Is global ozone recovering?

M. Hegglin[1], N. Harris[2], W. Steinbrecht[3]
and many others!!

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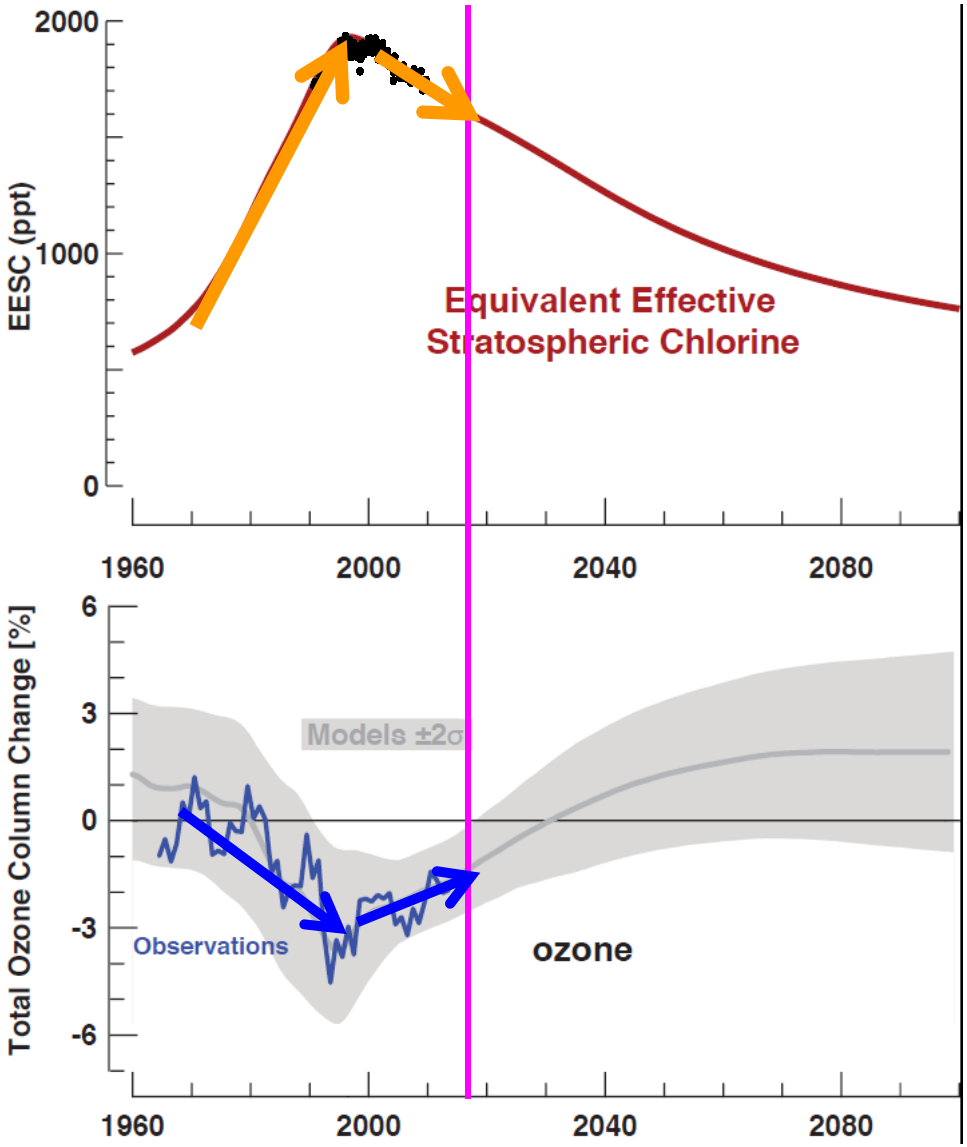
[3] Deutscher Wetterdienst, Hohenpeißenberg, GER

Outline

- Turnaround of ozone depleting substances (ODS), equivalent effective stratospheric chlorine (EESC) and ozone
- Diagnosing ozone increases
- Real-world difficulties
- Latitude altitude patterns / regions of largest ODS sensitivity
- Clearest signs for recovery
- Expectations & attribution, need for model simulations
- Lack of total ozone recovery: ODS vs. transport changes
- Tropical trends and tropospheric changes
- Summary

Montreal Protocol effective?

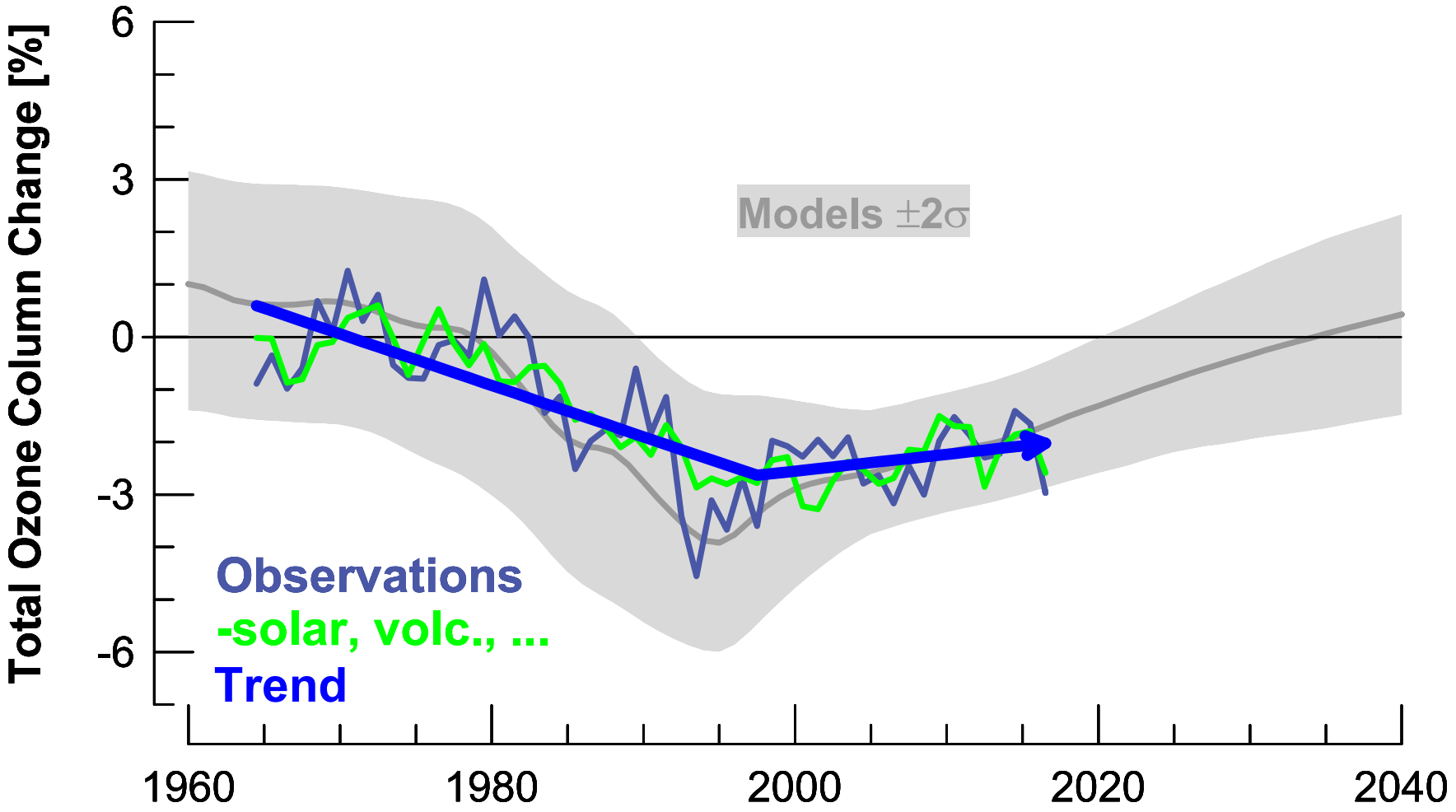


- **EESC ≈15% to 25%** down from peak
- Decline 3x slower!!

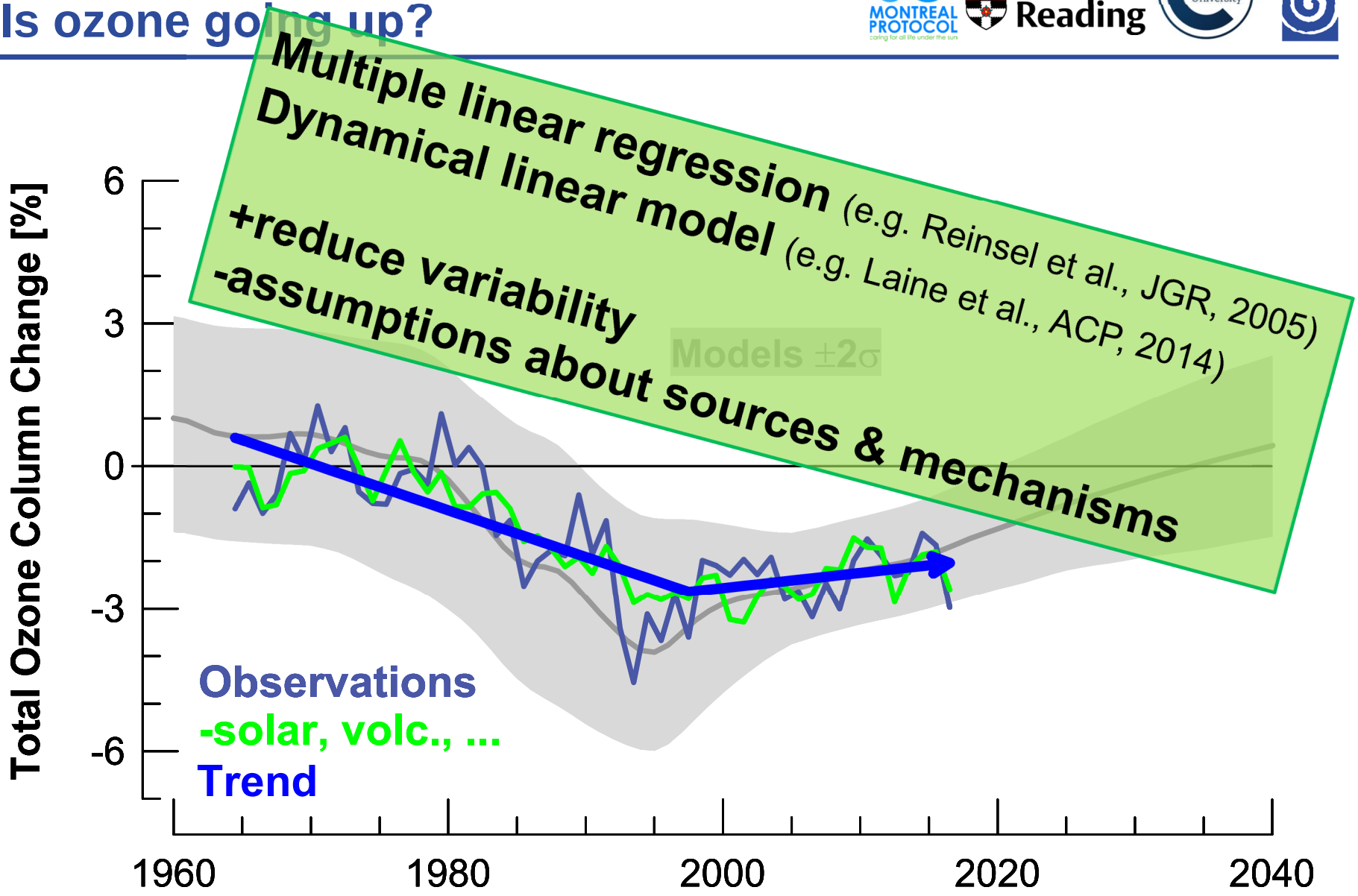
- **Is ozone responding & going up?**
- Due to ODS decline?
- Due to transport & other changes?

WMO, 2014

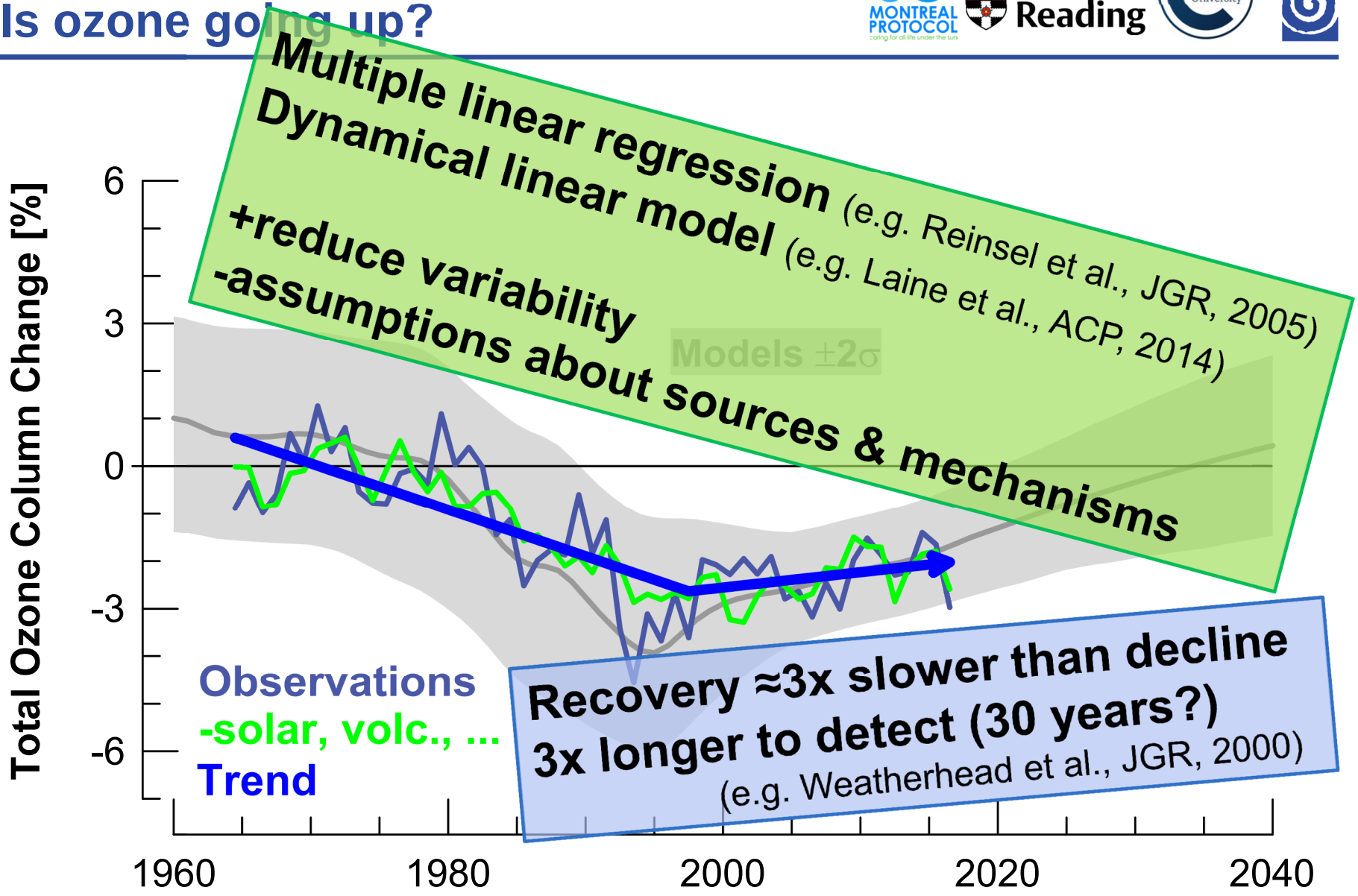
Is ozone going up?



