Dynamics for El Niño-La Niña asymmetry constrain equatorial-Pacific warming pattern

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1. Abstract

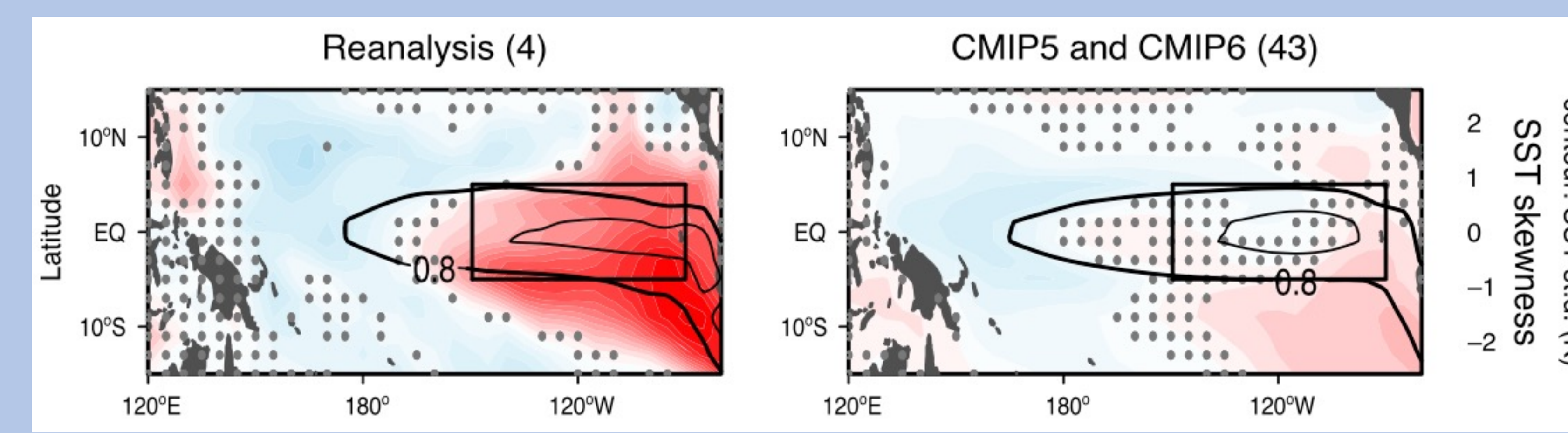
The El Niño-Southern Oscillation (ENSO) results from the instability of and also modulates the strength of the tropical-Pacific cold tongue. *While climate models reproduce observed ENSO amplitude relatively well, the majority still simulates its asymmetry between warm (El Niño) and cold (La Niña) phases very poorly*. The causes of this major deficiency and consequences thereof are so far not well understood.

Analysing both reanalyses and climate models, we here show that simulated ENSO asymmetry is largely proportional to subsurface *nonlinear dynamical heating (NDH)* along the equatorial Pacific thermocline. Most climate models suffer from too-weak NDH and too-weak linear dynamical ocean-atmosphere coupling. Nevertheless, a sizeable subset (about 1/3) having relatively realistic NDH shows that *El Niño-likeness of the equatorial-Pacific warming pattern is linearly related to ENSO amplitude change in response to greenhouse warming.*

