# *On the Use of Chemical Tracers to Diagnose Convective Transport Pathways from the PBL to the UT/LS*

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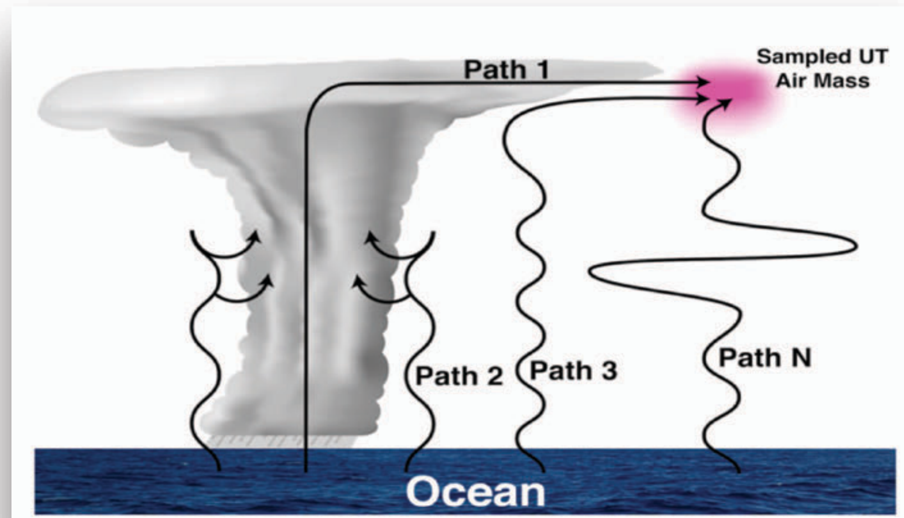
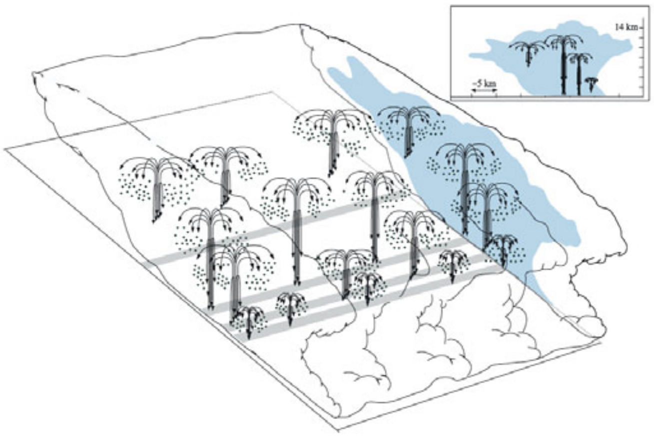
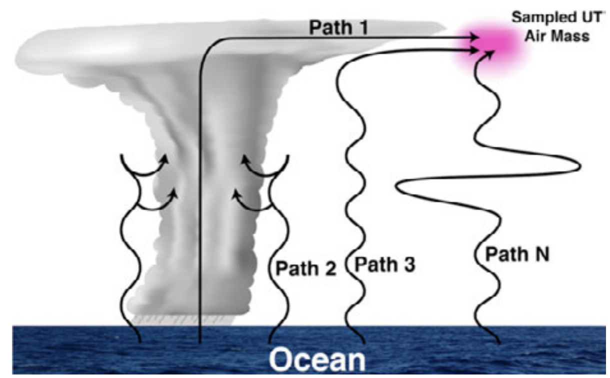



GEWEX UTCC PROES Meeting, Oct 22-23 2018, UPMC Sorbonne Univ., Paris, France




<u>Travel time from the PBL to the UT</u>

- <u>Convective cores (10 m/s)</u>:
  15 (km)/10 (m/s) = 25 min
- <u>Outside of the core/inside clouds (1 cm/s)</u>:
  15 (km)/1 (cm/s) = 17 days
- <u>Large-scale ascent (1 mm/s)</u>:
  15 (km)/1 (mm/s) = 174 days

