Global ozone depletion and increase of UV radiation caused by pre-industrial tropical volcanic eruptions

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Abstract

Large explosive tropical volcanic eruptions inject significant amounts of gases into the stratosphere, where they disperse globally through the large-scale meridional circulation. Halogens from tropical eruptions have been thought to be negligible based on observations of the largest eruptions of the satellite era, and thus most studies focus on sulfuric acid aerosols. More recent observations and plume modeling indicate that explosive volcanism can be a big source of halogens to the stratosphere. Here, we present the first study, based on observations, of sulfur, chlorine and bromine releases from tropical volcanic eruptions from the Central American Volcanic Arc over the last 200 ka combined with state-of-the-art coupled chemistry climate model simulations using CESM1(WACCM). The simulations reveal global, long-lasting impact on the ozone layer affecting atmospheric composition and circulation for a decade. Column ozone drops below 220 DU (ozone hole conditions) in the tropics, Arctic and Antarctica, increasing biologically active UV by 80 to 400%. Given the current decline in anthropogenic chlorine, halogen and sulfur rich explosive tropical eruptions may become the major threat to the future ozone layer.

Model and experiments

WACCM model

- CESM1(WACCM) (Marsh et al., 2013)
- High top version of Community Atmosphere Model (CAM4)
- 66 vertical layer; model top at 5.1 x 10^{-6} hPa (~150 km)
- 1.9x2.5 horizontal resolution
- MOZART middle atmosphere chemistry
- Prescribed SSTs
- Preindustrial atmospheric composition

Average CAVA eruption parameters and implementation:

- Location: 15N, 91W
- Injection altitude: 30 hPa
- Injected chlorine: 2.9 Mt (Kutterolf et al, 2015)
- Injected bromine: 9.5 kt (Kutterolf et al, 2015)
- Assumed halogen injection to the stratosphere: 10% (Textor et al, 2003)
- Degassed sulfur: 5.7 Mt (Metzner et al, 2014)
- Sulfur aerosol forcing implemented using prescribed WACCM forcing for 1982 El Chichon eruption (SPARC, 2006)

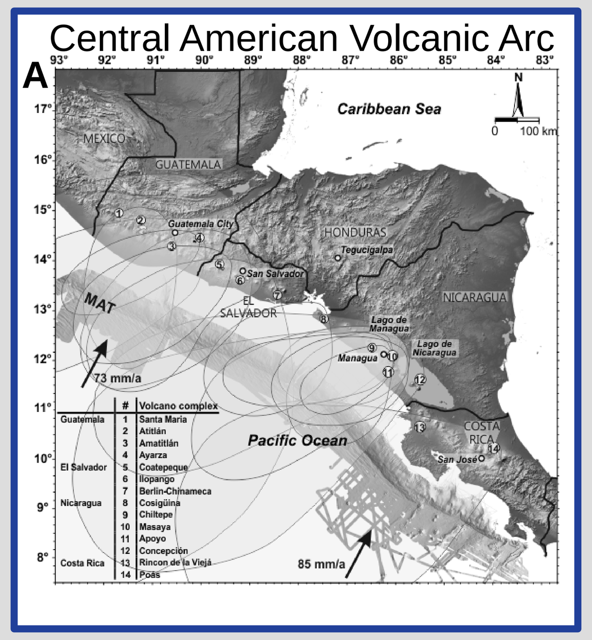
Experiment summary				
Experiment names	CTR	Halog+SAD	Halog	SAD
Simulations	1x30 yrs	8x12 yrs	8x12 yrs	8x12 yrs
Halogen input	N/A	Yes	Yes	No
Sulfur forcing	N/A	Yes	No	Yes

Conclusions

Our pre-industrial simulations show:

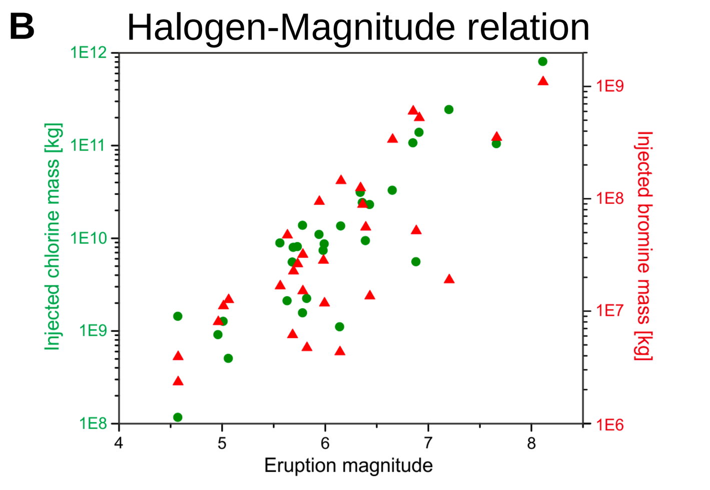
- A combined sulfur and halogen injection leads to global stratospheric halogen enhancement ad ozone depletion lasting ~10 years (Box 1,2).
- Interaction between sulfur aerosols and halogen gas to deepen ozone depletion (Box 2).
- Multi-year Antarctic ozone depletions on the scale of modern ozone holes (Box 4).
- Strong global and regional increases in surface ultraviolet radiation (Box 5).
- More than 80% increase over large parts of the populated NH and < 400% in the Antarctic (Box 5).
- Potentially large impacts on human health, agriculture and the environment (Box 5).
- UV anomaly might be detectable in ice core or plant pollen proxies.
- Halogen-rich eruption reduces the EQ-NP temperature gradient during the first post-eruption winter (Box 6).
- NH polar vortex significantly weakens the first post-eruption winter (Box 6).
- During years 3-6 NH polar vortex is strengthened during SON, with extensions to the surface during DJF (Box 6).
- The same pattern is seen over the NH polar regions during JJA of years 1-3 (Box 6).

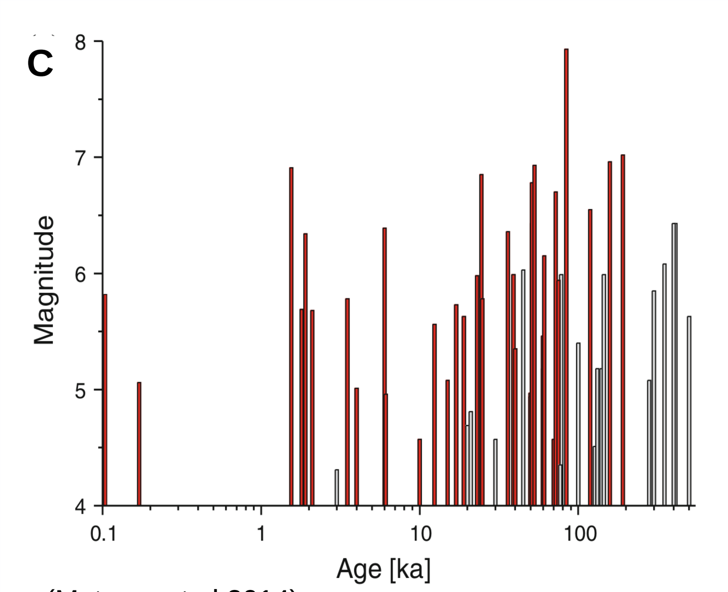
Background



Central American Volcanic Arc:

- One of the most volcanically active regions in the world (A)
- Large halogen-rich eruptions are common (B,C).
- An almost complete dataset of sulfur (Metzner et al, 2014), chlorine and bromine (Kutterolf et al 2013, Krüger et al 2015, Kutterolf et al, 2015) from past 200 kyrs is available.
- Recurrence time of ~130 years for Magnitude > 6 eruptions (Metzner et al 2014).
- Potential for large halogen injections to the stratosphere (B,C).
- Relevance for the 21st century as ozone depleting substances (ODSs) decline.
- Input to pre-indurstrial coupled chemistry climate model simulations.
- Recent observations support halogen injection to the stratosphere from small and moderate volcanic eruptions (e.g. Carn et al 2016).

