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Tropical Cyclone Forecasting:
Linkage between Theory and Practice

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Introduction

Tropical cyclone forecasting is a business with high stakes. Forecasts have to be accurate to enable responsive actions to reduce damage and the loss of lives. Under-warning would mean inadequate preparation and consequently dramatic losses. Over-warning would mean the community wasting enormous amounts in futile preparations. The forecaster's life would be made easier if the landfall point could be accurately pinpointed in advance and if the location of heavy rain, high winds and storm surge could be equally predicted with precision especially around landfall time. His requirements are therefore sharply focused and quantitative in nature.

The pursuit of tropical cyclone research per se has its focus elsewhere. It seeks to understand the phenomenon from an intellectual perspective, finding answers to questions like structure, energetics and propagation mechanism. A model, conceptual or numerical or in the form of a set of equations, enabling the researcher to understand or explain the selected aspect of the tropical cyclone is often accepted as a satisfying end to the line of investigation. When presented with these research results, the front-line forecaster might feel enlightened about the science. But how to convert the better understanding into gains in terms of forecast accuracy remains a severe challenge.

This paper attempts to look at this difficult issue from a number of angles and to discuss what might be done to bridge the researcher and forecaster communities.

Forecasters' Wish List

According to enquiries made by the Typhoon Research Coordination Group of the ESCAP/WMO Typhoon Committee (Lam, 2000), the main topics of current interest in respect of tropical cyclone analysis and forecasting are:

(a) tropical cyclone vortex initialization in NWP models;

(b) application of satellite-derived surface wind and precipitation in analysis, for operation warning and for NWP;

(c) ensemble forecasting of tropical cyclone tracks, either in the true NWP sense or optimizing consensus forecast based on outputs of several models;

(d) application of radar data to tropical cyclone forecasting, especially with regard to landfalling tropical cyclones;
seasonal tropical cyclone rainfall forecasting, with an El Nino perspective.

Operational tropical cyclone forecasters have for a long time pinned their hope on the development of numerical modelling; see for example Bell (1979). By the early 1990s, NWP forecasts of 48-hour and 72-hour positions showed skill comparable to operational forecasts (Lam, 1993). Towards the end of the decade, signs were that even 24-hour NWP forecast positions compared favourably with operational forecasts; see Fig. 1 (after Lam, 2001). Front-line forecasters are relying increasingly on the guidance from numerical models which are available via the WMO Global Telecommunication System (GTS). Work such as that of Heming, et al (1995) has shown that realistic vortex initiation is a key factor in the accurate forecasting of tropical cyclone track, especially in the short-term. Item (a) reflects the trust placed on operational NWP and the wish that it be further improved.

![Figure 1: Comparison of ECMWF model forecasts (based on GTS data) and HKO subjective forecasts of tropical cyclone positions over the verification area 10-30°N, 105-125°E. The skill score is determined relative to forecasts by a simple climatology-persistence method. Positive value means performance better than this method. After Lam (2001).](image)

As discussed in Lam (2001), present-day tropical cyclone warning services demand that high winds and heavy rain be adequately anticipated. A good starting point for the operation would be a precise knowledge of the wind and rain distribution in a tropical cyclone before it hits land. Conventional meteorological observations could not help in this respect. Satellite observations would appear to be the only hope when tropical cyclones are beyond radar range. This explains the emphasis put on satellite in item (b).

In item (c): ensemble forecasting, it is clear that forecasters see the value of operational NWP products as guidance material. However, the occasional divergence in forecast tracks by different models could be bewildering. The not infrequent occurrence of large errors as much as 1 000 km in 72 hours is also frustrating. Now that the outputs of several global as well as regional models are routinely available via GTS, one fruitful line of pursuit would indeed be the development of some optimal way of utilising these products.
The critical moments to an operational forecaster would be those few hours before
tropical cyclone landfall. Very often, NWP products are already many hours too old, the observed track
having deviated significantly from the predicted track. Little or no new synoptic data are available to aid
the updating of the evolving synoptic situation. The tropical cyclone is probably beginning to interact
with orography and to show some degree of irregularity in its track. The forecaster is very much on his
own, with the radar as his only tool with the necessary spatial coverage and frequent updating. Item (d):
application of radar data is therefore a key component for any attempt to improve the capacity of
forecasters in the very-short-range forecasting of landfalling tropical cyclones.

Item (e): seasonal forecasting belongs to a very different time scale and falls in the realm
of climatology. To address this issue requires a completely different suite of skill and knowledge.

**Numerical Modelling**

Numerical modelling has emerged as the common denominator between academic
research on and operational forecasting of tropical cyclones.

