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Analysis of Arctic Spring and Summertime Aerosol Optical and Deposition Properties using Long-Term Reanalyses: Implications for the Influence of Regional Biomass Burning Processes

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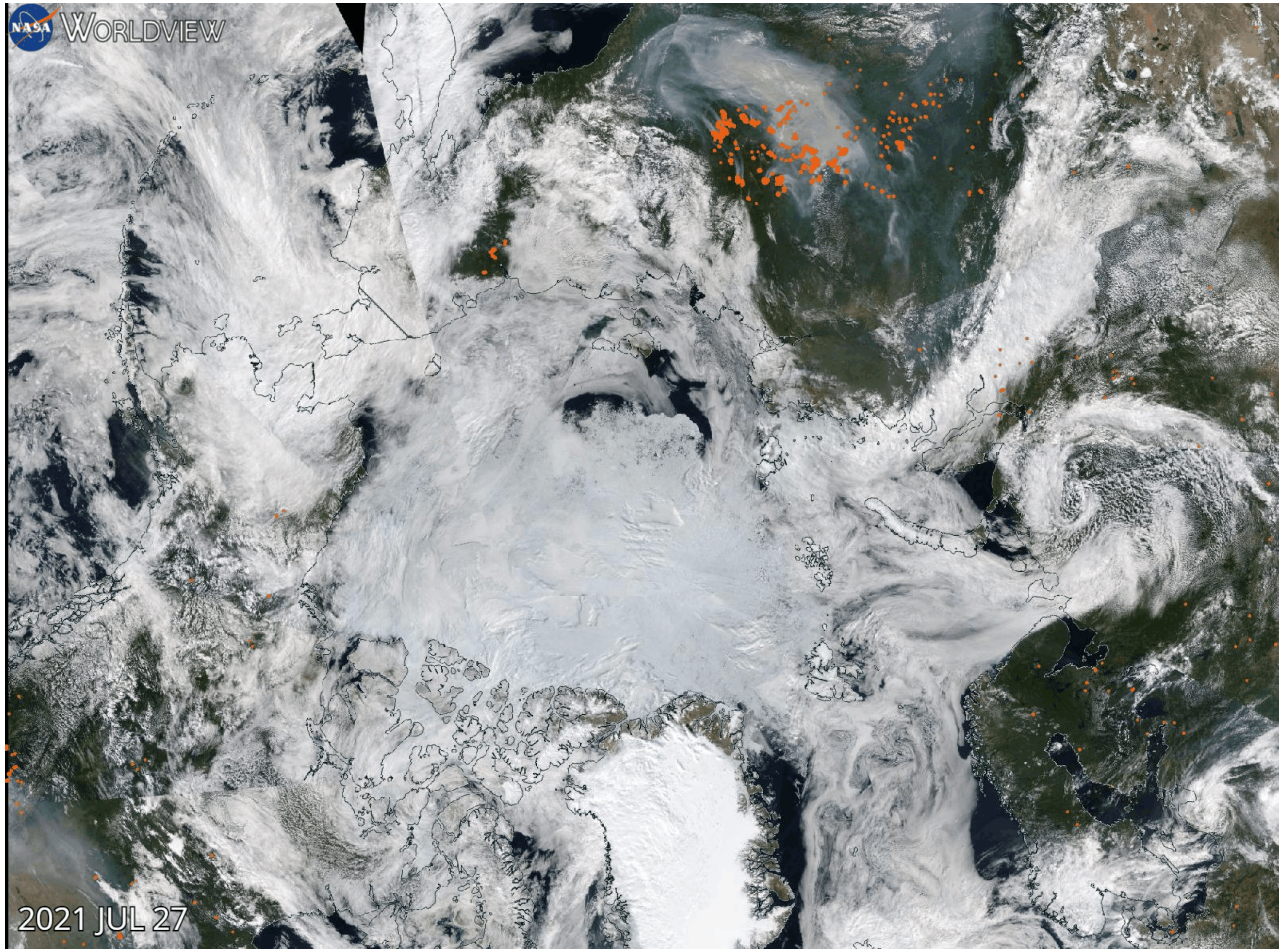
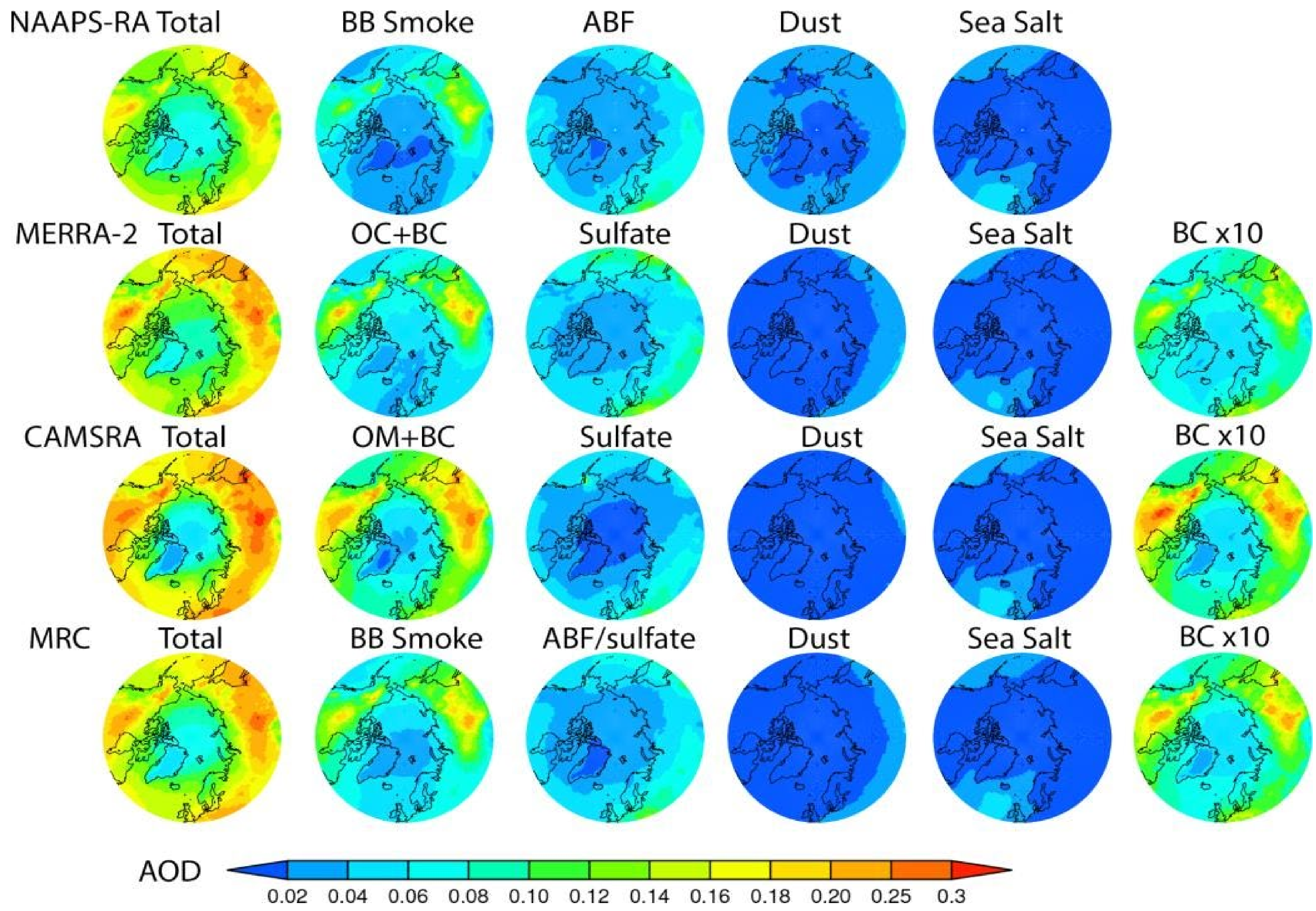
Example of biomass burning smoke transport to the Arctic

