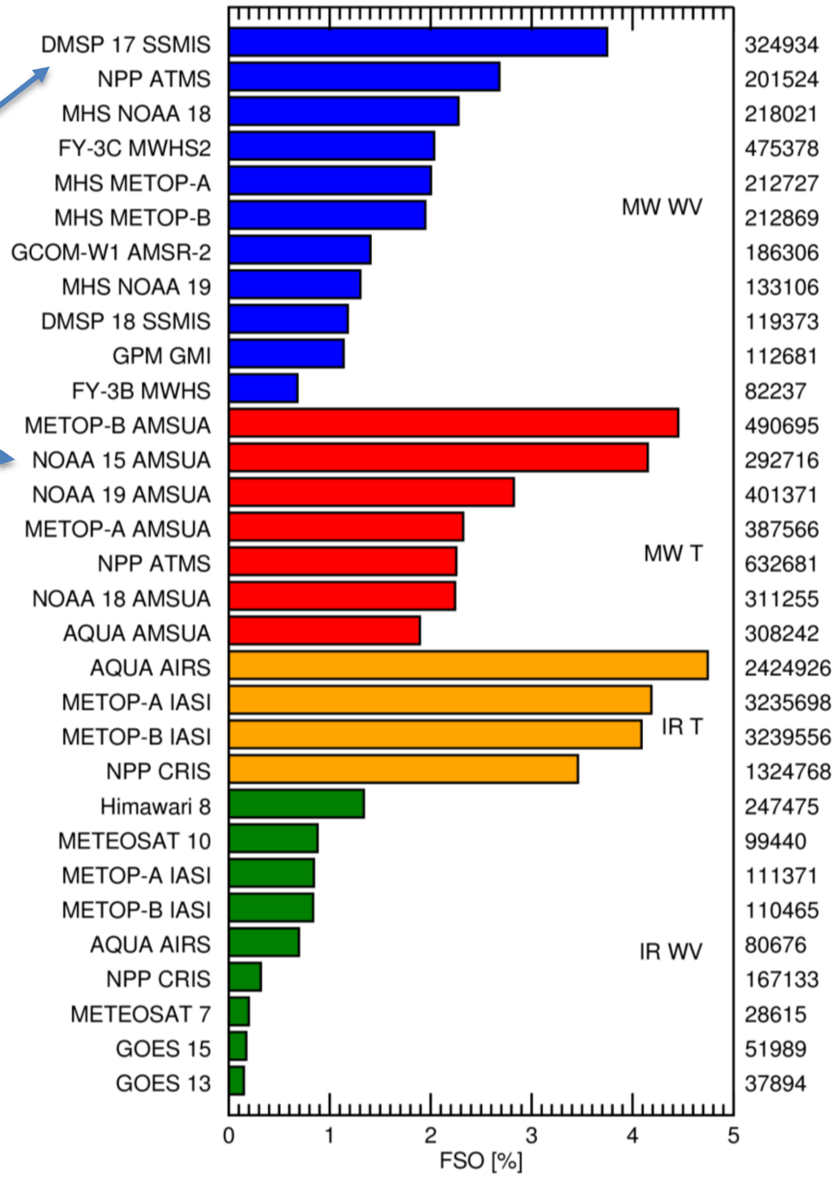
ATMS and Metop-B MHS added in clear skies

All-sky assimilation of all four MHS (transferred from clear-sky)

FSO of satellite radiances, August 2016

100% = full operational observing system

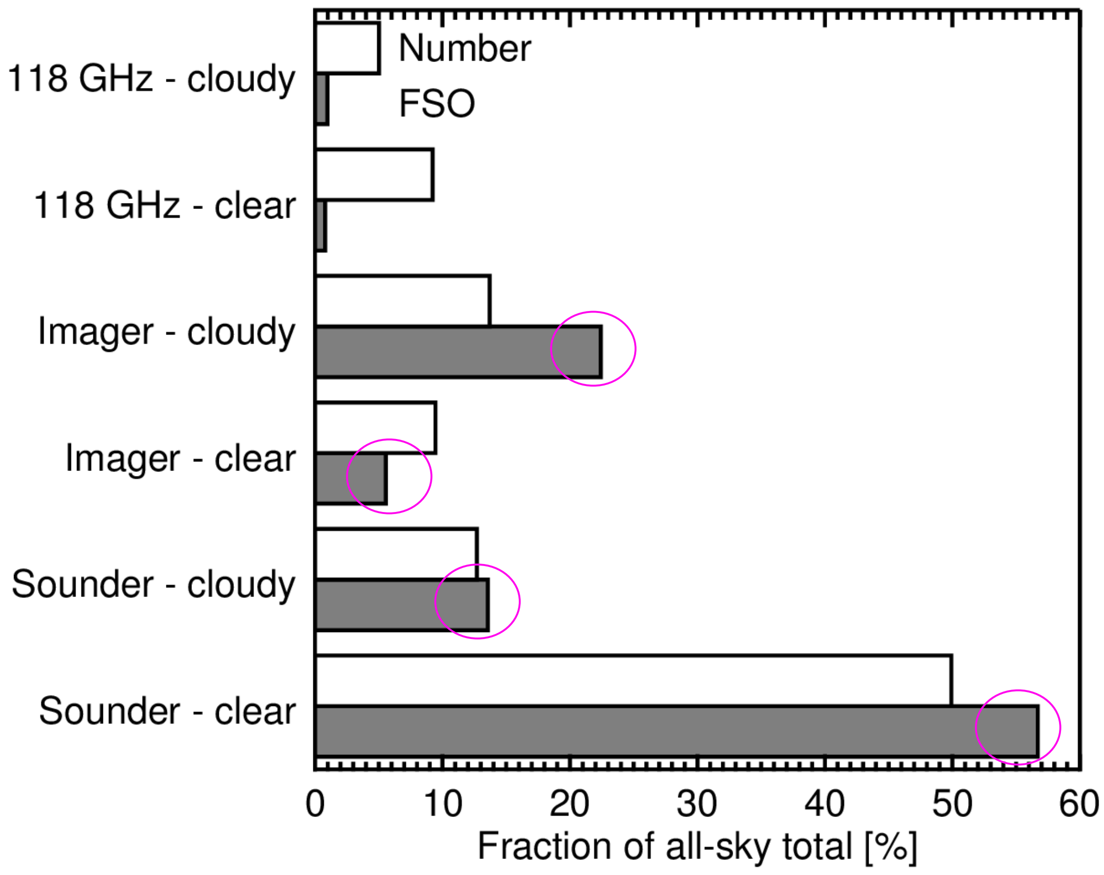
An SSMIS (combining imaging and humidity sounding channels) is nearly equivalent to the best of the temperature-sounding AMSU-As



Microwave WV	20.4%
Microwave T	20.1%
Infrared T	16.5%
Infrared WV	5.4%

Importance of cloudy and precipitating scenes

100% = 9 all-sky instruments

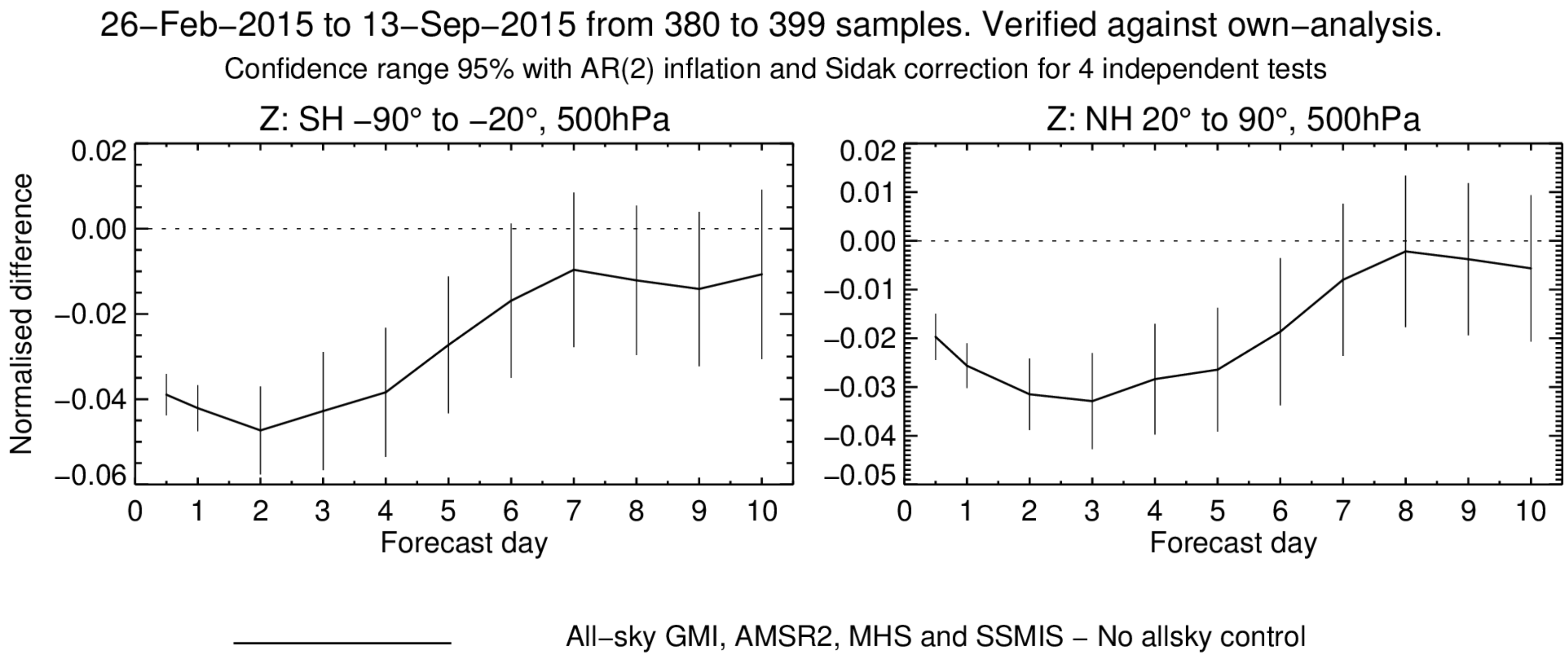


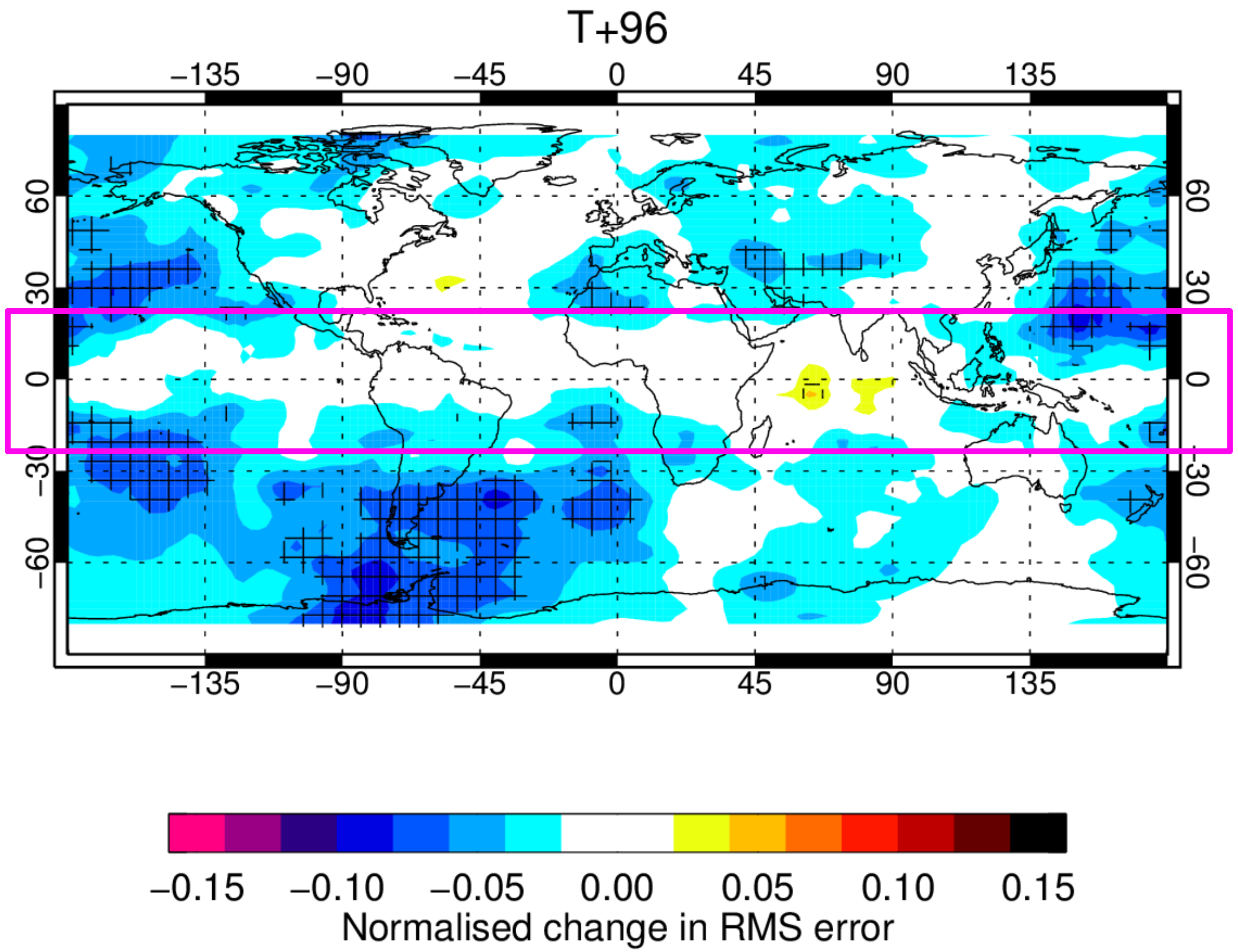
Imagers: Cloudy and precipitating scenes give more FSO than clear-sky scenes

Sounders: Cloudy and precipitating scenes have same per-obs FSO as clear-sky scenes

High FSO => real improvements in medium-range synoptic forecasts

Mechanism: 4D-Var can infer dynamical initial conditions from observed WV, cloud and precipitation





Normalised change in RMSE of 500hPa geopotential: all-sky on – all-sky off

February – September 2015, using 399 samples. Cross hatching indicates 95% significance

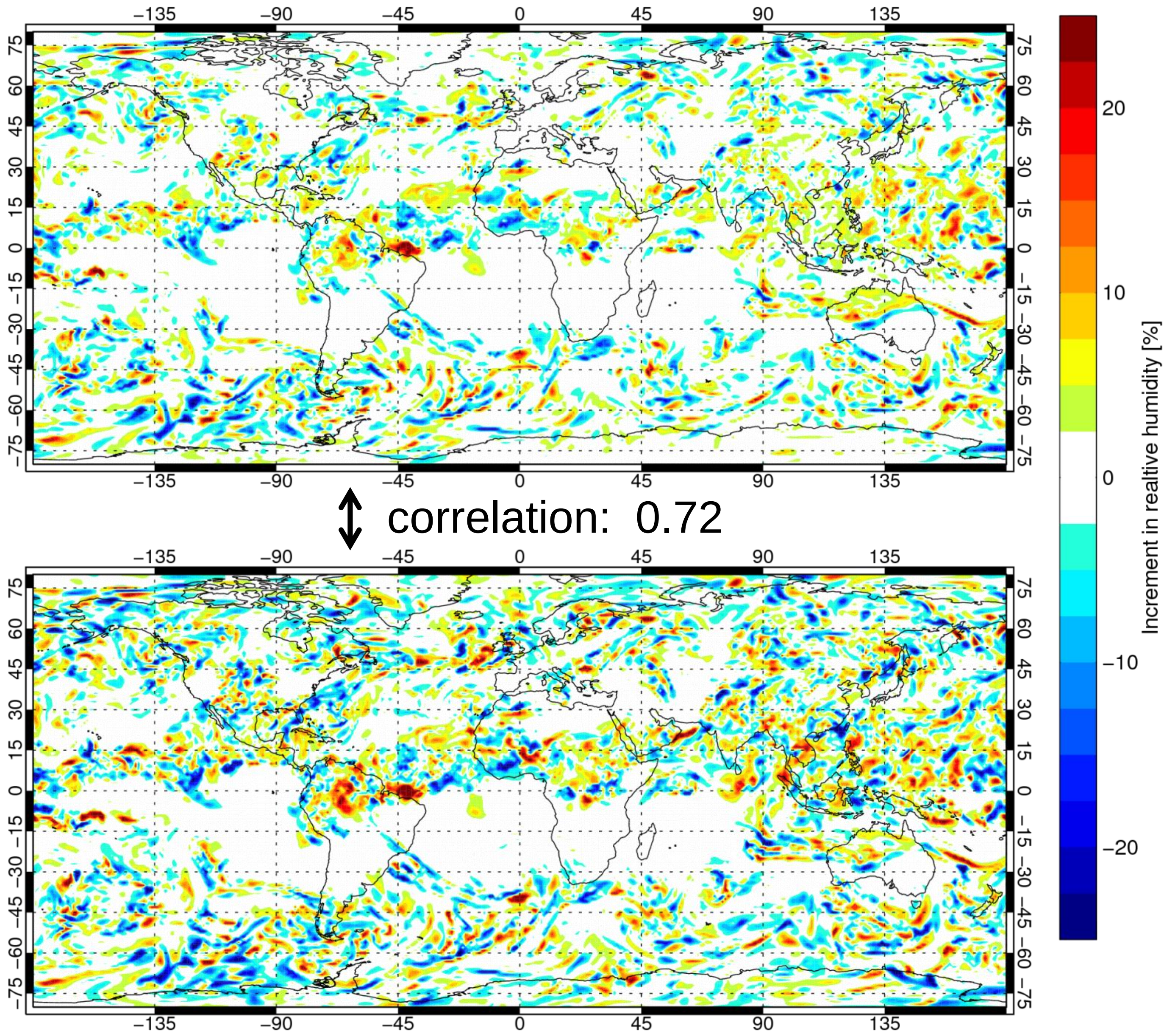
What about the tropics?

