QOS 2021
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Online Meeting

[C_226]

Origin of Tropospheric Air Masses in the Tropical West Pacific

and related transport processes inferred from balloon-borne Ozone and Water Vapour observations from Palau

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PhD thesis + 2 Manuscripts *

Motivation
(I)

Tropospheric
O_3 variability
(II)

Air mass
definition
(III)

Transport
Pathways and
Processes
(IV)

Take Away
Messages
(V)

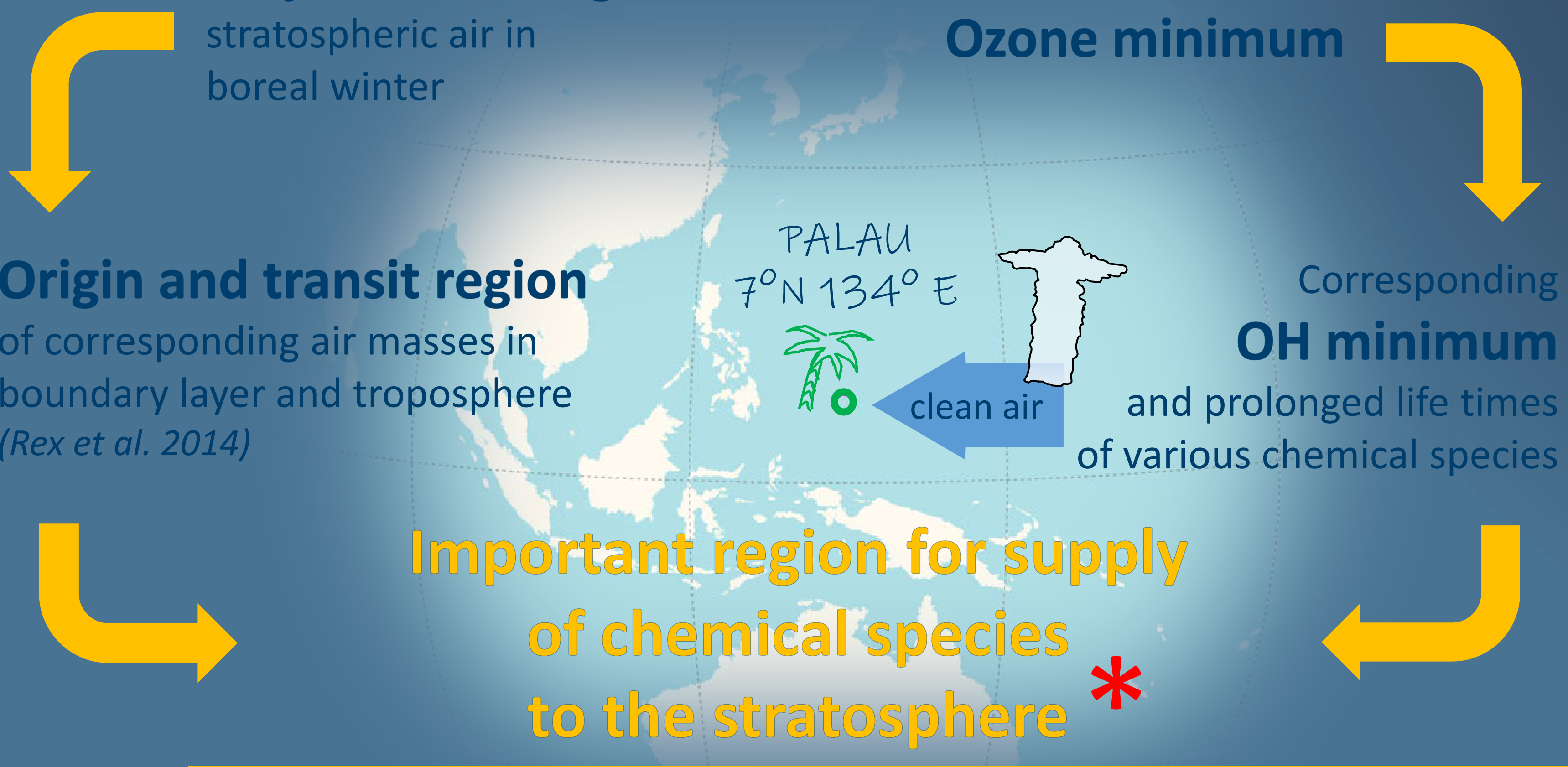
StratoClim
This project is funded by the EU
AWI
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

NAVIGATION

Main Menu (X) Chapters */ More Info /Back

(I) Motivation

Why the Tropical West Pacific (TWP)?



Major source region for stratospheric air in boreal winter

Persistent tropospheric **Ozone minimum**

Origin and transit region of corresponding air masses in boundary layer and troposphere *(Rex et al. 2014)*

Corresponding **OH minimum** and prolonged life times of various chemical species

Important region for supply of chemical species to the stratosphere *

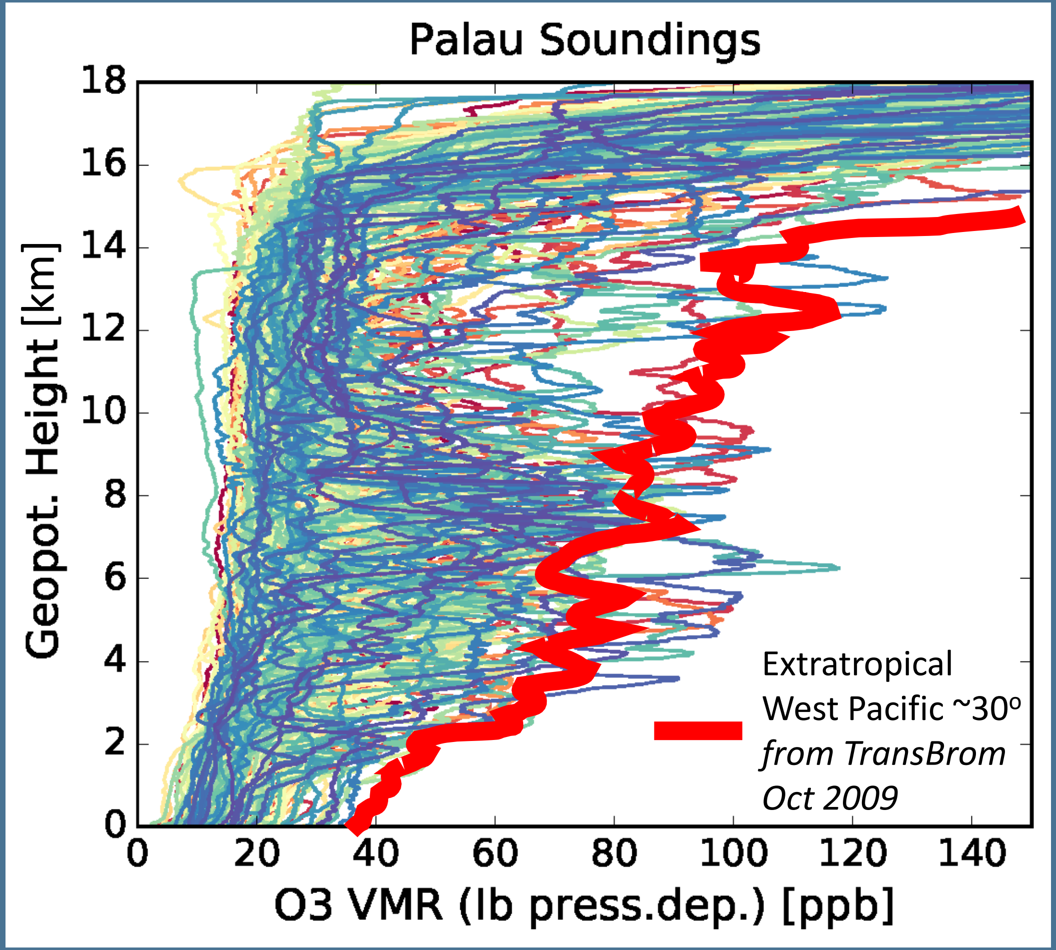
Need for monitoring of air composition and understanding of underlying processes and transport pathways to TWP

Key feature of the clean TWP troposphere: close coupling of the O_3 concentration and oxidizing capacity (OH), influencing overall transport of chemical species to the stratosphere.

To improve the limited availability of tropospheric O_3 observations from this key region, the **Palau Atmospheric Observatory** * was established in 2016 as part of the EU-project StratoClim.

(I) O_3 Dataset

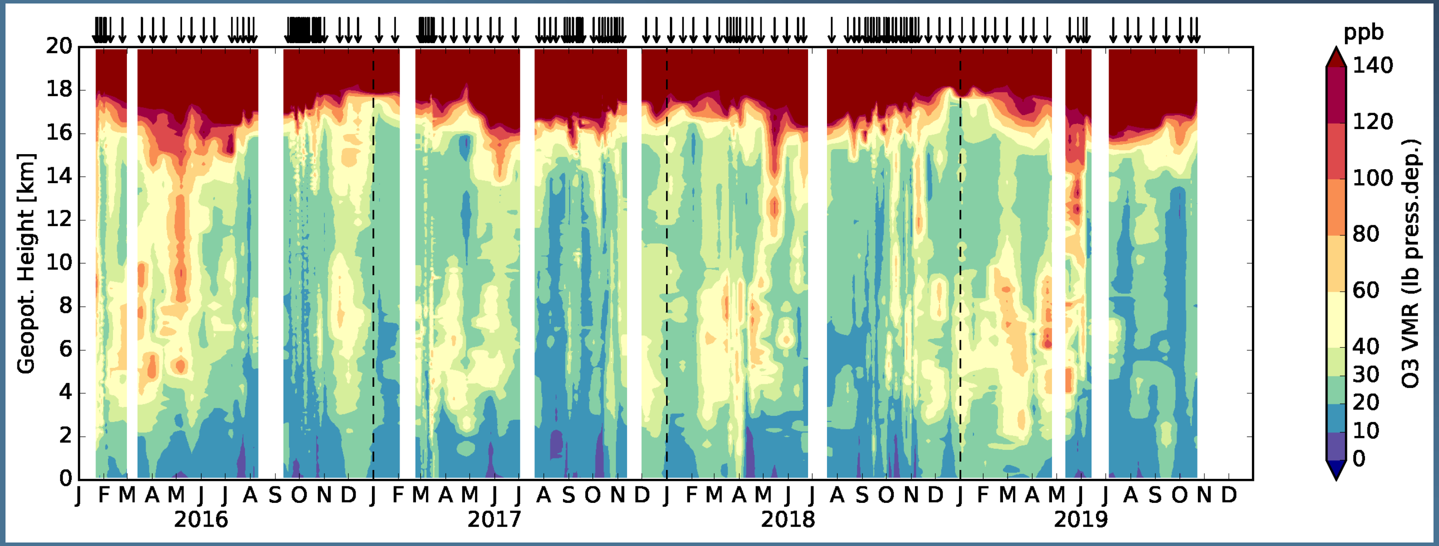
QUADRENNIAL
OZONE SYMPOSIUM



First characterization of tropospheric O_3 seasonality in the TWP with a multi-year continuous time series from ECC ozonesonde measurements every two weeks or in intensive campaigns (SPC 6A, Vaisala RS92/41). → Müller 2020

Special focus on quality issues of tropical soundings due to controversy around near-zero O_3 observations in the TWP *(e.g. Voemel and Diaz 2010, Rex et al. 2014, Thompson et al. 2019)*

Tropospheric profiles with altitude:
145 sondes, 01/2016-10/2019



Time-height-cross-section

(I) Why O_3? As a chemical tracer…

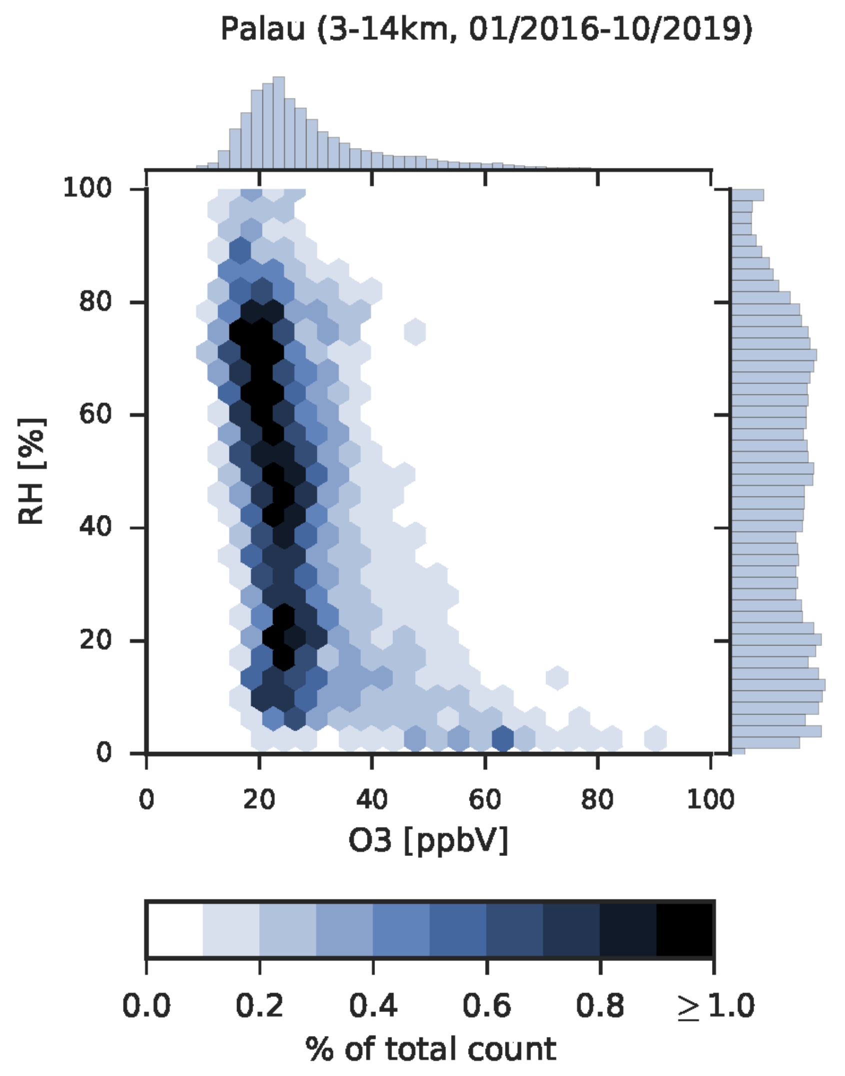
…for **local convective activity** in clean maritime air: **"low" O_3**
(*e.g. Folkins, 2002; Folkins et al., 1999; Kley et al., 1996; Paulik and Birner, 2012; Solomon et al., 2005*) and

… for **long range transport** processes to the region, either related to air pollution or stratospheric intrusions: **"high" O_3**
(*e.g. Andersen et al., 2016; Browell et al., 2001; Randel et al., 2016; Tao et al. 2018; Thouret et al., 2000; Pan et al. 2015*).

