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A Consensus Winter Temperature Forecast for the Pearl River Delta Region

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A Consensus Winter Temperature Forecast for the Pearl River Delta Region

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Abstract

In view of the potential socio-economic consequences of winter temperature anomalies, e.g. a colder-than-normal winter causing health concerns for the elderly and the under-privileged, or a warmer-than-normal winter affecting climate-sensitive businesses, the categorized winter temperature forecast issued by the Hong Kong Observatory in November each year often attracts a lot of public and media attention. However, forecasting winter temperature is a very challenging task given that temperature variability in winter is by far the largest among the four seasons in this region.

There were previous attempts by the Observatory to forecast Hong Kong's winter temperature in category terms (below normal, near normal and above normal) using pre-season atmospheric and oceanic indices. With the advent of climate modelling, the availability of forecast products from major climate prediction centres around the world has provided further guidance in formulating such seasonal forecasts. In this study, the prognostic capability of a selection of pre-winter predictors documented in the literature and other research studies was examined. Skills of hindcasts and forecasts from a number of the WMO Global Producing Centres for Long Range Forecasts were reviewed. A systematic and objective consensus approach integrating the various predictors and guidance material to generate categorized winter temperature forecast for the Pearl River Delta region was developed and tried out with promising results.

1. Introduction

In the early 2000s, the Hong Kong Observatory (HKO) made attempts to develop a conceptual model [1] to forecast the winter (December-February) temperature of Hong Kong in category terms using pre-winter atmospheric and oceanic predictors, e.g. monsoon index and sea surface temperature (SST). The conceptual model looked at empirical probabilities of winter temperature categories conditioned by the observation (tercile category) of the predictors. Graphical forecasts from dynamical climate models around the world were also considered during the forecast formulation process. The statistical forecasts from the conceptual model and dynamical forecasts were integrated using a consensus approach, through expert judgment rather than objective mechanism. The conceptual model was experimented for a couple of years [2] and no systematic objective verification had been conducted. Owing to the lack of hindcast data at the time, no verification or cross-validation exercise had been conducted to justify the inclusion of the dynamical climate model output in the forecast formulation.

In this study, we investigate the prognostic capability of pre-season predictors of winter temperature of Hong Kong, drawing on the experience gained in the development of the conceptual model and potential predictors suggested in the literature. The predictors are climate indices either provided by major climate centres or computed from re-analysis data. We also review the skills of dynamical climate model hindcasts and forecasts from some of the WMO Global Producing Centres for Long Range Forecasts, with a view to incorporating useful model output in the winter temperature forecast. Based on a rather intuitive approach, we develop a systematic and objective method to integrate useful information from the pre-season predictors and climate model output to generate categorized winter temperature forecast for Hong Kong. The method is verified against independent observations. Sensitivity tests are conducted for: (i) station data and (ii) re-analysis data for computing the predictors; and it can be shown that the method is very robust and insensitive to changes in these two aspects.

2. Data and Methodology

2.1 Data

Long records of winter temperature of Hong Kong, Macao (1950/51 – 2013/14 for both stations) and Guangzhou (1951/52 – 2013/14) are used for training and verification purposes. The NCEP/NCAR Re-analysis (NNR) [3] and the Japanese 55-year Re-analysis (JRA-55) [4] data are used for computing the pre-season predictors. NNR has a long record dating back to 1948 while JRA-55 starts from 1958. Sea surface temperature (SST) data of the Niño regions provided by the Climate Prediction Center (CPC) of US National Oceanic and Atmospheric Administration are used to construct one of the predictors. Hindcasts and forecasts of ECMWF, NCEP and JMA climate models are used to examine model skills in predicting the winter temperature of Hong Kong. Table 1 shows the hindcast period, initial dates and ensemble size and type of the three sets of hindcast data. For each of the three models, direct model forecasts for Hong Kong are extracted using bi-linear interpolation of the four nearest grid points around Hong Kong and the ensemble mean is computed.

