CESM2-SLH: Implementation of Short-Lived Halogen Sources and Chemistry in CESM (CAM6 and CAM6_dev): Current Release and Future Steps

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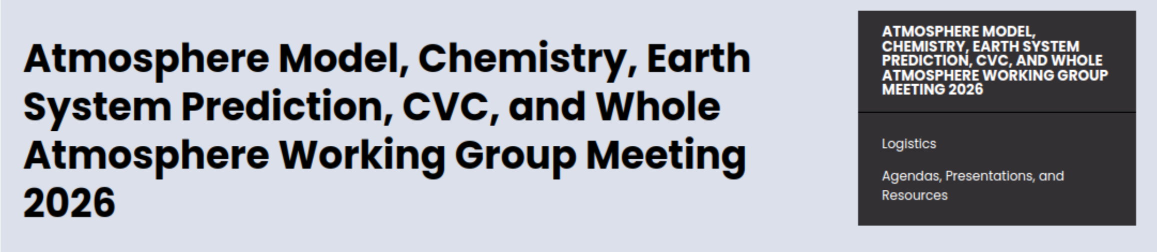


Boulder, February 2026

CESM2-SLH Description Paper & Repository

The EGU interactive community platform

ABSTRACTS & PRESENTATIONS PREPRINTS ABOUT

Table 6: Summary of the different model compsets and configurations implemented in CESM2-SLH.

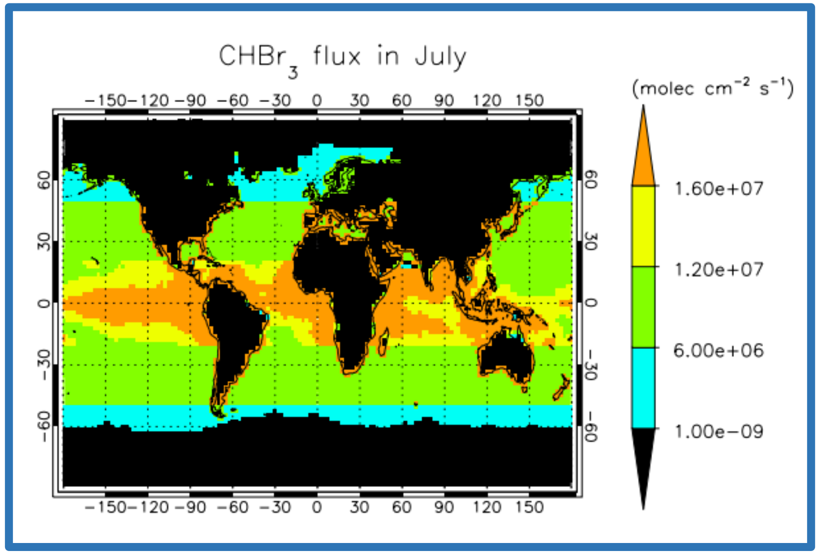
Simulation name	SLH compset	parent's compset	resolution (lat × lon)	Vertical levels	chem_mech.in (chem_proc)	Period of time evaluated
suggested						
FCnudged_slh	Fcnudged_slh	FCnudged	(1.9º × 2.5º)	32L	trop_strat_mam4_slh	1980 - 2020
FCHIST_slh	FCHIST_slh	FCHIST	(1.9º × 2.5º)	32L	trop_strat_mam4_slh	1950 - 2020
available						
FCnudged_slh	Fcnudged_slh	FCnudged	(0.9º × 1.25º)	32L	trop_strat_mam4_slh	2000-2005
FCHIST_slh	FCHIST_slh	FCHIST	(0.9º × 1.25º)	32L	trop_strat_mam4_slh	2000-2005
FWnudged_slh	FWnudged_slh	FWSD	(1.9º × 2.5º)	70L	waccm_tsmlt_mam4_slh	2000-2005
BWHIST_slh	BWHIST_slh	BWHIST_BCG	(1.9º × 2.5º)	70L	waccm_tsmlt_mam4_slh	2000-2005

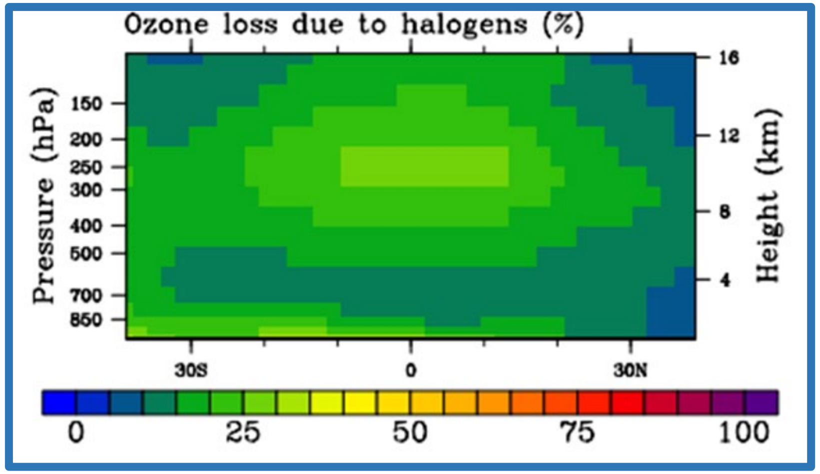
GitHub: https://github.com/RafaPedroFernandez/CESM/tree/cesm2.2-asdbranch_slh

Mendeley Dataset: https://doi.org/10.17632/f87hvrv25v.1

Importance of SLH Chemistry

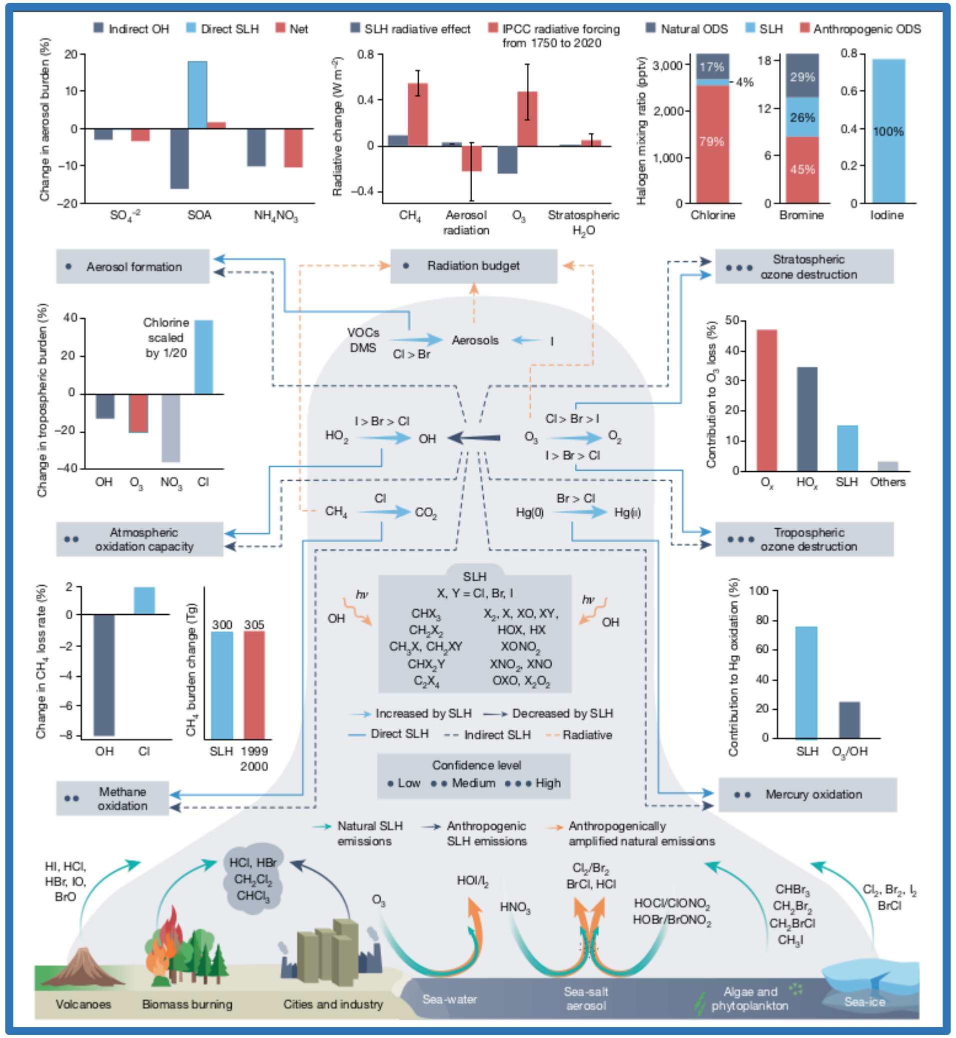
Summarize more than 10 years of research in SLH Chemistry using CESM1 (CAM4-Chem)





From the first VSL halocarbon oceanic emission inventory with seasonal chl-a variability

To the latest review of SLH impacts on Ozone, Methane, Oxidative Capacity, Mercury and Radiative Balance

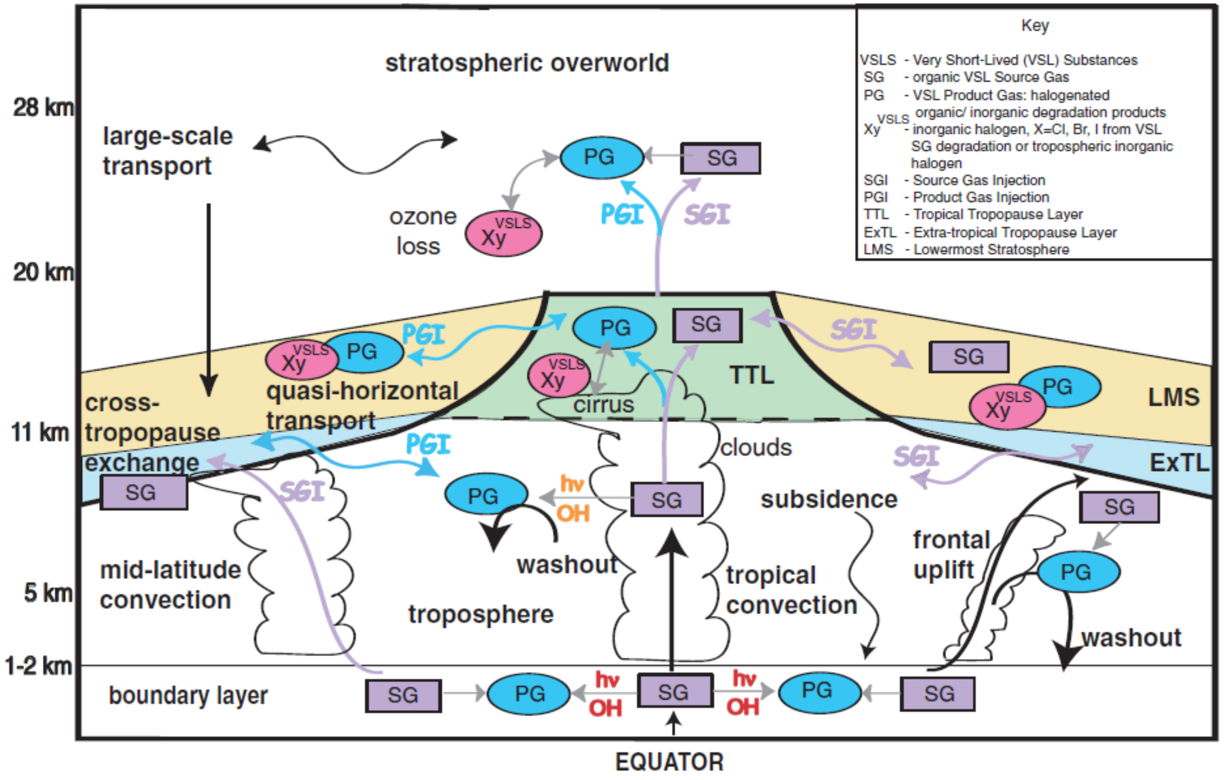


(Saiz-Lopez et al., ACP, 2012; Ordoñez et al., ACP, 2012)

