Short-Lived Halogen Chemistry in the Community Earth System Model (CESM2-SLH): Current Developments and Atmospheric Implications

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European Research Council
Established by the European Commission

CESM Workshop, Boulder, June 2024

Outline

1. **Relevance of implementing SLH chemistry in CESM**
   - ***Influence on the abundance of O_3, OH, CH_4, Aerosols, etc.***
   - ***Impacts in the MBL, Free Troposphere and Lower Stratosphere***

Atmospheric Implications

2. **Release of CESM2-SLH:**
   - ***Technical description of the main reactions and processes***
   - ***Summary of namelist options, chem_mech.in and compsets***
   - ***Dependence of Halogen abundance for different configurations***

Technical Description

3. ***Evaluation of different CESM2 compsets***
   - ***Global Impacts for HAL vs. NoHAL sensitivities***
   - ***Zonal Averages, Vertical Profiles and Trends***

Model Sensitivities

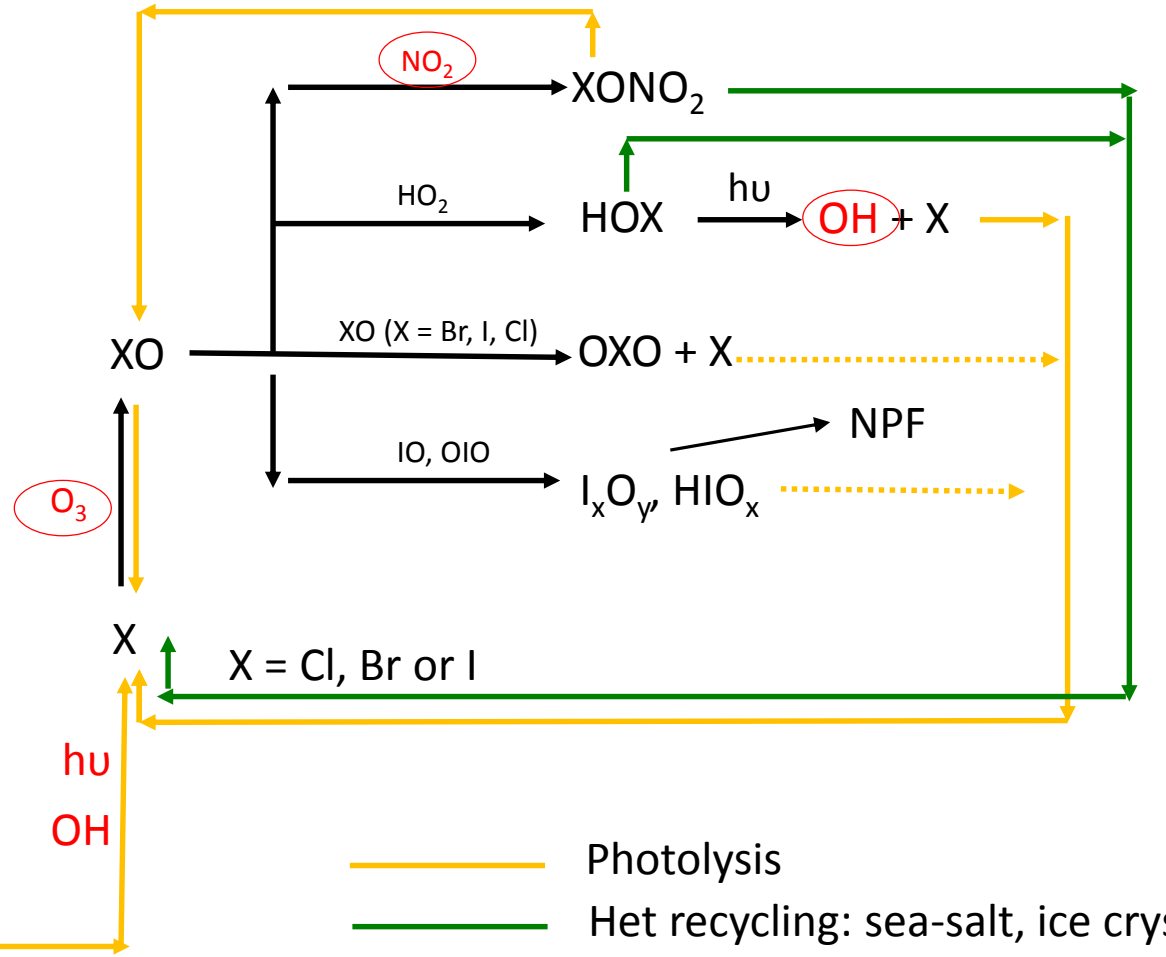
1. Atmospheric Implications

Introduction to SLH chemistry

Short-lived halogens (τ < 6 months)

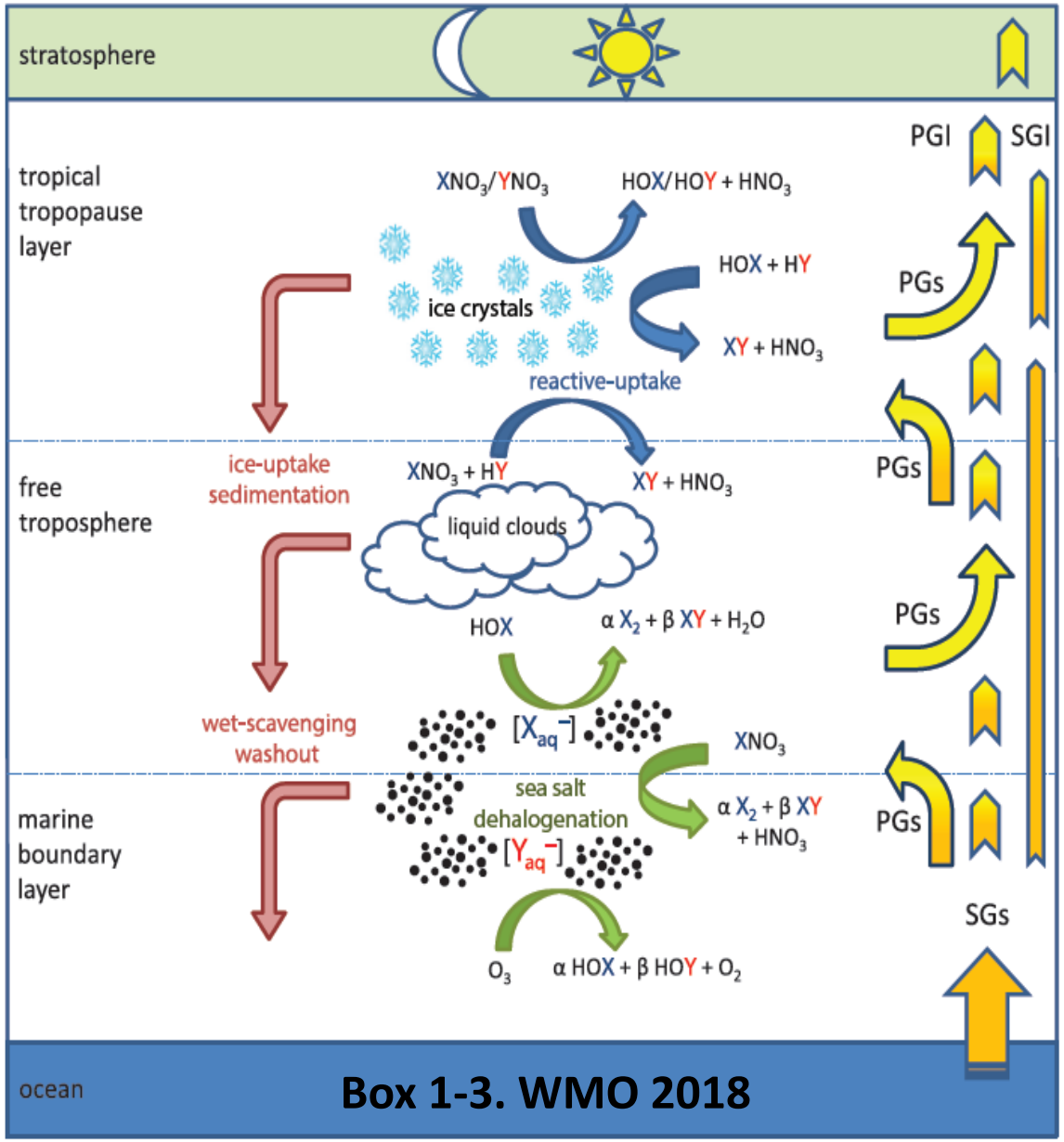
Source gas	Local Lifetime (WMO, 2010)	Main loss
CH_2BrCl	137 days	OH, hv
CH_2Br_2	123 days	OH, hv
$CHBrCl_2$	78 days	OH, hv
$CHBr_2Cl$	59 days	hv, OH
$CHBr_3$	24 days	hv, OH
CH_3I	7 days	hv, OH
CH_2ICl	~ 2–3 h	hv
CH_2IBr	~1 h	hv
CH_2I_2	~ 5 min	hv
HOI/I_2	1 min	hv

Faster cycling for iodine than for bromine and chlorine



Saiz-Lopez and von Glasow, *Chemical Society Reviews*, 2012

Reactive transport of SLH: Sources and Sinks



Box 1-3. WMO 2018

Long-Lived ODS (stratosphere):

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

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

$CH_3Cl + OH \rightarrow Cl + CH_3O_2$

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

VSL Halogens (Natural + Anthro):

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

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

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

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

$\tau < 0.5$ yr

Inorganic Halogens Washout (NEU + FRA):

gas_wetdep_list: HCl,HBr,HOBr, $BrONO_2$, ~~HOI~~, $IONO_2$

Gas_wetdep_ice-uptake_list: HCl, ~~$BrONO_2$~~,~~$IONO_2$~~

$BrONO_2 \rightarrow$

$HOI / IONO_2 \rightarrow$

sinks

SSA-dehalogenation (on-line computation)

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

$HOCl + SSA \rightarrow Cl_2 \rightarrow 2\ Cl$

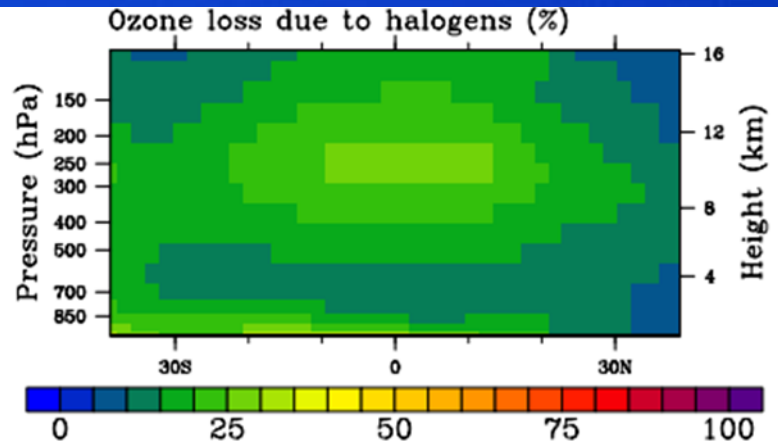
$HNO_3 + SSA \rightarrow HCl \rightarrow Cl$

