Critical Impact of Land-Atmosphere Feedbacks on Midlatitude Wintertime Surface Temperature Variance

30th Annual CESM Workshop

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Collaborators:

Bowen Ge[1]

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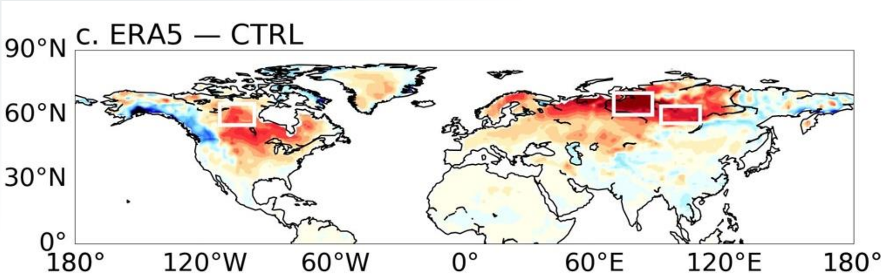
Model error in T_{2m} variance:



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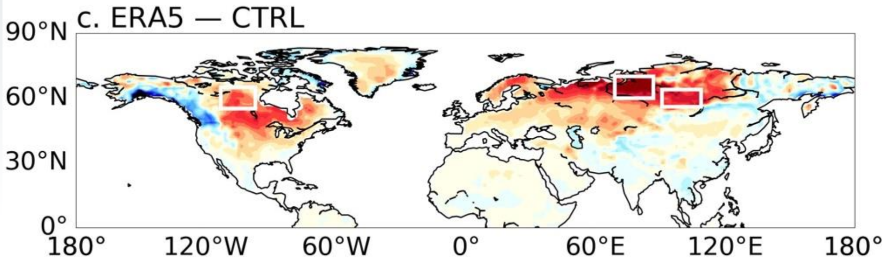

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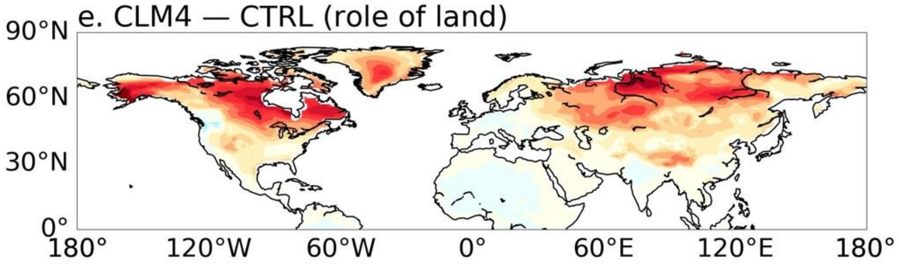

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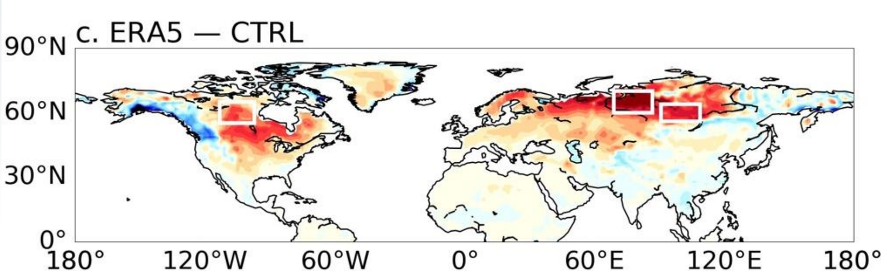

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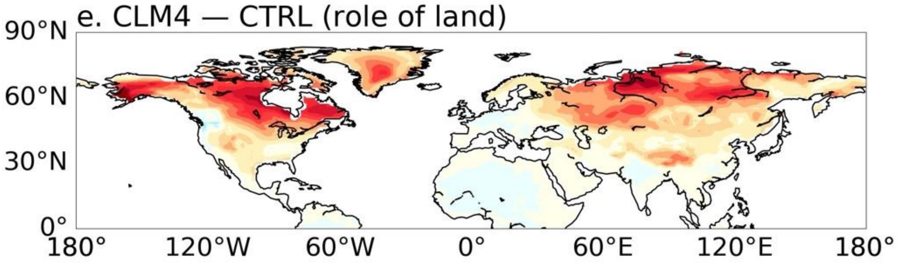
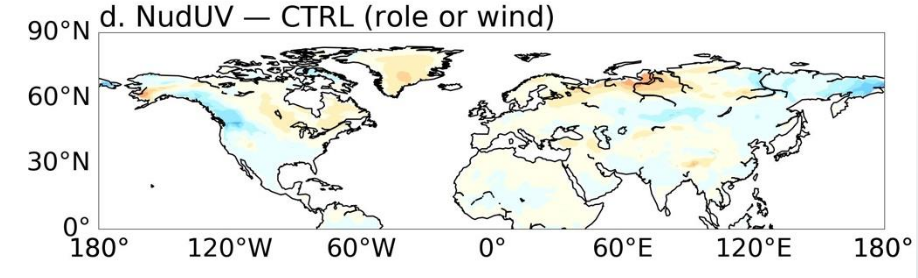


Atmospheric circulations:



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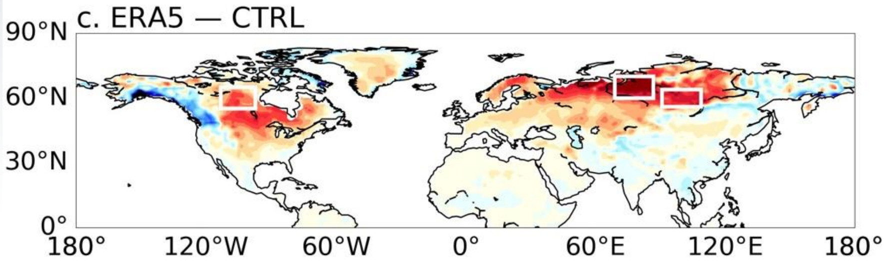

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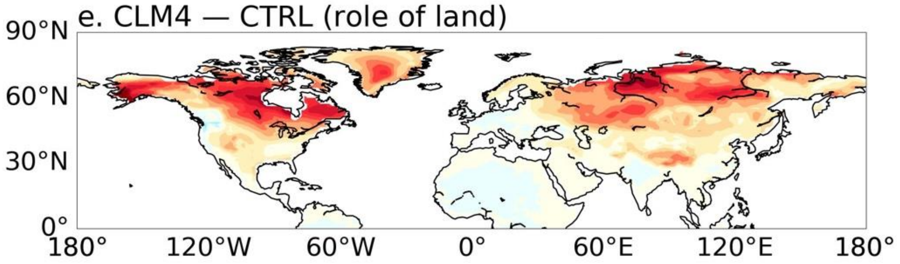

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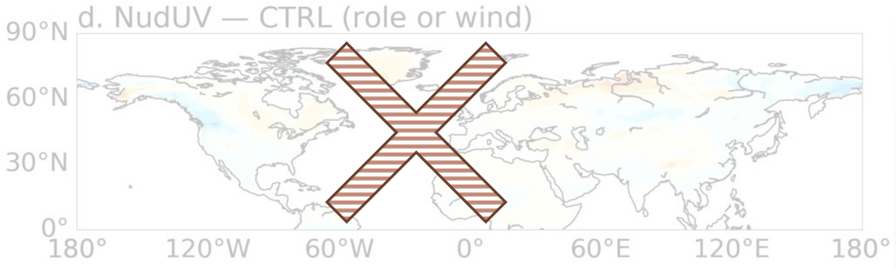

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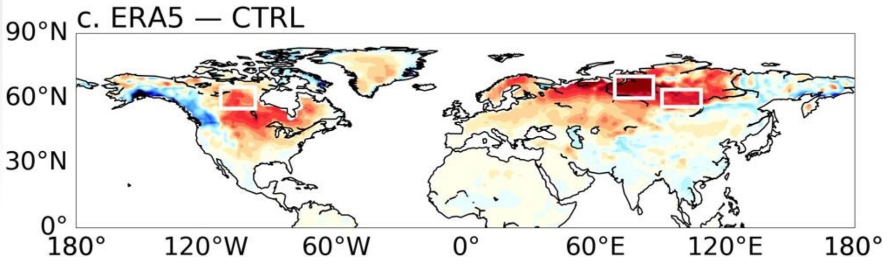

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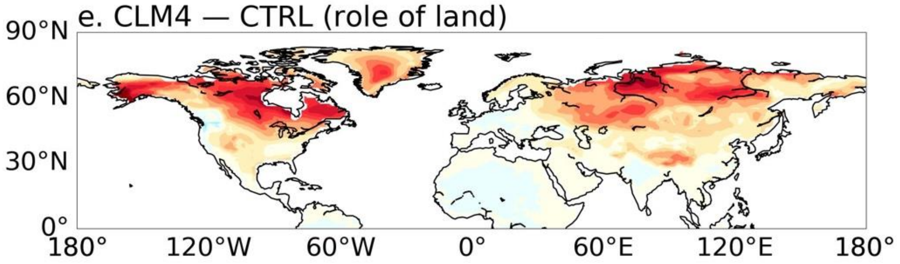

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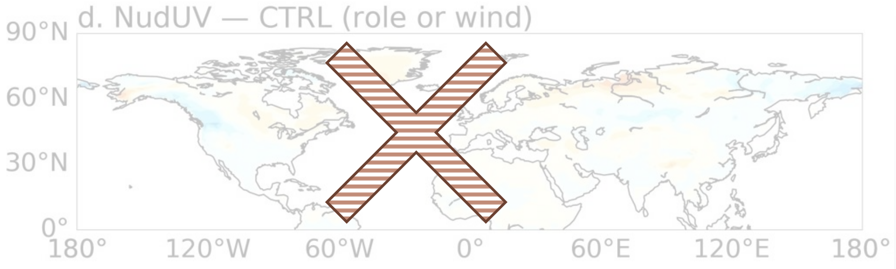

$$\overline{T'^2} \propto \frac{-1}{\alpha}\left(\partial_y \bar{T}\right)^2$$

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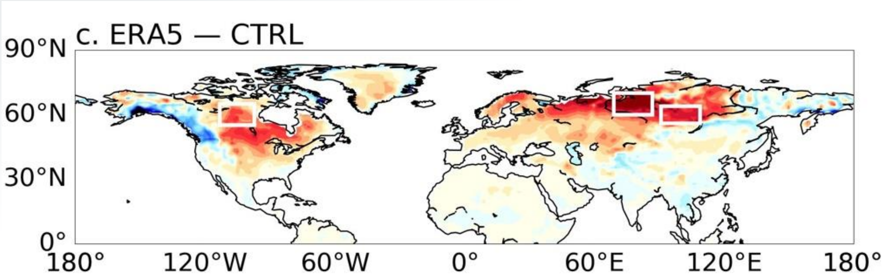

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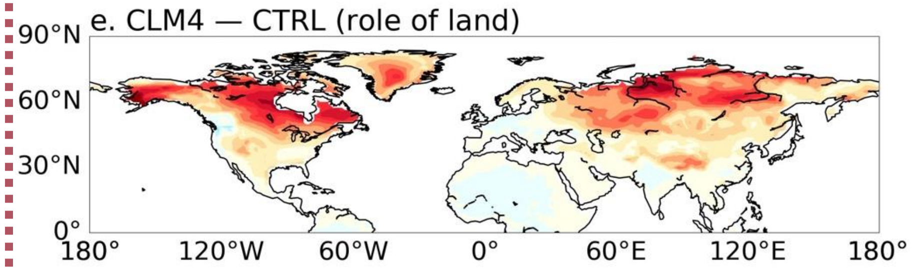

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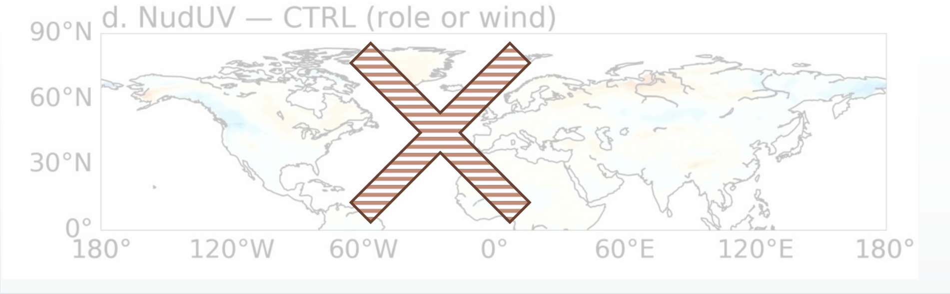

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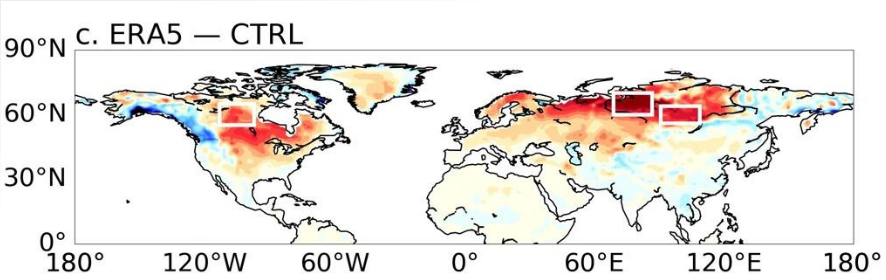

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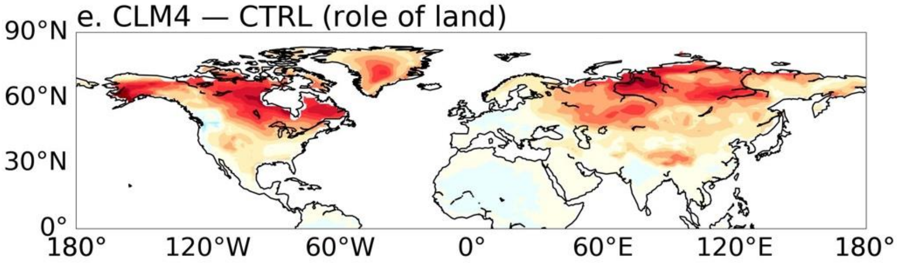

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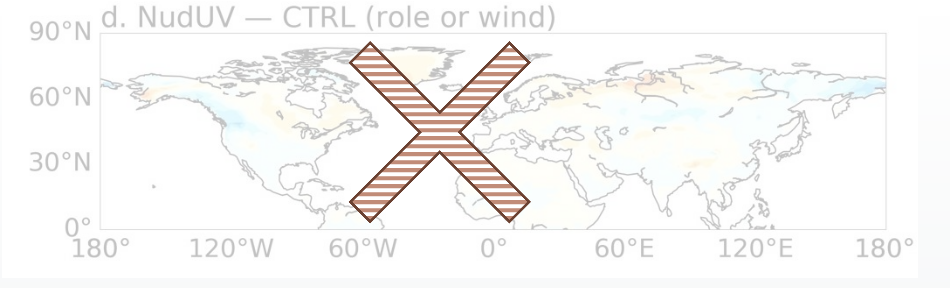
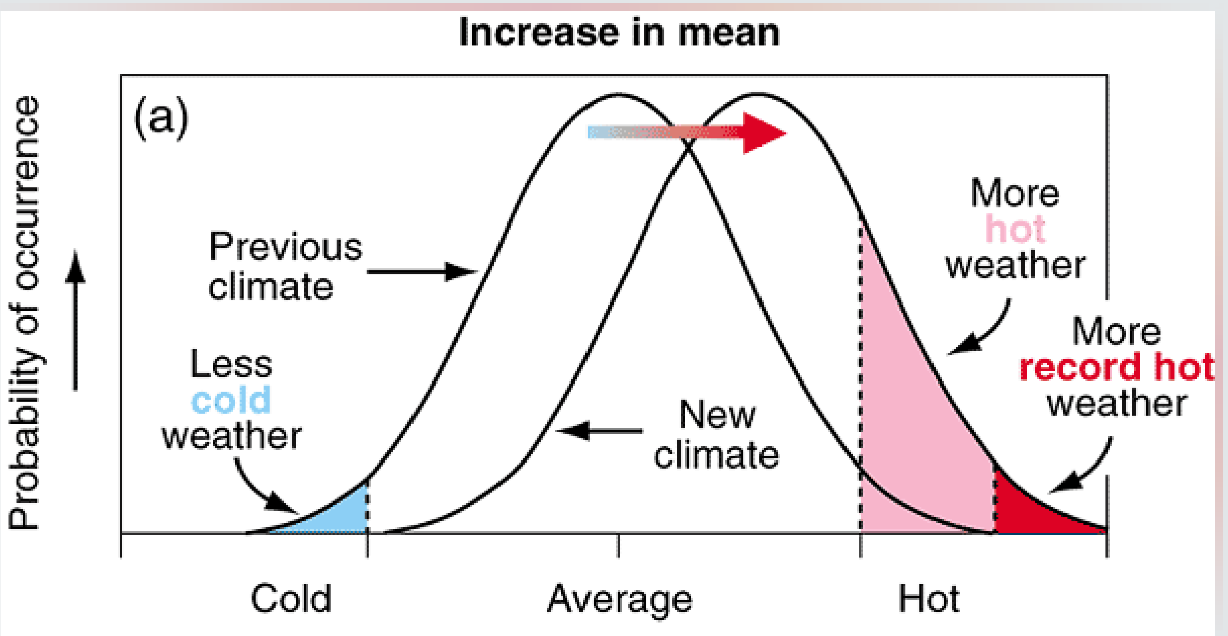


$$\overline{T'^2} \propto \frac{-1}{\boxed{\alpha}} \left(\partial_y \bar{T}\right)^2$$

$$\frac{-1}{\alpha} \propto \boxed{L'^2}$$

Mixing length

*Changes in **temperature variance** influence the **frequency** of future **extreme events** under **global warming***



