NUMERICAL SIMULATION OF THE OZONE MINI-HOLES FORMATION IN THE ARCTIC AND SUBARCTIC

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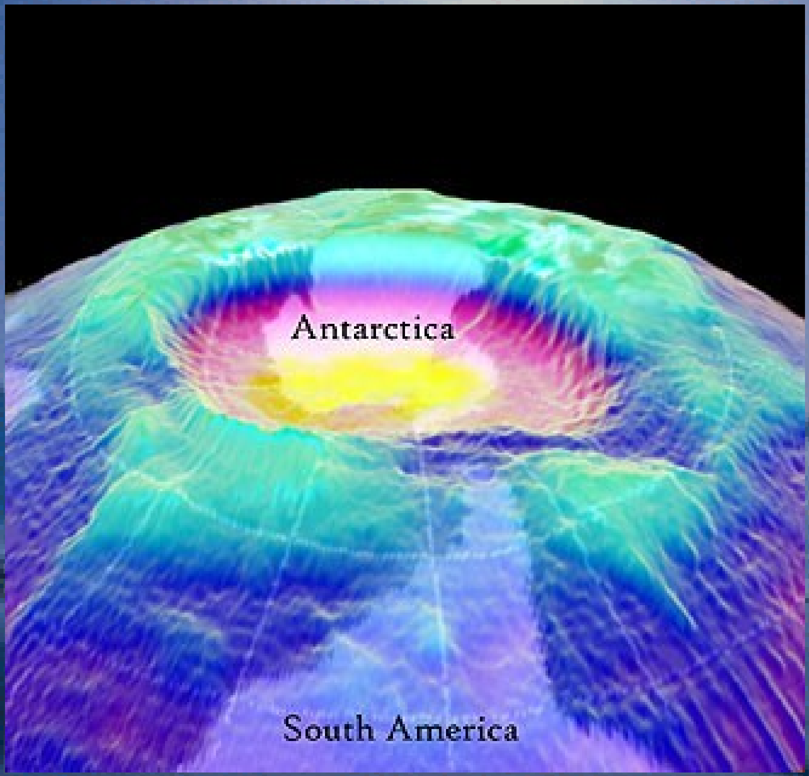
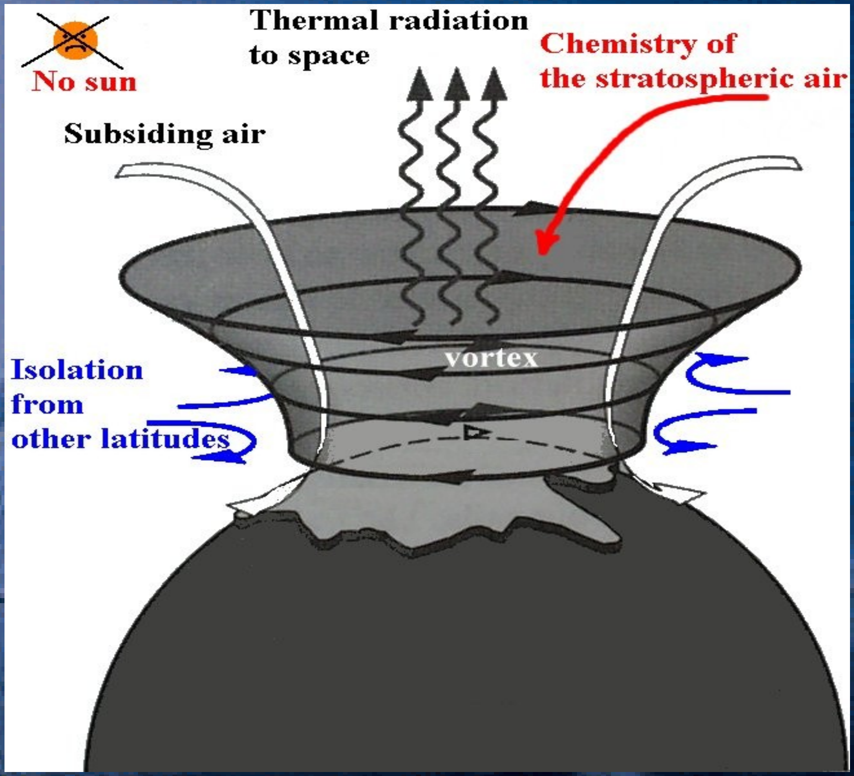
POLAR OZONE HOLES

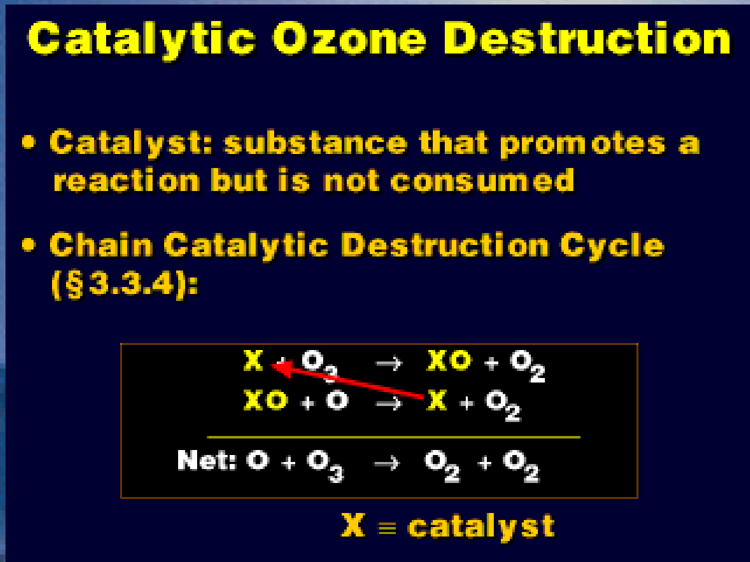


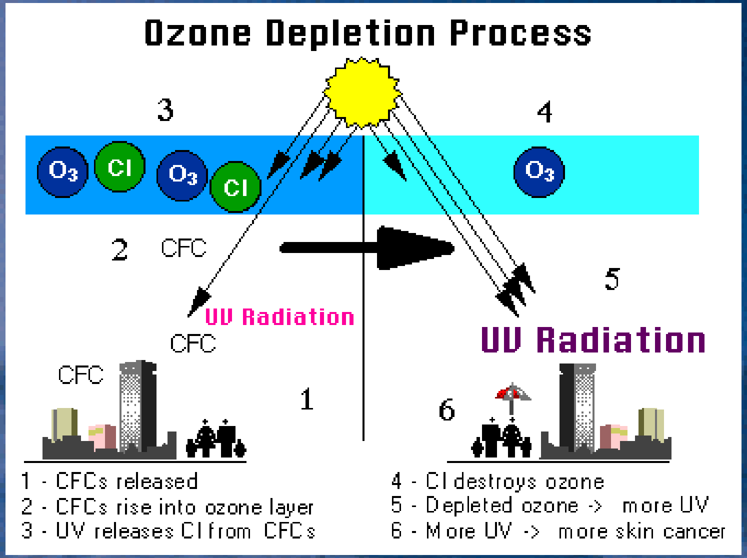


- Isolation of the polar stratosphere within the circumpolar vortex
- Low temperatures
- Formation of polar stratospheric clouds
- Heterogeneous chemical reactions on the PSC surface
- Denitrification and dehydration
- Catalytic chemical destruction of ozone in the chlorine and bromine cycles after sunrise at the end of the polar night

- It isolates the air within the polar stratosphere from exchange with mid-latitudes.
- The air inside the vortex cools.
- **Polar stratospheric clouds** form.
- In the absence of sun, cooling occurs more rapidly and ozone is destroyed.
- The **stability** of the circumpolar vortex is important.

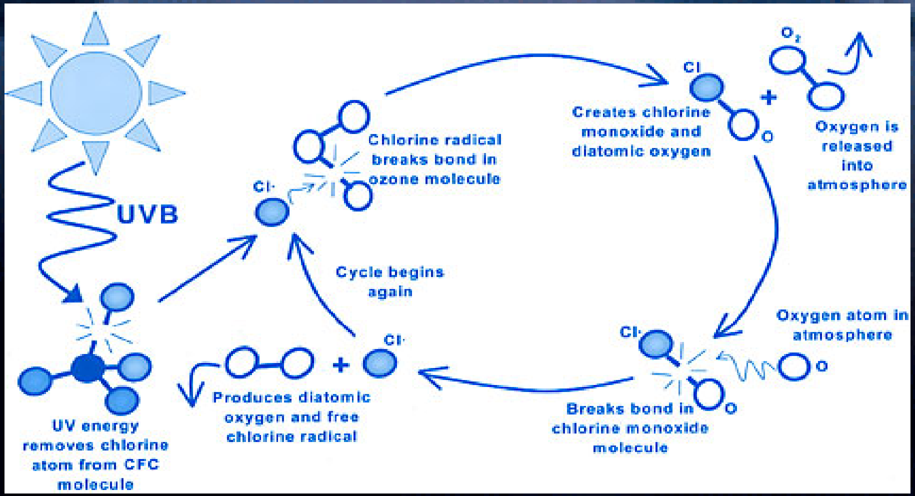
OZONE DEPLETION

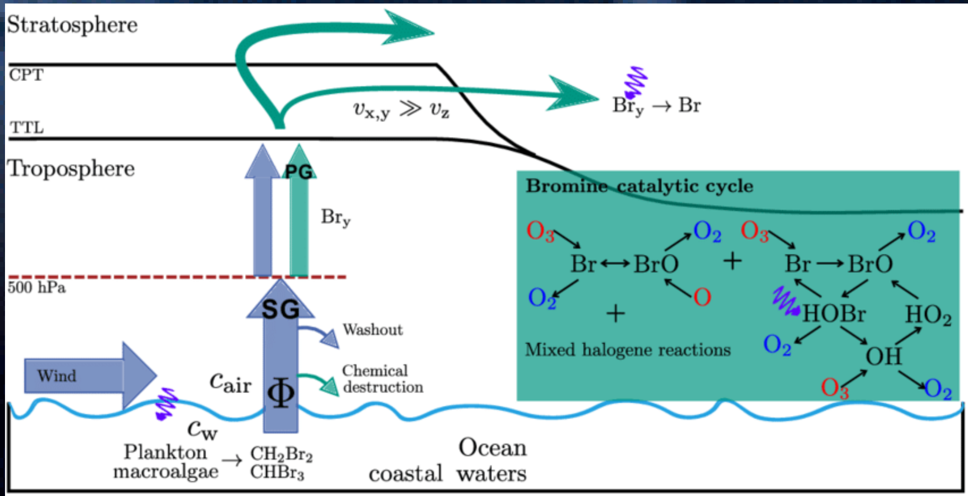




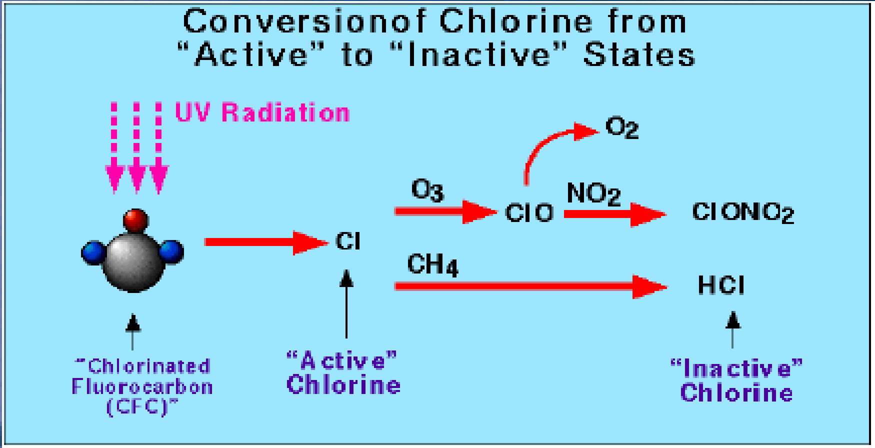
X – **NO (70%)**, OH (10-12%), **Cl (5%)**, Br