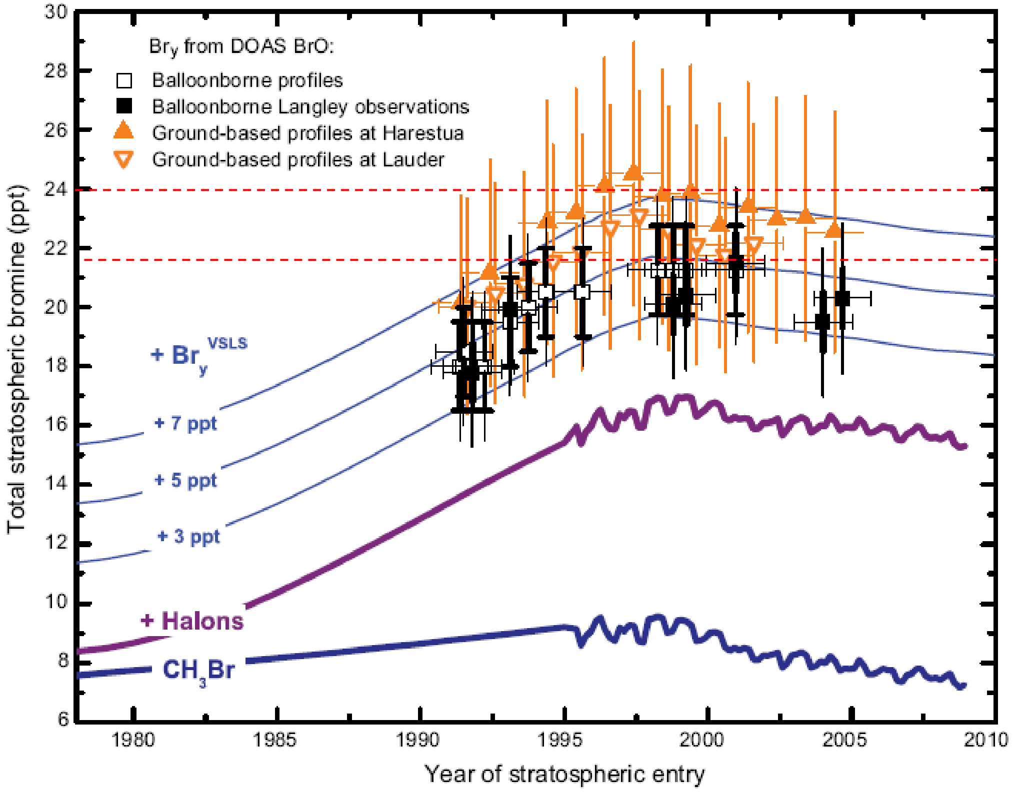
(Saiz-Lopez et al., Nature, 2025)

Scientific Assesment on Ozone Depletion (UNEP/WMO)

WMO/UNEP (2006)



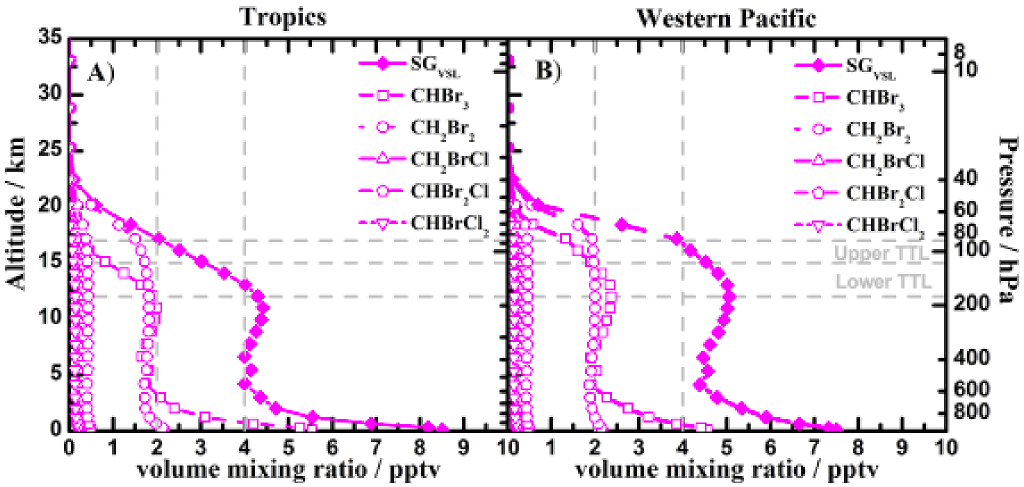
WMO/UNEP (2010)



State-of-the-art Halogen chemistry scheme

SG_{VSL} vs. PG_{VSL}

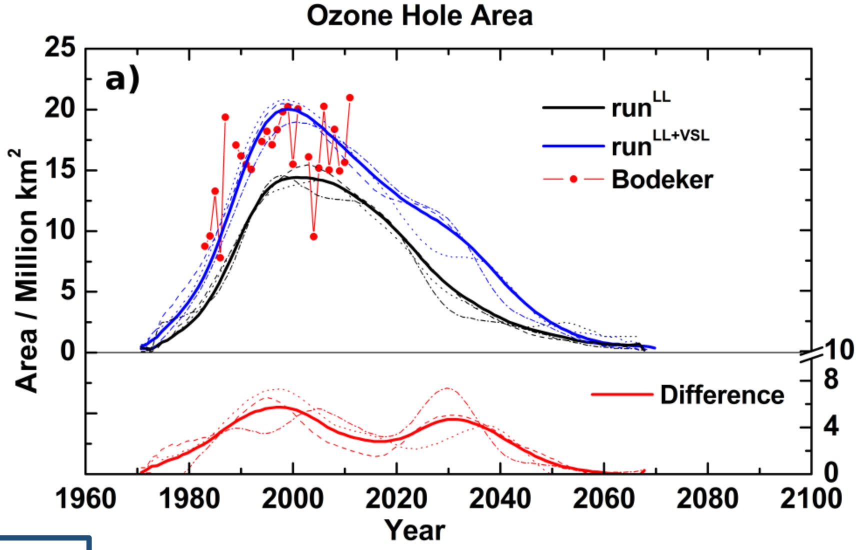
SLH injection to the Stratosphere



(Fernandez et al., ACP, 2014)

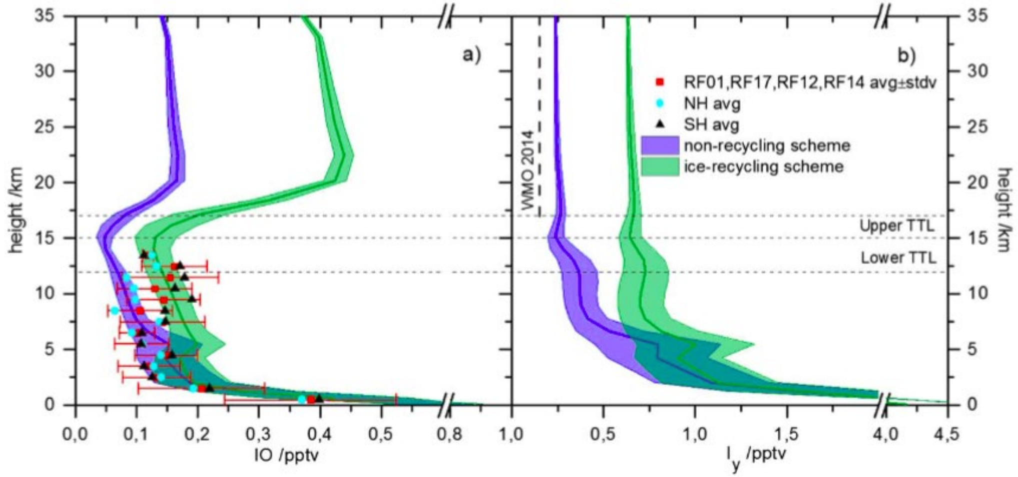
CH_2Br_2, $CHBr_3$

SGI + PGI = 5 pptv Br_y



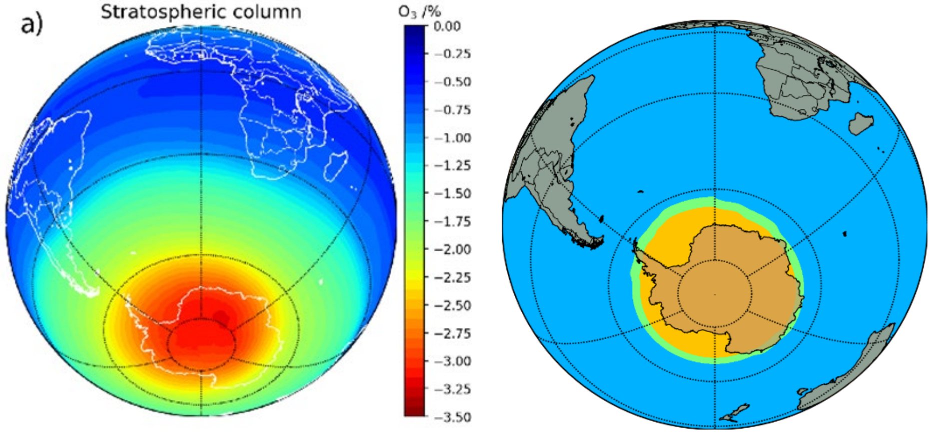
(Fernandez et al., ACP, 2017)

Increase the size and depth of the Antarctic Ozone Hole



PGI = 0.7 pptv I_y

CH_3I, HOI, I_2

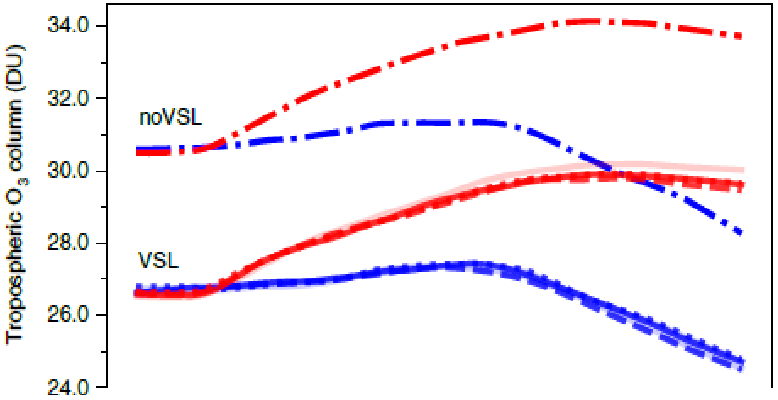


(Saiz-Lopez et al., ACP, 2014; Saiz-Lopez et al., GRL, 2015)

(Cuevas et al., PNAS, 2022)

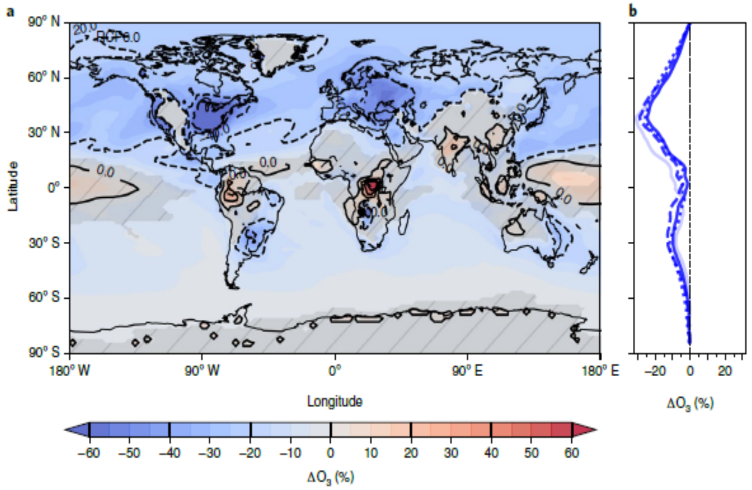
SLH influence on Tropospheric Oxidants

Chemistry-Climate simulations (RCP 6.0 & 8.5) through the 21st century showed that:



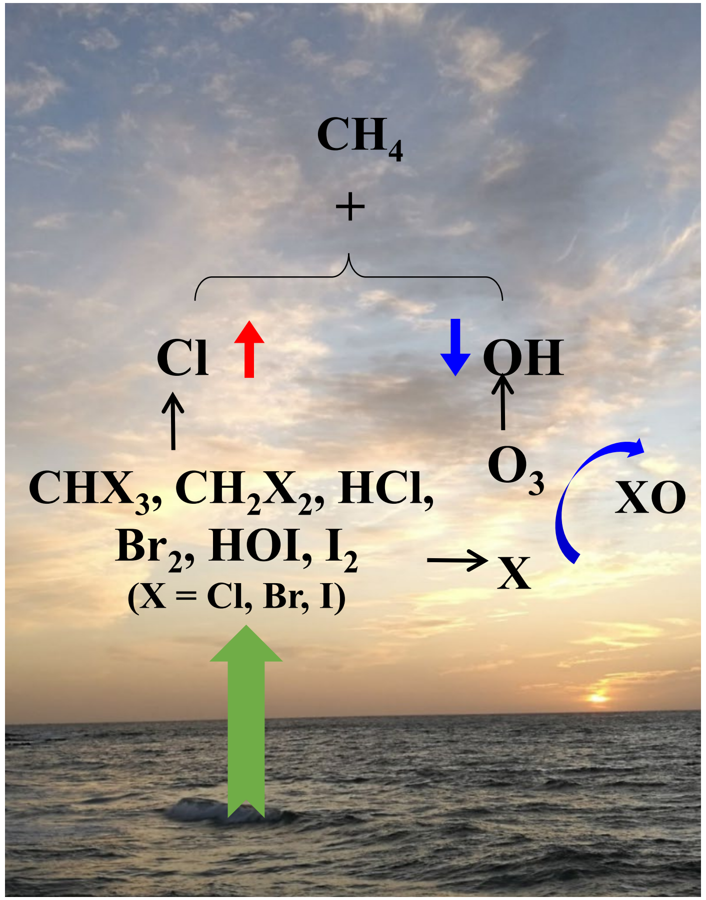
↓O_3

SLH reduce Ozone Burden by aprox. 13-15 % with an heterogeneous global distribution



Despite directly increasing Chlorine, SLH reduce Methane Loss indirectly due to changes in OH production

↑CH_4

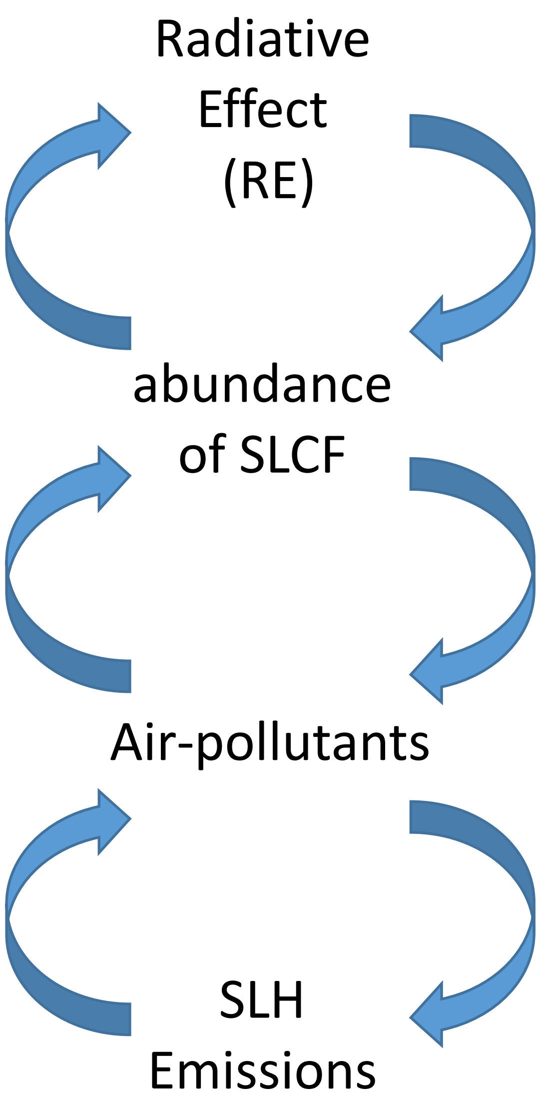


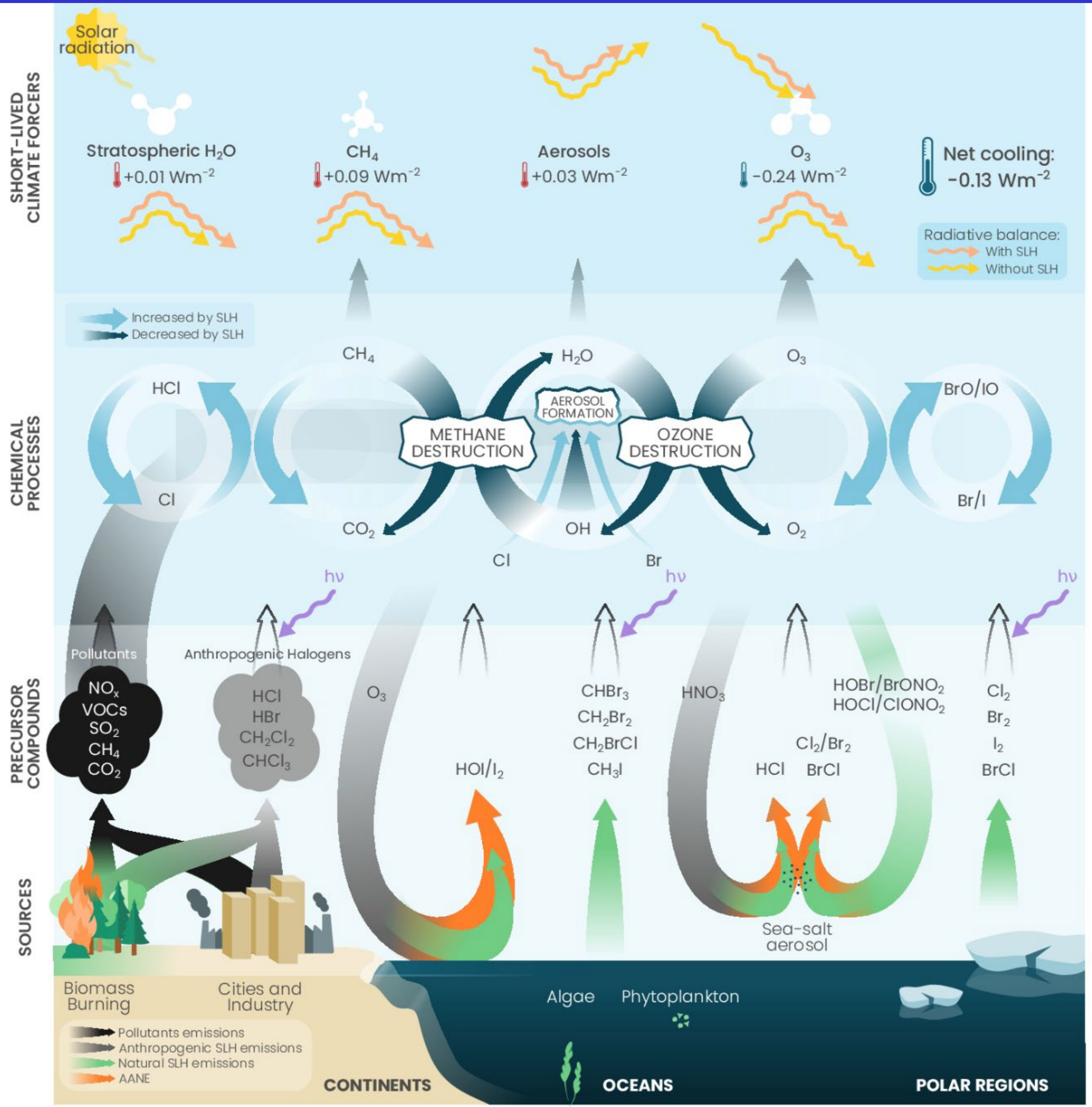
Next talk from Ben Gaubert

(Iglesias-Suarez et al., Nat.CC, 2020)

(Li et al., Nat.Comm., 2022)c

Radiative Effect of SLH





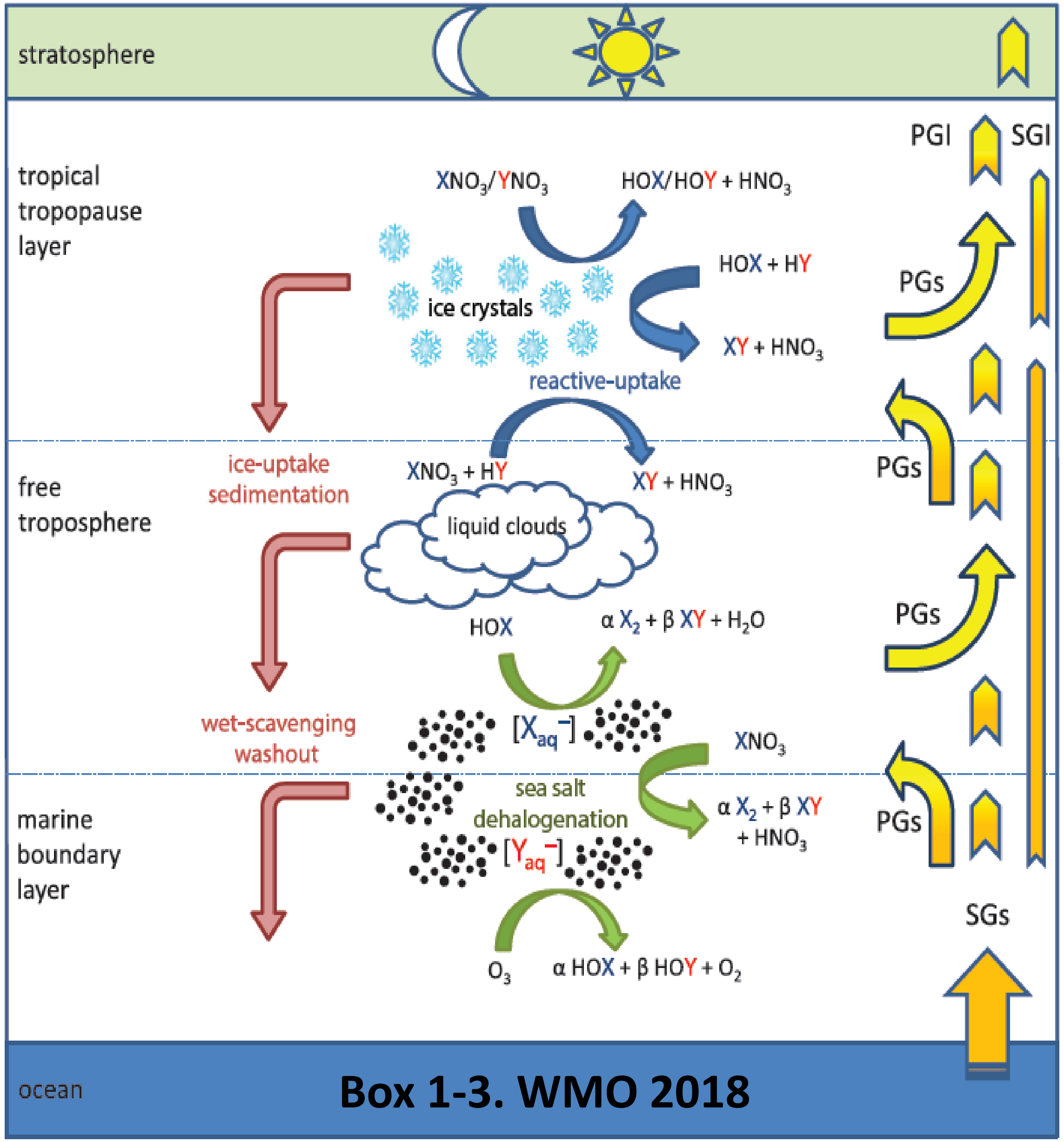
Global Radiative Balance

Chemistry-Climate Coupling

Anthropogenically Amplified Natural Emissions

(Saiz-Lopez et al., Nature, 2023)

Reactive transport of SLH: Sources and Sinks



Box 1-3. WMO 2018

Lifetime

Long-Lived ODS (stratosphere):

$CFC\text{-}12 + h\nu / O^1D \rightarrow 2\ Cl$

$CF_3Br + h\nu / O^1D \rightarrow 2\ Br$

$CH_3Cl + OH \rightarrow Cl + CH_3O_2$

$CH_3Br + OH \rightarrow Br + H_2O + HO_2$

τ = 0.9 yr
τ = 0.8 yr

VSL Halogens (Natural + Anthropogenic):

$CH_2Cl_2 + h\nu \rightarrow 2\ Cl$

$CH_2Cl_2 + OH \rightarrow CHCl_2O_2 \rightarrow COCl_2 \rightarrow 2\ Cl$

$CH_2Br_2 + OH/Cl \rightarrow 2\ Br + H_2O/HCl$

$CHBr_3 + OH/Cl \rightarrow 3\ Br + H_2O/HCl$

τ < 0.5 yr

SSA-dehalogenation (on-line computation)

