Massachusetts Institute of Technology

SPARK CLIMATE SOLUTIONS

Diagnosing the OH response to ENSO and its underlying drivers

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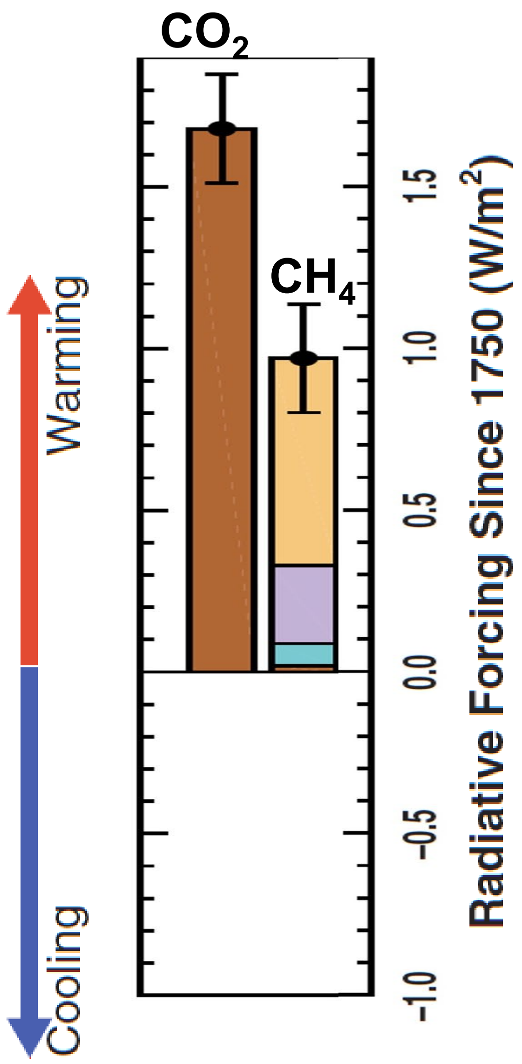
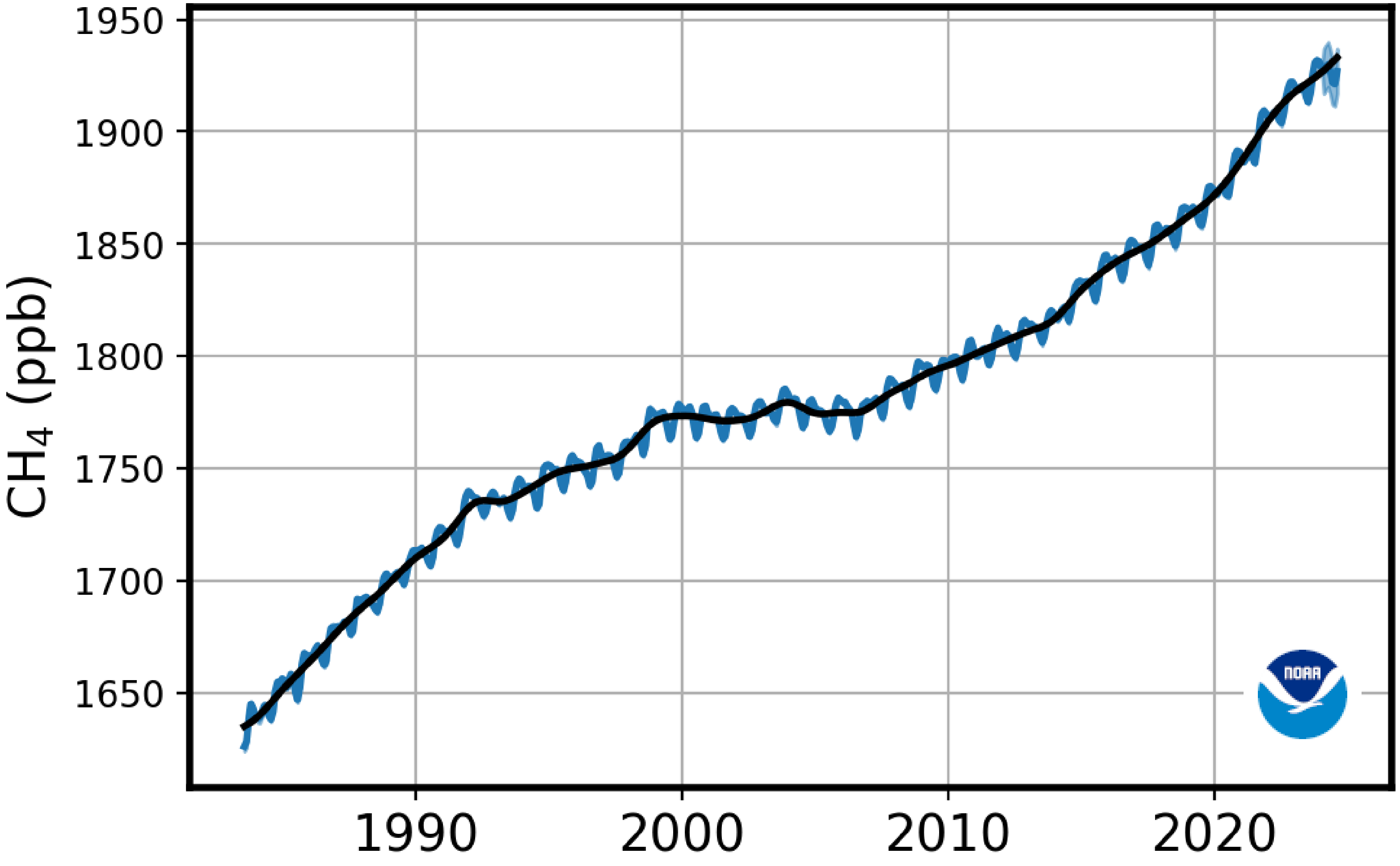
1. MIT; 2. Columbia University; 3. NCAR

OH is the key to interpreting the historical methane trend

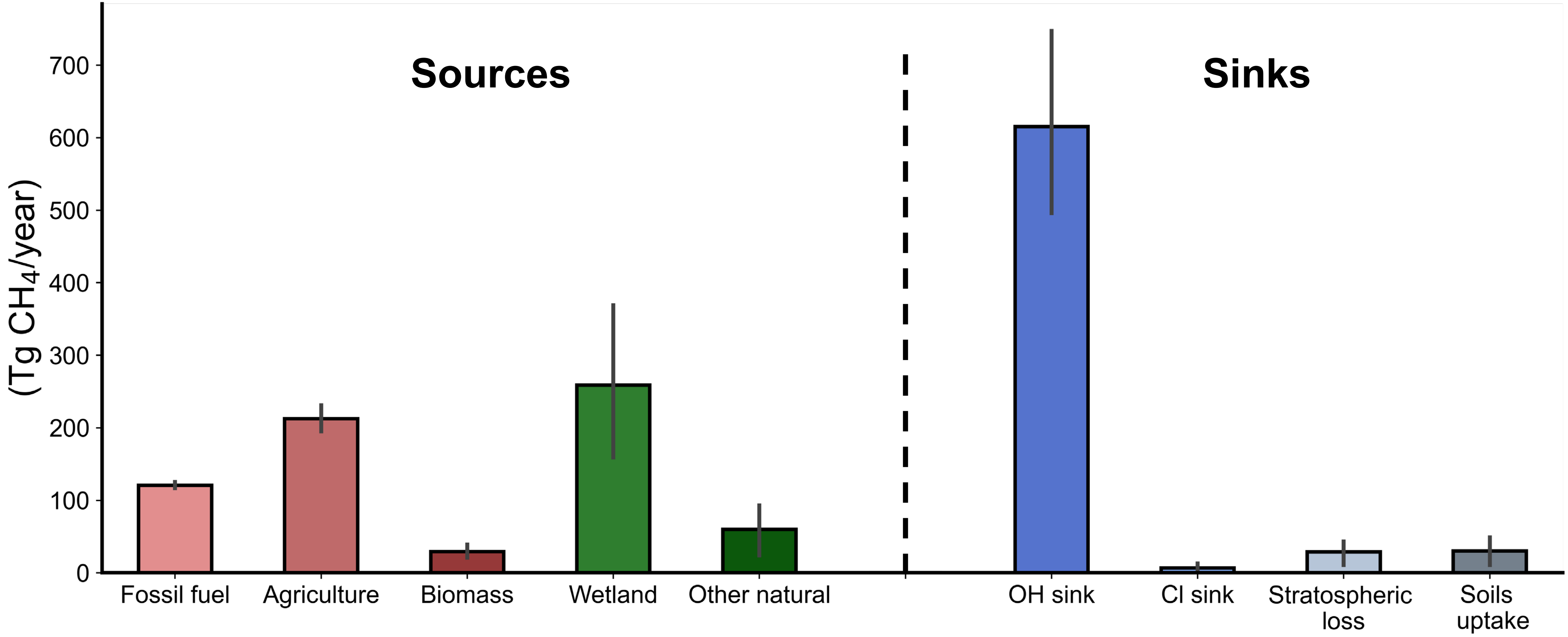




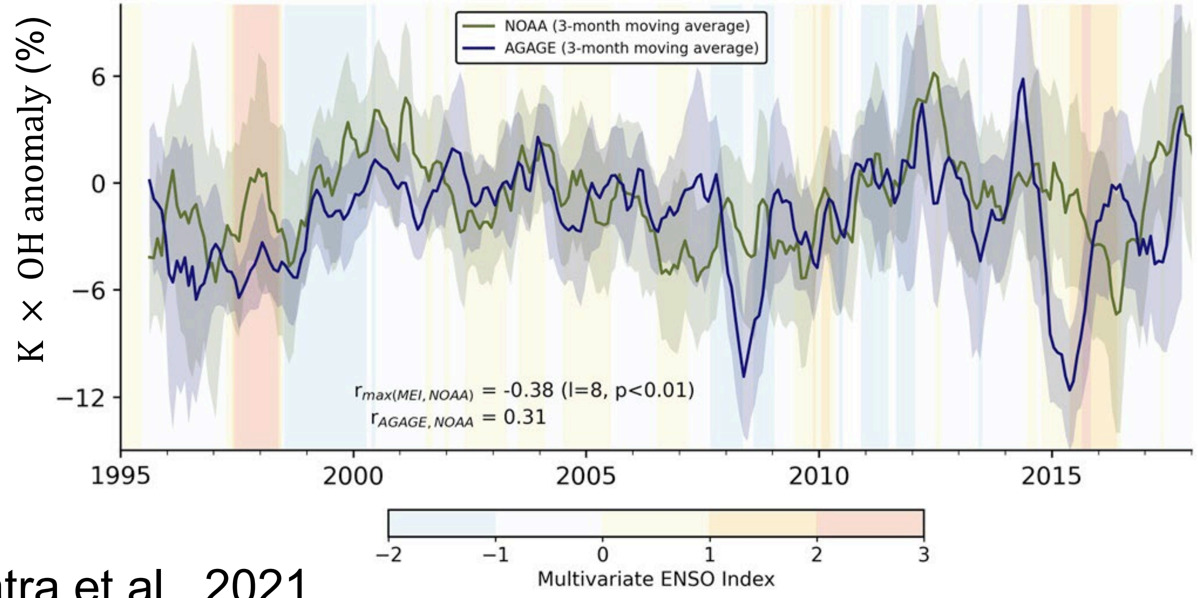
Adapted from Fiore et al., 2015; IPCC 2021

OH is the key to interpreting the historical methane trend

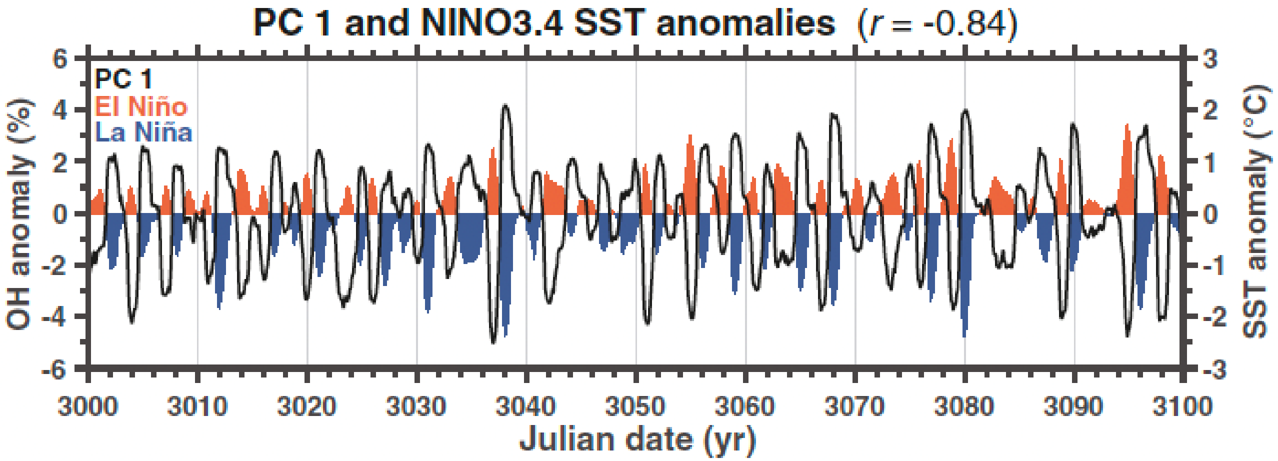
➢ **Reaction with OH contributes to ~90% of total CH_4 loss.**



