THE ROLE OF STRATOSPHERE-TROPOSPHERE COUPLING IN SUB-SEASONAL TO SEASONAL PREDICTION USING THE S2S DATABASE

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SPARC Stratosphere-troposphere Processes And their Role in Climate

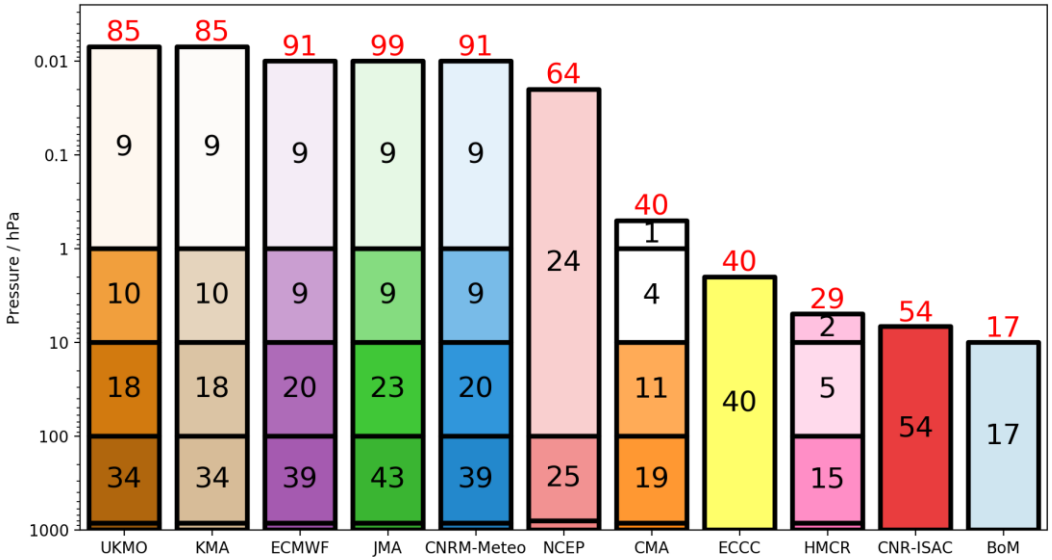
OUTLINE

- Today I will discuss work undertaken as part of a community effort to study stratospheric processes and their coupling to the troposphere driven by the Stratospheric Network for the Assessment of Predictability (SNAP)
- This should be considered a ‘first look’ - there is much more work that could or should be done
- Aim is to provide a baseline assessment of stratospheric predictability, learn where models differ and to identify ways in which we might perform further diagnosis or experiments to understand these differences

Status on 2018-10-25	Time range	Resolution	Ens. Size	Frequency	Re-forecasts	Rfc length	Rfc frequency	Rfc size	Volume of real-time forecast per cycle	Volume of reforecast per update
BoM (ammc)	d 0-62	T47L17	3*11	2/week	fix	1981-2013	6/month	3*11		6 TB
CMA (babj)	d 0-60	T106L40	4	daily	fix	1994-2014	daily	4		
CNR-ISAC (isac)	d 0-32	0.75x0.56 L54	41	weekly	fix	1981-2010	every 5 days	5		
CNRM (lfpw)	d 0-32	T255L91	51	weekly	fix	1993-2014	4/month	15		6.6 TB
ECCC (cwao)	d 0-32	0.45x0.45 L40	21	weekly	on the fly	1998-2017	weekly	4		
ECMWF (ecmf)	d 0-46	Tco639/319 L91	51	2/week	on the fly	past 20 years	2/week	11		
HMCR (rums)	d 0-61	1.1x1.4 L28	20	weekly	on the fly	1985-2010	weekly	10		
JMA (rjtd)	d 0-33	TI479/TI319L100	50	weekly	fix	1981-2010	3/month	5	3.8 GB	900 GB
KMA (rksl)	d 0-60	N216L85	4	daily	on the fly	1991-2010	4/month	3		
NCEP (kwbc)	d 0-44	T126L64	16	daily	fix	1999-2010	daily	4		
UKMO (egrr)	d 0-60	N216L85	4	daily	on the fly	1993-2016	4/month	7		

- We make use of all the models in the S2S database
- Since this is community effort, not every model is included in every comparison (but there are a number of common models e.g. ECMWF)

VERTICAL RESOLUTION



- S2S models are a mixture of high-top (fully Stratosphere resolving) and low-top models
- Generally, high-top models also have higher vertical resolution throughout the atmosphere

Approximate vertical resolution of models in S2S database
Black – number of levels in this range
Red – total number of levels

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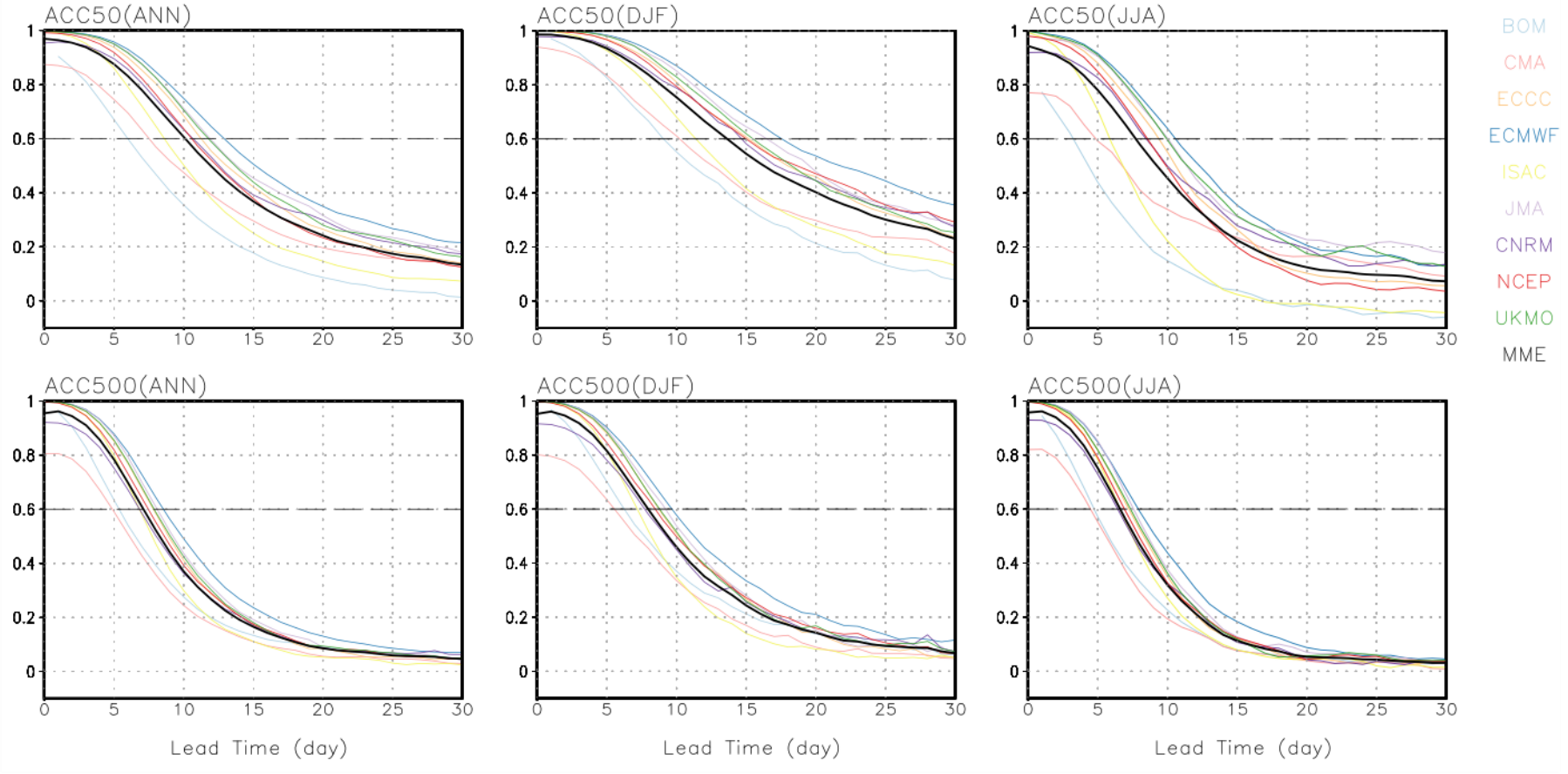
BASELINE SKILL



