How well forecast were the 2004 and 2005 Atlantic and US hurricane seasons?

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The 2004 and 2005 hurricane seasons with seven intense hurricane landfalls on the US and an estimated total damage bill of over US$200 billion (Swiss Re 2005, 2006) rank as the most active and damaging consecutive hurricane years on record. The 2005 North Atlantic hurricane season was the most active and destructive on record. It included four intense hurricane landfalls on the US (intense hurricanes have 1-min sustained wind speeds of at least 111 mph or 178 km hr^{-1}) and caused a total damage bill estimated at nearly US$180 billion (Swiss Re 2006). The most notable event was hurricane *Katrina*, the most damaging hurricane and costliest US natural disaster ever. *Katrina* killed over 1300 people and caused a staggering total loss estimated at US$135 billion.

This paper examines how well the publicly-available seasonal outlooks anticipated the exceptionally high Atlantic and US hurricane activity in 2004 and 2005. It compares the performance of forecasts (deterministic and probabilistic) issued by different centres at different lead times. The paper also shows that seasonal forecast precision, reinforced by the forecast successes in 2004 and 2005, is now high enough to offer practical benefits.

2004 and 2005 hurricane seasons

The 2004 hurricane season was one of the worst on record with a total damage bill of US$56 billion (Bell *et al.* 2005; Swiss Re 2005). Florida was struck by four hurricanes (three of which were intense). This was the first time a single US state had been struck by so many hurricanes since four hurricanes hit Texas in 1886.

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* The authors are involved with the production of the Tropical Storm Risk forecasts discussed in this article.

The 2005 hurricane season set numerous seasonal, monthly and single storm records (Bell *et al.* 2006; Lea and Saunders 2006; Wikipedia 2006). The seasonal records broken include:

- Highest number of named tropical storms: 27. *Previous record was 21 set in 1933.*
- Highest number of hurricanes: 15. *Previous record was 12 set in 1969.*
- Highest number of category 5 hurricanes: 4 (*Emily, Katrina, Rita* and *Wilma*). *Previous record was 2 set in 1960 and 1961.*
- Highest number of intense (category 3 or greater) hurricanes to strike the US: 4. *Previous record was 3 set in 1893, 1909, 1933, 1954 and 2004.*
- Highest insured damage from a hurricane season: US$67 billion (Swiss Re 2006). *Previous record was US$28 billion (Swiss Re, 2005) set in 2004. If normalised losses are used (i.e. the estimated insured losses that storms from the past would make under current societal conditions) then 2005 ranks second after 1926.*
- Highest number of intense hurricanes within the Gulf of Mexico: 5. *No other year since 1950 has had more than two intense hurricanes in the Gulf.*
- Latest end to a hurricane season: 6 January. *Previous record was 5 January set in 1954/5.*
- First occasion the North Atlantic has had more tropical storms than the North-West Pacific. The North-West Pacific basin had 24 tropical storms in 2005.

Figure 1 shows a montage of the four hurricanes approaching Florida in 2004. Figure 2 shows a montage of the five intense hurricanes responsible for the US$180 billion damage bill in 2005. The latter all made landfall around the Gulf of Mexico. The high Atlantic hurricane activity in 2004 and 2005 appears due to a combination of warm sea surface temperatures and weaker than normal trade winds over the tropical North

Fig. 1 Composite satellite image of hurricanes Charley, Frances, Ivan and Jeanne 'targetting' Florida in August and September 2004. Image courtesy of Univ. Wisconsin-Madison, Space Science and Engineering Center.

Fig. 2   Composite satellite image of intense hurricanes Dennis, Emily, Katrina, Rita *and* Wilma *in 2005. The storms all made landfall around the Gulf of Mexico causing nearly US$180 billion in damage. The smaller size of* Dennis *and* Emily, *compared to* Katrina, Wilma *and* Rita, *is evident. Image courtesy of Univ. of Wisconsin-CIMSS.*

Atlantic and Caribbean Sea. The high US landfalling hurricane activity in 2004 and 2005 appears due to steering currents that favoured storms being steered towards the US rather than recurving at sea (Saunders and Lea 2005; Klotzbach and Gray 2006).

