Variability in upwelling across the tropical tropopause and correlations with tracers

Marta Abalos (1), William J. Randel (2) and Encarna Serrano (1)

(1) Universidad Complutense de Madrid
(2) NCAR

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Motivation and Context

- **Tropical upwelling magnitude and variability are not well constrained by observations** → uncertainties in trends, forcings of variability...

- **What determines the observed variability in tracers concentration near the tropical tropopause?** → air masses enter the stratosphere mainly through the TTL

Large vertical gradients across the tropical tropopause enhance the effect of upwelling on tracer variability

Our aim:

To investigate variability in upwelling across the tropical tropopause and its influence on tracers (O₃ and CO) on a range of timescales
Motivation and Context

Large seasonal cycles in $T$, $O_3$ and $CO$ in this region


What determines the seasonal cycle in $O_3$ and $CO$?

- Randel et al. 2007, Schoeberl et al. 2008: vertical structure of amplitude and phase explained by *upwelling* acting on background vertical gradients
- Konopka et al. 2010, Ploeger et al. 2012: *in-mixing* explains $O_3$ seasonality (mainly from Asian monsoon upper-level circulation) in 3D lagrangian model
Tracer Observations

Time series of **O₃** and **CO** observations (MLS) and **T** (ERA-Interim)

Common variability on seasonal and sub-seasonal timescales

Variability in upwelling and correlations with tracers
What links the variability of temperature and tracers?

\[ \frac{\partial T}{\partial t} = -\bar{v} \cdot \frac{1}{a} \frac{\partial T}{\partial \phi} - \bar{w} \cdot \bar{S} + Q \]

\[ S \propto \frac{\partial \bar{\theta}}{\partial z} \]

\[ \frac{\partial \bar{X}}{\partial t} = -\bar{v} \cdot \frac{1}{a} \frac{\partial \bar{X}}{\partial \phi} - \bar{w} \cdot \frac{\partial \bar{X}}{\partial z} + P - L + \nabla \cdot \mathbf{M} \]

Tendency

Upwelling on background vertical gradient

(Andrews et al. 1987)

(Eddy term neglected in thermodynamic eq.)

- Investigate relation between upwelling and tendencies in tracers and temperature
- Relative contribution of each term to the seasonality

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Tropical upwelling estimates

3 estimates:

Residual circulation, Momentum balance, Thermodynamic balance

Main uncertainties:

- **Residual circulation**: $\overline{w}^*$
  Strongly depends on $w$ from ERA-Interim (no observations)

- **Momentum balance**: $\overline{w}_m^*$
  Eddy fluxes only include resolved waves (no GW)

- **Thermodynamic balance**: $\overline{w}_Q^*$
  $Q$ approximated by radiative heating rates from NCAR-CRM (no clouds). No eddy term.
Tropical upwelling estimates

Residual circulation  Momentum balance  Thermodynamic balance

Correlations: 0.65-0.75 → confidence also in sub-seasonal variability

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Co-variability of upwelling and tracers: Seasonal cycles

Thermodynamic balance

\[ \frac{\partial T}{\partial t} = -\bar{v} \cdot \frac{1}{a} \frac{\partial T}{\partial \phi} - \bar{w} \cdot S + \bar{Q} + \text{residual} \]

Seasonal cycle in upwelling:
Adiabatic cooling

\[ \bar{Q} \approx \frac{\bar{T} - \bar{T}_{eq}}{\tau_{rad}}, \tau_{rad} \approx 1 - 2 \text{ months} \]

Response:
Diabatic heating

\[ \frac{\partial T}{\partial t} \]

Seasonal cycle in T

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Co-variability of upwelling and tracers: Seasonal cycles

Ozone balance

\[ \frac{\partial \chi}{\partial t} = -\bar{v}^* \frac{1}{a} \frac{\partial \chi}{\partial \phi} - \bar{w}^* \frac{\partial \chi}{\partial z} + P - L + \text{residual} \]

- Ozone tendency follows seasonality in upwelling
- Chemical production and loss rates (WACCM): semi-annual variability
- Residual: uncertainties in the rest of the terms plus mixing by eddies
Co-variability of upwelling and tracers: Seasonal cycles

**CO balance**

\[
\frac{\partial X}{\partial t} = -\bar{v} * \frac{1}{a} \frac{\partial X}{\partial \phi} - \bar{w} * \frac{\partial X}{\partial z} + P - L + \text{residual}
\]

- **CO tendency:** seasonal cycle (more noisy) follows seasonality in upwelling
- **Chemical loss** (~100 days damping timescale) + small production (WACCM)
- **Residual:** uncertainties in the rest of the terms plus mixing by eddies
Co-variability of upwelling and tracers: Sub-seasonal fluctuations

\[ \frac{\partial T}{\partial t} \quad \frac{\partial O_3}{\partial t} \quad \frac{\partial CO}{\partial t} \]

70 hPa 2010

6 days \(<\tau<1\) year

\[ \bar{w}^*, \bar{w}_m^*, \bar{w}_Q^* \]

Common sub-seasonal fluctuations between upwelling and tracer tendencies

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Co-variability of upwelling and tracers: Sub-seasonal fluctuations

Statistically significant linear correlations at sub-seasonal timescales
Co-variability of upwelling and tracers: Sub-seasonal fluctuations

Compare to simplified case of upwelling alone controlling variability in T and tracers

→ In this case: \( \frac{\partial X}{\partial t} / \frac{\partial T}{\partial t} = \frac{X_z}{S} = \text{const} \)

Result: Upwelling is not the only driver of variability in T and tracers, but it is a primary forcing
Summary

Ozone and CO from MLS and temperatures from ERA-Interim show common variability near the tropical tropopause.

What is the role of upwelling in forcing this common variability?
3 estimates of upwelling: substantial variability, reasonably good agreement.

- Balance equations highlight the tracers seasonality is mainly driven by upwelling.
- Correlated fluctuations of tracers and upwelling also when isolating fast variability.
Thank you!

Contact:
mabalosa@fis.ucm.es