The SPARC LOTUS Initiative

LONG-TERM OZONE TRENDS AND UNCERTAINTIES IN THE STRATOSPHERE

LOTUS

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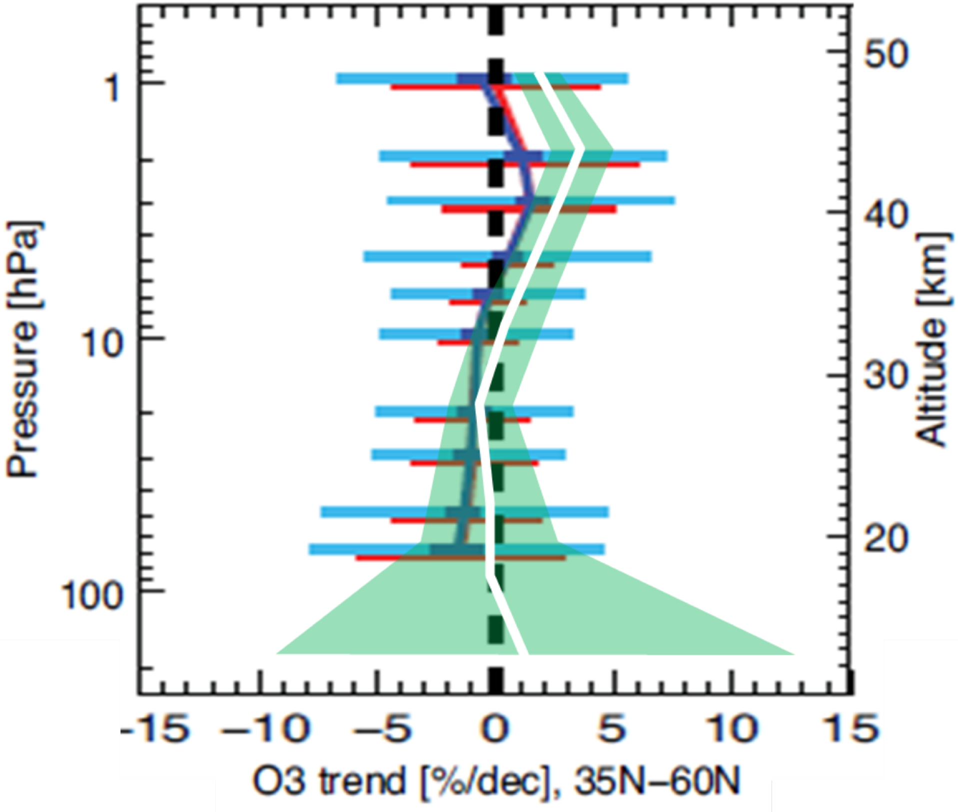
Rationale

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.

Satellite Merged Data Sets

Merged Data Set	Instruments
SBUV MOD	SBUV series Nimbus-4, -7, NOAAs 11,14,16,17,18,19
SBUV Cohesive	SBUV series Nimbus-7, NOAAs 9,11,16,17,18,19
GOZCARDS	SAGE I v5.9_rev, SAGE II v7, HALOE v19, Aura MLS v4.2
SWOOSH	SAGE II v7, HALOE v19, UARS MLS v5, SAGE III v4, AURA MLS v4.2
SAGE-OSIRIS-OMPS	SAGE II v7, OSIRIS v5.10, OMPS-LP USask2D v1.0.2
SAGE-CCI-OMPS	SAGE II v7, OSIRIS v5.10, GOMOS ALGOM2s v1, MIPAS IMK/IAAv7, SCIAMACHY UB v3.5, ACE-FTS v3.5/3.6, OMPS-LP USask2D v1.0.2
SAGE-MIPAS-OMPS	SAGE II v7, MIPAS IMK/IAA v7, OMPS-LP NASA v2.5, ACE-FTS v3.5/3.6

- Same instrument data included in multiple merged data sets
- Many records are mix of limb sensors and occultation instruments
- Some are in vmr/pressure, others number density/altitude, some incl. unit conversion

