Influence of large-scale climate variability on the inter-annual variation of surface ozone depletion events in the Arctic spring

Ja-Ho Koo[1] (jahokoo@atmosp.physics.utoronto.ca), Yuhang Wang[2], Tianyu Jiang[2], Yi Deng[2], Samuel J. Oltmans[3], Sverre Solberg[4]
[1] Department of Physics, University of Toronto, Toronto, ON, Canada [2] School of Earth and Atmospheric sciences, Georgia Institute of Technology, Atlanta, GA, USA
[3] Earth System Research Laboratory, NOAA, Boulder, CO, USA [4] Norwegian Institute for Air Research (NILU), Kjeller, Norway

Introduction

In the Arctic spring, surface ozone can decrease extremely due to chemical loss catalyzed by halogen (mainly bromine) radicals. These ozone depletion events (ODEs) are usually accompanied by greatly enhanced surface deposition of reactive gaseous mercury having a harmful contribution to the ecosystem. The monthly ODE frequency shows large inter-annual variation. To analyze whether some of these variations are due to regional climate variability, we use surface ozone measurements at 3 monitoring sites in the Arctic such as Barrow, Alert, and Zeppelinfjellet (ZPL) during the past 30 years. In years with high ODE frequencies at Barrow and Alert in April, the Western Pacific (WP) teleconnection pattern is usually reveals negative phase, which is the period showing strengthened subtropical jet across the Pacific but the weakened storm track from western Pacific into the Arctic. Both factors seem to reduce transport of ozone-rich air masses from mid-latitudes to the Arctic, creating a favorable environment for ODEs in the Arctic. Correlations of ODEs at ZPL with WP pattern indicate the decadal shift from the 1990s to 2000s looks to reflect a much stronger influence of the WP pattern on ODEs at ZPL in the more recent decade. In other words, it could potentially be used as a proxy to diagnose ODE changes and subsequent environmental impacts in the Arctic spring in the future.

Data description

A. Surface ozone measurements

- Barrow (71.3° N, 156.8° W) : NOAA Global Monitoring Division (1975 – 2009)
- Alert (82.5° N, 62.3° W) : Environment of Canada (1993 – 2008)
- Zeppelinfjellet (ZPL, 78.9° N, 11.9° E) : Norwegian Institute of Air Research (1990 – 2008)

B. Climate indices : Using five indices in the Northern hemisphere

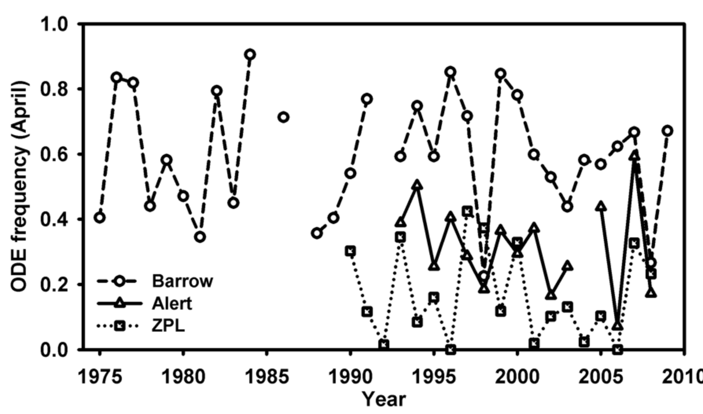
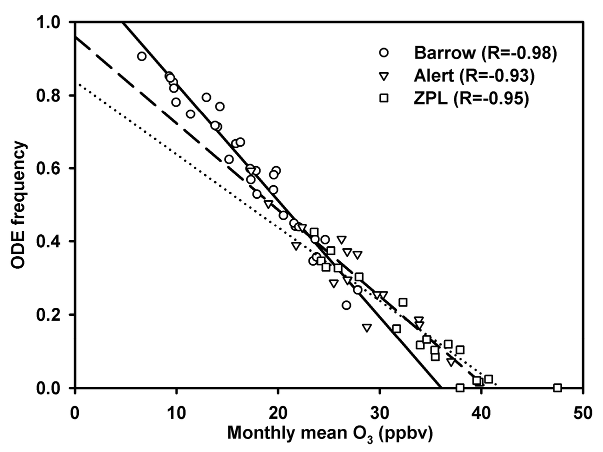
- WP (Western Pacific), PNA (Pacific North American), AO (Arctic Oscillation), and NAO (North Atlantic Oscillation) : from NOAA Climate Prediction Center
- PDO (Pacific Decadal Oscillation) index : from JISAO, University of Washington

