Summary of 2000 Atlantic Tropical Cyclone Season and Verification of Authors' Seasonal Forecasts

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Summary

A year with above average Atlantic basin activity but below average US landfall strikes. Predictions proved best at short leads.

The Tropical Storm Risk (TSR) consortium presents a validation of their seasonal forecasts for Atlantic basin, USA landfalling, and Caribbean Lesser Antilles landfalling tropical cyclones in 2000. These forecasts were issued on 1st December 1999, 26th May 2000 and 2nd August 2000. All span the official Atlantic hurricane season from 1st June to 30th November, and include separate predictions for tropical storms, hurricanes and intense hurricanes. We show that the 2nd August pre-main season forecast performed the best, exactly predicting the basin number of intense hurricanes. All the TSR forecasts proved correct to within 2-standard errors of the observed totals.

Features of the 2000 Atlantic Season

- The 2000 Atlantic season recorded above average activity, with 14 named storms, 8 hurricanes and 3 intense hurricanes. This compares to 1971-2000 climatologies of 9.4, 5.6 and 2.0 respectively. It was the third consecutive year with above average activity making 1995-2000 the most active 6-year period on record.
- Six tropical storms, of which five made hurricane strength, formed between 11th and 28th September. Only 4 years in the last 100 have seen more hurricanes form in September.
- Despite a significant positive relationship existing between basin hurricane and landfalling hurricane numbers, only 1 affected the US mainland in 2000. The probability of so few US hurricane strikes in a season with 14 named Atlantic storms is just 25%.
- The total US damage bill is estimated to be under US $30m. This compares to a 1926-1999 annual average of US $5.2bn (indexed to 2000 dollars). Hurricane Keith was the most damaging Atlantic storm causing losses in Central America of US $200m.
- The 2000 season continues the recent trend of late starts, ranking as the 8th latest since 1950.

Individual Storm Summary 2000						
No.	Name	Dates	Peak Wind	Minimum Pressure	Hurricane Category	Category at US Landfall
1	Alberto	04-23 Aug	110	950	3	
2	Beryl	13-15 Aug	45	1007	-	
3	Chris	18-19 Aug	35	1005	-	
4	Debby	19-24 Aug	65	994	1	
5	Ernesto	02-03 Sep	35	1005	-	
6	Florence	11-17 Sep	70	985	1	
7	Gordon	14-18 Sep	65	981	1	1
8	Helene	15-22 Sep	55	996	-	TS
9	Isaac	21 Sep-01 Oct	120	943	4	
10	Joyce	25 Sep-02 Oct	80	976	1	
11	Keith	28 Sep-06 Oct	115	942	4	
12	Leslie	05-07 Oct	35	1006	-	
13	Michael	17-20 Oct	85	965	2	
14	Nadine	19-22 Oct	50	997	-	

Verification of Forecasts

1. Atlantic Total Numbers

Atlantic Total Numbers 2000				
		Named Tropical Storms	Hurricanes	Intense Hurricanes
Average Number (± SD) (1971-2000)		9.4 (± 3.5)	5.6 (± 2.3)	2.0 (± 1.4)
Actual Number 2000		14	8	3
TSR Forecast (± SD)	02 Aug 2000	10.4 (± 2.5)	6.3 (± 1.6)	3.0 (± 1.3)
	26 May 2000	8.7 (± 3.0)	5.1 (± 2.3)	2.1 (± 1.4)
	01 Dec 1999	10 (± 4)	6 (± 3)	3 (± 2)
Gray Forecast (± SD)	04 Aug 2000	11	7	3
	07 Jun 2000	12	8	4
	08 Dec 1999	11	7	3

The number of intense hurricanes was correctly forecast by TSR and Gray at the shortest leads, but under-predicted by TSR and over-predicted by Gray in early June. Hurricane and storm numbers proved more difficult to predict, though increasing the storm and hurricane thresholds by 5 knots reduces the number of observed storms by 3 and the number of hurricanes by 2. These numbers are then very close to those forecast by TSR and Gray in early August 2000. Whilst there are many border line cases in the storm catalogue, 2000 had an exceptional number. For more details on Gray's forecasts see http://typhoon.atmos.colostate.edu/forecasts/.