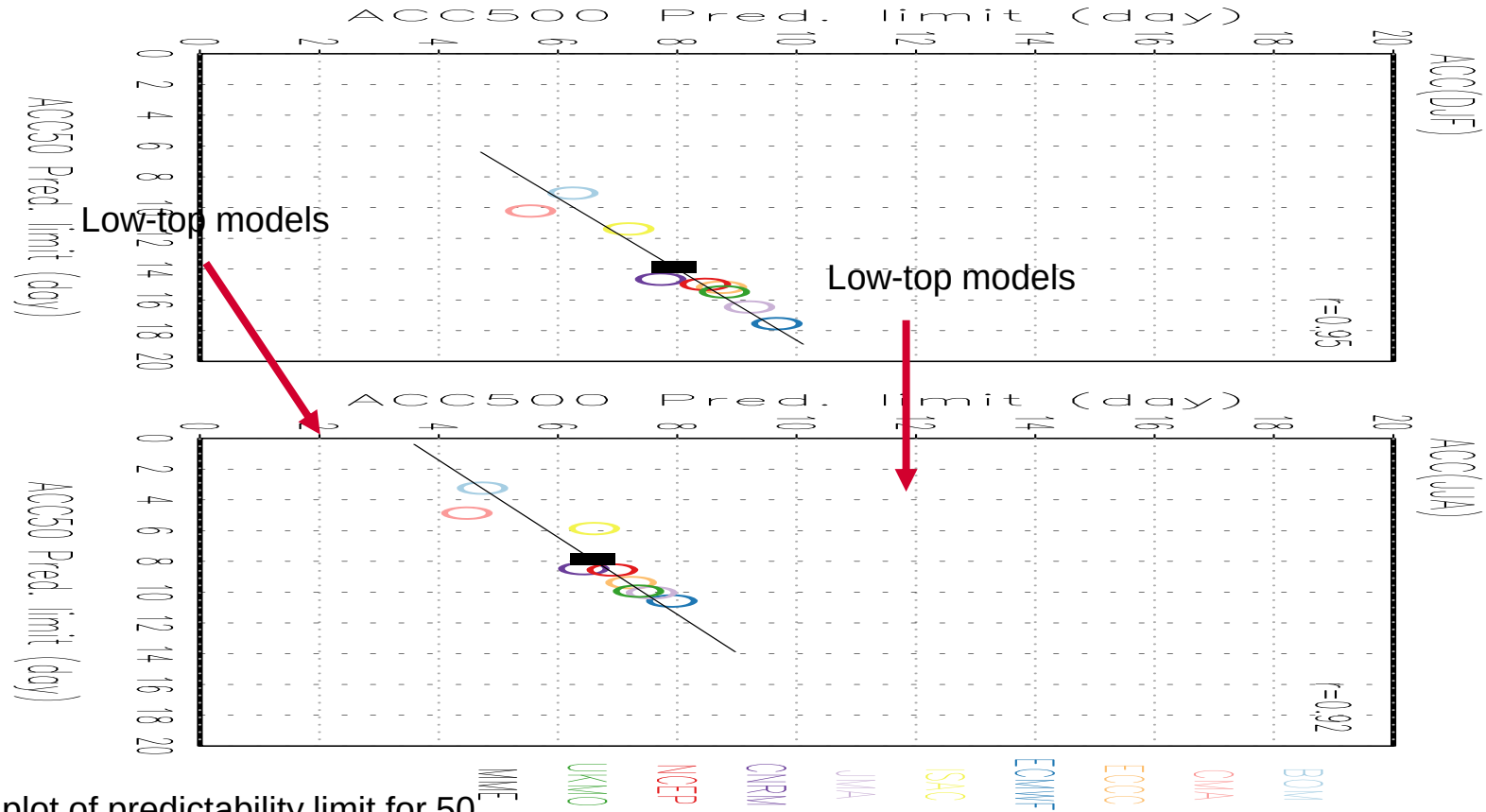
Anomaly correlation coefficient for Geopotential Height north of 30N (All, DJF, JJA)
Hera Kim & Seok-Woo Son

- On large-scales, Stratospheric forecasts are more skillful than Tropospheric
- Significant seasonality in the Stratosphere

Model	NH				SH			
	DJF		JJA		DJF		JJA	
	50hPa	500hPa	50hPa	500hPa	50hPa	500hPa	50hPa	500hPa
BOM	9.1	6.3	3.2	4.7	4.9	5.2	6.6	5.5
CMA	10.2	5.5	4.9	4.5	7	4.1	6.7	3.7
ECCC	15.2	8.7	9.4	7.2	11	7.8	10.7	7.8
ECMWF	17.6	9.7	10.6	7.9	11.8	8.3	12.3	8.6
JMA	16.5	9.2	10	7.6	10	7.7	10.5	7.9
CNRM-Meteo	14.7	7.7	8.5	6.4	10.4	7	10.9	7.2
NCEP	15	8.5	8.6	6.9	10	7.2	10.1	7.3
UKMO	15.5	8.8	9.9	7.4	10.9	7.5	10.9	7.6

Day where ACC drops below 0.6
Hera Kim & Seok-Woo Son

- Seasonality in skill is less pronounced in the SH



Scatter plot of predictability limit for 50 & 500hPa (NH)
Hera Kim & Seok-Woo Son

- Strong association of predictability limit in the Stratosphere and Troposphere
- Causality not implied here – system complexity also important
- Low-top models clustered below Multi-Model average

