

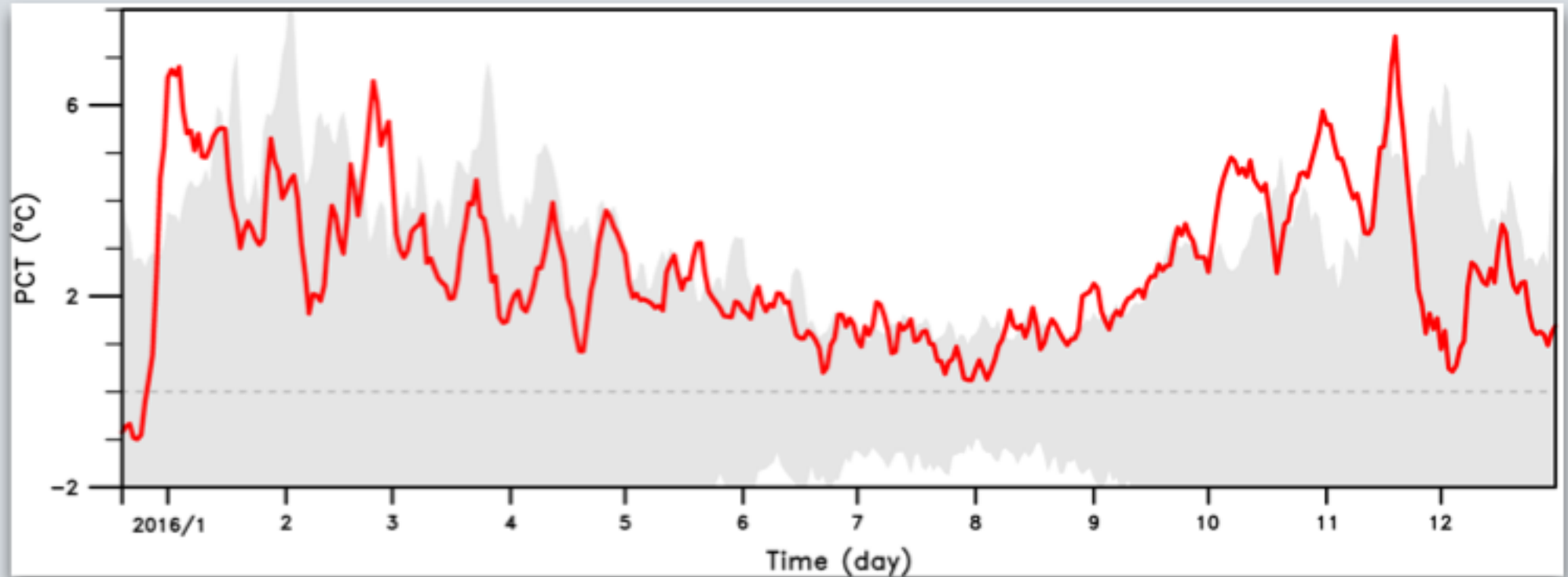
# A major cause of unprecedented **Arctic warming** in January 2016: A critical role by Atlantic windstorm

Baek-Min Kim  
Korea Polar Research Institute



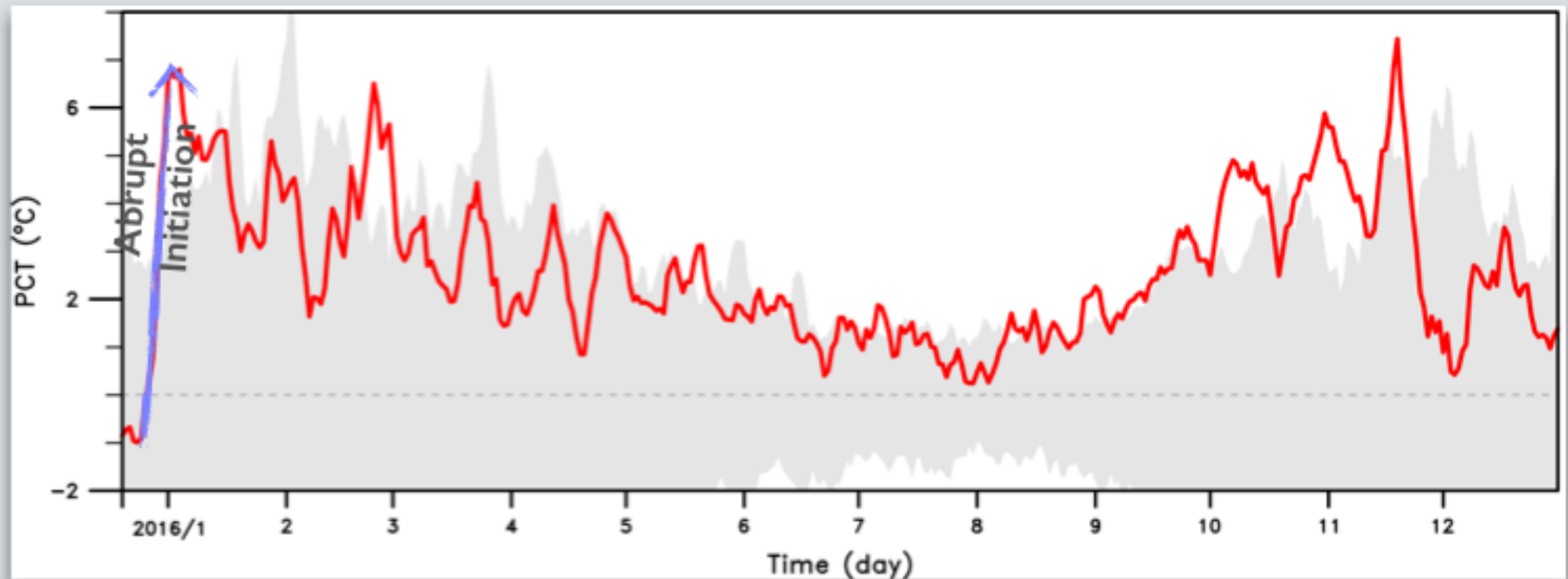
Collaboration with:  
Ja-Young Hong (KOPRI)  
Joo-Hong Kim (KOPRI)  
Xiangdong Zhang (IARC/UAF)  
et al.

## ARCTIC TEMPERATURE VARIABILITY: LARGE & MULTI-TIME SCALE



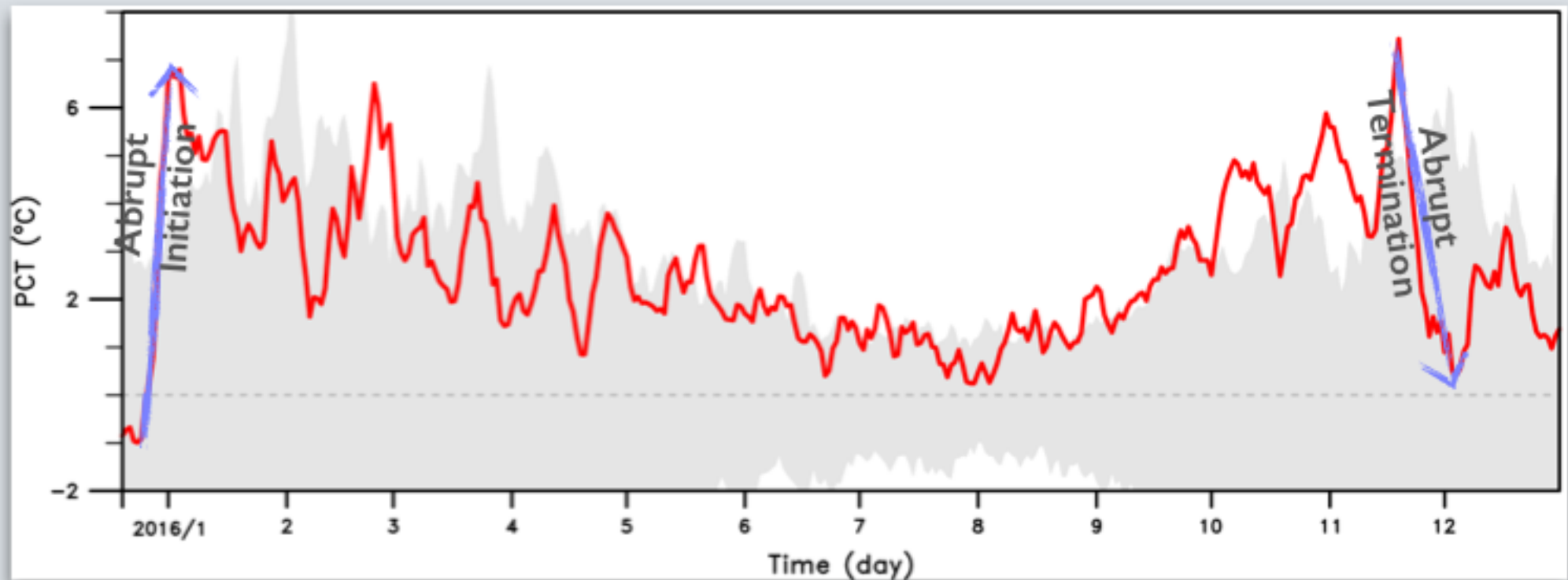
<Daily Polar Cap Temperature Anomaly in 2016 & its daily range (gray shading, max/min in history)>

## ABRUPT INITIATION/TERMINATION SOMETIMES...



<Daily Polar Cap Temperature Anomaly in 2016 & its daily range (gray shading, max/min in history)>

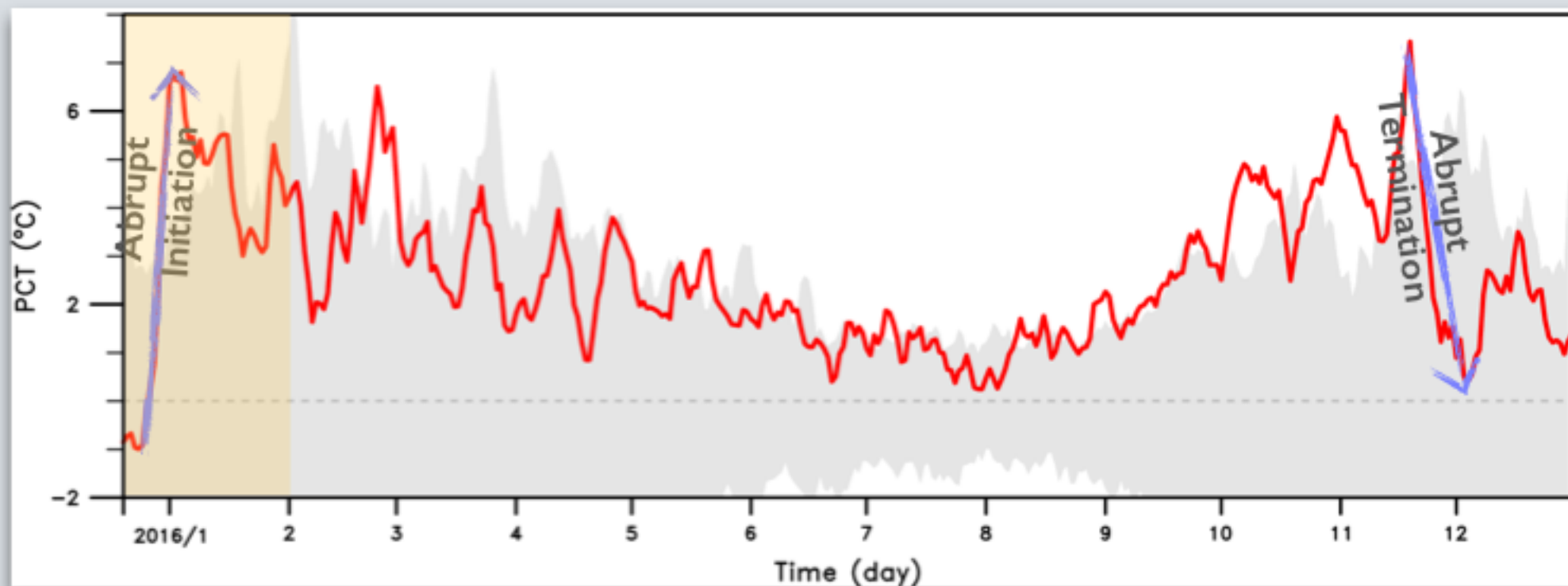
## ABRUPT INITIATION/TERMINATION SOMETIMES...



