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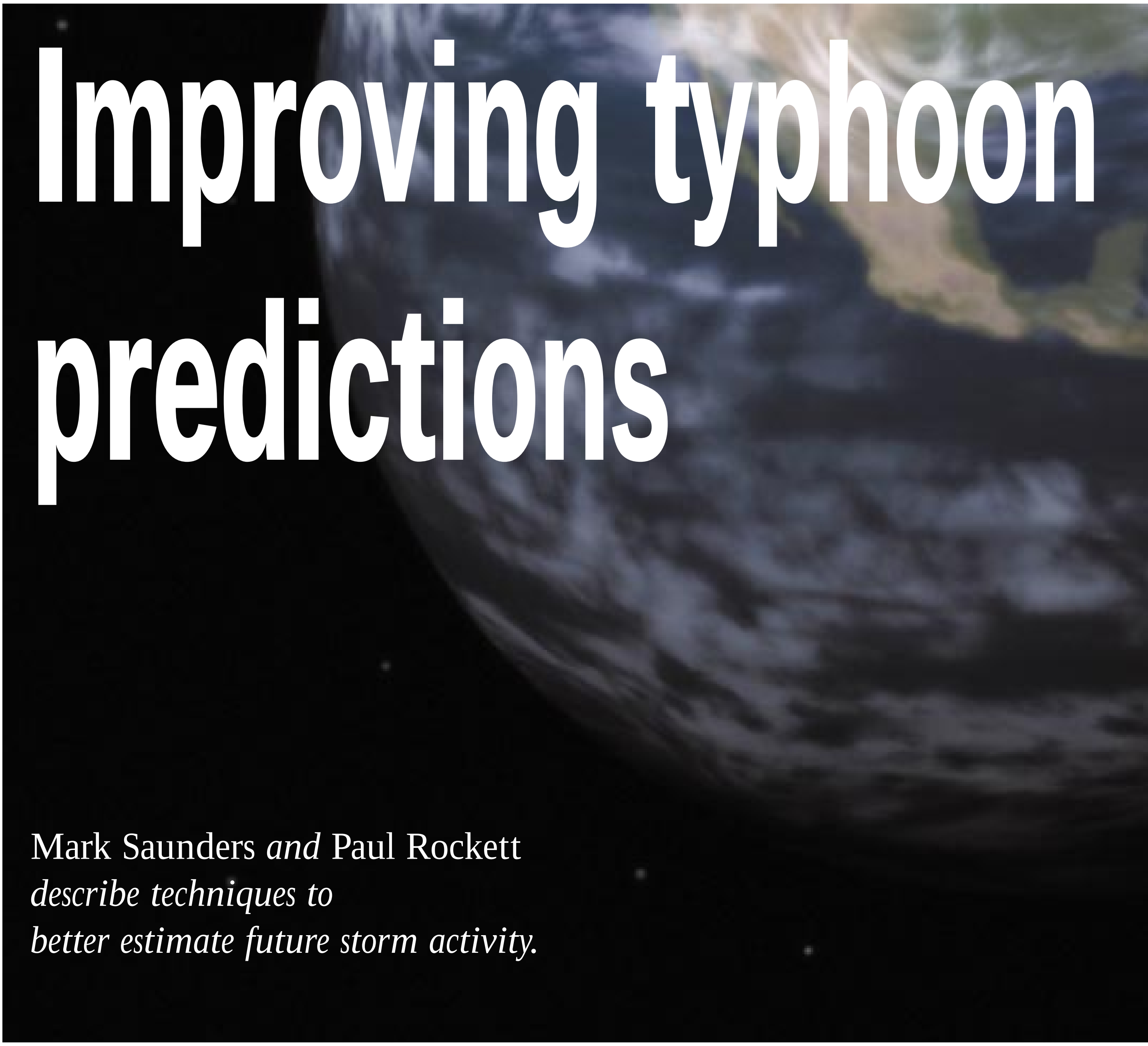