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

non-stoich. sources

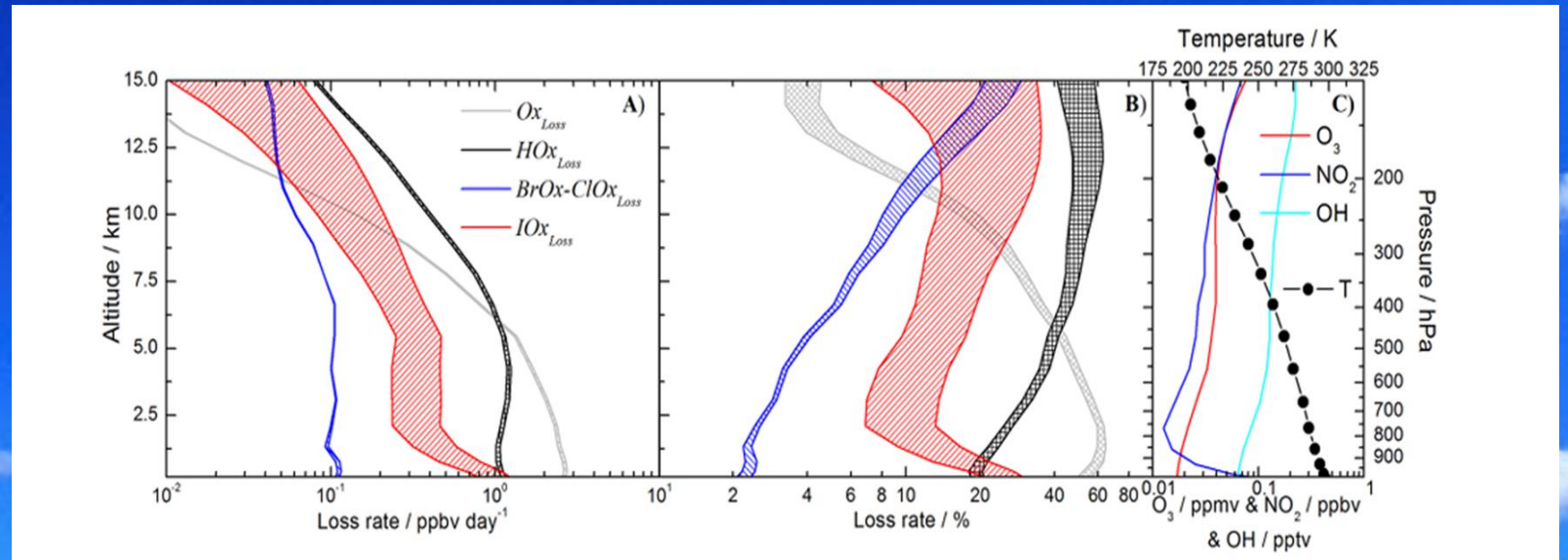
Impact on Atmospheric Composition: Tropospheric Ozone

- **Iodine dominates ozone loss over Br and Cl**
- **Largest % contribution of SLH located in the free troposphere**



Natural halogens reduce global tropospheric ozone by ~15-17%.

Saiz-Lopez et al., ACP, 2012

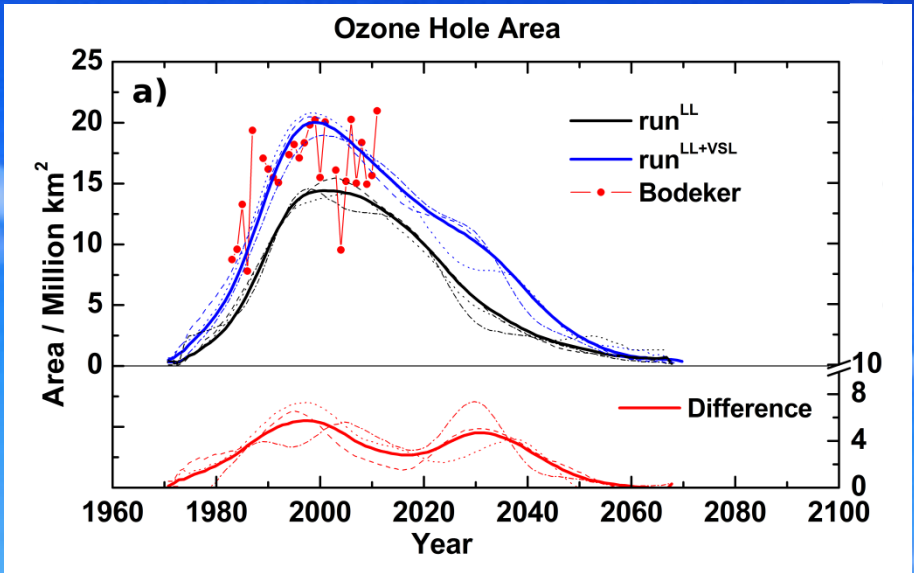


Saiz-Lopez et al., ACP, 2014

Natural halogens (I, Br, Cl)

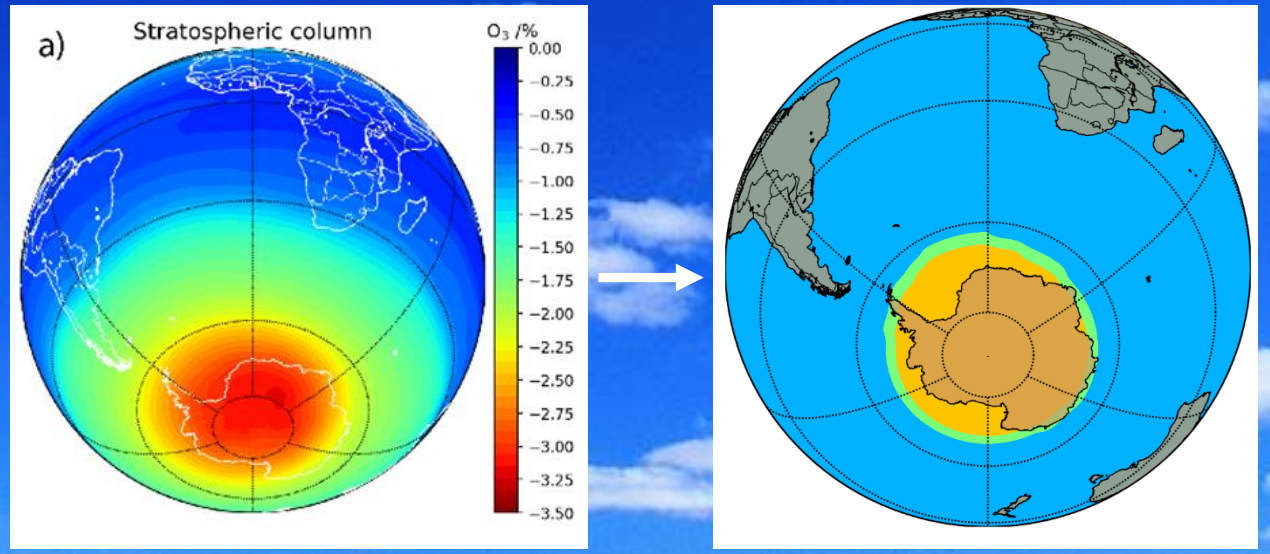
Impact on Atmospheric Composition: Stratospheric Ozone

The inclusion of Short-Lived Br produces an extension of the Ozone Hole Area of ~ 40 % during the 2000th decade, and almost doubles the ozone hole extension during the 2030th decade.



Fernandez et al., ACP, 2017

Stratospheric ozone loss caused by iodine (0.7 pptv) reduce about 10-20% ozone in the Antarctic lower stratosphere. It is equivalent to that of 3-4 pptv of bromine, expanding the size of the ozone hole by 11% or 1.2 million km² (green)



Cuevas et al., *PNAS*, 2022

Natural halogens (I, Br, Cl)

Impact on Atmospheric Composition: Methane Lifetime

Halogen influence on Oxidation Capacity:
(clean environments)

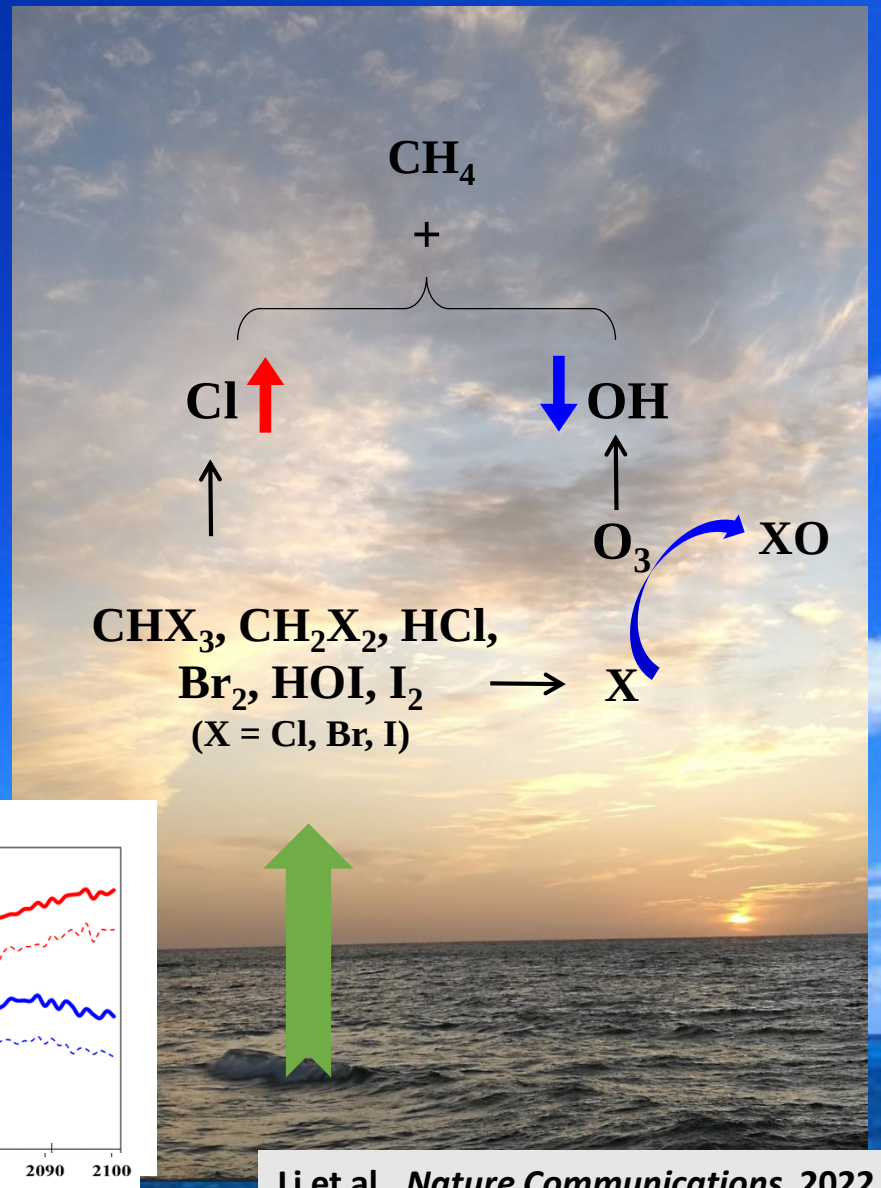
$X + O_3 \rightarrow XO + O_2$
$O_3 + h\nu \rightarrow O^1D + O_2$
$O^1D + H_2O \rightarrow 2\ OH$

