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Predictability of Sudden Stratospheric Warmings in sub-seasonal forecast models

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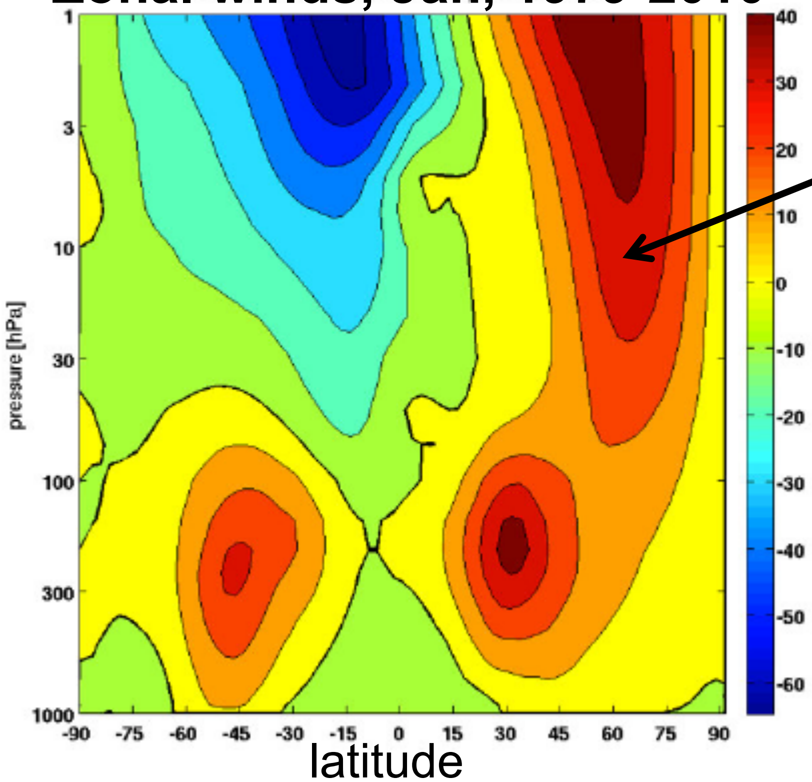
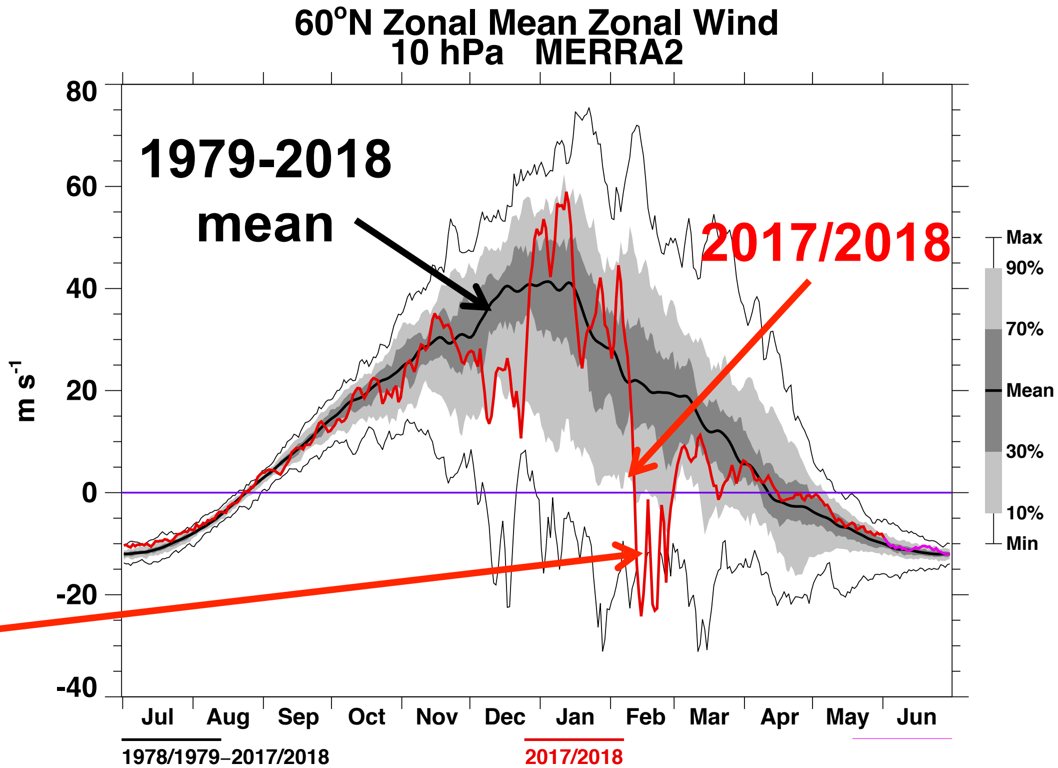
Polar stratospheric vortex and its disruptions (SSWs)

Zonal winds, Jan, 1979-2010



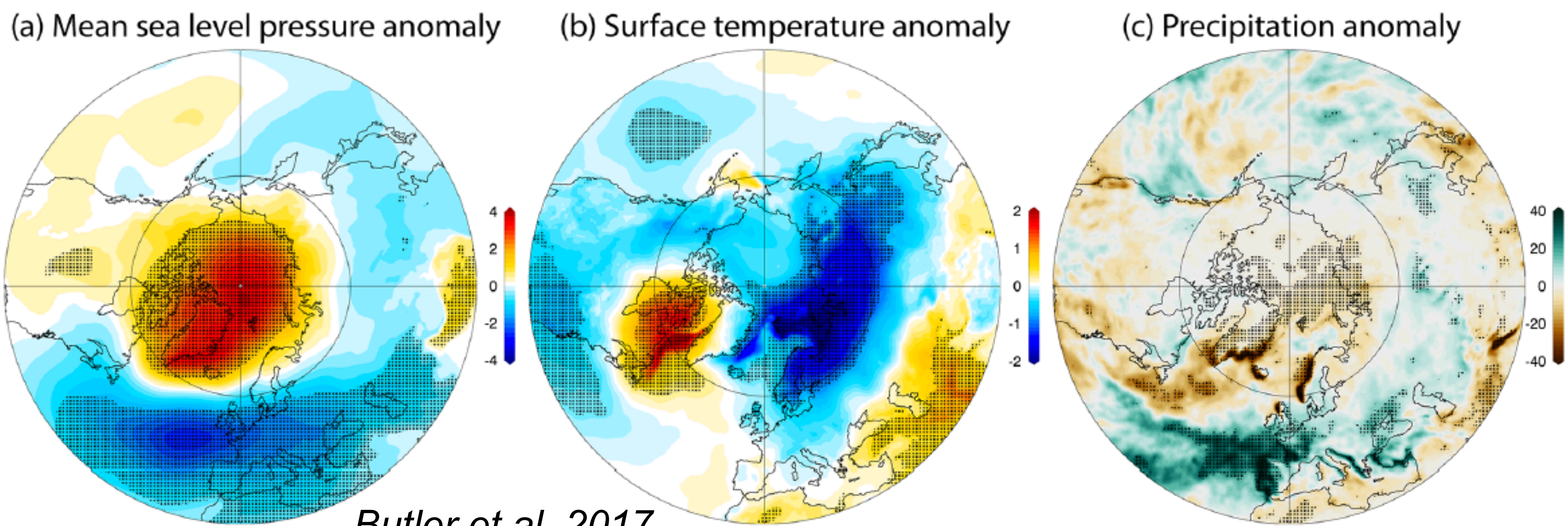
Polar vortex surrounded by westerly polar night jet is a **normal state** of the wintertime Arctic stratosphere



P. Newman (NASA), E. Nash (SSAI), S. Pawson (NASA)

Break downs of the vortex occur during Sudden Stratospheric Warmings (SSWs)

SSWs and surface weather



Butler et al. 2017

- Many SSWs are followed by anomalies in surface weather lasting for up to two months:
  - Negative phase of the North Atlantic Oscillation
  - Cold spells across northern Eurasia and eastern US
  - Precipitation anomalies over Atlantic and western Europe

SSWs provide source of enhanced subseasonal predictability

When do SSWs become predictable?