Improving typhoon predictions

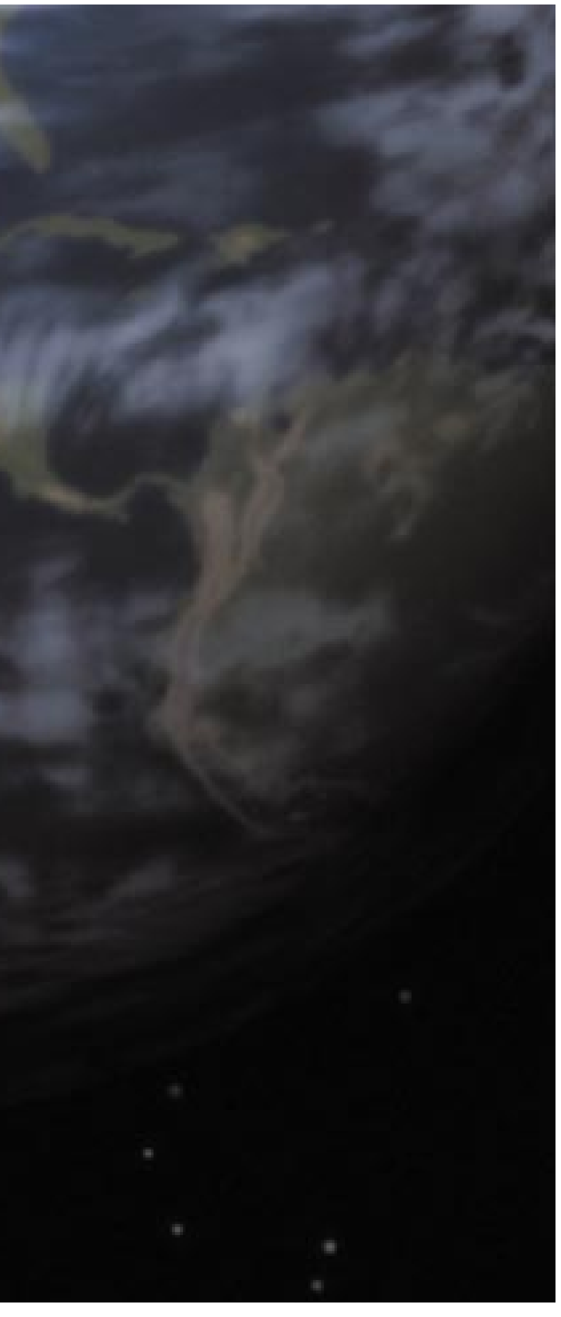
Mark Saunders *and* Paul Rockett *describe techniques to better estimate future storm activity.*

Tropical cyclones are the most costly and deadly type of natural disaster affecting much of Japan, South Korea, Taiwan, the Philippines and coastal areas in other east Asian countries. The annual damage bill and fatality rate impacts in east Asia 1990-1999 averages respectively US$3.3bn and 740 deaths. However, substantial inter-annual variability exists in regional tropical cyclone losses. For example, in 1991 and 1988 Japan experienced losses of $7.5bn and zero respectively, measured in 2000 dollars.

Typhoons, described as one minute of sustained winds of over 73mph (63 knots), and intense typhoons one minute of sustained winds of over 110mph (95 knots), cause the vast majority of the damage and death from tropical cyclones in east Asia. The 1991-2000 period has seen an annual average of 9.1 intense typhoons and 17.8 typhoons in the northwest Pacific basin, and an annual average typhoon strike rate on Japan, Taiwan and the Philippines of 2.4, 1.7 and 1.9 respectively. Already the 2001 season has seen several typhoons make landfall on east Asian shores (figure 1).

Skilful typhoon predictions will benefit insurers and reinsurers, as well as society, government and other businesses by reducing the risk, uncertainty and financial volatility inherent to varying active and inactive tropical storm seasons. Predictions are a relatively new resource for the industry and, understandably, confidence in their quality needs building before insurance and reinsurance executives employ them routinely in business decisions. The purpose of this article is to describe the typhoon predictions now available, their methodologies and skill, and the prospects for further improvements in the coming years.

