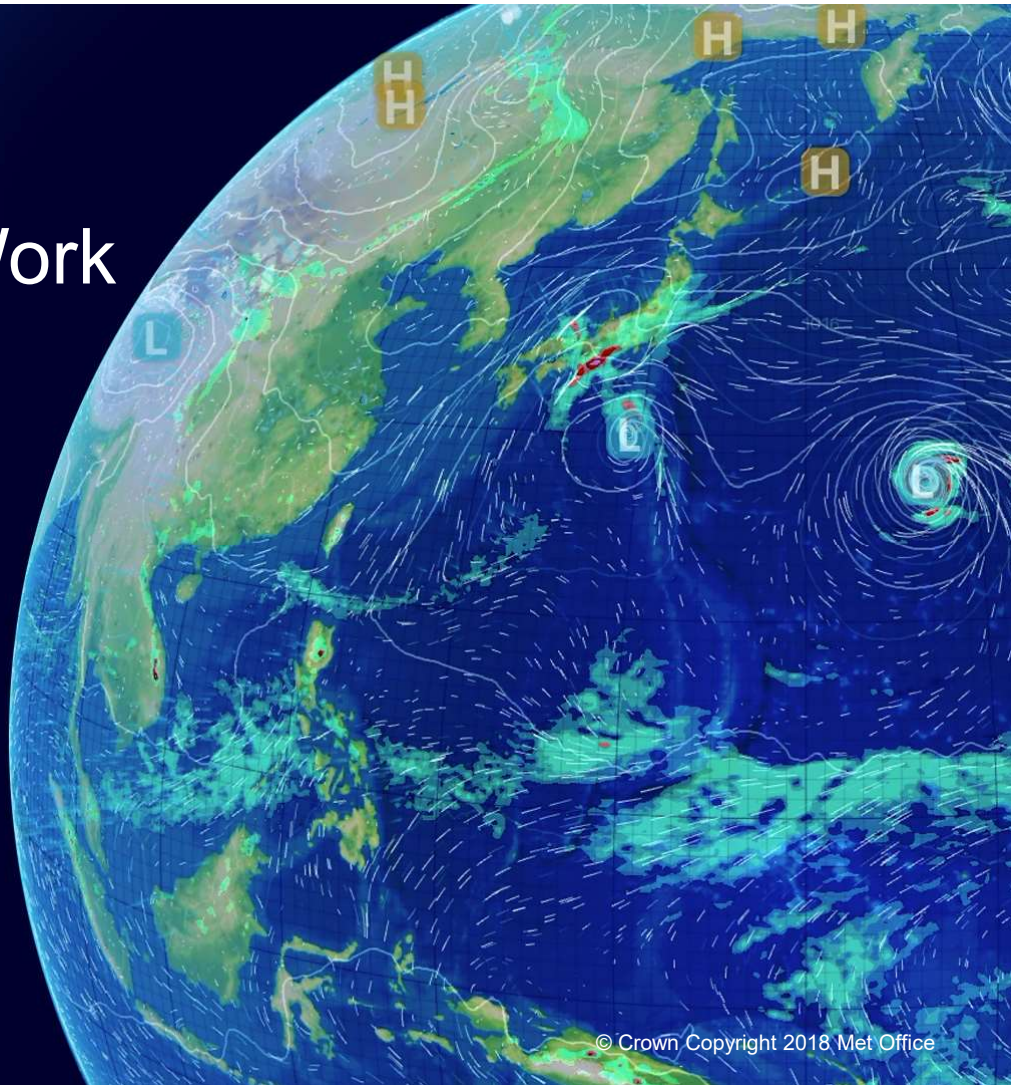
Overview of Convection Permitting Ensembles Work at the Met Office

