# LOTUS: Long-term ozone trends and uncertainties in the stratosphere

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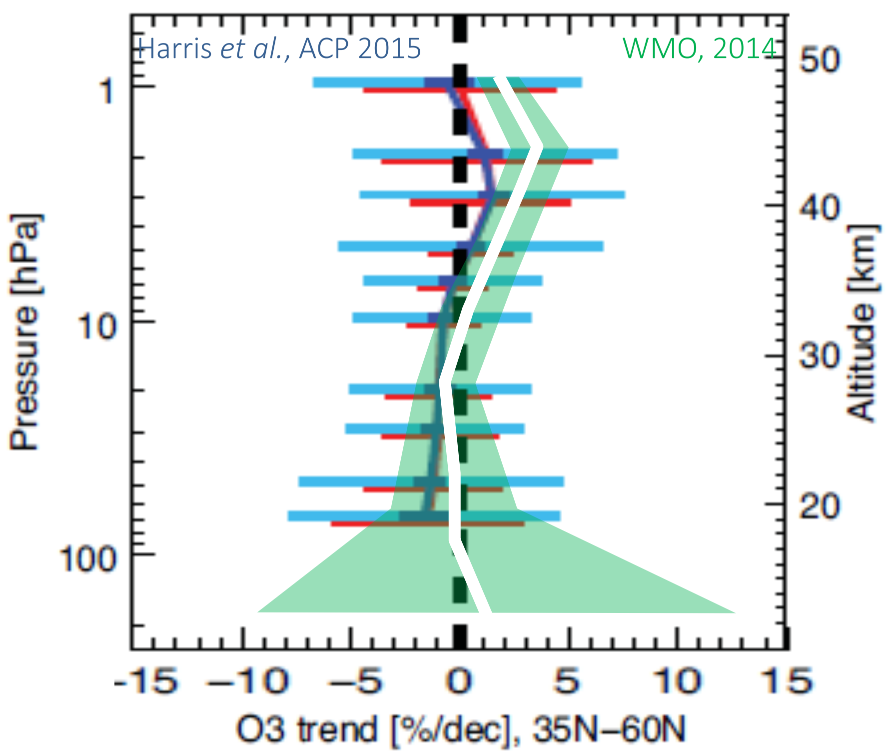
V. Sofieva, R. Damadeo, B. Hassler
and 30 participants

# Rationale

- Different ozone profile trend results by WMO/UNEP 2014 Ozone Assessment and by SI2N initiative.
- Evaluation of trend significance is very sensitive to assumptions made, and we don't know which ones are more realistic.
- It is crucial to resolve this issue before the next WMO/UNEP Ozone Assessment (2018).
- WMO/UNEP Ozone Assessments are based on assessed published results.



# LOTUS initiative

- Long-term Ozone Trends and Uncertainties in the Stratosphere
- SPARC initiative started in 2016

## Coordination team

I. Petropavlovskikh (NOAA/CIRES, US), D. Hubert (BIRA-IASB, BE) & S. Godin-Beekmann (LATMOS, FR)

## MIDI team

(Multi-Instrument Data Integration)

Leads : V. Sofieva (FMI, FI) & R. Damadeo (NASA-LaRC, US)

Members : S. Frith, J. Wild, W. Steinbrecht, C. Vigouroux, A. Laeng, T. Verhoelst, M. Weber, D. Loyola, L. Froidevaux, D. Degenstein, K. Walker, H. Smit, T. Leblanc, R. Querel, R. Schofield, …

