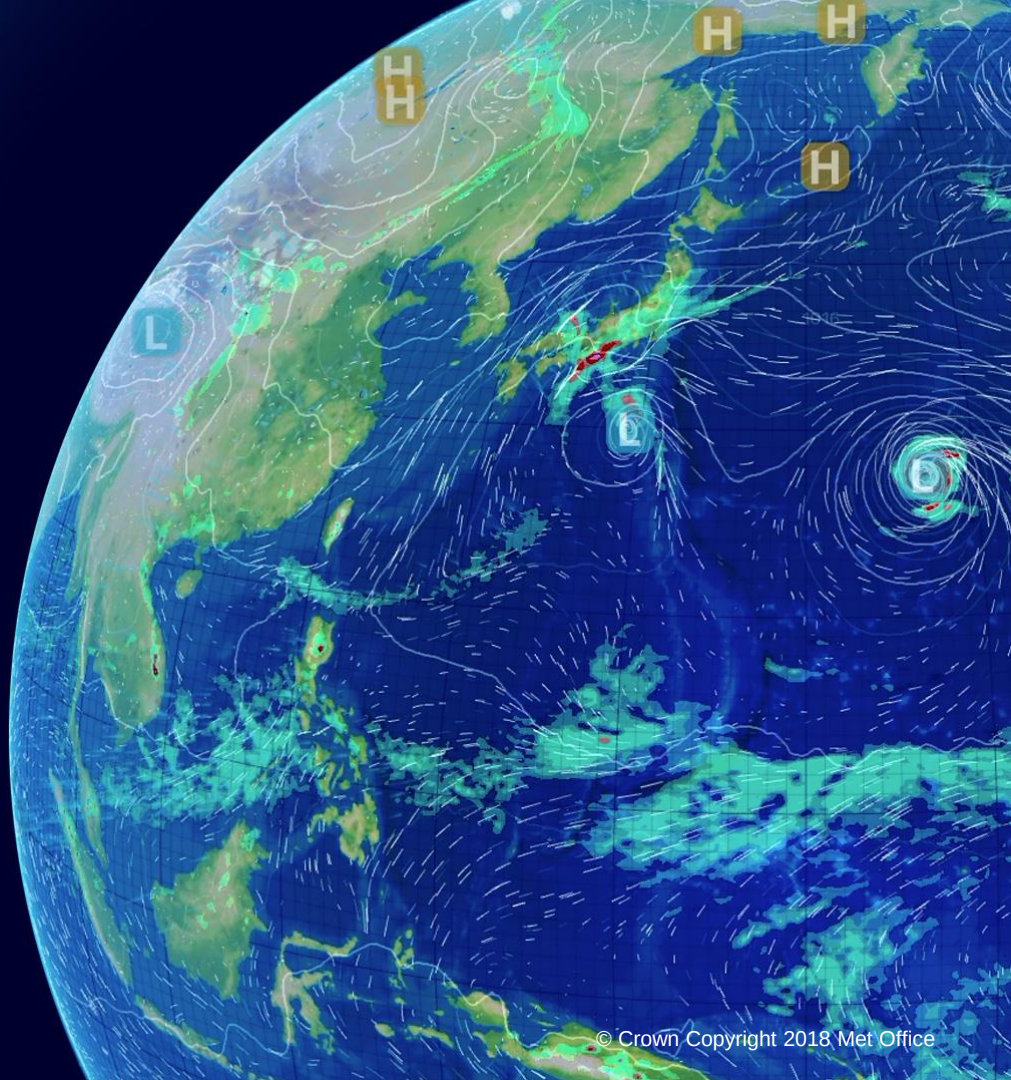
Use of TIGGE/global ensembles in tropical cyclone research and operational forecasts

Helen Titley, Met Office

With thanks to:
Munehiko Yamaguchi, JMA
Linus Magnusson, ECMWF
Becky Bowyer, Met Office

Workshop on predictability, dynamics and applications research using the TIGGE and S2S ensembles

ECMWF, Reading, UK, 2-5 April 2019



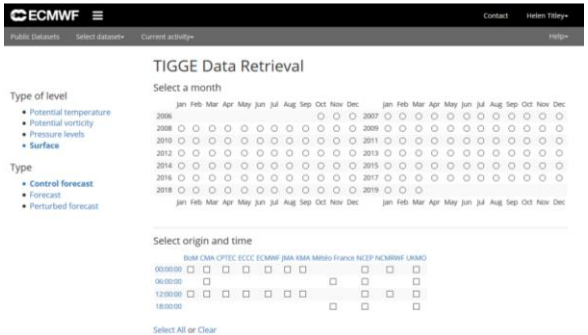
Introduction

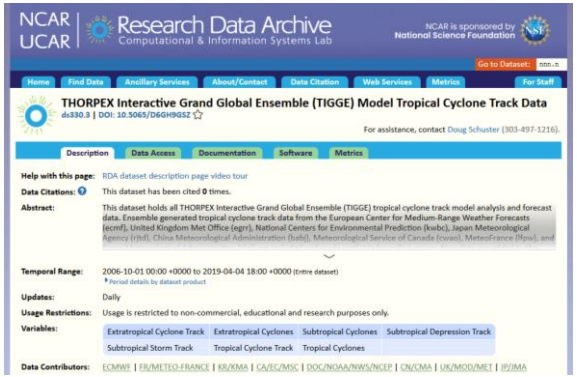
THORPEX
A World Weather Research Programme

Second THORPEX International Science Symposium (STISS)

