A Re-Evaluated Canadian Ozonesonde Record: Changes in the Vertical Distribution of Ozone Over Canada from 1966 to 2012

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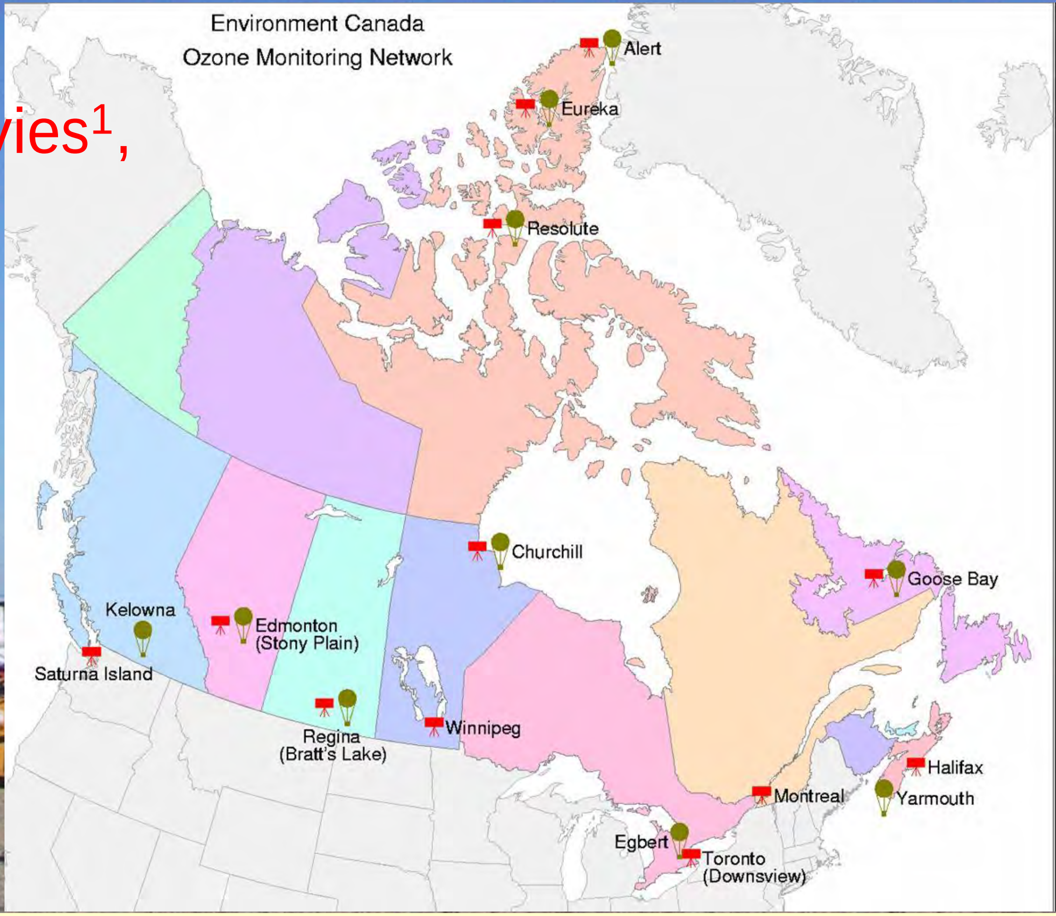
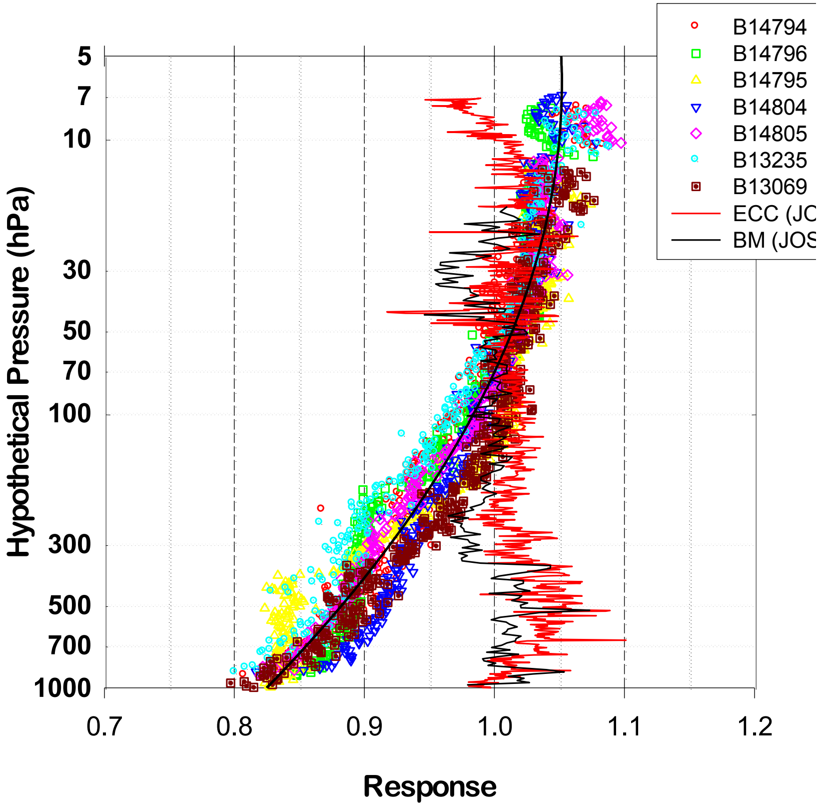


Motivation

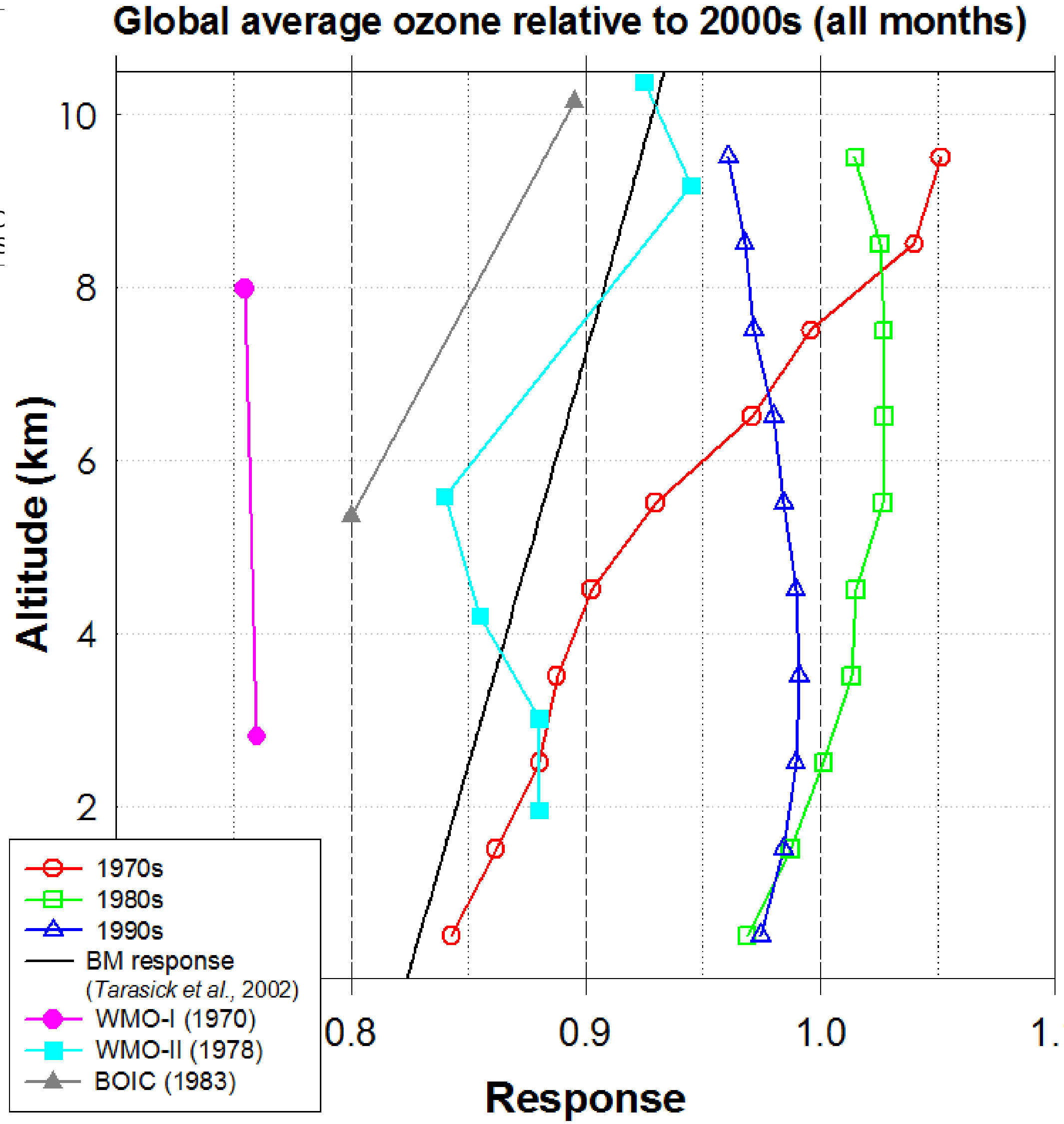
- SPARC/IO$_3$C/IGACO-O$_3$/NDACC (SI^{2}N) "Initiative on Past Changes in the Vertical Distribution of Ozone"
- Re-visit SPARC Report No. 1 (1998)
- Objectives for ozonesondes:
  - Homogenize data sets, removing biases resulting from known changes
  - Improve data quality and quantify uncertainty
  - Document!

Canadian ozonesonde network – changes in ozonesondes and associated radiosondes

Year	Change	Possible Effect
1979	ECC 3A introduced	~15% increase in tropospheric response response relative to BM sondes. Sonde T measured via rod thermistor.
1984	ECC 4A introduced	redesigned pump; maximum change <1%, at 50-20 hPa. Sonde "box" T measured; new rod thermistor.
1993	ECC 5A introduced	New pump correction; maximum change ~1%, at 100 hPa.
1993	Vaisala RS-80, RSA-11 introduced	Older VIZ sonde: warm bias in daytime; pressure errors. May introduce altitude shifts in profile; ozone increases of up to ~2% at 20 hPa.
1996	ECC 6A	No differences below about 20-25 km [*Smit et al*., 2000].
2000	ENSCI 1Z design change	High bias with 1% KI solution [*Smit et al*., 2007].
2004	3cc solution (new sites)	Better ozone capture in troposphere
2006	Vaisala RS-92 introduced	RS80s low by ~20m in the troposphere, high by 100m at 10hPa (Steinbrecht et al., 2008)
2007	Thermistor in ECC pump	More accurate measurement of air volume



Above: Response of BM sondes prepared according to standard procedures in the 1970's in Canada (*Mueller* [1976]).



Above right: Decadal average tropospheric ozone from sondes as a function of altitude. Also: fit to BM response data from *Tarasick et al.* [2002]; average differences between BM and ECC response from WMO ozonesonde intercomparisons, and response of BM sondes with respect to a UV-photometer on the same balloon in BOIC.

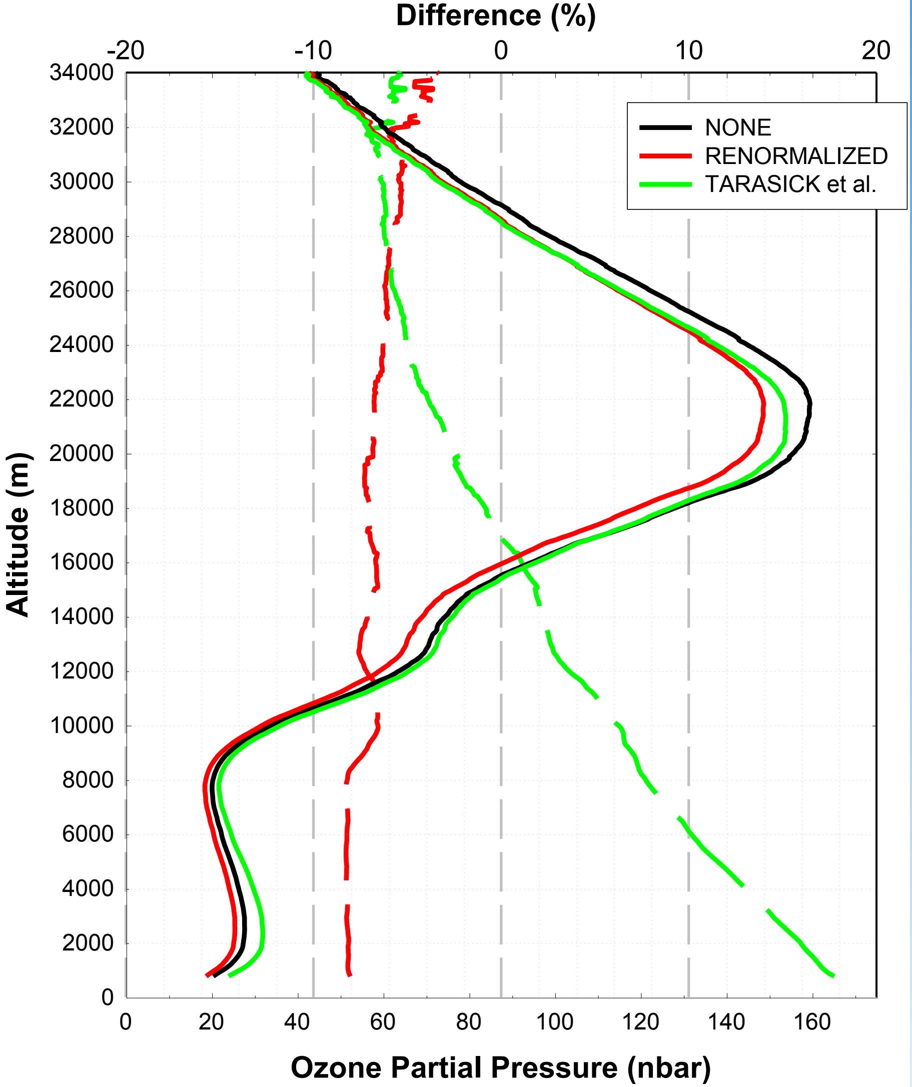
Normalizing, or "correcting": began with older Brewer-Mast sondes, which had a typical response of about 80% of the actual ozone amount. ECC sonde response is much closer to 100%, but normalization reduces overall uncertainties in ozonesonde data. The correction factor is also a useful data quality control indicator.

Canadian total ozone record had been extensively revised, but not sonde record. Differences sometimes large (~35%). In some cases a total ozone value for the previous day appears to have been used. Now revised. New ozone residual calculation: now interpolated from 2011 MLS climatology (McPeters and Labow).