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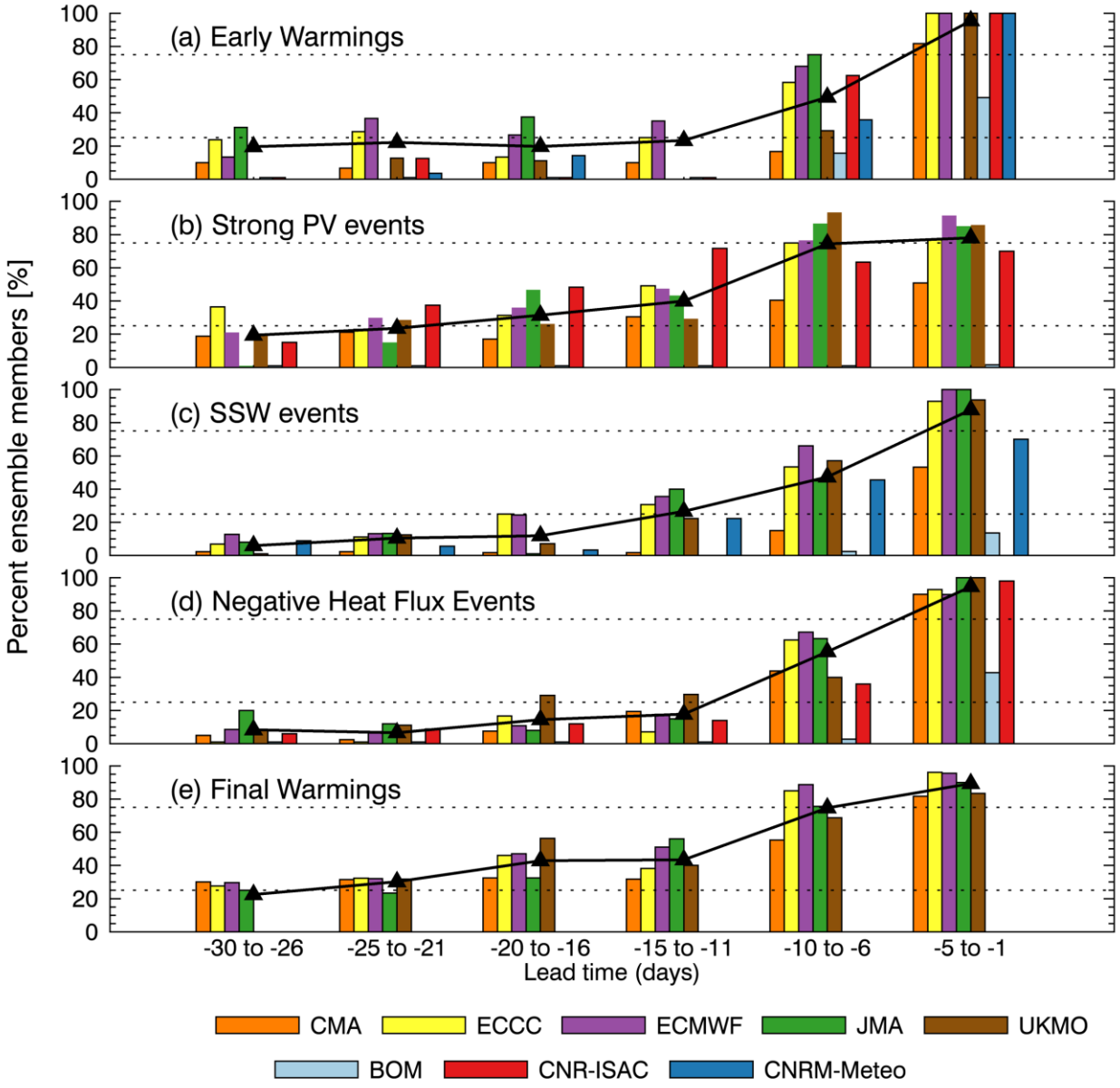
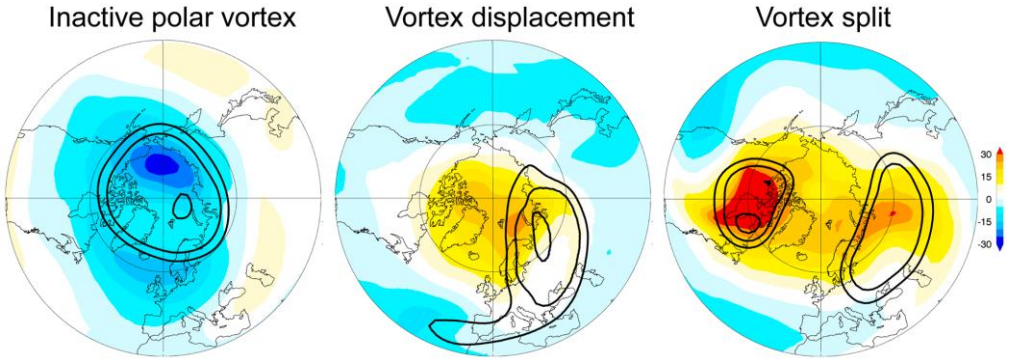
STRATOSPHERIC EVENTS

- Early winter weak vortex: Less than -1σ 10hPa ZMZW anomalies persisting for more than 1 week, 1st Nov to 15th Dec
- Strong Polar Vortex: ZMZW @ 10hPa and 60N exceed 80th percentile of NDJFM values (41.2ms^{-1})
- Mid-winter SSW: ZMZW reversal @ 10hPa and 60N
- Negative heatflux: 5-day mean 50hPa meridional heatflux less than the 5th percentile (-13.5 K ms^{-1})
- Final warmings: 10hPa, 60N ZMZW reversal and does not recover to westerly values

- Most Stratospheric events can be accurately detected up to 10 days before the event
- Strong polar vortex events and final warmings show some elevated probability at longer lead times
- False Alarms not considered here (or a more formal verification)



Average percentage of ensemble members which correctly predict different classes of event
Amy Butler



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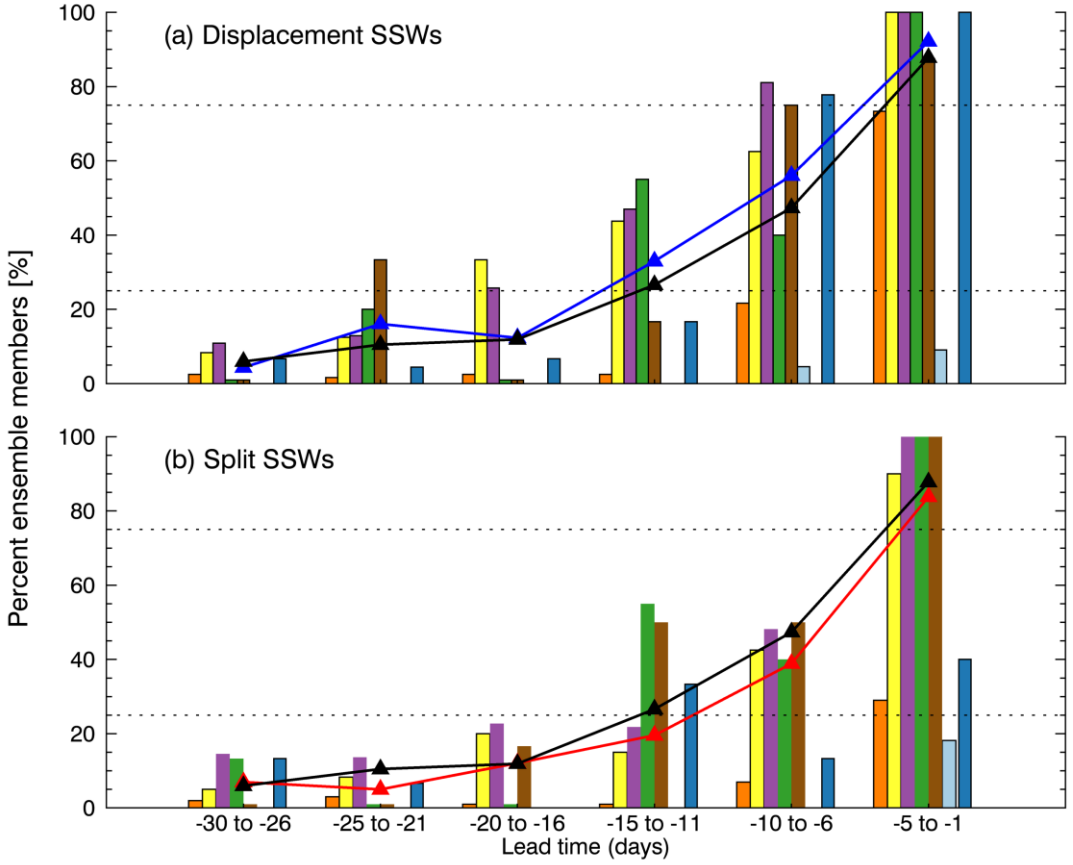
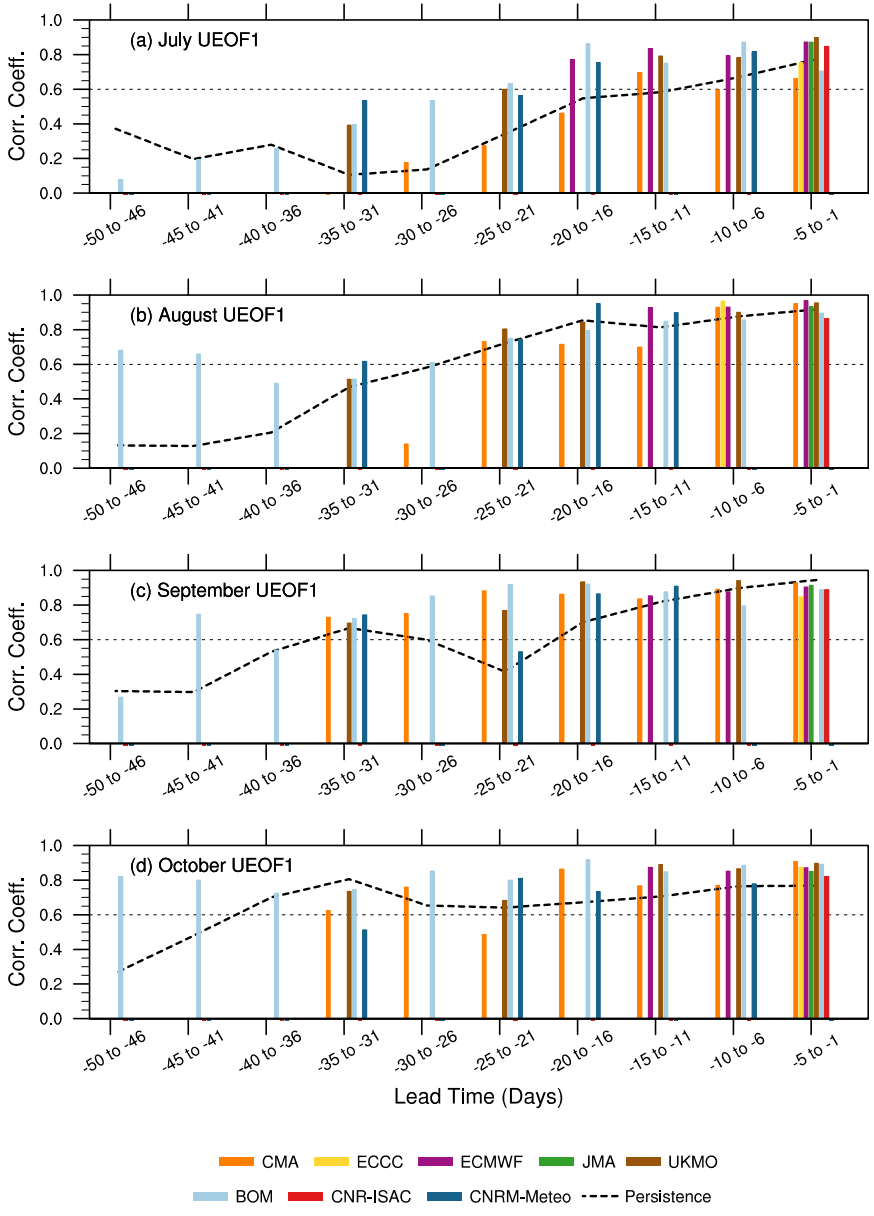
Source: Butler et al. doi:10.5194/essd-9-63-2017
Also see the SSW compendium website:
https://www.esrl.noaa.gov/csd/groups/csd8/sswcompendium/