$BrONO_2 + SSA \rightarrow Br_2 + BrCl \rightarrow Cl + 2\ Br$

$HNO_3 + SSA \rightarrow HCl \rightarrow Cl$

$N_2O_5 + SSA \rightarrow ClNO_2 + HNO_3 \rightarrow Cl$

Br and Cl source

Oceanic Iodine Flux (on-line computation)

$O_3(g) + I^-(aq) \rightarrow HOI(aq) + I_2(aq) \rightarrow HOI(g) + I_2(g)$

I source

Inorganic Halogens Washout (NEU + FRA):

Including *in-cloud* and *below-cloud scavenging* and *ice-uptake* of reservoir species (Cl, Br and I).

non-stoich. sink

Reactive transport of SLH: Sources and Sinks

- **Offline emissions:** The *srf_emis_specifier* within the *&chem_inparm* group has been expanded to include the offline emissions of $CHBr_3$, CH_2Br_2, CH_2BrCl, $CHBr_2Cl$, $CHBrCl_2$, CH_3I, CH_2I_2, CH_2IBr, CH_2ICl, CH_2Cl_2, C_2Cl_4, I_2, and

- **Boundary conditions:** CH_3Cl and $C_2H_4Cl_2$ have been included in the *flbc_list* within the *&chem_surfvals_nl* group, as these species contribute to the atmospheric SLH chlorine loading. An updated *flbc_file* including the projected

- **Absorption cross-sections:** To compute the photolysis of gas-phase organic and inorganic halogen species, wavelength-dependent absorption data of several SLH have been added to the default short-wave (*xs_short_file*) and

- **Dry deposition:** The following species have been included in the *drydep_list* within *&drydep_inparm*: $ClONO_2$, HCl, HOCl, $ClNO_2$, $BrONO_2$, HBr, HOBr, $BrNO_2$, Br_2, $IONO_2$, HI, HOI, INO_2, I_2O_2, I_2O_3, I_2O_4, $CHCl_2O_2$, and $COCl_2$.

- **Wet deposition:** The *gas_wetdep_list* within *&wetdep_inparm* has also been extended with the following species: $ClONO_2$, HCl, HOCl, COFCl, $BrONO_2$, HBr, HOBr, $ClNO_2$, $BrNO_2$, Br_2, BrCl, $IONO_2$, INO_2, HI, IO, OIO, ICl, IBr,

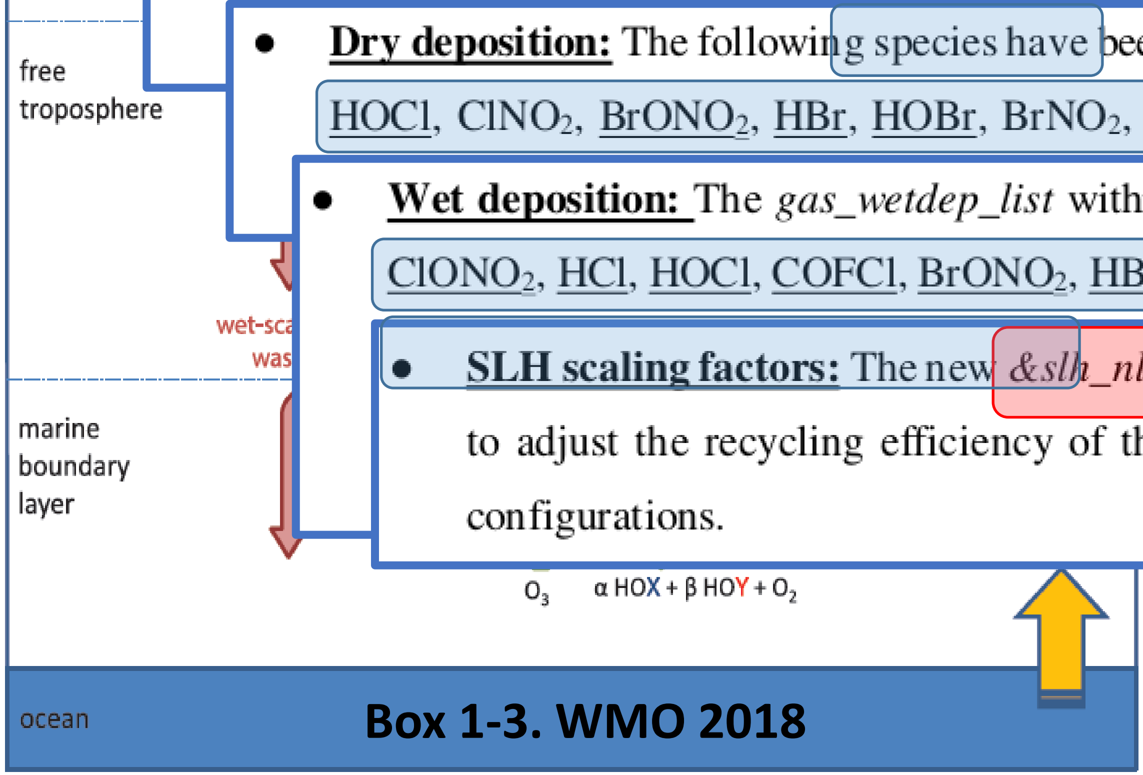
- **SLH scaling factors:** The new *&slh_nl* namelist section was incorporated, providing a set of scaling factors intended to adjust the recycling efficiency of the main processes affecting SLH sources and sinks when shifting between configurations.

Lifetime

τ = 0.9 yr

τ = 0.8 yr

τ < 0.5 yr



Box 1-3. WMO 2018

Inorganic Halogens Washout (NEU + FRA): Including *in-cloud* and *below-cloud scavenging* and *ice-uptake* of reservoir species (Cl, Br and I).

non-stoich. sink

SSA-dehalogenation (Br and Cl on-line sources)

SSA-dehalogenation (Halogen Reservoirs):

$BrONO_2 + SSA \rightarrow 0.65\ Br_2 + 0.35\ BrCl$
$BrNO_2 + SSA \rightarrow 0.65\ Br_2 + 0.35\ BrCl$
$HOBr + SSA \rightarrow 0.65\ Br_2 + 0.35\ BrCl$
…
$ClONO_2 + SSA \rightarrow 1.00\ Cl_2$
$ClNO_2 + SSA \rightarrow 1.00\ Cl_2$
$HOCl + SSA \rightarrow 1.00\ Cl_2$

non. stoich. source

Het-recycling of Natural VSLHalogens (Fernandez et al., 2014; 2021)

Updates for chlorine chemistry

SSA-dehalogenation (Acid displacement):

$HNO_3 + SSA \rightarrow HCl$

$N_2O_5 + SSA \rightarrow ClNO_2 + HNO_3$

Enhanced Chlorine-uptake due to anthropogenic pollution (Li et al., 2022; based on Hossaini et al., 2016)

Free Regime Approximation (FRA)

v_d

$$F_{ssa} = v_d \times \gamma_i \times SAD_{ssa} \times DF(Lat,t)$$

Sea-salt aerosol

Br^- / Cl^-

$BrONO_2 \rightarrow 0.65\ Br_2 + 0.35\ BrCl$
$BrNO_2 \rightarrow 0.65\ Br_2 + 0.35\ BrCl$
$HOBr \rightarrow 0.65\ Br_2 + 0.35\ BrCl$

MBL

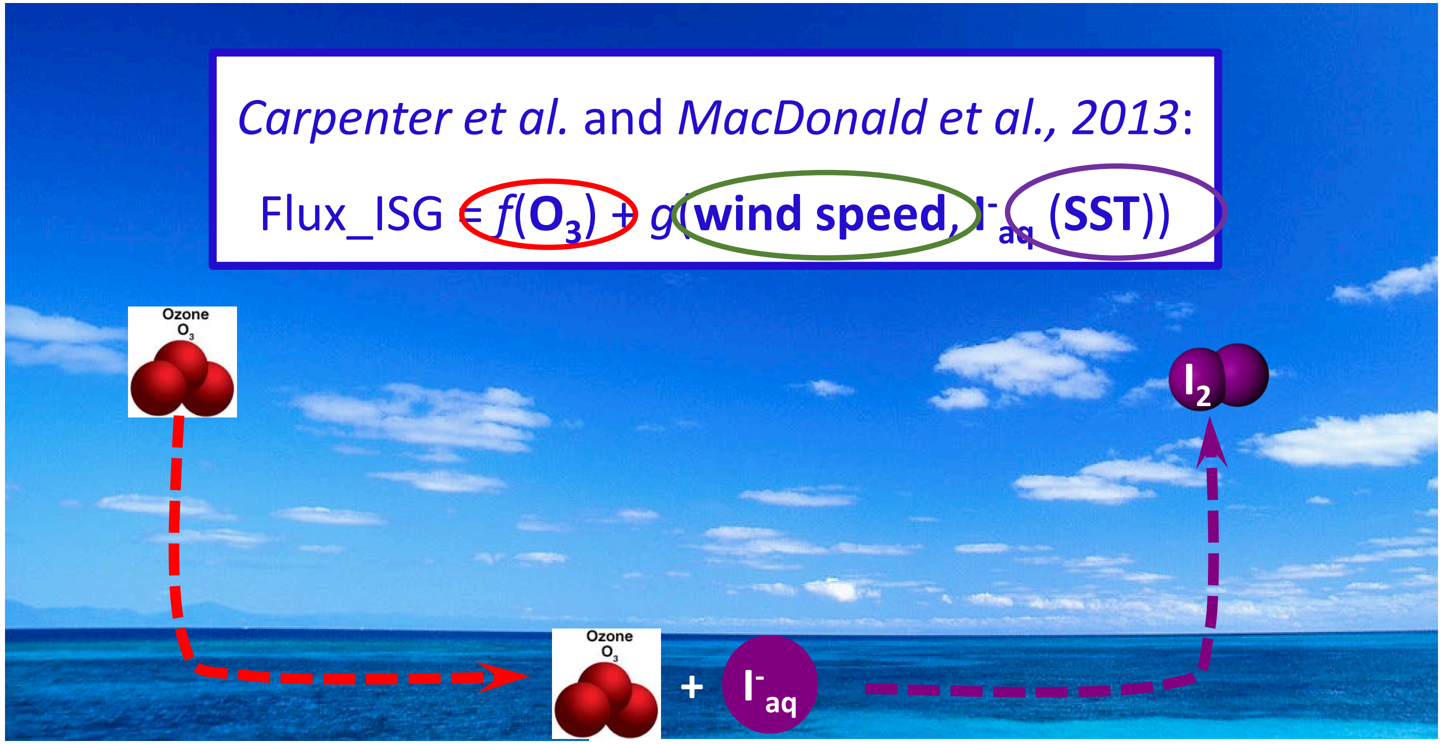
(based on McFiggans et al., 2000)

Do not keep track of halide content on aged Sea-Salt !!! (infinite halide reservoir)

Strong dependence on SSA distribution → **resolution**

Ozone-driven Iodine Emissions (on-line)

Model + Laboratory studies (*Garland et al., 1980, 1981*): The mechanism for dry **deposition of O_3 to seawater** surfaces, its **reaction with I^-_{aq}** and **the emission of iodine** (I_2?) "**linearly with ozone** concentration up to 100 ppb".



