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(Subseasonal-to-) Seasonal prediction of the boreal winter stratosphere

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Weather and Climate Dynamics
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Quantifying stratospheric biases and identifying their potential sources in subseasonal forecast systems

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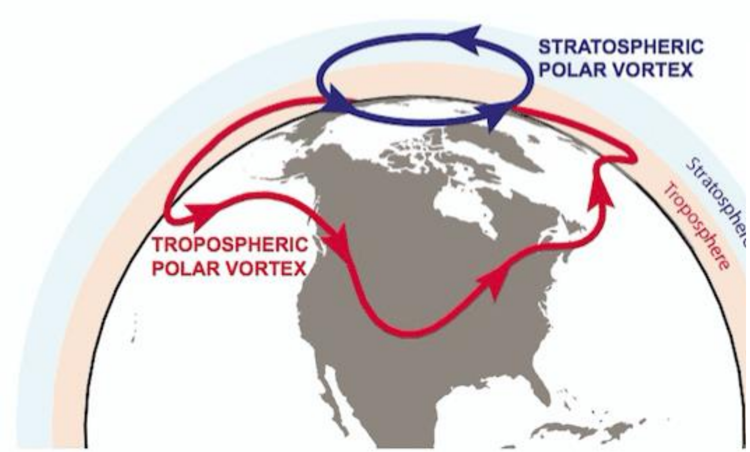
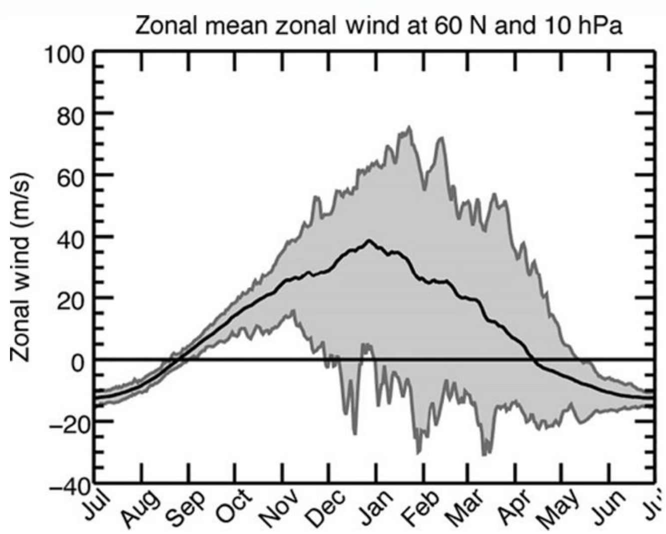
Stratospheric polar vortex in the Northern Hemisphere winter





Butler et al. (2019, Chp.11)

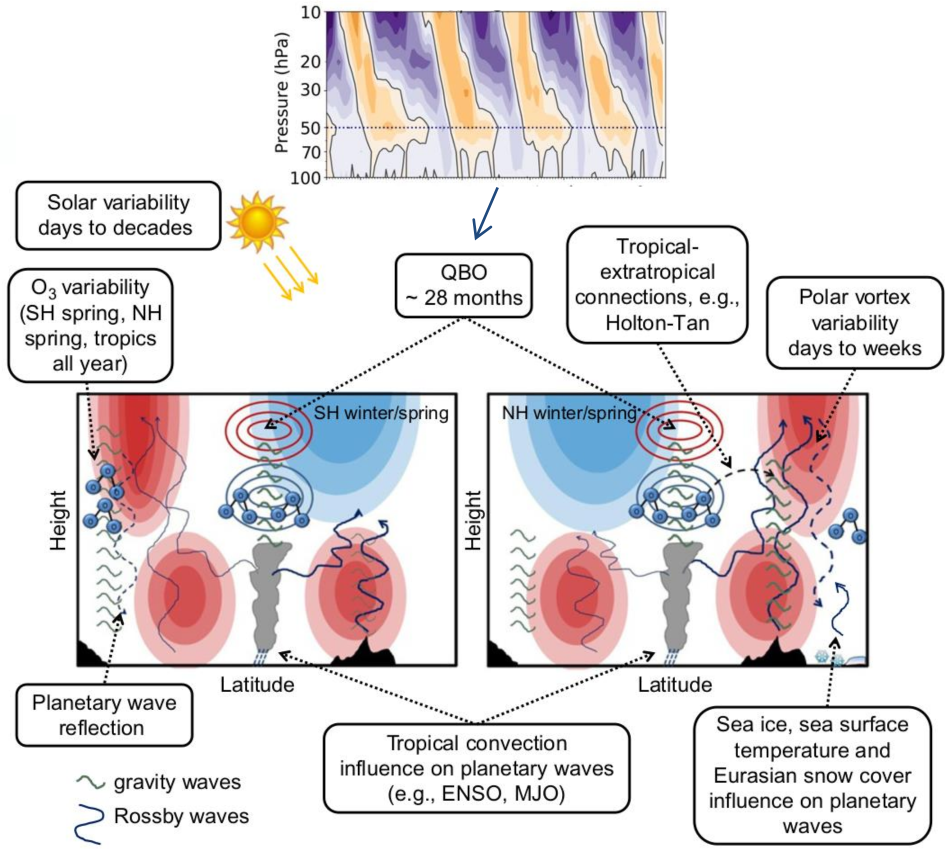
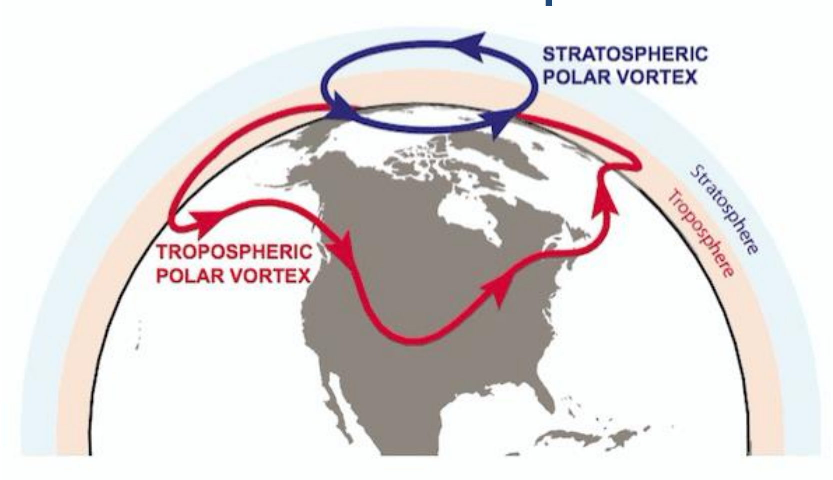
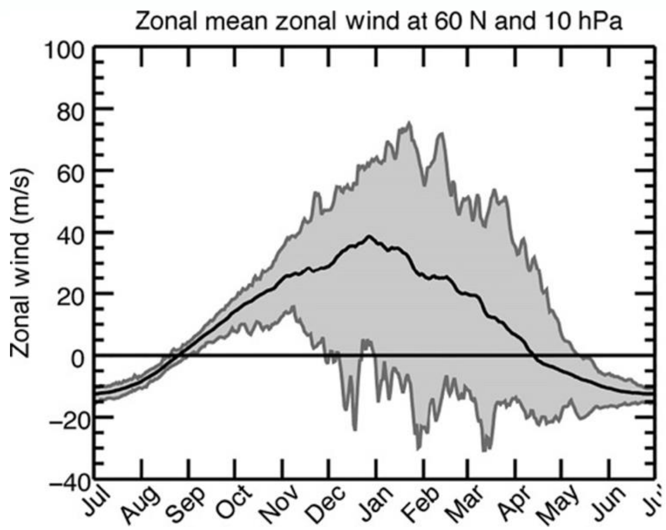


FIG. 1 Schematic showing phenomena of known relevance to stratosphere-troposphere coupling. Contours show the zonal mean zonal wind schematically (*red*-filled contours indicate mean westerly winds and *blue*-filled indicate easterly winds). Left panel shows Southern Hemisphere (SH) winter and spring and right panel shows Northern Hemisphere (NH) winter and spring. *Red*- and *blue*-unfilled contours indicate zonal mean, zonal wind anomalies associated with the QBO.

"Sub-seasonal predictability and the stratosphere"

Stratospheric polar vortex in the Northern Hemisphere winter





Butler et al. (2019, Chp.11)

"Enhanced seasonal forecast skill following stratospheric sudden warmings"

Sigmond et al. (2013)

"The Climate-system Historical Forecast Project: do stratosphere-resolving models make better seasonal climate predictions in boreal winter?"

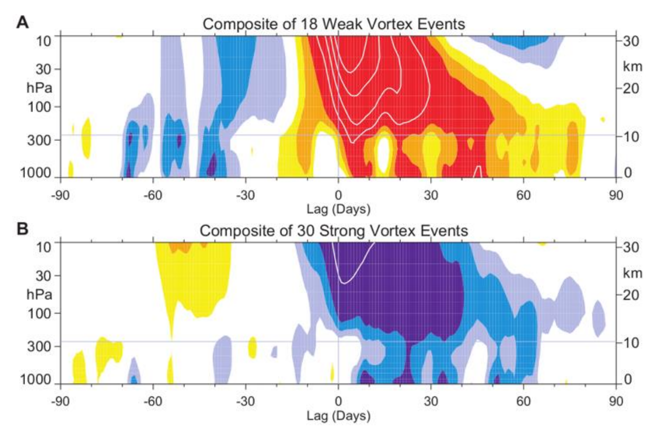
Butler et al. (2016)

"Seasonal winter forecasts and the stratosphere"

Scaife et al. (2016)

"Long-range prediction and the stratosphere"

Scaife et al. (2022)



Baldwin & Dunkerton (2001)

SCIENTIFIC QUESTIONS:

- What is the current status of stratospheric predictability in seasonal forecast systems?

- How do they represent upward troposphere-stratosphere coupling?

- Does wave-forcing initialization have an impact on the SPV skill?

