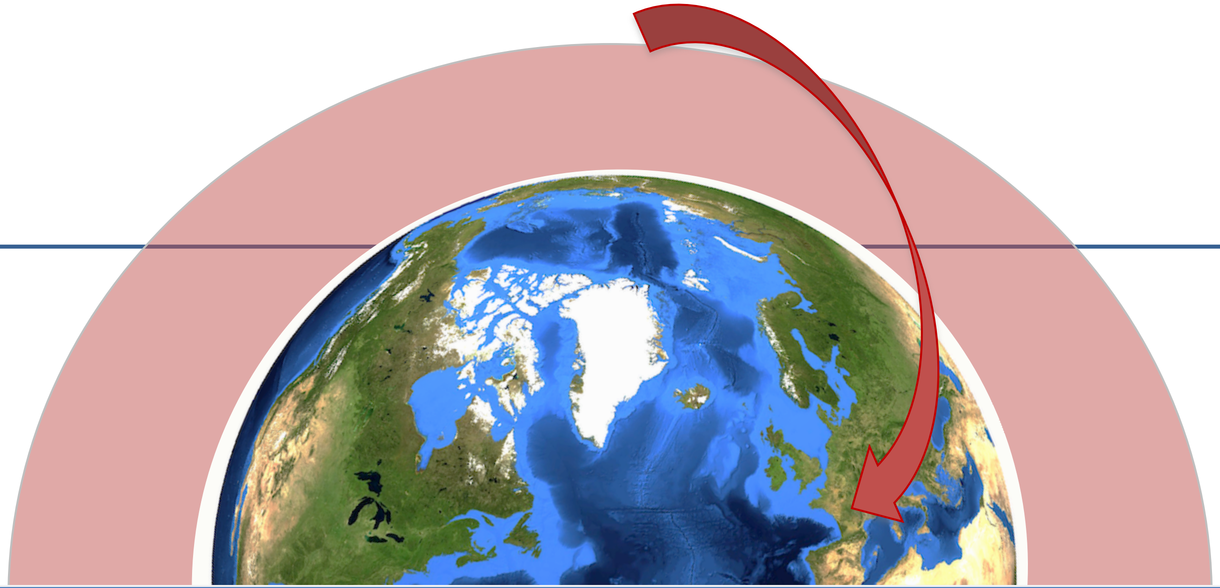

# The dynamics and predictability of sudden stratospheric warmings and their surface impacts


## Daniela Domeisen
**Atmospheric Predictability, ETH Zurich**

with contributions from
**Bernat Jiménez-Esteve, Alexander Wollert, Hilla Gerstman-Afargan, Amy Butler, Andrew Charlton-Perez, Peter Hitchcock, Christian Grams, Lukas Papritz**




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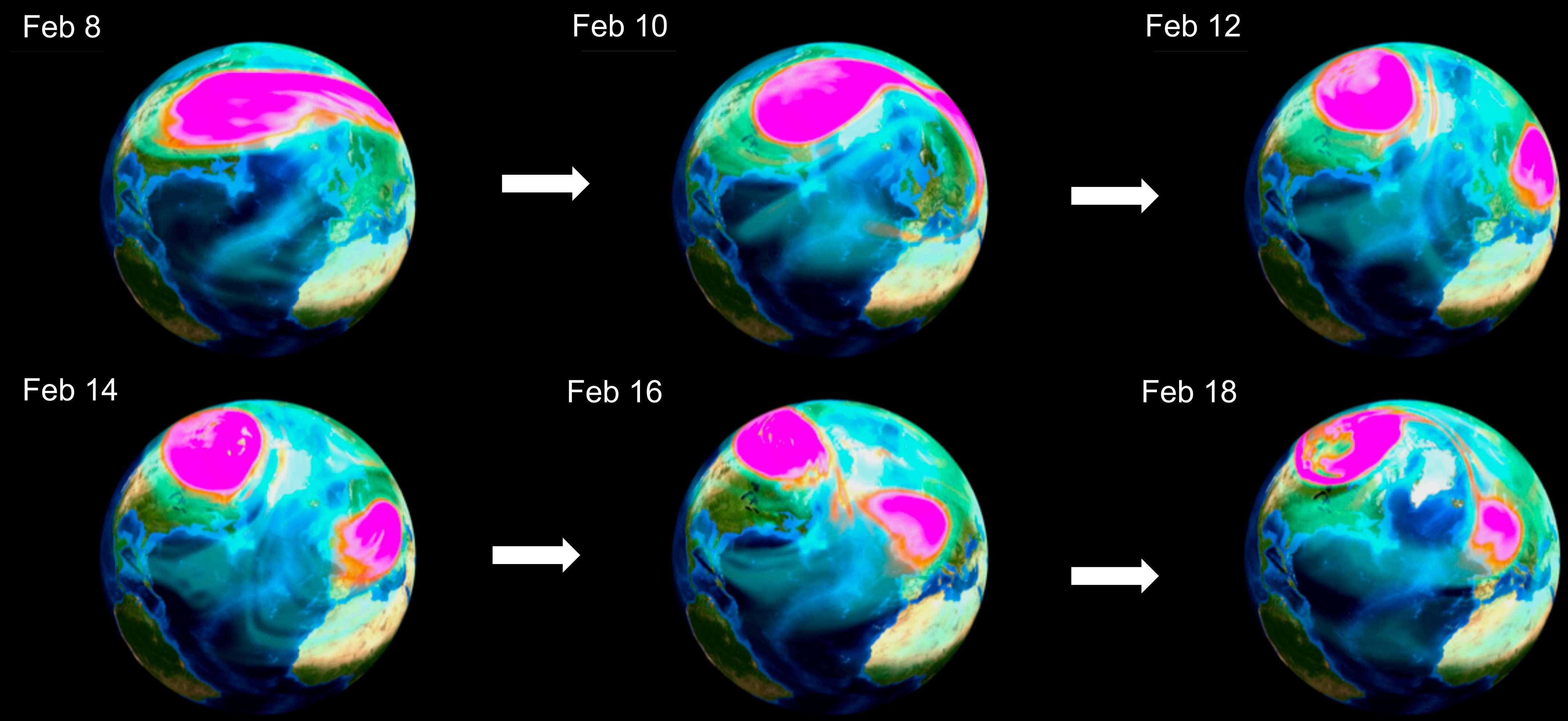
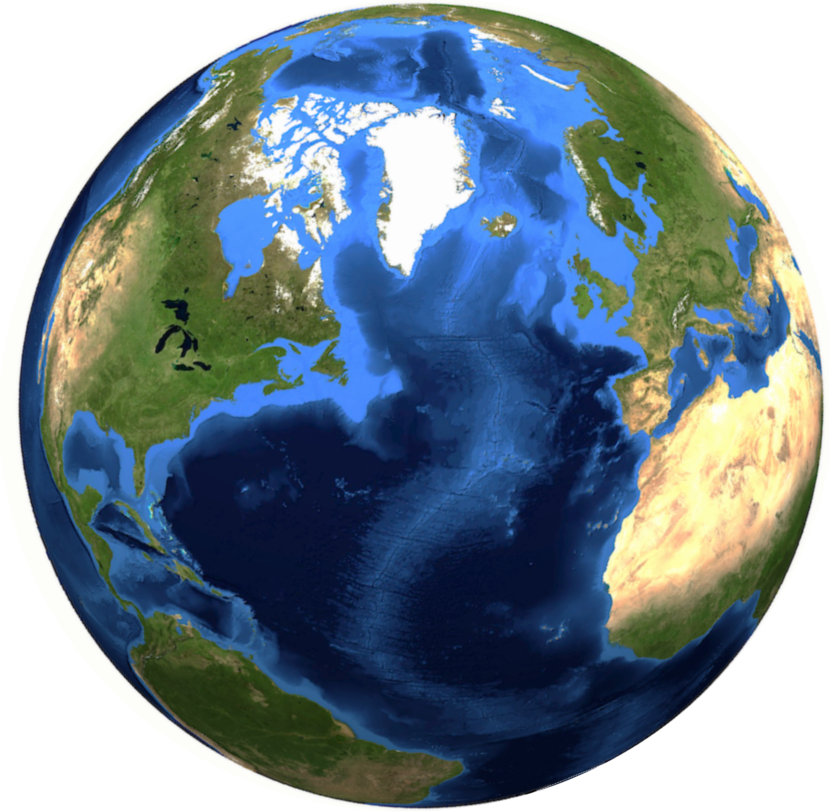
# THE SUDDEN STRATOSPHERIC WARMING EVENT ON FEBRUARY 12, 2018




Figures: potential vorticity at 10hPa by Alexander Wollert

# PART I: WHY DO WE CARE ABOUT THE STRATOSPHERE?

Part I. The diversity of sudden stratospheric warming events



Part II. The diversity of the tropospheric impact

# WHAT IS THE PREDICTABILITY LIMIT FOR SUDDEN STRATOSPHERIC WARMINGS?



The central date of a sudden stratospheric warming (SSW) event is not predictable beyond ~2 weeks.

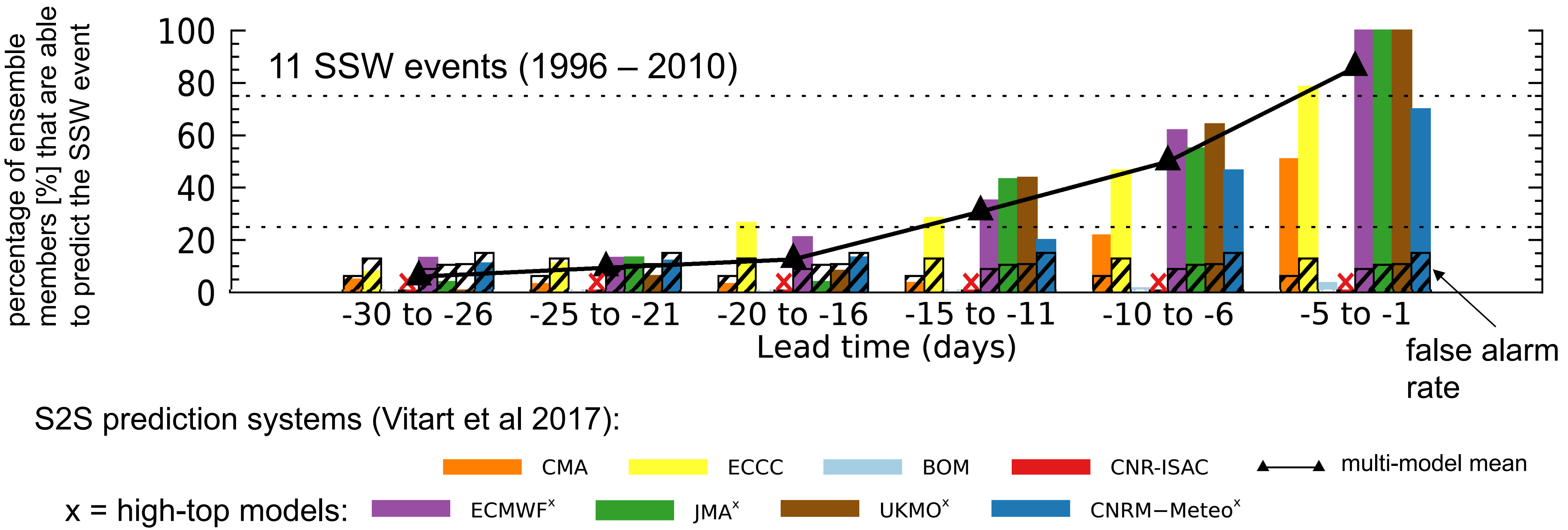



Figure: M. Taguchi & A. Butler.
From: Domeisen et al., 2019, JGR special issue on S2S prediction