C. Jet stream and Storm track intensity

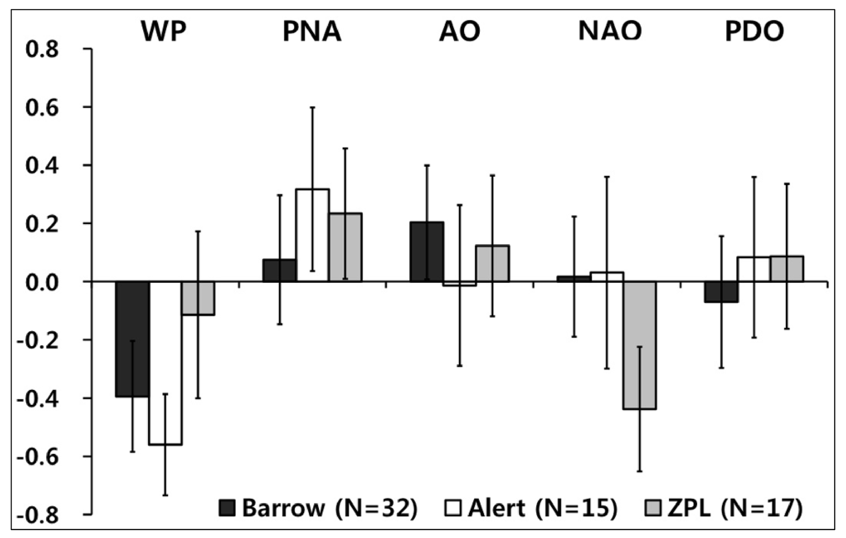
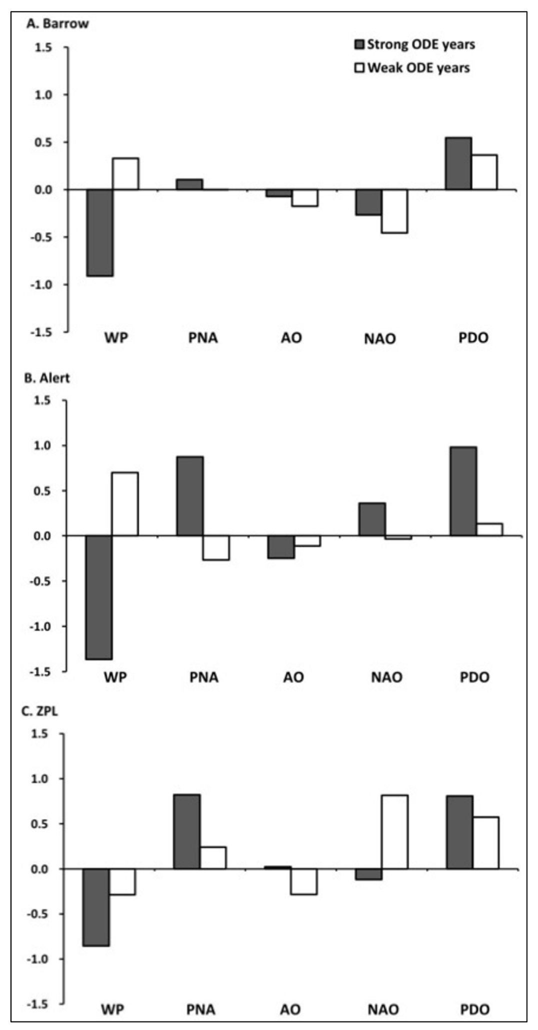
- Jet stream : Using 300-hpa wind speed from NCEP/NCAR reanalysis data.
- Storm track intensity : Storm tracking using the sea level pressure from the NCEP/NCAR reanalysis data, then interpolating intensity on each grid (2.5 by 2.5°).

ODE frequencies and climate variability

· **ODE frequency** : the ratio of ODE hours to total hours in April

· High ODE frequency decreases mean ambient ozone level near the surface.
· Strong inter-annual variation of ODE frequencies appears for all 3 sites - 60% difference year to year at maximum.

