CENTER FOR CLIMATE SYSTEMS RESEARCH
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

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"How different would tropospheric oxidation be over an ice-free Arctic?"

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Motivation:

- Climate projections suggest a complete Arctic sea-ice retreat is likely in the future during summer.

- Less ice will cause less light reflection and slower tropospheric photolysis.

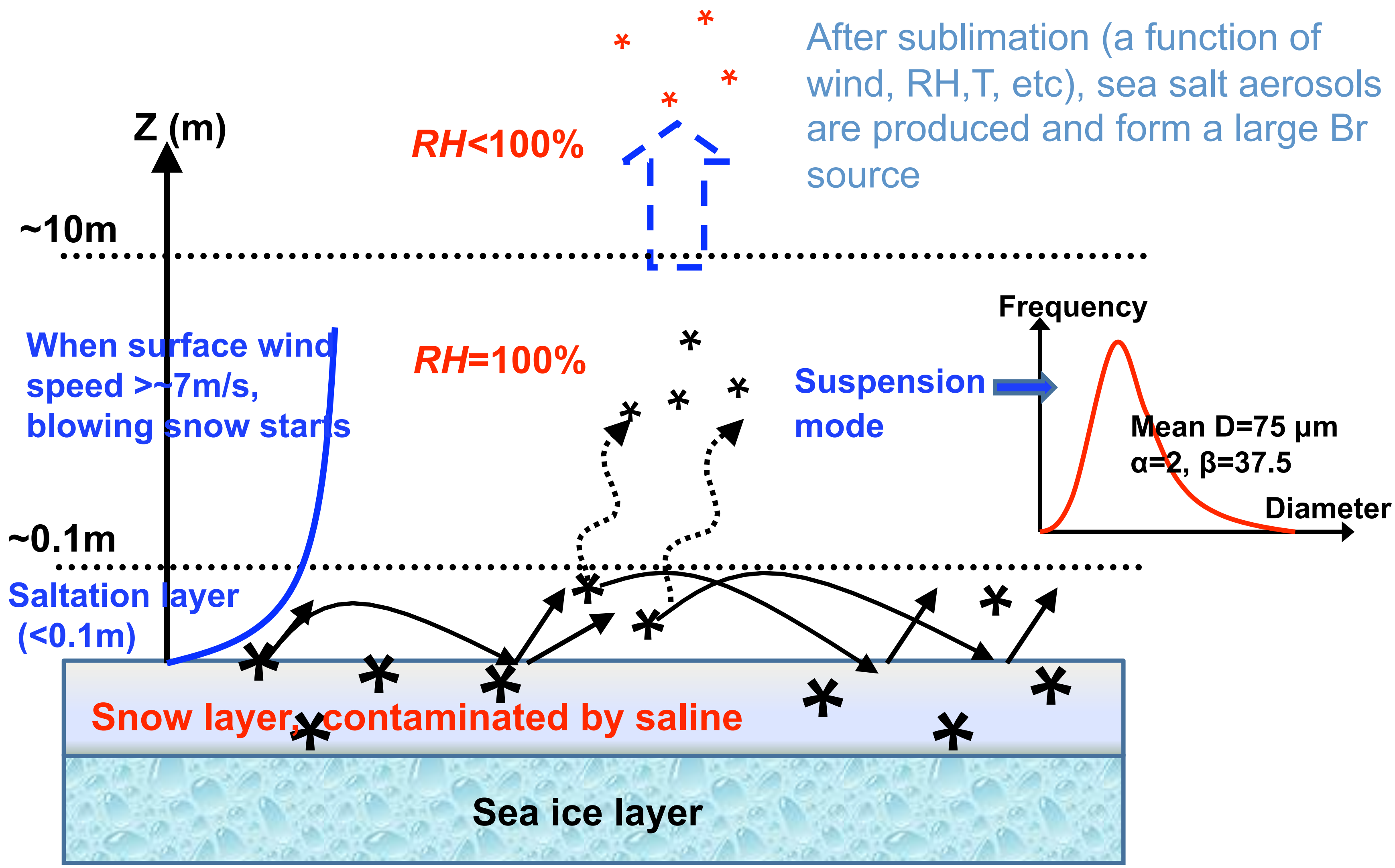
- Also, it could lead to changes in bromine release from sea-ice, and affect tropospheric ozone in addition to OH.

Model Information:

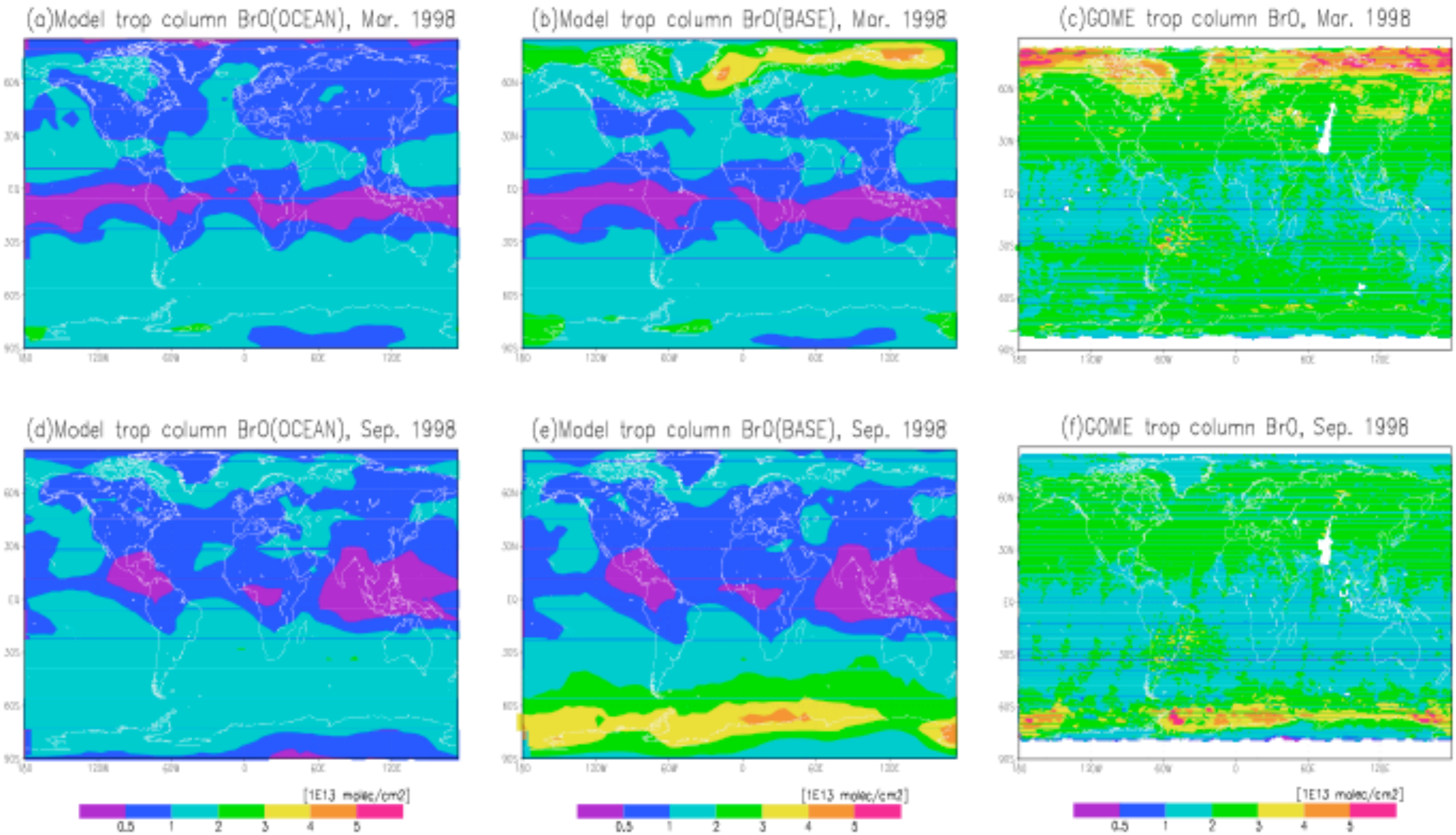
We use a tropospheric chemistry-transport model (*p*-TOMCAT) to examine how tropospheric oxidation, as driven by O3 and OH, may differ over an ice-free Arctic.

- **Horizontal resolution is 2.8°x2.8°, 31 vertical layers;**
- **Forced by ECMWF reanalysis data (1998-2000);**
- **Monthly sea ice data from NSIDC; multi-year sea-ice from R. Kwok;**
- **Photolysis using the Fast-JX scheme (*Voulgarakis et al. 2009*);**
- **Full bromine chemistry including blowing snow-sourced bromine on sea ice (*Yang et al., 2008*).**

Mechanism of sea salt production and bromine release from blowing snow on sea ice *(Yang, Pyle and Cox, GRL, 2008)*