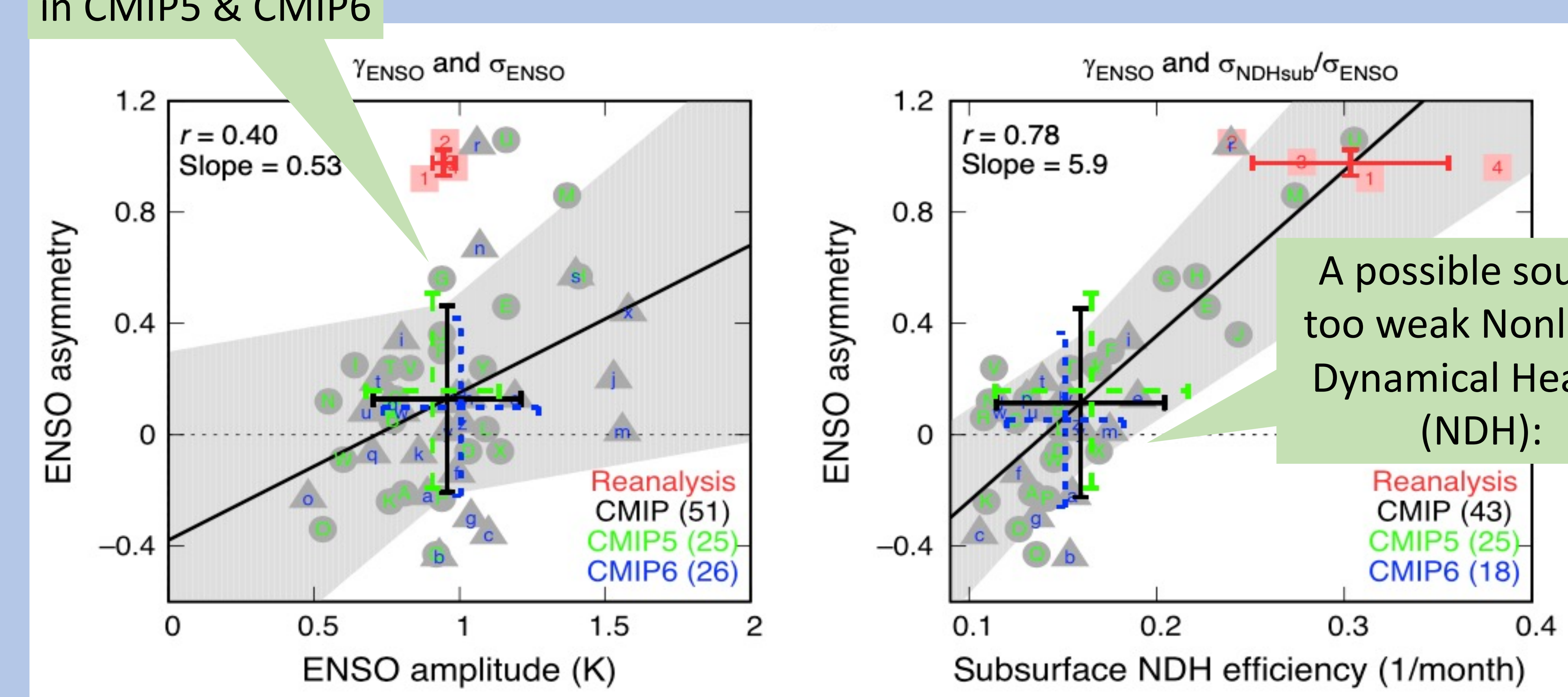
Therefore, better simulating the dynamics of ENSO asymmetry potentially reduces uncertainty in future projections.

Improving understanding of ENSO dynamics is critical to constrain the future warming pattern uncertainty!

2. Problem: too weak El Niño-La Niña asymmetry in CMIP models



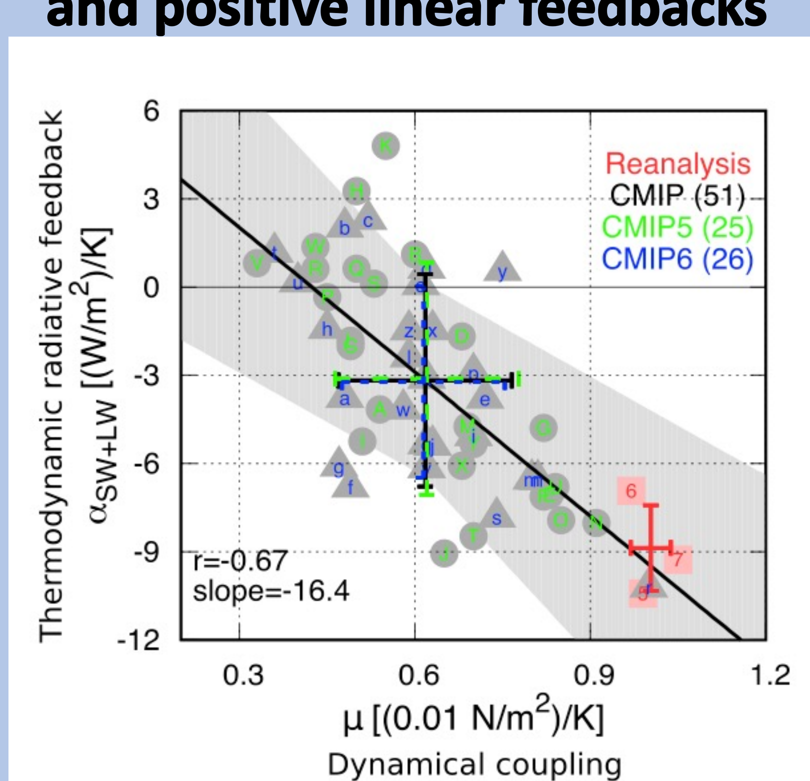
Poor asymmetry in CMIP5 & CMIP6



A possible source: too weak Nonlinear Dynamical Heating (NDH):