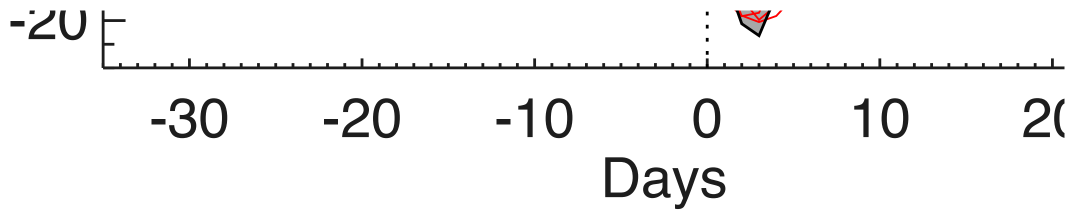
Various studies suggest various predictability limits for various SSW events

Table 1. Quantification of the predictability of SSW events obtained from a range of studies.

Year	Model	Event (SSW)	Predictability	References
1970	GFDL GCM	March 1965	2 days (captured only tendency)	Miyakoda *et al.* (1970)
1983	ECMWF	February 1979	10 days	Simmons and Strüfing (1983)
1985	UCLA GCM	February 1979	5 days	Mechoso *et al.* (1985)
2004	JMA NWP	December 1998	30 days	Mukougawa and Hirooka (2004)
2005	ECMWF	September 2002 (Antarctic)	7 days	Simmons *et al.* (2005)
2005	JMA NWP	December 2001	14 days	Mukougawa *et al.* (2005)
2006	NOGAPS- ALPHA	September 2002 (Antarctic)	5 days	Allen *et al.* (2006)
2007	ECMWF	Various	10 days	Jung and Leutbecher (2007)
2007	JMA NWP	December 2003	9 days	Hirooka *et al.* (2007)
2009	NCEP SFSIE	Various	15 days	Stan and Straus (2009)
2010	NOGAPS	January 2009	5 days	Kim and Flatau (2010) and Kim *et al.* (2011)
2010	HadGAM1	Various	9–15 days	Marshall and Scaife (2010)
2013	Met Office	January 2013	14 days	Scaife (2013)
2013	GEOS-5	January 2013	5 days	Lawrence Coy and Steven Pawson (http://gmao.gsfc.nasa.gov/researchhighlights/SSW/)

Tripathi et al. 2015, QJRMS

SSW predictability in ECMWF system



- Ensemble mean forecast tells about SSW predictability in deterministic sense
- Ensemble spread tells about SSW predictability in probabilistic sense

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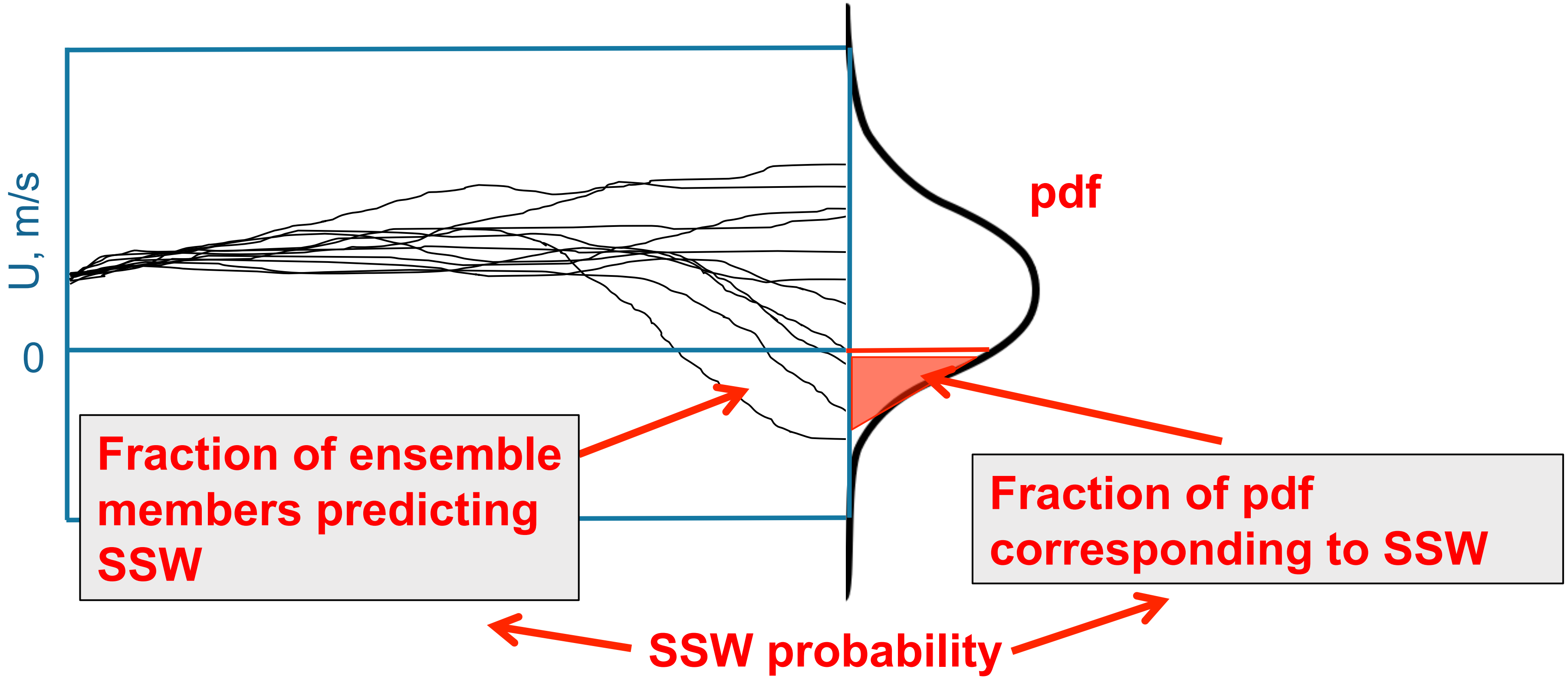
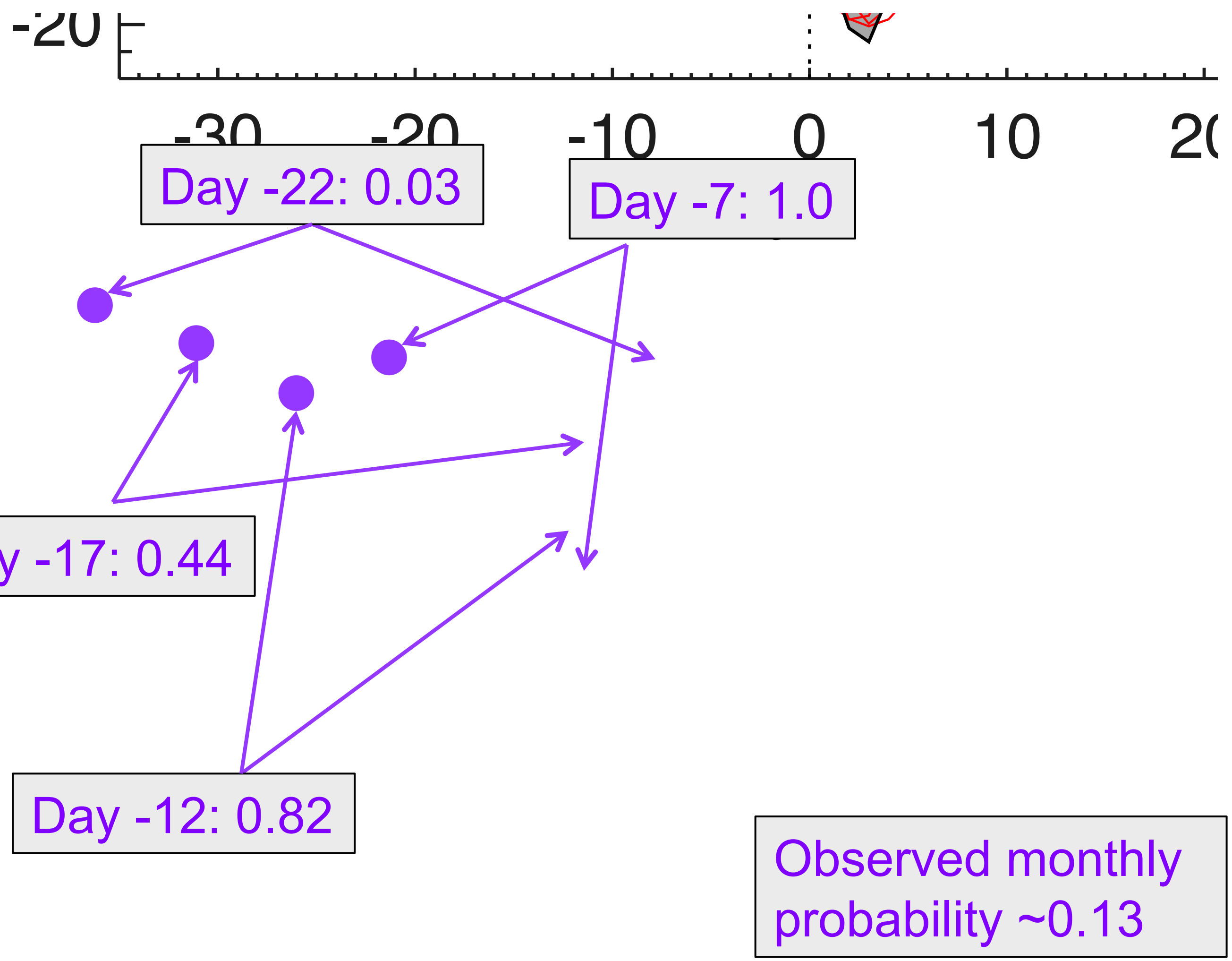
Forecasting SSW probability



