11C.7 SEASONAL PREDICTION OF U.S. LANDFALLING HURRICANE WIND ENERGY FROM 1 AUGUST

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1. INTRODUCTION

Hurricanes rank historically above earthquakes and floods as the major geophysical cause of property damage in the United States. The annual mean damage bill and its standard deviation for hurricanes striking the continental US 1950-2002 is US $ 4.8 billion and US $ 7.7 billion respectively. Skillful seasonal prediction of US landfalling hurricane activity would benefit business, government and society by forewarning of damage and disruption. However, significant seasonal landfalling skill has not been reported to date. This contrasts with the demonstrated significant skill for the seasonal prediction of North Atlantic hurricane activity from 1 August. Here we show that seasonal US landfalling hurricane wind energy 1950-2002 is predictable from the 1 August start of the main Atlantic hurricane season with significant ($p < 0.01$) and useful skill. Predictability arises from a large-scale pattern of North Atlantic tropospheric wind variability in July which establishes persistent steering winds that either favour or hinder US hurricane landfall. Predictions from this model are linked significantly ($p \sim 0.01$) to US hurricane economic and insured losses 1950-2002, and offer application to business.

2. DATA AND METHODOLOGY

We use the National Oceanic and Atmospheric Administration Accumulated Cyclone Energy (ACE) index as our measure of landfalling hurricane wind energy and define this as the US ACE index. This index reflects a combination of intensity and duration and thus is a better measure of 'overall landfalling activity' than the more widely used numbers of tropical storms, hurricanes or intense hurricanes making US landfall. Tropical storm and hurricane maximum sustained wind data are obtained from the US National Hurricane Center's North Atlantic hurricane database. Our analysis uses monthly wind data averaged between 925 and 400 millibars (mb) (about 750 to 7000m above sea level) from the National Center for Environmental Prediction/National Center for Atmospheric Research reanalysis during 1950-2002. The motion of hurricanes is determined by height-averaged winds between these levels. US hurricane economic and insured loss data are obtained from Pielke and Landsea (1998) and from Collins and Lowe (2001) respectively for the period 1950-2002. All correlation coefficients (r) refer to the Pearson product-moment coefficient of linear correlation unless otherwise stated.

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3. RESULTS

The third empirical orthogonal function (EOF) of the July 925-400mb height-averaged *u*-wind (zonal or east-west wind) over the North Atlantic, Caribbean Sea and Gulf of Mexico has a significant and stationary link to the US ACE index 1950-2002 (not shown). The strength and significance of the vector wind anomalies associated with this lagged mode match closely those linked to the US ACE index (not shown). The third EOF of the height averaged *u*-wind has a tri-pole structure with wind anomalies directed either towards or away from the US East Coast at latitudes between 20°N and 40°N and zonal wind anomalies of opposite sign at higher and lower latitudes. The wind steering associated with this mode either favours or hinders the US landfall of hurricane wind energy.

We assess the seasonal predictability of the US ACE index using cross-validated hindcasts with 5-year block elimination applied to two different linear regression models: the 'July height-averaged *u*-wind model' and the 'North Atlantic total ACE index model'. The former employs the PC of the third EOF of the July July *u*-wind, PC3, as the sole predictor. The latter uses the observed ACE index at sea (known from ~ 1 December) as the predictor. Hindcast skill is computed using two skill measures: the correlation (r) between the hindcast and observed values, and the mean square skill score (MSSS) defined as the percentage reduction in mean square error of the model hindcasts compared to hindcasts made with the 1950-2002 mean or climatology value. p-values are computed from bootstrapped estimates of r .

