~~Transient Responses of Northern Hemisphere Wintertime Circulation to Stratospheric Soot Injection~~

Wintertime Stratospheric Circulation Response to Smoke Injection from a Regional Nuclear Conflict

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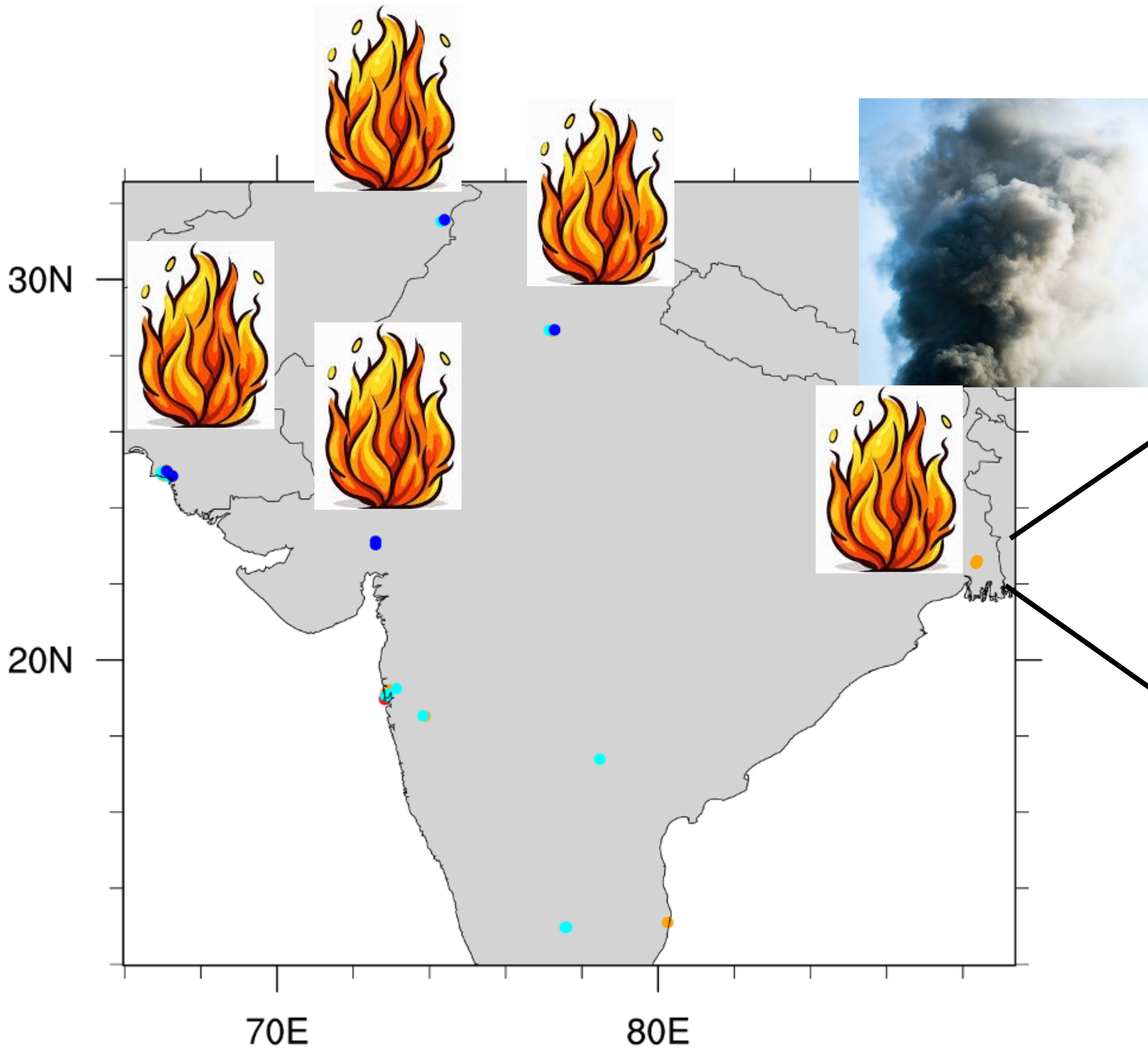
WAWG Meeting

Feb 4, 2026

"Regional Conflicts" using Smaller Scale Nuclear Weapons

India Pakistan Conflicts



Mills et al. (2007; 2014), Toon et al. (2019), Bardeen et al. (2021)

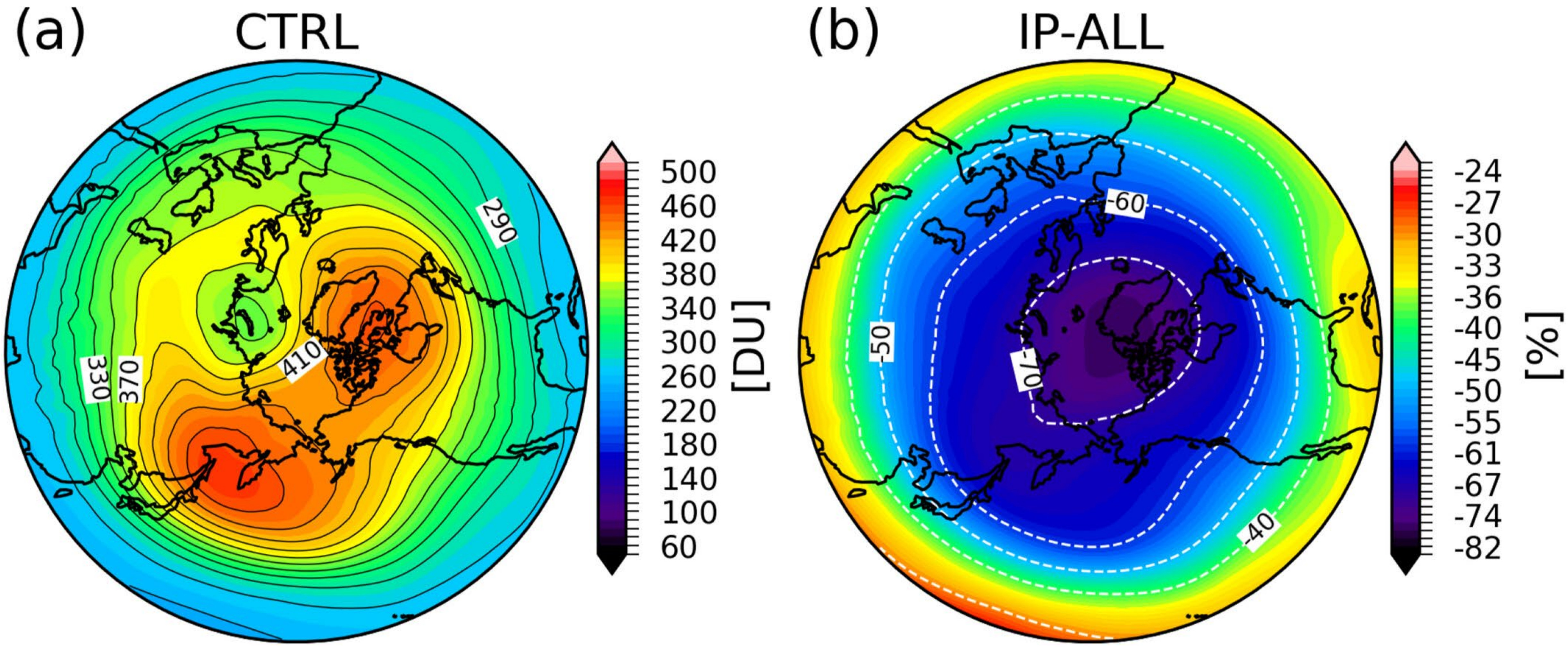
New study:
70:30 ratio for BC/OC

~5 Tg of smoke injection into the atmosphere

large-scale urban fires

Chemical Response

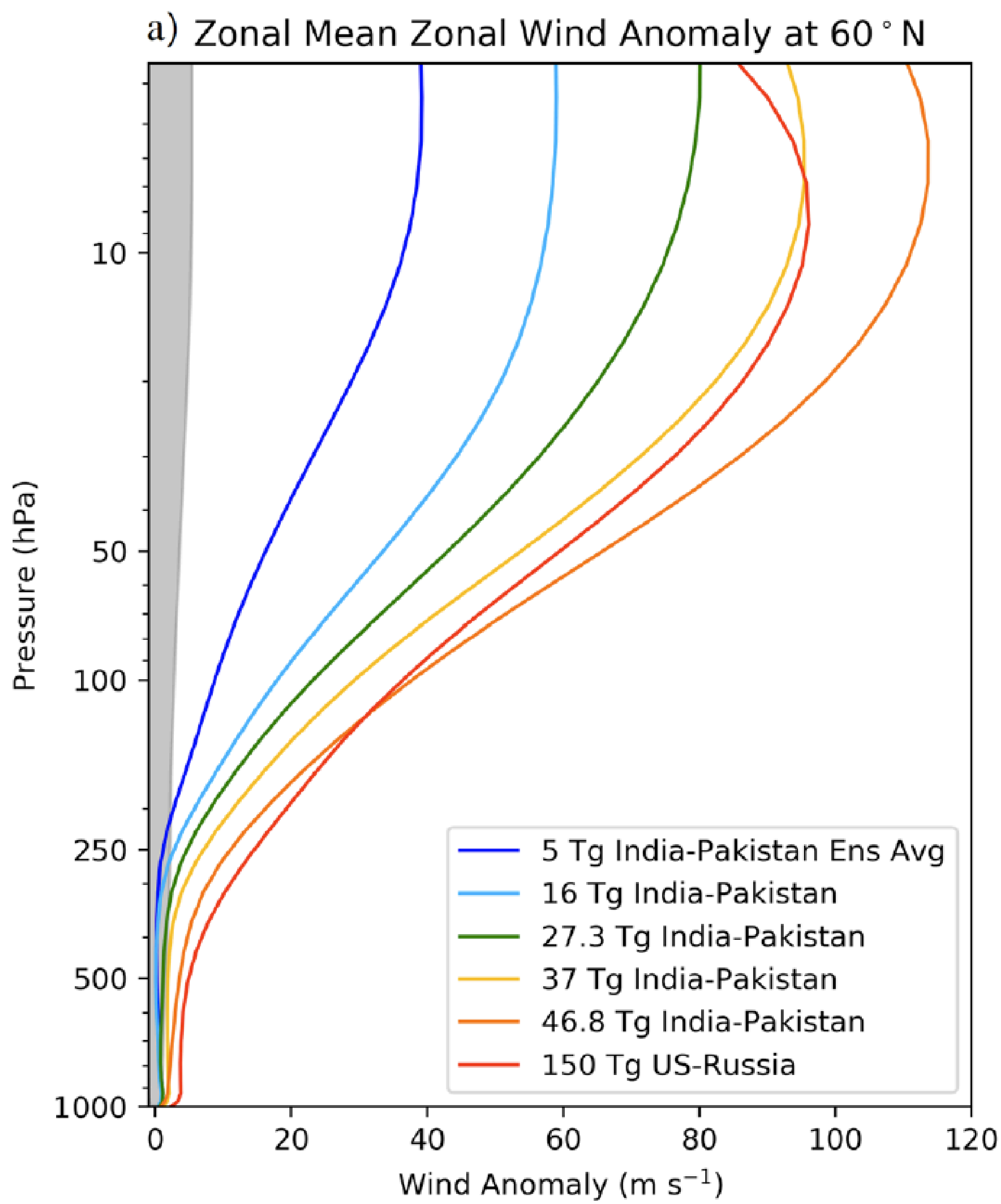
Change in total column ozone from the 5 Tg soot injection (India-Pakistan) cases



The Arctic ozone hole!