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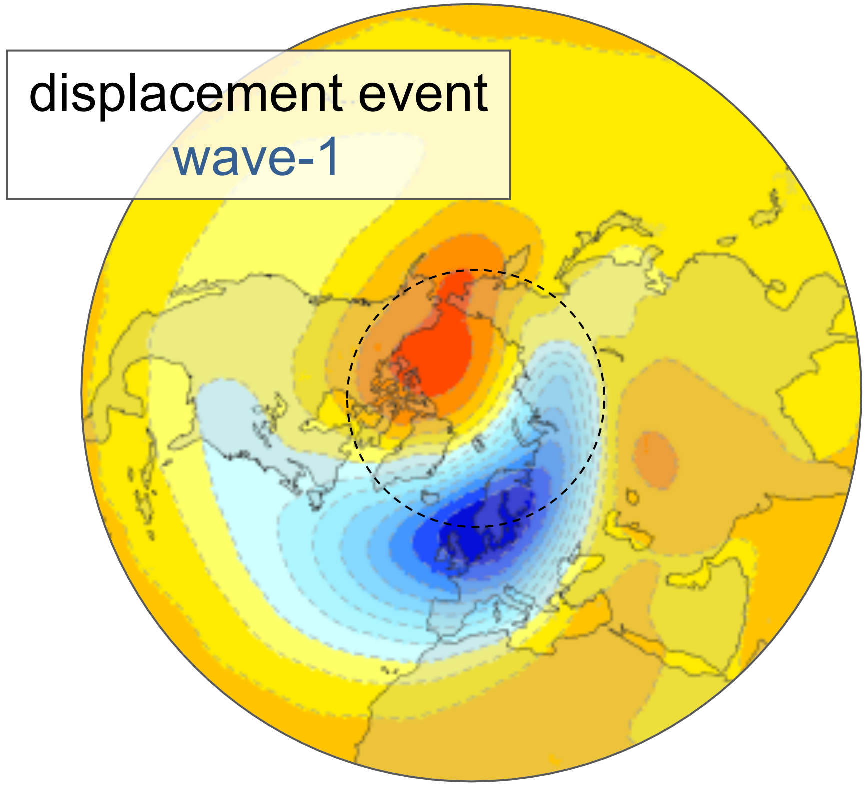
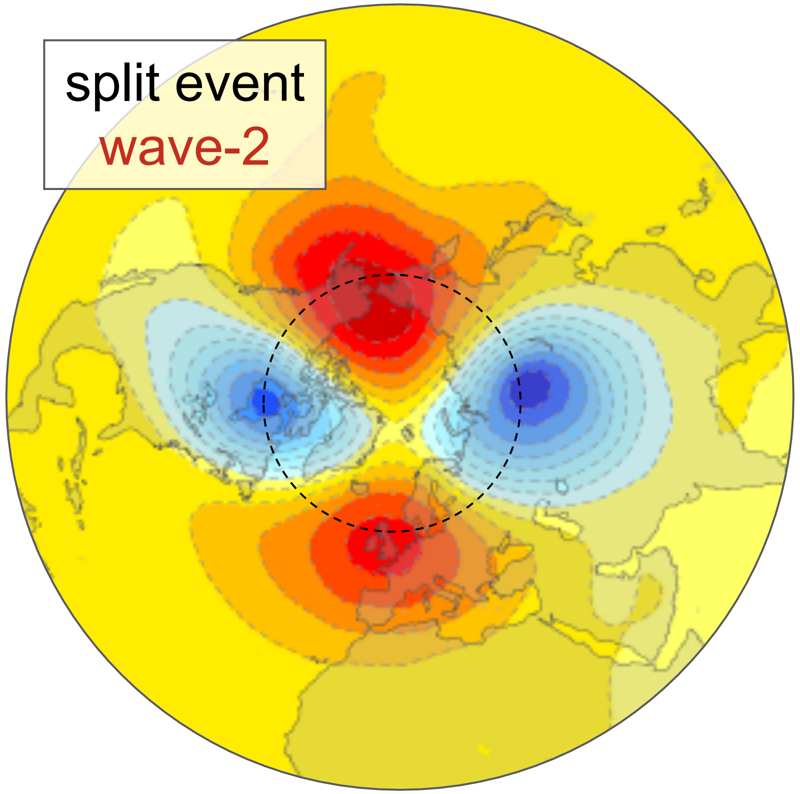
# DIFFERENT TYPES OF SUDDEN STRATOSPHERIC WARMINGS



In the stratosphere (10hPa): Sudden Stratospheric Warming (SSW) events can be characterized as…




Jan 5, 2004




Jan 24, 2009



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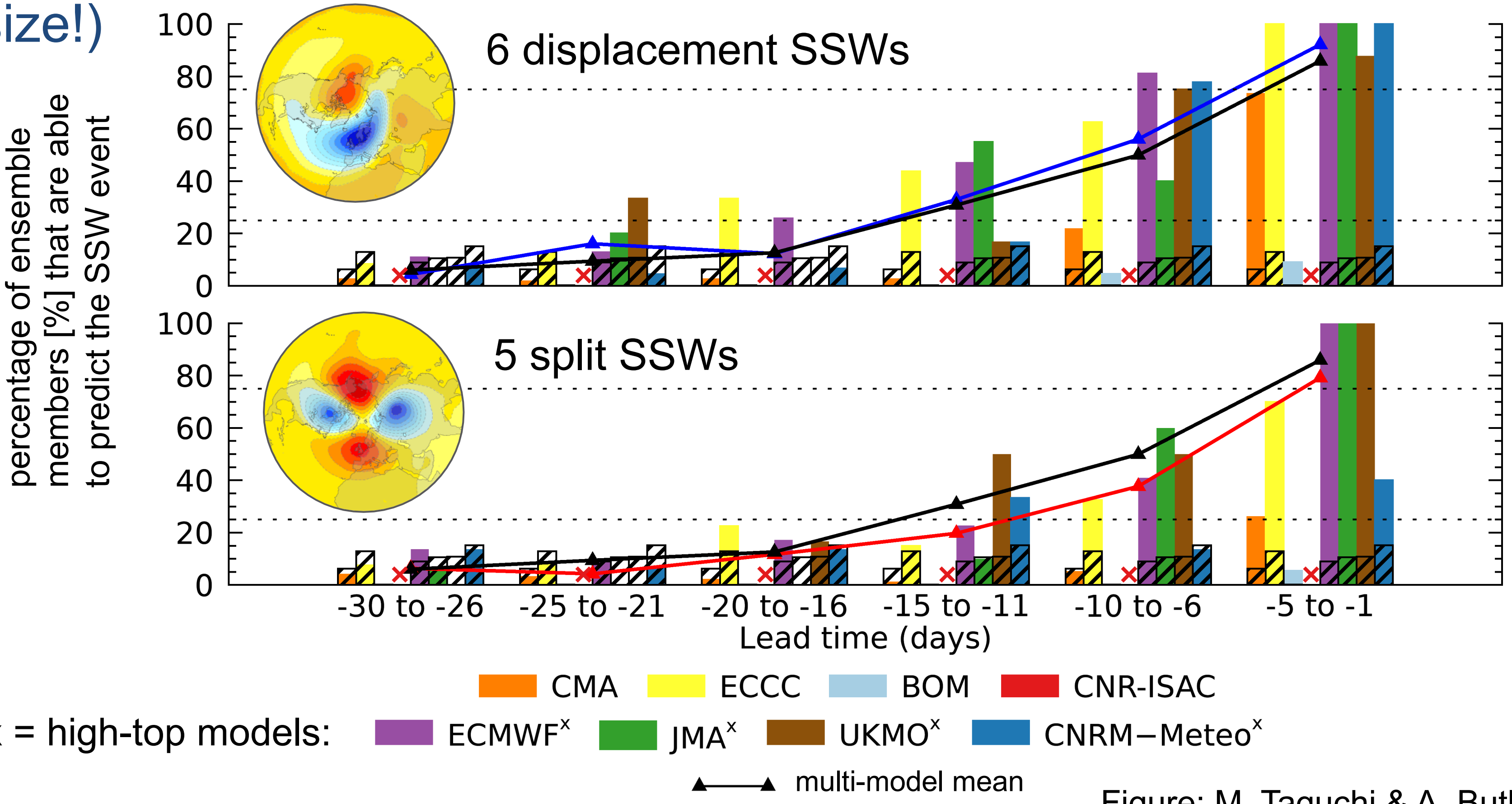
# THE PREDICTABILITY DIFFERS FOR DIFFERENT TYPES OF SSW EVENTS



## Split SSW events tend to be less predictable than displacement events (note the small sample size!)

Data: S2S prediction systems (Vitart et al 2017)




Can the difference in predictability of these events tell us anything about the different dynamics of these events?

SSW = sudden stratospheric warming

Figure: M. Taguchi & A. Butler. From: Domeisen et al., 2019, JGR special issue on S2S prediction



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# THE DYNAMICS: SSWS ARE CAUSED BY UPWARD PROPAGATING WAVES



## Upward propagation of planetary Rossby waves is limited to a range of background wind speeds whose limits depend on the wave characteristics

zonal phase speed of the wave

$$0 < \bar{u} - c < U_c = f(1/k^2)$$

background zonal wind

critical velocity

zonal wavenumber

The majority of waves are stationary (c = 0), but c ≠ 0 can have important consequences:

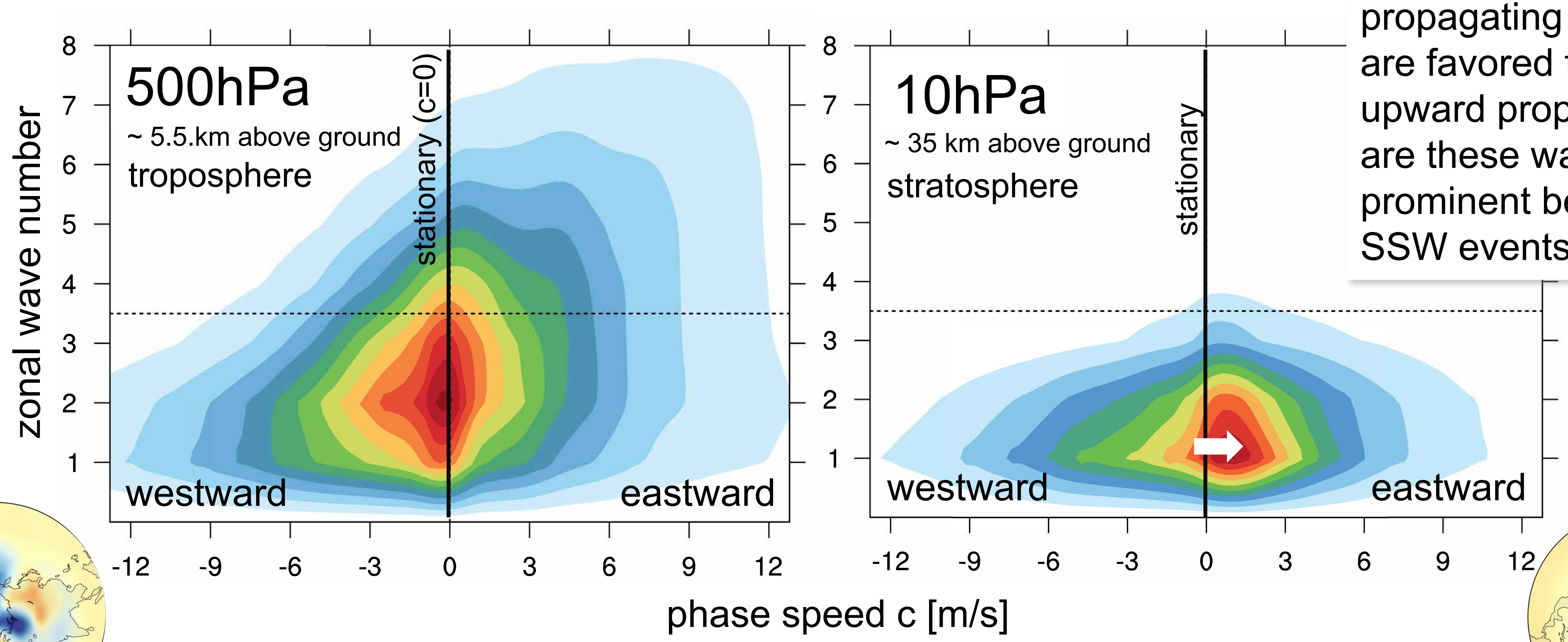
For c > 0, the propagation window opens towards higher wind speeds u.