2. US Landfalling Numbers

US Landfalling Numbers 2000				
		Named Tropical Storms	Hurricanes	Intense Hurricanes
Average Number (± SD) (1971-2000)		3.0 (± 1.8)	1.5 (± 1.3)	0.5 (± 0.5)
Actual Number 2000		2	1	0
TSR Forecast (± SD)	02 Aug 2000	3.6 (± 1.6)	1.9 (± 1.4)	0.8 (± 0.5)
	26 May 2000	3.1 (± 1.7)	1.5 (± 1.2)	0.7 (± 0.8)
	01 Dec 1999	3 (± 2)	2 (± 1)	1 (± 1)

We define a landfalling event in terms of the maximum sustained 1-minute windspeed of a storm whose eye comes within 140km of land. This definition accounts for the fact that the radius of damaging winds typically extends this far out from a storm centre.

Whilst all forecasts were within 1 standard error of the actual values, the models predicted activity above the 1971-2000 climatology values whilst the actual values were below. In prior years, total basin numbers and landfalling events have exhibited a reasonable positive correlation but in 2000, this broke down. The TSR model relies on this principle holding and consequently failed to forecast landfalling events to a greater accuracy.

As our landfalling definition is different to Gray's, his results cannot be compared. Nevertheless, he also over-predicted the number of landfalling events in 2000.

3. Lesser Antilles Landfalling Numbers

Lesser Antilles Landfalling Numbers 2000				
		Named Tropical Storms	Hurricanes	Intense Hurricanes
Average Number (± SD) (1971-2000)		1.3 (± 1.2)	0.5 (± 0.7)	0.2 (± 0.4)
Actual Number 2000		2	1	0
TSR Forecast (± SD)	02 Aug 2000	1.4 (± 1.2)	0.6 (± 0.7)	0.3 (± 0.4)
	26 May 2000	1.2 (± 1.1)	0.4 (± 0.6)	0.2 (± 0.4)

The Lesser Antilles forecasts were also obtained as a percentage of basin numbers, so under-estimating these led to an under-prediction of Lesser Antilles tropical storm and hurricane numbers. Nevertheless, the TSR forecasts were all accurate to 1 standard error.

Environmental Factors in 2000

We examine the principle environmental factors known to influence Atlantic hurricane activity in an attempt to understand the tendency for seasonal forecasts in 2000 to: (a) under-predict basin activity, and (b) over-predict US landfalling activity. We conclude that, given the underlying environmental conditions, basin activity in 2000 was perhaps more active than expected. We suggest that the low number of US landfalls may be related to unfavourable wind shear conditions and to anomalously strong southerly winds which caused storms to recurve early.

1. Known Influences

The conditions favourable to tropical storm development are pre-existing low pressure areas at least 5^{o} away from the equator, warm sea surface temperatures (SSTs), little or no vertical wind shear and upper level divergence. The first condition ensures that there is enough Coriolis Force to provide the initial disturbance with the necessary cyclonic circulation pattern. Fuelled by the latent heat of condensation, these disturbances require SSTs of at least 26^{o}C to provide the necessary water vapour required to build and sustain their warm core. Nevertheless, if the winds aloft are blowing strongly in one direction, whilst those at the surface are blowing in the opposite direction, the resulting vertical wind shear will inhibit the formation of a warm core. Furthermore, even if windshear is low, the rising air must be able to escape by outflow aloft; otherwise pressure will rise and the storm intensity will weaken.

The principle of sound seasonal Atlantic hurricane predictions is to forecast the key environmental conditions at the height (August-September-October (ASO)) of the hurricane season. We find that the most important contemporaneous (ie ASO) factors are:

1. SSTs in the Tropical Atlantic [10^{o}N-20^{o}N, 10^{o}W-60^{o}W]
2. SSTs in the Caribbean [10^{o}N-20^{o}N, 60^{o}W-85^{o}W]
3. Caribbean 925hPa U-Winds [10^{o}N-20^{o}N, 60^{o}W-90^{o}W]

The first two predictors are fairly straightforward to explain. The SST regions are where the majority of tropical storms develop, so we expect more storms to occur when these SSTs are higher. The third predictor is the surface westerly component of windshear, which we find has a stronger influence on tropical storm and hurricane numbers than total windshear itself. On average, the ASO 925hPa surface U-winds in this region are -5.7ms^{-1} (i.e. they are weak Easterlies). We find that when these winds are lighter than average (anomalies are positive), conditions become more favourable for tropical storm development.

A number of researchers claim that ENSO is the most important single parameter influencing Atlantic seasonal hurricane variability. ENSO is included in our model as the primary predictor for the strength of the Caribbean 925hPa U-winds.