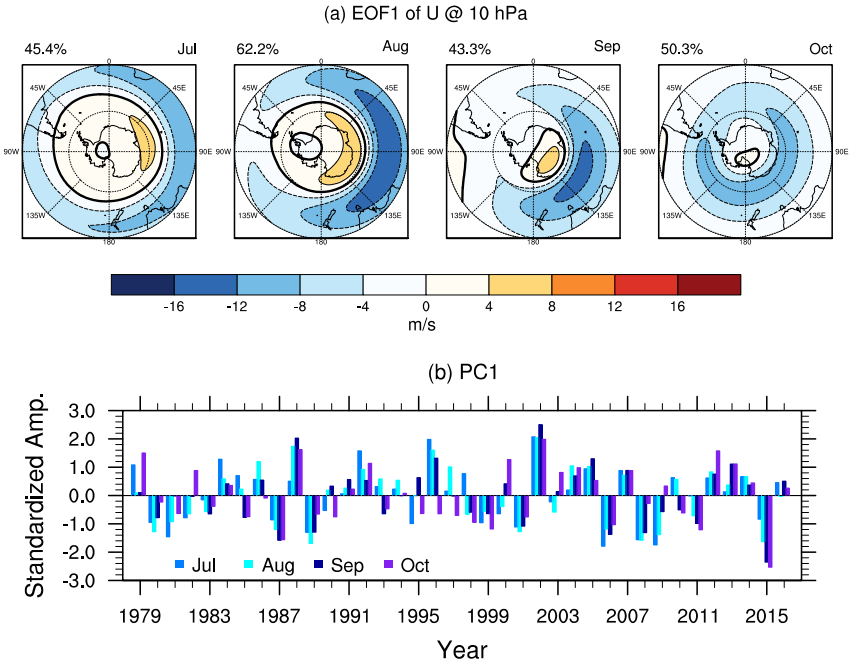
- Some evidence that Vortex Displacement events can be predicted at longer lead times than Vortex Splitting events



Average percentage of ensemble members for splitting and displacement SSWs
Amy Butler



Correlation of ensemble mean forecasts of 1st EOF of zonal wind at 10hPa



First EOF of 10hPa zonal wind
Eun Pa Lim

- For SH, the vortex is less variable but there is significant impact of Stratospheric variability in Spring on the subsequent Summer SAM state
- Sub-seasonal forecasts outperform persistence forecasts of Spring Stratospheric variability

