Toward a global view of extratropical UTLS tracer distributions

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SPARC GA Sept 2008

PERSPECTIVE

SPARC General Assembly 2004:

Knowledge about UTLS tracer distributions was mainly derived from aircraft and balloon measurements supported by trajectory studies.

They helped to evolve our understanding of a finite chemical transition layer across the tropopause, with partly tropospheric, partly stratospheric character – known as the ExTL.

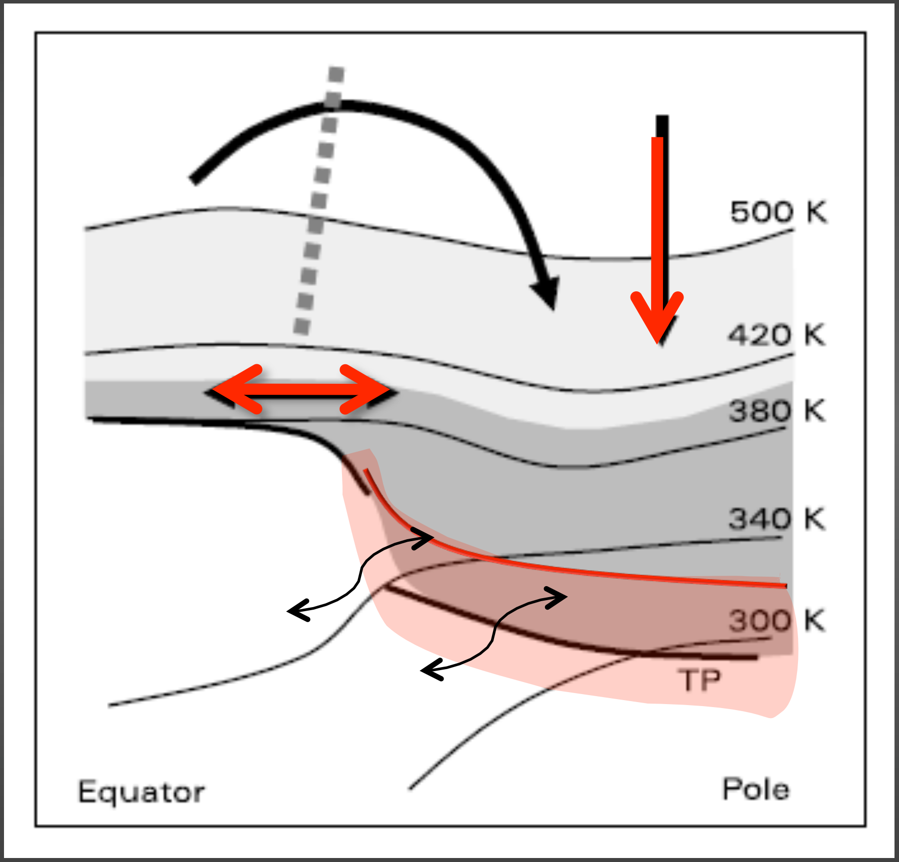
Since 2004 and beyond:

We are now entering an era in which satellite instruments are able to provide measurements of the UTLS on a global scale.

At the same time, chemistry-climate models are reaching a stage of maturity where they are being used to investigate chemical climate change in the UTLS.

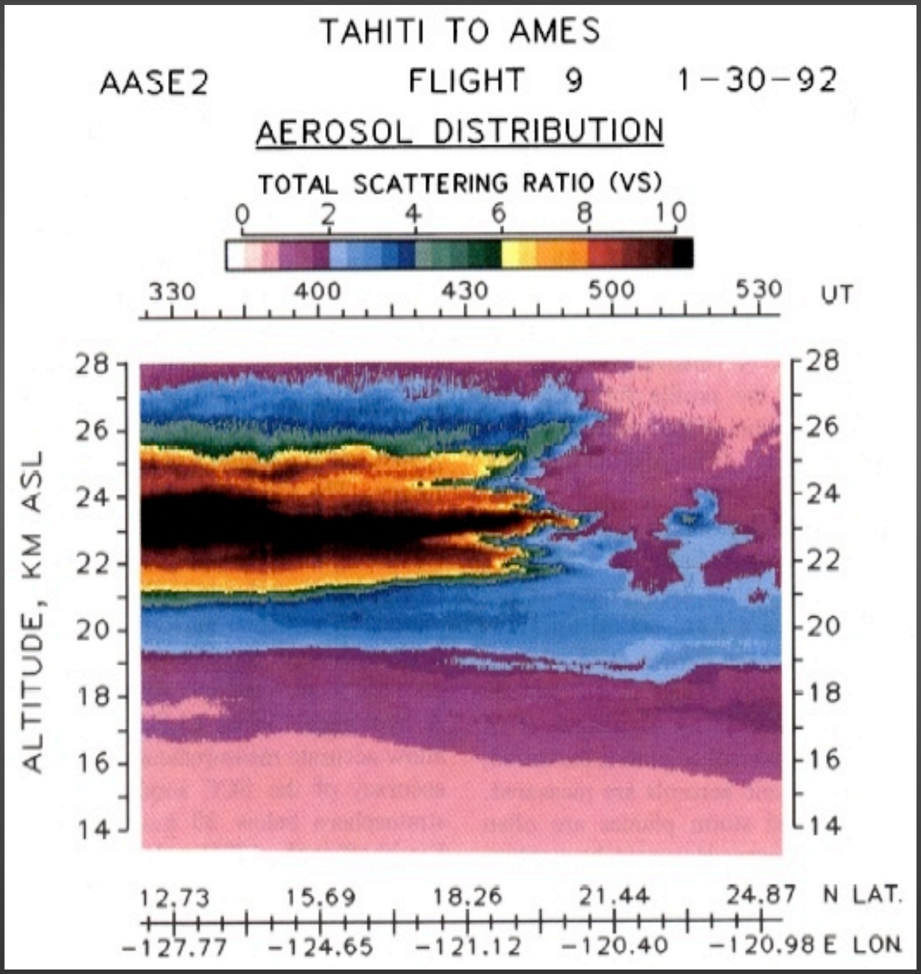
Satellite data offer a promising resource to extend our knowledge on temporal and spatial scales, to test the representativeness of aircraft measurements, and to validate UTLS tracer distributions in chemistry-climate models.

The main transport pathways determining UTLS tracer distributions have been identified.



Hegglin and Shepherd, JGR 2007

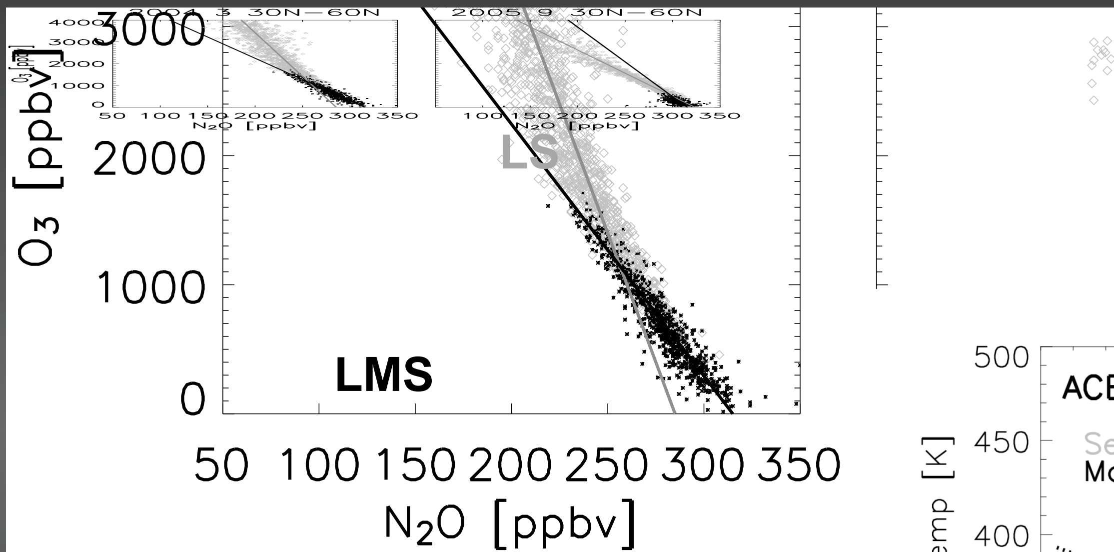
Aircraft observations show fast lateral transport within the tropically controlled transition layer.



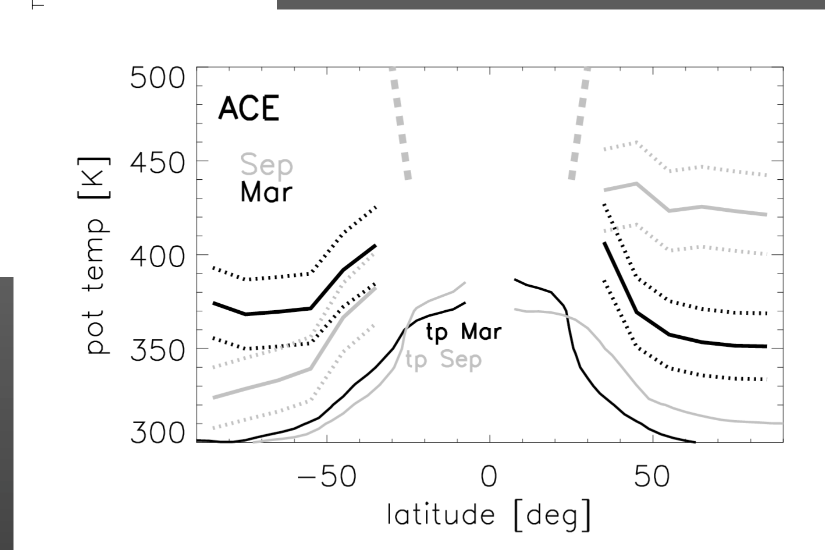
Aerosol observations measured by airborne lidar 7 months after the Mt. Pinatubo eruption.

Grant et al., JGR 1994

The ‘flushing’ of the mid and high latitudes with younger air from the tropical lower stratosphere between spring and autumn is reflected in the seasonal change in the O_3-N_2O correlation slopes.



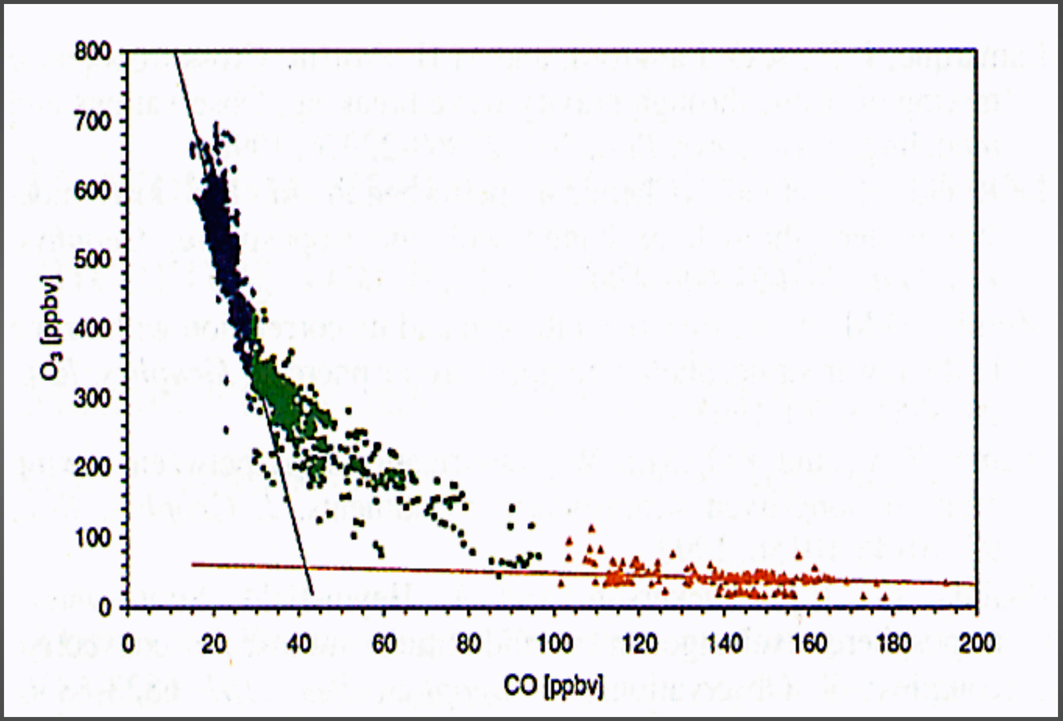
Hegglin and Shepherd, JGR 2007



See also Bill Randel’s poster P76!!!

The potential temperature level at which the lowermost stratosphere (LMS) and lower stratospheric (LS) correlation slopes intersect determines the upper boundary of a ‘chemically defined’ LMS.

