The impact of increasing vertical resolution in the atmospheric boundary layer

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Support for higher vertical resolutoin

Dynamical considerations
Essentially try to resolve vertical waves
e.g., Skamarock et al. 2019;
Lindzen & Fox-Rabinovitz 1989;
Pecnick & Keyser 1989

$$\frac{\Delta x}{\Delta z} = \frac{N}{f} = m_{\text{front}} \gtrapprox 200$$

Chemical plume dispersion
Zhuang et al. 2018 argue Δx/Δz ≈ 1000

This shows a prototype of L58

Changes in the atmospheric boundary layer

Tompkins & Emanuel 2000 suggest Δp ≲ 25hPa is needed for convergence of T and q profiles in RCE. They note that one of the models used was very sensitive to boundary layer resolution (but not the other).

Teixeira 1999 showed improvements in cloud-topped boundary layers (and hints at other features) in IFS going from L31 to L40, including (and emphasized) including the lowest level near 10m.

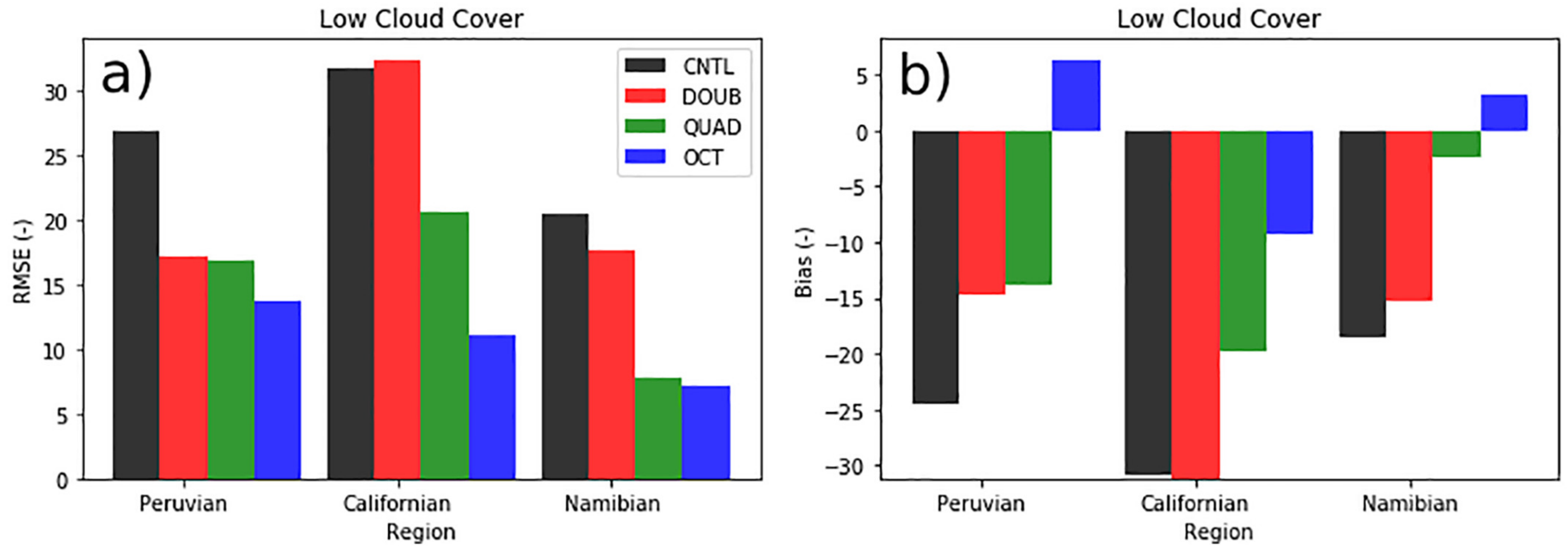
Edwards et al. 2020 review boundary layer parameterization for large-scale models, discussion issues of moving to “gray scale” but barely touch on vertical resolution.

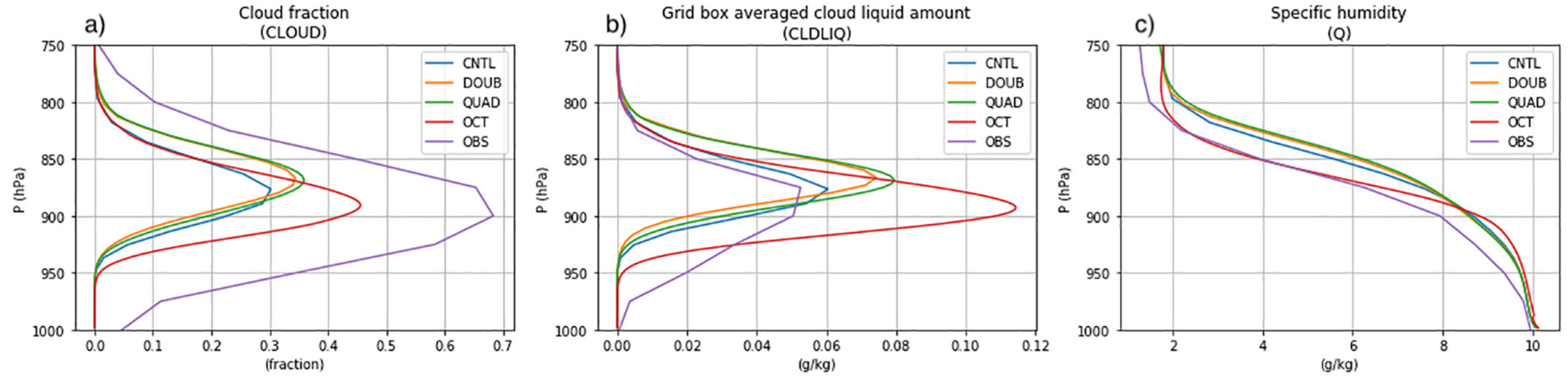
Davy 2018 reviews PBL climatology in GCMS, notes some indication of correlation between vertical resolution and model errors, but does not go into detail about the near-surface resolution.

Holtslag et al. 2013 discuss challenges in representing stable boundary layers (wind turning, diurnal cycle)

Vignon et al. 2017 use LMDZ model with high v-res to look at stable PBL in Antarctica; increased resolution near surface is better. (see also Couvreux et al. 2020.)

Bogenschutz et al. 2021 — Improvement in stratocumulus with increased vertical resolution; noted that moving lowest level downward required much shorter timestep. Note, they start from E3SM 72 levels with Δz ≈ 135m in Sc layer.