Ozone -Depleting Substances (ODS) — containing Chlorine and Bromine

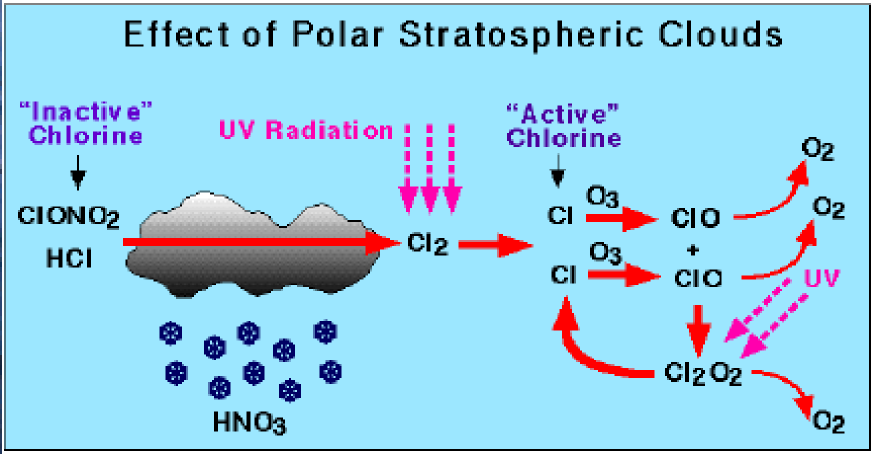


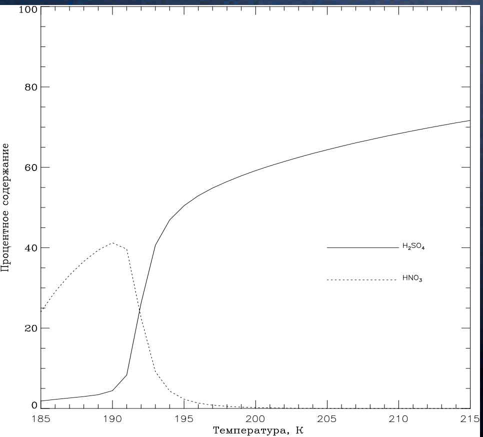


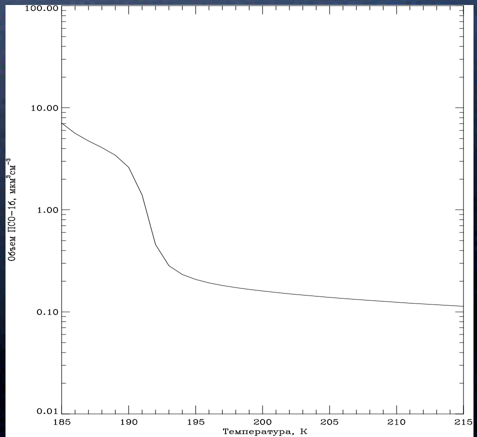
Heterogeneous Activation on the PSC



- They form in the lower stratosphere on sulfate aerosol at temperatures below 200 K.
- Heterogeneous processes on the surface of PSOs lead to chlorine and bromine activation.
- Gravitational sedimentation of PSO particles leads to denitrification and dehydration of the polar stratosphere.
- PSCs regularly form in Antarctica and rarely in the Arctic.

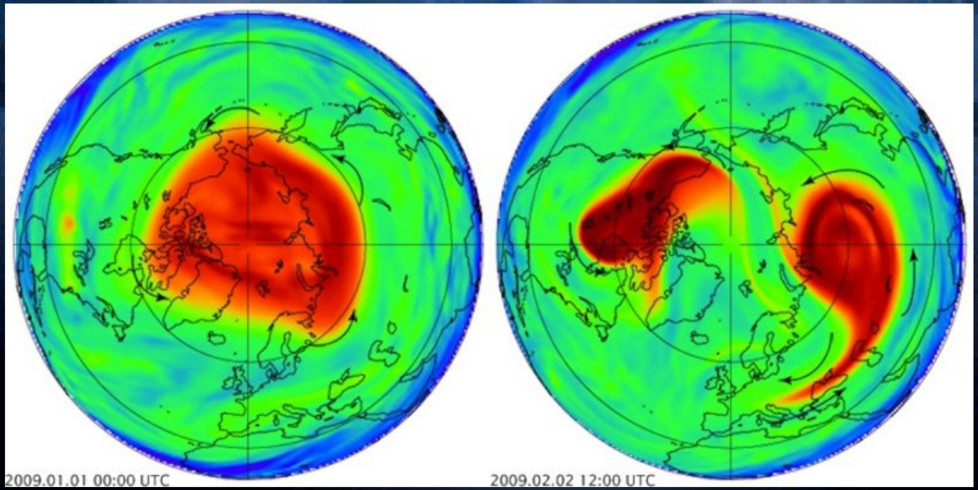






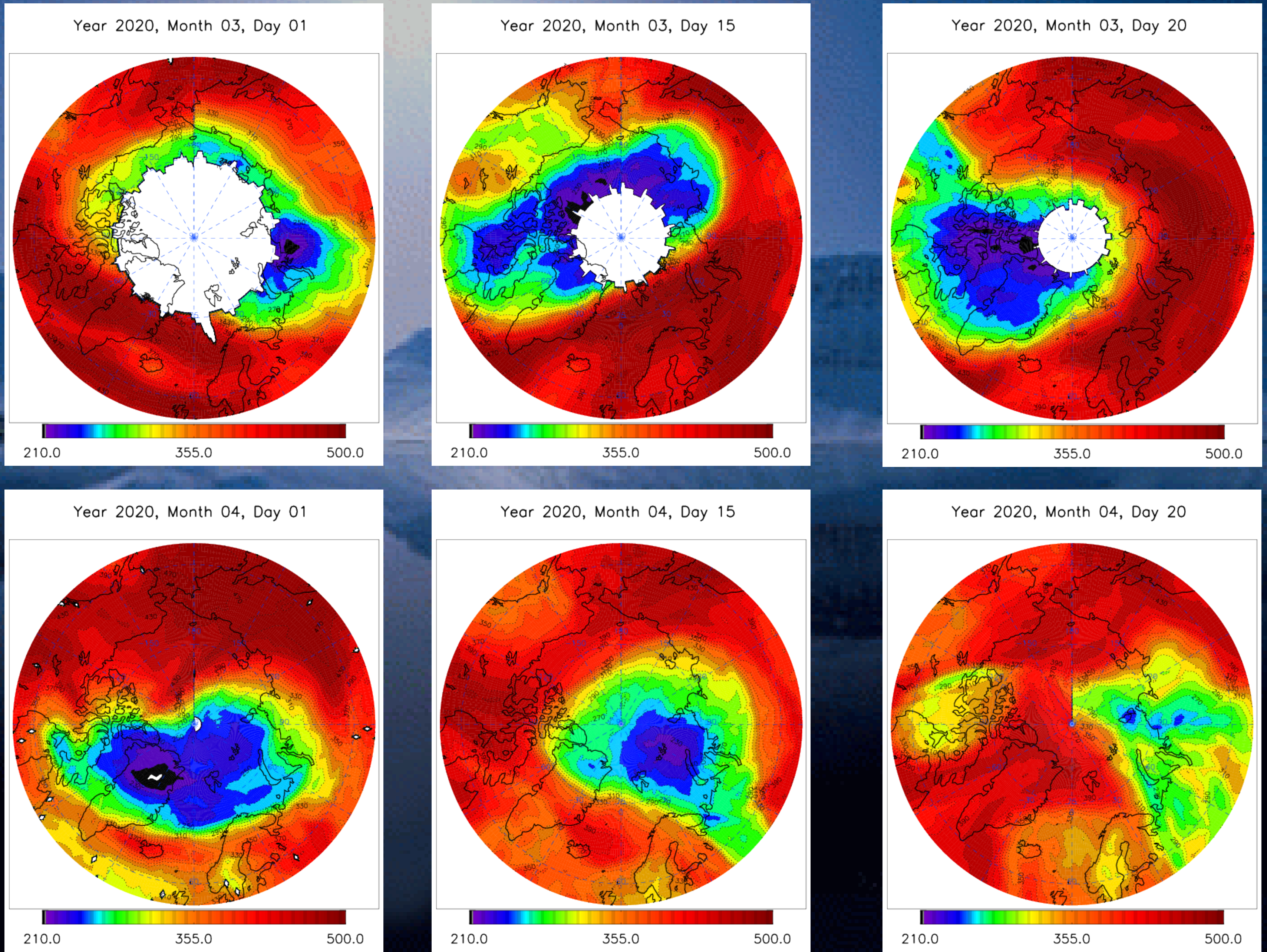
- Active chlorine (bromine) destroys ozone in halogen catalytic cycles
- Inactive chlorine (bromine) is neutralized by nitrogen and hydrogen compouns
- Denitrification and dehydration of the polar stratosphere allow chlorine (bromine) to be in active form for a long time and destroy ozone