$$\frac{\partial T'}{\partial t} = \underbrace{-u'\frac{\partial \bar{T}}{\partial x} - v'\frac{\partial \bar{T}}{\partial y} - w'\frac{\partial \bar{T}}{\partial z} - \bar{u}\frac{\partial T'}{\partial x} - \bar{v}\frac{\partial T'}{\partial y} - \bar{w}\frac{\partial T'}{\partial z}}_{\text{Linear dynamical heating (LDH)}} \underbrace{-u'\frac{\partial T'}{\partial x} - v'\frac{\partial T'}{\partial y} - w'\frac{\partial T'}{\partial z}}_{\text{NDH}} + \underbrace{R'}_{\text{Residual}}$$

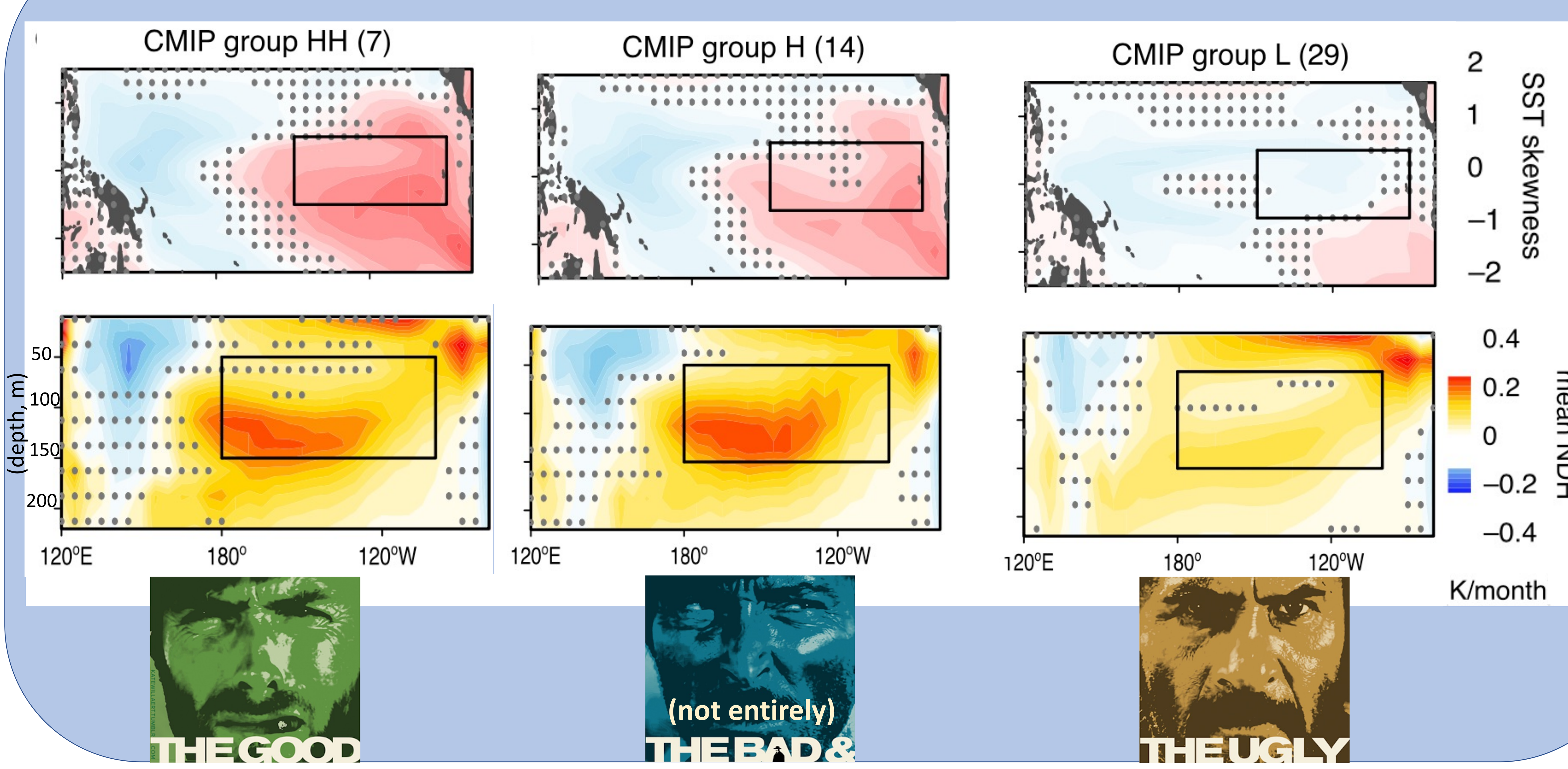
3. A key problem: Compensating errors in negative and positive linear feedbacks



