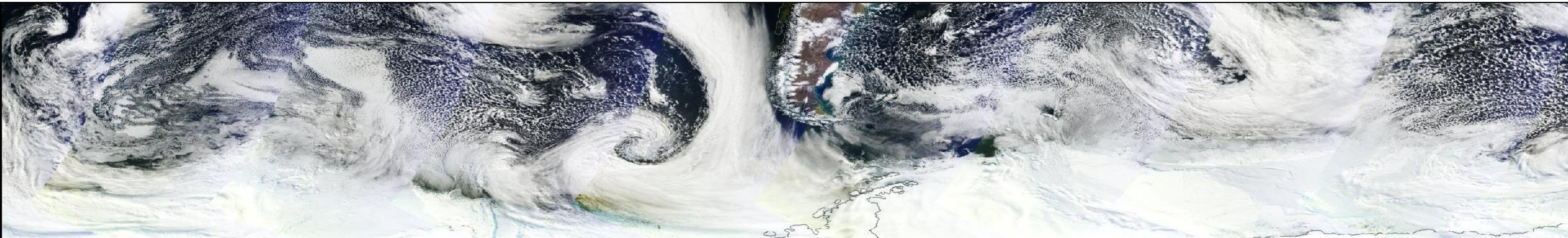
Observation-informed model development for cloud and precipitation

Richard Forbes, Alan Geer, Katrin Lonitz (ECMWF)
Maike Ahglrimm (ASR-funded at ECMWF, now DWD)

4th Workshop on assimilating satellite cloud and precipitation observations for NWP (ECMWF, Feb 2020)



Observation-informed model development for cloud and precipitation

1. On improving cloud and precipitation prediction in NWP

2. Using observations to inform parametrization development

3. Future potential for making the most of all-sky assimilation?

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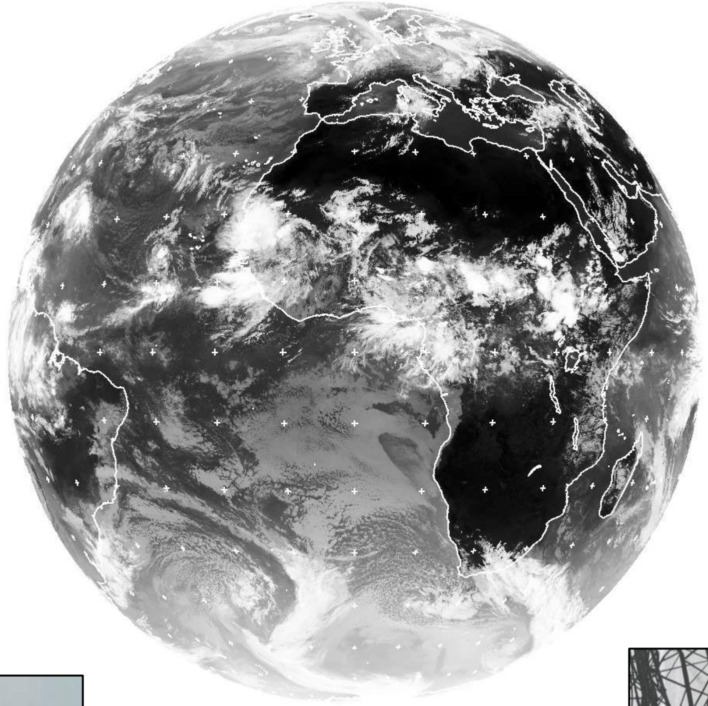
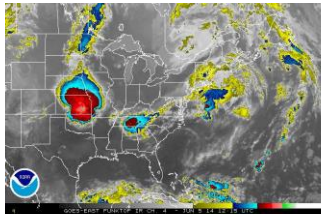
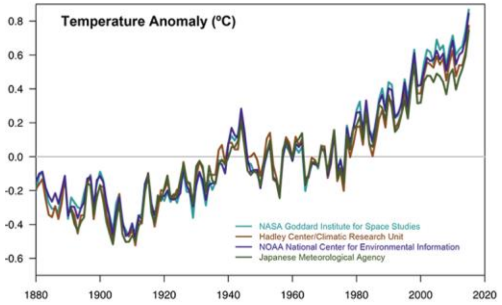
On improving cloud and precipitation prediction

Need to evaluate local to global impacts, across timescales…

Deep convection, tropical cyclones, snow, freezing rain, stratocumulus, high-latitude cloud, fronts, supercooled liquid water, drizzle, fog, cirrus, floods, mesoscale convective systems, MJO, global radiation…



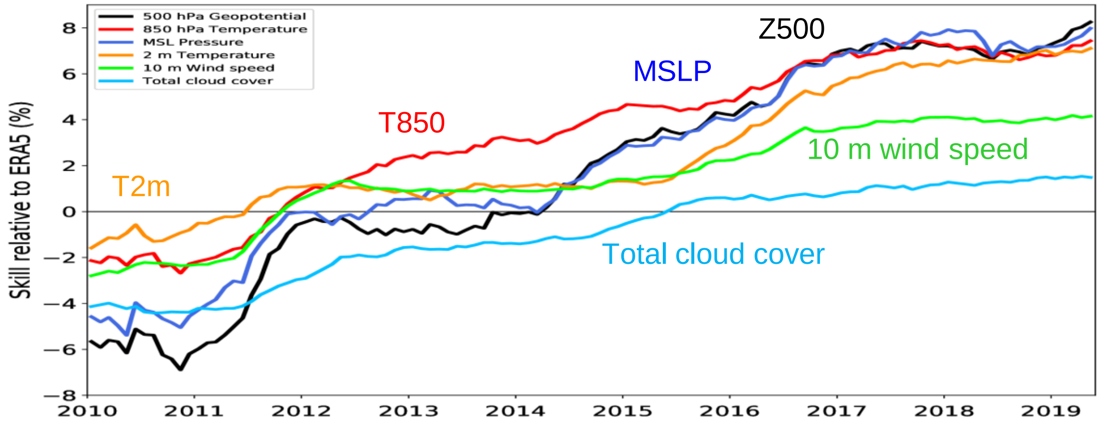




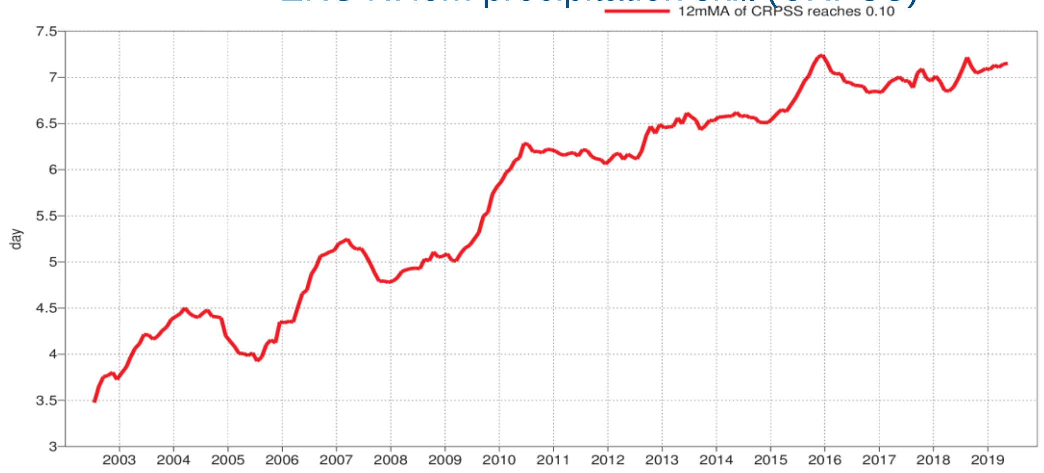
Days, weeks, months, years….,

On improving cloud and precipitation prediction – skill going up, biases going down!

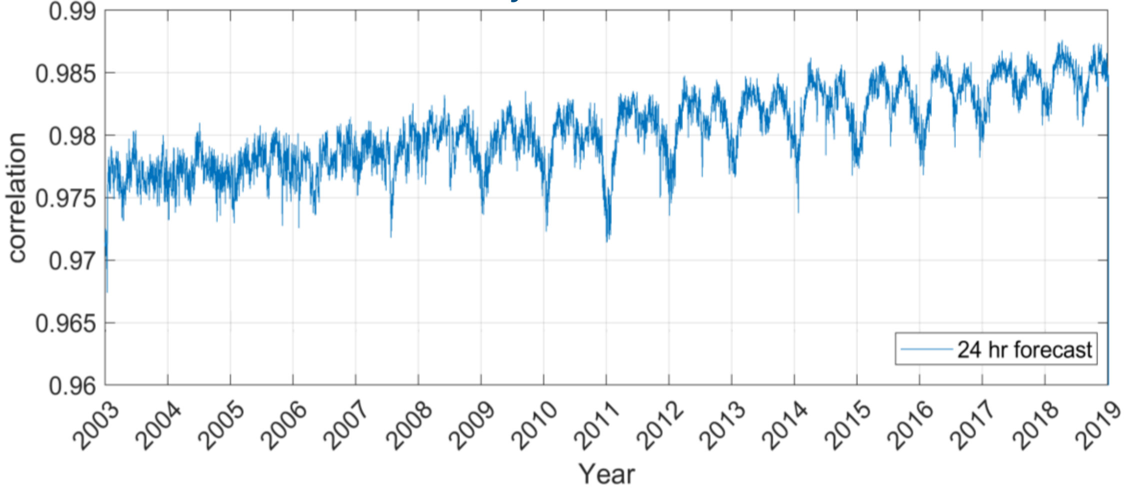
NHem day-5 skill (stdev) HRES relative to ERA5



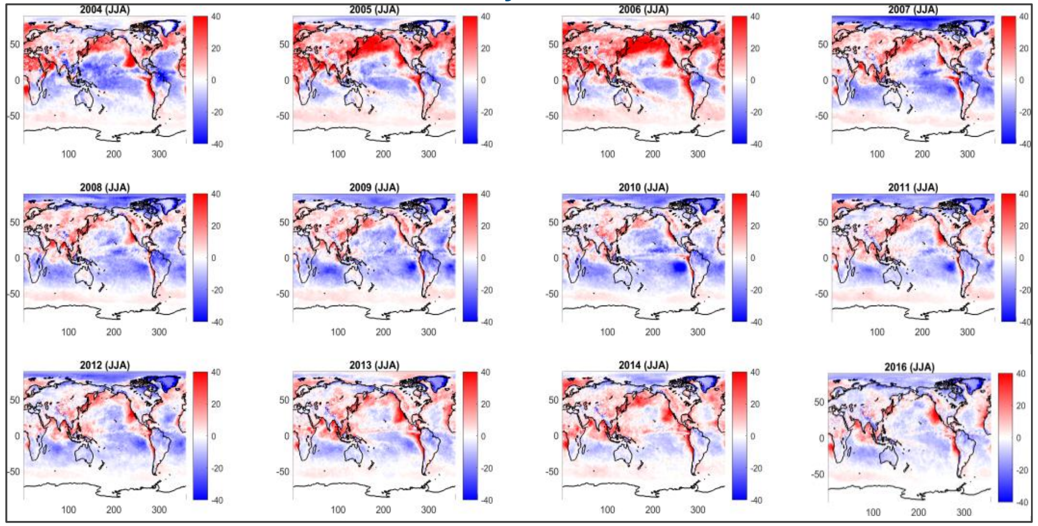
ENS NHem precipitation skill (CRPSS)



Global SW radiation day-1 correlation HRES vs CERES



Global TOA SW radiation day 1 JJA bias HRES vs CERES



On improving cloud and precipitation prediction – some challenges for the future

- Model errors are getting smaller
  - need to look ever closer at detailed physical processes