Table 1 compares the hindcast skill for different time periods from the two models. Using the July height-averaged *u*-wind model, the US ACE index (landfalling hurricane wind energy) is predictable from the 1 August start of the main Atlantic hurricane season with a correlation skill of ~0.5 and a skill improvement over climatology of 20-25%. This skill is significant to $p < 0.01$ over the 1950-2002 period and to $p < 0.05$ over each of the sub-periods 1950-1976 and 1977-2002. The strength, significance and stationarity of hindcast skill from the July *u*-wind model matches that achievable from knowing the observed North Atlantic total ACE index at the official hurricane season end on 30 November. A scatter plot of observed US ACE index versus hindcast US ACE index is shown in Figure 1 for the depth-averaged July *u*-wind model. 92% (24 out of 26) of the below median hindcasts correspond to actual values in the lower or average terciles, while 85% (22 out of 26) of the above median hindcasts correspond to actual values in the upper or average terciles. Furthermore the model correctly anticipates 89% (16 out of 18) of actual values in the upper tercile as above median and 78% (14 out of 18) of actual values in the lower tercile as below median.

Prediction model	Period	Hindcast skill and significance		
		MSSS (%)	*r*	*p*-value
July PC3 u-wind 925-400 mb	1950-2002	23	0.49	0.007
	1950-1976	24	0.48	0.03
	1977-2002	23	0.48	0.04
Observed North Atlantic total ACE	1950-2002	23	0.48	0.003
	1950-1976	19	0.43	0.02
	1977-2002	28	0.53	0.01

Table 1. Predictive skill for the seasonal US ACE index (landfalling hurricane wind energy). The Table compares the strength, significance and stationarity in skill from two models. the July height-averaged *u*-wind model (hindcasts available from 1 August) and the North Atlantic total ACE index model (hindcasts from ~ 1 December). Skill significance is shown for the *r* measure.

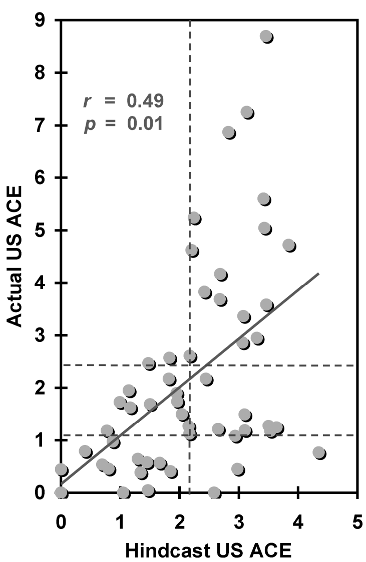

Figure 1. Scatter plot of cross-validated hindcast US ACE index versus observed US ACE index 1950-2002. Hindcasts are from the July height-averaged *u*-wind model. The ACE unit is x10^4 knots^2. The dashed lines mark the hindcast median value (vertical dashed line) and the observed upper and lower tercile values (horizontal dashed lines).

The US ACE index hindcasts offer sound potential for socio-economic benefit. Using the appropriate Spearman rank correlation, r_{rank}, our early August US ACE index hindcasts are linked significantly (p ~ 0.01) to US hurricane economic losses 1950-2002 (Pielke and Landsea, 1998) and to US hurricane insured losses 1950-2002 (Collins and Lowe, 2001). For economic losses: r_{rank} = 0.36; p = 0.01. For insured losses; r_{rank} = 0.33; p = 0.02. These significant links to loss are evident also from Figure 2 which compares the hindcast US ACE index values against economic and insured losses stratified by year and above/below median value. For economic loss the hindcast model correctly anticipates the sign of 74% (20 out of 27) of the above median loss years and 73% of the below median loss years. For insured loss the hindcast model anticipates the sign of 70% (19 out of 27) of the above median loss years and 69% of the below median loss years. The two-tailed probability of obtaining the 2x2 contingency table of US ACE index hindcast and US economic loss by random chance is 0.001; for insured loss the probability is 0.006.

