Middle Atmosphere Circulation

Impact of Meteorological Forcing on the Lifetime of a Long-Lived Tracer of Atmospheric Circulation

Sarah Vervalcke, PhD student at ULiège
sarah.vervalcke@aeronomie.be

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ROYAL BELGIAN INSTITUTE FOR SPACE AERONOMY

27.03.2025

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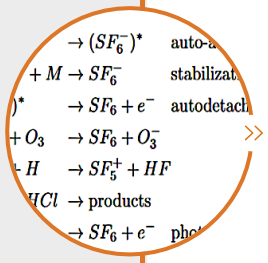
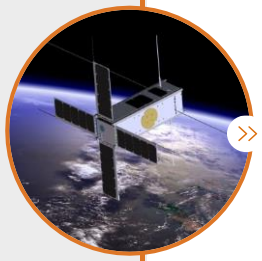
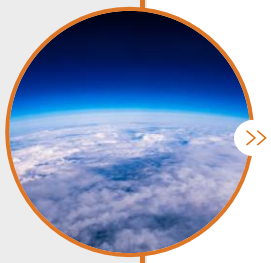
Middle atmosphere circulation



The BASCOE model



Trace gas lifetimes



Conclusions

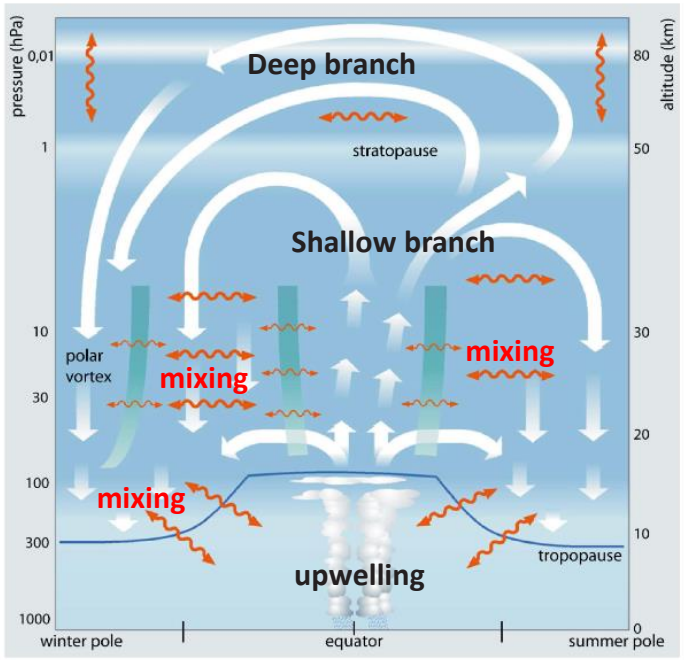
Middle atmosphere circulation

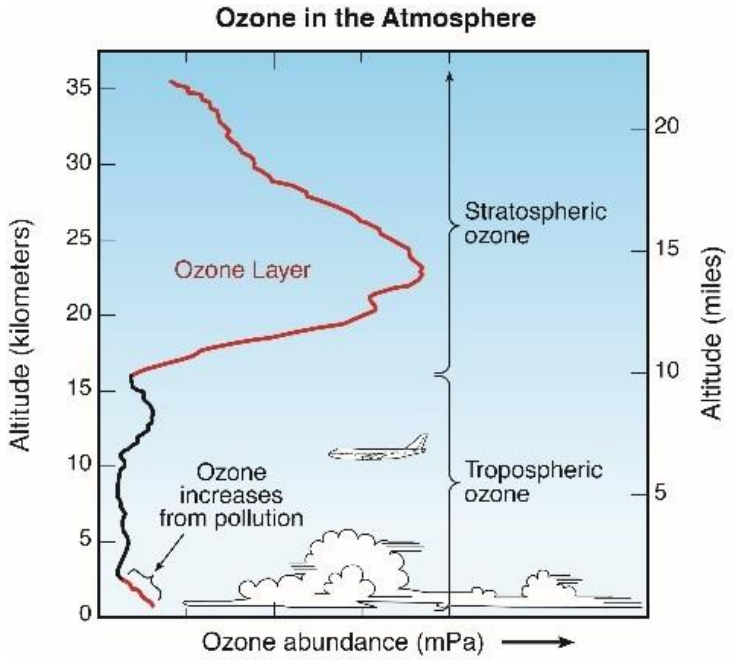
Middle atmosphere = upper troposphere (tropopause region) + stratosphere + mesosphere + lower thermosphere