2.2 Predictors for investigation

We first take a look at the predictors adopted in the conceptual model developed by Leung *et al*. (2006), namely the January-November SST of Niño 3.4 region, the summer (June-August) Unified Monsoon Index (JJA UMI) which is defined as the meridional flow at 1000 hPa averaged over 7.5 – 20^{o}N and 107.5 – 120^{o}E, and the strength of October-November subtropical ridge as indicated by the proportion of area (or number of grid points) with geopotential height of 5880 m or above at 500-hPa level in the region bounded by 10 – 90^{o}N and 110 – 180^{o}E (SRa). Since HKO has adopted the area-weighted average of SST anomalies of the Niño 1-4 regions, or Niño Z [5], as the index to monitor the ENSO status (http://www.hko.gov.hk/lrf/enso/enso-backgnd.htm#def), Niño 3.4 SST adopted by Leung *et al*. (2006) is replaced by Niño Z SST (or SST_NZ) for consistency between ENSO monitoring and seasonal forecasting operations. The start of the observation period for the SST_NZ index is adjusted to September in order to address the concern that SST conditions in the early part of the year may come in as noise rather than signal in predicting winter temperature (e.g. a decaying La Niña in the first half of the year may mask the impact of a developing El Niño in autumn and winter if the average condition of January to October is taken).

For the strength of subtropical ridge, alternative representations have also been suggested by the National Climate Center of China Meteorological Administration (http://cmdp.ncc-cma.net/Monitoring/Bulletin/201410/monitoringc/data-e.pdf) and other researchers [6]. By evaluating the accumulated positive difference of geopotential height above a certain threshold within a certain region, we create another subtropical ridge index, namely SRs, taking 5880 gpm as the threshold over the same region as defined for the SRa index.

Cheung *et al*. (2014) demonstrated that the Ural blocking SST_UBI index (defined as the difference between SST over the regions 25 – 35^{o}N, 170^{o}E –

135°W and 35 – 50°N, 135 – 145°W) and the western Pacific-like SST_WPI index (defined as the SST over the region 30°S – 25°N, 170°E – 100°W) observed in autumn (September-November) could be taken as the precursory signals for the number of cold days in Hong Kong in the ensuing winter. As the number of cold days is closely linked to the winter temperature, these two indices are also included for evaluation in this study.

Liu *et al*. (2013) showed that anomalies observed in September-October for the SST over the mid-latitude area of the North Pacific (35 – 50°N, 130 – 145°W), the sea ice concentration over the Kara Sea region of the Arctic Ocean (75 – 82°N, 65 – 85°E), and the upper-air (200-hPa – 300-hPa) temperature over the mid-latitude region of East Asia (30 – 50°N, 80 – 140°E) tend to persist into the winter, thereby affecting the strength of the East Asian Winter Monsoon. These three indices, denoted by SST_LG, I_ice and I_tmp respectively, are therefore included in this study.

Sun *et al*. (2014) showed that the Arctic Ocean – East Asian temperature contrast (AE) index (temperature difference between the regions 70 – 82°N, 0 – 70°E and 41 – 55°N, 85 – 124°E) observed in September-October could serve as a precursory signal for the second mode (or the dipole mode) of winter temperature variation over eastern China (east of 100°E) that typified the trends of opposite temperature anomaly signs between southern and northern China. The AE index is also included in this study.

Apart from the predictors suggested by the aforementioned studies, we also investigate other predictors with potential prognostic values: (i) A_ice - Arctic sea ice (70 – 82°N, 0 – 70°E); (ii) SNO - Eurasian snow accumulation (50 – 70°N, 60 – 120°E); and (iii) SST_SCS - SST over the south China coastal waters (19 – 25°N, 111 – 117°E).

Table 2 is a summary of the pre-winter predictors considered in this study and their observation periods; and Figure 1 shows the observation regions defined for these predictors. While the SST_NZ index is computed from SST data provided by CPC, other predictors can be computed from the NNR or JRA-55 data. Owing to the operational constraint for winter forecast to be issued by mid-November, the observation periods for most of the predictors end in October.

2.3 Screening of the predictors

Table 3 shows the coefficient of determination (r^2) between the potential predictors and the winter temperature of Hong Kong during the period 1950/51 - 1979/80. Many of the potential predictors show very weak correlation with the winter temperature of Hong Kong. To screen out poor predictors, a minimum requirement of 0.1 for r^2 is set. Six predictors meet the requirement (bolded in Table 3) and are shortlisted for further examination.

2.4 Translating the predictors to winter temperature

Apart from linear regression (LR), two other methods are also used to generate temperature forecasts, namely standardized anomaly mapping (SAM) and quantile-quantile mapping (QQM). In SAM, the standardized anomaly of the predictor with reference to a climatological period of 30 years is taken as the standardized anomaly forecast of the predictand. In QQM, the relative position of the predictor in a training data set will first be determined. The value of the predictand with the same position in the predictand's training data set will then be taken as the forecast.

