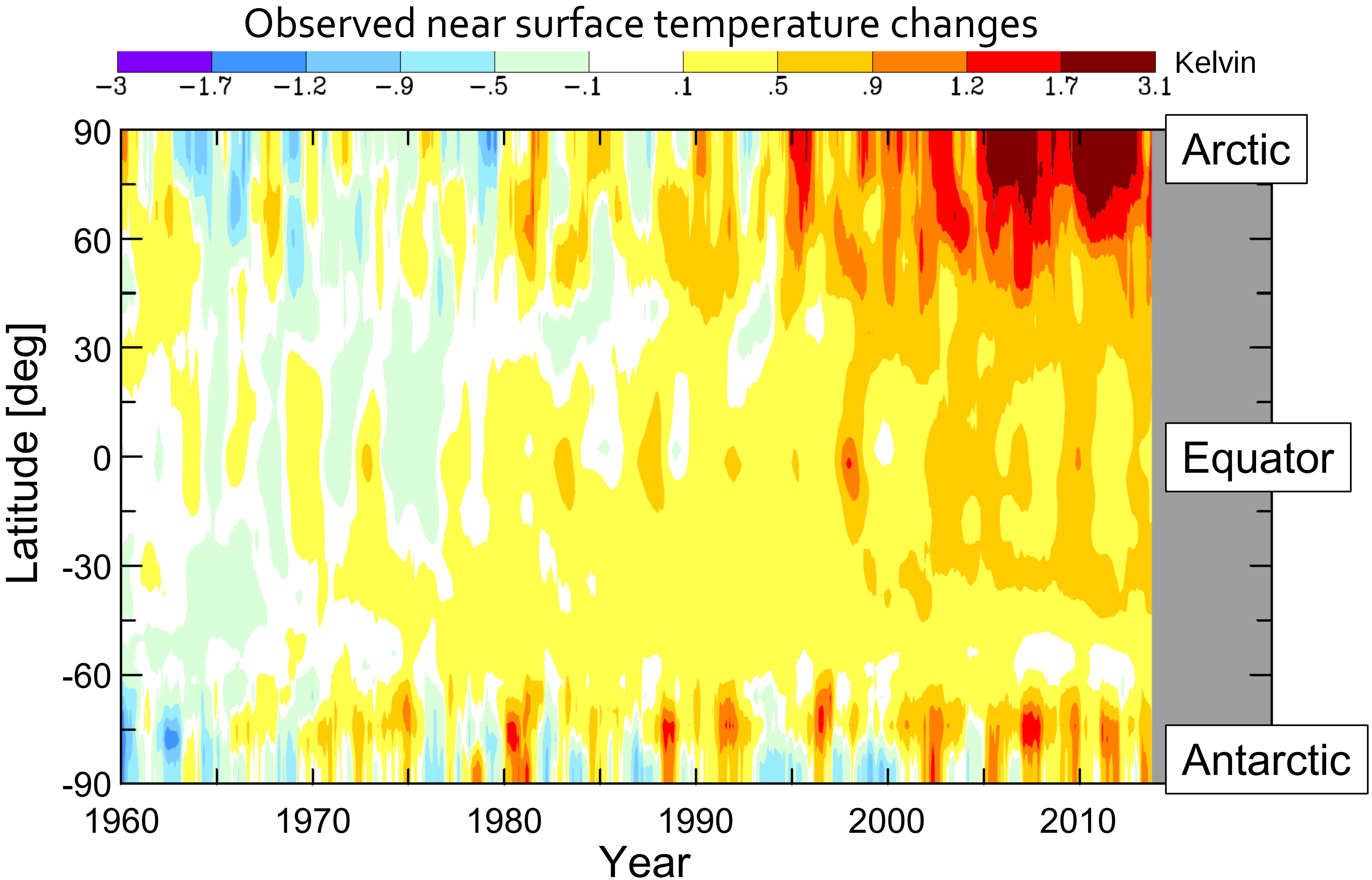
Arctic Climate Change and the Role of Ozone

Markus Rex

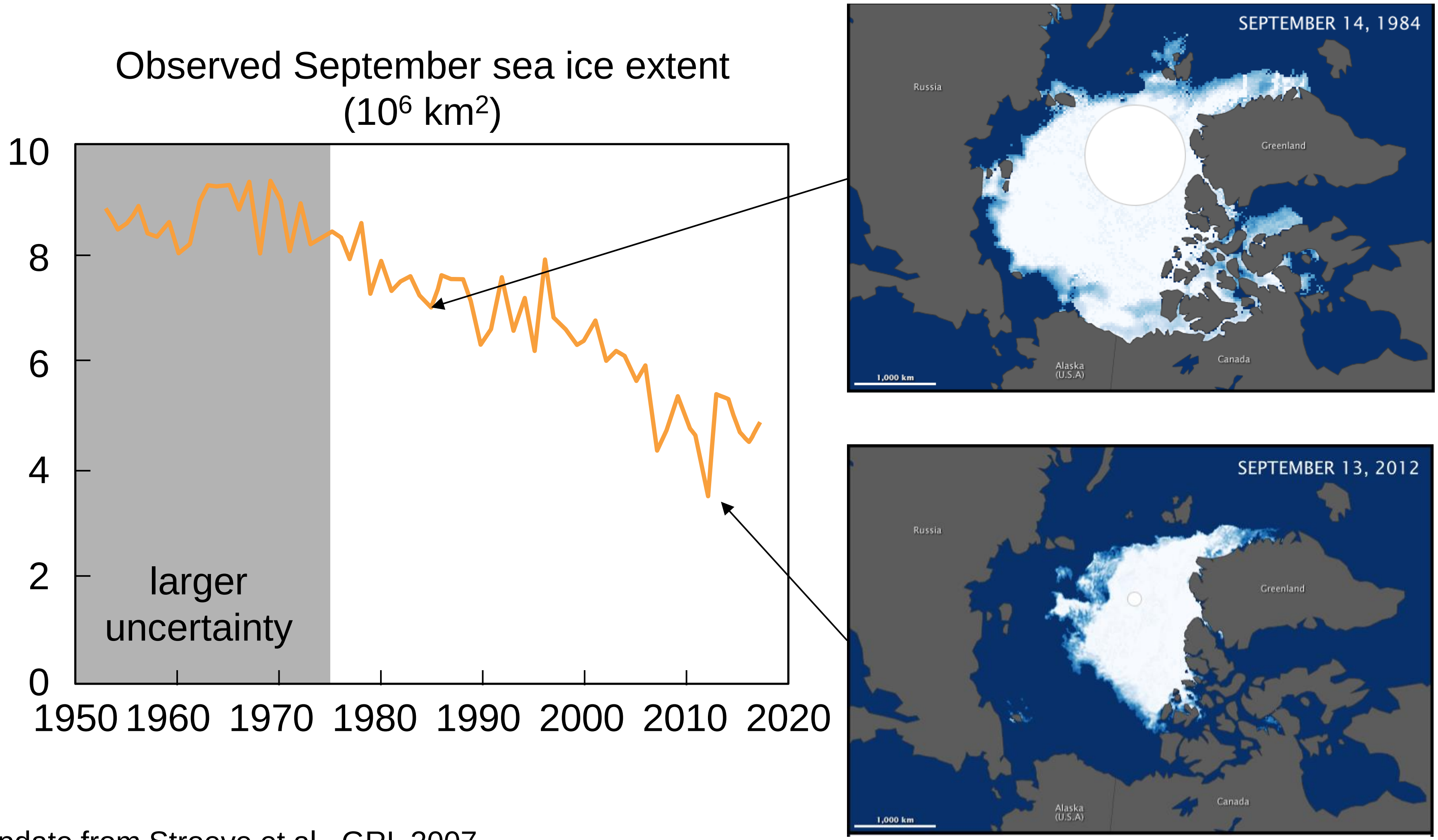
Alfred Wegener Institute

The Arctic is the key area for climate change



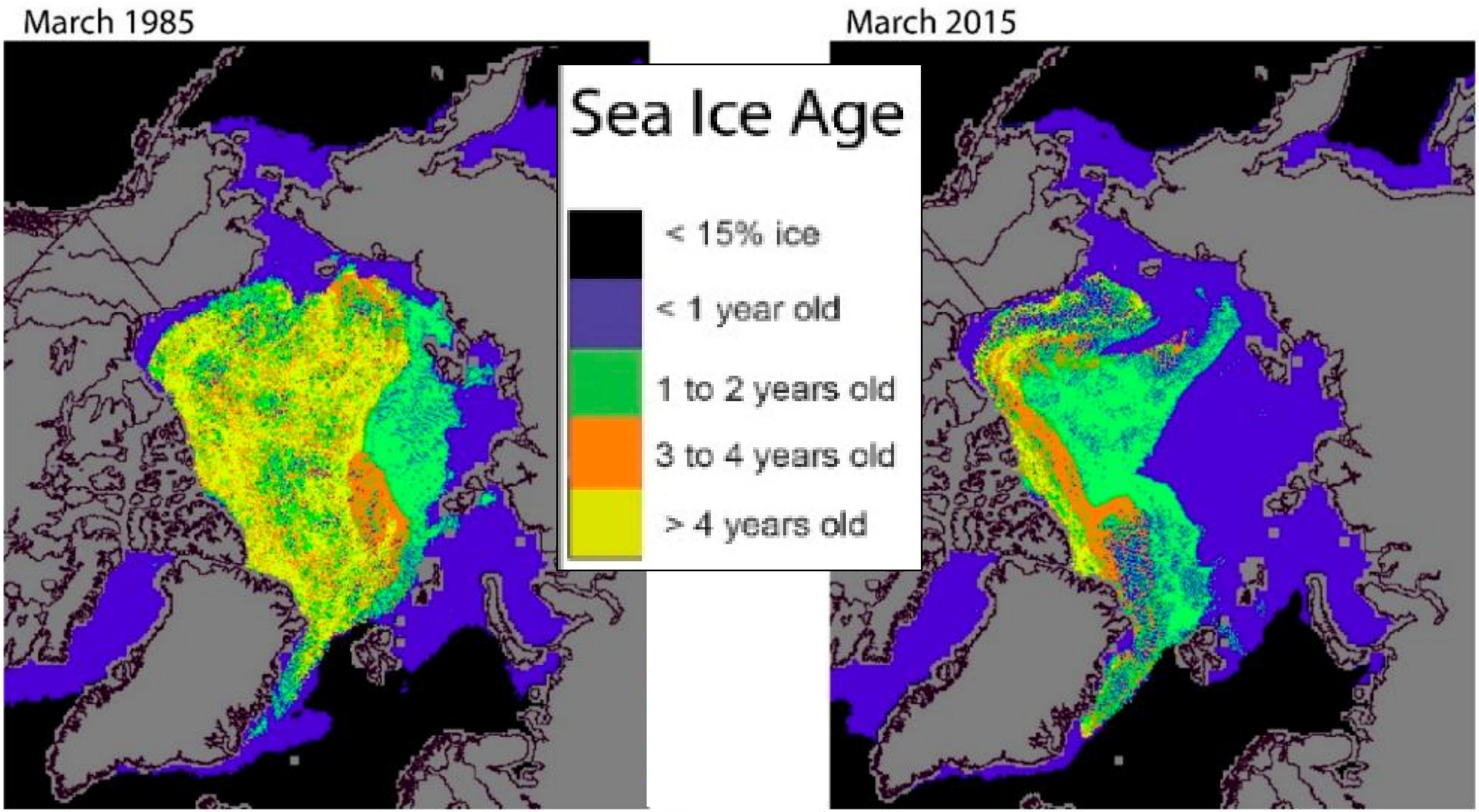
http://data.giss.nasa.gov/gistemp/time_series.htm