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- What is the current status of stratospheric predictability in seasonal forecast systems?
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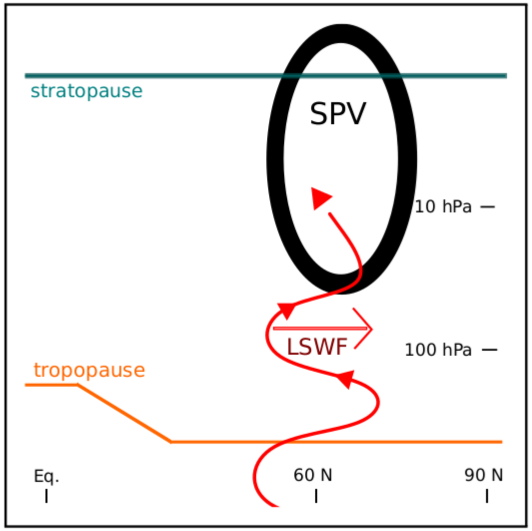
$$\Delta\overline{U}_{10}(\varphi,p,t) \approx \Delta\overline{U}^{*}(\varphi,\tau_p,t) \approx -A\int_{t_0}^{t}\Delta[v^{*}T^{*}{}_{100}](t')e^{-(t-t')/\tau_p}\,dt'$$

vertical Rossby wave flux

Hinssen & Ambaum (2010)

$[v^{*}T^{*}{}_{100}]$ ← zonal-mean meridional eddy heat flux at 100hPa over 40ºN-80ºN

lower-stratosphere wave forcing (LSWF)



Waves propagating upwards from the troposphere (LSWF) break in the SPV and decelerate it [latitude-pressure]

SCIENTIFIC QUESTIONS:

- What is the current status of stratospheric predictability in seasonal forecast systems?
- How do they represent upward troposphere-stratosphere coupling?
- Does wave-forcing initialization have an impact on the SPV skill?

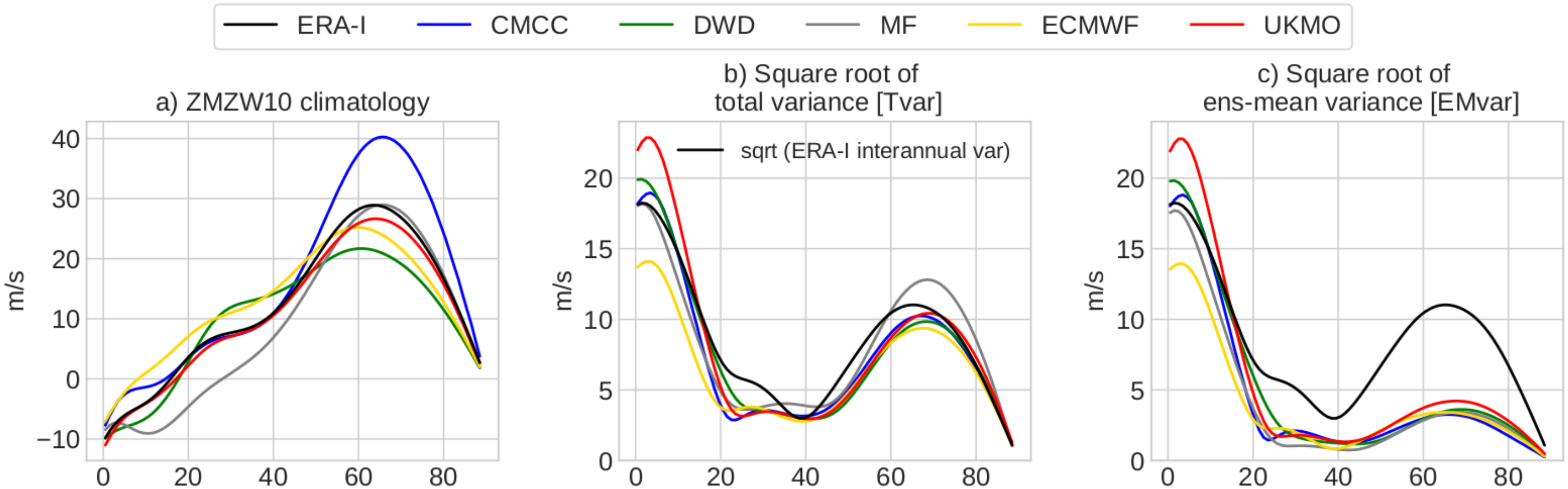
Copernicus Climate Change Service (C3S) multi-model dataset

Nov 1993/94-2016/17
NDJF

General description of the 5 seasonal prediction systems.

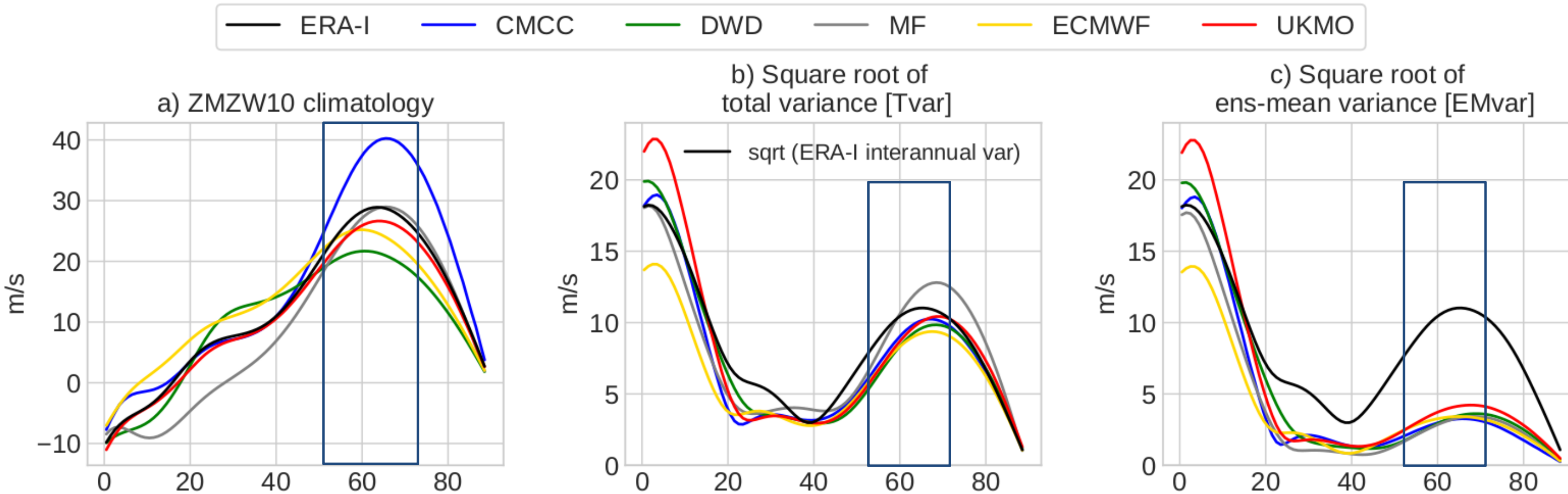
Models	Resolution *	Initial Conditions **	Ensemble Size
CMCC (system 3)	1° lat/long 46 L	1st November	40 members
MF (system 6)	TL359 91 L	20th, 25th October 1st November	2×12 members 1 member
ECMWF (SEAS5)	$T_{CO}319$ 91 L	1st November	25 members
DWD (system 2)	T127 95 L	1st November	30 members
UKMO (GloSea5, system 13)	N216 95 L	25th October 1st, 9th November	7 members for start date

Zonal-mean zonal wind at 10hPa / DJF average



variability & predictability

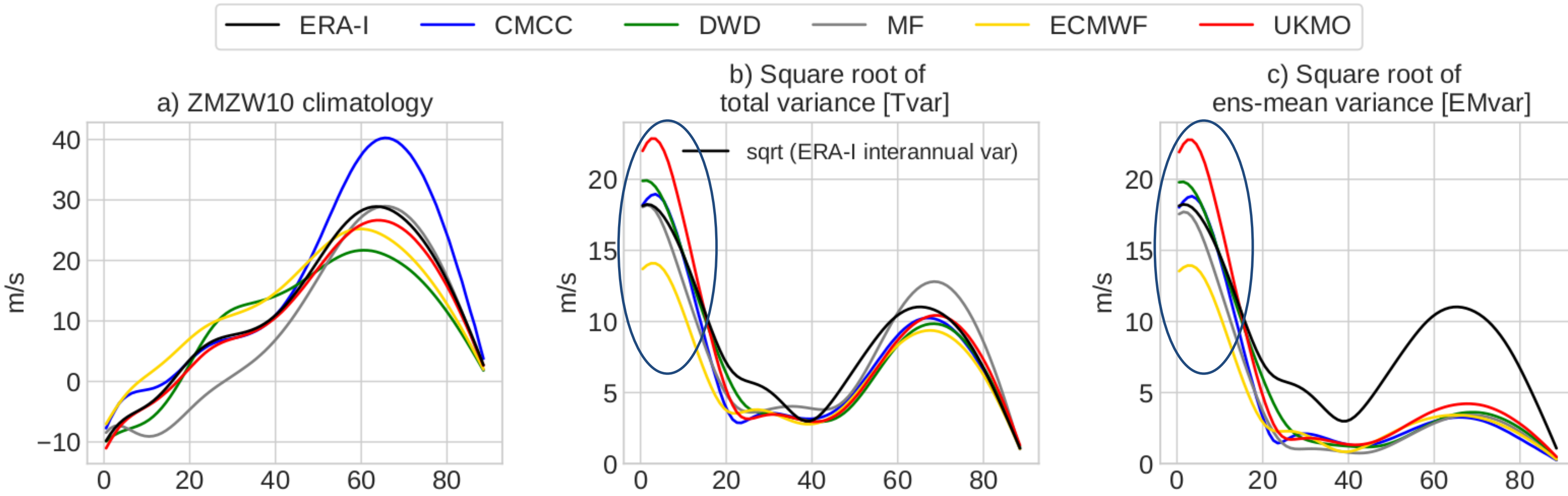
Zonal-mean zonal wind at 10hPa / DJF average



polar vortex
U[55ºN-70ºN]