Yook et al. (2025) Earth's Future

Stratospheric Polar Vortex (SPV) Response



Coupe and Robock (2021)

Aerosol-induced heating of the lower stratosphere

Strengthening of the wintertime SPV

Other aerosol injection/tropical heating scenarios:
volcanic eruptions, geo-engineering, nuclear wars, solar-cycle etc.

Proposed Mechanisms

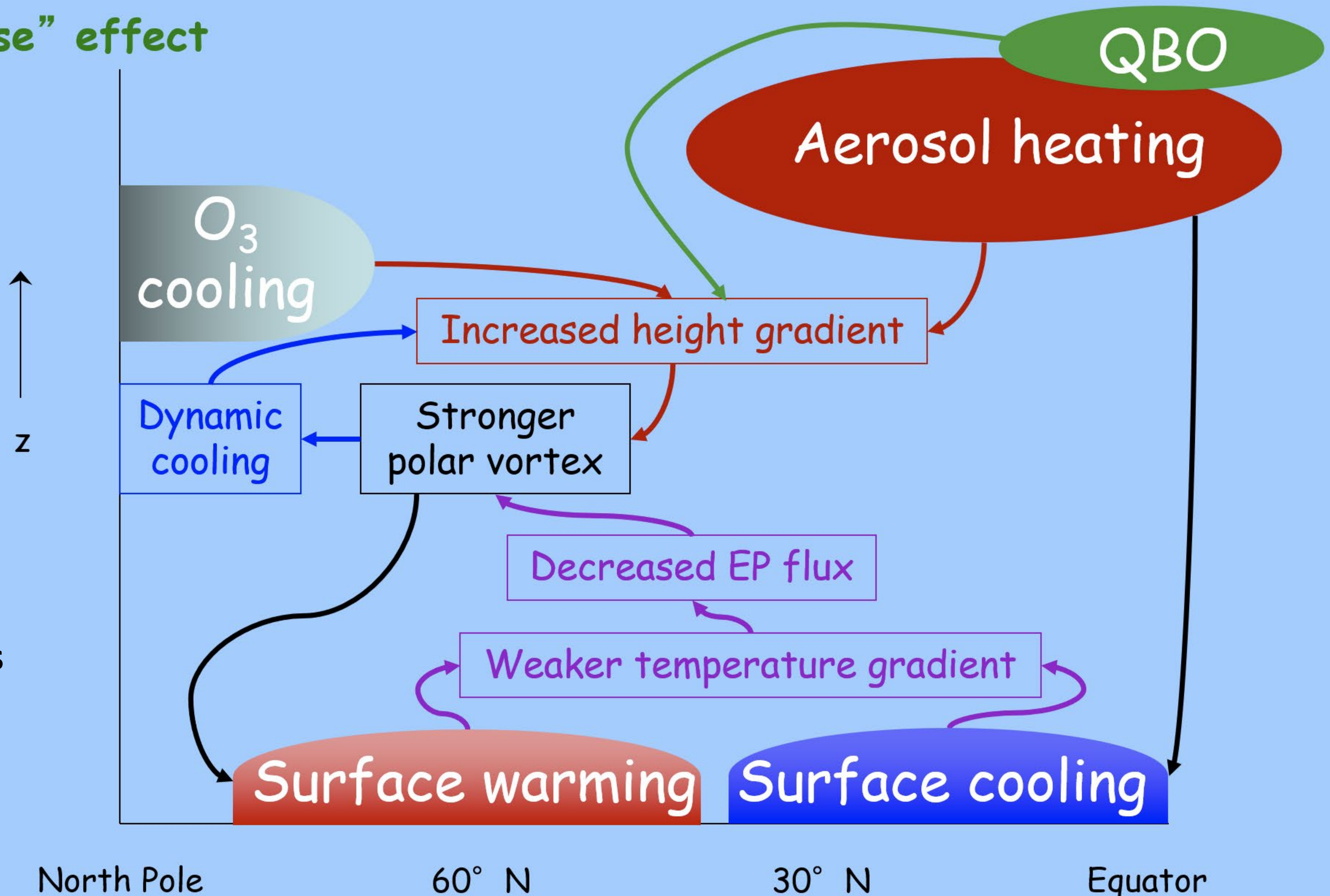