Hope and Expectation

Cloud transitions

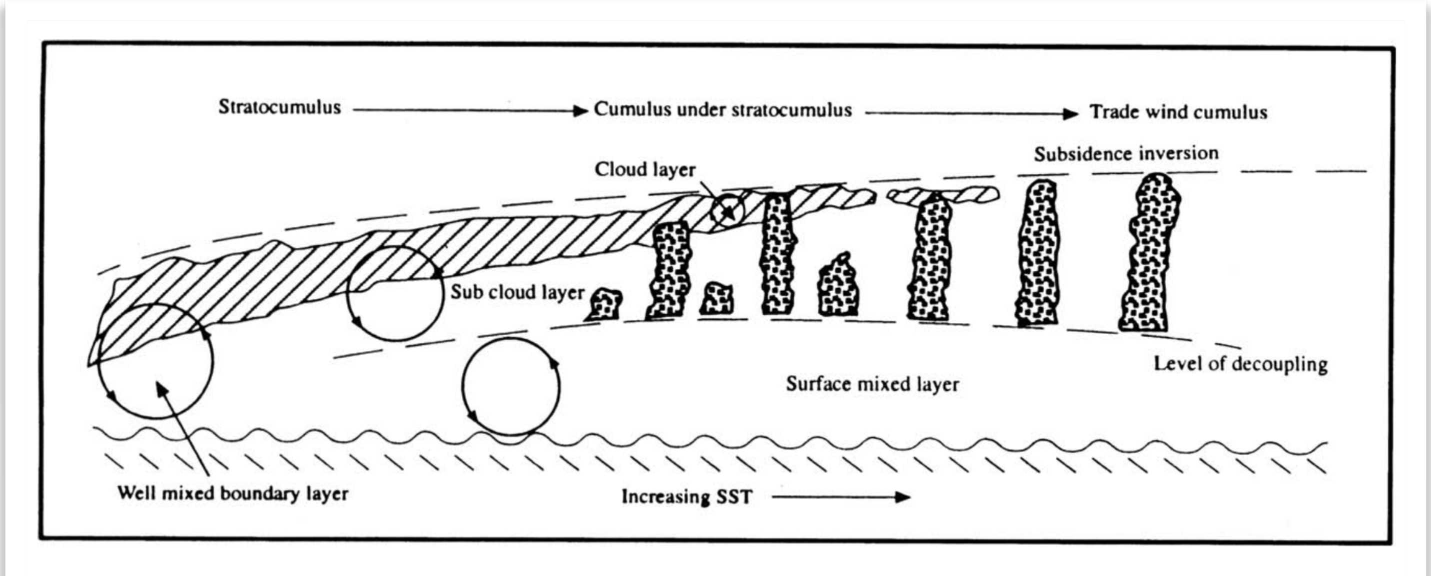
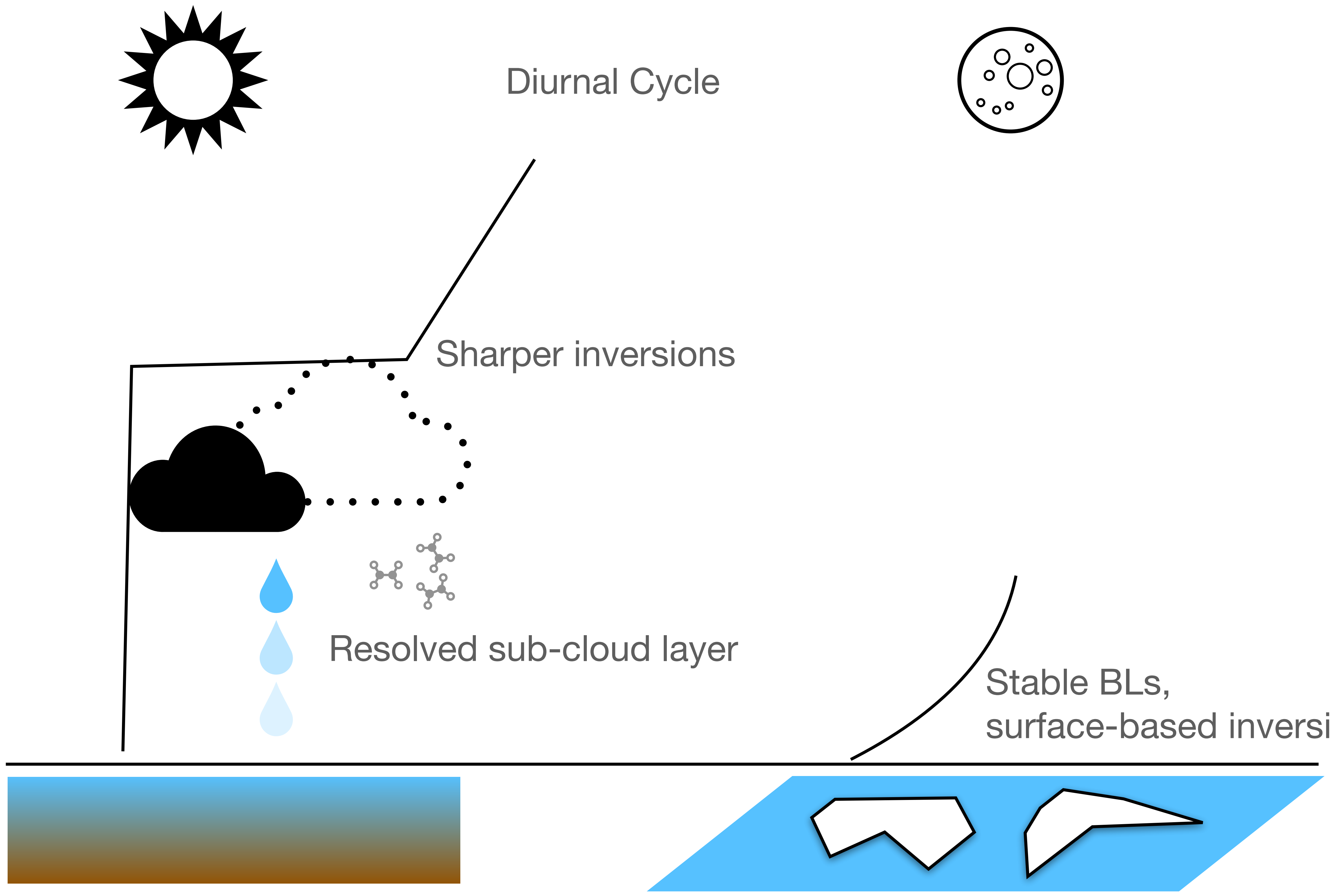
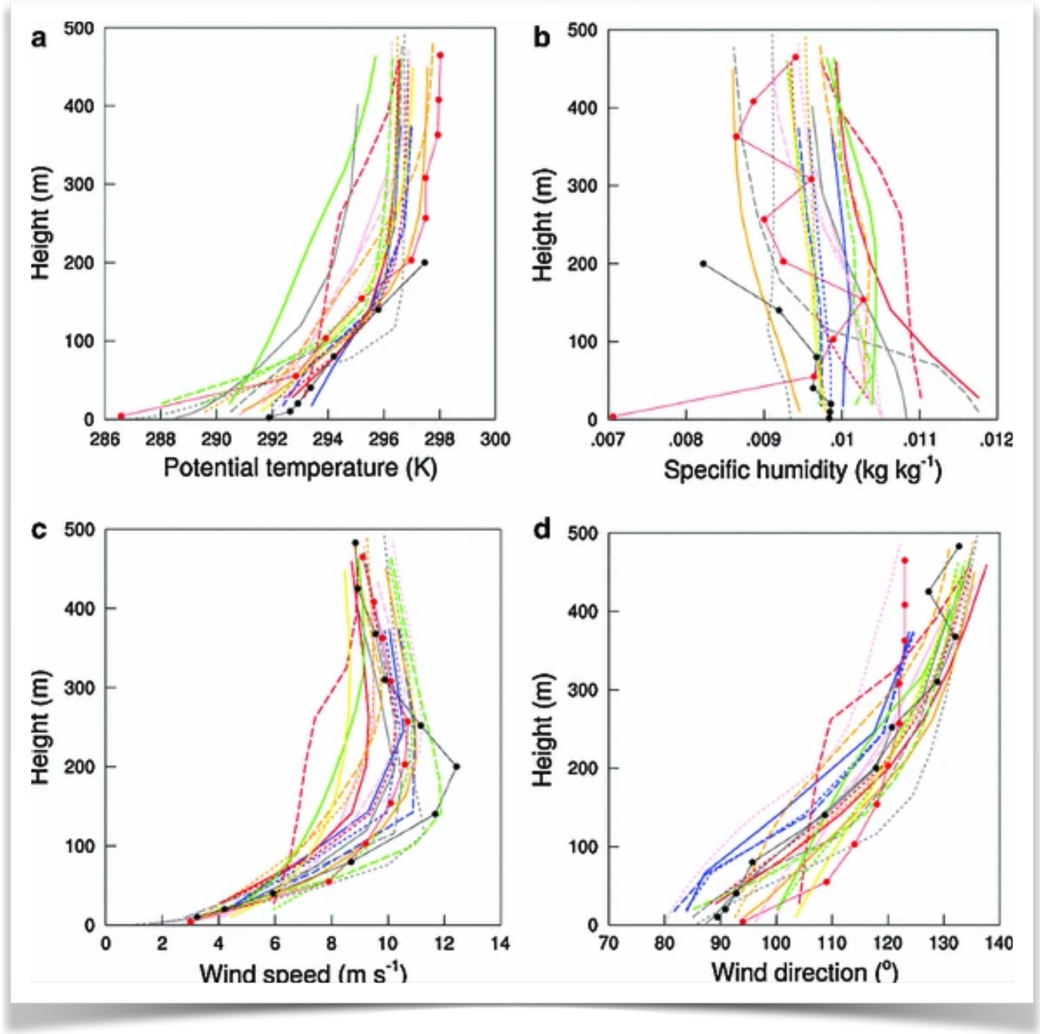


