Extratropical prediction skills of the subseasonal-to-seasonal (S2S) prediction models

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DATA

Model	Rfc length	Resolution	Rfc period	Rfc frequency	Ens. size	Ref.
BoM	D 1-62	T47 L17	1981-2013	6/month	33	ERA-I
CMA	D 0-59	T106 L40	1994-2014	6/month	4	NCEP-R1
ECCC	D 1-32	0.45°x0.45° L40	1995-2014	Weekly	4	ERA-I
ECMWF	D 0-46	T639/319 L91	1997-2016	2/week	11	ERA-I
CNR-ISAC	D 0-32	0.75°x0.56° L54	1981-2010	Every 5 days	1	ERA-I
JMA	D 1-34	T319 L60	1981-2010	3/month	5	JRA-55
KMA	D 0-60	N216 L85	1991-2010	4/month	3	ERA-I
CNRM-Meteo	D 0-60	T255 L91	1993-2014	2/month	15	ERA-I
NCEP	D 0-44	T126 L64	1999-2010	6/month	4	CFSR
UKMO	D 0-60	N216 L85	1993-2015	4/month	4	ERA-I

Variable of Interest : Geopotential Height, north of 30°N

Analysis Period: 1999-2010 (common period)

ABSTRACT

This study examines the extratropical prediction skill of the subseasonal-to-seasonal (S2S) prediction models. A total of ten models that have participated in the S2S project are evaluated by computing mean squared skill score (MSSS) of extratropical geopotential height for the common reforecast period of 1999-2010. It is found that multi-model mean skill and inter-model skill spread are 9.99 ±1.84 days at 500 hPa but 12.35 ±3.84 at 50 hPa in the Northern Hemisphere. Quantitatively similar results are also found in the Southern Hemisphere with 9.81 ±1.71 days at 500 hPa and 12.91 ±3.62 days at 50 hPa.

A higher prediction skill in the stratosphere is partly due to a well-predicted polar vortex in winter. In summer, the stratospheric prediction skill becomes comparable to or even lower than the tropospheric prediction skill. This is not physically meaningful but caused by weak stratospheric variability that is taken into account in computing MSSS. Except in the summer stratosphere, the model prediction skills are largely controlled by eddy errors rather than zonal-mean errors. Specifically, eddy phase errors play a crucial role in setting the prediction limit with a relatively minor contribution of eddy amplitude errors. This result suggests that S2S prediction skill could be improved by better representing wave propagation. A linear correlation between the stratospheric and tropospheric prediction skills further suggests that the tropospheric prediction skill could be improved by better constraining stratospheric circulation in the models.

DIAGNOSIS

MSSS (Mean Squared Skill Score)

$$MSE(\tau) = \frac{1}{N_f}\sum_{i=1}^{N_f}\frac{\sum_{j=1}^{N_g}\{Z_{M,i}(j,\tau) - Z_{O,i}(j,\tau)\}^2 cos\varphi_j}{\sum_{j=1}^{N_g} cos\varphi_j}$$

$$MSE_O(\tau) = \frac{1}{N_f}\sum_{i=1}^{N_f}\frac{\sum_{j=1}^{N_g}\{Z_{O,i}(j,\tau) - \widehat{Z_O}(j,\tau)\}^2 cos\varphi_j}{\sum_{j=1}^{N_g} cos\varphi_j}$$

N_f: number of hindcasts

N_g: number of grids

Z_M: hindcasts

Z_O: Reanalysis (ERA-I)

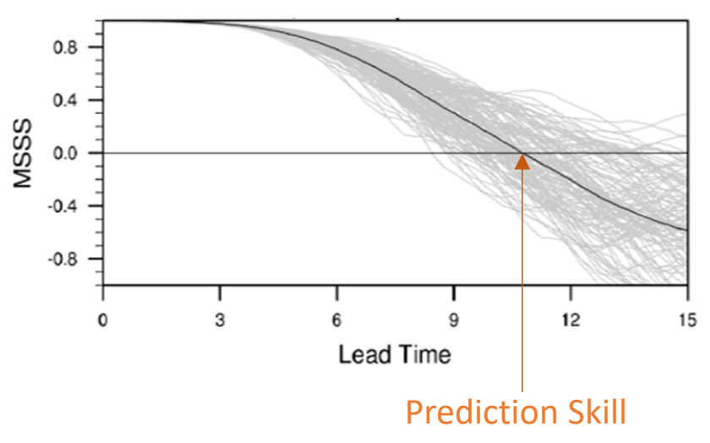
$\widehat{Z_O}$: climatology

τ: lead time (day)
from initialization

$$MSSS(\tau) = \frac{MSE_O(\tau) - MSE(\tau)}{MSE_O(\tau)} = 1 - \frac{MSE(\tau)}{MSE_O(\tau)}$$