(polluted environments)

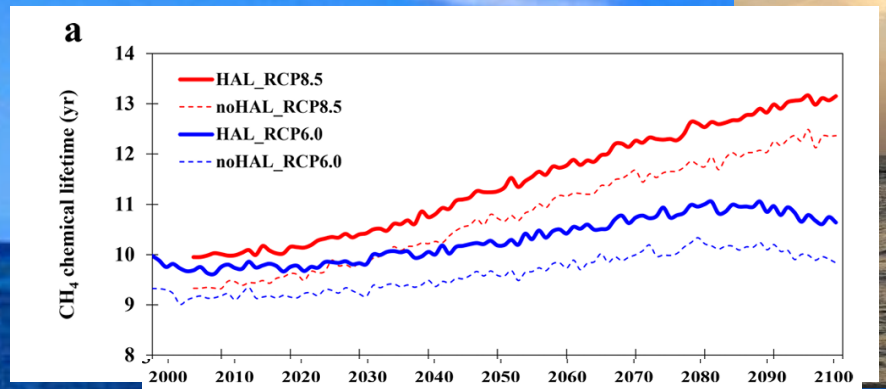
$Cl + VOCs \rightarrow RO_2 + HCl$
$RO_2 + NO \rightarrow NO_2 + RO$
$RO + O_2 \rightarrow HO_2 + Products$
$HO_2 + NO \rightarrow NO_2 + OH$
$XO + HO_2 \rightarrow HOX$
$HOX + h\nu \rightarrow X + OH$

VSL Halogens indirectly decrease OH

VSL Halogens indirectly increase OH



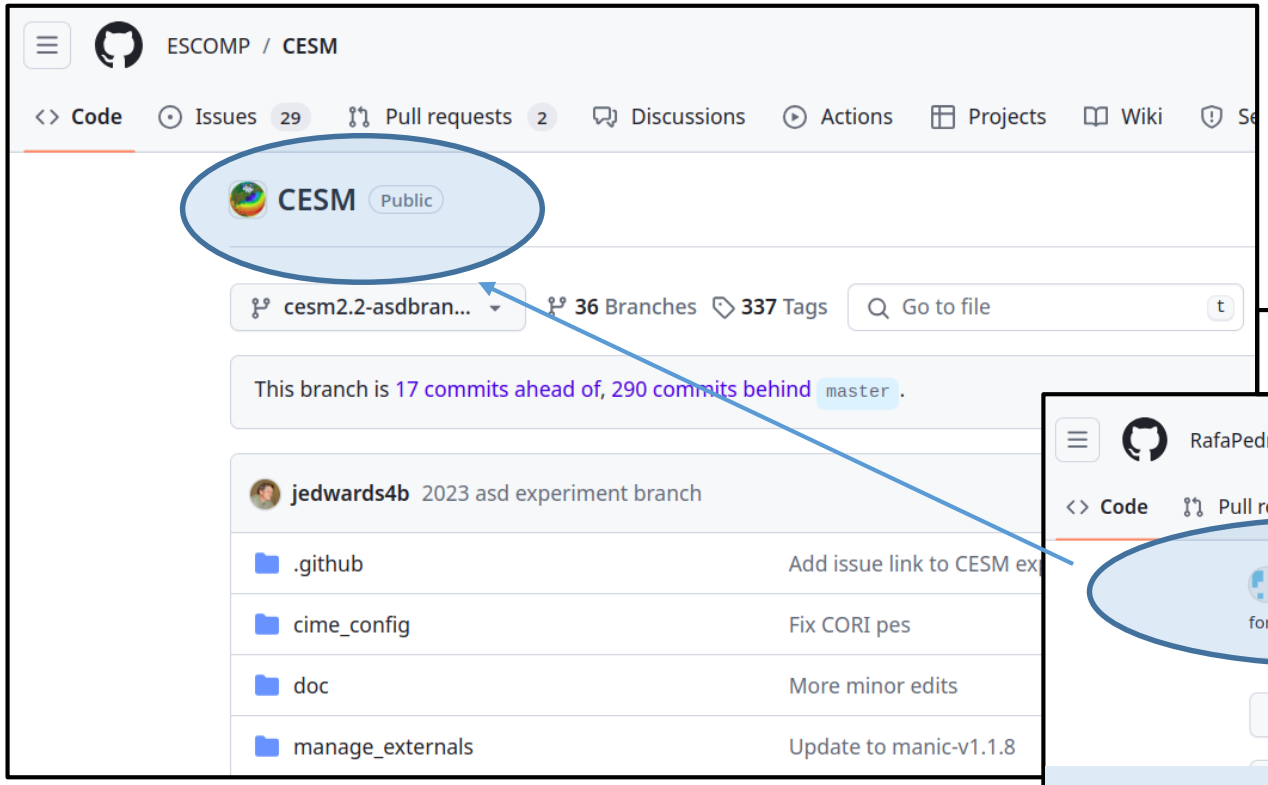
Reactive halogens increase methane´s lifetime by 6-9%. This increases by about 8% the methane burden, which is equivalent to the methane increase in the last 3-4 decades.



Li et al., *Nature Communications*, 2022

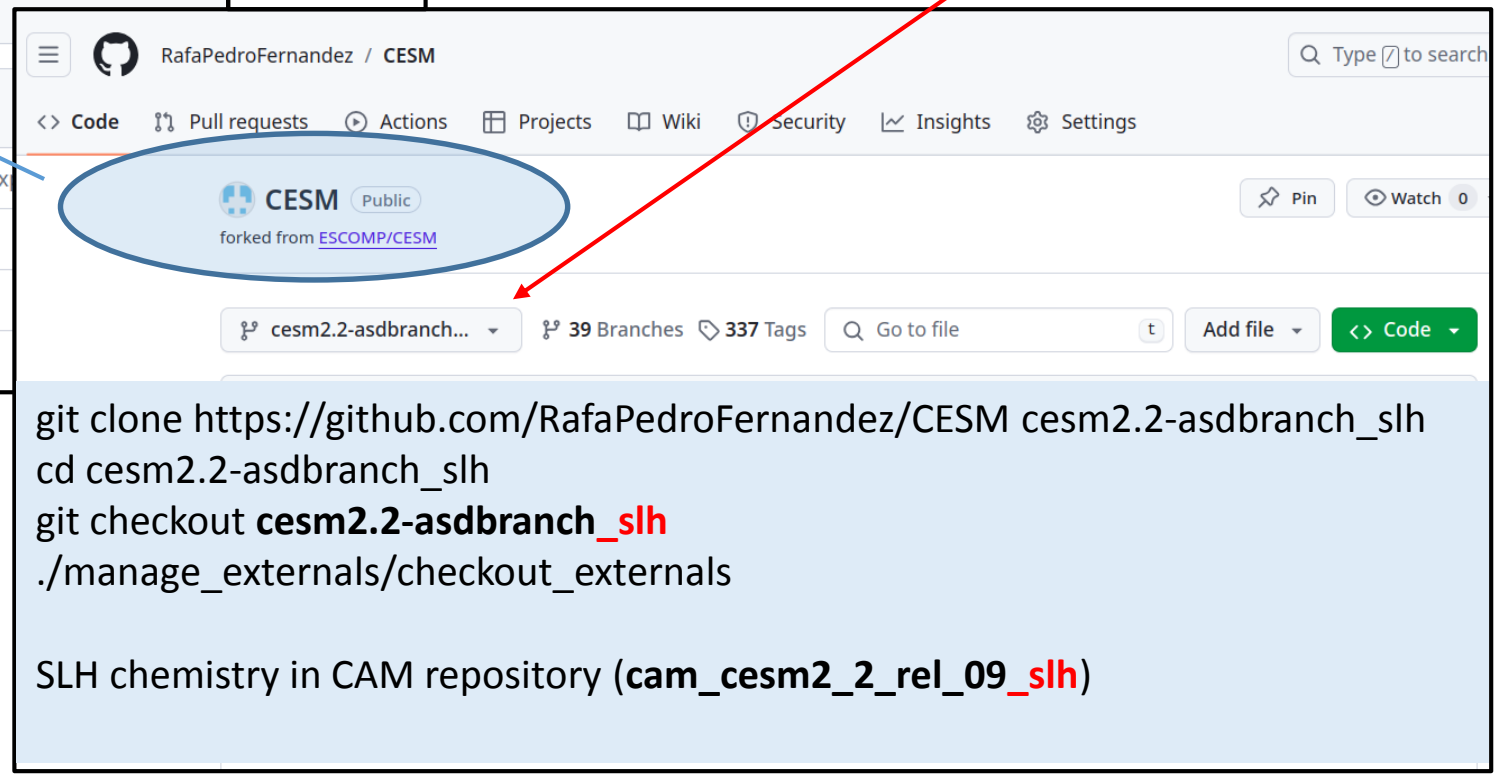
2. Technical Description

CESM2-SLH Repository (github)



CESM Branch:
cesm2.2-asdbranch_slh

Fork



git clone https://github.com/RafaPedroFernandez/CESM cesm2.2-asdbranch_slh
cd cesm2.2-asdbranch_slh
git checkout **cesm2.2-asdbranch_slh**
./manage_externals/checkout_externals

SLH chemistry in CAM repository (**cam_cesm2_2_rel_09_slh**)

CAM Branch:
cam_cesm2_2_rel_09_slh

Thanks a lot to Francis Vitt, Jim Edwards and Brian Dobbins for valuable help !!!

