Cloud macrophysical properties

The role of subgrid-scale heterogeneity, and attributing radiation biases

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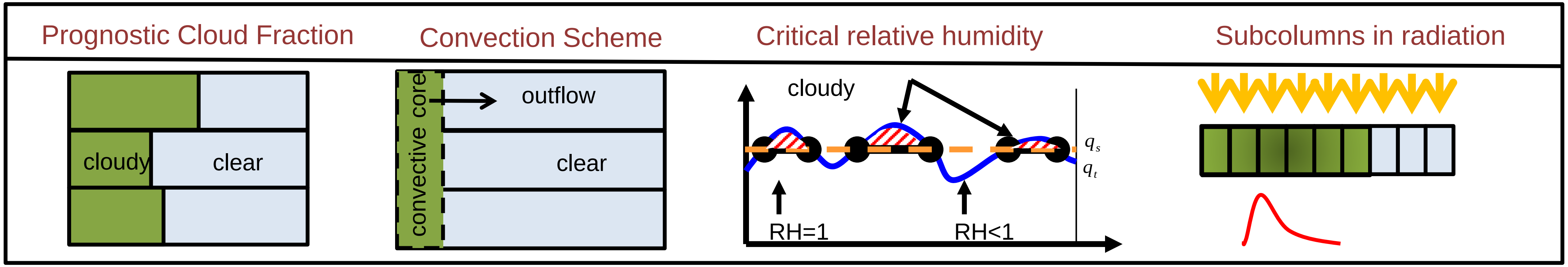
Why do we care about subgrid-scale heterogeneity?

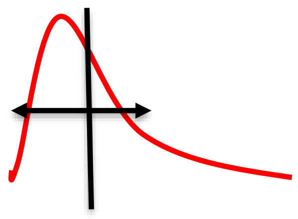
- IFS predicts bulk properties of **mass mixing ratios** for cloud ice and liquid, rain and snow, and **cloud fraction**
- **Cloud scheme itself makes no explicit assumptions** about how cloud condensate is distributed within cloudy part of the grid box, nor which part of the grid box is inhabited by precipitation
- However, there are many ways in which heterogeneity is represented in separate parts of the model



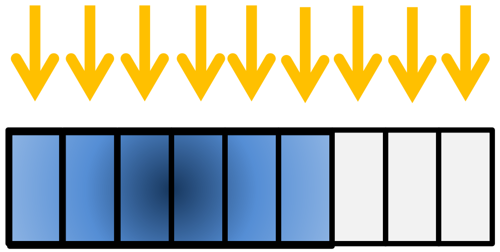
Focus today:
How do assumptions about horizontal distribution of in-cloud condensate on sub-columns affect radiative transfer?

McICA approach in radiation – assumed distribution

- Use assumed shape of the cloud condensate distribution – log-normal, Gamma
- Prognostic cloud scheme provides grid box mean condensate
- Parameterize width of distribution in the form of FSD=stddev/mean (fractional standard deviation)
- Nice feature of this scheme: easy to prescribe any distribution you like



- shape
- mean
- width

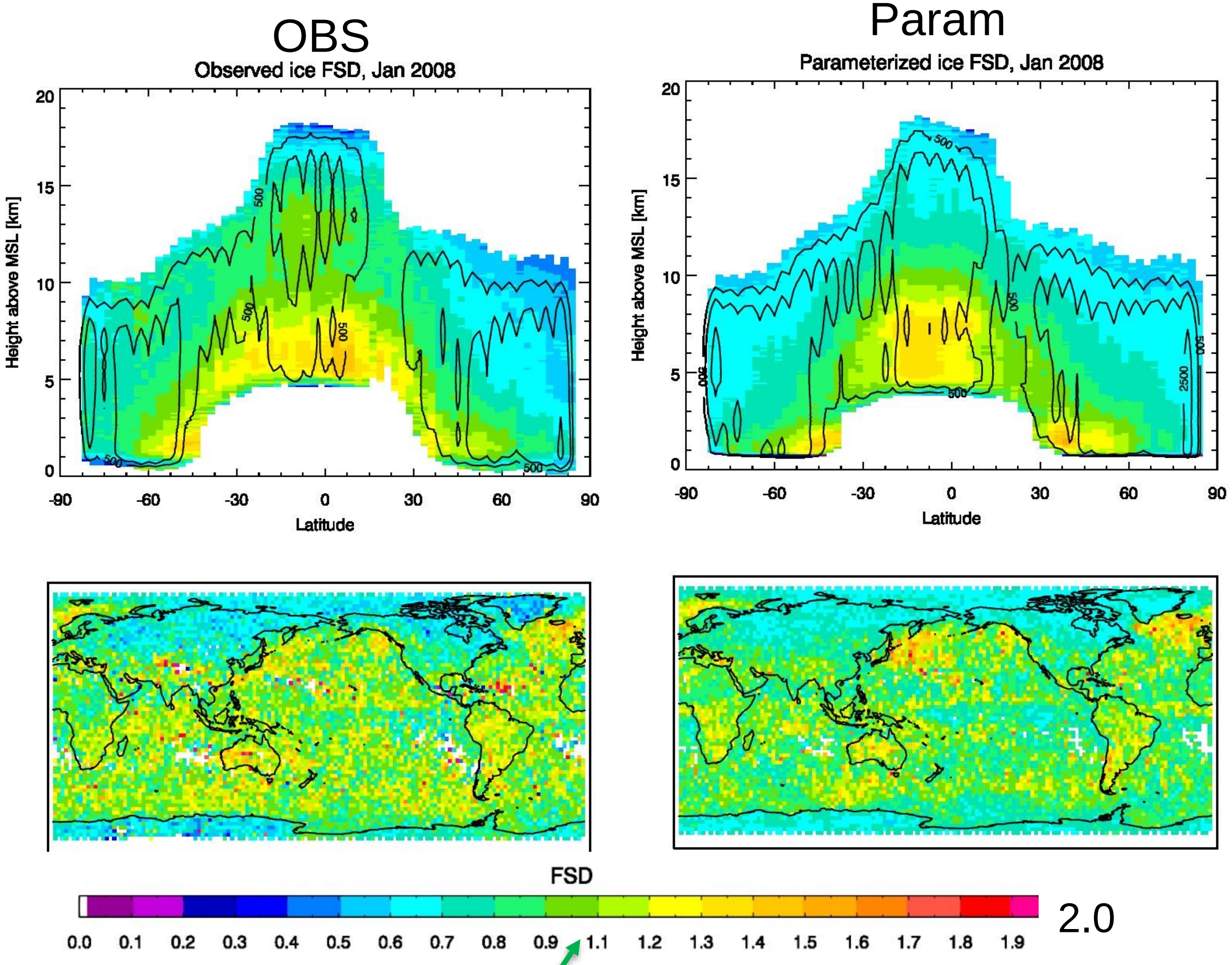


Default choices for McRad:
Gamma distribution,
FSD=1

Low values of FSD:
more homogeneous cloud, more reflective in the SW, trapping more OLR

High values of FSD:
more heterogeneous condensate, less reflective in the SW, trapping less OLR

Observations (CloudSat) show that FSD in ice cloud is variable and regime-dependent



current assumption in radiation:
FSD=1
(Scale 0 to 2)

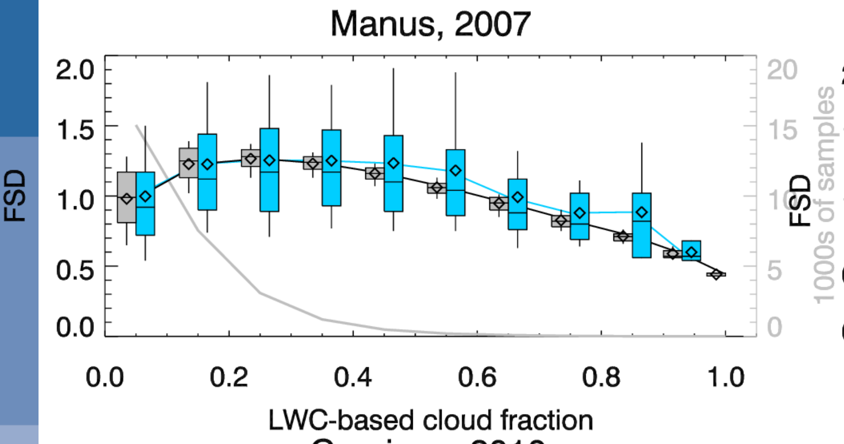
- Variability (as measured by FSD) is lower for overcast scenes than for broken cloud cover – edge phenomenon
- Variability is greater in areas associated with active convection – use detrainment ratio as measure of how dominant convection is for the cloud's existence
- Variability is lower in colder/drier regions (high altitude, high latitude)
- Variability depends on scale of grid box (horizontal, vertical layer thickness)