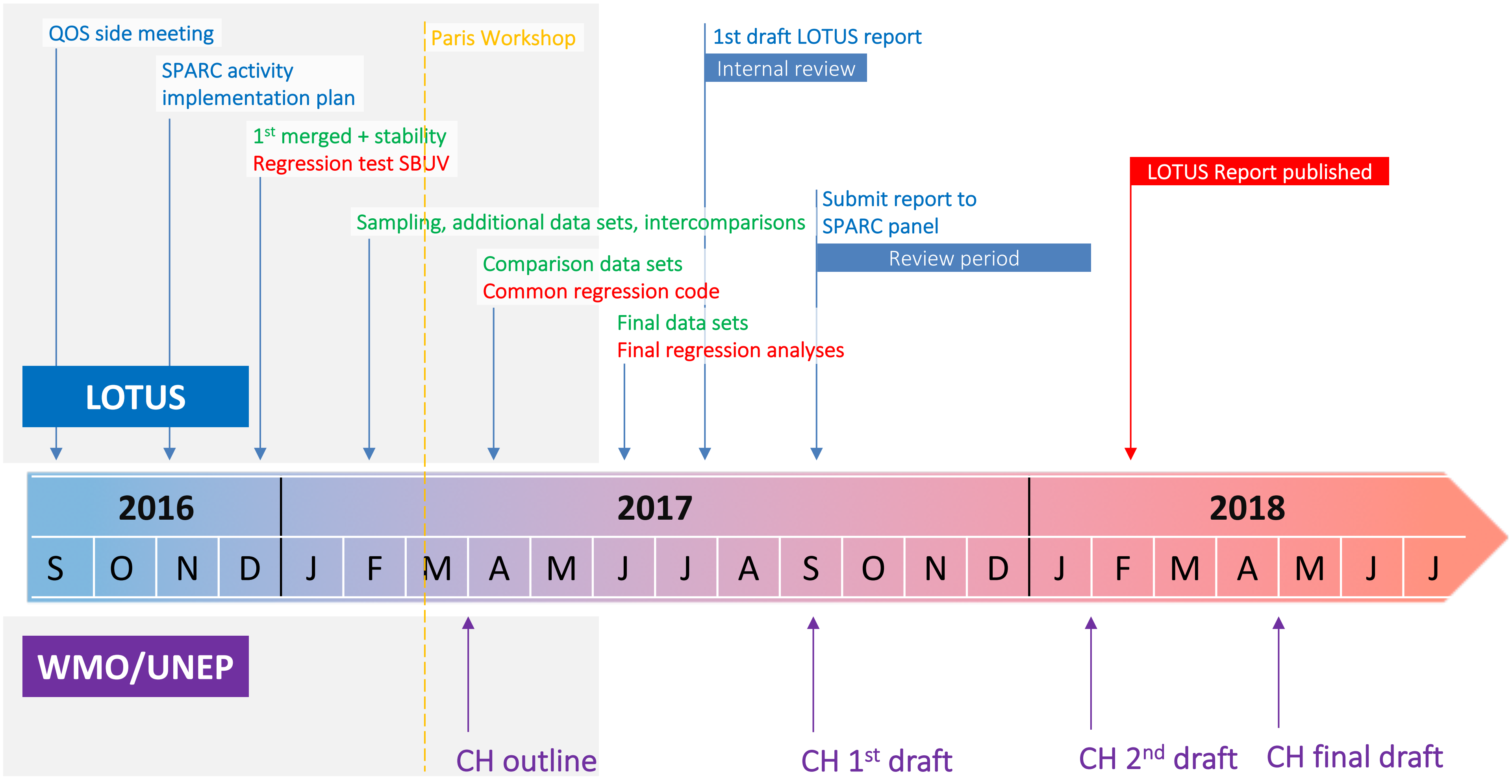
## ROAST team

(Regressions of Ozone Analyzed for Stratospheric Trends)

Leads : R. Damadeo (NASA-LaRC, US) & B. Hassler (Bod.Sc., NZ)

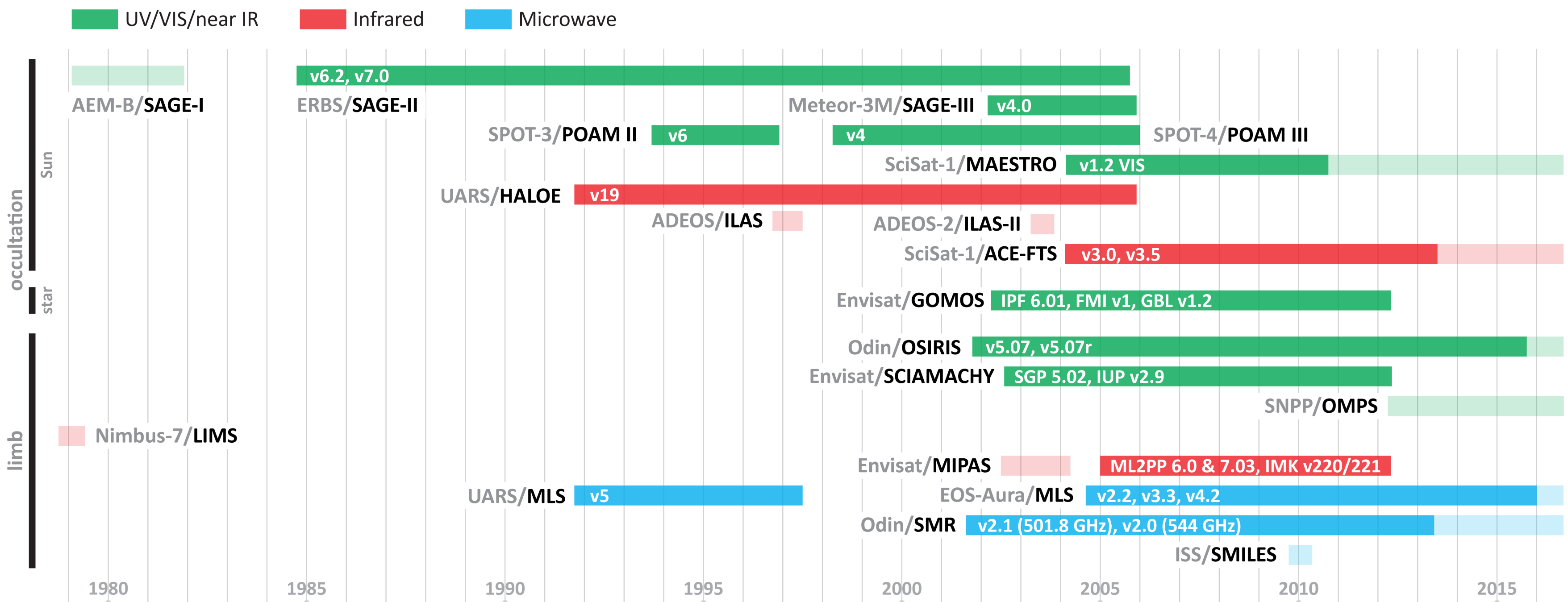
Members : S. Frith, J. Wild, W. Steinbrecht, C. Vigouroux, A. Laeng, K. Tourpali, D. Balis, C. Zerefos, T. von Clarmann, K.-L. Chang, M. Coldewey-Egbers, M. Laine, R. Stübi, E. Maillard Barras, R. Portman, J. Tamminen, B. Weatherhead, …

# LOTUS timeline



# stratospheric ozone profile data sets

## Limb ozone profile data sets




+ nadir profile data

+ ground-based profile data (ozonesonde, lidar, FTIR, MWR, Umkehr)

# Overview of merged data sets

**Satellite**

- Nadir (pres, vmr)
  - SBUV MOD v8.6 NASA (1970-2016)
  - SBUV COH v8.6 NOAA (1978-2016)
- Limb (alt, ndens)
  - SAGE II–CCI–OMPS (1984-2016)
  - SAGE II–OSIRIS–OMPS (1984-2016)
  - SAGE II–MIPAS–OMPS (1984-2017)
- Limb (pres, vmr)
  - GOZCARDS v2.10 (1991-2016)
- Limb (mixed)
  - GOZCARDS v2.20 (1979-2016)
  - SWOOSH v2.6 (1984-2016)
- Particle Filter
  - SBUV NOAA/NASA + GOZCARDS/SWOOSH
  - SAGE-OSIRIS/CCI/MIPAS-OMPS

**Ground-based data**

| Instrument | Station, period since |
|---|---|
| Lidar | OHP (1986), Hohenpeißenberg (1987), Table Mountain (1988), Mauna Loa (1993), Lauder (1994) |
| Microwave | Bern (1994), Payerne (2000), Mauna Loa (1995), Lauder (1992) |
| FTIR | Izana (1999), Lauder (2001), Jungfraujoch (1995), Wollongong (1996) |
| Umkehr | Mauna Loa (1984), Lauder (1987), Arosa (1956), OHP (1984), Boulder (1984), Fairbanks (1994), Perth (1984) |
| Ozonesondes | NOAA and SHADOZ datasets + NDACC/WOUDC stations |

# Changes in individual data sets: ongoing work…

- SBUV v8.6 : no changes
- SAGE II v7 : correction for sampling bias correction
- OSIRIS v5.10 : correction for drift in  absolute pointing
- GOMOS ALGOM : improved screening, aerosol model
- MIPAS v7, SCIAMACHY v3.5:  updated Level-1 data, ...
- Aura MLS v4.2, ACE-FTS v3.6: no major changes
- OMPS-LP USASK v1.02: new data set
- ...

