What are the different pathways/physical mechanisms that should be targeted for modeling studies?

Gudrun Magnusdottir and Yannick Peings

Department of Earth System Science
University of California Irvine

Outline

- Potential Mechanisms associated with Arctic Amplification (AA)

- Open questions associated with the mechanisms

- Potential modeling studies to tackle these questions

Thanks to D. Handorf, M. Hell, H-J. Kim, M. Ogi and W. Tian for their input !

Potential mechanisms associated with AA

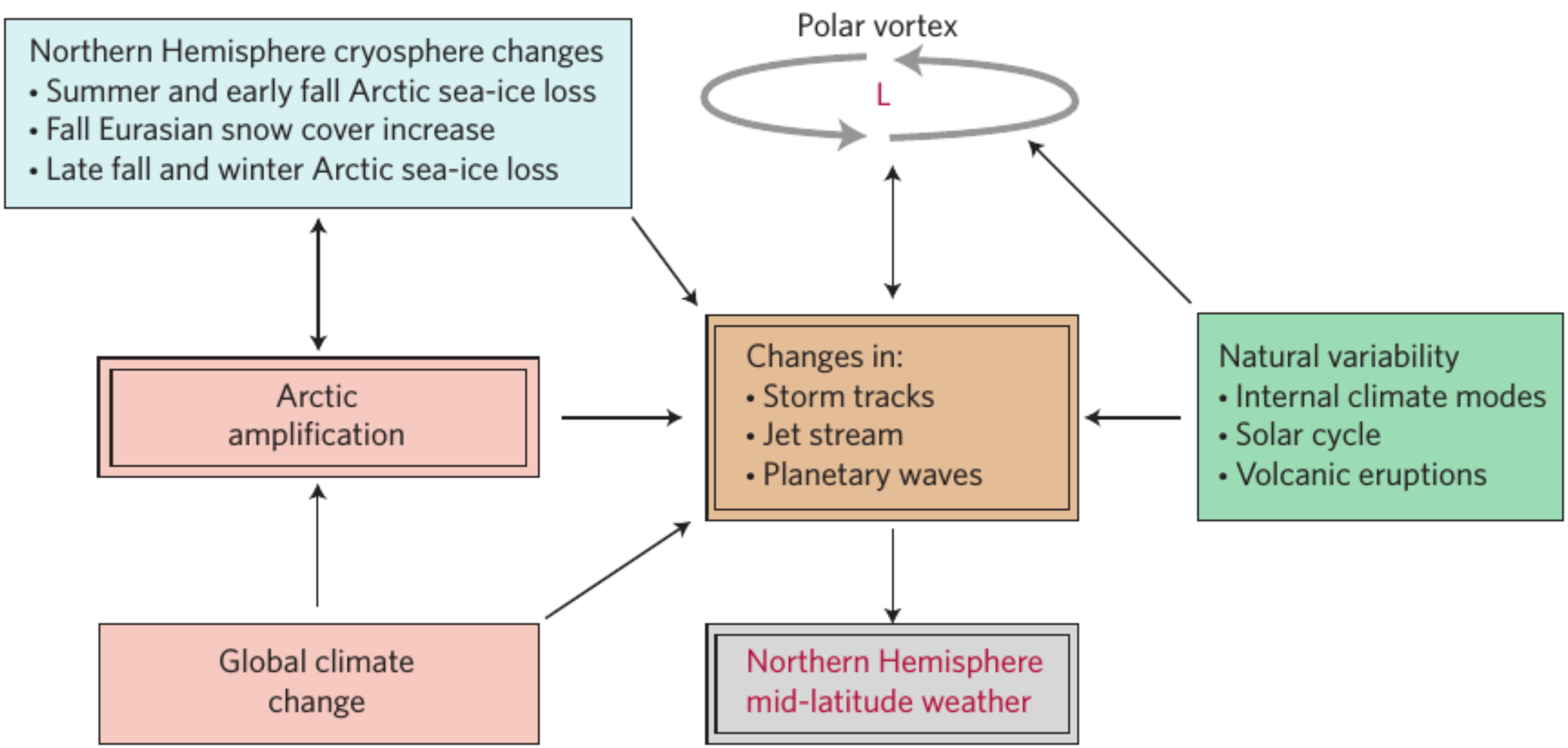
1. AA has been suggested as a driver of recent cooling trend in mid-latitudes, as well as responsible for increased jet stream meandering, blockings and associated extreme events (e.g., Cohen et al. 2014, Francis and Vavrus 2012, 2015). However, in observations, attribution of the recent trends to AA is debated and hampered by large internal variability (e.g., Barnes 2013, Screen and Simmonds 2013, Barnes and Screen 2015, Overland et al. 2015).

2. Arctic sea ice anomalies can perturb the stratospheric polar vortex through changes in upward planetary wave propagation and eddy-mean flow interactions (e.g., Kim et al. 2014, Peings and Magnusdottir 2014, Jaiser et al. 2016, Sun et al. 2015, King et al. 2016, Nakamura et al. 2016).

3. A "warm Arctic–cold continent pattern" forced via stationary Rossby waves has been identified in observations and models (e.g., Honda et al. 2009, Mori et al. 2014, Kug et al. 2015).

4. "Tug of war" between the NH zonal mean climate response to greenhouse gases and Arctic sea ice loss as projected at the end of the 21st century. The direct dynamical effect of pan-Arctic sea ice loss is a negative circulation feedback that weakens the impact of the extratropical circulation response to greenhouse warming by pushing the jet equatorward and dynamically warming the polar stratosphere (Deser et al. 2015, Tomas et al. 2016, Blackport and Kushner 2017)

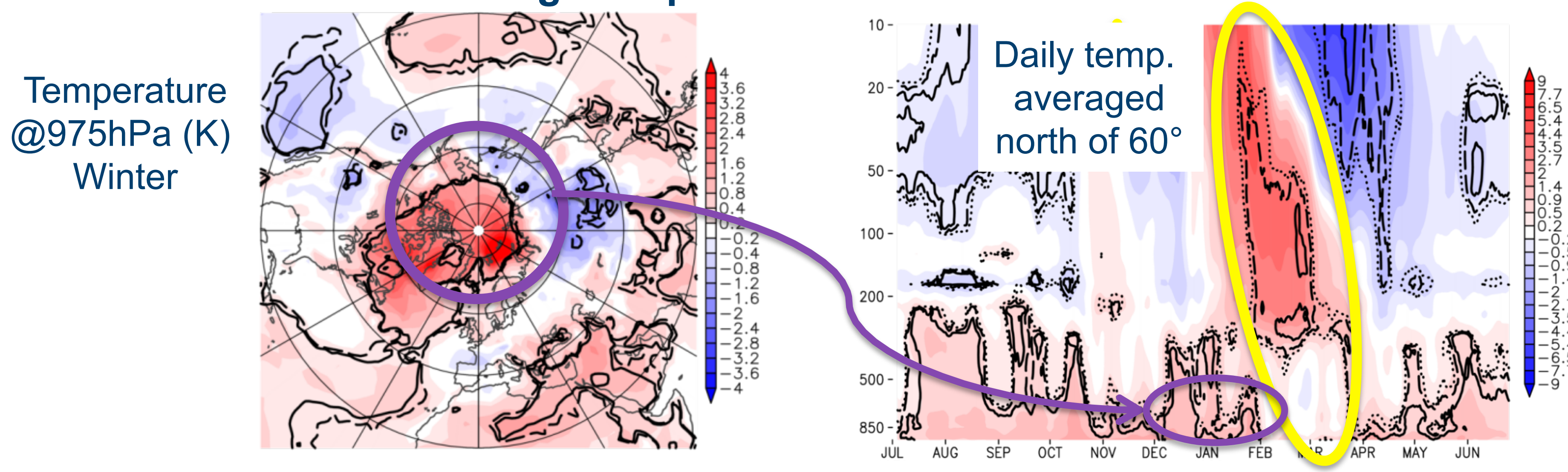
1. AA has been suggested as a driver of recent cooling trend in mid-latitudes, as well as responsible for increased jet stream meandering, blockings and associated extreme events (e.g., Cohen et al. 2014, Francis and Vavrus 2012, 2015). However, in observations, attribution of the recent trends to AA is debated and hampered by large internal variability (Barnes 2013, Screen and Simmonds 2013, Barnes and Screen 2015, Overland et al. 2015).



