Republic of Rwanda

THE KIGALI AMENDMENT 2016–2026

UN environment programme ozone secretariat

Vienna Convention MONTREAL PROTOCOL

MOP38

2-6 NOVEMBER 2026 | KIGALI, RWANDA

THIRTY-EIGHTH MEETING OF THE PARTIES TO THE MONTREAL PROTOCOL

VSLSS: A GROWING UNCONTROLLED THREAT TO THE OZONE LAYER

MONDAY
2 NOVEMBER 2026

13:00 - 15:00

MH2-A



Chlorinated very short-lived substances in the atmosphere: trends and significance

Steve Montzka, NOAA, with input from SAP co-chairs

Accra/Helsinki side event on VSLS's growing uncontrolled threat to the ozone layer
2 November 2026

Sources of information used in this analysis:

- 2022 & 2026 Scientific Assessment Panel Reports (WMO/UEP)
- The peer-reviewed scientific literature

  (e.g., An et al., 2021; Bednarz et al., 2023; Brioude et al., 2010; Claxton et al., 2019; Liang et al., 2025; Weubbles et al., 2011; Zhang et al., 2026)
- Data from NOAA and AGAGE (publicly available)

Focus of today's presentation:

- Some facts about VSLSs compared to long-lived ODSs
- Why a single ODP is not appropriate for VSLS
- Present-day abundances of chlorinated VSLS and contributions to stratospheric halogen
- shining a spotlight on CH_2Cl_2
- relevance to the ozone layer today and in the future

Thanks to colleagues at NOAA and AGAGE

VSLS have lifetimes in the troposphere of less than 0.5 yr *(SAP definition)*

VSLS are not typically controlled by the Montreal Protocol

- there are exceptions (CH_2BrCl, some HCFC isomers)
- some are produced in very large quantities (up to 50,000 kt/yr)

VSLS are currently estimated to account for about:

4% of total stratospheric chlorine

25% of total stratospheric bromine

For iodine, the VSLS contribution is not well quantified

The main VSLS in the current atmosphere (source gases):

For chlorine: CH_2Cl_2, $CHCl_3$, C_2Cl_4, 1,2-dichloroethane

Sources: solvents, foaming & cleaning agents, feedstocks, etc.