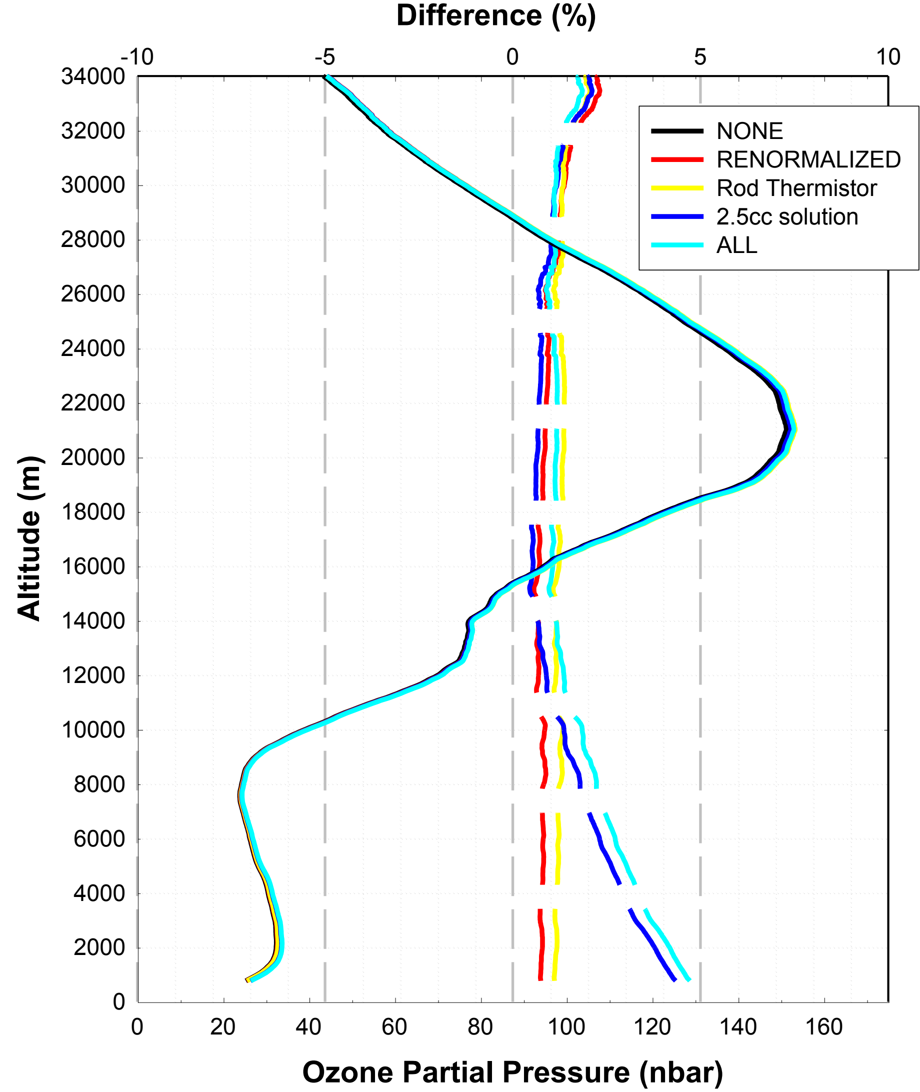
Radiosonde Changes: Difficult to correct, as manufacturers do not in general advertise changes, and even intercomparison data may not be useful as manufacturers will fix errors. Expected systematic differences in the ozone profile are probably small below 50hPa.

Pump corrections: Surprisingly difficult to determine accurately…

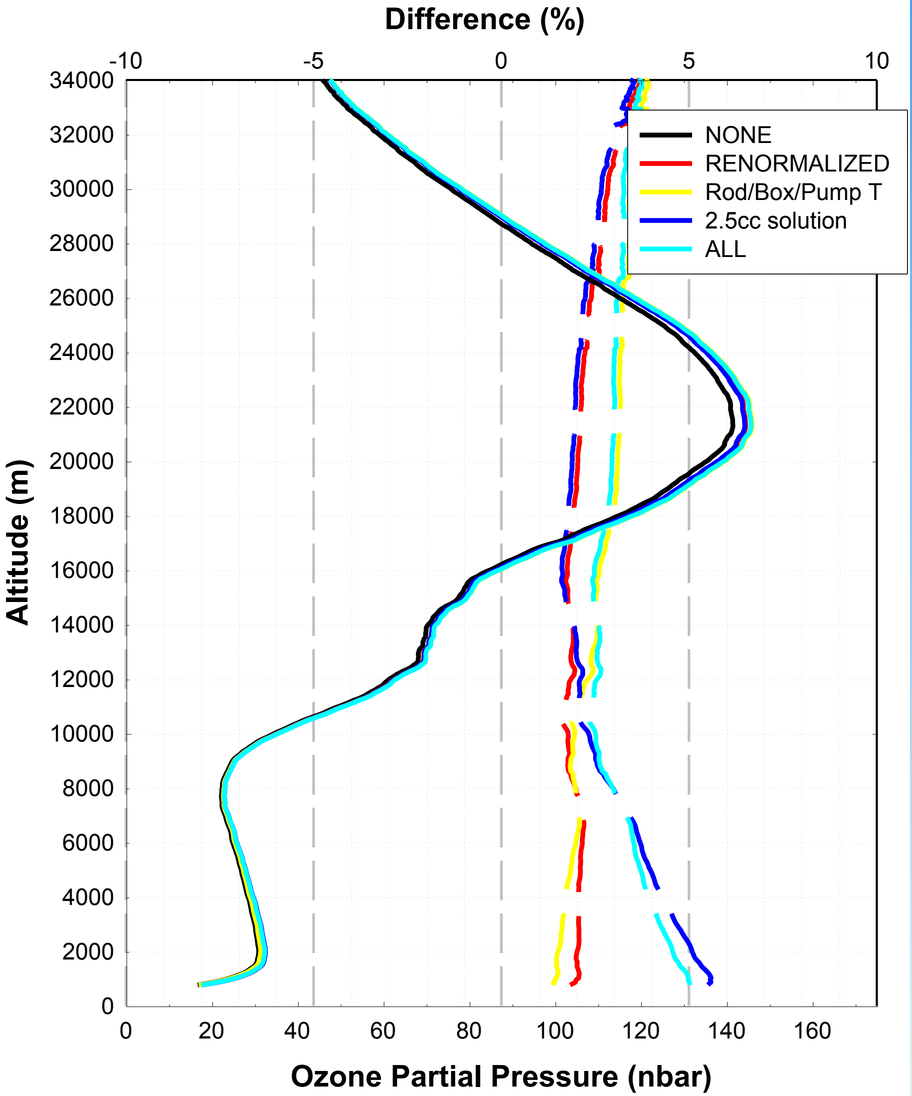
Sonde response: 20-sec response response time introduces an effective 200m shift in the profile; could be corrected by deconvolution. Slow secondary response (5 min) may increase ozone at the top of the profile. However, "wrong" pump correction may be compensating?



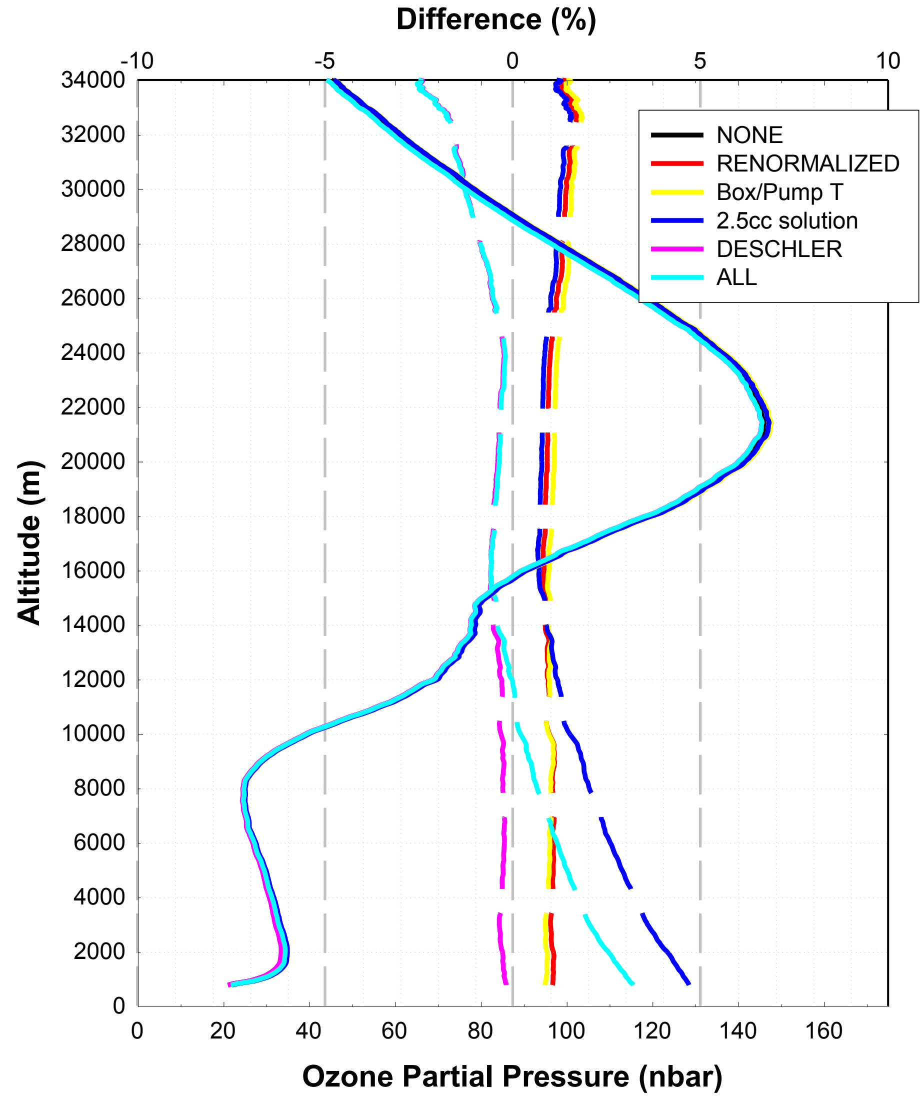
Edmonton: Reprocessed 1972-1978



Edmonton: Reprocessed 1980-1989



Edmonton: Reprocessed 1990-1999



Edmonton: Reprocessed 2000-2009

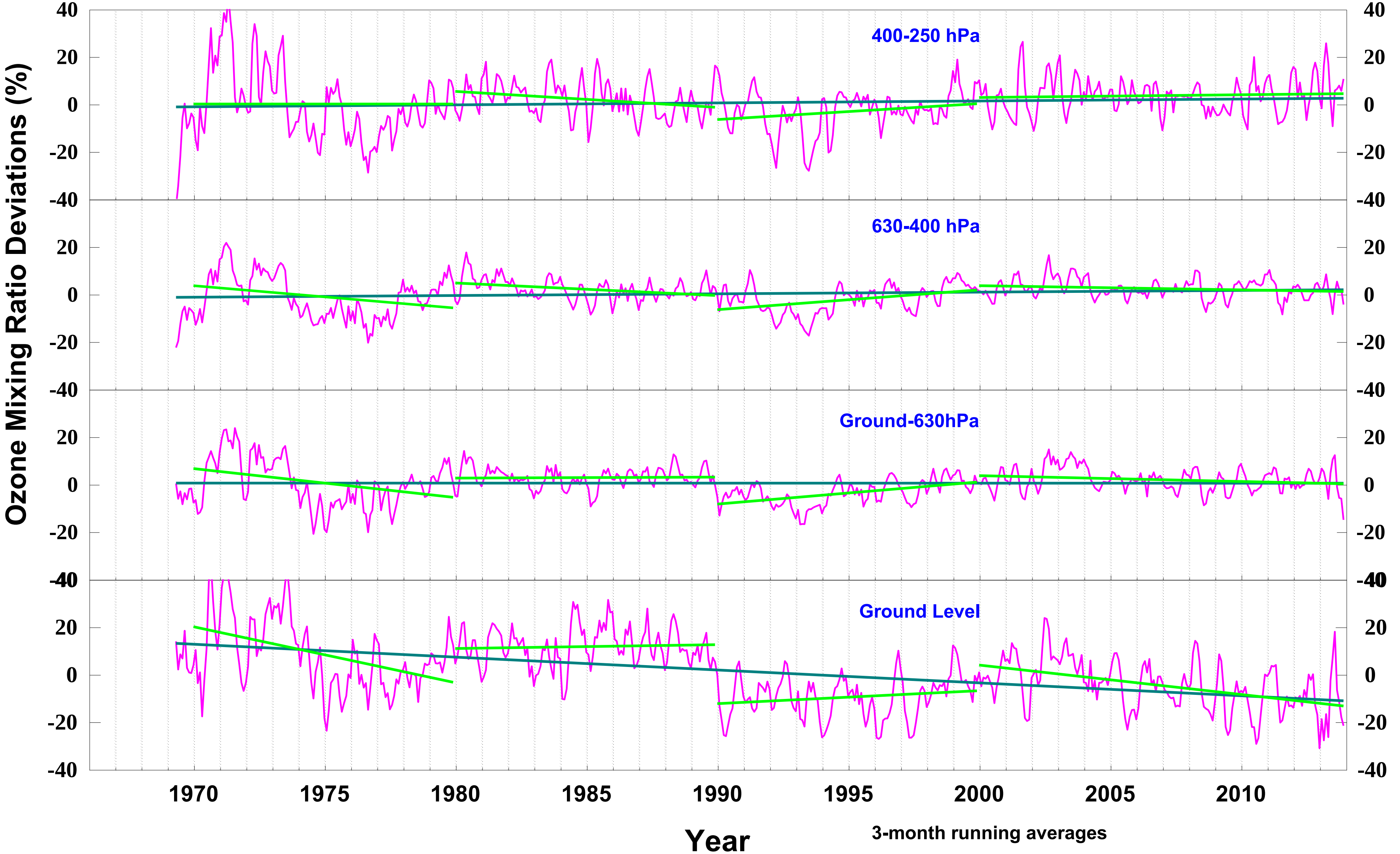
Results: reduced uncertainty

Tropospheric changes: increases of up to 5% after 1979; up to 20% before 1980 (Brewer-Mast sondes), reducing with altitude.

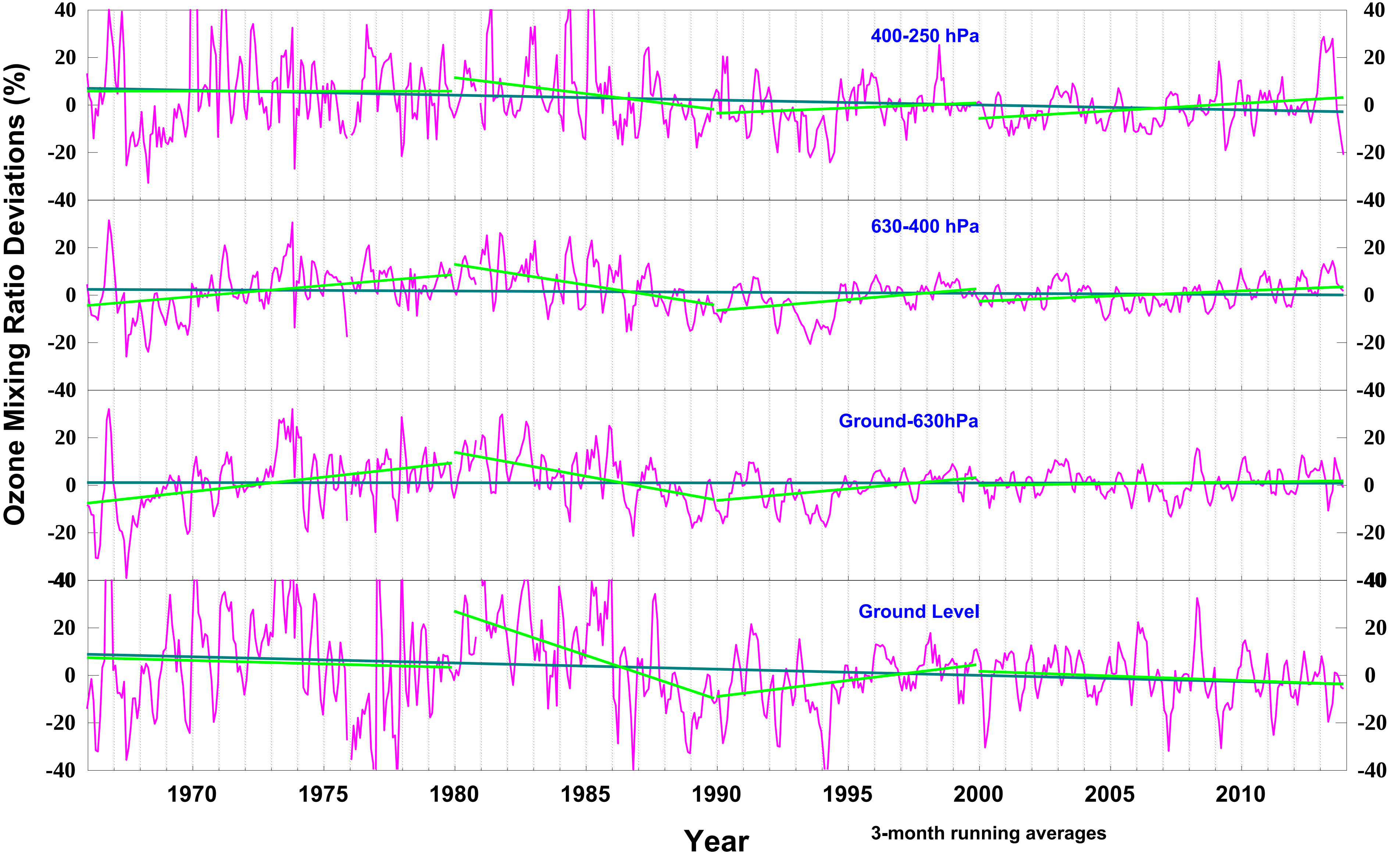
Stratospheric changes: decreases of up to 6% before 1980, less below 25km. Increases of ~1% in 1980s, ~2-3% in 1990s; little change in 2000s.

