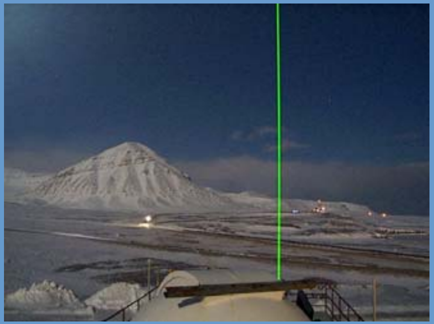
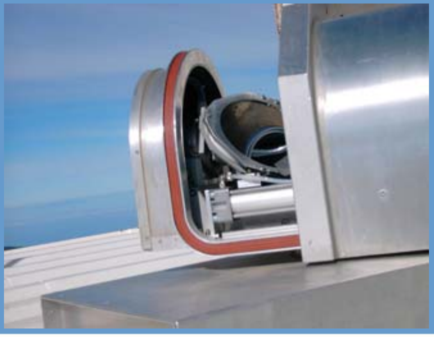
Network for the Detection of Atmospheric Composition Change

Exploring the Interface between Changing Atmospheric Composition and Climate

Ozone Profile Measurements within the NDACC





Mike Kurylo, Geir Braathen, Stuart McDermid and the NDACC Science Team

www.ndacc.org

Special Thanks To

Ian Boyd
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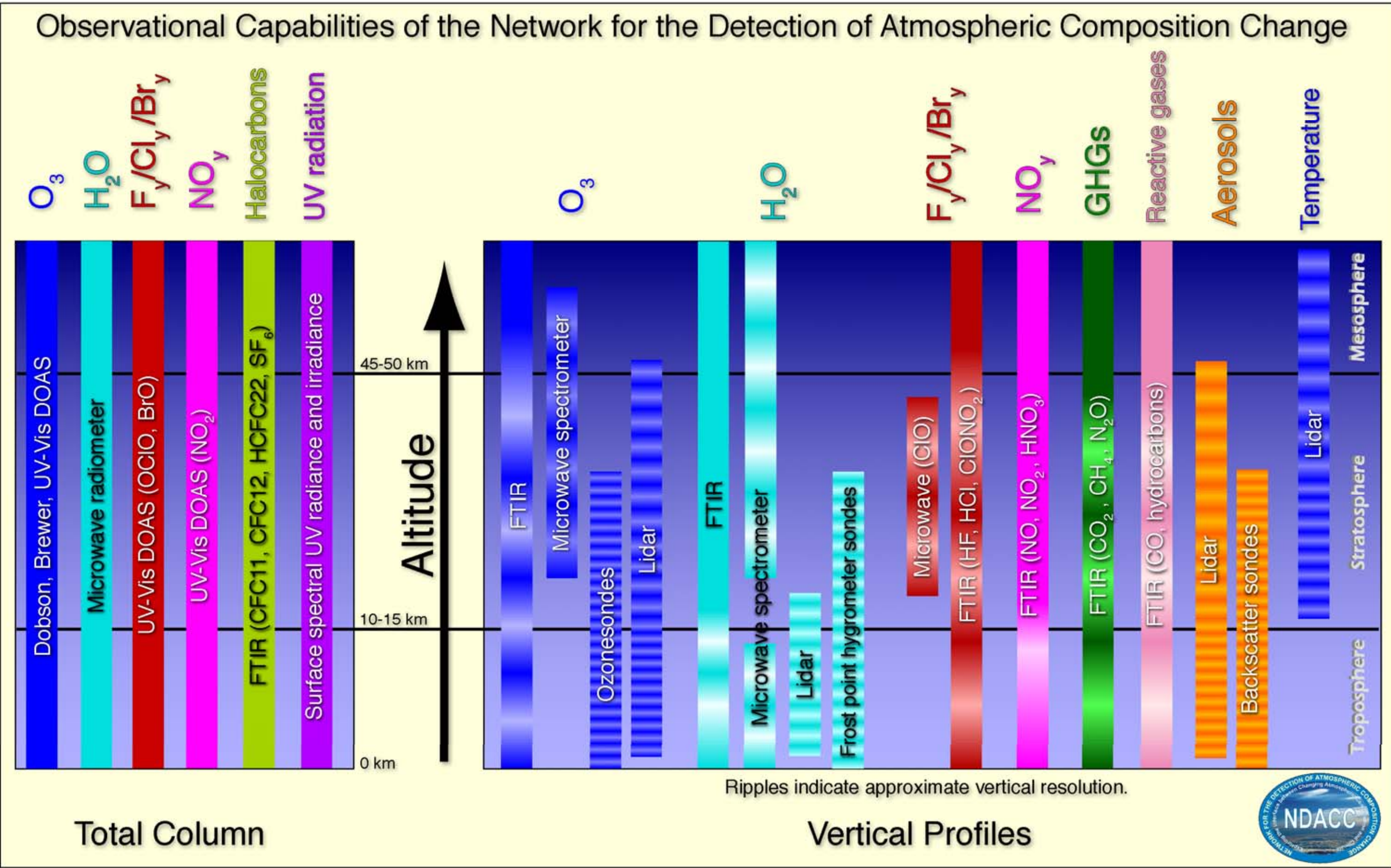
Corinne Vigouroux
and many others

Presentation Outline

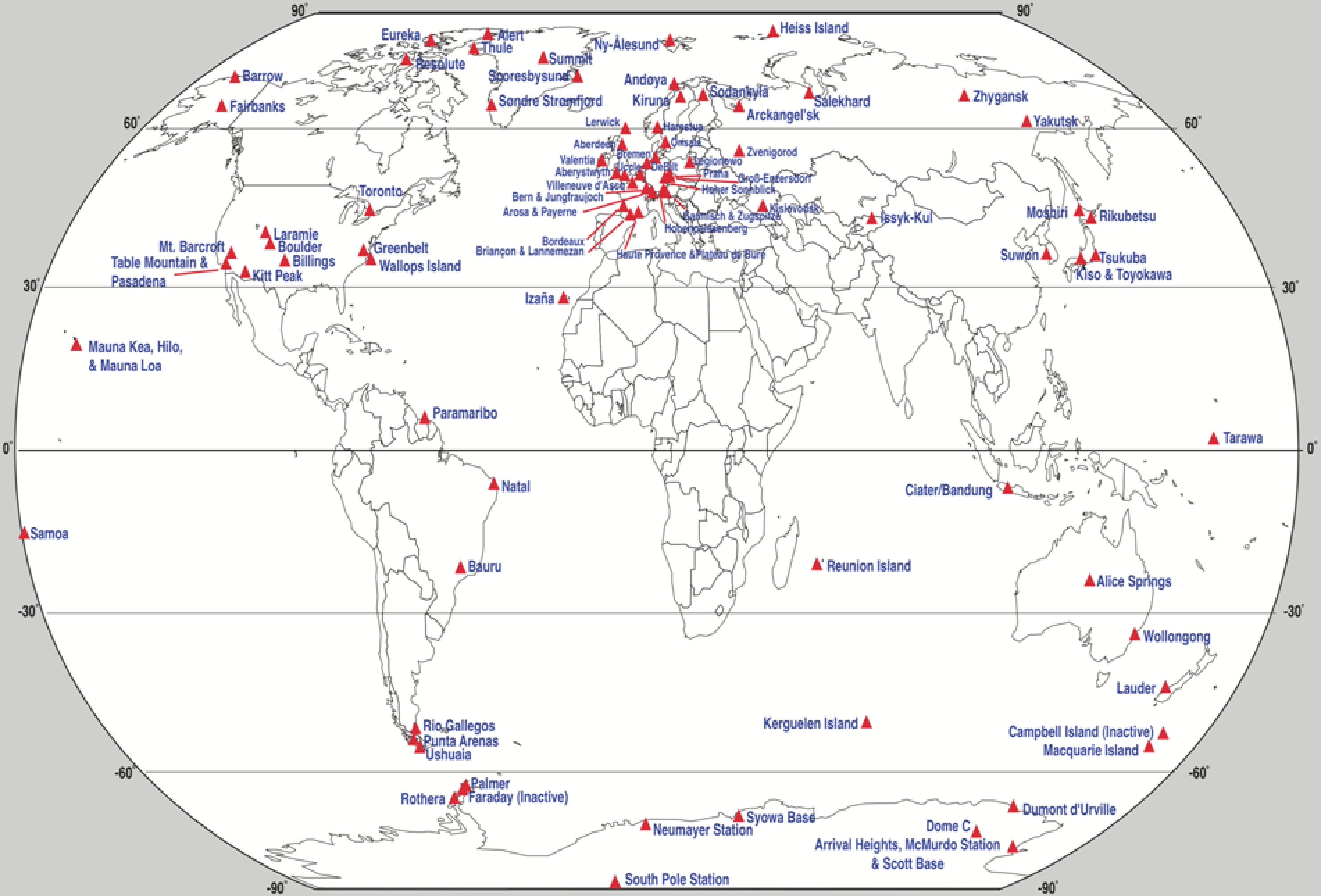
NDACC Remote-Sensing Measurements Pertinent to the SPARC/IO3C/ IGACO-O3/NDACC (SI2N) Activity on Assessing Past Changes in the Vertical Distribution of Ozone