Landshut, Germany
4 – 8 December 2006

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

Literature search for papers using TIGGE data

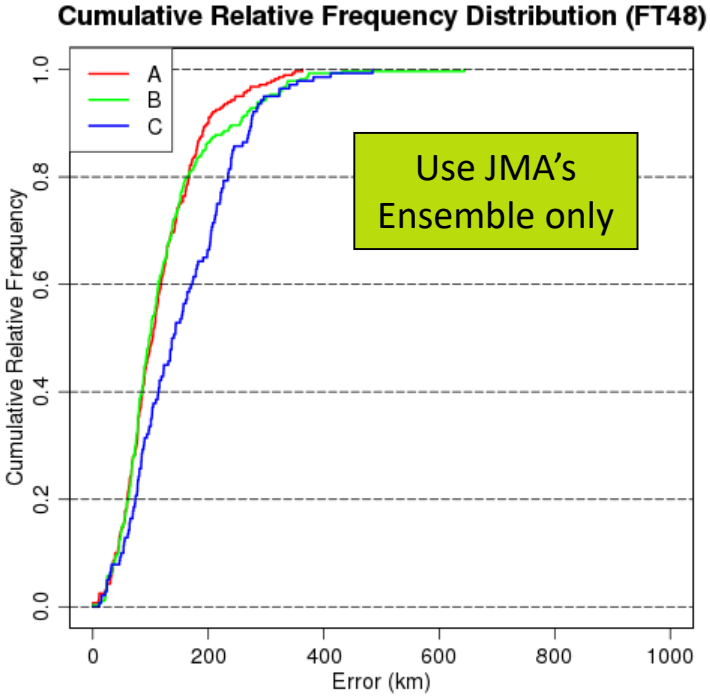
Author(s)	Title	Journal	TC topic(s)
Reynolds et al. (2007)	Interpretation of Adaptive Observing Guidance for Atlantic Tropical Cyclones	Monthly Weather Review	Predictability, Adaptive observation
Majumdar and Finocchio (2010)	On the Ability of Global Ensemble Prediction Systems to Predict Tropical Cyclone Track Probabilities	Weather And Forecasting	Track forecats
Majumdar et al. (2010)	Characteristics of Target Areas Selected by the Ensemble Transform Kalman Filter for Medium-Range Forecasts of High-Impact Winter Weather	Monthly Weather Review	NAEFS, Predictability, Adaptive observation
Galarneau Jr. et al (2010)	Predecessor Rain Events ahead of Tropical Cyclones	Monthly Weather Review	Precipitation, Dynamics
Yamaguchi and Majumdar (2010)	Using TIGGE Data to Diagnose Initial Perturbations and Their Growth for Tropical Cyclone Ensemble Forecasts	Monthly Weather Review	Predictability, Dynamics
Yamaguchi et al. (2011)	Singular Vectors for Tropical Cyclone–Like Vortices in a Nondivergent Barotropic Framework	Journal Of The Atmospheric Sciences	Dynamics
Majumdar et al. (2011)	Characteristics of Ensemble Transform Kalman Filter adaptive sampling guidance for tropical cyclones	Quarterly Journal Of The RMS	Predictability, Adaptive observations
Belanger et al. (2012)	Extended Prediction of North Indian Ocean Tropical Cyclones	Weather And Forecasting	Genesis forecasts
Schumacher and Galarneau Jr. (2012)	Moisture Transport into Midlatitudes ahead of Recurving Tropical Cyclones and Its Relevance in Two Predecessor Rain Events	Monthly Weather Review	Precipitation, Dynamics
Gombos et al. (2012)	Ensemble Statistics for Diagnosing Dynamics: Tropical Cyclone Track Forecast Sensitivities Revealed by Ensemble Regression	Monthly Weather Review	Dynamics, Predictability
Yamaguchi et al. (2012)	Tropical cyclone track forecasts using JMA model with ECMWF and JMA initial conditions	Geophysical Research Letters	Predictatility
Hoffman and Gombos (2012)	Hurricane Irene (2011) “worst-case” estimates of wind damage to property from exigent analysis of ECMWF ensemble forecasts	Geophysical Research Letters	Worst case scenario
Yamaguchi et al. (2012)	On the relative benefits of a multi-centre grand ensemble for tropical cyclone track prediction in the western North Pacific	Quarterly Journal Of The RMS	Track forecasts, Multi-centre
Hoover et al. (2013)	Physical Mechanisms Underlying Selected Adaptive Sampling Techniques for Tropical Cyclones	Monthly Weather Review	Predictability, Adaptive observation
Shieh et al. (2013)	Extreme Rapid Intensification of Typhoon Vicente (2012) in the South China Sea	Weather And Forecasting	Intensity forecasts
Halperin et al. (2013)	An Evaluation of Tropical Cyclone Genesis Forecasts from Global Numerical Models	Weather And Forecasting	Genesis forecasts
Qian et al. (2013)	Probabilistic Evaluation of the Dynamics and Prediction of Supertyphoon Megi (2010)	Weather And Forecasting	Forecast performance, Dynamics
Tsai and Elsberry (2013)	Detection of tropical cyclone track changes from the ECMWF ensemble prediction system	Geophysical Research Letters	Track forecasts
Klotzbach (2014)	Prediction of Seasonal Atlantic Basin Accumulated Cyclone Energy from 1 July	Weather And Forecasting	Cyclone Energy forecasts
Magnusson et al. (2014)	Evaluation of Medium-Range Forecasts for Hurricane Sandy	Monthly Weather Review	Forecast performance, Dynamics
Komaromi and Majumdar (2014)	Ensemble-Based Error and Predictability Metrics Associated with Tropical Cyclogenesis. Part I: Basinwide Perspective	Monthly Weather Review	Genesis forecasts, Predictability
Majumdar and Torn (2014)	Probabilistic Verification of Global and Mesoscale Ensemble Forecasts of Tropical Cyclogenesis	Weather And Forecasting	Genesis forecasts
Qi et al. (2014)	Selective ensemble-mean technique for tropical cyclone track forecast by using ensemble prediction systems	Quarterly Journal Of The RMS	Track forecasts
Bassill (2014)	Accuracy of early GFS and ECMWF Sandy (2012) track forecasts: Evidence for a dependence on cumulus parameterization	Geophysical Research Letters	Track forecasts, Intercomparison
Komaromi and Majumdar (2015)	Ensemble-Based Error and Predictability Metrics Associated with Tropical Cyclogenesis. Part II: Wave-Relative Framework	Monthly Weather Review	Genesis forecasts, Predictability
Colby Jr. (2015)	Global Ensemble Forecast Tracks for Tropical Storm Debby	Weather And Forecasting	Track forecasts
Yamaguchi et al. (2015)	Global Distribution of the Skill of Tropical Cyclone Activity Forecasts on Short- to Medium-Range Time Scales	Weather And Forecasting	Genesis forecasts, Multi-centre
Shu and Zhang (2015)	Influence of Equatorial Waves on the Genesis of Super Typhoon Haiyan (2013)	Journal Of The Atmospheric Sciences	Genesis forecasts, Dynamics
Bassill (2015)	An analysis of the operational GFS simplified Arakawa Schubert parameterization within a WRF framework: A Hurricane Sandy (2012) long-term track forecast perspective	Journal Of Geophysical Research: Atmospheres	Track forecasts
Dong and Zhang (2016)	OBEST: An Observation-Based Ensemble Subsetting Technique for Tropical Cyclone Track Prediction	Weather And Forecasting	Track forecasts
Halperin et al. (2016)	Verification of Tropical Cyclone Genesis Forecasts from Global Numerical Models: Comparisons between the North Atlantic and Eastern North Pacific Basins	Weather And Forecasting	Genesis forecasts
Don et al. (2016)	Mixture-Based Path Clustering for Synthesis of ECMWF Ensemble Forecasts of Tropical Cyclone Evolution.	Monthly Weather Review	Track forecasts
Kowaleski and Evans (2016)	Regression Mixture Model Clustering of Multimodel Ensemble Forecasts of Hurricane Sandy: Partition Characteristics	Monthly Weather Review	Track forecasts, ET
Chen et al. (2016)	A probabilistic climatology-based analogue intensity forecast scheme for tropical cyclones	Quarterly Journal Of The RMS	Intensity forecasts
Du et al. (2016)	Selective ensemble-mean technique for tropical cyclone track forecast by using time-lagged ensemble and multi-centre ensemble in the western North Pacific	Quarterly Journal Of The RMS	Track forecasts
Yamaguchi et al. (2017)	WGNE Intercomparison of Tropical Cyclone Forecasts by Operational NWP Models: A Quarter Century and Beyond	Bulletin Of The AMS	Track forecasts
Zhang and Yu (2017)	A Probabilistic Tropical Cyclone Track Forecast Scheme Based on the Selective Consensus of Ensemble Prediction Systems	Weather And Forecasting	Track forecasts
Leonardo and Colle (2017)	Verification of Multimodel Ensemble Forecasts of North Atlantic Tropical Cyclones	Weather And Forecasting	Track forecasts
Yamaguchi and Koide (2017)	Tropical Cyclone Genesis Guidance Using the Early Stage Dvorak Analysis and Global Ensembles	Weather And Forecasting	Genesis forecasts