	Mean K	Std Dev	Trend
BM data			
Original	1.27	0.303	2.7%/decade
Renormalized	1.20	0.198	
Response correction	1.03	0.179	2.2%/decade
ECC data			
Original	0.97	0.101	-2.6 +/- 0.6 %/decade
All corrections	0.99	0.087	0.6 +/- 0.5 %/decade

Northern Midlatitudes (Edmonton, Goose Bay, Churchill)



Arctic (Resolute, Alert, Eureka)



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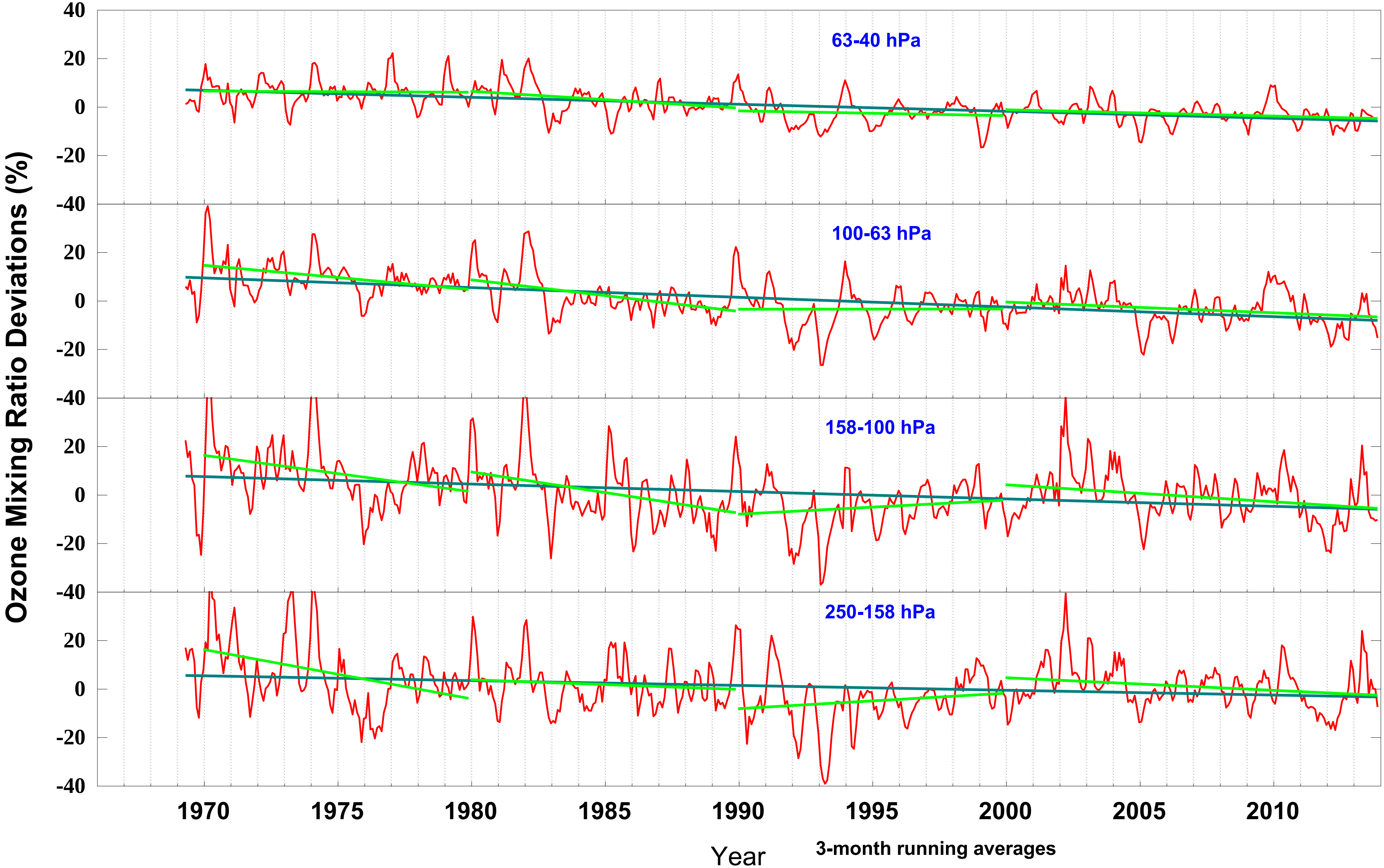

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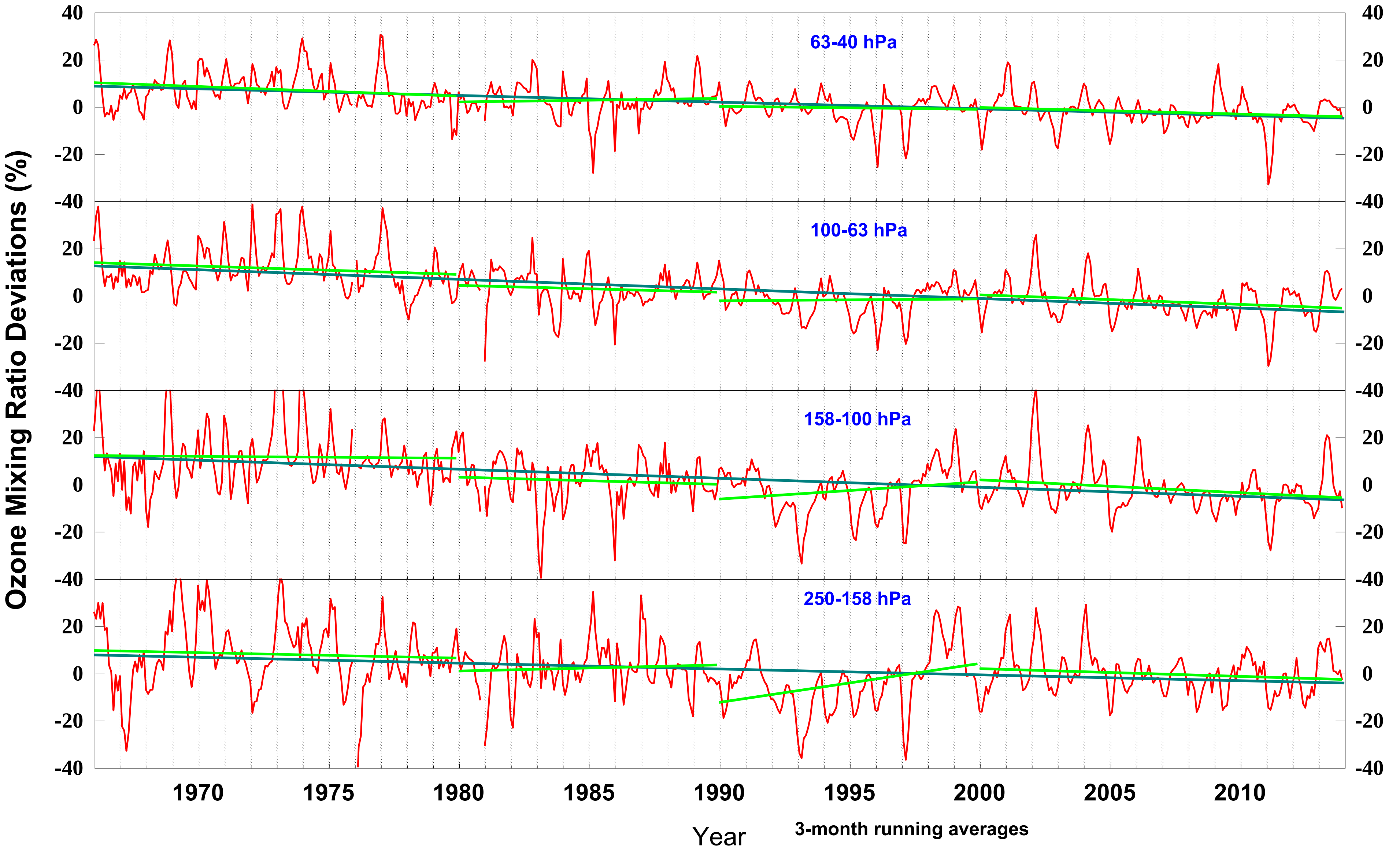
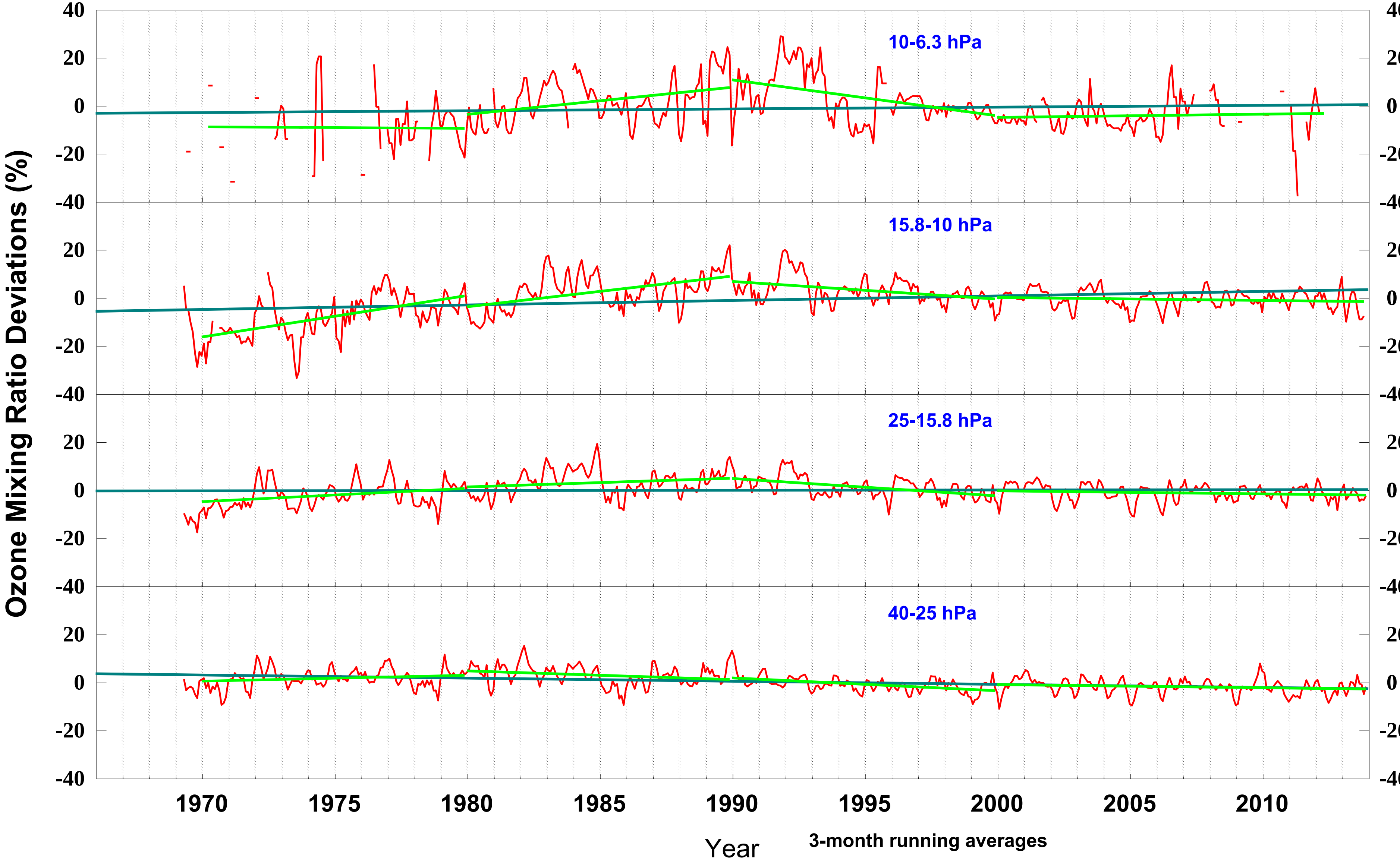
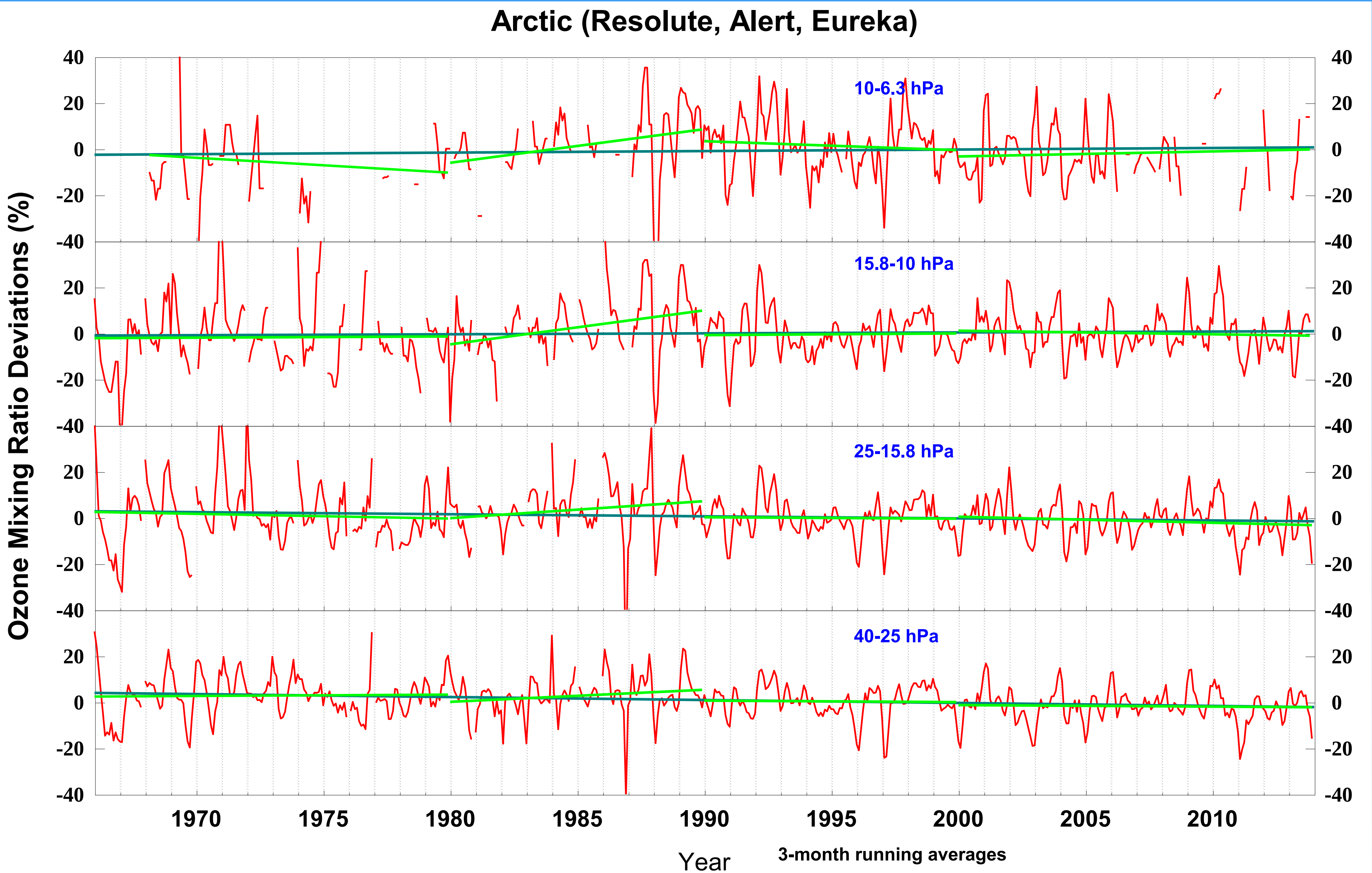


