climate change initiative

LONG-LIVED GREENHOUSE GAS PRODUCTS PERFORMANCES

lolipop cci

Middle atmospheric mean transport derived from satellite data of tracers

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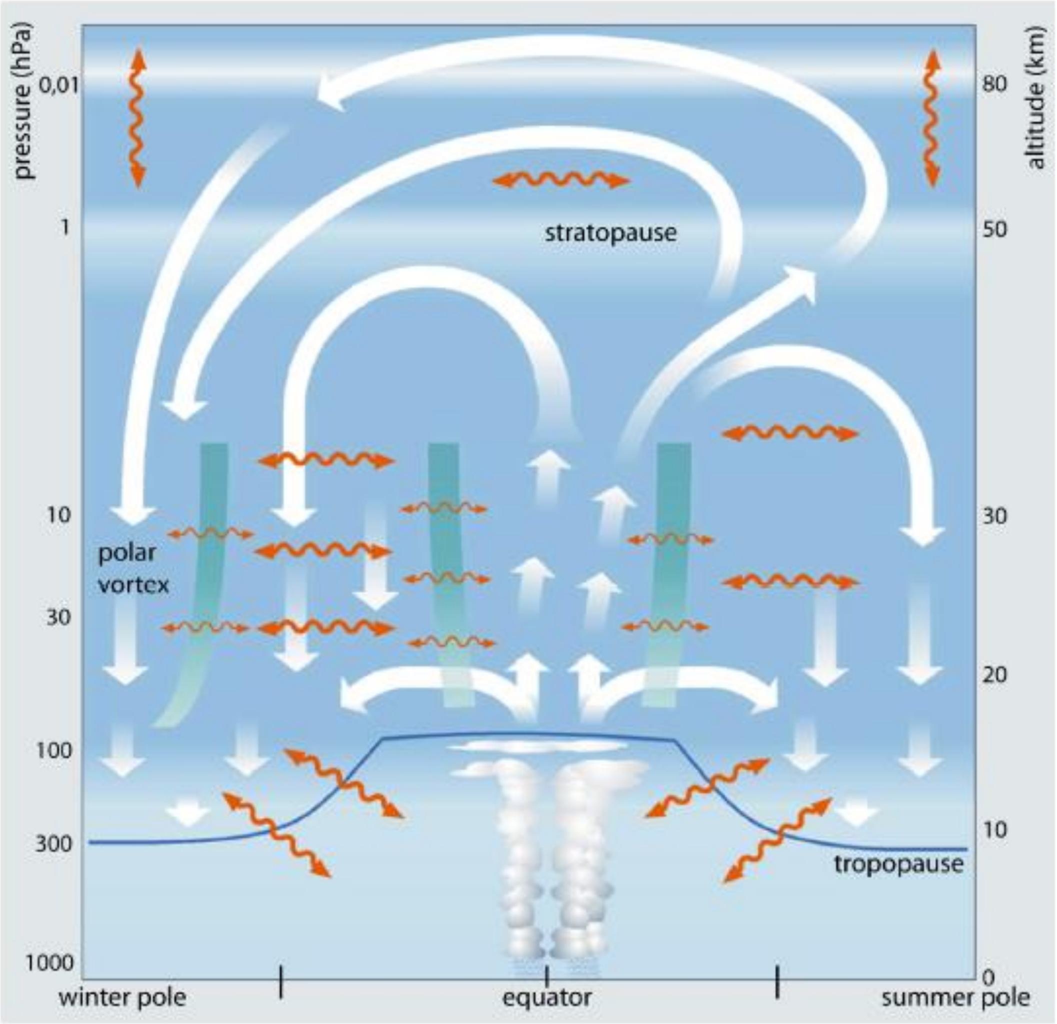
Detailed look into the Brewer-Dobson circulation

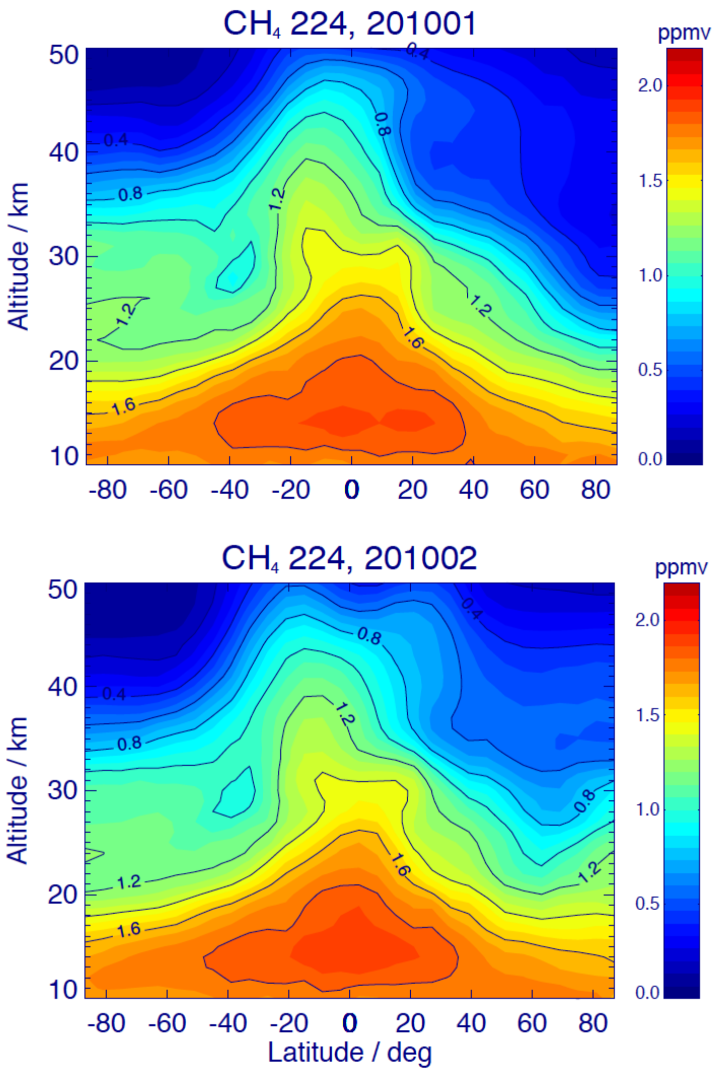


- The Brewer-Dobson circulation is the mechanism that distributes trace gases in the middle atmosphere (10 – 80 km)
- BDC is expected to accelerate due to climate change
- Standard approach so far: compare age of air from observations to that of model simulations
- Problem: suitable age tracers
- “Integral quantity”: no resolved information along the path through the atmosphere
- We would like to obtain a better-resolved picture with information along the path => ANCISTRUS

