Characterization and Evaluation of Convective Transport Time Scales over the Tropical Western Pacific

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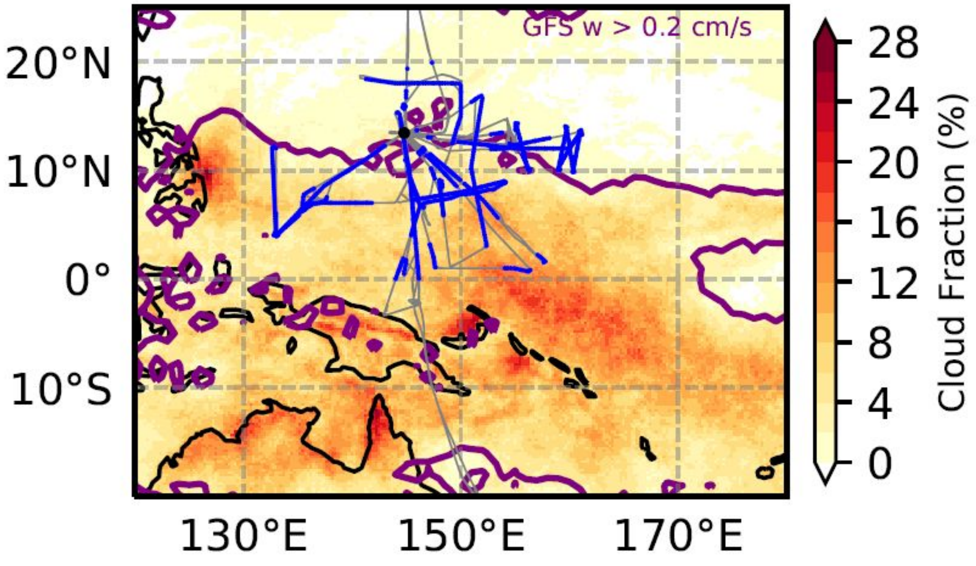
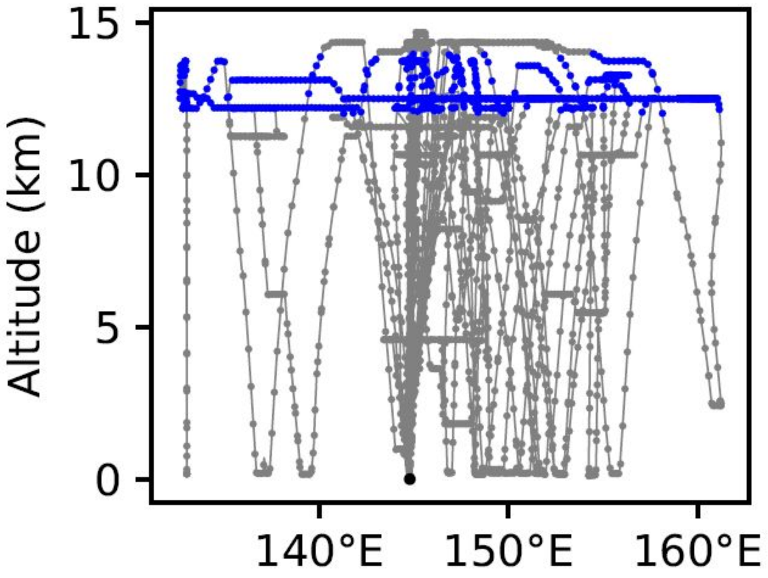
Developing a TTD using CONTRAST data

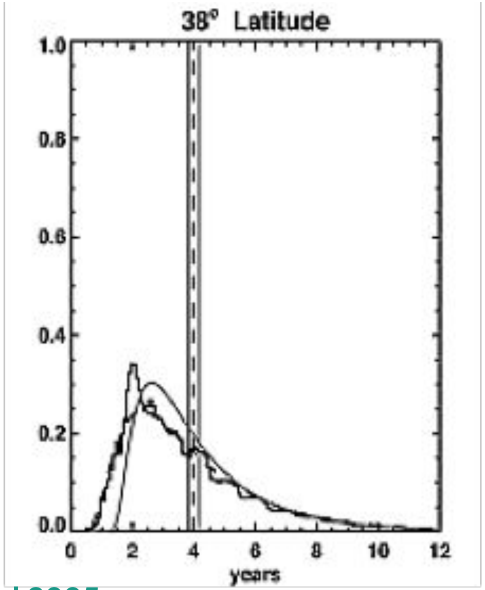
Develop a TTD using the CONTRAST data, measurements collected in a convectively active region

Use measured species to describe the spectrum of transit pathways between the local BL → local UT





Transit Time Distribution (TTD)



Schoeberl et al 2005

Age spectra computed from the model at 30 km and the latitude indicated in the graph title. Locations are shown in Figure 1. Solid lines show the model spectra. Shaded (smooth) and dashed lines show the fit spectrum using the radioactive tracers and the four chemical constituents, respectively. Vertical lines show the mean ages.

- Demonstrated by stratosphere application (Hall & Plumb 1994, Schoeberl et al 2005, Ehhalt et al, 2007, many more)
- Adapted to troposphere transport diagnostic, directly following Luo et al 2018 (also studies a la Orbe et al 2013, 2016)
- Characterize transport, diagnose & quantify transport processes

- **G(t) is a weighting function of the transport times of all different contributing air masses**

Transit Time Distribution (TTD)

UT, time t

BL, time 0

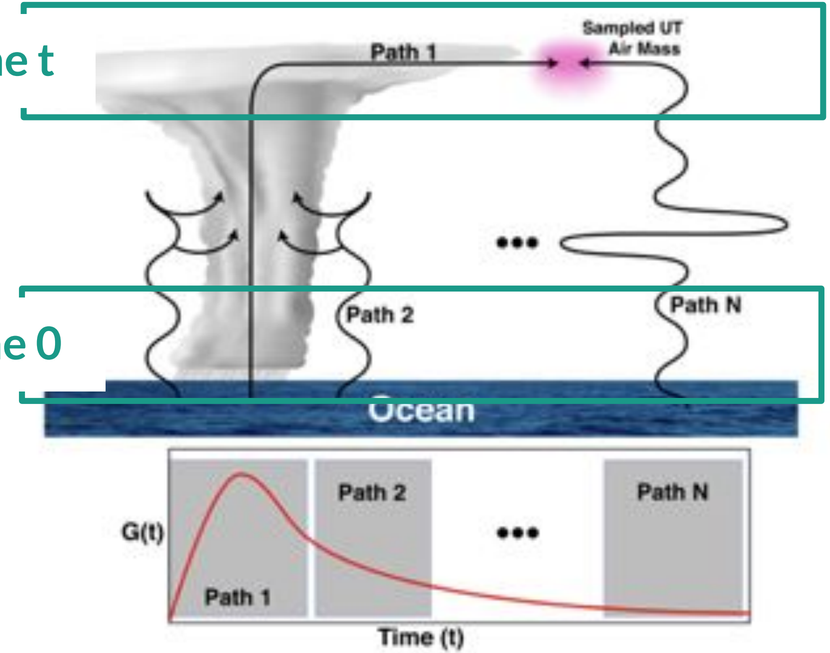


Figure 1. Schematic of transport paths in the convectively dominant tropical western Pacific. A transit time spectrum, *G(t)*, is defined to describe the relative contributions of these different paths. UT = upper troposphere.

For a trace gas, *i* :

$$\mu_i(t) = \frac{m_i(t)}{m_i(0)} = e^{-t/\tau_i}$$

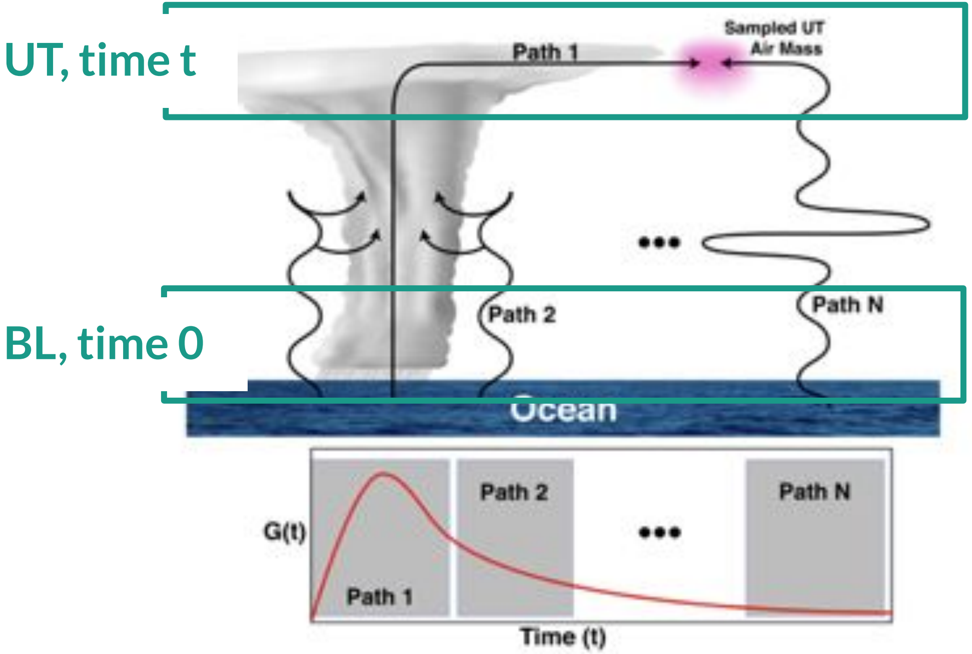
For a group of trace gases, mixing of parcels:

$$\mu_i(z) = \frac{UT}{BL} = \frac{m_i(z)}{m_i(0)} = \int_0^{\infty} e^{-t/\tau_i} G(z,t)\,dt$$

Utilize analytical solution from Hall & Plumb 1994:

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

Transit Time Distribution (TTD)



