J1.1 ECONOMIC SIGNALS IN GLOBAL TEMPERATURE HISTORIES

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1. INTRODUCTION

Kalnay and Cai (2003) found substantial land-use-related bias in ground-based U.S. temperature records when compared to altitude-adjusted radiosonde records. Specifically, they estimated that the impact of local land-use change (including urbanization) is nearly five times larger than the corrections made in the U.S. Historical Climate Network (USHCN) (Karl et al., 1990 and updates).

It is possible to estimate the effect of these biases by substituting the magnitude of the urban effect reported by Kalnay and Cai (2003) for the magnitude of the land-use effect that is currently incorporated into the modified USHCN data. Current USHCN data shows a statistically significant rise of 0.55°C in the 20th century. But, when the Kalnay and Cai corrections are applied, no significant warming remains in the record (Figure 1). Obviously, it is not completely appropriate to simply back-subtract the Kalnay and Cai corrections to the entire USHCN, as their analysis began only in mid-century, in 1950. However, it is also clear that some changes that occurred after 1950 were progressive developments from changes that were initiated earlier.

However, the fact that this crude correction removed any significant warming signal from the USHCN prompts two further questions:

1) How much has the “land use” signal has contributed to climate change on a global basis?

2) How does this signal compare to the magnitude of greenhouse-related temperature changes?

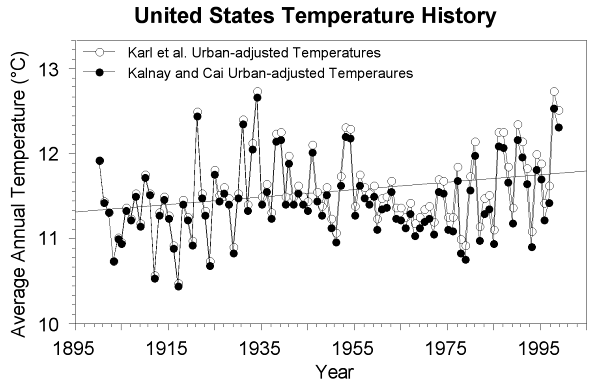

Figure 1. Two versions of the USHCN-derived temperature history of the United States. The open circles are data to which a correction for urbanization has been applied according to the technique described by Karl et al. (1988). There is a statistically significant rise of 0.55°C over the course of the 20th century (solid line). The filled circles are data to which a correction for land-use has been applied based upon a technique described by Kalnay and Cai (2003). There is no statistically significant rise of in these data.

1.1 Greenhouse Signal

Based upon theoretical aspects of greenhouse warming quantified by Staley and Jurica (1970), Michaels et al. (2000) found that the rate of increase in cold half-year temperatures is directly proportional to the amount of dry air residing climatologically in a given IPCC latitude/longitude gridcell. This provides dispositive evidence of greenhouse warming, versus “circulation-related” warmings such as those demonstrated by Thompson and Wallace (2001). As shown in Figure 2, when the mean gridcell dewpoint is less than 0°C (dry), the rate of warming in the last half of the 20th century is a function of the surface barometric pressure, while when the dewpoint is above 0°C there is no significant relationship between surface pressure and warming (Figure 2).

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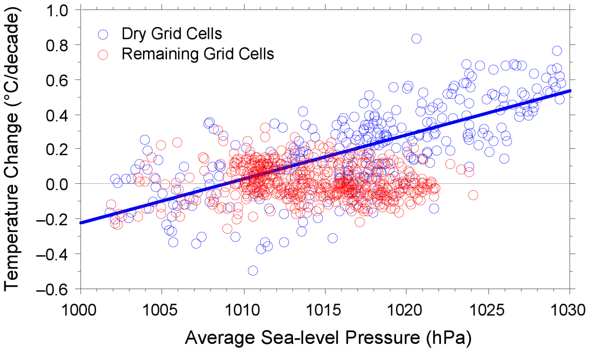

Figure 2. Relationship between average gridcell pressure and gridcell temperature change for the Northern Hemisphere winter season. Dry grid cells: gridcells with a seasonal average dewpoint temperature less than 0°C (from Michaels et al., 2000).

The consistency of this warming with physical explanations of greenhouse changes (Staley and Jurica, 1970) allows it to be used as a specific surrogate for greenhouse warming, in agreement with many projections made from theoretical models. For example, over two-thirds of the observed surface warming in the second half of the 20th century is confined to the cold (dry) half-year. In the cold half-year, gridcells comprising 26% of the area of the Northern Hemisphere (for which adequate data are available) have average dewpoints that are less than 0°C, and yet these are responsible for 78% of the total hemispheric warming in the second half of the 20th century (Michaels et al., 2000).