<Daily Polar Cap Temperature Anomaly in 2016 & its daily range (gray shading, max/min in history)>



## TODAY'S TALK: PHYSICAL PROCESSES INSIDE THE ABRUPT WARMING EVENT IN JAN. 2016



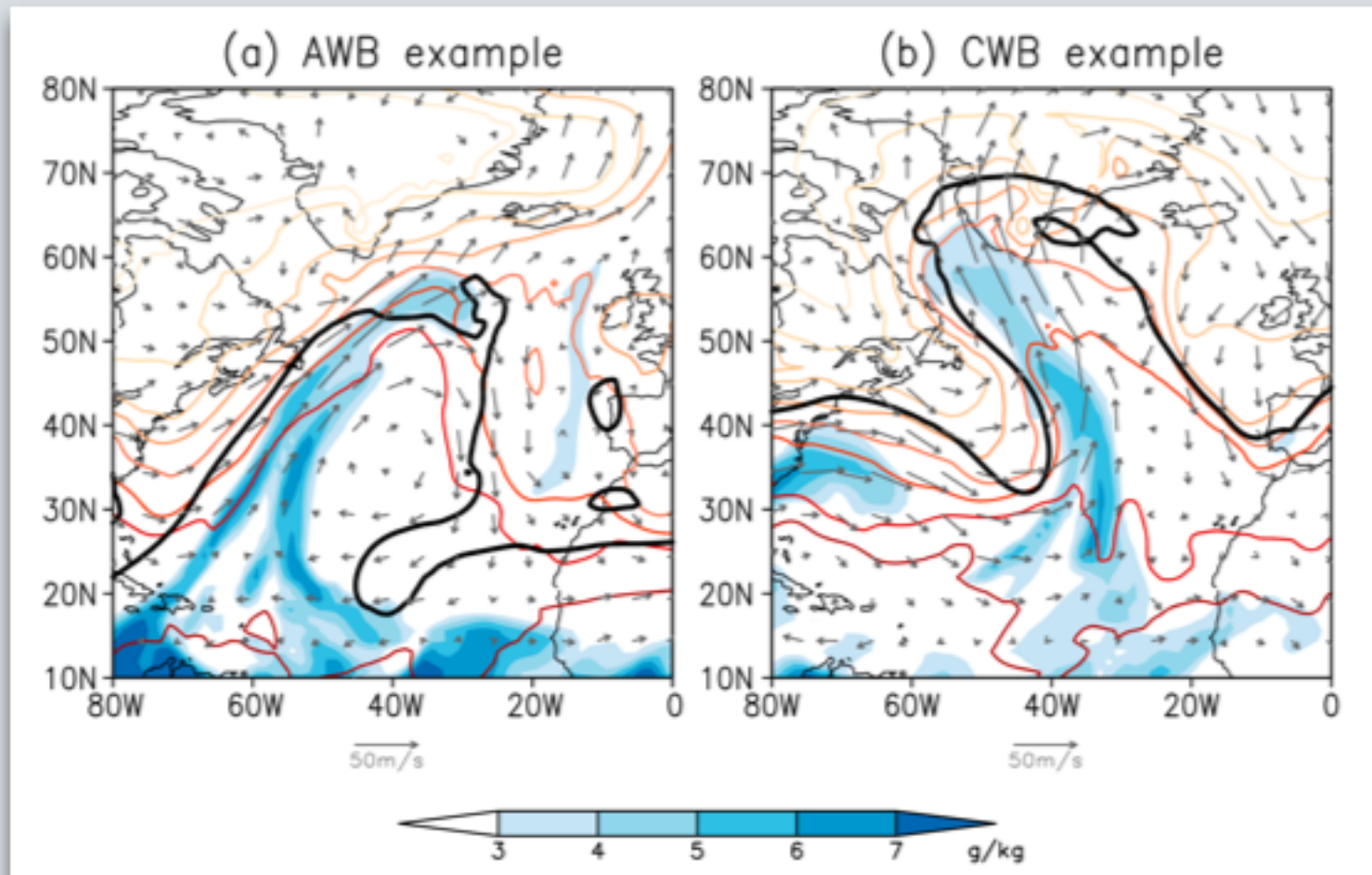
<Daily Polar Cap Temperature Anomaly in 2016 & its daily range (gray shading, max/min in history)>

Kim, B.-M., J.-Y. Hong, S.-Y. Jun, X. Zhang, H. Kwon, S.-J. Kim, J.-H. Kim, S.-W. Kim, and H.-K. Kim (2017), **Major cause of unprecedented Arctic warming in January 2016: Critical role of an Atlantic windstorm**, Sci. Rep., 7, 40051, doi:10.1038/srep40051.

## SUGGESTED MECHANISM OF EXTREME ARCTIC WARMING EVENT

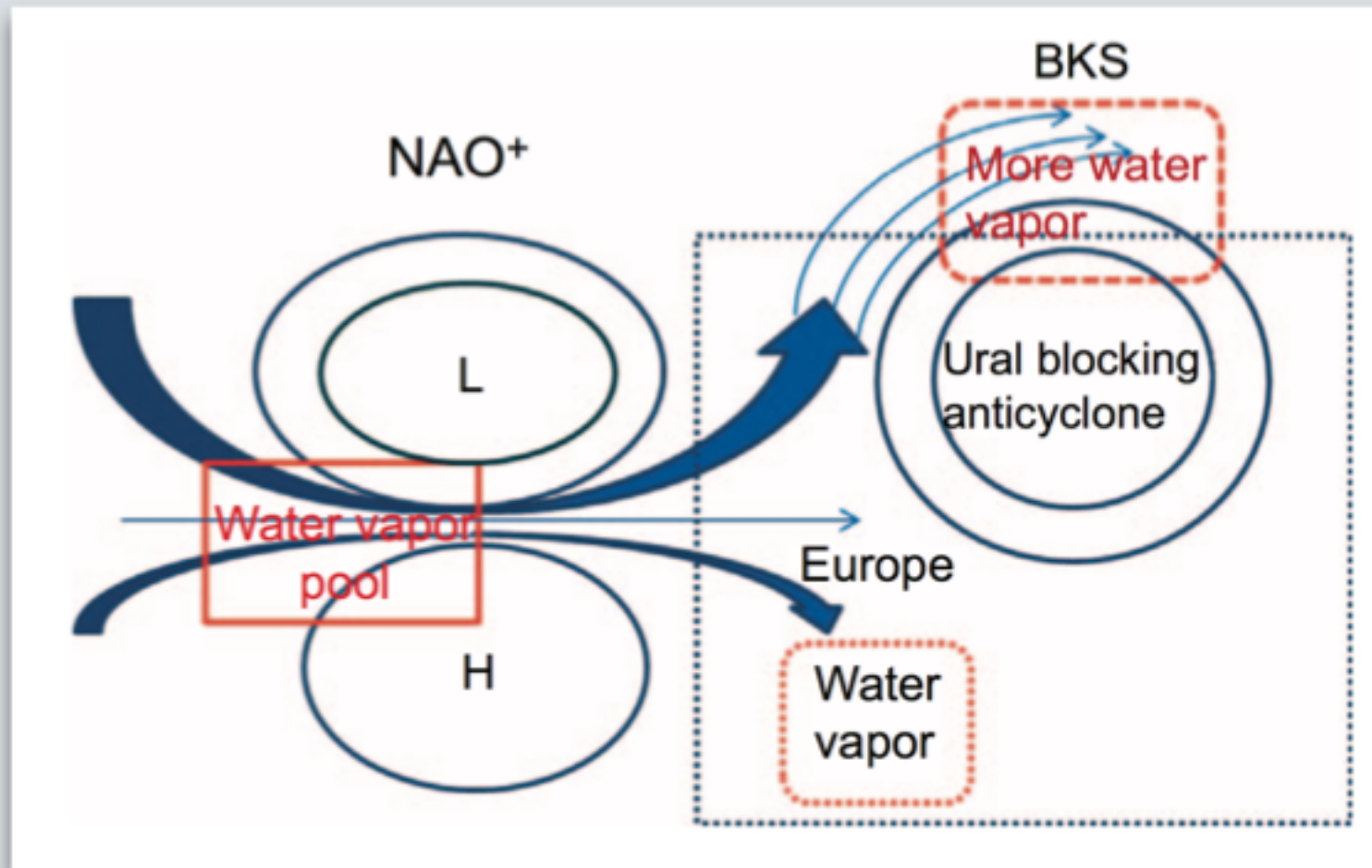
- Meridionally oriented circulation that favors the intrusion of warm mid-latitude air masses
  - The TEAM (Tropically Excited Arctic warming Mechanism)  
(Lee et al, 2011a, b; 2012; Flounroy et al., 2016)
  - Constructive interference between stationary waves and transient eddies  
(Goss et al., 2016; Baggett et al., 2016)
- Extreme meridional heat & moisture intrusion in synoptic time-scale  
(Woods et al., 2013; Liu and Barnes, 2015; Woods and Caballero, 2016)
- Sea-ice loss induced by moisture intrusion and consequent downward IR forcing  
(Park, DS et al. 2015; Park, HS et al., 2015a,b)

# LIU AND BARNES (2015)



<WV mixing ratio (shading), 2PVU (solid)>

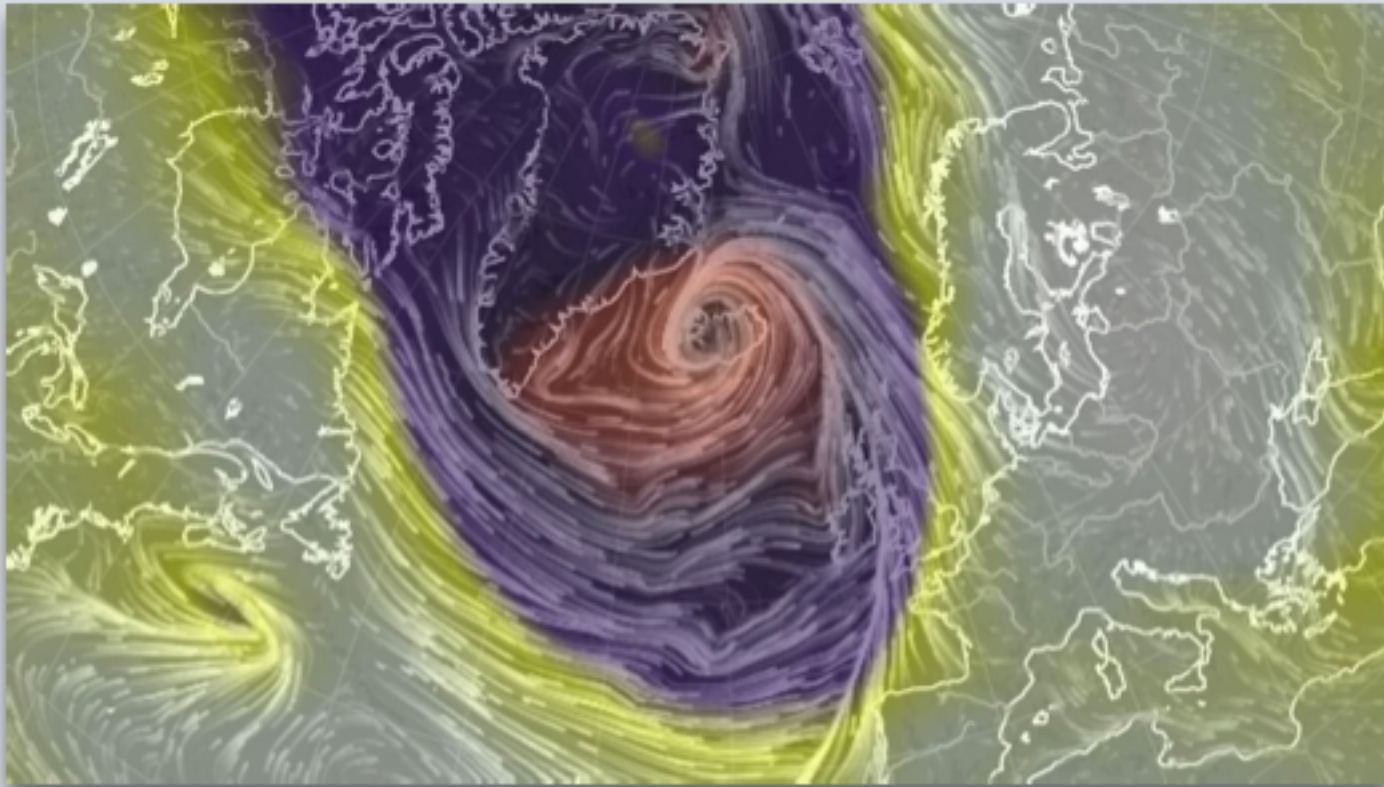
Liu, C., and E.A. Barnes (2015),  
Extreme moisture transport into the Arctic linked to Rossby wave breaking,  
J. Geophys. Res. Atmos., 120(9)



Luo, B., D. Luo, L. Wu, L. Zhong, and I. Simmonds (2017),  
Atmospheric circulation patterns which promote winter Arctic sea ice decline,  
Environ. Res. Lett., 54017



# THERE WAS A MARVELOUS STORM



Earth Simulator(2015.12.30)

“The storm is a meteorological marvel, intensifying so rapidly that the term ‘bomb genesis’ is perhaps an understatement to describe its intensification”