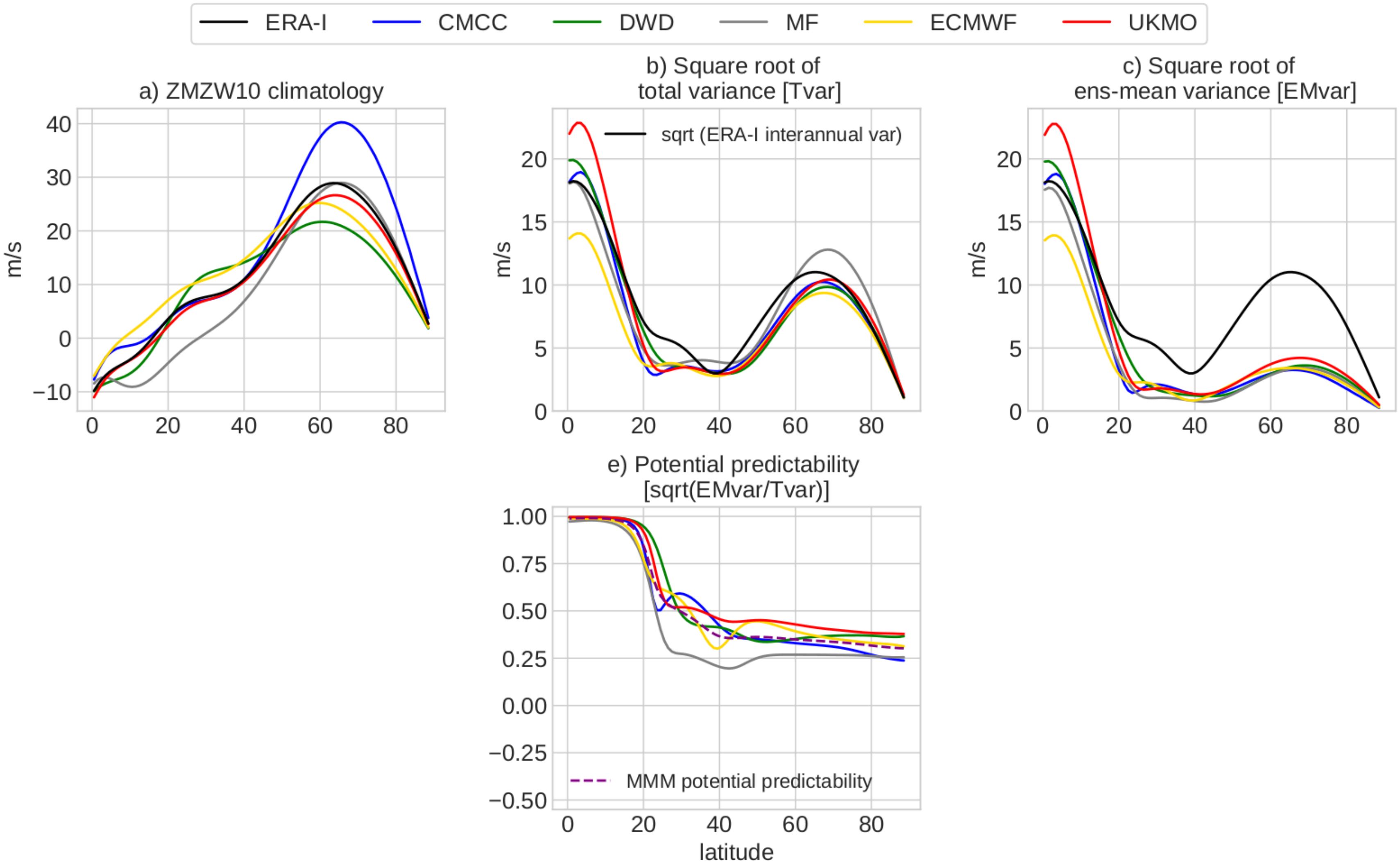
variability & predictability

Zonal-mean zonal wind at 10hPa / DJF average



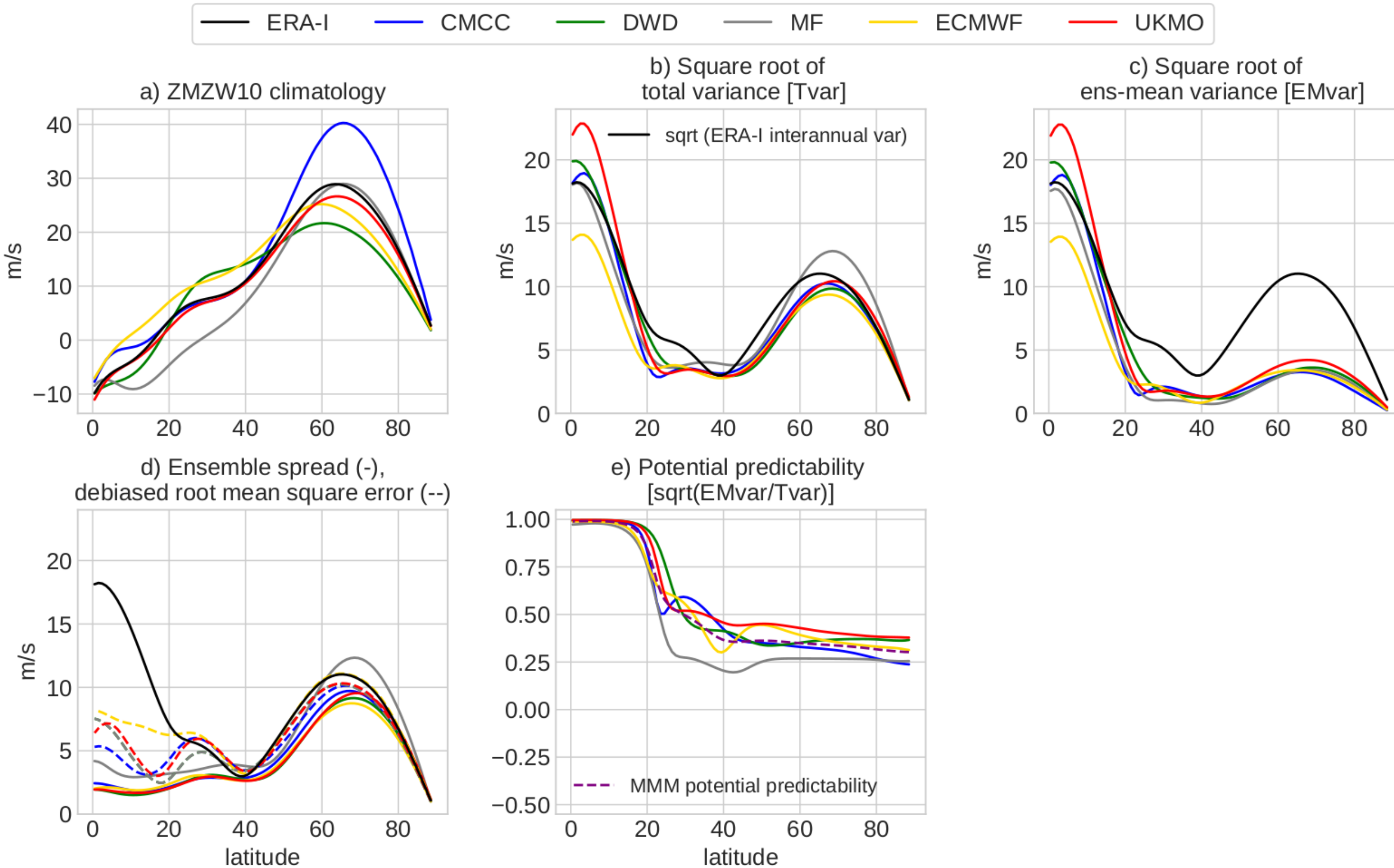
QBO-related variability

Zonal-mean zonal wind at 10hPa / DJF average

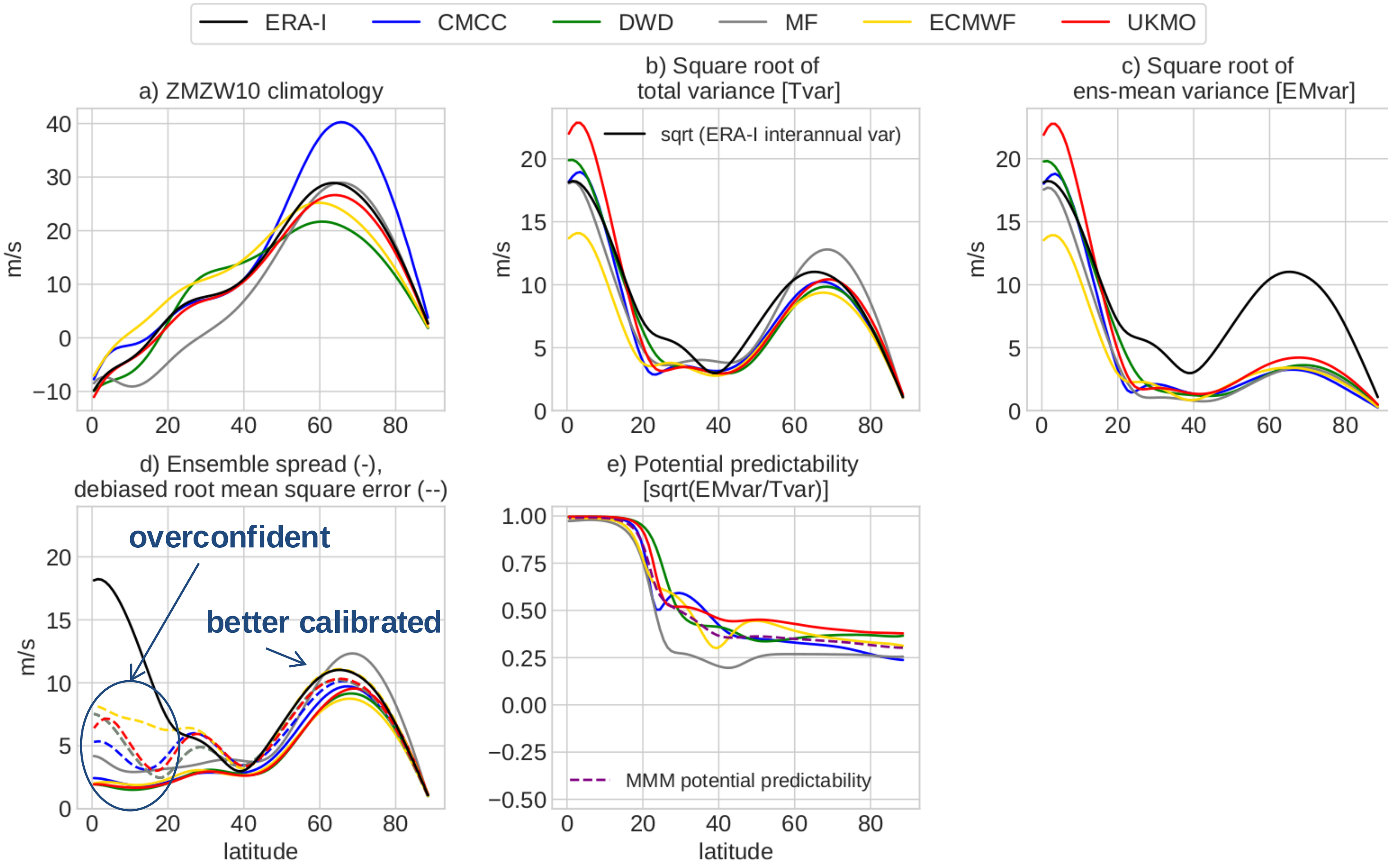


variability & predictability

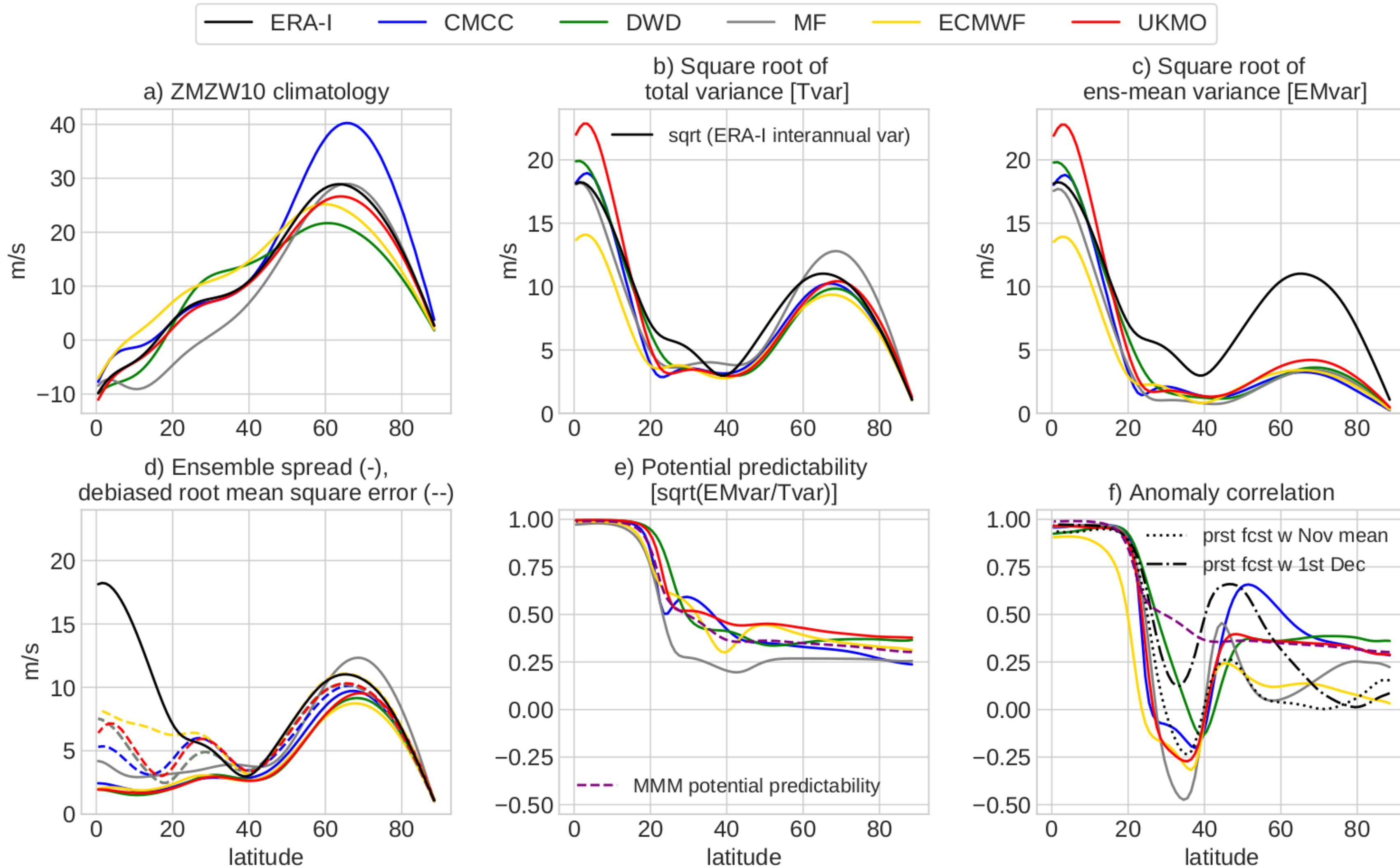
Zonal-mean zonal wind at 10hPa / DJF average



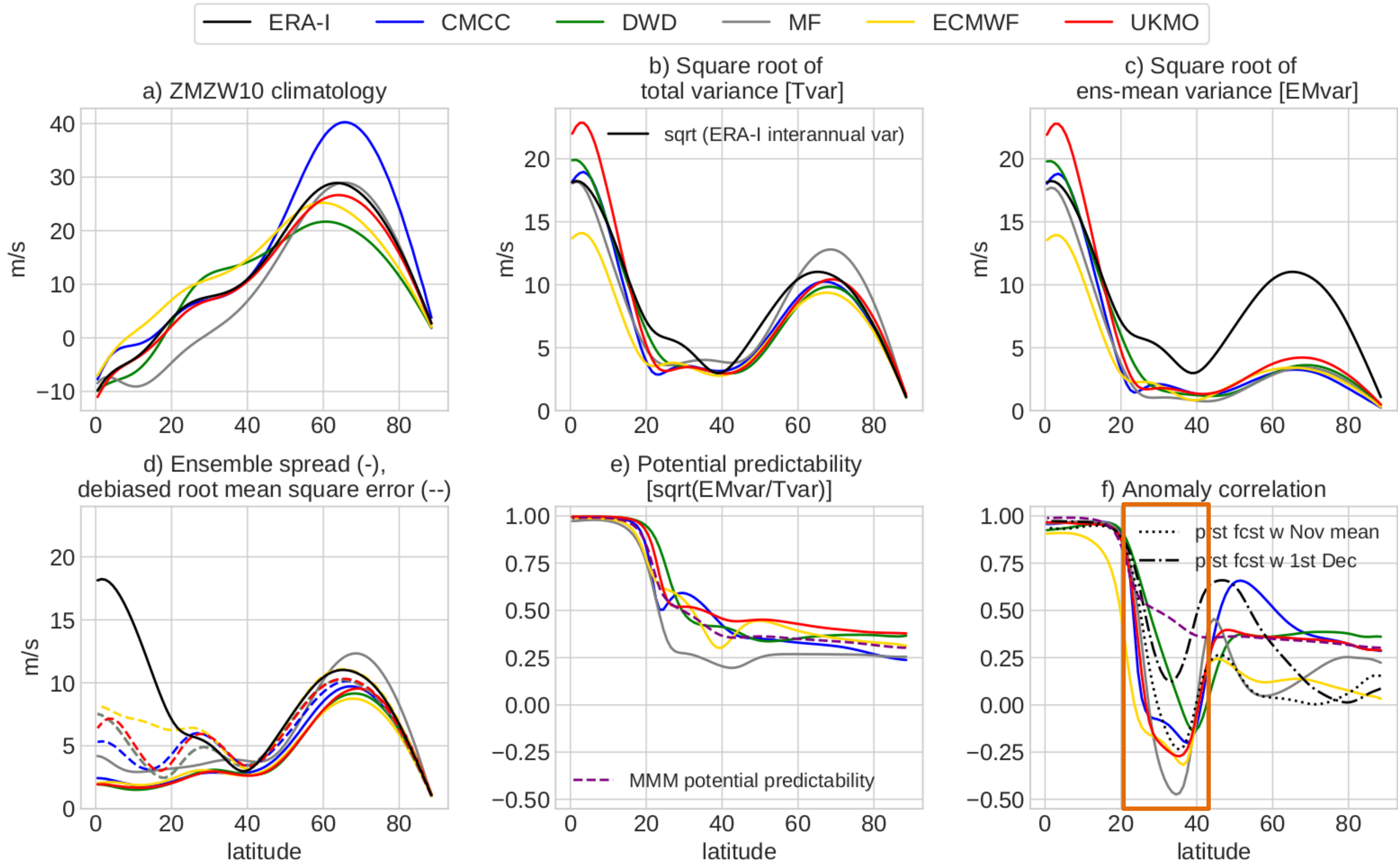
Zonal-mean zonal wind at 10hPa / DJF average