Global models initially developed without paying special attention to tropical cyclones
have proved to have good guidance value in operational forecasting in the range of 24 to 72 hours. This
is not unexpected since tropical cyclones are basically governed by the same physical laws as any other
systems in the atmosphere. Nevertheless, it has been shown that bogussing leads to improvements in the
near range, as exemplified by Heming et al (1985), pointing towards the peculiarities of the tropical
cyclone problem in the NWP context, especially in respect of the specification of the initial state of the
atmosphere. The work cited here is of particular interest because it was the result of a Hong Kong
academic collaborating with the UK Meteorological Office. Given the right motivation and a suitably
identified topic, academia and forecasters could work together with positive results.

There is room for further improvement in applying NWP to tropical cyclone forecasting.
Even the most sophisticated models in operation could not escape large forecast errors. According to
Carr and Elsberry (2000a), about one third of the 72-hour forecasts (by NOGAPS and GFDN) in 1997 had
errors exceeding 300 n mi (555 km). The largest NOGAPS error was 1226 n mi while that for GFDN
was 931 n mi. How such large errors could have occurred is a challenging intellectual question for the
academia. How the forecaster could cope with or avoid being misled by such NWP guidance is an
equally challenging operational question. This is a subject where we have common ground between
researchers and forecasters. The work described in Carr and Elsbery (2000a, 2000b) is an excellent
example of an effort to link up the two communities. Their research relates the large forecast position
errors to the excessive prediction by models of certain categories of synoptic patterns bearing on tropical
cyclone movement. It provides a rational approach helping forecasters decide on the choice of NWP
results, aided by synoptic experience, to enhance the value of "consensus forecasts" based on the outputs of
multiple models. On the other hand, by identifying the excesses in the forecasting of various synoptic
patterns, the work tells numerical modellers where problems of models might lie. How the formulation
of a model or the way it is operationally executed should be modified to bring about the better forecasting
of certain synoptic patterns is an immensely complicated branch of NWP studies. Aspects to be
investigated could include physical processes, the initialization algorithm and data availability issues.
This is a rich field for theoretical researchers. Thus the Carr and Elsberry group was facilitating
advancement in both theoretical and operational fronts by playing a linkage role.

**Satellite and Radar**

One prominent step forward in the last decade is the increasing volume and diversity of
meteorological information available from satellites. Meteorological services have been using satellite
imageries to fix tropical cyclone positions and estimate their intensity by the Dvorak method for many
years. While the new generation of microwave sensors might have been motivated by independent
research initiatives, their outputs soon found their way into the observation of tropical cyclones. Recent
developments such as TRMM, SSM/I, AMSU and QuikSCAT all offer unprecedented hopes of detailed analyses of the physical properties viz. temperature, wind and rainfall of tropical cyclones (see, for example, Kidder et al, 2000, in respect of AMSU).

The extent to which the front-line forecaster could benefit from latest satellite technology is illustrated by the case of a weak tropical depression in the northern part of the South China Sea. Fig. 2 and 3 show the satellite image (an overlay of IR and VS) and the synoptic observations respectively at 00UTC 29 August 2001. One would have a hard time locating the centre of the tropical depression and guessing its wind field over the sea. Fig. 4 shows the wind field at about the same reference time, derived from QuikSCAT data available on the Internet. The academic researcher would warn that some data might be "contaminated" and should be treated with caution. However, the forecaster would find the information reassuring once he has cross-checked it with the synoptic data and the satellite image for internal consistency. He could then go about his track forecast and warning for mariners with enhanced confidence.

This is again another area where common ground exists between researchers and forecasters. Researchers could pursue work to derive new application products such as wind fields and tropical cyclone precipitation potential (Kidder et al, 2000) to support forecasters. They might also concentrate on studying the evolution of environmental fields and that of tropical cyclone themselves through the utilization of the new observed parameters in numerical models. In the course of doing so, it would lead to improved capability of operational NWP models to represent tropical cyclones and their environmental circulations. Thus academic pursuit and operational interest do come together.
Figure 3: Synoptic observations at 00UTC 29 August 2001. The same question as in Fig. 2: where is the tropical depression?

Figure 4: QuikSCAT wind field around 22 UTC 28 August 2001. The centre of the tropical depression was located east of Hainan Island on the left-hand side of the frame.
The application of radar to weather forecasting probably attracts less attention from the academia. The study of radar data is more difficult; the objects to be studied viz. mesoscale systems are intrinsically complex and not readily amenable to simple theoretical conceptualization. Thus one often finds operational meteorologists conducting radar-based case studies and relatively less reported work on generalization.

As mentioned earlier, the operational forecaster requires accurate quantitative predictions of rains and wind. An example of how a meteorological service attempts to make better use of radar data in this direction is the work of the Hong Kong Observatory in the last few years. The application of correlation and extrapolation techniques to yield the depiction of "wind" and the forecast of rain in the next couple of hours is described in Li et al (1999). It soon found application in the location of tropical cyclone centres and the portrayal of asymmetric wind distribution in tropical cyclones (Lai, 1999). Fig. 5 illustrates what the forecaster now sees in the real-time as a tropical cyclone approaches the coast. Combined with local observations from wind profilers and automatic weather stations, the forecaster is able to anticipate imminent changes in wind with some quantitative measure.

