Cause of the intense tropics-wide tropospheric warming during El Niño events

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El Niño cloud radiative effect due to SST warming pattern

Changes in shortwave cloud radiative effect (SWCRE) are observed during El Niño, and generally ascribed to a change in atmospheric stability due to free tropospheric warming (see also Ceppi and Fueglistaler 2021, Fueglistaler 2019)

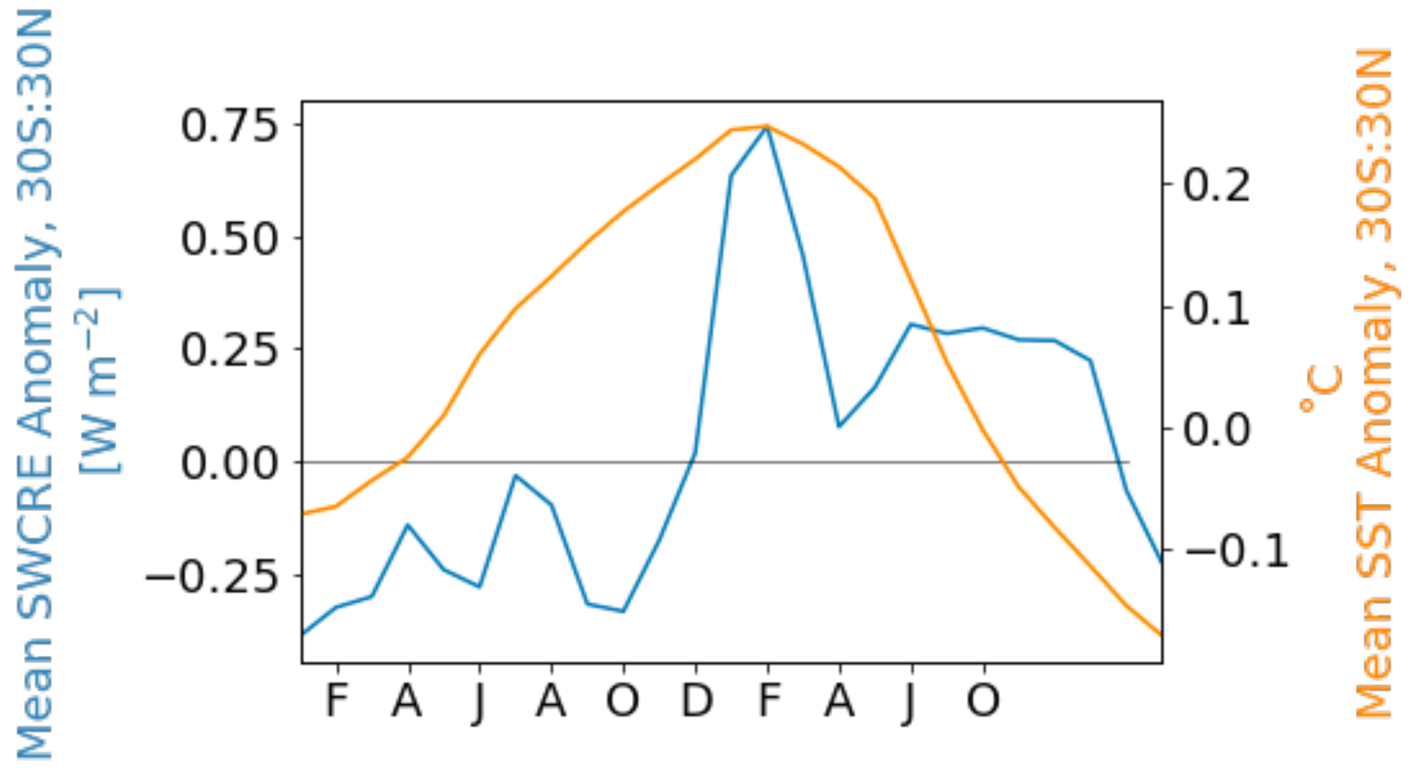

Figure 1. Composite El Nino event following the calendar year, from 39 events (100 years) in a coupled global climate model (GFDL-FLOR). cf. Figures 2, S2 of Ceppi and Fueglistaler 2021.