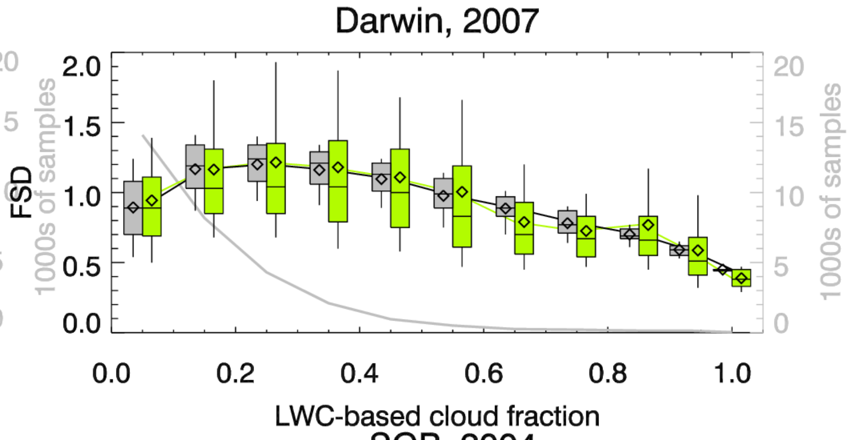
Parameterization is scale dependent, and captures:

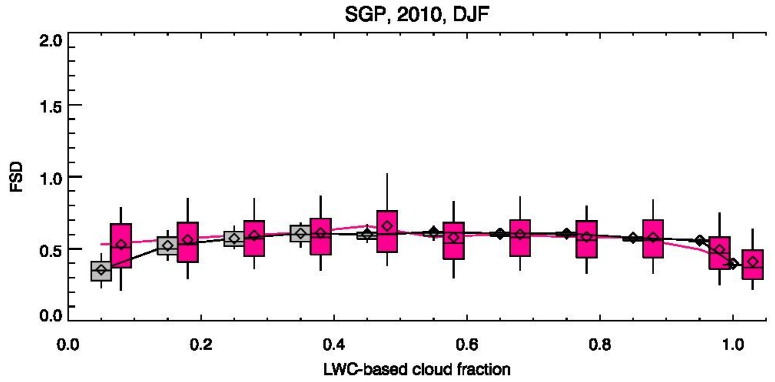
- Enhanced heterogeneity in winter storm tracks, summertime NH continent
- apparent height dependence in zonal mean

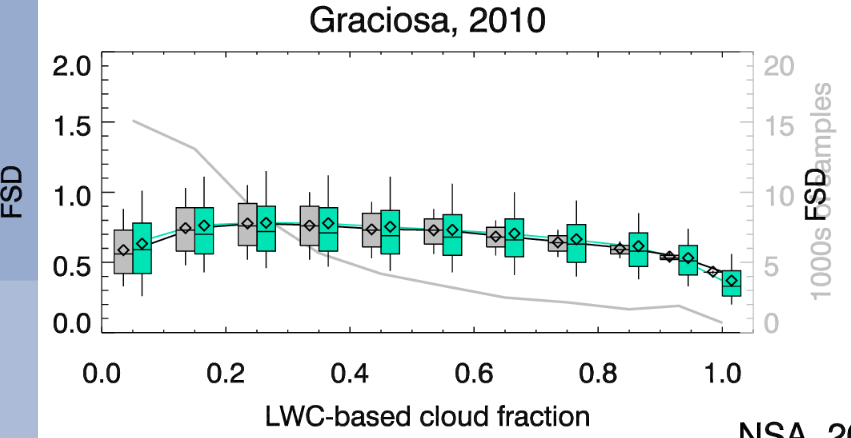
Liquid condensate FSD also varies with regime – ground based radar/lidar/MWR obs