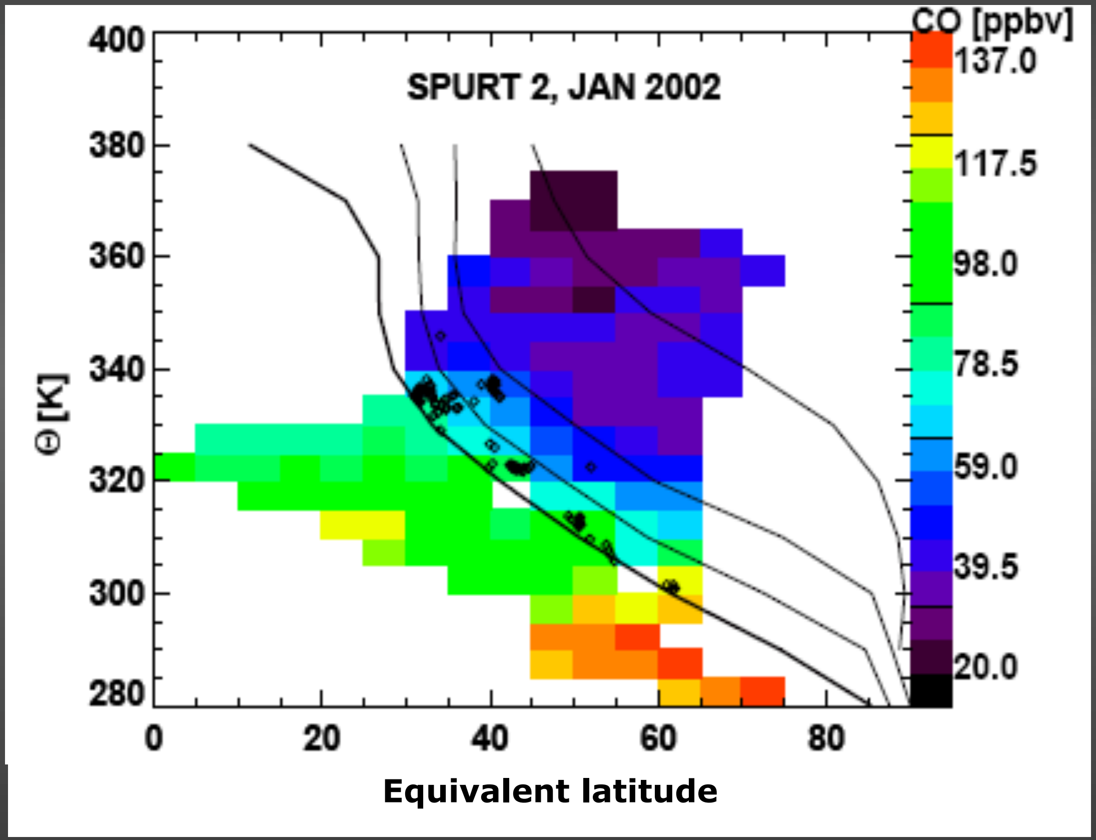
Tracer-tracer correlations are used to reveal mixing between tropospheric and stratospheric air masses.



Fischer et al., GRL 2000

The green points connecting the tropospheric and the stratospheric branch were interpreted as the result of isolated mixing events.

These observations helped evolve our understanding of a finite chemical transition layer across the tropopause, with partly tropospheric, partly stratospheric characteristics.



Hoor et al., ACP 2004

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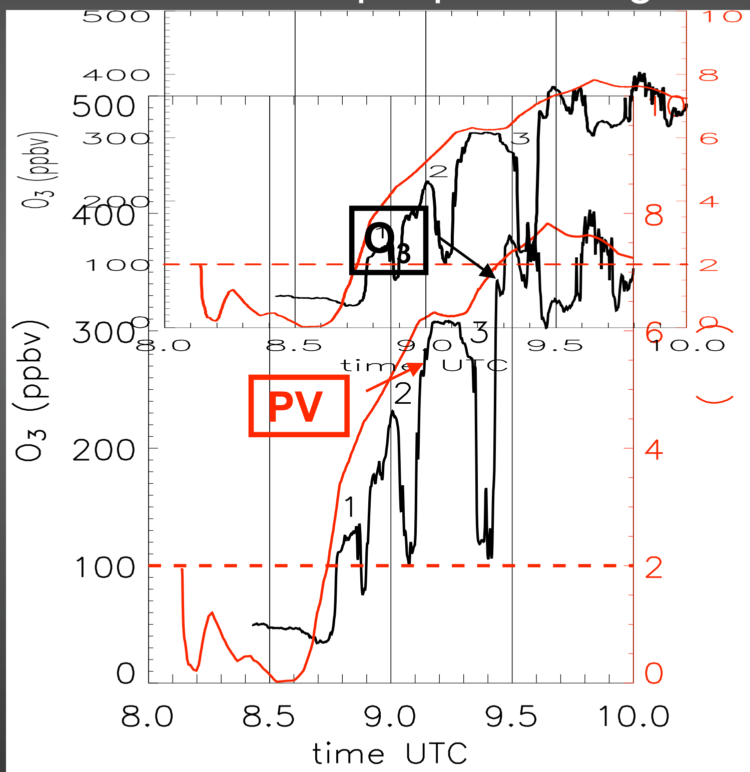
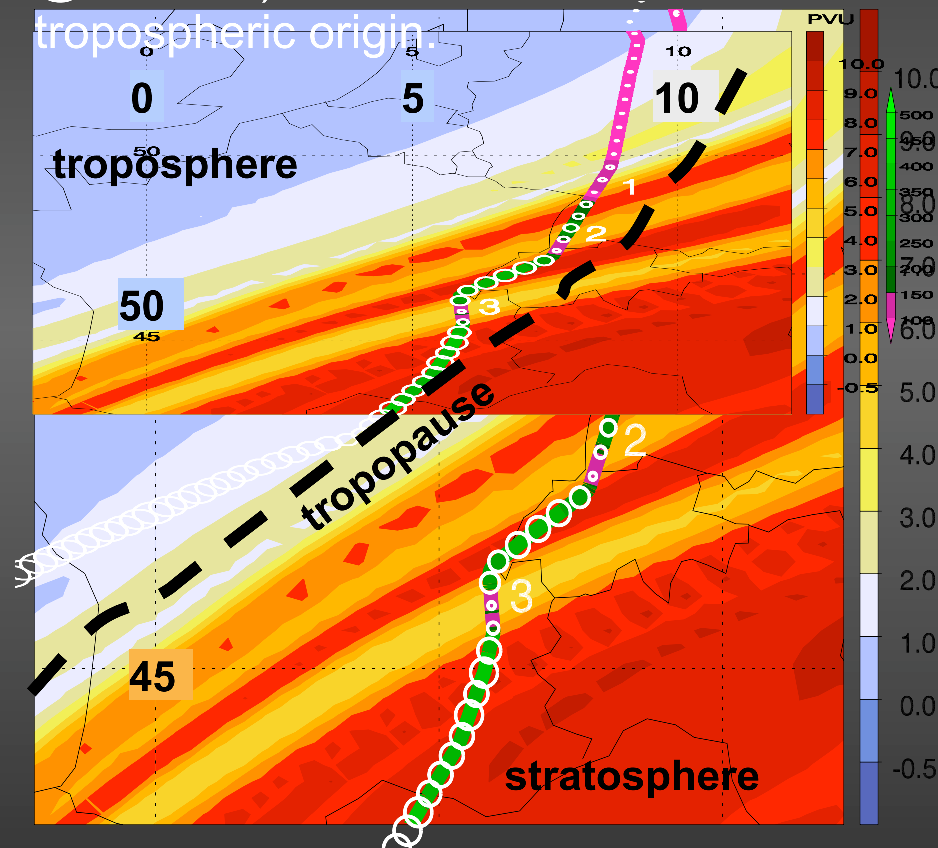
Aircraft measurements allowed us to get insight into different stratosphere-troposphere exchange processes.

While PV increases steadily, O_3 shows three distinct drops indicating air masses of tropospheric origin.



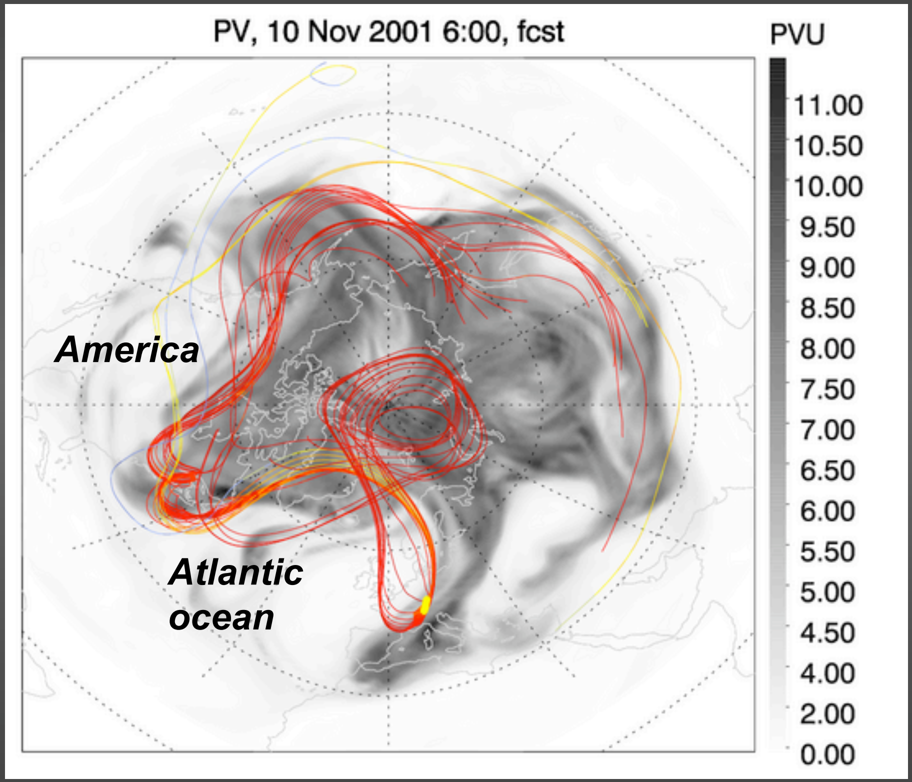
RDF reconstructed PV-field (2 days, @210 hPa) reveals filaments of tropospheric origin.



Flight → ... → *Hohn, 55°N* *Faro, 35°N*

Hegglin et al., ACP 2004

Synoptic scale disturbances around the tropopause lead to stirring and filamentary tracer structure due to breaking Rossby waves.



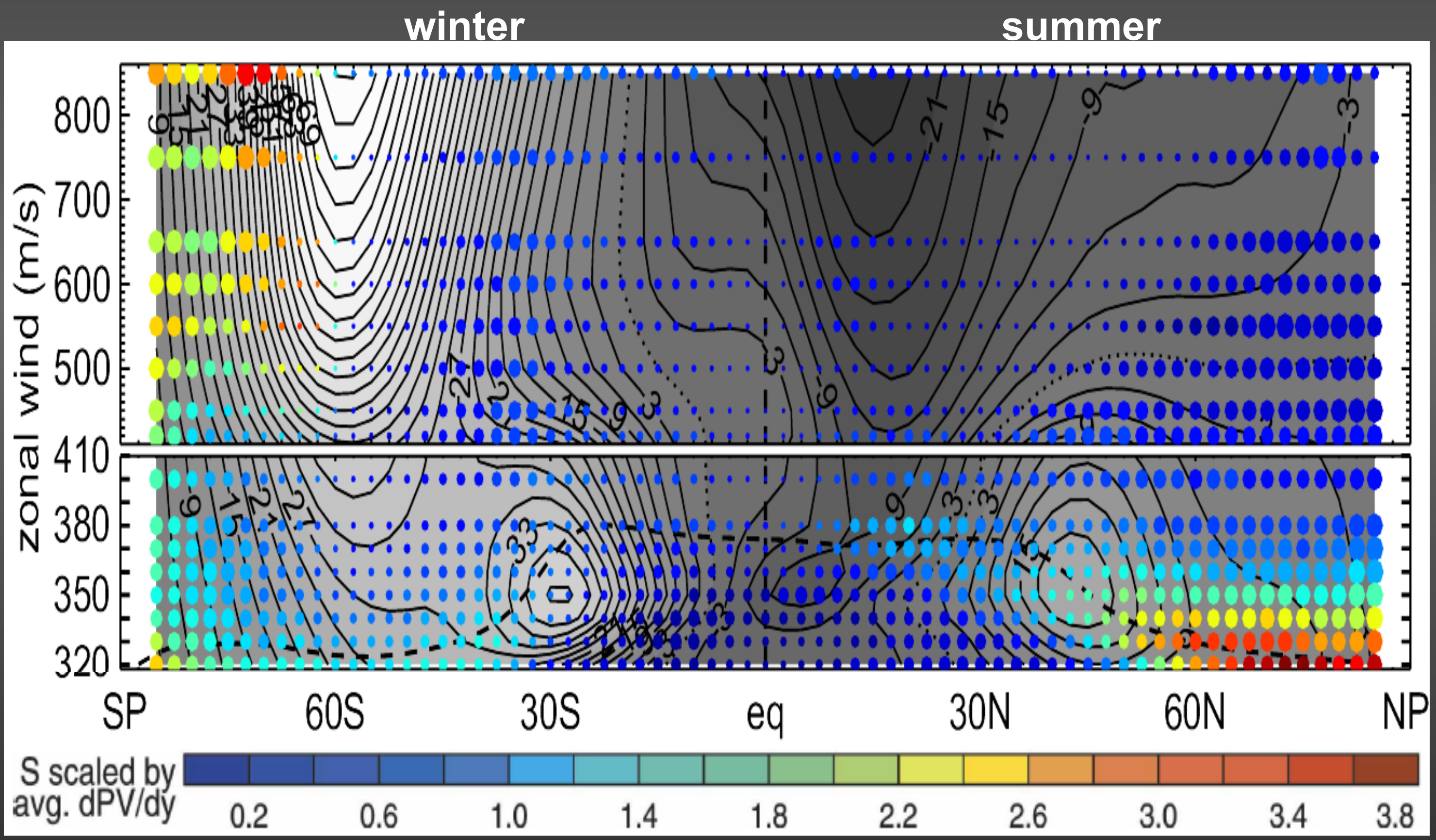
Ertel potential vorticity at θ=360 K (~12 km) for 10 November 2001.