- Calculate probability of SSW for each day as a fraction of ensemble members predicting SSW, **OR** a fraction of pdf corresponding to SSW
- Focus on maximum predicted daily value of SSW probability in monthly forecast

SSW predictability in ECMWF system



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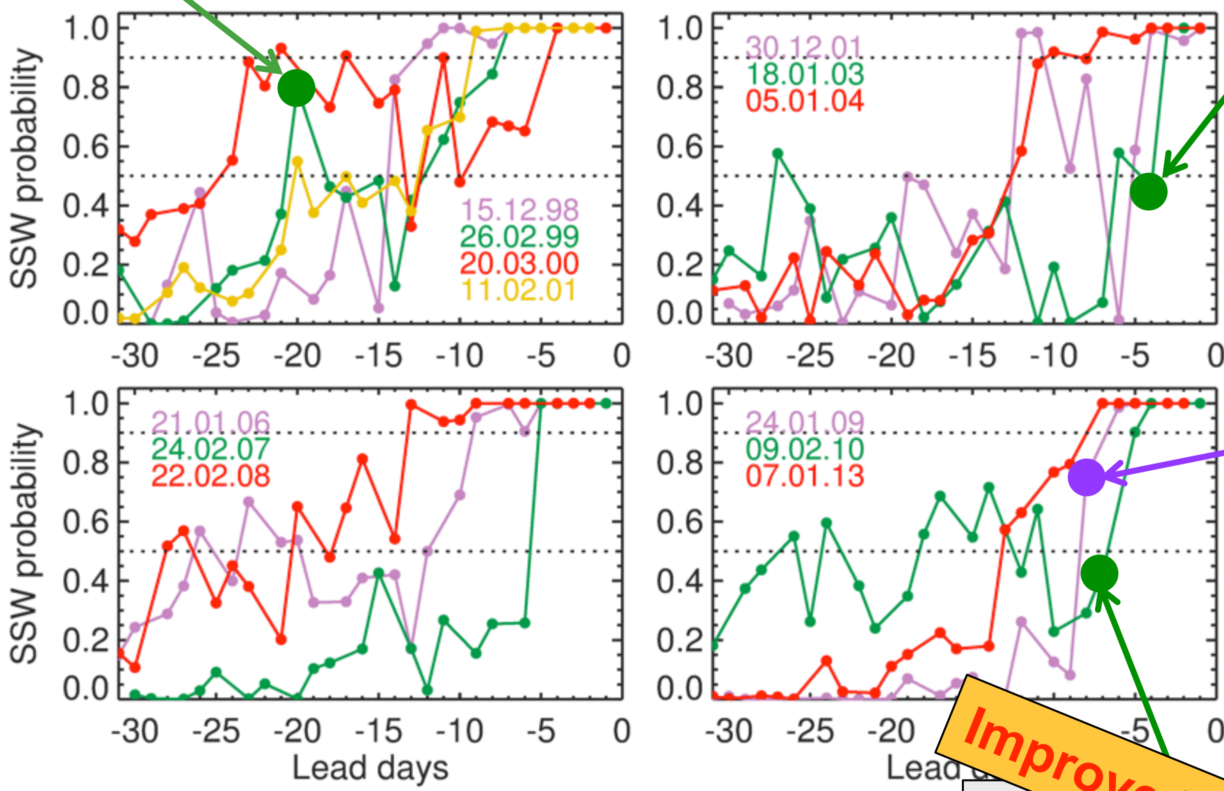
SSW predictability in ECMWF system

Enhanced ... ability at
lon... nes

How is this possible?

... short event,
diffic... dict even if
forecast err... mall

Not interesting case



Shor... dictability
also in ...
forecast sys...

Unpredictable?