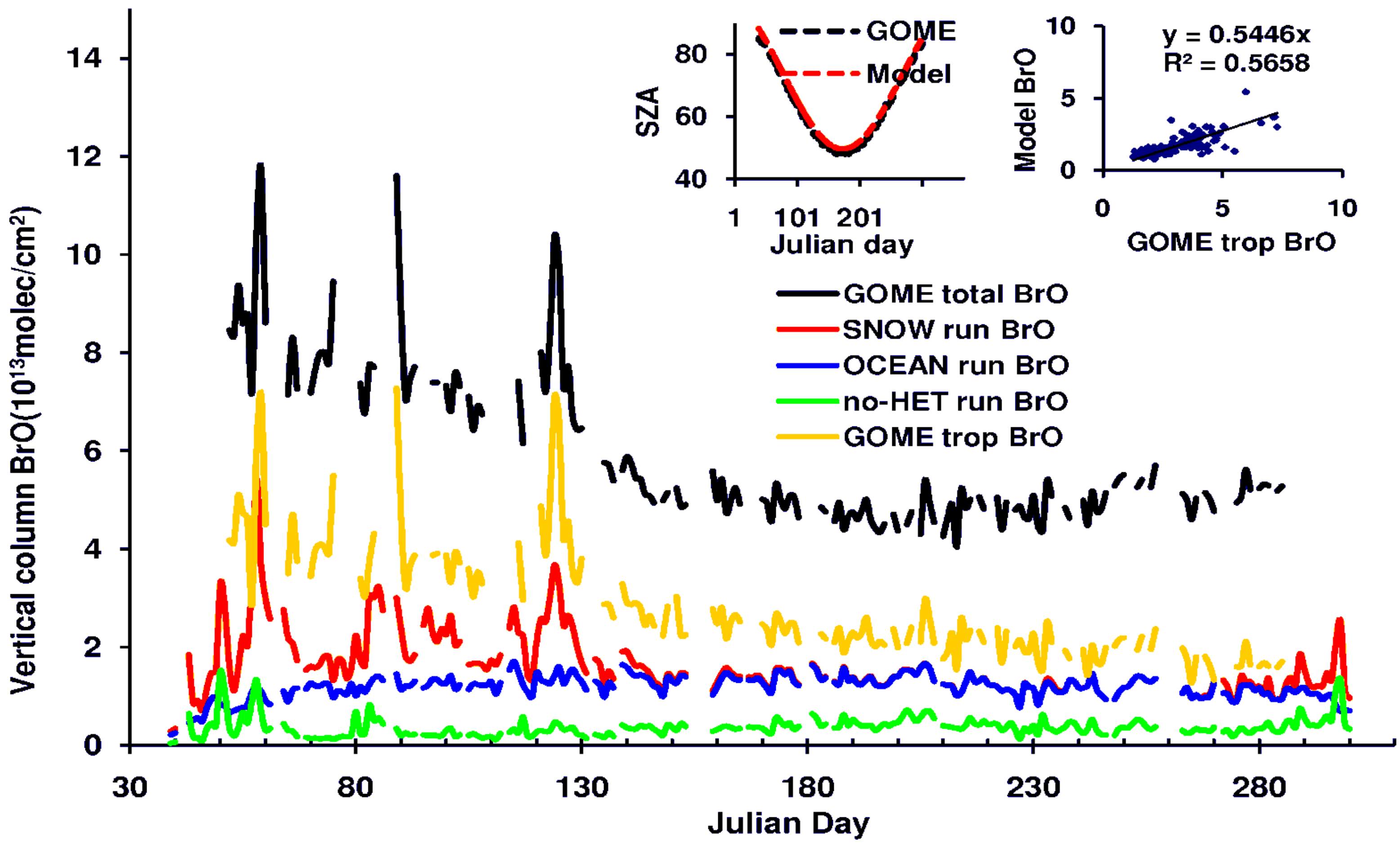


Tropospheric column BrO evaluation



Monthly mean (March 1998) tropospheric BrO column (in units of 10^{13} molecules/cm^2) from model runs without (left), with snow-sourced Br (middle) and from GOME trop. BrO (right) (*Yang et al., ACP, 2010*).

Daily column BrO (1998) over Barrow (73°N,157°W)

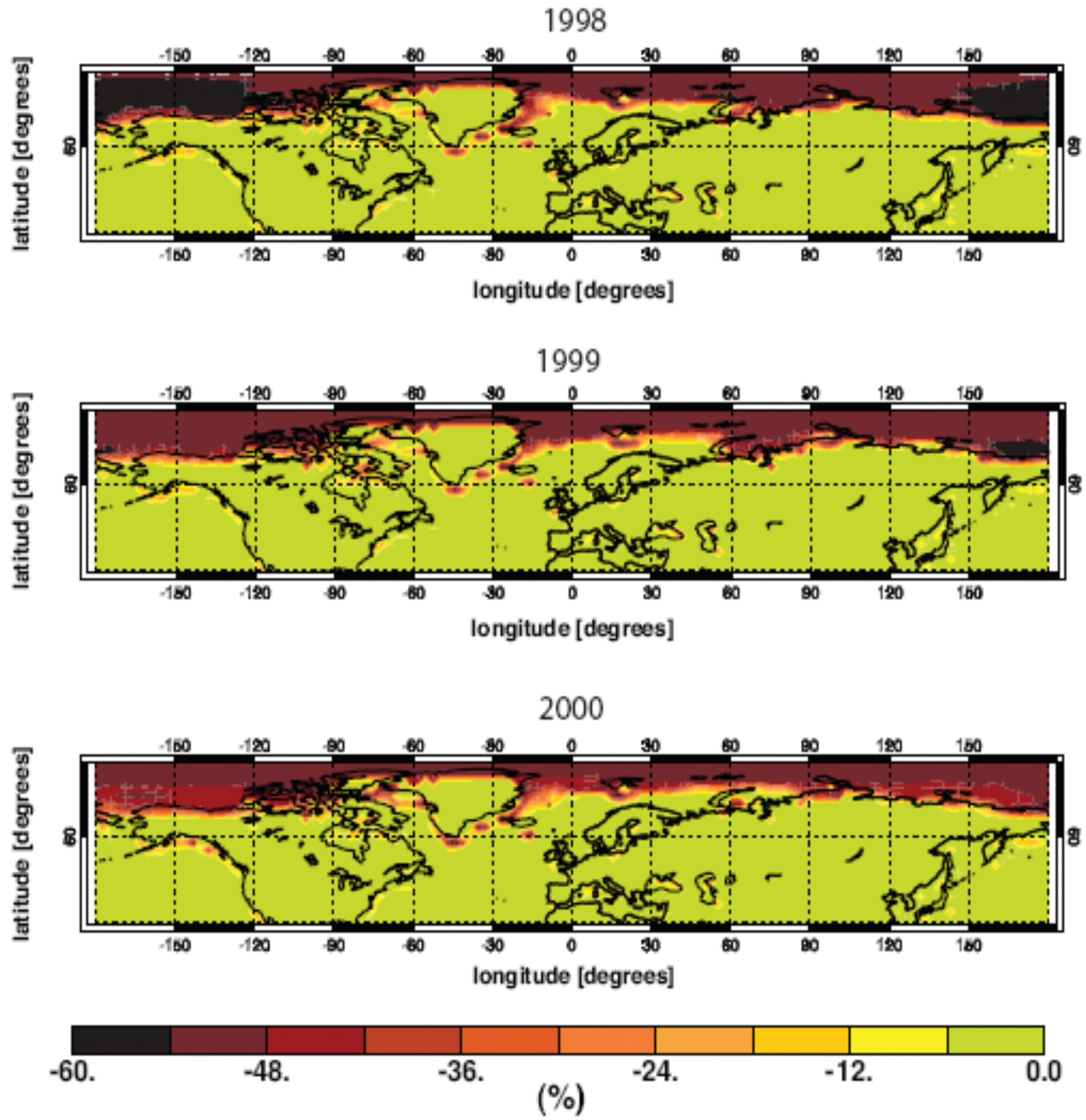


(*Yang et al., ACP, 2010*)

Effects on surface OH in summer

- **Removing sea-ice changes OH drastically (changes of up to 60%).**

- **The changes are mainly confined to polar latitudes (due to short OH lifetime).**