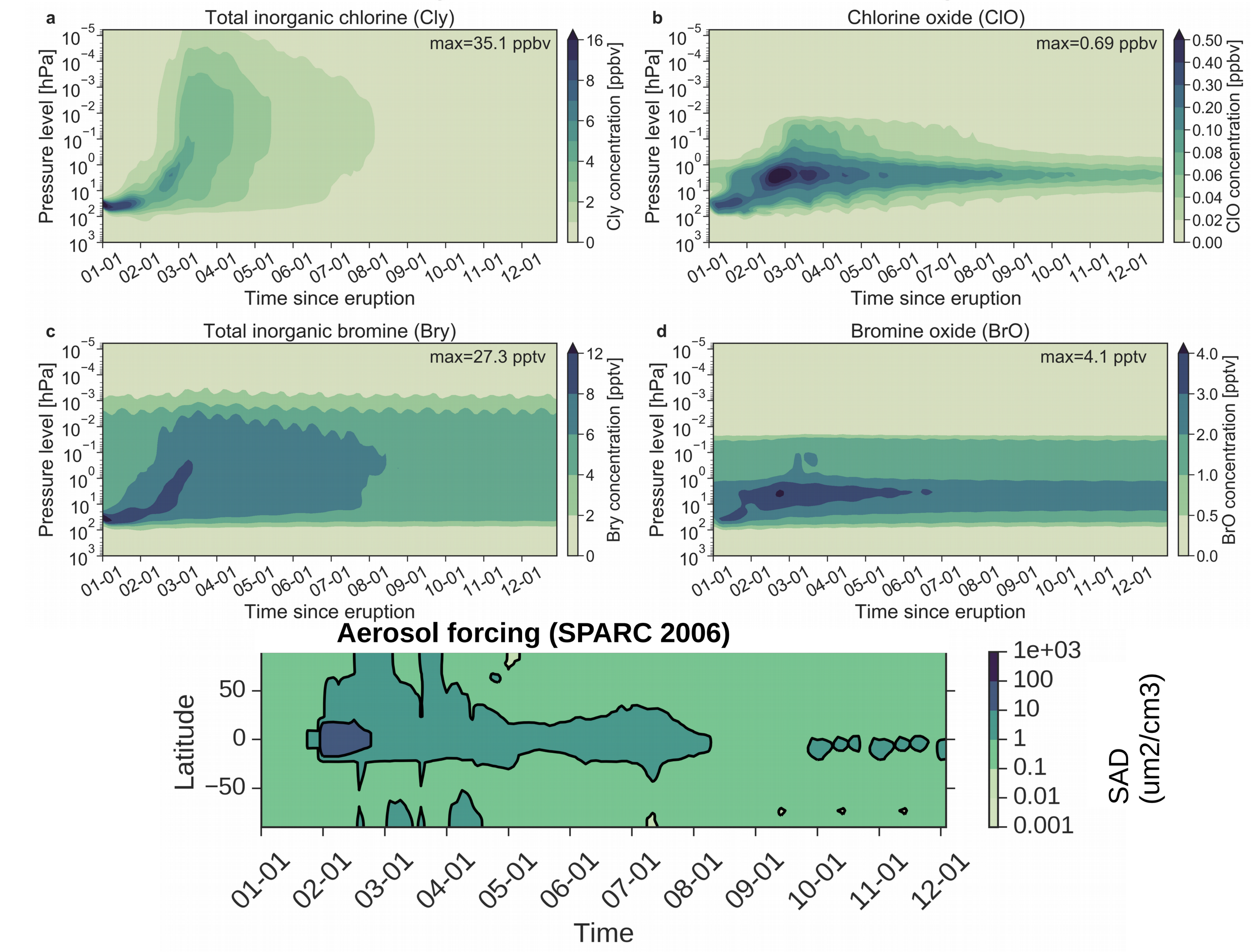




(Metzner et al 2014)