Zonal-mean zonal wind at 10hPa / DJF average



Zonal-mean zonal wind at 10hPa / DJF average



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prediction skill

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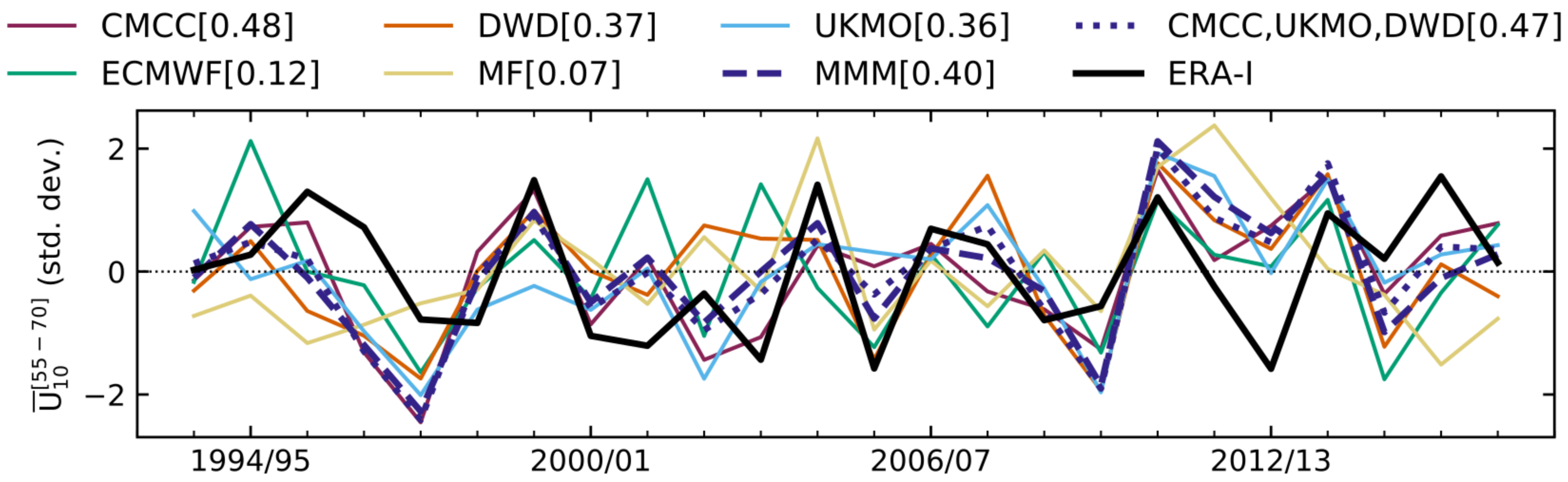
Zonal-mean zonal wind at 10hPa, [55ºN-70ºN] / DJF average



prediction skill

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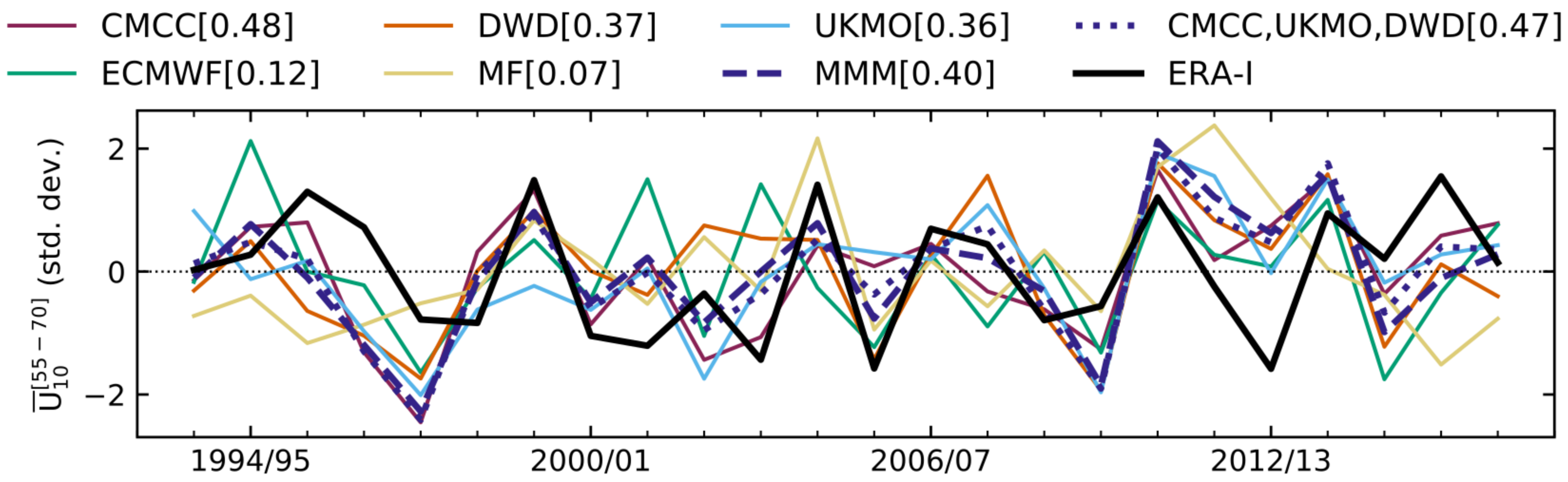