Perfect prediction: MSSS=1

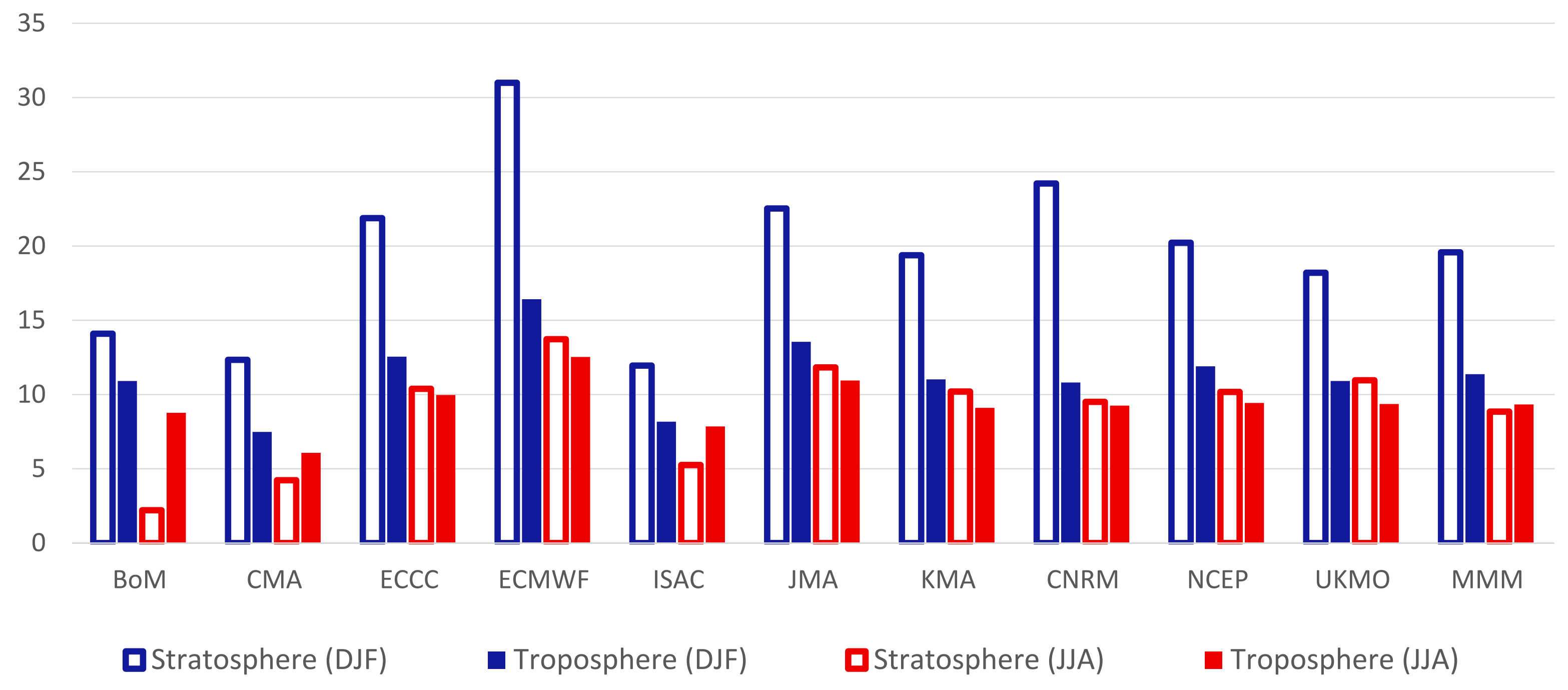
Prediction skill: MSSS > 0



MSSS skill is the lead time [day] when MSSS crosses 0 line, where the magnitude of mean squared error (MSE) of the models is the same as the magnitude of observational variance.