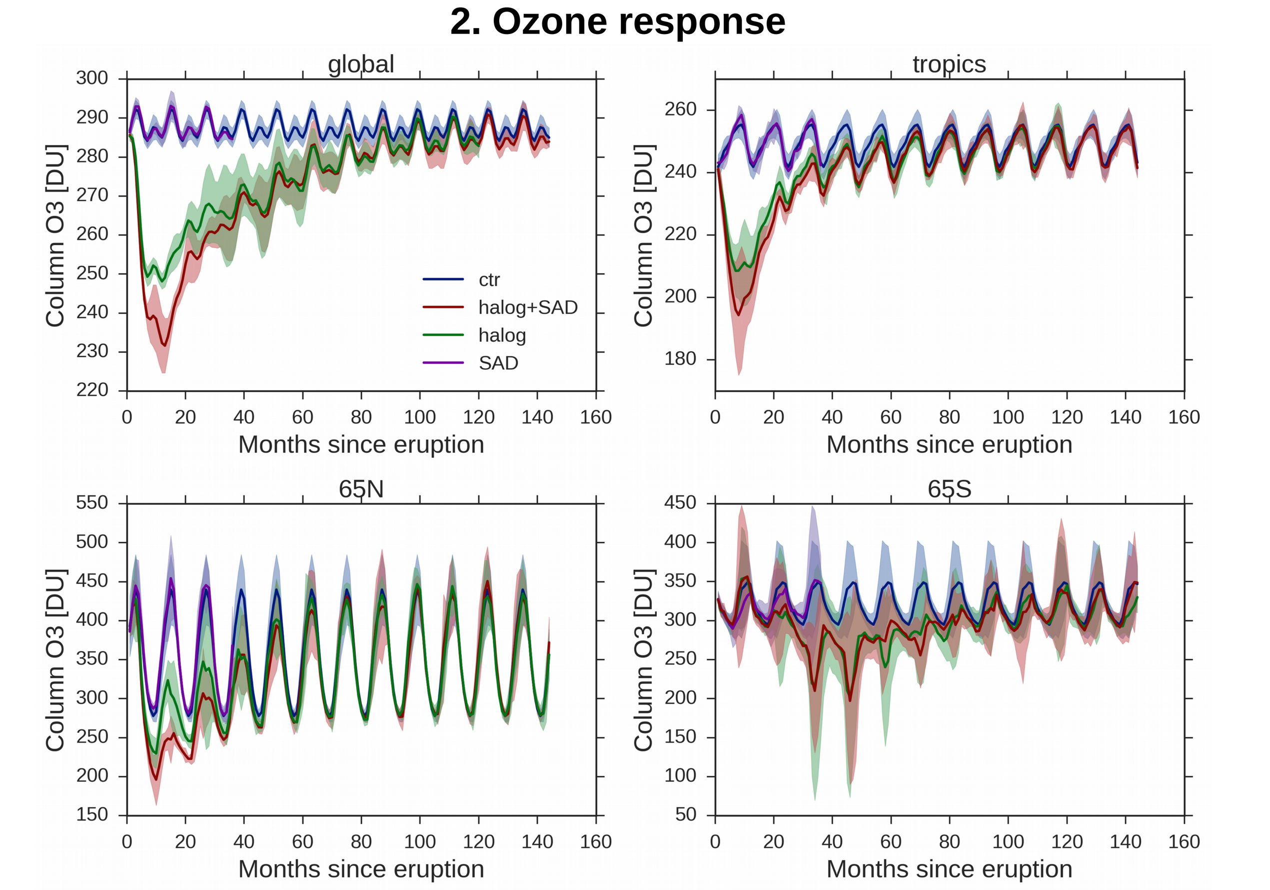
Results

1. Halogen and sulfur aerosol forcings



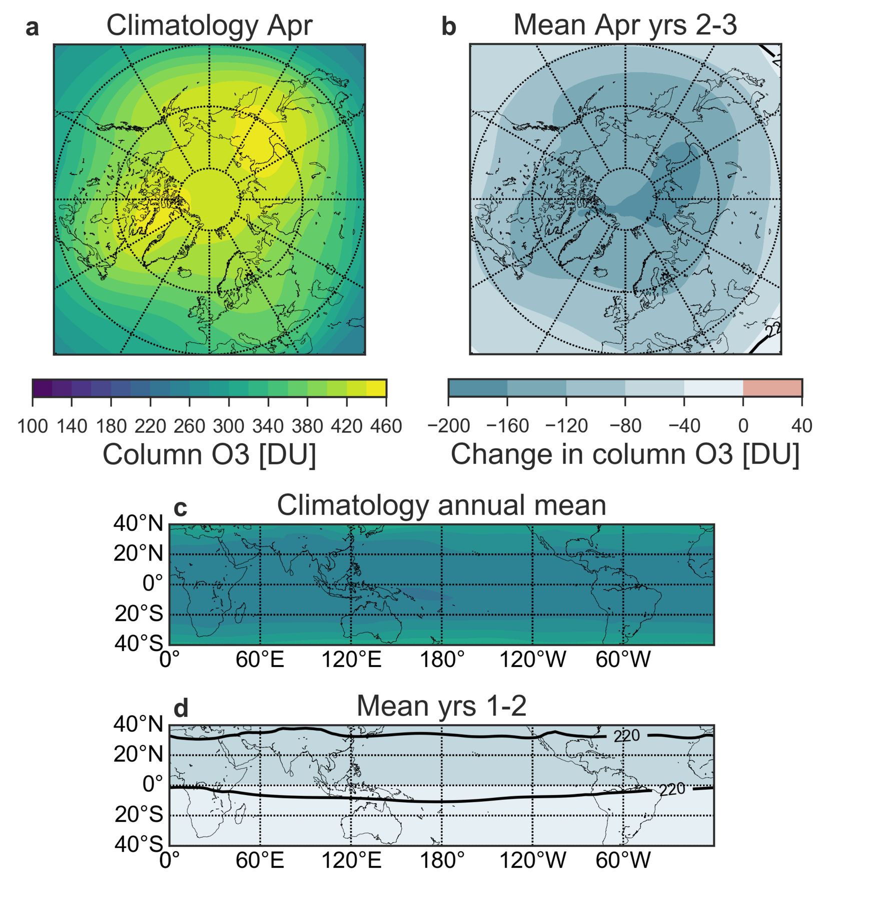
Stratospheric halogen