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New Connections Between Tropical Dynamics and Lower Stratospheric Chemistry

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Motivation: Why We Care About Tropical Stratospheric Chlorine Chemistry

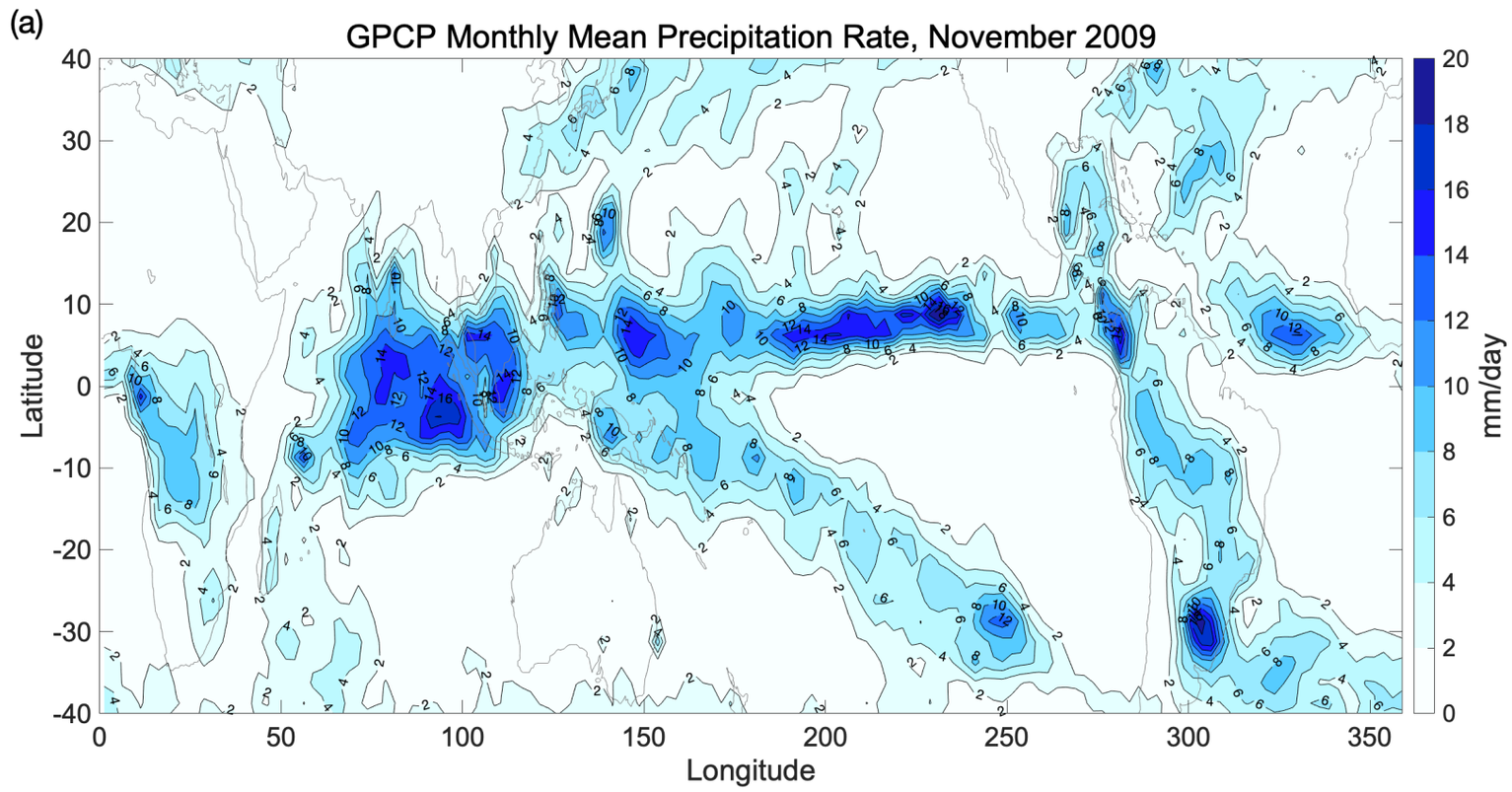
- Due to ozone's strong local radiative impact, changes near the tropical tropopause can feed back onto temperature, water concentrations, and potentially dynamical changes in the stratospheric circulation

- The tropics can provide an important testbed for heterogeneous chlorine chemistry, with different forcing mechanisms and concentrations than at the poles

In the deep tropics during fall and spring there's a lot of latent heat release nearly symmetric across the equator…

- Intense precipitation marks areas of high latent heat release and are better indicator of diabatic heating than SSTs

- We focus on months near the equinoxes so influence of summer monsoons is limited