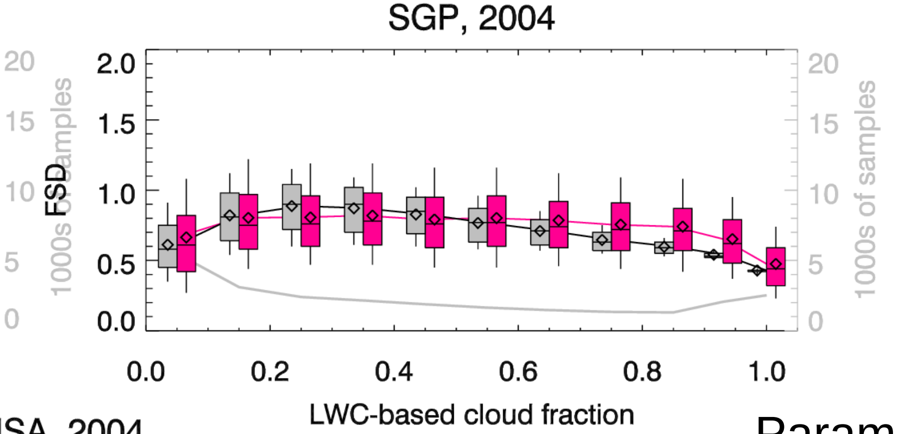
Good inter-seasonal variation

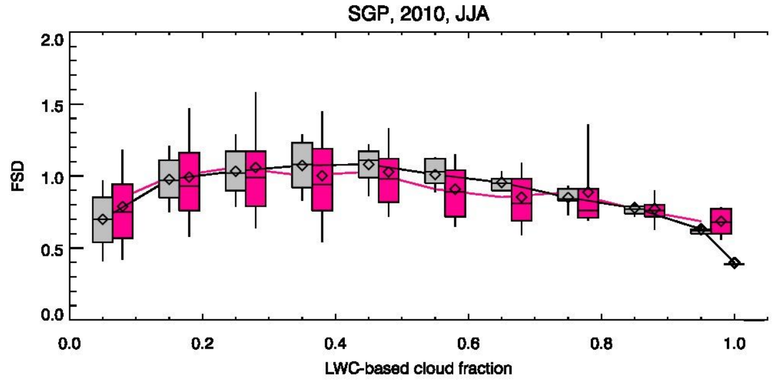


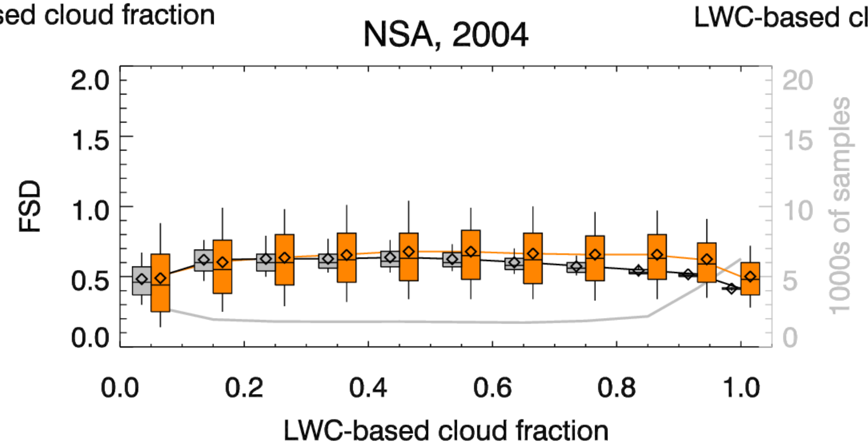












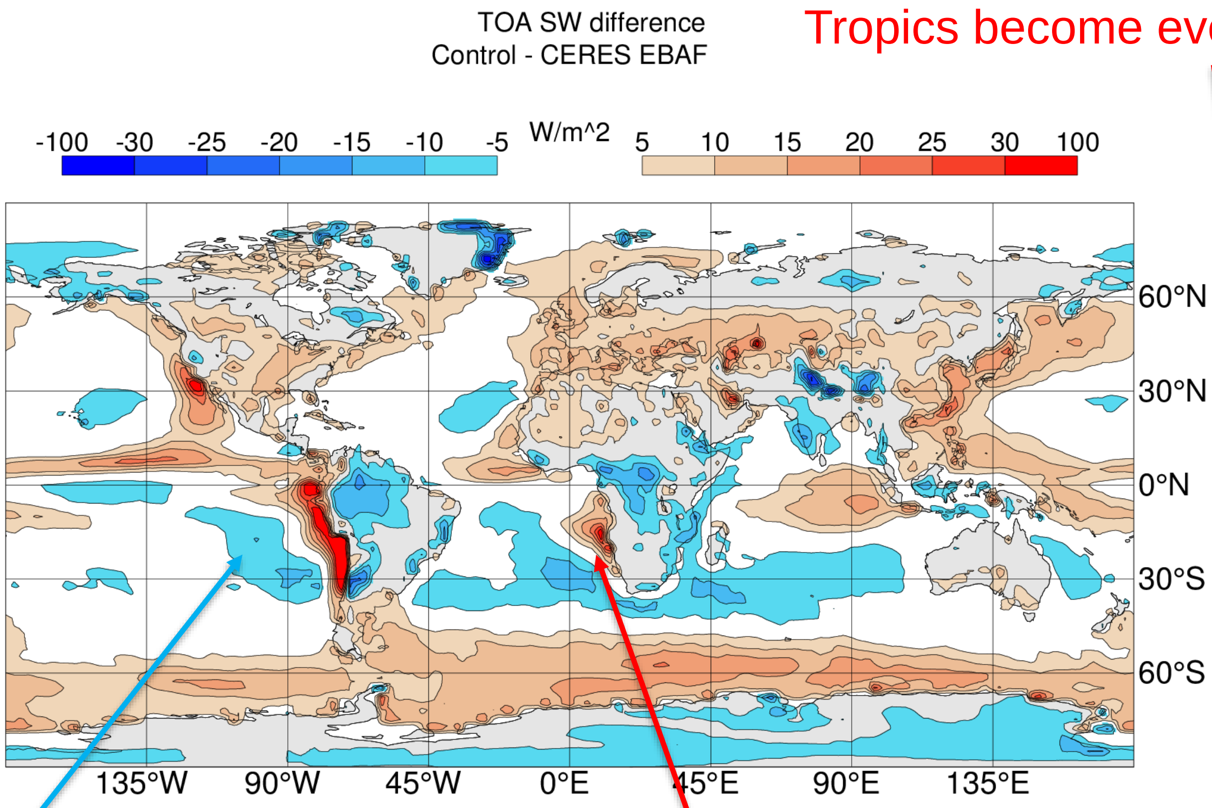
Parameterize regime-dependent FSD based on warm BL cloud observations, as function of **cloud fraction** and **total water mixing ratio**

- Enhances contrast between Cu and Sc
- Net effect in mid-lat/poles is to make clouds more homogeneous overall

Impact on radiation – longrange experiments

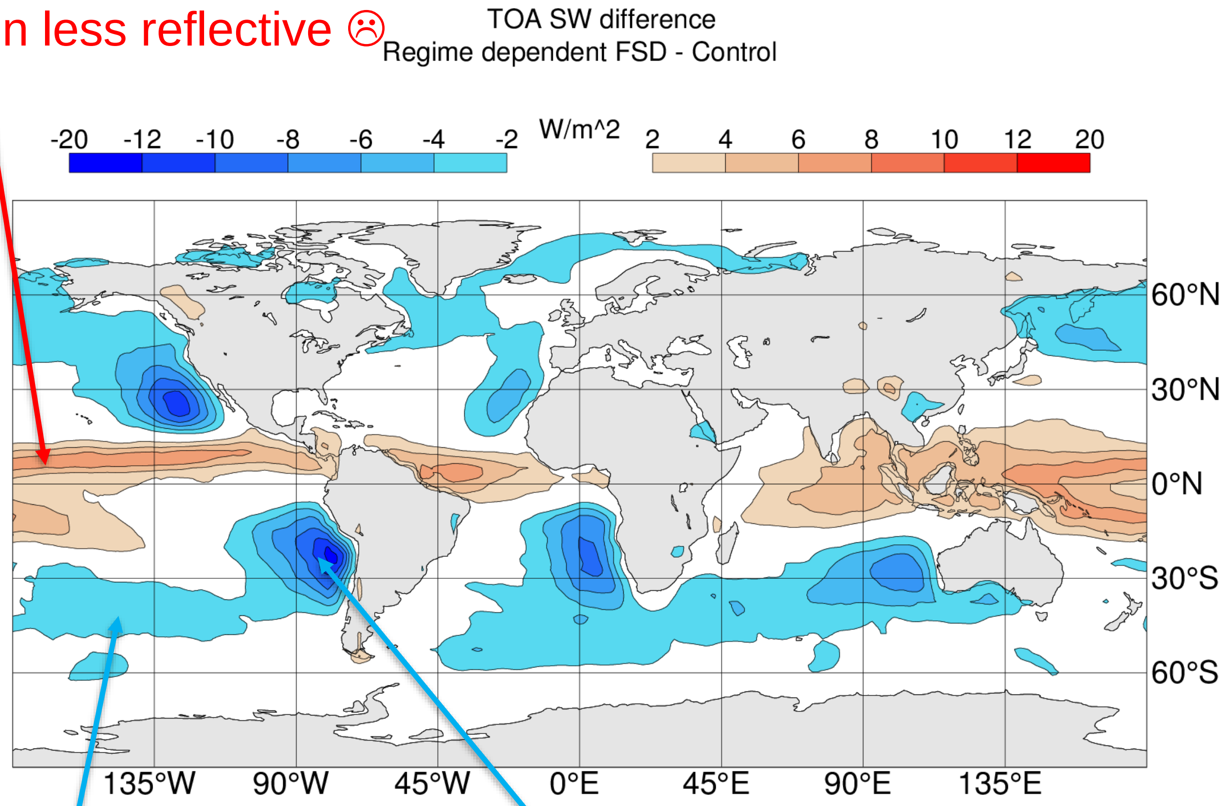
Ensemble of 3, 30 years of 6 month long runs, uncoupled, T255(80km), modified CY43R1

