Evaluating medium-range forecast performance of regional-scale circulation patterns.

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Abstract

Accurate sub-seasonal to seasonal (S2S) weather forecast between 2 weeks and several months is crucial to making informed decisions regarding changes in the risk of extreme weather events, resource management, agriculture, forestry, public health, energy, etc. However, significant gaps exist between the needs of society and what forecasters can produce, especially over longer lead times. Using three goodness-of-fit metrics, this study examined the ability of the SOMs-generated CFSv2 to forecast the correct (observed) circulation pattern, as opposed to the actual observed gridded field over a 90-day forecast period. Mean sea-level pressure (MSLP), near-surface wind (wnd10m), 850-mb temperature (t850), and 700-mb geopotential heights (z700) from the North American Regional Reanalysis were used to categorize the synoptic-scale circulation for three regions (East, West, and Gulf) across North America from January 1979 – December 2016. Expectedly, forecast skill generally decreased from the first day down to the skill of climatology (after 10 -15 days) and also varied regionally, seasonally, and between variables. The forecasts for the winter and summer seasons outperformed others, while t850 and z700 forecasts outperformed wnd10m, except in the west region. More importantly, this study found that the SOMs-generated CFSv2 forecasts improve upon the skill of the raw CFSv2 forecast near the one 1 – 2 weeks lead time. This study thus demonstrates the potential utility of a SOMs-based forecasting method in medium-range weather forecasts.

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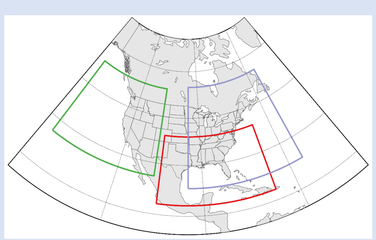
INTRODUCTION & OBJECTIVES

- Efforts to improve the accuracy of sub-seasonal to seasonal (S2S) forecasts have increased rapidly in recent years (Brunet et al., 2010; Robertson et al., 2015), because they inform decision making in many crucial systems. An important process in improving the accuracy of forecast models is by verification of model's skill, often done by performing many past predictions called hindcasts or reforecasts (Doblas-Reyes, 2013).
- In this study, the ability of the second version of the Climate Forecast System (CFS) to forecast the correct (observed) circulation pattern, as opposed to the actual observed gridded field, is examined using three goodness-of-fit metrics. Self-Organizing maps (SOMs) were used to make the circulation pattern clusters and have been shown to effectively represent atmospheric circulation patterns through a continuum of synoptic classes (Sheridan & Lee, 2011).
- Also, because of the utility of SOMs, we hypothesize that SOMs-based CFS forecasts will improve upon raw CFS forecasts. Hence, the performance of the CFS SOMs forecast against the raw CFS forecasts over a 90-day period was evaluated.

DATA, METHODS & STUDY AREA

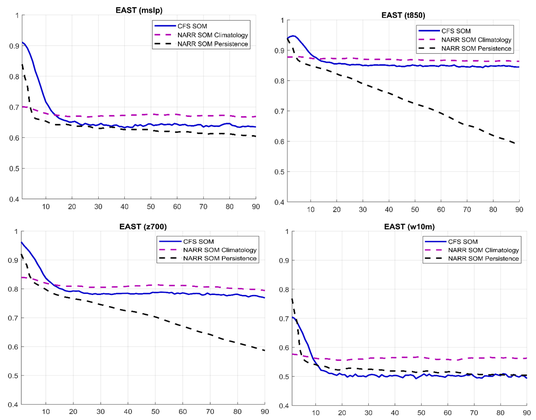
- Four weather variables [mean sea-level pressure (mslp), windspeed (w10m), 850-mb temperature (t850), and 700-mb geopotential heights (z700)] from the NARR were used to categorize the synoptic-scale circulation of three regions in North America from Jan 1979 – Dec 2016. Each of the four variables were also obtained from the CFS from April 2011 to Dec 2016, and spatially interpolated into the NARR grid.
- SOMs were used to classify circulation patterns (CPs) for each region and each variable (12 total) from 1979 – 2016 using NARR data. The SOMs created from the NARR for each region and variable were also created for the CFS operational forecast data from April 2011 – December 2016 to determine the ability of the CFS to forecast SOM-based patterns.
- Three different metrics were used to evaluate the accuracy of the 90-day CFS CP forecast:
  1.) Perfect match (PM) metric.
  2.) SOMs-Distance (SDT) metric.
  3.) SOMs-Step (STP) metric.
- To measure the performance of the SOM-generated CFS forecast against the raw CFS forecasts, the SDT and climatology of the former is compared to the NMAE and climatology of the latter.
- Finally, the frequency with which the CFS SOMs-based forecast can replicate observed NARR CPs across various time windows is assessed.