RH as a tracer for **vertical displacement**:
High humidity due to convection, dryness due to large scale descent
(*e.g. Hayashi et al., 2008; Andersen et al., 2016; Cau et al. , 2007; Dessler and Minschwaner, 2007*)

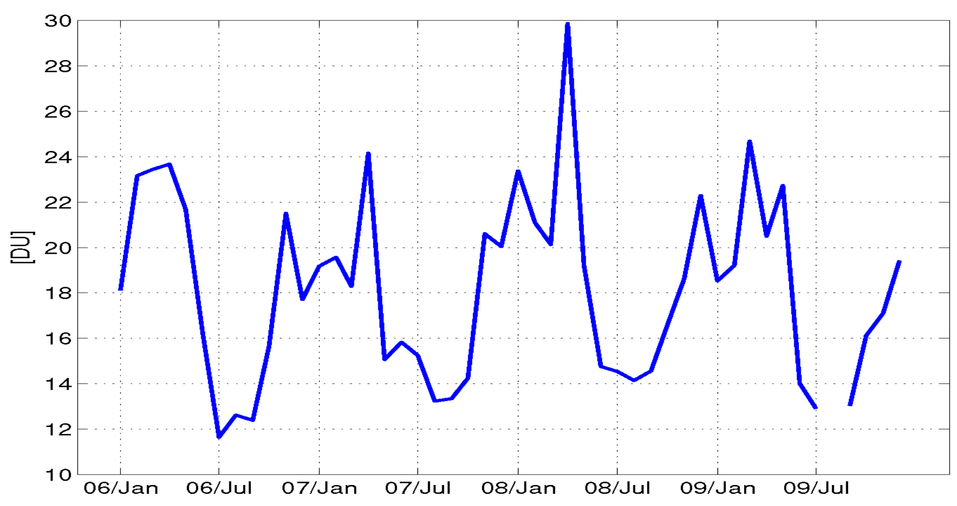
Central Question:
Can we identify air mass origin and its seasonality with the observed O_3/RH relation?

Free-tropospheric O_3/RH distribution

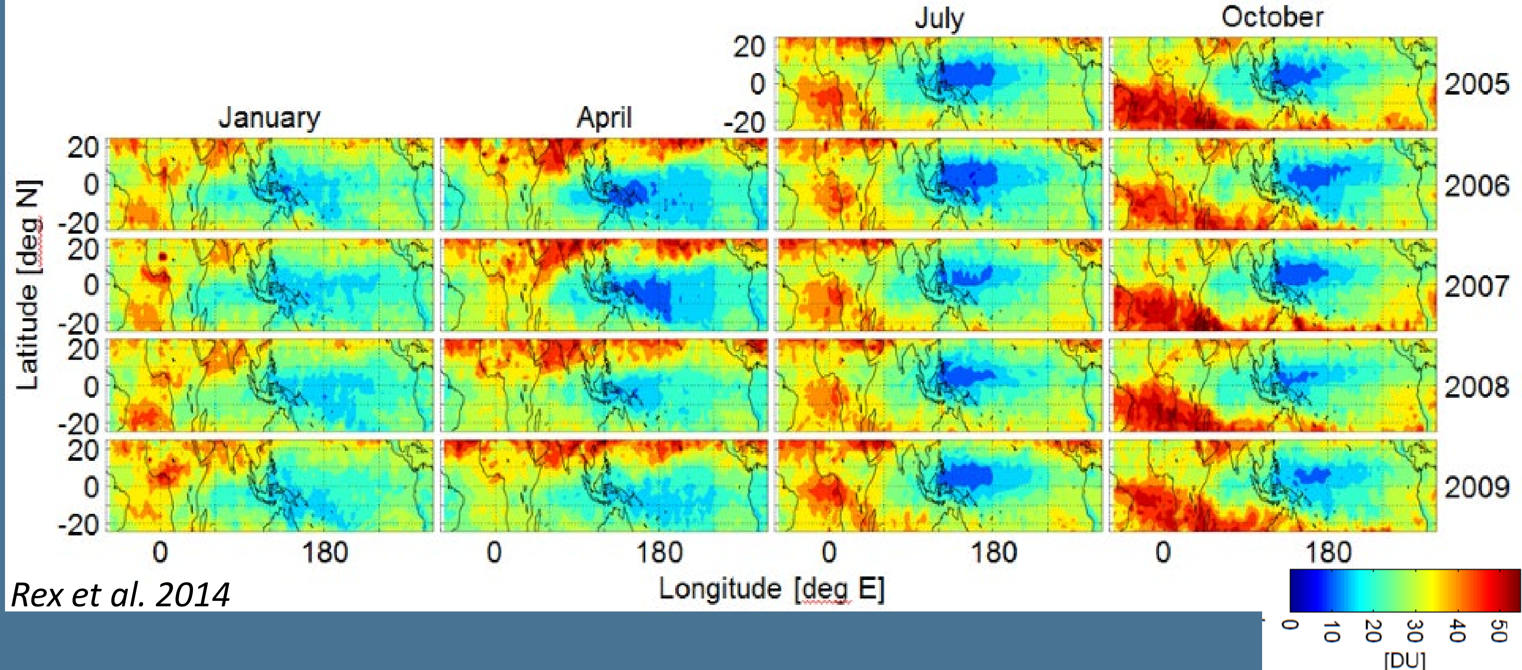


unique for Palau compared to stations of the tropical **SHADOZ ozonesonde network** *

(II) Tropospheric O_3 variability

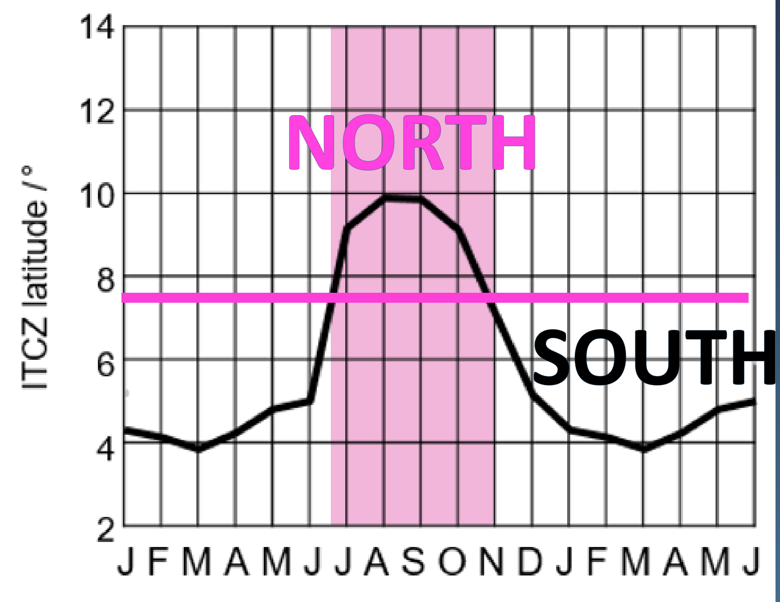


Tropospheric O_3 column from TES (on Aura Satellite)
◀ @ Palau
and in the tropics
▼



Rex et al. 2014

- **Seasonal drivers:** circulation (Walker, Hadley, West Pacific Monsoon, Brewer-Dobson)
→ modulated by Inter Tropical Convergence Zone (ITCZ)
- Hot, humid & wet climate all year: high convective activity
- **Important Variation:** ENSO



TRMM (1998-2009) average for 125-175° E, 0-20°N, adapted from *Shonk et al. 2018*

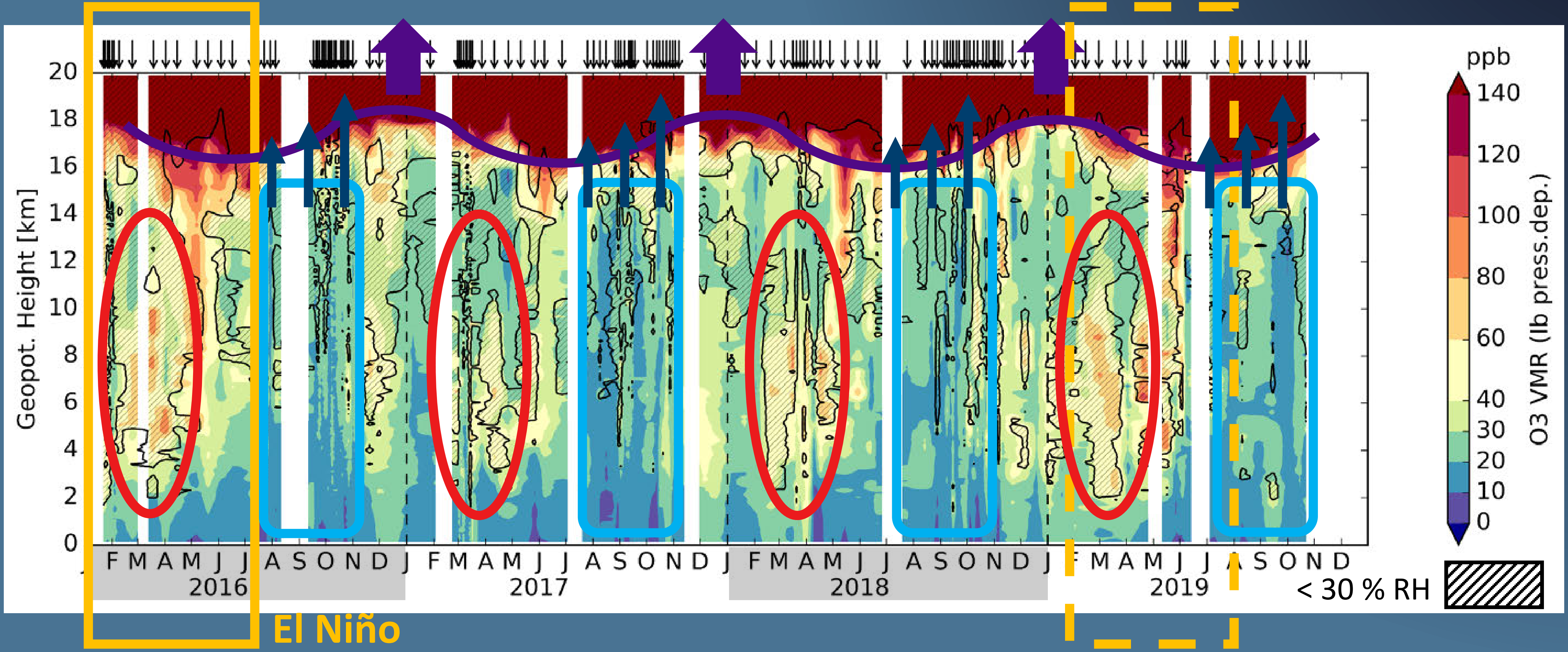
Movement of the ITCZ

(II) Tropospheric O_3 variability

Annual TTL cycle: Brewer Dobson circulation *

+ enhanced high altitude **convective outflow**

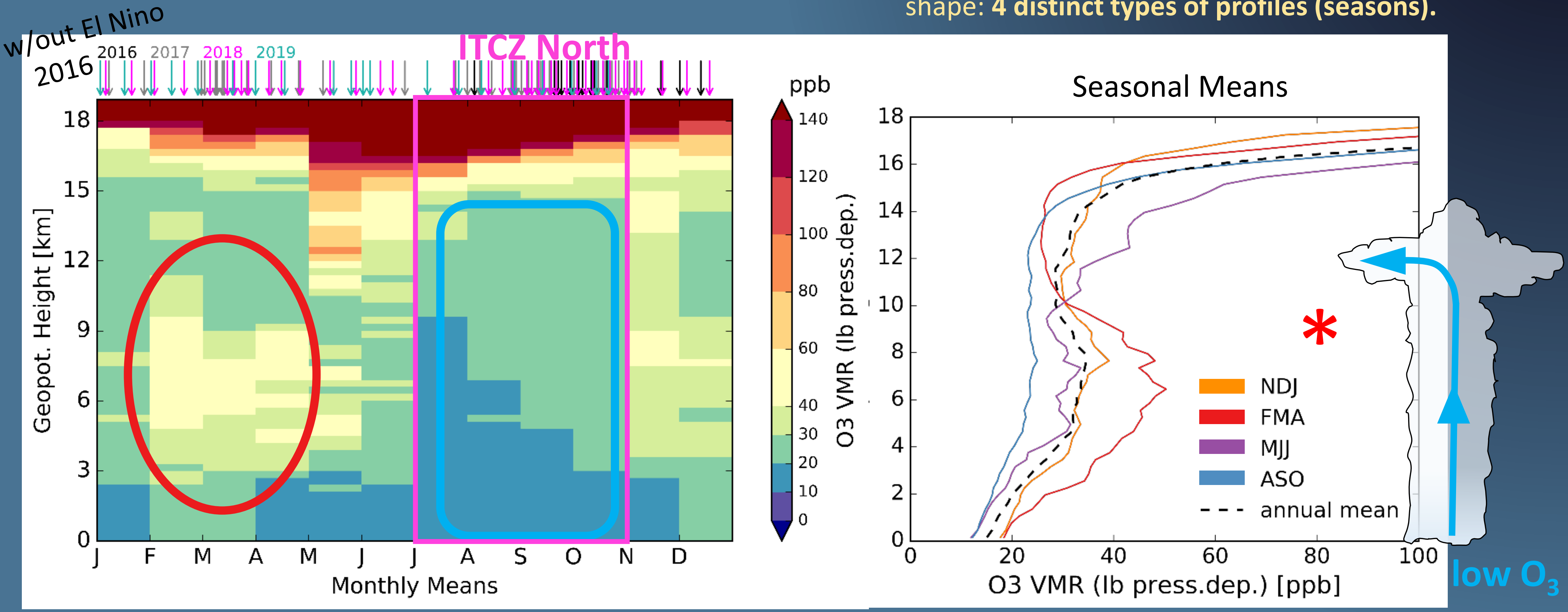
Onset of transport to the stratosphere and the **tropospheric O_3 minimum** occur simultaneously