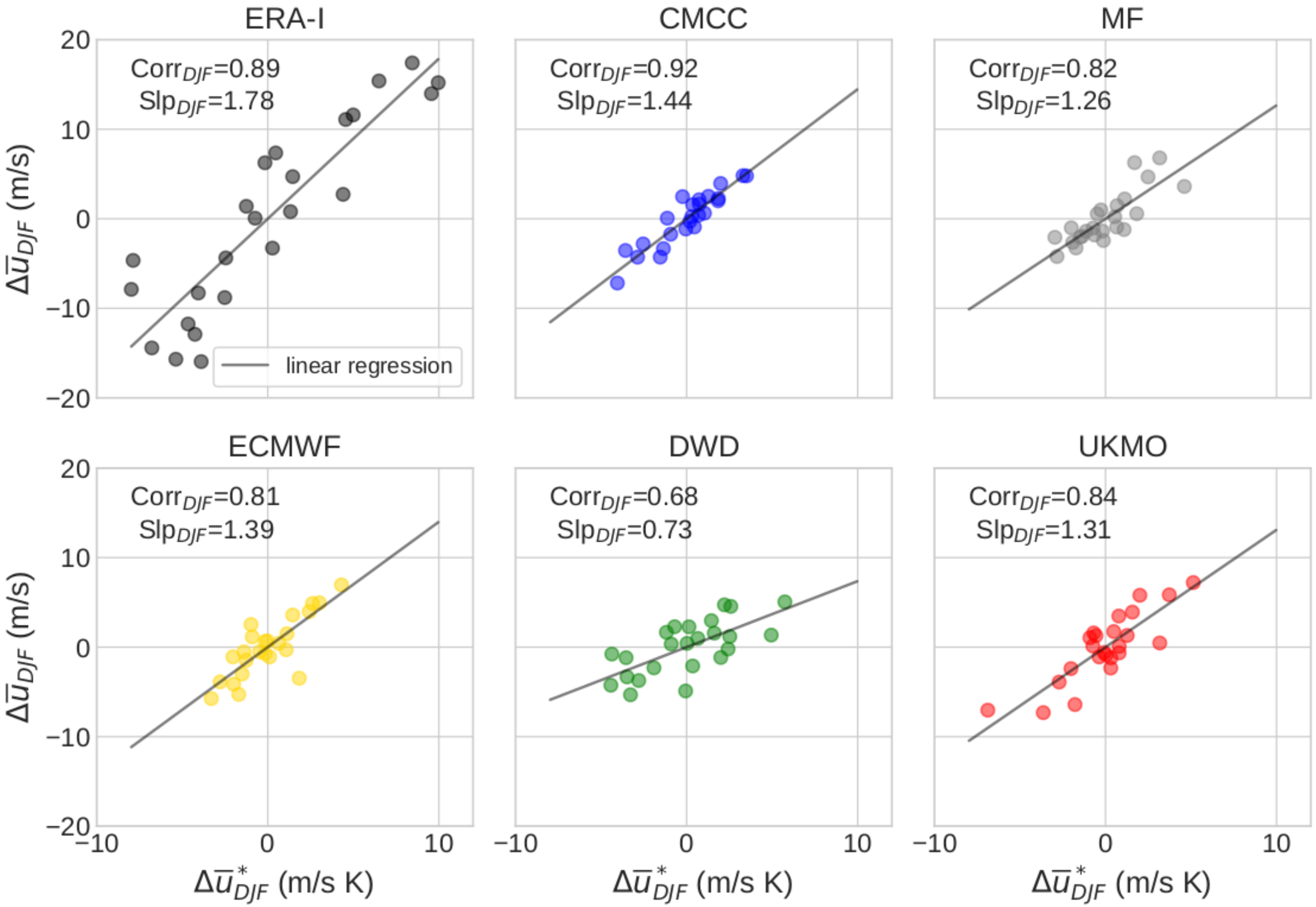
v*T* main source of SPV variability

Andrews et al. (1987); Newman et al. (2001)

$$\Delta\overline{U}^{*}(\varphi,\tau_p,t) \approx -A\int_{t_0}^{t}\Delta[v^{*}T^{*}{}_{100}](t')e^{-(t-t')/\tau_p}\,dt'$$

$[v^{*}T^{*}{}_{100}]$ eddy heat flux at 100hPa, [40ºN-80ºN]

seasonal timescale



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stratospheric dynamics

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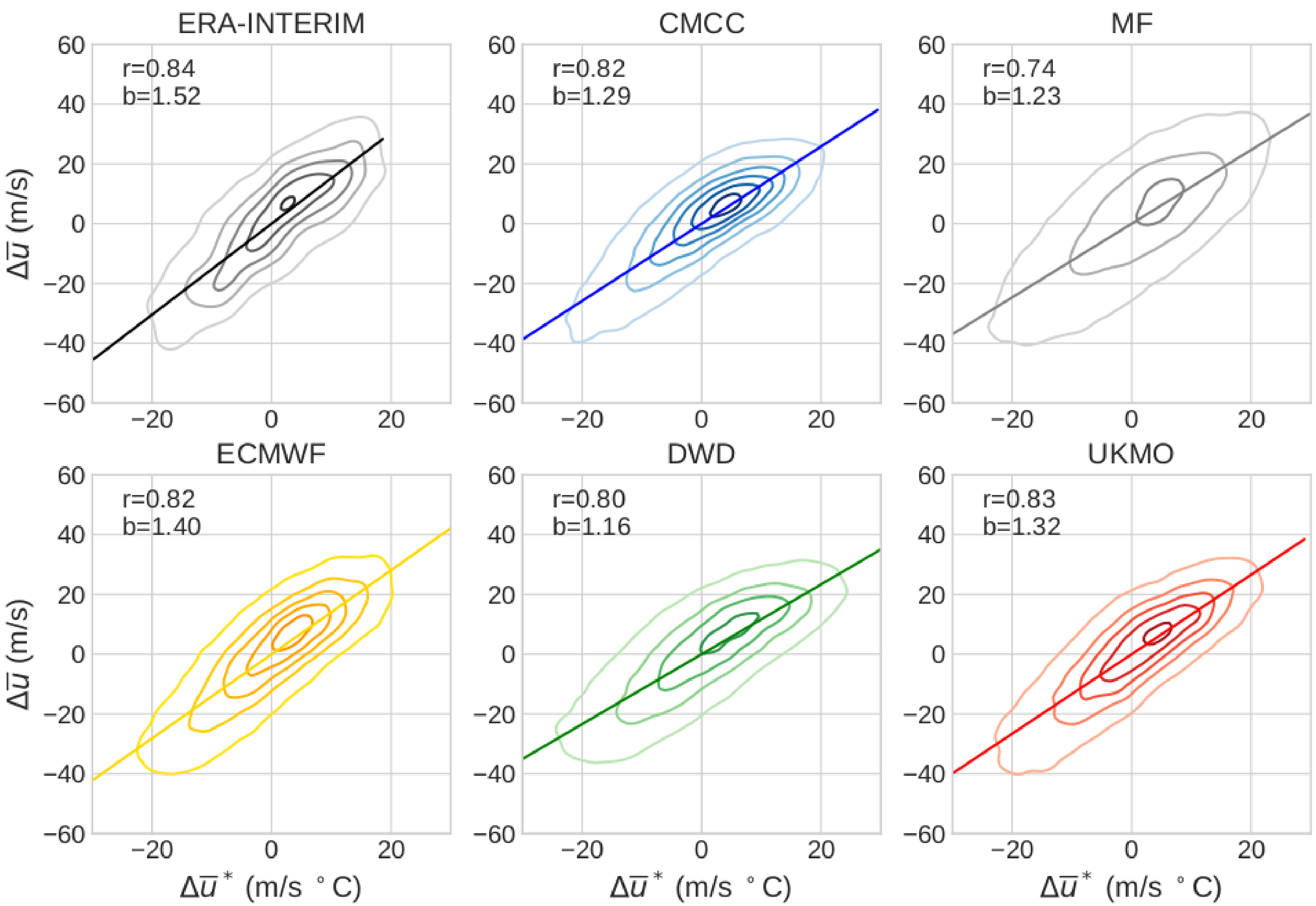
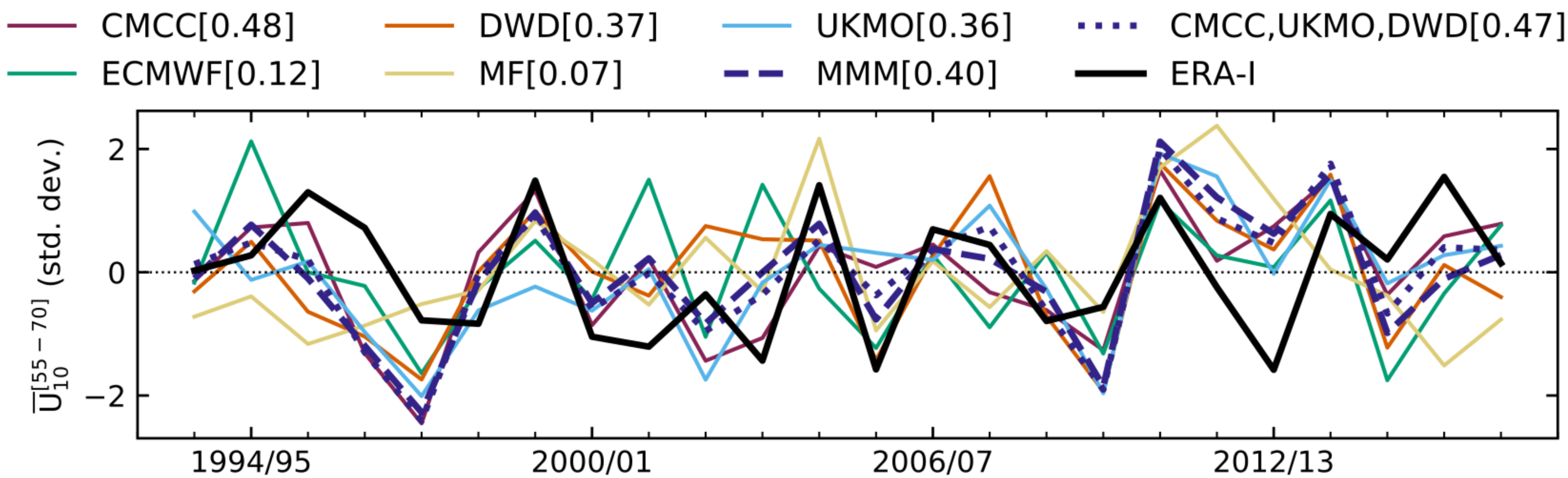
daily timescale



prediction skill

Zonal-mean zonal wind at 10hPa, [55ºN-70ºN] / DJF average



v*T* main source of SPV variability

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$$\Delta\overline{U}^*(\varphi,\tau_p,t) \approx -A\int_{t_0}^{t}\Delta[v^*T^*{}_{100}](t')e^{-(t-t')/\tau_p}\,dt'$$