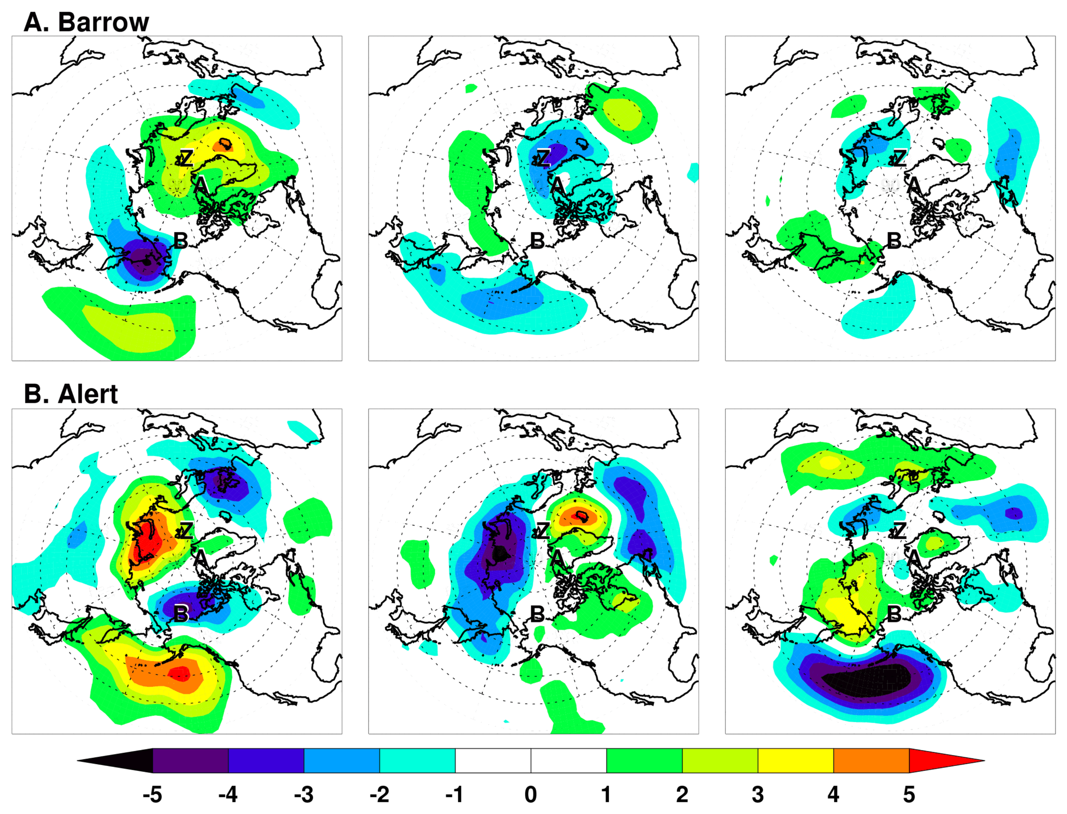
· High correlations between WP index and ODE frequency at Barrow and Alert.

· Negative phase of WP index for strong ODE years, and positive phase of WP index for weak ODE years.

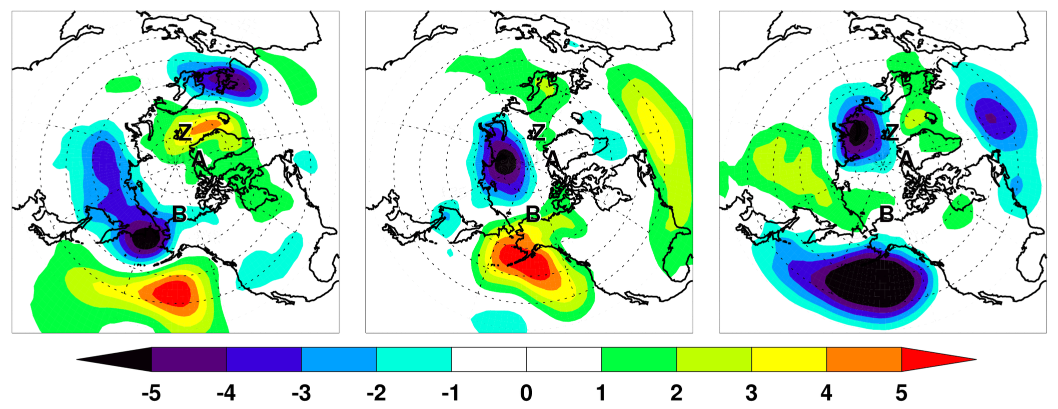
· ODE frequency at ZPL does not correlate with WP index in general, but it shows large correlation with WP pattern in a recent decade (will show later).