**<u>Objectives of the study</u>**:

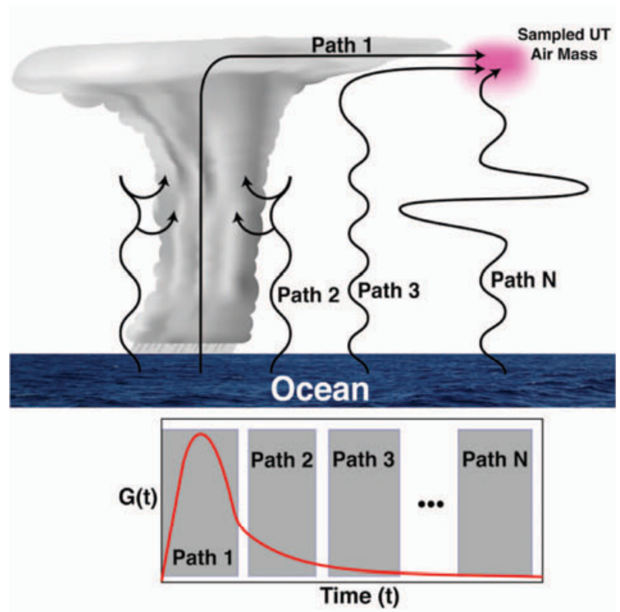
- quantify the contributions of these different transport pathways using tracer measurements, and
- develop observation-based metric for evaluating model representation of convective transport.

# **Outlines**

1. Behavior of chemical tracers from a recent field campaign - CONTRAST

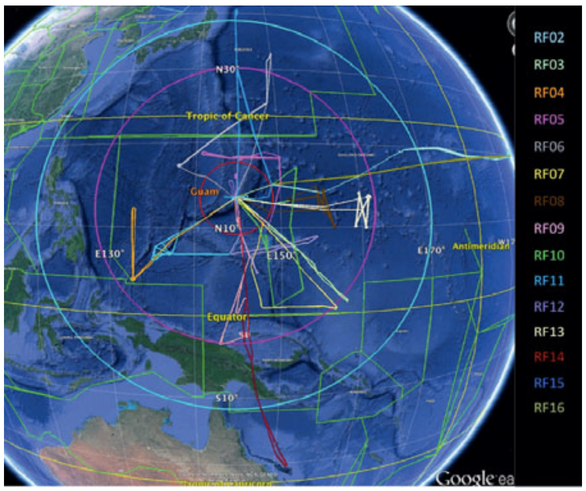
2. A metric for quantifying contributions of different transport paths – Transit Time Spectrum

3. Summary & implications




**The idea**: UT air mass is a ”cocktail” coming from different transport paths. Because each path has a characteristic transit time (from PBL to UT), we can use a suite of tracers with different lifetimes to probe the relative contributions of these paths.