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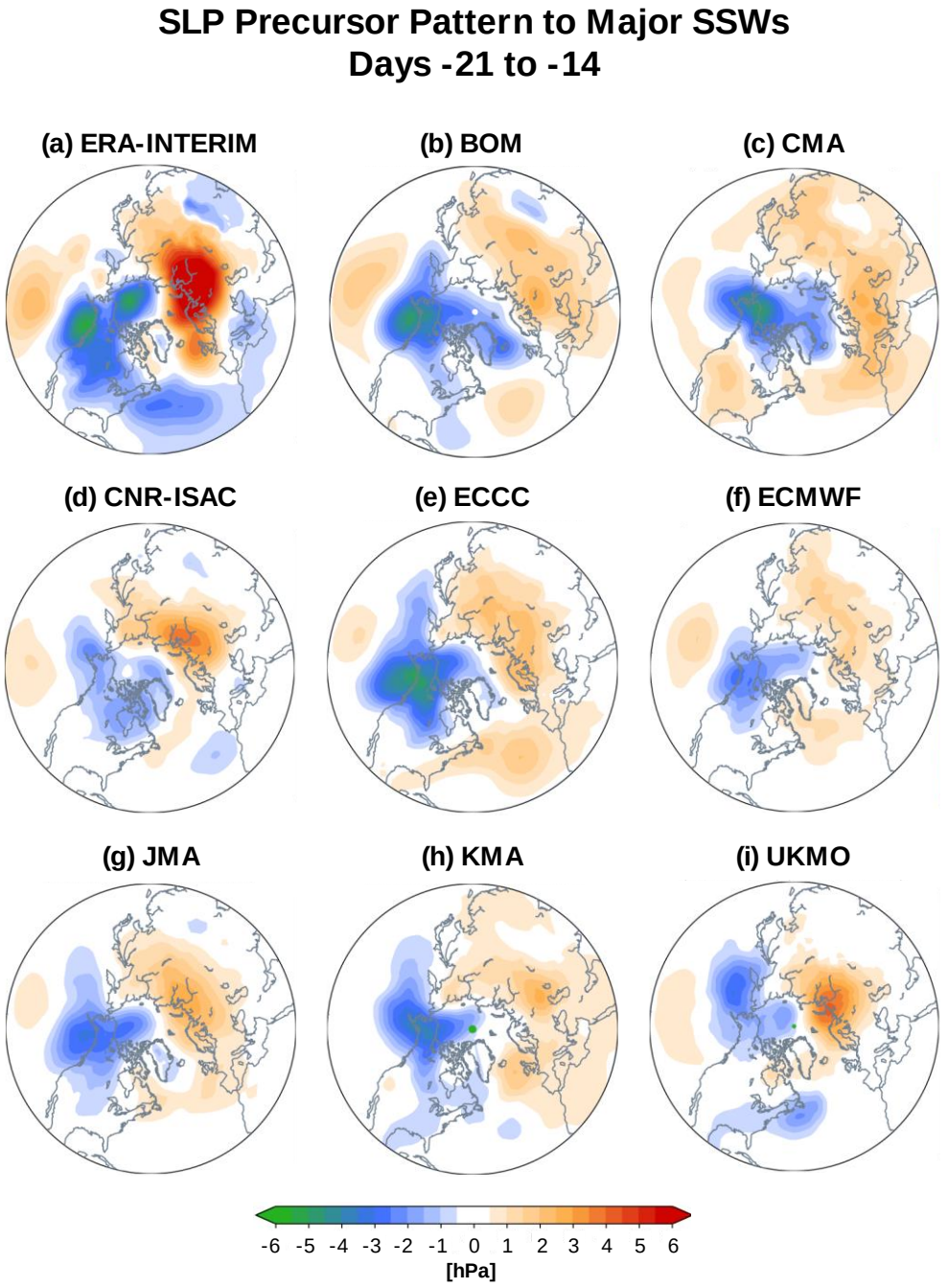
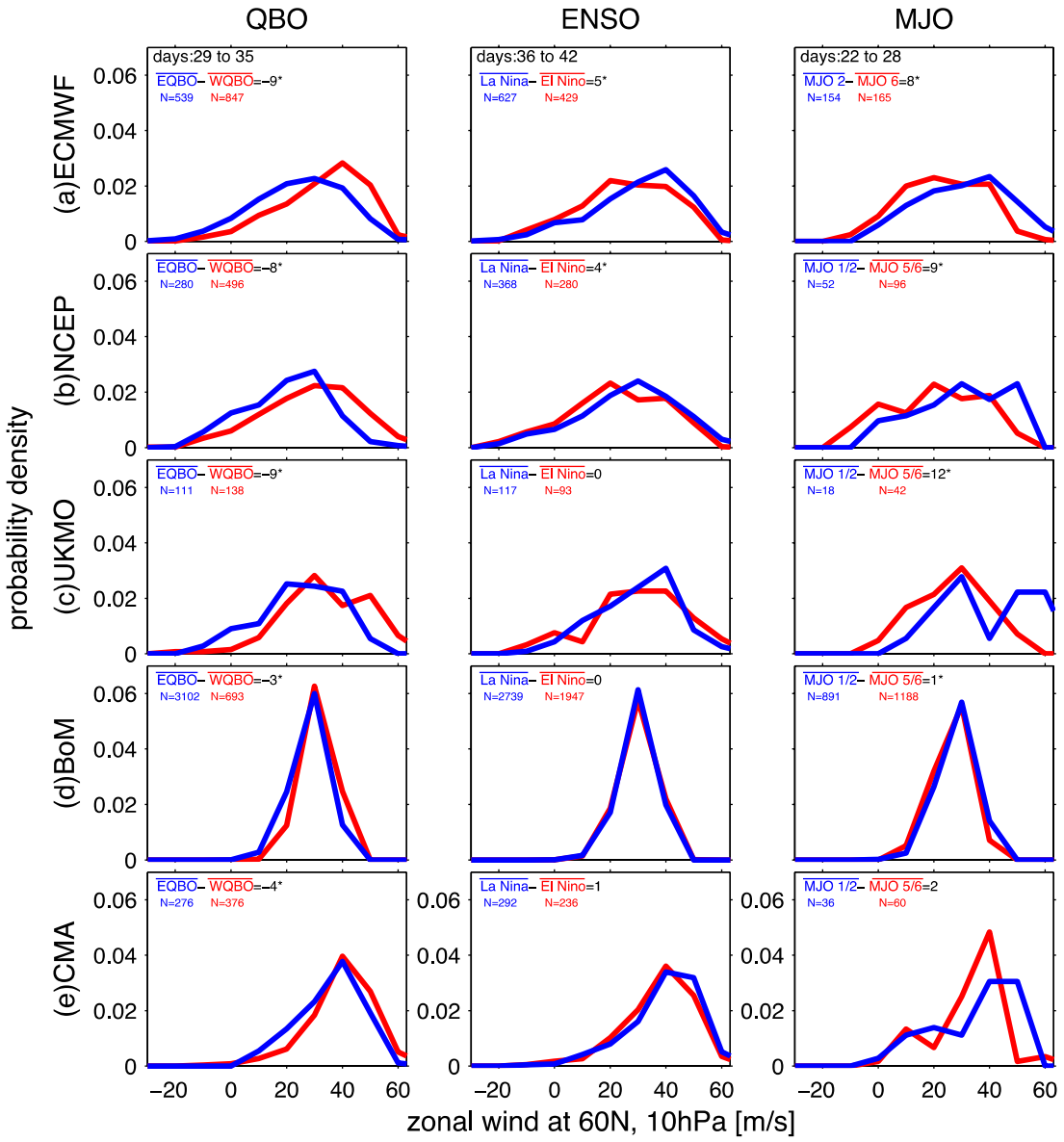
PRECURSORS

- Two dominant Tropospheric precursors to SSWs on sub-seasonal timescales (amplification of the background stationary wave pattern)
- Aleutian low precursor captured by most systems
- Significant variation in strength/position of Siberian ridge precursor

MSLP precursors to mid-winter SSW events (mean of all members which lead to major SSW)
Jason Furtado



- Shifts in the PDF of stratospheric winds at sub-seasonal and longer timescales in association with the QBO, MJO and ENSO in high-top modelling systems
- These shifts are not (as expected) captured by two low-top systems
- Easterly QBO, El Niño and MJO phase 6 are associated with weaker vortex conditions



ZMZW PDF for forecasts initialized during opposing phases of QBO, ENSO & MJO
Chen Swartz & Chaim Garfinkel

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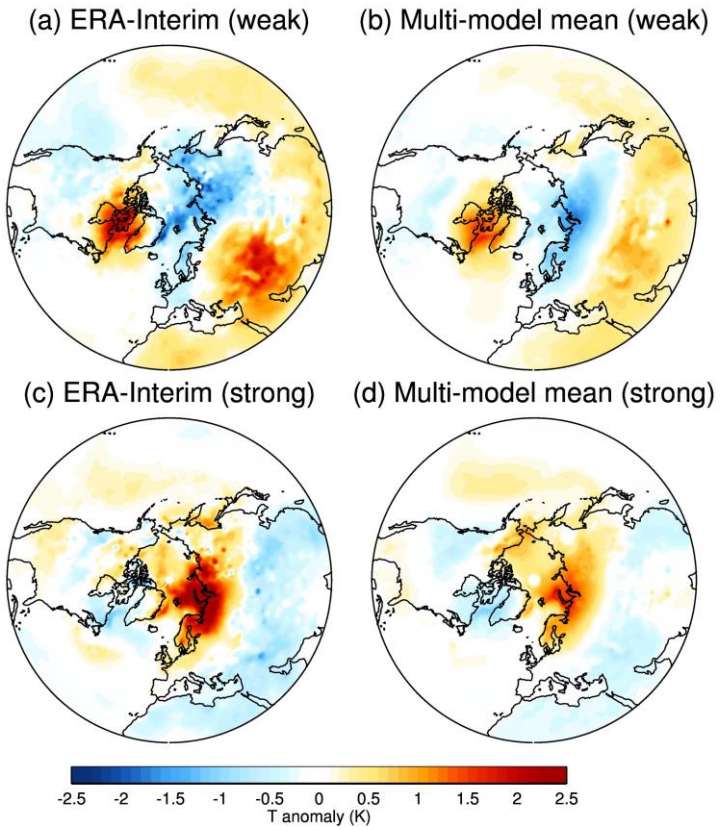
STRATOSPHERE-TROPOSPHERE COUPLING