- **NDACC Measurement Capabilities / Sites**
- **Lidar Measurements**
- **FTIR Measurements**
- **Microwave Measurements**

More than Two Decades of High Quality Measurements



NDACC Sites

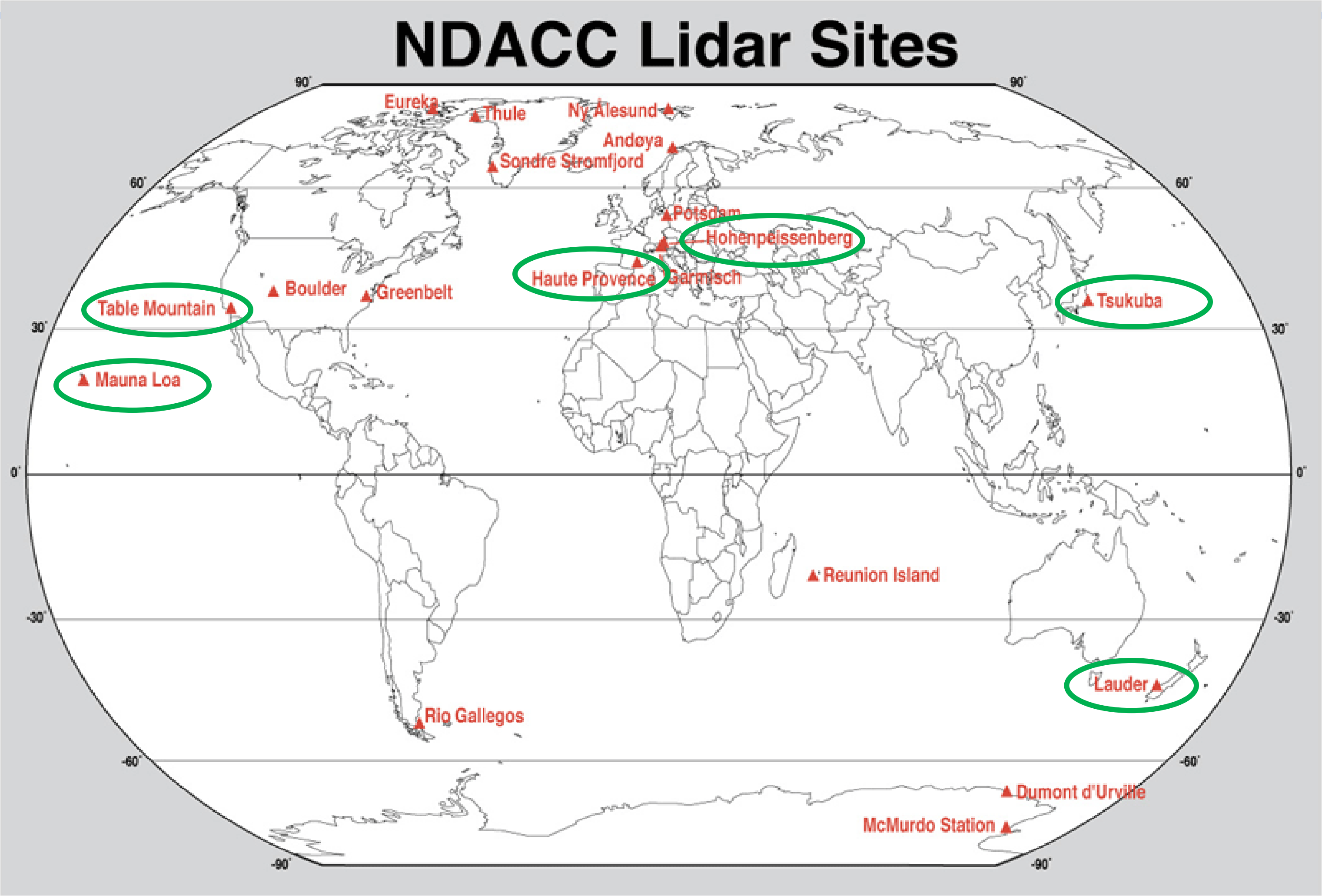


90°
60°
30°
0°
-30°
-60°
-90°
Eureka
Alert
Thule
Resolute
Summit
Ny-Ålesund
Heiss Island
Barrow
Scoresbysund
Andøya
Kiruna
Sodankylä
Salekhard
Zhygansk
Fairbanks
Søndre Strømfjord
Arckangel'sk
Yakutsk
Lerwick
Harestua
Aberdeen
Onsala
Zvenigorod
Valentia
Bremen
Legionowo
Aberystwyth
Uccle
DeBilt
Praha
Groß-Enzersdorf
Villeneuve d'Ascq
Hoher Sonnblick
Bern & Jungfraujoch
Kislovodsk
Arosa & Payerne
Garmisch & Zugspitze
Issyk-Kul
Toronto
Moshiri
Rikubetsu
Bordeaux
Briançon & Lannemezan
Haute Provence &Plateau de Bure
Laramie
Mt. Barcroft
Boulder
Greenbelt
Table Mountain &
Pasadena
Billings
Wallops Island
Kitt Peak
Suwon
Tsukuba
Kiso & Toyokawa
Izaña
Mauna Kea, Hilo,
& Mauna Loa
Paramaribo
Tarawa
Natal
Ciater/Bandung
Samoa
Bauru
Reunion Island
Alice Springs
Wollongong
Lauder
Rio Gallegos
Punta Arenas
Ushuaia
Kerguelen Island
Campbell Island (Inactive)
Macquarie Island
Palmer
Rothera
Faraday (Inactive)
Dumont d'Urville
Syowa Base
Neumayer Station
Dome C
Arrival Heights, McMurdo Station
& Scott Base
South Pole Station

Stratospheric Ozone Profiles at Several NDACC Lidar Stations (Nair et al.)