Systematic SW bias vs CERES EBAF observations



Tropics become even less reflective ☹

Impact of parameterization



Cu: 10-15W/m2 too bright

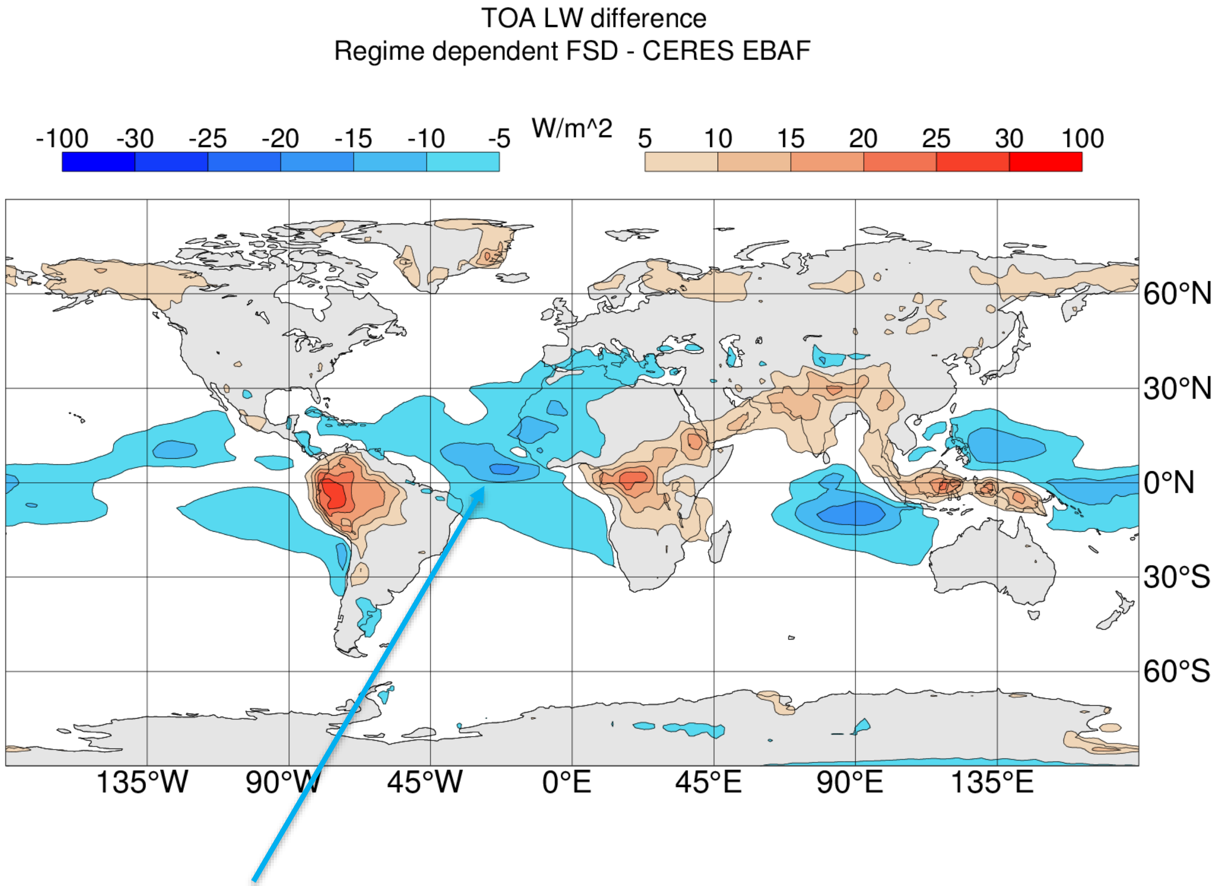
Sc: ~50W/m2 too dark

2-5W/m2 more reflexion ☹

around 15W/m2 more reflexion ☺

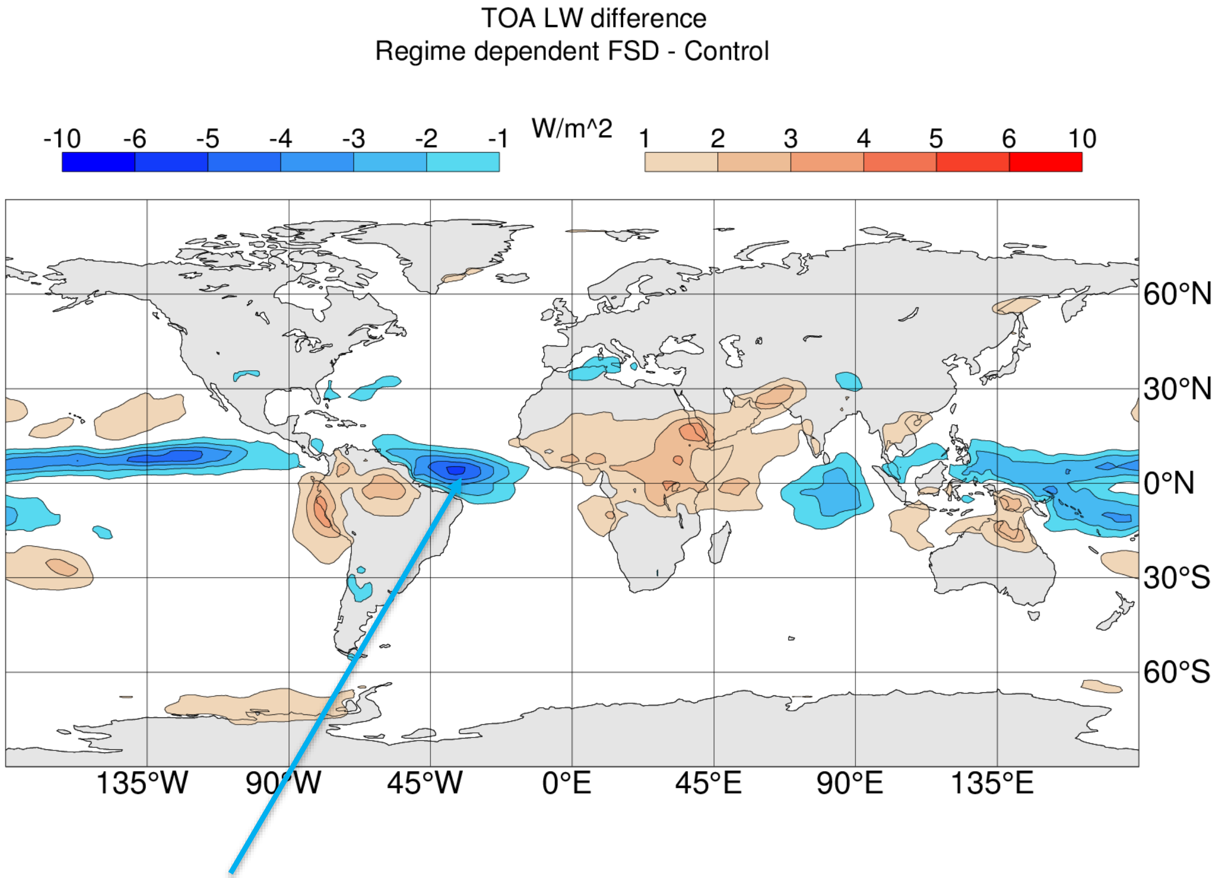
Longwave impact

LW bias relative to CERES EBAF (Control)