-Andrew Freedman (Journalist)-

## THERE WAS A MARVELOUS STORM

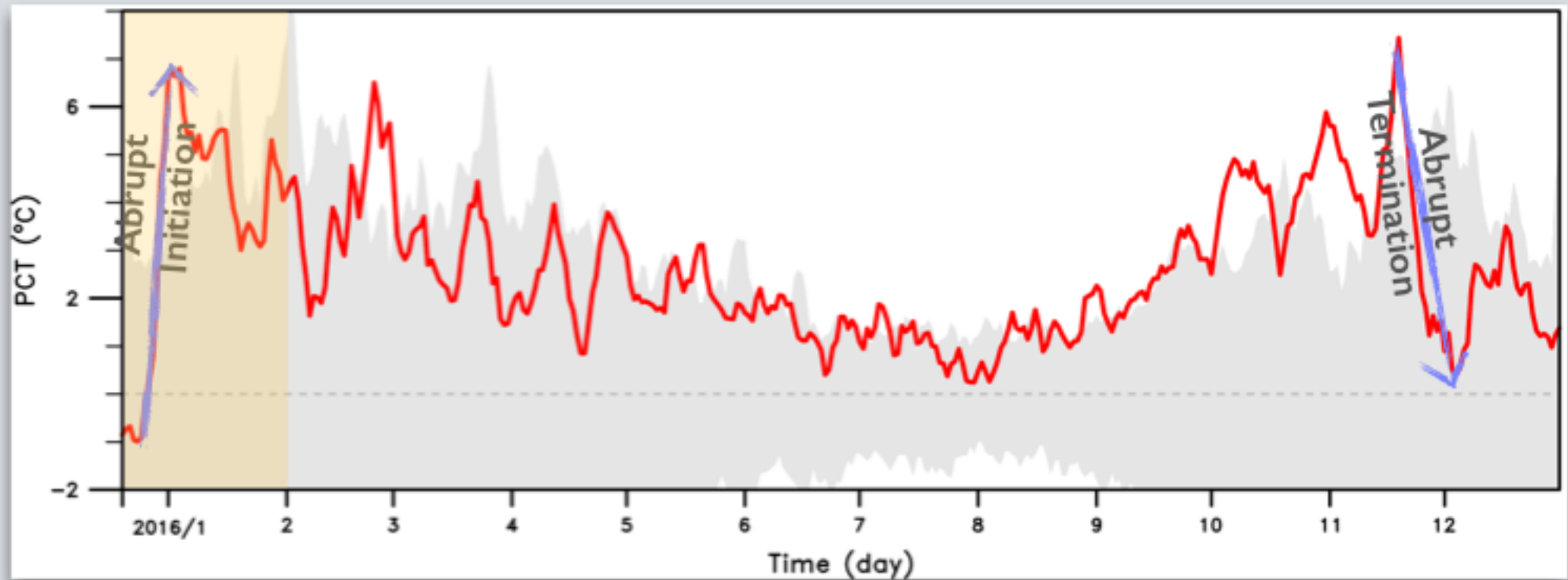
“The storm is a meteorological marvel, intensifying so rapidly that the term ‘bombogenesis’ is perhaps an understatement to describe its intensification”

-Andrew Freedman (Journalist)-

Rank	Name	Date	Minimum central pressure (hPa)
1	Braer	11 January 1993	913
2	Noname	15 December 1986	916
3	Dirk	24 December 2013	927
4	Frank	30 December 2015	928
5	Vivian	26 February 1990	940

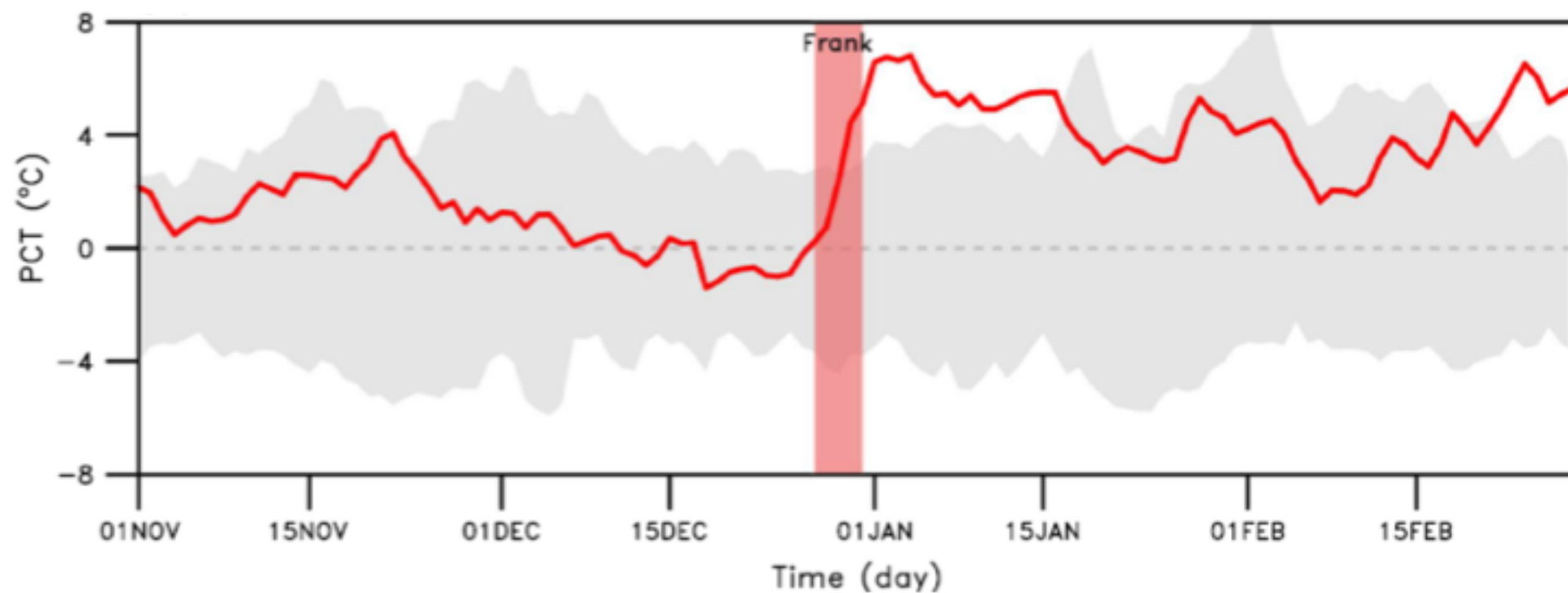
THERE WAS A MARVELOUS STORM

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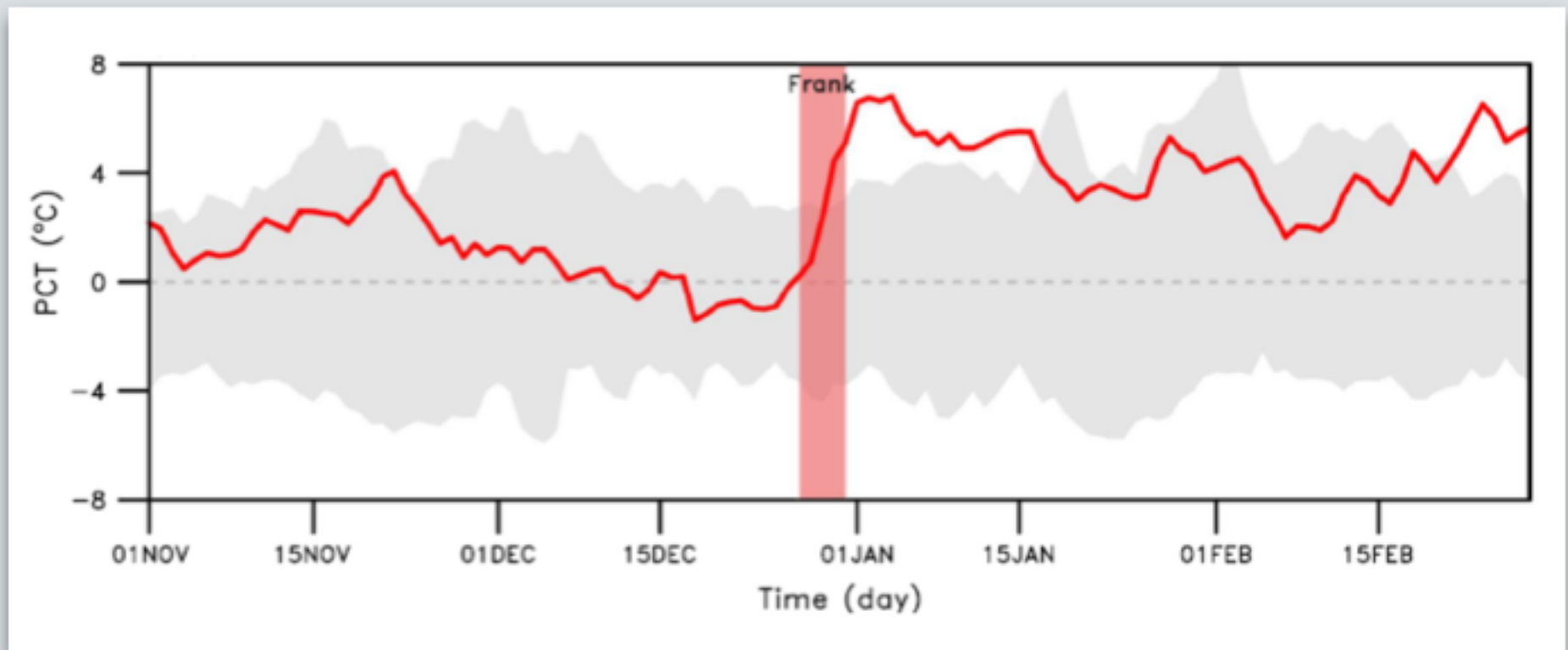
THERE WAS A MARVELOUS STORM



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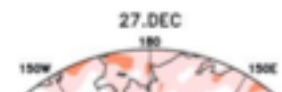
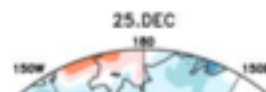


Kim, B.-M., J.-Y. Hong, S.-Y. Jun, X. Zhang, H. Kwon, S.-J. Kim, J.-H. Kim, S.-W. Kim, and H.-K. Kim (2017), Major cause of unprecedented Arctic warming in January 2016: Critical role of an Atlantic windstorm, *Sci. Rep.*, 7.

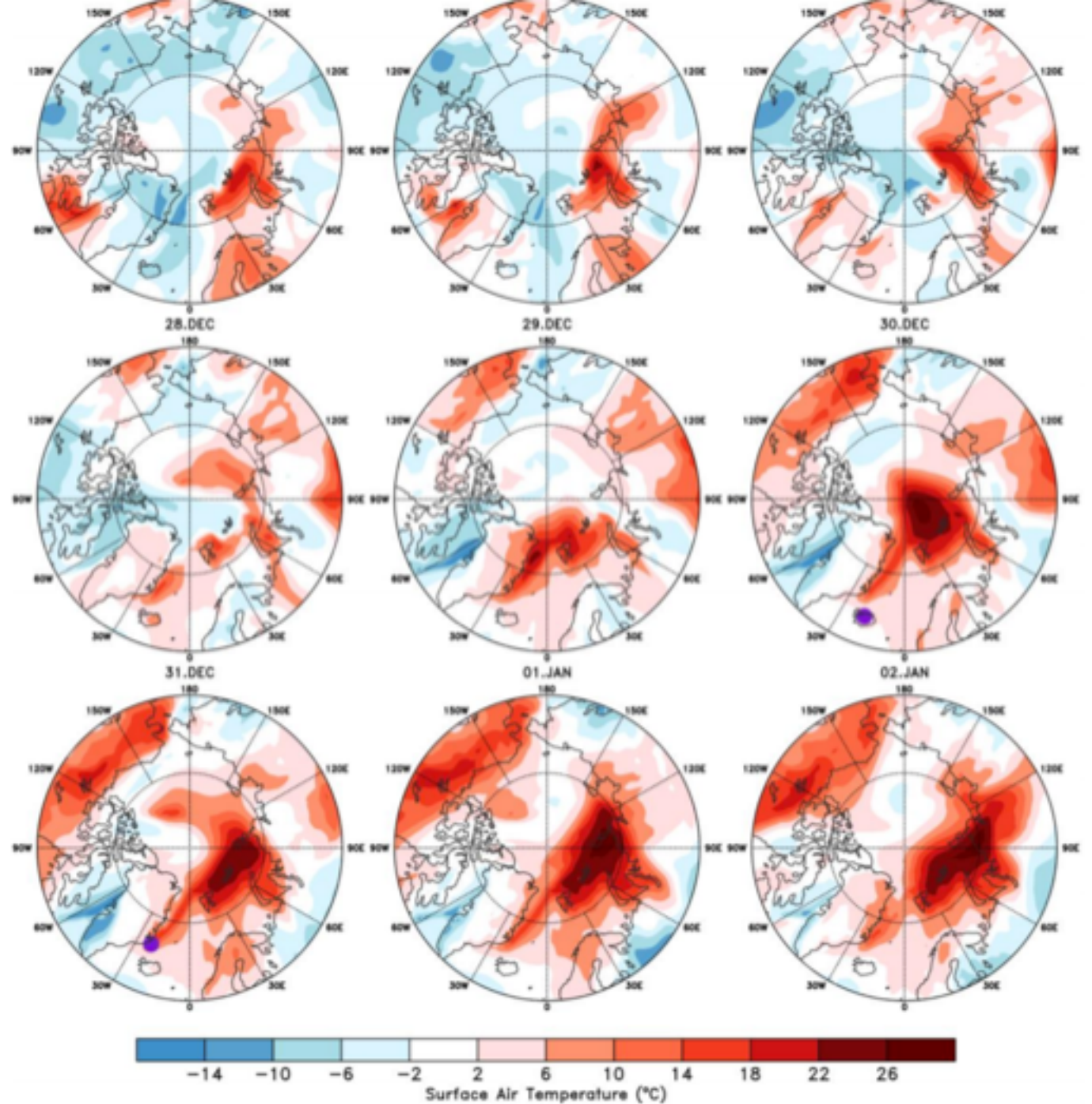
Moore, GWK (2016), The December 2015 North Pole warming event and the increasing occurrence of such events, *Sci. Rep.*, 6.