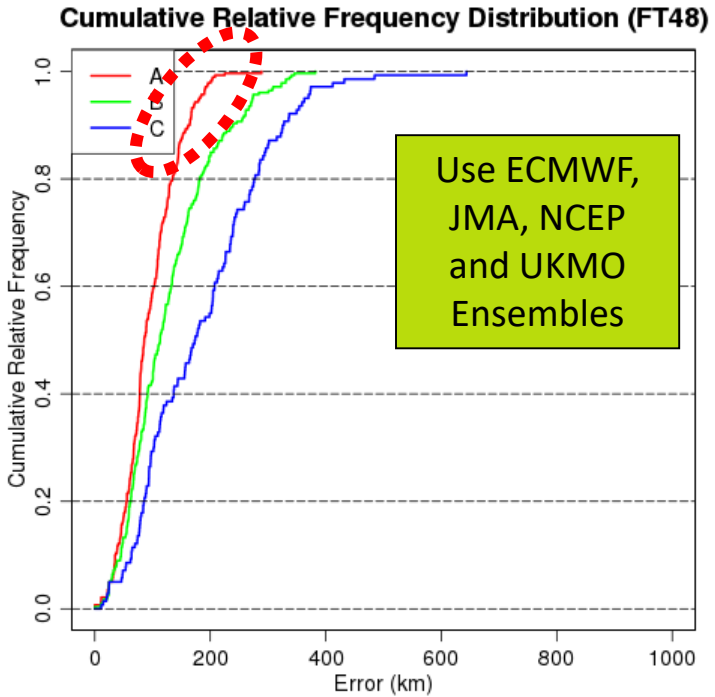
Multi-model ensemble TC forecasting

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)

