Seasonal temperature forecast verification for Q1/Q2 2018

Climate Forecast Applications Network

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SUMMARY

In late 2017, CFAN introduced a new U.S. seasonal temperature forecast product that projects spatial patterns of 3-month anomaly averages on a monthly basis at lead times of 3 and 4 months. The forecast method is based on a data mining approach driven by insights from climate dynamics.

Verification of the seasonal forecasts made in Q1/Q2 of 2018 shows an overall correlation of 0.72 between seasonal regional temperature forecasts and observations. Forecasts at both lead times correctly predicted the signs of regional temperature anomalies in 24 of 35 cases (69% success rate). Greatest forecast accuracy was identified for Midwest, Plain/Rockies, and Southwest. Forecast skill was highest for MAM and AMJ forecasts, and lowest for JFM. Forecast skill was generally better for recent spring-summer windows than for winter, owing in part to refinements in the forecast process.

INTRODUCTION

In late 2017, CFAN introduced a new U.S. seasonal temperature forecast product that projects spatial patterns of 3-month anomaly averages on a monthly basis at leads of 3 and 4 months. Here we provide an overview of forecast methods and a retrospective analysis of observed climate anomalies and forecast performance during early 2018.

Forecasts are issued the second week of each month, giving projections of local and regional U.S. temperature anomalies over 3-month windows that begin with the month of publication and the subsequent month. Here we compare seasonal temperature observations from January to July 2018, which includes 5 seasonal windows from January-February-March (JFM) to May-June-July (MJJ). Temperature forecasts are produced for each of 1218 sites in the U.S. Historical Climatology Network, a subset of U.S. station temperature records with greatest measurement consistency over time. Forecasts are presented as spatial °C anomaly maps and averages for 7 U.S. regions (Northeast, Southeast, Midwest, South-Central, Plain/Rockies, Northwest and Southwest).

At local to regional scales, seasonal U.S. temperature anomalies on the order of ±1 to 2°C typically arise from stochastic or persistent deviations in midlatitude weather patterns. Temperature-related regional circulation anomalies may have multiple sources, including patterns of tropical sea surface temperatures (SSTs) and slow variations in the coupled circulations of the tropical and extratropical troposphere and stratosphere. Our forecast approach aims to anticipate future U.S. temperature deviations from recent atmospheric anomalies and tendencies at regional, hemispheric and global spatial scales.

FORECAST METHODOLOGY

Forecasts are developed primarily from globally-gridded atmospheric data in the NCEP-NCAR Reanalysis (NNR) from near-surface (1000 hPa) to stratospheric levels (10 hPa). Atmospheric conditions are determined from a variety of thermodynamic and dynamical NNR variables, including temperatures, geopotential heights, winds, relative vorticity and relative divergence.

The forecast process begins with an objective Principal Components (PC) analysis of historical USHCN temperature anomalies during the target seasonal window, typically using 1995-2017 data. While each station record contains unique information, 70 to 80% of total seasonal variance among the 1218 temperature records can normally be explained by just 3 spatial patterns and corresponding statistically independent time series that reflect the year-to-year variability of each pattern. Figure 1 shows temperature PC patterns and time series for March-April-May (MAM). The primary forecast objective is to estimate future values of the three leading seasonal three PC indices, which are converted to local and regional °C anomalies for presentation.

