On the uneven decline of atmospheric CFC-11:

bumps in the road to ozone recovery

or

variations in atmospheric transport and/or loss?

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CFC-11 (CCl_3F) in the atmosphere today:

→ Accounts for 20-25% of ozone-depleting chlorine reaching the stratosphere (second largest contributor)

→ Was the largest contributor to atmospheric Cl ***declines*** from 2007-2012

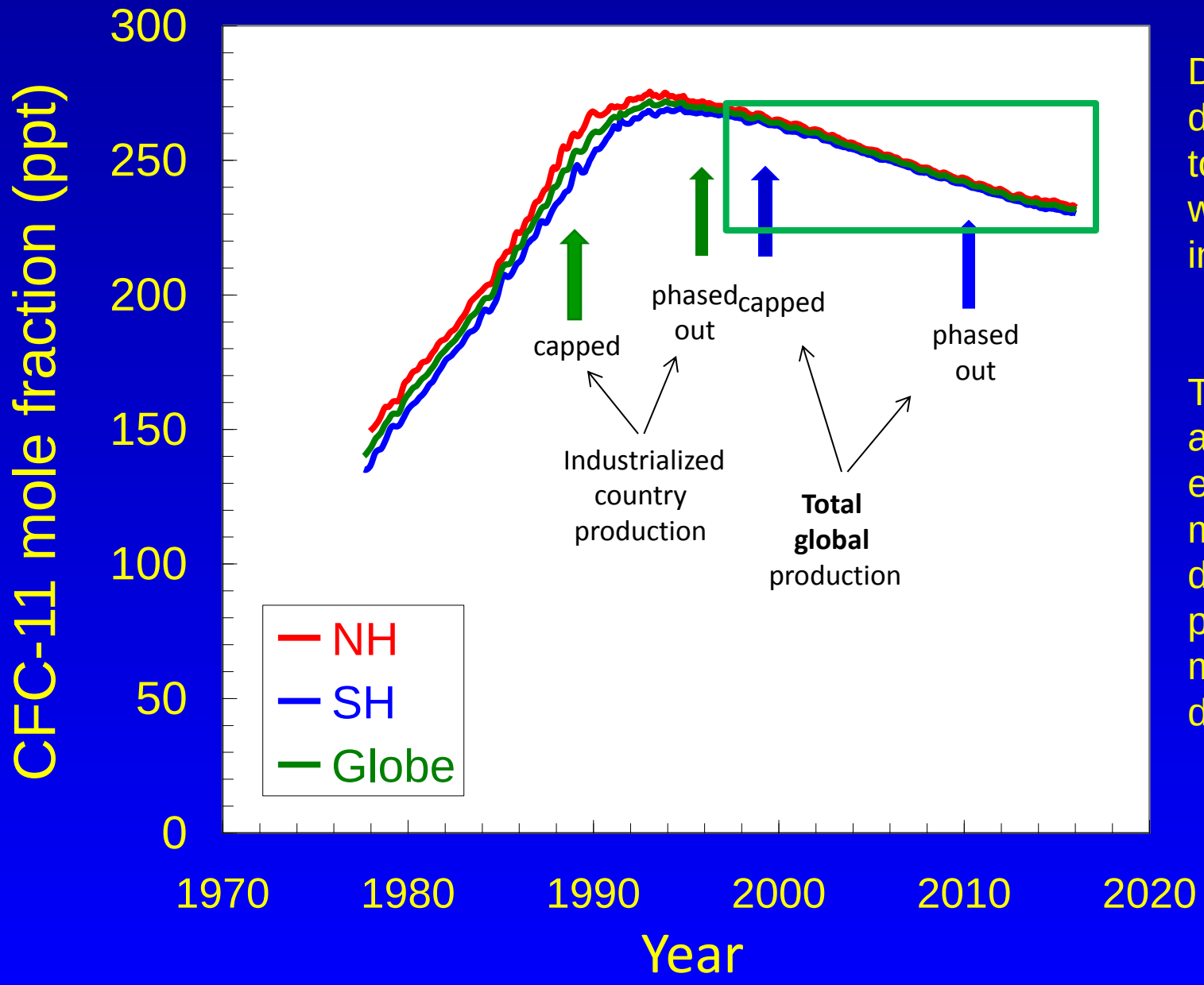
→ Near-zero global production ***for all uses*** since 2007 (as reported to UNEP's Ozone Secretariat)

But…

Significant emissions persist…

a large "bank" of chemical remains in existing equipment (~1200 Gg in 2012).