Arctic Ozone Evolution

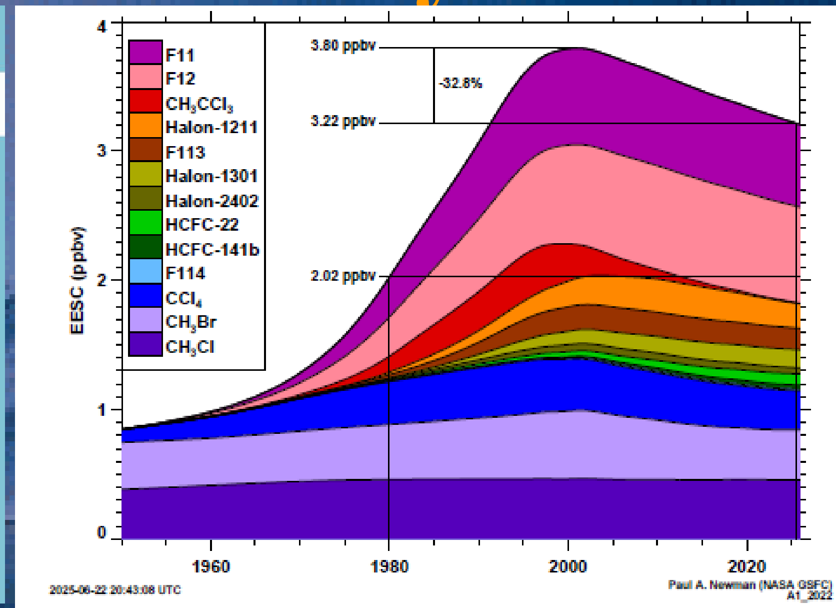


- Large-scale quasi-stationary longitudinal perturbations of atmospheric parameters (stationary planetary waves) are forced oscillations of the atmosphere that are excited in the troposphere due to inhomogeneities of the orography and heating of the underlying surface
- Planetary waves propagating from the troposphere to the stratosphere interact with the mean flow and affect the stability of the circumpolar vortex
- As a result of sudden stratospheric warming (SSW), the circumpolar vortex can divide, shift and collapse.

Arctic Column Ozone Mini-Holes



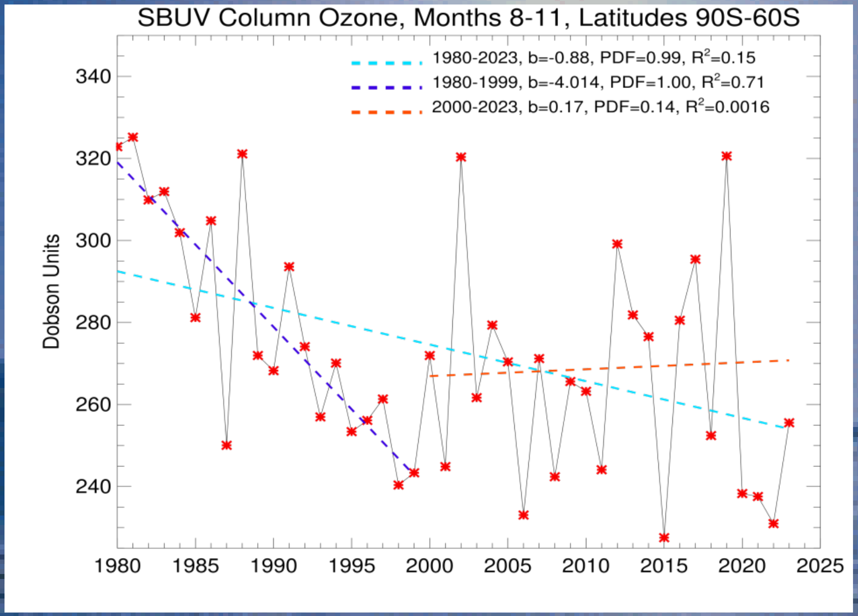
The Montreal Protocol on Substances that Deplete the Ozone Layer

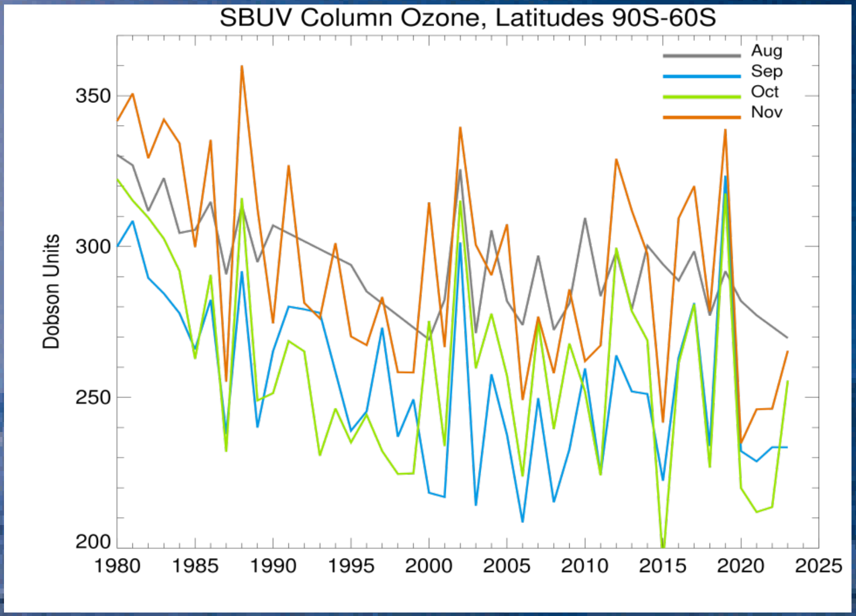


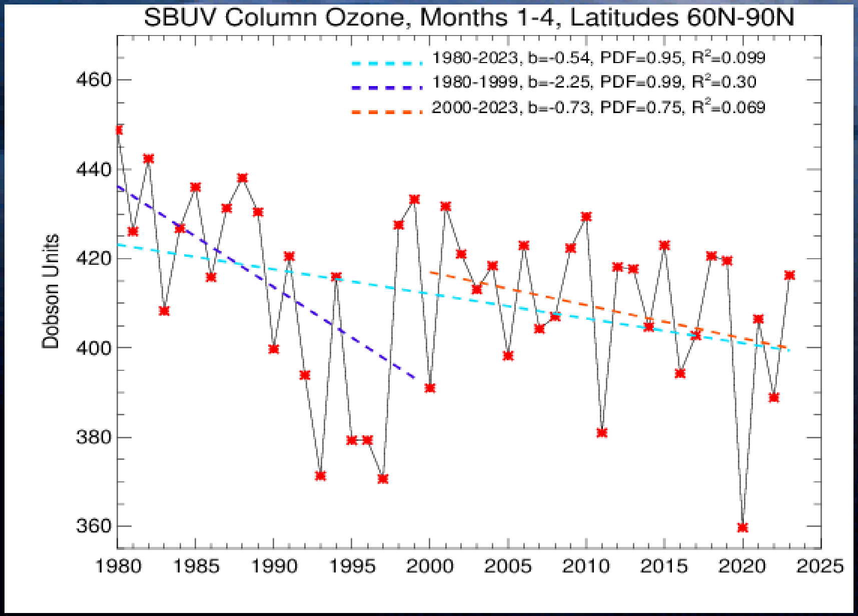
- The Montreal Protocol on Substances that Deplete the Ozone Layer is a global agreement to protect the Earth's ozone layer by phasing out the chemicals that deplete it.
- This phase-out plan includes both the production and consumption of ozone-depleting substances.
- The landmark agreement was signed by 197 countries in 1987 and entered into force in 1989.
- Montreal Protocol regulates the production and consumption of nearly 100 man-made chemicals referred to as ozone depleting substances (ODS)

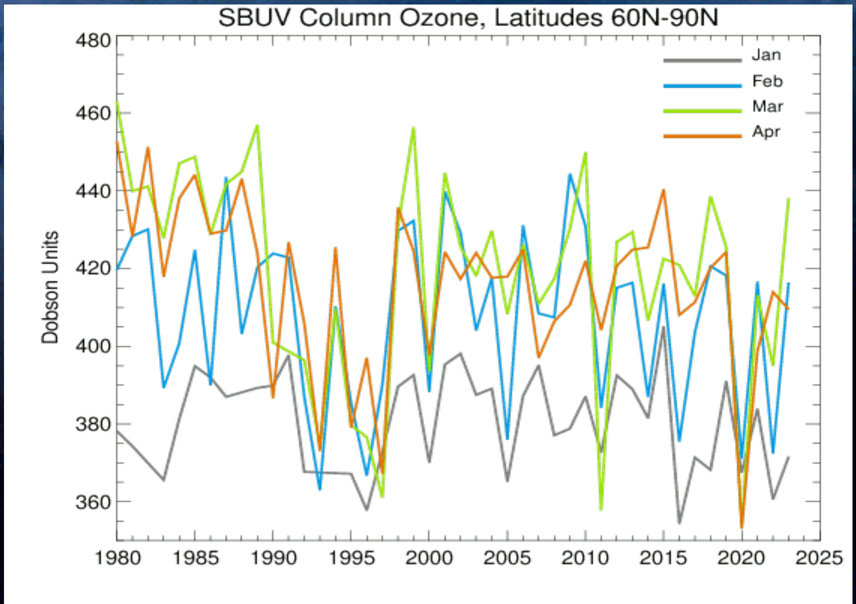
- EESC - Equivalent effective stratospheric chlorine.
- The units of EESC are in parts per billion by volume
- The dominant natural compounds are methyl chloride (CH_3Cl) and methylbromide (CH_3Br)
- The dominant anthropogenic compounds are the chlorofluorocarbons CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and CFC-113(CCl_2FCClF_2), carbon tetrachloride (CCl_4), methyl chloroform (CH_3CCl_3), and the bromine gas Halon-1211.

SBUV Monthly Mean Column Ozone









Satellite Data

NOAA's Solar Backscattered Ultra Violet (SBUV) Data

Space satellites with the SBUV type equipment crossed the equator approximately 14 times a day at the same local mean solar time, i.e., in longitude, the aisle points were at an angular distance of ~ 26 ° from each other.

Measurements with SBUV (SBUV / 2) instruments are performed near the local vertical within an angle of ± 11.3 °.

