The Bureau of Meteorology

Forecast Location Confidence

Super Ensemble Approach

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Acknowledgements

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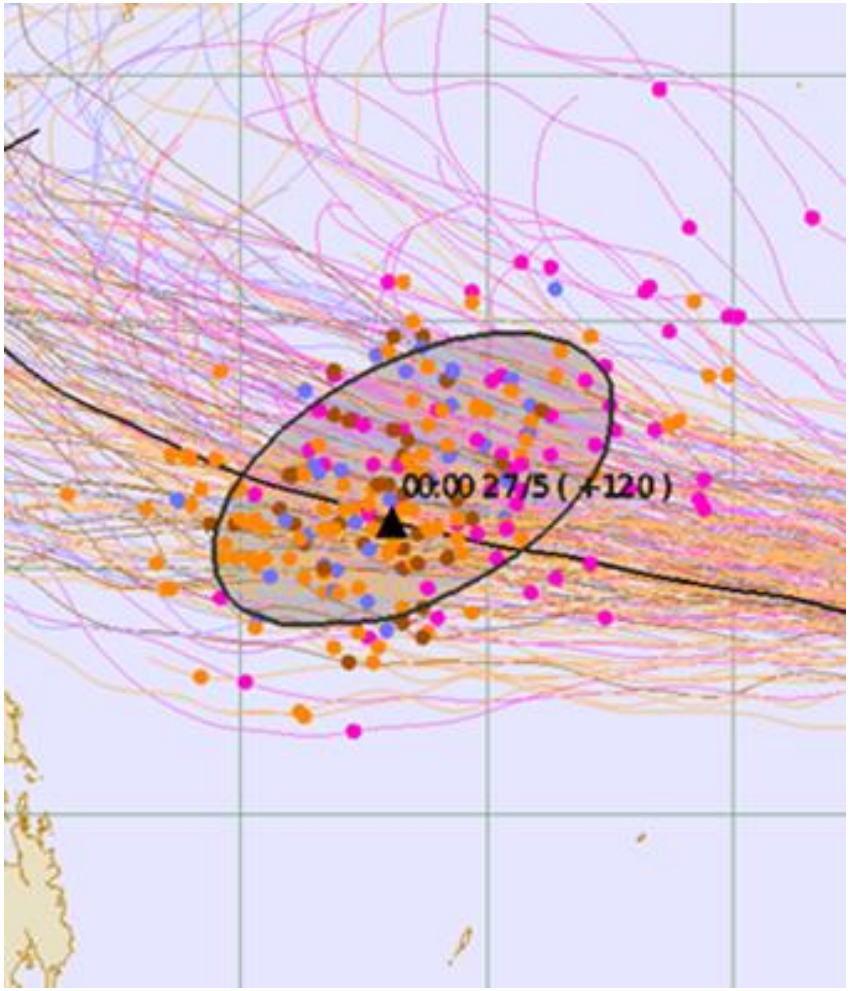
Tropical Cyclones, Bureau of Meteorology

Outline

- Introduction
- Super Ensembles & Clustering
- Gaussian Mixture Model
- Optimisation & Calibration
- Operational Implementation
- Case Studies
- Summary

Introduction

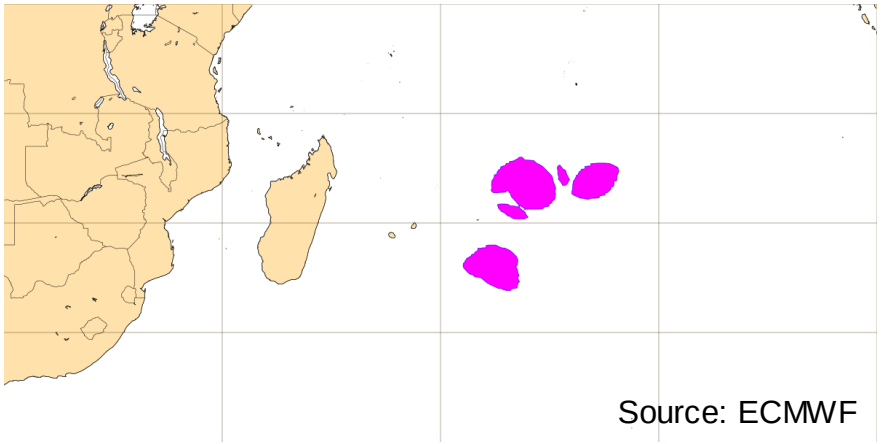
- Ensembles offer multiple forecast scenarios
- Spread of ensemble members can approximate forecast confidence
- Forecast Confidence Areas can be built from ensemble output
- Confidence Areas are independent of forecast track

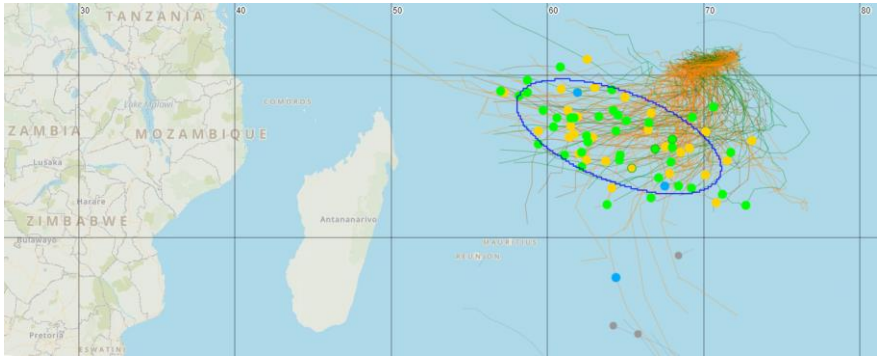


Ensembles

Strike Probabilities

- Dependent on intensity threshold and strike radius
- Output can become skewed to individual members (gaps begin to appear)
- Has strengths, but not useful for all applications





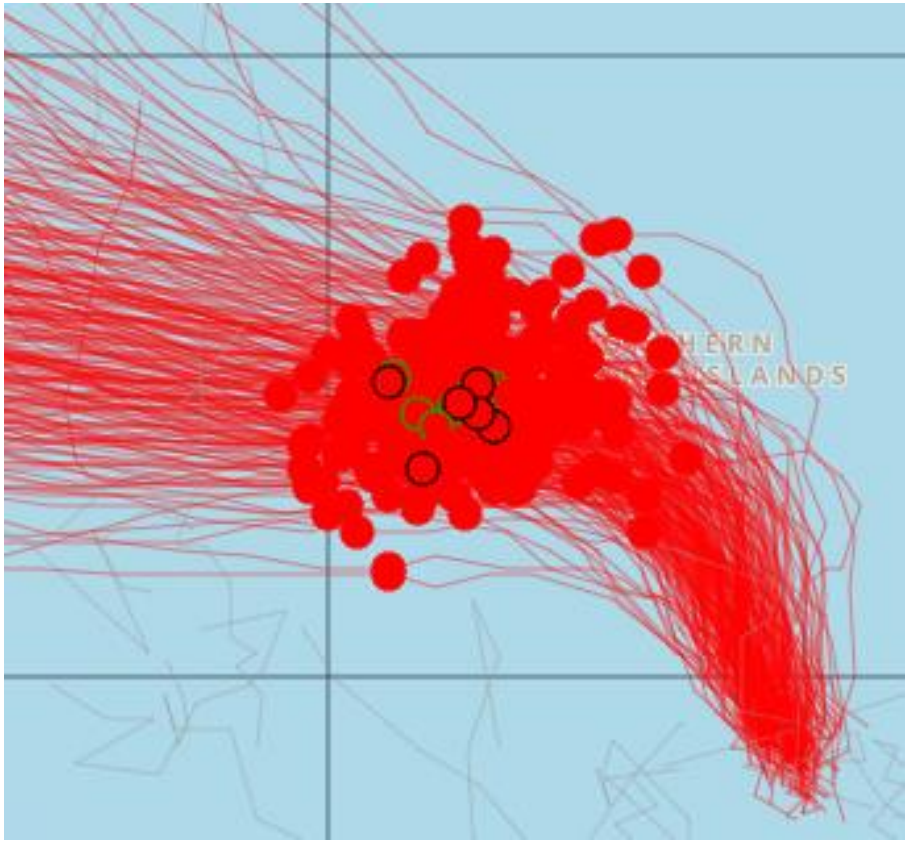
Ensemble Solutions

Assume every ensemble member is;