FIG. 4. A schematic of the transition from stratocumulus to trade wind cumulus.

Albrecht et al. 1995



Stable boundary layer



Bosveld et al. 2014

Recent examples

- Lee et al. 2019 L64→L91, but also show that L64->L65 to add add a near-surface layer with 10m thickness has a large impact on surface fluxes.

- Harlaß et al. 2015 L31→L62, show improved tropical Atlantic biases going

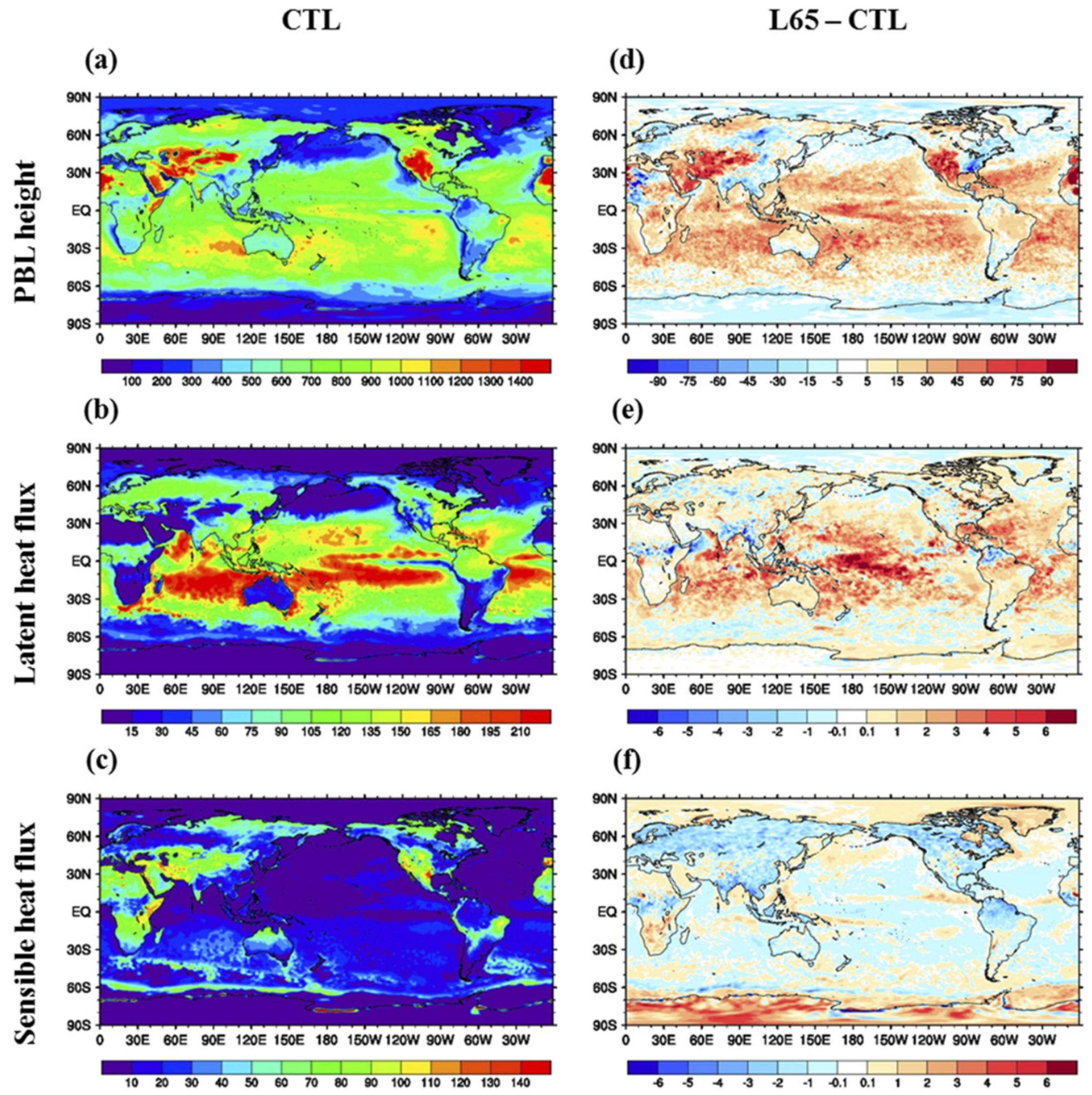


FIG. 3. Daily mean (a) PBL height (m), (b) latent heat flux (W m^{-2}), and (c) sensible heat flux (W m^{-2}) for 48–72-h forecasts in CTL during the month of July 2016. (d)–(f) Differences between CTL and L65 (L65 minus CTL).