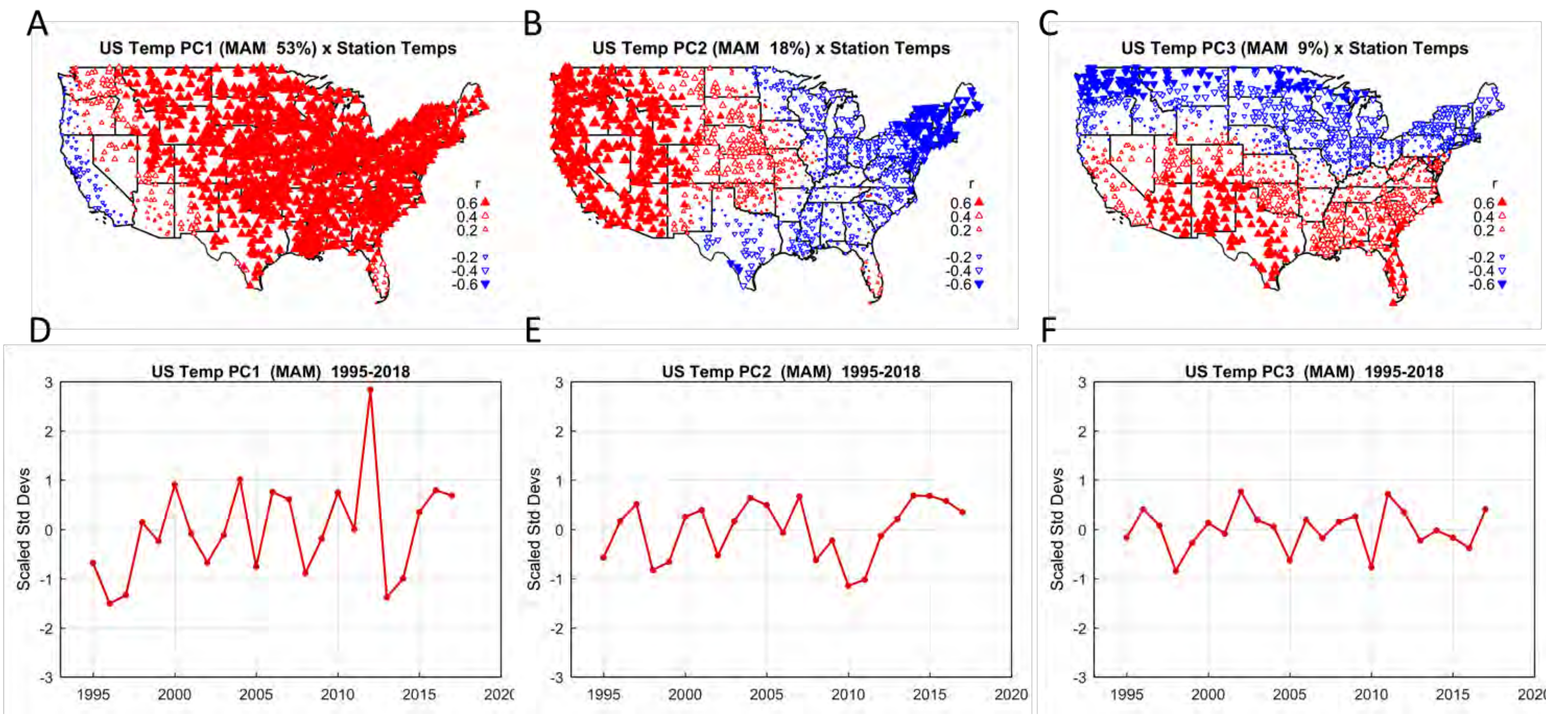

Figure 1. Leading Principal Components of MAM U.S. temperature anomalies (1995-2017), based on 1218 station records in the U.S. Historical Climatology Network. A-C. PC spatial patterns, represented by local temperature correlations with PC time series in D-F. Time series are scaled to fractions of variance explained by the PC indices, relative to PC1 (std dev = 1). Overall U.S. temperature variability during MAM is dominated by a single mode (PC1) that accounts for 53% of all station variance, while PCs 2 and 3 capture less influential internal temperature contrasts.