MSSS Prediction Skills in S2S models [day]

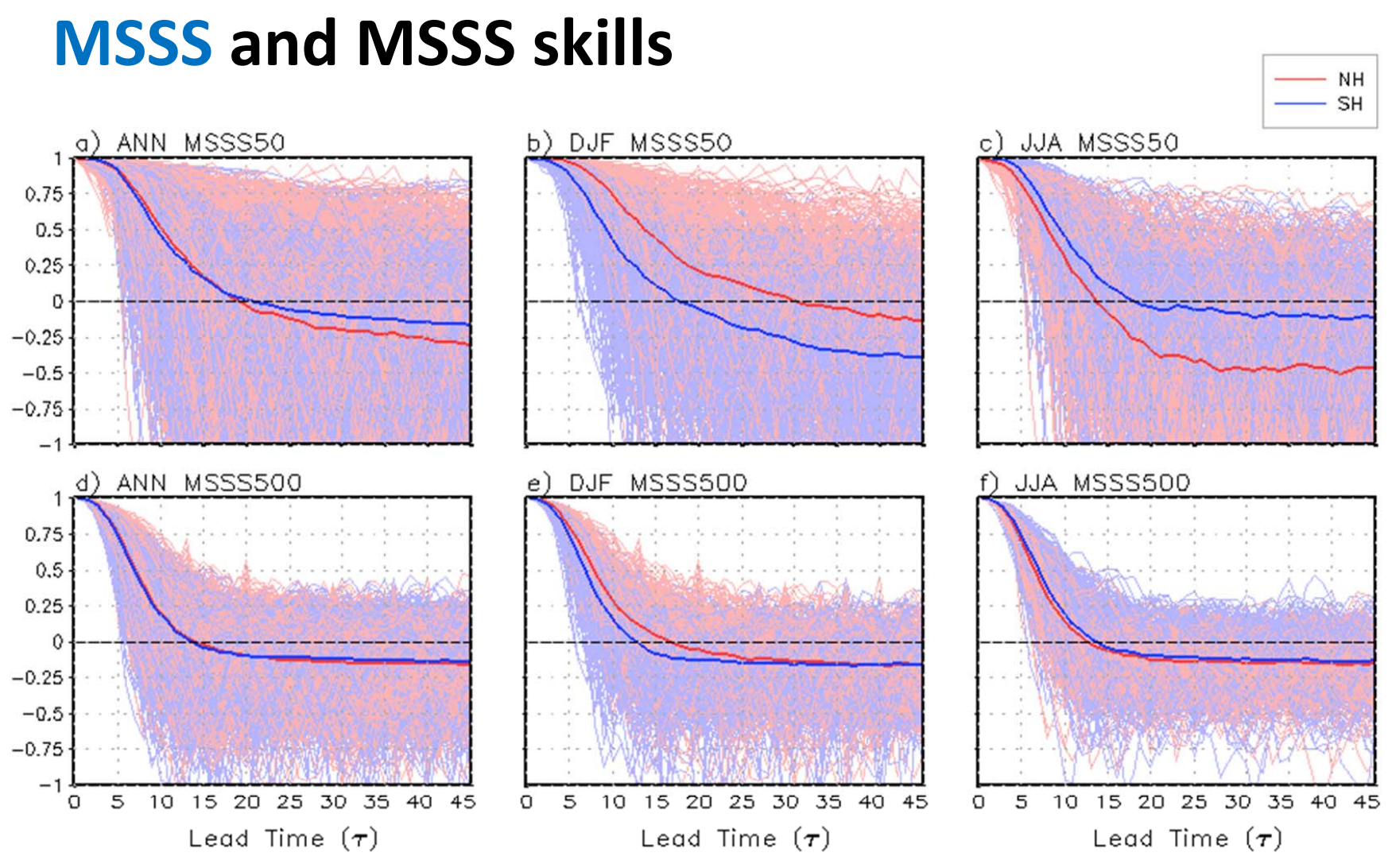
	DJF		JJA	
Level	50 hPa	500 hPa	50 hPa	500 hPa
BoM	14.10	10.91	2.21	8.77
CMA	12.34	7.48	4.23	6.07
ECCC	21.88	12.55	10.39	9.97
ECMWF	30.99	16.42	13.73	12.53
ISAC	11.95	8.17	5.26	7.85
JMA	22.53	13.55	11.83	10.94
KMA	19.38	11.02	10.20	9.10
CNRM	24.21	10.81	9.51	9.25
NCEP	20.22	11.90	10.18	9.43
UKMO	18.2	10.91	10.96	9.36
MMM	**19.58** ±5.56	**11.37** ±2.41	**8.85** ±3.49	**9.33** ±1.63



