Changing aerosol transport to the Arctic from present day to the end of 21st century

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Introduction

- Absorptive aerosols (black carbon and dust) in the Arctic can darken the snow and ice surface and alter the atmospheric temperature, which pose a threat to the Arctic climate and ecosystem.
- A large portion of Arctic aerosols originate from middle latitude region.
- Study how the transport of those aerosols may change in a warming climate is important for our understanding of the Arctic climate.
- Multiple experiments are designed to quantify the change of aerosol tracers' transport change from present day to future climate.

Experiment design

- Multiple individually tagged tracers represent emissions from 200 locations covering most of the North Hemisphere land region.
- Tracers use same emission rate and are passive.
- Community Atmosphere Model 4.0 (CAM4) driven by SST represents:
  - ***PRD*** climate (averaged SST from 1982 to 2001)
  - ***RCP*** climate (averaged SST from 2090 to 2099 under RCP 8.5 scenario).
- Simulation runs for 15 years with annually repeating SST for PRD and RCP. Analysis focuses on January.
- Experiment Transport (***EXP:T***): all tracers have constant e-folding liftetime of 4 days. Then the only factor that determines the tracers' distribution is transport.

Polar dome definition

- Polar dome can be seen as a boundary separates the cold polar region and warm middle latitude with high wind speed and sharp temperature and geopotential height gradient. The polar jet stream (or the tropospheric polar vortex) is similar concept.
- In this study, we define the position of the dome by the following steps:
  (1) Calculate the latitudinal gradient of 500hPa geopotential height.
  (2) Find the corresponding geopotential height when the gradient reaches maximum.
  (3) Use this geopotential height to locate a isopleth on the 500hPa geopotential height field.
  (4) The isopleth indicates the position of polar dome.

Tracer transport change (EXP: T)

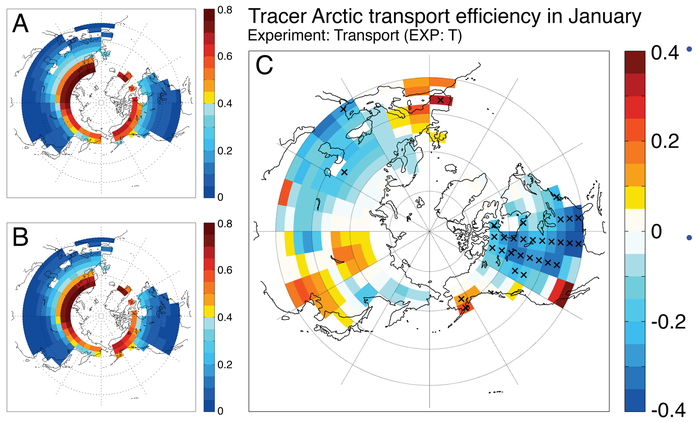

Fig 1. Contour plot of Arctic transport efficiency of the 200 tracers in January for PRD climate [plot A], RCP climate [plot B] and the relative change (RCP-PRD)/PRD [plot C] for EXP:T. Change significant at $p<0.05$ level are shown with 'x' sign (using Wilcoxon rank-sum test).

- The Arctic transport efficiency is defined as the ratio of the Arctic burden to the global burden for a specific tracer.
- Increase transport efficiency for tracers emitted from East Asia and Europe and decrease for tracers from North America in RCP.

Changing polar dome

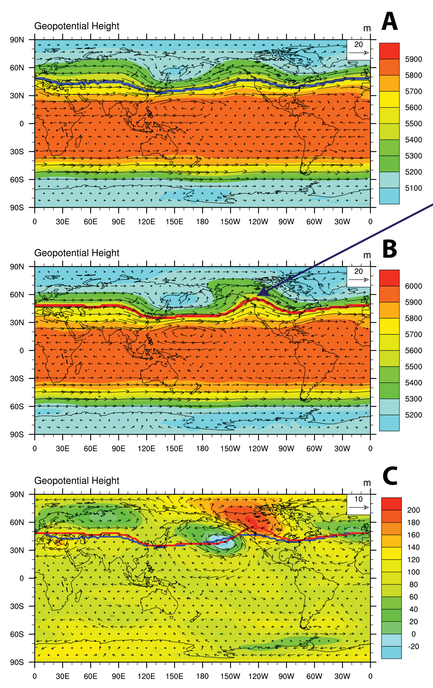

Fig 2. The 15 years mean 500hPa geopotential height and wind (unit: m/s) for PRD [upper], RCP [middle] and their difference (RCP-PRD) [lower] in January. The bold blue line and red line represents the polar dome's 15 years mean position for PRD and RCP climate.