enhancement lasts ~10 years.

2. Ozone response



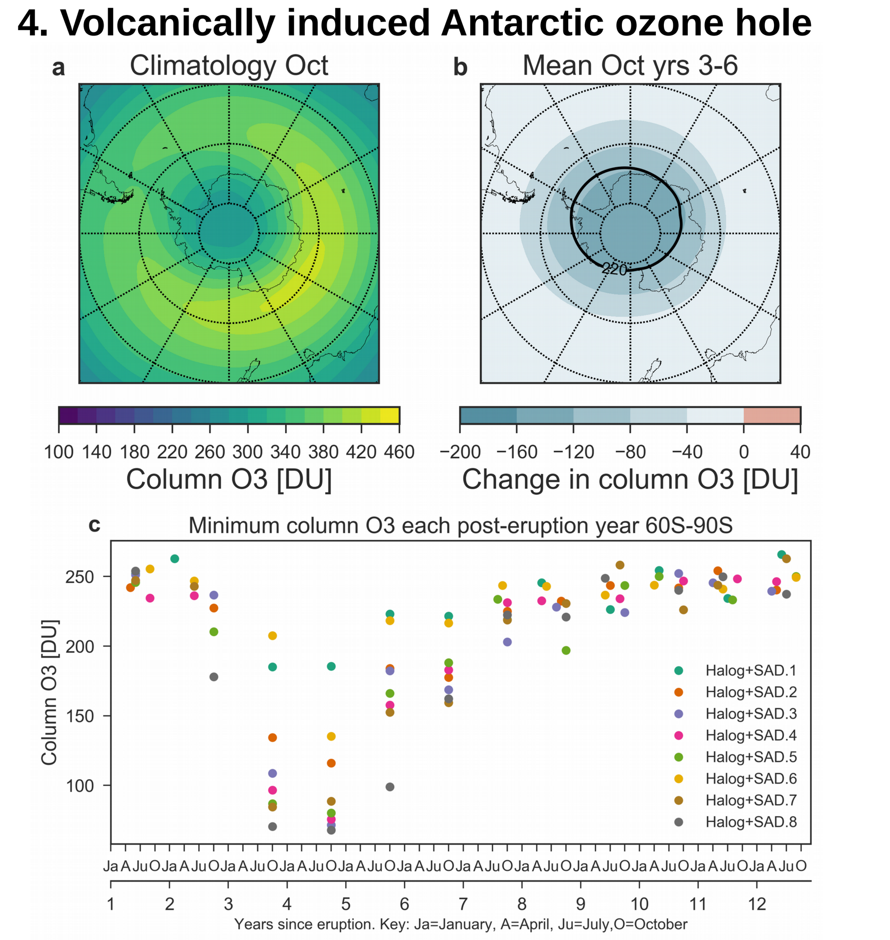
Global ozone depletion lasts a decade, strong regional responses.