(IPCC 2001)

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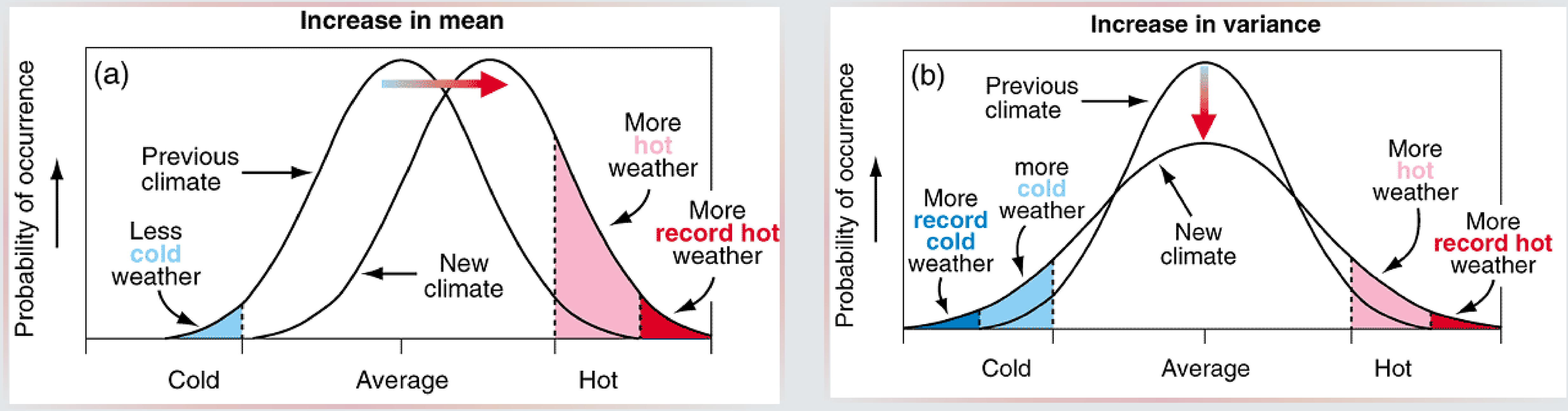

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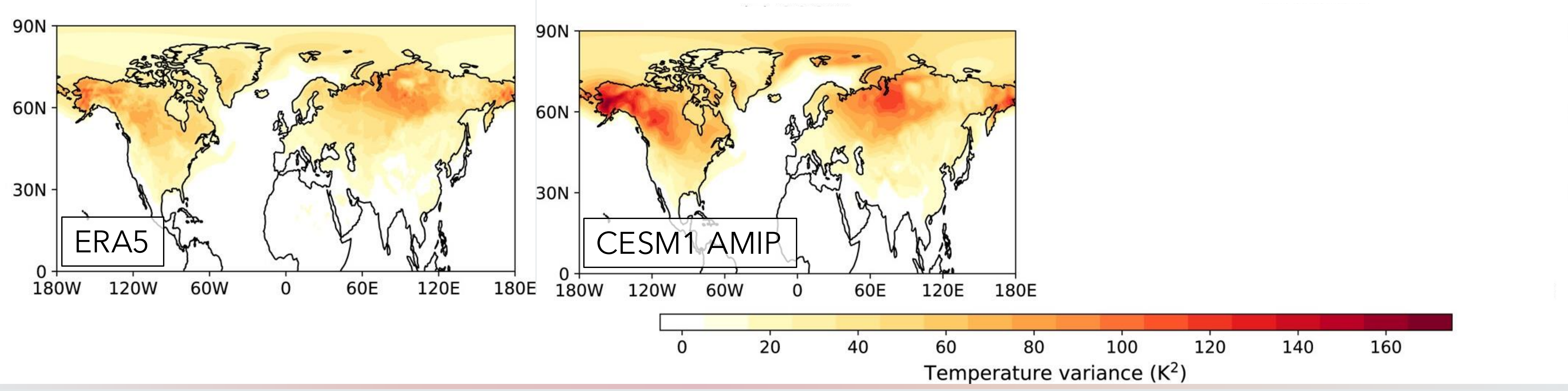
Land processes** in climate models contribute to **biases** in simulating **wintertime land T_{2m} variance



(Simpson et al., 2022)

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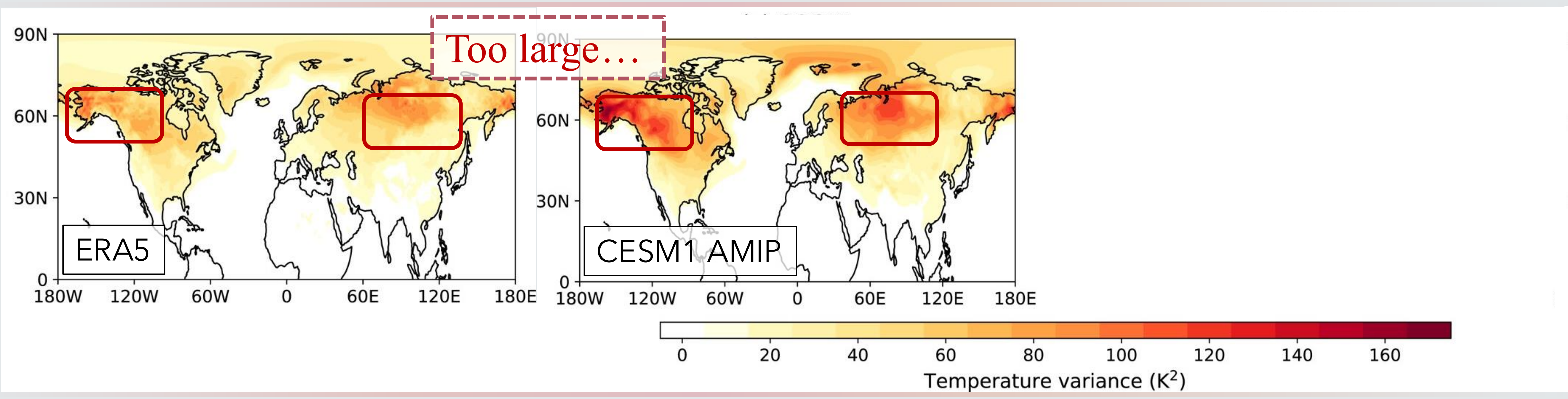

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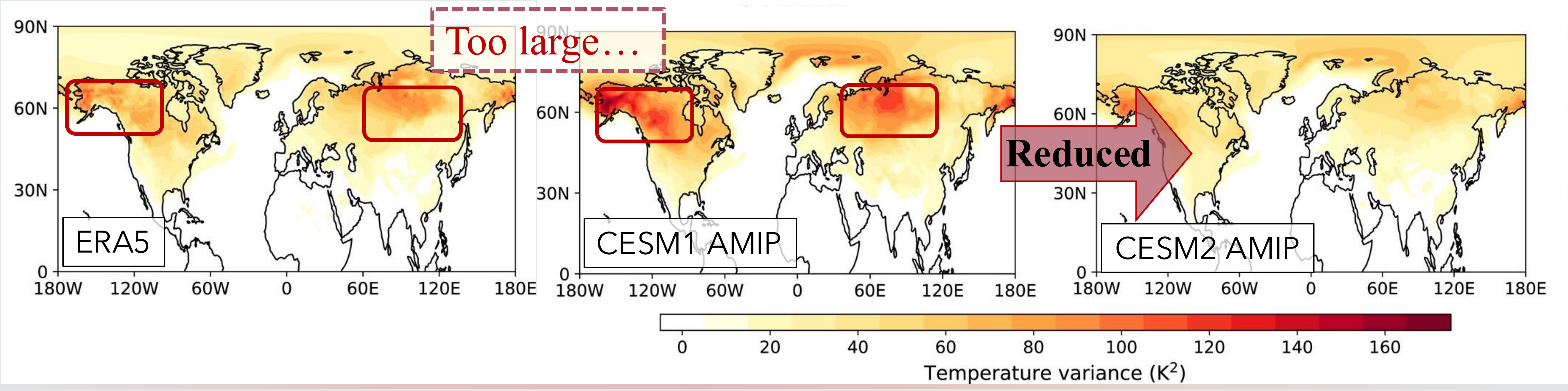

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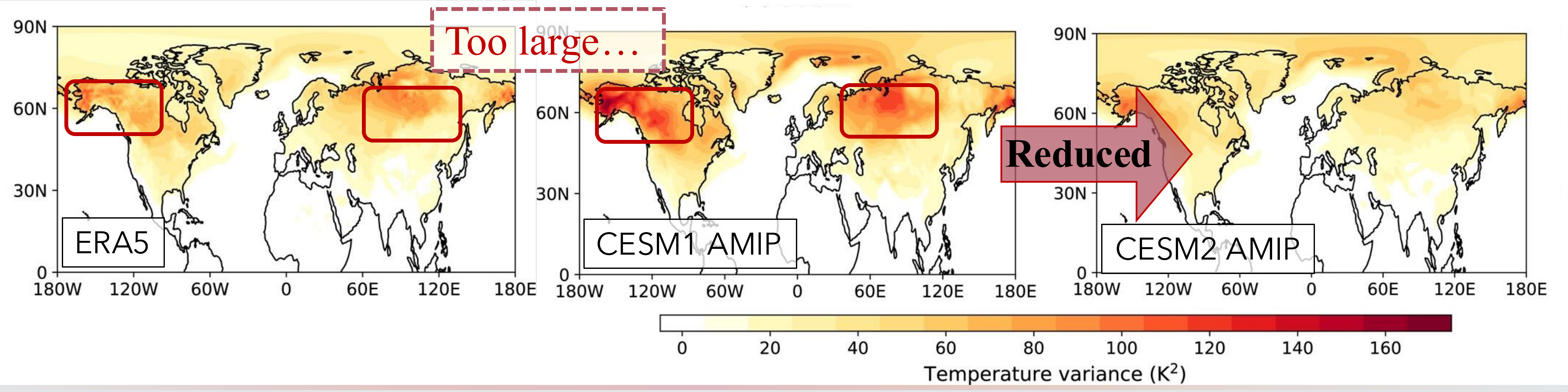
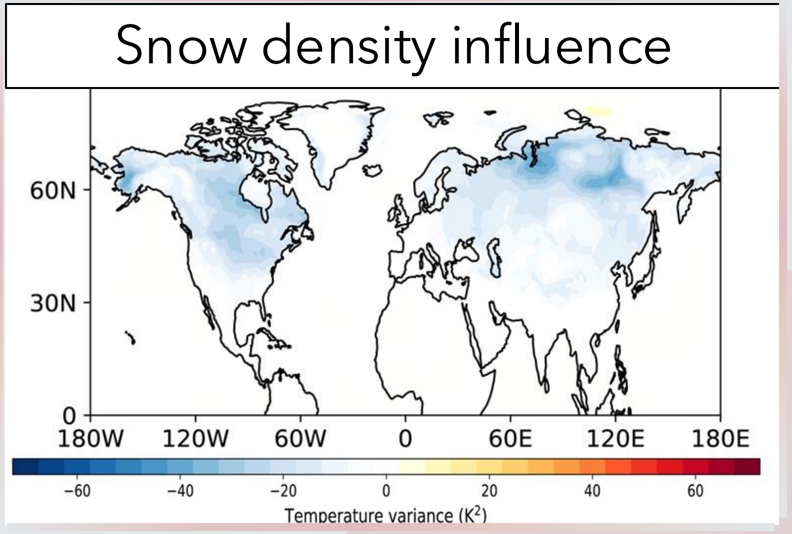


Higer snow density in CESM2 land model

Higher surface energy flux sensitivity to T_{2m}

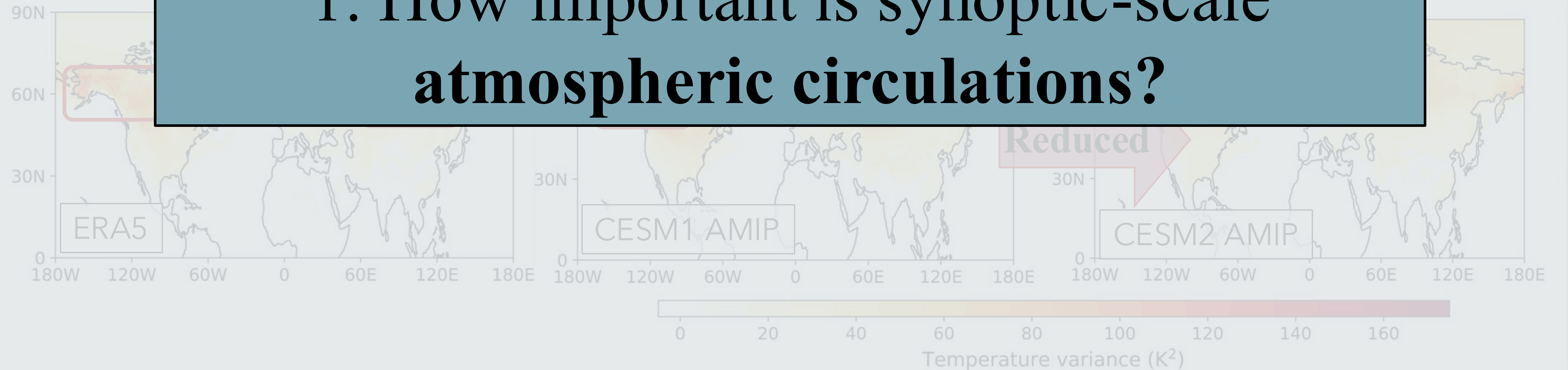
Larger damping to T_{2m} anomaly



(Simpson et al., 2022)

Questions to be answered:

1. How important is synoptic-scale atmospheric circulations?



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(Simpson et al., 2022)

Questions to be answered:

1. How important is synoptic-scale **atmospheric circulations?**

2. What is the role of **land-atmosphere feedback** in simulating T_{2m} variance?

Higer snow density in CESM2 land model

Higher surface energy flux sensitivity to T_{2m}

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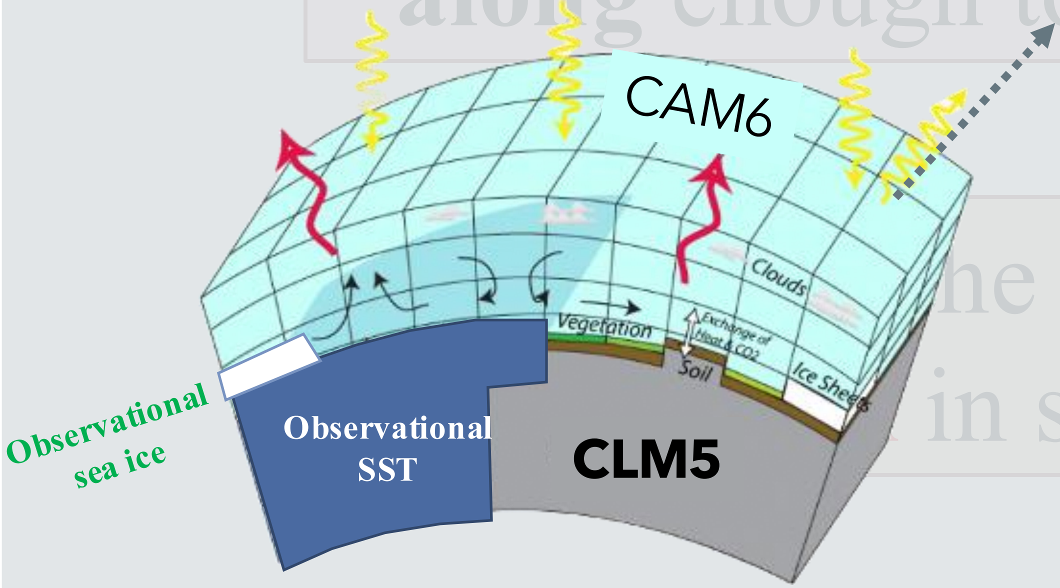
Snow density influence