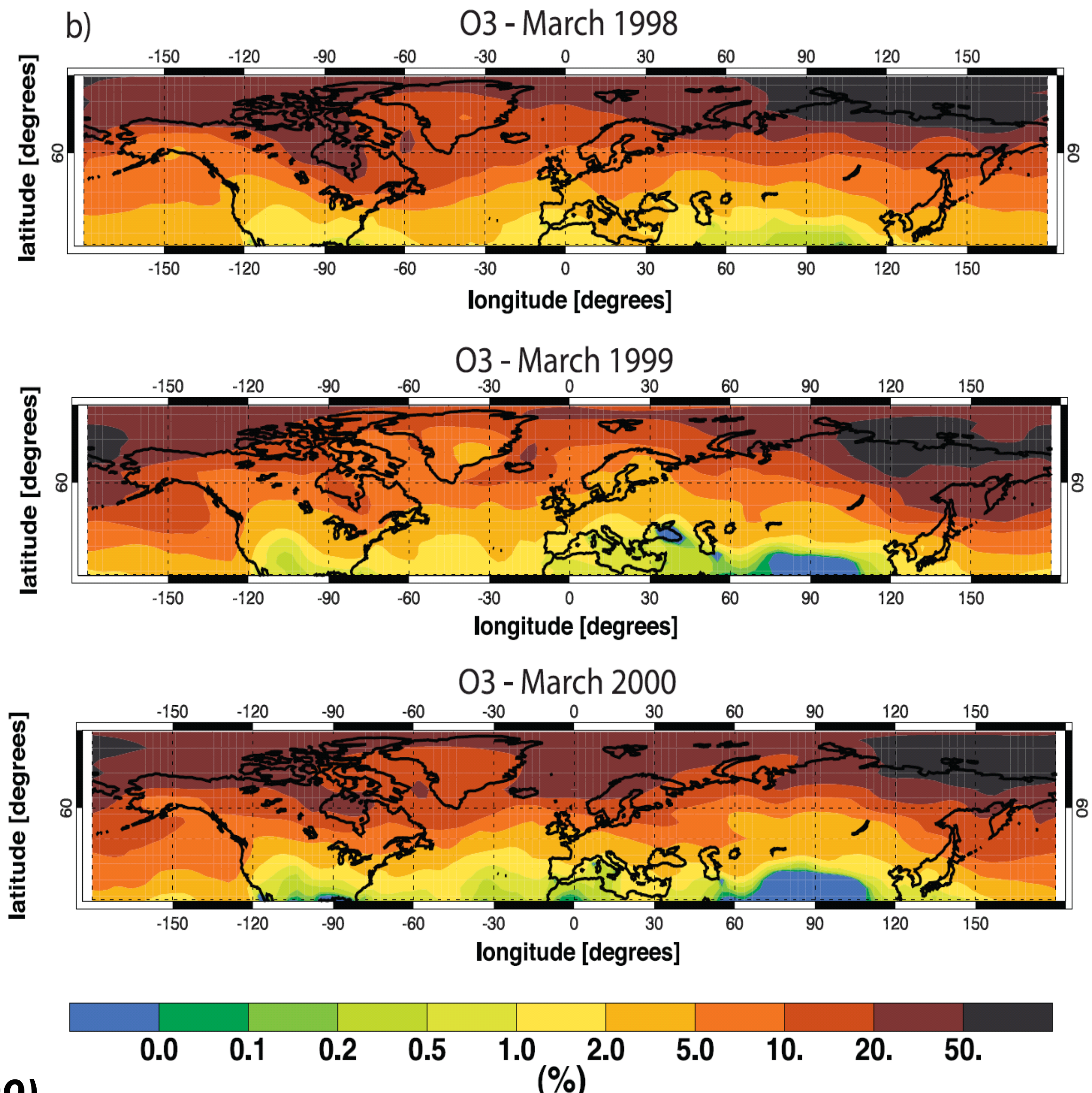


(Voulgarakis, et al., GRL, 2009)