Severe loss of sea ice in the Arctic



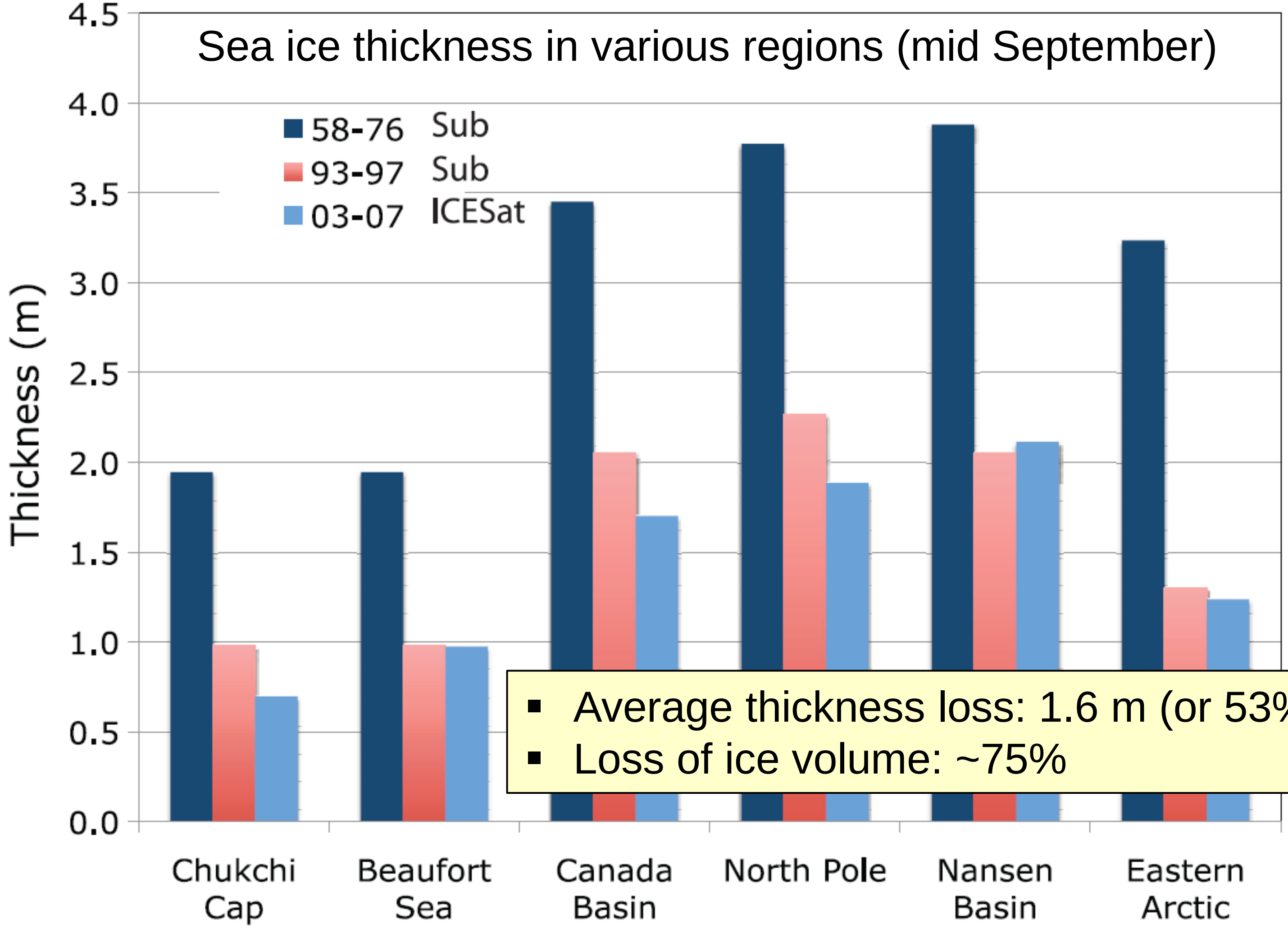
Update from Stroeve et al., GRL 2007

Transition from multi-year to first year ice



Perovich et al. 2015

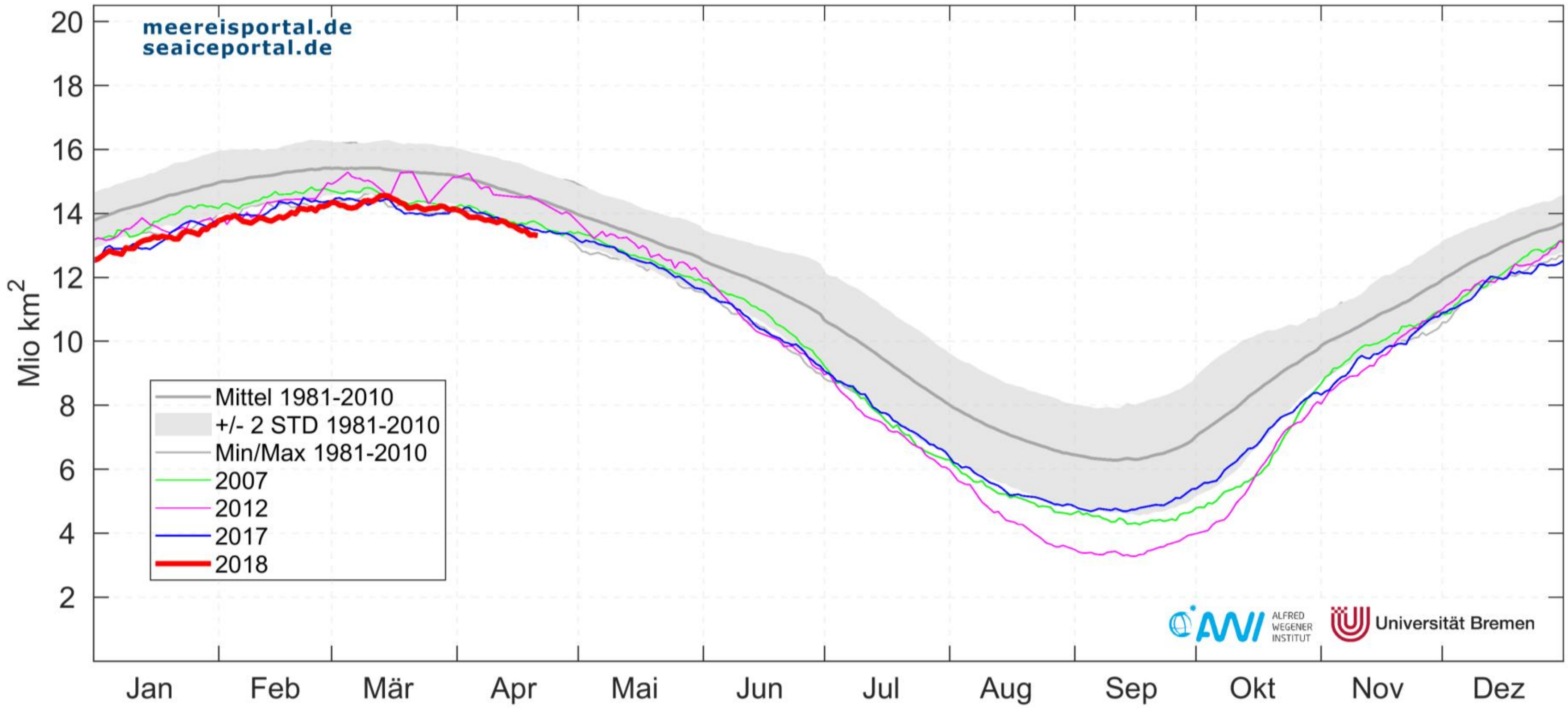
Large reductions in sea ice thickness



- Average thickness loss: 1.6 m (or 53%)
- Loss of ice volume: ~75%

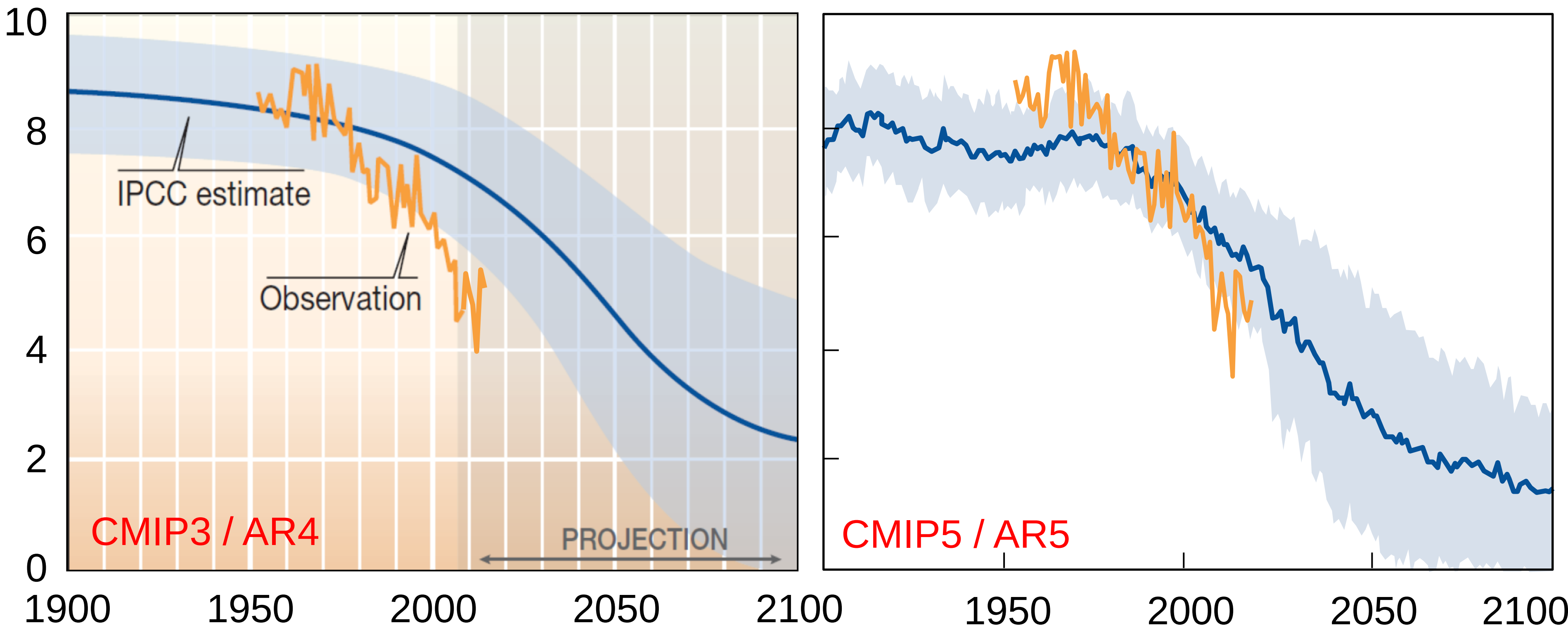
Kwok & Rothrock (2009)

Situation in 2017 & 2018



Arctic climate change is not well represented in state-of-the-art Earth System Models