2001 has been a busy year for tropical storm landfalls in east Asia. This GMS satellite image (Figure 1) shows typhoon Utor striking Hong Kong and southern China on 5 July, 2001. Utor killed at least 23 in China, 121 in the Philippines and one person in Taiwan. It was one of the strongest storms to strike the region in



recent years with flood and wind damage in the southern Chinese province of Guangdong alone estimated at US$290m. Utor also caused most of Hong Kong to shut down for business for two days. (Image courtesy of Tim Olander, University of Wisconsin-Madison Cooperative Institute for Meteorological Satellite Studies, US.)

Methodologies

Typhoon predictions come in two types: seasonal forecasts of overall activity for the coming season, and track and intensity forecasts for individual events with up to five days lead time. Forecast models are of two main forms, based either on a statistical analysis of the past behaviour of storms (statistical forecasts) or from an application of our knowledge of the physics of the atmosphere and ocean (dynamical forecasts).

Seasonal forecasts

Seasonal forecasts provide an idea of the level of typhoon activity to anticipate during the coming season. In the northwest Pacific, typhoons can occur in all months of the year, but historically 90% of activity happens after 1 June each year, making this, for practical purposes, the start of the main typhoon season.

A number of organisations now issue seasonal forecasts for the Atlantic, northwest Pacific and Australian basin regions. Northwest Pacific seasonal typhoon forecasts are issued by the University of Hong Kong (see http://aposf02.cityu.edu.hk/~mcg/index.htm) and by the TropicalStormRisk.com (TSR) venture (see http://www.tropicalstormrisk.com). These forecasts began routinely in 2000. The University of Hong Kong predictions are issued in early April, and are updated in June. The TSR forecasts are issued in late May/early June, and for the 2002 season will be available updated monthly from early April to early August. These forecasts provide an indication of the numbers of tropical storms of various intensities that can be expected in the season ahead.

While it is impossible to give forecasts of precise positions of landfall at such long range, predictions can be made of the risk to broad regions, such as Japan or the south China coast. These forecasts are often probabilistic in nature. They are derived from a statistical assessment of the major climatic factors affecting tropical cyclone activity in each region. These factors may be either contemporaneous or lagged.

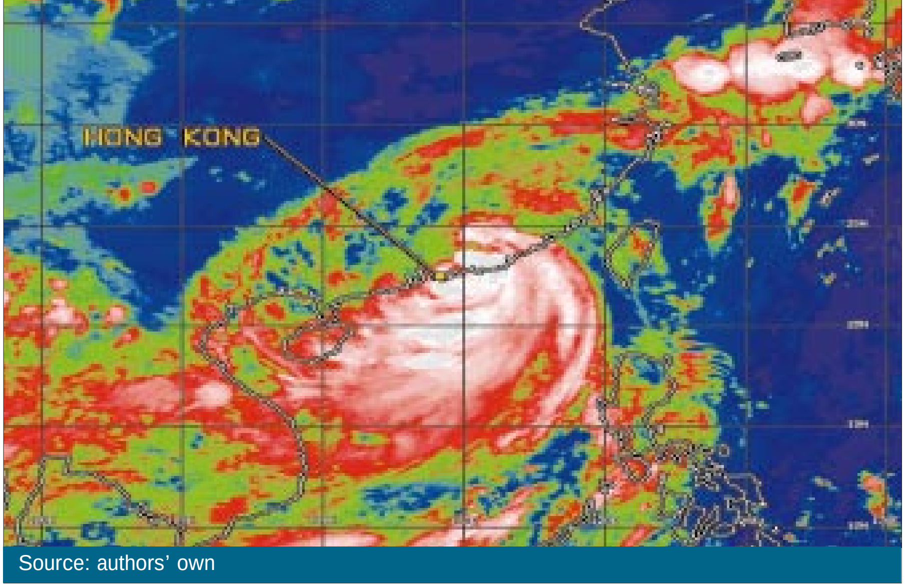
Lagged factors are climatic conditions prevailing at the time of the forecast that are known to be precursors of typhoon activity in the coming season. Contemporaneous factors are climatic conditions that prevail during the main typhoon season itself. In order for contemporaneous factors to be useful in seasonal typhoon forecasts they must be sufficiently predictable themselves at the necessary lead times. ENSO (El Niño-Southern Oscillation) is an example of a contemporaneous predictor useful in typhoon seasonal forecasts. High (low) typhoon activity is observed when ENSO is in its positive (negative) phase during the main typhoon season from July to October.

