The Way Forward

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Never make predictions, especially about the future

What is the ”Way Forward”?

- Science
- Compliance
- Technology
- Policies

What role does science play?

- **Vienna Convention, Article 3:** The Parties undertake, as appropriate, to initiate and co-operate in, directly or through competent international bodies, the conduct of research and scientific assessments
- **Montreal Protocol, Article 6:** Assessment and review of control measures
  - Beginning in 1990, and at least every four years thereafter, the Parties shall assess the control measures provided for in Article 2 and Articles 2A to 2I on the basis of available scientific, environmental, technical and economic information.
- We inform the parties on issues related to ozone, ozone depletion, the stratosphere, and the compounds that replaced ozone depleting substances – particularly with respect to their climate effects
- We are verifying compliance and providing ”accountability” information.
  - Are the amendments working?

The Science Assessment Process

The Customers:

- Governments, via the Montreal Protocol and Vienna Convention
- Industry, Public, Science community

Important factors:

- The expertise of the Lead Authors, Coauthors, Contributors, Chapter Editors
- Critical reviews by experts

What the assessments are:

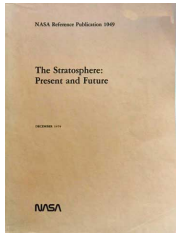
- State of science:
  - What we know & what we don't, framed in policy-useful terms.
  - What is new & significant ("What?" & "So what?") since the last assessment (2014)
- Assessed viewpoints - an update, not a review, and not an encyclopedia.
- "One-stop shopping":
  - Science of the ozone layer (Scientific Assessment Panel
  - Impacts of ozone change (Environmental Effects Assessment Panel)
  - Technology/economics of options (Technology and Economic Assessment Panel)

Continued Ozone Assessments have provided further information for Protocol adjustments

WMO World Plan of Action on the Ozone Layer - 1977

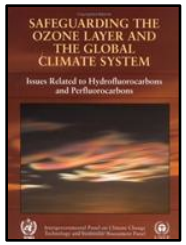
1980 1990 2000 2010

Scientific Assessment of Ozone Depletion:
1989, 1991, 1994, 1998, 2002, 2006, 2010, 2014 (WMO/UNEP)



Montreal Protocol

Vienna Convention

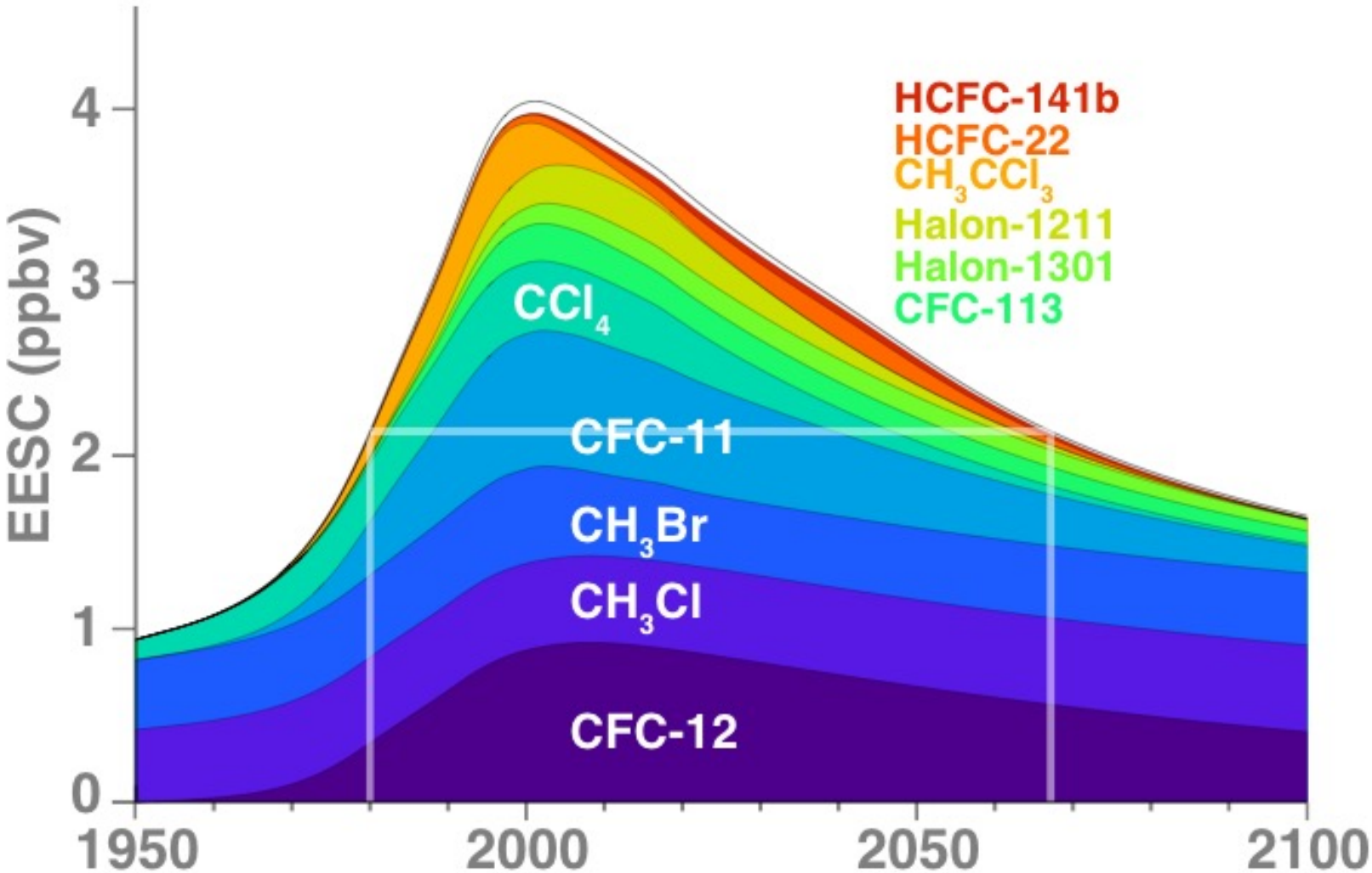


Safeguarding the Ozone Layer and the Global Climate System: 2005 (IPCC/TEAP)

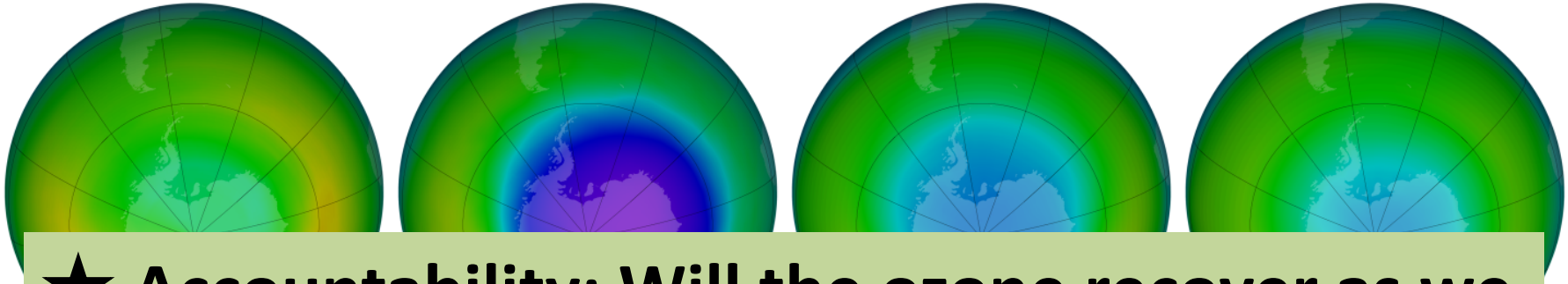
Where are ozone levels headed?

Following Dr. Langematz

Effective equivalent stratospheric chlorine (EESC) is expected to decline in the 21st century because of the MP



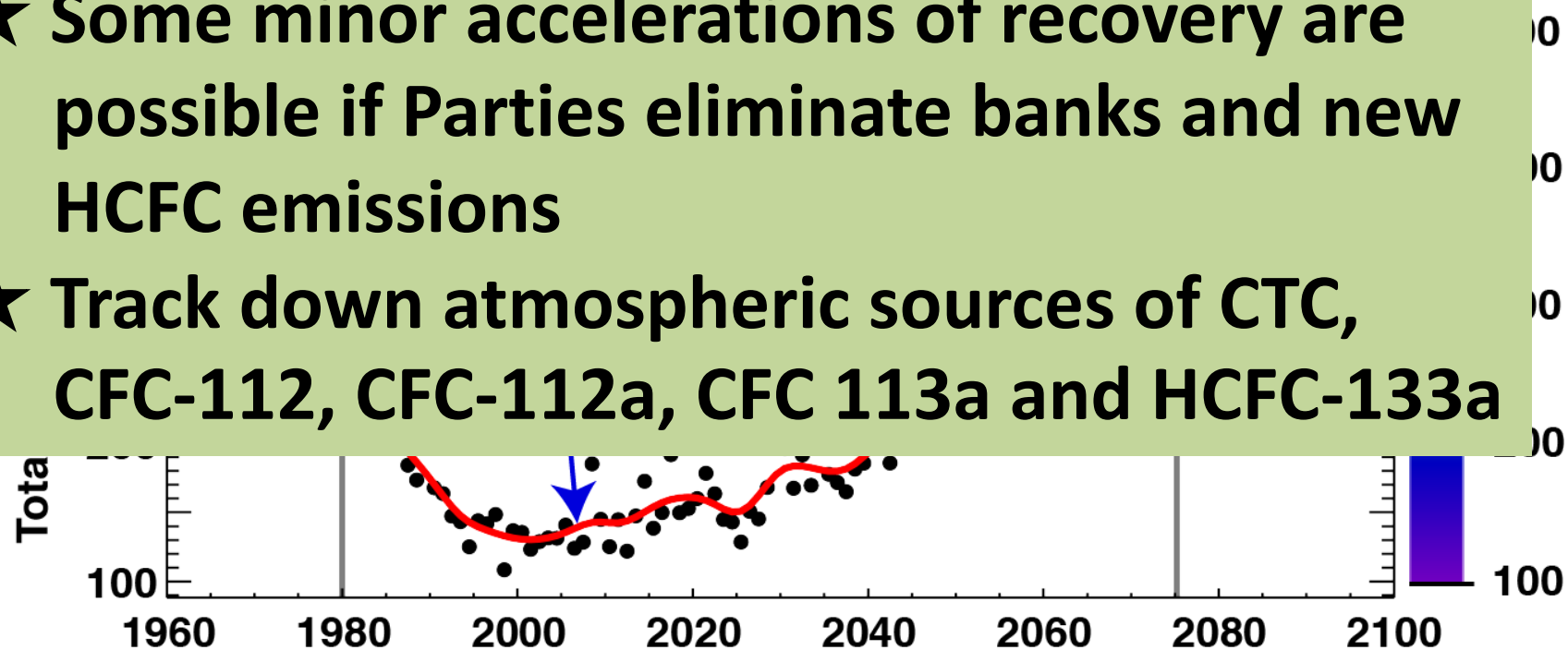
The Antarctic ozone hole will recover in the latter half of the 21st century