Northern Midlatitudes (Edmonton, Goose Bay, Churchill)




Arctic (Resolute, Alert, Eureka)
Ozone Mixing Ratio Deviations (%)
10-6.3 hPa
15.8-10 hPa
25-15.8 hPa
40-25 hPa
40
20
0
-20
-40
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
3-month running averages

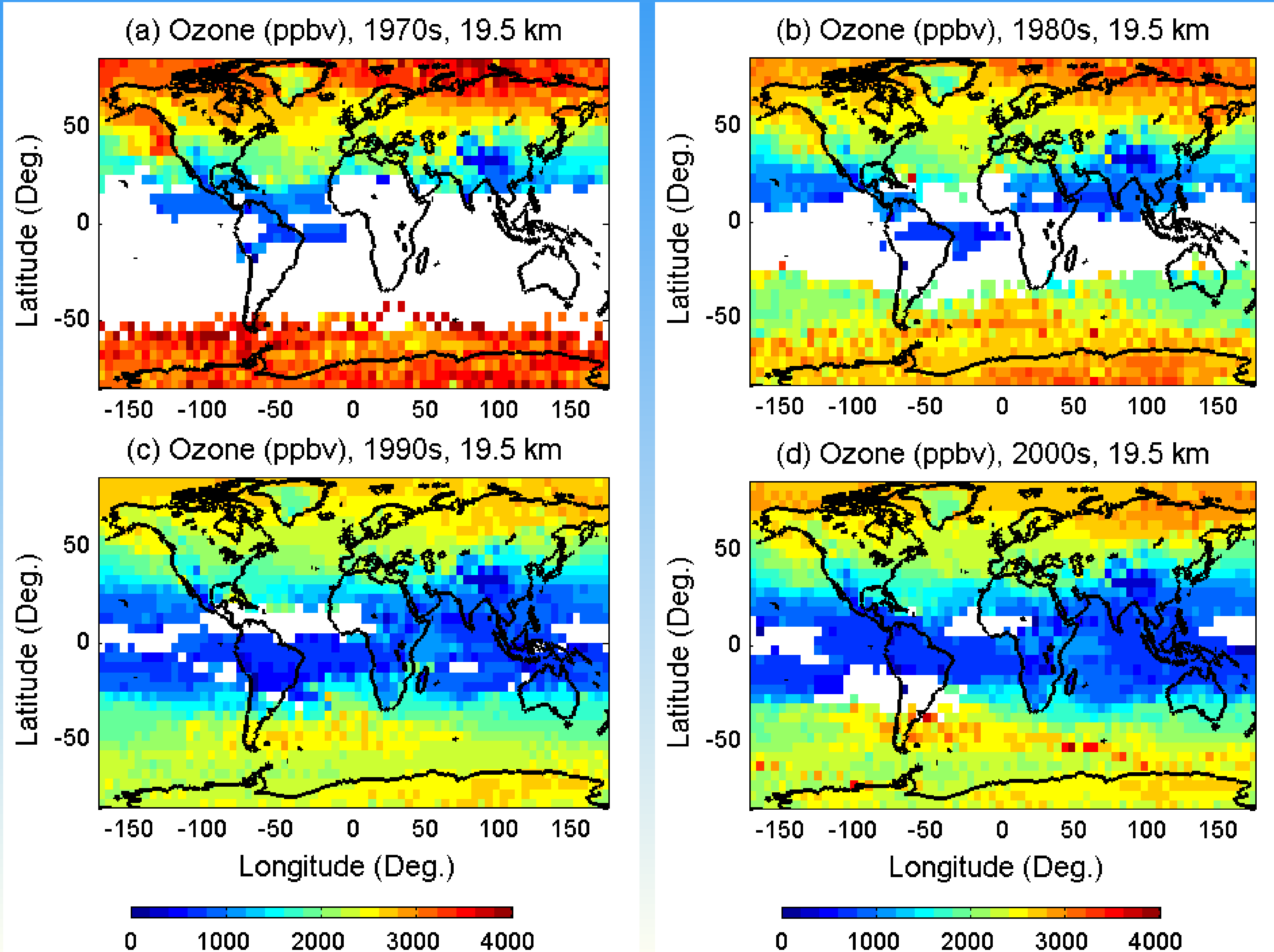
Stratospheric and tropospheric interannual ozone variability are correlated

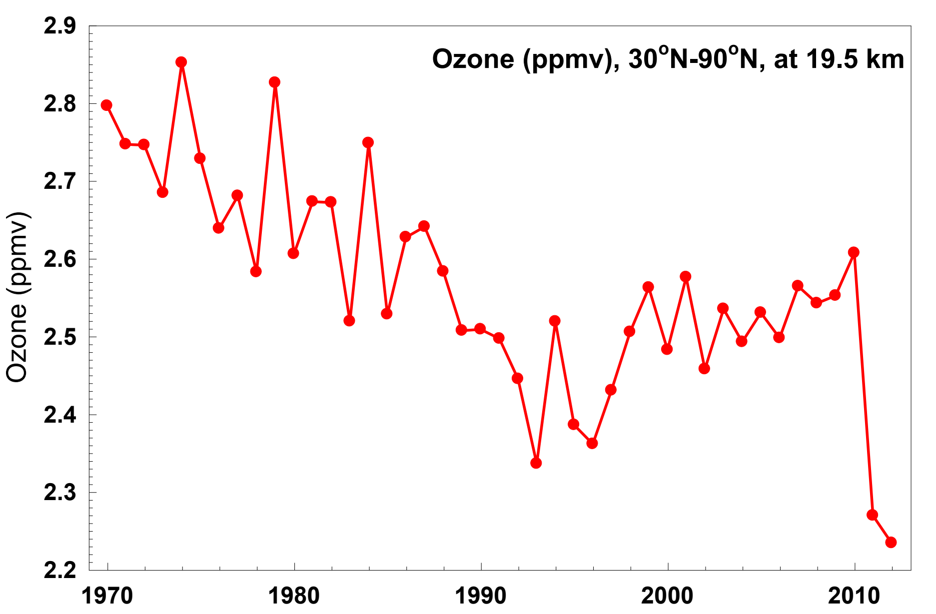
	Northern midlatitudes				Arctic			
	Ground	Gnd-630	630-400	400-250	Ground	Gnd-630	630-400	400-250
250-158 hPa	0.38	0.44	0.49	0.41	0.40	0.43	0.37	0.37
158-100 hPa	0.26	0.29	0.38	0.32	0.28	0.41	0.42	0.23
100- 63 hPa	0.26	0.32	0.41	0.32	0.15	0.26	0.32	0.20
63 - 40 hPa	-0.05	0.01	0.14	0.14	0.09	0.06	0.01	-0.02

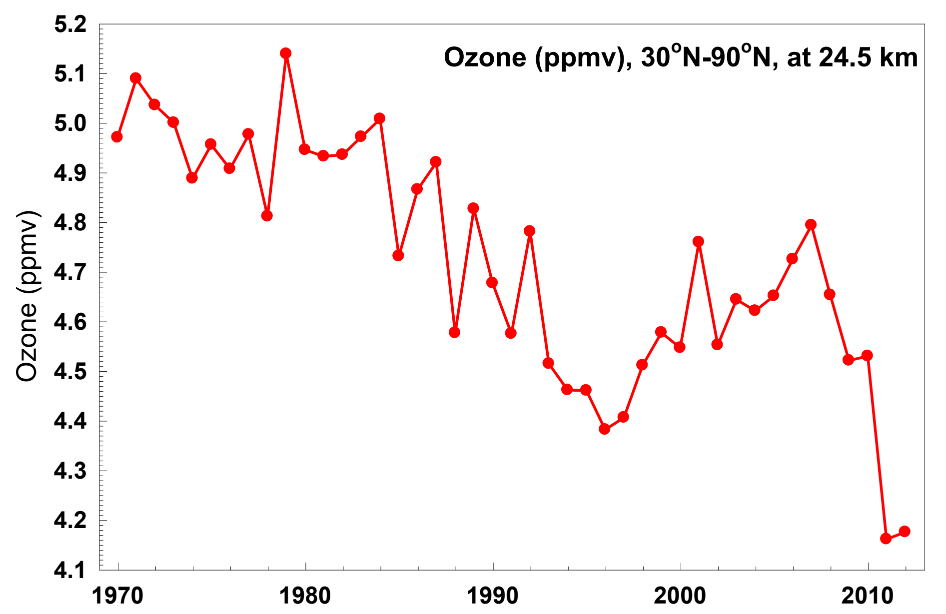
Correlations between annual average ozone mixing ratio anomalies in the troposphere and in the lower stratosphere, for northern midlatitude and Arctic stations, 1966-2013. Statistically significant (95% confidence) correlations are indicated by shading. Stratosphere and troposphere are explicitly separated.

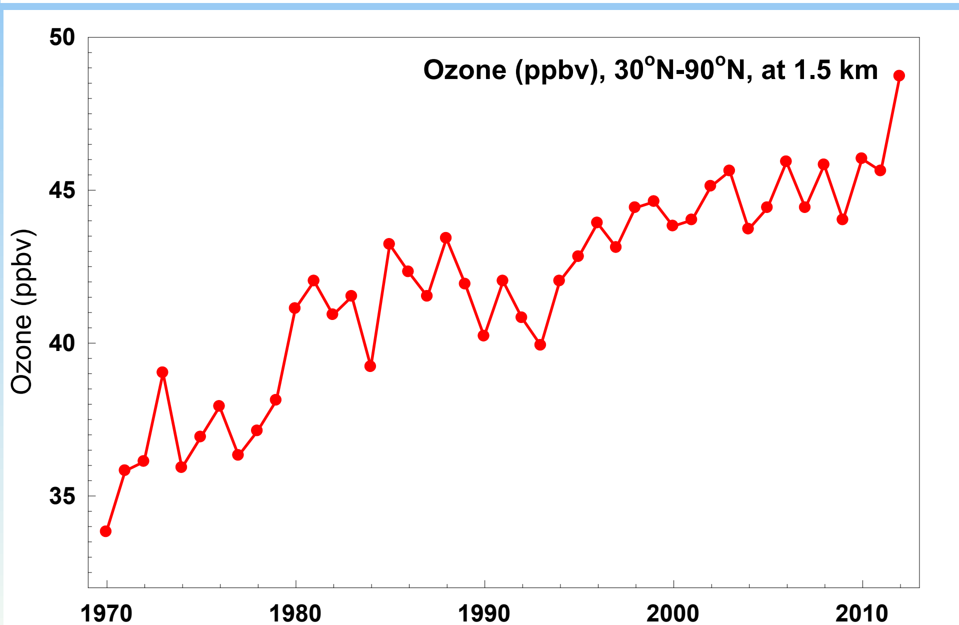
Gridded Global Ozone Dataset from Trajectory Mapping of WOUDC Ozonesonde Data

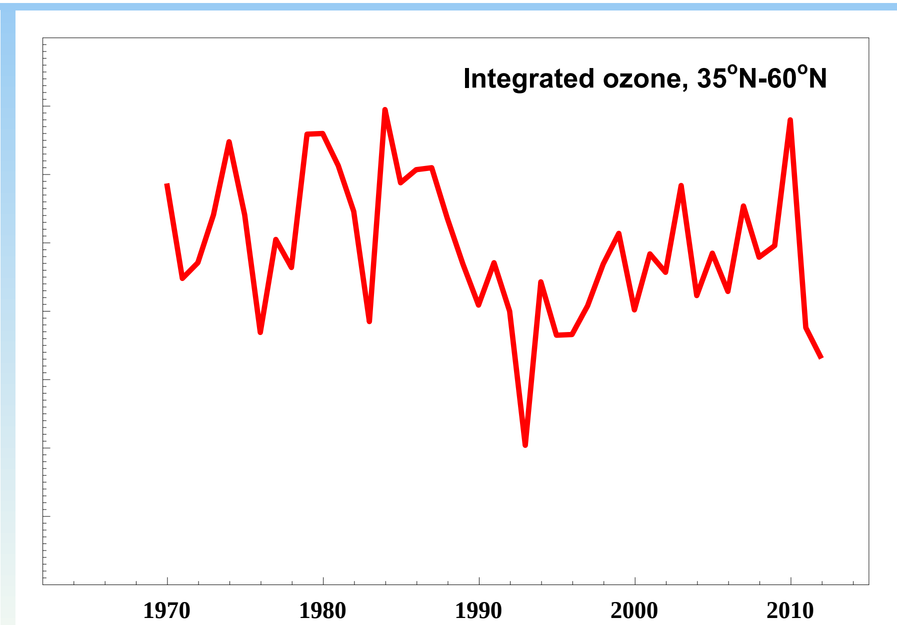
- Ozonesonde data, 116 stations, 44 years (1965-2008), 52,000 profiles (now 1965-2012, 77,000 profiles)
- use forward and back-trajectory calculations for each sounding to map ozone measurements to a number of other locations, and so to fill in the spatial domain.
- HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model), NOAA, Air Resources Laboratory, version 4.8 (http://ready.arl.noaa.gov/HYSPLIT.php)
- NCEP reanalysis data (1965 – present)
- Global mapping: 5°×5° horizontal, 1 km vertical resolution
- *Liu et al.*, 2013, *ACP* SI2N Special Issue


(a) Ozone (ppbv), 1970s, 19.5 km
(b) Ozone (ppbv), 1980s, 19.5 km
(c) Ozone (ppbv), 1990s, 19.5 km
(d) Ozone (ppbv), 2000s, 19.5 km
Latitude (Deg.)
Longitude (Deg.)
50
0
-50
-150
-100
-50
0
50
100
150
0
1000
2000
3000
4000







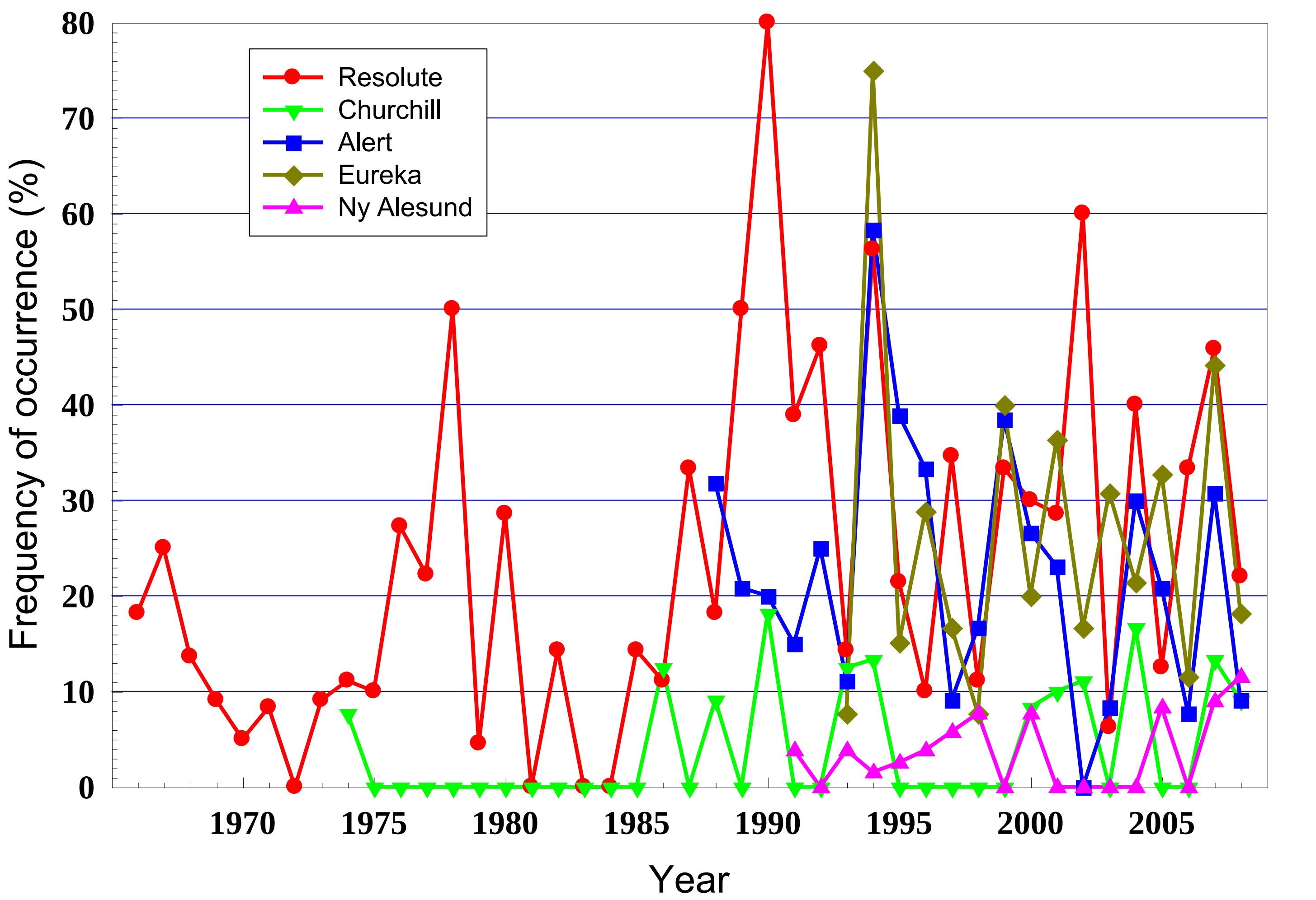


Area-weighted averages using data only from grid cells with ozone data in all years.