Mid-troposphere: **O_3 minimum** from July-October, layers **of enhanced O_3** from February-April, often **anti-correlated with RH**

(II) Tropospheric O_3 variability

Annual mean: typical (tropical) „S-Shape“, monthly means grouped according to similar shape: **4 distinct types of profiles (seasons).**

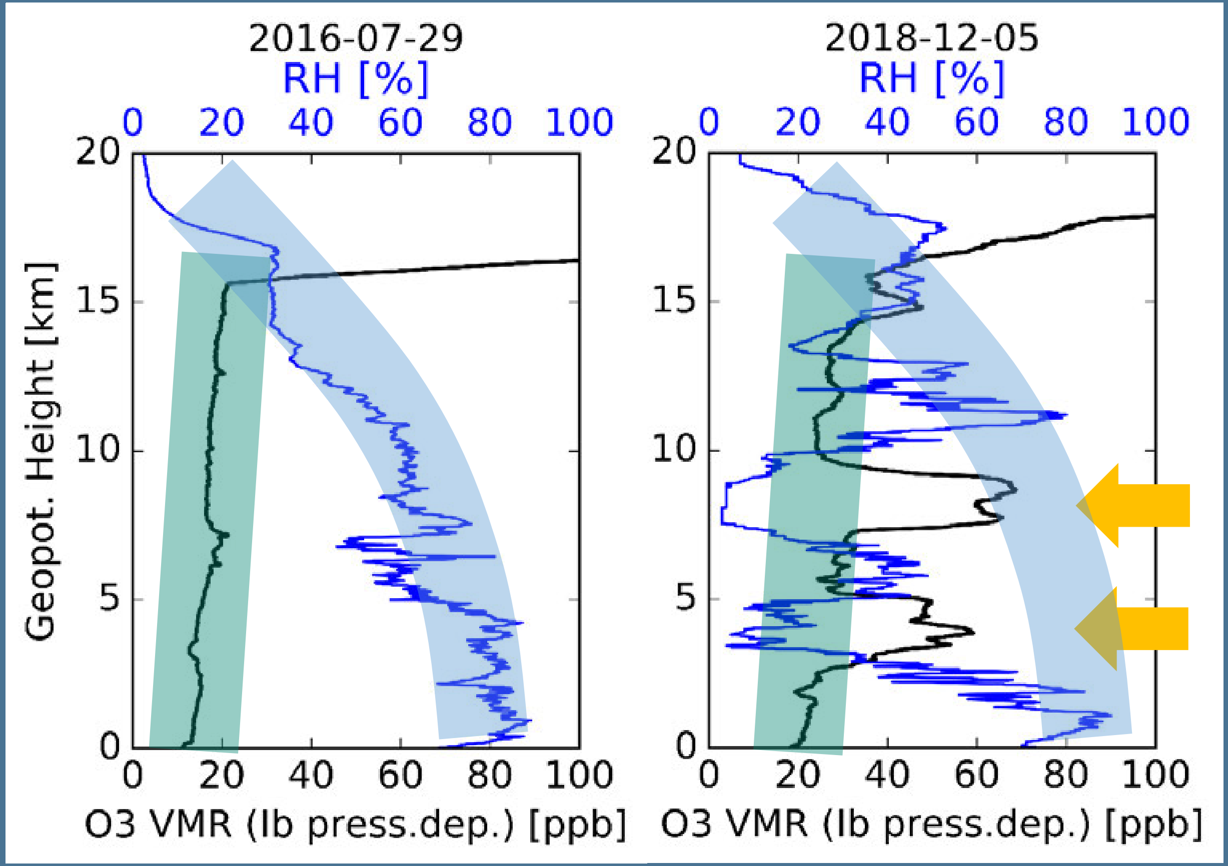


Monthly means highlight annual cycles, **O_3 minimum** corresponds with the **ITCZ located North** of Palau.

Deep convective detrainment can explain upper dent in the „S“ (10-14 km); between 5-10 km or the belly of the „S“: weak cloud-mass divergence, greatest anomalies from annual mean in ASO and FMA.

(III) Air mass definition

Example tropospheric O_3 and RH profiles



convectively controlled, well-mixed **background:**

LOCAL mode

interruptive layers, controlled by transport:

NON LOCAL mode

Underlying processes:

Local boundary layer air masses lacking pollution (→**low in O_3**) are lifted locally by convection (**humid**), creating a uniform profile.

LOCAL mode

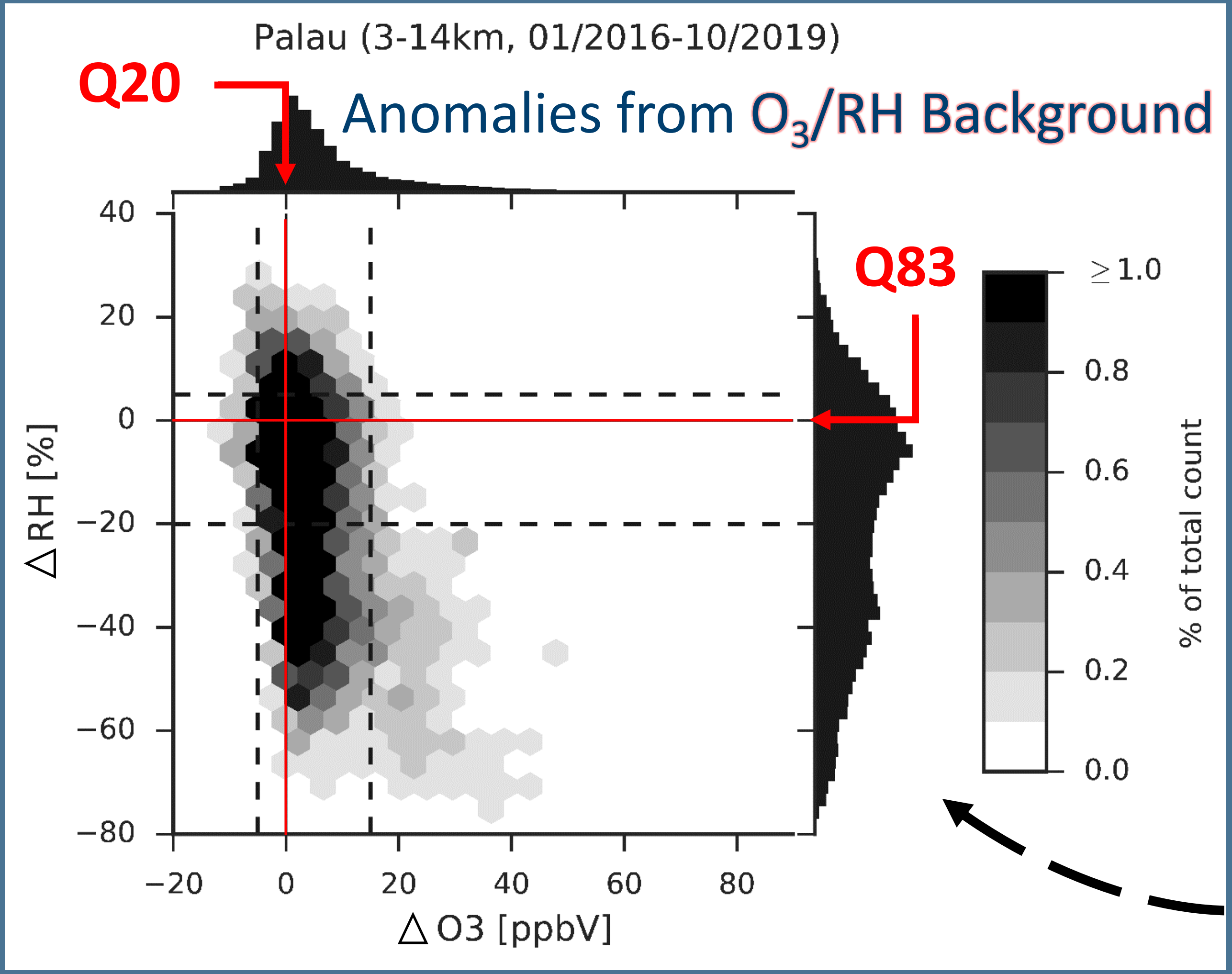
No known mechanism for in situ production of **high O_3** or **dehydration** in the mid-troposphere - origin either transport from the (extratropical) stratosphere or non-local ground pollution, lifted convectively in the area of origin then undergoing dehydration during transport, e.g. via large-scale descent and radiative cooling. (*compare Dessler and Minschwaner, 2007; Andersen et al., 2016*)

NON LOCAL mode

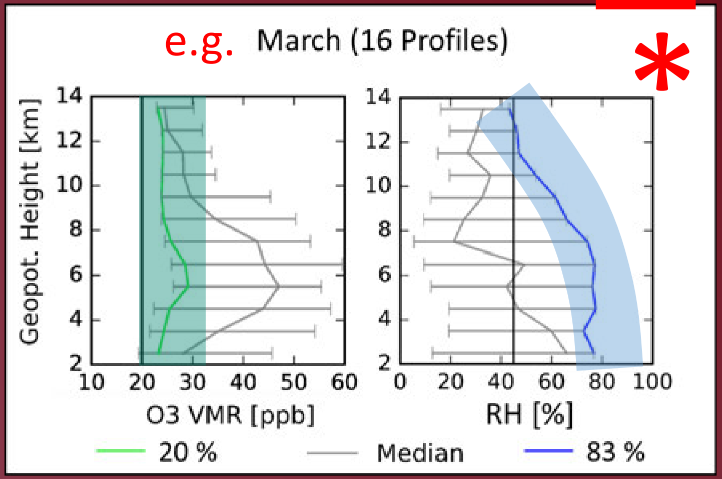
Layered structures and respective background are hidden in **the belly of the „S“** of mean profiles!

(III) Air mass definition

- First step: define **background profiles** for both tracers
- Second step: determine **anomalies** against this background

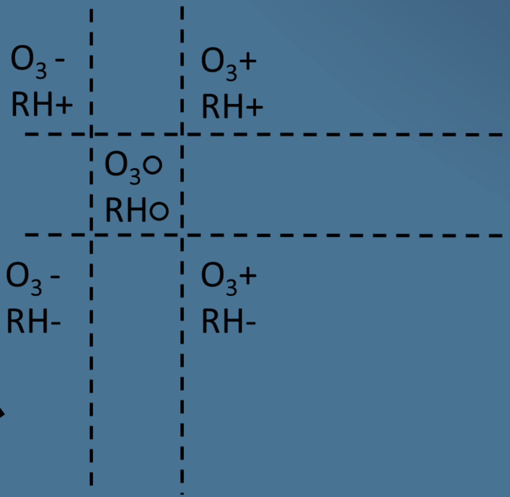


Background profiles:
the monthly 20th (O_3) and 83rd (RH) quantile,
Q20 and Q83
(altitude dependent)



- Third step: **bimodality in RH anomalies** motivates classification in O_3RH groups

