Stratospheric dynamics following the eruption of Mt. Pinatubo

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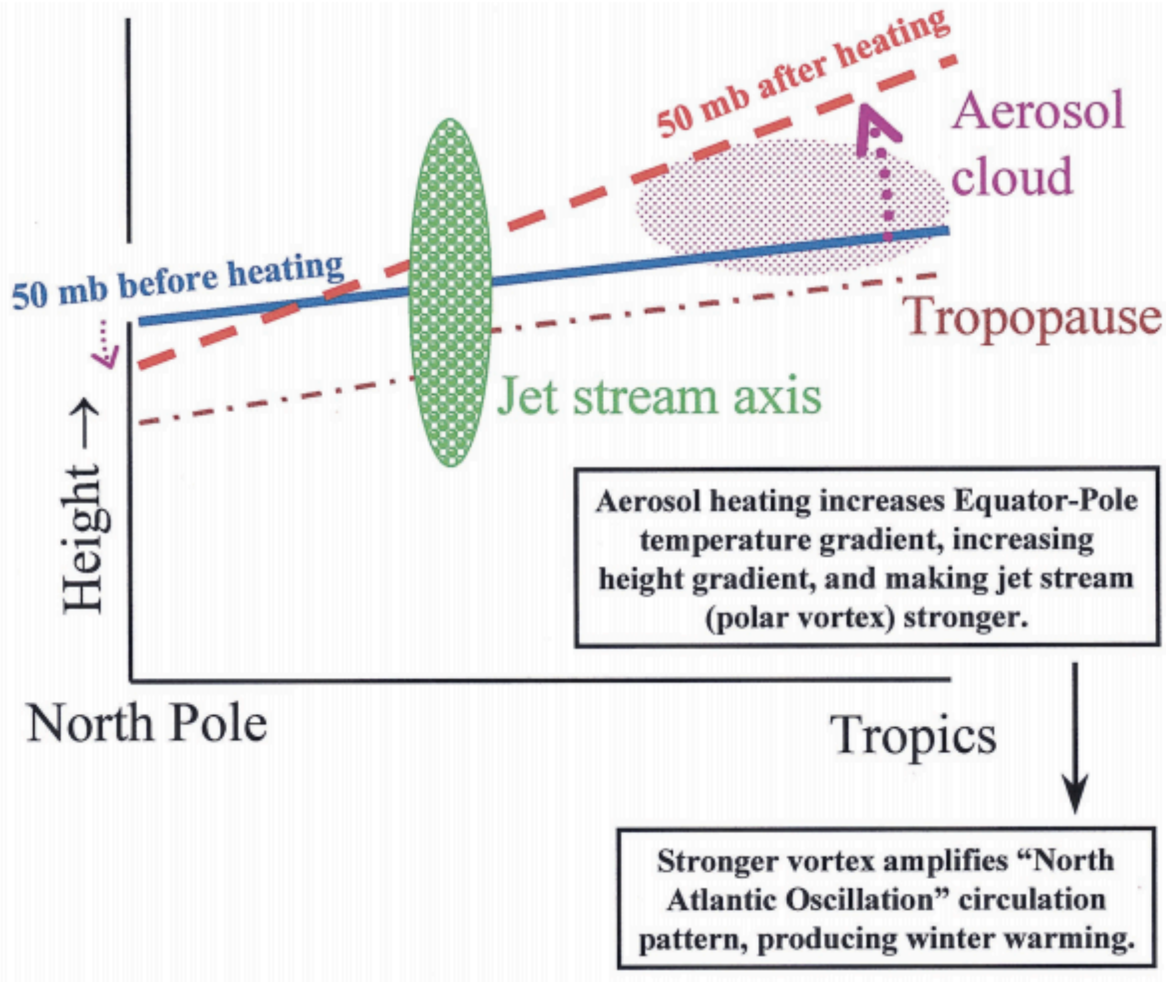
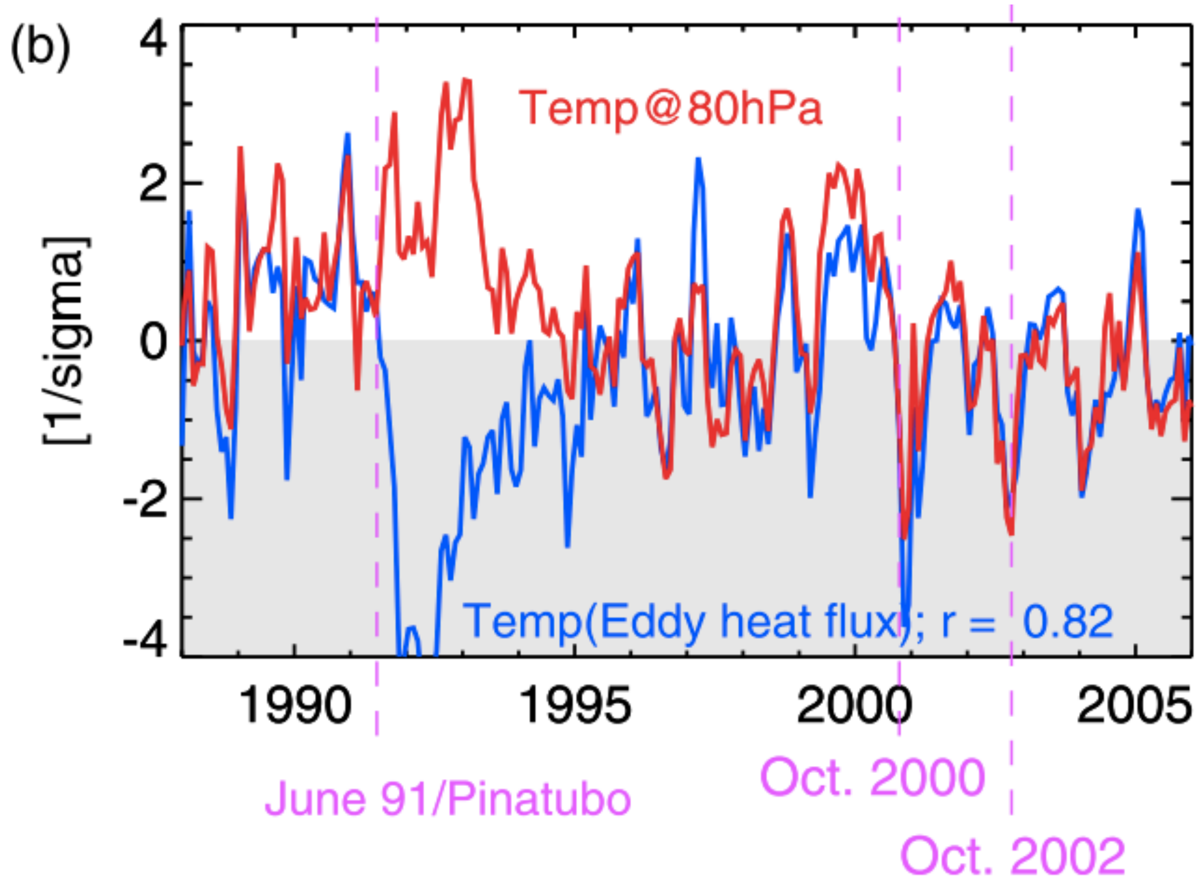
Motivation



(Robock, 2000)