Interannual OH variability is likely linked to ENSO



Patra et al., 2021



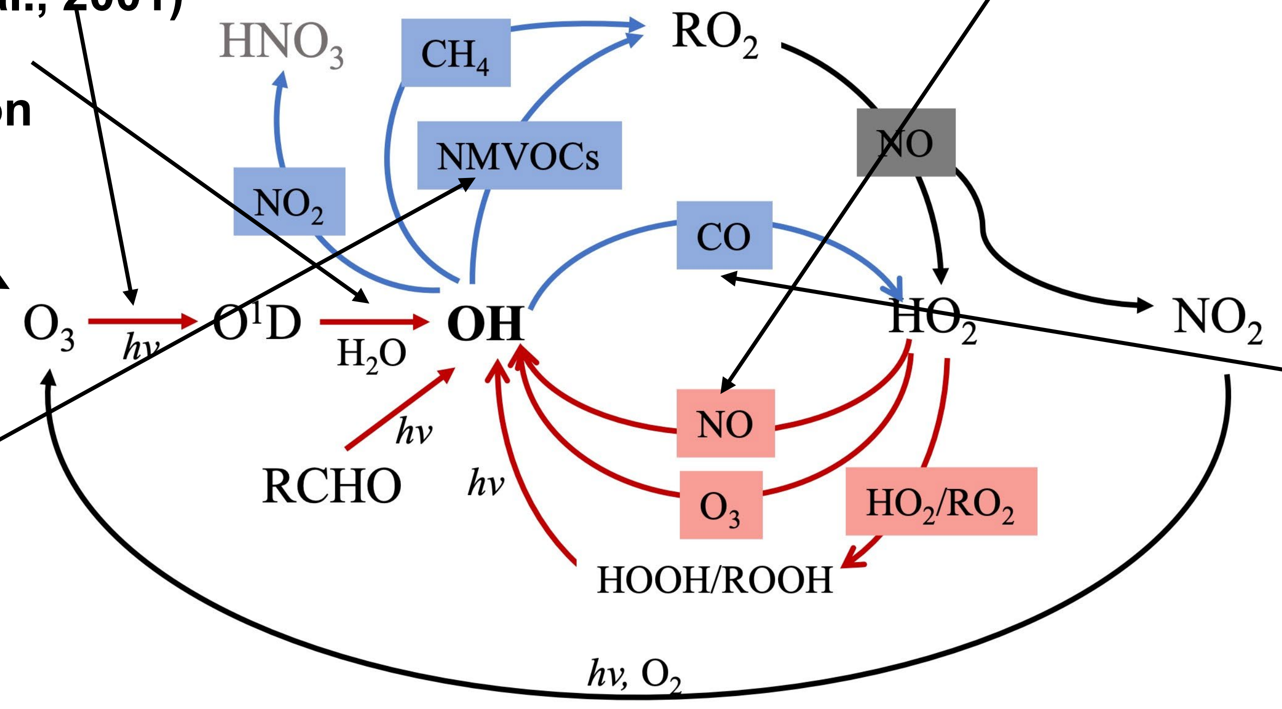
Turner et al., 2018

- **OH indirectly estimated by methyl chloroform (MCF) observations.**
- **Interannual variations in OH anomaly are related in part to ENSO variability.**
- **OH simulation in absence of external forcing.**
- **ENSO is the dominant mode of OH variability.**

Potential drivers of the OH response to ENSO

- **Lightning NO emissions (Turner et al., 2018)**

- **Meteorological factors:**
  - **Cloud cover (Prinn et al., 2001)**
  - **Moistening**
  - **Atmospheric circulation**

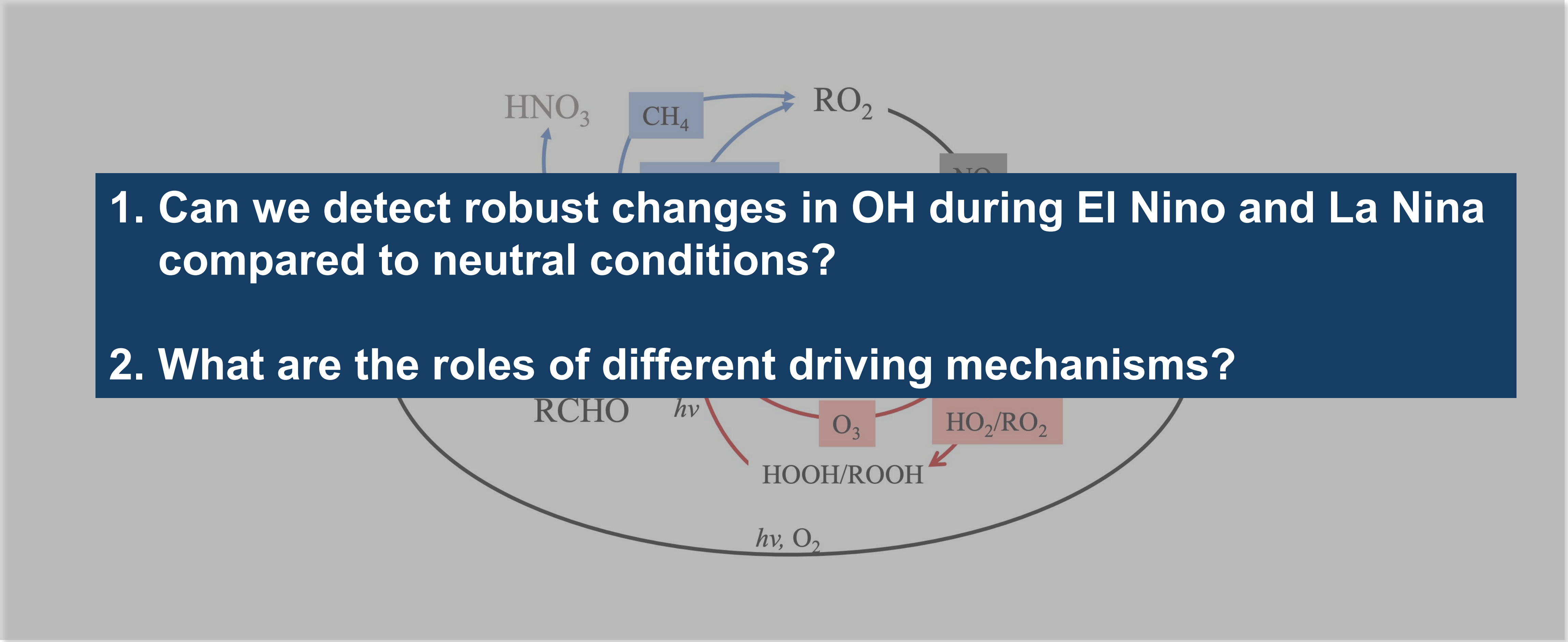


- **Biomass burning emissions (Prinn et al., 2005)**

- **BVOC emissions**

Competing? Amplifying? Offsetting?

Potential drivers of the OH response to ENSO

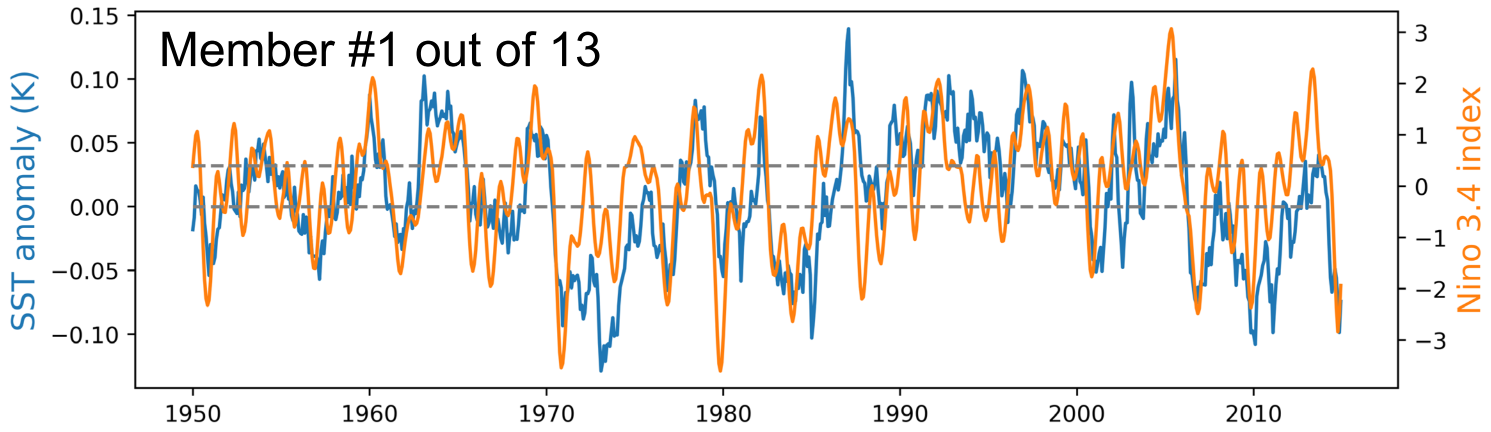


1. Can we detect robust changes in OH during El Nino and La Nina compared to neutral conditions?

2. What are the roles of different driving mechanisms?

Composite SST patterns under ENSO phases

- **13-member initial condition CESM2-WACCM6 ensemble**



$$SST\ anomaly_i = SSTi - \sum_{i=1}^{13} SST_i/13$$

- El Nino: Nino 34 > 0.4
- Neutral: -0.4 <= Nino 34 <= 0.4
- La Nina: Nino 34 < -0.4

Composite SST patterns under ENSO phases

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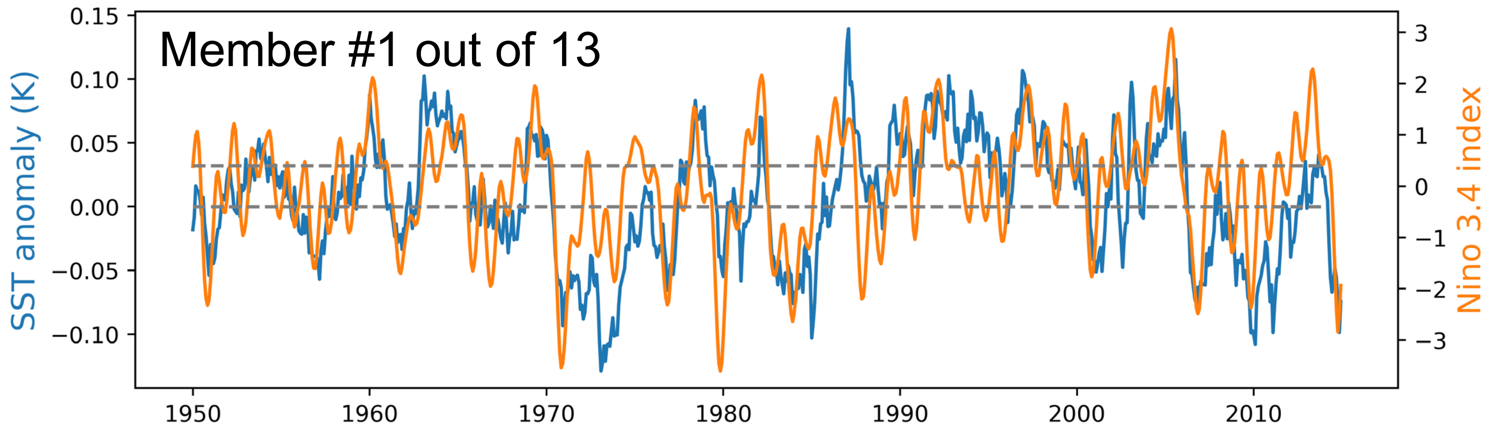