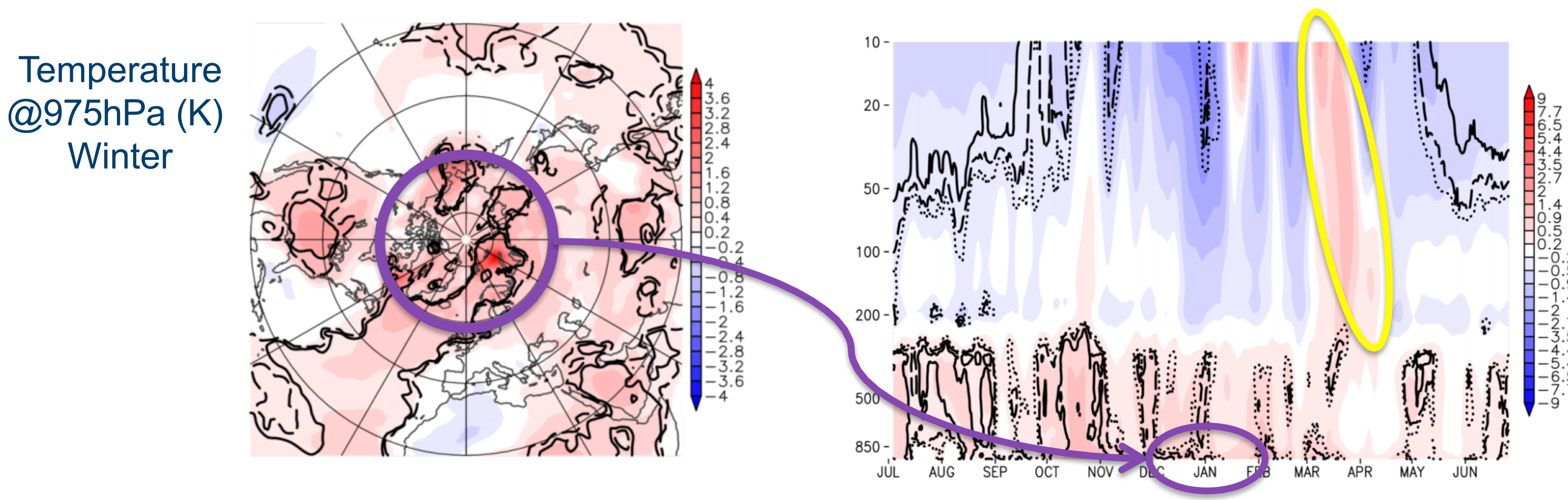
Cohen et al. (2014)

2. Arctic sea ice anomalies can perturb the stratospheric polar vortex through changes in upward planetary wave propagation and eddy-mean flow interactions (Kim et al. 2014, Peings and Magnusdottir 2014, Jaiser et al. 2016, Sun et al. 2015, King et al. 2016, Nakamura et al. 2016).

ERA-Interim low ice minus high ice period



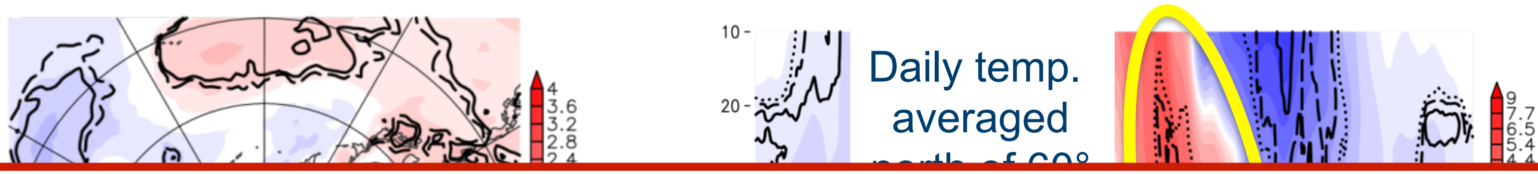
ECHAM6 low ice minus high ice period



Courtesy of Doerthe Handorf

2. Arctic sea ice anomalies can perturb the polar vortex through changes in upward planetary waves propagation and eddy-mean flow interactions (Kim et al. 2014, Peings and Magnusdottir 2014, Jaiser et al. 2016, Sun et al. 2015, King et al. 2016, Nakamura et al. 2016).