Extras

Trends in frequency of depletions

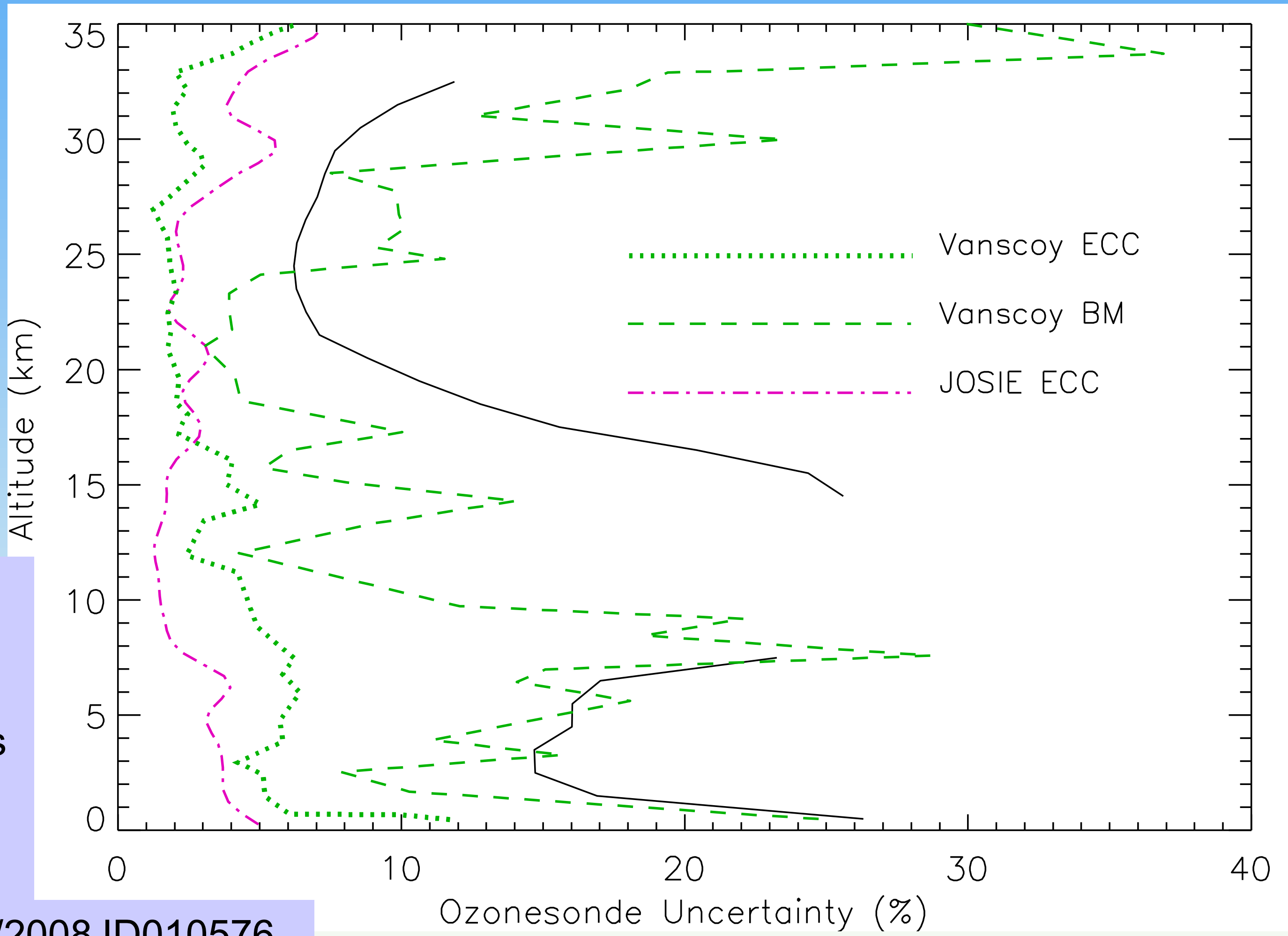
- Resolute (1966-2008): 5.8 ± 4.3% per decade
- Churchill (1974-2008): 2.0 ± 1.9% per decade.
- Surface measurements indicate shift to more events earlier in the year.



Liu, G., J.J. Liu, D.W. Tarasick, V.E. Fioletov, J.J. Jin, O. Moeni, X. Liu, C.E. Sioris and M. Osman (2013), A global tropospheric ozone climatology from trajectory-mapped ozone soundings, *Atmos. Chem. Phys., 13,* 10659-10675, doi:10.5194/acp-13-10659-2013.

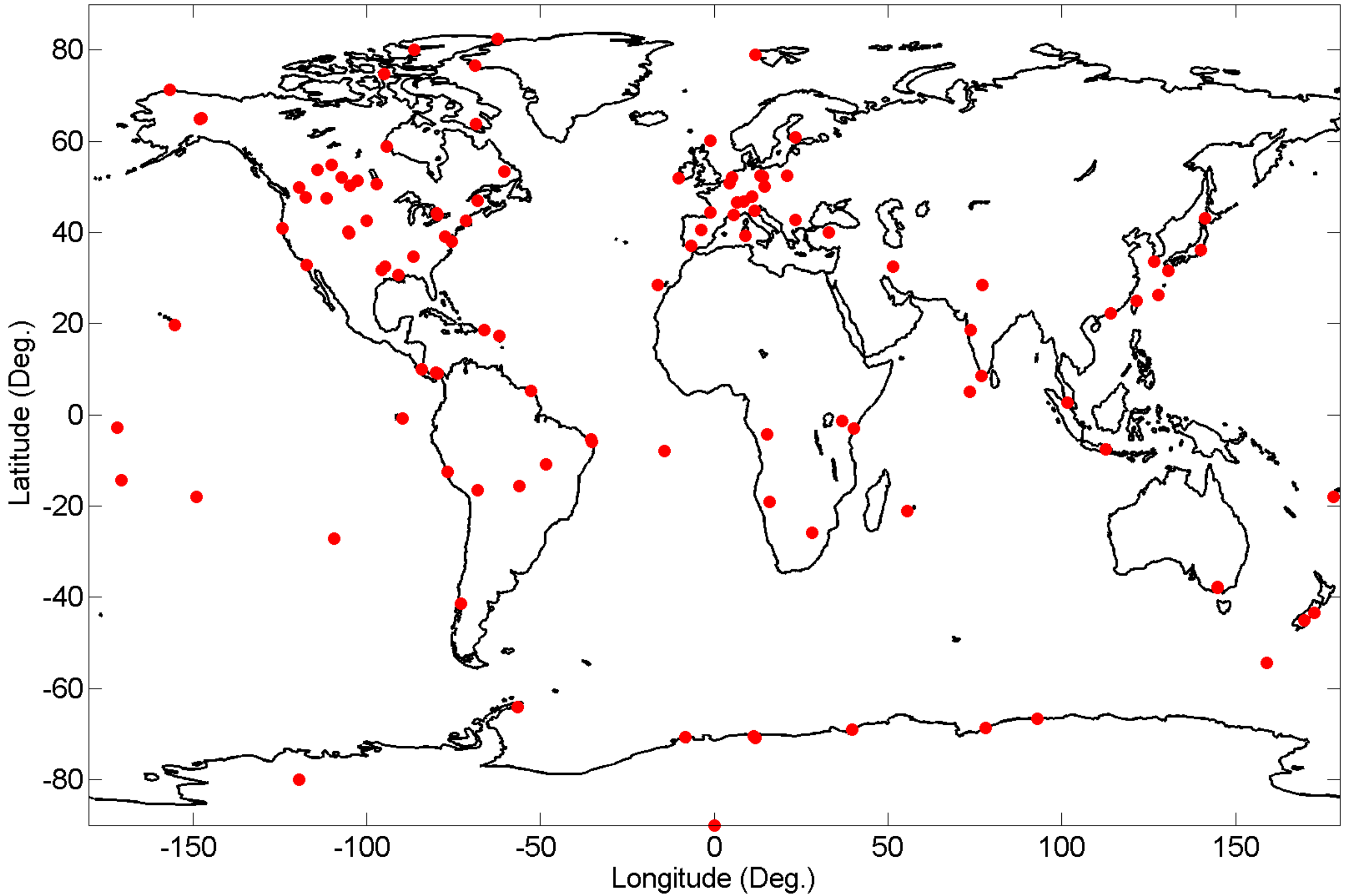
Liu, J., D.W. Tarasick, V.E. Fioletov, C. McLinden T. Zhao, S. Gong, C. Sioris, J. Jin, G. Liu, and O. Moeini (2013), A Global Ozone Climatology from Ozone Soundings via Trajectory Mapping: A Stratospheric Perspective, *Atmos. Chem. Phys.,* accepted.

Ozone soundings are the major source of information on ozone amounts in the free troposphere, capable of precise (3-5%) measurements of ozone with ~100m vertical resolution.



Liu, G., et al. (2009), Ozone correlation lengths and measurement uncertainties from analysis of historical ozonesonde data in North America and Europe, *J. Geophys. Res.*, 114, D04112, doi:10.1029/2008JD010576.

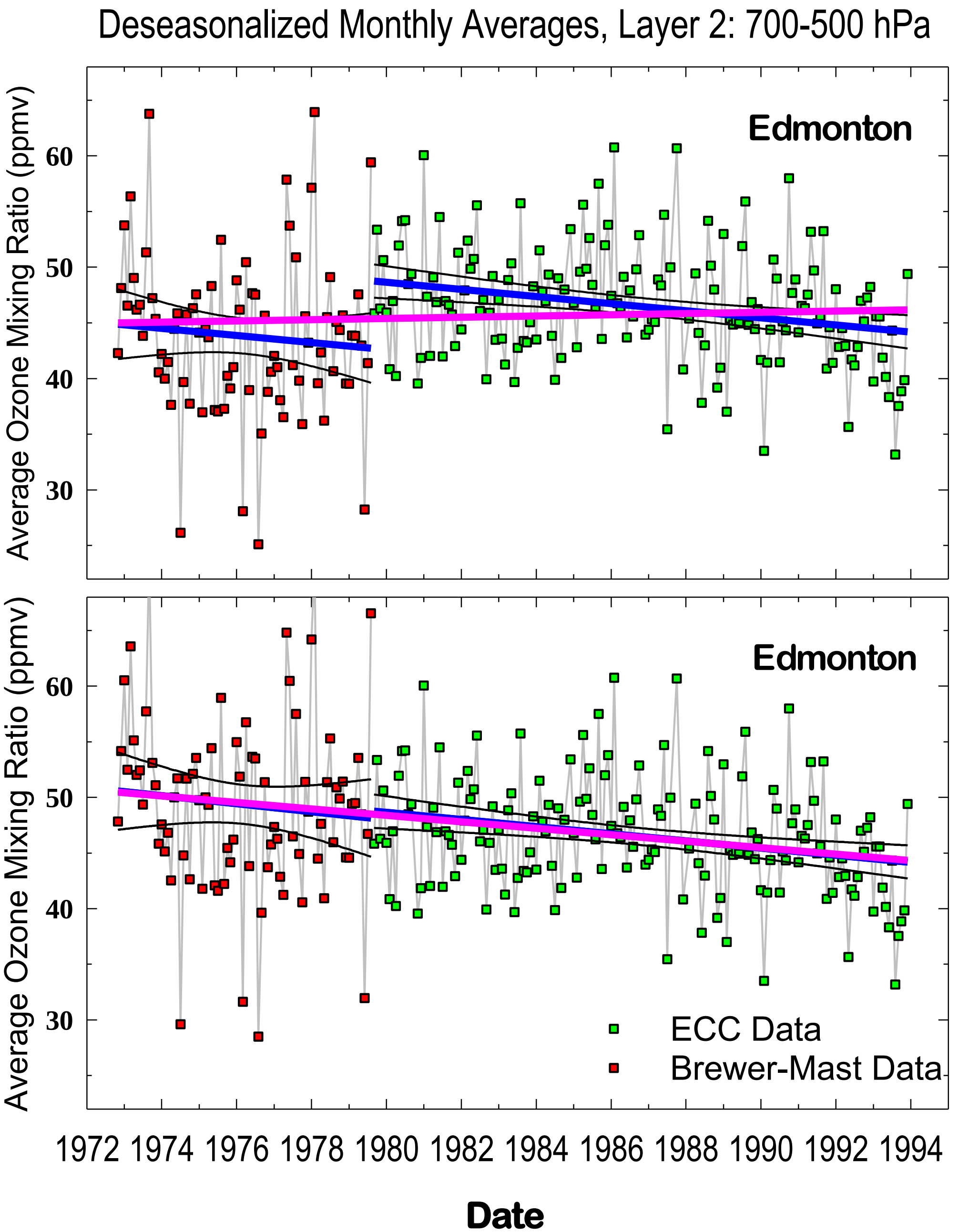
Ozone Sounding Sites, 1965 - 2012

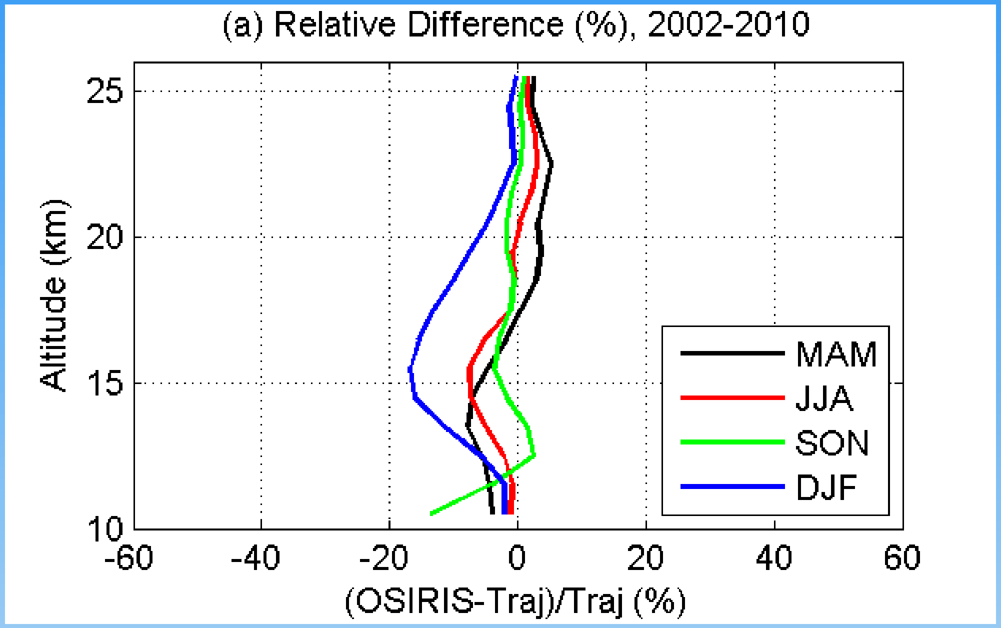


Upper panel: Trends in the middle troposphere at Edmonton from Brewer-Mast and ECC data. The thick purple line is the trend that is calculated by combining the two data sets.