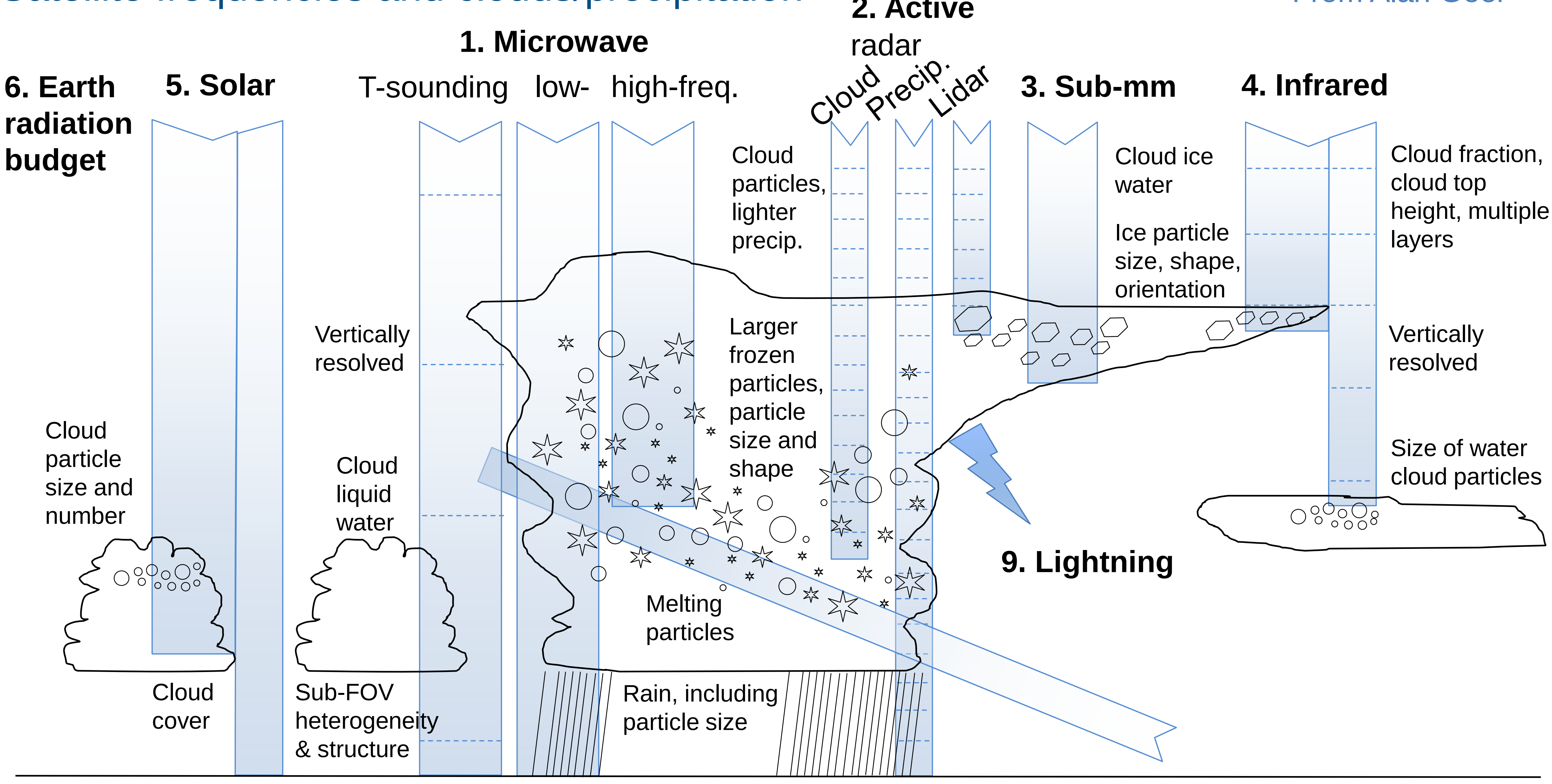
- Higher resolution
  - resolving smaller scale motions (convective permitting/resolving)
  - details of the microphysics becomes more important (macrophysics less important)
  - in a seamless global modelling system still needs to work at lower resolutions

- Increasing expectations
  - from the continuing improvement in the skill of weather forecasts to reducing uncertainty in climate prediction

- Increasing information from cloud and precipitation observations
  - need to make the maximum possible use of the data

Satellite frequencies and clouds/precipitation

From Alan Geer



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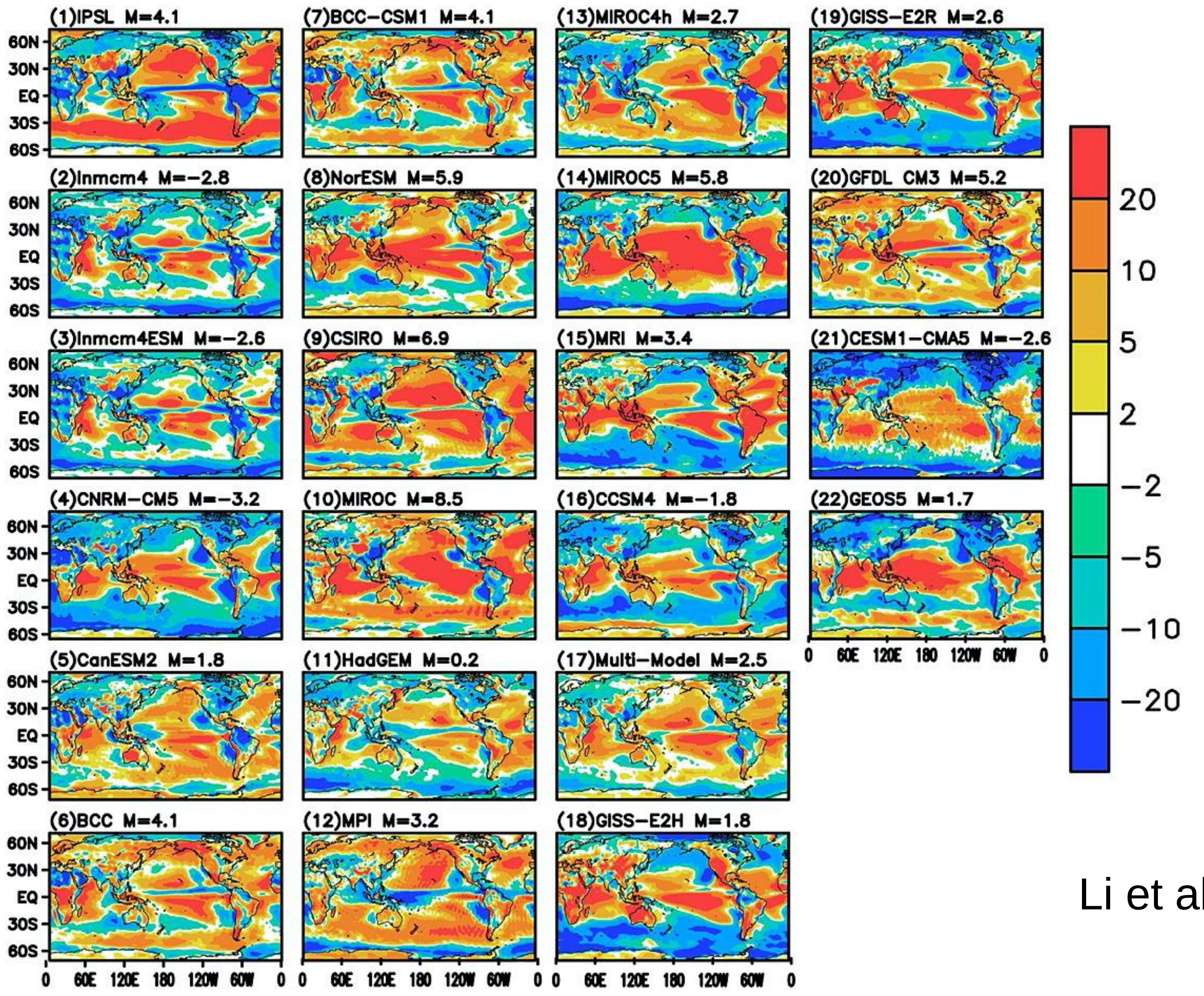
Global model outgoing shortwave radiation errors – dominated by cloud errors



CMIP5 climate models annual mean SW radiation bias versus CERES-EBAF (W m^{-2})

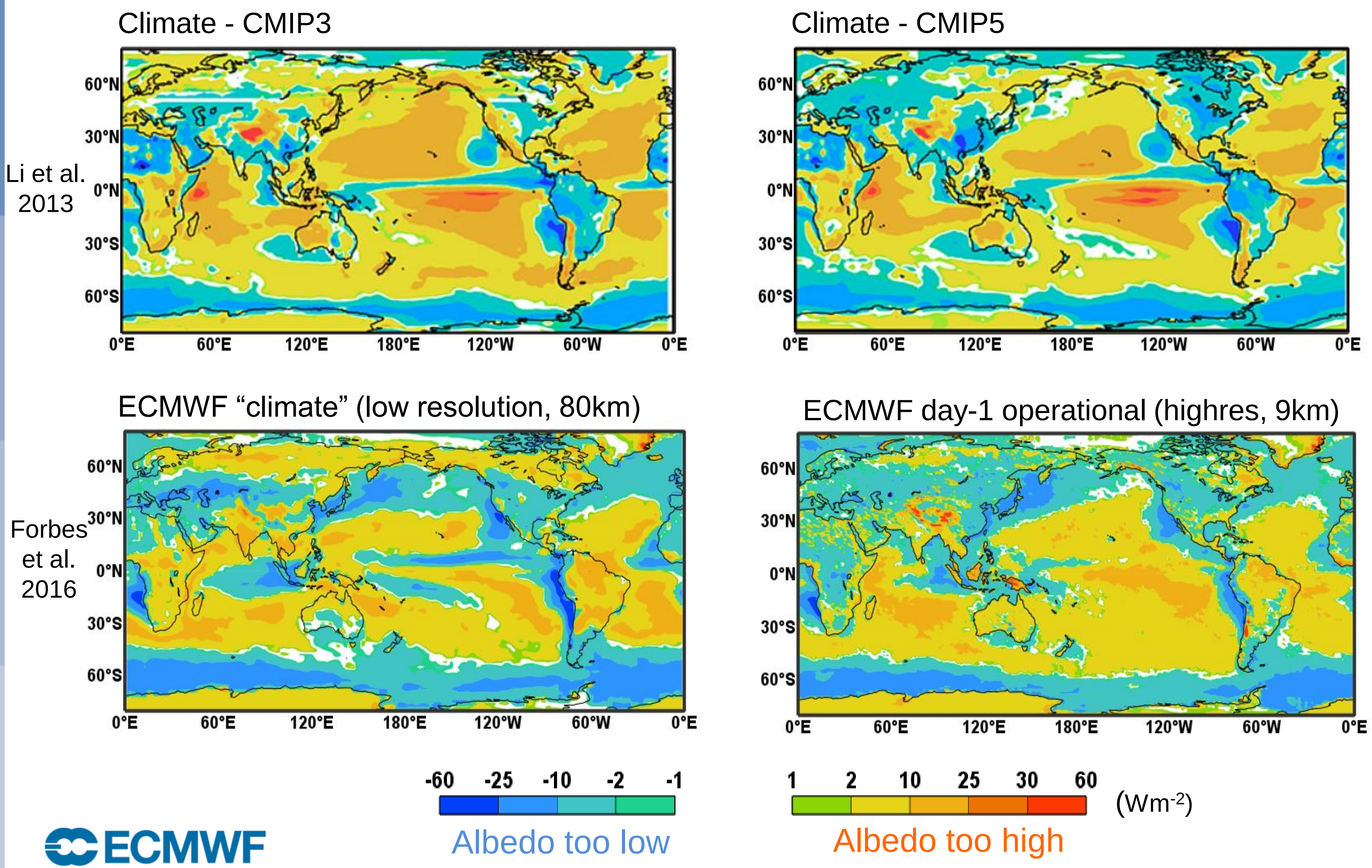
An illustration of the huge variation in cloud representation in different models a few years ago!