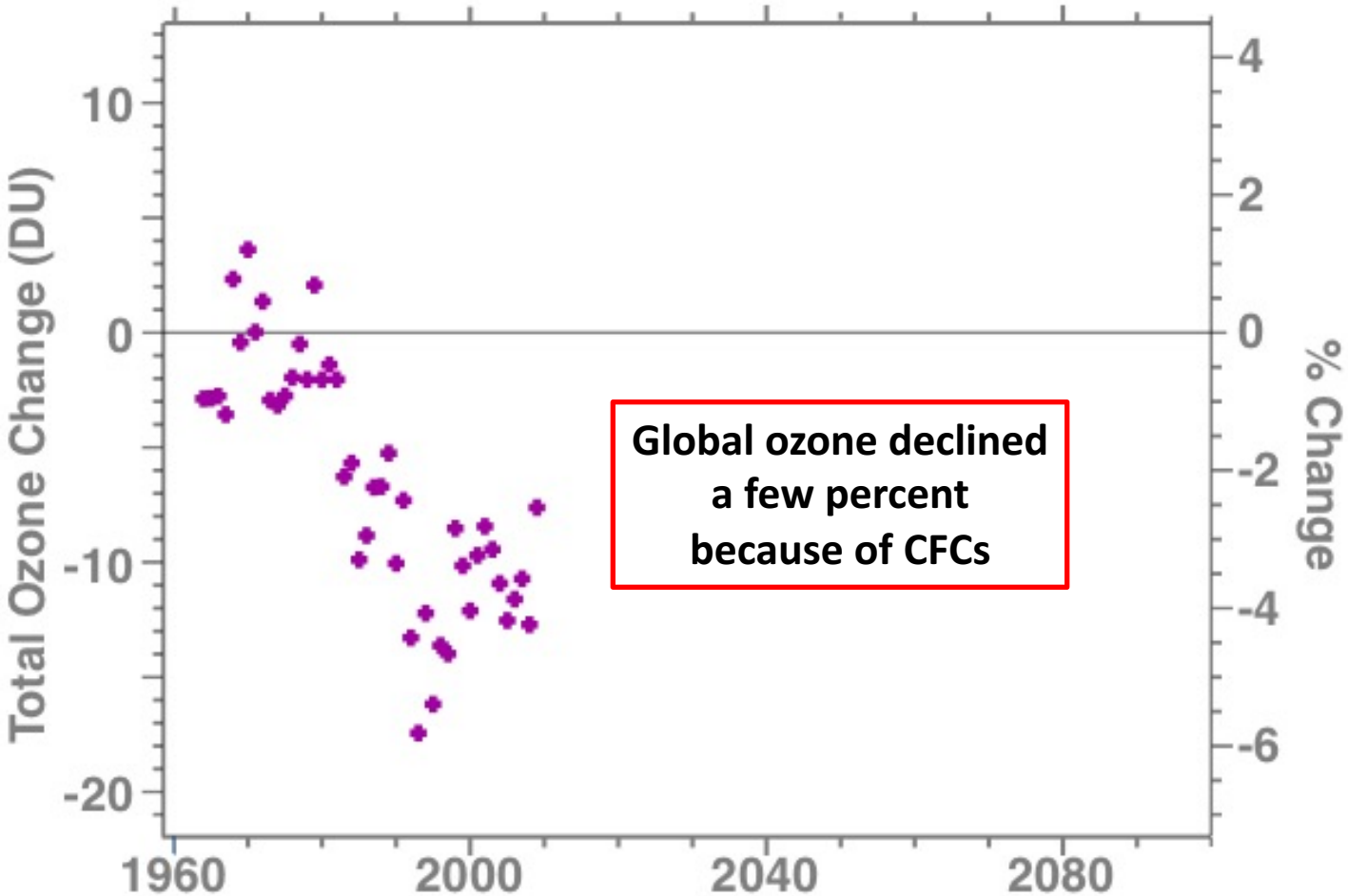
★ Accountability: Will the ozone recover as we scientists have projected?

★ Some minor accelerations of recovery are possible if Parties eliminate banks and new HCFC emissions

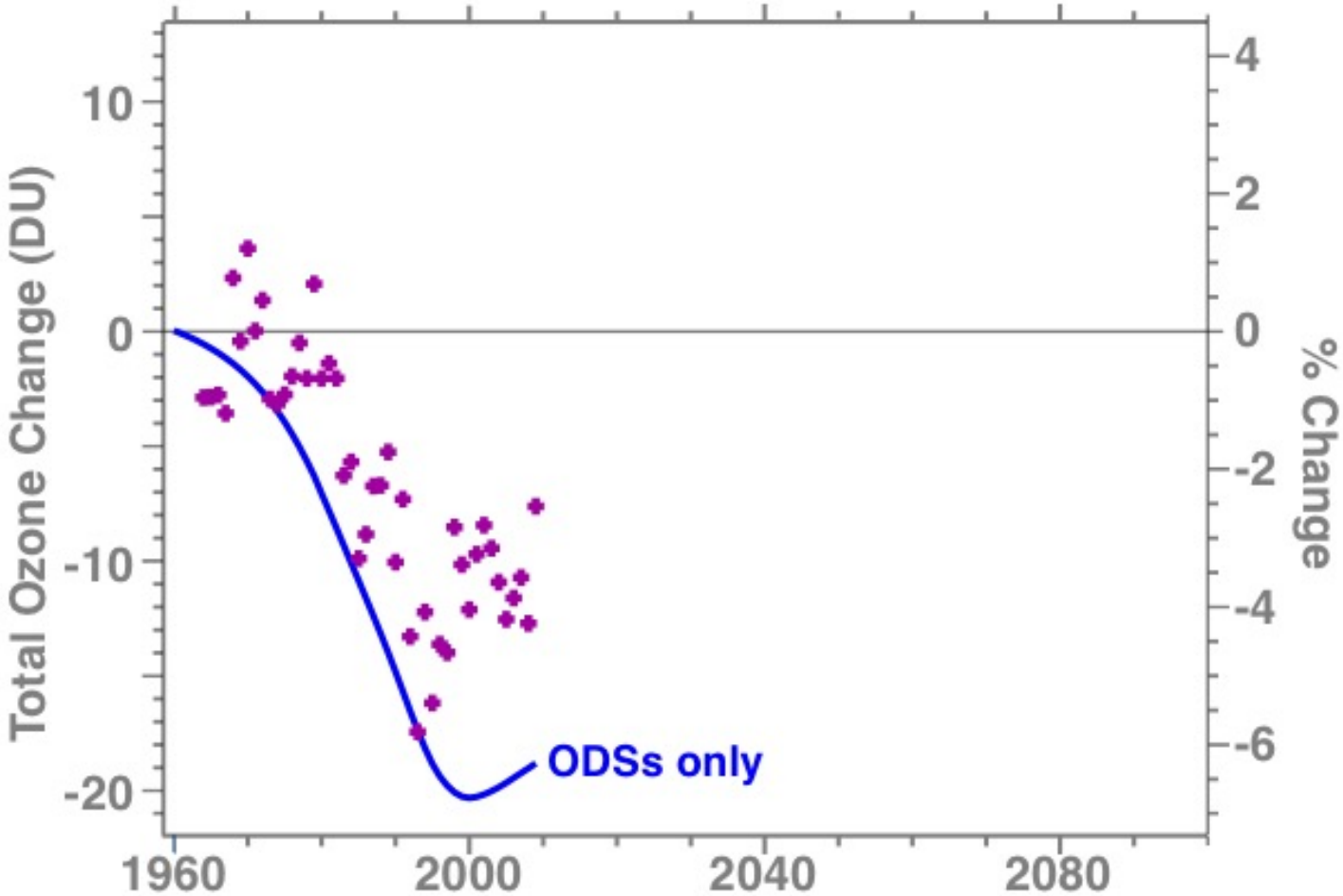
★ Track down atmospheric sources of CTC, CFC-112, CFC-112a, CFC 113a and HCFC-133a



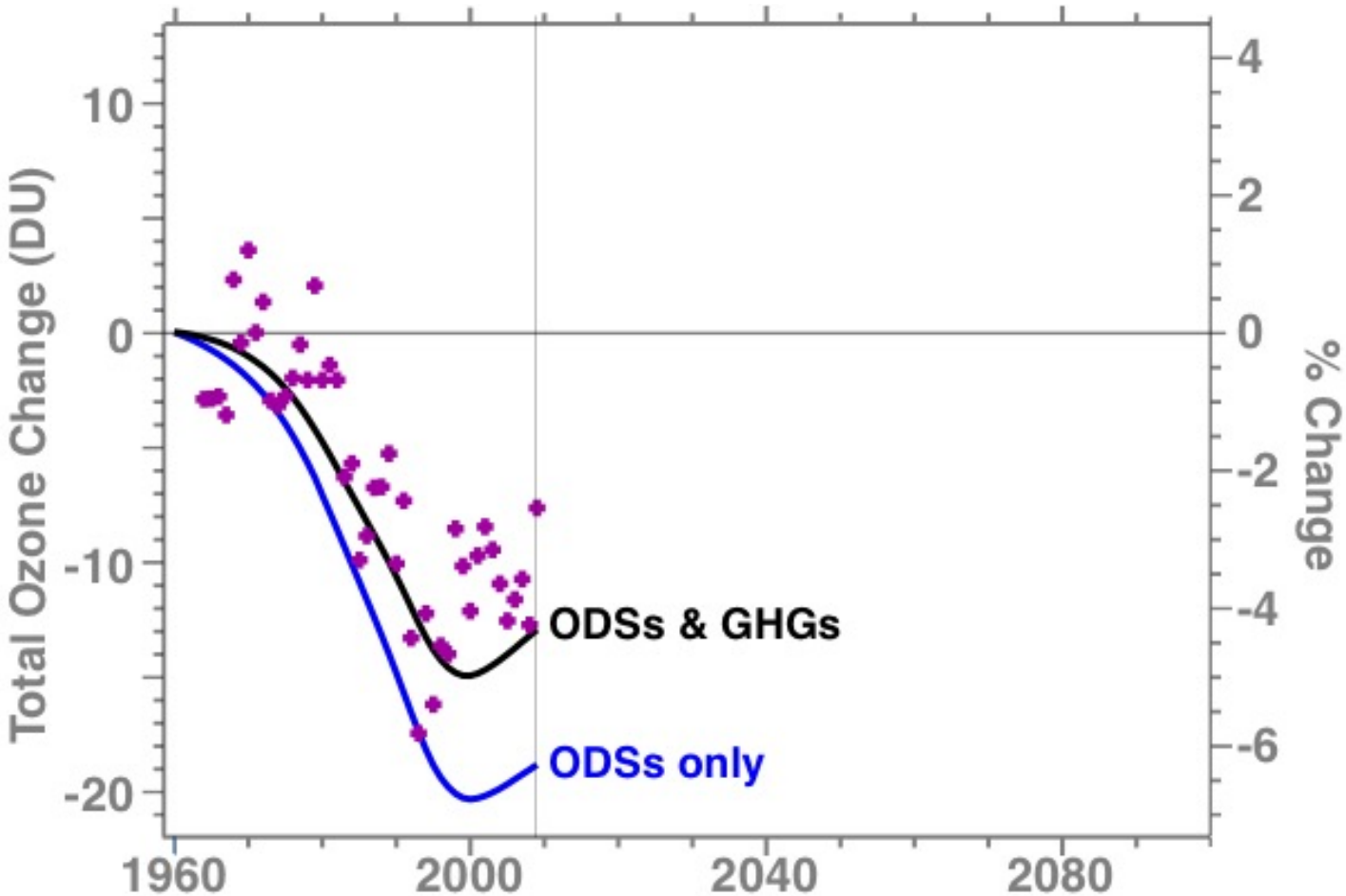
Where is the stratosphere and ozone headed?