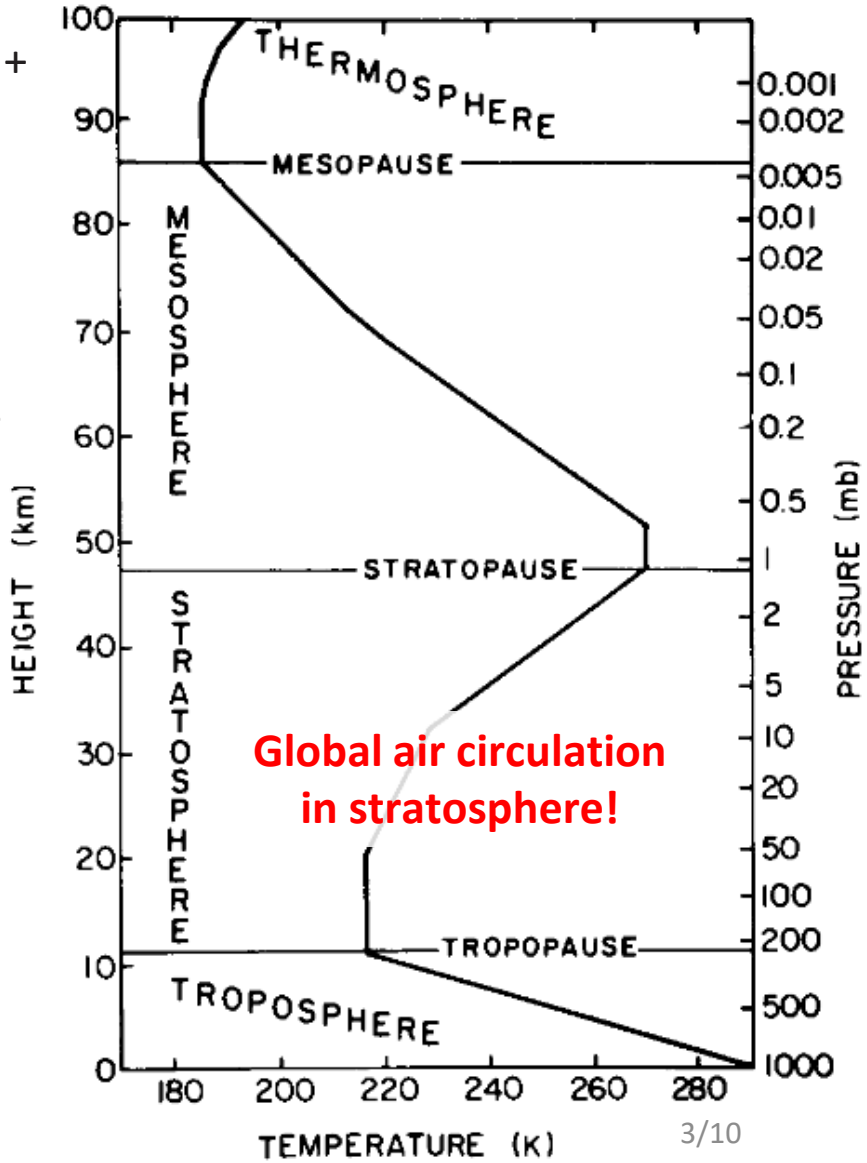
Why study atmospheric circulation?

- 🛡️ Stratospheric ozone layer! Protects us from UV radiation.
- 🌍 Distribution of (greenhouse) gases…
- 📈 Making better predictions for the state of the atmosphere.

Brewer-Dobson circulation

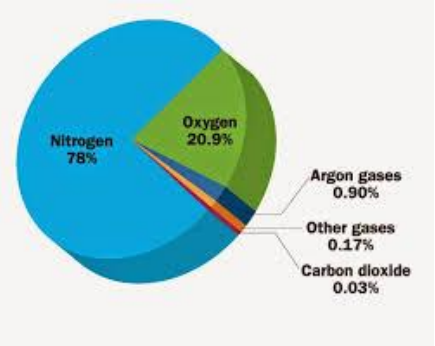






Middle atmosphere circulation

How to measure the Brewer-Dobson circulation?
Follow **trace gas concentrations**! (< 1% of atmos. composition)