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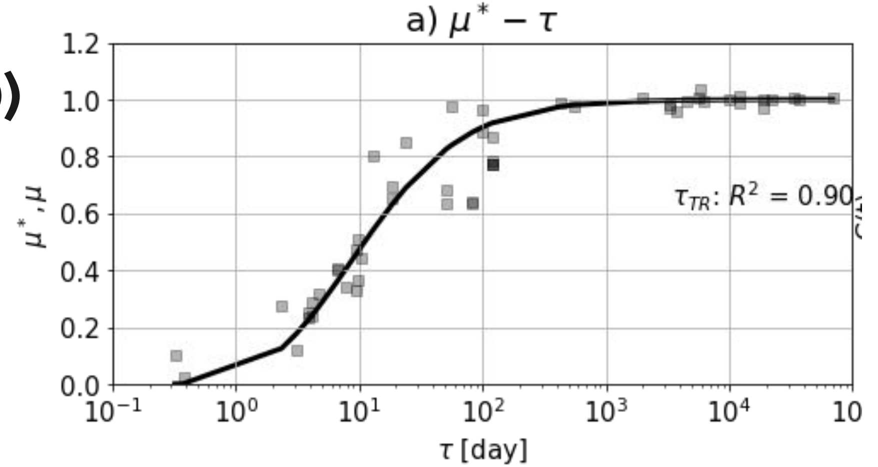
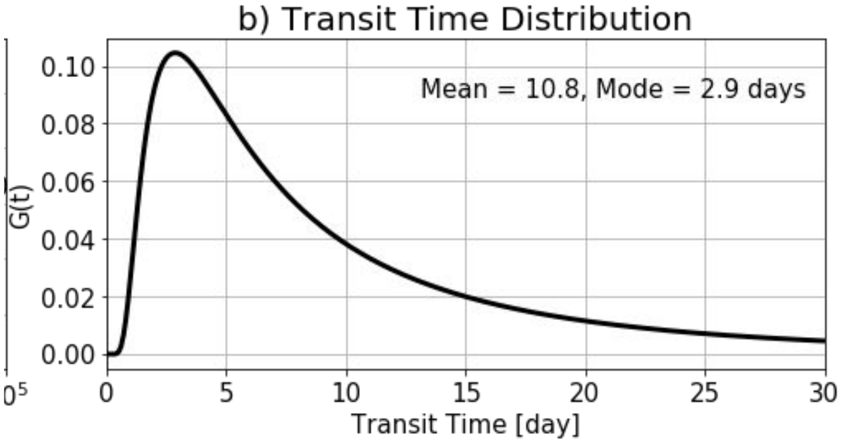
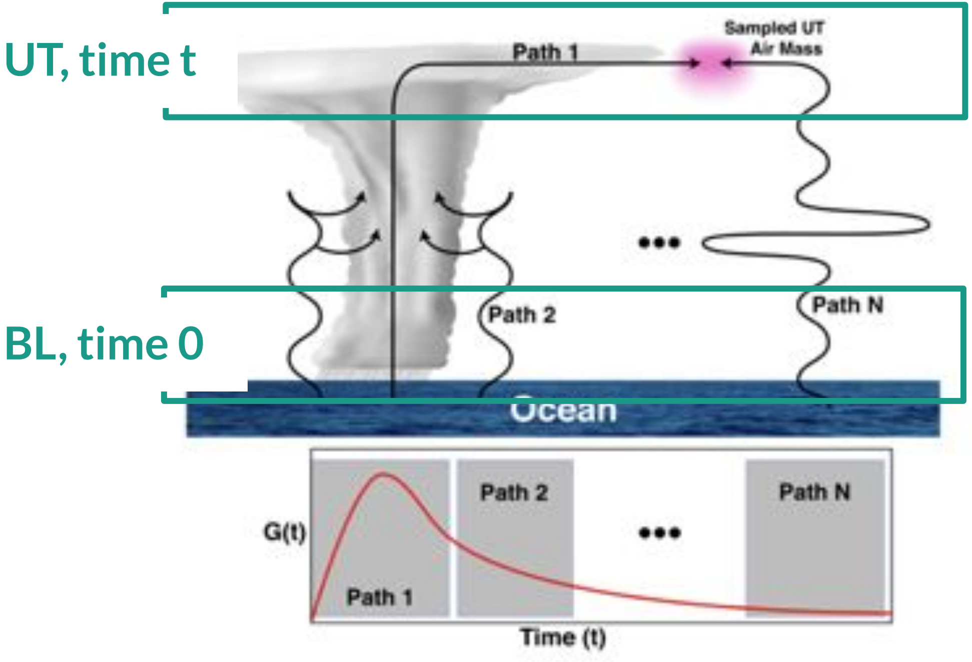




Transit Time Distribution (TTD)



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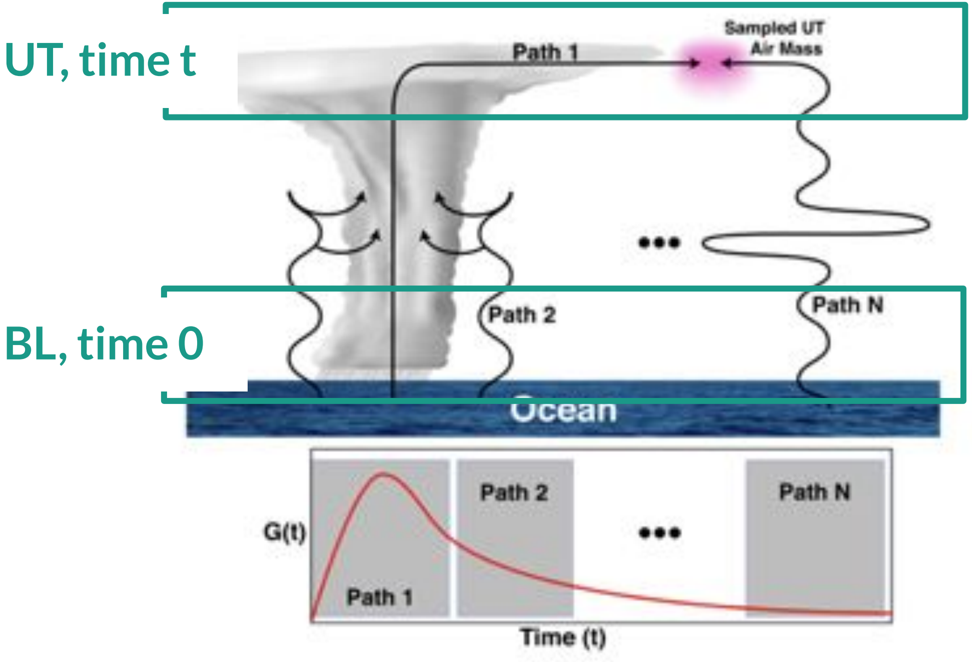
Major Assumptions:

1. Use of constant species lifetime τ for each species *i*

2. Homogenous BL input to UT, no outside contributions besides our BL "box"

3. Campaign average of all samples represents atmospheric conditions

Transit Time Distribution (TTD)



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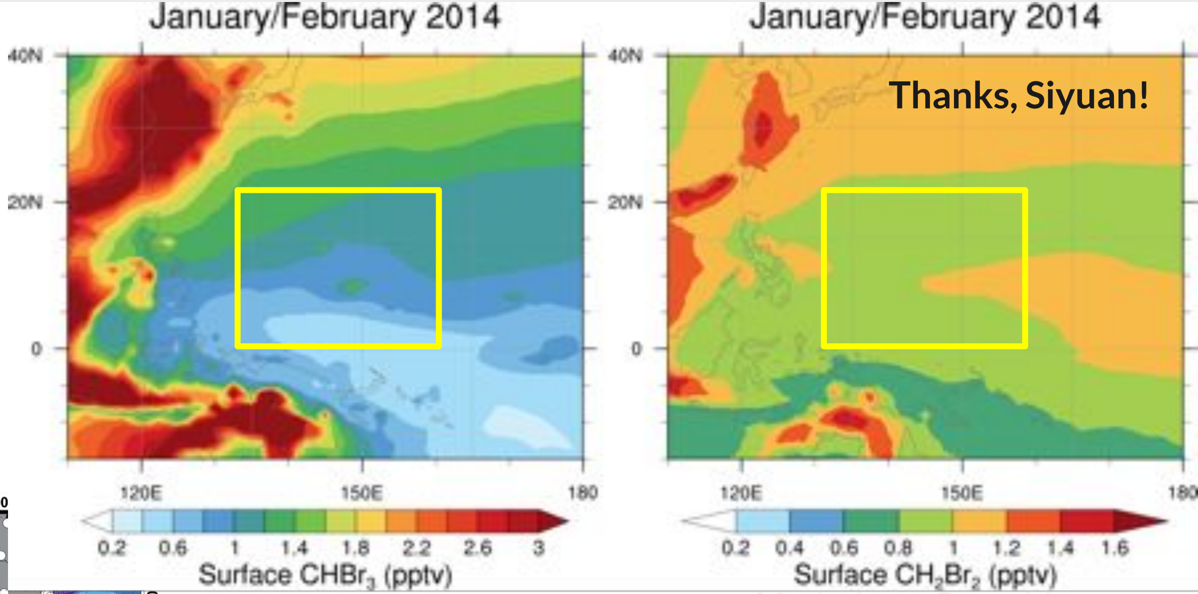
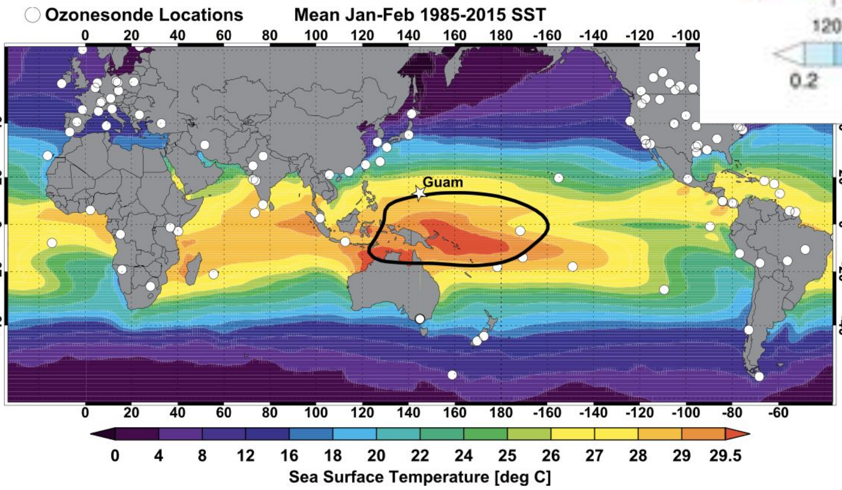
BL uncertainty