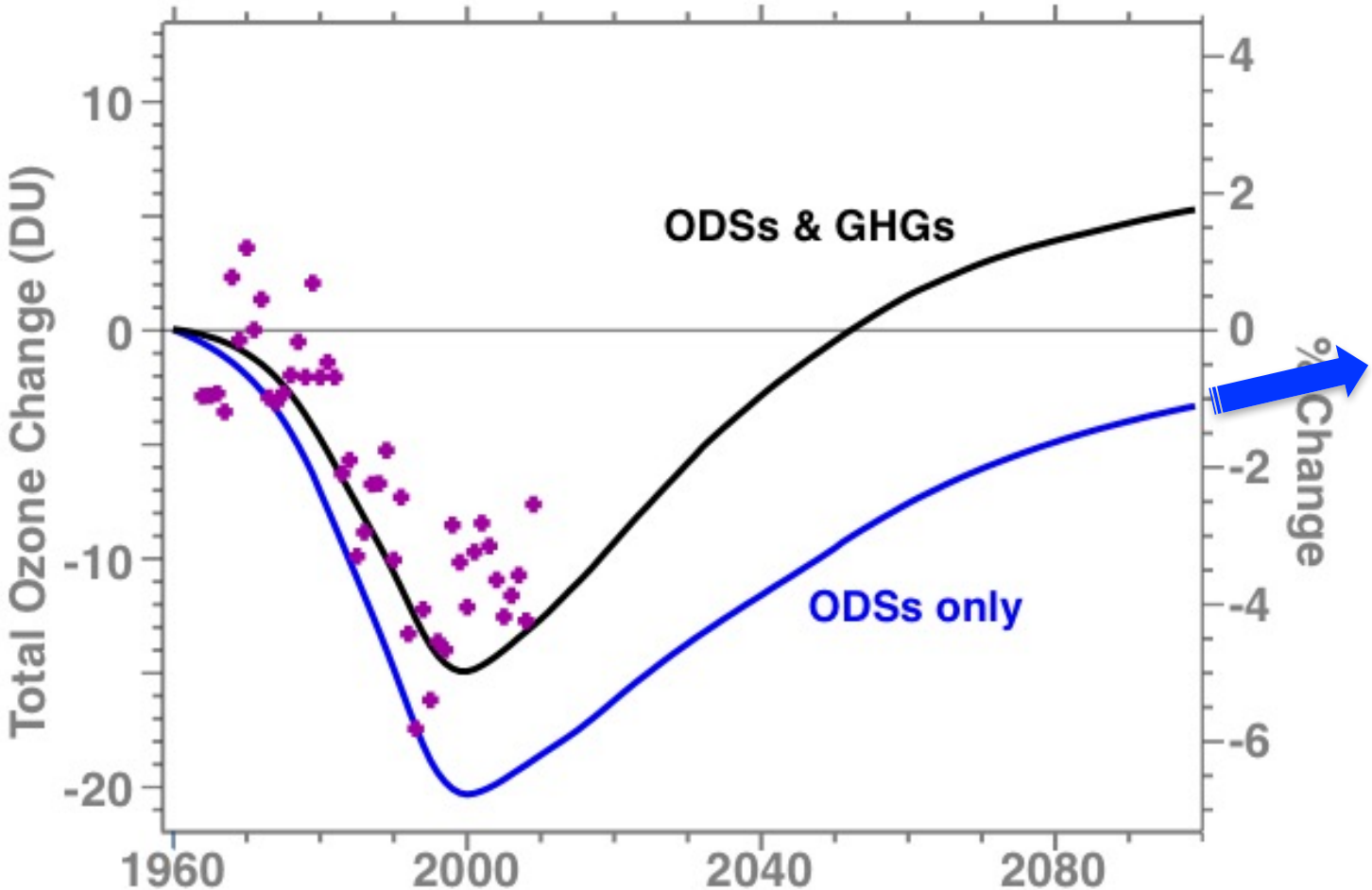
Increasing ODSs depleted ozone, but the MP reversed that trend



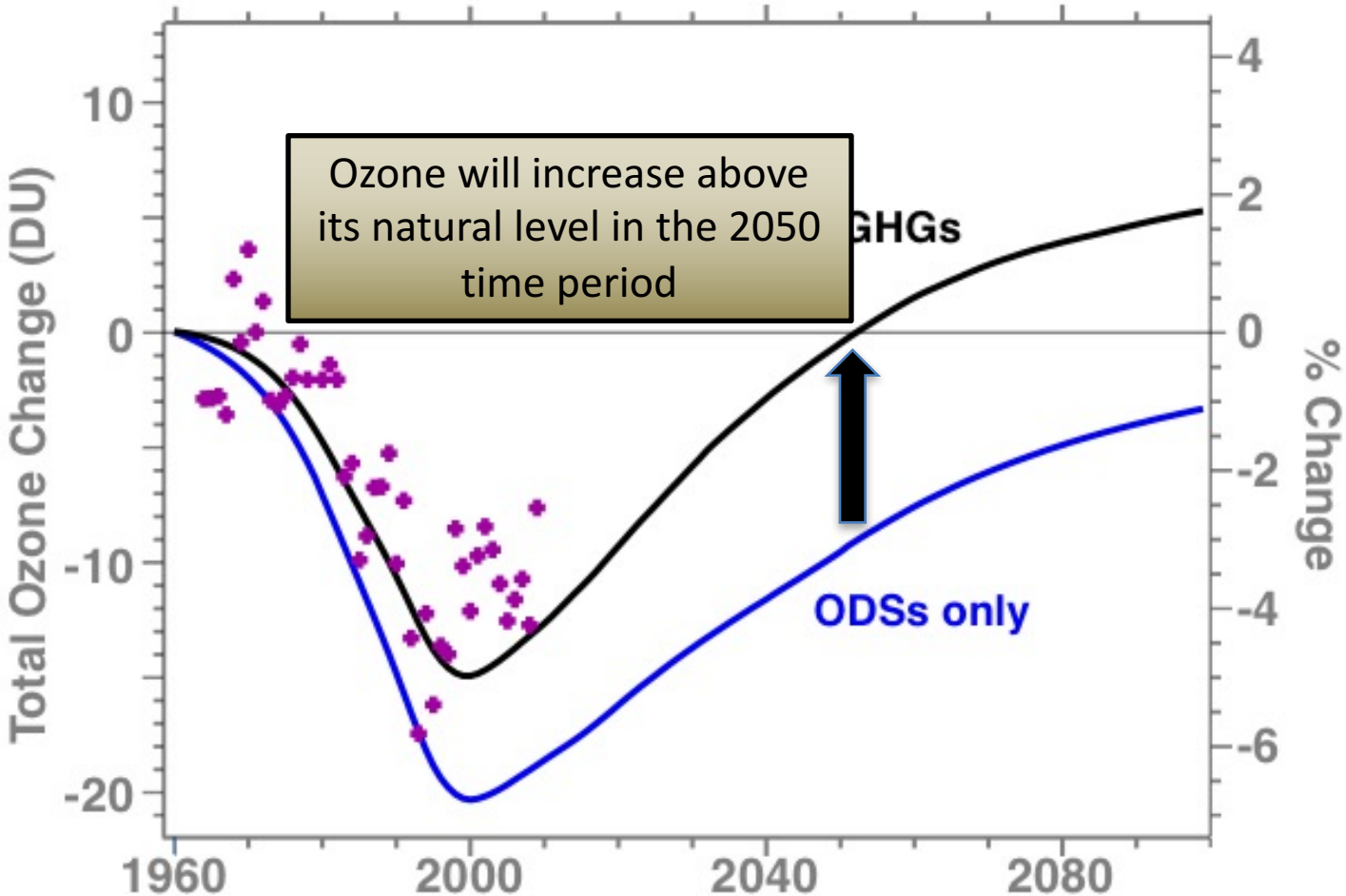
GHGs lessened ozone depletion



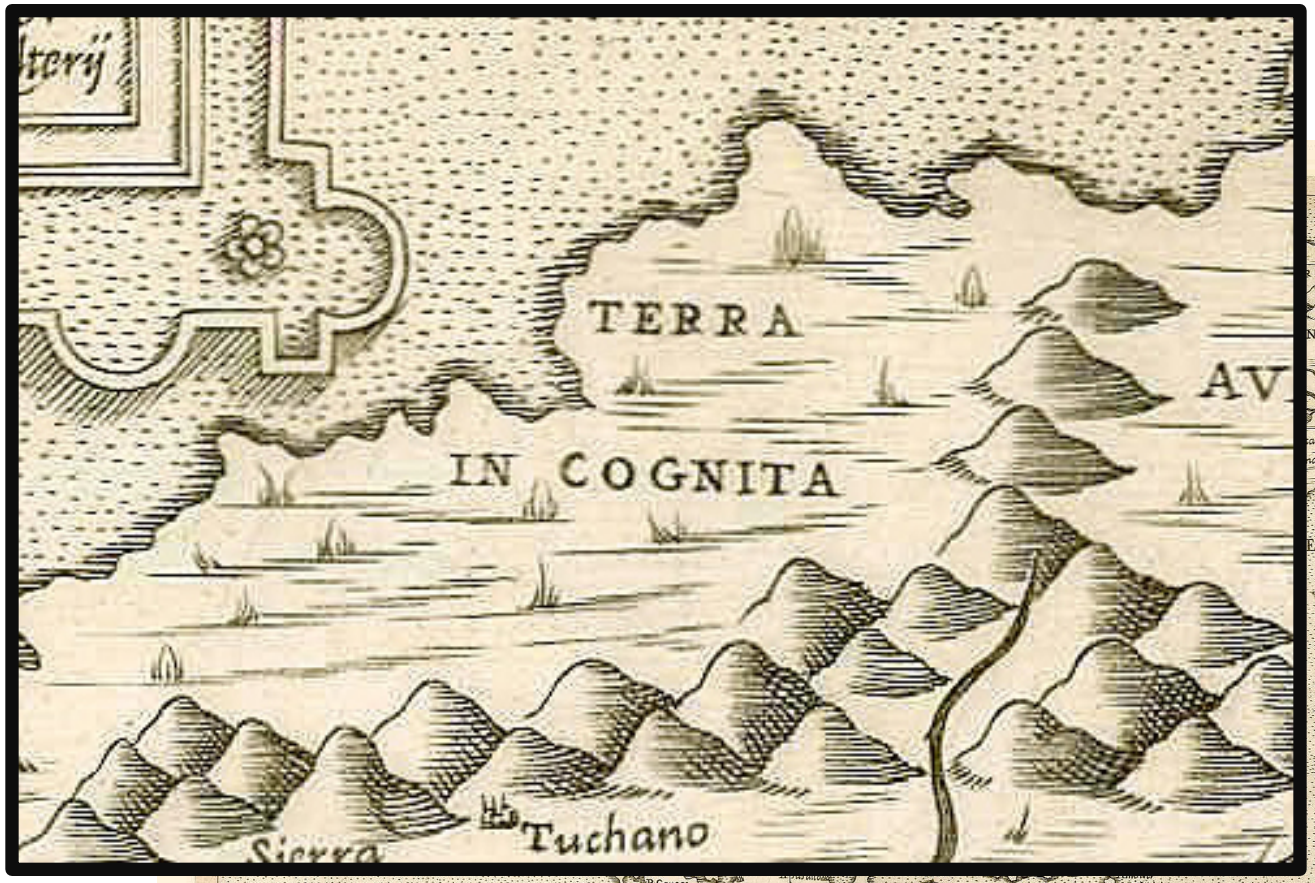
The impact of ODSs will be with us into the 22nd Century