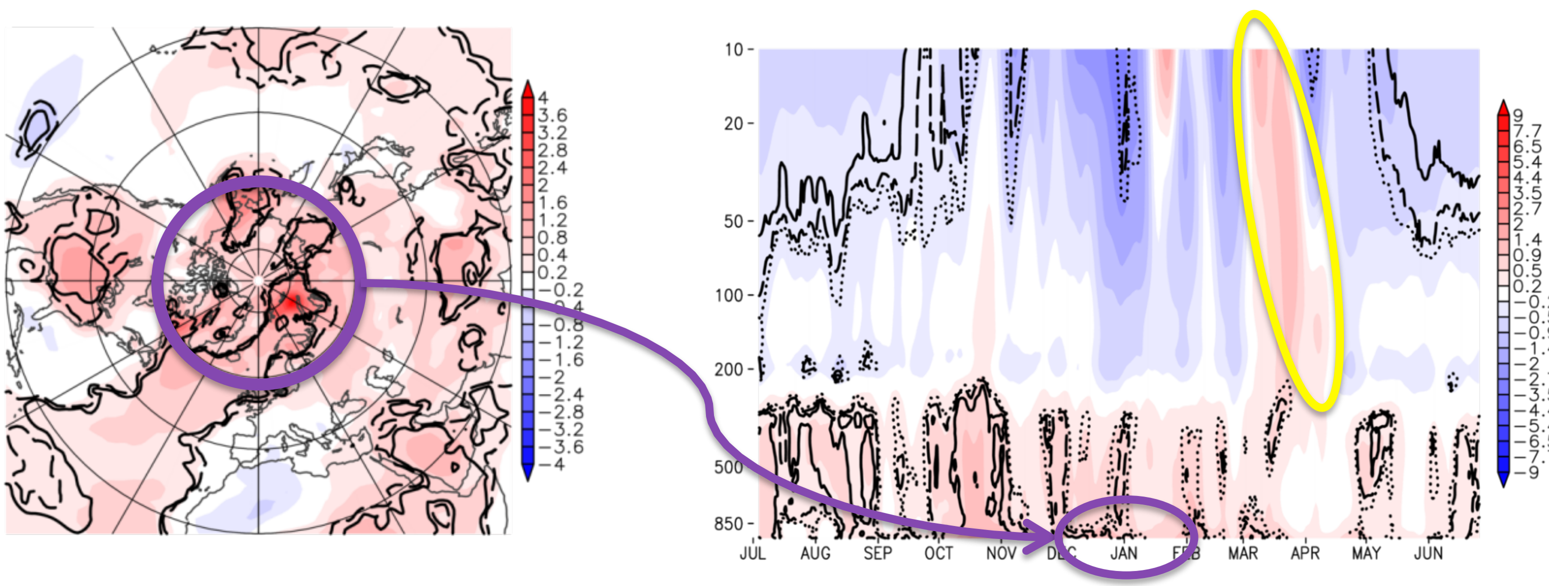
Temperature



- No WACS pattern
- Polar cap tropospheric warming in model not as strong as in observations
- Cooling of stratosphere is well represented in summer autumn and spring
- No significant warming of polar stratosphere in late winter
  → weak (and too late) stratospheric response in ECHAM6
  → Deficits in representation of planetary wave forcing or propagation in ECHAM6?

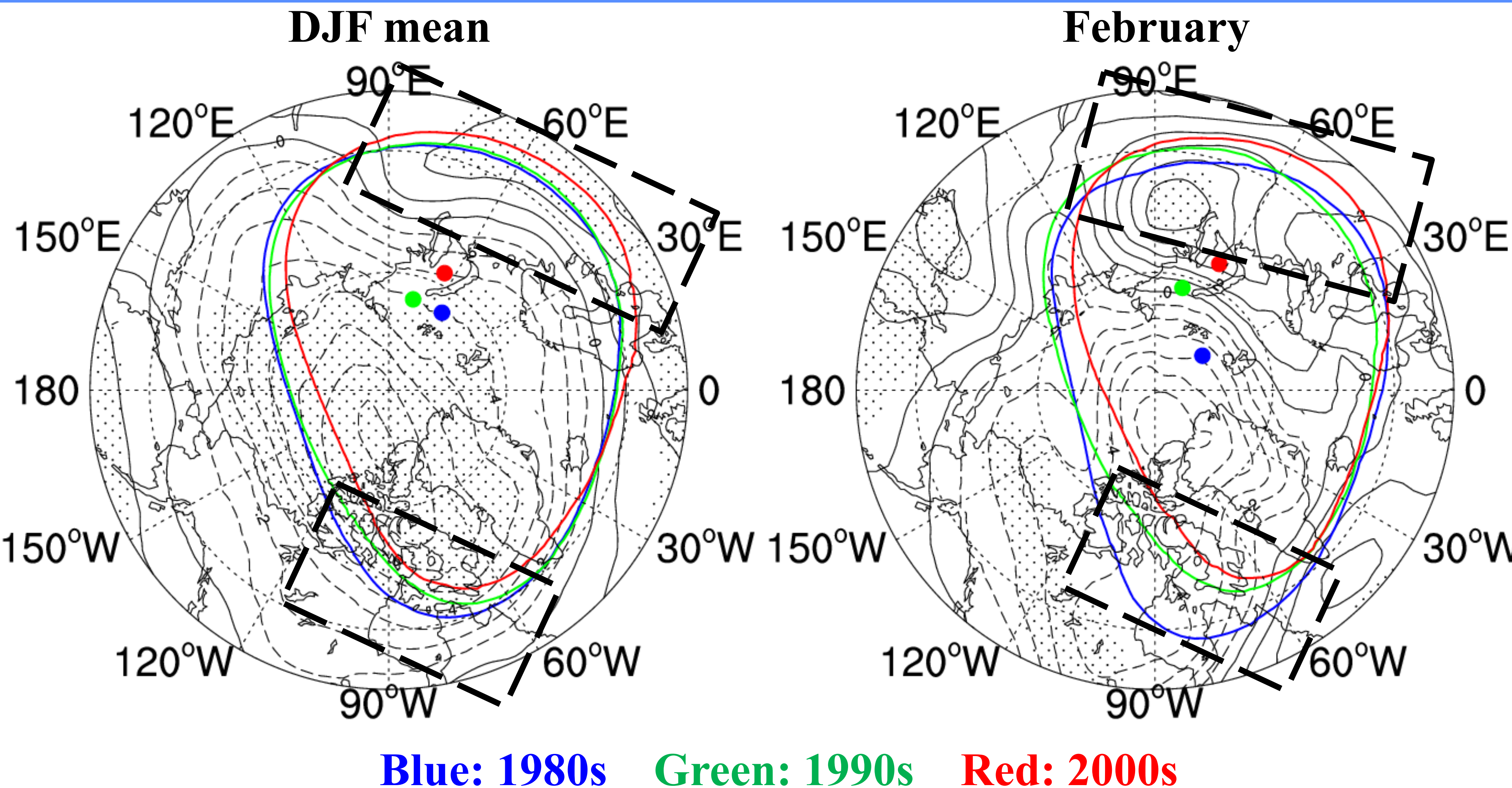
ECHAM6 low ice minus high ice period → No WACS pattern

