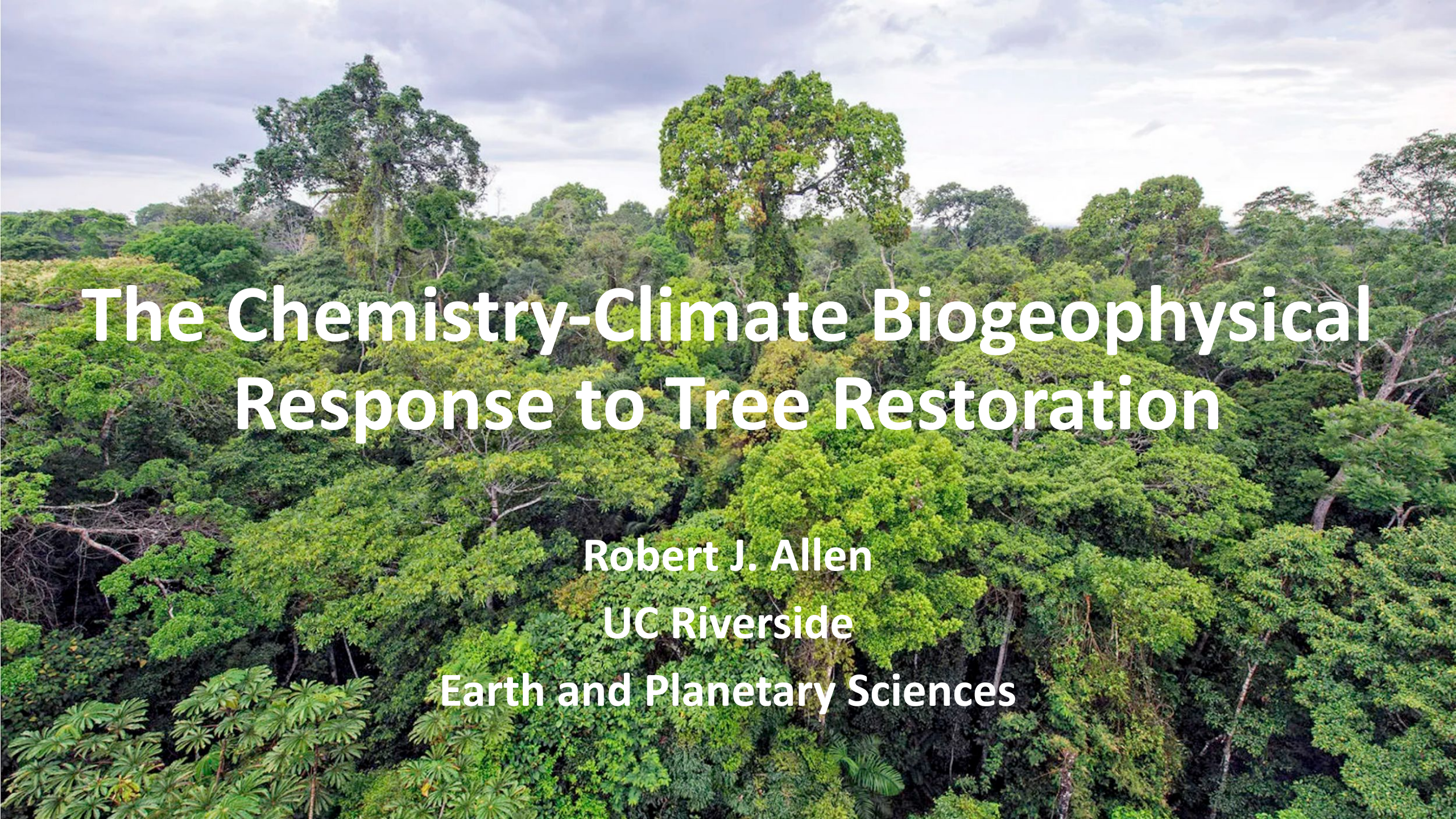

The Chemistry-Climate Biogeophysical Response to Tree Restoration

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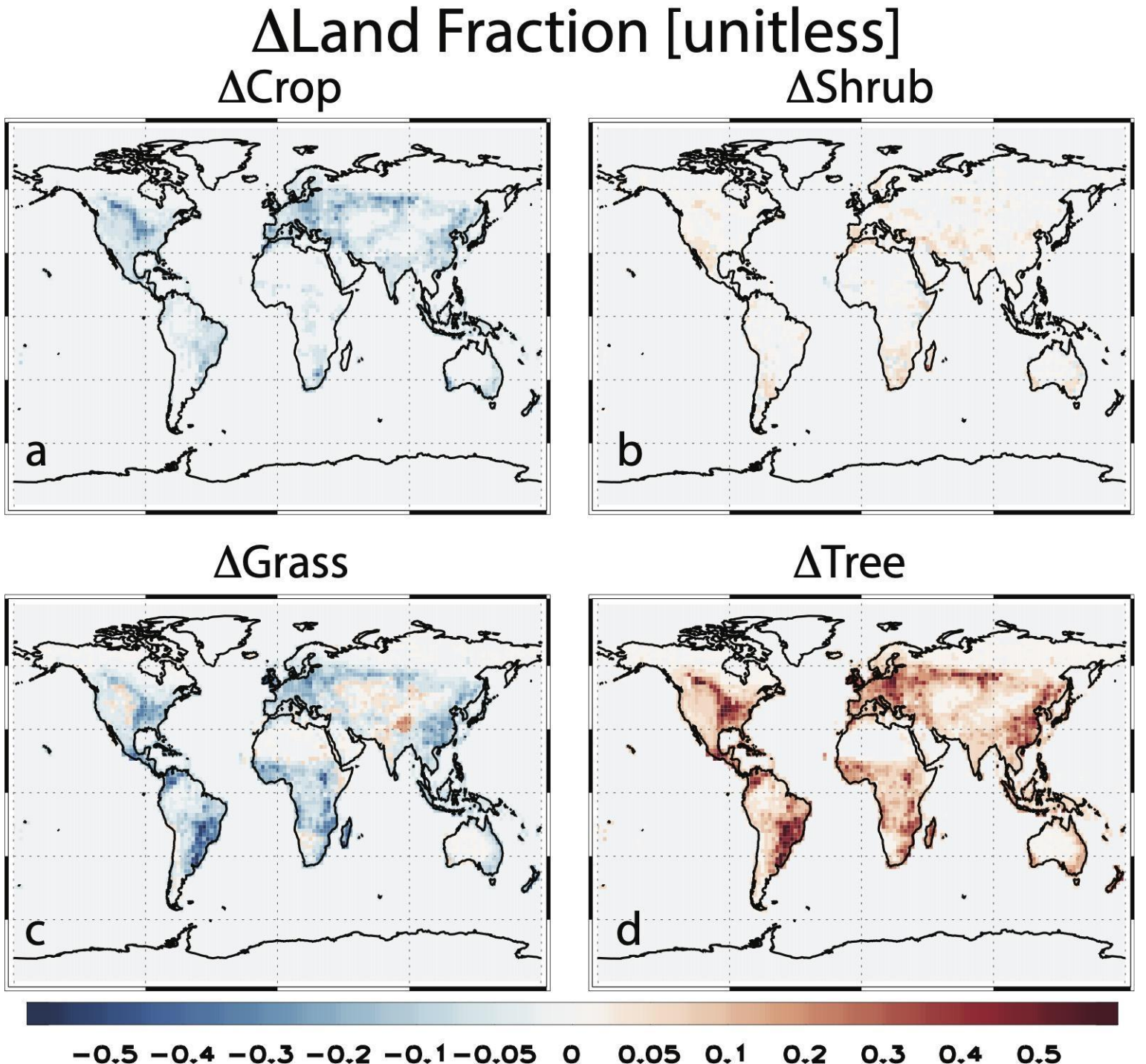
Background

- **Tree restoration (TR) captures CO_2 (biogeochemical effect)** & helps to ***mitigate*** **climate change**.
- **Biogeophysical effects (e.g., *decreased* albedo, *increased* ET)** can **enhance** or **diminish** the **negative biogeochemical effect**.
- Importance of **atmospheric chemistry** & **SLCFs,** including **BVOC** impacts on **aerosols**, **methane** and **ozone** remains uncertain:
  - **Net atmospheric chemistry effect** associated with **historical cropland expansion** is a **negative climate forcing** (Unger et al., 2014).
  - A similar study that also included **aerosol cloud interactions** found that **global deforestation** led to an overall **positive radiative forcing** from **SLCFs** (Scott et al., 2018).
  - **Forestation** led to a **combined albedo** and **chemistry radiative effect** that **offset up to a third** of the ***enhanced*** **land carbon storage** (Weber et al., 2024).

