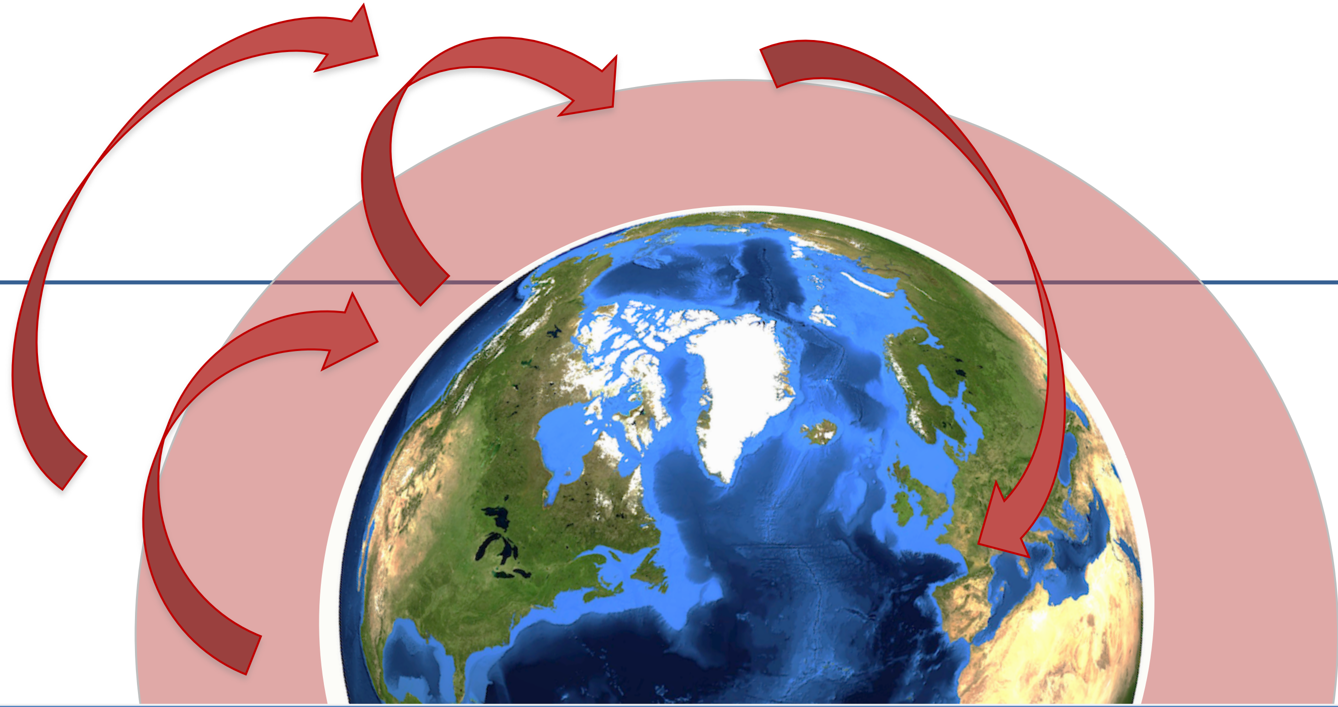


The role of the stratosphere for sub-seasonal to seasonal forecasting

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

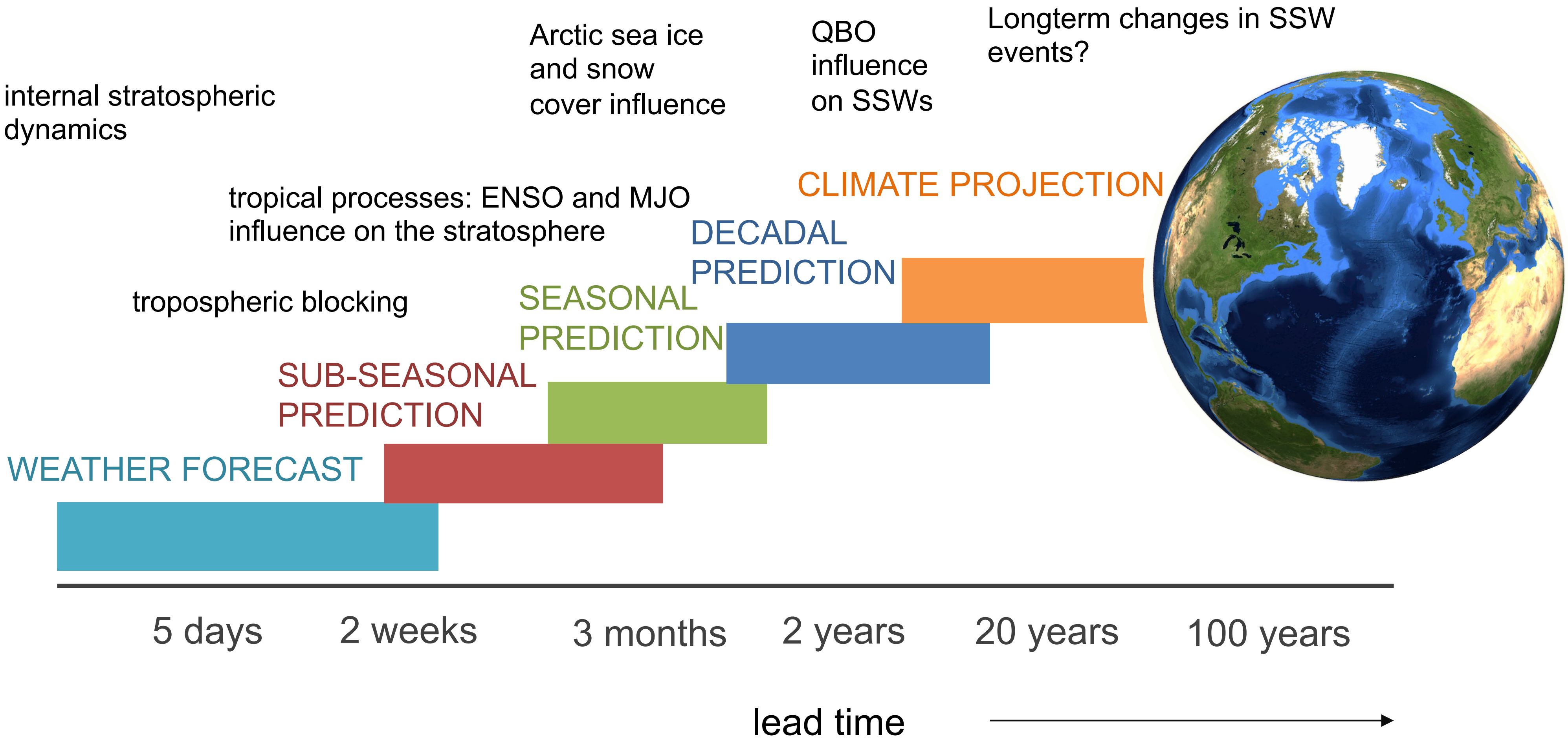
with contributions from

Bernat Jiménez-Esteve, Ole Wulff, Alexander Wollert, Hilla Gerstman-Afargan, Amy Butler, Chaim Garfinkel, Andrew Charlton-Perez, Isla Simpson, Gualtiero Badin, Inga Koszalka, Olivia Martius, Blanca Ayarzagüena, Mark Baldwin, Etienne Dunn-Sigouin, Jason Furtado, Peter Hitchcock, Alexey Karpechko, Hera Kim, Jeff Knight, Andrea Lang, Eun-Pa Lim, Andrew Marshall, Greg Roff, Chen Schwartz, Seok-Woo Son, Masakazu Taguchi

ETH zürich

WEATHER AND CLIMATE PREDICTION

The stratosphere exhibits variability on all of these timescales



ETH zürich

SUB-SEASONAL TO SEASONAL PREDICTION: WHERE DO WE STAND?

Limited prediction skill in midlatitudes

Prediction skill (ACC) for December - February

Model: Max-Planck-Institute Earth System Model (MPI-ESM-LR)
[Baehr et al., 2015]

Initialization: November

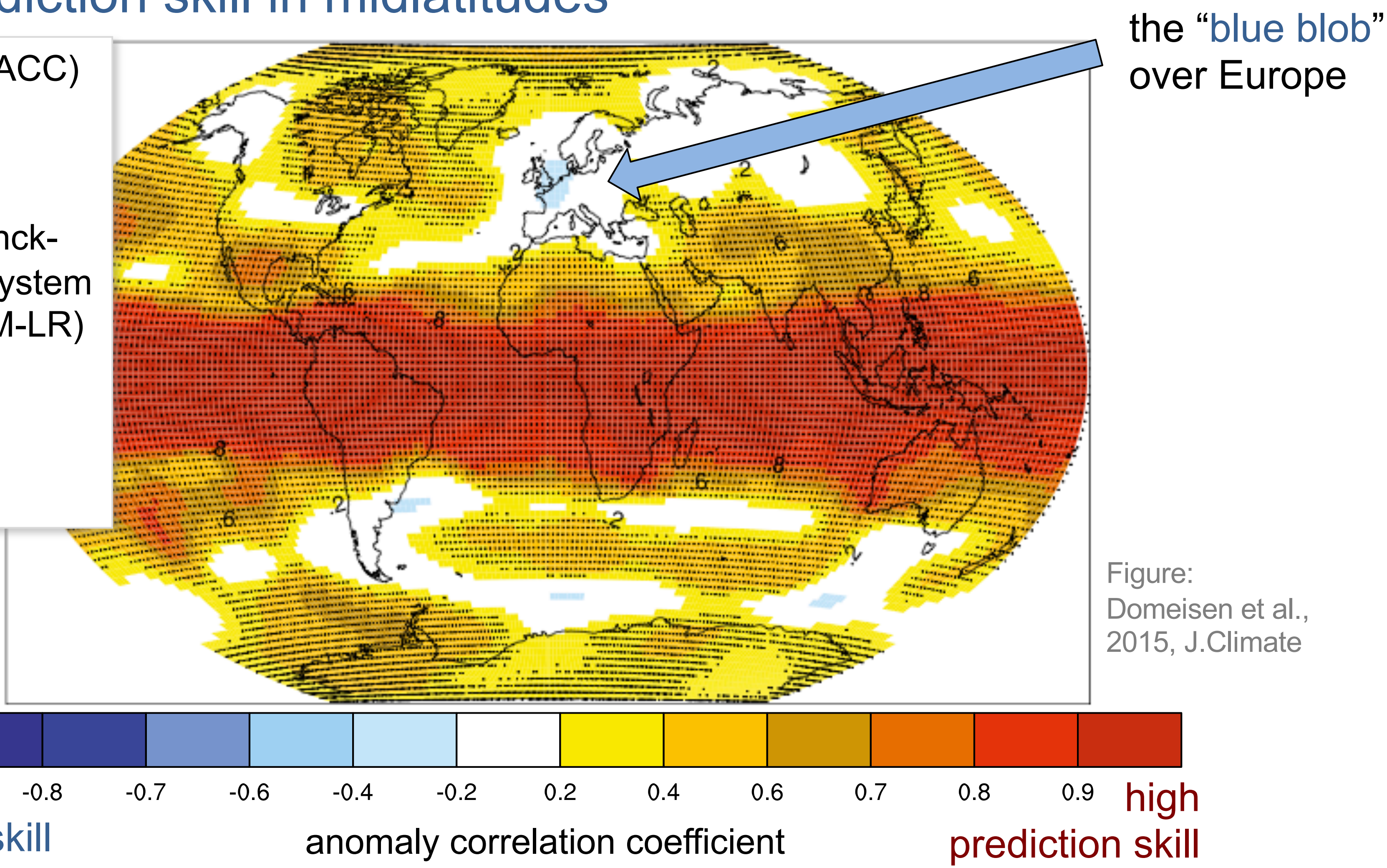
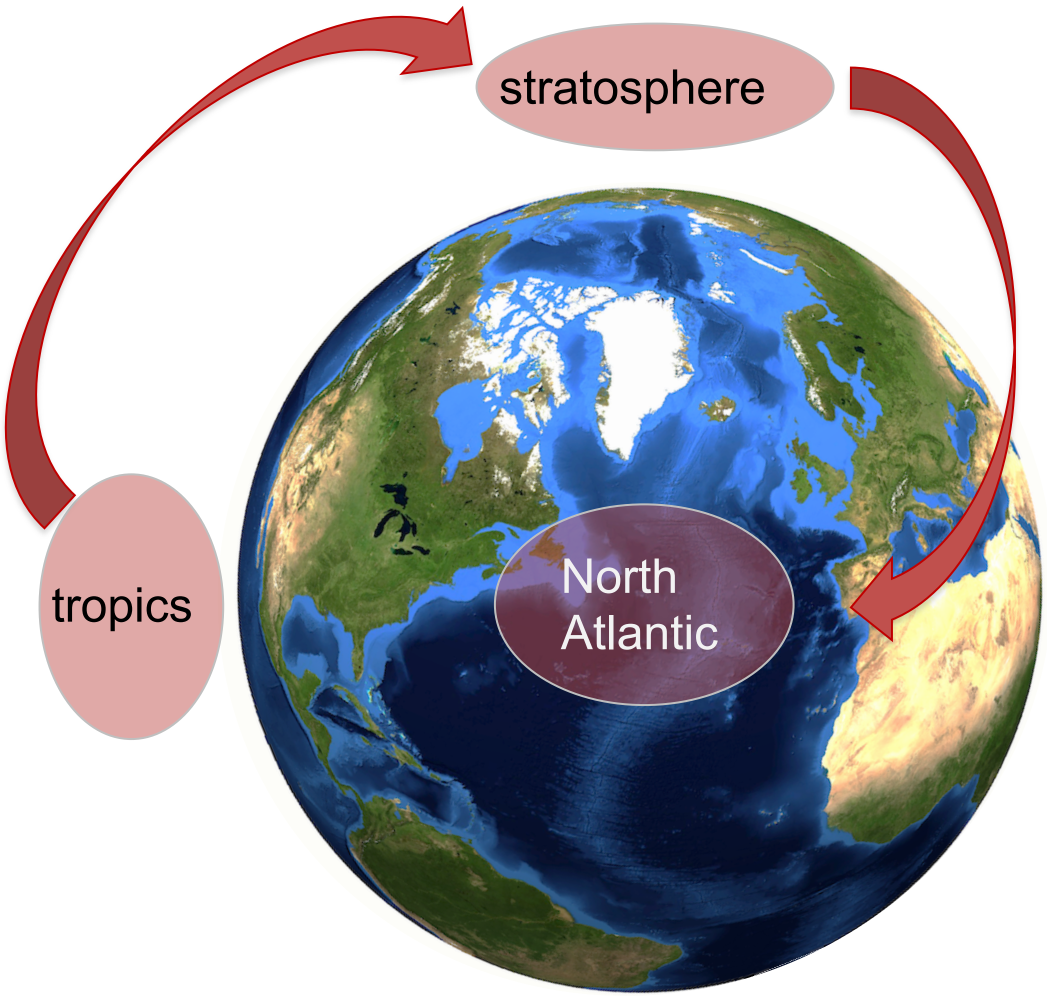