To cater for the possible effects of climate change, the training data set is shifted in accordance with the climatological period. For example, with 1971 - 2000 as the climatological period and 2004 being the year to verify, the temperature training data period would be 1971 - 2003; and with 1981 - 2010 as the climatological period and 2014 being the year to verify, the temperature training data period would be 1981 - 2013. All three methods in the previous paragraph are able to generate quantitative temperature forecasts. Thus, an ensemble of 18 forecasts (or members) can be generated with the six selected predictors.

The provision of seasonal forecast to the public is normally framed in categorical terms, i.e. "normal to below-normal" or "normal to above-normal" temperature[1]. Quantitative temperature forecast in terms of standardized anomaly generated by any one of the three methods is as such converted to category forecast by the following procedures:

(i) normal to below normal (NB) if the anomaly sign is negative; or
(ii) normal to above normal (NA) if otherwise.

2.5 Consensus category forecast

To integrate the category forecasts converted from the 18 ensemble members, a simple consensus approach is invoked, i.e. voting. The consensus category forecast is determined by the following procedures:

(i) NB if the number of members for NB > half of the ensemble size;
(ii) NA if the number of members for NA > half of the ensemble size; or

[1] According to the current operational practice, observations falling within the range bounded by climatological mean +/- half of the standard deviation are considered normal. Observations above (below) the range are classified as above (below) normal.

(iii) adopt the category forecast based on the ensemble mean if otherwise.

2.6 Dynamical climate model output

Direct model forecasts for the winter temperatures of Hong Kong are extracted from the hindcast data of ECMWF, NCEP and JMA ensemble members using bi-linear interpolation of the four nearest grid points around Hong Kong, and ensemble means for the respective models are computed. The r^2 between the winter temperatures of Hong Kong and the direct model forecasts are computed over the hindcast periods (similar but not exactly the same) of the models. The results reveal that NCEP and JMA forecasts have very low correlation with actual observations, with r^2 at 0.01 or below, whereas ECMWF performs much better with r^2 at 0.24. Adopting the minimum requirement of 0.1 for r^2 (sub-section 2.3), only ECMWF is included in the forecast formulation process.

3. Verification and sensitivity tests

3.1 Forecast for Hong Kong

We compute the selected predictors (except SST_NZ) using the NNR data and generate an ensemble of 18 category forecasts and the resultant consensus category forecast for Hong Kong for each winter from 1980/81 to 2013/14. Table 4 shows the verification results for the 18 ensemble members in terms of the number of correct forecasts, broken down in a matrix according to the combination of predictor and forecast generation method. The verification result of the consensus forecast derived from the 18 members is shown at the bottom row of the table. Theoretically, a random forecast of two adjacent tercile categories (either NB or NA) would have a chance of about 70% being correct. Hence, in this case, a random forecast of NB or NA would result in about 24 years (out of 34 years) being correct. Table 4 shows that all ensemble members perform better than a random forecast. If a persistent NA forecast is considered as an alternative reference forecast on account of the background warming trend over the past few decades, a persistent NA forecast in the 34 years would get 28 years correct. Against this, only four out of the 18 ensemble members would out-perform the persistent NA forecast. However, the consensus forecast still has superior performance, scoring 32 years out of 34 years and hence out-performing the persistent NA forecast.

A quantitative forecast can be derived from the ensemble based on the condition set by the resultant consensus. A composite of forecast standardized anomalies consistent with the consensus category forecast is computed using the following procedures:

(i) take mean of the standardized anomalies ≦ 0.5 if the consensus category forecast suggests NB; or

(ii) take mean of the standardized anomalies ≧ -0.5 if the consensus category forecast suggests NA.

The root-mean-squared error (RMSE) of the quantitative forecast during the period 1980/81 – 2013/14 is 0.79, a 23% reduction in error when compared to an RMSE of 1.02 by climatological forecast.

3.2 Sensitivity to station data

The sensitivity to station data of the method of generating consensus category forecast is investigated by applying the method to data from Macao and Guangzhou. Verification results of the consensus category forecast and the quantitative forecast (using procedures in the second paragraph of 3.1) for Macao, Guangzhou and Hong Kong during the period 1980/81 – 2013/14 are shown together in Table 5. It is clear that the method works not only for Hong Kong, but also for Macao and Guangzhou in the Pearl River Delta region.

3.3 Sensitivity to re-analysis data

The sensitivity to re-analysis data for computing the prediction is investigated by using the JRA-55 data to compute the predictors (except SST_NZ). The ensemble of 18 members, the resultant consensus forecast and the quantitative forecast conditioned by the consensus are re-computed and Table 6 shows the verification results of the consensus category forecast and the quantitative forecast for the three stations during the period 1980/81 – 2013/14. Similar performance (compared to Table 5) can be achieved. Hence, the method is also robust to changes in the re-analysis data used for computing the predictors.