Too much OLR escaping

Impact of parameterization relative to Control



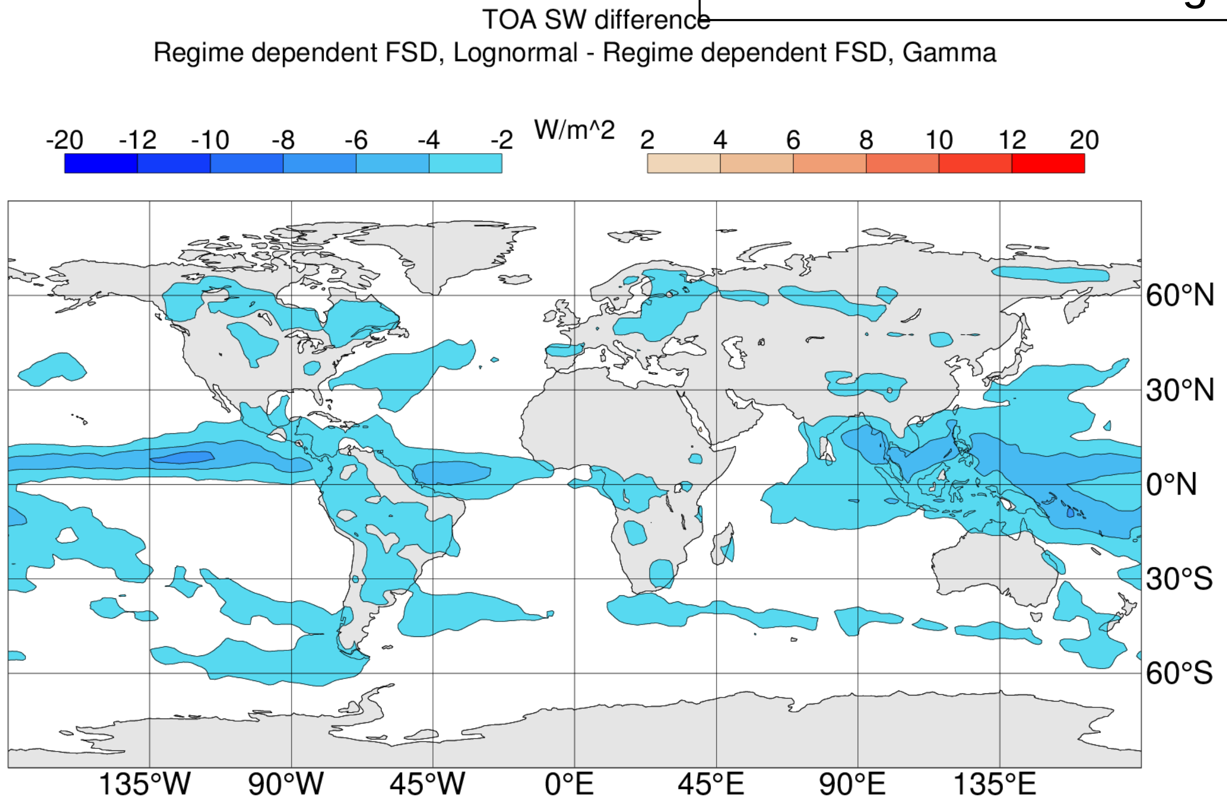
Even more OLR escaping ☹

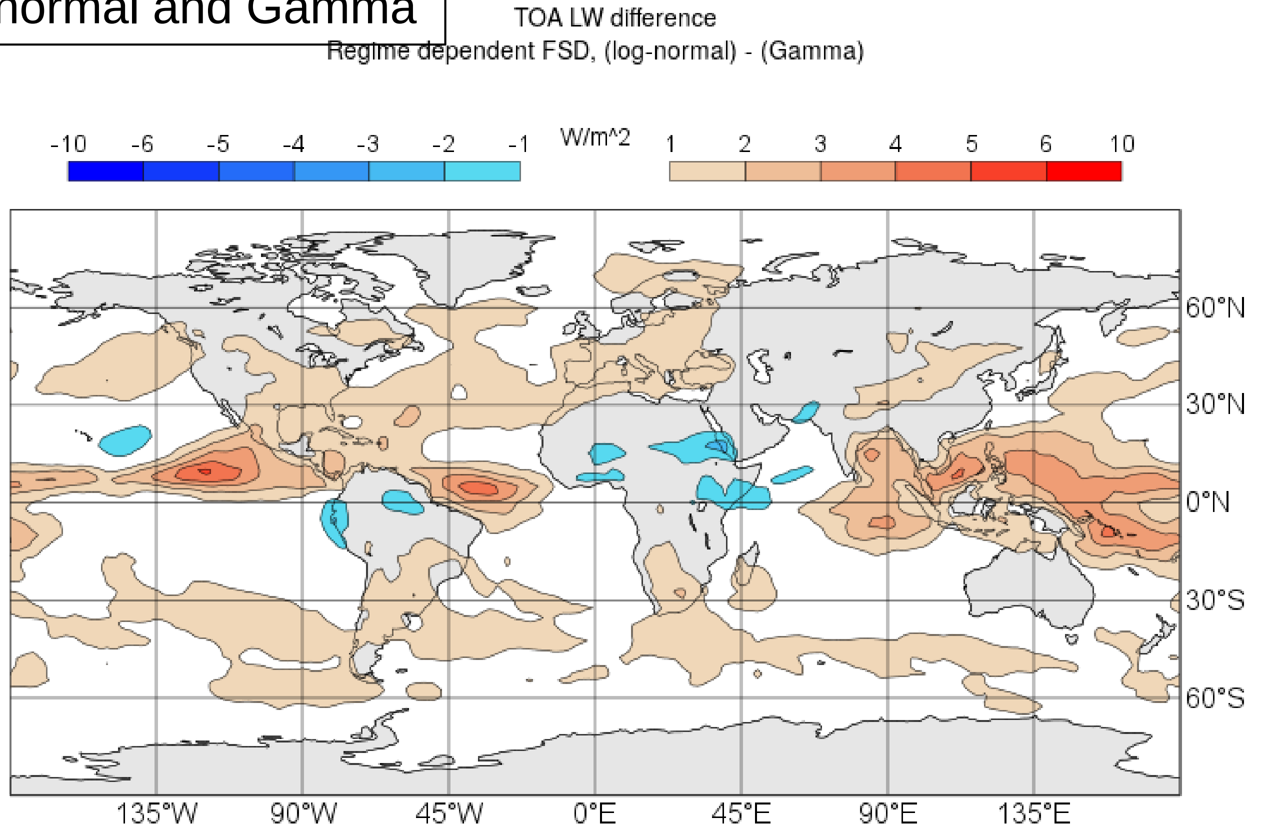
So far, have used default Gamma function

Differences log-normal vs. Gamma

- Cloud albedo and transmittance most sensitive for low optical depth – e.g. thin ice clouds with low condensate
- Gamma: more samples with very low condensate values compared to log-normal (optically thinner clouds)
- Log-normal enhances tropical albedo and traps more OLR – compensating for deterioration from regime-dependent FSD

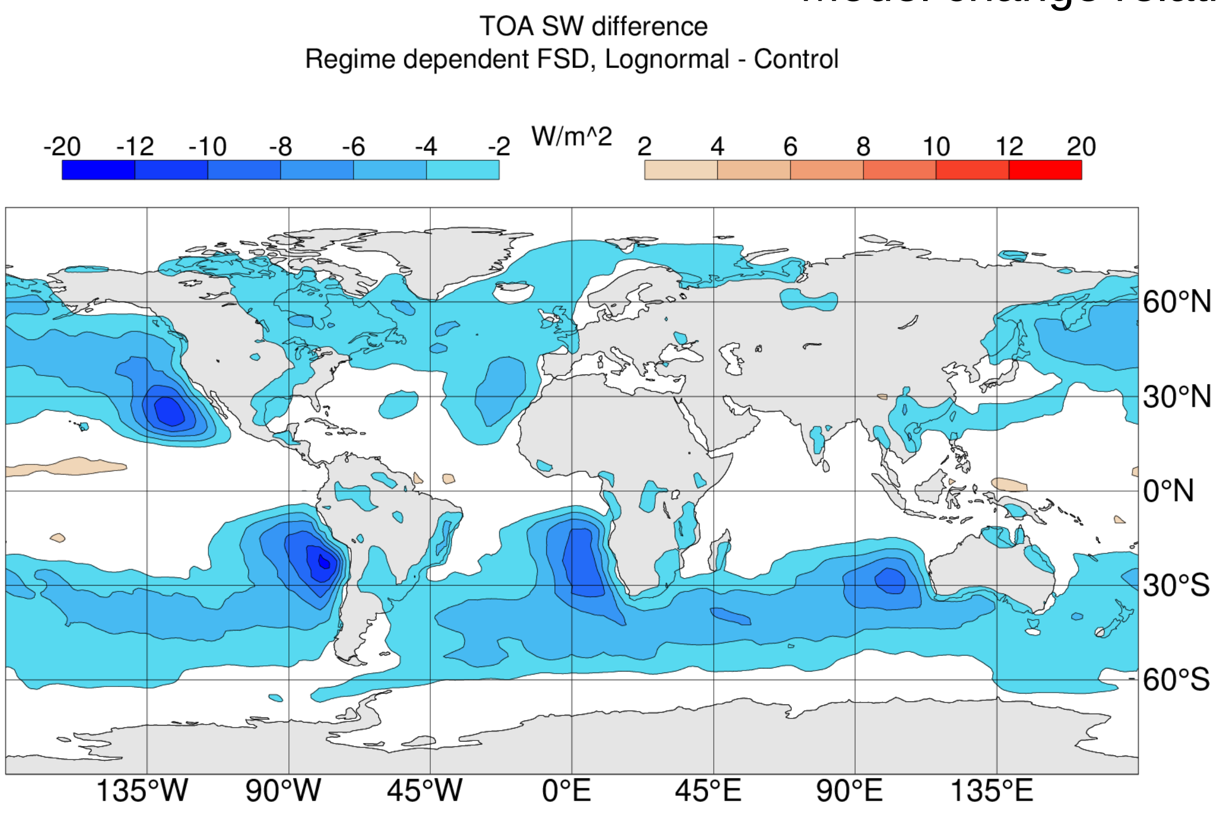
Difference between log-normal and Gamma

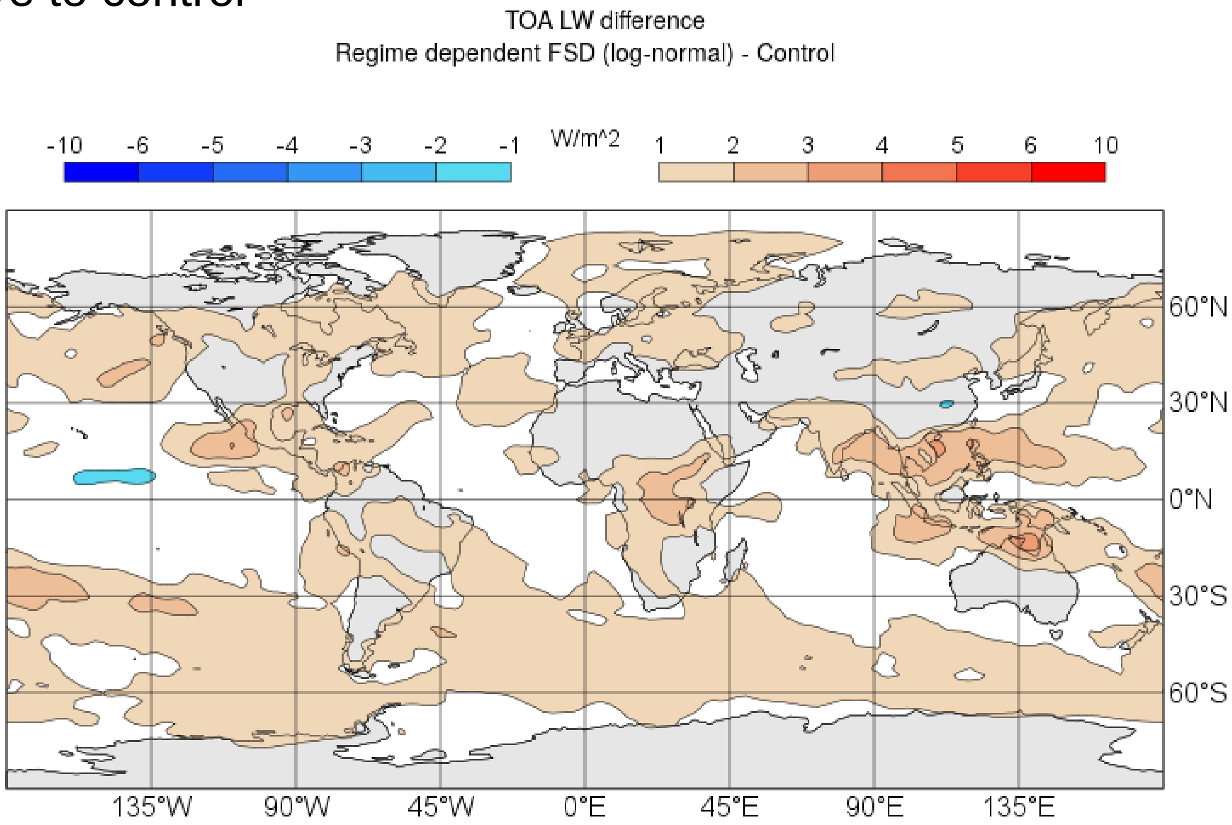




Log-normal the better choice in the tropics (for this model configuration)