CO_2 acts to increase global ozone

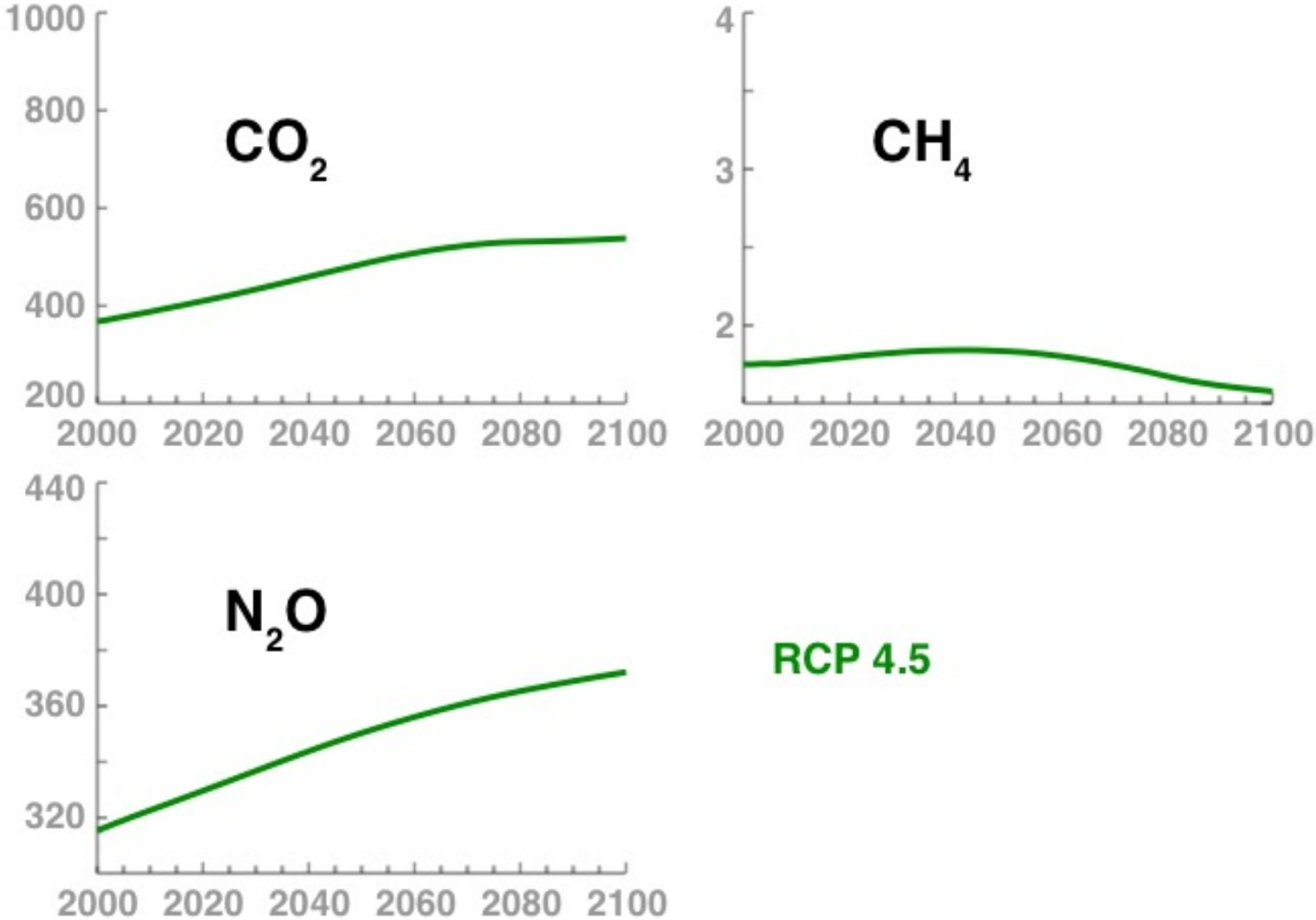


North America map (1566) published Forlani

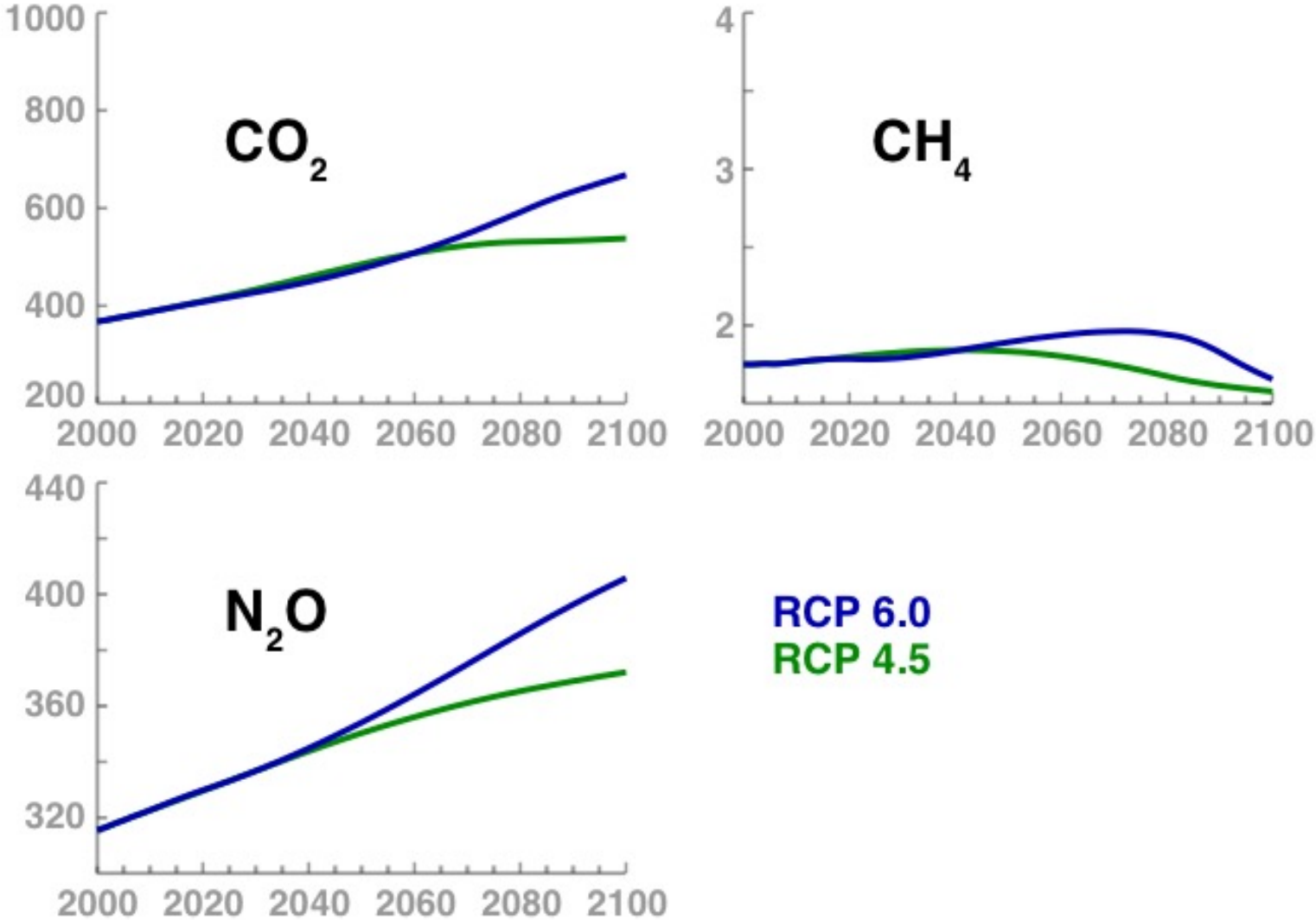


If GHGs are so important, then where are they headed, and what will happen to ozone?

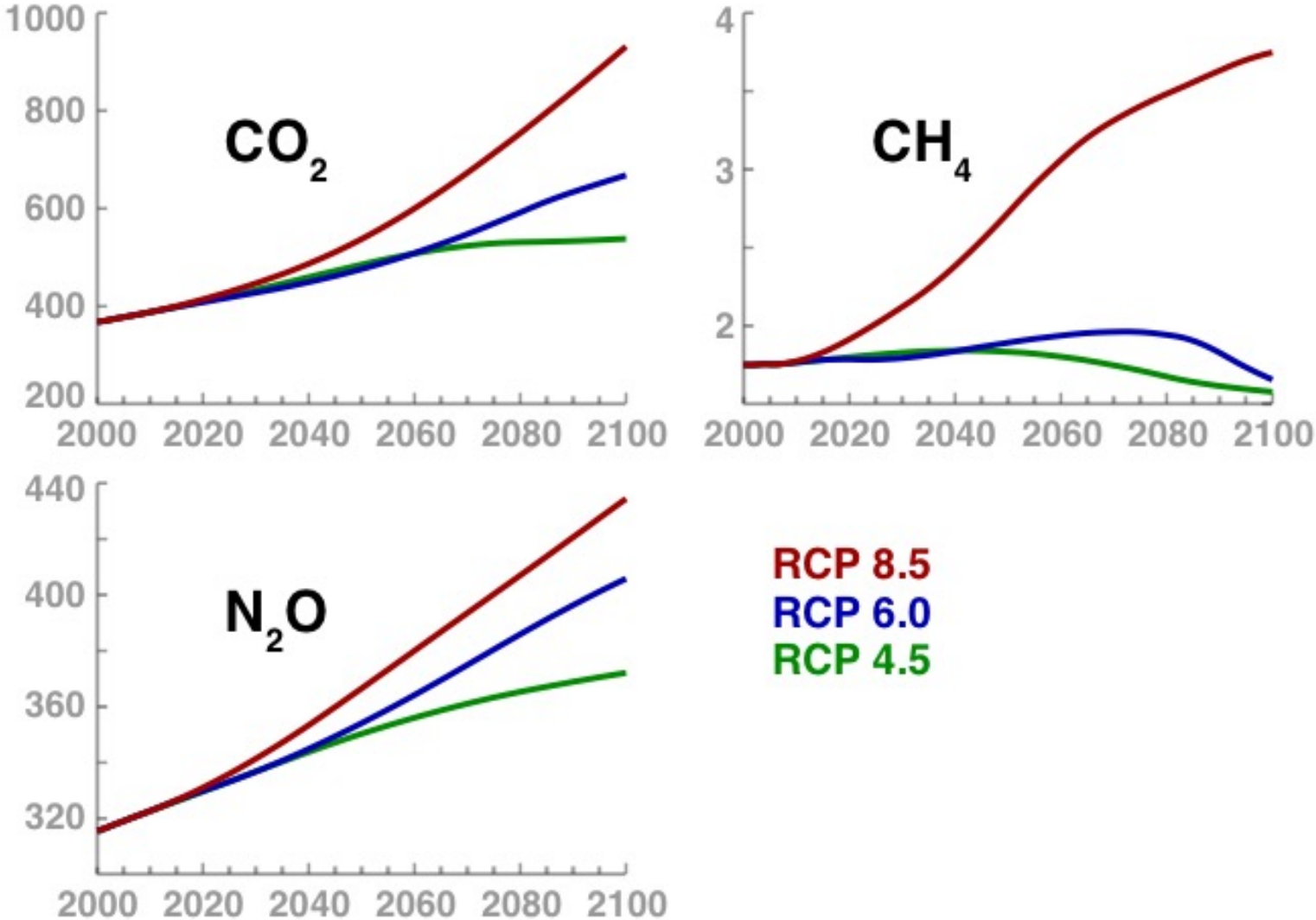
What is the trajectory for GHGs? 4.5 W/m^2