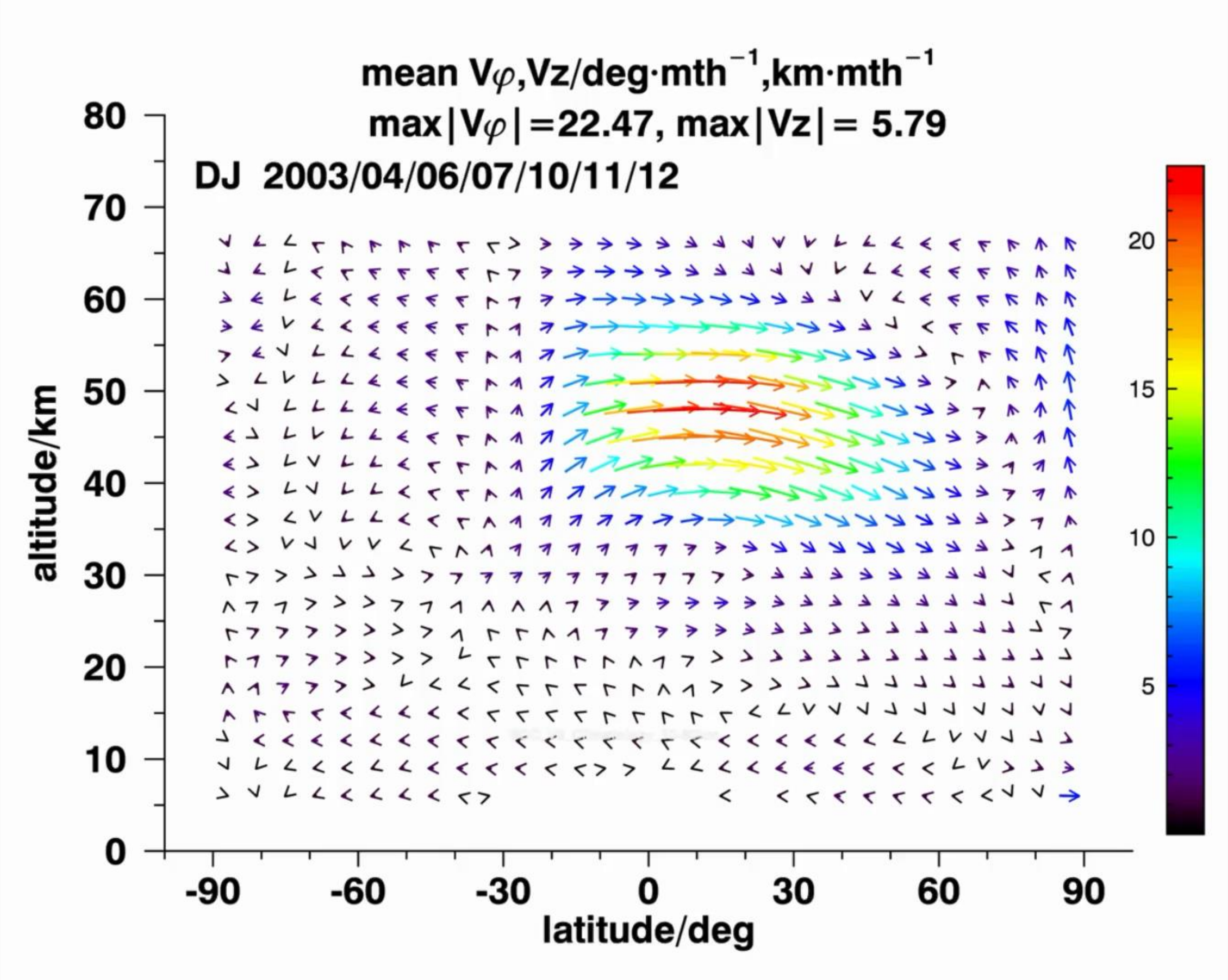
Figure from Boenisch et al., 2011

Method of ANCISTRUS: Use tracers and invert the continuity equation

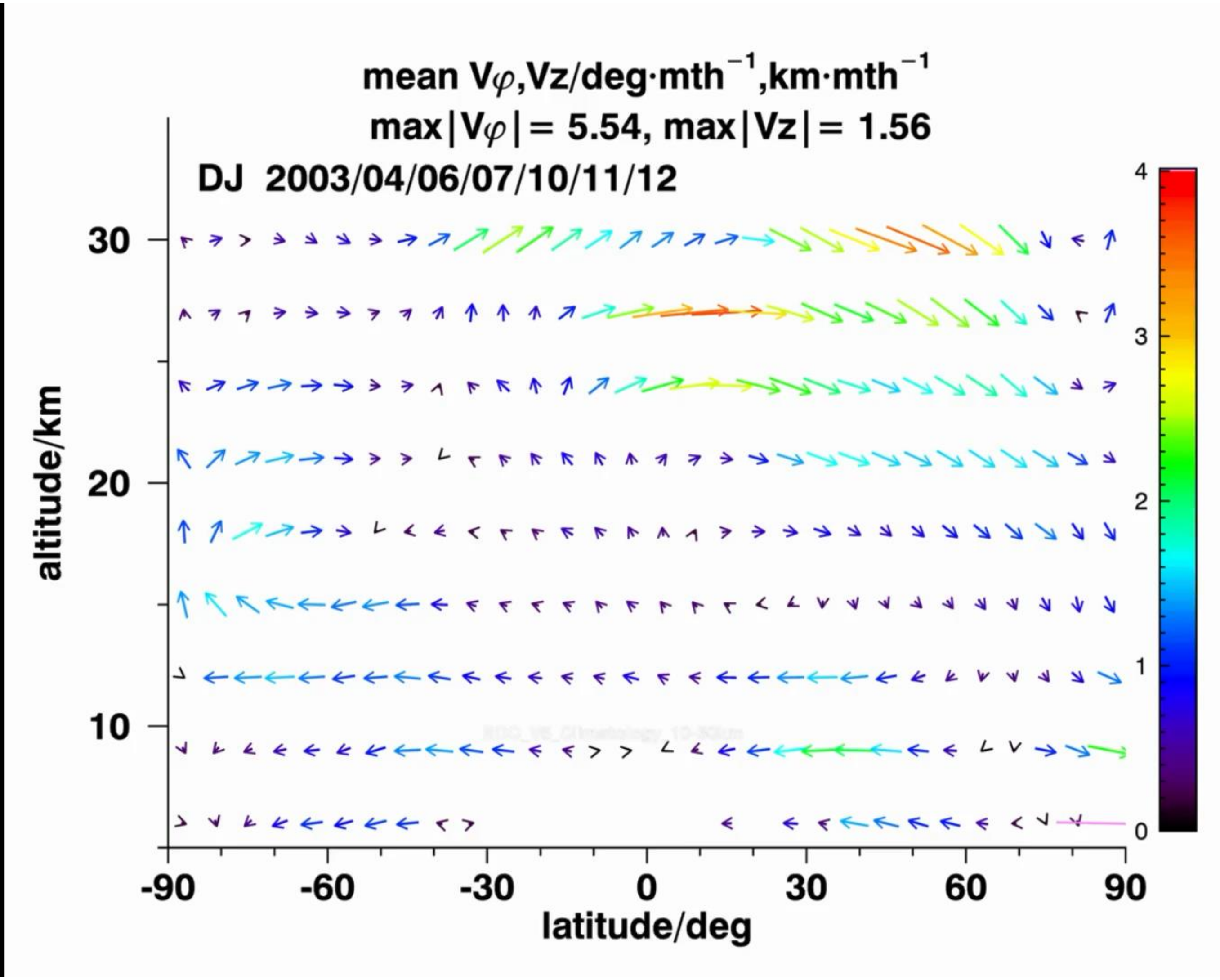
- We use monthy (weekly, bi-weekly, …) zonal means of tracers: H_2O, N_2O, CH_4, CO, CFC-11, CFC-12, HCFC-22, CCl_4, SF_6 (in future additionally: CFC-113, CF_4, NO_y, CO_x)
- The change of the tracer abundance in an altitude-latitude bin is driven by chemical sinks and transport;
- Chemical sinks are modelled (photolysis with photolysis rates precalculated using the TUV scheme; OH; $O^1(D)$; Cl)
- The mean meridional and vertical transport is derived by inversion of the continuity equation :
- (v, w, K_ϕ, K_z) = continuity equation $^{-1}$ $(vmr, density, vmr_0, density_0)$
- The inversion is solved for all latitude-altitude bins simultaneously