Bromoform

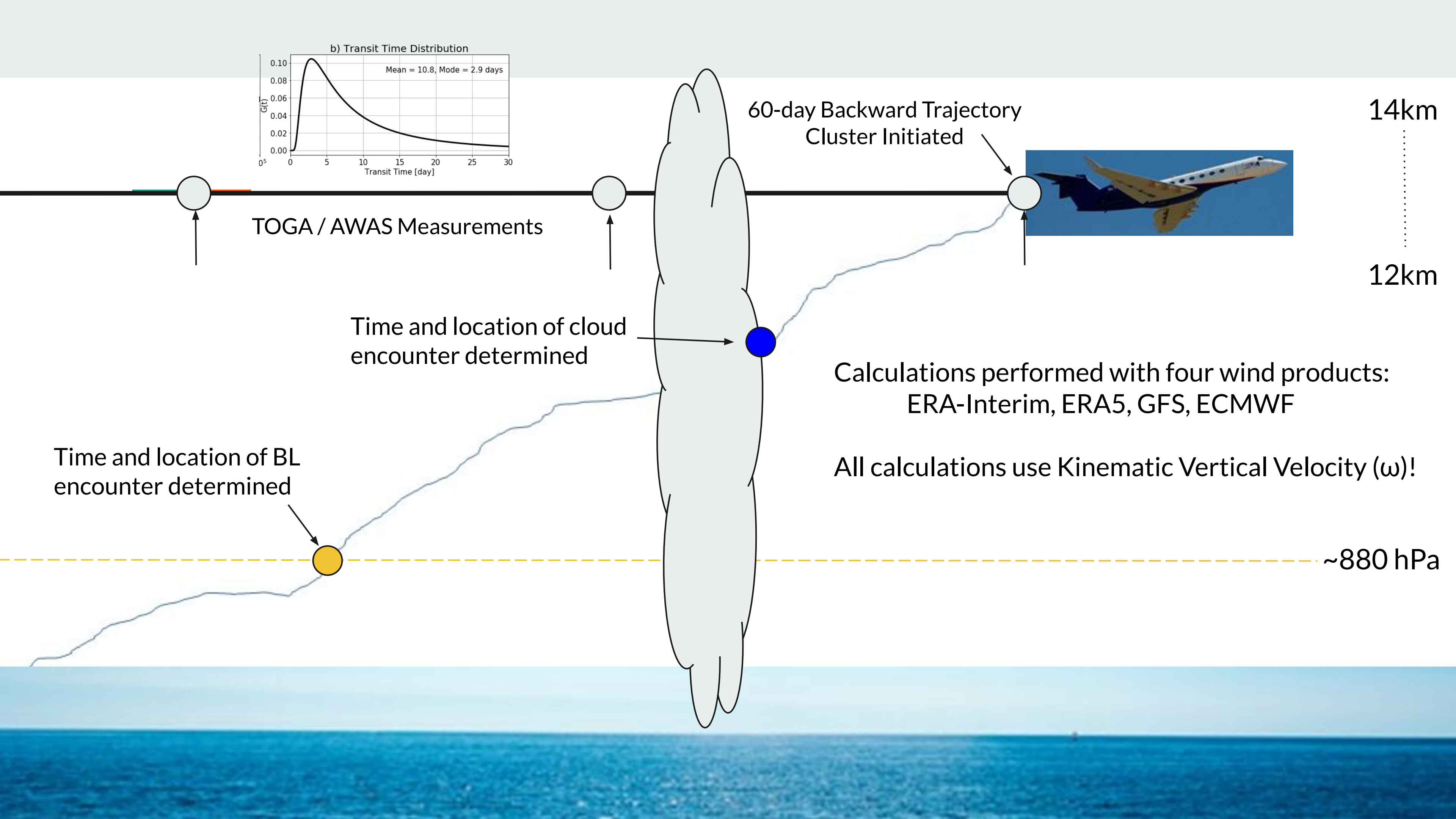
Methylene Bromide

Pan et al 2017, BAMS

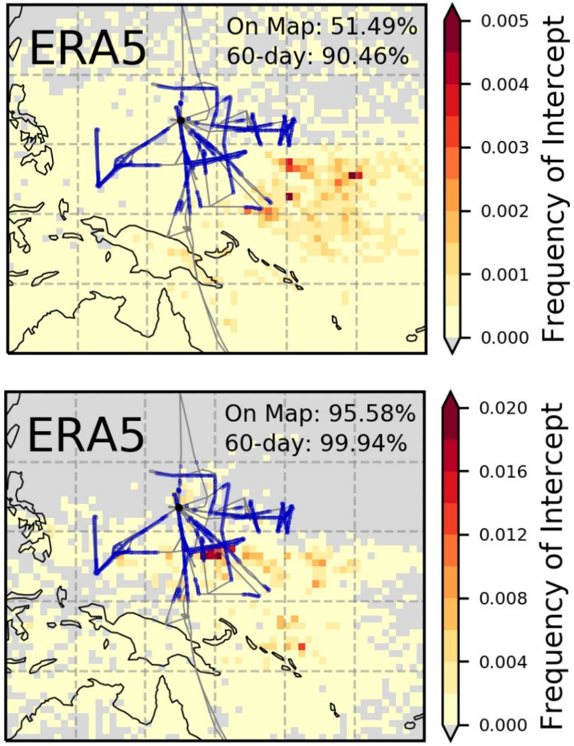


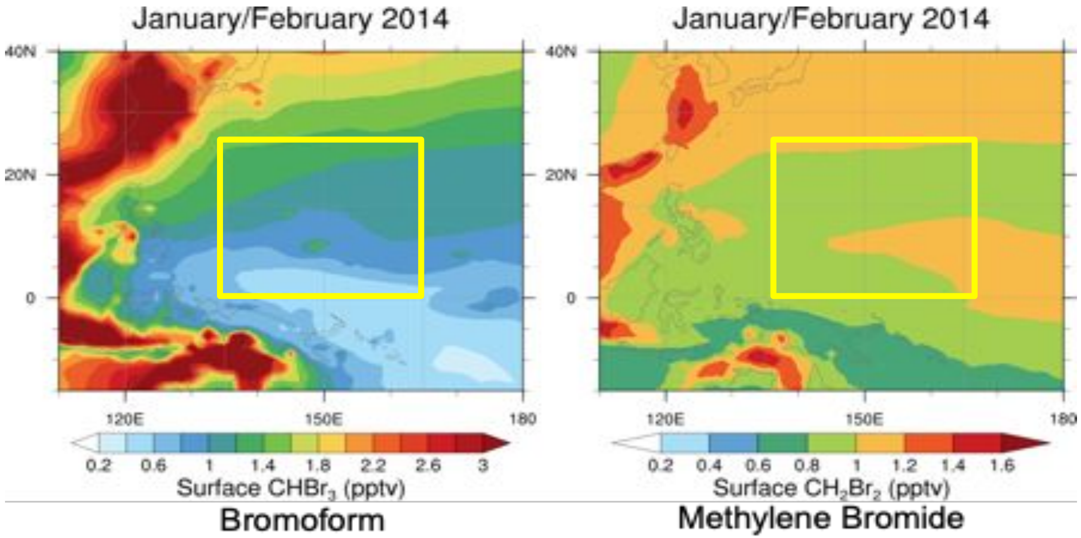
Variations in surface mixing ratios, variations in convective “hot spots”

What is really contributing to the sampled UT?


b) Transit Time Distribution
Mean = 10.8, Mode = 2.9 days
G(t)
Transit Time [day]
60-day Backward Trajectory
Cluster Initiated
14km
12km
TOGA / AWAS Measurements
Time and location of cloud
encounter determined
Calculations performed with four wind products:
ERA-Interim, ERA5, GFS, ECMWF
All calculations use Kinematic Vertical Velocity (ω)!
Time and location of BL
encounter determined
~880 hPa

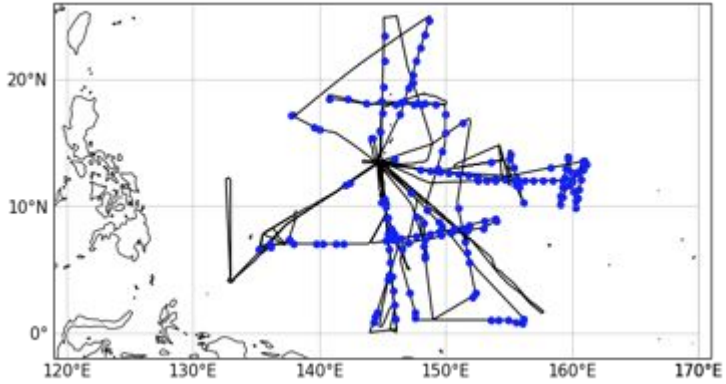
Trajectory calculations confirm the contributing BL is largely concentrated near / just south of the equator

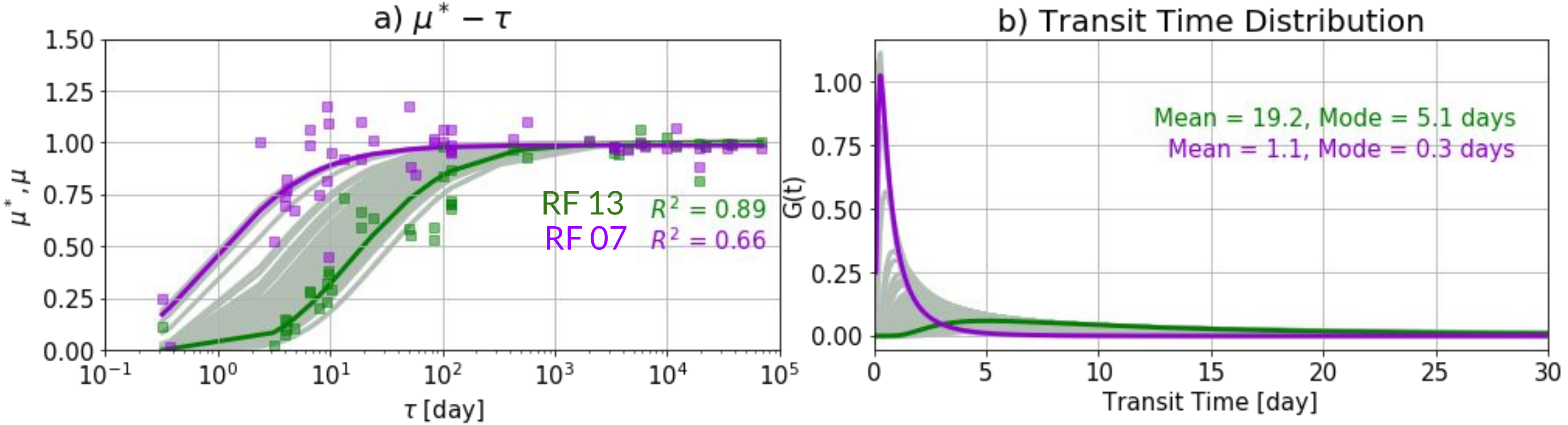




Case Studies

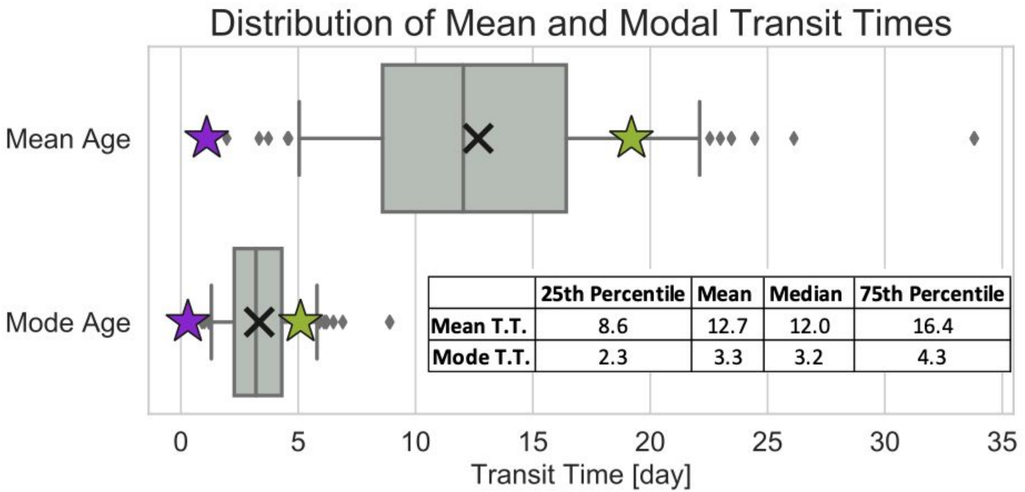
- Each AWAS cannister + collocated TOGA measurements within 2 minutes
- Corresponds to ~80 km local average sample each
- Cluster 3 samples per case study