Is ozone going up?



Is ozone going up?



Time to detect trend

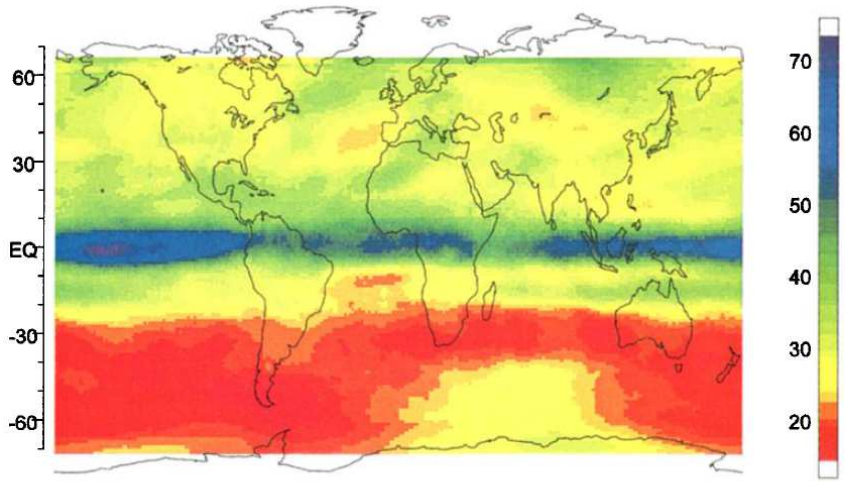


Plate 5. The expected number of years to detect the predicted trend for ozone. Estimates assume that a trend is detected at the 95% confidence level. The estimates make use of the magnitude of variation and autocorrelation of the noise as well as the magnitude of the predicted trends in ozone. The predicted trends are based on the GSFC 2-D model as reported in the WMO Scientific Assessment of Ozone Depletion 1998 [*WMO*, 1999]. The estimates for the magnitude and autocorrelation of noise in the ozone signal are based on the Nimbus 7 TOMS ozone record.

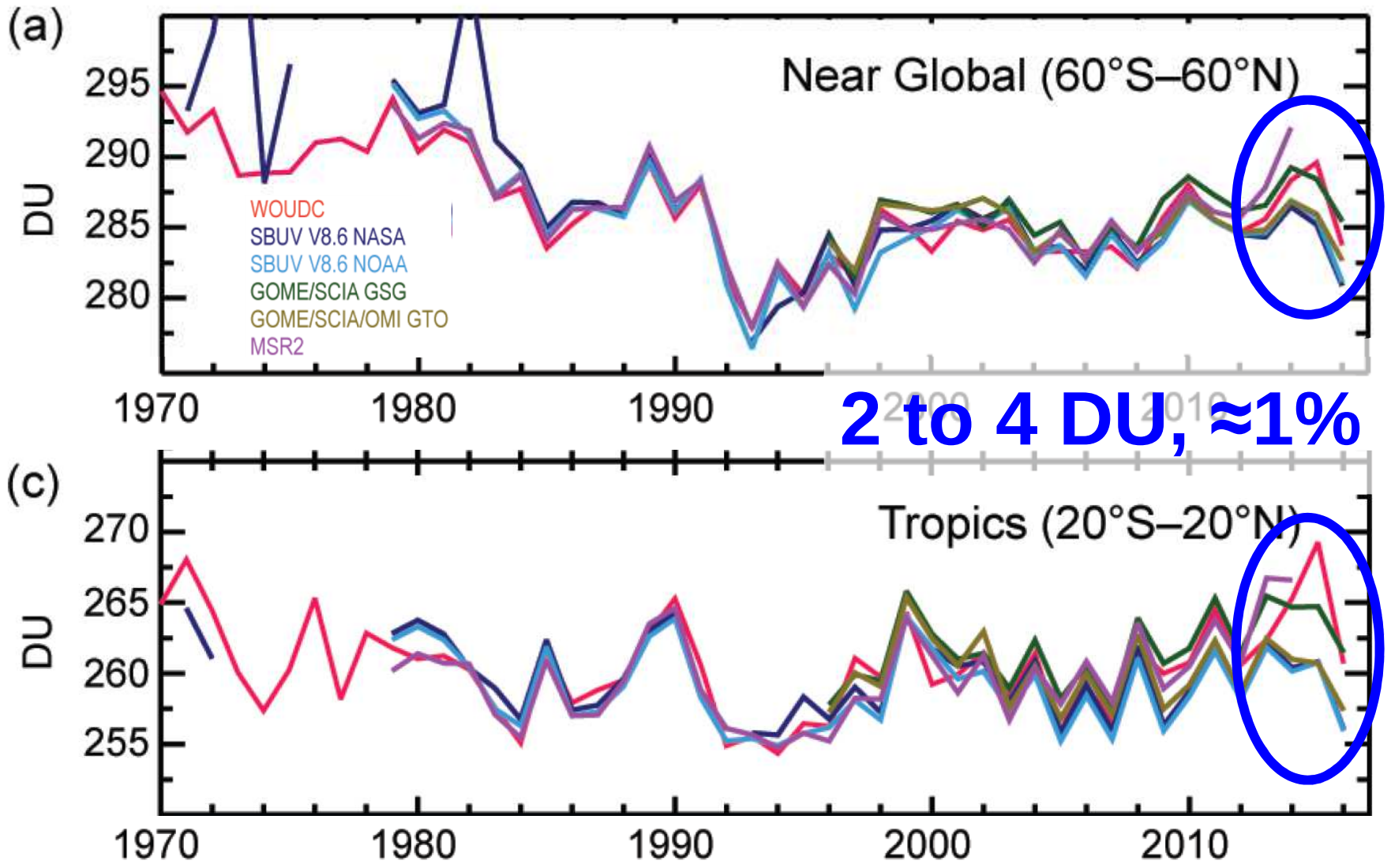
15 to 40 years

Years of Monthly Data Needed to ected Regions

Region	σ_N	ϕ	Years to Detect 10 DU per Decade	Expected Trend, DU per Decade	Years to Detect Expected Trend
30°N–60°N	6.31	0.82	11.5	2.1	32.4
0°–30°N	3.47	0.82	7.7	1.1	34.5
30°S–0°	3.08	0.77	6.5	1.4	24.5
60°S–30°S	5.20	0.81	9.8	3.6	19.4
0°–60°N	4.05	0.88	9.8	1.5	34.8
0°–60°S	3.23	0.84	7.6	2.3	20.2
60°S–60°N	1.91	0.82	5.0	1.9	15.0
20°S–20°N	2.74	0.74	5.8	1.0	27.0

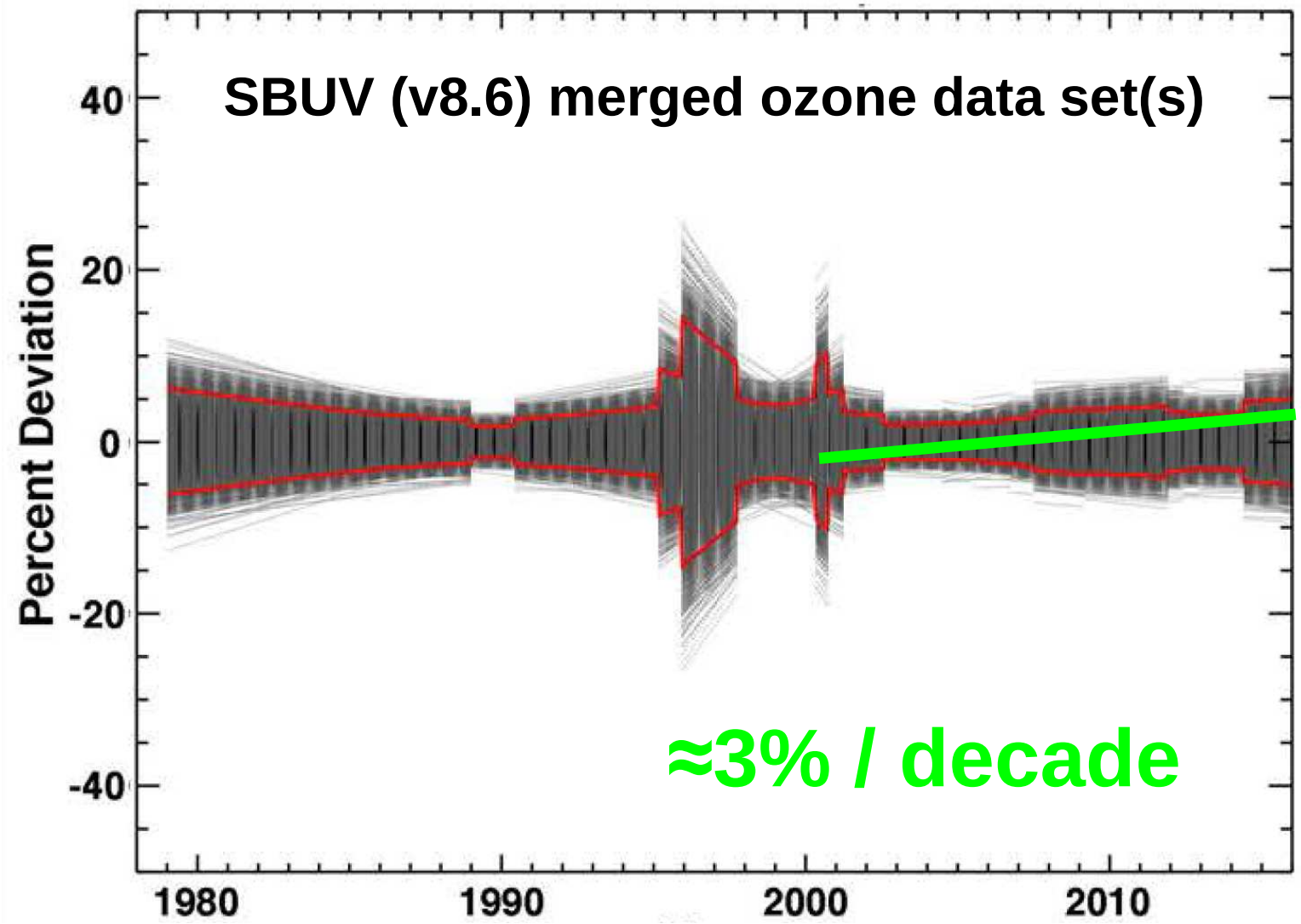
Weatherhead, JGR, 2000

Complications – limited accuracy



Weber et al., BAMS, 2017

Complications – data merging



Frith et al., ACPD, 2017

Detecting upward trends

Look for regions where:

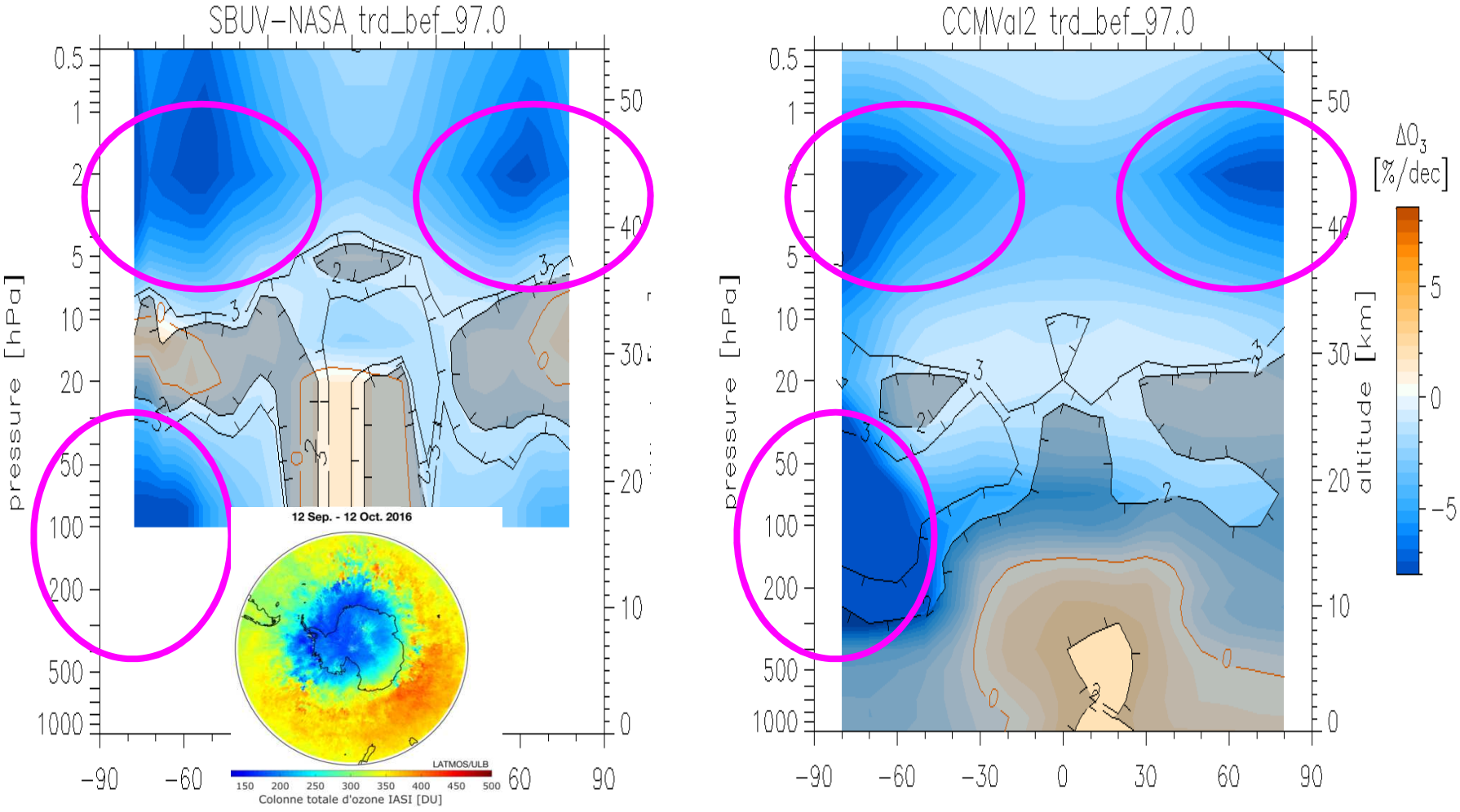
- trends / ODS effects are large
- variability is low
- measurements are good
- clear trends in the past