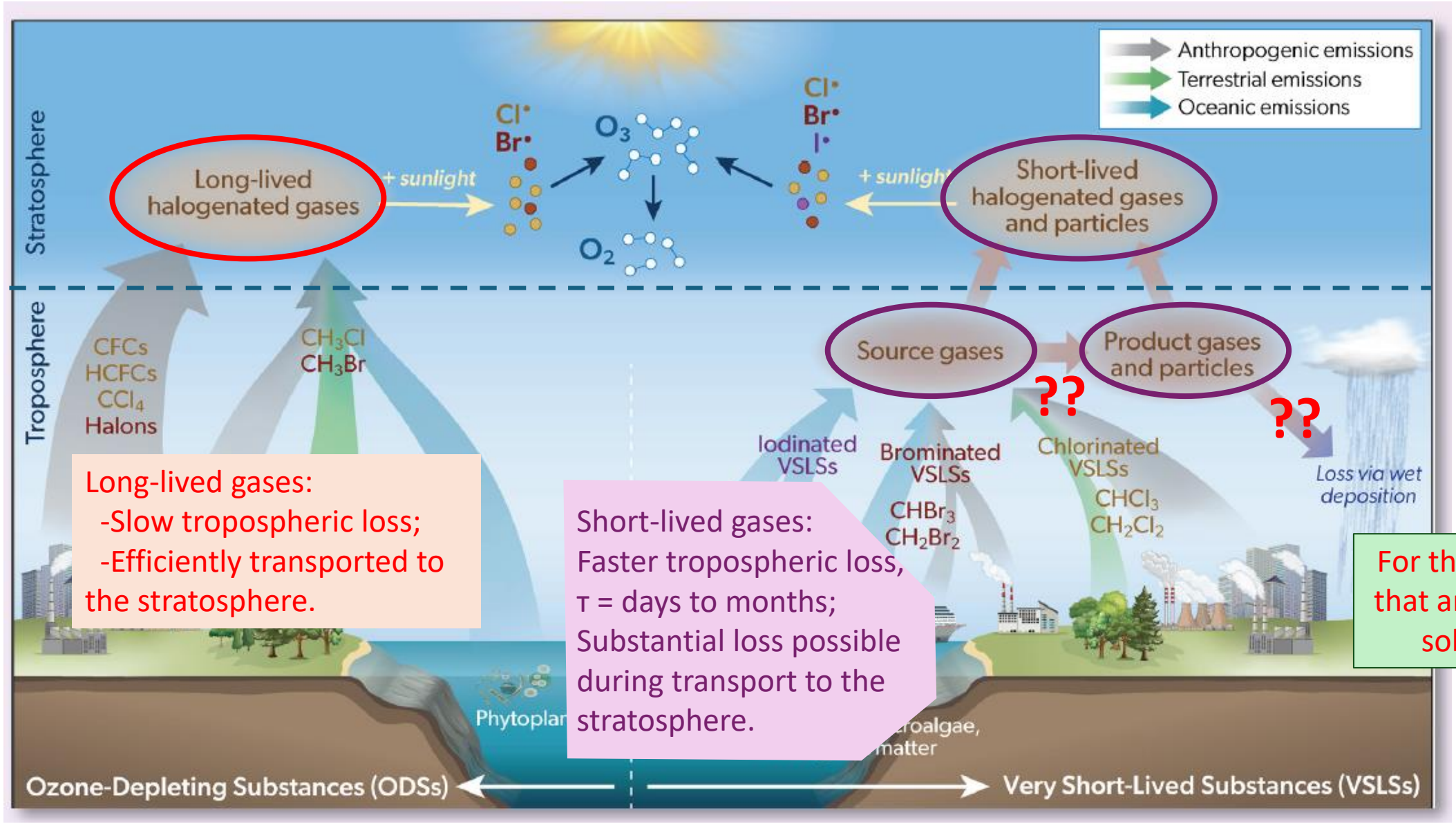
→ **predominantly human-derived**

For bromine: $CHBr_3$, CH_2Br_2, $CHBr_2Cl$

Sources: primarily from the ocean, with small anthropogenic sources (water treatment)

→ **predominantly natural**

VSLSs *versus* Long-lived controlled ODSs



From SAP Ozone Assessment Report, 2022, Box 1-3

Accurately estimating the fraction of a VSLS emission reaching the stratosphere and a VSLS ODP is more complicated than for long-lived gases

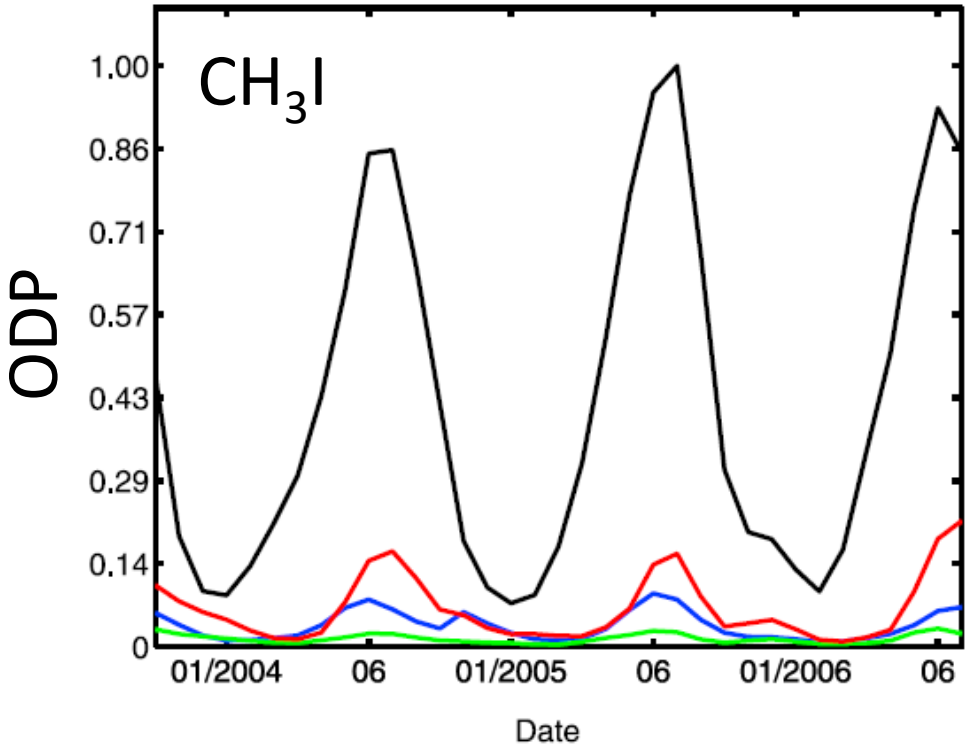
(*and it is more uncertain for the shortest-lived VSLS*)