Intensity forecasts

Accurate typhoon forecasts not only save lives, but can be used as a risk quantification tool for insurers and reinsurers once a storm has formed. If the risk of landfall can be quantified in near real-time, enterprising executives can use loss estimates to optimise capital, organise claims response units and even trade catastrophe bonds.

When a tropical cyclone is active, forecasts of the storm position and maximum winds at 12, 24, 36, 48, 72, 96 and even 120 hours ahead are issued every six hours by the meteorological agency with warning responsibility in the region of

Figure 1: Typhoon Utor striking Hong Kong



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“ The only near certainty in forecasting is that the forecast will be wrong.”

the storm. For the northwest Pacific, the two main sources are the Japan Meteorological Agency (http://ddb.kishou.go.jp/typhoon/cyclone/cyclone.html) and the US Navy and Army Joint Typhoon Warning Center (JTWC) on Guam (http://www.npmoc.navy.mil/jtwc.html). Forecasters at these centres consider independent predictions made by a number of dynamical and statistical prediction models produced both in-house and by other organisations. The JTWC, for example, takes guidance from the UK Meteorological Office and the NOAA Geophysical Fluid Dynamics laboratory amongst others.

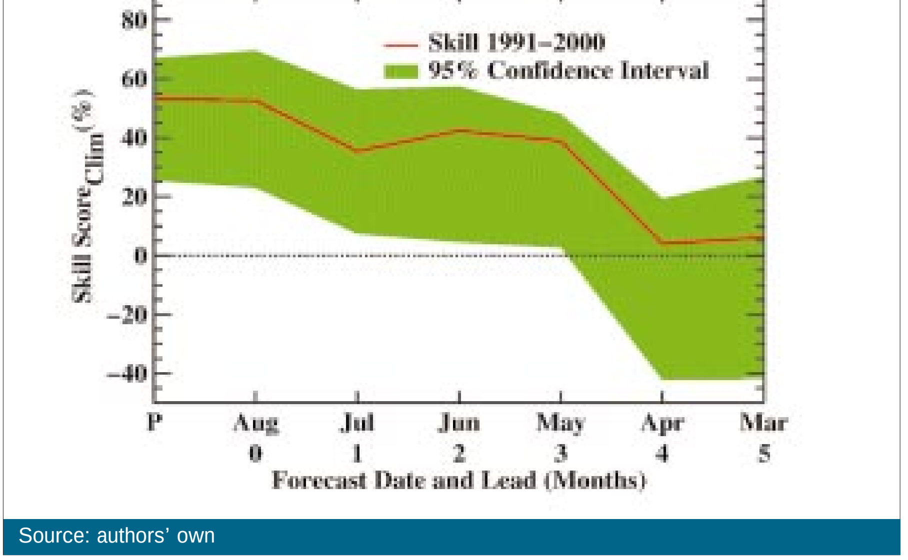
Dynamical models

Dynamical models use state-of-the-art computing techniques to apply our knowledge of the physics of the atmosphere and ocean to forecast what may occur ahead, knowing its initial state. To achieve this, the atmospheric system must be simplified sufficiently to allow the model runs to be completed in time to make a useful forecast. This is done either by calculating the atmospheric variables (temperature, humidity, windspeed, etc.) at certain grid points only, or by representing the distribution of these variables through the atmosphere by a set of mathematical equations, the parameters of which are calculated.