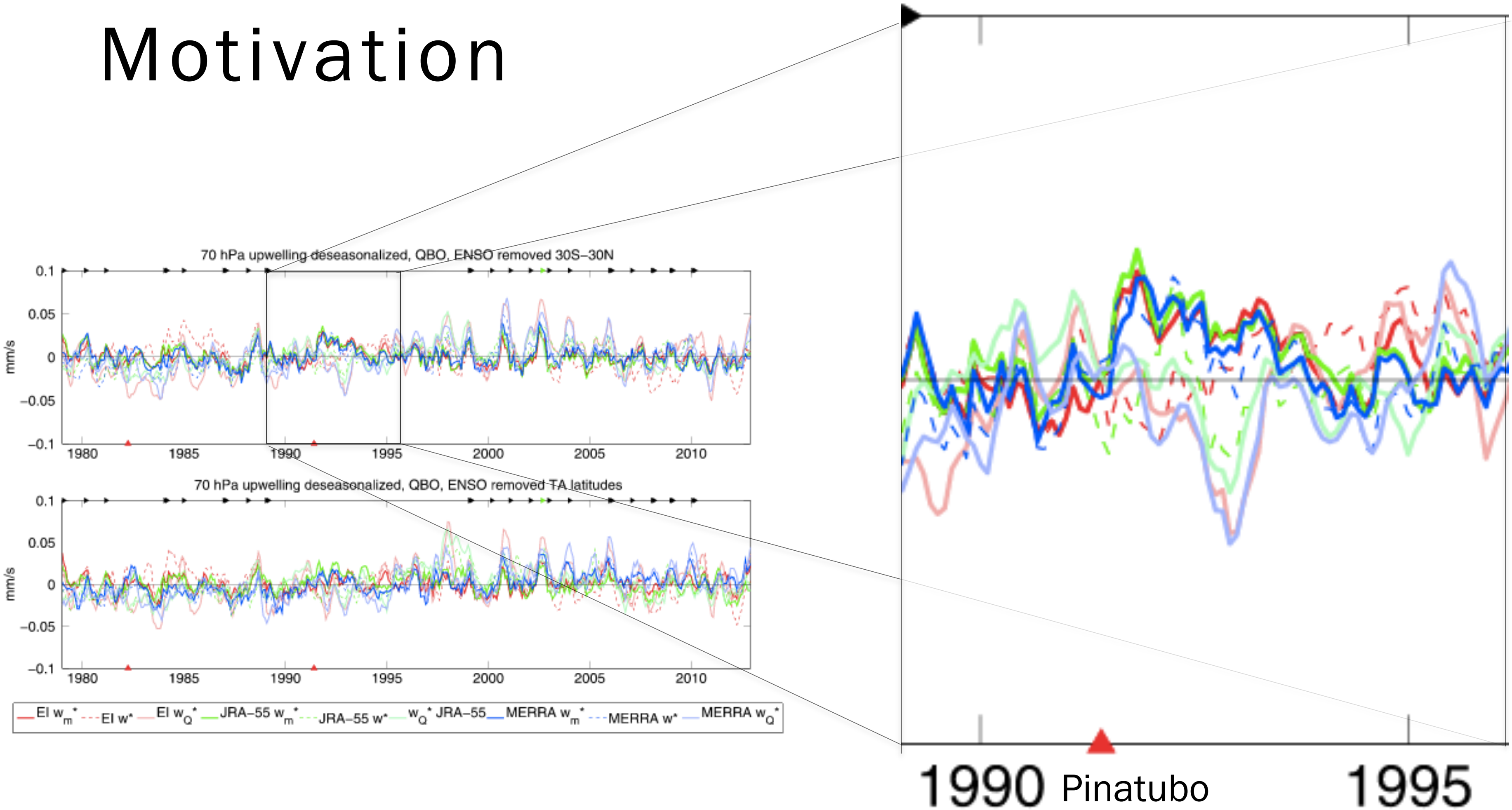
Motivation



(Fueglistaler, 2012)

Following Pinatubo, enhanced eddy heat fluxes indicate a strengthened the Brewer-Dobson circulation (Fueglistaler, 2012; Poberaj et al., 2011).

Motivation



Following Pinatubo, estimates using thermodynamic variables show weakened upwelling, while estimates using circulation show strengthened upwelling.

(Abalos et al. 2015)

Theory: Newtonian Cooling

Newtonian Cooling approximation: Diabatic heating (Q) relaxes the temperature to a prescribed equilibrium (Te) on a timescale (τ):

$$\frac{\partial T}{\partial t} + \frac{\bar{v}^*}{a}\frac{\partial T}{\partial \phi} + \bar{w}^* S = \frac{T_E - T}{\tau} + Q_{aerosol}$$

[Temperature T, TEM meridional and vertical velocities (v*,w*), Earth radius a, latitude ϕ, stratification S, diabatic heating Q]

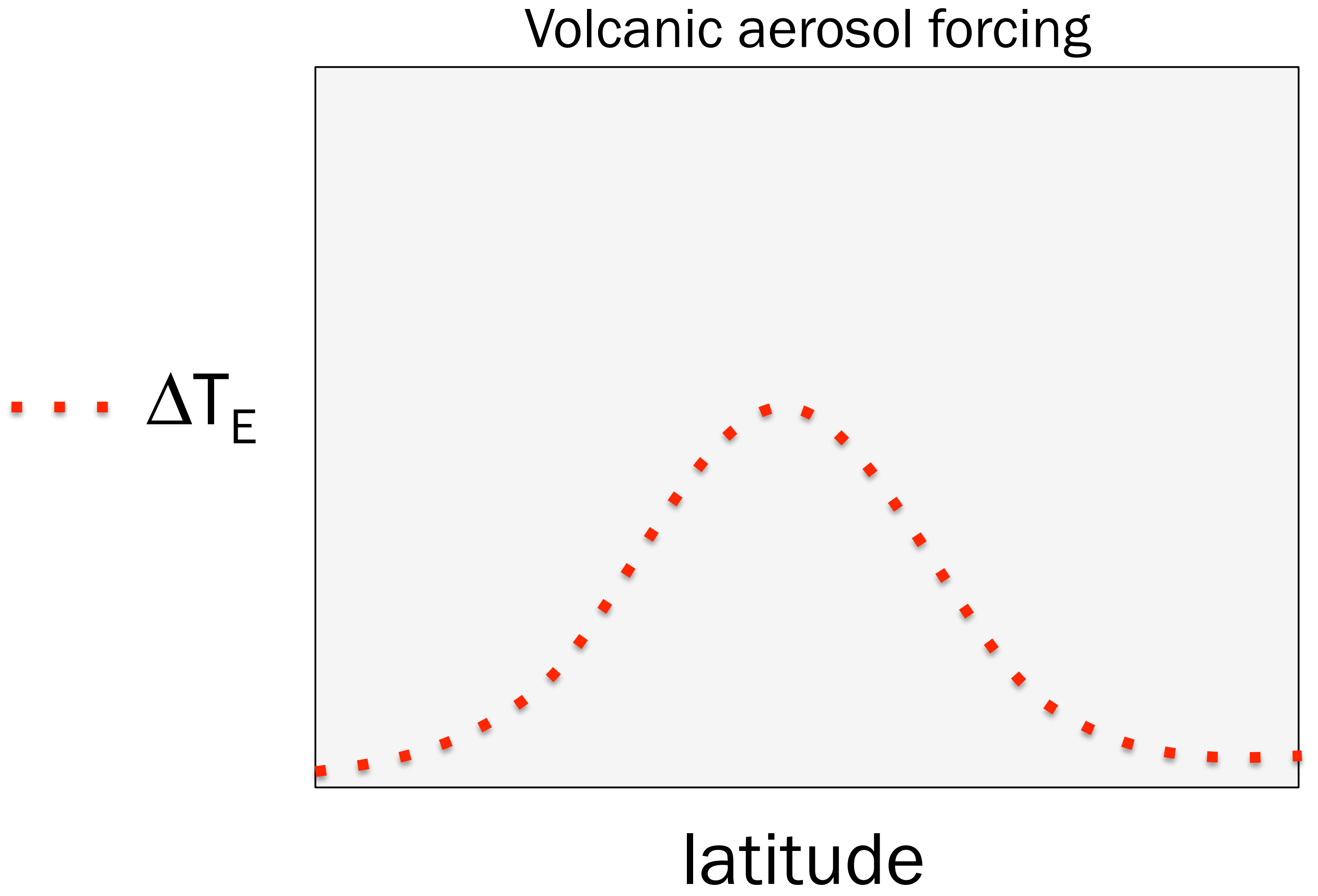
Assuming steady state and negligible meridional fluxes, $Q_{aerosol}$ is balanced by changes in upwelling and temperature:

$$1 = \frac{\Delta(\bar{w}^* S)}{Q_{aerosol}} + \frac{\Delta T}{Q_{aerosol} * \tau}$$