"stratospheric gradient" mechanism

"tropospheric gradient" mechanism

"wave feedback" mechanism

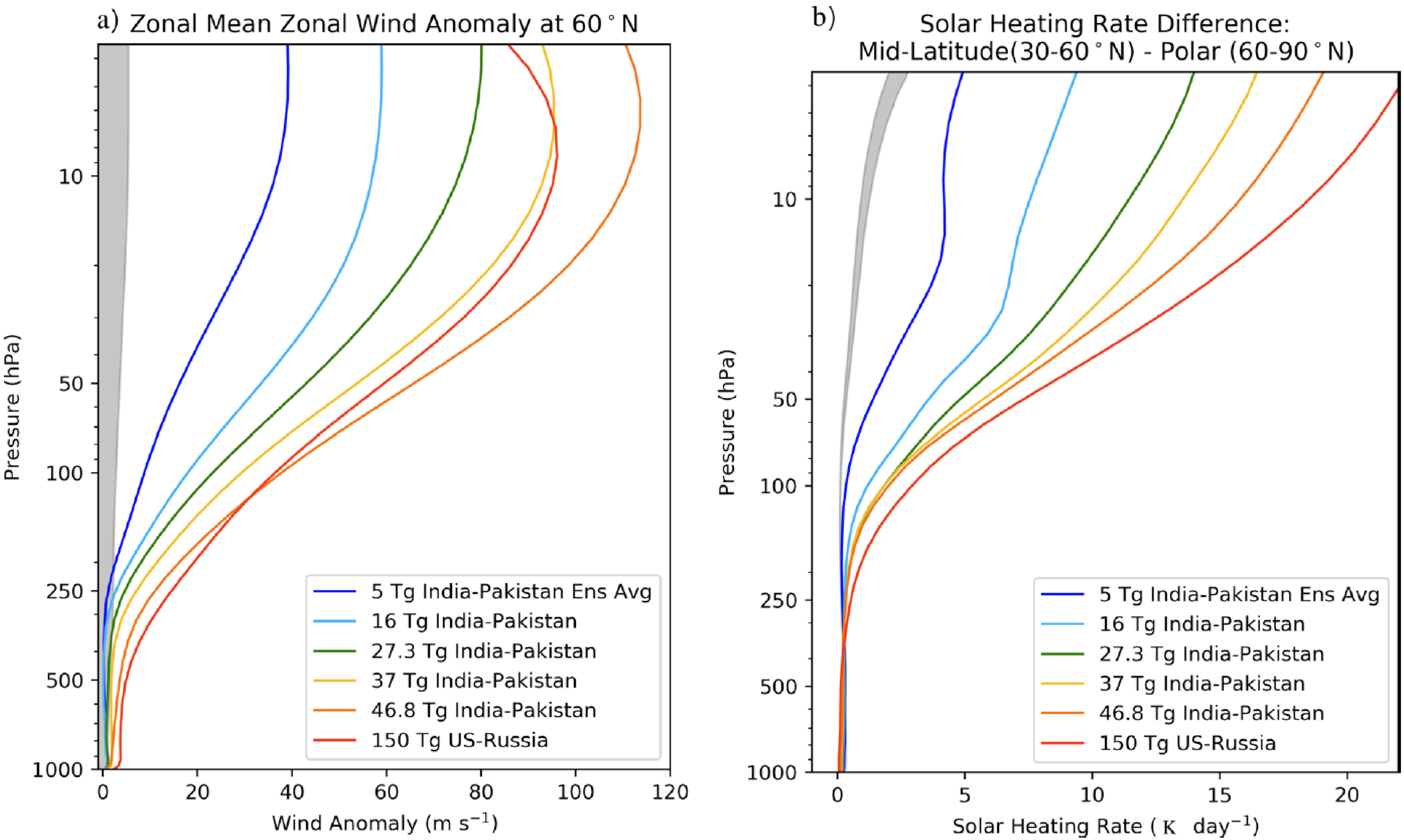
"QBO phase" effect

Ways Volcanic Eruptions Force Positive AO Mode in Winter



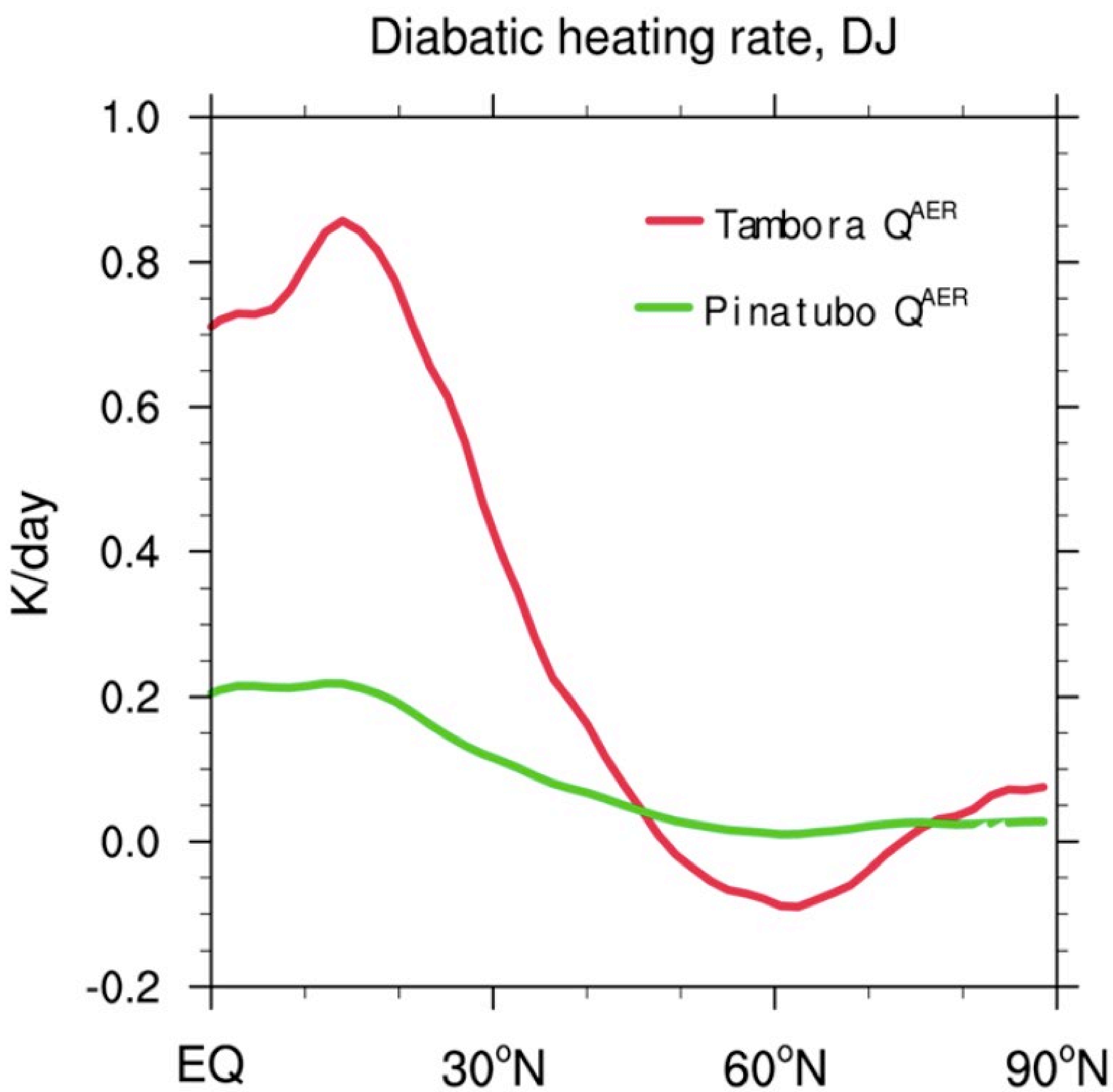
* This slide is courtesy of Alan Robock

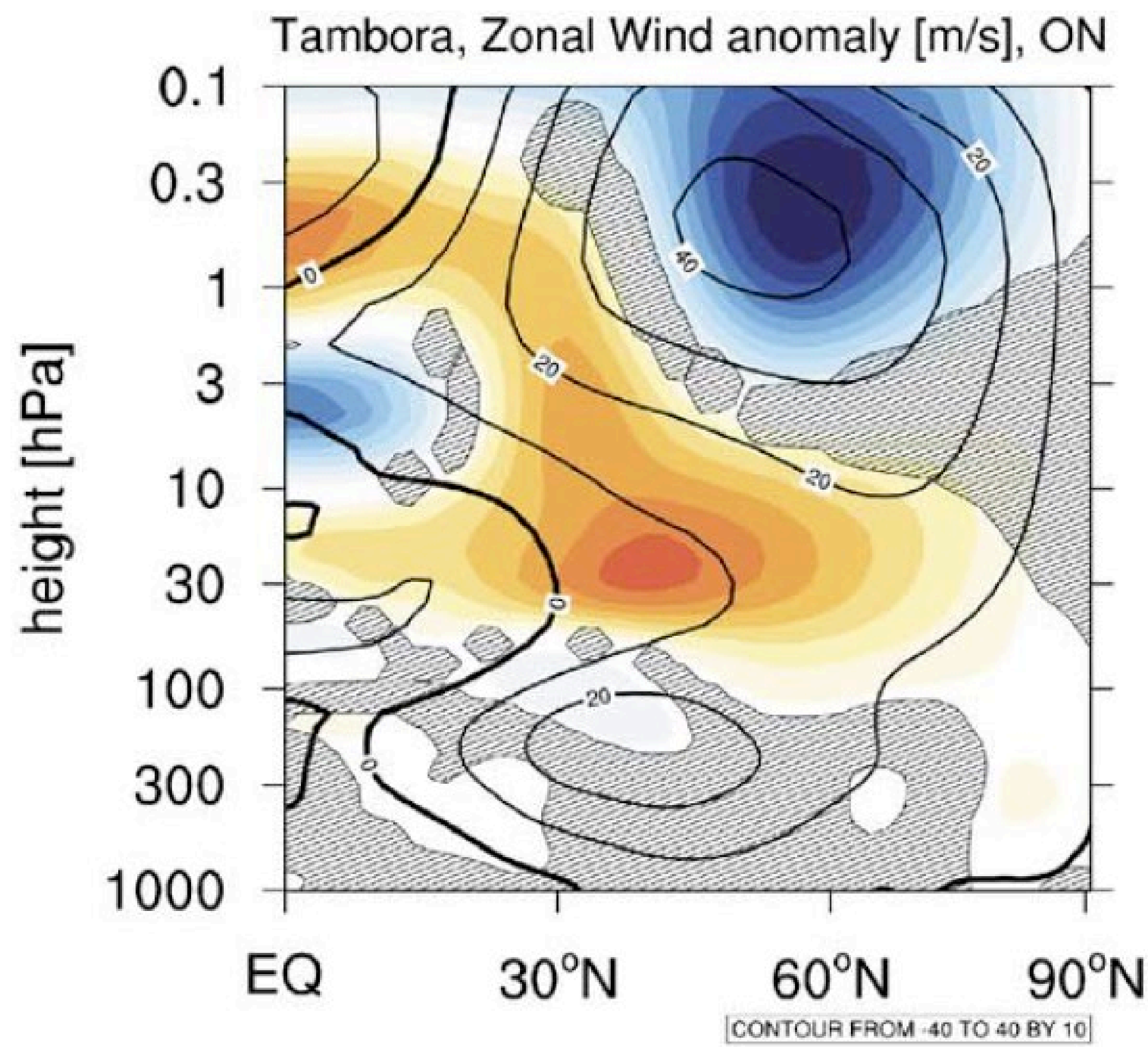
Stratospheric Gradient Mechanism



Coupe and Robock (2021)