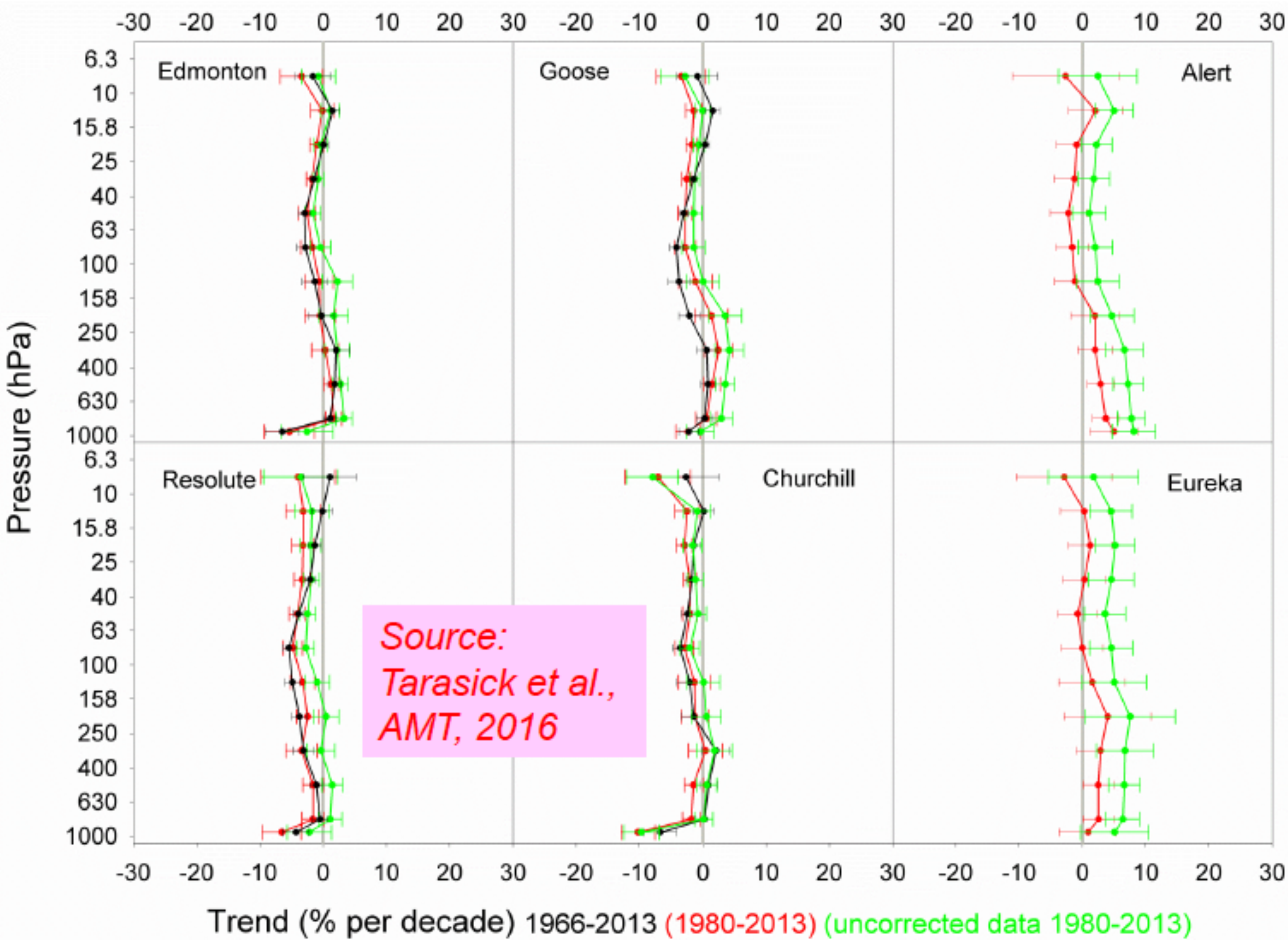
# O3S-DQA Homogenisation: Objectives

JÜLICH
FORSCHUNGSZENTRUM

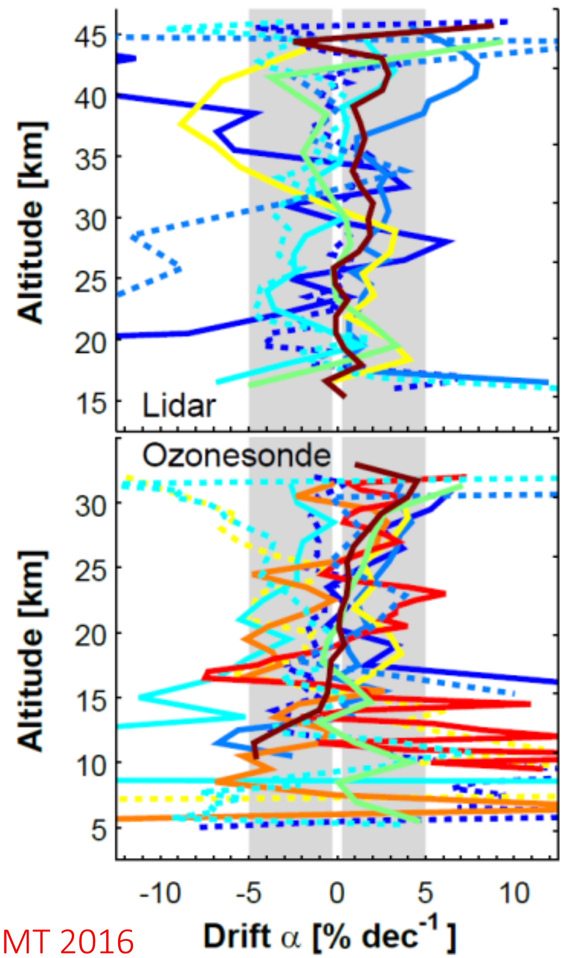
“Ozone Sonde Data Quality Assessment (O3S-DQA)” activity started in 2011 has following three major objectives:

1. Homogenization of a selected ozone sonde data set with the **goal to reduce uncertainty from 10-20% down to 5-10%** **(focus on SST-transfer functions, but also other instrumental aspects)**
2. **Documentation** of the homogenization process and the quality of ozonesonde measurements including **quantification of the uncertainty of each ozone sonde measurement**
3. Storage of additional **raw data of O3S** and the **overall uncertainty of each O3S-measurement**

# O3S-DQA: O3 Trends Before & After

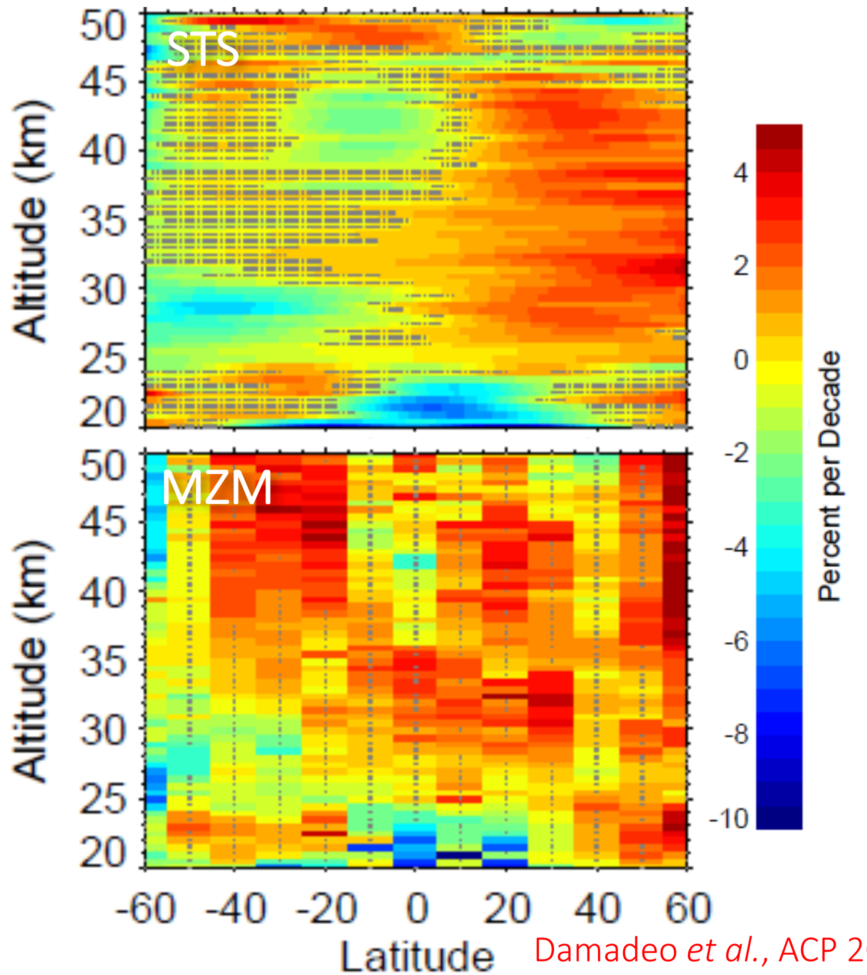


# Uncertainties in ozone profile data records: stability, sampling




Hubert *et al.*, AMT 2016

SAGE II Ozone recovering trends




Damadeo *et al.*, ACP 2014

# Ground-based intercomparisons

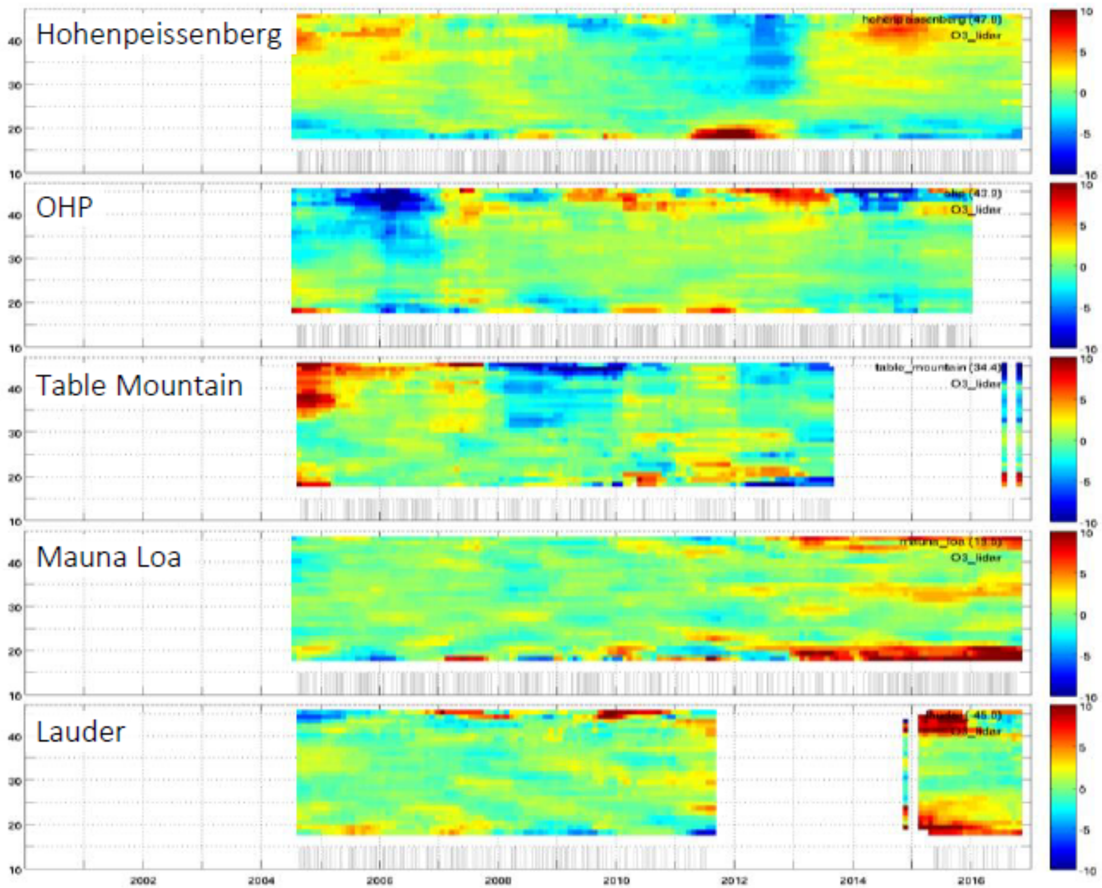
**Ground-based network data are stretched to their limits as well**