CESM2-SLH (cesm2.2-asdbranch_slh)

chem_proc (pp_#)

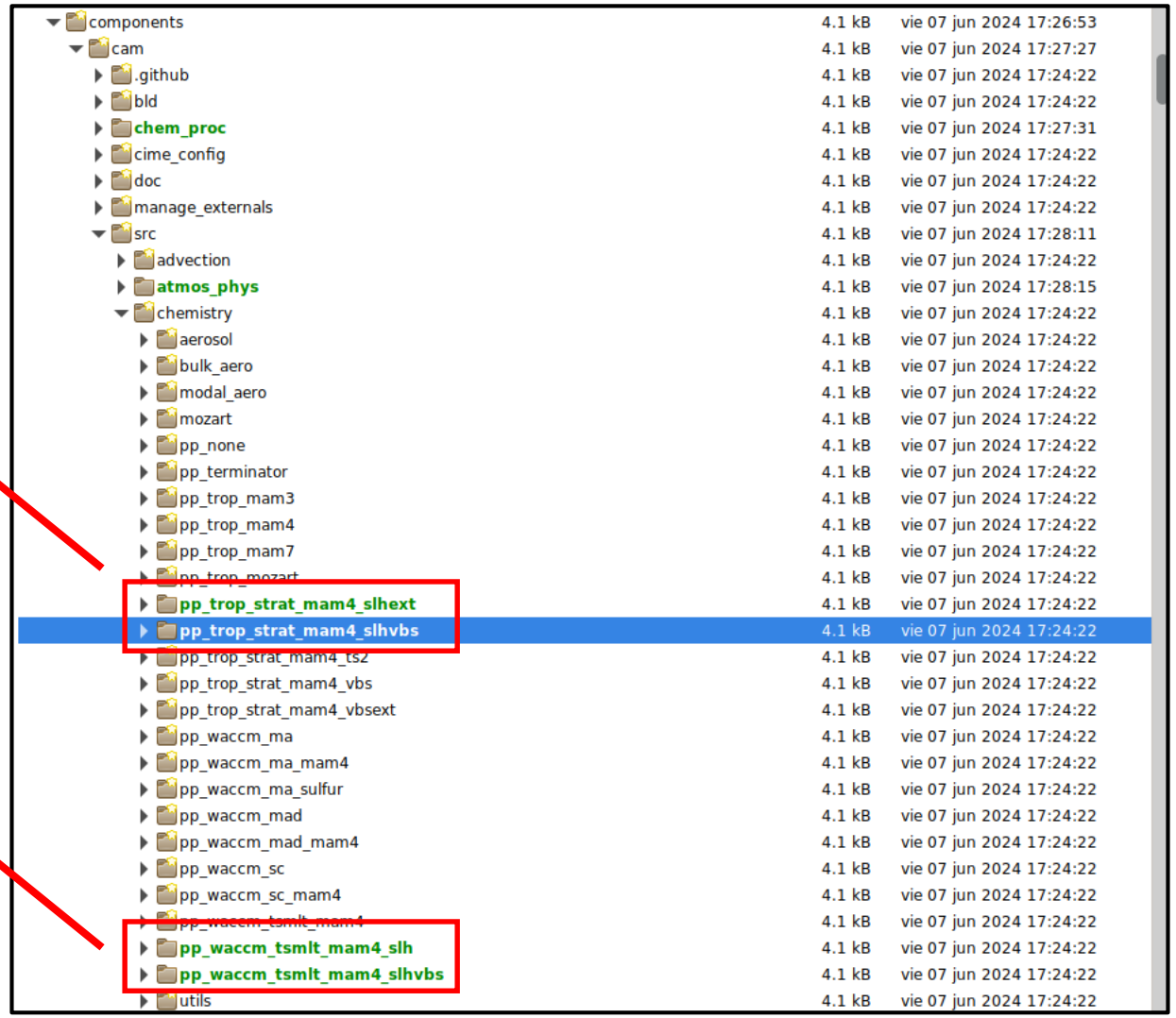
pp_trop_strat_mam4_slh

* Comments
* User-given Tag Description: TS1.2_simpleVBS_VSL
* Tag database identifier : MZ352_TS1_simpleVBS_SLH_20240229
* Tag created by : lke
* Tag created from branch : TS1-simpleVBS_SLH
* Tag created on : 2023-06-22 11:09:21.598137-06
* Comments for this tag follow:
* lke : 2023-06-22 : SLH halogens in **MOZART-TS1.2**.

pp_waccm_tsmlt_mam4_slh

* Comments
* User-given Tag Description: TSMLT1 for CESM2.0
* Tag database identifier : MZ197_TSMLT1_20240229
* Tag created by : lke
* Tag created from branch : **TSMLT1**
* Tag created on : 2018-04-23 17:47:30.657331-06
* Comments for this tag follow:
* lke : 2023-06-22 : SLH halogens in MOZART-TS1.2.
  (NOTE .. hand-written by rpf instead of using CAFE)

cam_cesm2_2_rel_09_slh



CAM 6 (cam_cesm2_2_rel_09_slh)

Species

Halocarbons

10 for Chlorine
5 for Bromine
4 for Iodine
19 Total

Inorganic

3 for Chlorine
3 for Bromine
15 for Iodine
21 Total

Photolysis

11 for Chlorine
7 for Bromine
17 Iodine
35 Total

SLHs + OH/Cl

17 for Chlorine
3 for Bromine
2 Iodine
22 Total

chem_mech.in

Default = No SLH → SLH = HAL

```
[jcfc113]          CFC113 + hv -> 2*CL + COFCL + COF2
[jcfc114]          CFC114 + hv -> 2*CL + 2*COF2
[jcfc115]          CFC115 + hv -> CL + F + 2*COF2
[jcf2cl2]          CFC12 + hv -> 2*CL + COF2
[jch2br2]          CH2BR2 + hv -> 2*BR
[jch2brcl]         CH2BRCL + hv -> BR + CL
[jch2cl2]          CH2CL2 + hv -> 2*CL
[jch2i2]           CH2I2 + hv -> 2*I
[jch2ibr]          CH2IBR + hv -> I + BR
[jch2icl]          CH2ICL + hv -> I + CL
[jch3br]           CH3BR + hv -> BR + CH3O2
[jch3ccl3]         CH3CCL3 + hv -> 3*CL
[jch3cl]           CH3CL + hv -> CL + CH3O2
[jch3i]            CH3I + hv -> I + CH3O2
[jchbr2cl]         CHBR2CL + hv -> 2*BR + CL
[jchbr3]           CHBR3 + hv -> 3*BR
[jchbrcl2]         CHBRCL2 + hv -> BR + 2*CL
[jchcl3]           CHCL3 + hv -> CHCL2O2 + CL
[jcl2]             CL2 + hv -> 2*CL
[jcl2o2]           CL2O2 + hv -> 2*CL
[jclno2]           CLNO2 + hv -> CL + NO2
```

```
[CH3BR_CL]         CH3BR + CL  -> HCL + HO2 + BR          ; 1.46e-11, -1040
[CH3BR_OH]         CH3BR + OH  -> BR + H2O + HO2          ; 1.42e-12, -1150
[CH3CCL3_OH]       CH3CCL3 + OH  -> H2O + 3*CL            ; 1.64e-12, -1520
[CH3CL_CL]         CH3CL + CL  -> HO2 + CO + 2*HCL        ; 2.03e-11, -1110
[CH3CL_OH]         CH3CL + OH  -> CL + H2O + HO2          ; 1.96e-12, -1200
[CH3I_CL]          CH3I + CL  -> I + HCL + HO2            ; 2.9e-11, -1000
[CH3I_OH]          CH3I + OH  -> I + H2O + HO2            ; 2.9e-12, -1100
[CHBR2CL_OH]       CHBR2CL + OH  -> 2*BR + CL             ; 9e-13, -420
[CHBR3_CL]         CHBR3 + CL  -> 3*BR + HCL              ; 4.85e-12, -850
[CHBR3_OH]         CHBR3 + OH  -> 3*BR                    ; 9e-13, -360
[CHBRCL2_OH]       CHBRCL2 + OH  -> BR + 2*CL             ; 9.4e-13, -510
[CHCL2O2_CH3O2_a]  CHCL2O2 + CH3O2  -> 2*CL + 2*HO2 + CH2O + CO  ; 1.2e-12
[CHCL2O2_CH3O2_b]  CHCL2O2 + CH3O2  -> COCL2 + CO + HO2   ; 8e-13
[CHCL2O2_HO2_a]    CHCL2O2 + HO2  -> COCL2 + H2O + O2     ; 3.92e-13, 700
[CHCL2O2_HO2_b]    CHCL2O2 + HO2  -> HO2 + CO + CL + HOCL  ; 1.68e-13, 700
[CHCL2O2_NO]       CHCL2O2 + NO  -> HO2 + 2*CL + NO2 + CO  ; 4.05e-12, 360
[CHCL2O2_NO3]      CHCL2O2 + NO3  -> HO2 + 2*CL + NO2 + CO  ; 2.3e-12
[CHCL3_CL]         CHCL3 + CL  -> COCL2 + CL + HCL        ; 3.3e-12, -990
[CHCL3_OH]         CHCL3 + OH  -> COCL2 + CL + H2O        ; 2.2e-12, -920
```

CAM 6 (cam_cesm2_2_rel_09_slh)

chem_mech.in

SLH

Odd-Halogens
OH/NO_2 + DMS

2+2 for Chlorine
4+1 for Bromine
39+1 for Iodine
45+4 Total

Heterogeneous Reactions
(mo_usrrxt.F90)

Tropo. Aerosols
9 for Chlorine
6 for Bromine
6 for Iodine

sinks
Free Regime Approx.
0 for Chlorine
1 for Bromine
4 for Iodine

non-stoich. sources
Sea-salt Dehalogenation
5 for Chlorine
3 for Bromine
3 for Iodine

```
**********************************
*** odd-bromine
**********************************
[BR2_OH]              BR2 + OH   -> HOBR + BR                    ; 2.1e-11, 240
[BR_CH2O]             BR + CH2O  -> HBR + HO2 + CO               ; 1.7e-11, -800
[BR_HO2]              BR + HO2   -> HBR + O2                     ; 4.8e-12, -310
[BR_NO2_M]            BR + NO2 + M  -> BRNO2 + M                 ; 4.2e-31, 2.4, 2
[BR_O3]               BR + O3    -> BRO + O2                     ; 1.6e-11, -780
[BRO_BRO]             BRO + BRO  -> 2*BR + O2                    ; 1.5e-12, 230
[BRO_CLOa]            BRO + CLO  -> BR + OCLO                    ; 9.5e-13, 550
[BRO_CLOb]            BRO + CLO  -> BR + CL + O2                 ; 2.3e-12, 260
[BRO_CLOc]            BRO + CLO  -> BRCL + O2                    ; 4.1e-13, 290
[BRO_HO2]             BRO + HO2  -> HOBR + O2                    ; 4.5e-12, 460
[BRO_NO]              BRO + NO   -> BR + NO2                     ; 8.8e-12, 260
[BRONO2_BR]           BRONO2 + BR  -> BR2 + NO3                  ; 1.78e-11, 365
[BRONO2_CL]           BRONO2 + CL  -> BRCL + NO3                 ; 6.28e-11, 215
[BRO_NO2_M]           BRO + NO2 + M  -> BRONO2 + M               ; 5.2e-31, 3.2, 6
```

```
[usr_ISOPNITB_aer]    ISOPNITB  -> HNO3
[usr_N2O5_aer]        N2O5  ->
[usr_N2O5_aer1]       N2O5  -> 2*HNO3 + N2O5
[usr_N2O5_aer2]       N2O5 + HCL  -> CLNO2 + N2O5 + HNO3
[usr_NC4CH2OH_aer]    NC4CH2OH  -> HNO3
```

```
*** Sea Salt Aerosol
**********************************
[het_ss_0]            BRONO2  -> 0.65*BR2 + 0.35*BRCL
[het_ss_1]            BRNO2  -> 0.65*BR2 + 0.35*BRCL
[het_ss_10]           N2O5  ->
[het_ss_11]           N2O5  -> 2*HNO3 + N2O5
[het_ss_12]           N2O5  -> CLNO2 + HNO3 + N2O5
[het_ss_2]            HOBR  -> 0.65*BR2 + 0.35*BRCL
[het_ss_3]            CLONO2  -> CL2
[het_ss_4]            CLNO2  -> CL2
[het_ss_5]            HOCL  -> CL2
[het_ss_6]            IONO2  -> 0.5*IBR + 0.5*ICL
[het_ss_7]            INO2  -> 0.5*IBR + 0.5*ICL
[het_ss_8]            HOI  -> 0.5*IBR + 0.5*ICL
[het_ss_9]            HNO3  -> HCL
```

CESM2-SLH Compsets

Config_compsets.xml

Validated for: 1.9° x 2.5° and 32L

CAM-Chem

Tested new compsets:

- **FCnudgedslhvbs**
- **FCHISTslhvbs**

...