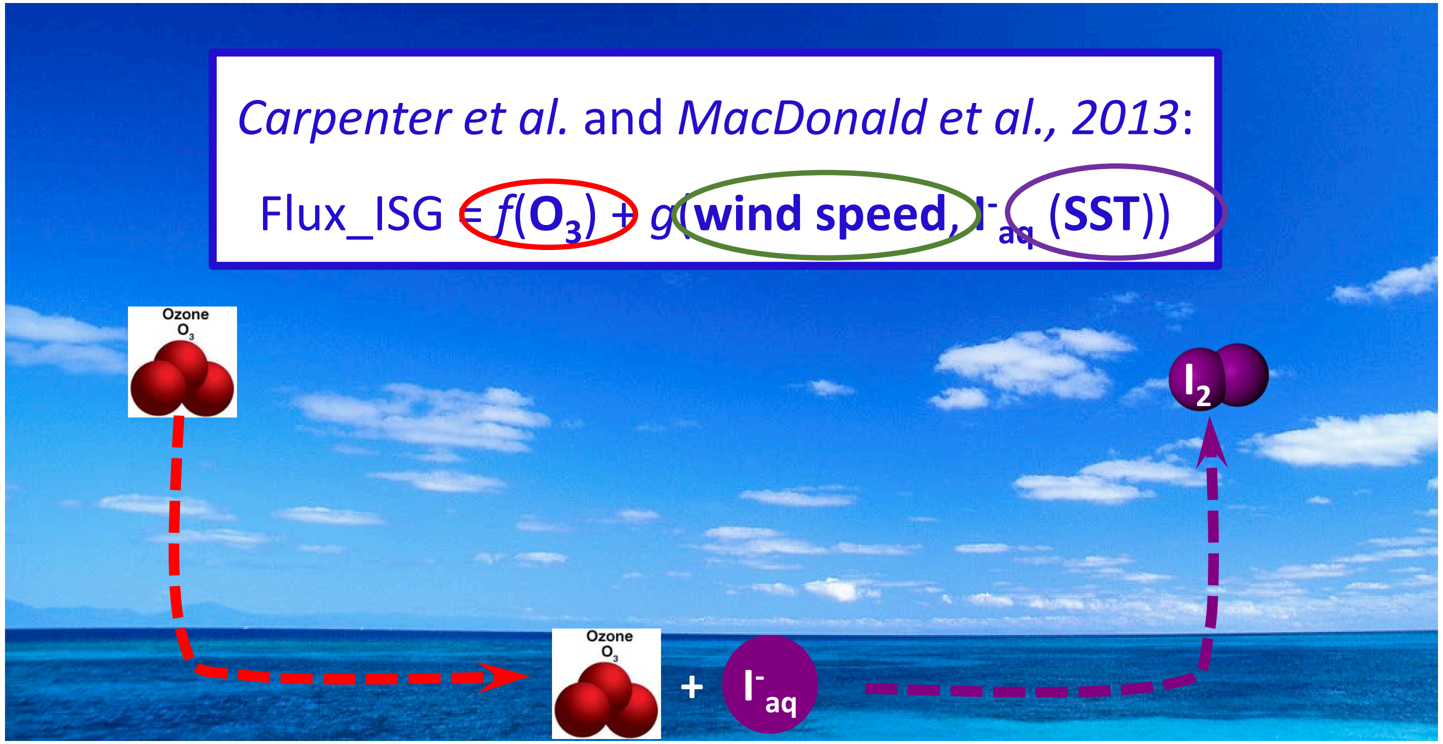
$$\left[I^-_{aq}\right] = 1.46\times 10^6 \times \exp\left(\frac{-9,134}{SST}\right)$$

$$F_{HOI} = [\mathrm{surf.O_3}]\times\left\{4.15\times 10^5\times\left(\frac{\sqrt{[I^-_{aq}]}}{ws}\right) - \left(\frac{20.6}{ws}\right) - 23,600\times\sqrt{[I^-_{aq}]}\right\}$$

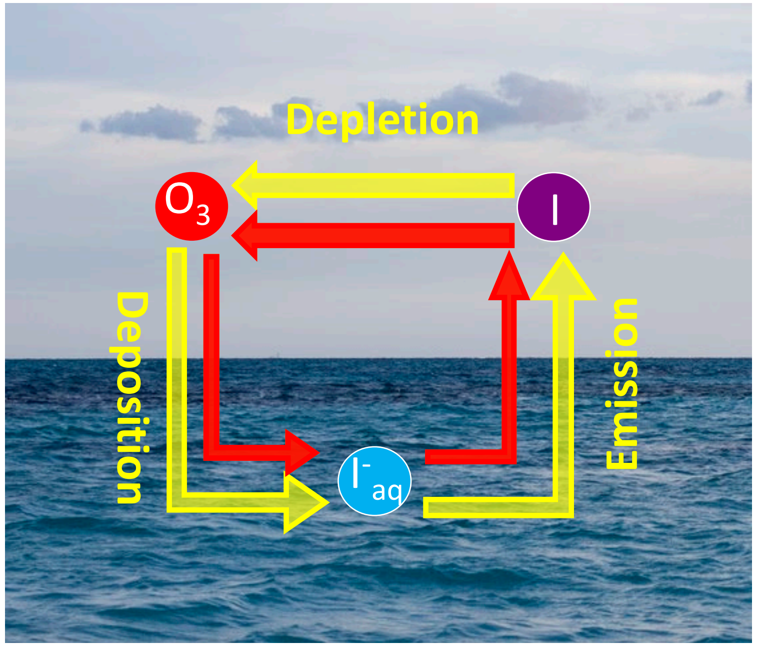
(Prados-Roman et al., ACP, 2015)

Ozone-driven Iodine Emissions (on-line)

Model + Laboratory studies (*Garland et al., 1980, 1981*): The mechanism for dry **deposition of O_3 to seawater** surfaces, its **reaction with I^-_{aq}** and **the emission of iodine** (I_2?) "**linearly with ozone** concentration up to 100 ppb".



Geochemical feedback



Natural buffer for O_3 pollution
And Global Warming

$$[I^-_{aq}] = 1.46\times 10^6 \times \exp\left(\frac{-9.134}{SST}\right)$$

$$F_{HOI} = [surf.O_3]\times\left\{4.15\times 10^5\times\left(\frac{\sqrt{[I^-_{aq}]}}{ws}\right) - \left(\frac{20.6}{ws}\right) - 23,600\times\sqrt{[I^-_{aq}]}\right\}$$

(Cuevas et al., Nat. Comm., 2018)

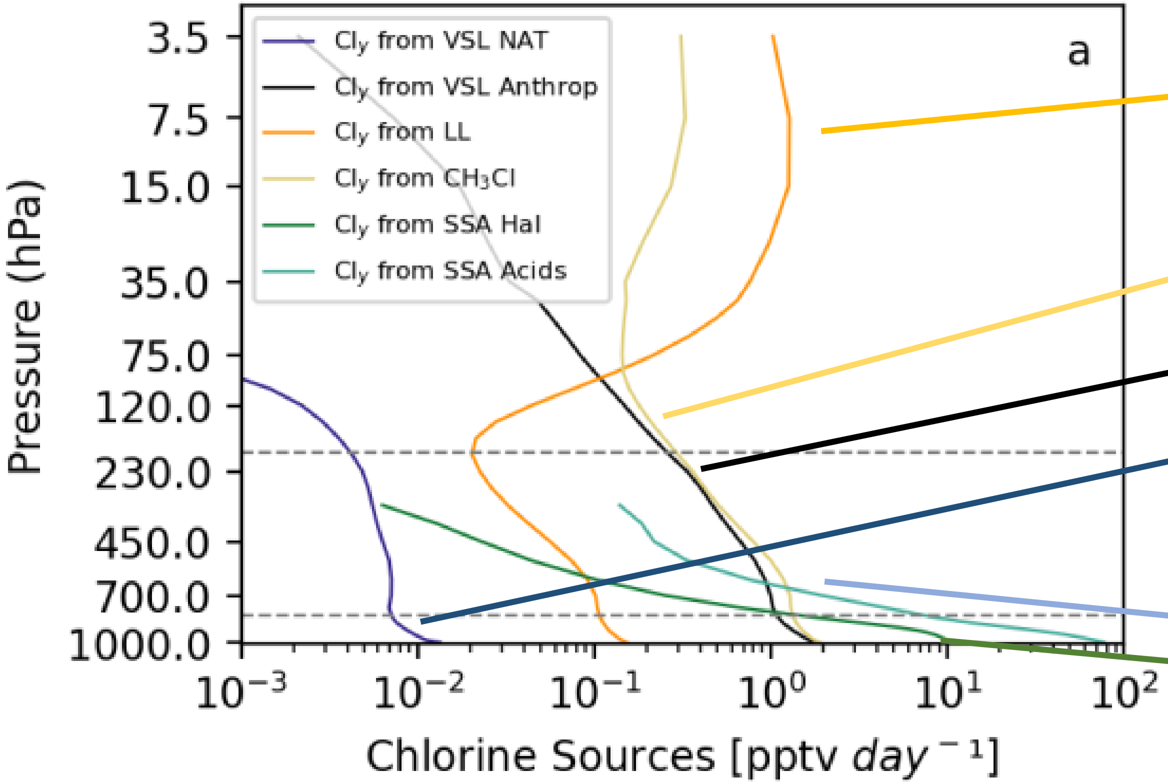
CESM2-SLH (CAM6) Results

Tuning Scaling Factors

Table 7: Adjusted values of *&slh_nl* scaling factors for each of the main CESM2-SLH compsets and resolutions.

compset resolution	FCnudged_slh (1.9° × 2.5°)	FCHIST_slh (1.9° × 2.5°)	FCnudged_slh (0.9° × 1.25°)	FCHIST_slh (0.9° × 1.25°)	Fwnudged_slh (1.9° × 2.5°)	BWHIST_slh (1.9° × 2.5°)
SSA-Sources						
SSAdehal_ScalingFactor	1.4	1.7	1.5	1.5	1.7	1.7
SSAhno3_ScalingFactor	1	1	1	1	1	1
SSAn2o5_ScalingFactor	1	1	1	1	1	1
FRA-Sinks						
LIQfraprx_ScalingFactor_I	1.5	1	1.5	1	1	1
ICEfraprx_ScalingFactor_I	1.3	1.7	0.9	0.9	1.9	2.8
ICEfraprx_ScalingFactor_Br	1	2	1	1	3	3

CESM2-SLH: Sources of Inorganic Chlorine (Cl_y)



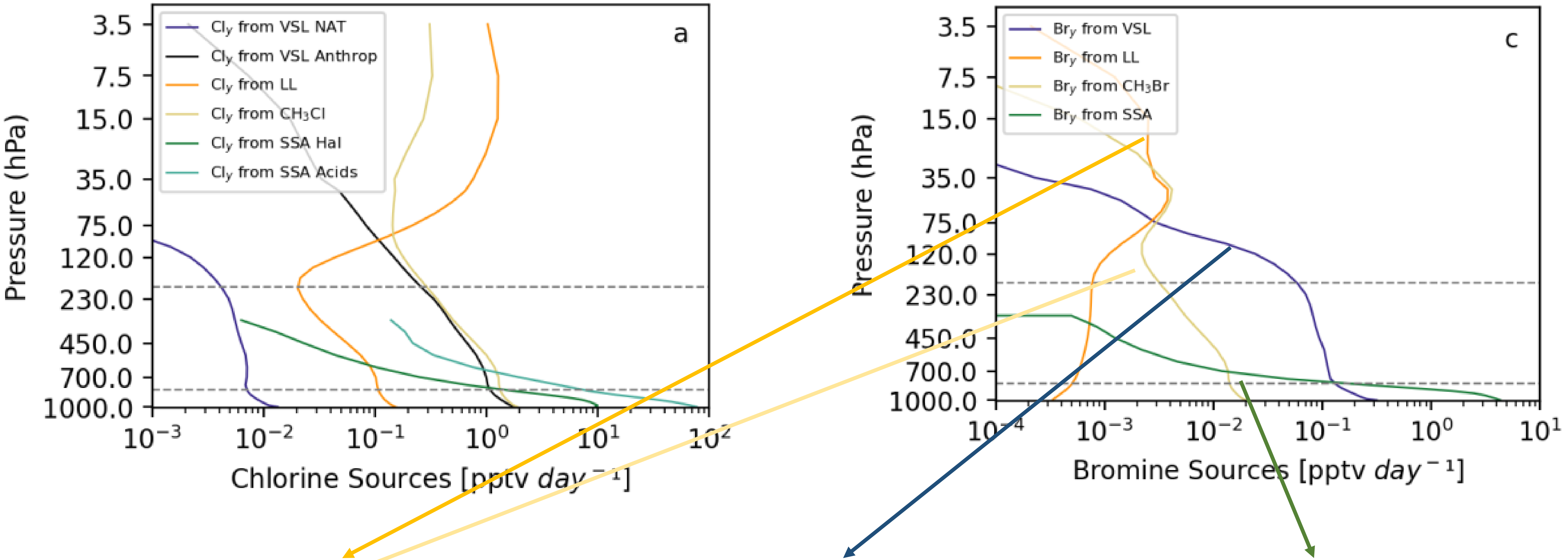
Long-Lived species (CFCs + HCFCs), dominate Cly sources in the stratosphere. CH_3Cl, which poses natural sources, represents the largest Cl source in the LMS.

Anthropogenic VSL (mostly CH_2Cl_2) contributes significantly in the FT and LMS.
Natural VSL^{Cl} sources are negligible.

The **inorganic Cl_y source from SSA-dehalogenation** surpasses the contribution from **Anthropogenic VSL** in the MBL.
Acid driven het-recycling surpass that from halogen reservoirs.