Seasonal forecast comparison

Four main organisations provided publicly-available seasonal outlooks for North Atlantic and US landfalling tropical cyclone activity in 2004 and 2005. These were Tropical Storm Risk (TSR) (http://www.tropicalstormrisk.com) led by the Benfield Hazard Research Centre at University College London, Colorado State University headed by Prof. W. Gray (http://typhoon.atmos.colostate.edu), the National Oceanic and Atmospheric Administration (NOAA) (http://www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml), and the Meteorological Institute, Cuba. In both years TSR issued monthly updated forecasts from early December through to early August. Colorado State issued forecasts in early December, early April, the end of May, early

August, early September and early October. NOAA and the Meteorological Institute, Cuba issued forecasts in early to mid-May and early August. Two of the groups, TSR and NOAA issued probabilistic and deterministic forecasts for Atlantic basin activity. TSR also issued probabilistic forecasts for US landfalling hurricane activity. The probabilistic forecasts gave the likelihoods that activity will be in the top, middle and lowest one-third of years since 1950. These tercile levels are defined respectively as 'high', 'medium' and 'low activity' years.

Forecast accuracy is assessed for tropical storm numbers, hurricane numbers, intense hurricane numbers and for the total Atlantic and US ACE indexes. The ACE (Accumulated Cyclone Energy) index is defined as the sum of the squares of the windspeeds of all storms for each six-hourly best track location whilst they are at least tropical storm in strength (Waple *et al.* 2002). Since the ACE index is sensitive to storm numbers, storm intensity and storm duration, it provides a better indication of overall activity than just considering the numbers of tropical storms or hurricanes. The US ACE index (Saunders

and Lea 2005) is defined as the sum of the squares of hourly windspeeds from storms over the US mainland that were at least tropical storm in strength. The US ACE index is strongly linked to US hurricane insured loss with a rank correlation of 0.68 over the period 1900–2005. The skill of the tercile probability forecasts is computed using the standard measure called the *rank probability skill score* (RPSS) (Wilks 1995; Goddard *et al.* 2003). The maximum RPSS is 1 and a positive RPSS indicates skill better than climatology.

All forecast groups predicted correctly that the 2004 Atlantic hurricane season would have above-average activity but underpredicted its very high values (Table 1). This includes the extended range forecasts issued by TSR and Colorado State in early December 2003. The TSR early August forecast proved marginally the most skilful prior main-season forecast (historically 95% of US intense hurricane landfalls and hurricane losses occur after 31 July). The tercile probabilistic forecasts for total Atlantic activity in 2004 (Fig. 3(a)) showed good skill back to early December 2003. All the TSR probabilistic forecasts (except early June) were more skilful than NOAA's May and August probabilistic forecasts. The probabilistic forecasts for the US ACE index (Fig. 3(b)) showed good skill predicting at all leads except early June that US landfalling hurricane activity in 2004 would be in the upper tercile (top one-third of years historically) to high (60–70%) probability. The February and August forecasts performed best with an RPSS of around 0.8.

The record-breaking 2005 hurricane season was correctly predicted by all groups to be more active than normal (Table 2). TSR's extended-range forecast in December 2004 called for activity 50% above norm. However, the full extent of the exceptional activity in 2005 was not anticipated until the pre-main season forecasts in early August. The TSR August forecast performed best overall, correctly predicting the ACE index value and that the number of tropical storms would break the previous Atlantic record. The TSR extended range forecast issued in early December 2004 outperformed that by Colorado State. The tercile probabilistic forecasts for total Atlantic activity (Fig. (4a)) showed very good skill back to early December 2004 with the August forecast having perfect skill (RPSS of 1). All the TSR probabilistic forecasts outperformed NOAA's May probabilistic forecast. The US landfalling probabilistic forecasts (Fig. 4(b)) showed very good skill predicting high (upper-tercile) US landfalling hurricane activity to 65% probability as far back as December 2004, rising to 85% probability in early August. The August (Saunders and Lea 2005) and July forecasts performed best overall with an RPSS of over 0.9.

