PREDICTION OF THE GLOBAL TEMPERATURE ANOMALY FOR 2007 FROM DYNAMICAL AND STATISTICAL METHODS

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Key Message: we forecast that our best estimate of global surface temperature in 2007 will be a record value of 0.54^{o}C above the 1961-90 average. This just exceeds the 1998 record of 0.52^{o}C, taken from a new Hadley Centre and Climatic Research Unit data set being used by the IPCC Fourth Assessment Report as the key data to assess observed global warming. This is appreciably warmer than the expectation for 2006.

1. INTRODUCTION

Global surface temperature (land surface air temperature combined with sea surface temperature) is an important indicator of global climate, and has been at or near record levels in recent years. Analysis of observed and model data has linked interannual to decadal fluctuations in global mean temperature to various natural phenomena including ENSO, volcanic activity and solar flux variability. Global temperature change on interdecadal time scales has also been linked to human activity, including changing greenhouse gas and aerosol concentrations and stratospheric ozone depletion and tropospheric ozone increases. The existence of these numerous forcings raises the possibility of skilful predictions of global temperature. In this study, indices of the known important climate forcings and influencing phenomena are used to make empirical predictions of the global temperature anomaly from a 1961-90 average one year ahead. Based on a multiple regression analysis, the state of ENSO is the most important predictor on the interannual time scale. On the multi-decadal time scale, the net radiative forcing of the atmosphere is most important.

We use two forms of multiple linear regression to make these forecasts (a) using observed or calculated predictors based on physical understanding which are forced into the regression and (b) a modified version where one of the predictors is a forecast of sea surface temperature anomaly (SSTA) in the Nino3.4 region of the Tropical Pacific. The latter was chosen to be the forecast made by the Met Office GLObal SEAsonal (GLOSEA) coupled ocean-atmosphere global circulation model. (see http://www.metoffice.gov.uk/research/seasonal/technical.html for more about GLOSEA) .

1.1 PREDICTORS

The six predictors listed below have been identified by more than one author to be related to large-scale temperature:

a) IHC: The Inter-Hemispheric Contrast (IHC) index (related to as the Atlantic Multidecadal mode). This is used in the form of the time series of the second covariance eigenvector of low frequency global SSTA for 1911-1995 as described in Folland et al (1999).
b) ENSO HF1: The High Frequency El Nino Southern Oscillation index 1 (ENSO HF 1). This is the time series of the first covariance eigenvector of high frequency (<13 years) global SSTA for 1911-95 in Folland et al (1999). This eigenvector pattern is related strongly to ENSO.
c) ENSO HF2: The High Frequency El Nino Southern Oscillation index 2 (ENSO HF 2). This is the time series of the second covariance eigenvector of high frequency (<13 years) global SST. This eigenvector pattern is also ENSO-related, but the time series is 6-9 months out of phase with HF ENSO 1. This pattern is also from Folland et al (1999).
d) VOLCANO: An index of global volcanic dust cover (VOLCANO) produced by Sato et al (1993). Dust veils from major volcanic eruptions, particularly in the tropics, lead to a significant drop in global temperature for a year or two after the eruption.
e) SOLAR: An index of solar irradiance (SOLAR) as supplied by Lean (Frohlich & Lean, 1998) and extrapolated to the present.
f) GLOSEA NINO 3.4: Predictions of the Nino3.4 area (170-120^{o}W, 5^{o}N-5^{o}S) SST anomaly made by the Met Office GLOSEA coupled ocean-atmosphere global circulation model are used to replace the current observed ENSO state as measured by ENSO HF1 to make a second forecast..
g) GSO: An estimate of the global mean anthropogenic net radiative forcing at the tropopause. This comes from changing concentrations of well-mixed anthropogenic greenhouse gases, the direct and indirect effects of sulphate aerosol emissions and from stratospheric and tropospheric ozone concentration changes (GSO). This index was calculated using the Hadley Centre's coupled ocean-atmosphere general circulation model, HADCM3. It is expressed as the annual mean forcing at the top of the troposphere in wm^{-2} (Johns et. al., 2001).

This year, an additional forcing has been added to the GSO equivalent to an addition of an extra 0.2 ppm/year to the CO2 concentration in each year between 1990 and 2010. This corrects an inaccuracy in the earlier forcing estimates because the scenario used has underestimated the observed increase in CO2. Forcings for years prior to 1990 are not changed.

Thus for the period 1990-2010, the corrected concentration estimate; $C_2=C_1+0.2x(year-1990)$ where C_1=original concentration estimate. The C02 concentrations are converted to forcings (F) in WM2 using the equation from Houghton et al. (2001, http://www.grida.no/climate/ipcc_tar/wg1/index.htm) page 358.