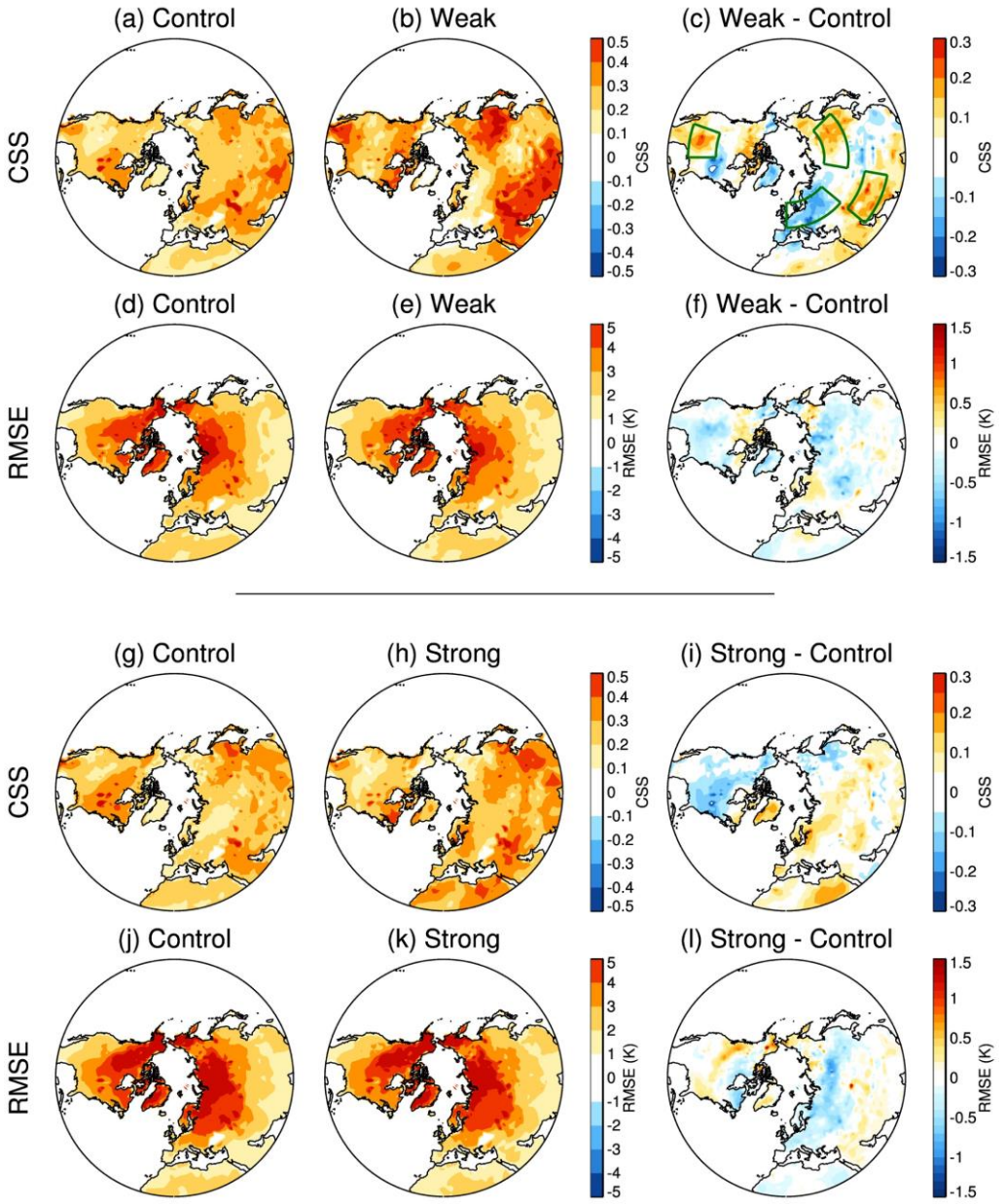
- For next few slides, compare skill of forecasts initialized when the Stratospheric vortex is anomalously weak and anomalously strong compared to a representative set of control forecasts
- The control forecast set is defined separately for the weak and strong cases so that the seasonal distribution of start dates is similar
- Weak vortex cases defined as 60N and 10hPa zonal mean zonal wind less than $5ms^{-1}$ in the re-analysis on day zero of the forecast
- Strong vortex cases defined as 60N and 10hPa zonal mean zonal wind less than $40ms^{-1}$ in the re-analysis on day zero of the forecast
- Examine both 2m Temperature and Northern Annular Mode index

- Weak vortex events are associated with cold anomalies over Siberia & Scandinavia and warm anomalies of NE Canada, Northern Africa and the Middle East
- Strong vortex events are associated with opposite and similarly sized anomalies over Eurasia and opposite and weaker anomalies over NE Canada and the Middle East

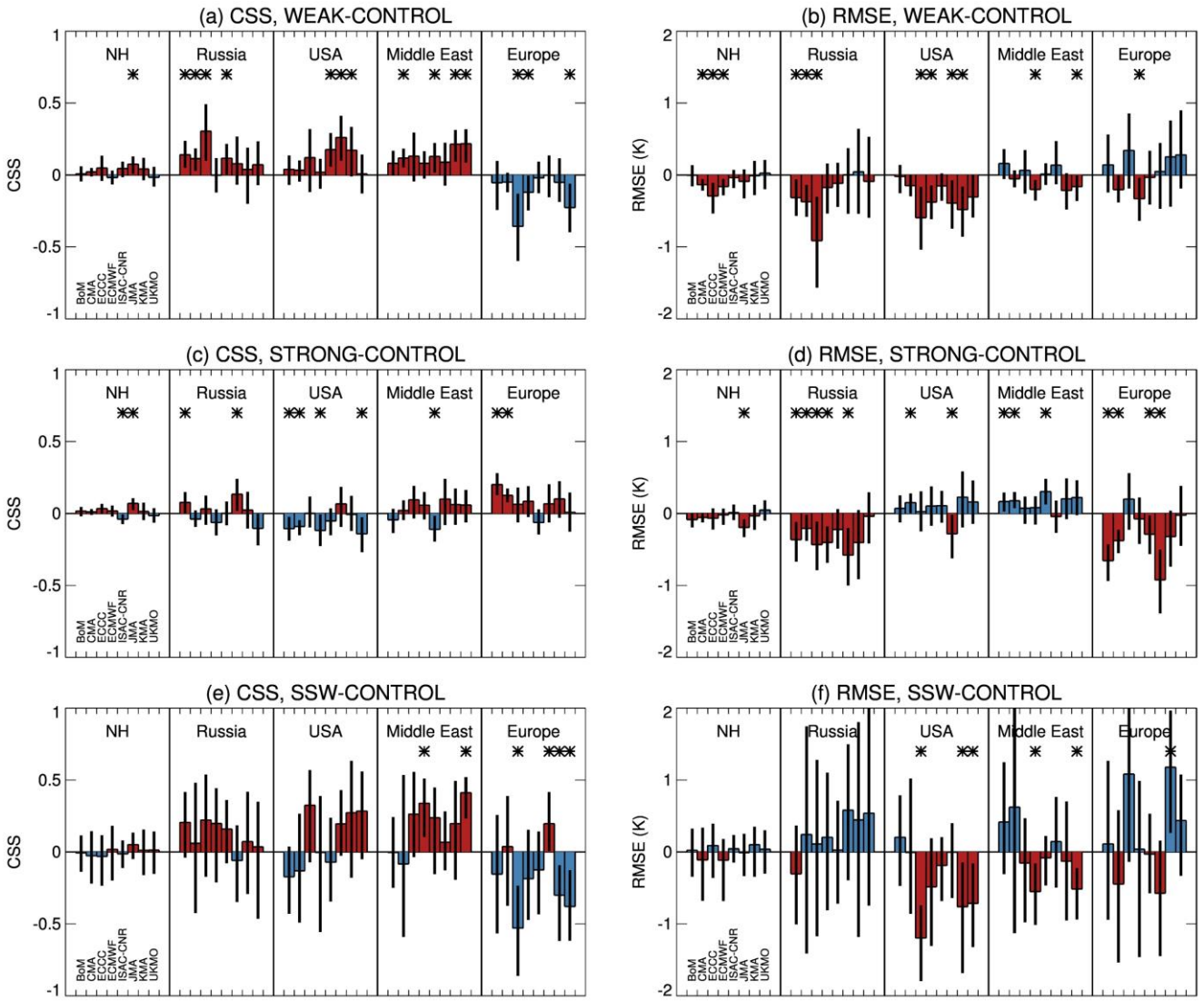


2m temperature anomalies following weak and strong vortex events (Weeks 3 & 4)
Isla Simpson