* it relies on accurate simulations of

a) timescales associated with transport & loss and their balance

→ **which widely vary by region and season, monsoonal flow, etc.**

b) representations of heterogeneous chemistry in a model determines fate of any PG that is formed



CH_3I example, mean lifetime ~ 2 weeks

Indian sub-continent

Eastern Asia

Mid- north America

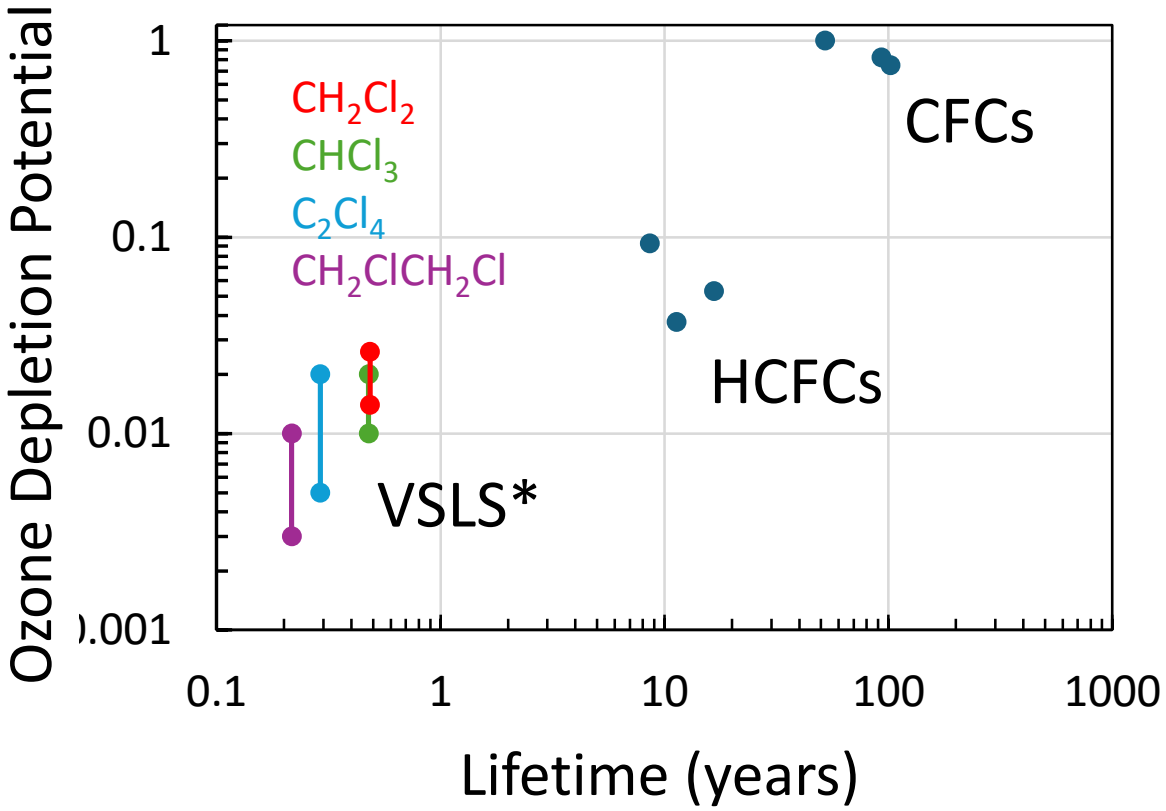
Europe

Brioude et al., 2011

The ODP of a CH_3I emission varies by orders of magnitude depending on the emission region, owing to:

- proximity of the emission to the tropics where air can be rapidly transported from the surface to the stratosphere

A chemical's ODP reflects in part it's atmospheric lifetime;
…and, for VSLS, is dependent on the emission region:



Compound	***ODP***
HCFC-22	0.037
HCFC-142b	0.053
HCFC-141b	0.093
* CH_2Cl_2	0.011 – 0.021
* $CHCl_3$	0.014 – 0.026
* C_2Cl_4	0.006 – 0.02
* CH_2ClCH_2Cl	0.003 – 0.01