Table 1

North Atlantic Hurricane Activity Deterministic Forecasts 2004

		ACE Index	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (1950–2003)		95 (±54)	2.5 (±1.9)	6.0 (±2.3)	9.9 (±3.3)
Actual Number 2004		228	6	9	15
TSR Forecasts (±FE*)	4 Aug 2004	145 (±36)	3.1 (±1.3)	7.6 (±1.1)	14.0 (±2.4)
	5 Jul 2004	114 (±36)	2.6 (±1.4)	6.6 (±1.3)	12.3 (±2.4)
	4 Jun 2004	101 (±34)	2.4 (±1.3)	6.1 (±1.5)	11.7 (±2.1)
	11 May 2004	120 (±40)	2.7 (±1.3)	6.8 (±1.8)	12.6 (±2.6)
	6 Apr 2004	128 (±50)	2.9 (±1.5)	7.2 (±2.1)	13.1 (±3.2)
	5 Mar 2004	122 (±53)	2.8 (±1.5)	7.0 (±2.4)	12.8 (±3.6)
	5 Feb 2004	139 (±53)	3.1 (±1.5)	7.6 (±2.4)	13.7 (±3.5)
	6 Jan 2004	132 (±59)	2.9 (±1.6)	7.2 (±2.6)	13.3 (±3.9)
	5 Dec 2003	132 (±59)	2.9 (±1.6)	7.2 (±2.7)	13.0 (±4.0)
Colorado State Forecasts	6 Aug 2004	–	3	7	13
	28 May 2004	–	3	8	14
	2 Apr 2004	–	3	8	14
	5 Dec 2003	–	3	7	13
NOAA Forecasts	7 Aug 2004	103–146	3–4	7–9	12–15
	19 May 2004	95–155	2–4	6–8	11–15
Meteorological Institute, Cuba Forecasts	1 Aug 2004	–	–	8	12
	2 May 2004	–	–	6	10

Average numbers computed from North Atlantic hurricane database available at http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html

*FE = Forecast Error   ACE Unit = ×10^4 knots^2

Table 2

North Atlantic Hurricane Activity Deterministic Forecasts 2005

		ACE Index	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (1950–2004)		98 (±57)	2.6 (±1.8)	6.0 (±2.4)	9.9 (3.3)
Actual Number 2005		250	7	15	27
TSR Forecasts (±FE*)	5 Aug 2005	249 (±36)	6.6 (±1.2)	11.4 (±1.5)	22.1 (±2.3)
	7 Jul 2005	190 (±42)	4.1 (±1.5)	8.8 (±1.9)	15.3 (±2.4)
	7 Jun 2005	159 (±42)	3.5 (±1.4)	7.8 (±1.9)	13.8 (±2.2)
	5 May 2005	158 (±44)	3.6 (±1.4)	7.8 (±2.1)	13.9 (±2.6)
	5 Apr 2005	155 (±50)	3.6 (±1.5)	7.8 (±2.1)	13.9 (±2.9)
	7 Mar 2005	156 (±52)	3.6 (±1.6)	7.9 (±2.3)	14.0 (±3.2)
	9 Feb 2005	151 (±53)	3.5 (±1.6)	7.7 (±2.3)	13.6 (±3.3)
	5 Jan 2005	157 (±56)	3.6 (±1.6)	7.8 (±2.4)	13.9 (±3.5)
	10 Dec 2004	145 (±56)	3.4 (±1.6)	7.5 (±2.5)	13.4 (±3.6)
Colorado State Forecasts	5 Aug 2005	–	6	10	20
	31 May 2005	–	4	8	15
	1 Apr 2005	–	3	7	13
	3 Dec 2004	–	3	6	11
NOAA Forecasts	2 Aug 2005	158–236	5–7	9–11	18–21
	16 May 2005	105–166	3–5	7–9	12–15
Meteorological Institute, Cuba Forecasts	1 Aug 2005	–	–	9	20
	2 May 2005	–	–	7	13