- FC2000climoslhvbs
- FCSDslhvbs

Updated default namelist files for each compset !

```
<compset>
  <alias>FCnudged</alias>
  <lname>HIST_CAM60%CCTS1%NUDG_CLM50%SP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV</lname>
</compset>
<!--  CESM2-SLH: Mapped and Tested. Please check (rpf) -->
<compset>
  <alias>FCnudgedslhvbs</alias>
  <lname>HIST_CAM60%CCTS1SLH%NUDG_CLM50%SP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV</lname>
<!--     <lname>HIST_CAM60%CCTS1SLH%NUDG_CLM50%SP_CICE%PRES_DOCN%DOM_MOSART_CISM2%NOEVOLVE_SWAV</
</compset>
```

```
<compset>
  <alias>FCHIST</alias>
  <lname>HIST_CAM60%CCTS1_CLM50%SP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV</lname>
</compset>
<!--  CESM2-SLH: Mapped and Tested. Please check (rpf) -->
<compset>
  <alias>FCHISTslhvbs</alias>
<!--     <lname>HIST_CAM60%CCTS1SLH_CLM50%SP_CICE%PRES_DOCN%DOM_MOSART_CISM2%NOEVOLVE_SWAV</lname:
  <lname>HIST_CAM60%CCTS1SLH_CLM50%SP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV</lname>
</compset>
<!--  CESM2-SLH: Mapped and Tested. Please check (rpf) -->
```

WACCM

- **FWHIST_BGCslh**

Not tested:

- FWnudged_slh
- FWHISTslh

```
<compset>
  <alias>FWHIST_BGC</alias>
<!--     <lname>HIST_CAM60%WCTS_CLM50%BGC-CROP_CICE%PRES_DOCN%DOM_MOSART_CISM2%NOEVOLVE_SWAV</lnar
  <lname>HIST_CAM60%WCTS_CLM50%BGC-CROP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV</lname>
  <science_support grid="f09_f09_mg17"/>
</compset>
<!--  CESM2-SLH: Mapped and Tested. Please check (rpf) -->
<compset>
  <alias>FWHIST_BGCslh</alias>
<!--     <lname>HIST_CAM60%WCTSSLH_CLM50%BGC-CROP_CICE%PRES_DOCN%DOM_MOSART_CISM2%NOEVOLVE_SWAV</
  <lname>HIST_CAM60%WCTSSLH_CLM50%BGC-CROP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV</lname>
  <science_support grid="f09_f09_mg17"/>
</compset>
```

Namelists options (SLH emissions and LBCs)

user_nl_cam / atm_in

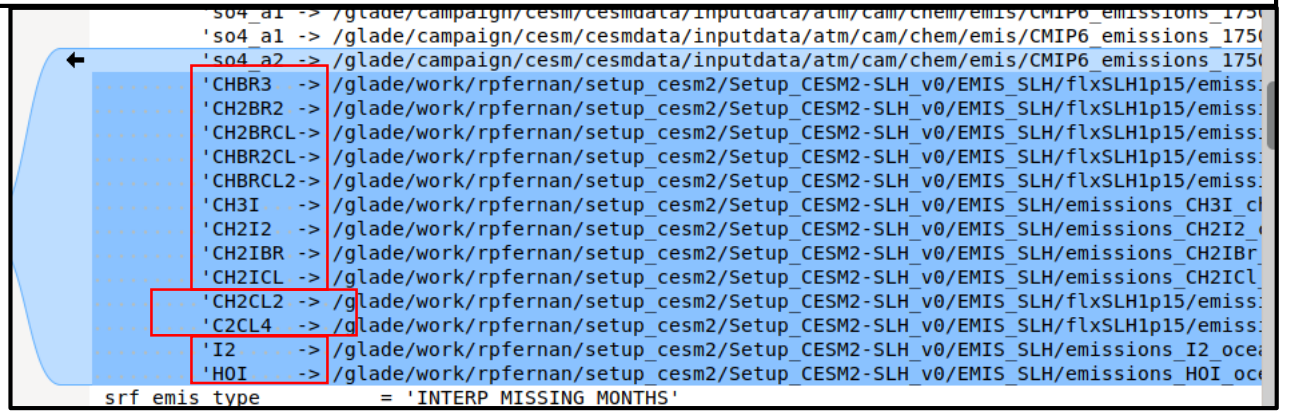
No_HAL | **SLH**

srf_emis_specifier

/glade/work/rpfernan/setup_cesm2/Setup_CESM2-SLH_v0/EMIS_SLH/

- Oceanic SLH (Br,Cl, I) based on Ordoñez Inventory
- Anthropogenic SLH^{Cl} follows Hossaini/Claxton

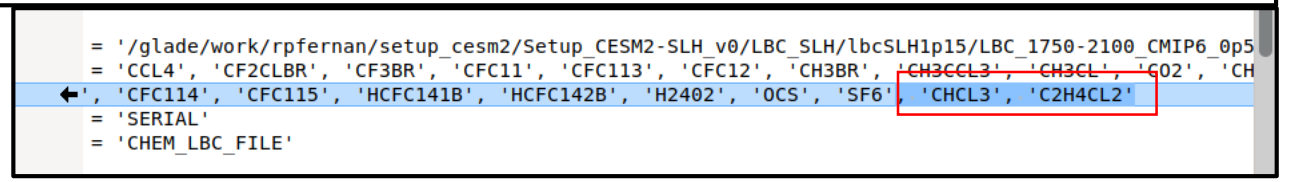
- Iodine emissions are just a place-holder …
  They are zeroed and computed on-line
  (iodine_emissions.F90)



flbc_list

/glade/work/rpfernan/setup_cesm2/Setup_CESM2-SLH_v0/LBC_SLH/

- Additional SLH^{Cl} species are included as LBCs
- Be sure no to include ~~CHBR3~~ and ~~CH2BR2~~



ncdata

/glade/work/rpfernan/setup_cesm2/Setup_CESM2-SLH_v0/ncdata_SLH/

- Make sure to use a SLH stabilized IC (*cam.i.*) !!!

Namelists options (Dry & Wet deposition)

user_nl_cam / atm_in

SLH

drydep_inparam

- Inorganic Halogen reservoirs are washed out with individual deposition velocities.
- *drydep_list* is automatically updated for *_slh compsets

```
&drydep_inparm
  drydep_list = 'ALKNIT', 'ALKOOH', 'BCARY', 'BENZENE', 'BENZOOH', 'BEPOMUC',
      'BIGALD', 'BIGALD1', 'BIGALD2', 'BIGALD3', 'BIGALD4', 'BIGALK', 'BIGENE',
      'BZALD', 'BZOOH', 'C2H2', 'C2H4', 'C2H5OH', 'C2H5OOH', 'C2H6', 'C3H6',
      'C3H7OOH', 'C3H8', 'C6H5OOH', 'CH2O', 'CH3CHO', 'CH3CN', 'CH3COCH3',
      'CH3COCHO', 'CH3COOH', 'CH3COOOH', 'CH3OH', 'CH3OOH', 'CO', 'CRESOL',
      'DMS', 'EOOH', 'GLYALD', 'GLYOXAL', 'H2O2', 'H2SO4', 'HCN', 'HCOOH',
      'HNO3', 'HO2NO2', 'HONITR', 'HPALD', 'HYAC', 'HYDRALD', 'IEPOX', 'ISOP',
      'ISOPNITA', 'ISOPNITB', 'ISOPNO3', 'ISOPNOOH', 'ISOPOOH', 'IVOC', 'MACR',
      'MACROOH', 'MEK', 'MEKOOH', 'MPAN', 'MTERP', 'MVK', 'N2O5', 'NC4CH2OH',
      'NC4CHO', 'NH3', 'NH4', 'NO', 'NO2', 'NOA', 'NTERPOOH', 'O3', 'O3S',
      'ONITR', 'PAN', 'PBZNIT', 'PHENOL', 'PHENOOH', 'POOH', 'ROOH', 'SO2',
      'SOAG0', 'SOAG1', 'SOAG2', 'SOAG3', 'SOAG4', 'SVOC', 'TEPOMUC',
      'TERP2OOH', 'TERPNIT', 'TERPOOH', 'TERPROD1', 'TERPROD2', 'TOLOOH',
      'TOLUENE', 'XOOH', 'XYLENES', 'XYLENOOH', 'XYLOL', 'XYLOLOOH', 'CLONO2',
      'HCL', 'HOCL', 'CLNO2', 'BRONO2', 'HBR', 'HOBR', 'BRNO2', 'BR2', 'IONO2',
      'HI', 'HOI', 'INO2', 'I2O2', 'I2O3', 'I2O4', 'CHCL2O2', 'COCL2'
  drydep_method = 'xactive_lnd'
```

wetdep_inparam

- A new wet-deposition list for ice_uptake was implemented in NEU routine (*gas_wetdep_ice_uptake_list*)
- Halogens are not longer mapped to HNO3
- Free Regime Approximation (FRA) for ice-uptake of iodine (IONO2, HOI, HI), and also for BRONO2. (chem_mehc.in & mo_usrrxt.F90)

```
&wetdep_inparm
 gas_wetdep_ice_uptake_list          = 'HNO3','CLONO2','HCL','HOCL','BRNO2','CLNO2','I2O2','I2
 gas_wetdep_list               = 'ALKNIT', 'ALKOOH', 'BCARY', 'BENZENE', 'BENZOOH', 'BEPOMUC', '
        'BIGALK', 'BIGENE', 'BRONO2', 'BZALD', 'BZOOH', 'C2H2', 'C2H4', 'C2H5OH', 'C2H5OOH', 'C2
        'C3H7OOH', 'C3H8', 'C6H5OOH', 'CH2O', 'CH3CHO', 'CH3CN', 'CH3COCH3', 'CH3COCHO', 'CH3COO
        'CH3OOH', 'CLONO2', 'CO', 'COF2', 'COFCL', 'CRESOL', 'DMS', 'EOOH', 'GLYALD', 'GLYOXAL',
        'H2SO4', 'HBR', 'HCL', 'HCN', 'HCOOH', 'HF', 'HNO3', 'HO2NO2', 'HOBR', 'HOCL', 'HONITR',
        'HPALD', 'HYAC', 'HYDRALD', 'IEPOX', 'ISOP', 'ISOPNITA', 'ISOPNITB', 'ISOPNO3', 'ISOPNOO
        'MACR', 'MACROOH', 'MEK', 'MEKOOH', 'MPAN', 'MTERP', 'MVK', 'N2O5', 'NC4CH2OH', 'NC4CHO'
        'NH3', 'NH4', 'NHDEP', 'NO', 'NO2', 'NOA', 'NTERPOOH', 'ONITR', 'PAN', 'PBZNIT', 'PHENOL
        'PHENOOH', 'POOH', 'ROOH', 'SO2', 'SOAG0', 'SOAG1', 'SOAG2', 'SOAG3', 'SOAG4', 'SVOC', '
        'TERP2OOH', 'TERPNIT', 'TERPOOH', 'TERPROD1', 'TERPROD2', 'TOLOOH', 'TOLUENE', 'XOOH', '
        'XYLOLOOH', 'BRCL', 'CLNO2', 'BRNO2', 'BR2', 'IONO2', 'INO2', 'HI', 'IO', 'OIO', 'ICL',
        'IBR', 'I2O2', 'I2O3', 'I2O4', 'CHCL2O2', 'COCL2'
 gas_wetdep_method             = 'NEU'
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!! Tropospheric Aerosol
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
[ice_fr_brono2]        BRONO2  ->
[ice_fr_hi]            HI  ->
[ice_fr_hoi]           HOI  ->
[ice_fr_iono2]         IONO2  ->
```

