Accuracy Check on Predictions of Near-Term Collapse

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Abstract

UK Foreign Office computer climate and economic models predict that, given no major policy changes worldwide, global warming could collapse the world economic system by 2040 (Ahmed 2015). To see whether this is at all realistic, a number of statistical tests were run using a new drought time series. Not only does it appear that warming and the spread of drought are linked, but also that they feed back on one another, raising the possibility that a real danger exists.

Keywords: Anthropogenic Global Warming; Drought

Introduction

Computer climate/economic models run by the UK Foreign Office predict that, given no major changes in policy worldwide, global warming could collapse the world economic system by 2040 (Ahmed 2015). Severe droughts seem to be more common in recent decades. Table 1 lists several.

Table 1: Recent major droughts

Year	Location	Notes
1982	Australia	Rainfall 22", 0.12 K temp. anomaly
1994	Australia*	Rainfall 17", 0.69 K temp. anomaly
2002	Australia*	Rainfall 14", 1.65 K temp. anomaly
2008	Australia*	"Rivers 'face disaster'"
1987-92	California	"notable for its six-year duration"
2000-02	California	"$1.5 billion for water-related..."
2007-09	California	"devastating urban/wildland fire..."
2012-15	California	"Worst drought in 1,200 years"
2005	Amazon River Basin	"Worst drought in 100 years"
2010	Brazil	"Severe drought"
2014-15	Sao Paolo, Brazil	"Severe drought"
2015	3 states in Brazil	"Worst drought in 80 years"
2009	East Africa	"Worst in decades"
2010	Russia	"Worst drought in at least 50 years"
2011	Mexico	"Worst in 70 years"
2011-15	Texas	"Worst drought ever"

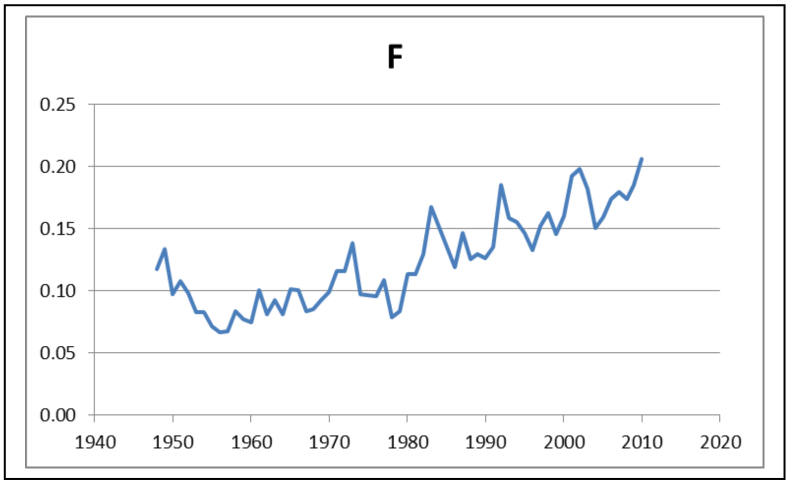
Ref: ABC News 2009, BBC 2015, Bryant 2008, California Dept. of Water Resources 2012, The Economist 2009, Fannin 2011, Gettleman 2009, Kolesnikova 2010, The Manchester Guardian 2006, Owens 2014, PBS NewsHour 2009, Salazar and Rodriguez 2011.

*The last three Australian disasters are now counted as a single "millennium drought," officially lasting from 1995 to 2009.

This is, however, anecdotal evidence. To find the trend in global drought, if any, requires a comprehensive numerical measure.

NOAA (2010) produced an updated time series for the Dai et al. (2004) PDSI dataset. These values use the Penman-Monteith equation for evapotranspiration rather than the earlier Thornthwaite equation. I extracted a global measure, F, for the years 1948 to 2010 (N = 63): the fraction of Earth's land surface in "severe drought" or worse ($PDSI_{PM} \leq -3.0$, chart in Fig. 1). Appendix A lists numerical values.