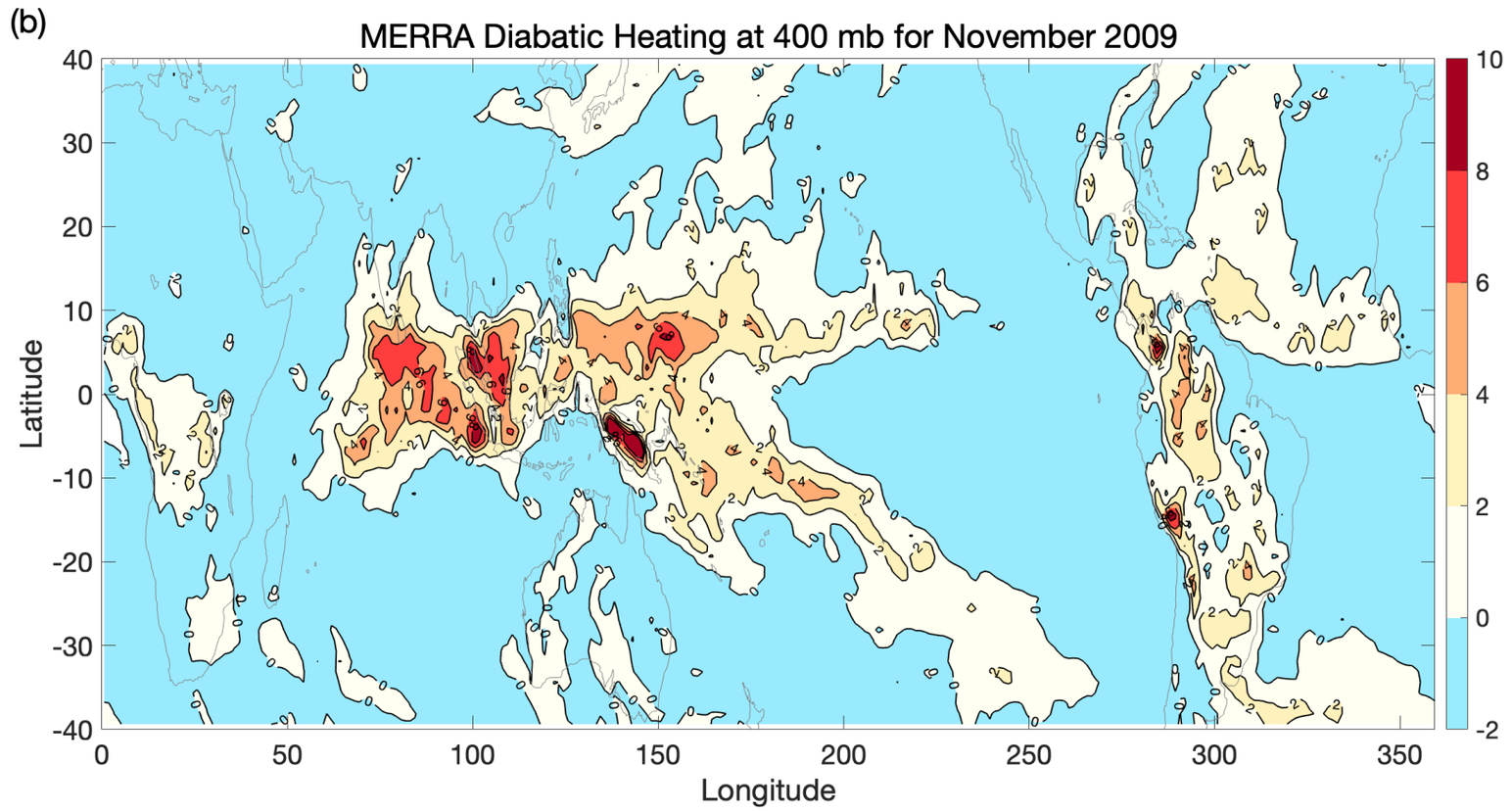


For the monsoonal case, see Solomon et al., 2016

…which sets up an equatorially symmetric Matsuno–Gill response to the heating…

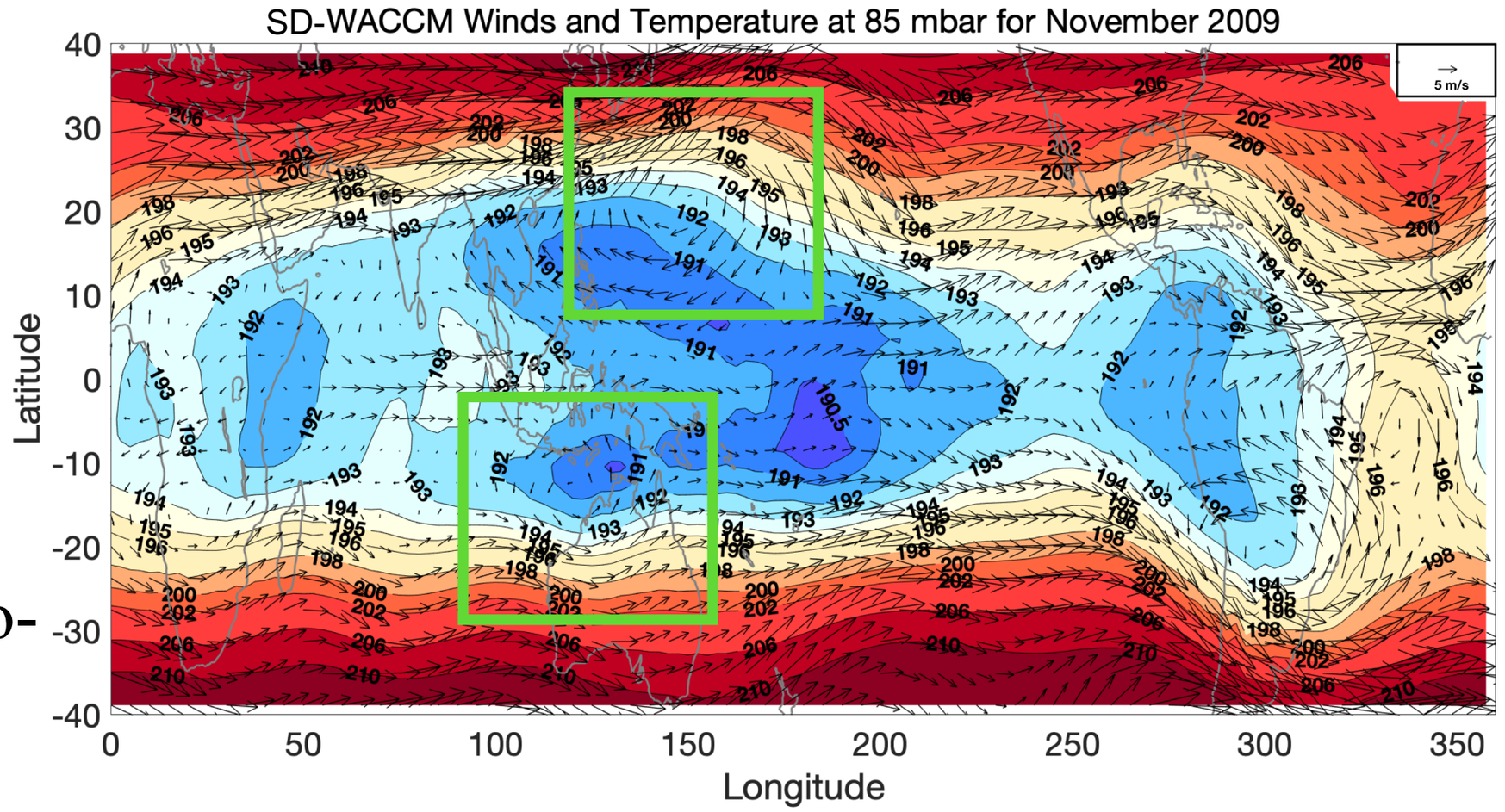
- The heating rates peak in the mid-troposphere, matching the prescribed vertical heating profile of the Gill model

- Reanalysis heating tracks observed precipitation well



…which generates two anticyclones in the lower stratosphere. These circulations can…