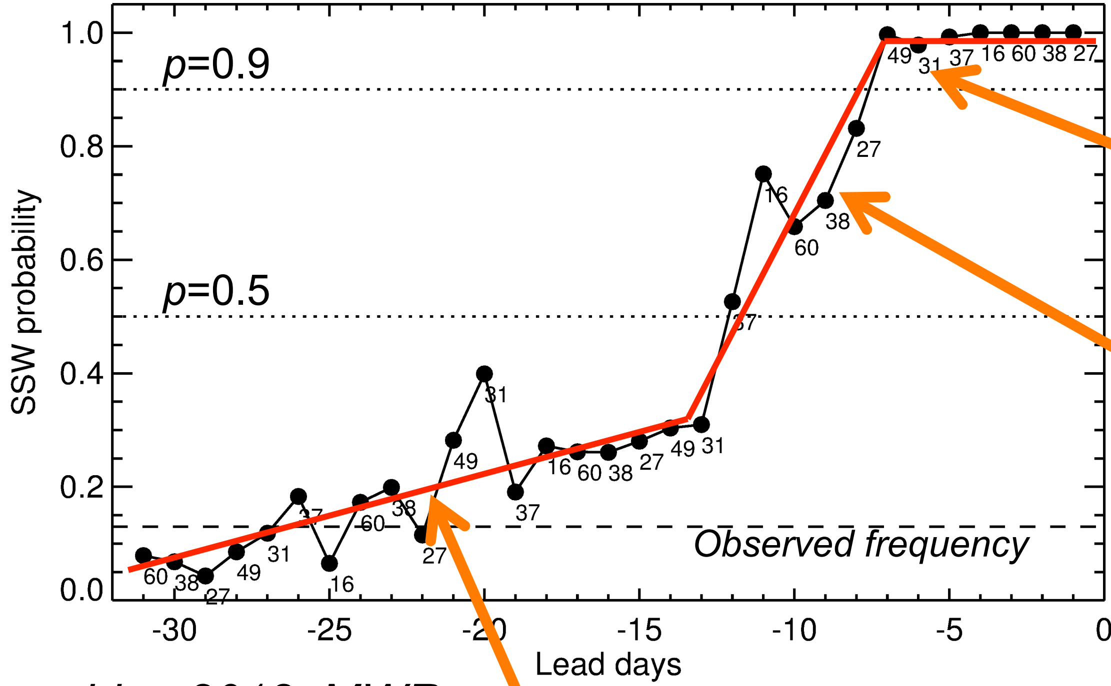
Large ... lready at
first day of fo...

Improve initialization?

Karpechko, 2018, MWR

SSW predictability in ECMWF system

SSW predictability averaged across 6 SSWs with strong tropospheric impacts



Karpechko, 2018, MWR

days 32-13:
Slow increase in predictability

days 13-7:
Fast increase in predictability

days 7-0:
Deterministic limit

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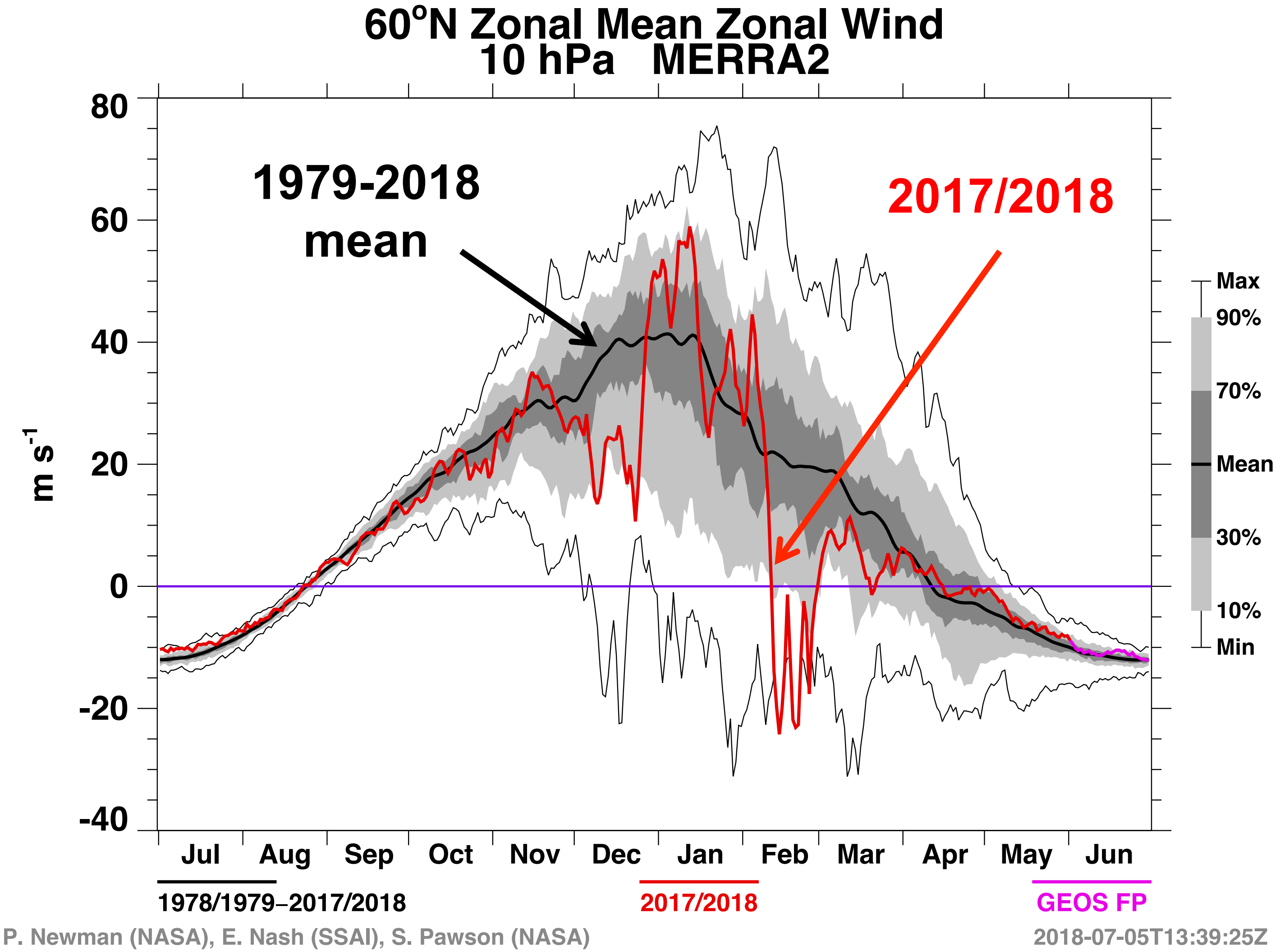
Sudden Stratospheric Warming 2018