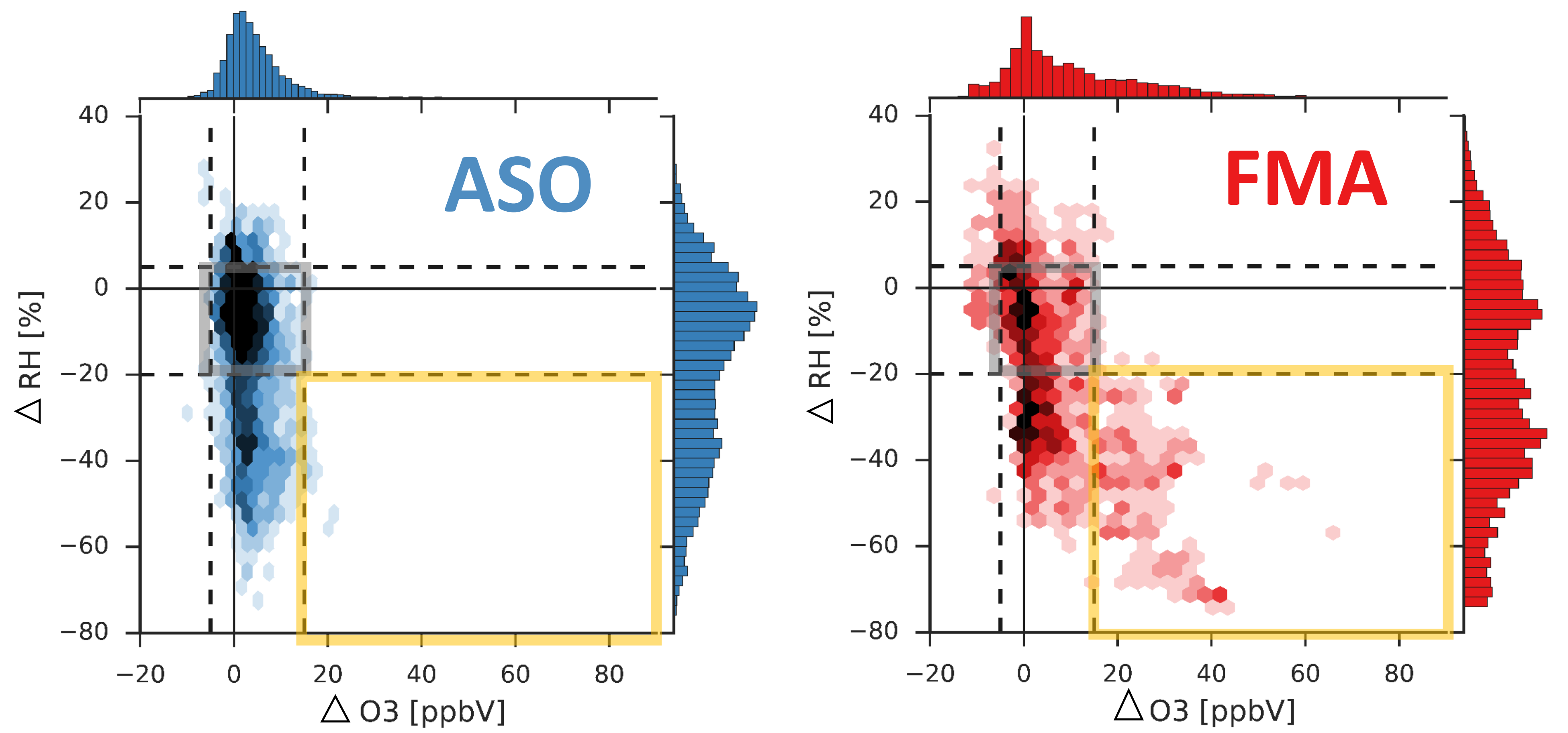
→ **air mass definition**



Classification in a 3x3 grid (dashed lines), with respect to the distributions,
focus in the following on **central background group** (O_3o RHo) and **dry O_3-rich anomaly** (O_3+RH-)

(III) Seasonal Air Mass Occurence

Anomalies from O_3/RH Background (3-14 km) per season



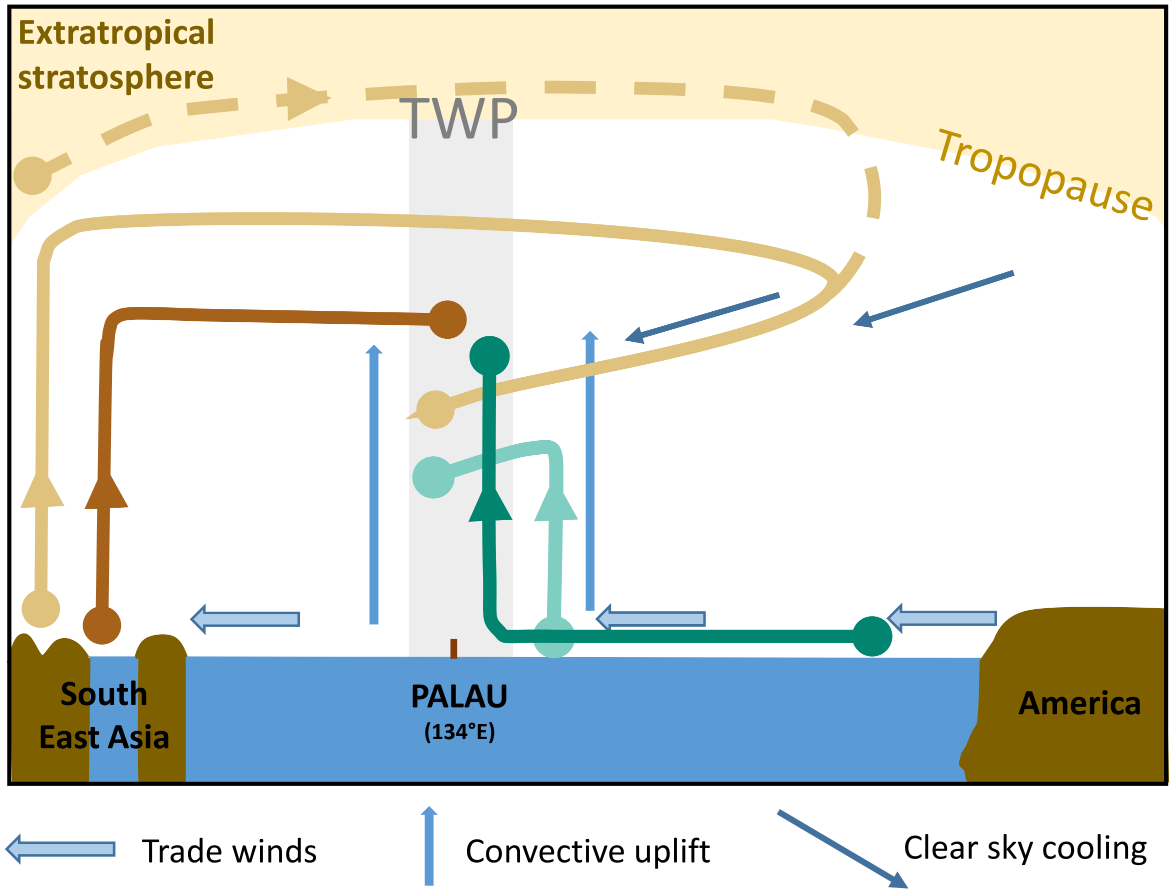
O_3oRHo:
humid, O_3-poor background, present year-round (!), but dominates **ASO**

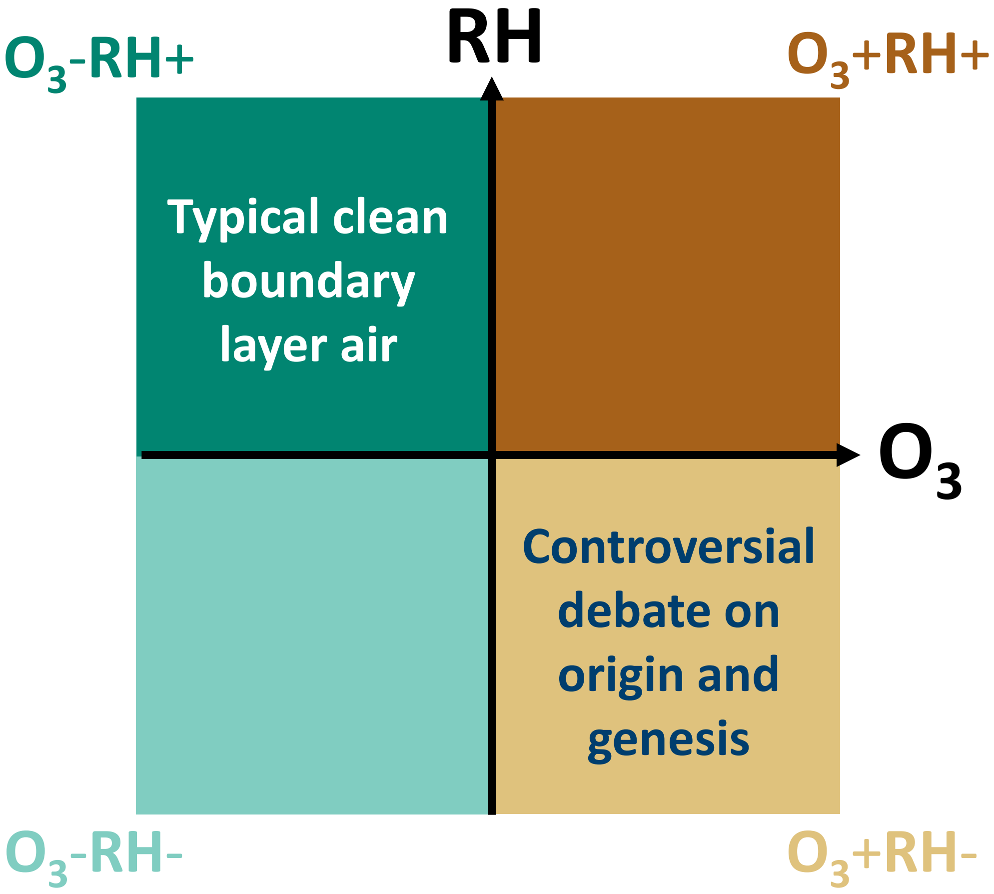
O_3+RH- :
dry, O_3-rich, most frequent in **FMA**

For more detailed statistics on all O3/RH anomaly groups, **click HERE** *

(IV) Transport Pathways and Processes

With our process understanding, we identified major transport pathways related to the O_3RH relation observed in Palau:





Typical clean boundary layer air

Controversial debate on origin and genesis

(IV) Backward Trajectories

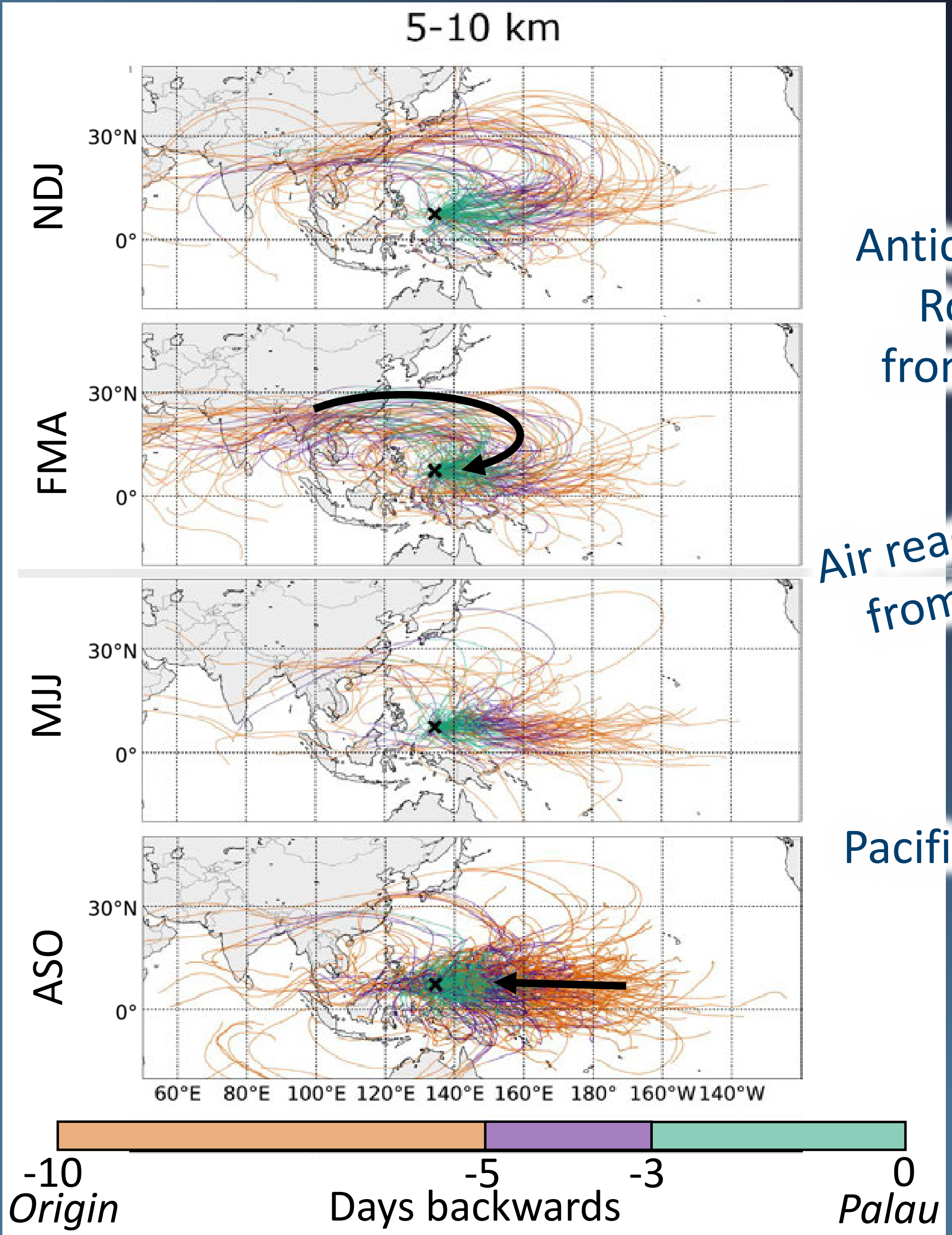
Transport module of Langrangian Chemistry and Transport Model ATLAS (Wohltmann et al. 2010)

Setup:

- driven by ERA5 reanalysis data, no diffusion, no convective model parameterization, 10-min time steps
- initialized from ozone sounding data, 01/2016-10/2019, 2-14 km, every 10th measurement
  → **focus on 5-10 km altitude range**

Assumptions:

- 10-day-backtrajectories for dynamical footprint
- Due to typical lifetime of marine boundary layer O_3: **5-day**-backtrajectory ending points = origin of air mass composition