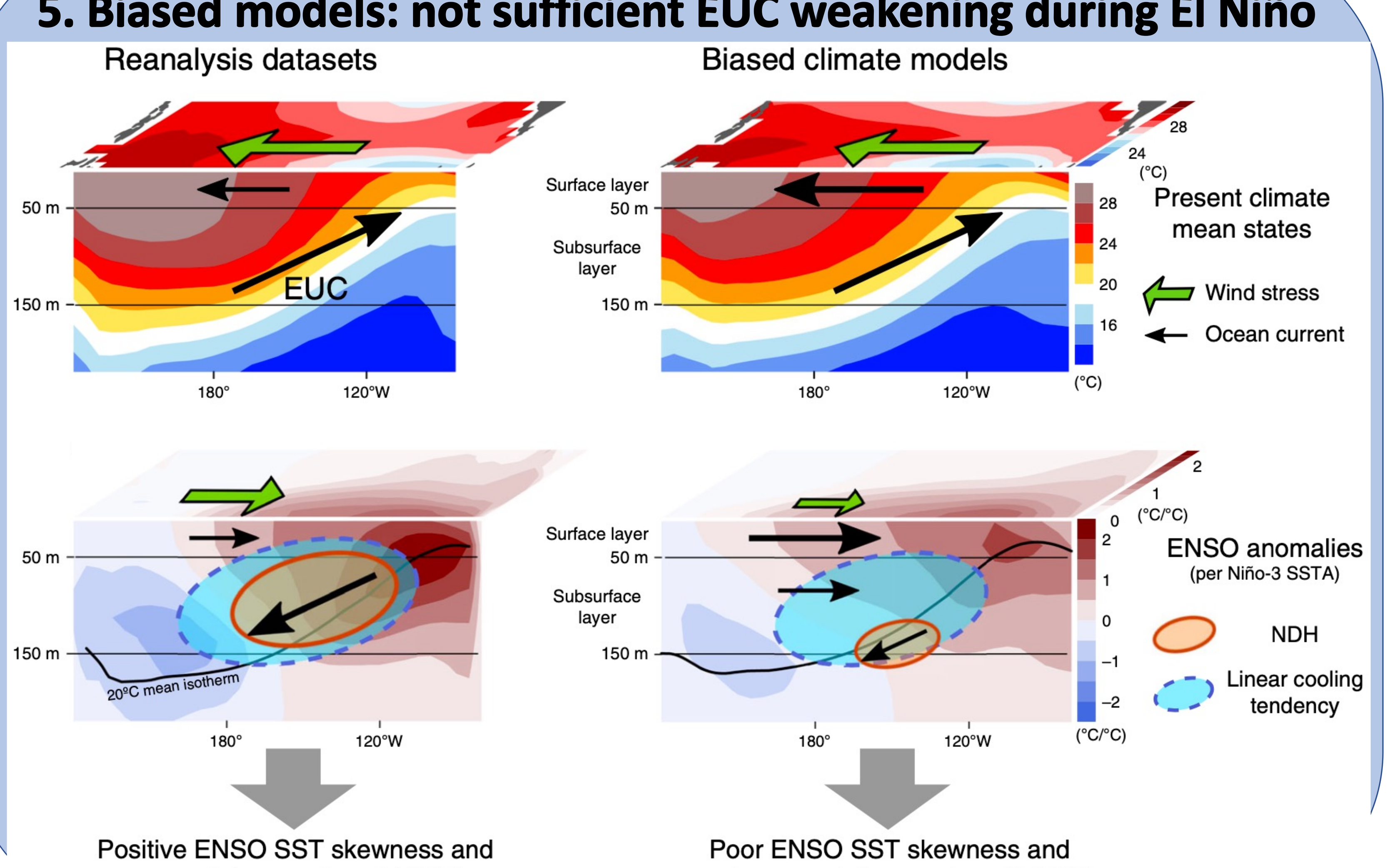
The positive SST-wind stress feedback and the negative shortwave feedback are both much too weak in most CMIP models! (e.g., Bayr et al. 2018 a,b)

Implication: Models can have the correct net linear ENSO growth rate *but* individual feedbacks – that are important for ENSO NDH – could be highly biased, resulting in biased ENSO skewness!