- A realistic solution
- Equally likely

Calculate cumulative probabilities for an area centred on the mode

Gridded probabilities created from GMM

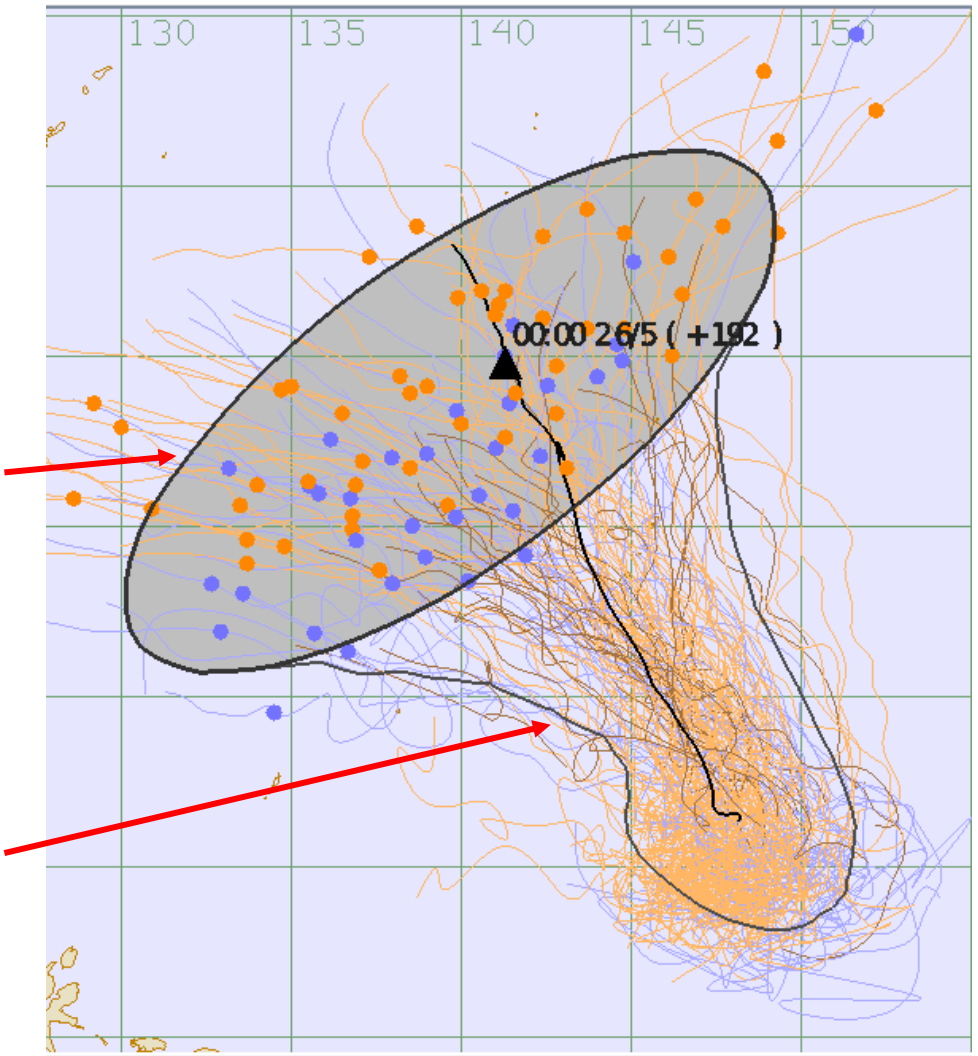


Terminology

Super Ensemble – A large forecast ensemble built from multiple centres and multiple run times (an ensemble of ensembles)

Forecast Confidence Area (FCA) – represents that timestep only

Forecast Confidence Cone (FCC) – amalgamation of all FCA from base time to timestep

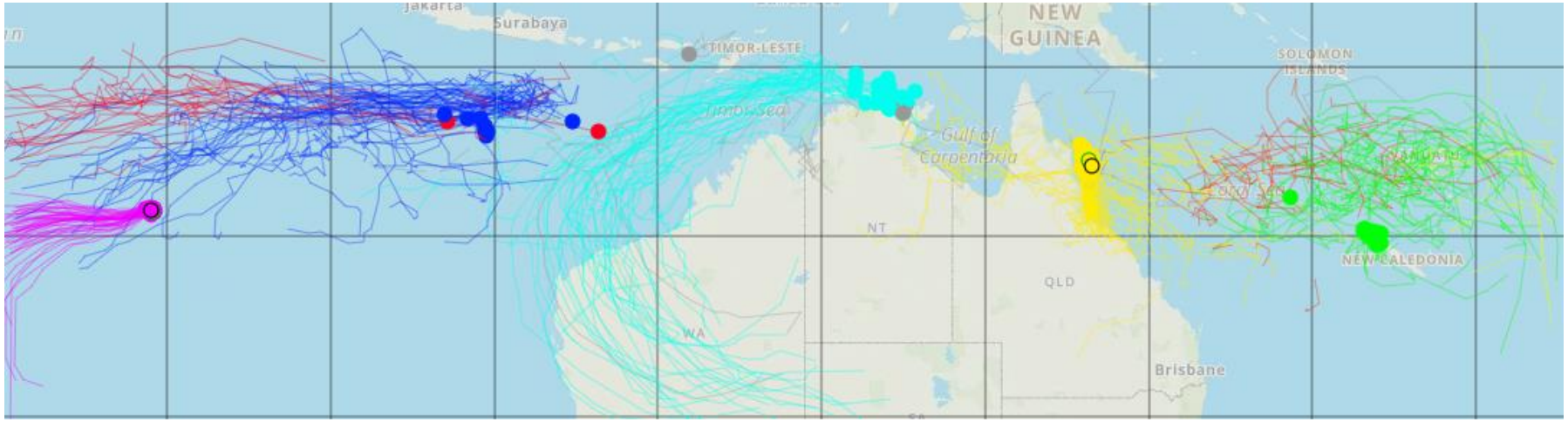


Super Ensembles & Clustering

Creating an ensemble of ensembles

Clustering

- Clustering assigns members from different ensembles to a disturbance
- Groups track that can be reasonably considered different forecasts for the same tropical system
- Can group members from different forecast centres and different run times
- Different vortex tracking methods used at different centres can lead to inconsistent outputs



Gaussian Mixture Model (GMM)

Approximating a probability density function from a set of sample points

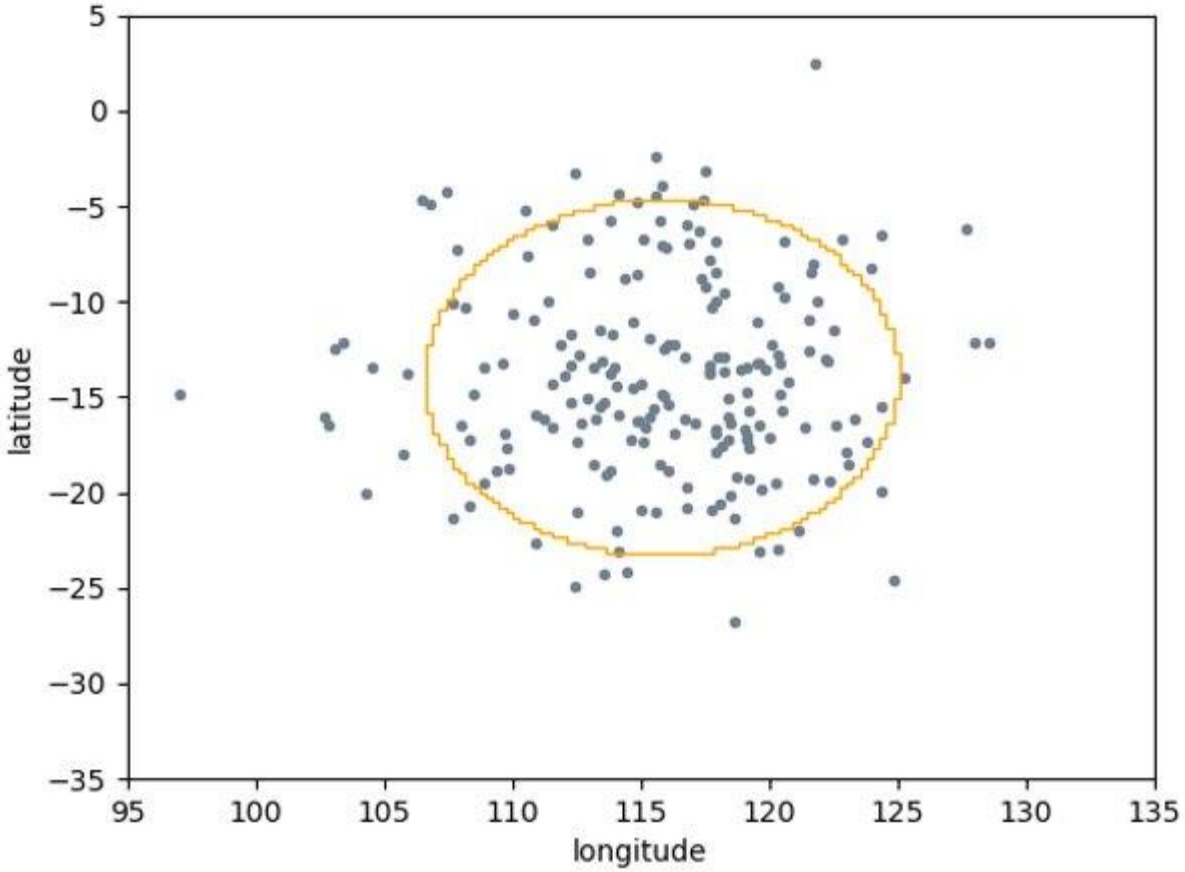
Gaussian Mixture Model

A weighted sum of Gaussian distributions

Can be elliptical and tilted

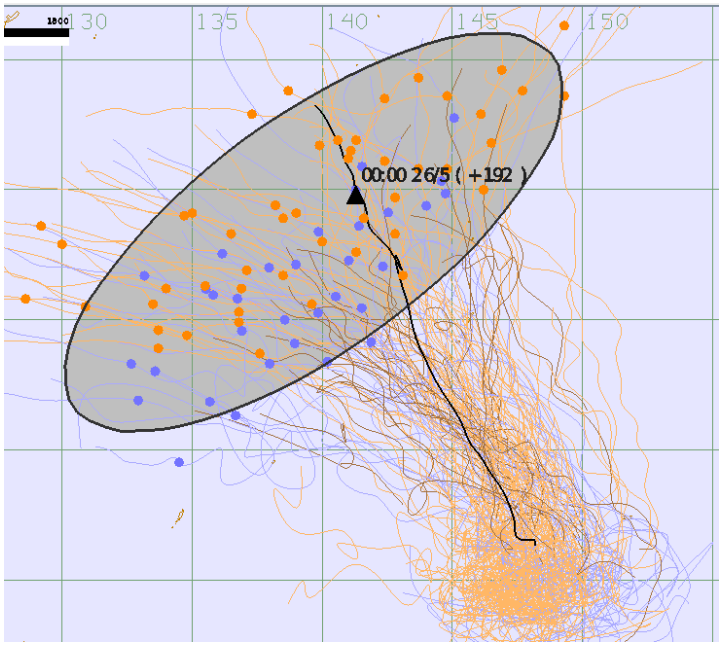
Assumes that data points are a true representation of a probability density function (PDF)

Attempts to recreate the PDF from the set of data points



Forecast Confidence Area

1. Use PDF to create Probability of Location (PoL) grid
   - Conditional on the system existing
   - Mutually exclusive; a system centre cannot be in two grid cells
   - Normalised so that the sum of the grid is 1
2. Find largest value in the grid (represents the mode of the PDF)
3. Create an area around the largest value that follows a contour of equal probability
   - Sum of values within the area is the cumulative probability
4. Adjust value of PoL contour to obtain desired cumulative probability