- S2S models have better prediction skills in winter than in summer, possibly owing to the better prediction of the polar vortex in winter.
- The prediction skill in the stratosphere is higher than in the troposphere in winter.
- In summer, difference between the stratospheric skill and the tropospheric skill is less significant than in winter.
- Some of the low-top models show lower prediction skills in the stratosphere than in the troposphere in summer.

Detailed analysis : (example) ECMWF model

MSSS and MSSS skills



	Annual		DJF		JJA	
Level	NH	SH	NH	SH	NH	SH
50 hPa	19.05	20.40	30.99	17.64	13.73	17.90
500 hPa	13.76	13.55	16.42	12.61	12.53	13.59

- ECMWF has higher MSSS prediction skills in the stratosphere than in the troposphere in the winter hemisphere.
- ECMWF has the highest MSSS prediction skill, 30 days, for the stratosphere in NH winter among all S2S models.
- MSSS prediction skills are higher in winter Hemisphere in both stratosphere and troposphere.
- Overall feature well represents the general S2S model.

Decomposition of prediction errors

$$MSE(\tau) = [MSE](\tau) + MSE^*(\tau)$$

$$= [MSE](\tau) + MSE^*{}_{amp}(\tau) + MSE^*{}_{phs}(\tau)$$

Eddy Errors (MSE*)

$$MSE^*{}_{amp}(\tau) = \frac{1}{2}\sum_{k=1}^{K}\left(A_M(k,\tau) - A_O(k,\tau)\right)^2$$

$$MSE^*{}_{phs}(\tau) = \sum_{k=1}^{K} A_M(k,\tau)A_O(k,\tau)\ \ \{1 - \cos\left(\Psi_M(k,\tau) - \Psi_O(k,\tau)\right)\}$$

Decomposition by zonal wave number (k)