New namelist options (&slh_nl)

Current Scaling Factors:

lght_no_prd_factor = 4.50D0

dust_emis_fact = 0.26D0

&slh_nl

- We added a new namelist option to allow users to adjust the efficiency of the online computation of sea-salt dehalogenation for bromine and chlorine, as well as the washout of mostly iodine species and $BrONO_2$, using a user-defined scaling factor (default value = 1.0).

user_nl_cam / atm_in

```
 &slh_nl
   icefraprx_scalingfactor               = 1.00D0
   liqfraprx_scalingfactor               = 1.00D0
   slhemiss_scalingfactor          = 1.00D0
   ssadehal_scalingfactor          = 1.00D0
 /
```

mo_usrrxt.F90

```
                if ( het_ss_3_ndx > 0 ) then
!                 rxt(i,k,het_ss_3_ndx) = 0.25_r8 * gamma_clono2_ss * sad_sslt_mask * 1.47e3_r8 * sq
                  rxt(i,k,het_ss_3_ndx) = SSAdehal_ScalingFactor * 0.25_r8 * gamma_clono2_ss * sad_s
                endif
                if ( het_ss_4_ndx > 0 ) then
!                 rxt(i,k,het_ss_4_ndx) = 0.25_r8 * gamma_clno2_ss  * sad_sslt_mask * 1.61e3_r8 * sq
                  rxt(i,k,het_ss_4_ndx) = SSAdehal_ScalingFactor * 0.25_r8 * gamma_clno2_ss  * sad_s
                endif
                if ( het_ss_5_ndx > 0 ) then
!                 rxt(i,k,het_ss_5_ndx) = 0.25_r8 * gamma_hocl_ss   * sad_sslt_mask * 2.01e3_r8 * sq
                  rxt(i,k,het_ss_5_ndx) = SSAdehal_ScalingFactor * 0.25_r8 * gamma_hocl_ss   * sad_s
                endif
```

chem_mech.in

```
*** Sea Salt Aerosol
**********************************
[het_ss_0]          BRONO2  -> 0.65*BR2 + 0.35*BRCL
[het_ss_1]          BRNO2   -> 0.65*BR2 + 0.35*BRCL
[het_ss_10]         N2O5    ->
[het_ss_11]         N2O5    -> 2*HNO3 + N2O5
[het_ss_12]         N2O5    -> CLNO2 + HNO3 + N2O5
[het_ss_2]          HOBR    -> 0.65*BR2 + 0.35*BRCL
[het_ss_3]          CLONO2  -> CL2
[het_ss_4]          CLNO2   -> CL2
[het_ss_5]          HOCL    -> CL2
[het_ss_6]          IONO2   -> 0.5*IBR + 0.5*ICL
[het_ss_7]          INO2    -> 0.5*IBR + 0.5*ICL
[het_ss_8]          HOI     -> 0.5*IBR + 0.5*ICL
[het_ss_9]          HNO3    -> HCL
```

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

v_d

Sea-salt aerosol

Br^- / Cl^-

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

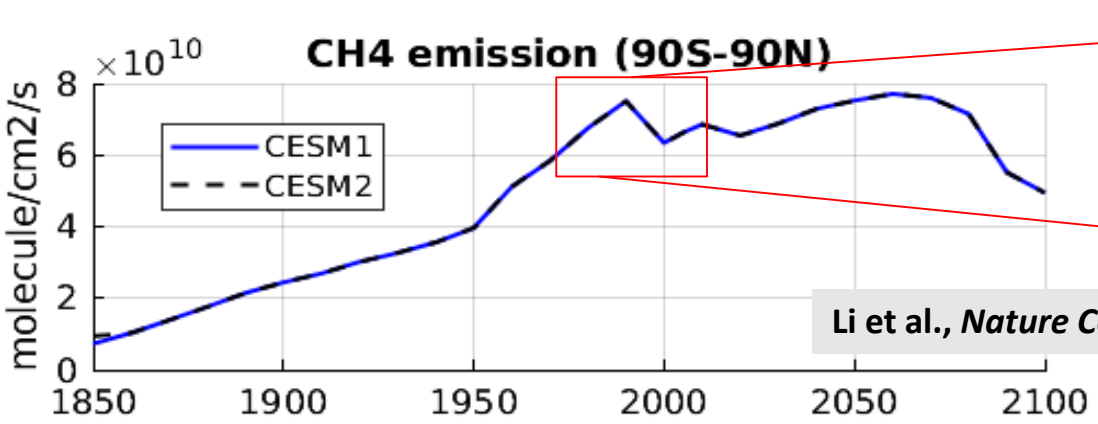
$BrNO_2 \rightarrow 0.65\ Br_2 + 0.35\ BrCl$

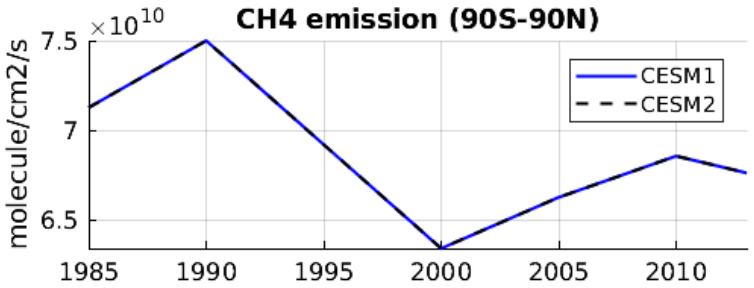
$HOBr \rightarrow 0.65\ Br_2 + 0.35\ BrCl$

MBL

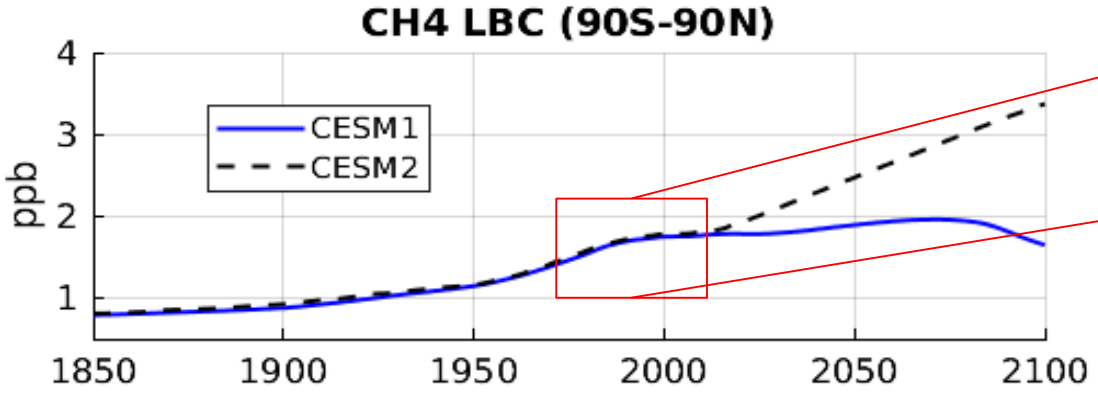
3. Model Sensitivities

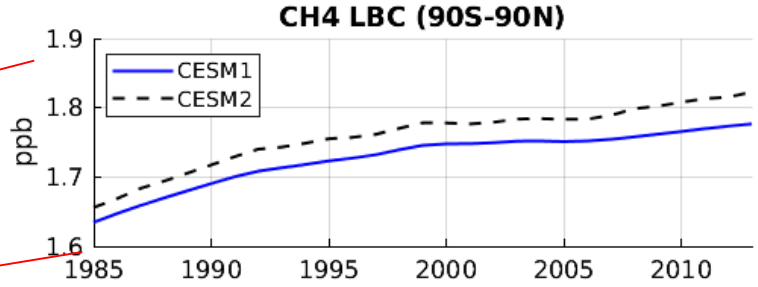
CESM2-SLH: Methane Emissions vs. LBCs





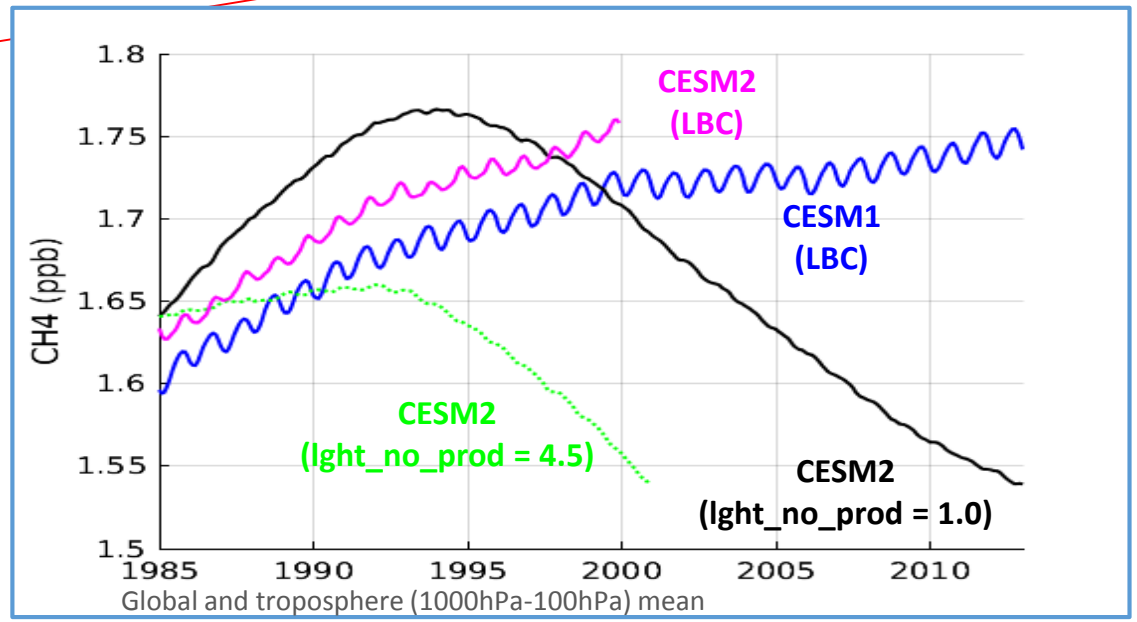
Li et al., *Nature Communications*, 2022





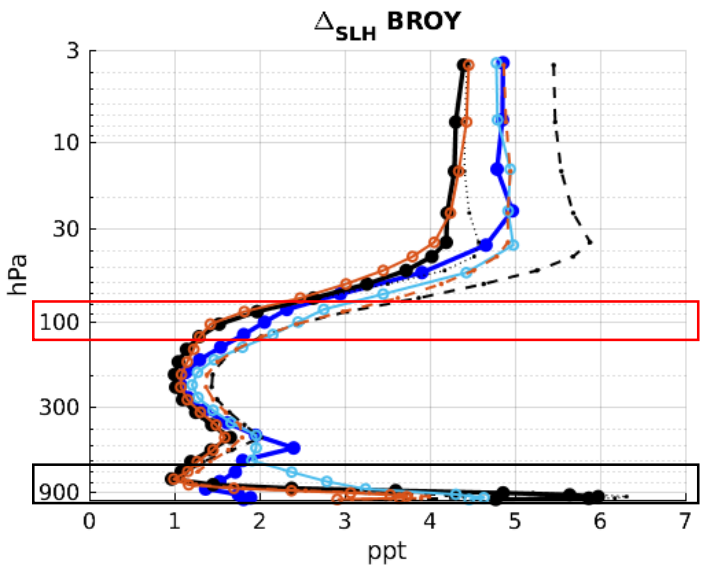
If we impose the CH4 emission files used in CESM1 into CESM2, then the CH4 surface abundance decreases after a peak value in 1995

Therefore the updated CESM2-SLH setup is based on CH4 LBCs.