Stuart Webster



Outline

- MOGREPS-UK
  - Currently the only MO ensemble system centred on a convective-scale DA analysis.
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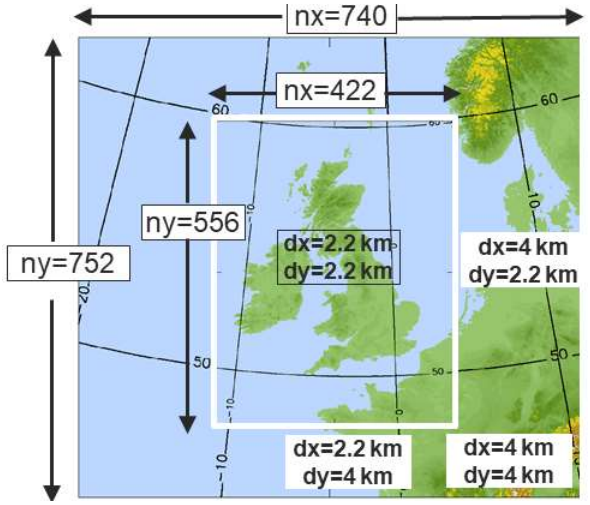
Met Office

Increasing the complexity of MOGREPS-UK



2013

Cold start

ICs from MOGREPS-G

6-hourly

12 members

T+36

2016

Re-centring on UKV analysis, perturbations from MOGREPS-G

Stochastic physics

6-hourly

12 members

T+54

2019

Re-centring onto UKV 4DVAR, perturbations from MOGREPS-G

Stochastic physics

Hourly + time-lagging

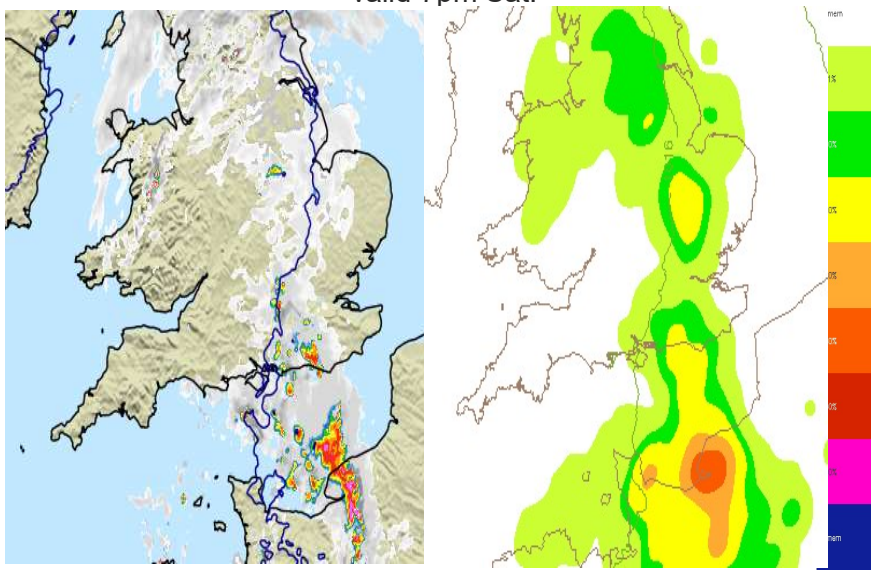
18 members

T+120

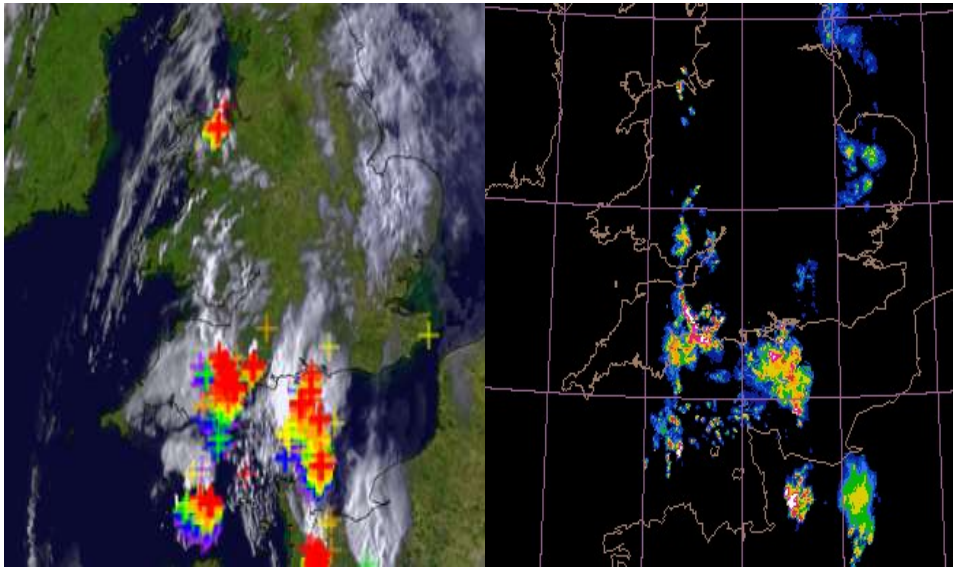
Occasional Forecast Busts

Thundery breakdown can be poorly captured by our models

UKV (left), and MOGREPS UK (right) available by midday Sat valid 7pm Sat.