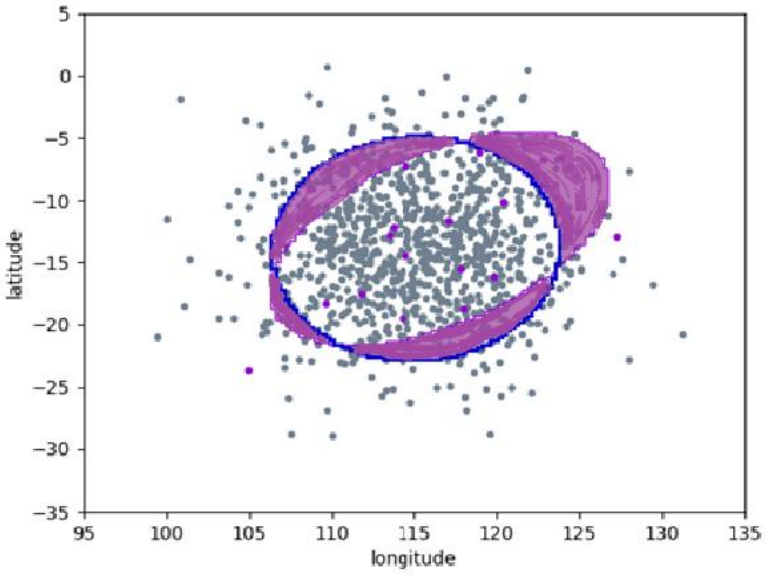
Optimisation & Calibration

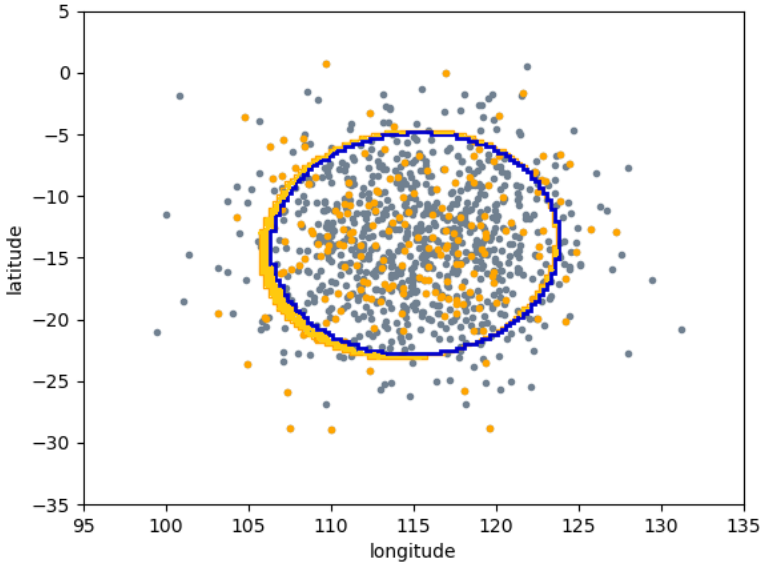
Having confidence in the confidence area

Optimising the PDF

- Data points in grey from a random distribution
- Purple dots and Yellow dots are subsets
- Shaded areas are difference between resulting areas from process

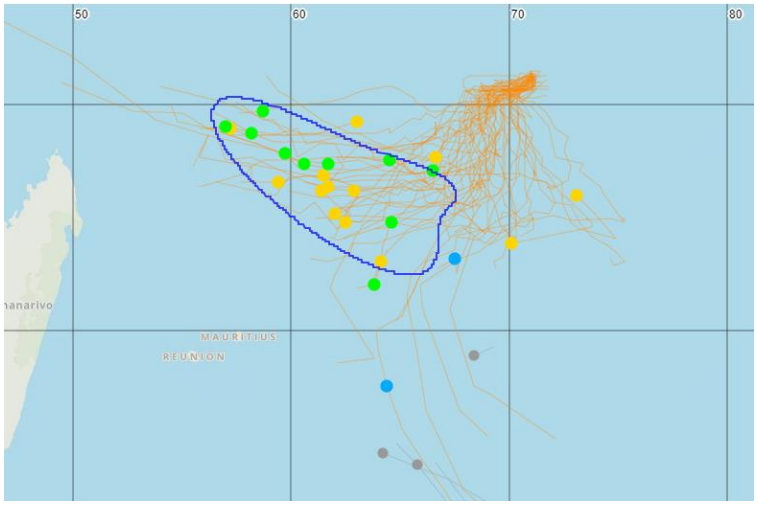
- Increasing the number of members decreases the error in the area – converges on true PDF

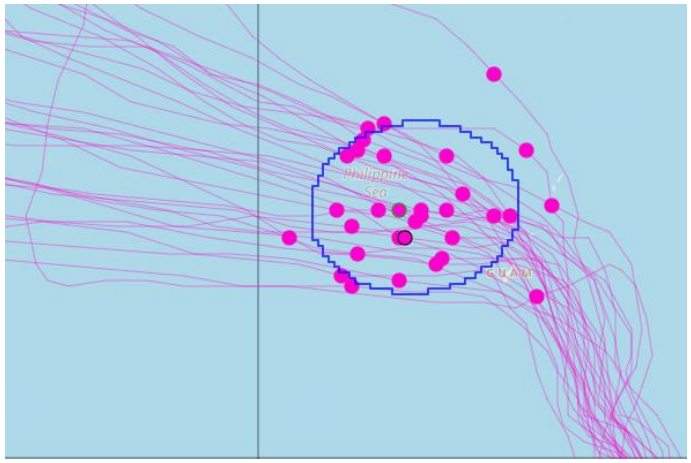


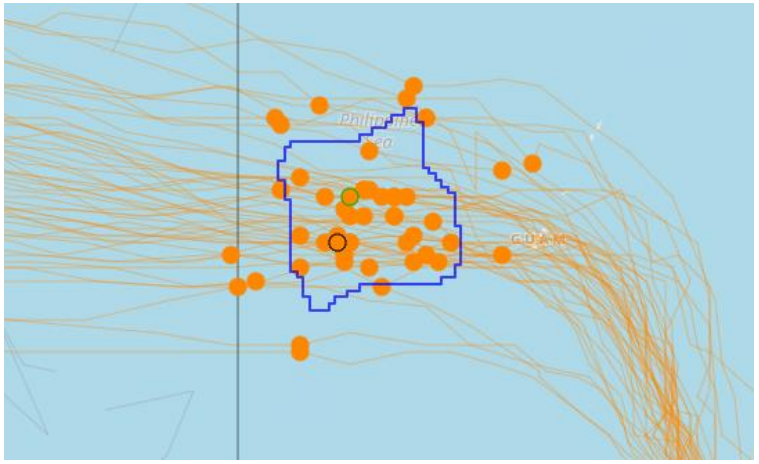


Optimising the PDF

- Comparison of different areas created by single ensembles
- Limited datapoints can lead to unpredictable shapes