Model change relative to control





With log-normal, deterioration in Tropics disappears, clouds overall trap more OLR, and reflect more SW

Main impact: mean FSD lower, globe has more homogeneous cloud, but enhanced contrast between Cu and Sc

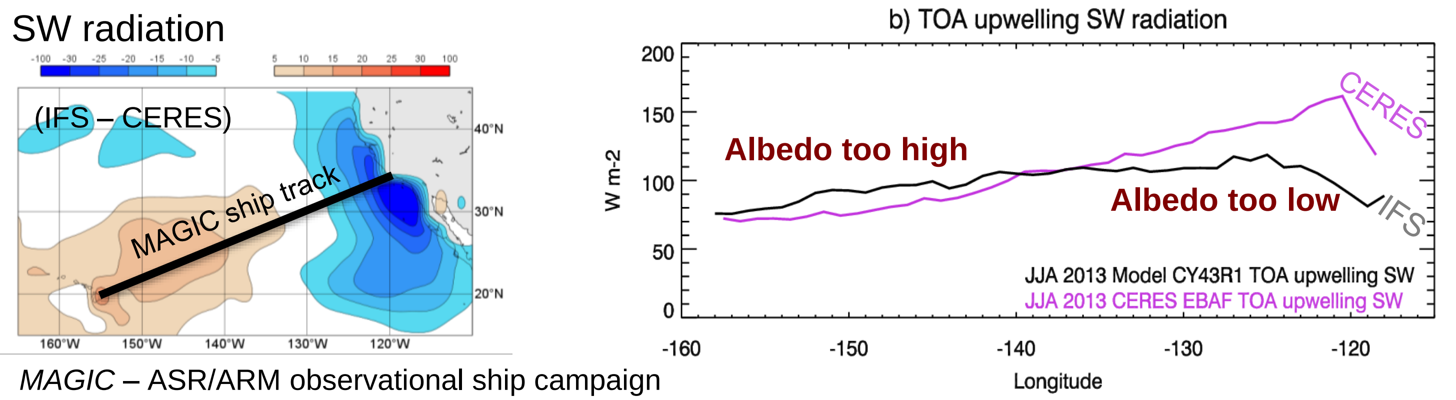
Summary: subgrid-scale heterogeneity

- Regime-dependent treatment of horizontal condensate heterogeneity can have impact on the order of 10W/m^2 in the SW, and order 5W/m^2 in the LW, ***without explicitly changing cloud cover or condensate amount***
- Net impact depends primarily on default assumption (FSD=1) – ***biggest impact from shift in global mean FSD***
- Parameterization adds ***regime-dependent contrast*** onto this background
- Parameterization relies ***on underlying cloud regime being correct*** – won't yield benefits if predicted regime is wrong (example: Sc regions with significant lack of cloud cover being treated like Cu)
- Needs to be tested and implemented in conjunction with other model changes to take full advantage of the scheme.

Attribution of shortwave radiation biases:

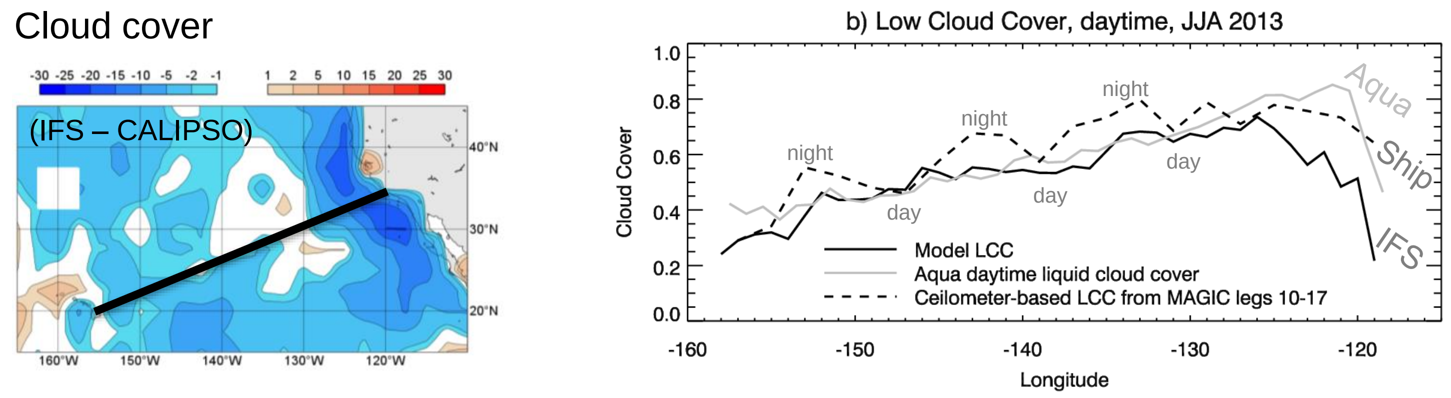
Example of a Pacific transect to investigate SW biases in marine BL clouds

Same SW bias found in short-term (12-36 hour) forecasts



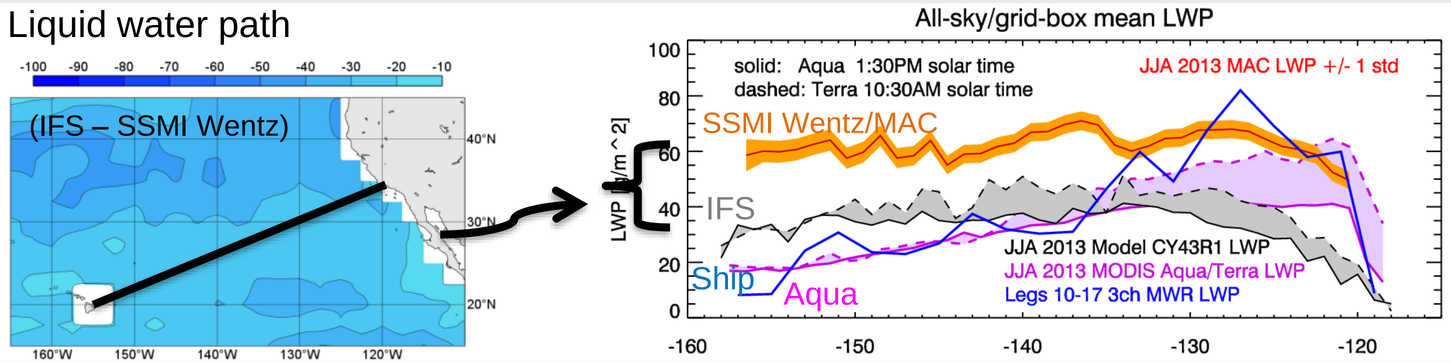
IFS albedo too high in trades

IFS albedo too low in stratocumulus



IFS cloud cover good in day

IFS cloud cover too low at night



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

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

Model composites over JJA 2013

Satellite observations for JJA 2013

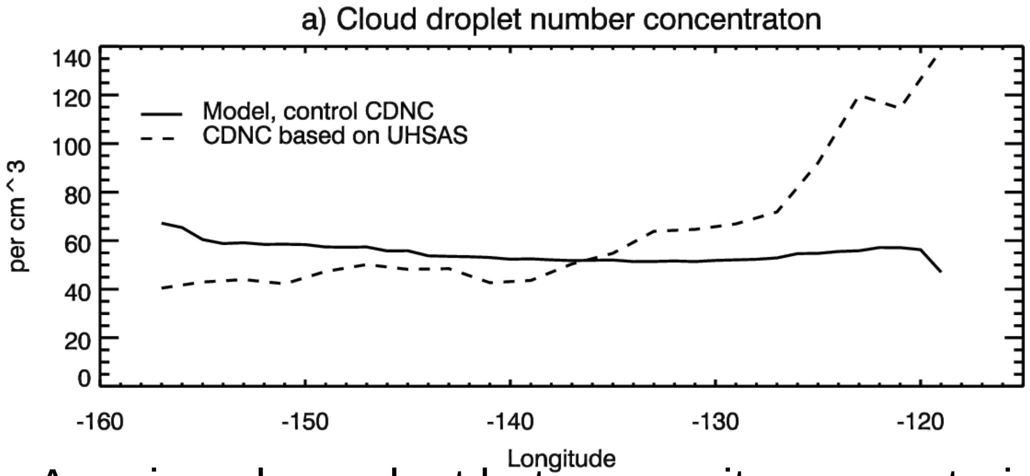
MAGIC: composite over eight round trips during JJA 2013 period (diurnal cycle!)