Movie showing smoke emitted from Siberian Fires traveling to the North Pole (July - Aug, 2021)

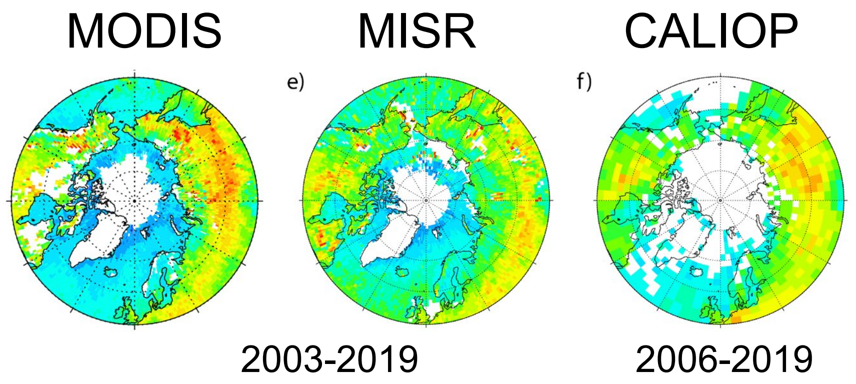


2003-2019 JJA-mean total and speciated AOD from the three aerosol reanalyses and AOD retrievals



- Similar spatial patterns of total and speciated AODs among the three reanalysis and satellite AODs.
- Biomass-burning (BB) smoke is the dominant contributor to total AOD over the Arctic (>60N) during JJA.
- BB smoke AOD tends to be relatively larger in CAMSRA and smaller in NAAPS-RA.
- Total, fine-mode and coarse-mode AODs are verified with AERONET data.

(Xian et al., 2022a)



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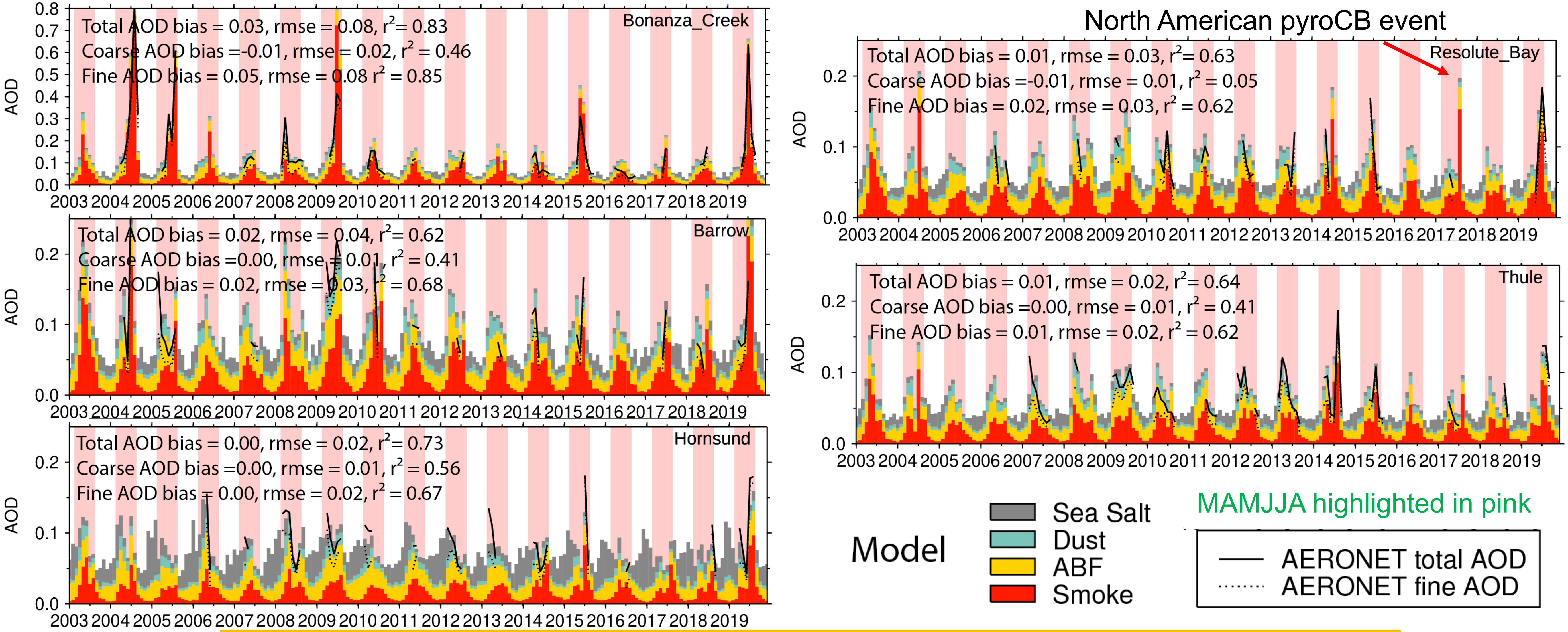
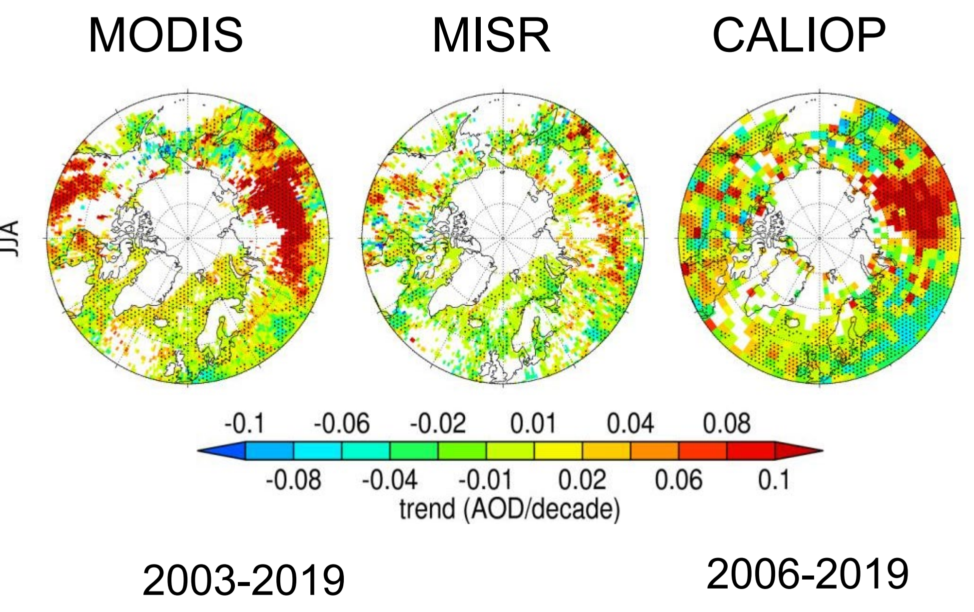
Interannual variability of Arctic AOD