Li et al. (2013, JGR)

Global model outgoing shortwave radiation systematic errors

Similarities across models, across resolutions, across timescales

Annual mean top-of-atmosphere SW radiation difference from CERES-EBAF

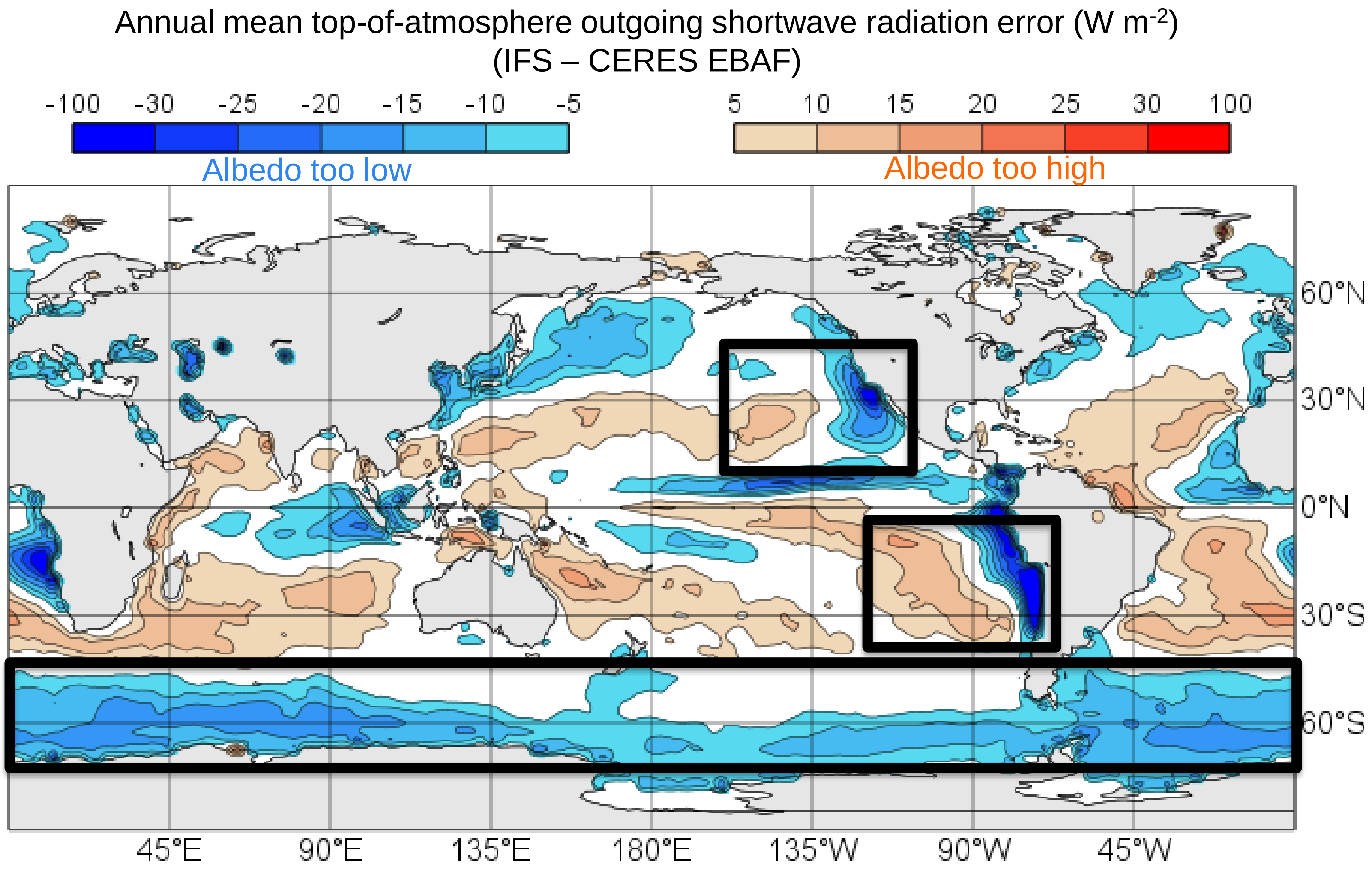


We can use observations and short-range NWP forecasts/DA system

…to understand and reduce regime-dependent systematic errors

…to improve global models across time and space scales

Annual mean outgoing shortwave radiation bias (IFS minus CERES-EBAF)

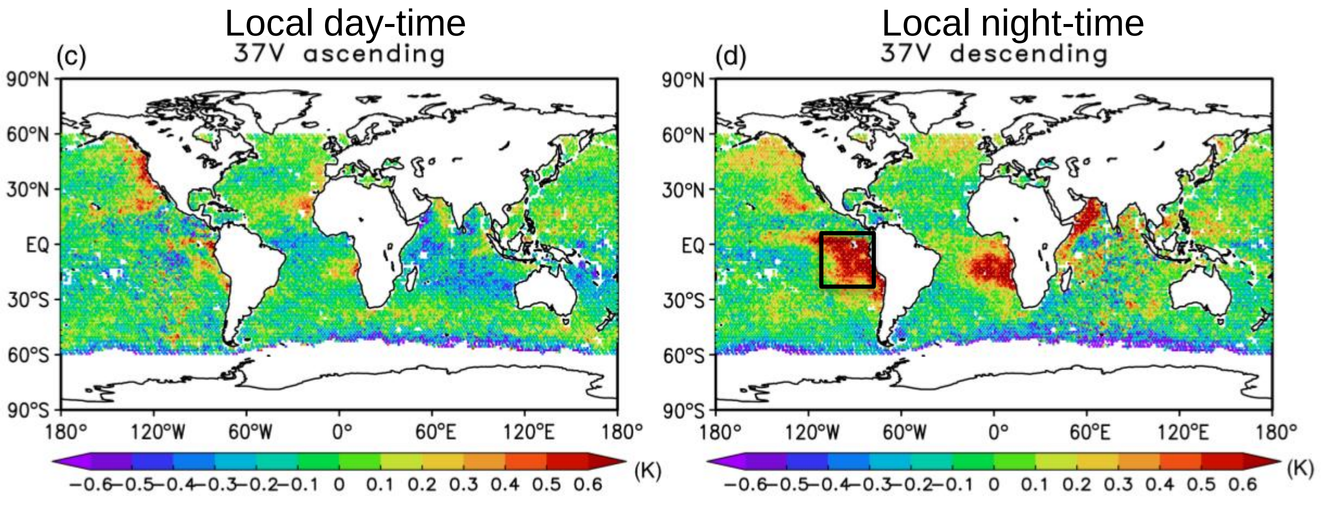


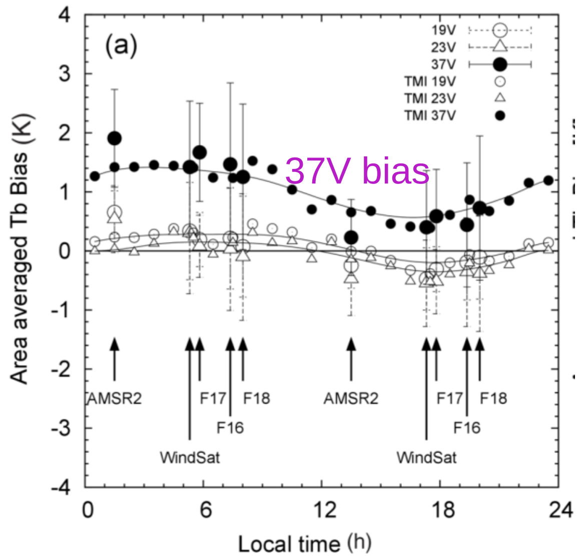
All-sky microwave assimilation encounters model systematic errors

Kazumori et al. (2016, QJRMS)

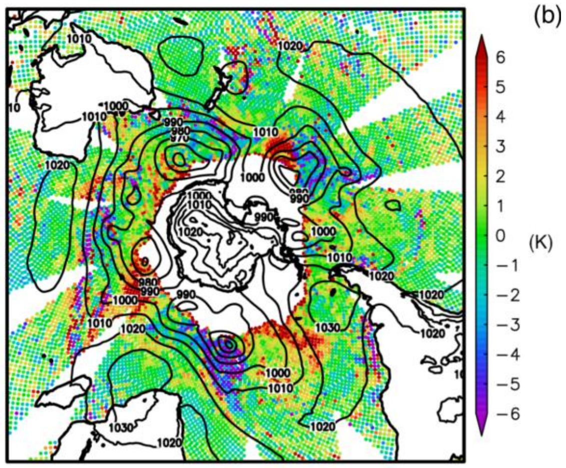
Microwave 37V all-sky first guess departures in the IFS system

1. Identified insufficient amplitude of liquid water path diurnal variation in regions of subtropical marine stratocumulus





2. Identified insufficient liquid water path in cold air part of the cyclones over the Southern Hemisphere storm track



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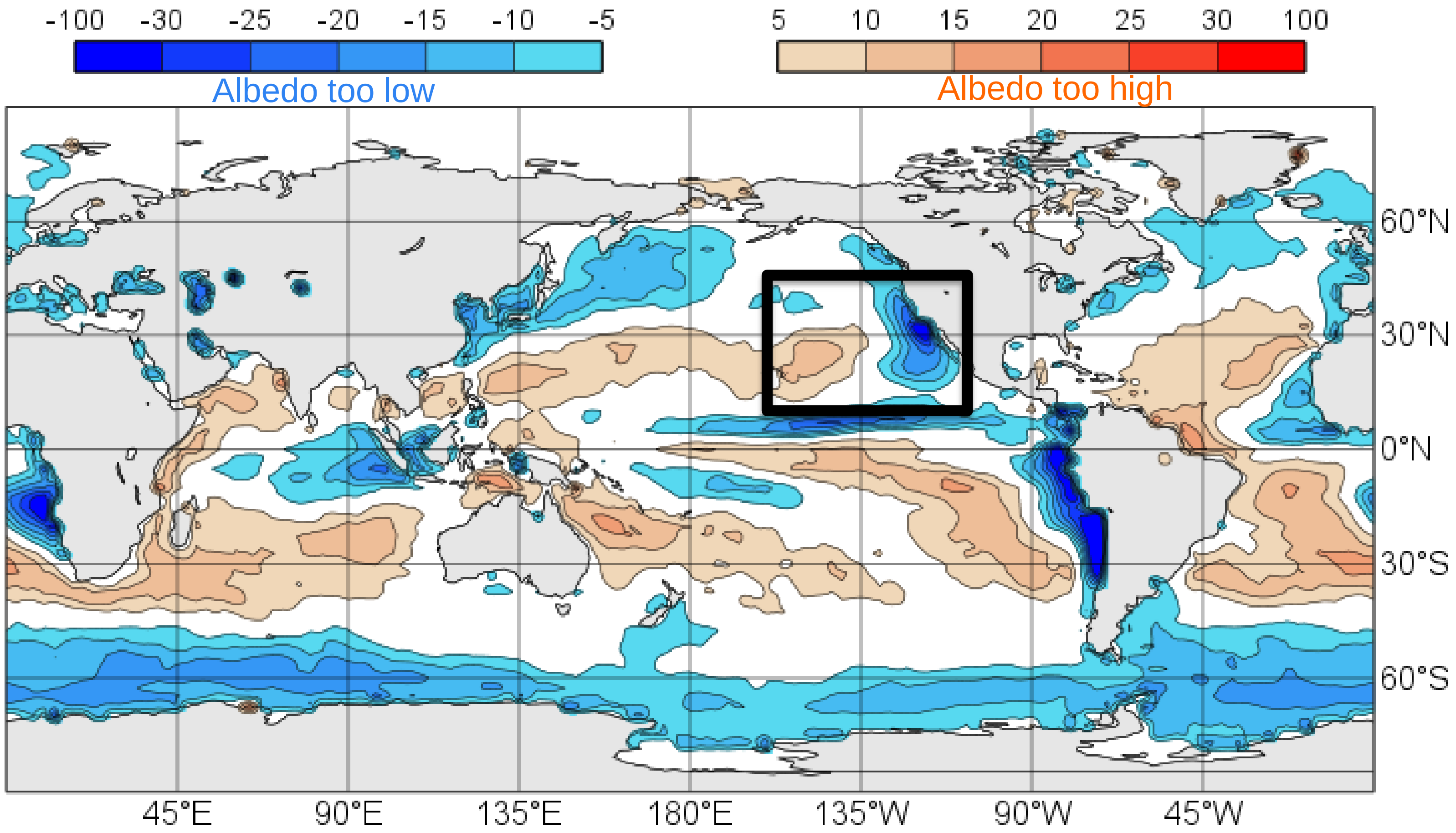
Annual mean outgoing shortwave radiation bias (IFS minus CERES-EBAF)
(1) Subtropical marine Stratocumulus to cumulus

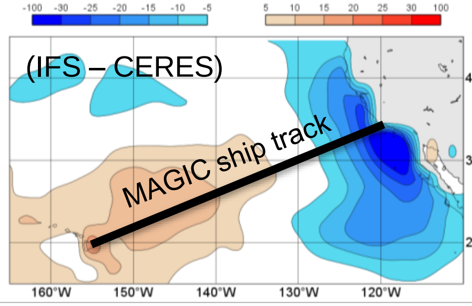
Annual mean top-of-atmosphere outgoing shortwave radiation error (W m^{-2})
(IFS – CERES EBAF)