4. Selecting a subset of models in terms of their ability to simulate NDH realistically

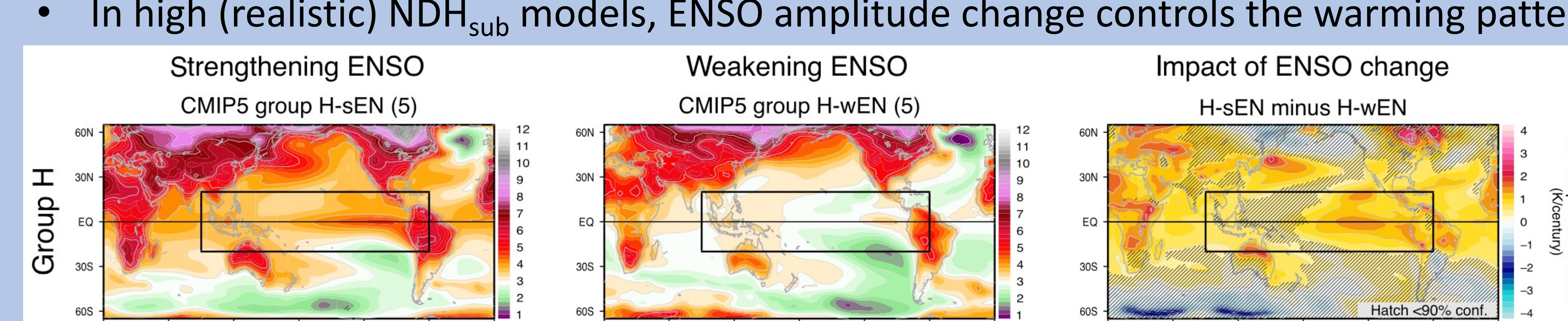


5. Biased models: not sufficient EUC weakening during El Niño

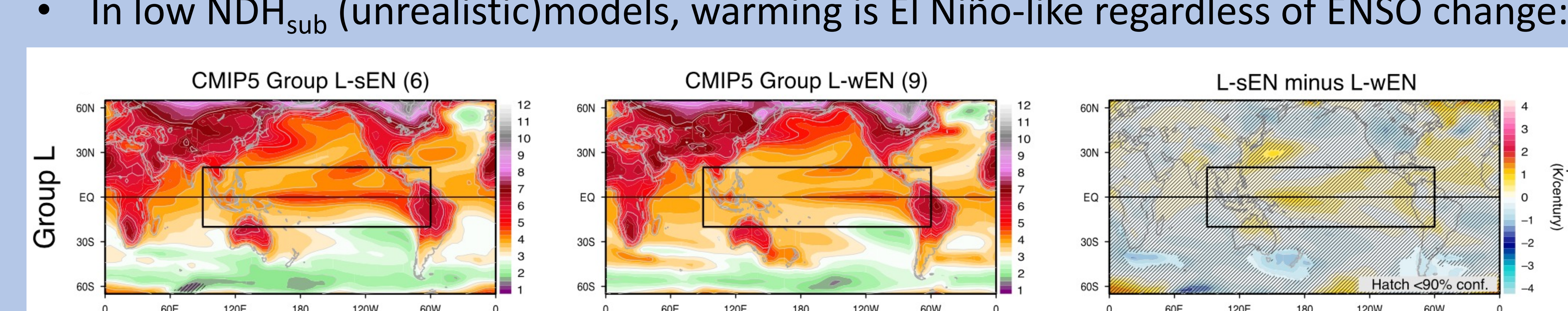


6. Summary

- NDH_{sub} variability constrains ENSO asymmetry in CMIP5/6
- In high (realistic) NDH_{sub} models, ENSO amplitude change controls the warming pattern:



- In low NDH_{sub} (unrealistic)models, warming is El Niño-like regardless of ENSO change:



- **ENSO amplitude change and hence the warming pattern are still uncertain!**

Reference: Hayashi, M., F.-F. Jin, and M. F. Stuecker (2020): Dynamics for El Niño-La Niña asymmetry constrain equatorial-Pacific warming pattern, *Nature Communications*