Humidity increments at 500hPa

06Z: 9h into the assimilation window

All-sky WV sounding only: 4 MHS, 1 SSMIS

Full observing system Including all-sky WV

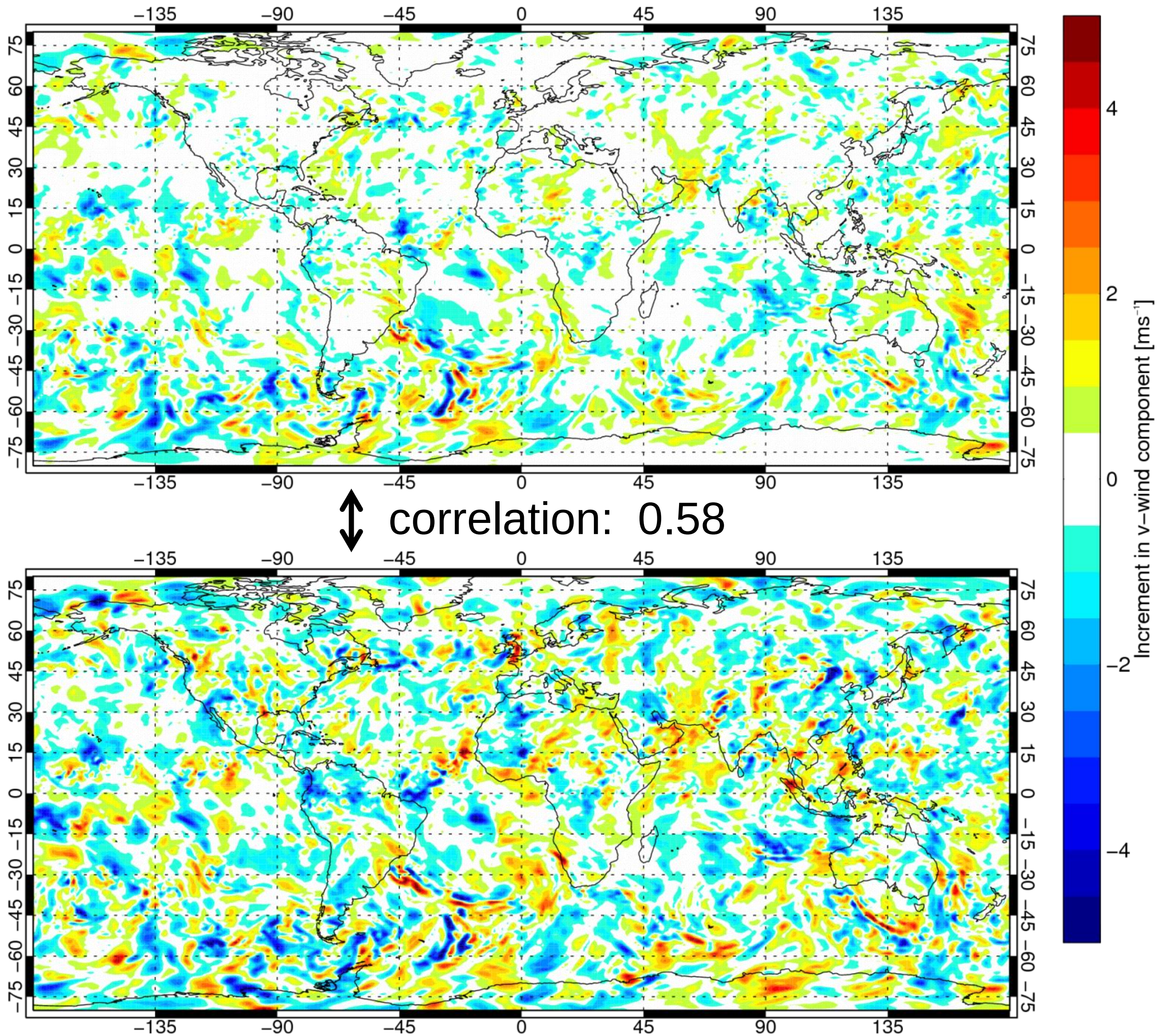


v-wind increments at 500hPa

06Z: 9h into the assimilation window

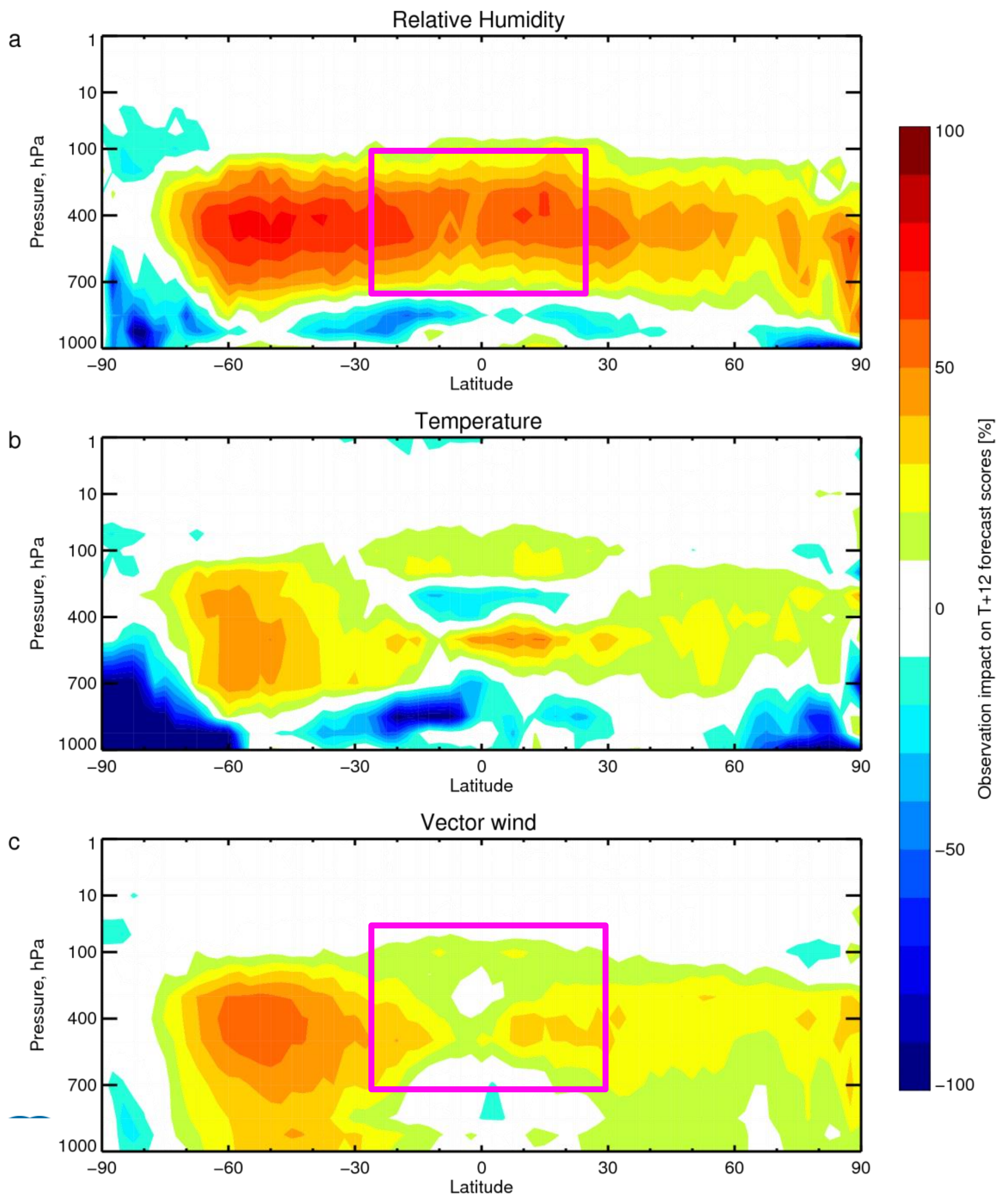
All-sky WV
sounding only:
4 MHS, 1 SSMIS

Full observing
system
Including all-sky
WV



Assimilate only all-sky WV sounding observations (4 MHS, 1 SSMIS)

66 different analyses and forecasts, always from a full-observing system FG



T+12 RMS forecast error reduction

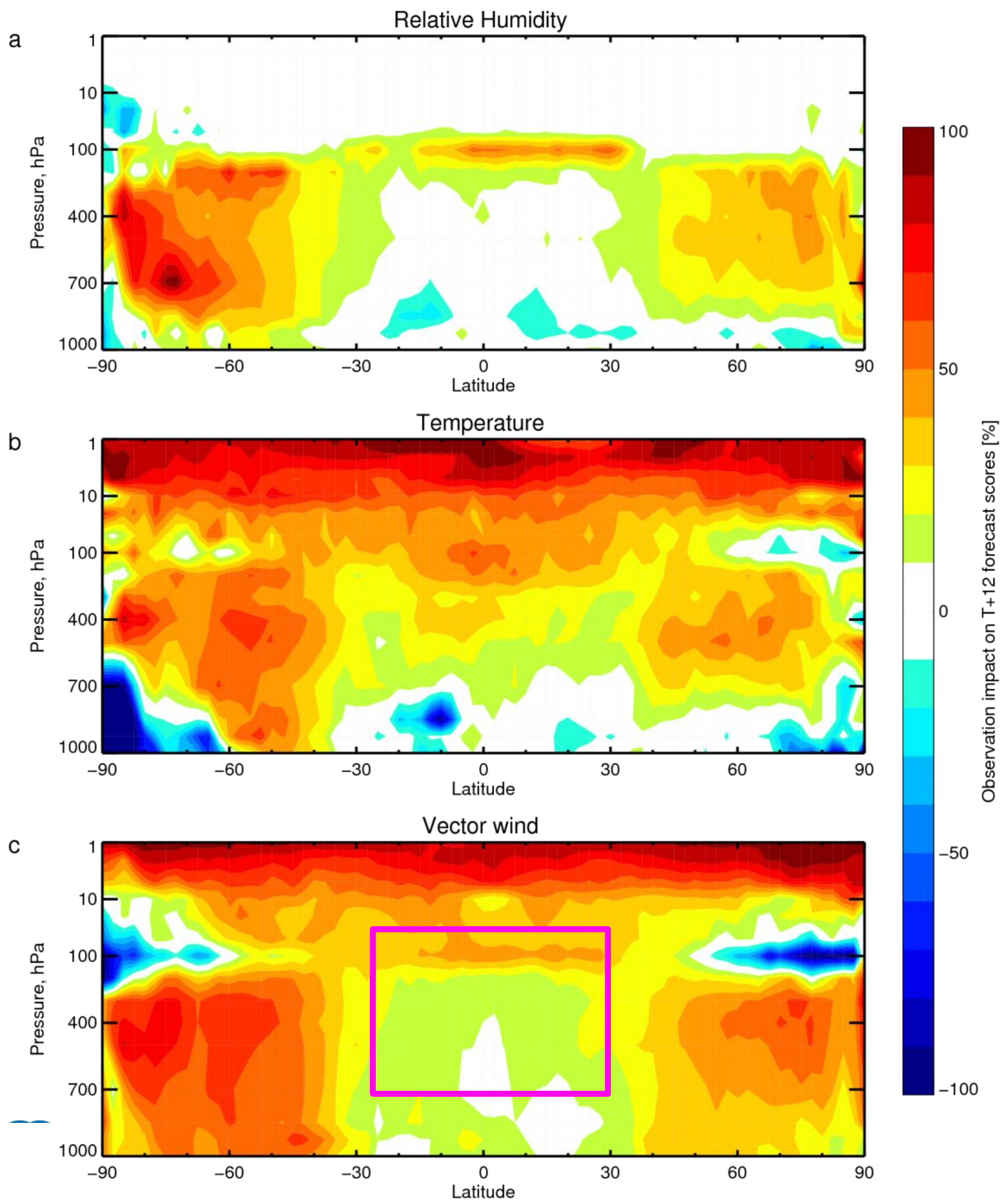
100% = full observing system

0% = no observations

-100% = worse than that!

Assimilate only microwave T-sounding obs (6 AMSU-A, ATMS)

66 different analyses and forecasts, always from a full-observing system FG



T+12 RMS forecast error reduction

100% = full observing system

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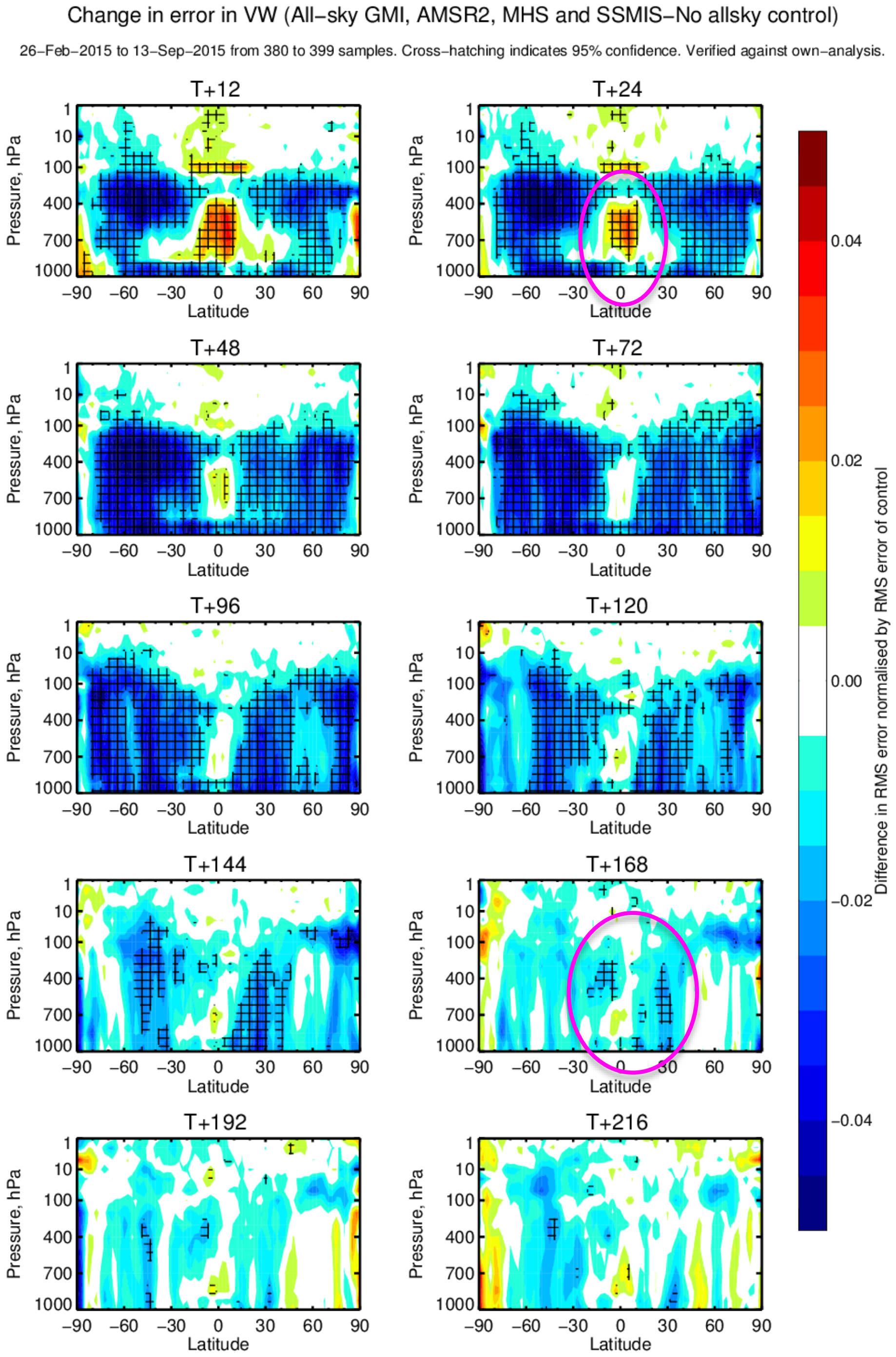
Does all-sky assimilation benefit tropical winds?

Vector wind verification against own-analysis



Day 1 “degradation”

vs.

Day 8: significant improvements

ECMWF

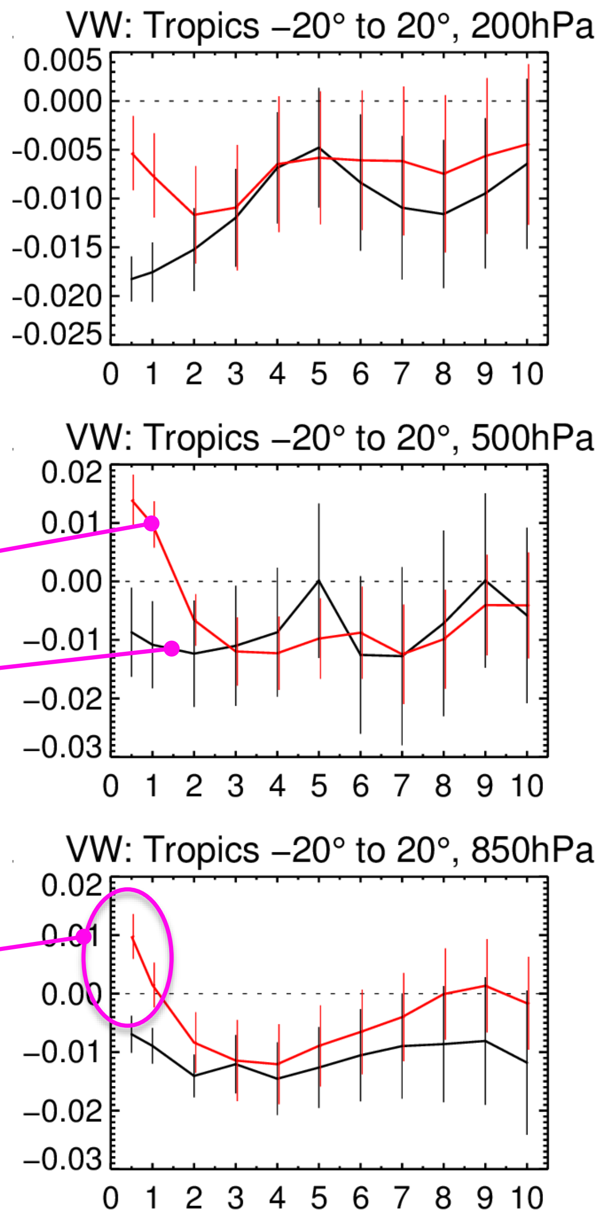
Impact of all-sky observations on tropical winds

Change in RMS forecast error relative to control

Verified against:

- own analysis
- SATOB observations

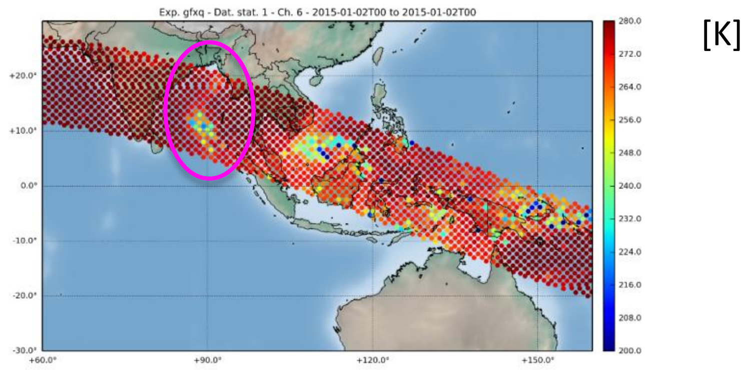
Early-range “degradation” is a verification artefact



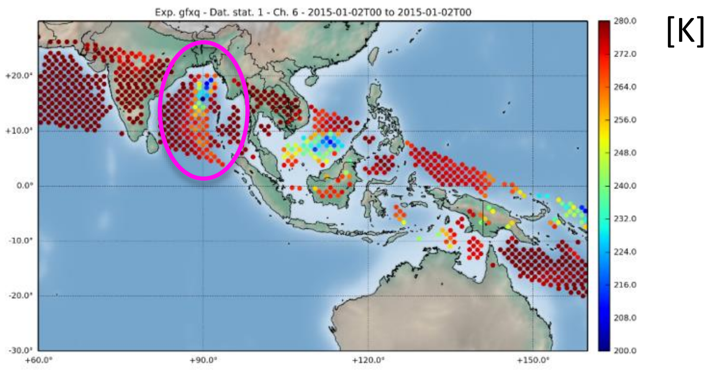
SAPHIR – tropical sensor with multiple overpasses per day

- MeghaTropiques satellite in 20° inclination orbit
- SAPHIR instrument has 5 183 GHz channels sensitive to humidity, cloud and precipitation through the troposphere
- Will be assimilated in all-sky conditions at ECMWF next year