Model Simulations

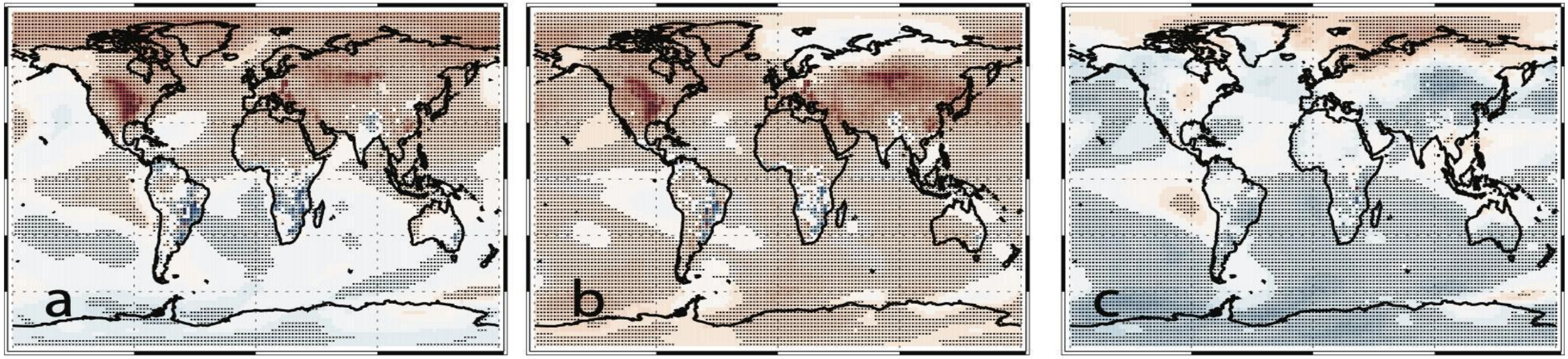
- **CAM6** present-day time-slice simulations coupled to a **slab ocean model**:
  - **TR experiment** & a **control with interactive atmospheric chemistry** → **CHEM**.
  - Identical pair ***without*** **interactive atmospheric chemistry** → **NOCHEM**.
- **CHEM** minus **NOCHEM** ***isolates*** the **chemistry-climate effect**.
- Integrated for **200 years**, the last **150 years** **used for analysis**.
- Analogous sets of **45-year** **climatological SST/sea-ice (FSST)** simulations:
  - Isolate **Effective Radiative Forcing** (**ERF**) and **Rapid Adjustments** (**RAP_ADJ**).
- All simulations use **prescribed atmospheric CO_2 concentrations** and thus ***do not include*** the **biogeochemical effects** on temperature/climate.
  - **BGC effects** estimated offline using the **TCRE.**

- **Tree Restoration (TR) methodology**:
  - **Step 1** → **Reforestation** → If the preindustrial (PI) tree fractional area for a grid cell is larger than that in present-day (PD), the PI value replaces the PD baseline.
  - **Step 2** → **Afforestation** → If an SSP in year 2100 has a larger tree fractional area for a grid cell than currently exists from Step 1, it replaces the current value.
- This perturbation is **instantaneously imposed** → we focus on a **biophysical *upper limit*** of **TR**.
- **+12.3 Mkm^2 Tree area** (135% area of US):
  - 5.6 Mkm^2 Tropical
  - 6.0 Mkm^2 Temperate
  - 0.8 Mkm^2 Boreal