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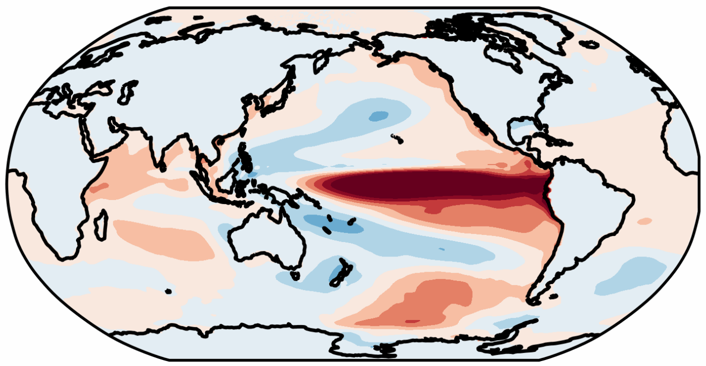
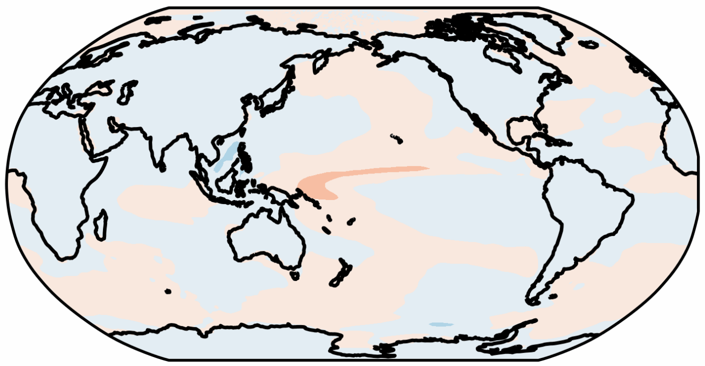
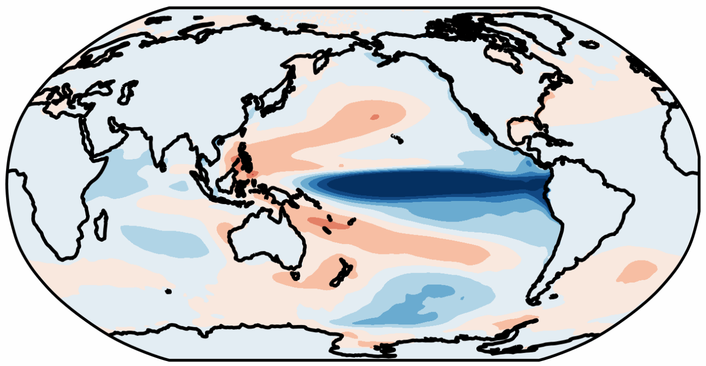
El Nino



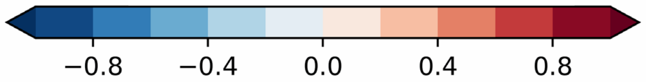
Neutral



La Nina



SST anomaly (K)



Mechanism denial experiments using CAM-Chem

Scenario	SST pattern	Lightning NO_x	Biogenic VOC (BVOC) emissions
Met + LNO + BVOC (CAM-Chem default)	El Nino La Nina Neutral	Parameterization based on cloud top height	MEGAN scheme

- **Drivers of OH Chemistry response to ENSO:**

1. Meteorological factors

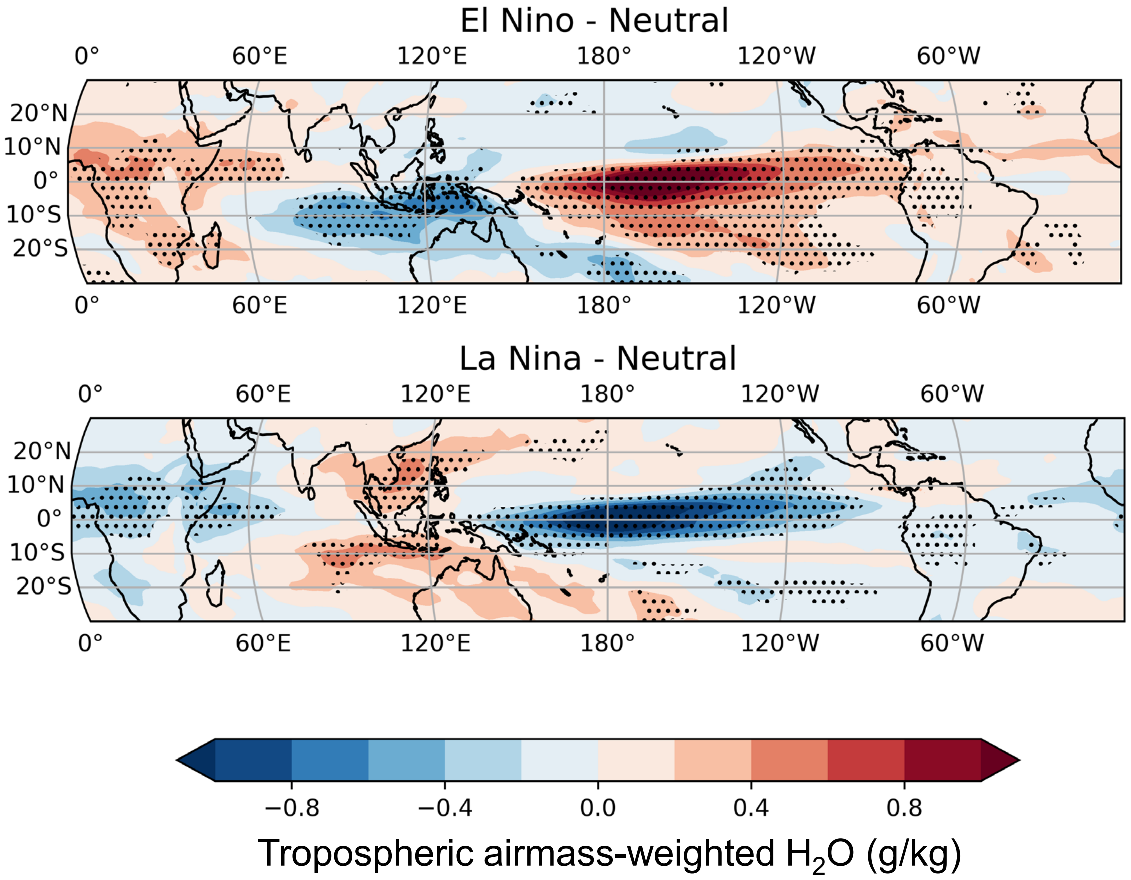
2. Lightning NO_x emissions

3. BVOC emissions

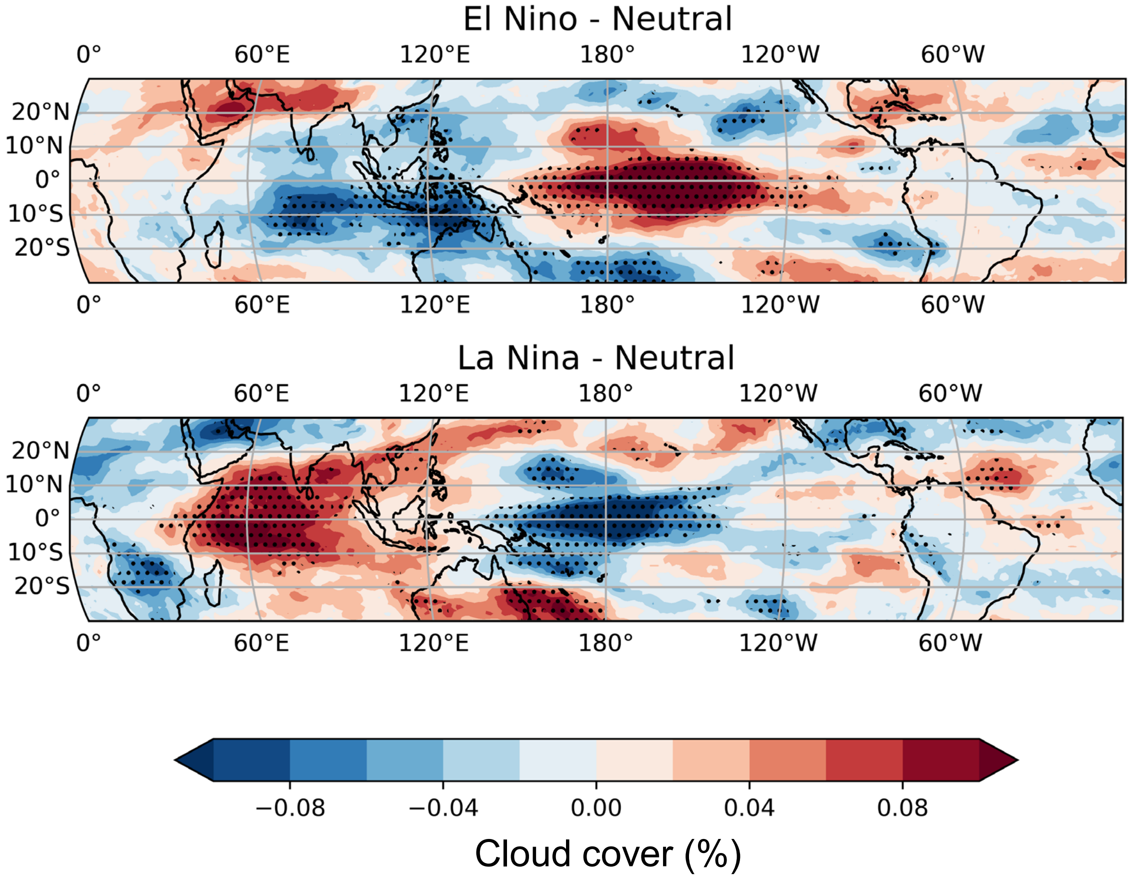
- **Each simulation is run for 7 years to assess the impact of atmospheric variability.**

Changes in cloud cover and water vapor during ENSO are significant in the lower latitudes (30S-30N)

➢ Changes in H_2O are consistent with SST anomalies.

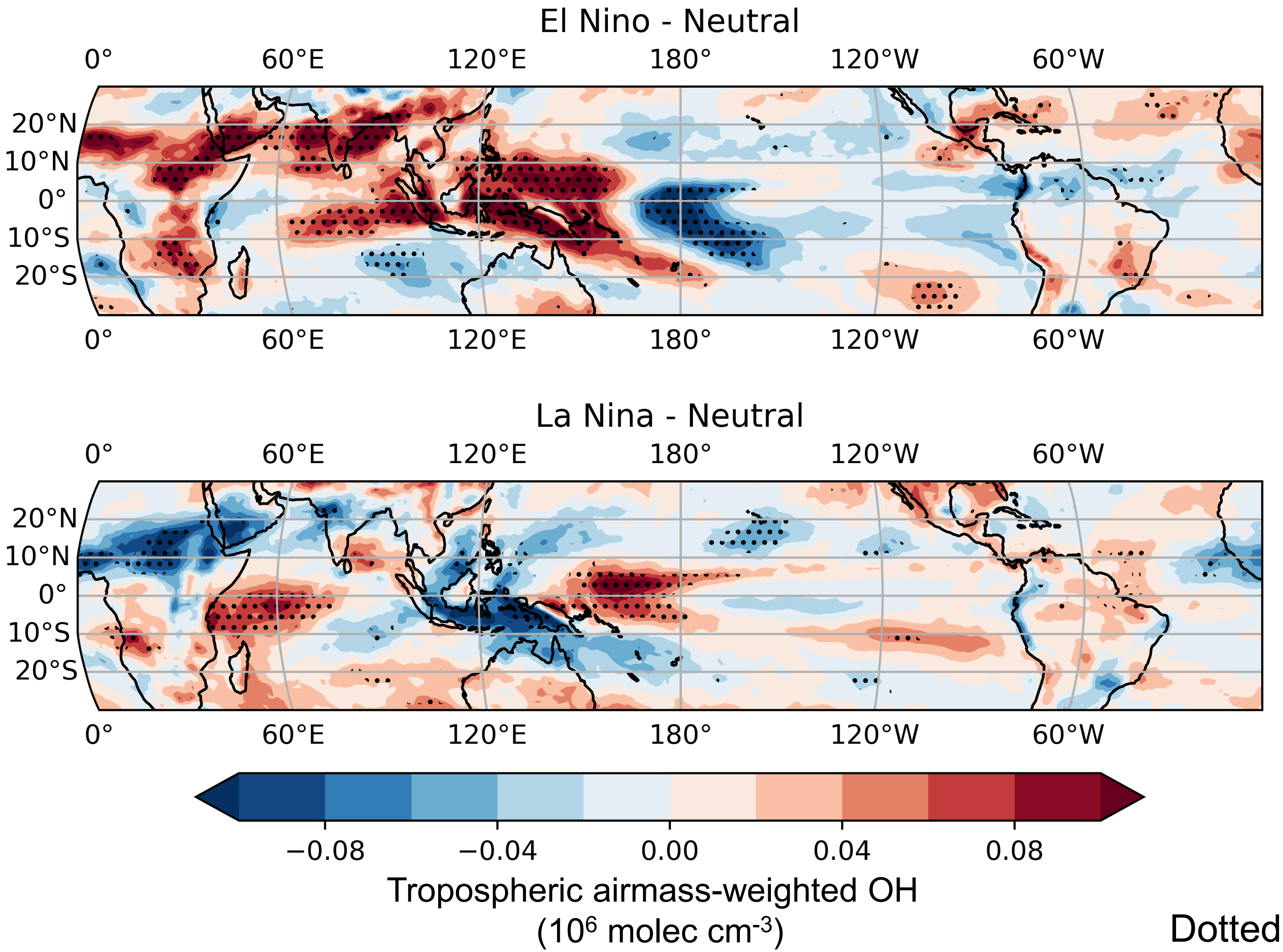


➢ Changes in cloud cover are driven by the shifts of convection.