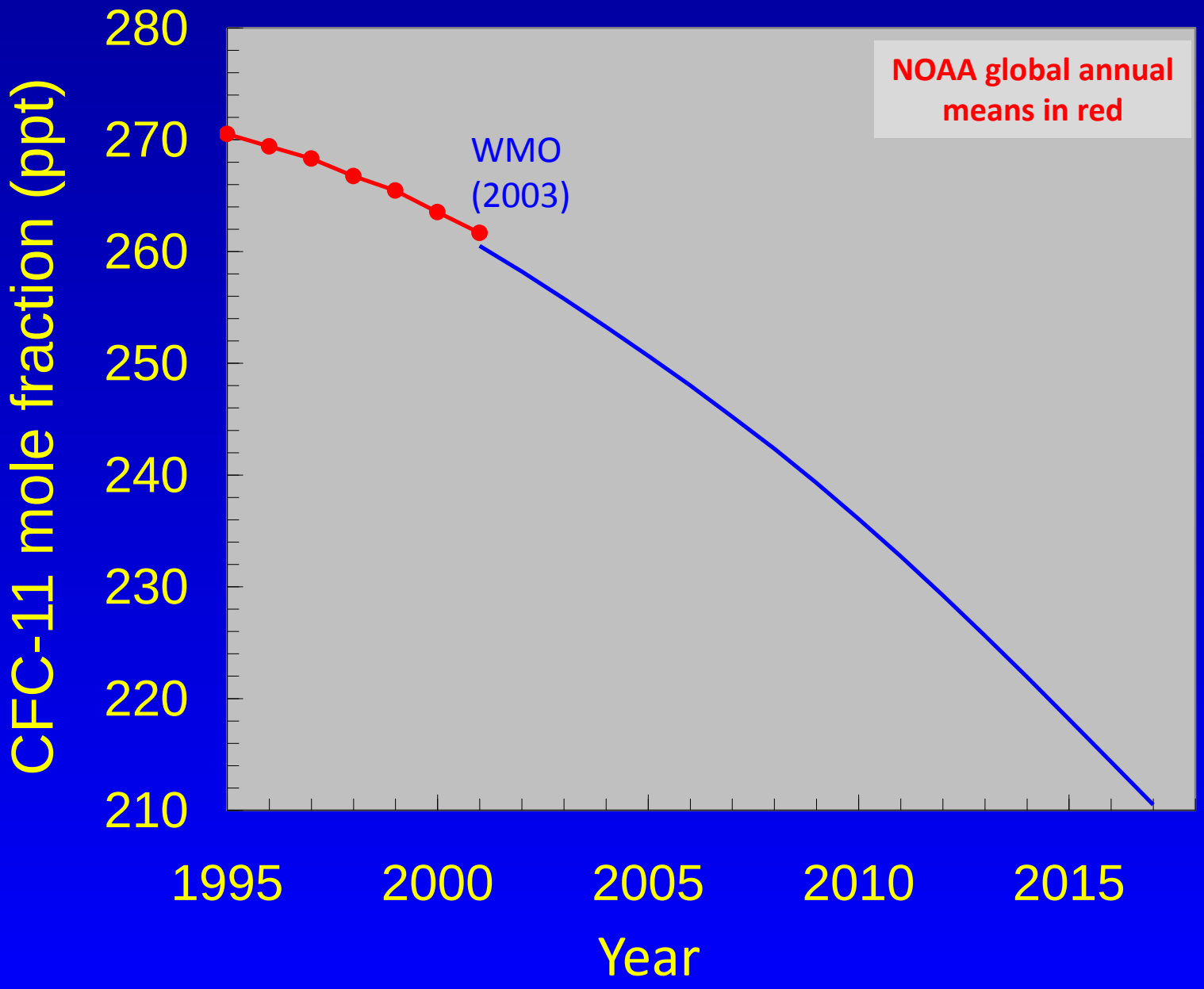
The NOAA CFC-11 atmospheric record



Derived with data from 5 to 12 sites with multiple instruments

The result of a concerted effort by many dedicated people over multiple decades!