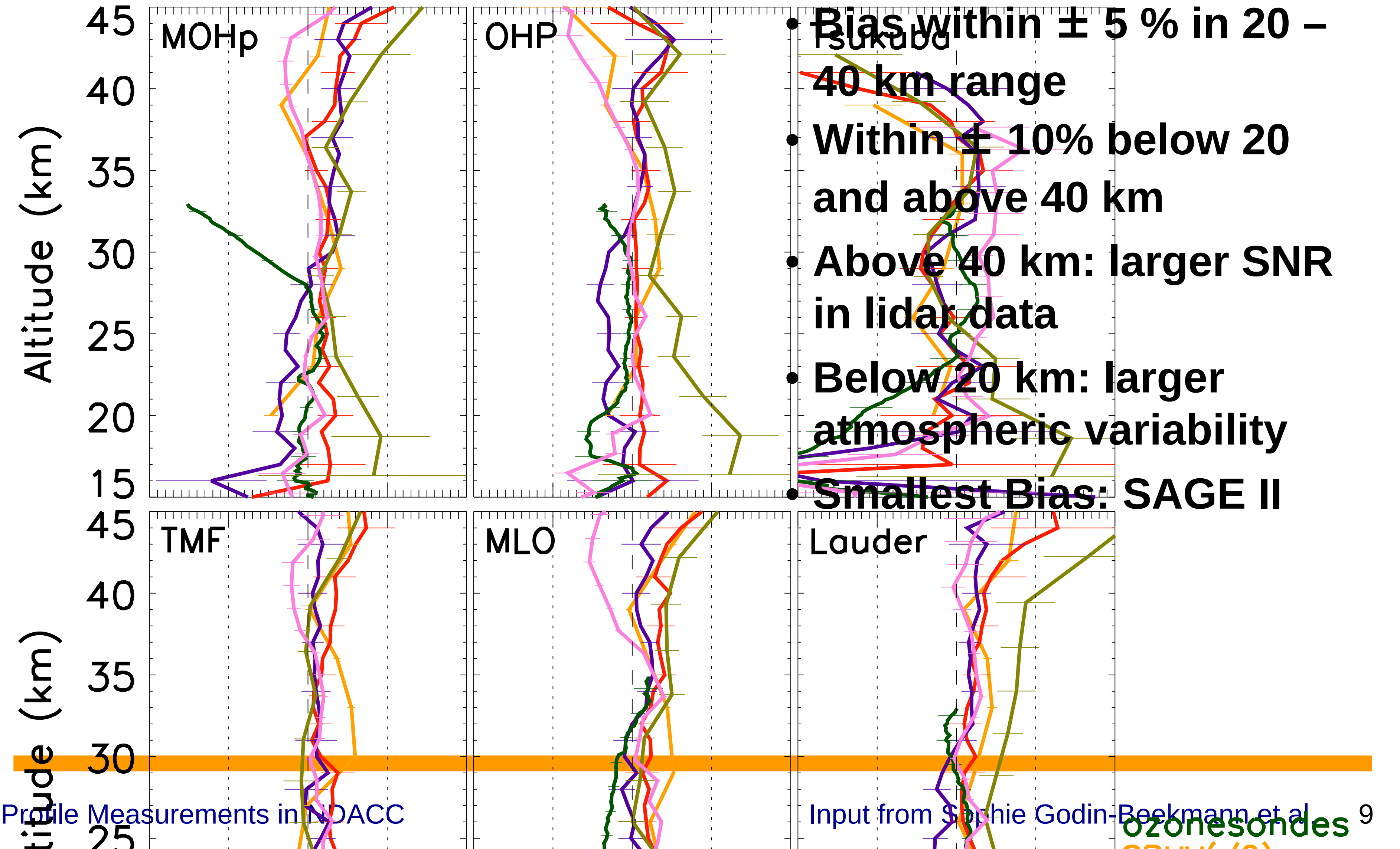
- Long NDACC lidar time series > 15 years
- Several long satellite ozone time series
- Check NDACC lidar data validation capacity and look at stability of ozone time series
- Study conducted at 6 NDACC stations with continuous lidar time series
  - MOHp, OHP, TMF, Tsukuba, MLO, Lauder
- Satellite data:
  - SBUV(/2) v8, SAGE II v6.2, HALOE V19, MLS (UARS v5 & Aura v3.3)
- Ozonesonde data is used when close to stations

Stations Used in This Study



Input from Sophie Godin-Beekmann et al.

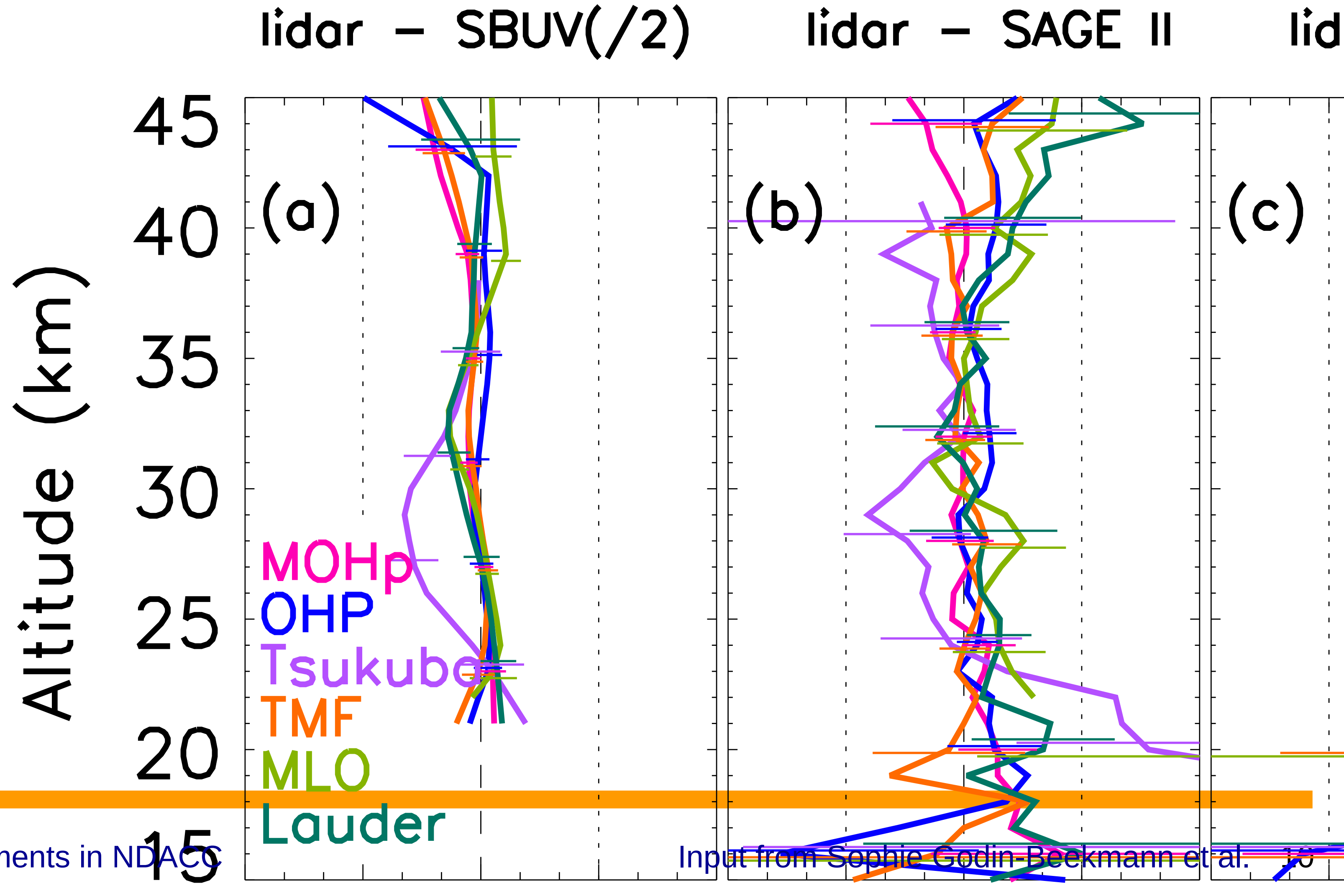
Average Biases with Lidar Measurements



- Bias within ± 5 % in 20 – 40 km range
- Within ± 10% below 20 and above 40 km
- Above 40 km: larger SNR in lidar data
- Below 20 km: larger atmospheric variability
- Smallest Bias: SAGE II