Dotted region: significant at 90^{th} confidence level

Direct meteorological changes during ENSO increase OH by 7% over Indonesia



- ➢ Insignificant changes in OH at the global scale.

Dotted region: significant at 90^{th} confidence level

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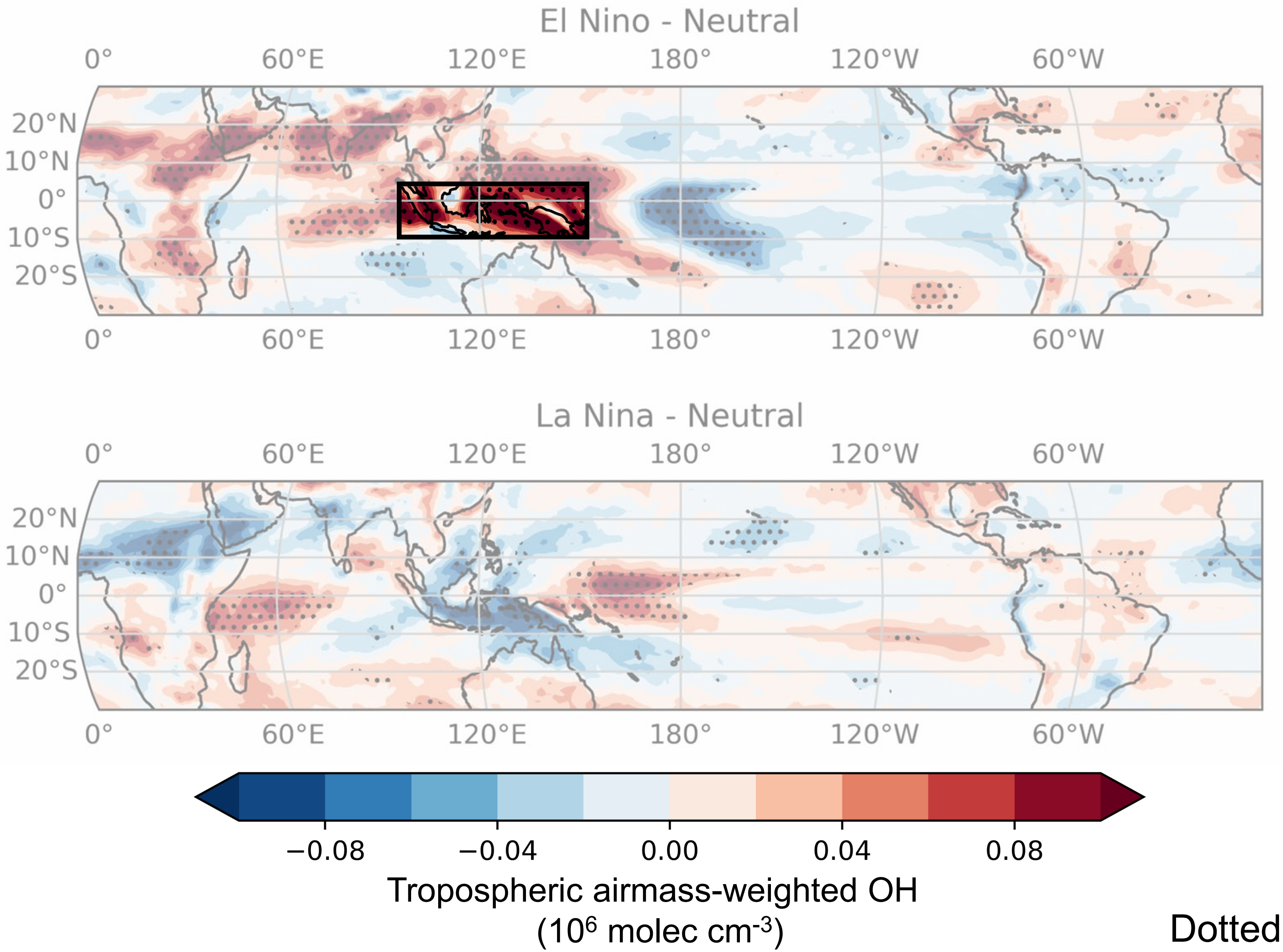

- Insignificant changes in OH at the global scale.
- El Nino: OH increases by 7% over Indonesia.

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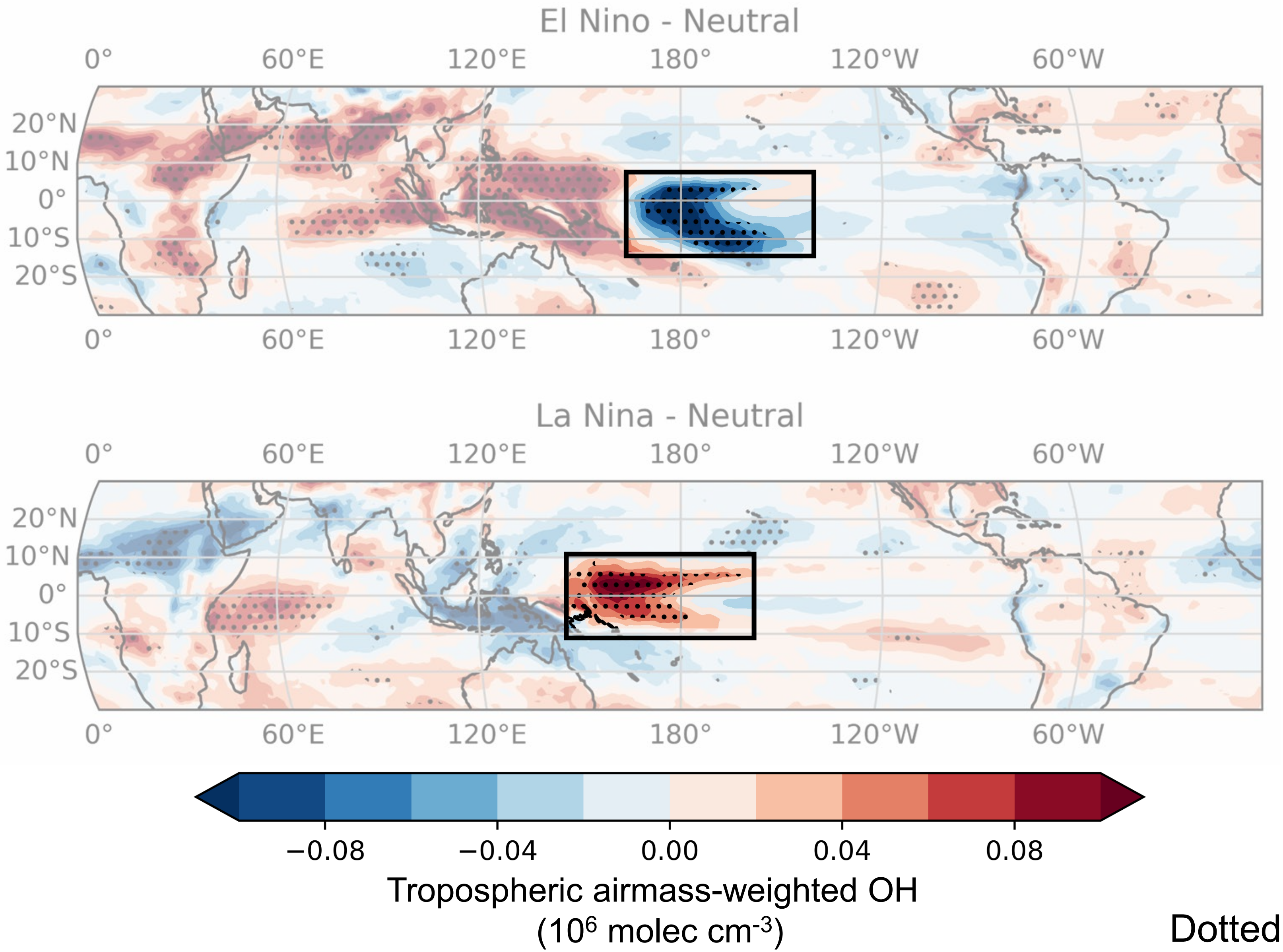
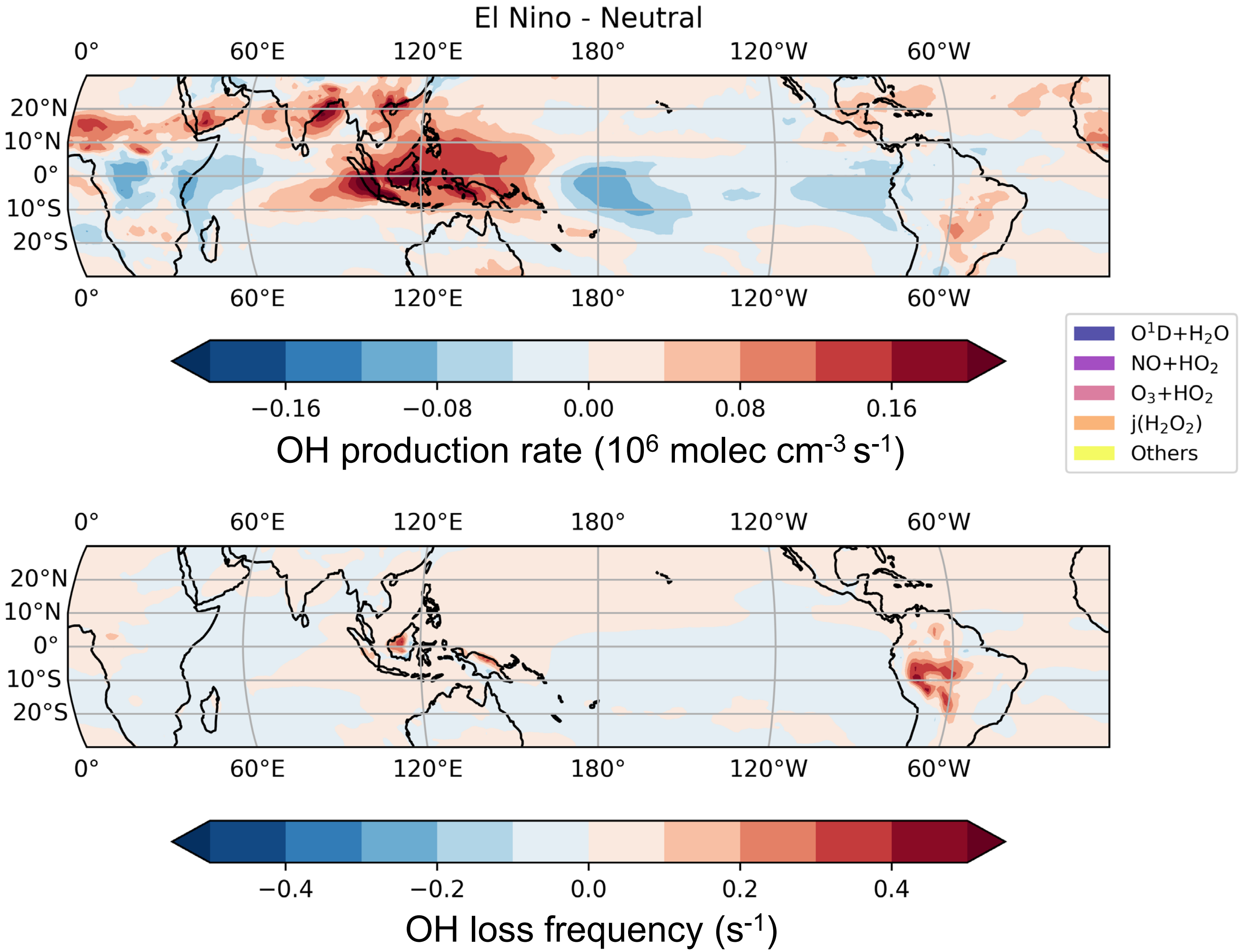


- Insignificant changes in OH at the global scale.
- El Nino: OH increases by 7% over Indonesia.
- El Nino vs La Nina: opposite changes in OH over Indonesia and tropical Pacific.