In such situations, a large number of data records is crucial

**Example… different temporal features of Aura MLS versus data at 5 lidar sites**

- Some features due to changes in lidar system
- Other features not significant or not well understood
- Similar picture for ozonesonde or MWR networks

Hubert et al., in prep.



# Overview: GOZCARDS and SWOOSH ozone data sets

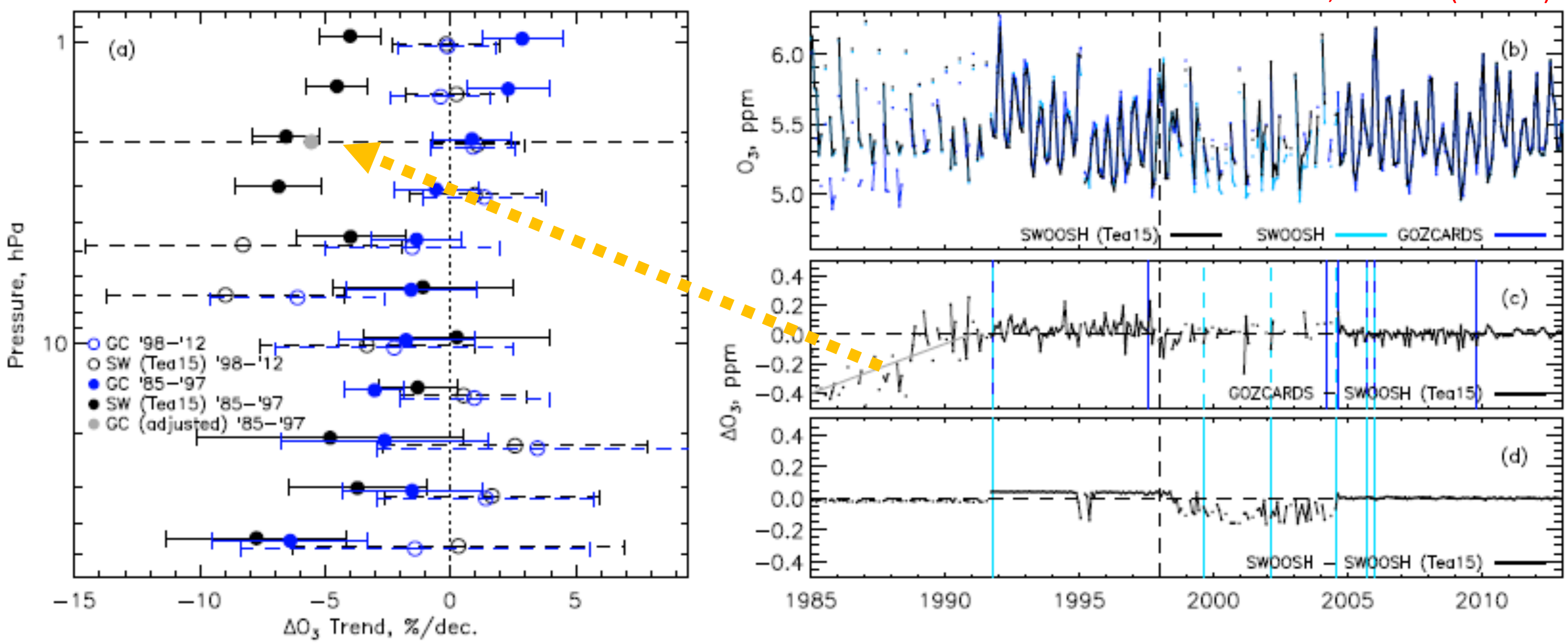
| | GOZCARDS<br>V1.01<br>1979 - 2016 | GOZCARDS<br>V2.10<br>1991 - 2016 | GOZCARDS<br>V2.20<br>1979 - 2016 | SWOOSH<br>V2.6<br>1984 - 2016 |
|---|---|---|---|---|
| **Data sets** | SAGE-I (V5.9rev)<br>**SAGE-II (V6.2)**<br>HALOE (V19)<br>UARS MLS (V5)<br>ACE-FTS (V2.2)<br>Aura MLS (V2.2)<br>(AMLS V2.2 stopped in 2015; we used adjusted V4.2 data for 2015-2016) | HALOE (V19)<br>Aura MLS (V4.2) | SAGE-I (V5.9 rev)<br>**SAGE-II (V7)**<br>HALOE (V19)<br>Aura MLS (V4.2) | **SAGE-II (V7)**<br>HALOE (V19)<br>HIRDLS (V7)<br>UARS MLS (V5)<br>SAGE-III (V4)<br>ACE-FTS (V2.2)<br>Aura MLS (V4.2) |
| **Vertical pressure grid spacing** | **6 levels per decade change in pressure** | 12 levels per decade change in pressure | 12 levels per decade change in pressure | 12 levels per decade change in pressure |
| **Adjustments (Average Offsets used to debias different data sets)** | 1. **Uses SAGE-II V6.2 as reference.**<br>2. Additive offsets are calculated from monthly zonal means in every 10 degree lat. bin. | 1. **Uses average of HALOE & Aura MLS as reference.**<br>2. Additive offsets are calculated from monthly zonal means in every 10 degree lat. bin. | 1. **Uses SAGE-II V7 as reference.**<br>2. Additive offsets are calculated from monthly zonal means in every 10 degree lat. bin. | 1. **Uses SAGE-II V7 as reference.**<br>2. **Additive offsets are calculated based on coincident profiles on PV/equivalent latitude coordinates.** |
| **Averaging method for different instrument data** | Uses equal weight for different instrument data sets | Uses equal weight for different instrument data sets | Uses equal weight for different instrument data sets | **Uses weighted average method** (by number of measurements from different instruments) |