2. Conditions During 2000 Season

The first parameter of interest is SST, the ASO anomalies for which are shown in Figure 1. Temperatures in the tropical north Atlantic were fairly average overall, though this was split unusally with temperatures north of 15^{o}N being generally cooler than average whilst those south of this latitude were generally warmer. Of the 7 storms that formed in this region (more than twice the average), only 3 formed in areas where SSTs were significantly warmer than average. Two of these storms (Alberto and Isaac) intensified over the cooler part. One feature which may have been important this year, was the unusally strong SST anomaly in the extra-tropical region. This no doubt played a part in the longevity of Isaac and Alberto and may have aided Florence, Leslie, Michael and Nadine's development. Nevertheless, the numbers forming in the extra-tropics were not unusually high.

The numbers of storms forming in the Gulf and Caribbean, when taken together, were also not significantly higher than normal.

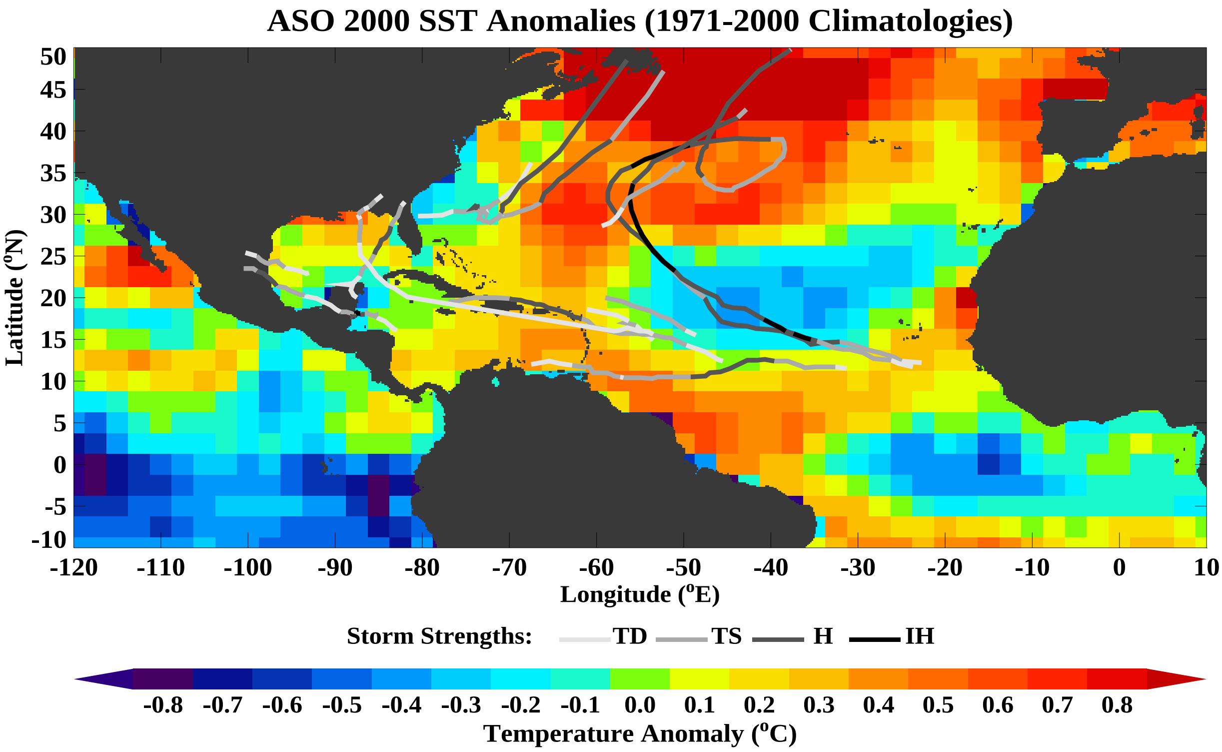

Figure 1: Sea Surface Temperature Anomalies for August-September-October 2000