The Convective Transport of Active Species in the Tropics (CONTRAST) Experiment



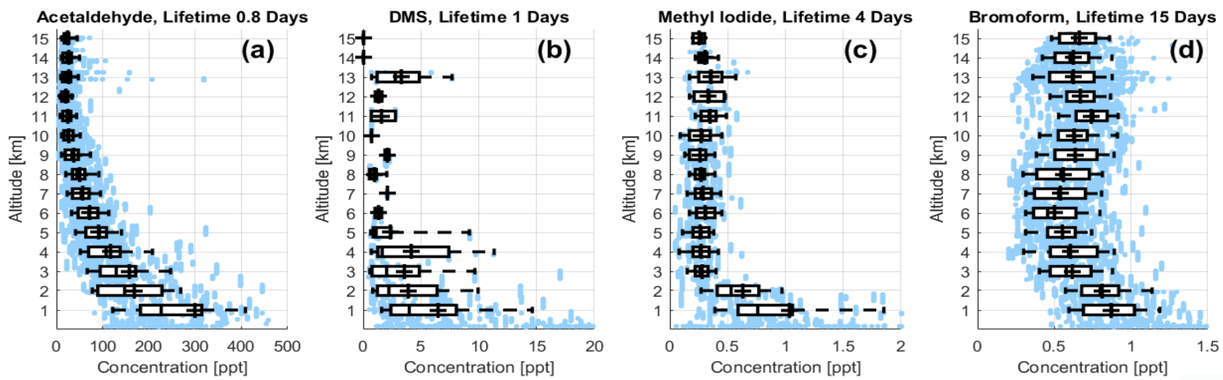

## Scientific Objectives:

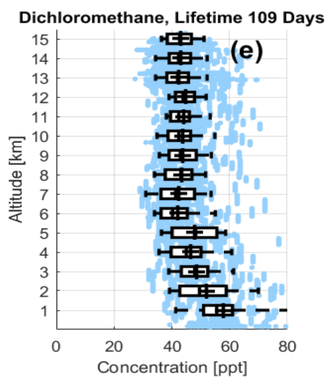
- Characterizing the influence of deep convection on the chemical composition and the photochemical budget of $O_3$ at the level of convective outflow
- Evaluate the budget of organic and inorganic bromine and iodine in the TTL
- Investigate transport pathways from the oceanic surface to the tropopause

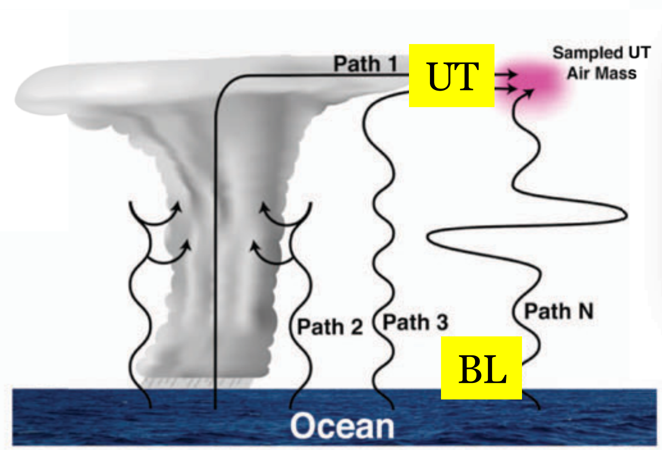

| ID | Instrument | Observed Trace Gas | Atmospheric Lifetime [Days] |
|---|---|---|---|
| 1 | TOGA | Acetaldehyde | 0.8 |
| 2 | TOGA | Dimethyl Sulfide (DMS) | 1 |
| 3 | TOGA | nButane | 1 |
| 4 | TOGA | Tetrachloroethylene | 1 |
| 5 | TOGA | Formaldehyde | 1.4 |
| 6 | TOGA | Ethyl Benzene | 2 |
| 7 | TOGA | Methyl Ethyl Ketone (MEK) | 3 |
| 8 | TOGA | Isopentane | 3.2 |
| 9 | TOGA | Methyl Iodide | 4 |
| 10 | TOGA | Isobutane | 6 |
| 11 | TOGA | Benzene | 10 |
| 12 | TOGA | Propane | 10.5 |
| 13 | TOGA | Methanol | 12 |
| 14 | TOGA | Bromoform | 15 |
| 15 | TOGA | Ethyl Nitrate | 15 |
| 16 | TOGA | Chlorobenzene | 20 |
| 17 | TOGA | Methyl Vinyl Ketone (MVK) | 30 |
| 18 | TOGA | Dibromomethane | 94 |
| 19 | TOGA | Dichloromethane | 109 |
| 20 | TOGA | Methyl Chloroform | 109 |
| 21 | TOGA | Chloroform | 112 |
| 22 | TOGA | Acetonitrile | 174 |
| 23 | TOGA | Methyl Bromide | 292 |
| 24 | TOGA | Carbon Tetrachloride | 9490 |

We define a ratio: $\mu_i^* \equiv \frac{m_i(UT)}{m_i(BL)}$ , where i is the tracer index