Cullather, R. I., Y.-K. Lim, L. N. Boisvert, L. Brucker, J. N. Lee, and S. M. J. Nowicki (2016), Analysis of the warmest Arctic winter, 2015-2016, *Geophys. Res. Lett.*, 43

Arctic



Arctic  
Amplification  
(25 Dec.-02 Jan)



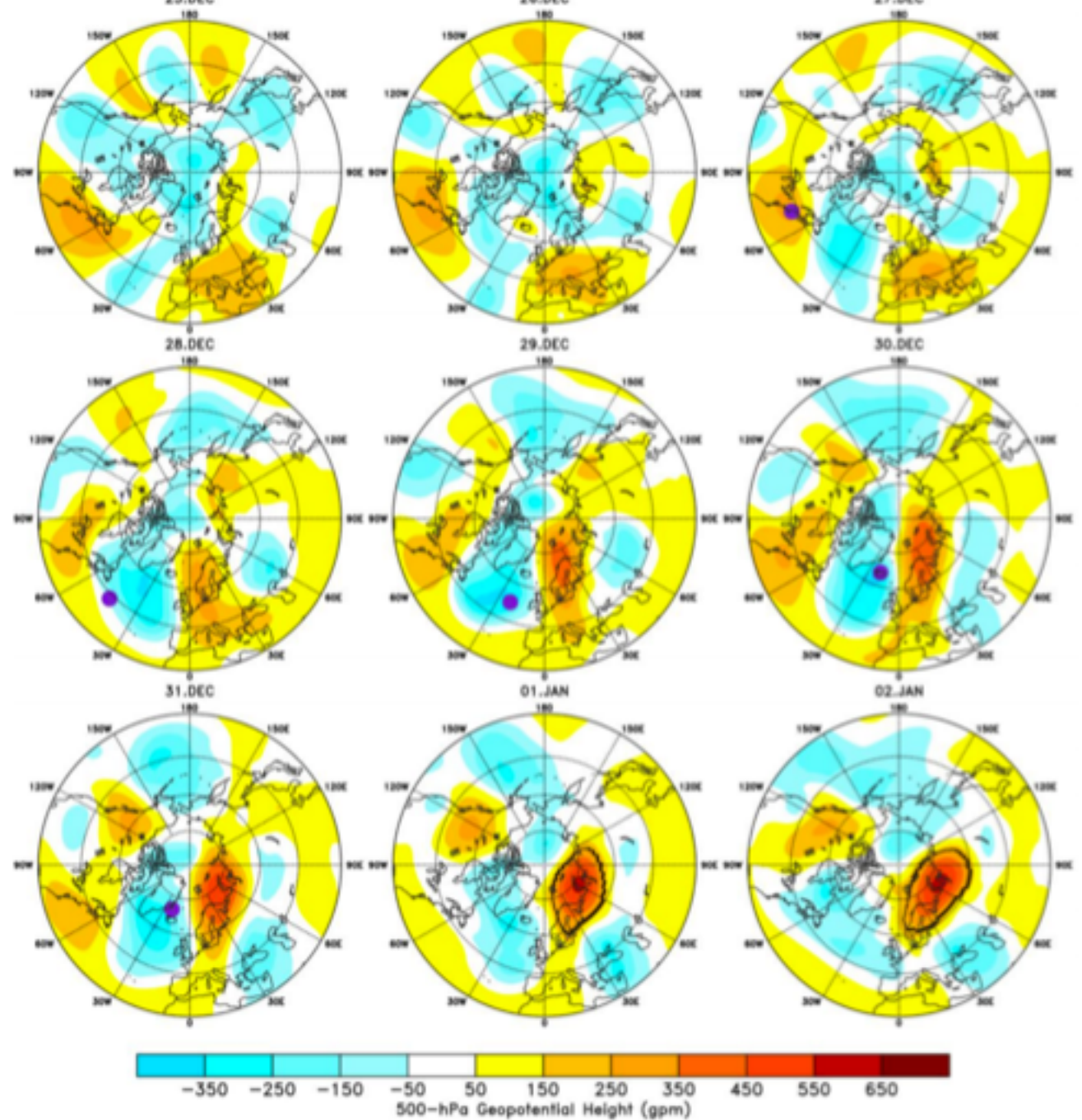
Arctic

25.DEC

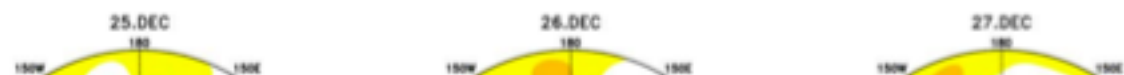
26.DEC

27.DEC

# Amplification (25 Dec.-02 Jan)

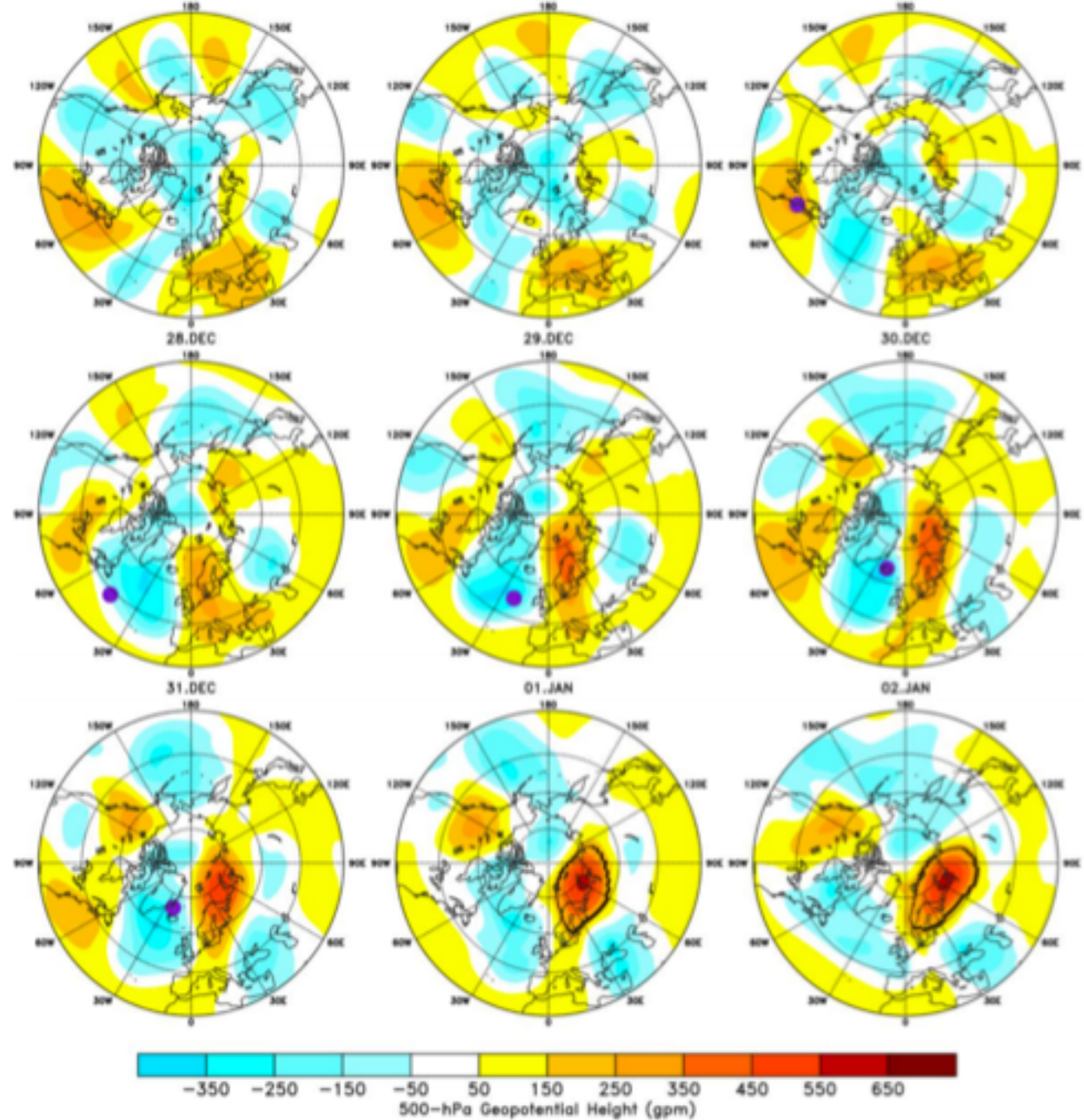


## Arctic Amplification



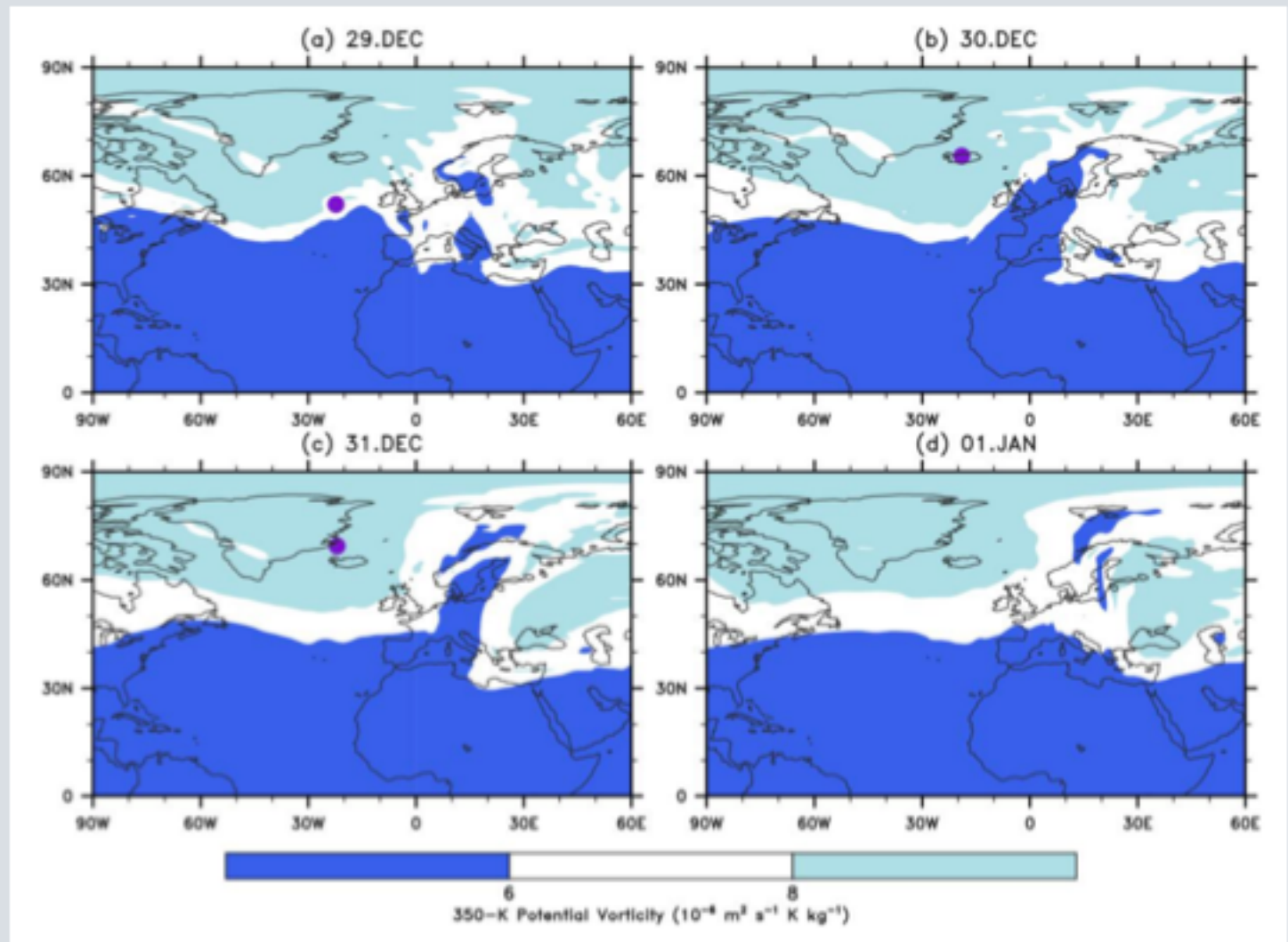


Amplification  
(25 Dec.-02 Jan)



