# Importance of Natural Variability in Global Warming

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Most dominant natural variability is Arctic Oscillation (AO)



**Global Warming** 



# AO pattern of Sea Level Pressure (SLP) and its anomaly for 2009/10

## 2009/10

The anomaly shows AO negative pattern





Wallace and Thompson (2002)

# AO pattern of Surface Air Temperature (SAT) and its anomaly for 2009/10

### 2009/10

The anomaly shows AO negative pattern





Wallace and Thompson (2002)

# **Arctic Oscillation and Global Warming**



- AO is defined by EOF-1 of SLP (Thompson and Wallace 1998).
- AO pattern of SAT shows warming at Siberia and North America and cooling at Greenland (Thompson et al. 2002).
- → About half of the variance of the observed warming pattern is explained by AO (Thompson et al. 2002).

## AO analyzed in IPCC-AR4 models

(Ohashi and Tanaka 2009)



#### Observation

Arctic Oscillation Index (365-day mean)

Barotropic Component of the Atmosphere



AOI by 10 IPCC-AR4 models

AOI by MRI ensemble projection

## Singular Eigenmode Theory of AO

Barotropic Height

DJF mean for 1950-1999



(Tanaka and Matsueda 2005)

 $M \frac{dU}{dt} + LU = N + F$  Primitive equations  $\frac{dx}{dt} = Ax + f$  Linearized by a basic state  $\frac{dx}{dt} = Ax \qquad \xrightarrow{EVP} \quad Vx = Ax$  $x = -A^{-1}f \qquad \xrightarrow{SVD} \quad x = -V\Sigma^{-1}U^{T}f$ 

**Climate basic state** 

**EVP and SVD analysis** 

# **AO in Observation and Barotropic S-mocel**



(Tanaka 2003, JAS)

# Singular Eigenmode Theory of AO

Observation

#### Theory





## Singular Eigenmode Theory



# AOI and PDO Pacific Decadal Oscillation



# Long-term variation of AOI and SAT

#### Arctic Oscillation Index (90-day mean)

Barotropic Component of the Atmosphere



AO is an unpredictable natural variability, which controls the decadal trends of SAT (surface air temperature).

Winter



Winter







2009/2010



### **EOF Analyses of IPCC Models and Observation**



• <u>The warming occurs by the anthropogenic forcing in the IPCC models, which is</u> <u>not seen in the observation. AO appears as EOF-2 in the model.</u>

## EOF Analyses of IPCC Models and Observation



- In observation, the warming occurs by natural variavility as AO pattern, while it occurs by Ice-albedo pattern in the IPCC models due to the anthropogenic forcing, which is not seen in observation.
- <u>The AO pattern appears in EOF-2 in the IPCC models with variance ratio of</u> <u>32.7:13.4 (i.e. 5:2 ) for the 10 model mean.</u>



#### Summary

Natural variability of AO is superimposed on the recent global warming. The long-term trend may be anthropogenic.

- The warming has stopped in the 21th Century by natural variability.
- Rapid warming after 1970s contains large fraction of unpredictable natural variability.
- Hence, the models should not fit with that rapid



<u>warming.</u>

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(Emori 2009)



Ohashi and Tanaka (2010, SOLA)

#### Internal variability superimposed on warming trend



**Atlantic Multi-decadal Oscillation (AMO)** 





AMO theory by Tung and Zhou (2015)

Tanaka and Tamura (2016, Polar Science)

#### Internal variability superimposed on warming trend



JRA55 SAT EOF3 1958/59-2011/12 (DJF) - 1 ð Time series (11.8%) 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 Northern hemisphere (0 N - 90N, 0E - 360E) 1958/59 - 2011/12 DJF -0.5 -1.0 0.0 0.5 1.0 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 Year

Correlation map for SAT and Albedo

N. H. Mean Temperature with Linear Trend Two Box Energy Balance Model



Global Warming (Arctic Amplification) superimposed on Barrens Sea Mode showing multi-decadal variation as in Planetary Albedo (1% change)

Tanaka and Tamura (2016, Polar Science)

# Anthropogenic global warming



Projections from computer models predict large temperature increases in future arctic winters (Dec., Jan., Feb.) after CO<sub>2</sub> has doubled in the atmosphere.

#### Big unknown in cloud radiation process which may cause Multi-decadal variation in planetary albedo

## NICAM glevel-10



#### Importance of Cloud Radiation Process for Albedo



#### NICAM running at CCS, University of Tsukuba





Typhoon Sinlaku(2008) and Hurricane Ike(2008)

# Summary



- Global warming is about 0.7K/100y in linear trend
- The warming is associated with Arctic Amplification
- Multi-decadal variability (AMO or PDO) is superimposed on the linear global warming trend
- Barrens Sea mode and AO in the atmosphere is associated with those oceanic phenomena
- We find that planetary albedo shows the same multi-decadal variability