Look at the past

WMO, 2014

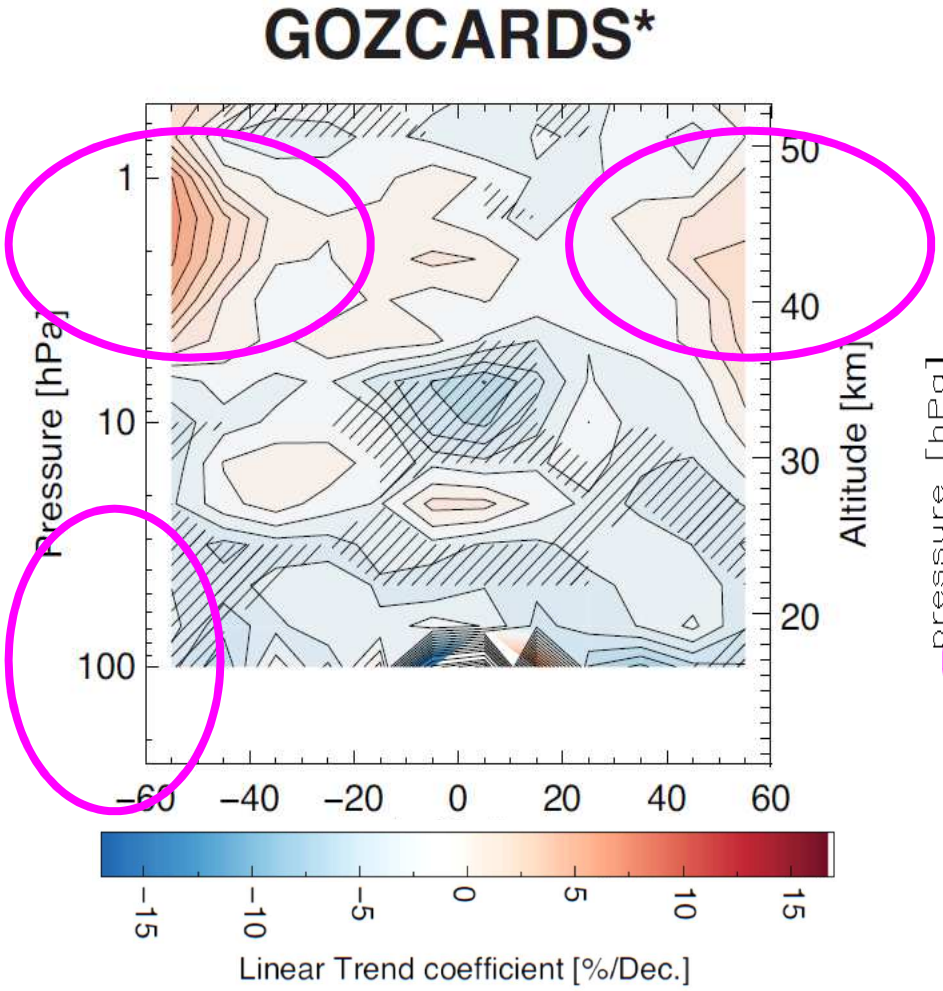
observed trend 1979 to 1997

modelled trend

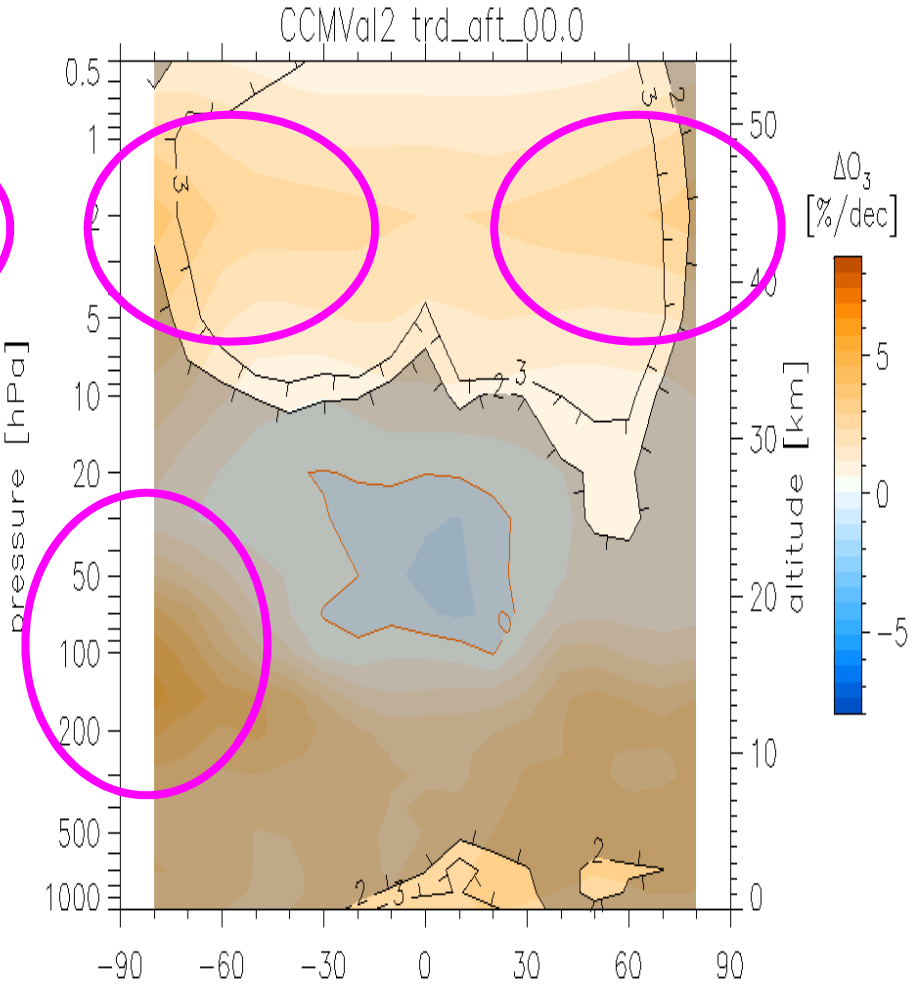


Ozone trends since 1997

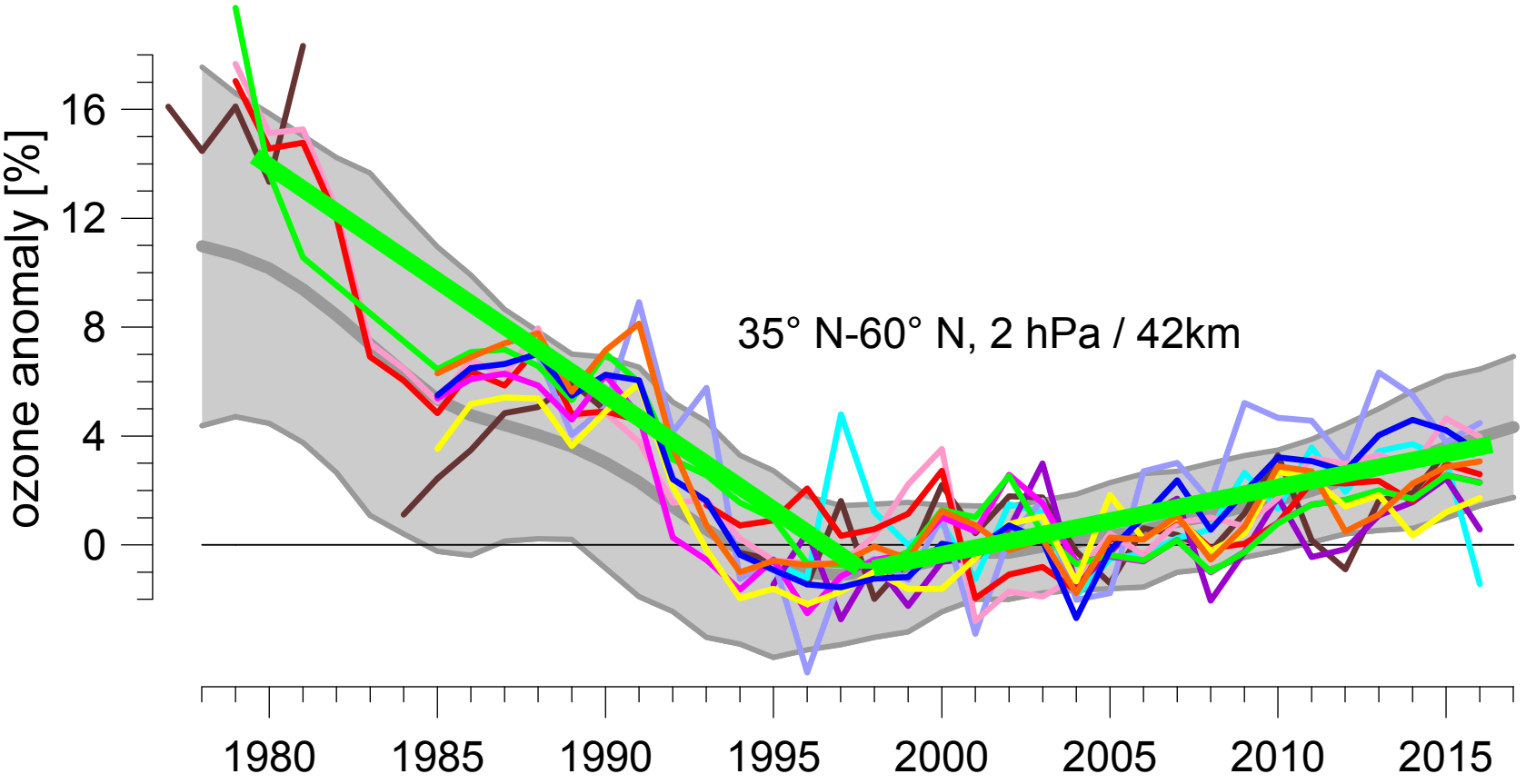
1998 to 2012, SI2N, Harris et al., 2015



model simulated, WMO 2014



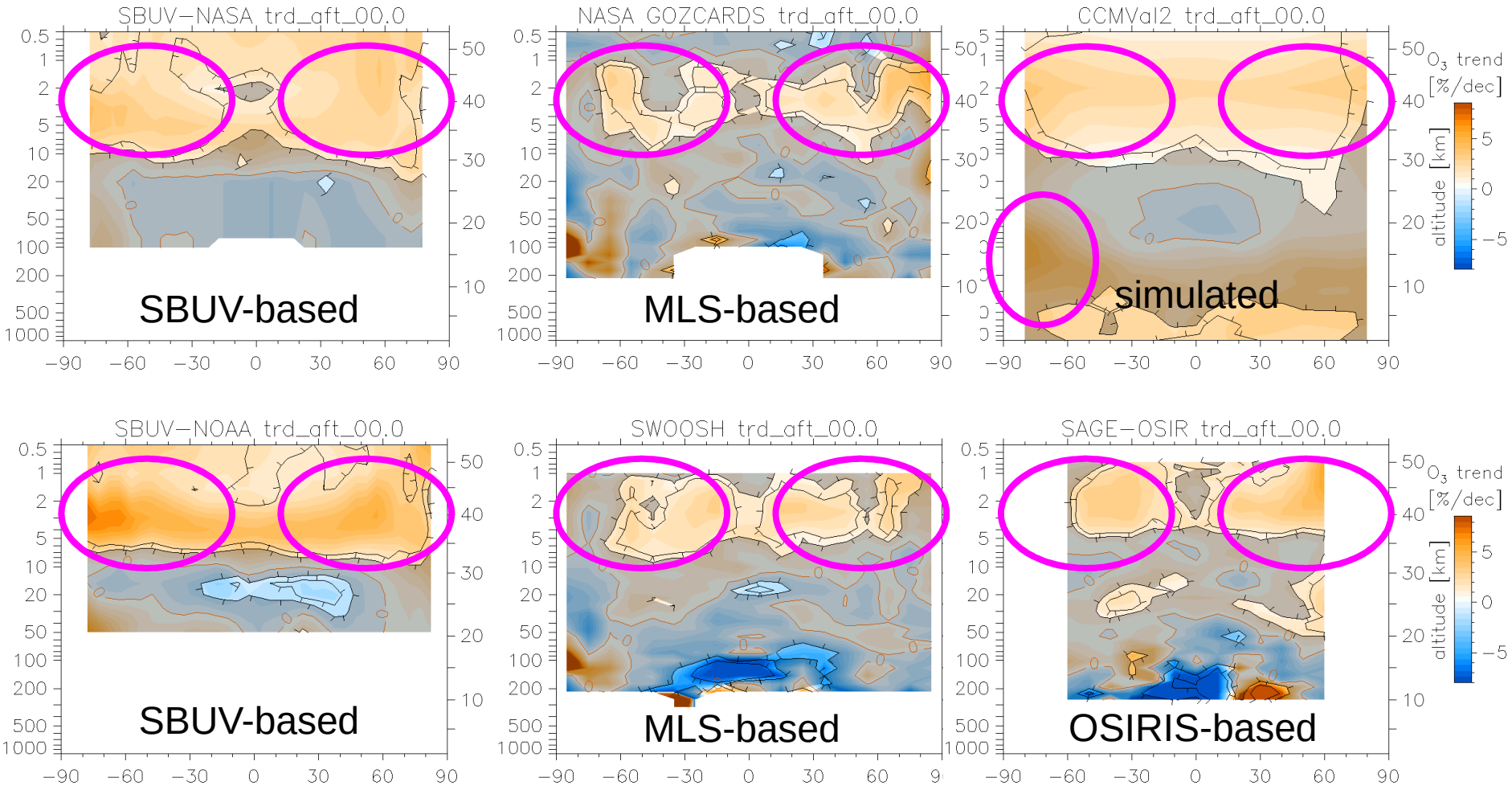
Ozone in upper stratosphere



Steinbrecht et al., ACP, 2017

Ozone trends since 2000

2000 to 2016



Steinbrecht et al., ACP, 2017

Ozone trends since 2000

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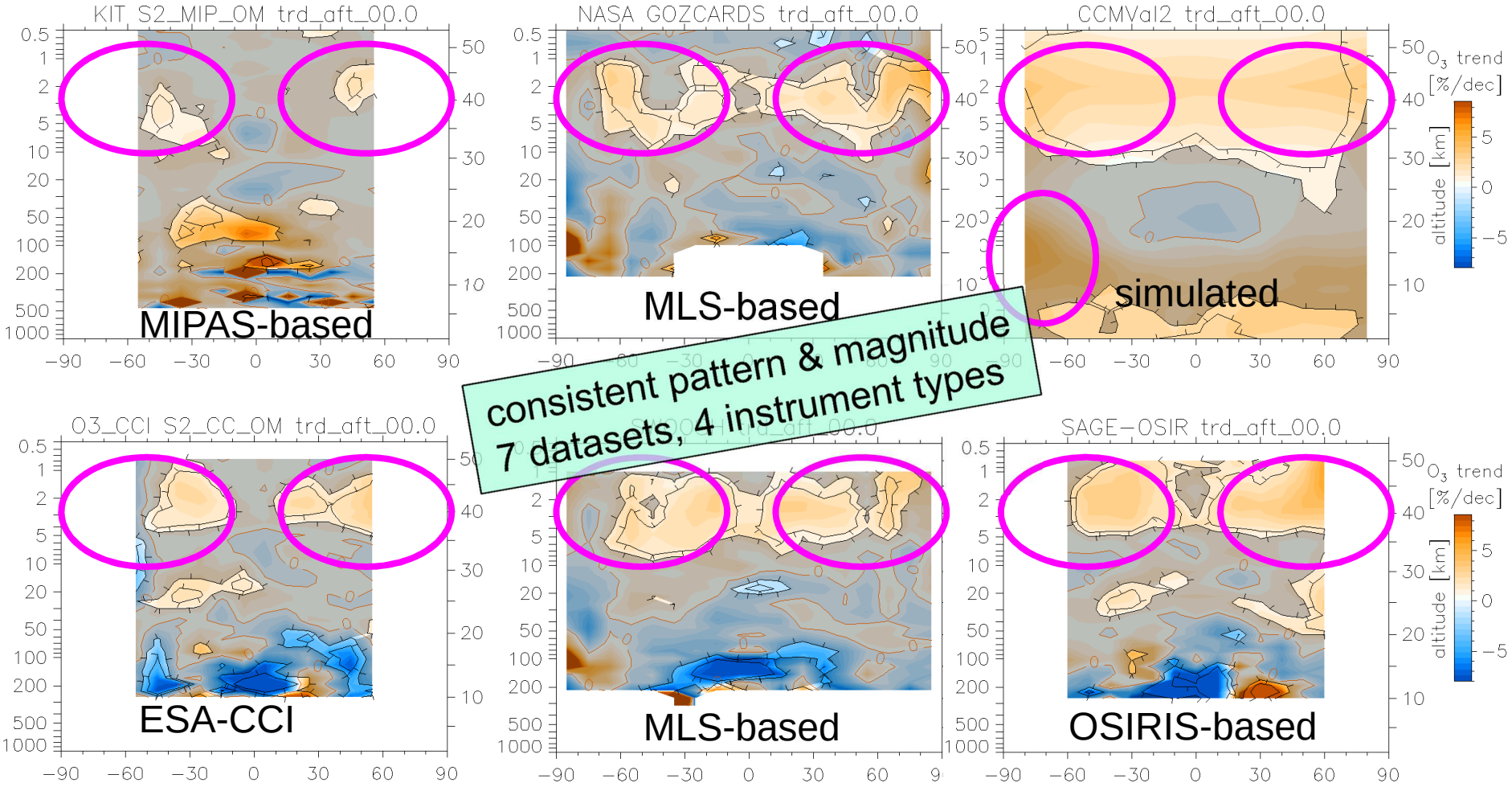
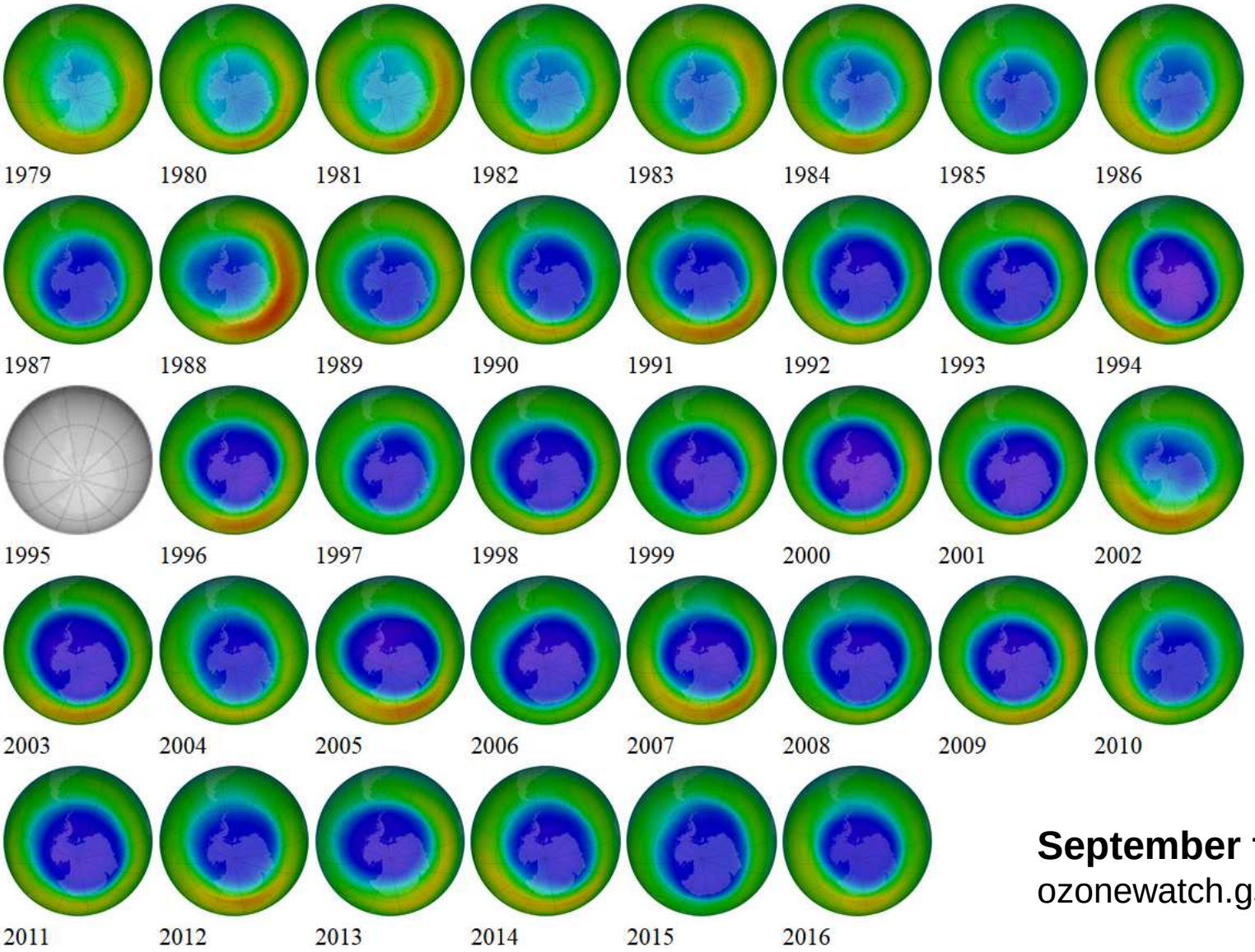


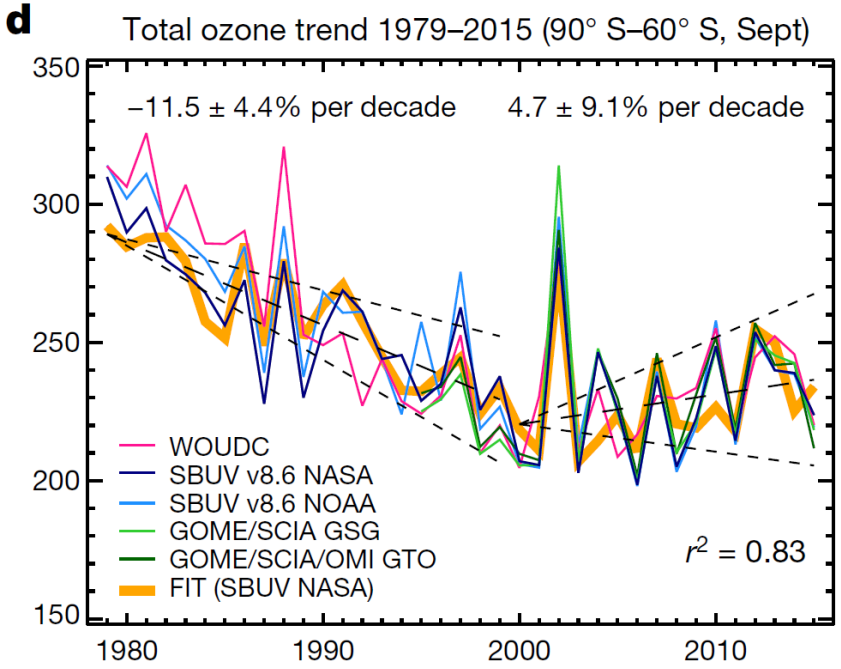
Steinbrecht et al., ACP, 2017

Increases over Antarctica?