Ground-Based Data Sources

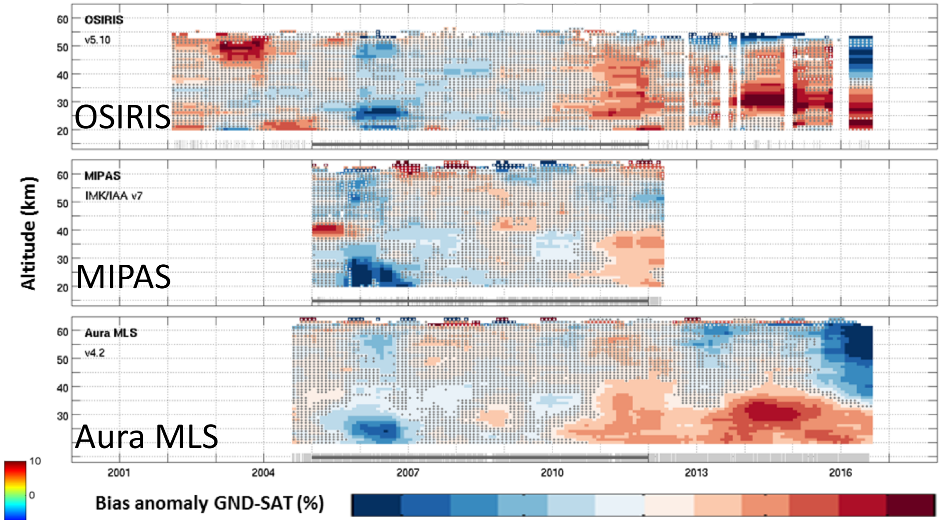
Instrument	Station, period since
Lidar	OHP (1986), Hohenpeißenberg (1987), Table Mountain (1988), Mauna Loa (1993), Lauder (1994)
Microwave	Bern (1994), Payerne (2000), Mauna Loa (1995), Lauder (1992)
FTIR	Izana (1999), Lauder (2001), Jungfraujoch (1995), Wollongong (1996)
Umkehr	Mauna Loa (1984), Lauder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

- No merging, single station only or zonal means
- Efforts to homogenize ozonesonde records continues

Data Complication: Stability

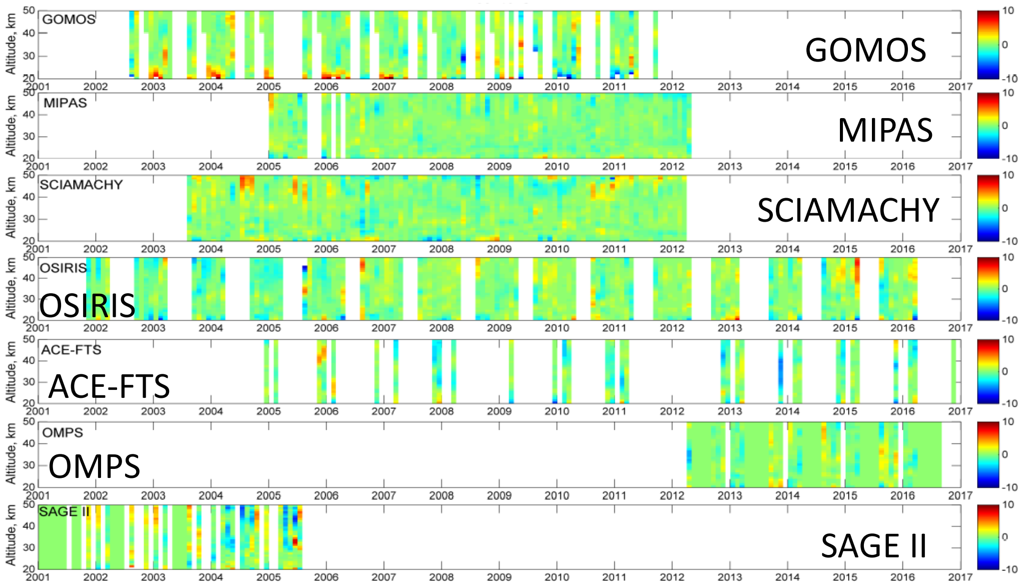
Determining long-term stability of individual instruments is very difficult as there is no reliable reference standard (to 1 % per decade)