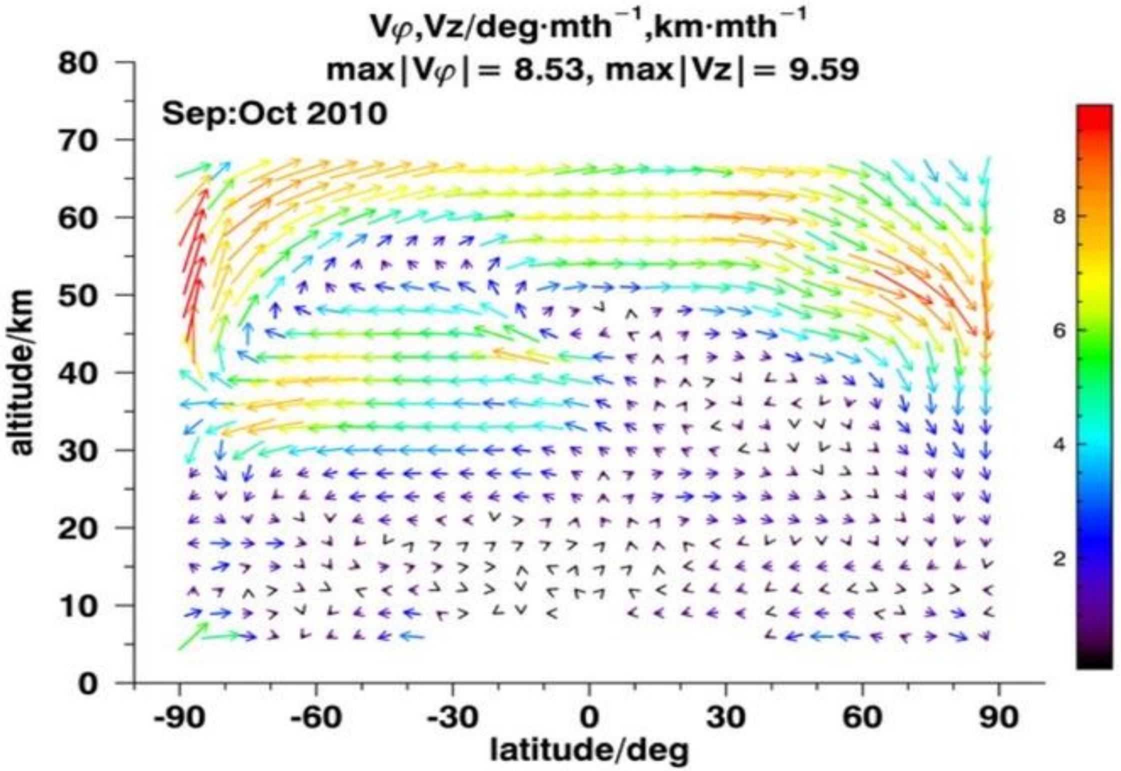
Multi-year DJ climatology of the Brewer-Dobson circulation