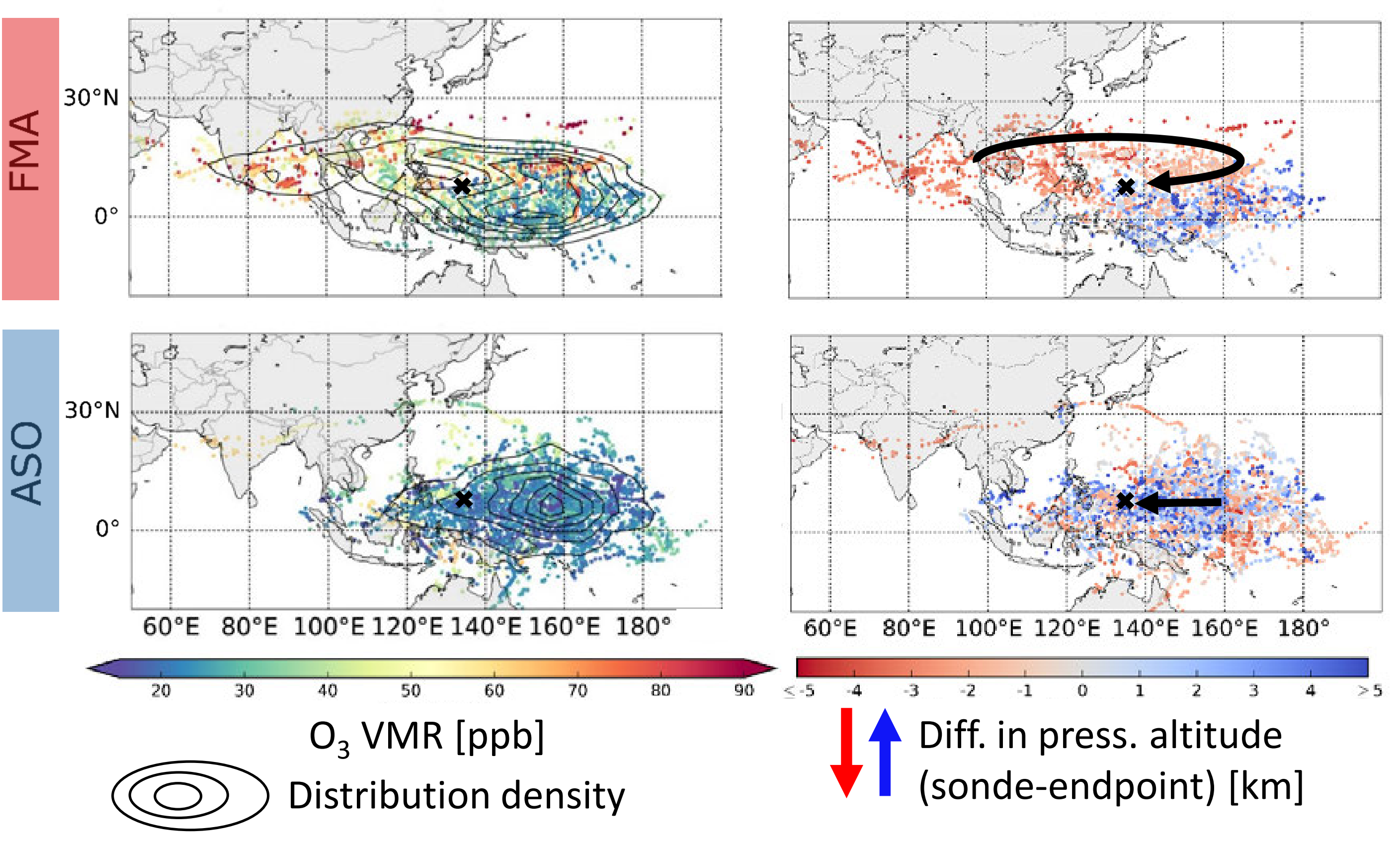
Anticyclonic Route from Asia

Air reaches Palau from the East

Pacific Origin

(IV) Origin of Air Masses

5-days-back trajectory ending points ≡ origin, trajectory start @ 5-10 km in Palau **x**



All Observations per season:

O_3 VMR distributions:

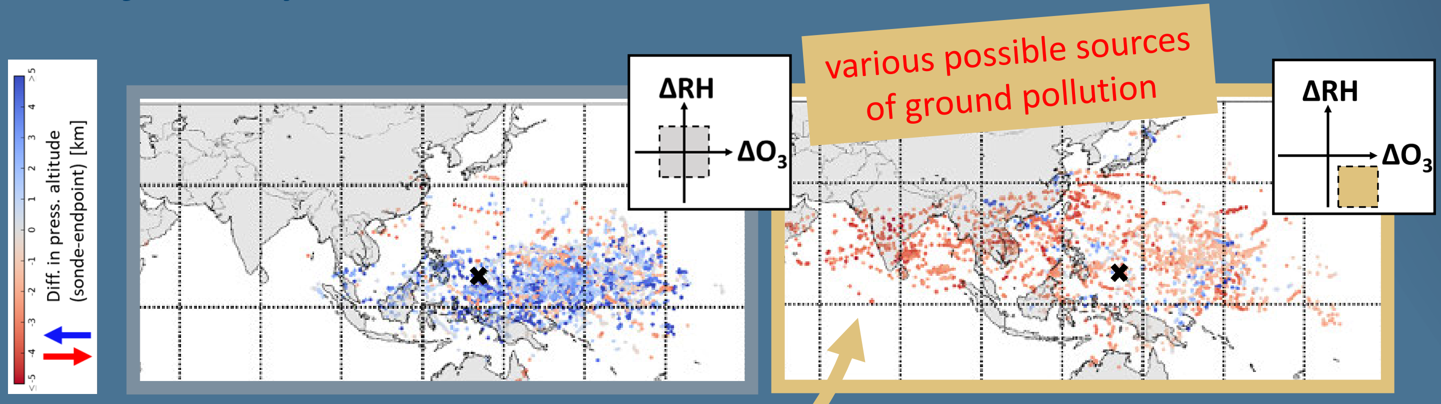
- Center of low O_3 in both seasons, FMA and ASO, East of Palau
- Secondary center of enhanced O_3 in FMA, North of Palau from India to East China

Vertical displacement:

- Mainly in FMA, North of Palau air masses **descend** towards Palau (**anti-cyclonic route**), consistent with large-scale descent within the Hadley circulation and subsequent dehydration
- **Ascent** dominates ASO air masses (**Pacific origin**), corresponding well with the dominance of convective uplift

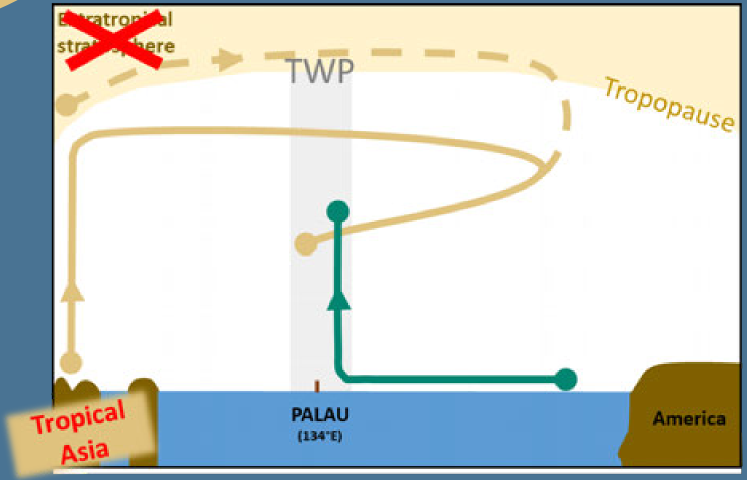
(IV) Origin of Air Masses

5-days-back trajectory ending points ≡ origin,
trajectory start @ 5-10 km in Palau **x**



various possible sources of ground pollution

Origin of **dry O_3-rich air** masses in areas of increased air pollution on the ground from industry or bio mass burning, speaking in favor for **a pollution based origin**



All Observations per O_3/RH group* :

Selection of trajectories for air masses identified as humid, O_3-poor background (O_3○ RH○) or **dry O_3-rich (O_3+RH-)** anomaly from the background separates air masses according to the processes controlling RH (Convective uplift, ASO; dehydration during descent, FMA) and locates spatially separate source regions

No indication for significant contribution of **stratospheric air:**

Potential Vorticitiy analysis for all trajectories (from 4 years, 138 profiles, 5-10 km) revealed essentially **no air mass crossing the 1.5 PVU threshold** for more than a day during 10 days backwards.

(V) Take home messages

- ✓ **Palau's four-year tropospheric O_3 time series** fills the observational gap in this key region of stratospheric entry.
- ✓ Using the ECC O_3 sounding data set (01/2016-10/1019), seasonal analysis, trajectory modelling and a statistical approach to distinguish air masses by O_3/RH relation, we **identified transport processes and pathways to the TWP:**

	Humid, O_3-poor	**Dry, O_3-rich**
Processes	Convective background	Large scale descent, pollution
Origin	Pacific or local	Tropical Asia (anticyclonic route)
Frequency	Year-round, dominates Aug-Oct	Most frequent in Feb-Apr

- ✓ **Watch out** for the upcoming publications!

References

Katrin Müller, 2020: Characterization of Ozone and the Oxidizing Capacity of the Tropical West Pacific Troposphere, **PhD thesis**, https://doi.org/10.26092/elib/463.

WATCH OUT: two papers to be submitted this fall:

K. Müller, Ingo Wohltmann, Peter von der Gathen and Markus Rex (*2021*): Air Mass Transport to the Tropical West Pacific Troposphere inferred from Ozone and Relative Humidity Balloon Observations above Palau, in prep.

K. Müller, Jordis Tradowsky, Christoph Ritter, Justus Notholt, Ingo Beninga, Wilfried Ruhe, Winfried Markert, Juergen Graeser, Sharon Patris and Markus Rex (*2021*): The Palau Atmospheric Observatory – continuous monitoring of tropospheric composition in the Tropical West Pacific, in prep.

This presentation is based on an two earlier conference presentations:

K. Müller. et al. (2020): AGU presentation, Origin of Tropospheric Air Masses in the Tropical West Pacific identified by Balloon-borne Ozone and Water Vapor Measurements from Palau, https://doi.org/10.1002/essoar.10505805.1

K. Müller. et al. (2021): EGU presentation, Origin of Tropospheric Air Masses in the Tropical West Pacific identified by Balloon-borne Ozone and Water Vapor Measurements from Palau

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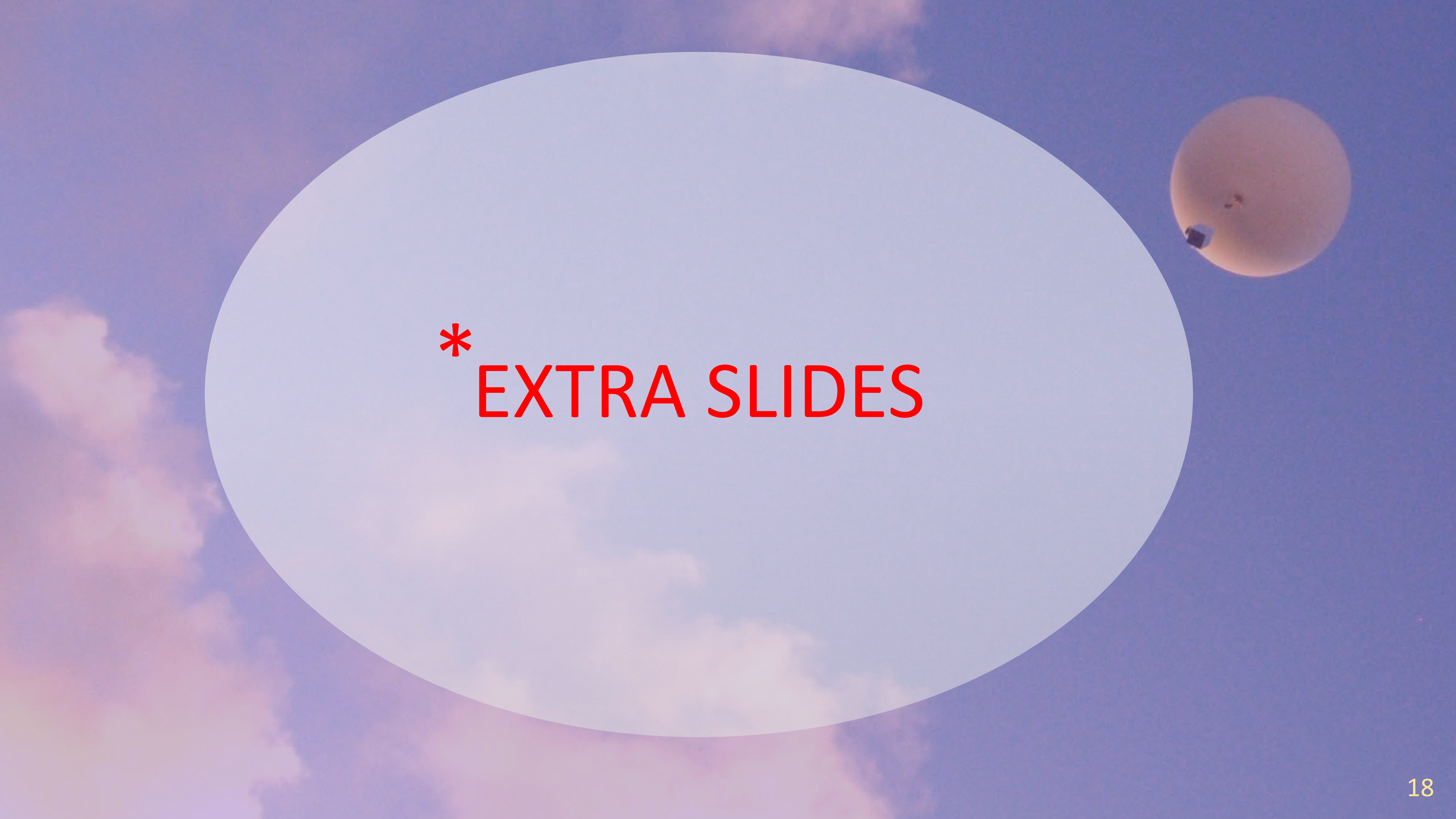
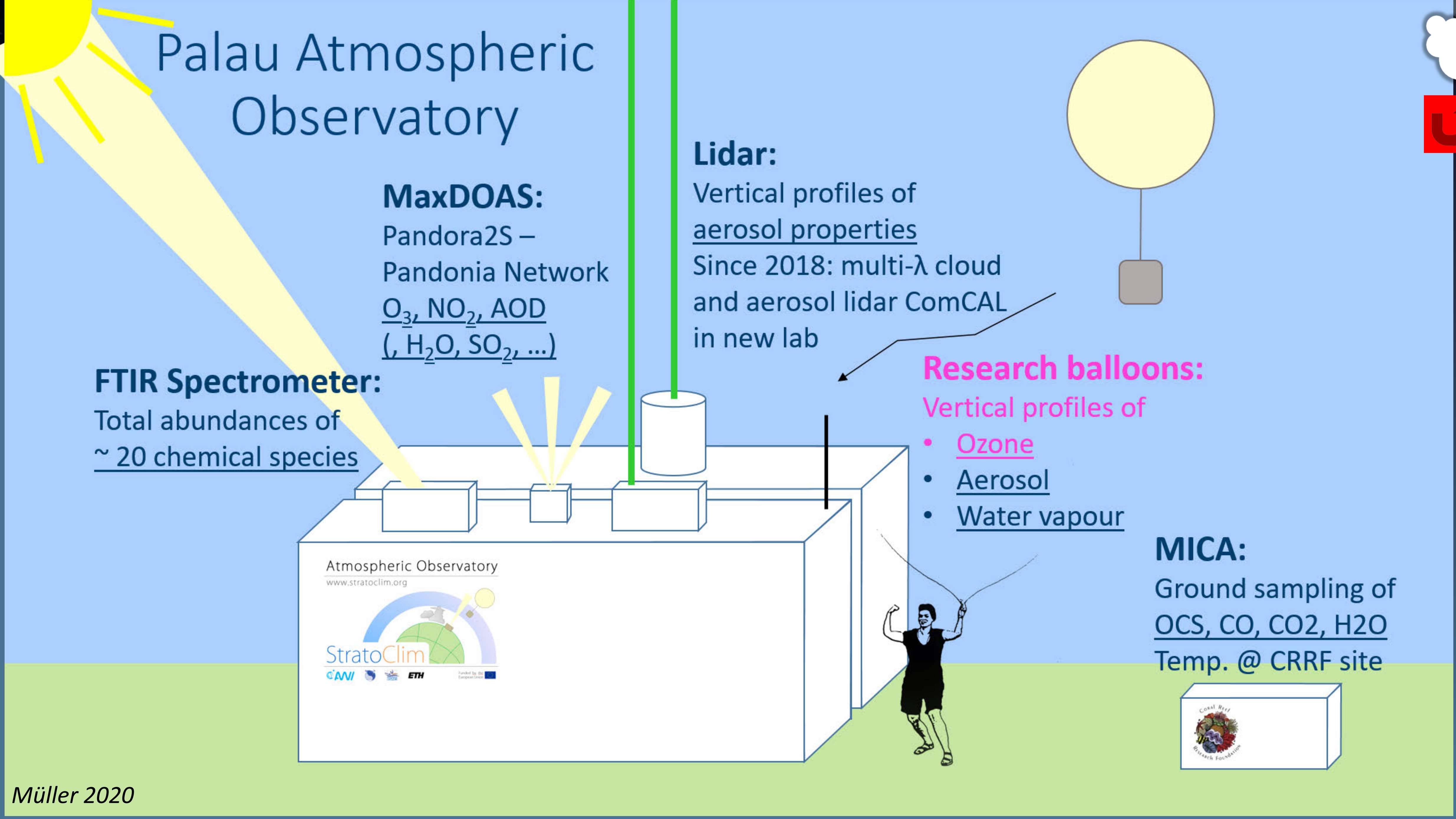