Temperature
@975hPa (K)
Winter



Courtesy of Doerthe Handorf

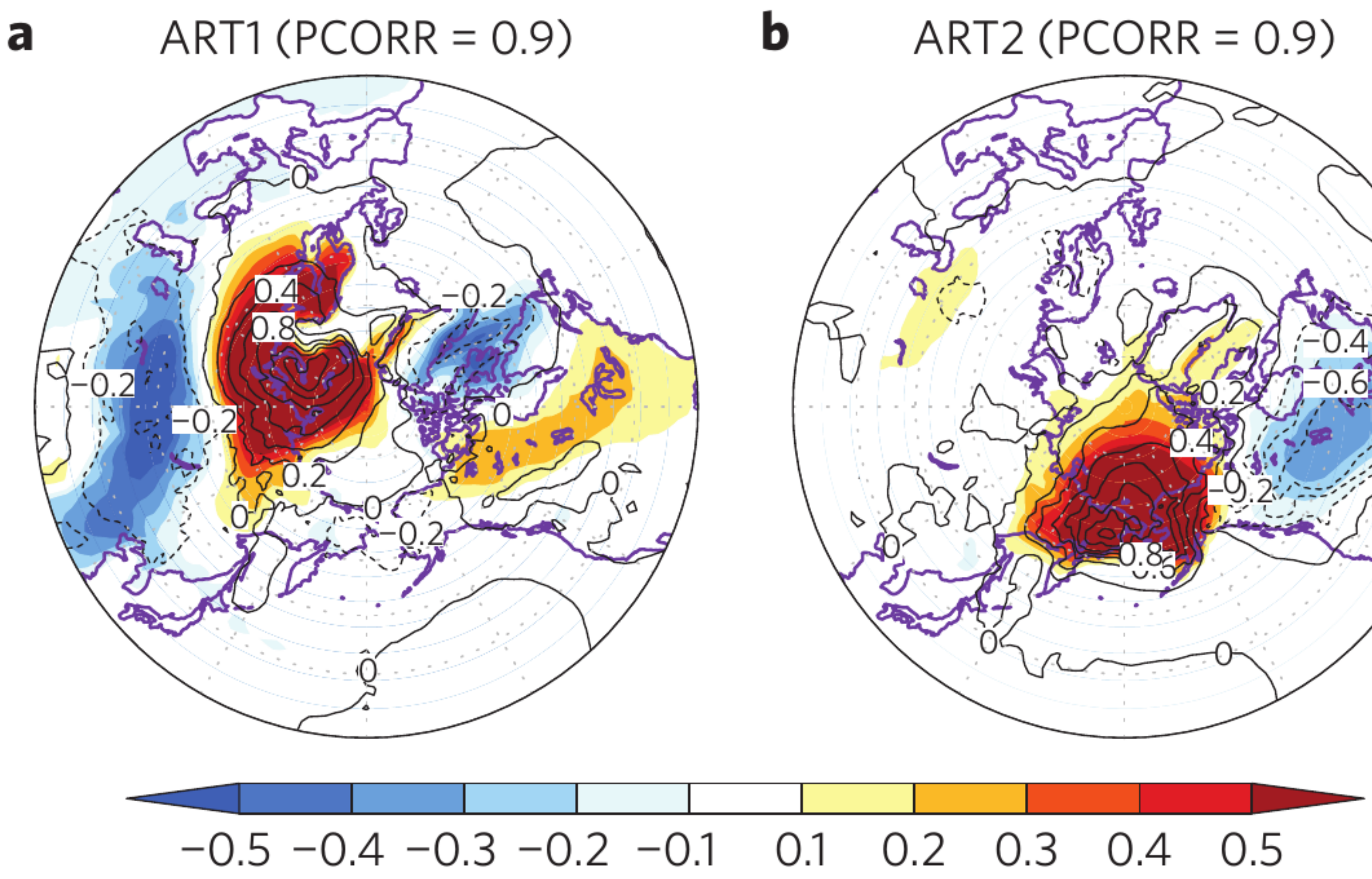
Location of Vortex in winter



The Arctic stratospheric polar vortex shifted persistently towards the Siberian continent in late winter (February) over the period 1980-2009. (Zhang, Tian, et al, Nature Climate Change, 2016)

Courtesy of Wenshou Tian

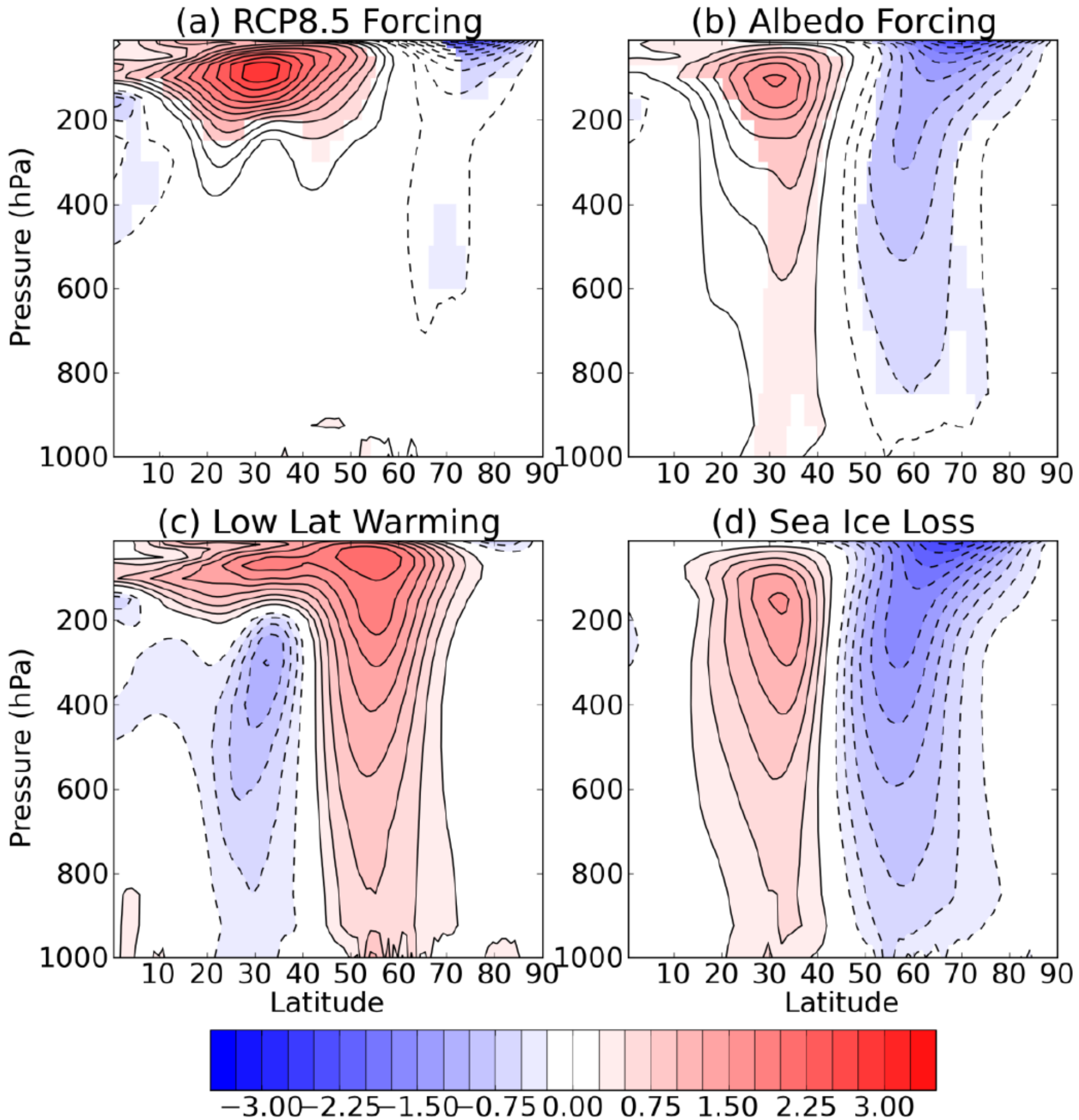
3. A “warm Arctic–cold continent pattern” forced via stationary Rossby waves has been identified in observations and models (Honda et al. 2009, Mori et al. 2014, Kug et al. 2015).



Kug et al. 2015

4. <u>"Tug of war" between the NH zonal mean climate response to greenhouse gases and Arctic sea ice loss as projected at the end of the 21st century</u>.