Bern MRO difference from satellite records



Adapted from Hubert et al., 2018

Anomalies from median of all instruments

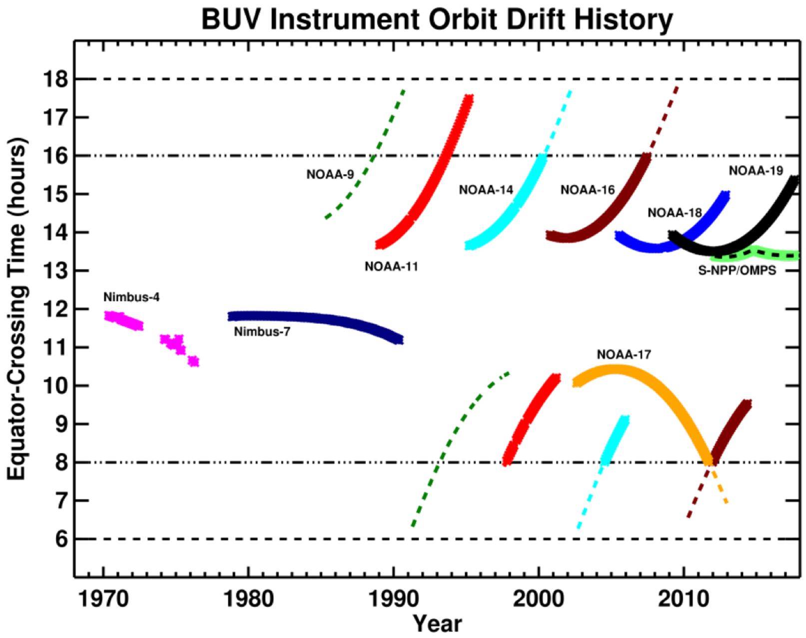


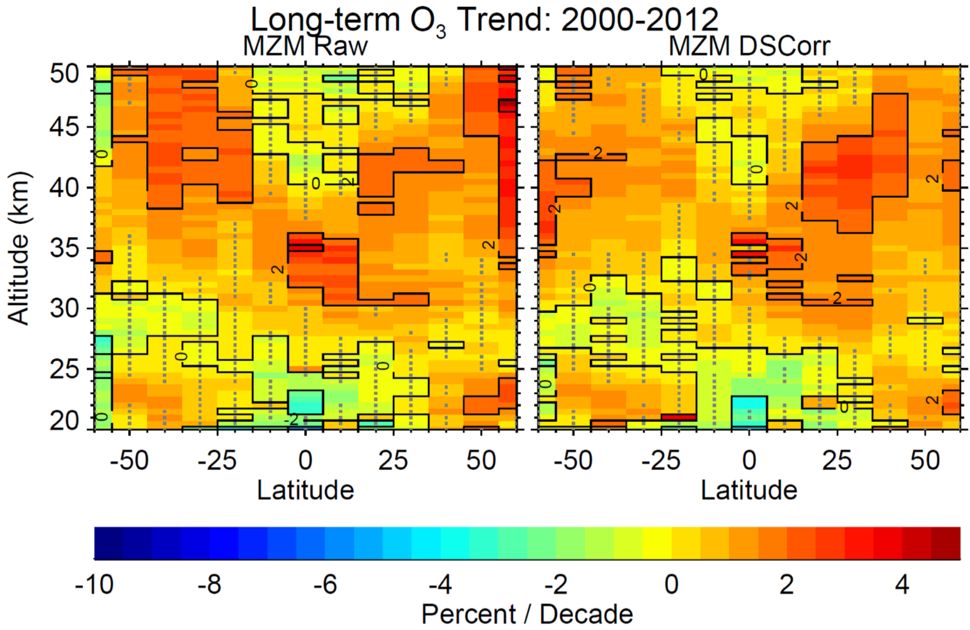
Various techniques comparing multiple data sets are used to identify outliers and establish best estimates of drift.

Sofieva et al. (2017)

Data Complication: Sampling Patterns

Spatial and temporal sampling patterns that vary in time can mimic long-term variability/trend in satellite (occultation) and ground-based records.





Diurnal cycle in ozone can alias into trend with non-uniform sampling of occultation sunrise/sunset events or slowly drifting orbits.