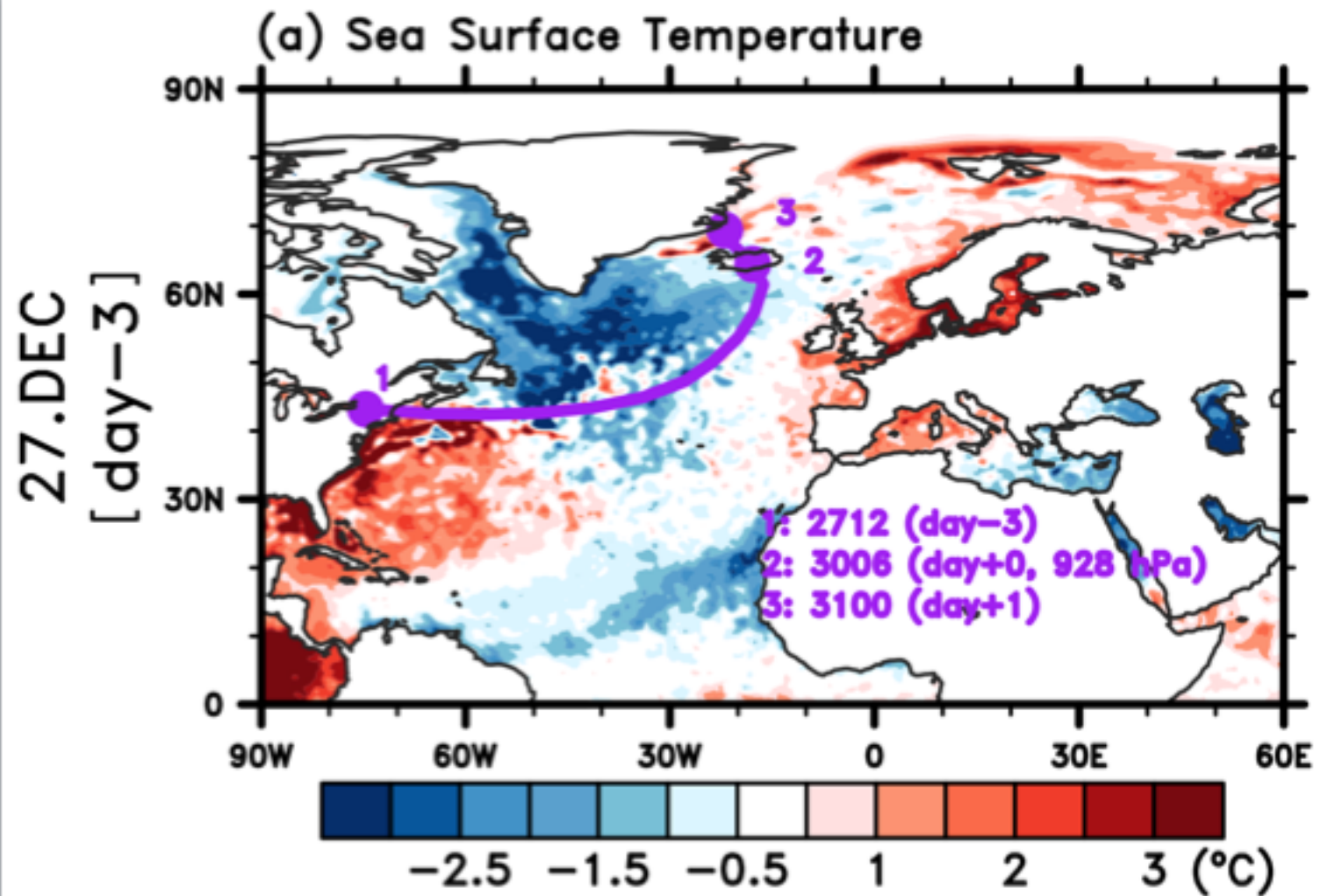
Wave Breaking

Wave Breaking  
(29 Dec.-01 Jan)



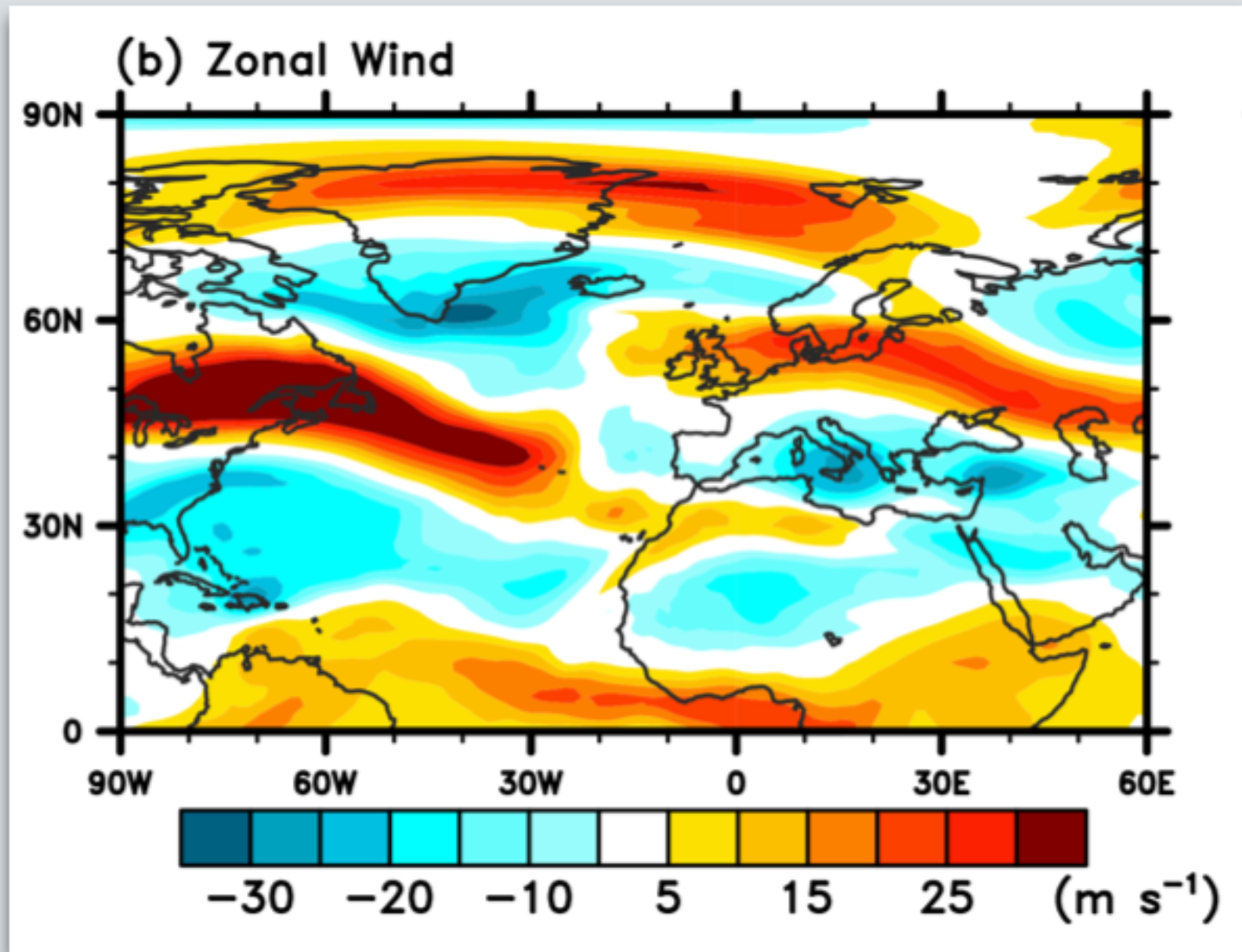
A clear signature of Anticyclonic Rossby Wave-breaking

Large-scale Background (27 Dec.)

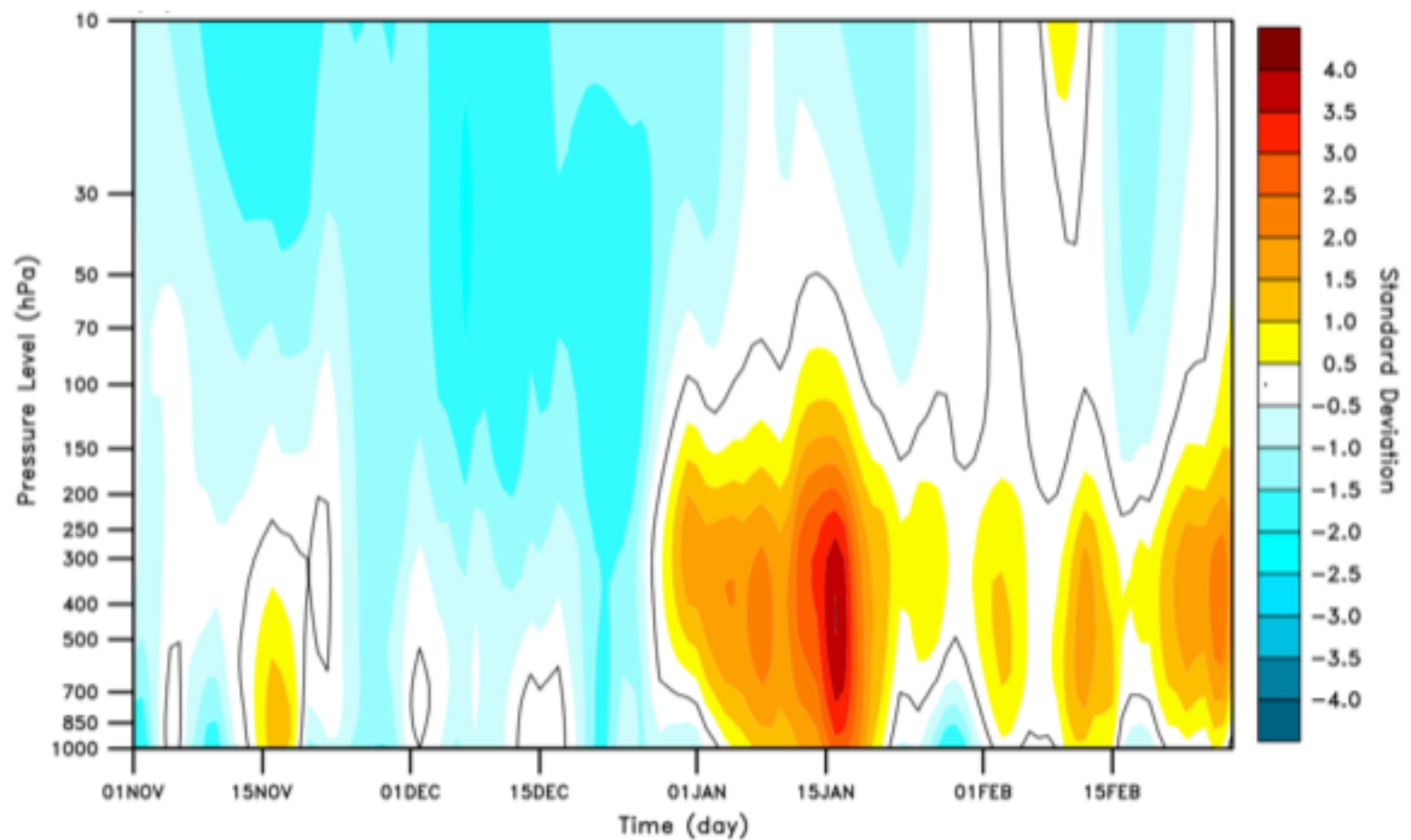


Large-scale Background (27 Dec.)





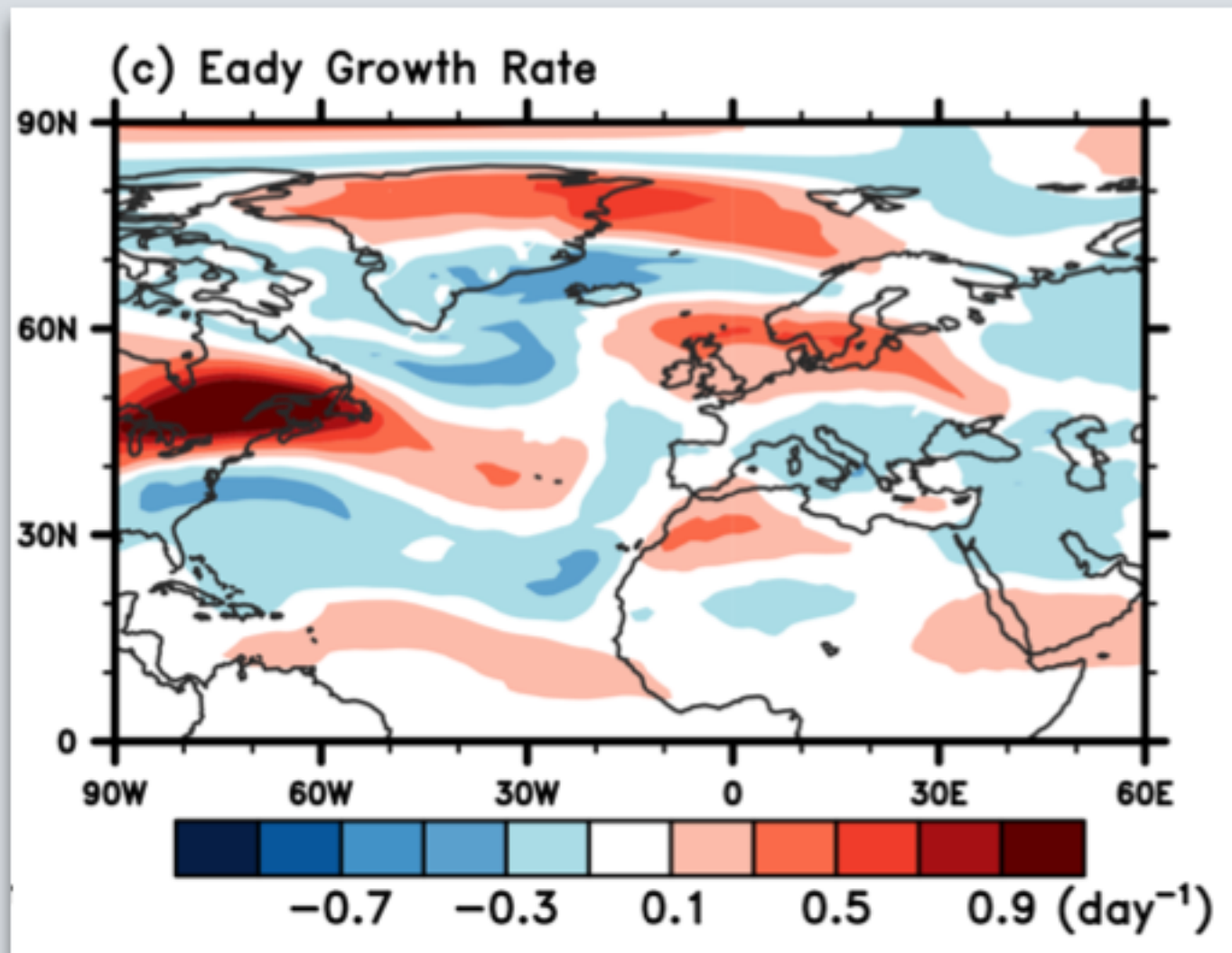
Regime shift by one single storm breaking?