(A) Economic Loss

Year	Hindcast	Loss	Loss (US $)
1992	-	+	43,152,000,000
1954	+	+	22,845,000,000
1955	+	+	17,204,000,000
1965	+	+	16,557,000,000
1960	+	+	15,918,000,000
1969	-	+	14,298,000,000
1972	-	+	13,978,000,000
1989	+	+	13,436,000,000
1979	+	+	11,264,000,000
1961	+	+	9,339,000,000
1964	+	+	9,193,000,000
1985	+	+	8,661,000,000
1999	+	+	6,222,000,000
2001	+	+	5,470,000,000
1983	-	+	5,289,000,000
1995	+	+	4,860,000,000
1996	+	+	4,544,000,000
1970	+	+	4,352,000,000
1998	+	+	4,327,000,000
1950	+	+	3,659,000,000
1957	-	+	3,187,000,000
1967	+	+	2,673,000,000
1975	+	+	2,290,000,000
1991	-	+	2,234,000,000
1971	+	+	1,580,000,000
1994	+	+	1,340,000,000
2002	-	+	1,220,000,000
1980	-	-	1,128,000,000
1974	-	-	934,000,000
1959	+	-	582,000,000
1956	-	-	457,000,000
1968	-	-	417,000,000
1976	-	-	400,000,000
1958	-	-	290,000,000
1951	+	-	237,000,000
1966	-	-	215,000,000
1963	+	-	193,000,000
1984	+	-	170,000,000
1973	-	-	124,000,000
1997	-	-	121,000,000
1988	+	-	114,000,000
1981	-	-	100,000,000
1978	-	-	98,000,000
1990	+	-	97,000,000
1993	-	-	83,000,000
1952	-	-	82,000,000
1962	-	-	55,000,000
1977	-	-	43,000,000
1986	-	-	38,000,000
1953	+	-	36,000,000
1982	-	-	35,000,000
2000	-	-	29,000,000
1987	-	-	18,000,000

(B) Insured Loss

Year	Hindcast	Loss	Loss (US $)
1992	-	+	29,016,728,835
1954	+	+	17,900,989,200
1965	+	+	13,648,961,535
1989	+	+	6,710,833,935
1964	+	+	5,769,253,080
1960	+	+	5,595,328,260
1970	+	+	5,413,513,710
1979	+	+	5,058,608,580
1983	-	+	4,635,839,685
1985	+	+	4,213,416,810
1961	+	+	4,119,318,330
1995	+	+	3,636,900,090
1950	+	+	3,628,429,710
1969	-	+	3,498,390,180
1955	+	+	2,887,893,585
2001	+	+	2,615,000,000
1996	+	+	2,464,532,190
1999	+	+	2,382,634,470
1998	+	+	2,003,554,155
1957	-	+	1,394,029,260
1959	+	+	1,189,865,610
1972	-	+	1,133,958,495
1991	-	+	1,094,842,830
1967	+	+	1,052,384,280
1975	+	+	927,940,320
2002	-	+	635,000,000
1980	-	+	336,384,765
1956	-	-	325,876,185
1966	-	-	249,843,030
1984	+	-	158,413,170
1976	-	-	151,621,935
1971	+	-	143,894,550
1974	-	-	140,590,770
1968	-	-	114,799,245
1953	+	-	110,872,155
1986	-	-	81,980,670
1952	-	-	65,229,510
1993	-	-	56,049,315
1997	-	-	48,913,245
1988	+	-	22,592,025
1977	-	-	13,525,590
1963	+	-	4,685,490
1987	-	-	594,870
2000	-	-	0
1994	+	-	0
1951	+	-	0
1990	+	-	0
1981	-	-	0
1978	-	-	0
1958	-	-	0
1982	-	-	0
1962	-	-	0
1973	-	-	0

Figure 2. Comparison of hindcast US ACE index with (A) US hurricane economic losses and (B) US hurricane insured losses 1950-2002. Hindcasts are from the July height-averaged *u*-wind model. The yearly value of each parameter is coded based upon whether it is above or below the median value with light grey indicating above-median and dark grey below-median. Rows are stratified vertically by economic loss (A) and by insured loss (B). The year (left column) is included for reference.

4. SUMMARY

To our knowledge this is the first example of skill for predicting seasonal US landfalling hurricane activity. The skill is significant and stationary over the reliable record back to 1950. The model has a sound physical basis. It will benefit risk awareness and offers good potential for application in business decision making.

5. REFERENCES

Collins, D. J. and Lowe, S., A macro validation dataset for U.S. hurricane models, Casualty Actuarial Society, Winter Forum, pp. 217-252 (2001).

Pielke, R. A., Jr., and Landsea, C. W., Normalised hurricane damage in the United States: 1925-1995. *Wea. Forecasting*, **13**, 621-631 (1998).