(Simpson et al., 2022)

Methods to address these questions:

1. How important is synoptic-scale **atmospheric circulations?**

2. Is **meridional temperature gradient along** enough to shape the T_{2m} **variance?**



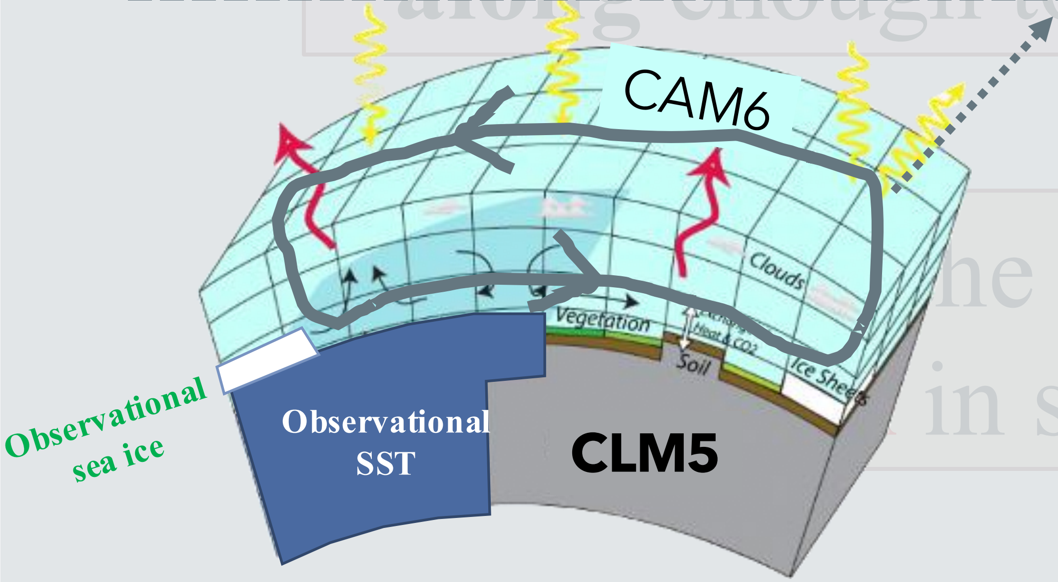
...he role of **land-atmosphere** ... in simulating T_{2m} variance?

Methods to address these questions:

1. How important is synoptic-scale **atmospheric circulations?**

Nudging winds towards ERA5 in CESM2 (FHIST compset)

Winds are nudged globally to ERA5 every six hours from bottom to top of the atmosphere



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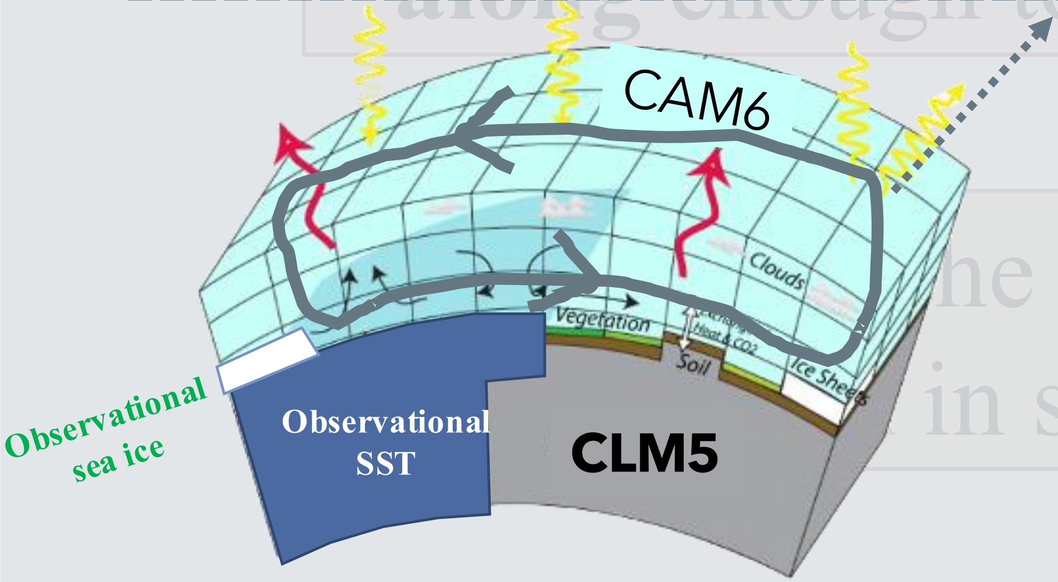


Goal: determine the importance of circulation

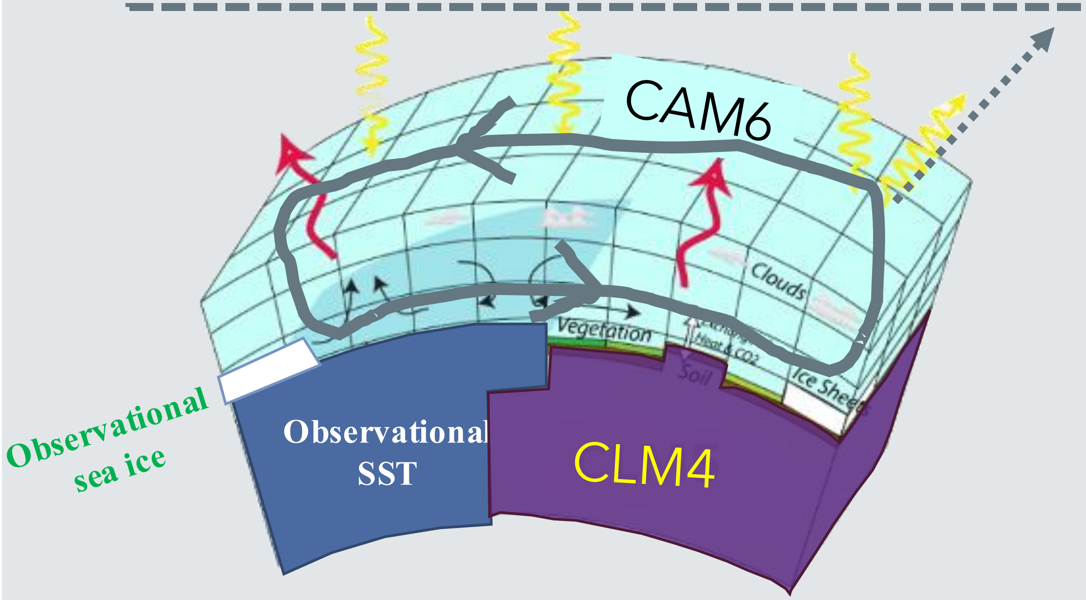
Control:	Wind Nudging:
CTRL	NudUV

Methods to address these questions:

2. What is the role of **land-atmosphere feedback** in simulating T_{2m} variance?

Nudging winds in CESM2 and switch **CLM5** to **CLM4**

Winds are nudged globally to ERA5 every six hours from bottom to top of the atmosphere



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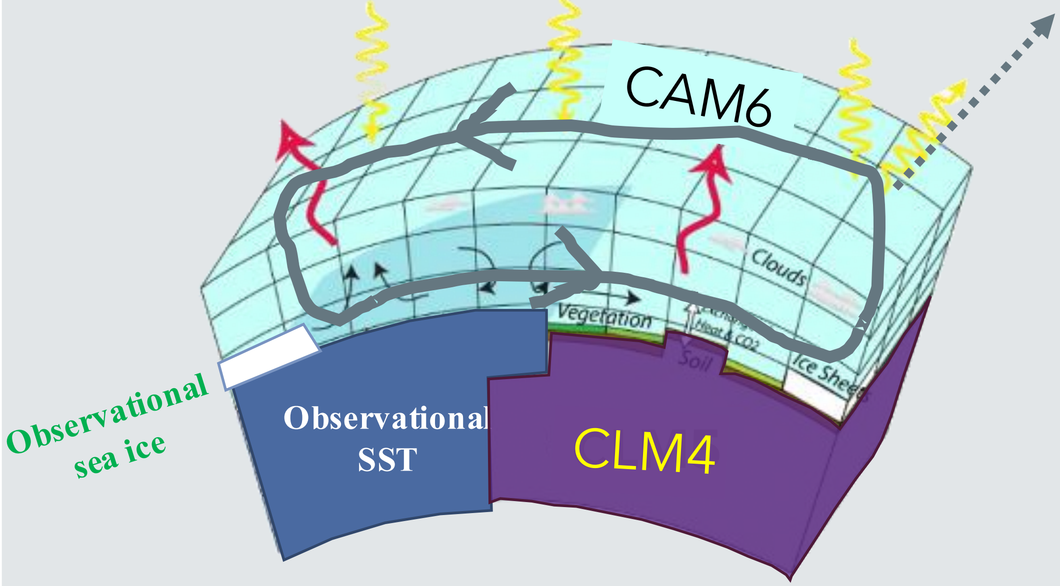

Goal: explore impact of different land-atmospheric feedback on T_{2m} variance

Control:	Wind Nudging:
CTRL	NudUV
Land:	**Wind Nudging + Land:**
CLM4	NudUV/CLM4

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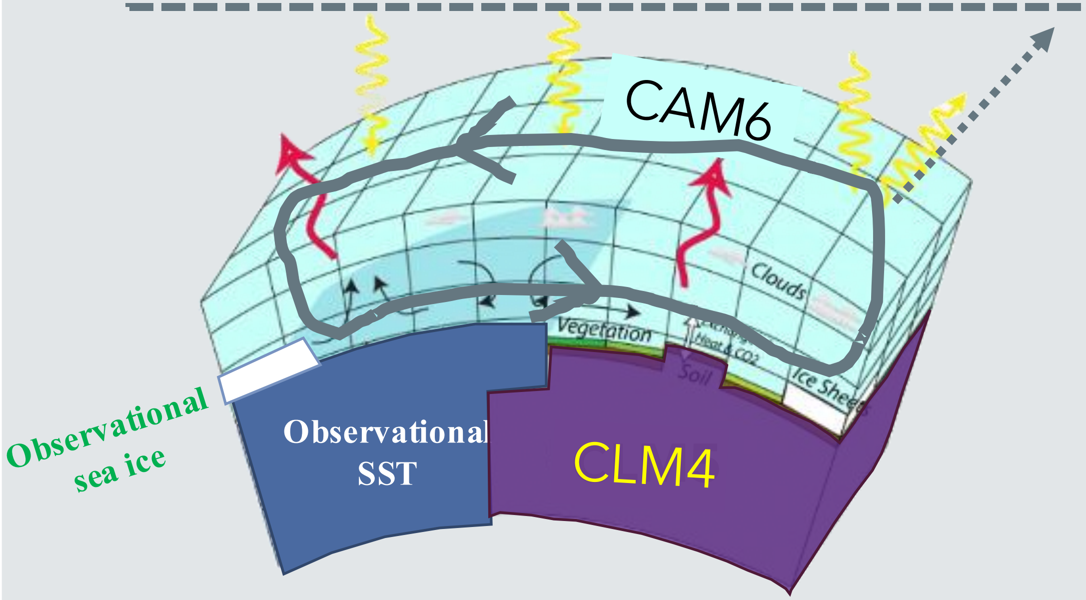

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Control:	Wind Nudging:
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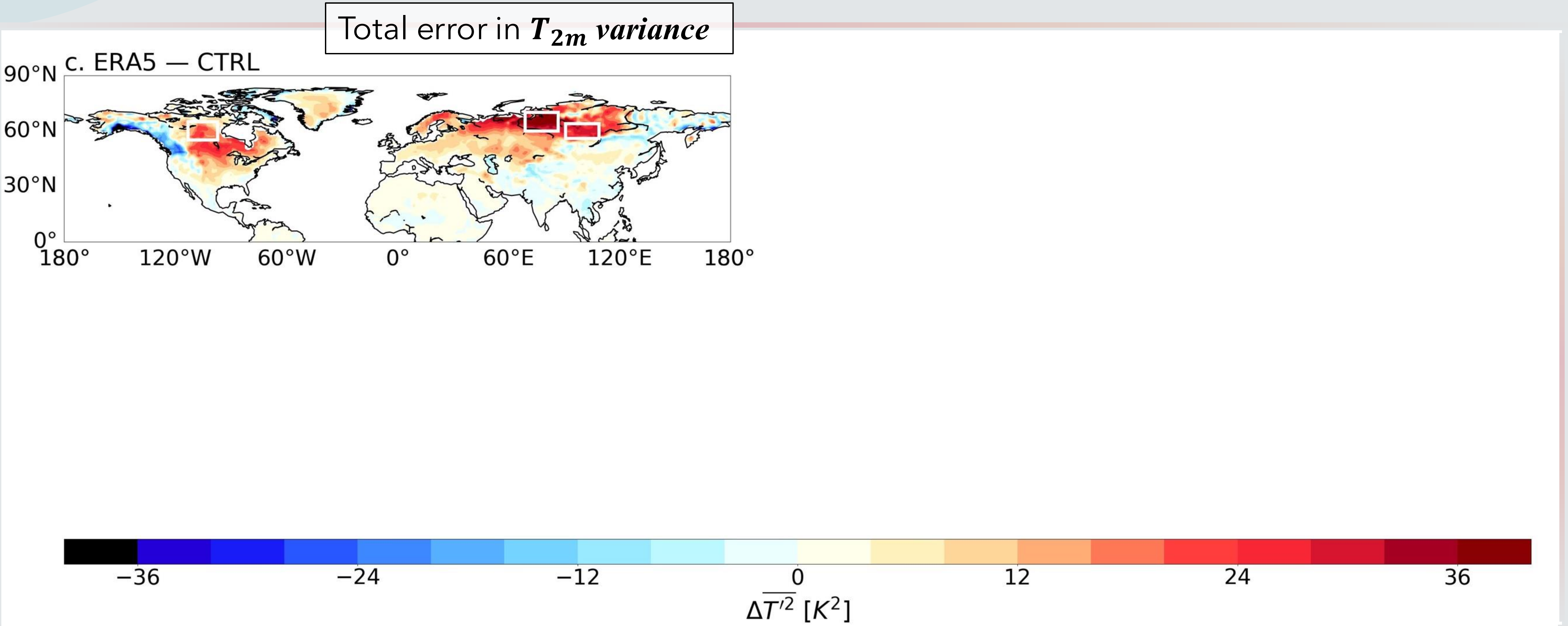
Land:	**Wind Nudging + Land:**
CLM4	NudUV/CLM4

Errors *in wintertime* $\boldsymbol{T_{2m}}$ ***variance*** *are* ***not*** *dominated by* ***circulations error***