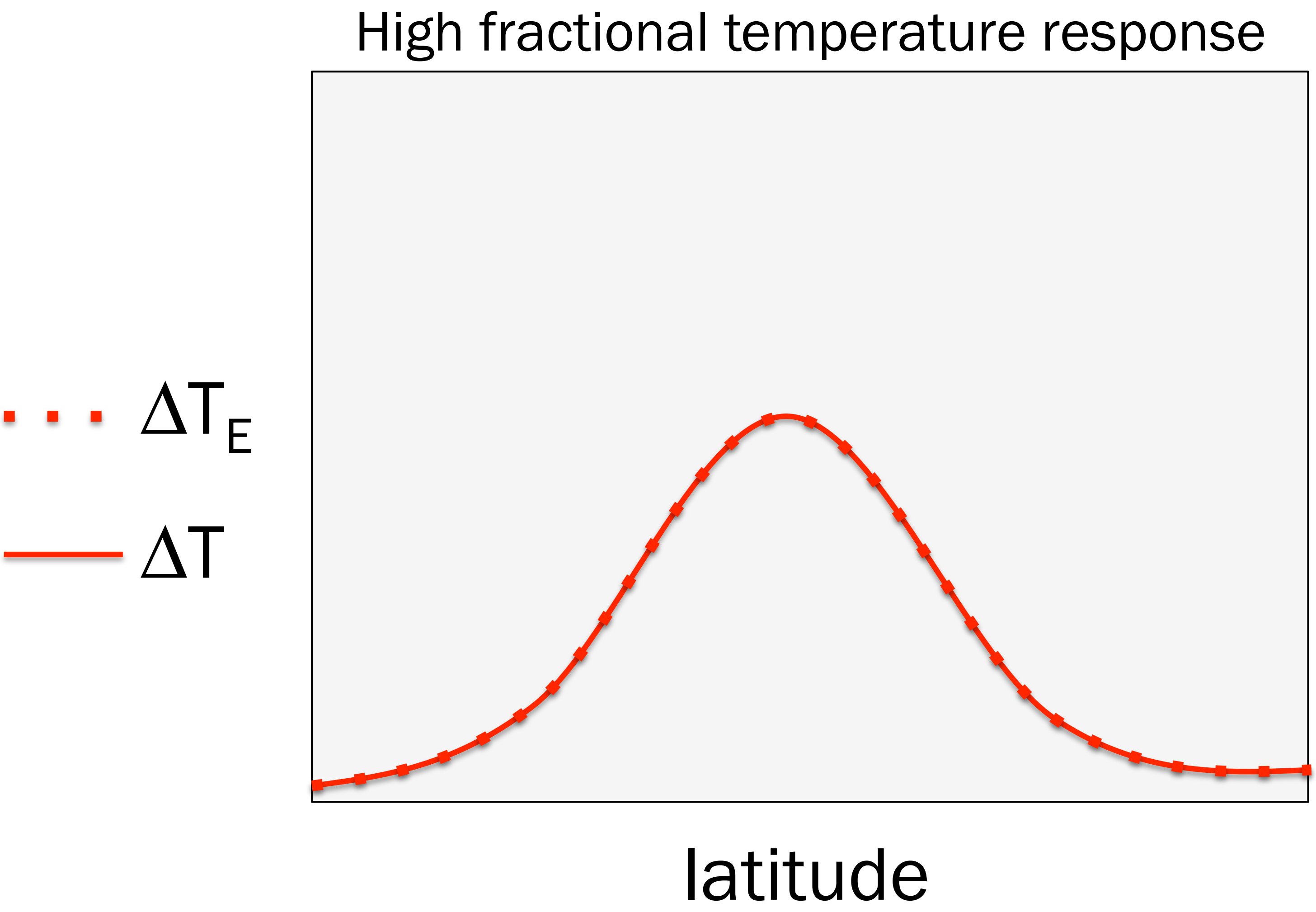
Fractional upwelling response

Fractional temperature response

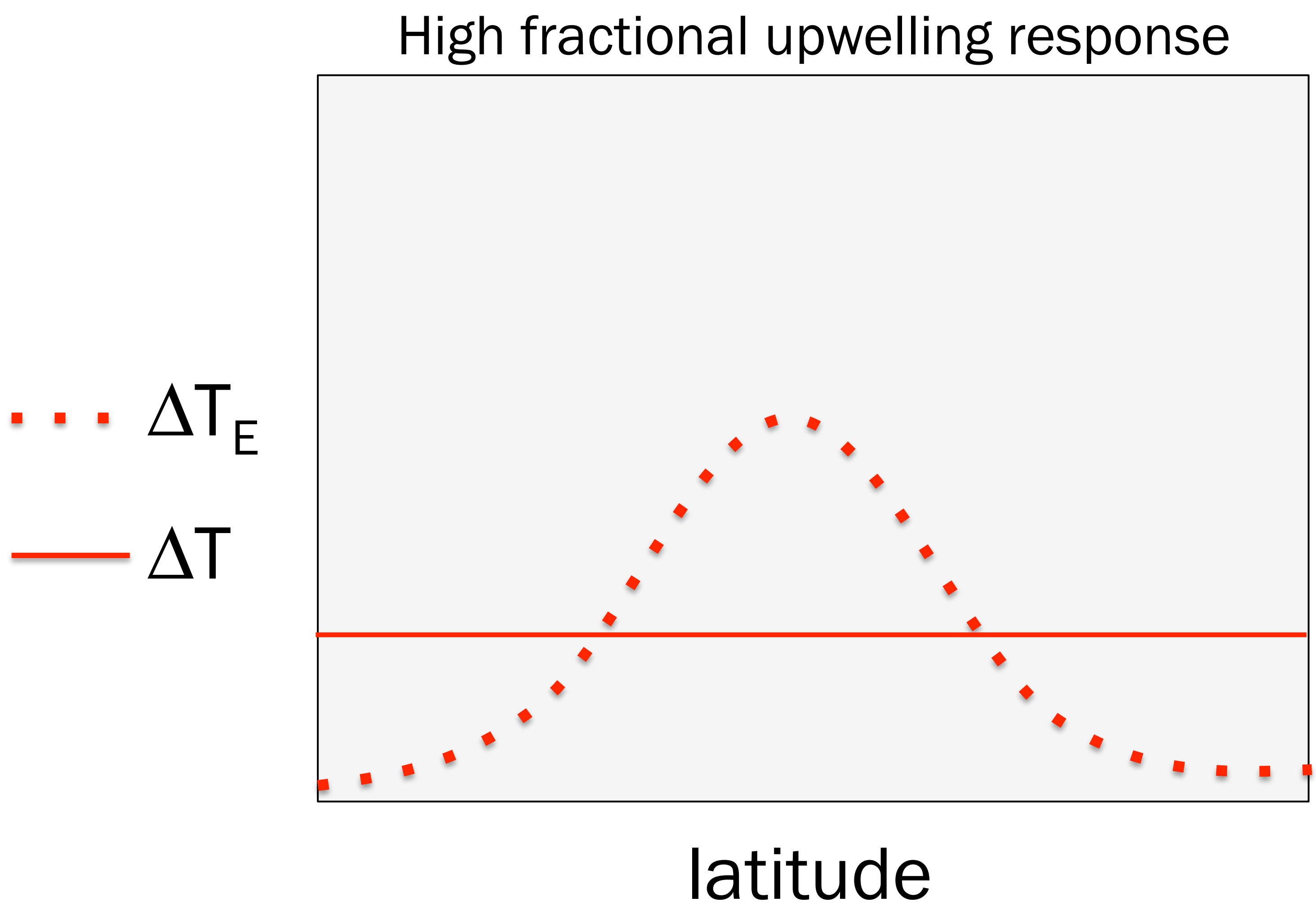
Theory: Newtonian Cooling



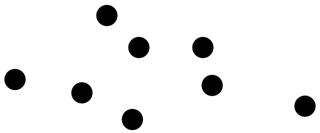
Theory: Newtonian Cooling