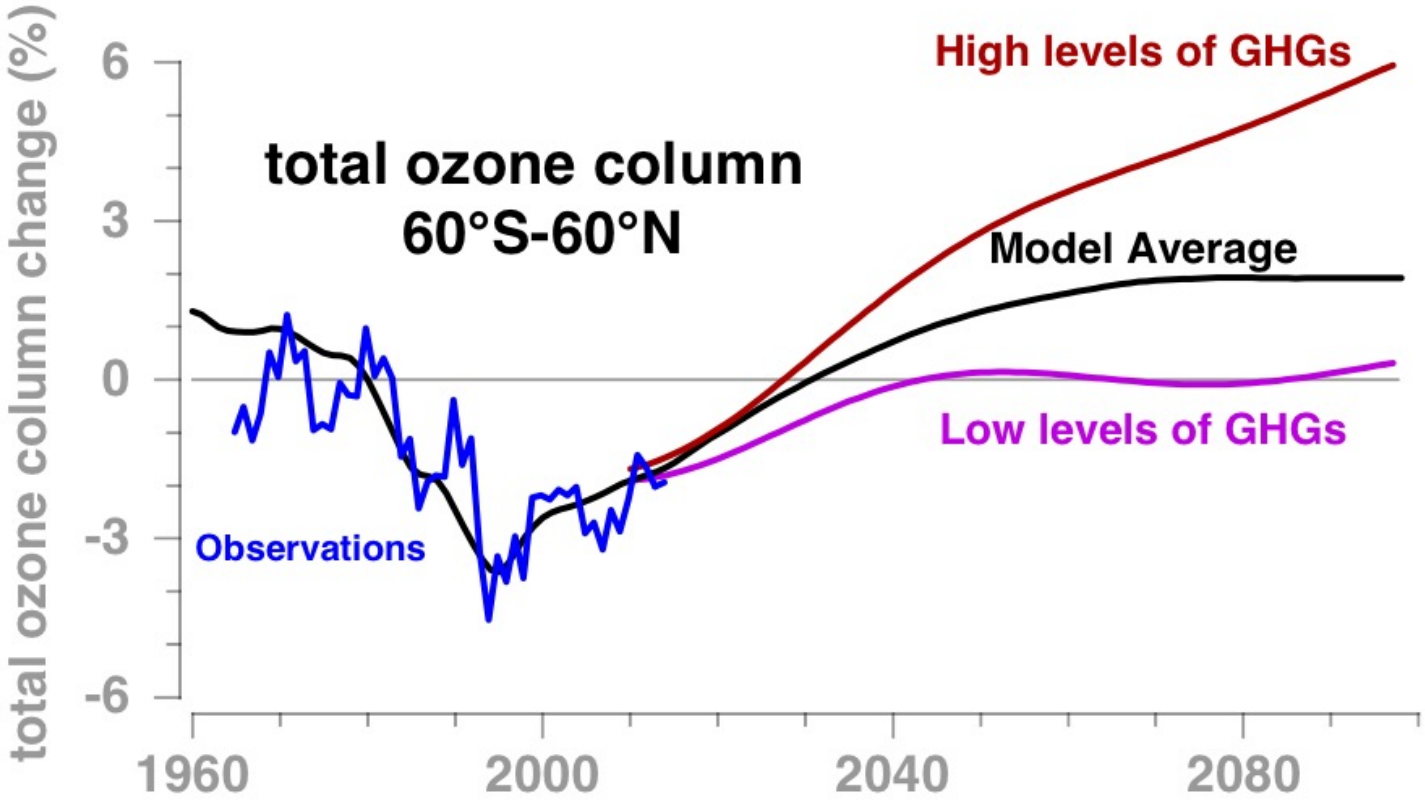
What is the trajectory for GHGs? 6.0 W/m^2



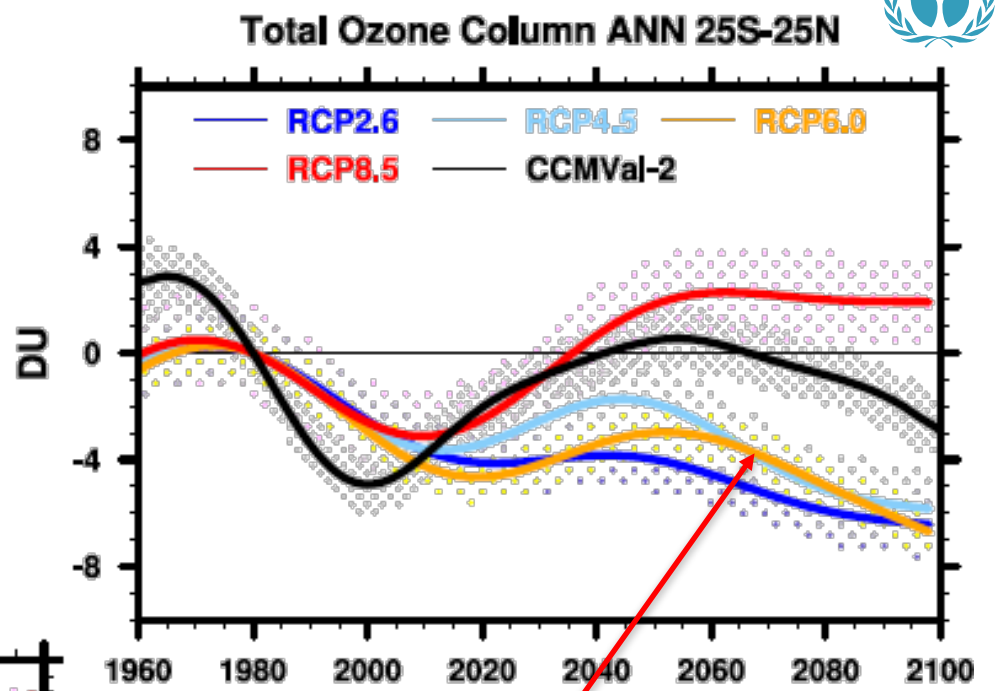
What is the trajectory for GHGs? 8.5 W/m^2

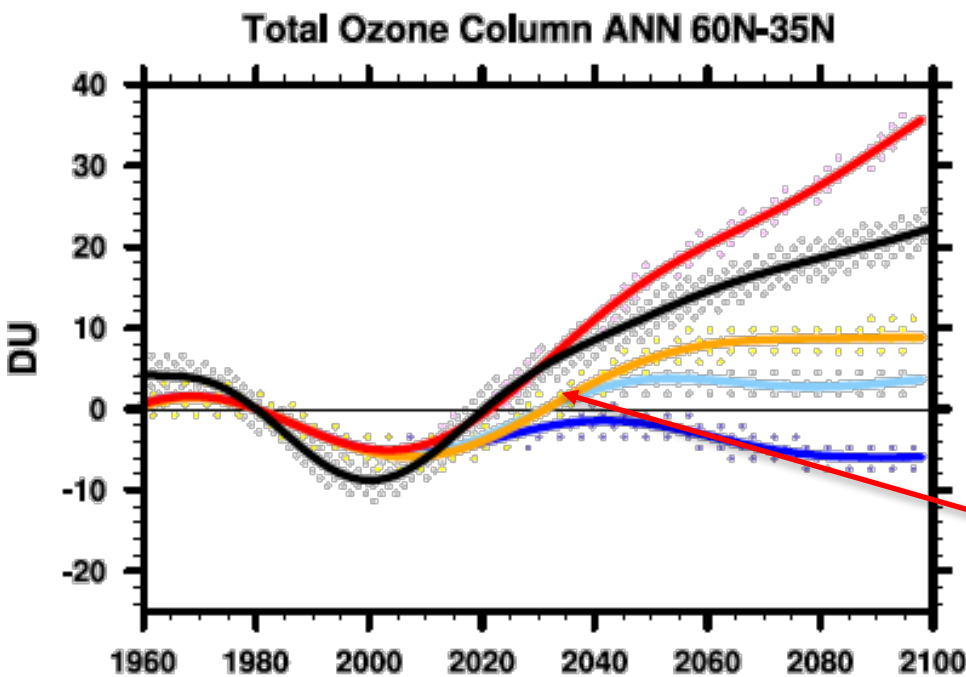


Future ozone will largely depend on the atmospheric abundances of GHGs



Ozone through the 21st century





Will tropical ozone decline?

Are we on our way to "super recovery"?

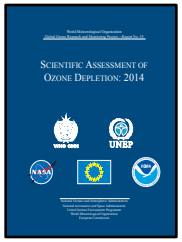


Figure 2-23. WMO/UNEP [2014]. Adopted from Eyring et al. [2013].

Ozone bottom line

- As ODSs decline, the evolution of the ozone layer in the 2nd half of the 21st century will large
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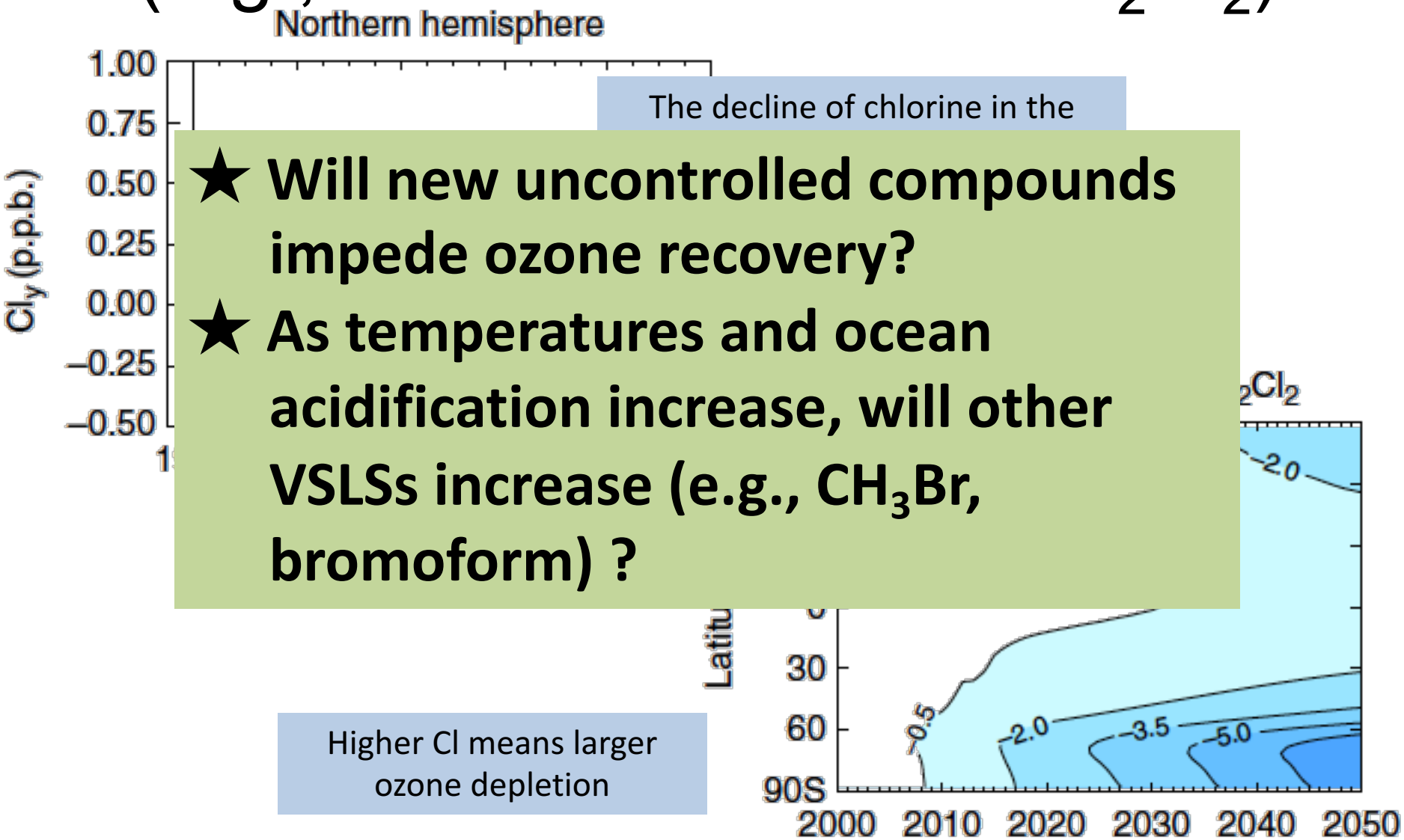
- The Antarctic ozone hole is less sensitive to CO_2, N_2O, and CH_4 abundances, and the hole ought to be recovered to 1980 levels in the 2070 time frame

★ **Where is ozone headed by the end of the 21st century, and does this have policy implications?**

Our biggest science uncertainty?