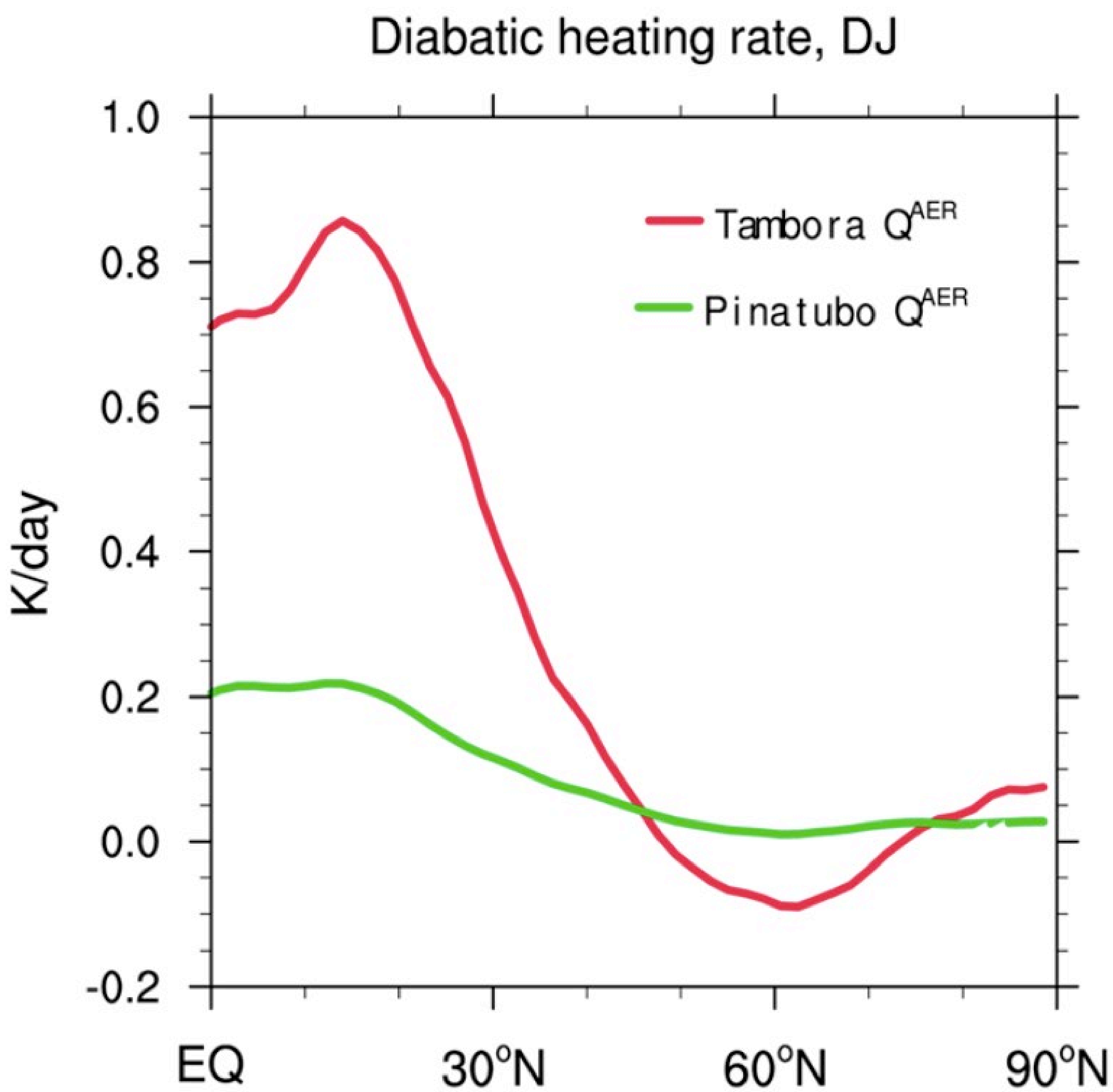
Wave Feedback Mechanism

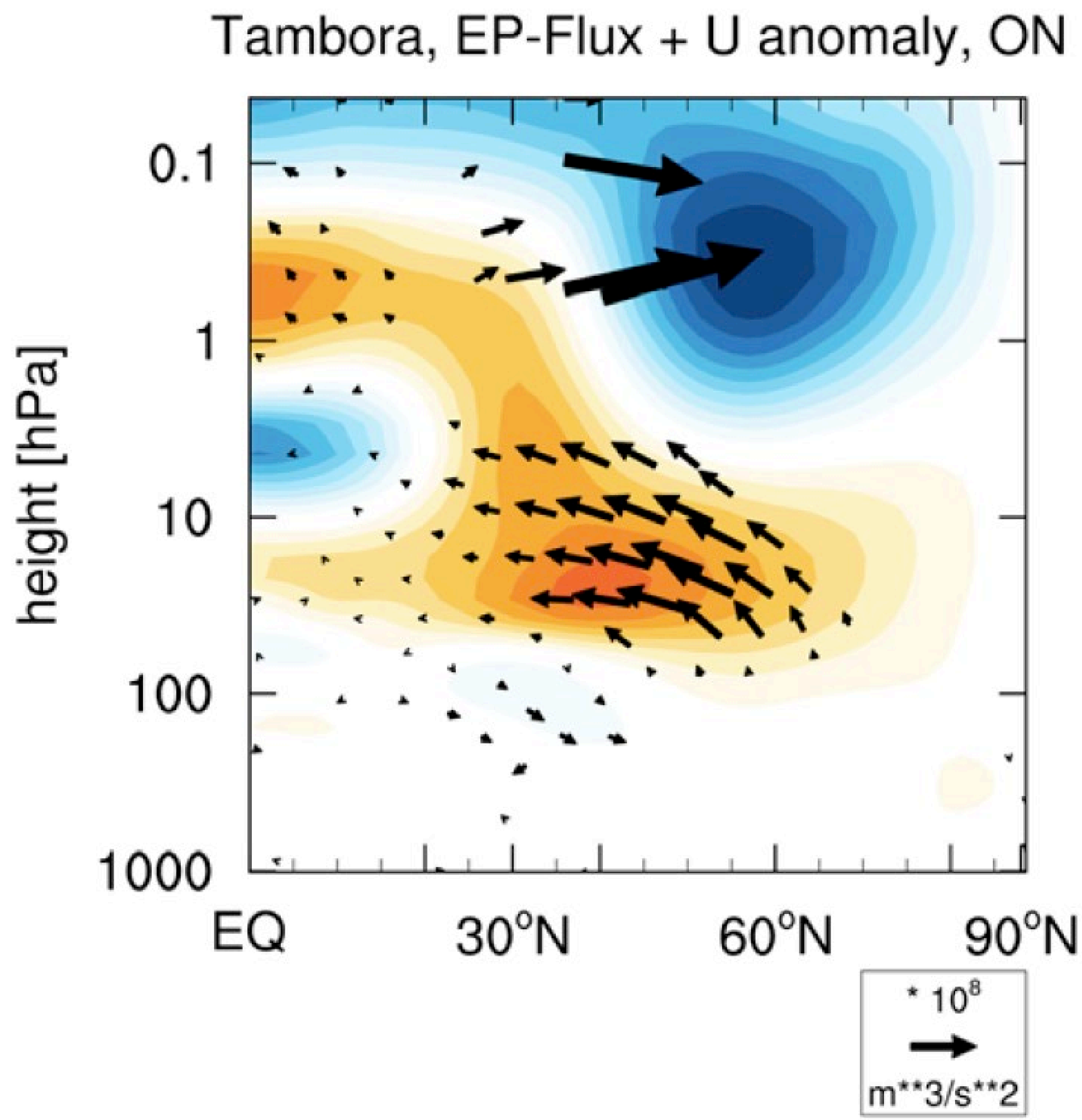




Bittner et al (2016)

Wave Feedback Mechanism



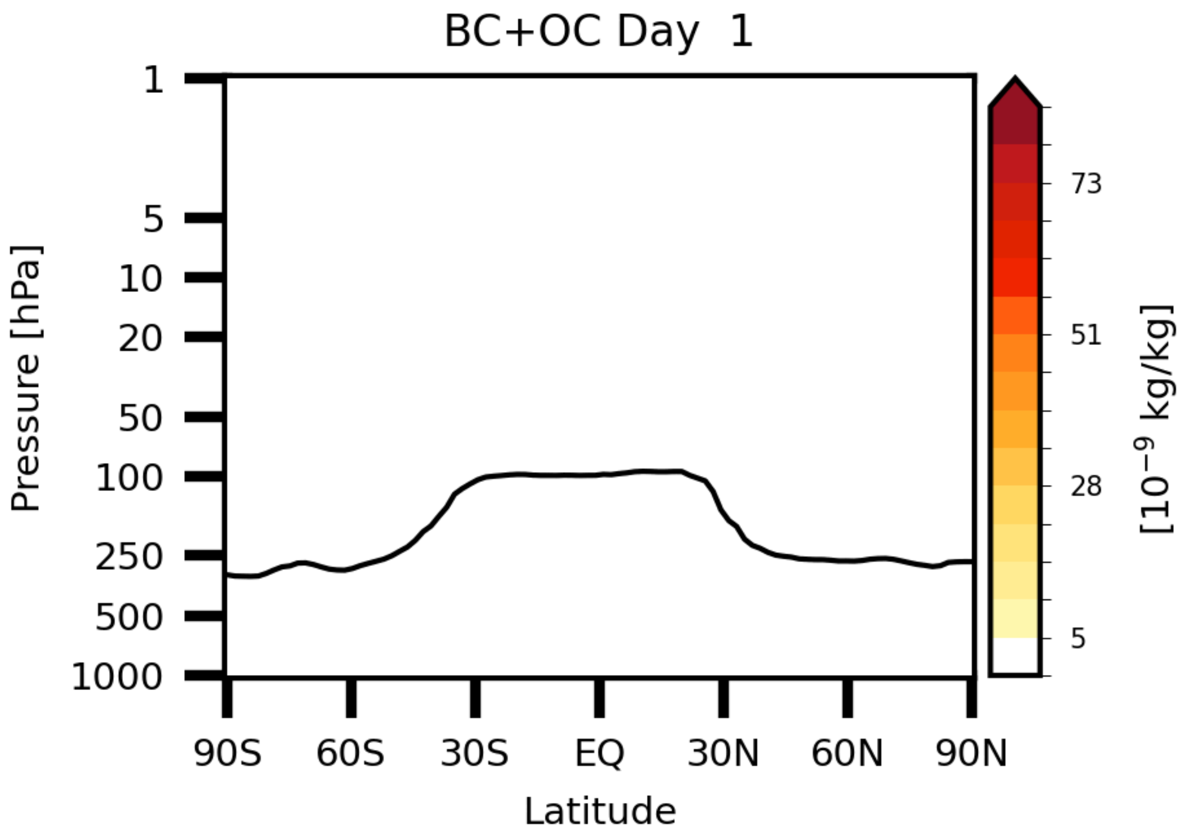


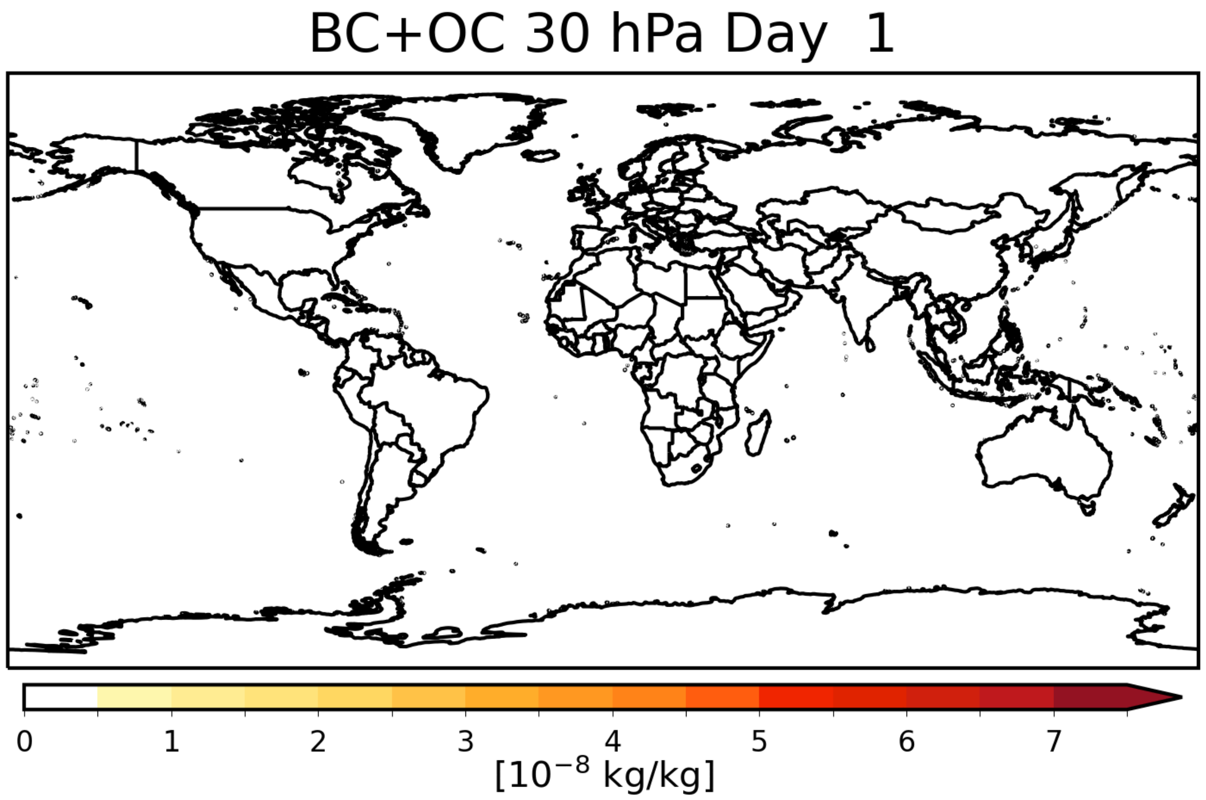
Bittner et al (2016)

Experiments

20-member ensembles (**CTRL** and **IP** case) run on WACCM4 with CARMA

All smoke particles (5Tg of BC and 1.6 Tg of OC) are initially emitted as a constant mixing ratio **between 150 and 300 hPa** over the potential conflict regions (India-Pakistan) during Jan 11-14.