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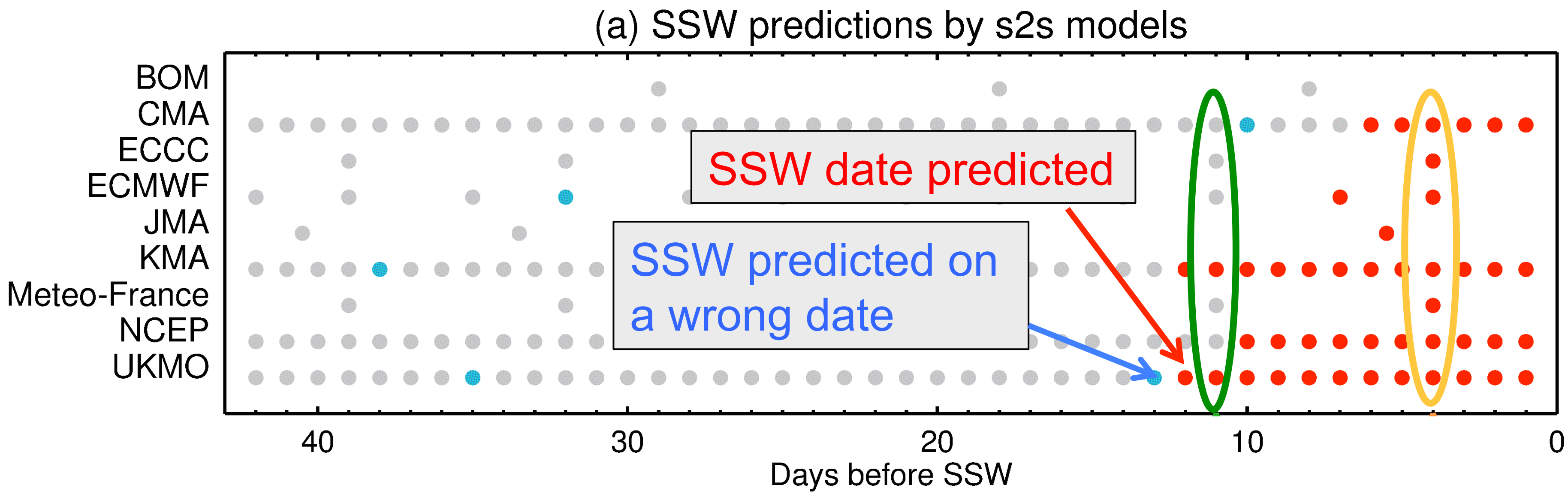
S2S predictions of SSW 2018



- SSW occurred on 12 February 2018
- Earliest deterministic forecasts by some models from 30-31 January (lead time 12-13 days)
- Forecasts from 1 February (lead time 11 days): SSW probability of ~0.3 predicted by S2S models (151 members in total)
- Forecasts from 8 February (lead time 4 days): SSW probability of 1.0 predicted by S2S models (151 members in total)

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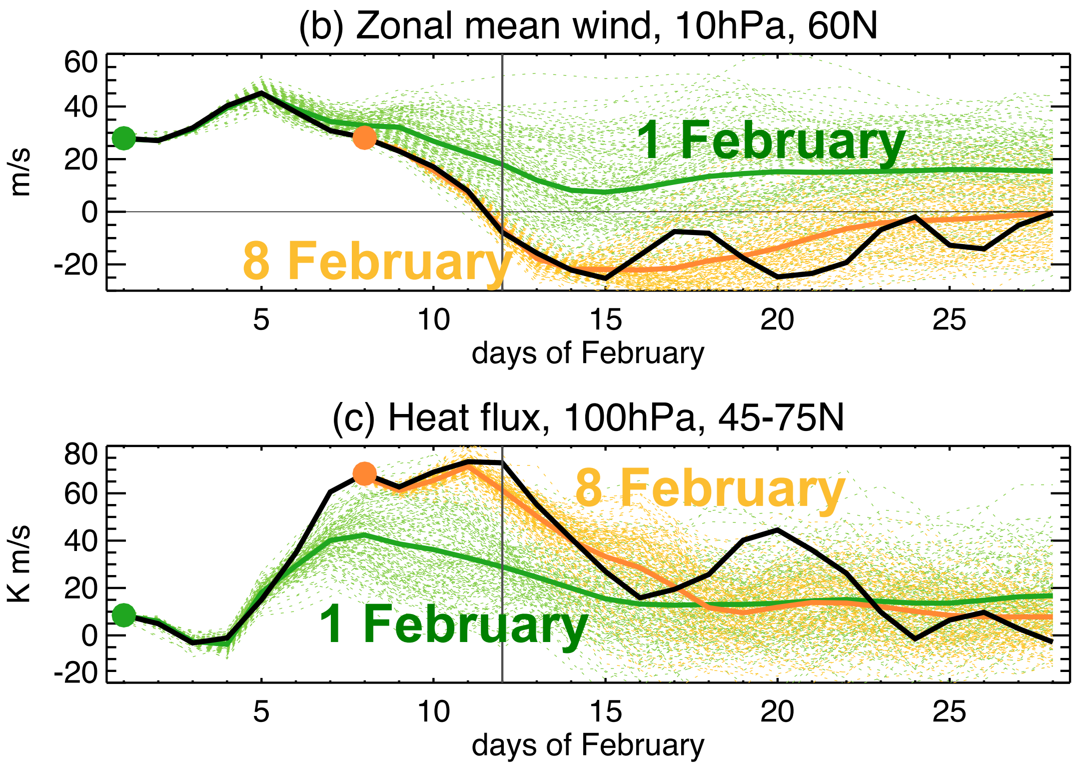
S2S predictions of SSW 2018



- Wind forecasts from 1 February strongly correlate with eddy heat flux forecasts across ensemble members (r=0.94) which is underestimated by most members (*see also Taguchi 2016*)
- Forecasts from 8 February correctly predicted the magnitude of the heat flux. Consequently, SSW was also well predicted

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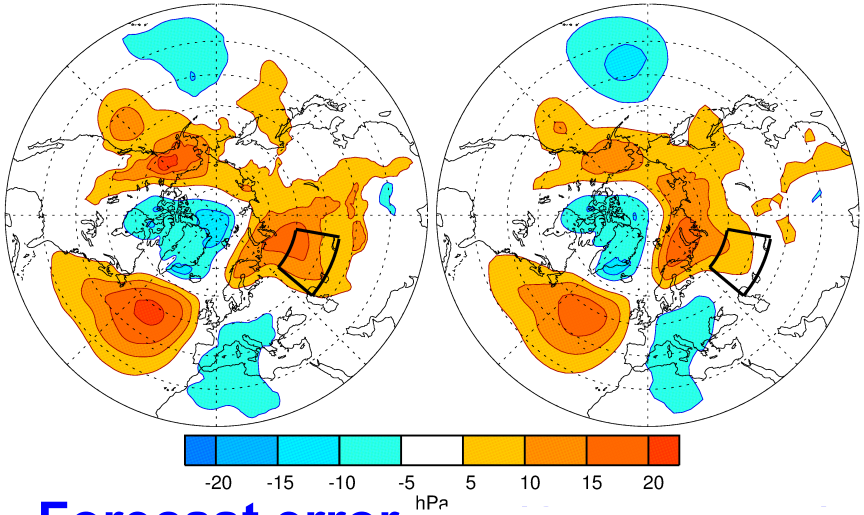
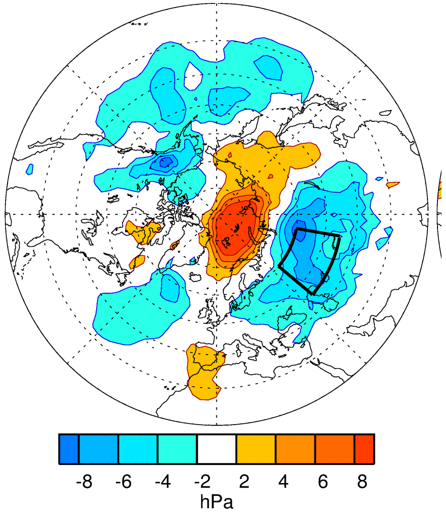
Tropospheric forcing of SSW 2018

