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A reconciled estimate of the influence of Arctic sea-ice loss on recent Eurasian cooling

Masato Mori[1], Y. Kosaka[1], M. Watanabe[2], H. Nakamura[1] and M. Kimoto[2]

[1]Research Center for Advanced Science and Technology, Univ. Tokyo
[2]Atmosphere and Ocean Research Institute, Univ. Tokyo

nature climate change LETTERS
https://doi.org/10.1038/s41558-018-0379-3

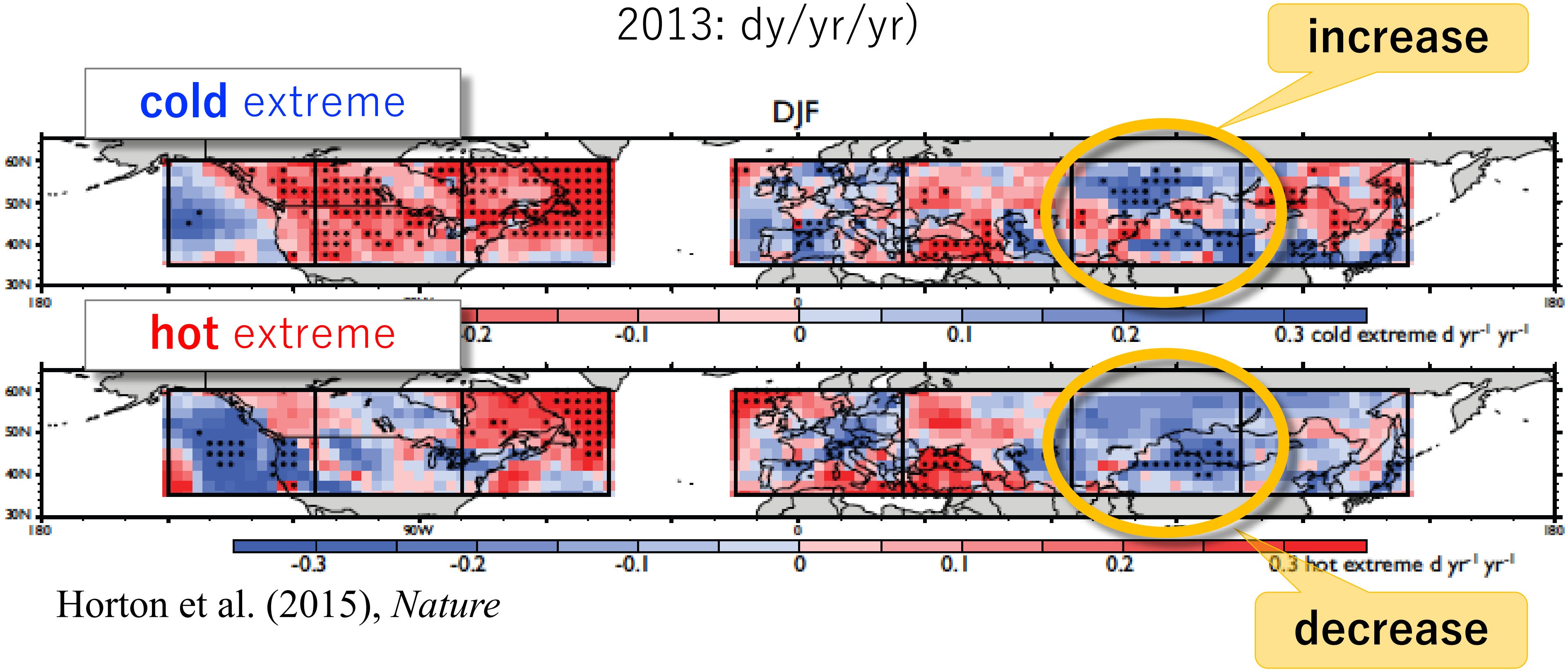
A reconciled estimate of the influence of Arctic sea-ice loss on recent Eurasian cooling

Masato Mori[1*], Yu Kosaka[1], Masahiro Watanabe[2], Hisashi Nakamura[1] and Masahide Kimoto[2]

5 Mar 2019, Joint US-Japan WS on Climate Change and Variability@Hawaii

Increasing cold extremes in central Eurasian winter

Extreme temperature occurrence trend in DJF based on daily max/min data (1990–2013: dy/yr/yr)



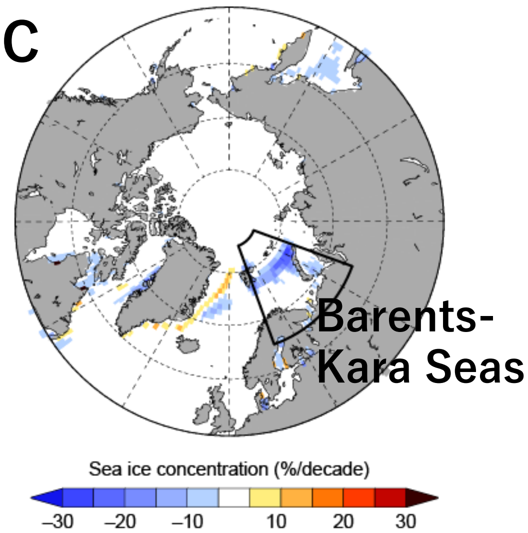
Horton et al. (2015), *Nature*

- Occurrence frequency of cold extremes are increasing in the central Eurasia. (e.g. Liu et al. 2012; Tang et al. 2013; Horton et al. 2015)

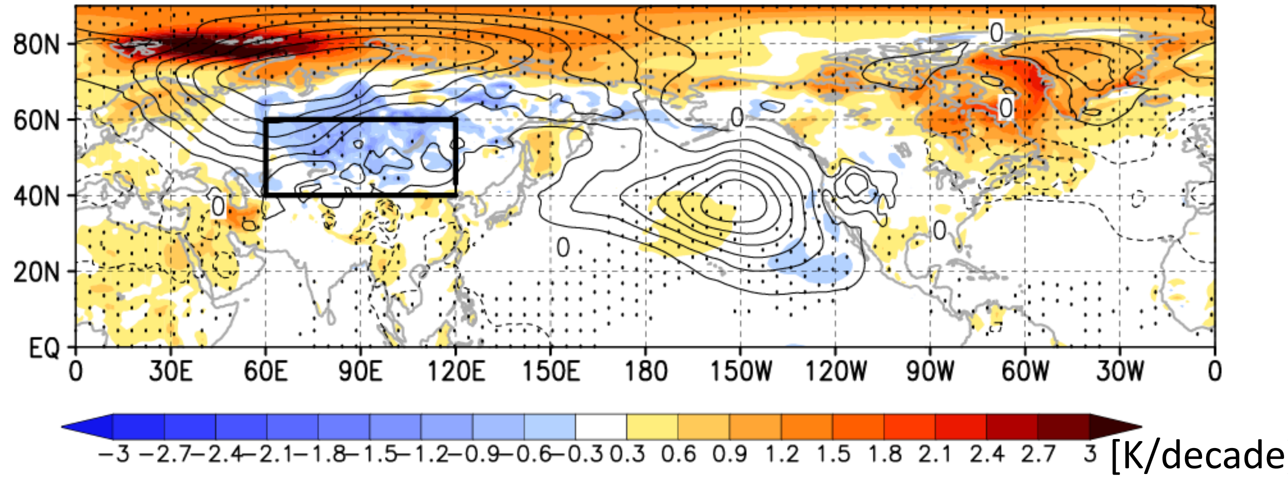
※ In this research, we will call this area simply as central Eurasia (CEU).