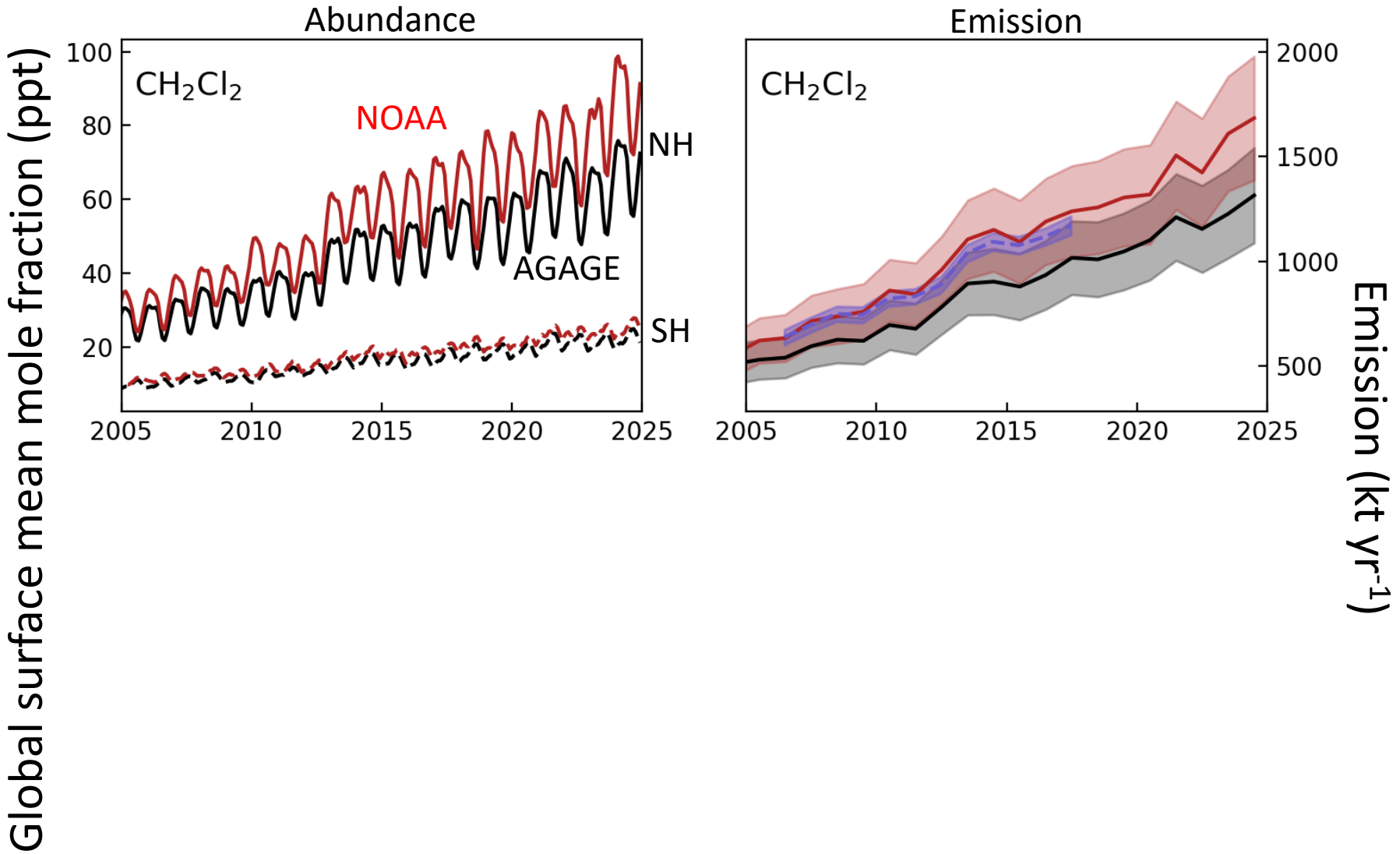
Ranges for VSLS represent variations in ODP for emissions from different regions or continents

- Based on modeling studies (APARC study ongoing):
Claxton et al., 2019; Bednarz et al., 2023; Wuebbles et al., 2011.

** For these longer-lived VSLS:*

- The ODPs for these VSLS are 10 to 70% as large as HCFC-22
- The ODP variations by region are factors of 2× to 3× (not 10× or more, per CH_3I)

Recent atmospheric trends for chlorinated VSLS:

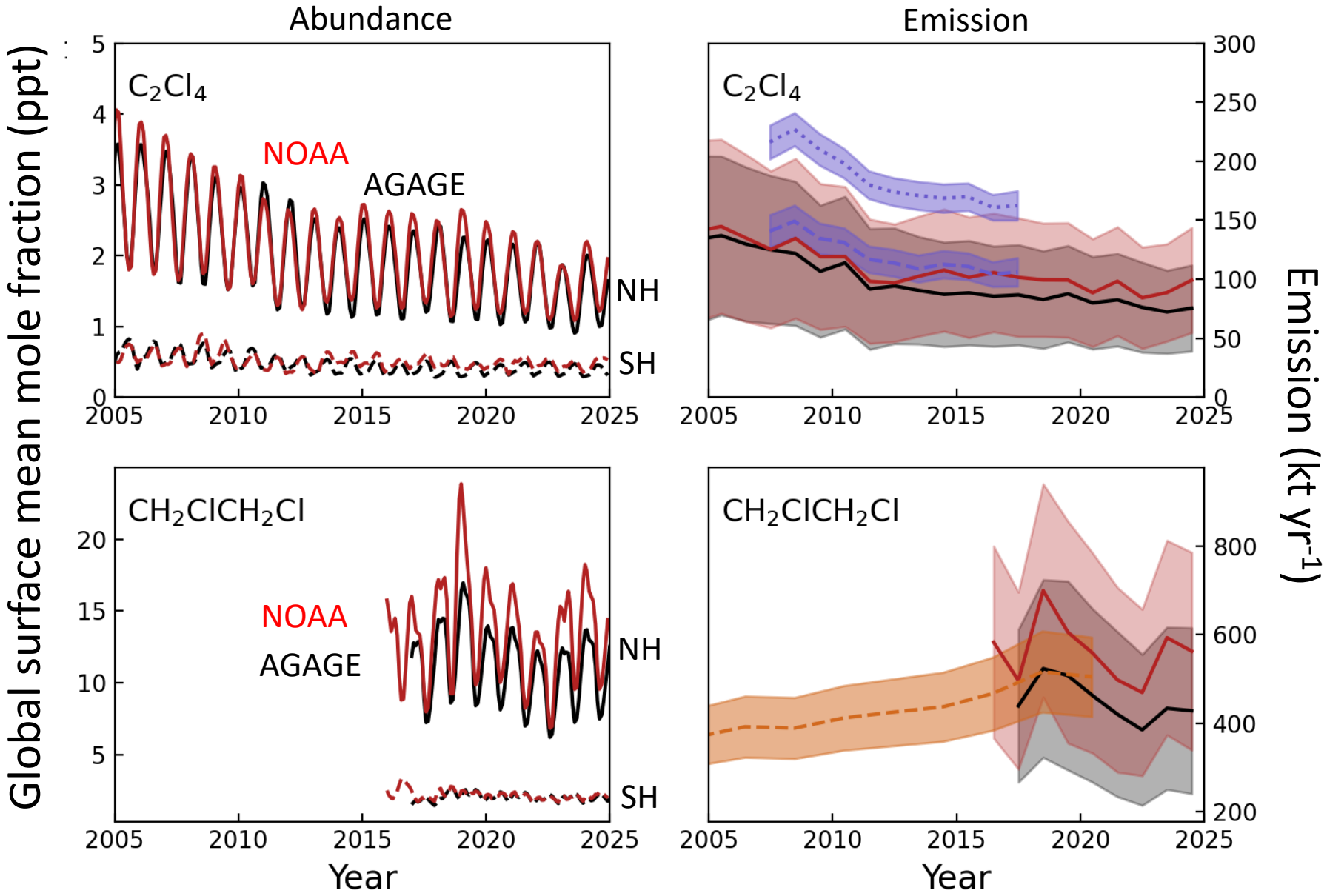


Contributions to tropospheric chlorine at Earth's surface:

CH_2Cl_2	100 ppt Cl

← Substantial natural contributions are apparent for $CHCl_3$

From SAP Ozone Assessment Report, 2026



Contributions to tropospheric chlorine at Earth's surface:

CH_2Cl_2	100 ppt Cl
$CHCl_3$	24 ppt Cl
C_2Cl_4	4 ppt Cl
CH_2ClCH_2Cl	14 ppt Cl
Others	??
Sum of these:	***142 ppt Cl***

VSLS Cl reaching the stratosphere (SG & PG) 140 ppt Cl

From SAP Ozone Assessment Report, 2026

Spotlight on CH_2Cl_2

*** Largest contributor to chlorine from VSLS**

-accounts for 70% of VSLS chlorine

*** Global emissions**

- recently are ~1500 kt yr^{-1} (*vs.* production of 1750-1900 kt yr^{-1})
- have approximately doubled in past 20 years