- There are broad regions of increase in skill particularly in the CSS metric for both weak and strong cases but these are not uniform for the multi-model skill
- In particular, over Europe, some indication of a degradation in skill following weak vortex events

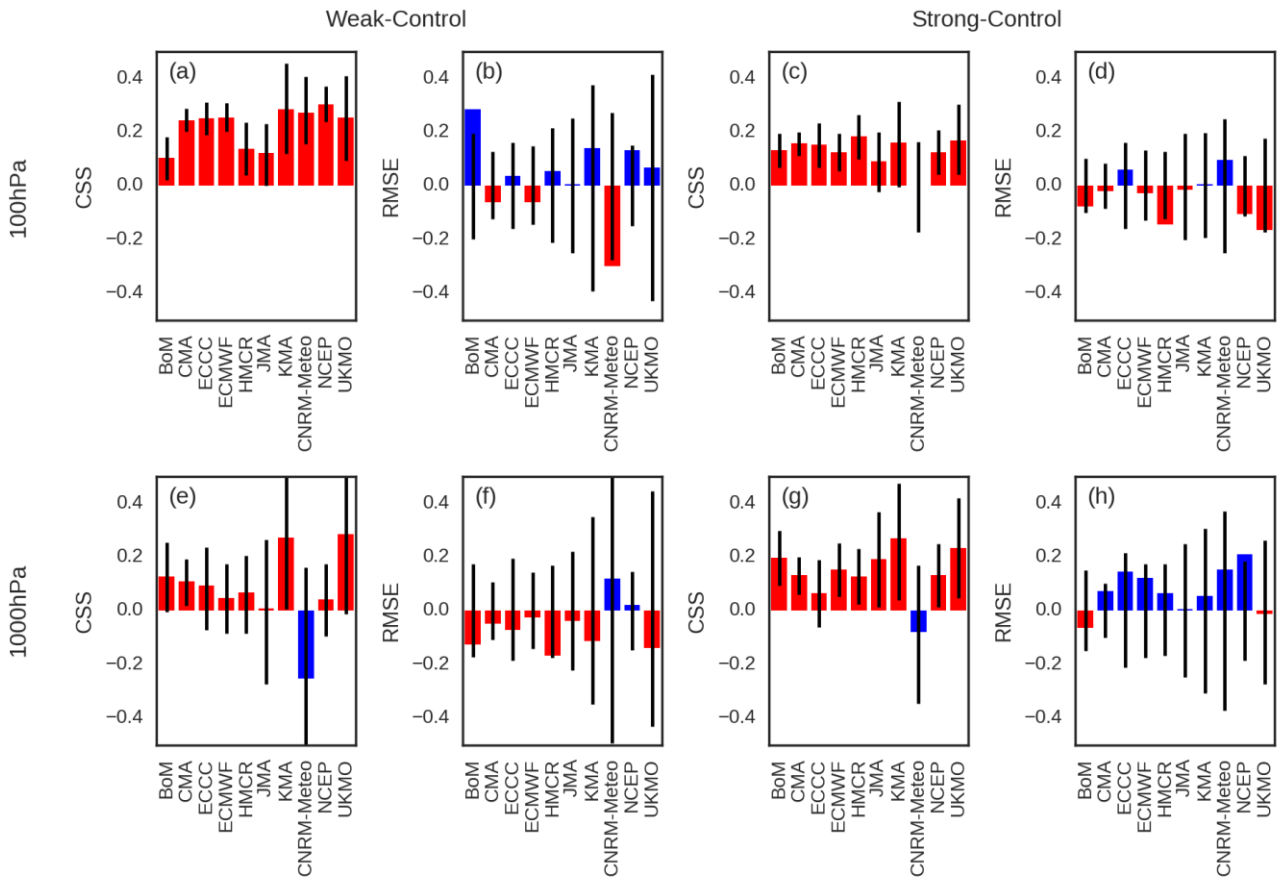


Multi-model CSS and RMSE for 2m temperature for Weeks 3 & 4 following weak and strong vortex events
Isla Simpson



- For Russia and the USA, increases in skill for most models
- Over Europe, little significant change in skill for most models, degradation in skill in the multi-model dominated by CMA and UKMO

Individual model difference skill for 2m temperature in various regions for Week 3 & 4 following weak and strong vortex events compared to control case
Isla Simpson



Individual model difference skill for NAM index at 100 and 1000hPa for Week 3 & 4 following weak and strong vortex events compared to control case
Andrew Charlton-Perez

- Most models show improved CSS skill for 100hPa NAM forecasts for both weak and strong cases
- Most models also show improvement in 1000hPa CSS skill although significant variation (UKMO/KMA largest)

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CONCLUSIONS

- There is good evidence that there is sub-seasonal skill associated with extra-tropical stratospheric variability that is captured to some extent by existing sub-seasonal prediction systems
- Dynamical events in the Stratosphere can be forecast on timescales at least to 10 days and in some cases on longer timescales
- Some of the precursor signals for stratospheric variability can be captured by S2S models, although there are likely areas in which these could be improved
- Forecasts initialized during times in which the stratosphere result in enhanced tropospheric skill on S2S timescales – although this has significant variability between modelling systems

