Use of TIGGE/global ensembles in tropical cyclone research and operational forecasts

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Introduction

Tropical Cyclones and TIGGE

Outline

1) TIGGE Literature search: Results from PDEF
2) Multi-model ensemble TC verification: recent results
3) Example of R2O transfer with TIGGE: North Western Pacific Tropical Cyclone Ensemble Forecast Project
4) Current use of global dynamical ensemble forecasts in operational TC forecasting: HIWeather questionnaire results
Multi-model ensemble TC forecasting

a) Cumulative relative frequency distribution of track forecasts

The size of the probability circle of typhoon track forecasts is determined based on the Confidence Levels A, B or C, which is determined based on the ensemble spread of ensemble TC track prediction.

Fukuda and Yamaguchi (2019, In Preparation)

With multiple ensembles, fewer cases where track forecast errors are large in spite of small ensemble spread
Multi-model ensemble TC forecasting

b) Strike probability

Tropical Cyclone Probability January 2018 - December 2018: Brier Skill Score

Titley and Bowyer (2019, In Preparation)
• Two examples of storm-based verification that illustrate the benefit of multi-model ensembles: Irma (2017) vs Matthew (2016).

• In both cases, the multi-model ensemble is of comparative skill to the strongest performing model.
c) TC activity

BSS by basin and lead time: left=best performing individual ensemble; middle=MCGE3 (3 ensembles); right= MCGE4 (4 ensembles)
**Step 1:** Multi-model ensemble TC track predictions using TIGGE CXML.

**Step 2:** Demonstrate the relative benefits of multi-model ensembles wrt a single-model ensemble (Yamaguchi et al. 2012, QJRMS)

The spread–error relationship is improved in the multi-model ensembles.

**Step 3:** Questionnaire survey to the Typhoon Committee Members regarding the project (Yamaguchi et al. 2014, TCRR)

**Step 4:** RSMC Tokyo provides real-time multi-model ensemble (ECMWF, NCEP, UKMO and JMA) TC track and activity predictions to Typhoon Committee.
The questionnaire aimed to provide a baseline on the current use of dynamical ensembles at operational tropical cyclone forecast centers, and help shape future research and development.

Four more detailed objectives:

i) Document current availability of ensemble forecasts and their use by operational forecasters

ii) Ascertain how uncertainty is represented and calculated in their operational warnings

iii) To obtain examples where probabilistic forecasts have been successfully integrated into operations, and where hurdles have prevented this

iv) To collate forecaster feedback on where they would like to see future research and development focus to enable them to make wider use of ensemble forecasts

Total number of 60 respondents from all over the world, and with interests in each TC basin.
“How important would you say ensemble forecasts are in each area of tropical cyclone forecasting?”
Questionnaire results: Current use of ensemble forecast information

“For each of the main areas of tropical cyclone forecasting, which ensemble forecast models do you use?”

“Do you use multi-model ensemble forecast data i.e. multiple dynamical ensembles”

- Yes, but only by comparing one ensemble with another: 42.1%
- Yes, in full probabilistic multi-model ensemble combination: 49.1%
- No: 8.8%
“Which ensemble-based or probabilistic products do you use”

Questionnaire results: Current use of ensemble forecast information
“Which of the following statements describe your use of ensemble forecast information in track forecasting?”
<table>
<thead>
<tr>
<th>Center name</th>
<th>How is uncertainty represented?</th>
<th>How is it calculated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSMC Tokyo</td>
<td>Circle containing 70% of TCs</td>
<td>Historical forecast error statistics (up to 72 hours) and ensemble spread (after 96 hours)</td>
</tr>
<tr>
<td>RSMC Honolulu</td>
<td>Cone containing 67% of TCs</td>
<td>Historical forecast error (5 year)</td>
</tr>
<tr>
<td>RSMC La Reunion</td>
<td>Cone containing 75% of TCs</td>
<td>Based on both ensemble spread and historical forecast error, (Dupont et al. 2011)</td>
</tr>
<tr>
<td>RSMC Miami</td>
<td>Cone</td>
<td>Previous 5 years of track error for that basin</td>
</tr>
<tr>
<td>RSMC New Delhi</td>
<td>Cone</td>
<td>Historical forecast error statistics</td>
</tr>
<tr>
<td>TCWC Jakarta</td>
<td>Cone</td>
<td>Consensus spread. Patterns obtained from wind model forecasts, and sometimes the form is modified manually to make the shape smoother.</td>
</tr>
<tr>
<td>TCWC Perth</td>
<td>Cone</td>
<td>Situation dependent, usually either consensus spread or climatological uncertainty but can be manually manipulated.</td>
</tr>
<tr>
<td>TCWC Wellington</td>
<td>Cone</td>
<td>Calculated based on consensus spread, ensemble spread and climatological uncertainty.</td>
</tr>
<tr>
<td>Joint Typhoon Warning Center (JWTC)</td>
<td>Error swath</td>
<td>Calculated by adding the JTWC 5-year running mean forecast track error to the forecast 34-knot wind radii at each forecast time.</td>
</tr>
</tbody>
</table>
How forecast uncertainty is communicated in operational forecasts and warnings: *Genesis*