The sharp PV edge corresponds roughly to the location of the jet stream.

Ultimately, small scale turbulent processes (e.g. by breaking gravity waves) lead to mixing and the disappearance of the filaments.

Evaluation of the properties of Rossby wave breaking events enables the quantification of irreversible transport.

NCEP/UKMO June-August climatology of reversal frequency (circle size) and normalized strength (circle colour) of Rossby waves.

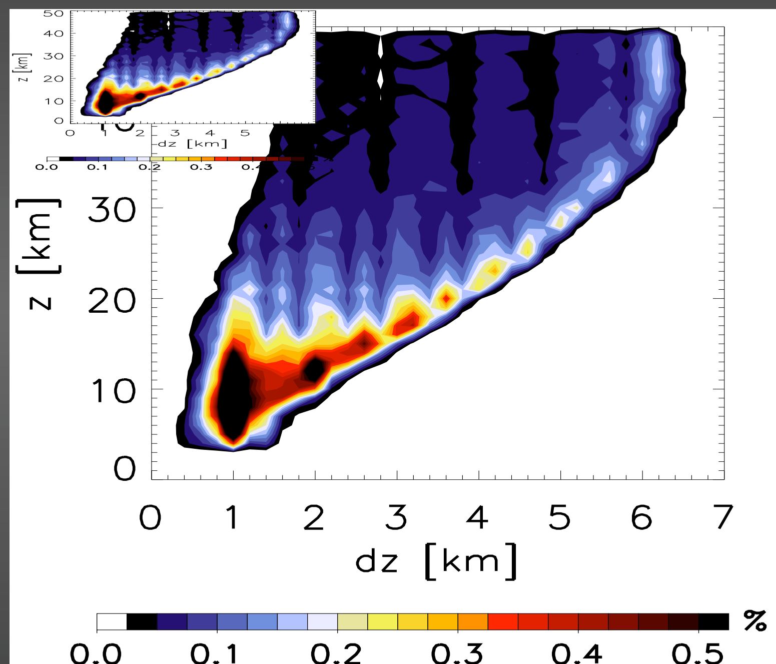


Hitchman and Huesmann, JAS 2007

The ACE-FTS on the Canadian SCISAT-1 satellite is a solar occultation instrument and offers high-precision measurements of a number of species.

Kaley Walker's poster P12 (on Friday)!!!

Probability density function of the vertical spacing between two ACE-FTS measurements as a function of altitude.



Hegglin et al., ACP 2008

The 'oversampling' with respect to the satellite's viewing geometry (3 km) might yield better vertical resolution than expected. This needs to be confirmed with real measurements.

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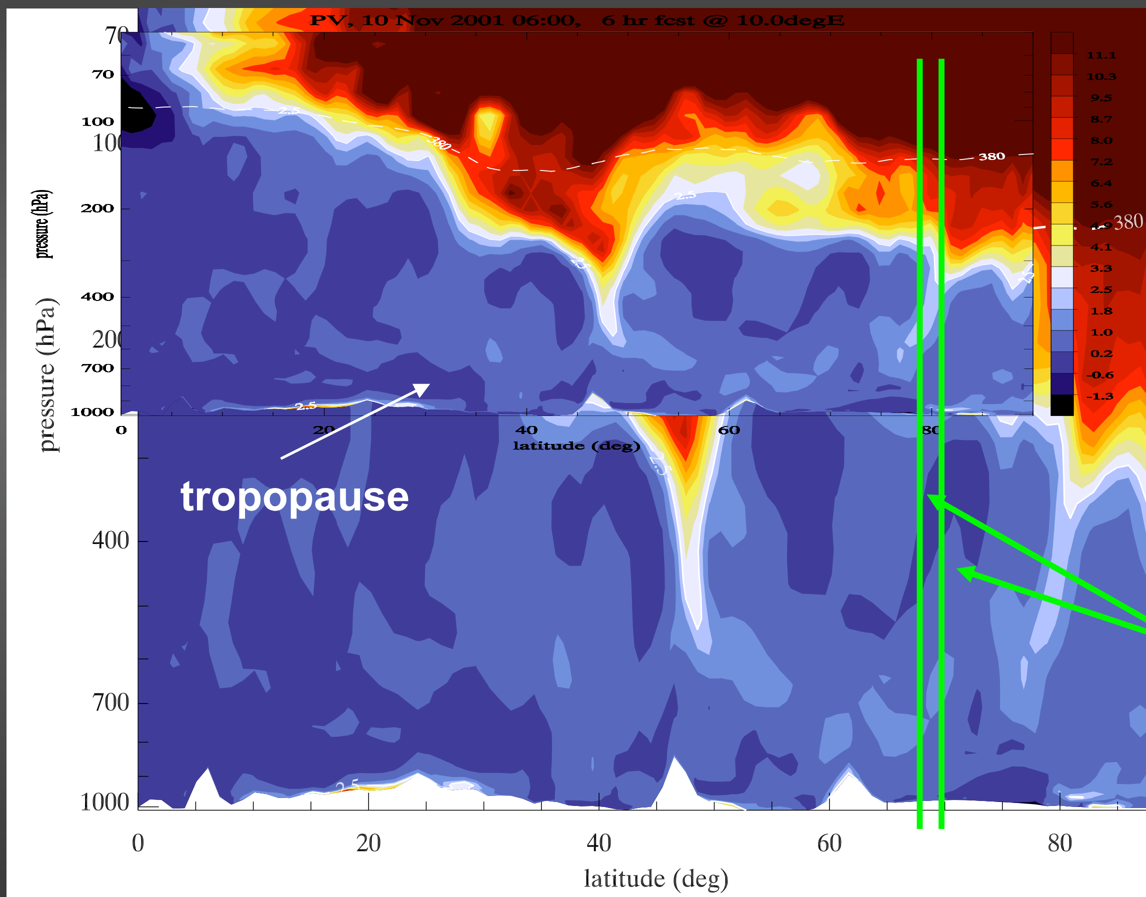
UTLS dynamical structures exhibit small vertical and horizontal length scales: <1 km in the vertical and <100 km in the horizontal.



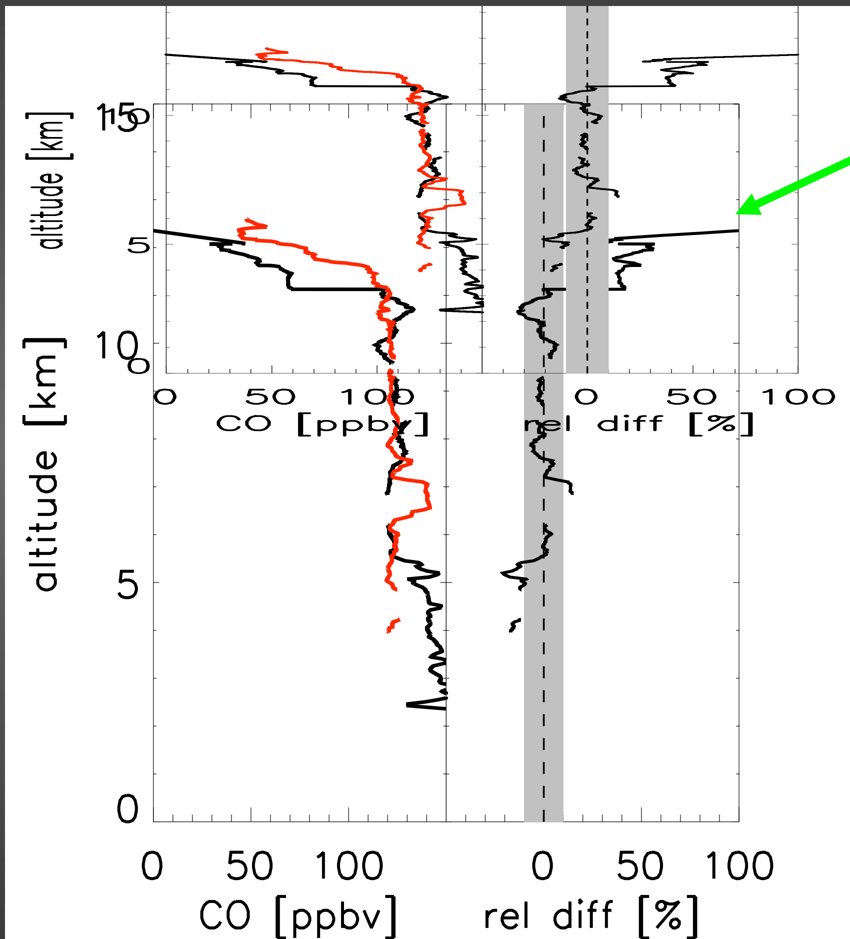
Vertical cross section of ECMWF potential vorticity in the NH at 6°E on November 10, 2001.

In practice, coincidence criteria are loosened so as to obtain enough coincidences.

Different tropopause heights may lead to large differences in tracer profiles!

Hegglin et al., ACP 2008

Validation of satellite measurements with coincident measurements suffers from geophysical noise.



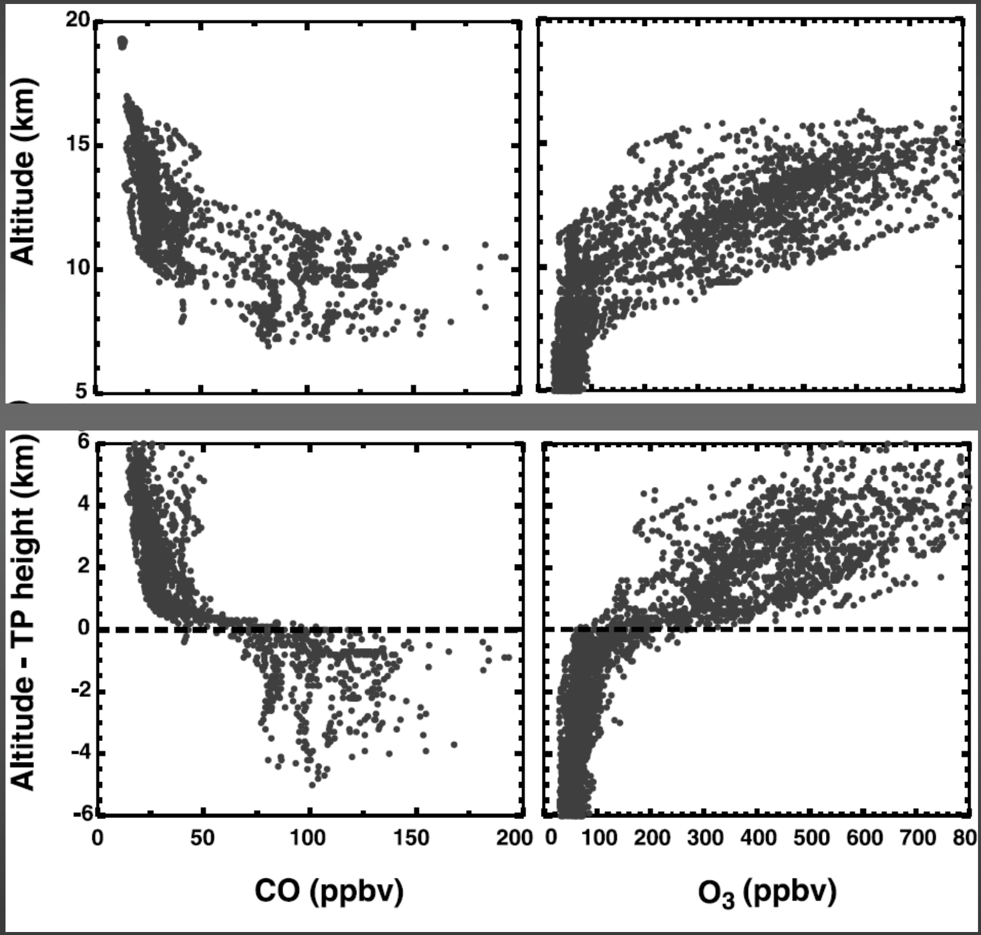
Hegglin et al., ACP 2008

In the tropopause region the derived relative error is up to 50%.

This is due to the small scale feature in the meteorological field and not due to a low instrument precision.

Aircraft profiles of CO taken during take-off and landing on 28 April 2003 in Hohn, GE 55°N.

The tropopause 'shapes' the distribution of O_3, H_2O and related chemical species.



CO and O_3 profiles near 65ºN as functions of geometric altitude (top) and in tropopause coordinates (distance relative to the tropopause height, bottom).