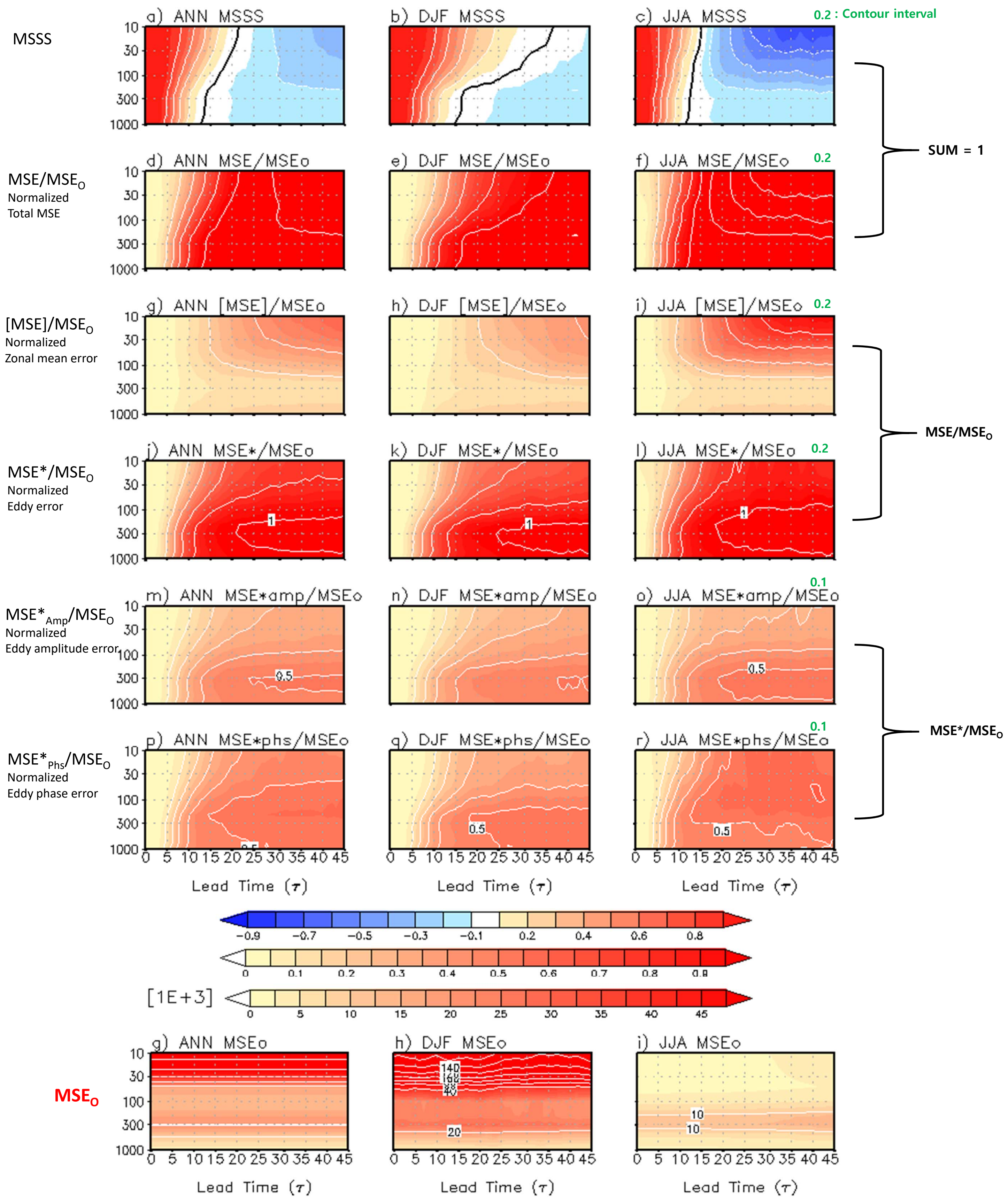
$$z(i,\tau) = [z(\tau)] + \sum_{k=1}^{K} a(k,\tau)\,cos(k\ \ 2\pi i/N) + \sum_{k=1}^{K} b(k,\tau)\,sin(k\ \ 2\pi i/N)$$

$$= [z(\tau)] + \sum_{k=1}^{K} A(k,\tau)\,cos\left(k\ \ 2\pi i/N - \Psi(k,\tau)\right)$$

$$A(k,\tau) = \sqrt{a^2(k,\tau) + b^2(k,\tau)}\ , \qquad \Psi(k,\tau) = arctan\,(b(k,\tau)/a(k,\tau))$$

- MSE can be decomposed into zonal mean error [MSE] and eddy error MSE*.
- Using the Fourier Transform, we can decompose MSE* by zonal wavenumber (k), and calculate amplitude and phase errors for k.