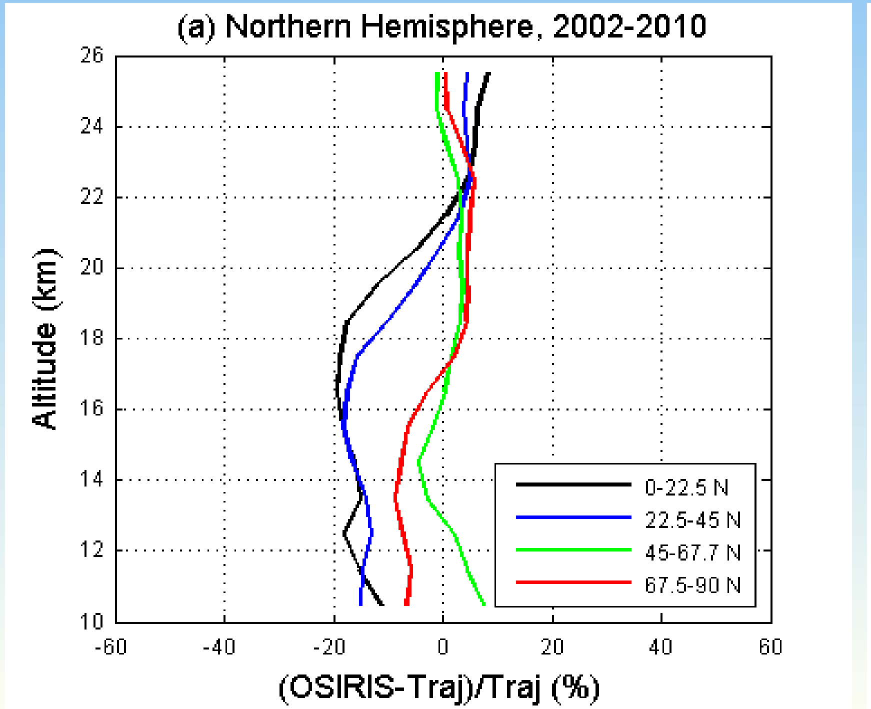
Lower panel: with corrections applied.

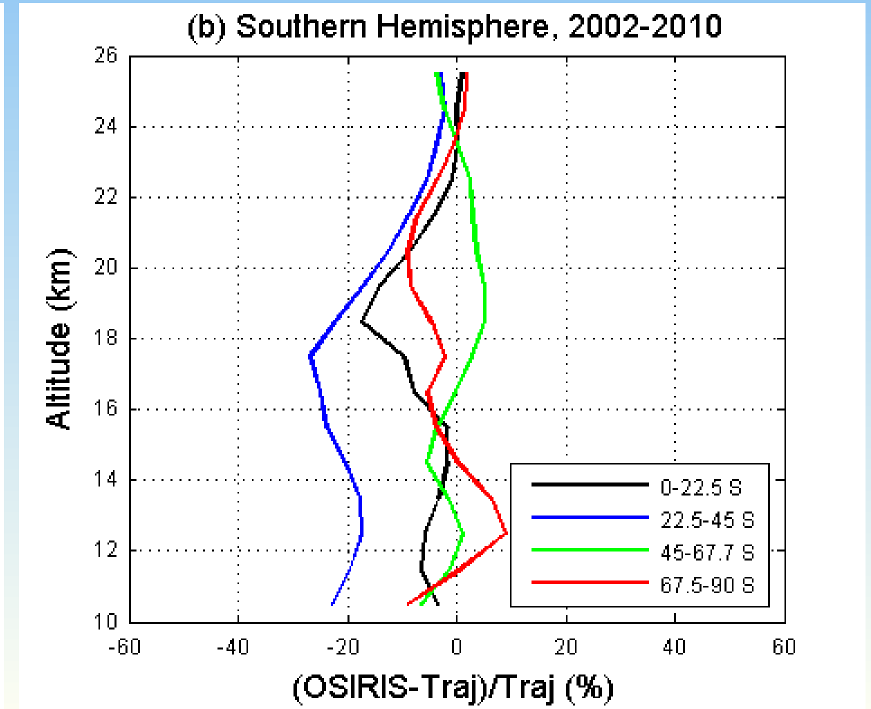
(From Tarasick, D.W., J. Davies, K. Anlauf, M. Watt, W. Steinbrecht and H.J. Claude [2002] Laboratory investigations of the response of Brewer-Mast sondes to tropospheric ozone, *J. Geophys. Res.*, **107**(D16), 4308, doi:10.1029/2001JD001167.

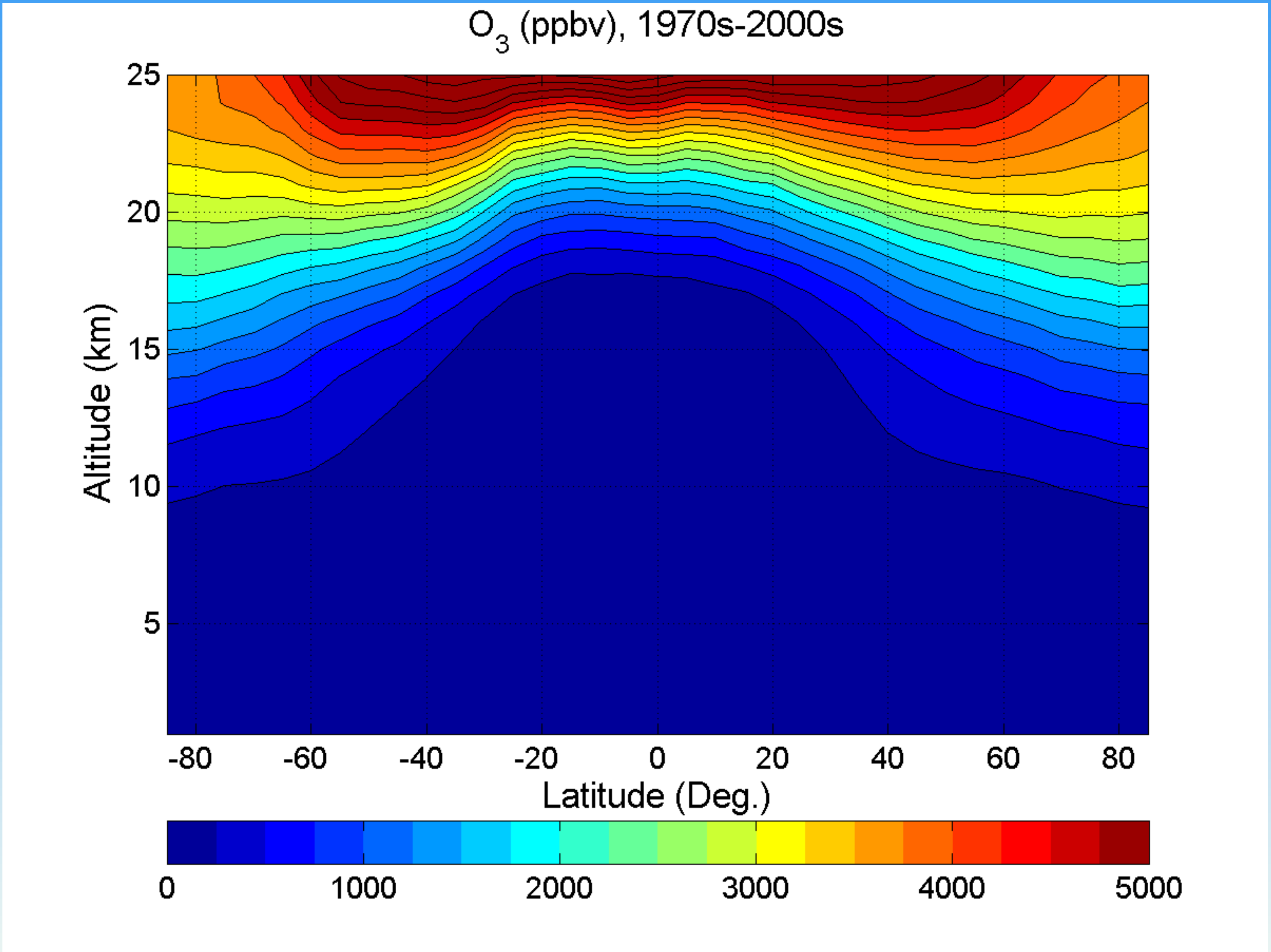




Relative difference between the climatology and OSIRIS data by season (left), and by latitude band (below), as a function of altitude.

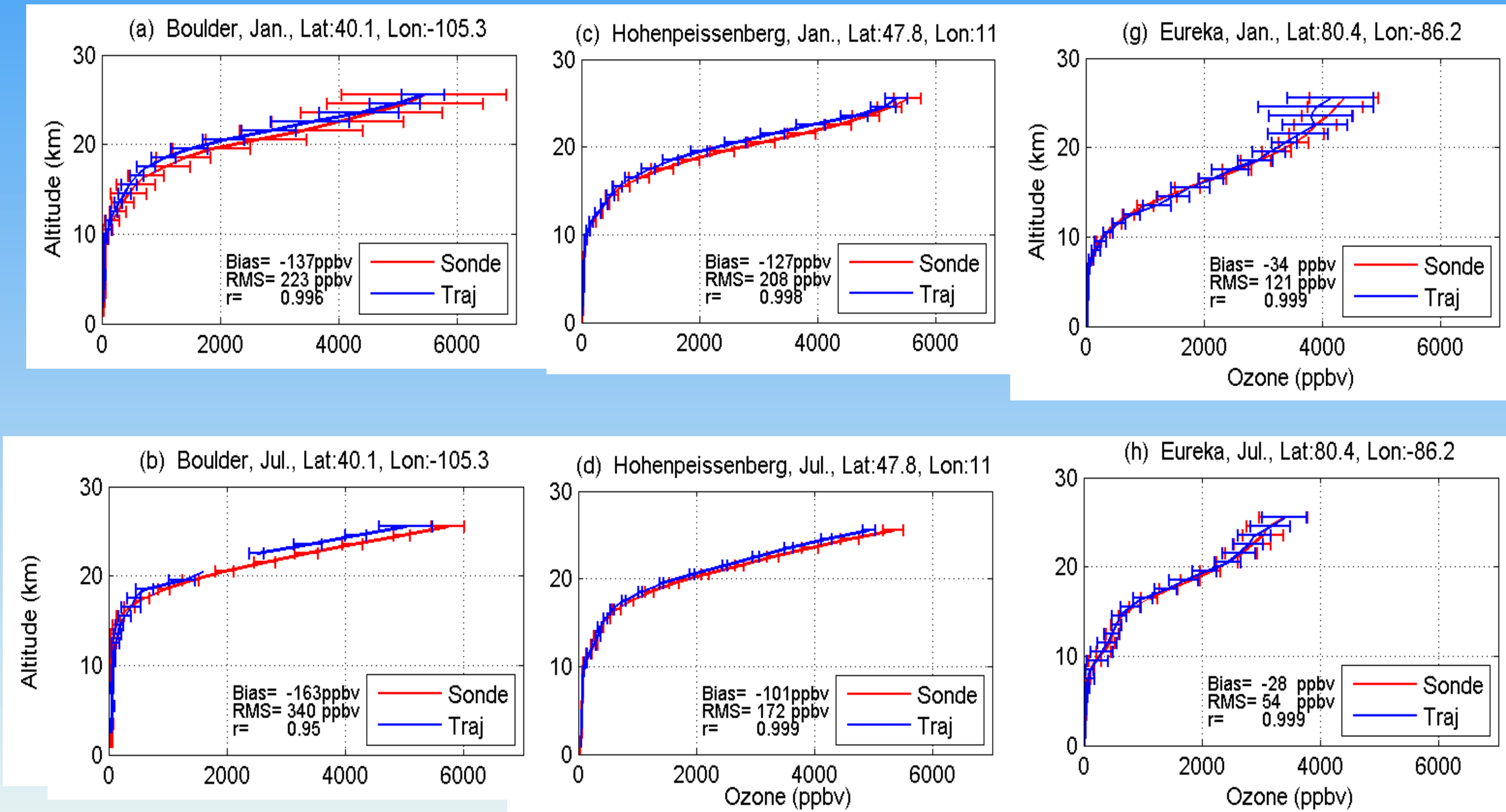




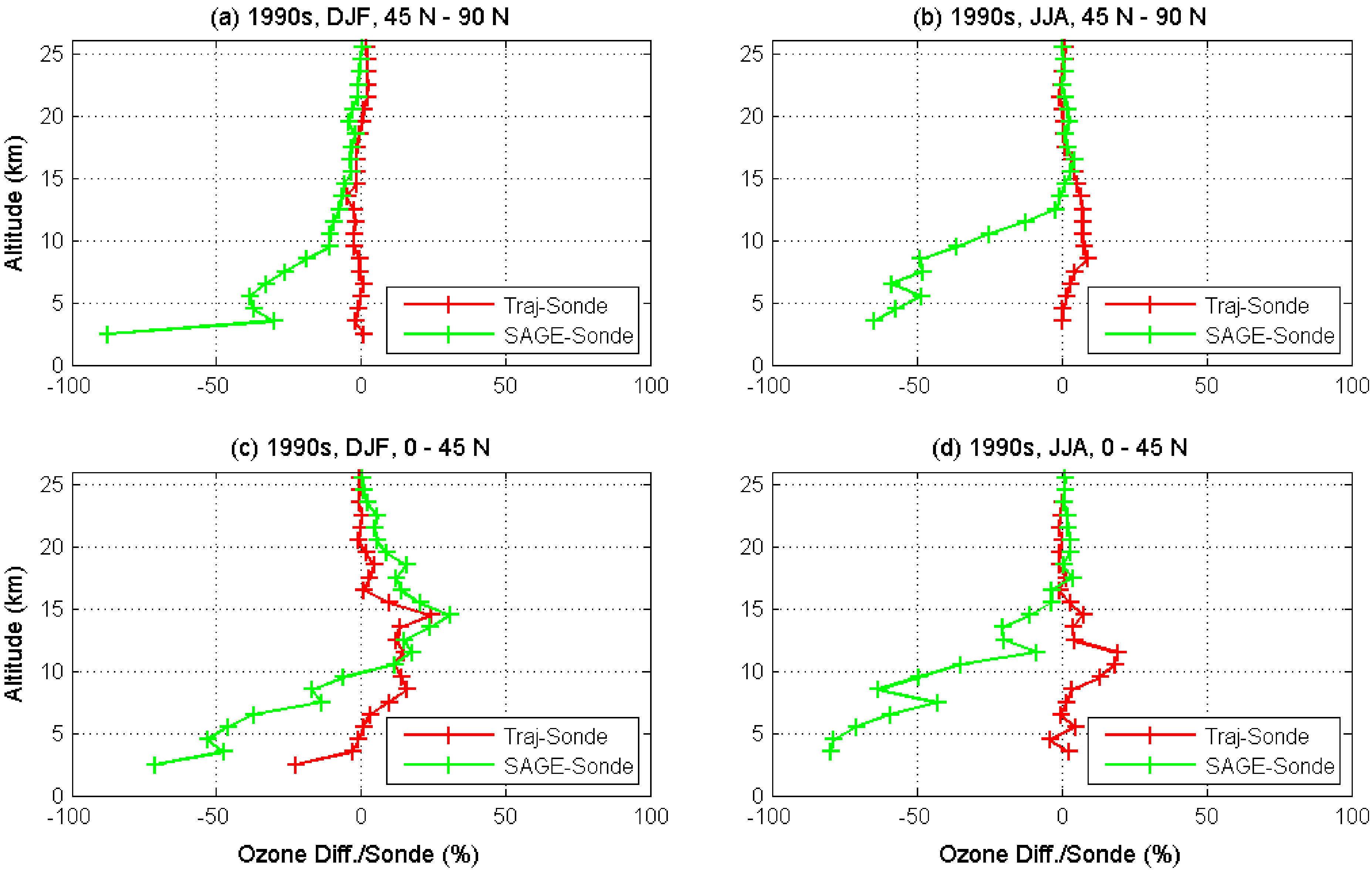


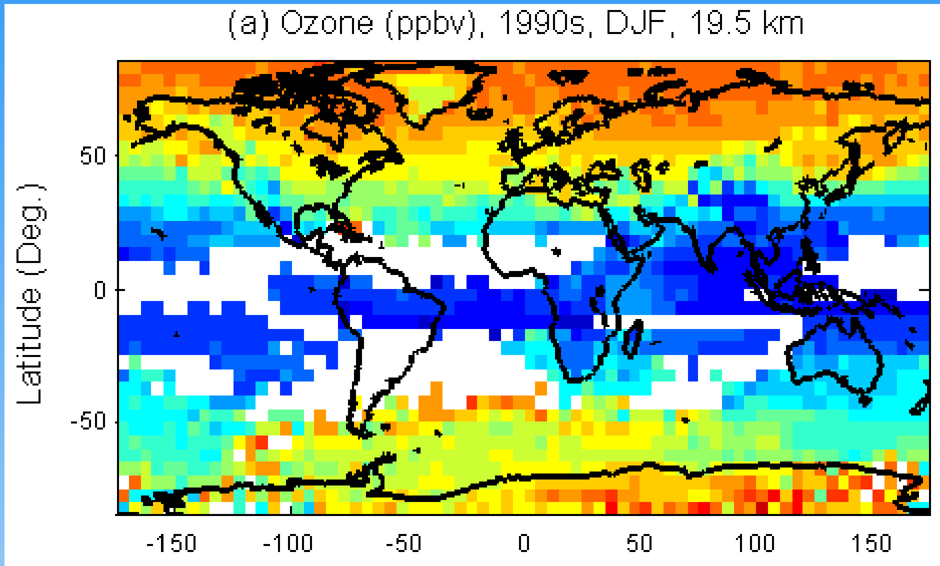
Stratosphere: Average latitude-altitude distribution (1970-2008)