Pan et al., JGR 2004

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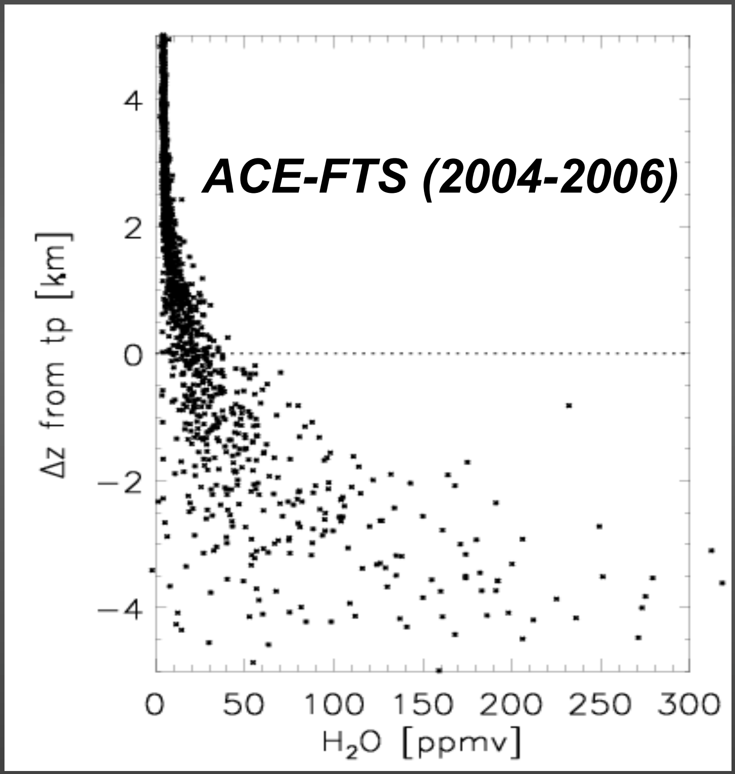
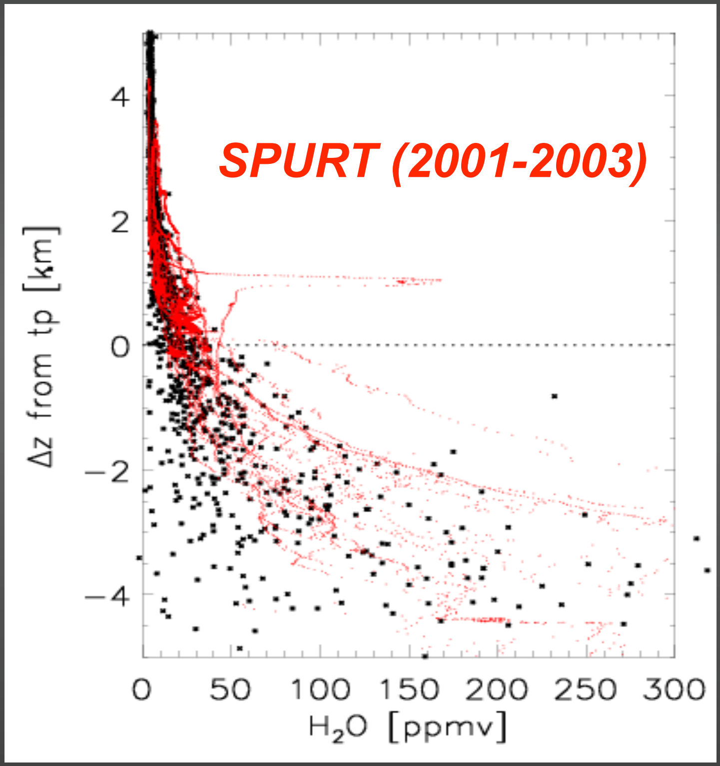
Tropopause coordinates can also be used for satellite validation with non-coincident measurements.

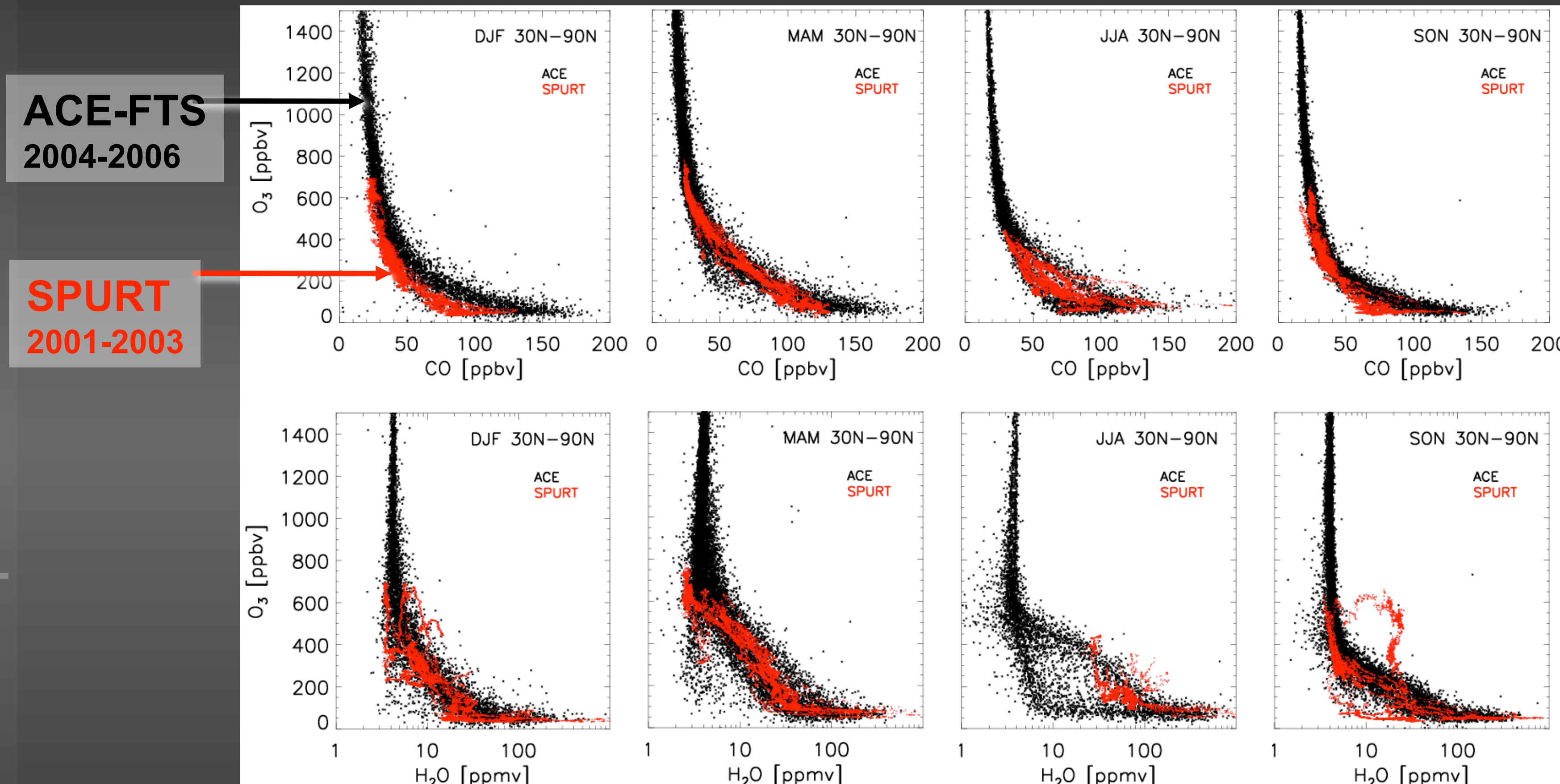
(SPURT H_2O data courtesy of Cornelius Schiller, Research Center Juelich, Germany)





The comparison with non-coincident SPURT aircraft data demonstrates the high accuracy of the ACE-FTS .

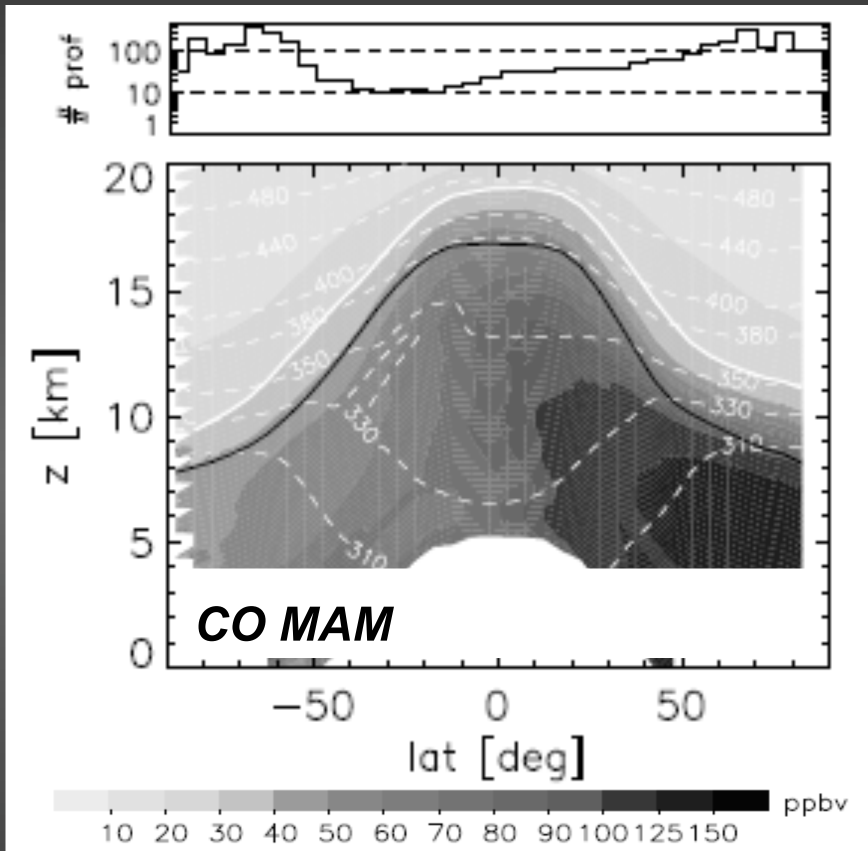
The use of tracer-tracer correlations reduces geophysical variability and allows non-coincident measurements to be used for the validation.

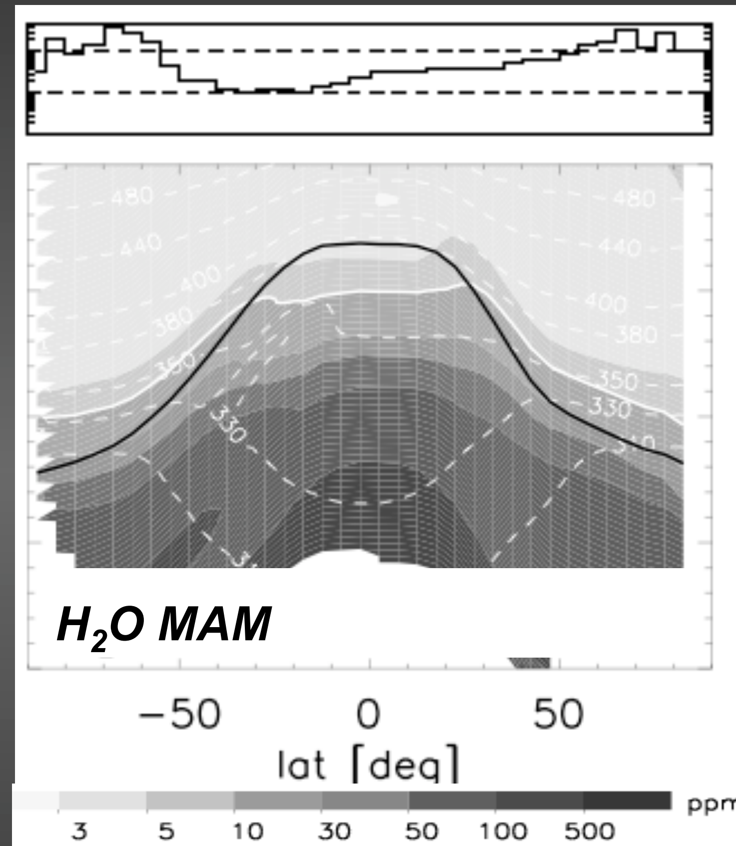


Hegglin et al., ACP 2008

The comparison with non-coincident SPURT aircraft data once again demonstrates the high accuracy (strictly, precision) of the ACE-FTS .

Zonal mean cross sections of ACE-FTS tracers in tropopause coordinates indicate the existence of the ExTL on a global scale.

