Circulation and cloud responses to patterned SST warming

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1. How does circulation change under contrasting SST warming patterns?

- Recent work has shown the importance of the geographic location of SST warming on cloud feedbacks and thus climate sensitivity estimates [1-4].
- Climatological circulation is key to the mechanism of the 'pattern effect': **but how does atmospheric circulation itself respond to patterned warming? And how is this linked to the cloud response?**

Mechanism

- **SST warming in convective regions** → Warm, moist air lofted to free-troposphere → Increased stability in subsiding regions → Negative low cloud feedback
- **SST warming in subsiding regions** → Warming 'trapped' by temperature inversion; No remote effects → Reduced stability in subsiding regions → Positive low cloud feedback

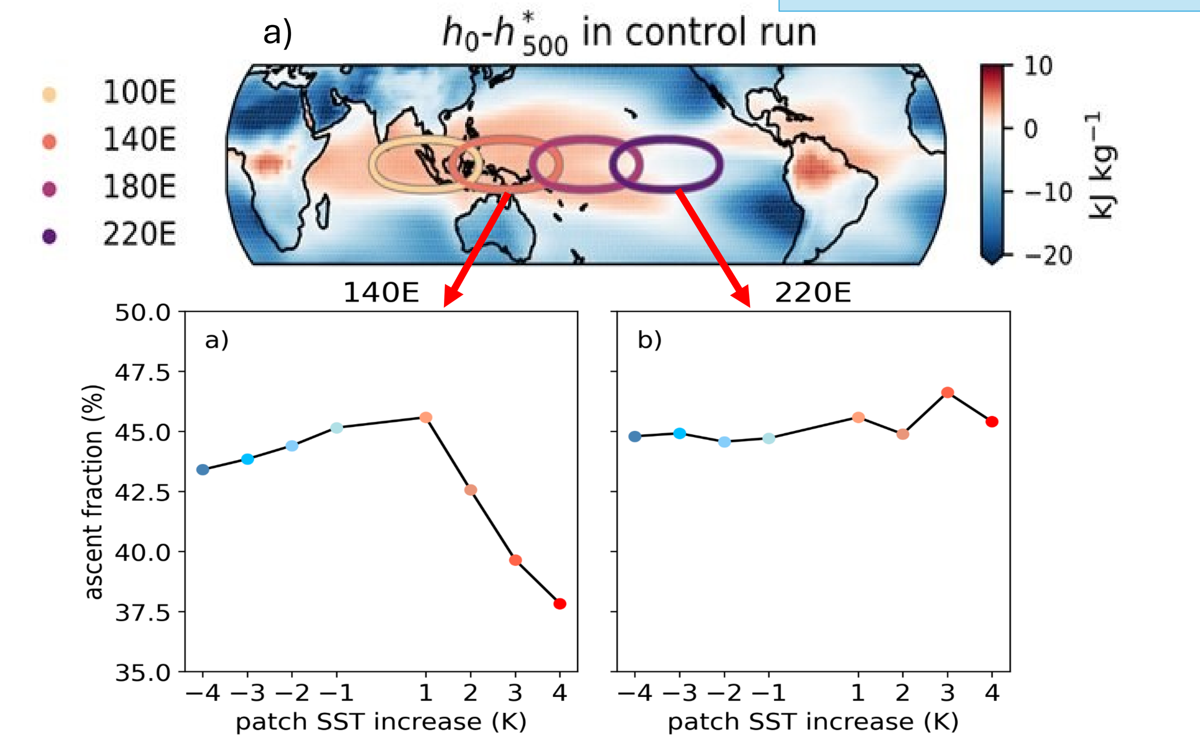


Figure 1: location of patches (a, from [4]), bulk circulation response to warming at 140E (b) and 220E (c)

Simulations:

- Atmosphere-only ICON simulations from [4]
- Control simulation and perturbed SST 'patch' simulations:
  - 4 patches (Fig. 1a)
  - -4K to 4K, 1K increments
- Bulk circulation metrics show contrasting circulation responses (Fig. 1b, c)
- Focus on ascent fraction: proportion of domain ascending at 500hPa

What drives differing responses? Turn to a moist static energy framework to interpret