Figure 1: Fraction of land in severe drought 1948-2010



Statistical Tests for Trend in F

I performed OLS regression of F against elapsed time, first linear, and then quadratic (to test for acceleration--table 2).

Table 2: OLS regressions of drought fraction F against time

Model	N	R^2	p <	DW
Linear fit	63	0.706	7.72×10^{-18}	0.799
Linear, Cochrane-Orcutt	62	0.822	4.01×10^{-10}	2.01
Quadratic fit	63	0.774	4.48×10^{-20}	1.03
Quadratic, Cochrane-Orcutt	62	0.832	3.15×10^{-12}	1.93

Both tests showed the expected, positive slope to very high significance levels, but produced low levels of the Durbin-Watson statistic. Serial autocorrelation in the residuals implies the potential for unreliable results. Regressions were therefore rerun under Cochrane-Orcutt iteration (Cochrane and Orcutt 1949), and remained highly significant. The quadratic fit is better than the linear, and the addition of the quadratic term survives both t and partial-F tests.

To approach the problem another way, I performed a between-means t-test. I separated F values into 1948-1979 (N = 32) and 1980-2010 (N = 31) sets. The mean for the first group was F = 0.094, and for the second group, 0.15. Student's t was significant at well past 99.99% confidence. Mean F is significantly higher in the later period.

Global Warming as a Cause

The causes of drought are, of course, complex. Inputs to the Penman-Monteith equation for evapotranspiration (FAO 2007) include not just temperature, but *net* radiation, soil properties, wind strength, and humidity. To say it all depends on temperature would be simplistic at best, misleading at worst.

However the equation estimates *regional* evapotranspiration and *local* drought--not drought on a global scale. Precipitation, for instance, matters, but total precipitation actually goes up with global warming, not down.

Global climate simulations show that under global warming, rainfall is distributed differently (Dai et al. 2004, Trenberth et al. 2004, Aydin et al. 2007, Dai 2010, Rao et al. 2010). Although rainfall is increasing globally, and so is drought, it is unlikely that more rain causes more drought. The distribution of rainfall is much more important.

Among the many contributing factors to global drought, the relative importance of temperature can be sought through analysis of variance. The question, therefore, is an empirical one: Do temperature anomalies affect drought more than other factors? And if so, by how much?

Table 3 shows regressions of F on NASA GISS land-sea temperature anomalies for 1948 through 2010.

Table 3: Regressions of F on temperature anomaly dT

Model	N	R^2	p <	DW
$F_t = f(dT_t)$	63	0.660	6.18×10^{-16}	0.841
$F_t = f(dT_t, F_{t-1})$	62	0.828	2.69×10^{-23}	-0.198*

*Durbin's h

A simple linear fit accounts for 66% of variance, but shows low DW. Rather than repeat Cochrane-Orcutt iteration, regressions were run using lagged variables of up to one year, the lag length chosen by the Schwarz Bayesian Information Criterion (Schwarz 1978).

A best fit accounts for 83% of variance. But with the dependent variable F also present as a lagged variable, DW is unreliable and Durbin's h (Durbin 1970) must be substituted. By this measure, autocorrelated residuals are not a problem with this regression. Temperature and past values of F account for 5/6 of F's variance. If any other factors matter, they only add up to 1/6 of variance in the period studied. Of course, they might become more important if conditions change.

Granger Tests and Tests for Integration

"Correlation is not causation." The SBIC indicates proper lag lengths of one year for F and four for dT. I performed the Sims partial F-test for Granger causality (Granger 1969, Sims 1972--table 4).

Table 4: Sims partial-F tests for Granger causality

1-year tests:	dT Granger-causes F:	$p < 0.0001$
	F Granger-causes dT:	$p < 0.0001$
4-year tests:	dT Granger-causes F:	$p < 0.0001$
	F Granger-causes dT:	$p < 0.0001$

Granger causality is highly significant in both directions, implying a (positive) feedback between temperature anomaly and drought.