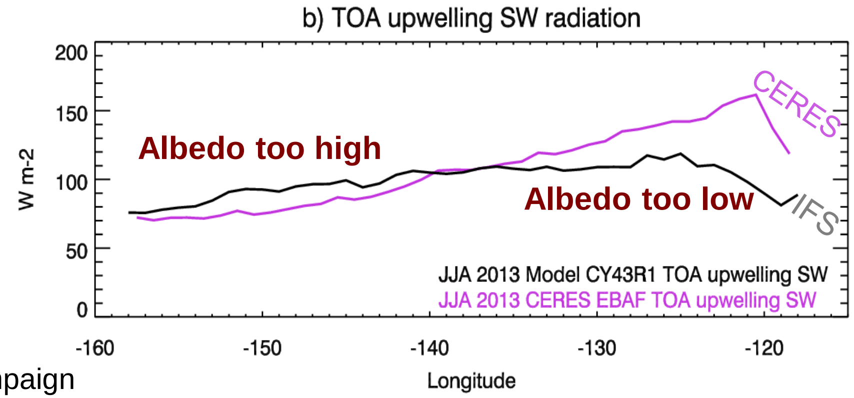
Understanding the subtropical marine cloud/shortwave radiation bias

Ahlgrimm et al. (2018, JAMES)

SW radiation



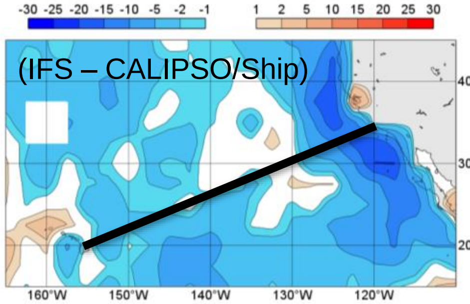
MAGIC – ASR/ARM observational ship campaign

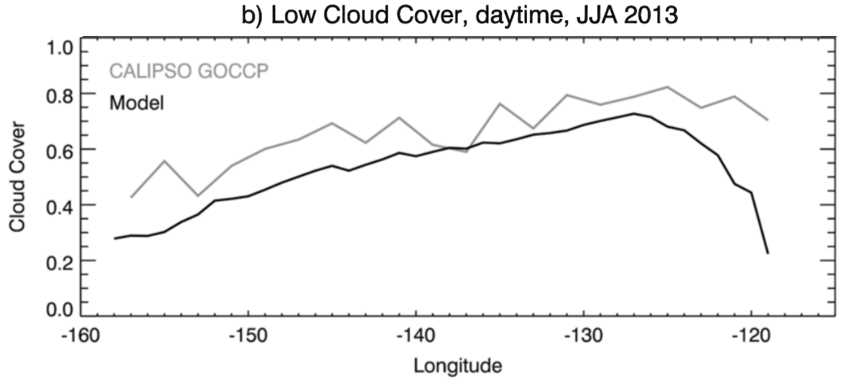


IFS albedo too high in trades

IFS albedo too low in stratocumulus

Cloud cover

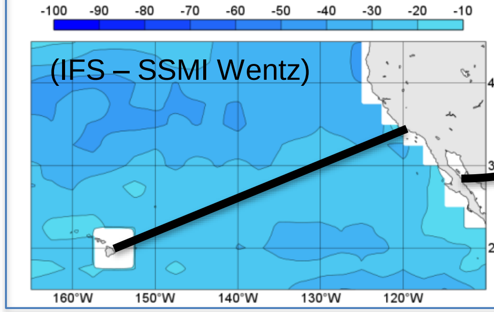


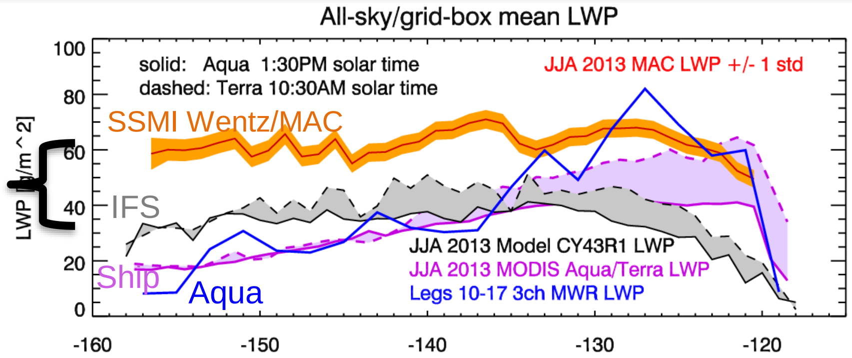


IFS cloud cover good in day

IFS cloud cover too low at night

Liquid water path





IFS LWP too low vs widely used satellite microwave retrievals *(Painemal et al 2016)*

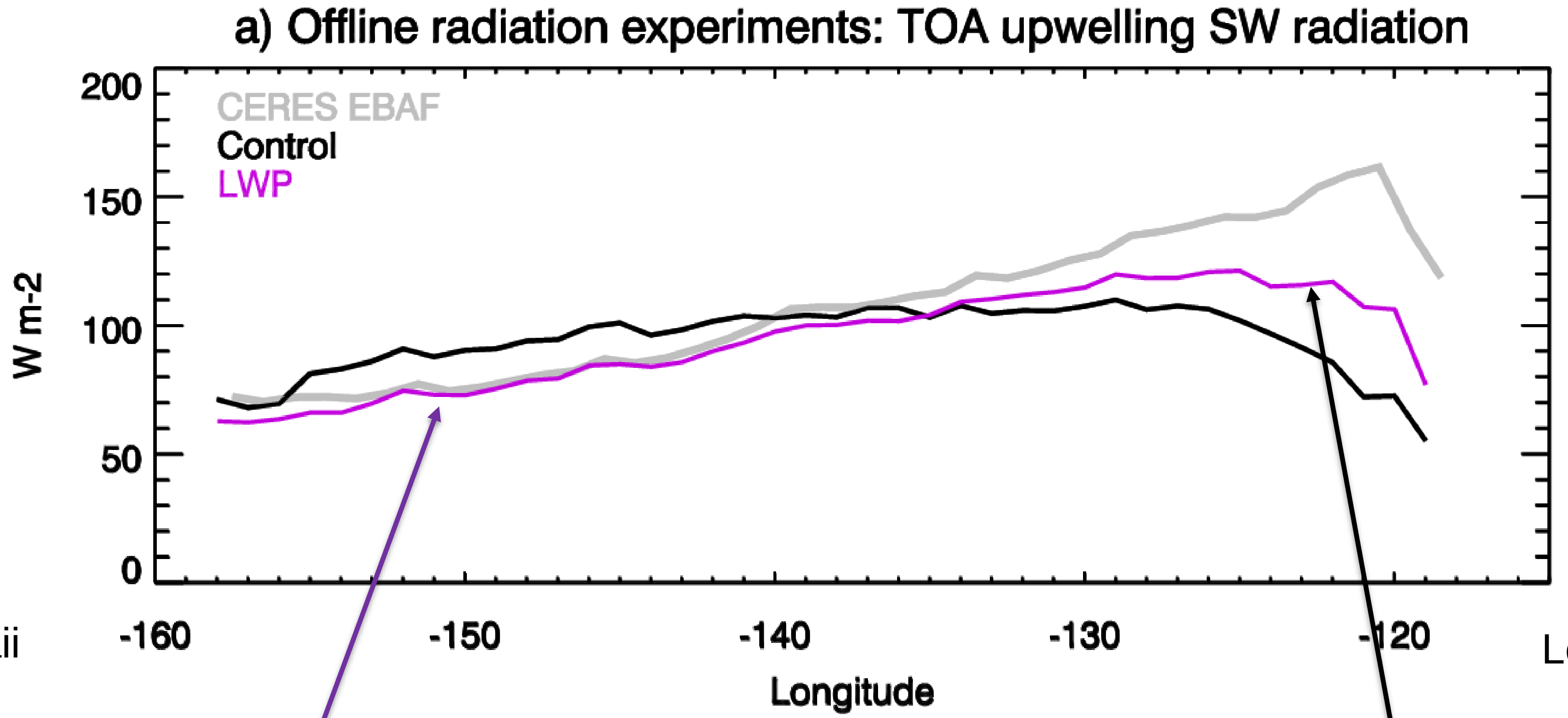
..but IFS LWP too high versus ship MWR and MODIS !

ECMWF

i) LWP bias primary cause of SW error in Trades

Ahlgrimm et al. (2018, JAMES)

Experiment: force LWP to be consistent with observed values



Hawaii

Los Angeles

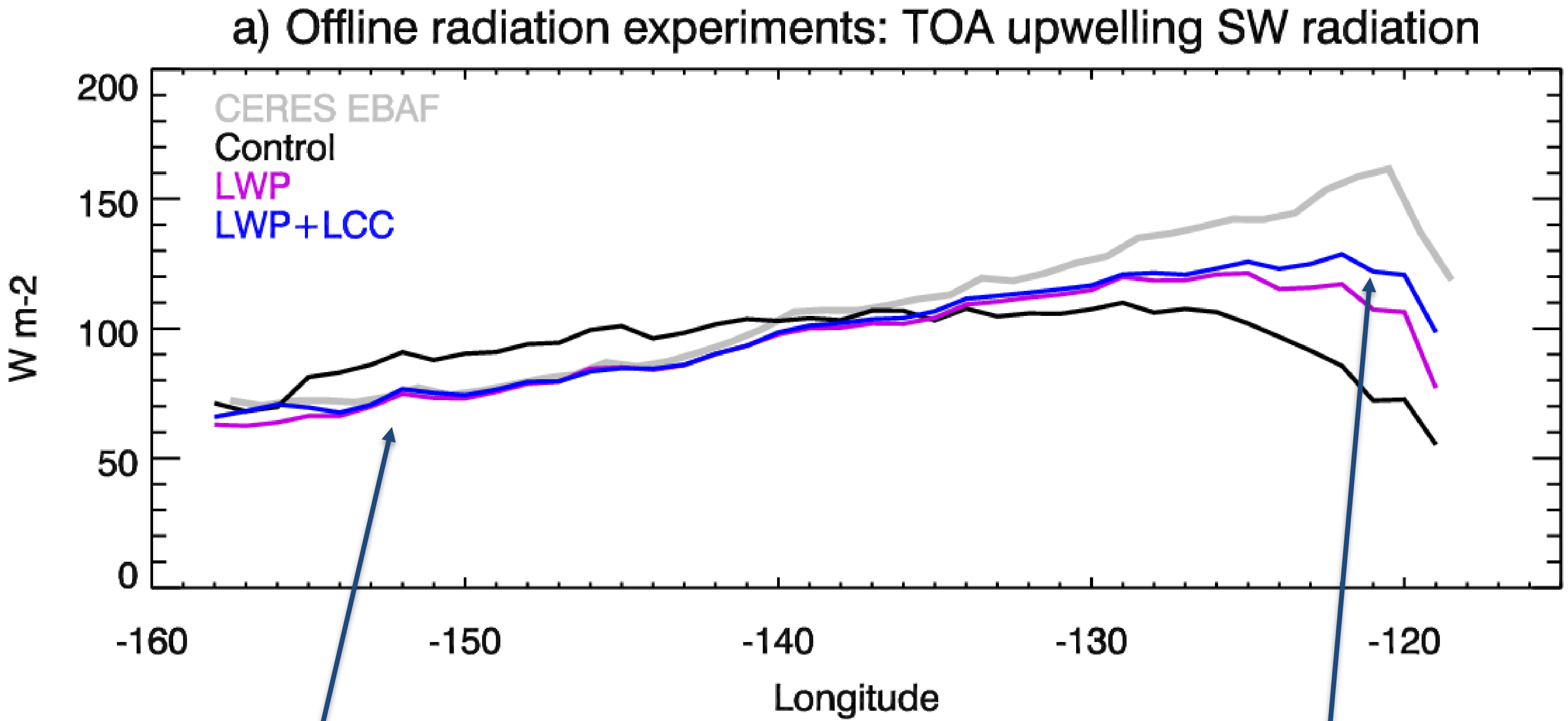
Reduced LWP largely eliminates SW bias.

