

Track Forecasting Are TCs 'unpredictable'?

- Conceptual frameworks
- The process
- NWP
- Consensus processes
- Ensembles





Answer: mostly no as changes in inner core processes have little effect on track; but sometimes yes!





TC Motion "Cork in a stream"

ENVIRONMENT STEERING

The dominant steering is on the scale of the outer circulation.

•To a first approximation, motion is governed by conservation of relative vorticity (vortex moves with the large-scale steering flow).



Use scales for tropical cyclone outer wind: $L \sim 500 \ km$ Rotational wind $V \sim 10 \ m/s$ Divergent wind $U \sim 1 \ m/s$ $\Delta P \sim 10^5 \ Pa$ $T \sim \frac{L}{V} \sim 5 \times 10^4 \ sec$ $\zeta \sim \frac{V}{L} \sim 2 \times 10^{-5} sec^{-1}$ $\delta \sim \frac{U}{L} \sim 2 \times 10^{-6} sec^{-1}$ $\omega \sim \delta \Delta P \sim 0.2 \ Pa/sec$ $\frac{\partial \zeta}{\partial t} = -V \cdot \nabla \zeta - \omega \frac{\partial \zeta}{\partial P} - \beta v - (\zeta + f) \delta - k \cdot \nabla \omega \times \frac{\partial V}{\partial P}$ $\overline{(1)}$ $\overline{(1)}$ (4) (2) (3) (4) 4×10^{-10} 4×10^{-10} 1×10^{-10} 4×10^{-11}





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Depth of the steering flow



Velden & Leslie (1993)



Moving TC Windfield Conceptual Model

- Look for wind max wind
- Compare winds on opposite sides of TC





Synoptic Steering patterns





Standard / Dominant Ridge

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What direction would TCs be steered at A/B/C?

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Secondary effects: i. the Beta effect

Conceptual Model of β-gyres for NH Tropical Cyclones with no Environmental Flow

TC circulation combined with the South-North variation of Coriolis induces asymmetries to produce a net NW steering current at a few knots (NH).



Size dependent

^a Combining Steering and Propagation to Estimate TC Motion



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Image: COMET



Secondary effects: ii. Trochoidal oscillations

Convective asymmetries induce a wobble short term Noticeable for slow moving TCs Official track usually smoothed Impacts landfall timing – storm tide



Wikipedia:<u>https://upload.wikimedia.org/wikipedia/commons/thumb/f/f0/Cycloids.svg/290p</u>x-Cycloids.svg.png





Secondary effects: iii. Fujiwhara effect

Interaction between two TCs → dependent on size & separation distance

A – Approach C – Capture 0 – Orbit M – Merger R – Recurve E - Escape

https://www.meted.ucar.edu/tropical/textbook_2nd edition/media/flash/fujiwhara_zeb_alex_1998.swf Merger example





NWP definitions

'Deterministic' track: single model (high resolution)
 EC, GFS, UK, HWRF, ACCESS, COAMPS, JMA etc. tracks
 Ensemble: general collection of member forecasts
 a. Consensus: Averaging of different deterministic tracks



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NWP definitions: Ensembles

 b. Ensemble: Single model run many times at lower res.
 Control (member with same initialization as deterministic) + 'perturbed' members)

e.g. EC 51 members; UK 18; GFS 21; ACCESS-GE 16

Ensemble mean: average of ensemble members

Lagged ensemble combine current and multiple runs to increase no. of runs

'Super' ensemble: combining en Indicates spread of possibilities Uncertainty/probabilistic output





Consensus Forecasting Suppose you have three TC forecasts...

- No problem... None of the forecasts go over my island
- Choose the forecast that is usually most accurate (ex: Forecast 1)
- Choose the forecast that was the most accurate yesterday
- Go with some kind of consensus



Forecast 1 Forecast 2 Forecast 3



Consensus: averaging



Forecast 1 Forecast 2 Forecast 3

Simple averageWeighted average

Suppose you take the simple average of the three forecasts

 This is a reasonable consensus forecast
 What if we give Forecast 1 more weight because we know it is usually more accurate?

• This is an even better consensus forecast most of the time



Consensus: considering spread



The range of uncertainty can be represented by the spread (range) of the forecasts

...or maybe even a bit wider since the individual forecasts contain error.



Consensus Track Forecasting

Consensus methods now widespread, because:

- Clear evidence of improvement (seasonal timescales) over individual guidance
- It's what forecasters naturally do
- Improved objectivity in track forecasting
- Removes the windscreen wiper effect





Why does it work?

The skill of a consensus depends on:

- The skill of the individual members
- Independence of error between members
- The number of members



Error vs Spread

- 1. Small Spread/Large Error: Nightmare
- 2. Large Spread/Large Error: Largest opportunity for improvement
- 3. Small Spread/Small Error: Ideal Case
- 4. Large Spread/Small Error: Opposing errors cancel each other out



Courtesy: R. Ellsberry



Low model spread- high error





Low model spread - low error

Ophelia: High confidence





Marcus 2018 – EC, UK, US ensembles 17/00z for T+96h High confidence in westerly track





High model spread – challenge to be selective



Dahlia high spread +72h





Model upgrades : GFS

Upgrade to FV3 impact on TC performance

While old GFS over-intensified TCs at 4+ days the FV3GFS model does a bit better.