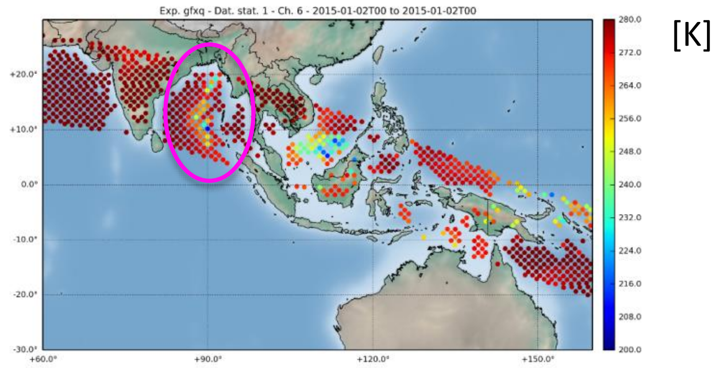
Observations



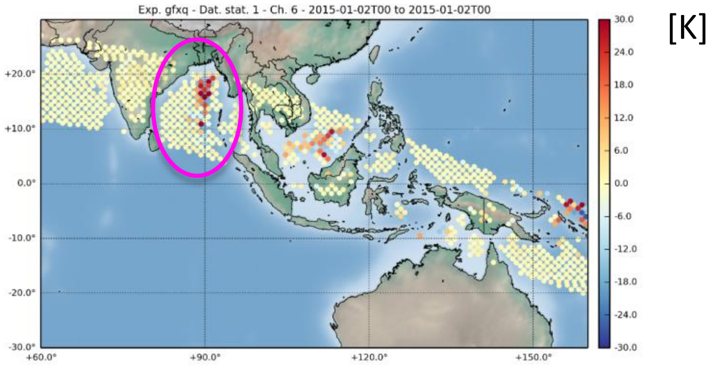
First guess



Analysis



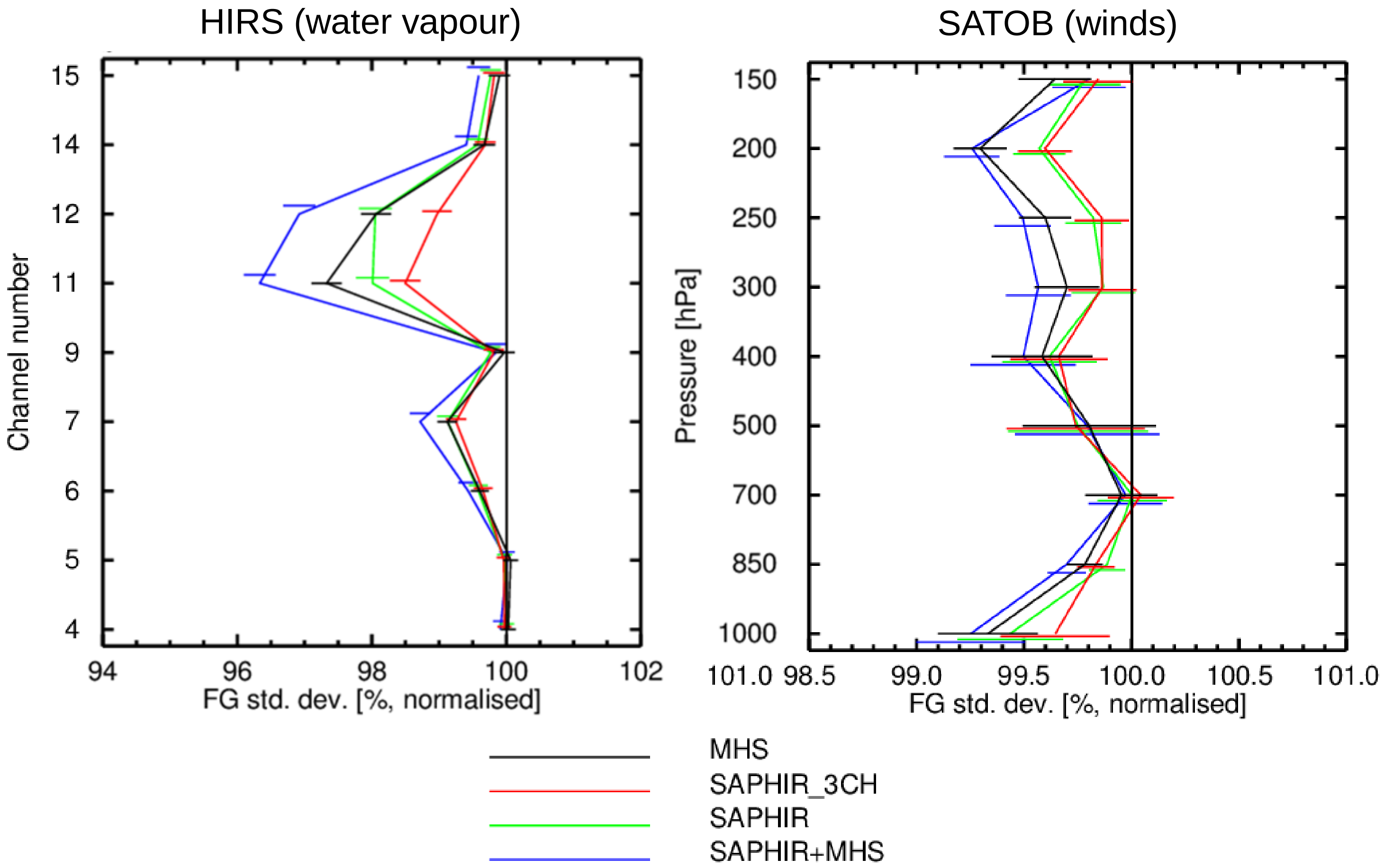
Reduction in absolute departure



Tropical obstats: FG standard deviations

baseline: 7 microwave WV instruments + rest of global observing system. MHS removed in tropics

in tropics add: 4 MHS or 1 SAPHIR, or 4 MHS and SAPHIR

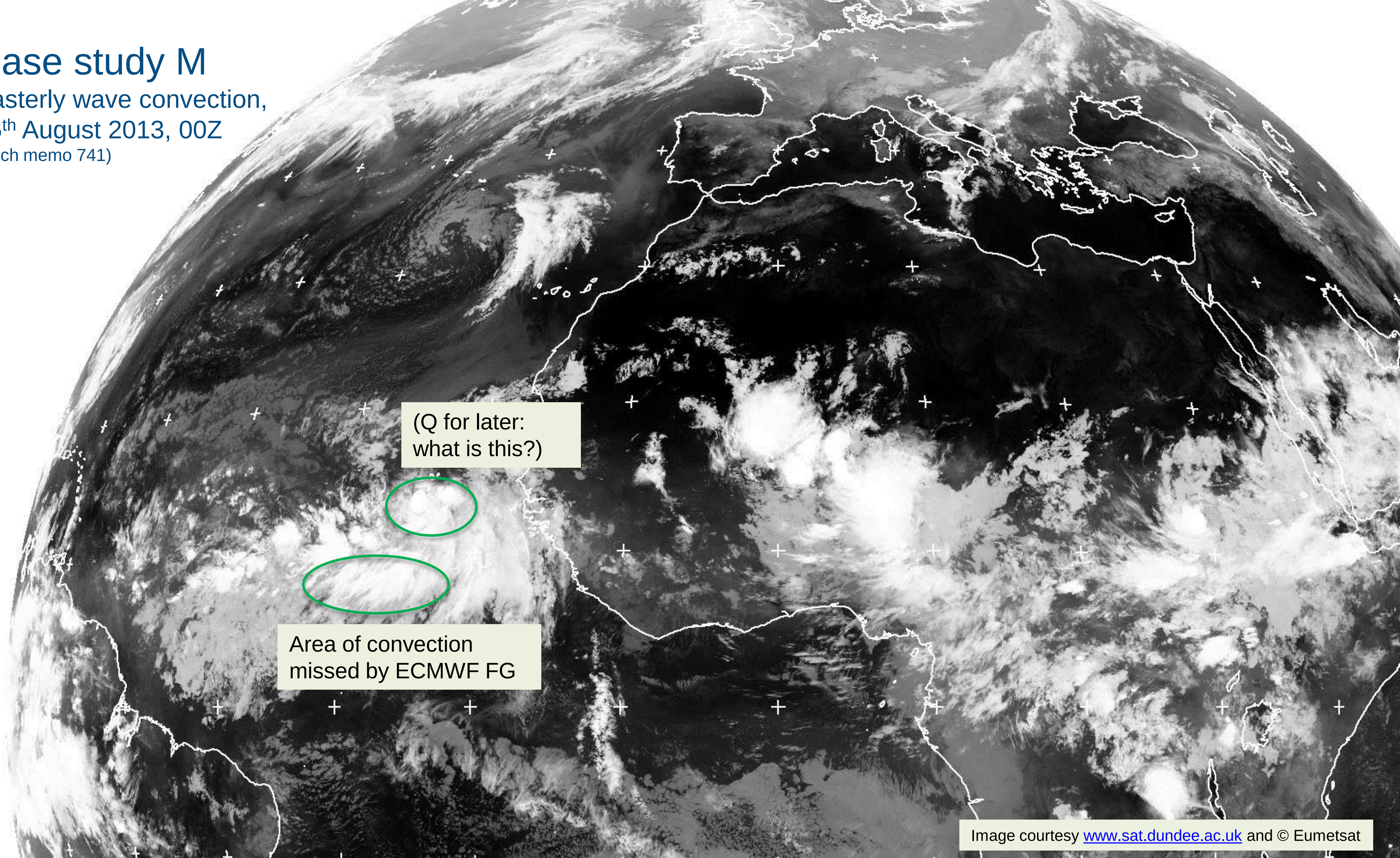


SAPHIR impact approaches that of the 4 MHS sounders in the tropics

SAPHIR adds information even on top of 11 existing sensors

Case study M

Easterly wave convection,
15th August 2013, 00Z
(Tech memo 741)

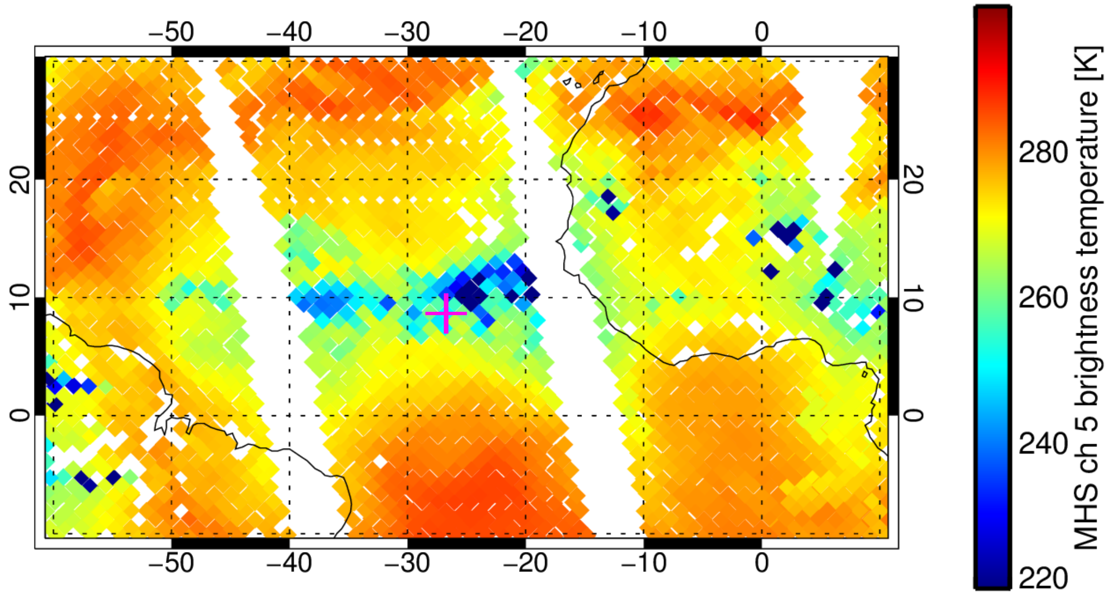


MHS channel 5 brightness temperatures

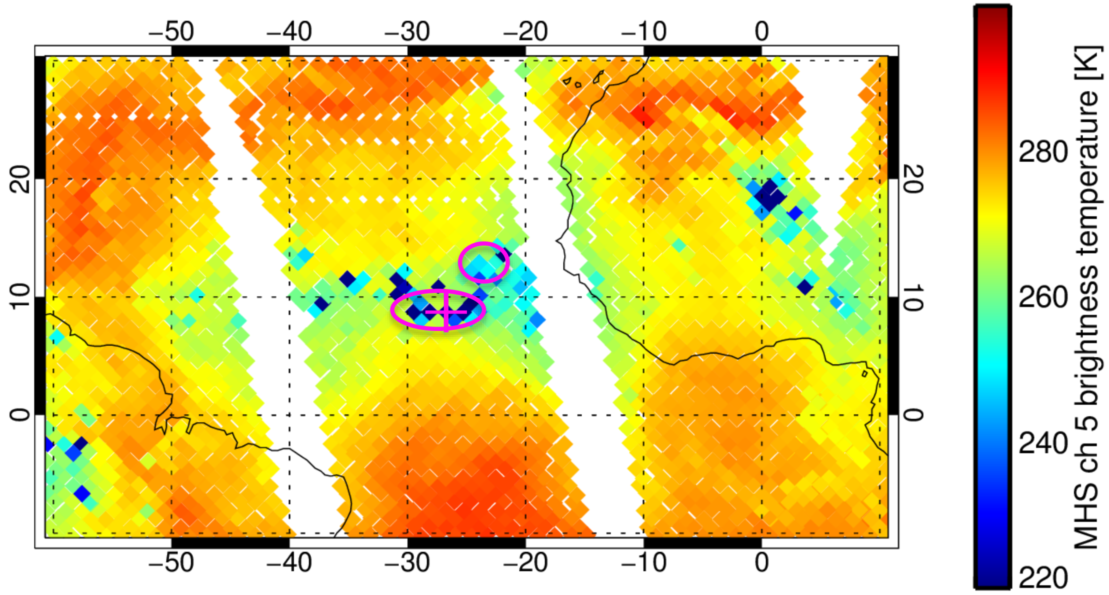
very low TB = hail/ graupel/ aggregates in convective cores

Single observation test with extra weight on the observation

First guess



Observations



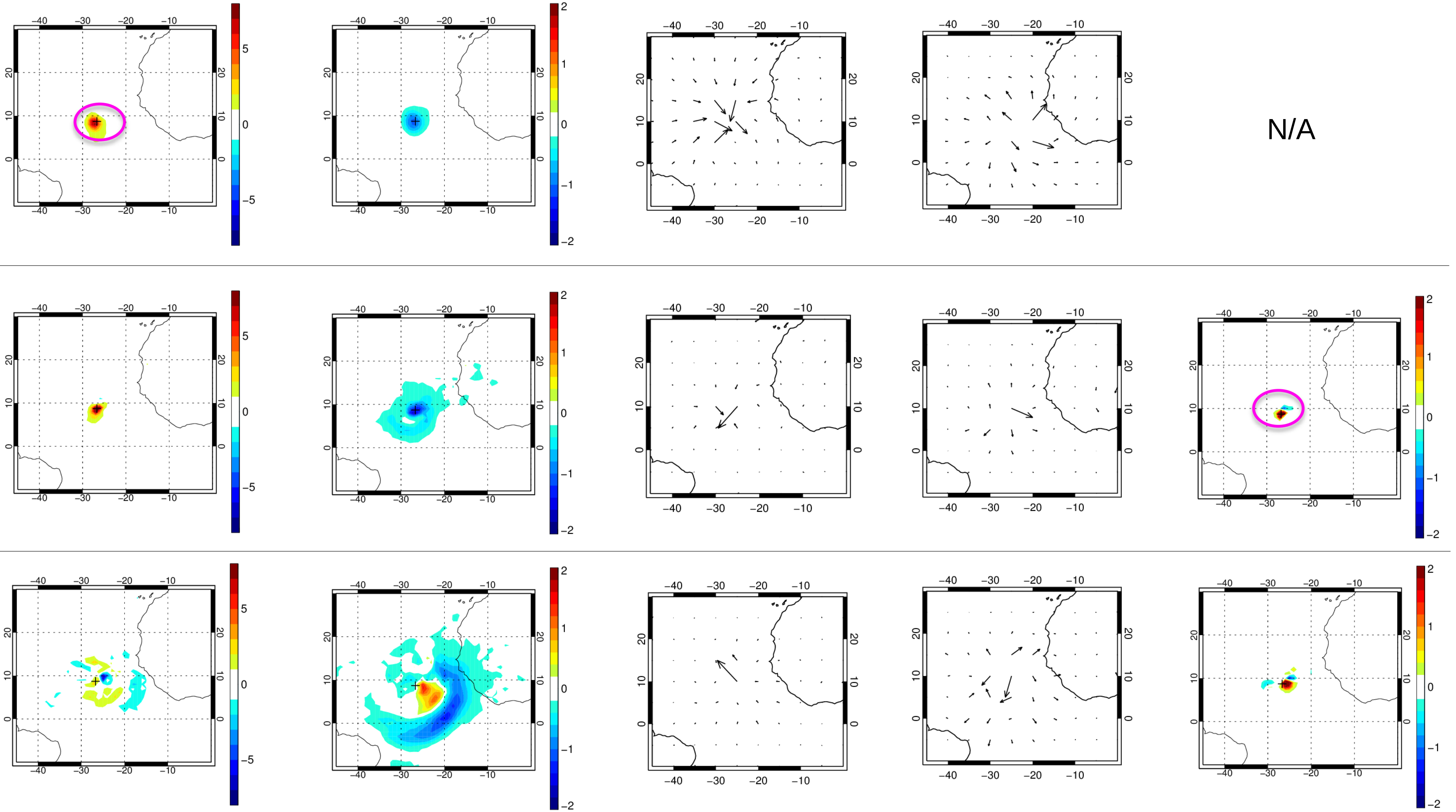
Model increments: single obs

Column WV [kg/m^2] | Sfc. pressure [hPa] | Low-level winds (850 hPa) | Upper-level winds (100 hPa) | Column rain [kg/m^2]

21Z (analysis time)

00Z (obs time)