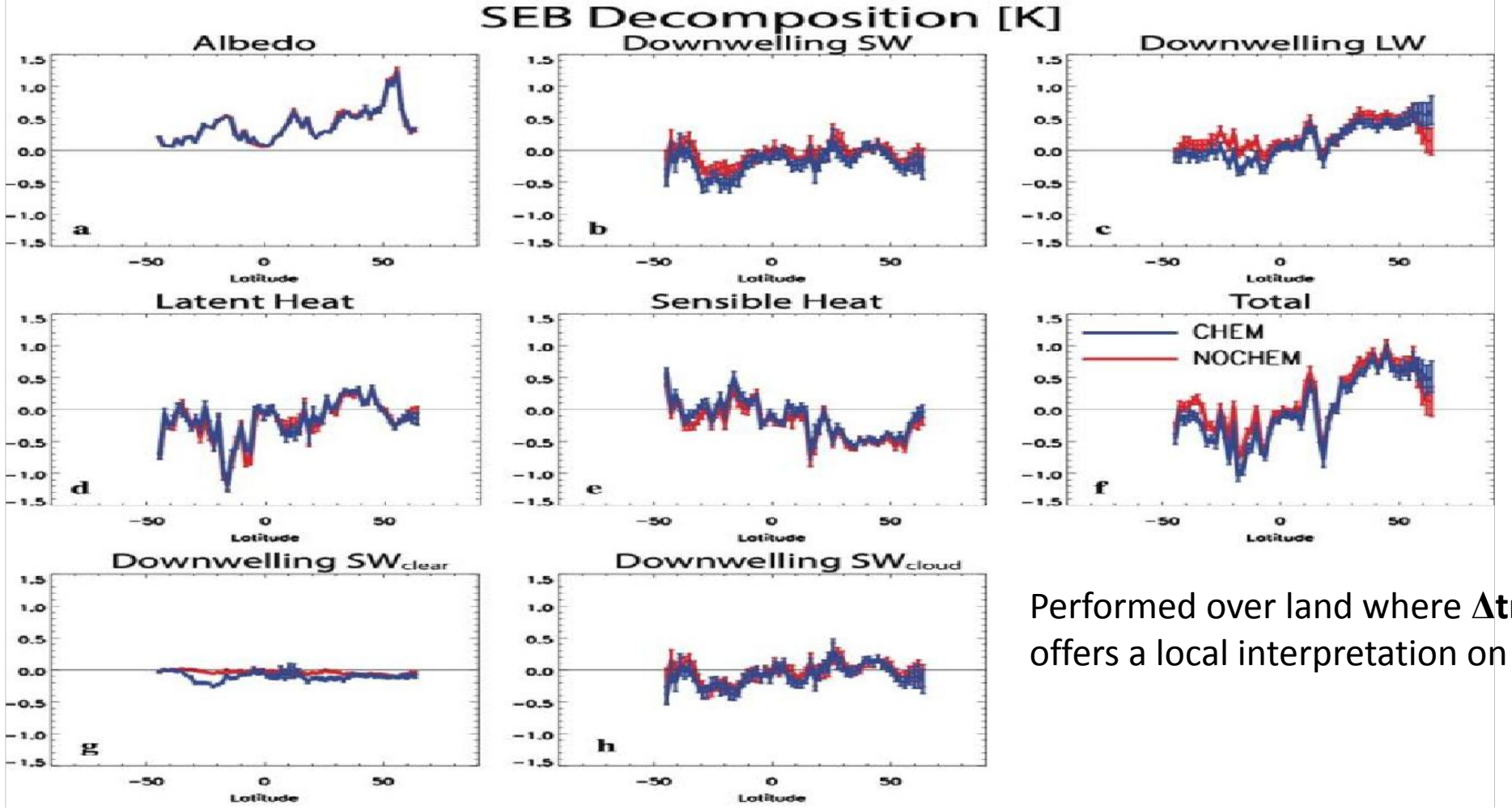
ΔNear-Surface Air Temperature [K]