Cloud and lightning (left) and rainfall (right) at 7pm Saturday



NB This type of event is something convection-permitting models struggle with.

Steve Willington

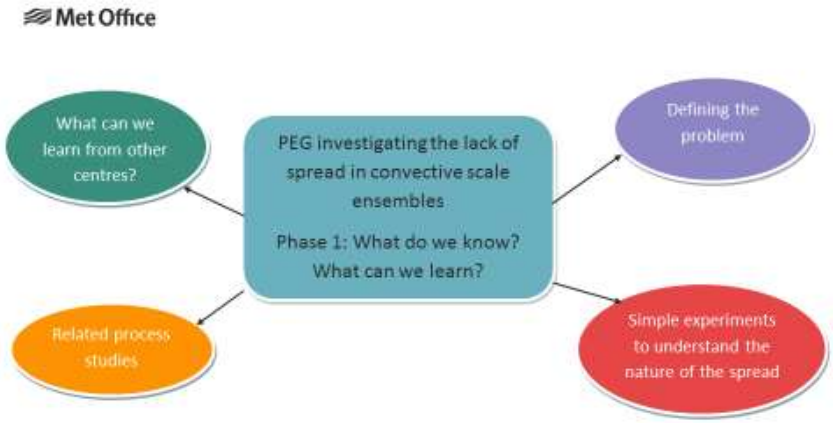
Investigating the lack of spread in convective-scale ensembles

Operational meteorologists have identified lack of spread in MOGREPS-UK as a **top model development priority**

A **P**rocess **E**valuation **G**roup (PEG) has been formed to investigate further

Aim: to bring together scientists and operational meteorologists to evaluate the ensemble and develop new strategies to *improve the value of MOGREPS-UK to forecasters*

First phase: to understand what we mean by 'lack of spread' and / or what is 'the correct spread' → any 'improvements' we make must translate to improvements for meteorologists



Anne Mccabe and Aurore Porson

Met Office

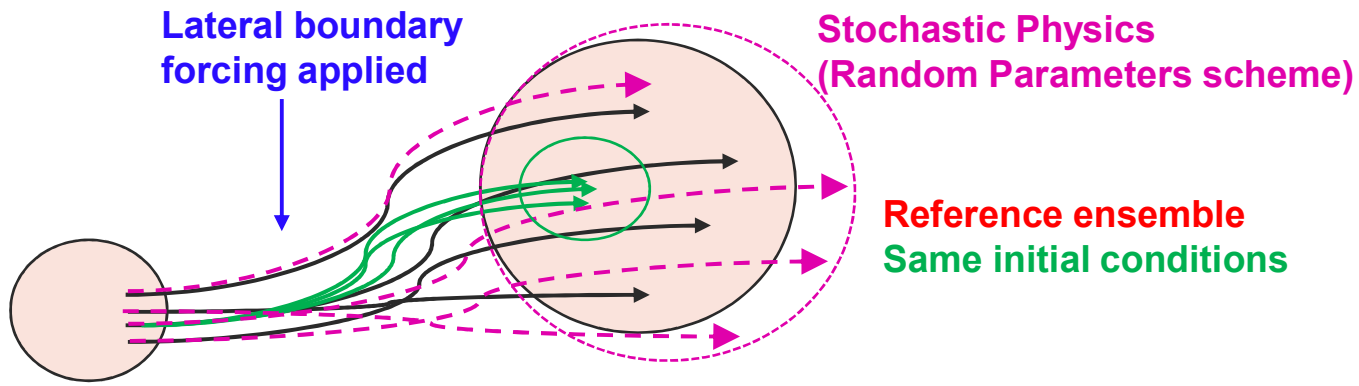
Sensitivity Tests

Exploring the sensitivity to sources of uncertainty

Back-to-basics sensitivity tests.

