



Description of Assessment Exercises in Support of WMO

Douglas Kinnison

¹Atmospheric Chemistry Observations and Modeling (ACOM) Laboratory

NSF National Center for Atmospheric Research (NCAR)

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Group Meeting
Boulder Co.
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Outline

WMO Scientific Assessment of Ozone Depletion: 2026

- Atmospheric Processes And their Role in Climate (APARC) Scenarios for Very Short-lived Halogens
- APARC Scenarios for Ozone Return Date

Model Version: CESM2 (WACCM6)

International Ozone Assessments have a 40-year history of policy impacts

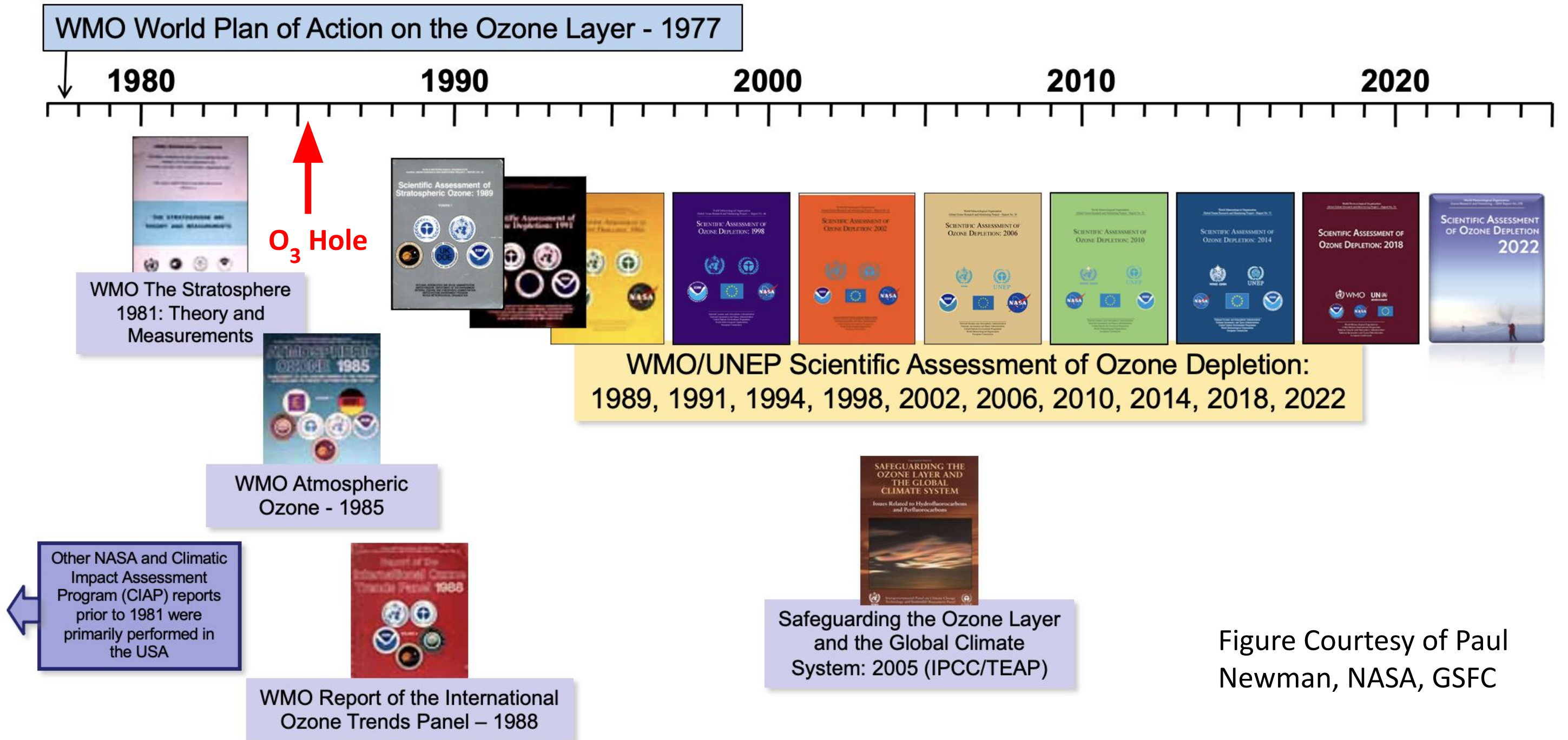
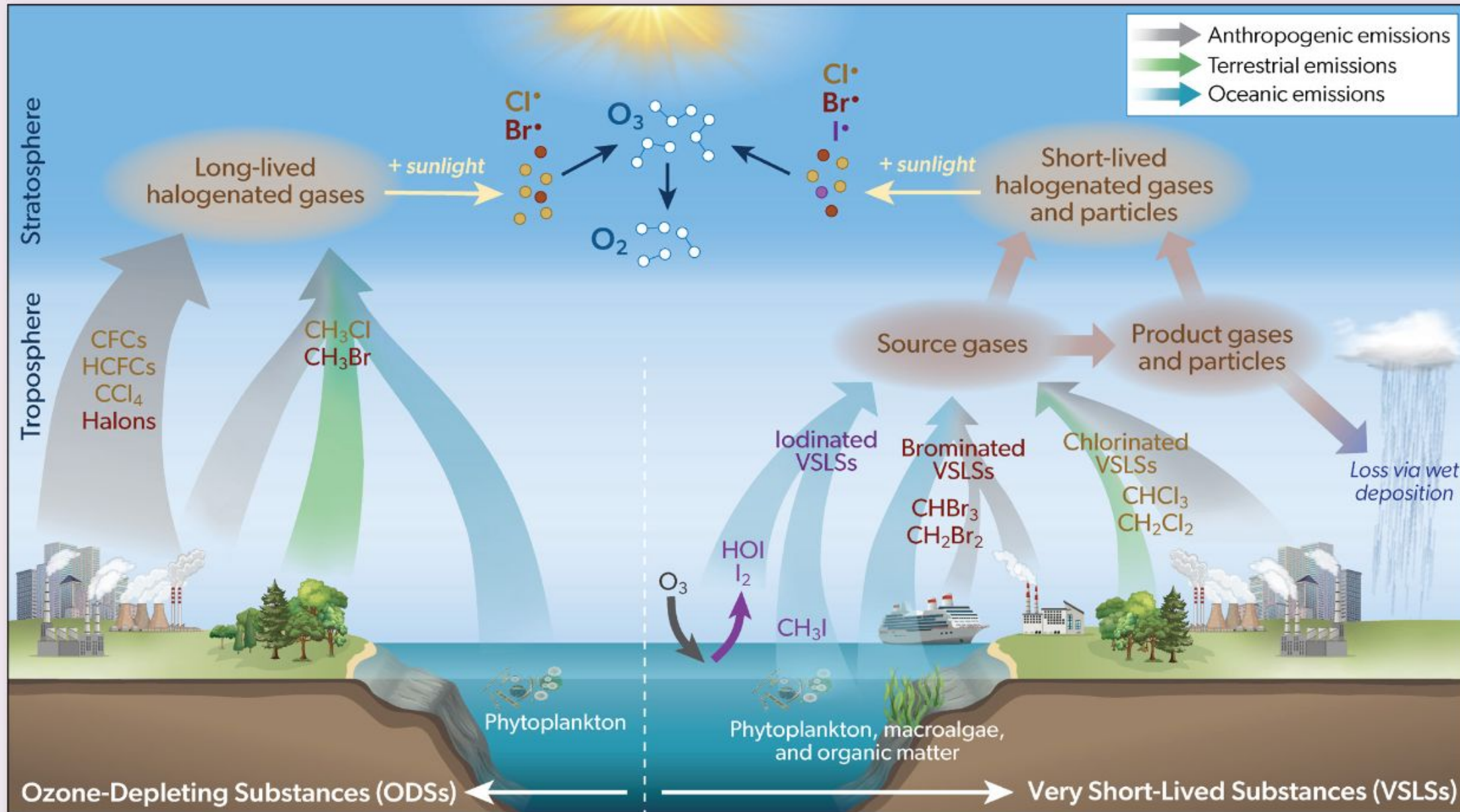