Bias in Sc partially improved

ii) Cloud cover and LWP both contribute to bias in stratocumulus

Ahlgrimm et al. (2018, JAMES)

Experiment: force total cloud cover towards observed values (in addition to LWP)



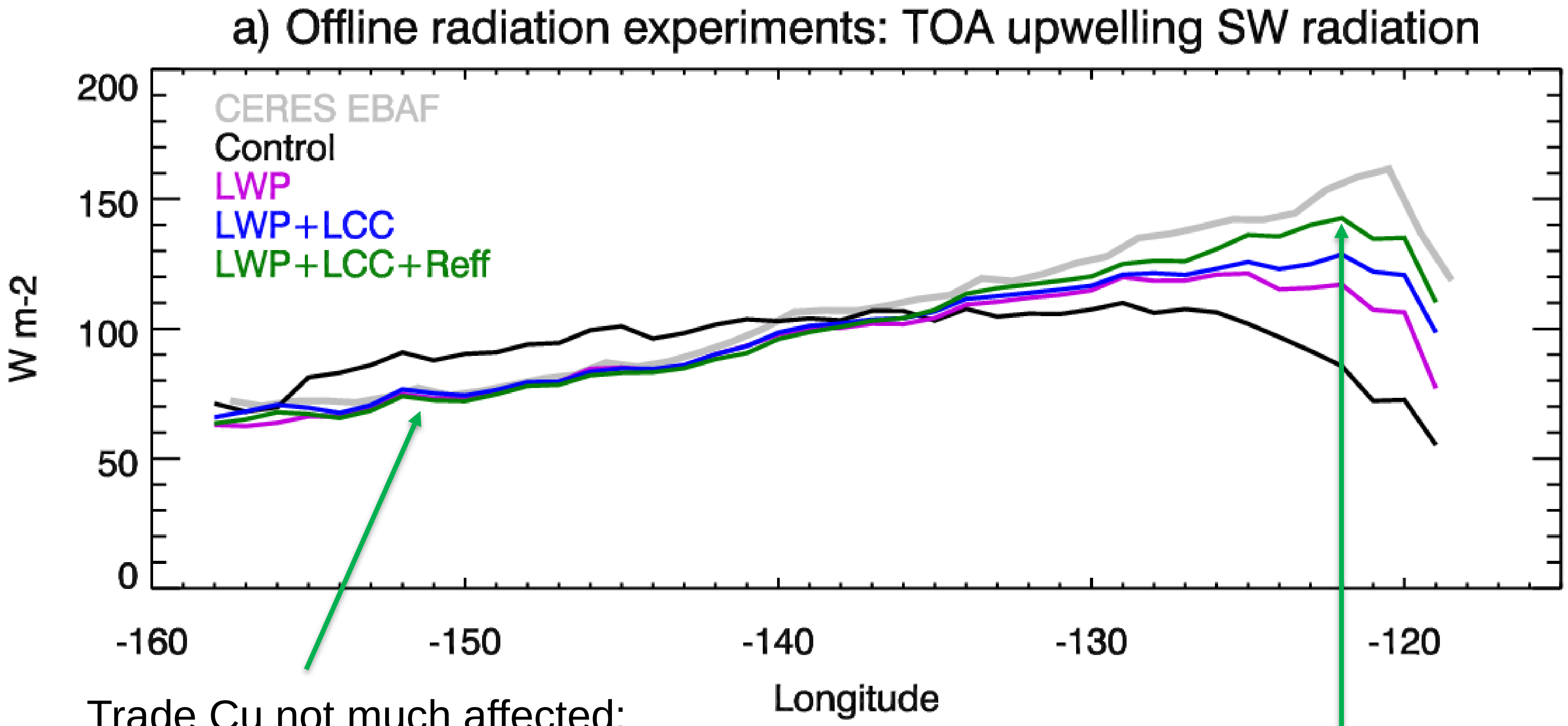
Trade Cu not much affected – CC was already good.

Additional improvement in Sc region!

iii) Effective radius gradient along track enhances albedo in Sc

Ahlgrimm et al. (2018, JAMES)

Experiment: use CDNC derived from ship-based observations in model calculation of effective radius



Trade Cu not much affected:

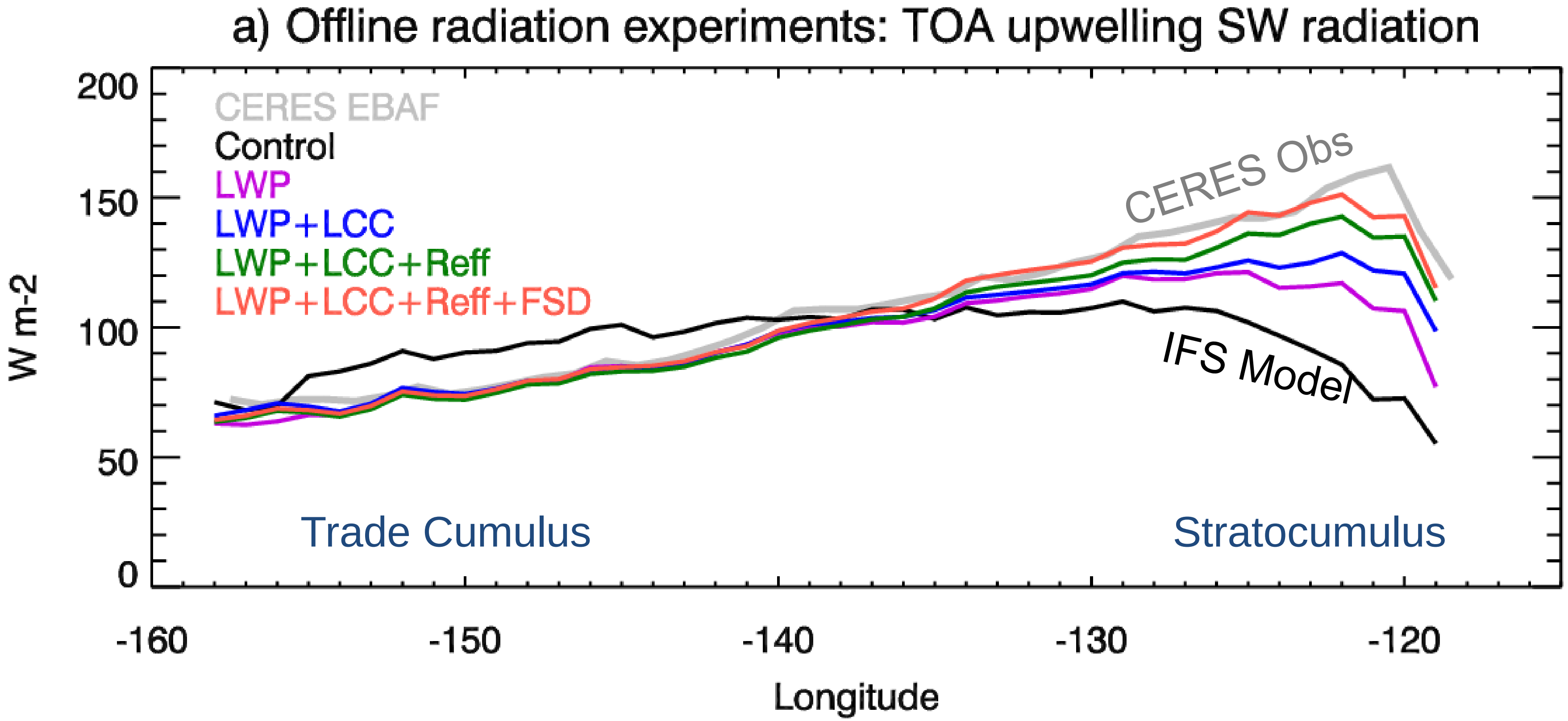
- new and old R_{eff} differ less
- smaller cloud fraction means less impact

Additional improvement in Sc region!

iv) Subgrid variability of liquid water content enhances Scu albedo

Ahlgrimm et al. (2018, JAMES)

Experiment: use in-cloud LWC variability fractional standard deviation (FSD) from satellite study

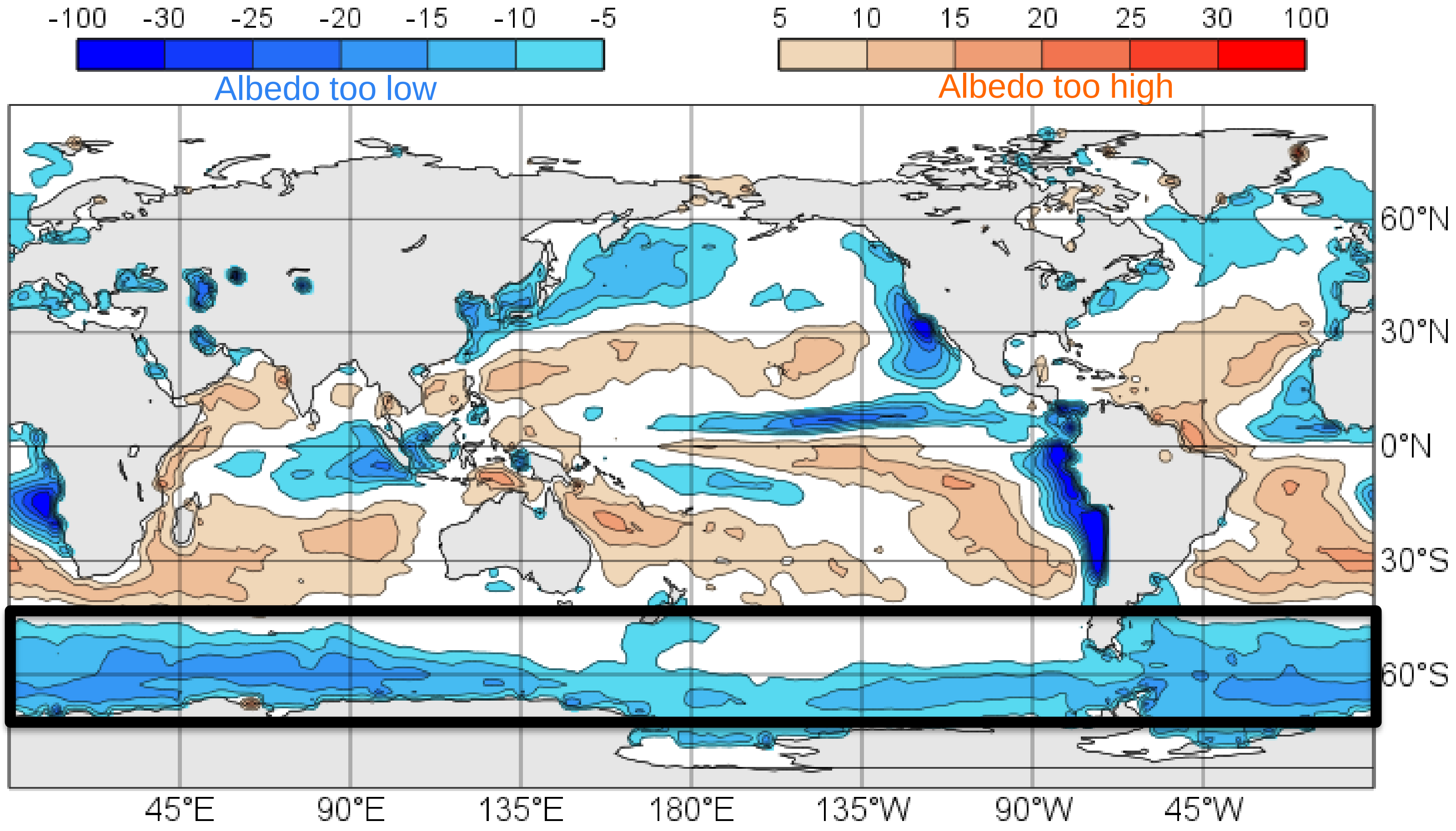


Carefully matched observation evaluation using many different satellite and ground-based instruments can disentangle the multiple sources of cloud error and explain the observed subtropical marine shortwave radiation systematic errors in the IFS!