**References** GOZCARDS: *Froidevaux et al.* (2015); SWOOSH: *Davis et al.* (2016)

**Note:** monthly means from occultation instruments are not "sampling-corrected" (as done by R. Damadeo)

# Updates of merged satellite records & comparison

Ball et al., ACPD (2017)




- There is now (much) improved understanding of the causes of differences between data sets
- Most merged records were updated since last assessment, using updated merging methods, updated single record data, …

# Sensitivity of trend to data sets used for merging

**For SAGE II-CCI-OMPS…**

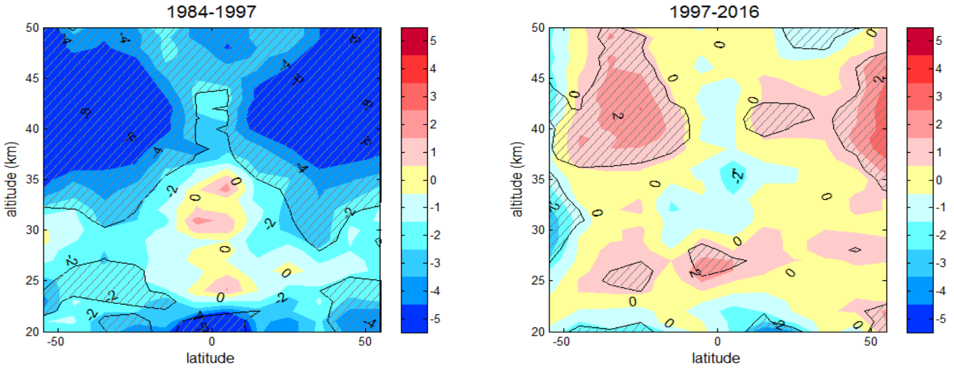
Test impact of periods with reduced data quality (SCIAMACHY, OMPS)

Test impact of conversion using retrieved T (MIPAS, ACE-FTS)

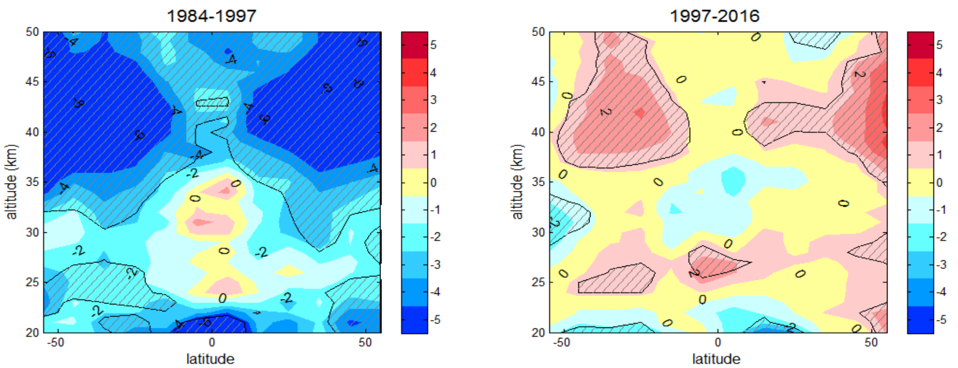
…

**Outcome**

Only minor changes in trend. The merging method used for SAGE II-CCI-OMPS seems insensitive to “outlying” data.




SAGE II & CCI (OSIRIS, GOMOS, SCIAMACHY, MIPAS, ACE-FTS) & OMPS (2D USask)




As above, but without MIPAS and ACE-FTS
→ minor changes in trends after 1997.

Sofieva et al., in prep.