Reanalysis **Forecast**



Forecast error



- SLP anomaly averaged over 1-11 February in reanalysis and forecast from 1 February show several anomalous anticyclones
- Anticyclones, in particular over northern Europe, are often associated with SSW forcing (e.g. Martius et al. 2009; Woollings et al. 2010)
- For the SSW 2018, errors in the forecasted location of the high over Ural turned out to be strongly correlated with the errors in stratospheric winds

see also Tripathi et al. 2016

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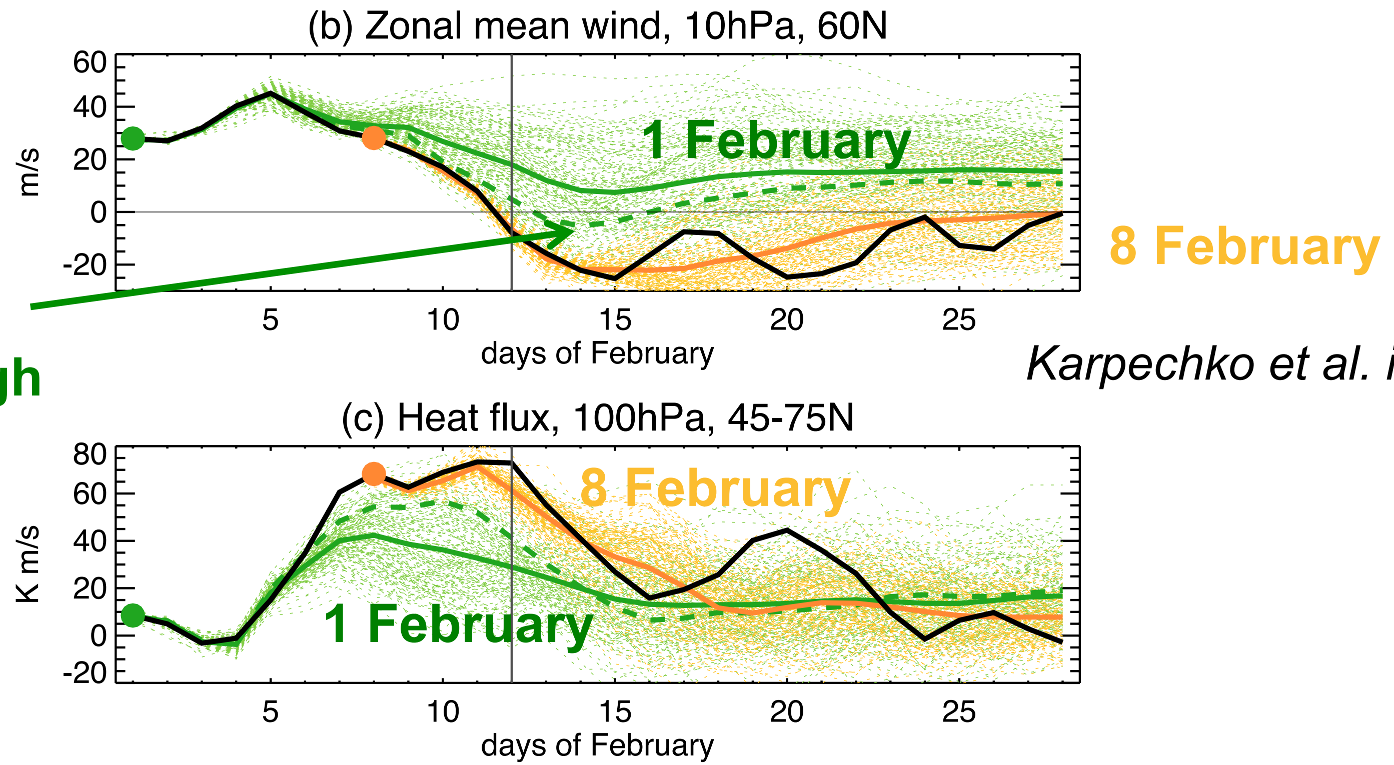
S2S predictions of SSW 2018

Subgroup with best forecast of the Ural high



Karpechko et al. in prep.

- Subgroup of ensemble members with best forecasts of the Ural high predicts stronger eddy heat flux to the stratosphere and eventually predicts an SSW to occur one day after the observed event

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SUMMARY

- There is large variability in predictability of SSW event (defined as a reversal of zonal mean zonal winds in mid-winter)
- Individual events are predicted with significant (*p*>0.5) probability 3-17 days in advance
- Weak, short-lived events have shortest predictability limits
- SSWs events with significant tropospheric impacts are predicted in probabilistic sense 8-13 days in advance **– consistent with most previous estimates –** although “deterministic“ predictability is limited to <~7 days
- The 2018 SSW was predicted at lead times 12-13 days by some models.
- The predictability of the 2018 SSW was limited by errors in the forecasted location of weather system and underestimated magnitude of the stratospheric wave forcing

ADDITIONAL SLIDES

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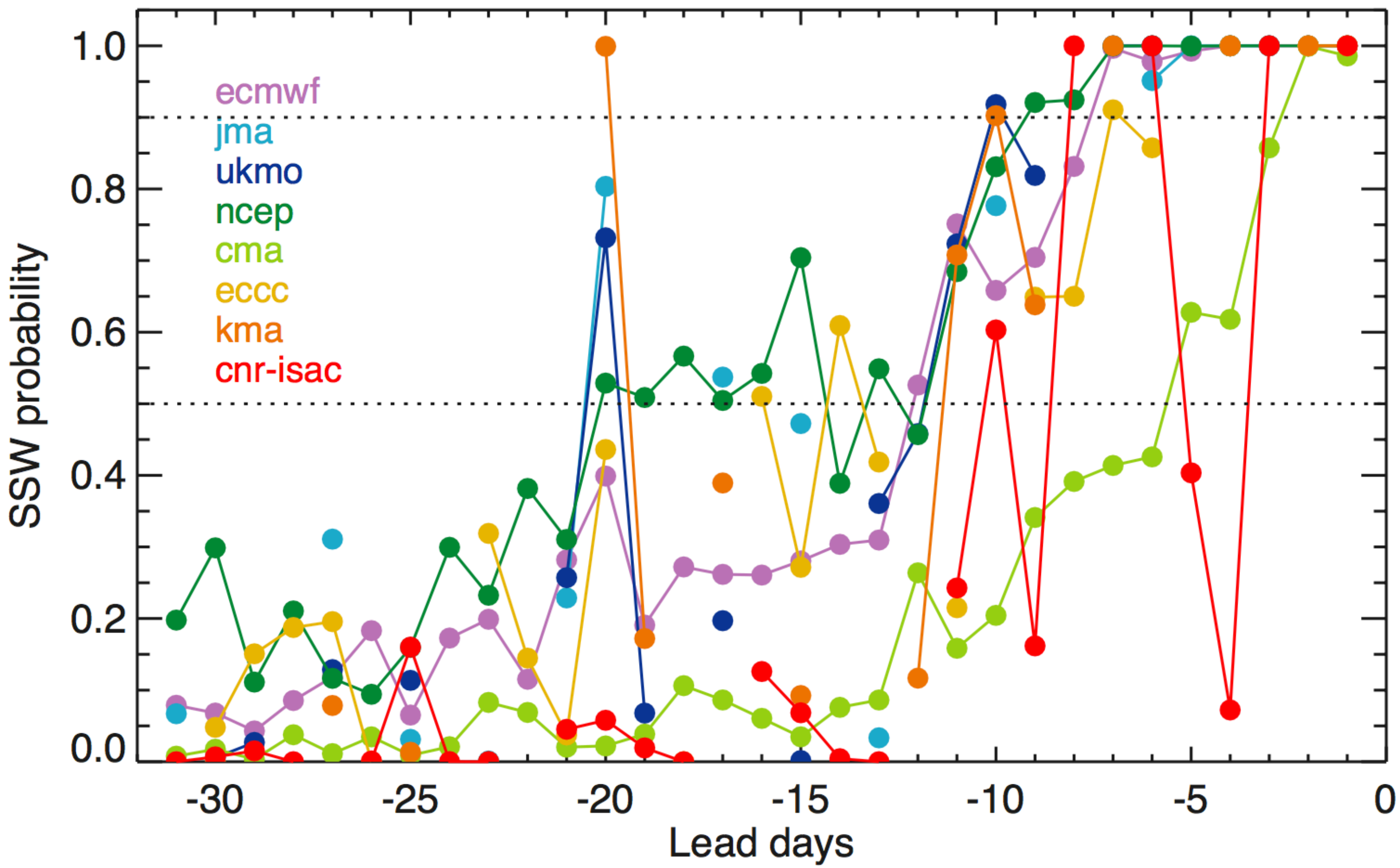
SSW predictability in S2S models