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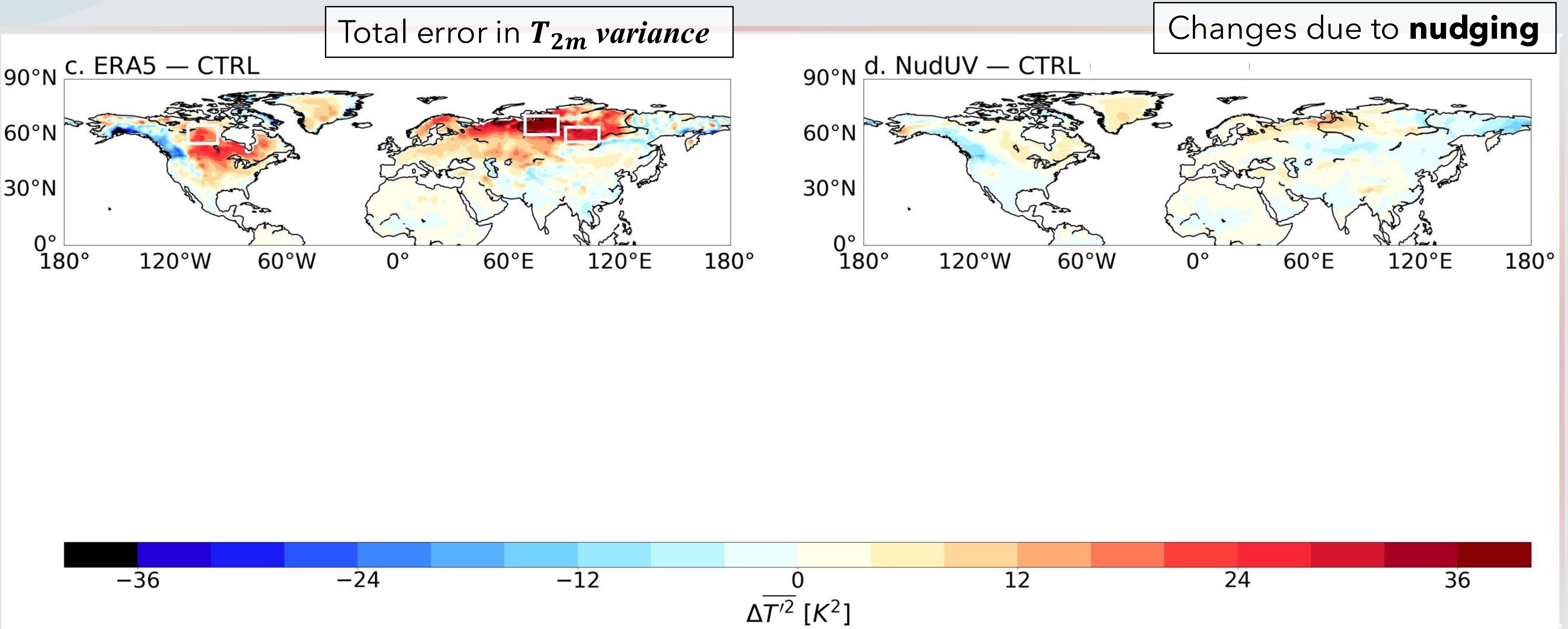

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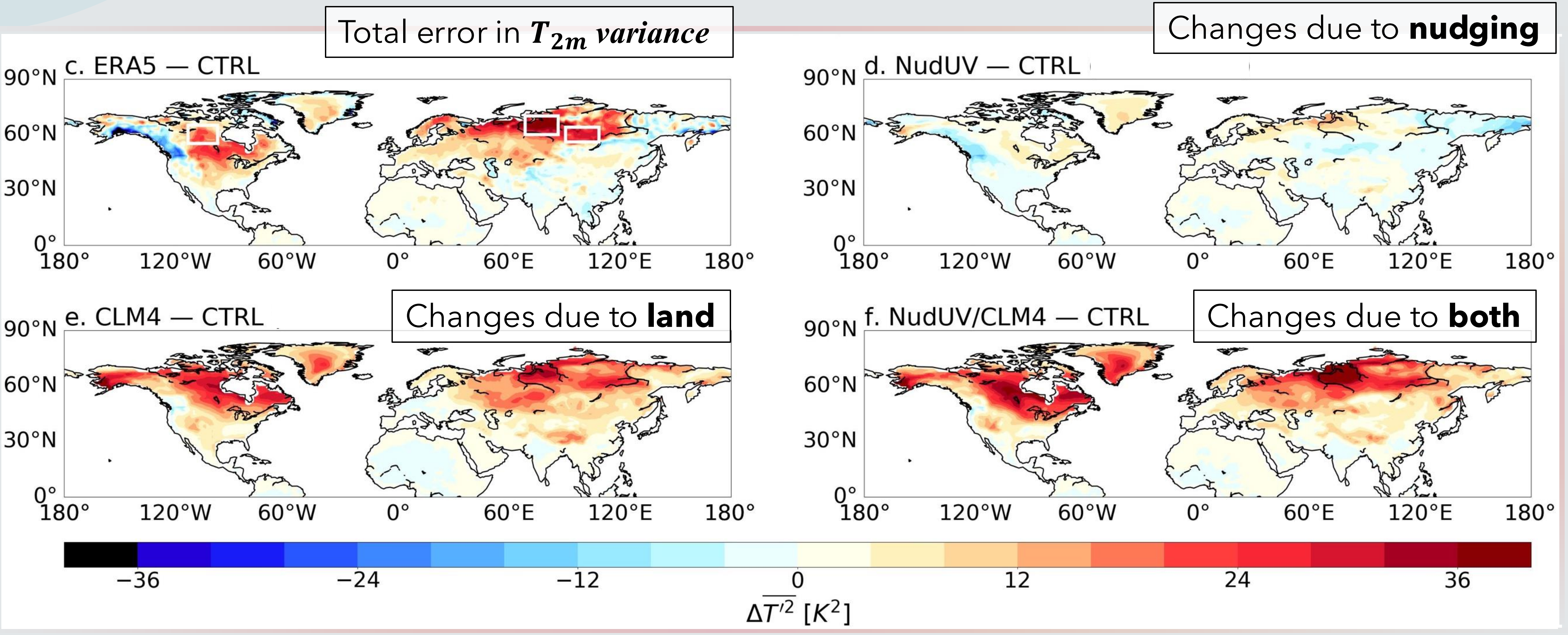

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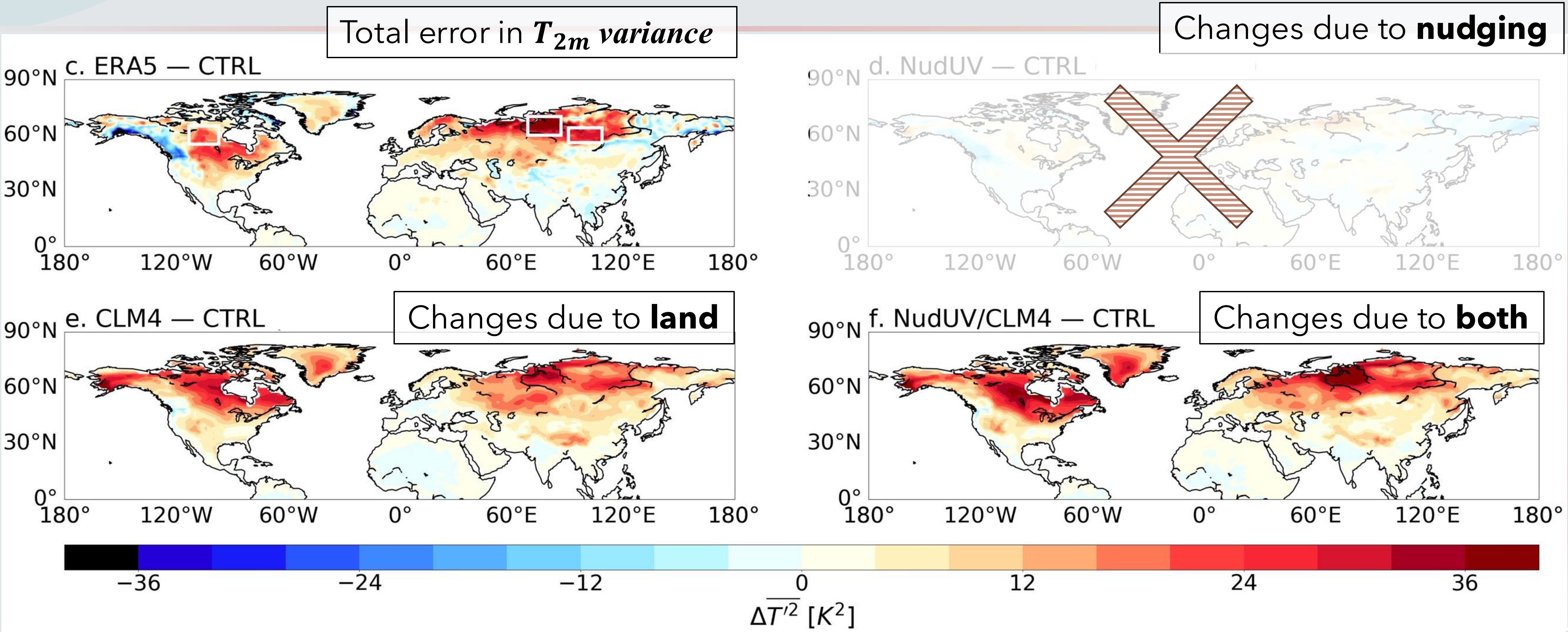

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Methods to address these questions:

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Near-surface air temperature tendency equation

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Near-surface air temperature tendency equation

Scaling framework:

$$\overline{T'^2} \approx \frac{C_a \overline{v'T'}(\partial_y \bar{T})}{\boldsymbol{\alpha_d + \alpha_L}}$$

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Near-surface air temperature tendency equation

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Land-atmosphere feedback

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Near-surface air temperature tendency equation

⇒

Scaling framework:

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⇒ Land-atmosphere feedback

Eddy mixing theory:

$$\overline{T'^2} \approx \left(\frac{\partial \bar{T}}{\partial y}\right)^2 L'^2$$

(e.g., Schneider et al 2015)

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$\Longrightarrow$ Land-atmosphere feedback

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From the surface air temperature tendency equation:

$$\frac{\partial T'}{\partial t} \approx -v'\frac{\partial \bar{T}}{\partial y} + \frac{1}{C_a}(LW' + SW' + SH' + LH')$$

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$$\overline{v'T'} \approx -\mathcal{D}(x,y)\left(\frac{\partial \bar{T}}{\partial y}\right) \qquad \overline{F_d{}'T'} \approx \alpha_d\,\overline{T'^2} \qquad \overline{F_L{}'T'} \approx \alpha_L\,\overline{T'^2}$$

$\mathcal{D}(x,y)$: *diffusivity*

$\mathcal{D}(x,y) \sim \sigma(\Psi)$

$\boldsymbol{\alpha_d}$: *sensitivity of net dry surface energy flux to air temperature*

$$\alpha_d = \frac{\partial(LW' + SW' + SH')}{\partial T}$$

$\boldsymbol{\alpha_L}$: *depends on background soil moisture, evaporative resistance, and saturated humidity*

$$\alpha_L = L_v \frac{\rho_a}{r_s}\bar{m}\gamma$$

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Land-atmosphere feedback

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$\mathcal{D}(x,y) \sim \sigma(\Psi)$

$$(\alpha_d + \alpha_L)\overline{T'^2} \approx C_a \overline{v'T'}\,\frac{\partial \bar{T}}{\partial y}$$

$$\overline{T'^2} \approx \frac{C_a \overline{v'T'}\left(\partial_y \bar{T}\right)}{\boldsymbol{\alpha_d + \alpha_L}} \approx \frac{-C_a \mathcal{D}\left(\partial_y \bar{T}\right)^2}{\boldsymbol{\alpha_d + \alpha_L}}$$

L'^2

$\boldsymbol{\alpha_d}$: *sensitivity of net dry surface energy flux to air temperature*

$$\alpha_d = \frac{\partial(LW' + SW' + SH')}{\partial T}$$

$\boldsymbol{\alpha_L}$: *depends on background soil moisture, evaporative resistance, and saturated humidity*

$$\alpha_L = L_v \frac{\rho_a}{r_s}\bar{m}\gamma$$

From mixing length:

$$\overline{T'^2} \sim \left(\partial_y \bar{T}\right)^2 L'^2$$

(e.g., Schneider et al 2015)

Relative contribution of ***mixing length*** *and* ***background temperature gradient***

$$\overline{T'^2} \approx \boxed{\left(\partial_y \bar{T}\right)^2} L'^2$$

$$\boxed{\left(\partial_y \overline{\theta}_s\right)^2}$$

*Relative contribution of **mixing length** and **background temperature gradient***

$$\overline{T'^2} \approx \left(\partial_y \overline{\theta}_s\right)^2 L'^2 \xrightarrow[\text{changes}]{\text{Fractional}} \frac{\Delta\overline{T'^2}}{\overline{T'^2}} \approx \frac{\Delta\left(\partial_y \overline{\theta}_s\right)^2}{\left(\partial_y \overline{\theta}_s\right)^2} + \frac{\Delta L'^2}{L'^2}$$

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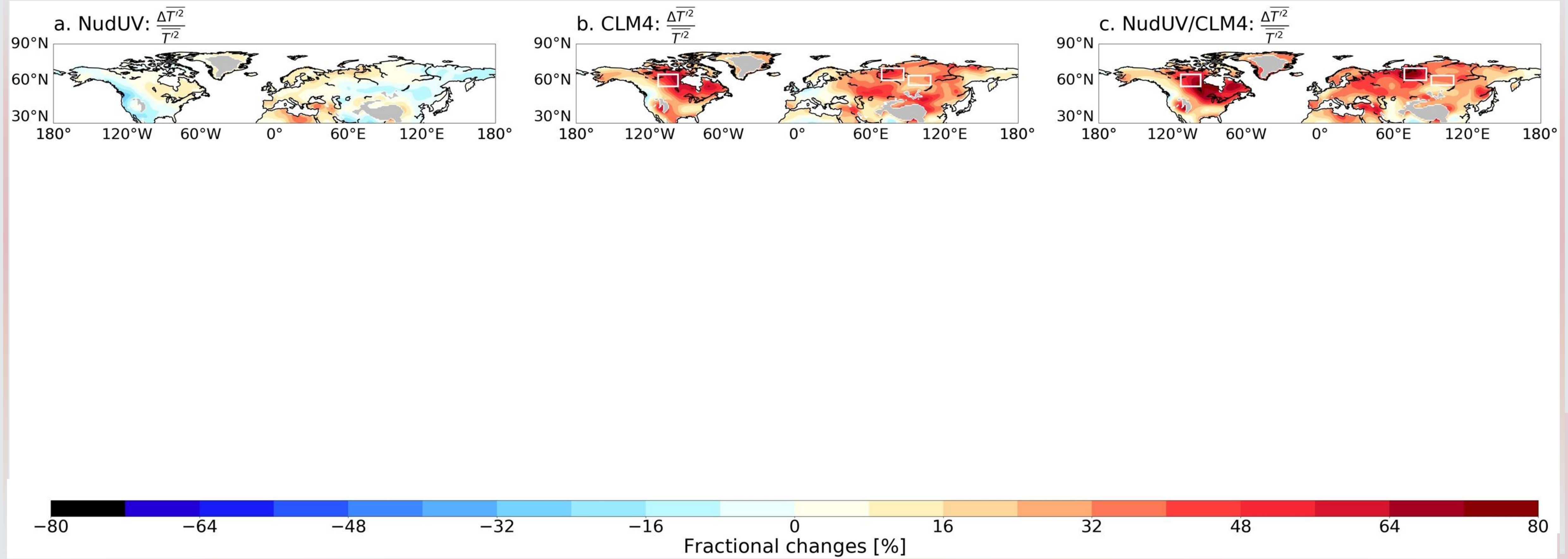
NudUV-CTRL