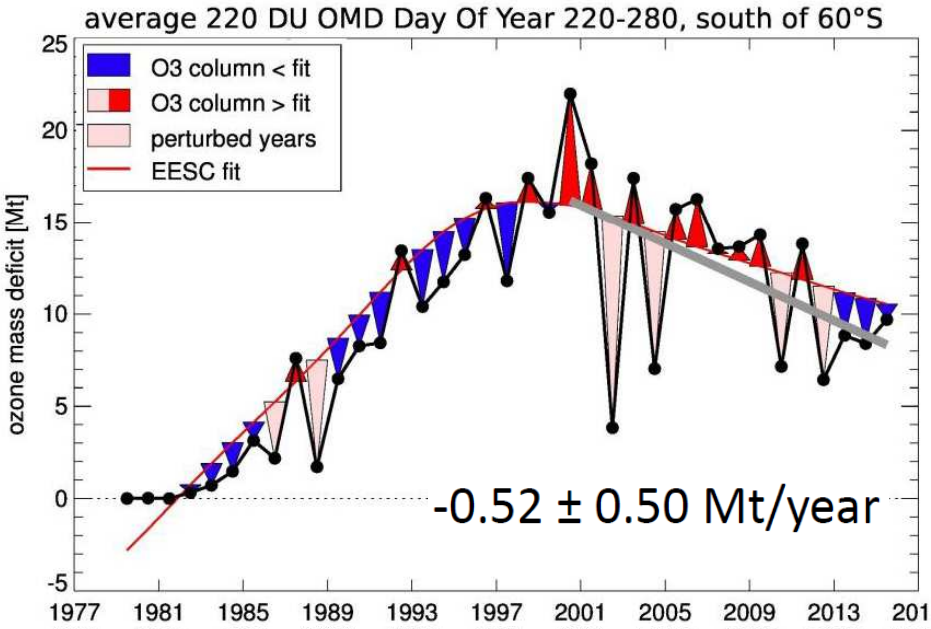


September total ozone
ozonewatch.gsfc.nasa.gov

increases over Antarctica

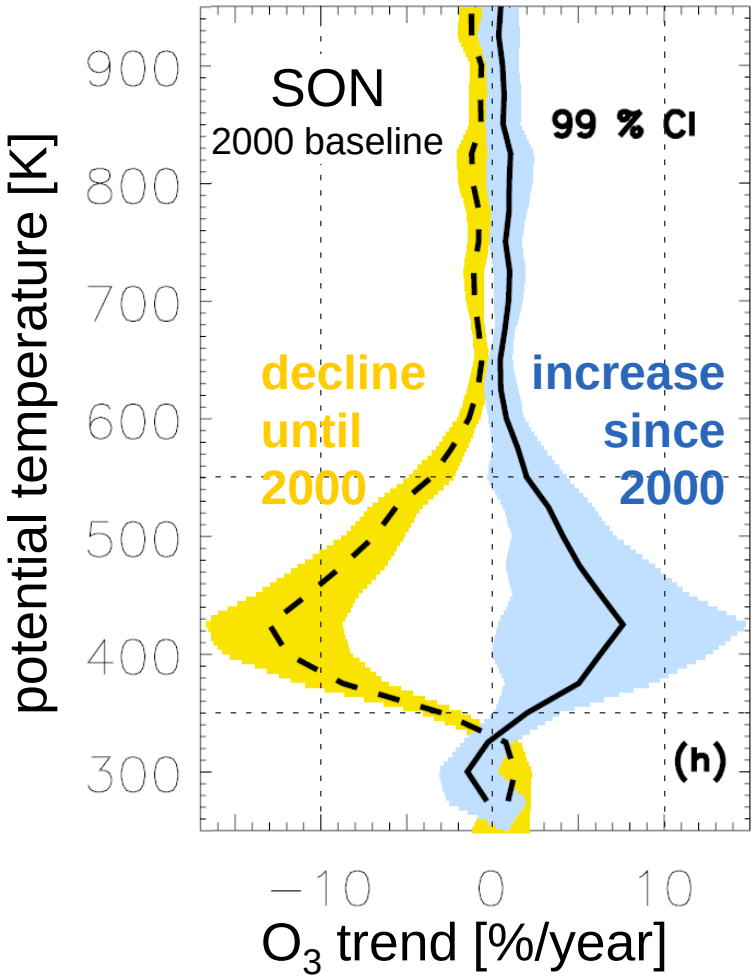


Chipperfield et al., Nature, 2017



de Laat et al., QOS, 2016

Increases over Antarctica



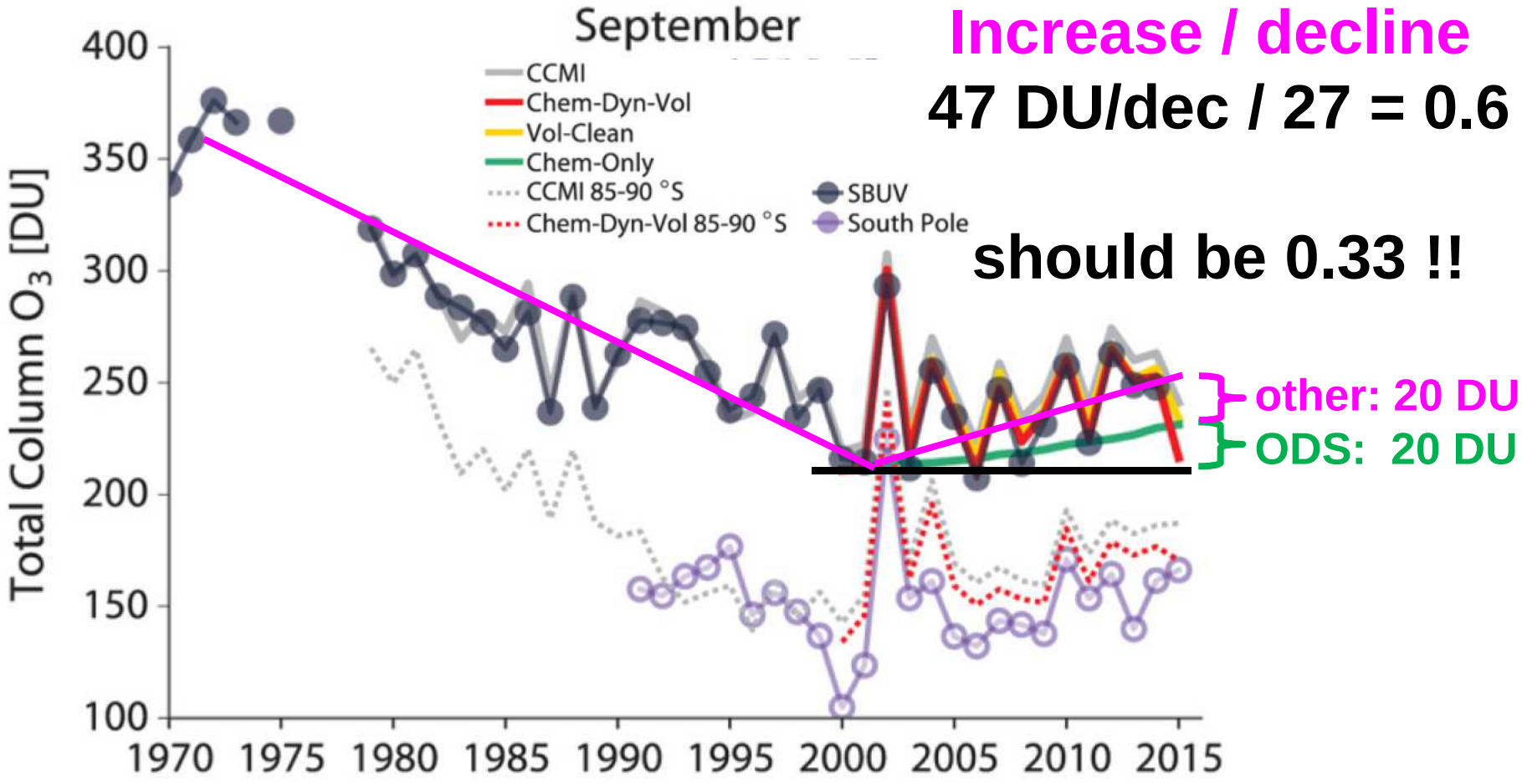
Kuttipurath & Nair, Nature, 2017

ozone increase
due to declining ODS?

increase/decline
≈0.33 !!
for ODS

Increase / decline
8 / 13 = 0.61

Increases over Antarctica (attributed)



Solomon et al., Science 2016

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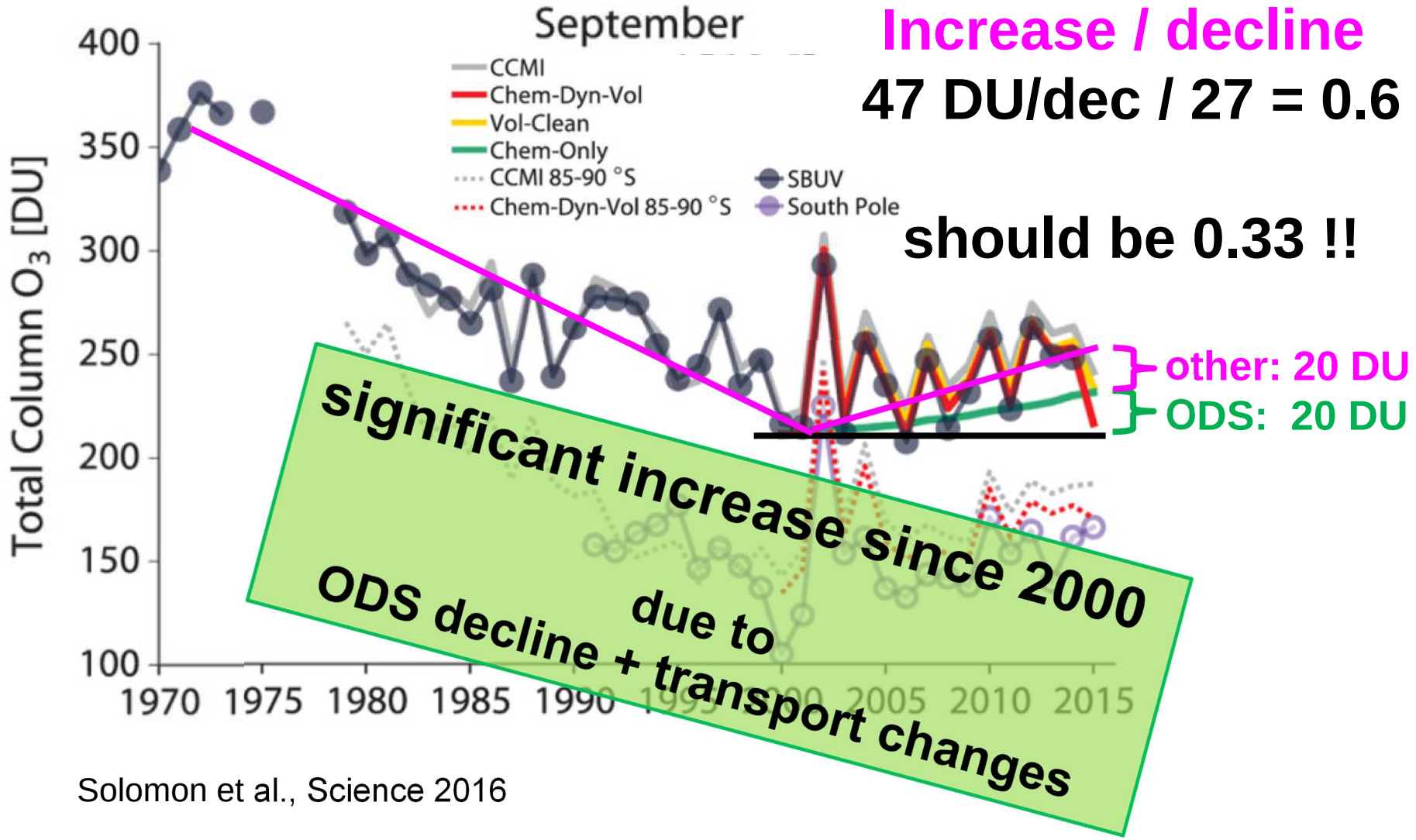
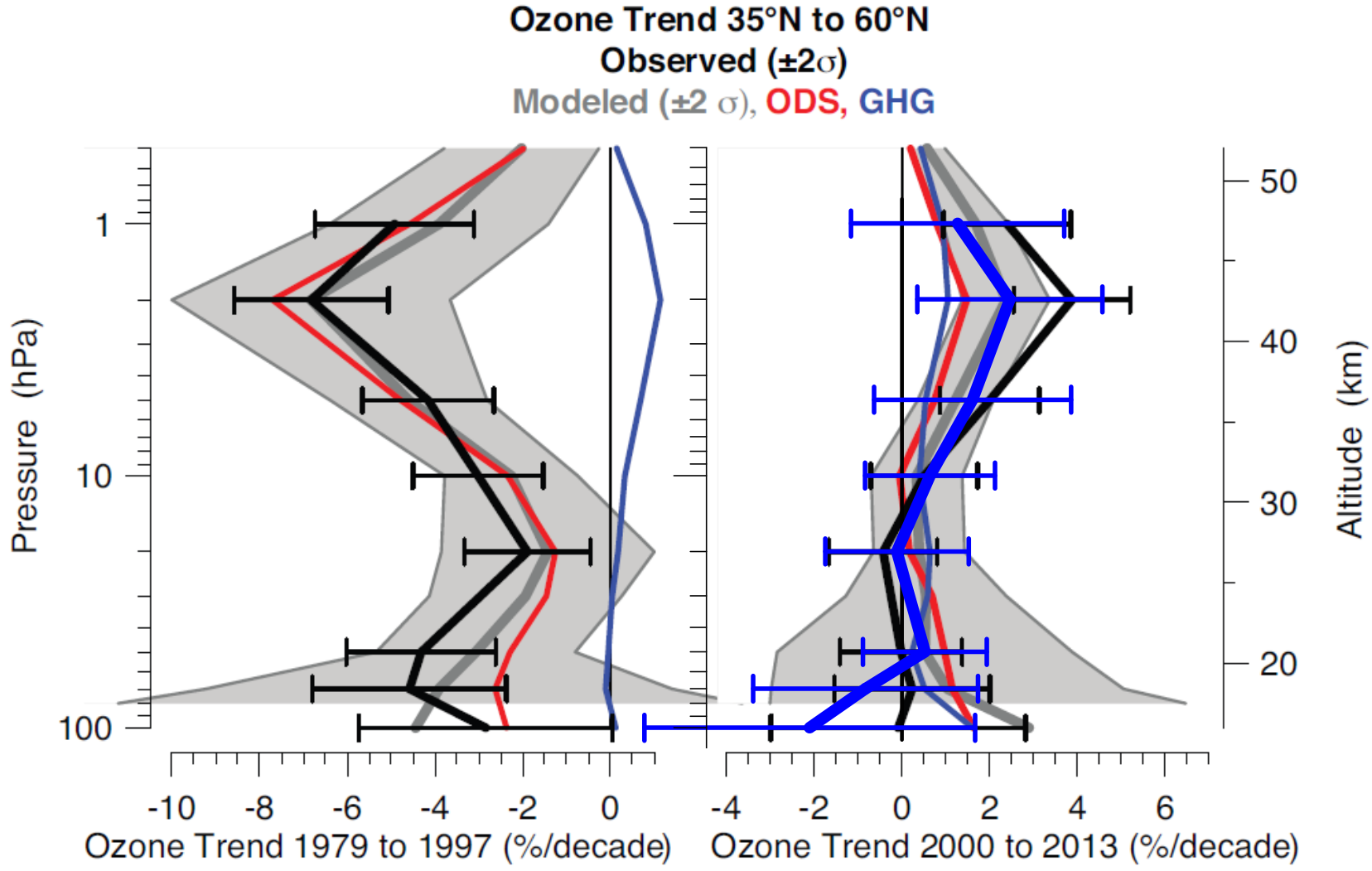


Solomon et al., Science 2016

Increases upper stratosphere (attributed)