Average numbers computed from North Atlantic hurricane database available at http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html
*FE = Forecast Error   ACE Unit = ×10^4 knots^2
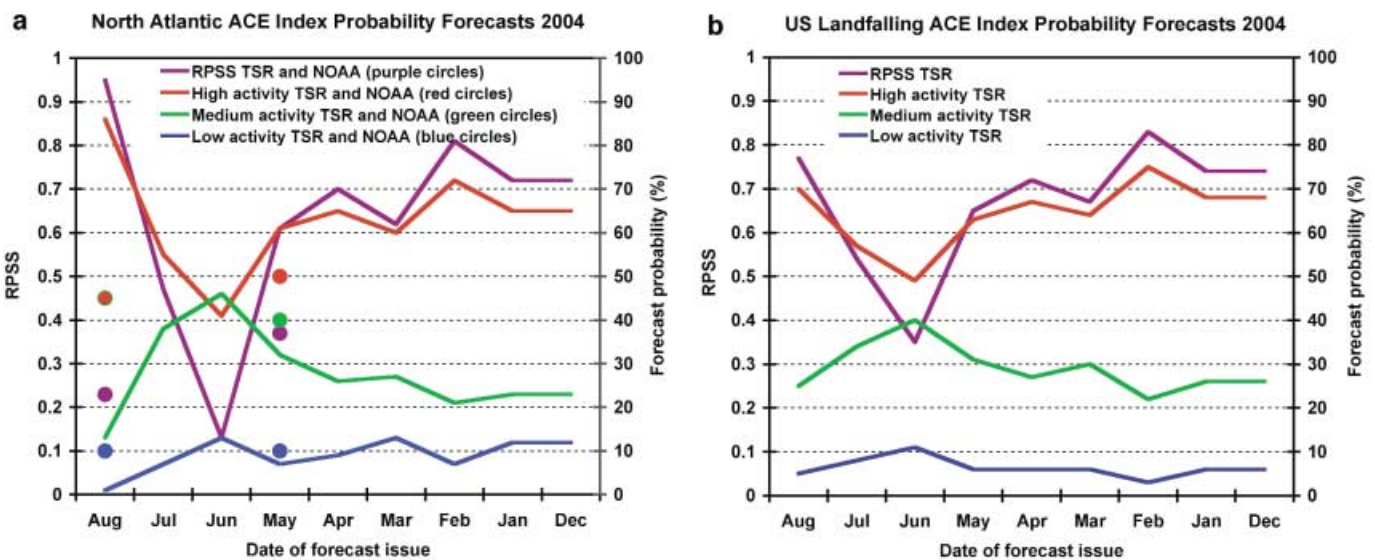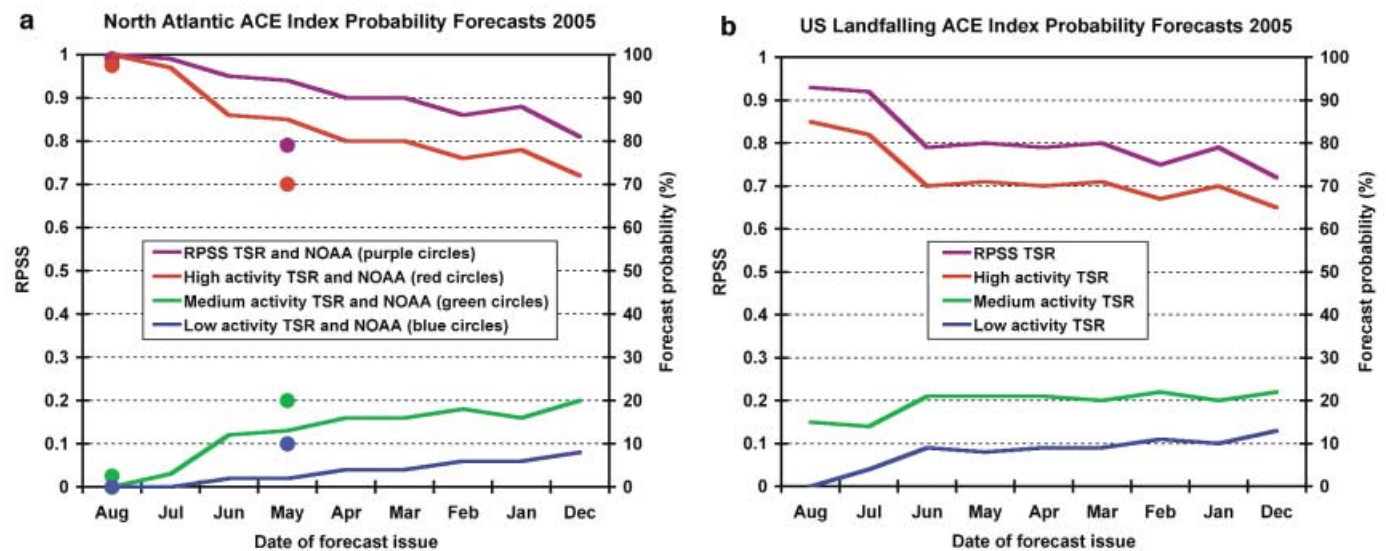
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Fig. 3 Verification of the publicly-available tercile probabilistic forecasts issued in 2004 for (a) the North Atlantic ACE index and (b) for the US ACE index. RPSS is the rank probability skill score of the probabilistic forecasts. High, medium and low activity denotes the forecast likelihood that the ACE index in 2004 would be in the upper, middle and lower one third of years historically (1950–2003). The vertical axis displays both the RPSS (left-hand side) and the forecast probability for each tercile (right-hand side).