*** With a mean lifetime of 0.5 yr, it's a "long-lived VSLS" (M. Ko, 1998)**

- its ODP varies by about a factor of 2 regionally

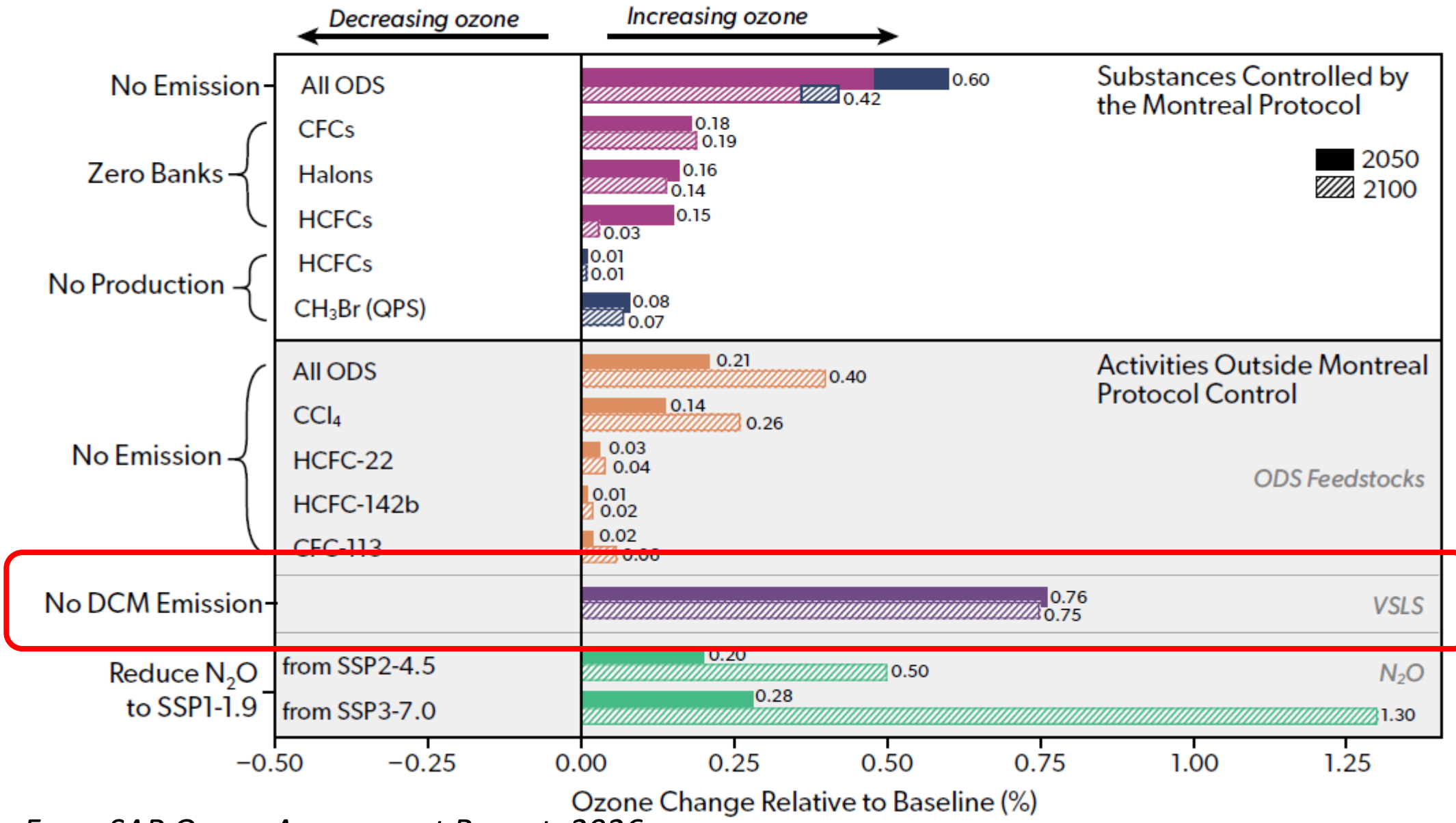
*** Largest emission coming from *Asia* *(90% of global total)*, *dominated by China***

- a region with fast transport to the stratosphere
- uses: flexible foaming agent, solvent, & feedstock (75% are emissive)