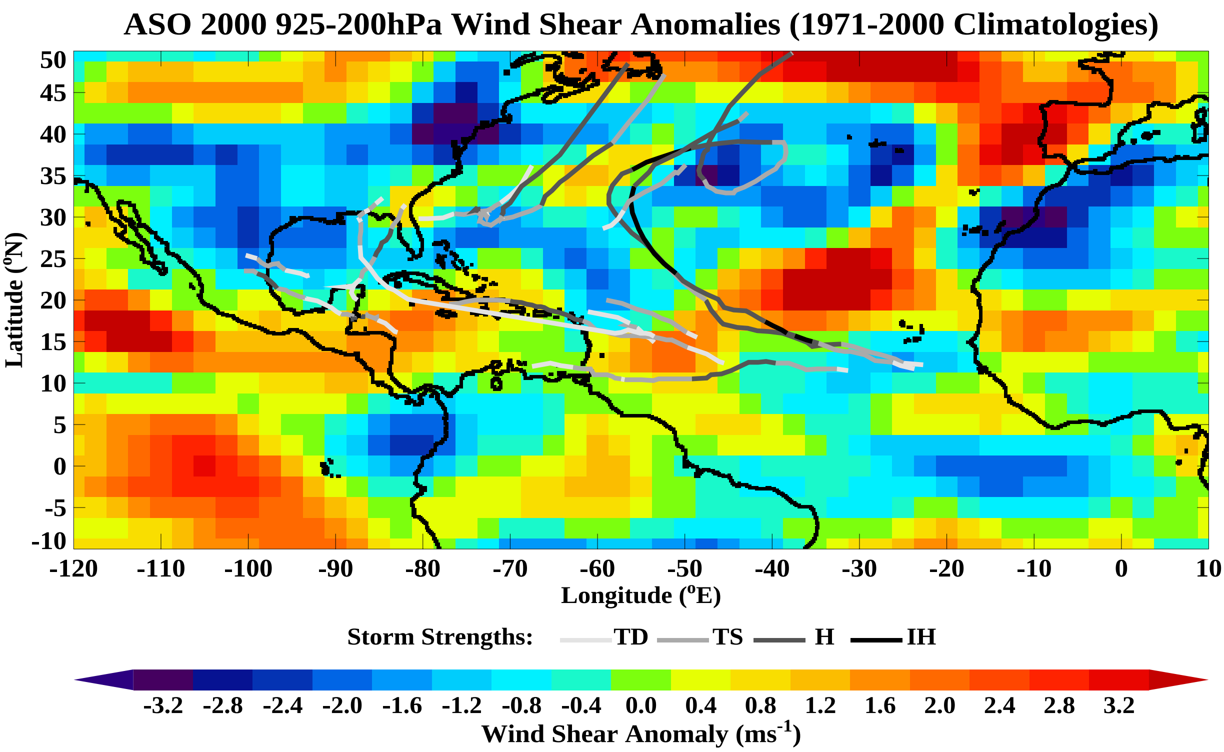

Figure 2: Vertical Wind Shear Anomalies for August-September-October 2000

The ASO 2000 anomalies for vertical wind shear are shown in Figure 2. Strong positive anomalies occur in a zone running diagonally from 15^{o}N, 60^{o}W, to 30^{o}N, 20^{o}W. Whilst Alberto and Isaac developed initially in low shear regions south of this zone, they managed to intensify while crossing it. Unusually, four storms developed in anomalously high shear regions. The remaining MDR storm (Joyce) skirted this zone's southern limits. Of further interest, the Caribbean saw generally high shear levels whilst the reverse was true in the Gulf, perhaps explaining why 3 storms formed in the latter and only 1 in the former. The extra-tropical Atlantic experienced slightly lower than usual vertical wind shear.

Figure 3 displays the ASO 2000 925hPa U-Wind anomalies. These were generally negative, though in our Caribbean main predictor region, they were close to neutral. The values in this figure are not readily consistent with the 2000 season being so active, particularly in the tropical north Atlantic.