The surface is most strongly coupled to the free troposphere where convection occurs

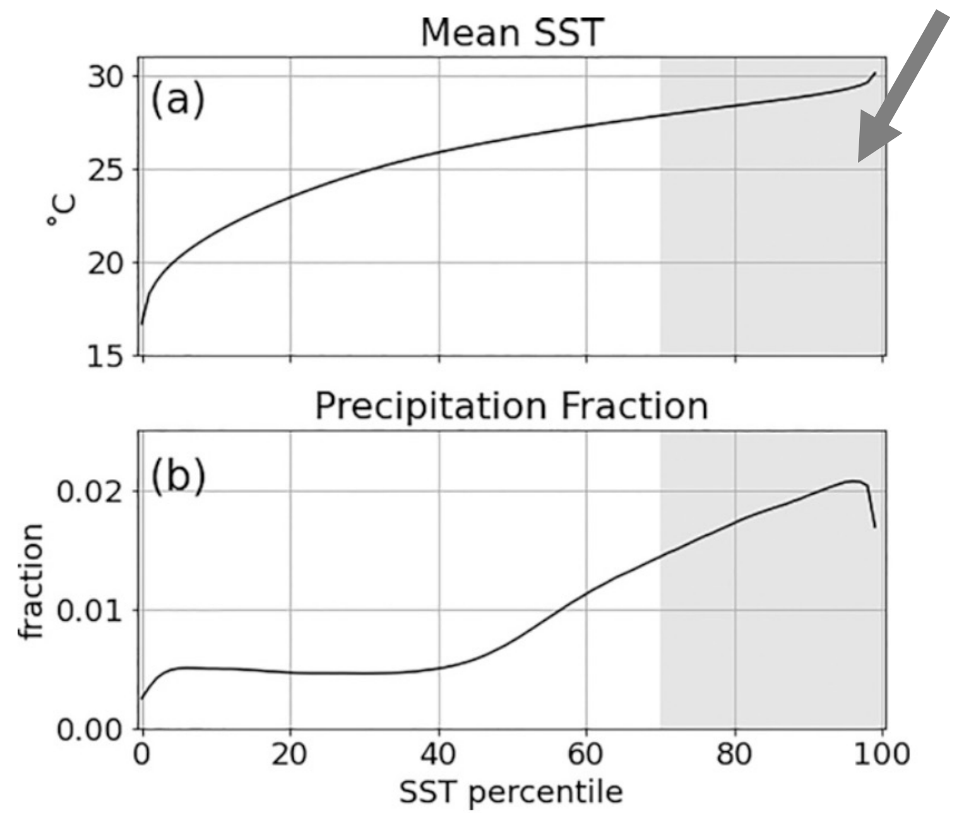

Figure 2. (top) Mean distribution of SST and (bottom) normalized precipitation distribution in equal-area SST percentiles. Data from ERA5. Shading highlights the top (i.e. warmest) 30 percentiles, where most rainfall occurs, approximating the deep convective regime.

The change in tropospheric stability is thus associated with the increase of already-high SST in the convective regime.

So, why does the surface warm at these high SSTs?