Temperature PC indices commonly display significant correlations with atmospheric anomalies and tendencies in prior months, implying a degree of seasonal predictability. Potential predictors are initially surveyed by correlating temperature PC indices with local atmospheric time series at leads of 1 to 3 months. Global correlation maps are produced for a variety of atmospheric variables at 17 vertical levels, and time series of each map pattern provide a basis for testing predictive skill. Forecast skill is assessed through a 'leave one out' approach wherein past temperature PC anomalies are estimated from information available in all other years. Predictor patterns are ranked according to several criteria, including forecast skill (correlations and mean absolute errors), spatial extent, and correspondence to recent conditions. A small set of most skillful predictor patterns (typically 10 to 20) is used to estimate unknown temperature PC indices in upcoming months from recent atmospheric anomaly patterns and their correspondence to historical precursors.

Most seasonal U.S. climate forecasts issued by government and private agencies rely heavily on current and projected states of the tropical Pacific ENSO system. ENSO indices are commonly used as predictors of future seasonal temperature anomalies, although strong, delayed relationships are generally restricted in geographical and seasonal scope, with greatest skill evident from fall to winter, when the ENSO system displays greatest seasonal persistence. This general approach relies on a priori selection of a known circulation pattern and index (e.g. ENSO), and quantitative forecasts are produced from expected temperature responses, based on past relationships and recent circulation anomalies. Our forecast approach, by contrast, begins with a quantification of U.S. temperature anomaly patterns, and objectively seeks circulation predictor patterns without regard to their structure or status as recognized climate phenomena.

These alternative approaches are distinguished by the initial use of known circulation (e.g. ENSO) patterns and indices, (which we term a circulation, or CIRC approach); or identification of indices that reflect organized patterns of U.S. temperature anomalies (a TEMP approach). We find that the TEMP approach generally offers greater predictability of U.S. temperatures. In certain scenarios, the CIRC approach may provide complementary or better predictive information, and we are currently developing methods that use both approaches in combination. Our primary circulation predictors are based on indices of ENSO, additional patterns of tropical SSTs, stratospheric equatorial and polar vortex winds and objectively-defined NH tropospheric circulation modes. Our forecast methods continue to be refined through the use of greater and more detailed atmospheric information and experimentation with new analytical approaches to improve forecast skill.

2018 Seasonal Climate Anomalies

Figure 2 illustrates observed temperature anomalies (1980-2017 baseline) during the 5 overlapping 3-month seasonal windows from January-February-March (JFM) to May-June-July (MJJ) 2018. USHCN station temperature anomalies (center column) reveal the prevalence of coherent, large-scale structures and substantial persistence of spatial patterns from late winter to early summer 2018. From JFM to AMJ, cool conditions generally prevailed over the northern Plains, Midwest and areas of the Northeast, in contrast to persistently warm conditions in the Southeast and Southwest. During the most recent MJJ period, coherent warmth is evident over nearly the entire continental U.S.. When viewed in a global context (Fig. 2, left column), it can be seen that zones of anomalous temperatures typically occur on spatial scales comparable to that of the continental U.S., and that subtle changes in the positions of these anomaly cells may have large impacts on regional temperatures within the U.S.

Our monthly forecast reports have repeatedly emphasized the prevalence of skillful U.S. temperature predictors identified in stratospheric circulation variables over the Arctic and the broader Northern Hemisphere (NH). In recent months, extreme stratospheric circulation anomalies occurred in connection with a February sudden stratospheric warming (SSW) event, characterized by splitting and displacement of the Arctic polar vortex. Additionally, strong easterly winds prevailed in the equatorial lower stratosphere throughout early 2018, marking an extreme phase of the stratospheric Quasi-biennial Oscillation (QBO), illustrated for the 30 hPa level in Fig. 3. The QBO is a ~28-month cycle of zonal winds in the tropical stratosphere that, like ENSO, displays substantial seasonal persistence, particularly during extremes of its alternating easterly and westerly phases.