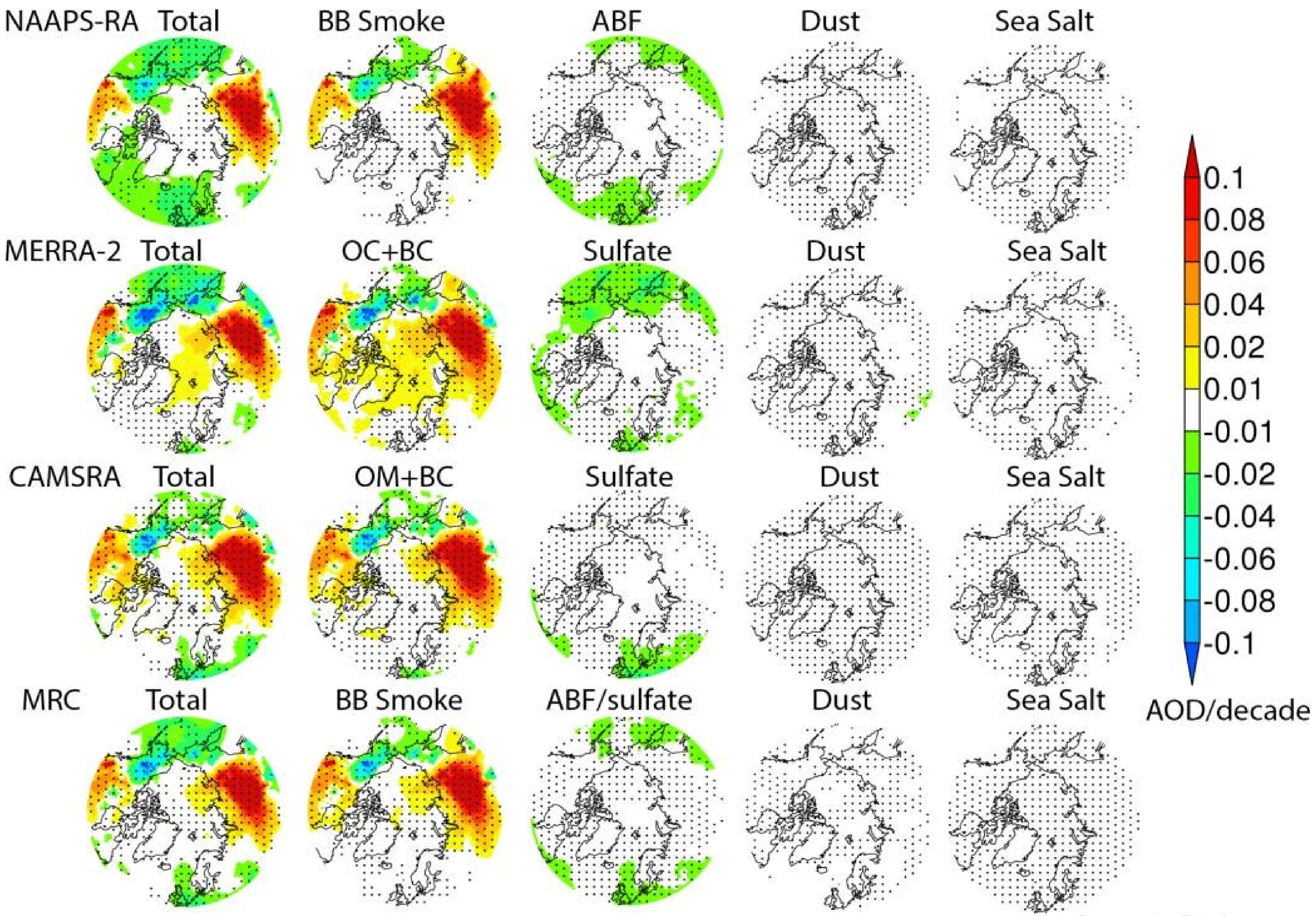


- Significant interannual variabilities, especially for sites influenced by BB smoke.
- Even for sites distant from BB source regions, BB smoke is the principal driver of interannual AOD variation, suggesting dominant contribution of BB smoke to local extreme AOD events.
- MRC performance is overall reasonable.