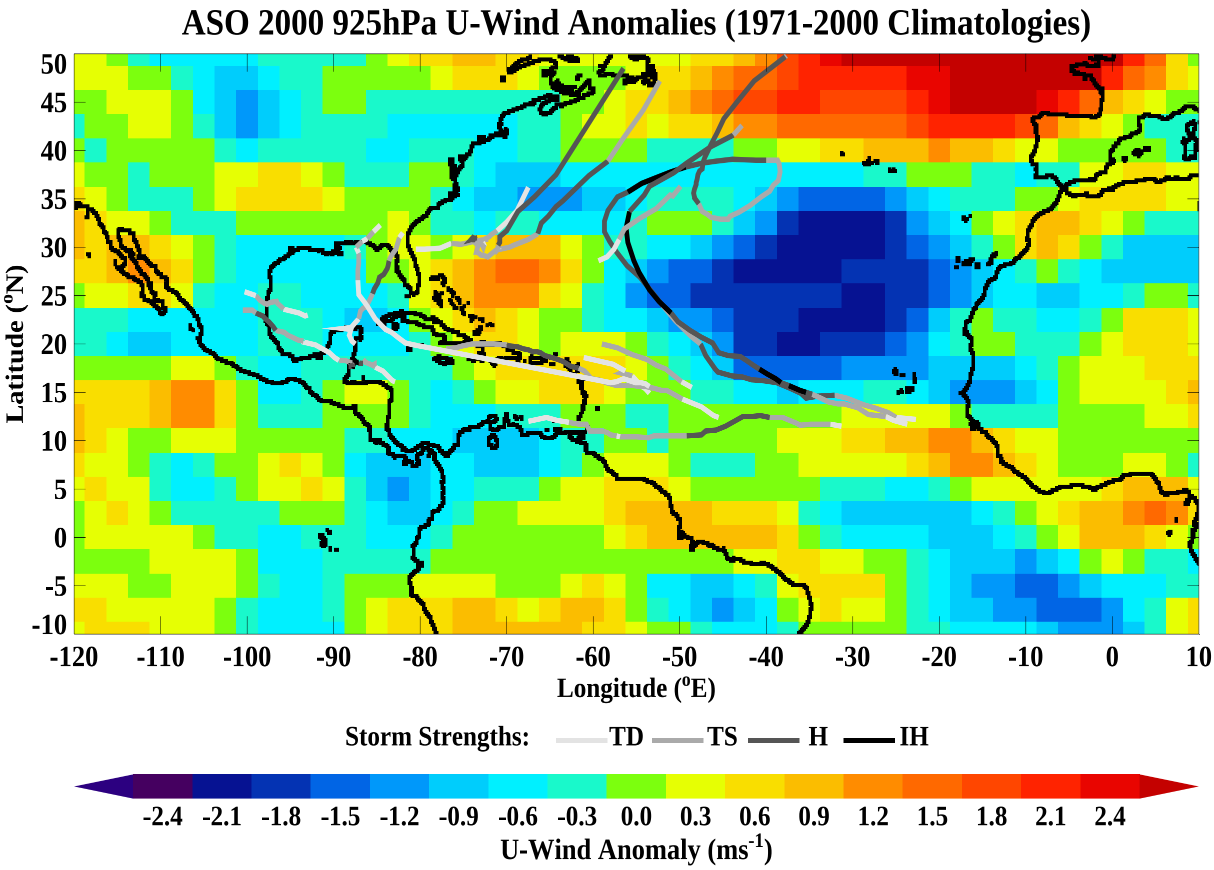

Figure 3: 925hPa U-Wind Anomalies for August-September-October 2000

3. Why Were US Landfalls Below Average for an Active Season?

There was slightly above average wind shear (Figure 2) in a region of the Atlantic where US landfalling hurricanes often form - west of 45^{o}W and into the Caribbean and the eastern part of the Gulf. This seemed to prevent the intensification of some storms (Beryl, Chris, Ernesto and Helene - Keith intensified despite the shear which in any case had weakened somewhat by the end of September) and assisted in weakening the most likely candidates for US hurricane landfalls (while they were active) - Debby and Gordon.

Away from this region the wind shear was generally below average. However, the high pressure region over the Azores was stronger than normal and there was also a small low pressure anomaly off the US East Coast (Figure 4). This led to anomalously strong southerly winds in the region 45-70^{o}W and north of 25^{o}N. It seems likely that this feature caused hurricanes Alberto and Isaac to be pulled northwards and recurve early (at around 60^{o}W). It may also have caused hurricanes Michael and Florence (which both formed around 75^{o}W, 30^{o}N) to be drawn away from the US coast - storms forming in this region can sometimes track northward and affect Cape Hatteras and the New England coast before recurving. By contrast southerly winds in the Gulf of Mexico/West Caribbean were weaker than usual. Of the three systems that formed here, two moved nearly westwards and thus struck northern Mexico rather than the US Gulf coast. One, hurricane Keith, formed almost exactly where Hurricane Mitch did in 1998. Their initial tracks are very similar but in 1998 the southerlies were much stronger and eventually moved Mitch north-east towards the Gulf coast of Florida.