09Z



Case study M

Easterly wave convection

00Z 15th August

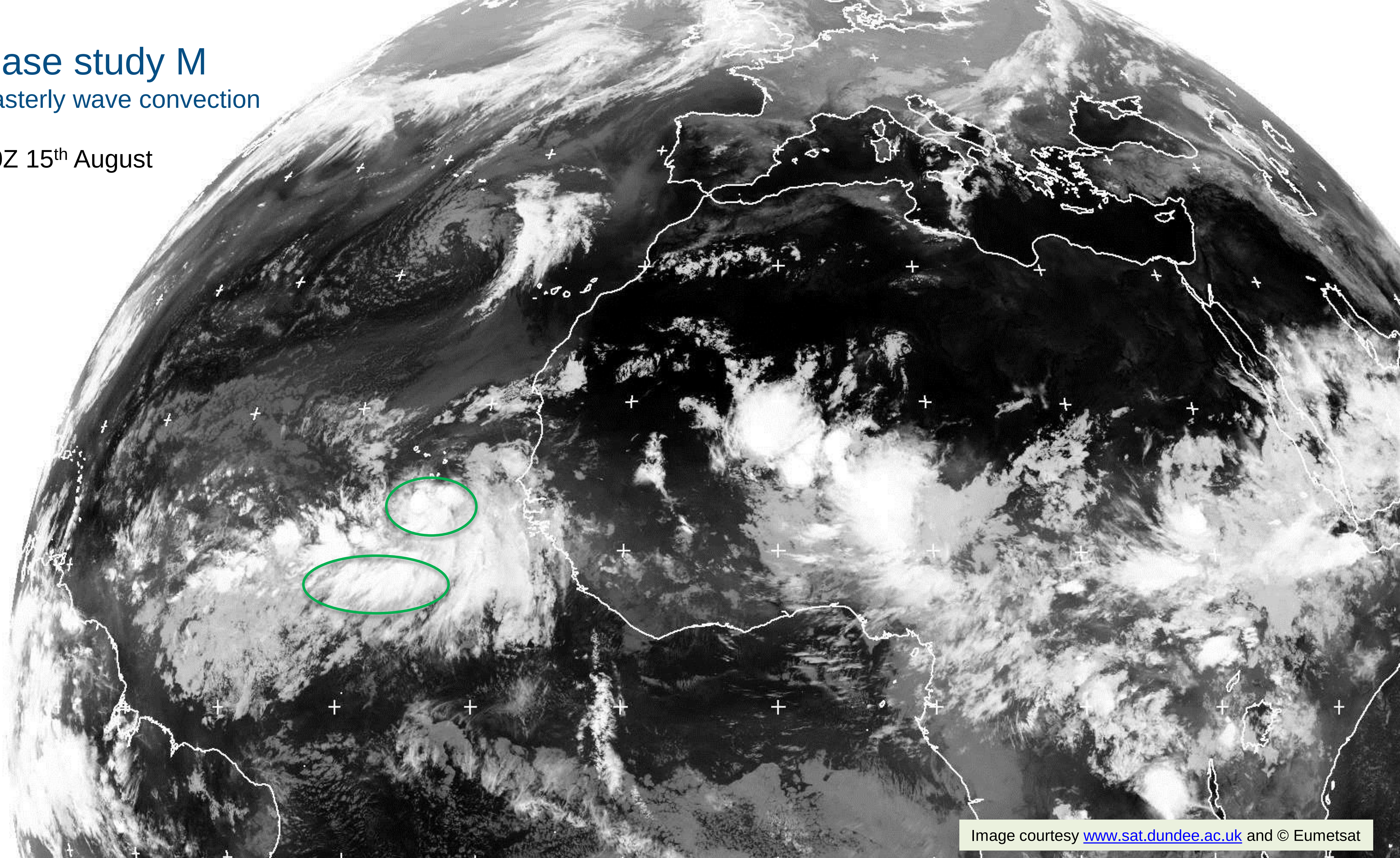
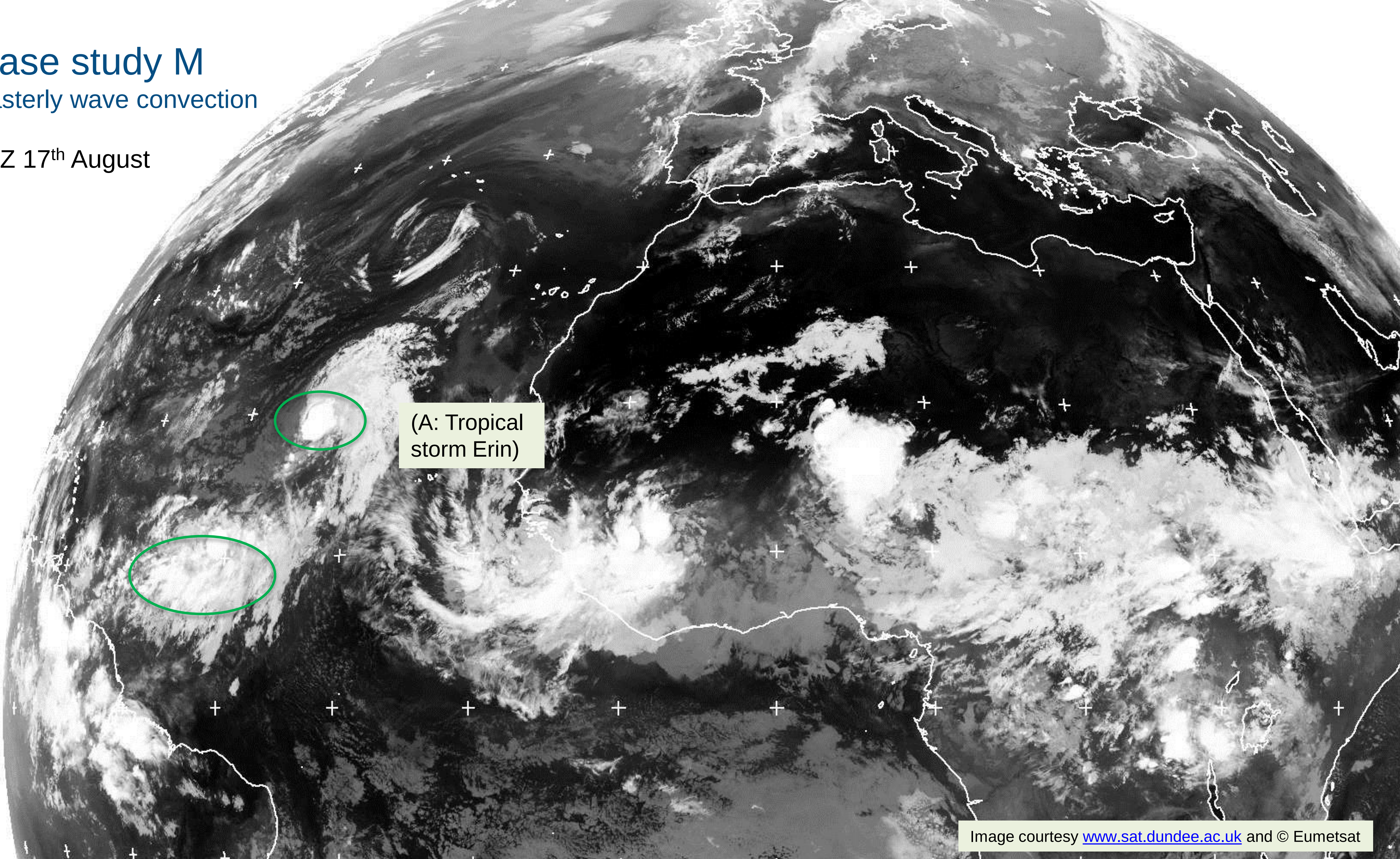


Image courtesy www.sat.dundee.ac.uk and © Eumetsat

Case study M

Easterly wave convection

00Z 17th August



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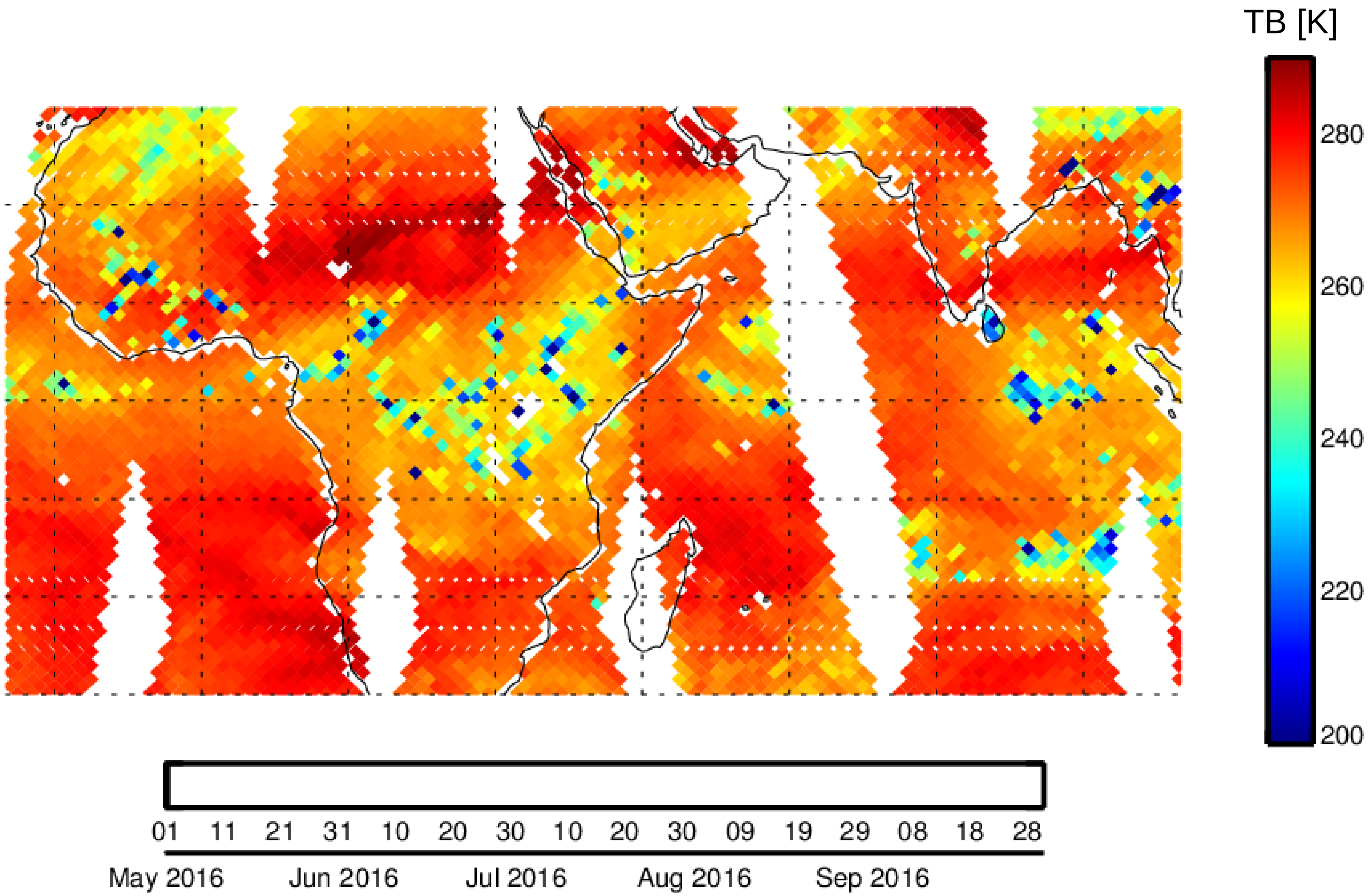
Boreal summer: monsoon and easterly waves

May to September 2016

May – September 2016 at 183 GHz

SSMIS F-17 ch 9 (183 ± 7 GHz) - 6am / 6pm LST coverage



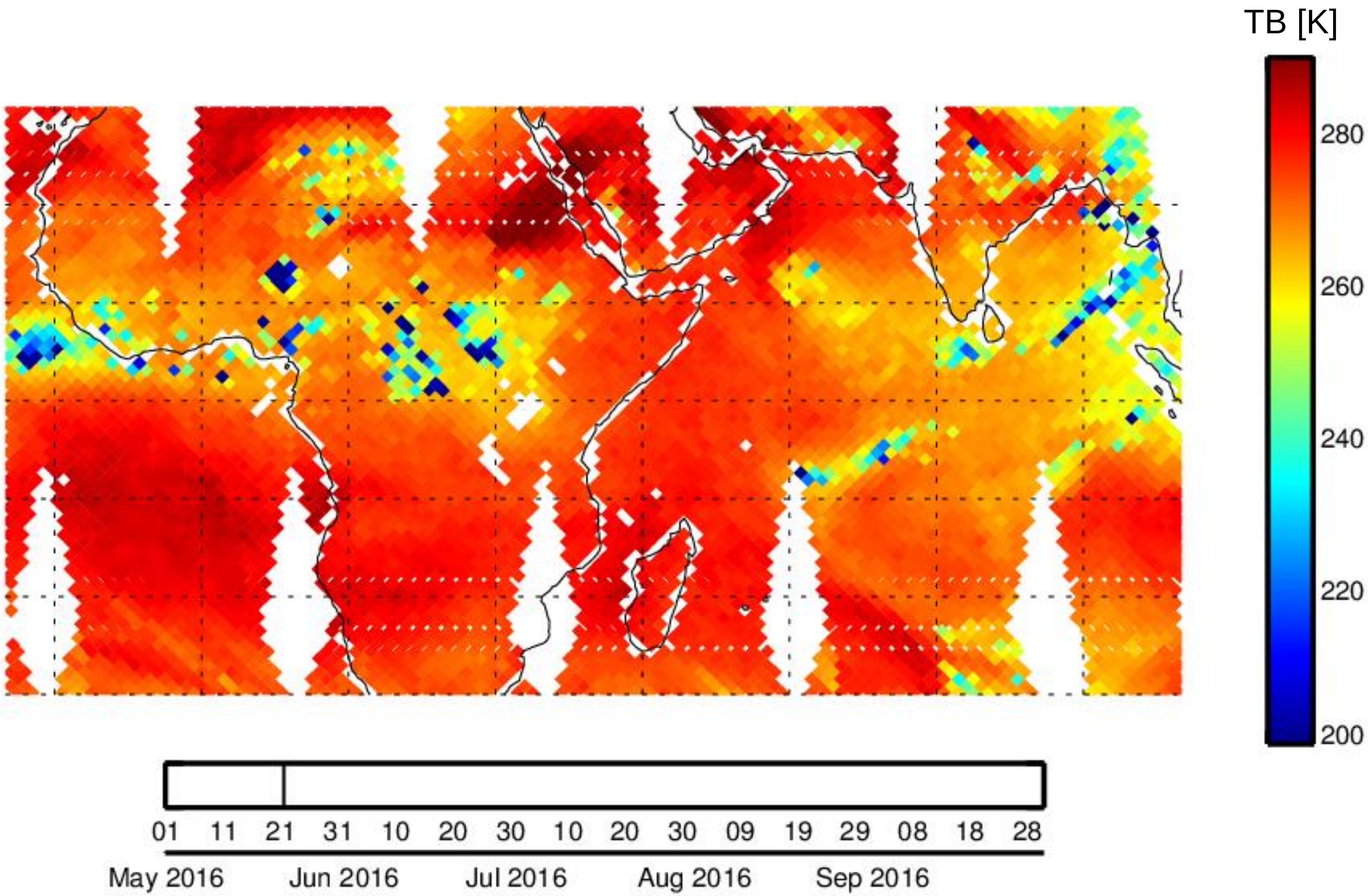
Clear, dry

Clear, moist

Strong convection

May – September 2016 at 183 GHz

SSMIS F-17 ch 9 (183 ± 7 GHz)



Clear, dry

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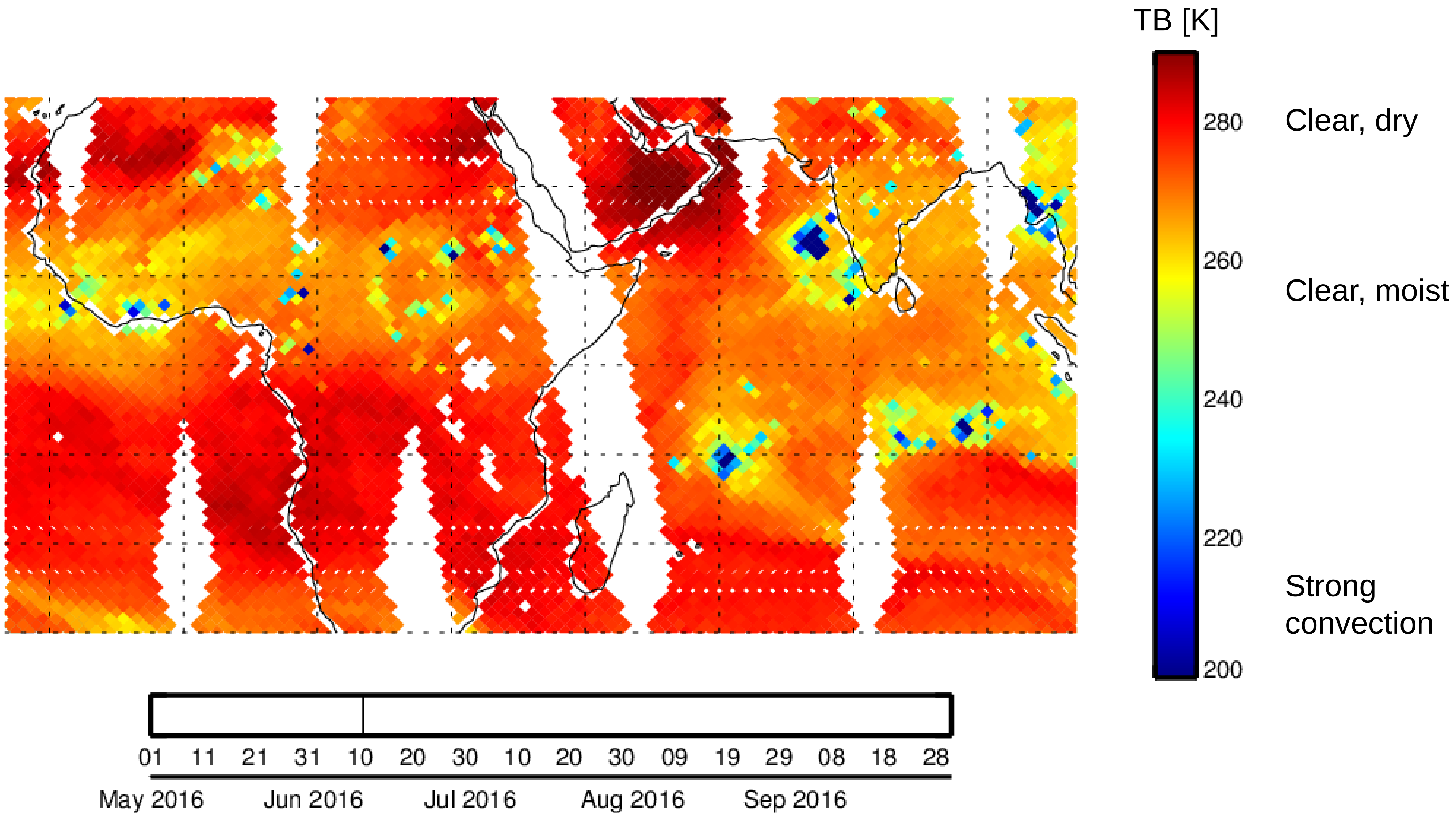
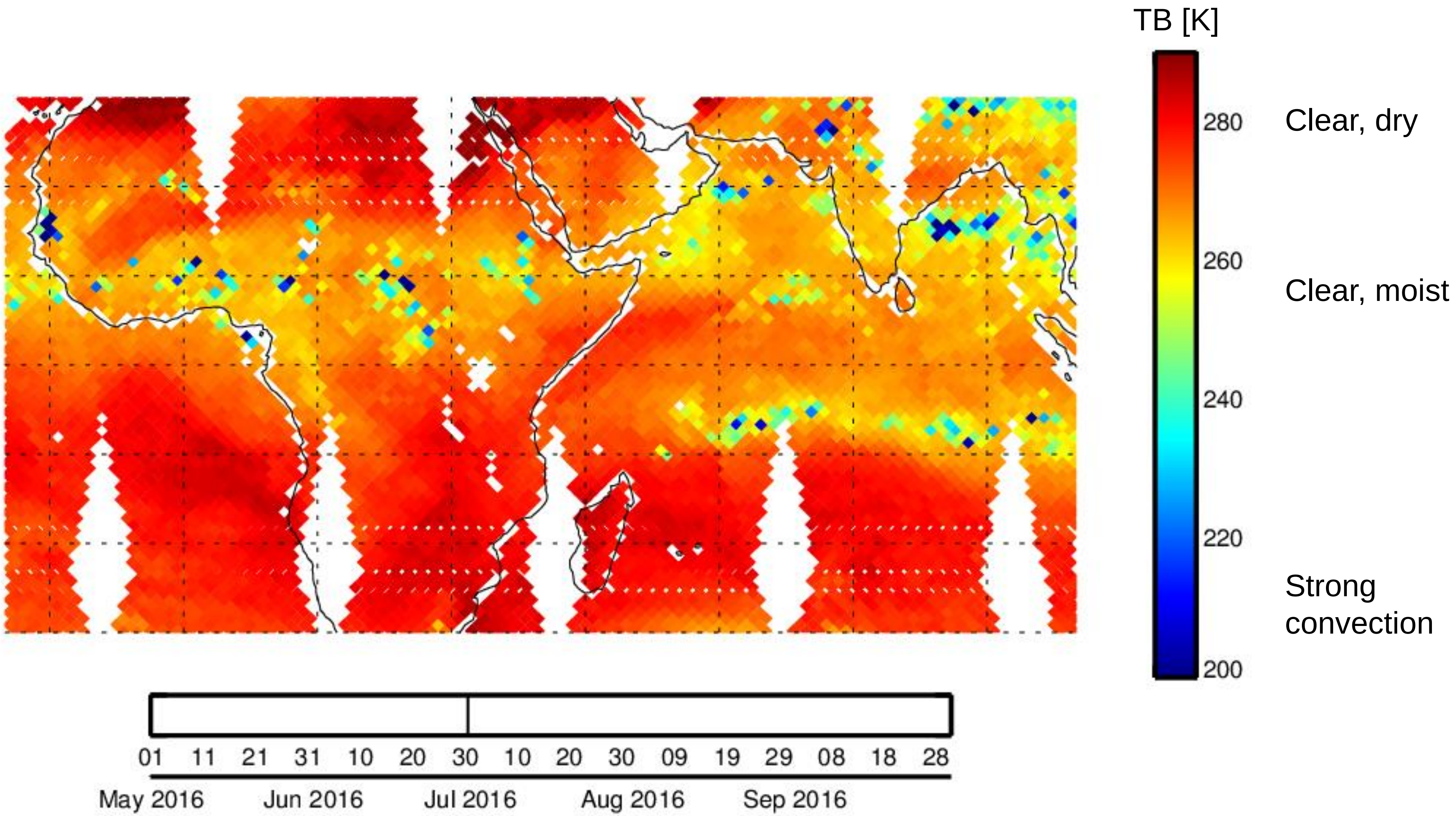