For c < 0, the propagation window closes for high wind speeds u.

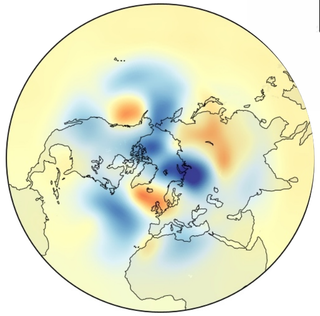
following Charney & Drazin (1961)

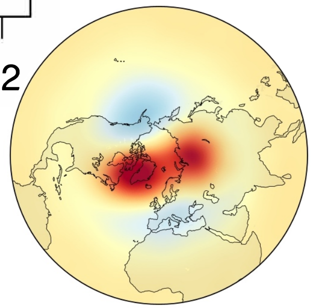
# HOW DO THESE CONSTRAINTS MANIFEST IN THE ATMOSPHERE?

## Peak moves towards eastward propagating waves with height




If eastward propagating waves are favored for upward propagation, are these waves prominent before SSW events?





Figures: Domeisen, Martius, Jiménez-Esteve, 2018, GRL



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# CAN SIMPLE MODELS REPRODUCE THIS?



Model: GFDL dry dynamical core (Held-Suarez)

Increased eastward phase speed for model simulation with SSW events

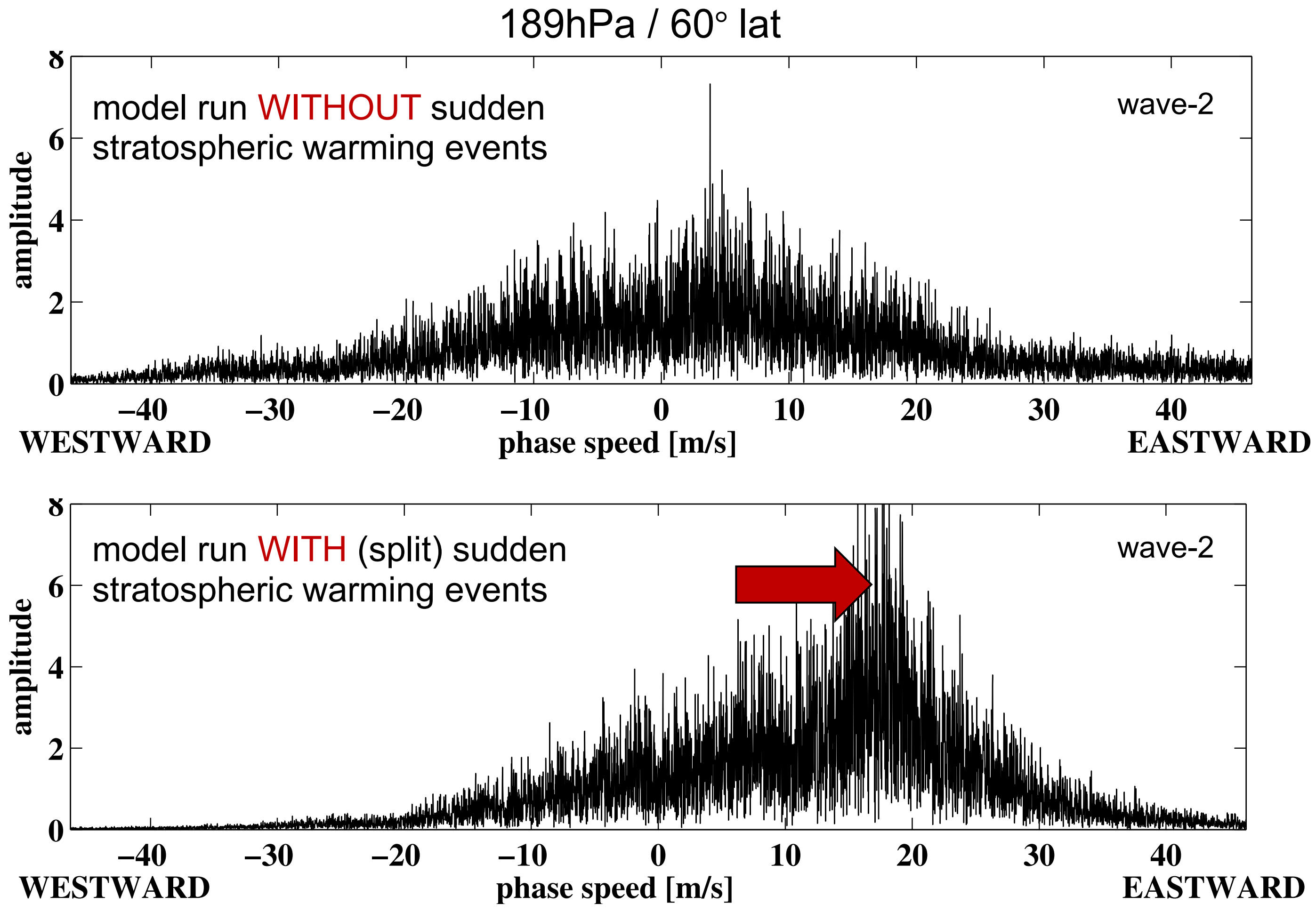
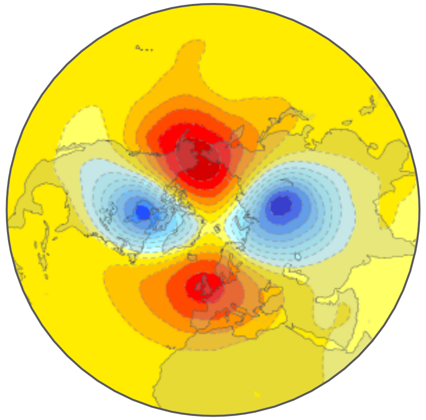