3.4 Value added by ECMWF

Figure 2 shows the standardized winter temperature anomalies observed at the HKO during the period 1980/81 – 2013/14, the quantitative forecast conditioned by the consensus category forecast and the percentage consensus. The two incorrect consensus forecasts are indicated by red triangles. It is interesting to note that there is a conspicuous lack of majority consensus among the ensemble members for one of the incorrect consensus forecasts in 1982/83. Despite large fluctuations in temperature in the most recent 14 winters, the consensus forecasts are all correct.

If, as suggested in 2.6, direct model forecasts from ECMWF are included in the consensus process, the number of correct forecasts for Hong Kong during 1980/81 - 2013/14 will increase from 32 to 33 (Figure 3).

4. Summary

Six pre-winter predictors are identified to examine their prognostic capability in predicting the winter temperature of Hong Kong. An objective and systematic approach to generate and integrate the temperature forecasts from these predictors is experimented and a consensus forecast so developed is found to have superior performance over random or persistent forecasts for an independent verification period of 34 years. The sensitivity of the new method to station data and re-analysis data for computing the predictors is investigated. The method is found to be robust to changes of stations in the Pearl River Delta region and the re-analysis data used.

It is noted that some of the SST-based predictors have a certain degree of overlap, namely SST_NZ and SST_WPI, SST_UBI and SST_LG. Since the approach of this study is to get a consensus forecast from a pool of skillful predictors instead of selecting the best predictor, these SST-based predictors are kept without going through further screening.

The capability of ECMWF, NCEP and JMA climate models in forecasting the winter temperature of Hong Kong is also examined. It is found that only ECMWF forecasts have good correlation with actual observations. The inclusion of ECMWF forecasts will slightly enhance the performance of the consensus forecast.

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Table 1 Hindcast period, initial date and ensemble size/type of hindcast data of ECMWF, NCEP, JMA climate models.

	Hindcast period	Initial date	Ensemble size/type
ECMWF	1981-2010	1 Nov	51 perturbed members
NCEP	1982-2010	28 Oct, 2 Nov, 7 Nov (00, 06, 12, 18 UTC)	12 time-lagged members
JMA	1979-2008	28 Sep, 13 Oct	10 hybrid (perturbed and time-lagged) members

Table 2 Potential pre-winter predictors of winter temperature of Hong Kong.

Predictor/ index	Definition	Observation period
SST_NZ	Area-weighted average of Niño 1-4 SST	Sep-Oct
JJA UMI	Meridional wind at 1000hPa over 7.5-20^{o}N 107.5-120^{o}E	Jun-Aug
SRa	Proportion of grid points exceeding 5880 gpm at 500 hPa over 10-90^{o}N 110-180^{o}E	Oct
SRs	Accumulated positive difference of GPH above 5880 gpm at 500 hPa over 10-90^{o}N 110-180^{o}E	Oct
SST_UBI	SST difference between 25-35^{o}N 170^{o}E-135^{o}W and 35-50^{o}N 135-145^{o}W	Sep-Oct
SST_WPI	SST over 30^{o}S-25^{o}N 170^{o}E-100^{o}W	Sep-Oct
SST_LG	SST over 35-50^{o}N 130-145^{o}W	Sep-Oct
I_ice	Sea ice over 75-82^{o}N 65-85^{o}E	Sep-Oct
I_tmp	Temperature between 300 and 200 hPa over 30-50^{o}N 80-140^{o}E	Sep-Oct
AE	Temperature difference between 70-82^{o}N 0-70^{o}E and 41-55^{o}N 85-124^{o}E	Sep-Oct
A_ice	Sea ice over 70-82^{o}N 0-70^{o}E	Sep-Oct
SNO	Snow accumulation over 50-70^{o}N 60-120^{o}E	Sep-Oct
SST_SCS	SST over 19-25^{o}N 111-117^{o}E	Sep-Oct

Table 3 Coefficient of determination between potential predictors and winter temperature of Hong Kong (1950/51 – 1979/80).