Effects on surface O_3 in spring

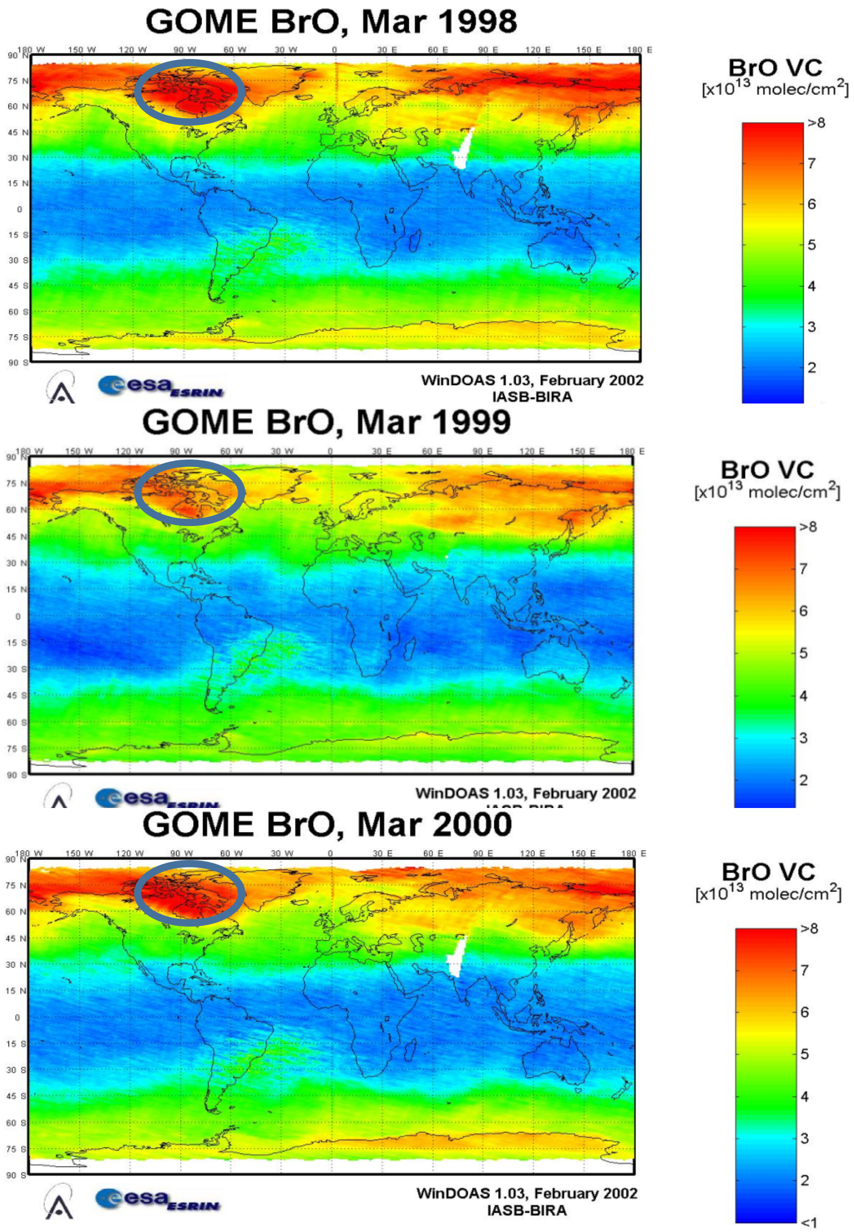
- Removing sea-ice will **reduce** snow-sourced Br emissions and lead to **lower BrO** concentration.

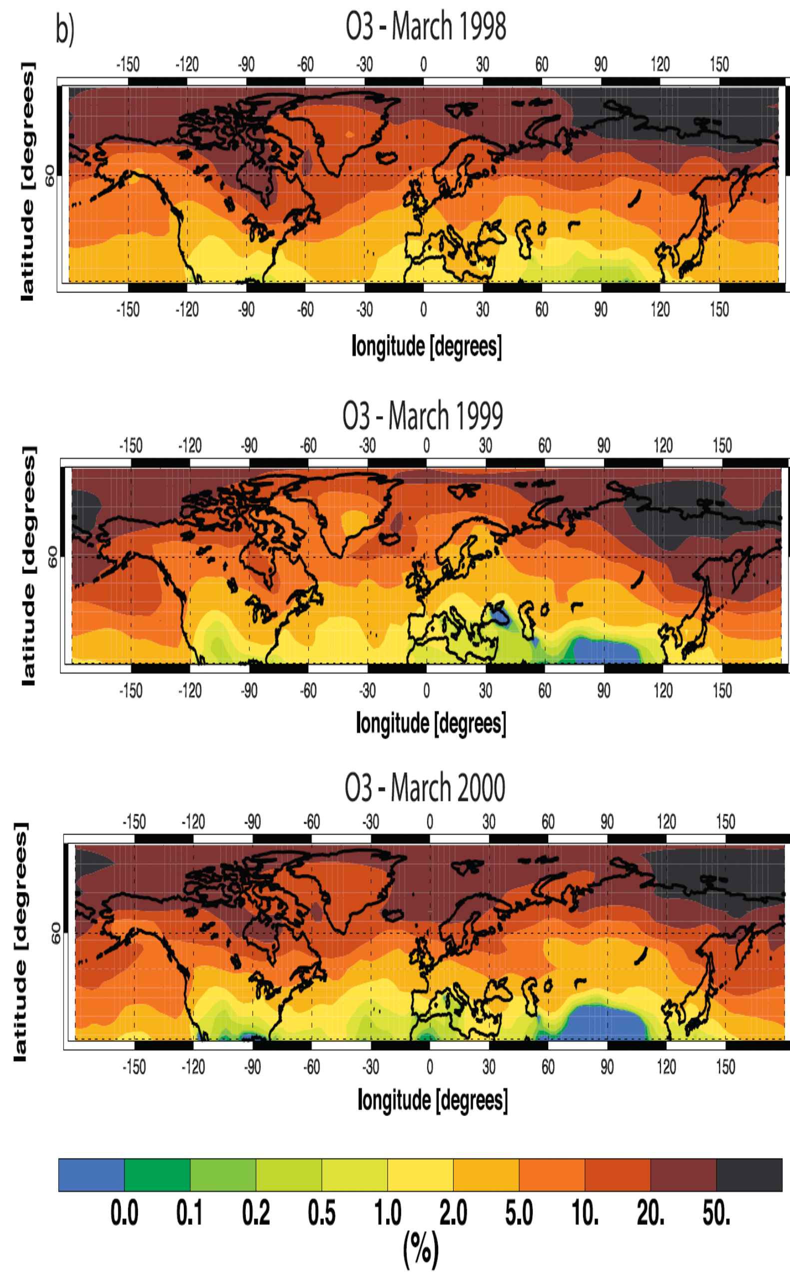
- This causes Arctic surface ozone **increases** by up to **more than 50%**; in extra-polar and high latitudes, the increase in ozone is **up to 20%.**