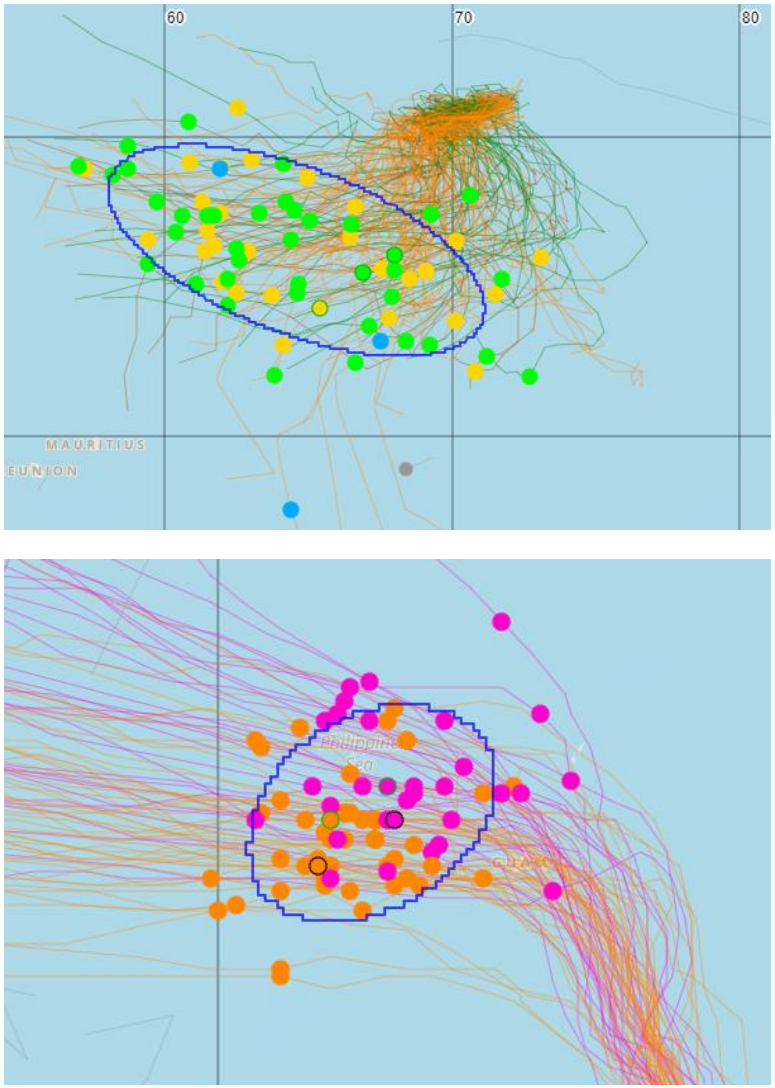




Ensemble Spread

Use of multi-centre ensembles

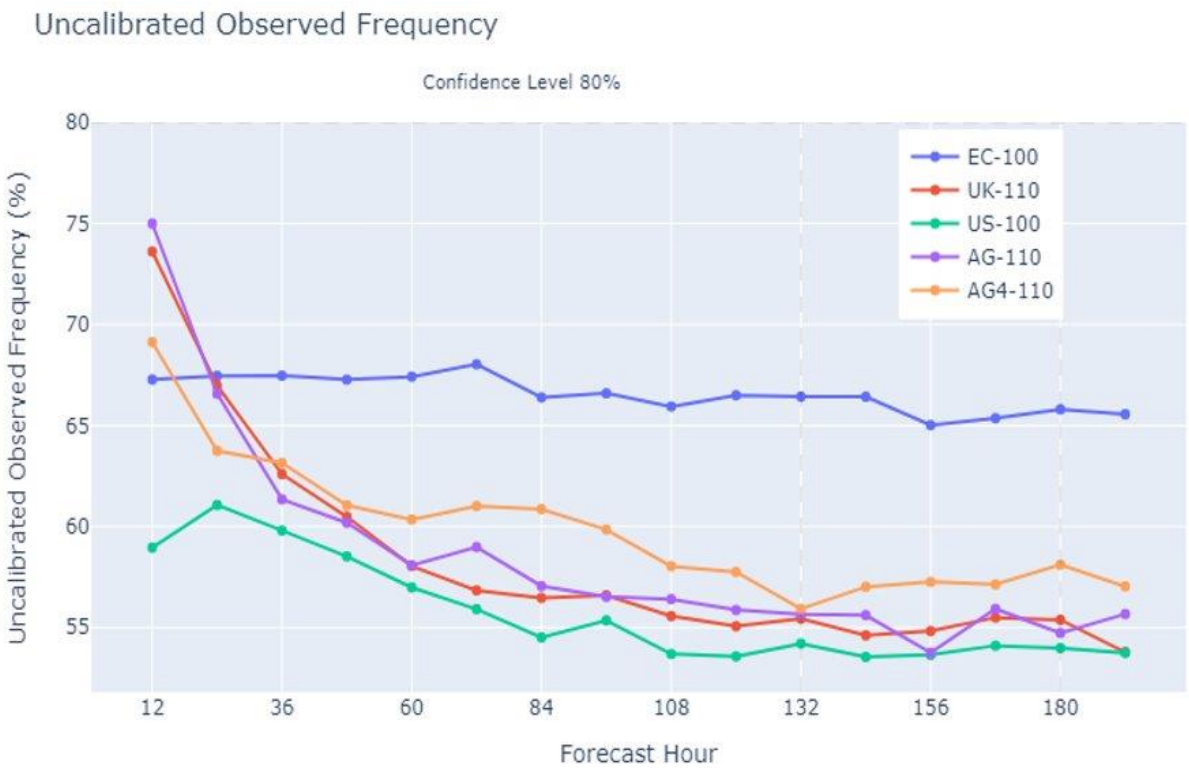
- More datapoints, reduce error
- Counter individual model bias
- Simpler shapes



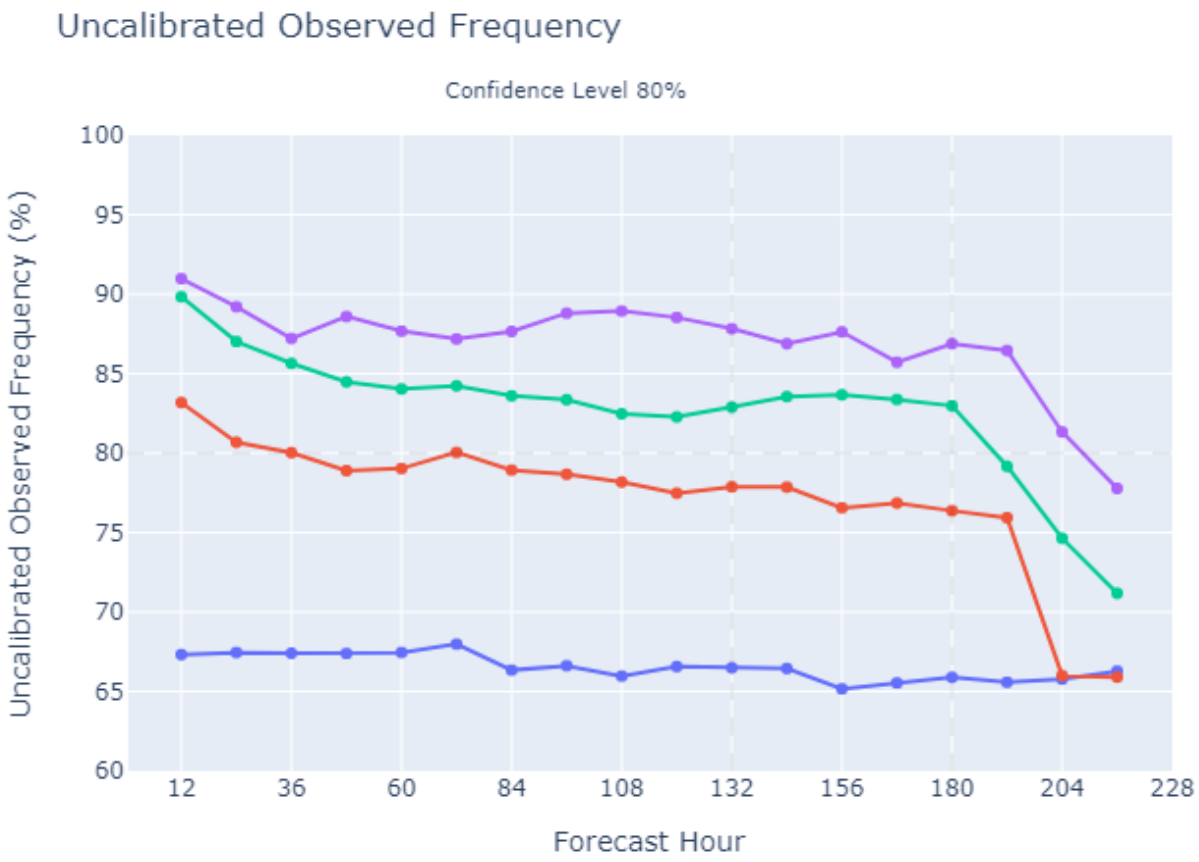
Uncalibrated Performance

How often was the observed location within our area?

Individual ensembles are under spread and/or biased



Uncalibrated Performance



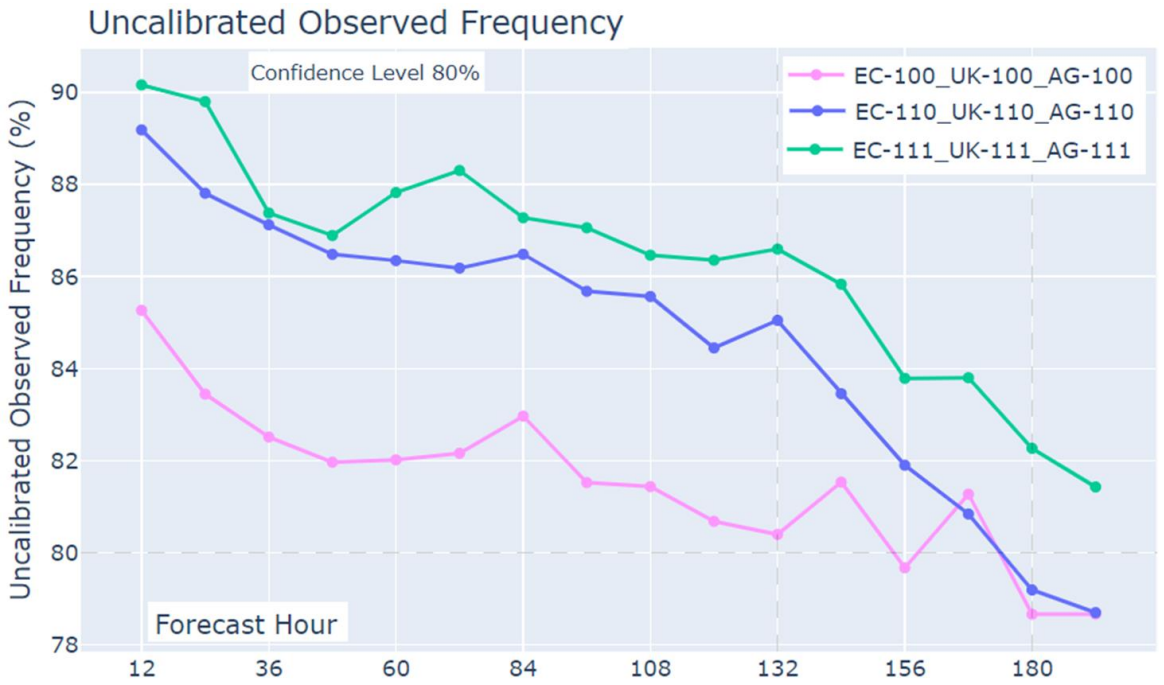
Multi-Centre Grand Ensembles

- Increase spread (can be over spread)
- Increase data-points
- Counter bias

Uncalibrated performance

Lagged ensembles

- Also increase spread
- Increase data points
- But overspread in short term

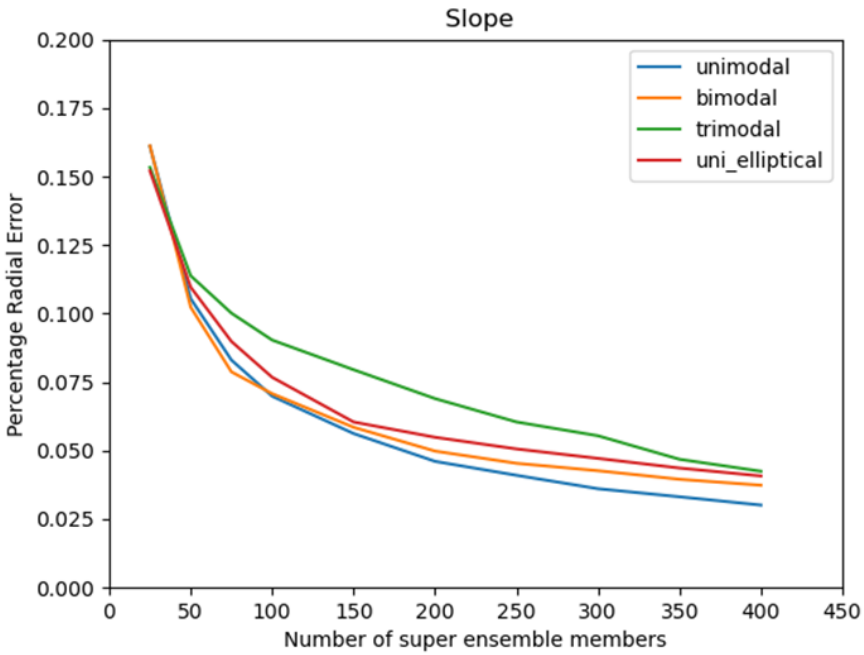


Super Ensemble Size

Include lagged ensembles;