1. Who causes the SST increase, the atmosphere or ocean?

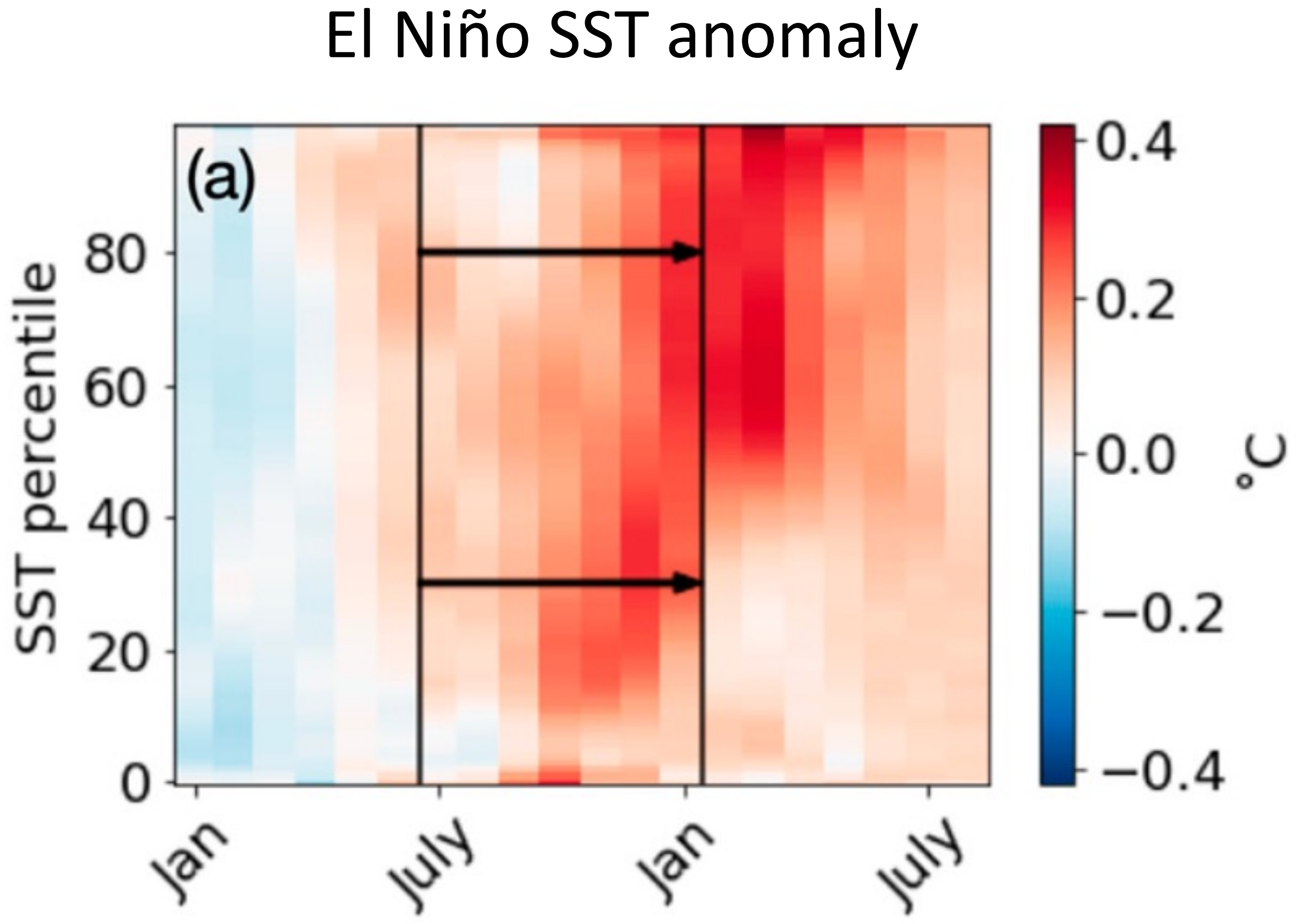

Figure 3. Sorted by SST in equal-area bins, as above. Data from ERA5.

Cold SSTs increase first, associated with the familiar weakened upwelling. Less well understood is the temperature increase at high SSTs which leads to the increased temperature in the free troposphere.

We find anomalous surface heat flux is responsible for this temperature increase, and specifically a decrease in evaporative cooling.