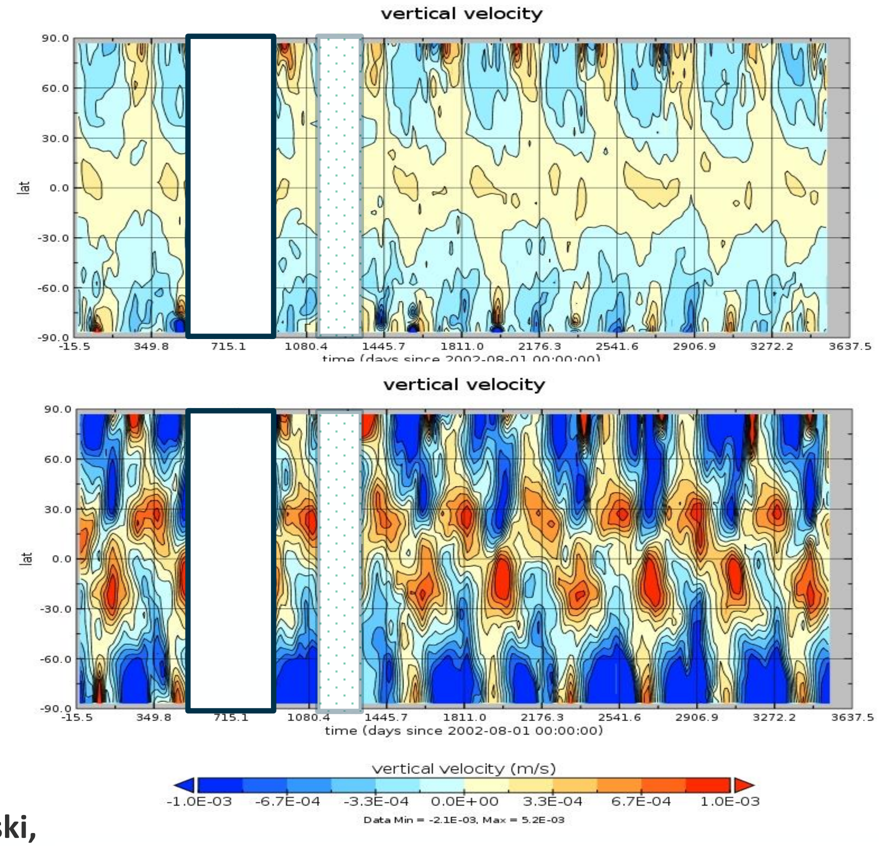


Zoom into the lower stratosphere



MIPAS tracer-retrieved residual 2-D velocities using the continuity equation





18 km

36 km

Contributions from the tracers:

above 50 km:	CH_4, CO, H_2O, N_2O
middle strat.:	CFC-11, HCFC-22, CFC-12
UTLS:	H_2O
reduced uncert.:	SF_6, CCl_4

von Clarmann, T. and Grabowski, U.: Direct inversion of circulation and mixing from tracer measurements – Part 1: Method, Atmos. Chem. Phys., 16, 14563–14584, https://doi.org/10.5194/acp-16-14563-2016

$$v_{\mathrm{effective}} = \overline{v} + \mathrm{cov}(v, \frac{\partial vmr_g}{\partial \phi}) \frac{\partial \phi}{\partial vmr_g}$$

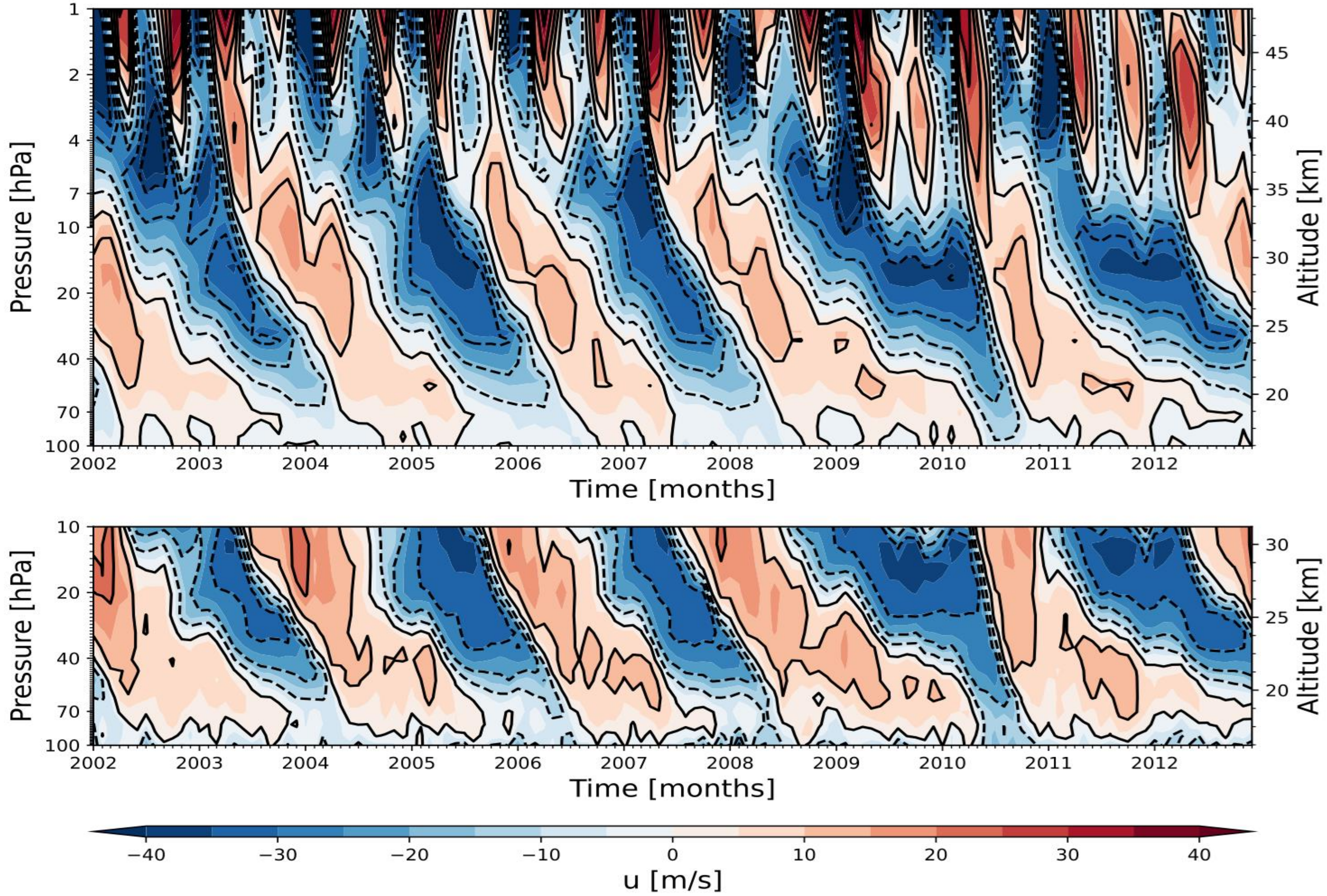
$$w_{\mathrm{effective}} = \overline{w} + \mathrm{cov}(w, \frac{\partial vmr_g}{\partial z}) \frac{\partial z}{\partial vmr_g}$$

Applications

2 applications so far:

- Analysis of the BDC-QBO interaction in reanalyzes and observational data (Kerzenmacher et al., in preparation)
- Variability of tropical lower stratospheric uplift from the water vapor tape recorder and ANCISTRUS (Brehon, M., Tegtmeier, S., Bourassa, A., Davis, S. M., Grabowski, U., Kerzenmacher, T., and Stiller, G.: Tropical upwelling as seen in observations of the tape recorder signal, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-4457, 2025)