Dotted region: significant at 90th confidence level

During El Nino, the OH increase over Indonesia is driven by the OH primary production pathway



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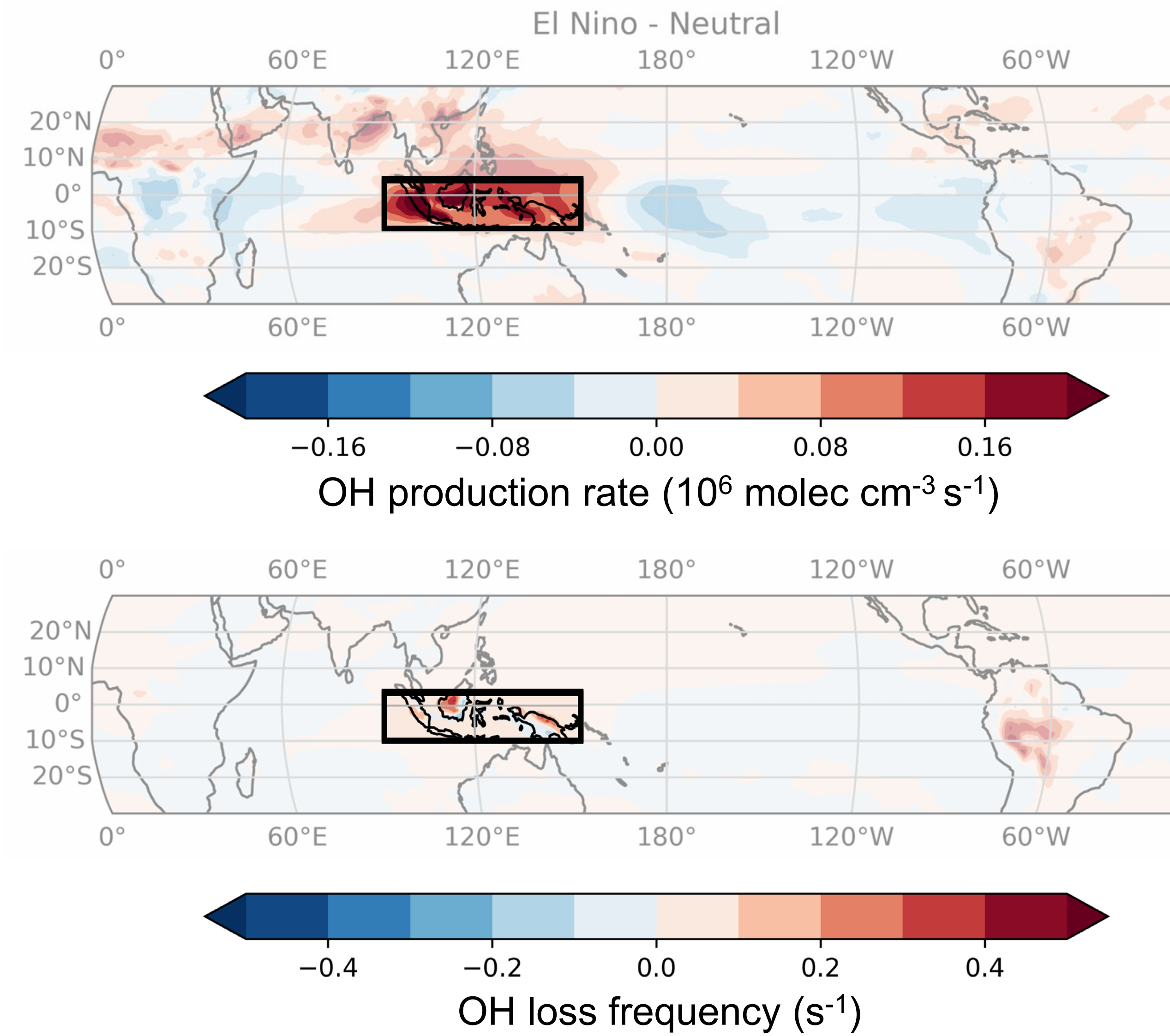
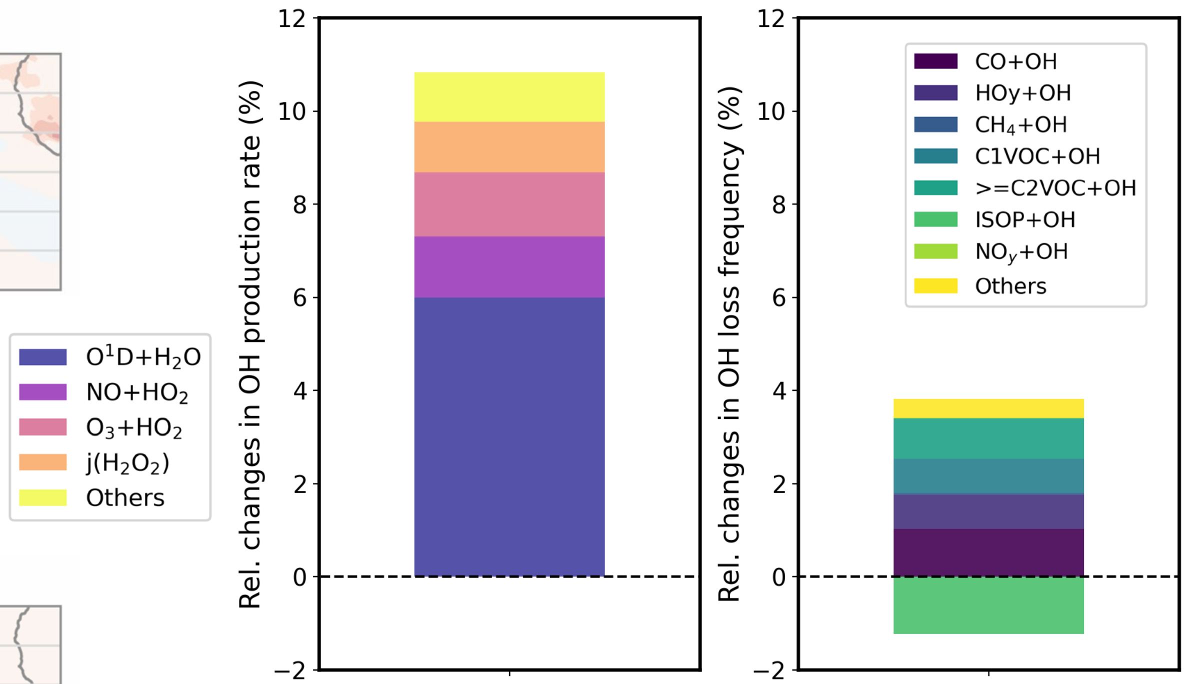
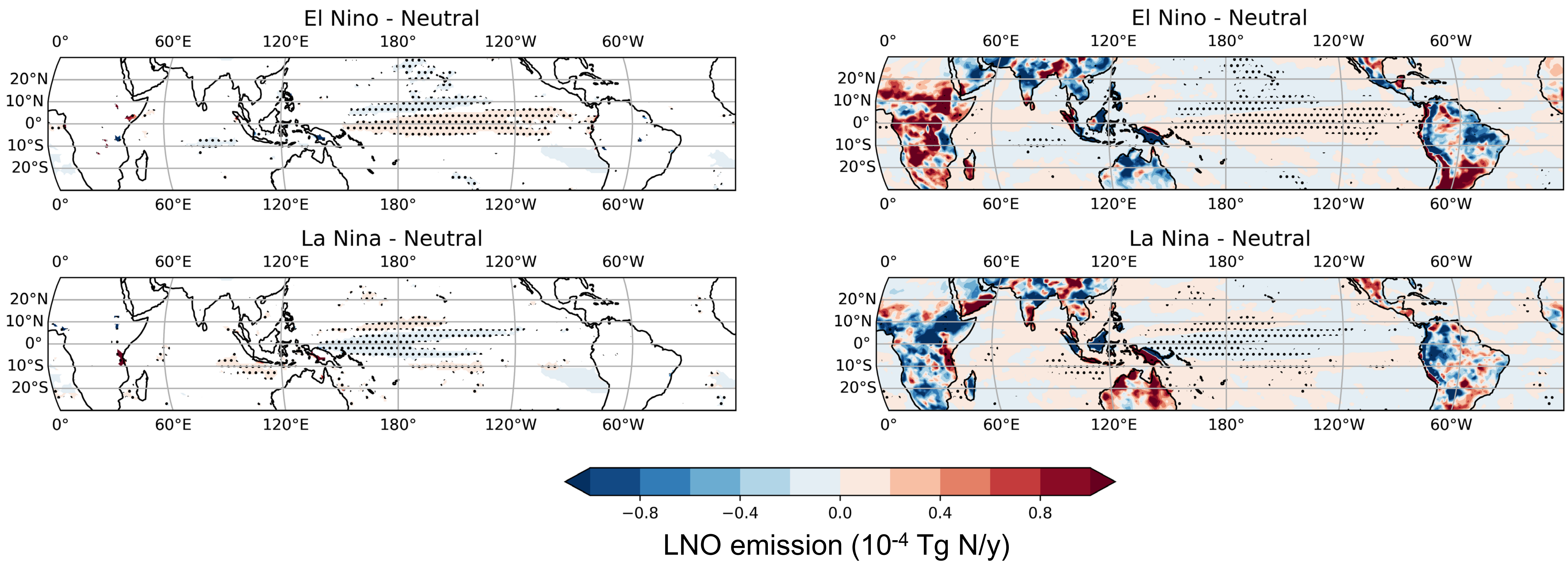




- During El Nino, total OH production rate increase by 10.8%.
- Increase in OH primary production rate attributes to15.6% increase of O_3 and 4.3% reduction of H_2O.

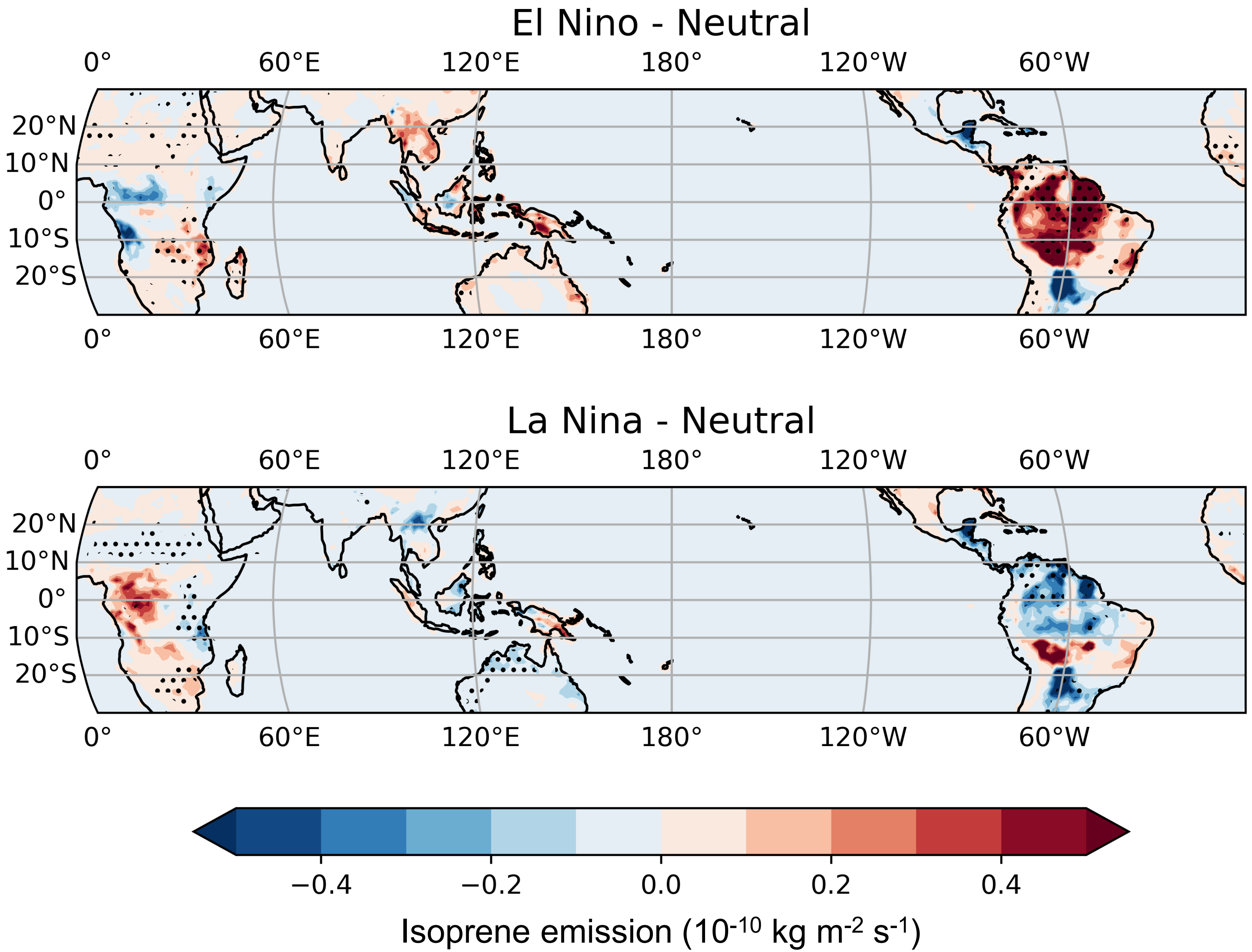
Changes in lightning NO (LNO) emissions during ENSO are subject to atmospheric variability, leading to insignificant changes in OH

- Changes in LNO emissions during ENSO are significant over the tropical Pacific.
- However, variations in LNO emissions driven by atmospheric variability are much larger over land.