The direct dynamical effect of pan-Arctic sea ice loss is a negative circulation feedback that weakens the impact of the extratropical circulation response to greenhouse warming by pushing the jet equatorward and dynamically warming the polar stratosphere (Deser et al. 2015, Tomas et al. 2016, Blackport and Kushner 2017)



Zonal mean U

Blackport and Kushner (2017)

Open questions associated with the mechanisms

1. What causes non-linearities in the response associated with polarity, amplitude and pattern of sea ice anomalies ? (Pethoukov and Semenov 2010, Peings and Magnusdottir 2014, Semenov and Latif 2015)

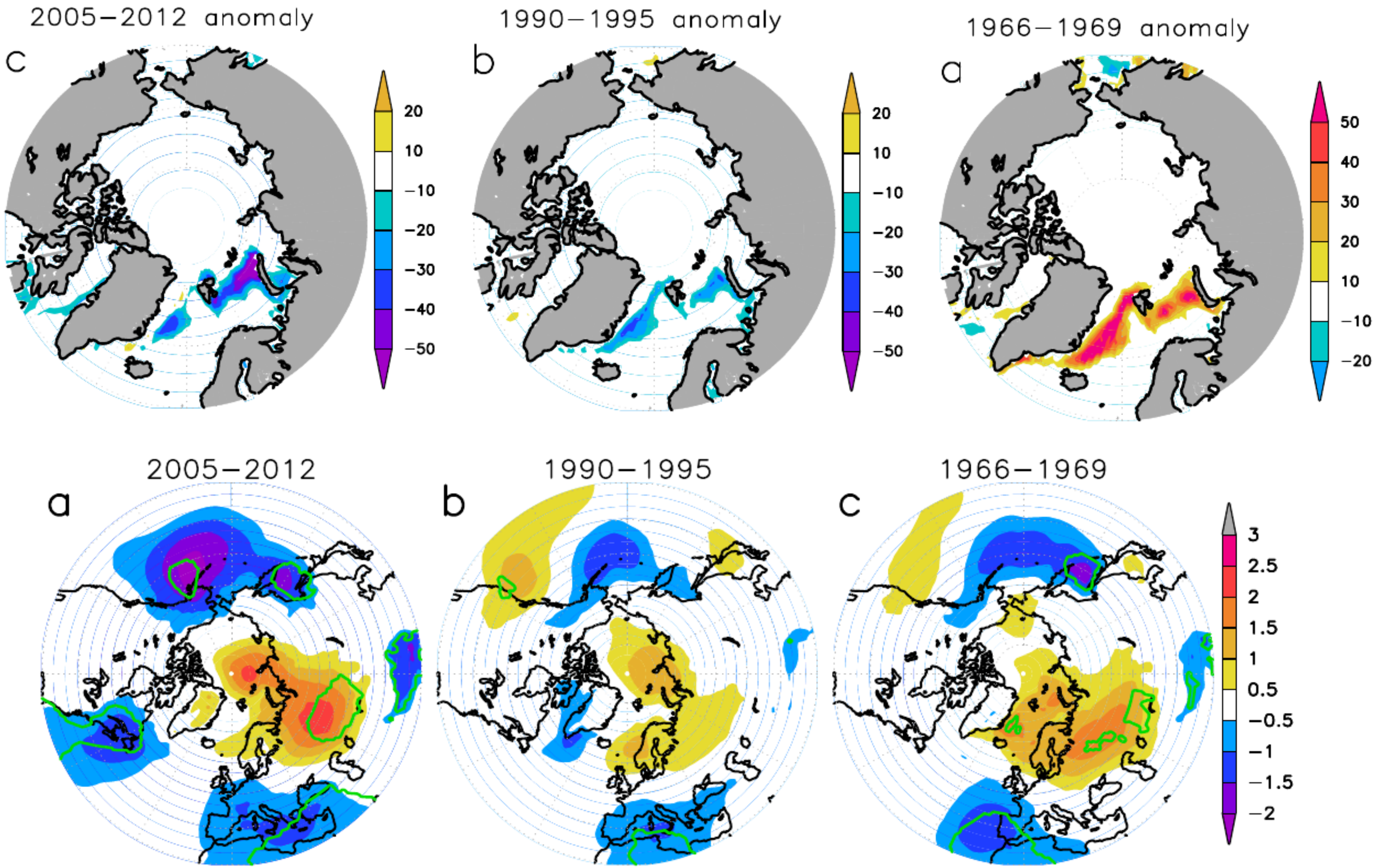
2. What portion of AA is driven by sea ice decline and what is its role in recent trends of extreme weather events ? (Screen 2014, Screen et al. 2014, Perlwitz et al. 2015)

3. Future evolution of the mid-latitude dynamics including jet streams/blocking/extreme weather events ? (Ayarzagüena and Screen 2016, Francis et al. 2012, Hassanzadeh and Kuang 2015, Harvey et al. 2014, Screen 2014, Barnes and Polvani 2015, Cattiaux et al. 2016, Peings et al. 2017, Vavrus et al. 2017)

4. Importance of stationary waves in the upward propagation mechanism? Causes for constructive vs destructive interference with the background climatological flow that lead to different stratospheric response? (Smith et al. 2011, Peings and Magnusdottir 2014, Sun et al. 2015)

5. Causal relationship between BK sea ice and the Warm Arctic Cold Siberia (WACS) pattern? (Sato et al. 2014, Mc Cusker et al. 2016, Sorokina et al. 2016)

1. What causes non-linearities in the response associated with polarity, amplitude and pattern of sea ice anomalies ? (Pethoukov et al. 2010, Peings and Magnusdottir 2014, Semenov and Latif 2015)

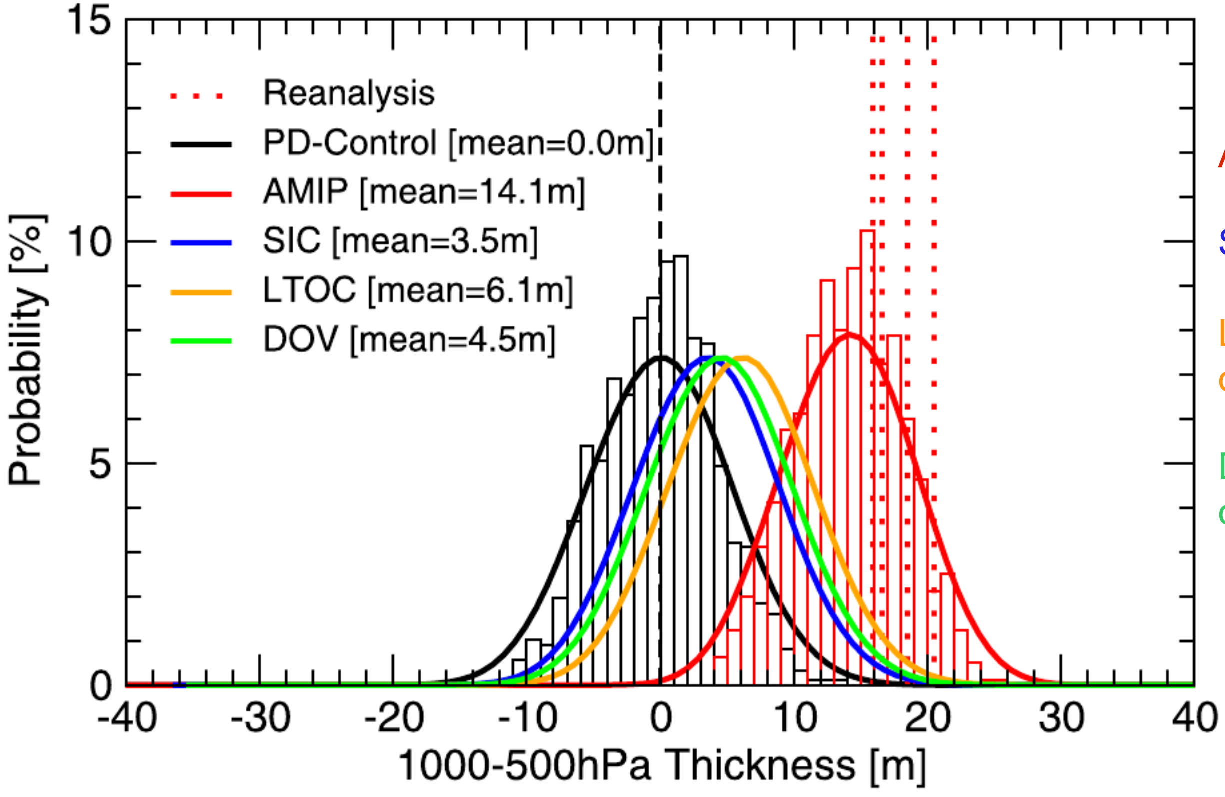


SIC anomalies

SLP response

Semenov and Latif (2015)