Man, technology, and politics

Very short lived substances (e.g., dichloromethane - CH_2Cl_2)



The decline of chlorine in the

★ **Will new uncontrolled compounds impede ozone recovery?**

★ **As temperatures and ocean acidification increase, will other VSLSs increase (e.g., CH_3Br, bromoform) ?**

Higher Cl means larger ozone depletion

Rockets

- Cryogenic rocket engines using liquid oxygen ar[illegible]de.
- S[illegible] hy[illegible]^3) ar[illegible]ne cr[illegible]

★ **Who is the controlling authority on rockets?**

★ **What are the emissions that could be controlled? HCl, aerosols, H_2O, …**

- Current column ozone losses from rockets are small (~0.03%, Ross et al., 2009), but the private rocket industry is rapidly expanding and projections are difficult

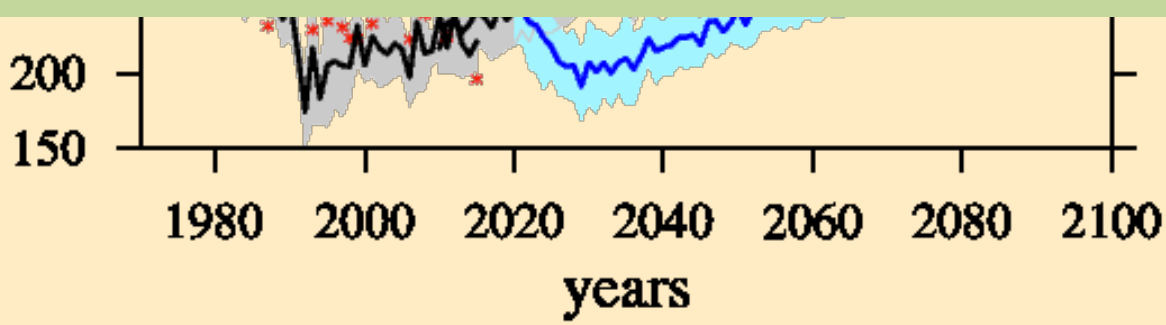
Geoengineering

- Dramatic consequences for O_3 with very la
oz

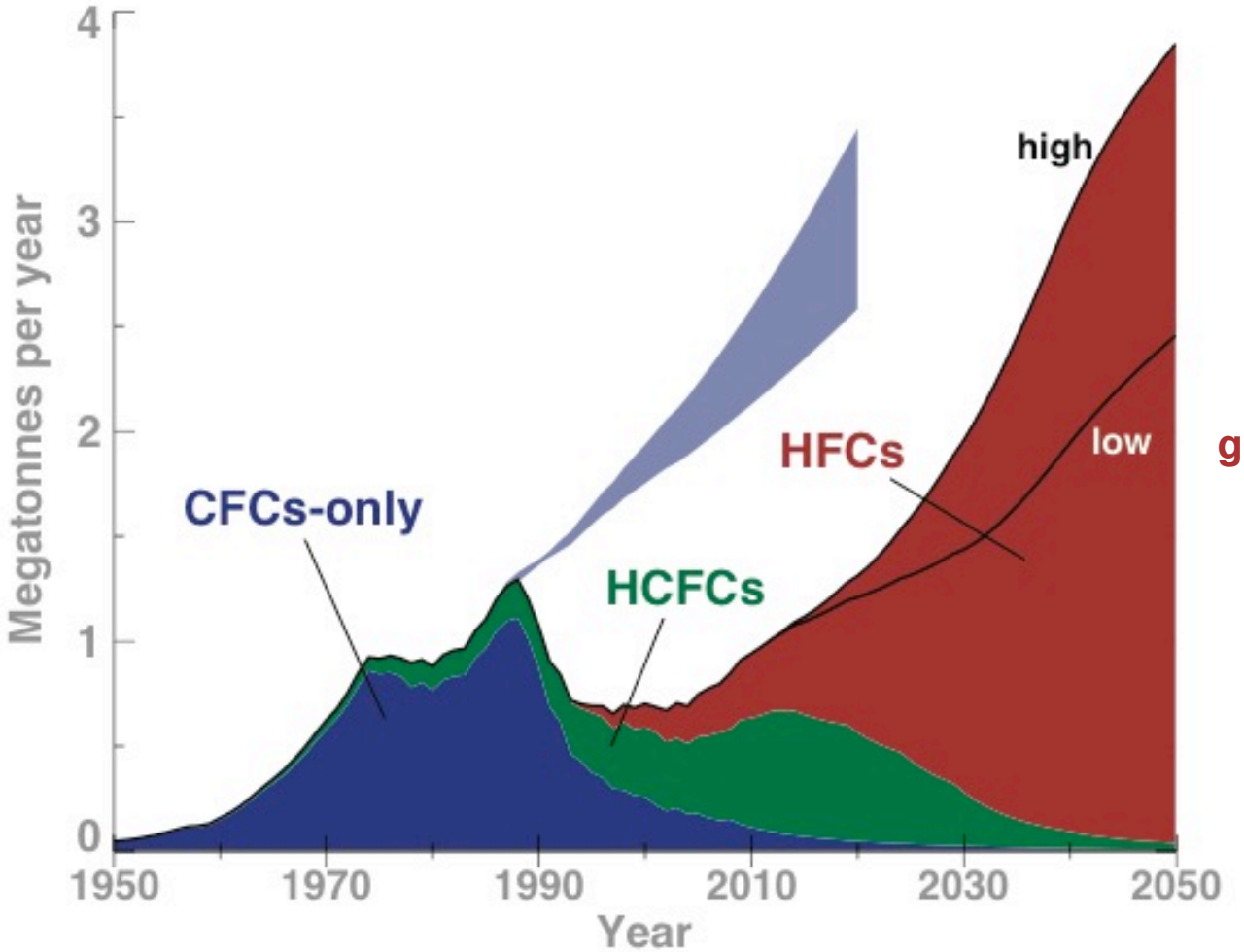
★ **Deliberate injection of particles and other non-ODS gases is not controlled**

★ **What are the these substances, and what is their outcome?**

★ **Who's in charge?**



Hydrofluorocarbons (HFCs) are being introduced to replace HCFCs for a variety of commercial and domestic applications



HFC projected growth after 2009

Figure 5-06, panel a, Scientific Assessment of Ozone Depletion: 2010

HFCs are the grandchildren of the CFCs, since they were created as replacements for HCFCs and CFCs

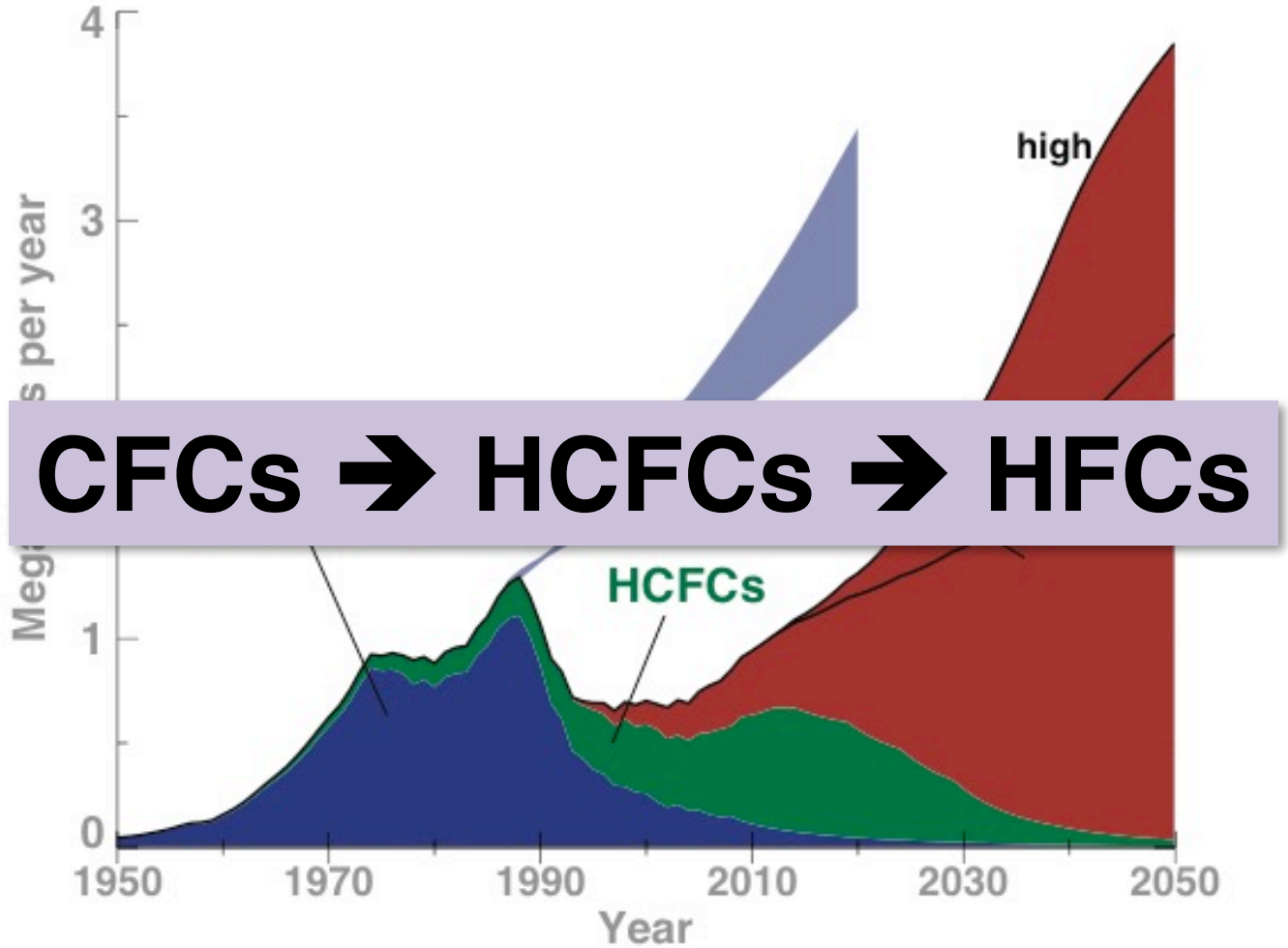
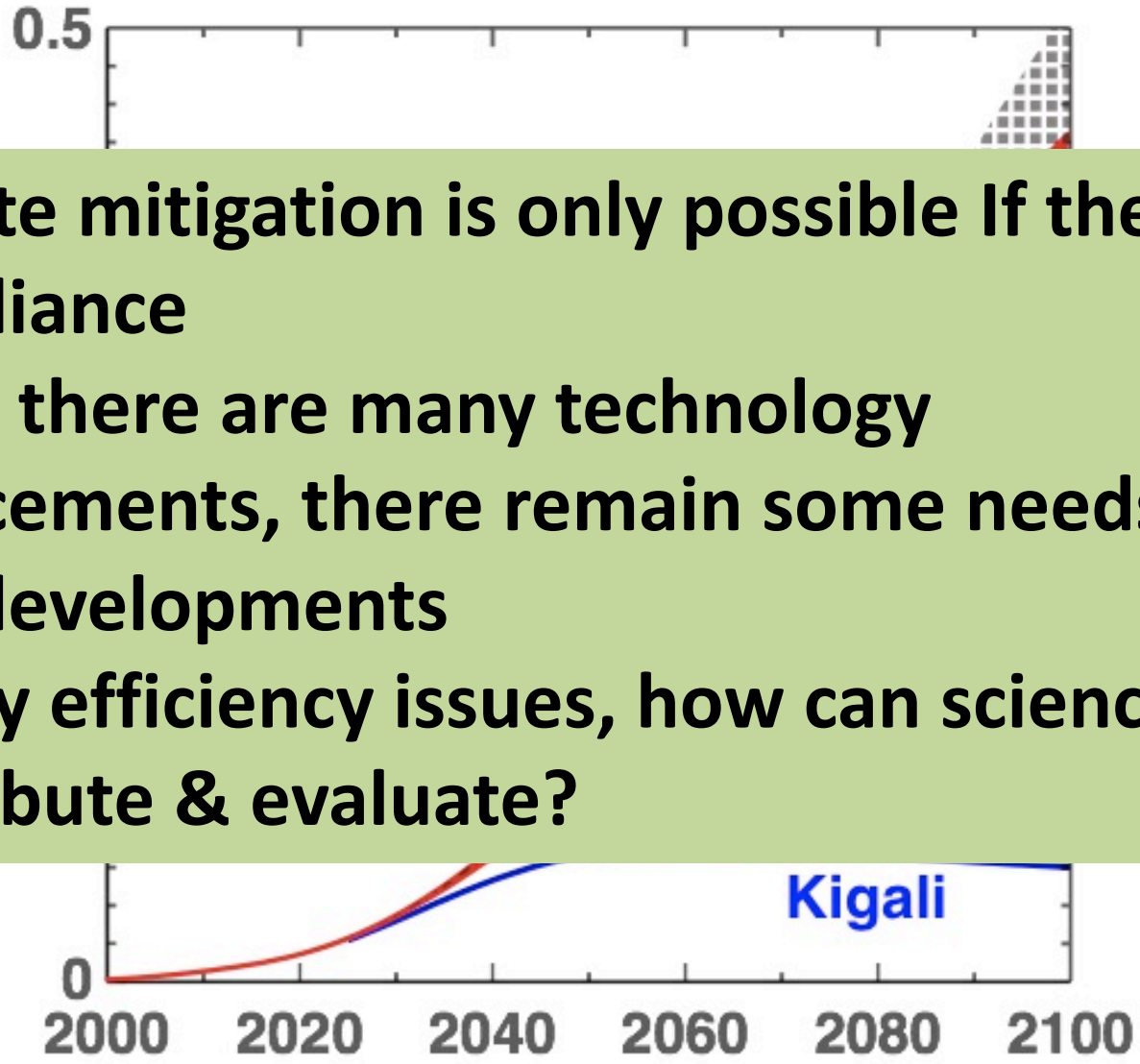


