Modeling Arctic reactive bromine in GEOS-Chem with a snowpack Br_2 flux

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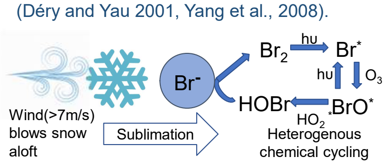
Objectives

- Add snowpack Br_2 flux across all Arctic sea ice and snowpack on land near coast
- Evaluate effect of snowpack Br_2 and blowing snow SSA mechanisms in GEOS-Chem model on predicted Arctic bromine chemistry
- Make accurate comparison to Arctic ground-based bromine monoxide observations

Sources of Reactive Bromine

Tropospheric reactive bromine is produced seasonally in the Arctic spring by heterogenous chemistry on frozen bromide-rich surfaces and can cause ozone depletion and mercury oxidation. High bromine monoxide (BrO) has been observed under storm conditions with high wind and aerosol (Frieβ et al., 2011) and under inversions in the lowest layers of the atmosphere (Peterson et al., 2015).

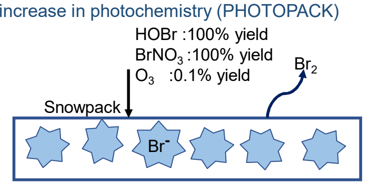
Blowing snow sea salt aerosol source (BLOW) implemented by Huang et al. 2017: High winds may blow saline snow aloft allowing for production of sea salt aerosols (Déry and Yau 2001, Yang et al., 2008).



Note- Simplified chemistry shown above. Full review of tropospheric bromine chemistry in GEOS-Chem in Sherwen et al, 2016.

Snowpack reactive bromine source (PACK): We add a snowpack Br emissions mechanism based on Toyota et al. (2011) with modifications to shut off land snowpack production: further than 200 km from coastline, in mountain ranges, and snow depth<10 cm

Br_2 is emitted on deposition of ozone and bromine species $BrNO_3$ and HOBr based on Toyota et al. (2011). Additional run with higher daytime ozone yield (75x) to simulate increase in photochemistry (PHOTOPACK)



Source Br_2 Emissions

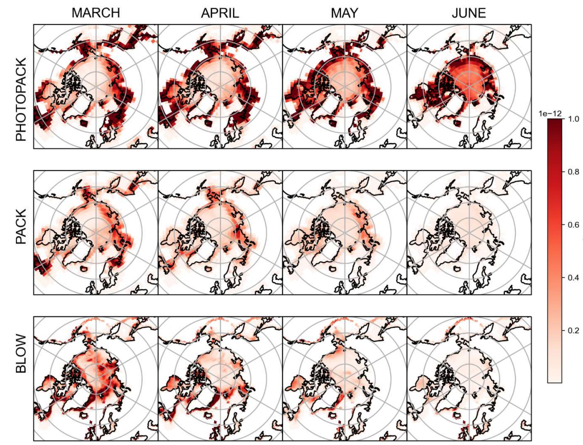


Figure 1: The top row shows emissions of Br_2 in the PHOTOPACK run, the middle row shows the emissions of Br_2 in the PACK run, and the bottom row shows emissions of particulate bromide from the BLOW mechanism . All units in monthly average kg Br_2 /m^2/s. Emissions are dependent upon spring 2015 meteorology and may not be representative of other years.