Annual mean outgoing shortwave radiation bias (IFS minus CERES-EBAF)

(2) Southern Ocean storm track

Annual mean top-of-atmosphere outgoing shortwave radiation error (W m^{-2})
(IFS – CERES EBAF)

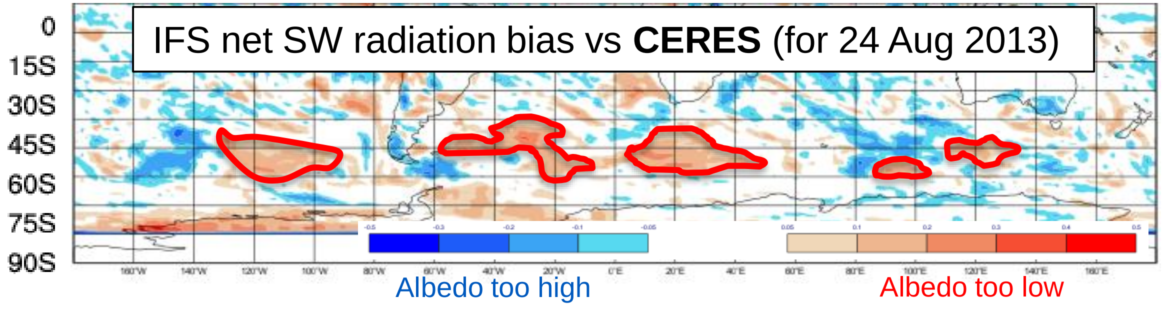


Using multiple satellite data to inform physics development

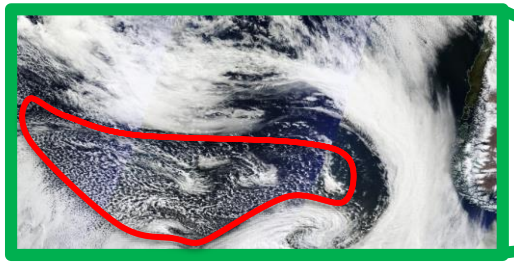
In the summer hemisphere over ocean, the IFS has too low albedo…

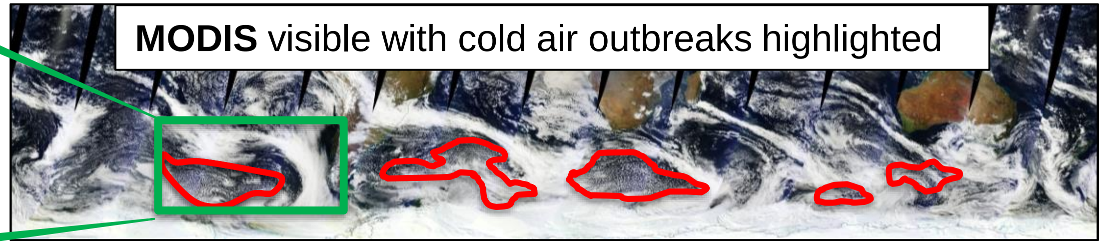
Forbes et al. (2016)
(ECMWF Newsletter 146)

1. Satellite broadband SW 24 hr differences show the error dominated by specific regions

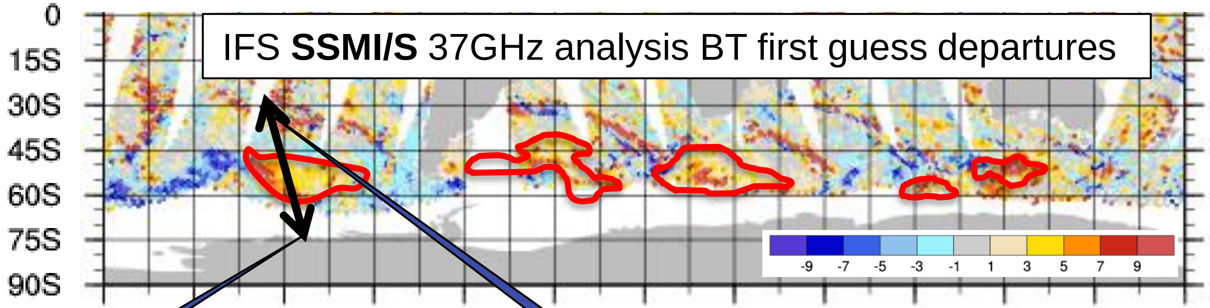


2. Satellite visible image shows these regimes are convective cold air outbreaks

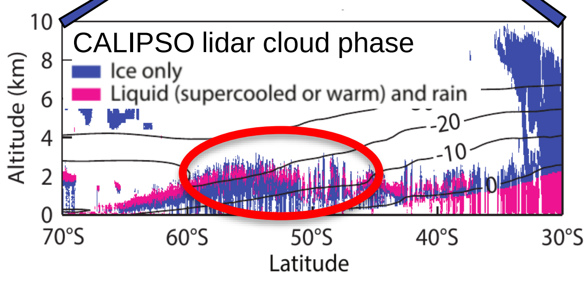


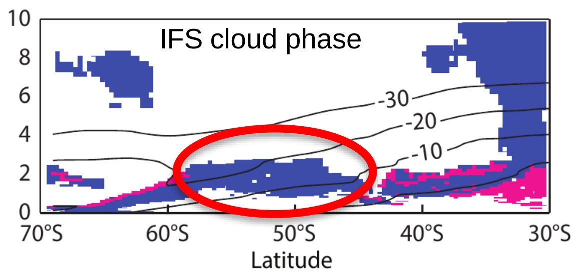


3. Satellite SSMI/S microwave radiance O-B departures show too little liquid water path.



4. Satellite lidar (CALIPSO) shows this is due to too little supercooled liquid water path.





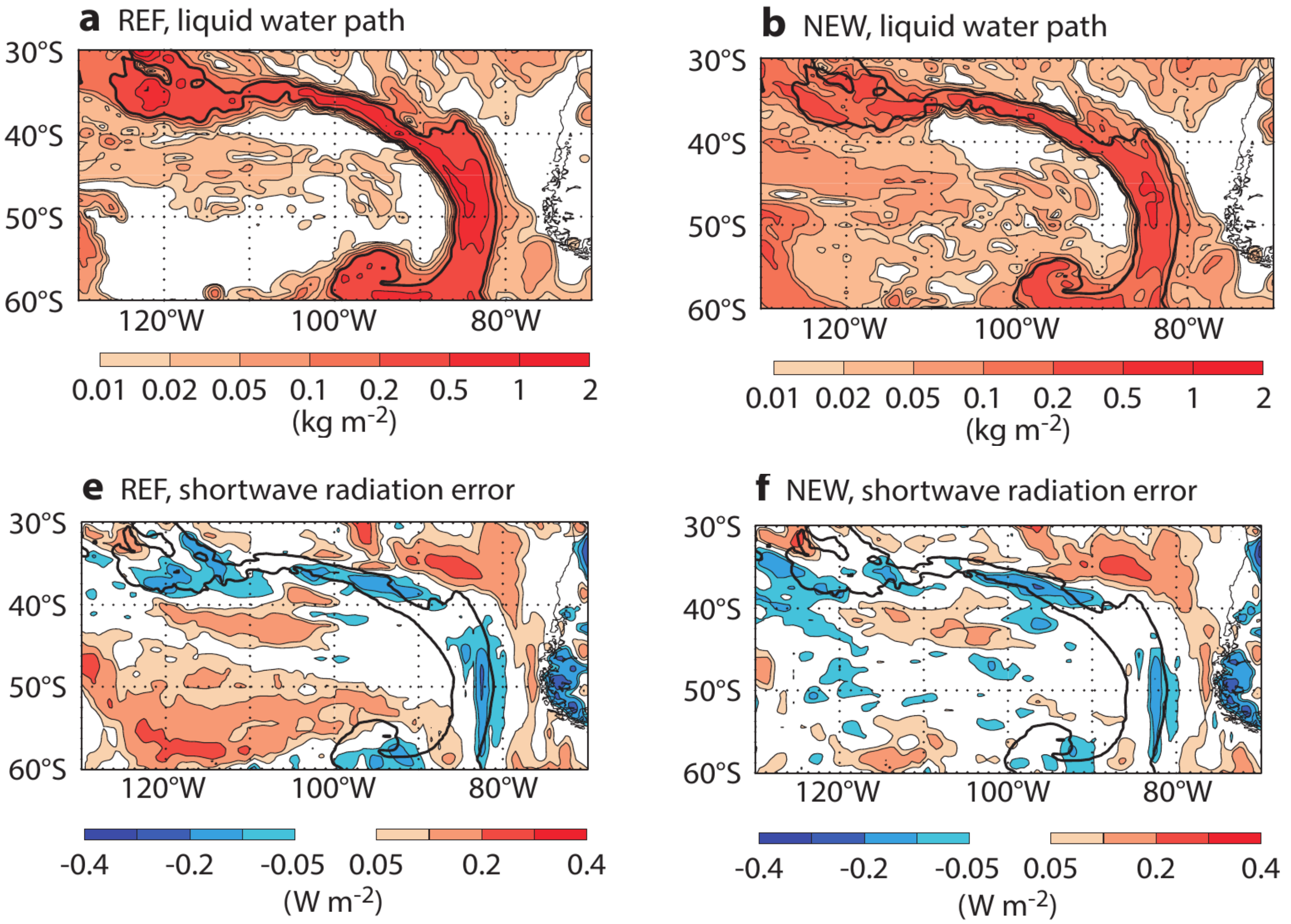
ECMWF

Change convection parametrization from liquid/ice fn(T) to all supercooled liquid if tops below ~600hPa: affects extra-tropical cold air outbreaks but not tropics.

More liquid water path (closer to SSMI/S) and SW radiation significantly reduced!

Forbes et al. (2016)
(ECMWF Newsletter 146)

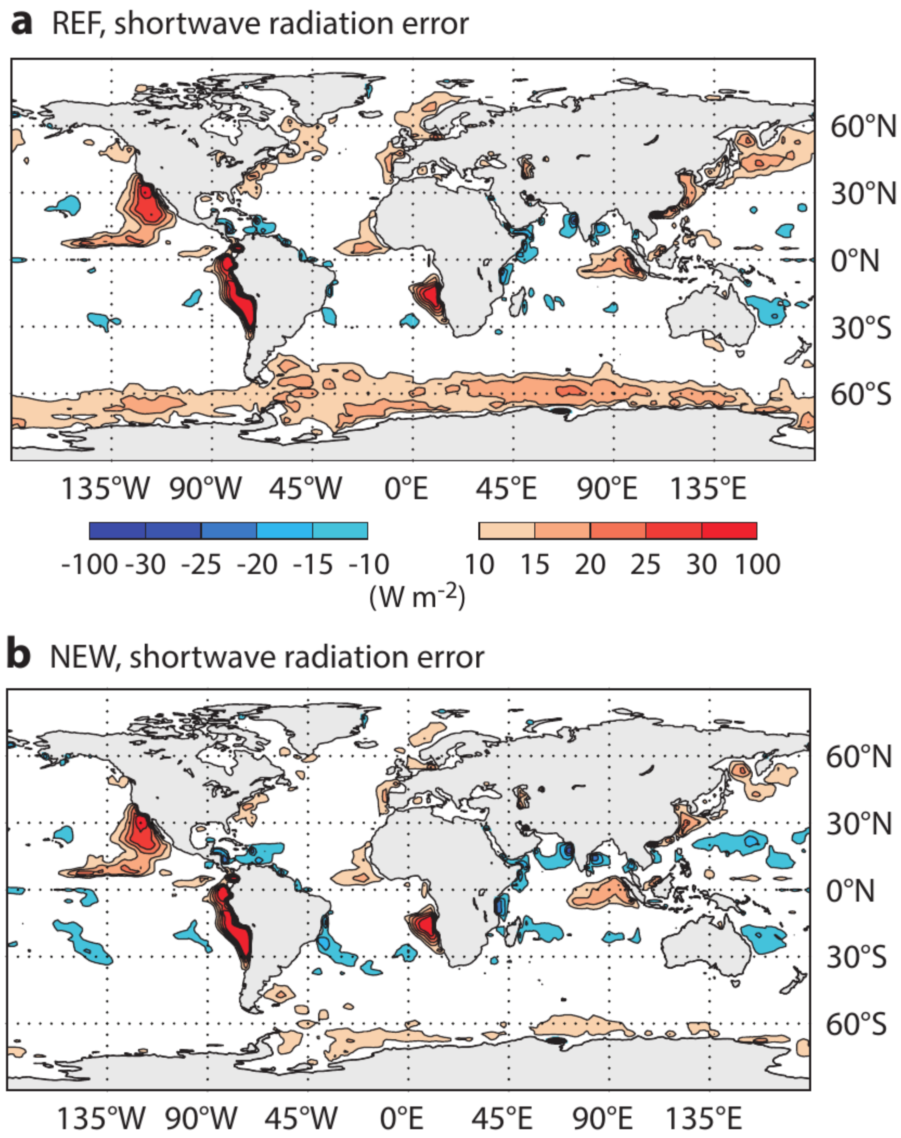
24 hour forecast



Impact of parametrization changes on the annual mean SW radiation bias

Forbes et al. (2016)
(ECMWF Newsletter 146)