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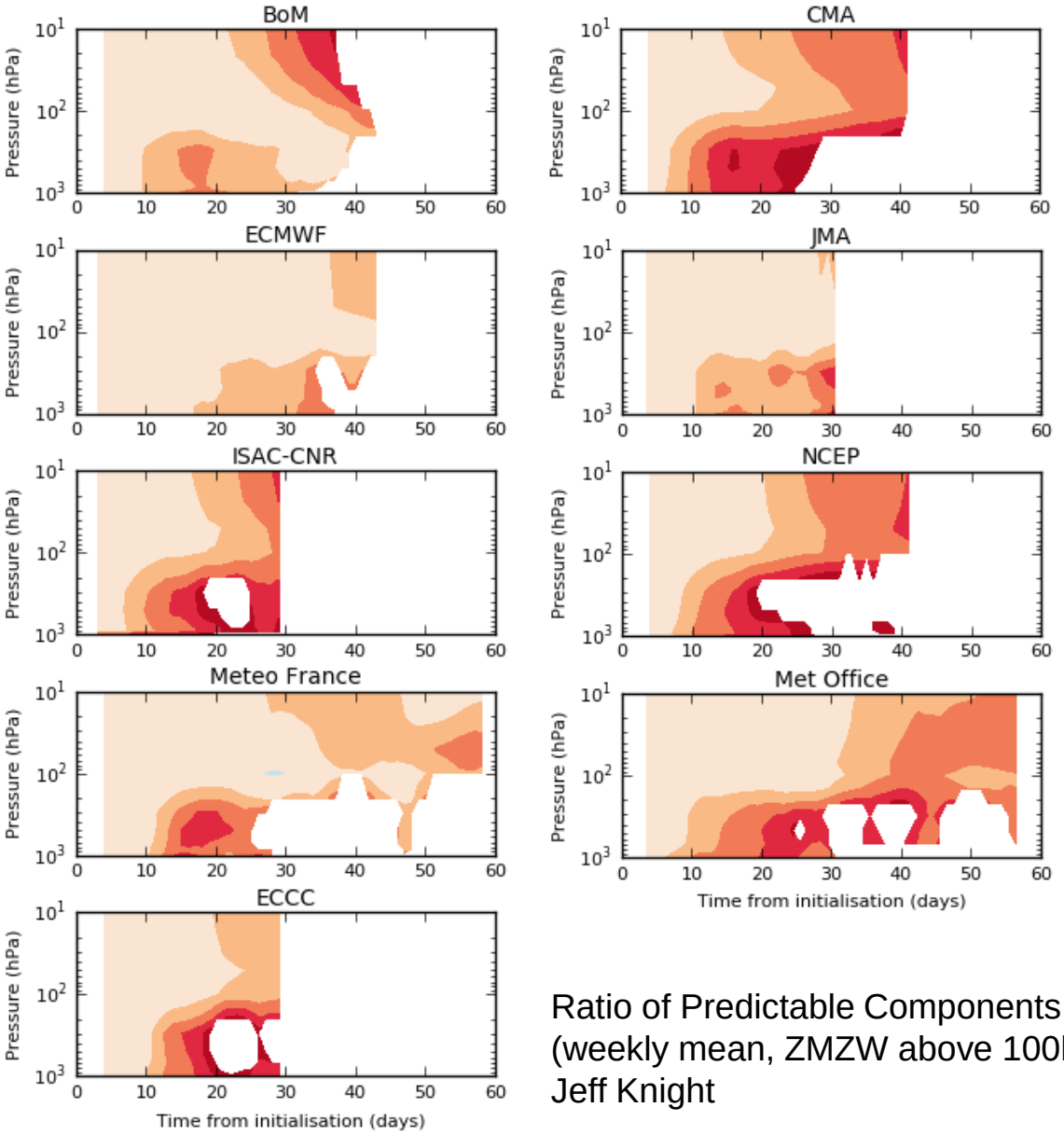
NEXT STEPS

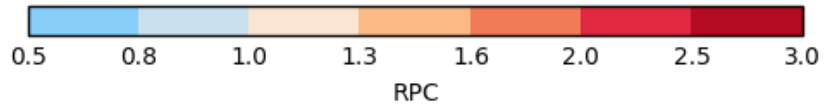
- Much of the analysis here would benefit from additional analysis of the forecast skill and stratospheric dynamics
- The S2S database, while a fantastic resource, has very limited data in the stratosphere which prevents a more comprehensive analysis of the stratospheric momentum budget and the dynamics of stratospheric events in the S2S models – we would like to request help with retrieving additional data and diagnostics
- Similarly, much progress in understanding stratosphere-troposphere coupling has been made using well designed experiments with stratospheric damping – further experiments with the S2S models would help to disentangle their differences and impacts of biases



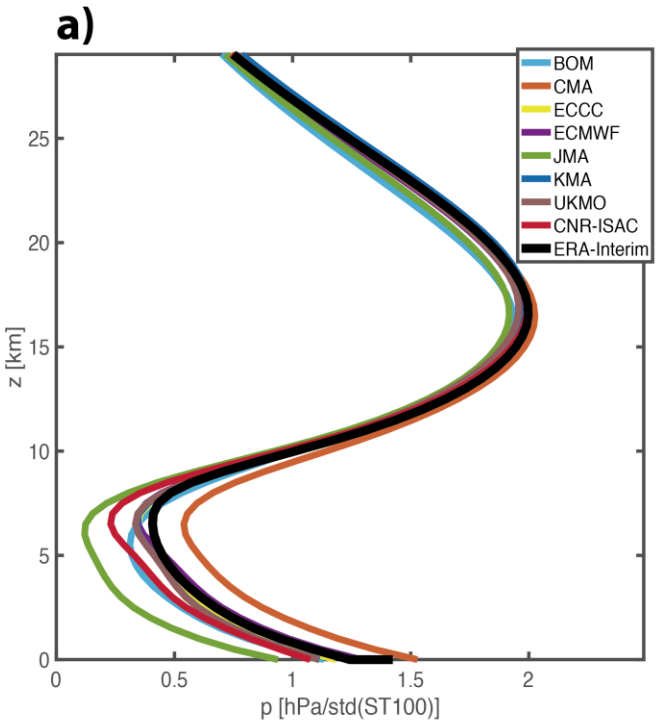
- Evidence of development of low signal-to-noise ratio (cf seasonal forecasts) on sub-seasonal timescales

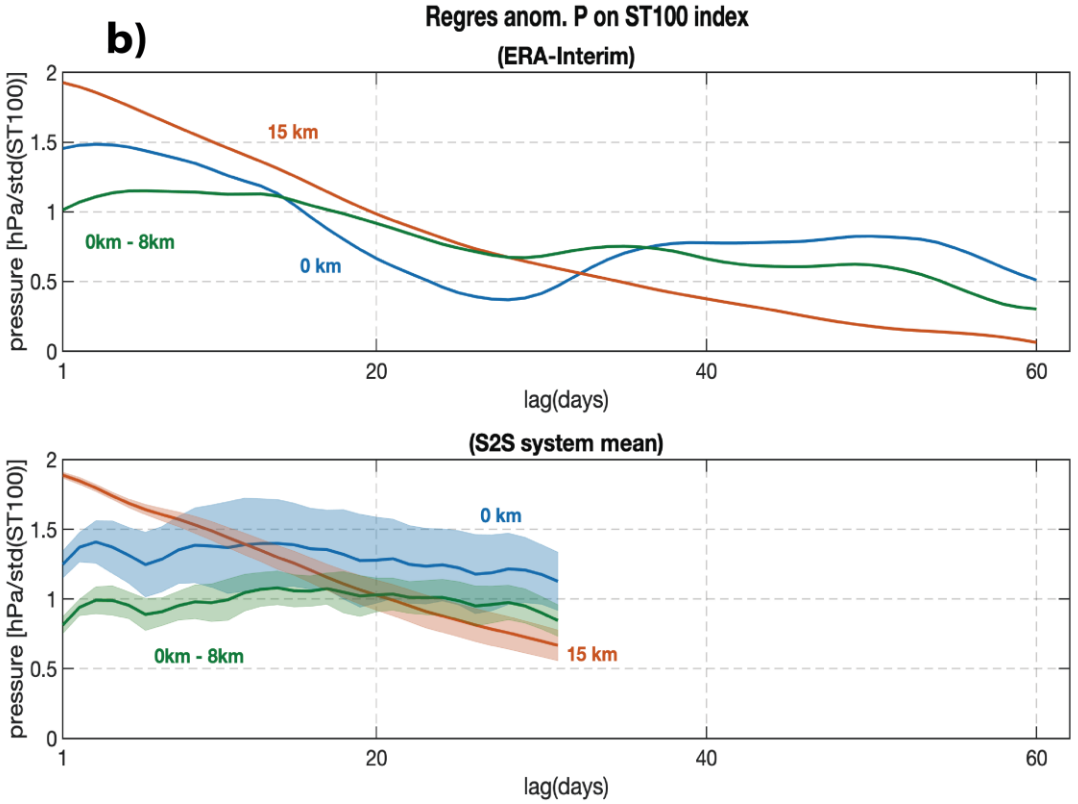
$$RPC = \frac{PC_{\text{obs}}}{PC_{\text{mod}}} \geq \frac{r}{\sqrt{\sigma^2_{\text{sig}}/\sigma^2_{\text{tot}}}}$$

Ratio of Predictable Components
(weekly mean, ZMZW above 100hPa and 90W-60E below 100hPa)
Jeff Knight



- Direct link between variations in the strength of the polar vortex in the lower Stratosphere and Troposphere well captured by models





Regression between 65-90N 100hPa temperature anomaly and 65-90N pressure anomaly at different heights
Blanca Ayarzagüena & Mark Baldwin