Trends in Lower Stratospheric Ozone from 1998 to Present, Based on Balloon-borne *In Situ* Measurements

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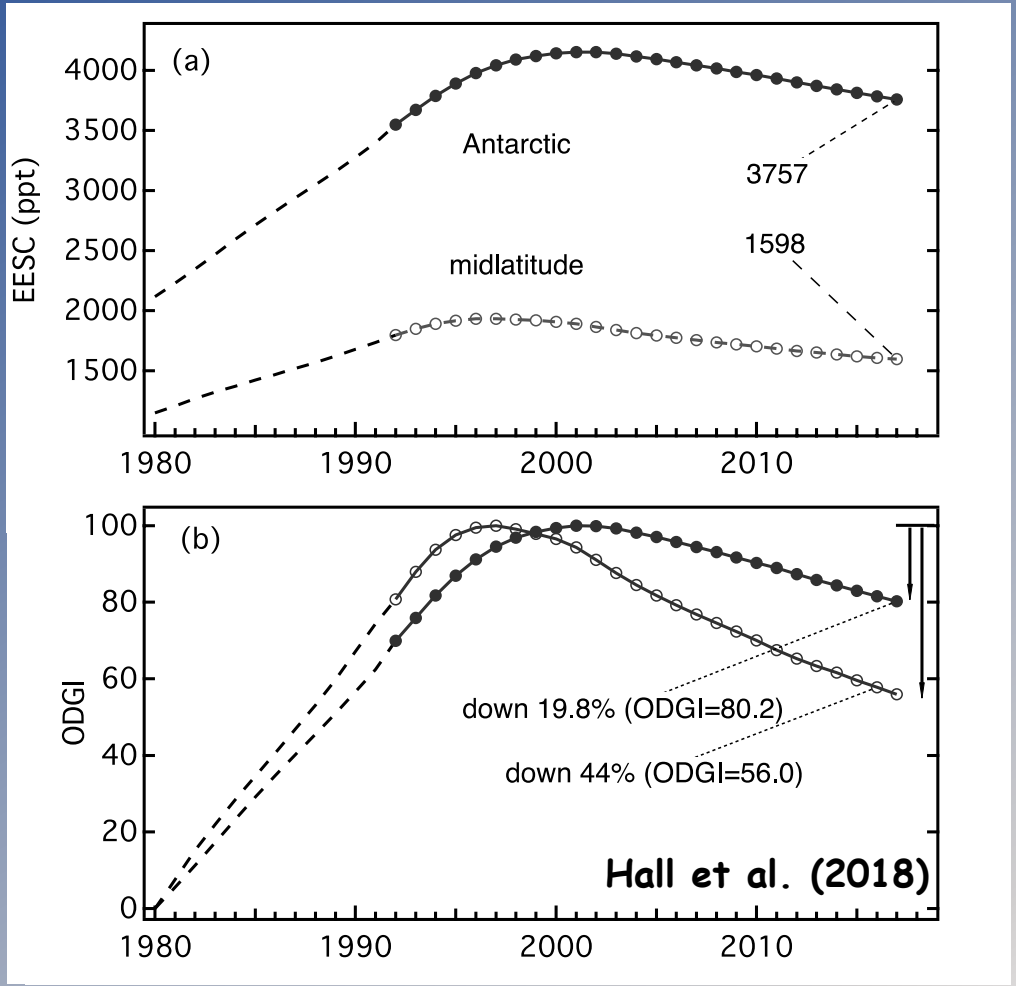
Decrease in Ozone-Depleting Halogen