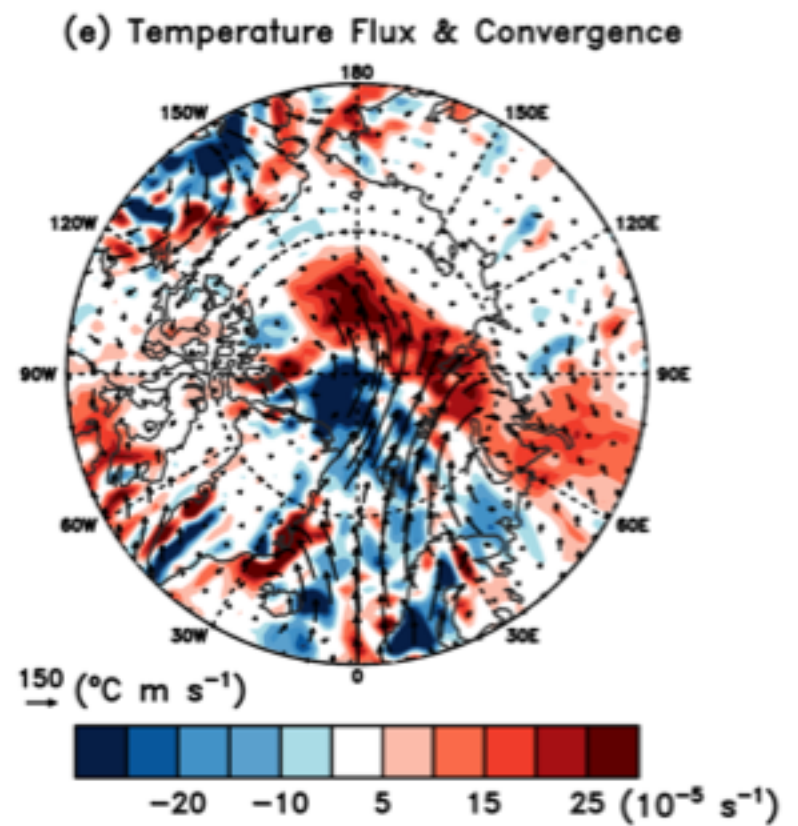
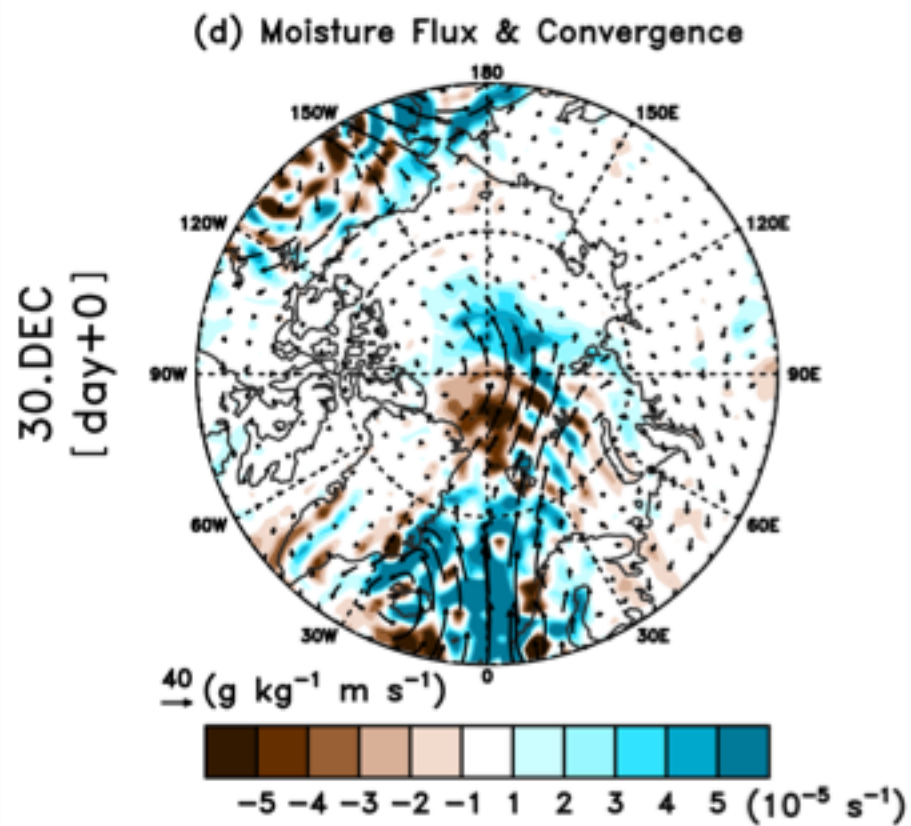
<Polar Cap Height (Arctic-averaged GPH) anomaly>

Large-scale Background (27 Dec.)



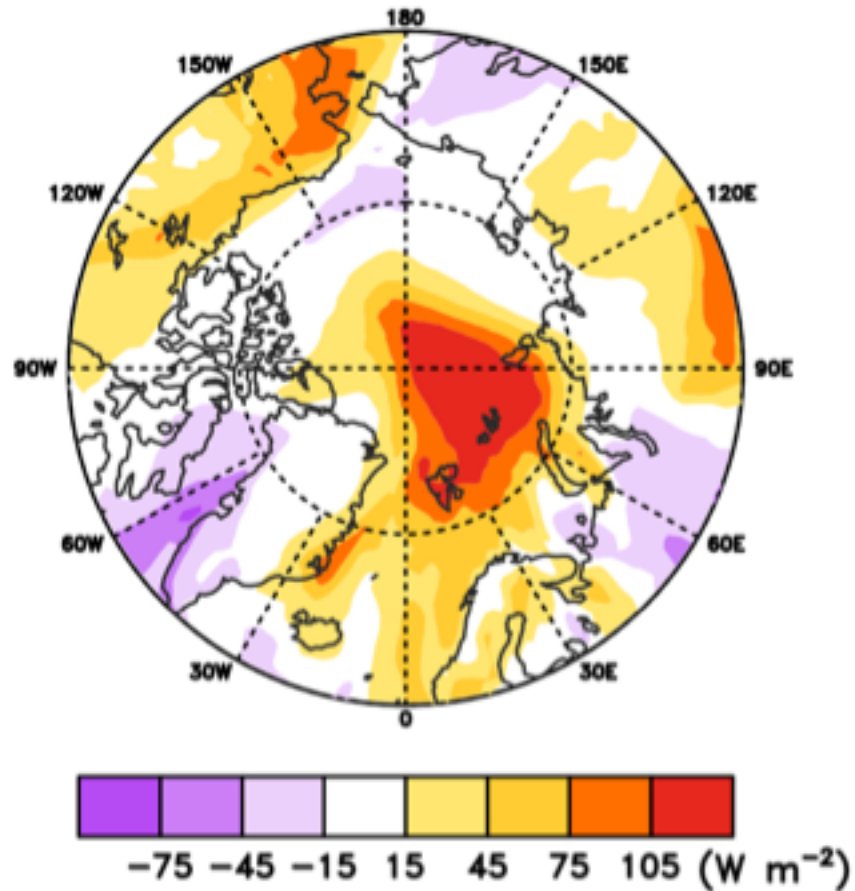


Heat & moisture intrusion (30 Dec.)

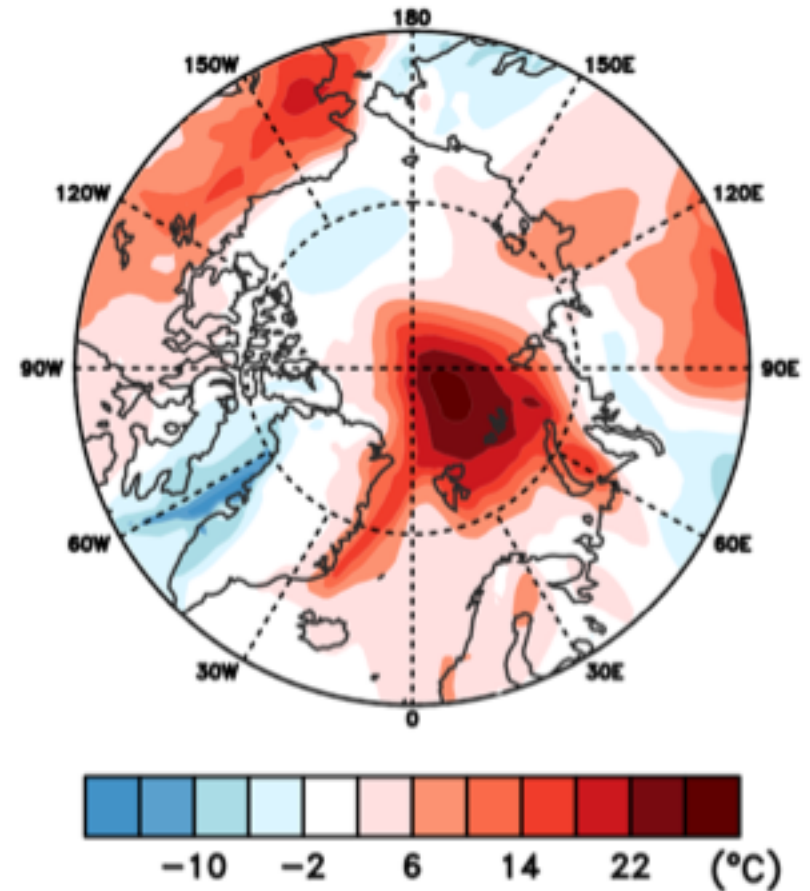


DLR & Temp. anomaly (30 Dec.)