- to increase members (data points)
- increase the spread
- increase the stability of output

Aim for at least 150 ensemble members

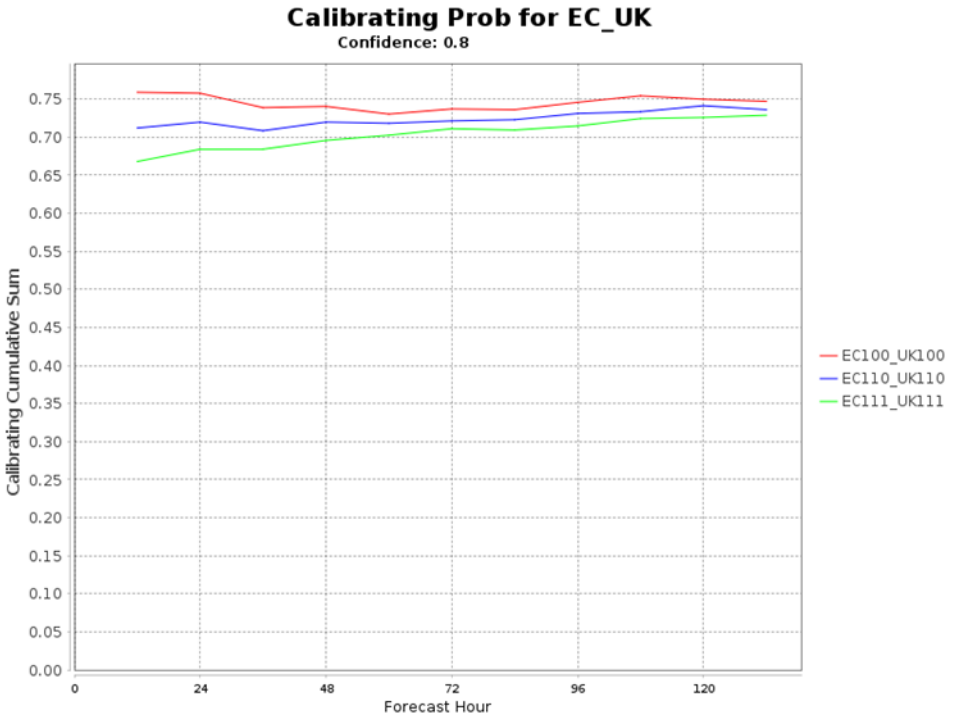


Calibration

Calibrated values

For historical forecast, finding the *XX* percentile of cumulative probabilities

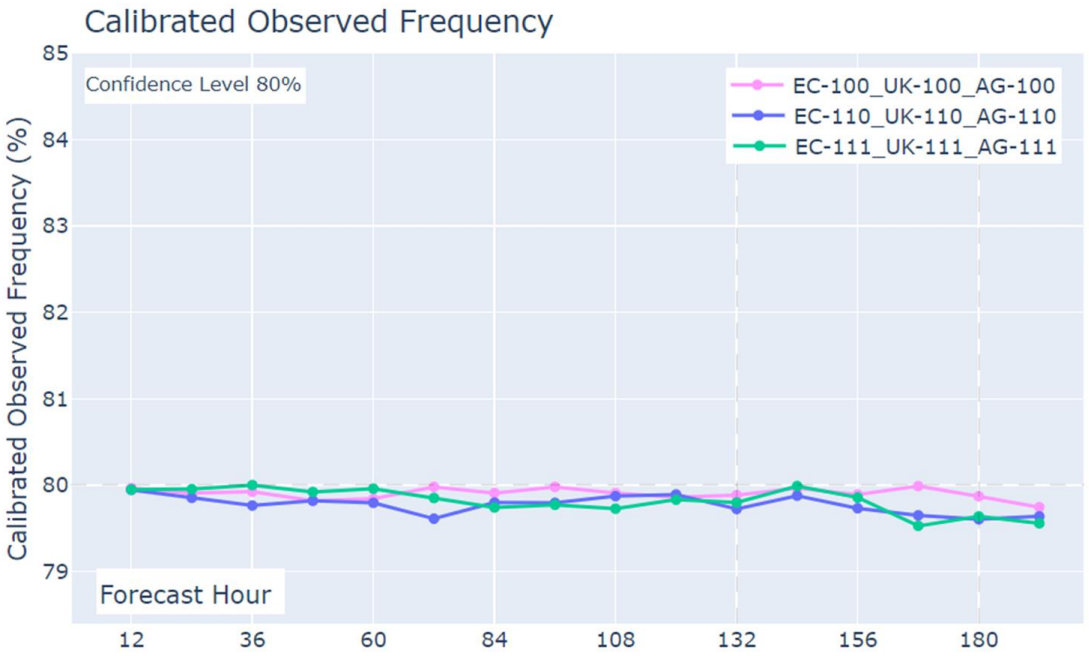
- Find the value of the PoL grid that corresponds to analysis position
- Sum all values of the PoL grid greater than or equal to this value
- Repeat with other forecasts
- Build dataset and determine percentile



Validation

Repeated K-Fold Cross Validation

- A whole disturbance is in either the training or test dataset
- Repeat with different combinations
- Derive a mean and standard deviation of the Calibrated Observed Frequency



Operational Implementation

Fitting the operational rhythm

Including Analysis Position

- Ensemble base times are before analysis time
- Spread of ensembles may be greater than uncertainty of analysis position
    - Particularly true when using lagged ensembles
- In rare instances, analysis position outside of ensemble spread

Weight to analysis in short term (~36 hours)

Areas and Cones

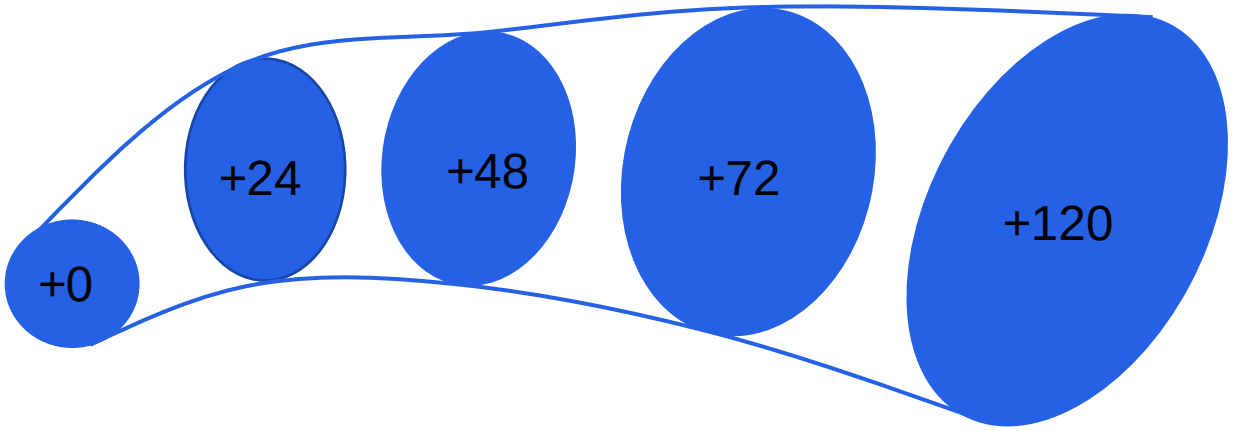
+0hr Confidence Area is a circle:

- centred on analysis position
- of radius equal to analysis position uncertainty

Forecast Confidence Cones created by linking together Forecast Confidence Areas

BOM Operations

- Areas for Cyclogenesis Products
- Cones for Official Forecast Track



Case Studies

Cyclogenesis & Forecast Track

Cyclogenesis – Intensity Filters

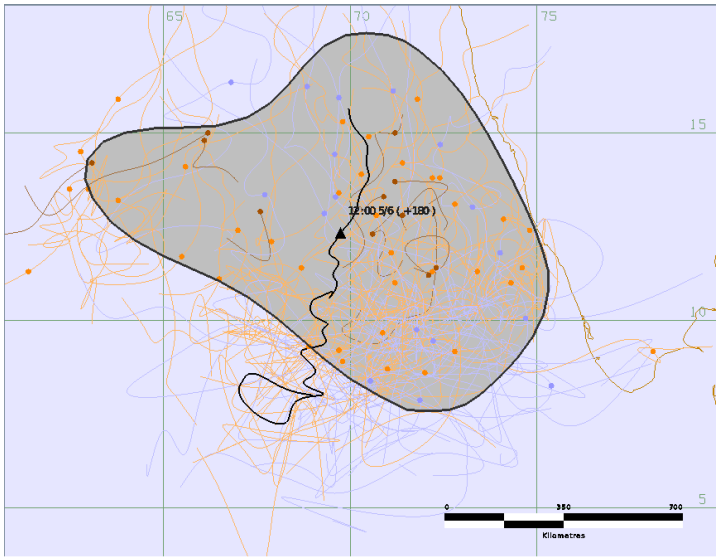
Pre-Biparjoy 30 May

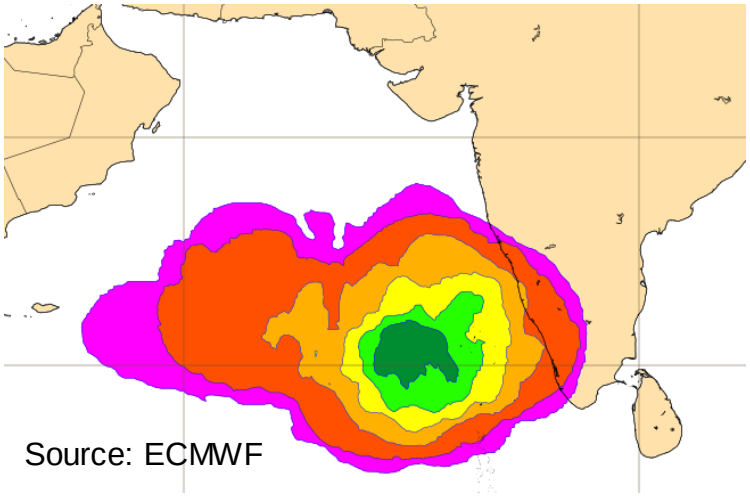
EC Strike Probabilities, first signal

- Tropical cyclone +96hr
- Tropical storm +168hr

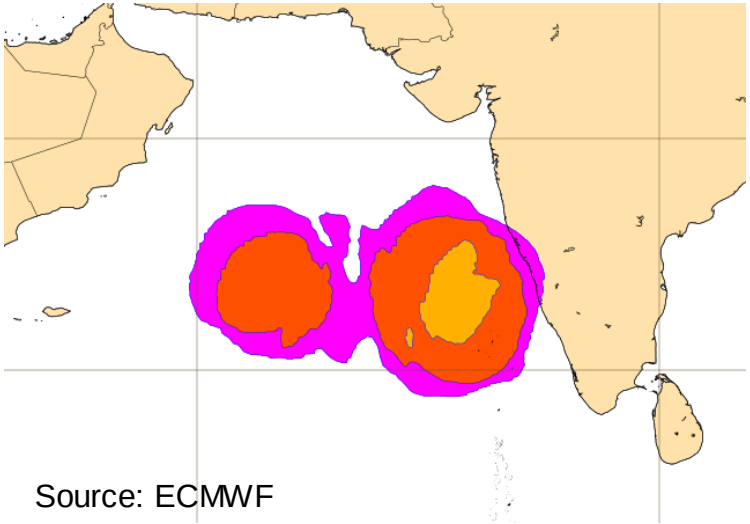
GMM Forecast Confidence Areas available from +48hr