A bit better structure but remains to be seen if SH cases are any different from Atlantic verification cases



North West Pacific Basin 2018



Operational HWRF (in purple) had the best intensity forecast skill for 2018 in the North West Pacific basin and low track errors till Day 2. We also saw low bias errors up to Day 2. Courtesy: A. Mehra NOAA





Model upgrades : HWRF





http://www.emc.ncep.noaa.gov/gc_wmb/vxt/HWRF/index.php

- Nested within GFS
- Current resolution is 13.5/4.5/1.5 km
- Air-Sea-Wave coupled system

 Two-way Ocean (MPIPOM or HYCOM)

One-way Waves (WW3)

• Still run for all systems globally can run 7 TCs at once inc. lows





Model upgrades : ECMWF



Coupled Ocean improvements for intensity

2019 upgrade: neutral overall – slight reduction in track error Improved wave model and ensembles (improved assimilation)

Deterministic: twice per day **9km**, 137 levels to 10 days Ensemble: twice per day 51 members **18 km** 91 levels to 15 days ahead Mon/Thurs 00UTC extended to 1 month ahead (Monthly Forecast 18/36km) https://www.ecmwf.int/en/about/media-centre/news/2019/forecasting-system-upgrade-set-improve-global-weather-forecasts



Model upgrades : UK



http://www.metoffice.gov.uk/research/modellingsystems/unified-model/weather-forecasting

Skill near to EC and GFS since major 2014 upgrade 2018 upgrade: Deterministic: 10km Ensembles (MOGREPS): 36 members at 20km resolution Control + 17 perturbed members, combined with previous cycle to get 36 total Available in TCModule



Also SWFDDP: http://swfddp.metservice.com/global-ukmo-pacific-tcdata/tc-tracks



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Model upgrades: ACCESS-G3

http://www.bom.gov.au/australia/charts/viewer/

ACCESS-G APS-3 resolution 12km(was 25km);

- significant improvement from G2
- GE ensembles
- track now contains R34, R48, R64 quadrant info.

ACCESS-TC remains a variable domain at 11km resolution when a TC is declared

ACCESS-TCX; run daily to 5 days - sorry not (yet) in Coral Sea; use for intensity not track



Track Forecasting – BoM Consensus approach

- Standard members: model tracks EC+GFS+UK+HWRF+ACCESS+JMA+COAMPS(CTCX)+ECEM
- ECEM: ensemble mean from EC could also filter EC ensembles in TCM Based on NRL verification work and Australian experience
- For tropical lows greater selective approaches:
- Using previous runs of EC/GFS/HWRF/UK case by case basis



Track map examples

INDIA Observed and Forecast Track 到上海的现象

NIO



WNP



CNP



ESP/ATL

Time in UTC, IST = UTC + 0530 hrs Observed track Forecast track Circle with radius as climatological track forecast error Cone of uncertainty







SIO



AUS

SPC



Courtesy: Elliott&Yamaguchi, IWTC VIII http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Topic1_AdvancesinForecastingMotion.pdf



Fiji Track map examples: uncertainty and threat areas



Courtesy: Fiji Met Service



Summary: NWP tracks delivers high skill Forecaster role to interpret and identify features

Consensus delivers the 'most likely' track while historical skill and ensemble spread describes range of likelihood Issues: ensemble spread representative?

sometimes under-dispersive can result in overconfident forecast

ensemble mean is misleading if multiple clusters ongoing work to improve combination for super ensembles Forecaster role to interpret and identify features including confidence to describe risk

Always review broadscale environment to apply a conceptual framework to explain motion.

COMET for more on ensembles: www.meted.ucar.edu/



Questions

 A developing low (~30kn) is steered by winds a. 850-500hPa b. 850-300hPa c. 700-300hPa
 YES or NO

You have five different models available that show TC forecasting skill. Should you still use the least skillful of these models?



Exercise

- Review <u>https://ruc.noaa.gov/tracks/</u> for Gita (date 2018 02 11 and Time 00)
- Compare model output. GEFS, MOGREPS, EPS (Europe)
- How similar are the model tracks?
- Is there an outlier? How much spread is there in each ensemble? What does this mean for Tonga?



ADVANCED Track Forecasting - ensembles

Australian Government Bureau of Meteorology Filtering, clustering and super-ensembles

Filter on position/intensity Cluster techniques

Useful SOMETIMES Bang for buck?

Super-ensembles coming...availability

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ADVANCED: Deterministic Vs Ensemble mean Black line - determistic

Why is the black line different from the highest probability?





ADVANCED Track Forecasting

Bifurcation TC Willy



Exercises: EC ensemble



What is the probability of impact at locations A, B and C?