Theory: Newtonian Cooling

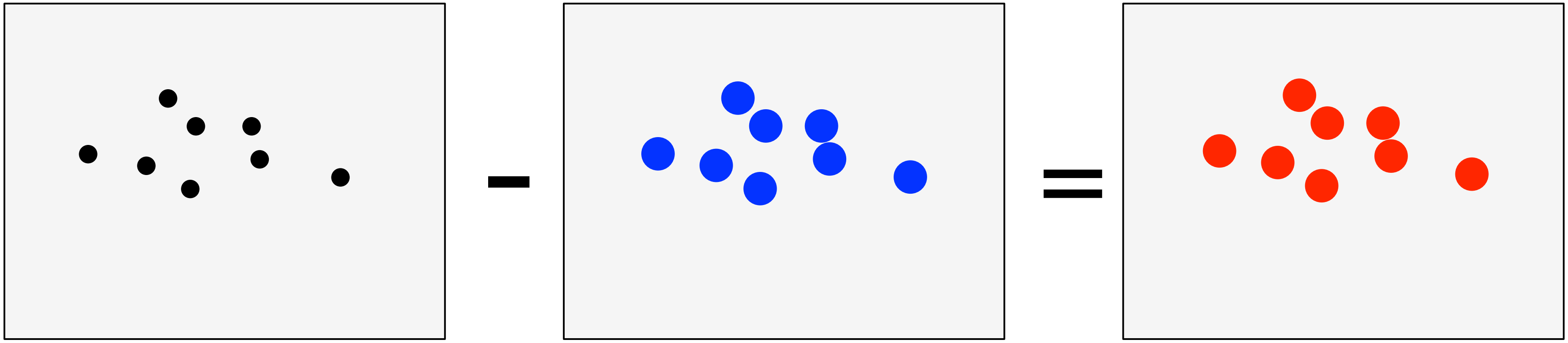


Methodology: Heating rates

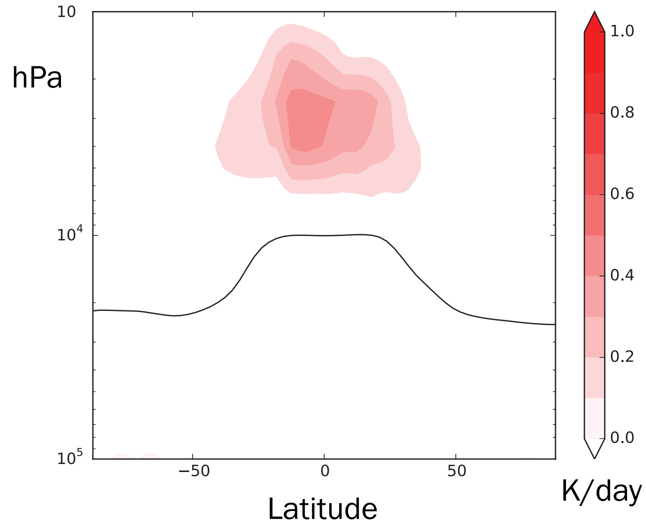
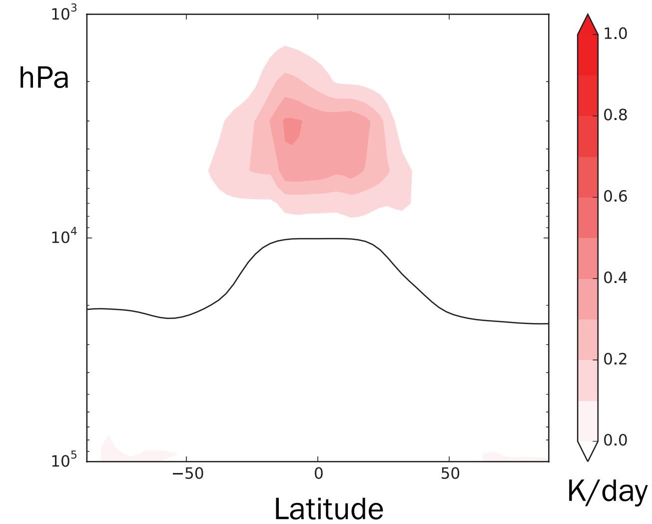
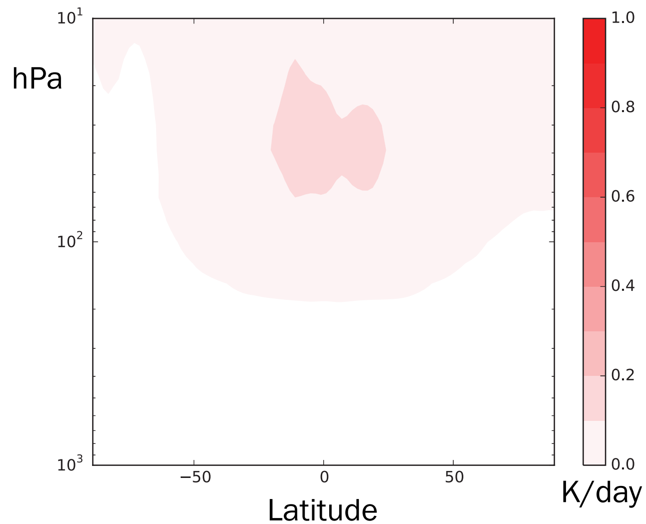
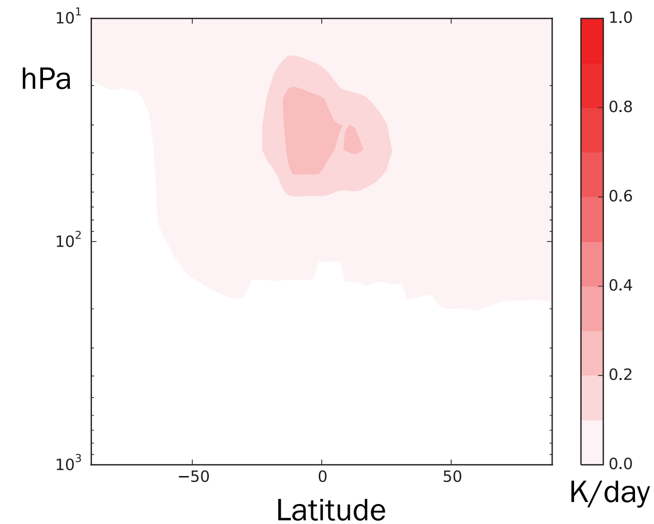