Stratospheric circulation anomalies during early 2018 are illustrated in maps of 30 hPa relative vorticity (RV30) in the right column of Figure 2. Blue shading reflects positive vorticity anomalies that, in the Northern Hemisphere, reflect anomalous cyclonic circulation around stratospheric upper pressure lows. A persistent low prevailed over Canada from JFM through AMJ, a feature that is spatially and physically consistent with cool temperatures observed during the same months over the northern U.S. Similar cyclonic circulation anomalies prevailed over much of the NH midlatitudes between 40°N and 70°N, suggesting strong involvement of global stratospheric circulation processes in U.S. temperature conditions during early 2018. Contrasting negative vorticity anomalies (red shading) prevailed over the subtropical and tropical NH, including the southern U.S. This circumglobal belt of negative vorticity anomalies (anticyclonic circulation) is largely a reflection of horizontal wind shear produced by strong tropical QBO easterlies that diminish in strength from the equator to ~30°N. Over the U.S., the 40°N boundary separating positive midlatitude RV30 anomalies and negative subtropical anomalies coincides with similar N-S contrasts in tropospheric circulation and temperatures that suggest a downward influence of stratospheric circulation anomalies upon tropospheric circulation and surface temperatures.

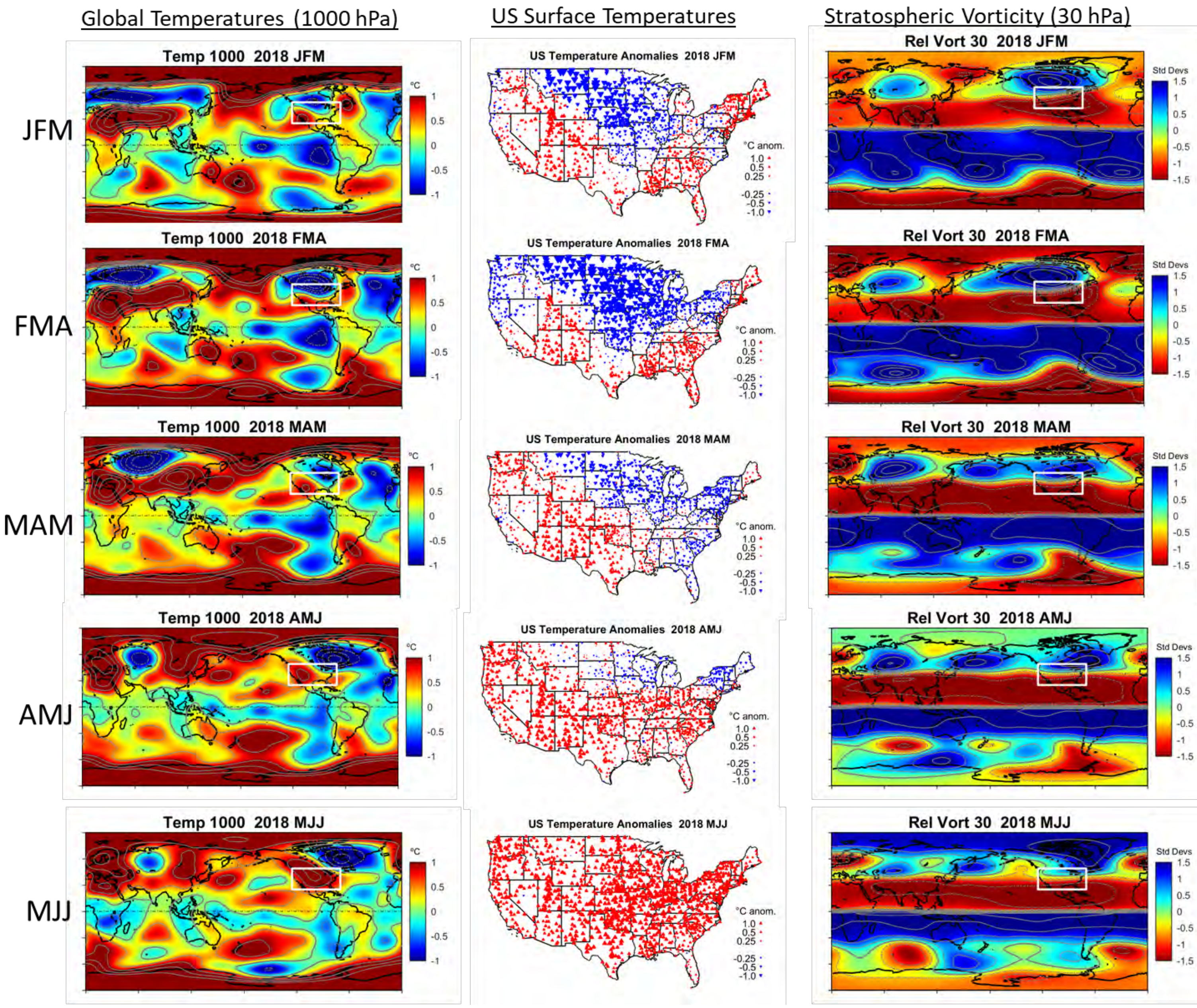

Figure 2. Seasonal climate anomalies from JFM to MJJ 2018. Maps display 3-month seasonal mean anomalies at monthly steps (top to bottom). Left: Near-surface 1000 hPa global temperatures (°C). Middle: U.S. station temperature anomalies (°C). Right: 30 hPa stratospheric relative vorticity (RV30) in standard deviations; RV color scale is reversed, with blue shading corresponding to positive vorticity anomalies (e.g. anomalous cyclonic circulation around NH stratospheric lows). White boxes surround the continental U.S. Global RV30 patterns suggest a predominant stratospheric influence on U.S. surface temperatures from JFM to AMJ. Coherent U.S. warmth during MJJ coincided with a displacement of the Canadian stratospheric low toward the Arctic, consistent with poleward expansion of warm U.S. surface temperatures.

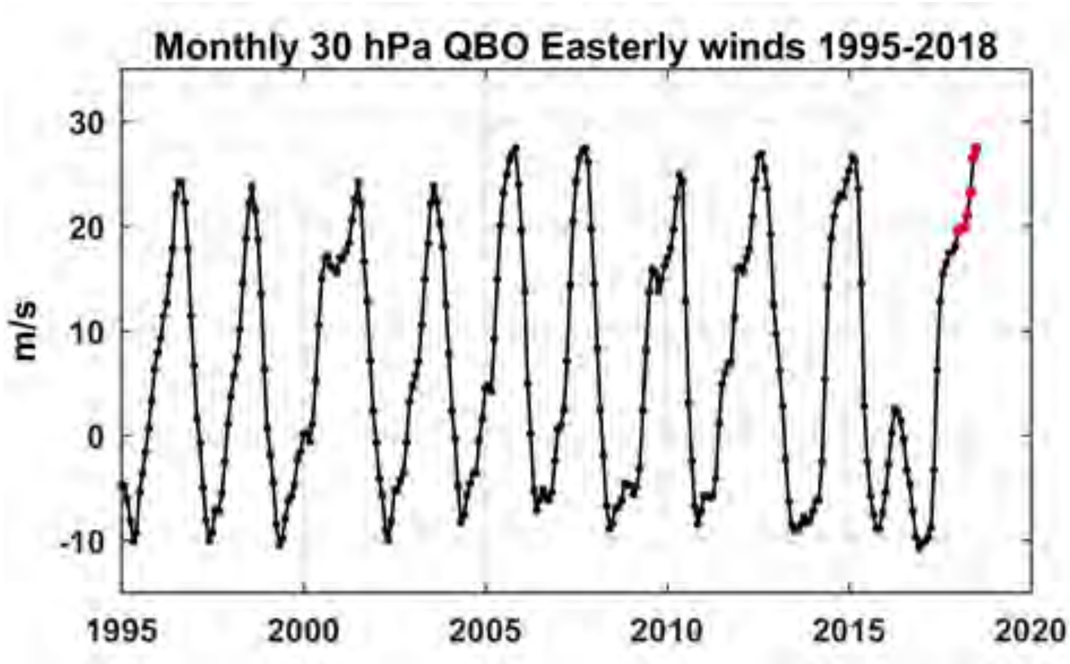

Figure 3. Monthly 30 hPa easterly equatorial winds from January 1995 to July 2018. Red markers highlight monthly values from January through July 2018.