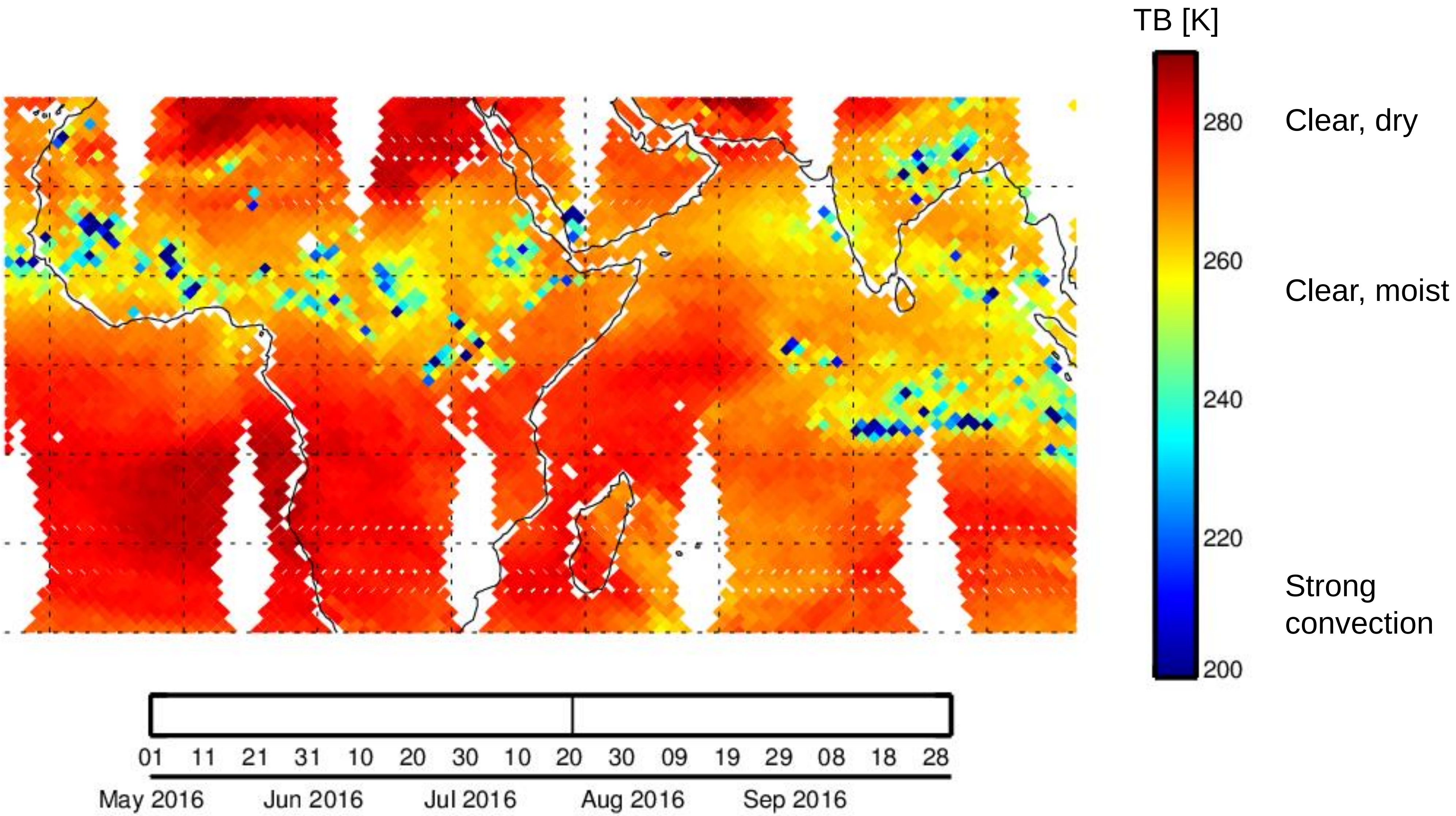
May – September 2016 at 183 GHz

SSMIS F-17 ch 9 (183 ± 7 GHz)



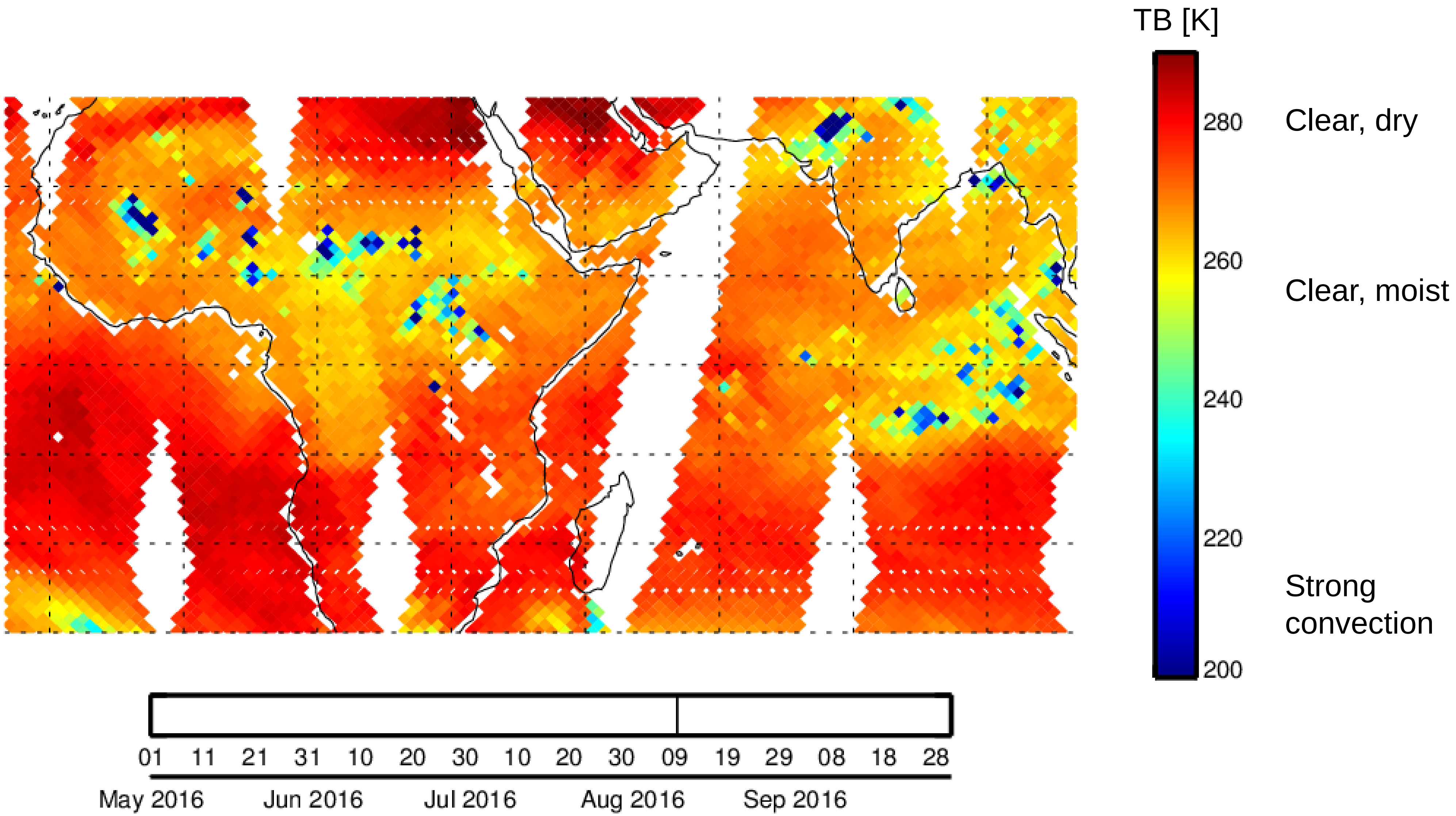
May – September 2016 at 183 GHz

SSMIS F-17 ch 9 (183 ± 7 GHz)



May – September 2016 at 183 GHz

SSMIS F-17 ch 9 (183 ± 7 GHz)



May – September 2016 at 183 GHz

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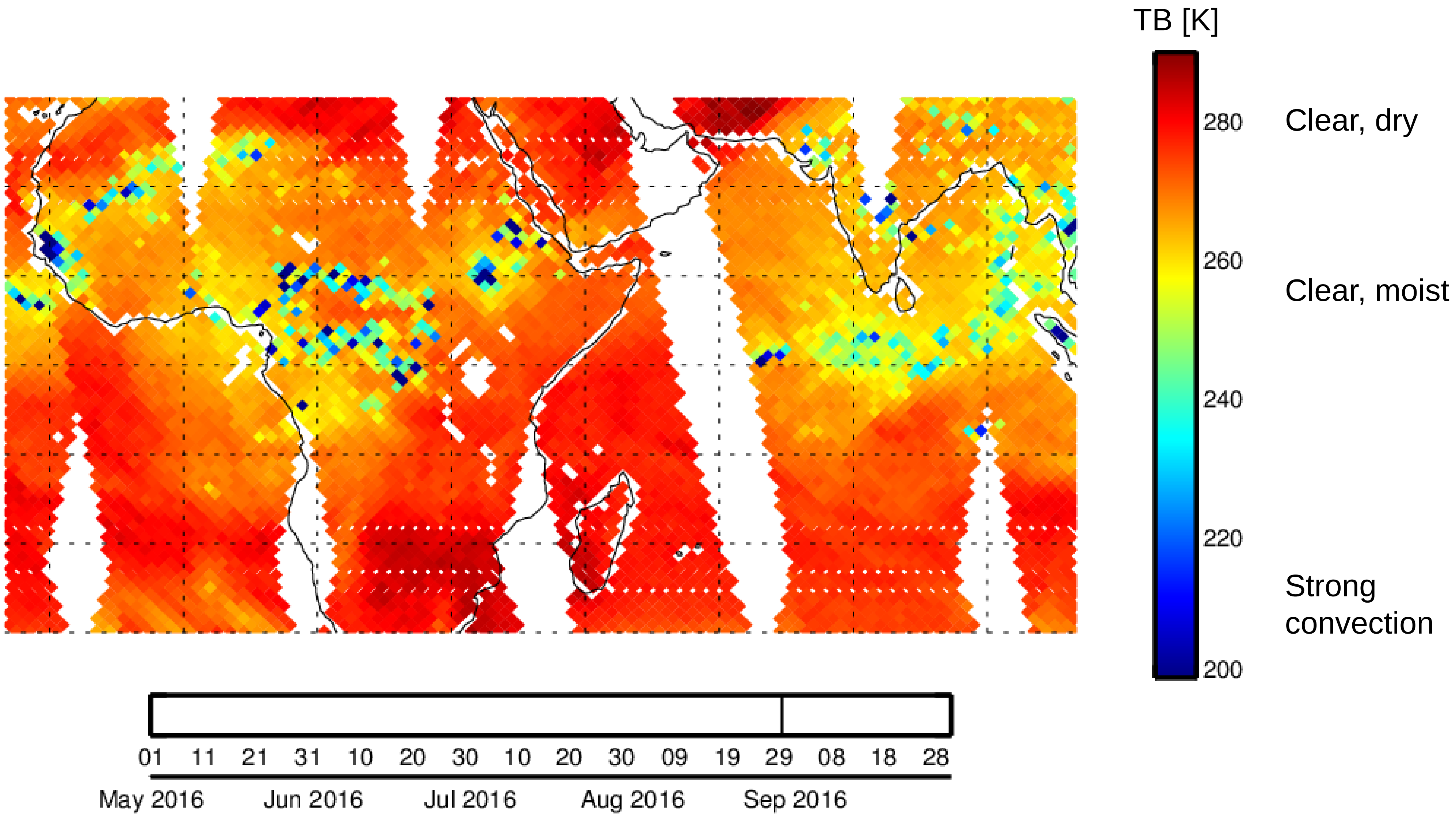
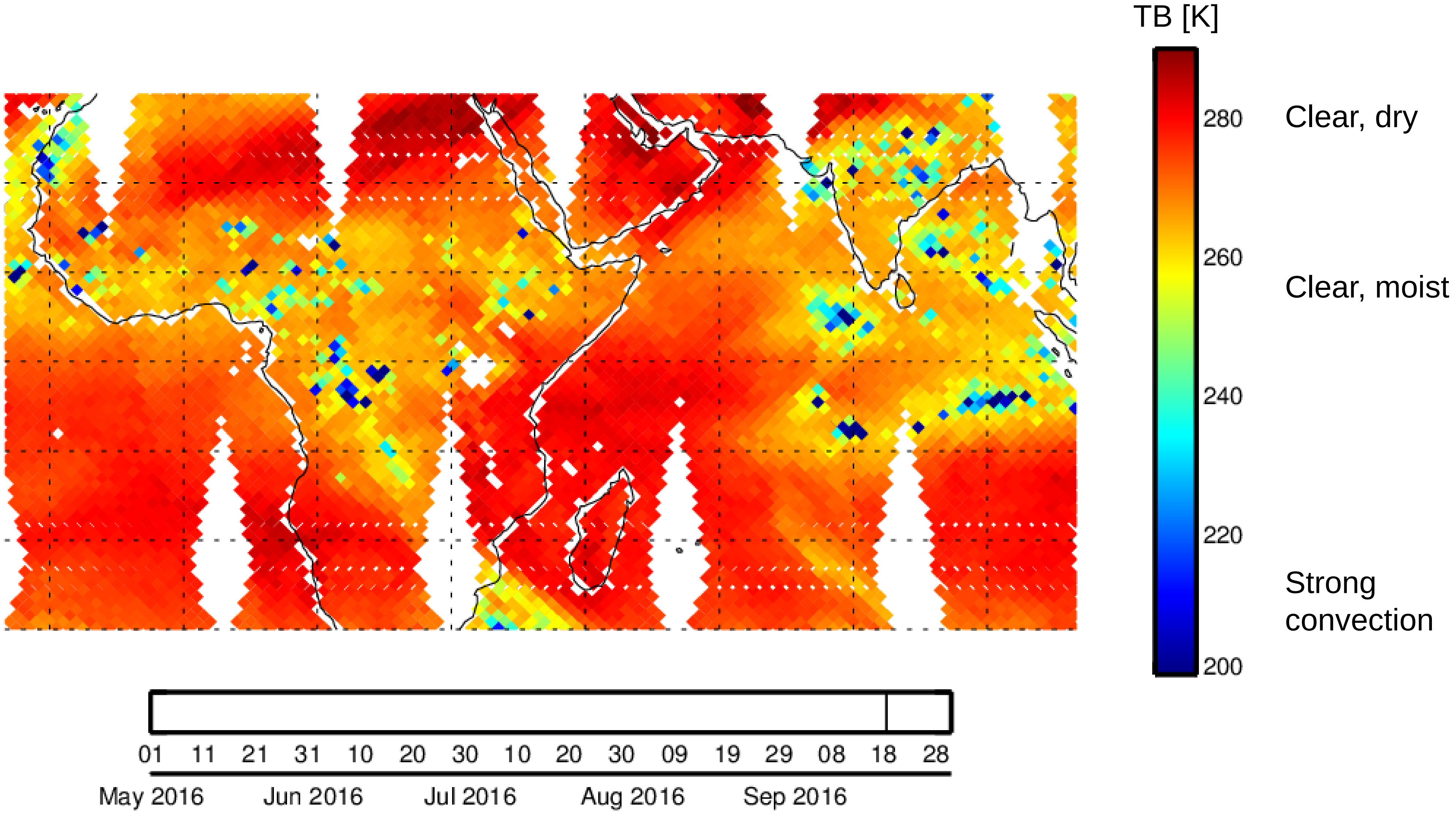


May – September 2016 at 183 GHz

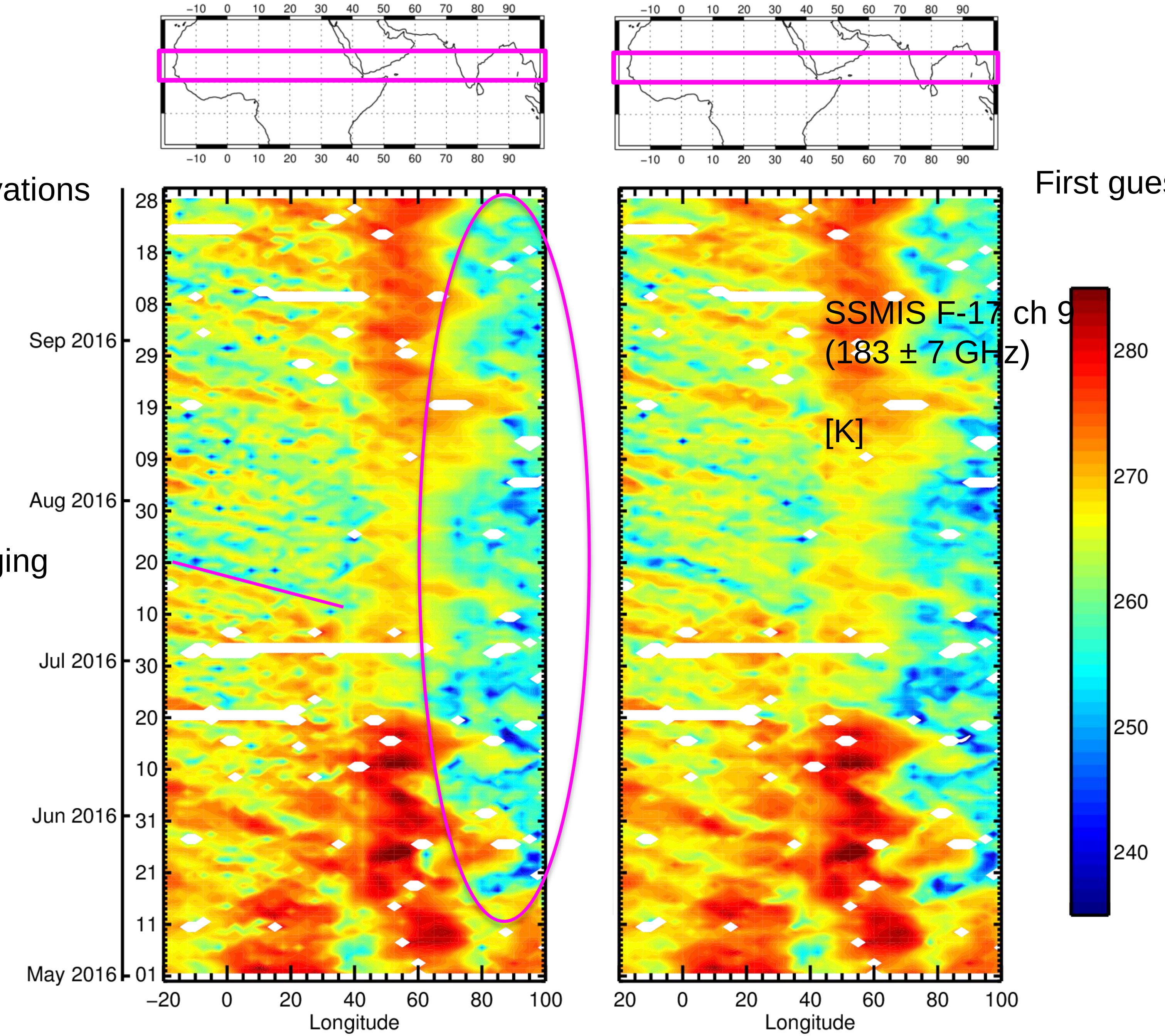
SSMIS F-17 ch 9 (183 ± 7 GHz)