In the same sense, greenhouse physics also predicts the largest warming should take place over the driest regions in the summer half-year and indeed, where records are available, the most extensive concentration of summer warming is in sub-Saharan Africa. Unfortunately, there is insufficient data for long-term analyses within the core of the Sahara itself, but it would be reasonable to assume that warming has been even greater there (Figure 3).

There should be a similar relationship between surface temperature and barometric pressure in the summer half-year, as both cores of the winter and summer warmings are related to the strength of anticyclones; one group of cold, shallow anticyclones centered over Siberia and North America in the winter, and the other, the deeper subtropical anticyclones of the world's desert belts.

As a result of this, our subsequent attempt to isolate "economic" signals in temperature histories that comprise the global record will factor in greenhouse changes by using surface pressure in dry gridcells as the surrogate for warming potential.

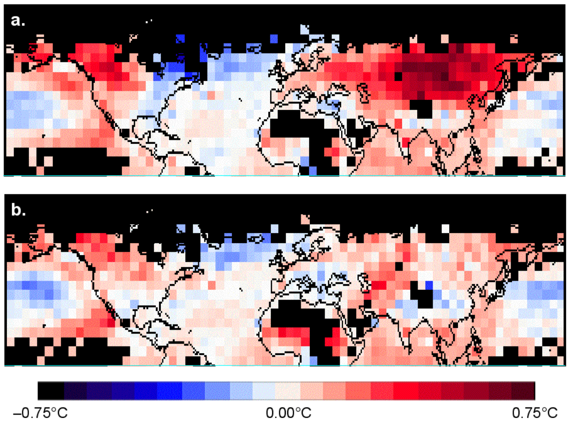

Figure 3(a) Winter season (October-March) and (b) summer season (April-September) temperature trends, 1946-1995 (°C/decade). (from Michaels et al., 2000).

1.2 Economic Hypotheses

Many investigators have demonstrated biases in temperature records due to the secondary effects of economic development, such as urban vs. rural landscapes (e.g. Jones et al., 1990), or direct urban heat island biases, such as found in South Africa (Balling and Hughes, 1966), Vienna (Bohm, 1998), China (Jones et al., 1990) and by a host of other climatologists for a number of other locations. As mentioned above, Kalnay and Cai (2003) have provided a stimulating quantification of the effect of land-use changes on large-area records, but other, more physically based studies have also been carried out, such as Pielke Sr., et al. (2002).

There is another family of possible economically-related biases that have not been as thoroughly investigated relating the quality of national records to national economies. We hypothesize that maintaining a high-quality climate monitoring network is clearly a "luxury good" for many economies.

The U.S. employs a full-time national staff of 450 for climate station installation and maintenance. The "luxury" nature of climate networks can be appreciated by noting that the number of active sites in the Global Historical Climatology Network has declined from 6000 to 2000, a measure of resources directed towards climate monitoring and station maintenance.

In addition, collection, processing and quality control of data are not uniformly distributed. In countries with relatively low educational achievement, skilled labor is relatively scarce and its real cost is higher than in more advanced countries, constraining the abilities of meteorological (climatological) services to hire and retain quality technical staff. We hypothesize there may be a relationship between educational level within a society and the quality of records. Thus we include national literacy rates as an input variable to our model.

In our subsequent model, we also input population, real per-capita income (1979), and real growth in Gross Domestic Produce (GDP). We also scale income for population by multiplying local per capita income by population for a measure of economic intensiveness.

Since daytime warming rates may be attenuated where particulate emissions, largely sulfates, are highly concentrated, we also input 1980 coal consumption as well as the increase from 1980 through 1998.

2. DATA AND METHODOLOGY

The dependent data in our model are the warming (or cooling) rates from 218 individual stations in 93 nations that are a major component of the Goddard Institute for Space Studies (GISS) compilation (Figure 4), a widely used record of world temperature published and updated by Hansen et al (http://www.giss.nasa.gov/data/), and another data vector, separately modeled, that consists of the IPCC 5 by 5 degree gridded data for the cells that correspond to the GISS station locations.