JJA AOD Trend (2003-2019): dominated by BB smoke



- Quite consistent trends from the three reanalyses, MODIS, MISR and CALIOP regarding spatial pattern, and magnitude to a large extent.
- The trend is mostly driven by BB smoke.
- Decreasing trend in sulfate.



Dots for statistical significance.

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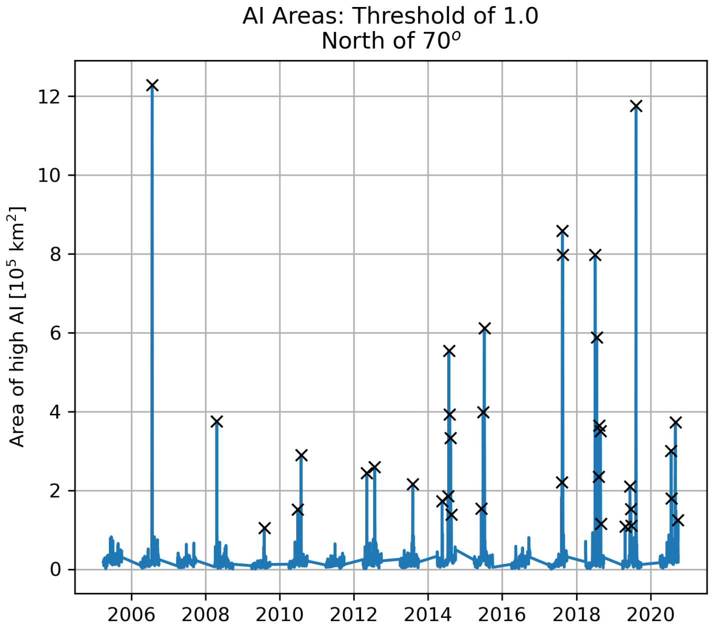
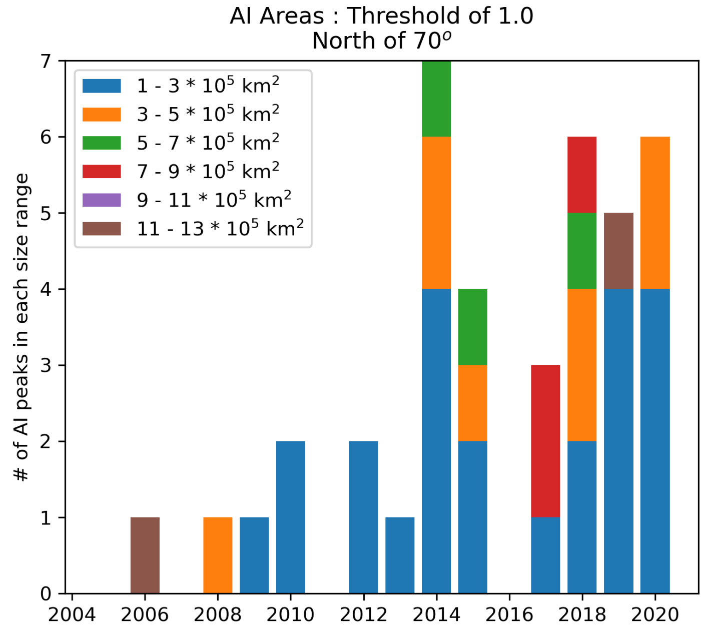
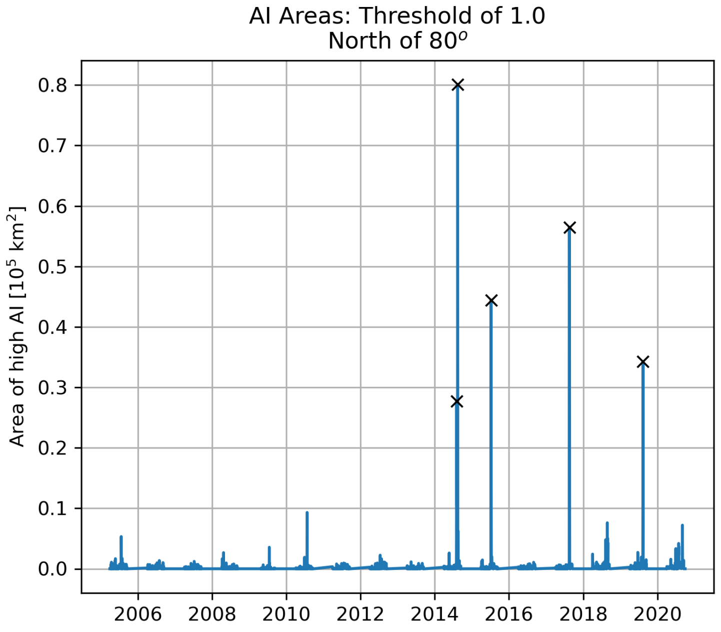
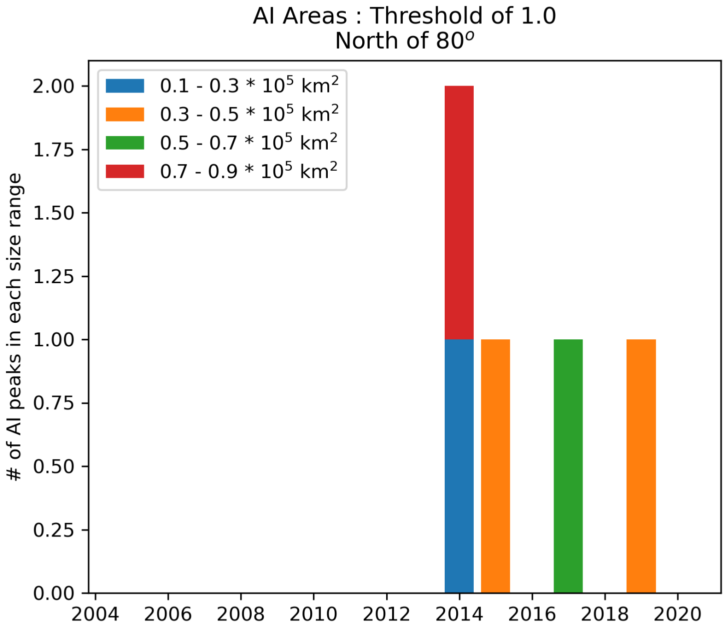
Arctic OMI Aerosol Index: more AI events in 2014-2020