Fig. 4 Verification of the publicly-available tercile probabilistic forecasts issued in 2005 for (a) the North Atlantic ACE index and (b) for the US ACE index. See Fig. 3 for definitions.

Forecast business application

The TSR early August forecast model (Saunders and Lea 2005) anticipates correctly whether US hurricane losses are above-median or below-median in 74% of the years between 1950 and 2003. The rank correlation link between these hindcast US ACE indexes and US hurricane insured loss is 0.48 for this 54-year period. This skill, reinforced by the success of the early August seasonal US landfalling hurricane forecasts for 2004 and 2005 (Figs. 3(b) and 4(b)), suggests that forecast precision from early August is now high enough to offer potential benefits to a range of US industry whose returns are affected by hurricane damage.

One such industry is the insurance industry.

Figure 5 shows the potential financial benefit to an individual insurance company of using the TSR early August forecasts. The diagram displays the probability of a US hurricane season's total insured loss conditional on the TSR forecast. The chance of a large total loss is clearly much higher in years when the forecast is high. For example, a total hurricane insured loss of $10 billion is eight times more likely to occur when the forecast is high compared to when it is low. Clearly if extra reinsurance cover were purchased in the high forecast years, a company's volatility in losses (or risk) would be reduced. One measure of volatility is the Expected Shortfall (ES) – the average loss

that can be expected every, say, 100 years. For the 1 in 100-year loss ES has values of $20 billion (low forecast), $40 billion (medium forecast) and $100 billion (high forecast).

For the damaging 2004 and 2005 hurricane seasons, the TSR early August forecasts predicted US landfalling hurricane activity in the upper quartile and upper decile respectively. Thus, TSR would have recommended that insurance companies purchase extra protection. By following this forecast guidance, individual insurers (and others whose returns are affected by US hurricane damage) could have reduced their losses in 2004 and 2005.