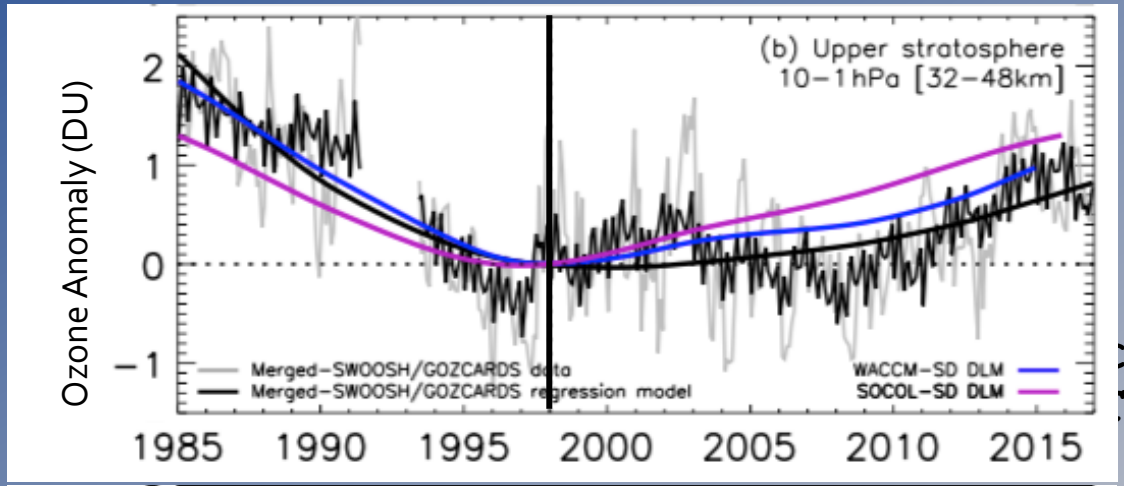


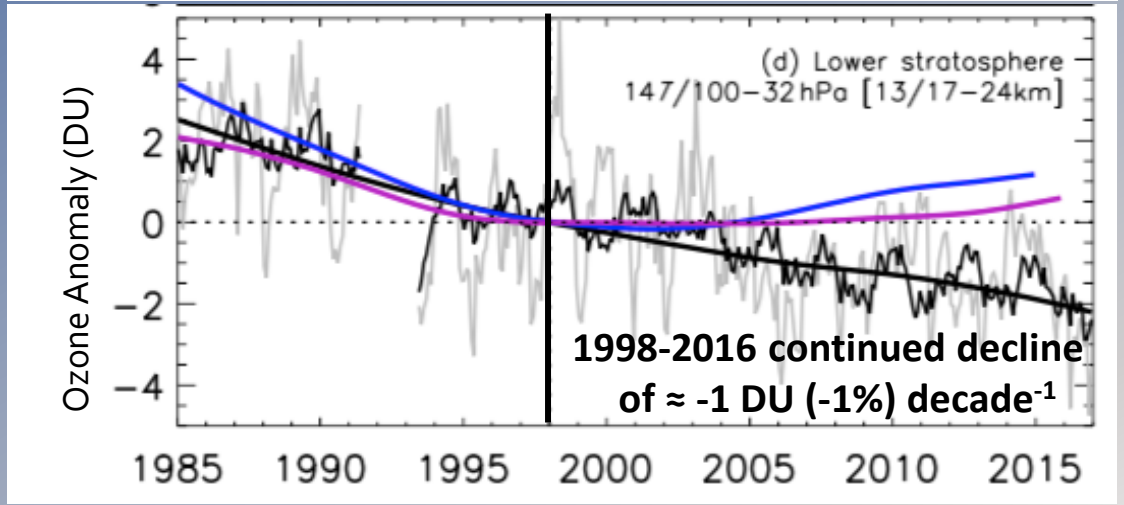
Thanks to the Montreal Protocol, the amounts of ozone-depleting chlorine and bromine in the stratosphere have decreased during the last 15-20 years.

Expectations that ozone depletion rates should have slowed by now…

perhaps even emerging signs of stratospheric ozone recovery.

Continuing Decrease in Lower Stratospheric (LS) Ozone



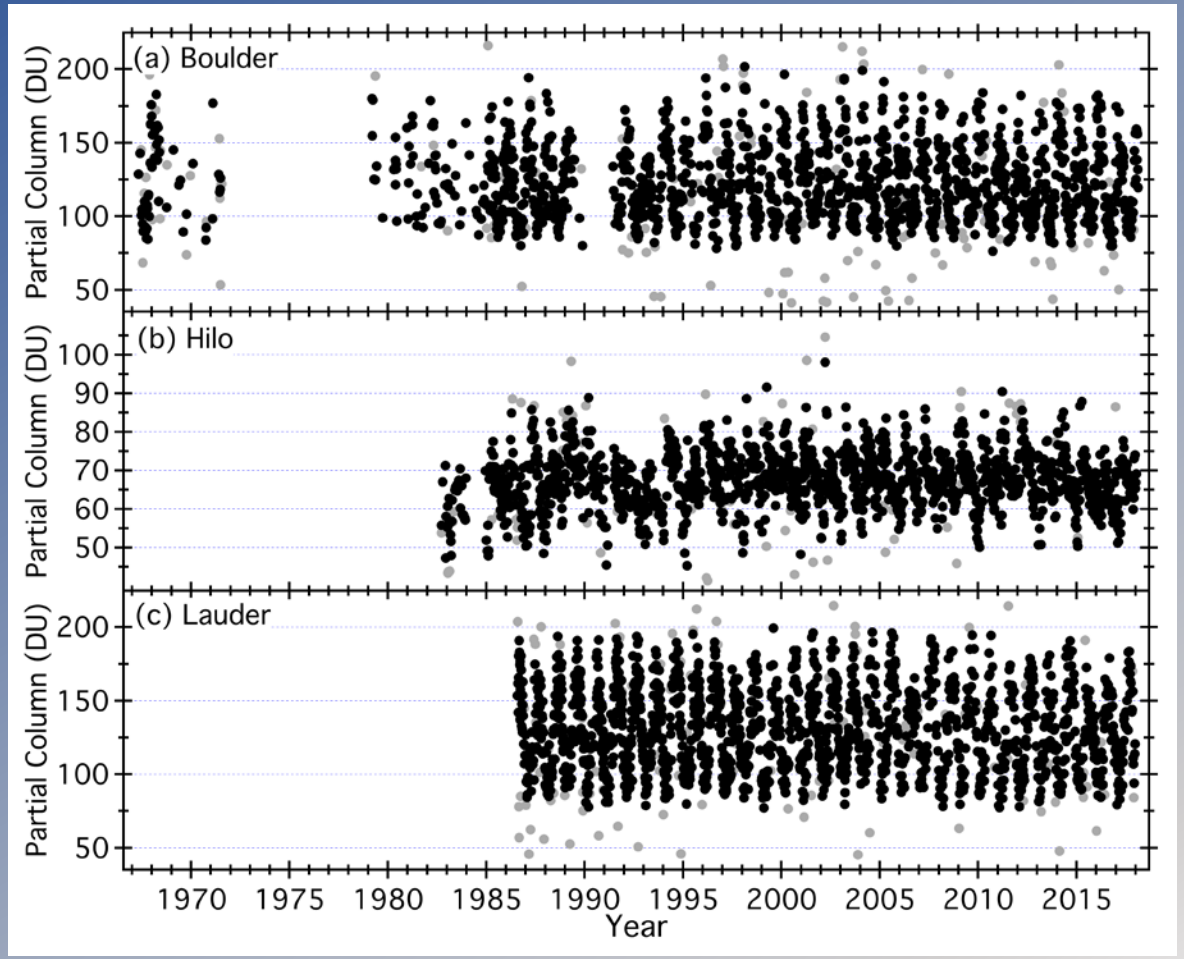


cline in lower stratospheric
hem. Phys.
Ball et al. (2018)

Merged Satellite Data
SWOOSH/GOZCARDS

Model Output
WACCM-SD
SOCOL-SD

Do Ozonesonde Records show the same Trends in LS Ozone?