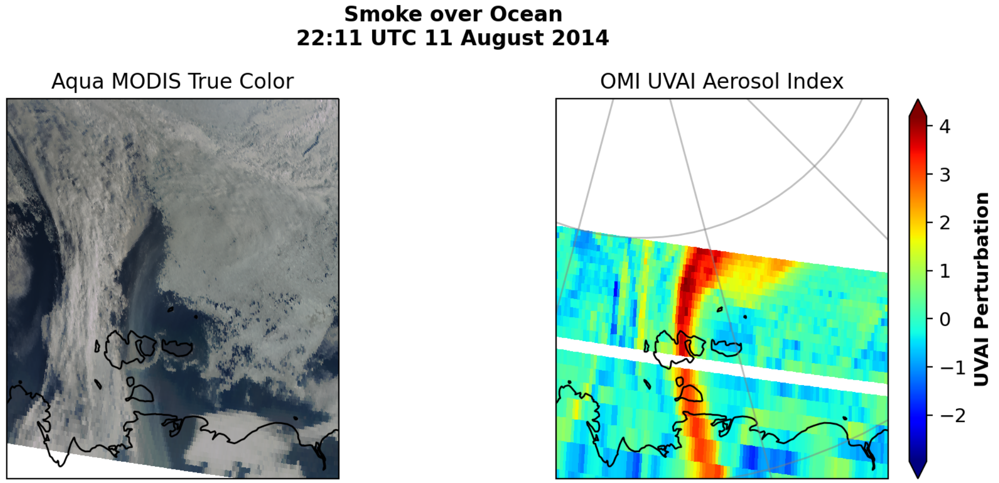


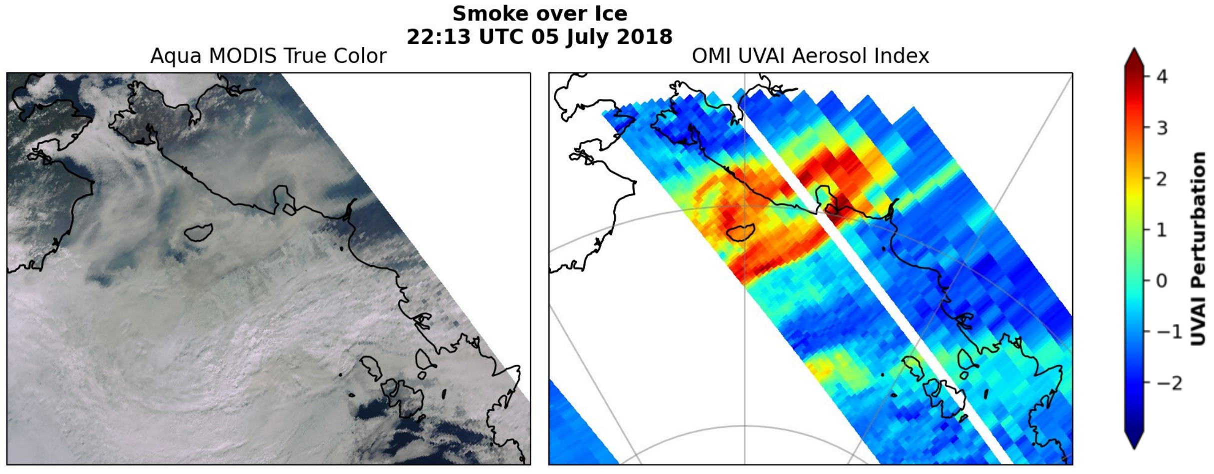




- The number of peaks in daily perturbed AI areas, as well as the size of each peak, are calculated per year
- More high-amplitude Arctic AI peaks north of 70 ^{o}N occurred in 2014-2020 than 2005-2013
  - Results are consistent with stats of extreme AOD events associated with biomass burning events
- All large (> 10^4 km^2) very high Arctic (>80 ^{o}N) AI peaks occurred between 2014 and 2019
- Sorenson, B.T., Zhang, J., Reid, J.S., Xian, P., and Jaker, S.: OMI UV aerosol index data analysis over the Arctic region for future data assimilation and climate forcing applications, Atmospheric Chemistry and Physics, 2023