CFC-11 evolution over time *vs.* scenario projections



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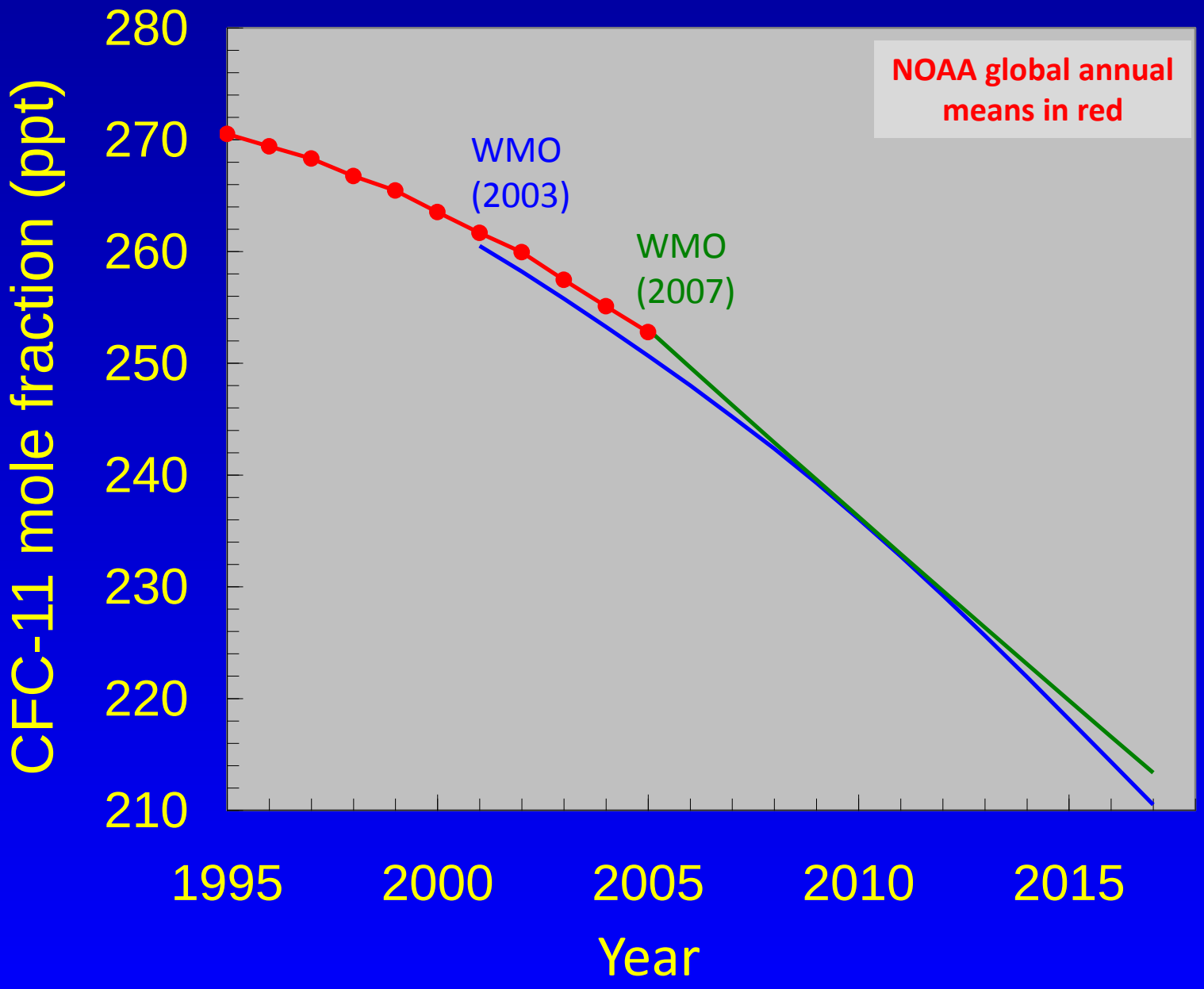

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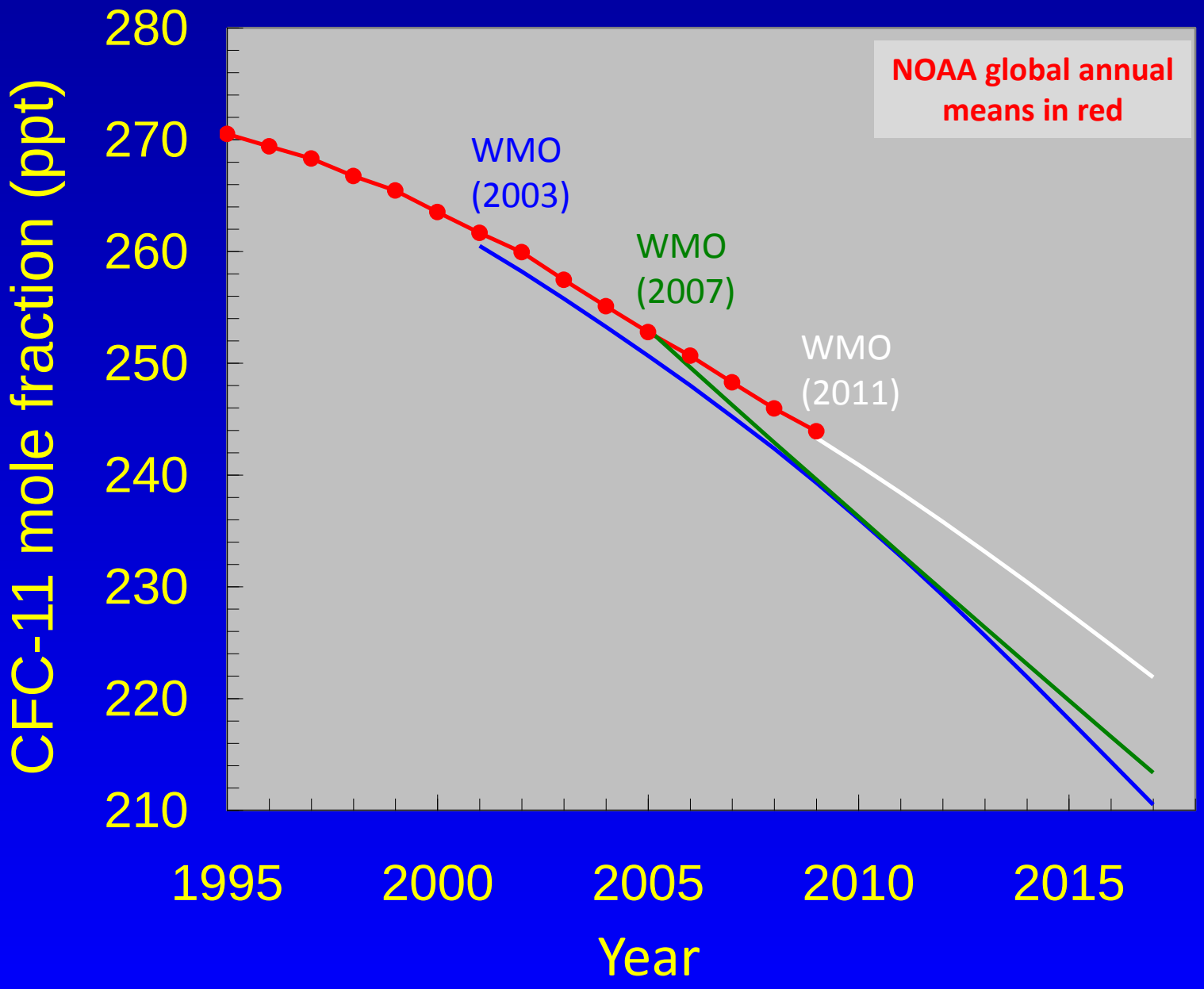