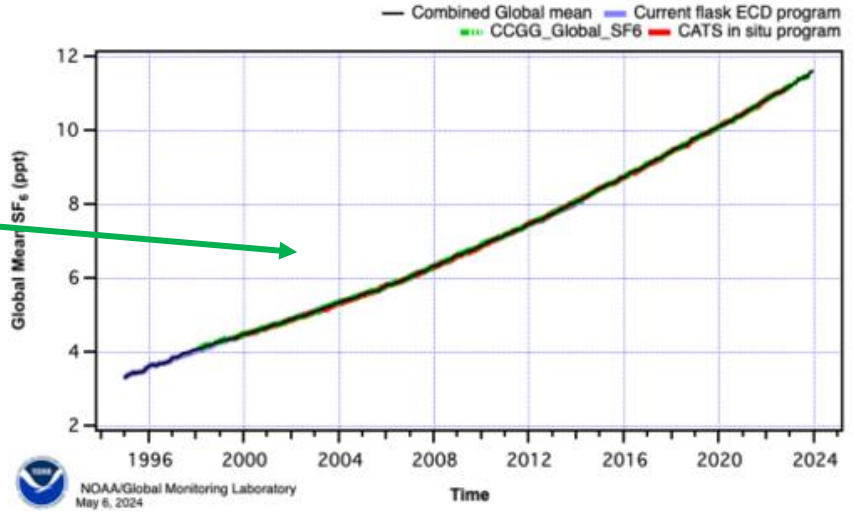


What makes **a perfect BDC tracer**?

🧪 Simple chemistry: source in the troposphere, inert in rest of atmosphere
⏳ Long-lived: tracer needs to reach various parts of the atmosphere
📈 Linear increase in source-region: the source is not variable over time

Perfect tracers do not exist… We compromise:

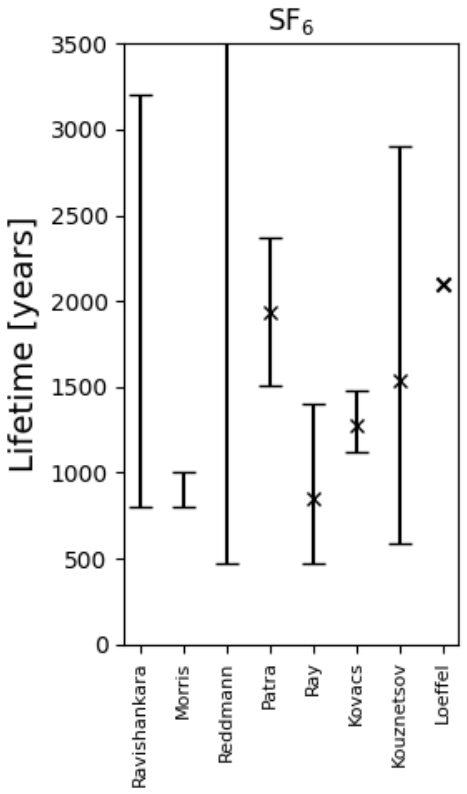
- Almost inert can already tell us something
- Almost linear increase can be corrected



Good candidates:

- Sulfur hexafluoride (SF_6): destruction in the mesosphere
- Carbon dioxide (CO_2): seasonal variations in the troposphere due to 🌿 cycles

Middle atmosphere circulation



🔍 **Focus on SF_6…**

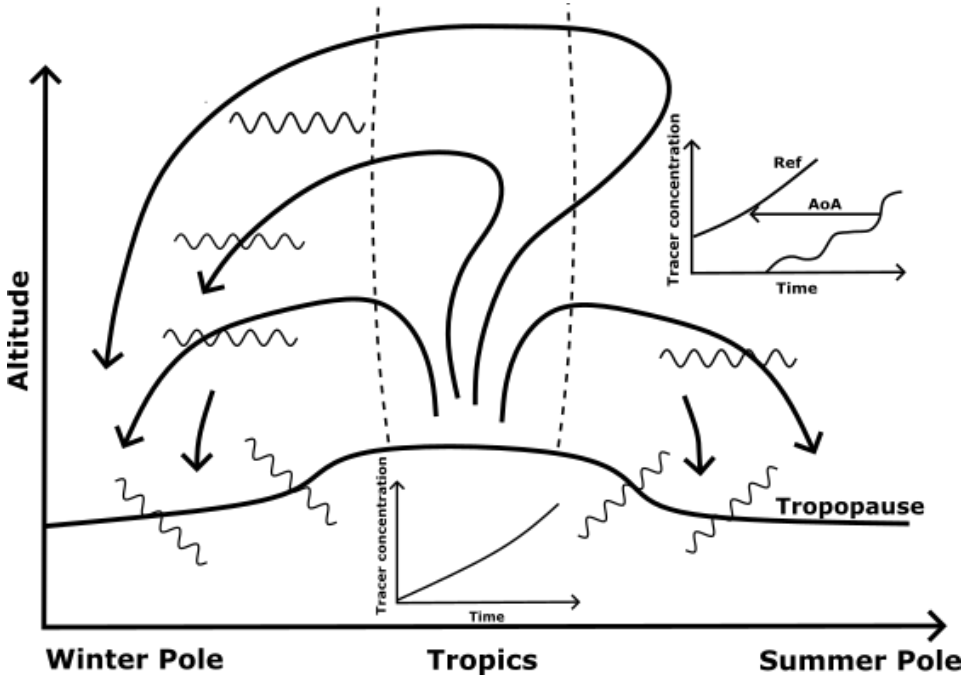
Use SF_6 concentrations to compute transit time (age of air) of an air parcel from source region (troposphere) to stratosphere.