The relation could still be a spurious regression. I therefore performed augmented Dickey-Fuller tests (Dickey and Fuller 1979, 1981) to find levels of integration for each variable of interest. While F is I(0) (stationary), temperature anomalies are I(1) (integrated). Thus regressions of F on dT must be spurious unless cointegration can be shown.

I performed the Engel-Granger cointegration test using lags of one and four years. The cointegrating regression exists, and the relation appears not to be spurious.

It is therefore difficult not to conclude, on the empirical evidence, that global warming increases the fraction of Earth's land surface in severe drought.

Near-Term Risk

The question now arises of how much agriculture the world can lose before the system is disrupted.

Twenty percent of Earth's land surface is now in severe drought, compared to 10% from 1948 to 1970. At what point does failing agriculture collapse the system? Will social panic disrupt it early? The answer is not yet known. The most optimistic possible assumption is that F must go to 100% before human agriculture collapses.

It is also necessary to know how fast airborne CO_2 might grow, and how fast severe drought grows in response. I tried three different growth scenarios for CO_2.

1. The mean growth rate of ambient CO_2 measured at Mauna Loa from 1959 to 2010 was 0.37% (Etheridge et al. 1998, Keeling and Whorf 2005, Keeling et al. 2009, NOAA 2014).
2. The rate in the most recent decade for which data is available (2001-2010) has risen to 0.54%.
3. An aggressive-exploitation "Drill, Baby, Drill!" figure might be 1.0%.

It is also necessary to predict temperatures. Note the earlier conclusion that dT and F each Granger-cause the other, producing a feedback. This discovery might be new for global figures, but was already demonstrated in regional work. Courel et al. (1984) showed that "The persistence of the Sahel drought, which reached a peak in 1973, appears to be typical for such dry episodes over past decades and centuries. Such strong persistence can be understood if a strong positive feedback mechanism is operating, partly driven by changes in surface properties. The key factors in the mechanisms thus far studied are the surface albedo and the soil moisture, both of which affect the radiation balance at the surface, the first directly, the second indirectly through its influence on the latent heat flux..."

When water is scarce, evapotranspiration must decrease, and thus the ground cannot lose as much heat to the atmosphere by latent heat exchange.

For temperature prediction I used the radiative forcing equation of Myhre et al. (1998):

$$RF = 5.35 \ln(C/C_0) \qquad 1$$

where RF is in W m^{-2}, ambient CO_2 concentration C is in ppmv, and C_0 is a reference concentration, usually taken as the pre-industrial 280 ppmv. By this relation, doubling CO_2 produces 3.7 W m^{-2} of radiative forcing. I assumed a climate sensitivity $\lambda = 0.75$ K W^{-1} m^{-2}.

To incorporate feedback from drought, I performed OLS regression with lags of 1-4 years, followed by Cochrane-Orcutt iteration to reduce residual serial correlation (table 5).

Table 5: Temperature regression with feedback from drought

Variable	**β**	**t**	**p**
dT	-0.3113	-5.63	6.72×10^{-7}
dT_2	0.2606	2.11	0.0399
M	11.54	5.15	3.70×10^{-6}
M_1	-11.22	-4.84	1.11×10^{-5}
F_4	1.304	2.03	0.0473

N	59	F	66.0
R^2	0.908	p_F	3.76×10^{-20}
SEE	0.0776	DW	1.97

Here dT is NASA GISS land-sea temperature anomaly, M the value from the Myhre et al. relation, M_1 is M lagged one year, F_4 severe drought lagged four years, and dT_2 temperature anomaly lagged two years.

I started from known values in 2006-2010. I used the equations above for temperature, ignoring the solar cycle, ENSO, etc. The cointegration equation determined F. Results are in Table 6.