Hourly BrO Predictions

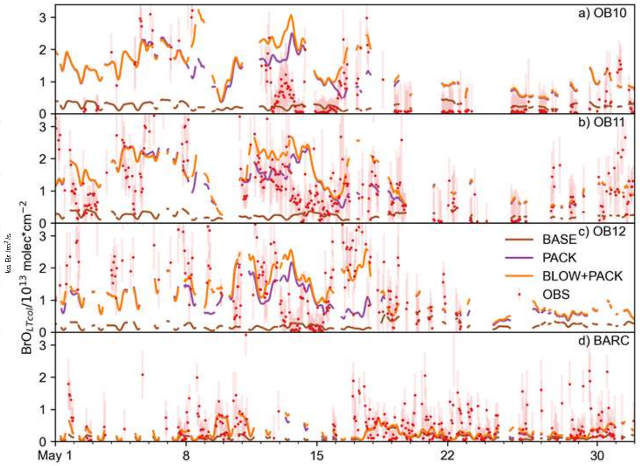


Figure 2: May Hourly BrOLTcol timeseries

Hourly timeseries of BLOW+PACK, PACK, and BASE BrO_{LTcol} on a) O-Buoy 10, b) O-Buoy 11, c) O-Buoy 12 and d) BARC at Utqiaġvik in the 2015 Arctic Spring. Observations and error bars in red, BASE BrO_{LTcol} in brown, PACK BrO_{LTcol} in purple, and BLOW+PACK BrOLTcol in orange. All BrO_{LTcol} plotted continuously except for gaps where dSCD O_4 >1*10^{43} molecules^{2}cm^{-5}

GEOS-Chem Model

We run the GEOS-Chem global 3-D atmospheric chemistry model version 12.9.3 with:

- Tropospheric halogen chemistry (Parrella et al, 2012, Sherwen et al., 2016)
- MERRA-2 meteorology at 2°x2.5° resolution
- Blowing snow sea salt aerosol Br_y source (Huang and Jaeglé 2017). We use constant snow salinity of 0.1 over FYI and 0.05 over MYI. (Huang et al., 2020).

Model was spun up for 6 total months for full 2015 simulation. We compare results to data from O-Buoys 10, 11 and 12 and at Utqiaġvik. (Knepp et al. 2010)

Model Run Domain

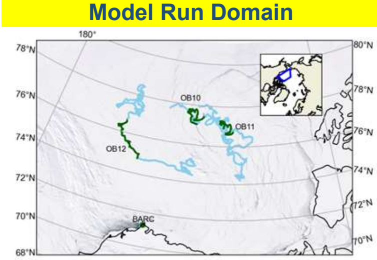


Figure 3: 2015 Arctic BrO Observation Platforms Blue lines show the drift tracks of O-Buoys, with green showing the locations with valid BrO measurements in spring 2015. Location of Barrow Arctic Research Center (BARC) in Utqiaġvik indicated by green dot. Inset map shows broader Arctic

Model Run Details and Error

Model Run	Blowing snow SSA	Millimoles Br yielded per mole O3 (daytime)	Millimoles Br yielded per mole O3 (nighttime)	O-Buoy 10 Model Run RMSE (BrO_{LTcol}/10^{12} molec/cm^2)	O-Buoy 11 Model Run RMSE (BrO_{LTcol}/10^{12} molec/cm^2)	O-Buoy 12 Model Run RMSE (BrO_{LTcol}/10^{12} molec/cm^2)	Utqiaġvik Model Run RMSE (BrO_{LTcol}/10^{12} molec/cm^2)
BASE	OFF	0	0	9.9	12.9	22.9	13.0
BLOW	ON	0	0	9.7	12.7	22.4	12.5
PACK	OFF	1	1	9.9	10.0	18.6	15.2
BLOW+PACK	ON	1	1	10.1	10.1	15.7	17.5
PHOTOPACK	OFF	75	1	30.0	24.8	26.2	30.1
BLOW+ PHOTOPACK	ON	75	1	30.3	24.6	26.3	31.4

Conclusions

Inclusion of bromine source from snowpack and from blowing snow (BLOW+PACK)is most consistent with the BrO observations in Arctic Spring 2015

Snowpack emissions (PACK) are likely a larger source of Arctic BrO than blowing snow SSA (BLOW)

Constant yield of Br_2 on ozone deposition leads to best agreement with observations

Increased daytime snow Br_2 yield in PHOTOPACK leads to highest Arctic Ocean Br_2 emissions in June

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