TOGA Trace Gas Measurements, Vertical Profiles



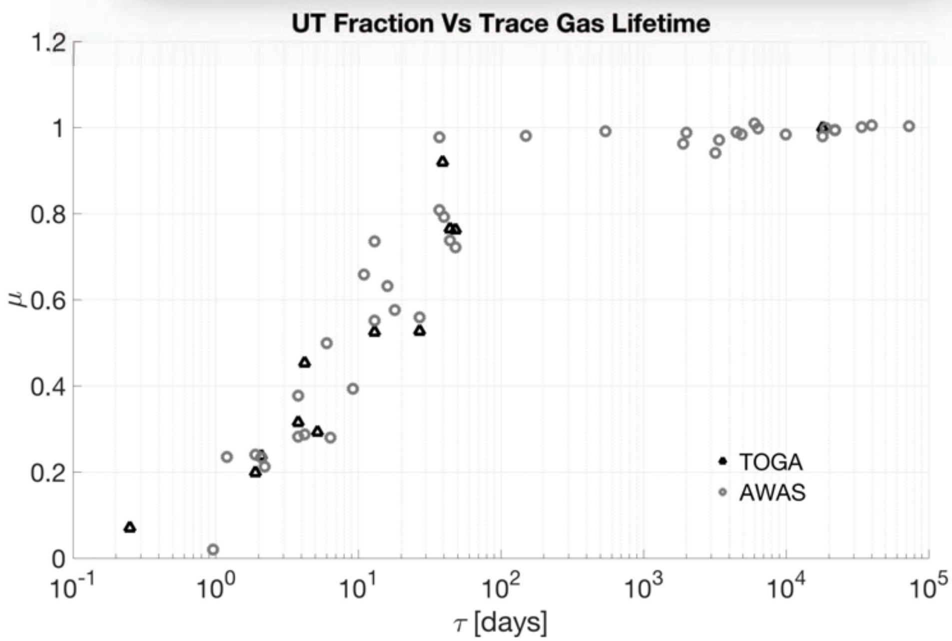



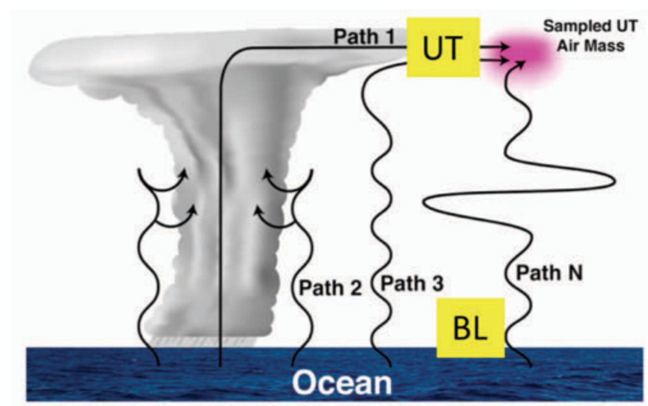

Sampled UT air mass is a "cocktail" from different transport paths

We define a ratio: $\mu_i^* \equiv \frac{m_i(UT)}{m_i(BL)}$ , where i is the tracer index

42 tracers observed during the CONTRAST field campaign over the TWP WP




How to extract some quantitative information about transport paths using the *μ*-LT relation*?