CLM4-CTRL

NudUV/CLM4-CTRL



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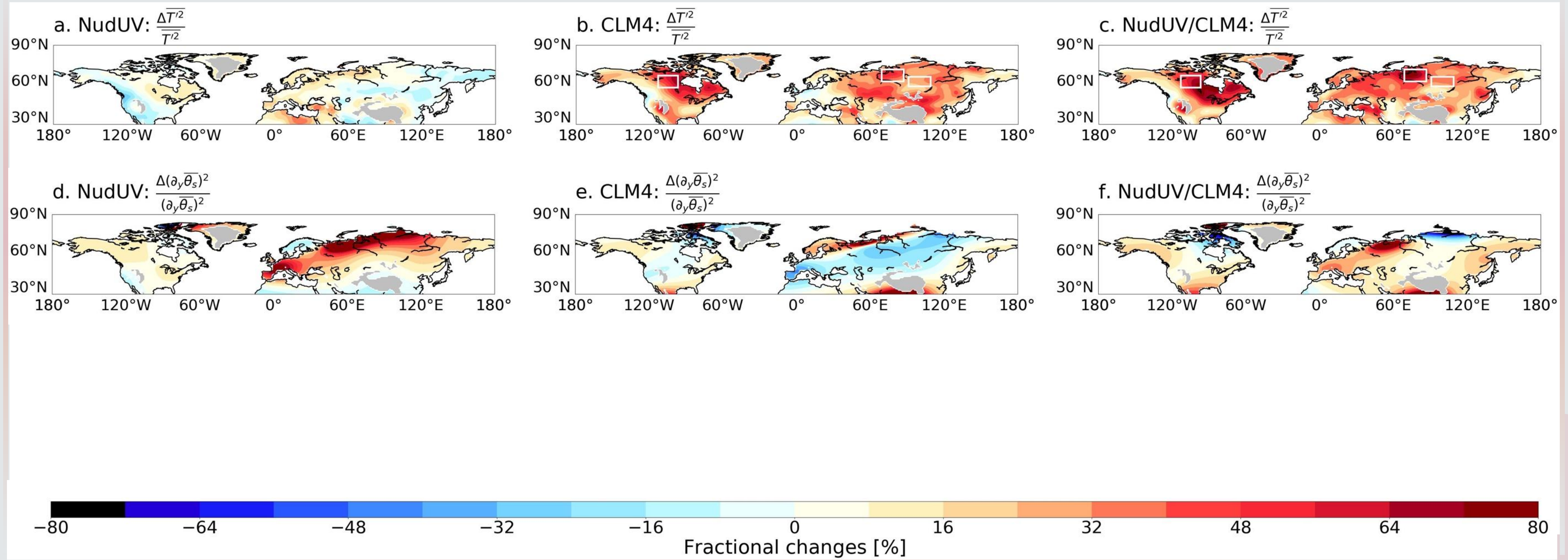
NudUV/CLM4-CTRL



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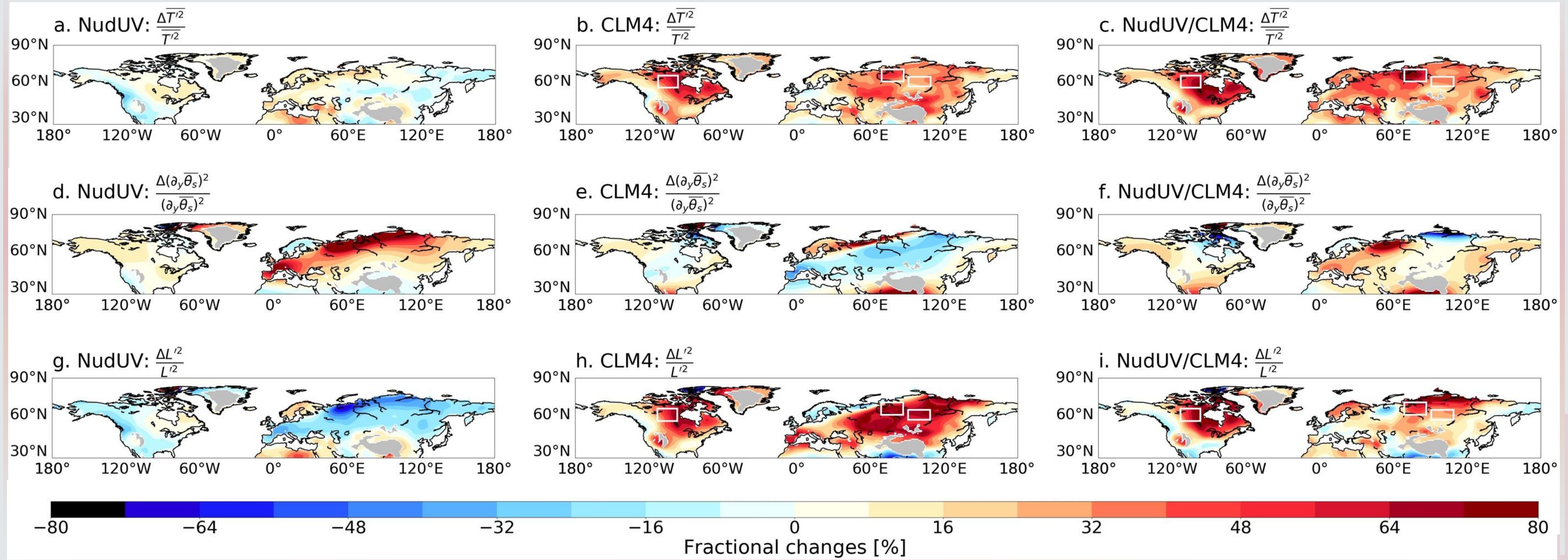
NudUV-CTRL | CLM4-CTRL | NudUV/CLM4-CTRL



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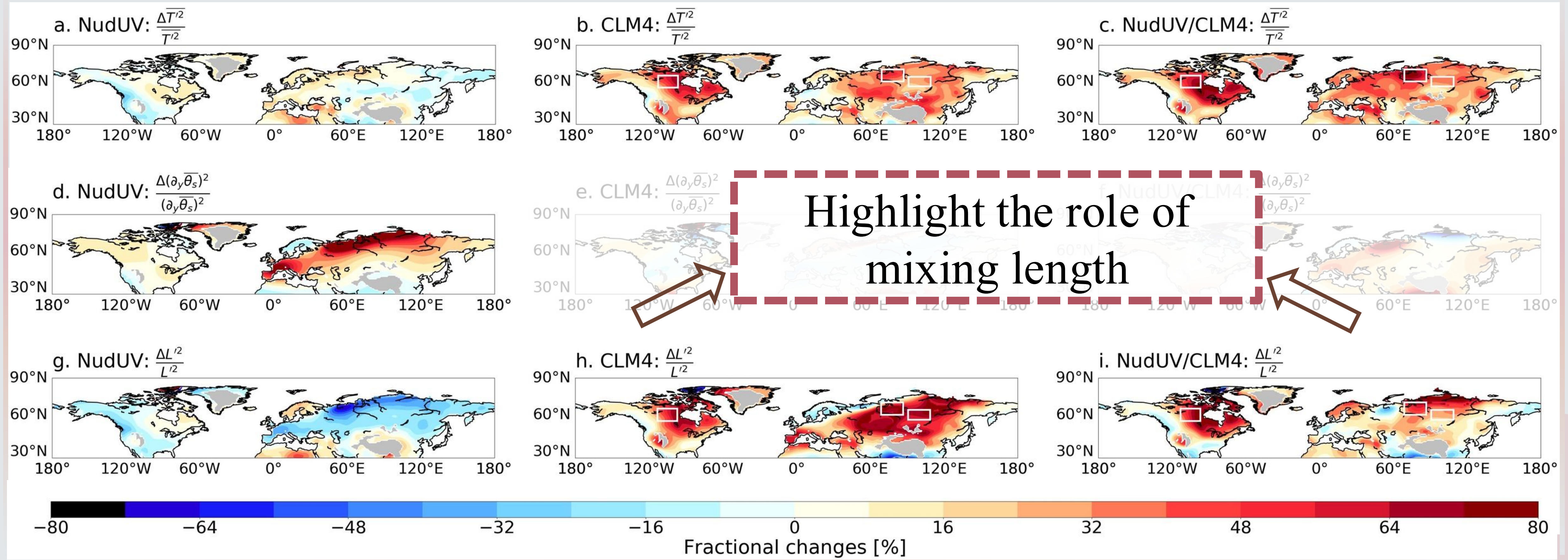

Land-atmosphere feedback *dominates fractional changes in* $\mathbf{L'^2}$ *and* $\overline{\mathbf{T'^2}}$

$$\boxed{\overline{T'^2} \approx \frac{-C_a \mathcal{D} \left(\partial_y \overline{\theta}_s\right)^2}{\boldsymbol{\alpha_d + \alpha_L}}} \longrightarrow L'^2 \approx \frac{-C_a \mathcal{D}}{\boldsymbol{\alpha_d + \alpha_L}}$$

L'^2

$\mathcal{D}$: *eddy diffusivity*

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$$\xrightarrow[\text{changes}]{\text{Fractional}} \quad \frac{\Delta L'^2}{L'^2} - \frac{\Delta \mathcal{D}}{\mathcal{D}} \approx \frac{\Delta\left(\frac{1}{\boldsymbol{\alpha_d + \alpha_L}}\right)}{\left(\frac{1}{\boldsymbol{\alpha_d + \alpha_L}}\right)}$$

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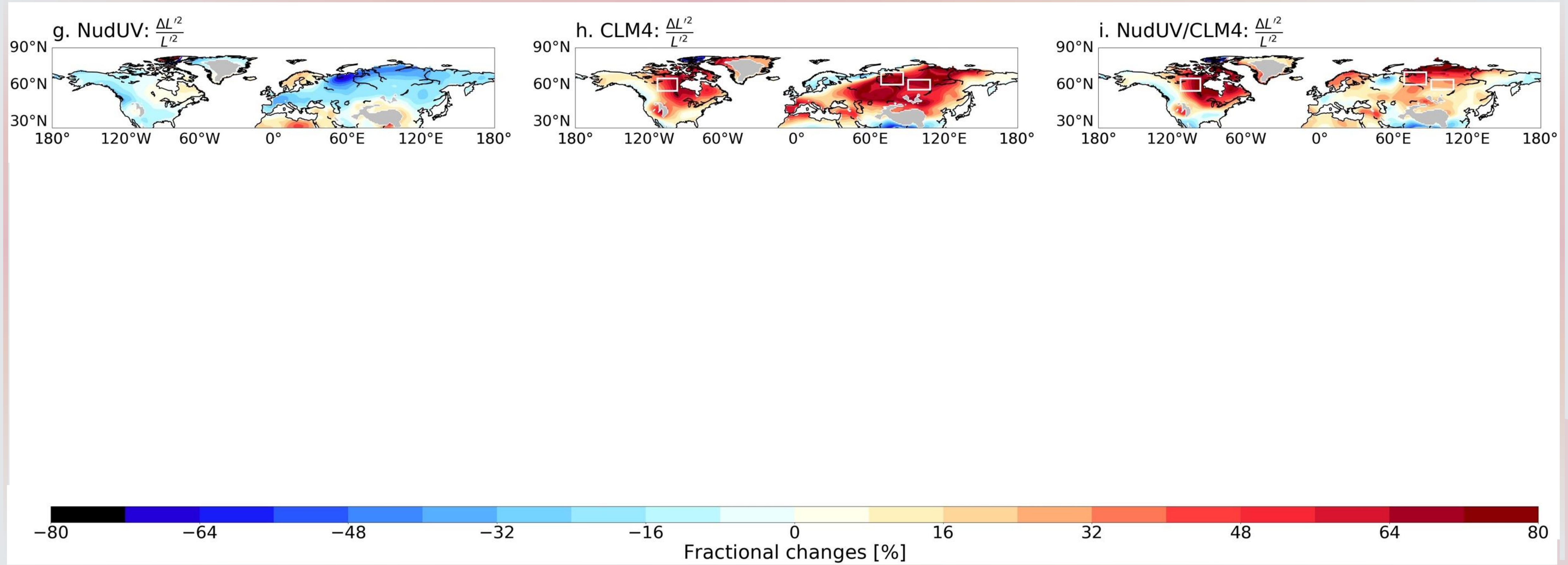
NudUV-CTRL

CLM4-CTRL

NudUV/CLM4-CTRL



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NudUV-CTRL

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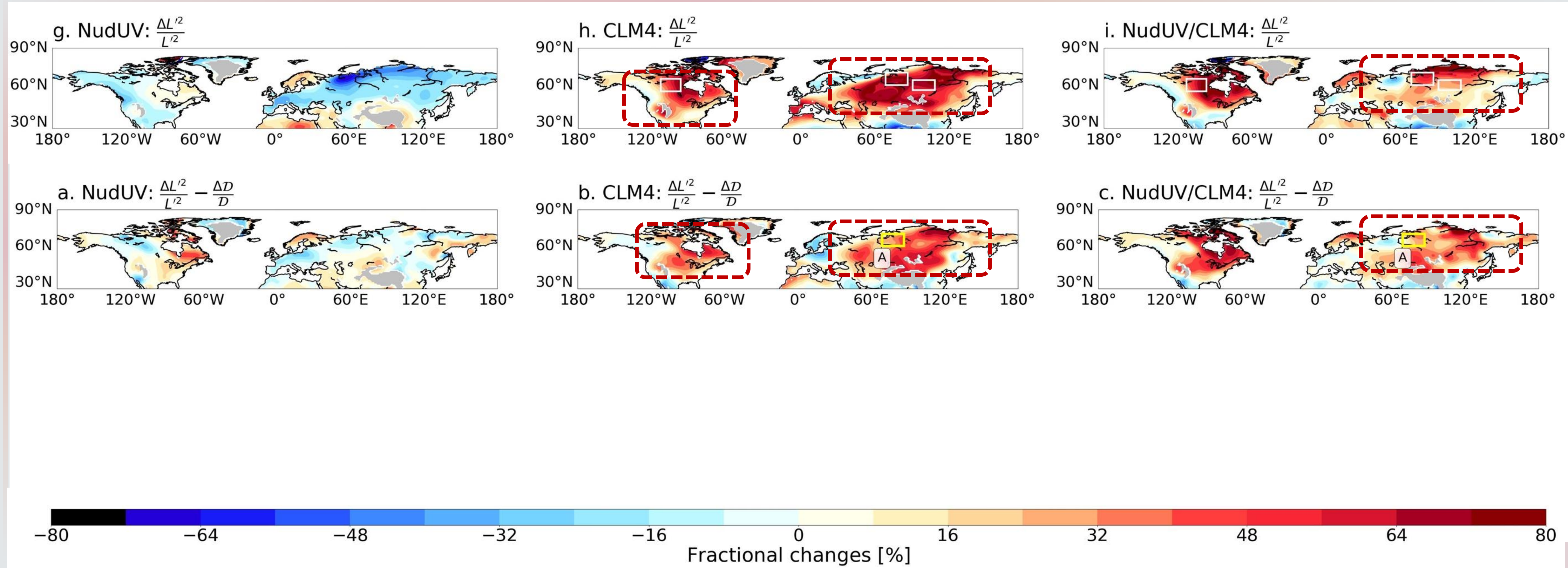

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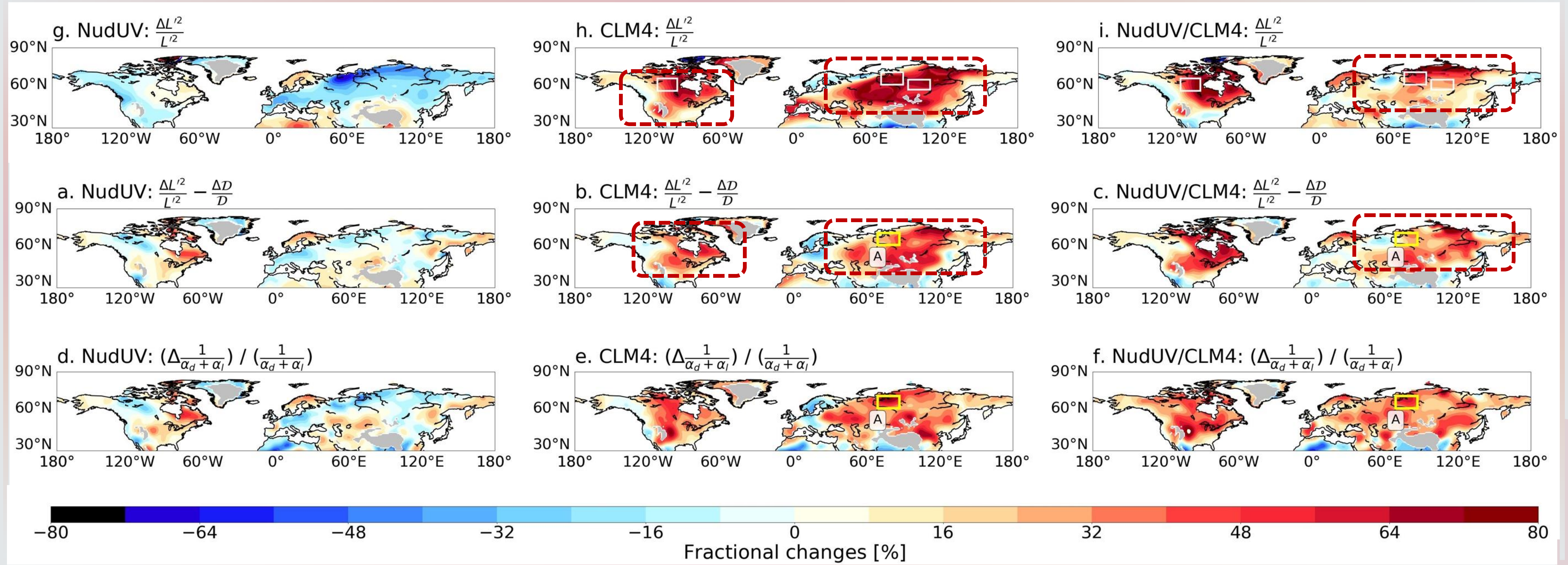
NudUV-CTRL