Figure: Domeisen et al., 2015, J.Climate

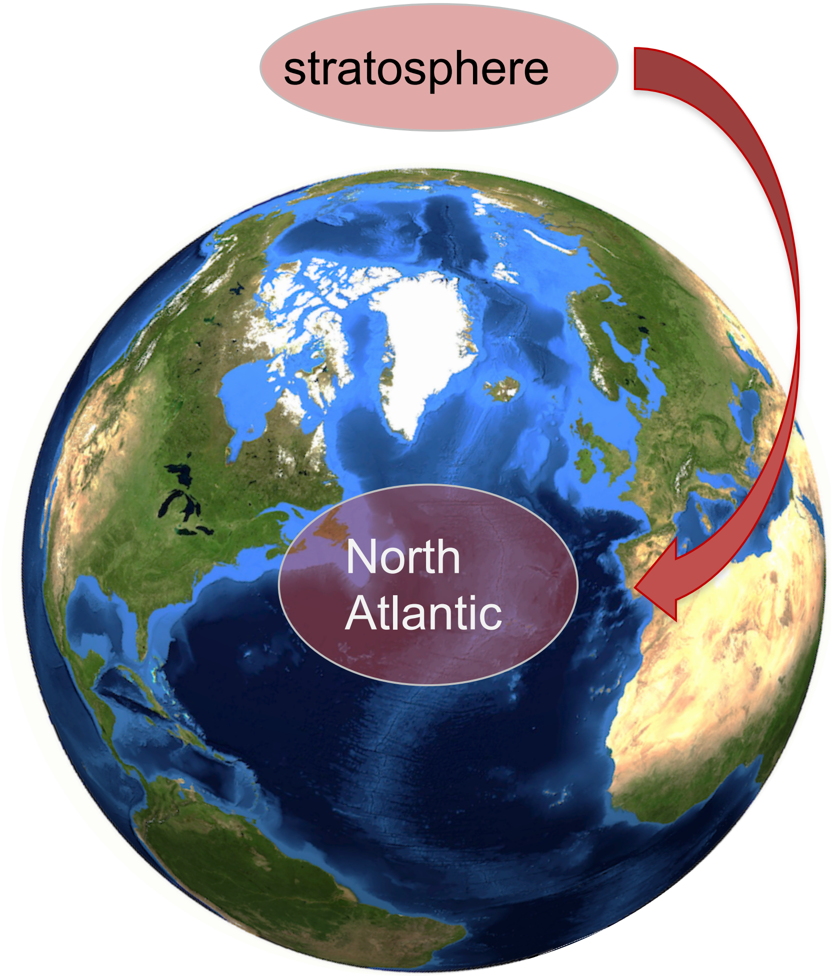
ETH zürich

CONTENTS



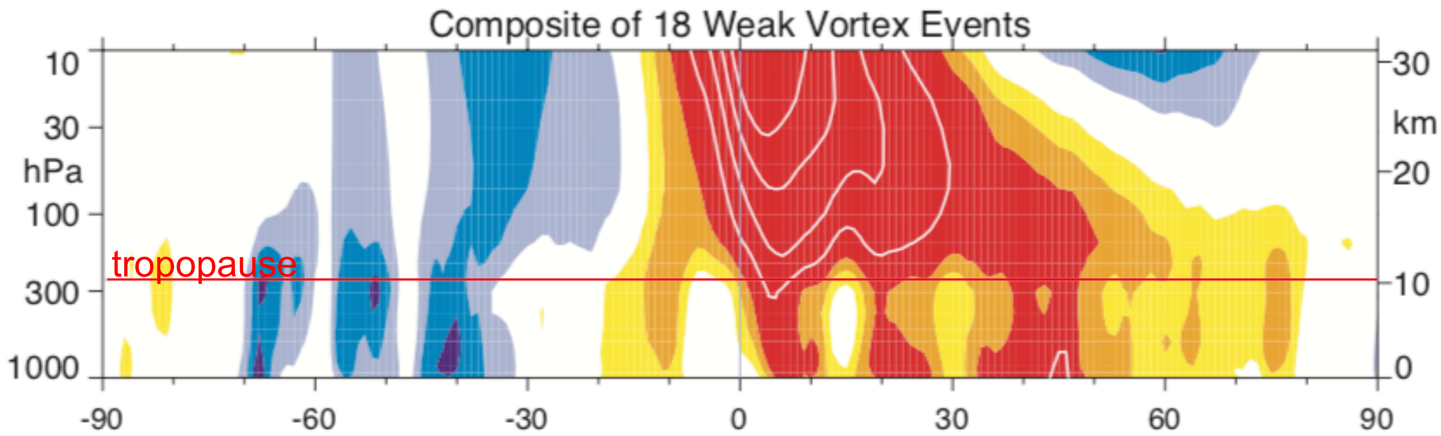
ETH zürich

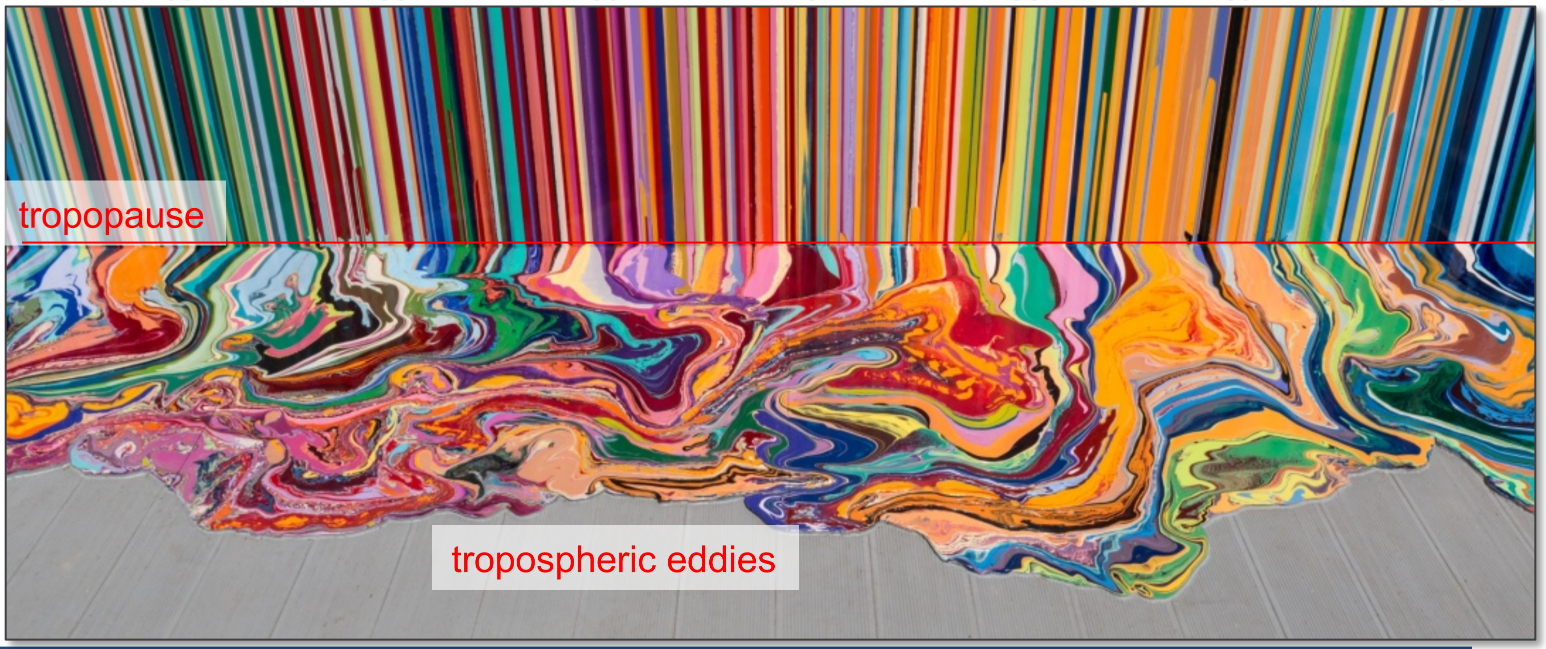
CONTENTS



WHAT HAPPENS IN THE STRATOSPHERE DOES NOT STAY IN THE STRATOSPHERE

Probably the most famous figure of stratosphere – troposphere coupling: “dripping paint”





“Wide acres of time”, Venice Biennale, 2017
Figure: elephant.art

ETHzürich

DOWNWARD INFLUENCE OF PERSISTENCE

The longer persistence of the stratosphere can leak through to the troposphere during months with an “active” stratosphere.

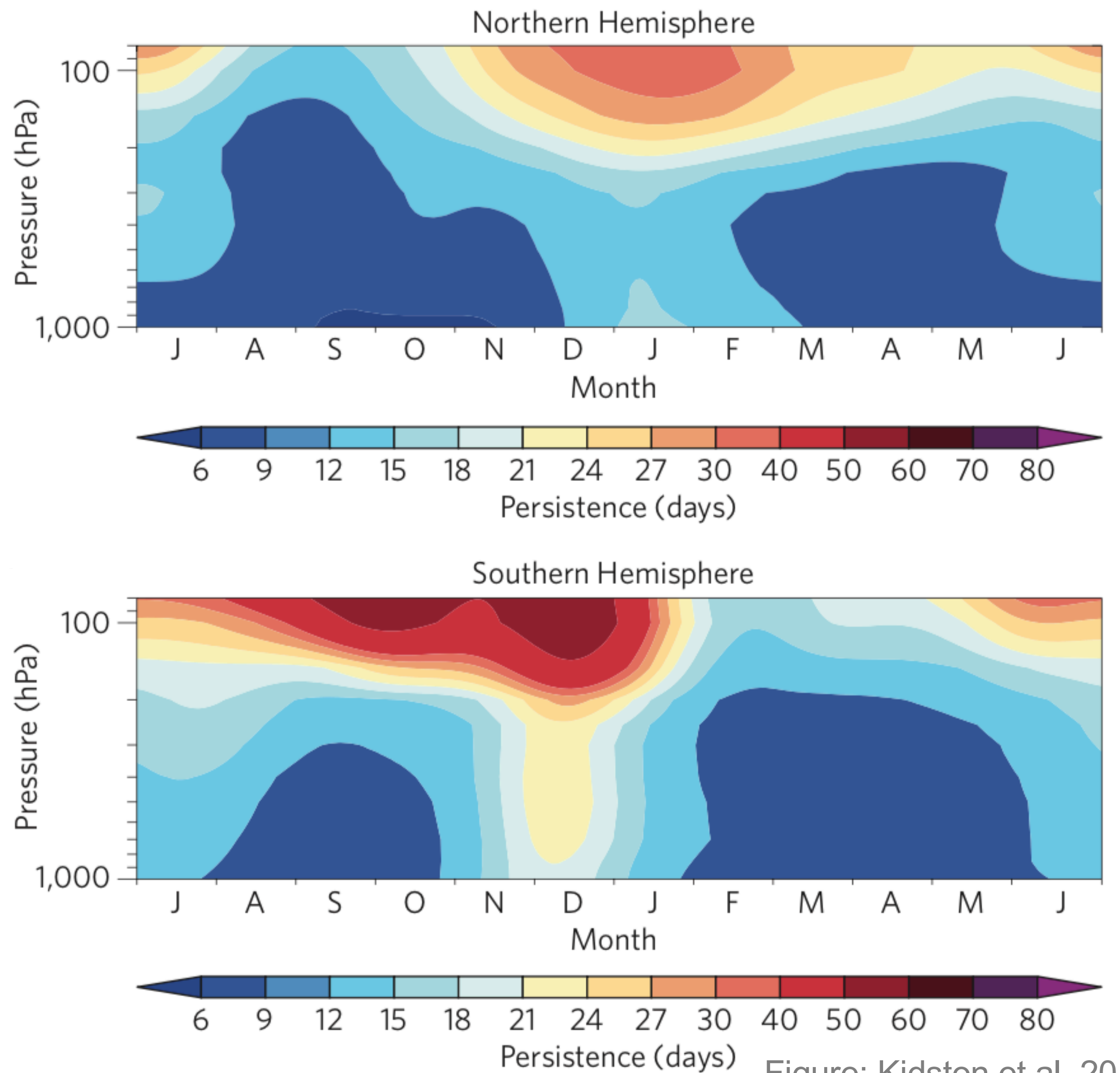


Figure: e-folding decorrelation time scales of the first EOF of deseasonalized NH/SH height variability (20–90N/S), i.e. the northern/southern annual mode

Figure: Kidston et al, 2015

ESTIMATE PREDICTABILITY FROM THE S2S PREDICTION DATABASE (VITART ET AL, 2017)

Prediction system	Initialization	Hindcast period	Ensemble size
BoM	ERA-interim/ALI	1981-2013	33
CMA	NCEP-NCAR R1	1994-2014	4
ECCC	ERA-interim	1995-2014	4
ECMWF×	ERA-interim	1997-2016	11
JMA×	JRA-55	1981-2010	5
CNRM-Meteo×	ERA-interim	1993-2014	15
CNR-ISAC	ERA-interim	1981-2010	1
NCEP×	CFSR	1999-2010	4
UKMO×	ERA-interim	1993-2015	2-7

Number of vertical levels per pressure range:

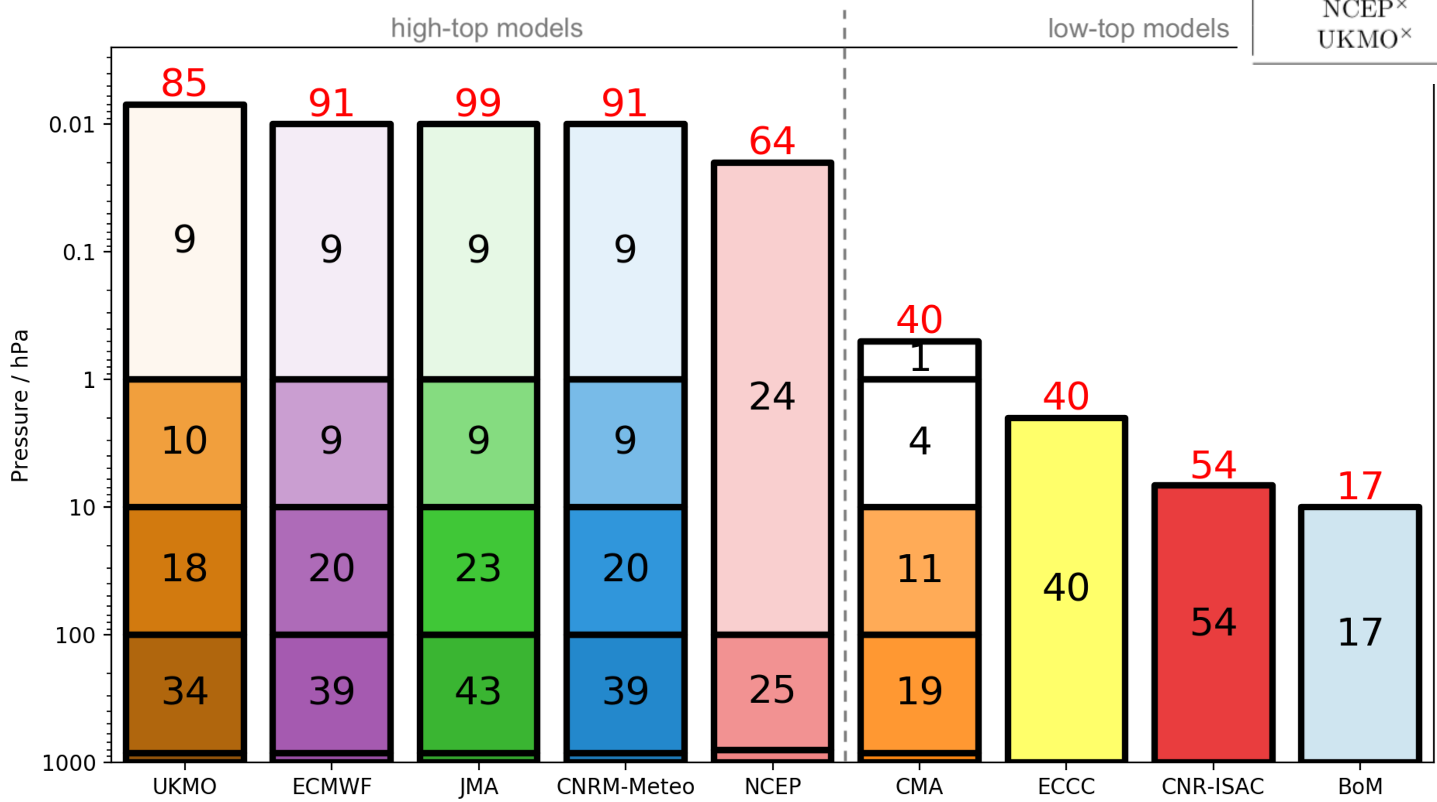


Figure: A. Charlton-Perez. from Domeisen et al., under review for the JGR special issue on S2S prediction