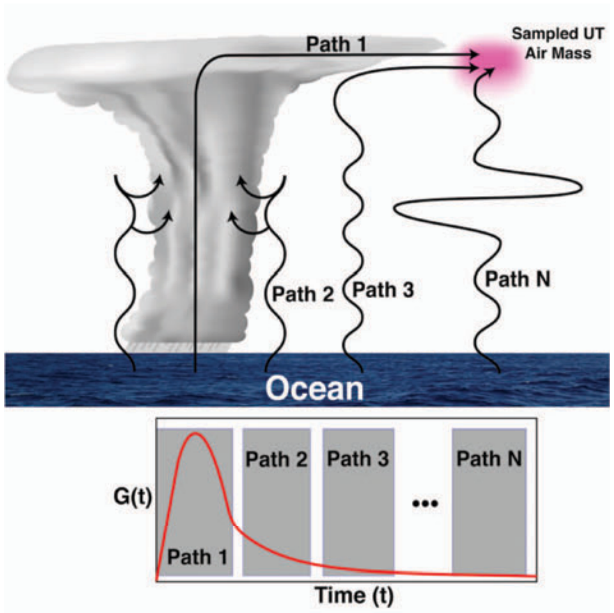


# Outlines

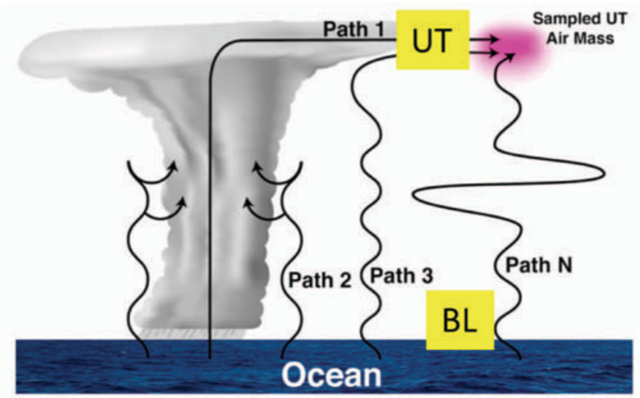
1. Behavior of chemical tracers from a recent field campaign - CONTRAST

2. A metric for quantifying contributions of different transport paths – Transit Time Spectrum

3. Summary & implications




**The idea**: because different paths have different characteristic time scale, we may use a suite of tracers with different lifetime to probe these paths. Short-lived tracers are only sensitive to fast paths, while long-lived tracers can go through all paths.




G(t) is essentially a ***weighting Function*** of the transport paths (or a formula for the UT "cocktail").

Assumptions:

1) Tracer mixing ratio decays exponentially with time following its lifetime ($\tau_i$)
2) MBL is the source of the transport and UT is the destination.

Along a single path

$$m_i(UT) = m_i(BL)e^{-t/\tau_i}$$

Along a multitude of paths
(each t represents a path)

$$m_i(UT) = m_i(BL)\int_0^\infty e^{-t/\tau_i} G(t)\,dt$$

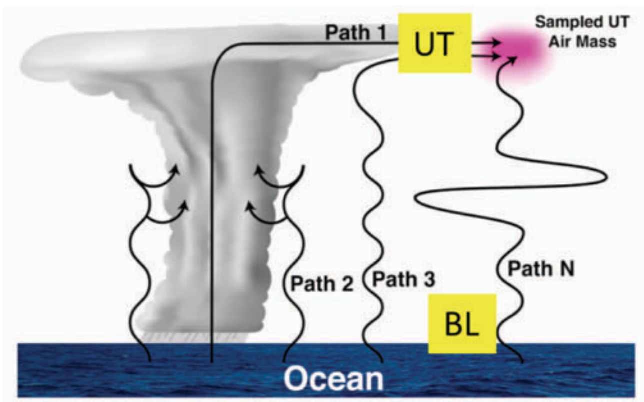
$$\mu_i^* = m_i(UT) / m_i(BL)$$

$$= \int_0^\infty e^{-t/\tau_i} G(t)\,dt \quad \text{............ (1)}$$

G(t) is a weight with which different transport paths (with different transit time t) contribute to the sampled UT air mass.

We call G(t) ***"transit time spectrum"***.

Schoeberl et al. (2005)




Equation (1) basically is the ***Laplace transform*** of G(t).

In principal, we could perform Inverse Laplace Transform to back out G(t). (Note that Eq (1) defines a matrix of i and ⍰t.)