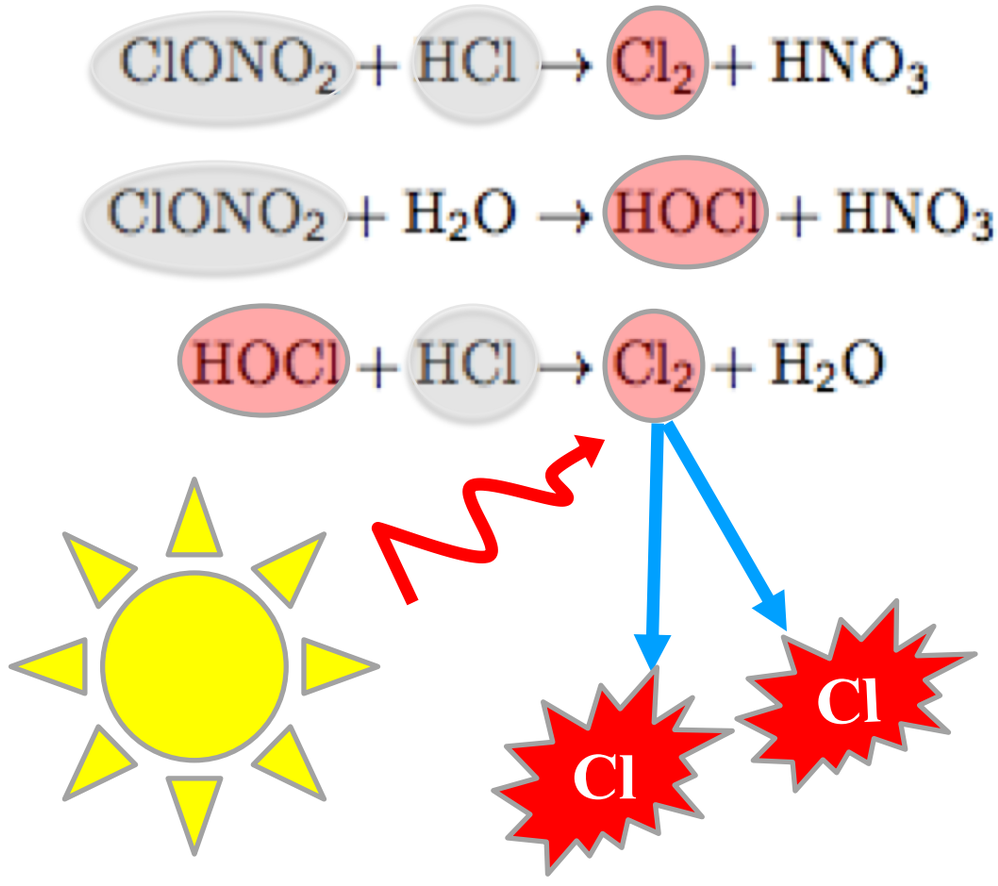
- Stratospheric thermal anomalies linked to pressure anomalies in the upper troposphere that form part of classic response to equatorially-symmetric Matsuno-Gill heating perturbations



…advect HCl from higher latitudes to the deep tropics where it's normally absent and temperatures are very cold => we can get chlorine activation.

- Chlorine Activation = conversion of relatively long-lived reservoir species ($ClONO_2$, HCl) to active forms (ClO, HOCl, Cl) capable of quickly destroying ozone

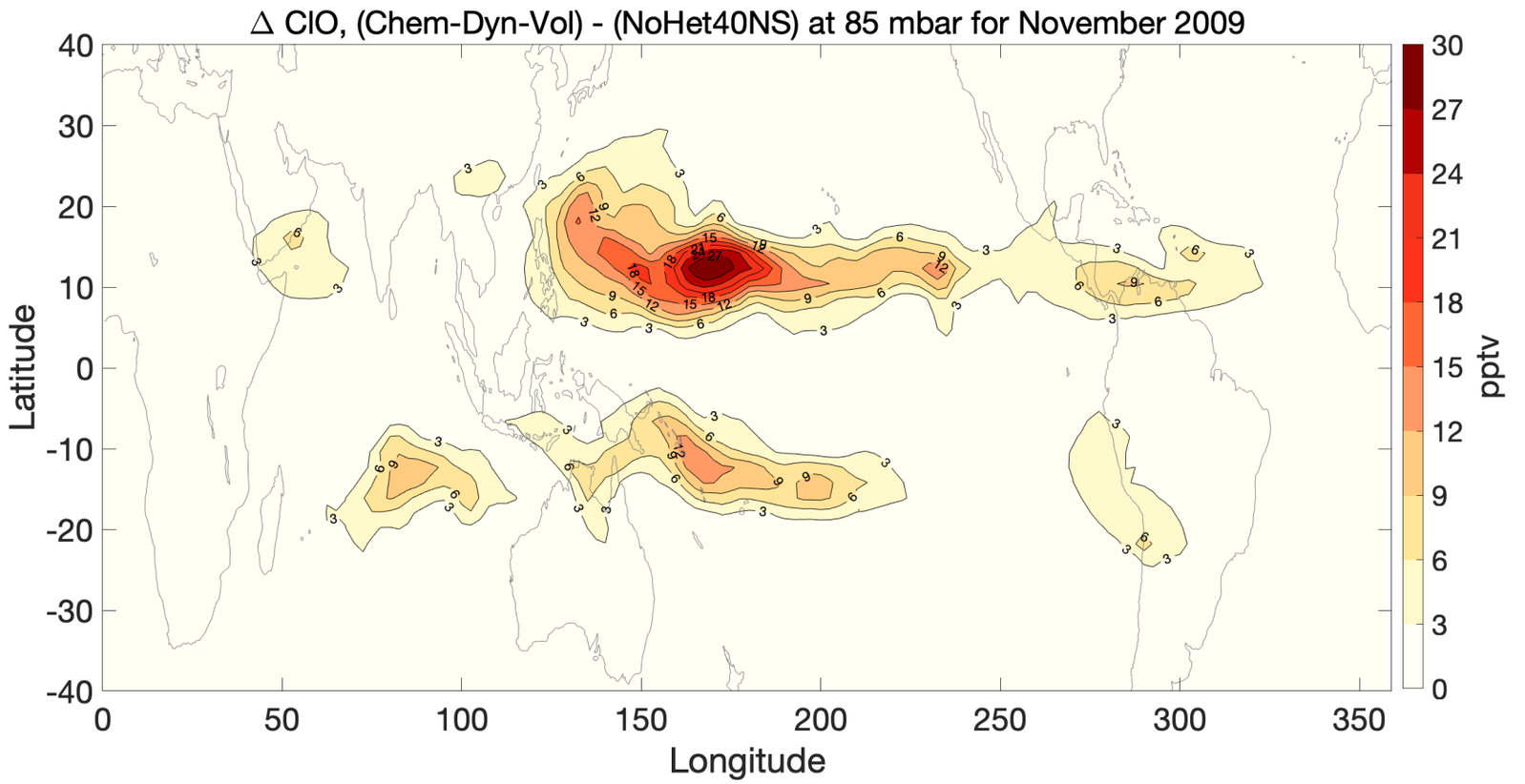
- Heterogeneous reactions on the surfaces of stratospheric aerosols, particularly sulfur-containing ones, can activate chlorine very efficiently and are extremely sensitive to temperatures