2. Estimating ascent fraction with a moist static energy (MSE) framework

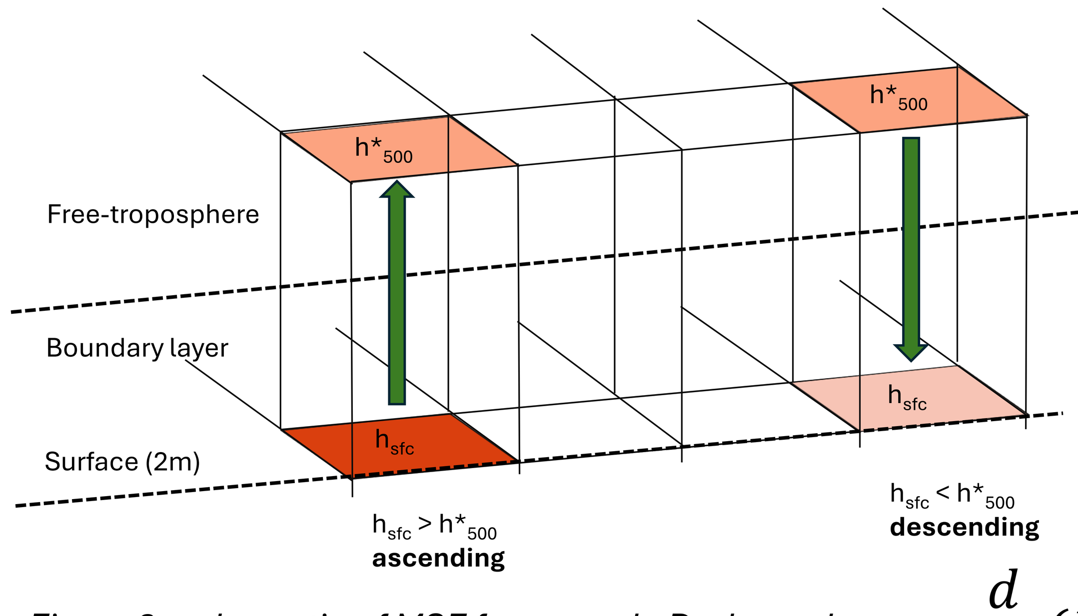


Figure 2: schematic of MSE framework. Darker colours indicate greater MSE, arrows indicate ascent/descent

Moist static energy: $h = c_pT + L_vq + gz$

T: temperature
q: specific humidity
z: height

1. What proportion of gridboxes have a sufficiently high surface MSE (h_{sfc}) to overcome the saturation MSE in the free troposphere (h^*_{500})? **Overestimates ascent fraction (Fig. 3a)**

2. Taking the entrainment of dry air into account, using the framework of [5]:

$$\frac{d}{dx}(h^*) = -\varepsilon\, L_v(q^* - q) = \frac{\hat{\varepsilon}}{z} L_v(q^* - q)$$

Integrate from LCL to 500hPa to obtain h^{*e}

3. Adjust index per gridpoint (i,j) with MSE lost due to entrainment $[h^{*e}]_{i,j}$. Ascent fraction estimate is proportion of gridpoints where $[\Phi^e]_{i,j}$ is positive: **Optimise entrainment parameter ($\hat{\varepsilon}$) to obtain an improved estimate of ascent fraction (Fig. 3b)**

$$[\Phi^e]_{i,j} = [h_{sfc}]_{i,j} - \hat{\varepsilon}[h^{*e}]_{i,j} - [h^*_{500}]_{i,j}$$

