Global, regional and local analysis of water vapour measurements in the upper TTL during STRATÉOLE 2

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Context

Stratospheric water vapour has a non negligible impact on the global radiative budget and plays an important role in the chemical equilibrium of this layer. However, its decennial trends is not always understood and not always correlated with the tropopause temperature trend which is the first factor explaining its entry into the stratosphere. Water vapour is modulated by different processes at the equator through the TTL(tropopause tropical layer), principal gate for incoming air mass into the stratosphere. The relative impact of these processes are not well enough understood, mostly because the tropics are not enough sampled.

STRATÉOLE 2 is a CNES (France) and NFS (USA) funded project proposed by French and American laboratories gives the opportunity to gather a large amount of data in this region to make progress in the understanding of dynamical processes in the upper TTL. It is based on *in situ* observations of the equatorial lower stratosphere from stratospheric superpressure balloons. This program aims at studying composition, key dynamical and microphysical processes with their interplays in the lower stratosphere and the TTL (tropopause tropical layer).

In this poster, we study processes responsible for water vapour abundance/variation in the TTL just above the tropopause. We take advantage of the IR spectrometer Pico-SDLA Bi Gaz (H_2O + CO_2 or H_2O + CH_4) to study the impact of wave and deep convection in the modulation of water vapour with flights sampling different regions of the globe. Balloons are launched from the Seychelles during several campaign : one in 2019-20 (one flight of Pico-SDLA), and another one in 2021-22 (four flights of Pico-SDLA). A last field campaign will take place in 2025-26.

Flights and Instruments

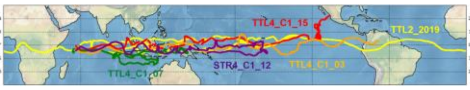

Fig. 1 : Balloon trajectories carrying Pico-SDLA Bi Gaz in the 2019-20 and 2021-22 STRATÉOLE 2 campaigns

← **Fig. 2 :** Pico-SDLA Bi Gaz under the ZEPHYR gondola in Seychelles in 2019

4 unitary spectra recorded every 4 to 12 mins

Over 400 000 *in situ* measurements in the TTL (H_2O, CH_4, CO_2)

Precision for H_2O: 130 ppbv

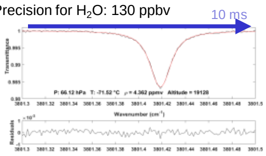

Fig. 3 : Unitary spectra of water vapour from Pico-SDLA at 19.1 km in the equatorial tropopause.

Methodology

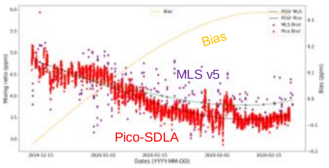

Fig. 4 : Comparison between Pico-SDLA nighttime series in 2019 (red scatters) and MLS v5 datas (purple scatters). Bias between Pico-SDLA and MLS is shown in orange together with their respective polynomials.

Unbiased MLS datasets to allow calculation of local anomalies

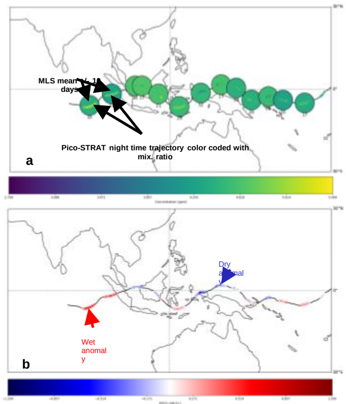

Fig. 5 : (b) Water vapour anomalies calculated between in-situ measurements and the selected local mean climatology from MLS v5 surimposed to the balloon trajectory (in black here, flight of 2019).

Water vapour anomalies are calculated between local Pico-SDLA in-situ measurements and a mean regional climatology (MLS v5 retrievals) to substract the contribution of the large-scale stratospheric circulation.

=> Highlight waves of periods shorter than 20 days

=> Highlight contribution of deep convection at local scale

Influence of atmospheric waves

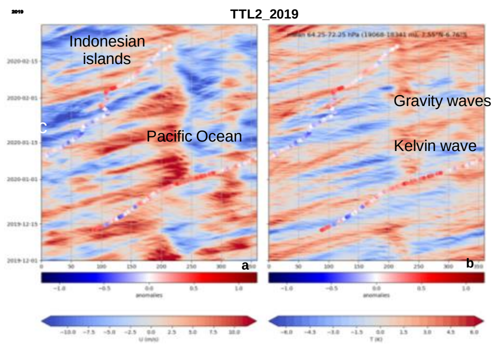

Fig. 6 : Hovmoeller diagram in zonal wind anomalies (a) and in temperature anomalies (b) with balloon trajectory surimposed and water vapour anomalies color coded.

Anomaly Analysis allows to quantify the local enhancement in water vapour due to a Kelvin wave over the Pacific ocean to be around 0.66 ppmv.

Over the Indian Ocean, the gravity wave leads to a drying of about 0.3 ppmv possibly due to a freezing/drying process.

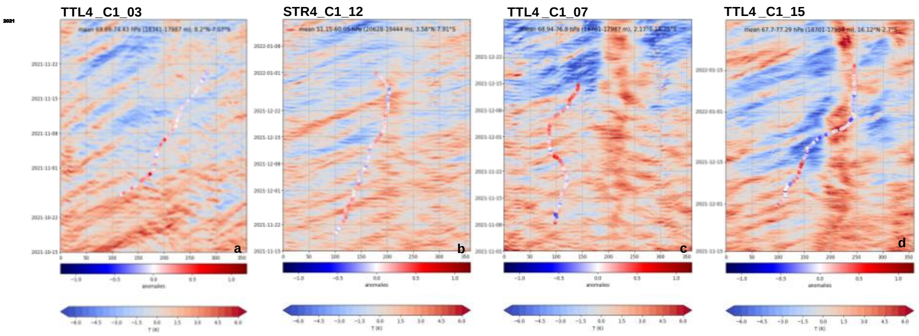

Fig. 7 : Hovmoeller diagram in temperature anomalies with balloon trajectory and anomalies color coded for the TTL4_C1_03 (a), STR4_C1_12 (b), TTL4_C1_07 (c) and TT4_C1_15 (d) flight.