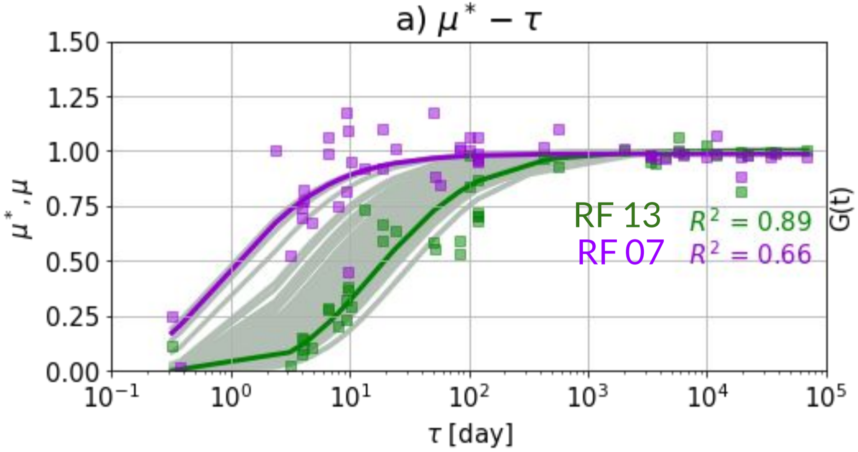


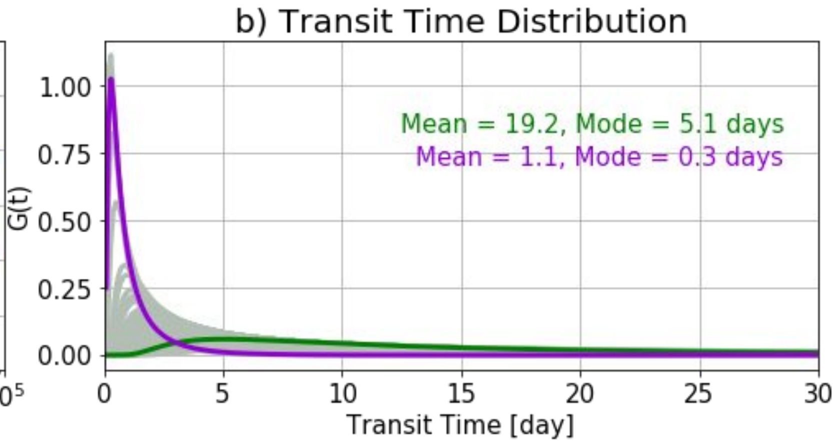
Case Studies

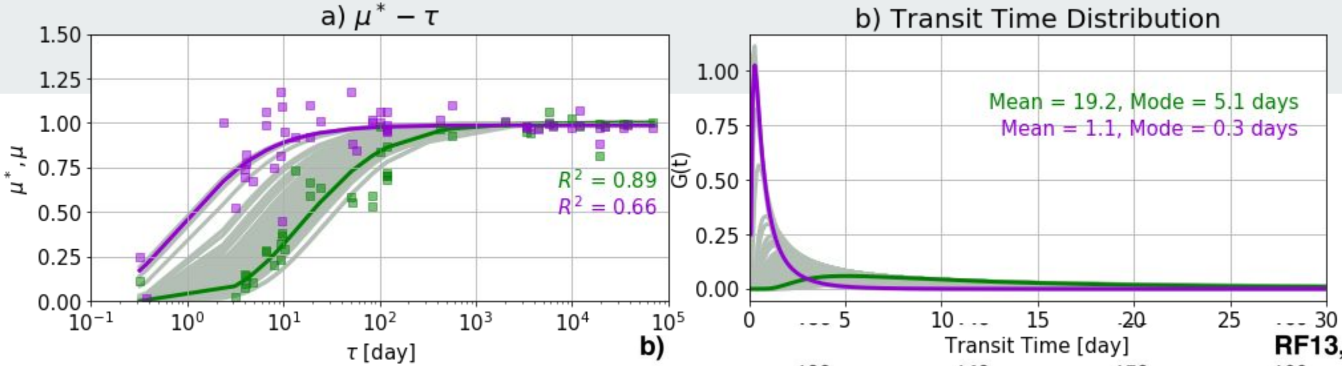
How can we explain the behavior of these two samples?



	25th Percentile	Mean	Median	75th Percentile
Mean T.T.	8.6	12.7	12.0	16.4
Mode T.T.	2.3	3.3	3.2	4.3

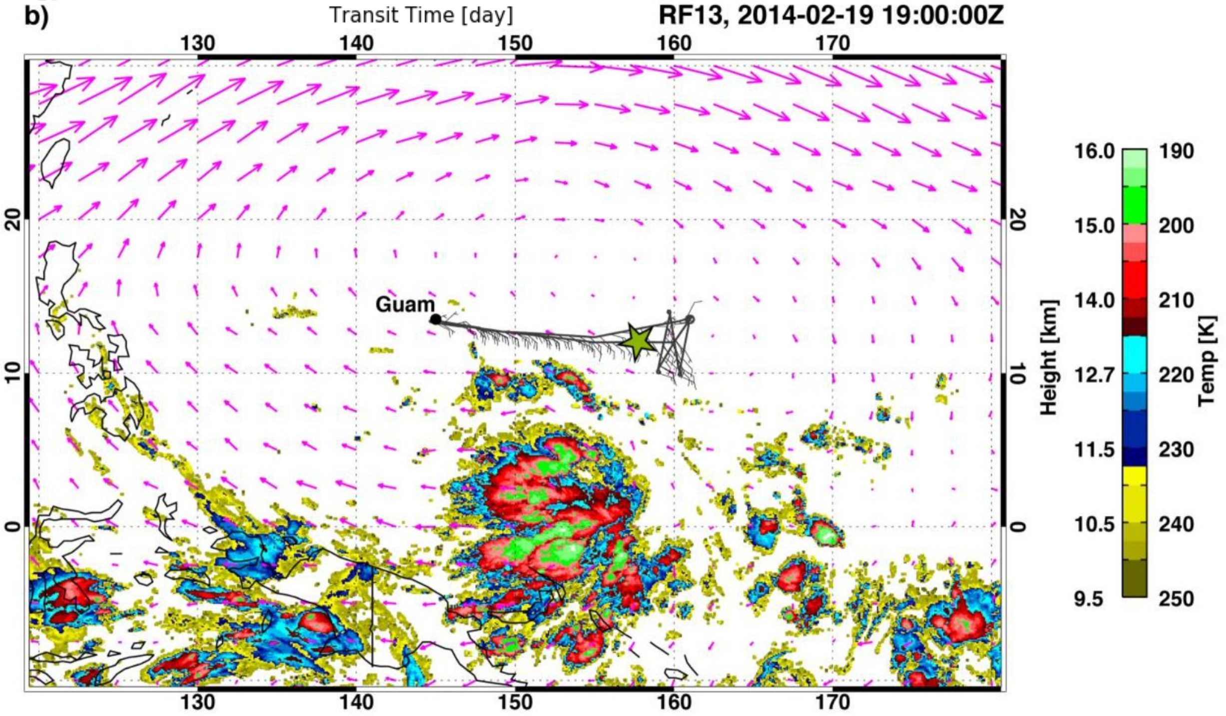


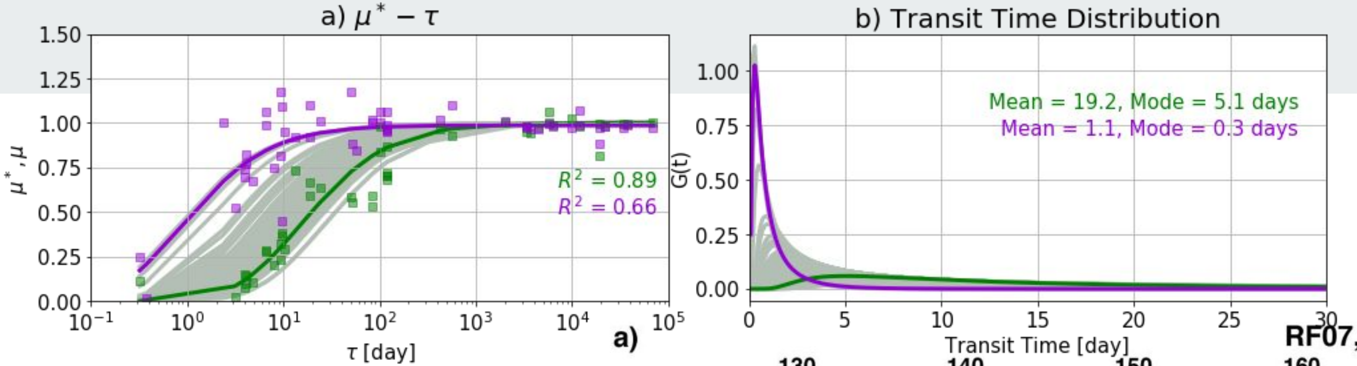




Dynamical Background

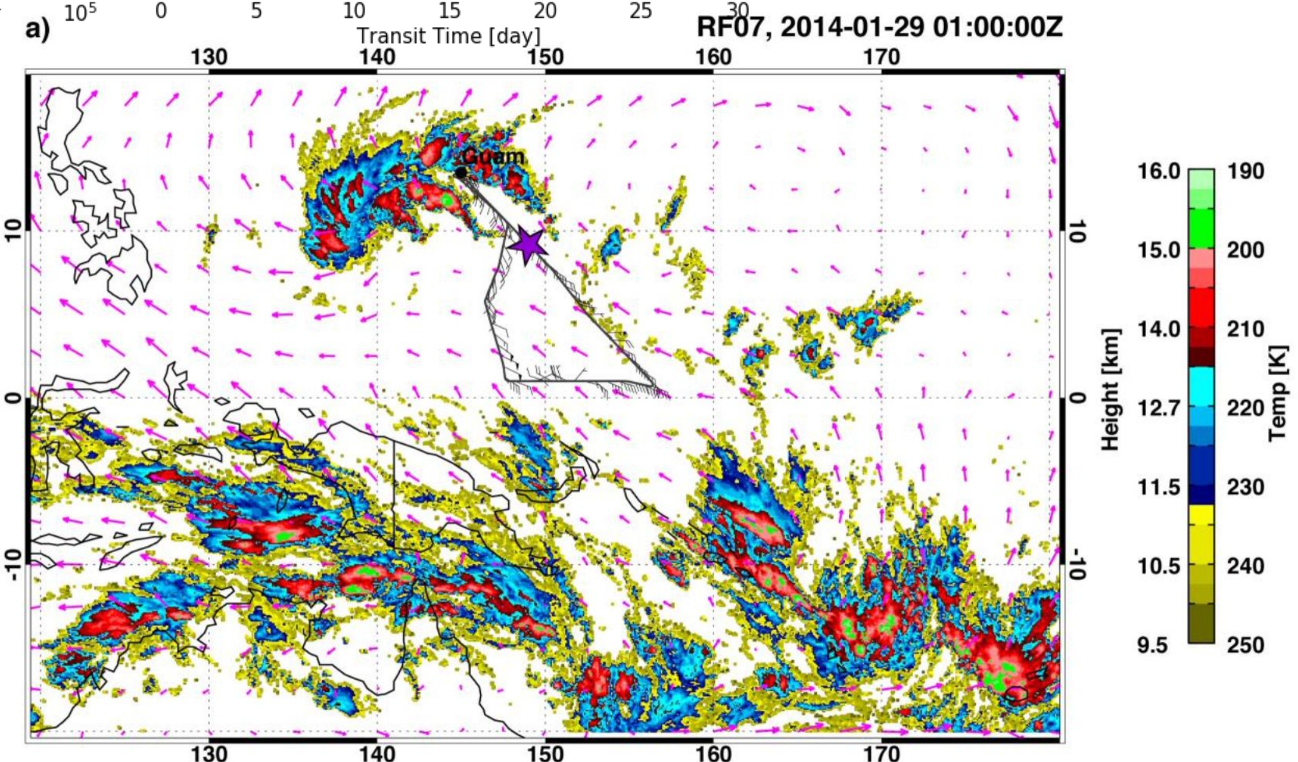
- Low UT mixing ratios of short lived species, consistent with convective influence
- In center of stagnant anticyclonic circulation
- Air lingering in the UT (but for how long? And from where?)