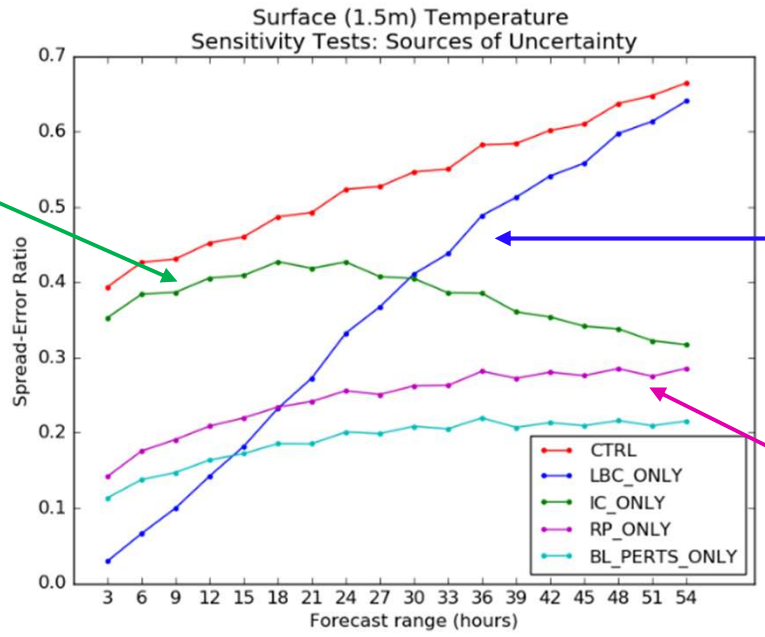
N.B. Using ETKF based MOGREPS-G

Experiments	Start dump	LBCs	Stochastic Physics
CTRL – Reference Ensemble	Perturbed	Perturbed	Perturbed
Exp 1 – uncertainty from initial conditions only	Perturbed	Control	Off
Exp 2 – uncertainty from LBCs only	Control	Perturbed	Off
Exp 3 – uncertainty from stochastic physics only	Control	Control	Perturbed



Initial results from MOGREPS-UK sensitivity tests

Initial conditions are most important in the early part of the forecast – they become less important after 12 hours but still dominate over LBC's until T+30.



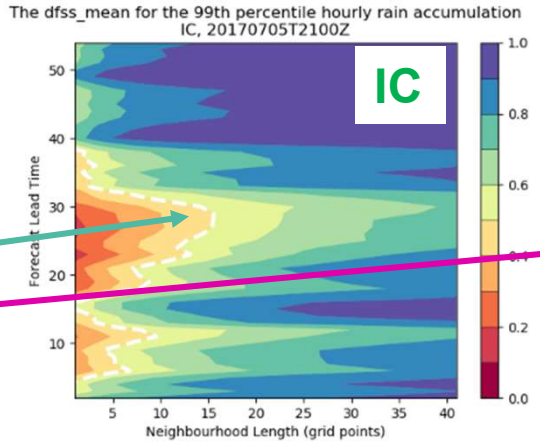
The impact of the LBC's shows a steady increase throughout the forecast

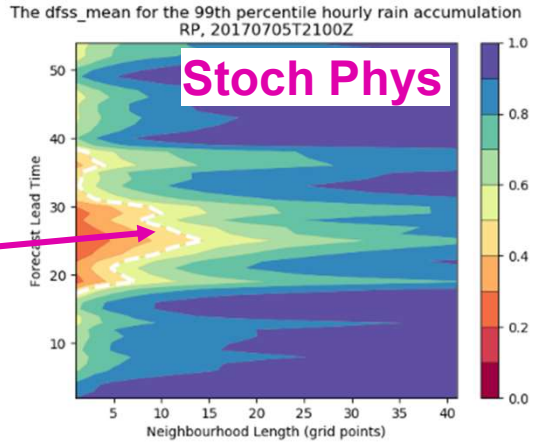
Stochastic physics generates 30 – 40% of the full ensemble spread