Connectivity between WP pattern and ODE frequency

SLP anomaly for weak , moderate, and strong ODE years



SLP anomaly for positive, moderate, and negative WP years



· The anomaly pattern of SLP also well shows the anti-relationship between the WP pattern and the ODE frequency at Barrow and Alert.

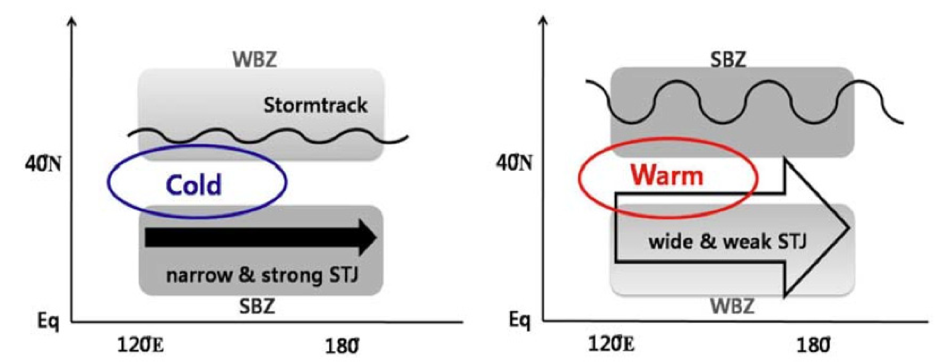
· Jet stream and Pacific storm track, which are associated with the WP pattern, also shows the large contrast between the most and least frequent ODE years.

· **For the negative (positive) WP pattern**
- Strong (weak) extension of jet stream to the Northern America
- Weak (strong) intensity of Pacific storm track from the mid-latitude to the Arctic

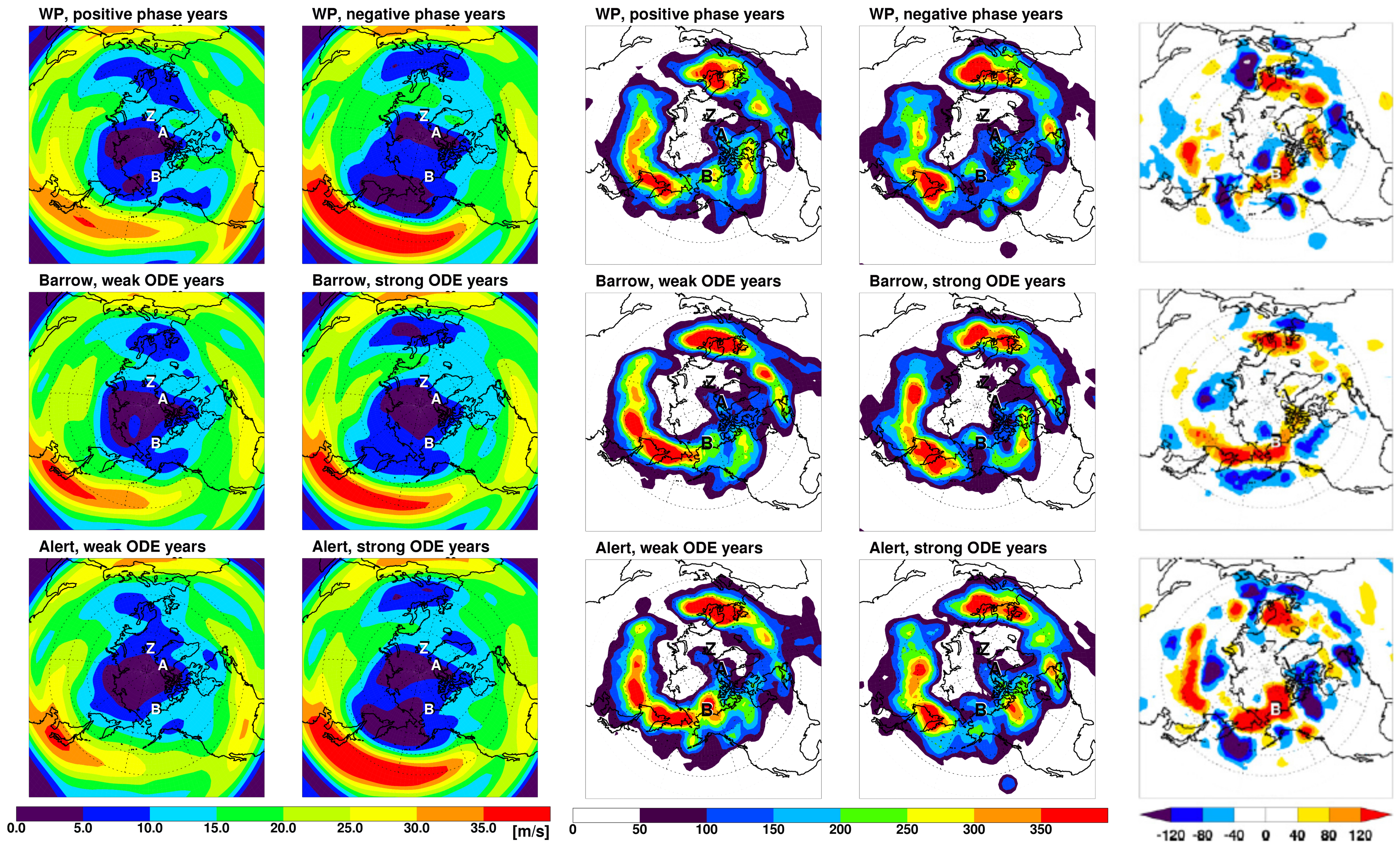
⇒ **Weak transport of ozone-rich air from the mid-latitude, and weak meridional air mixing.**