+192hr forecasts: EC Strike Probabilities for Tropical cyclone (Top right), Tropical storm (bottom right) and GMM (left)



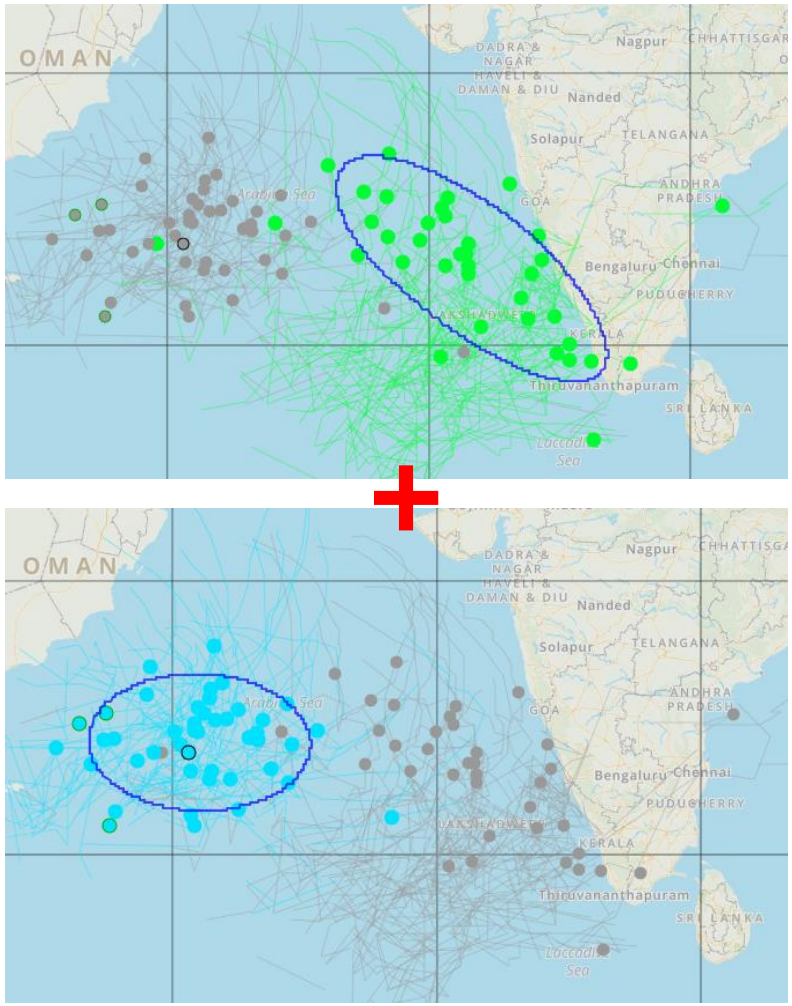


Source: ECMWF

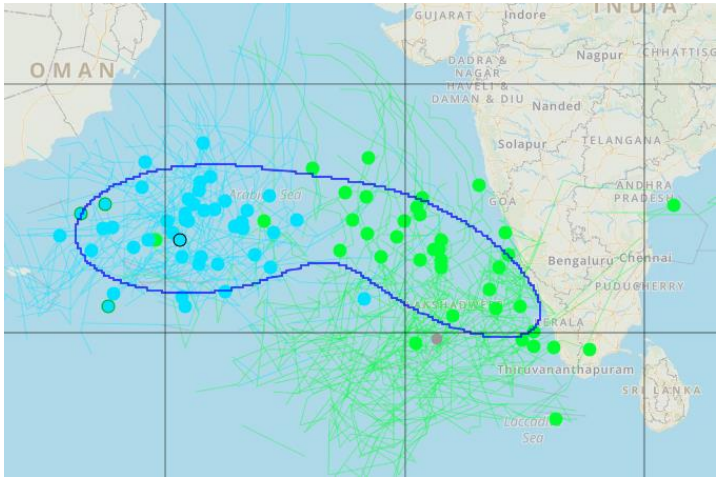


Source: ECMWF

Cyclogenesis – Multiple Systems

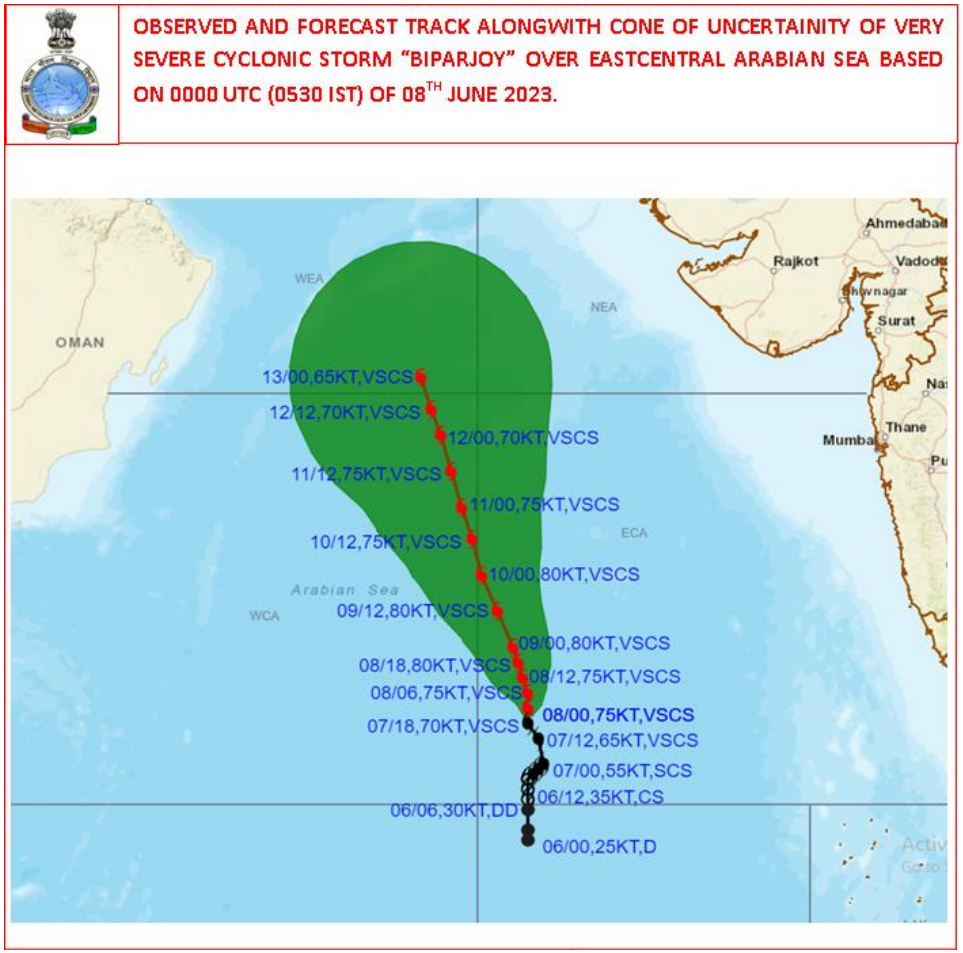


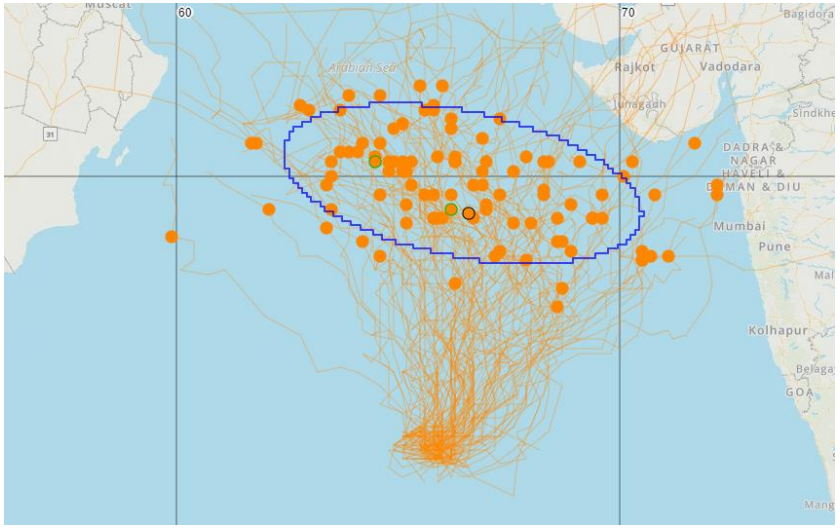
- Clustering may resolve multiple systems
- Can be combined back into one