*** Emissions likely to continue increasing in future unless mitigation steps taken**

Scenario in Chapter 7 of Ozone Assessment

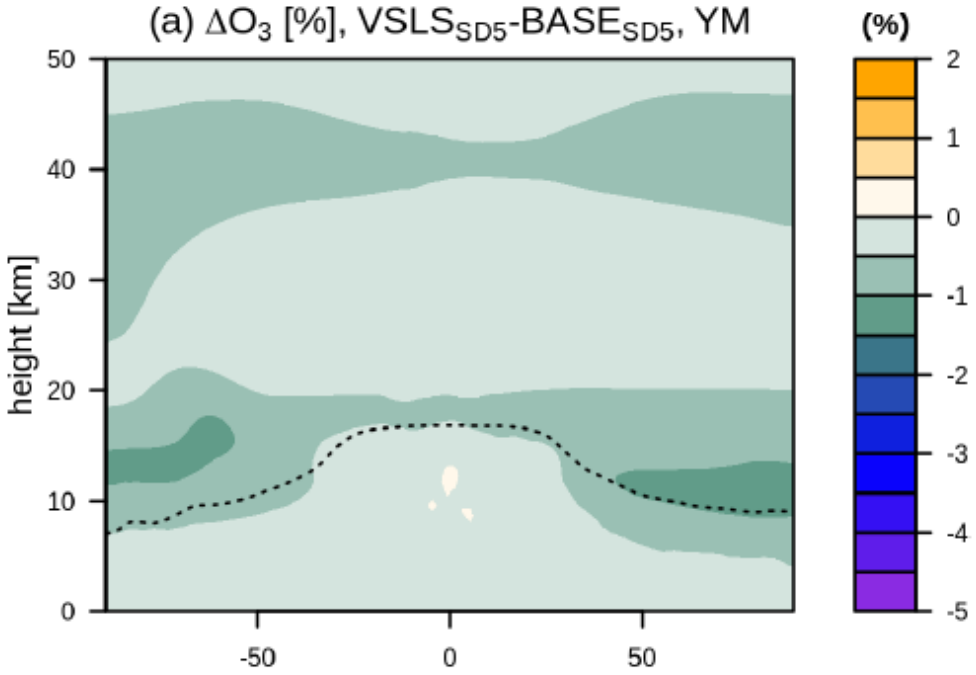
Ozone Depletion Avoided in 2050 and 2100 from Future Control Scenarios

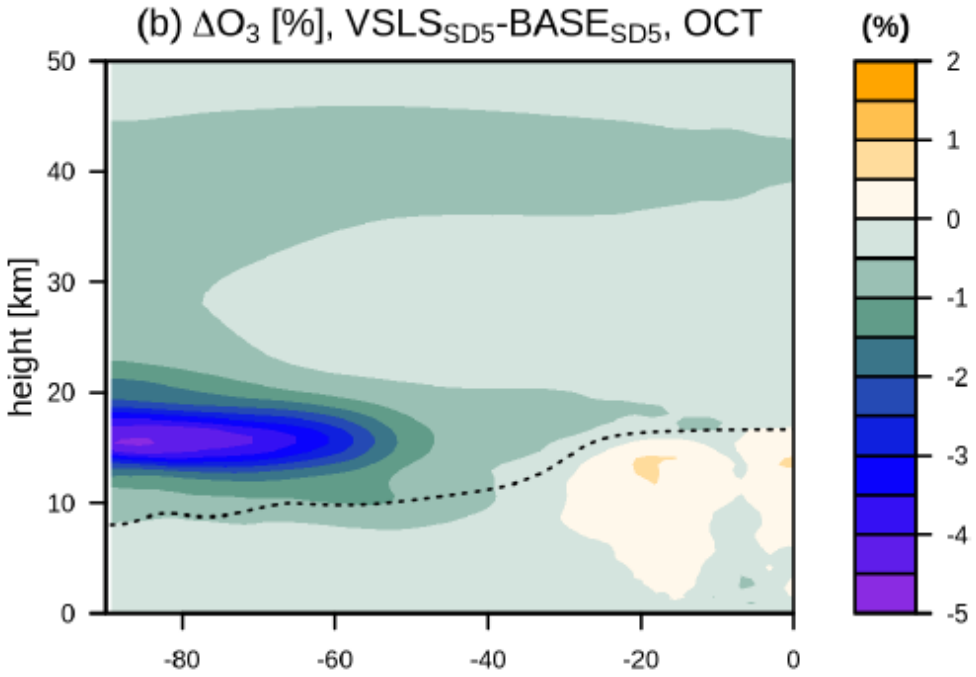


Assumptions in the CH_2Cl_2 scenario:
Emissions continue to grow through 2035, and subsequently held constant through 2100

From SAP Ozone Assessment Report, 2026

On the influence of Cl-VSLS on stratospheric ozone





<<Yearly mean

In a 3-D model simulation:
"the inclusion of Cl-VSLS resulted in 0.5 % – 1% yearly-mean ozone reductions in the tropical lower and upper stratosphere on average over the second decade of the 21st century".