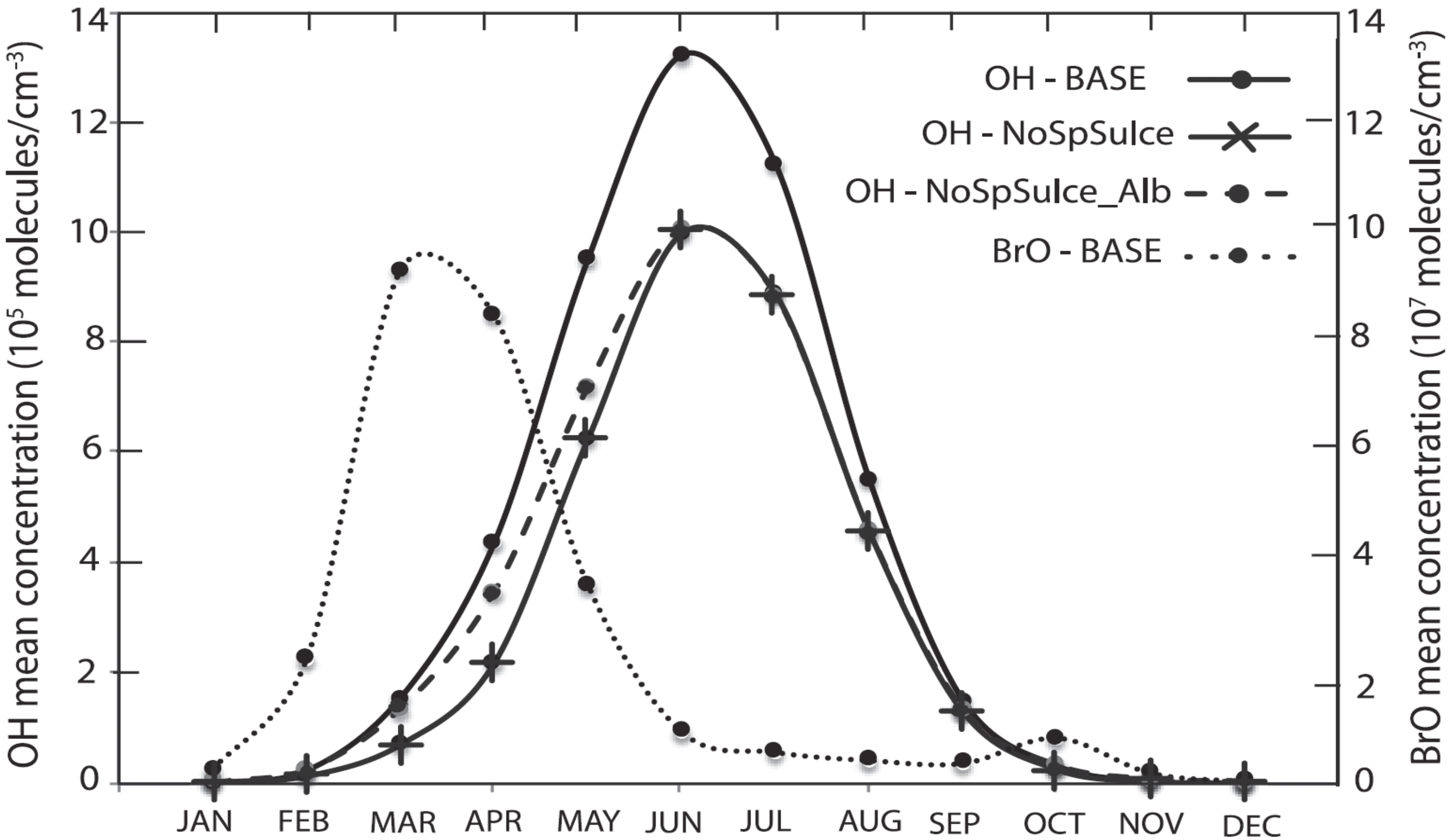
(Voulgarakis, et al., GRL, 2009)

Surface O_3 changes match GOME BrO distributions





Seasonal variation of surface OH and BrO (65°-90°N)



Removing sea ice leads to reduced surface albedo, and thus photolysis rates are reduced significantly, which lowers summer OH greatly.

(Voulgarakis, et al., GRL, 2009)

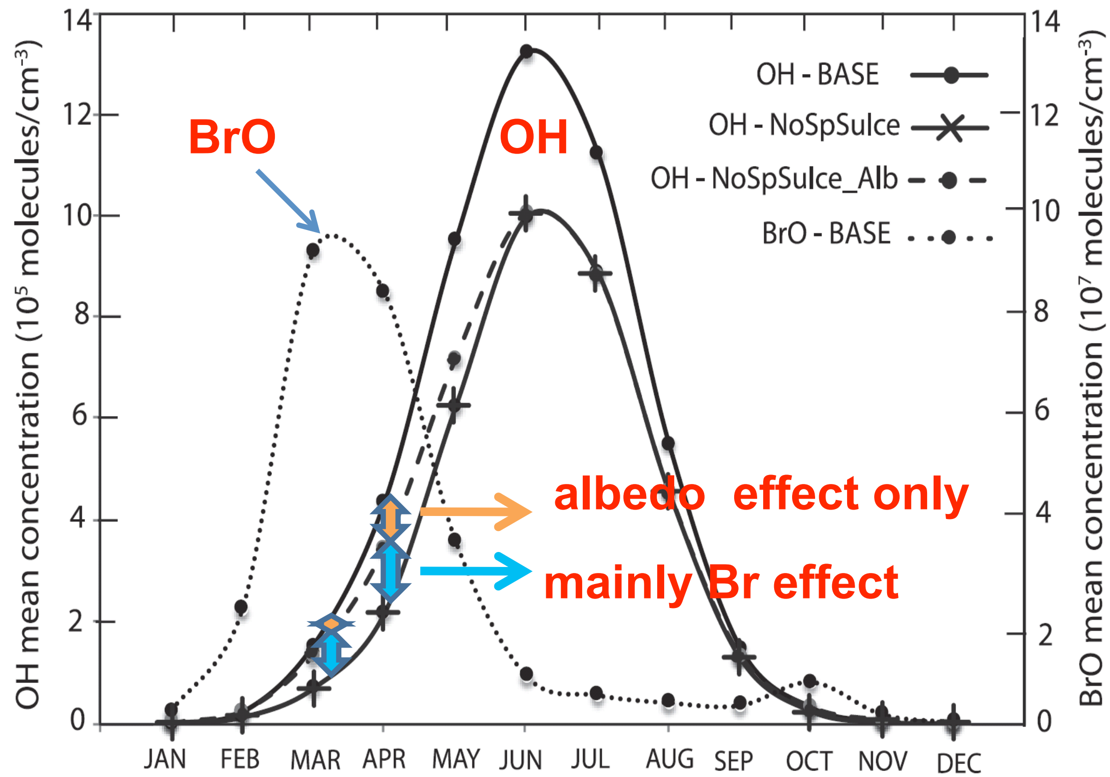
In polar spring, Br chemistry controls the polar boundary layer OH changes