May-September 2016

Observations

First guess



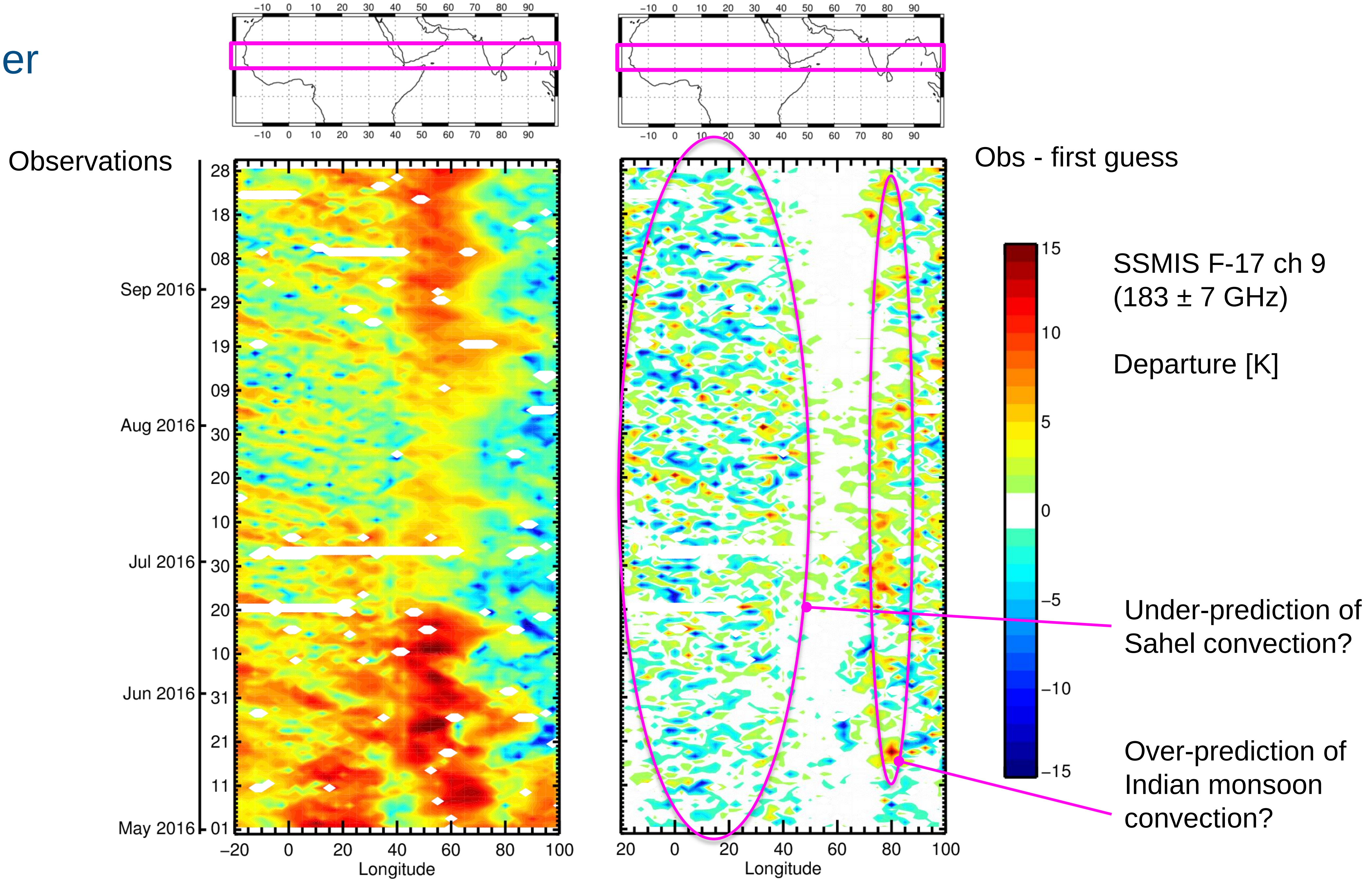
Easterly waves bringing rain to the Sahel

Asian monsoon

SSMIS F-17 ch 9 (183 ± 7 GHz)

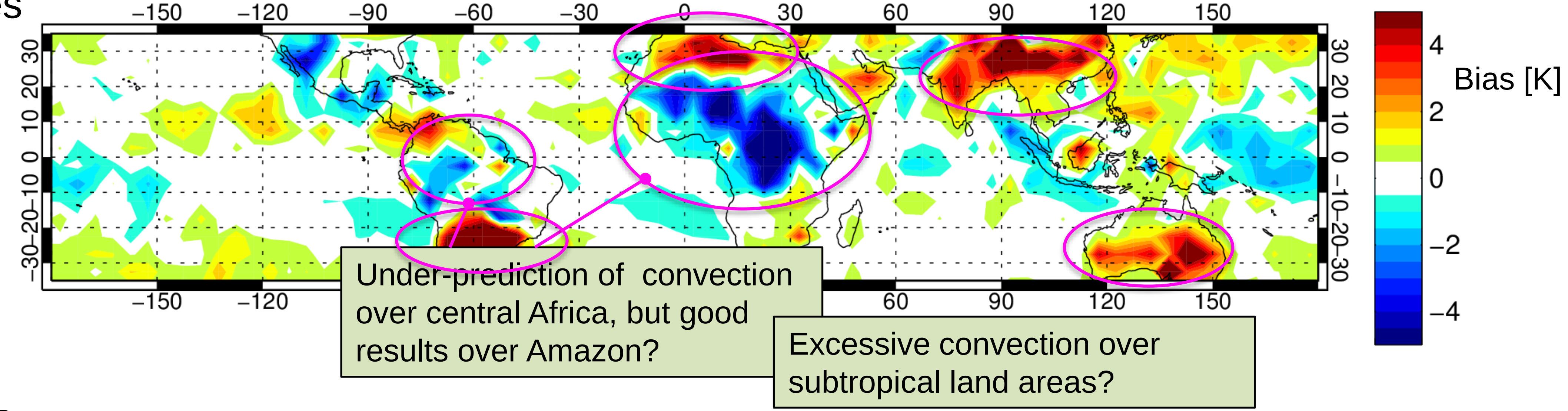
[K]

May-September 2016

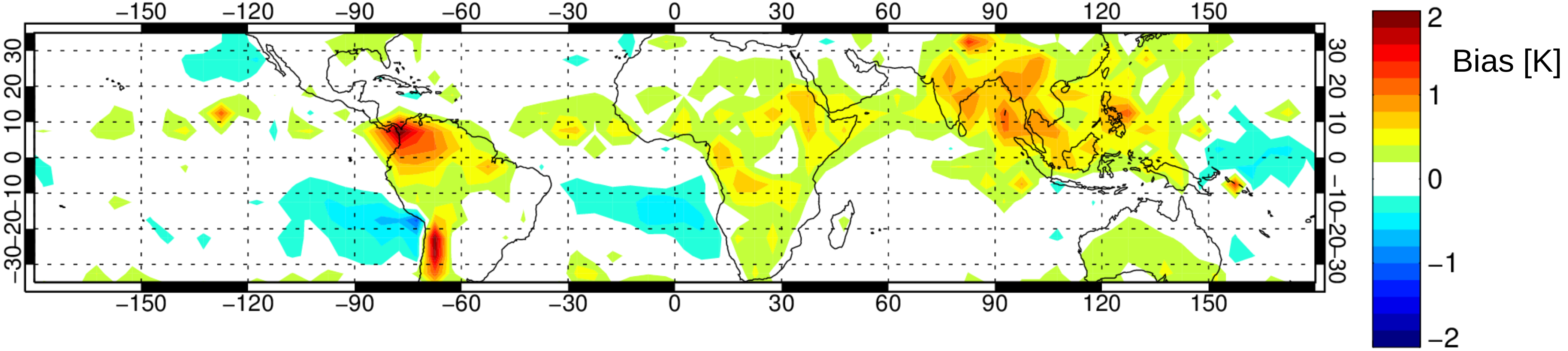


May-September SSMIS ch. 9 mean bias (after VarBC)

Cloudy scenes

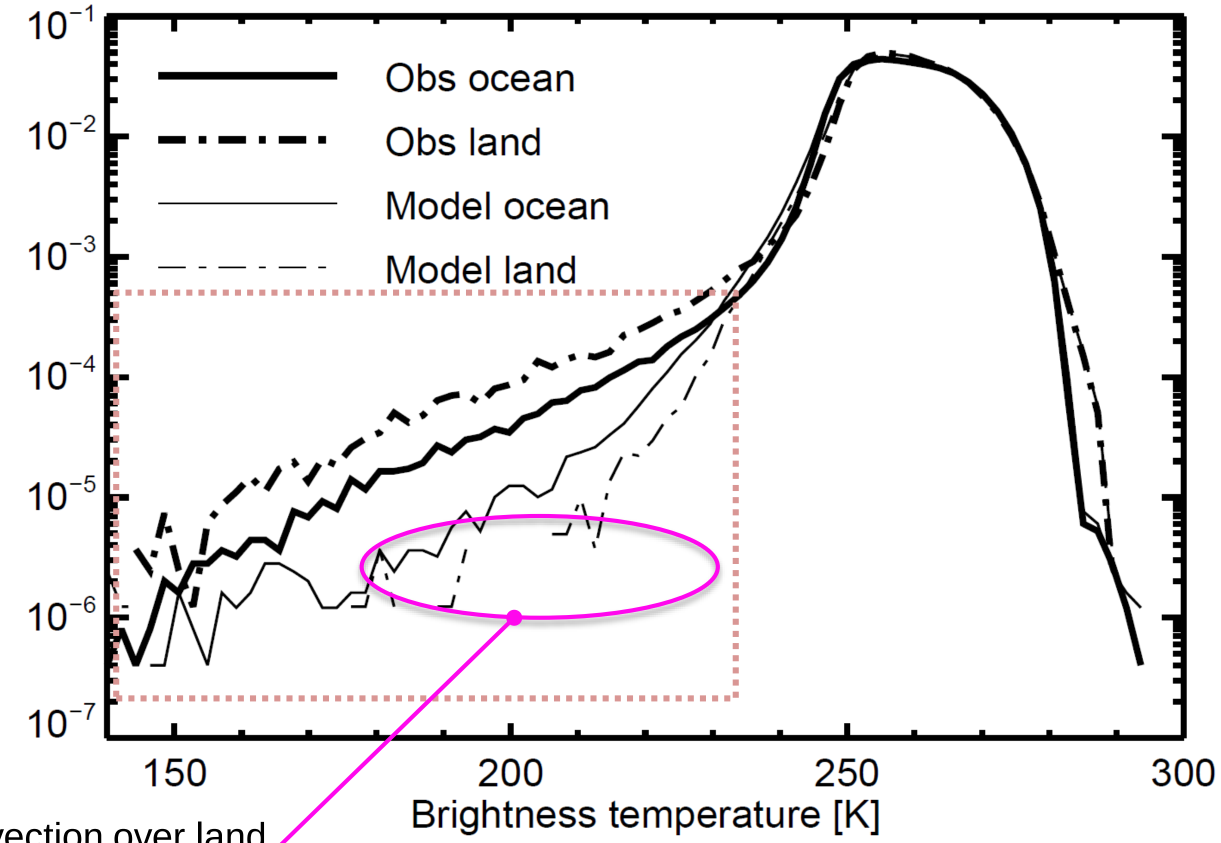


Clear scenes



Simulated vs. observed brightness temperatures at 183±1 GHz

Low brightness temperatures ≈ deep convection



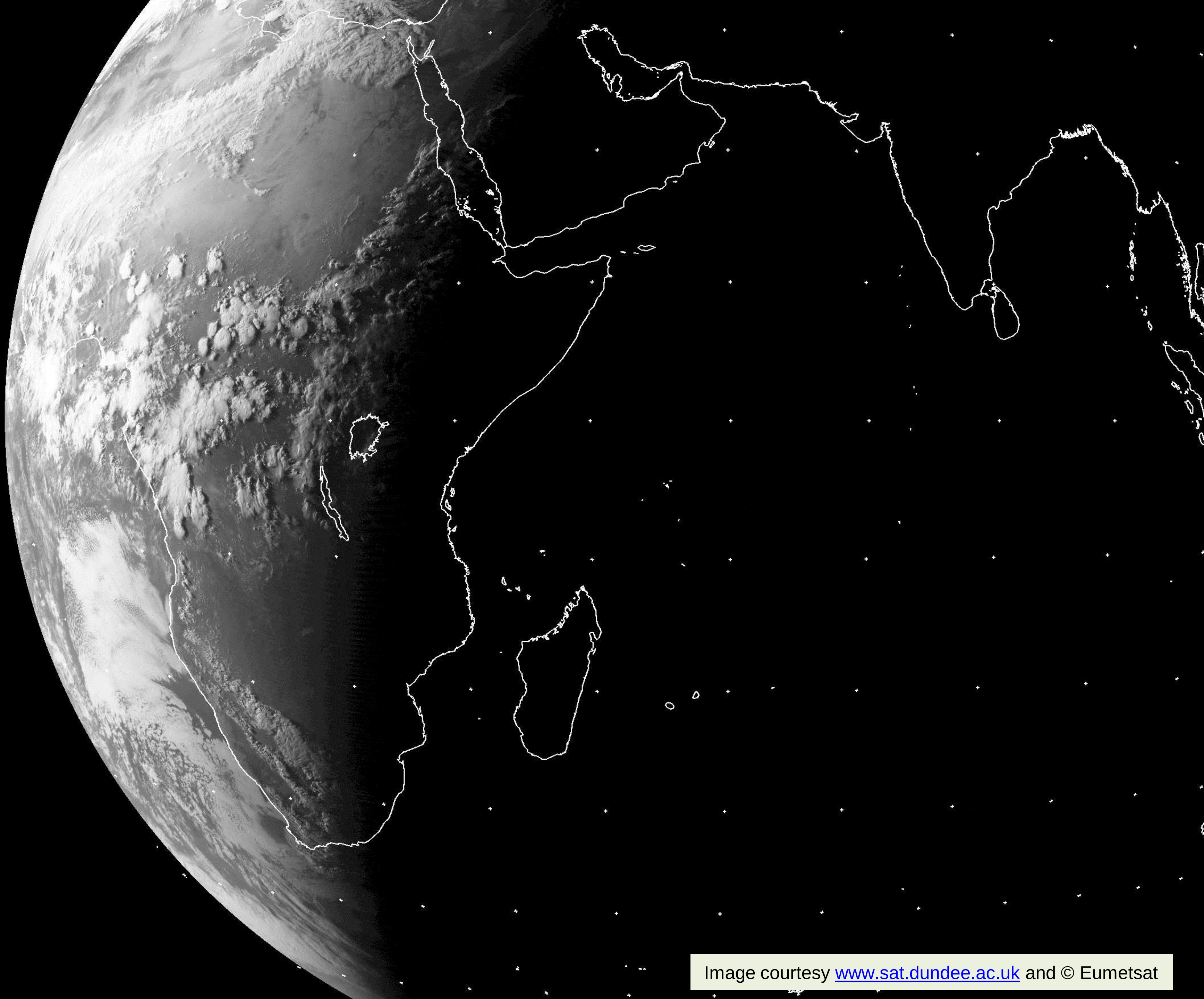
Observations show more convection over land than ocean.

Simulations show barely any convection over land without an artificial boost (Cmax kludge)