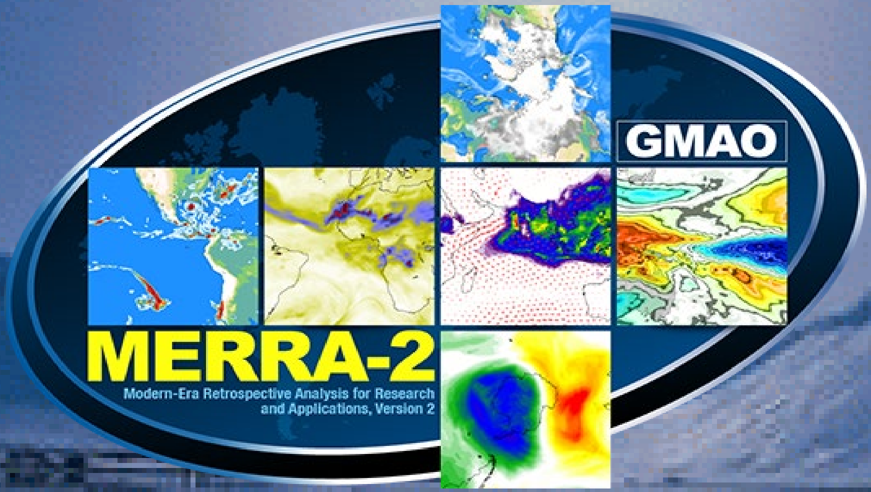
The SBUV spatial resolution is 180 × 180 km², the SBUV / 2 resolution is 168 × 168 km².

The SBUV and TOMS/OMI Overpass algorithms interpolates satellite measurements to values at the WOUDC World Ozonometric Network stations (World Ozone and Ultraviolet Radiation Data Centre)

NASA Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI)

The Total Ozone Mapping Spectrometer (TOMS) is a NASA satellite instrument for measuring ozone concentration. Of the five instruments built, four entered successful orbit on the Nimbus-7, Meteor–3, Advanced Earth Observing Satellite (ADEOS), and Earth Probe (EP) satellites. As a continuation and replacement of the TOMS series of instruments, an ozone monitoring instrument (OMI) was launched on the Aura satellite in 2004, which provides data on the total ozone content to date.

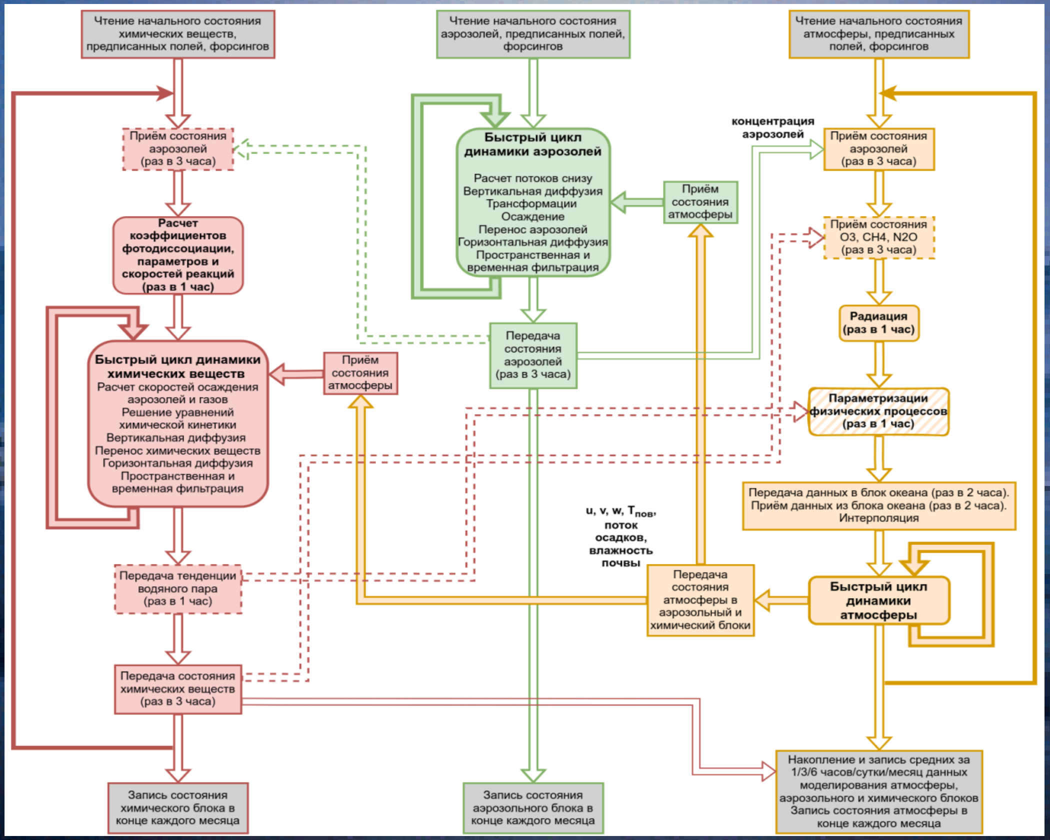
Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2)



MERRA assimilates **partial column ozone retrievals** from a series of Solar Backscatter Ultraviolet Radiometer (SBUV) instruments on NASA and NOAA spacecraft between January 1980 and September 2004: starting in October 2004, retrieved ozone profiles from the Microwave Limb Sounder (MLS) and total column ozone from the Ozone Monitoring Instrument on NASA's EOS Aura satellite are assimilated.

- The Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2) is a global atmospheric reanalysis produced by the NASA Global Modeling and Assimilation Office (GMAO). It spans the satellite observing era from 1980 to the present.
- High spatial (½° latitude by ⅝° longitude by 72 model levels) and temporal (hourly) resolution;
- Incorporates observations from more recent satellite instruments
- Improved estimates of surface mass balance and surface temperatures over ice sheets

INM RAS - RSHU Chemistry-Climate Model (INMCM60/ARTs-ESM with Chemistry)



The global chemistry-climate model of the Institute of Numerical Mathematics of the Russian Academy of Sciences (INM RAS) and the Russian State Hydrometeorological University (RSMU) (1.5x2 degrees horizontal resolution, 73 vertical levels from the surface up to 60 km) is used to evaluate the variability of climatic characteristics and trace gases.

The variability of oxygen, nitrogen, chlorine, bromine, hydrogen and carbon gases is considered;

Model of formation and evolution of sulphate aerosol and polar stratospheric clouds (**PSC**);

Heterogeneous reactions on the surface of **sulphate aerosol** and **polar stratospheric clouds** are considered;

The processes of gravitational sedimentation of aerosol particles, as well as the exchange of gases between the stratosphere and troposphere

Atmospheric gas fields calculated with the CCM were used as initial conditions for each year of calculations with the **assimilation of MERRA-2 data** (horizontal wind fields, temperature, humidity, and pressure). The data were assimilated daily using the method of successive refinements and nudging.

SCENARIOUS (North to 60N):