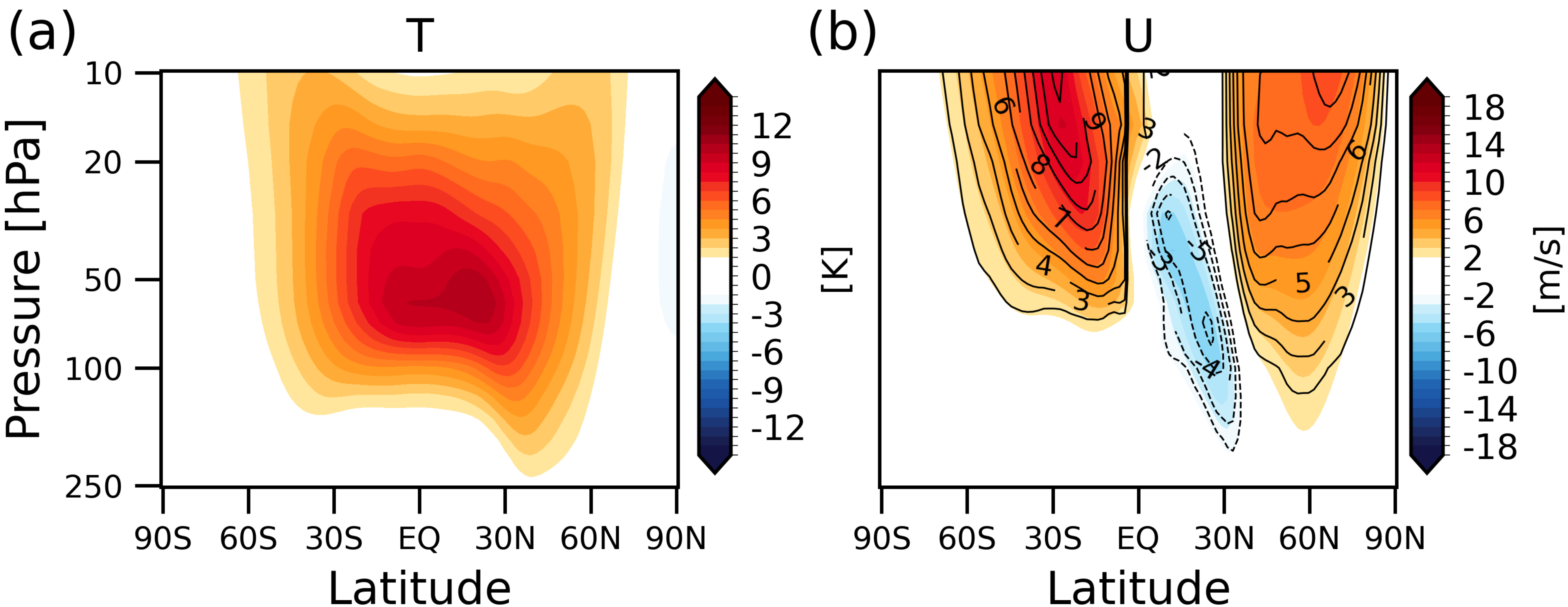




The smoke plume rapidly **"self-loft"** into the stratosphere due to the BC's radiative effects

Zonal-mean Temperature and Zonal-Wind Anomalies

(1-month average after the aerosol injection)



Shading: actual U

Contours: U from thermal wind

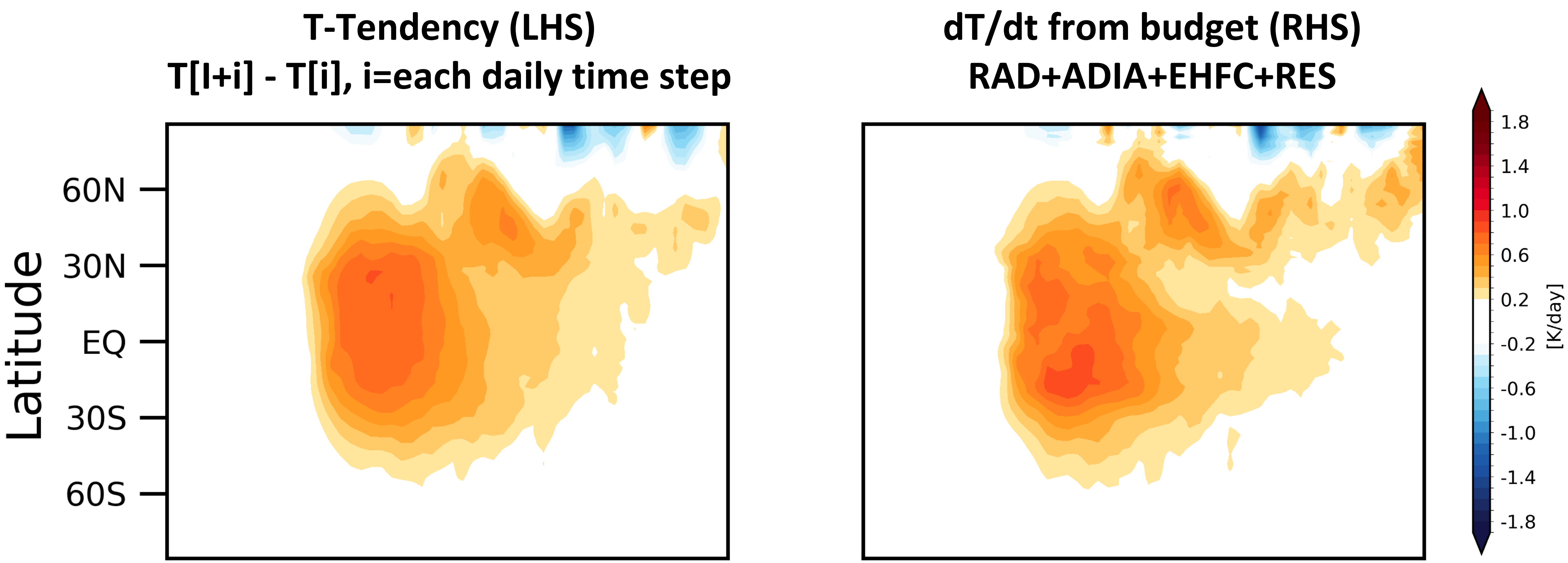
Temperature Budget

$$\frac{\partial \overline{T}}{\partial t} = \overline{Q} - \overline{\omega}\left(\frac{\partial \overline{T}}{\partial p} - \kappa\frac{\overline{T}}{p}\right) - \frac{1}{a\cos\phi}\frac{\partial(\cos\phi(\overline{v'T'}))}{\partial\phi} + \left(-\left(\frac{\partial(\overline{\omega'T'})}{\partial p} - \kappa\frac{(\overline{\omega'T'})}{p}\right) - \overline{v}\frac{\partial\overline{T}}{\partial y} + \overline{Q_{GW}}\right)$$

RAD **ADIA** **EHFC** **RES**

(Vertical EHFC+mean heat transport+GWs)

DYN: ADIA + EHFC + RES



Average in Stratospheric Layers (100-10 hPa)

Temperature Budget

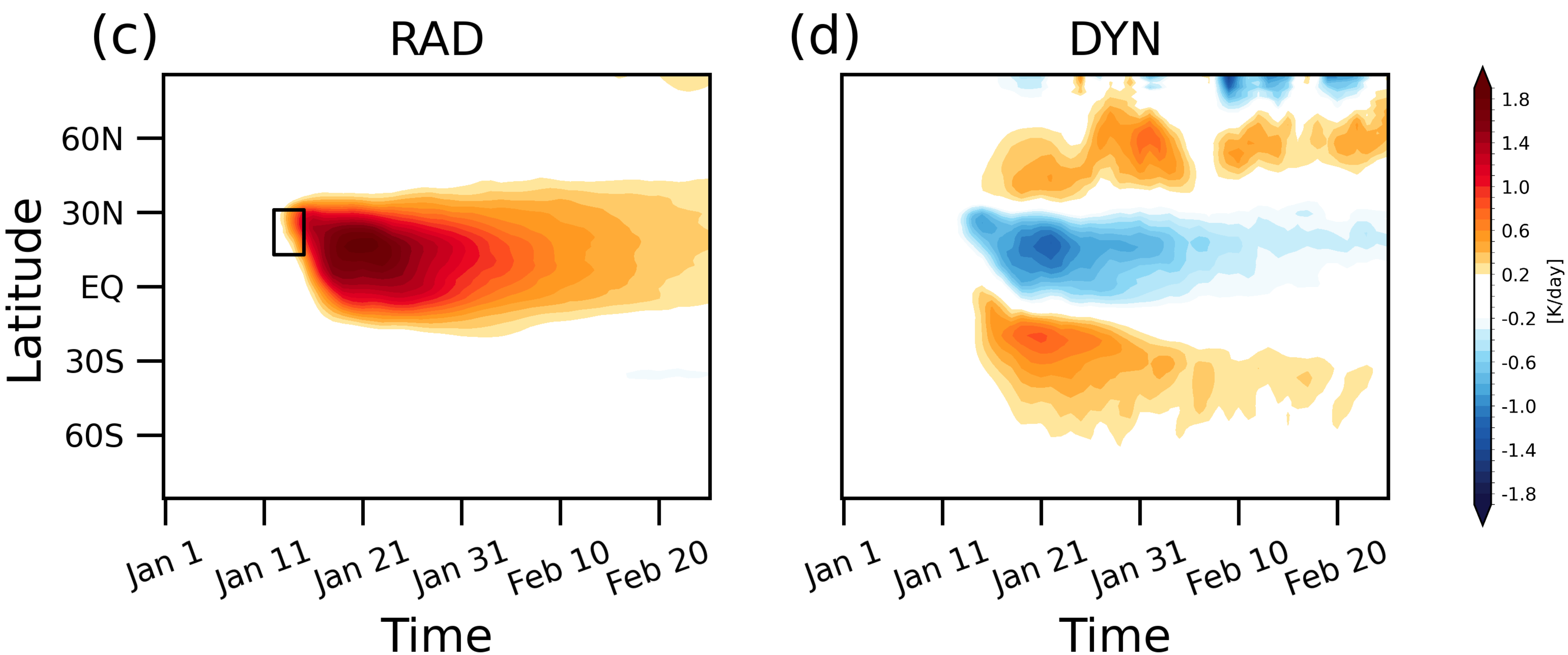
$$\frac{\partial \overline{T}}{\partial t} = \overline{Q} - \overline{\omega}\left(\frac{\partial \overline{T}}{\partial p} - \kappa\frac{\overline{T}}{p}\right) - \frac{1}{a\cos\phi}\frac{\partial(\cos\phi(\overline{v'T'}))}{\partial\phi} + \left(-\left(\frac{\partial(\overline{\omega'T'})}{\partial p} - \kappa\frac{(\overline{\omega'T'})}{p}\right) - \overline{v}\frac{\partial \overline{T}}{\partial y} + \overline{Q_{GW}}\right)$$

RAD **ADIA** **EHFC** **RES**

(Vertical EHFC+mean heat transport+GWs)