Figure Courtesy of Paul Newman, NASA, GSFC

APARC Very-Short Lived Substances (VSLs) Assessment



Box 1-3 Figure 1. Schematic of long-lived ozone-depleting substances (ODSs) and halogenated very short-lived substances (VSLs).

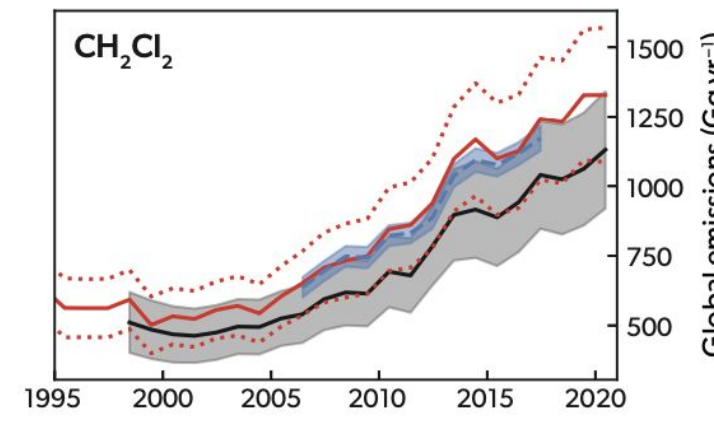
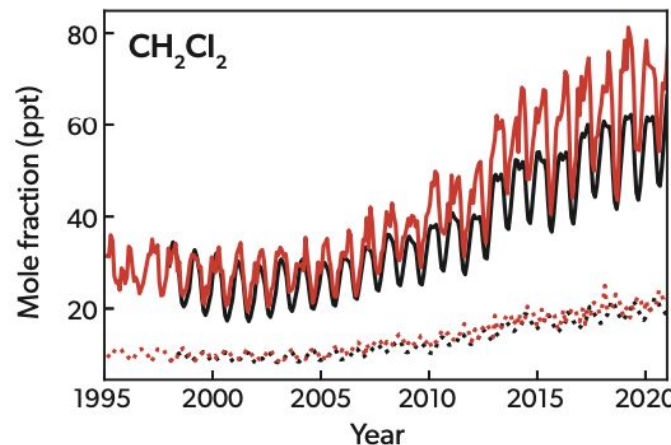
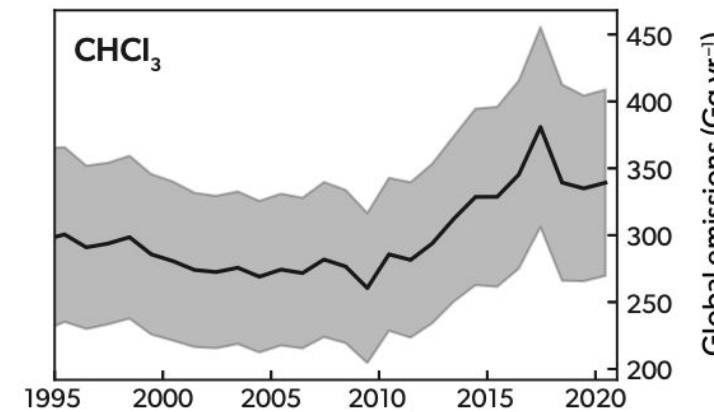
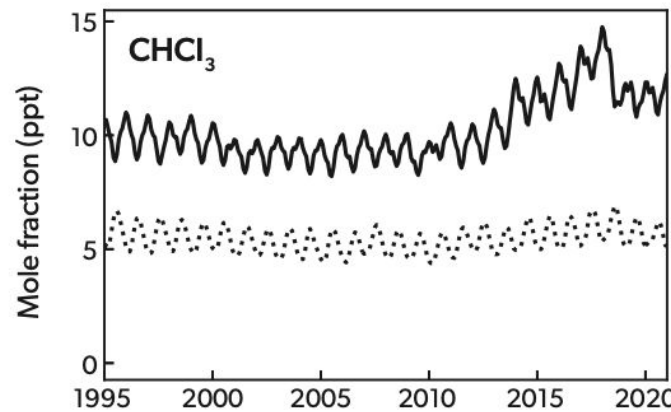
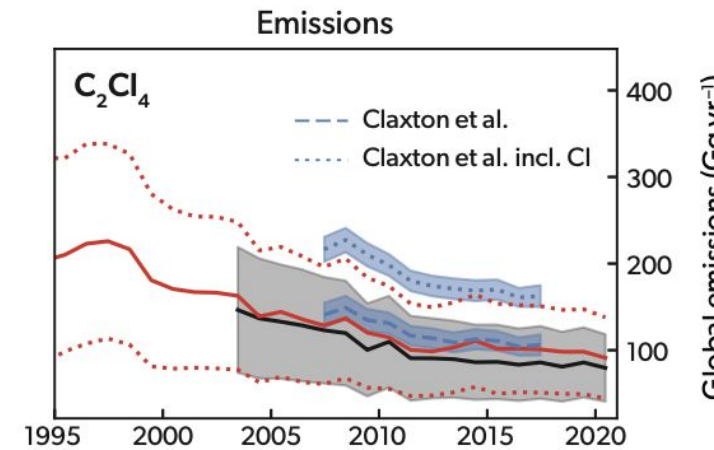
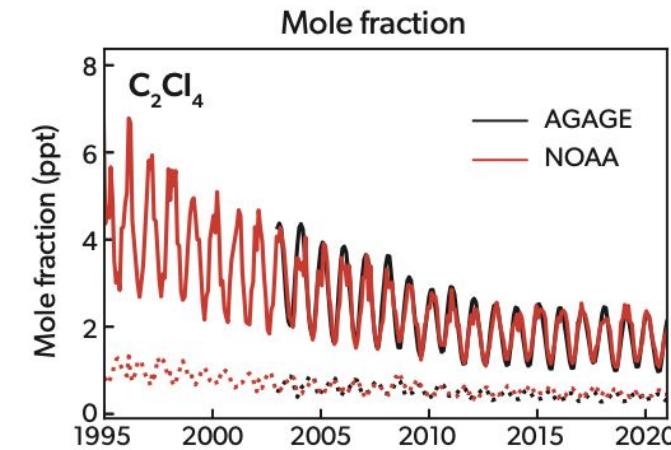
Hemispherical Differences of Most Abundance CI-VSLS