Observed trend (DJF: 1979/80–2013/14)

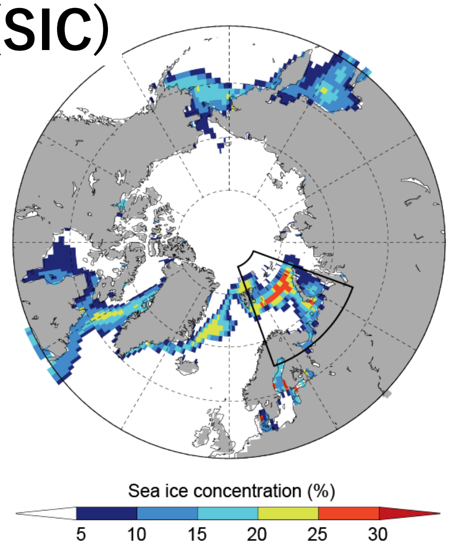
SIC



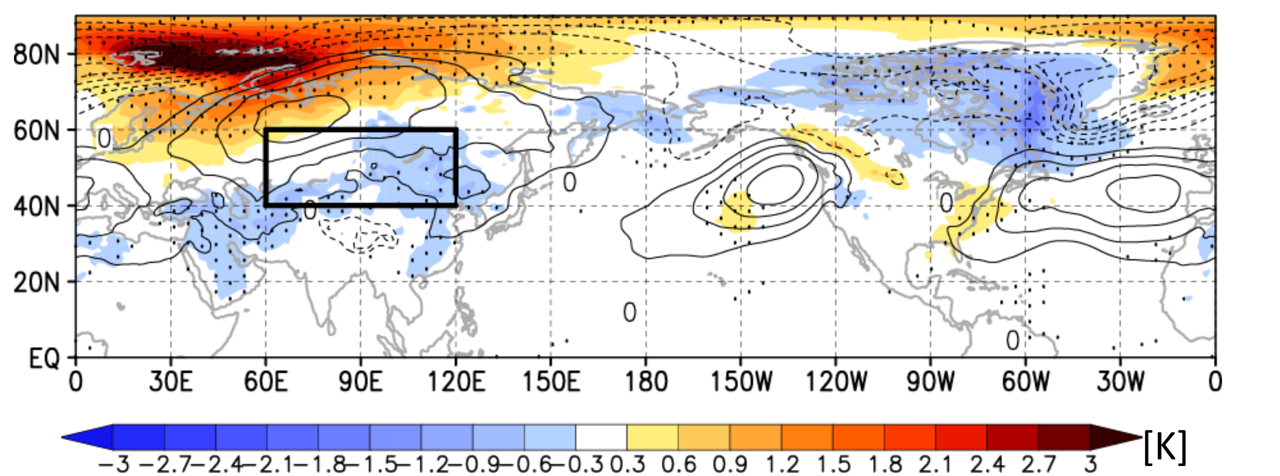
SAT (color) & **SLP** (contour)



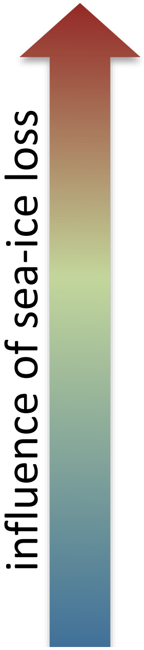
σ (SIC)



De-trended winter **SAT** & **SLP** anomalies
regressed on SIC in BK Seas (sign reversed)



Whether or not the cause of Eurasian cooling is due to sea-ice reduction is controversial



- There is significant link between sea-ice loss and central Eurasian cold winter (**observational studies**). (e.g., Inoue.et al. 2012; Tang et al . 2013; Chen et al. 2016)

- Sea-ice loss can force Eurasian cold winter (**modeling studies**).
  (e.g., Honda et al. 2009; Pethoukov and Semenov 2010; Liu et al. 2012; Orsolini et al. 2012; Kim et al. 2014; Mori et al. 2014; Peings and Magnusdottir 2014; Screen et al. 2015; Kug et al. 2015; Nakamura et al. 2015, 2016; Semenov and Latif 2015)

- There is an influence of sea-ice loss, but it’s not robust. (Chen et al. 2016)

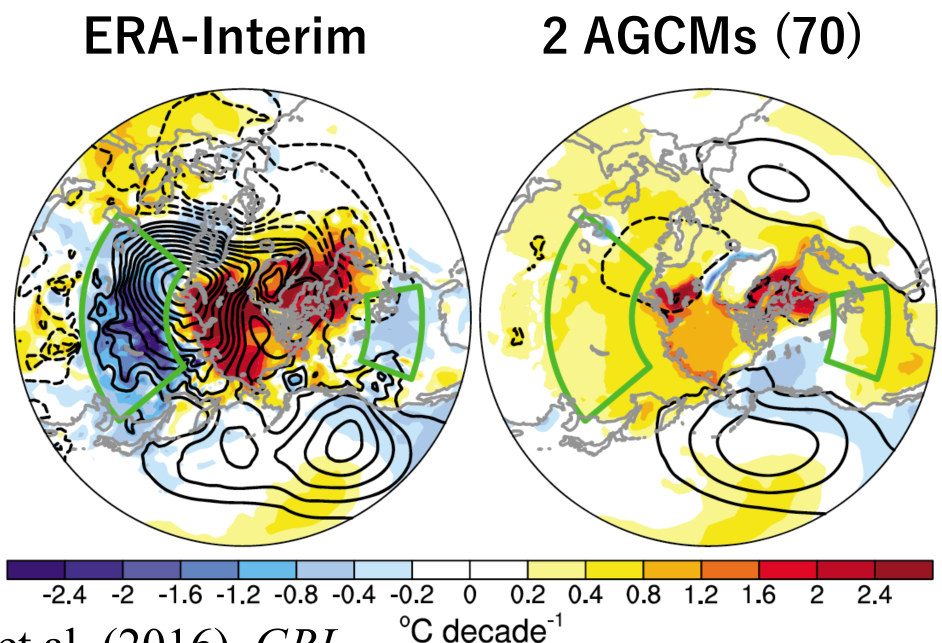
- There is no influence of sea-ice loss (recent cooling is internal variability).
  (Sun et al. 2016; McCusker et al. 2016; Ogawa et al. 2018)

Some studies deny the influence of sea-ice loss

- Ensemble-mean of AMIP-type historical large ensemble simulation does not reproduce central Eurasian cooling trend.