WMO, 2014 Steinbrecht et al., ACP, 2017

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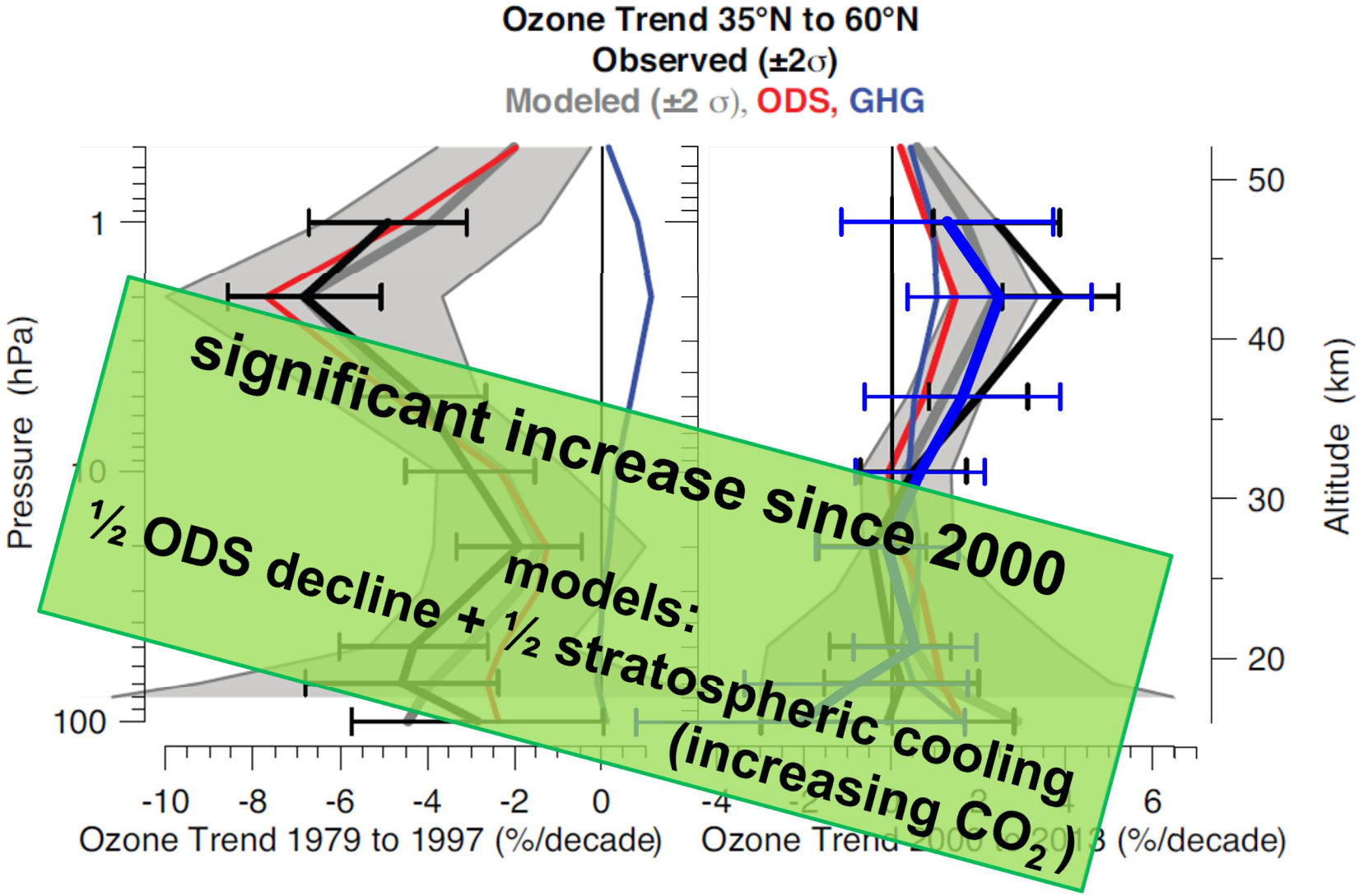
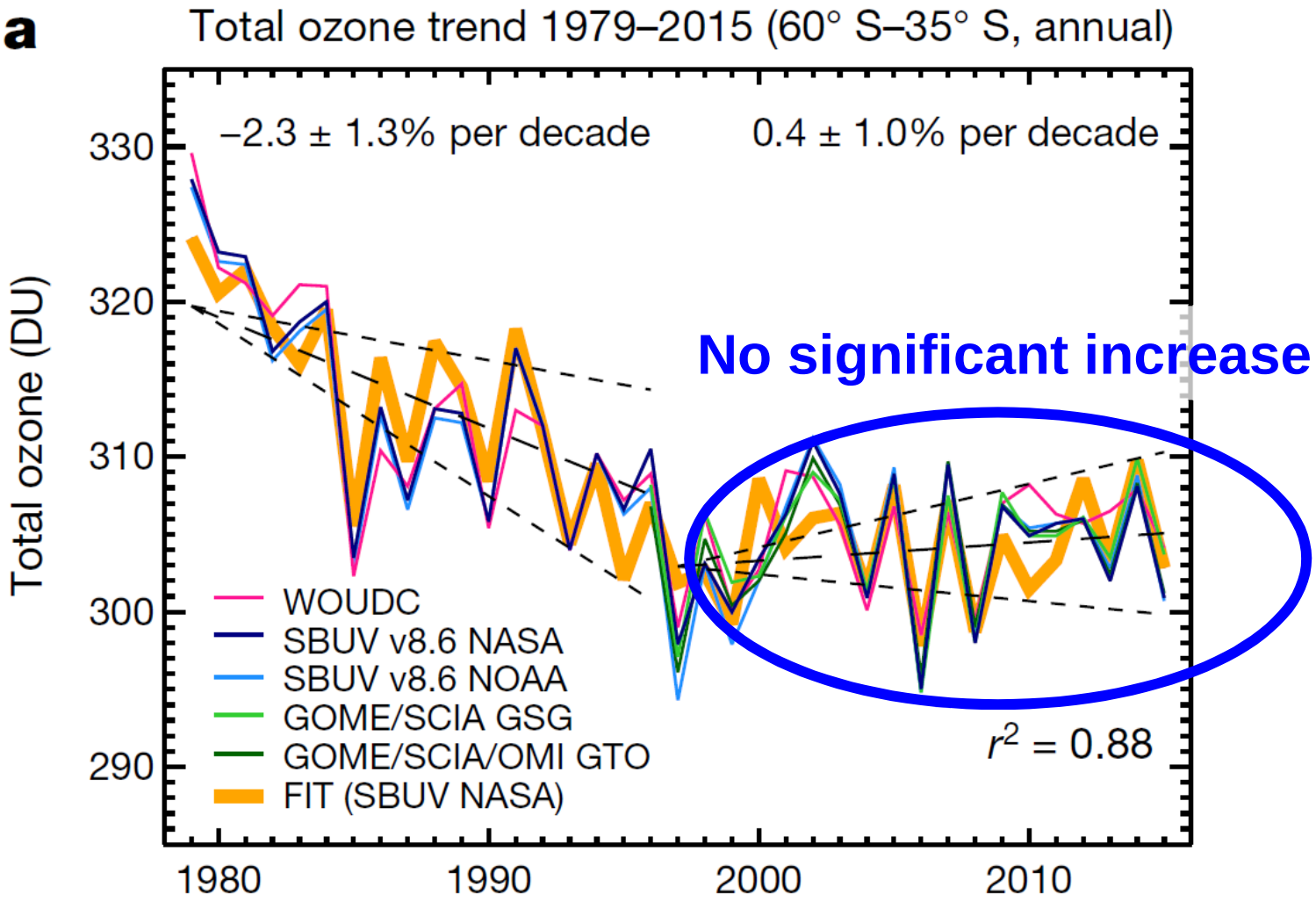


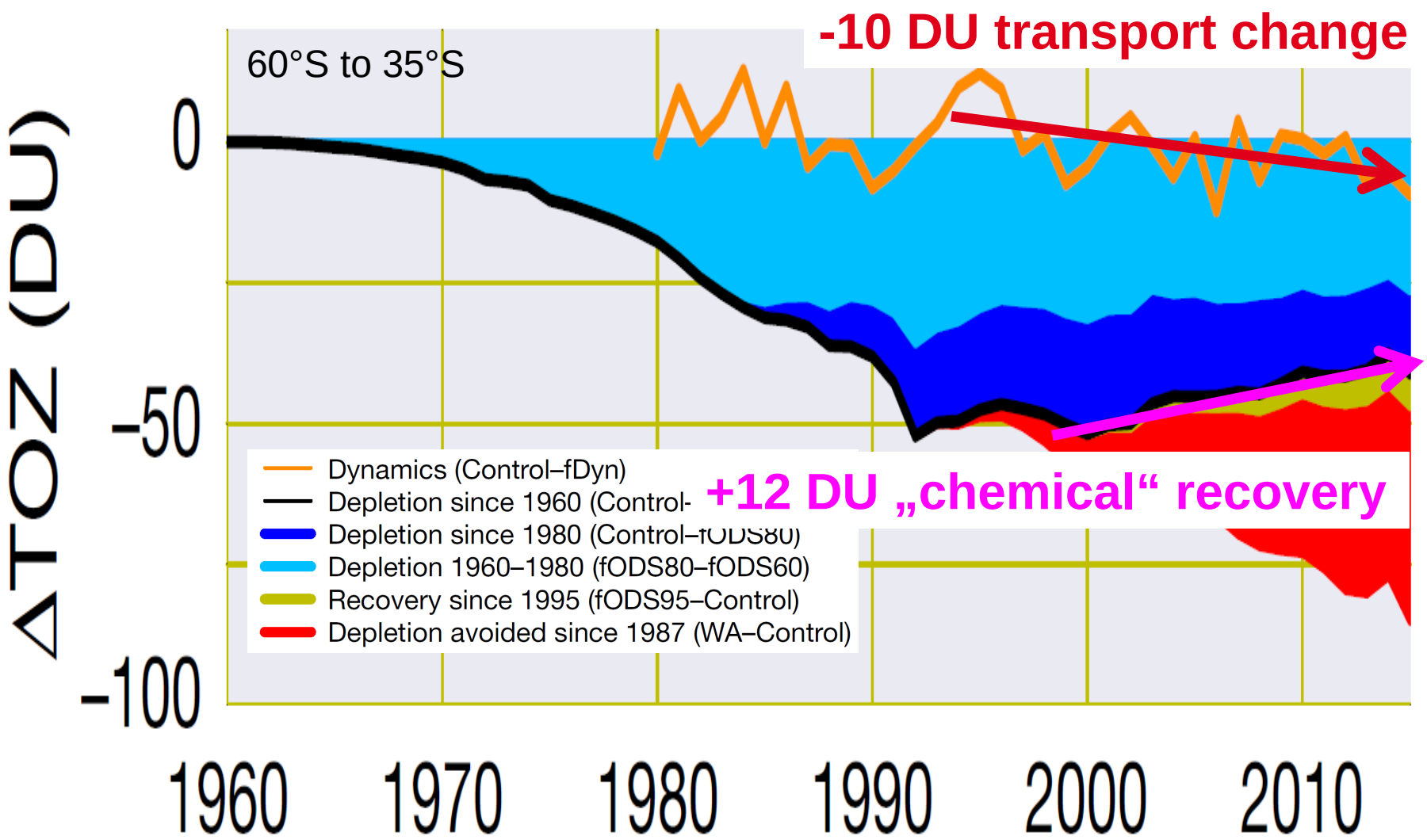
WMO, 2014 Steinbrecht et al., ACP, 2017

Total ozone ≈constant



Chipperfield et al., Nature, 2017; **Weber et al., ACPD, 2017**

Model simulations (TOMCAT-CTM)



Chipperfield et al., Nature, 2017

Model simulations (TOMCAT-CTM)

-10 ± 5 DU transport change

+12 ± 3 DU „chemical“ change

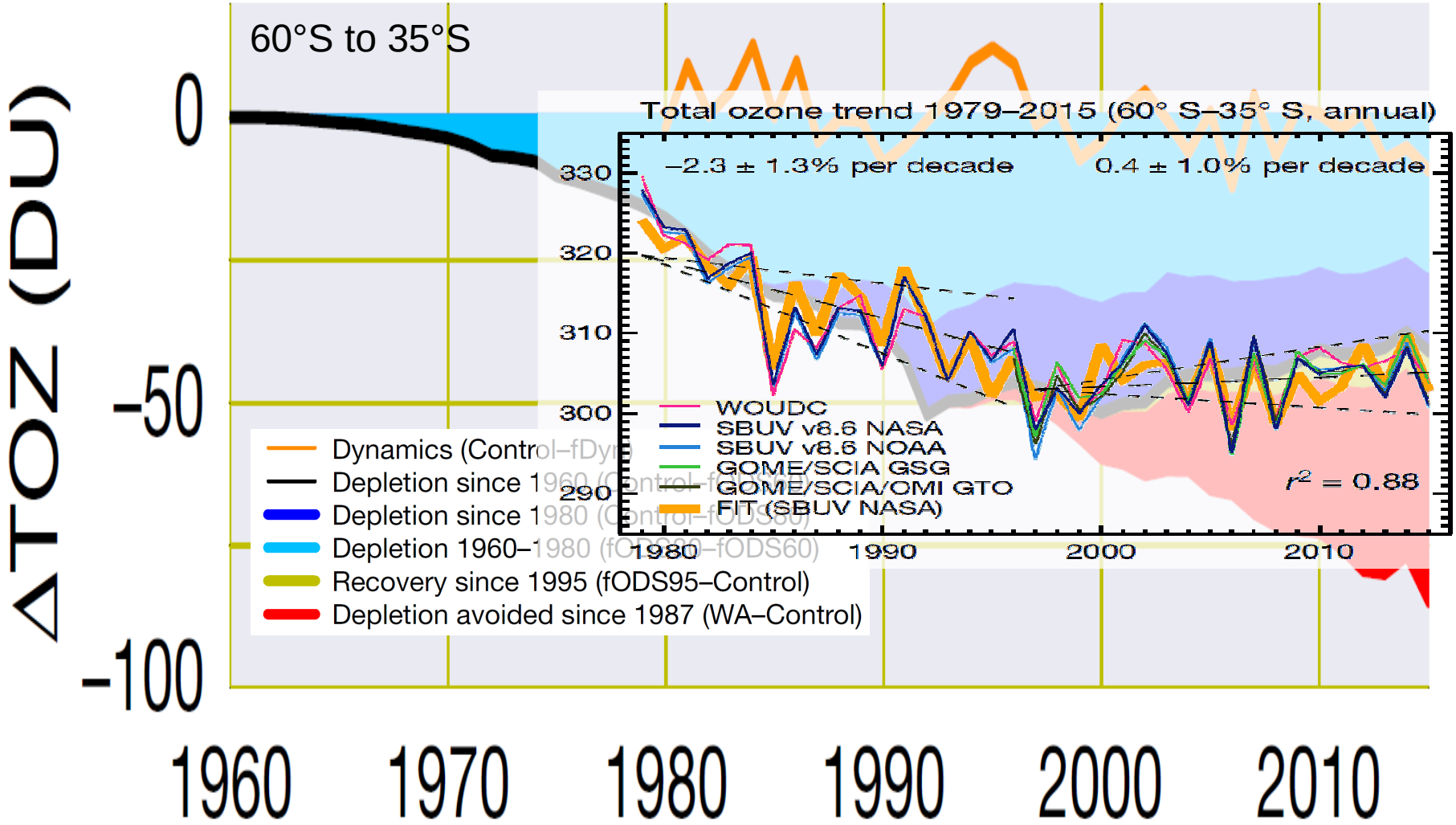
==========

+2 ± 6 DU net change

+0.35 ± 1% per decade (300 DU, 20 years)