$F= 5.35 \ln(C/C_0)$ where C=Current CO2 concentration and C_0 = Pre industrial CO2 concentration

The corrected GSO forcing GSO_2 is therefore evaluated from the original GSO forcing estimate GSO_1 given original (C_1) and corrected (C_2) concentration estimates:

$$GSO_2=GSO_1 + 5.35*\ln(C_2/C_1)$$

The CO2 concentration assumed for 2007 is: 384.96ppm

Predictor data for the following periods are used.

IHC October-December 2006
ENSO HF1 October-December 2006
ENSO HF2 October-December 2006
VOLCANO December 2006 (extrapolated from data ending in 1997 assuming no significant recent activity)
SOLAR January-December 2006 (Extrapolated from data up to 1998 by Lean allowing for the solar cycle(pers. comm.)

GSO	January-December 2006
GLOSEA NINO3.4	January-April 2007 forecast (used in place of ENSO HF1)

The predictor periods were chosen to extract maximum skill from data available at the time of the forecast.

1.2 PREDICTAND

The predictand is mean global land air and SST anomalies relative to 1961-90 for the forthcoming year. This is chosen to be the HadCRUT3 data set (Brohan et al, 2006). The global value of HadCRUT3 is the average of the two hemispheres. HadCRUT3 is not optimally averaged but does have error estimates. A future version of HadCRUT3 will be optimally interpolated in a rather different way from previous data and used here. Previous optimum averaging methods (Folland et al, 2001) appear to underestimate the component of uncertainty due to data gaps, though other components are not significantly affected.

1.3 FORECAST METHOD

Two forecasts are made using multiple linear regression (METHODS 1 and 2) A global temperature anomaly forecast is produced by applying each regression equation to the predictor indices described above. The two regression equations are:

1. An equation using predictors a-f of section 1.1, calculated using data for 1947-2005.
2. An equation using predictors a, c, d, e, f and g of section 1.1 calculated using data for 1960-2002.

The shorter training period is used here as GLOSEA hindcasts have been produced for this period as part of the DEMETER project (see http://www.ecmwf.int/research/demeter/) and are used to correct for bias in the GLOSEA forecast compared to observations.

The forecast from each model is modified to use "inflated" linear regression to retain the same total variance in the forecasts as in the observations. However because of the high total correlation skill of these methods, the level of inflation is small. The Forecast Probability Distribution Function (FPDF) for each method is based on the assessed standard errors of the regression predictions, assuming the forecast errors are normally distributed.

1.4 ASSESSMENT METHODS

To estimate forecast skill, trial forecasts (hindcasts) were made using the jack-knife method in a fairly severe way. Jack-knife forecasts were made for every year in the data period used to create the forecast equations using equations calculated using the majority of the remaining years. The forecast year is always excluded from the regression equation, along with data for the 5 years before and 5 years after the forecast year to minimise artificial hindcast skill due to persistence. During the first and last five years of the data period only a one sided exclusion of data is possible. We used the following assessment metrics:

(a) Standard (Pearson) Correlation. This ignores biases between forecast and observed values and the difference in standard deviation between the forecast and the observed value. We use a total correlation score (correlation) and a high frequency correlation (HF correlation). The latter calculates correlations on time scales less than about 10 years.

(b) RMS (Root Mean Square error): RMS scores are very appropriate as the forecast standard deviation is equal to that observed.

2. PERFORMANCE OF HINDCASTS AND FORECASTS OF OPTIMALLY AVERAGED GLOBAL TEMPERATURE ESTIMATES

2.1 JACKKNIFE HINDCAST SKILL 1947-2006

Jack-knife multiple regression forecasts are plotted against observed global temperatures in Figure 1 for METHOD 1. The total jack-knife correlation of 0.92 is very high for a climate prediction scheme. Because an important aim of the forecasts is to indicate how next year will differ from this year, the HF correlation of 0.70 gives a more realistic estimate of skill on this time scale. Nevertheless the excellent reconstruction of the low frequency is only possible because the shape of the low frequency forcing has been captured well. So our technique to some extent corroborates estimates of the time-dependent shape of the total net radiative forcing that we use. However, as long as the shape of such forcing is well captured, our method is not sensitive to the overall magnitude of radiative forcing change. In Figure 1, the 95% confidence interval is plotted in green and the best estimate forecasts in red.

Table 1 shows the contributions of the different predictors in METHOD1. The regression equation is built up in a stepwise manner, with predictors incorporated in order using the results of an F test. The importance of each predictor is shown by the standardised regression coefficient. This is the coefficient estimated when both predictor and predictand index are standardised. Bold numbers show the skill of the complete regression equation.