September sea ice extent (10^6 km^2)
Models versus observations



Updated from Stroeve et al., 2007

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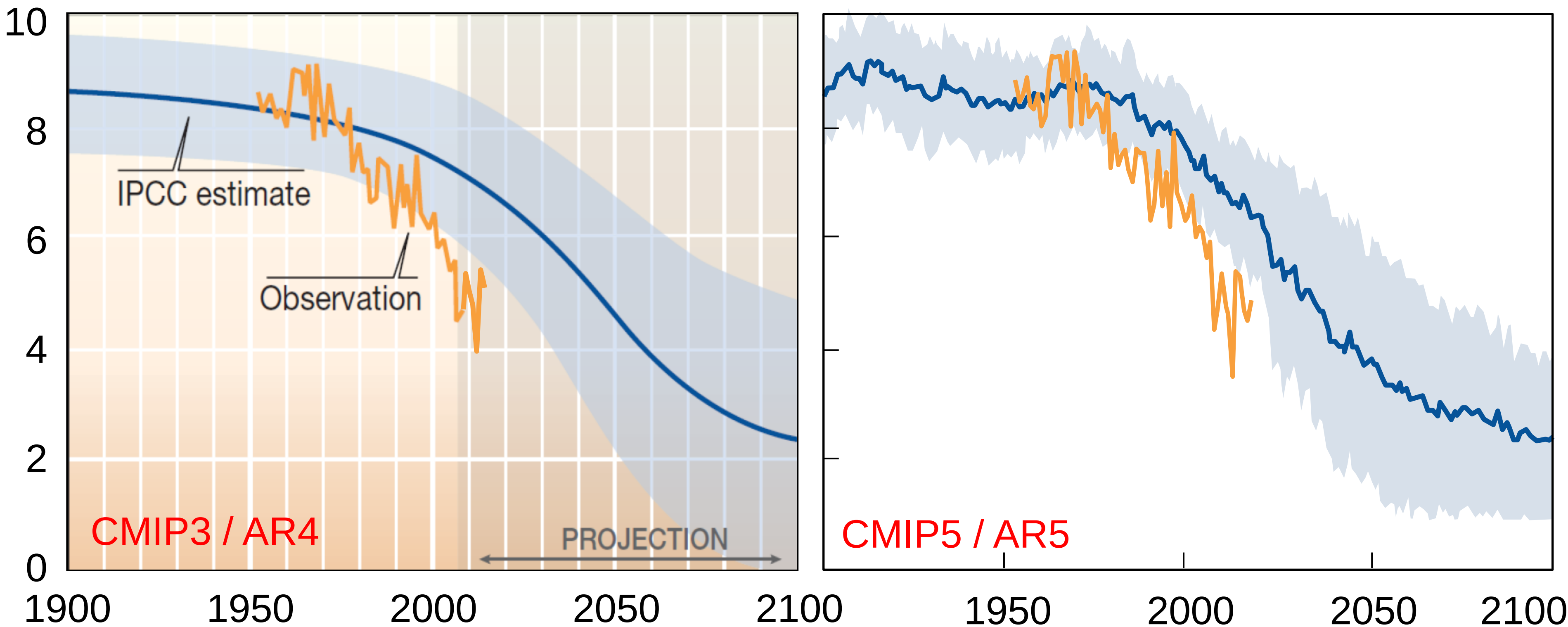
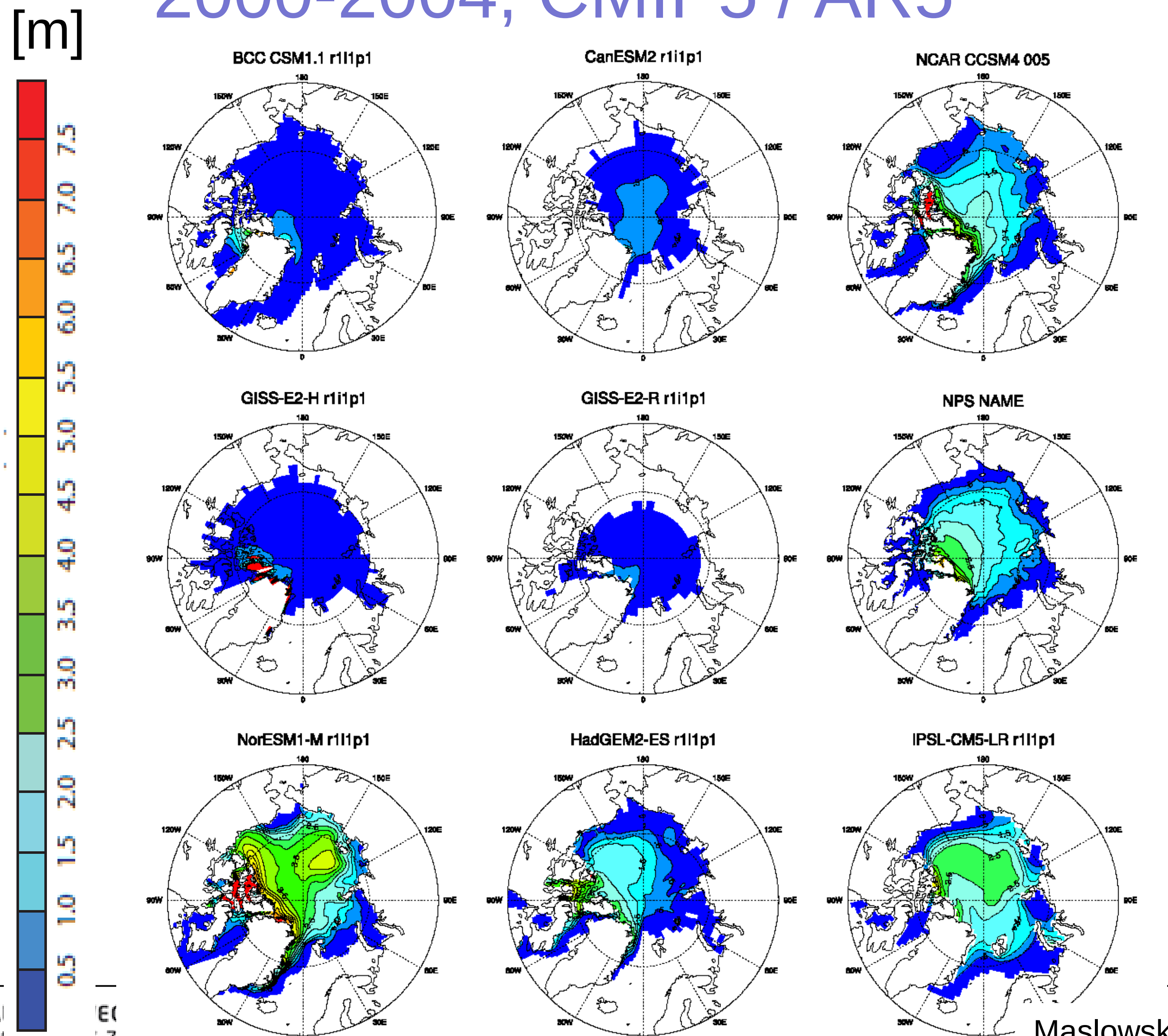


Updated from Stroeve et al., 2007

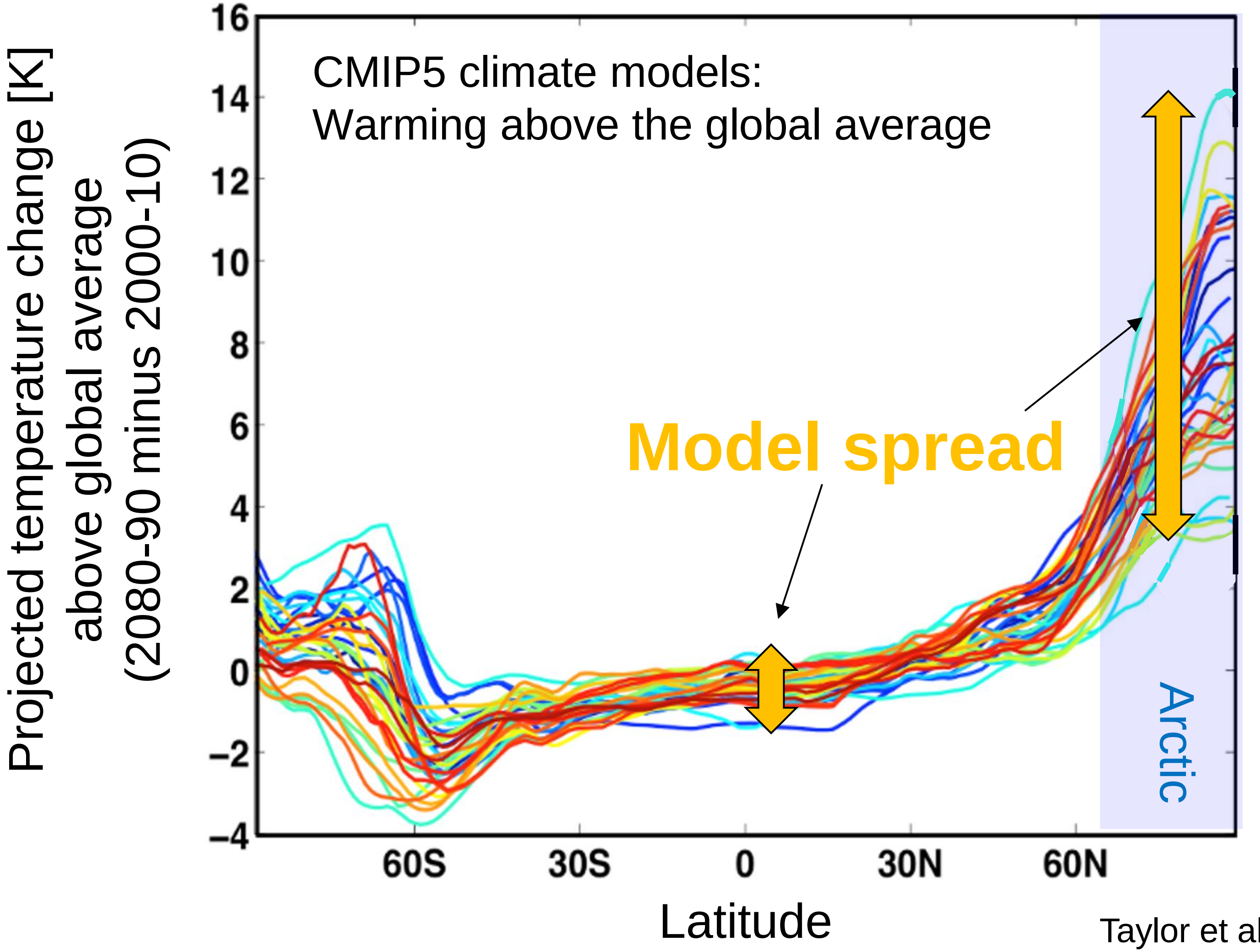
Update from Stroeve et al., GRL 2012

September sea-ice thickness 2000-2004, CMIP5 / AR5



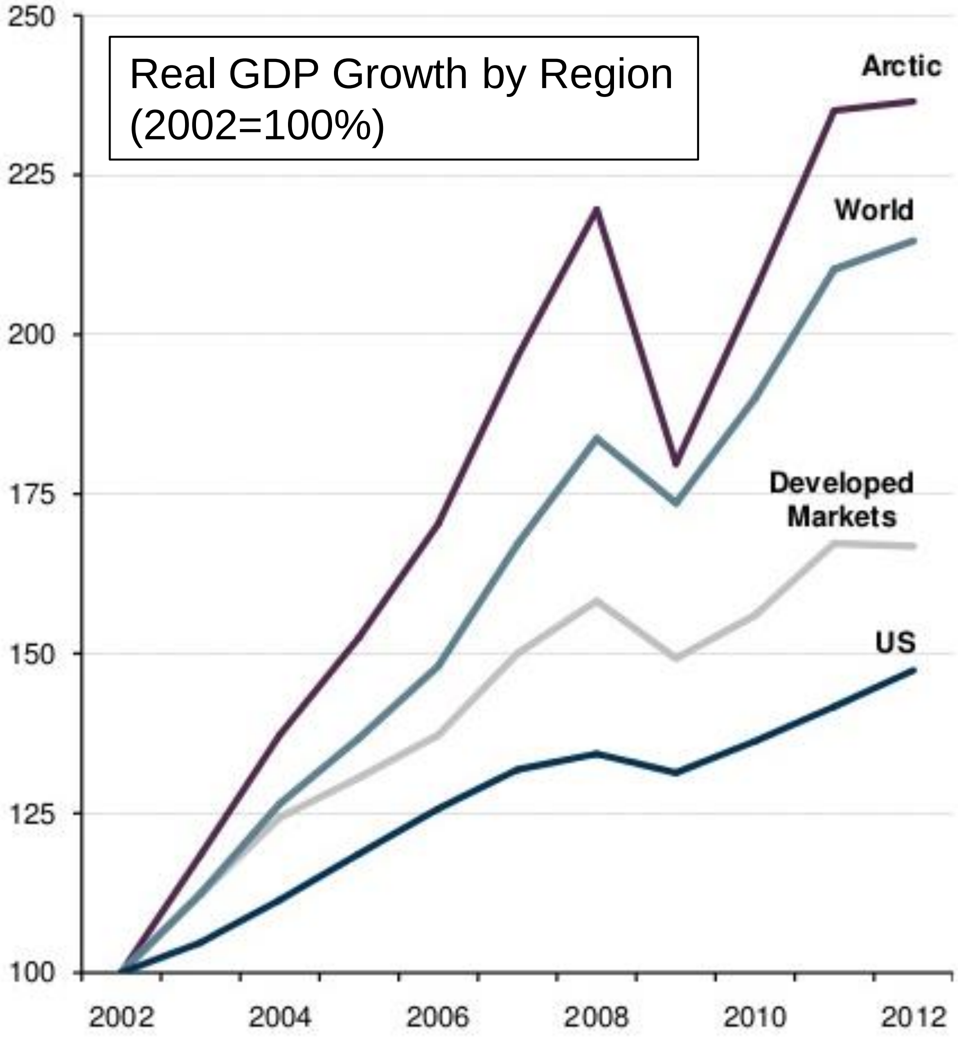
Maslowski et al., 2012

Arctic is the area of largest uncertainty in climate projections



Taylor et al., based on RCP8.5

Rapid economic development in the Arctic



Rapid development in several areas:

- Shipping
- Mining / resource extraction
- Fishing

Investments planned in Arctic Infrastructure 2014-2024:
~100 billion US$

Investment needs over next two decades:
~1000 billion US$

Source: Guggenheim Partners, 2014

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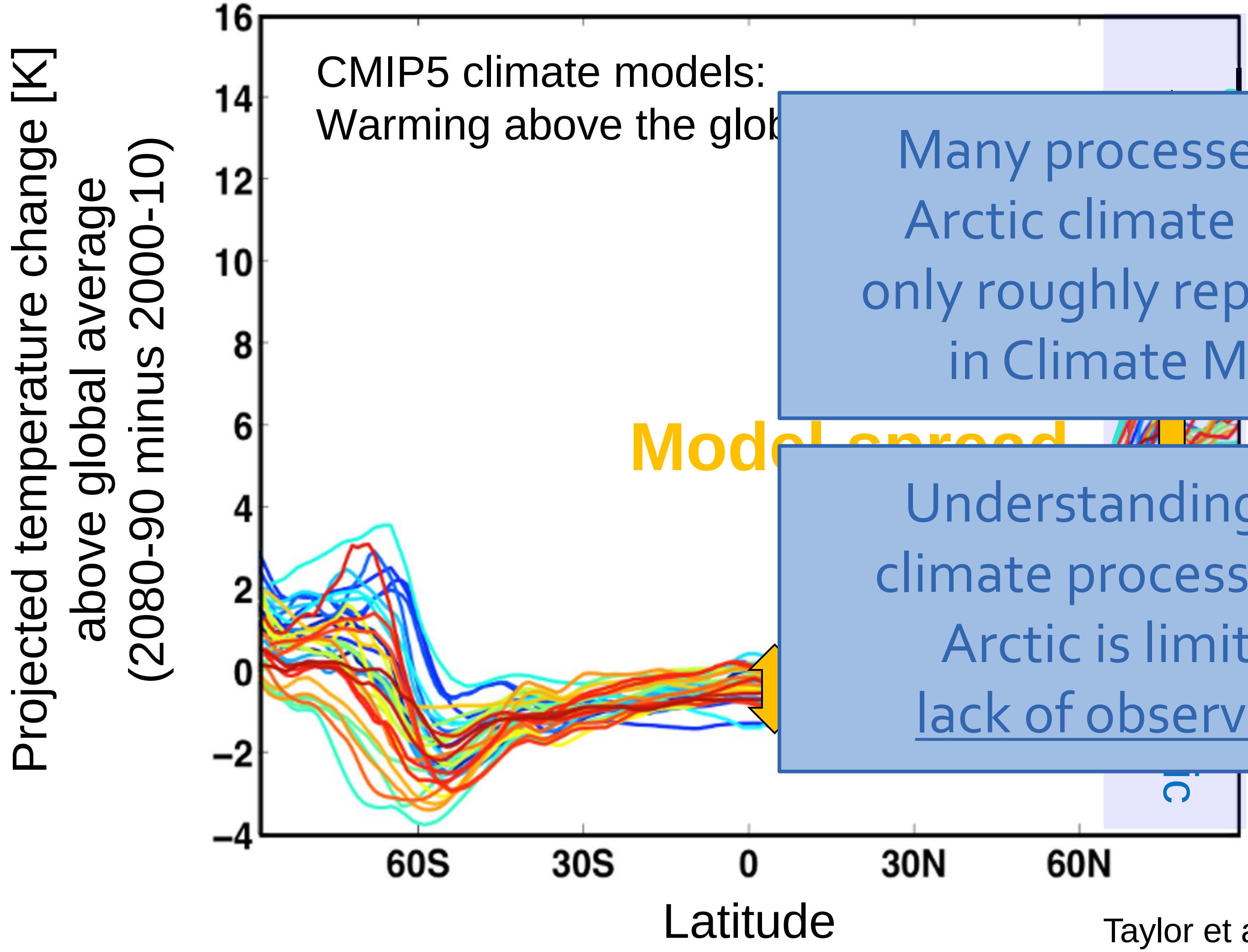


Many processes in the Arctic climate system only roughly represented in Climate Models

Understanding of key climate processes in the Arctic is limited by lack of observations!

Taylor et al., based on RCP8.5

MOSAiC
International Arctic Drift Expedition

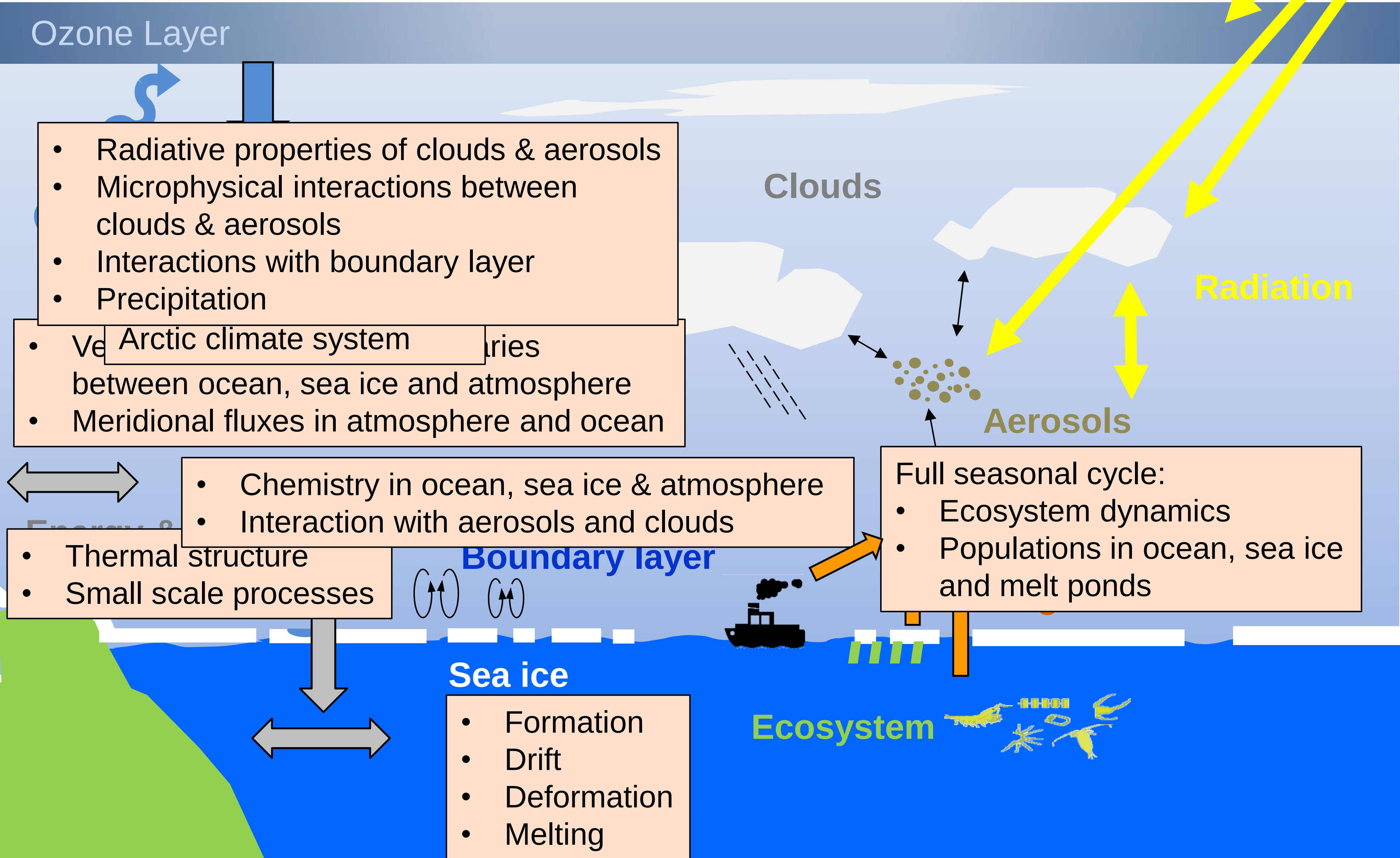
Multidisciplinary drifting Observatory for the Study of Arctic Climate

IASC

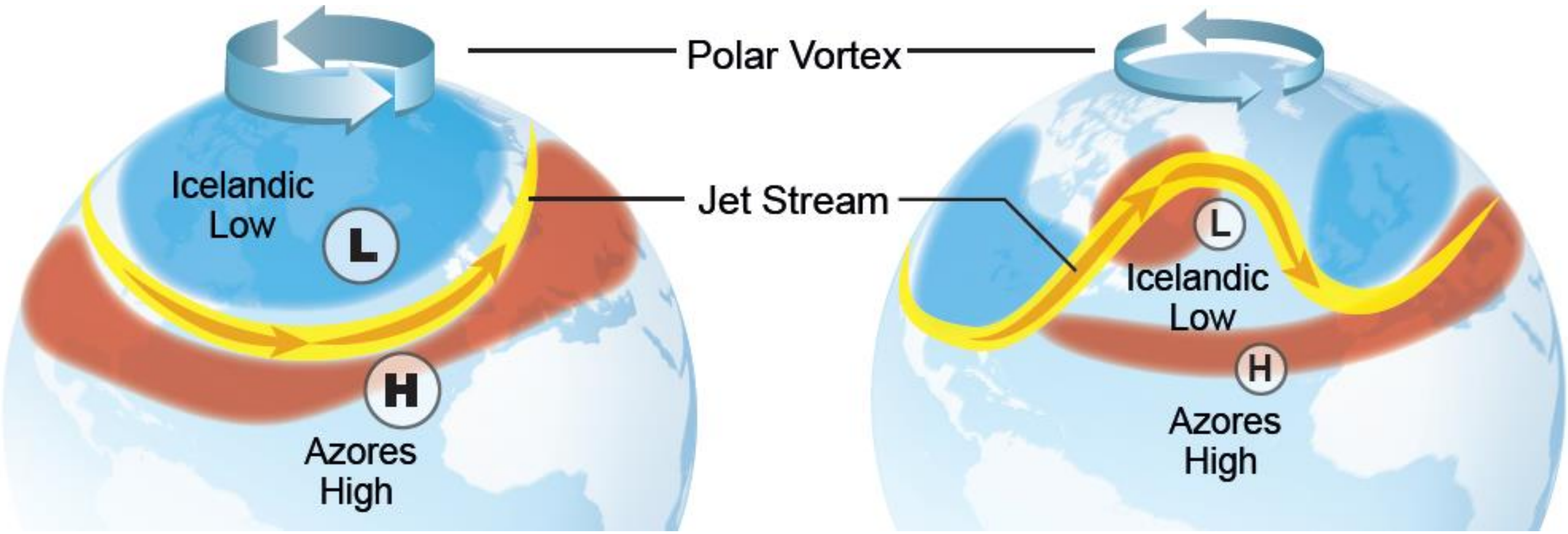
A major international research initiative under IASC to improve the representation of Arctic processes in weather forecast and climate models

MOSAiC International Arctic Drift Expedition

Main scientific focus areas



Link between Arctic and European climate: The Arctic Oscillation (AO)



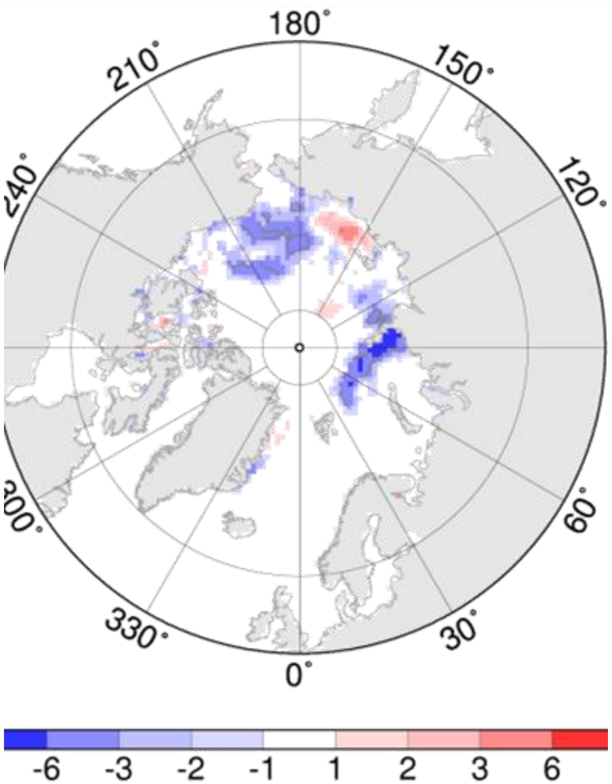
High AO Index

Low AO Index

Link: Sea ice changes ⇔ atmospheric circulation

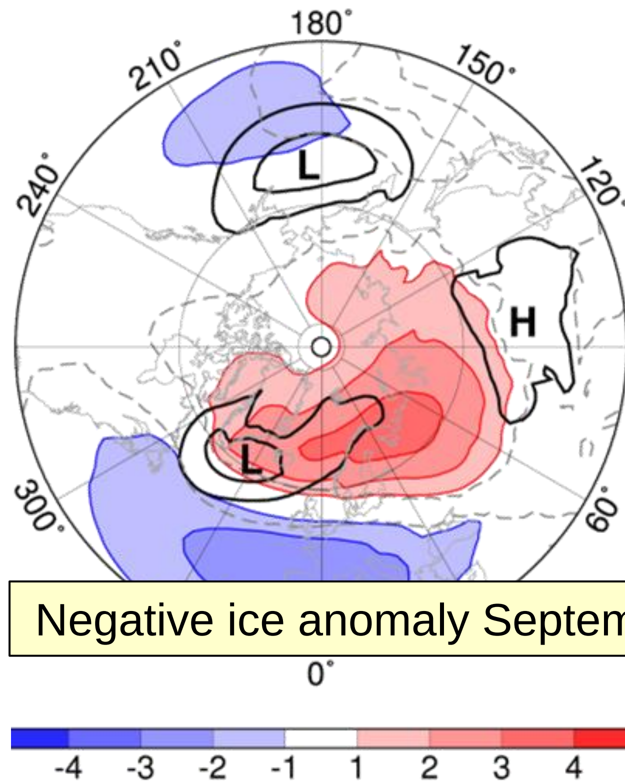
Maximum covariance analysis, ERAi 1979-2015