Observation-based estimate of BB smoke direct radiative forcing



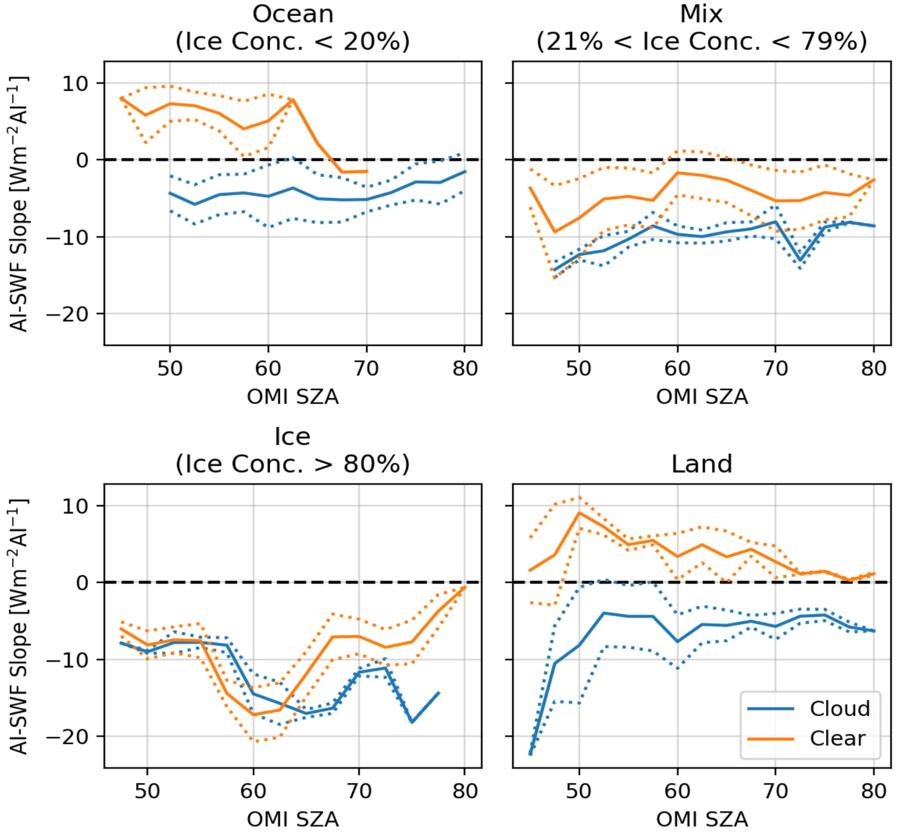


- Surface conditions in the Arctic are changing
  - Melting of ice exposes dark land and ocean surfaces.
  - Smoke over dark surfaces (ocean/land) has brightening effect (above, left)
  - Smoke over bright surfaces (cloud/ice) has darkening effect (above, right)
  - Positive trend of BB smoke (Xian, et al., 2022a, Sorenson, 2023)

- *How does these combine to affect the change in Arctic radiative balance?*

- **Goal: Using QA-ed OMI AI data with colocated CERES fluxes, MODIS data, and SSMI/S sea ice concentration data, generate a purely observational estimate of aerosol forcing and forcing trends over the Arctic**.

- Derived the relationship between OMI AI and CERES SWF for different viewing angles, surface types, and cloud conditions.



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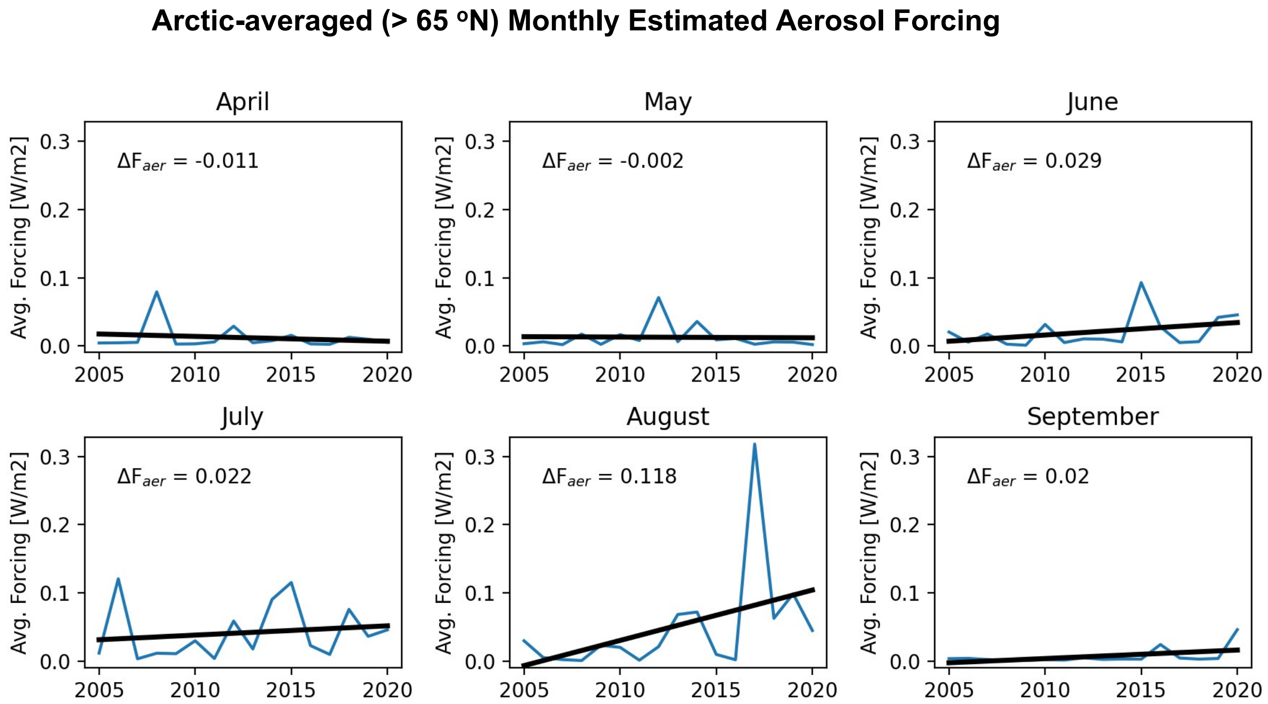
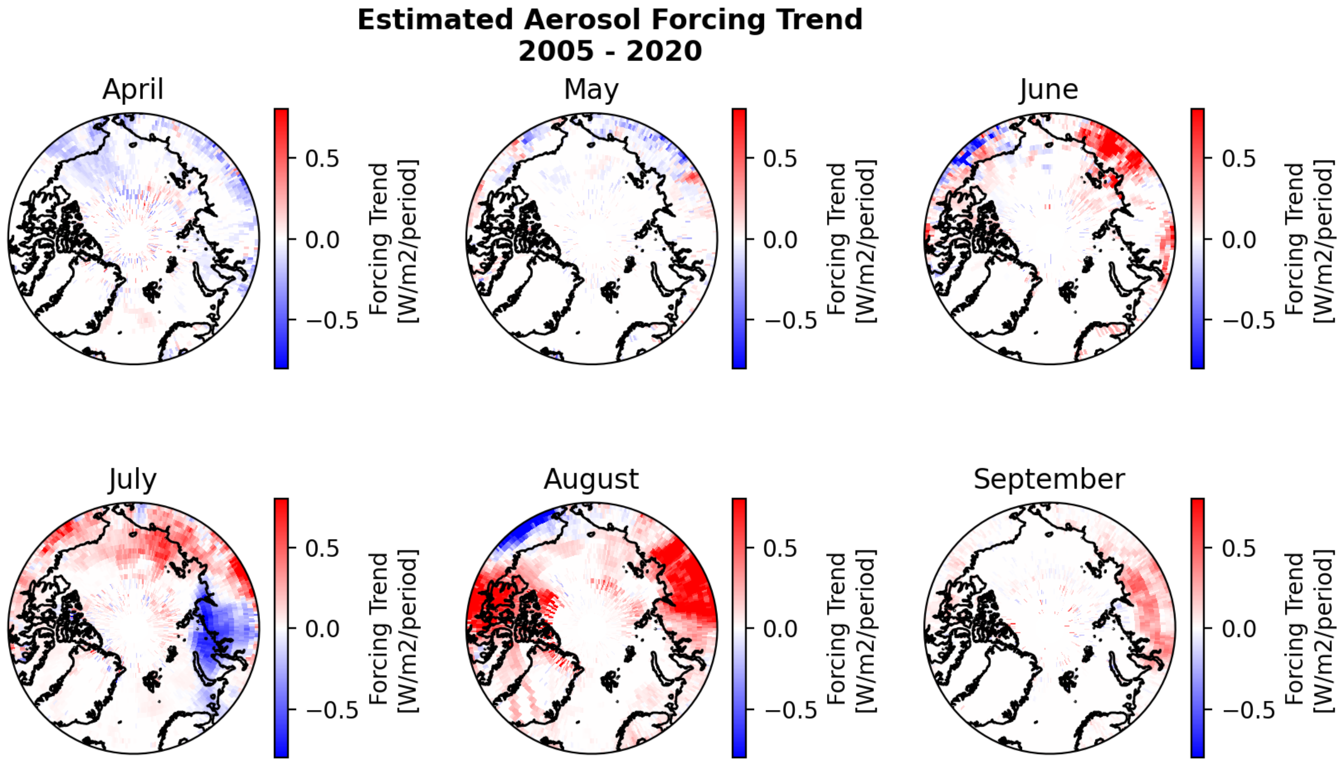
Trend of BB smoke direct radiative forcing