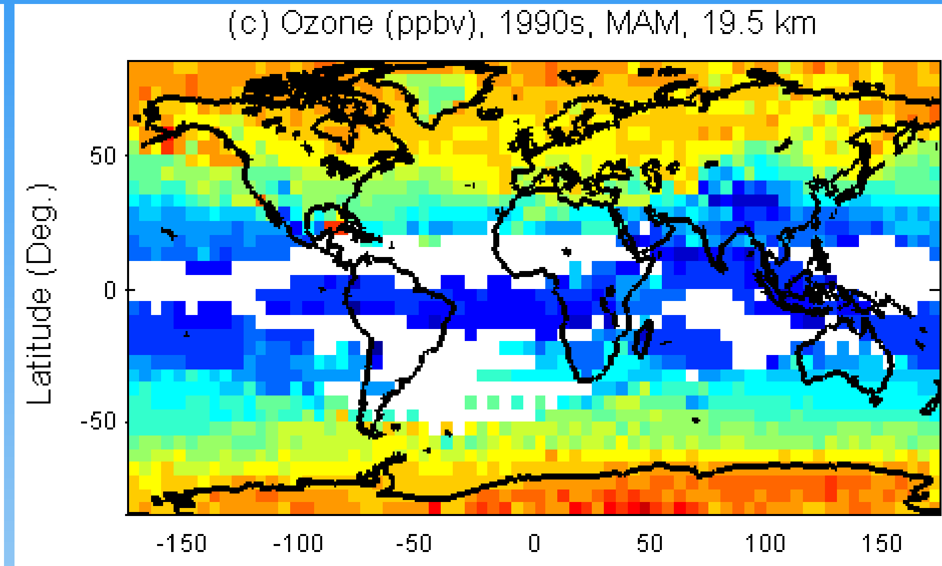
Validation against independent data

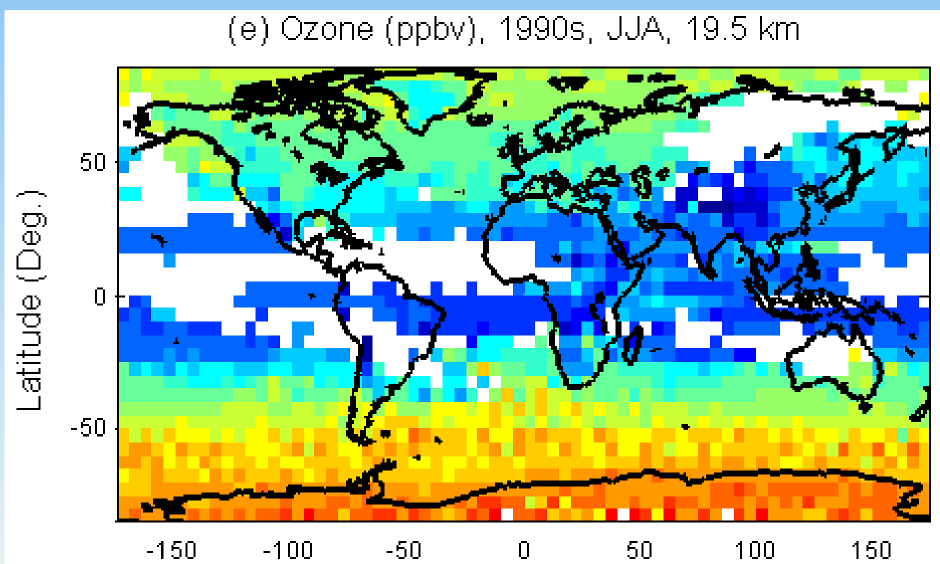


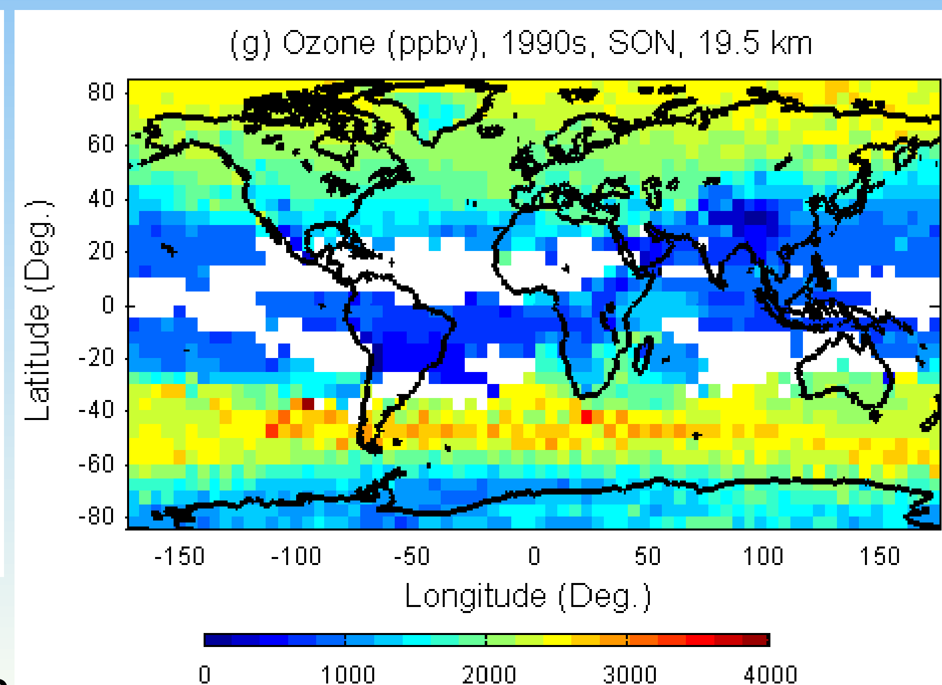
Validation against SAGE







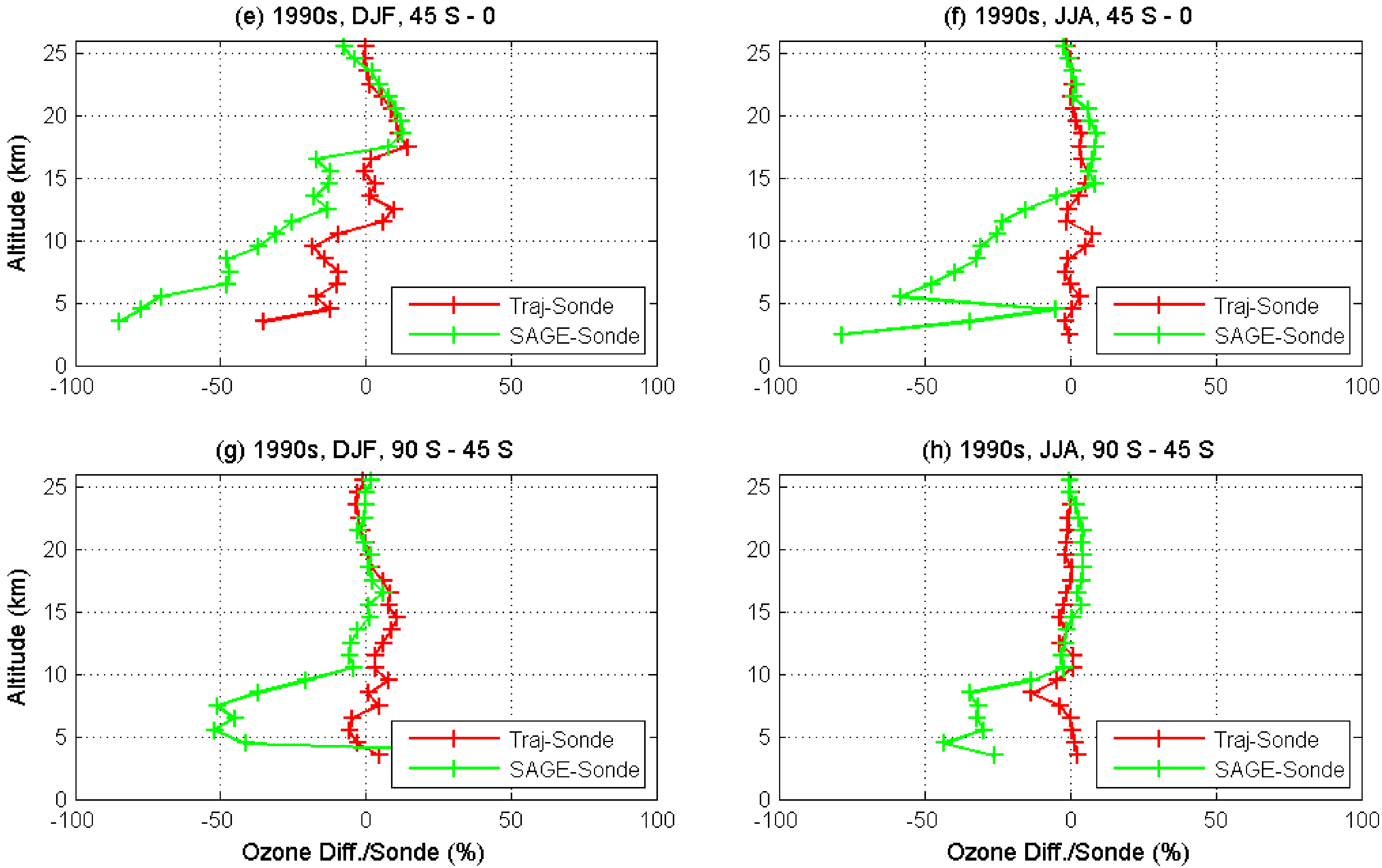




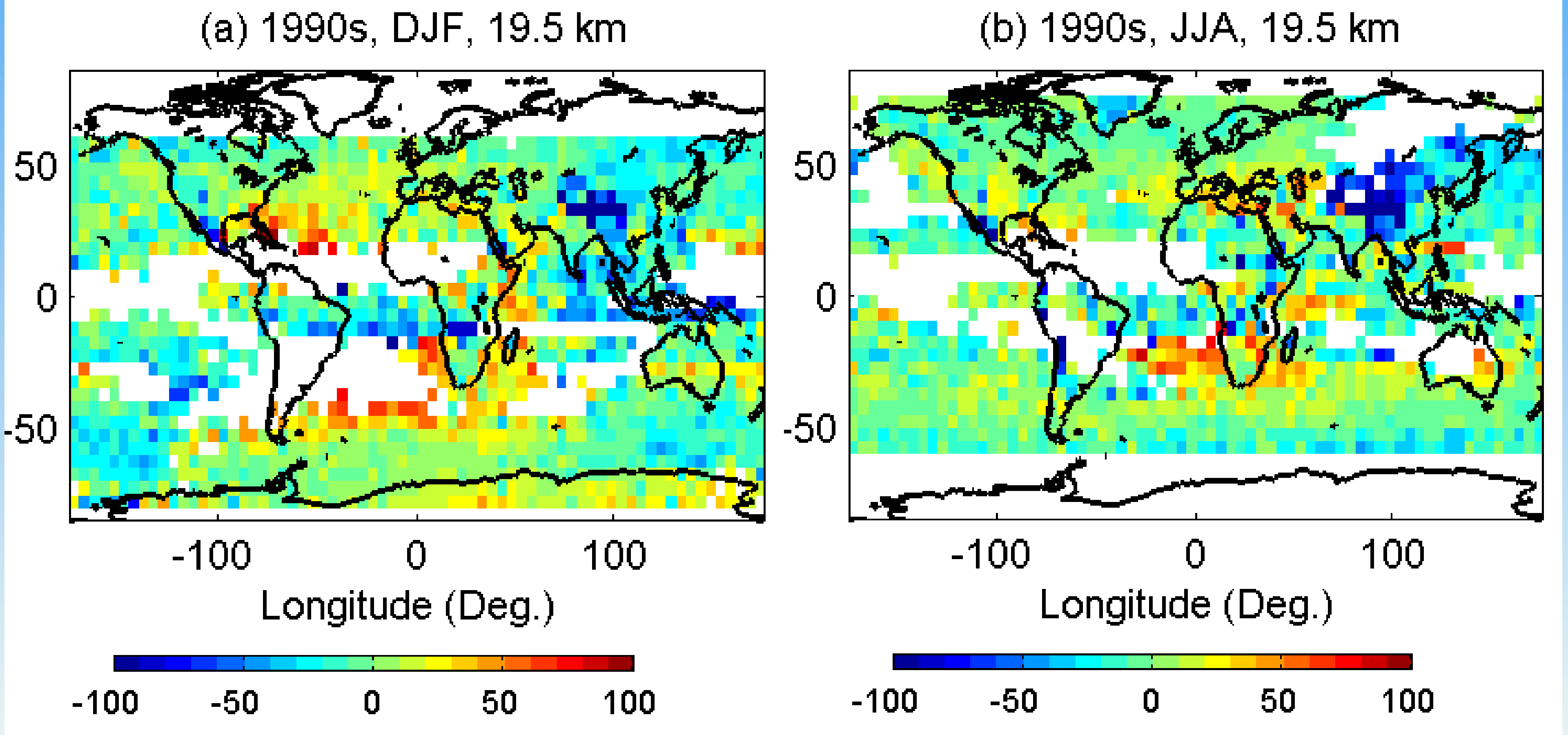
Seasonal variation at 19.5 km

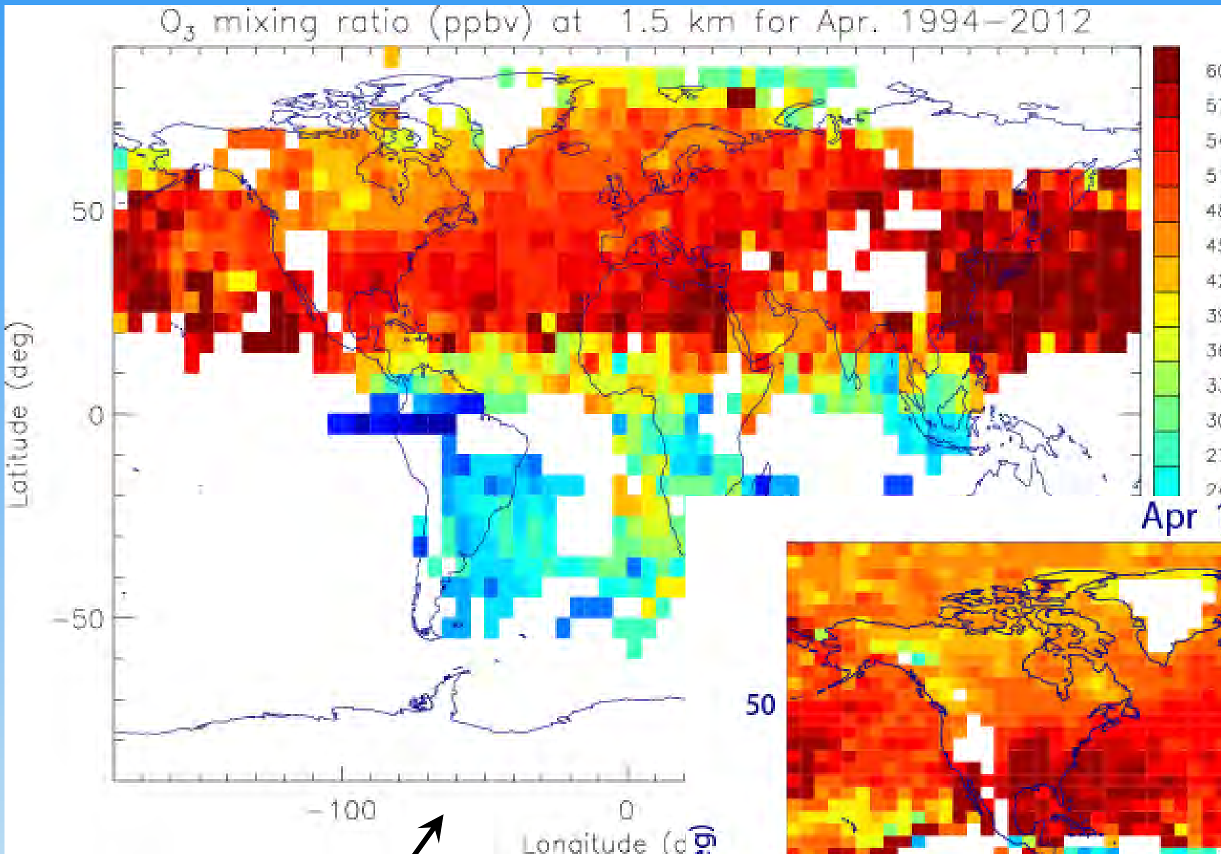
White areas indicate missing data

Validation against SAGE

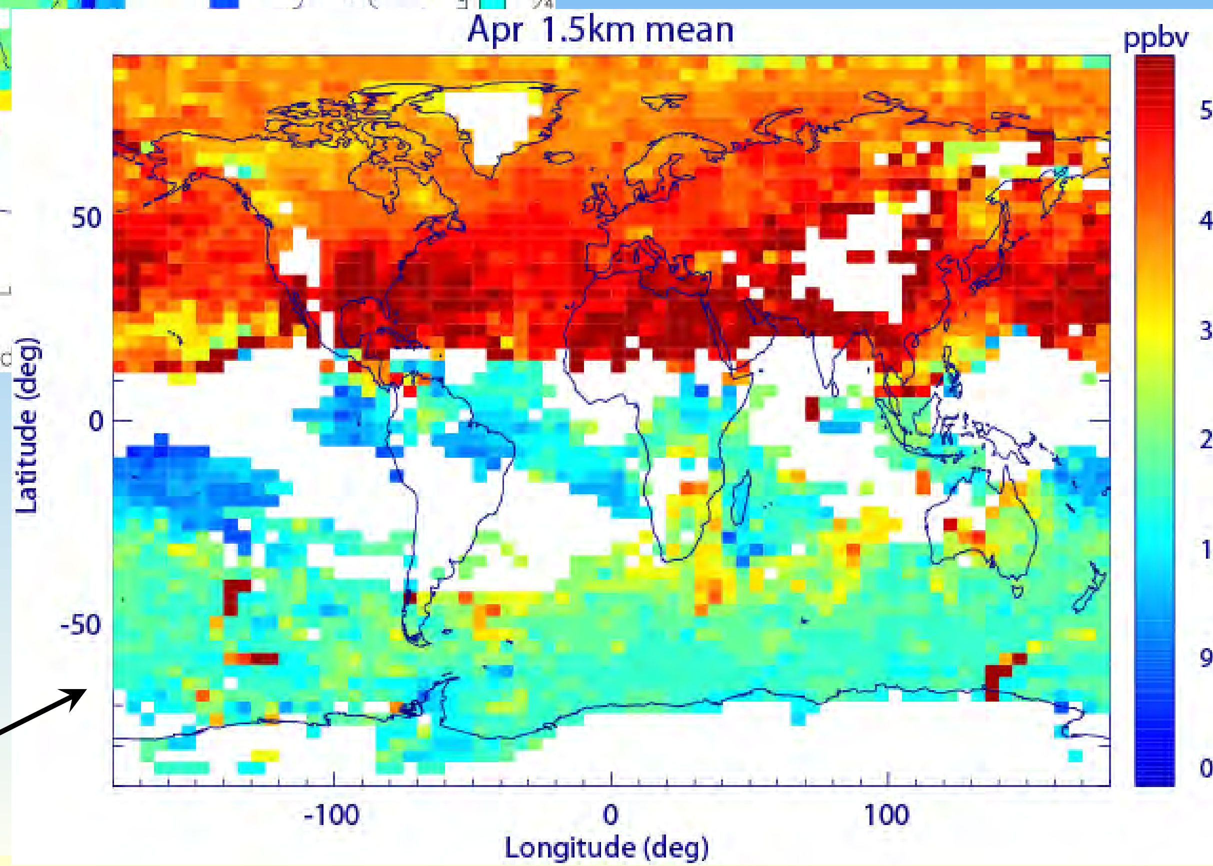


Relative difference in ozone mixing ratio between the ozone climatology and SAGE data in NH winter and summer in the 1990s at 19.5 km