September sea ice anomaly

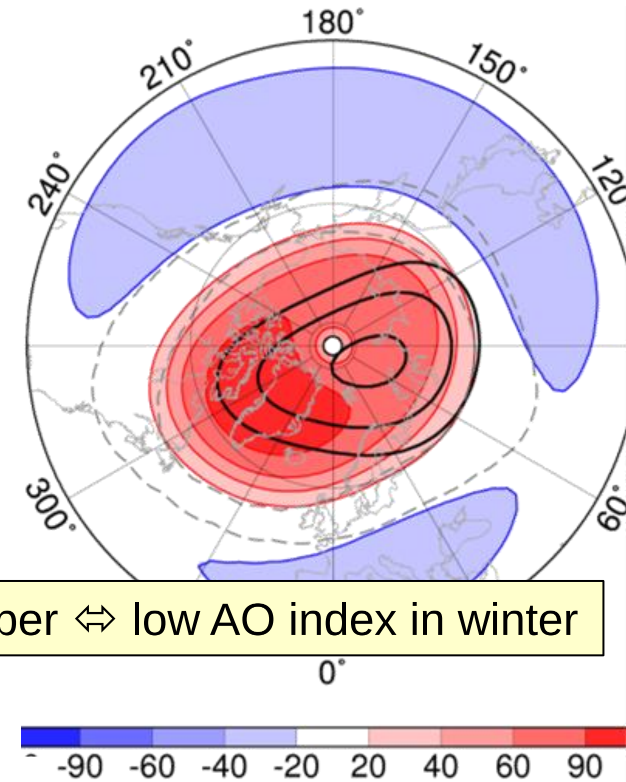


Atmospheric pressure anomalies in following winter:

Surface



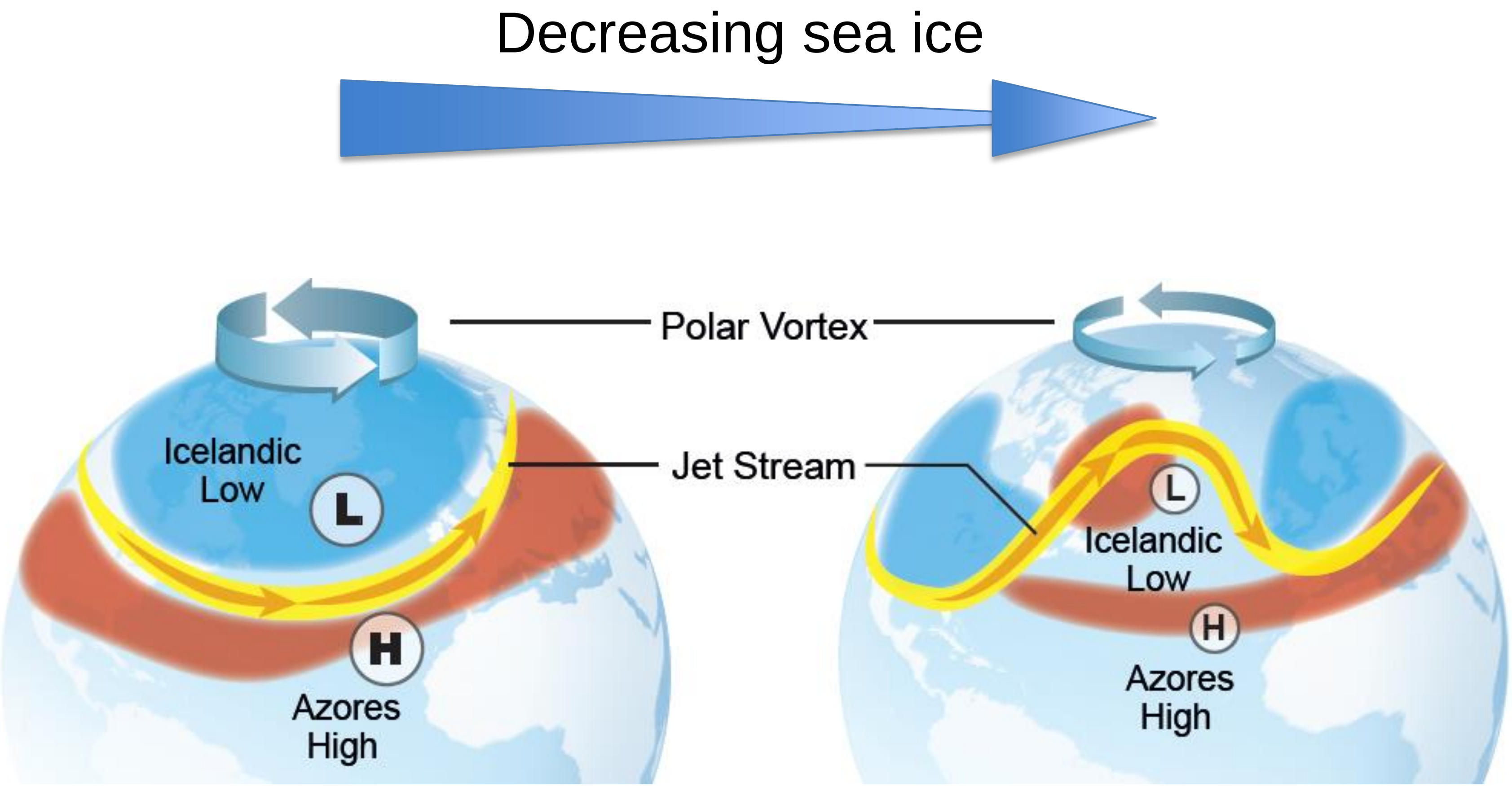
Lower stratosphere



Negative ice anomaly September ⇔ low AO index in winter

Jaiser et al. 2013, 2016 , Handorf et al. 2015

Effect of decreasing sea ice on northern hemispheric weather patterns



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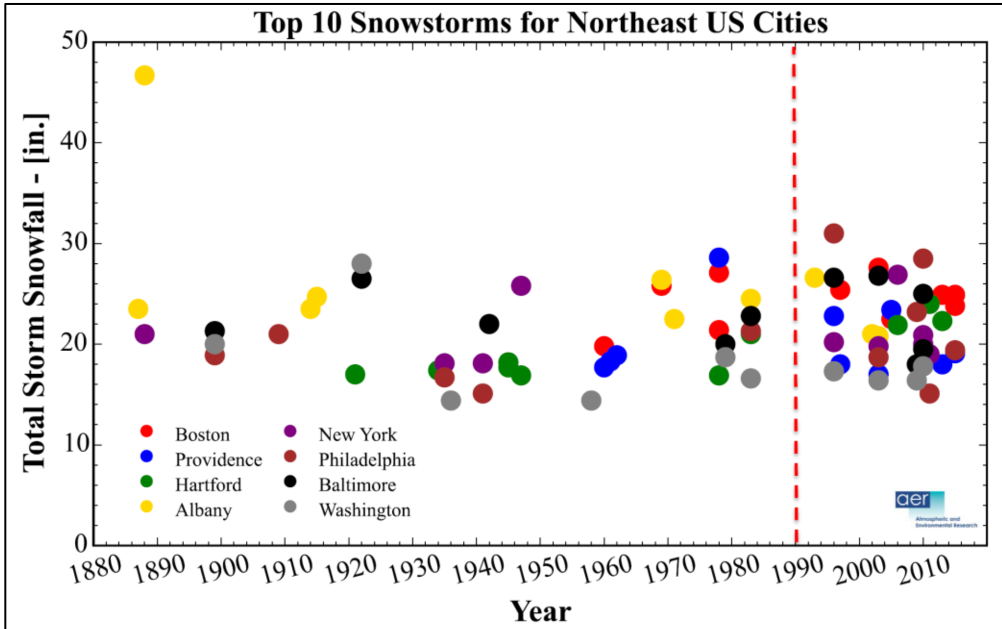
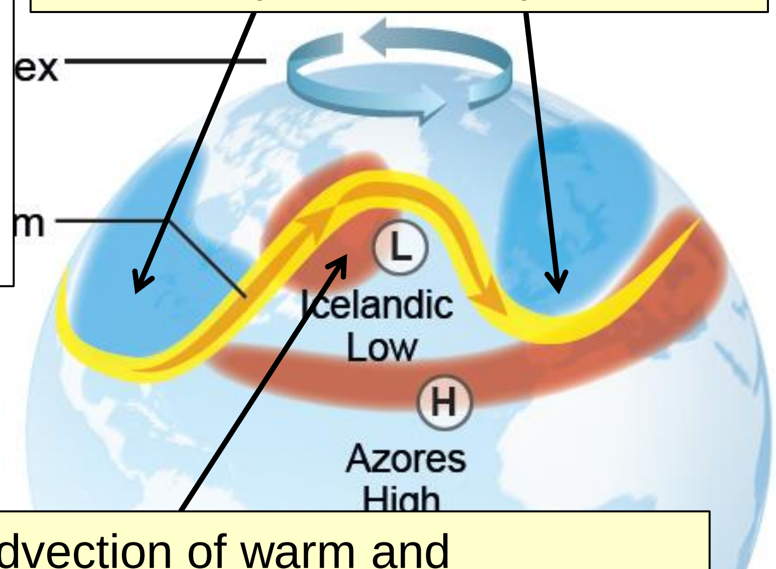