ETH zürich

MODELS WITH A GOOD STRATOSPHERE MAKE BETTER PREDICTIONS FOR THE TROPOSPHERE

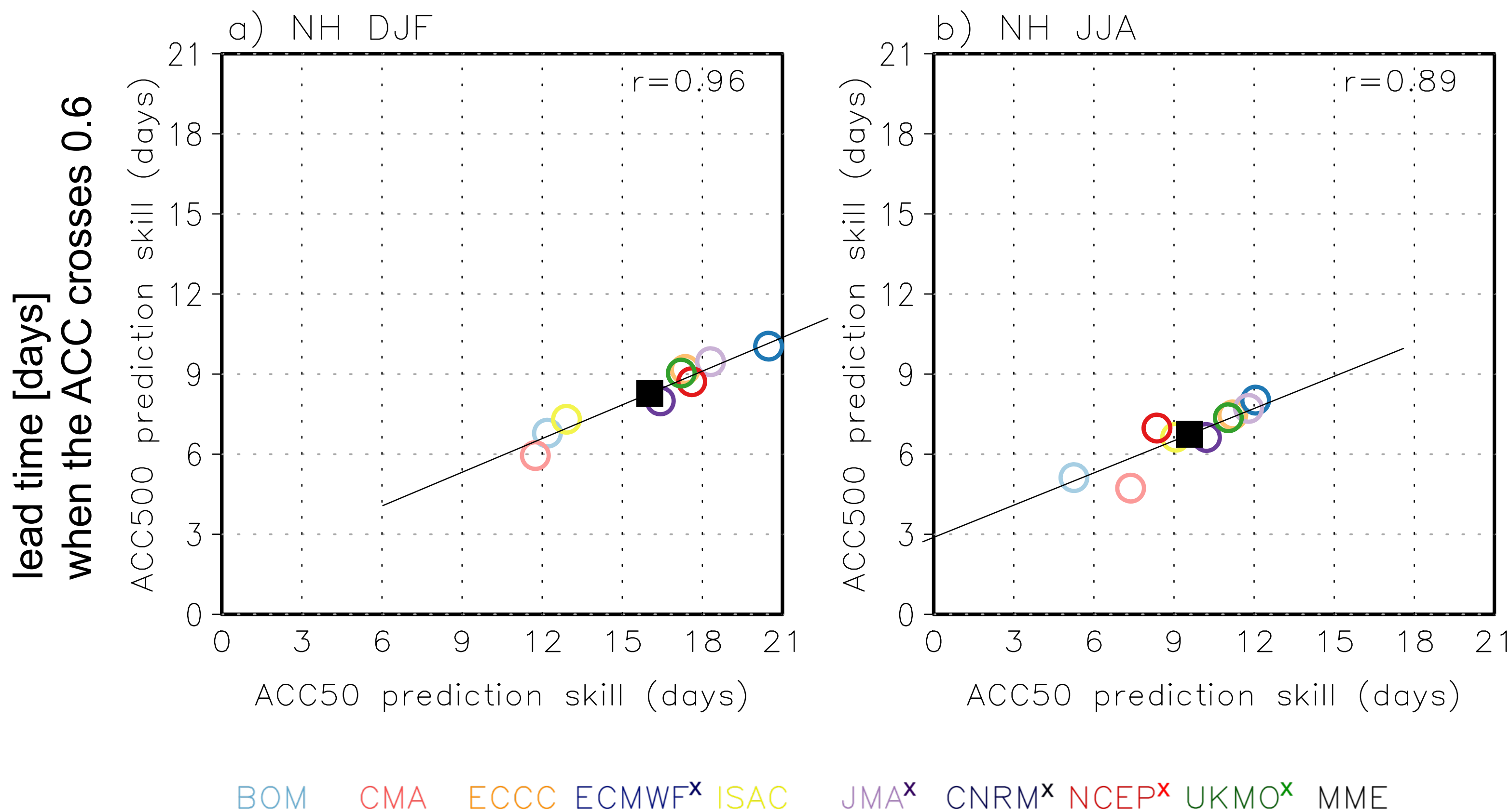
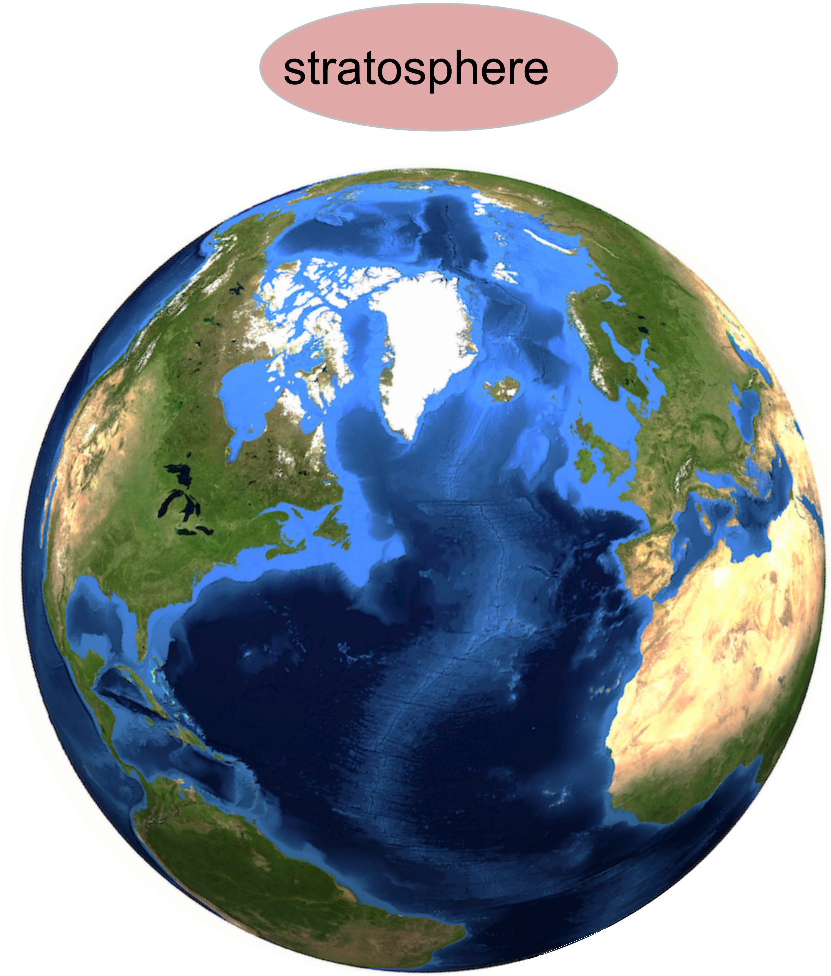
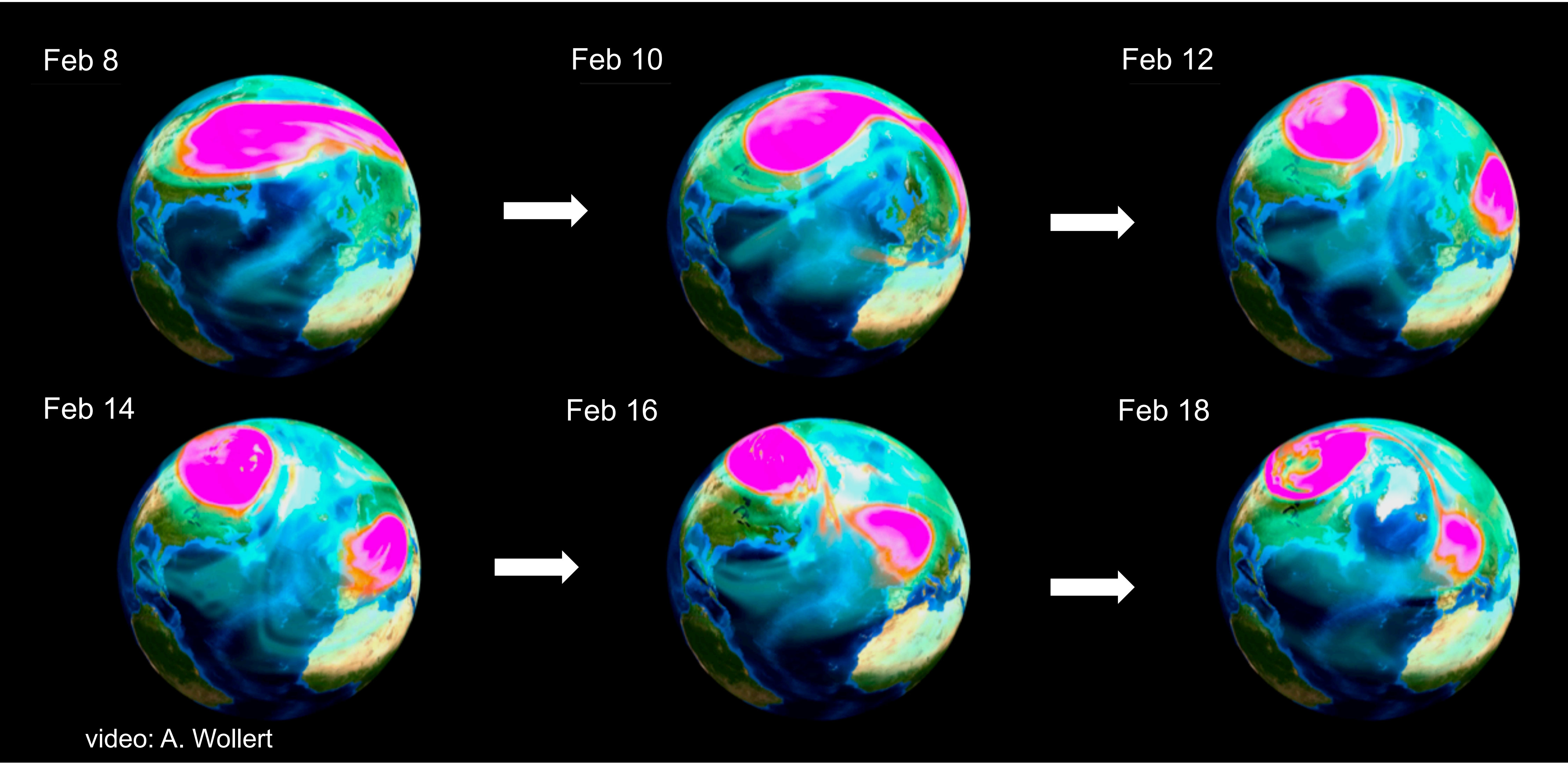


Figure: H. Kim.
from Domeisen et al., under review for the JGR special issue on S2S prediction

CONTENTS



THE SUDDEN STRATOSPHERIC WARMING EVENT ON FEBRUARY 12, 2018



WHAT IS THE PREDICTABILITY LIMIT FOR SSW EVENTS?

In an idealized model:

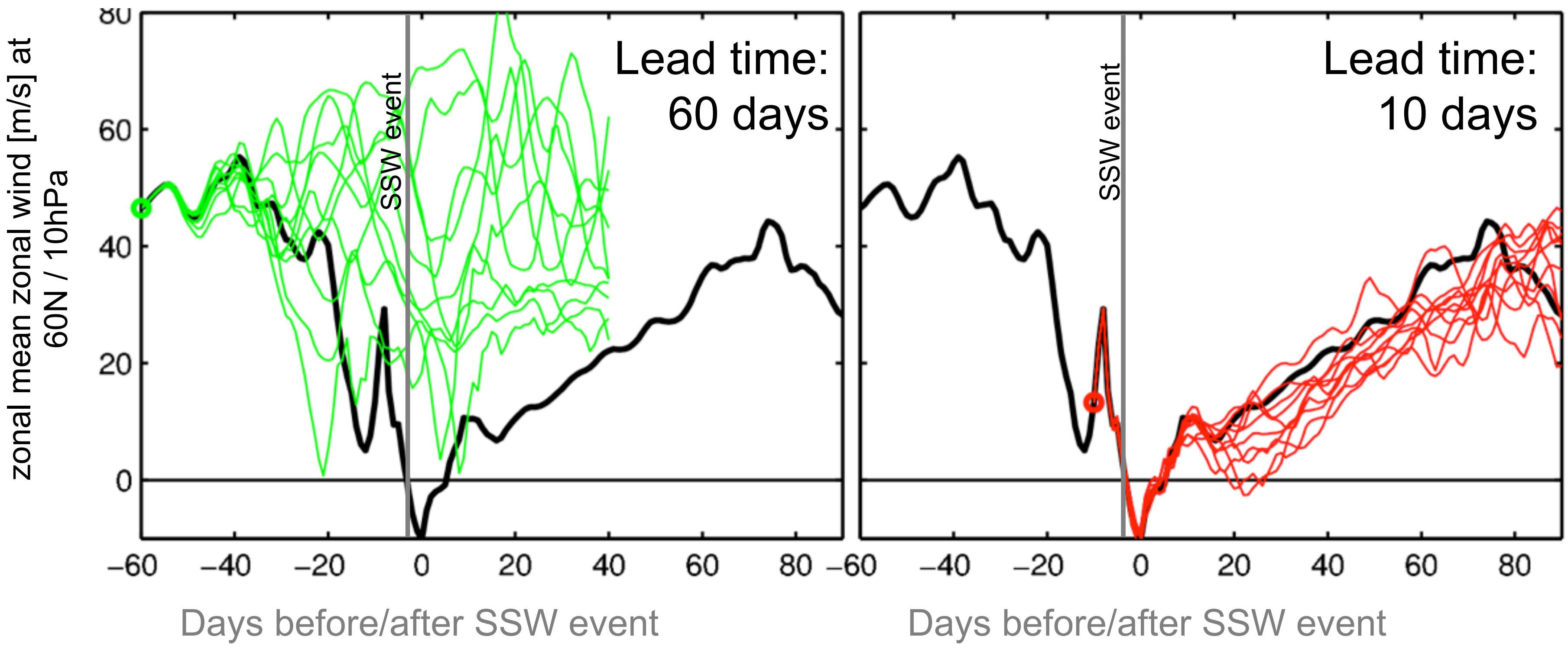


Figure: Gerber et al (2009)

PREDICTABILITY LIMIT FOR STRATOSPHERIC EVENTS

Sudden stratospheric warming events are often not predictable on sub-seasonal timescales

Strong vortex events and final warmings have a higher predictability

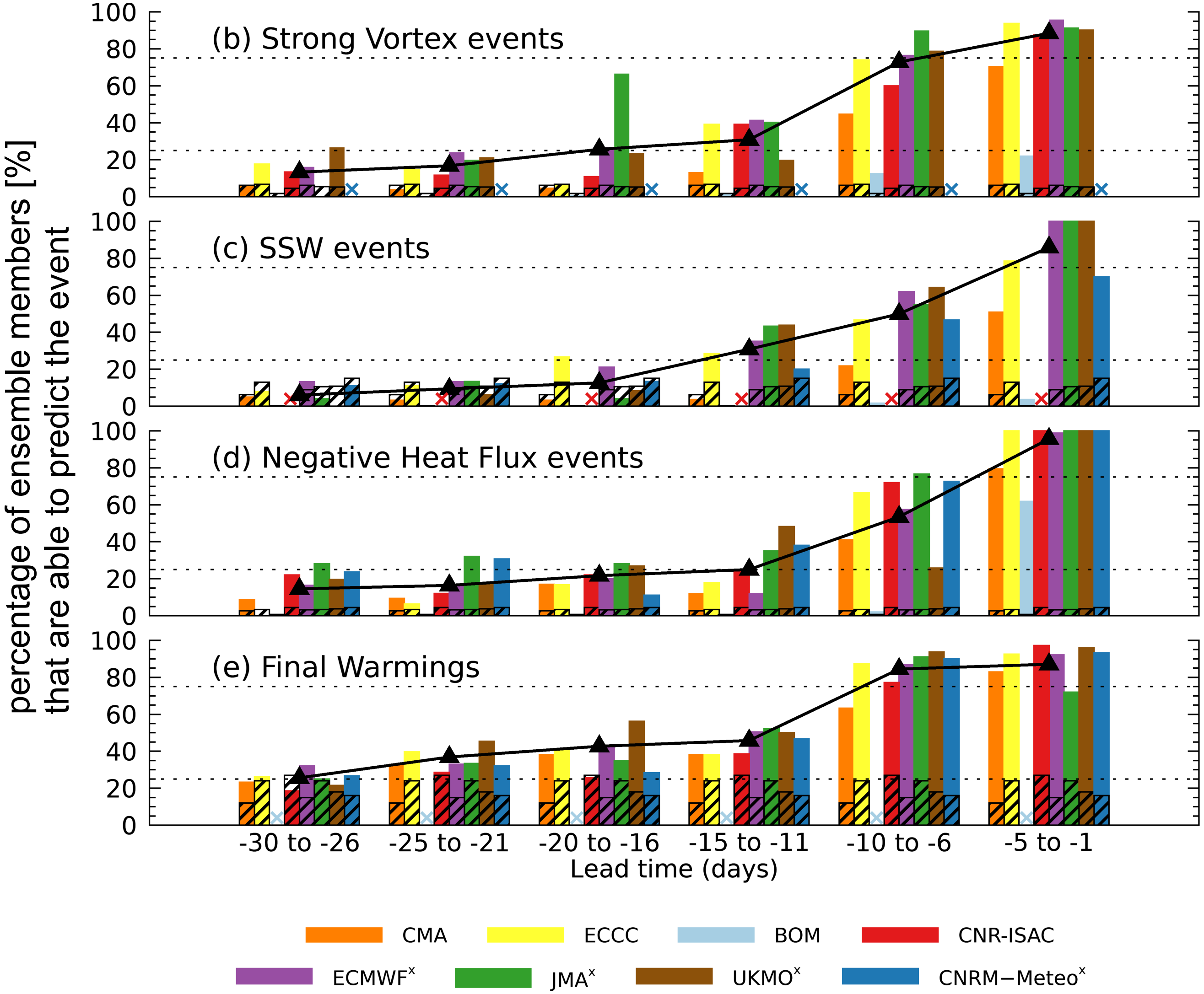
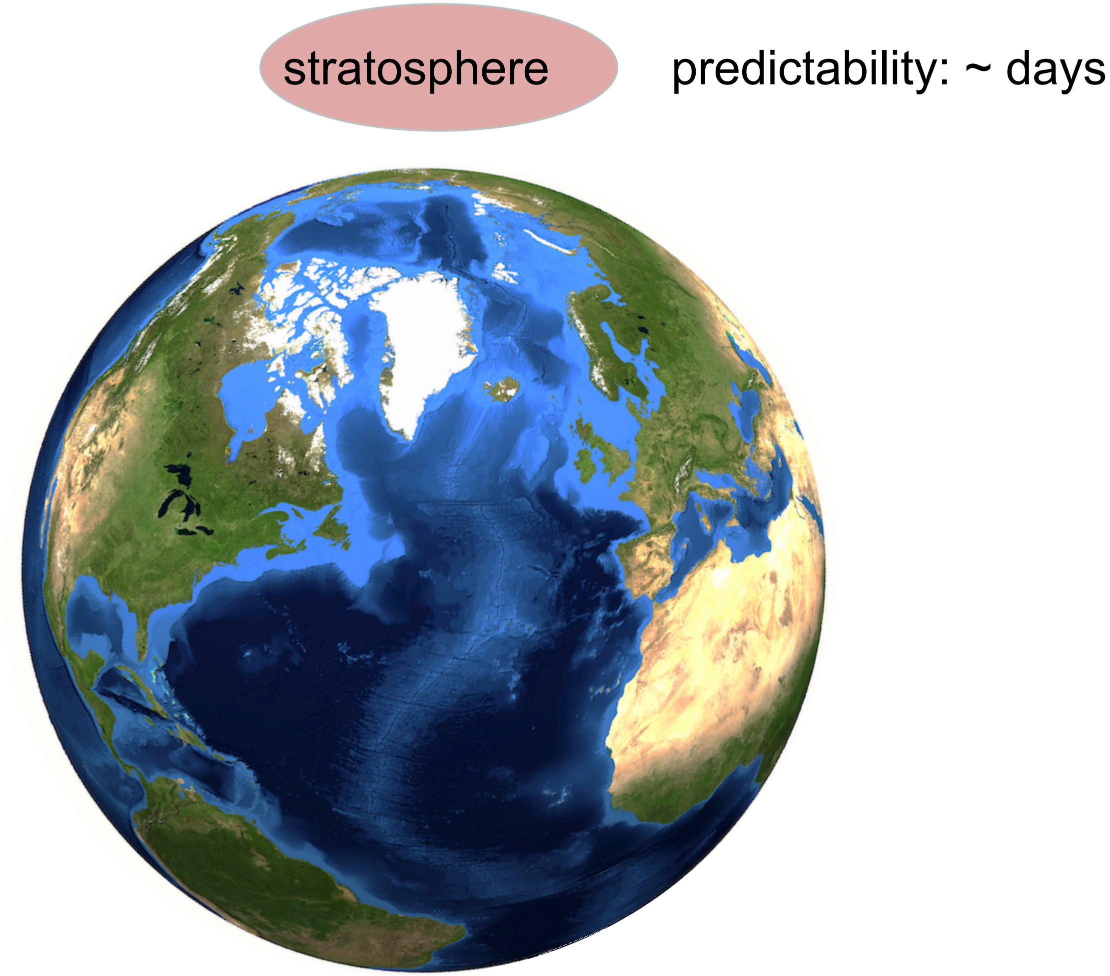


Figure: A. Butler.
from Domeisen et al., under review for the JGR special issue on S2S prediction