Inhomogeneity of Arctic warming and sea ice loss, especially near the Chukchi Sea, potentially leads to the increase of polar dome wave amplitude in Eastern Pacific.

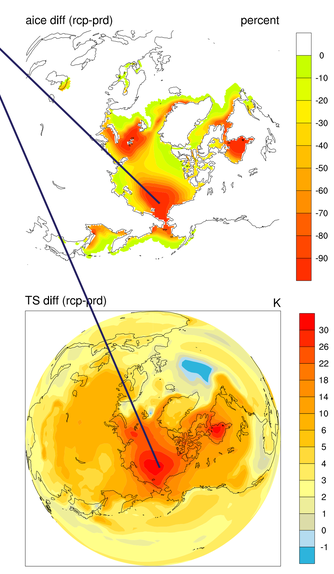

Fig 3. The difference of sea ice coverage and surface temperature between present day and future climates (RCP-PRD) in January.

Case study (EXP:T)

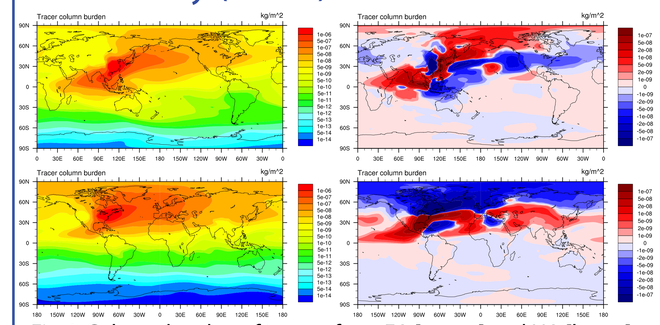

Fig 4. Column burden of tracers from EA [upper] and NA [lower]. Left shows PRD and right shows the difference of RCP-PRD.

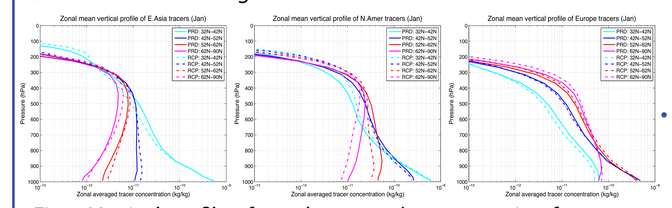

Fig 5. Vertical profile of zonal averaged concentration for tracers emitted from EA [left], NA[middle] and EU [right]. Plot for PRD and RCP climate with four latitude zones.

- East Asia (EA) tracers mix into the Arctic near Bering Sea and Alaska.
- EA tracers concentrates at middle troposphere in high latitude region.
- North America (NA) tracers also show larger high altitude concentration in the Arctic.
- Change in free tropospheric wind can affect EA and NA tracers' transport to the Arctic.
- Europe (EU) tracers can travel to the Arctic via low level transport and its burden concentrates near surface.

Observational evidence of polar dome change

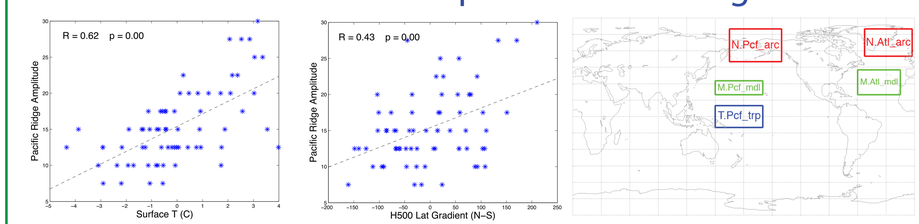

Fig 6. Plot of Correlation between polar dome (planetary wave) amplitude and (left panel) Arctic surface temperature (N.Pcf_arc) and (middle panel) 500hPa geopotential height gradient between high latitude Arctic and mid-latitude Pacific(N.Pcf_arc - M.Pcf_mdl). Right panel shows the regions used in analysis.

With regression technique, we analyzed the NCEP/NCAR reanalysis data and found that the polar dome ridge amplitude only shown significant correlations with temperature and pressure gradient in certain regions as discussed before. While has no significant correlations with variables in other regions.

Summary

- In future climate, passive tracers emitted from East Asia experience increased transport efficiency to the Arctic due to a northward migration of the polar dome in eastern Pacific.
- This change of the polar dome decreases the Arctic transport efficiency of North America passive tracers, as the wind direction shifts south over the north Atlantic.
- Northward expansion of the polar dome in the eastern Pacific is associated in this model with large sea ice loss and warming in the Chukchi Sea.
- We find the polar dome amplitude expansion significantly correlates with warming in Alaska and Chukchi Sea by analyzing reanalysis data.