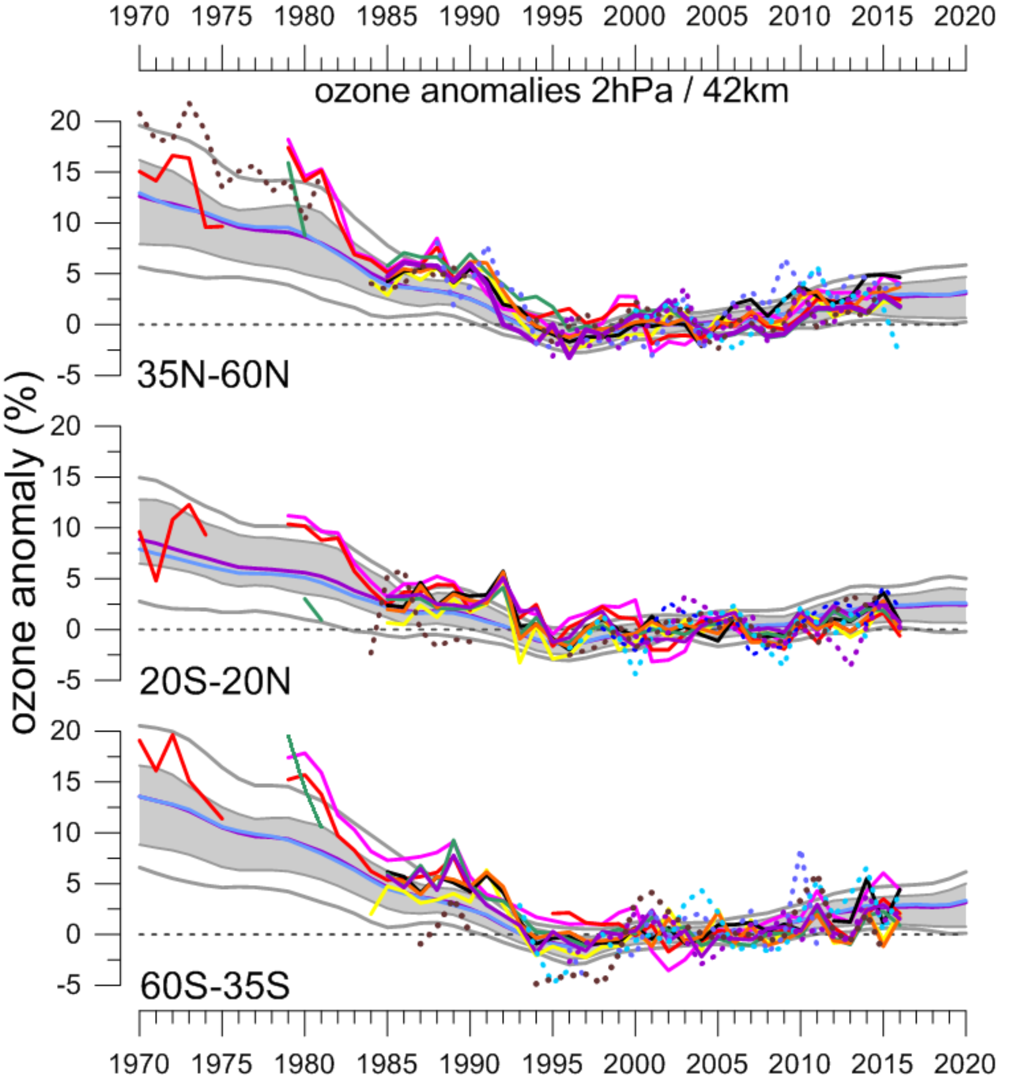
Data Complication: Native Coordinates And Vertical Resolution

Trends computed on altitude will vary from those computed on pressure if temperature changing. Minor cooling since mid-1990s in upper stratosphere.

Spurious ozone trends possible in conversion from altitude to pressure coordinates due to temperature record.

MS/US trends vary smoothly in altitude, so effects of vertical resolution differences expected to be minimal.

All effects relatively small, but so is expected ozone recovery rate.