CLM4-CTRL

NudUV/CLM4-CTRL



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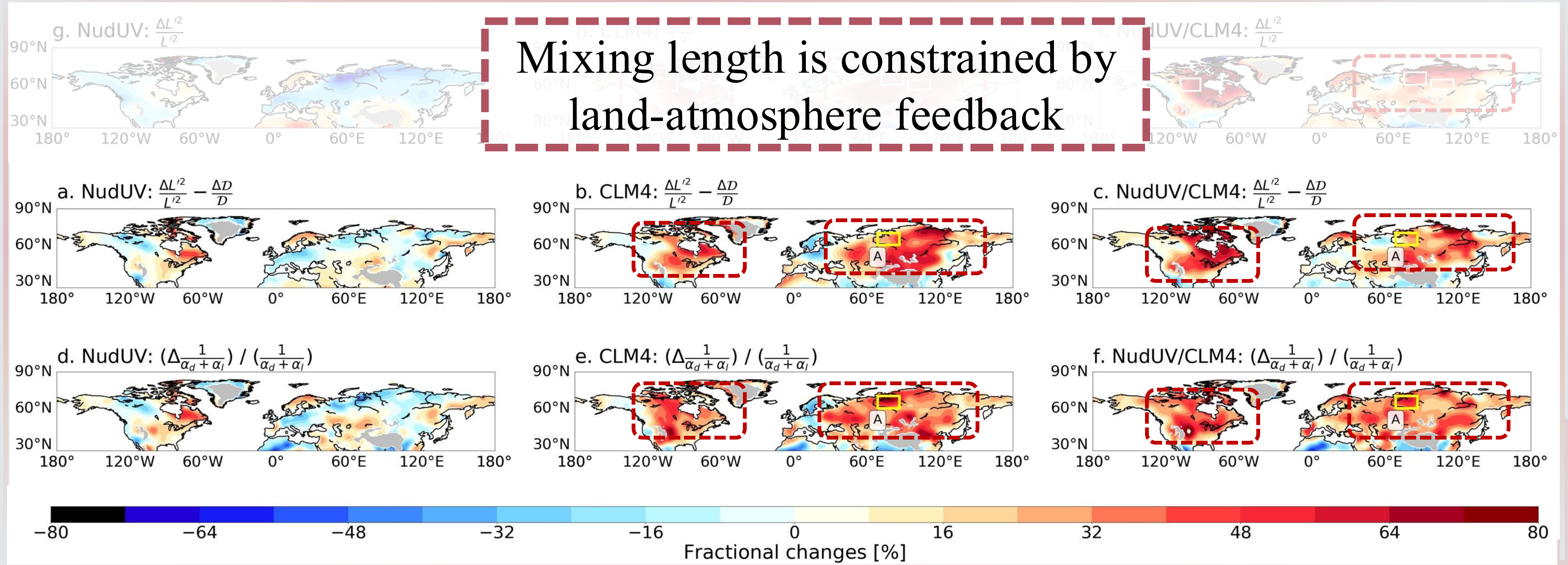
L'^2

NudUV-CTRL

CLM4-CTRL

NudUV/CLM4-CTRL

Mixing length is constrained by land-atmosphere feedback



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Eddy heat flux

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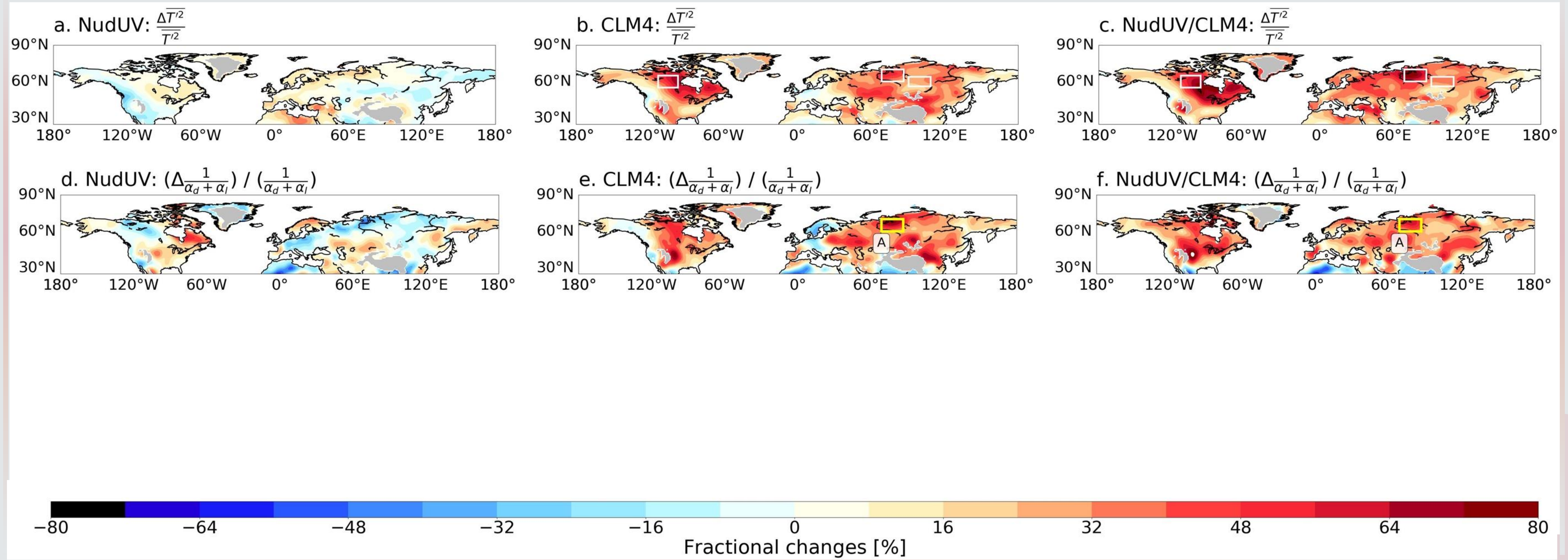
Eddy heat flux

NudUV-CTRL

CLM4-CTRL

NudUV/CLM4-CTRL



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NudUV-CTRL

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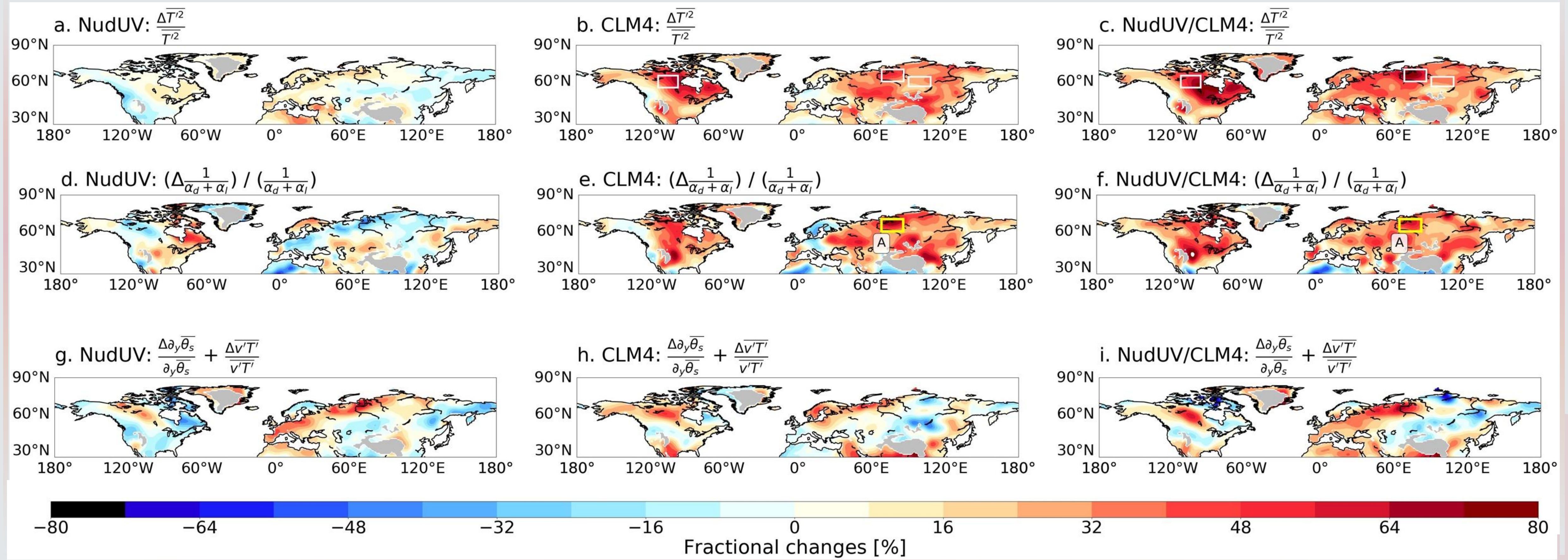
NudUV/CLM4-CTRL



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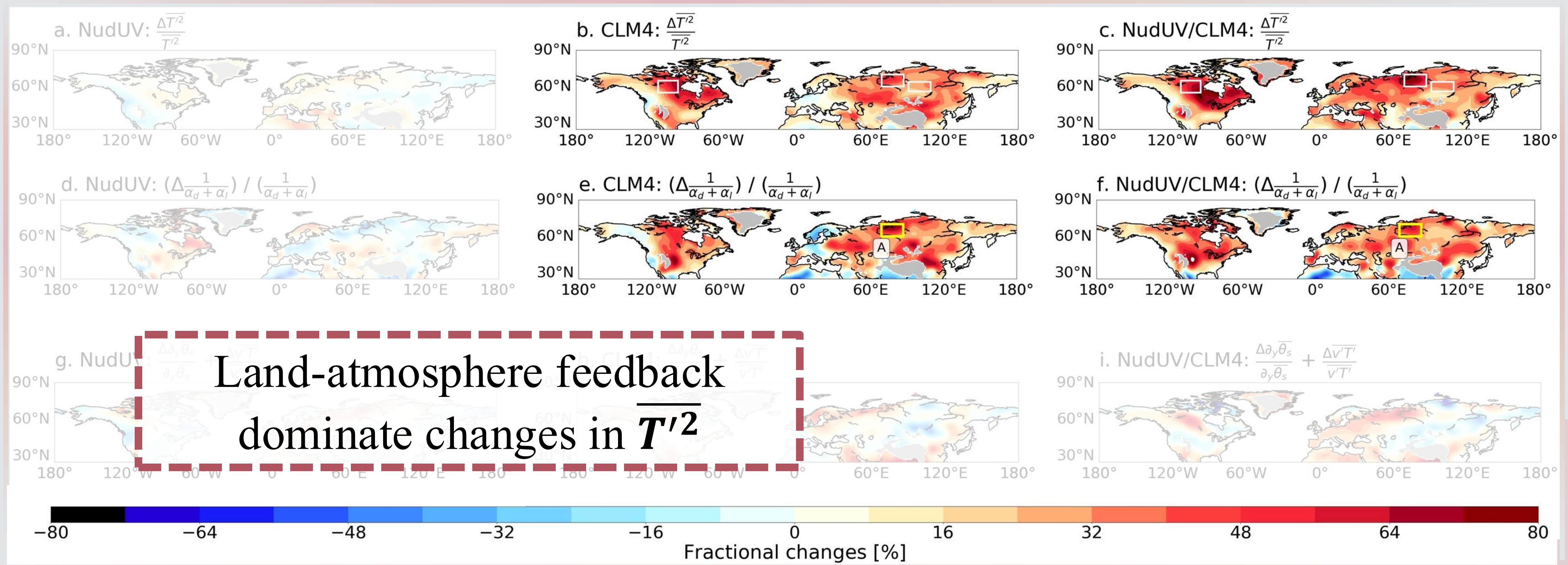
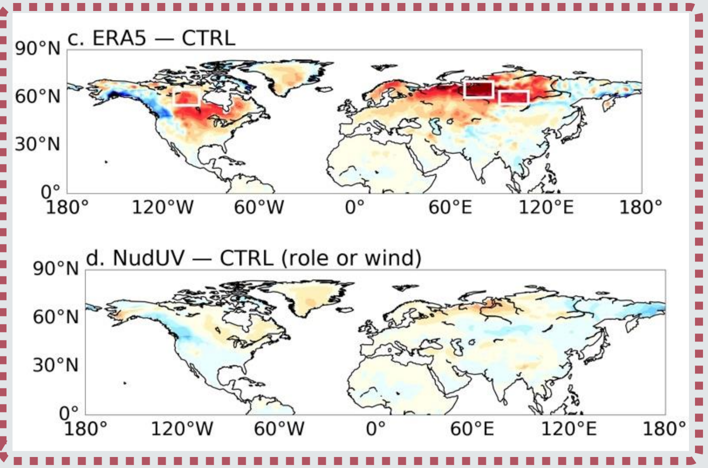
NudUV-CTRL | CLM4-CTRL | NudUV/CLM4-CTRL



Take-home messages:

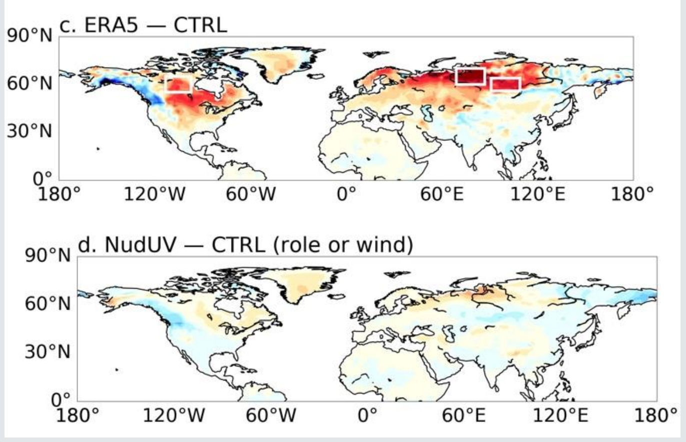
- *Correcting synoptic circulation bias does not address model bias in simulating near-surface temperature variance*



Email me *: melodylu@atmos.ucla.edu*

Take-home messages:

- *Correcting synoptic circulation bias does not address model bias in simulating near-surface temperature variance*
- *Land-atmosphere feedbacks damp the near-surface temperature variance and constrain the mixing length*



$$\overline{T'^2} \approx \frac{-C_a \mathcal{D}\left(\partial_y \overline{\theta}_s\right)^2}{\boldsymbol{\alpha_d + \alpha_L}}$$

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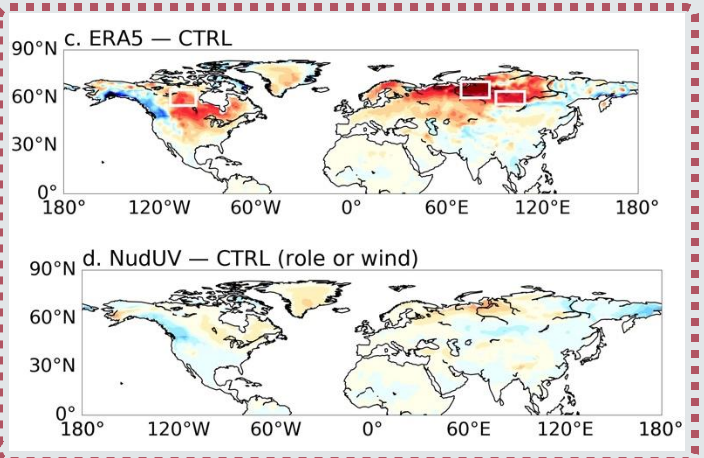

- *Land-atmosphere feedbacks damp the near-surface temperature variance and constrain the mixing length*