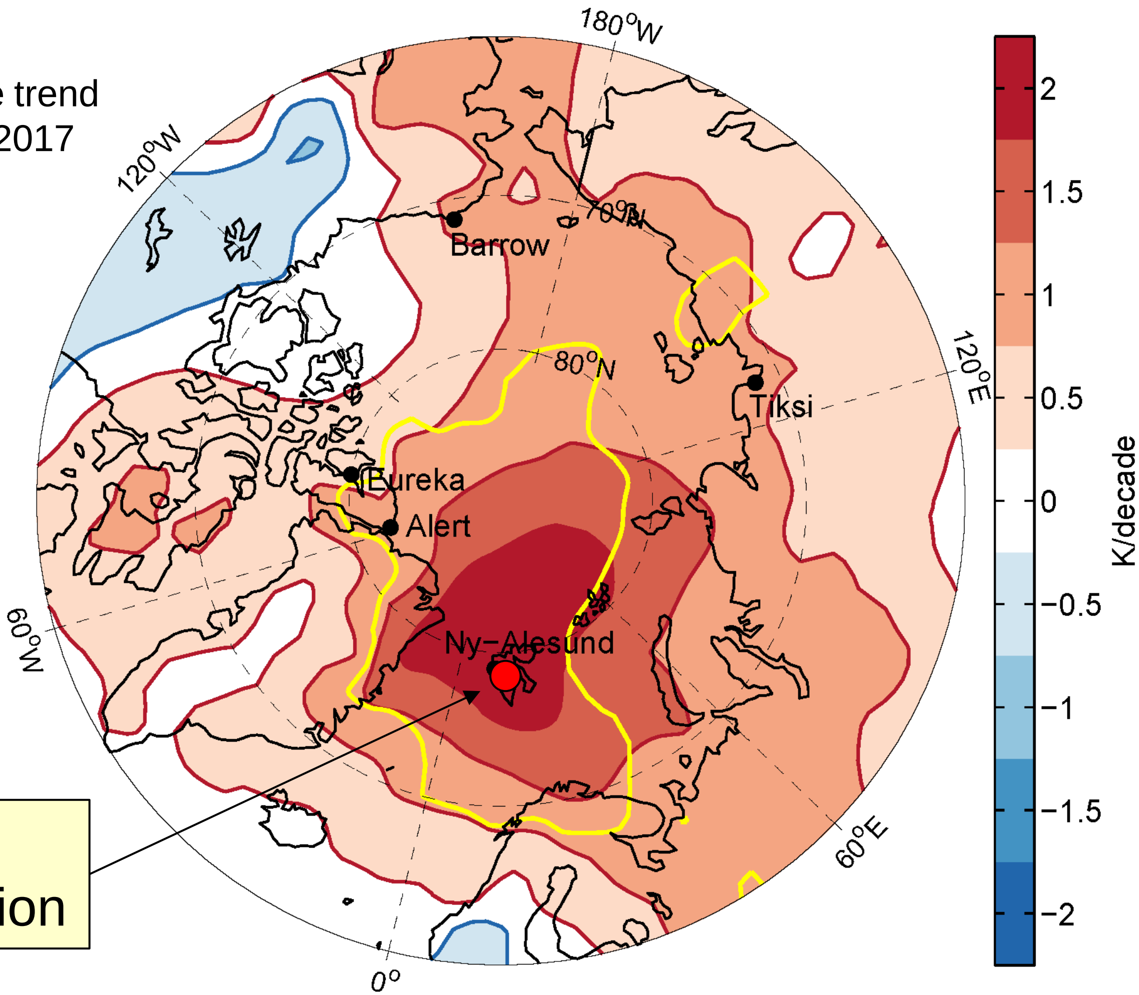


Potential for cold air outbreaks
➔ Cold spells in Europe and US

Advection of warm and
humid air into the Atlantic sector of the Arctic

Winter warming is most severe in the Atlantic sector of the Arctic

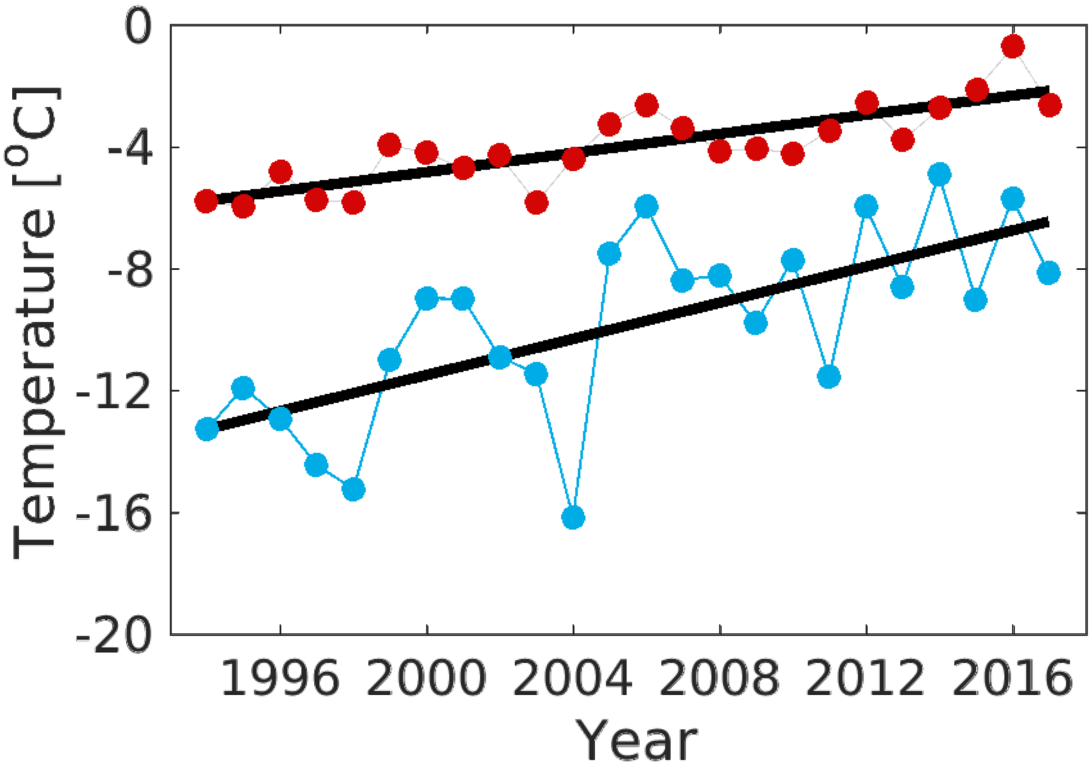
850 hPa temperature trend
ERA-interim, 1996 - 2017



AWIPEV
research station

M. Maturilli et al.

Climate Change at AWIPEV
- In the Atlantic sector of the Arctic -

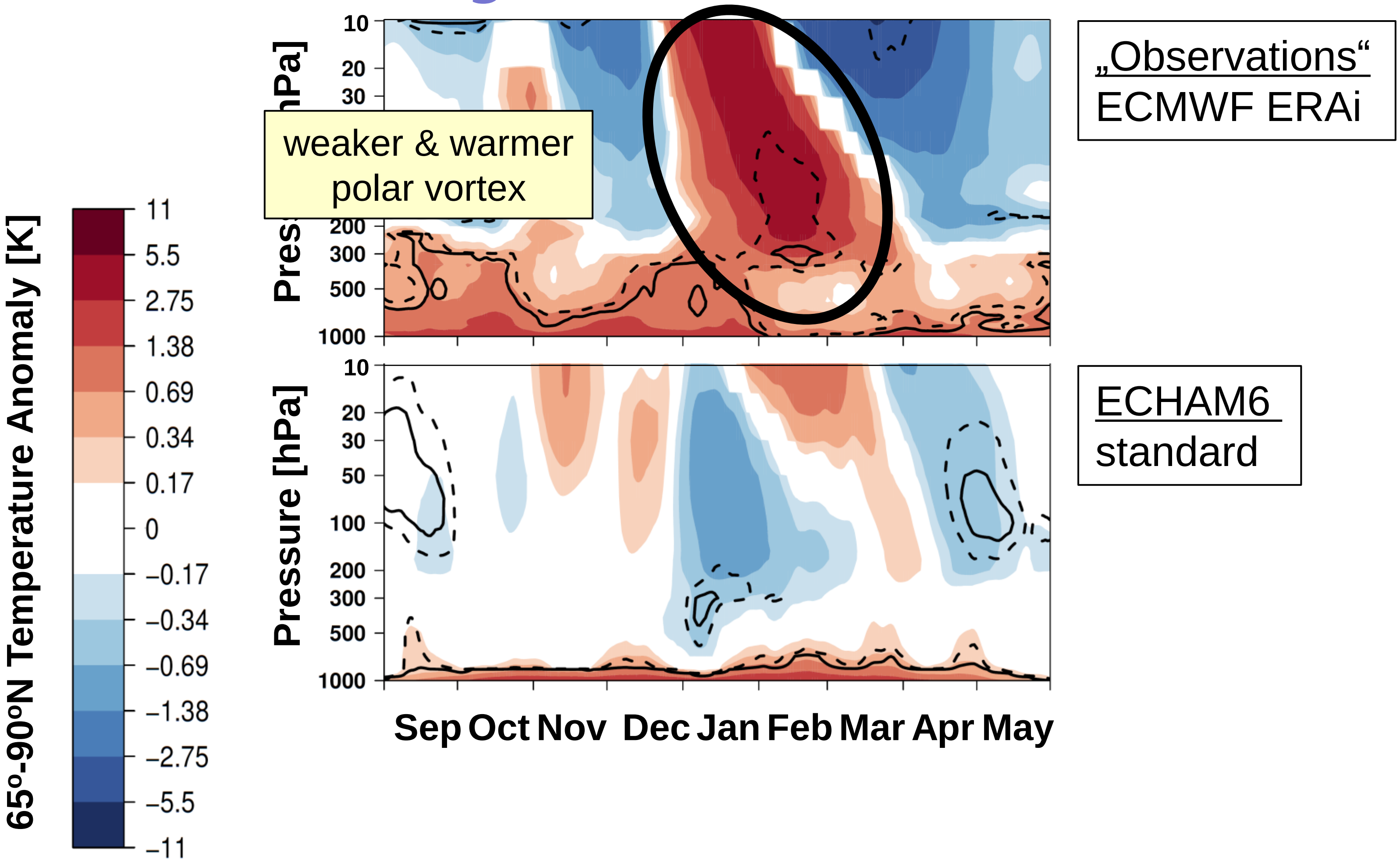


Annual mean trend:
+1.5±0.7°C
per decade

Winter trend:
+3.0±2.0°C
per decade

M. Maturilli et al.

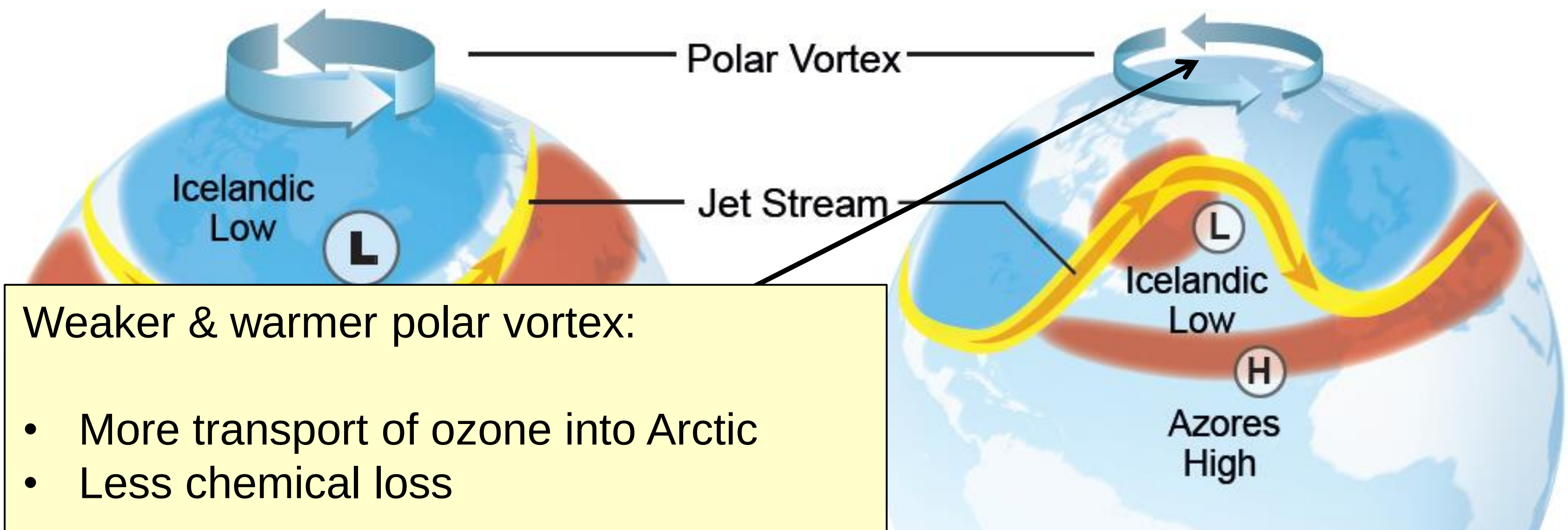
Low ice versus high ice conditions in Climate Model