Dynamical models can be applied to the whole atmosphere (global models) or to smaller local areas (local models). Despite recent advances in model resolution (current gridded global dynamical models typically have a resolution of about one degree in latitude and longitude with around 20 levels through the atmosphere), global models are still too coarse to represent the important physical processes within a typhoon. In some global models this is overcome by using a ‘bogussing’ scheme. Under such a scheme, once a suspect tropical cyclone is identified artificial data is introduced into the model to better represent the storm.

Dynamical models have good uses in many operational track forecasting situations. They are not employed generally for seasonal predictions, since even tiny errors in the initial state of the model can become massively amplified when forecasting at long lead times. This is a result of the well-known ‘Butterfly Effect’. Attempts have been made to use dynamical models to investigate future changes in typhoon activity due to global warming, but to date the results have proved inconclusive.

Figure 2: typhoon seasonal prediction skill



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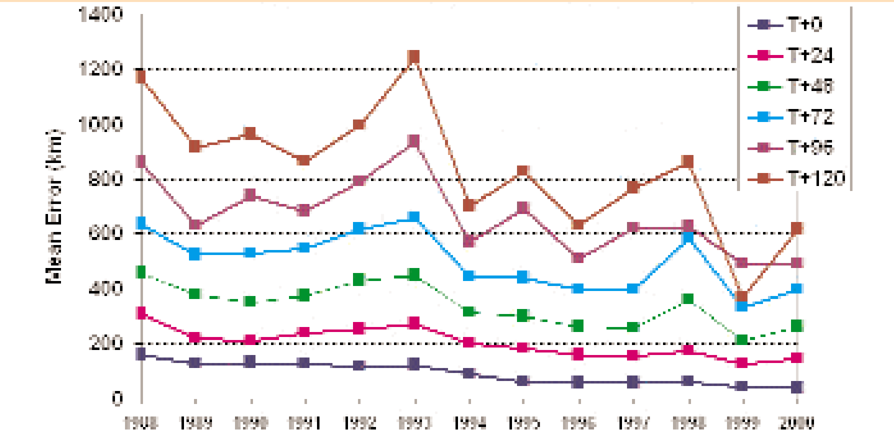
Statistical models

Statistical methods are used in all types of typhoon predictions: seasonal, track and intensity forecasts. In all cases, analyses of past data are made to quantify the probability of an event occurring, given certain conditions. Linear regression analysis is applied to past data to identify links between the desired forecast quantity and potential predictors. Predictors which have a strong statistical link to the forecast quantity are incorporated into a linear prediction model. In the case of seasonal forecasting, the predictors are climatic factors which strongly influence tropical cyclone frequency in the regions of interest.

The advantage of statistical methods is that they are easier and quicker to run than dynamical models. In the case of seasonal predictions, they are more useful than dynamical models because they are free of the large amount of noise that results from the Butterfly Effect inherent in these models. On the downside, since they are based on (often limited) past data, they are likely to have little skill in situations not previously encountered (under changed climate conditions, for example). Dynamical models are not susceptible to this problem. Dynamical track and intensity models typically outperform their statistical equivalents.

Figure 2 illustrates the TSR (TropicalStormRisk.com) seasonal forecast skill for the annual number of typhoons forming in the northwest Pacific. The plot displays the mean skill (and 95% confidence interval) as a function of monthly lead from August to March. The skill measure is the percentage improvement in root mean square error

Figure 3: NorthWest Pacific tropical cyclone forecast positional errors – Met Office global model



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over the 1971-2000 climatology forecast. Positive skill indicates the forecast model performs better than climatology, while negative skill indicates it does worse than climatology. All hindcasts are made solely using prior data. The figure shows that reliable seasonal typhoon forecasts may be made as early as the beginning of May; 90% of annual typhoon activity occurs after 1 June.