*EXTRA SLIDES

Palau Atmospheric Observatory



MaxDOAS:
Pandora2S –
Pandonia Network
O_3, NO_2, AOD
(, H_2O, SO_2, …)

FTIR Spectrometer:
Total abundances of
~ 20 chemical species

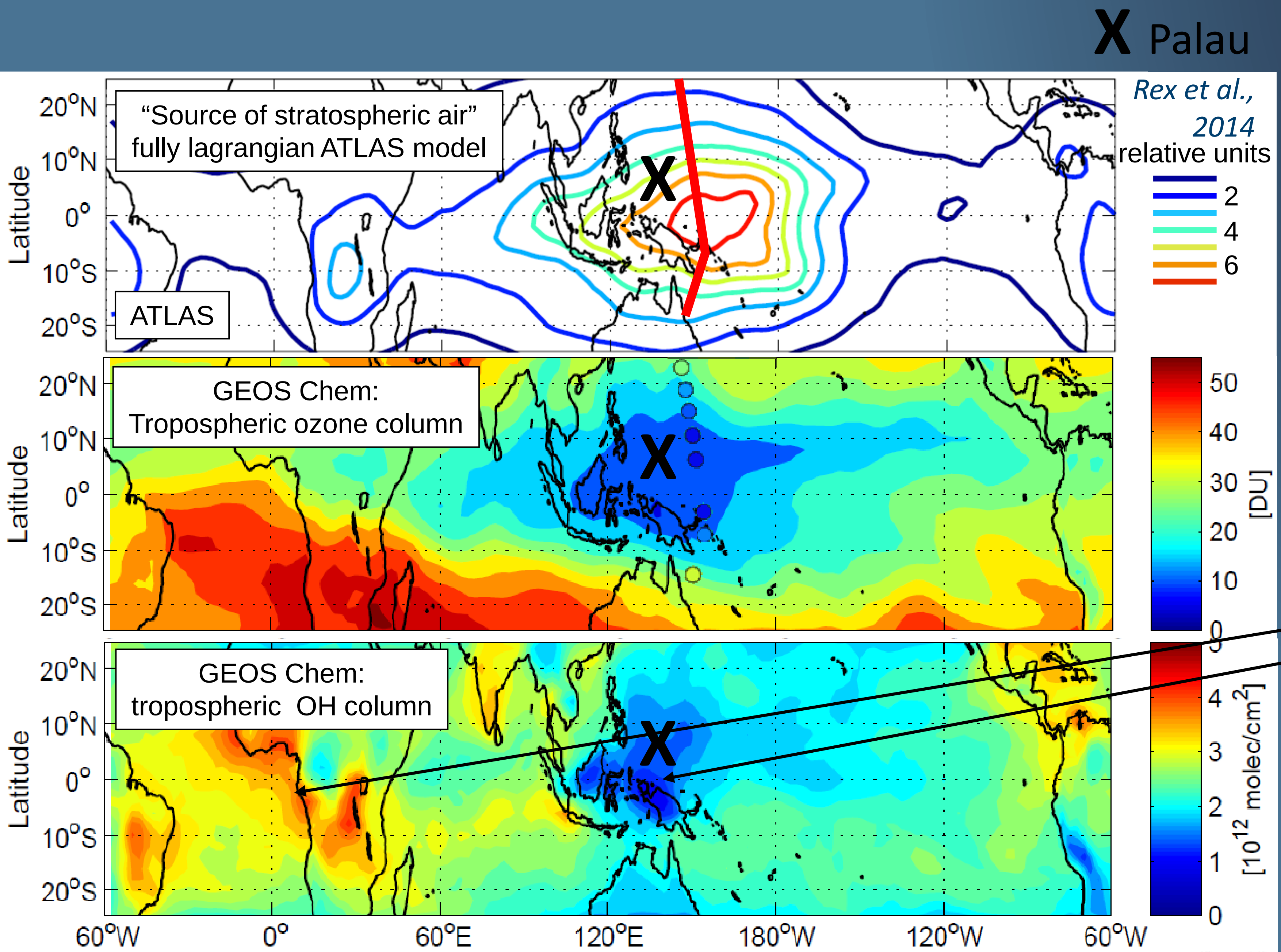
Lidar:
Vertical profiles of
aerosol properties
Since 2018: multi-λ cloud
and aerosol lidar ComCAL
in new lab

Research balloons:
Vertical profiles of
- Ozone
- Aerosol
- Water vapour

MICA:
Ground sampling of
OCS, CO, CO2, H2O
Temp. @ CRRF site

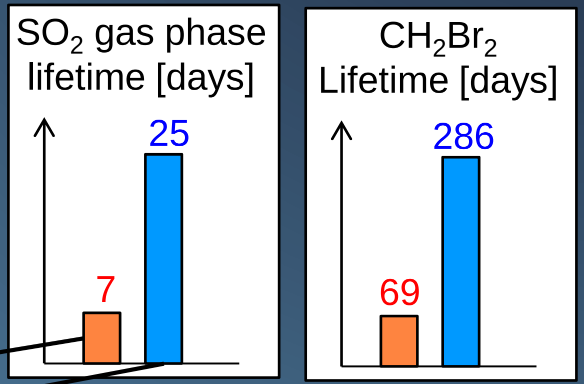
Müller 2020

(I) Motivation - TransBrom



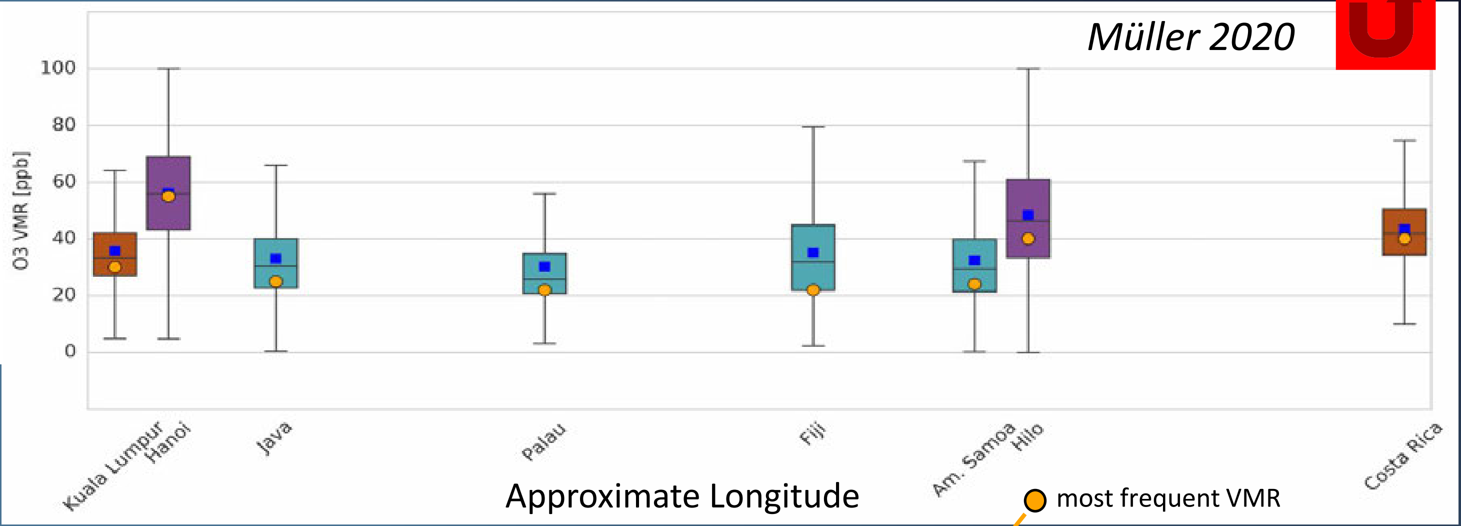
Rex et al., 2014

Density distribution function of the horizontal positions of the trajectories between boundary layer and Lagrangian Cold Points; **red thick line:** TransBrom Cruise 2009; filled circles: from ozonesonde measurements

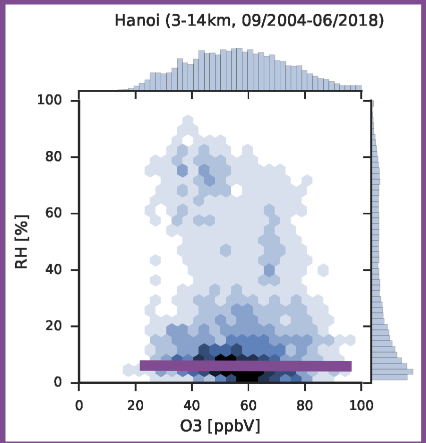


Lifetime comparison for tropical Atlantic and West Pacific (values for mid-troposphere- 500 hPa at the equator for typical conditions)

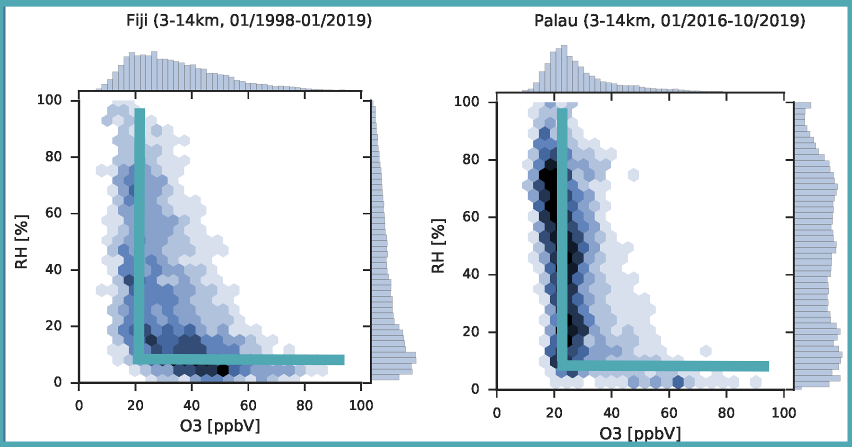
(I) O_3/RH Comparison with SHADOZ



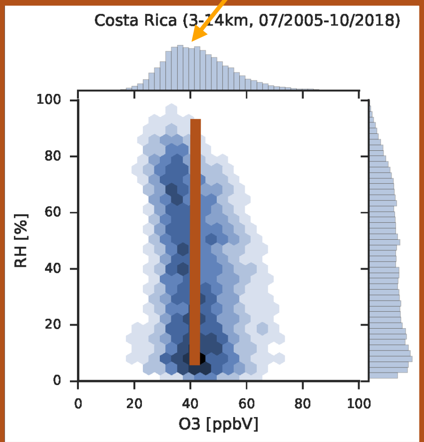
Analyses of 7 selected SHADOZ stations reveals **3 types of free-tropospheric O_3/RH distributions** (see Müller 2020). Seasonal distributions (not shown here) highlight uniqueness of Palau