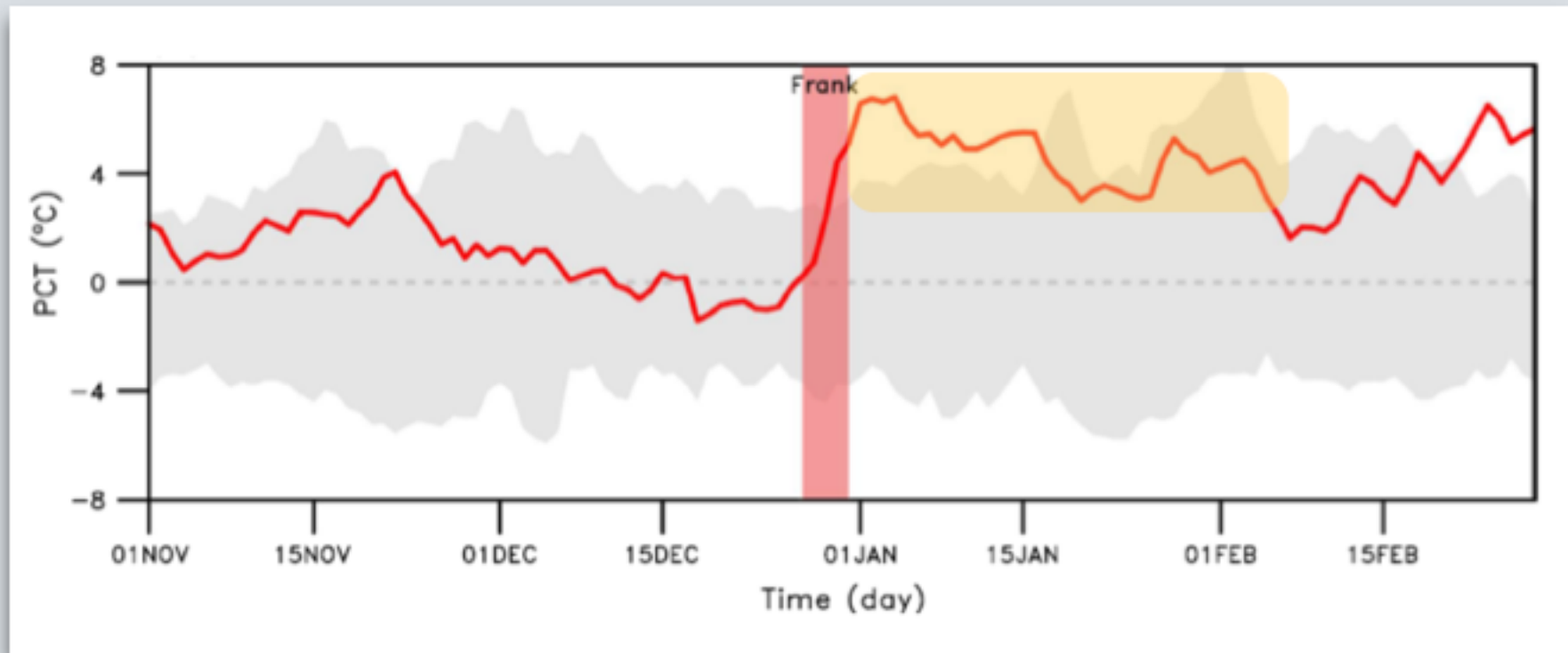
(f) Surface Downward Longwave Radiation



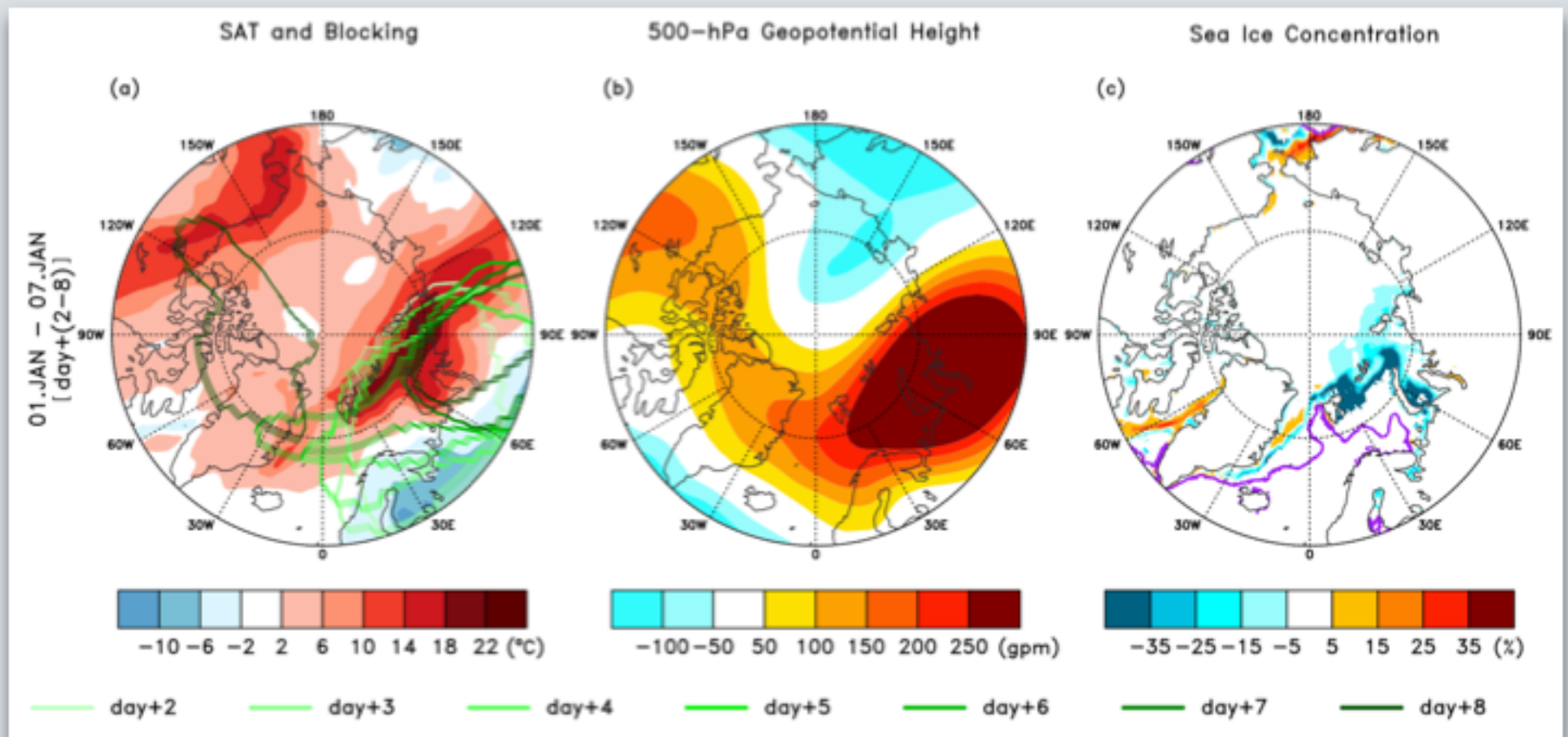
(g) Surface Air Temperature



Extreme warmth is maintained after the storm. Why? (01 Jan. - 07 Jan.)



Occurrence of Ural blocking & significant sea-ice loss (01 Jan. - 07 Jan.)

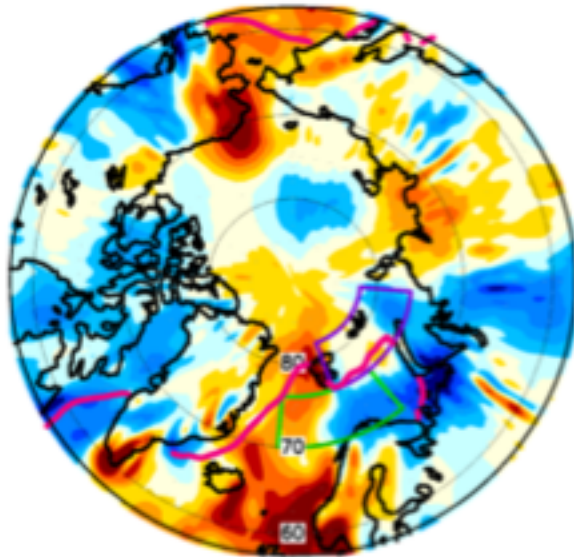


Warm advection by Ural blocking & Turbulent heat flux from bottom might be a sustaining mechanism after the storm

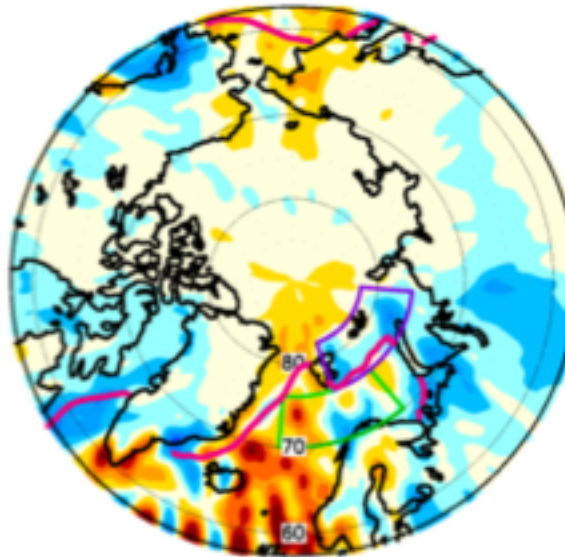
Relative contribution of energy transport & sea-ice loss



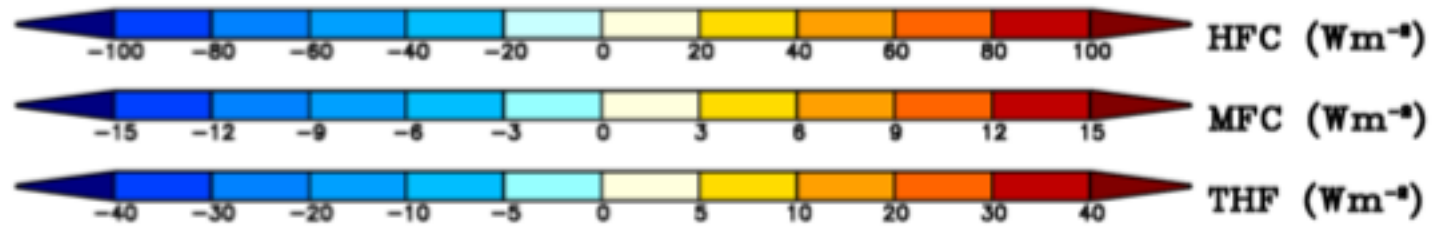
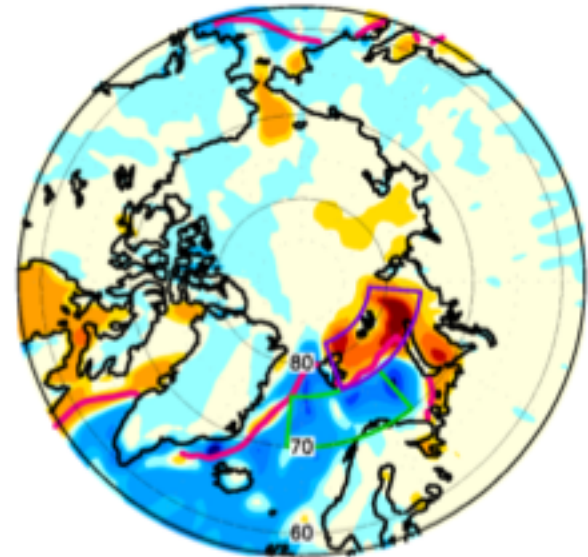
(a) Heat flux conv



(b) Moisture flux conv



(c) Turbulent heat flux

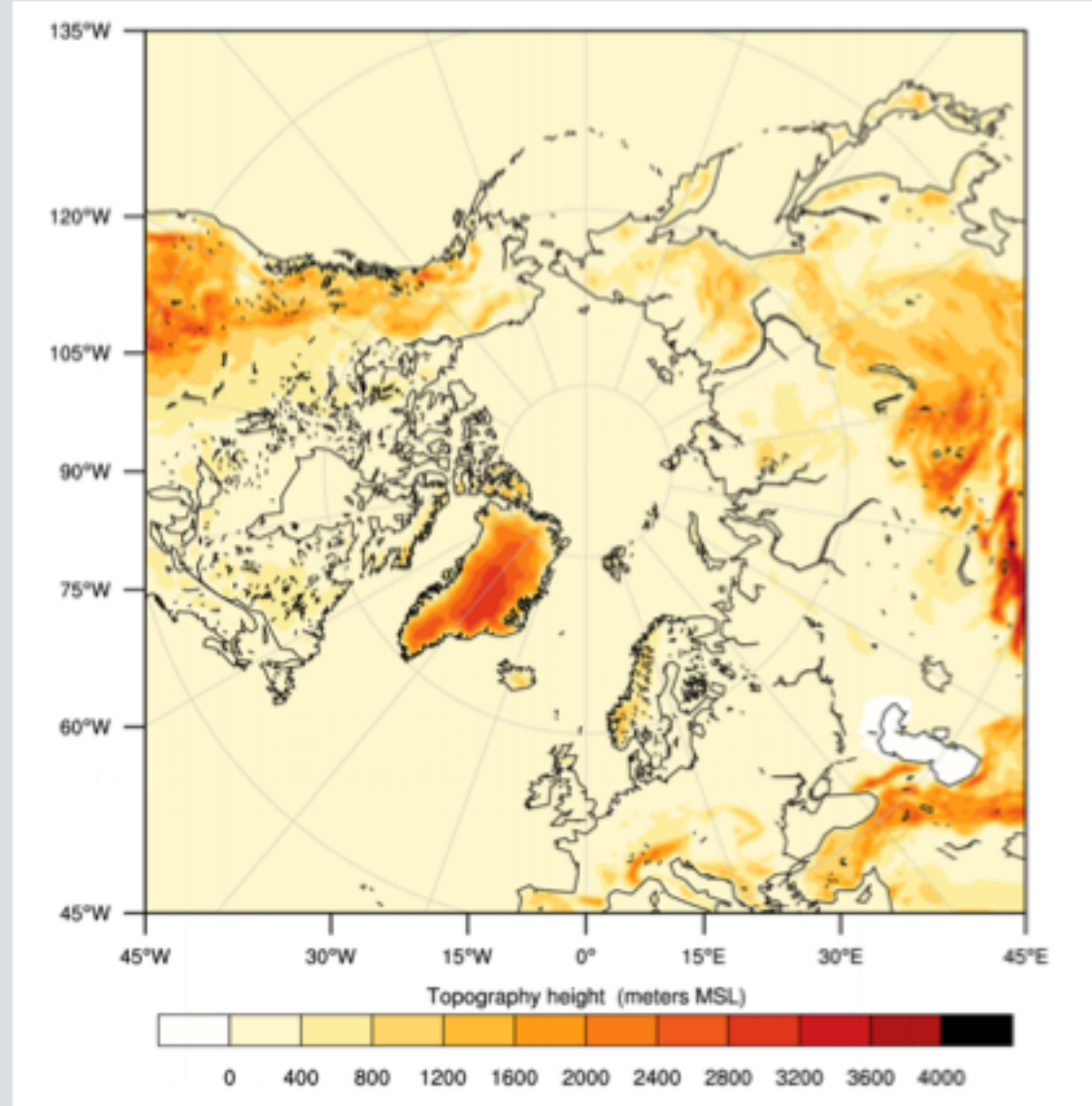


Kim & Kim (2017, accepted in JC)

Kim, H.-M. & B.-M. Kim (2017),  
Relative contributions of atmospheric energy transport and sea-ice loss to the recent warm Arctic  
winter, Journal of Climate (Accepted)

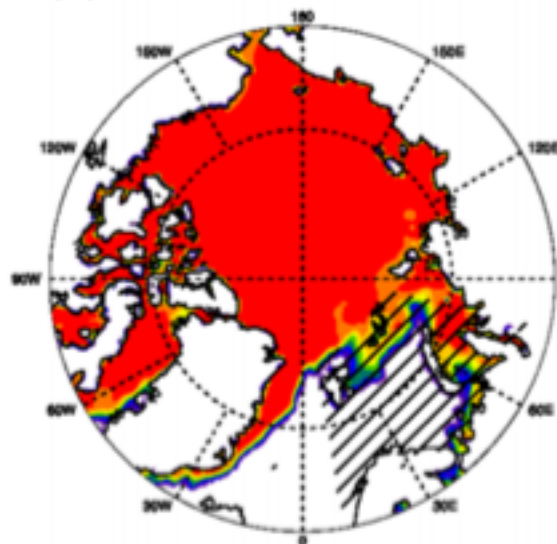
Polar WRF simulation with sea-ice sensitivity

- Polar Weather Research and Forecast model (WRF) with a 36 km horizontal resolution
- IC: NCEP FNL analysis
- 5 lagged ensembles
- Simulation period:  
27 Dec. 2015-20 Jan. 2016