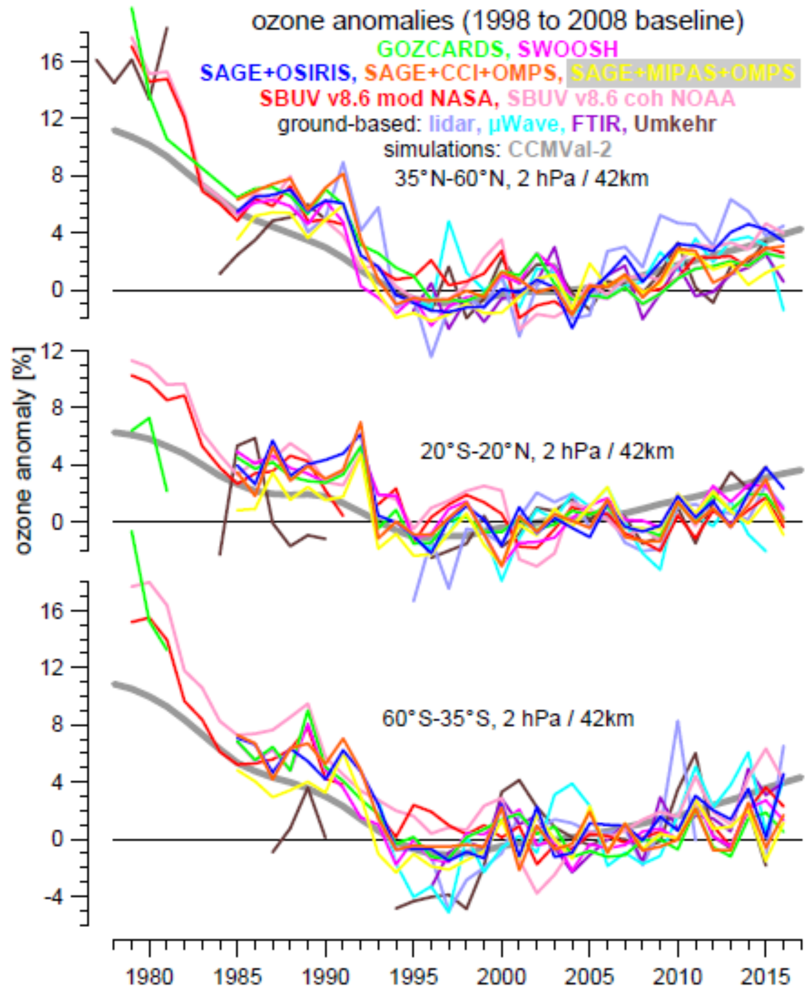
# Time series

Comparison of zonally averaged anomaly time series in upper stratosphere

Overall good agreement between the satellite/ground-based data records

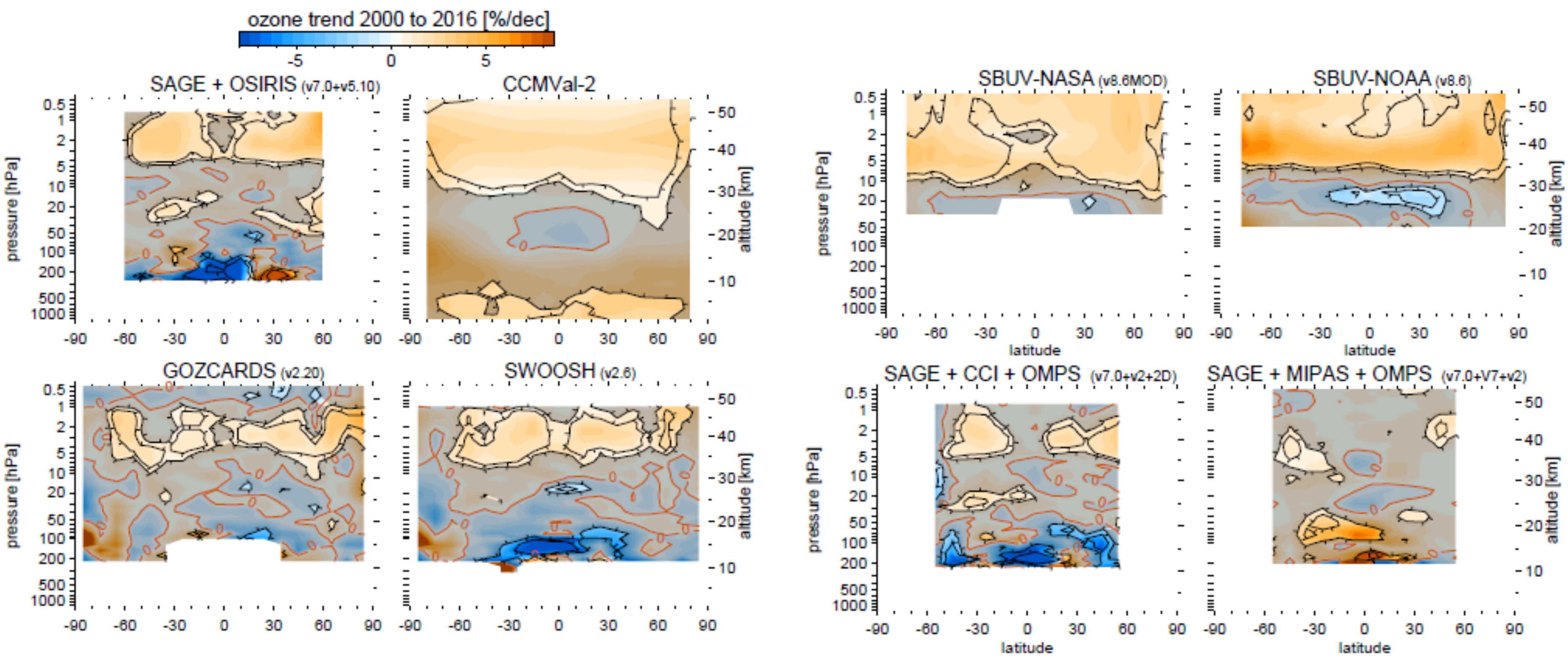
Consistent picture of decline, levelling of and increases in upper stratosphere.

Consistent inter-annual variations.




Steinbrecht et al., ACPD (2017)