TABLE 1 PERFORMANCE OF JACKKNIFE HINDCASTS 1947-2006 ADDING 1 PREDICTOR AT A TIME, USING SIX PREDICTORS (METHOD 1)

Predictor added	Standardised Coefficient (1947-2006)	Correlation 1947-2006	HF Corr. 1947-2006	RMS 1947-2006 ^{o}C	RMS Stand. Units
GSO	0.83	0.90	0.05	0.105	0.466
ENSO HF 1	0.30	0.91	0.55	0.095	0.425
VOLCANO	-0.21	0.94	0.66	0.079	0.357
IHC	0.06	0.93	0.67	0.079	0.355
SOLAR	0.09	0.93	0.67	0.085	0.384
ENSO HF 2	-0.07	**0.92**	**0.70**	**0.088**	**0.395**

The strongest predictor, the GSO index, predicts the warming trend this century and the accelerated warming over the past 30 years but does not predict variability on time scales less than 20 years. The second predictor, ENSO HF 1, contributes most to interannual skill. The third predictor, VOLCANO, is important only during the 2 or 3 years following a major eruption. It is negligible in the 2007 forecast.

TABLE 2 SUMMARY PERFORMANCE OF JACKKNIFE FORECASTS USING GLOSEA NINO3.4 SST FORECASTS AS A PREDICTOR.

GLOSEA hindcasts produced as part of the DEMETER project were used for these assessments.

Predictors	Assessment Period	Correlation	HF Corr.	RMS °C	RMS S. U.
Method 1	1947-2006	0.92	0.70	0.088	0.395
Method 2 (ENSO represented by GLOSEA NINO 3.4)	1960-2002	0.92	0.64	0.079	0.419

The skill of the 2 methods is quite similar.

ASSESSMENT OF FORECAST FOR 2006

The 2006 forecast has been recalculated to be compatible with the new HadCRUT3 temperature dataset used for this forecast by recalculating the forecast exactly as before but using the HadCRUT3 dataset. Thus we do not include the changes to the forcing data used in the 2007 forecast.

	Forecast Year	2.5%	25%	50%	75%	97.5%	Obs (to Oct)
Method 1 (1947-2005)	2006	0.16	0.27	0.33	0.39	0.51	0.42
Method 2 (1960-2002)	2006	0.25	0.35	0.41	0.46	0.57	0.42
Weighted Mean	2006	0.21	0.31	**0.37**	0.43	0.54	

(http://www.metoffice.gov.uk/research/seasonal/global/pdf/global_temp_2006.pdf)

The forecasts for 2006 were expressed as the boundaries corresponding to the following values of the cumulative probability of the forecast, starting at the coldest level:

The mean forecast anomaly of 0.37°C was based on a skill weighted average of the two methods. The observed anomaly to October 2006 is 0.42 °C, so the 2006 forecast was rather too cold but well within the 95% confidence range.

3. FORECAST FOR 2007)

The best estimate forecasts of global temperature anomaly made by the two methods were:

1. USING SIX EMPIRICAL PREDICTORS INCLUDING OBSERVED ENSO INDEX, OCT-NOV 2006 0.52°C

2. AS 1 BUT USING GLOSEA NINO3.4 SST FORECAST FOR NOVEMBER 2006- APRIL 2007 0.56°C

The associated probability forecasts are expressed as the boundaries corresponding to the following values of the cumulative probability of the forecast, starting at the coldest level. The mean and standard deviation is calculated by weighting the forecasts according to their intrinsic skill as measured by mean square error in the cross validated tests.

	2.5%	25%	50%	75%	97.5%
Method 1	0.35	0.46	0.52	0.58	0.70
Method 2	0.41	0.51	0.56	0.62	0.72
Weighted Mean	0.38	0.49	0.54	0.60	0.71

Our best estimate forecast of the global temperature anomaly for 2007 is 0.54+-0.16°C, with a 95% confidence interval from 0.38°C to 0.71C. This is a best estimate forecast for the warmest year on record, warmer than the hitherto warmest year, 1998 (0.52°C). Thus there is a 60% probability that 2007 will be as warm or warmer than the warmest year (1998, 0.52°C) .

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Figure 1: Jack-knife hindcasts of optimally averaged global mean temperature anomalies for 1947-2006 (red line) and forecast for 2007 (0.52^{o}C) (red+) using method 1 only. The black line represents Brohan et al (2006) observations and includes a preliminary estimate for 2006. The 5% and 95% confidence limits are marked by lines in green.