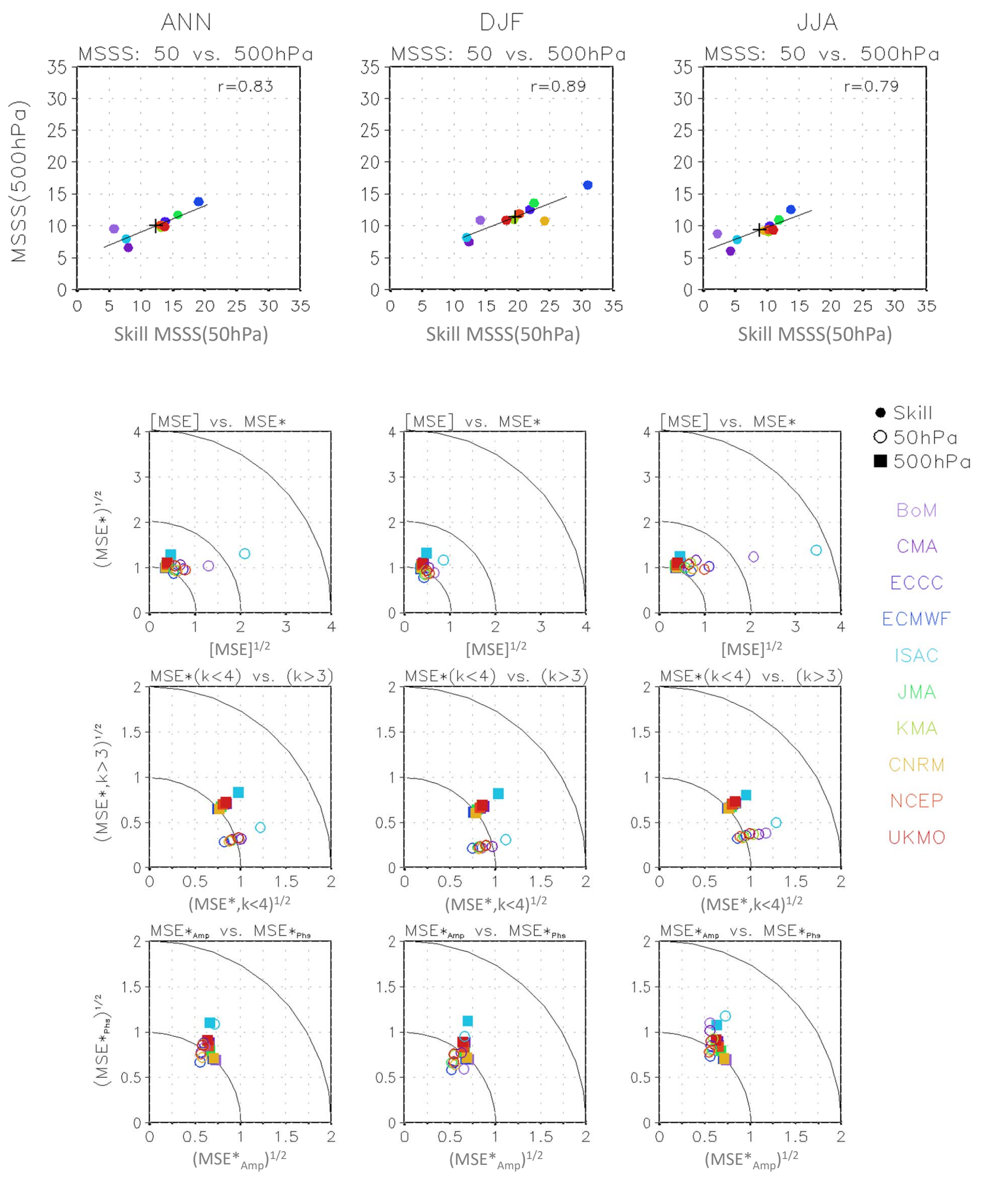
MSSS and MSE components



- Most of the prediction error is explained by MSE*, and MSE* shows troposphere-heavy characteristic.
- Large zonal mean error in the summer stratosphere contributes to the lower MSSS in summer stratosphere than in winter stratosphere. However, it turns out that the large error in the summer is due to weak stratospheric variability used as the denominator (MSE_O) in computation.
- When MSE* is decomposed into eddy amplitude error (MSE^*_{Amp}) and eddy phase error (MSE^*_{Phs}), models have more difficulty in simulating the phase than the amplitude of waves.
- Both MSE^*_{Amp} and MSE^*_{Phs} are troposphere-heavy except that MSE^*_{Phs} in the summer stratosphere is comparable to that in the troposphere.

Model spread

MSSS skill and MSE components in S2S models



- The stratospheric prediction skills and the tropospheric prediction skills have a linear relationship.
- Several models show large [MSE] in the summer stratosphere which leads to large model spread of [MSE].
- Except for the models with large stratospheric [MSE] in summer MSE* is generally larger than [MSE] especially in winter.
- When the sum of planetary scale waves and the sum of the others are compared, MSE* in the stratosphere is largely due to the fail in the representation of planetary scale waves.
- As shown in ECMWF results, MSE^*_{Phs} is larger than MSE^*_{Amp}.

Summary

- ECMWF well represents general characteristic of S2S models.
- In winter, stratospheric prediction skill predominates the tropospheric prediction skill, while such feature is not seen in summer.
- MSE* is larger than [MSE] except for summer stratosphere.
- MSE^*_{Phs} explains more of MSE* than MSE^*_{Amp} does.