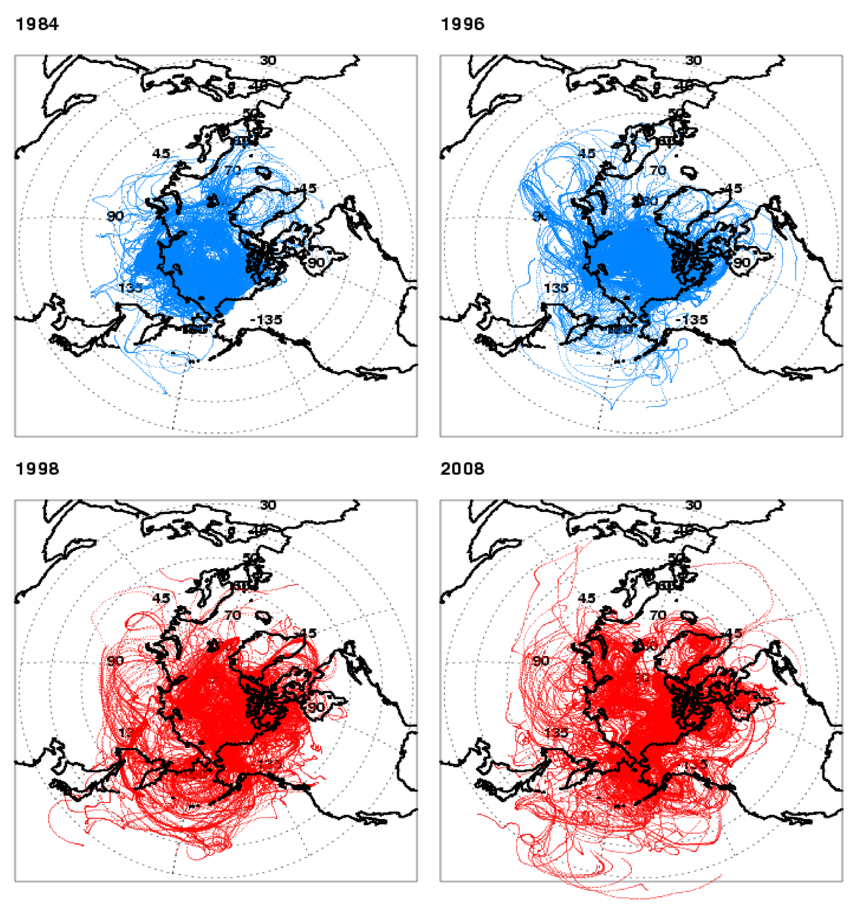
⇒ **Favorable conditions of strong Arctic ODEs.**

Lee et al., (JGR, 2010) : Jet stream (around 30° N) and Pacific storm track (around 50° N) respond oppositely to the temperature anomaly between two regions (around 40° N), in which the western Pacific is located.