(Fernandez et al., GMDD, 2025)

CESM2-SLH: Sources of Inorganic Bromine (Br_y)



Long-Lived species (**Halons**), dominate Bry sources in the stratosphere.
CH_3Br, which poses natural sources, represents an important Br source in the LMS.

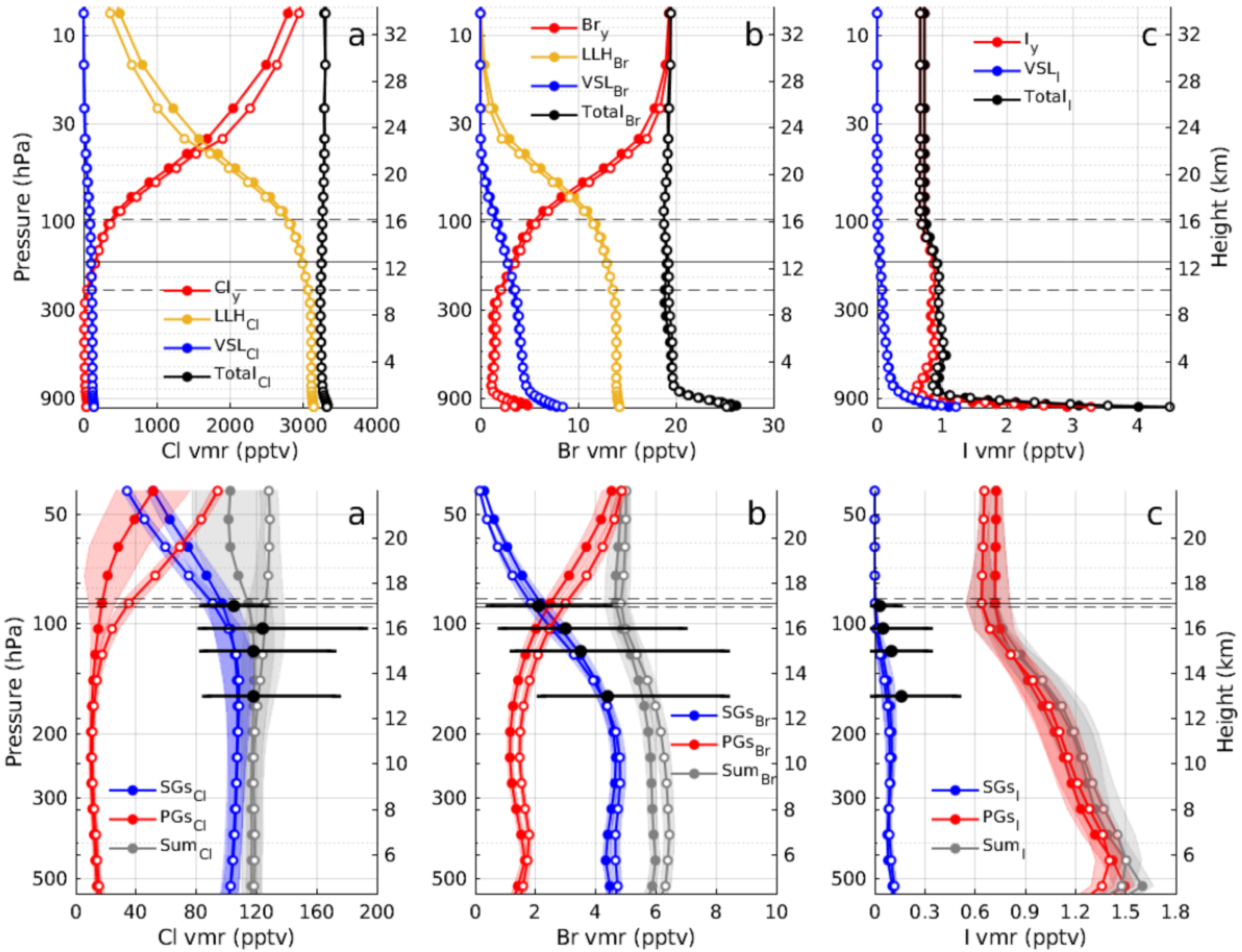
Bromine release from natural VSL sources (**$CHBr_3$ + CH_2Br_2**) largely surpass the contribution arising from CH_3Br and **LL halons** in the FT, UT and LMS.

The **inorganic Br_y** source in the MBL is dominated by **SSA-dehalogenation**.
SSA transport to the FT is less efficient in CESM2 compared to CESM1.

(Fernandez et al., GMDD, 2025)

CESM2-SLH: Source Gas (SGs) and Product Gas (PGs) Injection

Chlorine **Bromine** **Iodine**



The conversion from Organic to Inorganic Halogen species occurs at different heights for Cl, Br and I.

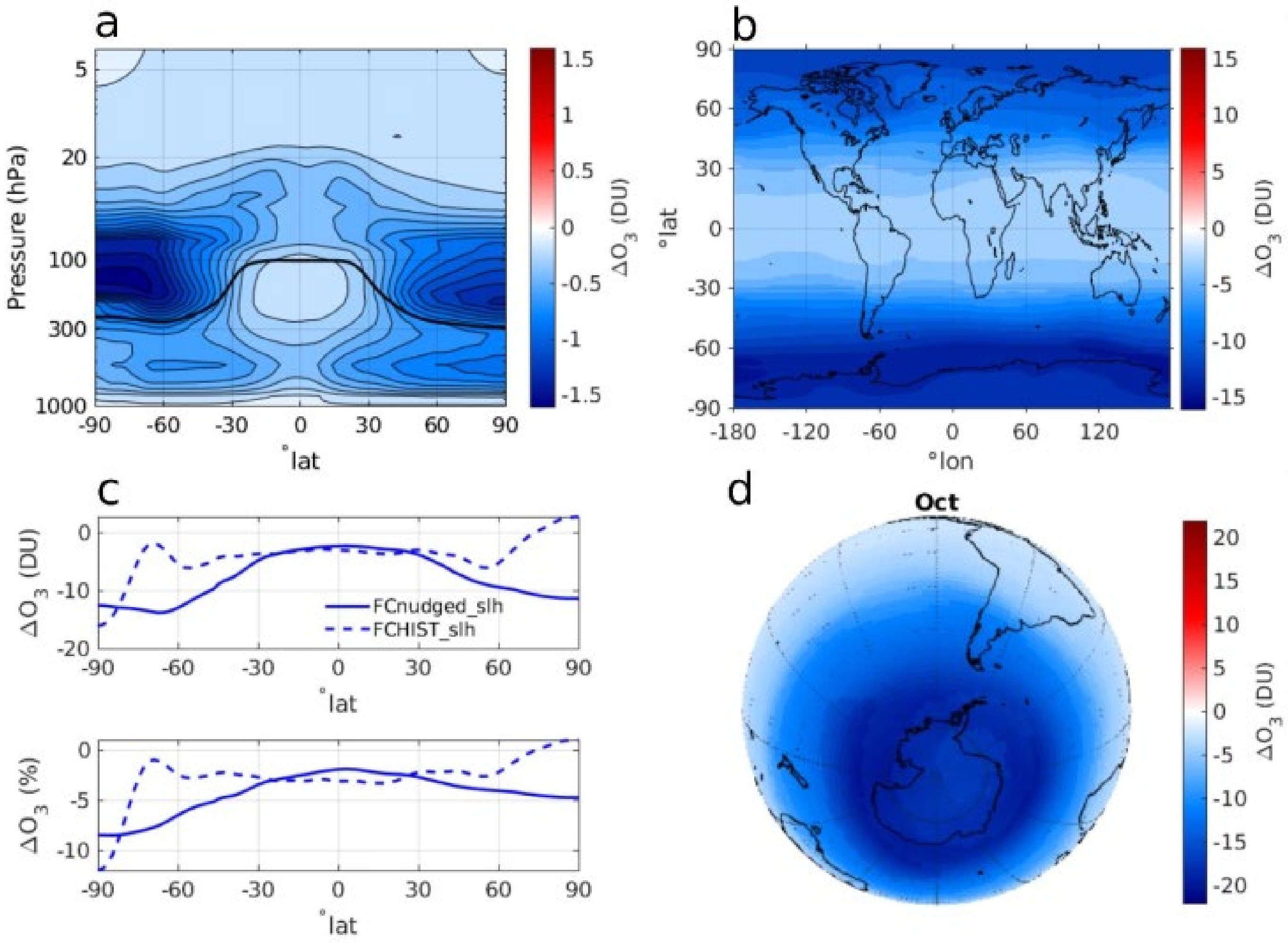
The contribution from SLH maximizes in the MBL and UTLS.

The vertical distribution of VSL SGs in the Tropical Troposphere lies within the best estimates from UNEP/WMO.

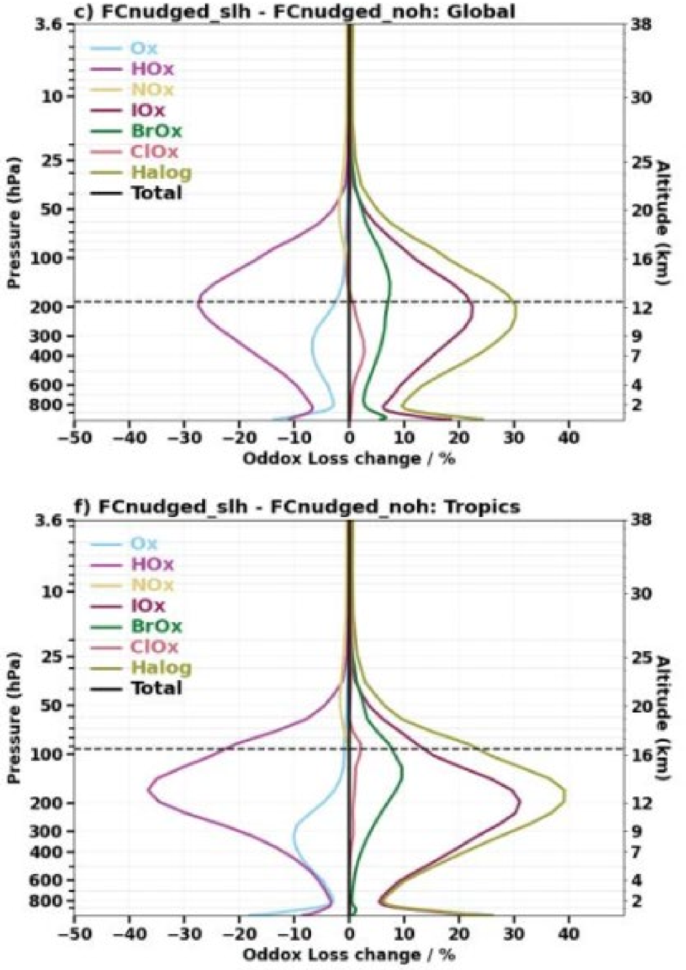
Iodine injection occurs mostly through PGI (Iy), while for Bromine both SGI and PGI contribute almost equally. For Cly, Stratospheric injection is dominated by SGI.