PBLH

LHFLX

SHFLX

Vertical Resolution →

SST Bias

Horizontal Resolution ↓

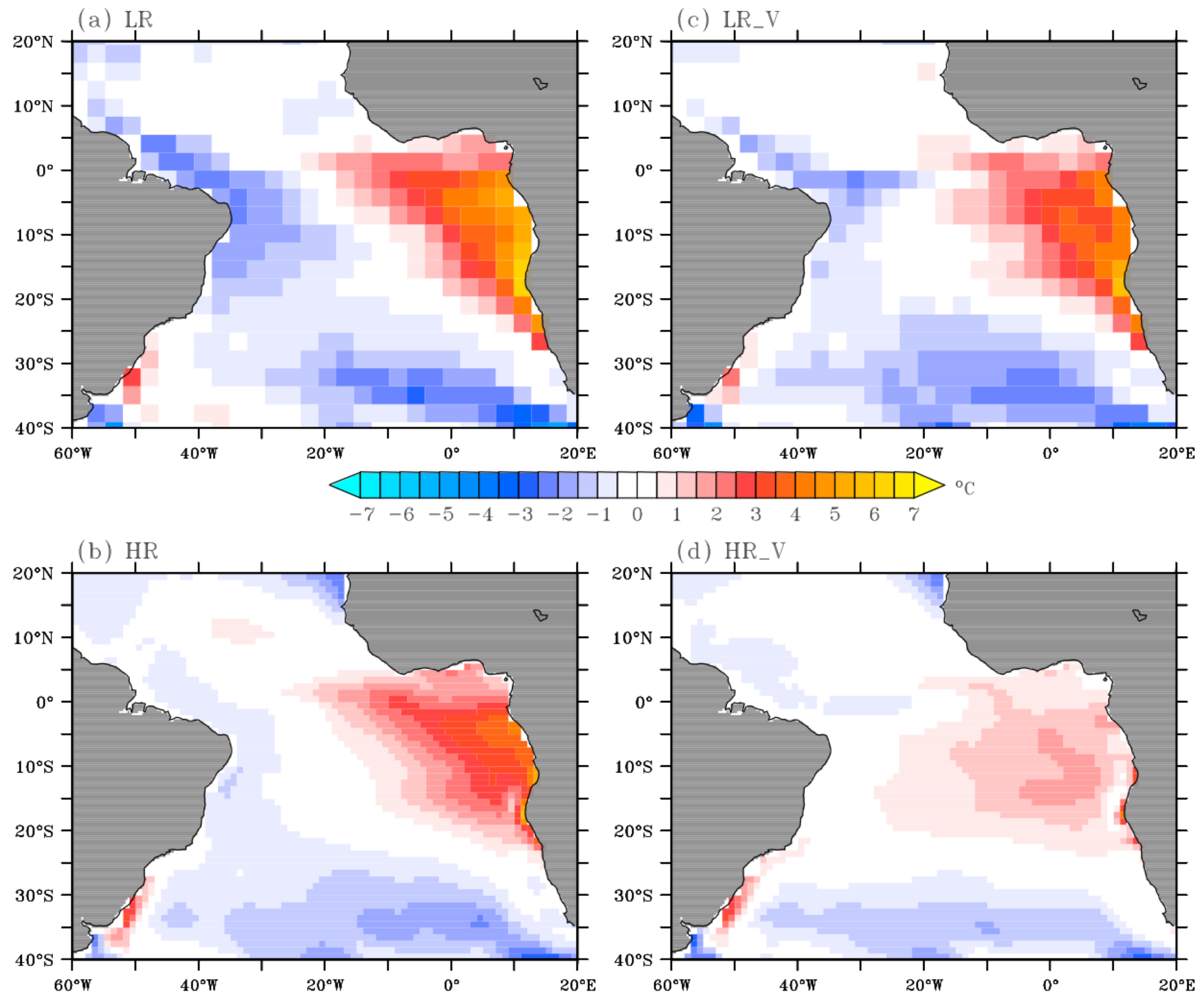