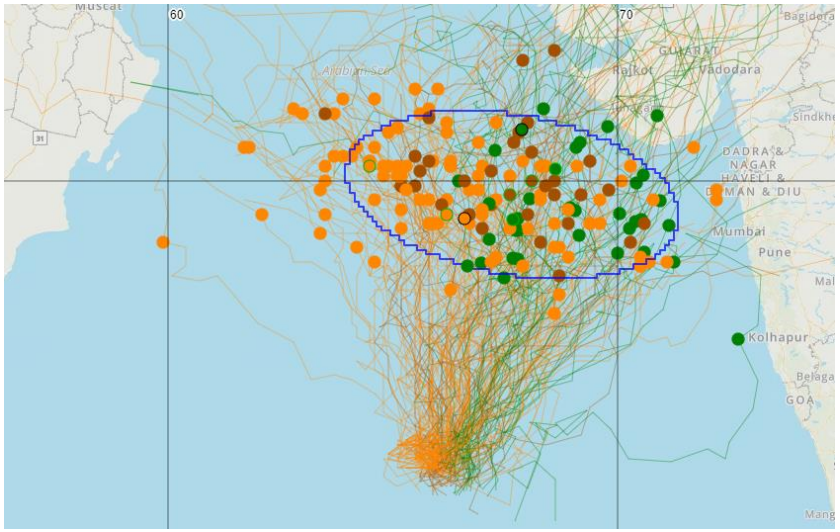


Confidence Area/Cone Comparison

Very Severe Cyclonic Storm Biparjoy - 8 June



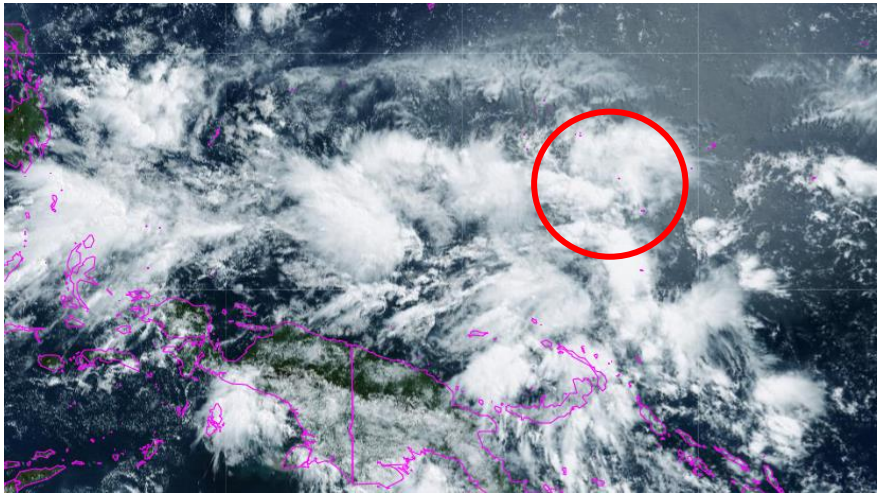




Cyclogenesis

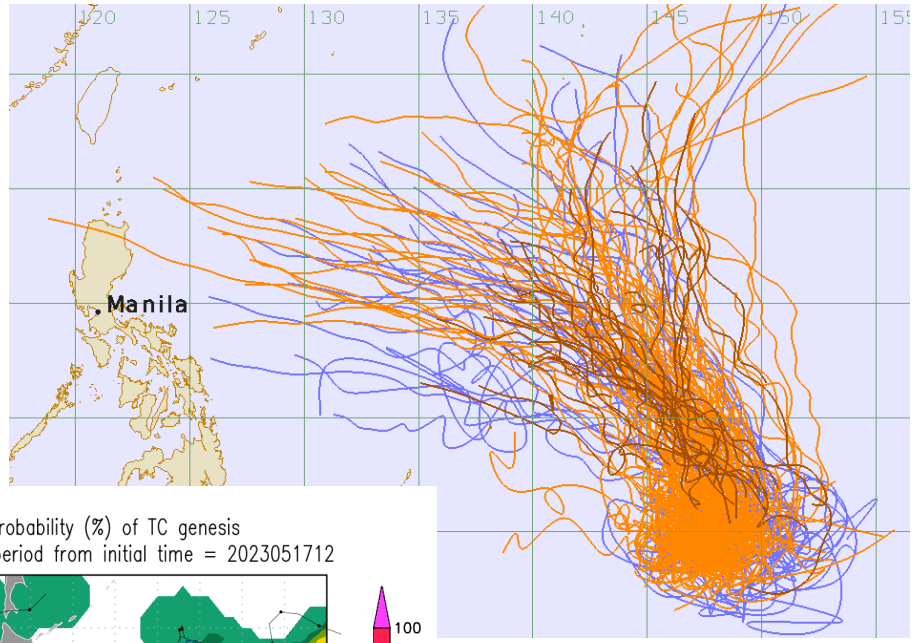
Pre-Mawar – 18 May

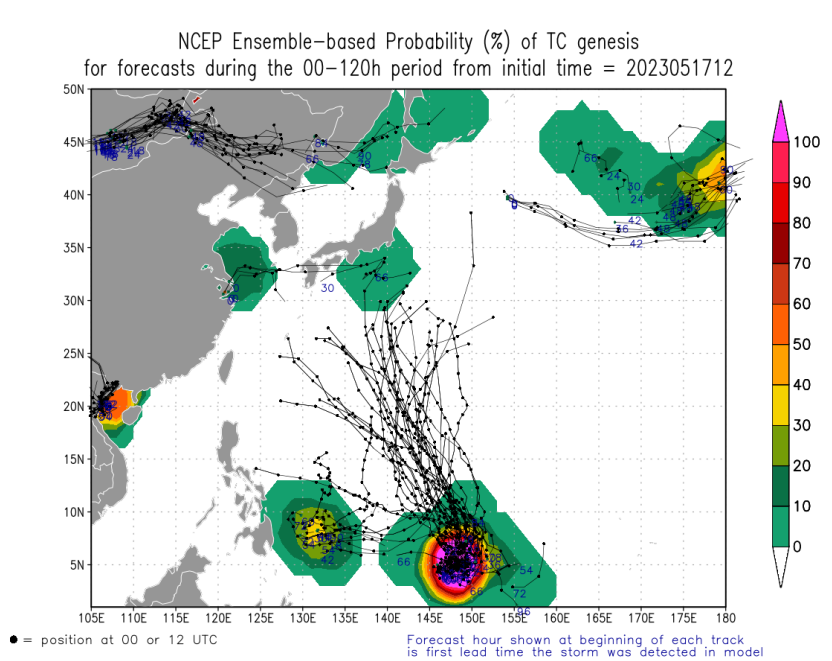
- NWP consistent in developing a system
- Relative confidence in the short term of moving north



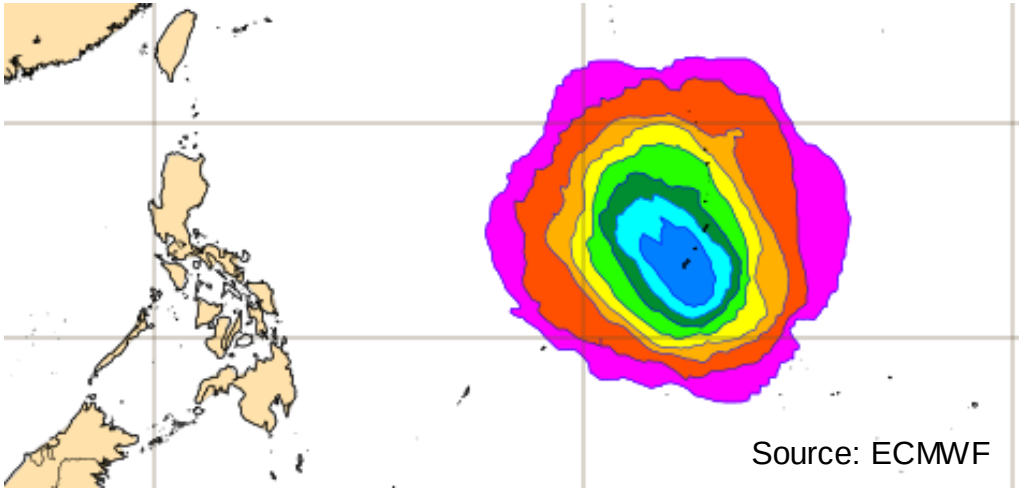
Ensemble Spread

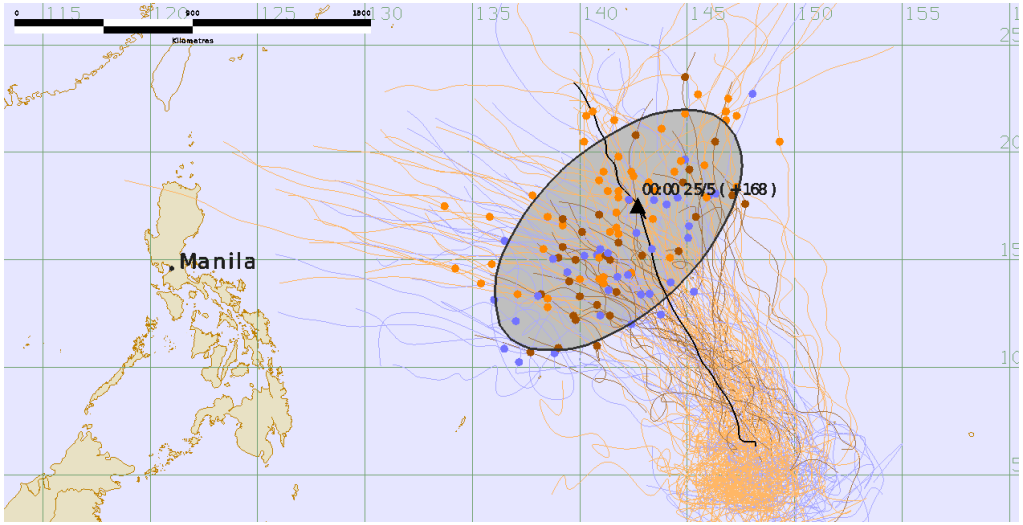
- Consensus in initial northward movement
- Spread increases in the longer term