Interactive Chemistry | No Interactive Chemistry | Chemistry Effects



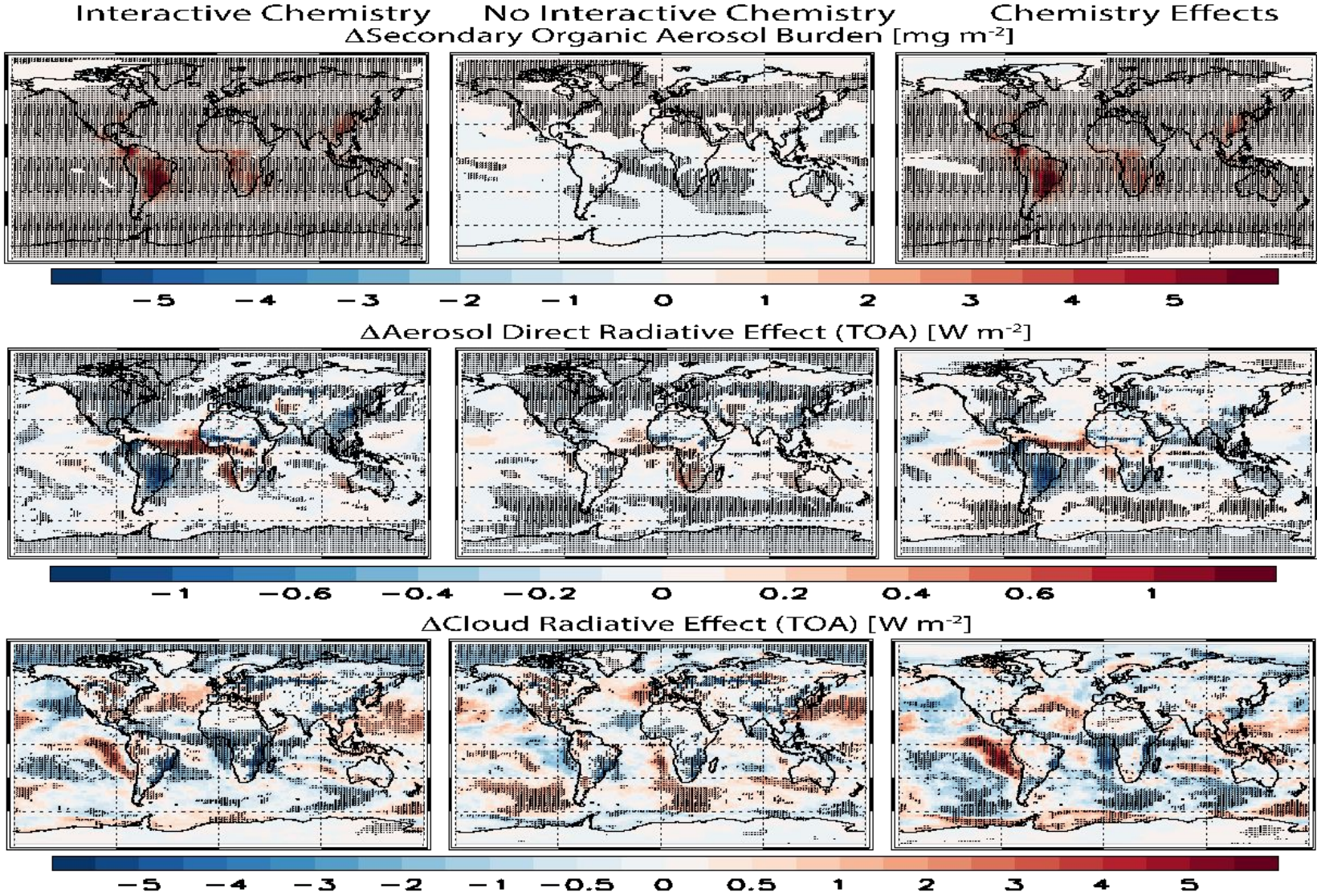
	Chemistry			No Chemistry			Chemistry Effects		
	NH	SH	GL	NH	SH	GL	NH	SH	GL
TAS	0.19 ± 0.03	−0.04 ± 0.03	0.07 ± 0.03	0.26 ± 0.03	0.11 ± 0.03	0.19 ± 0.03	−0.06 ± 0.05	−0.16 ± 0.04	−0.11 ± 0.04