QBO in observations and reanalyses



ERA5 monthly zonal mean zonal wind (= $\bar{u}$)

Singapore radiosonde zonal winds

Anomalies in vertical and meridional mean residual winds caused by the QBO

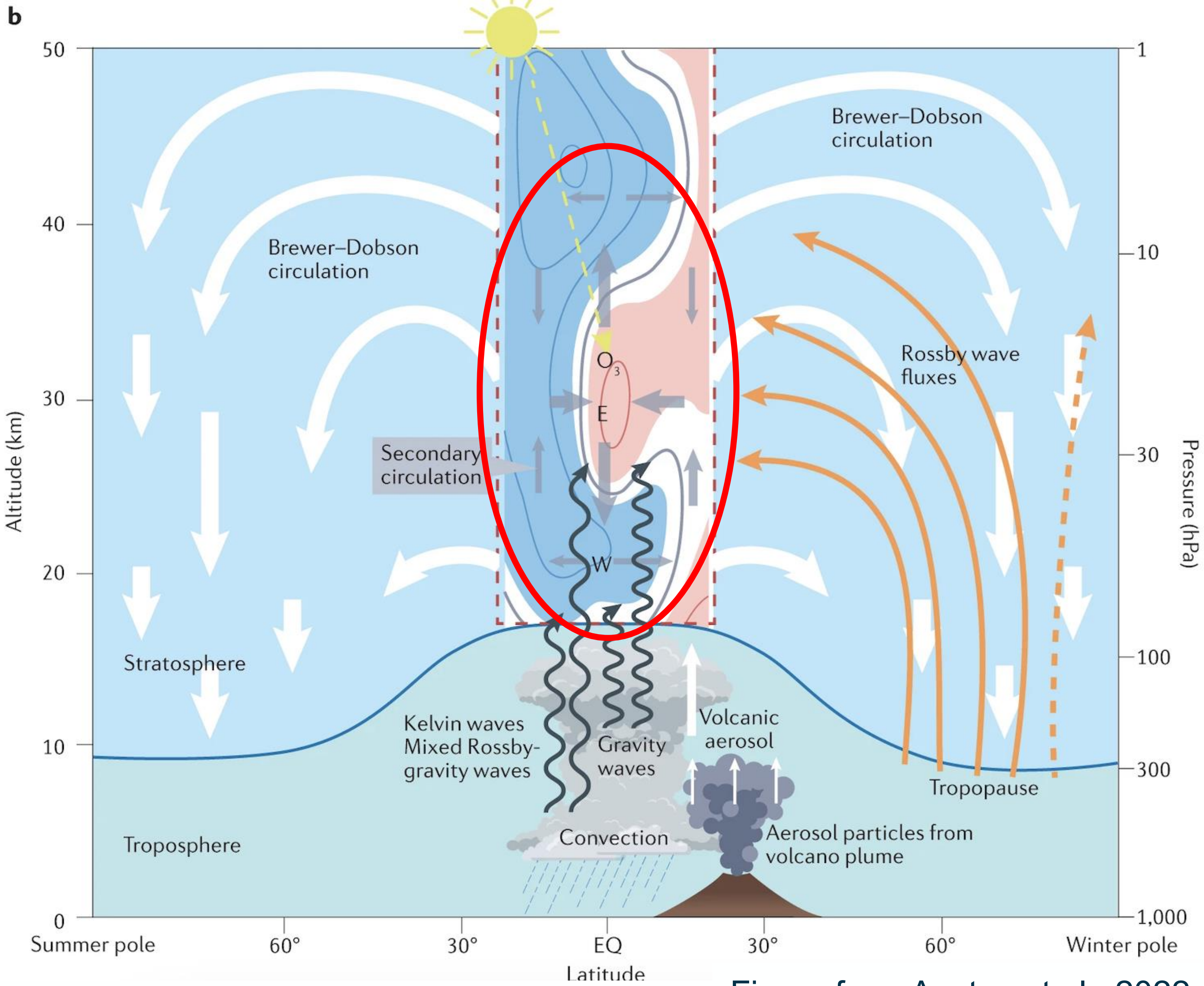
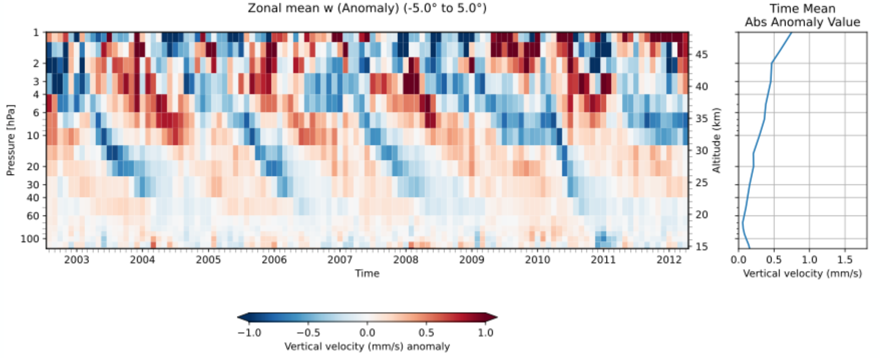
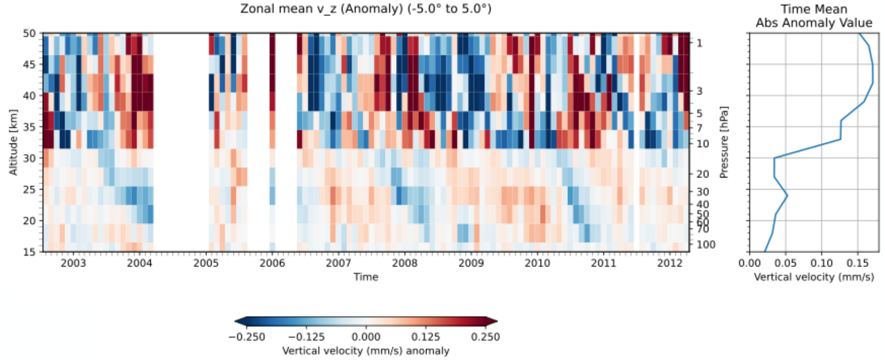


Figure from Anstey et al., 2022

The QBO introduces a secondary circulation in the tropical stratospheric uplift regime, together with temperature anomalies