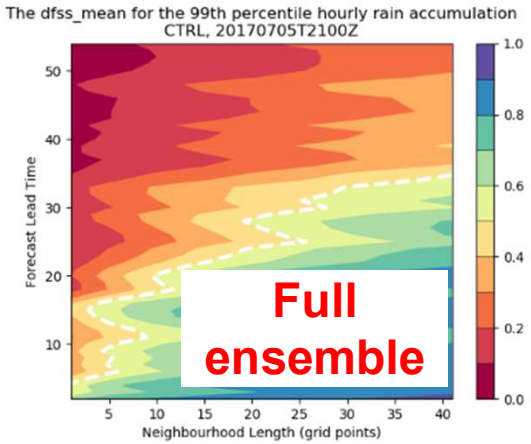
Met Office

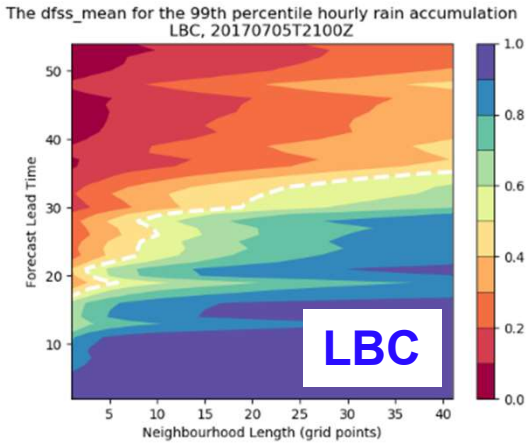
Case study: Thunderstorms 6th July 2017; dFSS for 21Z cycle. Time of interest is T+20

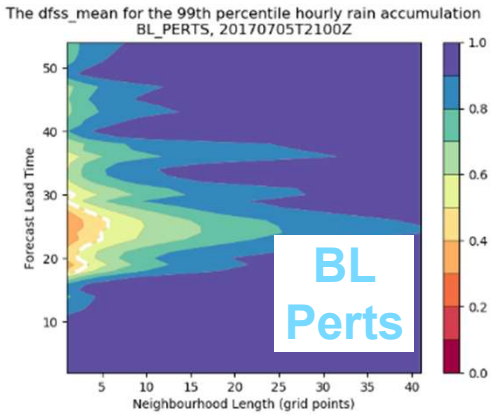
Initial Condition & **Stochastic Physics** ensembles show variability at similar scales











White dashed line gives ‘believable scale’

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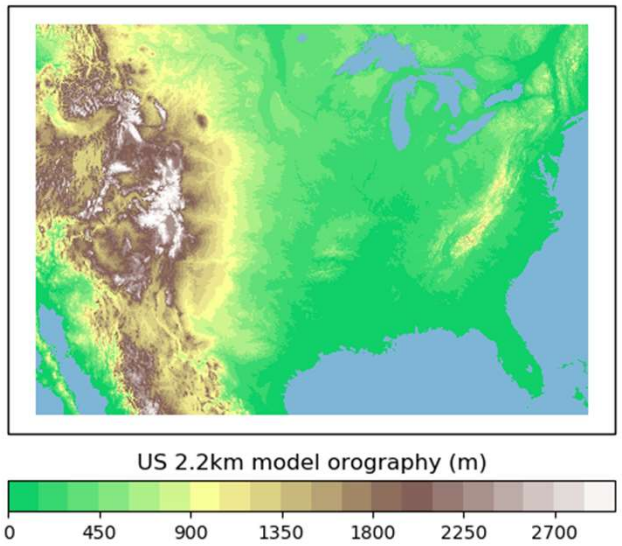
HWT 2019

What can we learn about our ensemble from the testbed?

Unified Model submission in previous years



- Developed a 4.4km CONUS and then 2.2km sub-conus domain
- 2.2km: 1700 x 1200 grid-points
- Various operational and pre-operational configurations up to RA1-M and RA1-T
- Development of new (for the UM) diagnostics: reflectivity, updraft helicity and vertical shear
- Developed a post-processing suite to reformat diagnostics and send to HWT organisers

Met Office

Formulation of the 2019 UM ensemble

Two time-lagged 12-member ensembles									
Start Time and run length	***Global driving members***								
	LAM members								
18Z	*18*	*19*	*20*	*21*	*22*	*23*	*18*	*19*	*20*
T+60	7	8	9	10	11	12	7	8	9
0Z	*1*	*2*	*3*	*4*	*5*	*6*	*1*	*2*	*3*
T+54	1	2	3	4	5	6	1	2	3
Science Configuration	RA2M			RA2M			RA2T		