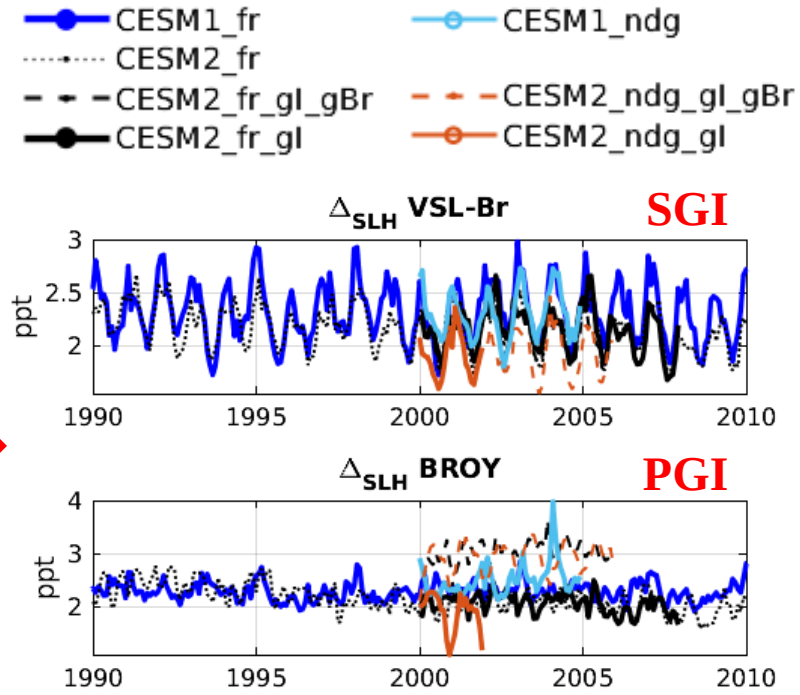


Bromine: surface abundance, SGI and PGI

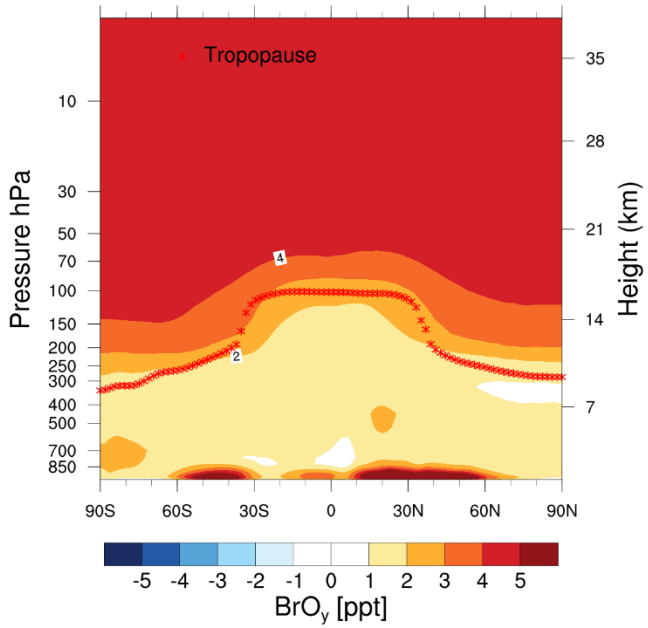
Tropical profile (20ºS - 20ºN)



TTL



ΔBROY (SLH – NoSLH)



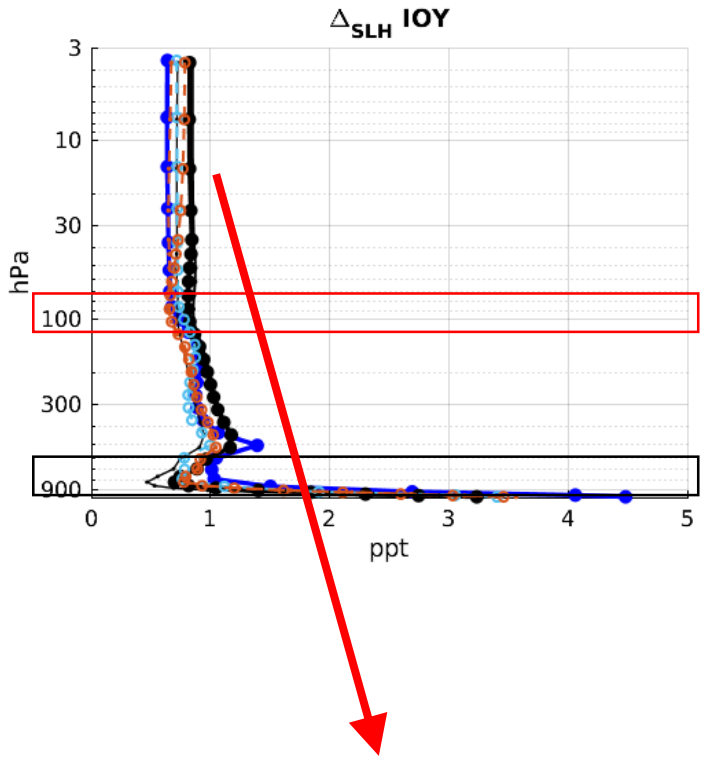
Transport of Halogen species that suffer washout in the Upper Troposphere depend on using FR vs. NDG setup

Use *icefraprx_scalingfactor* (&slh_nl) to adjust washout efficiency.

SGI and PGI (~5 pptv Br_y) have been adjusted for 1.9° x 2.5° and 32L

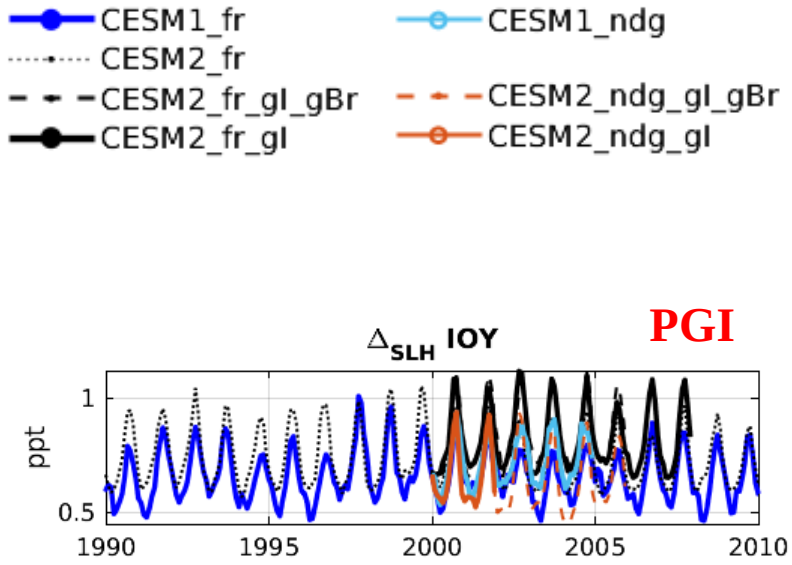
Iodine: surface abundance and PGI

Tropical profile (20ºS - 20ºN)

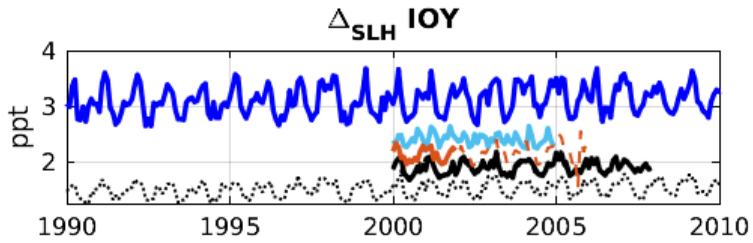


Iodine PGI remains below 0.75 I_y pptv for 1.9° x 2.5° and 32L

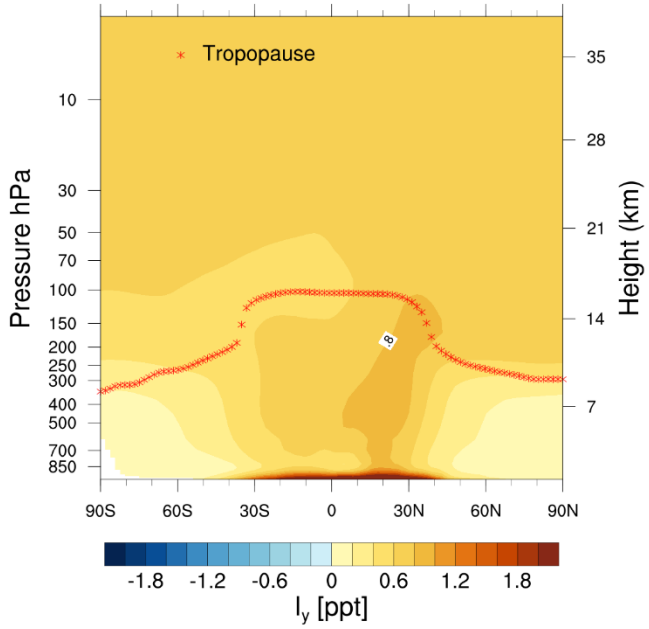
TTL



Surface



ΔIOY (SLH – NoSLH)