WMO-2022
Chapter 1

Left Column
derived from
observations

Solid lines are NH

Dotted lines are SH



Tetrachloroethene
(C_2Cl_4)
LT = 109 days (66-245 days)

Choroform
($CHCl_3$)
LT = 178 days (97-1145 days)

Dichloromethane
(CH_2Cl_2)
LT = 176 days (95-1070 days)

CI-VSLS differ regionally with the longest lifetimes at high latitudes and altitudes

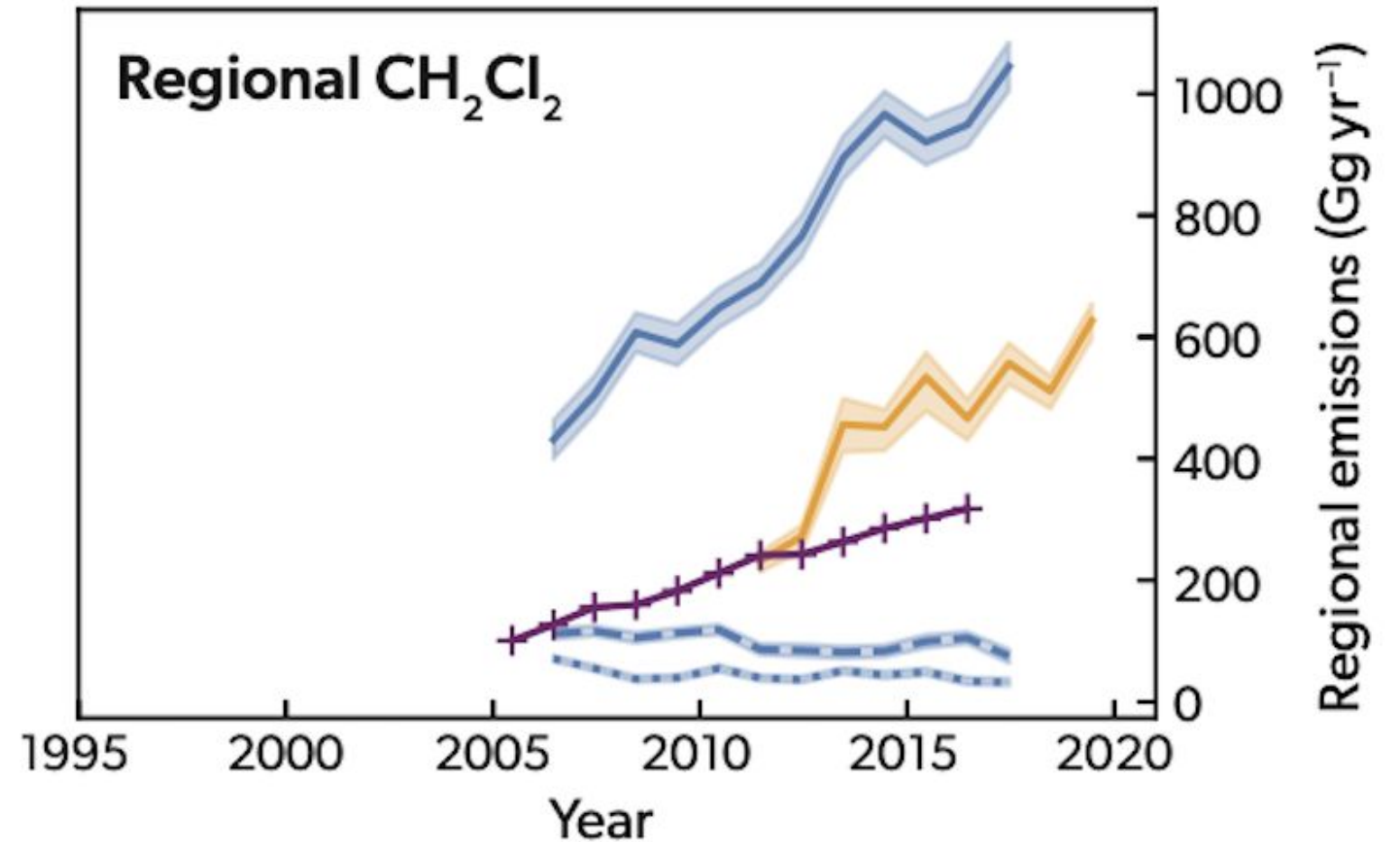
Regional Differences

WMO-2022
Chapter 1

Left Column
derived from
observations

Solid lines are NH

Dotted lines are SH



CAM-Chem6 with VSLs recent study

Behrooz Roozitalab et al., Measurements and Modeling of the Interhemispheric Differences of Atmospheric Chlorinate Very Short-Lived Substances, *Journal of Geophysical Research: Atmospheres*, 129, e2023JD039518. <https://doi.org/10.1029/2023JD039518>

[org/10.1029/2023JD039518](https://doi.org/10.1029/2023JD039518)

Primary Objectives

- Assess the impact of industry-related emissions of chlorinated VSLs on stratospheric ozone.
- Assess new metrics (including integrated ozone depletion (IOD) and stratospheric ozone depletion potential (SODP)) for evaluation of the impact of VSLs on ozone depletion.
- Evaluate the impact of VSLs on long-term trends (past and future) in lower stratospheric ozone. “future will not be the first priority”

Assessment Organizers:

**Ryan Hossaini (UK), Martyn Chipperfield (UK),
Lucy Carpenter (UK), Doug Kinnison (USA), and Susann Tegtmeirer (Canada)**

Scenarios / Deliverables

- A set of community model simulations for:
 - (i) 1990s to 2022 and (with and without VSLS) using Nudged Meteorology (2-sims)
 - (ii) A set of Ozone Depletion Potential (ODP) Simulations will also be requested (4 species x 3 regional emissions scenarios = 12 sims).

$$\text{ODPx} = \text{delta TCO due unit emission of X} / \text{delta TCO to unit emission of CFC-11}$$

- First multi-model assessment of ozone and halogen changes due to VSLS.
- Evaluation of metrics for VSLS impacts on ozone.
- Peer-reviewed publications based on multi-model assessments of (i)

Activity Timeline

- **Jan-Feb 2025:** Window for expression of interest open
[Alfonso Saiz-Lopez Group (CSIC, Spain), Rafa Fernandez (ICB-CONICET, Argentina), & Multiple NCAR-ACOM Scientists will contribute the CESM2 (WACCM6) effort]
- **Late Feb 2025:** Virtual Workshop - Protocol finalized.
- **Mar 2025 to Sept 2025:** Model runs initiated, completed & submitted to CEDA Archive
- **Sept** – Analysis and preparation of publications

APARC Ozone Return Date Simulations in Support of WMO-2026

World Meteorological Organization
Ozone Research and Monitoring – GAW Report No. 278

SCIENTIFIC ASSESSMENT OF OZONE DEPLETION 2022



- **Scenario Uncertainty:** Impact of Chlorine and Bromine (EESC) forecast
- **Structural Uncertainty:** Important to have a good representation of Model Dynamics, Temperature, and Chemistry
- **Internal Variability:** Need for multiple realizations (Variability)

WMO 2026: SPARC REFD2 Assessment Status



Model simulations in the CEDA archive – April, 2024

Institute-Model	refD1 hindcast	refD2 ssp245	senD2-sai ssp245	senD2-ssp 126	senD2-ssp 370
CSIRO-ACCESS	3	1			
ECCC-CMAM	5	3	3		
DLR-EMAC	1	3			
GSFC-GEOSCCM	1				
NIES-MIROC32	3	1		1	1
JAMSTEC-MIROC-ES2H		3	3		
CNRM-MOCAGE	4*	4*	4*		
NIWA-UKCA2	3	3	3	3	3
IPSL-REPROBUS	1				
ETH-SOCOL	3				
NCAS-UKESM1	3				
NCAR-WACCM	4	3	3	?	?