Figure 5-06, panel a, Scientific Assessment of Ozone Depletion: 2010

In October 2016, the world's nations added the Kigali Amendment to the Montreal Protocol to control HFCs

Climate change will be mitigated by about 0.25-0.5 K by 2100



- ★ Climate mitigation is only possible If there is compliance
- ★ While there are many technology replacements, there remain some needs for new developments
- ★ Energy efficiency issues, how can science contribute & evaluate?

Various fluorinated compounds are building up in the atmosphere

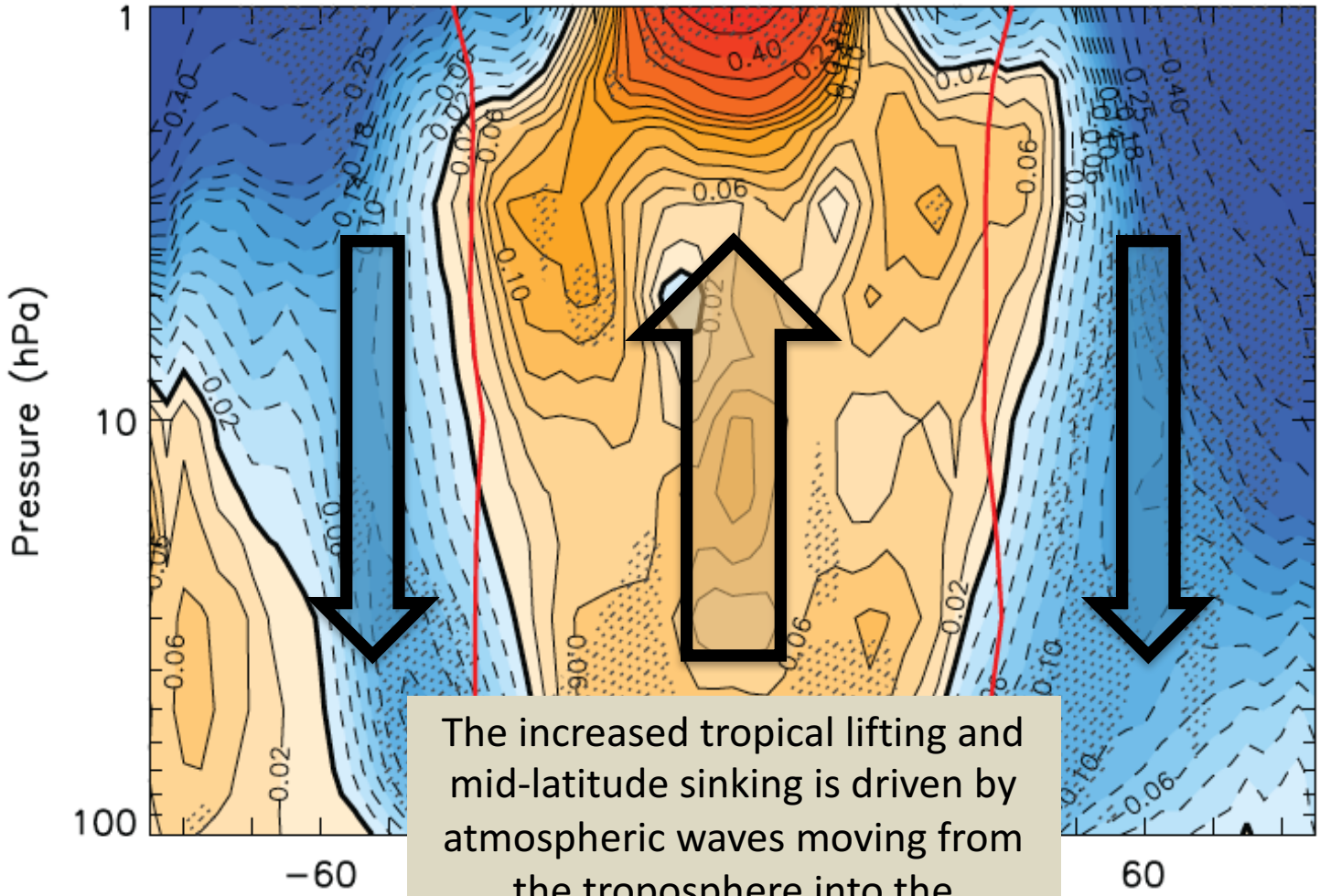
★ **The perfluorocarbons are currently at very low levels, and are therefore weak radiative forcing agents. Will they eventually need to be dealt with as their levels continue to increase?**

Formula	Life	100-y GWP
SF6	3,200	23,500
SO_2F_2	36	6,690
NF_3	500	16,100
CF_4	50,000	6,630

Uncertainties on Chem, rad, dyn

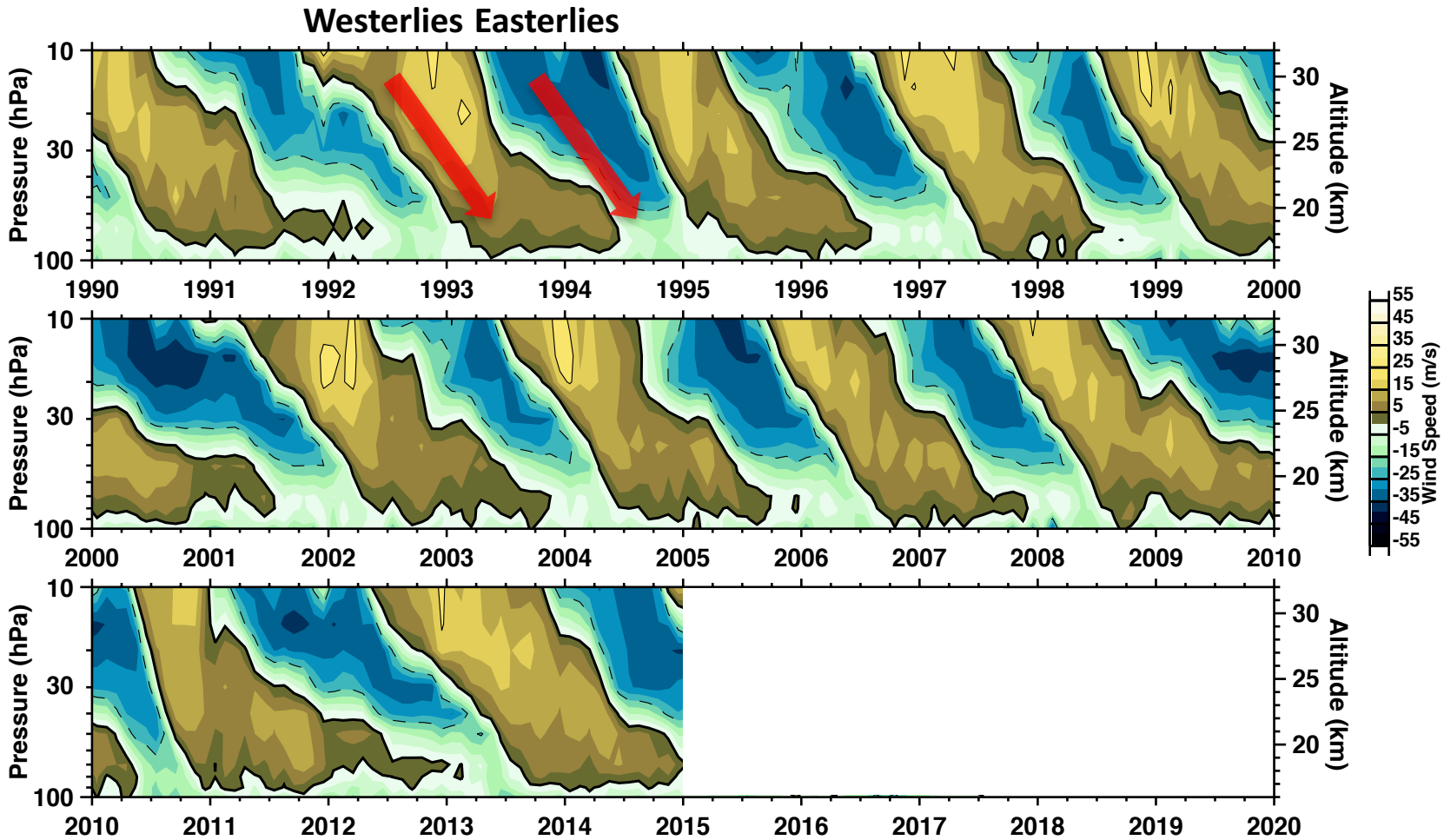
- Sources & sinks of ODSs and GHGs lead to:
  - ΔCl, ΔBr, ΔNO, ΔHO → ΔO_3, well understood
  - ΔGHGs, ΔO_3, ΔH_2O, ΔAerosol → ΔT, reasonably well understood
  - ΔSulfur → ΔAerosol: not well understood
- Dynamical changes:
  - Convection (tropical and extra-tropics)
  - Forcing of large scale waves
  - Brewer-Dobson circulation increase

Models project the Brewer-Dobson circulation of the stratosphere will accelerate because of climate forcing