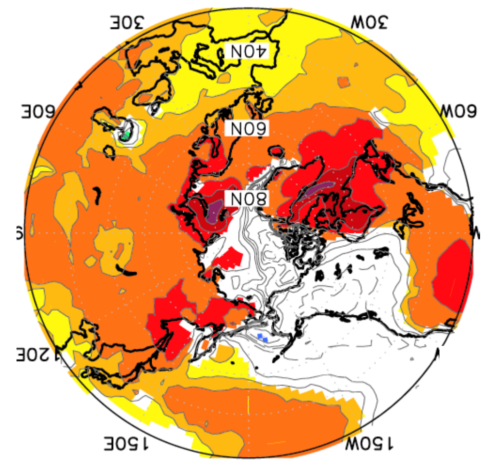
(Sun et al. 2016; Ogawa et al. 2018)

SAT & SLP trend (DJF: 1991—2014)



Sun et al. (2016), *GRL*

5 AGCMs (100)



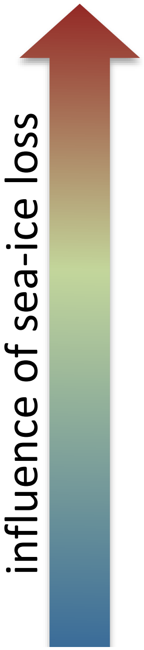
(DJF: 1982-2014)

Ogawa et al. (2018), *GRL*

- Recent cooling is consequence of atmospheric internal variability.

(Sun et al. 2016; McCusker et al. 2016; Ogawa et al. 2018)

Whether or not the cause of Eurasian cooling is due to sea-ice reduction is controversial



- ☐ There is significant link between sea-ice loss and central Eurasian cold winter (**observational studies**). (e.g., Inoue.et al. 2012; Tang et al . 2013; Chen et al. 2016)
- ☐ Sea-ice loss can force Eurasian cold winter (**modeling studies**). (e.g., Honda et al. 2009; Pethoukov and Semenov 2010; Liu et al. 2012; Orsolini et al. 2012; Kim et al. 2014; Mori et al. 2014; Peings and Magnusdottir 2014; Screen et al. 2015; Kug et al. 2015; Nakamura et al. 2015, 2016; Semenov and Latif 2015)
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Remote influence of sea-ice loss on mid-latitudes is in controversial. (Screen et al. 2018)

- ➢ Sea-ice has little impact on the mid-latitude atmosphere, and the observed cooling is largely explained by internal variability that happened by chance.
- ➢ The model may not fully express the influence of sea-ice anomalies.

We try to robustly estimate a sea-ice forced signal from ***observational*** record with the aid of model simulation. → We can evaluate adequacy of the model response.

How sea-ice forced components are extracted

U.S. Department of Commerce I National Oceanic & Atmospheric Administration I NOAA Research I Earth System Research Laboratory I Physical Sciences Division

FACTS Facility for Climate Assessments

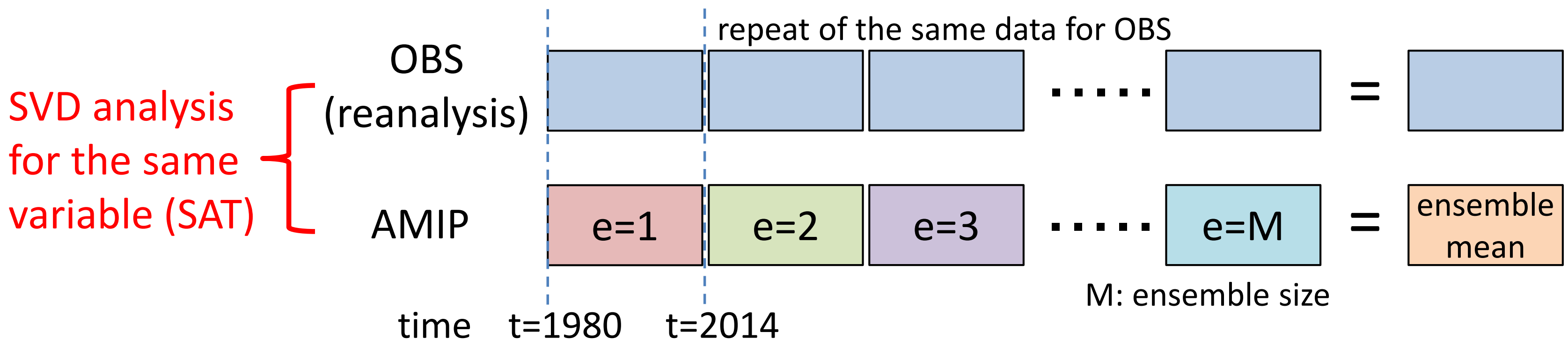
https://www.esrl.noaa.gov/psd/repository/alias/facts

AMIP-type historical ensemble simulation by NOAA-FACTS (6 AGCMs) and MIROC4-AGCM (**AMIP-FACTS**)

- period : 1979—2014
- ensemble : 219 member (total)
- forcing : natural and anthropogenic