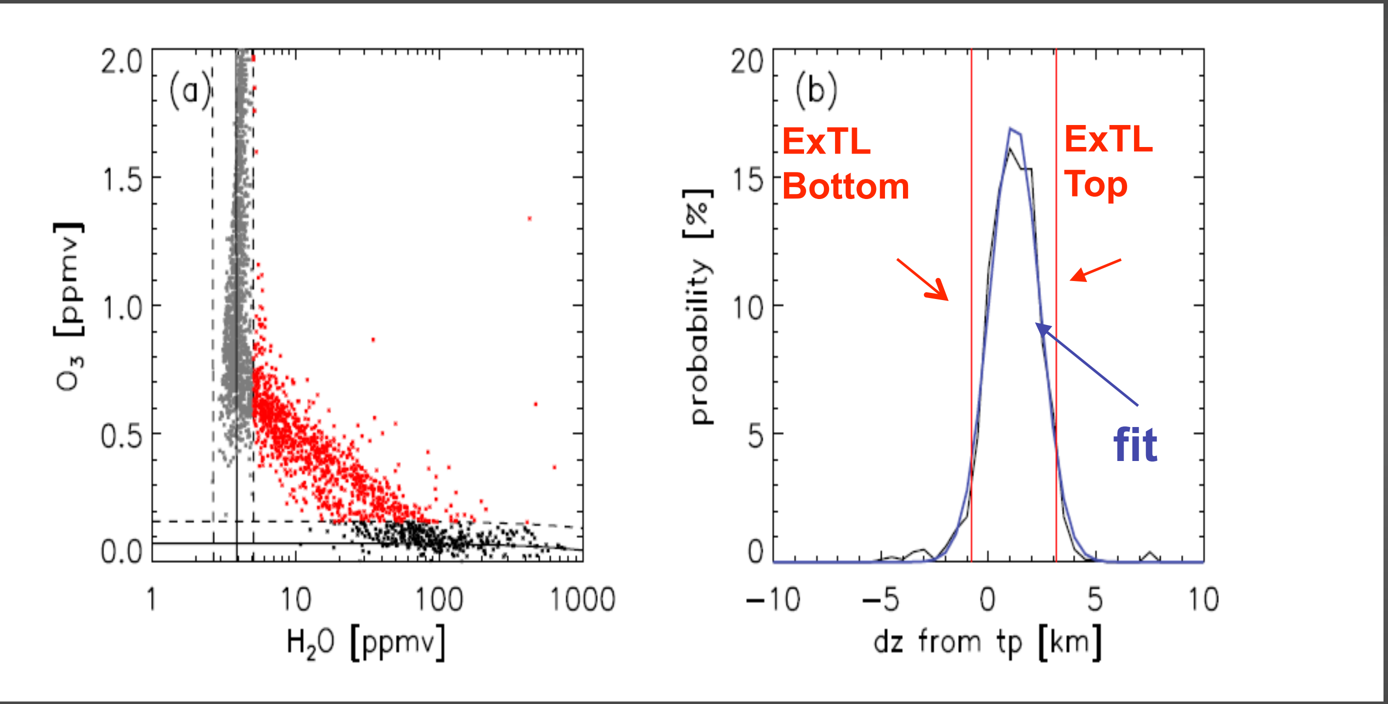




Hegglin et al., JGR under revision

- Strong gradients are observed in the horizontal as well as in the vertical.
- Differences in the distributions of CO and H_2O result from dehydration.

The ExTL depth is derived empirically for 10° latitude bins using the correlation method of Pan et al. [2004, 2007] applied to CO-O_3 and H_2O-O_3.



Hegglin et al., JGR under revision

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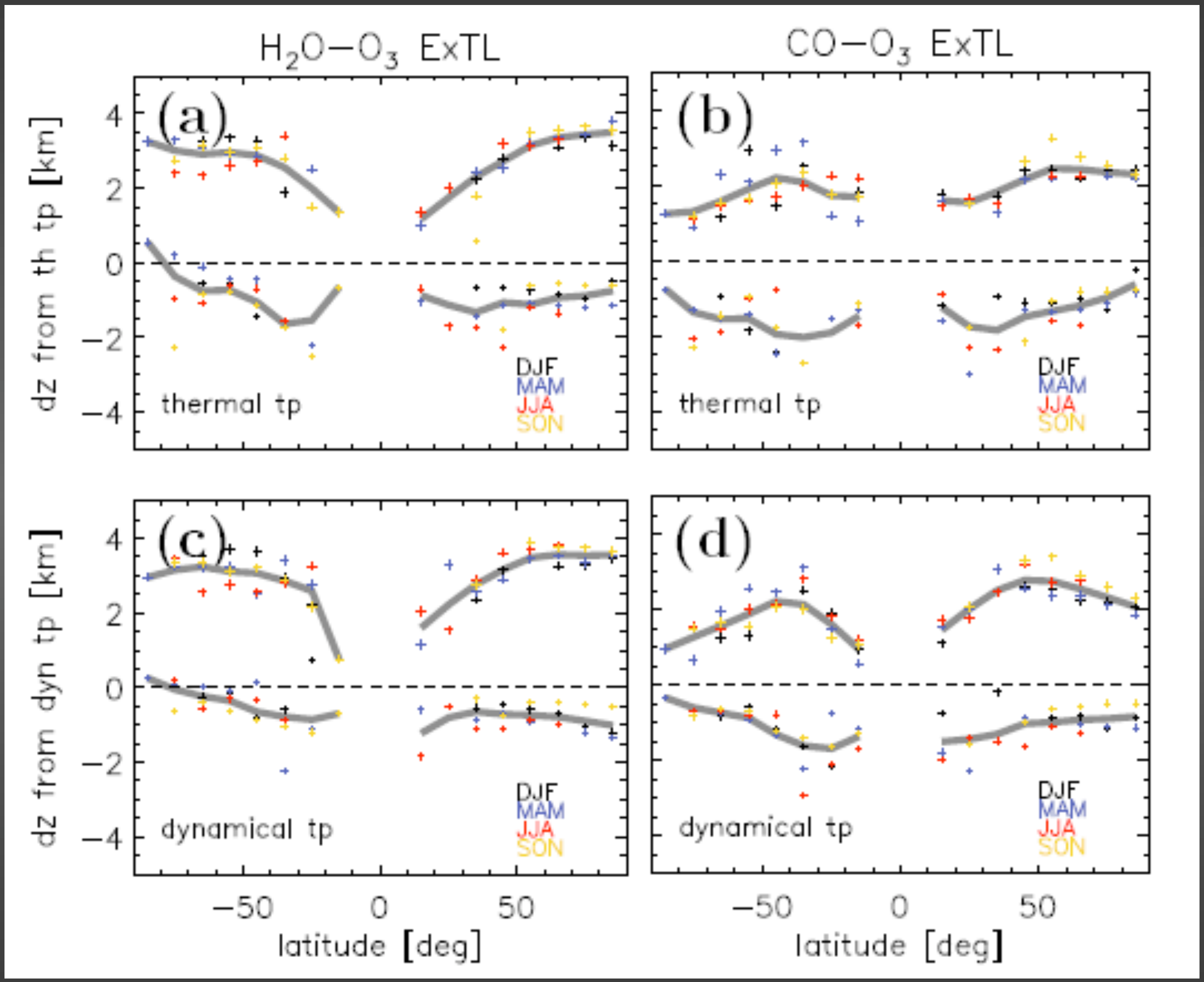
The ExTL depth derived from CO-O_3 is generally smaller than the one derived from H_2O-O_3.



Hegglin et al., JGR under revision

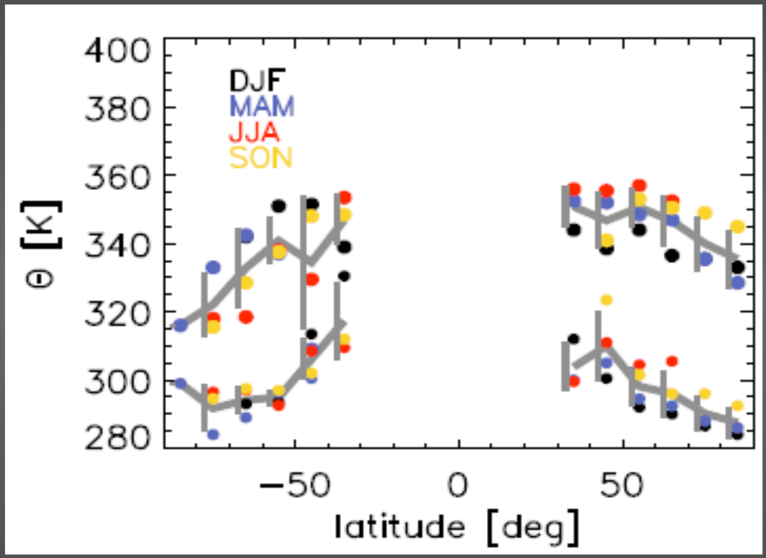
The evaluation shows a persistent influence of the stratosphere on the troposphere.

The ExTL depth derived relative to the thermal and dynamical (here 3.5 PVU) tropopauses are similar (-1 to 3 km).

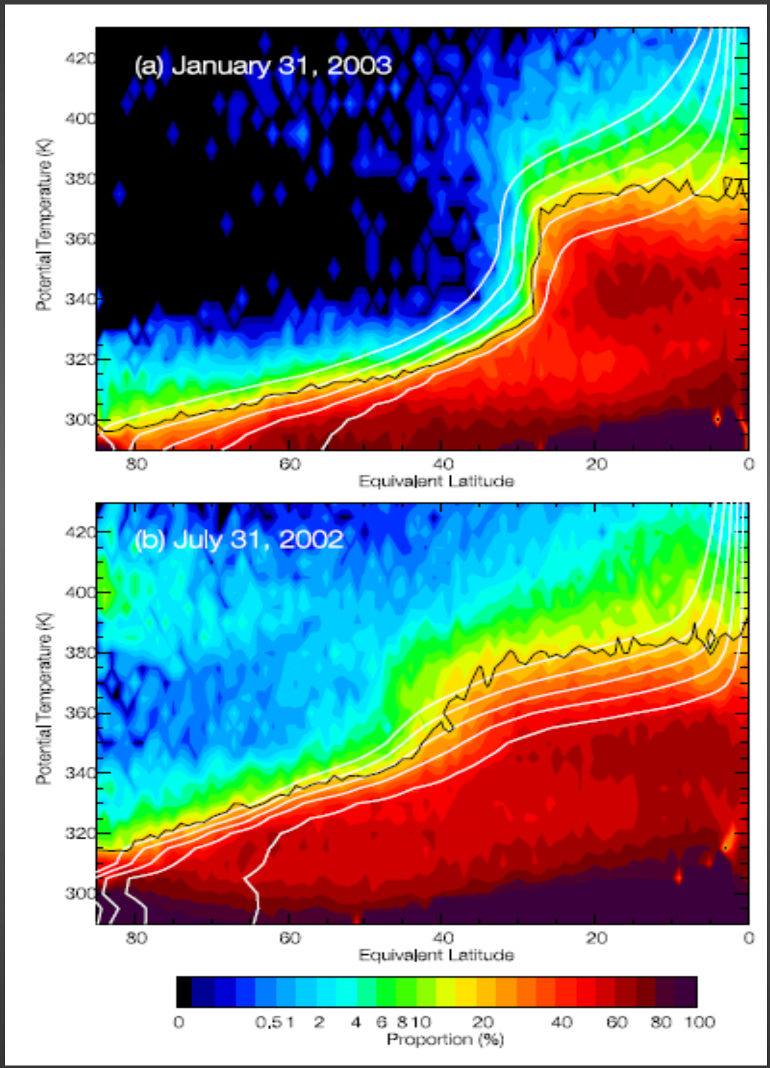
Posters by Hoor P33, Pan P70, and Zahn P109

Troposphere-stratosphere transport is confined to around 20-30 K above the tropopause.

ExTL depth in potential temperature derived from the CO-O3 correlation method.



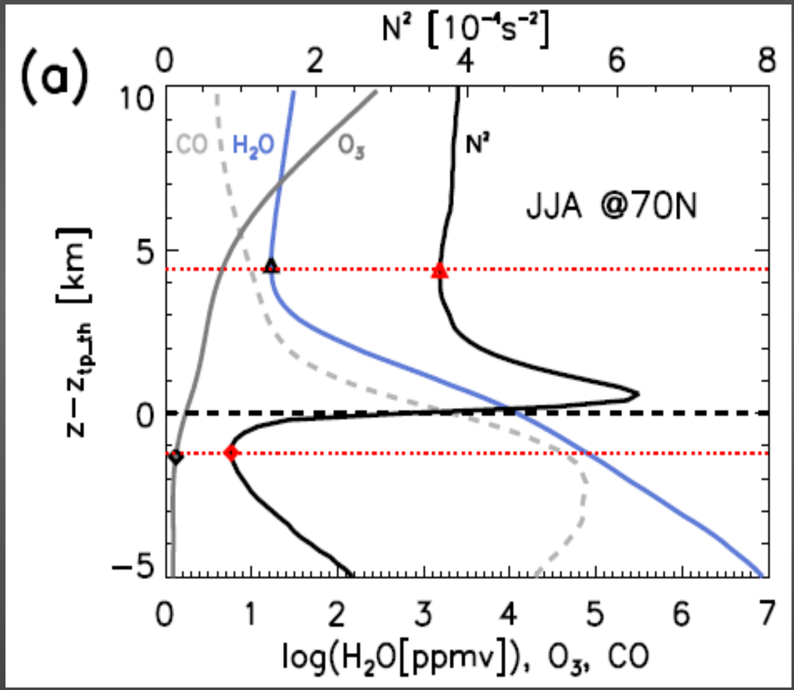
Hegglin et al., JGR under revision



Berthet et al., 2007

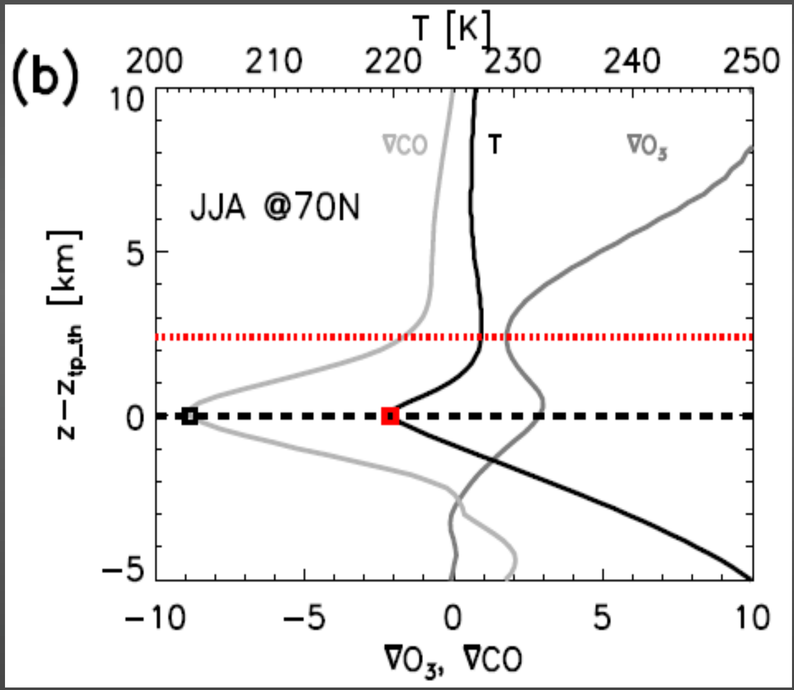
ACE-FTS tracer and GPS temperature climatologies (here vertical profiles in tropopause coordinates) can be used to investigate the characteristics of and the relation between the ExTL and the TIL.