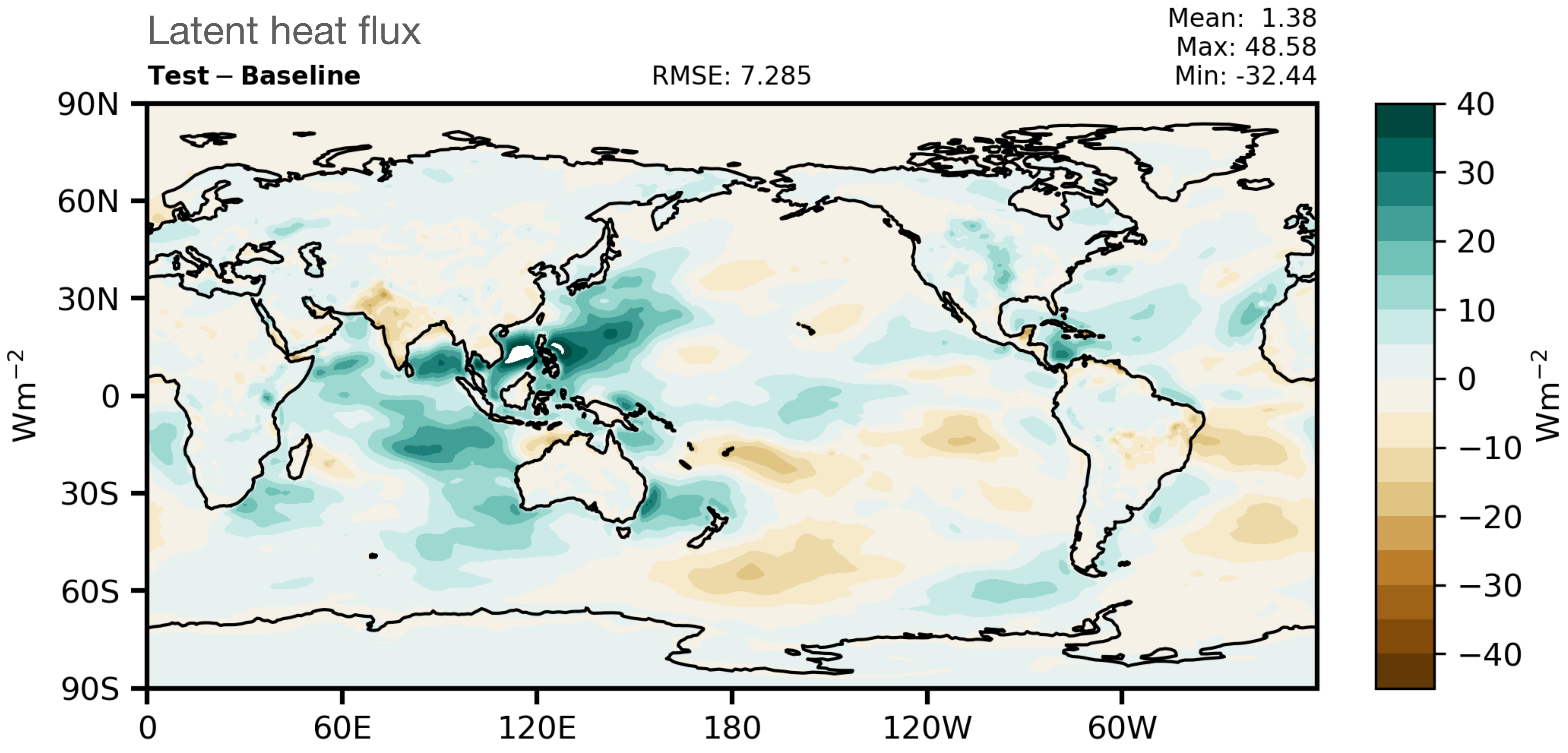
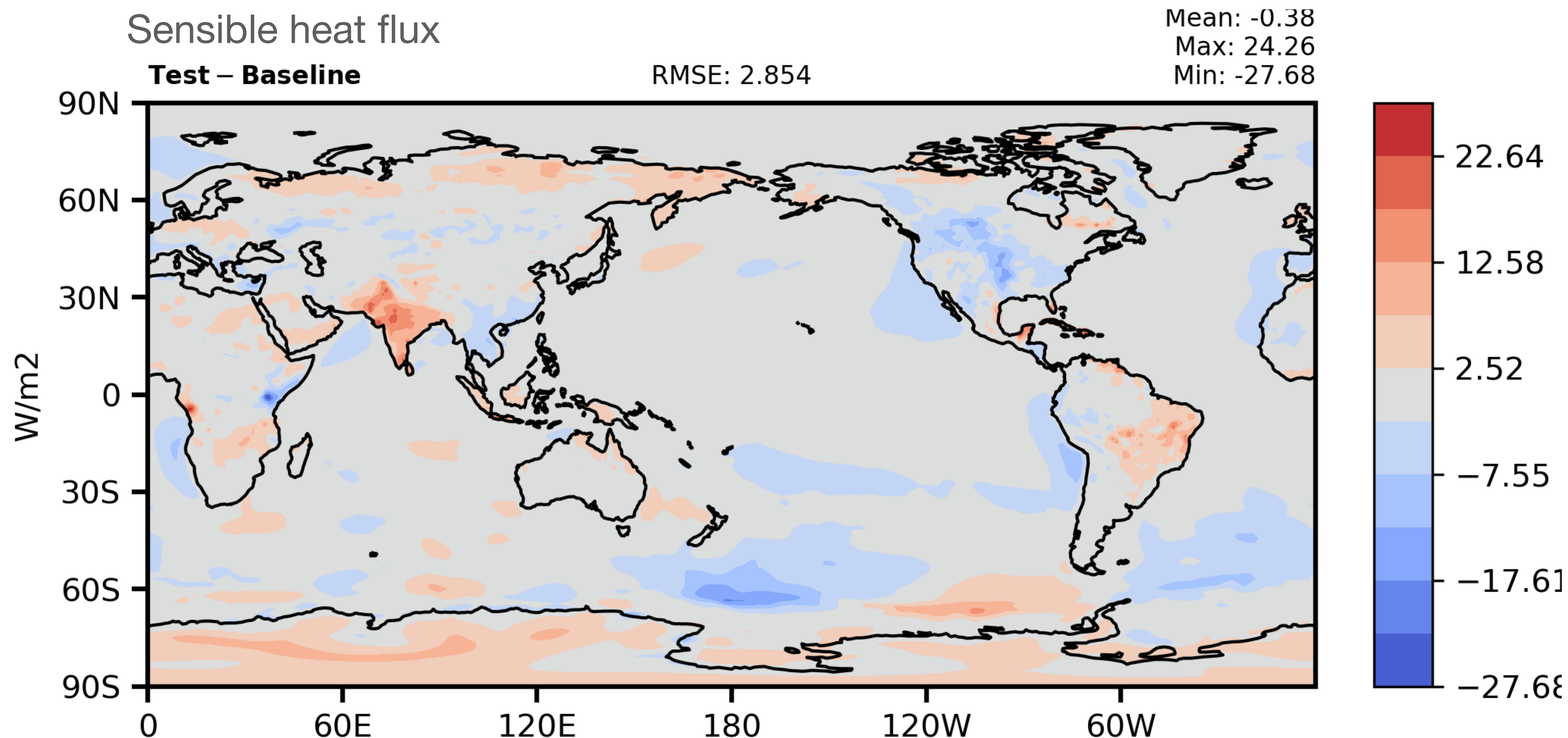
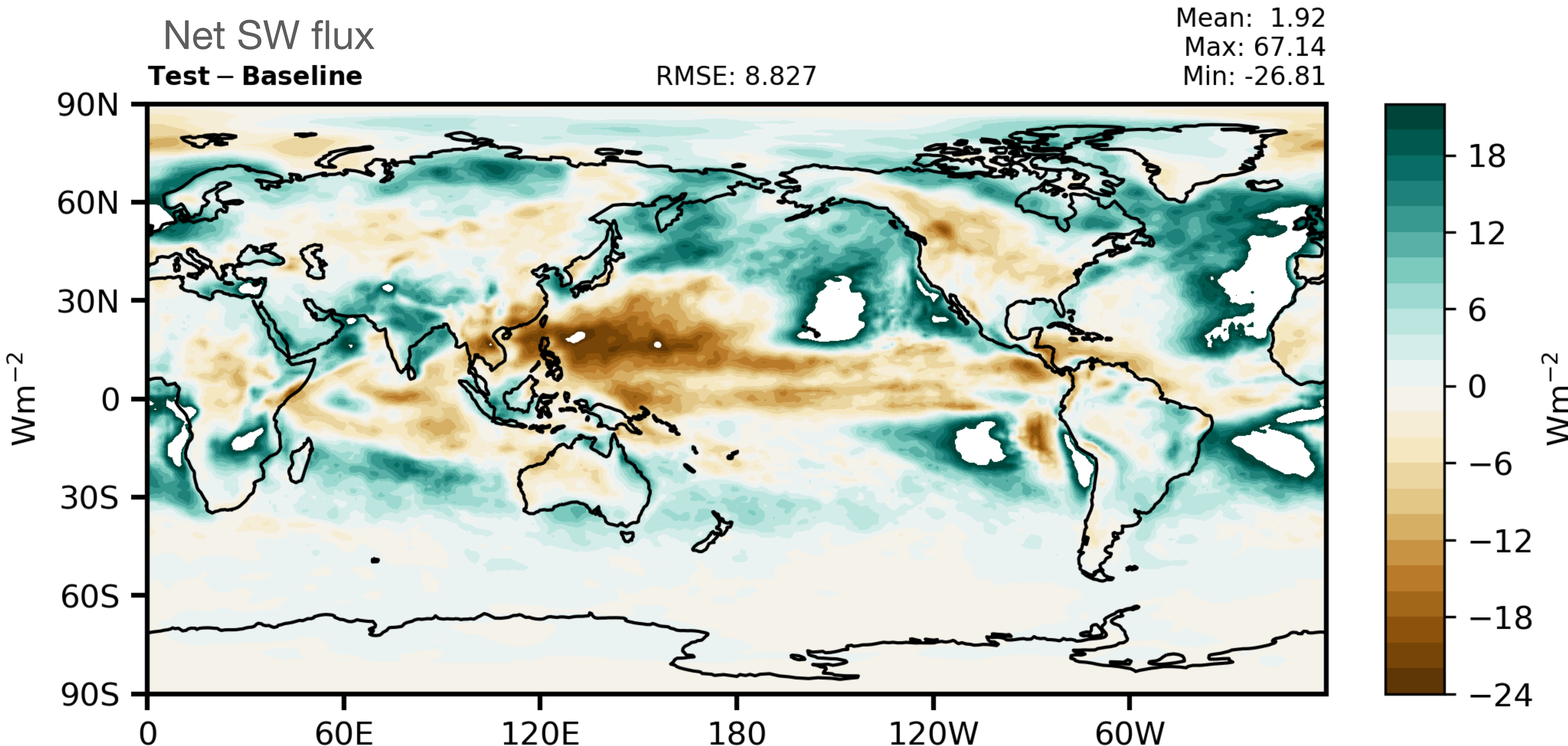