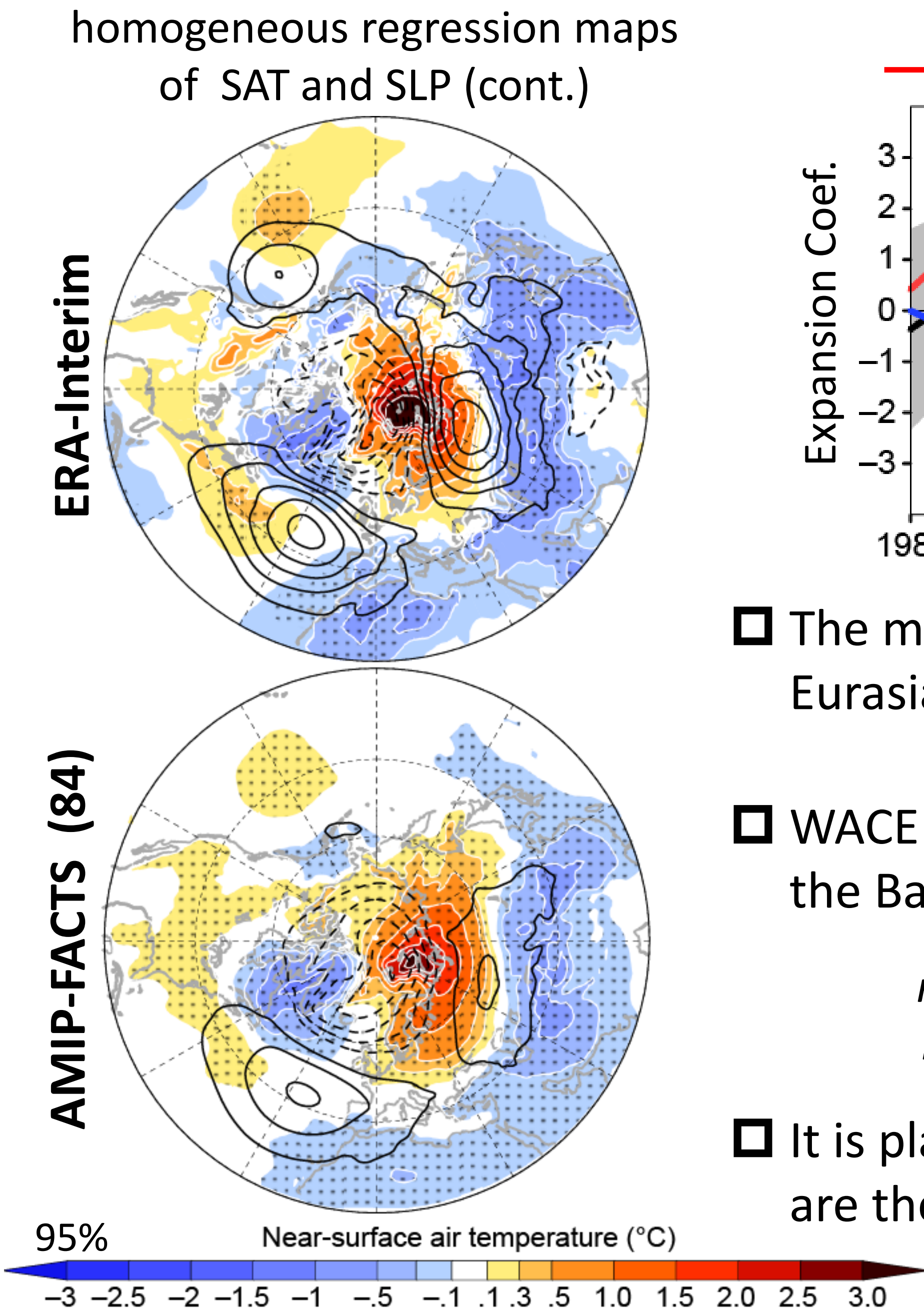
AGCM	ensemble
CAM4	20
LBNL-CAM5.1	50
ECHAM5.4	30
ESRL-GFSv2	50
GEOS-5	12
GFDL-AM3	17
MIROC4-AGCM	40

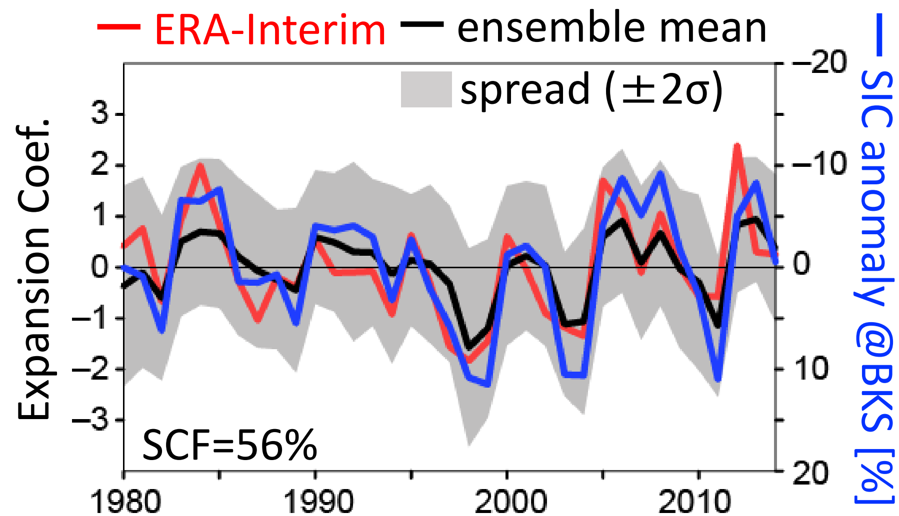
If similarly fluctuating components are present in both observed and simulated historical series, it would be a forced variations.



The large ensemble size ensures that influence of noise arising from atmospheric internal variability is well suppressed, and we can anticipate that SVD analysis extracts a robust forced signal commonly contained in observed and simulated historical data.

SVD1 for SAT between ERA and AGCM (DJF: detrend)