2. Why does evaporative cooling decrease at warm SSTs?

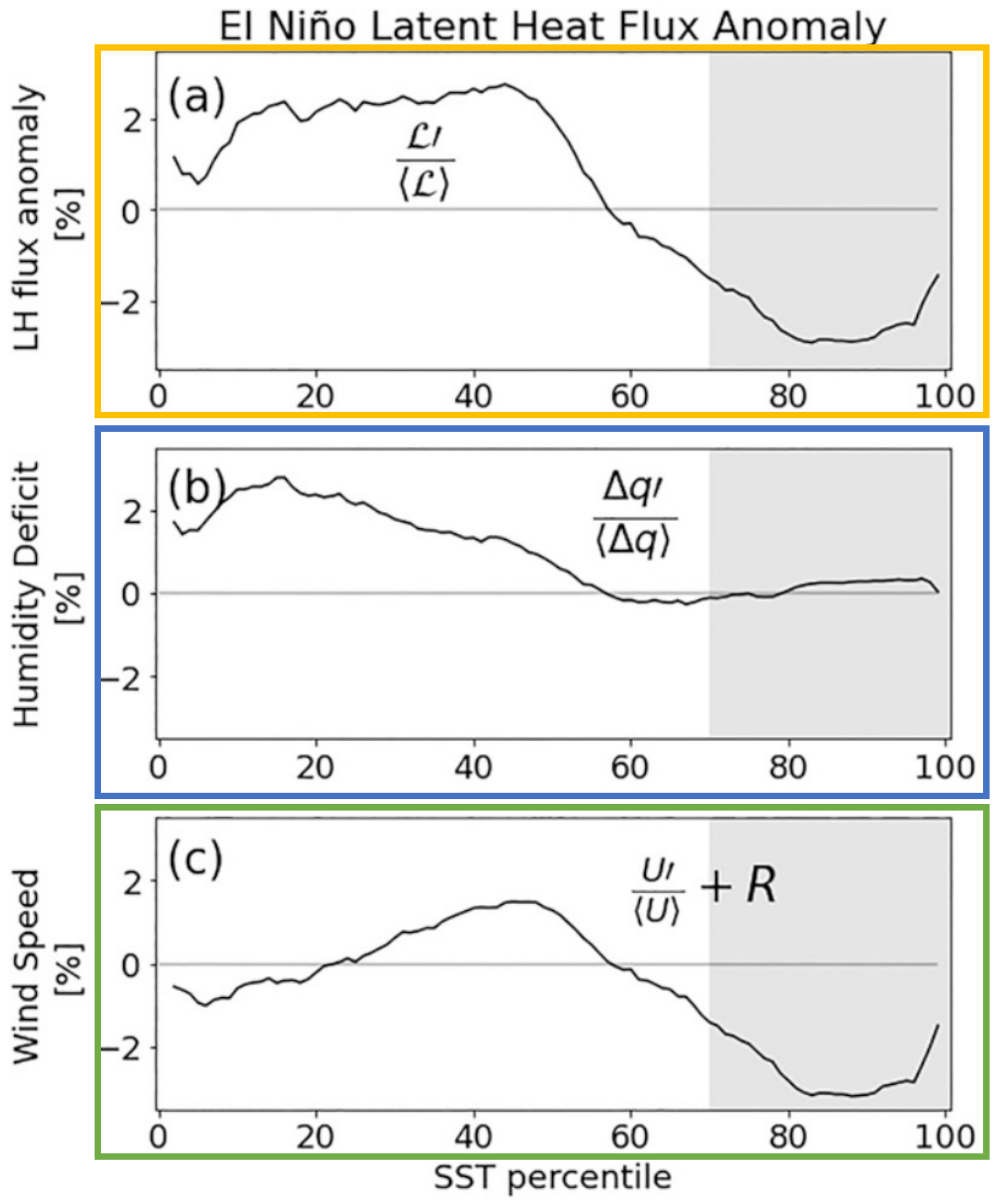

Figure 4. (a) The anomalous latent heat flux in SST percentiles during El Niño months in ERA5, as a fraction of the mean flux. This anomaly is the sum of (b) the anomalous humidity deficit at the sea surface and (c) anomalous surface wind speed [see equation], i.e. black lines in (b) and (c) add to that in (a).

Latent heat flux can be estimated with the humidity deficit and surface wind speed (Large and Yeager 2004, 2009)

$$\boxed{\mathcal{L}} = \rho C_{\mathrm{E}} \boxed{(q - q_{\mathrm{sat}}(\mathrm{SST}))} \boxed{|\Delta \vec{U}|}$$

Assuming density and C_E are invariant, we can ascribe changes in latent heat flux to variations in wind speed and humidity deficit

$$\boxed{\partial \ln(\mathcal{L})} = \boxed{\partial \ln(U)} + \boxed{\partial \ln(\Delta q)} + R,$$

We find a weakening of surface winds in the convective regime is responsible for limiting evaporative cooling, increasing SSTs.

This implies the free tropospheric warming is a consequence of the changes in circulation (not the other way around!)

Asymmetric cooling in the boundary layer in the non-convective regime (coupled to the colder tropical SSTs) and the free troposphere (coupled to the warmest tropical SSTs, which are warmed by the decreased wind speed) changes the properties of low (non-convective) clouds during the mature and decaying phase of El Niño: the El Niño cloud radiative effect.

A decrease in wind speed, associated with rearrangement of the large-scale circulation, damps evaporation and causes warming in the convective regime, leading to the El Niño cloud radiative effect