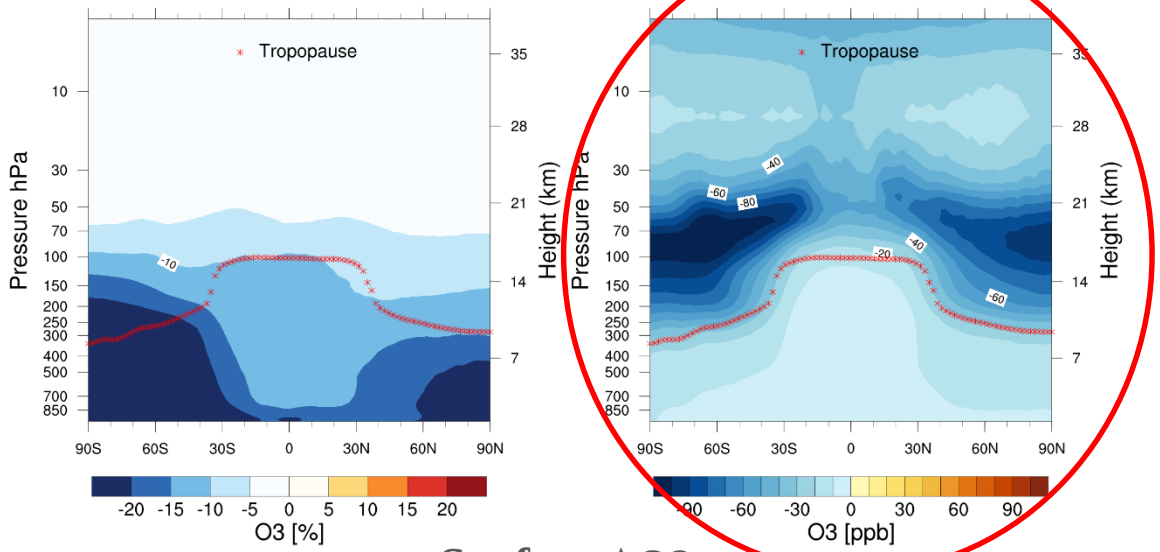


For the case of Iodine, washout in the Lower Troposphere is controlled by HOI

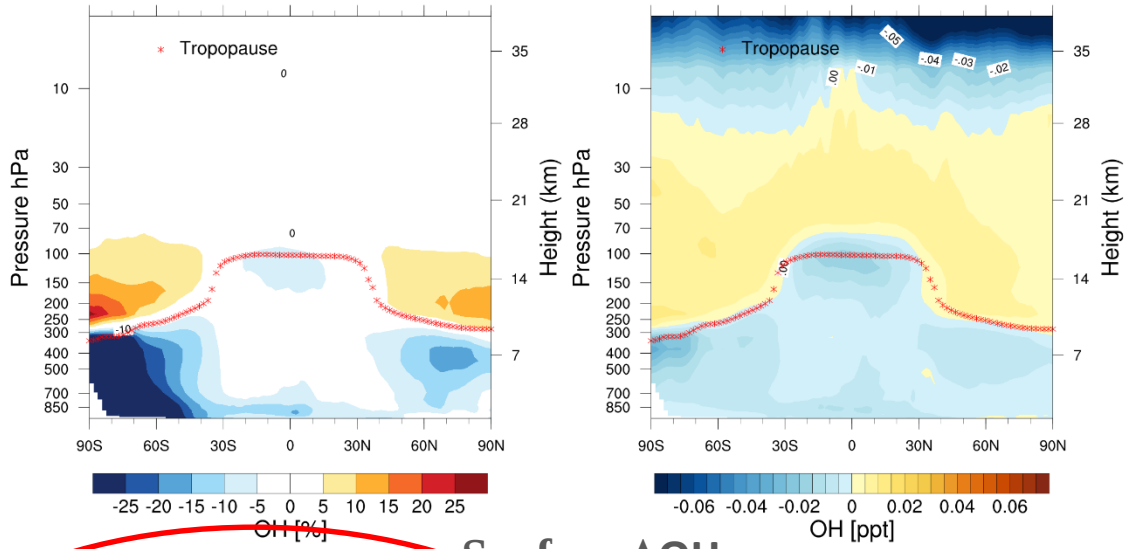
liqfraprx_scalingfactor **(&slh_nl)**

CESM2-SLH: Ozone and OH

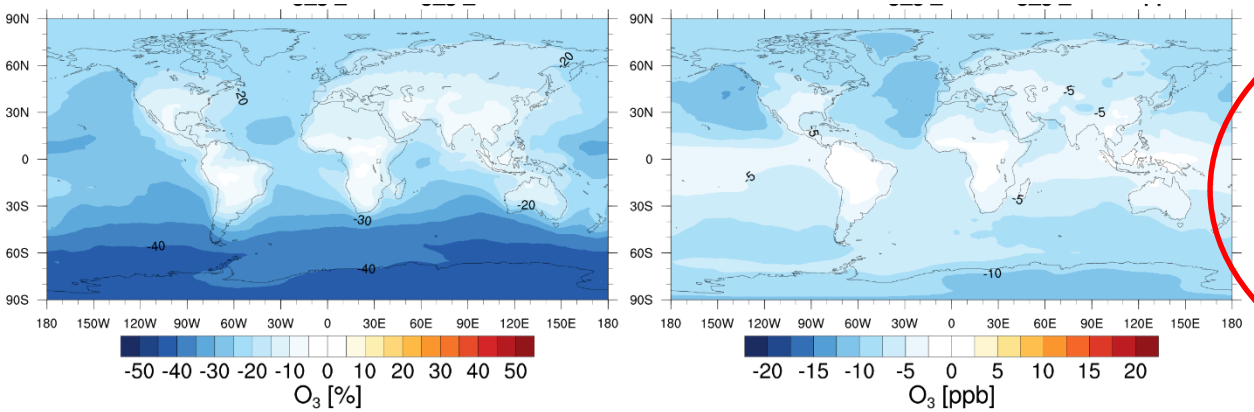
ΔO3 (SLH – NoSLH)



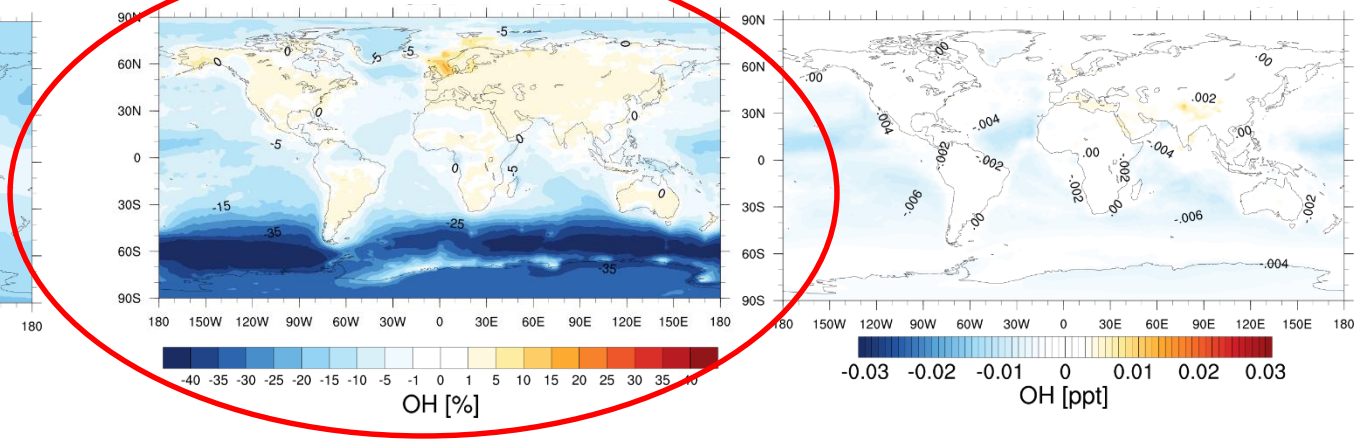
ΔOH (SLH – NoSLH)



Surface ΔO3



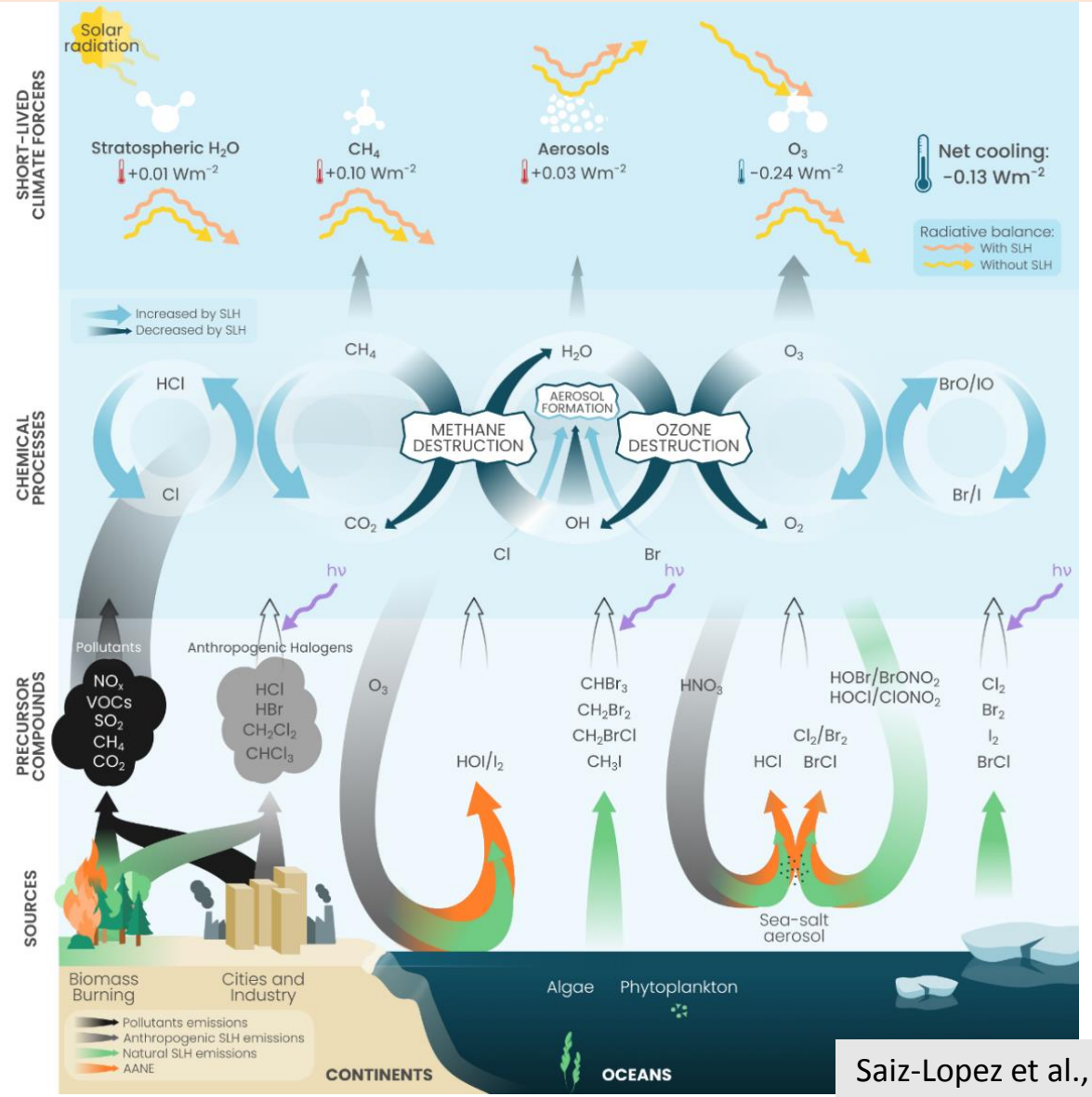
Surface ΔOH



Changes in Ozone and OH abundance due to SLH in CESM2 are in line with previous developments in CESM1 !!!

CESM2-SLH and Climate

Natural halogens exert an indirect cooling effect on climate



Saiz-Lopez et al., *Nature*, 2023

Thanks for your attention !!!

CESM2-SLH branch:
cesm2.2-asdbranch_slh

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