- **Though, in spring, surface ozone increases after sea-ice is removed, OH decreases significantly.**

- **This could be explained by the Br-related OH/HO_2 ratio change in spring [*Platt and Hönninger, 2003*]:**

$Br + O_3 \rightarrow BrO + O_2$
$BrO + HO_2 \rightarrow HOBr + O_2$
$HOBr + h\nu \rightarrow Br + OH$

Net: $O_3 + HO_2 \rightarrow 2O_2 + OH$



Conclusions

- A complete Arctic sea-ice removal could reduce polar summer surface OH by 30-60%.

- Removal of sea-ice in spring (an extreme scenario) could increase surface Arctic ozone by up to more than 50%, and extra-polar surface ozone by up to 20%, even in significantly inhabited regions, due to long-range transport.

- In early spring, Br-chemistry may control boundary layer OH changes due to the Br-mediated effect on the OH/HO_2 ratio.

Thank you !!

Model experiments:

- **BASE**: no perturbation applied

- **NoSpSuIce**: sea-ice completely removed in spring and summer (including effects from both albedo and Br chemsitry)

- **NoSpSuIce_Alb**: same as NoSpSuIce except that the sea-ice perturbation was only allowed to influence chemistry through albedo effects and not through changes in the bromine chemistry

Effects on surface OH (August)