Skillful predictors of U.S. temperatures during early 2018 included stratospheric midlatitude circulation anomalies and the tropical stratospheric QBO, factors that, in hindsight, display close connections to observed temperature anomaly patterns.

Forecast Skill Assessment

Over the course of the forecast evaluation period, refinements in the forecast process have been made. These refinements include larger and more varied atmospheric input data sets, as well as increased rigor in leave-one-out forecast tests. This has resulted in improved forecast skill with time, although it is not obvious how to separate this trending improvement from intrinsic variations in predictability over the annual cycle.

Figure 4 compares the regional seasonal U.S. temperature anomaly forecasts with observations, showing a correlation coefficient of 0.72. 70 comparisons are illustrated (7 regions x 5 seasonal windows x 2 forecasts [3- and 4-month leads]). The regions are defined in Figure 5.

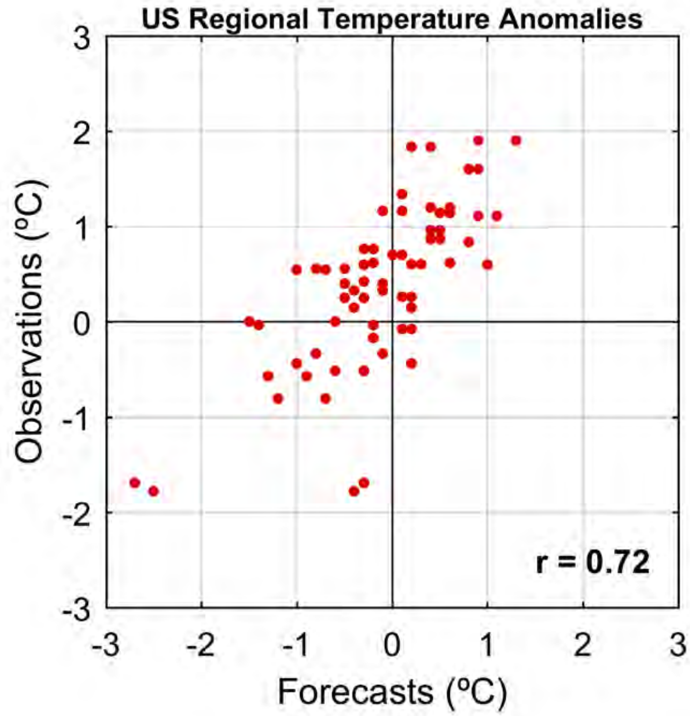

Figure 4. Comparison of regional U.S. temperature anomaly forecasts (x-axis) and observed anomalies (y-axis). 70 comparisons are shown (7 regions x 5 seasonal windows x 2 forecasts [3- and 4-month leads]).