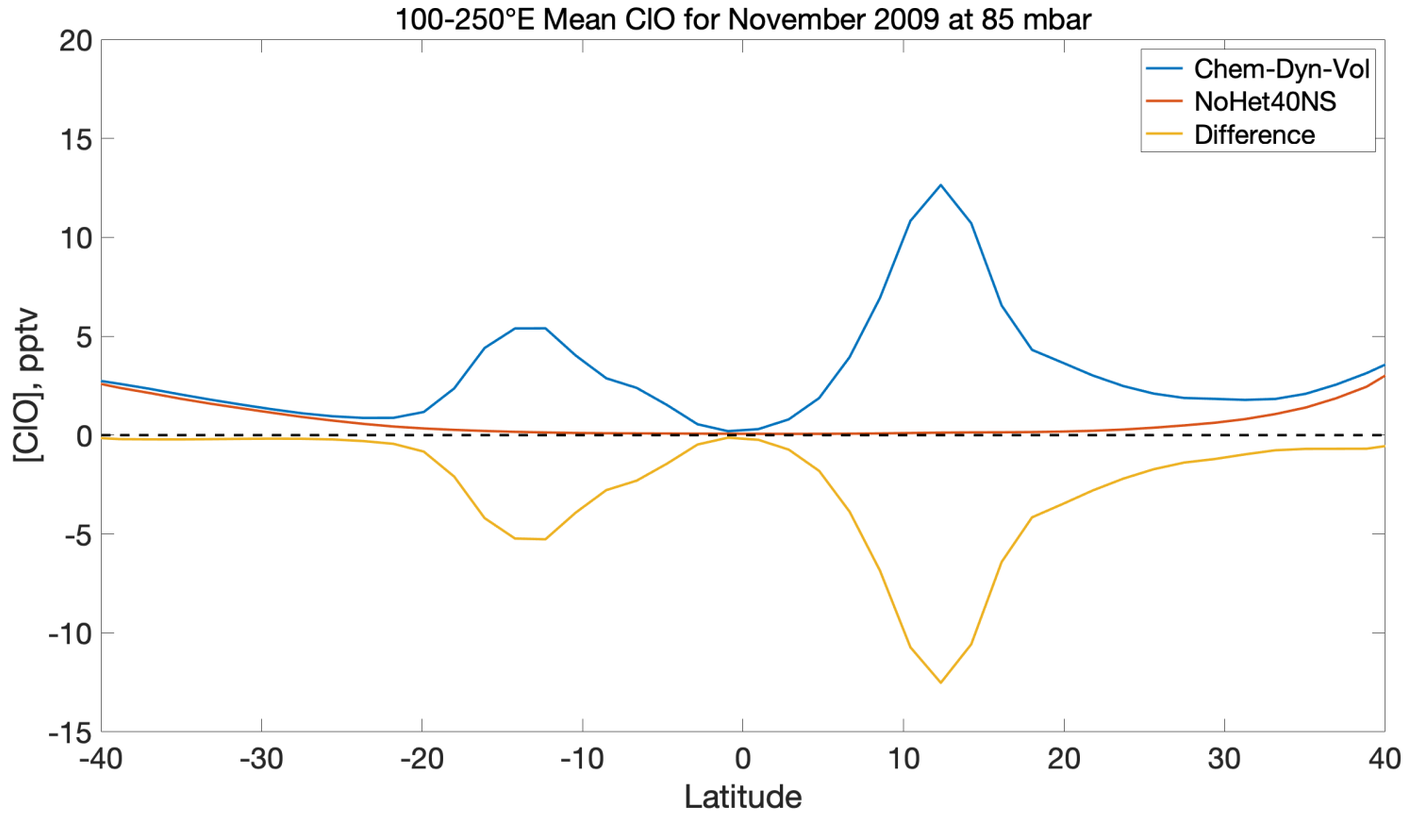


We can indeed see this chemistry happening in the (model) tropical UTLS

- We run the SD-WACCM model with heterogeneous chlorine chemistry turned on then off to isolate the chemical response vs dynamical changes