12 member **RA2M** time-lagged EPS

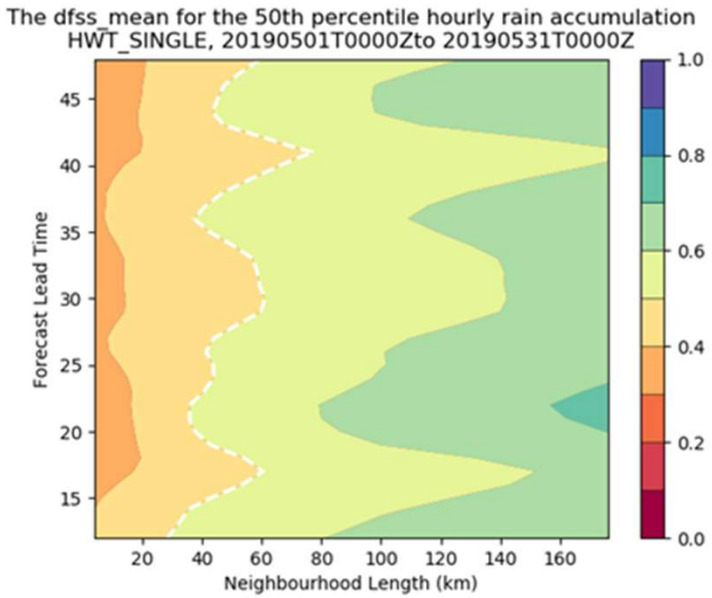
12 member mixed **RA2M & RA2T** time-lagged EPS

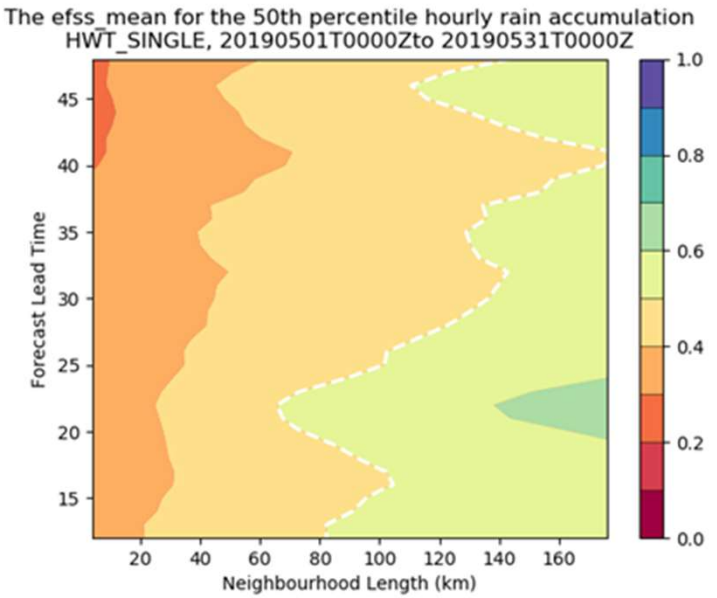
Neither ensemble contained a control

Aurore Porson, Anne Mccabe, Kirsty Hanley, Andrew Hartley, Humphrey Lean, David Walters, Mike Bush, Mark Weeks, Nigel Roberts, Jon Petch…