2. What portion of AA is driven by sea ice decline and what is its role in recent trends of extreme weather events ? (Screen 2014, Screen et al. 2014, Perlwitz et al. 2015)



AMIP : SST + sea ice

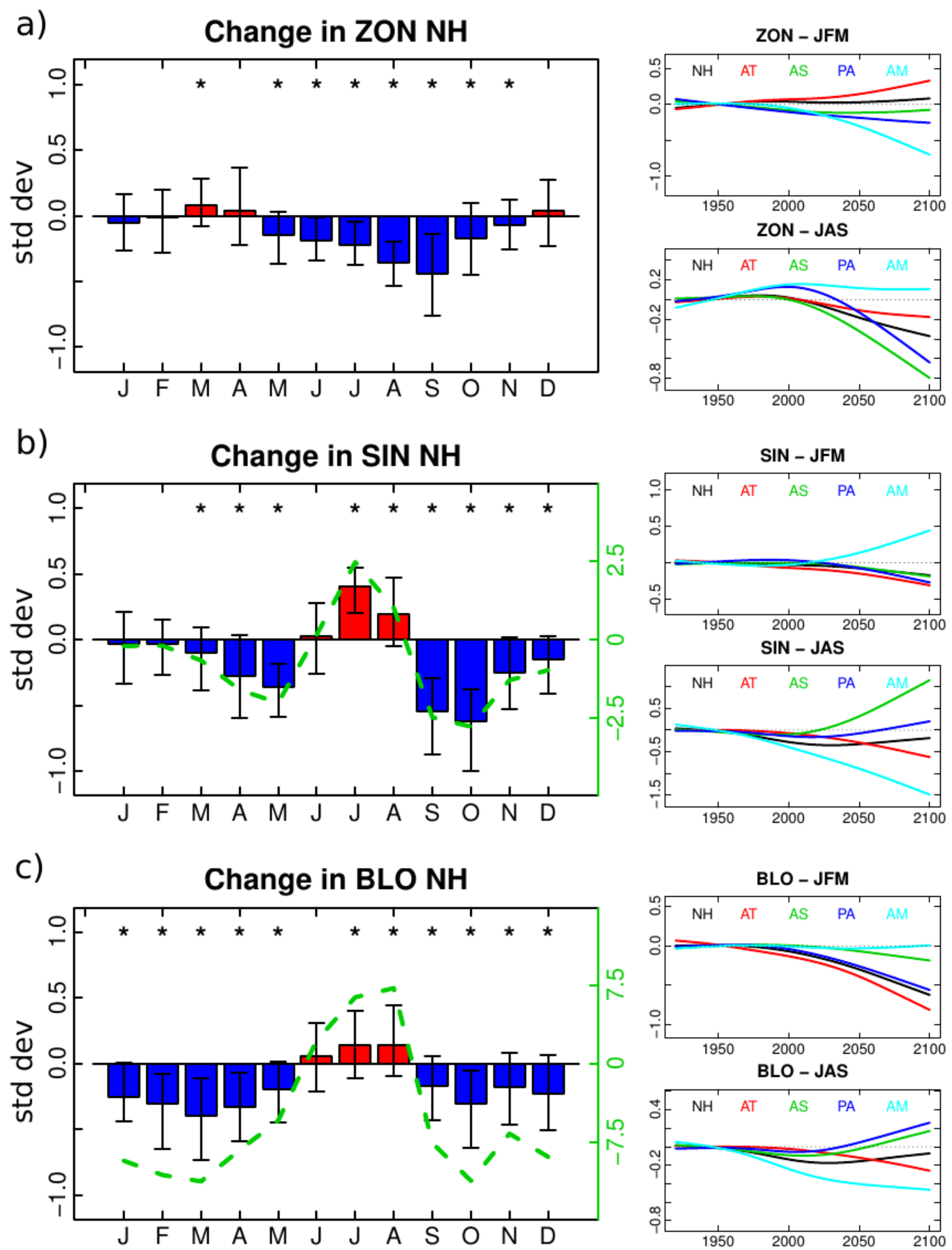
SIC : sea ice only

LTOC : long-term oceanic trend

DOV : decadal oceanic variability

Perlwitz et al. (2015)

3. <u>Future evolution of the mid-latitude dynamics</u> including jet streams/blocking/extreme weather events ? (Ayarzagüena and Screen 2016, Francis et al. 2012, Hassanzadeh and Kuang 2015, Harvey et al. 2014, Screen 2014, Barnes and Polvani 2015, Cattiaux et al. 2016, Peings et al. 2017, Vavrus et al. 2017)