Simulations submitted since January 2022

Simulations submitted since June 2023

* multiple simulations using combinations of different forcings and physics with the same meteorology

Table Courtesy of David Plummer

REFD2: 17 realizations (6-models)

Uses the Halogen Forecast from CCMI-2022

Equivalent Effective Stratospheric Chlorine (Engel et al., 2018)

EESC return dates in blue

CCMVal-2 (RD 2065)
WMO 2010

CCMI-2022 (RD 2075)
WMO2026

CCMI-1 (RD 2070)
WMO 2018

Equivalent effective stratospheric chlorine (EESC) has been adopted as an appropriate metric to describe the **combined effects of chlorine and bromine released from halocarbons on stratospheric ozone**. The above figure is for a mean age of **5.5 years** (representative of the SH polar lower stratosphere) with an alpha factor for **bromine reactivity equal to 60**.

Figure Courtesy of David Plummer

Example: model hindcast to projection, 63-90S October

CESM2(WACCM6)

CMIP6 SSP2-45

(circa 2020)

TCO Observations

□ **SBUV-MOD**

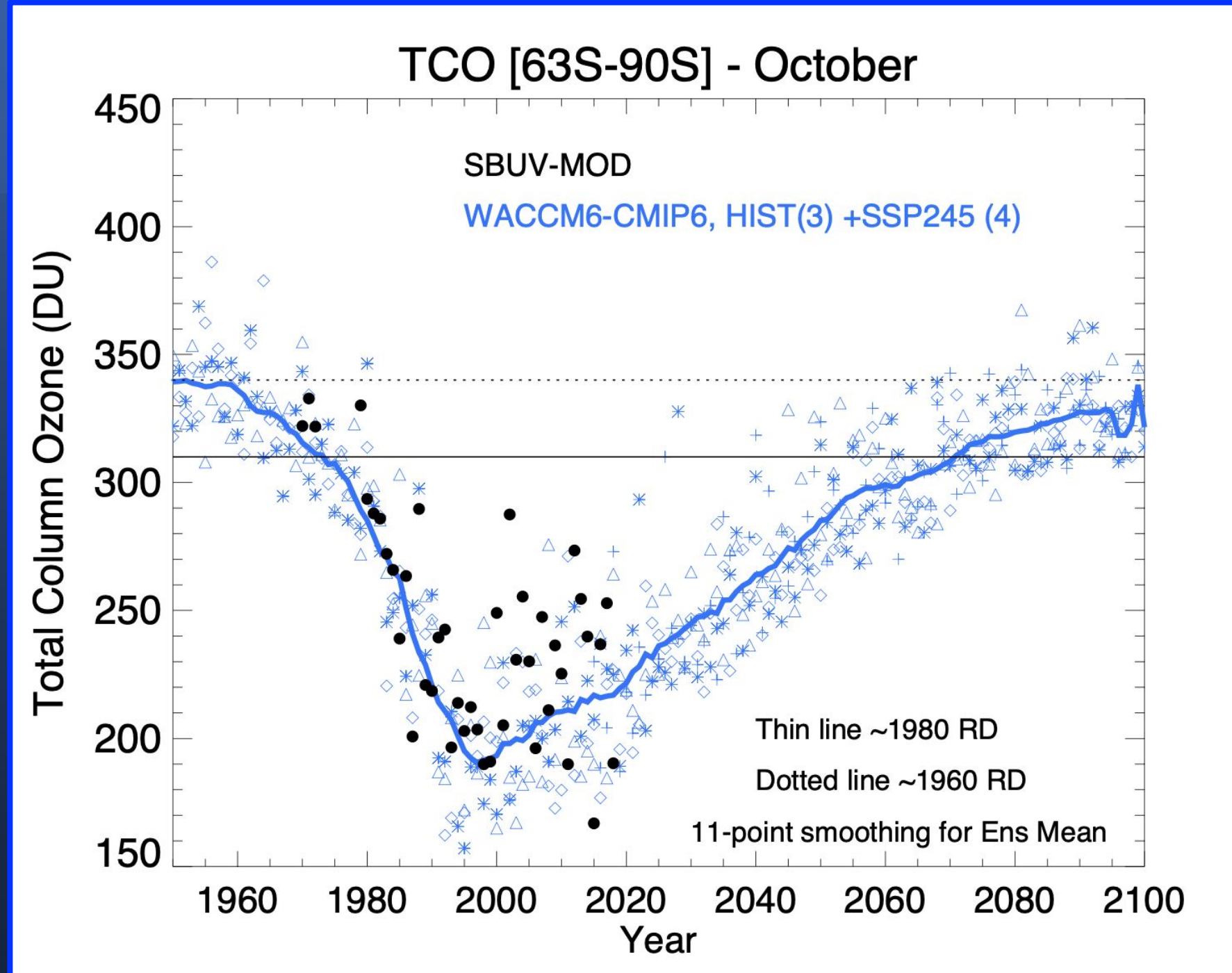
Hindcast to forecast period

□ **1850-2100**

□ **Interactive ocean**

□ **4-ensemble members**

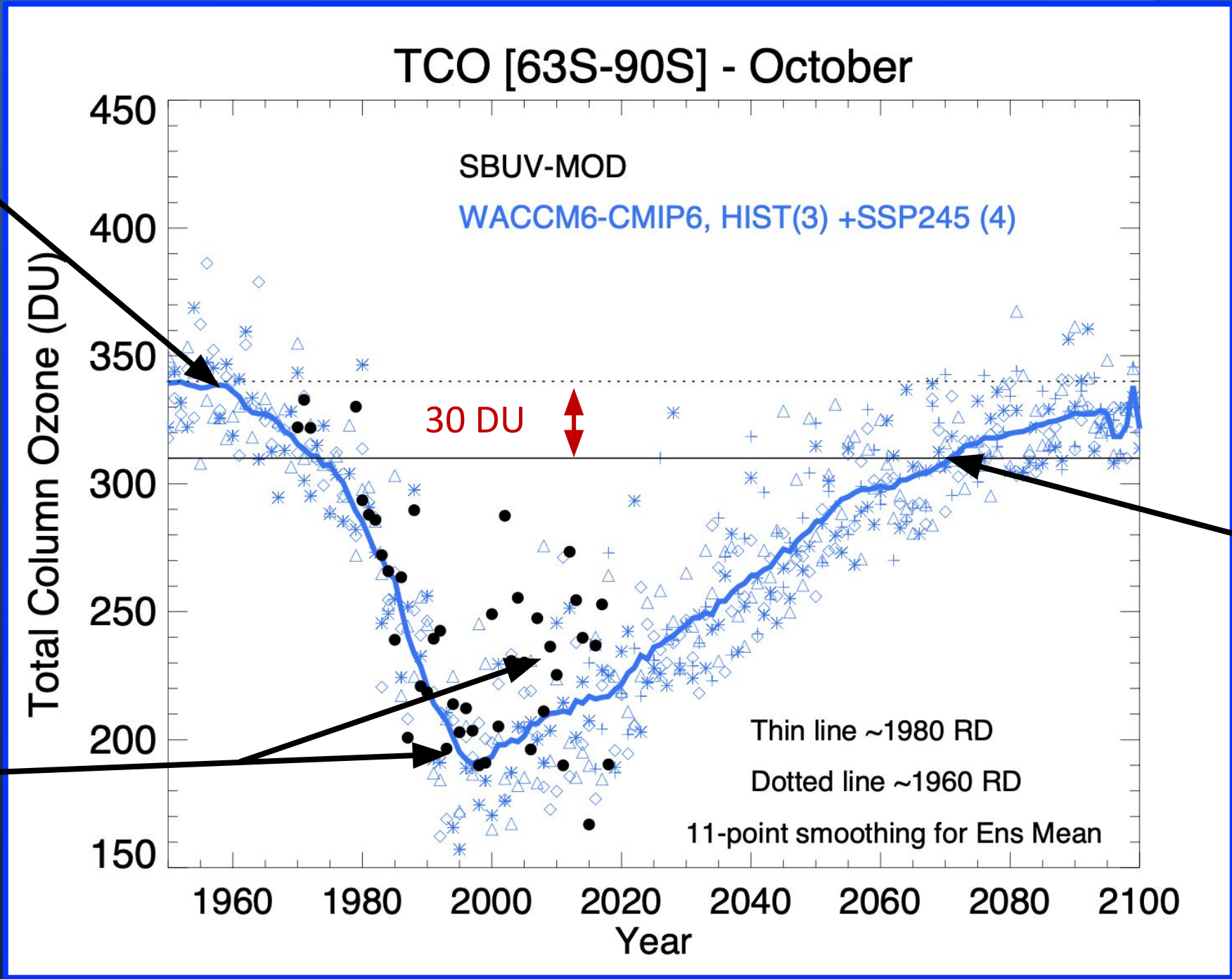
□ **11-year smoothing**



Example: model hindcast to projection, 63-90S October

Return to 1980 is **NOT** full Recovery, ~1960. (Langematz et al., ACP, 2016)

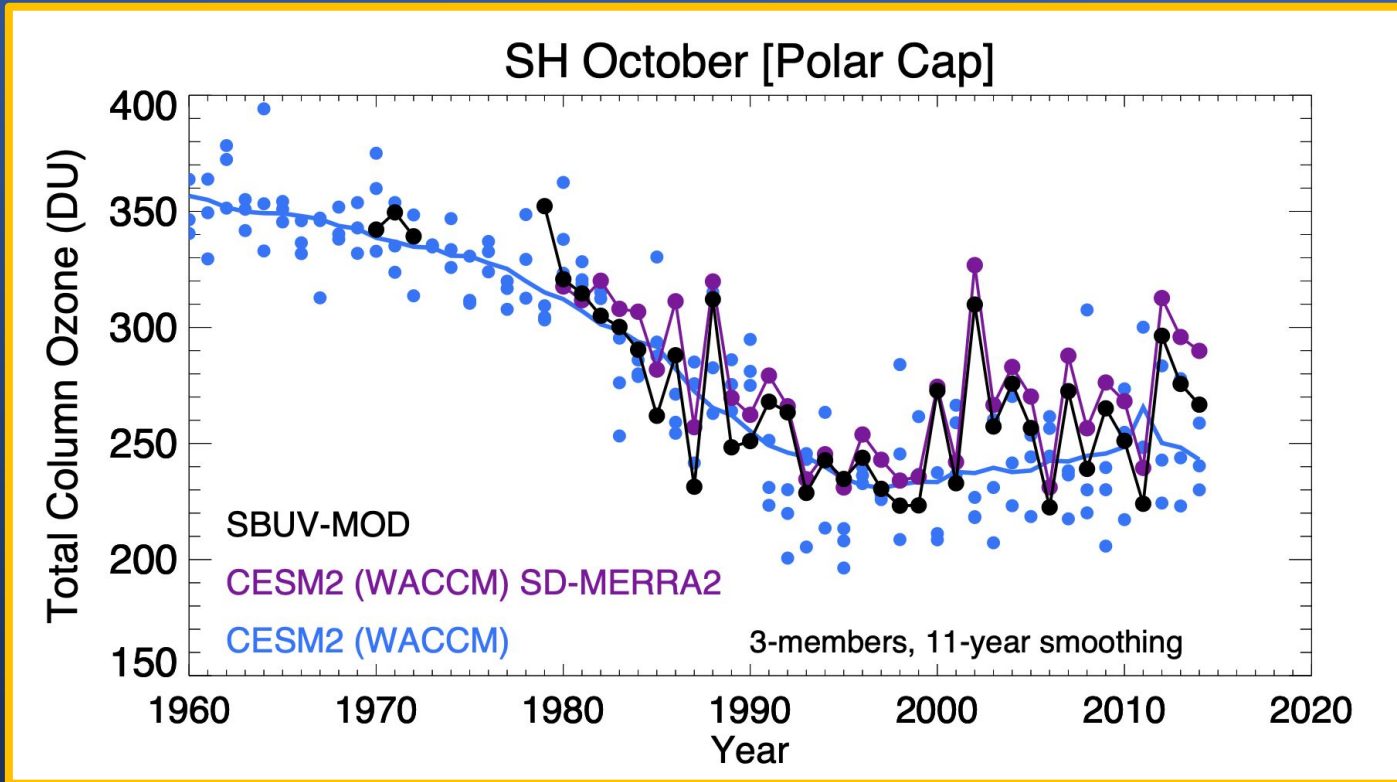
More variability at **high EESC**.
Models must represent the historical record before any forecasts are believable.



Internal variability across realizations can be large near the ensemble mean return date. (WMO)