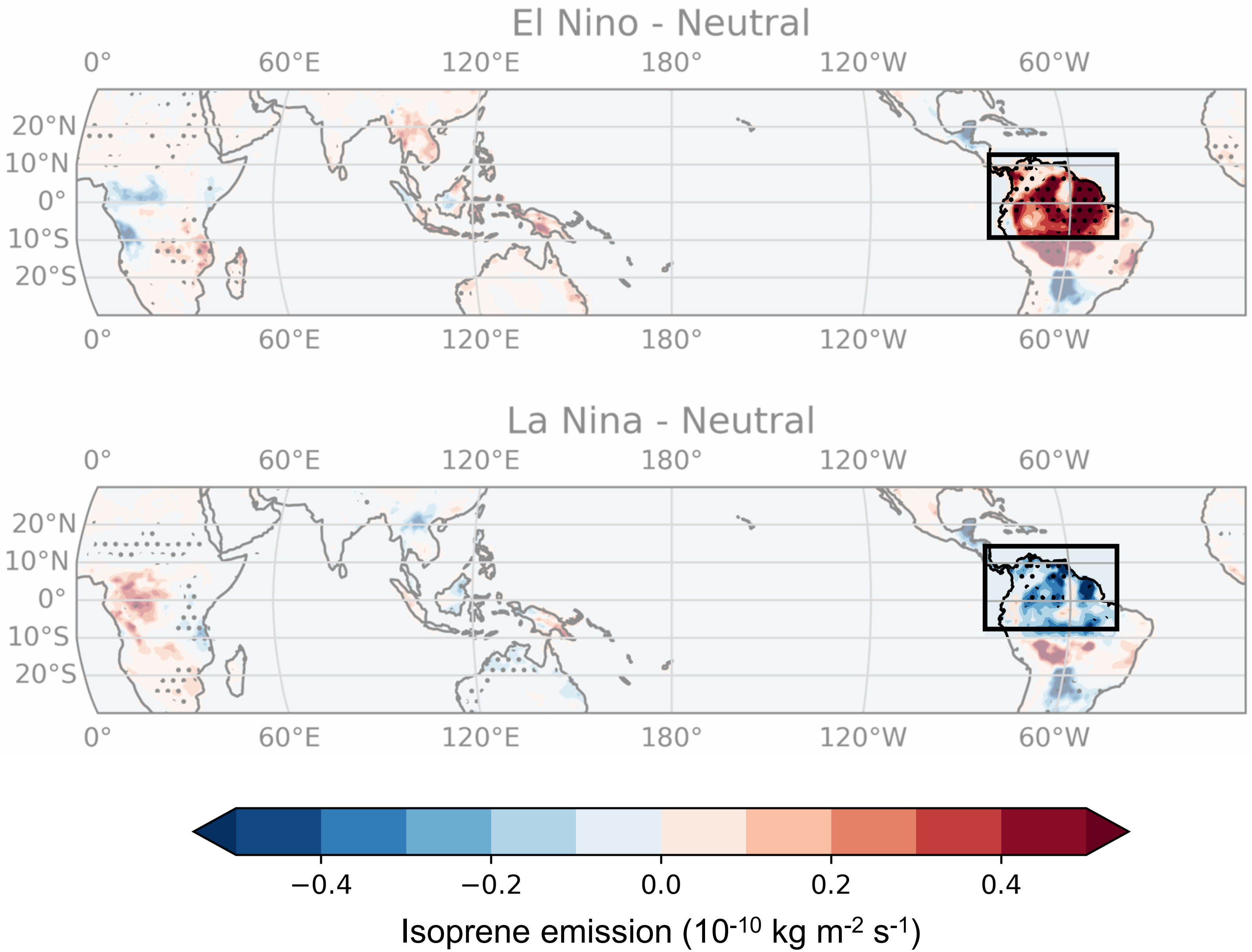


- **Changes in LNO emissions during ENSO lead to insignificant impacts on OH, both globally and locally.**

Changes in BVOC emission during ENSO are significant over tropical South America

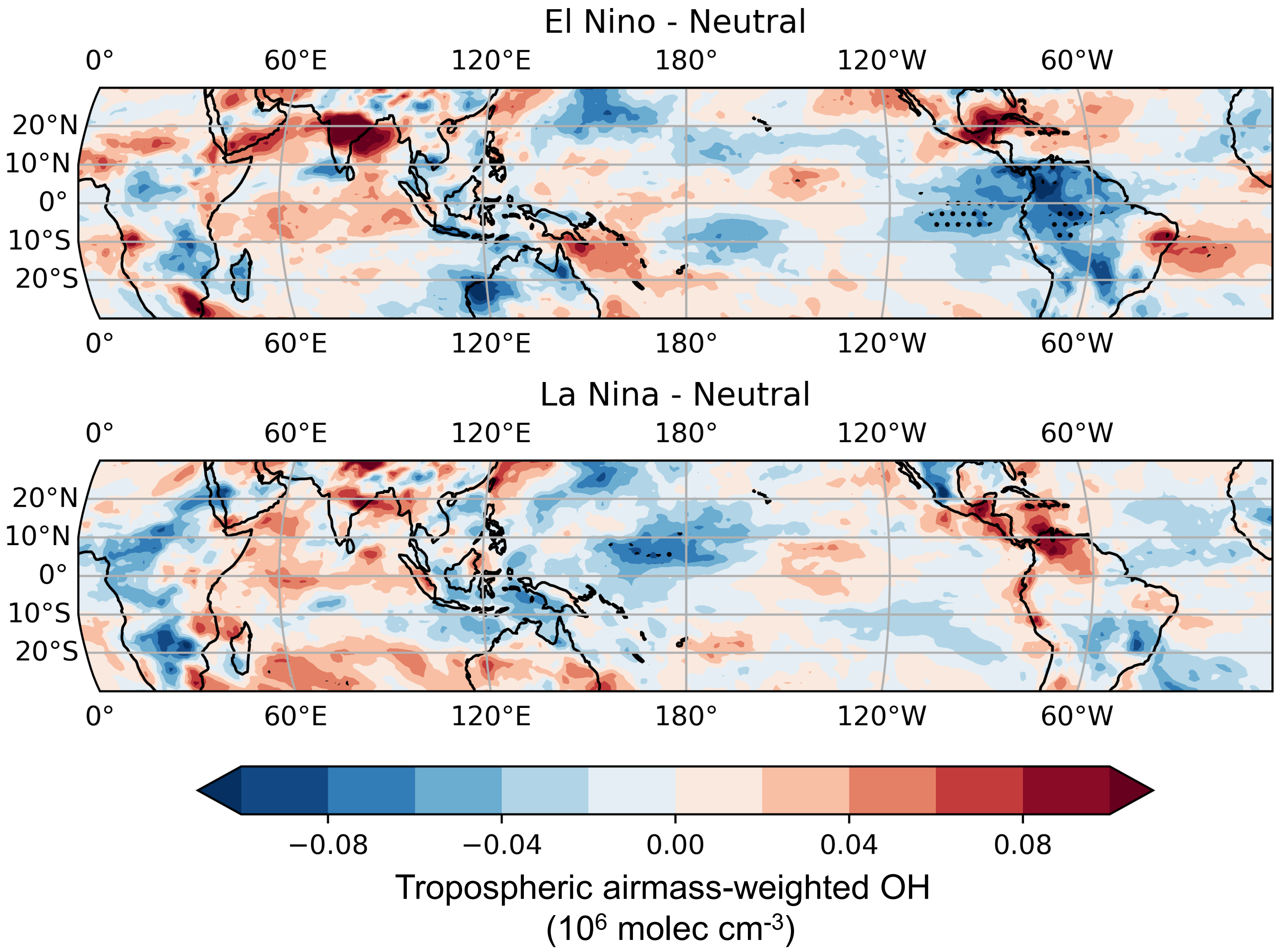


Changes in BVOC emission during ENSO are significant over tropical South America



- Over tropical South America, isoprene emissions increase by 7.7% during El Nino and decrease by 2.2% during La Nina.

Significant impacts on OH due to BVOC emissions during ENSO over tropical South America



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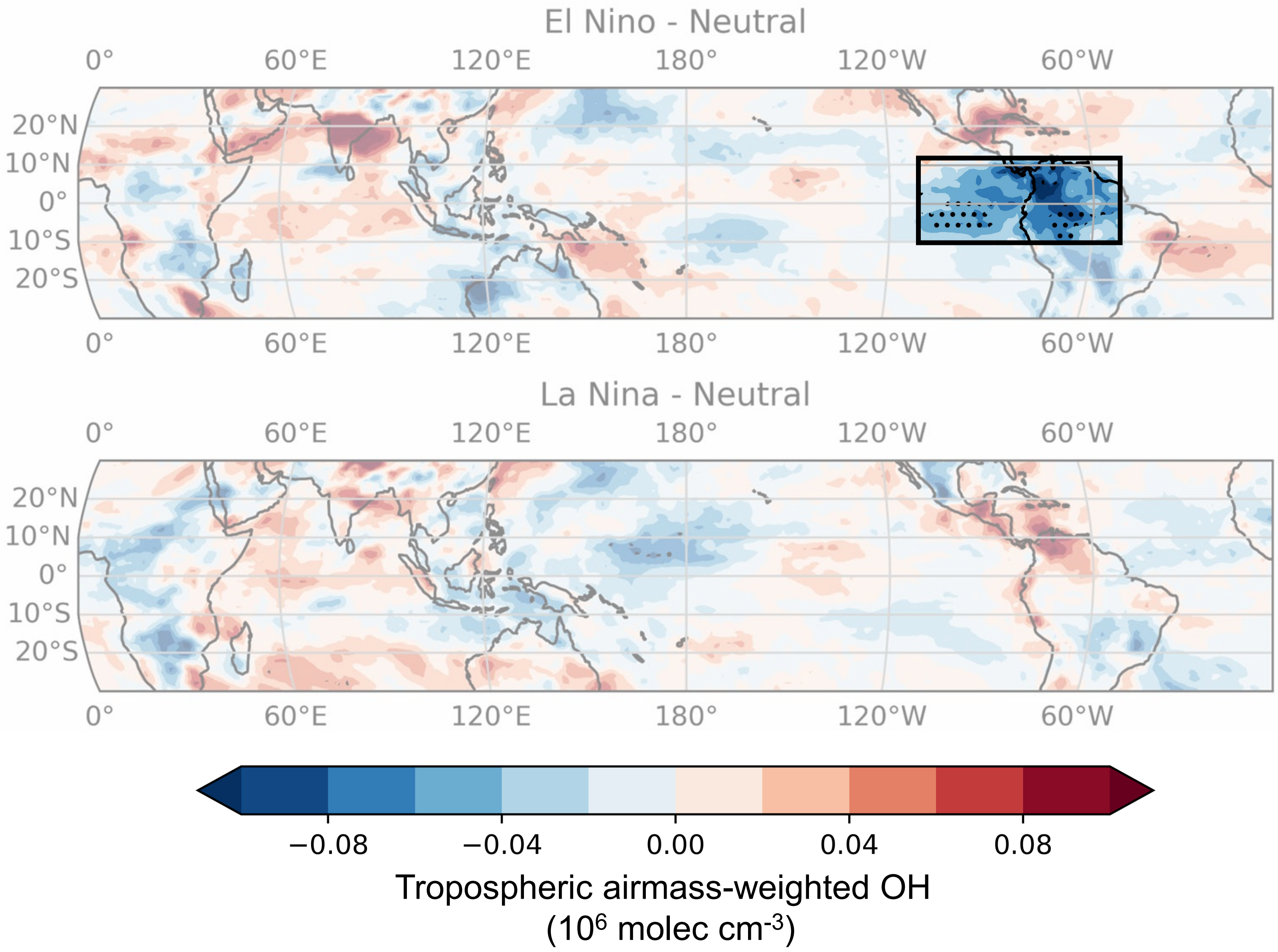
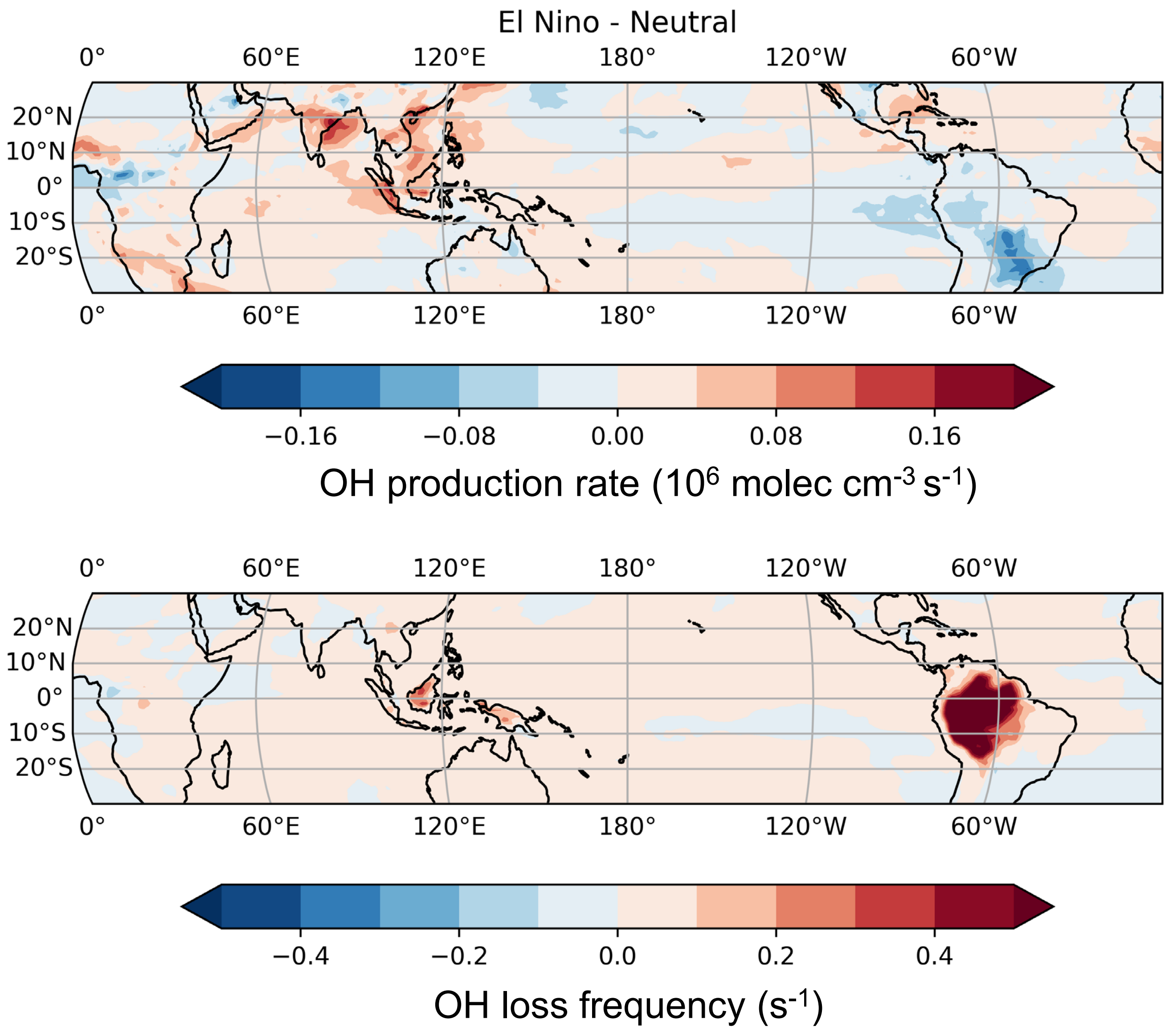