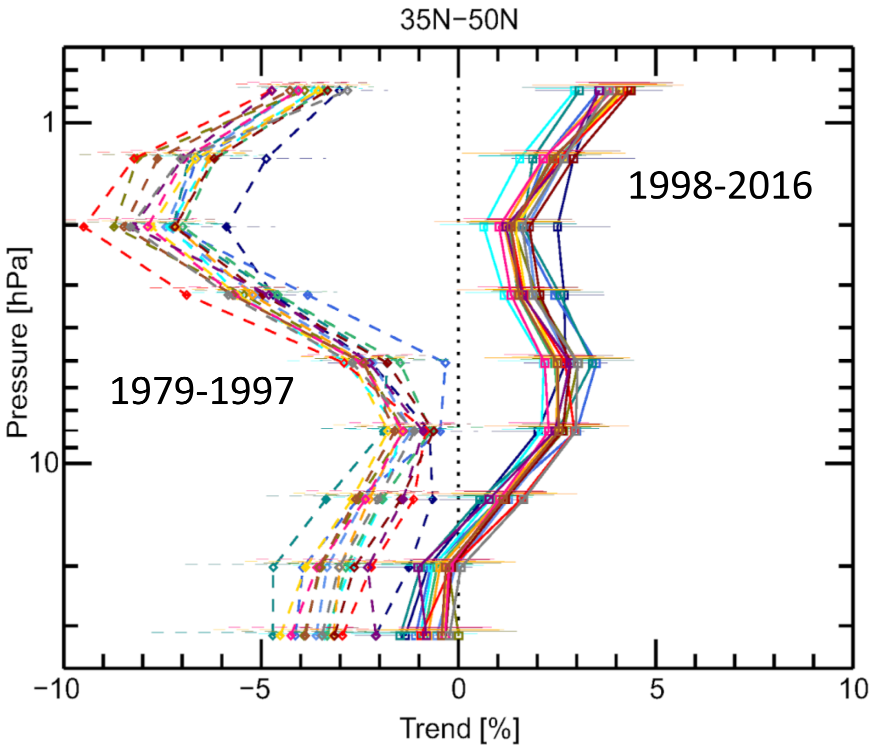
Sensitivity Test: Existing Models and Proxies

Same data set regressed using 15 community models showed potential uncertainty from choice of proxies in regression model

Tested sensitivity to various proxies by changing one at a time and evaluating difference in trend/uncertainty

Based on results, developed final “LOTUS regression” model optimized for US/MS
https://arg.usask.ca/docs/LOTUS_regression/

Long-term ozone change forced by ozone depleting substances and GHGs. Trend proxy reflects net ozone change from all forcing, and is consistent with recent studies.