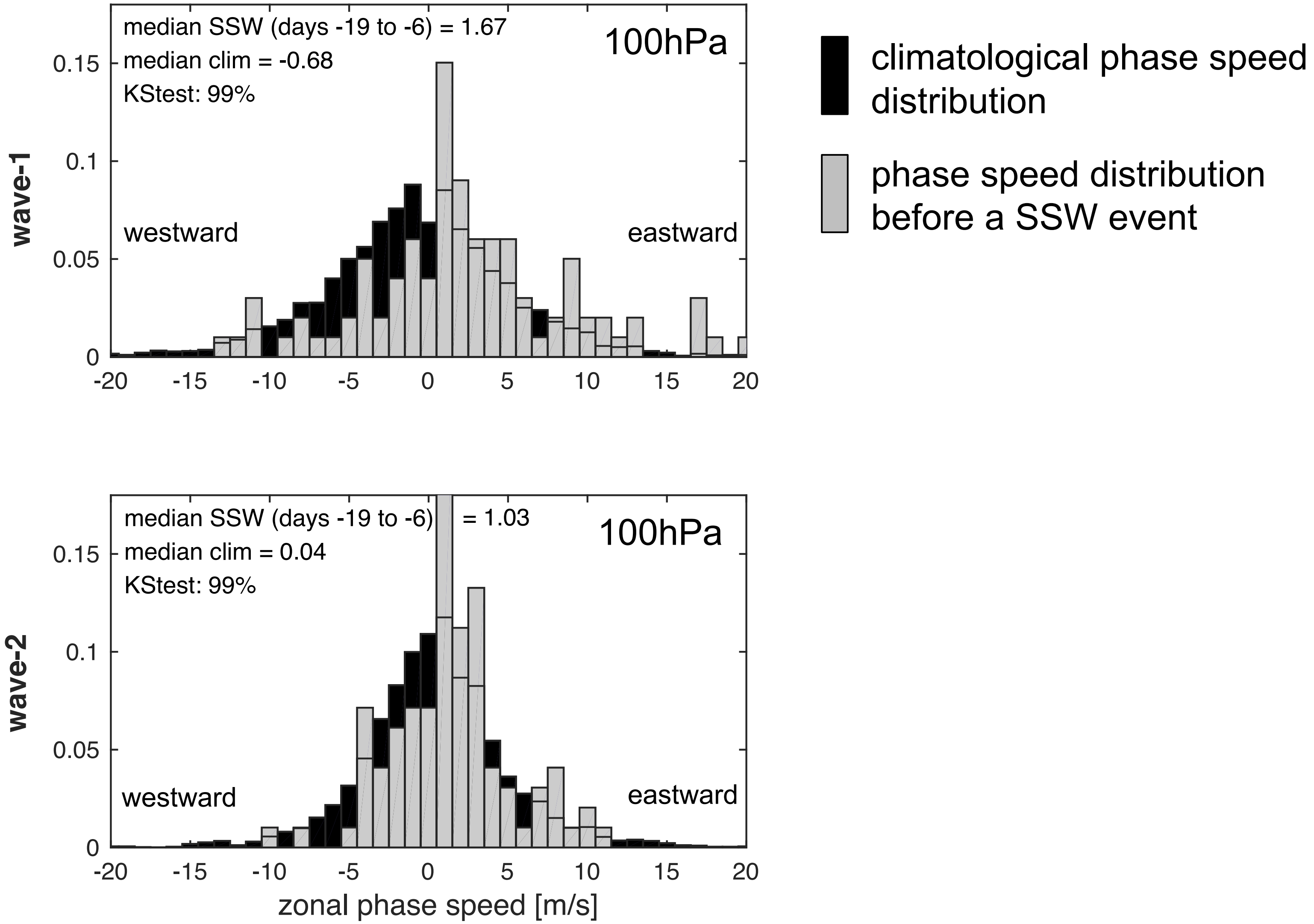

Figure: Domeisen & Plumb, 2012, GRL

# ARE EASTWARD PHASE SPEEDS FAVORED BEFORE SSWS IN REANALYSIS?

Part I – Part II

Increased eastward phase speed before split SSW events






Split SSW events are likely helped along by increased zonal phase speeds

Figure: Domeisen, Martius, Jiménez-Esteve, 2018, GRL



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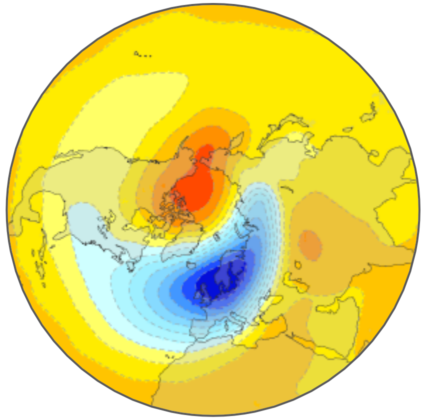
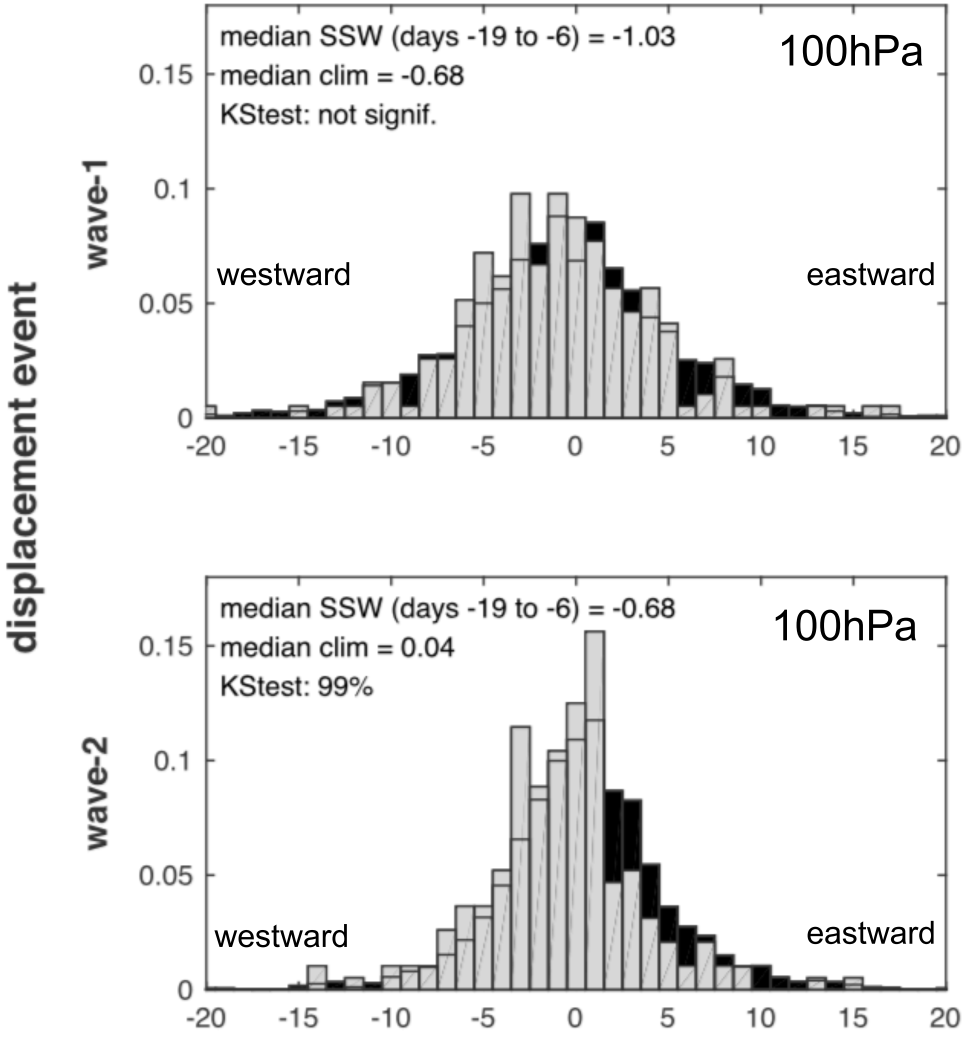
# THIS IS NOT THE CASE FOR DISPLACEMENT SSWS



Phase speed does NOT play a major role before displacement SSW events

Displacement events instead exhibit a large increase in amplitude of wave-1.






■ climatological phase speed distribution

□ phase speed distribution before a SSW event

wave-2 is not helping with displacement events

Do split and displacement SSW events exhibit different predictability because they are driven by a different mechanism?

Figure: Domeisen, Martius, Jiménez-Esteve, 2018, GRL



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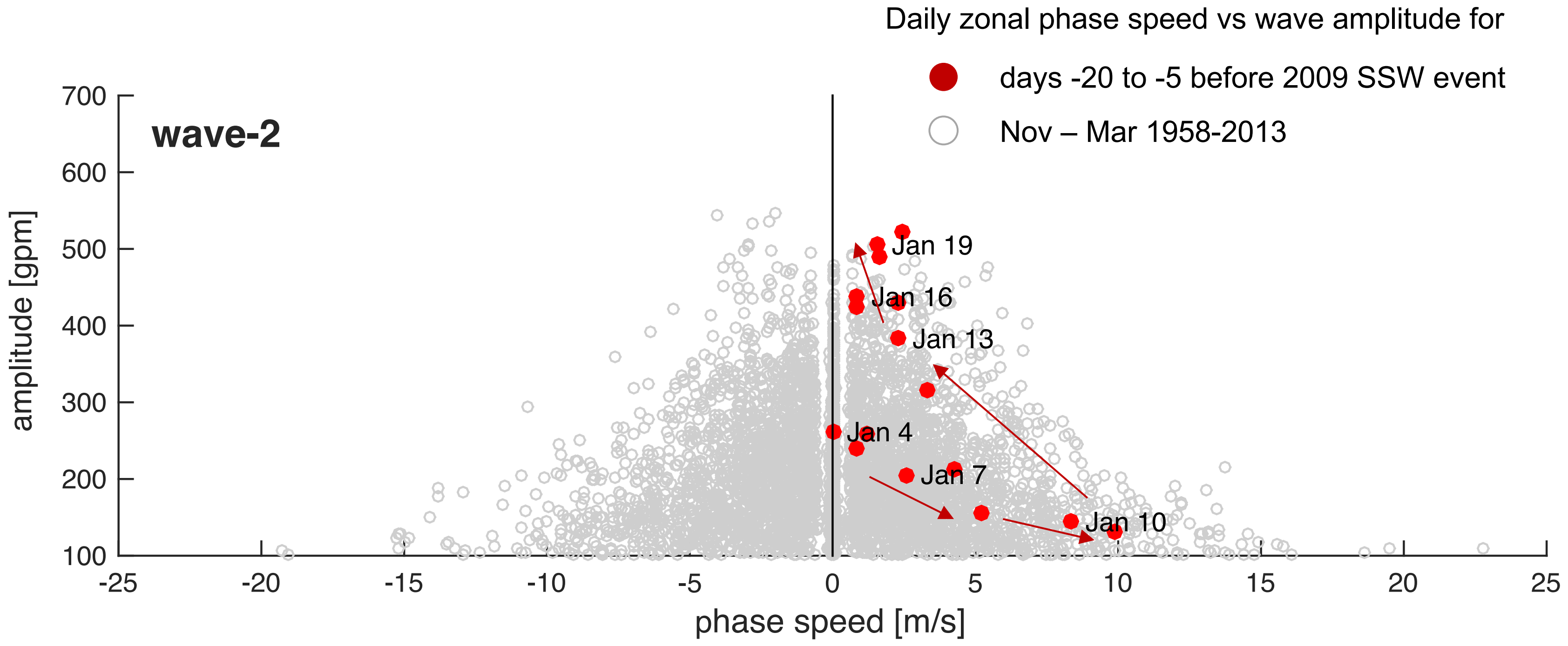
# CASE STUDY: THE 2009 SPLIT SSW EVENT



Sudden stratospheric warming event on January 24, 2009

The acceleration and subsequent deceleration of the phase speed hints at a resonant effect responsible for the 2009 SSW event.
see also: Matthewman & Esler, 2011; Plumb 2010



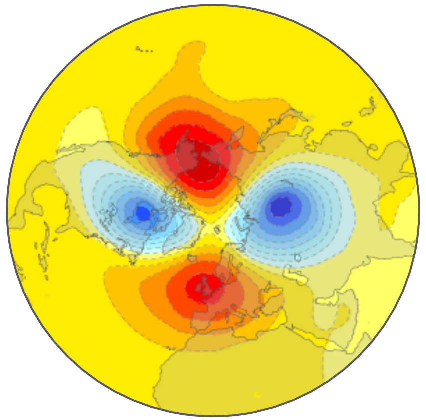



Figure: Domeisen, Martius, Jiménez-Esteve, 2018, GRL



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# SUMMARY – PART I



1. Eastward zonal phase speeds increase wave propagation into strong winds and can thereby help to efficiently weaken the vortex before SSW events.

2. Strong changes in phase speed can hint at resonant behavior.

3. The very unpredictable 2009 event shows strong signs of resonance, which might be responsible for the low predictability.

Domeisen, Martius, Jiménez-Esteve, 2019; see also: Matthewman & Esler, 2011

Stratospheric event
Predictability: days to weeks

Predictability likely depends on the mechanism causing the event.



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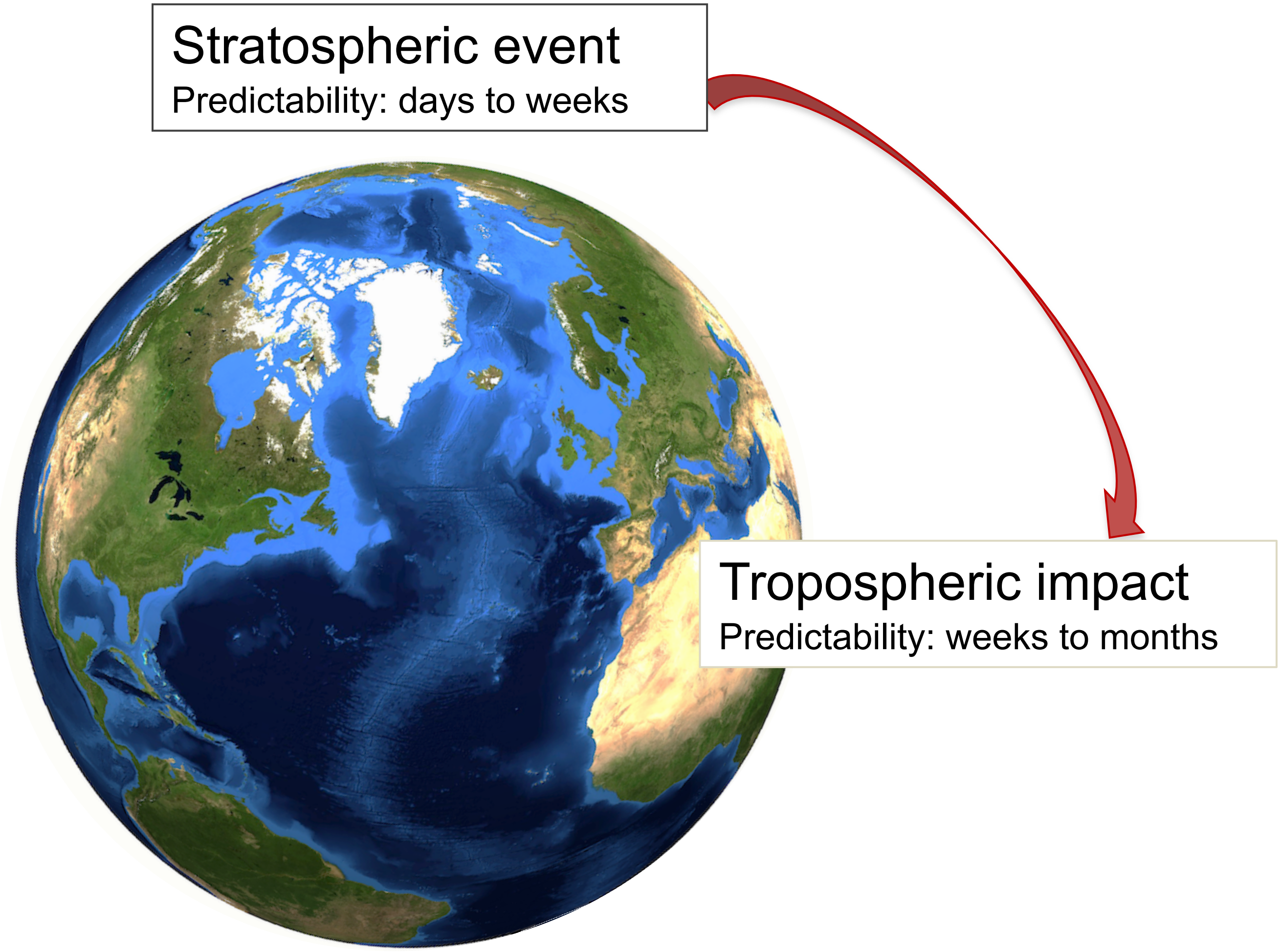
# PART II: THE SURFACE IMPACT OF THE STRATOSPHERE

What is the surface impact of SSWs and what does it depend on?