Monthly average of *dFSS* and *eFSS*

dFSS = dispersion Fractions Skill Score
eFSS = error Fractions Skill Score





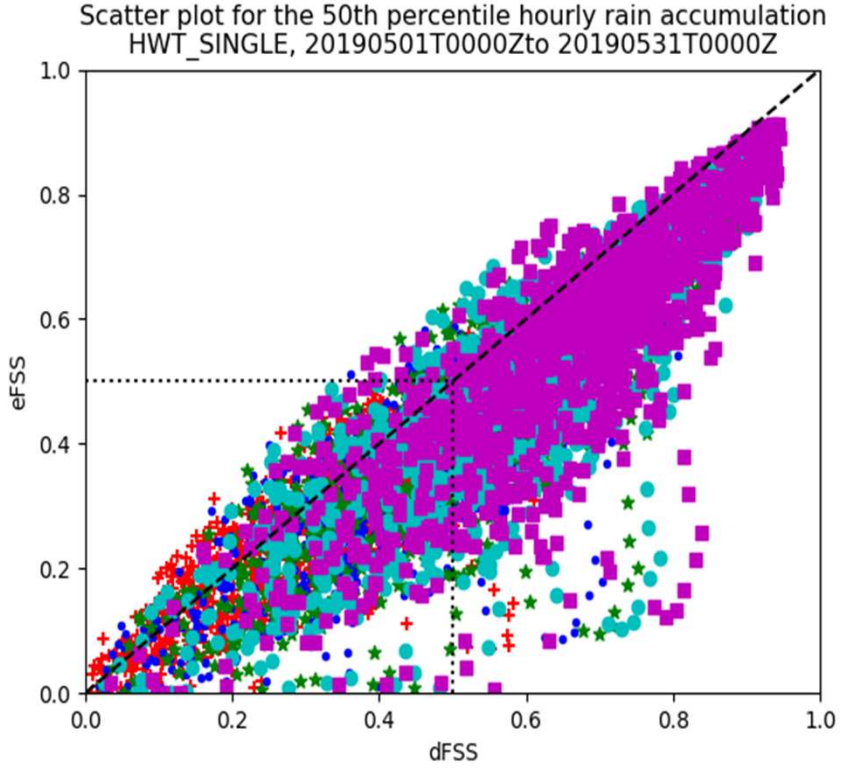
UM HWT-ensemble is under-spread at all lead times and at all scales

Met Office

Scatter plot of dFSS against eFSS for all cycles and all lead times for the testbed period shows large case-by-case variability.

There are many cases where the spread and error match well (although the general trend shows the ensemble is under-spread overall).

The different colours correspond to different neighbourhood lengths: 4km, 36km, 72km, 100km and 176km



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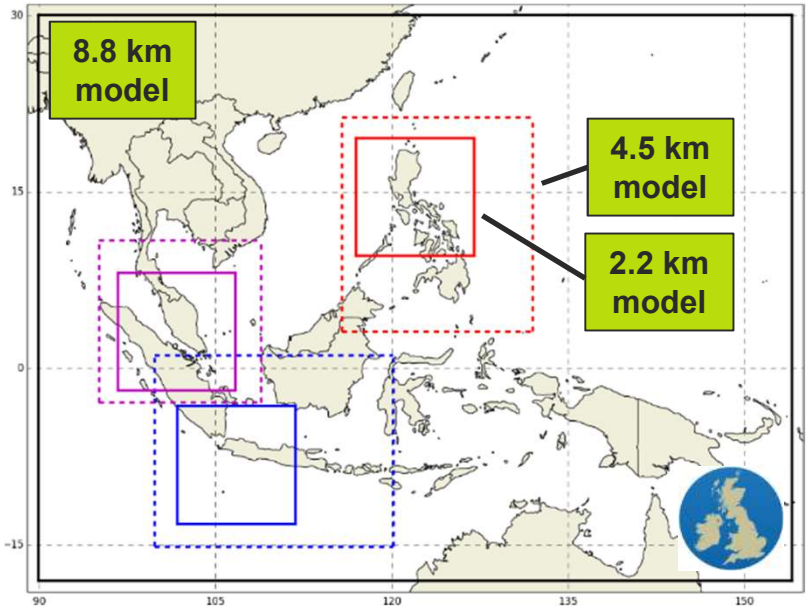
WCSSP SE Asia

- aiming to improve advice on the impacts of extreme weather on 1-10 day timescale.
- In-region partners: Indonesia, Malaysia and the Philippines.