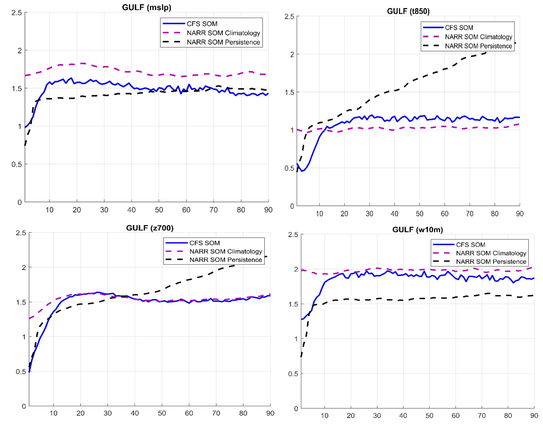
The three regions used in the SOM-based atmospheric pattern classifications; East (purple), Gulf (red), and West (Green).

RESULTS

A. Accuracy of 90-day CFS CP forecast



All-year SDT between the 90-day CFS SOMs forecast and the observed NARR SOMs in the East region compared to climatology and persistence. The Y-axis is SDT and X-axis is days of lead time.



All-year STP between the 90-day CFS SOMs forecast and the observed NARR in the Gulf region relative to climatology and persistence. The Y-axis is SDT and X-axis is days of lead time.

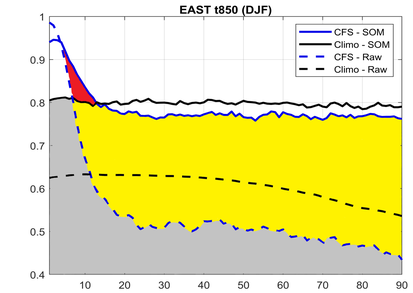
Summary of minimum and maximum SDT for all SOMs forecasts across regions and seasons. Forecasts with minimum SDT > 0.7 and maximum SDT > 0.9 are in bold. Blue and red shades represent the higher and lower SDT respectively for all variable and region.

Region	Variable	Minimum SDT				Maximum SDT			
		DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
EAST	mslp	0.55	0.58	**0.72**	0.63	**0.91**	**0.92**	**0.92**	**0.91**
	t850	**0.76**	**0.79**	0.94	**0.84**	**0.95**	**0.94**	**0.97**	**0.95**
	z700	**0.70**	**0.71**	**0.88**	**0.76**	**0.96**	**0.96**	**0.97**	**0.96**
	w10m	0.46	0.47	0.52	0.48	0.70	0.69	0.72	0.71
GULF	mslp	0.56	0.63	**0.73**	0.68	0.88	0.89	0.85	0.85
	t850	**0.72**	**0.74**	**0.97**	**0.82**	**0.92**	**0.93**	**0.97**	**0.93**
	z700	0.62	0.59	**0.79**	0.62	**0.90**	0.88	**0.94**	0.88
	w10m	0.41	0.43	0.44	0.49	0.68	0.62	0.55	0.71
WEST	mslp	0.36	0.47	0.68	0.53	0.87	0.83	0.80	0.84
	t850	**0.76**	**0.73**	**0.89**	**0.77**	**0.94**	**0.93**	**0.96**	**0.93**
	z700	0.57	0.62	**0.86**	0.67	**0.94**	**0.95**	**0.98**	**0.95**
	w10m	0.45	0.47	0.63	0.50	0.75	0.72	0.76	0.72

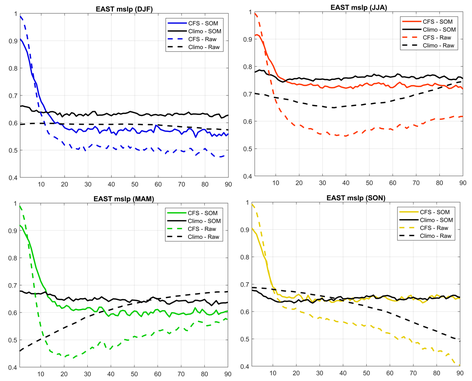
Total number of days where CFS SOMs forecast > NARR SOMs climatology over the 90-day forecast period. Blue and red shades represent higher and lower values respectively for all variable and region.

Region	Variable	Season			
		DJF	MAM	JJA	SON
EAST	mslp	12	12	14	46
	t850	12	14	9	10
	z700	16	11	86	9
	w10m	7	10	9	8
GULF	mslp	10	11	10	18
	t850	11	12	0	13
	z700	12	14	10	13
	w10m	13	7	85	8
WEST	mslp	12	9	8	12
	t850	11	11	9	10
	z700	24	11	15	12
	w10m	84	86	13	37

B. Skill of 90-day CFS SOMs forecast over raw CFS forecasts



Example Illustration of the skill of the 90-day CFS SOM forecast over the raw CFS forecasts. The area of the graph shaded grey and yellow are all raw forecasts below the SOMs forecast and SOMs climatology. Yellow area is the skillfulness of the SOM forecast over the raw forecast, while the red-shaded region is the value-added skill of the SOM-based forecast over just using the output of the CFS forecast. The Y-axis is SDT and X-axis is days of lead time.