- OH decreases by 2.8% due to BVOC emissions over tropical South America during El Nino.
- No significant changes in OH during La Nina.

During El Nino, the OH reduction due to BVOC emissions is driven by the OH loss frequency



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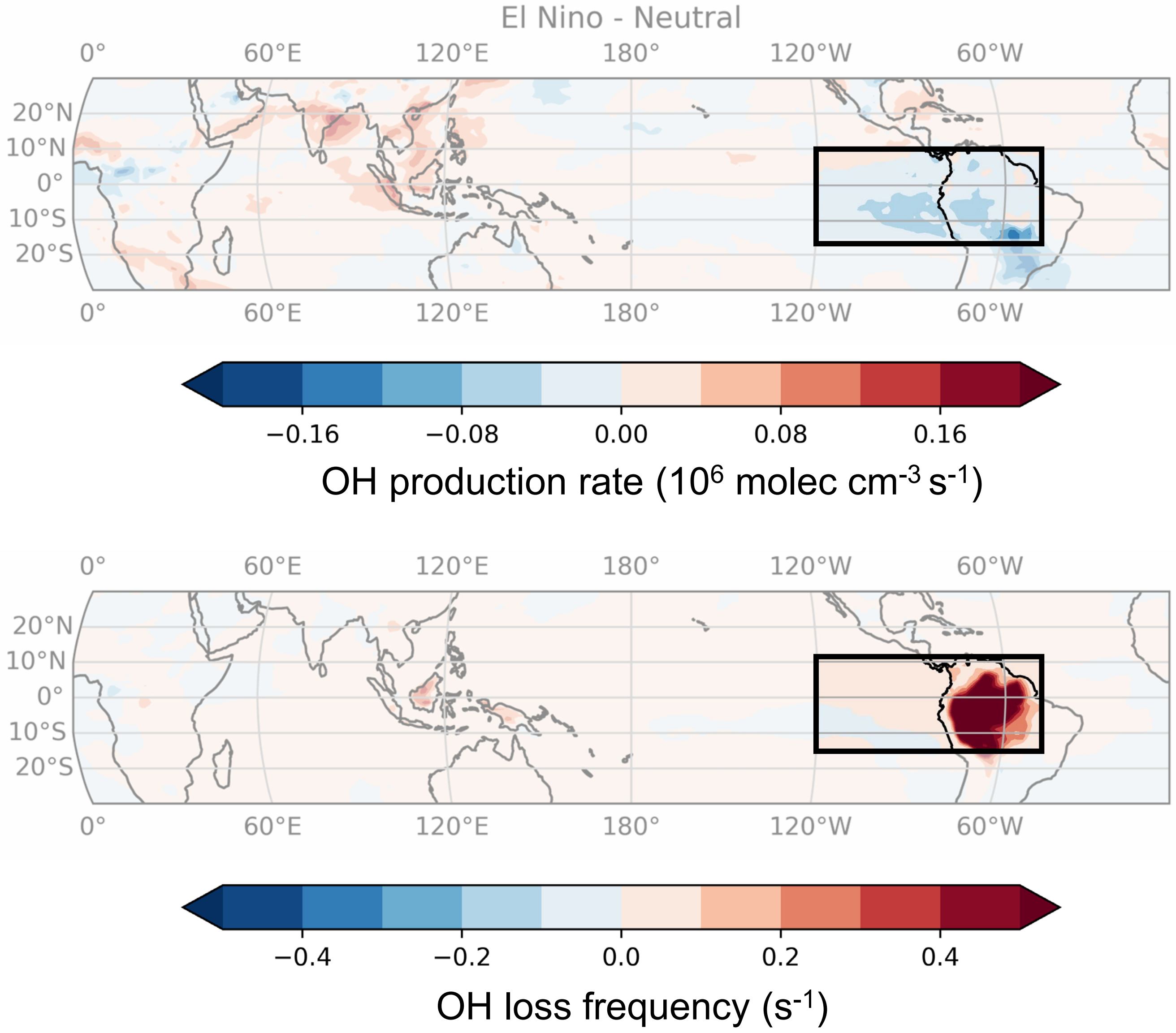
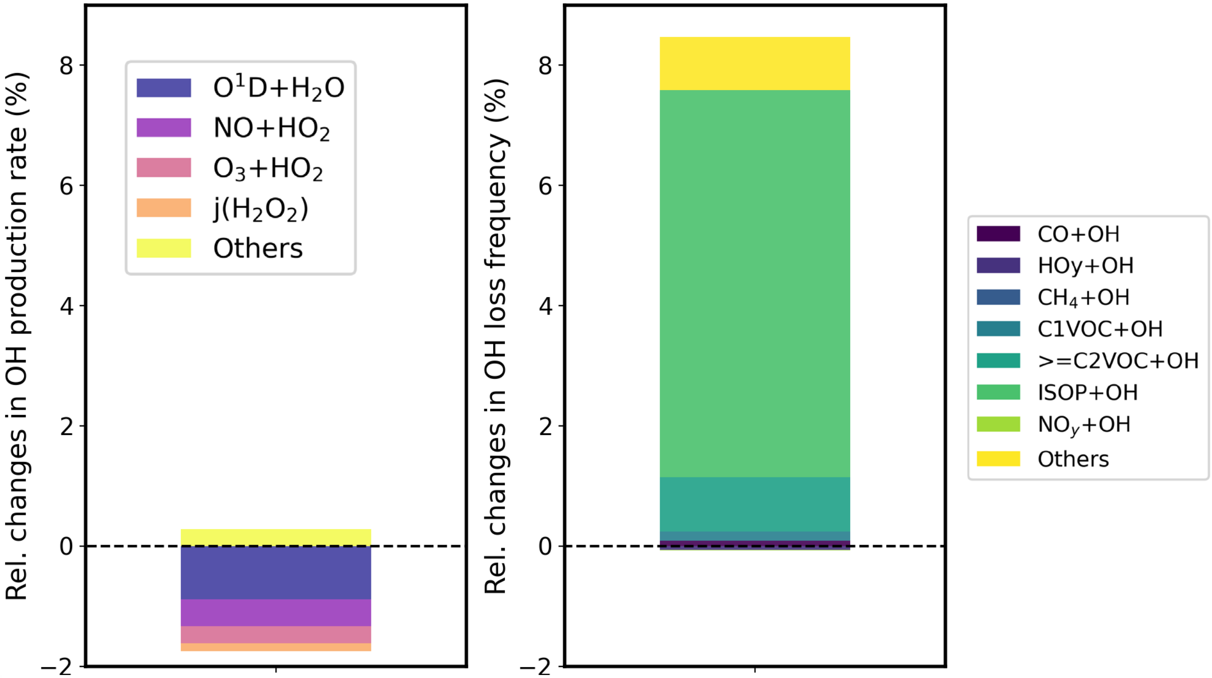




- BVOC emissions changes during El Nino, leads to total OH loss frequency increase by 8.4%.
- Increase in OH loss frequency attributes to 17.5% increase of isoprene.

Conclusion & Future work

Met only scenario

- 7% OH increase over Indonesia during El Nino.
- Driven by increase in OH primary production.

LNO emissions

- Subject to atmospheric variability.
- Insignificant impact on OH.

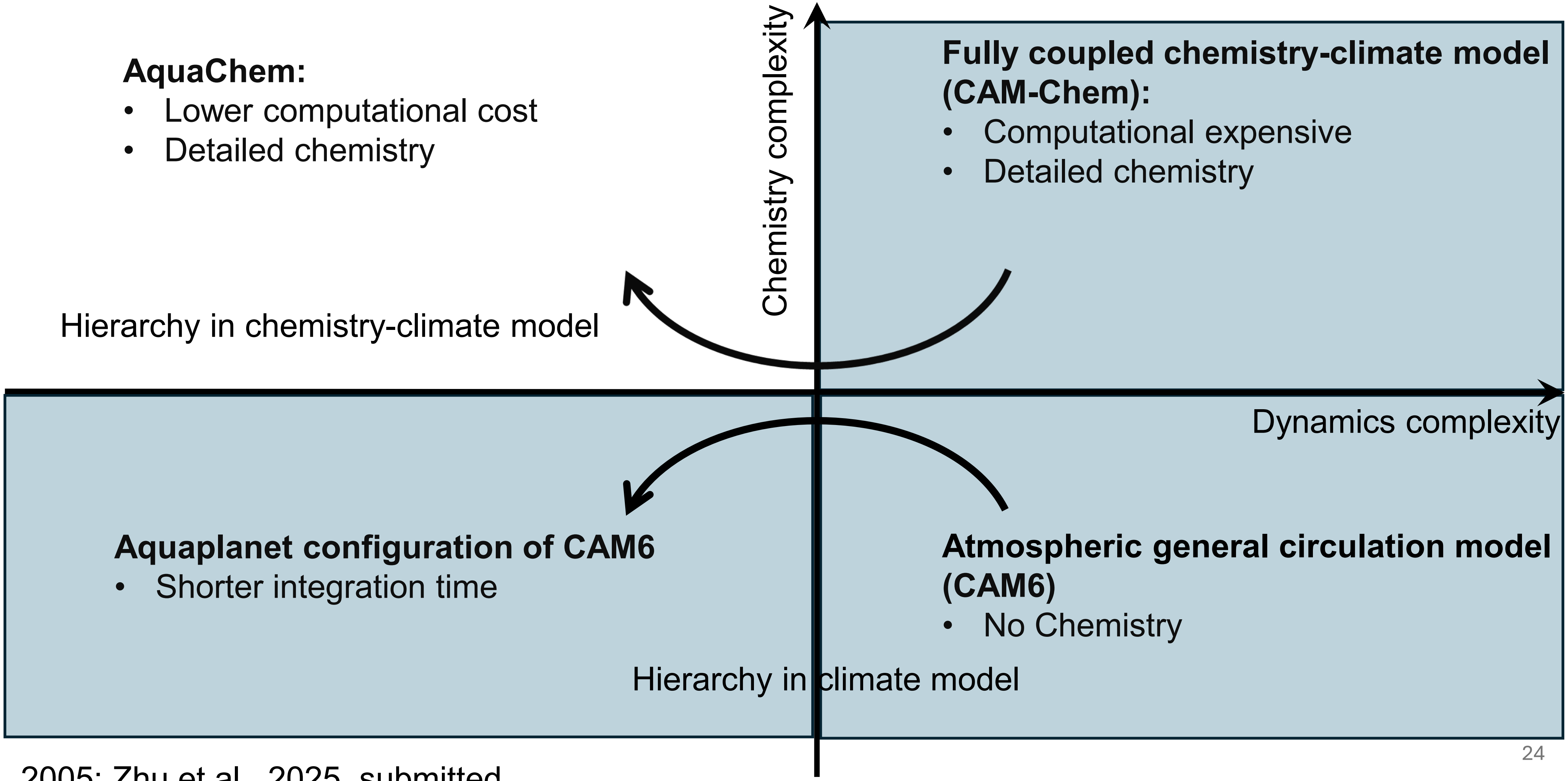
BVOC emissions

- 7.7% increase in isoprene emissions over South America during El Nino.
- 2.8% reduction in OH.