- See dual-hemisphere "bulls-eye" pattern response on flanks of anticyclones





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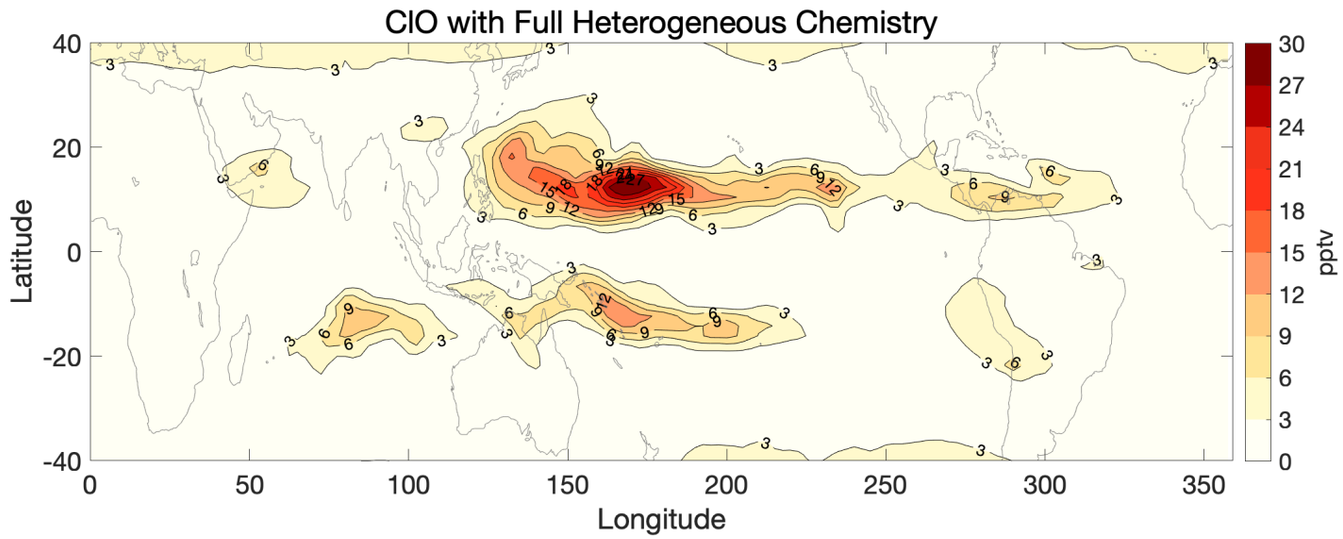
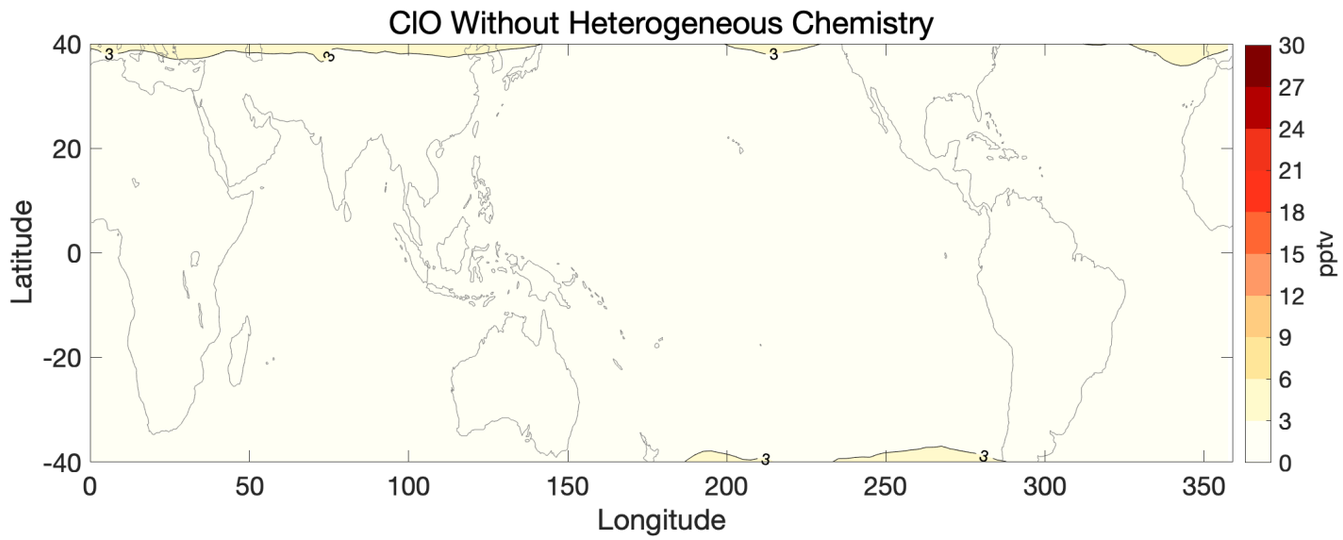
Activation levels reach 25–30 pptv, which should be measurable by aircraft