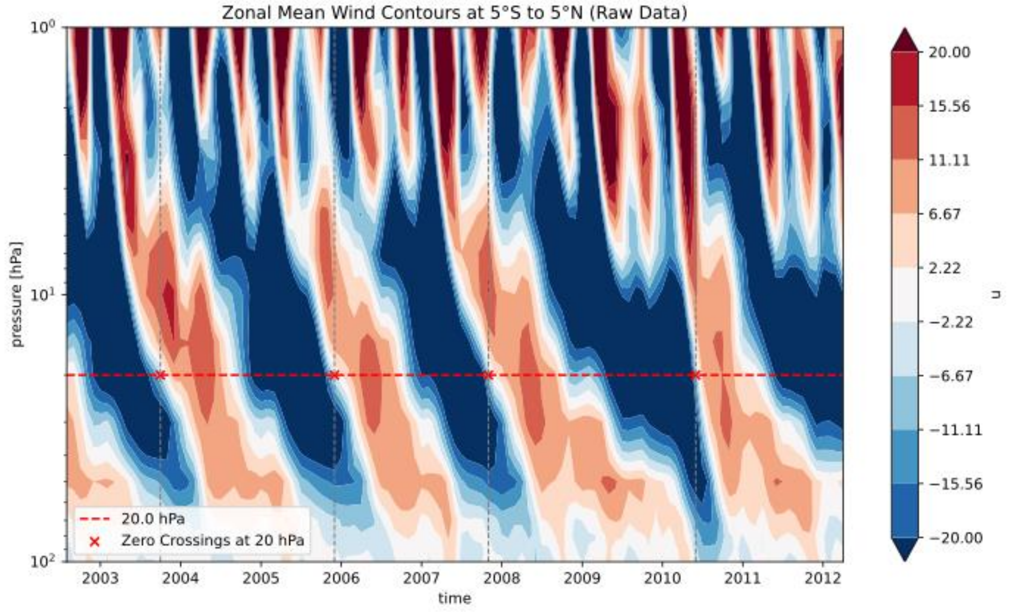


Comparison of residual transport and temperature anomalies from ERA-5 and MIPAS

Karlsruhe Institute of Technology

esa

Method: Composite of vertical and meridional mean residual velocity anomalies and mean temperature anomalies at the onset of the QBO-W phase at 20 hPa following the SPARC S-RIP report



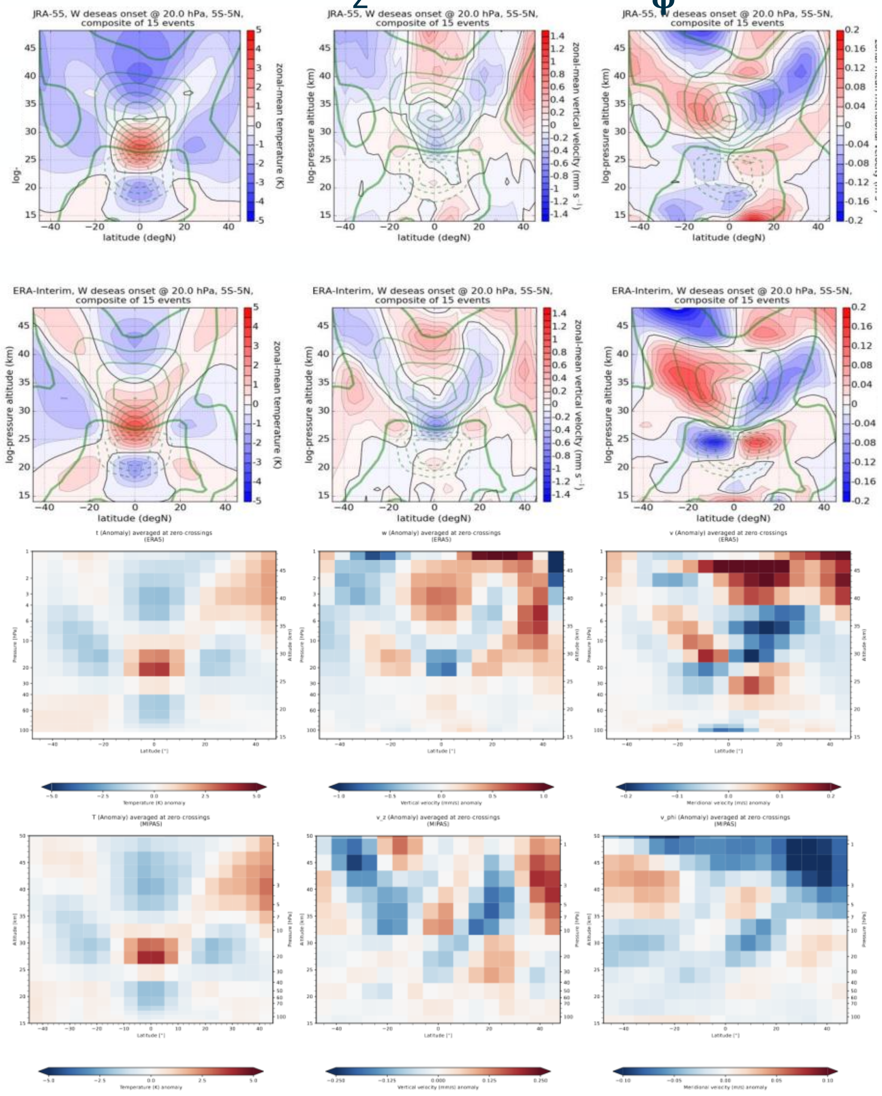
T anom. | v_z anom. | v_ϕ anom.

JRA-55 (SPARC S-RIP)