Figure 1. Sea surface temperature (SST) bias with respect to HadISST (°C) in JAS. (a) LR (T42, L31); (b) HR (T159, L31); (c) LR_V (T42, L62); and (d) HR_V (T159, L62).

Indications (AMIP L32→L58)







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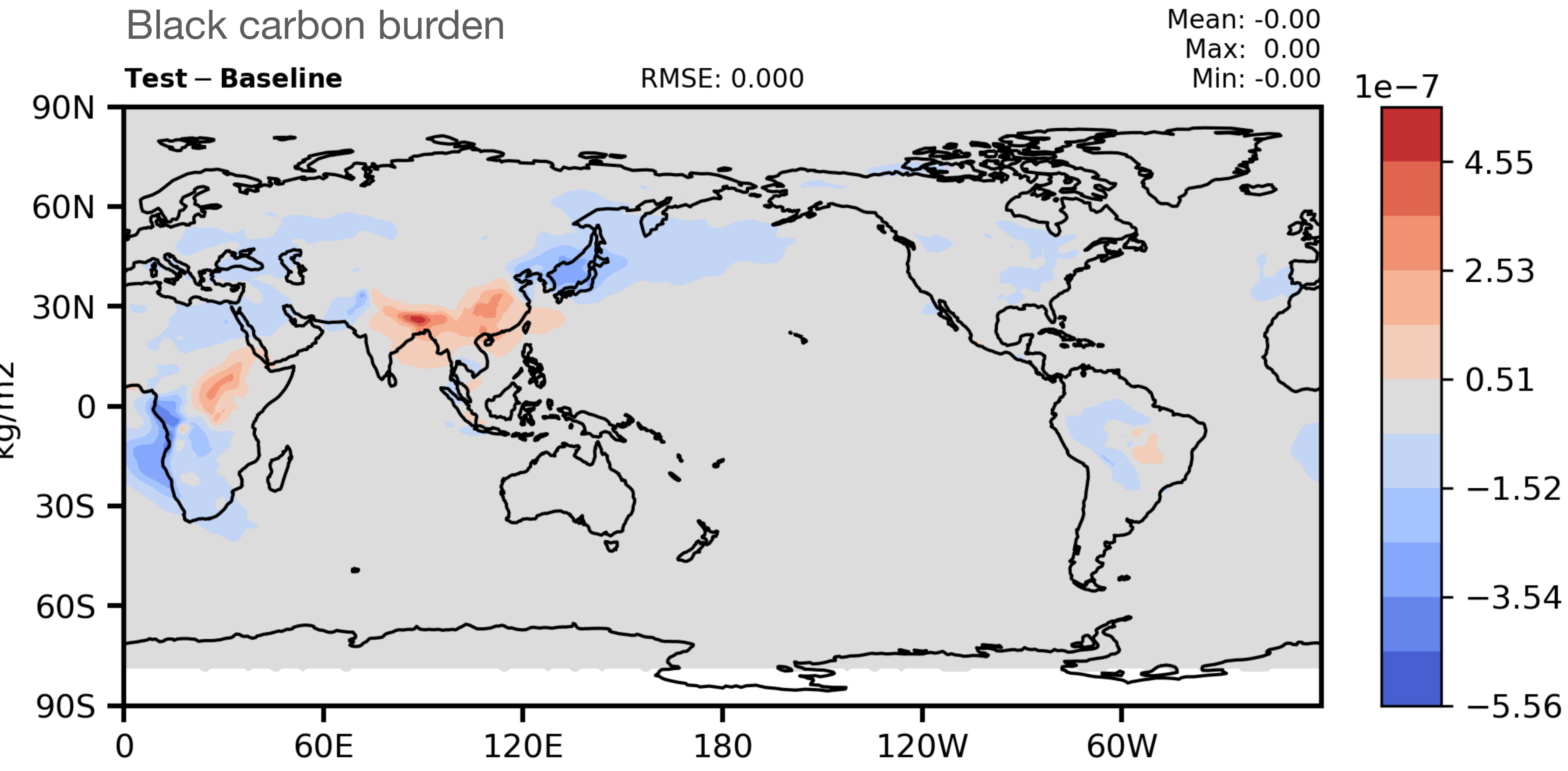
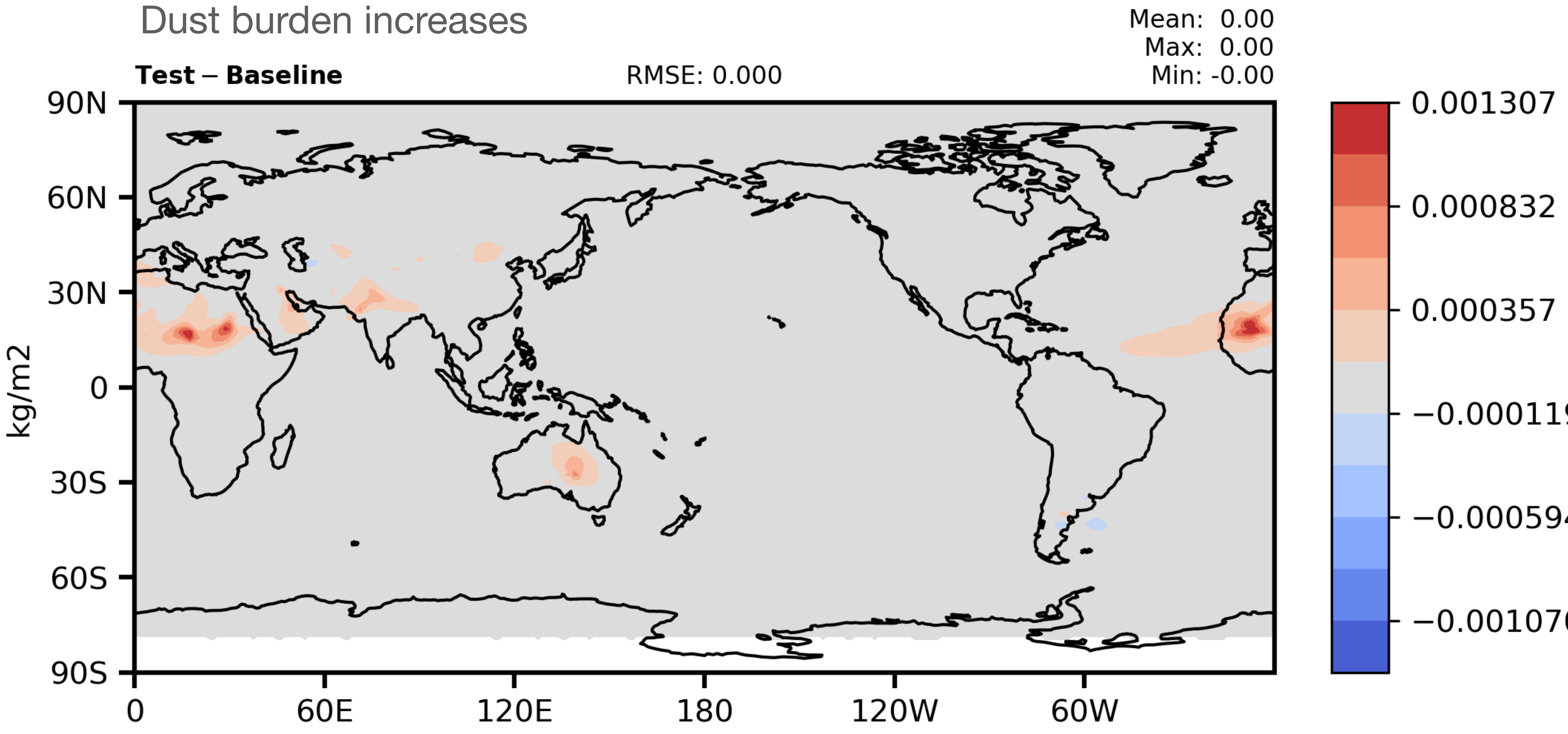
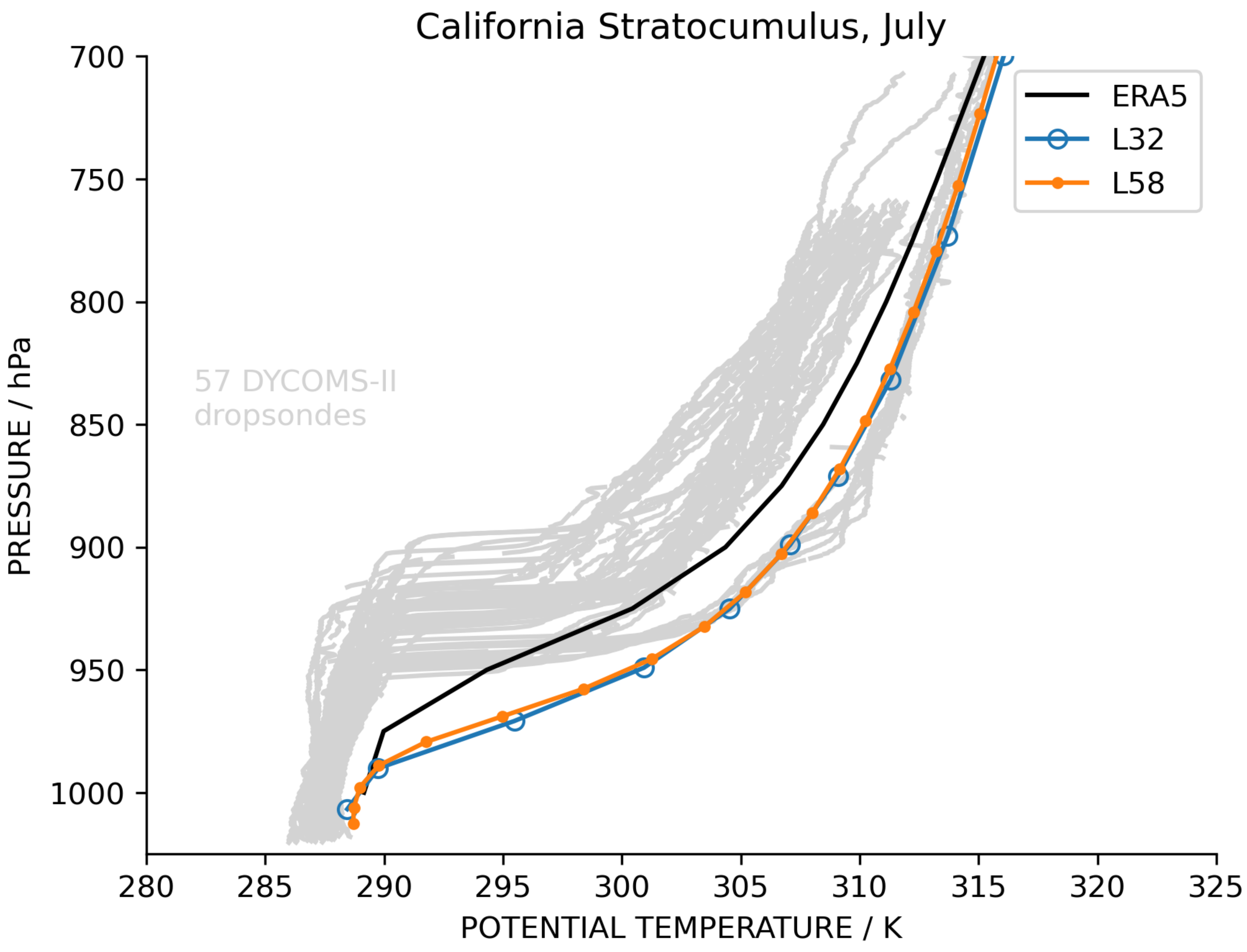
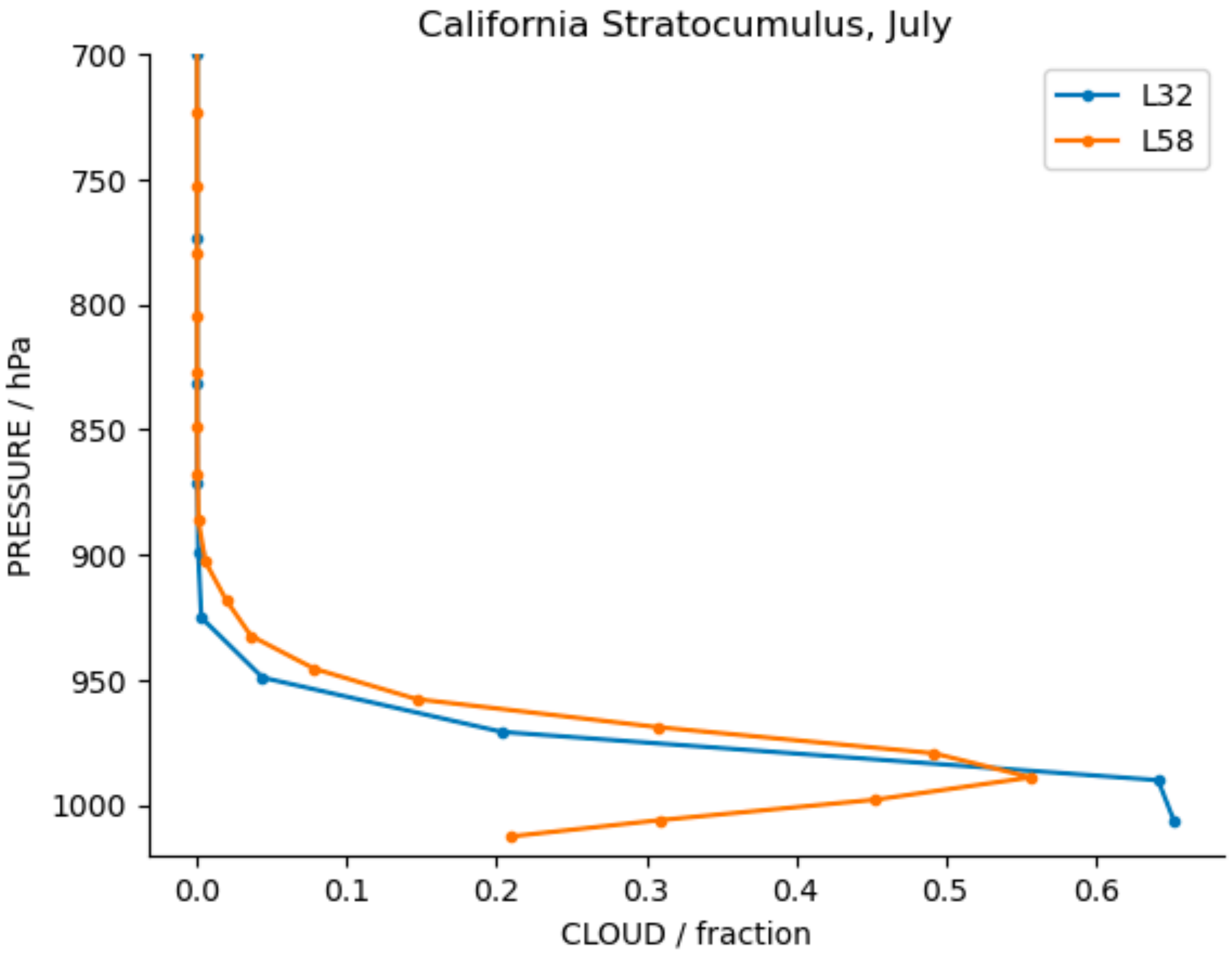