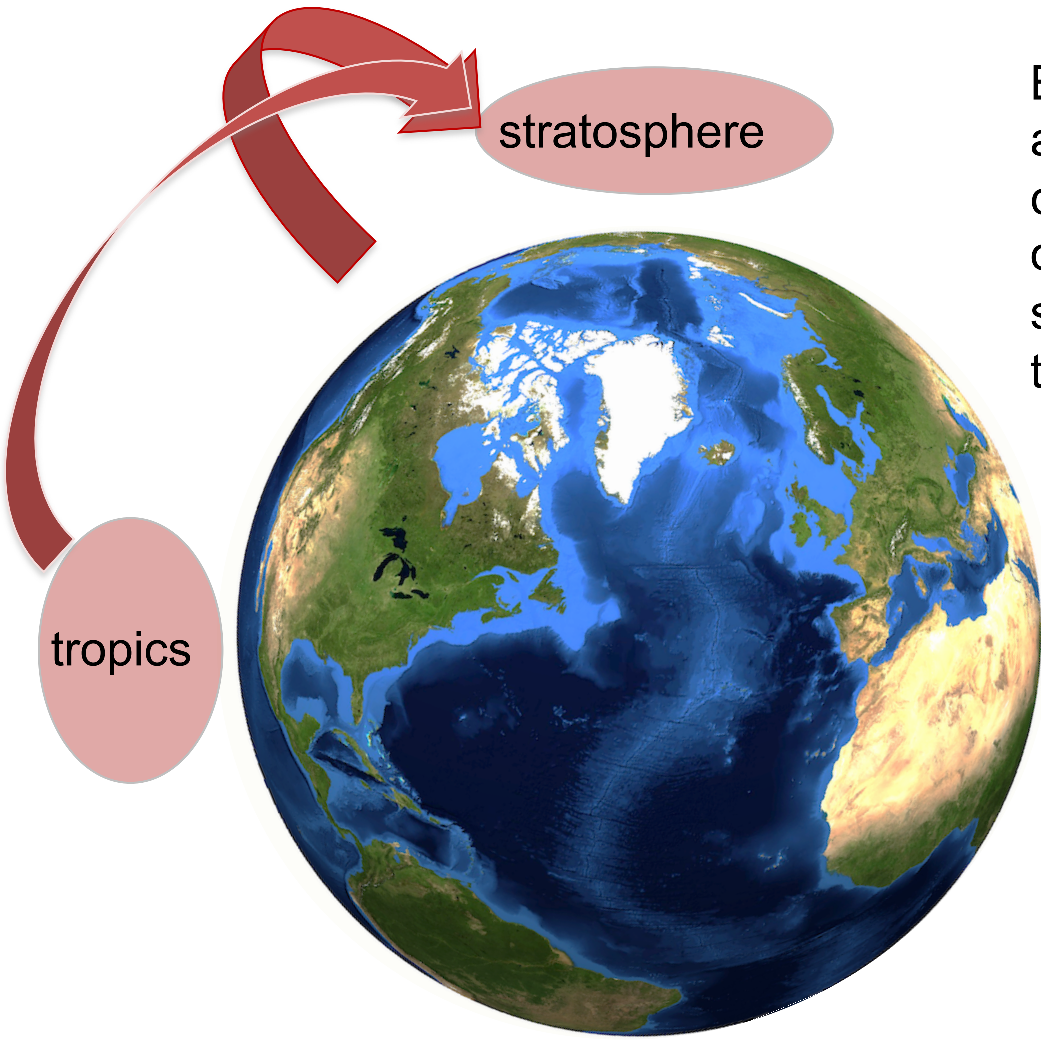
ETHzürich

PREDICTABILITY OF SSW EVENTS IS LIMITED TO WEATHER TIMESCALES



ETH zürich

CONTENTS



But: there are precursors and teleconnections that can affect the frequency of stratospheric events on sub-seasonal to seasonal timescales

PRECURSORS AND TELECONNECTIONS THAT AFFECT THE FREQUENCY OF STRATOSPHERIC EVENTS

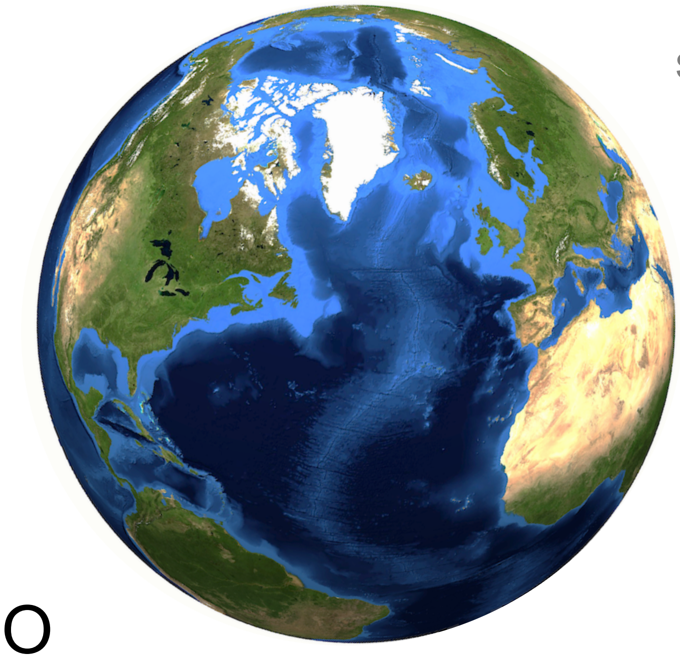
Processes that alter wave propagation into the polar stratosphere can affect the strength of the polar vortex

sea ice

solar forcing

extratropical tropospheric forcing, e.g. blocking

snow cover



QBO

ENSO

MJO

TROPOSPHERIC STRUCTURE BEFORE SSW EVENTS

Tropospheric precursors agree overall with reanalysis, except in strength and over Eurasia

Figure: Average Northern Hemisphere sea level pressure anomalies (hPa) 5 to 30 days before major SSW events between 1996-2010 in ERA-Interim. Areas enclosed by solid brown lines denote where the composite mean is significant.

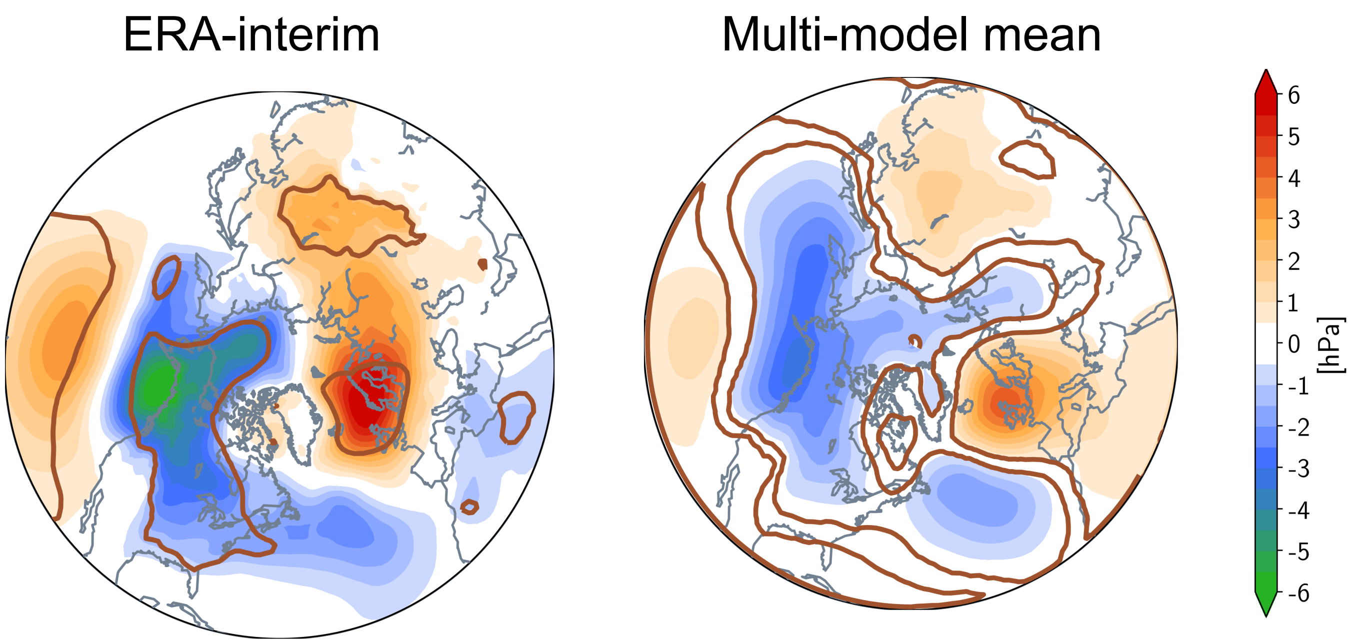
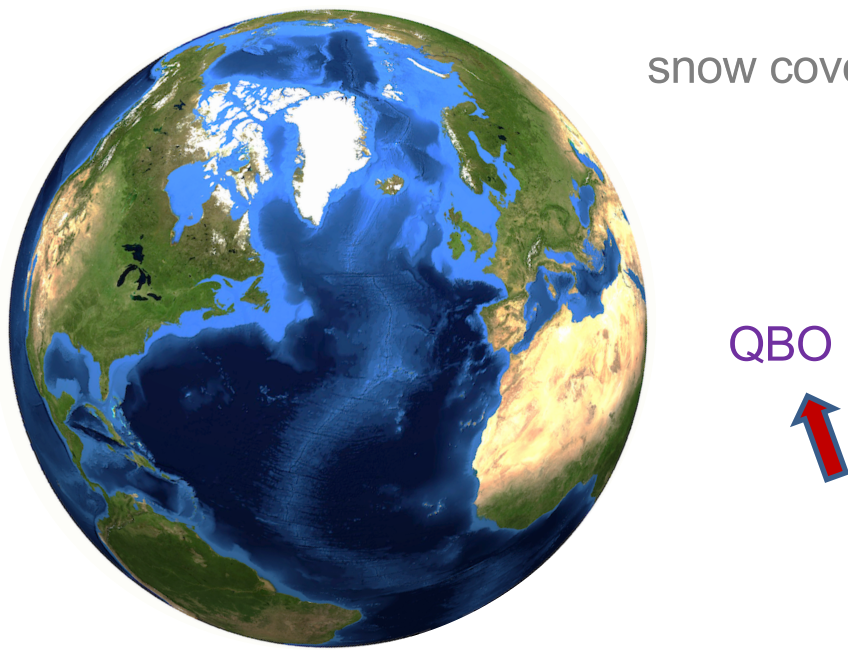


Figure: J. Furtado.
from: Domeisen et al., under review for the JGR special issue on S2S prediction

THERE ARE PRECURSORS AND TELECONNECTIONS THAT CAN AFFECT THE FREQUENCY OF SSW EVENTS

Processes that alter wave propagation into the polar stratosphere can affect the strength of the polar vortex



GLOBAL IMPACTS
OF THE QUASI-BIENNIAL OSCILLATION

There are a range of remote impacts from the QBO

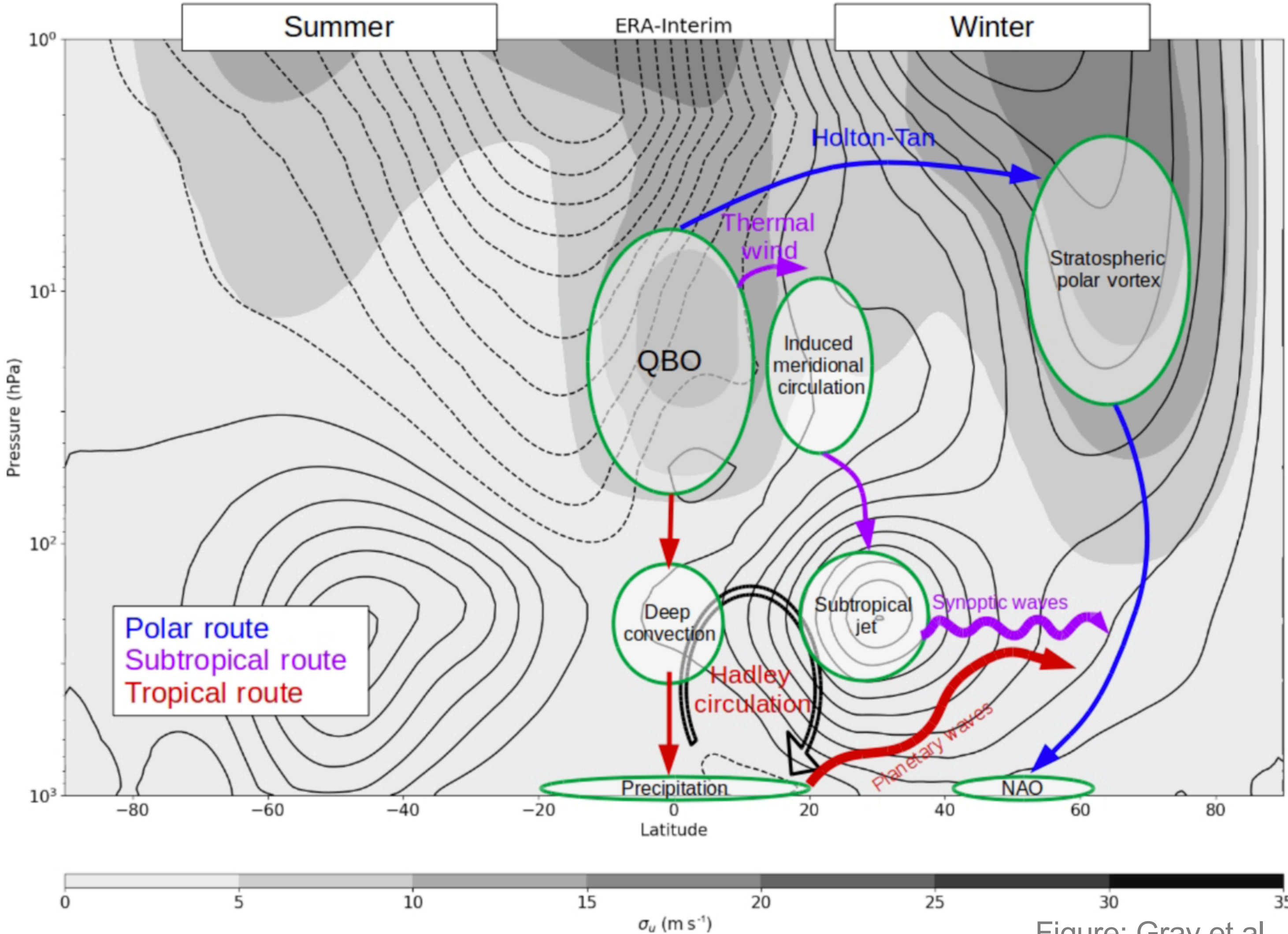


Figure: Gray et al., 2018

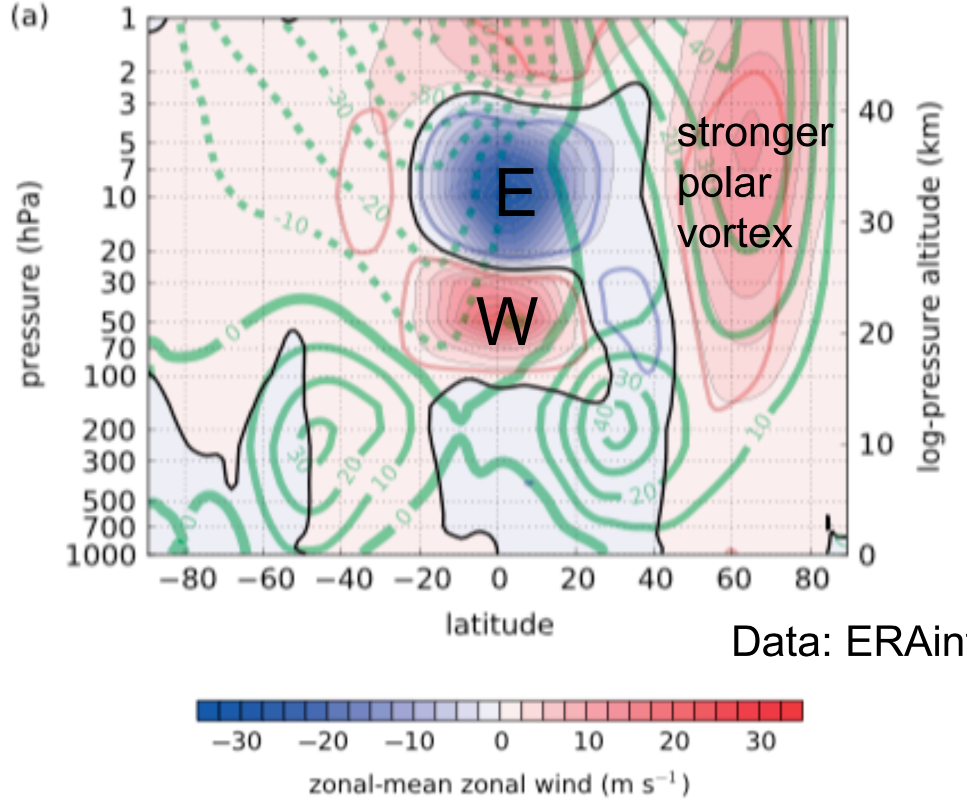
ETH zürich

A CONNECTION BETWEEN THE TROPICAL AND THE EXTRATROPICAL STRATOSPHERE

HOLTON-TAN EFFECT

Westerly QBO winds in the lower stratosphere lead to a strengthening of the winter polar vortex through decreased refraction and reflection of waves towards the polar stratosphere, and vice versa for eQBO.