SF_6 = greenhouse gas! Important for climate.

⏱️ **SF_6 atmospheric lifetime** ???
For reference: CO_2 lifetime is 5-200 years

No consensus on SF_6 lifetime

Compute lifetime to…
- see if our model works
- add a lifetime value to the list
- assess transport in the model?



The BASCOE model

Belgian **A**ssimilation **S**ystem for **C**hemical **O**bs**E**rvations

⚙️ Based on a chemistry transport model (CTM)
🌡️ User needs to provide meteorology (winds and temperature) to drive the model
💻 Computes volume mixing ratios of gases in the atmosphere by solving chemical equations

Different meteorologies have different transport characteristics (speed etc)…
For this study we use three **reanalysis data** sets.

ECMWF — ERA5, Hersbach et al. 2020, Q.J.Roy.

NASA GMAO — MERRA2, Gelaro et al. 2017, J.Clim.

気象庁 Japan Meteorological Agency — JRA-3Q, Kosaka et al. 2023, JMSJ

Input for 3 different BASCOE simulations!

The BASCOE model

Questions

👀 What do observations tell us? Do they agree with the model?

→ Use MIPAS (2002-2012) and ACE-FTS (2004-…) satellite observations

→ Test different chemical species*

⚙️ What is the effect of choosing one data set over another on our simulations?

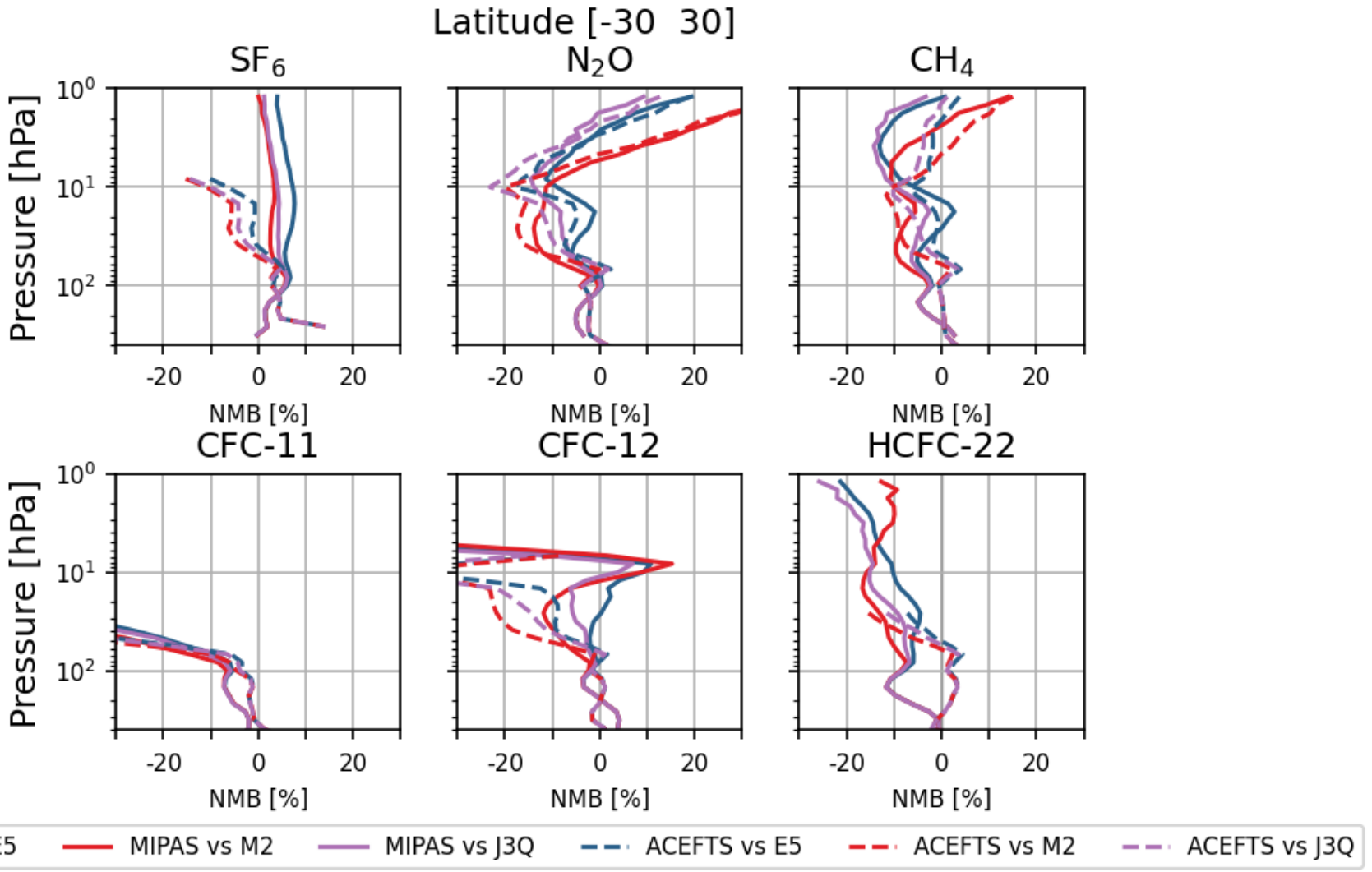
→ Chemistry of SF_6 important in upper atmosphere