Predictor/index	Coefficient of determination
SST_NZ	**0.17**
JJA UMI	0.01
SRa	**0.15**
SRs	**0.13**
SST_UBI	**0.18**
SST_WPI	**0.12**
SST_LG	**0.10**
I_ice	0.004
I_tmp	0.02
AE	0.003
A_ice	0.01
SNO	0.007
SST_SCS	0.05

Table 4 Performance of the 18 ensemble members and the consensus forecast in terms of the number of correct category forecasts (1980/81-2013/14 winters). The predictors are computed using NNR data.

	SST_ NZ	SRa	SRs	SST_ LG	SST_ UBI	SST_ WPI
SAM	27	25	25	28	26	29
QQM	28	27	26	30	26	28
LR	30	27	26	30	26	27
Consensus	**32**					

Table 5 Performance of the consensus category forecast (in terms of number of correct forecasts) and the quantitative forecast conditioned by the consensus (in terms of RMSE) for Hong Kong, Macao and Guangzhou during the period 1980/81 – 2013/14.

	Category forecast		Quantitative forecast	
	Persistent NA	Consensus	Climatology	Composite conditioned by consensus
Hong Kong	28	32	1.02	0.79
Macao	28	32	1.09	0.88
Guangzhou	26	32	1.20	0.99

Table 6 Similar to Table 5, but the predictors are computed using the JRA-55 data.

	Category forecast		Quantitative forecast	
	Persistent NA	Consensus	Climatology	Composite conditioned by consensus
Hong Kong	28	31	1.02	0.87
Macao	28	32	1.09	0.90
Guangzhou	26	32	1.20	1.00

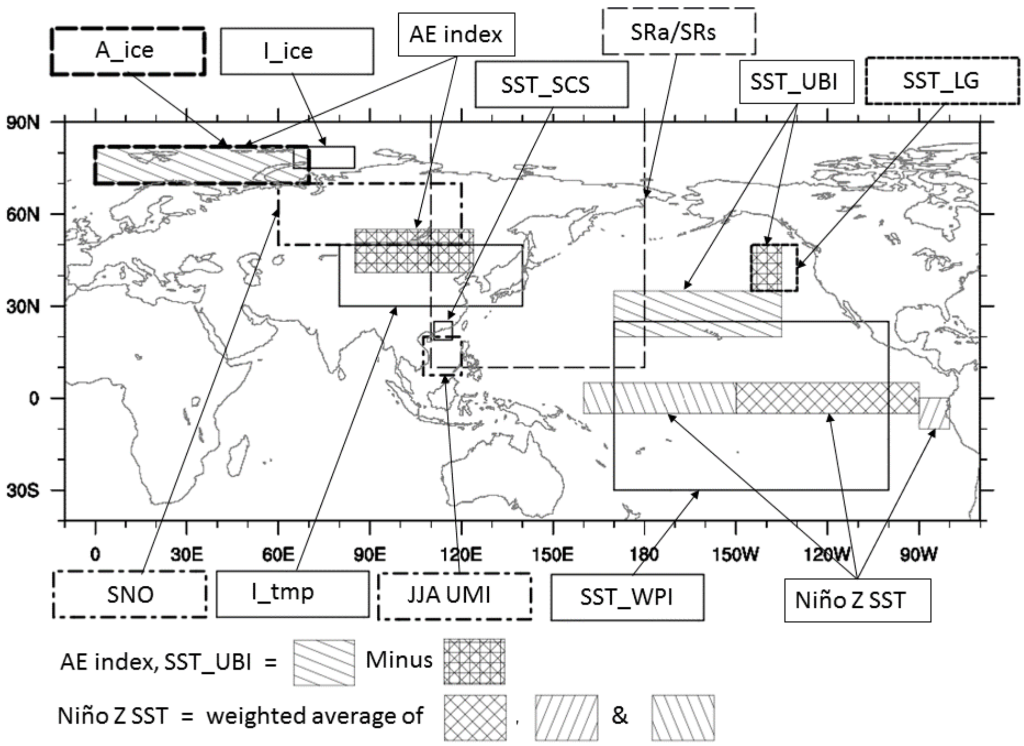

Figure 1 Potential pre-winter predictors of winter temperature of Hong Kong and the corresponding region of definition.