RAD (Radiative): Q

DYN (Dynamical): ADIA + EHFC + RES

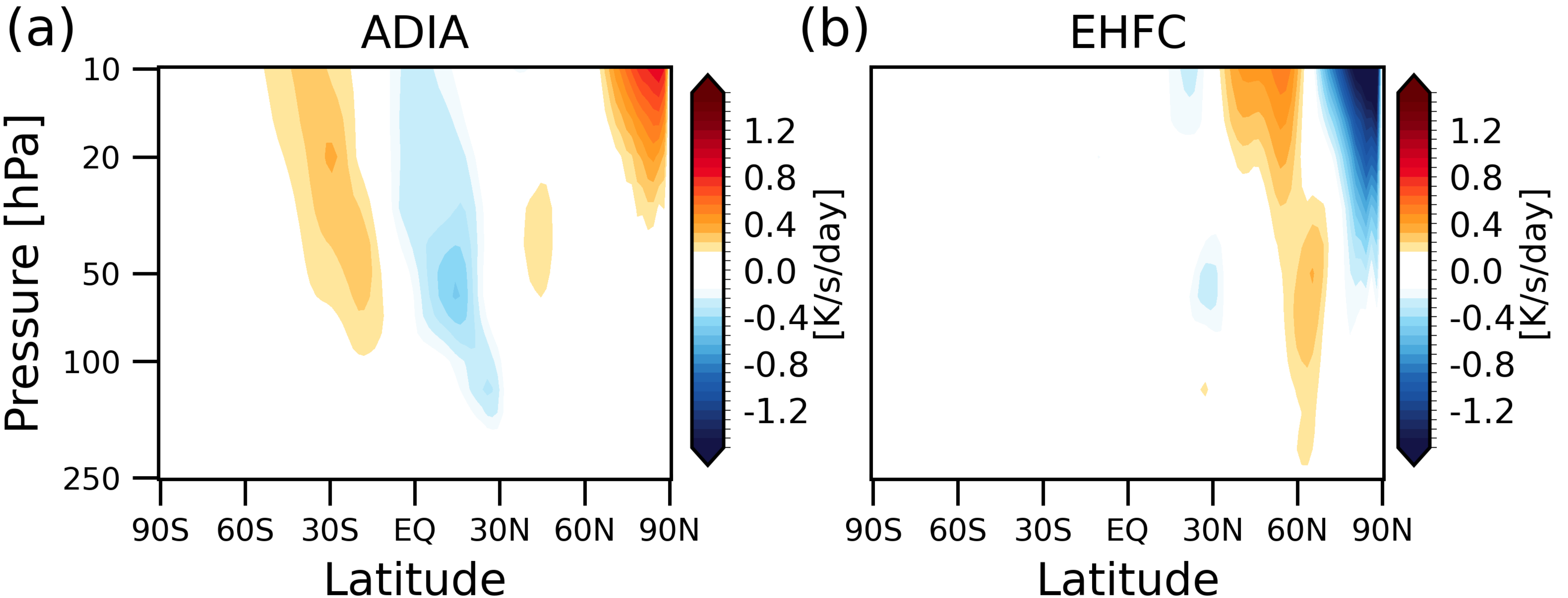


Temperature Budget

$$\frac{\partial \overline{T}}{\partial t} = \overline{Q} - \overline{\omega}(\frac{\partial \overline{T}}{\partial p} - \kappa\frac{\overline{T}}{p}) - \frac{1}{acos\phi}\frac{\partial(cos\phi(\overline{v'T'}))}{\partial\phi} + (-(\frac{\partial(\overline{\omega'T'})}{\partial p} - \kappa\frac{(\overline{\omega'T'})}{p}) - \overline{v}\frac{\partial \overline{T}}{\partial y} + \overline{Q_{GW}})$$

RAD **ADIA** **EHFC** **RES**

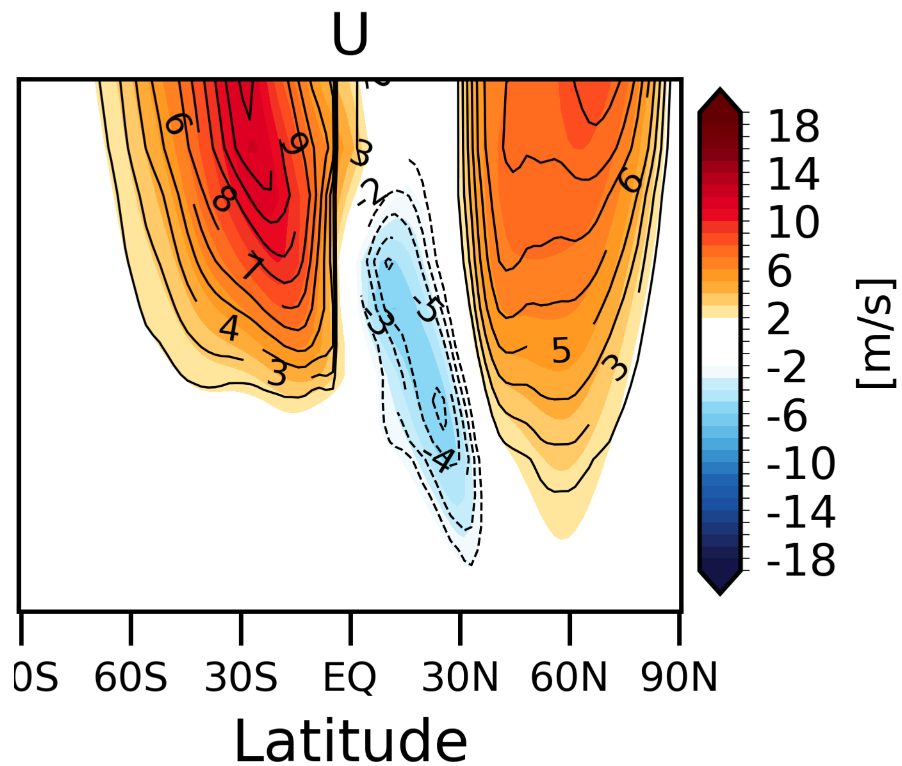
Adiabatic Processes **Eddy Heat Flux Convergence**



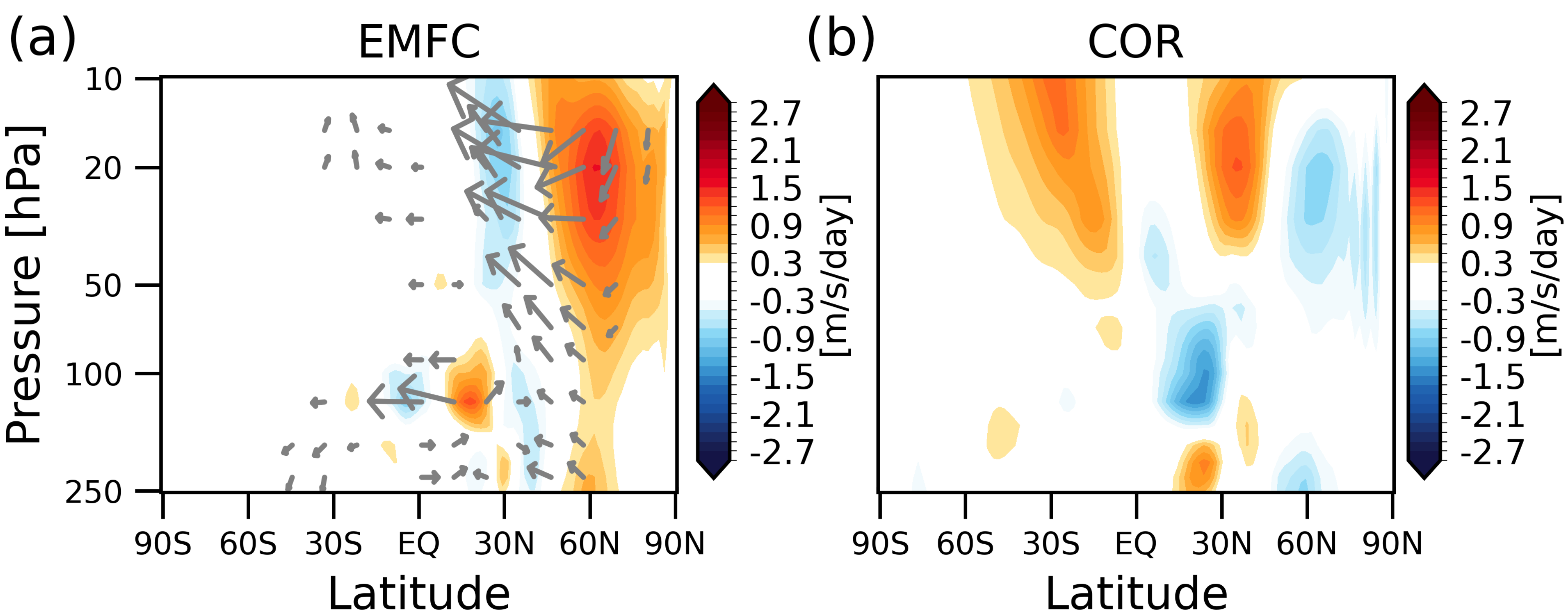
Zonal-Momentum Budget

$$\frac{\partial \overline{U}}{\partial t} \simeq \overline{v}\{f - \frac{1}{acos\phi}\frac{\partial(\overline{u}cos\phi)}{\partial\phi}\} - \frac{1}{acos^2\phi}\frac{\partial cos\phi\overline{u'v'}}{\partial\phi} - (\overline{u}\frac{\partial\overline{\omega}}{\partial p} + \frac{\partial\overline{u'\omega'}}{\partial p} - \overline{F_r})$$