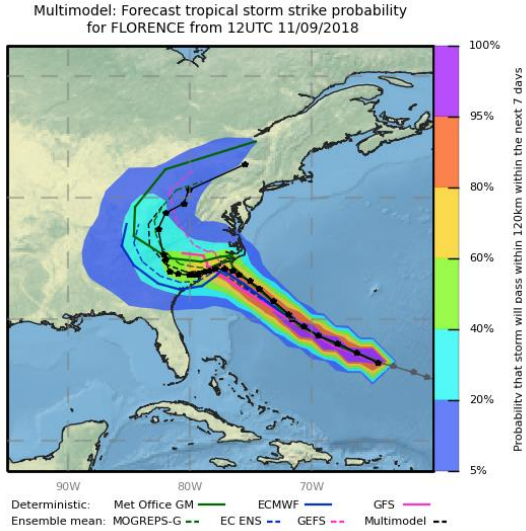


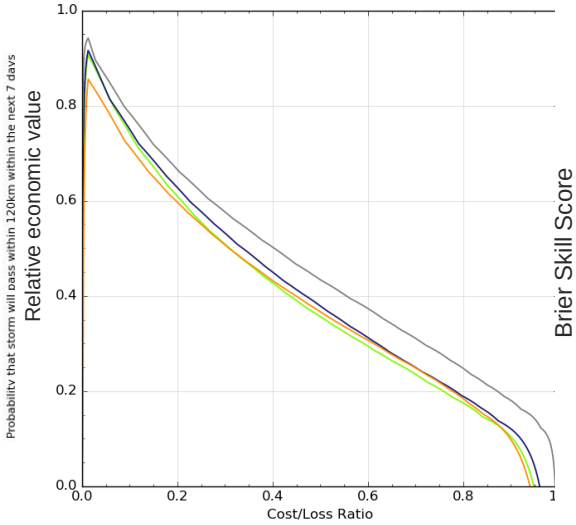


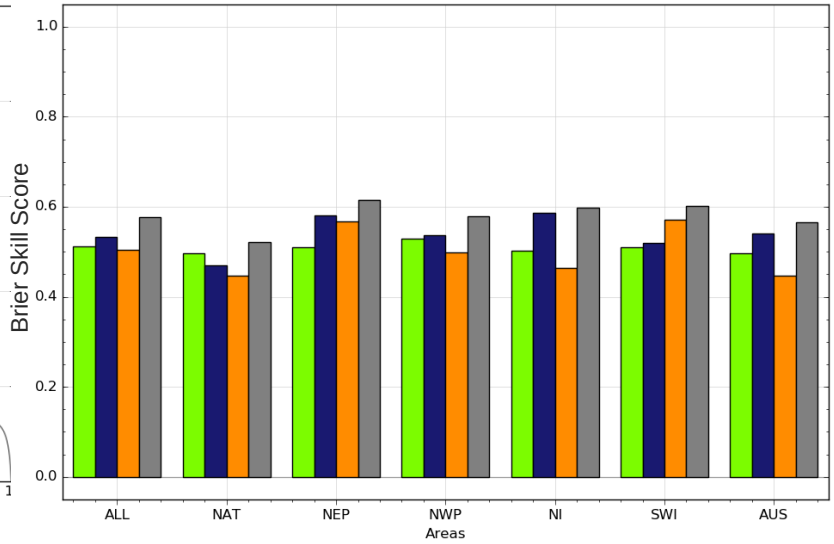
With multiple ensembles, fewer cases where track forecast errors are large in spite of small ensemble spread

Multi-model ensemble TC forecasting

b) Strike probability



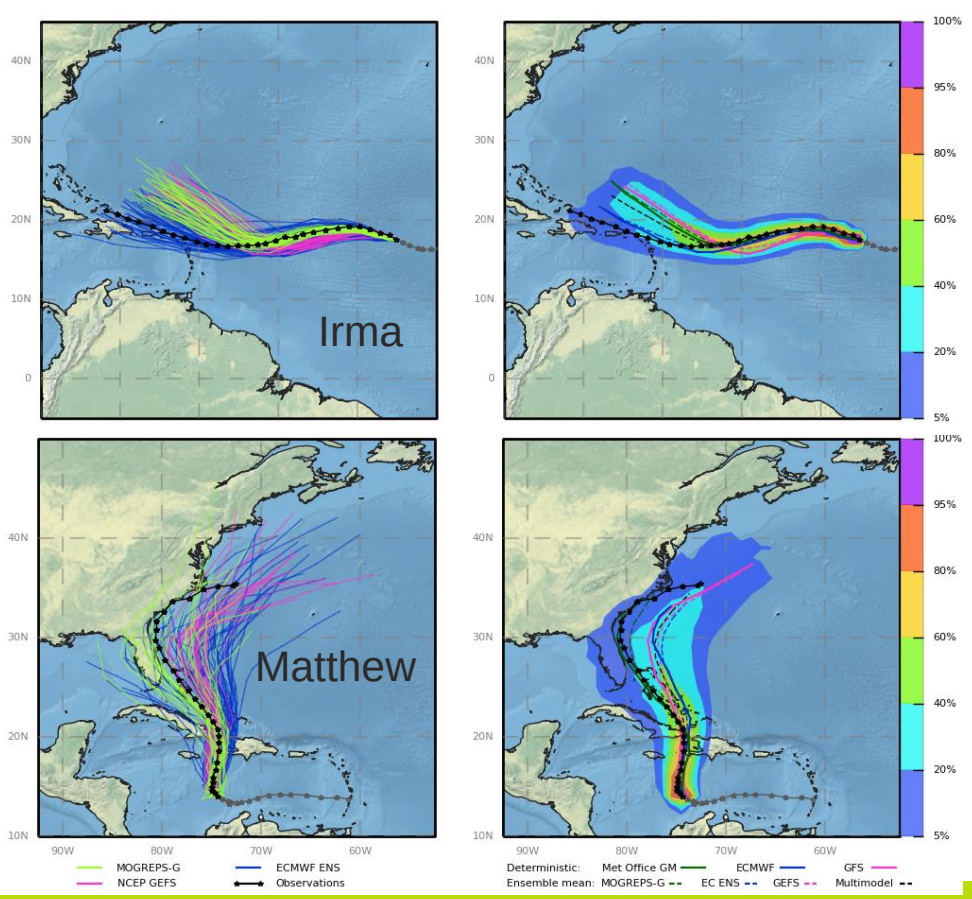


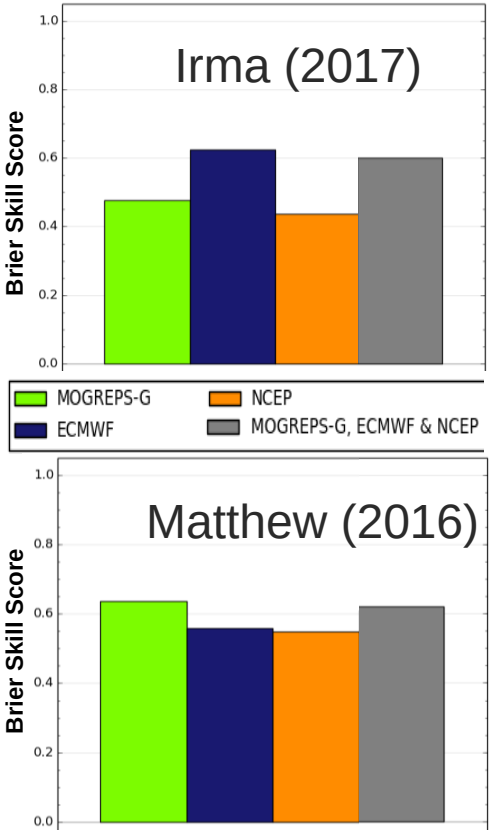


Titley and Bowyer (2019, In Preparation)