# Trend cross sections



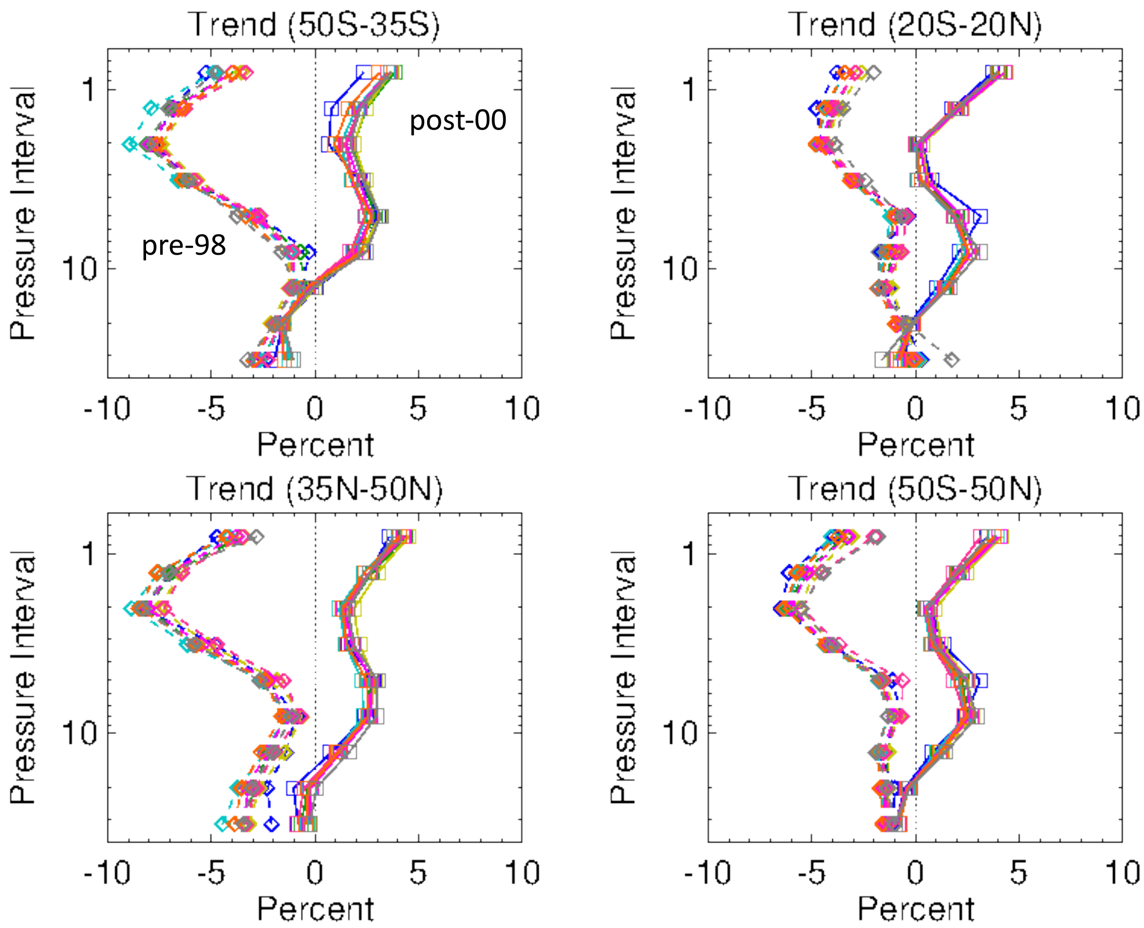

Steinbrecht et al., ACPD (2017)

# Regression test

**Test of current regression codes on common profile data set**
SBUV MOD v8.6 NASA (1970-2016)

**Big success… 15 teams participated (4 of which in Ozone_cci)**
Each using different methods to compute trend, different proxies, different treatment of uncertainties, …

**Outcome**
Trend results agree within ~1%/decade.
Larger differences noted for other regressed terms, e.g. solar & QBO



# Further development of regression analyses

USASK team developed a regression toolset that is being used for

- Sensitivity tests
  - Choice of regression terms
  - Choice of proxies
  - Start/end period
  - Treatment of autocorrelation
  - Use regression uncertainties (or not)
- All trend analyses using final set-up(s)
  - One code to obtain consistent results

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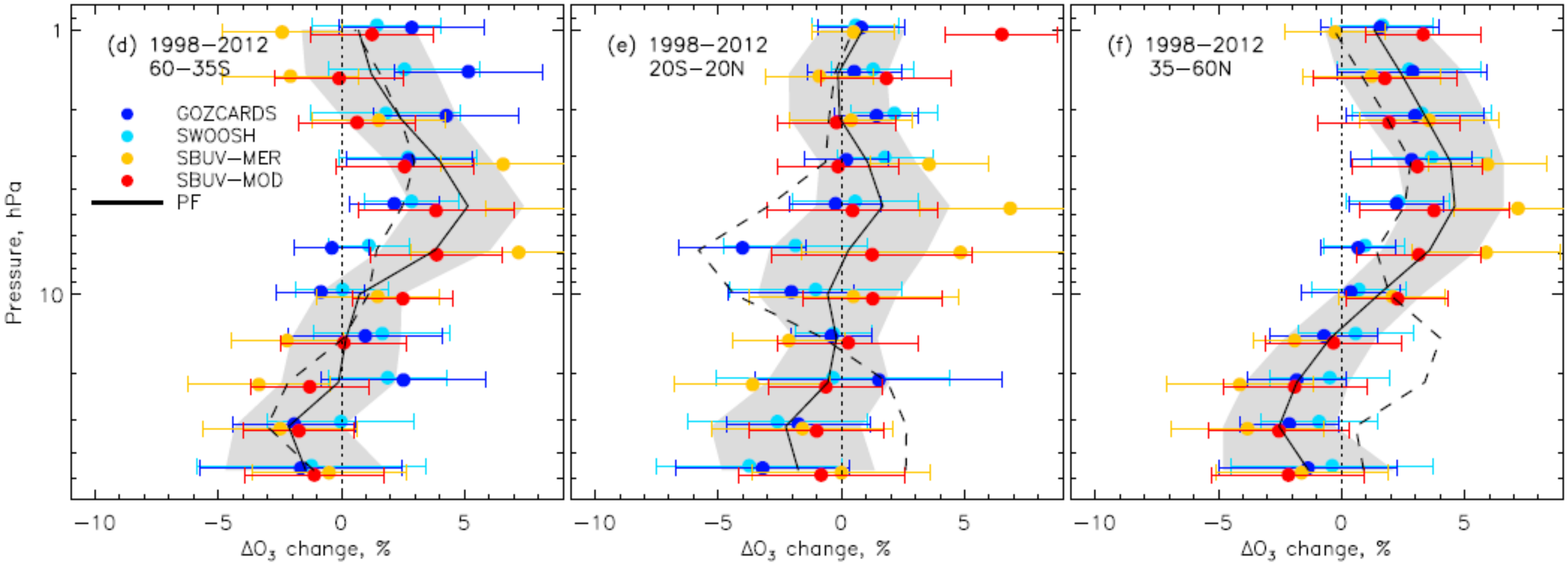
# Different trend models

Multilinear Regression (MLR) vs
Dynamical Linear Modelling (DLM)

The Bayesian DLM approach jointly fits for the non-linear time-varying trend, the regression coefficients of the five proxies and seasonal modes




Ball et al., ACPD (2017)

- Changes in ozone are generally not linear
- MLR method (dashed), leading to artificial hemispheric asymmetry in lower stratosphere

# Conclusions

- On going work on regression analyses with the new (merged) data sets)
- 1st draft report due on August 2017 in time for the WMO/UNEP Ozone Assessment 2018
- 2nd phase:
  - more sensitivity tests on proxies to be used
  - Test of alternative trend models

LOTUS nearing blooming season…

# Thank you !

LONG-TERM OZONE TRENDS AND UNCERTAINTIES IN THE STRATOSPHERE

LOTUS