ECMWF

Ahlgrimm, Forbes et al (2018, in prep.)

Observations suggest:

1. In trade cumulus regime, an overestimate of LWP is a major contributor to the SW bias
2. In stratocumulus, both cloud cover and LWP are underestimated
3. Observations suggest a gradient in aerosol concentration/CDNC/effective radius from the (more polluted) continent to the (cleaner) islands of Hawaii, which the model does not represent



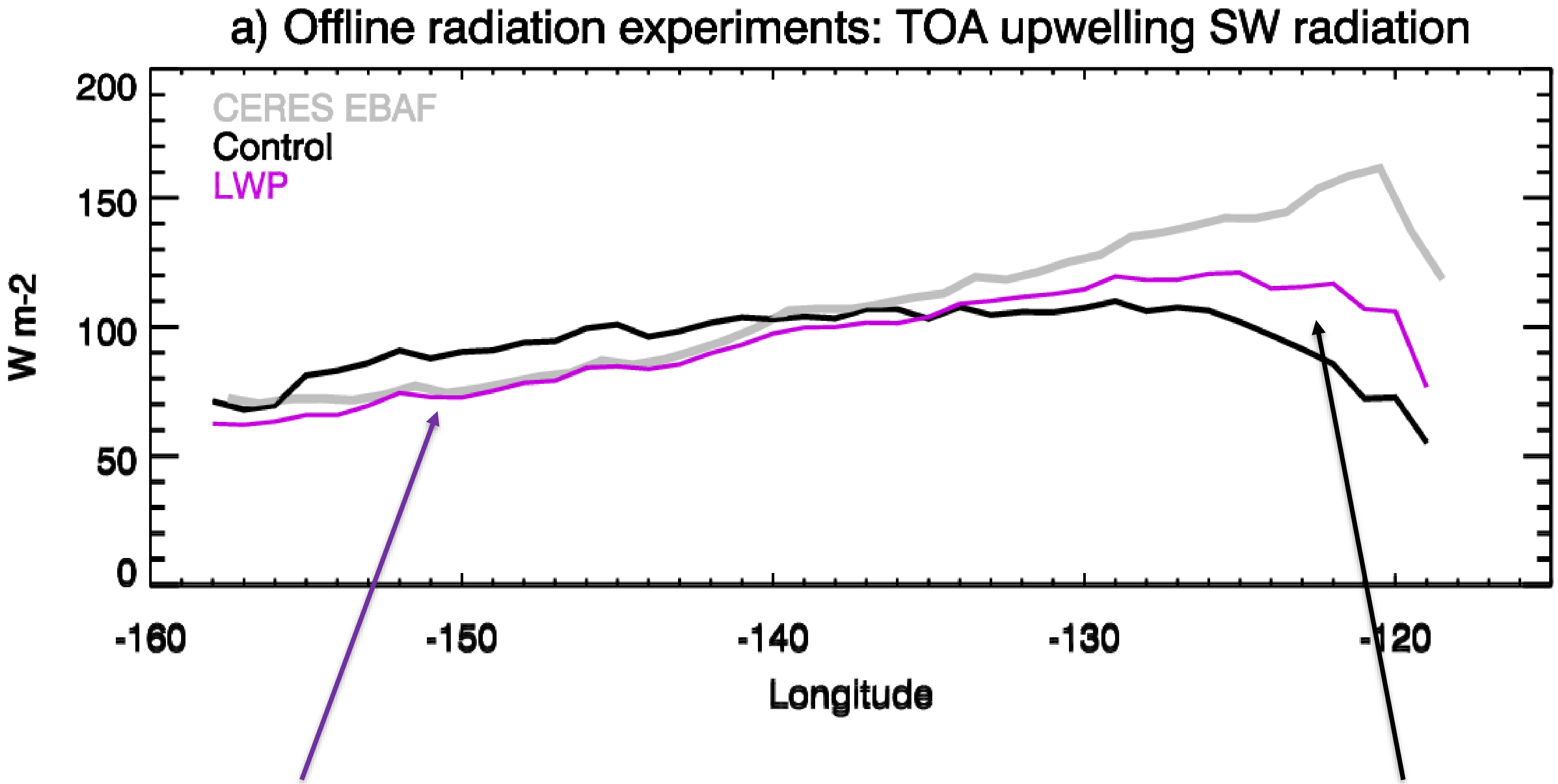
Observations (CDNC derived from UHSAS) suggest more polluted conditions near coast

CAMS climatology agrees (not shown)

4. A regime dependent heterogeneity parameterization will enhance the contrast between Sc and Cu

Now, test with offline ECRAD!

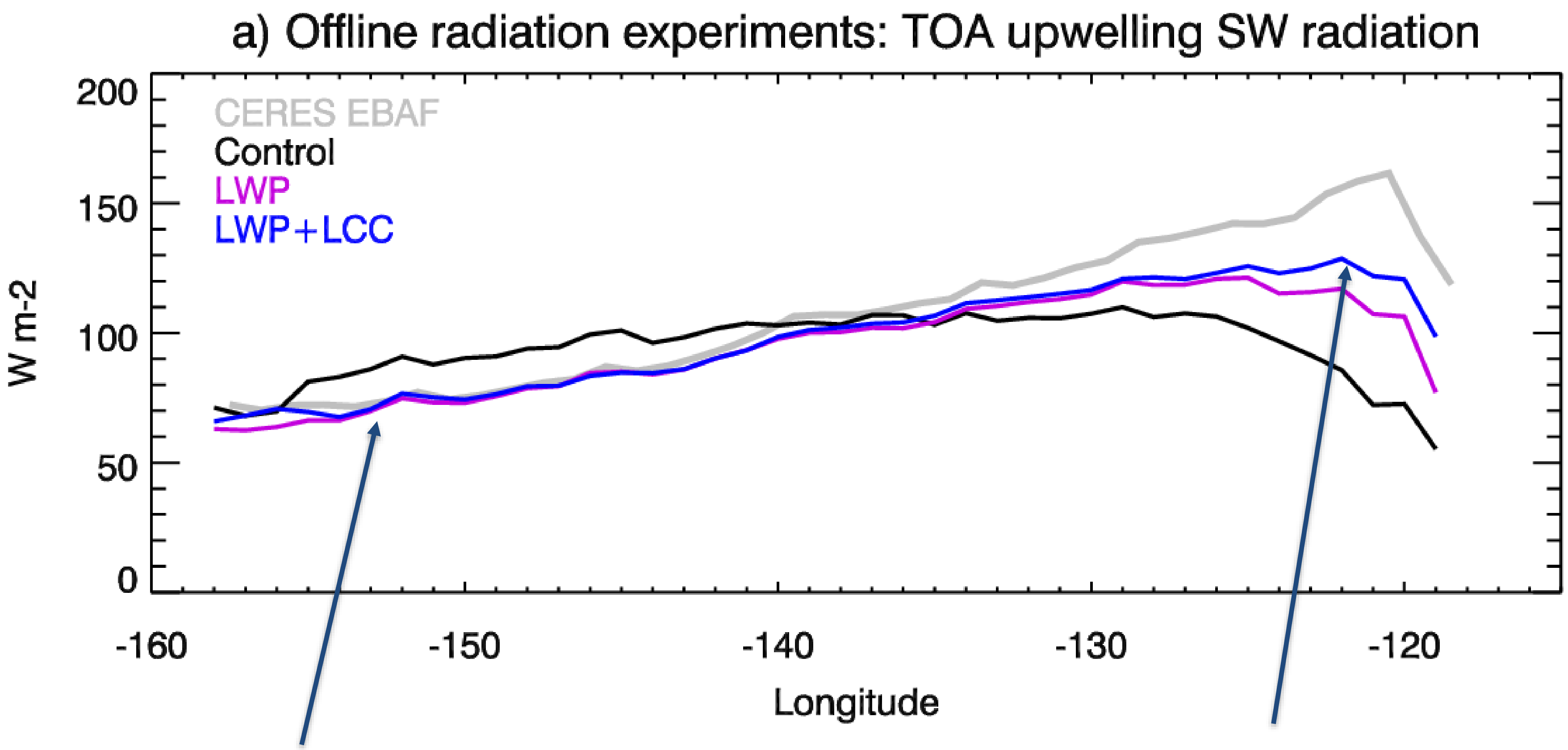
1) LWP bias primary cause of SW error in Trades



Experiment: nudge LWP towards observed values
Hypothesis confirmed: tuned LWP largely eliminates SW bias.