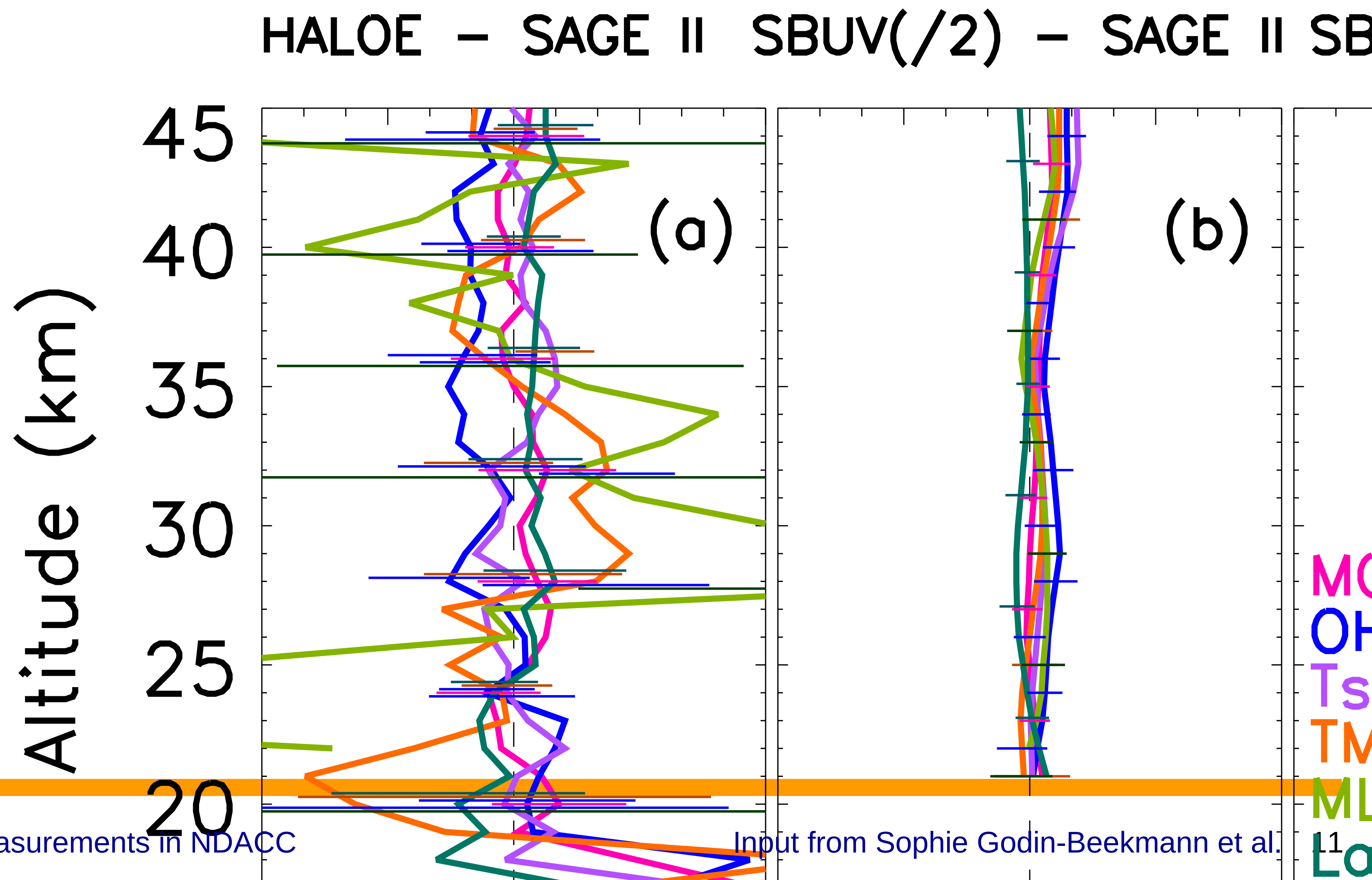
Input from Sophie Godin-Beekmann et al.

Drift in Lidar Data Relative to Satellites

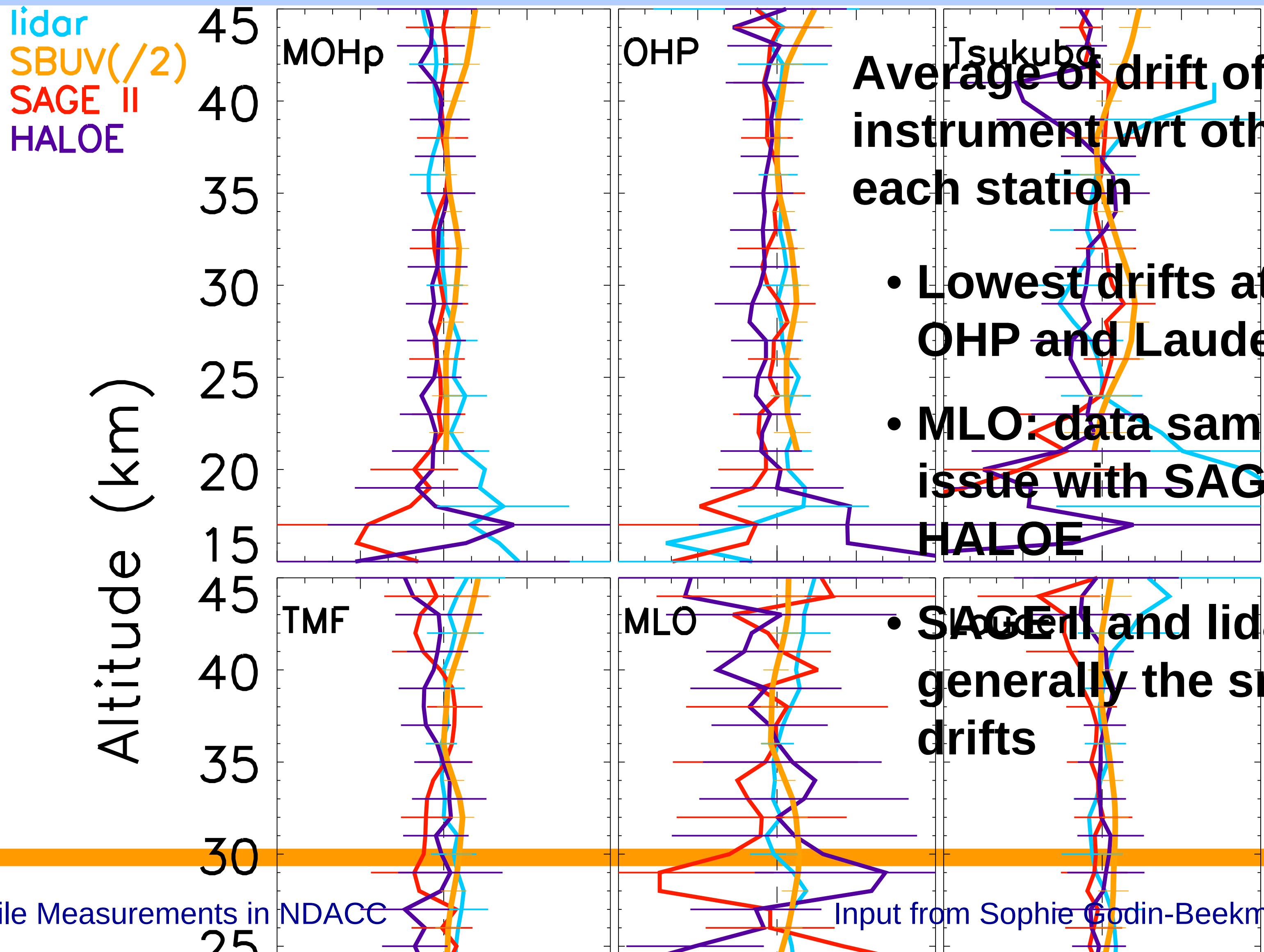


Input from Sophie Godin-Beekmann et al.