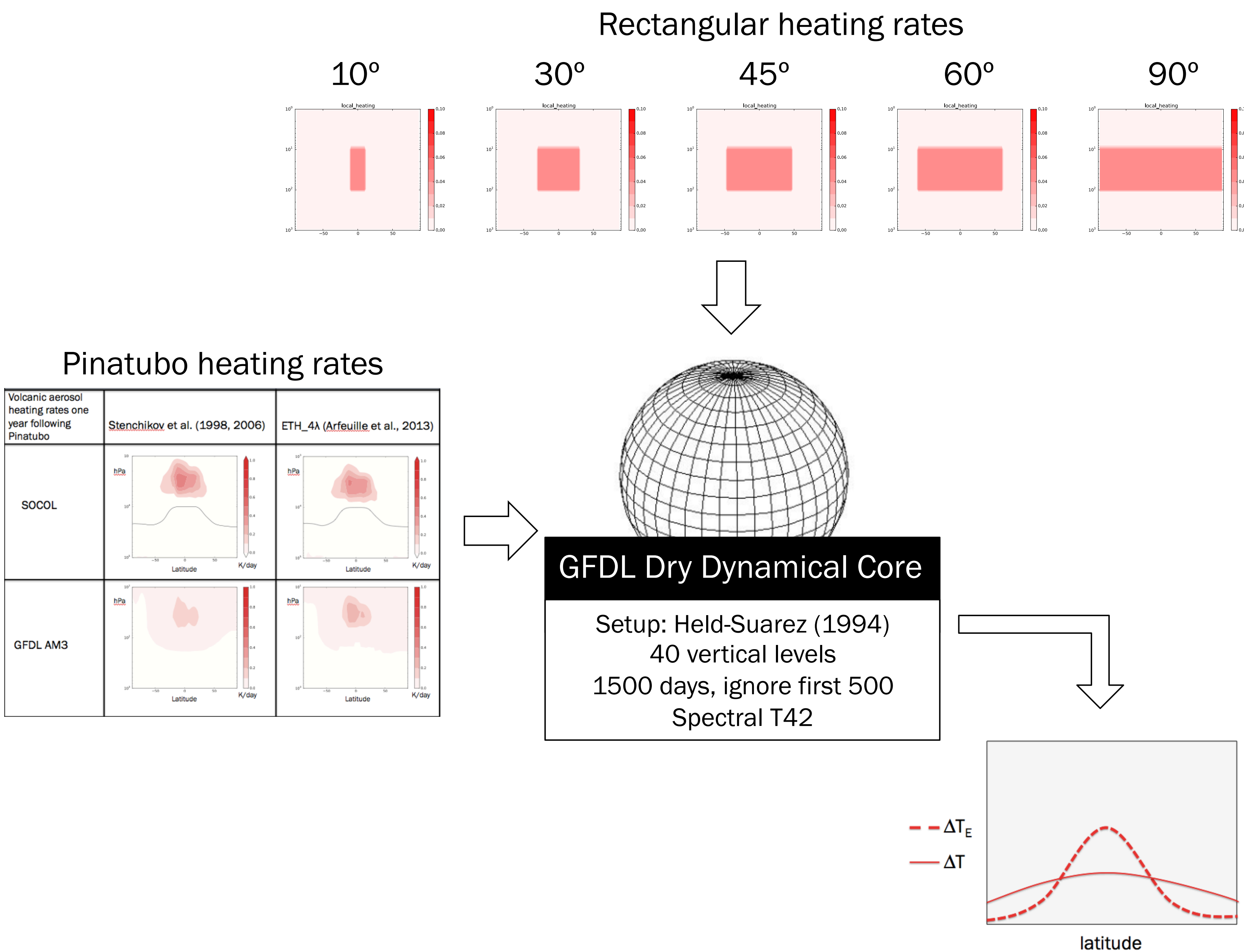
Aerosol datasets:
1. Stenchikov et al. (1998,2006)
2. ETH-4λ (Arfeuille et al., 2013)

General circulation models:
1. SOCOL
2. GFDL AM3

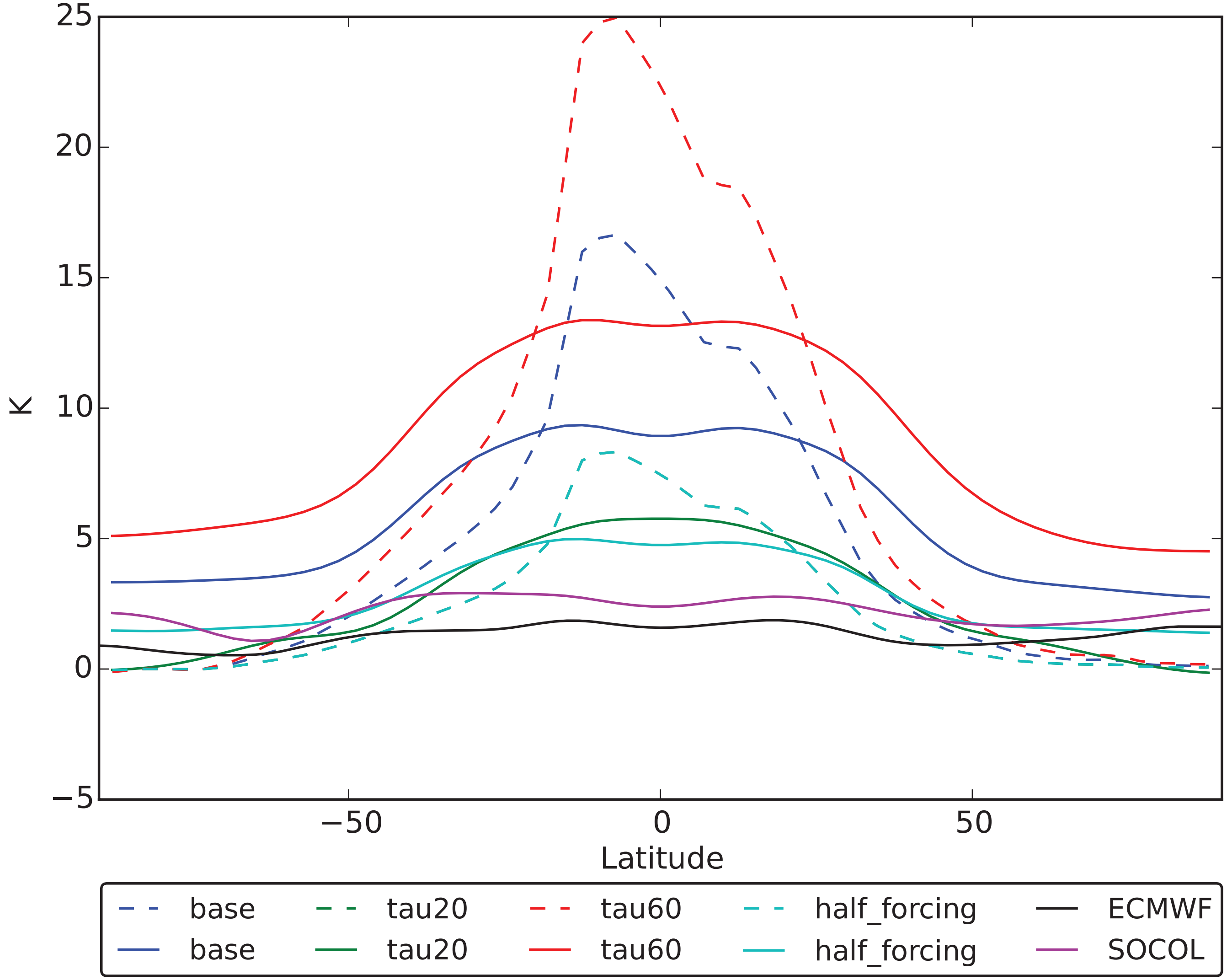


Heating rate − Heating rate without aerosol = Aerosol heating rate

Volcanic aerosol heating rates	Stenchikov et al. (1998, 2006)	ETH_4λ (Arfeuille et al., 2013)
SOCOL		
GFDL AM3		