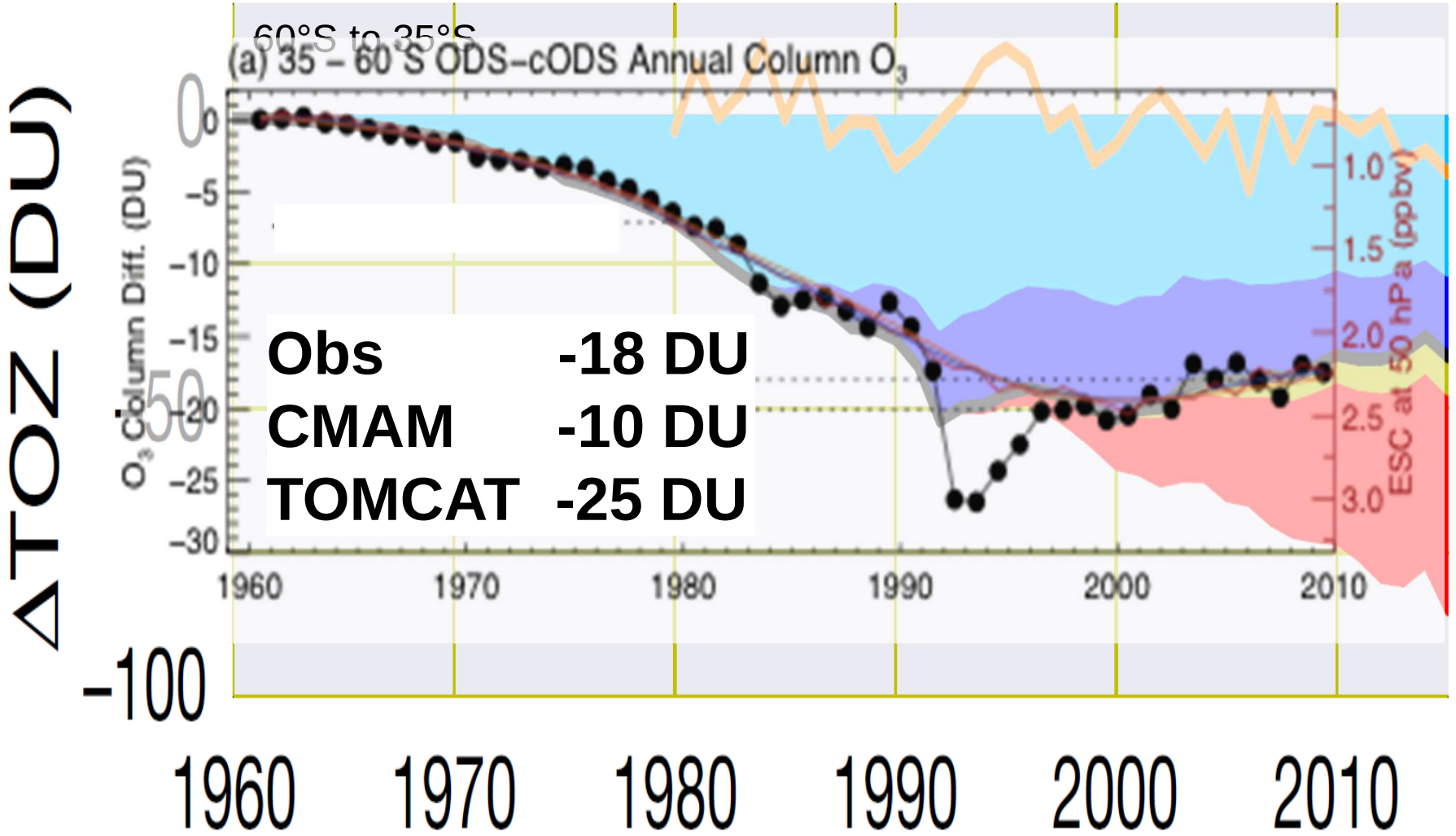
60°S to 35°S, ≈2000 to ≈ 2015

Model simulations (TOMCAT-CTM)



Chipperfield et al., Nature, 2017

Models differ!!



Chipperfield et al., Nature, 2017 Shepherd et al., Nature Geosc., 2014

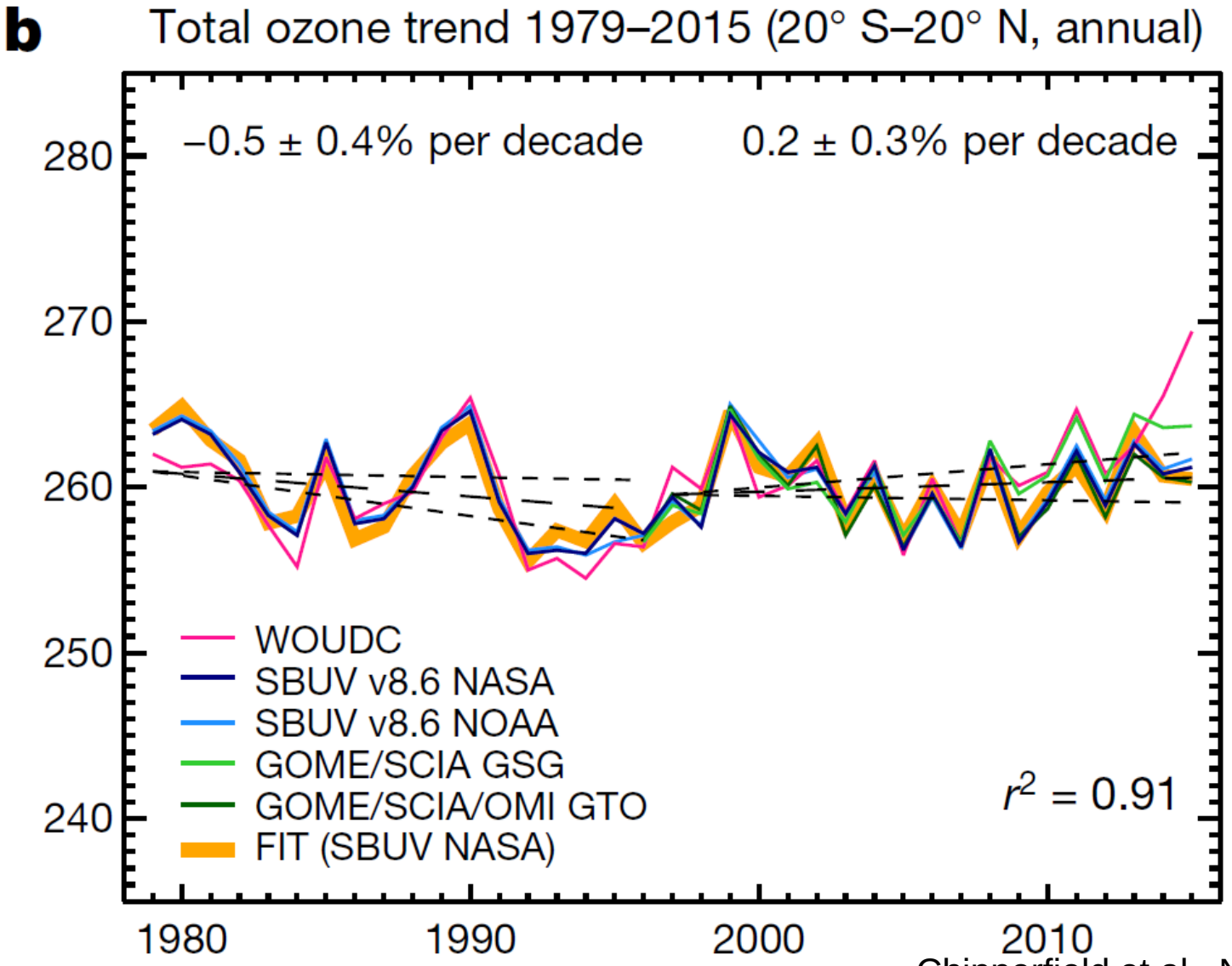
Recovery of total ozone

- **decline ended in mid-1990s (Montreal worked!)**
- **no significant increases since**
- **(small) chemical increases offset by (decadal) transport changes?**

- **unexpected for increased Brewer Dobson circulation?**
- **related to warming hiatus?**
- di-chloro methane unlikely (Hossaini et al., Nature, 2017: 2 DU / 50 years = 0.2 DU / decade = 0.07% / decade)

- **to be watched**
- **WMO 2018?**

Tropical ozone columns



Chipperfield et al., Nature, 2017

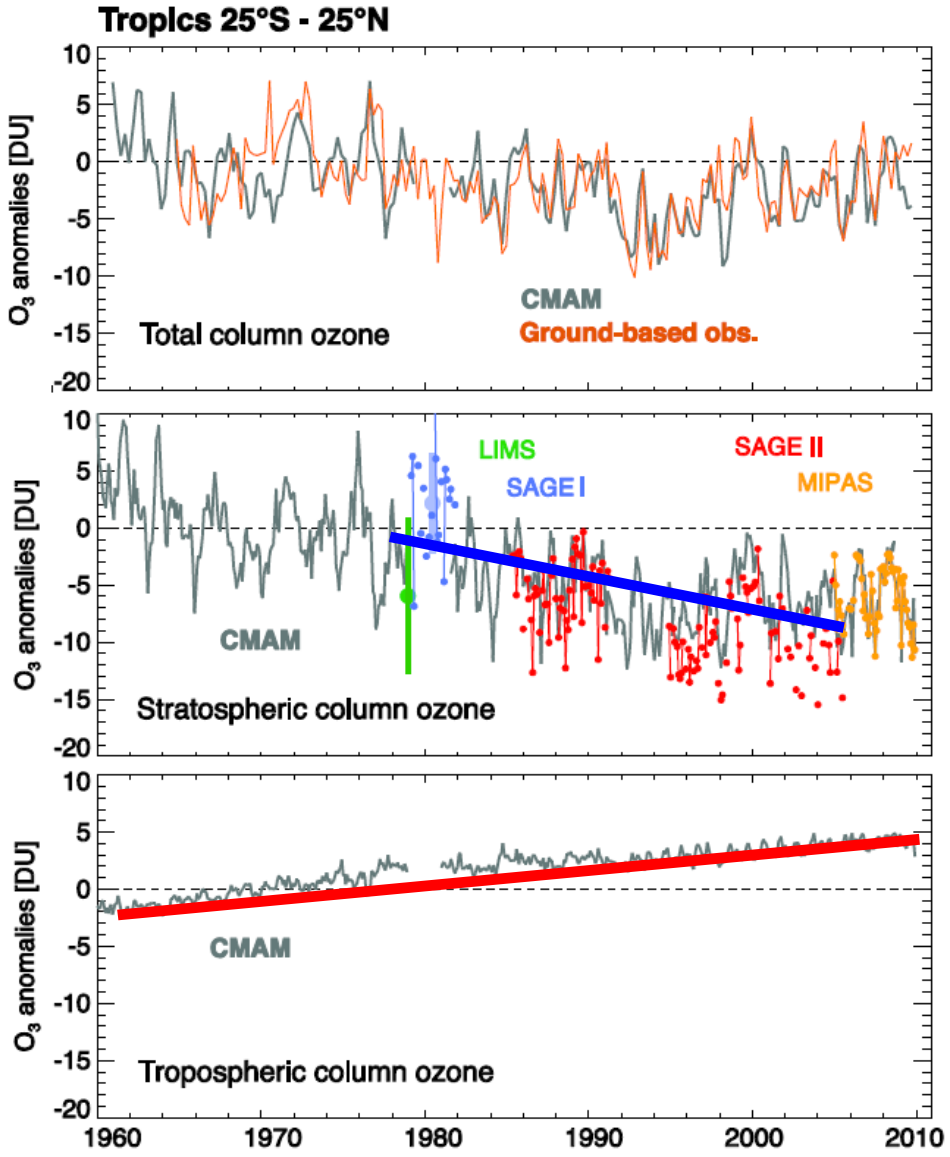
Tropical ozone trends

Shepherd et al., NGEO, 2014

stratospheric decrease

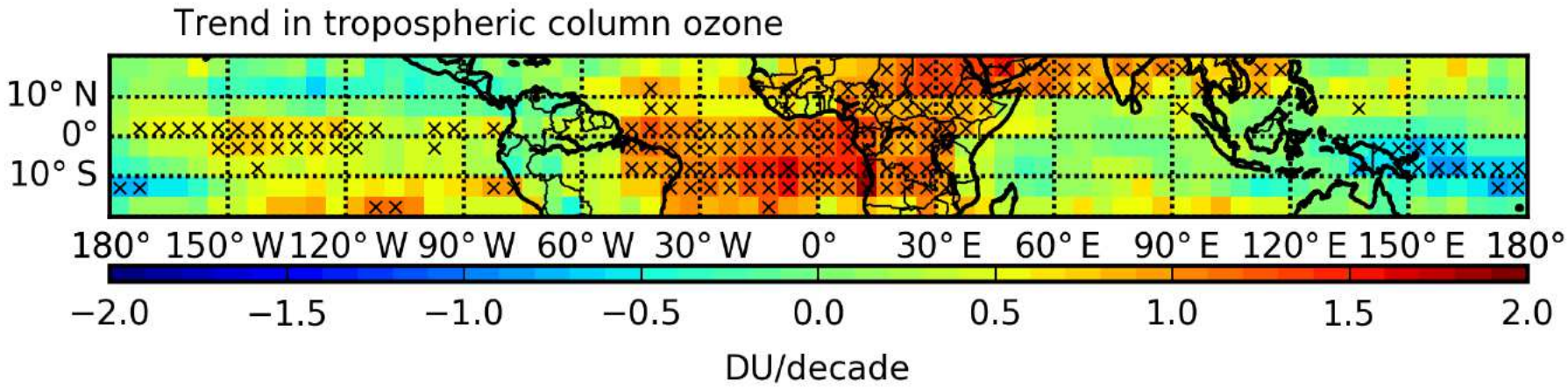
compensated by

tropospheric increase?