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# WHY DO WE CARE ABOUT SUDDEN STRATOSPHERIC WARMING EVENTS?



## Negative NAO tendency after a sudden stratospheric warming event changes the weather over Europe

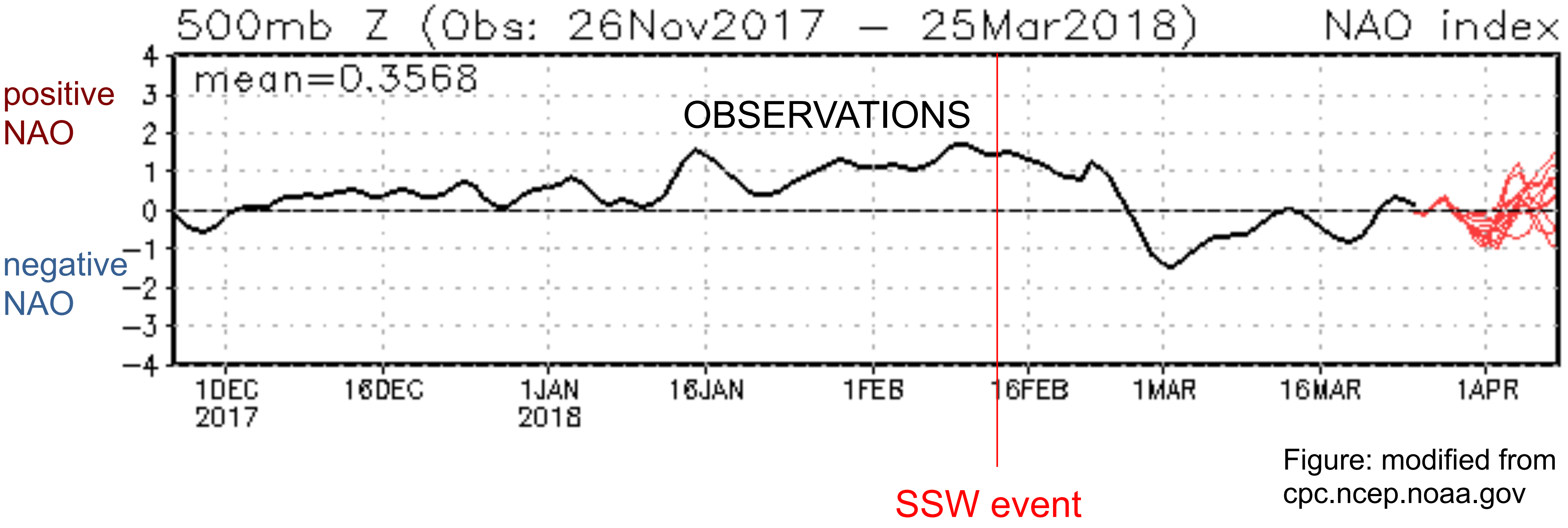


Figure: modified from cpc.ncep.noaa.gov

# WHY DO WE CARE ABOUT SUDDEN STRATOSPHERIC WARMING EVENTS?



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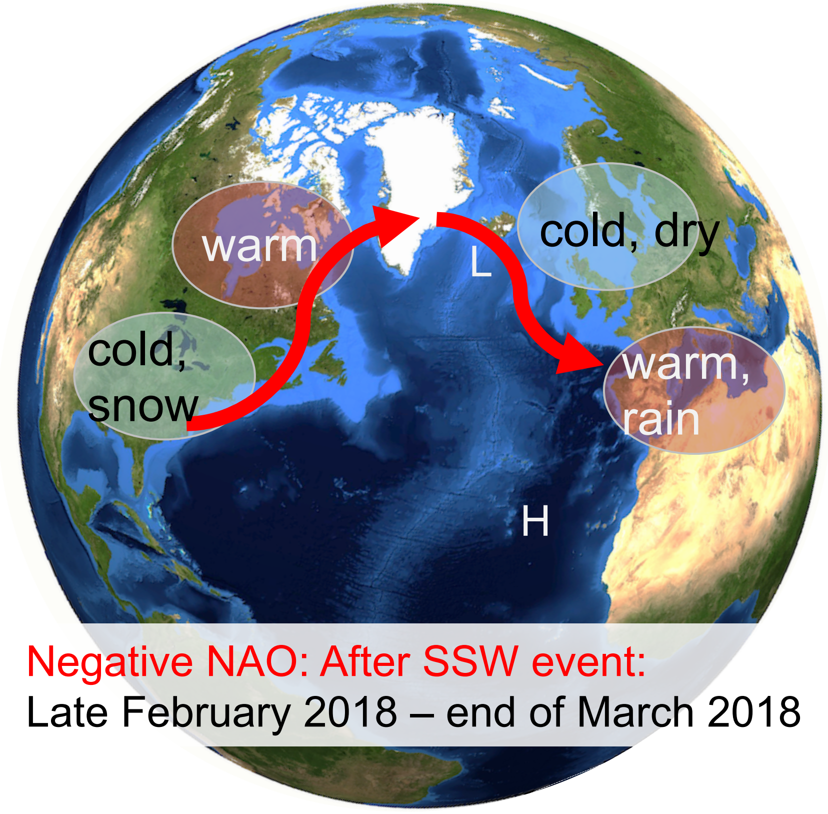
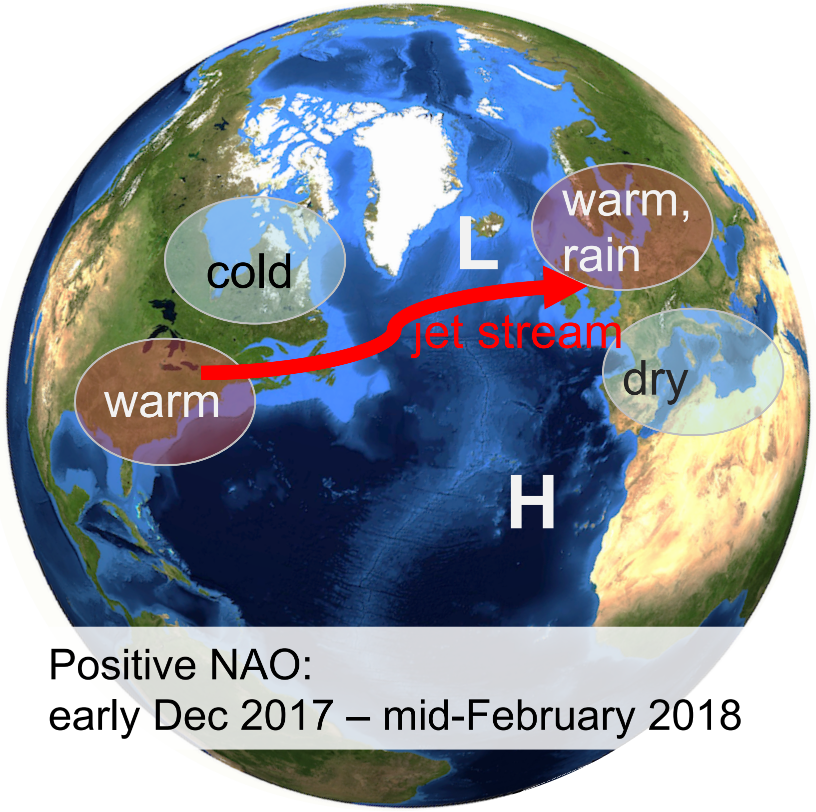



Negative NAO: After SSW event:
Late February 2018 – end of March 2018




Positive NAO:
early Dec 2017 – mid-February 2018

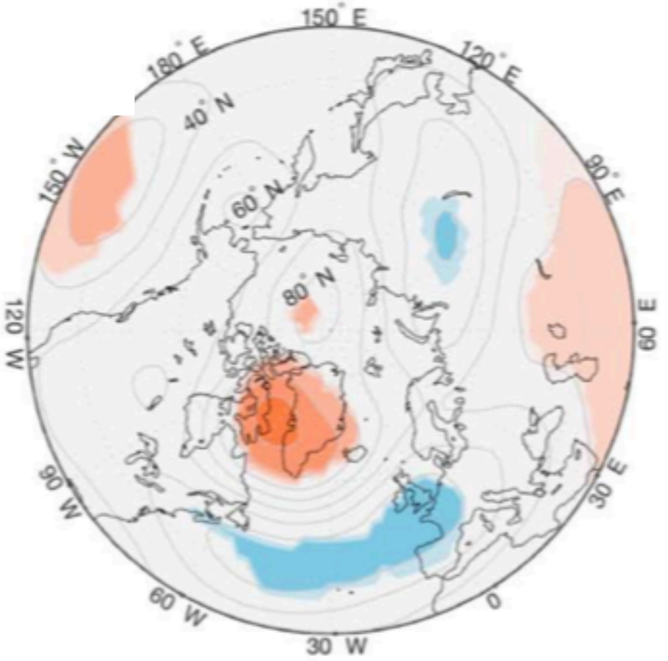
Sudden stratospheric warming events lead to a wavy jet stream with cold weather in northern and central Europe.

# WHAT IS THE "DOWNWARD IMPACT" OF SSW EVENTS?



all SSW (24)

days 8 to 52 after SSW event

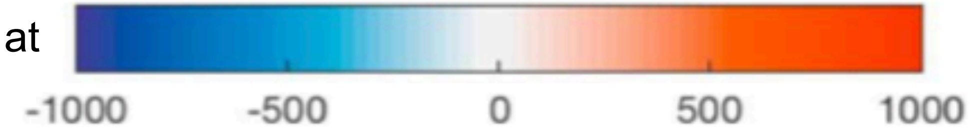



A negative NAO / NAM event is generally seen as the response to SSW events.

see e.g. Baldwin & Dunkerton, 2001; Charlton-Perez et al, 2018; Karpechko et al 2017

NAO = North Atlantic Oscillation
NAM = Northern Annular Mode

Shading: values significant at $p < 0.05$ level.