1 year low resolution forecast

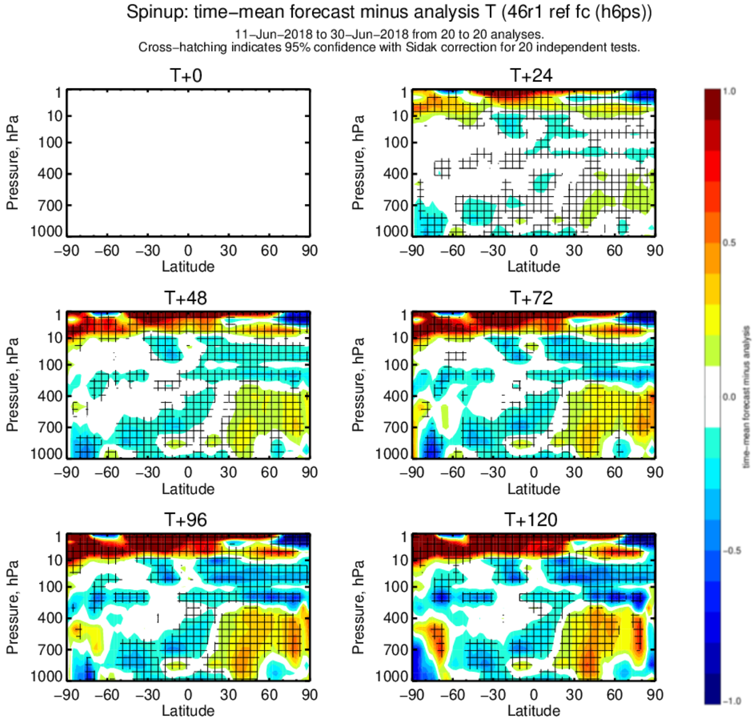


Dramatically reduced SW error over SH ocean AND NH oceans

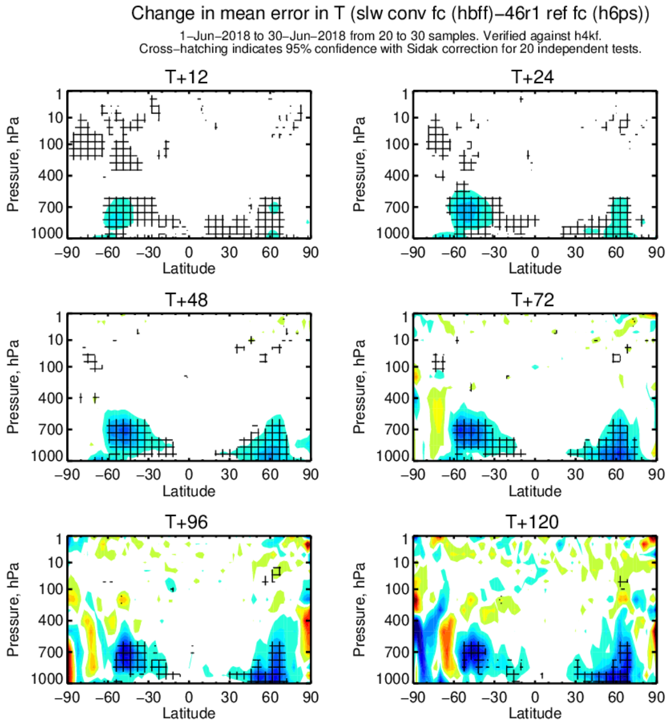
In coupled mode, SH ocean warm SST bias also reduced

This change didn't go in to the operational model because of the negative impact on temperature from increasing the supercooled liquid water in convective cold air outbreaks (less condensation heating)

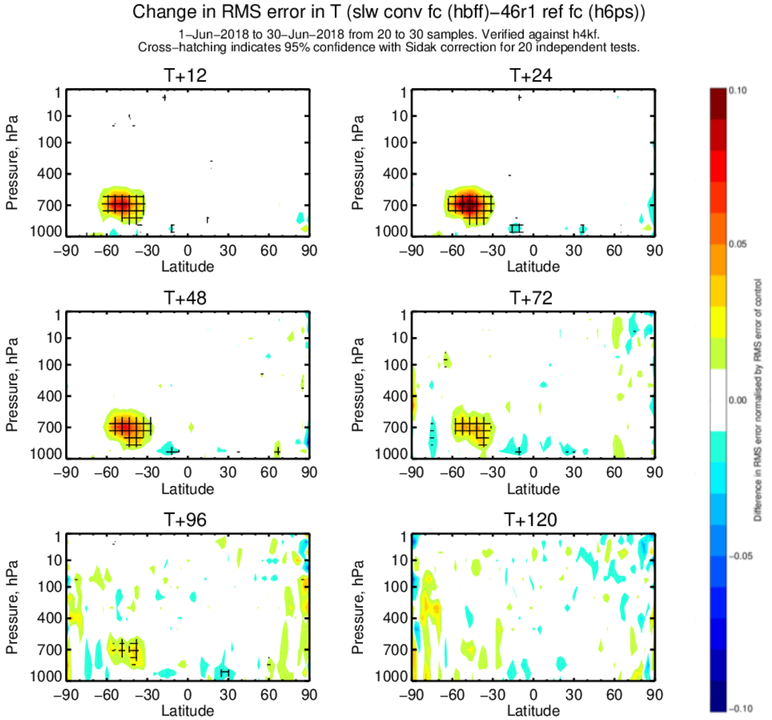
Control temperature bias



Mean temperature change (exp-ctl)



RMSE temperature change (exp-ctl)



….BUT…may be a compensating error – combined with other changes, getting closer to neutral…

ECMWF

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The challenge of making sense of observations for model development

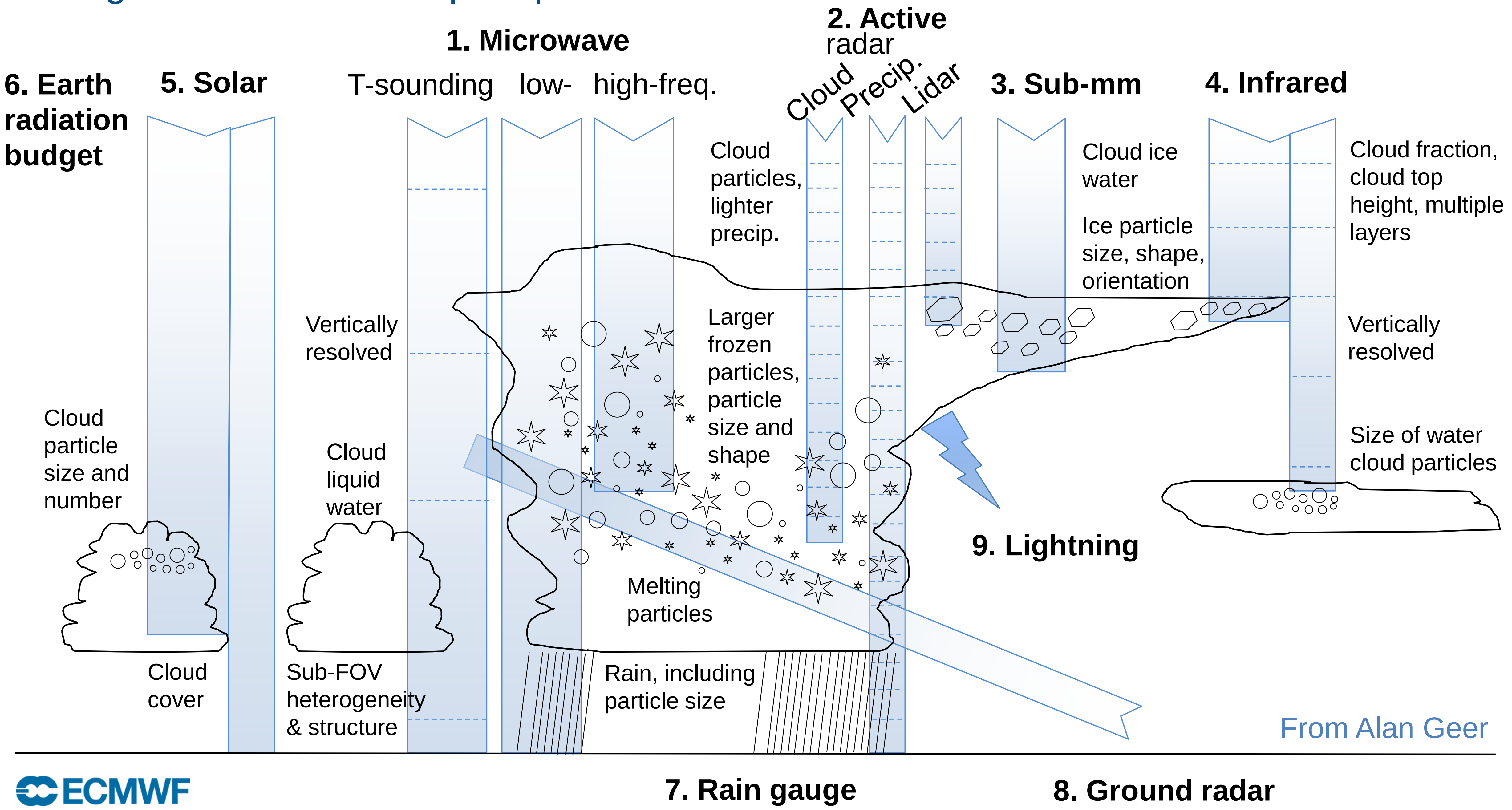
Just one piece of the puzzle

OR

An avalanche of disparate data

Collectively solving the puzzle
with complimentary sources of data

Making the most of cloud/precipitation-affected data



From Alan Geer

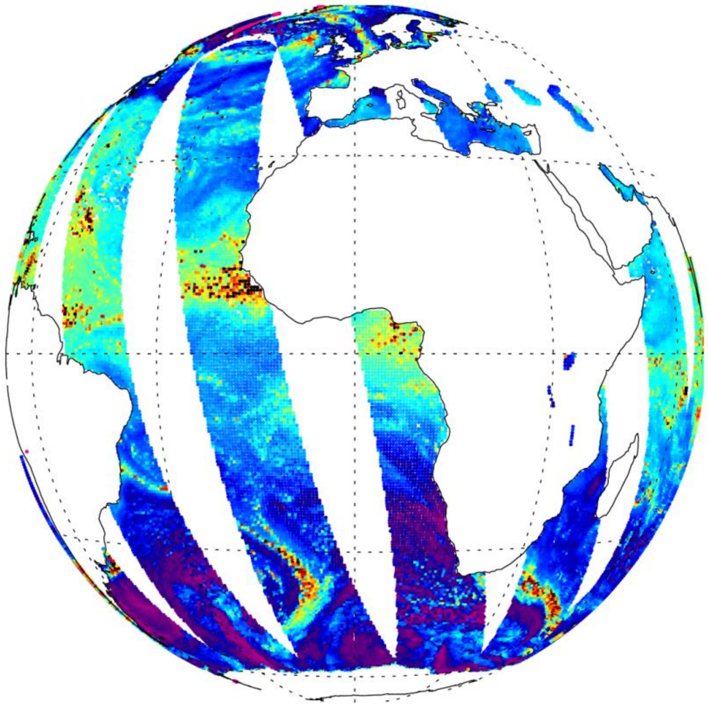
ECMWF

We can already do a lot of evaluation with “off-line” data (retrievals/simulators).

Can evaluation in the all-sky system bring sufficient advantages?