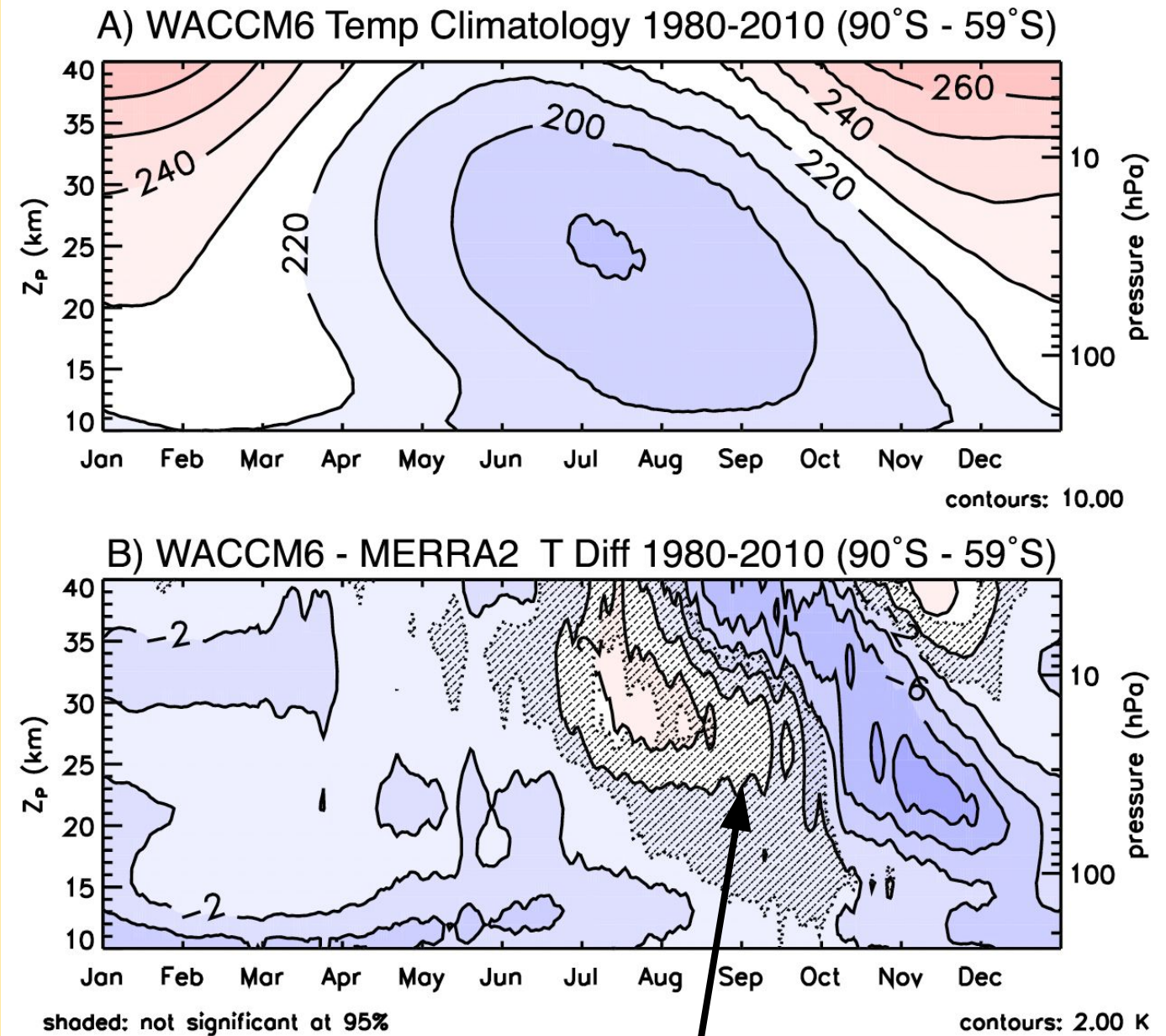
Southern Hemisphere Polar Spring Temperature and TCO

Excellent Agreement between Ens. Mean and Obs.



SD-WACCM shows that ozone depletion is accurate.

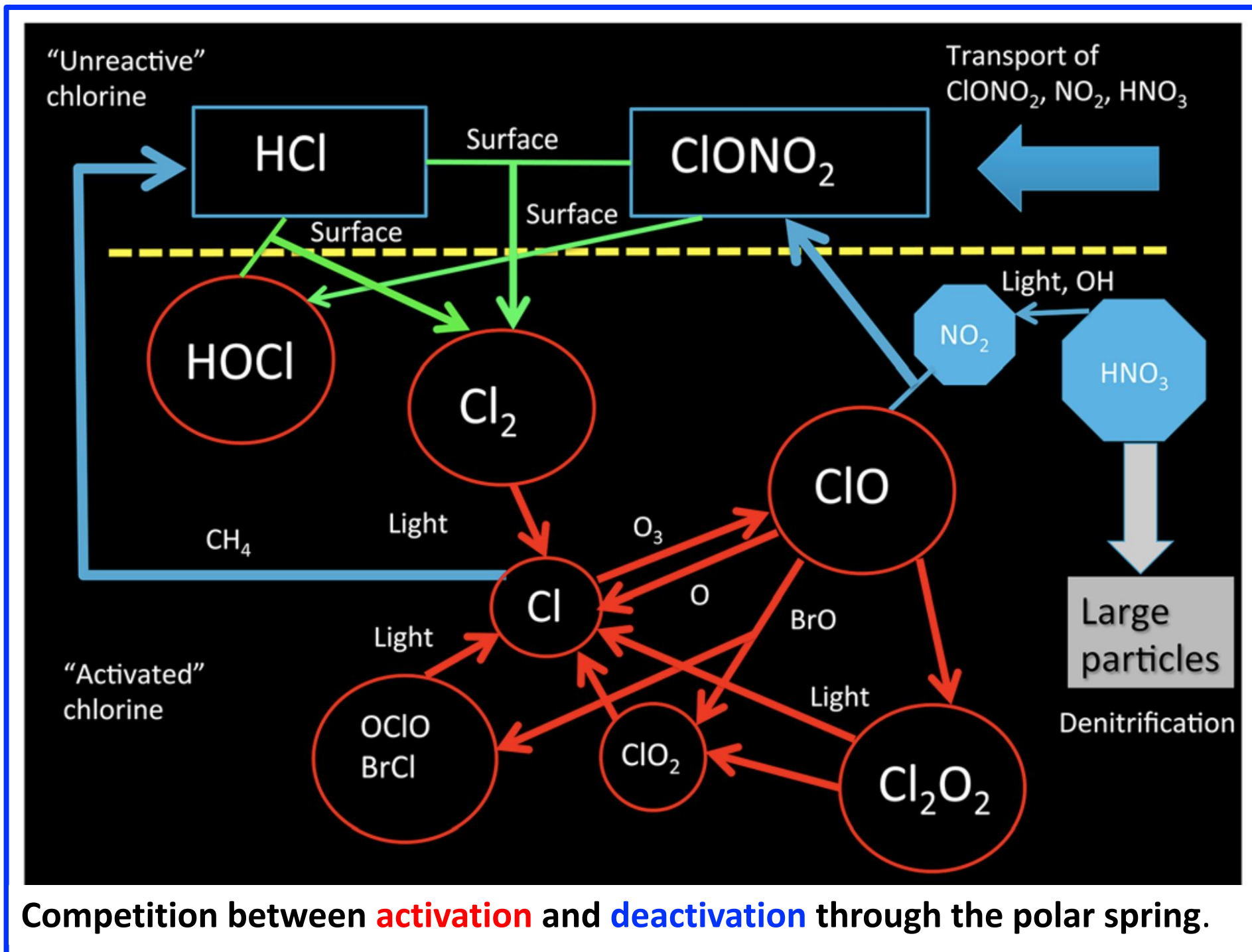
Orographic GWs are adjusted to get good temperatures.



Shaded differences are not significant at the 95% level based on *t* test.

Temperatures are +/- 1K accurate in the ozone hole region.

Figure Courtesy of R. R. Garcia



Why do we care about Denitrification?