Rectangular heating rates
10º
30º
45º
60º
90º
local_heating
Pinatubo heating rates
Volcanic aerosol heating rates one year following Pinatubo
Stenchikov et al. (1998, 2006)
ETH_4λ (Arfeuille et al., 2013)
SOCOL
GFDL AM3
hPa
Latitude
K/day
GFDL Dry Dynamical Core
Setup: Held-Suarez (1994)
40 vertical levels
1500 days, ignore first 500
Spectral T42
ΔT_E
ΔT
latitude

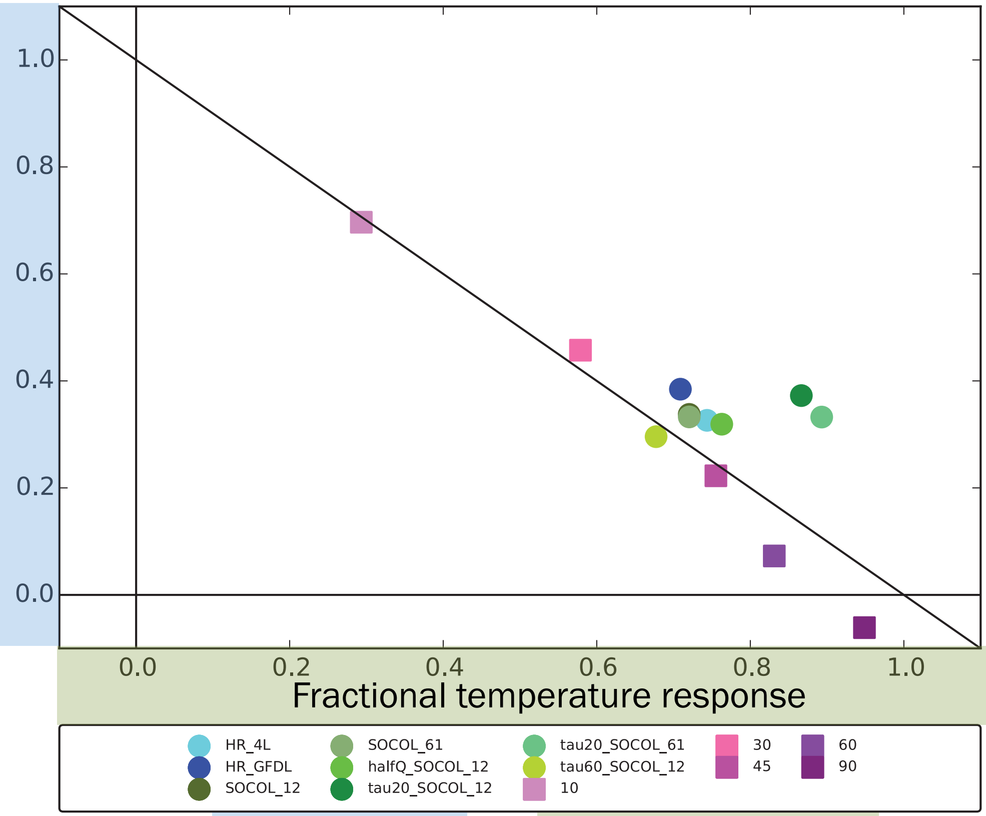
Results: Temperature response



ΔT_E (dashed) ΔT (solid)

Fractional upwelling response vs. fractional temperature response in GFDL Dry Dynamical Core

Fractional upwelling response



$$1 = \frac{\Delta(\bar{w}^* S)}{Q_{aerosol}} + \frac{\Delta T}{Q_{aerosol} * \tau}$$

Fractional upwelling response

Fractional temperature response

What factors affect fractional upwelling response?

From non-dimensionalized quasi-geostrophic equations assuming steady-state, Newtonian cooling (τ) and linear momentum damping (κ):

$$0 = \alpha \frac{\partial^2 \hat{T}}{\partial \hat{y}^2} - \frac{\partial^2}{\partial \hat{z}^2}(\hat{T} - \hat{T_E})$$

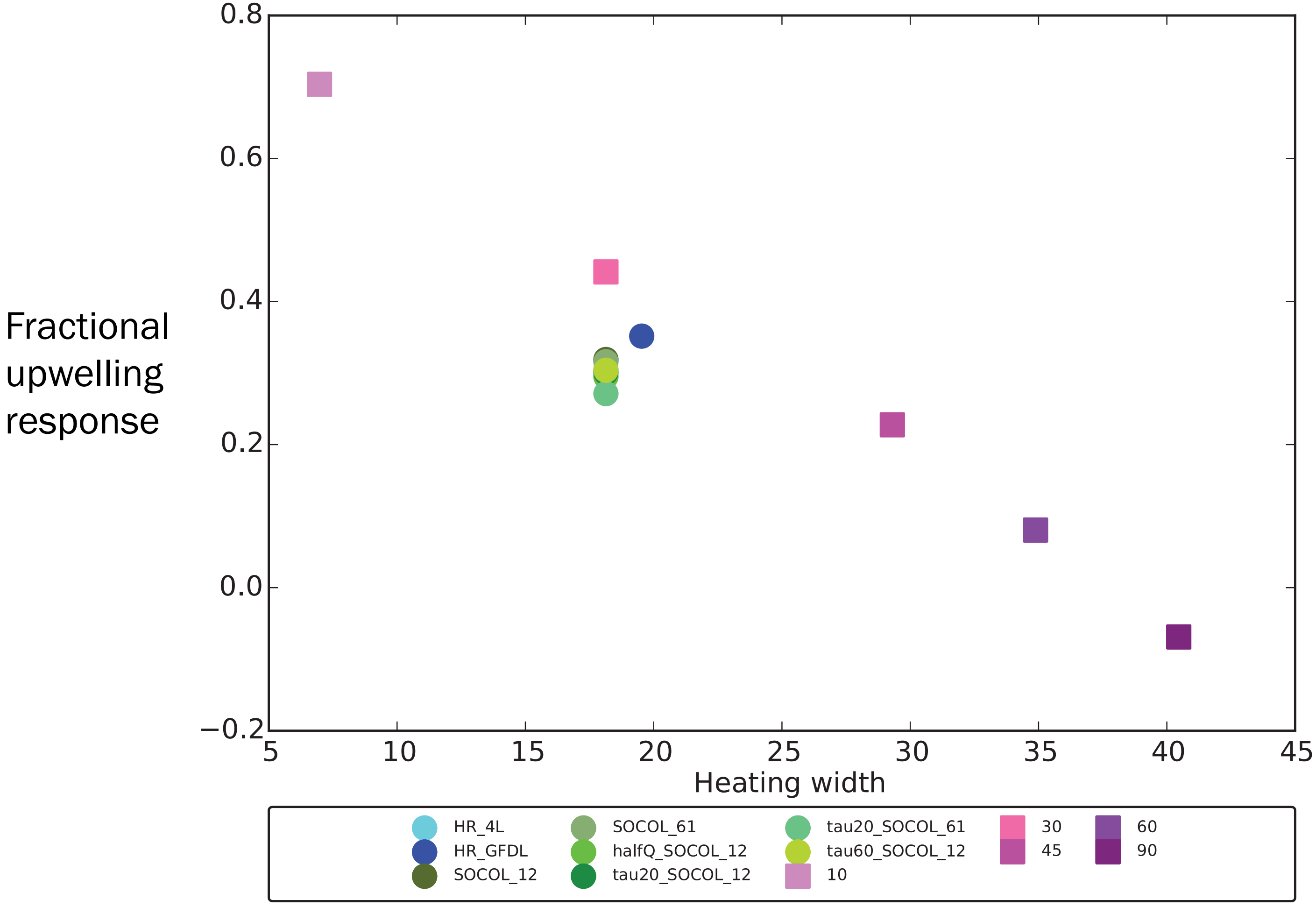
$$\alpha = \frac{N^2 H^2}{f^2 L^2} \tau \kappa$$