$[v^*T^*{}_{100}]$ eddy heat flux at 100hPa, [40ºN-80ºN]

B) SPV deterministic skill

	40-80° N	
	ACC_F (← $[v^*T^*{}_{100}]$_NDJF)	$ACC_{F(N)}$ (← $[v^*T^*{}_{100}]$_Nov)
CMCC	**0.49**	0.30
MF	0.09	0.11
ECMWF	0.08	**0.28**
DWD	0.22	**0.43**
UKMO	**0.36**	0.31

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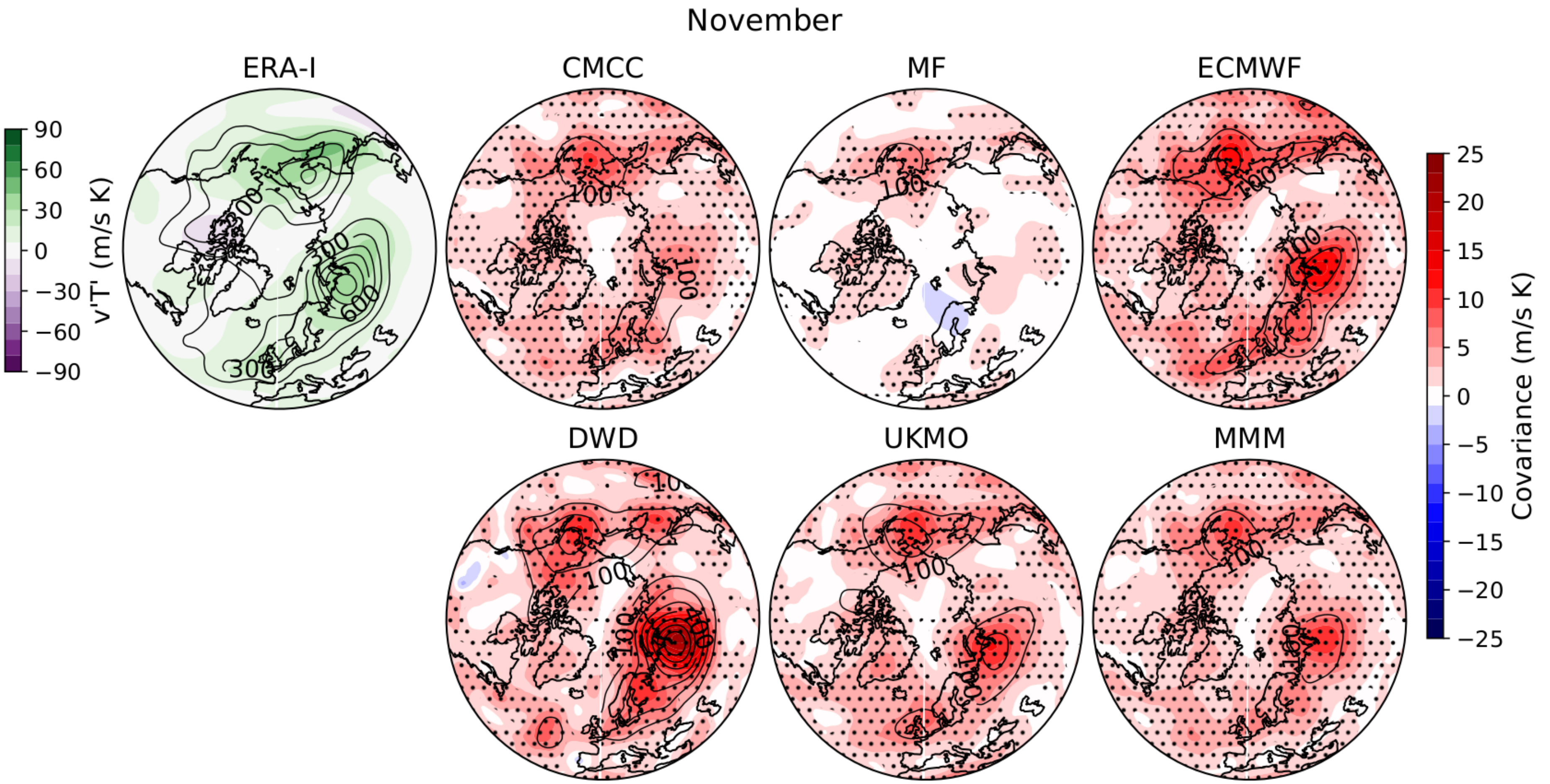
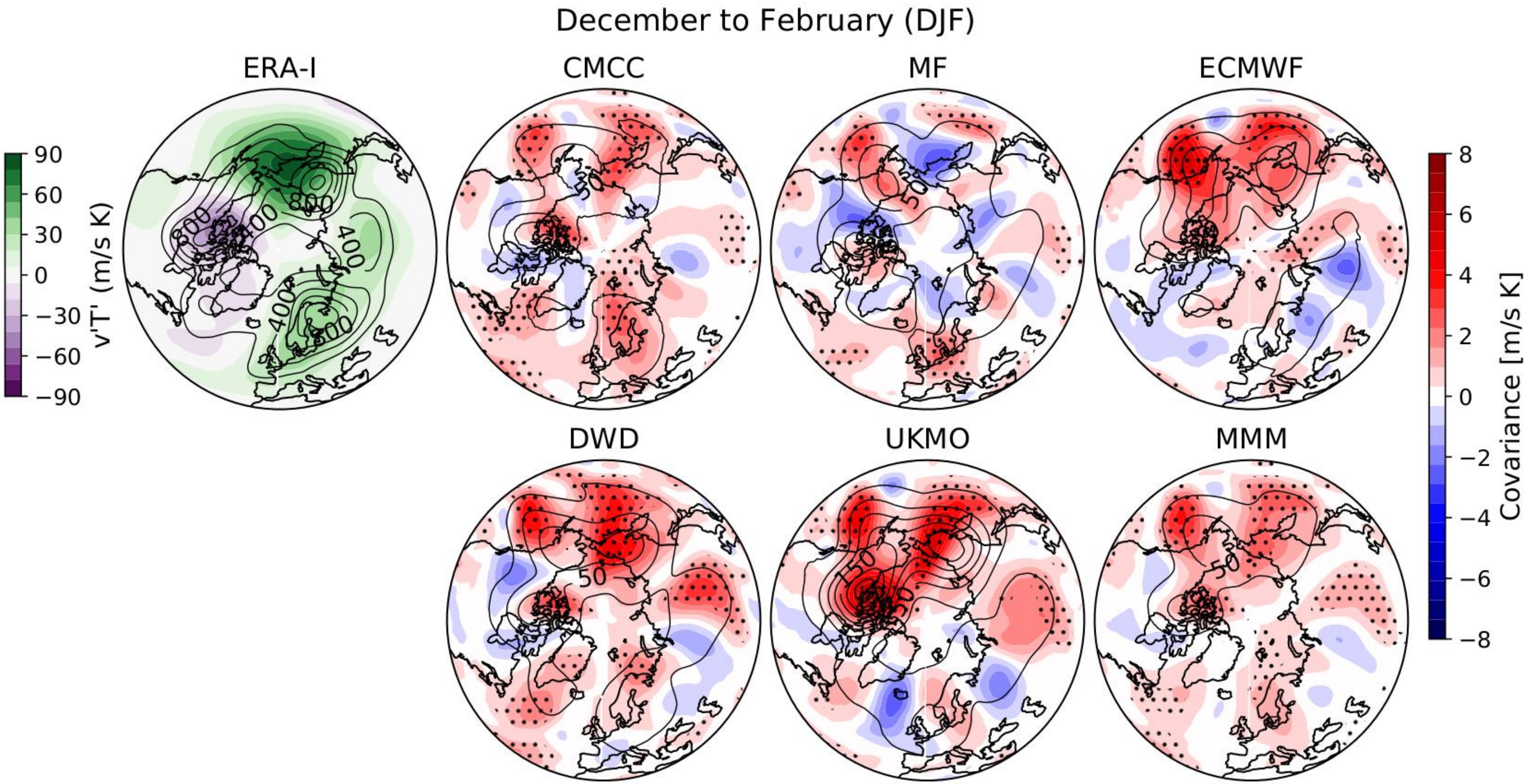
[v*T*] eddy heat flux at 100hPa