H_2O, CO, O_3, and N^2 mean profiles in tropopause coordinates.



(GPS data from Randel et al. 2007)

Mean profiles of CO and O_3 gradients, and temperature in tropopause coordinates.

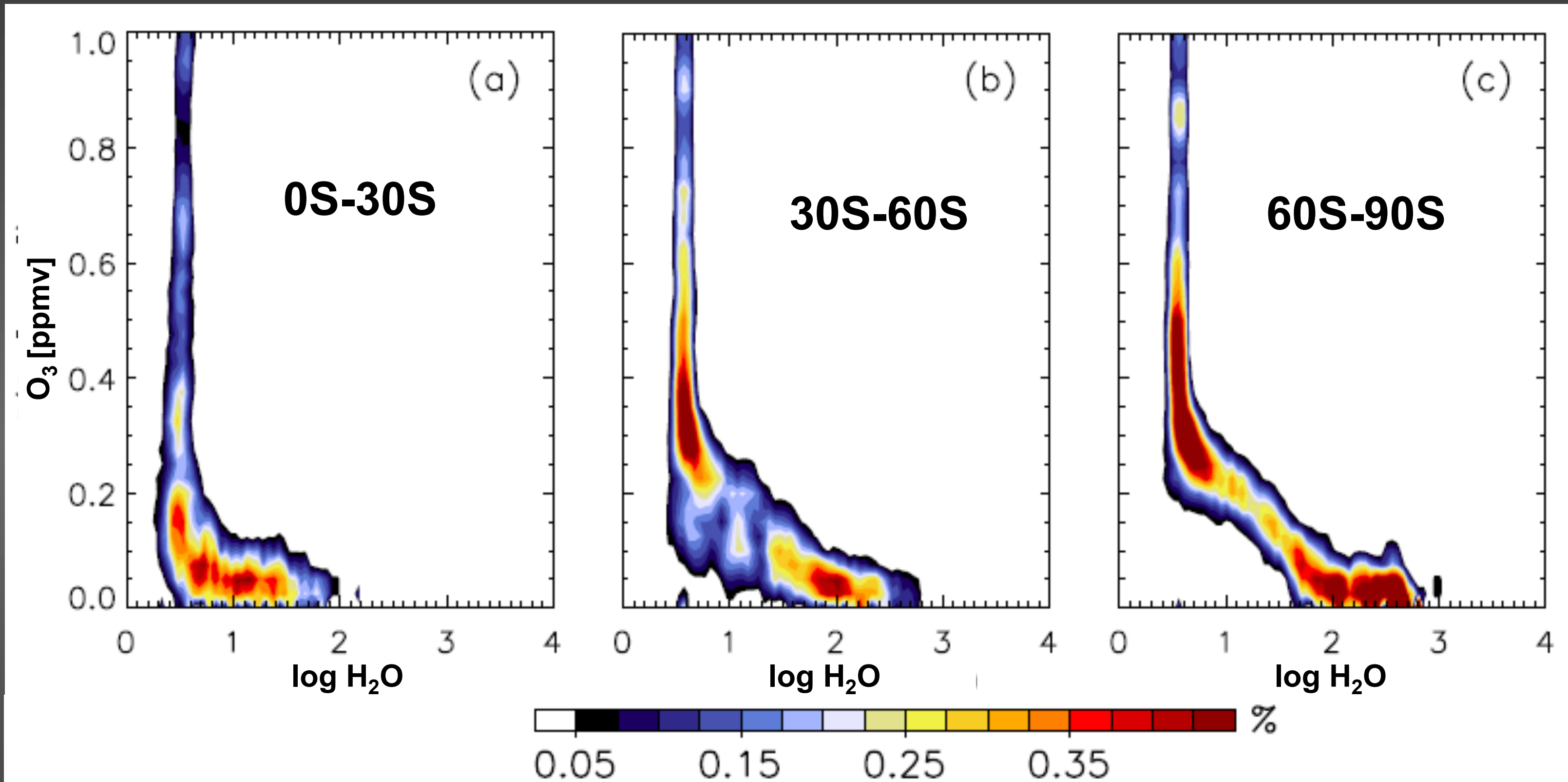


Hegglin et al., JGR under revision

The absolute maximum in the CO gradient is found at the thermal tropopause, indicating that it represents a localized minimum in vertical mixing.

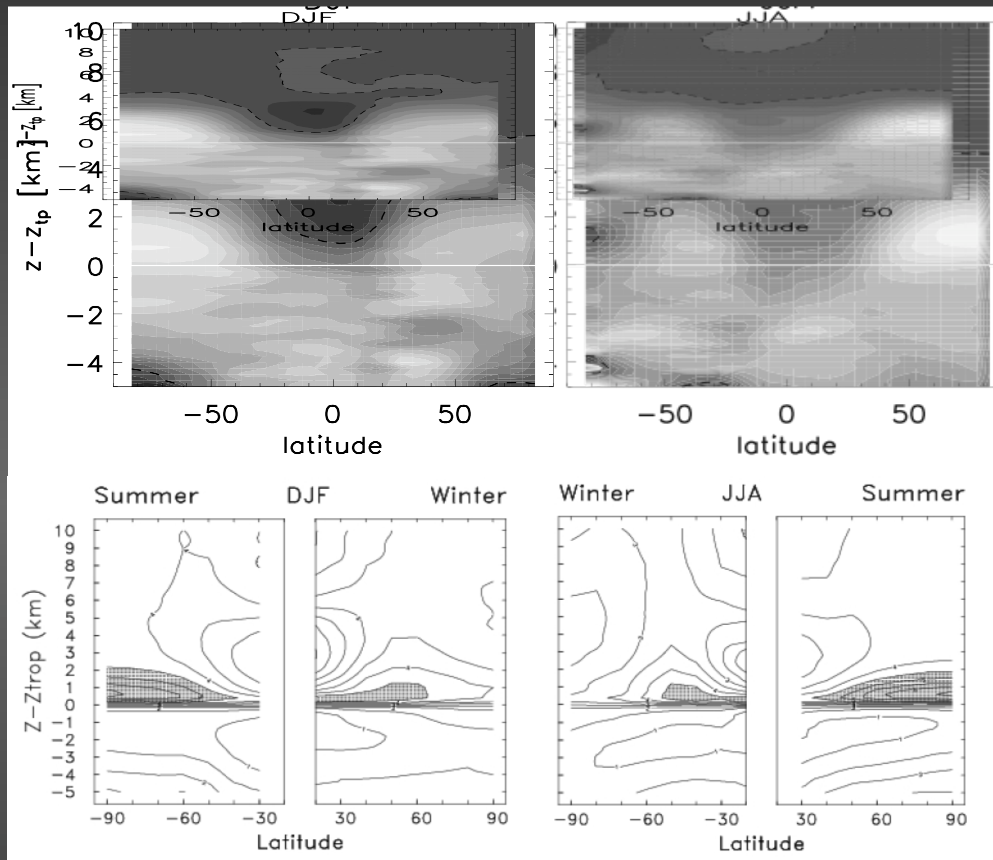
The abundance of the satellite data allow us to use joint PDFs which account for sampling biases.

Hegglin et al., JGR under revision



The minima in the PDFs indicate that mixing is limited in the extratropical tropopause region, similar to the minima found in PDFs of stratospheric tracers, which indicate the presence of mixing barriers such as the tropical pipe or the polar vortex *[Sparling, 2000; Hegglin and Shepherd, 2007]*.

The relative vertical H_2O gradients and the static stability structure of the TIL show similar seasonal behaviour and vertical scales.



Relative vertical H_2O gradients for ACE in DJF and JJA in tropopause coordinates (*Hegglin et al., JGR under revision)*

Climatological latitude-height cross sections of N^2 from GPS data by Randel et al. (JGR 2007).

The comparison provides observational support for the hypothesis that H_2O plays a radiative role in forcing and maintaining the structure of the TIL as suggested by Randel et al. [2007].

CONCLUSIONS

Satellite instruments have started to offer valuable measurements in the UTLS on a global scale and with high temporal coverage.

Validation demands new approaches due to the large geophysical variability and the scarcity of coincident measurements in the region.

The measurements will improve our knowledge of different transport processes and identify potential gaps in our understanding.

- e.g. different tracers give different ExTL depths

Future efforts can focus on the quantification and the investigation of the mechanisms responsible for the observed structures.

The diagnostics presented here can be used to test the representation of UTLS tracer distributions in chemistry climate models – a focus of the CCMVal project.

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The role of the subtropical jet in mixing and transport between the troposphere and the stratosphere is an open science question: barrier or blender? (cf. Gulf Stream: Bower et al. ~1991).

Visit Gloria Manney's poster P84 (presented by Michelle Santee)!!!

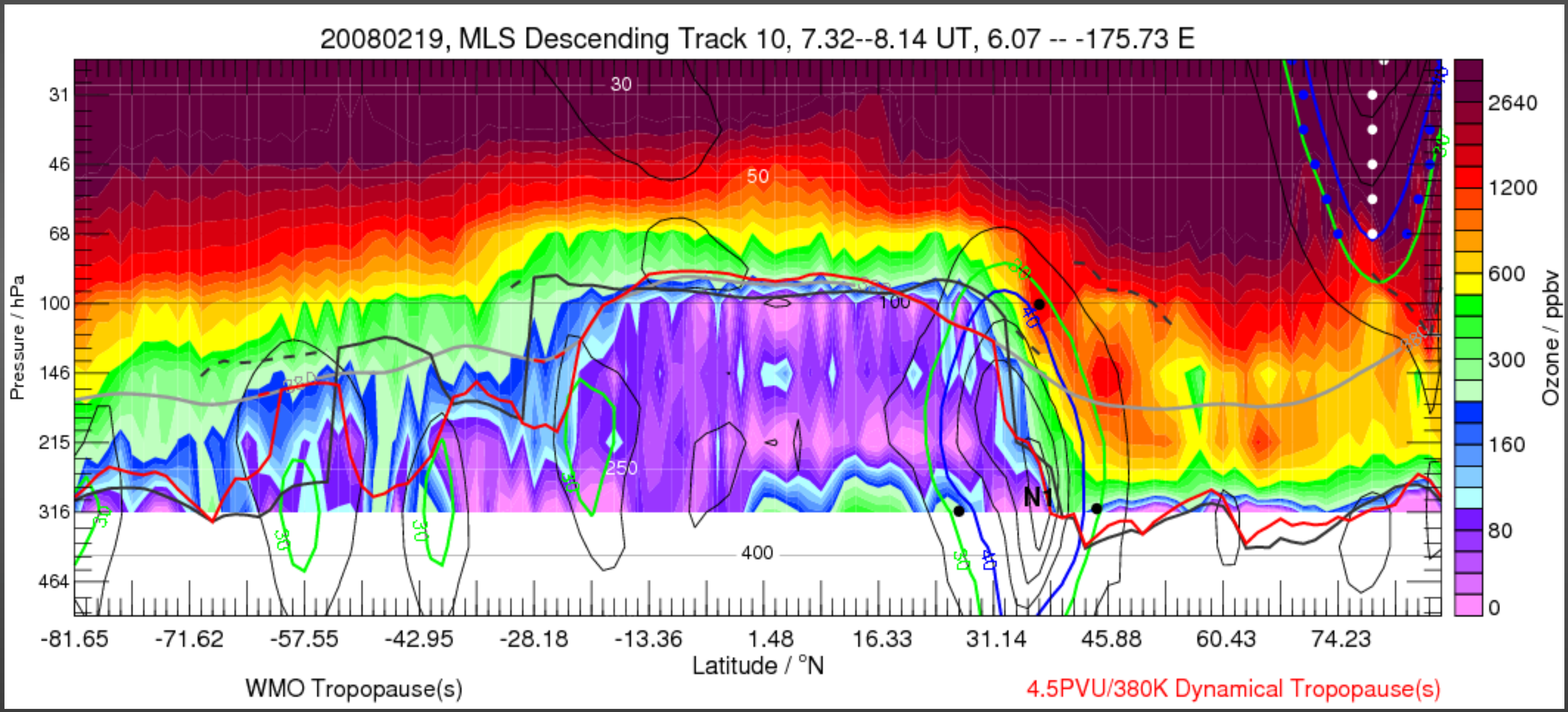
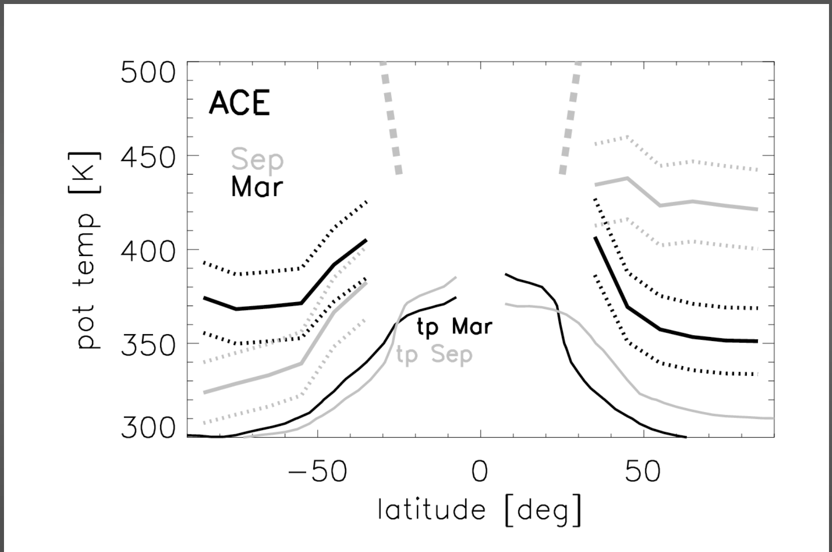
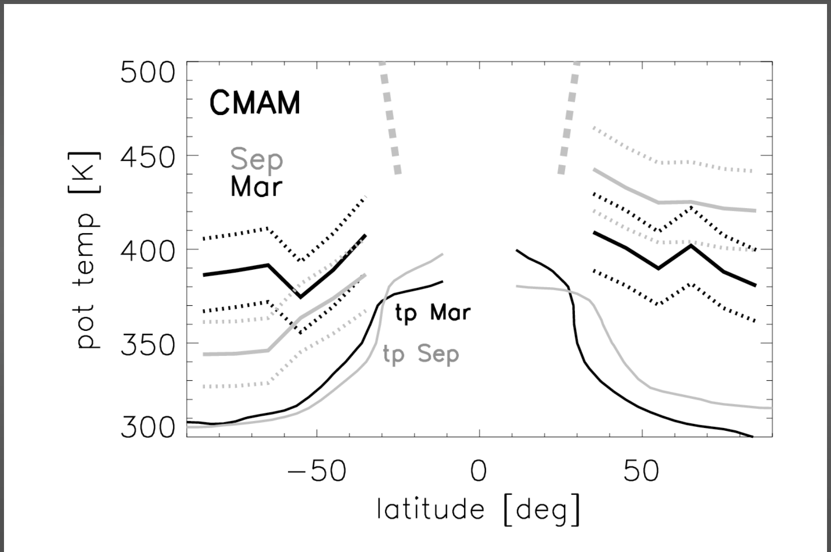