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<th>Center name</th>
<th>How is uncertainty represented?</th>
<th>How is the uncertainty calculated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSMC Tokyo</td>
<td>Not represented</td>
<td>n/a</td>
</tr>
<tr>
<td>RSMC Honolulu</td>
<td>High/medium/low categories with assigned probabilities</td>
<td>Subjectively, forecasters use climatology, multi-model consensus, <em>ensembles</em>, satellite observation trends.</td>
</tr>
<tr>
<td>RSMC La Reunion</td>
<td>Probability categories (very low, low, moderate, high, very high)</td>
<td><em>Ensemble based</em> and forecaster judgement</td>
</tr>
<tr>
<td>RSMC Miami</td>
<td>Percentages to nearest 10% that are grouped into high/medium/low categories</td>
<td>Combination of <em>ensembles</em>, multi-model ensemble, and forecaster experience</td>
</tr>
<tr>
<td>RSMC New Delhi</td>
<td>Nil, low, Fail, Moderate, High corresponding to 00, 1-25, 26-50, 51-75, 76-100% of probability</td>
<td>Based on consensus derived from about 10 deterministic and <em>probabilistic</em> model guidance</td>
</tr>
<tr>
<td>TCWC Jakarta</td>
<td>high/medium/low</td>
<td>Climatological, consensus</td>
</tr>
<tr>
<td>TCWC Perth</td>
<td>High/moderate/low/very low</td>
<td>Assigned by forecaster</td>
</tr>
<tr>
<td>TCWC Wellington</td>
<td>Low potential/moderate potential/ high potential</td>
<td>Uncertainty is based on <em>ensemble</em> (mostly ECMWF and MOGREPS tropical storm strike/genesis probabilities) and forecaster diagnosis and prognosis of the environmental conditions susceptible to TC genesis.</td>
</tr>
<tr>
<td>Joint Typhoon Warning Center (JTWC)</td>
<td>Low (&lt;40%), Medium (40-60%), High (&gt;60%) classification</td>
<td>Deterministic and <em>ensemble</em> model forecasts, MJO and statistical-dynamical tools</td>
</tr>
</tbody>
</table>
Hurdles to integration in to operations

Availability of ensemble data e.g. lack of access to ensemble data, lack of inclusion of ensembles in key operational tools, and late availability time in an operational context.

Customer acceptance of confidence based or probabilistic products by the potential users of warning information who are used to deterministic weather bulletins.

Performance of the ensemble forecasts e.g. concerns that resolution is not sufficient for intensity prediction, unrealistic ensemble spread, and that ensembles can struggle to represent the vortex and get the structure that is essential to assess the hazard risks.

Lack of familiarity with the interpretation of ensemble and probabilistic forecasts and problems with synthesizing the enormous amount of data in a time-restricted operational environment.
Future use of ensemble forecast information

Recommendations for where respondents would like to see future research and development:

- **Improvement in the skill of ensemble forecasts**, in particular for tropical cyclone intensity.
- **Collaboration between NWP centers and forecasting centers** to share data, products, verification, and expertise on interpreting and using ensemble forecasts.
- **User-oriented verification**: real time for current TC, basin or season; optimal combination of deterministic/ensemble and global/regional models.
- **Change in operational working practice** towards using dynamic situation-based uncertainty, and probabilistic information.
- A focus on how to **communicate uncertainty** in forecasts and warnings to the general public.
- Development of more ensemble-based **hazard forecasts** and **impact-based forecasts**.

Pulled through in to recommendations of IWTC-9  *(Hawaii, Dec 2018)*
Titley, Yamaguchi and Magnusson (2019, In preparation, for TCRR special issue).
Summary of use of TIGGE and global ensembles in TC research/operations

• Literature search by WMO/WWRP PDEF shows TIGGE papers have been constantly published at a pace of approximately 15 papers per year. TCs are the most studied research area, followed by heavy precipitation/floods.

• Recent verification continues to show the value in multi-model ensemble forecasts for tropical cyclone track, strike probability and activity forecasting.

• The North Western Pacific Tropical Cyclone Ensemble Forecast Project is a good example of Research to Operations (R2O) TIGGE TC forecasts.

• HIWeather questionnaire shows that although ensemble forecasts are widely used, there is great potential to increase the pull through of probabilistic forecast information into operational tropical cyclone forecasts and warnings.