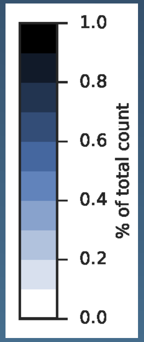
Predominantly dry air over a wider range of O_3 VMR



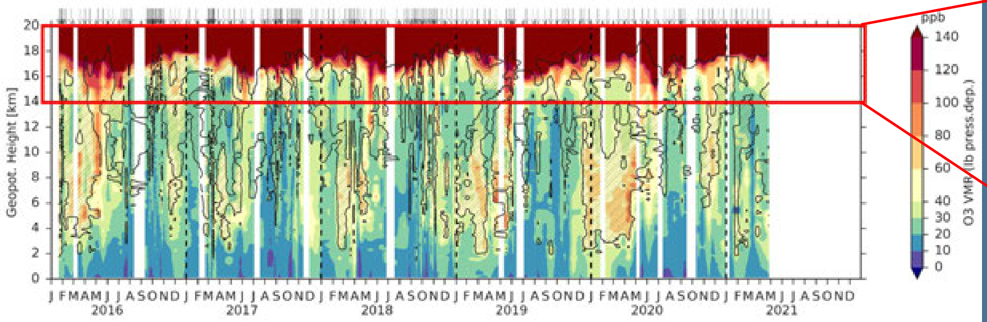
„L"-shaped: low O_3 over whole RH range + tail towards higher O_3 corresponding to low RH



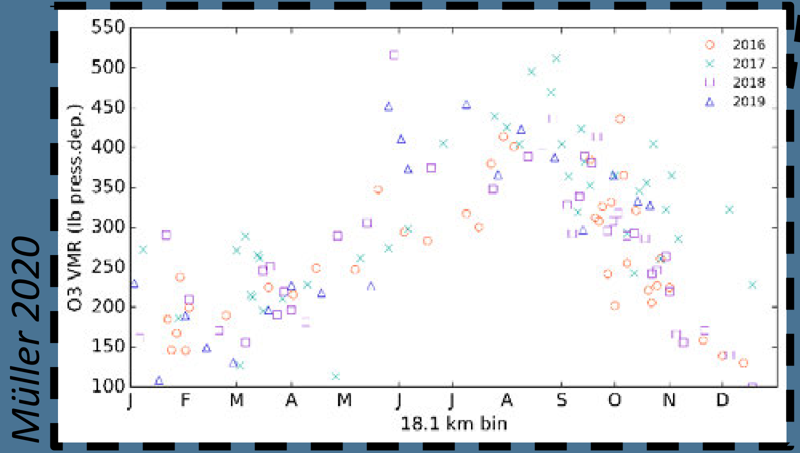
Gaussian distribution of O_3 + evenly distributed RH

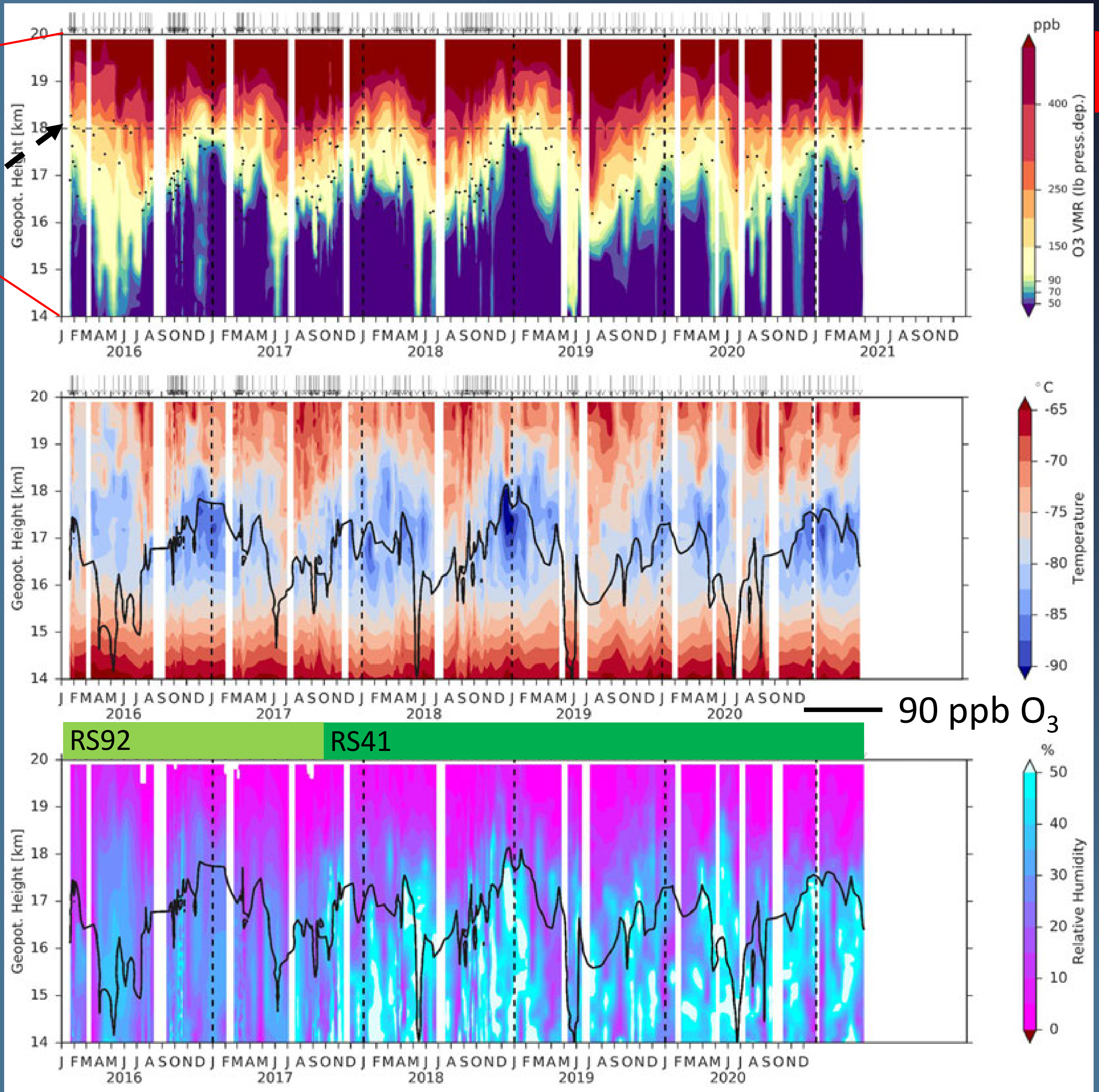


(II) TTL



300m Layer around 18.15km

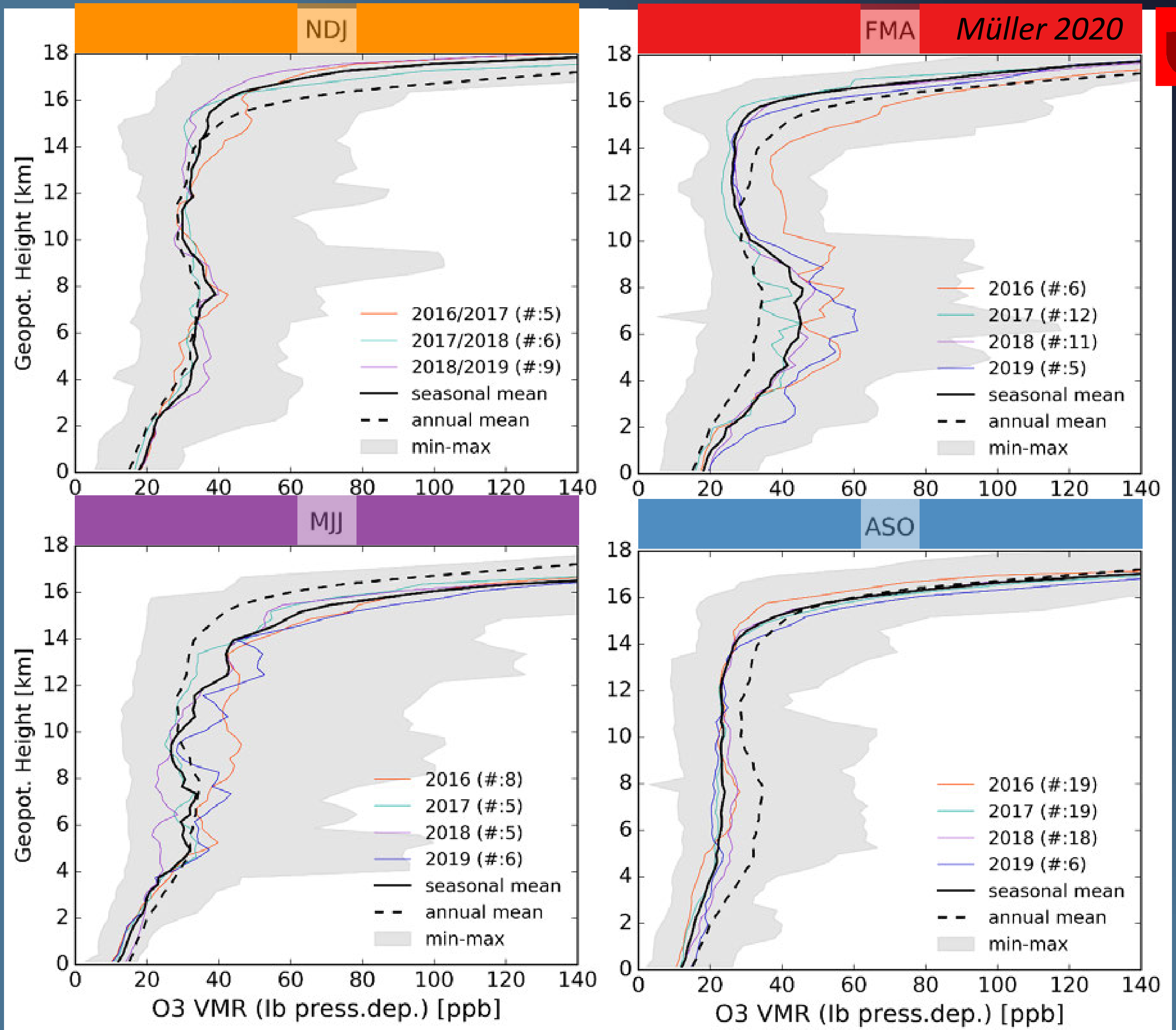




- Greatest amplitude of the TTL O_3 cycle occurs around 18 km
- Feedback during **El Nino 2016** in the UT: suppressed convection with less uplift of ozone-poor air from the ground or wash-out of O_3 precursors

(II) Seasons

- November-January: NDJ, February-April: FMA, …, chosen due to similar profile shapes
- Low O_3 (<25ppb) and enhanced mid-trop. O_3 (>50 ppb) observed in all seasons
- greatest anomalies from the annual mean: **FMA** & **ASO**
- Air masses deviating from a low O_3 background signal occur as **filaments or layers**, predominantly in the **5-10 km** layer, disguised in the averaged belly of the ‚S‘