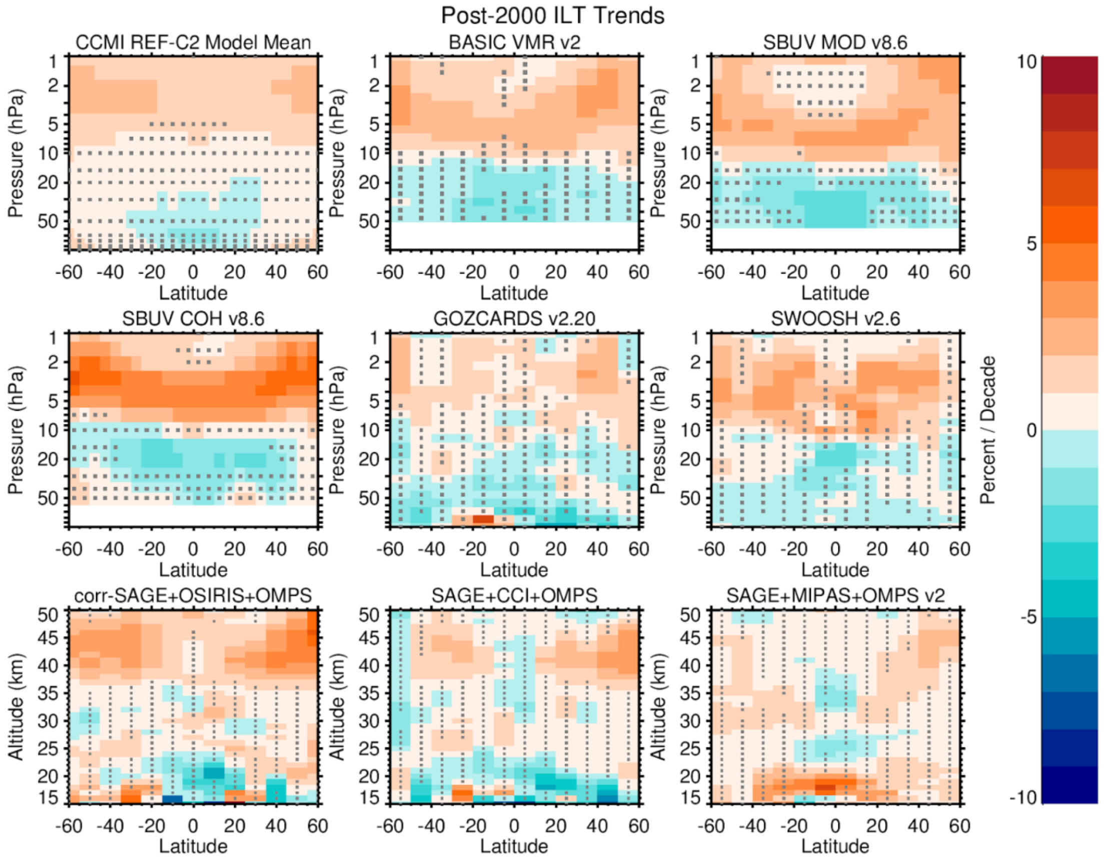


Trend Results: Satellites at Native Resolution

Results show similar patterns but clear discrepancies exist

Upper stratospheric trends agree with model expectations but lower stratospheric trends are varied

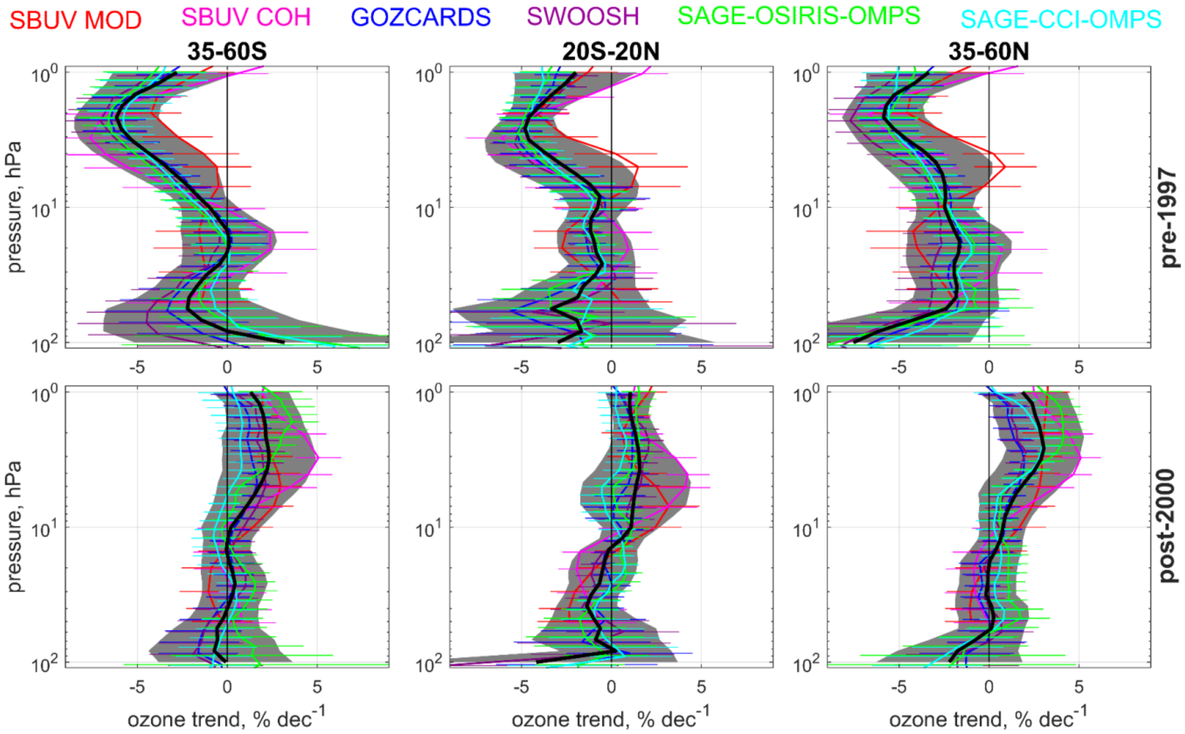
Addressing differences requires revisiting the merging process using original instrument data