→ Driving data sets disagree in this region

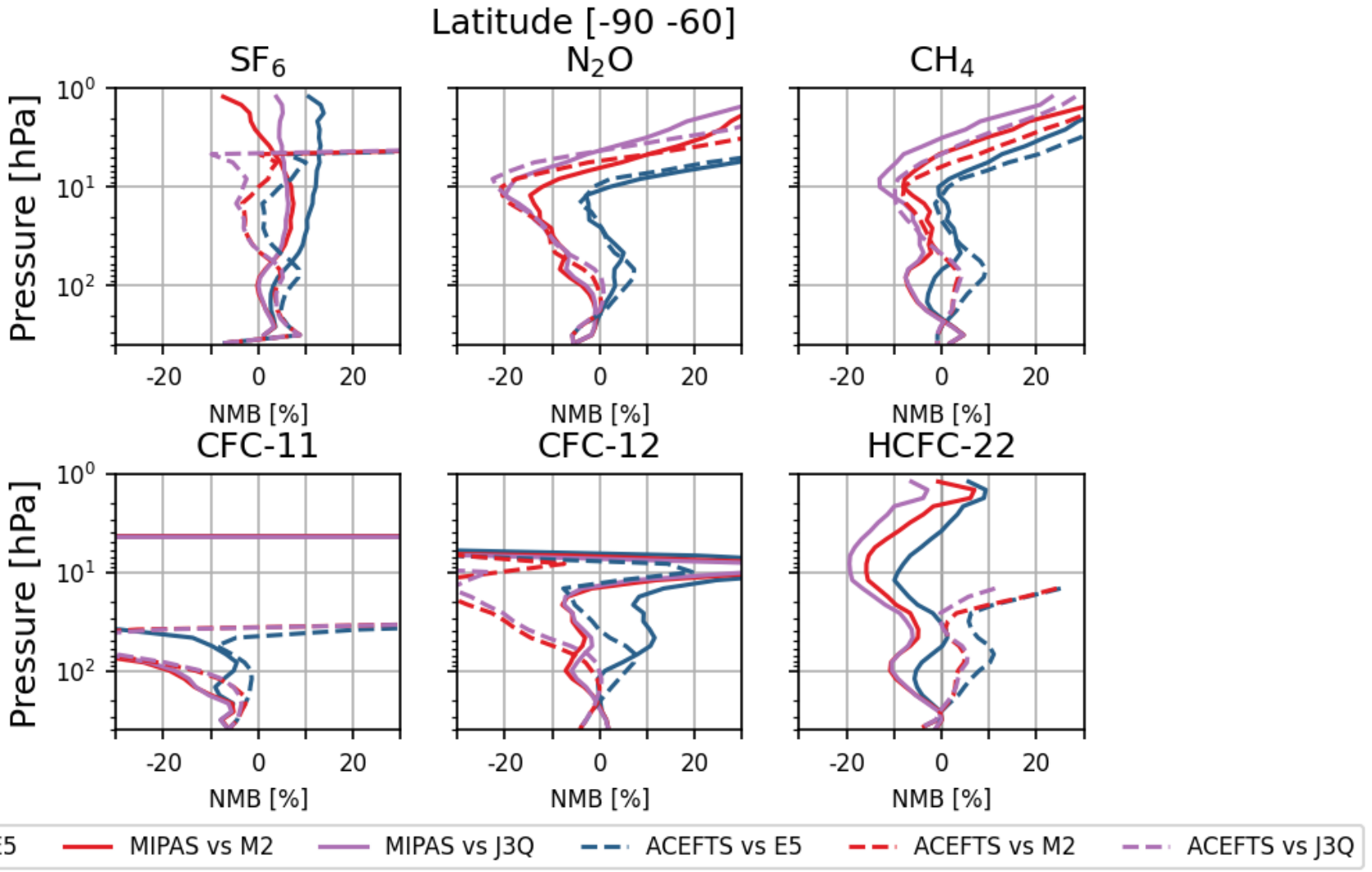
→ Test different chemical species*

* SF_6, N_2O, CH_4, CFC-11, CFC-12 and HCFC-22

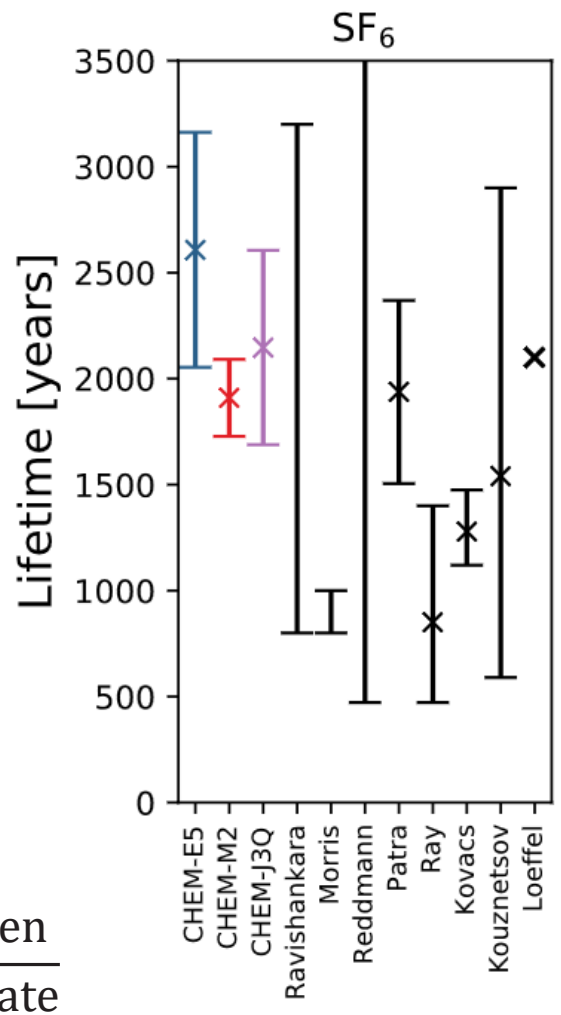
The BASCOE model (vs observations)