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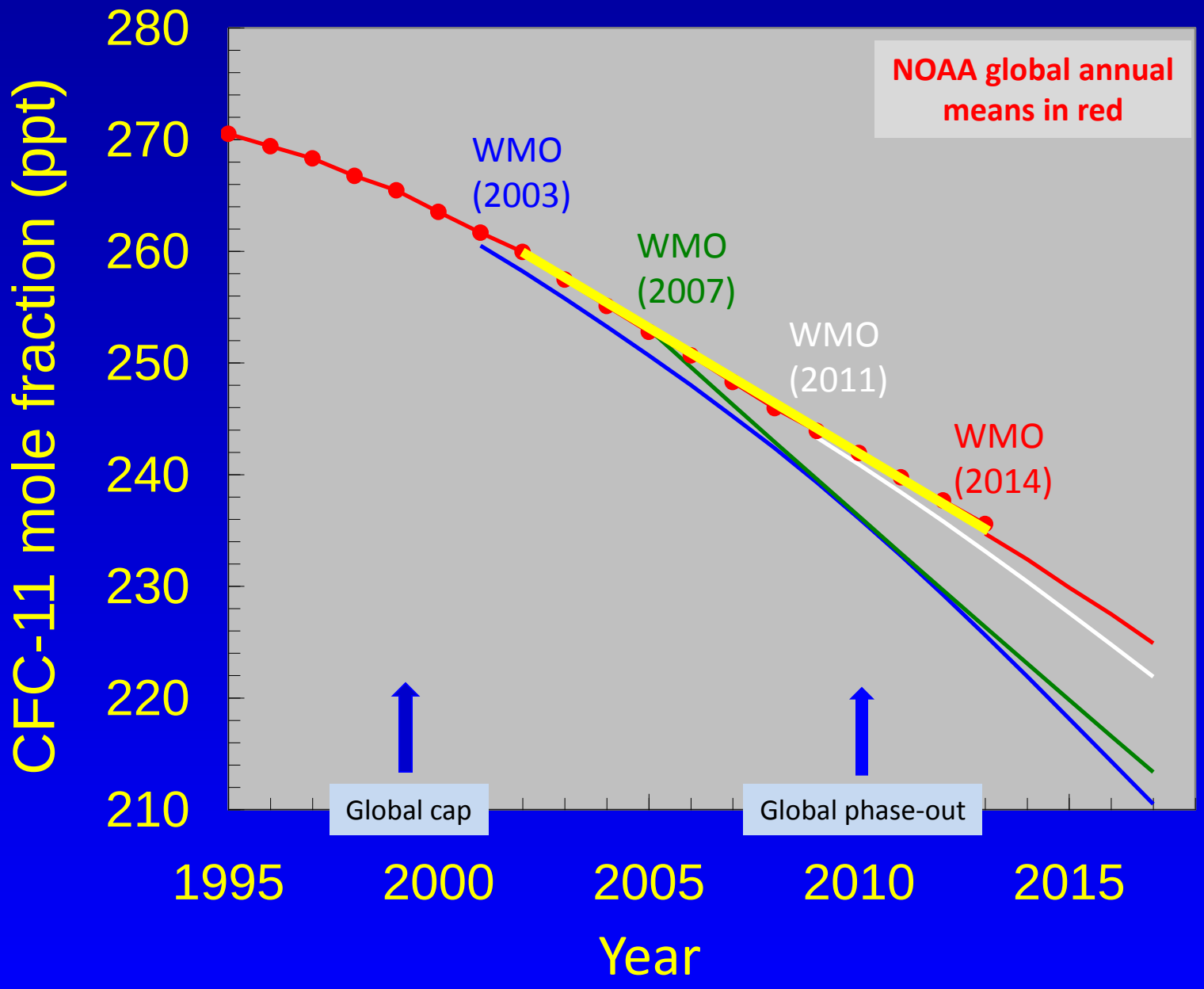

