HIGH IMPACT FORECASTING IN THE FUTURE – TIGGE AND PLANS FOR A GLOBAL INTERACTIVE FORECAST SYSTEM

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1. INTRODUCTION

The objective of the future Global Interactive Forecast System (GIFS) is the production of internationally coordinated advance warnings and forecasts for high impact weather events to mitigate loss of life and property, and to contribute to the welfare of all World Meteorological Organization (WMO) nations, with a particular emphasis on least developed and developing countries. It is expected that the international coordination of the design, future development, and operation of global observing, data assimilation, numerical modeling, and user application techniques for high impact weather forecasting will yield significant improvements in the range and quality of services, leading to a range of socio-economic benefits, including saving property and lives.

This paper describes the THORPEX Grand Global Interactive Ensemble (TIGGE) project that is paving the way for a GIFS system, and discusses what might be possible within a GIFS system.

2. TIGGE

Begun in 2005, TIGGE is a major research project to improve ensemble prediction and its use in mitigating high impact weather. Bougeault et al. (2009) provide a detailed description of the project. The goals of TIGGE include (TIP 2005):

- enhanced collaboration on development of ensemble prediction, internationally and between operational centres and universities,
- development of new methods for combining ensembles from different sources and correcting for systematic errors (biases, spread over- and under-estimation),
- a deeper understanding of the contribution of observation, initial and model uncertainties to forecast error,
- a deeper understanding of the feasibility of interactive ensemble system responding dynamically to changing uncertainty (including use for adaptive observing, variable ensemble size, on-demand regional ensembles) and exploiting new technology for grid computing and high-speed data transfer,
- to test concepts of a TIGGE Prediction Centre to produce ensemble-based predictions of high-impact weather, wherever it occurs, on all predictable time ranges, and
- the development of a prototype future Global Interactive Forecasting System.

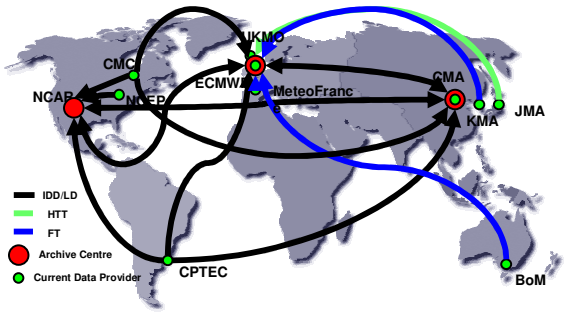

Fig. 1. Data flow between TIGGE data providers and TIGGE archive centers.

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Table 1. Operational ensembles in TIGGE

Center	Ensemble members	Model resolution	Forecast length	Forecasts/ day	GB/ day	Fields/ day	Files/ day
ECMWF	51	N200 (Reduced Gaussian)	10 day	2	115	289,734	328
ECMWF	51	N128 (Reduced Gaussian)	10-15 day	2	24	138,978	160
UKMO	24	1.25º x 0.83º	15 day	2	21	175,680	488
JMA	51	1.25º x 1.25º	9 day	1	7	113,192	74
NCEP	21	1.00º x 1.00º	16 day	4	10	316,596	1040
CMA	15	0.56º x 0.56º	10 day	2	28	72,510	82
CMC	21	1.00º x 1.00º	16 day	2	8	163,674	260
BOM	33	1.50º x 1.50º	10 day	2	8	147,972	164
Météo-France	11	1.50º x 1.50º	2.5 day	1	.15	7,558	33
KMA	17	1.00º x 1.00º	10 day	2	5	64,124	164
CPTEC	15	1.00º x 1.00º	15 day	2	14	97,084	244
Total				**22**	**240**	**1,587,102**	**3,037**

Three TIGGE archive centers have been established to store and redistribute ensemble data for research:

- China Meteorological Administration (CMA), http://wisportal.cma.gov.cn/tigge/
- National Centre for Atmospheric Research (USA), http://tigge.ucar.edu
- European Centre for Medium-range Weather Forecasts (ECMWF), http://tigge-portal.ecmwf.int

Ten international centers (called "data providers") contribute output from their operational numerical ensemble prediction systems (EPSs) to TIGGE with a 2-day delay (Table 1). The data flow between the data providers and archive centers is shown in Fig. 1.