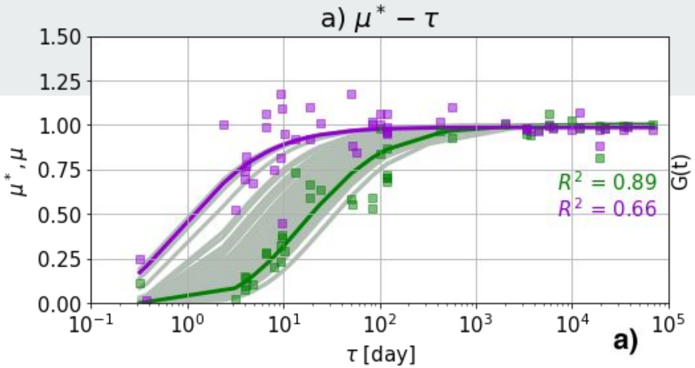


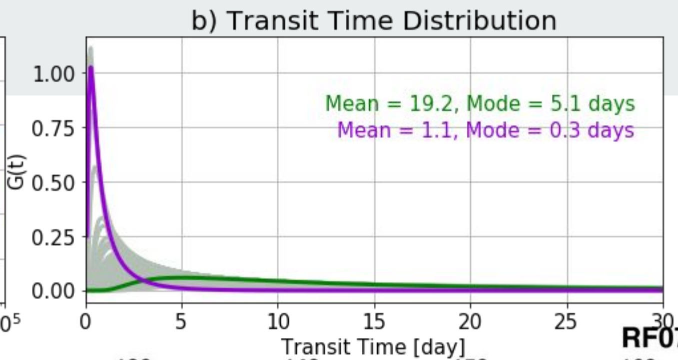


Dynamical Background

- Enhanced UT mixing ratios of short lived species, consistent with convective influence
- Direct wind flow from SH deep convection
- Outside sampled study area but suspect similar chemical composition







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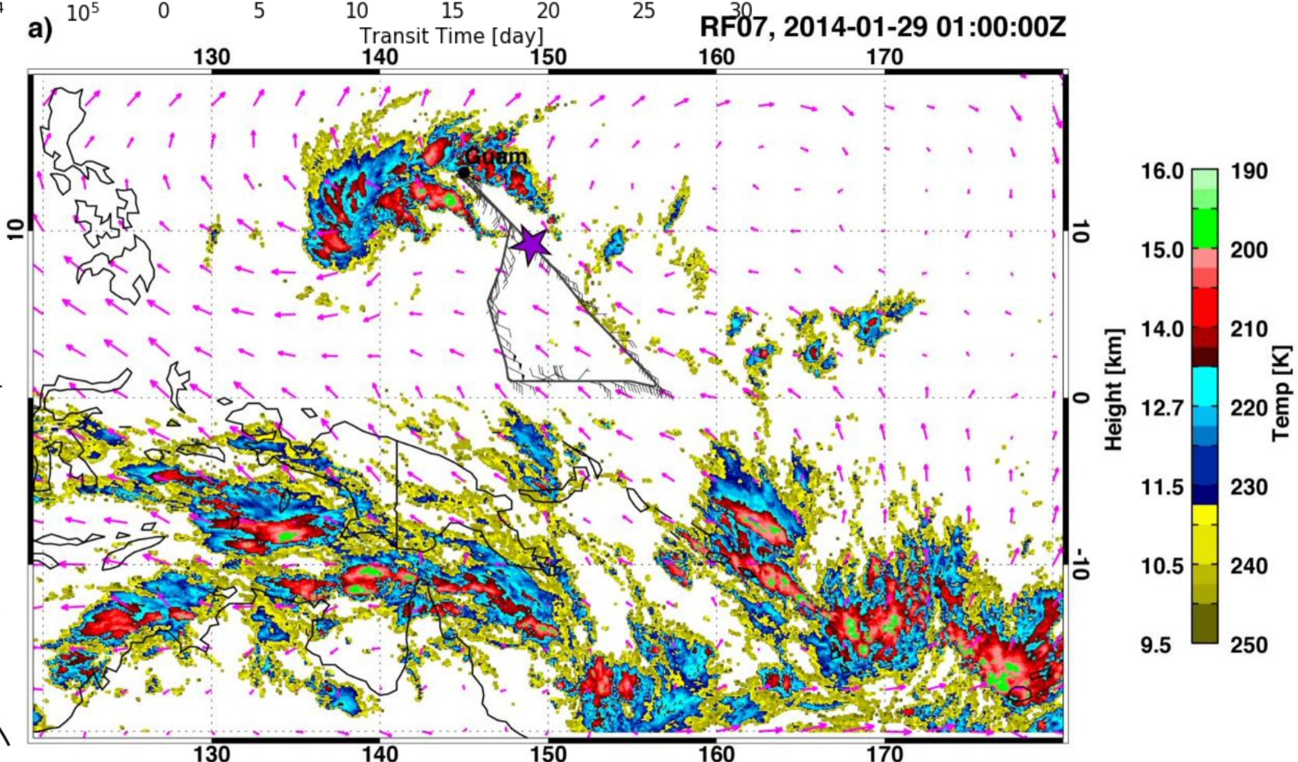
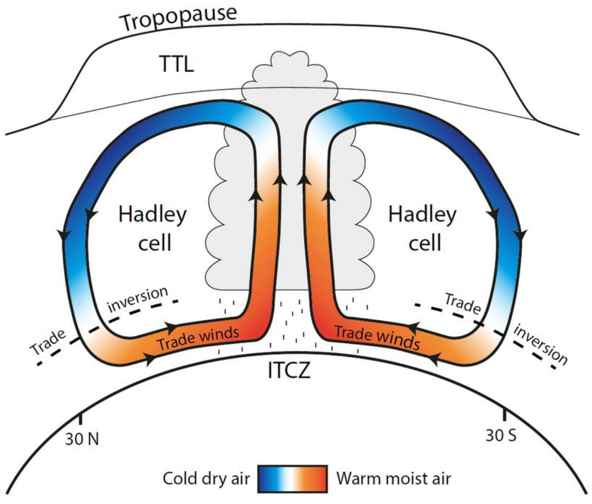
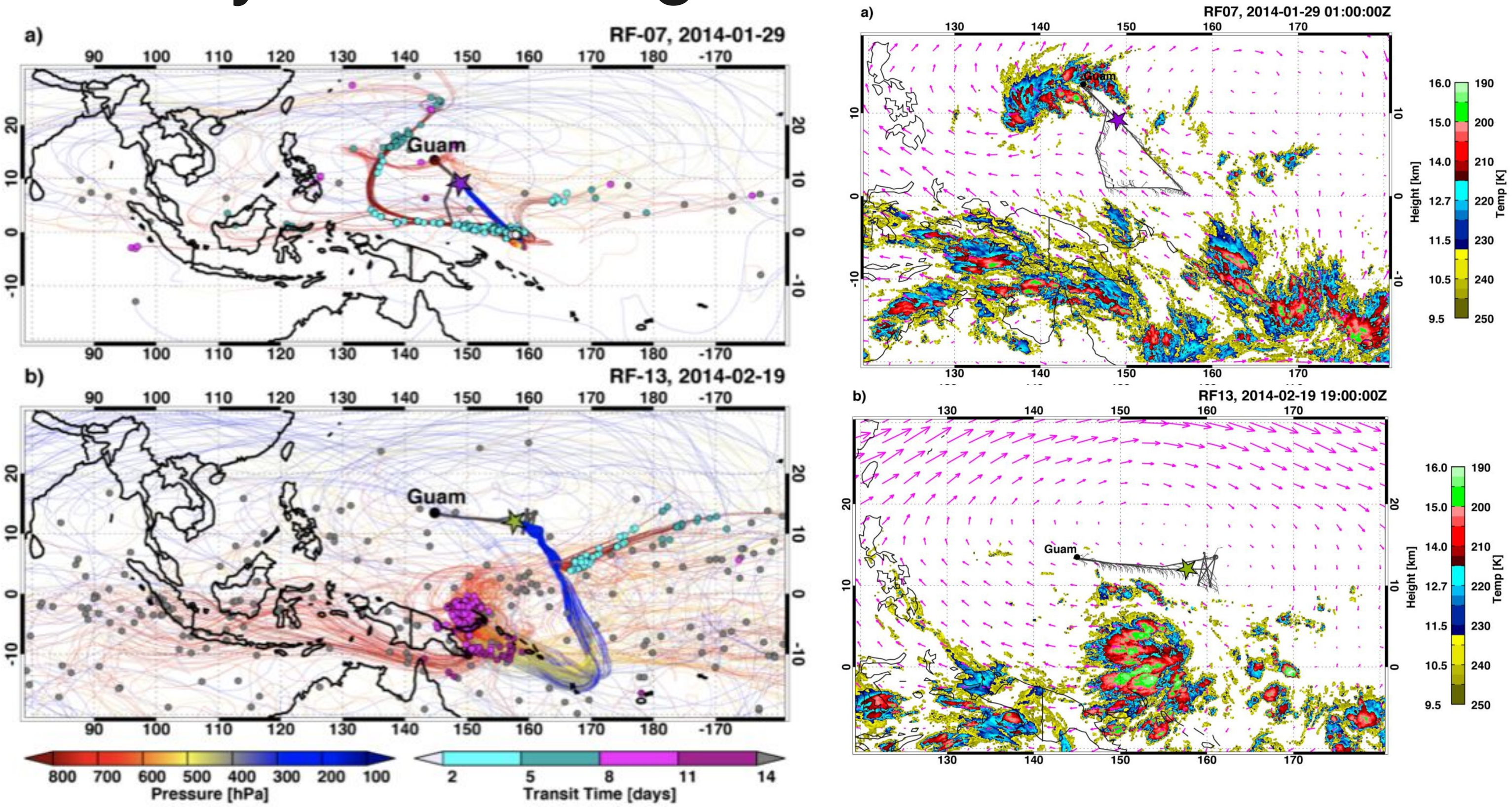




Trajectory Calculations Show Consistency With Known Dynamical Backgrounds!