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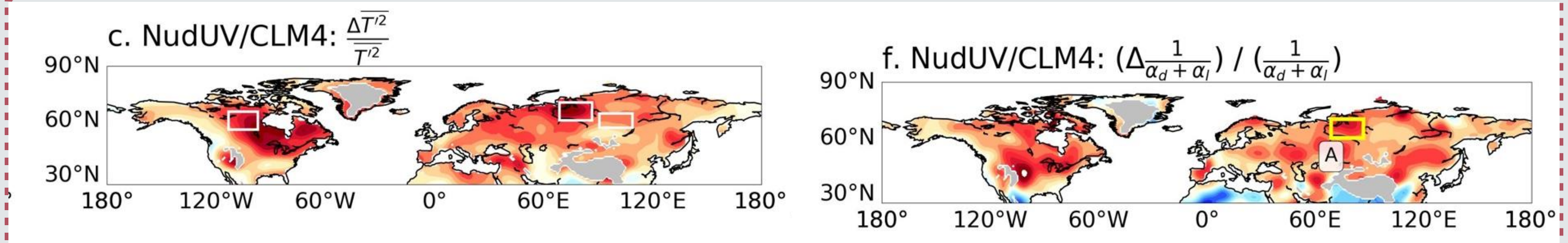
- *Accurately representing of land processes in climate models is important for projecting future changes in near-surface temperature variability as well as extreme weather events*



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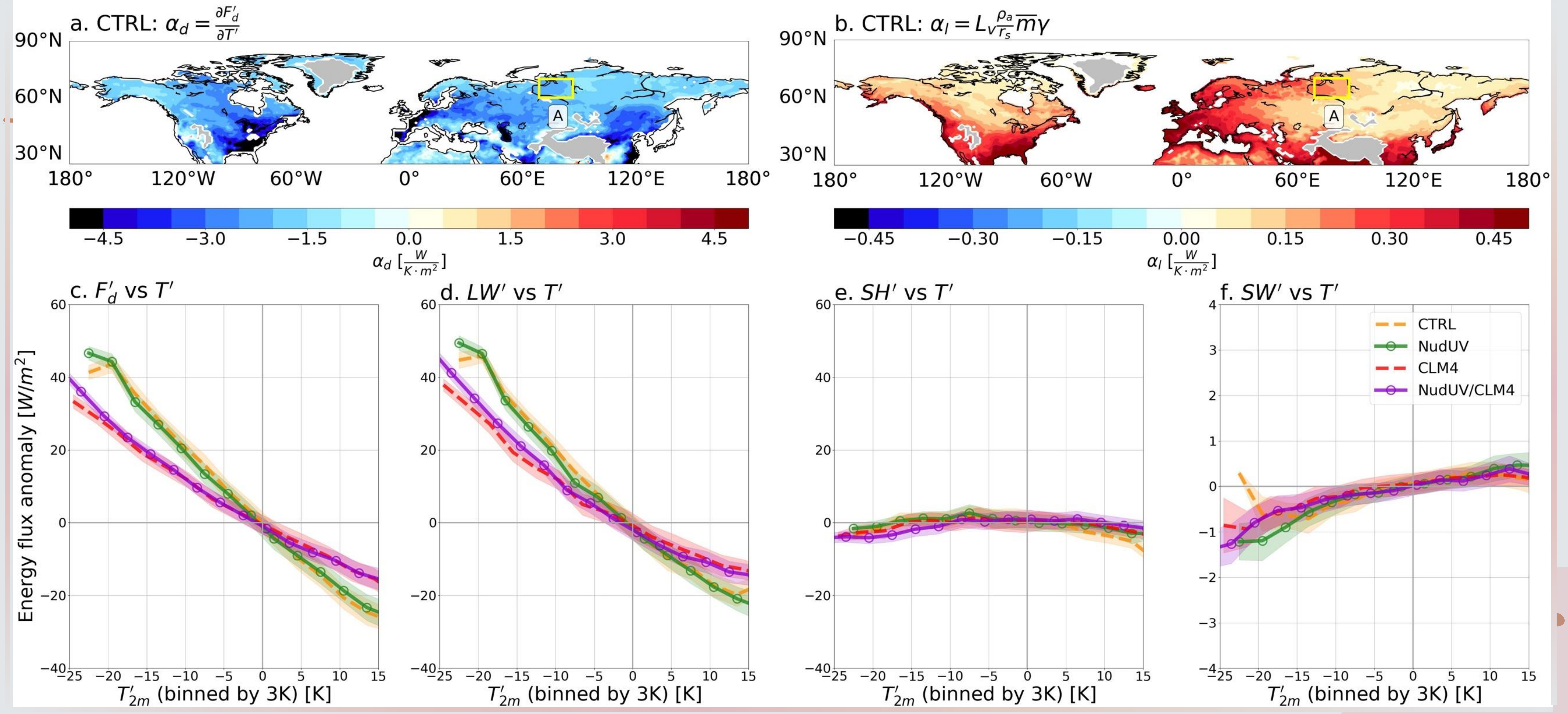
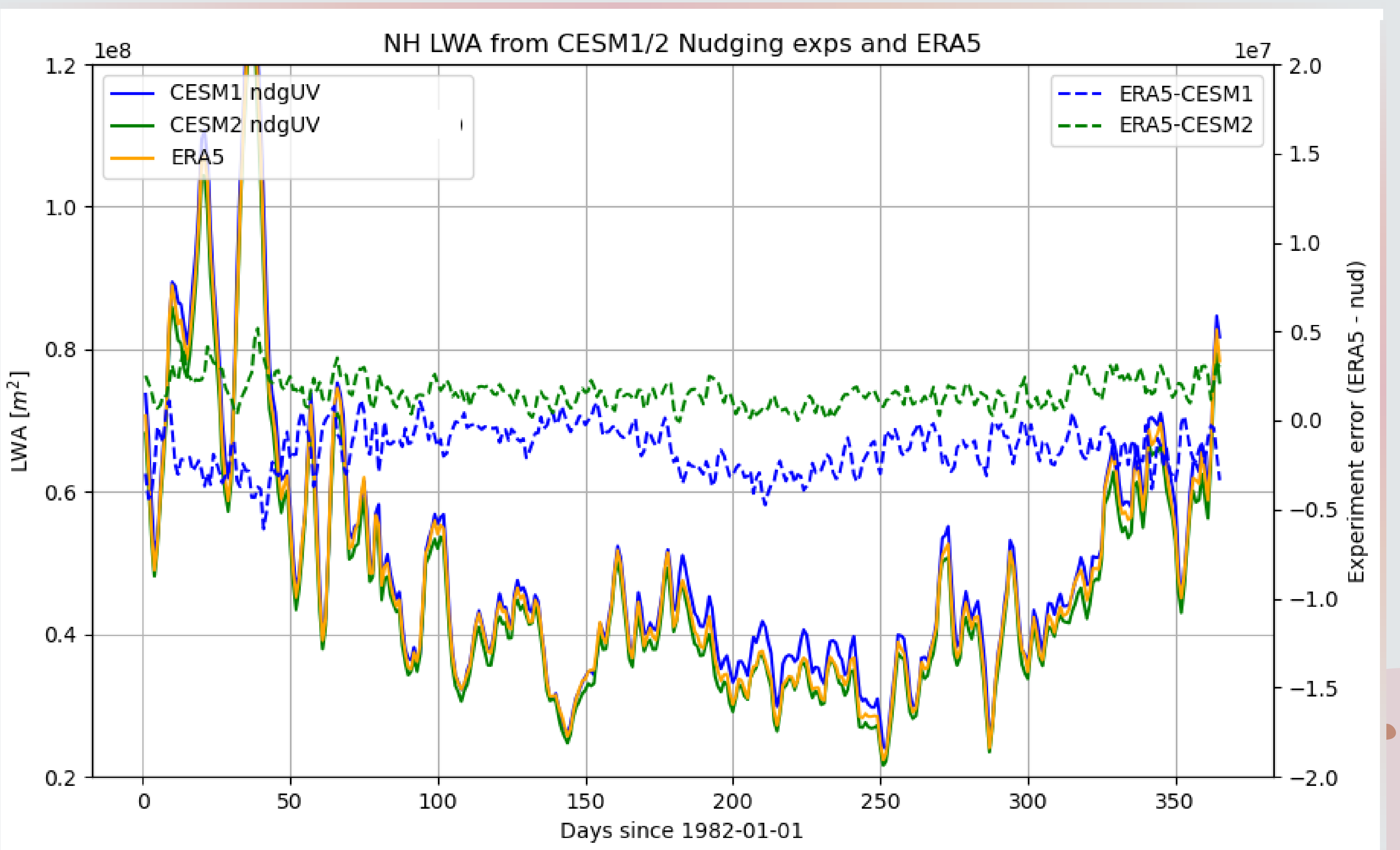
A ***negative*** *feedback between* ***longwave radiative flux*** *and* ***surface air temperature dominates*** *local land-atmosphere interactions during winter*



Synoptic-scale circulations *are effectively corrected through* ***wind nudging***

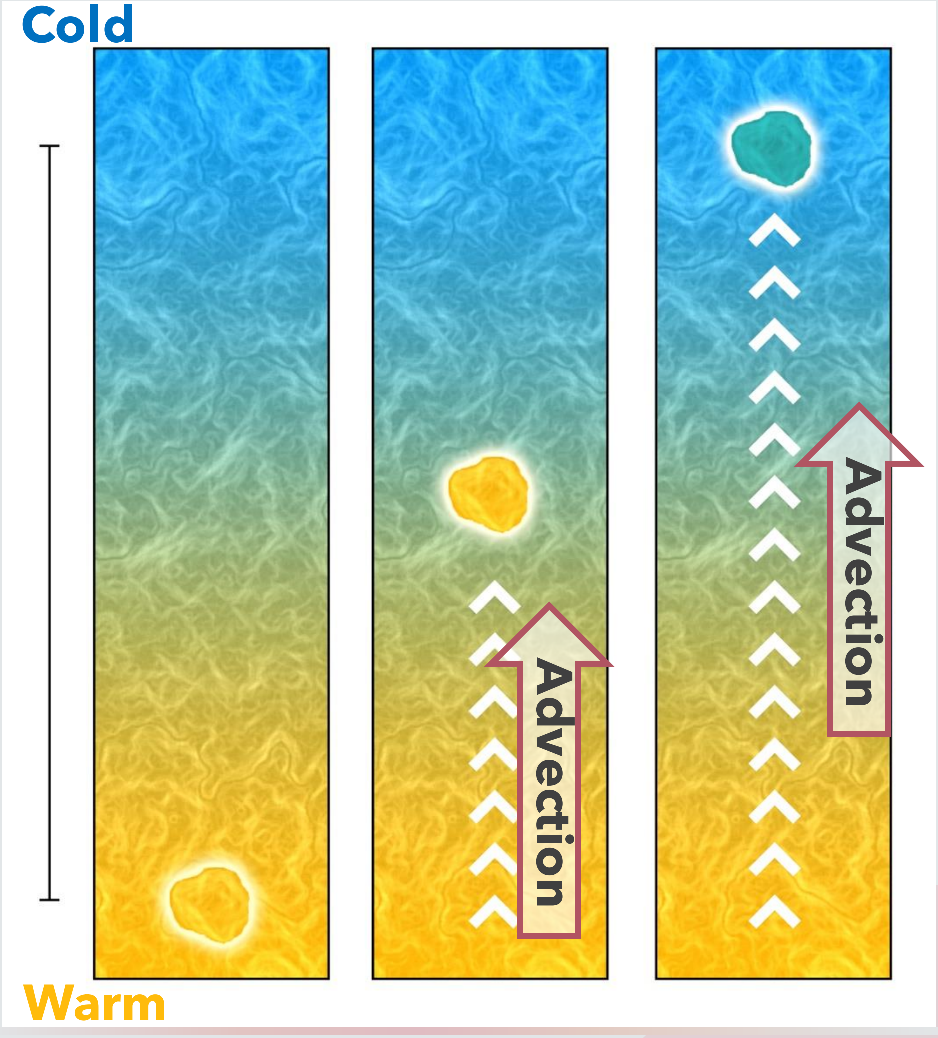
The **wind-nudging** technique **improves** local wave activity (LWA) and, consequently, **blockings**.

Evolution of Northern Hemispheric mean LWA in 1982



Temperature variance** are dominated by free-tropospheric **advection**, primarily controlled by the **background meridional gradient

Eddy mixing theory



(e.g., Schneider et al 2015)

(Credit: Wikipedia)

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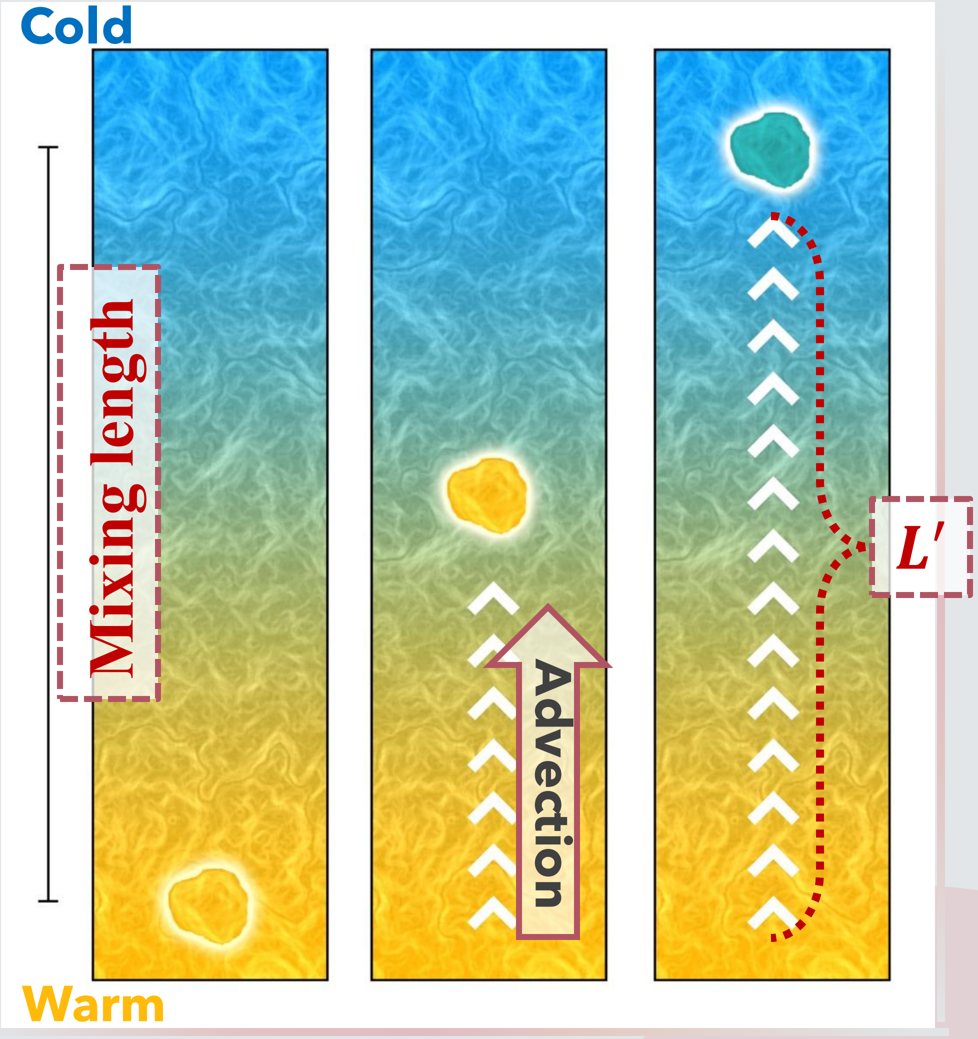