A full list of model fields can be viewed at the data portals listed above. The upper fields include geopotential height, specific humidity, temperature, U- and V-velocity at eight pressure levels (1000, 925, 850, 700, 500, 300, 250, 200 hPa), geopotential height at 50 hPa, potential vorticity at the 320K potential temperature level, potential temperature, U-and V-velocity at the 2 PVU potential vorticity surface. A large number of surface and single-level fields are available including pressure, 10m U- and V-velocity, air temperature (including daily max and min), dewpoint, precipitation (liquid and solid), total column water, cloud cover, sunshine duration, several radiative and heat fluxes, soil moisture and temperature, CAPE and CIN.

Interested researchers may register as TIGGE users at one or more of the data portals, enabling them to download ensemble data in GRIB2 format. The three portals offer the capability of extracting particular fields from selected ensembles, for a specified area or point, and for specified days.

3. EARLY RESULTS FROM TIGGE

Research results using TIGGE data are beginning to quantify the value of multi-model ensemble forecasts. Bougeault et al. (2009) describe results from several recent studies (see also http://tigge.ecmwf.int/references.html). Preliminary

conclusions based on these early studies suggest that multi-model ensembles outperform most individual ensembles for 500 hPa geopotential height, and appear to outperform all individual ensembles for 850 hPa temperature and surface level fields such as temperature and rainfall. Bias correction is critically important for removing a large fraction of the total error. The best multi-model ensemble may not include all available models, but rather should be comprised of the most skilful models. The greatest impact of including multiple models may be later in the forecast period.

There is a strong need for more studies to evaluate the benefit of multi-model ensembles in predicting high impact weather at the surface, to address the THORPEX goal of mitigating the adverse effects of severe weather. Other science questions that should be addressed using TIGGE data include:

- What is the best combination of input models, and how does this depend on the variable being predicted, the season and region?
- Should models be given different weights, and if so, how?
- How long should the training period for bias correction be?

A more pragmatic question is what is the best use of resources? In order to justify the large effort involved in exchanging and combining ensembles from several sources, the benefit of multi-model ensembles must be clearly shown to outweigh the costs of producing them. As individual EPSs continue to improve due to better data assimilation and model physics, multi-model ensembles will also improve but their relative benefit may become less pronounced.

4. THE GIFS CONCEPT AND DEVELOPMENT

GIFS will rely on real-time access to ensemble forecast data from global and regional ensembles. The goal is to provide 14-day weather forecasts with useful skill and quantifiable levels of uncertainty that can be used to generate probabilistic forecasts in support of effective socio-economic decision-making.

A possible scenario in a GIFS world might look something like this:

The 14-day GIFS global ensemble forecast for the Australian Gold Coast region during winter shows a trough predicted over eastern Australia, with mean precipitation of 2 mm and POP_{10mm} =10%. Forecasters note this situation for monitoring. A week later the 7-day GIFS forecast appears to confirm the development of a significant event, with a low pressure center over eastern Australia, mean precipitation of 15 mm, POP_{10mm}=50% and POP_{50mm}=10%. Emergency managers along the southeastern Queensland coast are given a "heads up" for possible heavy rain, and are updated on the situation as it develops.

Starting three days before the event, an East Coast low appears very likely so additional satellite observations are assimilated into the global models to improve their initial conditions in sensitive regions. A request is made to run a limited area model (LAM) ensemble nested in an ensemble of global EPSs. The high resolution LAM EPSs predict POP_{10mm}=90%, POP_{50mm} =70%, POP_{100mm}=20%, and P(gale force winds)=50%. The weather forecast office prepares to put extra meteorologists on duty. The forecasts are refined as the event gets closer, with extra targeted observations and LAM runs. Emergency managers in the region are notified of the likely occurrence of severe weather. They make a decision to act, calling for the evacuation of several Gold Coast communities. Shops and homes are sand-bagged, and further steps are taken to protect property and livestock.