500hPa geopotential height [m]

Figure: Domeisen, 2019, JGR-Atmospheres



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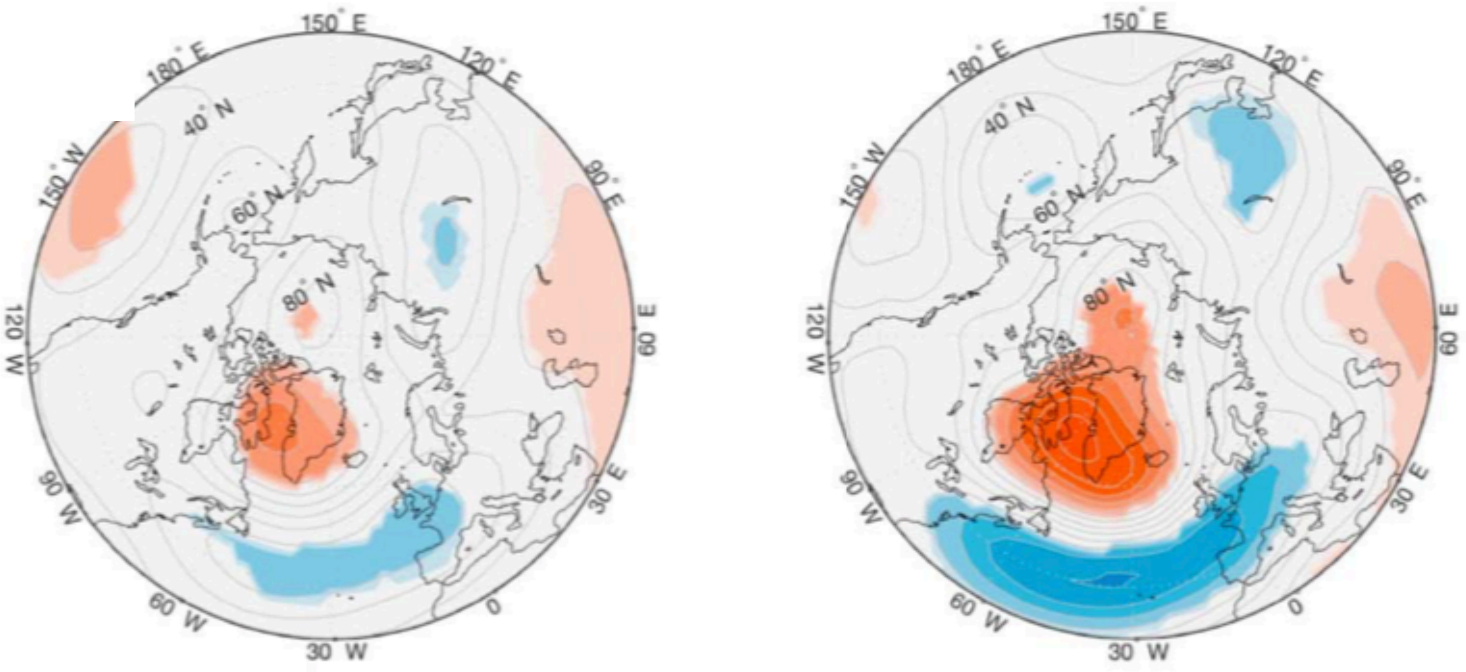
# NOT ALL SSW EVENTS EXHIBIT A “DOWNWARD IMPACT”



days 8 to 52 after SSW event

all SSW (24)

SSW followed by persistent NAO (14)



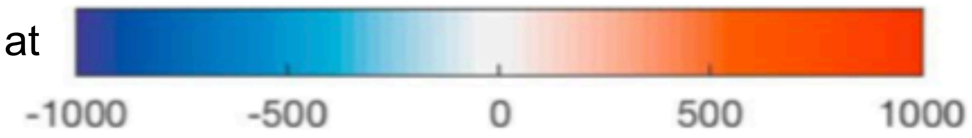

This signal is dominated by the ~ two thirds of SSW events that exhibit a negative NAO signal.

Domeisen, 2019.

see also: Charlton-Perez et al, 2018; Karpechko et al 2017

NAO = North Atlantic Oscillation

Shading: values significant at $p < 0.05$ level.




500hPa geopotential height [m]

Figure: Domeisen, 2019, JGR-Atmospheres



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# NOT ALL SSW EVENTS EXHIBIT A “DOWNWARD IMPACT”

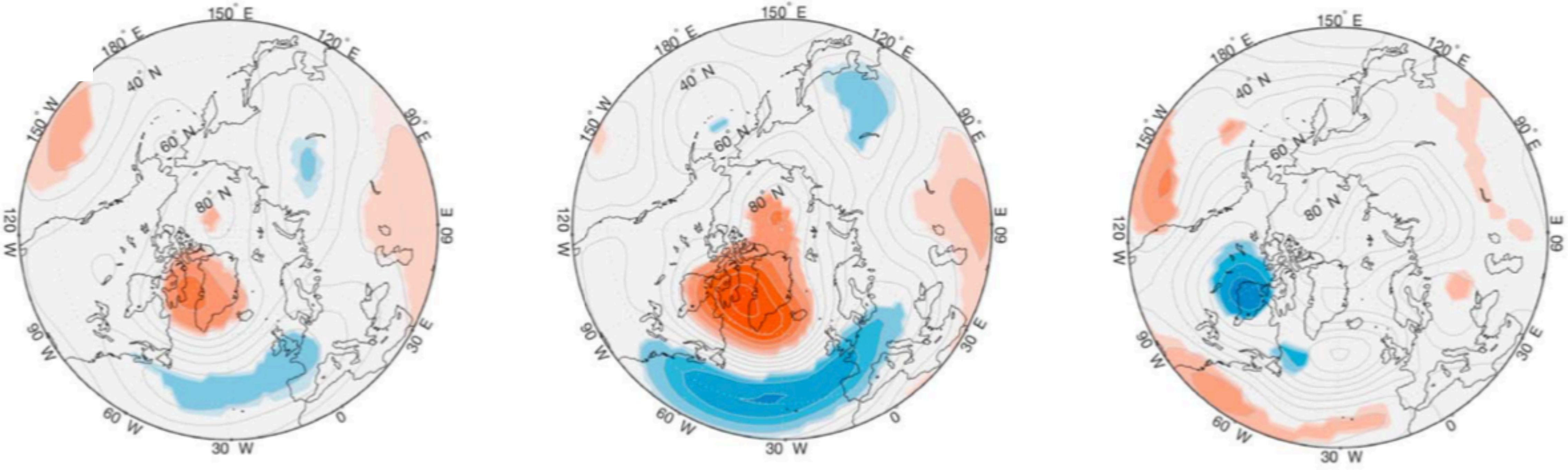


days 8 to 52 after SSW event

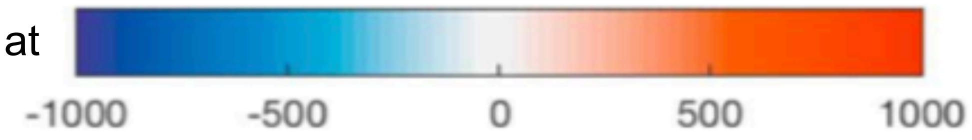
all SSW (24)

SSW followed by persistent NAO (14)

SSW not followed by persistent NAO or switch to negative NAO (8)




Shading: values significant at $p < 0.05$ level.




500hPa geopotential height [m]

Figure: Domeisen, 2019, JGR-Atmospheres

Note: in turn, only 25% of persistent negative NAO events are preceded by a SSW event.



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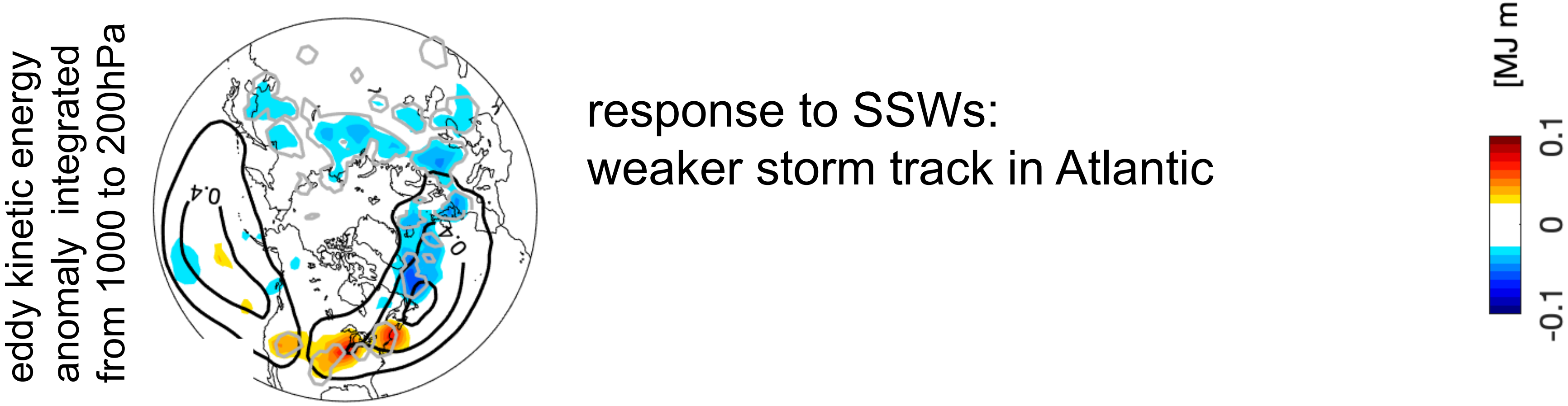
# THE DIVERSITY IN THE SURFACE IMPACT OF SSWS MANIFESTS IN THE STORM TRACK RESPONSE

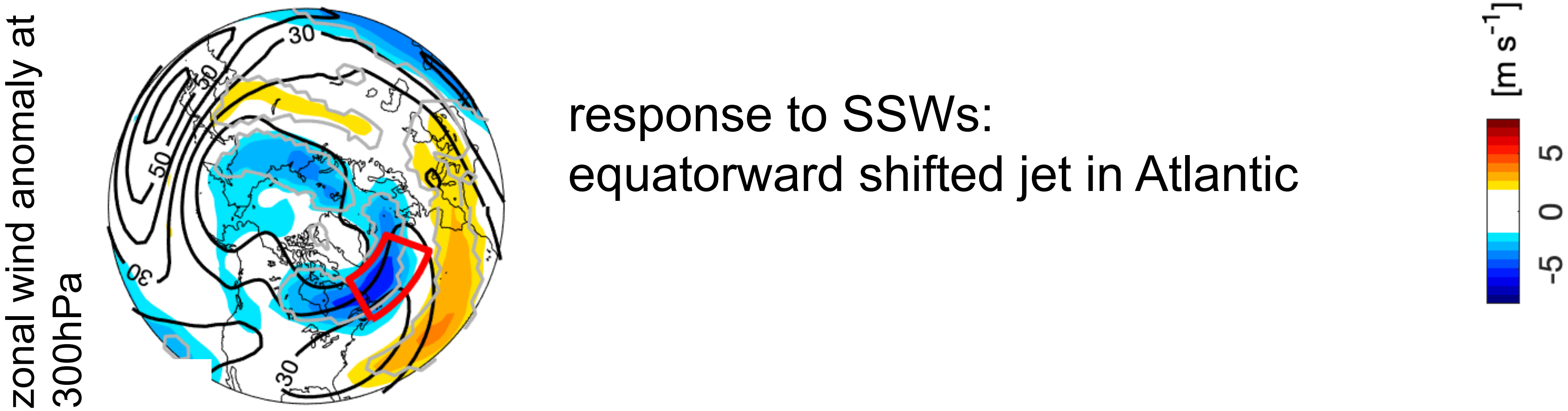


all SSW events (24)




response to SSWs:
weaker storm track in Atlantic

Figure: tropospheric circulation averaged over 30 days following SSW events




response to SSWs:
equatorward shifted jet in Atlantic

from: Afargan-Gerstman & Domeisen, in rev.