Multi-model ensemble TC forecasting

- 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



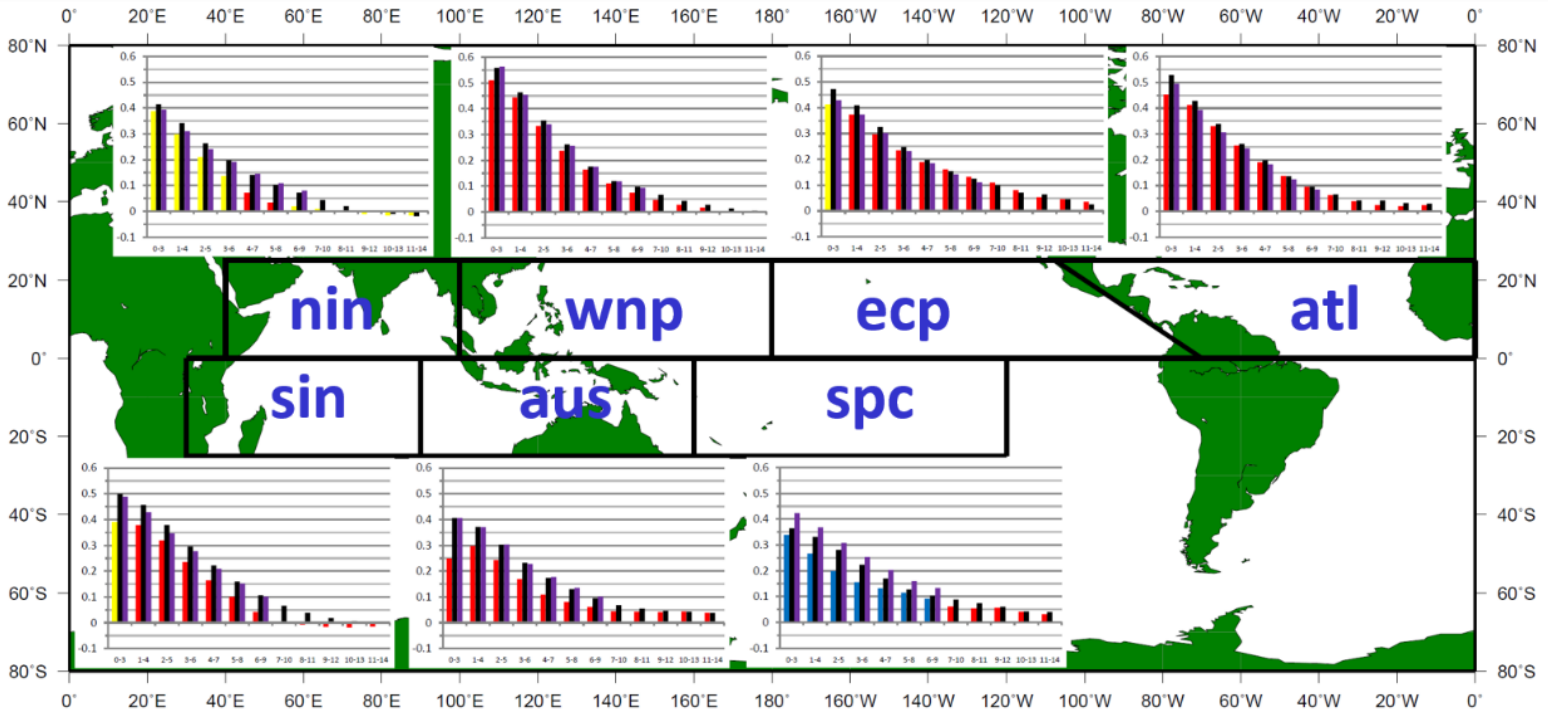


Titley and Bowyer (2019, In Preparation)

Multi-model ensemble TC forecasting

c) TC activity

BSS by basin and lead time: left=best performing individual ensemble; middle=MCGE3 (3 ensembles); right= MCGE4 (4 ensembles)

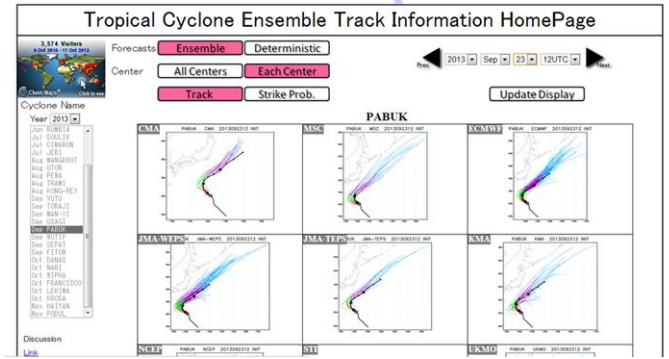


Yamaguchi, et at (2015)
Weather and Forecasting

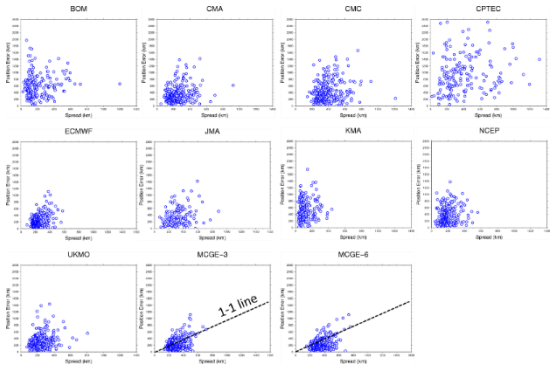
North Western Pacific Tropical Cyclone Ensemble Forecast Project (NWP-TCEFP)

R2O in TC forecasting with TIGGE

Step 1: Multi-model ensemble TC track predictions using TIGGE CXML

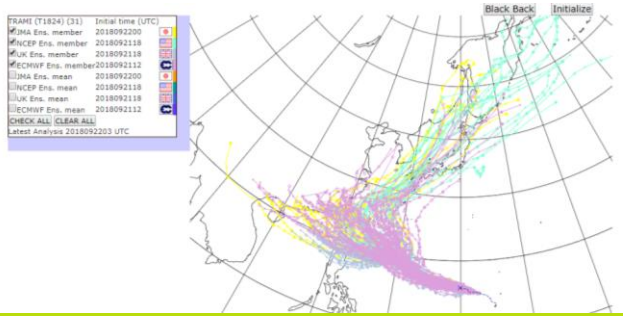


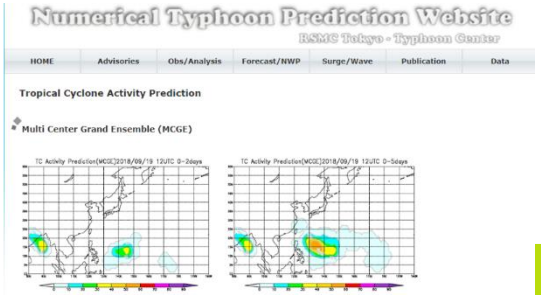
Step 2: Demonstrate the relative benefits of multi-model ensembles wrt a single-model ensemble (Yamaguchi et al. 2012, QJRMS)



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

Step 4: RSMC Tokyo provides real-time multi-model ensemble (ECMWF, NCEP, UKMO and JMA) TC track and activity predictions to Typhoon Committee





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

HIWeather questionnaire

- 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.