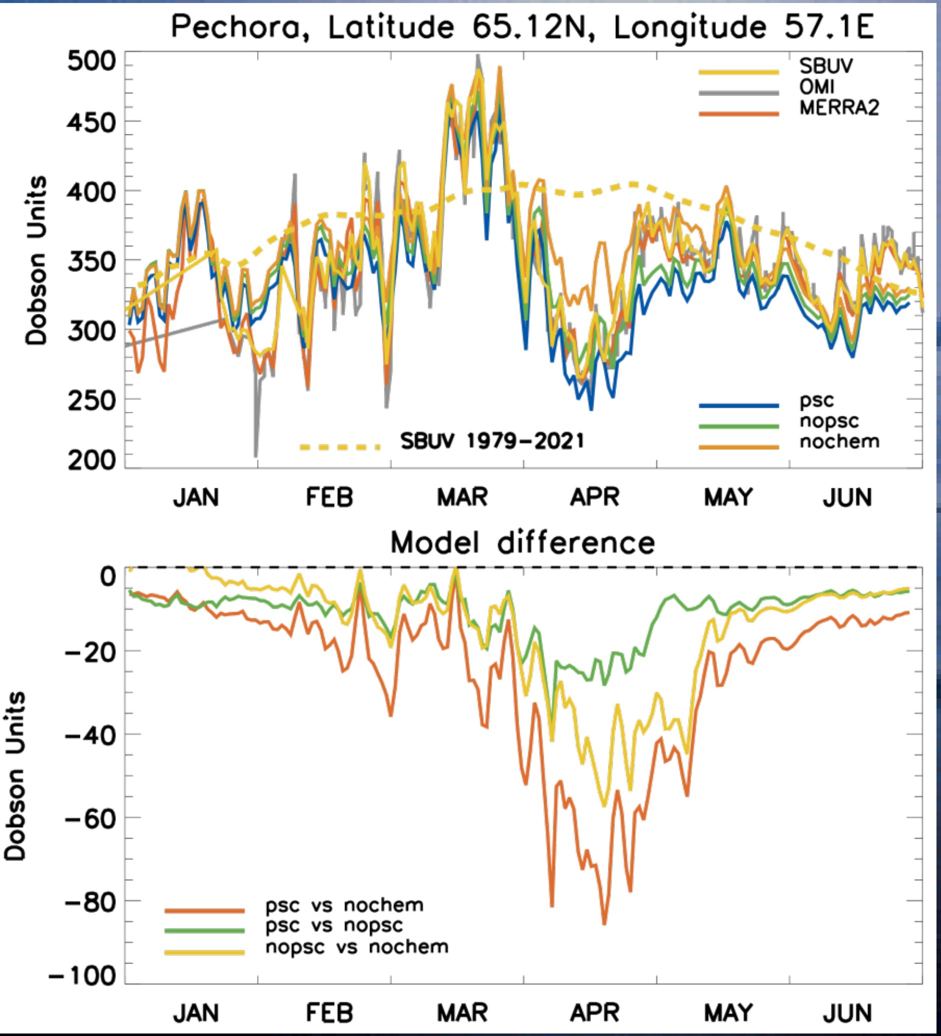
PSC – whole chemistry with PSCs

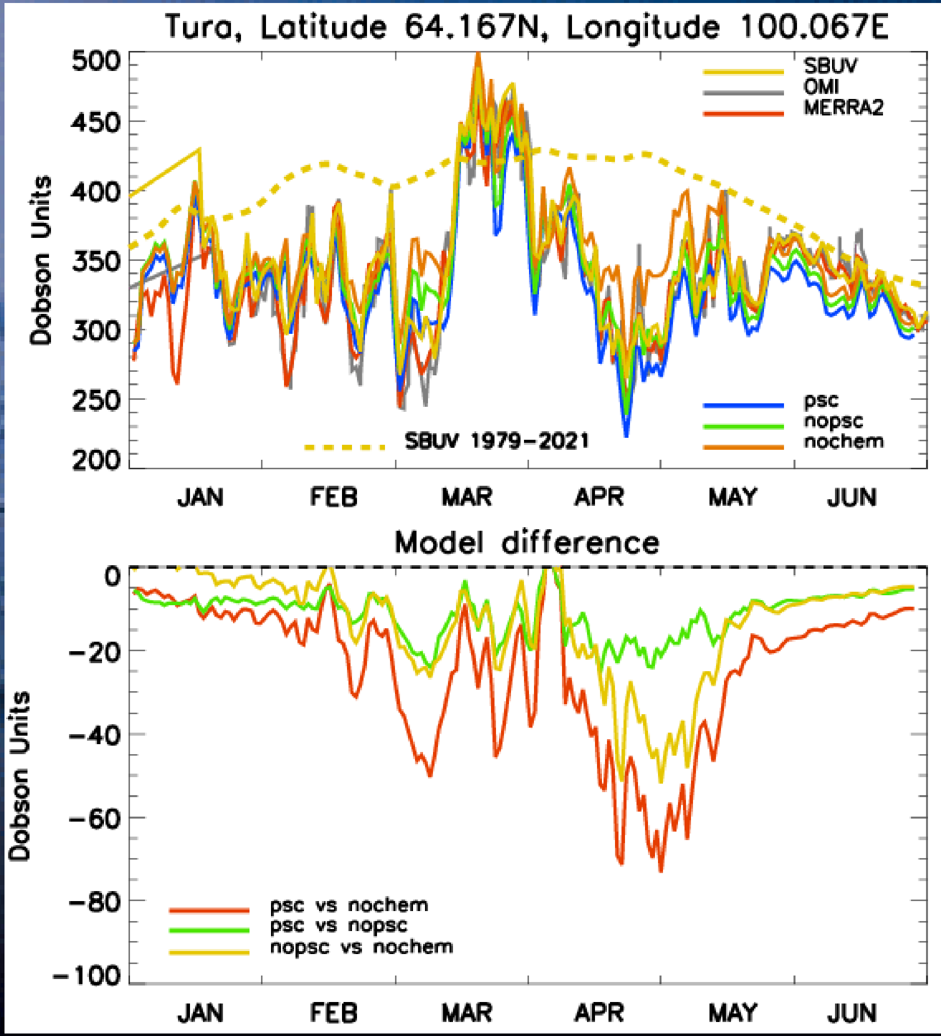
NOPSC – chemistry without PSC

NOCHEM – no chemistry

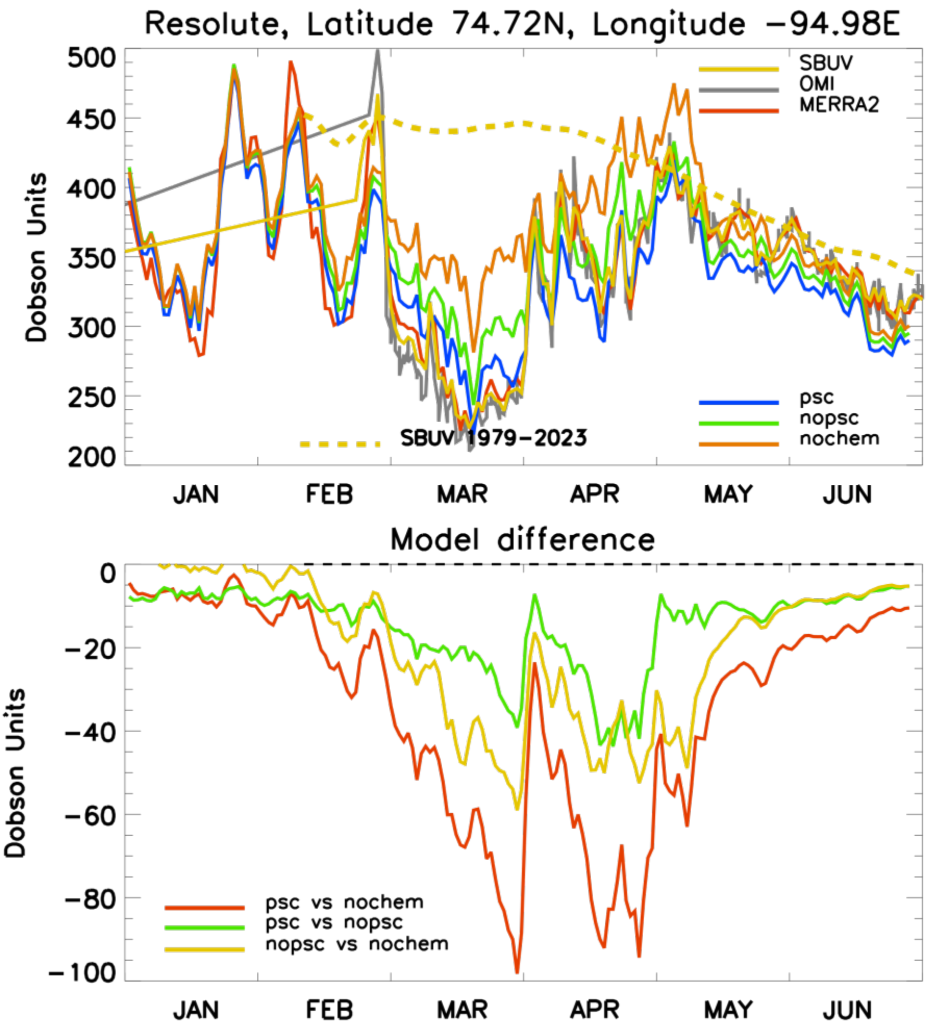
December-April

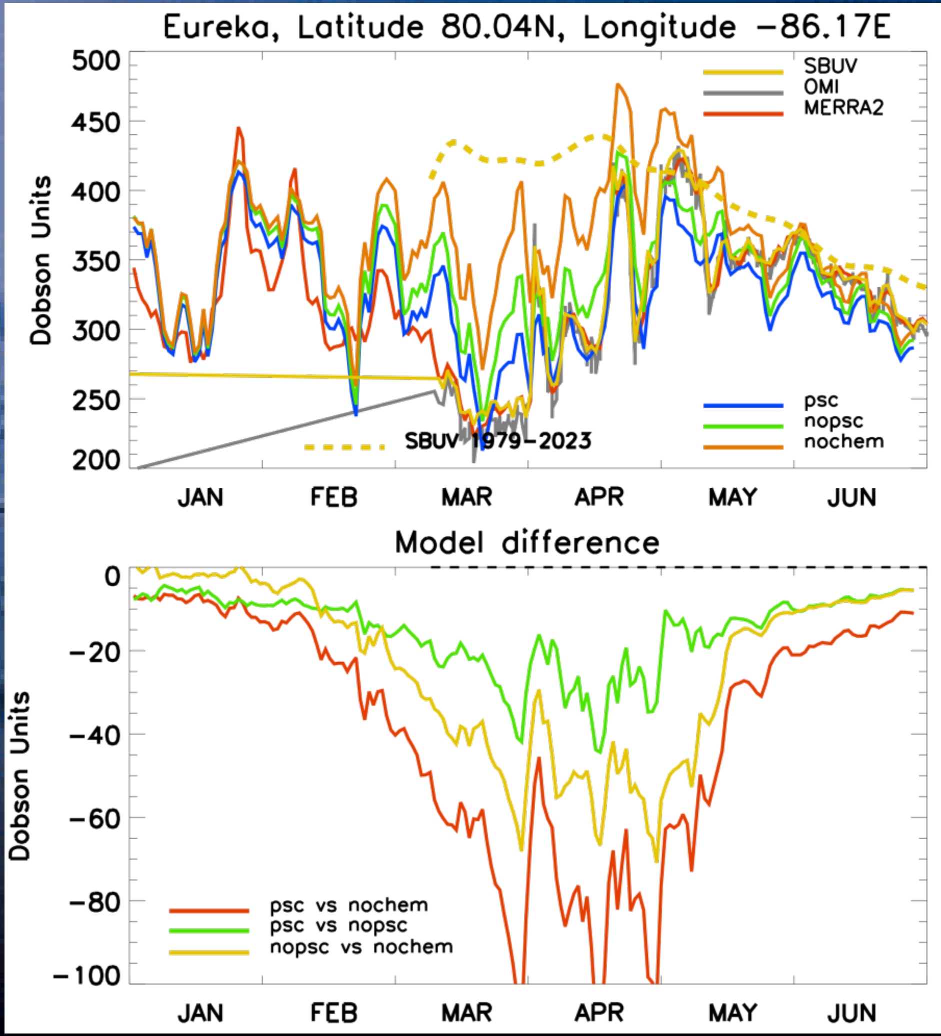