One ultimate objective of our work is the adjudicate differences between Microwave Sounding Unit (MSU) and surface records; but that is beyond the scope of this initial report. Another objective is to parse greenhouse versus other influents of observed trends in the greenhouse era, and our early work, along with that of many others, argues that 1979 is indeed a fairly “safe” starting point for any research centering on greenhouse changes.

The overall model can be stated as:

(1) $$\hat{Y} = \sum_{i=1}^{n_1} b_i Climate_i + \sum_{j=1}^{n_2} b_j Economic_j + \sum_{k=1}^{n_3} b_k Social_k$$

(2) $$Y = \sum_{i=1}^{n_1} b_i Climate_i + \sum_{j=1}^{n_2} b_j Economic_j + \sum_{k=1}^{n_3} b_k Social_k + e$$

where,

$\hat{Y}$ is the predicted warming trend at each of the 218 stations or 205 gridcells (13 IPCC cells were “blank”).

Figure 4. Locations of stations used in this study.

$\sum_{i=1}^{n_1} b_i Climate_i$ is a linear combination climate factors consisting of surface pressure in dry regions (a greenhouse surrogate), coal use (a sulfate surrogate), a dummy variable for coastal proximity, and the cosine of latitude, b_i are least-squares derived coefficients for each climate term.

$\sum_{j=1}^{n_2} b_j Economic_j$ is a linear combination of economic factors, consisting of population, scale of economic activity (see above), coal growth rate, and national GDP growth rate, b_j are least-squares derived coefficients for each climate term.

and

$\sum_{k=1}^{n_3} b_k Social_k$ is a linear combination of data management factors, consisting of literacy rate and the number of months of missing data in the local record. An additional dummy variable valued at 1 or 0, indicated a record from the Former Soviet Union (FSU), because of the dramatic decline in management stability that took place during the period of study. We recognize this will confound the climate signal because of the concentration of winter greenhouse warming at the same location, and discuss the magnitude of this interaction in the results section. b_k are least-squares derived coefficients for each climate term, and

e is the unexplained residual for each iteration.

The station climate data were obtained from GISS as adjusted for homogeneity by Hansen et al. (1999), and the gridded data were from the Climate Research Unit at the University of East Anglia. The data comprise approximately 10% of the active stations in the GISS inventory. They were selected only if they were in continuous operation from 1979 to 2000. Individual trends were calculated from the 268 monthly anomalies from January, 1979 through December, 2000.

3. RESULTS

The results from the global sample are given in Table 1. The first column are the parameter estimates (βs) and the figures in parentheses are the associated t-statistics. In all the Tables, bold applies to parameters with 95% confidence of significance, and * to those with 90% confidence of significance.

3.1 Global Discussion

In this and subsequent models, the parameters for the GISS station and IPCC gridded data are largely similar; for space considerations we limit discussion to the gridded data. Also, in this and subsequent discussion, we emphasis the variable “Soviet” is both a climate and a social variable. A further analysis examines the power of this variable after allowing for other climatic and economic impacts.

In order of statistical significance, for variables with 95% confidence of significance, the order of most powerful influents (and variable type) on the gridded trends is Per Capita Income (economic), Soviet (social and climatic), GDP growth (economic), Coal Use (climatic), Latitude (climatic) and Pressure (climatic). In terms of statistical confidence, at the global and annual scale, it is somewhat surprising that the three most significant predictors of the gridded trends are (largely) non-climatic.

However, a clear-cut statement along these lines is difficult because of the variable “Soviet.” Note that the coefficient is 0.28°C/decade, which would prompt the hypothesis that this is related to very large warming trends (as great as 0.8°C/decade) that are common there in the winter half-year. This is analyzed in the next section and yields an interesting result that argues that this is not necessarily the case.

Even so, the Soviet record requires great scrutiny to disentangle Soviet and greenhouse signals. Nonetheless, the power of the non-Soviet economic terms certainly argues that the land-use effects detected by Kalnay and Cai (2003) over the United States may very well be a significant and large contaminant of extant records that are thought to have been corrected for spurious, non-climatic trends.

3.2 Seasonal Sample and Moisture Splits

As noted in Michaels et al. (2000), theoretical considerations and observed temperature trends both confirm a preponderance of greenhouse warming in cold anticyclones, as evidenced by the proportionality between surface pressure and warming rate when dewpoints average below 0°C (“dry” air), as shown in Figure 2. Further evidence was cited for enhanced warming to also reside preferentially in warm (subtropical) anticyclones, particularly in Africa. Consequently, we stratified the gridded IPCC data into cold and warm half-years and then broke those two categories into a global sample, and during the cold season, a sample restricted to “dry” air, i.e. with dewpoints below freezing.