COR **EMFC** **RES**



***EP-flux (vectors)**



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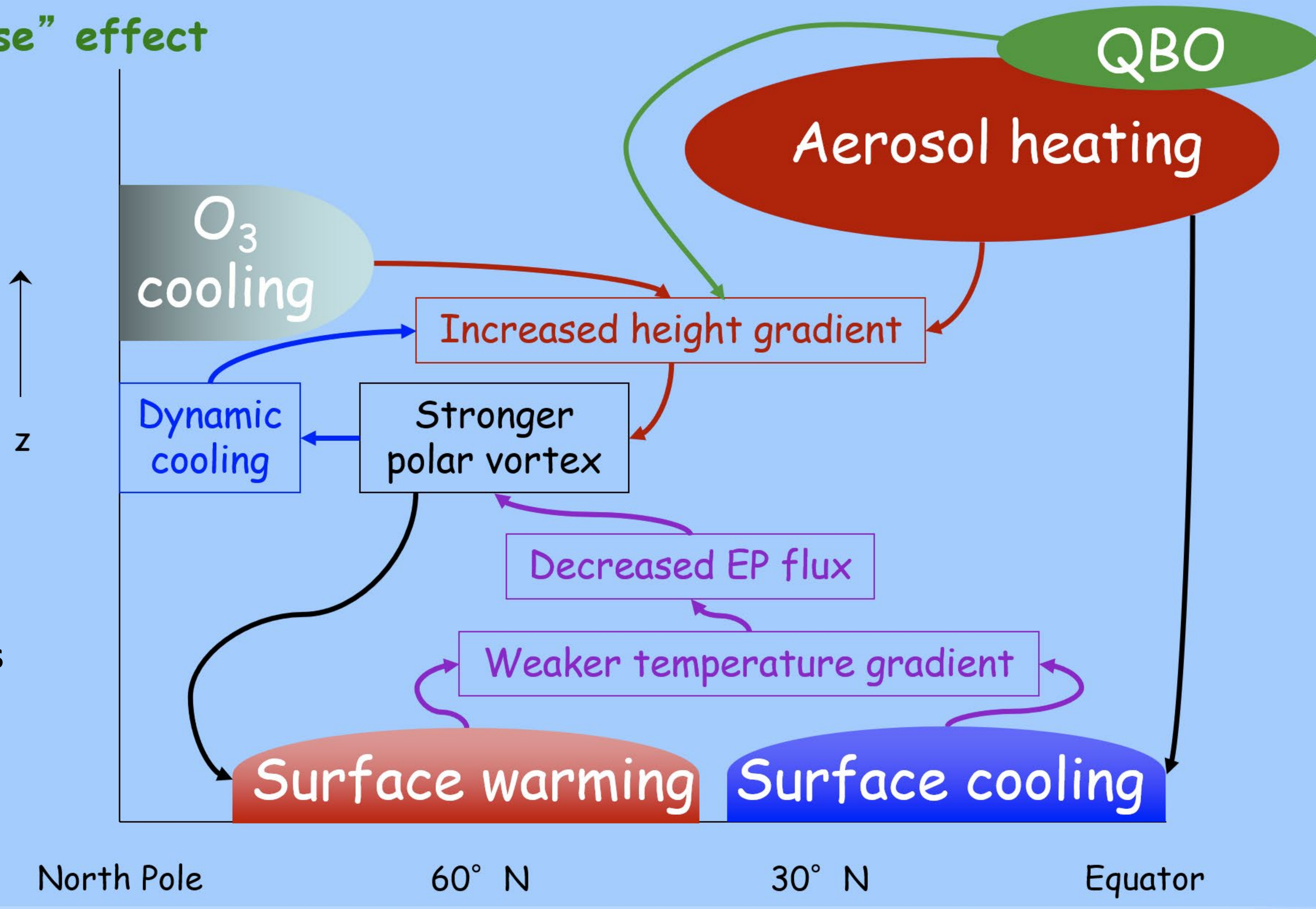

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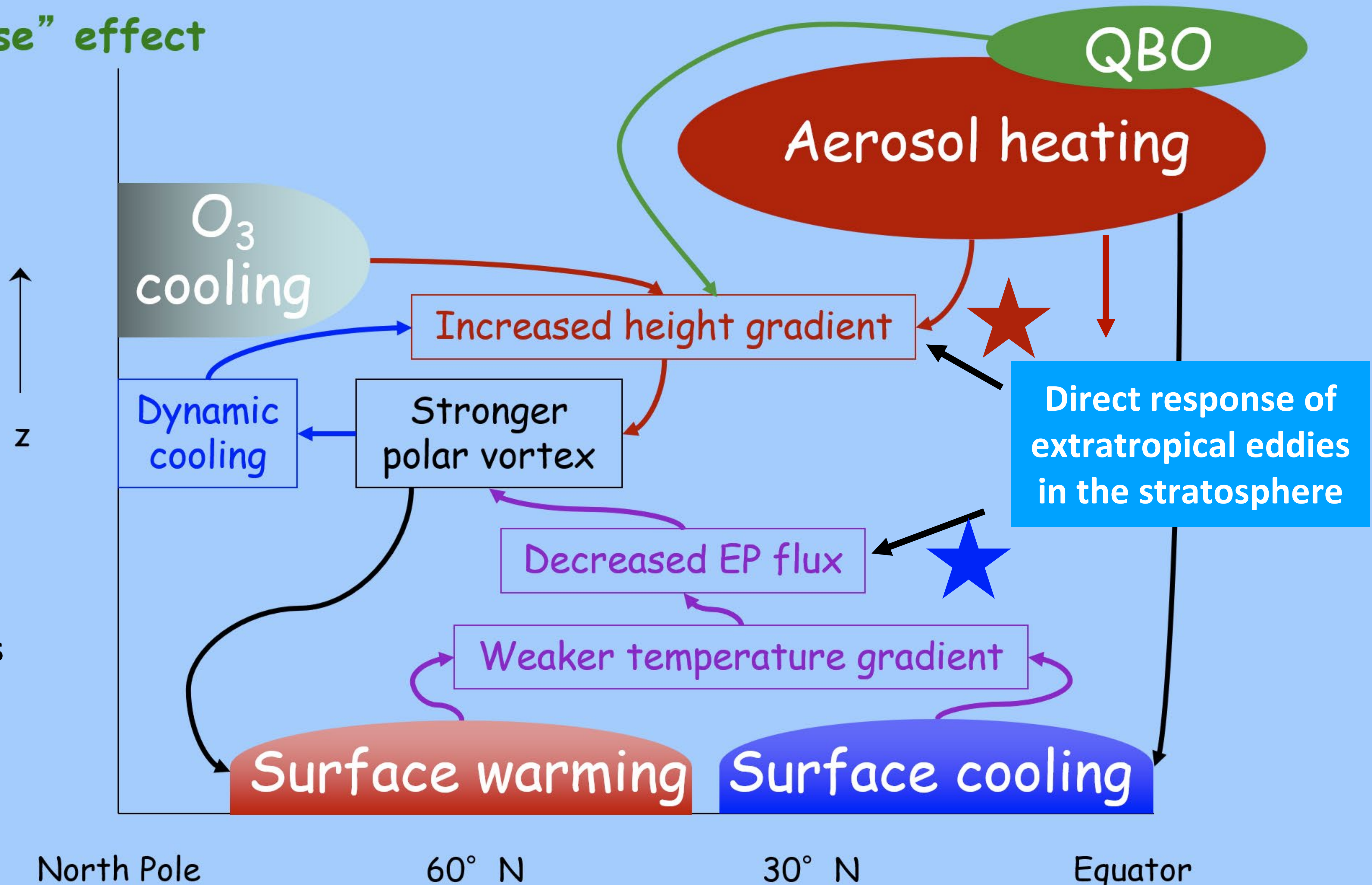

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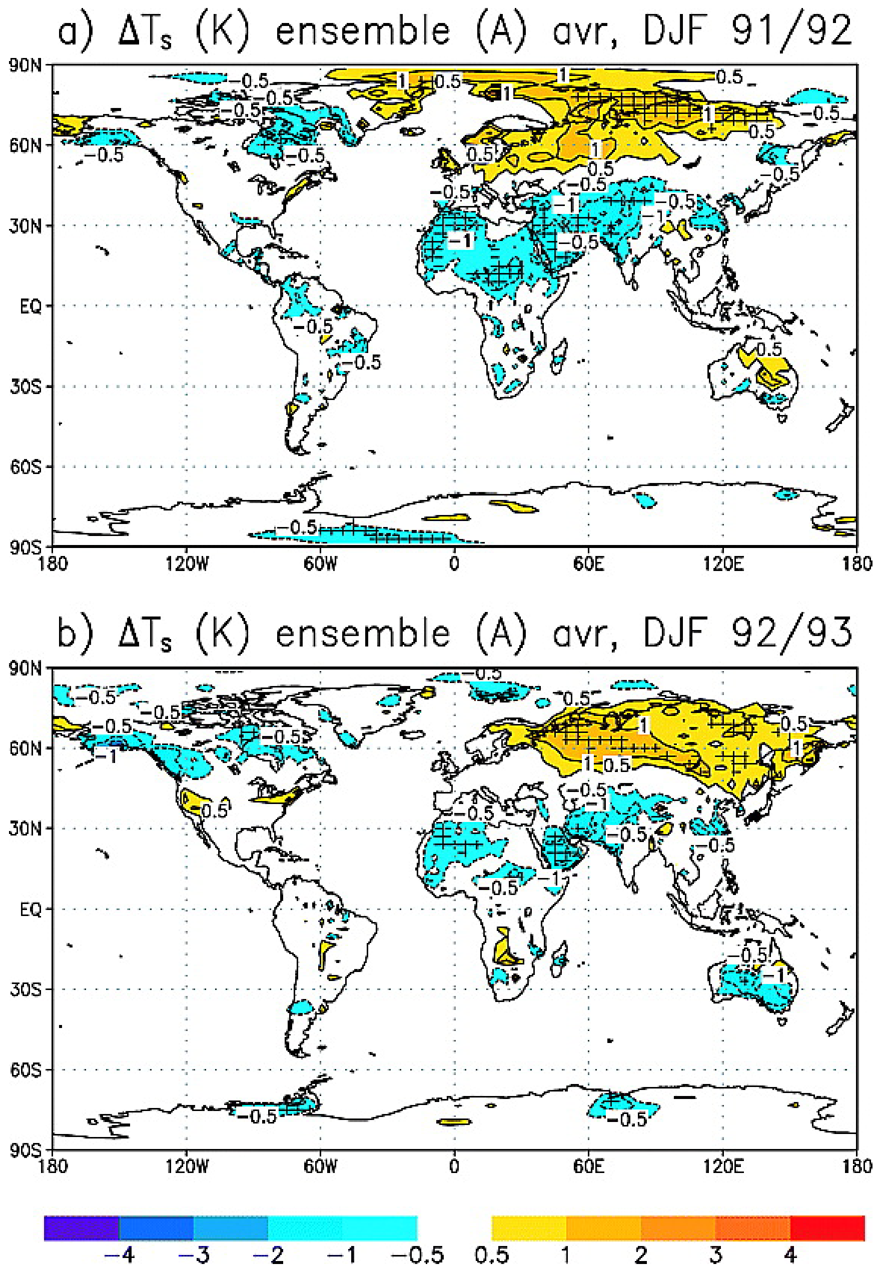
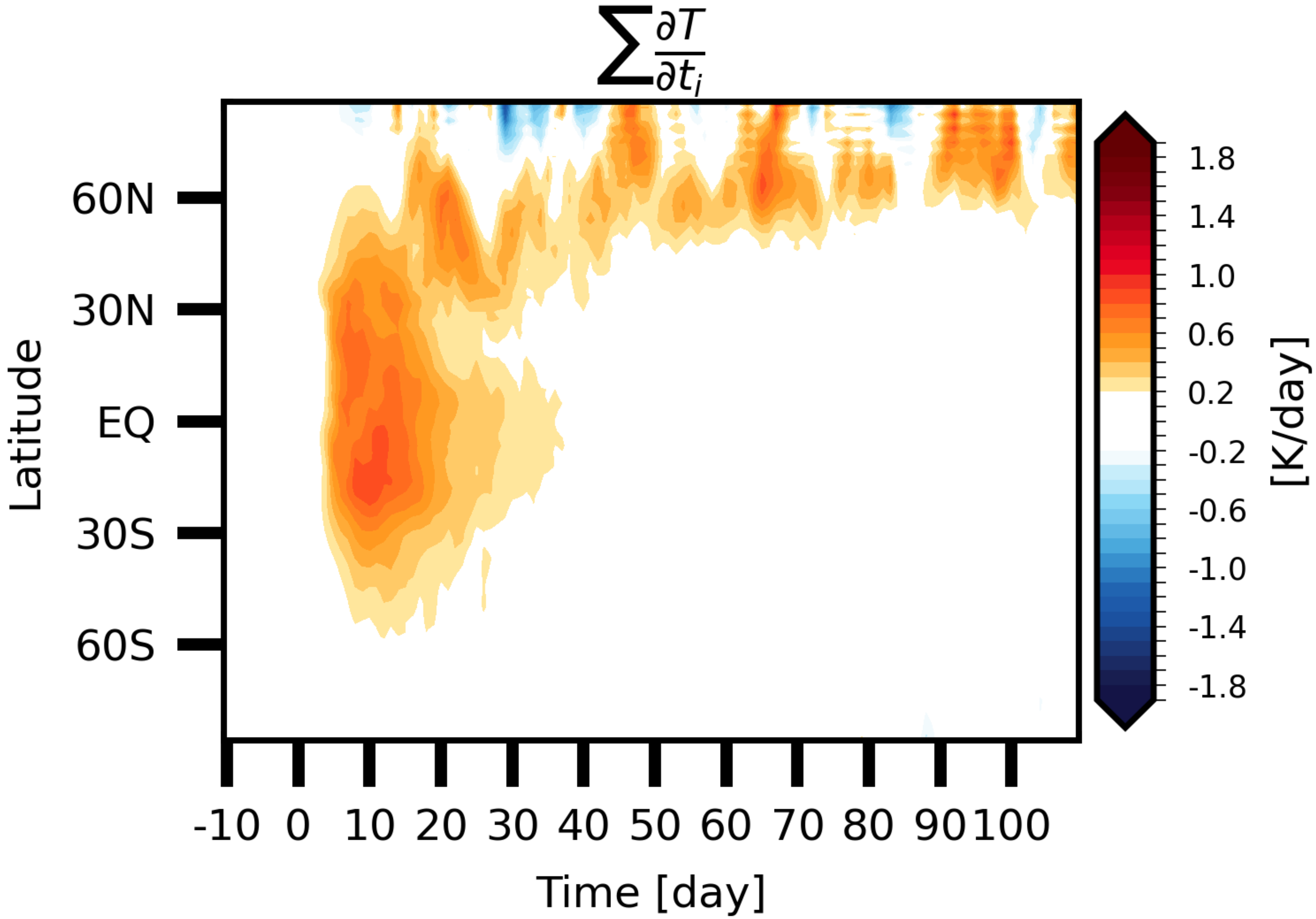
Q & A