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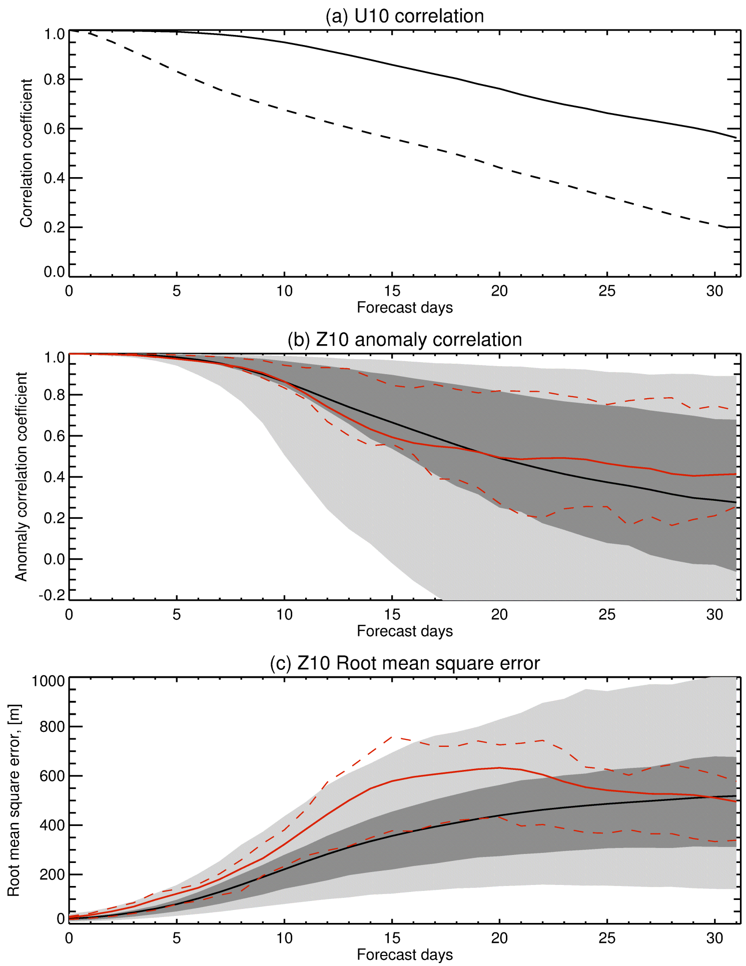
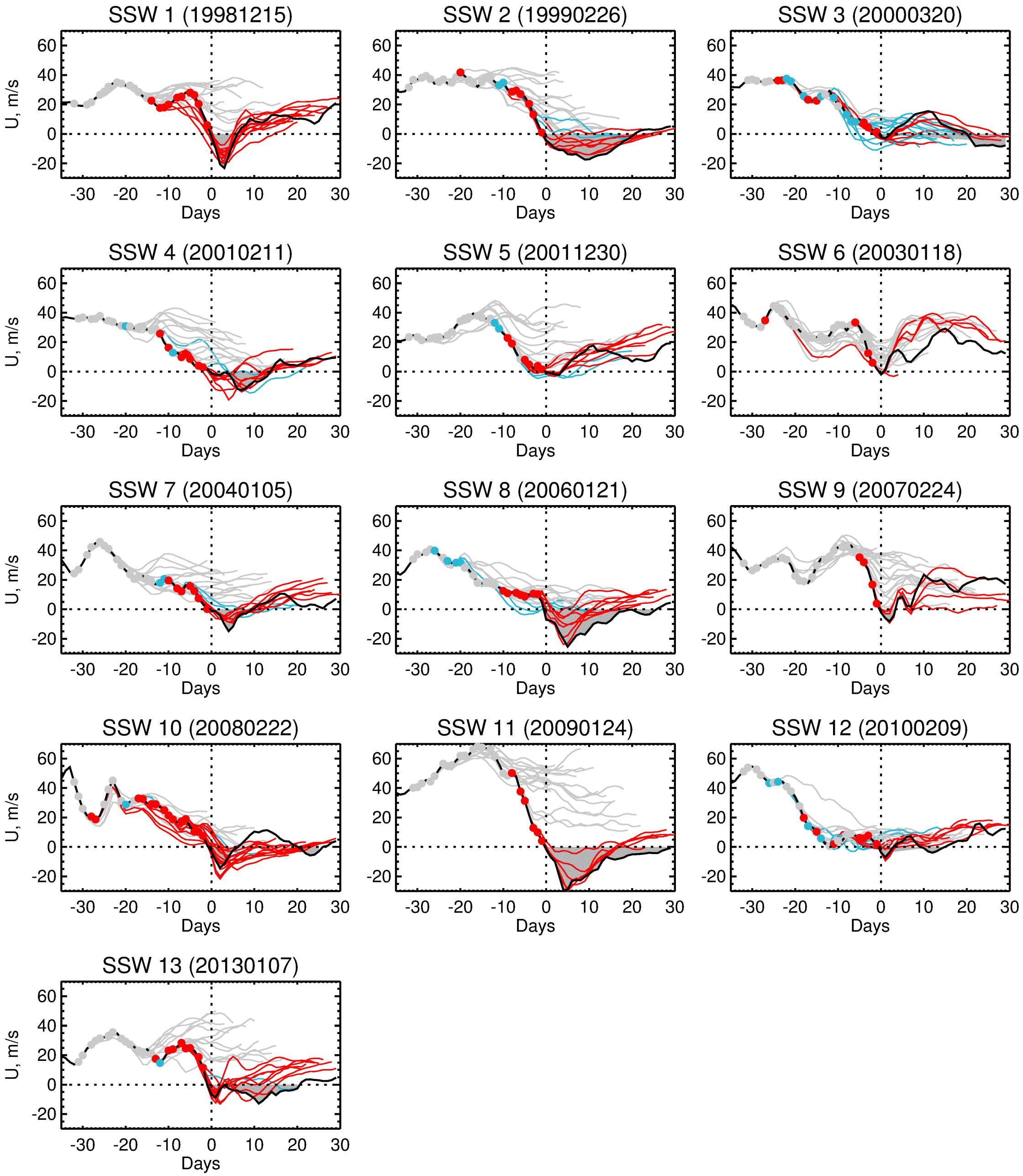
Stratospheric forecast skill