3. Strong Arctic and tropical ozone responses



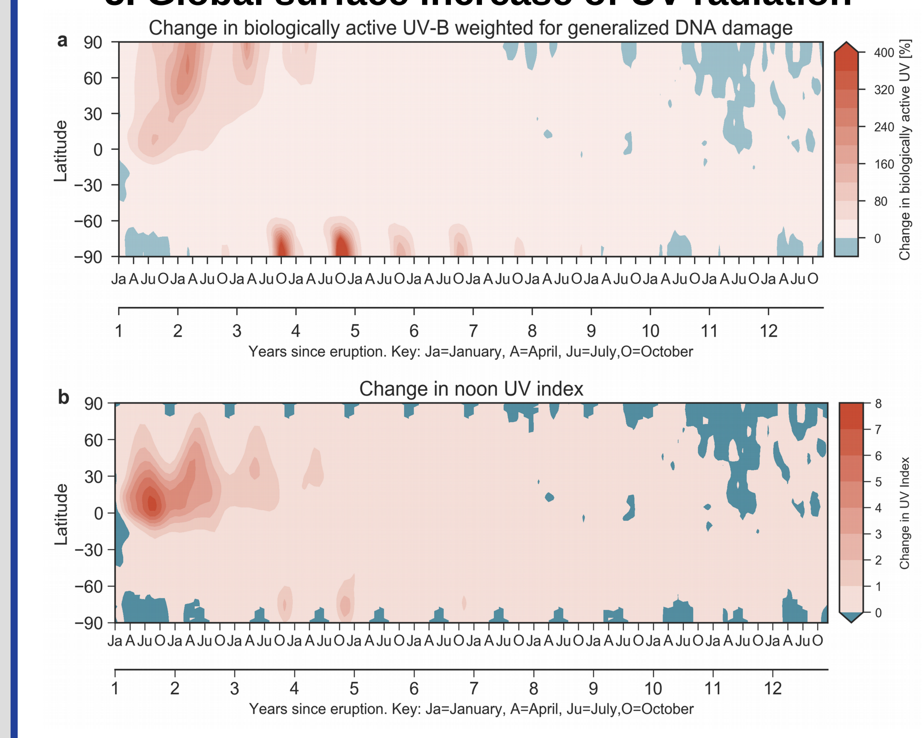
Tropics are below 200 DU for a period of 2 years. Large ozone depletions over the Arctic.