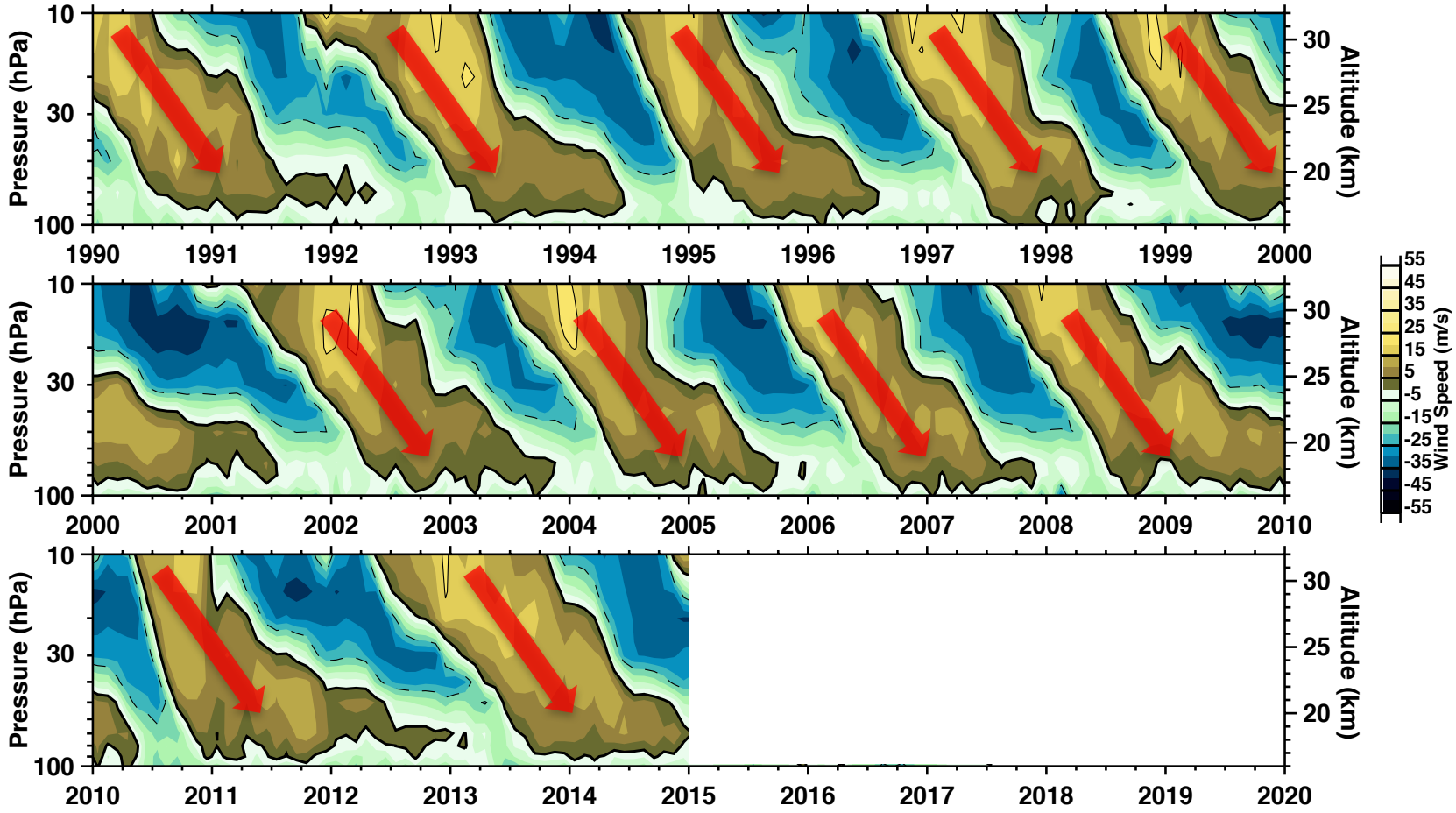


The increased tropical lifting and mid-latitude sinking is driven by atmospheric waves moving from the troposphere into the stratosphere

The **quasi-biennial oscillation (QBO)** is a tropical lower stratospheric, downward propagating zonal wind variation, with an average period of ~28 months



The QBO is the ”old faithful” of the stratosphere, regularly recurring on an ~28 month period



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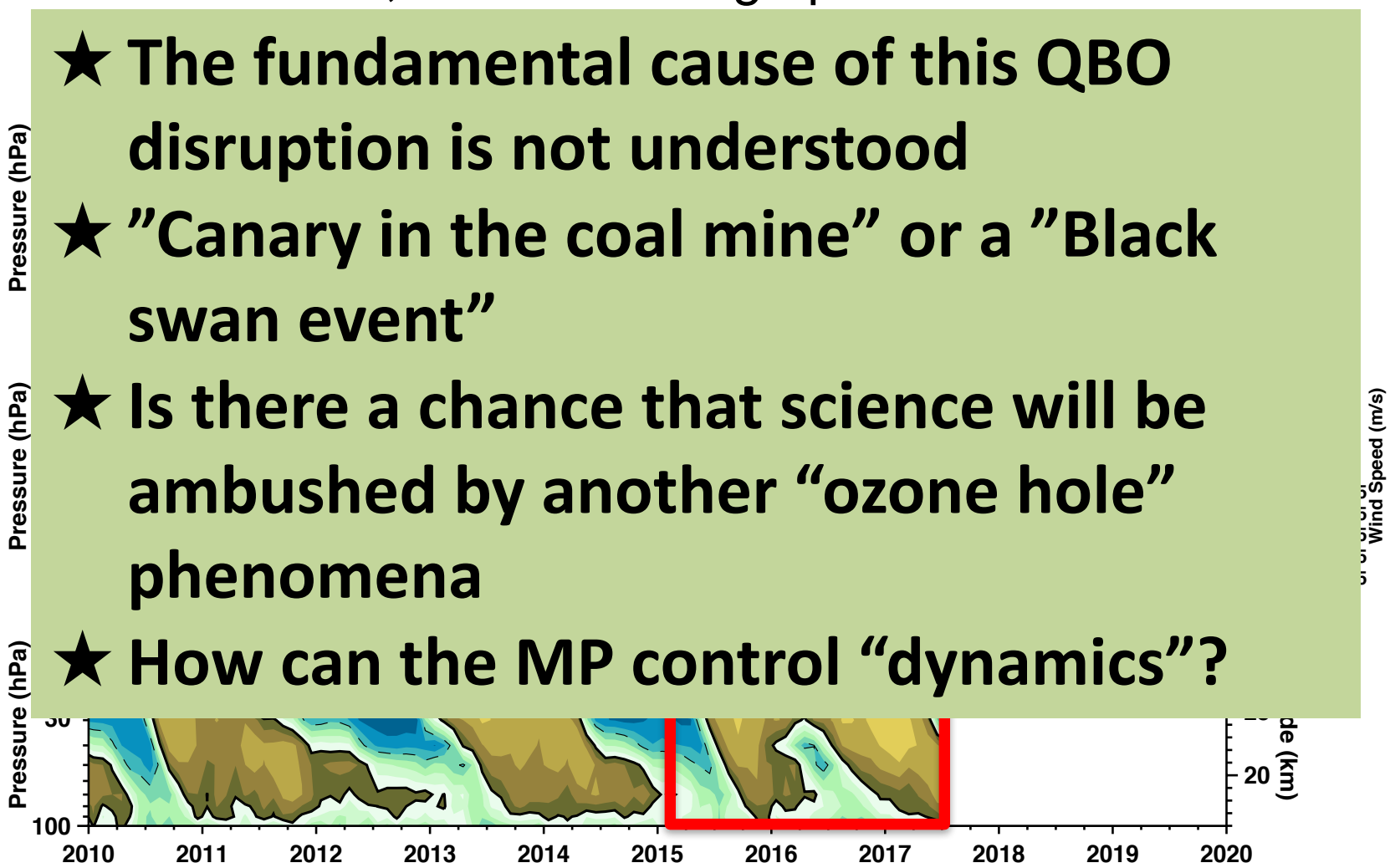
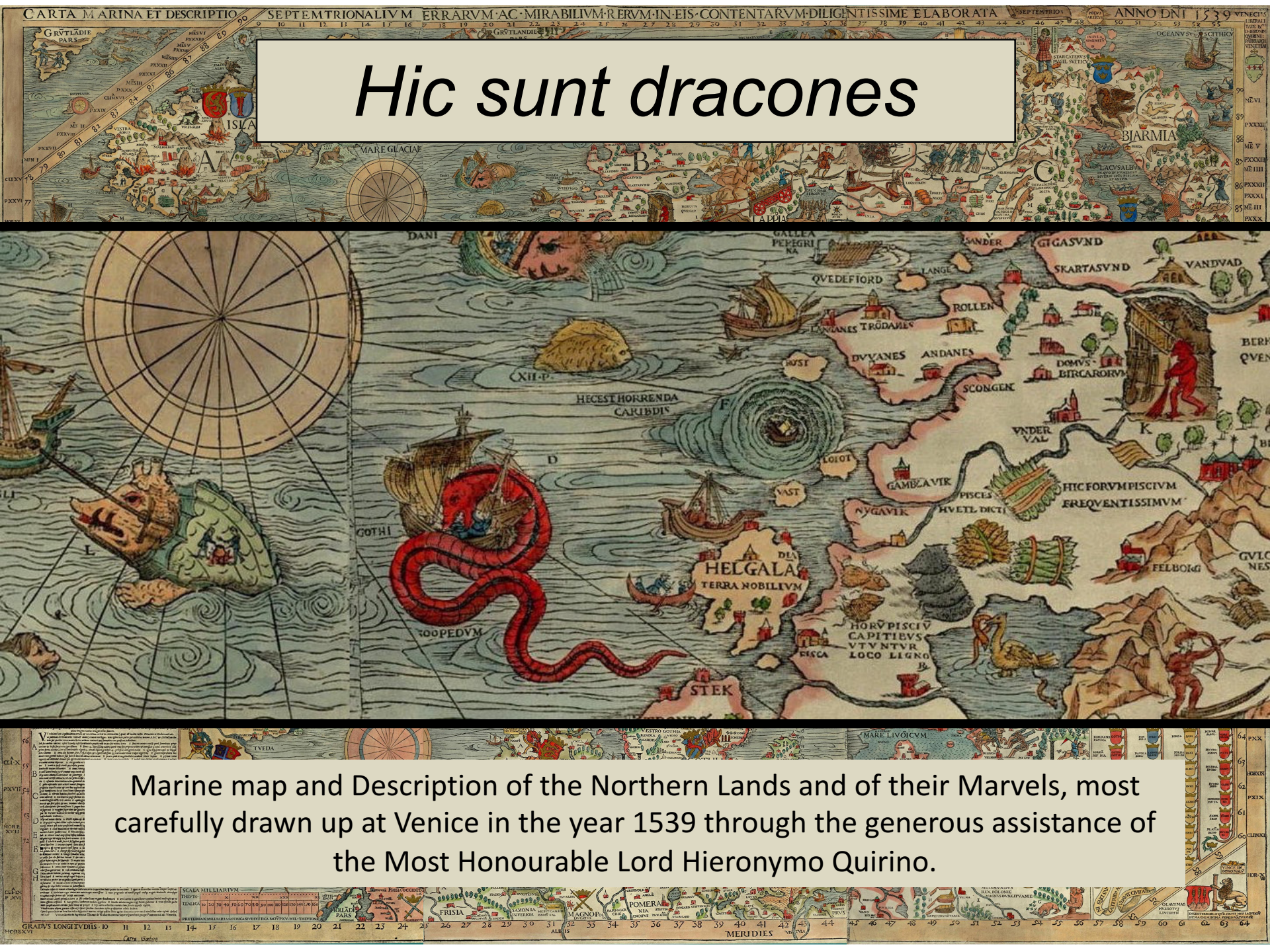
- ★ **The fundamental cause of this QBO disruption is not understood**
- ★ **”Canary in the coal mine” or a ”Black swan event”**
- ★ **Is there a chance that science will be ambushed by another “ozone hole” phenomena**
- ★ **How can the MP control “dynamics”?**



Hic sunt dracones



Marine map and Description of the Northern Lands and of their Marvels, most carefully drawn up at Venice in the year 1539 through the generous assistance of the Most Honourable Lord Hieronymo Quirino.

The End