Tropospheric Gradient Mechanism



Stenchikov et al. (2002)

Why focusing on the first 30 days?



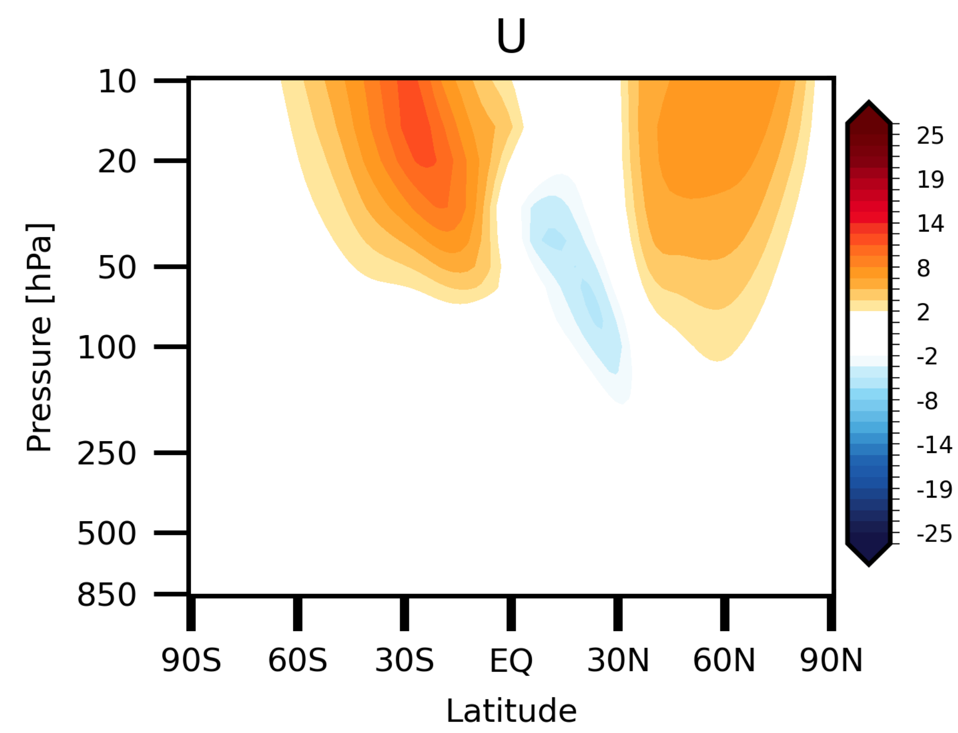
Conclusion

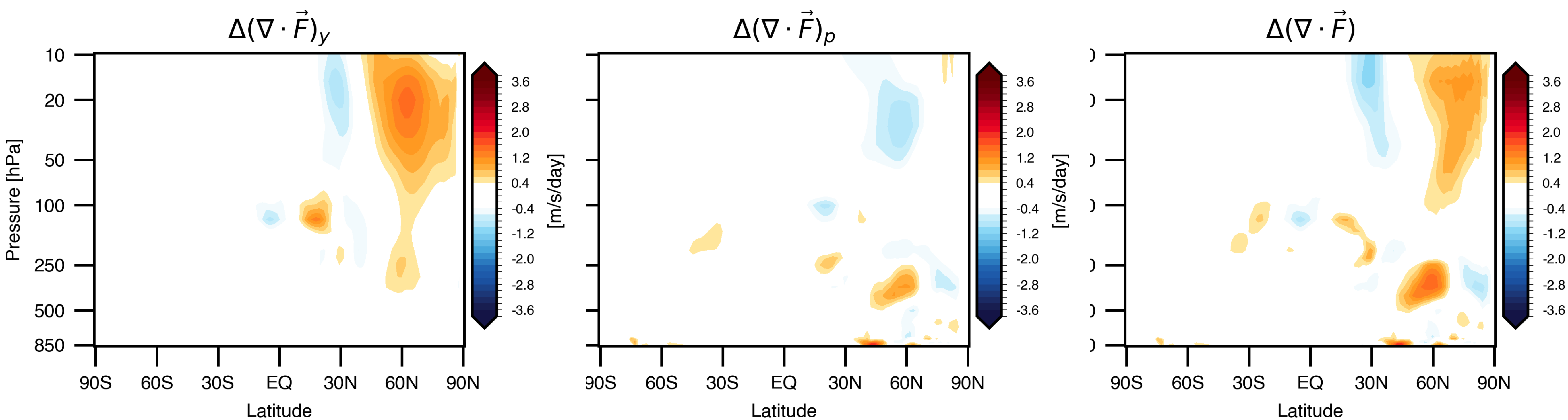
Our results show that a regional war scenario releasing 5 Tg of soot could cause approximately a 40% reduction in global ozone within the first year of the simulation.

This loss is driven by two main mechanisms: (1) stratospheric warming, which accelerates chemical reaction rates, and (2) enhanced catalytic cycles from halogen emissions on smoke particles.

The resulting ozone depletion leads to substantially increased global UV-B exposure, indicating that even a regional nuclear war could trigger serious global environmental consequences.

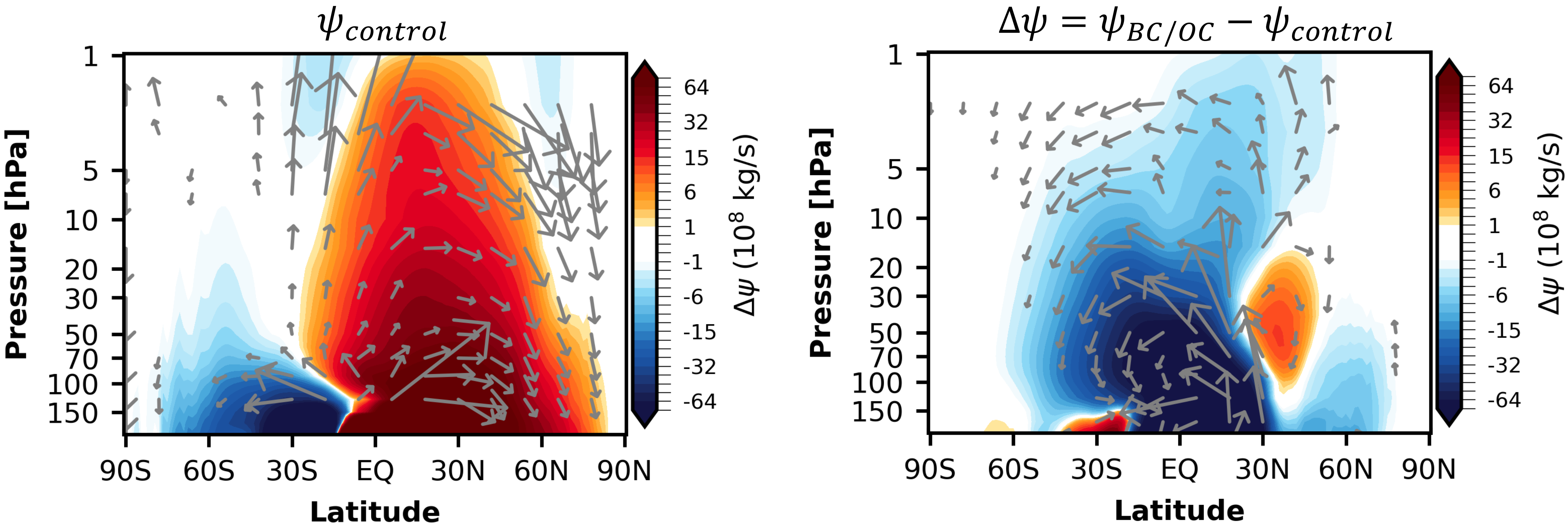
Wave-mean flow interaction





Transient Circulation Anomalies (January)

Transformed Eulerian Mean mass-stream function (residual circulation)



Slowing down of the Brewer-Dobson circulation (tropical upwelling / extratropical sinking)