Future work

- Biomass burning

AquaChem: Bridge the climate modeling community and the atmospheric chemistry community



Held, 2005; Zhu et al., 2025, submitted

- Back up slides (TBD)

AquaChem: Bridge the climate modeling community and the atmospheric chemistry community

Held, 2005; Zhu et al., 2025, submitte

AquaChem:
- Lower computational cost
- Detailed chemistry

Chemistry complexity

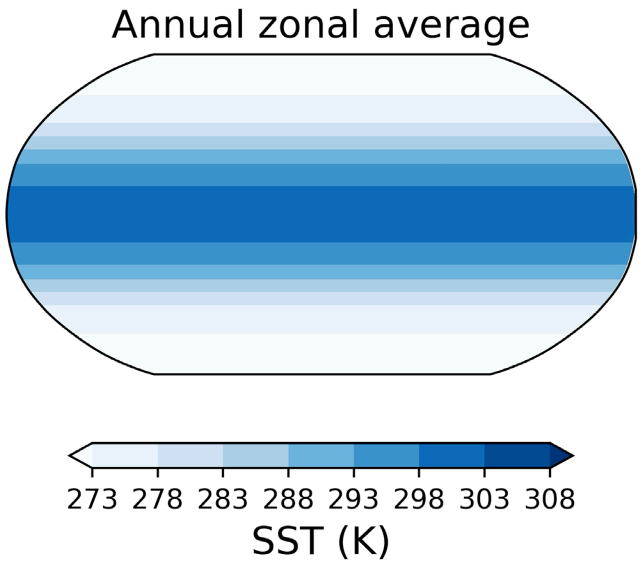
Fully coupled chemistry-climate model (CAM-Chem):
- Computational expensive
- Detailed chemistry

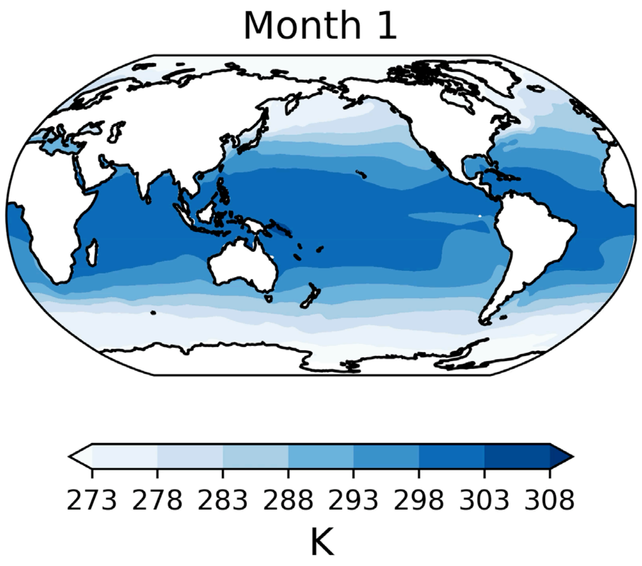
Hierarchy in chemistry-climate model

- **No land, water-covered**

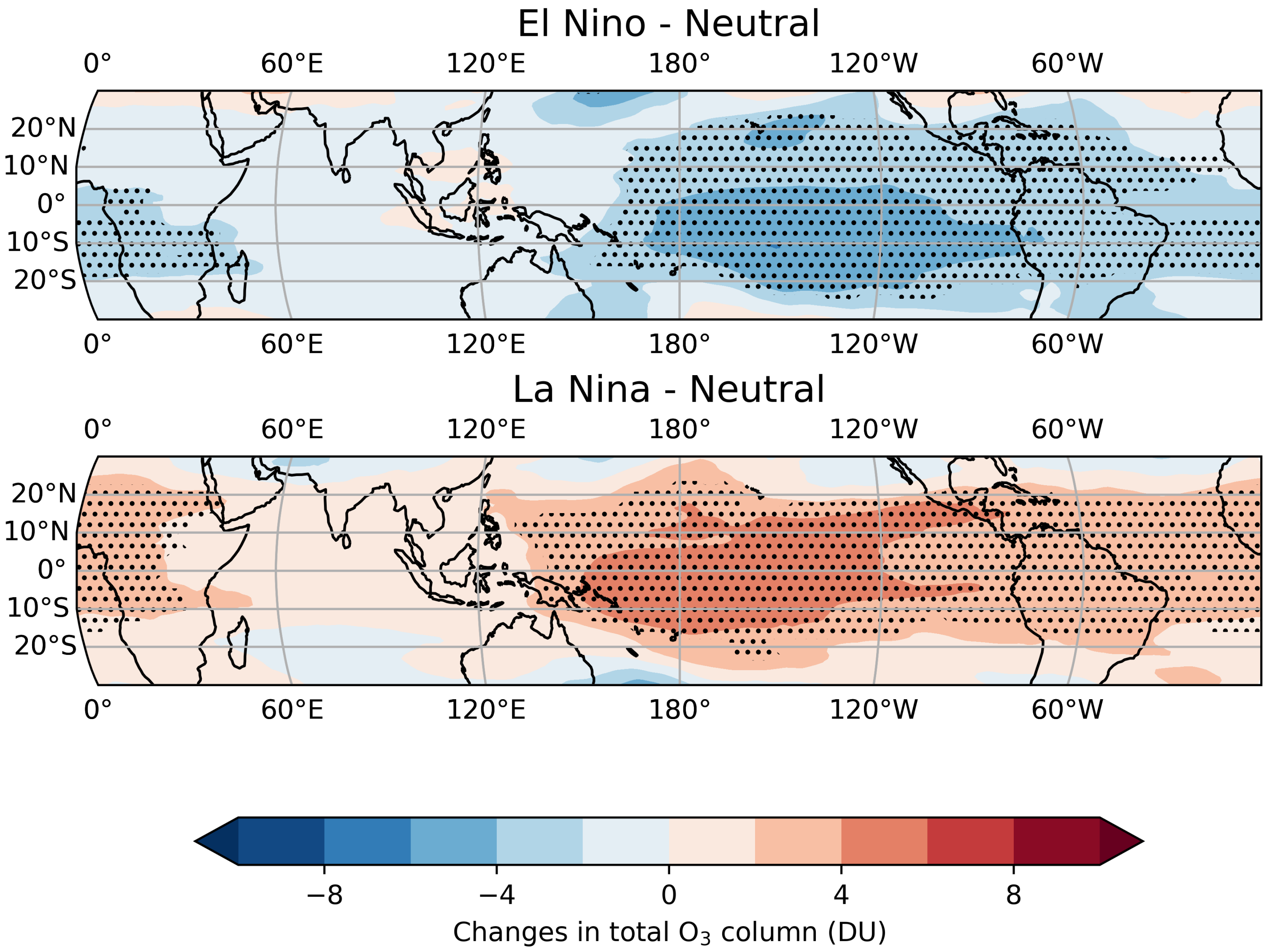
- **Simplified dynamics**
- Hadley Cell
- Upper tropospheric jet

- **Simplified emissions**
- No monthly variation

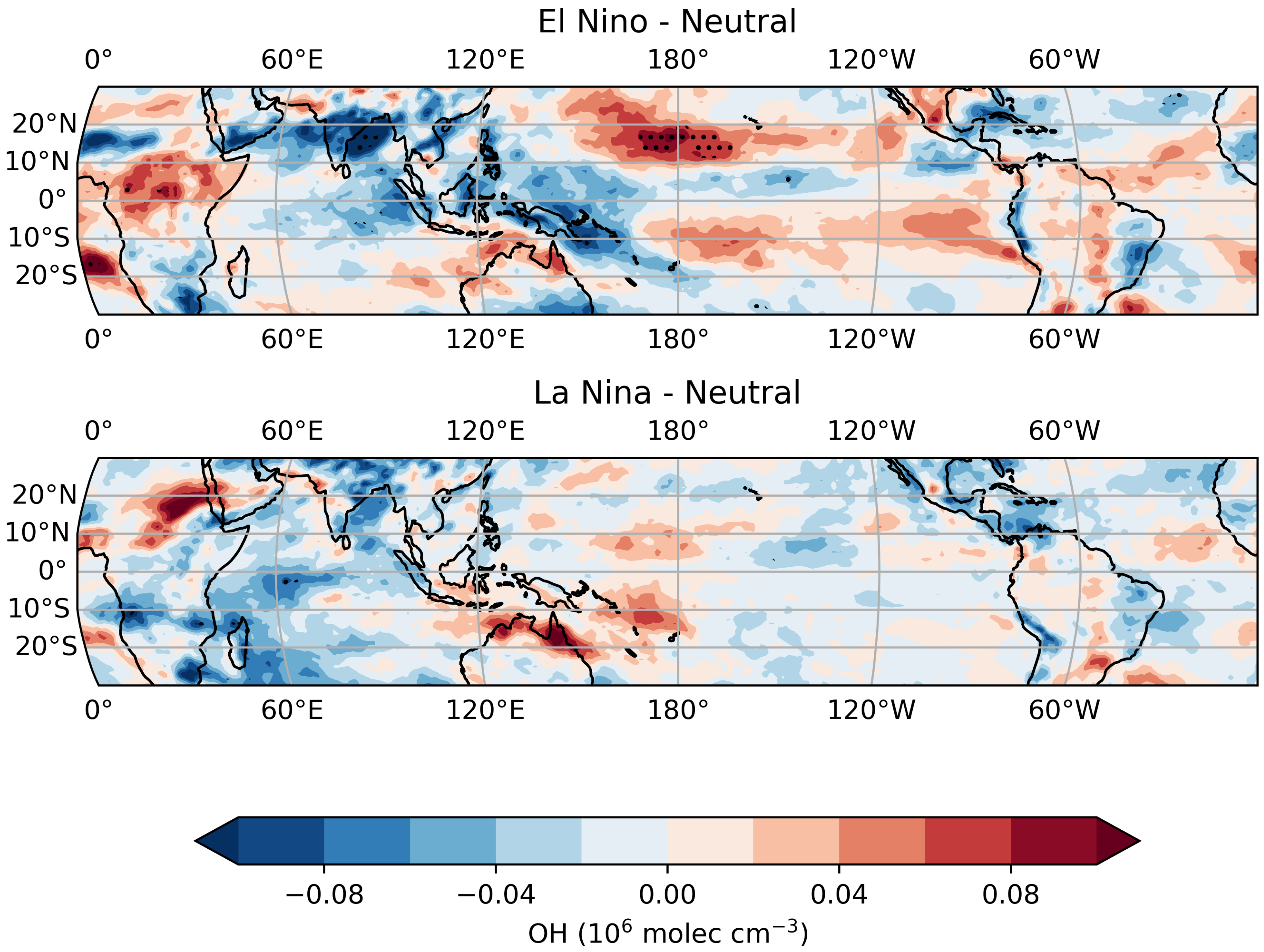




ENSO leads to significant changes in total O_3 column



Lightning NO emission changes during ENSO subject to atmospheric variability



- Insignificant changes in OH at the global or at local scale.