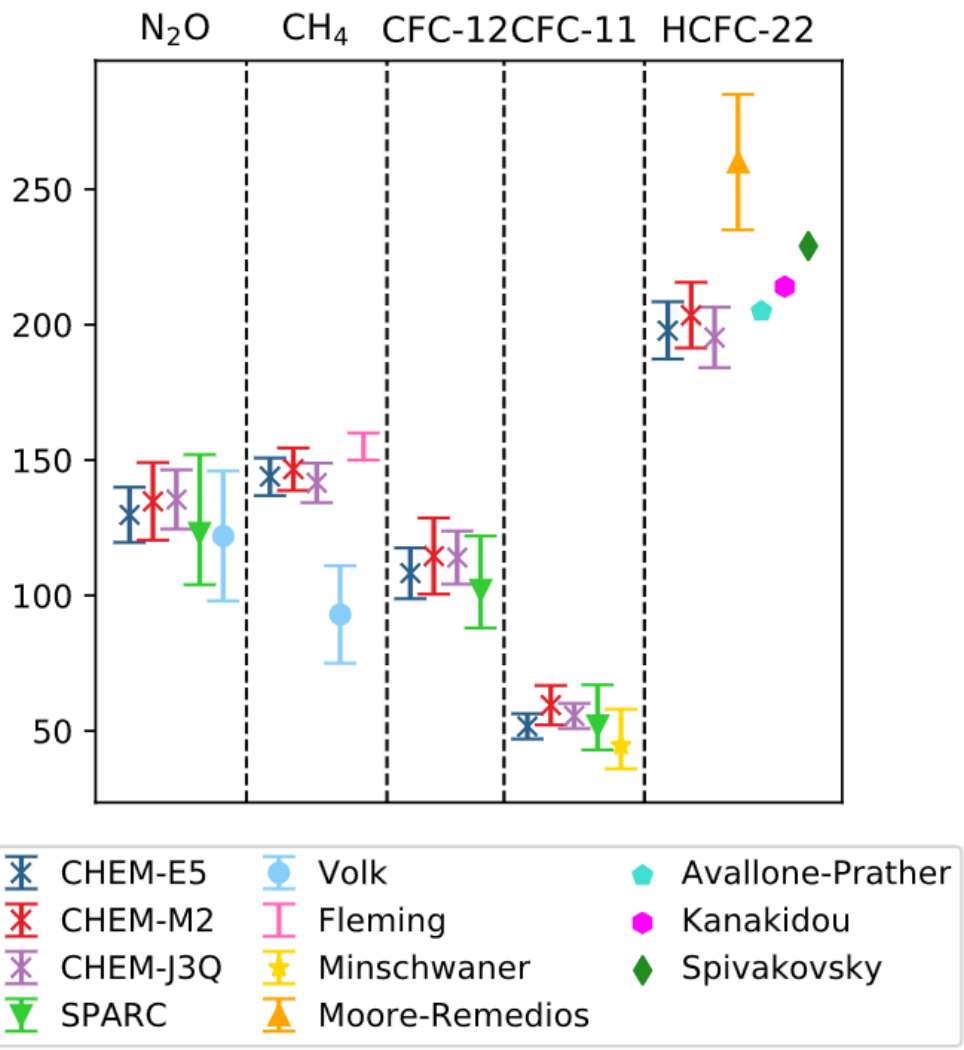


The BASCOE model (vs observations)