N^2 = squared buoyancy frequency
H/L = aspect ratio of heating
f = Coriolis parameter

If $|\alpha| \ll 1$, $T \approx T_E$ — High fractional temperature response

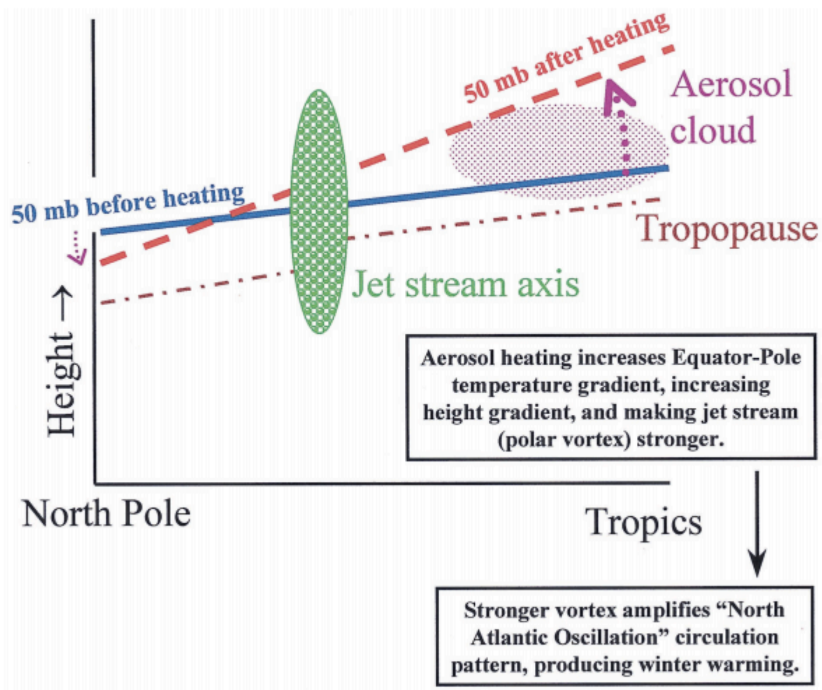
If $|\alpha| > 1$, $T < T_E$ — High fractional upwelling response

Upwelling vs. heating width



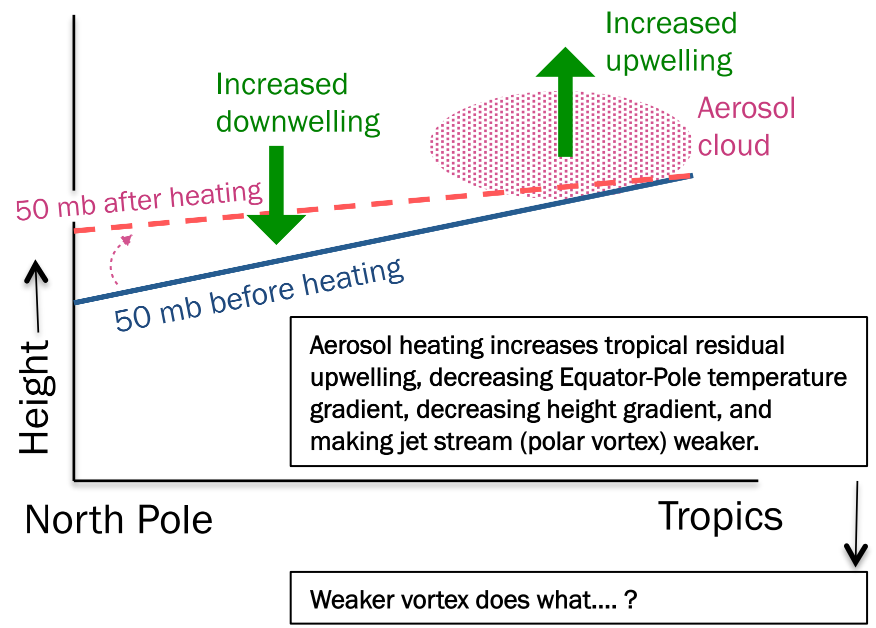
Height gradient revisited

High fractional temperature response

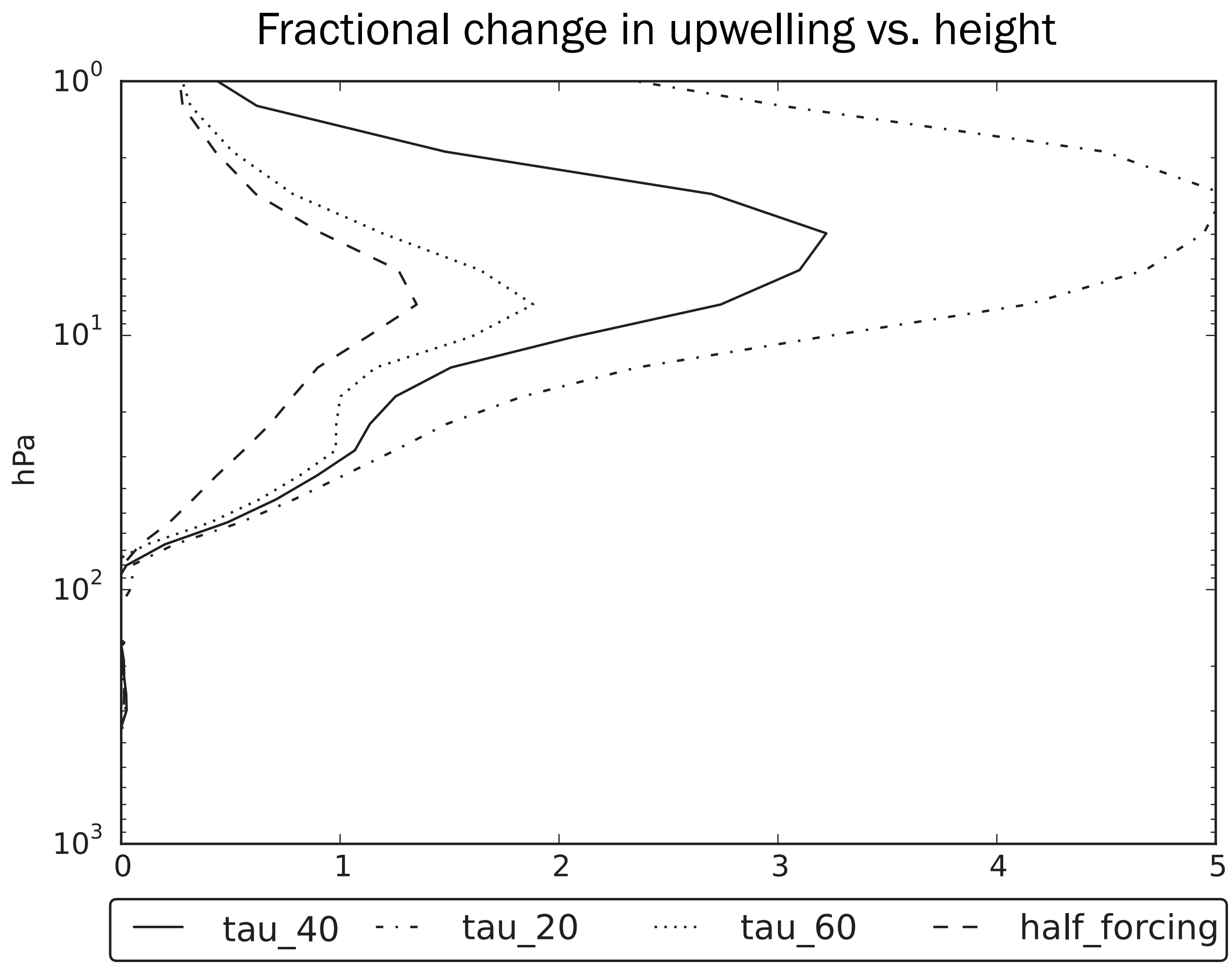


(Robock, 2000)