The East Coast low arrives as predicted, causing significant disruptions to transport and communication. Thanks to the excellent weather forecasts and appropriate emergency response, the damage asso-ciated with the event is mitigated and no lives are lost.

Several aspects of the GIFS are worth noting. Exploring the use of targeted observations has been a goal of THORPEX since its inception. The request to include additional observations in the vicinity of the developing event is meant to reduce the forecast uncertainty caused by insufficient observations.

Ensemble predictions play an important role throughout the forecast period, first as an early indication of interesting weather up to two weeks ahead, and later in quantifying the uncertainty in the high impact weather forecasts. Both global and regional ensembles are important tools, with the focus on weather at the surface. A special working group on TIGGE-LAM is developing the protocols to allow high resolution mesoscale models to be nested in TIGGE global ensemble members to provide more detailed short range forecasts for specific regional domains, and also for relocatable domains encompassing high impact weather events.

Ensemble data are expected to be collected from a number of centers (although in principle GIFS products could be derived from individual ensembles), using protocols and systems developed as part of the WMO Information System (WIS). WIS is the WMO strategy currently being developed for managing and moving weather, water and climate information in the 21st century. It adopts a two-pronged approach: (1) continuation and improvement of the GTS via dedicated telecommunication means (leased links, data networks, satellite), and (2) flexible data discovery, access, and retrieval via the internet. (For more information see http://www.wmo.ch/pages/themes/wis/index_en.html).

The processing of GIFS forecasts may be done at a dedicated (physical) GIFS center, or a virtual GIFS center built on contributions from existing centers. Probabilistic predictions of high impact weather will be derived from the ensemble output using a suite of GIFS applications for bias-correcting the model fields, calibrating the ensembles, and generating forecasts and warnings that are relevant to users. It is anticipated that some products will be produced on a routine basis, while others may be made at the request of national and local forecast offices. Common software will also be available for verifying GIFS forecasts.

GIFS will provide user support to forecasts offices to help and inform users in selecting from multitude of similar options in product generation. This will be based on meta-information on available procedures, and verification statistics for different ensemble-selection options.

The GIFS will share many technical similarities with the North American Ensemble Forecast System (NAEFS; Toth et al. 2006), which is an operational multi-model ensemble system that combines the US and Canadian EPSs to produce real-time forecasts over North America. In fact, NAEFS and TIGGE will likely evolve into a single operational system (GIFS).

The forecast offices (which may not be the same as the GIFS centers) work closely with external users to advise them of the likely weather and associated uncertainties in the forecast. Feedback from the users is sought in the development and refinement of forecast and warning products so that they can be most effective in decision making.

GIFS will build on the success of the recent World Weather Research Programme (WWRP) Severe Weather Forecast Demonstration Project (SWFDP) conducted in southern Africa (Coiffier and Chen 2008). This project involves the provision of forecasts derived from three global ensembles (US, UK, ECMWF) and a high resolution regional implementation of the Met Office Unified Model. The Regional Specialized Meteorological Center at the South African Weather Service (SAWS) office in Pretoria receives the ensemble predictions and post-processes them into a variety of probabilistic medium- and short-range forecasts that are displayed on a registered SWFDP web site. SAWS forecasters also interpret the ensemble output, along with satellite and surface data, to provide simplified warning products. The ensemble graphics and warning products do not require much bandwidth to transmit to the forecast offices of developing nations in the region, and have literally transformed the process (and accuracy) of high impact weather forecasting in southern Africa (Coiffier and Chen 2008).

5. GIFS PROTOTYPE – ENSEMBLE TROPICAL CYCLONE TRACKS

As a prototype, GIFS products are being developed in support of probabilistic tropical cyclone (TC) warning services. A practical aim is to start out small to test the establishment of international collaborations, as well as recently and newly developed software and IT infrastructure. Limiting the data exchange and processing needs to TC information requires only small bandwidth and computing resources, thereby allowing experimentation to "get it right". The choice of tropical cyclone forecasting also targets a need for improved ensemble-based track and intensity

forecasting as identified by the 2006 International Workshop on Tropical Cyclones.