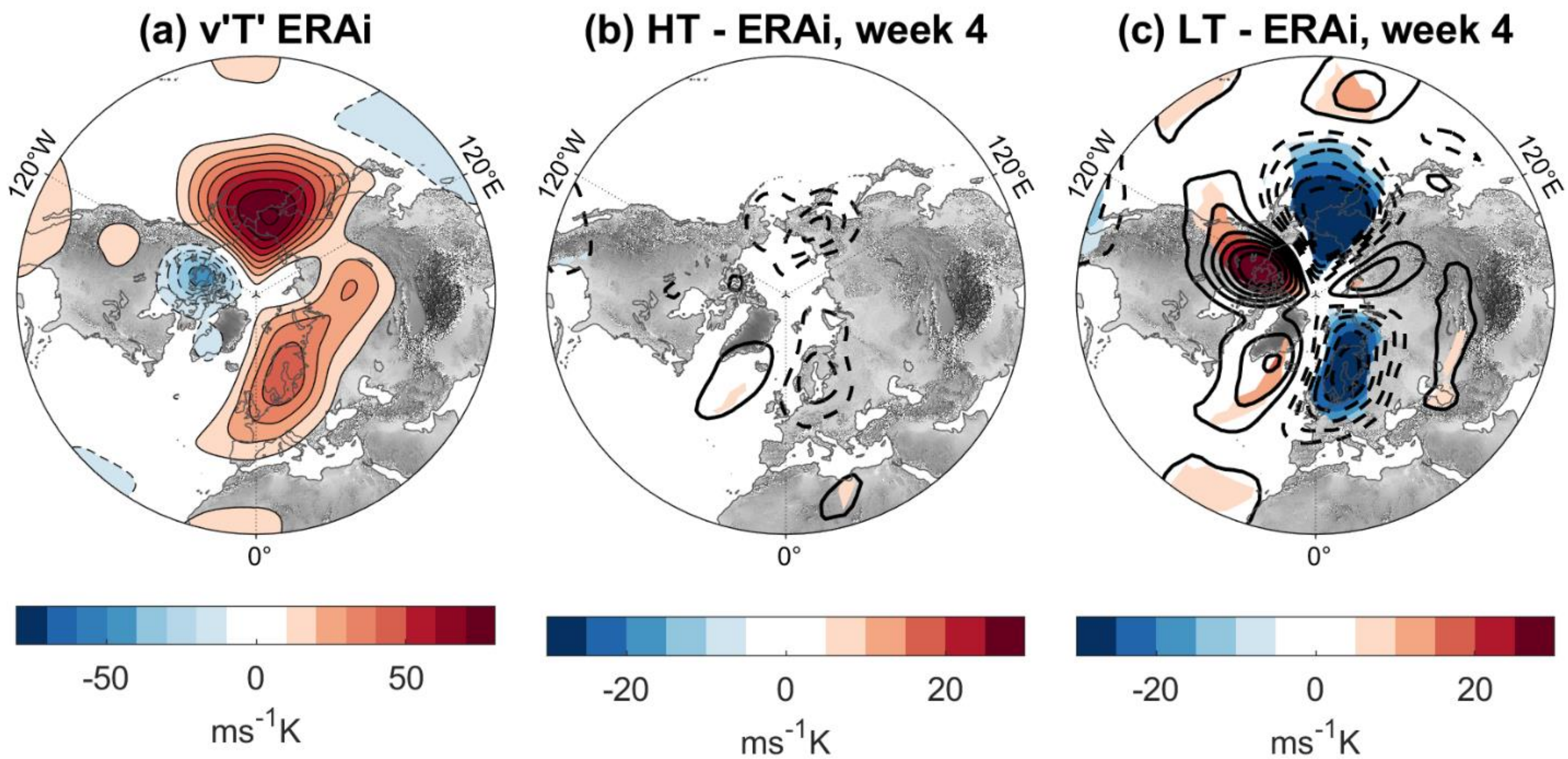
prediction skill

[v*T*] eddy heat flux at 100hPa



model bias

[v*T*] eddy heat flux at 100hPa / DJF climatology



S2S Prediction Project Database (*Vitart et al. 2017*)

hindcasts 1999-2010

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In the boreal winter stratosphere:

- **deep tropics: high predictability / high prediction skill related to the QBO**
  middle-subpolar latitudes: prediction skill close to potential predictability
  subtropical latitudes: prediction skill is lower than potential predictability

- **seasonal/daily coupling between eddy heat flux at 100hPa (LSWF) and polar vortex strength at 10hPa (SPV) is reasonably well simulated by the forecast systems, besides model biases in the SPV climatology**

- **troposphere-stratosphere coupling (LSWF) provides prediction skill for SPV**
  v*T* shows high prediction skill in November [0 lead-time]
  v*T* shows marginal skill in DJF, mainly over the North Pacific, while in reanalysis the key region appears to be Eurasia

- **forecast quality assessment in the stratosphere [subseasonal-2-seasonal] shall include probabilistic skill scores**

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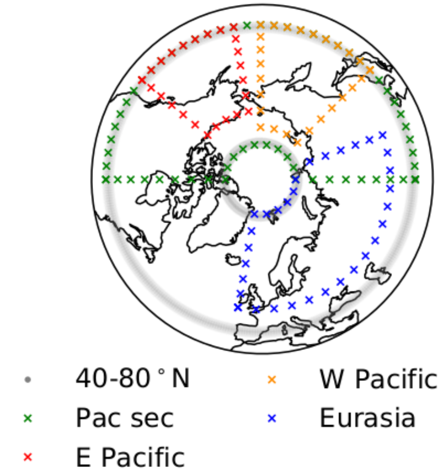
Table 1: **Strength of the link between SPV and regional LSWF**. Correlation between DJF anomalies of SPV winds ($\Delta\overline{U}$) and DJF wind anomalies reconstructed from regional LSWF ($\Delta\overline{U}^{*}_{reg}$, see Eq. 1). The latter are calculated using $v'T'$ from the regions selected in the figure on the right. Bold values are significant at 95% confidence level.

	40-80° N	W Pacific	E Pacific	Pac sec	Eurasia
CMCC	**0.91**	-0.05	**0.75**	**0.40**	**0.85**
MF	**0.82**	-0.33	**0.61**	**0.55**	**0.51**
ECMWF	**0.84**	-0.22	**0.53**	0.26	**0.71**
DWD	**0.74**	**-0.35**	**0.45**	0.07	**0.69**
UKMO	**0.89**	**-0.40**	**0.68**	0.19	**0.64**
ERA-I	**0.91**	0.14	0.01	0.11	**0.72**



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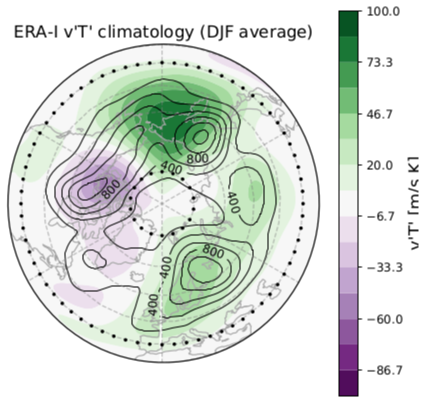
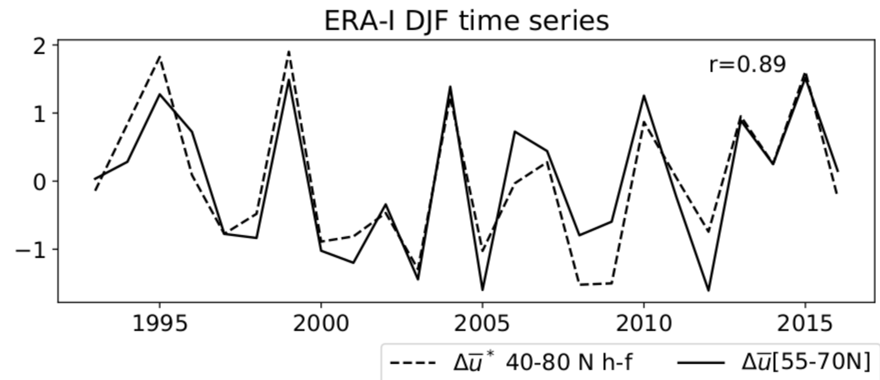
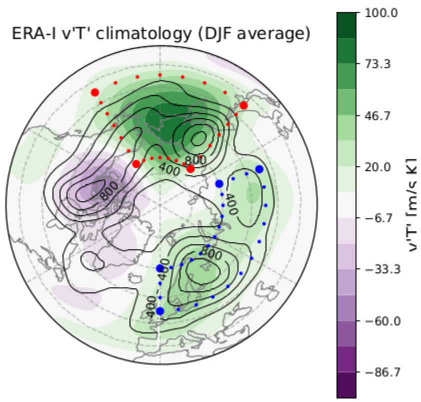
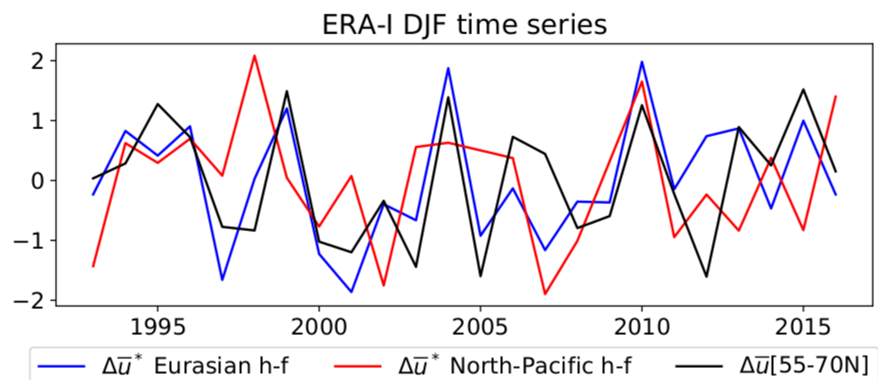
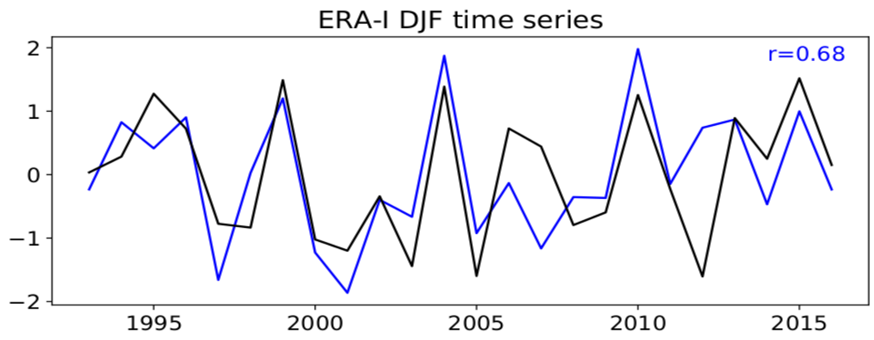
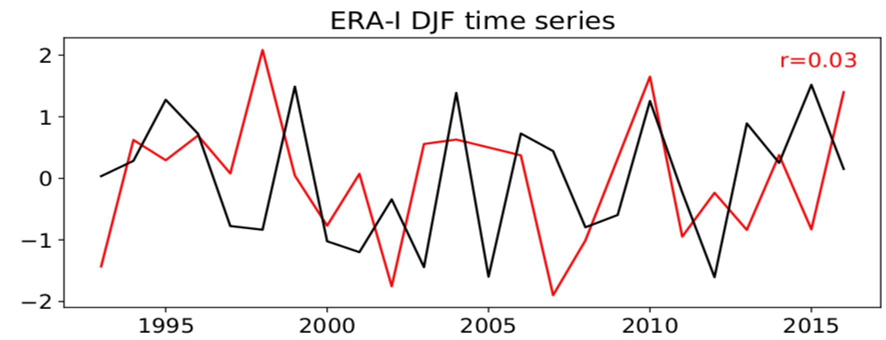