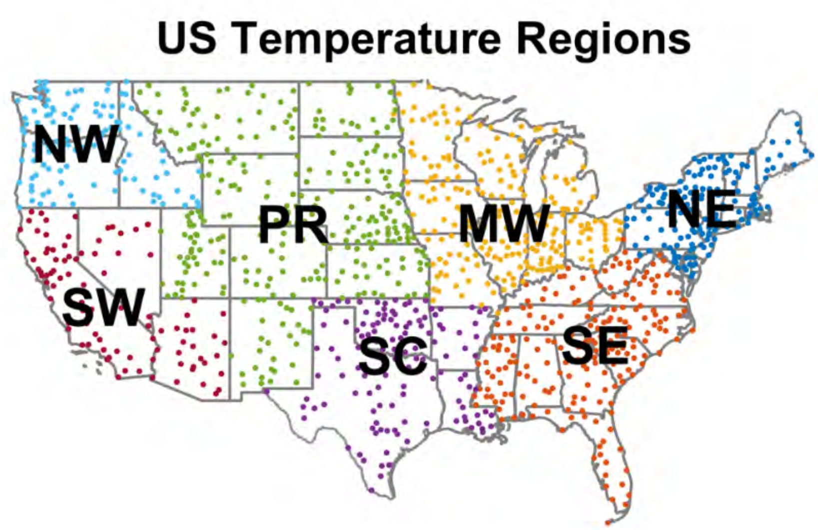

Figure 5. U.S. temperature regions, denoted by colors of markers representing the 1218 observational sites in the U.S. Historical Climatology Network (USHCN). NE=Northeast; SE=Southeast; MW=Midwest; SC=South-Central; PR=Plains/Rockies; NW=Northwest; SW=Southwest.

Table 1 shows forecast skill metrics averaged for individual seasons and regions. Forecasts, made 1 month in advance of the 3-month target window have a mean absolute error (MAE) of 0.68°C, compared to a 0.62°C MAE of forecasts made at the onset of the forecast period. Forecasts at both lead times correctly predicted the signs of regional temperature anomalies in 24 of 35 cases (69% success rate).

A

Season	Abs Err	Sign
JFM	0.70	36%
FMA	0.92	64%
MAM	0.42	64%
AMJ	0.25	86%
MJJ	0.97	93%

B

Region	Abs Err	Sign
Northeast	0.78	50%
Southeast	0.60	60%
Midwest	0.67	100%
S Central	0.79	60%
Rockies/Plains	0.51	90%
Northwest	0.69	60%
Southwest	0.52	60%

Table 1. Temperature forecast skill, as reflected by mean absolute errors of forecast vs. observed °C anomalies (Abs Err) and percentage of forecasts with correct anomaly sign (Sign). A. Skill by season (N=14). B. Skill by region (N=10). Red indicates highest skill; blue lowest skill.

Overall forecast skill was best during AMJ, when regional MAEs averaged 0.25°C and anomaly signs were correct for 86% regional forecasts. A relatively small MAE (0.42 °C) was also achieved for the previous MAM window. Forecasts for MJJ temperatures correctly anticipated warmth in 13 of 14 cases (93%); however a large MAE (0.97°C) resulted from underestimations of strong warmth observed in all regions, ranging from +1.1 to +1.9°C. Regional anomaly signs were poorly predicted for JFM (36% success rate), and relatively large absolute errors (0.92°C) were identified in forecasts of FMA temperatures.

Forecast skill was generally better for recent spring-summer windows, owing in part to refinements in the forecast process, which include larger and more varied atmospheric input data sets, as well as increased rigor in leave-one-out forecast tests.

Regionally, the signs of temperature anomalies were successfully predicted in all Midwest forecasts (10/10) and in 90% of forecasts for the Plains/Rockies. All regional temperature anomaly signs were predicted at success rates ≥50%, with a minimum of 50% for the Northeast. Regional MAEs were smallest for the Plain/Rockies (0.51 °C) and Southwest (0.52°C), and greatest in South Central (0.79 °C) and Northeast regions (0.78 °C).

Maps of forecast and observed temperature anomalies are shown in Figure 6.