- **Chemistry effects** yield **cooling**, esp. in the **SH.**

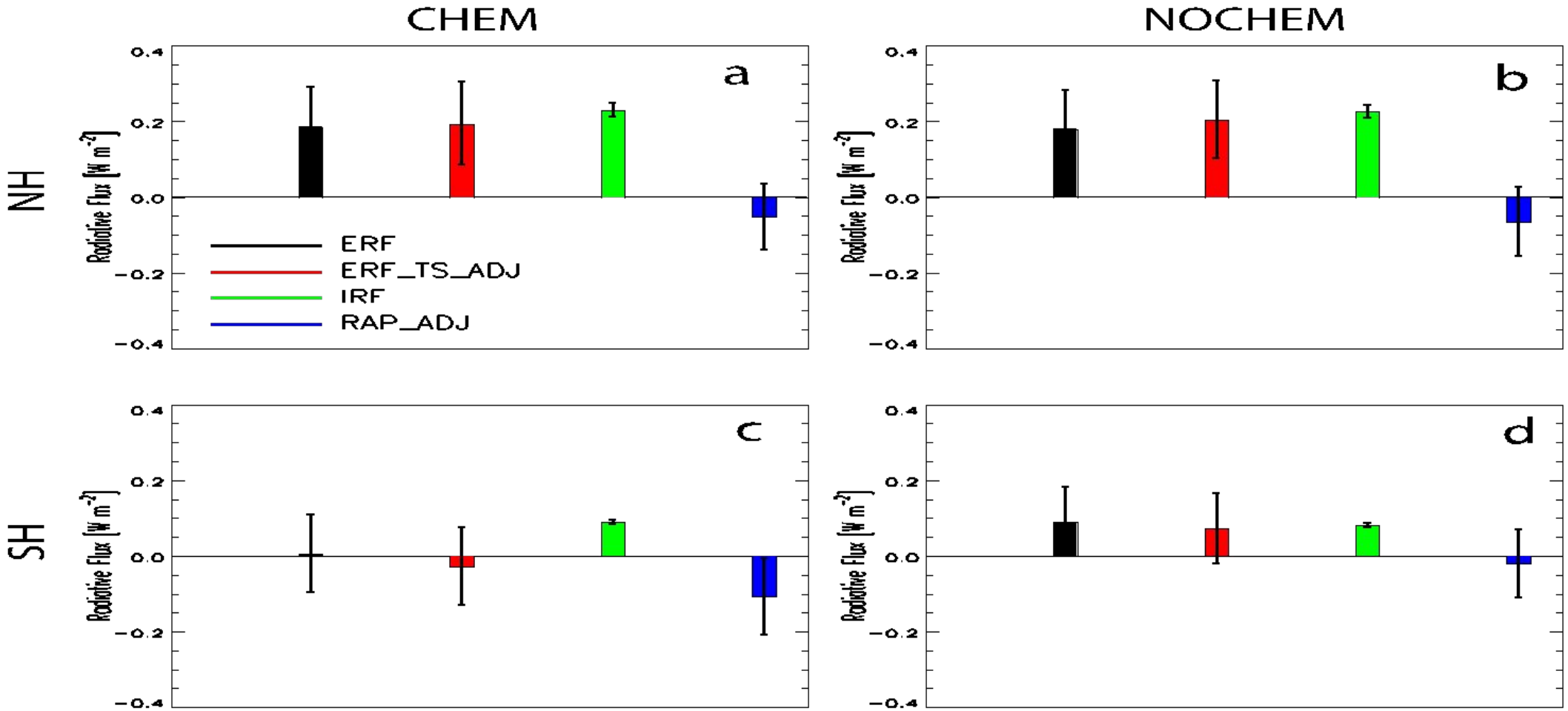


Performed over land where **Δtree_frac > 0.1** offers a local interpretation on mechanisms.