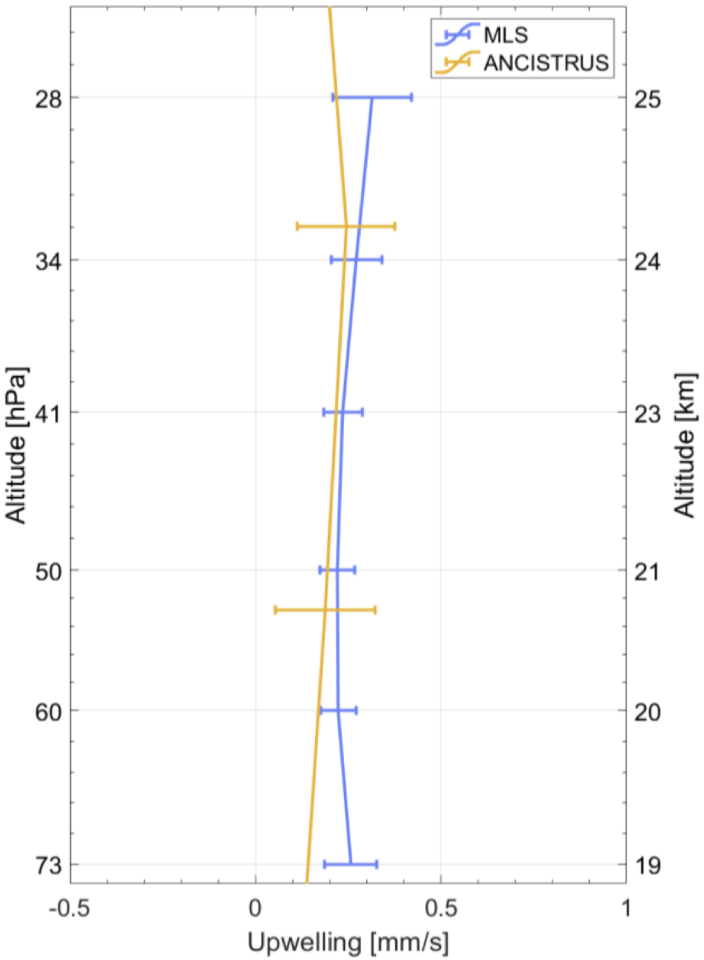
ERA-I (SPARC S-RIP)

ERA-5

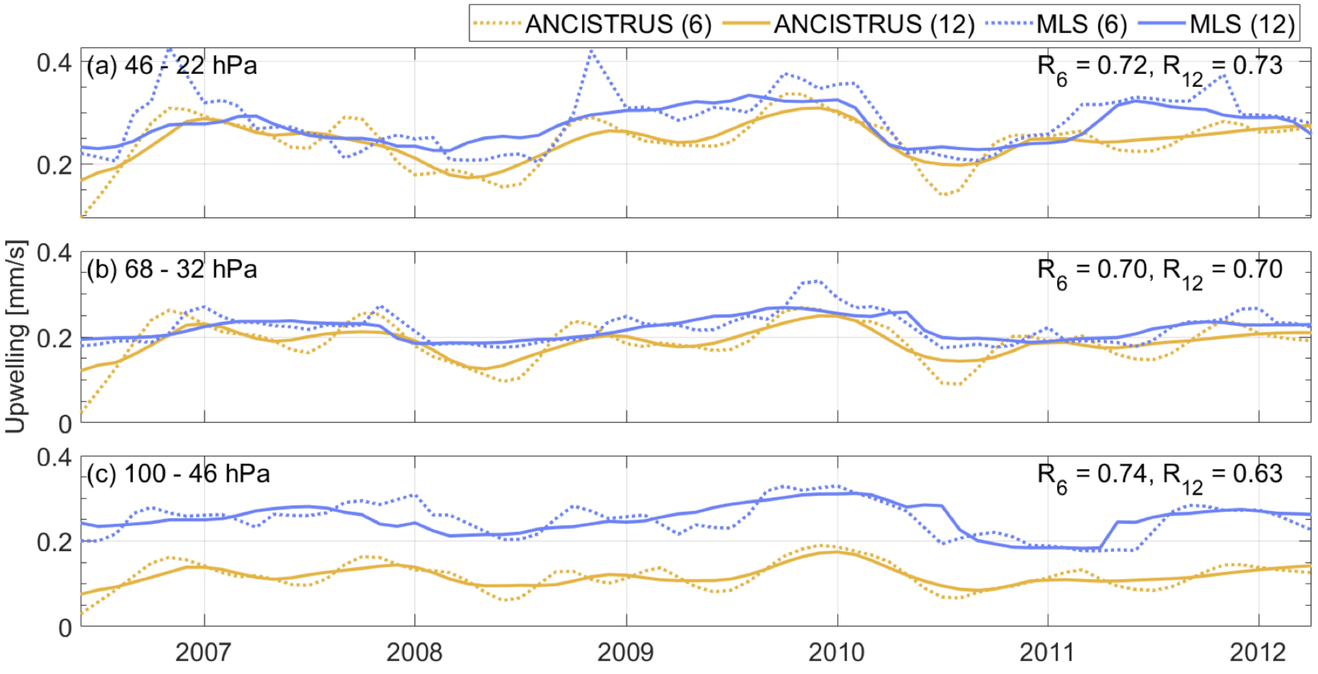
MIPAS-ANCISTRUS



Residual uplift in the tropical pipe from the water vapor tape recorder and MIPAS-ANCISTRUS