From Geer and Baordo (2014) using sector snowflake over land and ocean

Evening
mesoscale convection

May 7th 2016, ~4.30pm



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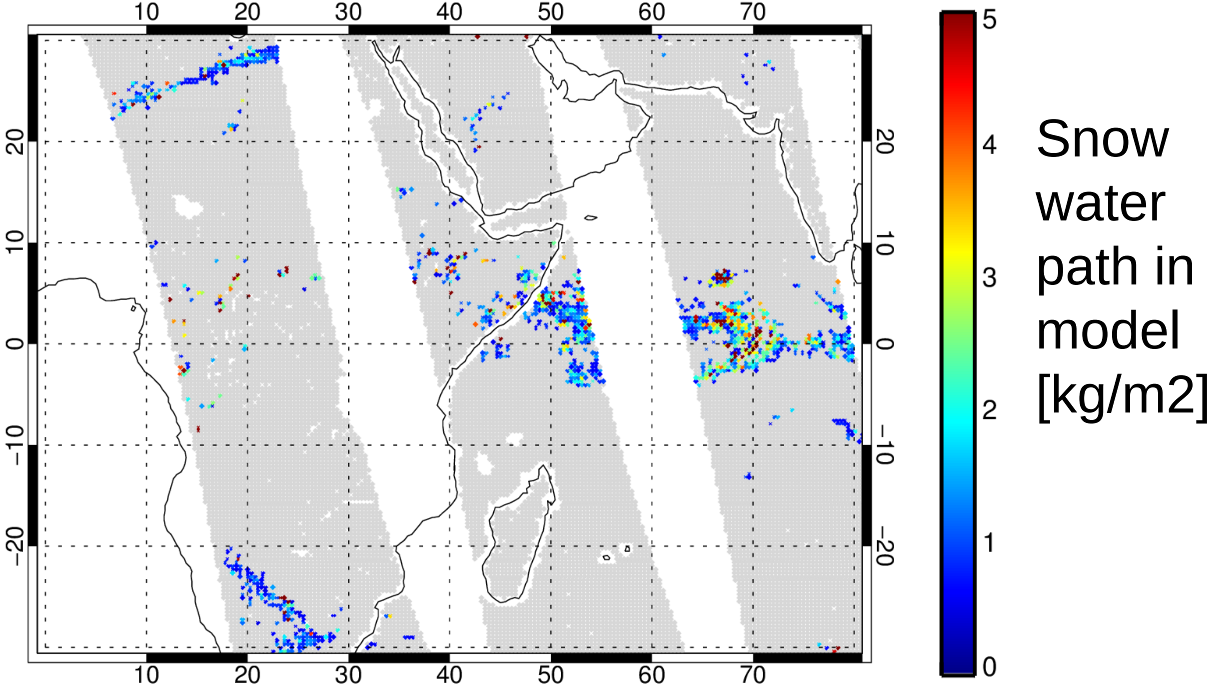
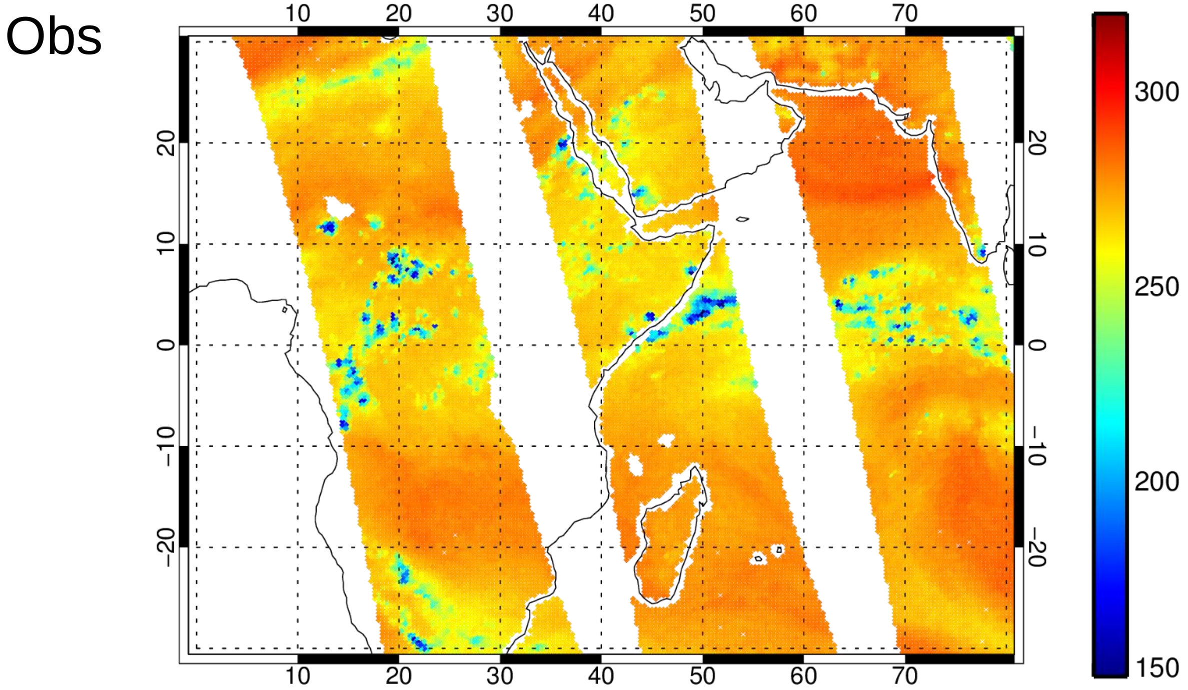
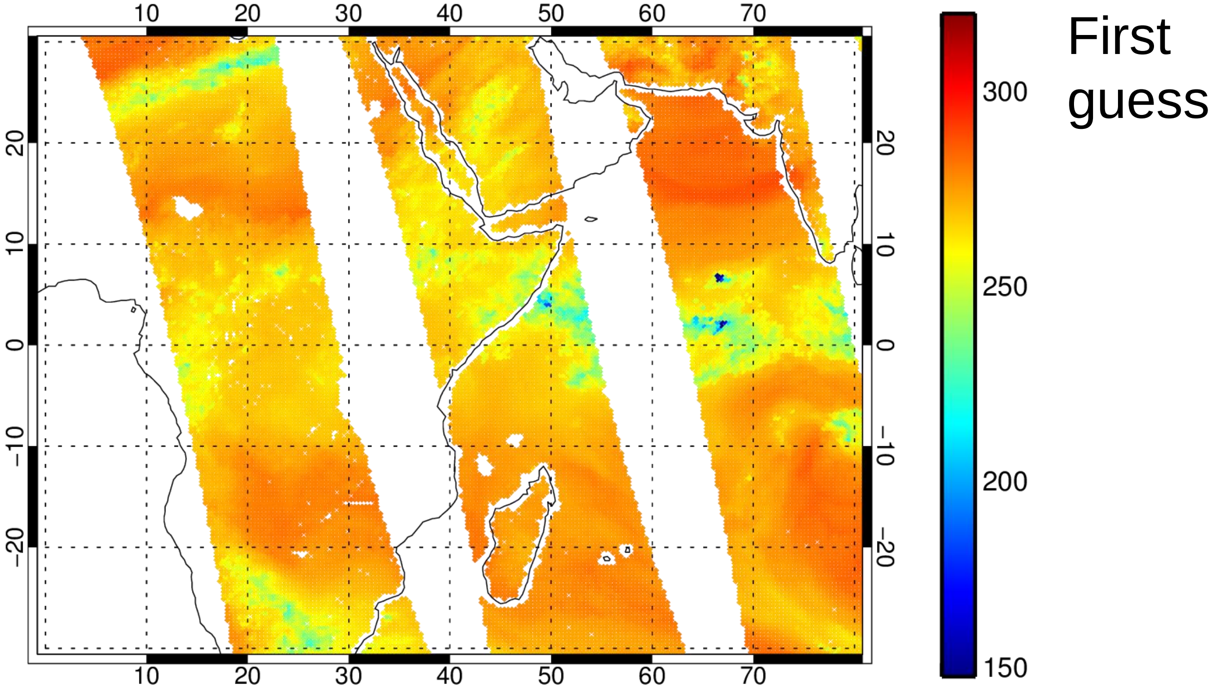
Evening mesoscale convection

SSMIS ch.9, May 7th 2016, ~6pm local time

- 40km superobs (8x usual data density)
- In model, turn off cloud fraction kludge over land surfaces (use effective cloud fraction as for ocean)





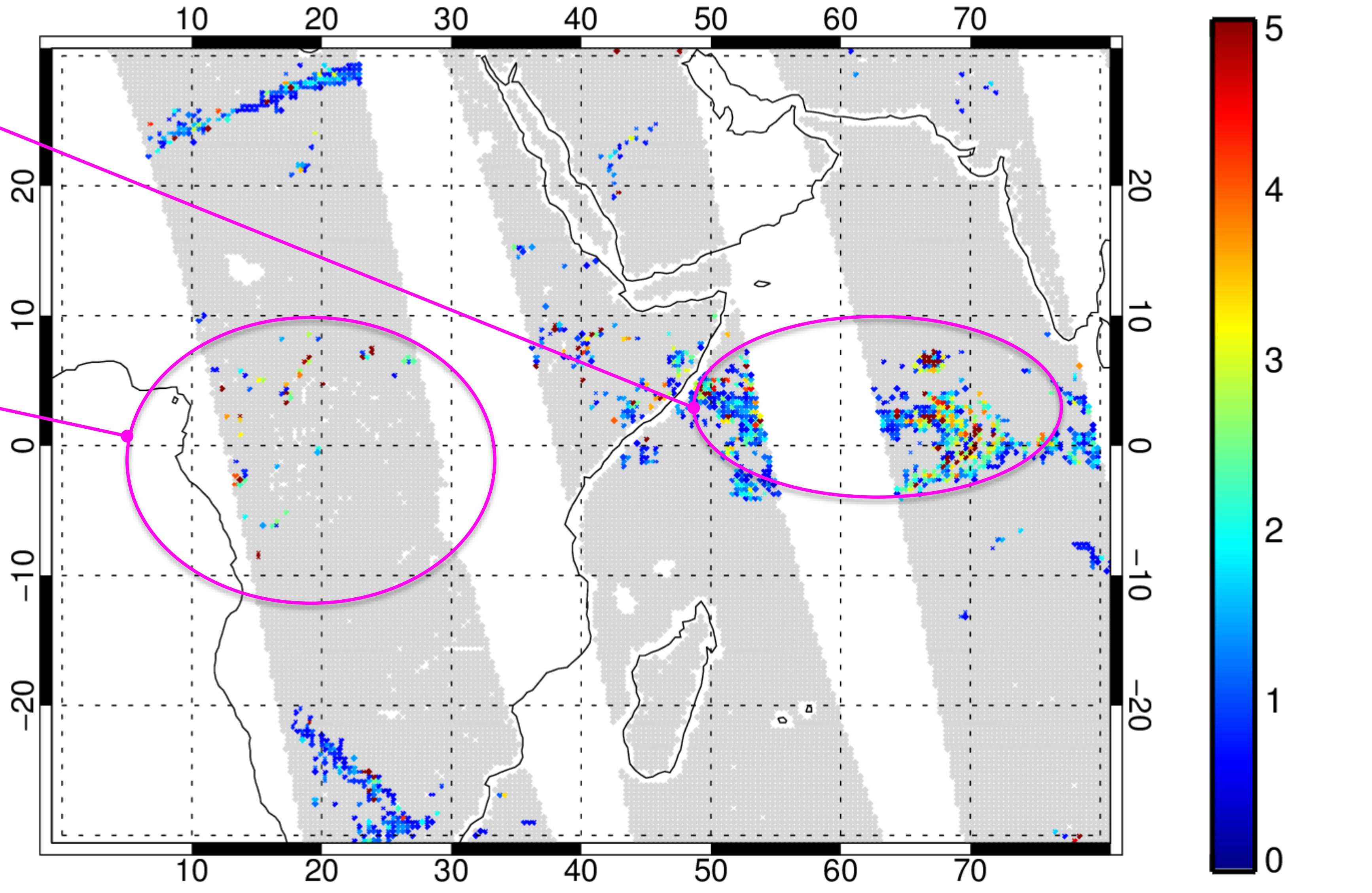


Convective issues in the forecast model

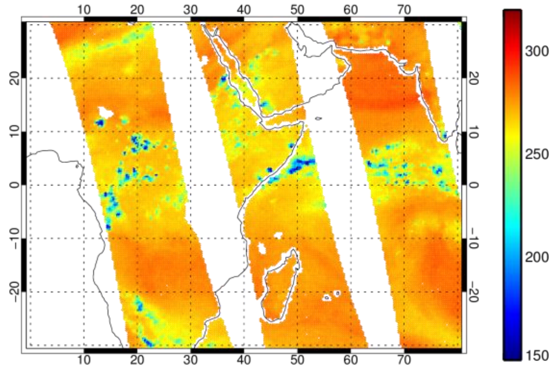
SSMIS locations, May 7th 2016, ~6pm local time

Over ocean, model creates realistic organised convection systems (~100km scale)

Over central Africa, convection is too sparse, too disorganised and on too small scales (<40km) Or is the party already over?



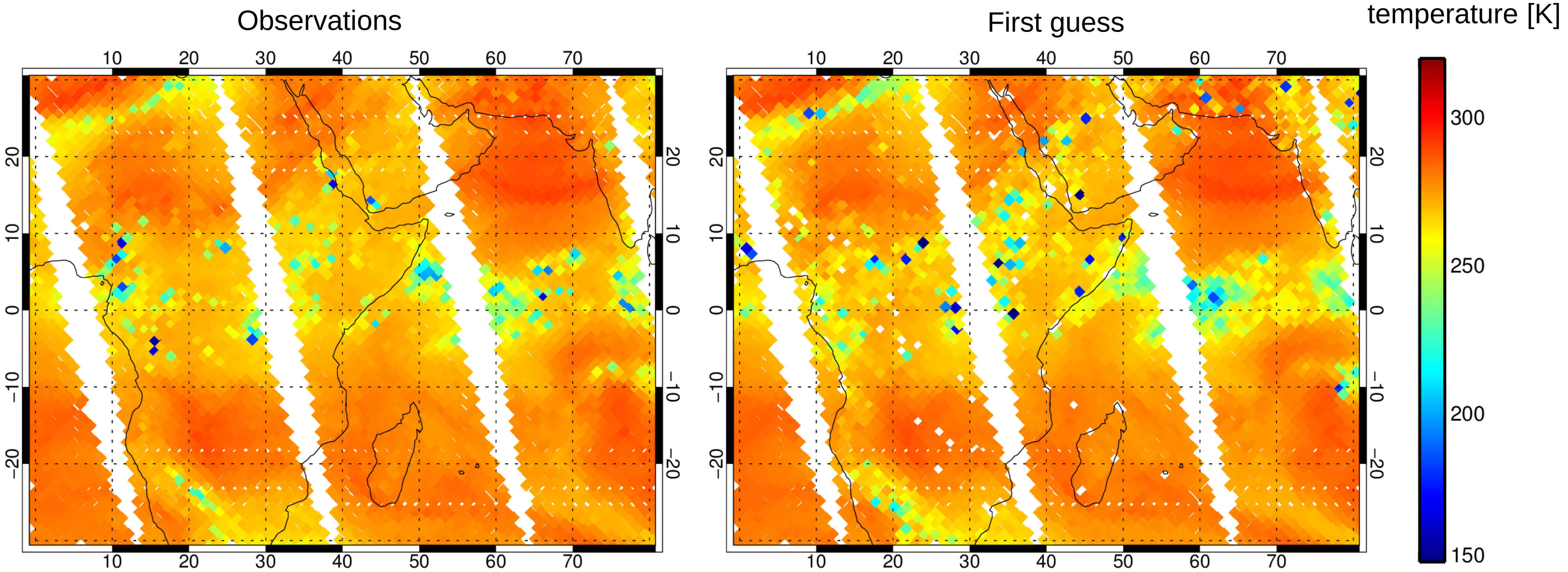
Observations



Convective issues in the forecast model

NOAA-19 MHS locations, May 7th 2016, ~3pm local time

Wind back the clock 3 hours and go back to using the Cmax cloud fraction kludge to boost simulated “convection”



Diurnal cycle with SAPHIR ch5 (183±7 GHz) Sahel

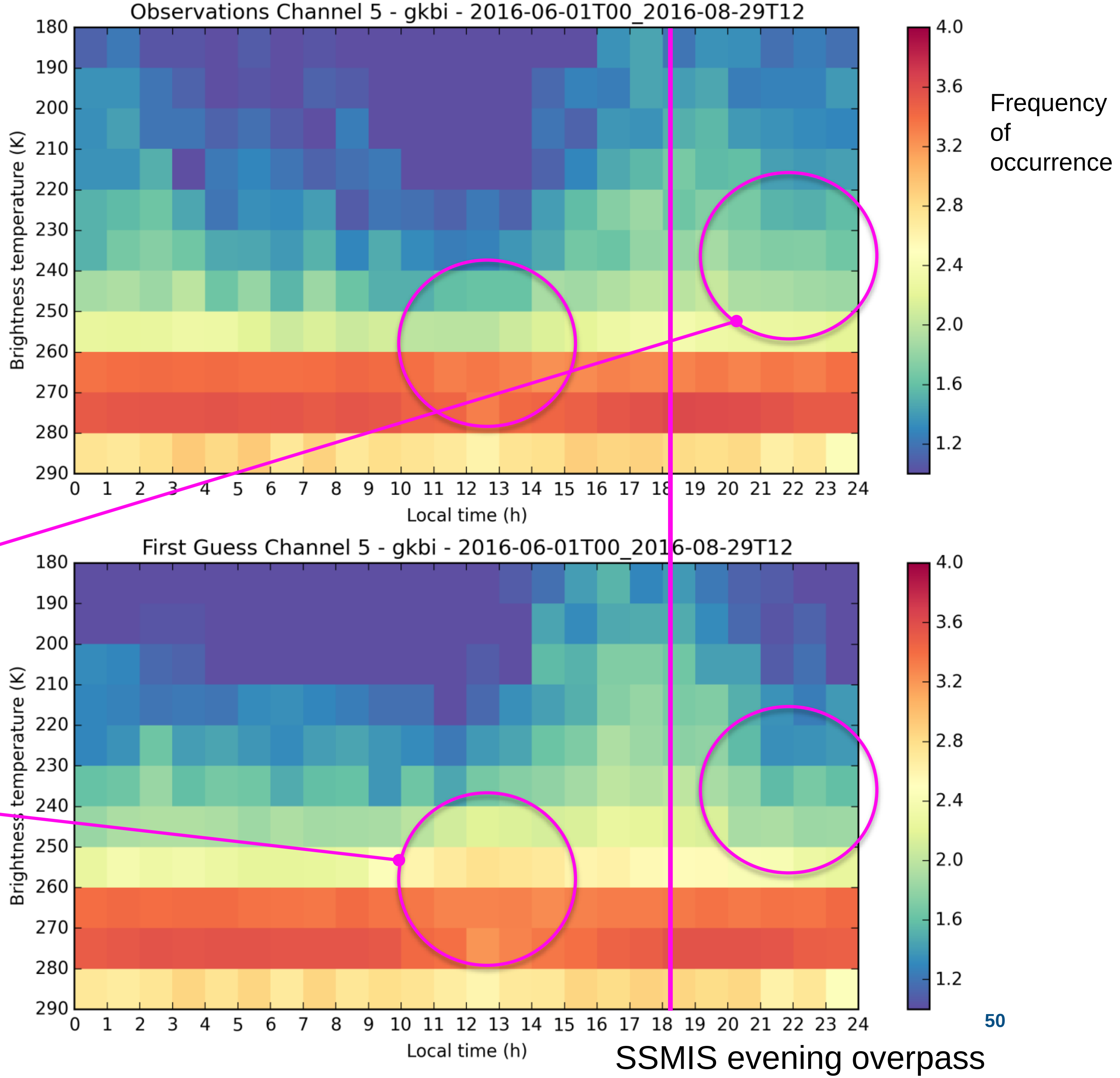
Land surfaces, 1st June – 29th August 2016
(Cmax kludge used, artificially boosting effect of model convection on Tb)