This analysis revealed much about the interaction between the “Soviet” dummy variable and greenhouse warming. Compare the global and dry region submodels within the cold season (Table 2). In the global model, the order of significance within the 95% confidence level is Per Capita Income (economic), Soviet (social/climate), Literacy (social), and GDP Growth Rate (economic). Note that Pressure does not make this list. However, in the dry region sample, where we would expect the greenhouse signal to be strongest, pressure indeed is the *only* significant variable explaining the distribution of warming trends, and Soviet (and all of the other economic variables) are absent.

This certainly leads one to the notion that the Soviet variable is more economic than climatic, inasmuch as it explains an insignificant amount of system behavior when entered in the season/data combination likely to show the strongest greenhouse signal. This behavior also leads to what we might call our first “conclusion hypothesis,” or an area to focus intensive future research:

Conclusion Hypothesis #1: *In the cold half-year, greenhouse warming is the main determinant of temperature change in dry regions. Over the rest of the domain, economic factors are the dominant cause.*

The warm season models yield similarly provocative results. In the global sample, the order of significance within the 95% confidence level is Soviet (social/climate), Per Capita Income (economic), Coal Use (climatic), GDP growth (economic), Latitude (climatic), Literacy (social), and Pressure (climatic).

During this season, social and economic variables enter the picture along with climate variables in association with temperature change. Clearly, during the more energetic warm season, when air masses are not as stratified as they are in the large source regions during the cold season, changes in the atmospheric greenhouse effect are not as strongly manifest.

These observations lead to a second "conclusion hypotheses":

Conclusion Hypothesis #2**:** *In the warm half-year, greenhouse warming is largely is not the dominant forcing, as economic and social variables become increasingly important.*

3.3 Stagewise Removal of Group Variables

An additional analysis of the variables in Table 1 allows an estimation of what the gridcell trends might be if the economic and social variables were removed from the data. In addition, this analysis allows for estimation of the contribution of "Soviet," although it remains a combination social/climatic variable (subject to the argument, above, that its social contribution is greater than its climatic one).

The results of this stagewise regression are given in Table 3. The average gridcell trend in the global data is 0.27°C/decade. (This is larger than the global IPCC trend of 0.17°C/decade for the period 1979–2000 because of the predominance of land stations and gridcells).

Removing the economic variables drops the average warming rate to 0.11°C/decade, and removal of the non-Soviet social variables drops it to 0.06°C/decade (an amount curiously close to the MSU-satellite mean global warming during the same period). Additionally removing Soviet drops the trend to 0.01°C/decade, but, again, it is not clear how much of this dummy variable is actually a greenhouse surrogate.

4. DISCUSSION AND CONCLUSIONS

This preliminary study clearly generates two hypotheses: 1) Economic factors are the dominant cause of warming outside of dry regions in the cold half-year, where greenhouse warming is dominant, and 2) A combination of economic and social effects are a significant determinant of regional warming trends in the warm half-year.

Obviously the conclusion resulting from this preliminary analysis is that economic factors have not been adequately accounted for in global temperature histories. In many ways, this is a more quantifiable restatement of Kalnay and Cai's (2003) findings that land-use issues have substantially contaminated the U.S. temperature history.

Our study clearly generates more questions than answers. If our hypotheses continue to be entertained, how much of the overall warming of the 20th century is a result of economic and social factors? In particular, the warming of the early part of the century, which is similar in magnitude to the one that occurred in the last third of the century, should be examined for these influences.