# THE DIVERSITY IN THE SURFACE IMPACT OF SSWS MANIFESTS IN THE STORM TRACK RESPONSE



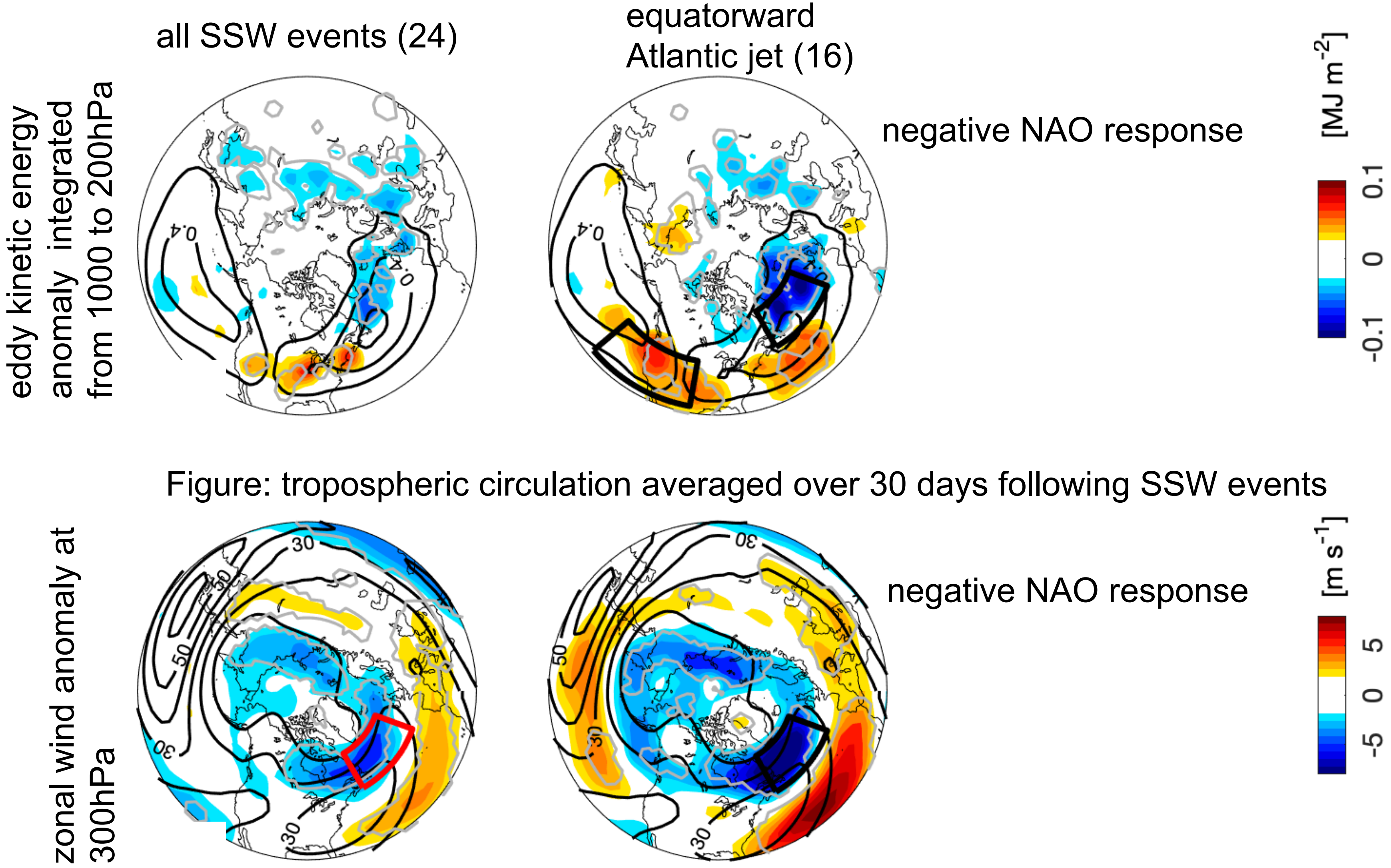



Figure: tropospheric circulation averaged over 30 days following SSW events

from: Afargan-Gerstman & Domeisen, in rev.



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# IS THE SURFACE IMPACT IN THE NORTH ATLANTIC MODULATED BY THE PACIFIC?



The opposite responses in the North Atlantic storm track also exhibit opposite "precursors" in the eastern North Pacific!

The troposphere can have a strong impact on the manifestation of the downward response to SSWs.

see also: Garfinkel et al 2013, Chan & Plumb, 2009

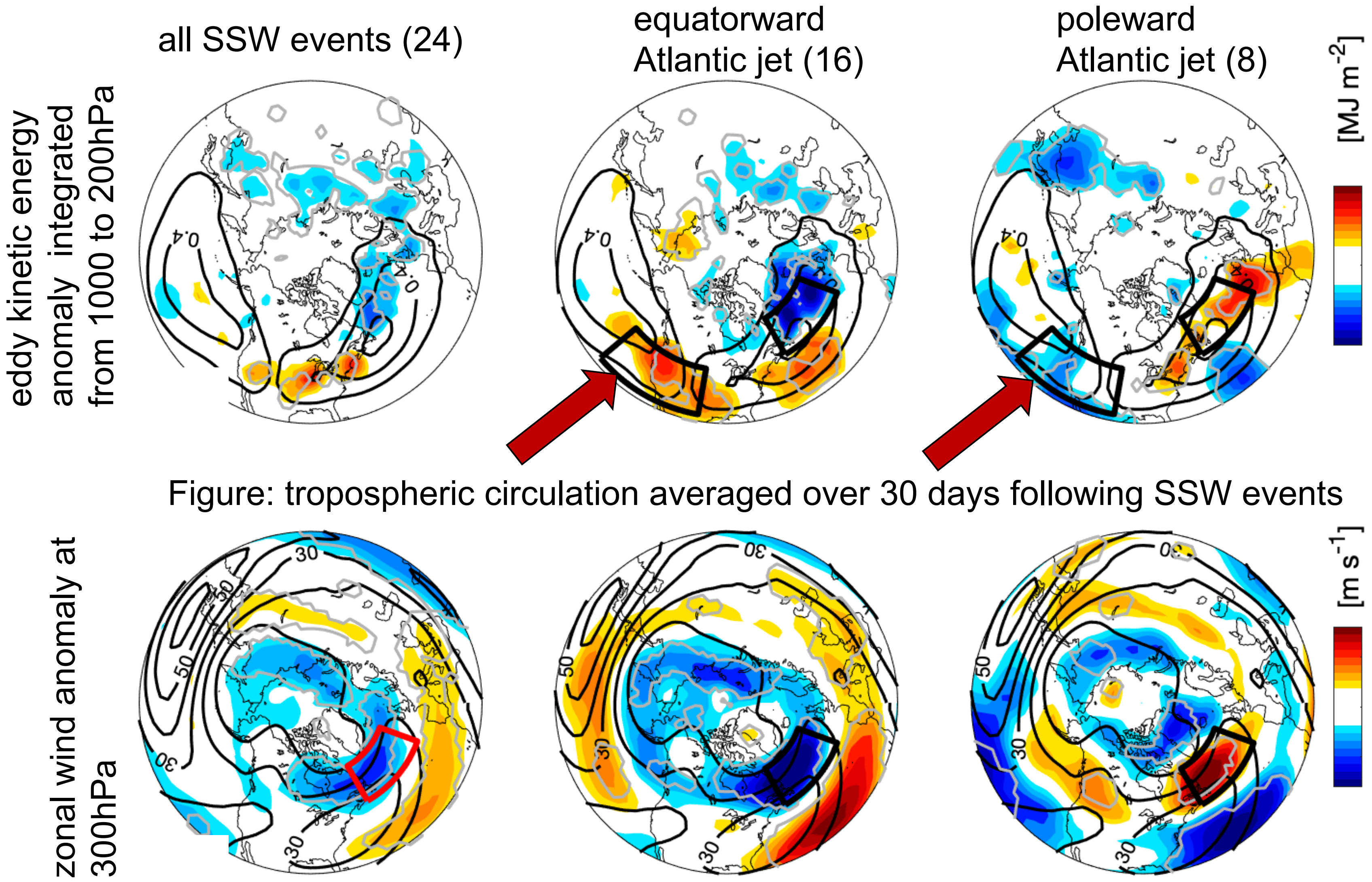
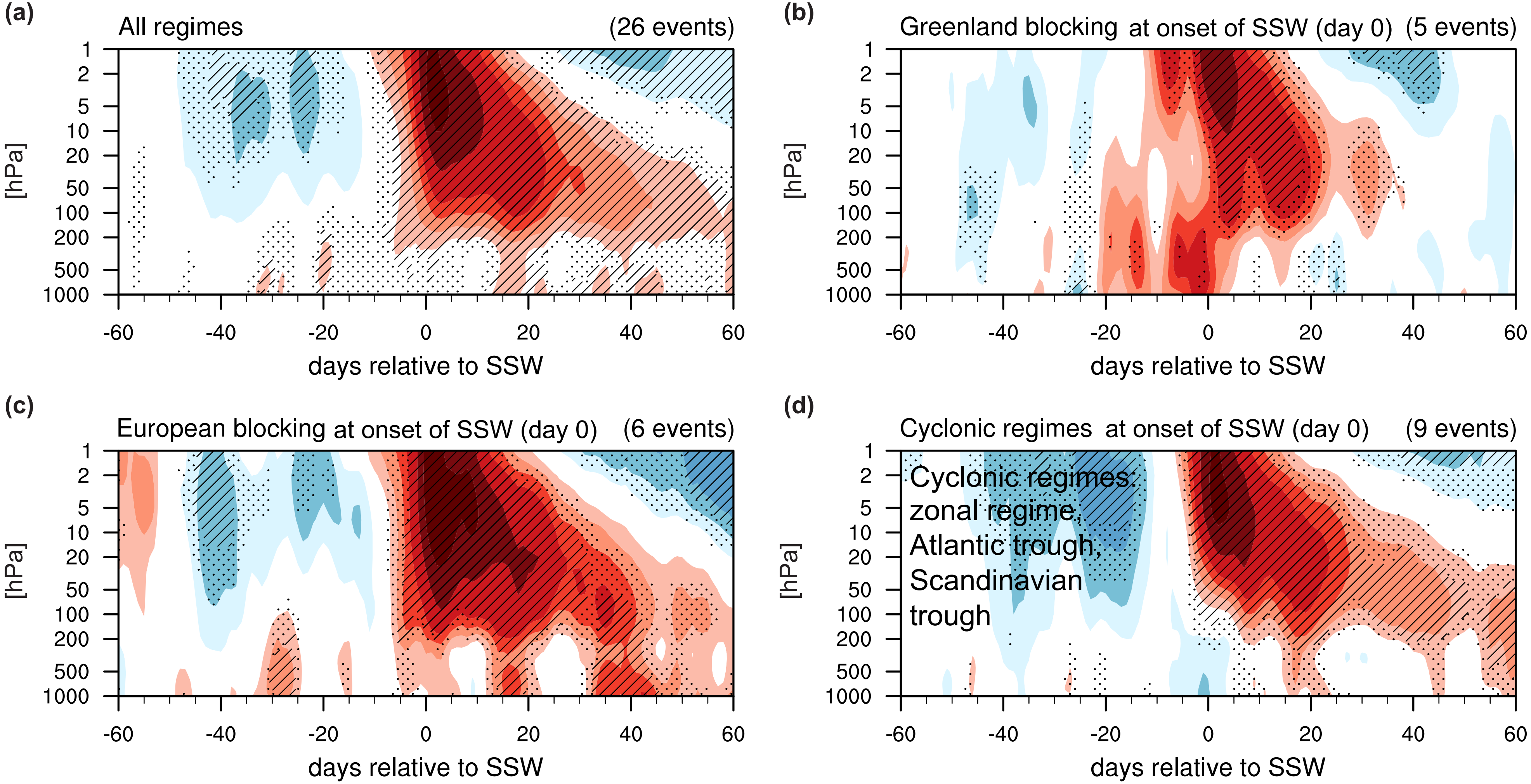



Figure: tropospheric circulation averaged over 30 days following SSW events

from: Afargan-Gerstman & Domeisen, in rev.

# TO WHAT EXTENT DOES THE SURFACE IMPACT OF SSWS DEPEND ON THE STATE OF THE TROPOSPHERE?

Part I – Part II

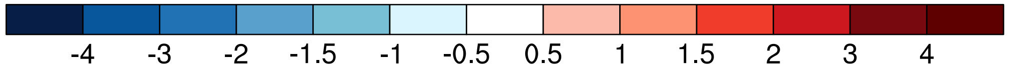



The events with “downward impact” are dominated by events that show blocking over Europe at the onset of the SSW.