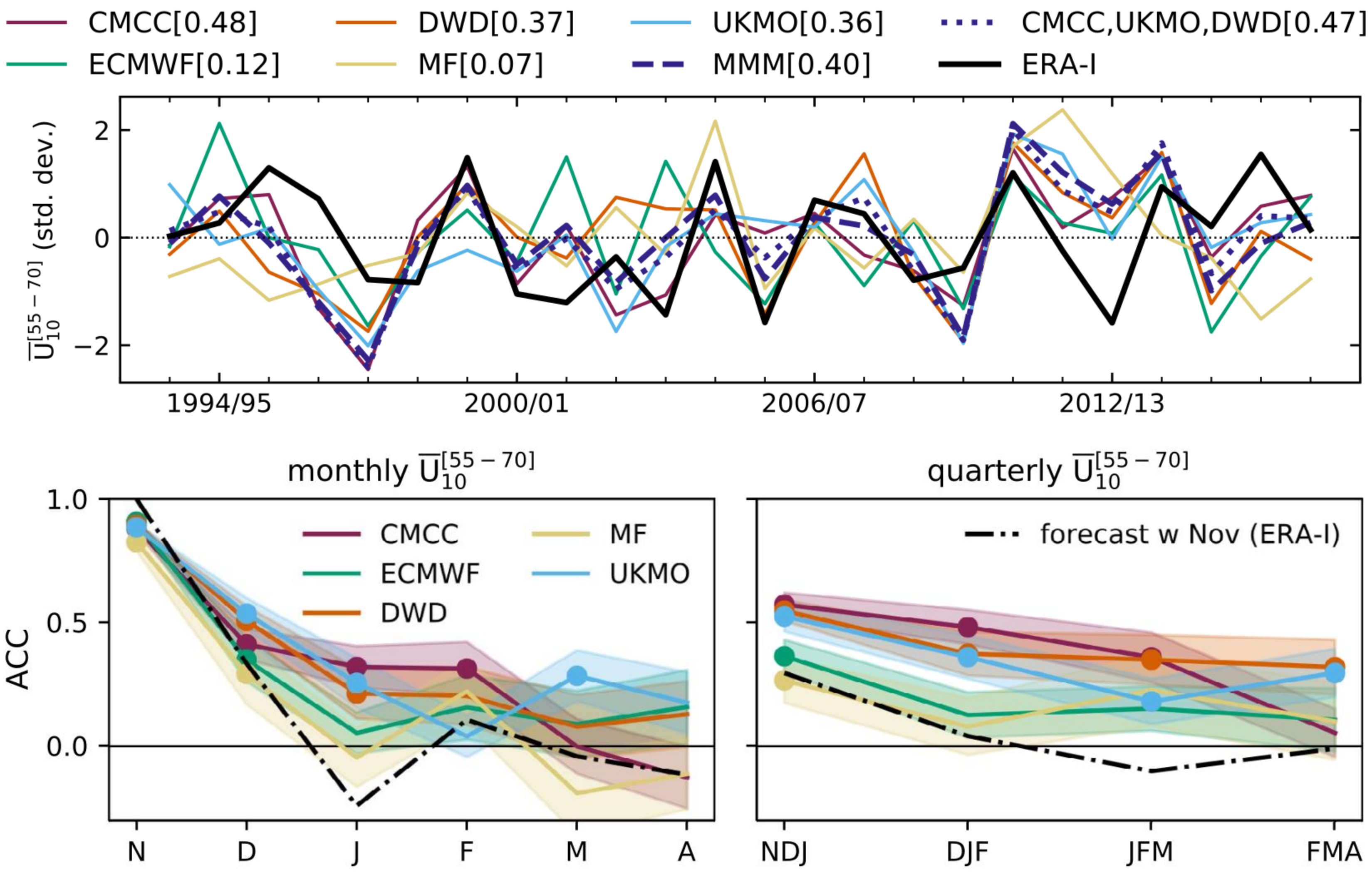






prediction skill

Zonal-mean zonal wind at 10hPa, [55ºN-70ºN] / DJF average



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probabilistic skill (SSW)

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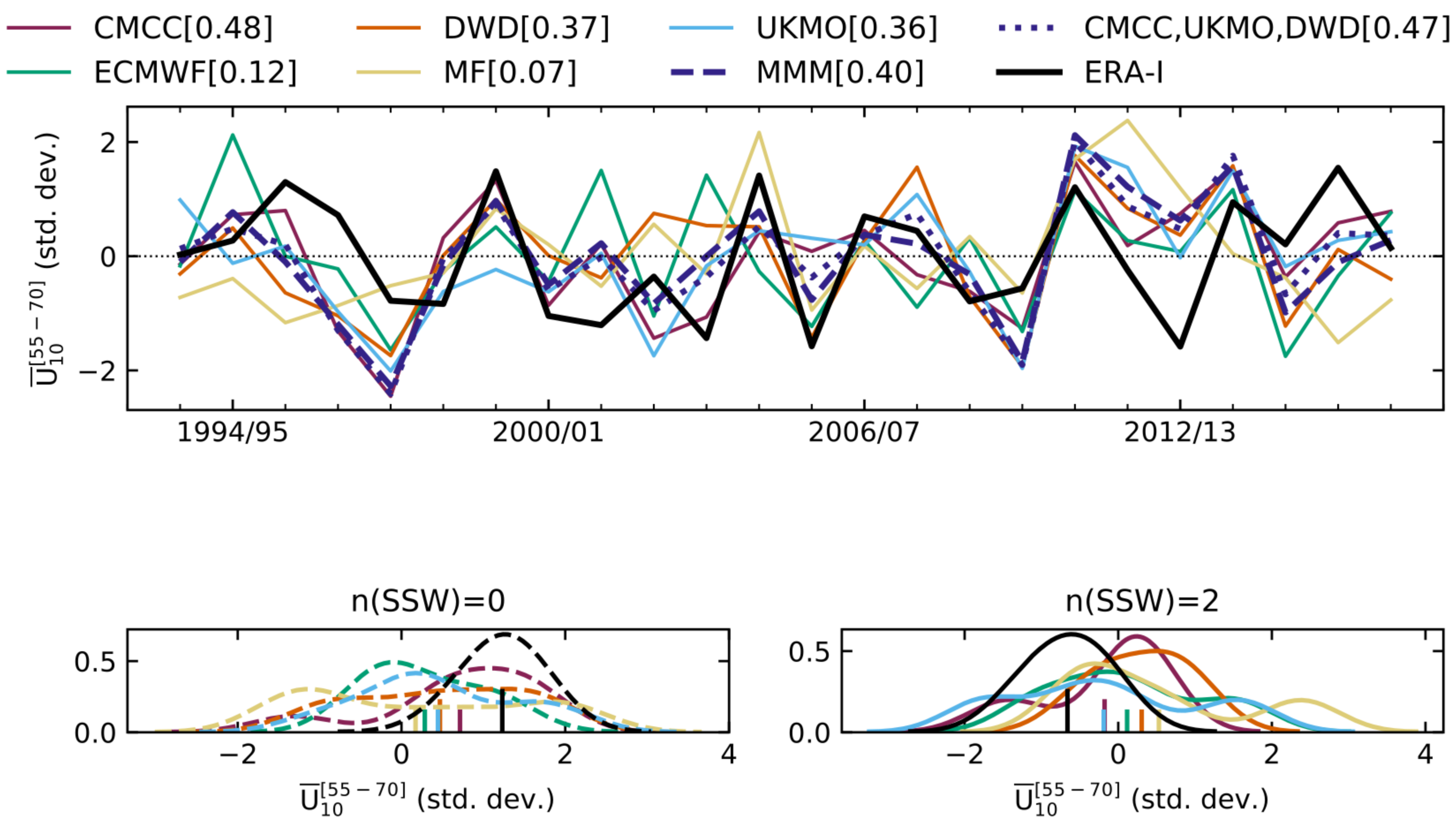
Zonal-mean zonal wind at 10hPa, [55ºN-70ºN] / DJF average



probabilistic skill (SSW)

Table 2 A) Probabilistic skill in predicting the number of SSWs per winter (DJF), with events selected using the 55_70N definition (Sect. 2.2). Skill is evaluated with BSS for three categories: occurrence of SSWs below, equal to, and above normal conditions (Bn/n/An). BSS is obtained by comparing the dynamical forecasts to a prediction based on observed climatological probabilities or assuming equiprobability (values in parenthesis), while its confidence level is determined with a binomial test which considers successful years ($BS < BS_{ref}$) equiprobable to unsuccessful years ($BS > BS_{ref}$); see Sect. 2.3 for details. Note that for CMCC normal conditions correspond to zero SSWs per winter and BSS_{Bn} cannot be calculated (n.c.)

A) SSW probabilistic skill

coeff:	BSS_{Bn}		BSS_{n}		BSS_{An}	
CMCC	n.c.	(n.c.)	-0.13	(0.04)	-0.30	(-0.09)
MF	0.03**	(0.04**)	0.00	(0.15)	-0.28	(-0.07)
ECMWF	0.06**	(0.07**)	-0.02	(0.17)	-0.08	(0.10**)
DWD	0.03**	(0.03**)	-0.03	(0.12)	-0.11	(0.08**)
UKMO	0.14**	(0.14**)	0.04*	(0.19)	0.02**	(0.19**)
ERA-I						

**/* significant at 95% / 90%

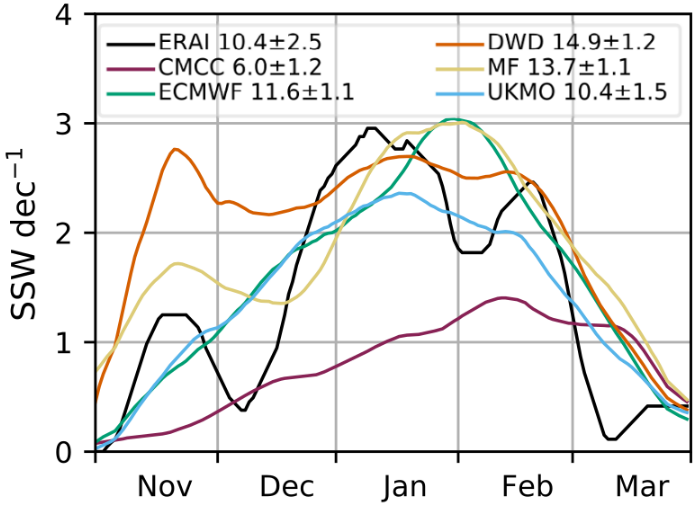


Fig. 5 November to March seasonal distribution of SSWs per decade in a [− 10,+ 10]-day window around the SSW date for ERA-Interim and the forecast systems, with SSWs selected using the 55_70N definition (see Sect. 2.2). The average SSW frequency per decade is indicated next to each label. Time-series are smoothed with an 11-day running mean