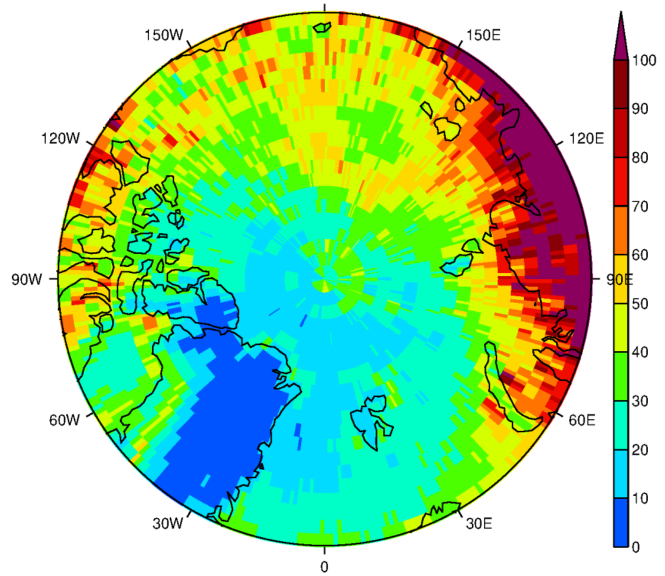




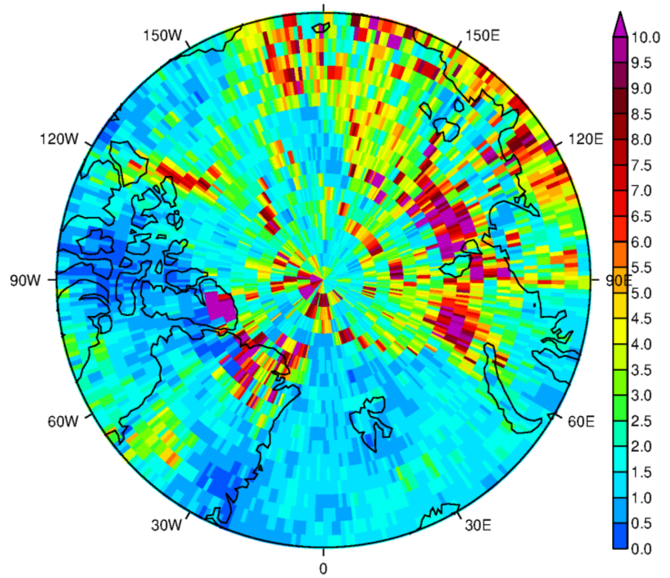
- **Using the OMI UVAI data, we create a purely observational estimate of Arctic aerosol radiative forcing. Positive trends in aerosol radiative forcing observed for the boreal summer months.**
- Observed, Arctic- and monthly-averaged aerosol forcing estimate on month-to-month basis is small (generally < 0.1 W/m2). However, during months with extreme aerosol loading (August 2017), can exceed 0.3 W/m2.
- Trends are calculated across the monthly-estimated forcing values over the Arctic. Mostly weak negative trend in forcing for April and May 2005 – 2020, but primarily positive trend in forcing for June, July, and August 2005 – 2020.
- Ongoing work is being done to further study the impacts of sea ice retreat on the forcing estimate, and to calculate the uncertainty of the estimated forcing values.