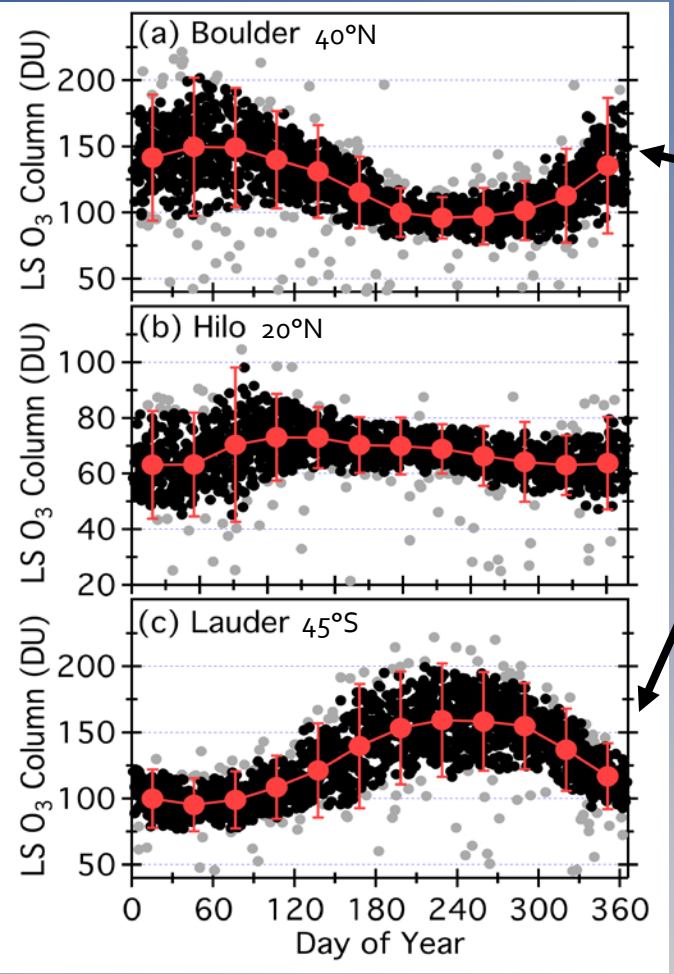
- Weekly Soundings for 30+ years
- 1600-1800 per site
- High vertical resolution
- BLD & HIH homogenized
- LDR is being homogenized

Use the Ball et al. (2018) fixed altitude limits to define LS ozone columns:

13-24 km for 30°-60°

17-24 km for 30°S-30°N

Seasonal Cycles in Altitude-Defined LS Ozone Columns



Large seasonal cycles, especially over the mid-latitude sites

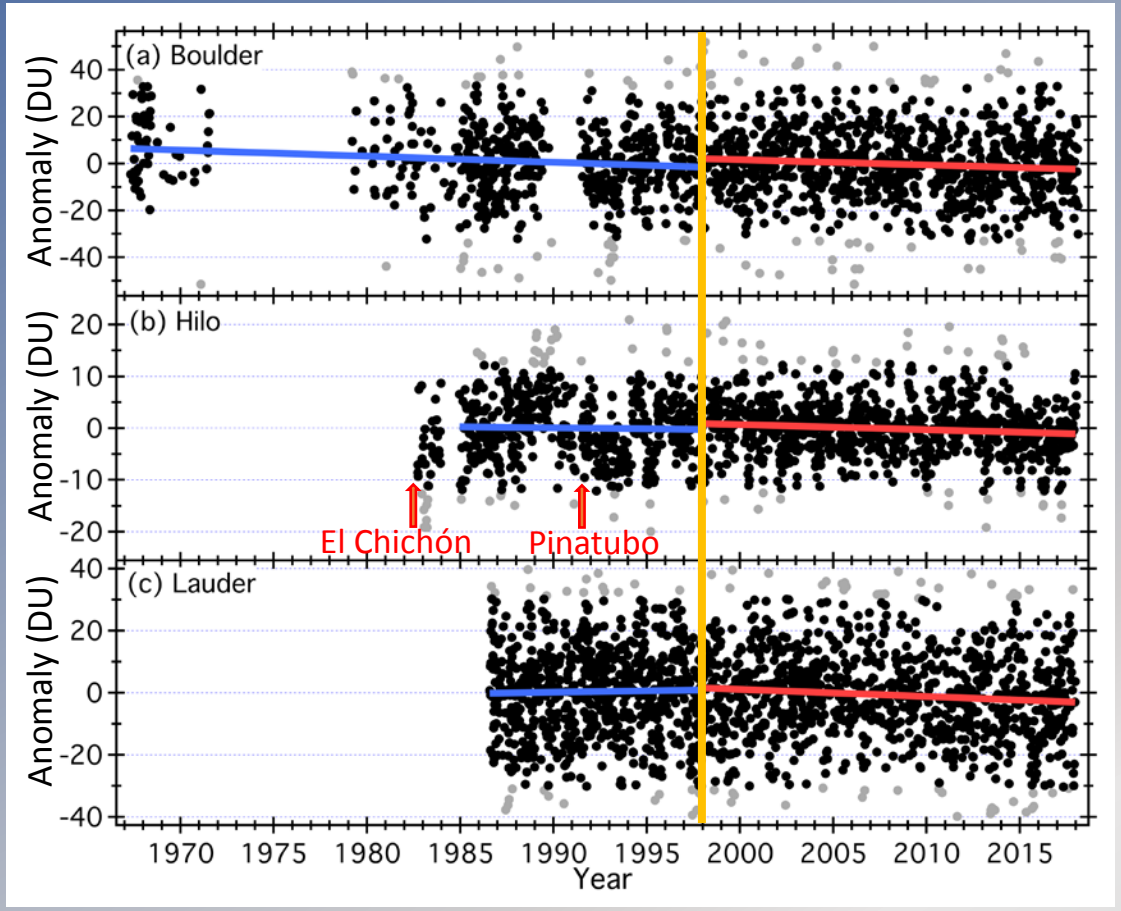
Subtract the climatological monthly means from each record of LS column values