Table 6: Model estimates of year of agricultural failure

Scenario	**Annual Airborne CO_2 Growth**	**Year F Reaches 100%**
slow	0.37%	2034
medium	0.54%	2028
fast	1.00%	2022

Of course this analysis extrapolates outside the range of observations. F likely cannot actually reach 100%. Remember that under global warming, coastlines receive increased rain. Of course, storms hurt crops, rather than helping.

Note also that the cointegration regression only accounts for 83% of the variance of F. The other 1/6 is from causes not accounted for. These may or may not prevent F from escalating too high.

Consider, too, that drought is not the only problem caused by global warming. Other dangers have been noted, such as:

- clashes over scarce resources (ABC 2009)
- ocean biota extinctions from temperature changes and acidification (Jacobson 2005; Skoloff 2010; Cavaliere 2012; Harris 2013; Hart and Safina 2013; Wittmann and Pörtner 2013)
- sea-level rise (Church and White 2006, 2009; McGranahan et al. 2007; Domingues et al. 2008; Nerem et al. 2010)
- land biota extinctions (Cotton 2003; Visser and Both 2005; Körner and Basler 2010; OFAH 2012; Krakauer 2012; Mitton and Ferrenberg 2012; Jeganathan et al. 2014)
- heat waves (Schär et al. 2004; Robine et al. 2008; Masters 2010).

These will also destabilize society.

Caveats

There are several possible weak points in this analysis.

1. Reliability of the data. Sheffield (2014) is suspicious of the NOAA/Dai et al. data set, but mistakenly believes it based on the older Thornthwaite equation for evapotranspiration. But if there are other problems with the data set, and if better data does not show the same secular increase in drought, then the thesis presented here is wrong.

2. If some natural factor exists that prevents drought from spreading too far, the increase may be less damaging. We know global warming brings more rain to coastlines, accompanied by flooding and harder storms. Maybe agriculture could persist in an intermediate zone between desert and swamp. This might be large enough to feed everyone without conflict.

3. Perhaps drought-resistant crops can be bioengineered, plus varieties that can withstand hard storms and periodic flooding. If these were developed and planted in time, it could prevent world starvation--if everyone cooperates, and unexpected problems with the bioengineered plants do not turn up. Imagine, for instance, that drought-proof corn, like many natural varieties, turns out deficient in the vital amino acid lysine.

4. If renewable energy advances quickly enough, and fossil fuel use declines, deforestation stops, and perhaps, giant industrial plants are built to remove CO_2 from the air, global warming might be mitigated and its effects milder.

Conclusion

If the analysis presented here is correct, and no major policy changes occur, the conclusion of the UK Foreign Office computer models that global warming threatens near-term collapse of civilization may be accurate.

Appendix: The F Time Series: Fraction of Earth's Land Surface in Severe Drought ($PDSI_{PM} \leq -3.0$)

Year	F	Year	F
1948	0.117	1980	0.113
1949	0.133	1981	0.113
1950	0.097	1982	0.130
1951	0.108	1983	0.167
1952	0.098	1984	0.151
1953	0.083	1985	0.135
1954	0.083	1986	0.119
1955	0.071	1987	0.147
1956	0.067	1988	0.125
1957	0.068	1989	0.129
1958	0.084	1990	0.126
1959	0.078	1991	0.136
1960	0.075	1992	0.185
1961	0.100	1993	0.158
1962	0.081	1994	0.155
1963	0.092	1995	0.147
1964	0.081	1996	0.133
1965	0.101	1997	0.153
1966	0.101	1998	0.163
1967	0.084	1999	0.146
1968	0.086	2000	0.160
1969	0.093	2001	0.192
1970	0.099	2002	0.198
1971	0.116	2003	0.182
1972	0.116	2004	0.150
1973	0.138	2005	0.159
1974	0.097	2006	0.174
1975	0.096	2007	0.179
1976	0.096	2008	0.174
1977	0.109	2009	0.185
1978	0.079	2010	0.206
1979	0.084		

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