- >195K HNO₃ (g), Liquid binary sulfate (LBS)
- ~195K NAT forms deNO_y occurs; larger particles, faster settling rate, more deNO_y
- ~192K Supercooled Ternary Solution forms (STS) – Liquid aerosols that swell and uptake HNO₃ and HCl. Main SAD that activates (inorganic chlorine)

Competition between **activation** and **deactivation** through the polar spring.

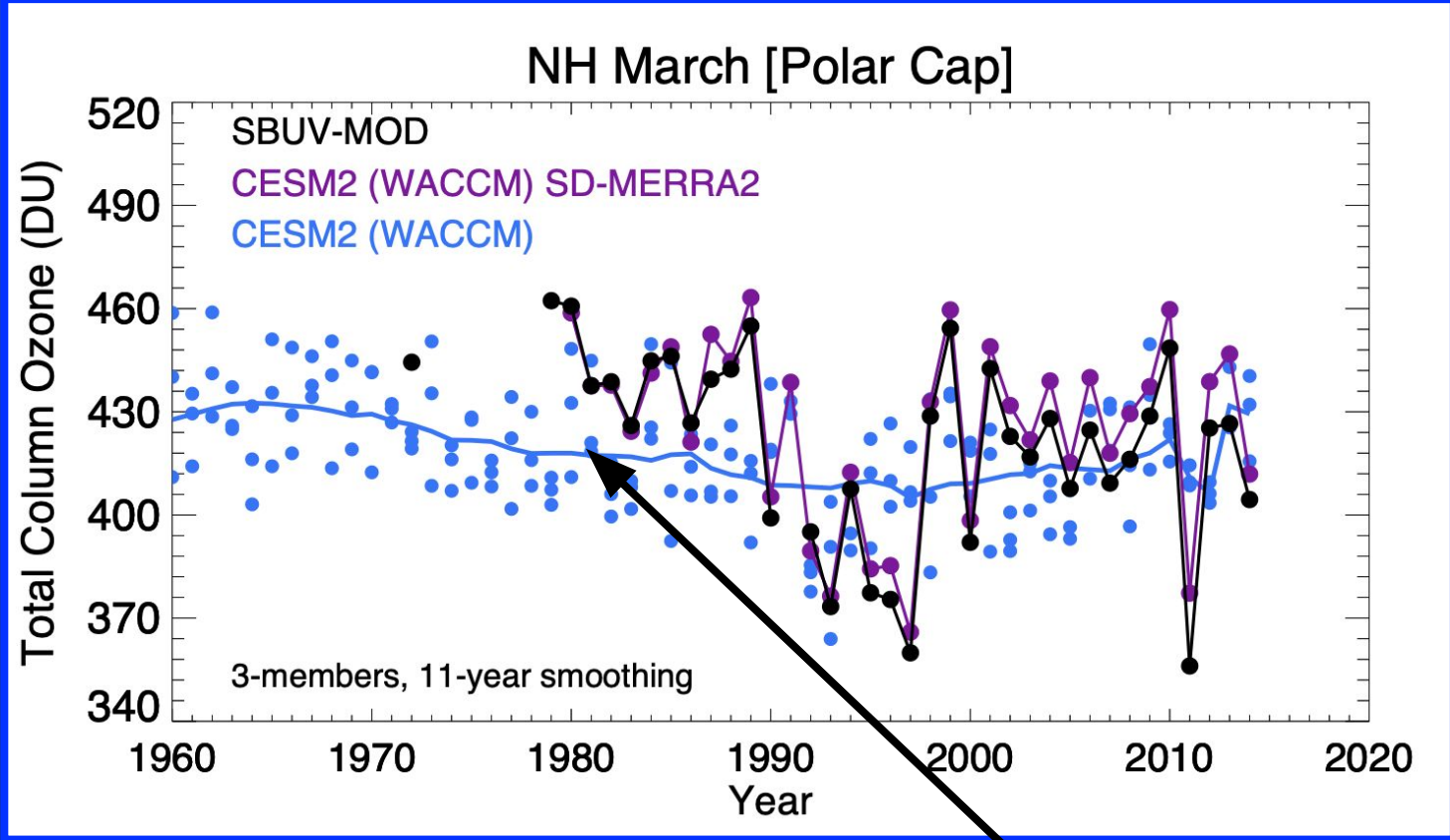
Solomon, Kinnison, Bandoro & Garcia, JGR, 2015

NH Polar Spring Stratospheric Sudden Warming Frequency impact on Ozone Depletion

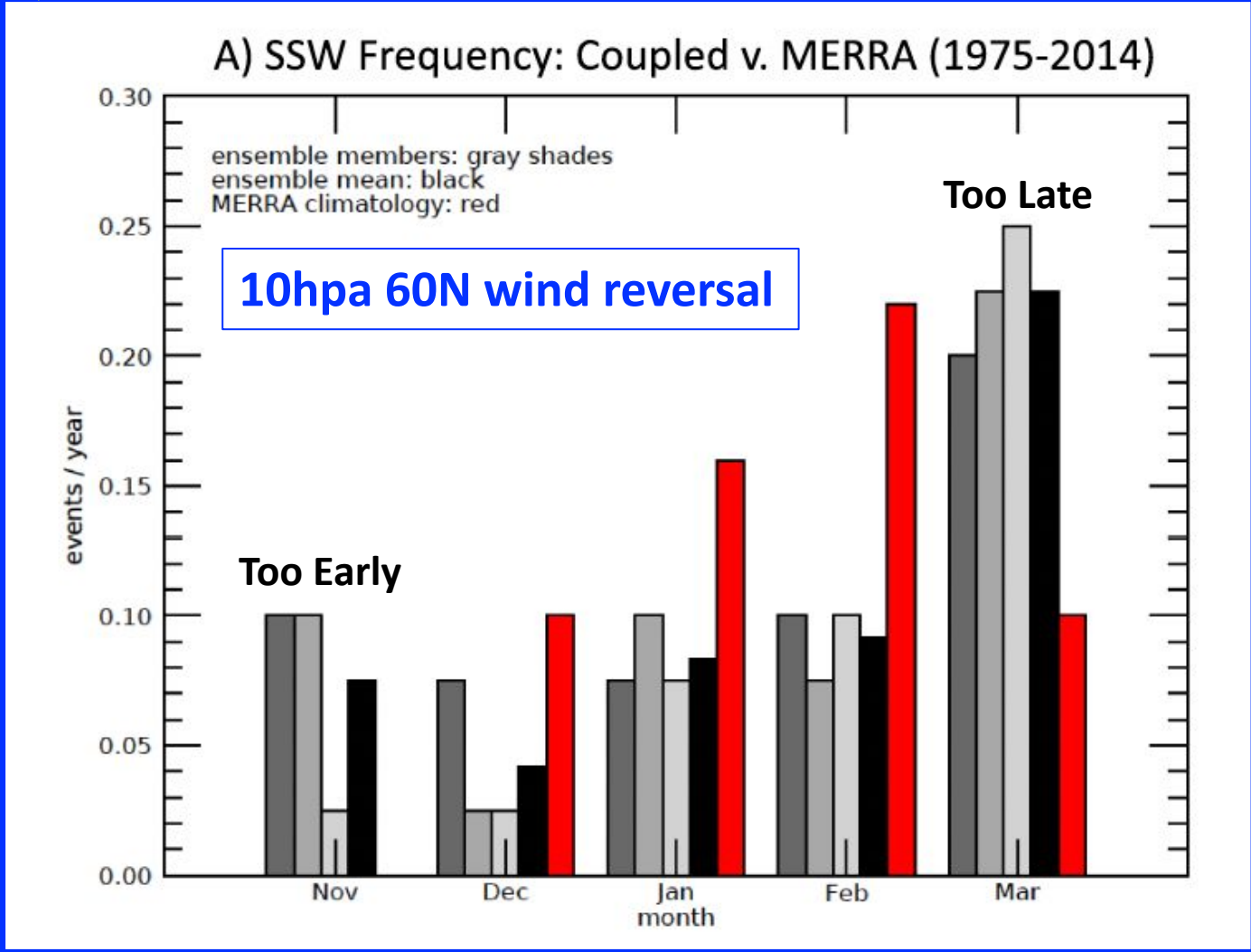
Why did WACCM fail to deplete ozone?