De-seasonalized LS column anomalies

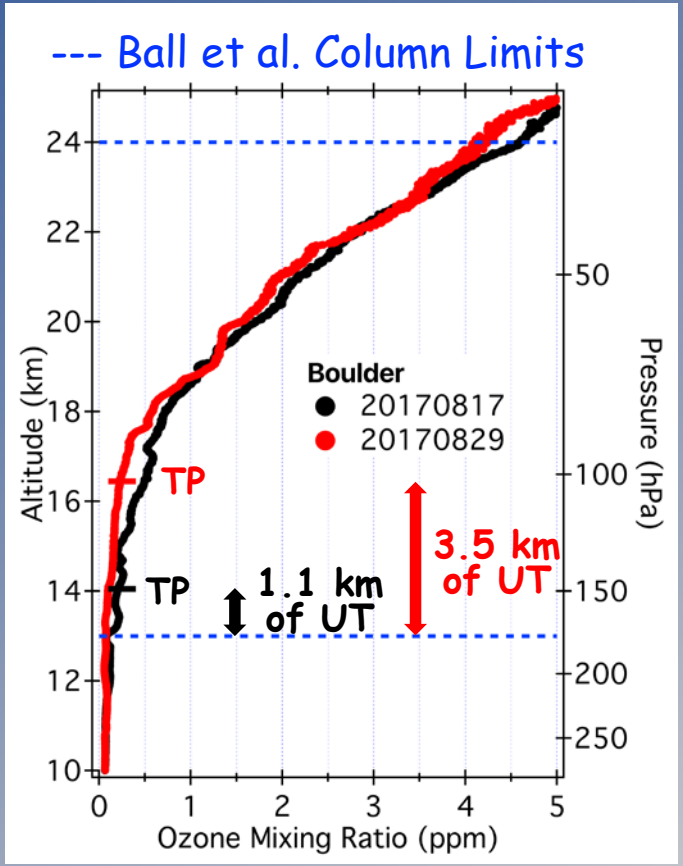
Ozonesonde-Based Trends in LS Ozone (% decade^{-1})

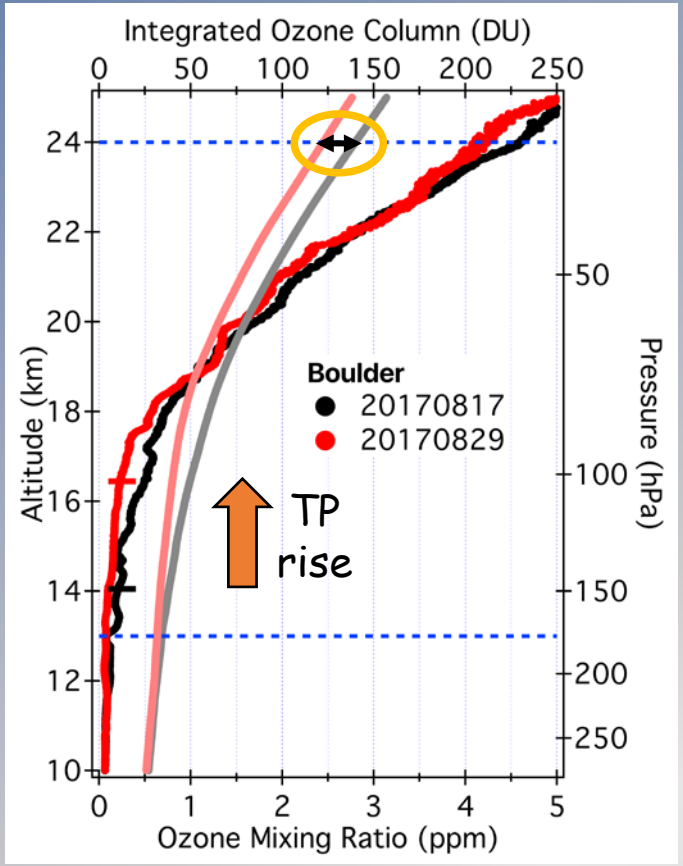
(LS columns defined by fixed altitude limits)

	Pre-1998	1998-2016
Boulder	-2.1 ± 1.6 % decade^{-1}	-1.8 ± 1.6 % decade^{-1}
Hilo	-0.6 ± 2.9	-1.4 ± 1.3
Lauder	+0.6 ± 2.7	-2.1 ± 2.4



Short-term variability in LS Ozone Columns
(defined by fixed altitude limits)