(Fernandez et al., GMDD, 2025)

CESM2-SLH: Odd Oxygen Loss Rates



(Fernandez et al., GMDD, 2025)



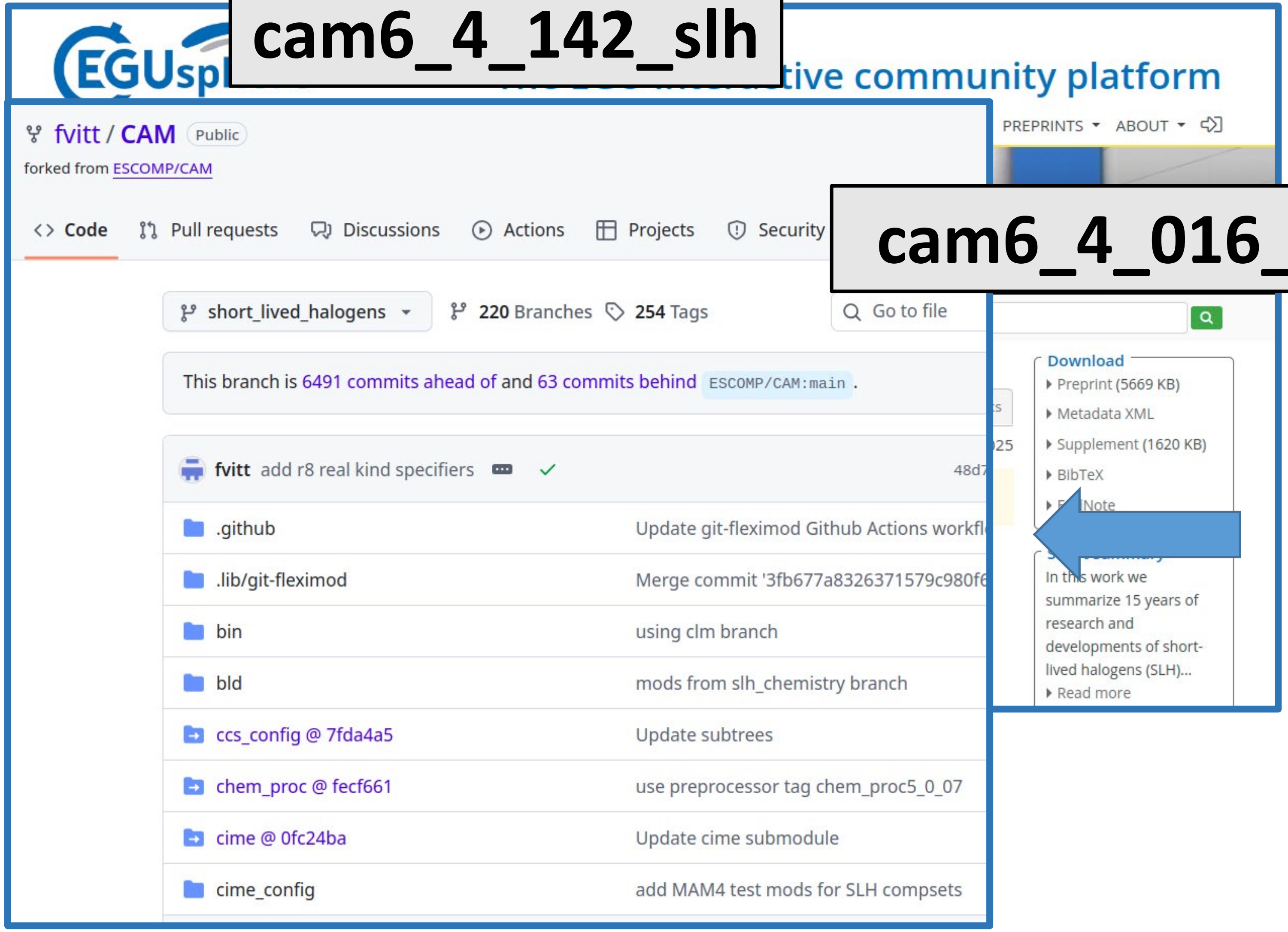
The influence on stratospheric ozone maximizes during austral Spring over Antarctica, where SLH Br and I increase Ozone Hole LMS destruction by 20 DU (14%).

Iodine- and Bromine-driven Odd-Ox loss increases by 10 – 30 % globally, which is compensated by a decrease in HOx and Ox losses.

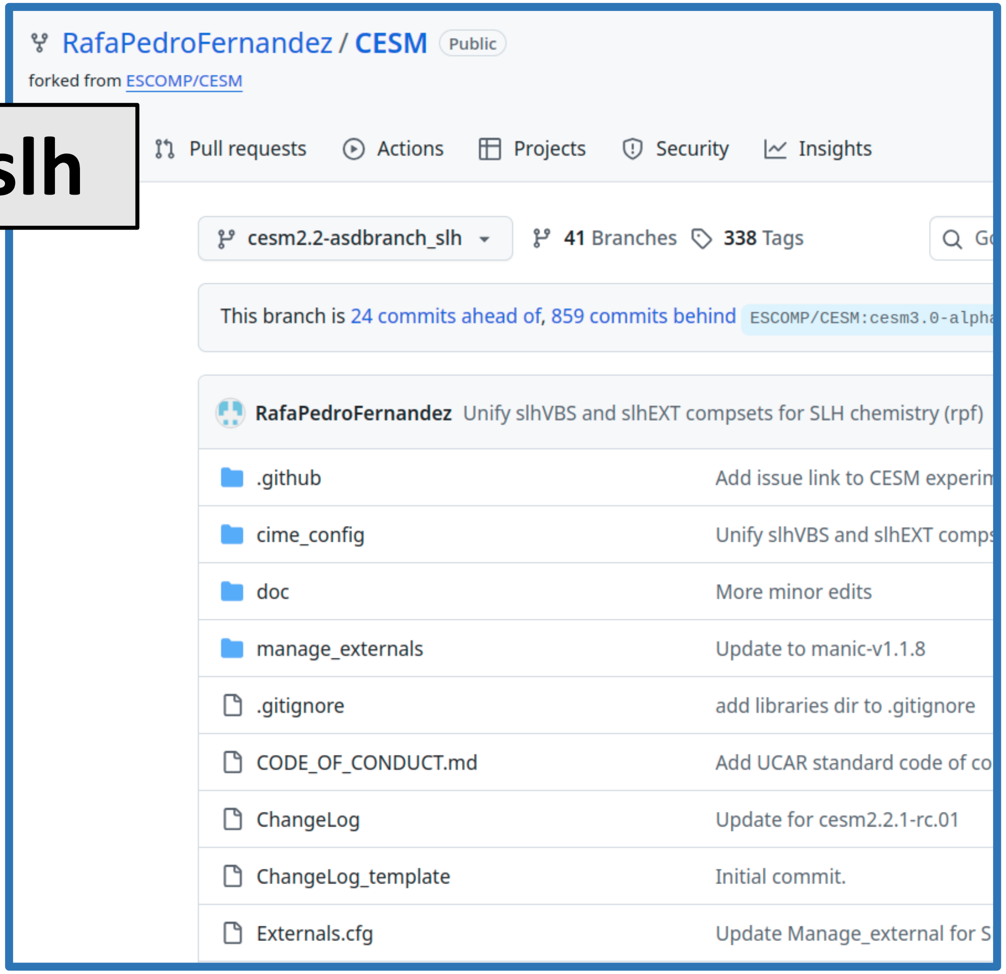
CAM6 porting to CAM6_dev

cam6_4_142_slh

cam6_4_016_slh



cesm2.2-asdbranch_slh



GitHub: https://github.com/fvitt/CAM/tree/short_lived_halogens

GitHub: https://github.com/RafaPedroFernandez/CESM/tree/cesm2.2-asdbranch_slh

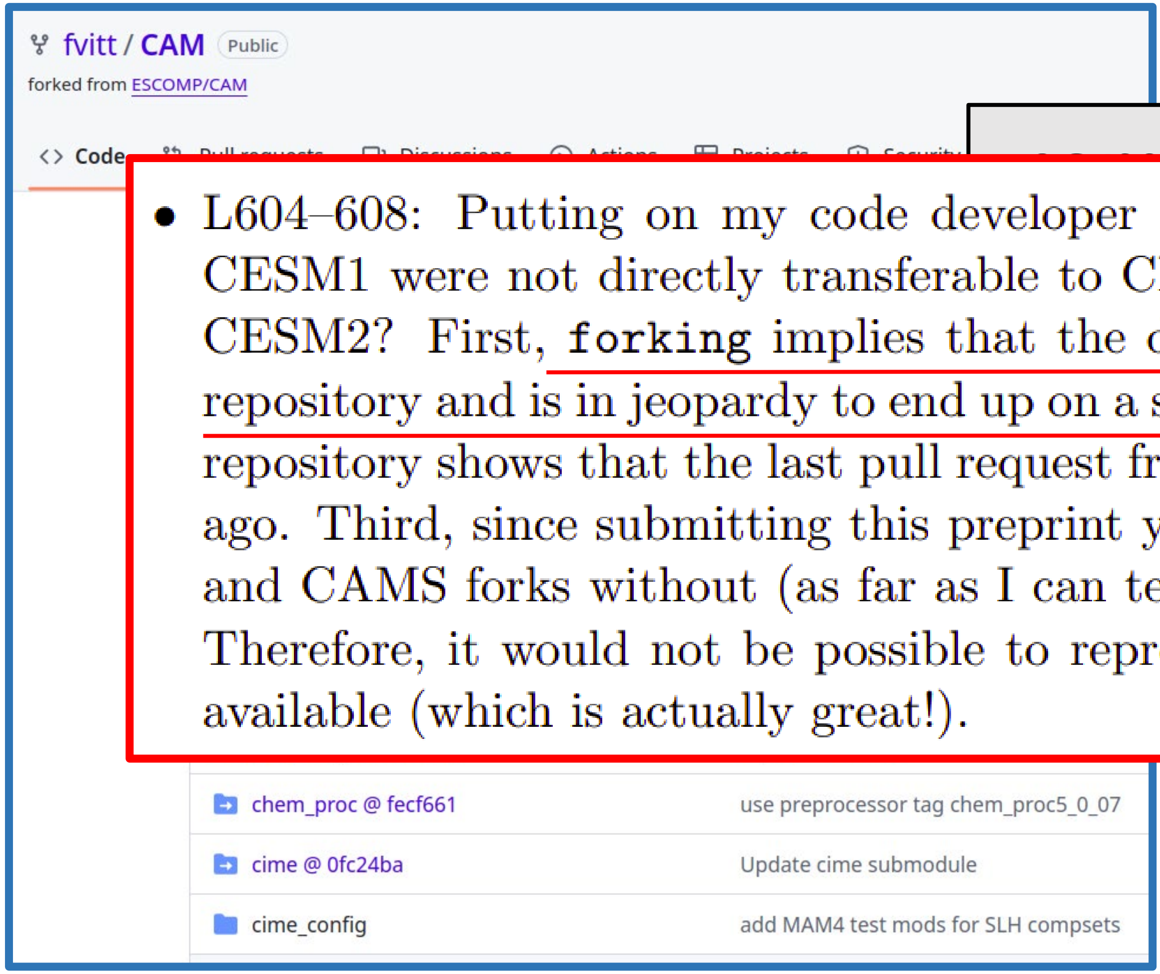
(Pull requested … Issues opened … getting close !!!)

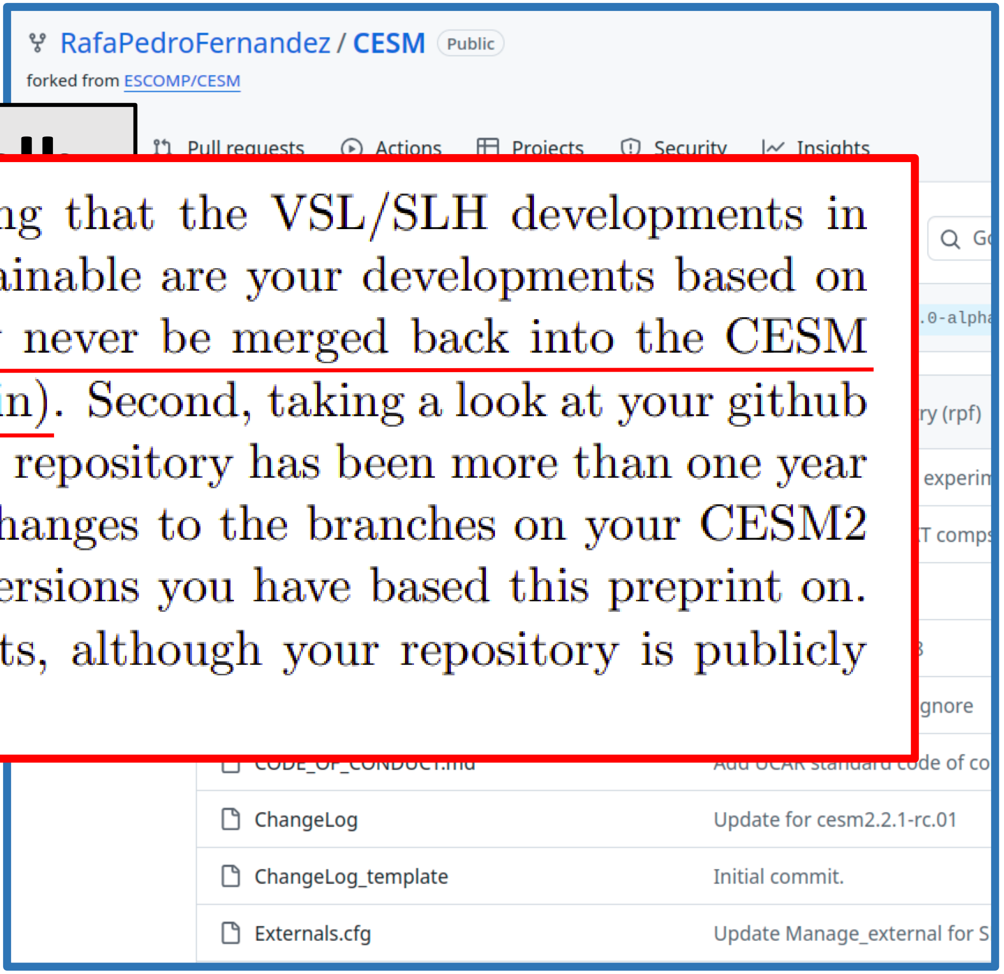
Mendeley Dataset: https://doi.org/10.17632/f87hvrv25v.1