January, westerly – easterly QBO



Data: ERAinterim

green lines: climatological winds

eQBO: easterly zonal winds in the lower equatorial stratosphere (commonly defined at 50 or 30hPa)

Figure: Anstey & Shepherd (2014), QJRMS

ETH zürich

THERE ARE PRECURSORS AND TELECONNECTIONS THAT CAN AFFECT THE FREQUENCY OF SSW EVENTS

Processes that alter wave propagation into the polar stratosphere can affect the strength of the polar vortex

sea ice

solar forcing

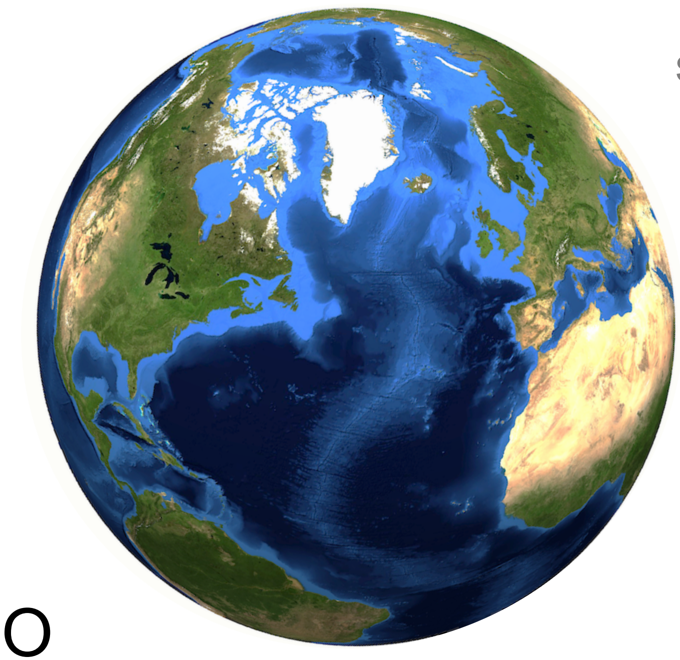
extratropical tropospheric forcing, e.g. blocking

snow cover

QBO

ENSO

MJO



THE EFFECT OF EL NINO ON THE STRATOSPHERE

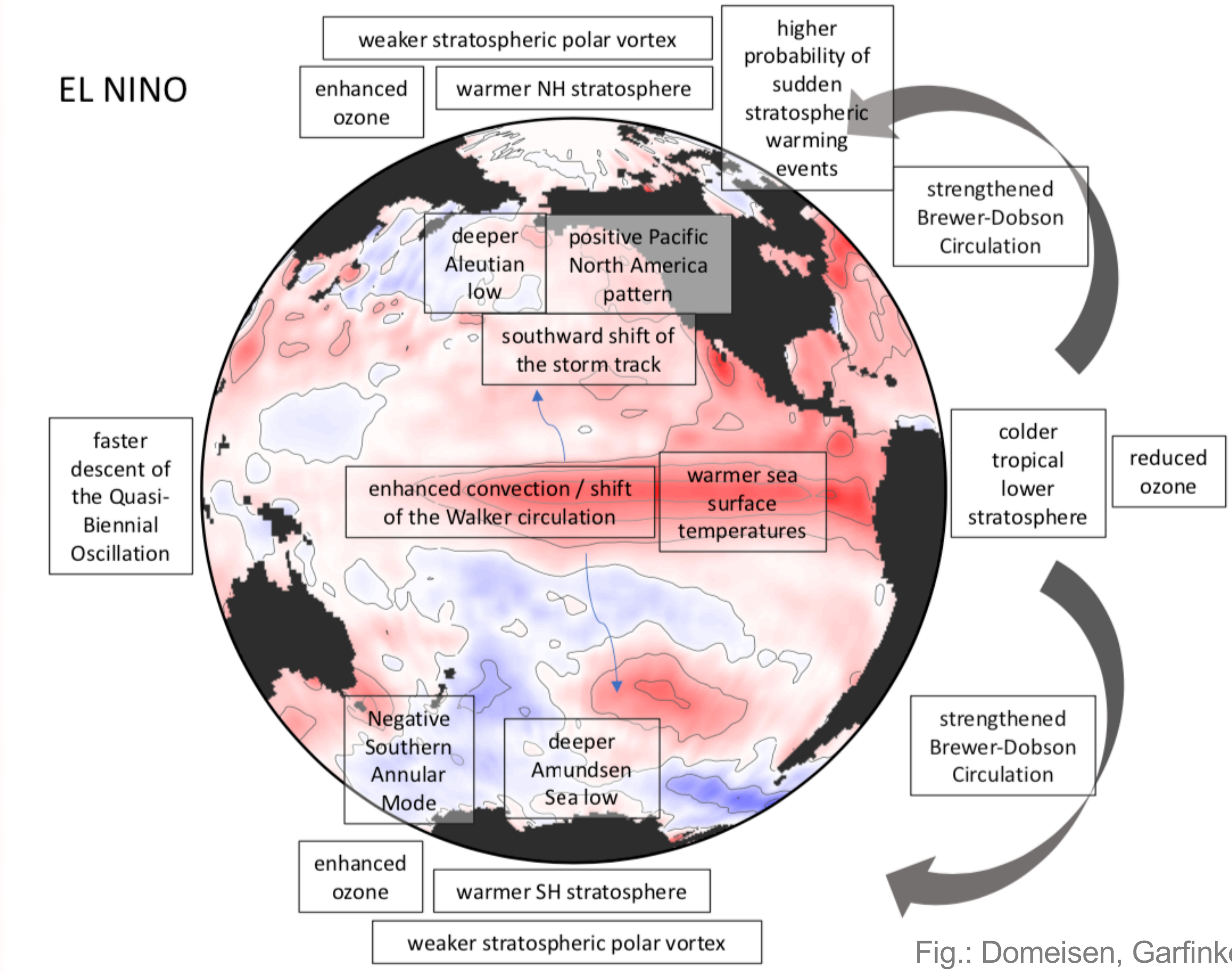
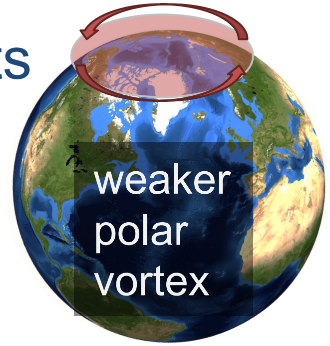
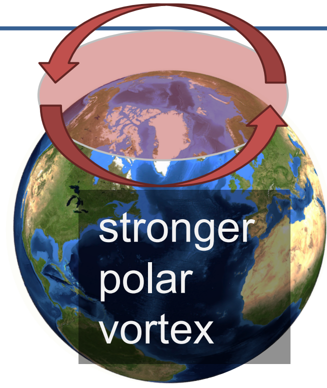


Fig.: Domeisen, Garfinkel, and Butler, Rev. Geophys., 2019

MADDEN-JULIAN OSCILLATION IMPACT ON THE EXTRATROPICAL STRATOSPHERE

Sub-seasonal predictability of SSW events





phase 6

phase 2

Madden-Julian-Oscillation

see e.g.:
Schwartz & Garfinkel, 2017, JGR

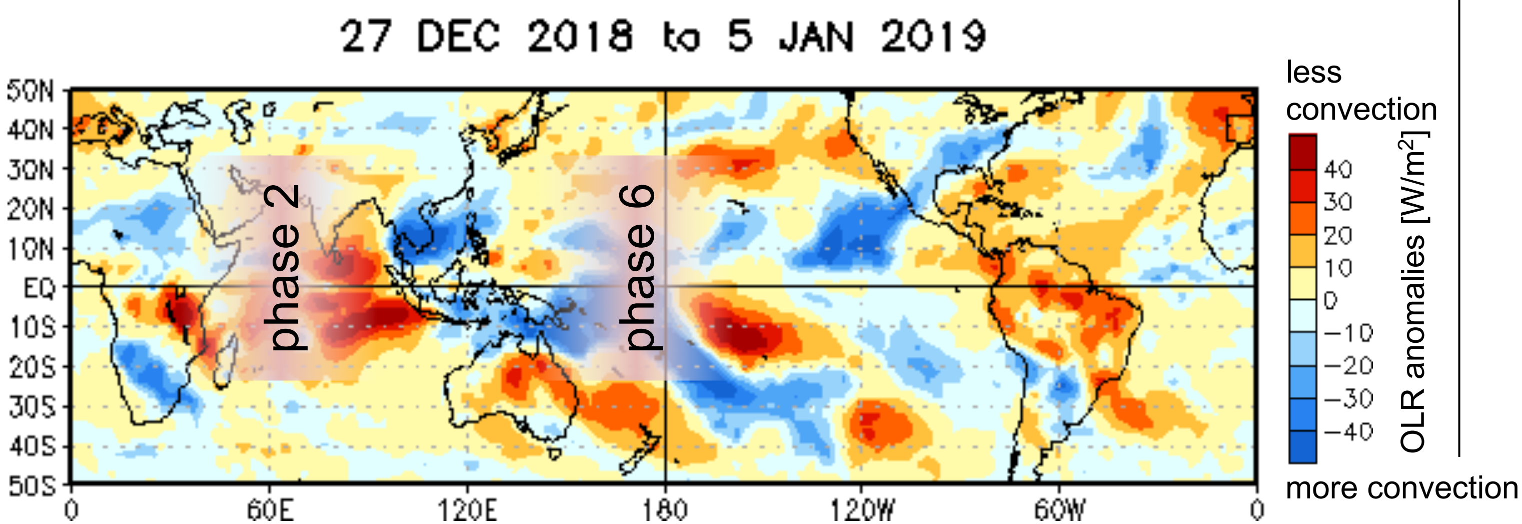
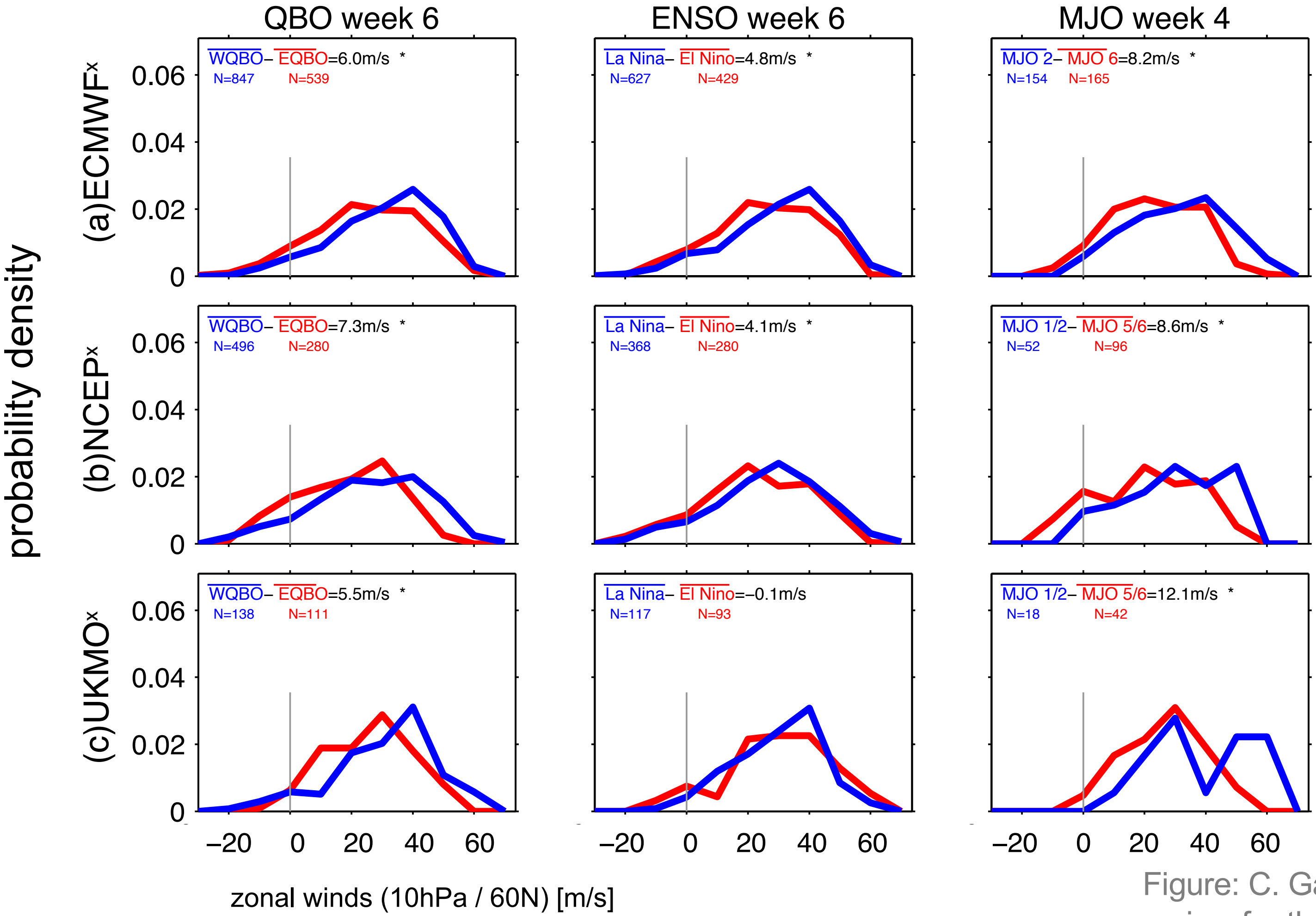


Figure: CPC NCEP NOAA

ETH zürich

MADDEN-JULIAN OSCILLATION IMPACT ON THE EXTRATROPICAL STRATOSPHERE IN THE S2S MODELS



ECMWF system:

increase in the probability for easterly winds by

66% for eQBO vs wQBO

30% for El Nino vs La Nina

139% for MJO phase 6 vs 2

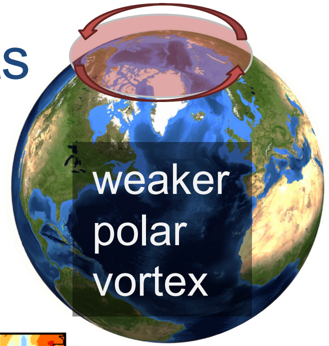
see also:
Schwartz & Garfinkel, 2017, JGR

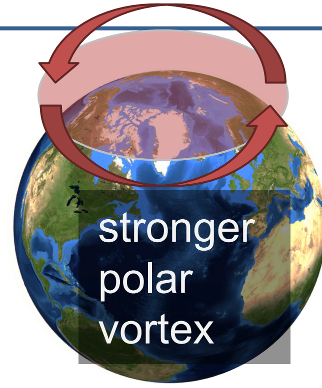
Figure: C. Garfinkel. from Domeisen et al., under review for the JGR special issue on S2S prediction

ETHzürich

THERE ARE PRECURSORS AND TELECONNECTIONS THAT CAN AFFECT THE FREQUENCY OF SSW EVENTS

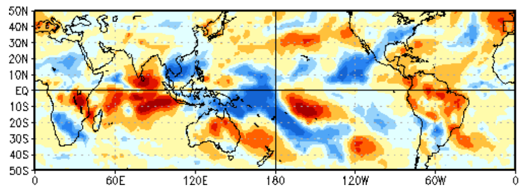
Sub-seasonal predictability of SSW events





Madden-Julian-Oscillation

see e.g.:
Schwartz & Garfinkel, 2017, JGR

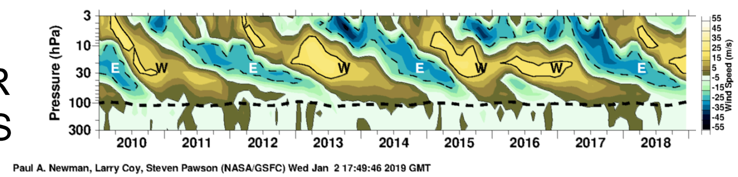


phase 6

phase 2

Quasi-Biennial-Oscillation

see e.g.:
Garfinkel et al., 2018, JGR
Watson & Gray, 2014, JAS
Labitzke, 1992, JATP

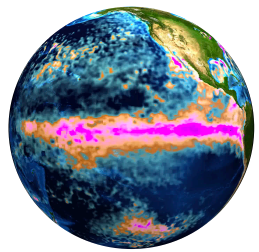


eQBO

wQBO

El Nino Southern Oscillation

see e.g.:
Domeisen, Garfinkel & Butler, 2018, Rev. Geophys.
Ineson & Scaife, 2008, Nature Geoscience
Brönnimann, 2007, Rev. Geophys.
Polvani et al, 2017, J. Clim.