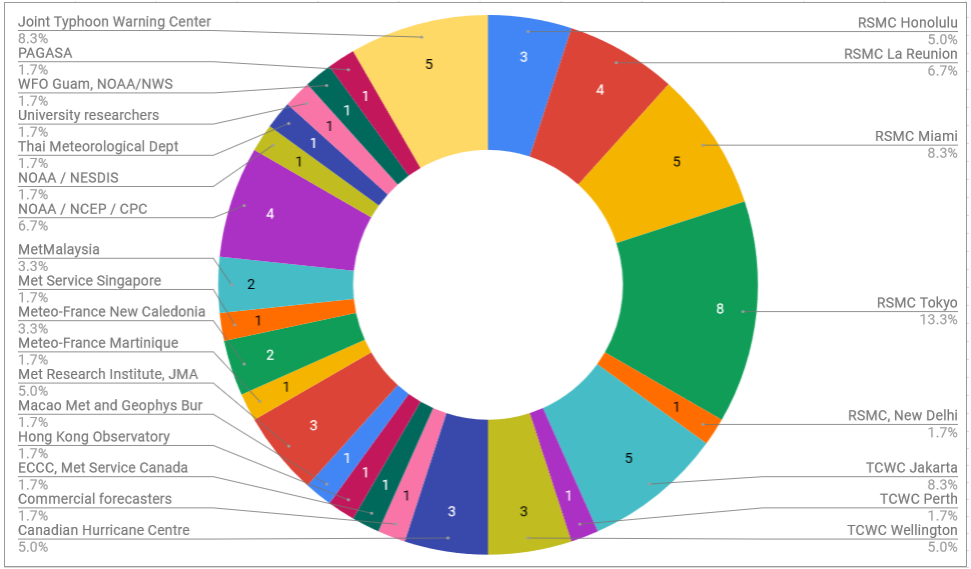
- Four more detailed objectives:

  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

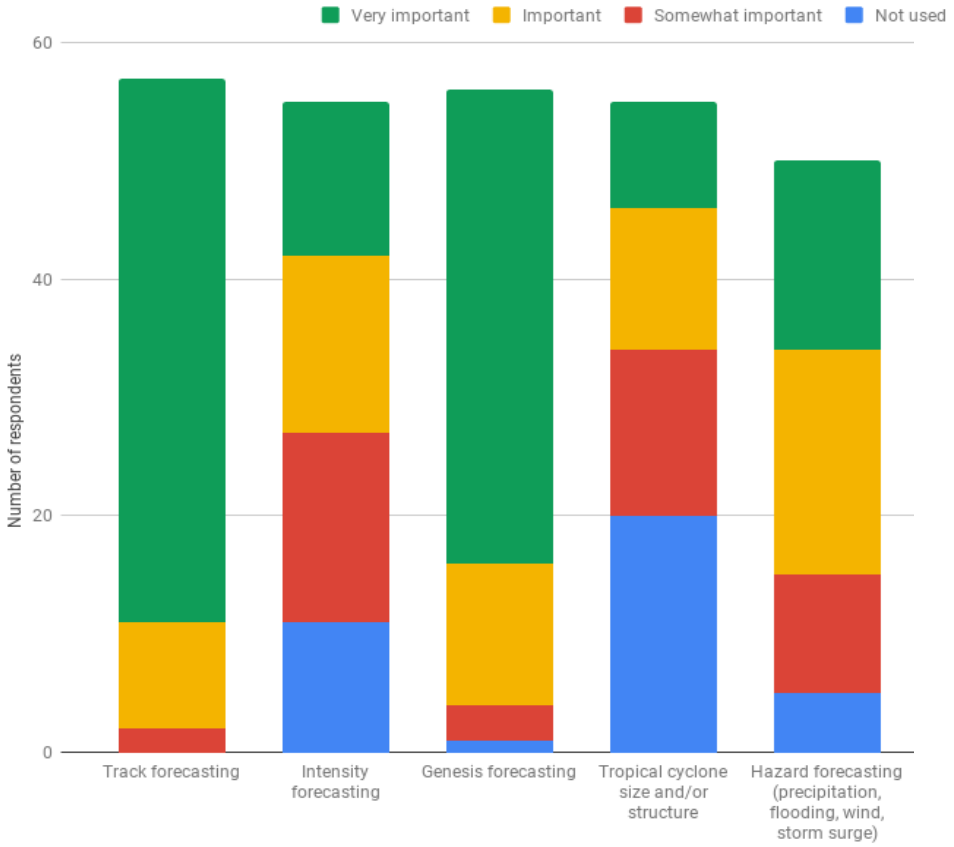
  iii) To obtain examples where probabilistic forecasts have been successfully integrated in to operations, and where hurdles have prevented this