Relative Drifts in Satellite Measurements



Average Drifts at NDACC Lidar Stations



Average of drift of each instrument wrt others at each station

- **Lowest drifts at MOHp, OHP and Lauder**
- **MLO: data sampling issue with SAGE II and HALOE**
- **SAGE II and lidar show generally the smallest drifts**

Conclusions

Lidar vs. Sondes and Satellite Measurements:

•Average differences within ± 5 % at 20-45 km

•Drifts wrt lidars: generally below ± 0.5 %/year at 20-40 km except in Tsukuba due to sampling problems

•Larger drifts below 20 km and above 40 km

•Good stability of lidars wrt other measurements

•Aura MLS good candidate for continuation of satellite ozone time series

•Issues with continuation of long term lidar ozone time series, lidar refurbishments (laser power – high stratosphere)

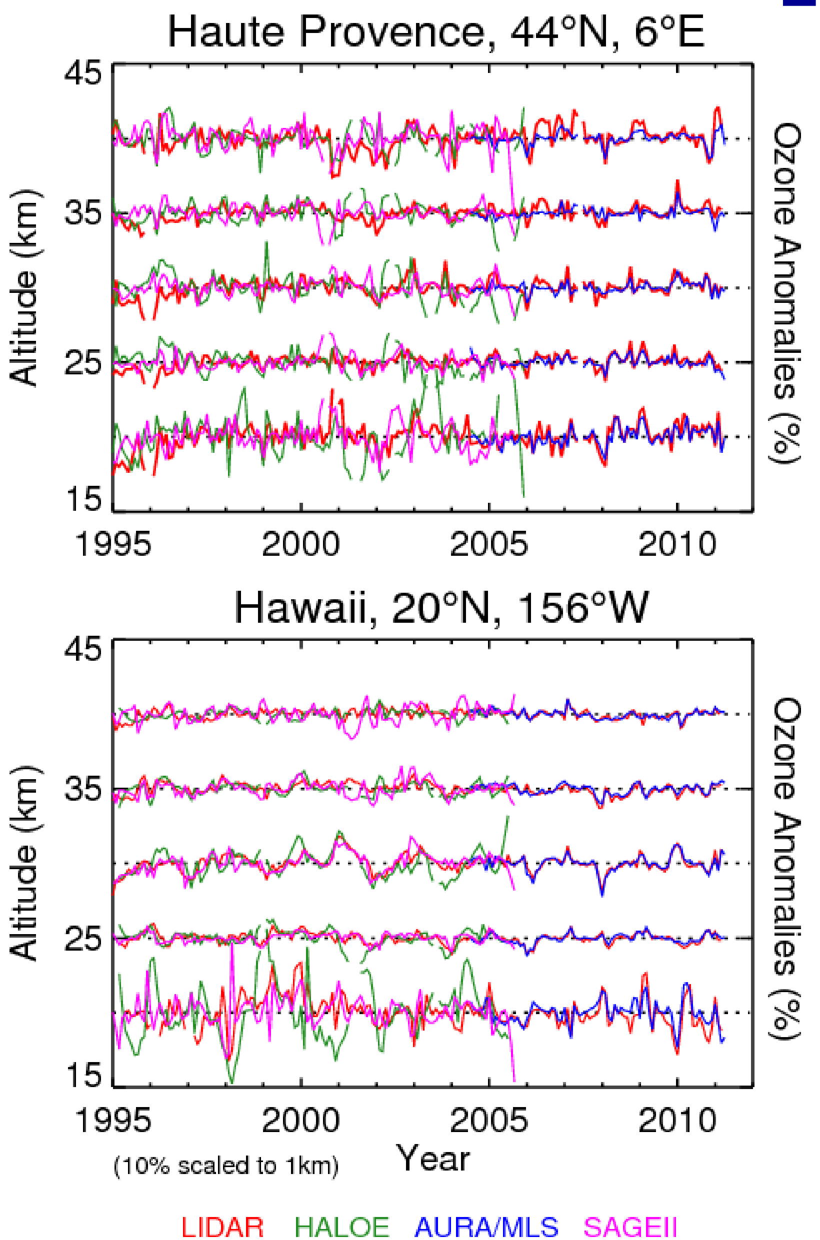
Ozone Long-Term Variability &Trends Using NDACC Lidars (Kirgis et al.)

Data from 5 Lidar Stations:

- **Hohenpeissenberg, 48°N**
- **OHP, 44°N**
- **Table Mountain, 35°N**
- **Mauna Loa, 20°N**
- **Lauder, 45°S**

Presented in Poster P-3

Ozone Long-Term Variability and Trends Using NDACC Lidars



- **The long-term lidar data record has increased in importance for filling existing gaps in past and present satellite missions.**
- **The long-term lidar record is ideally suited for validating subsequent satellite missions.**
- **On average, low drifts and biases exist between recent missions and the lidar time series (Nair et al., 2011 and 2012).**
- **Some discrepancies still need to be explained.**

Input from Kirgis et al.

Multi Linear Regression Model Used to Fit Ozone Anomalies Time Series

Deseasonalized ozone monthly mean anomalies (in % deviation from the climatological mean) were fit using a backward elimination method.

$\Delta O_3(z,t) = \alpha \bullet$Solar (11 year Solar Cycle)

$+ \beta \bullet$ENSO (El Niño Southern Oscillation)

$+ \eta \bullet$NAO (North Atlantic Oscillation)

$+ \gamma_1 \bullet QBO_1$ (Quasi Biennal Oscillation @ 30hPa)

$+ \gamma_2 \bullet QBO_2$ (Quasi Biennal Oscillation @ 50hPa)

$+ \varepsilon \bullet$ODGI (Ozone Depleting Gas Index, Hofmann and Montzka, 2009)

$+ \zeta_1 \bullet$Horizontal Transport (Wohltman et al., 2005)

$+ \zeta_2 \bullet$Vertical Transport (Wohltman et al., 2005)

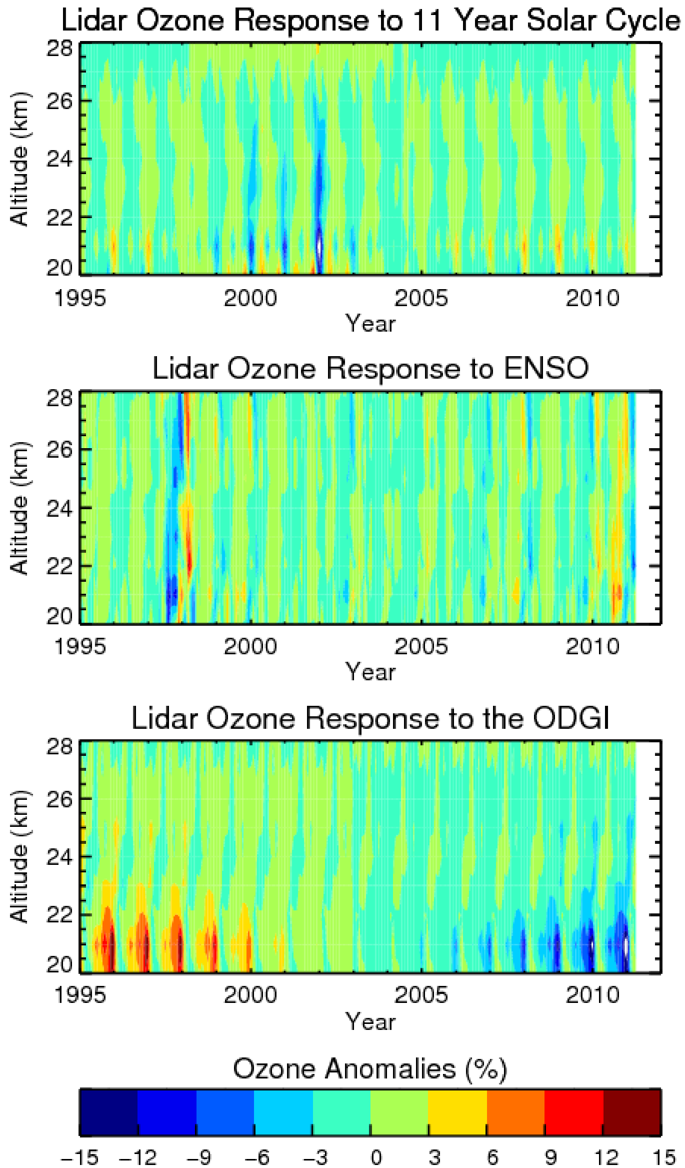
$+ \mu \bullet$Eliassen-Palm flux @ 100hPa

Where α, β, η, γ, ε, ζ_1 and ζ_2 are coefficients of the form :

$A_1 + A_2\cos(wt) + A_3\sin(wt) + A_4\cos(2wt) + A_5\sin(2wt)$ and $w = 2\pi/(12 \text{ months})$

The choice of the Ozone Depleting Gas Index (reverse hockey stick) instead of the classical linear trend significantly improved (~10%) the fit.