Figure courtesy of Gloria Manney, NASA JPL

THE 'FLUSHING' OF THE LOWERMOST STRATOSPHERE

Testing the 'chemically defined' LMS in CMAM...

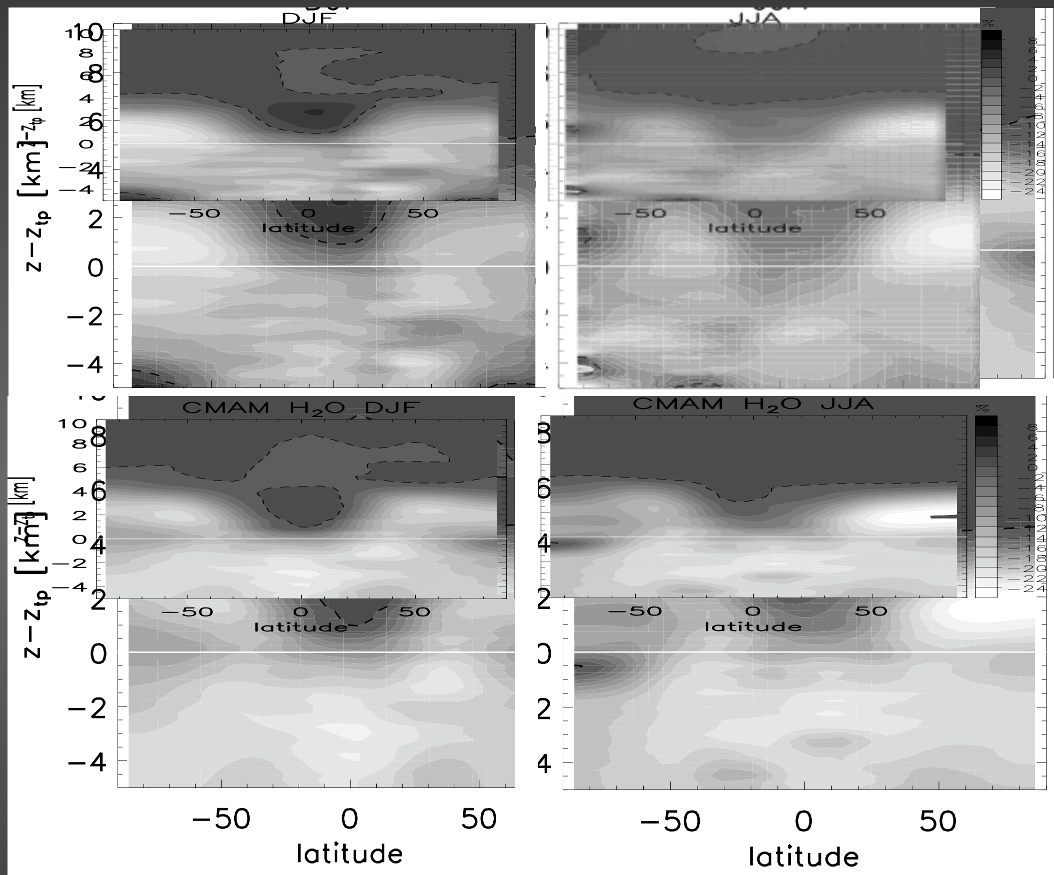




Hegglin and Shepherd, JGR 2007.

CMAM's chemical LMS is nicely reproducing ACE, except in NH spring.

THE REPRESENTATION OF THE ExTL IN THE RELATIVE GRADIENT OF H2O



H_2O normalized vertical gradients for ACE in DJF and JJA relative to the thermal tropopause height.

Same, as above, but for CMAM.

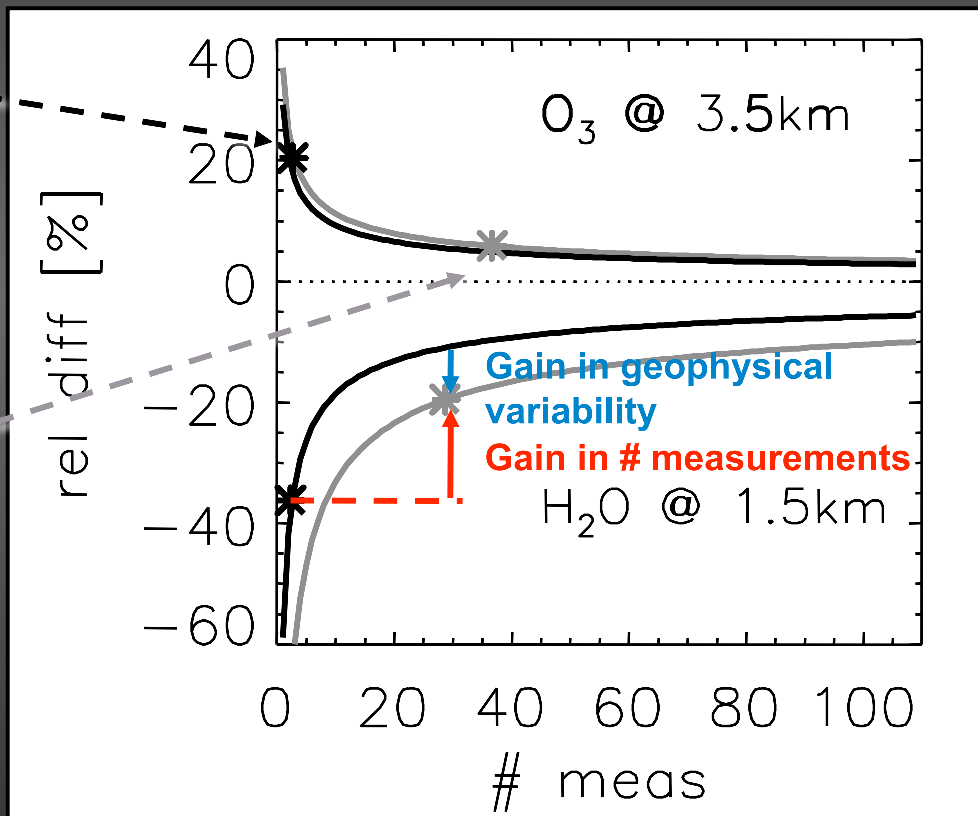
In JJA, CMAM does a good job in representing the ExTL as given by the relative H_2O gradient. In DJF, the diagnostics reveals that the maximum value is found at slightly higher altitudes above the tropopause than expected.

TRADE-OFF

Using the Canadian Middle Atmosphere Model (CMAM), we can quantify the trade-off between increasing the number of measurements and geo-physical variability when encompassing a wider range of longitudes/times.

ACE restricted

ACE full



Hegglin et al., ACP 2008

Standard errors of the mean (σ/√N) as a function of number of measurements (N).

The gain in geophysical variability is more than compensated for by the gain in the number of measurements.

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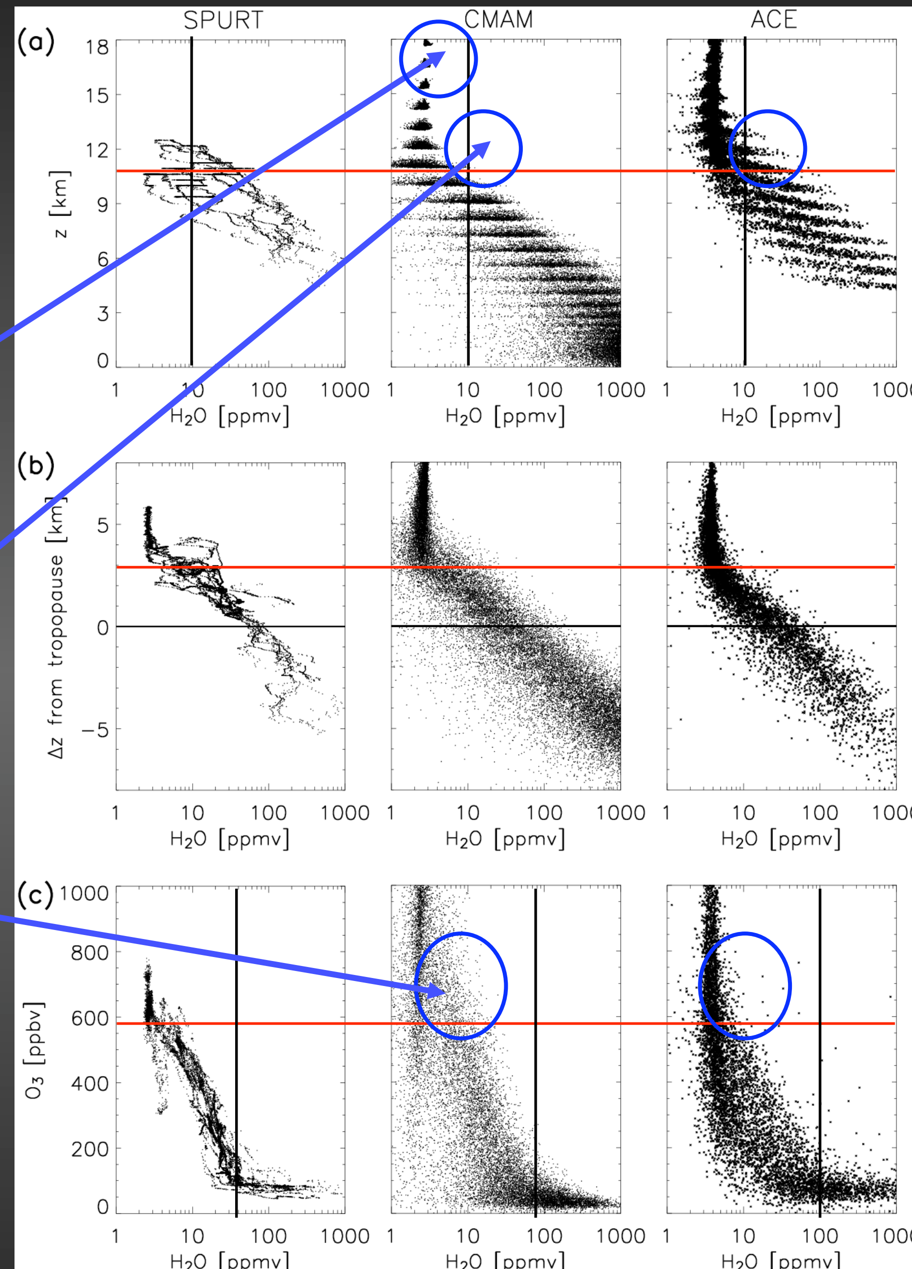
VALIDATION OF THE EXTL

Comparison between SPURT, ACE, and CMAM data in geometrical altitude, altitude relative to the tropopause, and as tracer-tracer correlations.