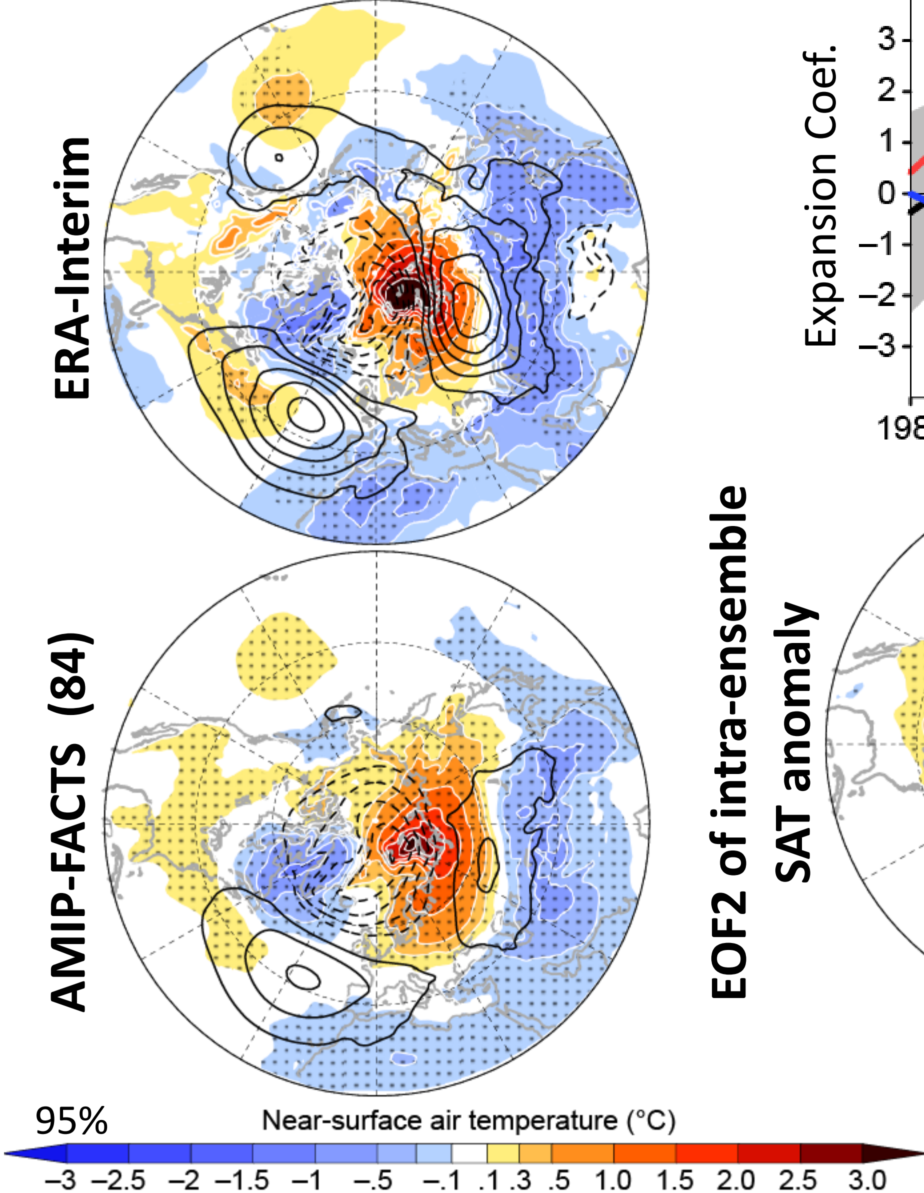
- The major forced pattern is "Warm-Arctic Cold Eurasian (WACE)" pattern.
- WACE is strongly tied to DJF-mean SIC anomaly in the Barents-Kara Seas (BKS).

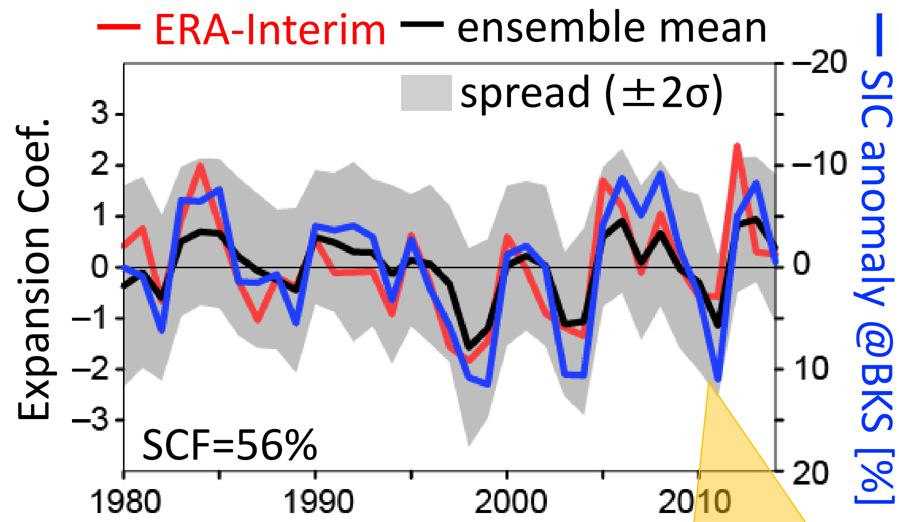
  r (EC_{ERA}, SIC@BKS) = -0.79
  r (EC_{em} , SIC@BKS) = -0.95

- It is plausible that Barents-Kara sea-ice anomalies are the main driver of the WACE pattern.

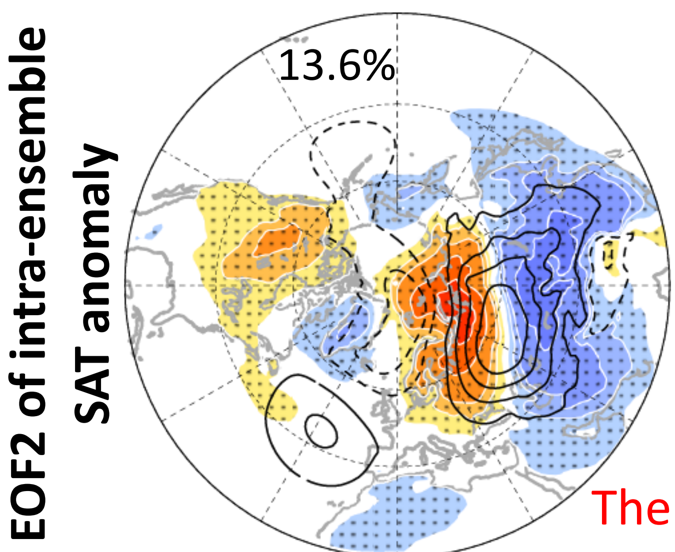
SVD1 for SAT between ERA and AGCM (DJF: detrend)

homogeneous regression maps
of SAT and SLP (cont.)