Issues with SSW Frequency



This lack of NH ozone depletion meant that there was no recovery! Results were not used from this model in WMO 2022 Assessment.



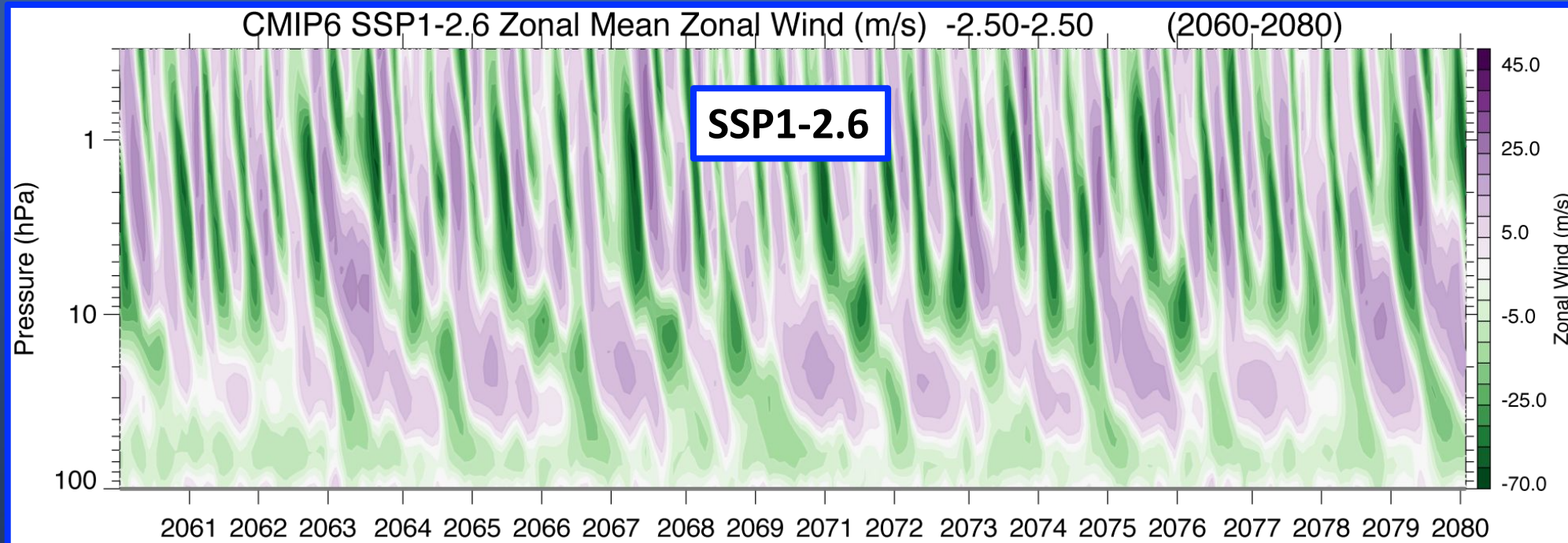
This process is difficult to tune!

Figure Courtesy of R. R. Garcia

**Deadline for Inclusion in WMO-2026 will be Early
Fall of 2025**

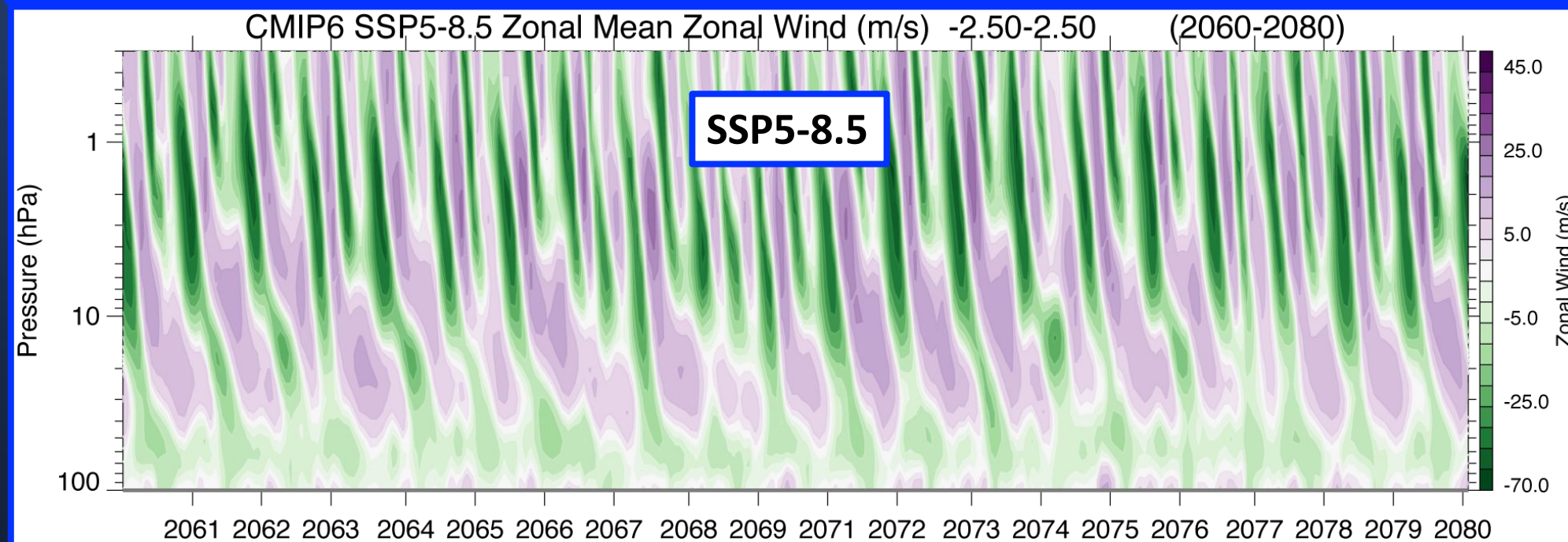
Thank You for your Attention

QBO Change Under Extreme Climate Change Scenario



Period ~28 month.

The QBO in WACCM is driven by tropical convection, which is enhanced by warmer SSTs. (Richter et al., QBOi, QJR Meteorol. Soc. 2020)



Period ~12 months

Does the QBO period affect the mean circulation and shorten the residence time of CFCs? Decreasing the Return Date??

CESM2 (WACCM6) Results (Courtesy of Mijeong Park)