Trend Results: Merged Satellites at Broad Latitude Bands

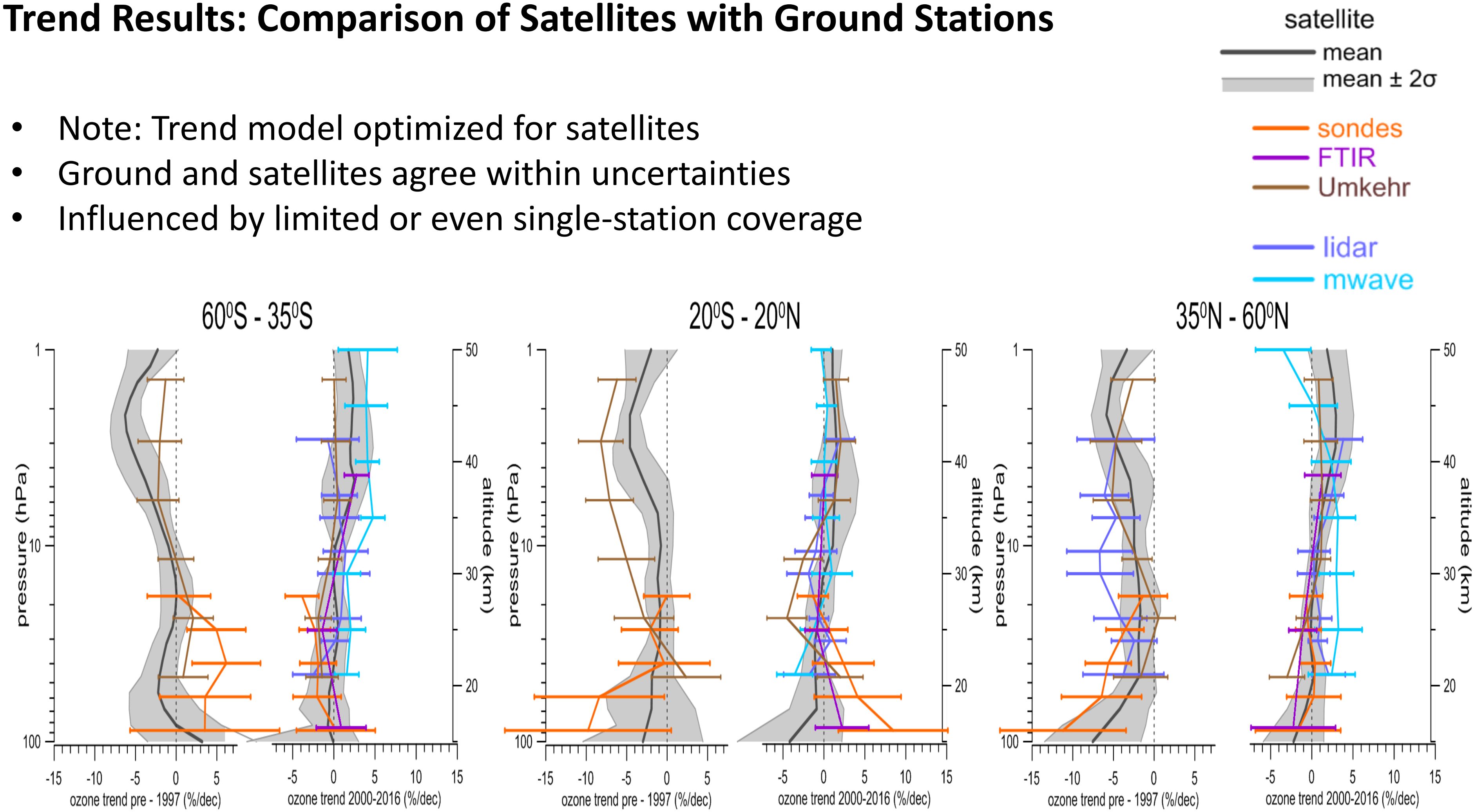
Post-2000 show significant +2-3%/dec trends in upper strat at NH mid-lat, significance of SH (+2%/dec) and tropics (+1%/dec) are close

Results in reasonable agreement with other recent studies (i.e., Harris et al., 2015; Steinbrecht et al., 2017) but uncertainty estimates vary