<u>Along a single path</u>

$$m_i(UT) = m_i(BL)e^{-t/\tau_i}$$

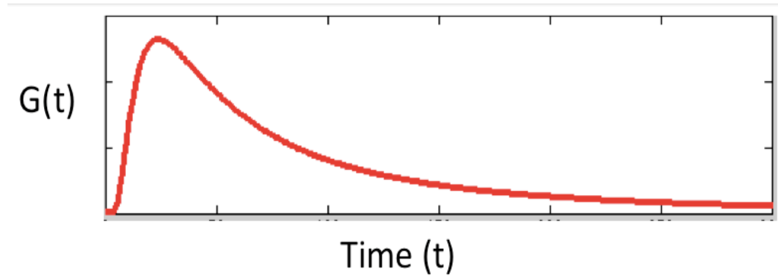
<u>Along a multitude of paths</u>

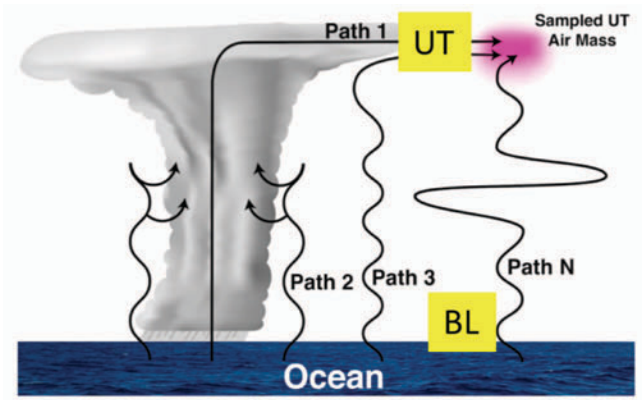
(each t represents a path)

$$m_i(UT) = m_i(BL)\int_0^\infty e^{-t/\tau_i}G(t)\,dt$$

$$\mu_i^* = m_i(UT)\,/\,m_i(BL)$$

$$= \boxed{\int_0^\infty e^{-t/\tau_i}G(t)\,dt} \quad \text{............} \;(1)$$



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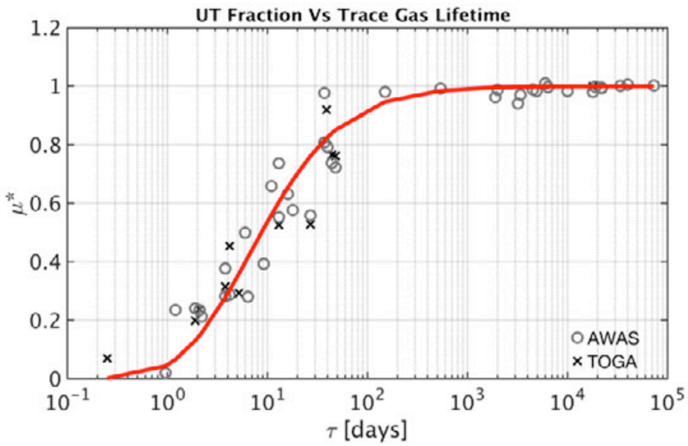
$$= \int_0^\infty e^{-t/\tau_i} G(t)\,dt \quad \text{............ (1)}$$

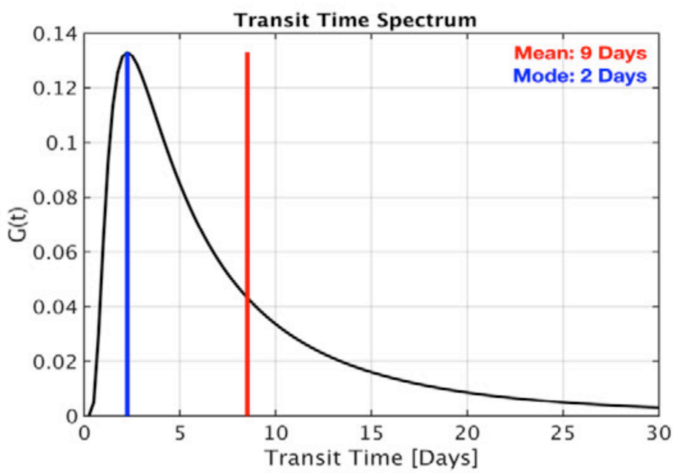
We use some a priori knowledge to constrain the retrieval of G(t): assume the transport follows a *vertical diffusion model*, in which case G(t) has an analytical solution

$$G(t) = \frac{z}{2\sqrt{\pi K t^3}} \exp\left(\frac{z}{2H} - \frac{Kt}{4H^2} - \frac{z^2}{4Kt}\right)$$