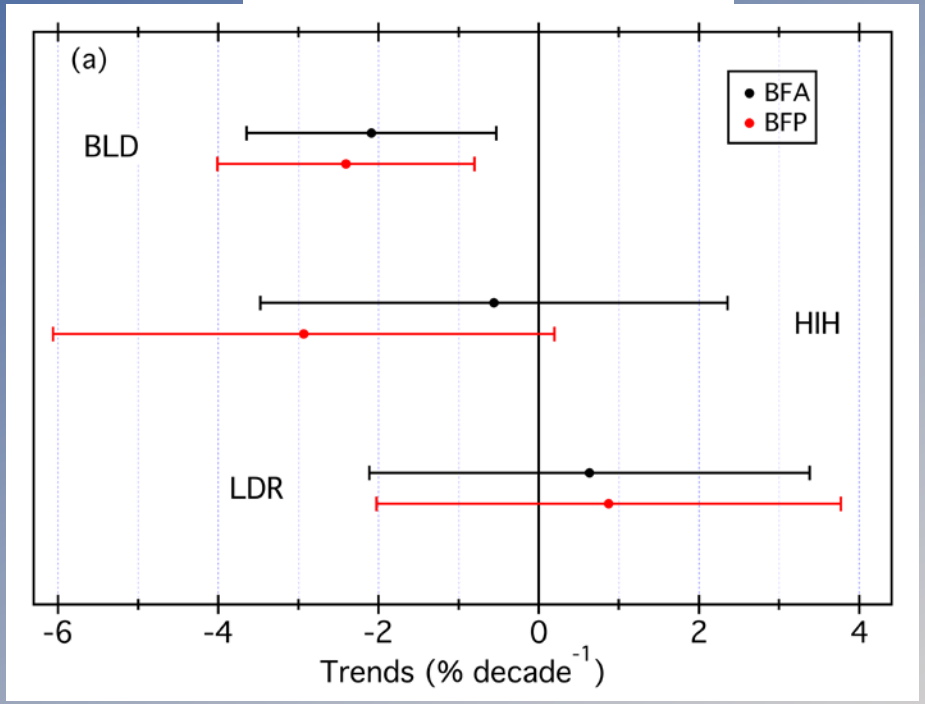


LS column changed by 15 DU due to 2.4 km rise in tropopause height over 12 days

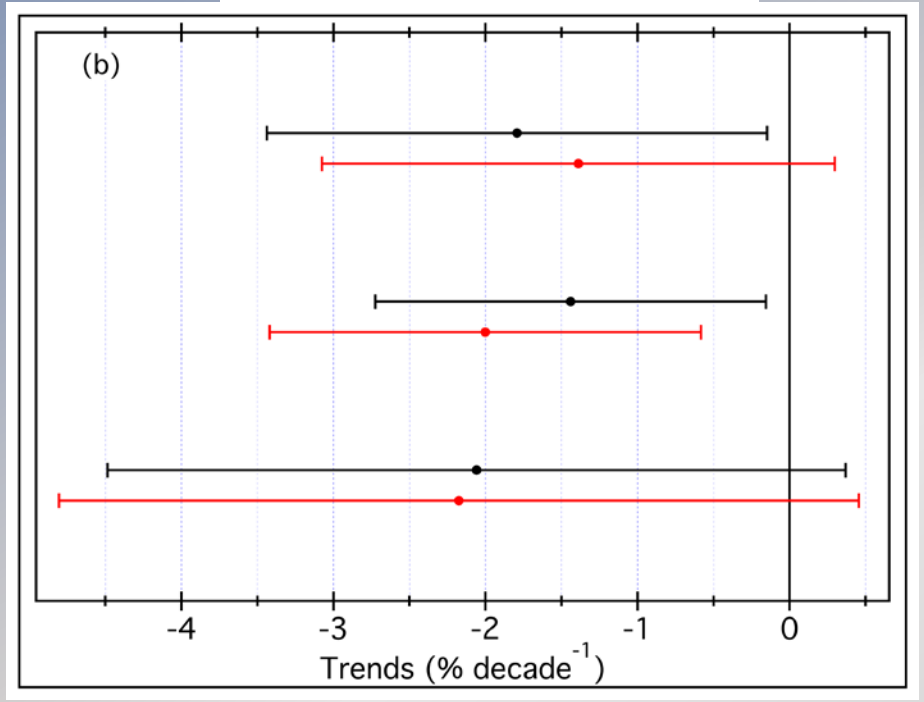
Ozonesonde-Based Trends in LS Ozone (% decade^{-1})

Ball et al. (2018) Fixed Altitude (BFA) and Fixed Pressure (BFP) limits

Pre-1998 Trends

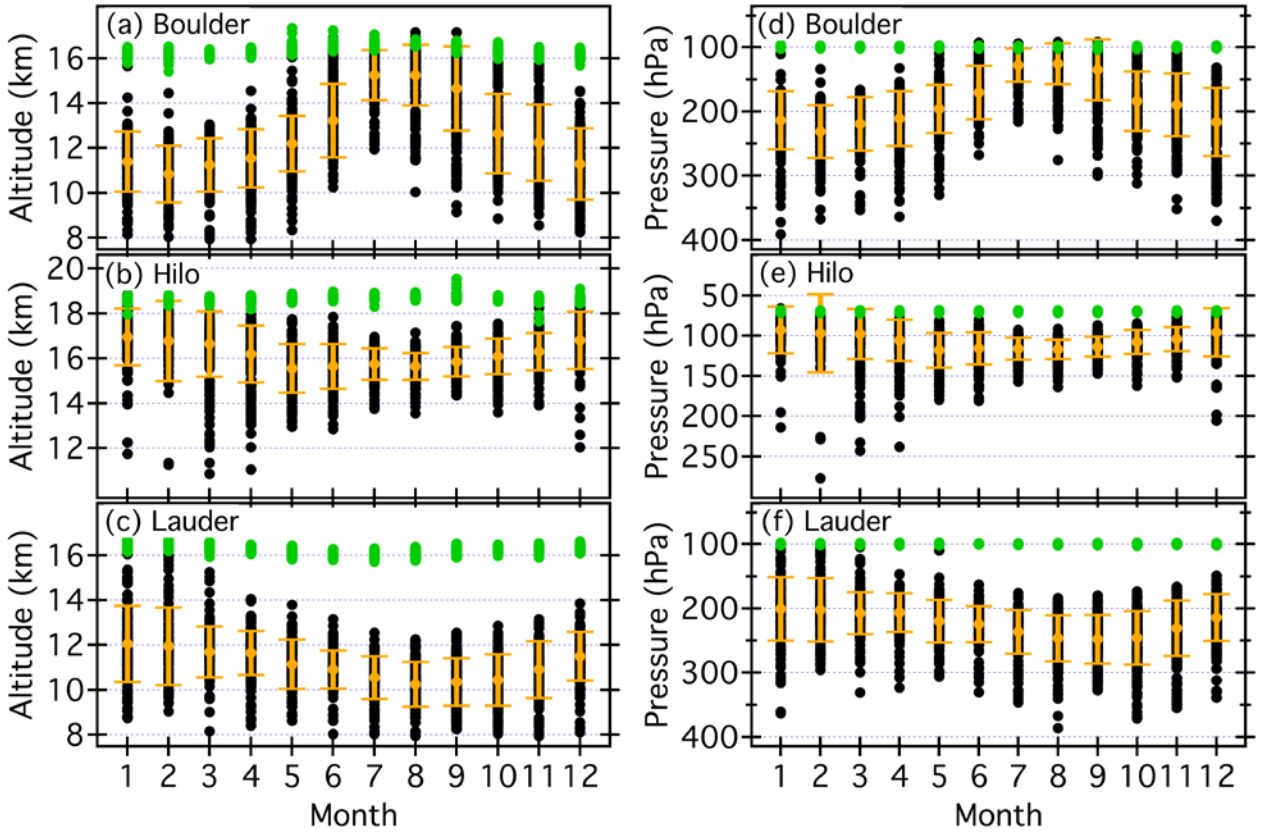


1998-2016 Trends



LS Columns Extend Well Below Tropopause!