Jet stream — Storm track intensity — differences

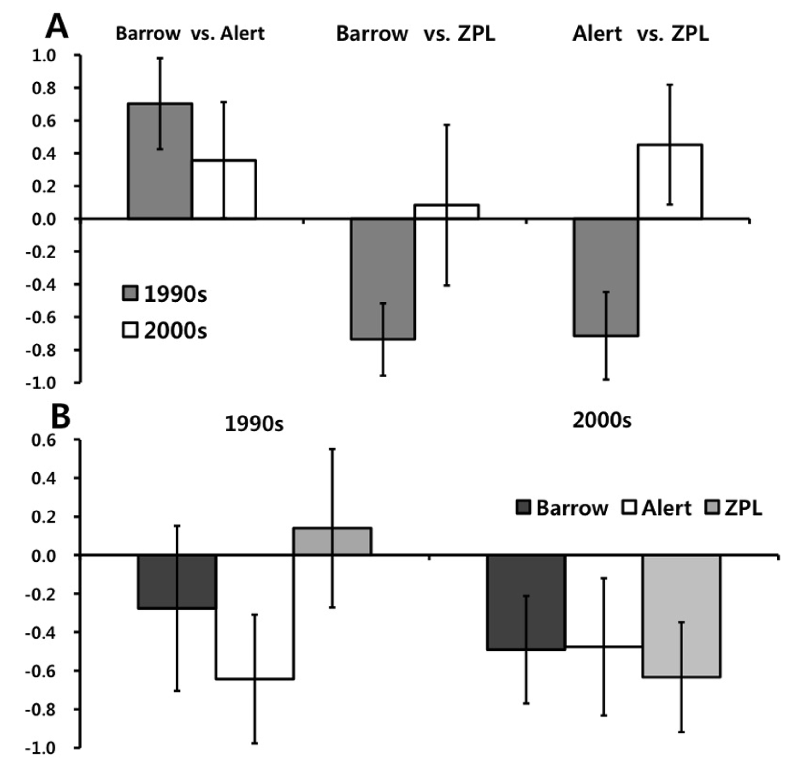




Backtrajectory (from HYSPLIT 4.0) comparison between the years of weak and strong ODE (at Barrow for example)

=> During the years of strong ODE occurences, relatively more backtrajectories from mid-latitude in the West Pacific region is identified, implying the larger transport of mid-latitude air mass (more polluted than the Arctic air mass).

Decadal-shift of ODE frequency at ZPL



· ODE frequencies are positively correlated between Barrow and Alert in the 1990s and 2000s consistently.

· ODE frequencies at ZPL, however, shows the decadal-difference.
- Negative correlations with those at Barrow and Alert in the1990s.
- But switching to the neutral or positive correlations in the 2000s
- While the ODE frequency at ZPL has a small and insignificant positive correlation with the WP index in the 1990s, the correlation turns largely negative in the 2000s.

⇒ Reflecting a much stronger influence of the WP pattern on ODEs at ZPL in the more recent decades.

Summary

· The ODE frequency at Barrow and Alert strongly reveals the negative correlation with the WP index, which is related to the variation of jet stream and storm track intensity in the western Pacific.
· The pattern of jet stream and storm track intensity in the western Pacific shows the large difference between strong and weak ODE years, indicating that the transport of ozone-rich air masses from the mid-latitude and the extent of meridional and vertical mixing are feasible factors affecting to the frequency of Arctic ODEs.
· Analysis of ODEs at ZPL shows that the high Arctic appears to be influenced more strongly by the WP pattern in the 2000s than 1990s. High sensitivity of Arctic climate to the pollution in the East Asia, or the global climate change in the recent decade may be the reasons and they should be more investigated in the future.

Acknowledgement: This work was supported by the NASA International Polar Year and Atmospheric Chemistry Modeling and Analysis Programs. NCEP/NCAR reanalysis data (http://www.esrl.noaa.gov/psd/data/gridded/reanalysis) were used in this study.