Prediction skills

The only true proof of a forecast is its long-term track record, but how can one judge the potential accuracy and usefulness of the University of Hong Kong and TSR seasonal forecast models which have been operational only since early 2000? One good result does not mean that the method is foolproof, any more than one bad result means that it is useless. The only near certainty in forecasting is that the forecast will be wrong. Even forecasts with limited skill can have real value. If a forecast is better than climatology (that is than long-term averages) only six years out of ten, an investor in a portfolio of weather derivatives should make money.

The skill of a forecasting model can be assessed by hindcasting, that is, computing what the model would have predicted in prior years had it been available at that time. A hindcast for, say, the 1990 typhoon season is built using data up to and including 1989. Figure 2 shows that seasonal typhoon forecasts have useful skill from early May. The TSR pre-season forecast for 2000 performed particularly well. Issued on 26 May 2000, it called for 25 tropical storms, 14 typhoons, seven intense typhoons and two typhoons reaching Japan landfall. All of these predictions proved correct. TSR's further prediction of three tropical storms making landfall in Japan was the only one in error.

Overall, the 2000 northwest Pacific typhoon season saw slightly below average activity. The University of Hong Kong and TSR seasonal forecasts are calling for near-average typhoon activity in 2001.

Figure 3 shows forecast positional errors for tropical cyclones in the northwest Pacific 1988-2000 from the UK Met Office global forecast model (see http://www.metoffice.govt.uk/sec2/sec2cyclone/tcerrors/ for further information). Mean annual errors are shown for forecasts at leads of 0, 24, 48, 72, 96 and 120 hours. The mean is for all storms which formed during the year. The figure shows that forecast track errors are decreasing steadily. Errors at all leads have fallen by around 50% over the last decade. (Figure courtesy of Julian Heming, Met Office, UK).

Typhoon track forecasts have been operational for over a decade, so an assessment of their skill is straightforward. Figure 3 shows the performance of a well-respected track model – the UK Met Office global model – for tropical cyclone positional errors in the northwest Pacific. The annual mean error is shown for five lead times out to 120 hours. Errors have clearly reduced over the period at all leads, typically by 50%. The two main causes for this reduction are better real-time satellite data, such as winds and atmospheric humidity, being assimilated into models, and improvements in computational power. For comparison, the skill of current Atlantic tropical cyclone track forecasts is typically 10% better than the errors in Figure 3.

Future prospects

The outlook is bright for further innovations and improvement to both seasonal and track typhoon predictions. Seasonal forecasting of annual typhoon activity is a new area of research. As such, its full potential has not been explored. We can be certain that skilful seasonal forecasts of typhoon and intense typhoon activity are available from the beginning of May (figure 2), and that skill increases as the season progresses. The products and services on offer from TSR and the University of Hong Kong will continue to expand. Monthly updated forecasts will be available for the 2002 season, as will forecasts for new landfalling regions. The planned incorporation of dynamical model data into the TSR forecasts will be a further novel development, and may bring useful benefits. The key factor which would provide seasonal typhoon skill at leads prior to May is improved prediction of ENSO.

Typhoon track errors have not reached predictability limits, and will continue to fall as computers become more powerful, as satellites provide better real-time monitoring of tropical environmental conditions, and as computer models improve. Typhoon intensity forecasts are also expected to become more accurate in future seasons.

With the recognition that a major cause of death, injury and damage in typhoon landfalls is freshwater flooding, a number of research groups are beginning to focus on the prediction of rainfall in tropical cyclones at landfall, and advances may be expected.

Both seasonal and track forecasts of typhoons have skill which can benefit insurers and reinsurers in their business decisions and assessment of risk. By sharing forecasts with customers, risk awareness increases, and risk mitigation strategies can be developed. The skill of all forecasts will increase in the coming years with further research. GR

By Mark Saunders and Paul Rockett

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