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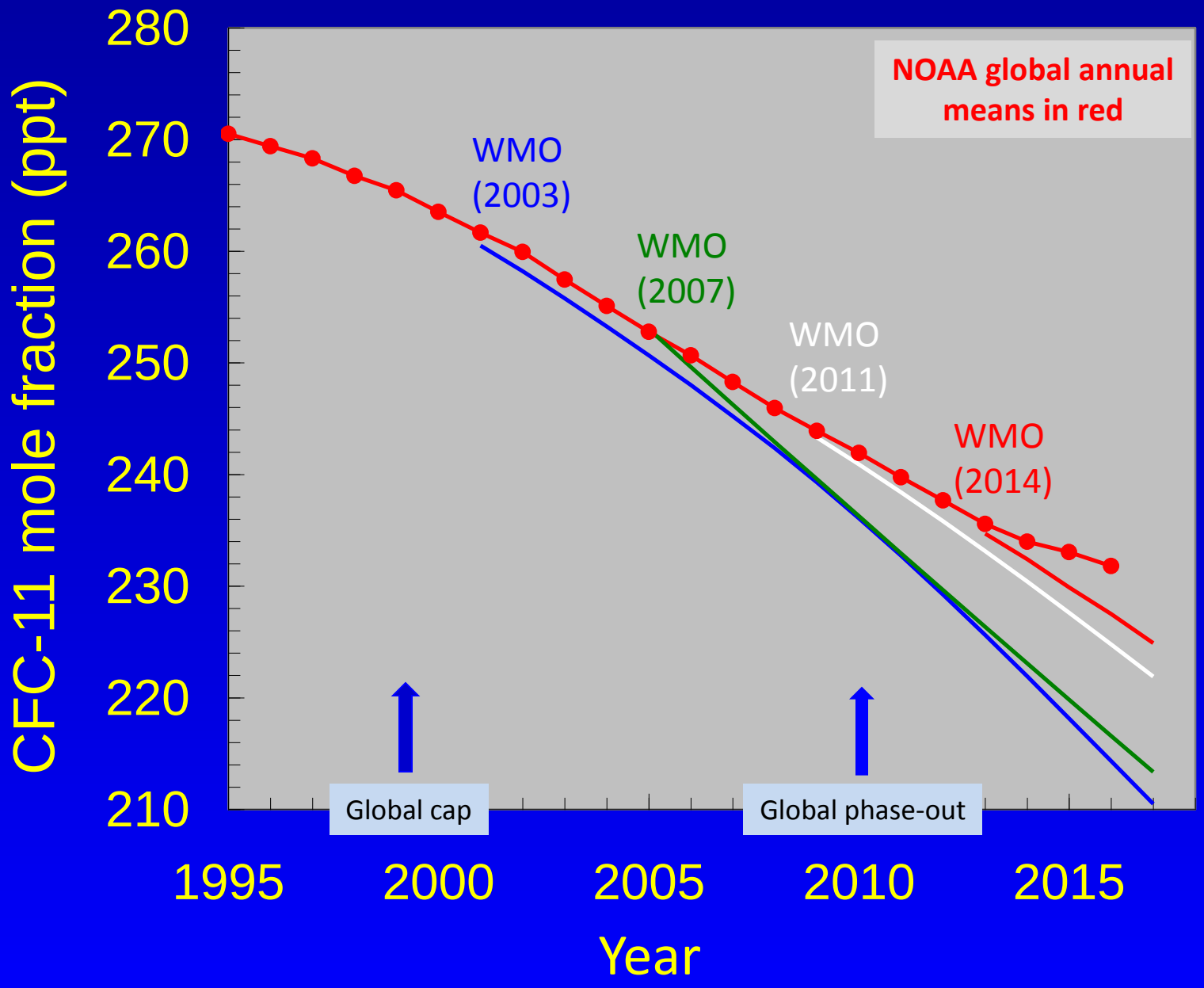
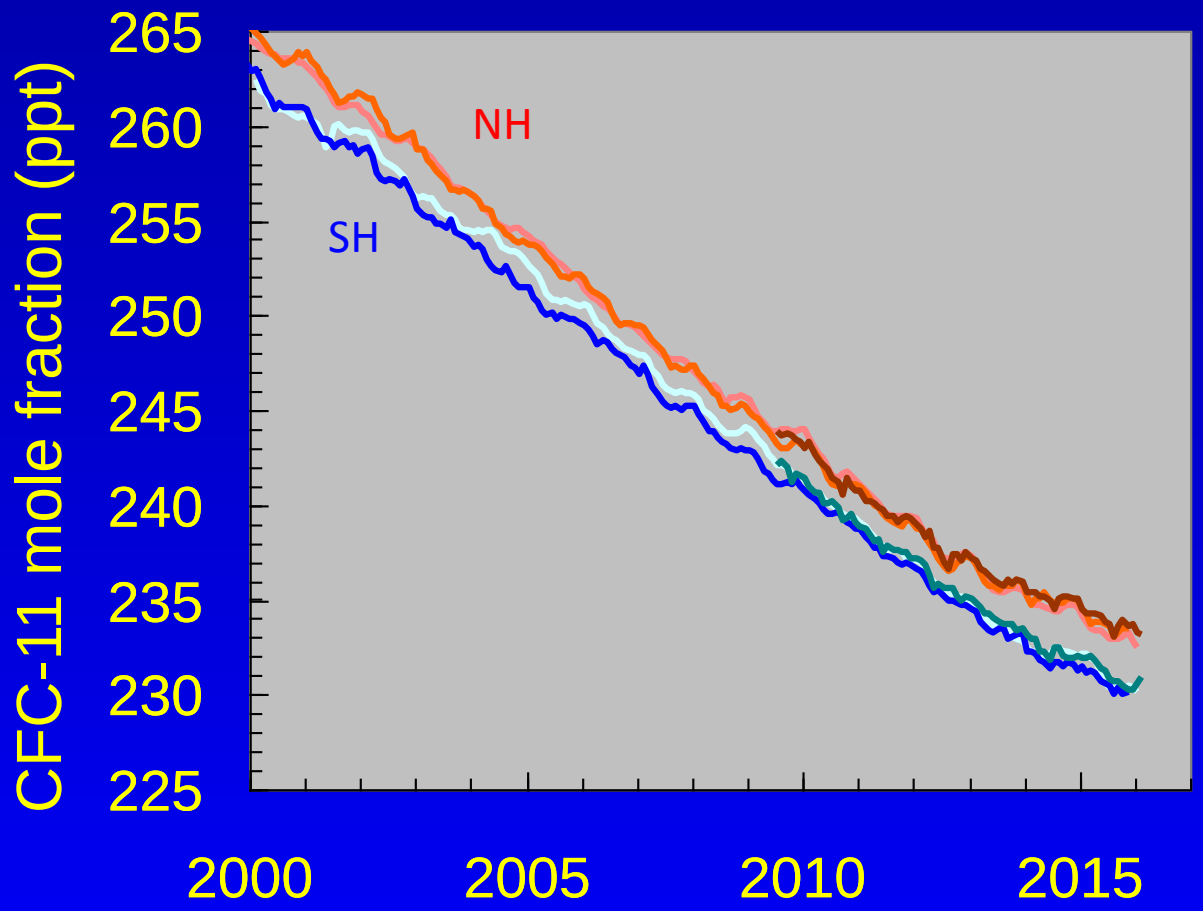