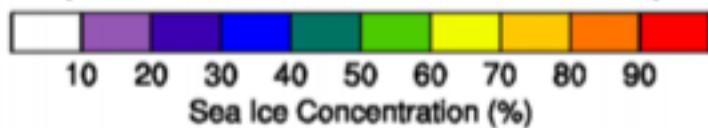
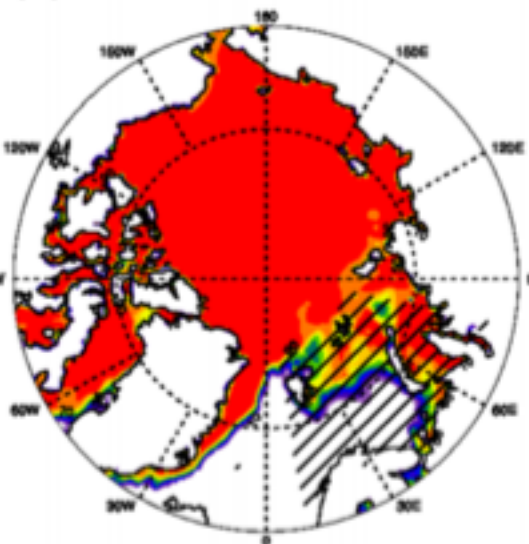


Polar WRF simulation with sea-ice sensitivity

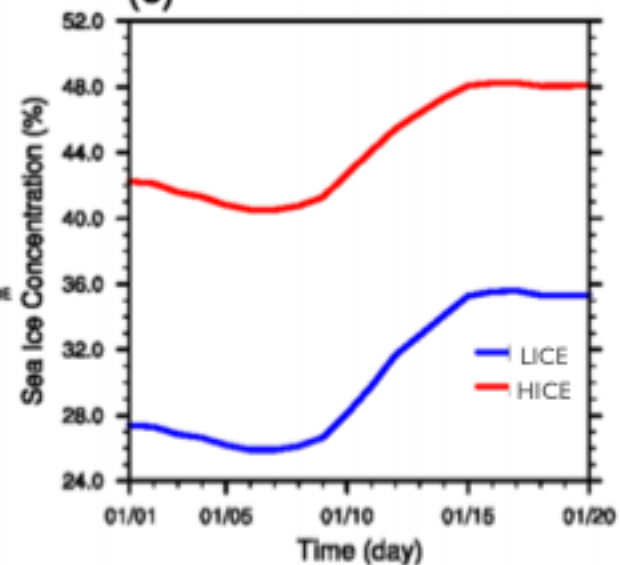
(a) LICE RUN



(b) HICE RUN



(c)

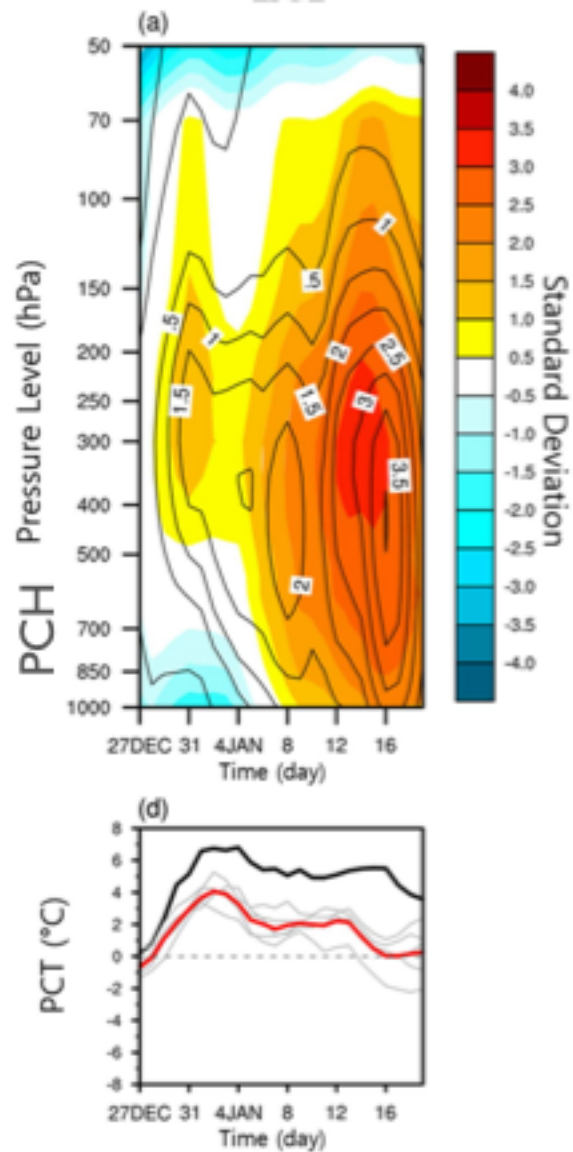


Polar WRF simulation with sea-ice sensitivity

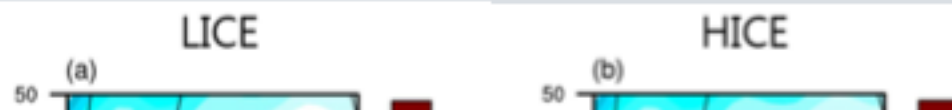
LICE

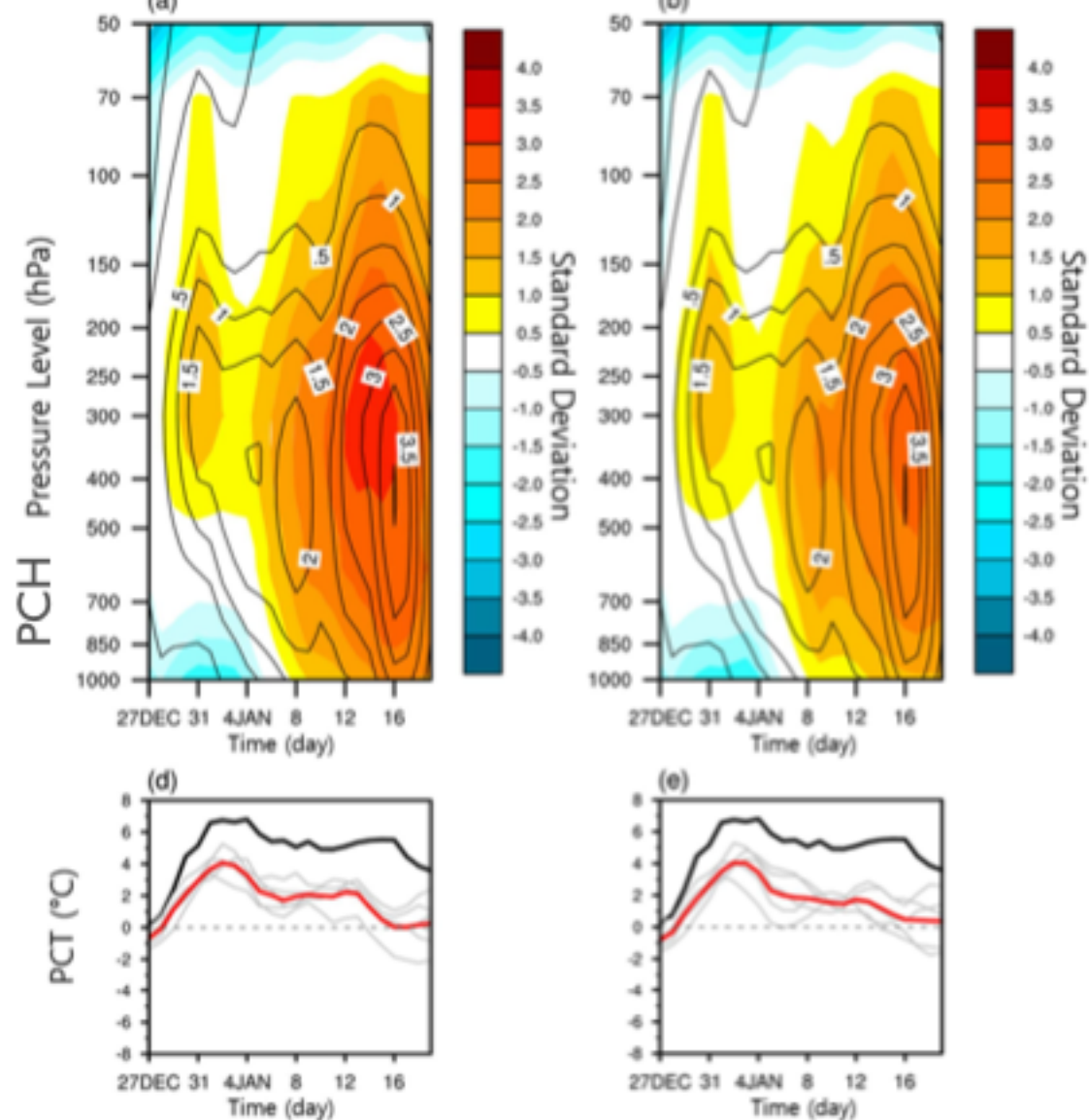
(a)





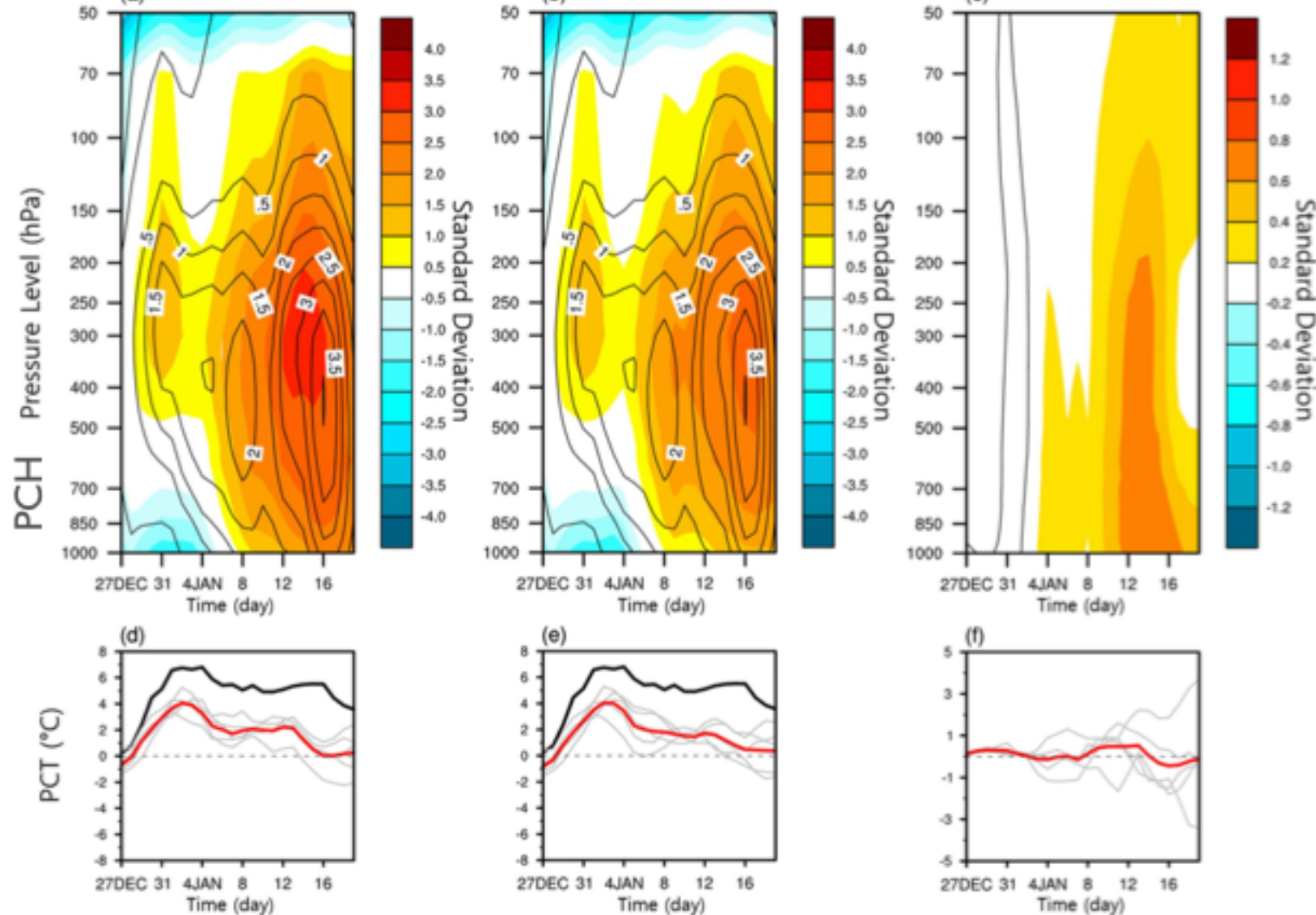
Polar WRF simulation with sea-ice sensitivity





Polar WRF simulation with sea-ice sensitivity





Final remarks

- I am still not sure if this single event can be directly linked to the concept of

- I am still not sure if this single event can be directly linked to the concept of Arctic amplification because community does not clearly define Arctic amplification yet (i.e. Time-scale or regional pattern).
- Also, it is not known how this kind of extreme events can be linked to the long-term Arctic warming trend.
- Therefore, we should investigate whether triggering a pulse of Arctic warming by an intense synoptic storm and the subsequent development of planetary-scale blocking flows have contributed to Arctic warming in a more general perspective (Case study is a case study...)