  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



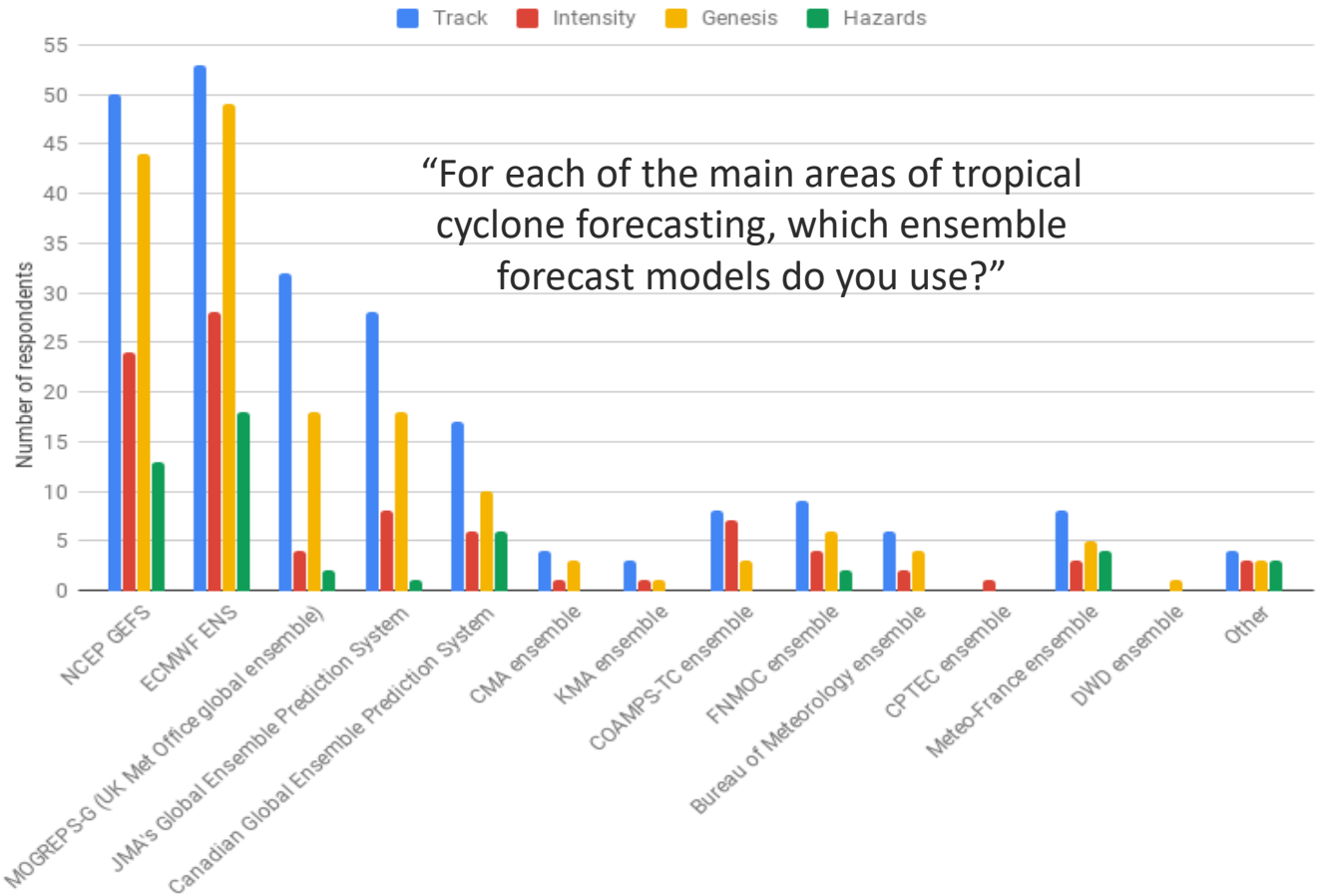
Total number of 60 respondents from all over the world, and with interests in each TC basin

Questionnaire results:
Current use of ensemble forecast information



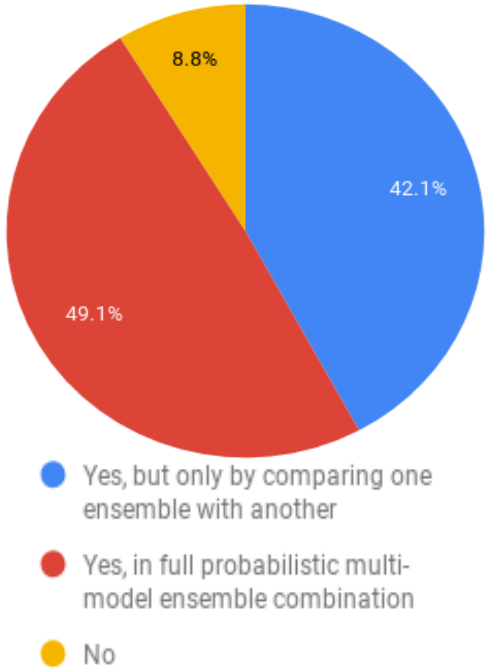
"How important would you say ensemble forecasts are in each area of tropical cyclone forecasting?"

Questionnaire results: Current use of ensemble forecast information



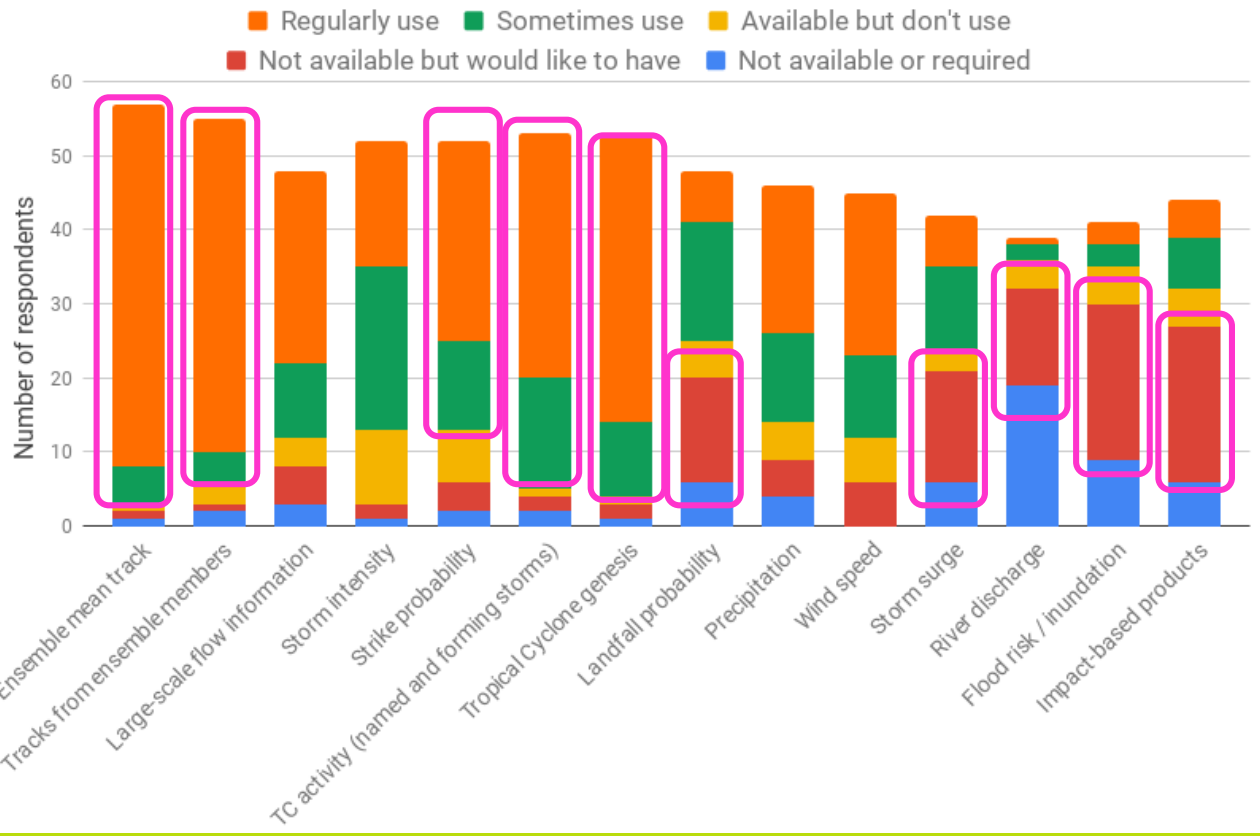
"For each of the main areas of tropical cyclone forecasting, which ensemble forecast models do you use?"