SSW 1 (19981215)
SSW 2 (19990226)
SSW 3 (20000320)
SSW 4 (20010211)
SSW 5 (20011230)
SSW 6 (20030118)
SSW 7 (20040105)
SSW 8 (20060121)
SSW 9 (20070224)
SSW 10 (20080222)
SSW 11 (20090124)
SSW 12 (20100209)
SSW 13 (20130107)
U, m/s
Days

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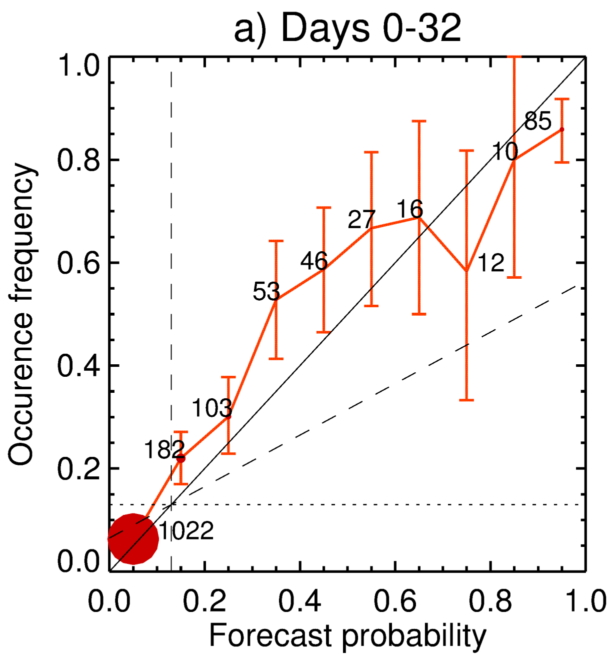
Reliability of SSW probability diagnostic

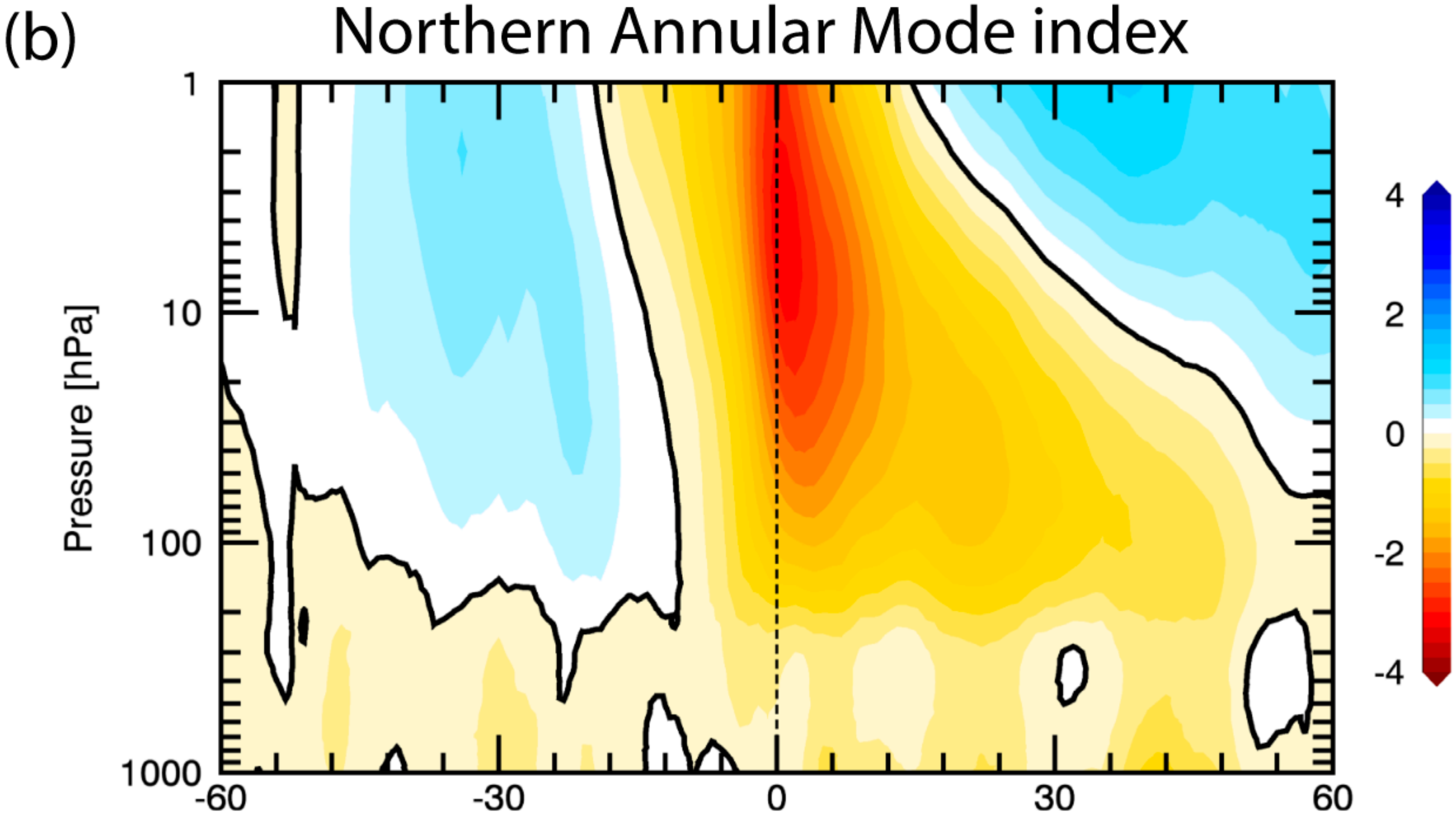


- In general SSW probability is a reliable diagnostic
- Underconfidence at medium probabilities may be due to small positive bias in forecast zonal winds
- Also reliable when only days 15-32 are considered!

ECMWF forecast system

- Forecasts for 32 days (currently for 46 days)
- Version with 91 levels since November 2013
- Hindcasts for four winters (2013/14-2016/17)
- Altogether 2120 hindcasts during 1993-2016 initialized between November and March
- Ensemble of 5 members (11 members for winters 2015/16-16/17)
- Cover 13 major SSWs from 1998 to 2013

Downward propagation



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SSW predictability

Central date	dSSW / nSSW	Split / Displacement	Predictability (days)	
			p=0.5	*p*=0.9
15.12.98	*nSSW*	*D*	*14*	*12*
26.02.99	**dSSW**	**S**	**11**	**7**
20.03.00	*nSSW*	*D*	*8*	*4*
11.02.01	**dSSW**	**S**	**12**	**9**
30.12.01	*nSSW*	*D*	*5*	*4*
18.01.03	*nSSW*	*S*	*3*	*3*
05.01.04	**dSSW**	**D**	**12**	**7**
21.01.06	**dSSW**	**D**	**10**	**9**
24.02.07	*nSSW*	*D*	*5*	*5*
22.02.08	*nSSW*	*D*	*17*	*13*
24.01.09	**dSSW**	**S**	**8**	**6**
09.02.10	**dSSW**	**S**	**5**	**5**
07.01.13	**dSSW**	**S**	**13**	**7**

- Most SSWs are predicted (in probabilistic sense) at lead time 8-13 days
- The range is between 3 and 17 days
- Displacements are predicted slightly better, but not significantly better, than splits