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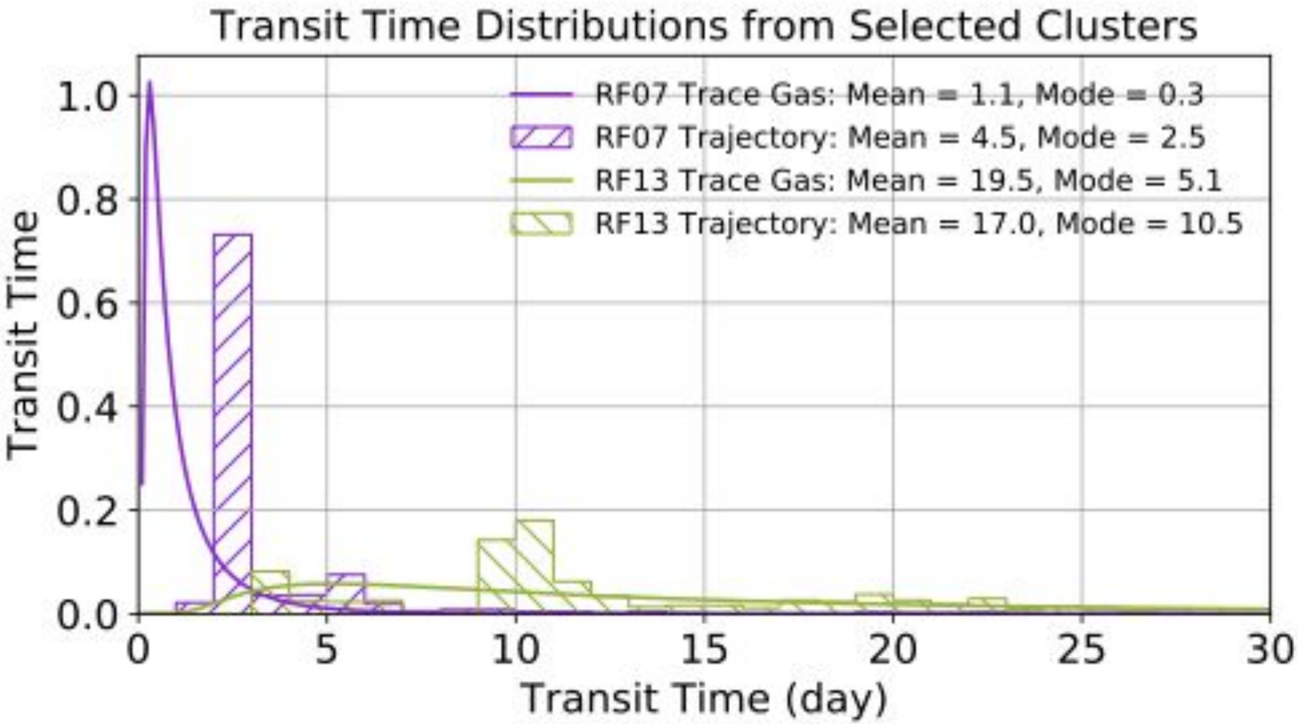
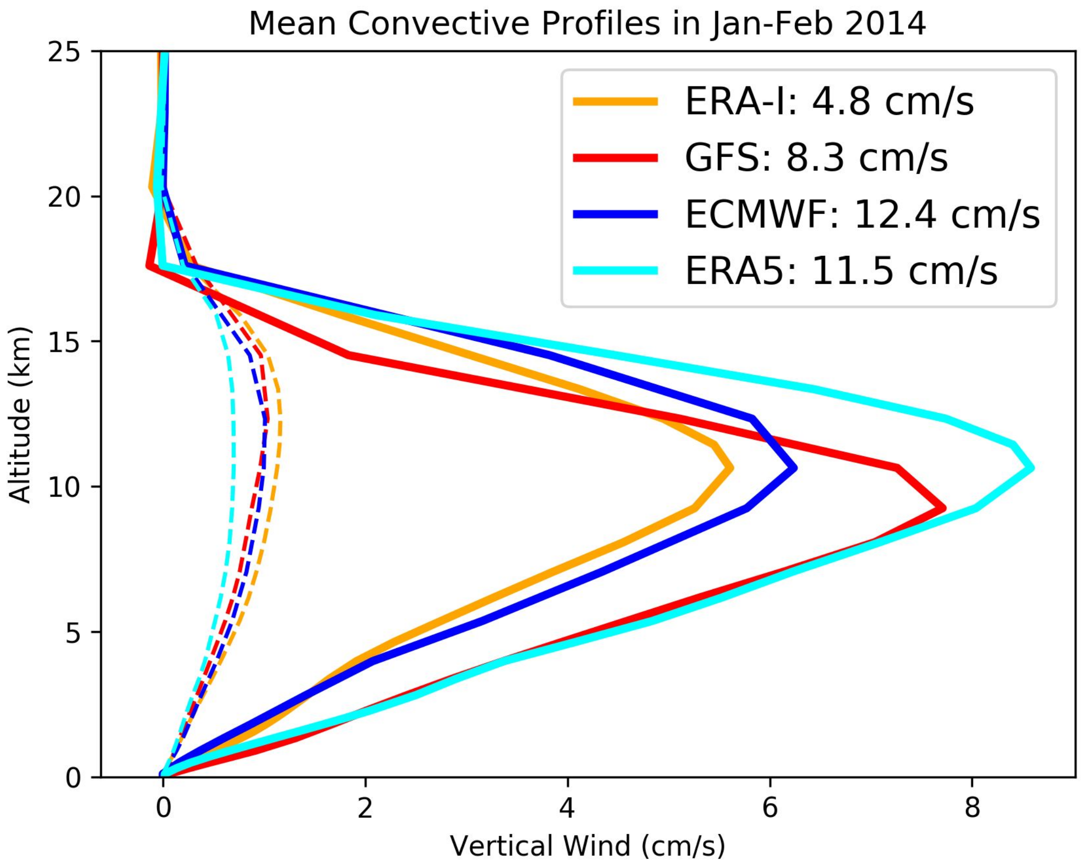
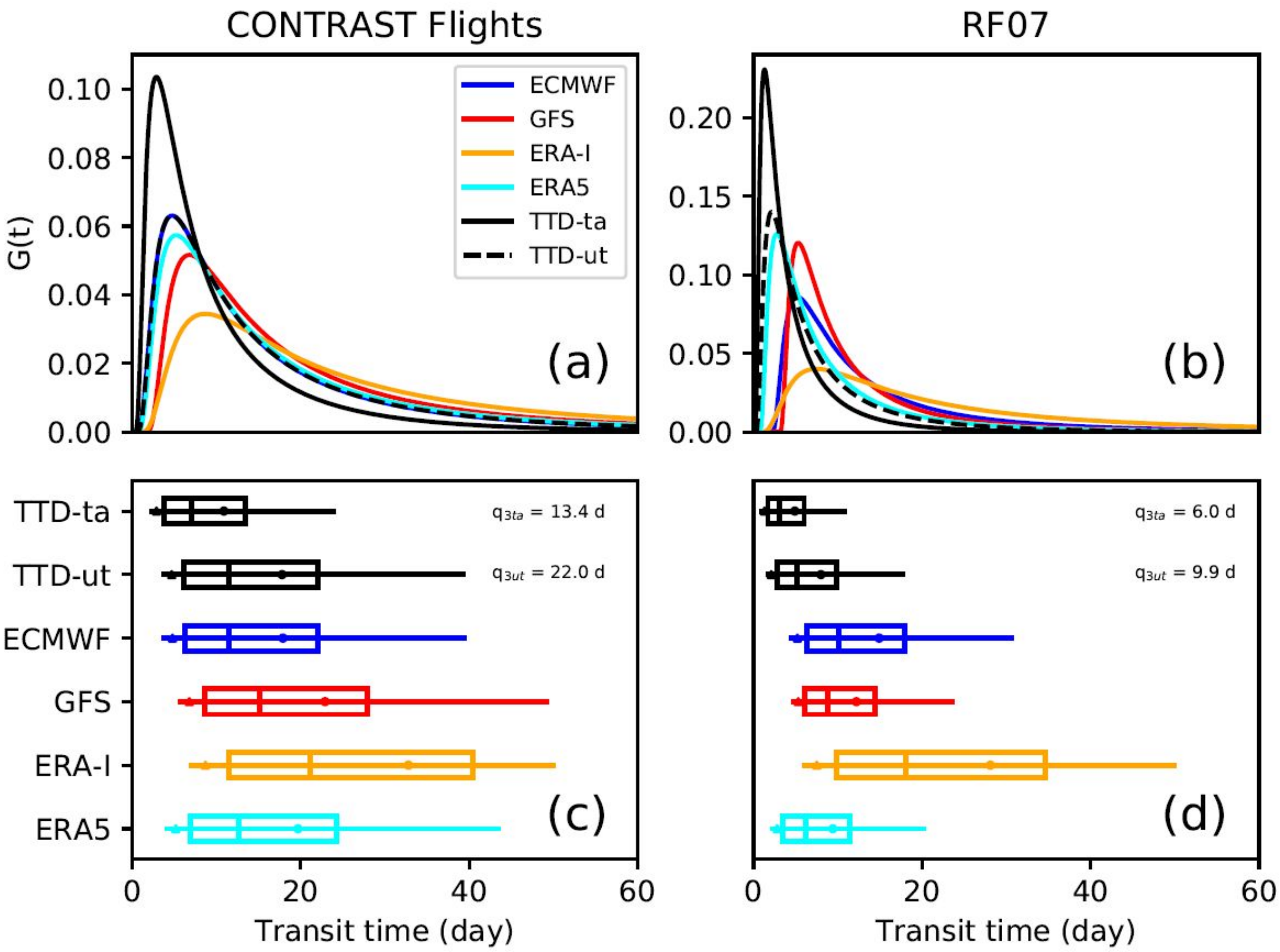


Grid point winds in the presence of observed convection show an order of magnitude enhancement in their ω fields, on average!