Bias in Sc partially improved

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

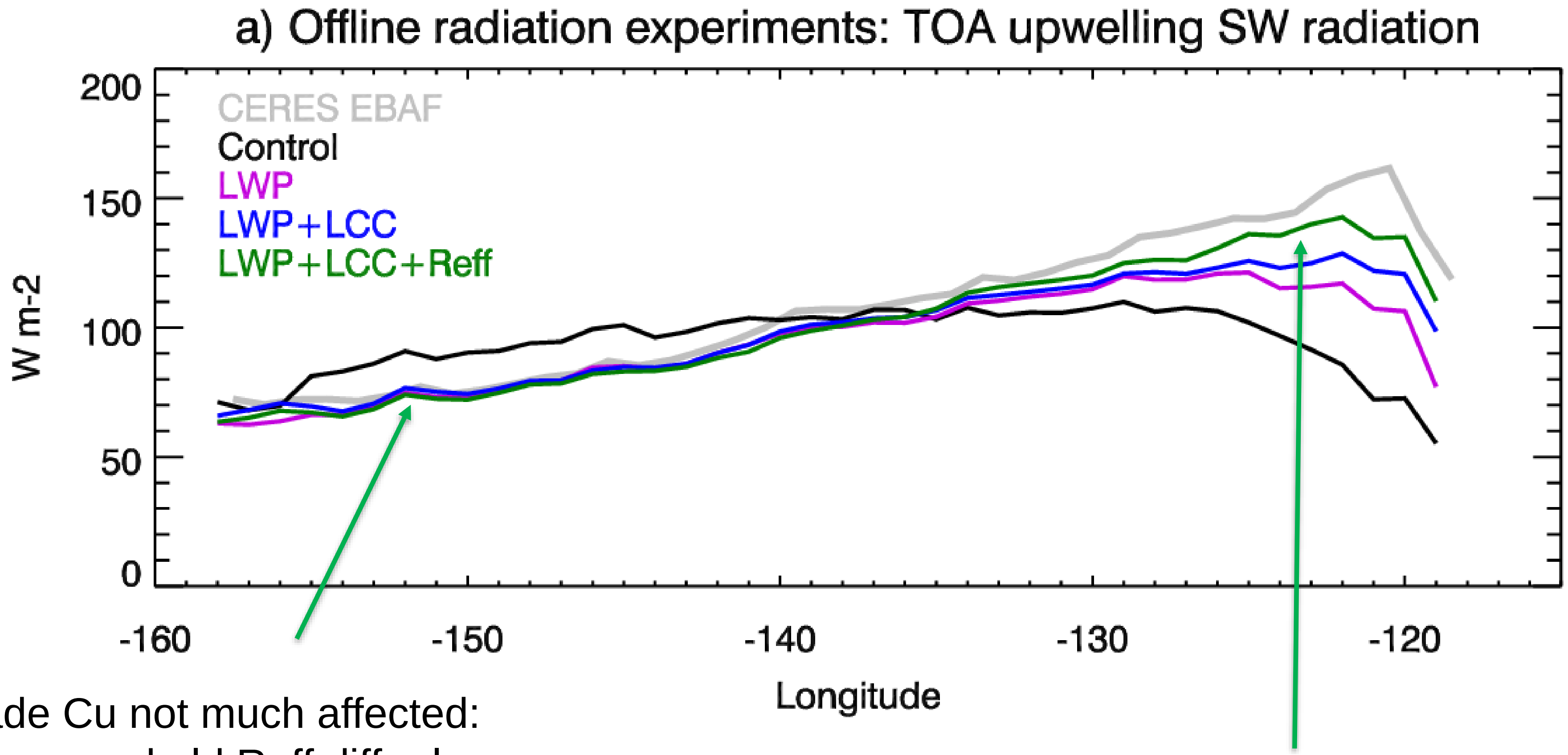


Trade Cu not much affected – CC was already good.

Additional improvement in Sc region!

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

3) Effective radius gradient along track enhances albedo in Sc



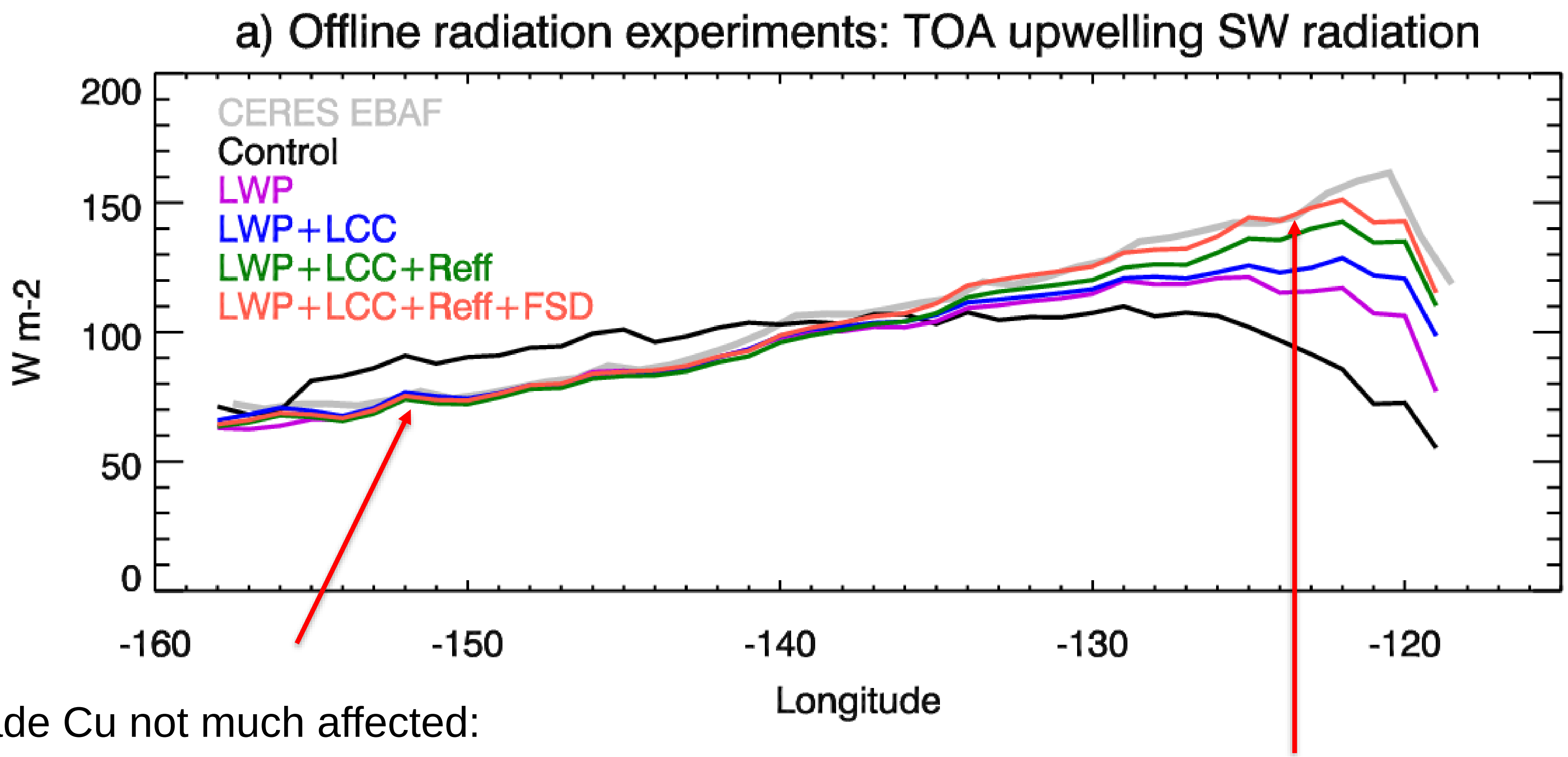
Trade Cu not much affected:

- new and old Reff differ less
- smaller cloud fraction means less impact

Additional improvement in Sc region!

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

4) Heterogeneity parameterization enhances contrast between regimes



Trade Cu not much affected:

- parameterised FSD similar to fixed value of 1
- smaller cloud fraction means less impact

Additional improvement in Sc region!

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

Conclusions:

- Careful comparison with observations gives **clearer picture** of model errors
- Offline radiation calculations can **quantify relative contribution** to the shortwave bias
- **Challenge still ahead!** How to get the model to produce observed cloud cover and water path is not obvious
- But: this exercise provides **clear priorities** for addressing the radiation bias
- Parameterization changes that modify cloud radiative properties (such as heterogeneity assumption, effective radius) can only yield full benefit if macroscopic cloud properties (in this case, fraction and liquid condensate) are correctly predicted
- (Of course, interactions exist. However, main patterns of radiation biases exist in short-term forecasts, thus are not a result of interaction on longer time-scales with circulation)
- (Vertical overlap – effectively changes projected cloud cover, could replace “nudging” done here, but little sense doing both at the same time)