, z is height, H is scale height, K is the diffusion coefficient, and t is time

Hall and Plumb 1994; Schoeberl et al. 2005




$$G(t) = \frac{z}{2\sqrt{\pi K t^3}} \exp\left(\frac{z}{2H} - \frac{Kt}{4H^2} - \frac{z^2}{4Kt}\right)$$

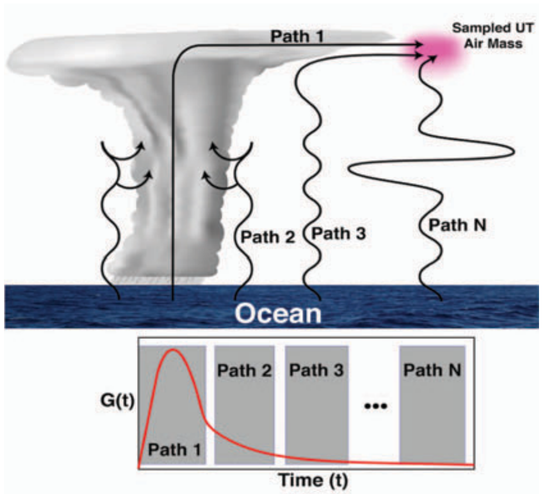
Following Schoberl et al. (2005), we minimizing F using least square fit

$$F = \sum_{i=1}^{N} (\mu_i - \mu_i^*)^2$$

For the UT (10-13km)

Mode: 2 days
Mean: 9 days

$$\bar{T} = \int_0^\infty t G(t)\, dt$$ (red line)

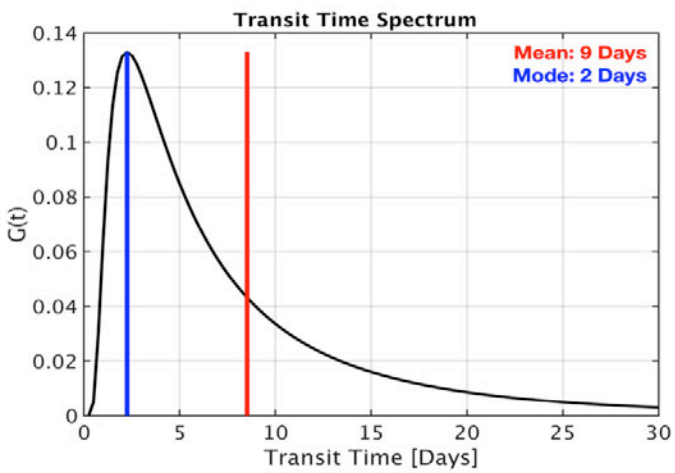



## A consistency check of the result

Masunaga and Luo (2016) estimated the convective mass flux ($M_c$) is about 0.005-0.015 kg $m^{-2}$ $s^{-1}$ over the TWP region.

$M_c = \rho_{air} w_{mean}$ ➡ $W_{mean} \approx 0.8$ -2.4cm/s

$T_{transit} = 13km/W_{mean} = 6 - 19$ days




For the UT (10-13km)

Mode: 2 days
Mean: 9 days

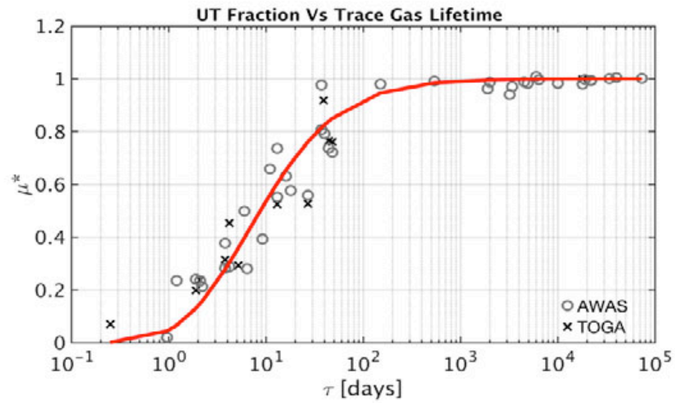
$$\bar{T} = \int_0^{\infty} tG(t)\,dt$$ (red line)