New Column Bc TP Heights and Pressures Bottom Limits



New LS Column Limits

Pressure

100-32 hPa for 30°-60°

70-32 hPa for 30°S-30°N

Approximate altitudes

~16-24 km for 30°-60°

~19-24 km for 30°S-30°N

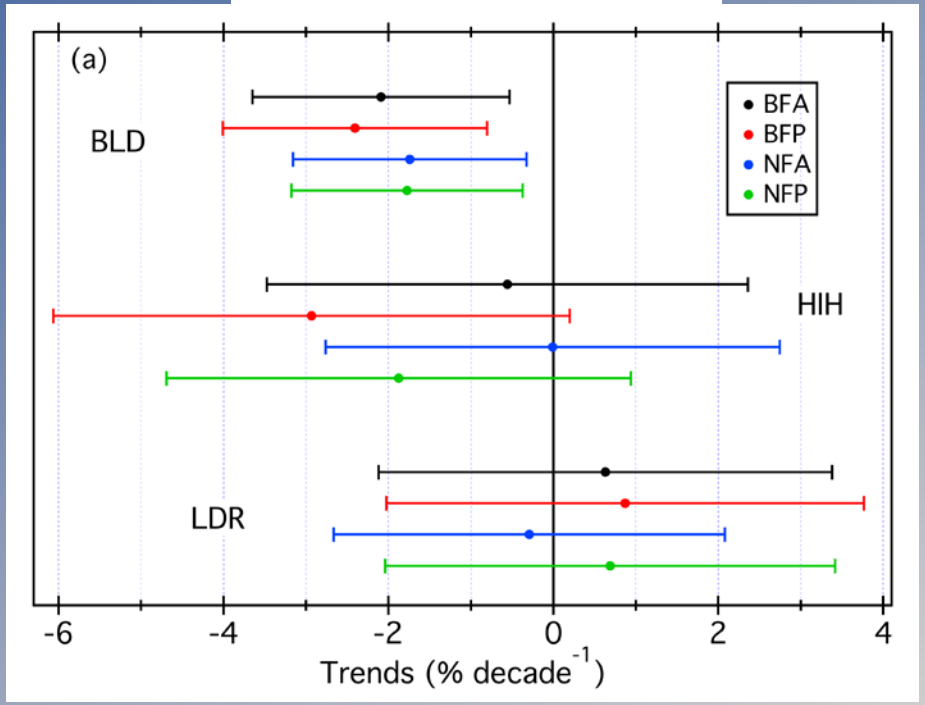
Need LS column limits that don't include large amounts of UT air.

They should reduce the short-term variability in LS O_3 columns!

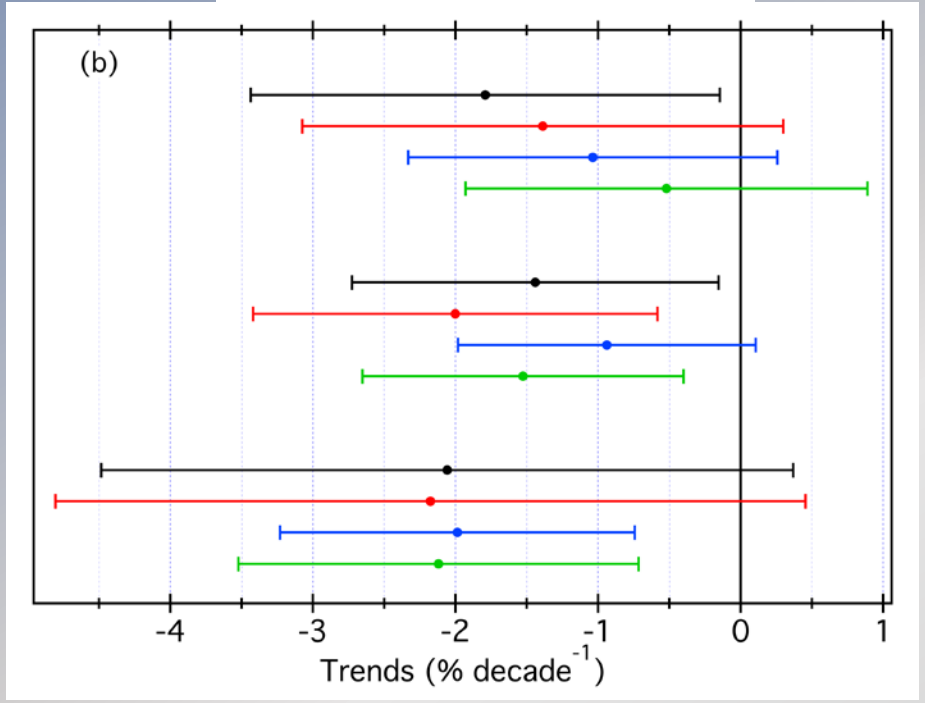
Ozonesonde-Based Trends in LS Ozone (% decade^{-1})

With New Fixed Altitude (NFA) and Fixed Pressure (NFP) limits

Pre-1998 Trends



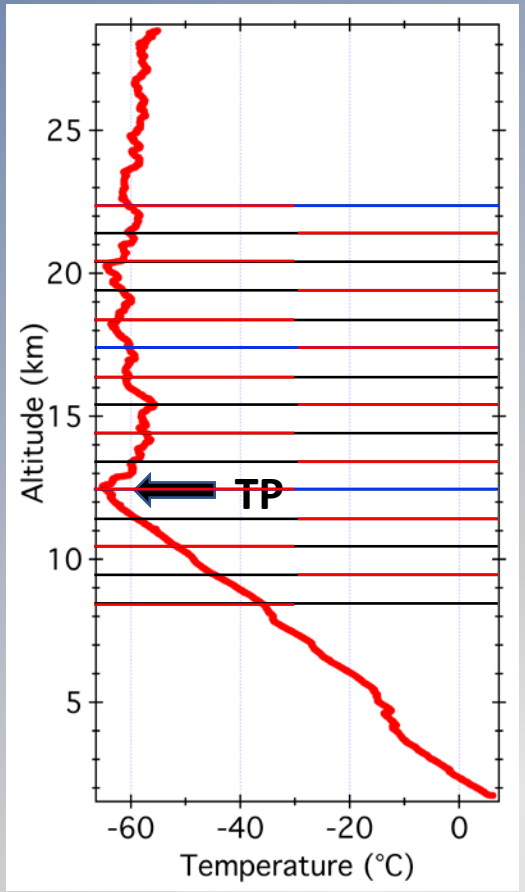
1998-2016 Trends



Switch to Tropopause-Relative Column Limits

Use lapse rate tropopause (WMO definition) determined from radiosonde temperature measurements for each ozonesonde flight.