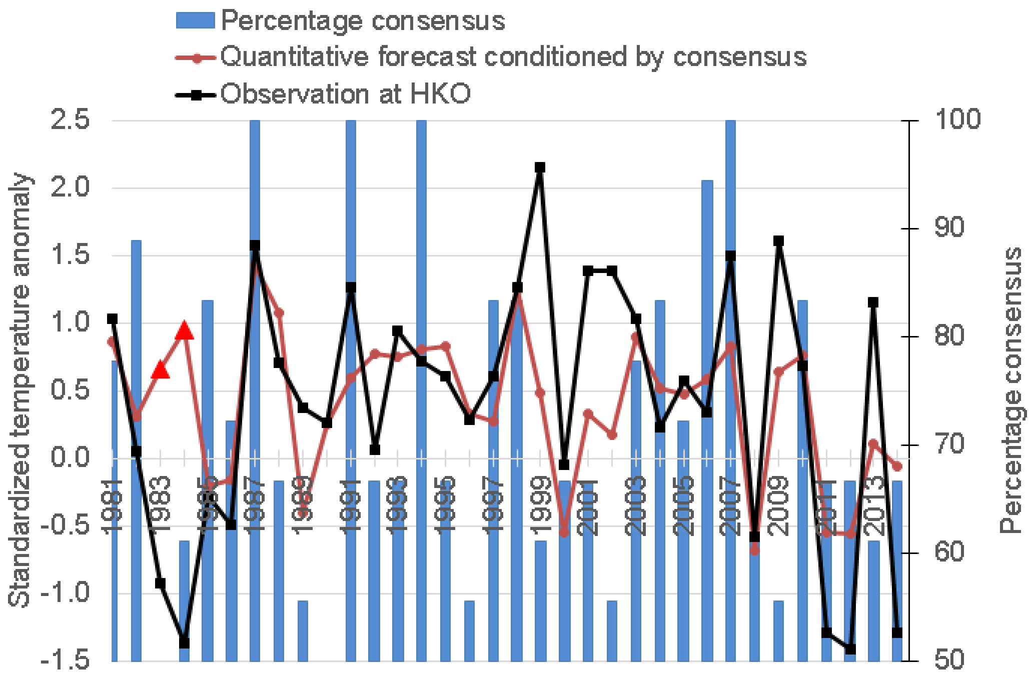

Figure 2 Winter temperature of Hong Kong (black) and quantitative forecast conditioned by the consensus category forecast (brown), presented in terms of standardized anomaly. Percentage consensus of the category forecasts are shown in blue bars. Incorrect consensus forecasts are marked by red triangles.

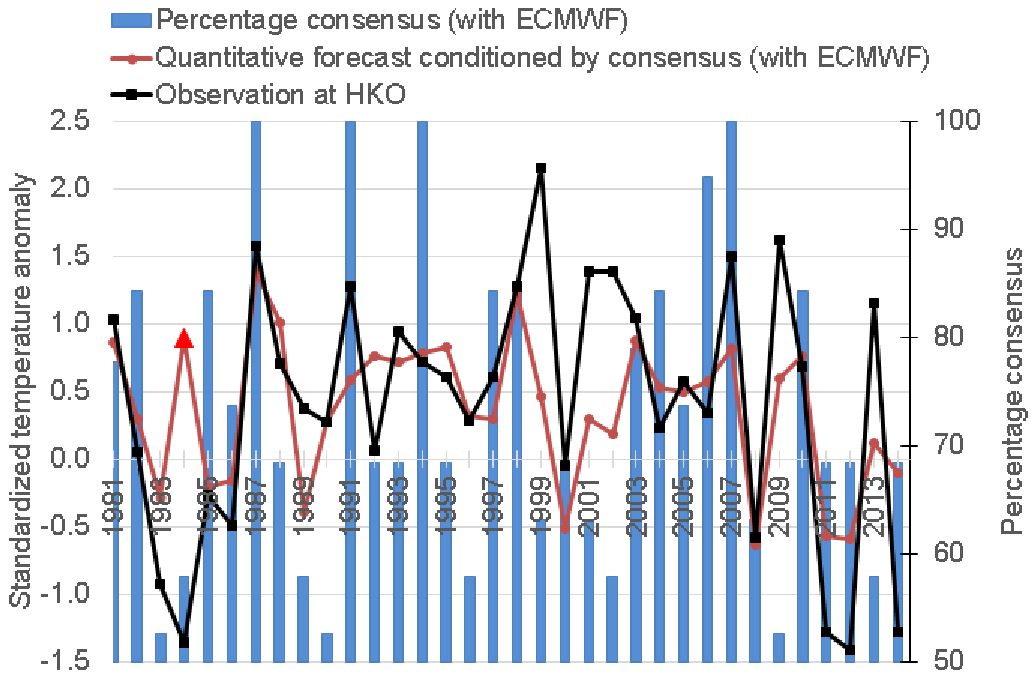

Figure 3 Same as Figure 2, but with ECMWF forecasts included.