Lower Stratospheric Ozone over Hawaii (20°N, 156°W)



Lower Stratosphere negative response over the tropics during solar maximum. Consistent with:

•*Kodera and Kuroda (2002) & Hood and Soukharev (2003)* - relative downwelling in the tropics near solar maxima.

•*Marsh and Garcia (2007)*: variability in LS ozone related to changes in tropical upwelling associated with ENSO.

Ozone decrease during 1997/98 El Niño event (increased over mid-latitudes (not shown). Consistent with:

•CCM's simulations by *Fisher et al. (2008) & Cagnazzo et al. (2009)* - explained by increase in residual circulation.

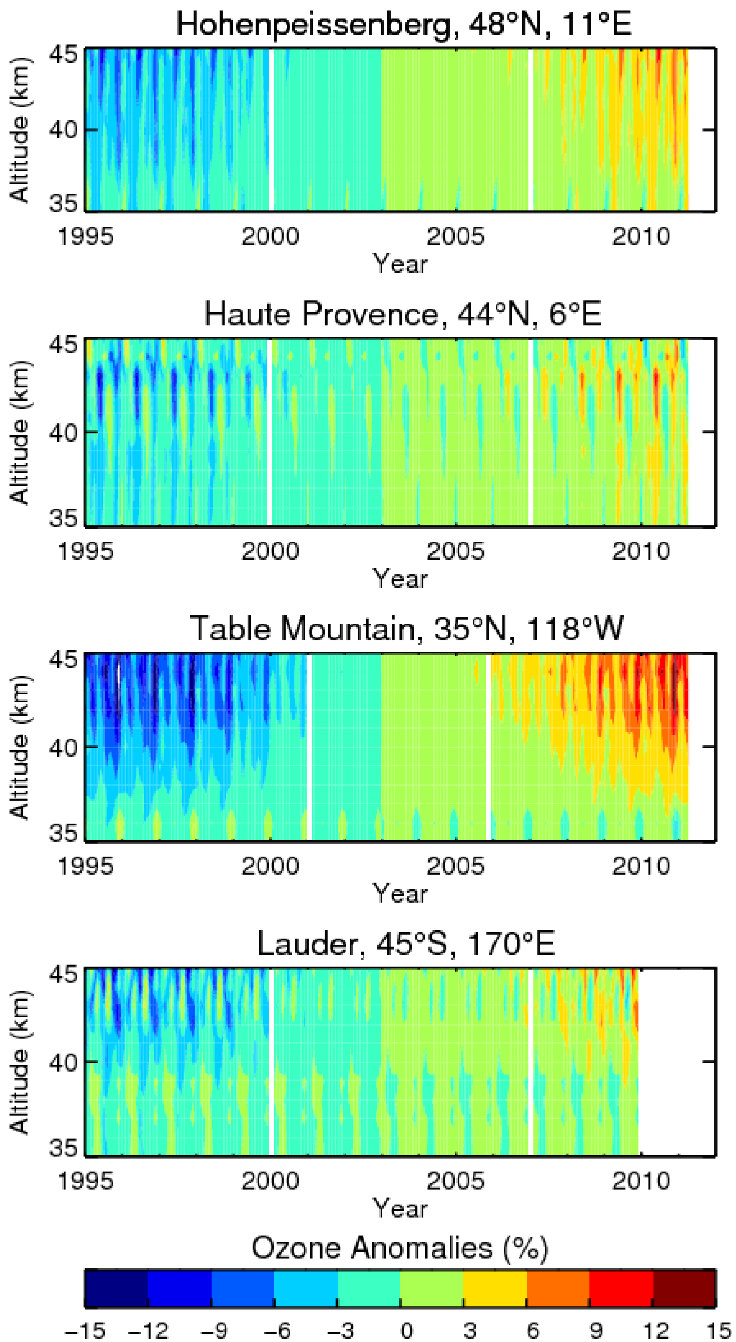
Steady ozone decrease in response to ODGI. Consistent with:

•Randel and Thompson (2011) - faster transit of air through the tropical lower stratosphere from enhanced tropical upwelling (less time for ozone production).

LS responses over Hawaii suggest that variability is strongly related to changes in tropical upwelling and thus to a change in the Brewer-Dobson circulation.

Input from Kirgis et al.

Lidar Ozone Response to the ODGI Over Mid-Latitude Sites



Ozone increase in the mid-latitude upper stratosphere over the past 16 years (a direct response to the Montreal Protocol).

Different timings are observed:

•Ozone decrease slows down and stops earlier at higher latitude than lower latitude.

•Recovery starts later at higher latitude compared to lower latitude.

Implications of CO_2-induced stratospheric cooling?

•see *Randel et al. (2009) & Li et al. (2011)*.

Input from Kirgis et al.

Ozone Variability and Trends from FTIR Data

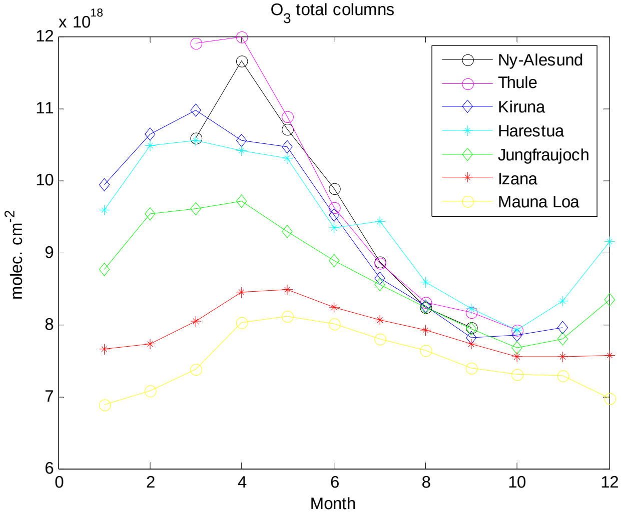
Data from 6 FTIR Stations:

- •Ny-Ålesund, 79°N
- •Thule, 77°N
- •Kiruna, 68°N
- •Harestua, 60°N
- •Jungfraujoch, 47°N
- •Izaña, 28°N