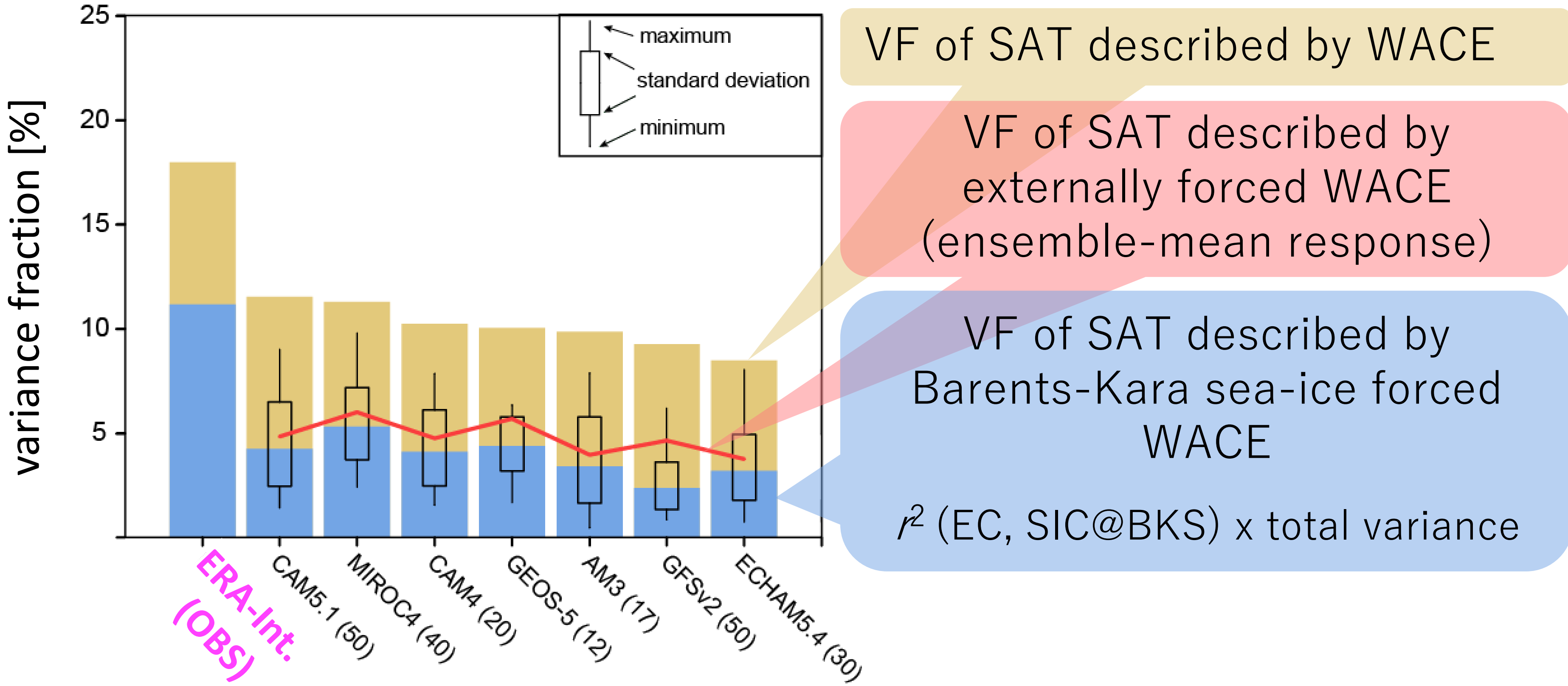


WACE variation in individual realizations is a mixture of internally generated and externally forced components



The origin of WACE is an intrinsic mode of variability, and sea ice is an agent that drives WACE well.

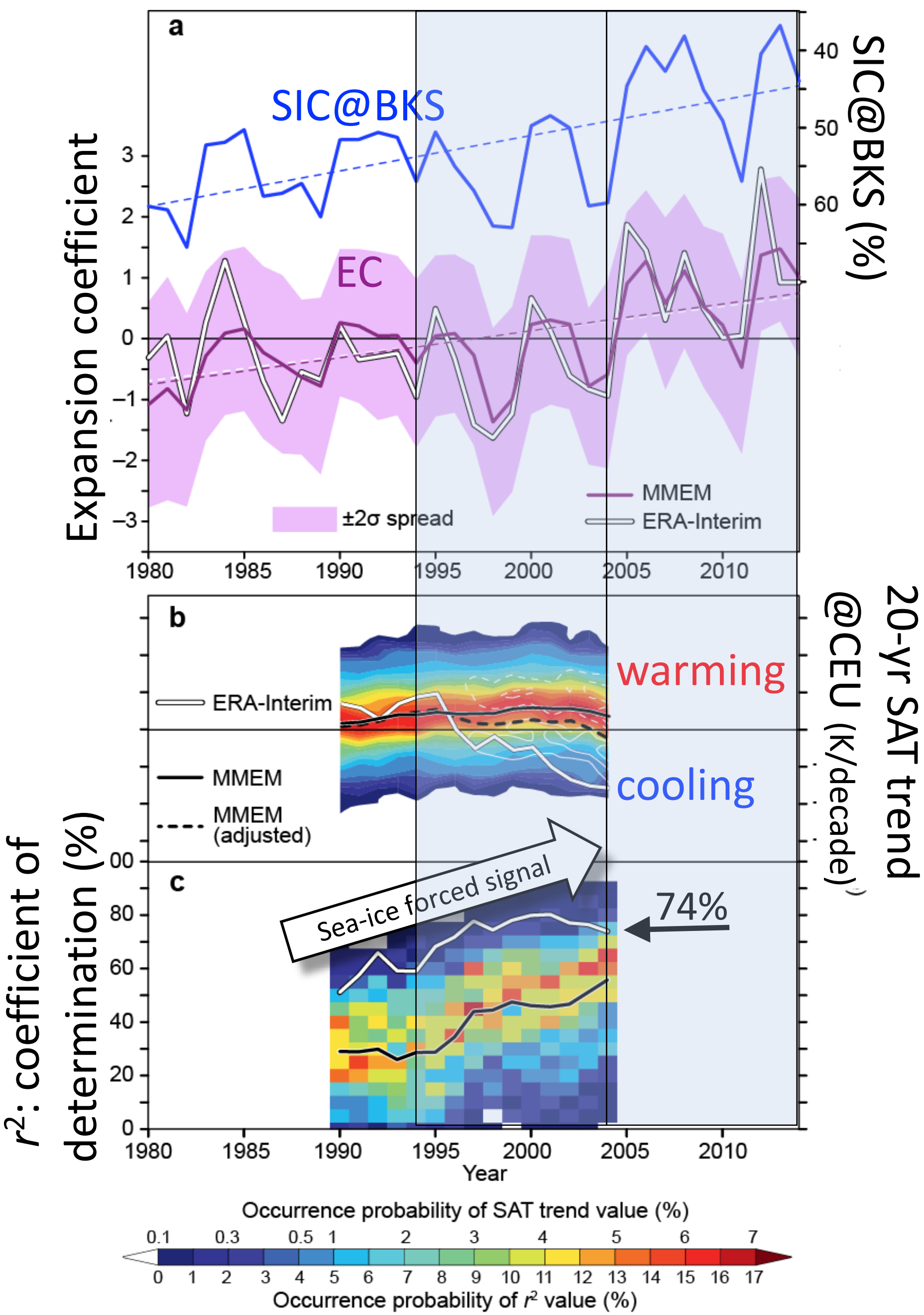
Variance fraction (VF) of SAT described by WACE



- All AGCMs underestimate the variance fraction (VF) of SAT described by WACE.
- Sea-ice forced WACE variance **in observation** can be measured by r^2.
  - r^2: coefficient of determination
- AGCMs systematically underestimate the **sea-ice forced** WACE magnitude (blue).
- Signal-to-noise ratio is underestimated and its degree is different between models.