Romanowsky et al., 2017

Effect of decreasing sea ice on northern hemispheric weather patterns

Decreasing sea ice

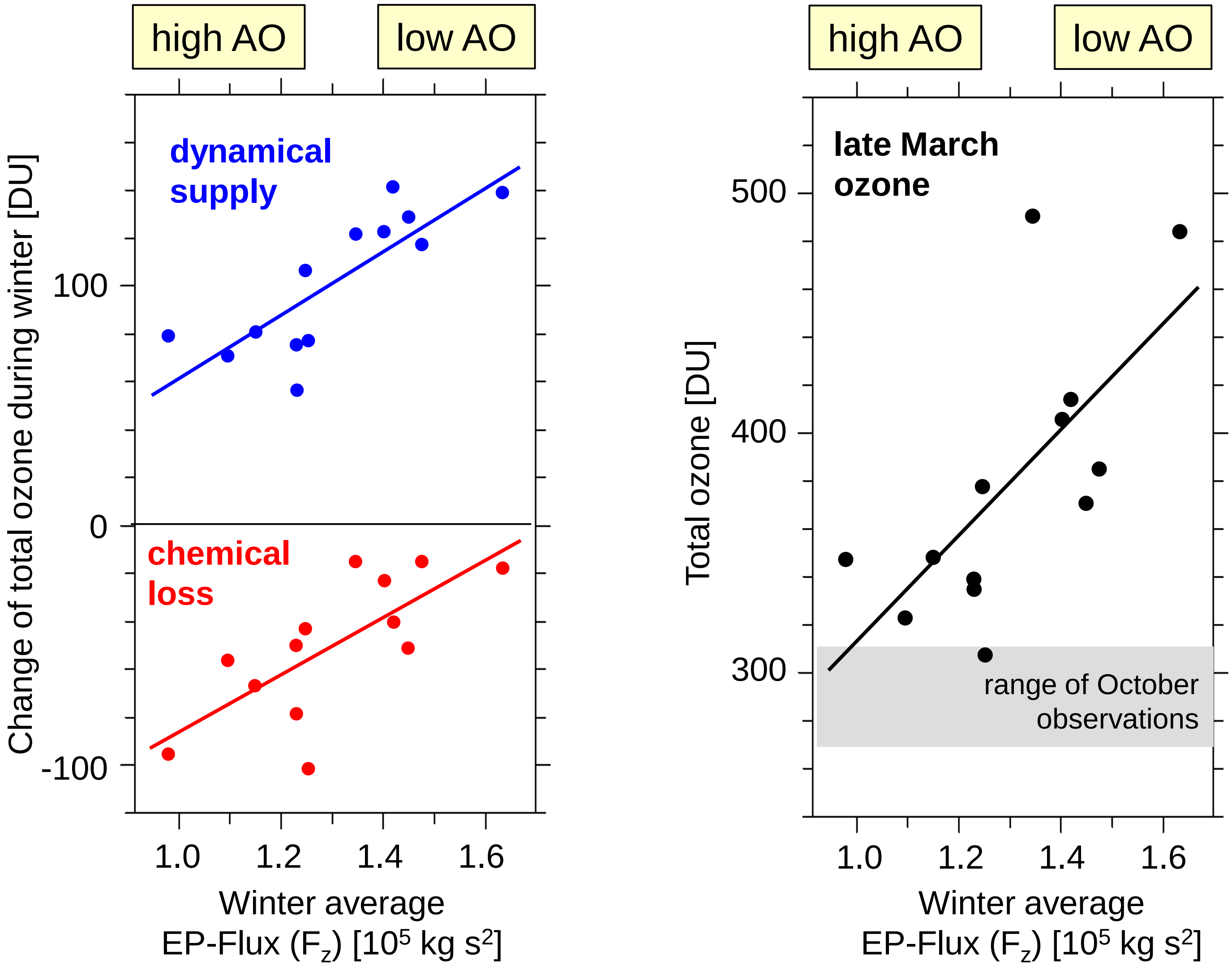


Weaker & warmer polar vortex:

- More transport of ozone into Arctic
- Less chemical loss

→ Radiative feedback further weakens AO

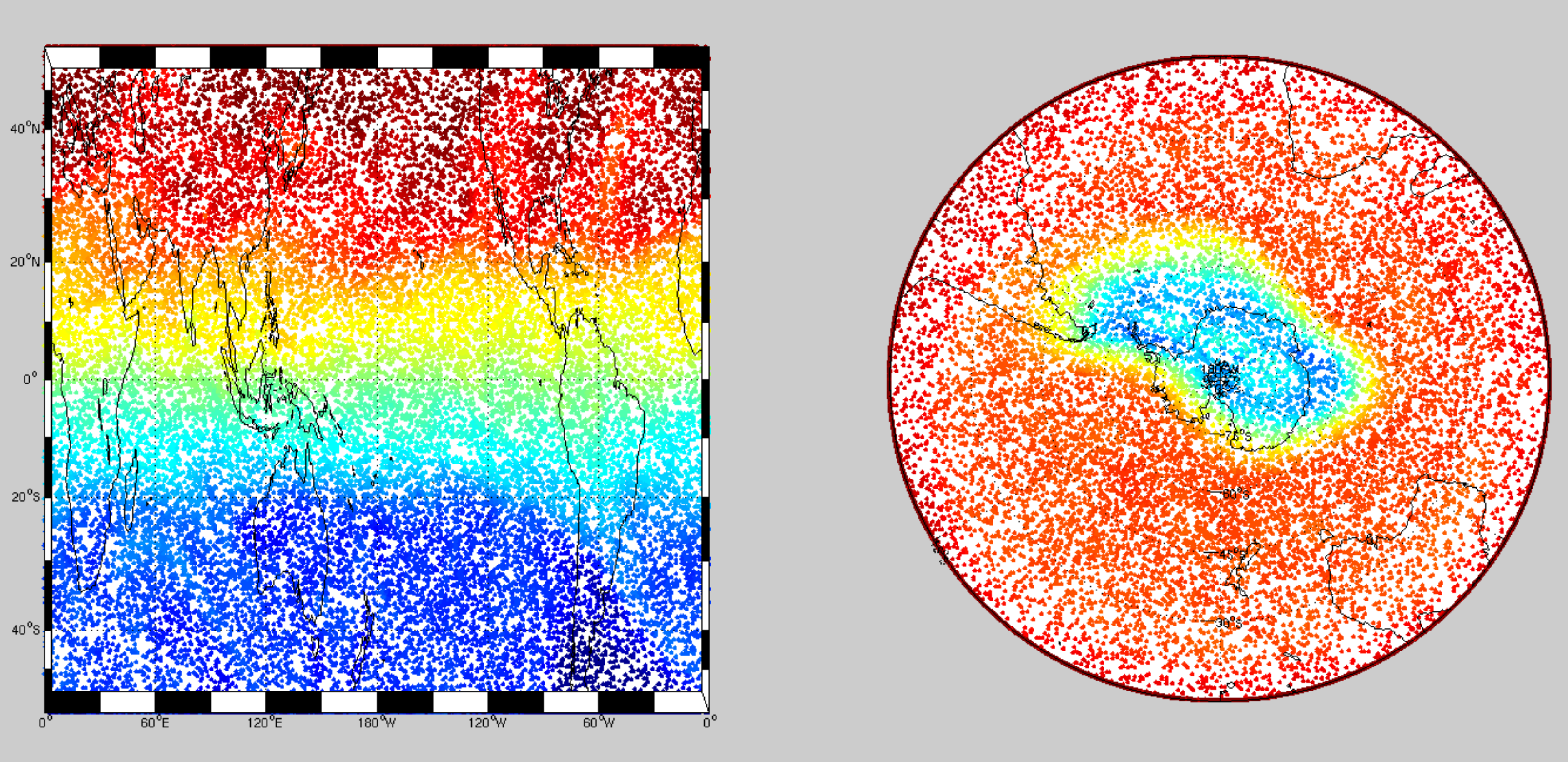
Chemical and dynamical contribution to the variability of the late winter Arctic ozone column



Tegtmeier et al., 2008

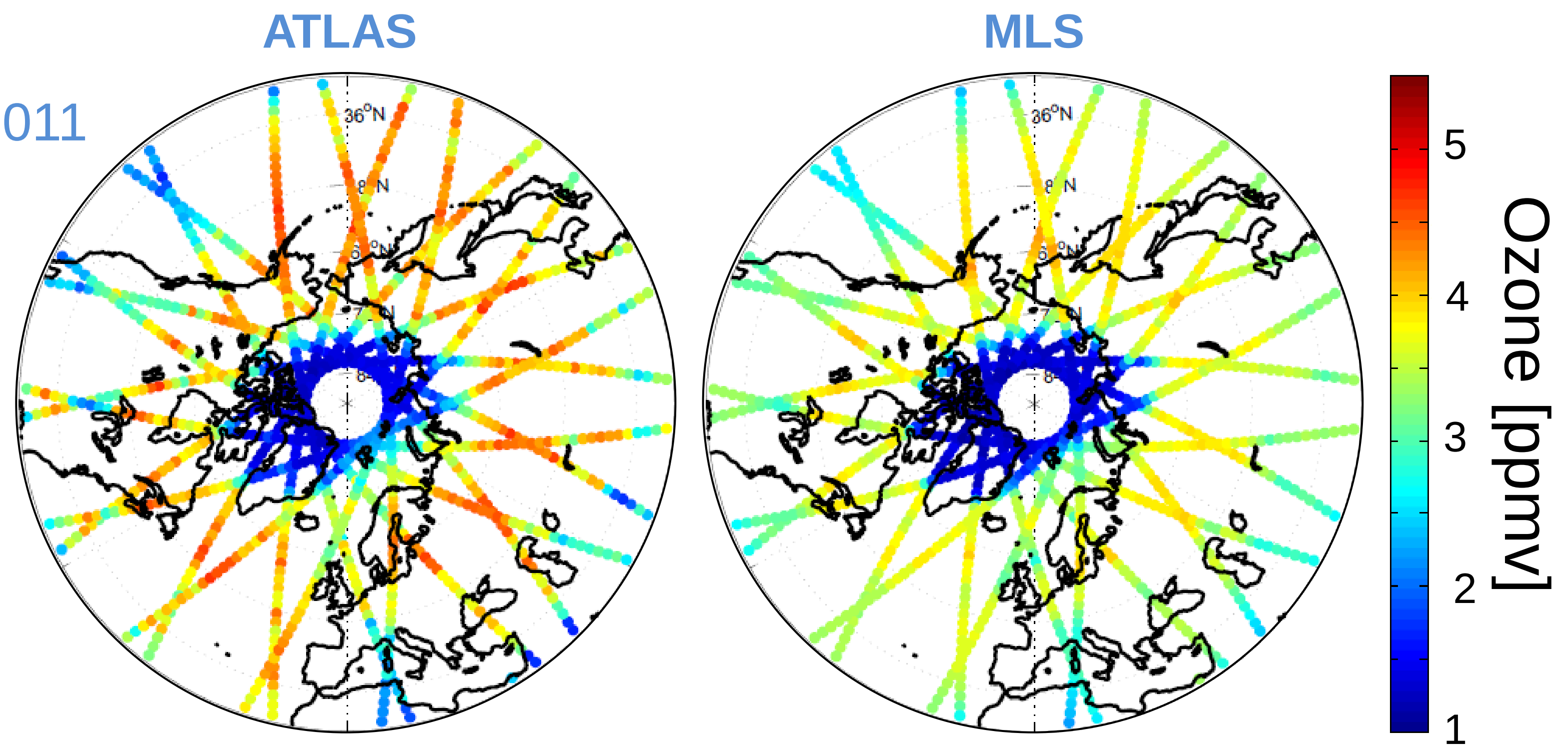
ATLAS: Lagrangian Chemical Transport Model

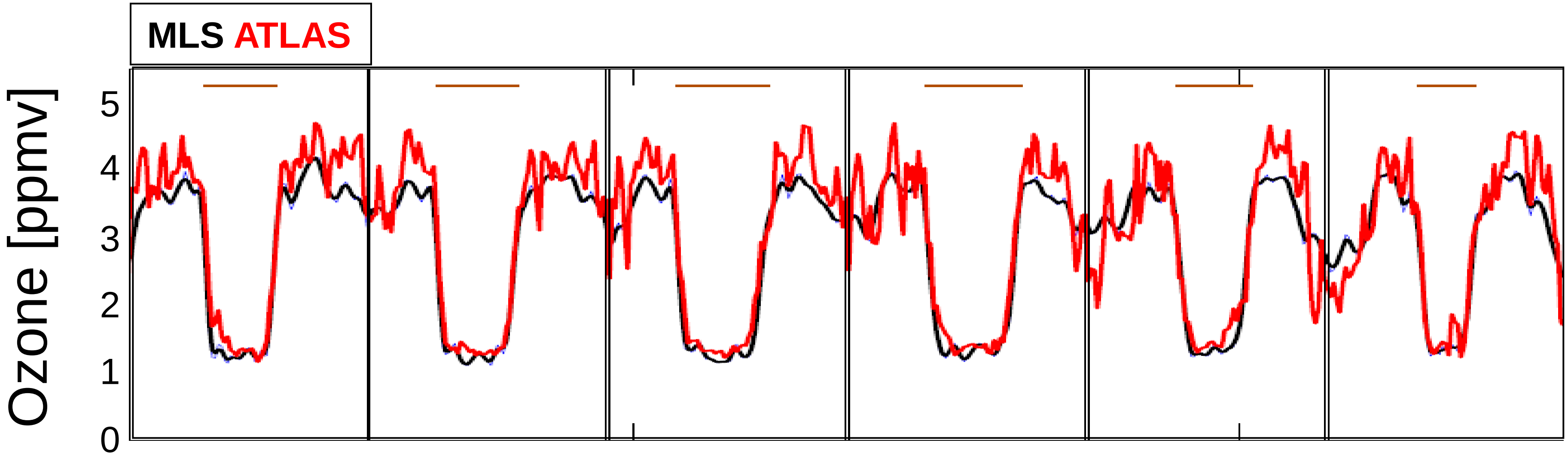
~20km altitude, 20 model days, dynamical tracer (PV), ~50km resolution run driven by ERA interim wind/temperature



- detailed homogeneous and heterogeneous **chemistry**
- Lagrangian particle sedimentation scheme for **aerosols**
- no numerical diffusion, sophisticated 3d **diffusion** scheme
- Tropospheric aerosol & **cloud microphysics** scheme
- Parametrization for **convection**

Ozone
16 March 2011
46 hPa





Computational effort to calculate ozone changes

ATLAS solves a set of 49 coupled differential equations based on 55 initial and boundary conditions.