Still have challenges





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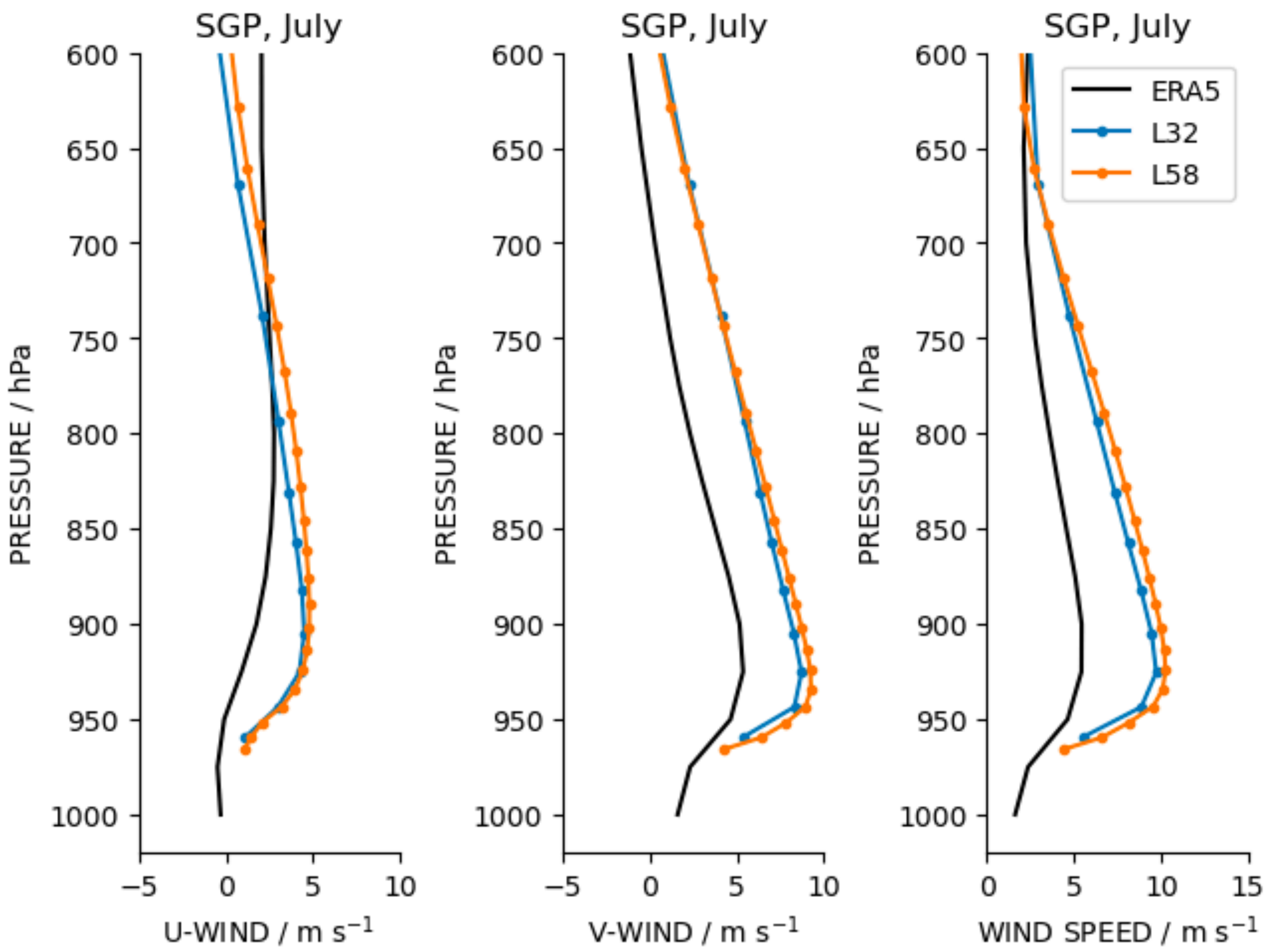

Moving to a vertical grid that has ~16 levels > 800 hPa (vs ~8 in L32)

Lowest level will be thinner, previously mid-point ~65m, current grid has mid-point ~20m

Expectations: better-resolved BL cloud layers (and subcloud layers), more diurnal variability, improved stable BLs

Potential impacts: radiative effects (b/c clouds), radiative+chemical effects (b/c aerosol), surface fluxes (b/c winds & stability)

Current results suggest substantial regional impacts on surface fluxes and winds (not all positive)

Analyses of the impacts of higher BL resolution are needed across the hierarchy of simulations (SCM, idealized, F-case, B-case)