Check against TP heights and pressures from MERRA2



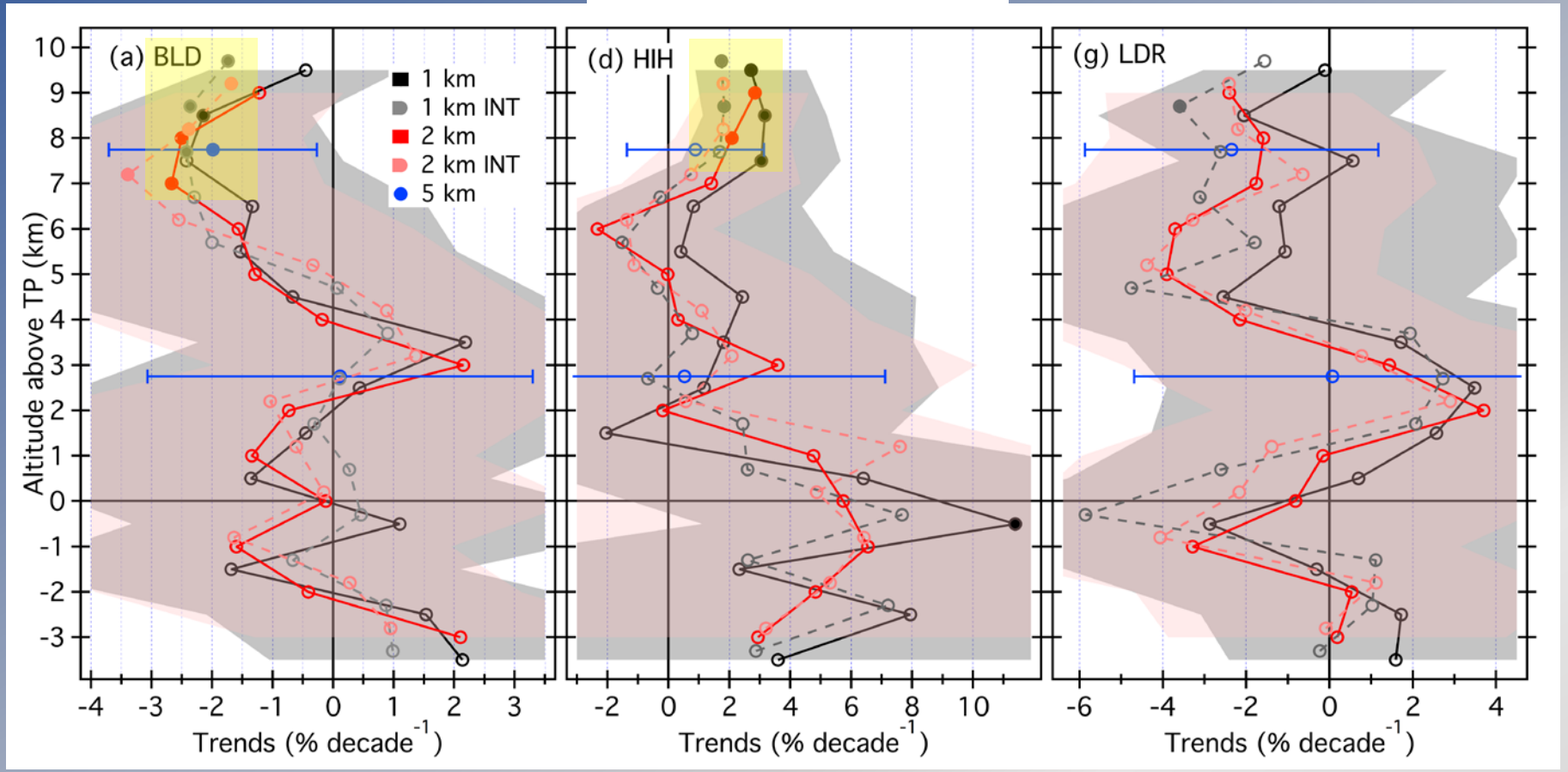
1 km limits

2 km limits

5 8 to 10 ts
7 to 9
6 to 8
5 to 7
4 to 6
3 to 5
2 to 4
1 to 3
0 to 2
-1 to 1
-2 to 0
-3 to -1
-4 to -2

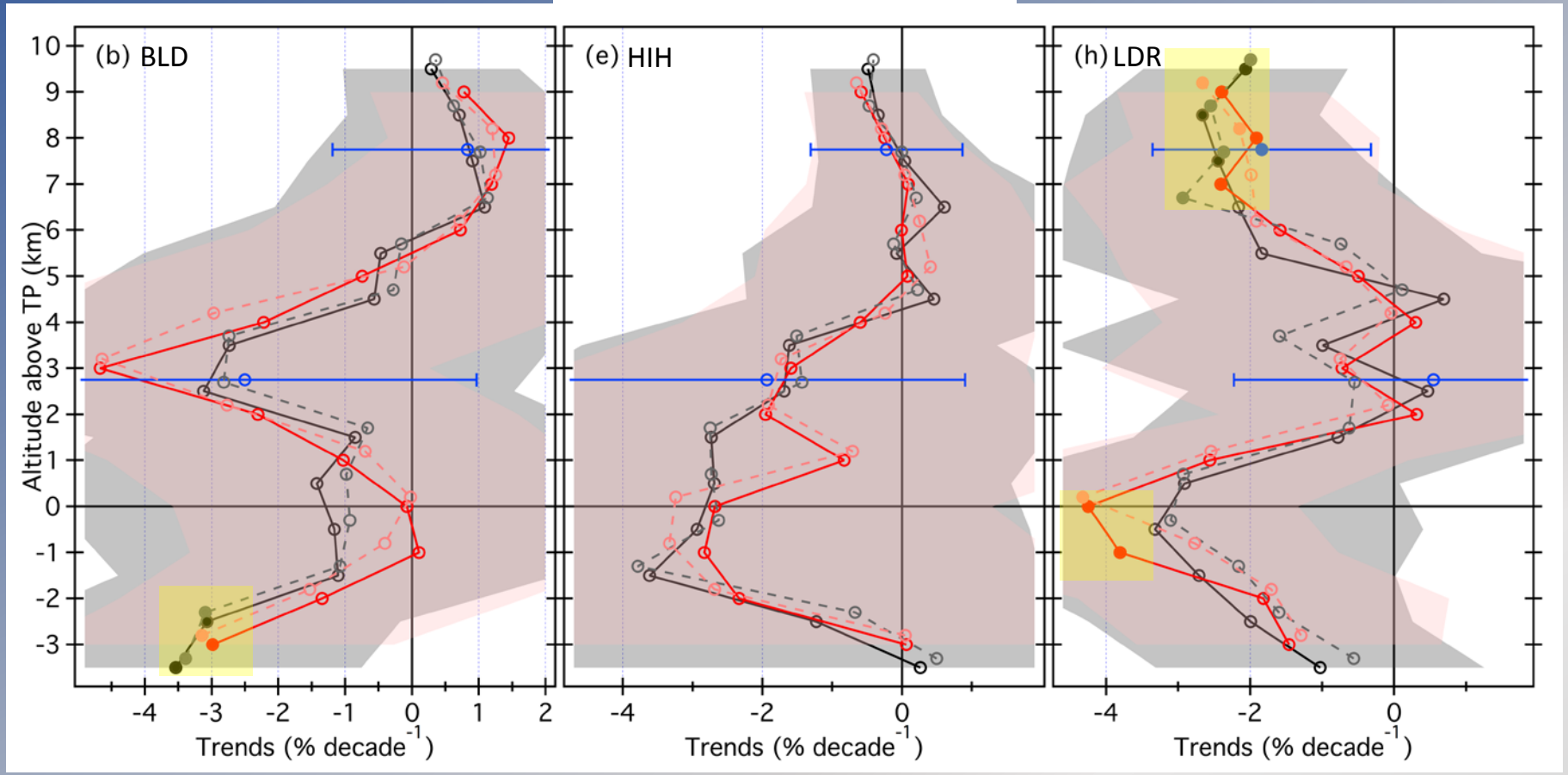
Ozonesonde-Based Trends in LS Ozone (% decade^{-1})