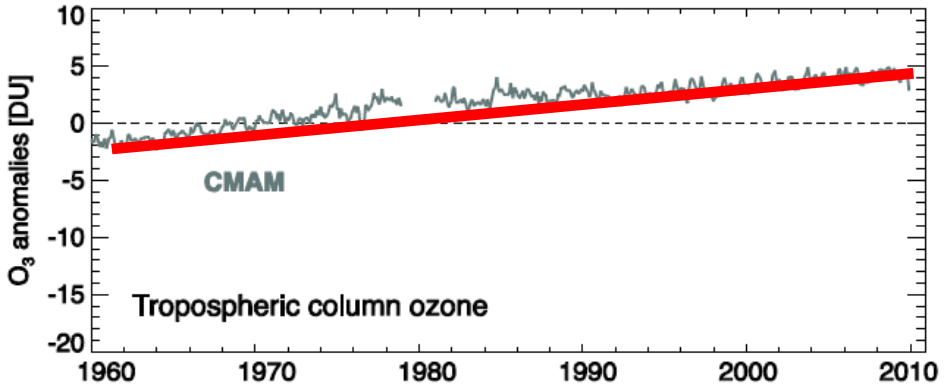
Tropical ozone trends

Heue et al. AMT 2016
GOME/SCIA/GOME2 1996-2015

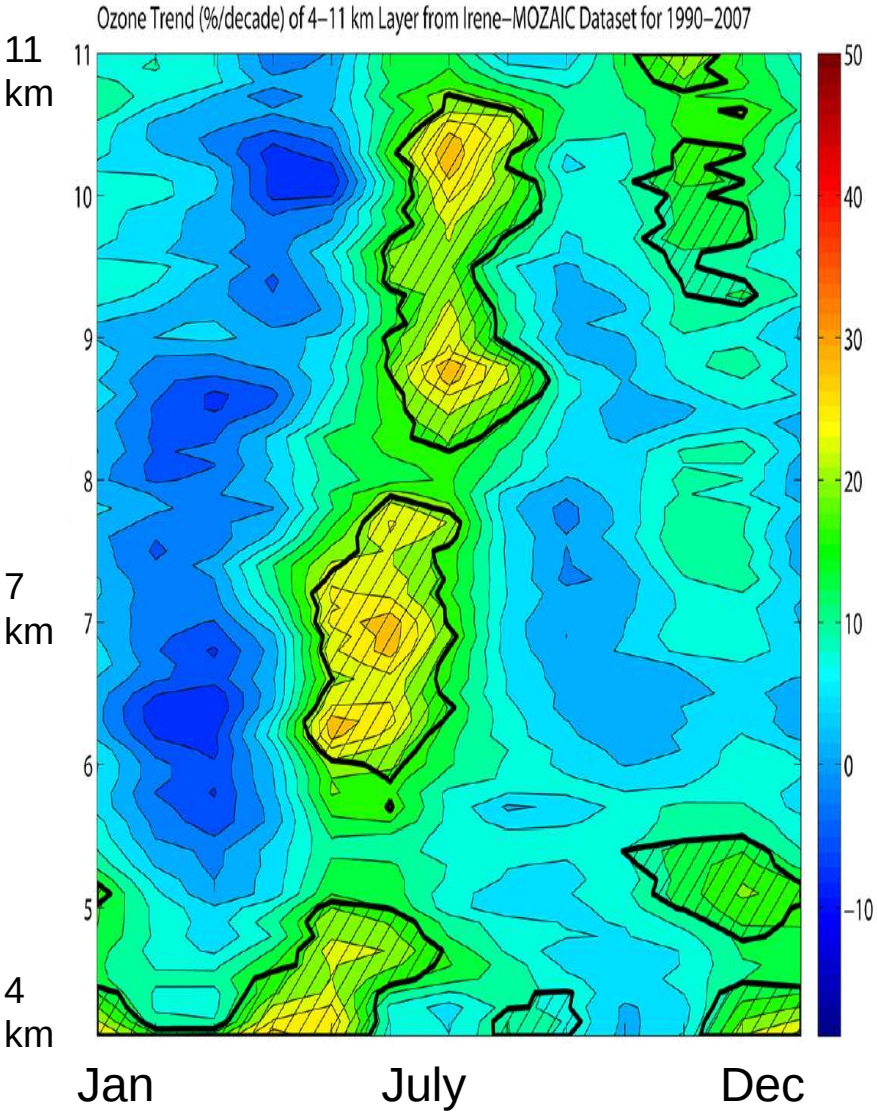


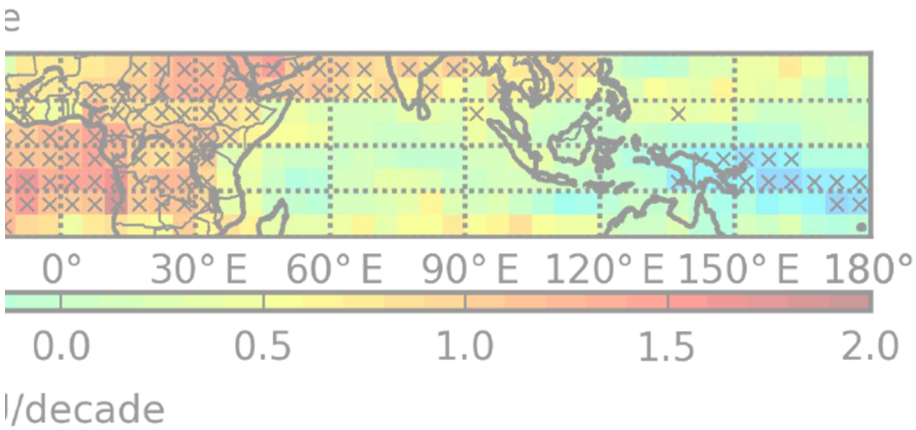
compensated by

tropospheric increase?

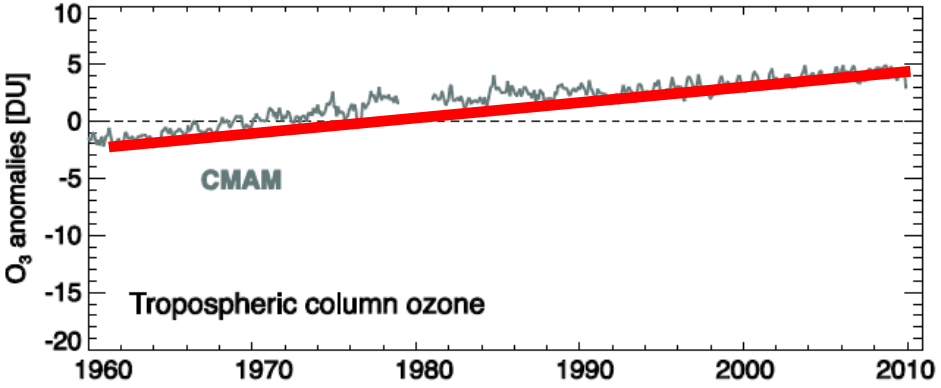


Tropical ozone trends

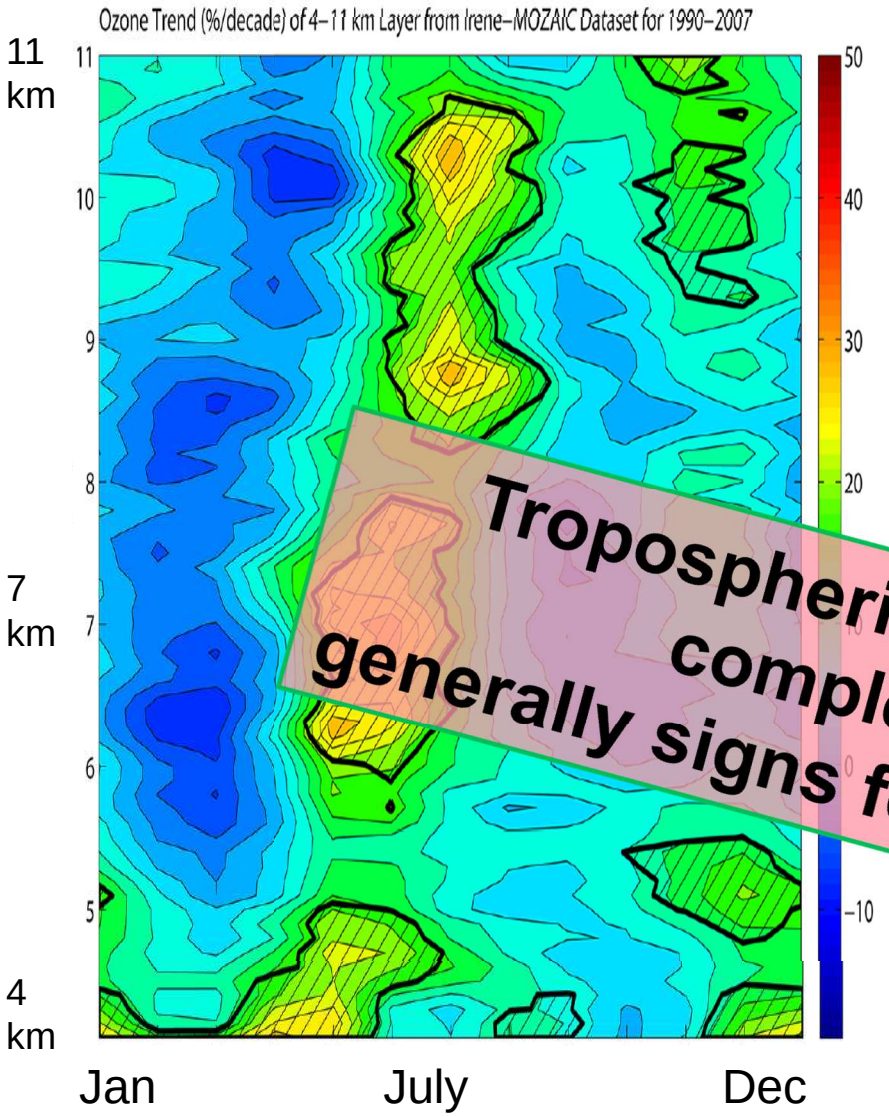




Thompson et al. ACP 2014
also in SHADOZ sondes (Irene, Reunion)
seasonal variation!



Tropical ozone trends



Thompson et al. ACP 2014

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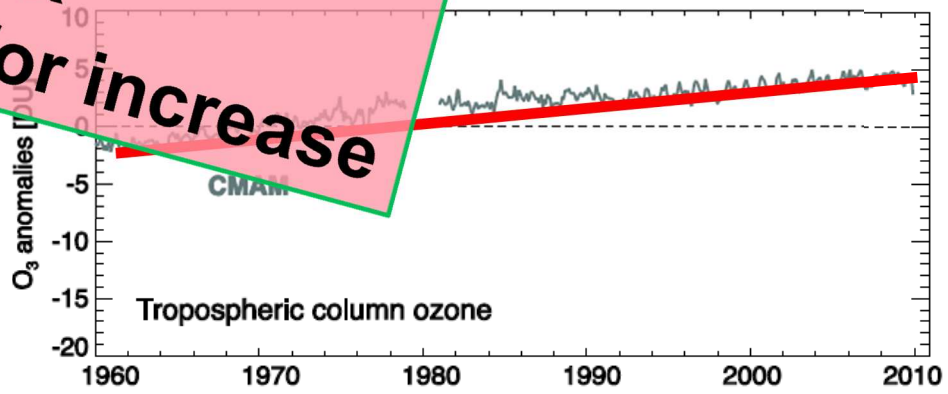
seasonal variation!

Tropospheric trends: complex

generally signs for increase



Summary

- Ozone is recovering in upper stratosphere
  - patterns & magnitude consistent with expectations
  - ODS + CO_2 as in WMO 2014
- Antarctic Sept. increase
  - larger than expected from ODS decline!!
- Column ozone: no clear increases yet
  - ≈ expected (takes 20 to 40 years!)
  - „chemical“ increase offset by (unexpected) transport decline?
  - tropospheric changes?
- to see actual recovery: need 1% accuracy, long-term observations & simulations