Dashed line: Index = 0, Blue = ascending

Solid line: vertical velocity at 500hPa = 0

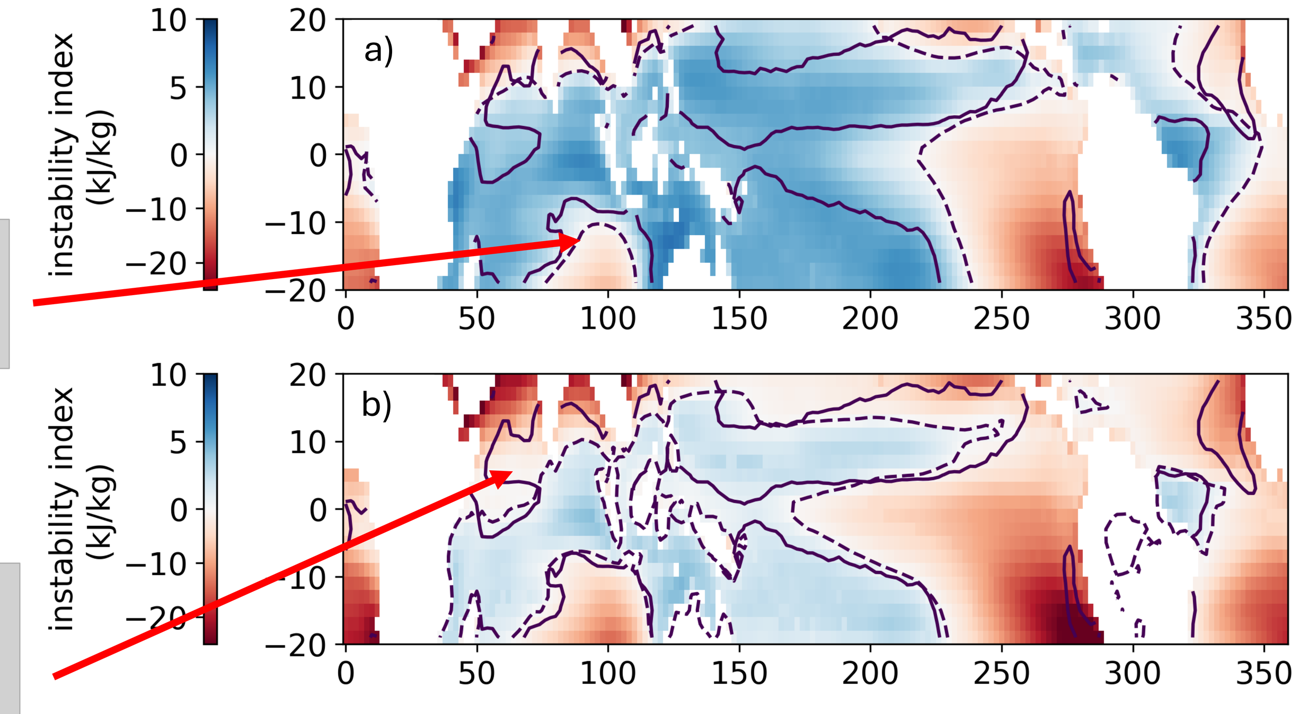


Figure 3: estimated ascent fraction (colour scale) for original index (a) and entrainment-adjusted index (b) for the sample month of January.