- There is a general consistency between the independent TTD formulations
- Trajectory-based TTDs under(over)represent short (long) transport pathways when evaluated with chemical-based TTDs
- Despite this, trajectory-based TTDs generally represent more than half of the convective transport processes in the chemical-based TTDs

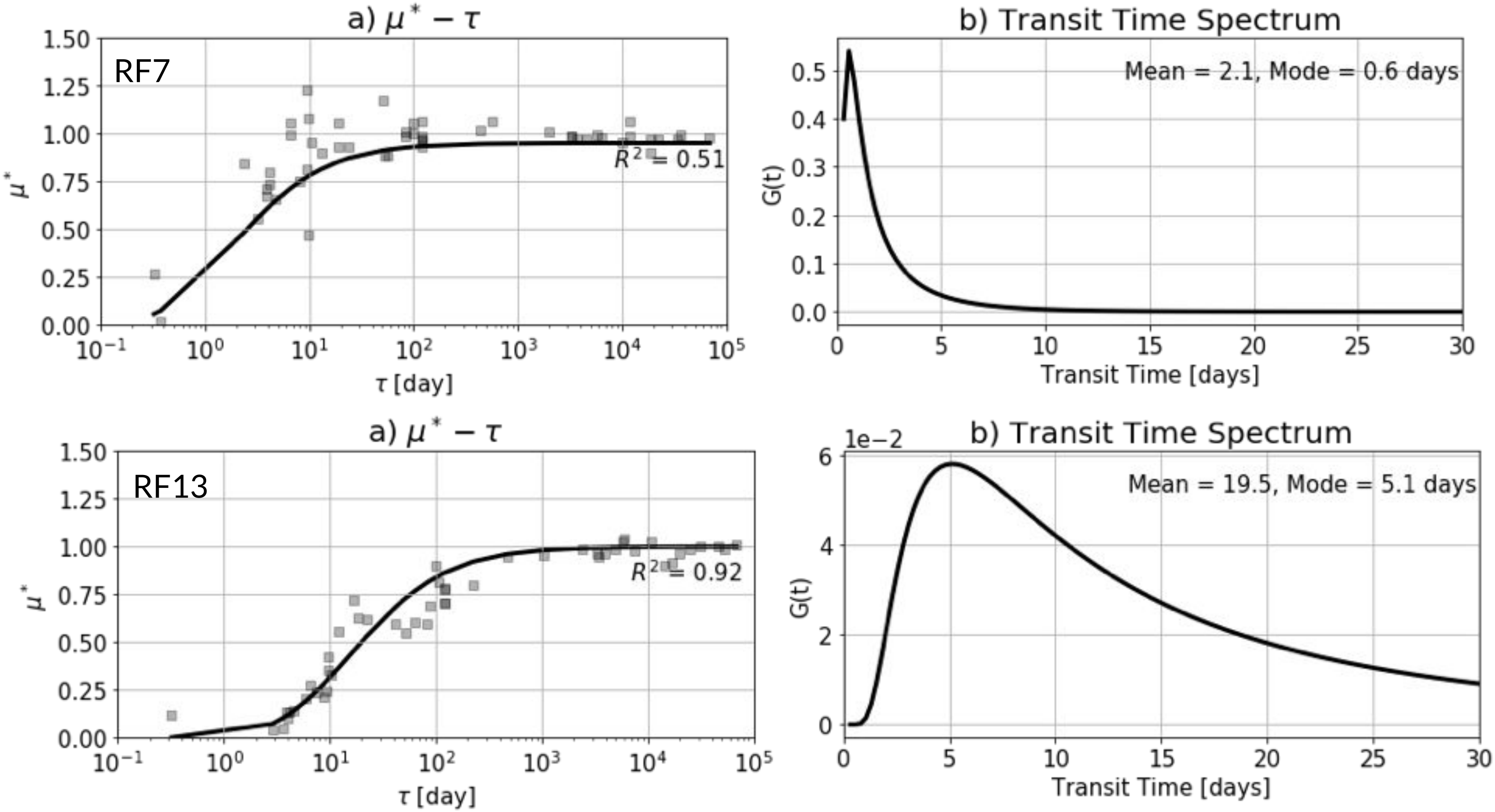
Conclusions

- Trace gas measurements with a range of lifetimes can be used to infer transport characteristics about the sampled air mass, which are shown to be consistent with the dynamical background

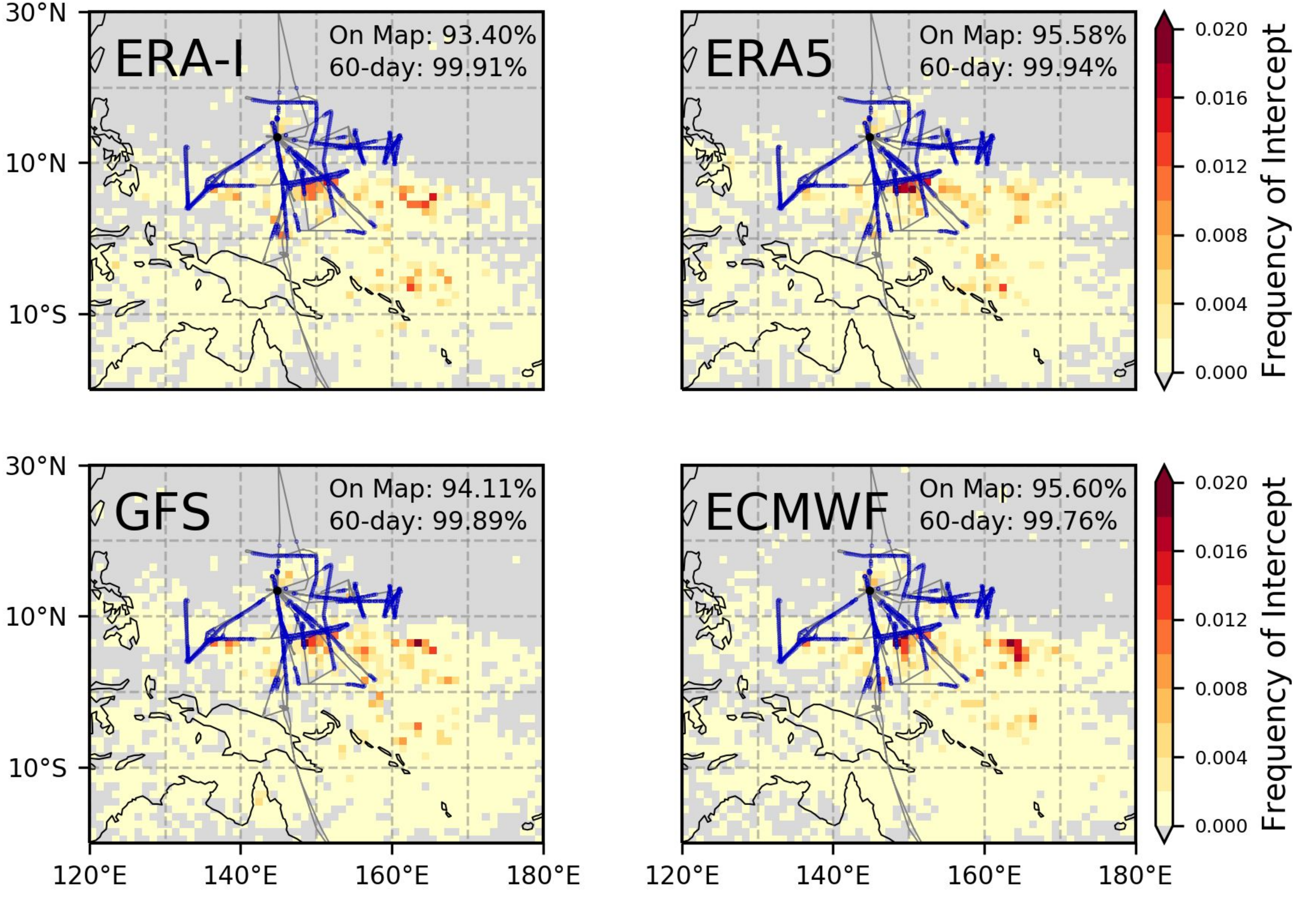
- Lagrangian trajectory models using kinematic vertical velocity capture a significant portion of convective transport processes, when evaluated using TTDs derived from trace gas measurements

These studies showcase a valuable diagnostic tool for connecting and evaluating observations and models alike!

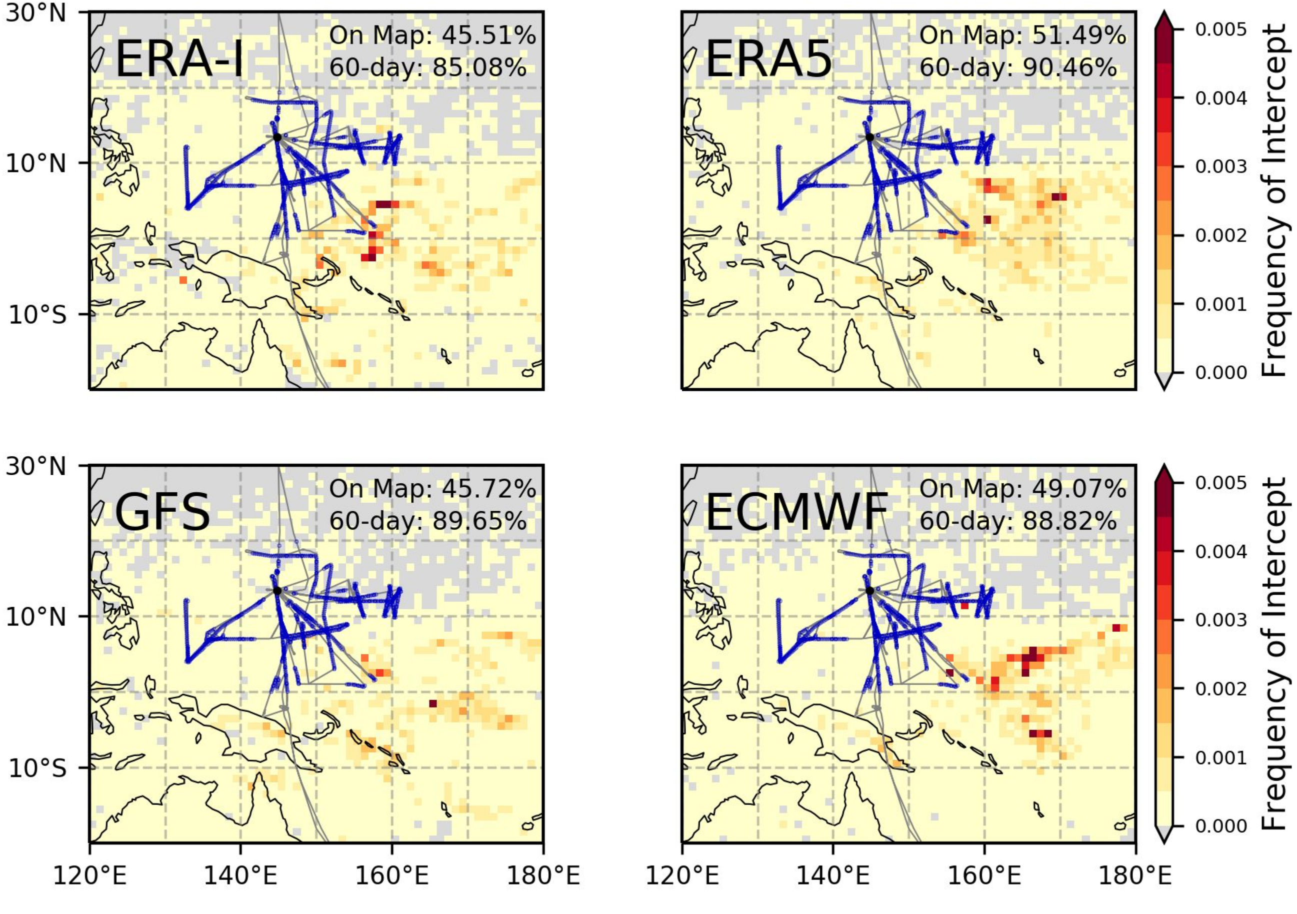
Extra Slides


a) $\mu^* - \tau$
RF7
$R^2 = 0.51$
μ^*
τ [day]
b) Transit Time Spectrum
Mean = 2.1, Mode = 0.6 days
G(t)
Transit Time [days]
a) $\mu^* - \tau$
RF13
$R^2 = 0.92$
μ^*
τ [day]
b) Transit Time Spectrum
1e−2
Mean = 19.5, Mode = 5.1 days
G(t)
Transit Time [days]