The slowdown in the atmospheric decline of CFC-11

→observed by 3 different methods at NOAA**:

1) *in situ* GC-ECDs at 6 sites
2) flasks, by GC-ECD, from 12 sites
3) flasks, by GC-MS, from 12 sites (since 2009)



The recent results from all three methods show:

→ **A 40% slowdown in decline**:

-2.2 ppt/yr (2002-2012)
(-0.9%/yr)
-1.3 ppt/yr (since 2013)

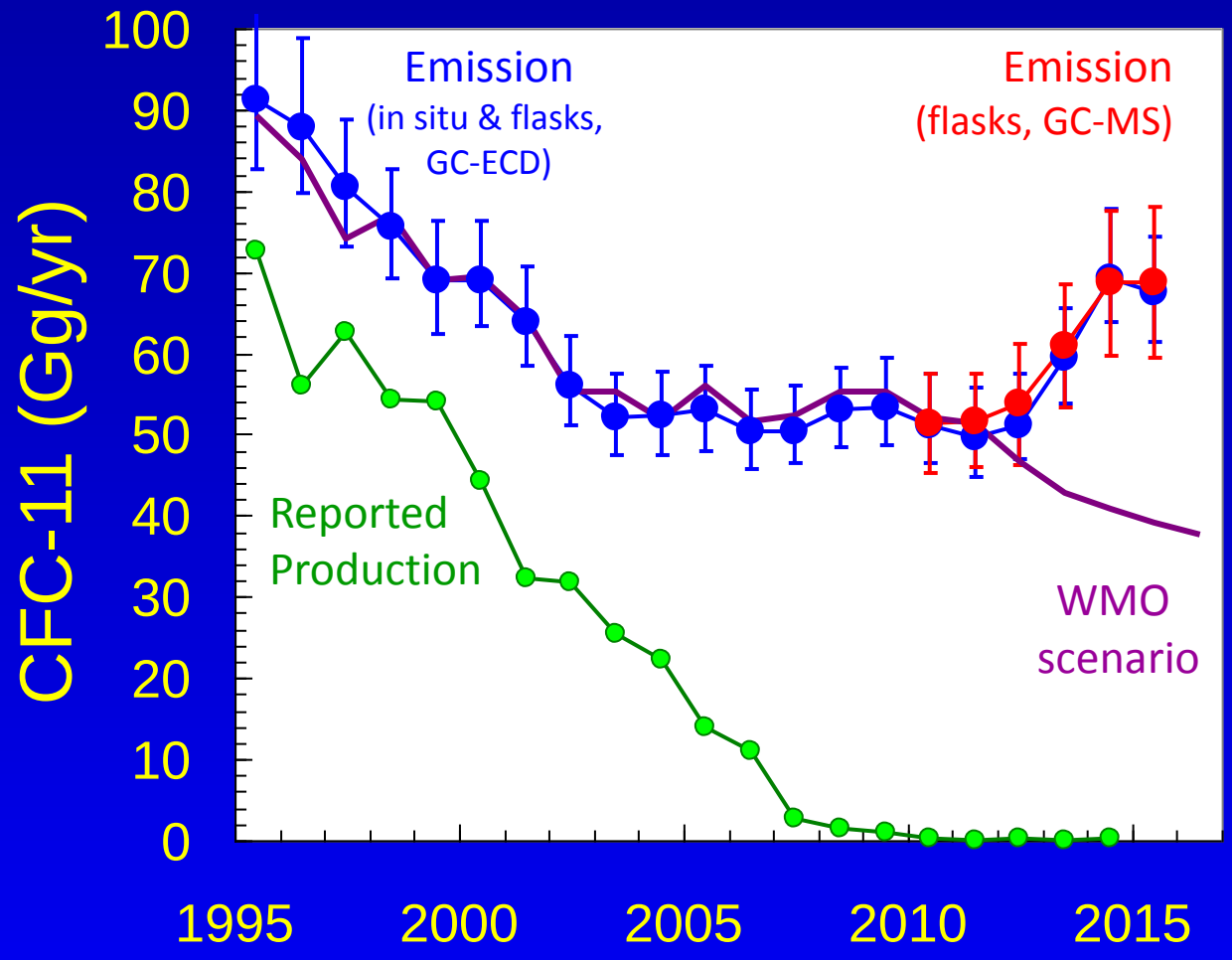
→ **A 50% larger hemispheric difference** (NH – SH)

→Increasing NH emissions?