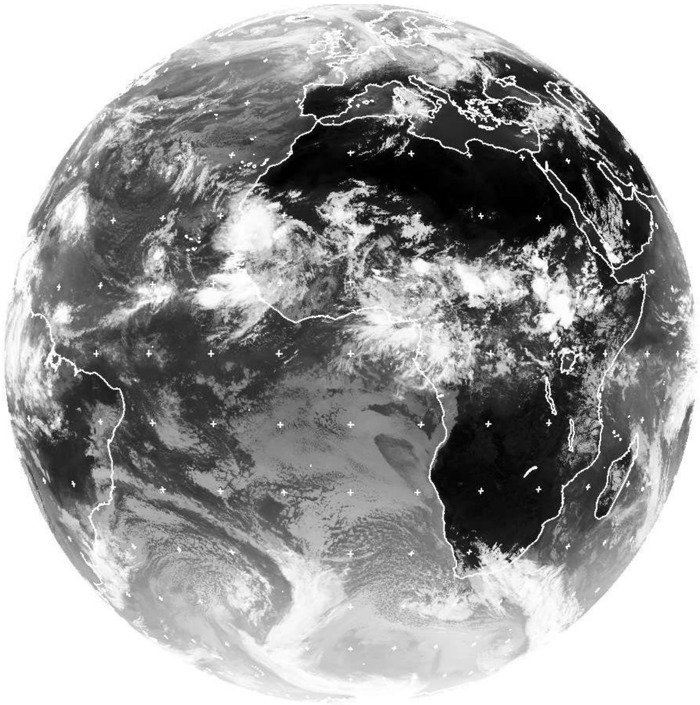
Microwave

AMSR-E channel 37v
8108 µm (37 GHz v-pol)



Infrared

SEVIRI channel 10
11-13 µm



Visible

SEVIRI channel 1
0.56-0.71 µm

from Dundee Satellite Receiving Station, © Eumetsat

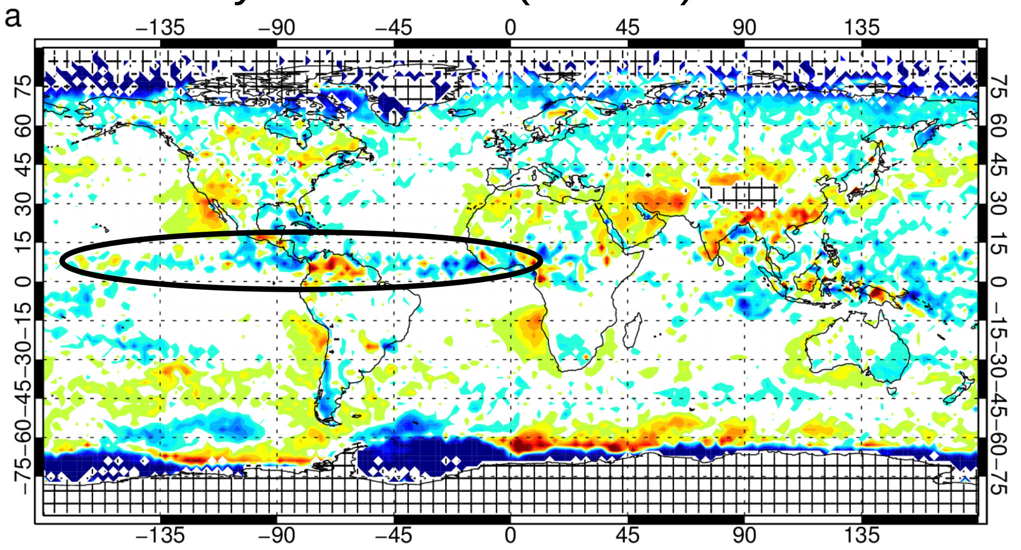
Window channels

24th August 2008 at around 12UTC

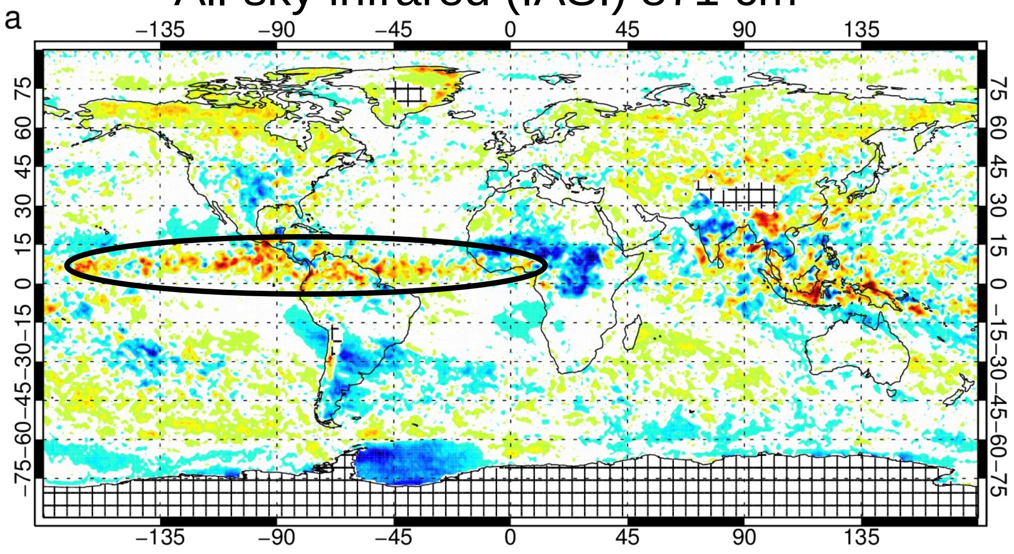
From Alan Geer

There are many sources of compensating errors in models
Can we disentangle multiple microphysical and macrophysical errors?

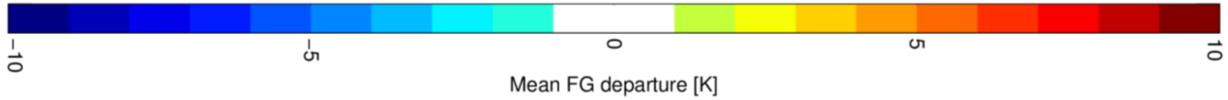
All-sky microwave (SSMIS) 150 GHz



All-sky infrared (IASI) 871 cm^{-1}



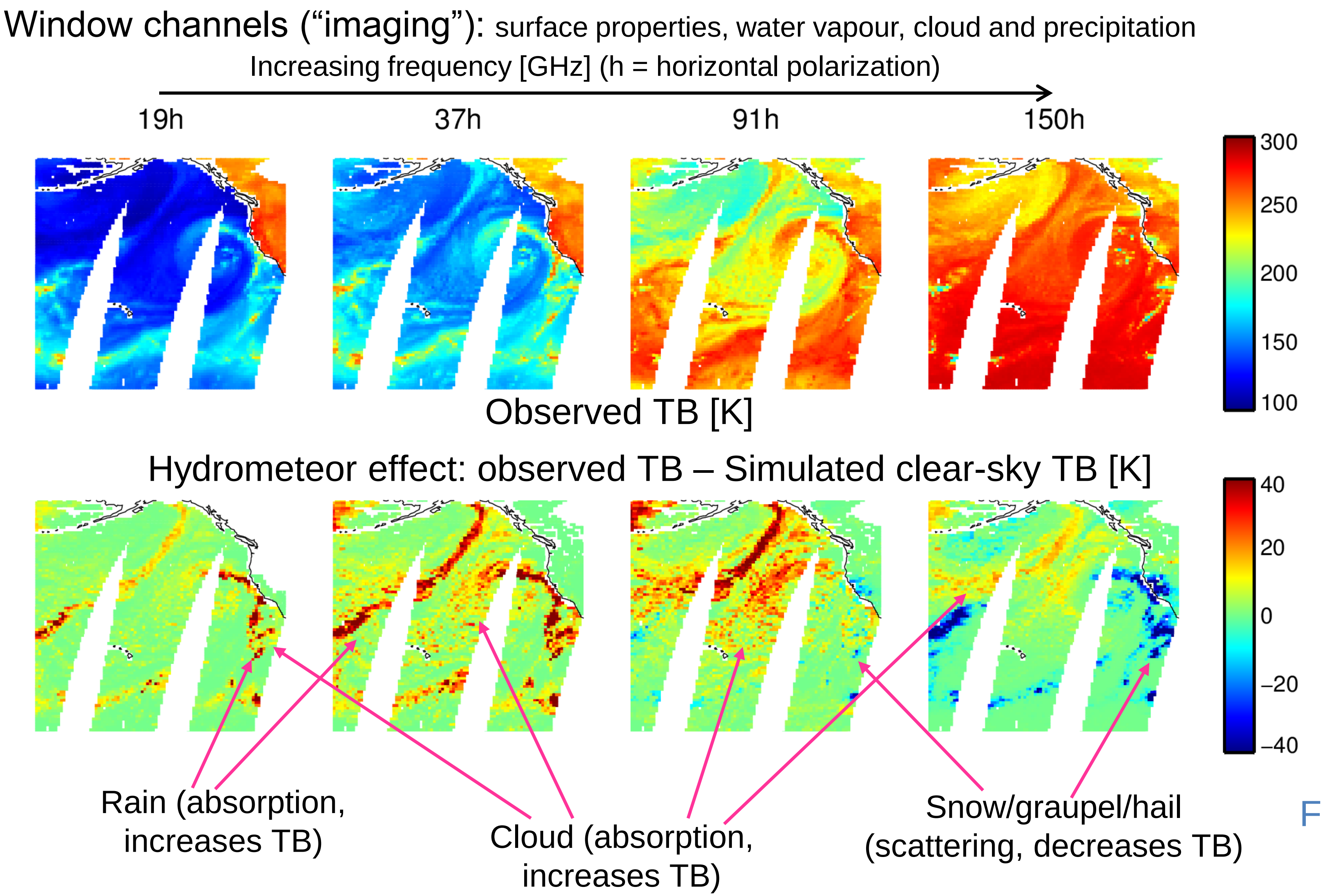
(obs – model) [K] Mean, 1-20 June 2017



From Alan Geer

Appropriate forward operators are crucial for successful all-sky assimilation

How much do we put in the forward operator, or predict in the model?

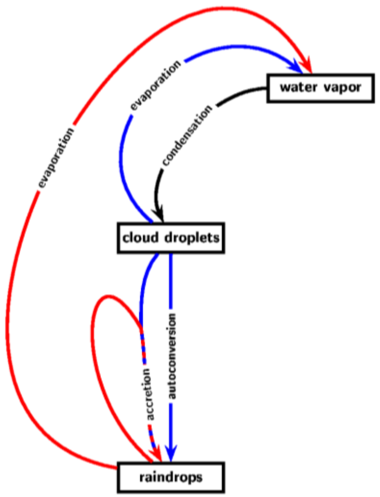


From Alan Geer

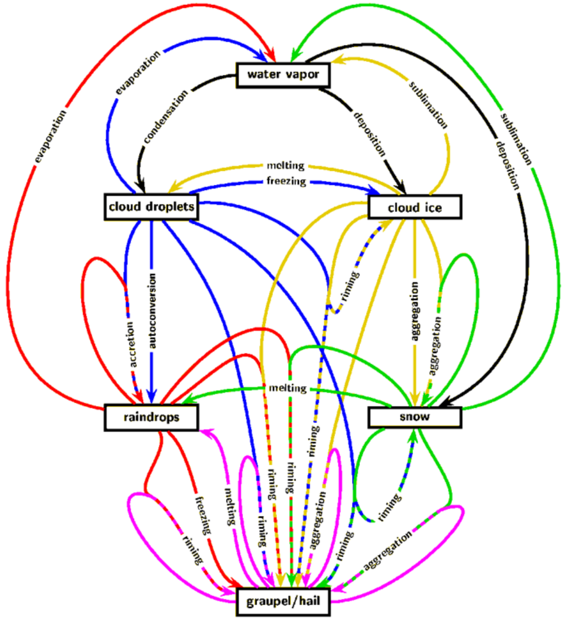
Many global models still have single-moment microphysics

Is all-sky assimilation a driver for more complex microphysics (particle size, shapes)?

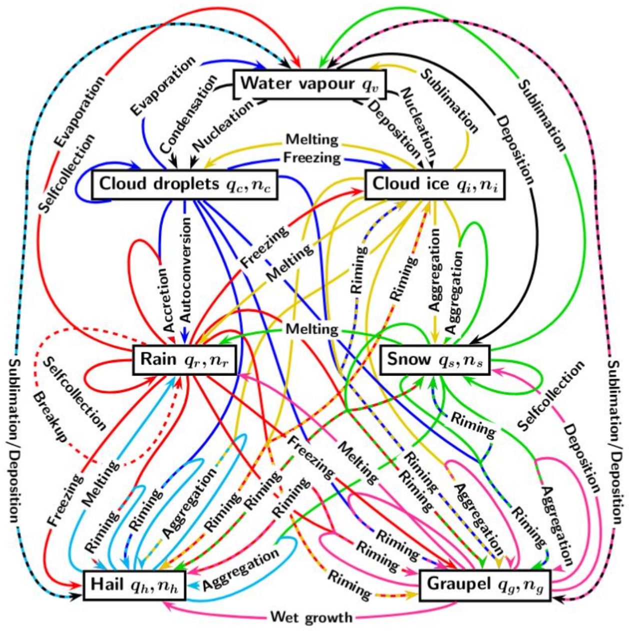
- Higher resolution (increasingly convective permitting) puts more emphasis on the formulation of the microphysics
- Potential for future developments: Graupel? Double-moment? Particle properties (P3)? Ice habit?



Simple schemes



Single moment liquid/ice schemes



Double moment liquid/ice schemes

Images from Axel Seifert

Concluding summary

"Observation-informed model parametrization development for cloud and precipitation"

- Big improvements in cloud/precipitation over time, but models still have large regime-dependent systematic errors
- Many cloud/precip systematic errors are present at all timescales, so can use DA!
- Using multiple data instruments/frequencies to constrain the evaluation is essential to make further progress in parametrization development
- There is potential to extract much more information from cloud/precip-affected observations. All-sky assimilation provides a unique framework for error diagnosis, yet to be fully explored.
- Is microphysical/macrophysical closure a realistic aim? (i.e. all important sources of errors obvious from overlapping sensitivities from different observations). Remaining gaps in the data?