2020 Eastern Hemisphere Stations



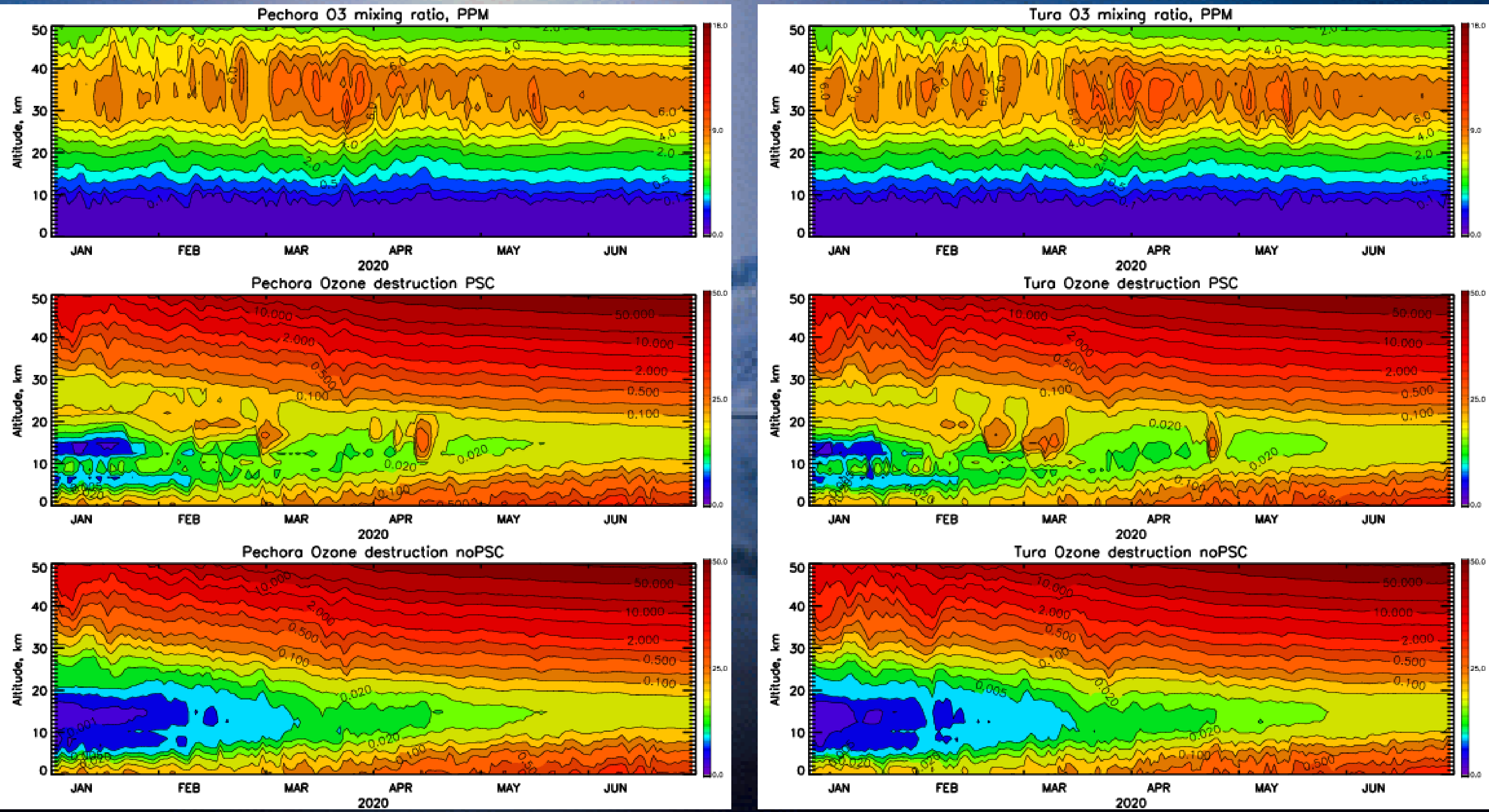


2020 Western Hemisphere Stations



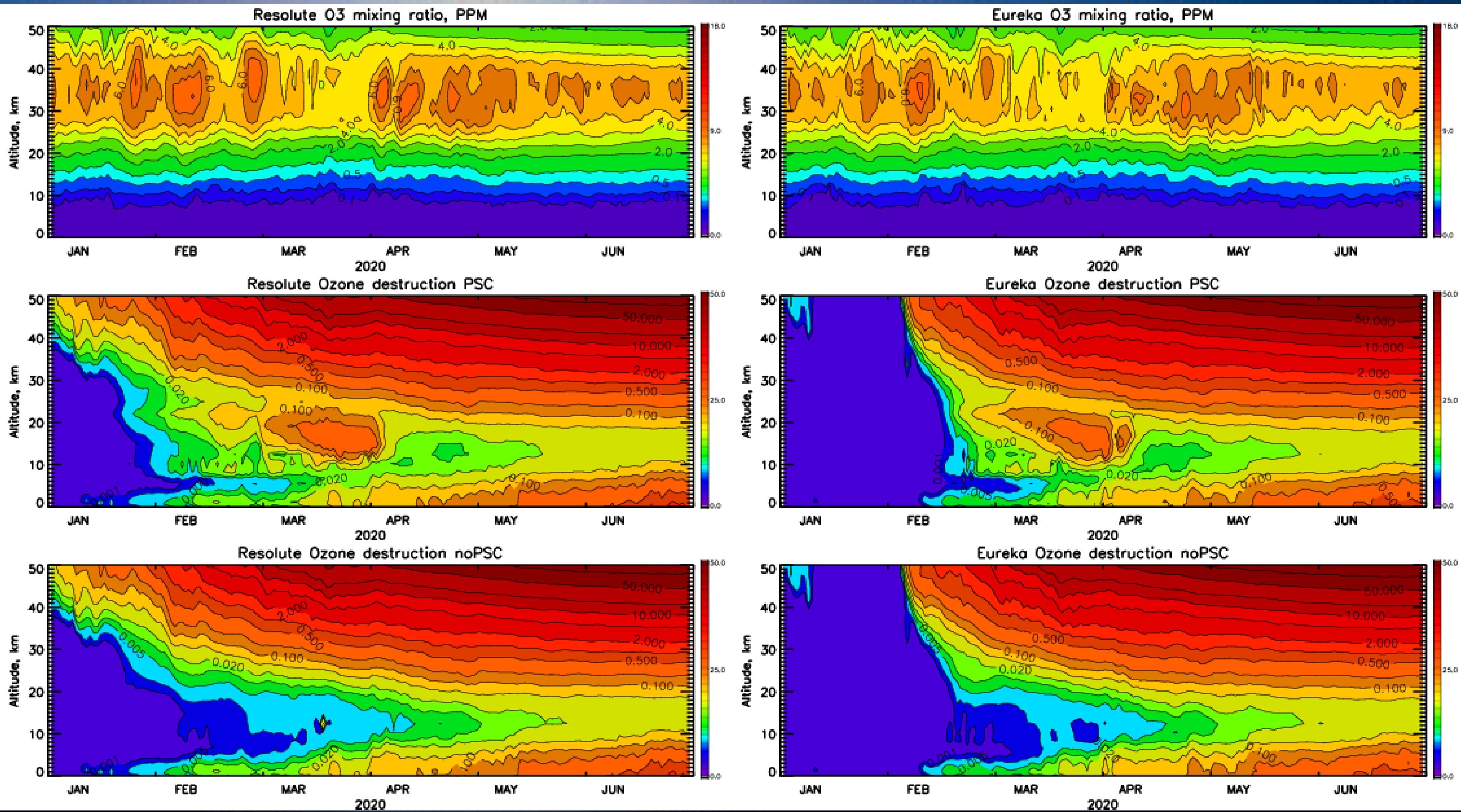


Eastern Hemisphere Stations



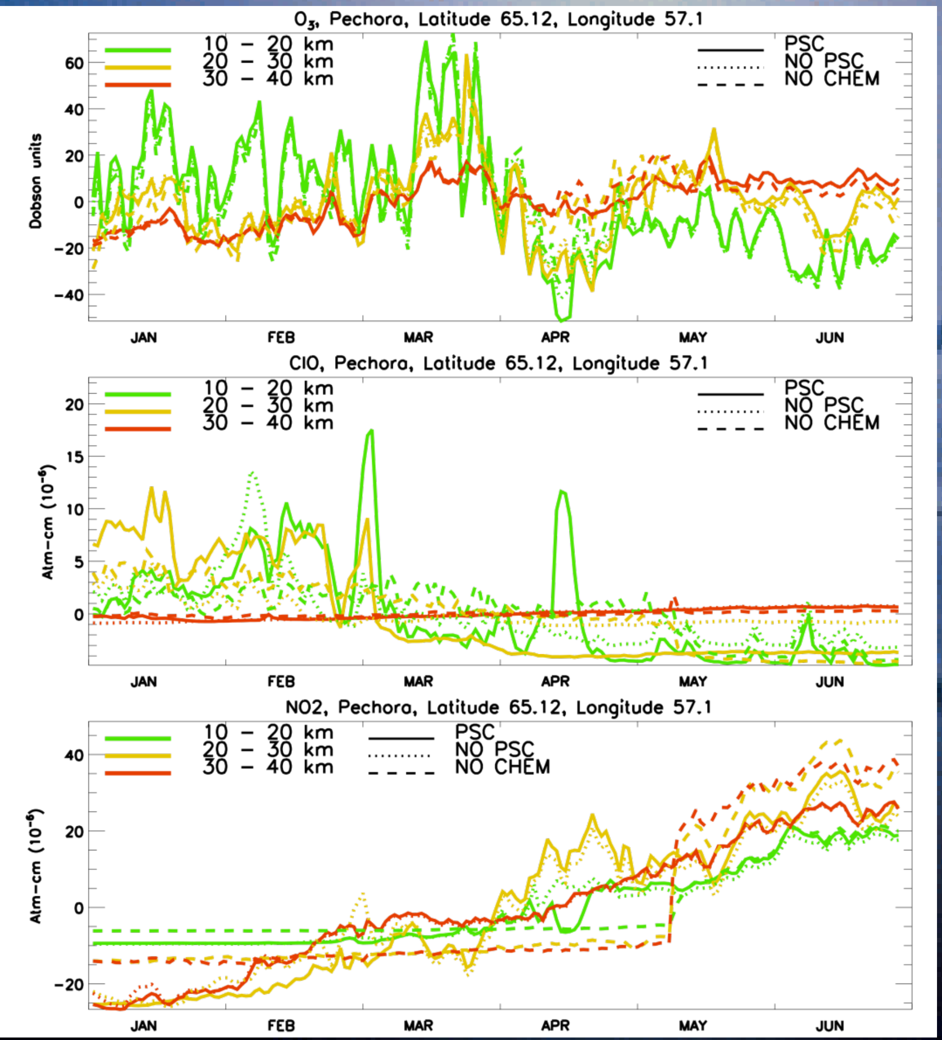
2020 Ozone Mixing Ratio and Destruction Vertical Distribution