**Calibration scale for GCMS is maintained independently from ECD instruments

Derived global emissions *vs.* reported production

(assuming a constant loss frequency)



Emissions become decoupled from production trends in the mid-2000s…

→ *drawdown in "bank"?*

A 30% ***INCREASE*** in emission is derived in 2014-2015

→ From all three measurement records

→ With multiple modeling approaches

How is this possible?

Fairly constant and invariant (+/-4%) emissions for over a decade, then a 30% increase.

Deriving emissions from global atmospheric changes:

for G = global mass
τ = global lifetime

$$\mathbf{dG/dt = Emission - Loss}$$

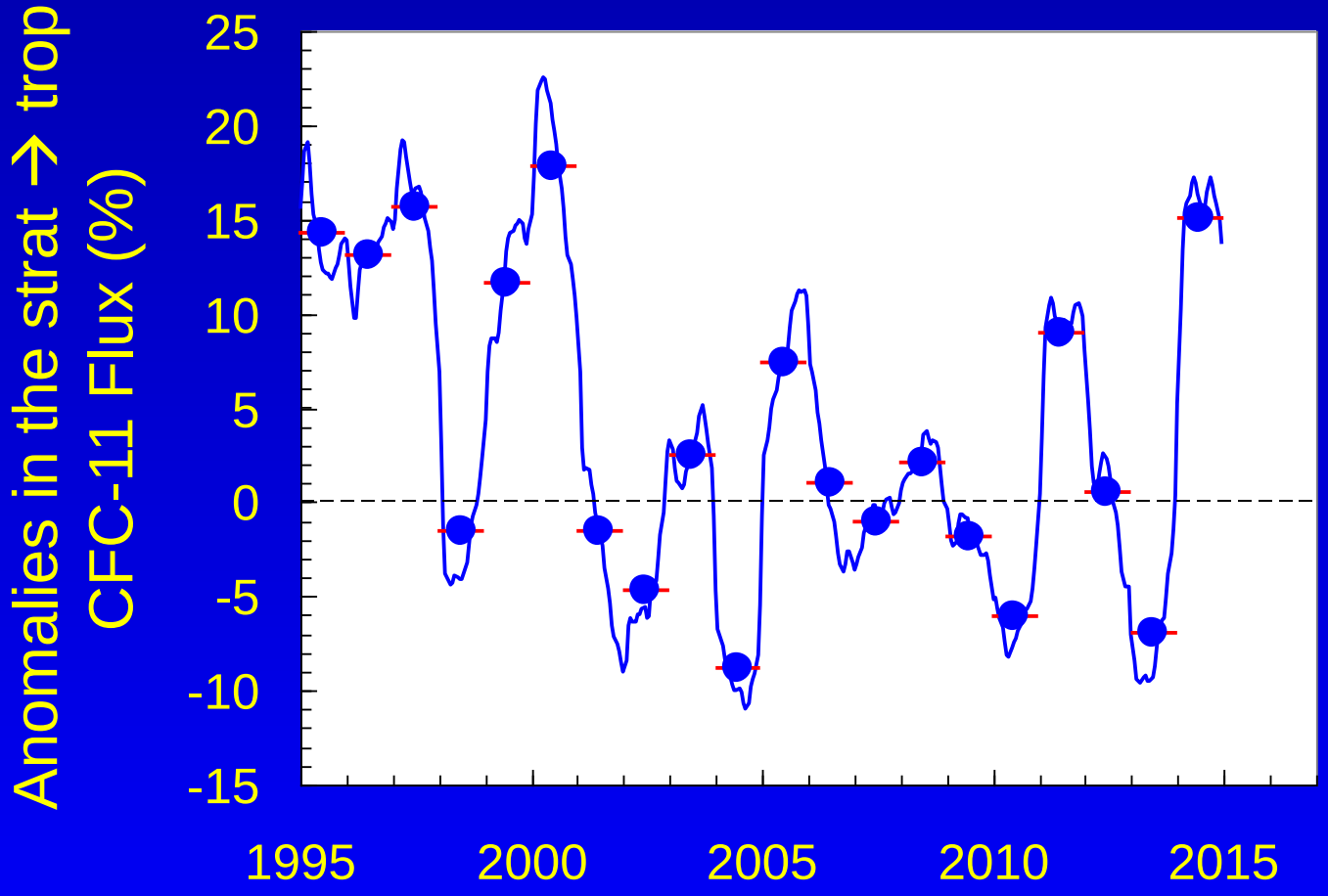
where loss is derived from annually repeating loss frequencies and transport.