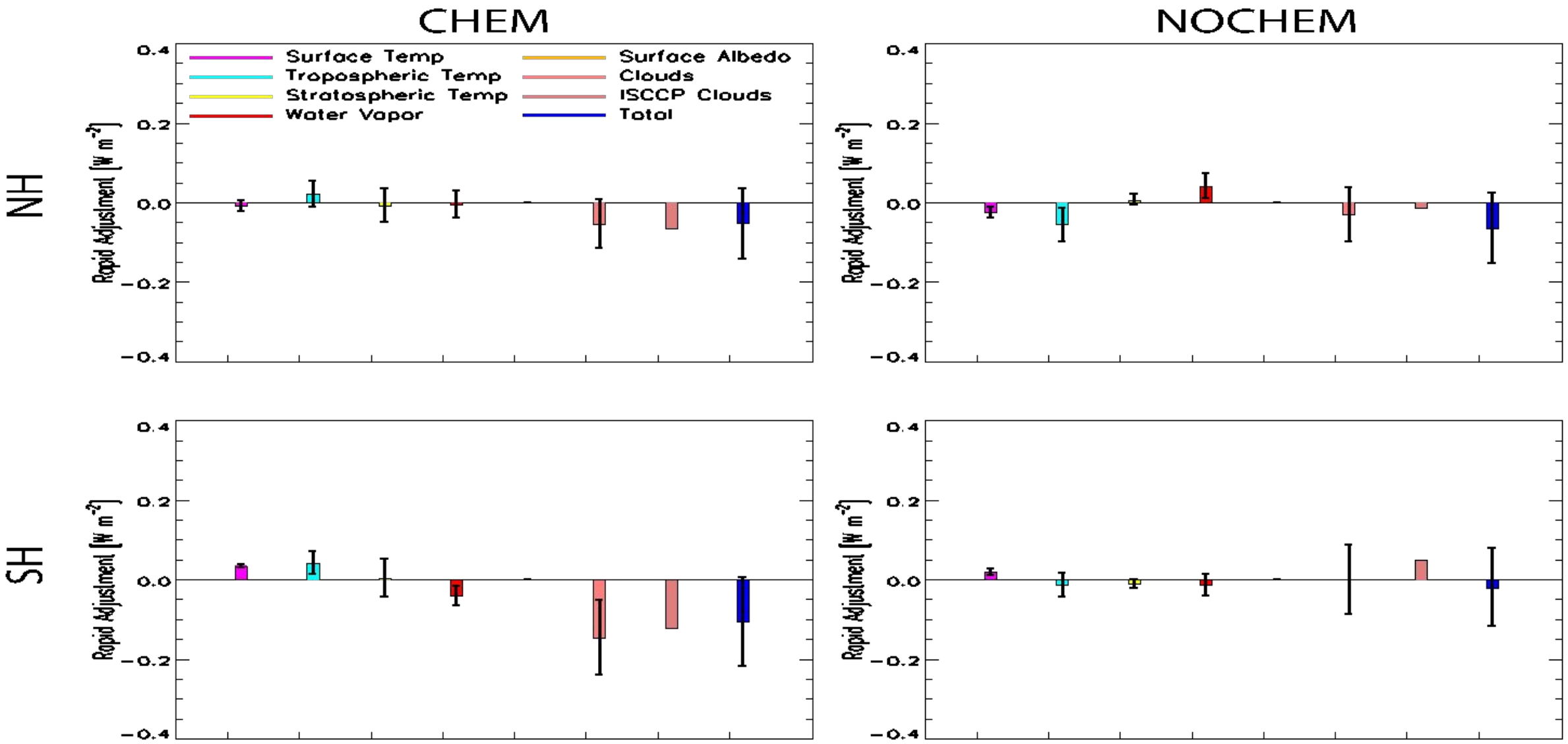
- **Warming** under both **CHEM** and **NOCHEM** largely due to **albedo term.**
- **LH/SH terms net cooling** under **CHEM and NOCHEM Strong LH cooling** in SH.
- ***Stronger* cooling** under **CHEM** due to ***larger* decrease** in **downwelling SW**.
  - ***Stronger* SW cooling** under **clear skies** for **CHEM**.
  - Clouds tend be associated with **SW cooling** under both **CHEM** and **NOCHEM**.



- Consistent with the ***reduced*** **NH warming** & **SH cooling, CHEM** yields:
  - **Increases** in **BVOCs** and **SOA**, esp. in SH Tropics.
  - **Larger negative Aerosol Direct Radiative Effect** over land (e.g., South America, US).
  - **Larger negative Cloud Radiative Effect,** esp. over SH oceans (outside of eastern Tropical Pacific).