<< October

"Reductions of up to 4 – 4.5% are found in the Antarctic lower stratosphere during spring."

(3-D simulations by Bednarz et al., 2023)

APARC activity

A broader community assessment of VSLS issues related to ozone depletion is underway:

Impact of chlorinated very short-lived substances on stratospheric ozone (VSLS-MIP1)

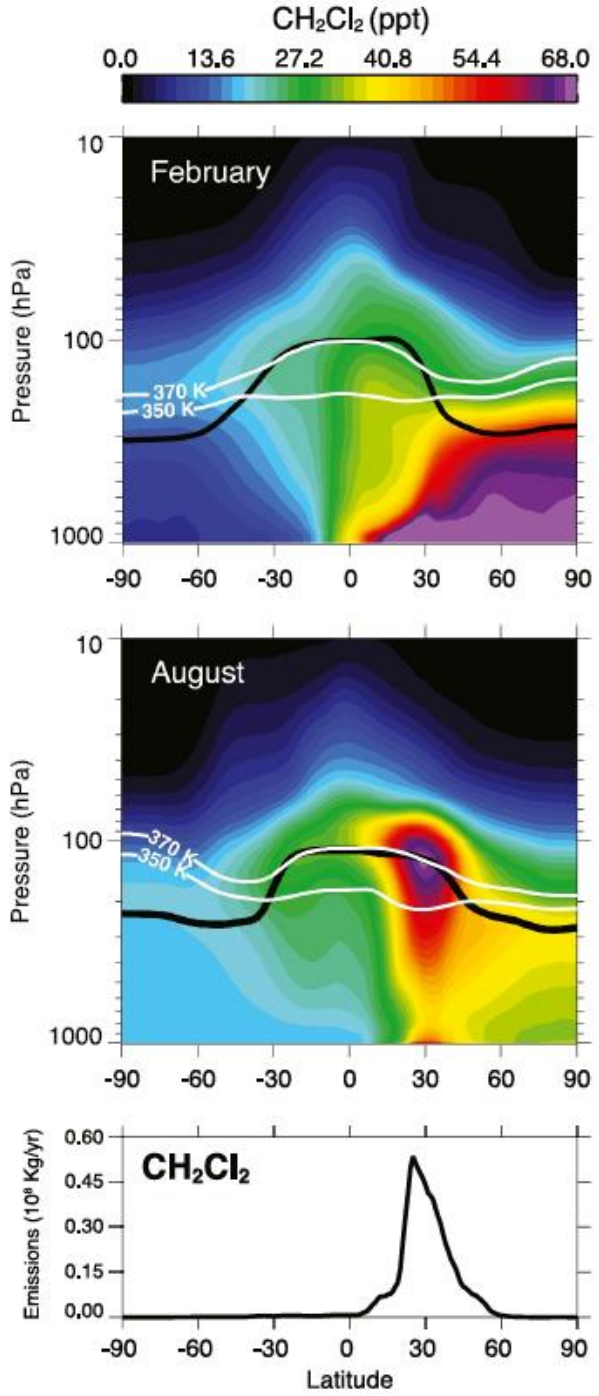
Ryan Hossaini, Lucy Carpenter, Martyn Chipperfield, Doug Kinnison, Susann Tegtmeier

https://aparc-climate.org/activities/vsls/

A. **Ozone depletion potential (ODP) & stratospheric ozone depletion potential (SODP).** Paper submission expected by end of 2026
B. **Quantify industry-related emissions of chlorinated VSLS (including future scenarios)** 2027
C. **Evaluate the impacts of chlorinated VSLS on long-term trends in stratospheric composition.** 2027

Summary:

- Atmospheric chlorine from very short-lived substances has increased over the past 25 years,
- This increase has offset a portion of the chlorine decline from controlled substances (ODSs),
- VSLS currently contribute ~4% to stratospheric chlorine and this contribution has augmented ozone depletion by 0.5 % annually and 4 – 5% in the Antarctic springtime,
- CH_2Cl_2 accounts for ~70% of VSLS Cl reaching the stratosphere; its use is dominated by emissive applications, primarily in eastern Asia,
- ODPs of chlorinated VSLS are 10-70% as large as the ODP of HCFC-22,
- ODPs of CH_2Cl_2 emissions vary by a factor of 2 depending on source region.



Liang et al., 2025