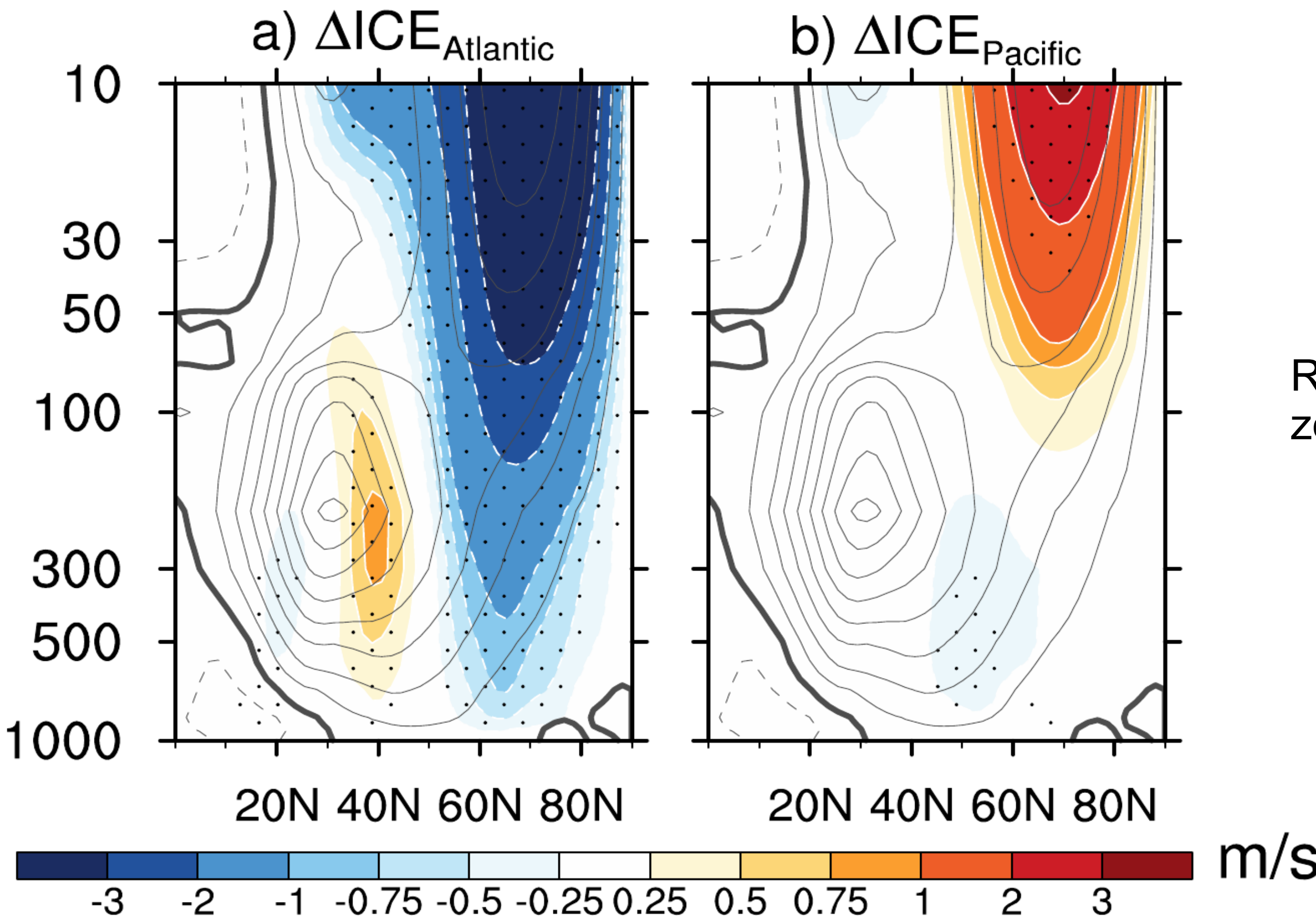


CESM-LENS

2071-2100 vs 1981-2010

Peings et al. (2017) – see poster session

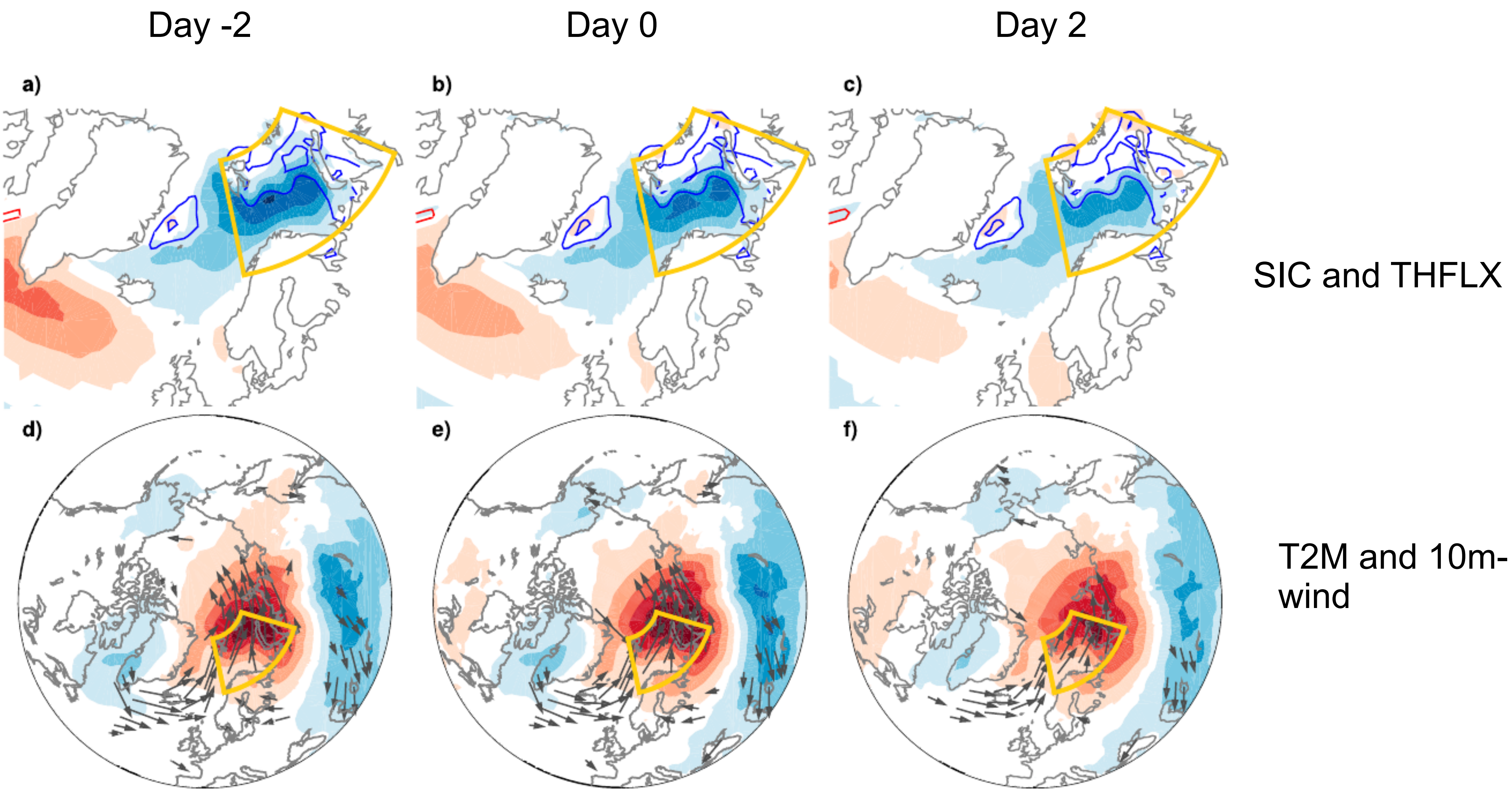
4. Importance of stationary waves in the upward propagation mechanism? Causes for constructive vs destructive interference with the background climatological flow that leads to a different stratospheric response? (Smith et al. 2011, Peings and Magnusdottir 2014, Sun et al. 2015). What is the role of stratospheric internal processes?



Response of zonal mean U

Sun et al. (2015)

6. Causal relationship between BK sea ice and the Warm Arctic Cold Siberia (WACS) pattern ? (Sato et al. 2014, Mc Cusker et al. 2016, Sorokina et al. 2016)



Sorokina et al. 2016

Potential modeling studies to tackle these questions

● Non-linear response to sea ice anomalies, Warm Arctic Cold Continents pattern

Set of coordinated AGCM experiments forced with a variety of patterns, amplitudes and both polarities in sea ice anomalies

● Role of sea ice decline in past trends of AA and mid-latitude climate

AMIP simulations forced with observed SIC decline

● Role of the stratosphere and mechanisms

Set of high-top simulations, possibly compared with corresponding low-top versions

● Dependence on background conditions, role of linear interference : AGCM studies including SST (AMO, PDO) or others sources of variability (snow, QBO, etc …)

Matrix of AGCM simulations combining sea ice anomalies with other boundary forcings (PDO, AMO, snow, QBO, etc …)

● Other issues:

Prescribe heat flux (instead of SIC) to bypass limitations of AGCM studies driven with prescribed SIC/SST

Use fully-coupled models for sea ice loss experiments (expensive),

Prescribe AA and not only sea ice anomalies, ...