Trace gas lifetimes

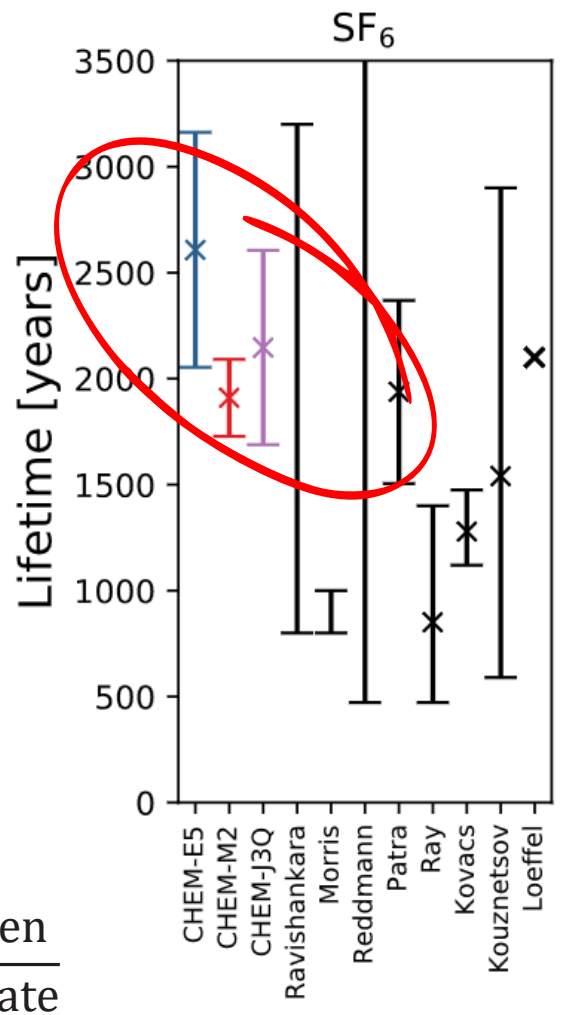


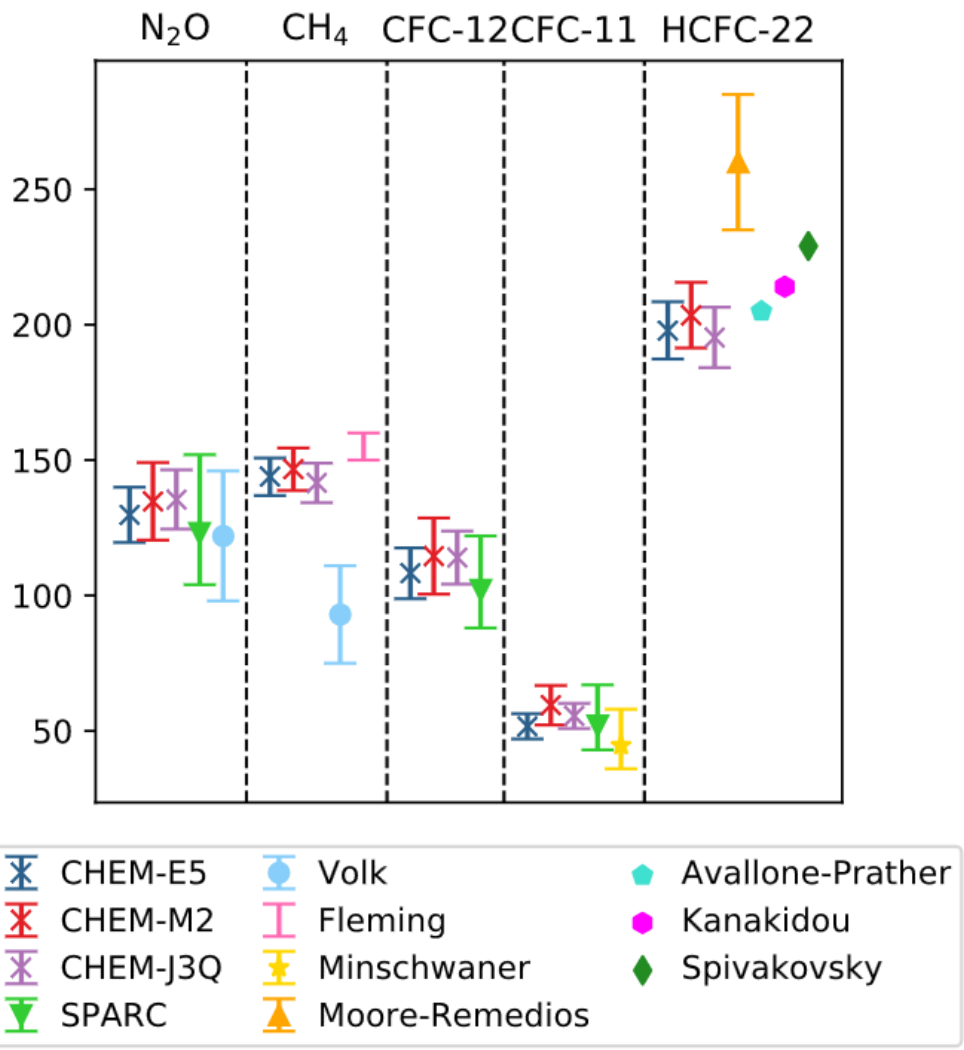


$$\tau = \frac{\text{atmospheric burden}}{\text{atmospheric loss rate}}$$

Average 2002-2012

Trace gas lifetimes





$$\tau = \frac{\text{atmospheric burden}}{\text{atmospheric loss rate}}$$

Average 2002-2012

Conclusions

- BASCOE simulations of trace gases agree well with MIPAS and ACE-FTS
- SF6 lifetime is very sensitive to meteorology due to the mesospheric sink
- Lifetimes of other long-lived gases agree well between different meteorologies
- ERA5 produces longer lifetime for SF_6 than MERRA2, but shorter lifetime for the other species

Image credits

- Middle Atmosphere temperature profile: Holton, J. R., Andrews, D. G., & Leovy, C. B. (1987). *Middle Atmosphere Dynamics* (Vol. 40). Academic Press Inc.
- Brewer-Dobson circulation: adapted from Bönisch et al. 2011, ACP
- Ozone layer:
  Stratospheric ozone: down and up through the anthropocene - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Vertical-ozone-profile-Most-ozone-resides-in-the-stratospheric-ozone-layer-Increases_fig9_332591878 [accessed 25 Mar 2025]
- SF_6 tropospheric increase: NOAA (n.d.). *Sulfur hexafluoride (SF6) - Combined Dataset.* Global Monitoring Laboratory. NOAA Global Monitoring Laboratory - Halocarbons and other Atmospheric Trace Species

THANK YOU!
MORE INFO?

www.aeronomie.be

sarah.vervalcke@aeronomie.be