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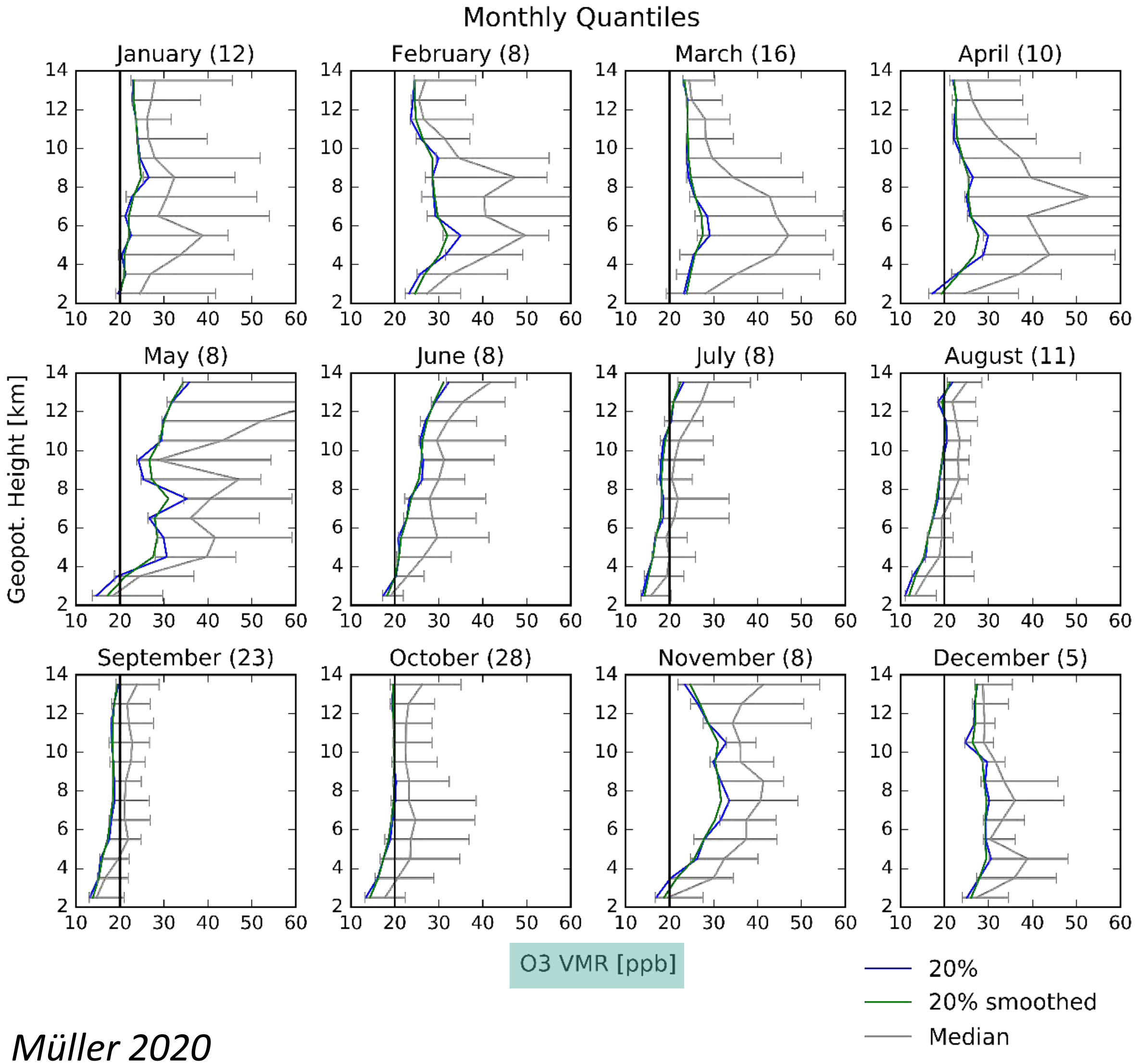
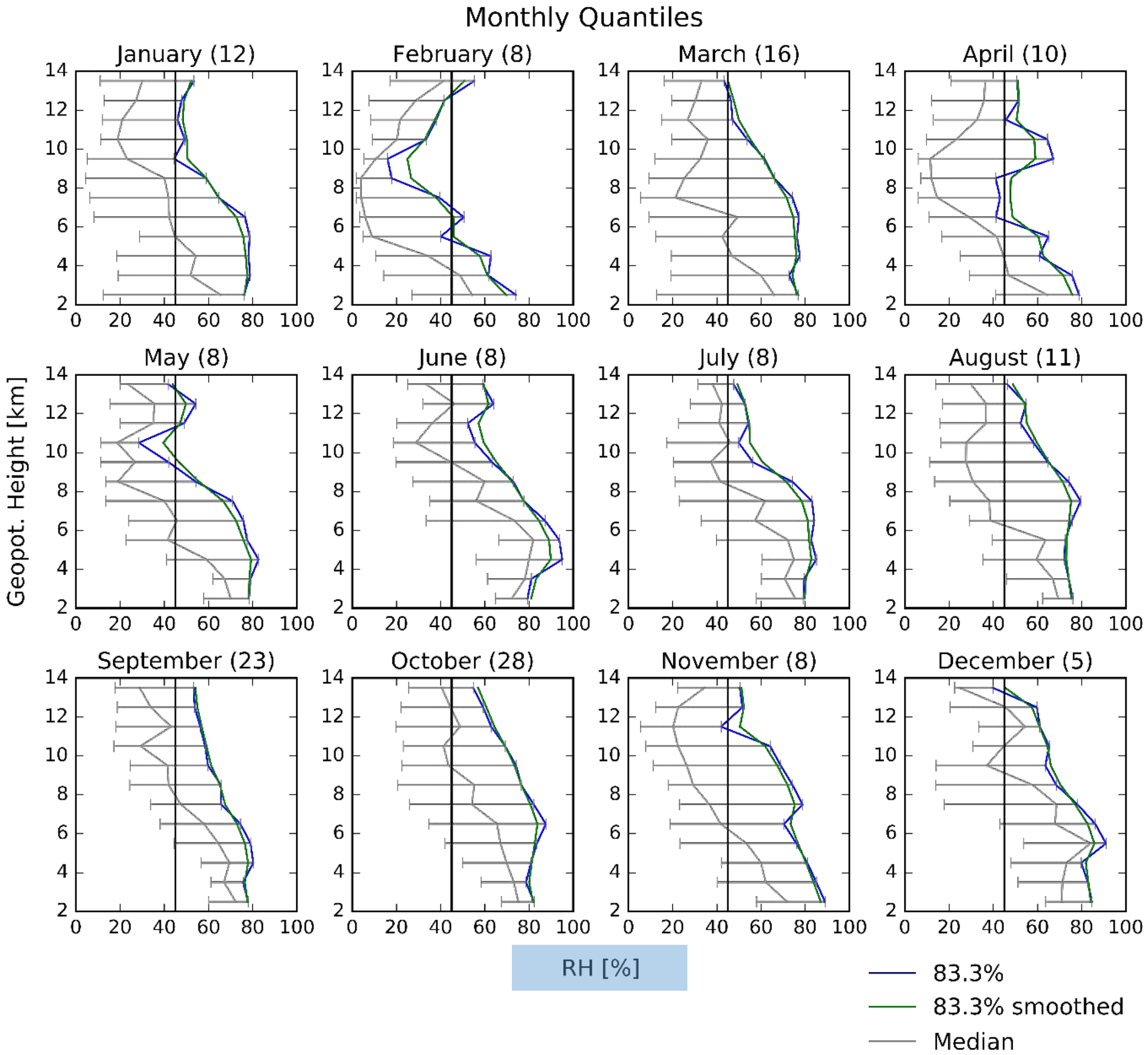
(III) Background Definition





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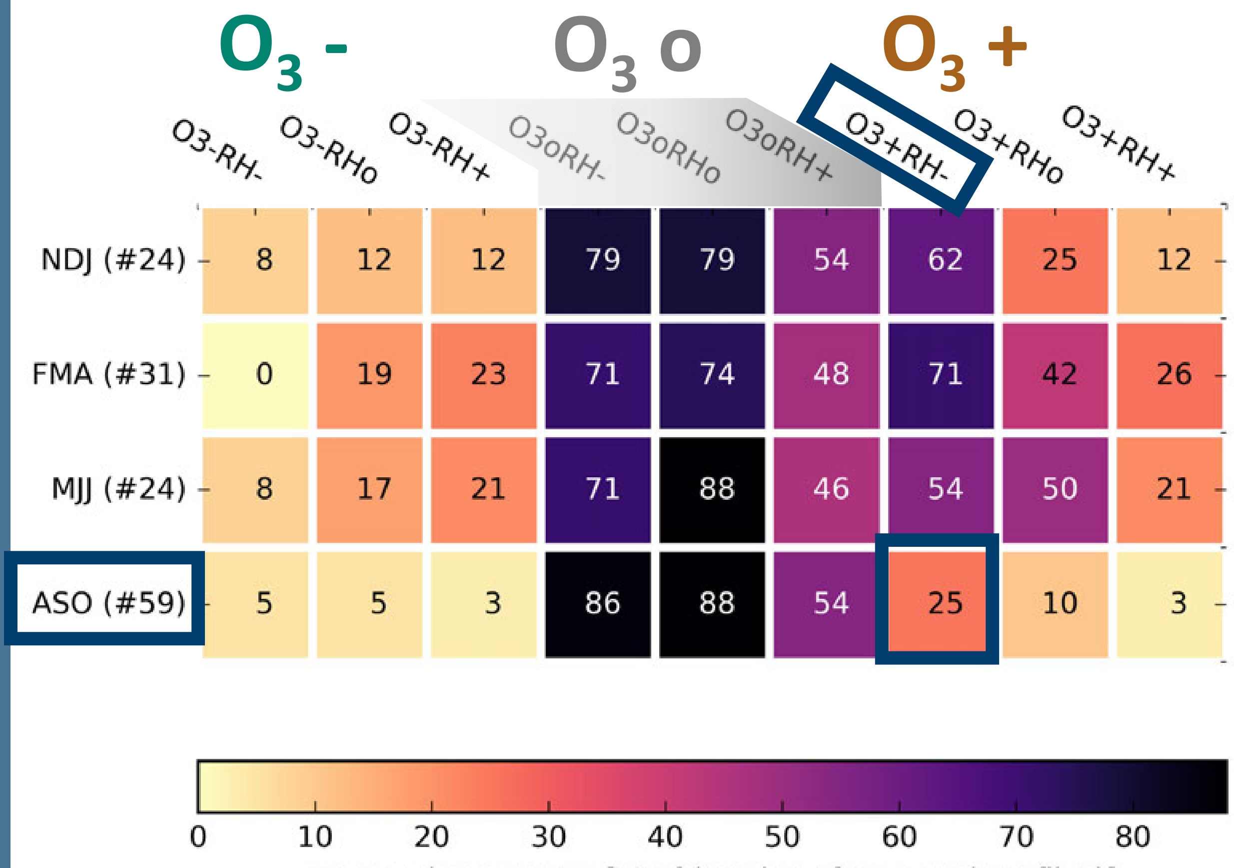
(III) Seasonal Occurrence of O_3/RH groups

Heatmaps for the seasonal occurrence of air masses for all nine anomaly groups, full time series, between **5-10 km** altitude



	O3-RH-	O3-RHo	O3-RH+	O3oRH-	O3oRHo	O3oRH+	O3+RH-	O3+RHo	O3+RH+
NDJ (#24)	8	12	12	79	79	54	62	25	12
FMA (#31)	0	19	23	71	74	48	71	42	26
MJJ (#24)	8	17	21	71	88	46	54	50	21
ASO (#59)	5	5	3	86	88	54	25	10	3

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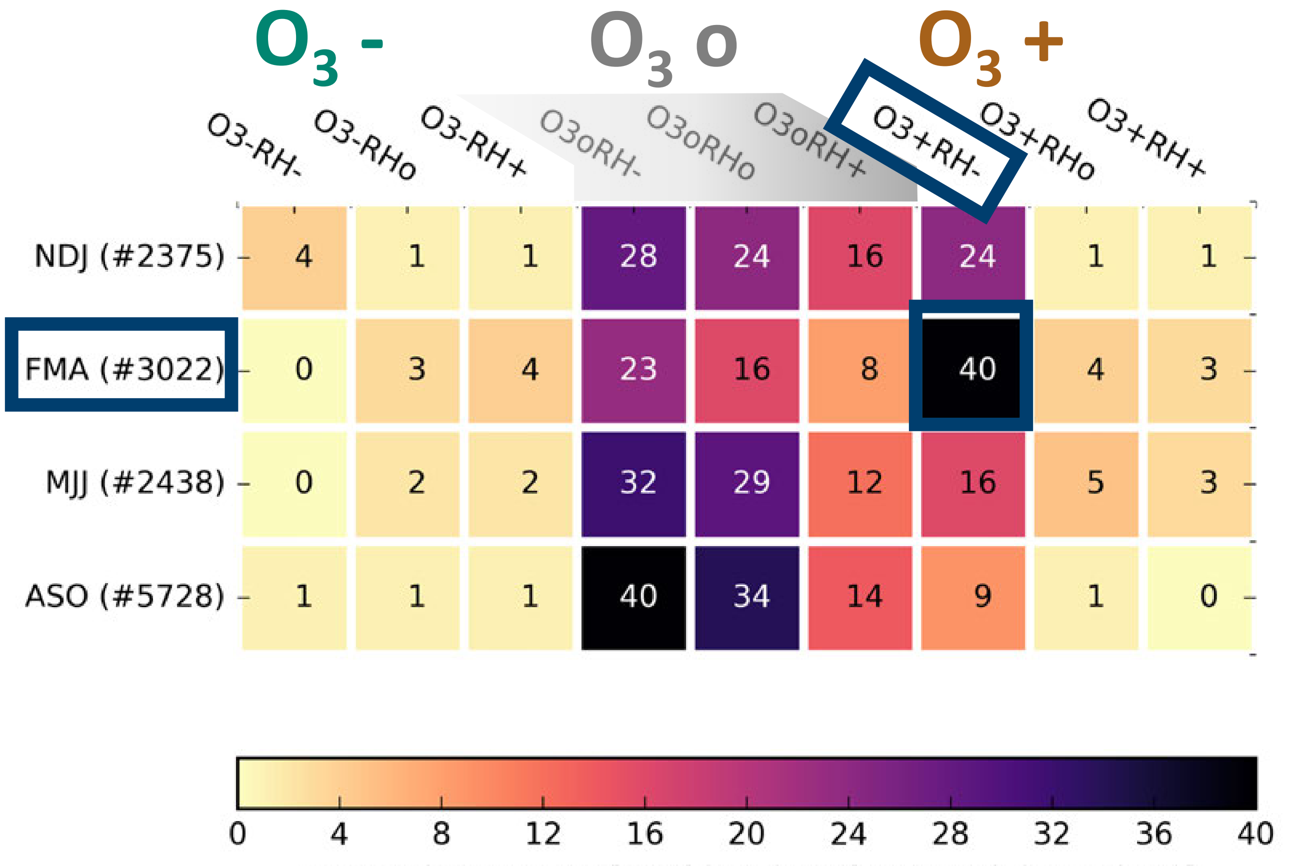
Example: O3+RH- air masses occur in 25% of all ASO profiles.



	O3-RH-	O3-RHo	O3-RH+	O3oRH-	O3oRHo	O3oRH+	O3+RH-	O3+RHo	O3+RH+
NDJ (#2375)	4	1	1	28	24	16	24	1	1
FMA (#3022)	0	3	4	23	16	8	40	4	3
MJJ (#2438)	0	2	2	32	29	12	16	5	3
ASO (#5728)	1	1	1	40	34	14	9	1	0

Example: O3+RH- air masses make up for 40% of all datapoints observed in FMA.