Tropical cyclone track forecasts from several NWP ensembles are now available to interested researchers (see http://www.bom.gov.au/bmrc/projects/THORPEX/TC/index.html). These data will be used to demonstrate the utility of multi-model ensembles for high-impact events. Sample multi-ensemble TC tracks and strike probability maps are shown in Fig. 2.

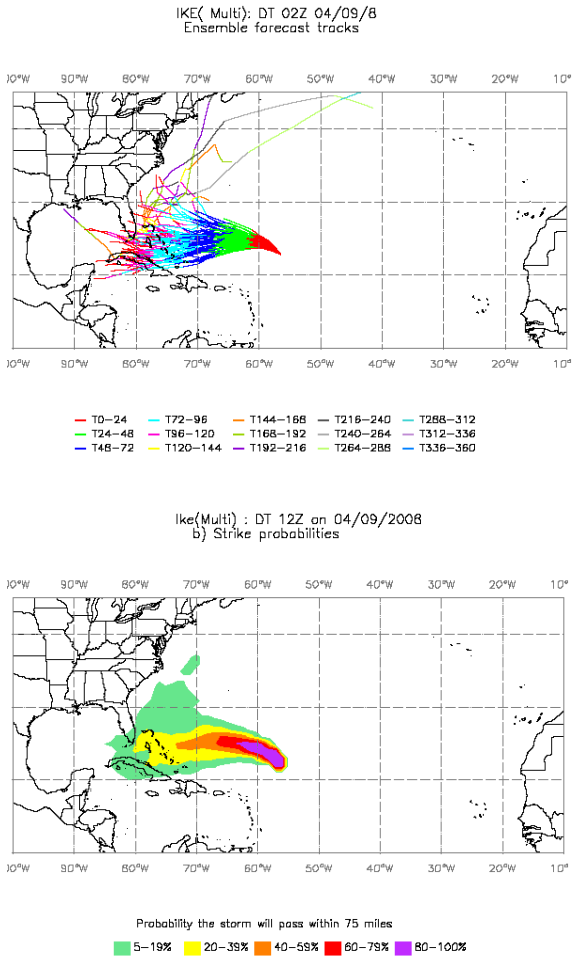

Fig. 2. Multi-model ensemble forecast tracks (top) and strike probabilities (bottom) for Hurricane Ike initiated at 12 UTC on 4th Sep 2008, combining outputs from the ECMWF EPS and UK Met Office MOGREPS ensembles. (courtesy of Piers Buchanan, Met Office; figure reproduced from Bougeault et al. 2009).

The TC forecasts are written in eXtensible Markup Language (XML), which is an internet standard widely used human-legible text format that encloses data within self-describing tags. Real time ensemble TC tracks were provided by seven international centers during the THORPEX Pacific Asian Regional Campaign (T-PARC). The data are archived and distributed at the TIGGE archive centres.

6. IS GIFS POSSIBLE?

A Global Interactive Forecast System is an ambitious concept, and will require a large commitment from WMO and from meteorological researchers and forecast services from developed nations in order to make it a reality. To secure buy-in for GIFS, the benefits of international cooperation in ensemble prediction must be clearly demonstrated, not only for improving high impact weather prediction for least developed and developing countries, but also improving high impact weather forecasts in the countries doing the bulk of the GIFS development work.

Several factors work in the favor of GIFS. WMO has a long history of successful international cooperation, with many seemingly insurmountable tasks having been accomplished over the years. The NAEFS is already operational in North America as a kind of a "mini GIFS", and many lessons have been learned from this system that can be applied in GIFS. The African SWFDP showed the benefit of providing advanced NWP-based guidance to developing nations, thus proving that the sharing of ensemble-based predictions can indeed mitigate the impact of severe weather in countries that cannot run their own models.

On the technical side, large volumes of TIGGE ensemble data are being successfully collected and used in research, and TC forecasts are also now available for experimentation. The WMO Information System will enable faster and more flexible data exchange using the latest digital technologies.

7. REFERENCES

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