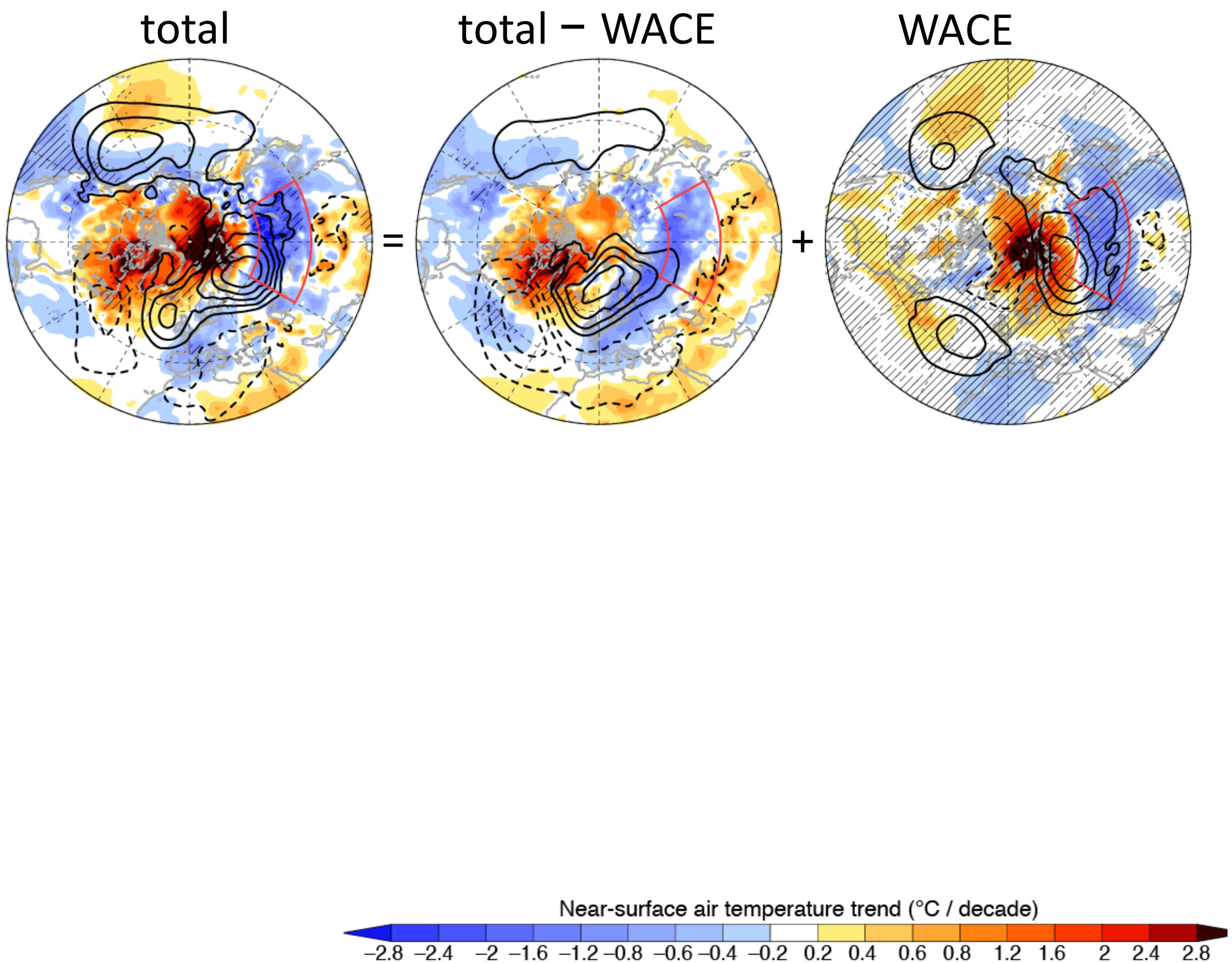
→ the potential reasons that models show a large diversity for sea-ice influence.

How much of recent Eurasian cooling is attributable to Arctic sea-ice loss?