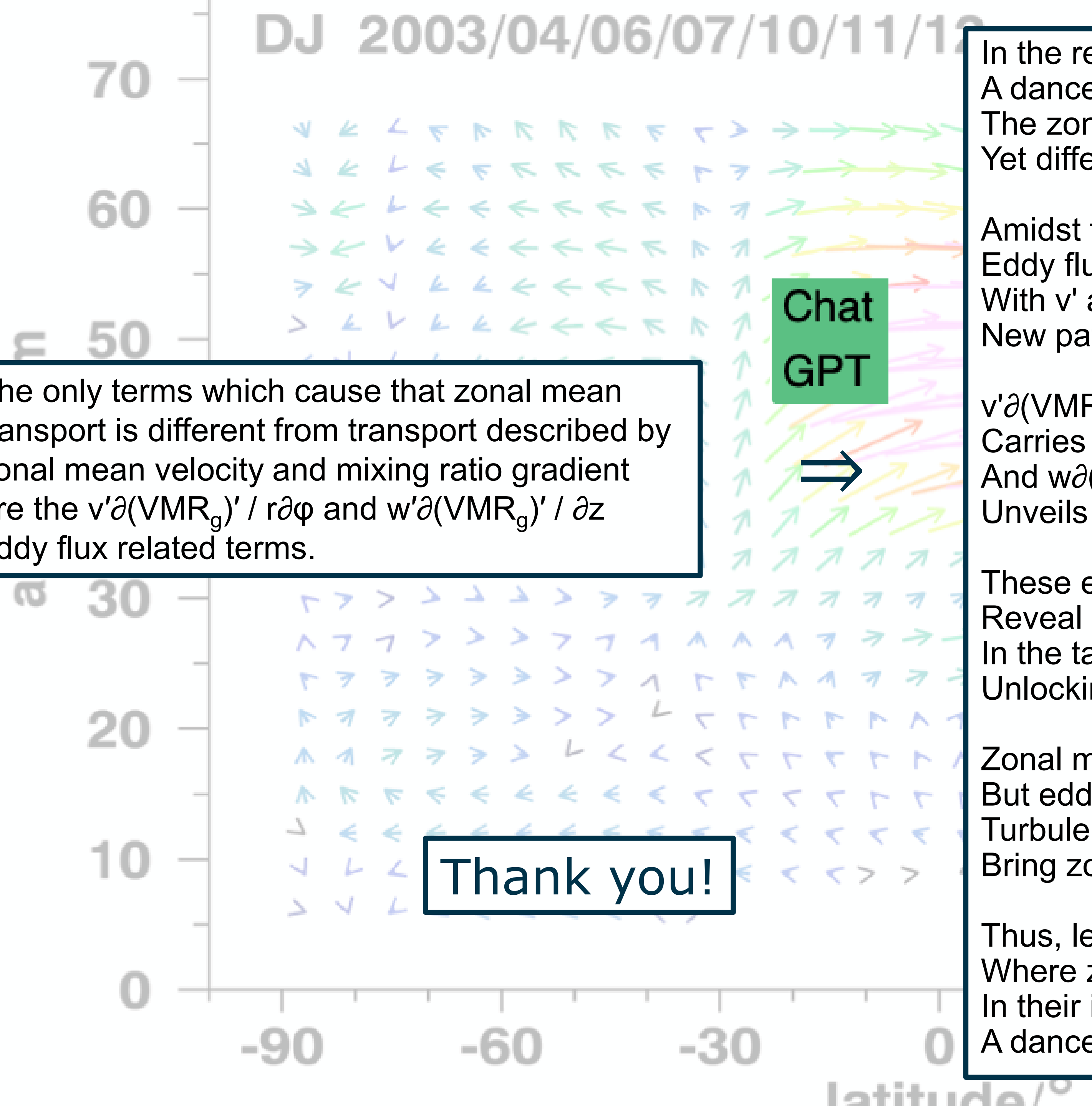


Uplift velocities are determined from the phase shift of the MLS time series of tropical water vapor at different pressure levels, and compared to ANCISTRUS vertical velocities (Brehon et al., https://doi.org/10.5194/egusphere-2025-4457)



Summary

- Tracer observations from satellites can be used to derive the mean residual circulation in the stratosphere.
- The method ANCISTRUS needs at least 4 tracers and the density to derive vertical and meridional zonal mean velocities, and vertical and meridional mixing coefficients.
- In the current application mixing is forced to zero and velocities contain transport by mixing as well.
- Time series have been analyzed for the secondary circulation that is imprinted on the tropical uplift by the QBO. ANCISTRUS shows agreement in structures with reanalyzes data, but hint to differences in the altitude regimes and velocities relative to each other.
- Another application compares uplift velocities with those derived from MLS observations of the tropical water vapour tape recorder. This comparison hints to somewhat too low ANCISTRUS vertical velocities in the lowermost stratosphere (probably due to too strong regularization); interannual variations show again a QBO signal.
- Future plans: extend to analysis of mixing coefficients, apply to other satellite data (e.g. MLS, SMR), compare to models.



The only terms which cause that zonal mean transport is different from transport described by zonal mean velocity and mixing ratio gradient are the $v'\partial(VMR_g)' / r\partial\varphi$ and $w'\partial(VMR_g)' / \partial z$ eddy flux related terms.

Chat GPT

$\Rightarrow$

In the realm where zonal winds prevail,
A dance of transport begins to unveil.
The zonal mean, steady and true,
Yet differences emerge, a captivating view.

Amidst the zonal mean's guiding hand,
Eddy flux terms come into the grand.
With v' and VMR_g' fluctuations at play,
New pathways of transport find their way.

$v'\partial(VMR_g')/\partial\varphi$, a meridional delight,
Carries whispers of mixing in its flight.
And $w\partial(VMR_g')/\partial z$, a vertical embrace,
Unveils the eddy's transport, a celestial chase.

These eddy flux terms, unique and rare,
Reveal how zonal mean alone cannot bear.
In the tapestry of transport, they're the key,
Unlocking the mysteries of fluidity.

Zonal mean velocity and gradient may strive,
But eddy flux terms keep the story alive.
Turbulent currents, in their swirling glee,
Bring zonal mean transport to a harmonious decree.

Thus, let us marvel at this poetic scene,
Where zonal mean and eddies convene.
In their interplay, we find nature's art,
A dance of transport that captivates the heart.

Thank you!

2-D continuity equation:

Local change of air density:

$$\frac{\partial \rho}{\partial t} = -\frac{1}{r}\frac{\partial \rho v}{\partial \phi} + \frac{\rho v}{r}\tan(\phi) - \frac{\partial \rho w}{\partial z} - \frac{2\rho w}{r}$$

v and w are the velocities plus contribution by the anti-symmetric part of the eddy flux tensor.

Local change of mixing ratio:

$$\frac{\partial vmr_g}{\partial t} = \frac{S_g}{\rho} - \frac{v}{r}\frac{\partial vmr_g}{\partial \phi} - w\frac{\partial vmr_g}{\partial z} + \frac{1}{(r)^2 \cos\phi}\frac{\partial}{\partial \phi}\left[K_\phi \cos\phi \frac{\partial vmr_g}{\partial \phi}\right] + \frac{1}{r^2}\frac{\partial}{\partial z}\left[r^2 K_z \frac{\partial vmr_g}{\partial z}\right]$$

K_ϕ and K_z are the mixing coefficients plus the contribution of the symmetric part of the eddy flux tensor (c.f. Ko et al., JGR 1985)

2-D continuity equation

Usual transport calculations:

(vmr, density) = continuity equation (v,w,K_ϕ,K_z; vmr_0,$density_0$)

What we do:

(v,w,K_ϕ,K_z) = continuity equation $^{-1}$ (vmr,density,vmr_0,$density_0$)

- Tracer analysis is the inverse solution of the continuity equation.
- The problem is solved along the standard methods of inversion theory (for details, see: von Clarmann and Grabowski, ACP, 2016)
- Chemical sinks are taken into account (photolysis with photolysis rates precalculated using TUV, OH, $O^1(D)$, Cl)
- For 4 unknowns, we need at least 4 observations. We (can) use: density, N2O, CH4, CFC-11, CFC-12, HCFC-22, CCl4, SF6, CO, H2O.
- In the current realization, K_ϕ and K_z are forced to zero by regularization: all mixing appears as effective transport

von Clarmann, T. and Grabowski, U.: Direct inversion of circulation and mixing from tracer measurements – Part 1: Method, Atmos. Chem. Phys., 16, 14563–14584, https://doi.org/10.5194/acp-16-14563-2016, 2016