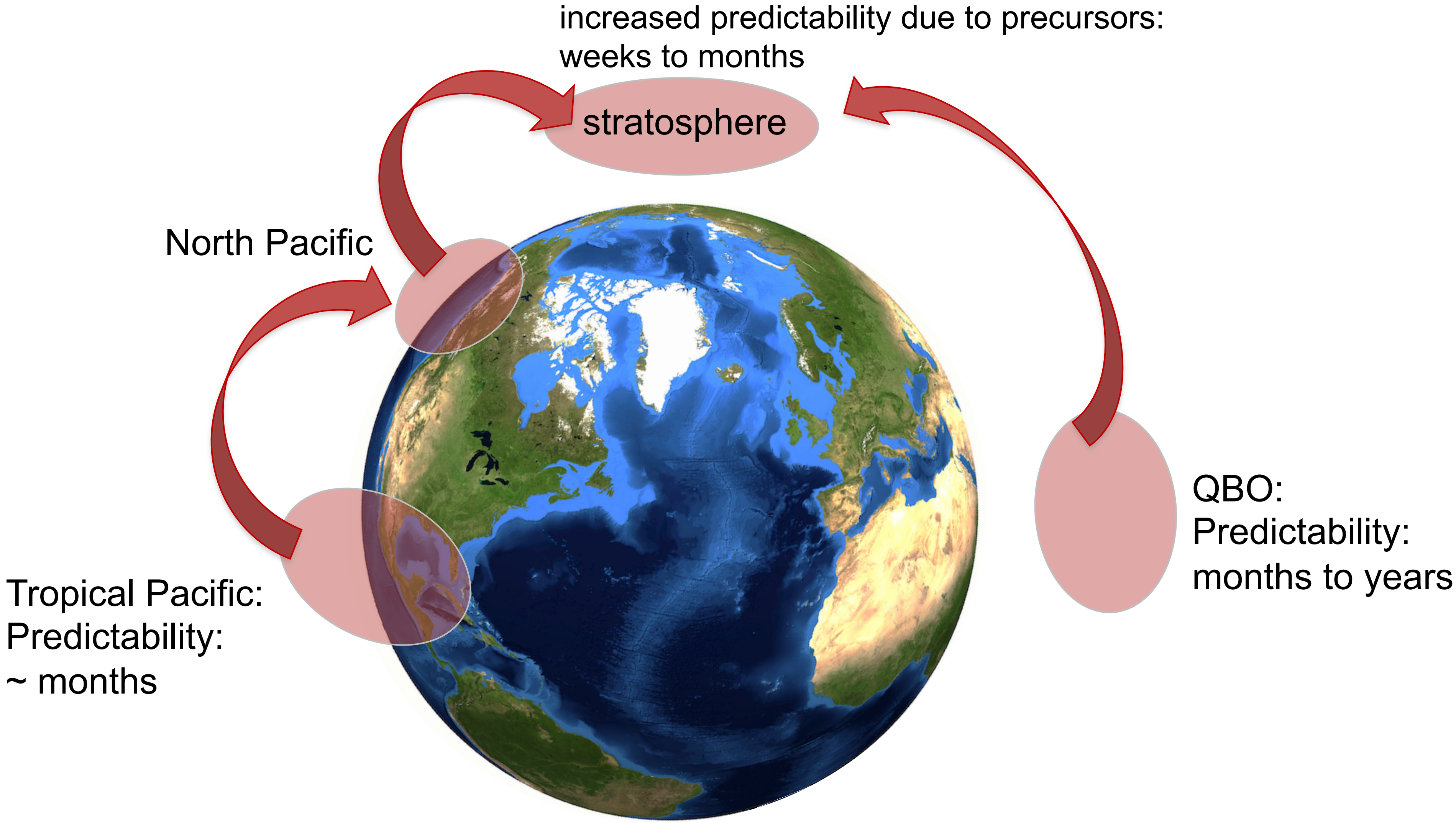


El Nino

La Nina

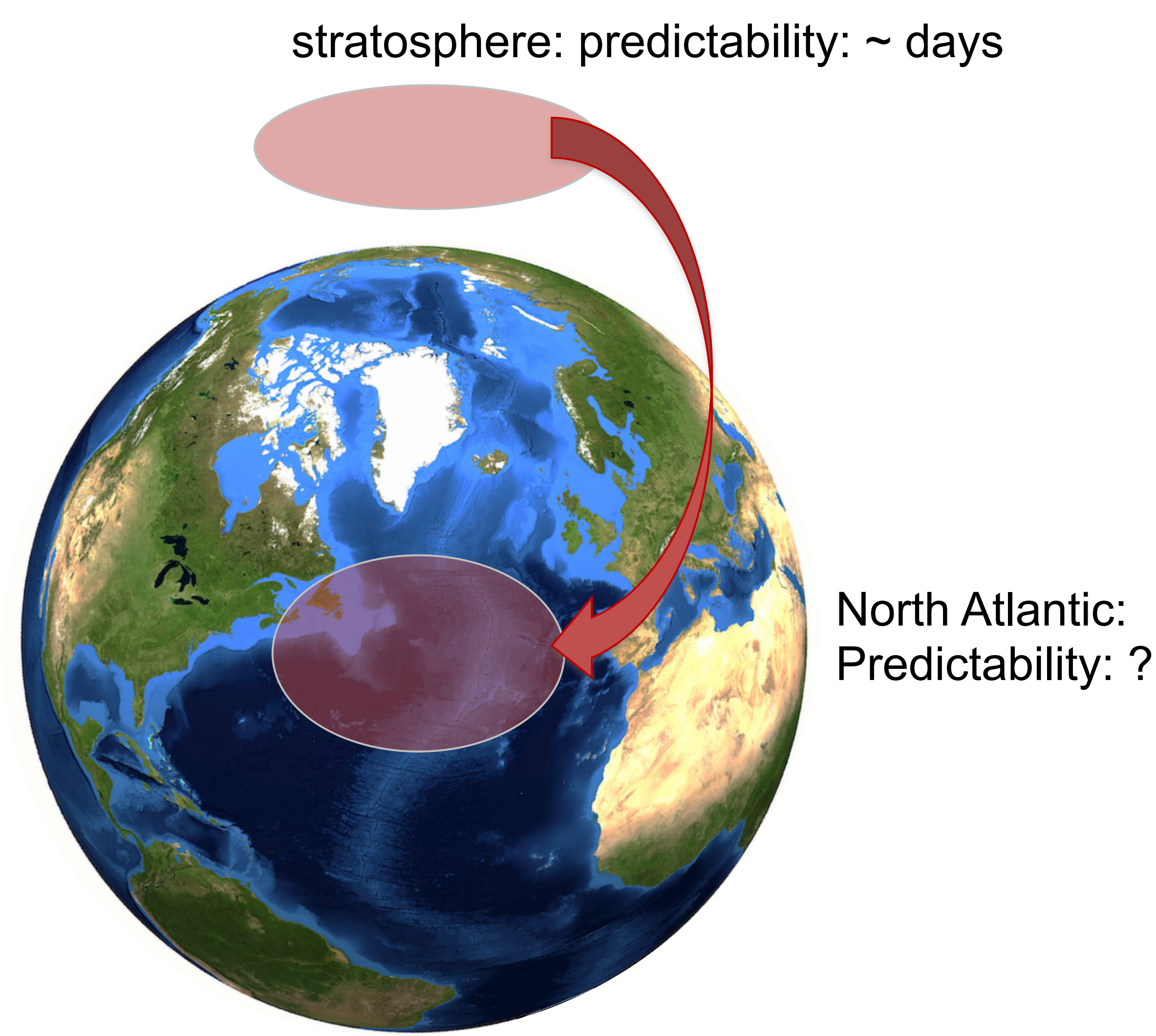
ETH zürich

PROBABILISTIC PREDICTABILITY OF SSW EVENTS ON S2S TIMESCALES



ETH zürich

CAN WE PREDICT THE RESPONSE TO STRATOSPHERIC EVENTS?



ETH zürich

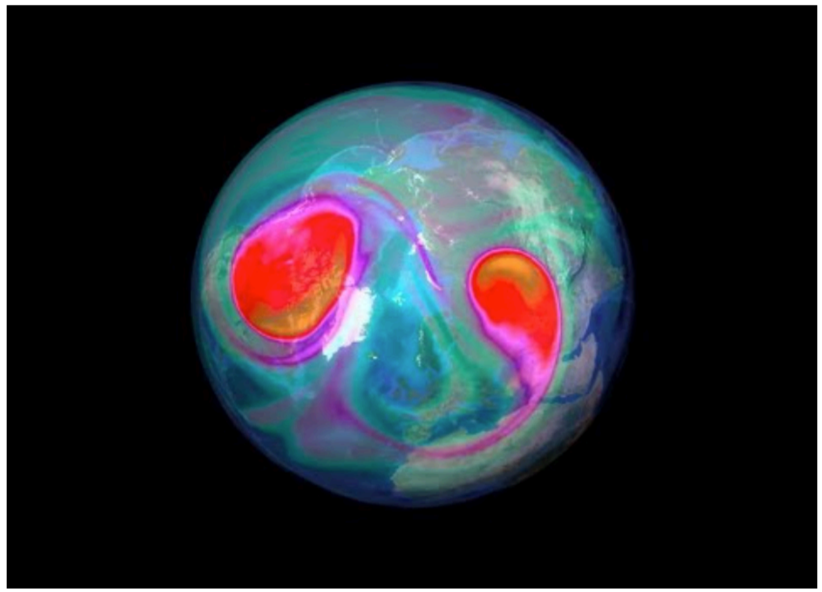
AFTER SUDDEN STRATOSPHERIC WARMINGS: TOP-DOWN INFLUENCE ON OUR WEATHER

…and phone calls from journalists

Warming in the stratosphere leads to cold winters

29.01.2019 | News
By: Peter Rüegg | 1 Comment

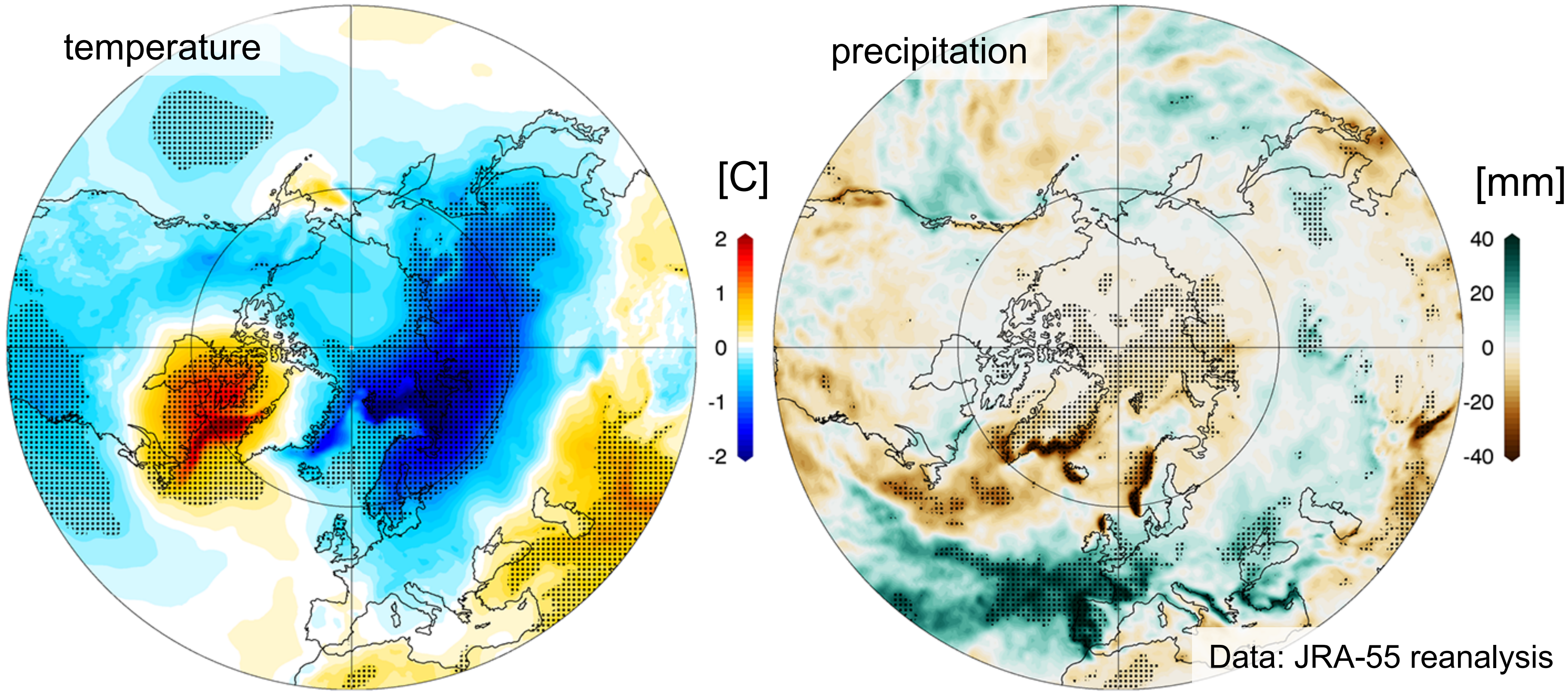
In the first week of January, the Arctic stratosphere suddenly warmed up, an occurrence known as "sudden stratospheric warming" (SSW). This phenomenon results in cold winter weather, just the kind we are facing now – ETH researchers have visualised the event that was observed before the current one – in February 2018. Daniela Domeisen explains how this phenomenon occurs in an interview.



ETH zürich

AFTER SUDDEN STRATOSPHERIC WARMINGS: TOP-DOWN INFLUENCE ON OUR WEATHER

After a stratospheric event: anomalies with respect to the long-term mean:



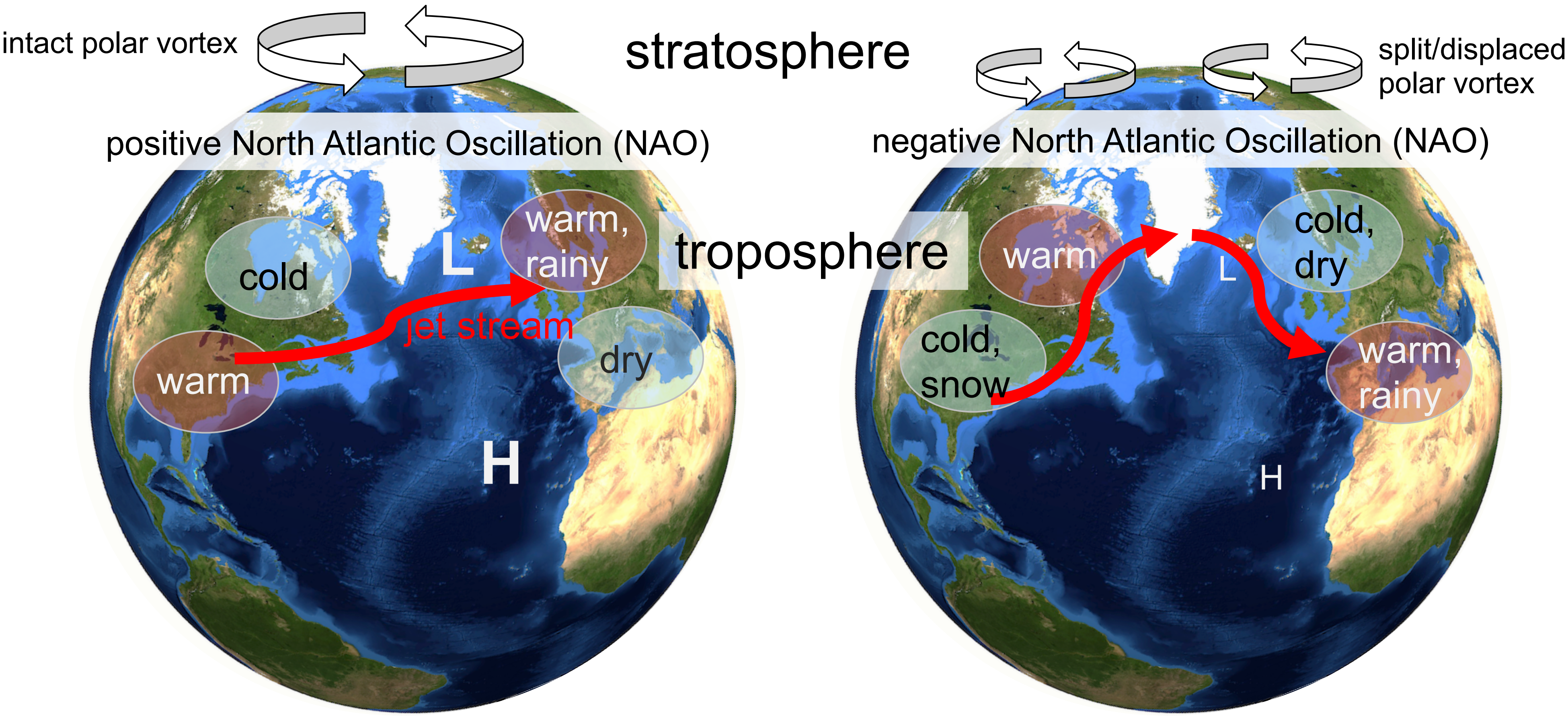
The average over 60 days after historical sudden stratospheric warming events. The stippling indicates regions that are significantly different from the climatology at the 95% level.

Figure: Butler et al., 2017, ESSD

ETH zürich

INFLUENCE OF THE STRATOSPHERE ON OUR WEATHER

After a stratospheric event, the jet stream over the North Atlantic often assumes a persistent wavy pattern, leading to extended cold air outbreaks in northern Europe.



ETH zürich

HOW WELL DO WE PREDICT THE NAO ON WEATHER TIMESCALES?

Limited operational predictability beyond about 1 week

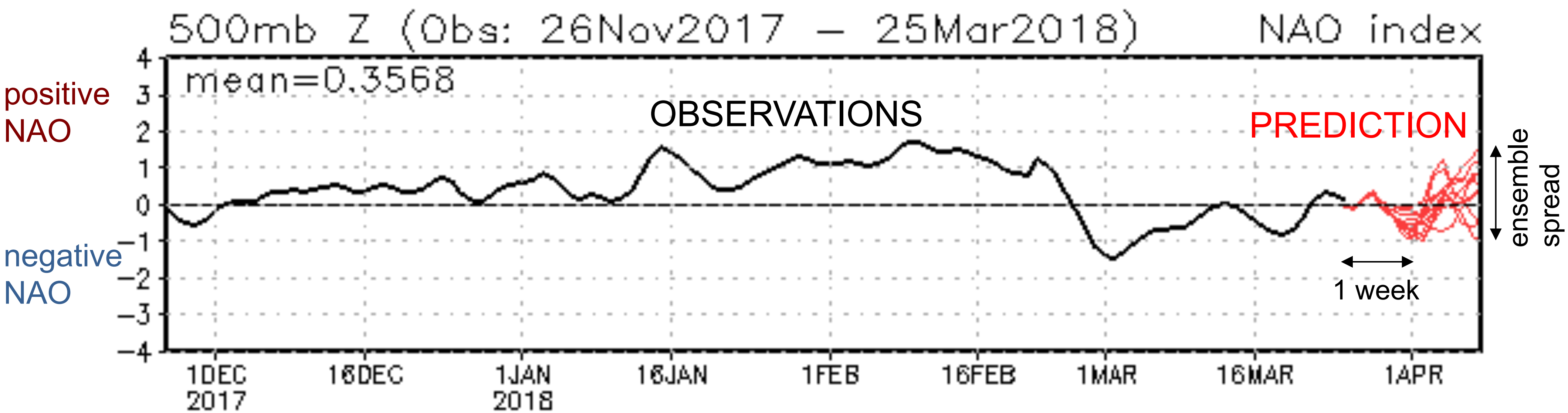


Figure: modified from cpc.ncep.noaa.gov

The theoretical prediction limit of the NAO and the AO lies at 2-3 weeks. This is more predictable than numerical models tell us and reaches into sub-seasonal timescales.