Table 1. Correlation coefficient for each Pico-SDLA H_2O flight, between water vapour anomalies and ERA5 temperatures at the same location and time.

Flights	TTL2_2019	TTL4_C1_03	TTL4_C1_07	STR4_C1_12	TTL4_C1_15
Correlations coeff.	0.56	-0.17	-0.26	-0.22	0.21

2019 : Good correletion between anomalies and temperatures. Strong infuence of atmospheric waves (e.g. Kelvin and gravity waves)

2021 : Slightly anticorrelated -> influence of other processes: deep convection likely

Influence of deep convection

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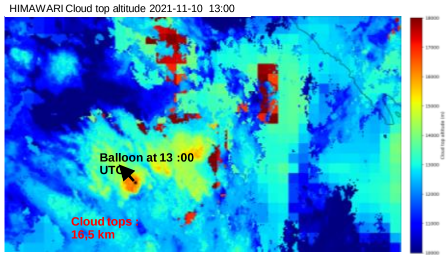
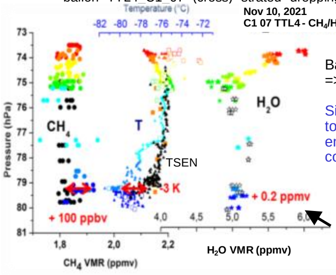


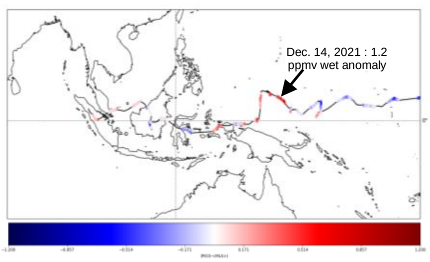
Fig. 8 : Image of cloud top altitude from geostationnary satellite Himawari. The ballon TTL4_C1_07 (cross) strated dropping in altitude while overpassing a



Balloon drop above deep convective systems => Vertical profiles measured

Signature of local hydration (~ 200 ppbv) linked to deep convection above the tropopause: CH_4 enhancement observed (~100 ppbv) and corresponding local cooling (~3 K)

Fig. 9 : Methane, temperature and water vapour measurements during the altitude drop (colored datapoints : descent, black : ascent) from Pico-SDLA and TSEN temperature sensor (LMD)



← **Fig. 10 :** Beginning of the flight TTL4_C1_15 with water vapour anomalies color-coded.

Overpass of the Raï tropical storm on Dec 13, 2022. Later on turned to super typhoon (Dec 14[th]).

Strong water vapour enhancements observed linked to air masses advected from Raï from Dec 12th to 14th.

Trajectory analysis shows that the probed air mass to be originating from Raï

=> Document the temporal evolution the water vapour budget associated to such extreme convective events

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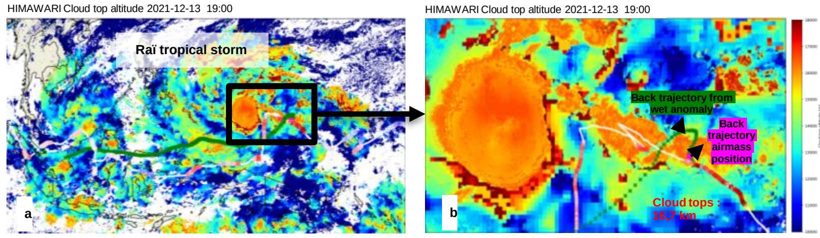

Fig. 11 : Images of cloud top altitude from geostationnary satellite Himawari with back trajectory (green) surimposed from the wet anomaly in Fig 10.

Conclusion

- 5 Pico-SDLA instruments have been flown at an altitude between 18.5 and 20.5 km, under super pressure balloons during the Strateole-2 test and scientific campaigns in 2019 and 2021, gathering more than 400 000 *in situ* measurements of water vapour, methane and carbon dioxide in the tropical tropopause layer (TTL).
- Water vapour measurements have shown the influence of large-scale circulation, atmospheric waves and deep convection on the modulation of the water vapour budget in the TTL.
- The correlation between water vapour absolute measurements and ERA 5 temperature shows a contrast between the 2019 and 2021 campaigns in the influence of deep convection on the water vapour signature.
- Results from the 2019 campaign show a predominant influence of atmospheric Kelvin and gravity waves (correlation factor : 0.56)
- Further analysis from mesoscale modelling will allow an estimation of the budget involved during such events

Flight	Ratio of anomalies	Ratio of dry anomalies	Ratio of wet anomalies	Anomalies can be explained by waves			Anomalies can be explained by deep convections			
				tot	dry	wet	tot	dry	wet	> 16,5 km
TTL4 C1_07	48,64%	27,8%	72,2%	38,88%	28,57%	71,43%	100%	27,8%	72,2%	83,3%
TTL4 C1_15	39,6%	52,63%	47,37%	31,57%	50%	50%	57,89%	45,45%	54,55%	90,9%
TTL2 2019	69,44%	44%	64%	90%	42,22%	64,44%	50%	18%	36%	14%

Table 2. Synthesis of anomalies and their explanations from TTL4_C1_07, TTL4_C1_15 and TTL2_2019 flights.

The other flights are being studied.