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Variable	**STATION DATA Global Sample**		**GRIDDED DATA Global Sample**	
DEPENDANT VARIABLE	$STREND_i$		$GTREND_i$	
CONSTANT	-12.727	(1.16)	**-9.124**	**(2.13)**
$PRESS_i$	0.013	(1.18)	**0.009**	**(2.18)**
$WATER_i$	0.103*	(1.91)	0.012	(0.39)
$COSABLAT_i$	-0.008	(0.20)	**-0.048**	**(2.46)**
POP_i	0.002	(0.60)	-0.002	(1.26)
$SCALE79_i$	-0.002	(0.51)	-0.000	(0.02)
$COAL80_i$	**-0.450**	**(2.72)**	**-0.323**	**(3.40)**
$COALGROW_i$	-0.007*	(1.68)	-0.002	(0.85)
$INC79_i$	**0.046**	**(4.46)**	**0.030**	**(5.22)**
$GDPGROW_i$	**0.091**	**(4.55)**	**0.039**	**(3.68)**
$SOVIET_i$	**0.592**	**(5.46)**	**0.288**	**(4.73)**
$SURFMISS_i$	-0.000	(0.09)	-0.001	(0.16)
$LIT79_i$	**-0.005**	**(2.99)**	**-0.002**	**(2.81)**
R^2	0.25		0.29	
Adj-R^2	0.20		0.25	
R^2 -Geog	0.04		0.06	
P(Econ=0)	**0.00**		**0.00**	
P(Sov=0)	**0.00**		**0.00**	
P(Soc=0)	**0.01**		**0.02**	
D.F.	205		192	

Table 1: Parameter estimates for surface data "fingerprint" model. *t*-statistic in parentheses, based on White's heteroskedasticity-consistent covariance matrix estimator. Parameters in **bold** are significant at 95%, * denotes 90% significance. Dependant variable is in ^{o}C/decade. R^2- Geog is the adjusted R^2 from a regression of the surface trends on the geographic variables ($PRESS_i$ through $COSABLAT_i$) only. *P*(Econ=0) is the probability value of an *F* test on the hypothesis that the economic influence variables (POP_i through $GDPGROW_i$) are jointly zero. *P*(Sov=0) is the probability value of a *t*-test on the hypothesis that the Soviet dummy is zero. *P*(Soc=0) is the probability value of an *F* test on the hypothesis that social factors potentially affecting data quality ($SURFMISS_i$ and $LIT79_i$) are jointly zero.

Variable	**COLD SEASON Global Sample**		**COLD SEASON Dry Regions**		**WARM SEASON Global Sample**	
CONSTANT	-8.373*	(1.68)	-18.239*	(1.96)	**-11.240**	**(2.31)**
$PRESS_i$	0.009*	(1.73)	**0.018**	**(2.17)**	**0.011**	**(2.36)**
$WATER_i$	0.031	(0.85)	0.069	(0.70)	0.001	(0.03)
$COSABLAT_i$	-0.022	(0.86)	0.023	(0.42)	**-0.064**	**(2.93)**
POP_i	-0.001	(0.35)	-0.025*	(1.80)	-0.002	(1.44)
$SCALE79_i$	-0.001	(0.40)	0.011	(1.16)	-0.000	(0.03)
$COAL80_i$	-0.002	(0.02)	-0.090	(0.47)	**-0.436**	**(3.81)**
$COALGROW_i$	-0.000	(0.00)	-0.013	(0.82)	-0.004	(1.43)
$INC79_i$	**0.033**	**(4.47)**	0.045	(1.33)	**0.026**	**(4.43)**
$GDPGROW_i$	**0.033**	**(2.18)**	**-**0.012	(0.23)	**0.039**	**(3.76)**
$SOVIET_i$	**0.223**	**(3.32)**	-0.035	(0.11)	**0.302**	**(4.45)**
$SURFMISS_i$	-0.003	(0.23)	-0.045	(1.25)	**-0.022**	**(2.22)**
$LIT79_i$	**-0.003**	**(3.01)**	-0.003	(0.22)	**-0.003**	**(2.85)**
R^2	0.23		0.34		0.25	
Adj-R^2	0.18		0.18		0.21	
R^2 - Geog	0.03		0.00		0.06	
P(Econ=0)	**0.00**		0.13		**0.00**	
P(Sov=0)	**0.00**		0.92		**0.00**	
P(Soc=0)	**0.01**		0.46		**0.00**	
D. F.	193		47		196	

Table 2: Parameter estimates for gridded trend model, cold/warm season sub-samples; global and dry regions. Dependent variable is seasonal temperature trend in gridded data set. Cold season: Oct-Mar in NH, Apr-Sep in SH; reverse for warm season. Variable definitions and notes as for Table 1.

Adjustment	Adjusted Sample Average Trend (^{o}C/decade)	Adjusted Sample Standard Deviation
Original Sample Average	0.270	0.237
Remove Economic Effects	0.110	0.125
Remove Social Effects	0.063	0.136
Remove Soviet Effect	0.011	0.053

Table 3: Values of sample average temperature trends in gridded data after successively removing extraneous socioeconomic biases.