Dry bias of CMAM

Lack of variability in tropopause height

Slightly too high dispersion.



In general, CMAM reproduces the extratropical tropopause transition layer well.

Schmidt et al., JGR 2008

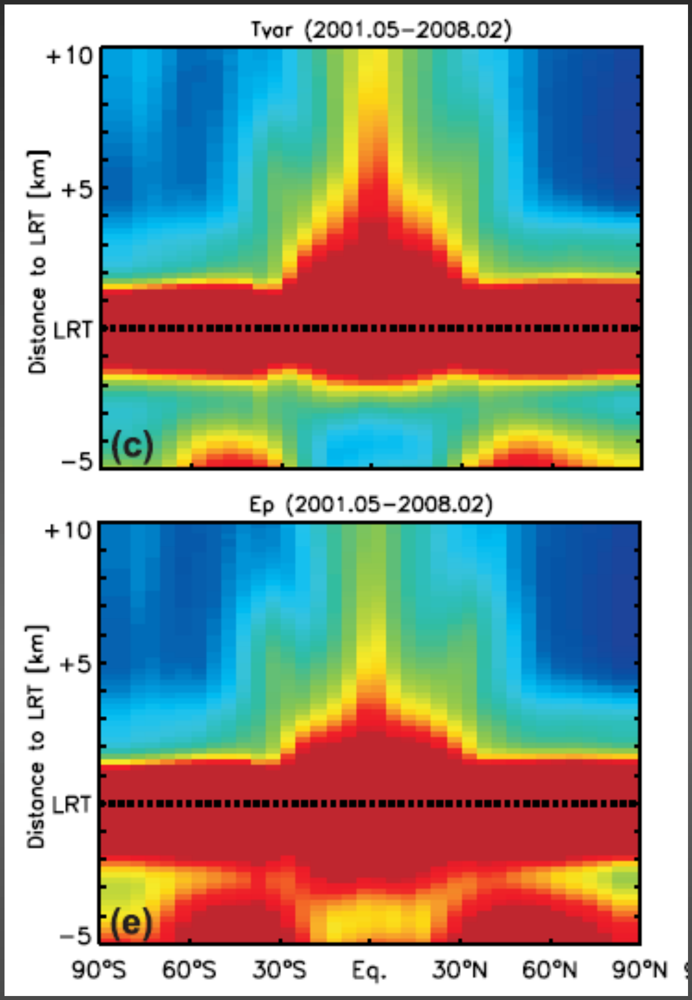
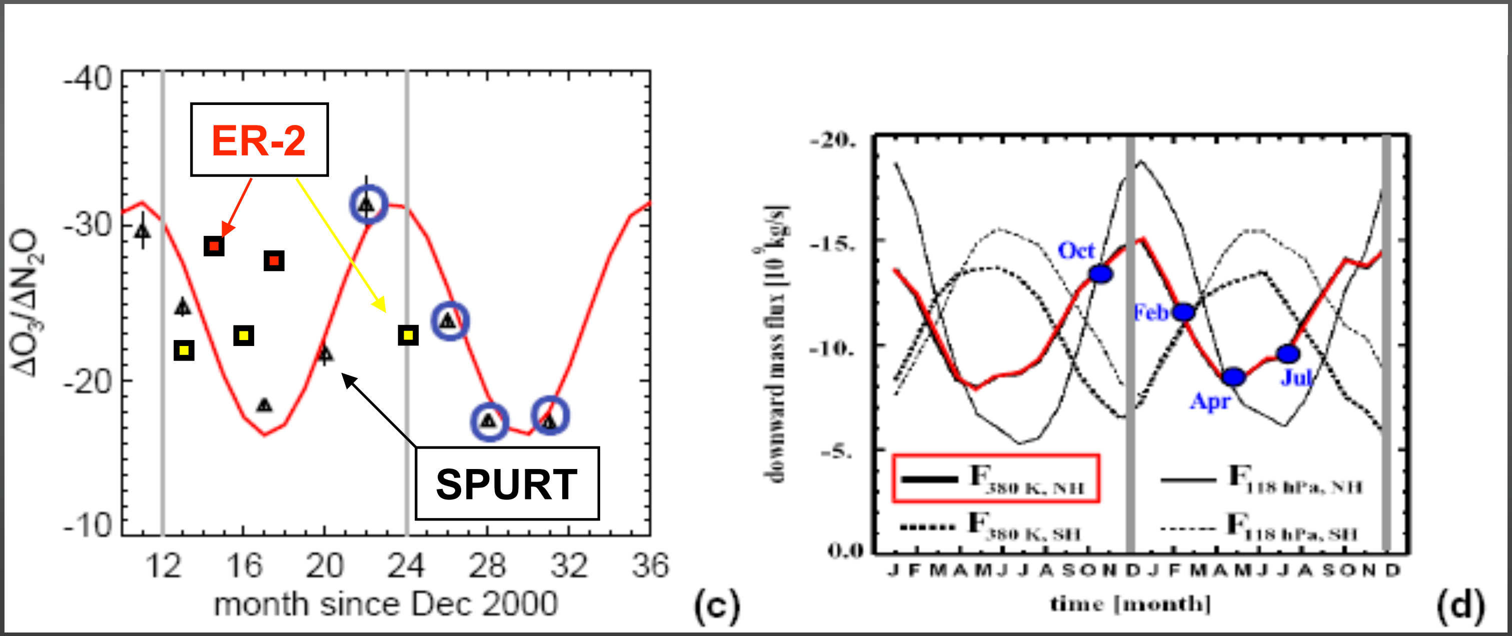


Figure 2. (a, b) Climatological normalized temperature, (c, d) temperature variance, and (e, f) potential energy relative to the lapse rate tropopause for the complete (left) and separate (right) filtering method and the time interval from May 2001 to February 2008. The horizontal dashed line marks the lapse rate tropopause. The latitudinal resolution is 5° between 77.5°N–77.5°S and 10° for 85°N and 85°S (34 latitude bands).

THE SEASONAL CYCLE IN THE O3-N2O CORRELATION SLOPES

Aircraft data from the SPURT project revealed a strong seasonality in the 'background' composition of the UTLS which is influenced by the seasonal strength of the Brewer Dobson circulation.

However, the ER-2 data show a different seasonality.



Hegglin et al., ACP 2006

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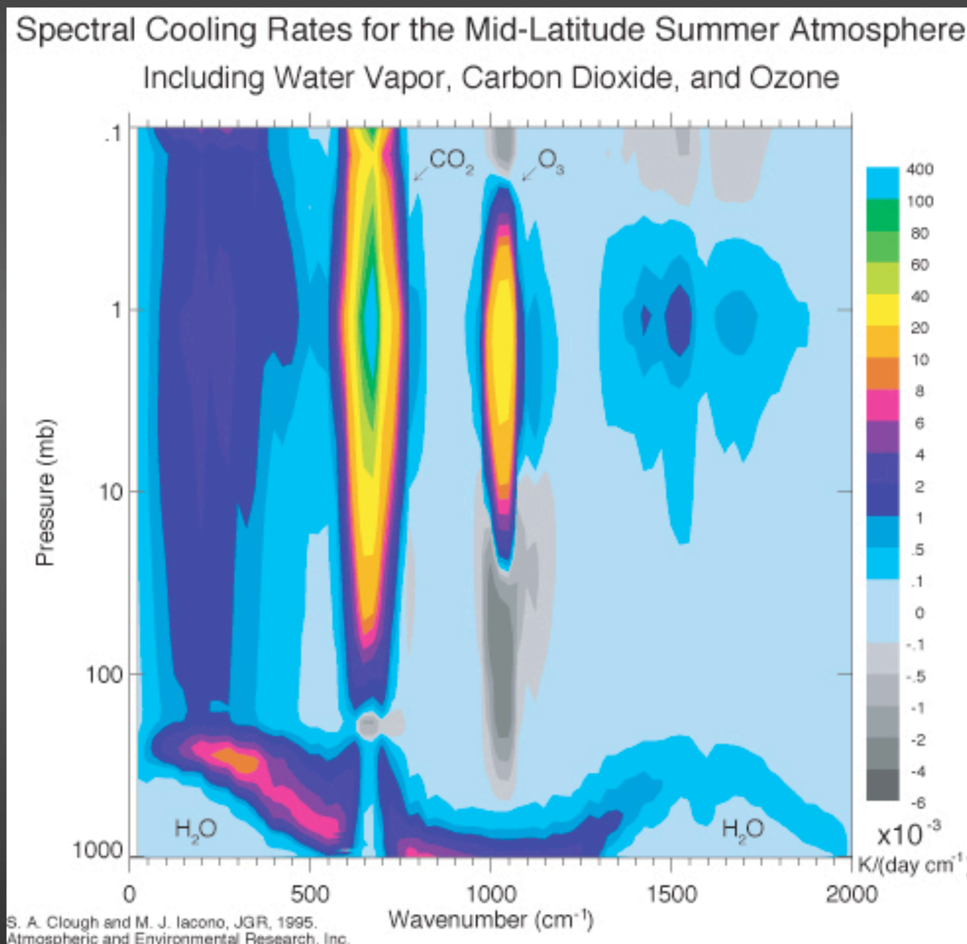
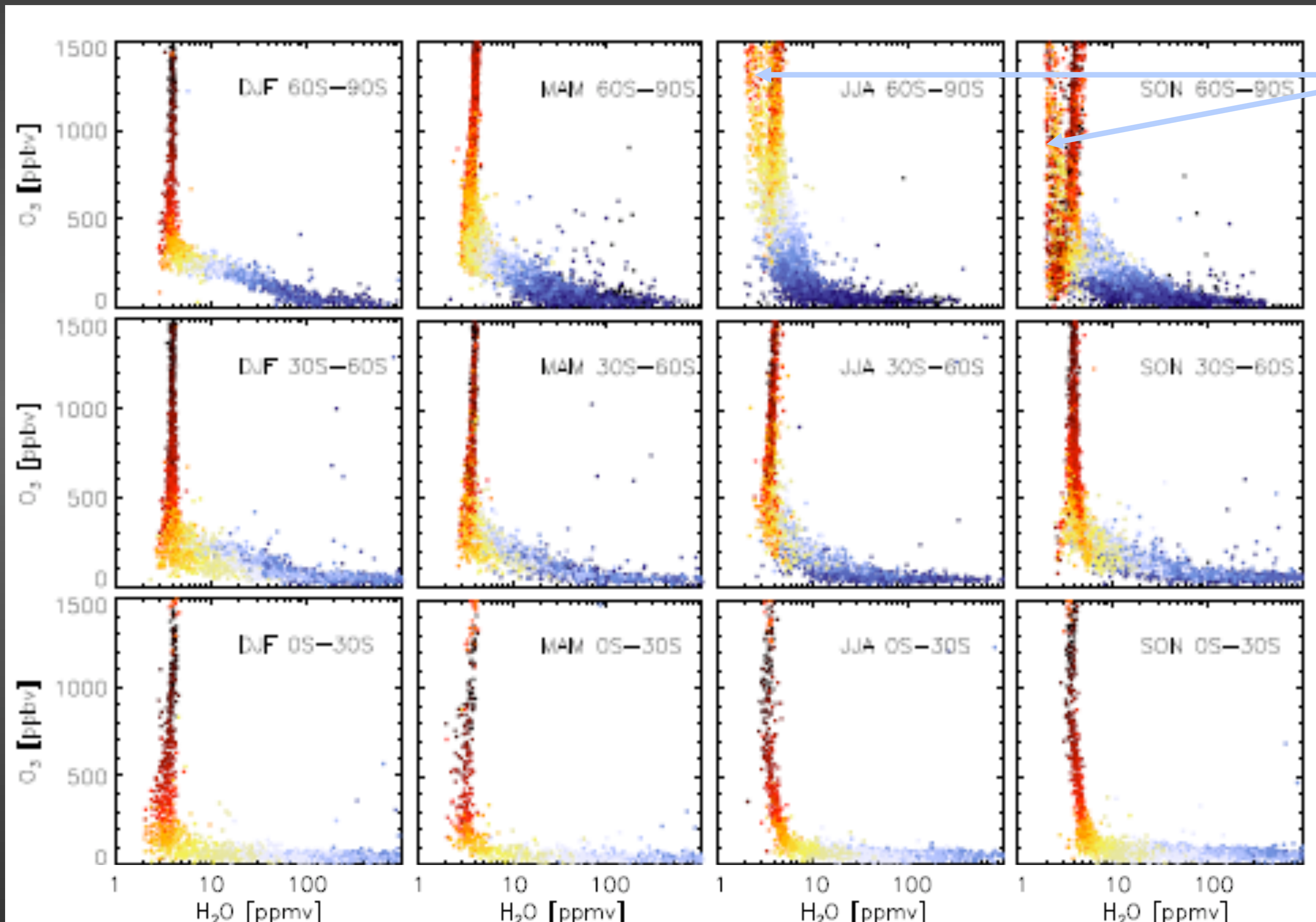
Radiative importance of the UTLS: The structure of spectral cooling rates around the tropopause is quite complicated, differing for different gases.



Net cooling around the tropopause is close to zero, implying strong temperature sensitivity to greenhouse gas changes

Clough & Iacono, JGR 1995

SEASONAL O3-H2O SCATTERPLOTS FOR SOUTHERN HEMISPHERE



Polar vortex air with lower H_2O and O_3 values.

Seasonal dependency of the stratospheric entrance value of H_2O.