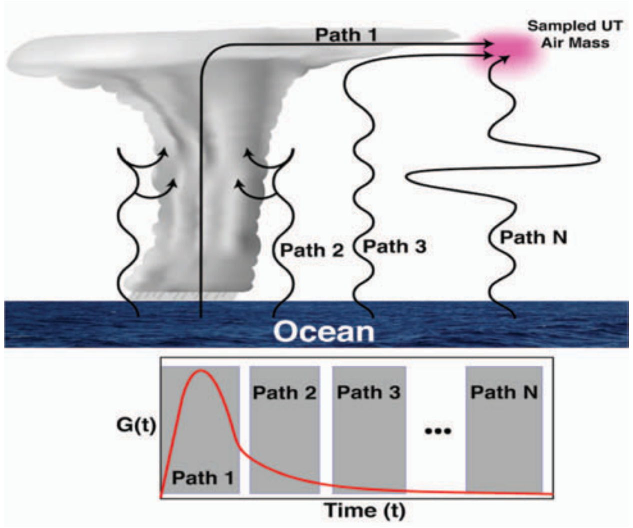
## **Summary**

- Chemical Tracers with different lifetimes can be used to probe convective transport pathways because an essential property of the transport paths is the characteristic transit time from the source (PBL) to the destination (UT)

- We demonstrated this concept by using a unique set of experimental data and a simple model, and defined an observation-based metric - ***Transit Time Spectrum or G(t)*** – for quantifying contributions from different transport paths.

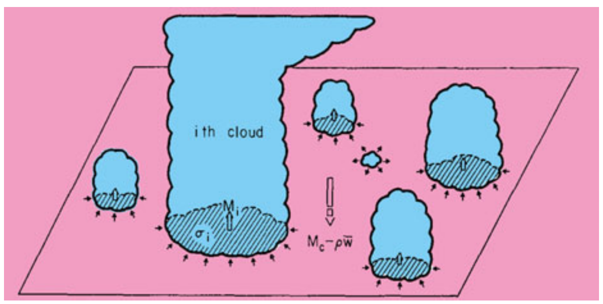
- The mean convective transport time scale derived from tracers (9 days) is broadly comparable with the estimate based on convective mass flux.



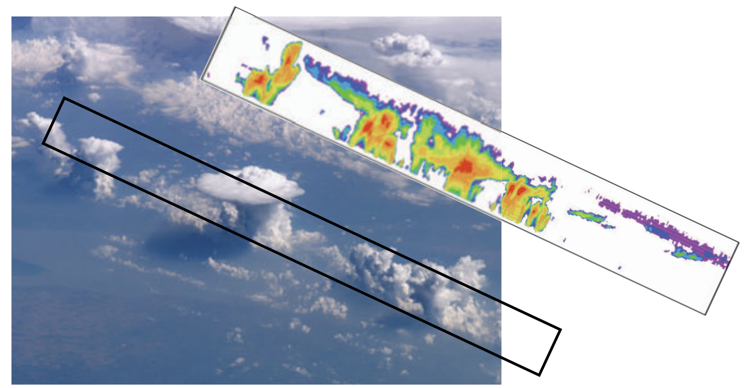



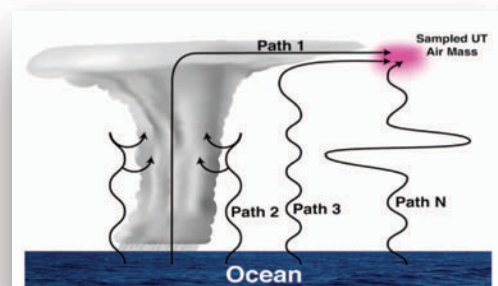
## Implication of the study

Formulation of convective parameterization is based on convective dynamics via convective mass flux




Global observations of convection mostly focus on observing hydrometeors






G(t) contains rich information about convective dynamics and has the potential of becoming an effective diagnostic of the representation of convection and convective transport in global models.