7-Day Forecast



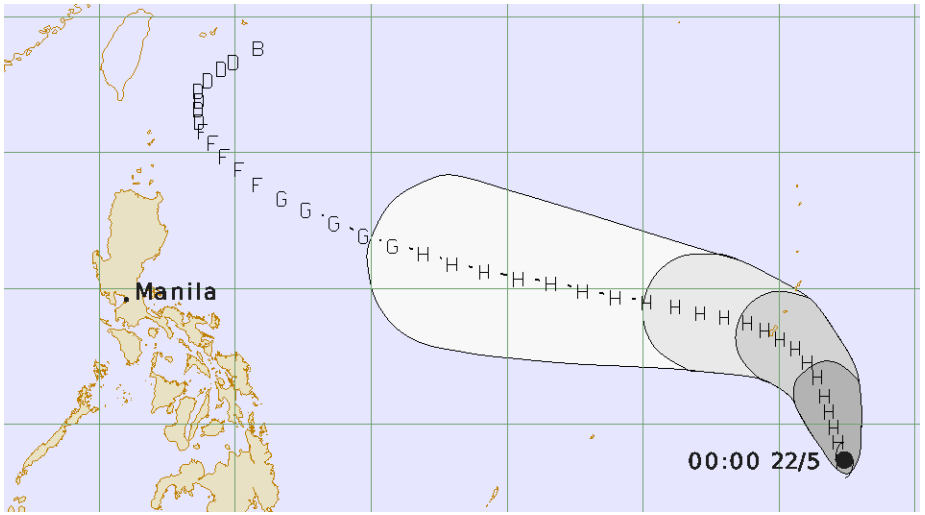


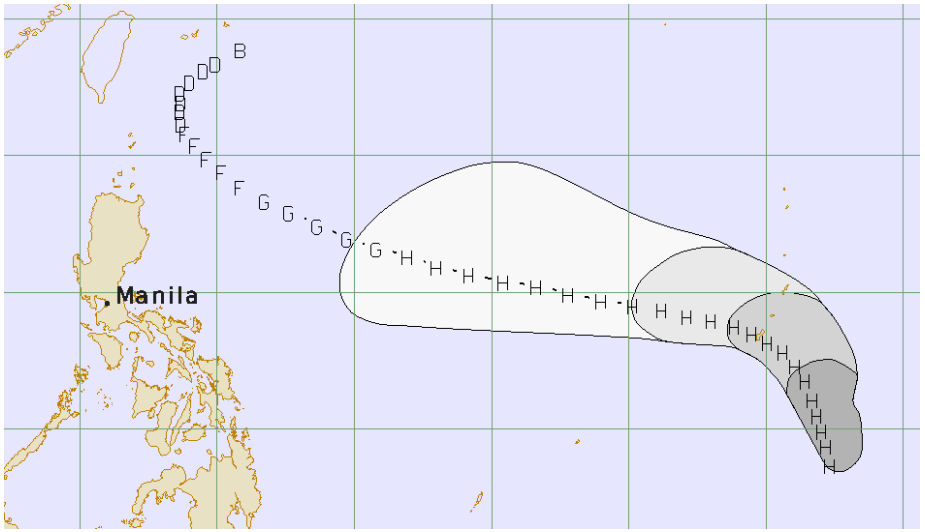
Confidence Cones on Forecast Track

Typhoon Mawar - 22 May

Top
- Areas based on climatological errors
- Spread symmetrically around forecast track

Bottom
- GMM Method
- Increased spread to the north for +120hr



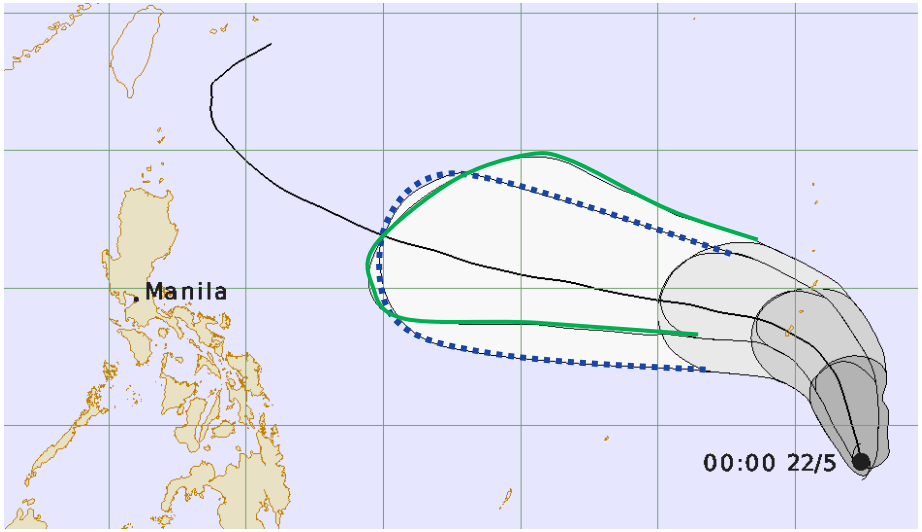


Confidence Cones on Forecast Track

Typhoon Mawar - 22 May

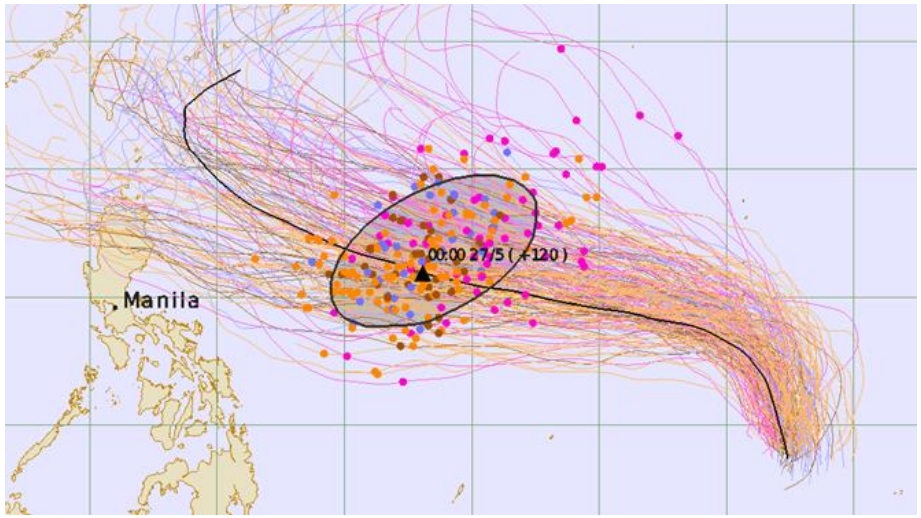
Top

- Comparison between Forecast Confidence Cones generated by each method
- Similar forward speed
- Differences in North-South positions



Bottom

- Ensemble forecast positions at +120hr with Forecast Confidence Area

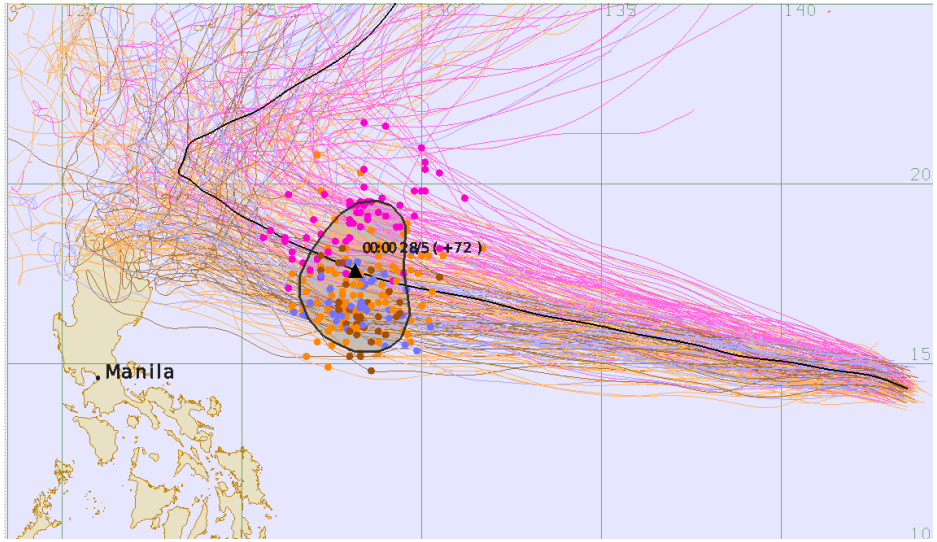


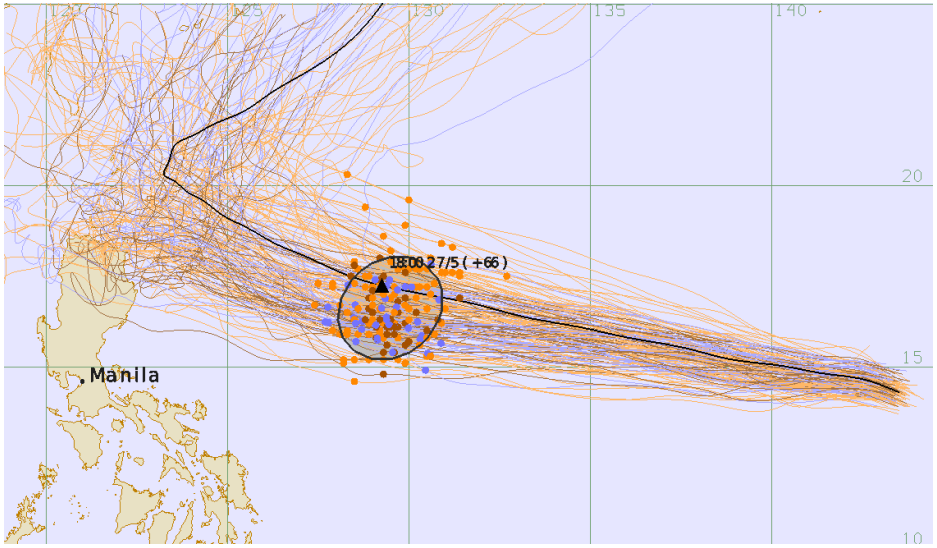
Ensemble Bias

Typhoon Mawar - 25 May

US GFS Ensemble members further north

- Including it makes larger shape but forecast position near centre
- Not including has smaller area with confidence area mostly south of forecast position





Summary

- Gaussian Mixture Model approach to create forecast confidence areas
- Super-ensemble used to increase data points
  - Capture true PDF
  - Provides adequate spread
- Calibration of super-ensemble combinations required

Current and Future Applications at BOM

- Already being used in official forecast tracks
- New graphical 7-day cyclogenesis forecast coming for 2023/24 season

The Bureau of Meteorology

Thank you

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www.bom.gov.au/cyclone