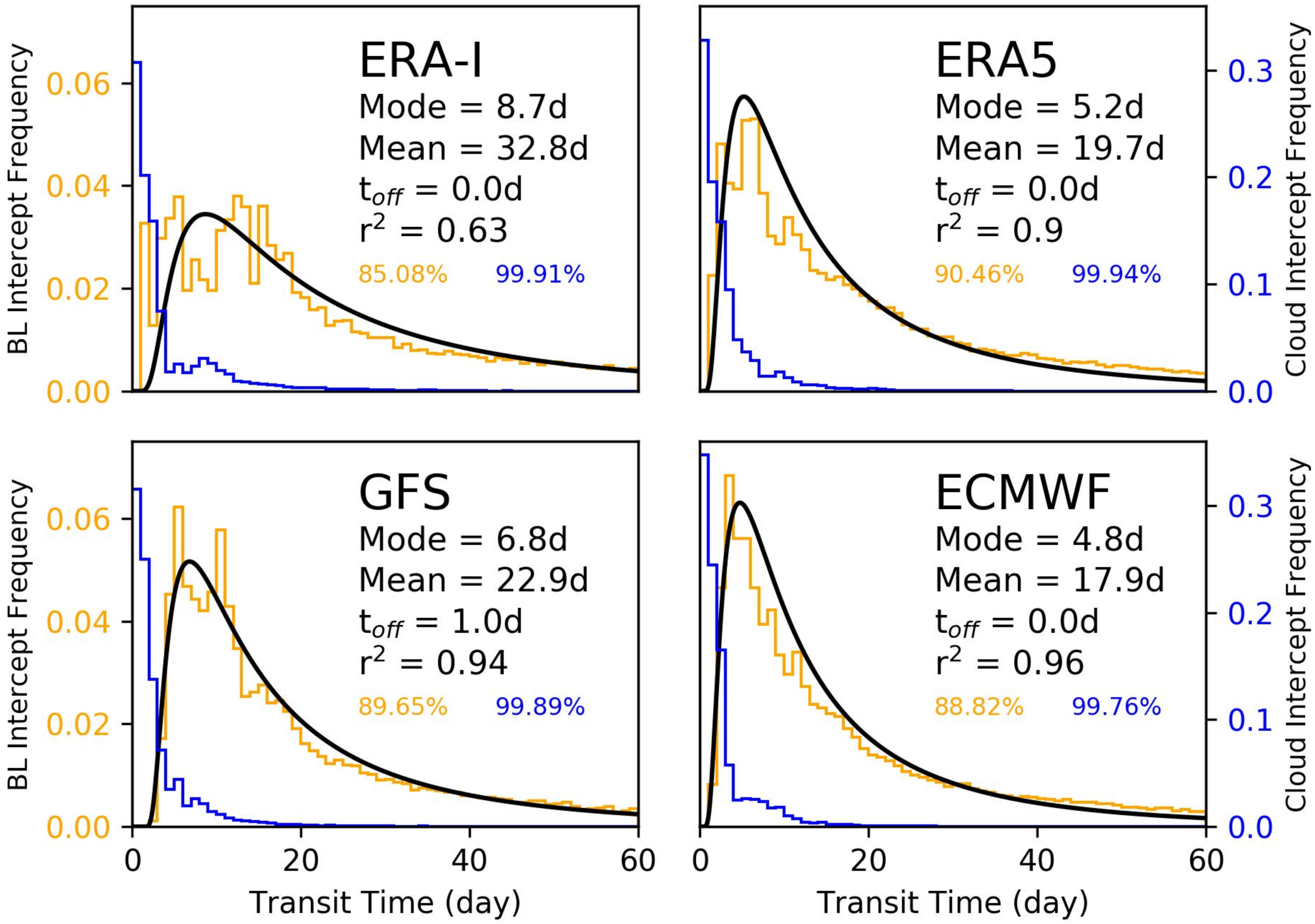
Convective Cloud Intercept during CONTRAST

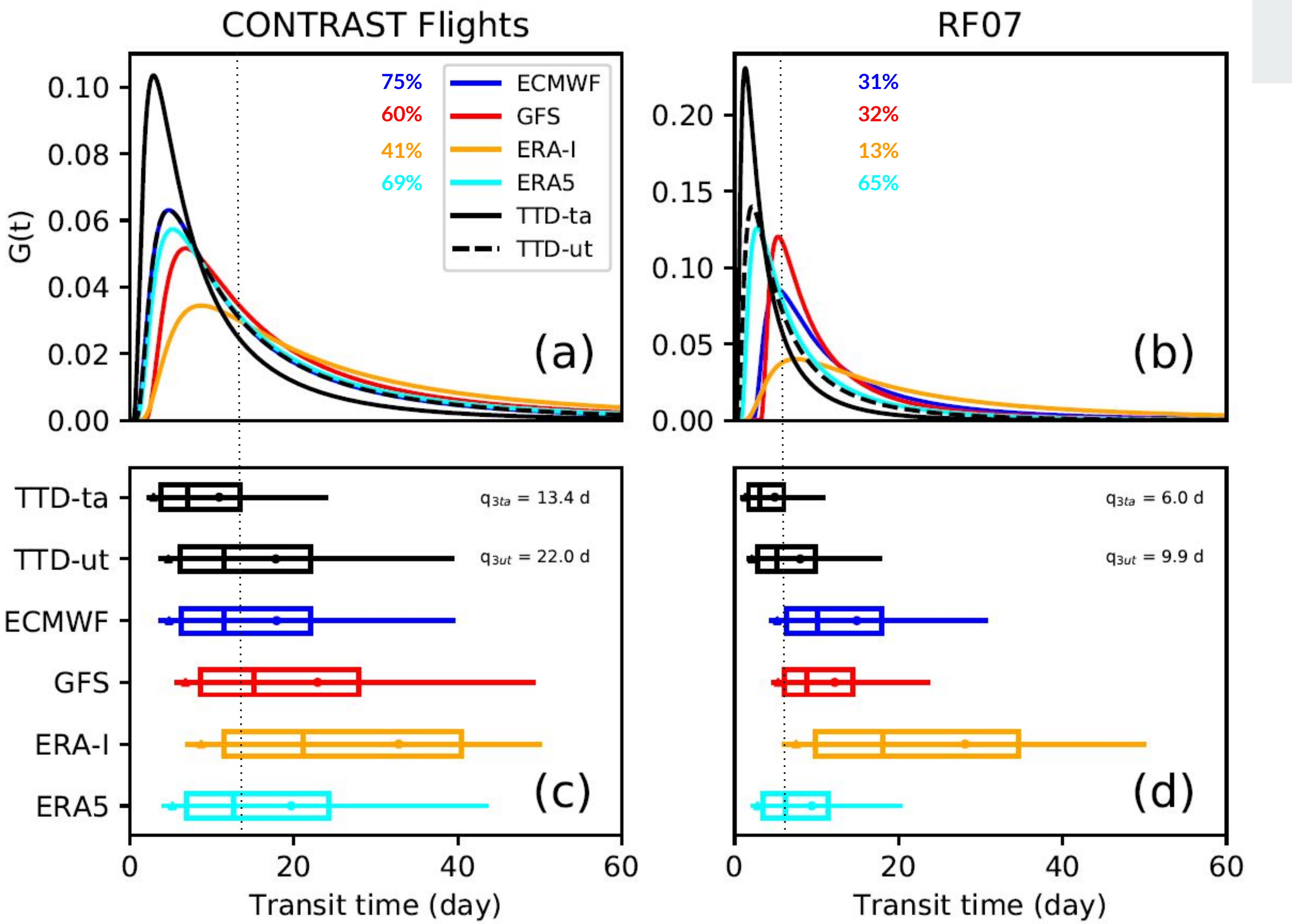


Boundary Layer Intercept during CONTRAST



Transit Time Distributions during CONTRAST





CONTRAST Flights
RF07
G(t)
ECMWF
GFS
ERA-I
ERA5
TTD-ta
TTD-ut
75%
60%
41%
69%
31%
32%
13%
65%
(a)
(b)
(c)
(d)
q_{3ta} = 13.4 d
q_{3ut} = 22.0 d
q_{3ta} = 6.0 d
q_{3ut} = 9.9 d
Transit time (day)
Transit time (day)

		Trajectory-Based TTDs				Chemical-Based TTDs	
	Product	ERA-I	ERA5	GFS	ECMWF	TTD-ta	TTD-ut
CONTRAST RFs	Mode (d)	8.7	5.2	6.8	4.8	2.9	4.7
	Mean (d)	32.8	19.7	22.9	17.9	10.9	17.8
	r^2	0.63	0.90	0.94	0.96	0.91	0.87
	p_1 (Eq. 3)	0.31	0.52	0.45	0.56	0.75	0.57
	% of $p_{1\text{-}ta}$	41	69	60	75	100	76
	p_2 (Eq. 3)	0.52	0.72	0.66	0.75	0.88	0.75
	% of $p_{2\text{-}ut}$	69	96	88	100	117	100
RF07	Mode (d)	7.5	2.8	5.3	5.2	1.3	2.1
	Mean (d)	28.1	9.4	12.2	14.9	4.9	8.0
	r^2	0.26	0.71	0.73	0.81	0.80	0.75
	p_1 (Eq. 3)	0.10	0.49	0.24	0.23	0.75	0.56
	% of $p_{1\text{-}ta}$	13	65	32	31	100	75
	p_2 (Eq. 3)	0.25	0.70	0.57	0.49	0.88	0.75
	% of $p_{2\text{-}ut}$	33	93	76	65	117	100

Table 2. A collection of TTD mode, mean, r^2 and p_1 and p_2 (Equation 2) values for trajectory-based and chemical lifetime-based TTDs (i.e., all curves shown in Figure 10). Percentages of p values relative to the values for the TTD-ta and TTD-ut curve are also included.

Name	Type	Native Resolution	Product Grid Size	Temporal Spacing
ERA-Interim	Reanalysis	80 km x 80 km	1.0° x 1.0°	6 hr
ERA5	Reanalysis	31 km x 31 km	0.25° x 0.25°	1 hr
GFS	Operational	25 km x 25 km	1.0° x 1.0°	6 hr
ECMWF	Operational	18 km x 18 km	0.25° x 0.25°	6 hr