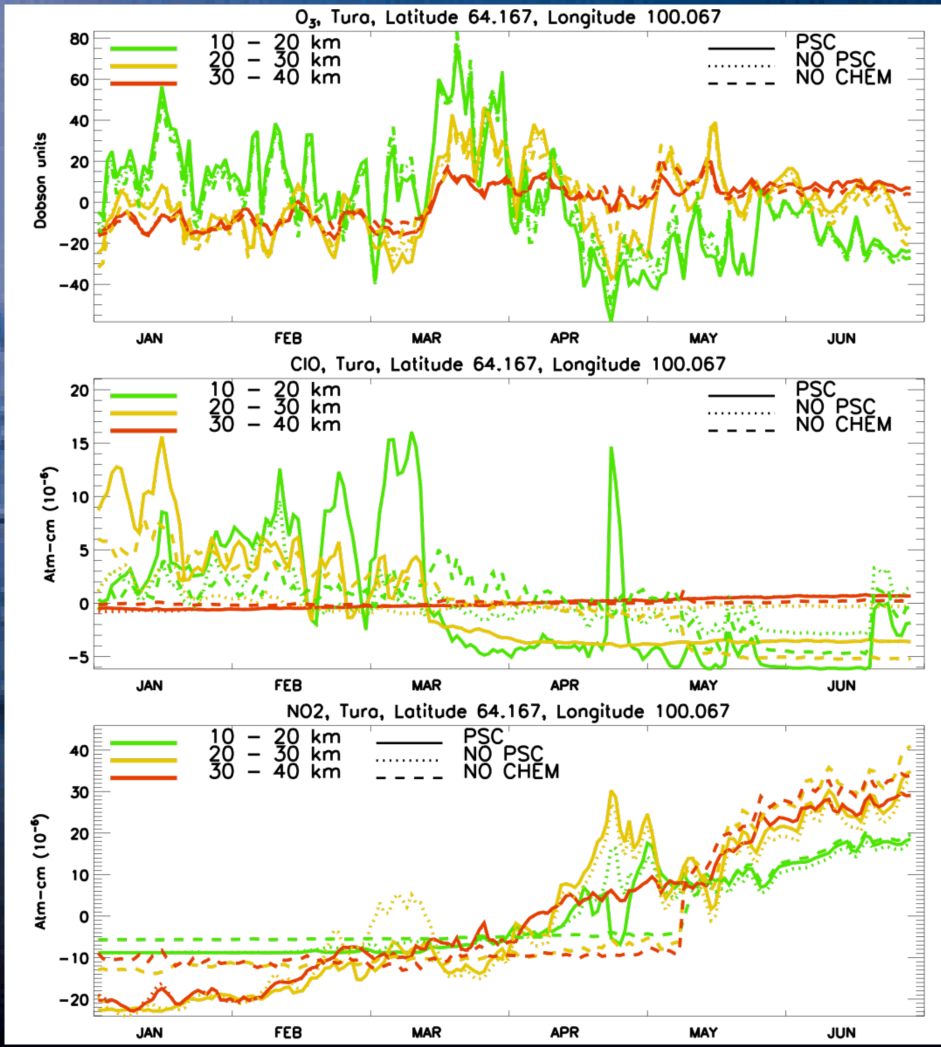
Western Hemisphere Stations



2020 Ozone Mixing Ratio and Destruction Vertical Distribution

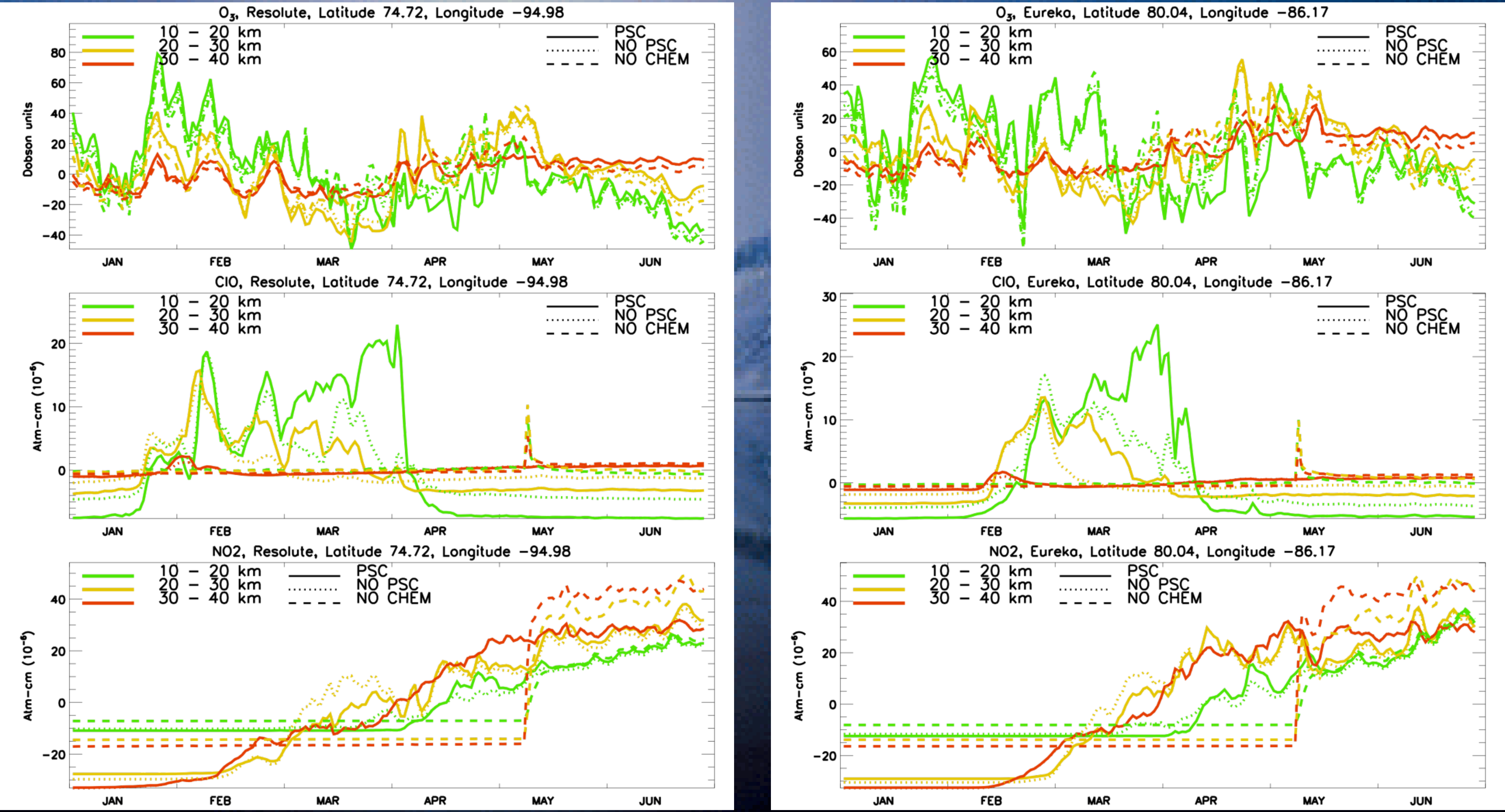
Eastern Hemisphere Stations





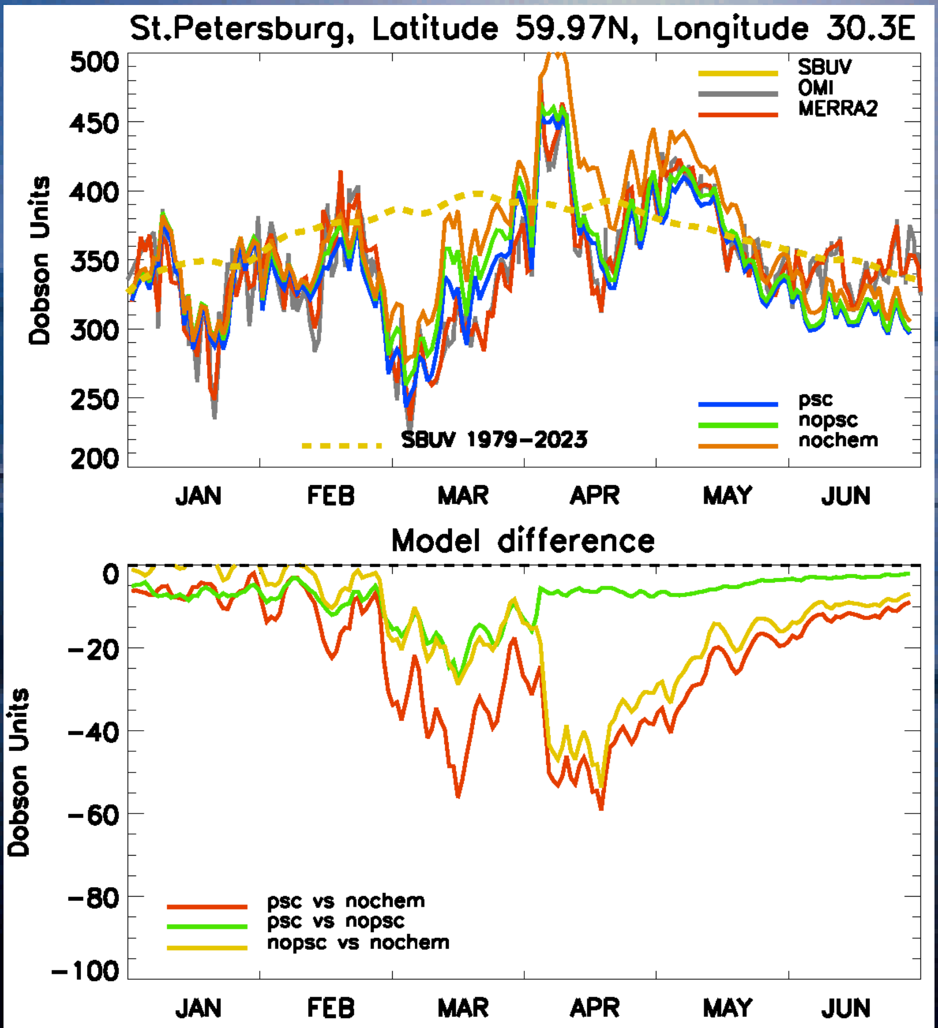
2020 Low and Upper Stratosphere Ozone, ClO and NO_2