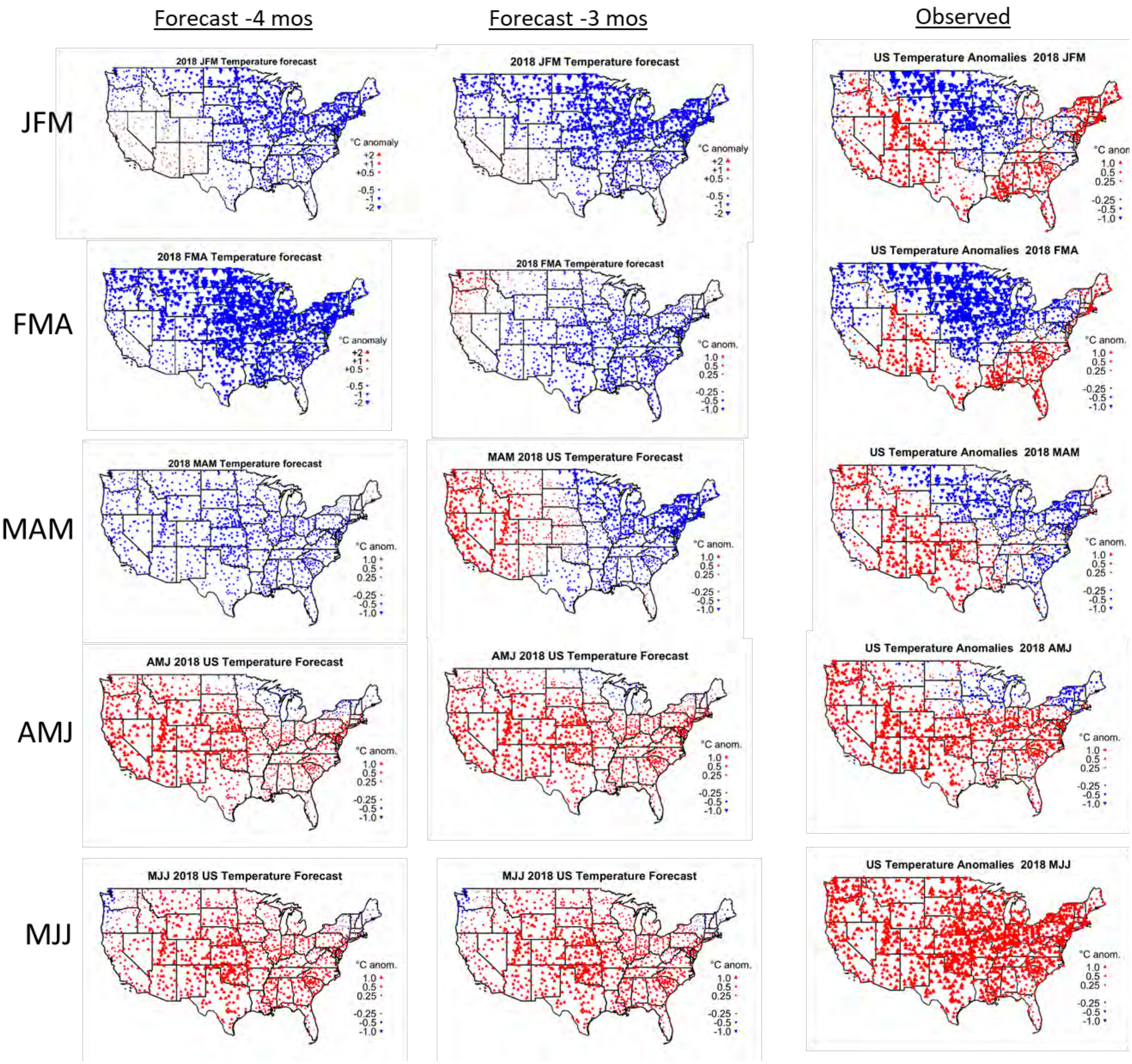

Figure 6. Temperature anomaly forecast maps and observations for the five 3-month seasonal windows from JFM to MJJ 2018 (top to bottom). Left column: Forecasts produced at 4-month leads. Center column: Forecasts at 3-month leads. Right column: Observed anomalies. Markers represent local forecasts and observations at 1218 surface temperature stations in the U.S. Historical Climatology Network.

PLANNED IMPROVEMENTS FOR 2019

CFAN has an ongoing program to conduct research on climate dynamics of relevance to seasonal forecasts. We are continuing to refine our methods and to increasingly automate the forecast process.

Based on client interests, we are developing plans to extend the forecasts to include:

- Europe
- additional forecast variables (precipitation, winds)
- extended time horizons (to 18 months)

We also plan to develop a hybrid statistical/dynamical seasonal forecast scheme, that incorporates this statistical approach as a basis for clustering the ECMWF ensemble seasonal forecasts.