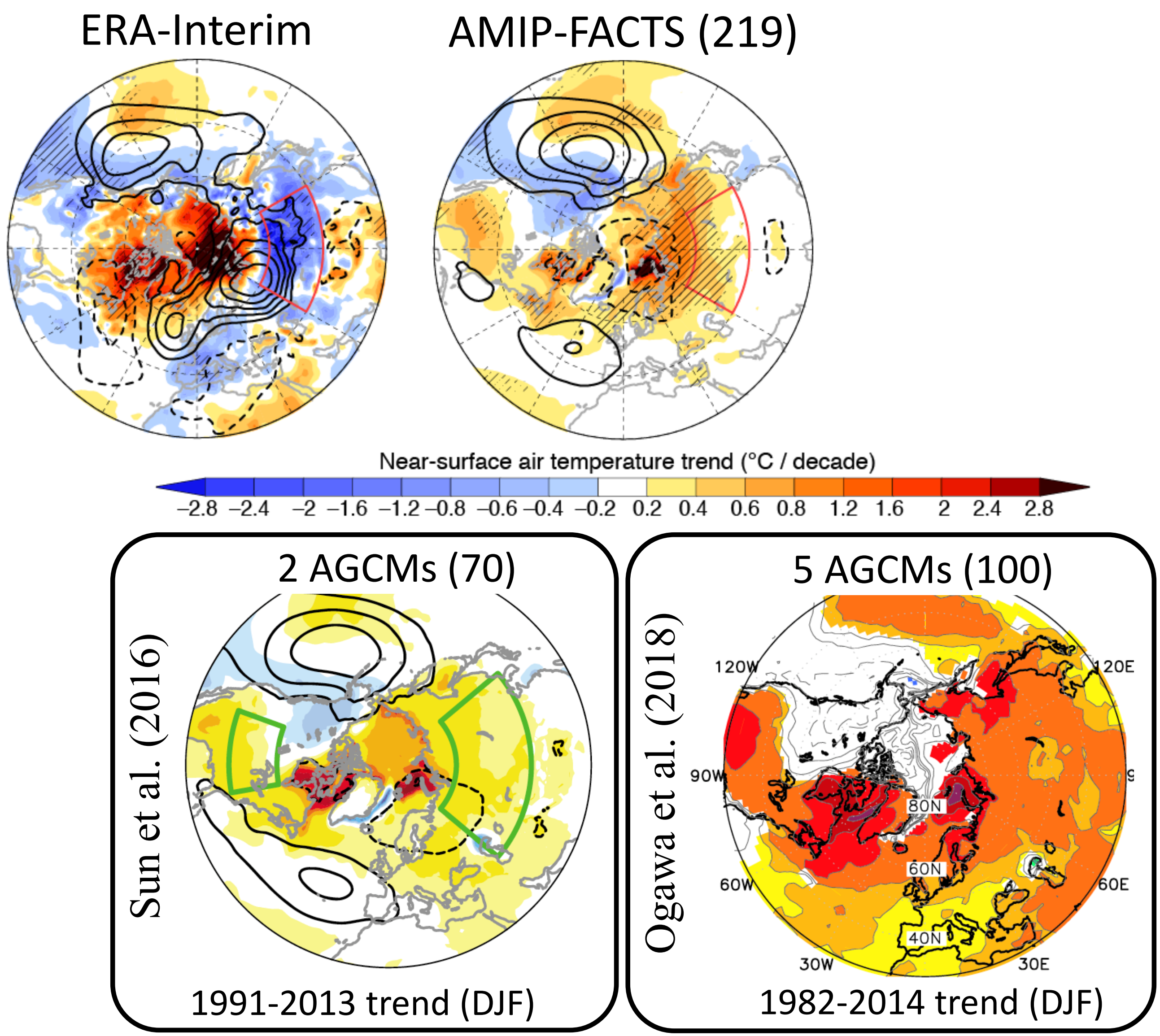
- Positive WACE trend reflects frequent occurrence of WACE+ regime in recent years, which is consistent with decreasing SIC trend.
- Warming trend in CEU gradually turns to cooling trend.
- Sea-ice forced WACE signal in observation has been enhanced year by year, it reaches to 74% in the last 20 years.

Trend of DJF-mean SAT & SLP for 1995-2014 in ERA-Interim



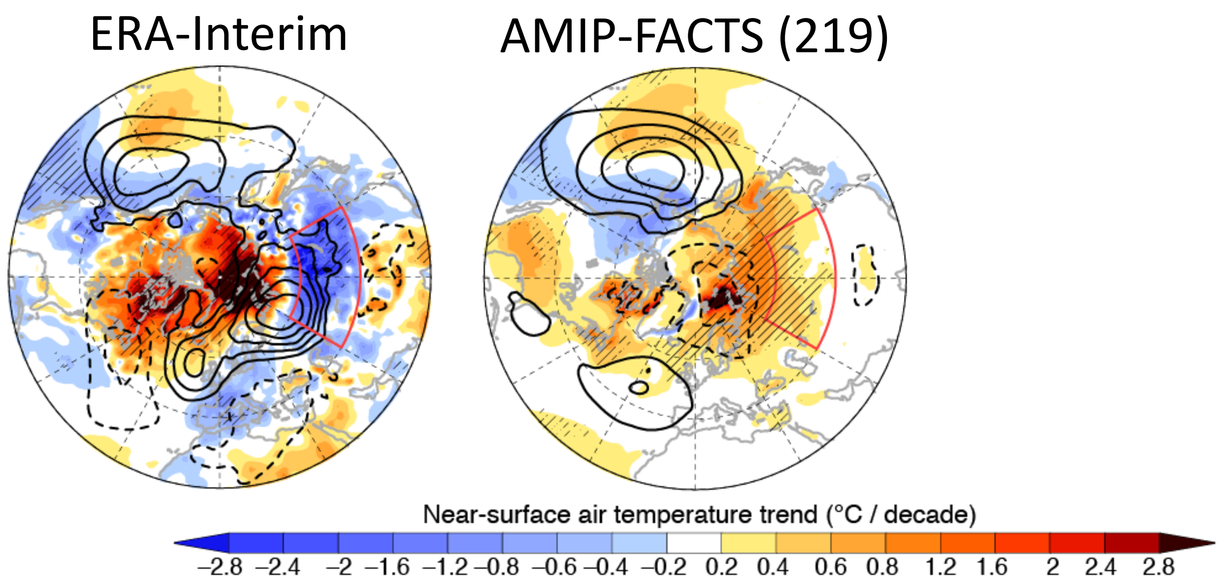
- WACE+ explains 59% of cooling at CEU.
- Negative AO-like pattern explains the residual cooling at CEU.
- How much of CEU cooling is explained by sea-ice loss? 59% x 74% (from r^2) = 44%

Trend of DJF-mean SAT & SLP for 1995-2014 in AGCMs



- ☐ Ensemble mean response does not show cooling at CEU !!
- ☐ This is ground of the argument that "Recent cooling is an extreme natural variability".

Trend of DJF-mean SAT & SLP for 1995-2014 in AGCMs



- Discrepancy between observational and modelling estimations strongly suggest that the underestimated sea-ice forced signal is obscured by other signals.
- Adjusting the WACE variance (magnitude) in model reconciles the model-observation discrepancy in Eurasian cooling.
- The occurrence probability of WACE in model is coherently increased with the decreasing sea ice, although the magnitude of WACE is underestimated.

Summary

- ✓ Arctic sea-ice loss influence on central Eurasian cooling has been suggested, but its significance remains controversial because of discrepant estimation among modelling and between modelling and observational studies.

- ✓ AGCMs well capture spatial structures of atmospheric response to BK sea-ice loss (WACE pattern), but it disappear from ensemble-mean response because the **magnitude of cold responses in midlatitude are underestimated in AGCMs**. This lowered signal-to-noise ratio in model can be a potential cause of diverse conclusions between modelling studies.

- ✓ Correction of this model bias can reconcile the model-observation discrepancy in the Eurasian cooling trend. At least **44% of the recent wintertime central Eurasian cooling is attributable to BK sea-ice loss.**

- ✓ The underestimation of response to sea-ice loss may originate in the lack of ocean-ice-atmosphere coupling process.

Acknowledgements: We acknowledge the modelling groups and their members who generated the FACTS climate model simulation data provided by the NOAA/ESRL/PSD.