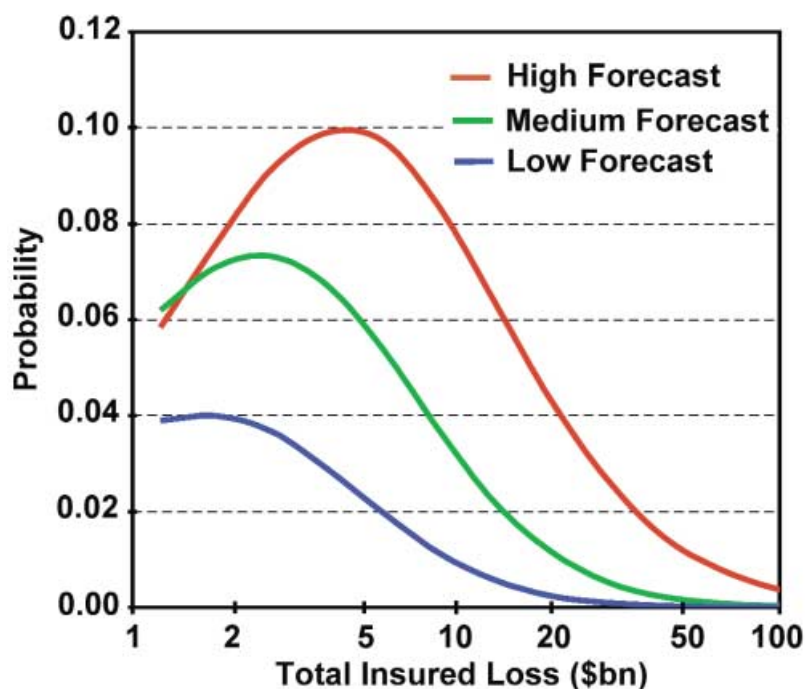A methodology which allows insurers and reinsurers to use these seasonal hurricane

Fig. 5 Probability of total US hurricane insured loss contingent on whether the TSR forecast for US landfalling hurricane activity issued on 1 August is high, medium or low (Saunders and Lea 2005)

forecasts to better manage their business and, potentially, rethink business decisions, has been developed recently by TSR and the Benfield ReMetrics team (Simmons and Saunders 2005). This methodology shows how the latest seasonal hurricane forecast:

- changes the expected or average level of US hurricane loss for the coming season,
- adjusts the expected likelihood of extreme losses for the coming US hurricane season and
- provides a better reference for the cost/benefit of adjustments to both outwards and inwards reinsurance.

Summary

The 2004 and 2005 Atlantic and US landfalling hurricane seasons were both predicted to have 'high activity' (i.e. within the top one third of years historically) to high (65–70%) probability from the previous December. By early August the forecast likelihood that US landfalling hurricane activity would be 'high' rose to 70% (2004) and 85% (2005). Overall the TSR forecasts slightly outperformed those from the other forecast groups (certainly the case for US landfalling hurricane activity). The recent advances in the seasonal prediction of hurricane activity reaching the coast of the United States (Saunders and Lea 2005) reinforced by the forecast successes in 2004 and 2005 show that the precision of seasonal hurricane forecasts from early August is now high enough to be practically useful.

Outlook for 2006

Current indications point to 2006 being another high activity Atlantic hurricane season. However, there is disagreement amongst the forecasters as to exactly how active. The Tropical Storm Risk early July forecast anticipates the Atlantic and US ACE indexes in 2006 being 40% above the long-term (1950–2005) norm (this compares to a forecast of 95% above-norm issued in early July 2005). The NOAA pre-season forecast for 2006 anticipates the Atlantic ACE index being 15–75% above the long-term norm. The Colorado State University pre-season outlook for 2006 anticipates overall activity being 95% above the 1950–2000 norm. Taking the average of the three current forecasts suggests that hurricane activity in 2006 will be notably below the record-breaking levels seen in 2005.

Acknowledgements

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