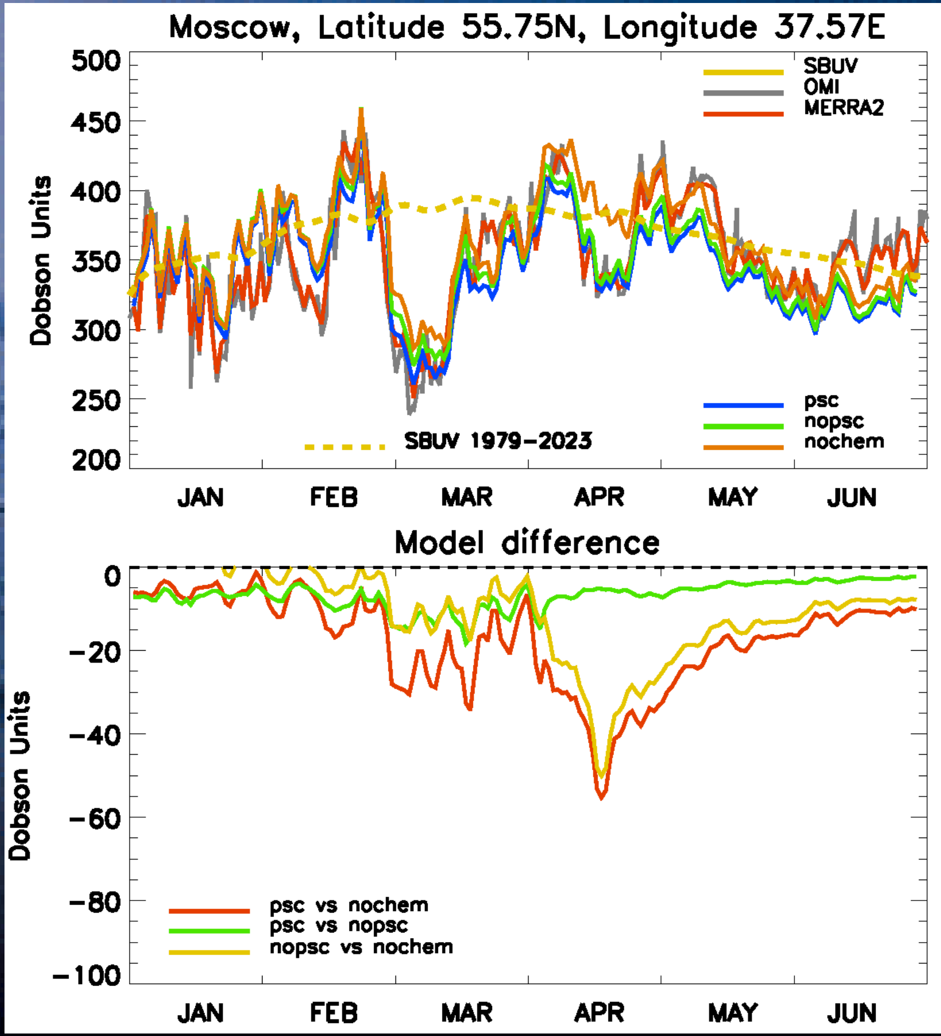
Western Hemisphere Stations



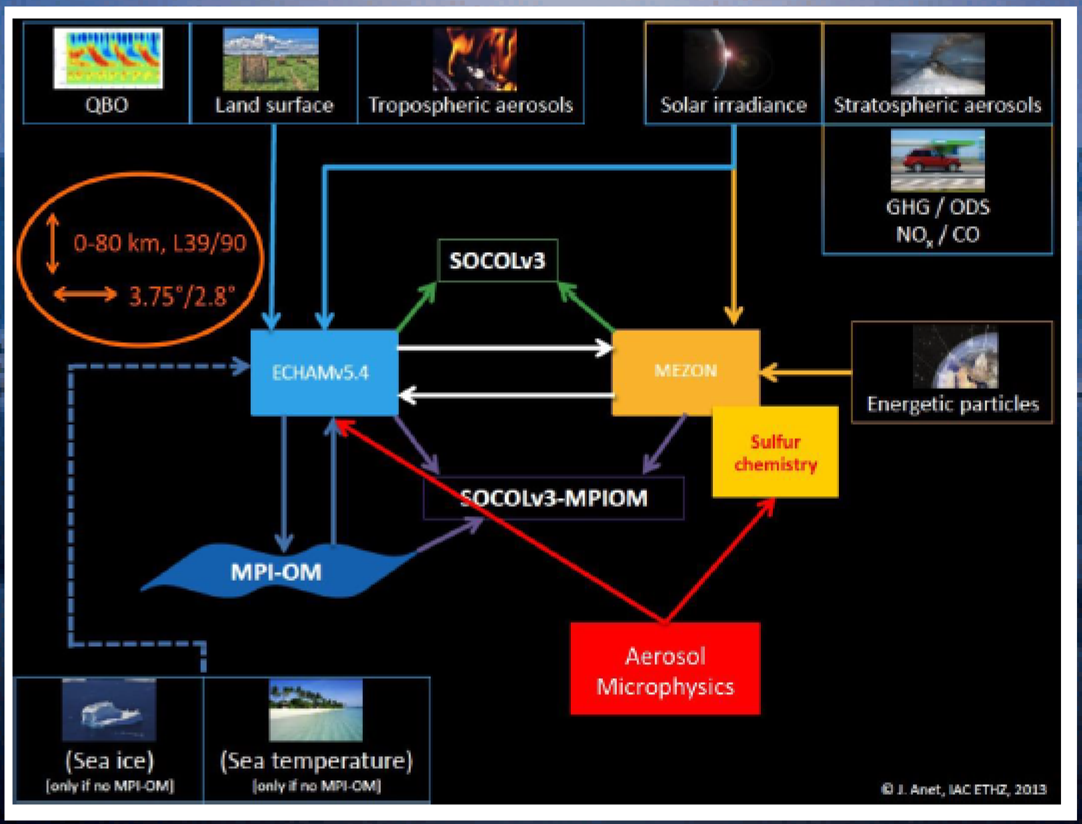
2020 Low and Upper Stratosphere Ozone, ClO and NO_2

2025 St.Petersburg and Moscow





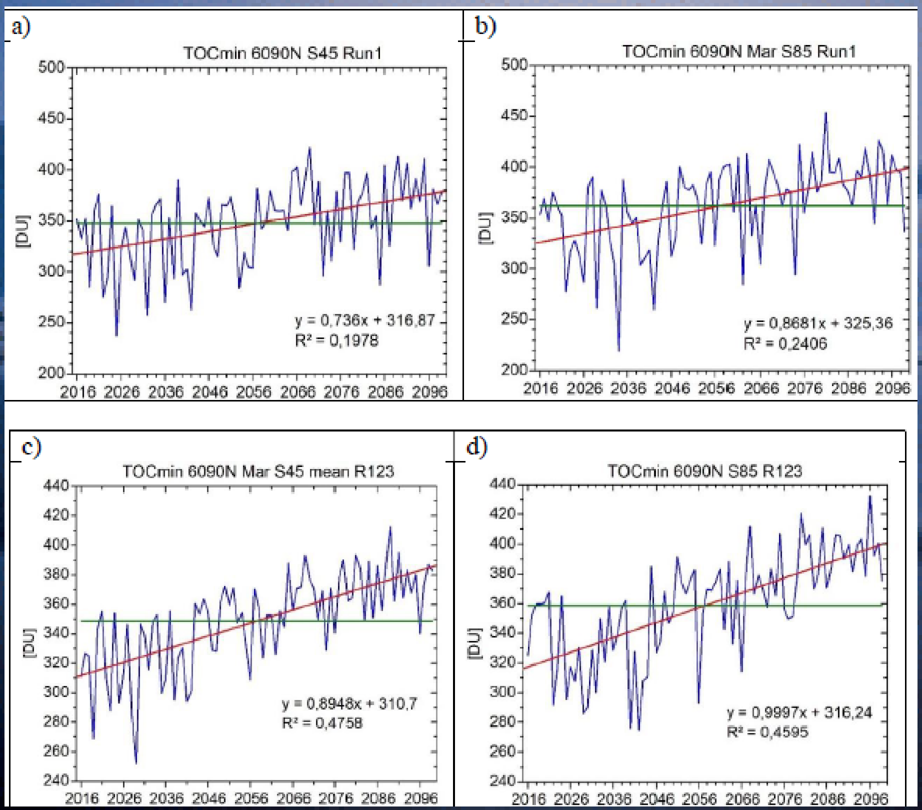
SOlar Climate Ozone Links (SOCOL) Chemistry-Climate Model

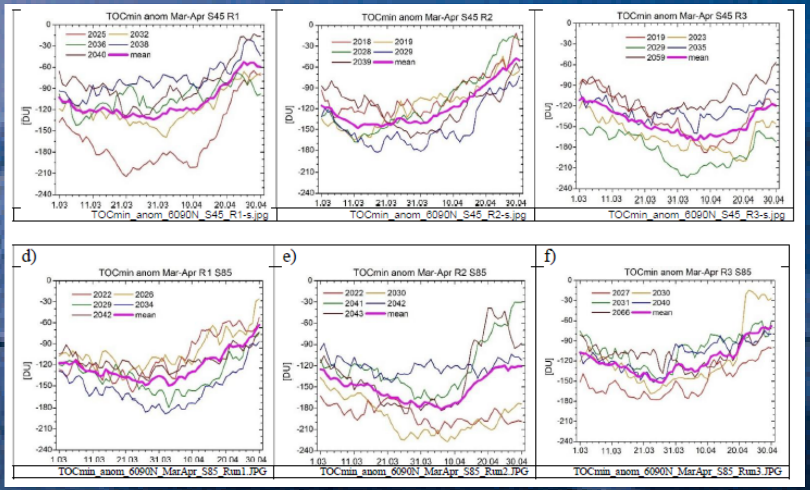


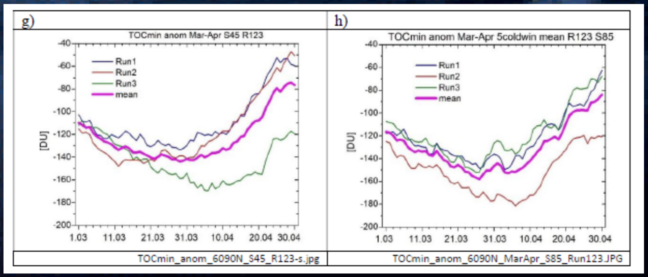
- SOCOL is a comprehensive chemistry-climate model, covering the atmosphere from the Earth's surface up to the mesosphere (about 80 km). The current SOCOL generation consists of the middle atmosphere version of the general circulation model (GCM) MA-ECHAM5 and a modified version of the UIUC (University of Illinois at Urbana-Champaign) atmospheric chemistry-transport model MEZON. The chemistry module covers stratospheric homogeneous and heterogeneous ozone chemistry and the most relevant chemical processes for describing the tropospheric background chemistry including an isoprene oxidation mechanism. SOCOL can be run at different horizontal resolutions (spectral truncation T31 or T42) and vertical levels (39 or 90). Depending on the application SOCOL can be run with a mixed-layer or a deep ocean module or with the comprehensive sulfate aerosol module AER (Sheng et al., 2015). A detailed description and evaluation of the current model version SOCOLv.3 is presented by Stenke et al. (2013).

Future Arctic Ozone

	Расчет 1	Расчет 2	Расчет 3
SSP2-4.5	2025 2032 2036 2038 2040	2018 2019 2028 2029 2039	2019 2023 2029 2035 2059
SSP5-8.5	2022 2026 2029 2034 2042	2022 2030 2041 2042 2043	2027 2030 2031 2040 2066







CONCLUSIONS

- There is no sign yet of ozone layer recovery in the Arctic and Subarctic.
- Tendencies for ozone miniholes to deepen are worsening.
- The main cause of the periodic deepening of ozone miniholes in the Arctic are dynamical processes that determine the stability of the polar vortex, possibly related to climate change.
- Chemical ozone destruction is largely determined by gas-phase reactions and heterogeneous reactions on sulfate aerosol.
- Heterogeneous reactions on polar stratospheric clouds contribute significantly to the formation of ozone miniholes, but inhibit gas-phase destruction in nitrogen catalytic cycles.
- Ozone anomalies in the Subarctic are significant and associated with Arctic miniholes.
- Under optimistic scenarios, the formation of ozone miniholes may weaken in the future, but short-term ozone depletion may still occur throughout the 21st century.


Thanks for Your Attention!!!