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

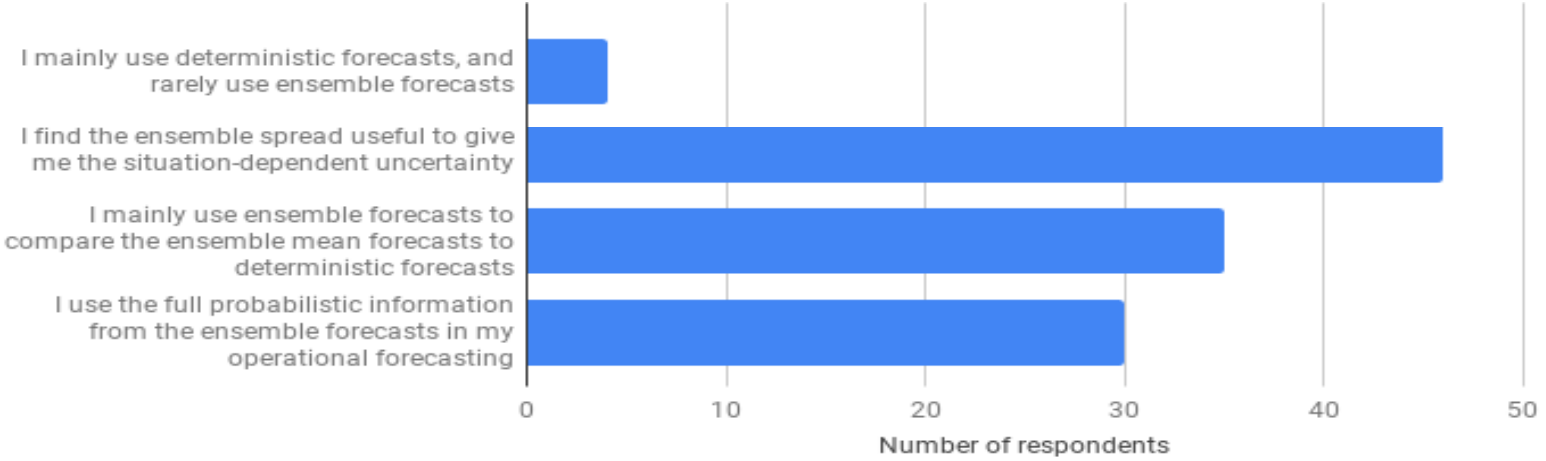


Questionnaire results:
Current use of ensemble forecast information

"Which ensemble-based or probabilistic products do you use"



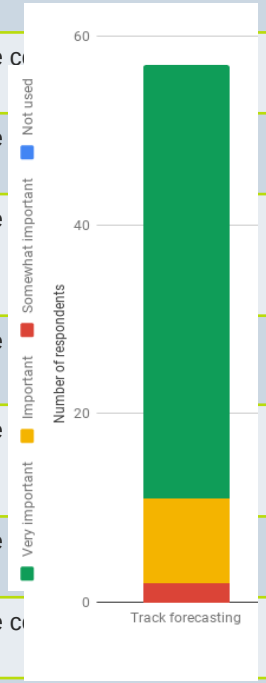
Questionnaire results:
Current use of ensemble forecast information

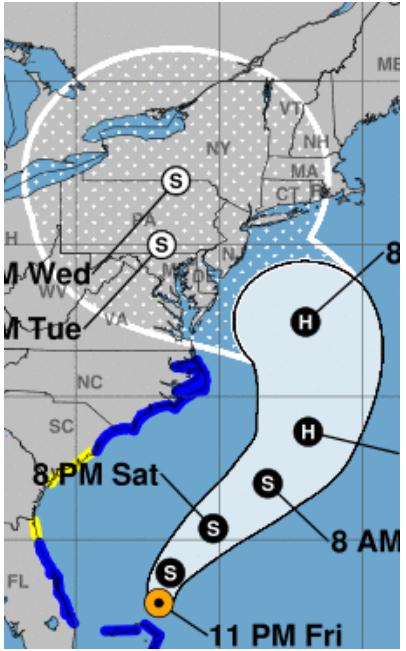


"Which of the following statements describe your use of ensemble forecast information in ***track*** forecasting?"

How forecast uncertainty is communicated in operational forecasts and warnings: *Track*

Center name	How is uncertainty represented?	How is it calculated?
RSMC Tokyo	Circle containing 70% of TCs	Historical forecast error statistics (up to 72 hours) and ensemble spread (after 96 hours)
RSMC Honolulu	Cone c	Historical forecast error (5 year)
RSMC La Reunion	Cone	Based on both ensemble spread and historical forecast error, (Dupont et al. 2011)
RSMC Miami	Cone	Previous 5 years of track error for that basin
RSMC New Delhi	Cone	Historical forecast error statistics
TCWC Jakarta	Cone	Consensus spread. Patterns obtained from wind model forecasts, and sometimes the form is modified manually to make the shape smoother.
TCWC Perth	Cone	Situation dependent, usually either consensus spread or climatological uncertainty but can be manually manipulated.
TCWC Wellington	Cone c	Calculated based on consensus spread, ensemble spread and climatological uncertainty.
Joint Typhoon Warning Center (JWTC)	Error swath	Calculated by adding the JTWC 5-year running mean forecast track error to the forecast 34-knot wind radii at each forecast time.





How forecast uncertainty is communicated in operational forecasts and warnings: *Genesis*

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

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

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.

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

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 in to operational tropical cyclone forecasts and warnings