Pre-1998 Trends



Ozonesonde-Based Trends in LS Ozone (% decade^{-1})

1998-2016 Trends



Conclusions

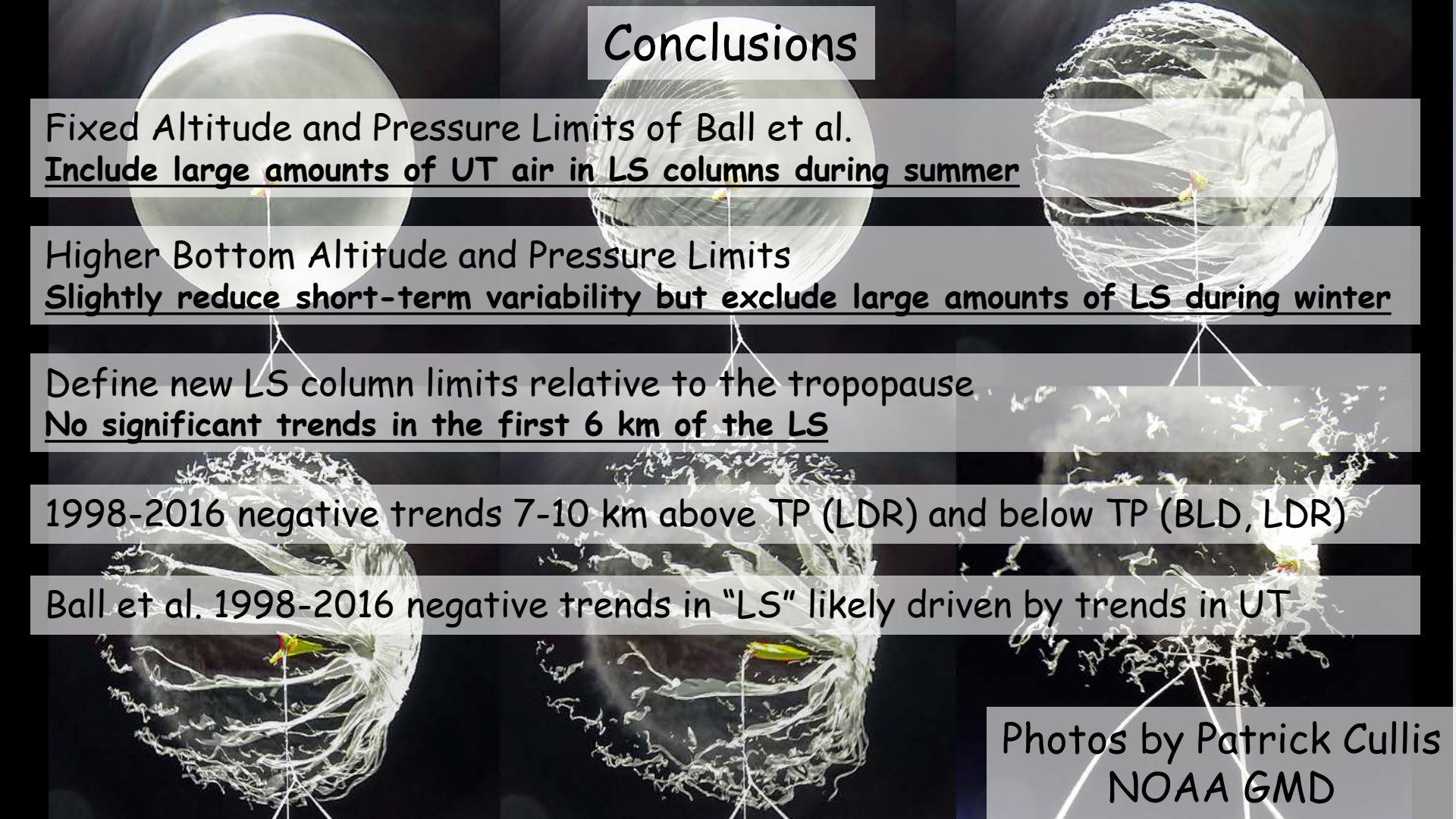
Fixed Altitude and Pressure Limits of Ball et al.
Include large amounts of UT air in LS columns during summer

Higher Bottom Altitude and Pressure Limits
Slightly reduce short-term variability but exclude large amounts of LS during winter

Define new LS column limits relative to the tropopause
No significant trends in the first 6 km of the LS

1998-2016 negative trends 7-10 km above TP (LDR) and below TP (BLD, LDR)

Ball et al. 1998-2016 negative trends in "LS" likely driven by trends in UT



Photos by Patrick Cullis
NOAA GMD