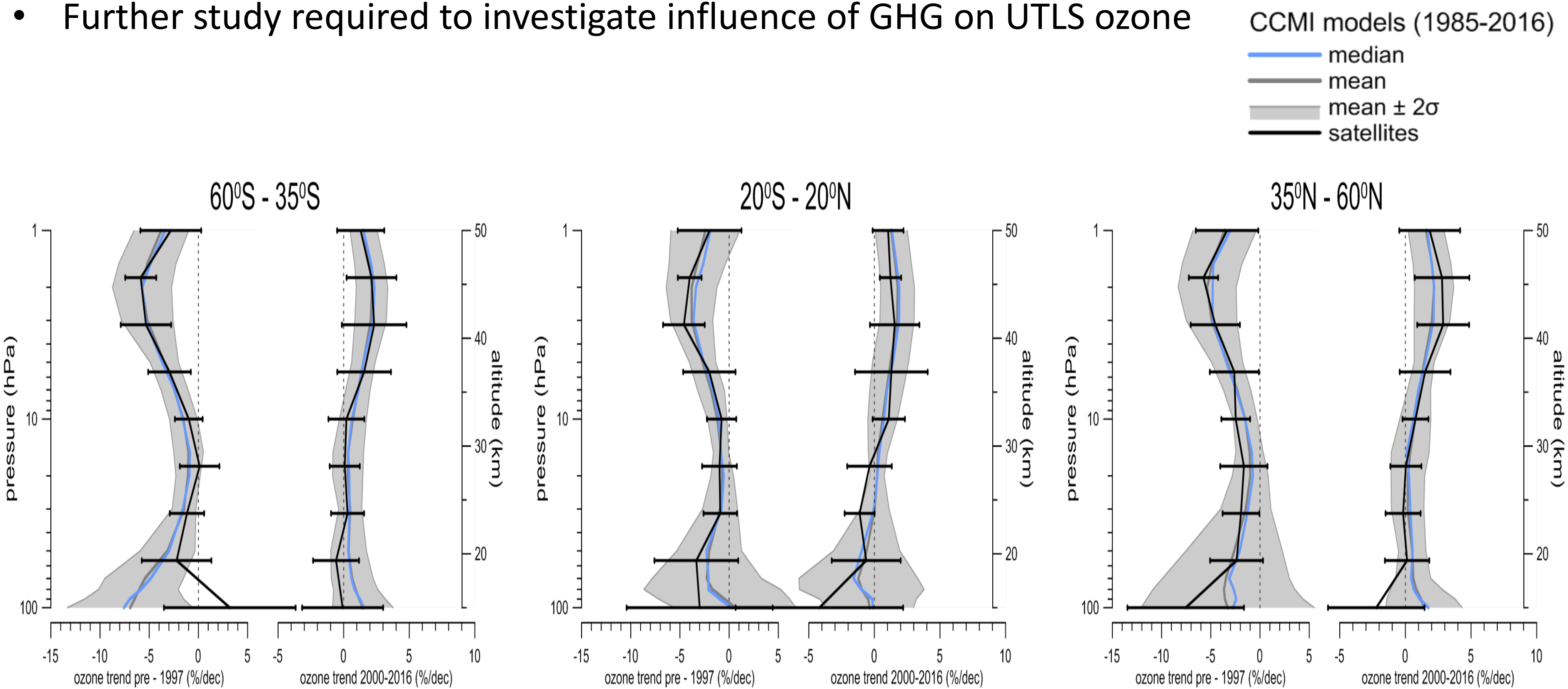
Trend Results: Comparison of Satellites with Ground Stations

- Note: Trend model optimized for satellites
- Ground and satellites agree within uncertainties
- Influenced by limited or even single-station coverage



Trend Results: Comparison of Satellites with Models

- Satellites show good agreement with models in middle to upper stratosphere
- Loss of agreement in lower stratosphere stems from increased instrument uncertainty
- Further study required to investigate influence of GHG on UTLS ozone



Conclusions and Next Steps

- Ozone trends in NH upper stratosphere are + 2-3 % per decade and statistically significant; upper stratospheric trends in the tropics and SH are smaller, marginally significant
- Data sets continually improving (not conforming!) through large-scale efforts such as LOTUS
- Uncertainty analysis very sensitive to assumptions made, easy to over- or under-estimate
- LOTUS report will be published as a SPARC publication soon!

Things to look into for next phase of LOTUS:

- Revisit merging techniques/uncertainties using original instrument data. Either model and remove geophysical variations or propagate uncertainties through merging process.
- Revisit trends from ground-based measurements, consider different proxy set
- Thoroughly investigate drifts and implement corrections
- Explore trends derived from total column data
- Explore trends in polar regions
- Explore trends in UTLS in conjunction with other SPARC efforts