These regimes show a favor for transitioning into Greenland blocking, the “canonical response” to SSWs.

Hatching (stippling): confidence intervals and the random distributions overlap by less than 25% (10%).

Units: Standard deviation of geopotential height anomalies for Atlantic sector.




Domeisen, Grams, Papritz, in prep.



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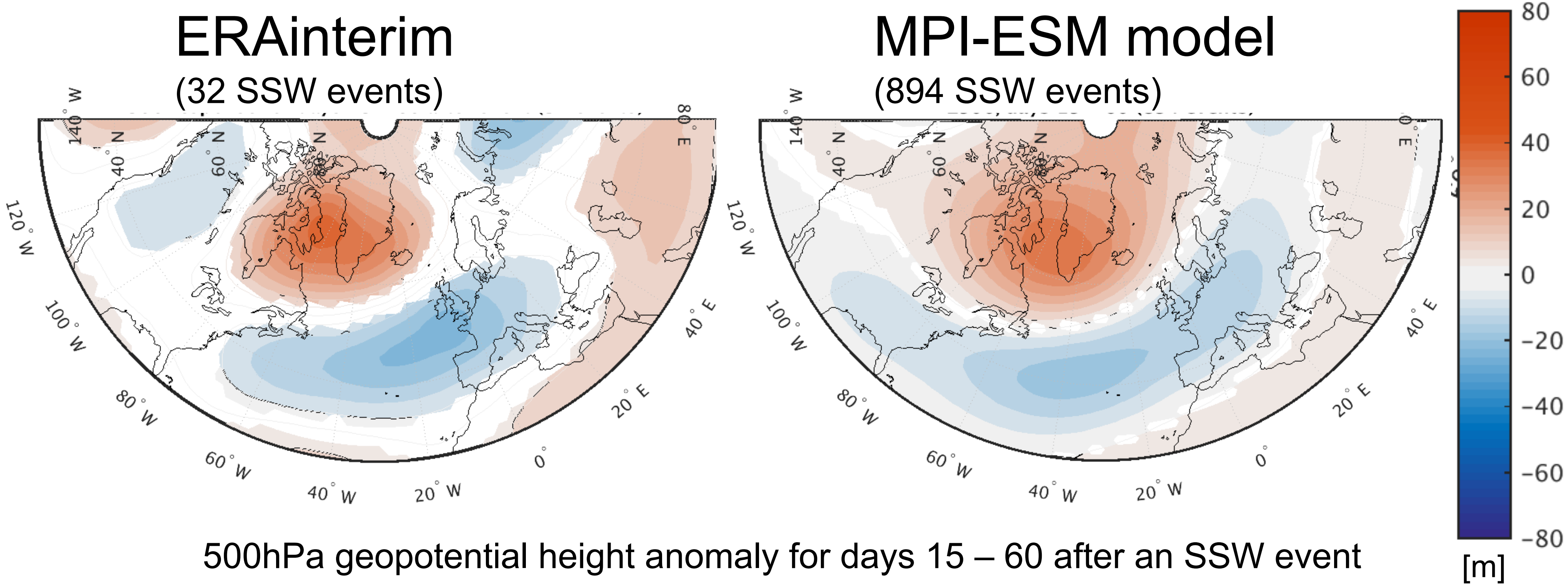
# HOW ABOUT THE ROLE OF THE STRATOSPHERE FOR THE SURFACE IMPACT?



## Negative NAO response to sudden stratospheric warming event in reanalysis




500hPa geopotential height anomaly for days 15 – 60 after an SSW event

Data: MPI-ESM seasonal prediction model: Baehr et al 2015

Domeisen, Hitchcock et al, in prep.



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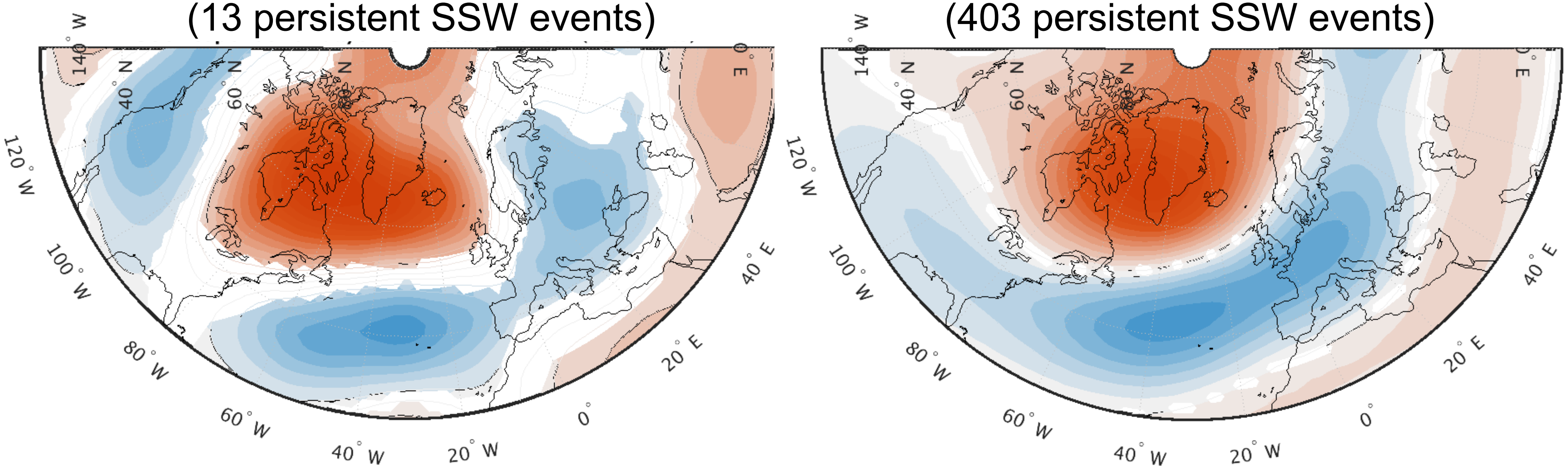
# HOW ABOUT THE ROLE OF THE STRATOSPHERE FOR THE SURFACE IMPACT?

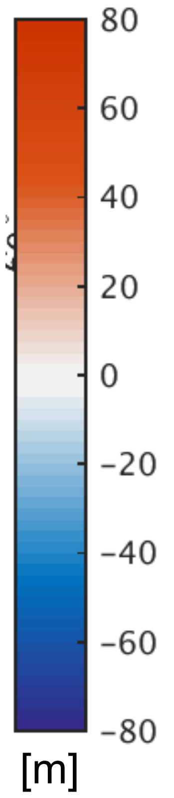


Negative NAO response in reanalysis and seasonal forecasting model is considerably stronger for persistent SSW events (Polar Jet Oscillation events)

ERAinterim
(13 persistent SSW events)

MPI-ESM model
(403 persistent SSW events)




500hPa geopotential height anomaly for days 15 – 60 after an SSW event

Data: MPI-ESM seasonal prediction model: Baehr et al 2015

Domeisen, Hitchcock et al, in prep.



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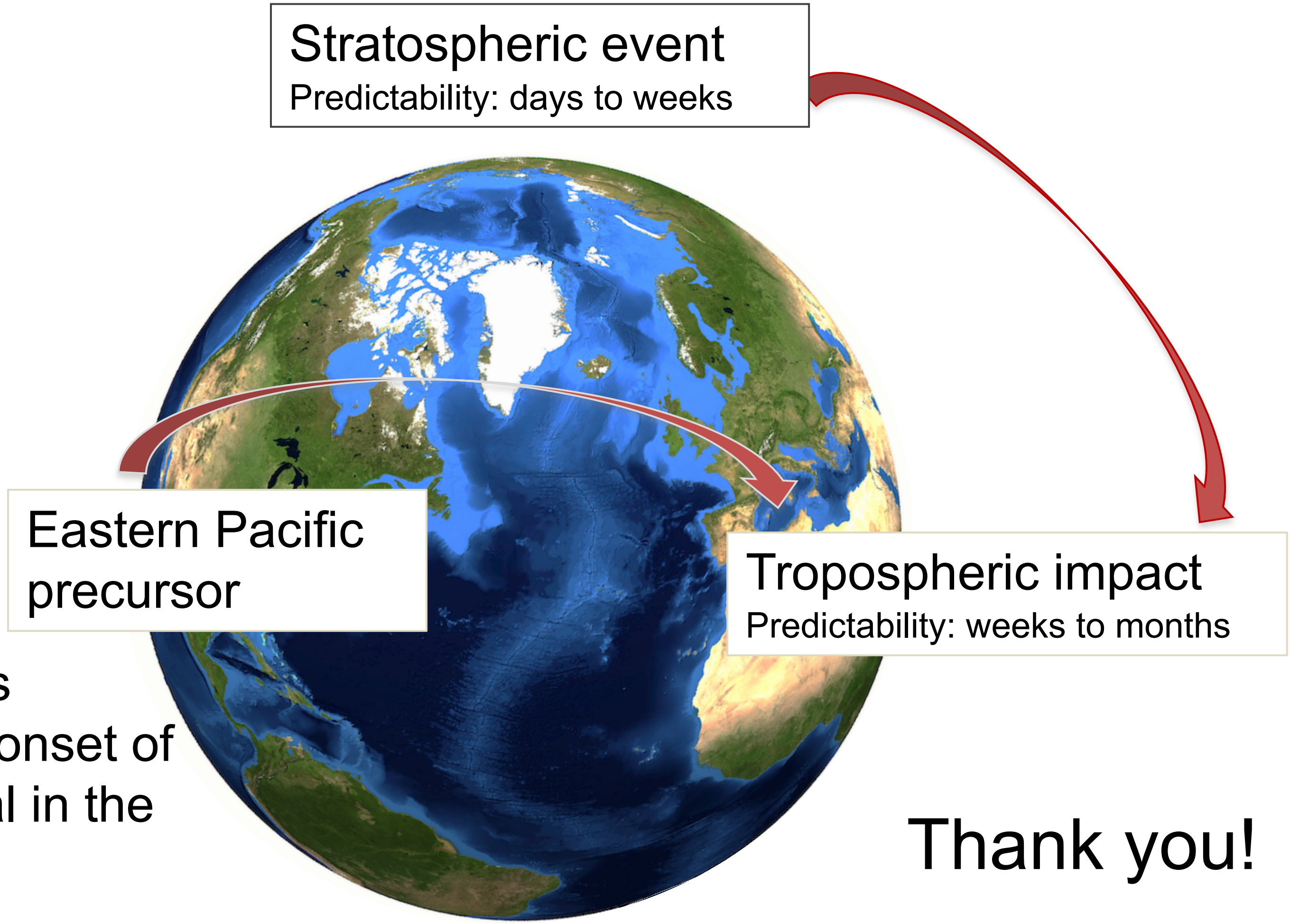
# SUMMARY PART II: THE SURFACE IMPACT OF THE STRATOSPHERE

Only two thirds of SSW events are followed by the “canonical” negative NAO event.
Domeisen, 2019, Charlton-Perez et al, 2018, Karpechko et al 2017

The storm track weakens for these two thirds of SSW events. The eastern Pacific might influence the storm track response over the North Atlantic.
Afargan-Gerstman & Domeisen, in rev.

The “downward response” of SSW events depends on the tropospheric state at the onset of the SSW and the persistence of the signal in the lower stratosphere.
Domeisen, Grams, Papritz, in prep..
see also: Garfinkel et al 2013, Chan & Plumb, 2009




Thank you!

SSW competition: @Domeisen_D

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Funded by the Horizon 2020 Framework Programme of the European Union
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SDSC Swiss Data Science Center
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