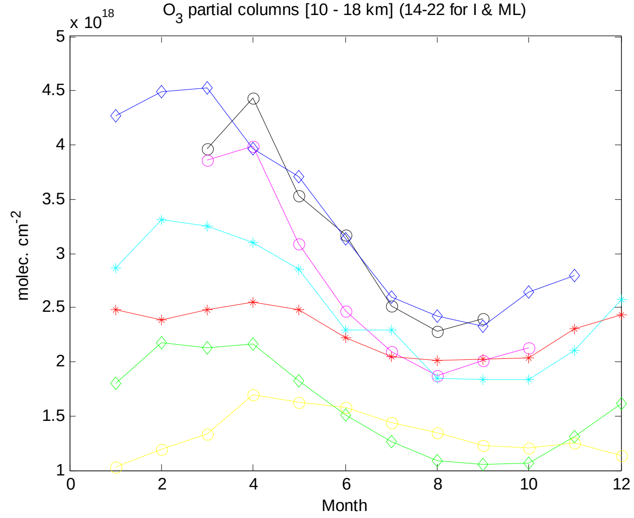
Presented in Poster P-8

Seasonal Variability Observed in FTIR Ozone Total and Partial Columns

Total Columns

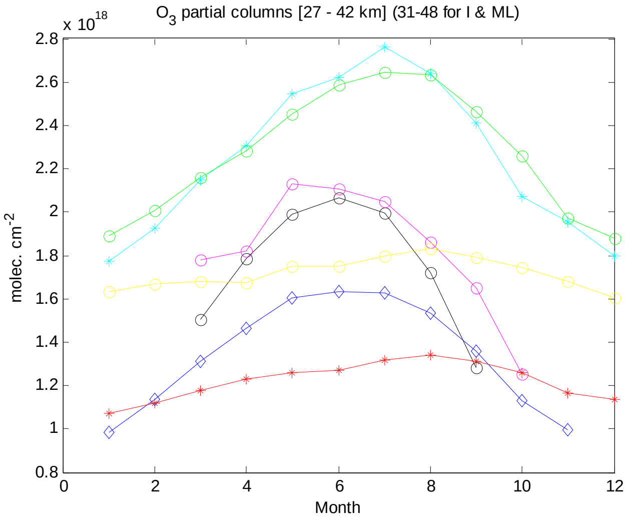


Partial Columns: 10-18 km



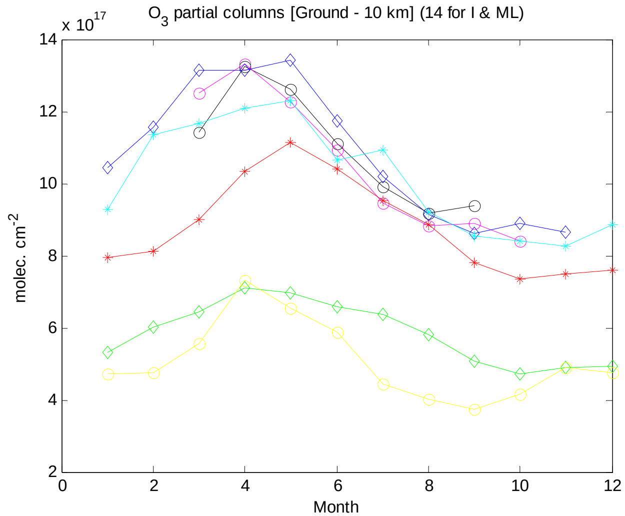
Maximum in **spring** for **total** columns (mid-high latitude): due to **lower-middle stratosphere** maximum in spring: **Brewer-Dobson circulation**

Partial Columns: 27-42 km



Max. in **summer in upper stratosphere** (mid-high latitude): **chemistry** dominates.

Partial Columns: Ground-10 km



Effect of EESC decrease on O_3 should be seen at these altitudes.

Trop.: - Max. in spring at high lat.: STE.
- Broad max. in spring-summer at mid-lat.: pollution in summer, STE in spring

Ozone Trends (%/decade), Obtained with a Bootstrap Resampling Method

FTIR station	Lat.	Period	**Gd-10km**	**10-18 km**	**18-27 km**	**27-42 km**	**Total ozone**
Ny-Alesund	**79°N**	1995-2011	-6.7±2.6	-3.5±4.2	-2.9±2.8	+5.9±2.1	-1.8±2.1
Ny-Alesund		19**99**-2011	-12.2±3.4	-13.3±5.7	-4.1±3.7	+2.8±2.6	-6.7±2.8
Thule	**77°N**	19**99**-2011	-7.7±3.8	-16.9±5.8	-5.5±3.2	+3.3±3.7	-7.3±2.6
Kiruna	**68°N**	1996-2011	-1.0±2.3	-2.6±3.0	+3.1±1.9	+10.0±2.1	1.5±2.8
Harestua	**60°N**	1995-2011	-8.3±3.7	-4.0±4.8	+1.7±1.9	+9.5±2.2	0.6±2.2
Jungfraujoch	**47°N**	1995-2011	-2.0±2.2	+0.8±3.1	+0.6±0.7	+1.4±0.8	0.7±0.9
Izaña	**28°N**	1999-2011	-0.8±2.8	-1.3±3.6	+0.7±0.8	+0.9±0.9	0.3±0.9

- Very good agreement Thule / Ny Alesund when same period is concerned.
- High variability in total O3 trends at high lat. stations depending on the period: due mainly to high variability in lower strato. trends; this is expected for these latitudes. We need more years.
- **Positive trends observed at all mid and high lat. stations in upper strat. EESC decrease?**
- Troposphere: **at high lat.:** trends correlate well with lower strato. (STE); **at Jungfraujoch** the negative trend is summer probably reflects a decrease in European emission of precursors.

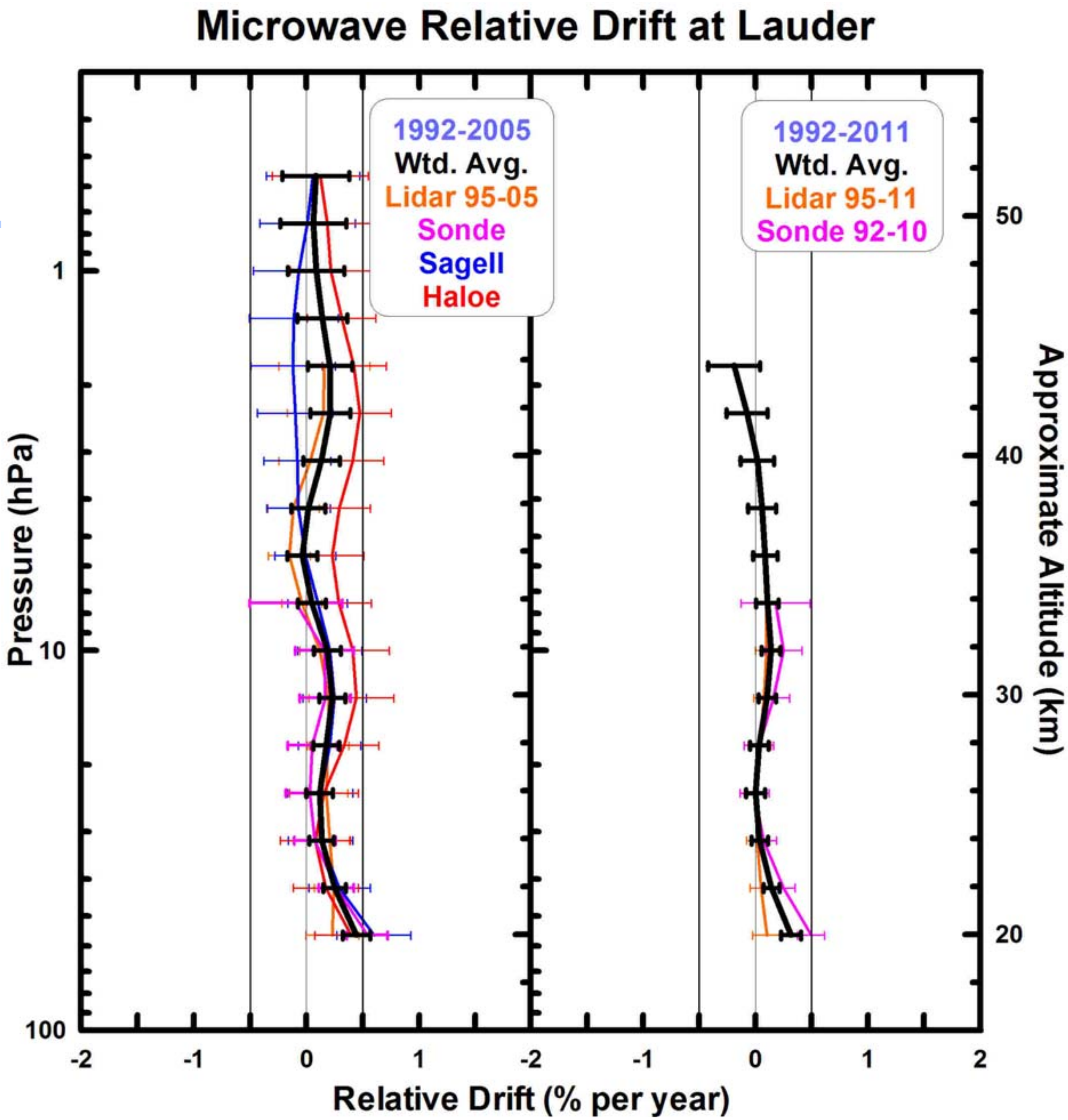
Additional Information

- Details in Vigouroux et al., ACP, 2008 (1995-2005 trends)
- Update (1995-2009) in WM0 2010, Chapter 2
- See poster P-8 for details on 1995-2011 trends.