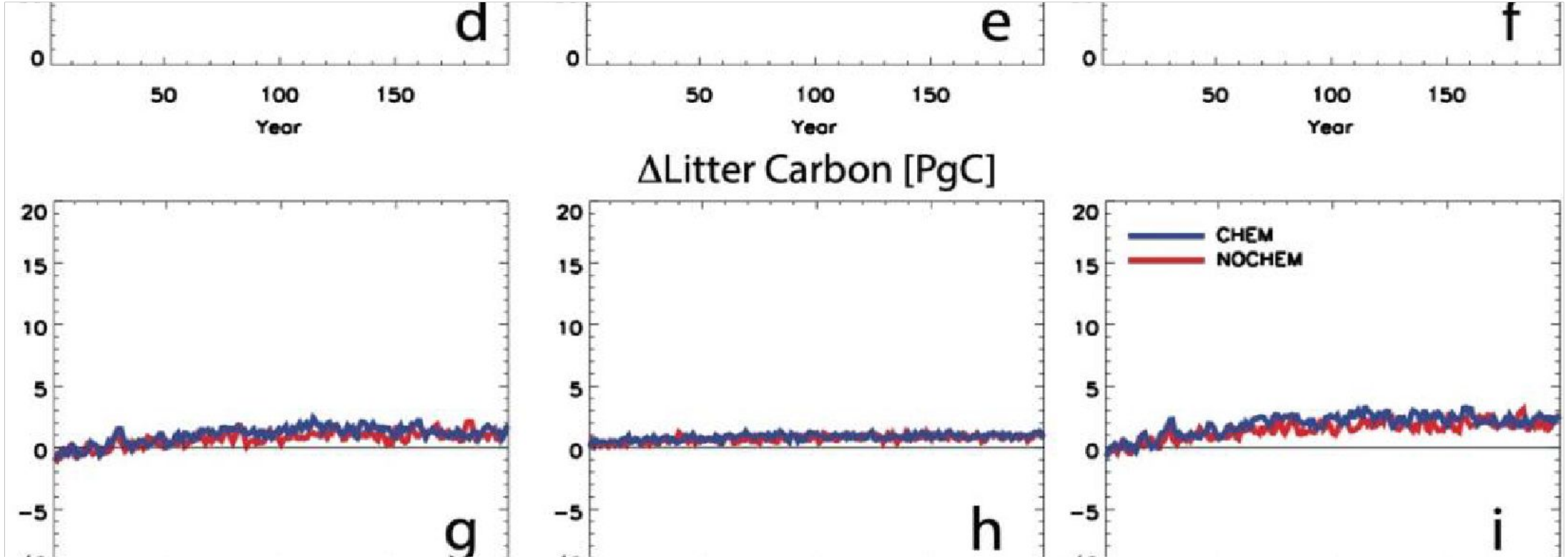


- **NH warming** is consistent with a **positive ERF** under both **CHEM** and **NOCHEM**.
  - Largely due to the **positive IRF** (from the **surface albedo radiative kernel**).
- **Similar statements** generally apply in the **SH** under **NOCHEM**.
- **SH cooling** under **CHEM** consistent with a ***relatively large*** **negative RAP_ADJ**.
  - Offsets **positive IRF**, leading to a ***negligible*** **ERF.**
  - Weakly **negative surface temperature adjusted ERF**.



- **Radiative kernels** to ***decompose*** **RAP_ADJ** into its components.
- **Negative RAP_ADJ** under **CHEM** in the **SH** is largely due to clouds.
  - Consistent results w/ **kernel difference method** and the **ISCCP simulator**.

Biogeochemical Cooling Dominates



- Both **CHEM** and **NOCHEM** yield similar ***increases*** in **land carbon storage**.
- The best estimate of the **TCRE** is 1.65 (1.0 to 2.3) K per 1000 PgC (Canadell et al., 2021).
- **CHEM** and **NOCHEM** yield ***similar estimates*** of **biogeochemical cooling**:
  - **CHEM □ -0.35 (-0.21 to -0.48) K.** (**biogeophysical warming** is **0.07+/-0.03 K**)
  - **NOCHEM □ -0.33 (-0.20 to -0.45) K.** (**biogeophysical warming** is **0.19+/-0.03K**)

Summary

- **Tree restoration** leads to **global mean cooling** due to **biogeochemical effects**.
- **Cooling *muted*** by **biogeophysical effects**, largely **surface darkening**.
- **Biogeophysical effects *mute* 58%** of the **biogeochemical cooling** under **NOCHEM**.
- **Biogeophysical effects mute 20%** of the **biogeochemical cooling** under **CHEM** □ ***increases*** to **31%** when **methane effects** are accounted for.
- Including **interactive chemistry** yields **larger net cooling** under **tree restoration**, largely associated with ***enhanced* SOA** and **cloud responses**.
- Strong **hemispheric asymmetries** due in part to **chemistry effects**:
  - **Biogeophysical cooling** in the **SH** under **CHEM**.

The End