Low Tb = deep convection

Clear skies

Overnight convective activity observed but lacking in model

Early convective peak in model, though without intense convection



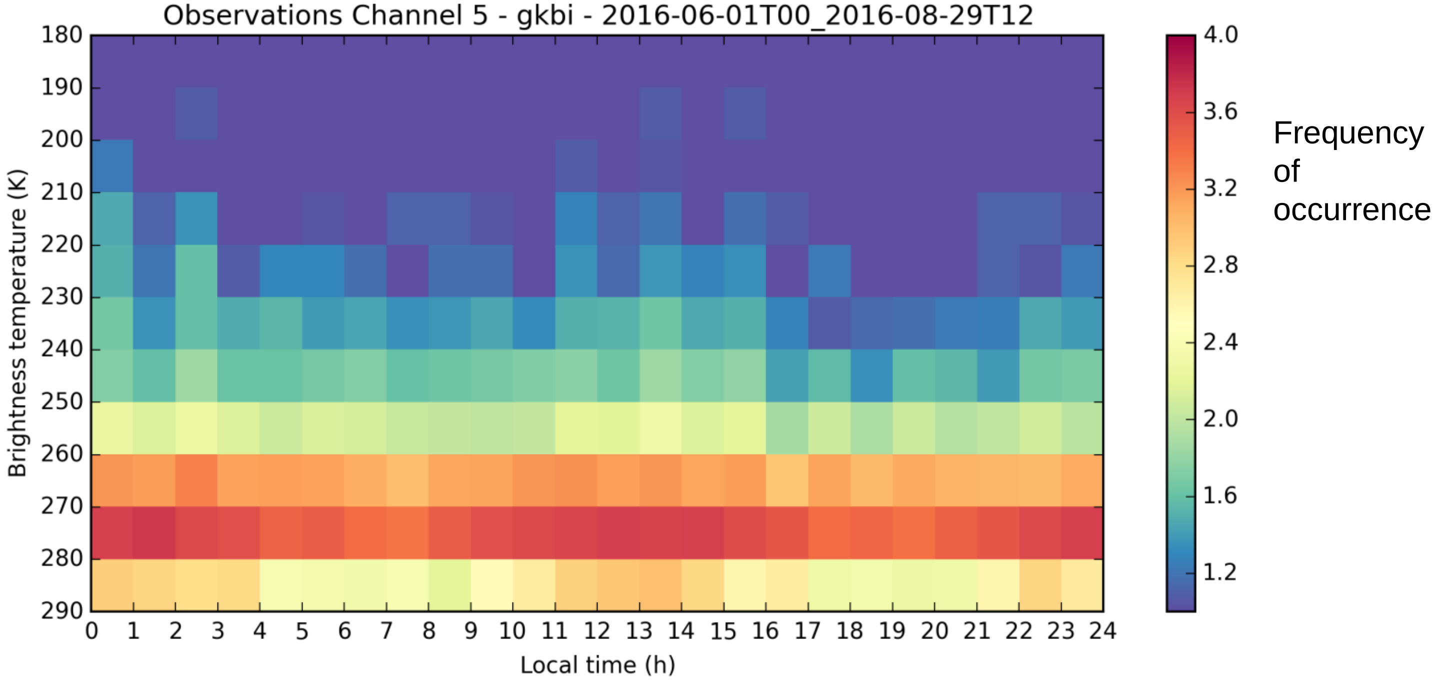
SSMIS evening overpass

Diurnal cycle with SAPHIR ch5 (183±7 GHz)
Indian ocean, ITCZ

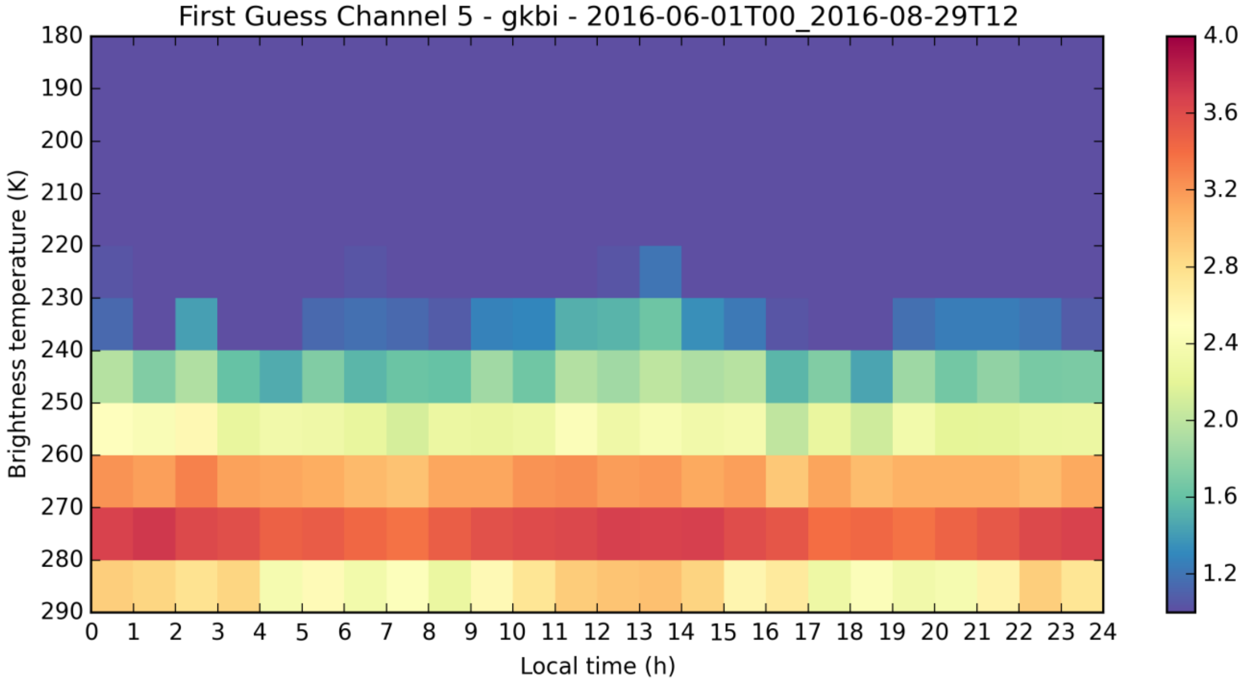
1st June – 29th August 2016
Ocean surfaces, no cloud fraction kludge required

Low Tb = deep convection

Clear skies

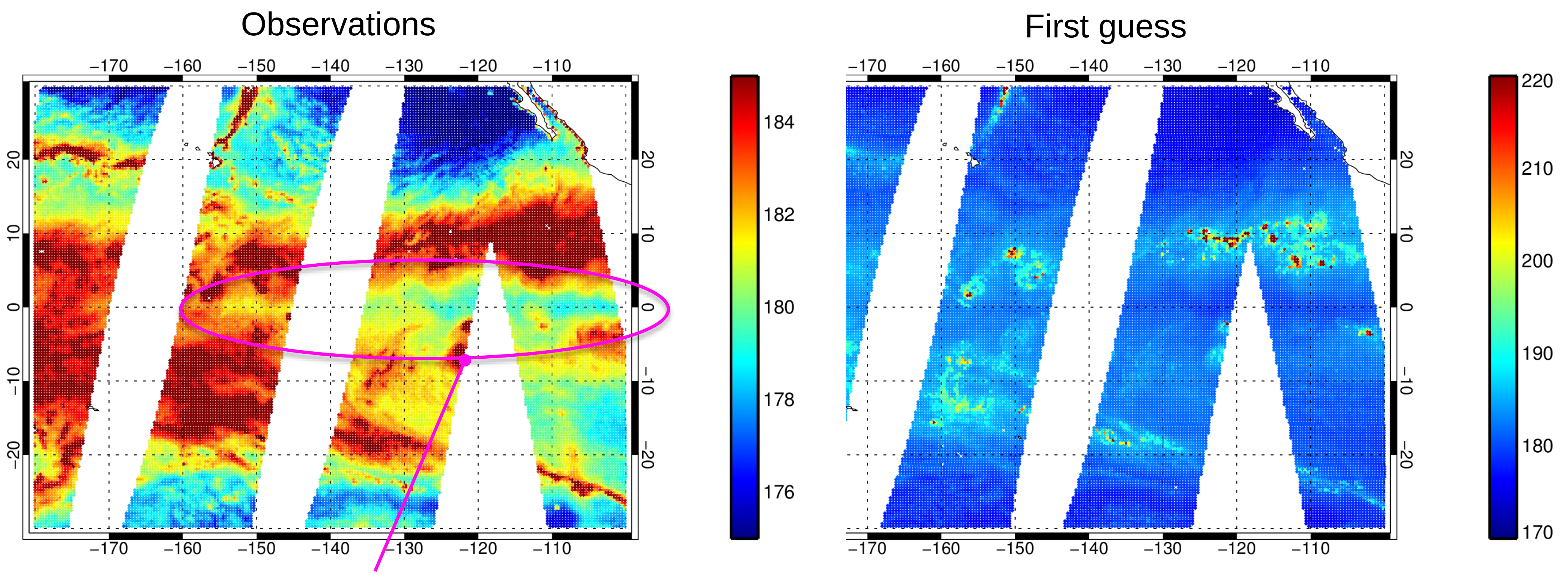


Continuous convective activity through the day, reasonably represented by model, if not to its full intensity.



Briefly… from 183 GHz (deep convective frozen particles) to 10 GHz over ocean (warm Tb = heavy rain)

AMSR2 10 GHz v-pol, 8th May 2016



Cold tongue – low SSTs – tropical instability waves

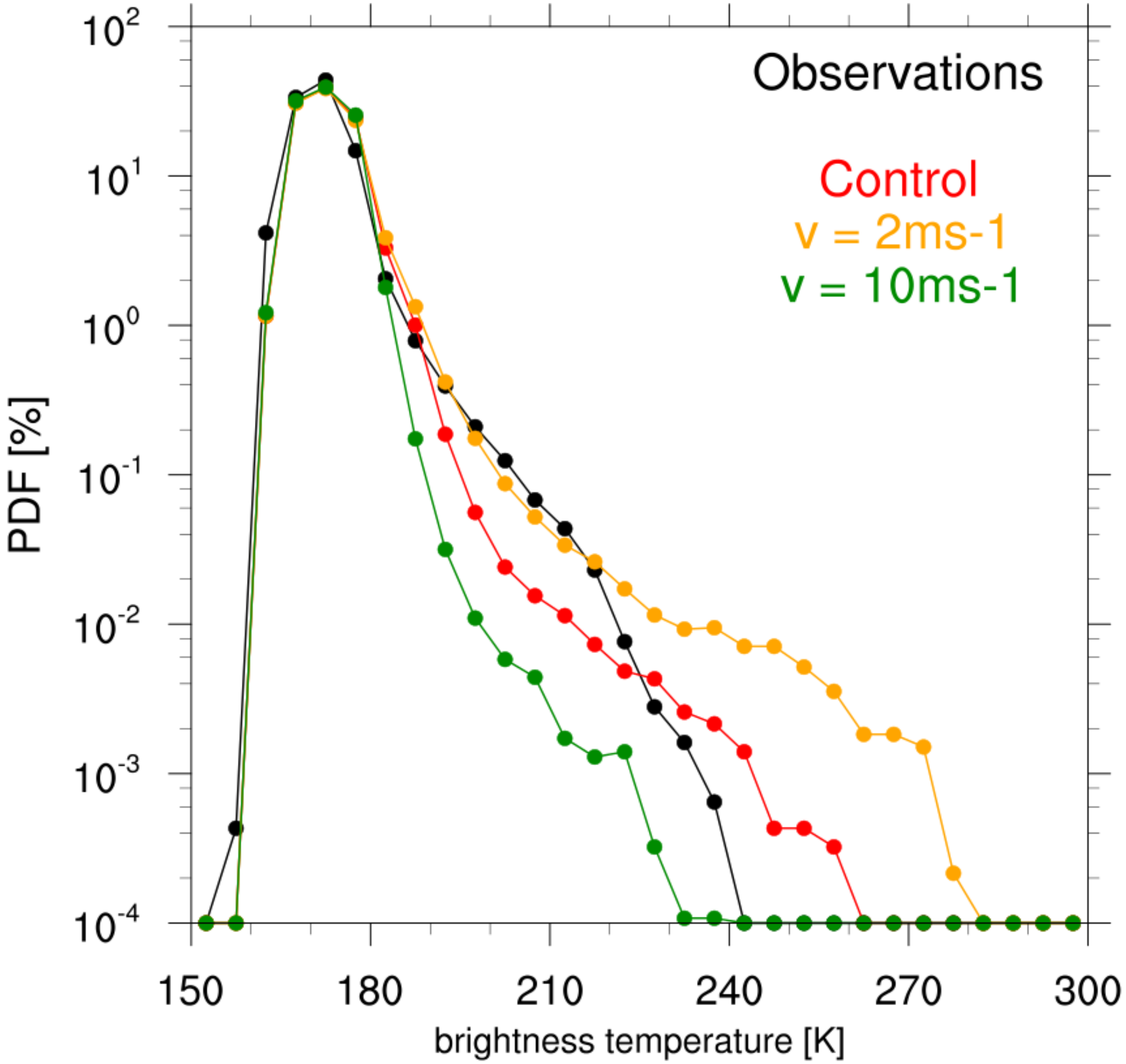
Sensitivity to radiative transfer assumptions

Scale-matching: important for small-scale intense features

PSD: unimportant?

Conversion of convective flux to density (though with unrealistically large uncertainty range)

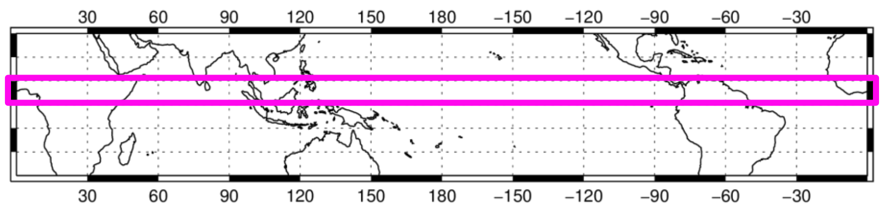
Most important (not shown): assumed sub-grid precipitation fraction in convection

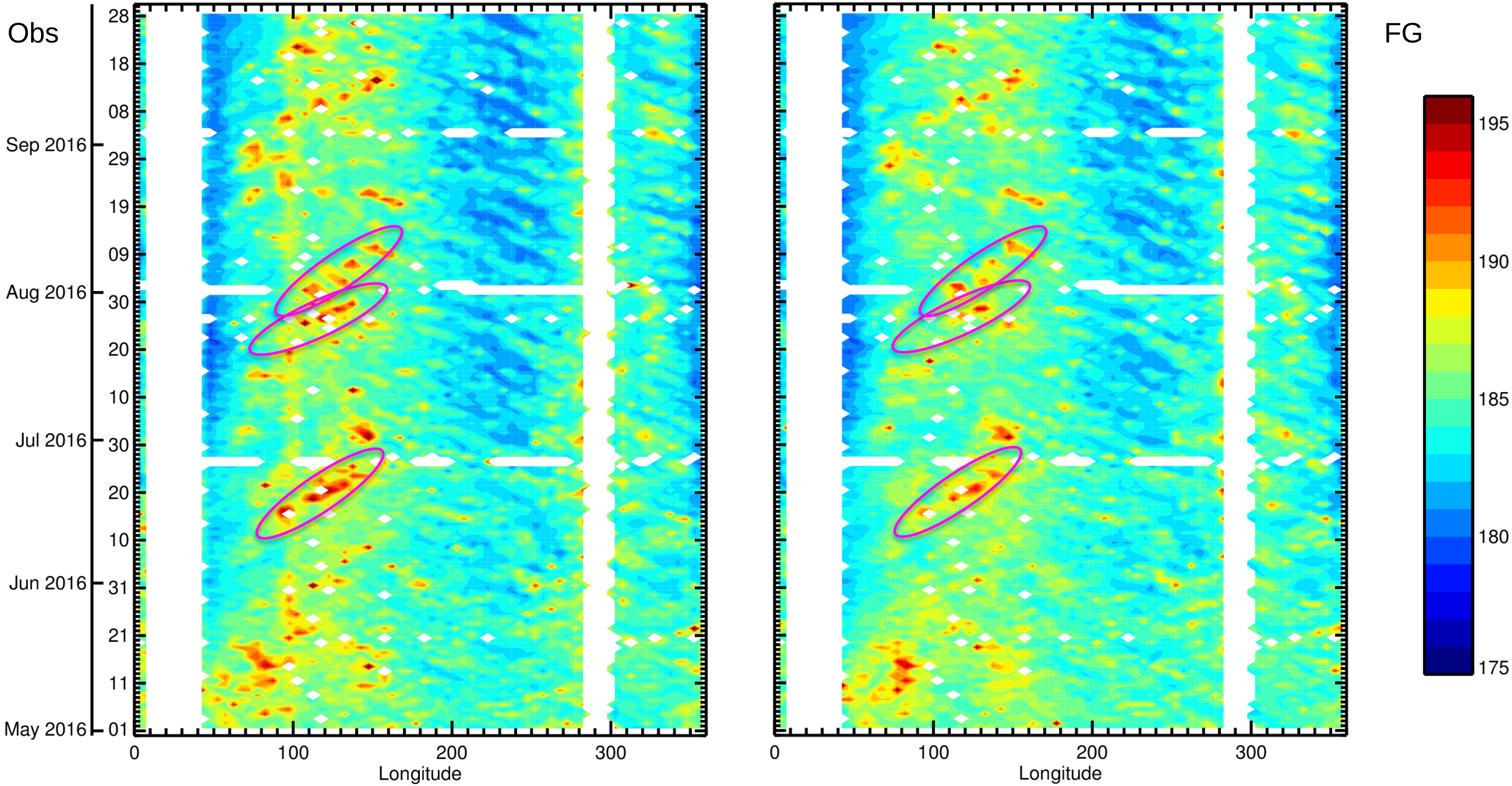


ECMWF

Kelvin waves? 10 GHz ~ rain

Better than the balloon results…?





Conclusions

- All-sky assimilation of microwave imagers and humidity sounders benefits moisture and wind analyses in the tropics
  - useful moisture and wind increments are being inferred from observations of convection
  - better methods are required for tropical forecast verification

- Over-ocean convective activity (proxy: 183 GHz scattering from big frozen particles in the convective core)
  - reasonably well modelled (is model over ocean already “mesoscale convection system resolving?”)
- African land convective activity
  - too sparse, too disorganised, too early

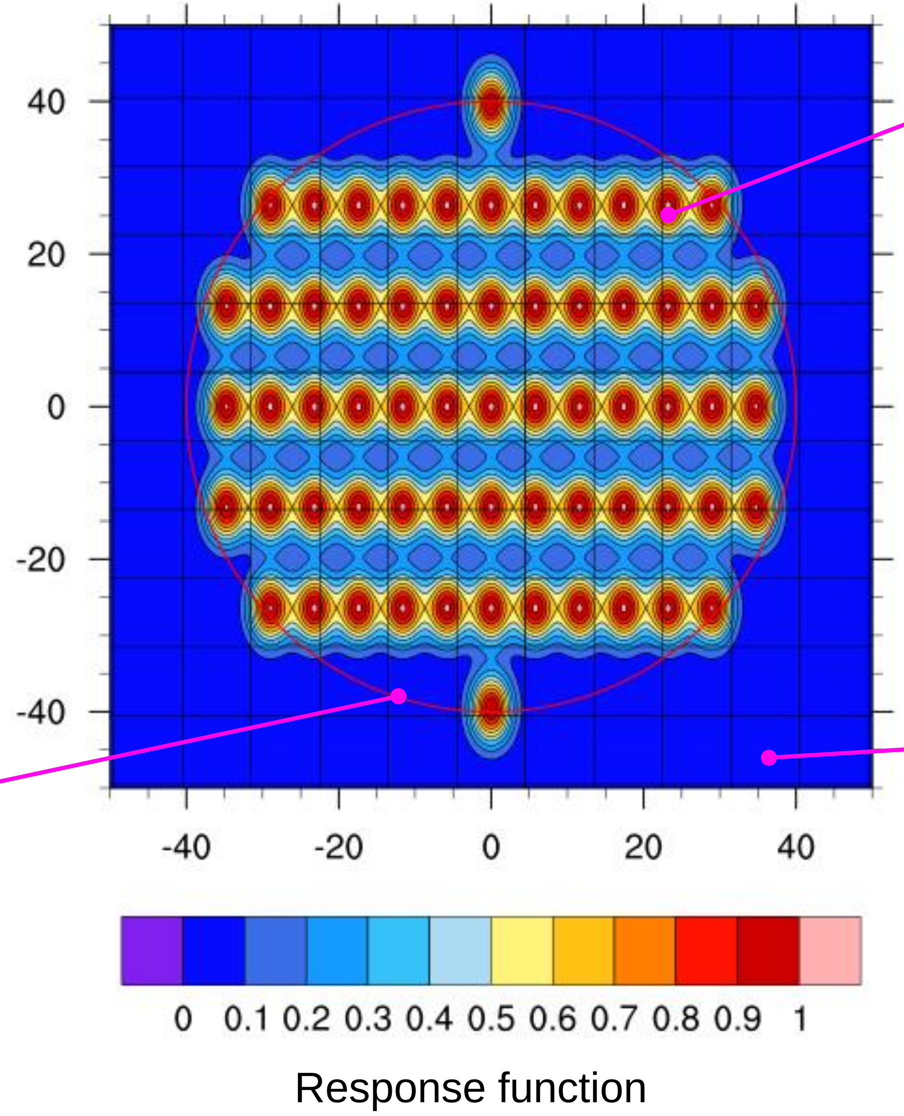
- Issues for further study include:
  - understand convection problems over Africa
  - it’s time for better modelling of sub-FOV heterogeneity

Preview: advanced superobbing and field of view modelling

First guess: simulated from multiple model grid points to provide “independent column approximation” radiative transfer

Observation: superobbed onto a standard field of view (e.g. 40km radius)

km from superob centre



89 GHz raw fields of view

T1279co model grid box (9km)

40km superobbing radius