NDACC Microwave Stations: Comparisons at Two Stations

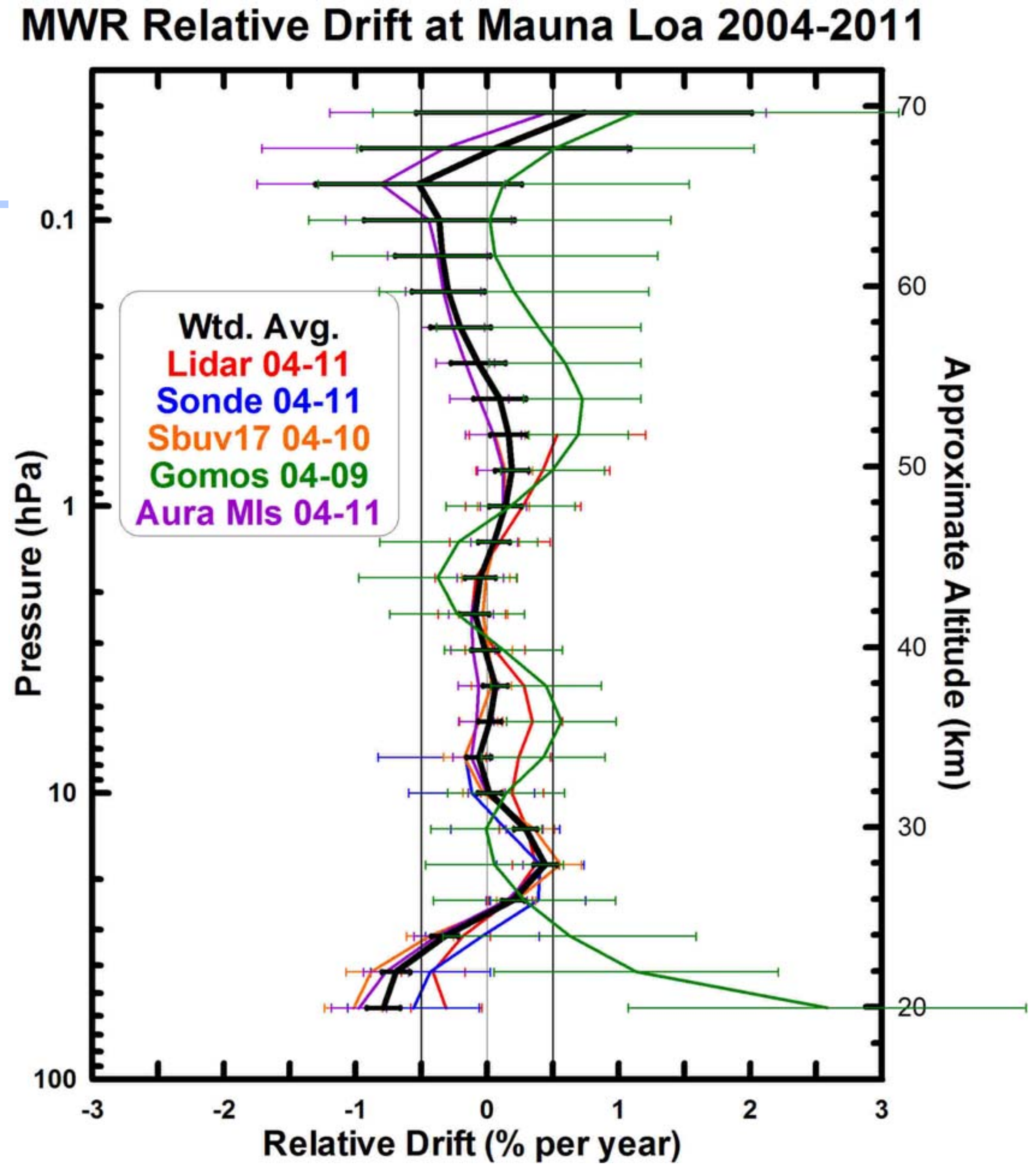
Input from Boyd et al.

Relative drifts between microwave ozone measurements and those from other ground-based and satellite instruments



Input from Boyd et al.

Relative drifts between microwave ozone measurements and those from other ground-based and satellite instruments



Conclusions

The microwave radiometers and the other ground-based and in situ NDACC instruments are suitable for long-term ozone trends detection as well as for serving as transfer standards for present and future satellite instruments.

NDACC Activities Pertinent to SI^{2}N

Lidar Studies

- Extension of Nair *et al.* comparison study:
  - To other satellites, new data versions, and merged ozone products
  - To other NDACC lidar stations (e.g., polar, Ny Ålesund, Andøya, Dumont d'Urville)
  - Collocated profiles and monthly means
- Expansion of Nair *et al.* to the determination of ozone trends at OHP using multiple data sources for total ozone and its vertical distribution
- Extension of Kirgis *et al.* ozone trend studies to OHP, Lauder, Hohenpeissenberg, Ny Ålesund, Andøya

NDACC Activities Pertinent to SI^{2}N

Lidar Studies (continued):

- Evaluation of drifts and mutual consistency of 11+ limb/occultation ozone profile data records, based on a common method using all NDACC lidars (incl. also Dumont d'Urville, Ny Ålesund, and Andøya) and global ozonesonde network, by D. Hubert *et al.* from SAGE II (1984) through UARS to ACE, Aura, Envisat, and Odin.
- Tropospheric lidar and sondes intercomparisons
- Inclusion of ISSI work on the assessment of lidar uncertainties and vertical resolution issues.
- Continuation of Steinbrecht work on ozone and temperature trends comparisons at multiple NDACC stations
- Extension of intercomparisons to include Umkehr and sondes where possible

NDACC Activities Pertinent to SI^{2}N

Microwave Studies:

- **Extension of microwave – lidar intercomparison at MLO and Lauder to cover the full lidar operational time periods – 1995 to present**
- **Extension of studies similar to those conducted at Lauder and MLO to other microwave ozone stations**
- **Intercomparison of microwave measurements at Bern and Payerne with lidar measurements at OHP and MOHp**
- **Intercomparison of measurements at MLO, Lauder, Bern, and Payerne with satellite measurements over their operational lifetimes**

NDACC Activities Pertinent to SI^{2}N

Microwave Studies (continued):

- **Continuation of ozone diurnal variability studies and comparison with other time-resolved data sources on this issue, including MLS, SBUV instruments making measurements in morning and afternoon, and SMILES**
- **Addition of intercomparison with UMKEHR, FTIR, and ozonesondes at MLO, Lauder, and possibly other sites.**

NDACC Activities Pertinent to SI^{2}N

FTIR Studies:

- Intercomparisons with satellites, sondes, lidars, and Umkehr at stations where sufficient data exist (such as the Alpine Stations)
- Extension of trend and intercomparison to other FTIR profiling sites.