- This distinctive spatial pattern of dual-hemisphere enhancement peaking near 10°N/S provides a clear target

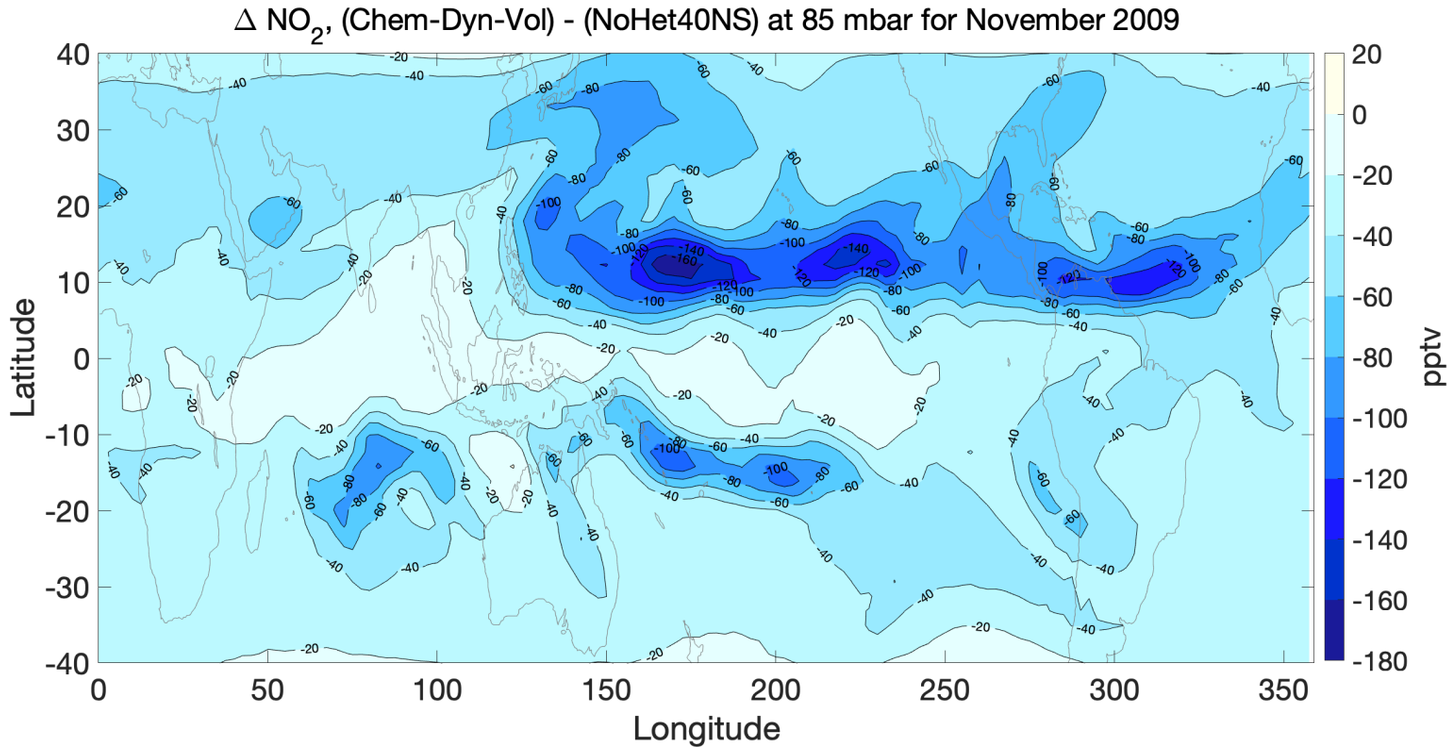


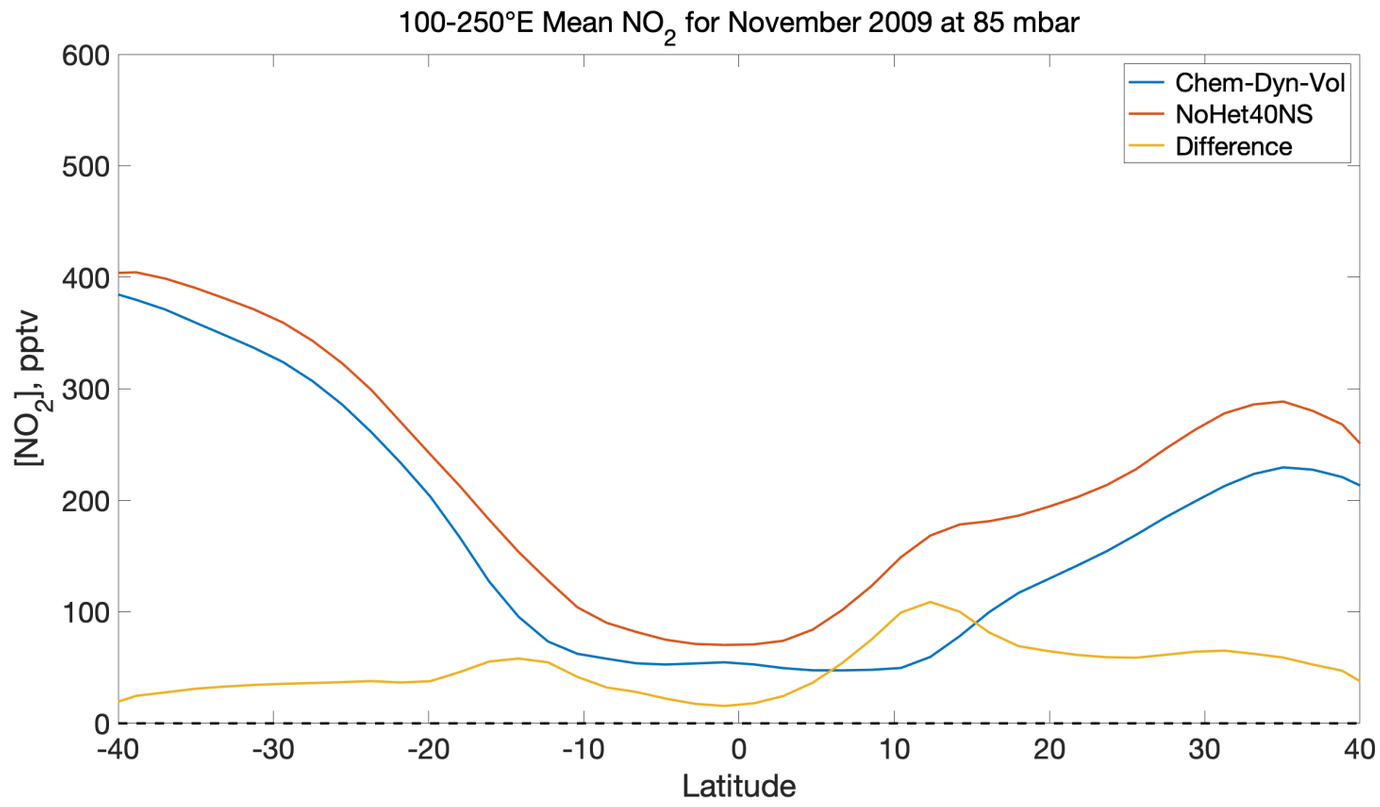
- Without this chemistry we see negligible ClO in the region, indicating *in situ* activation



We can also see this response in NO_2

- Due to higher background mixing ratios, NO_2 is more observable than ClO
- Relative depletions reach over > 100 pptv in many places, which should again be measurable at least by aircraft if not by satellite





Key Takeaways

- This expands our knowledge of **where and when** heterogeneous chlorine chemistry can happen via a previously overlooked connection between deep tropical meteorology and stratospheric chemistry
- We have a clear target for future aircraft or satellite campaigns to observe
- This is **not unique** to chlorine chemistry but will impact ANY chemical reactions in the UTLS with
  1. Strong temperature sensitivity
  2. Reactants with a steep equator-to-pole concentration gradient

Summary:

- Anticyclones from tropospheric tropical heating are able to drive chlorine activation in the SD-WACCM model via a combination of reservoir chlorine entrainment and colder temperatures
- Thus a symmetric Matsuno-Gill response can activate chlorine in near-equinox months in the deep tropics in both hemispheres
- This extends the findings of Solomon et al., 2016, which described how an antisymmetric Matsuno-Gill response activates chlorine in monsoonal months in the subtropics in a single hemisphere
- The main limitation to confirming either scenario in the real world is the data sparseness in the region for the species of interest