Domeisen et al., 2018, JClim; **Eade** et al. 2014, GRL; **Buizza** et al., 2015, QJRMS; **Scaife** et al., 2018, CAS; **Zhang** et al 2019, JAS

PERSISTENCE OF NEGATIVE NAO EVENTS INCREASES AFTER SSW EVENTS

Persistent positive NAO phase is suppressed after SSW event

About two thirds of SSW events are followed by persistent NAO events

But: less than 25% of persistent NAO events in winter are preceded by SSW events

SSW = Sudden Stratospheric Warming
NAO = North Atlantic Oscillation

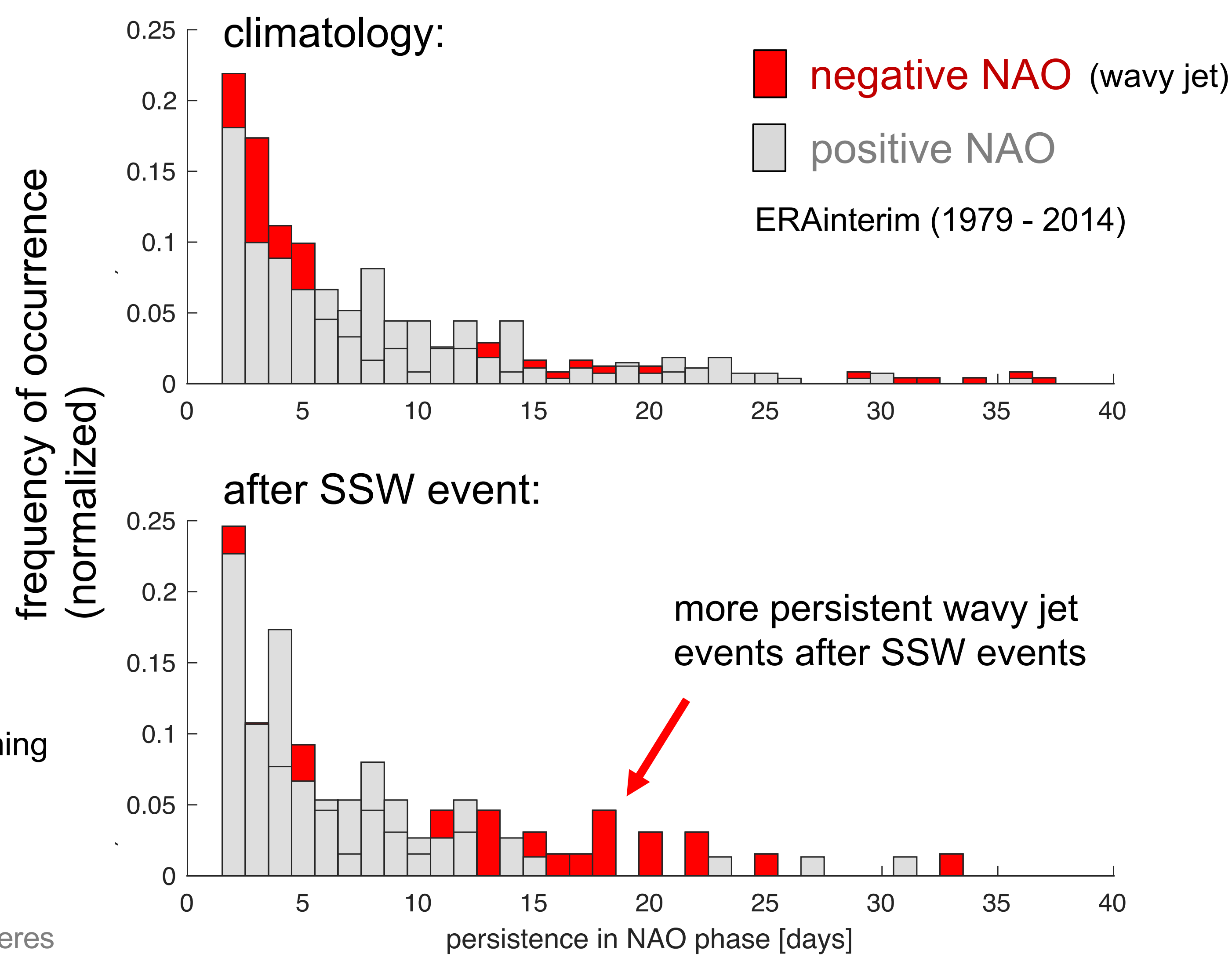


Figure: Domeisen, 2019. JGR-Atmospheres

CAN WE PREDICT THE RESPONSE TO STRATOSPHERIC EVENTS?

2m temperature anomaly (week 3 + 4)
after weak vortex event:

S2S prediction database:
Vitart et al (2016)

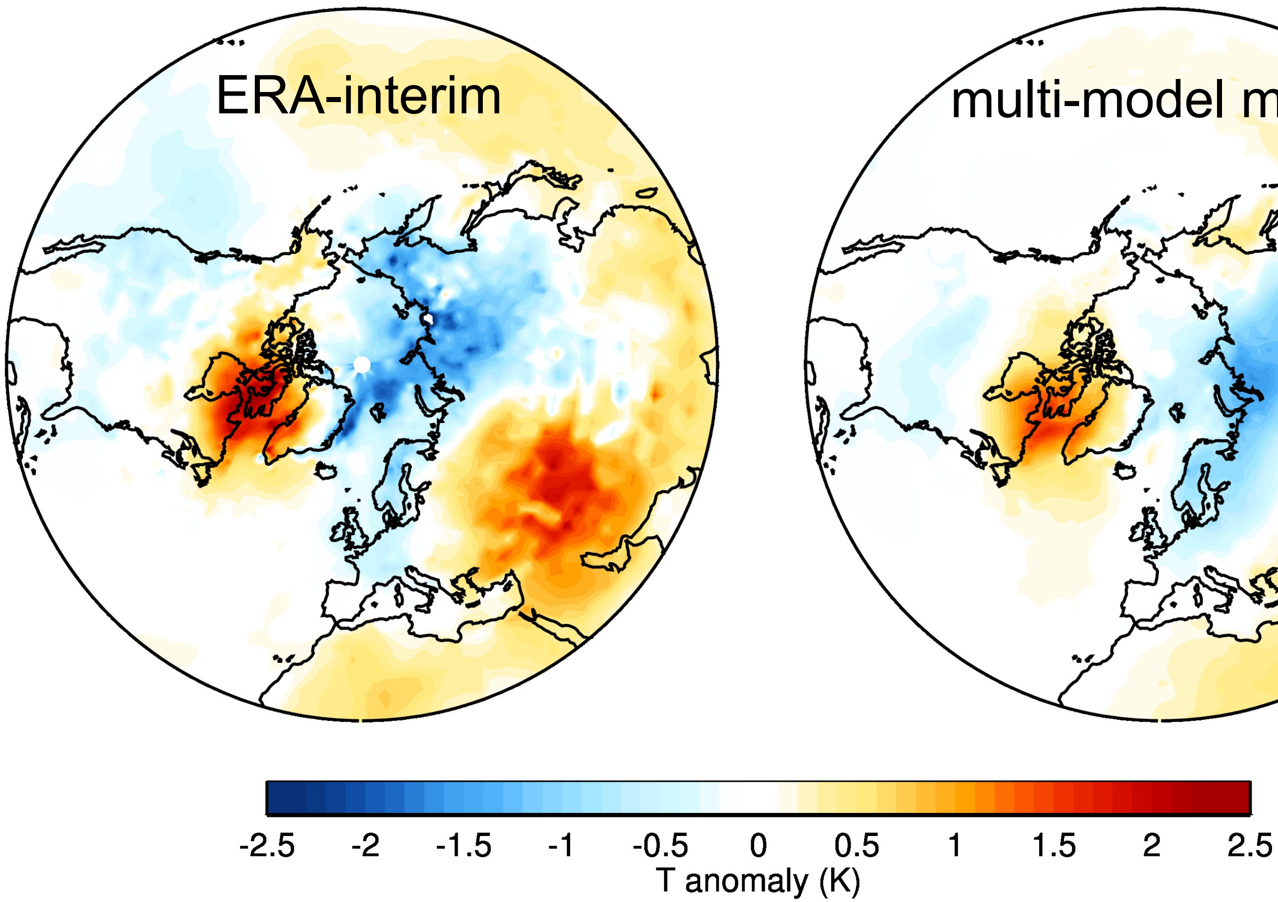
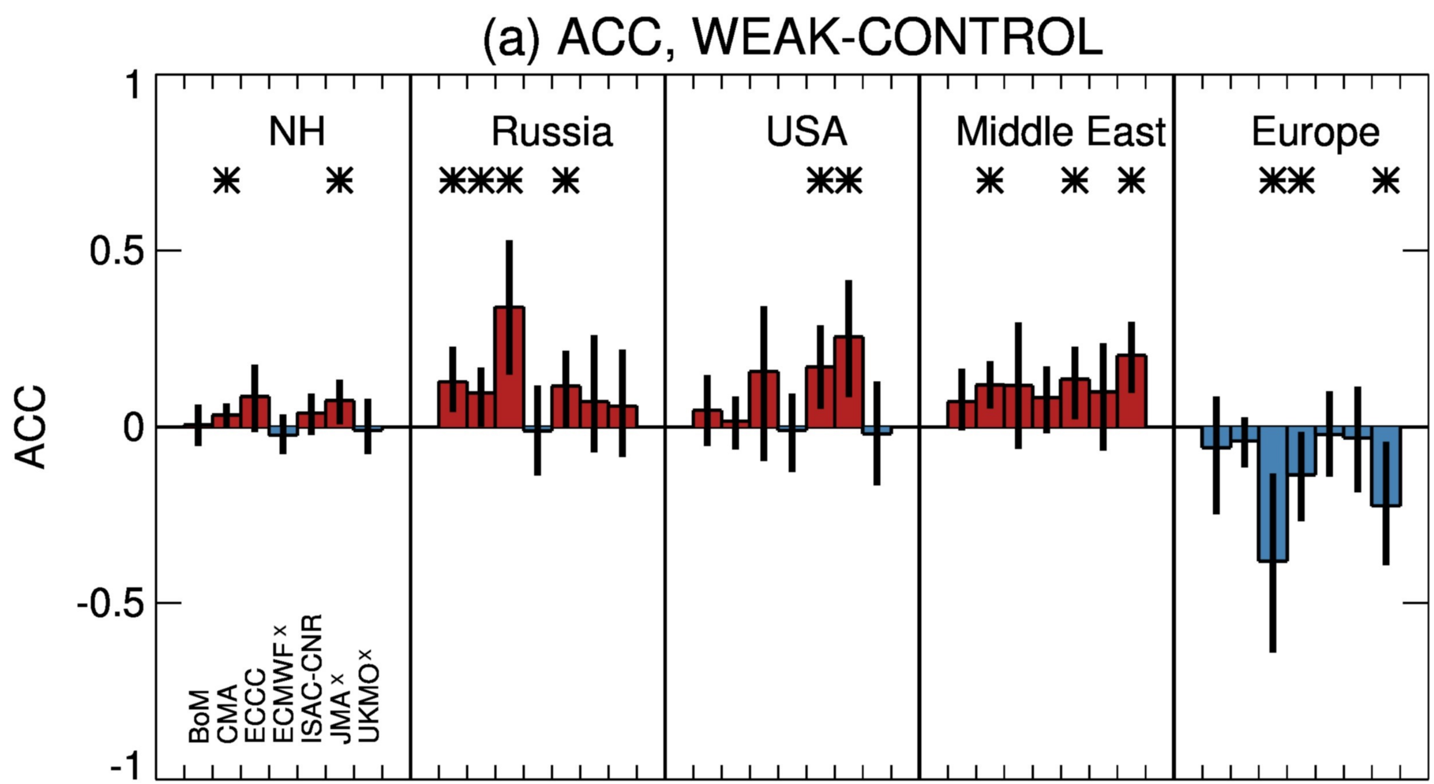


Figure: Isla Simpson.
from: Domeisen et al., in rev. for the JGR special issue on S2S prediction

CAN WE PREDICT THE RESPONSE TO STRATOSPHERIC EVENTS?



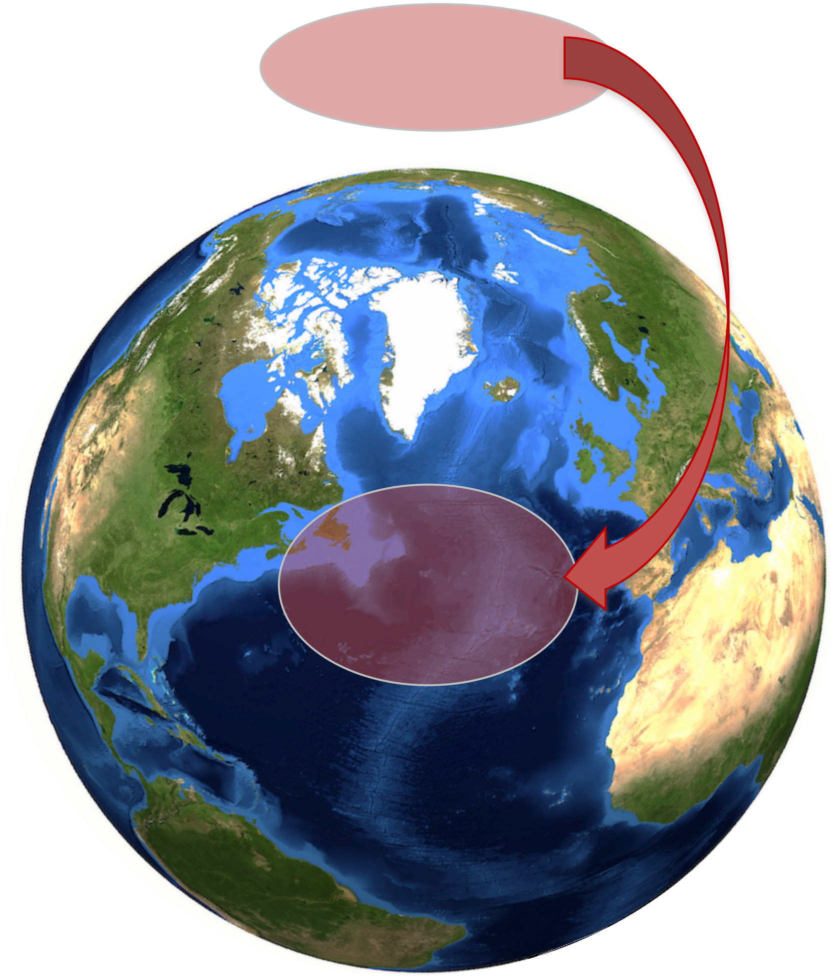
Data: S2S prediction database (Vitart et al, 2016)

Anomaly correlation coefficient difference between initializations during weak vortex and control for 2m temperature

Figure: Isla Simpson.
from: Domeisen et al., in rev. for the JGR special issue on S2S prediction

ETH zürich

CONTENTS

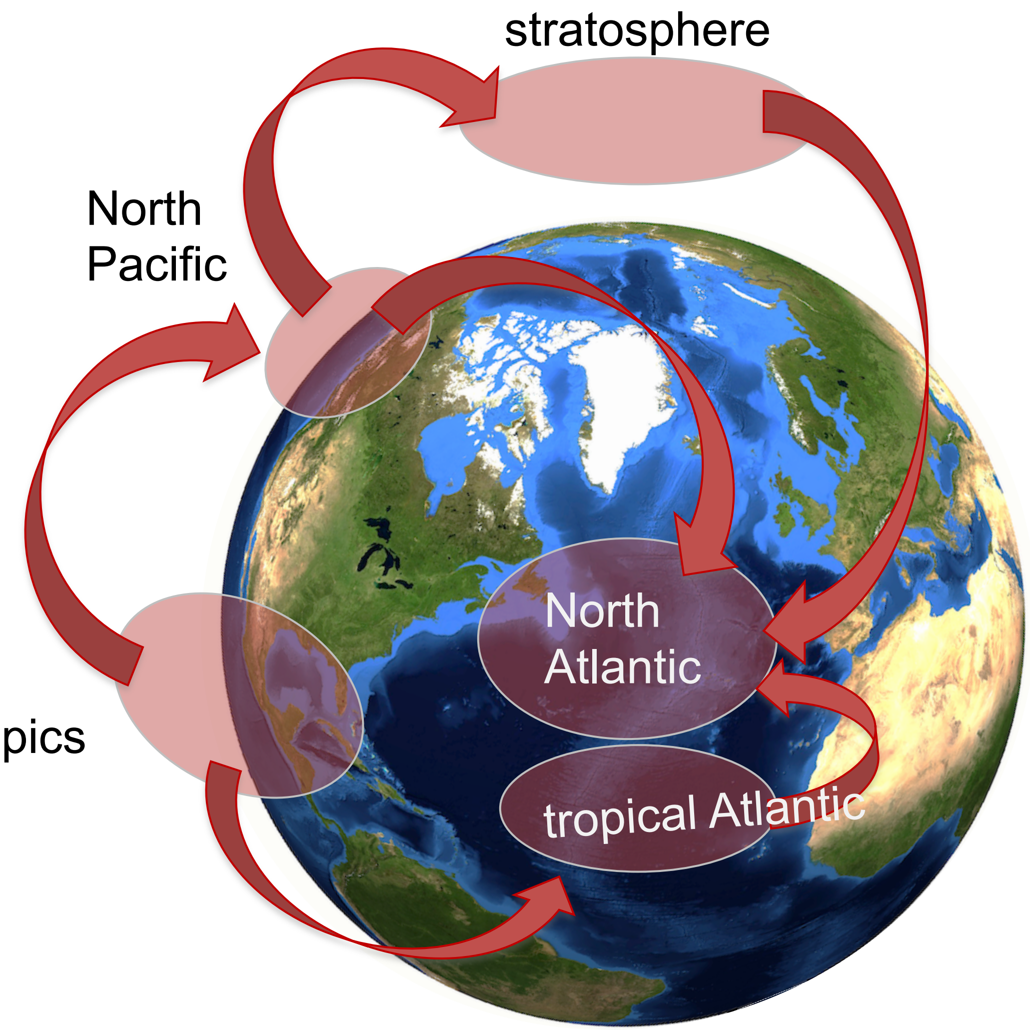


Predictability at the surface is generally increased after SSW events, but not necessarily over Europe

ETH zürich

MANY OPEN QUESTIONS REMAIN

One answer to the question "why is the skill of seasonal forecasts over Europe so low?"



many paths lead to Europe:

North Pacific – North Atlantic (via troposphere)
Jiménez-Esteve & Domeisen, 2018, JClim