High fractional upwelling response



Preliminary Results: Role of damping



Based on QG scaling, we expect that fractional change in upwelling should increase with τ, but instead we find that it decreases.

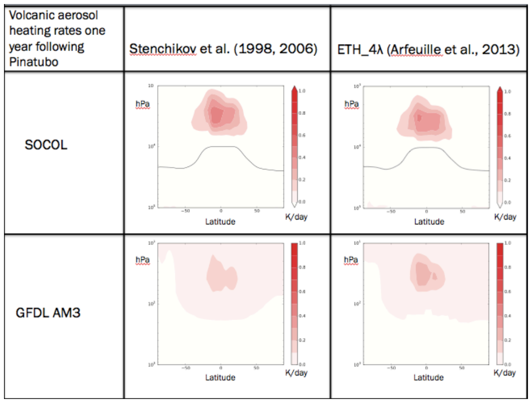
Future Work

- Use fully-coupled models and reanalysis data to characterize the fractional upwelling response to Mt. Pinatubo.

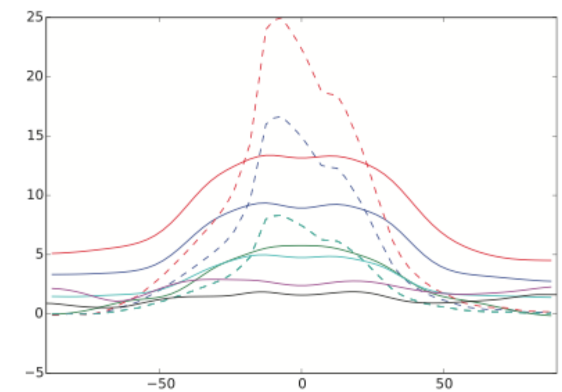
- Explore the role of damping in determining the fractional upwelling response.

- Explore the role of seasonality in the fractional upwelling response.

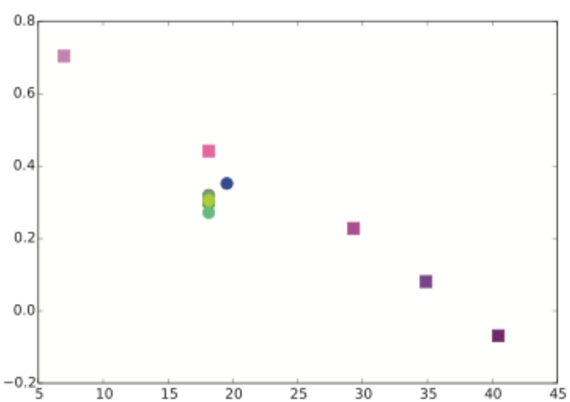
Summary



- Two GCMs that use the same aerosol datasets but independent processing of optical properties can produce estimates of volcanic aerosol heating rates that differ by up to 0.2 K/day, a factor of two.



- Tropical heating perturbations in the stratosphere, like those following major volcanic eruptions such as Mt. Pinatubo, lead to a combination of increased temperature and increased tropical upwelling.



- Based on QG theory and idealized modeling experiments, narrow heating induces a high fractional upwelling response and wide heating induces a high fractional temperature response.

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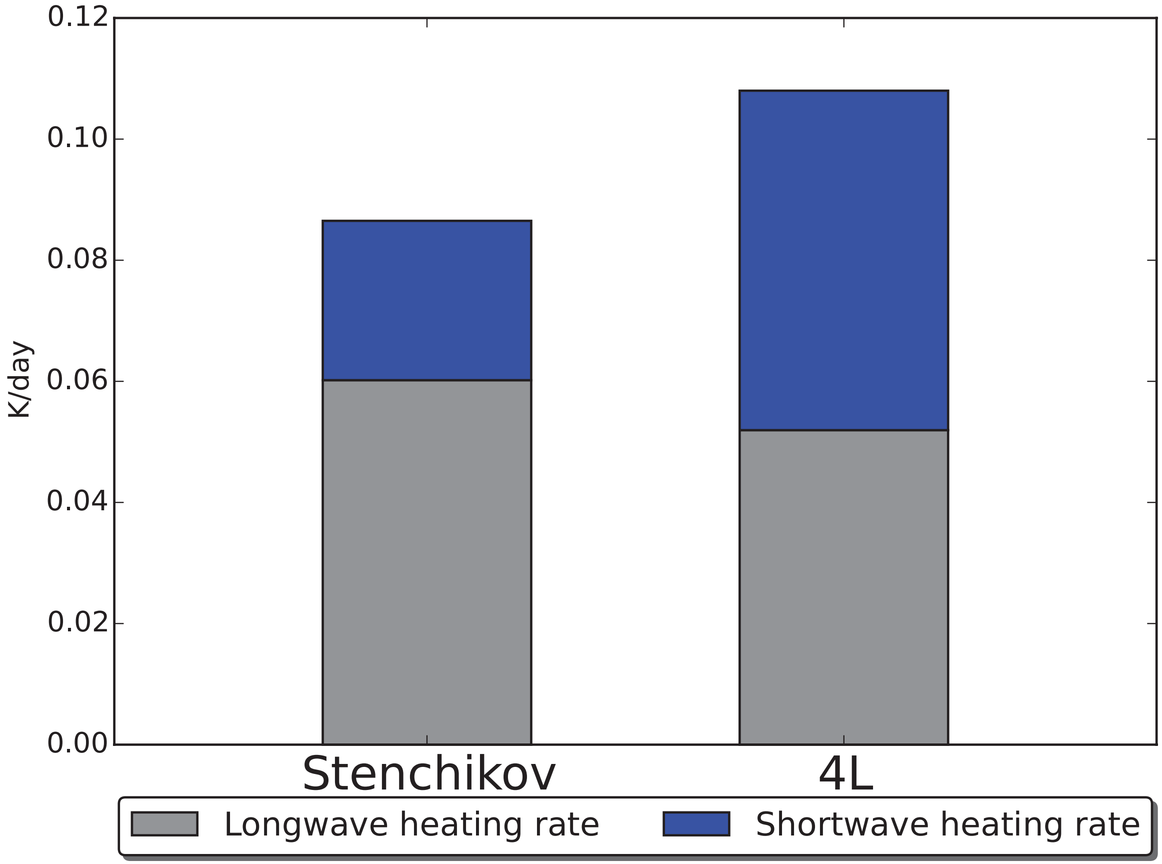
Extra Results: Longwave & shortwave



When derived using GFDL AM3, ETH-4L (Arfeuille et al., 2013) is found to have slightly larger aerosol heating rates, with a larger contribution from shortwave aerosol and smaller contribution from longwave compared to Stenchikov et al. (1998, 2006).