4. Volcanically induced Antarctic ozone hole



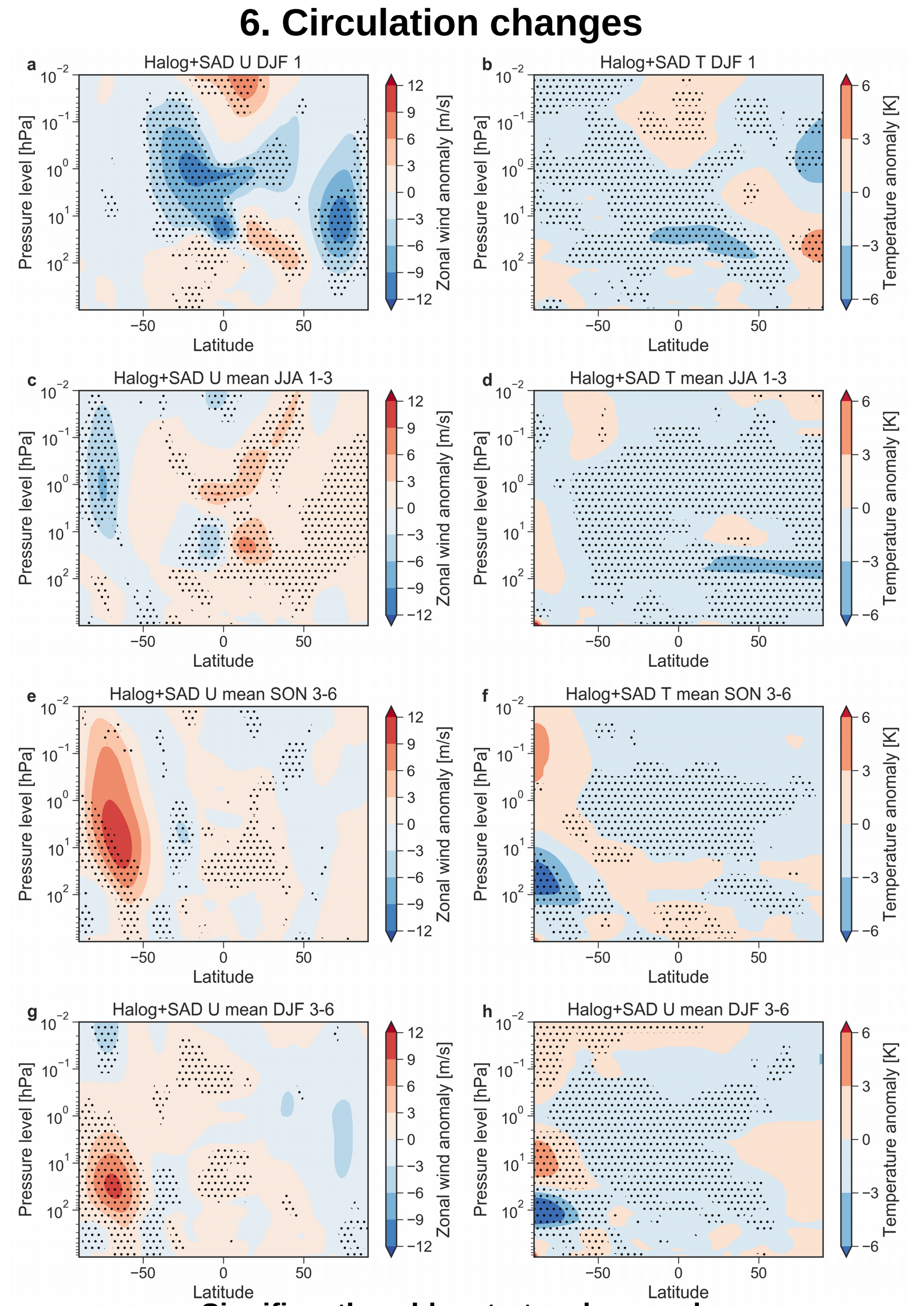
Antarctic minimum ozone values below 100 DU.

5. Global surface increase of UV radiation



Ozone depletion causes enhancement of up to 400% of surface UV radiation .

6. Circulation changes



Significantly colder stratosphere and strengthening of the polar vortices.

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