CAM6_SLH porting into CAM6_dev_SLH

cam6_4_142_slh

cesm2.2-asdbranch_slh



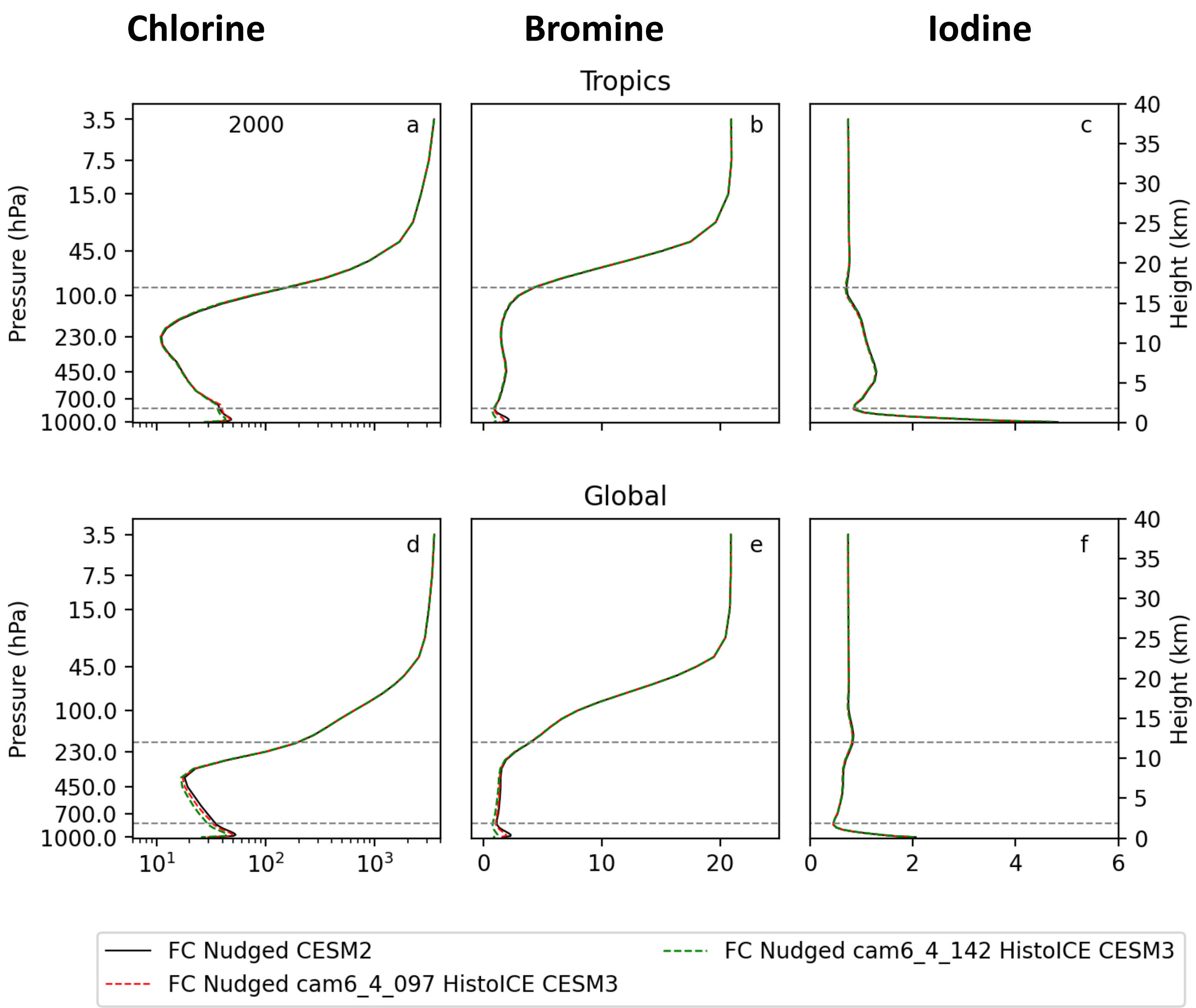


- L604–608: Putting on my code developer hat... Considering that the VSL/SLH developments in CESM1 were not directly transferable to CESM2, how sustainable are your developments based on CESM2? First, `forking` implies that the development may never be merged back into the CESM repository and is in jeopardy to end up on a stale branch (again). Second, taking a look at your github repository shows that the last pull request from the upstream repository has been more than one year ago. Third, since submitting this preprint you have added changes to the branches on your CESM2 and CAMS forks without (as far as I can tell) tagging the versions you have based this preprint on. Therefore, it would not be possible to reproduce your results, although your repository is publicly available (which is actually great!).

GitHub: https://github.com/fvitt/CAM/tree/short_lived_halogens

(Pull requested … Issues opened … getting close !!!)

Results (CAM6_dev_SLH)



cesm2.2-asdbranch_slh

cam6_4_016_slh

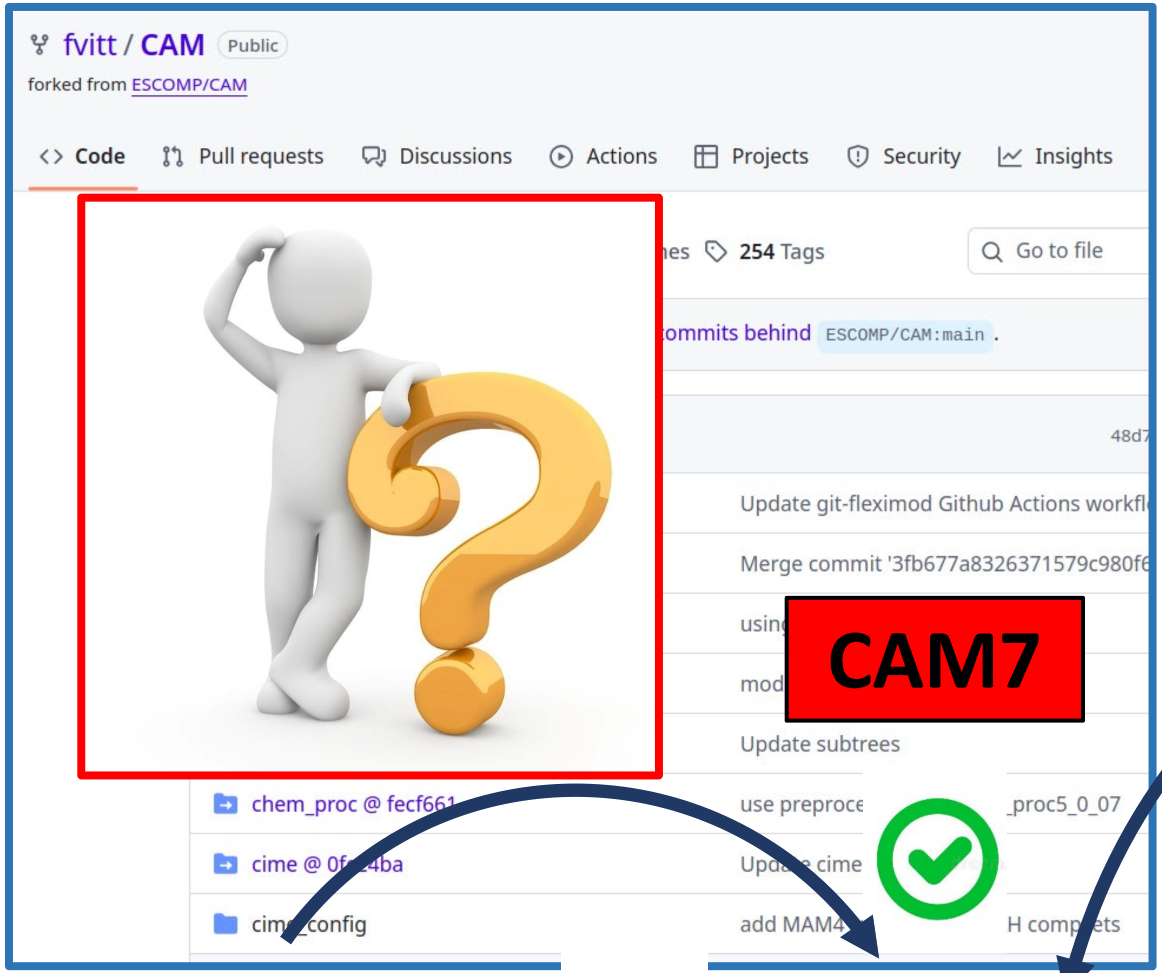
cam6_4_142_slh

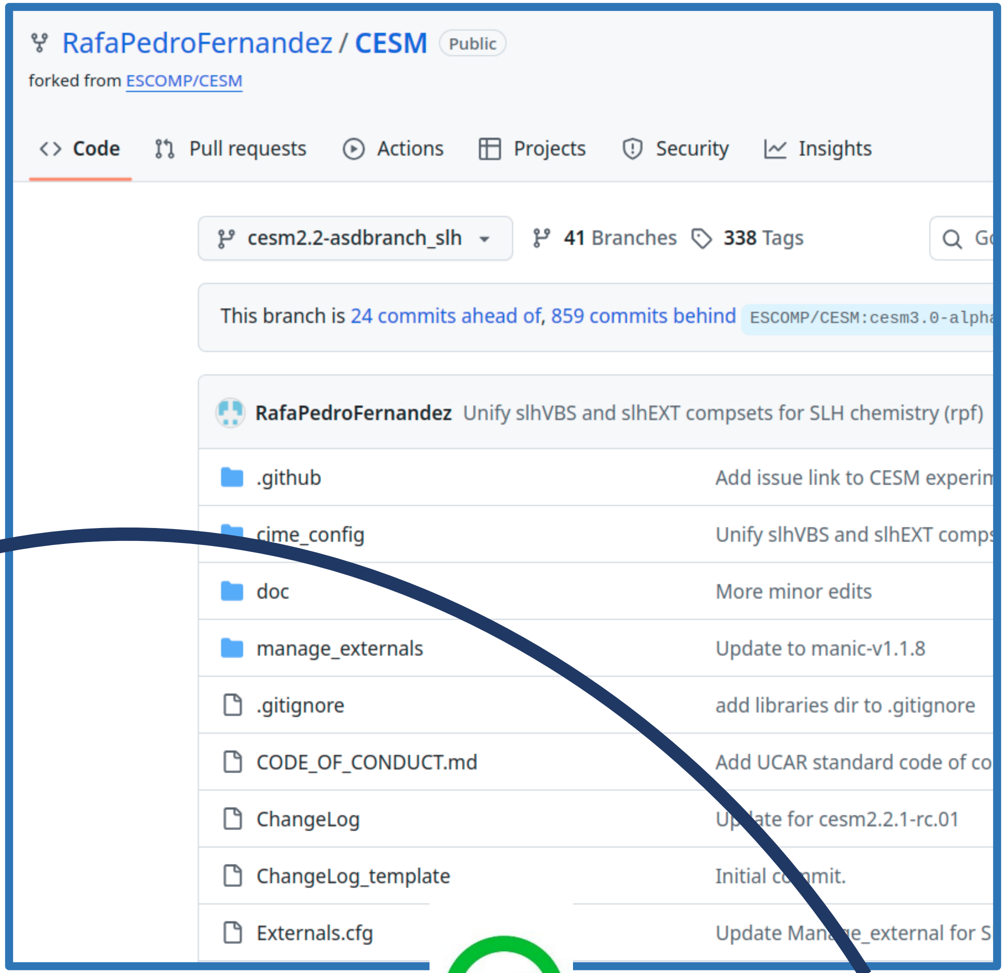
(Preliminar Results, 2026)

Fully-Coupled (BW,BC) CAM6_dev_SLH

cam6_4_142_slh

cesm2.2-asdbranch_slh





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Publication number: NSF 26-203

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