…stratospheric loss signals propagate to the troposphere (Nevison *et al.*, 2014)

- → **How significant are variations in the loss signal?**
- → **Can we avoid aliasing loss variability in derived emissions?**

Time-varying anomalies in the strat → trop flux of CFC-11

→ Derived from a model of stratospheric circulation with reanalysis meteorology (**E. Ray *et al*., 2014**), photolytic fluxes, and trace gas photolysis cross sections:



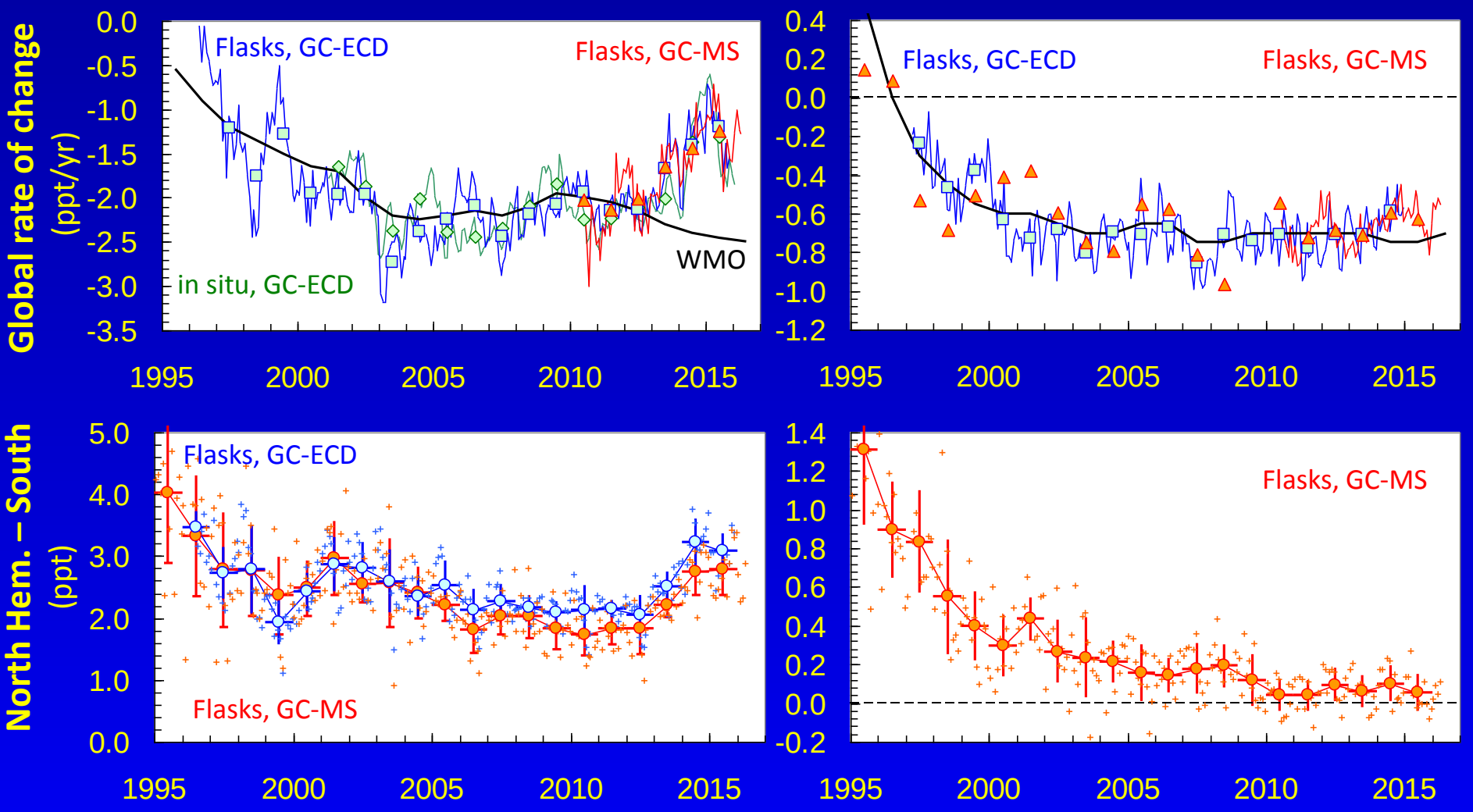
In mass units:

+ 16 Gg

- 8 Gg

anomaly is primarily NH

Transport anomalies should affect other trace gases



Conclusions:

1) The atmospheric decline of CFC-11 slowed significantly during 2013-2016, and has been slower than expected for over a decade. Total Cl decline has significantly slowed too.

2) Derived CFC-11 emissions have not decreased since 2005 and appear to have increased by 30% since 2012 (~18 Gg/yr) despite a phase-out of global production in ~2007. Such a large emission increase seems very difficult to understand given past compliance with the Montreal Protocol.

3) Inter-annual variations in CFC-11 transport from the stratosphere likely influence the magnitude of emissions derived from remote surface measurements. Although these variations seem unlikely to entirely account for the observed anomalies derived for CFC-11 during 2013-2016,

4) Emissions derived from surface observations should be more reliable with an accurate accounting of loss variability.