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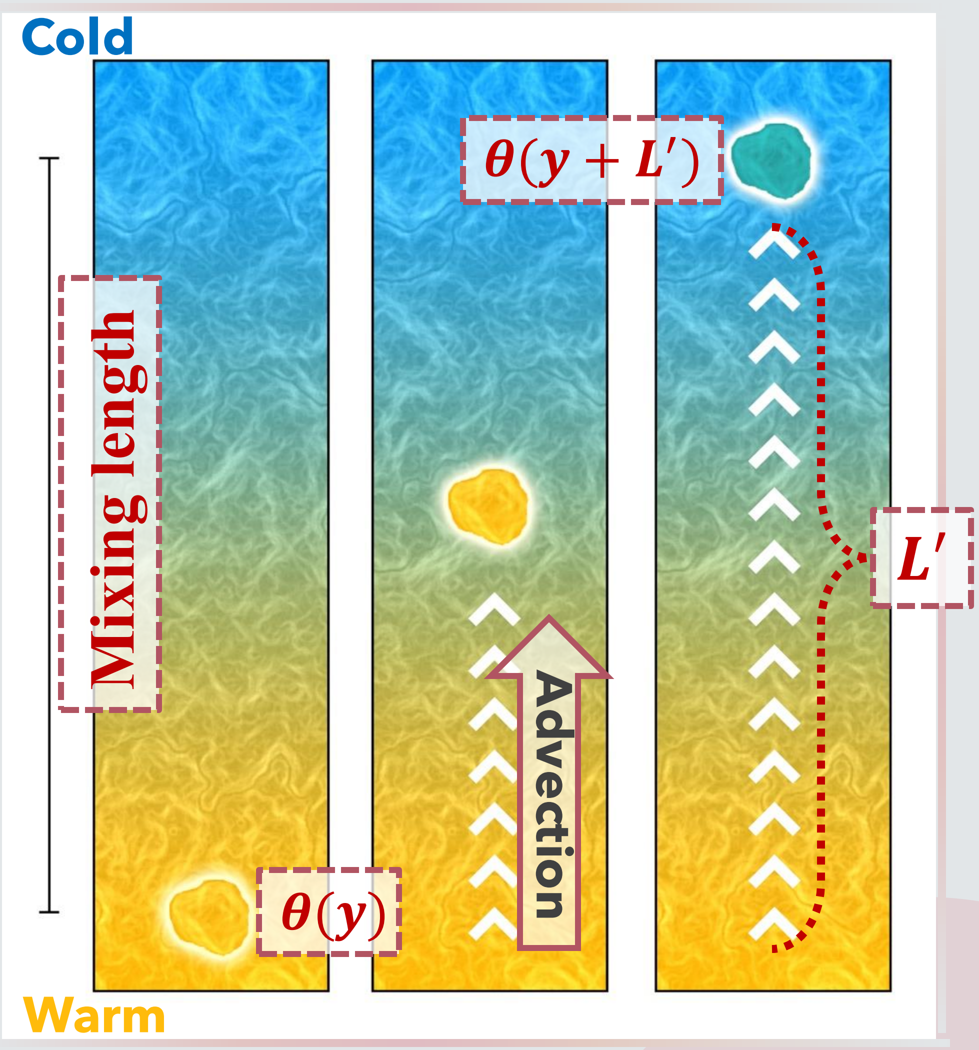
Taylor expansion:

$$\theta' = \theta(y + L') - \theta(y) \approx -\frac{\partial \bar{\theta}}{\partial y} L' + \frac{1}{2}\frac{\partial^2 \bar{\theta}}{\partial y^2} L'^2 + \cdots$$



(e.g., Schneider et al 2015) θ: low-level potential temperature

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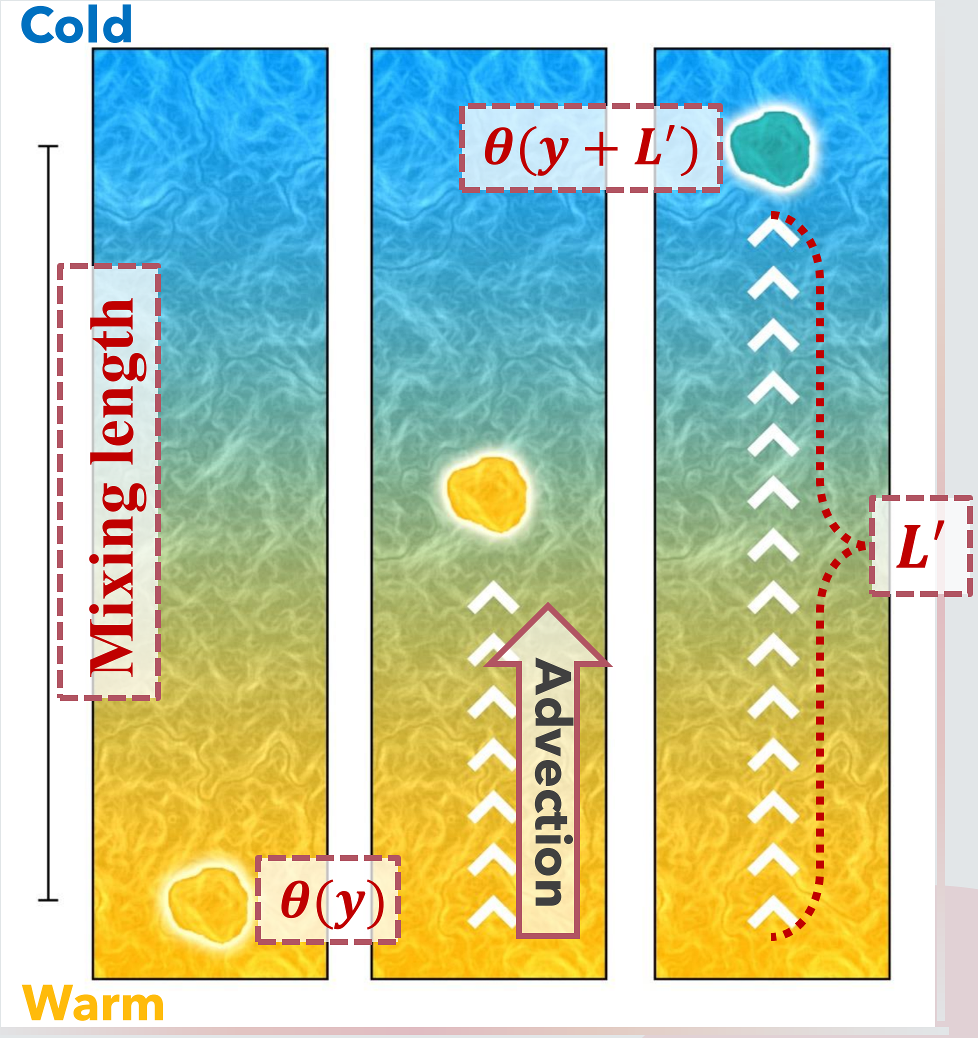

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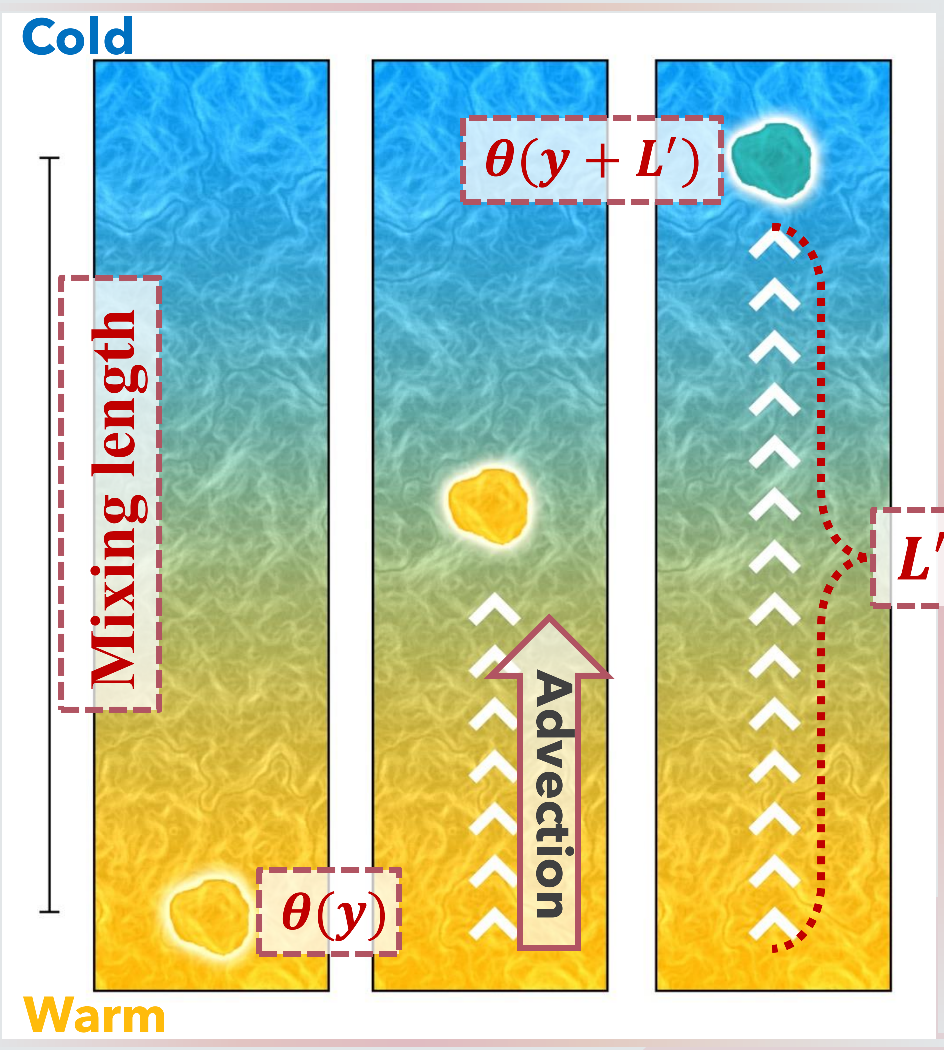

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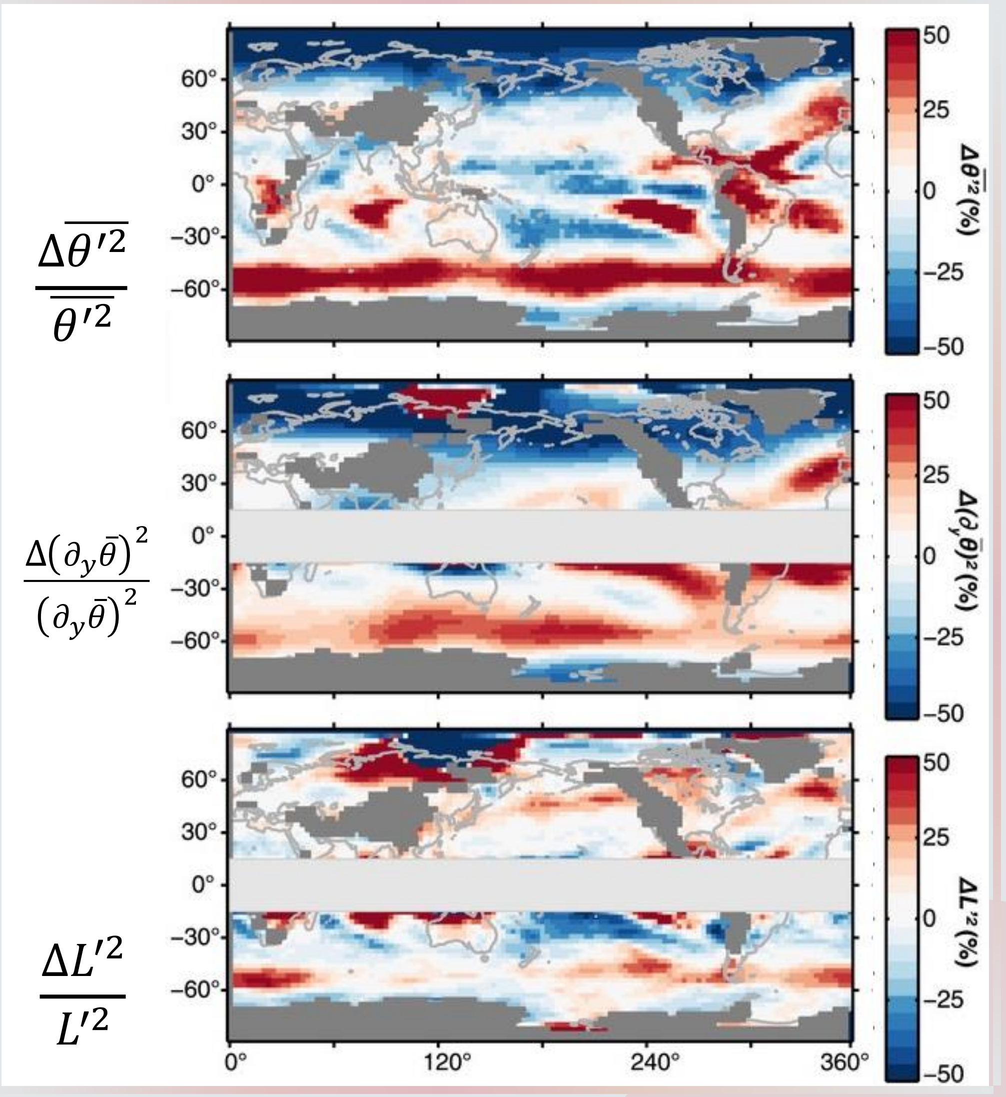
DJF, RCP8.5, @850hPa



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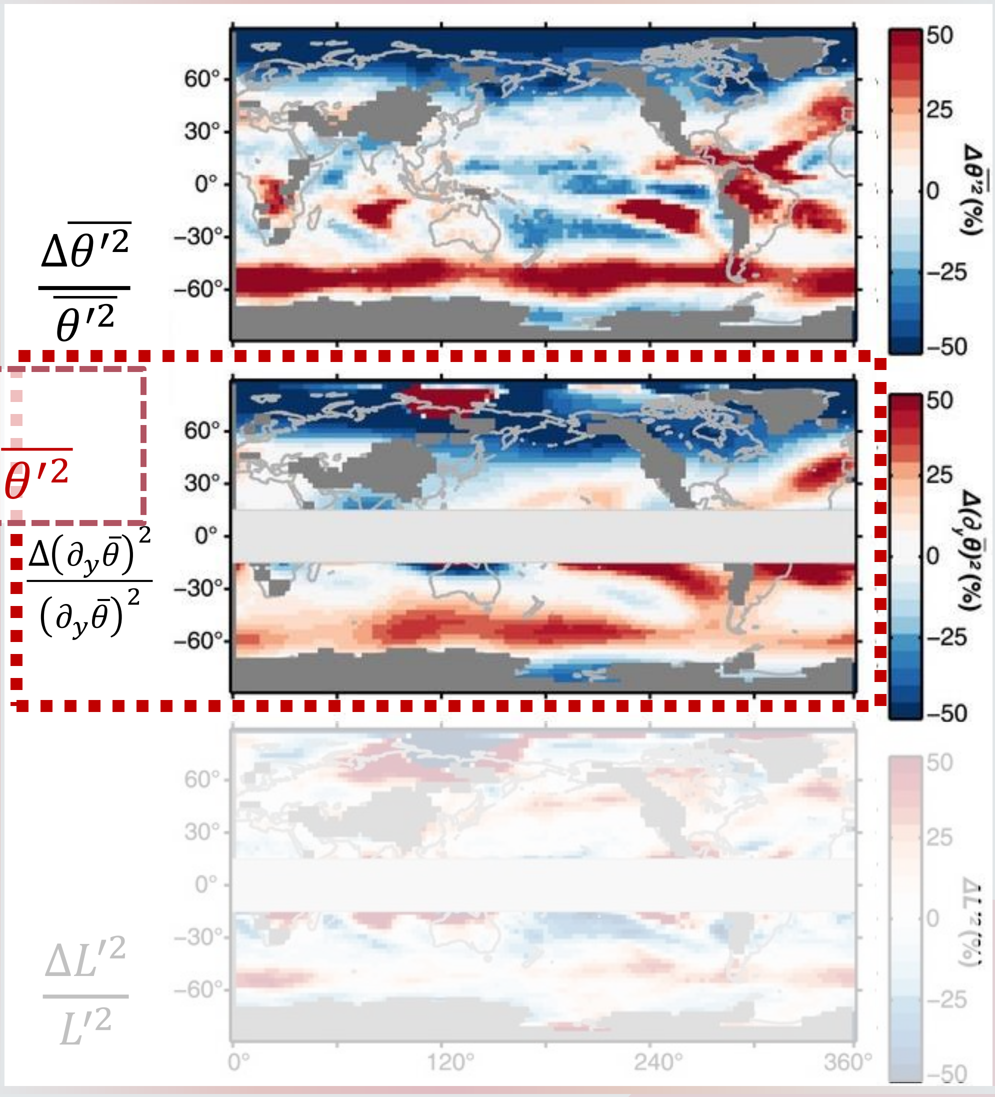
Dominates changes in $\overline{\theta'^2}$



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