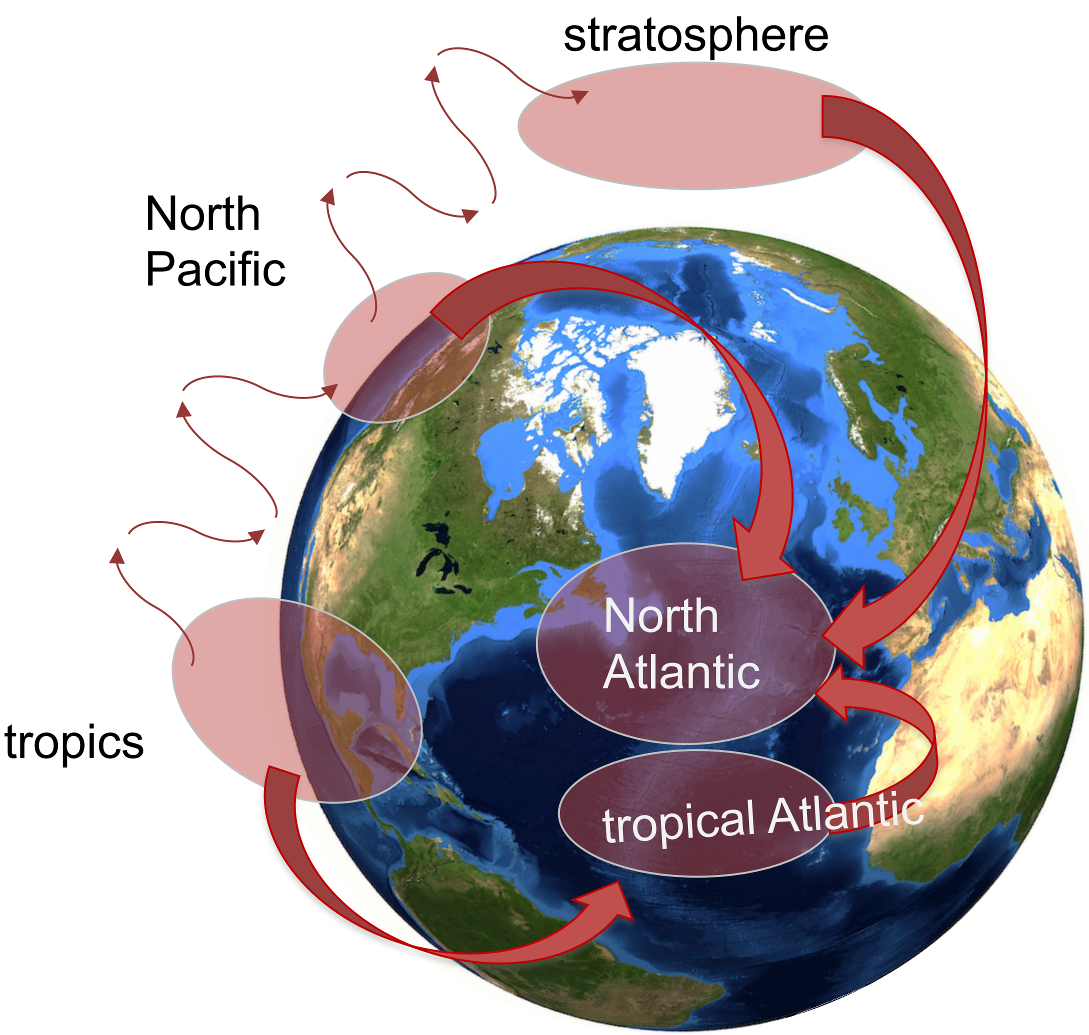
North Pacific – stratosphere
e.g. Ineson & Scaife, 2008, Domeisen et al., 2015, Butler et al., 2016, Iza & Calvo, 2015

Tropical Atlantic pathway
e.g. López-Parages & Rodríguez-Fonseca, 2012, Wulff et al., 2017, GRL

ETH zürich

MANY OPEN QUESTIONS REMAIN

One answer to the question “why is the skill of seasonal forecasts over Europe so low?”



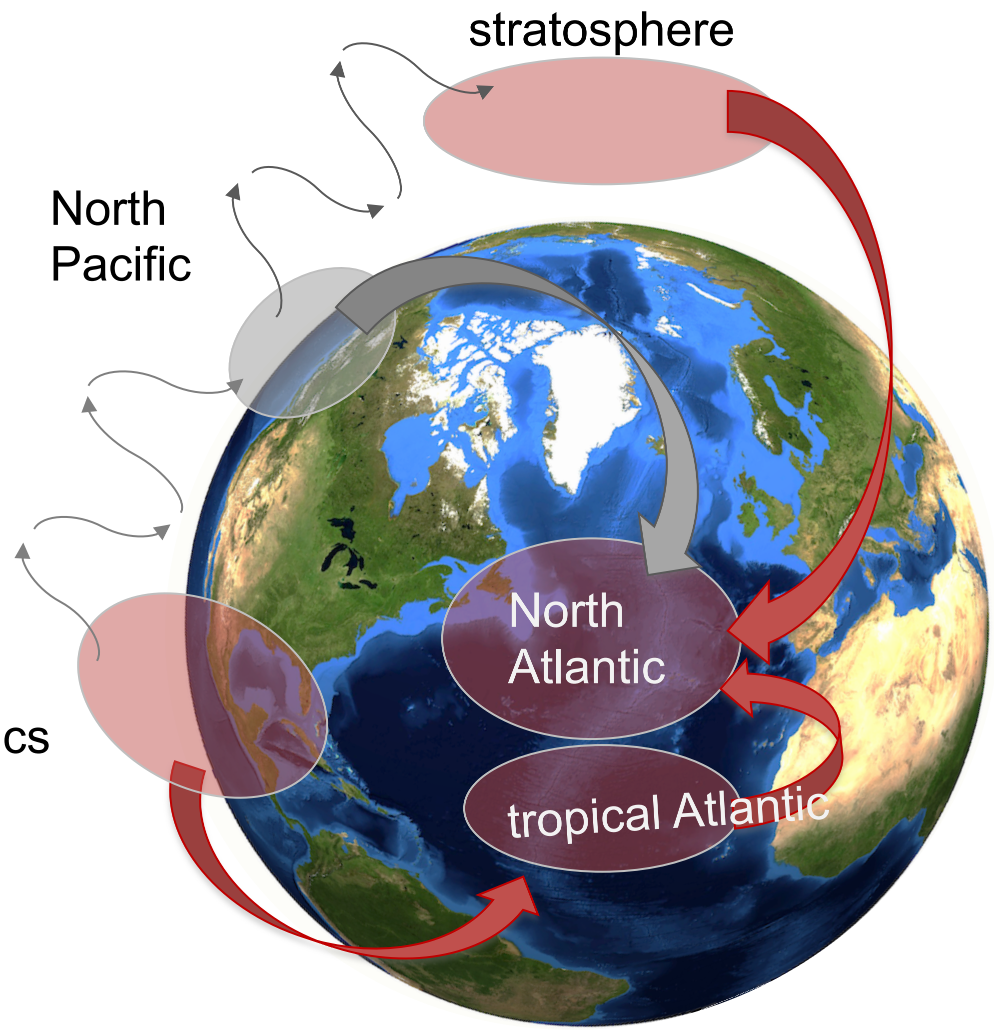
many paths lead to Europe

nonlinearity

e.g. Frauen et al., 2014,
Garfinkel et al., 2018,
Jiménez & Domeisen, 2019

MANY OPEN QUESTIONS REMAIN

One answer to the question “why is the skill of seasonal forecasts over Europe so low?”



many paths lead to Europe

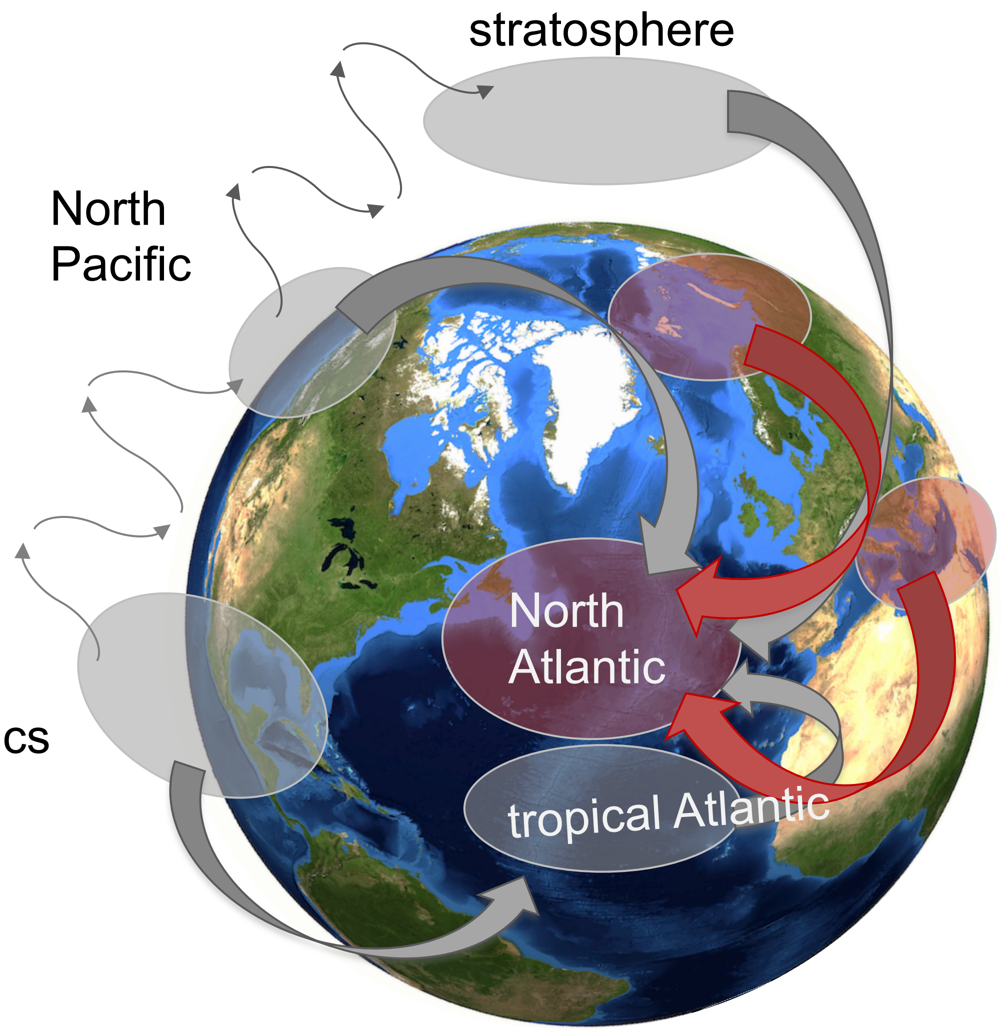
nonlinearity

teleconnections may not remain constant over time (non-stationarity)

e.g. Lopez-Parages et al., 2015, Woollings et al., 2018; Garfinkel et al, 2019, JGR

MANY OPEN QUESTIONS REMAIN

One answer to the question "why is the skill of seasonal forecasts over Europe so low?"



many paths lead to Europe

nonlinearity

teleconnections may not remain constant over time (non-stationarity)

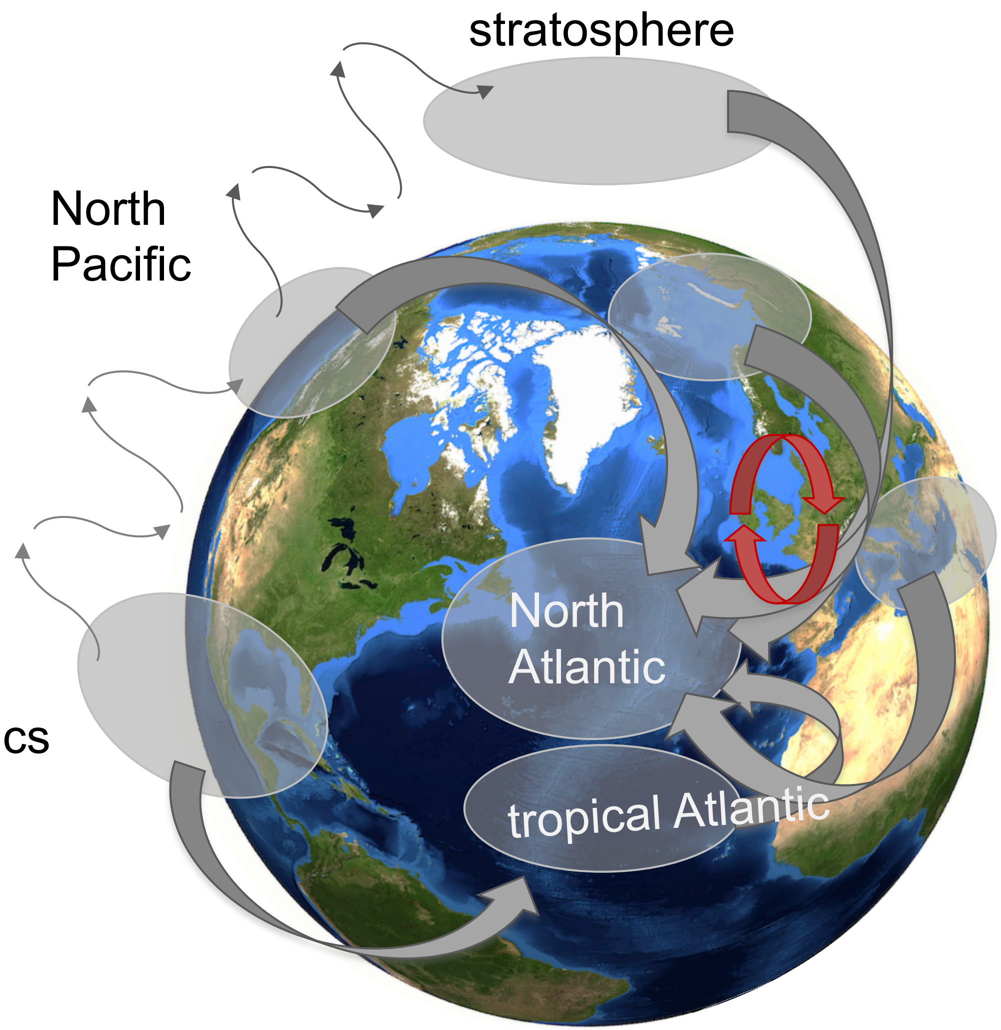
additional drivers: sea ice, snow cover, etc

e.g. Sun et al., 2015, Dobrynin et al., 2018

ETH zürich

MANY OPEN QUESTIONS REMAIN

One answer to the question "why is the skill of seasonal forecasts over Europe so low?"



many paths lead to Europe

nonlinearity

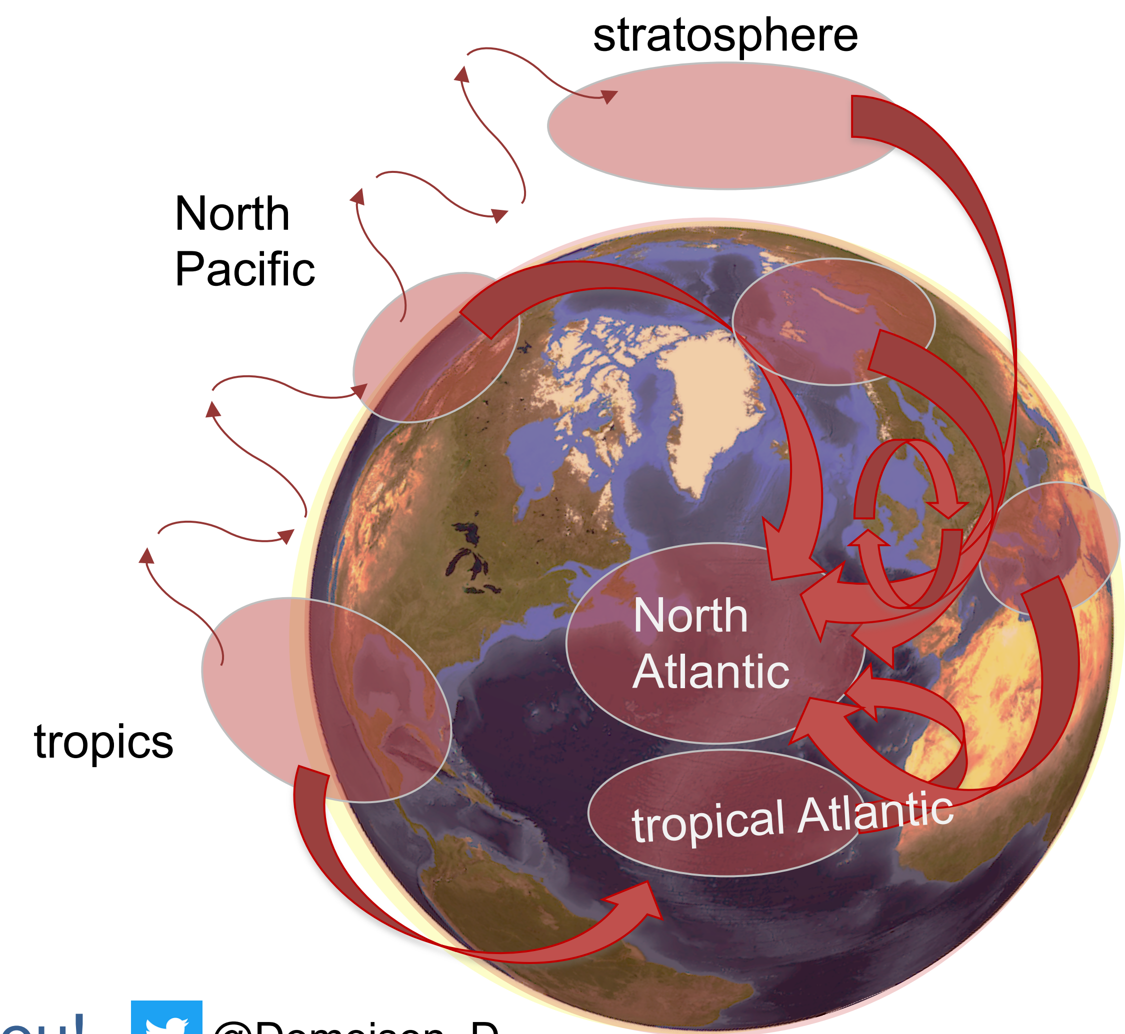
teleconnections may not remain constant over time (non-stationarity)

additional drivers: sea ice, snow cover, etc

local feedbacks:
e.g. soil moisture
e.g. Fischer et al., 2007, Orth et al., 2016

ETH zürich

MANY OPEN QUESTIONS REMAIN



many paths lead to Europe

nonlinearity

teleconnections may not remain constant over time (non-stationarity)

additional drivers: sea ice, snow cover, etc

local feedbacks

climate change

Thank you! @Domeisen_D

ETH zürich