3. Using instability space to interpret contrasting responses to patch warming

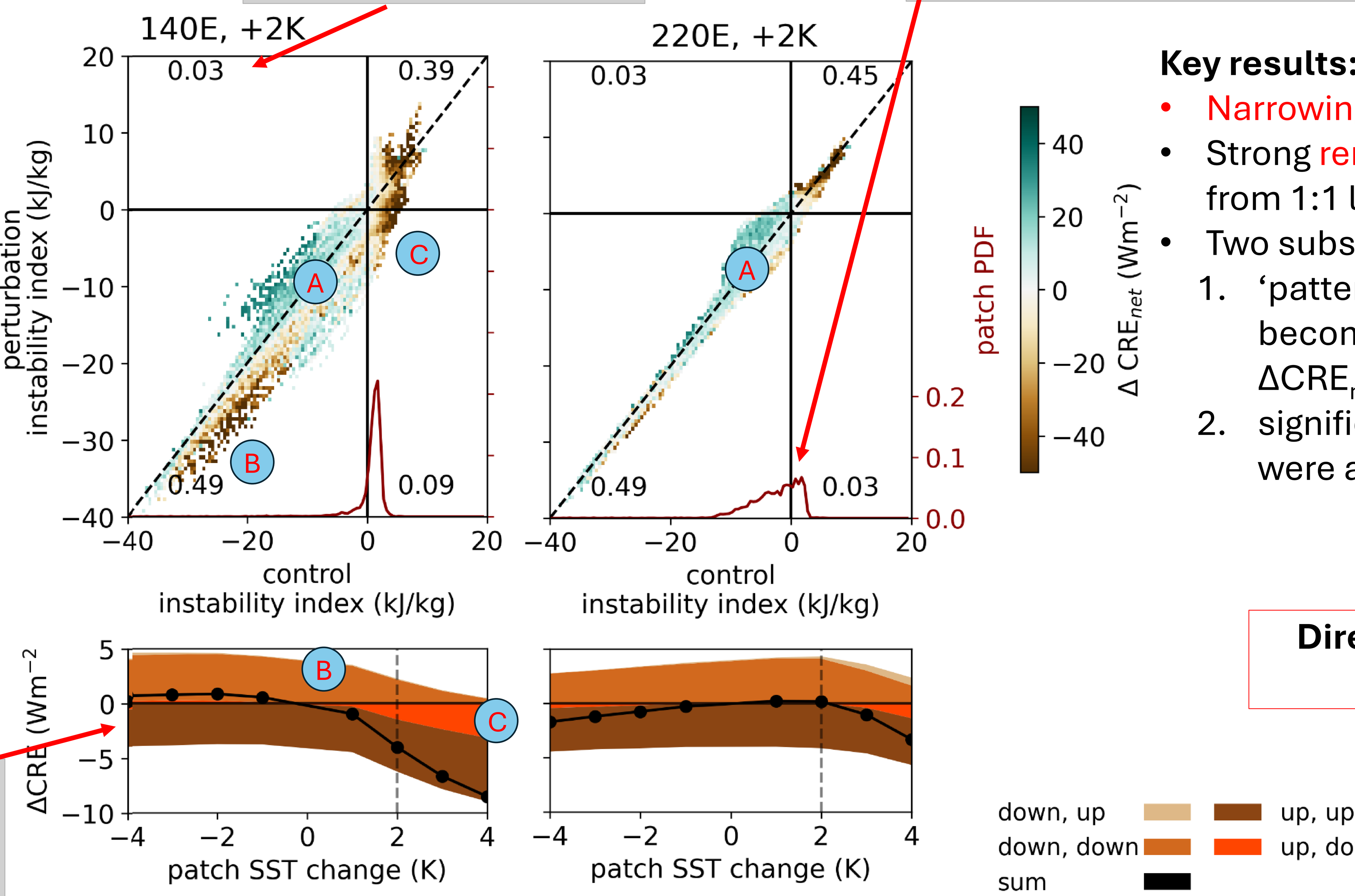
What on earth is this?!

- Discretize gridpoints
  - by control simulation instability (x-axis)
  - by perturbed instability (y-axis)
- **1:1 line** (dotted):
  - below = gridpoints more stable with warming
  - above = gridpoints less stable with warming
- **Colour scale :** ΔCRE_{net} of gridpoints in that discretized 'bin'
- **Bottom–left quadrant : 'down, down'** subsiding in both control and perturbation
- **Top-right quadrant: 'up, up'** ascending in both control and perturbation
- **Top-left quadrant: 'down, up'** move from subsiding to ascending with warming
- **Bottom-right quadrant: 'up, down'** move from ascending to subsiding with warming

Integrating over each quadrant gives the contribution to the total change in ΔCRE_{net}, which changes with warming/cooling

% points in quadrant

Instability probability density function of the patch – are warmed/cooled points ascending or descending?



Key results:

- Narrowing ascent with warming for 140E (Fig. 1a)
- Strong remote effects for 140E, not 220E: spread from 1:1 line in subsiding regions (A)
- Two substantial contributors to ΔCRE_{net} for 140E:
  1. 'pattern effect' clear: subsidence regions becoming more stable and with negative ΔCRE_{net} (B)
  2. significant contribution from regions which were ascending and now descending (C)

Direct link between ascent fraction change and ΔCRE_{net}

Apologies that this poster is not being presented in-person. For a narrated presentation, please see supplementary material:

Please email any questions or comments!

References:

[1] Andrews & Webb (2018) *J. Clim.*, **31**(2), https://doi.org/10.1175/JCLI-D-17-0087.1

[2] Dong et al. (2019) *J. Clim*, **32**(17), https://doi.org/10.1175/JCLI-D-18-0843.1

[3] Rugenstein et al., (2023) , *EOS*, **104**, https://doi.org/10.1029/2023EO23041

[4] Williams et al., (2023), *Geophys, Res. Lett.*, **50**, https://doi.org/10.1029/2022GL101499

[5] Singh & O'Gorman (2013), *Geophys. Res. Lett.*, **40**(16), https://doi.org/10.1002/grl.50796