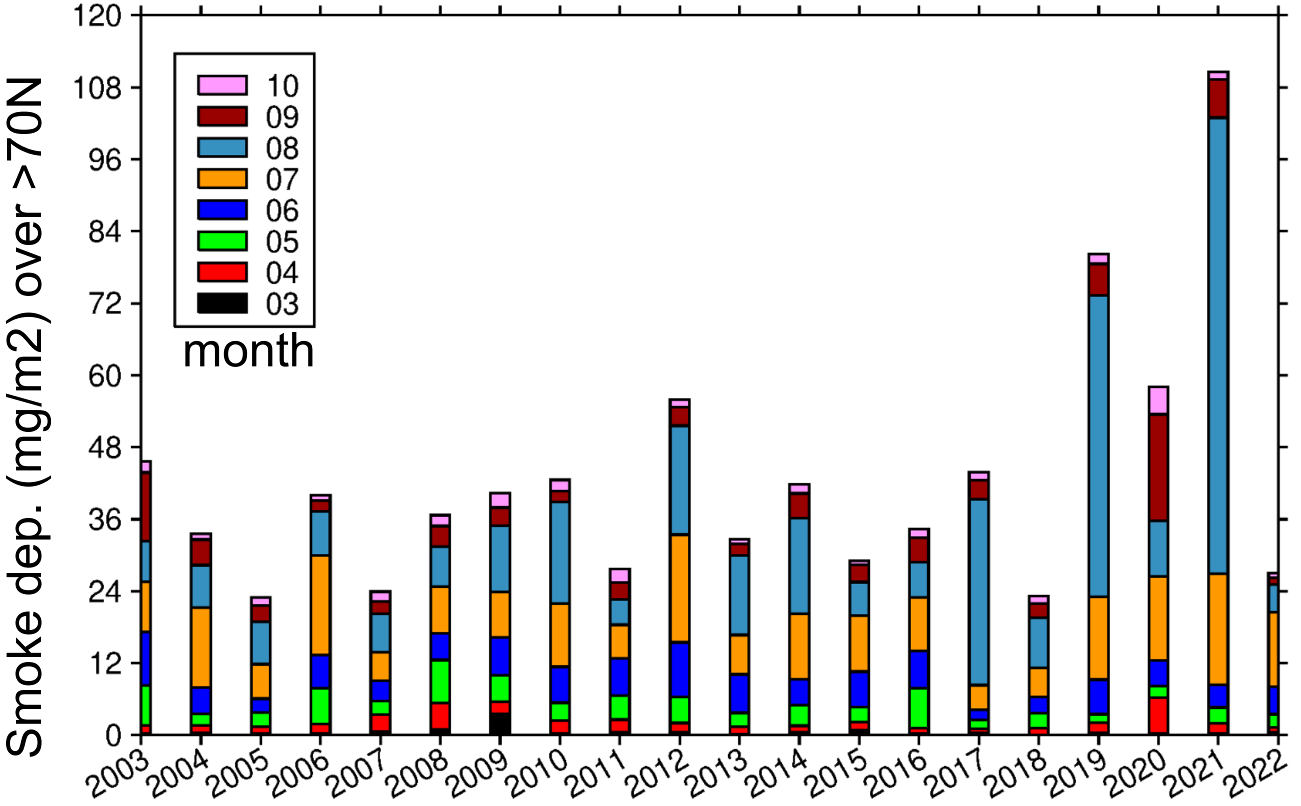
2003-2022 BB smoke deposition in the Arctic

2003-2019 climo (Mar-Oct)

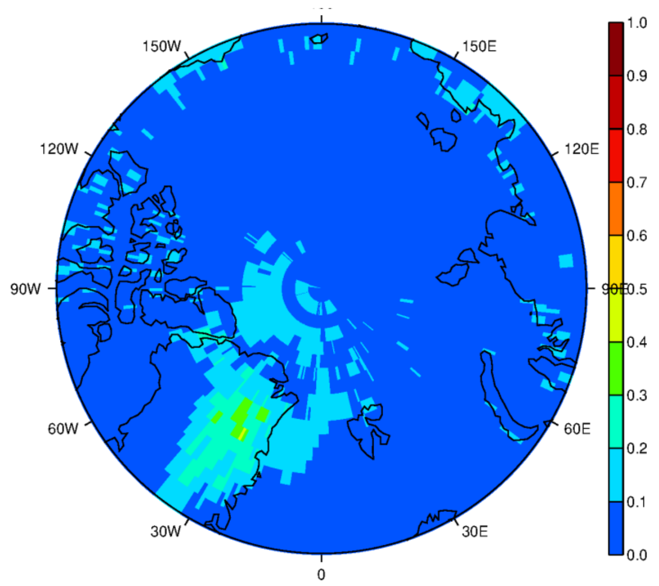


ratio (2021/climo)





Ratio of dry to total deposition



- BB smoke deposition in the Arctic is dominated by wet removal. Dry deposition is only relatively important over Greenland.
- Interannual and regional variations are large.
- Increasing BB smoke deposition in more recent years.
- More July, August deposition in more recent years, which is consistent with seasonal shift of extreme AOD events from spring-summer to summer (Xian et al., 2022b).
- Implication for surface albedo impact.

Summary on Spring and Summertime AOD, BB smoke RF and BB smoke deposition: Climatology and Trend

- ***Arctic AOD climatology***: The total AODs from space-borne remote sensing and the aerosol reanalyses show quite consistent climatological spatial patterns and interannual trends for both spring and summer seasons sub-Arctic (60-70°N).
- ***AOD Trend:*** Total AOD exhibits a general negative trend in the Arctic in MAM, and strong positive trends in North America, Eurasia boreal regions (except Alaska and northeast Siberia) in JJA.
- ***Impact of BB smoke on AOD interannual variability***: The interannual variability of total AOD in the Arctic is substantial and predominantly driven by fine-mode, and specifically BB smoke AOD in both seasons and more so in JJA than in MAM.
- ***Observation-based estimate of BB smoke direct radiative forcing:*** on month-to-month basis is small (generally < 0.1 W/m2). However, during months with extreme aerosol loading, can exceed 0.3 W/m2. For thick smoke cases, local RF can exceed 100 w/m2. Positive trend for summer 2005-2020.
- ***BB smoke deposition:*** is dominated by wet deposition in the Arctic. There is an increase in BB smoke deposition, especially for July and August, in more recent years. Large interannual and regional variations.
- ***Recommendation***: Climate models should take into account BB emissions besides anthropogenic climate forcers and BB interannual variabilities and trends in Arctic climate change studies.

References:

Xian, P., Zhang, J., O'Neill, N. T., Toth, T. D., Sorenson, B., Colarco, P. R., Kipling, Z., Hyer, E. J., Campbell, J. R., Reid, J. S., and Ranjbar, K.: Arctic spring and summertime aerosol optical depth baseline from long-term observations and model reanalyses – Part 1: Climatology and trend, Atmos. Chem. Phys., 22, 9915–9947, https://doi.org/10.5194/acp-22-9915-2022, 2022.

Xian, P., Zhang, J., O'Neill, N. T., Reid, J. S., Toth, T. D., Sorenson, B., Hyer, E. J., Campbell, J. R., and Ranjbar, K.: Arctic spring and summertime aerosol optical depth baseline from long-term observations and model reanalyses – Part 2: Statistics of extreme AOD events, and implications for the impact of regional biomass burning processes, Atmos. Chem. Phys., 22, 9949–9967, https://doi.org/10.5194/acp-22-9949-2022, 2022.

Sorenson et al., An investigation into the use of OMI UV aerosol index for data assimilation and aerosol climate forcing applications over the Arctic region, ACP, 2023

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