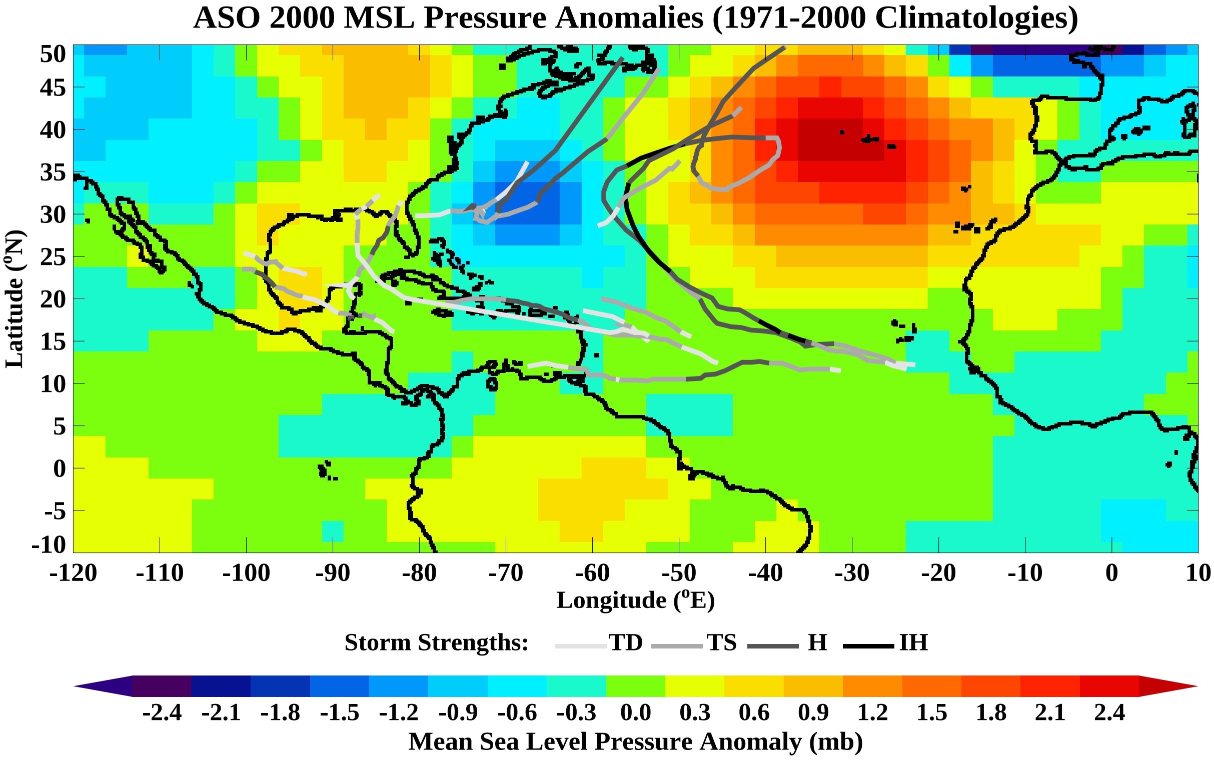

Figure 4: Sea Level Pressure Anomalies for August-September-October 2000

Definitions

Definitions				
Tropical Cyclone Type	**Category**	**Peak 1-Min Sustained Wind**		**Minimum Pressure (mb)**
		knots	**mph**	
Tropical Storm	TS	34-63	39-73	-
Hurricane	1	64-82	74-95	>980
Hurricane	2	83-95	96-110	965-980
Hurricane	3	96-113	111-130	945-965
Hurricane	4	114-135	131-155	920-945
Hurricane	5	>135	>155	<920

Our forecast is validated using track data obtained from the Unisys Weather Website (http:\\weather.unisys.com). Position and maximum windspeeds are supplied at 6-hour time intervals. We interpolate these to 15-minute intervals.

Future Forecasts and Verifications

1. Long-range forecast for the Australian 2001/02 cyclone season will be issued in April and an end-of-season summary for the 2000/01 season will be released in May.
2. Pre-season forecasts for the Atlantic and NW Pacific 2001 seasons will be issued in early June.

Tropical Storm Risk.com (TSR)

TropicalStormRisk.com (TSR) is a venture which has developed from the UK government-supported TSUNAMI initiative project on seasonal tropical cyclone prediction. The TSR consortium comprises leading UK insurance industry experts and scientists at the forefront of seasonal forecasting. The TSR insurance expertise is drawn from the UK composite and life company *CGNU Group*, the *Royal and Sun Alliance* insurance company, and *Benfield Greig*, a leading independent global reinsurance and risk advisory group. The TSR scientific grouping brings together climate physicists, meteorologists and statisticians at *UCL* (University College London) and the *Met. Office*. TSR forecasts are available from http://tropicalstormrisk.com.

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