Fig. 5: TREC-analysed wind field for Typhoon Maria at 2300 UTC 31 August 2000, based on echo movements over a 6-minute interval.

There are opportunities for the academic to contribute too. Empirical experience indicates that localised heavy rain occurs when lines of echoes merge or cross each other. The Hong Kong Observatory established partnership with the Chinese University of Hong Kong in applying pattern recognition techniques to the automatic interpretation of radar echo patterns. Initial results are encouraging (Lai et al, 2000), as illustrated in Fig. 6.
Fig. 6  Sample output based on a combination of artificial neural network and Hough transformation to identify rain bands. Lines crossing in the highlighted box left of the centre hints at heavy rain.  After Lai et al (2000).

Linking Forecasters and Researchers

The meteorological service is typically under great pressure to deliver a good warning service. Thus resources are often directed to the day-to-day operation. But progress would be limited unless the scientific basis of the operation is maintained and advanced, making optimal use of emerging knowledge and technology. In the circumstances, engaging the support of scientists outside the meteorological service has to be taken as a serious option to ensure advancement.

Scientists especially those in universities have a very different agenda from the forecaster. The work has to be intellectually interesting and the results have to publishable. For a long time, meteorology being such a practical scientific discipline lacks glamour and has failed to attract much of their attention. Fortunately, the general atmosphere of universities worldwide has changed in the last decade or so, with an increasing emphasis on research with applications for the betterment of human living. Work in the meteorological field fit into this category very well and now has a better claim for the attention of researchers than before. Nevertheless, the prerequisites to securing the involvement of researchers are still: (a) demonstrating the intellectual challenge of the meteorological problem, and (b) some assurance that the results are publishable.

Another prerequisite applies to the meteorological service. It must adopt an open mind, dropping the notion that it holds the turf for applied meteorological research, especially tropical cyclone research. As a corollary, it should be prepared to make meteorological data available to those researchers enticed to take up this line of work.
As discussed above, in respect of tropical cyclone research, three key subject areas viz. numerical modelling, satellite and radar offer fertile common ground for researchers and forecasters. Research in these areas will address the main current interests of forecasters and will also pose challenge to researchers. There are also ample opportunities for either researchers or forecasters to take up some kind of "facilitator" role bridging the two communities as well as working on what one might call "mid-stream research".

Another positive development is the emergence of journals which publishes papers on the application of science and technology to forecasting, such as *Meteorological Applications* and *Weather and Forecasting*. They should provide the necessary motivation which academics desire.

The initiative to engage researchers in tropical cyclone research thus lies in the court of meteorological service. It will happen only if a positive outreach strategy is adopted. Briefly stated, the meteorological service should identify its operational needs in the medium to long term and the broad scientific or technological problems to be solved. These should be presented to the local research community in a frank and open manner. One should of course emphasize the intellectual value of the scientific enquiries as well as the social value of the eventual applications. Cooperative project could then be worked out, which could take a great variety of forms.

At one end of the spectrum where resources allow, the meteorological service should strive to establish a long-term strategic alliance with a selected university partner to provide a focus for sustained collaborative work. In the absence of a meteorology faculty, numerical modelling could be taken up by physicists and mathematicians while satellite and radar applications could be taken by engineers. One key to success is the participation of forecasters through spelling out their requirements, often in quantitative terms, and to share with the researchers their empirical observations and rules of thumb. From our own experience, this is often where inspiration for good work comes from.

At the other end of the spectrum where little financial resource is available, one could link up with university departments through jointly supervising studies leading to student theses. In this case, the meteorological service would have to narrow down its requirements into specific projects with a size and complexity manageable by the students. The research results would also likely require some degree of interpretation or modification before they become applicable operational products.

One final point: academics cannot devote all their time to applied meteorological research and are used to more leisurely pace in their work. Meteorological services have to be understanding and patient when they decide to collaborate with academics. Indeed, it also means that the choice of projects to be the subject of collaborative efforts would have to be judiciously made, giving due allowance for the intrinsic characteristics of academics.

**Looking Ahead**

The emergence and expansion of tertiary institutions in the Typhoon Committee region offers an unprecedented opportunity for meteorological services to tap into a new intellectual resource for the advancement of tropical cyclone research. It will however depend on the extent to which meteorological services are prepared to reach out to the research community. While financial resource could influence the mode of researcher-forecaster cooperation, it should not stop it from happening.

The development of numerical modelling and the application of radar and satellite will provide great opportunities for tropical cyclone forecasting research. The Typhoon Committee could perform a catalyst function by promoting the identification of current problems, the international exchange of ideas through its Research Fellowship Scheme and the presentation of research results in its Annual Report, at international conferences and in internationally recognized journals.
References


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