References

Ayarzagüena, B. and J.A. Screen (2016) Future Arctic sea-ice loss reduces severity of cold air outbreaks in midlatitudes, Geophys. Res. Lett., 43, 2801-2809.

Barnes, E. A., and J. A. Screen (2015), The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it?, WIREs Clim. Change, 6, 277–286, doi: 10.1002/wcc.337.

Barnes E. A. (2013) Revisiting the evidence linking Arctic amplification to extreme weather in midlatitudes. Geophys. Res. Lett., 40, 4728–4733, doi:10.1002/grl.50880.

Blackport R. and P. J. Kushner (2017) Isolating the atmospheric circulation response to Arctic sea-ice loss in the coupled climate system. DOI:http://dx.doi.org/10.1175/JCLI-D-16-0257.1

Cattiaux J., Y. Peings, D. Saint-Martin, N. Trou-Kechout and S.J. Vavrus (2016) Sinuosity of mid-latitude atmospheric flow in a warming world, Geophysical Research Letters, 43, 8259-8268. doi:10.1002/2016GL070309

Cohen J., and co-authors (2014) Recent Arctic amplification and extreme mid-latitude weather. Nature Geoscience, doi:10.1038/ngeo2234.

Deser C., R. A. Tomas and L. Sun (2015) The role of ocean-atmosphere coupling in the zonal-mean atmospheric response to Arctic sea ice loss. J. Climate, 28, 2168-2186, doi: 10.1175/JCLI-D-14-00325.1.

Francis J. A., and S. J. Vavrus (2012) Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophys. Res. Lett., 39, LO6801, doi: 10.1029/2012GL051000.

Francis J.A. and S.J. Vavrus (2015) Evidence for a wavier jet stream in response to rapid Arctic warming. Environ. Res. Lett., 10, doi: 10.1088/1748-9326/10/1/014005.

Hassanzadeh, P., and Z. Kuang (2015), Blocking variability: Arctic Amplification versus Arctic Oscillation, Geophys. Res. Lett., 42, 8586–8595, doi: 10.1002/2015GL065923.

Honda M., J. Inoue and S. Yamane (2009) Influence of low Arctic sea ice minima on anomalously cold Eurasian winters. Geophys. Res. Lett., 36, L08707, doi: 10.1029/2008GL037079.

Jaiser, R., T. Nakamura, D. Handorf, K. Dethloff, J. Ukita, K. Yamazaki (2016) Atmospheric winter response to Arctic sea ice changes in reanalysis data and model simulations. JGR, doi: 10.1002/2015JD024679

Kim B.-M., S.-W. Son, S.-K. Min, J.-H. Jeong, S.-J. Kim, X. Zhang, T. Shim and J.-H. Yoon (2014) Weakening of the stratospheric polar vortex by arctic sea-ice loss. Nature Communications, 5, doi: 10.1038/ncomms5646.

King, M. P., M. Hell, and N. Keenlyside, Investigation of the atmospheric mechanisms related to the autumn sea ice and winter circulation link in the Northern Hemisphere, Climate Dynamics, 2015.

Kug J.-S., J.-H. Jeong, Y.-S. Jang, B.-M. Kim, C. K. Folland, S.-K. Min and S.-W. Son (2015) Two distinct influences of Arctic warming on cold winters over North America and East Asia. Nature Geoscience, DOI: 10.1038/NGEO2517.

Liptak J. and C. Strong (2014) The winter atmospheric response to sea ice anomalies in the Barents Sea. Journal of Climate, 27, 914-924,

Mori M., M. Watanabe, H. Shiogama, J. Inoue, and M. Kimoto (2014) Robust Arctic sea-ice influence on the frequent Eurasian cold winters in past decades, Nature Geoscience, doi:10.1038/ngeo2277

Nakamura, T., K. Yamazaki, K. Iwamoto, M. Honda, Y. Miyoshi, Y. Ogawa, Y. Tomikawa, and J. Ukita (2016) The stratospheric pathway for Arctic impacts on midlatitude climate. Geophys. Res. Lett., 43, 3494–3501, doi:10.1002/2016GL068330.

Overland, J., J. Francis, R. Hall, E. Hanna, S. Kim, and T. Vihma (2015) The Melting Arctic and Mid-latitude Weather Patterns: Are They Connected? J.Climate. doi: 10.1175/JCLI-D-14-00822.1

References

Peings Y. and G. Magnusdottir (2014) Response of the wintertime Northern Hemisphere atmospheric circulation to current and projected Arctic sea ice decline: a numerical study with CAM5. J. climate, 27, 244–264.

Peings Y., J. Cattiaux, S. Vavrus and G. Magnusdottir (2017) Late 21st Century Changes of the Mid-latitude Atmospheric Circulation in the CESM Large Ensemble. J. Climate, in revision.

Perlwitz J., M. Hoerling and R. Dole (2015) Arctic Tropospheric Warming: Causes and Linkages to Lower Latitudes. Journal of Climate 28 (6), 2154-2167

Petoukhov V. and V. Semenov (2010) A link between reduced Barent-Kara sea ice and cold winter extremes over northern continents. J. Geophys. Res., 115, D21111, doi:10.1029/2009JD013568.

Sato, K., J. Inoue and M. Watanabe (2014) Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter.

Screen J. A., and I. Simmonds (2013) Exploring links between Arctic amplification and mid-latitude weather. Geophys. Res. Lett., 40, 959–964, doi:10.1002/GRL. 50174.

Screen J.A. (2014) Arctic amplification decreases temperature variance in northern mid- to high-latitudes, Nature Clim. Change, 4, 577-582

Screen, J.A., C. Deser, I. Simmonds & R. Tomas (2014) Atmospheric impacts of Arctic sea-ice loss, 1979-2009: Separating forced change from atmospheric internal variability, Clim. Dyn., 43, 333-344

Semenov V. A. and M. Latif (2015) Nonlinear winter atmospheric circulation response to Arctic sea ice concentration anomalies for different periods during 1966–2012 Environmental Research Letters, 10 (5). 054020. DOI 10.1088/1748-9326/10/5/054020.

Smith, K. L., P. J. Kushner, and J. Cohen (2011) The role of linear interference in northern annular mode variability associated with Eurasian snow cover extent, Journal of Climate, 24(23), 6185–6202.

Sorokina S. A., C. Li, J. J. Wettstein, and N. G. Kvamstø (2016) Observed atmospheric coupling between Barents Sea ice and the warm-Arctic cold-Siberian anomaly pattern. J. Climate, 29, 495–511, doi:10.1175/JCLI-D-15-0046.1

Sun L., C. Deser and R. A. Tomas (2015) Mechanisms of stratospheric and tropospheric circulation response to projected Arctic sea ice loss. J. Climate, J. Clim., 28, 7824–7845, doi:10.1175/JCLI-D-15-0169.1.

Tomas, R. A, C. Deser and L. Sun, 2016: The role of ocean heat transport in the global climate response to projected Arctic sea ice loss. J. Climate, 29, 6841-6859, doi: 10.1175/JCLI-D-15-0651.1.

Vavrus S., F. Wang, J. Martin, J. Francis, Y. Peings and J. Cattiaux (2017) Changes in North American Atmospheric Circulation and Extreme Weather: Evidence of an Arctic Connection. Journal of Climate, in revision.