ΔO_3 calculated at each time step and each model point: For a 100-year model run the system needs to be solved ~2.5 trillion (10^{12}) times.

Computational effort is 4 years for one 100 year run
→ much too large to be included in climate models.

But: Virtually all of these calculations are redundant!

From ATLAS to SWIFT

Extra-polar approach (polar approach different)

Values of ΔO_3 form a hypersurface in the 55 dimensional parameter space.

Development of SWIFT:

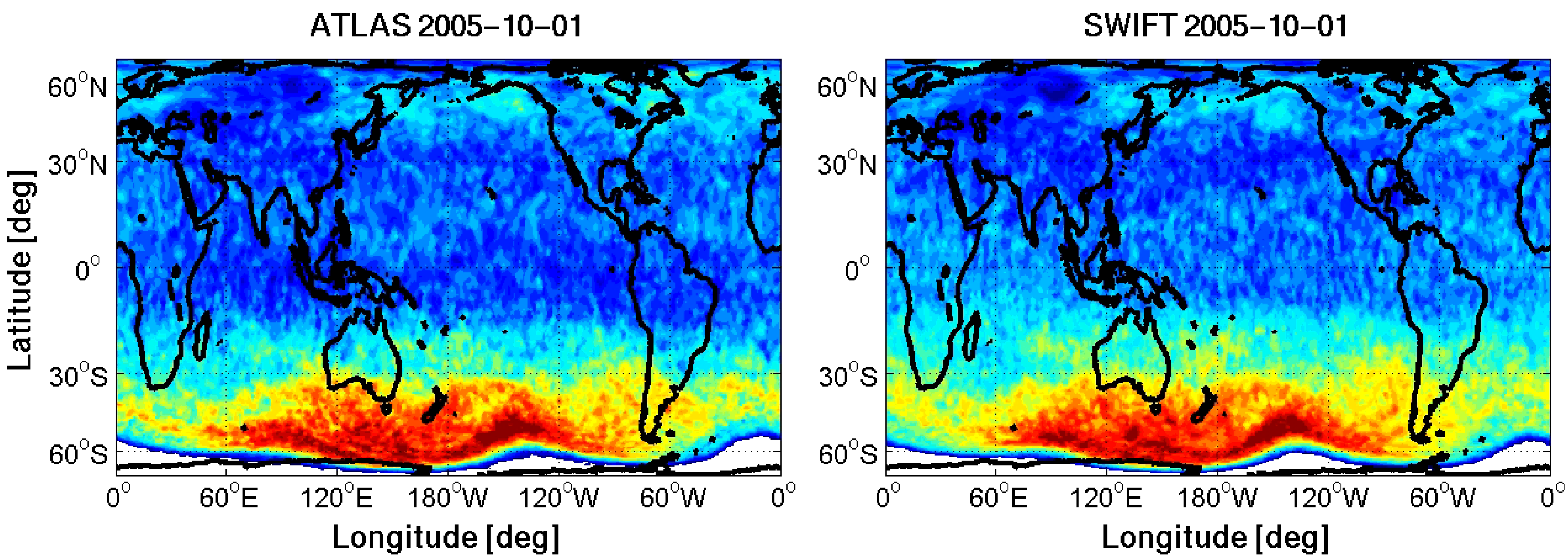
1. Linear combinations of parameters to reduce the number of dimensions such that ΔO_3 still forms a compact hypersurface in the reduced space.
2. Shape of hypersurface is characterized by full runs of ATLAS.
3. An automatic procedure constructs a closed polynomial expression (~150 terms, 4^{th} order) that approximates its shape.
4. SWIFT solves this expression to give results very similar to those of ATLAS → much faster!

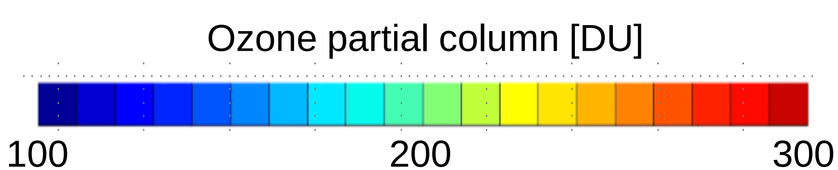
SWIFT: Fast interactive Ozone for Climate Models

Numerical effort for ozone calculations

ATLAS
~2 weeks per year
on 48 cores

SWIFT
~ 2 hours per year
on one core

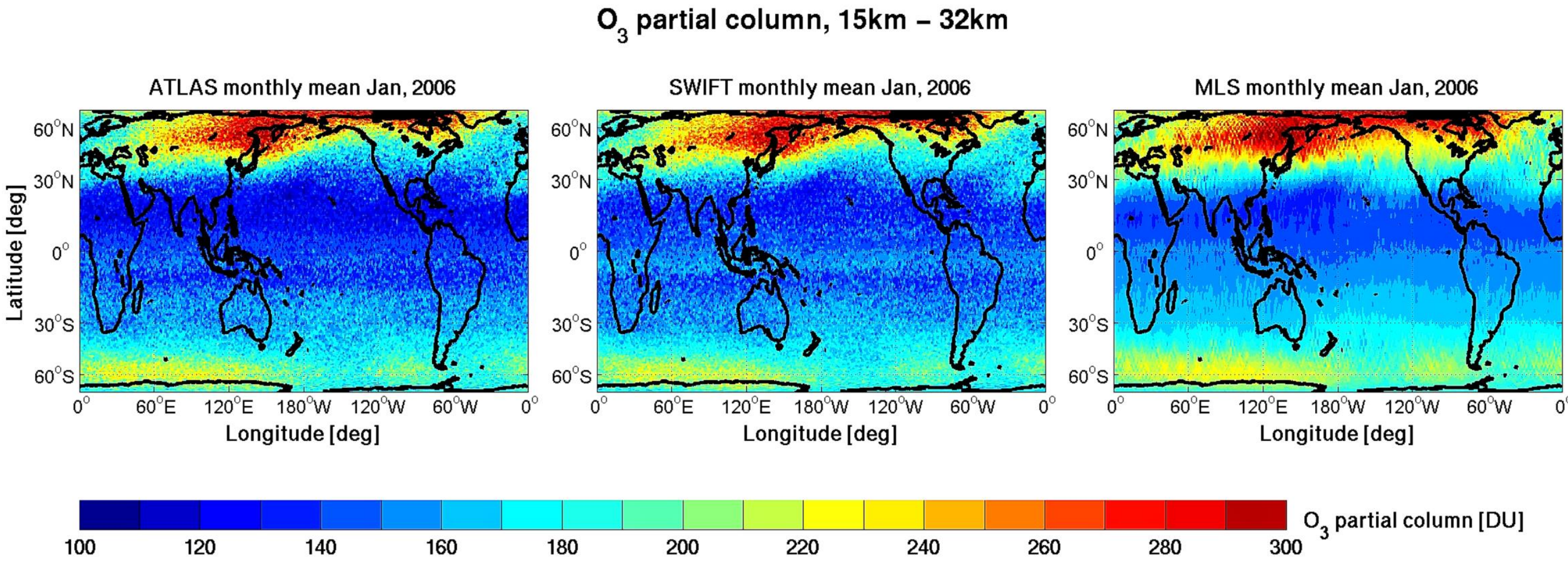




Kreyling et al, PhD, 2017

ATLAS & SWIFT

Comparison with MLS observations



Kreyling et al, PhD, 2017

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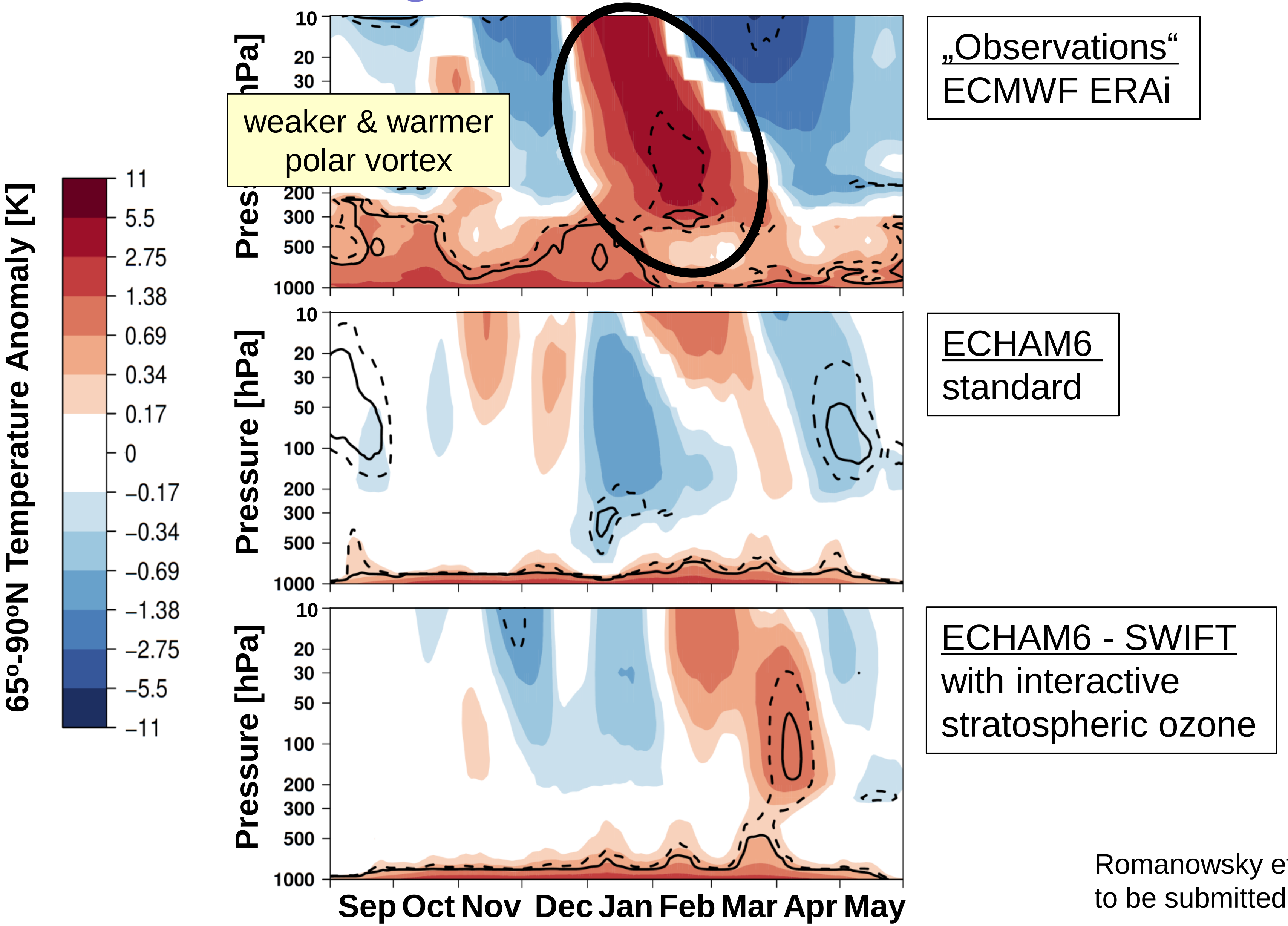

Romanowsky et al., to be submitted

Two Main Messages

1. Arctic sea ice decrease affects atmospheric circulation and increases transport of warm, humid air into the central Arctic:
   → positive feedback contributes to Arctic Amplification of global warming.

2. Interactions with the stratospheric ozone layer play a role in this feedback and need to be taken into account when modelling it.