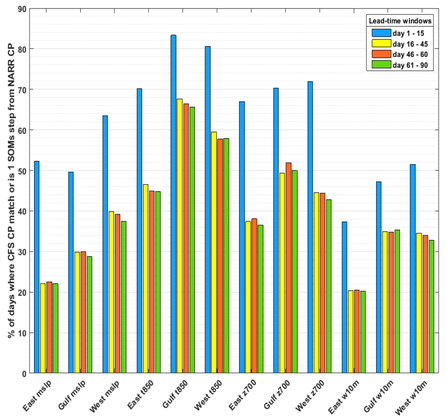


Skill of 90-day CFS SOM forecast over raw CFS forecasts for MSLP in East region. The Y-axis is SDT and X-axis is days of lead time.

CFS SOM forecasts improvement over raw CFS forecasts. Check marks show forecasts with value added by the SOM-based forecast while the times sign shows forecast where no improvement over the raw forecast is seen.

Region	Variable	Season			
		DJF	MAM	JJA	SON
EAST	mslp	✓	✓	✓	✓
	t850	✓	✓	✓	✓
	z700	✓	✓	✓	✓
	w10m	×	✓	×	×
GULF	mslp	×	✓	✓	×
	t850	✓	✓	×	✓
	z700	✓	✓	✓	×
	W10m	×	×	×	×
WEST	Mslp	×	✓	×	×
	T850	✓	✓	✓	✓
	Z700	✓	✓	✓	✓
	w10m	✓	✓	✓	×

C. Frequency distribution of exact matches between CFSv2 CP and NARR CP over selected lead-time windows



Percentage of days of exact matches and 1 SOMs-step off between NARR CP and CFS CP out of all possible days (April 2011 – December 2016).

GULF z700 Per 100 days count of exact matches and 1 SOMs-step off between NARR CPs and CFS CPs compared with the average of the monthly counts of exact matches and 1 SOMs-step off between 1000 random samples of the same CFS CPs and NARR CPs per 100 days. Blue font P-values are statistically significant.

Month	Days	Forecast day 1 - 7			Forecast day 8 - 14			Forecast day 15 - 21			Forecast day 22 - 28		
		CFS CP	Rd.CFS CP	P-value	CFS CP	Rd.CFS CP	P-value	CFS CP	Rd.CFS CP	P-value	CFS CP	Rd.CFS CP	P-value
Jan	155	74.2	54.9	0.000	60.0	56.7	0.124	70.3	62.3	0.002	68.4	63.8	0.035
Feb	142	85.9	68.3	0.000	70.4	65.6	0.035	58.5	54.6	0.092	52.1	50.6	0.332
Mar	155	70.3	46.2	0.000	47.1	40.4	0.005	49.0	42.8	0.018	38.1	37.5	0.463
Apr	180	75.6	47.8	0.000	56.1	43.7	0.000	38.9	40.9	0.809	34.4	36.0	0.779
May	186	78.5	47.0	0.000	51.6	47.9	0.072	50.0	47.0	0.114	55.4	49.2	0.008
Jun	180	88.3	58.1	0.000	77.8	58.8	0.000	82.8	73.6	0.000	80.6	74.9	0.001
Jul	186	96.8	88.7	0.000	80.6	74.6	0.000	72.6	67.7	0.000	55.9	51.6	0.014
Aug	186	80.6	68.1	0.000	62.4	52.9	0.000	55.9	52.1	0.029	59.7	55.7	0.021
Sep	180	71.7	54.3	0.000	58.9	52.8	0.005	51.1	46.7	0.041	45.6	44.8	0.416
Oct	157	78.3	52.3	0.000	50.3	44.2	0.025	38.2	39.2	0.676	39.5	35.9	0.151
Nov	150	68.7	42.5	0.000	38.7	35.5	0.163	37.3	36.5	0.440	37.3	39.2	0.841
Dec	155	69.7	48.7	0.000	56.1	46.2	0.000	41.3	43.6	0.917	46.5	45.3	0.346

BRIEF SUMMARY OF RESULTS

- For all variables in all regions, forecast skill is highest on the first day but rapidly decreases over the next 15 – 20 days before levelling off to the skill of persistence and climatology.
- Considerable differences in forecast skill exist among the variables: mslp and z700 have higher forecast skill than t850 and w10m.
- t850 tends to have very high SDTs (because it is more easily resolved in climate models)but forecast skill is low relative to NARR climatology.
- Forecast skill also expectedly varies regionally and seasonally depending on the modes of geographic and seasonal climate/weather variations: Forecast skill is lowest in the summer and highest in the spring.
- The SOMs-based CFS forecasts improve upon the raw CFS forecast in 33 out of 48 cases.
- No improvement was found with w10m in the Gulf region, but the most CFS SOMs forecast improvement were in z700 and t850.
- Seasonally, the biggest forecast improvement is in spring; and regionally, the East region showed the biggest forecast improvement.
- The frequency of accurately forecasted CFS CPs, relative to the NARR visibly drops after the first 15 days and remains almost constant thereafter. Frequency can reach 90% of entire forecast period.
- The most accurately forecasted CPs are t850 and z700 CPs, while mslp and w10m are the least accurately forecasted CPs.
- Monthly frequency of accurately forecasted CFS CPs are significantly different from random chance in the first 7 forecast days in all variables and regions, but monthly statistical significance decrease with greater forecast time windows.

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