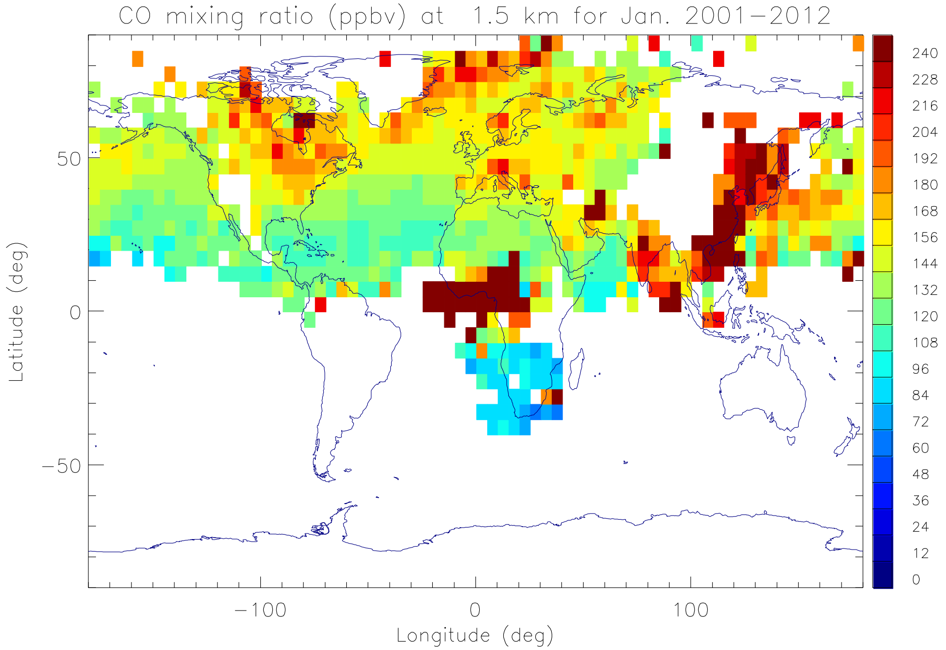


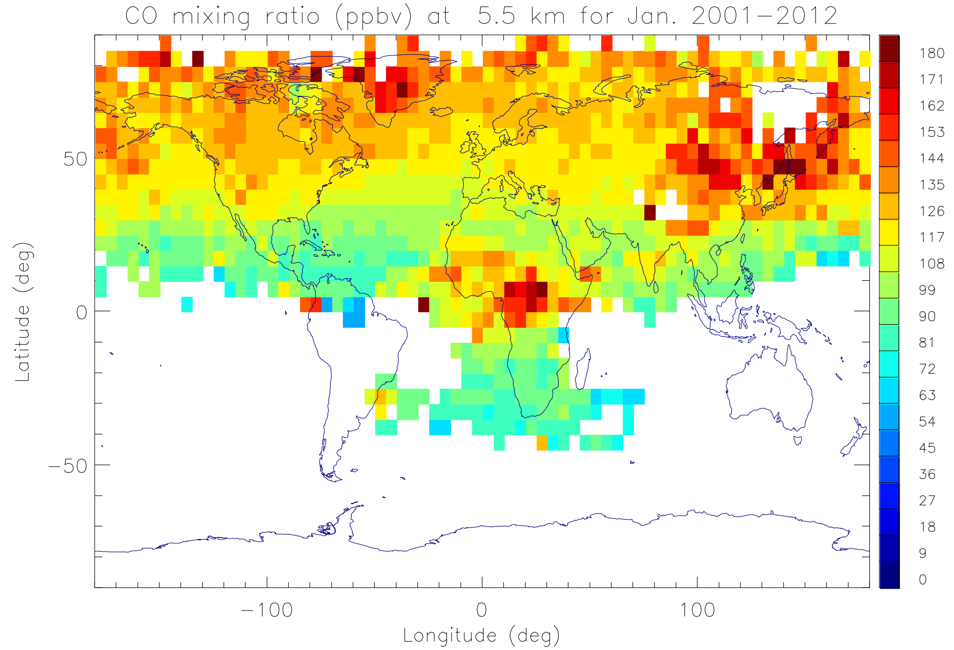
Ozone data from sparse measurements projected using meteorological winds (air parcel trajectories). *More detail, longer record than satellites.*



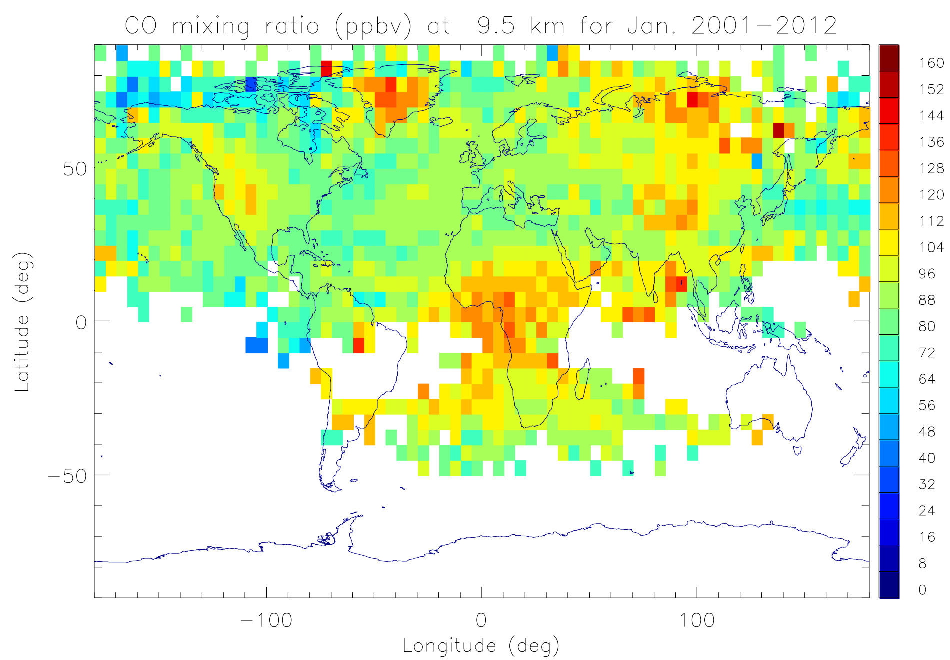
Trajectory-mapped ozone data from commercial aircraft

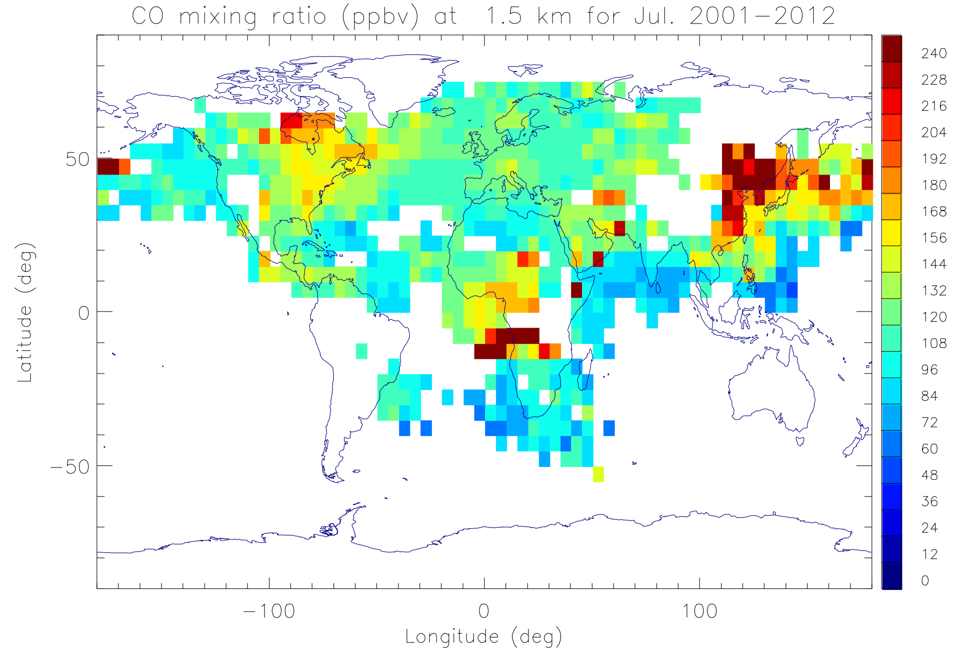
And from ozonesondes

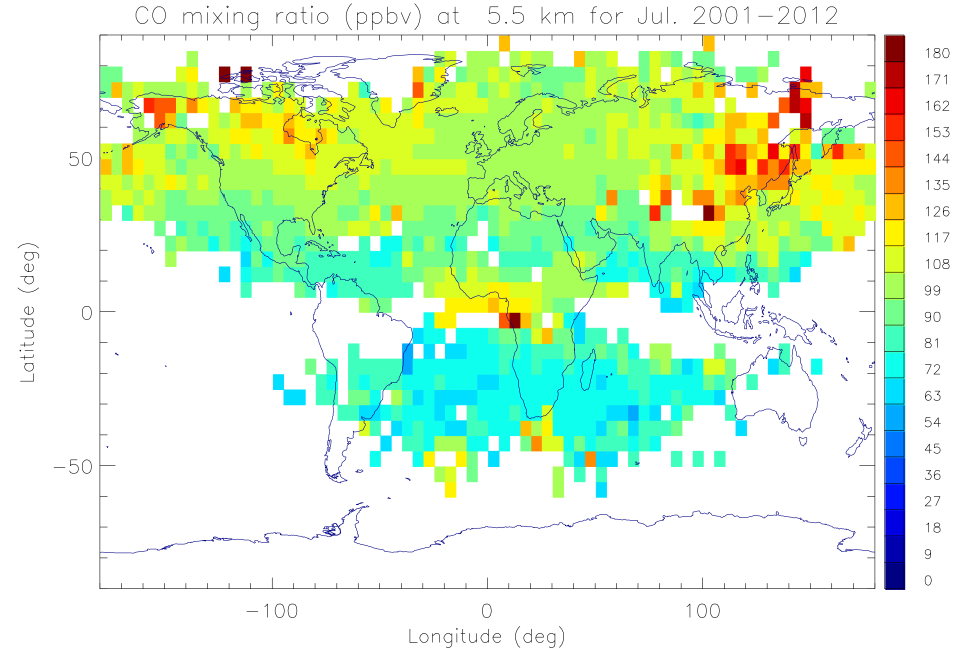




CO climatology







CO climatology