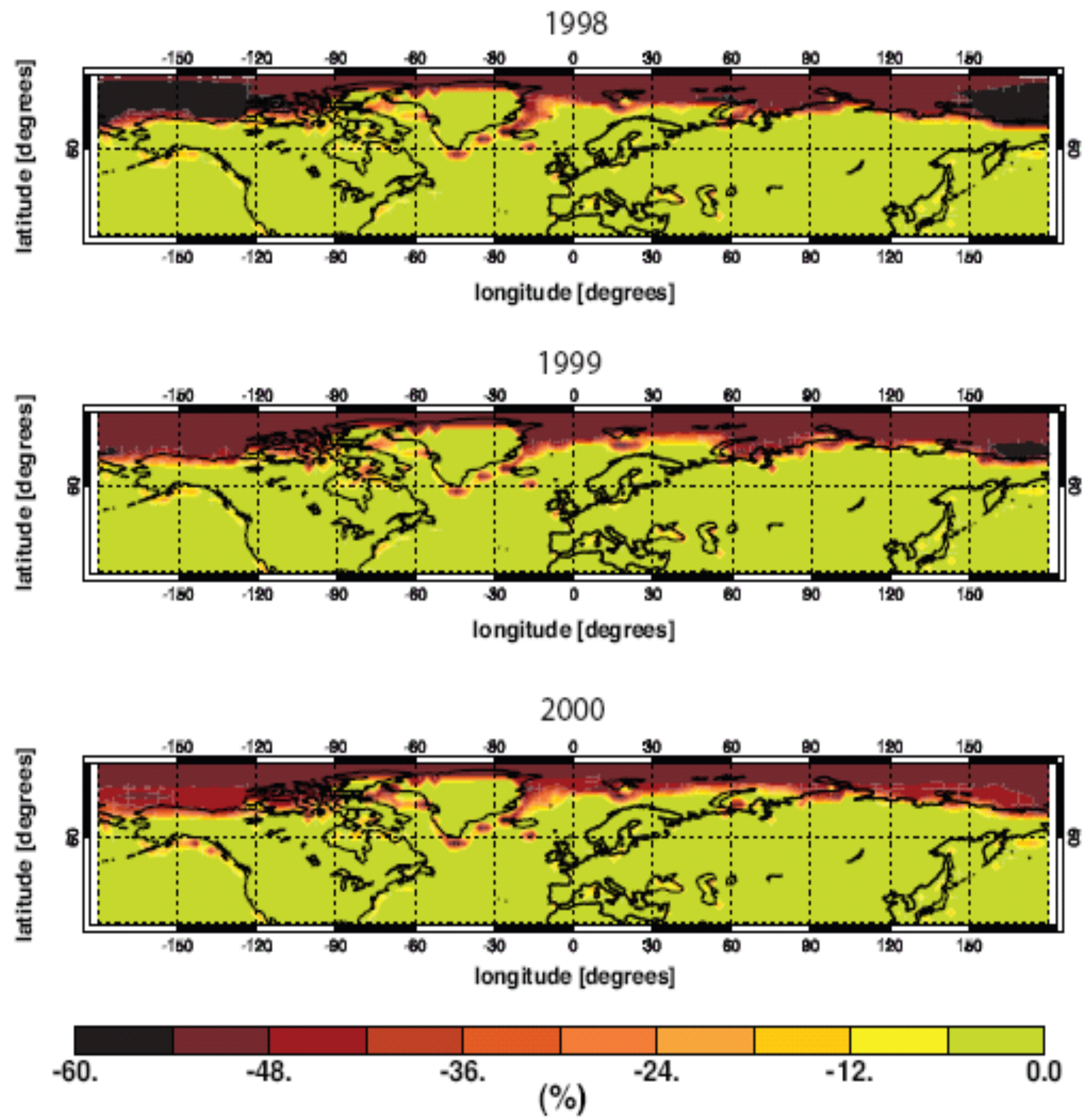
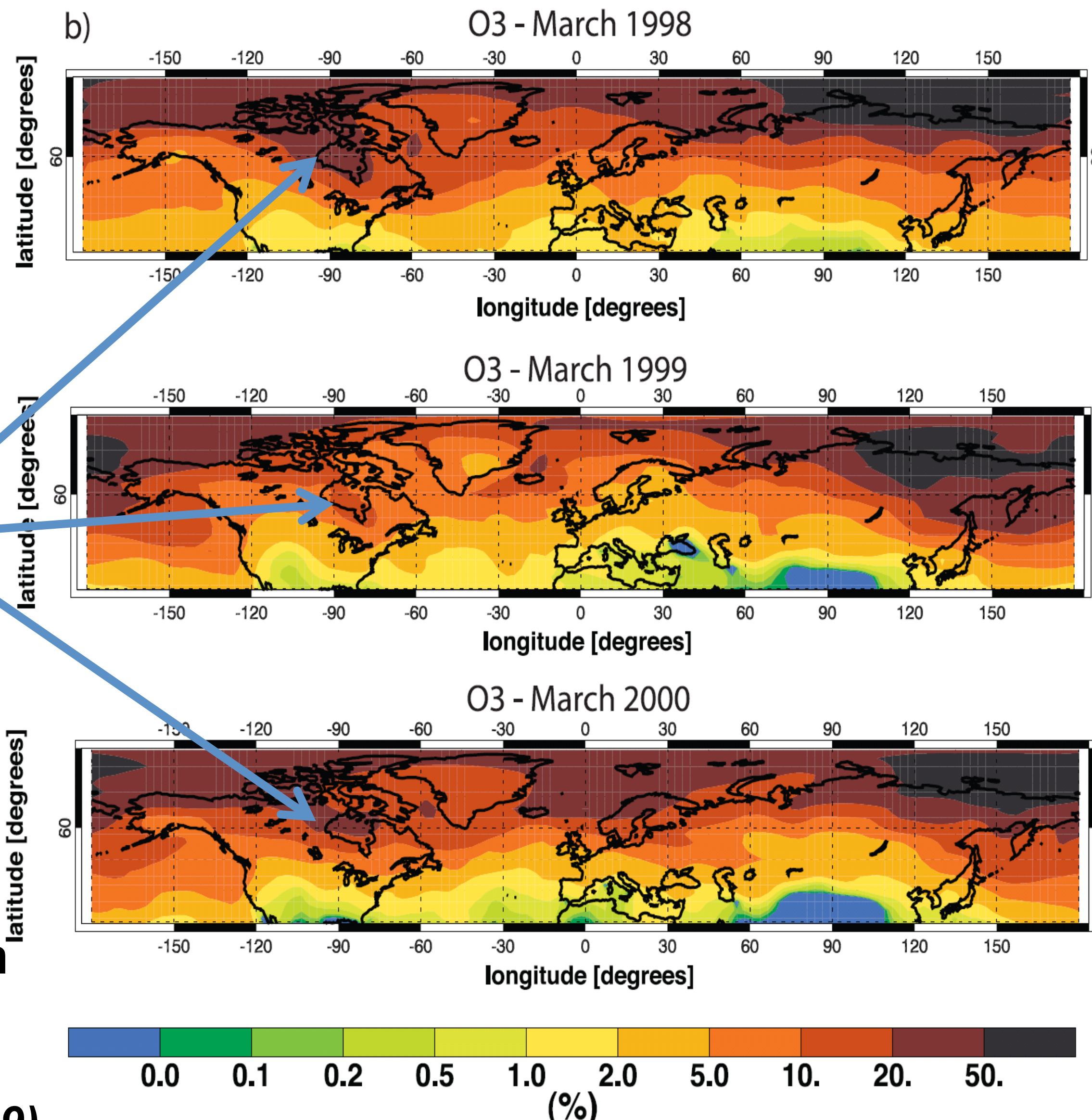


Figure 1. (a) Percentage (%) difference in monthly mean surface OH concentrations in August 1998-2000, between the run in which late-summer sea-ice is removed (NoAugSepIce) and the run in which no perturbations were applied (BASE).

Effects on surface O_3 in spring

There are significant year-to-year variations, mainly due to **meteorology–related Br emission** from sea ice (sea-ice coverage is the same for all runs!), and the meteorology-related changes in ozone transport patterns from year to year.



(Voulgarakis, et al., GRL, 2009)

Impact on annual mean boundary layer O3 and OH burden

	NoSpSuIce-Base[a]	NoSpSuIce_Alb-Base[b]
	65°N–90°N	
BL OH	−28.0%	−21.4%
BL $P(O_3)$	−15.8%	−15.3%
BL $L(O_3)$	−37.2%	−12.9%
BL O_3	3.6%	−0.9%
	45°N–65°N	
BL OH	−4.0%	−2.6%
BL $P(O_3)$	−0.9%	−0.9%
BL $L(O_3)$	−4.6%	−1.5%
BL O_3	1.0%	−0.3%

- The effects on annual mean boundary layer OH are large (close to 30% reduction) at polar regions and detectable at lower latitudes.
- Annual OH reduction is not exclusively driven by albedo changes but the decreased bromine release also plays a role (because bromine increases the OH/HO2 ratio).
- Annual mean boundary layer ozone is 3.6% higher at polar regions when sea-ice disappears for summer/spring (NoSpSuIce).