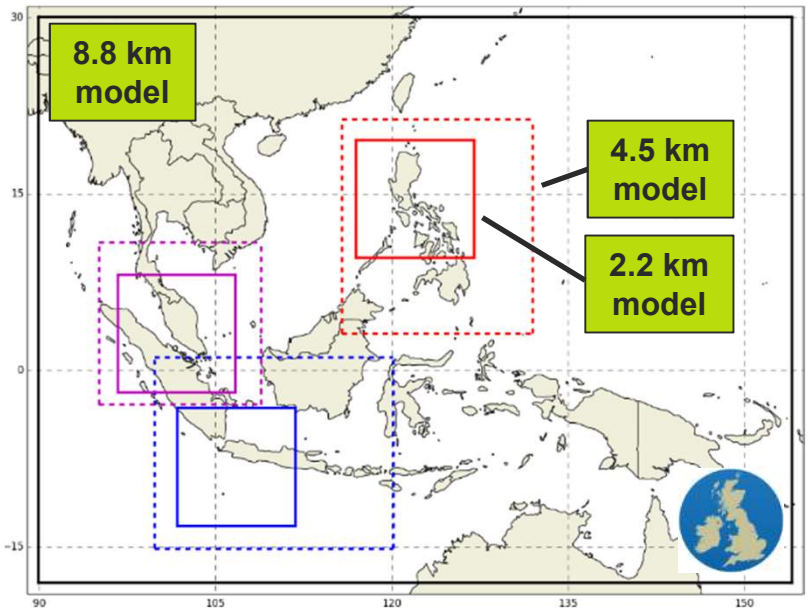
Newton Fund

Ensemble Model domains



- Real time forecasts out to T+120, twice per day.
- Outer convection-permitting model over the whole of SE Asia (90E-154E, 17S-30N).
- Nested inside that, from 09/2018 to 04/2019, three set of multiply-nested models were run, one set for each partner country.
  - All ensembles have 18 members, downscaling MOGREPS-G ICs.
- 8.8 km resolution mirrors the ½ resolution cost-saving approach of the global.
  - But obviously takes us even further into the grey-zone.
  - Only worth investigating (in my opinion) since the inclusion of moisture conservation in RA1.
  - 800 x 600 mesh is still comparable to MOGREPS-UK.
- These ensembles are currently being evaluated as part of a UK Universities Project (FORSEA)

Ensemble Model domains



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  - 800 x 600 mesh is still comparable to MOGREPS-UK.
- Since April 2019 just the outer 8.8 km nest has been routinely run.

Comparing deterministic and ensemble forecasts over Indonesia

Deterministic

- **4.4 km** L90 using RA2T
- Run to T+120 twice per day
- Nested inside operational global deterministic
  - N1280 (10 km x 15 km), GA7.2

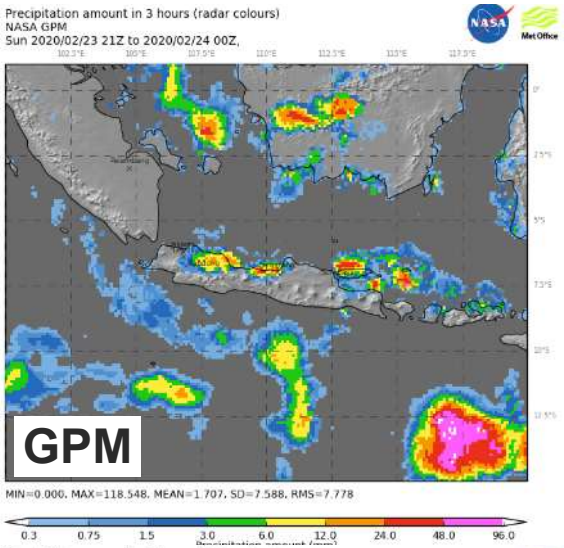
Ensemble

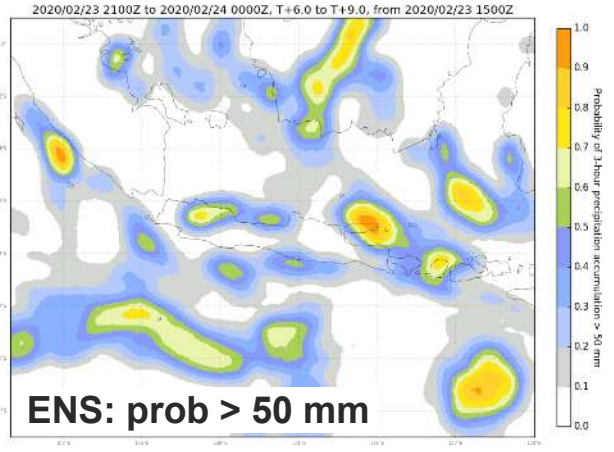
- **4.5 km** L90 using RA2T
- Run to T+120 twice per day
- 18 members
- Nested inside MOGREPS-G
  - N640 (20 km x 30 km), GA7.2
  - Ens4DEnsVar

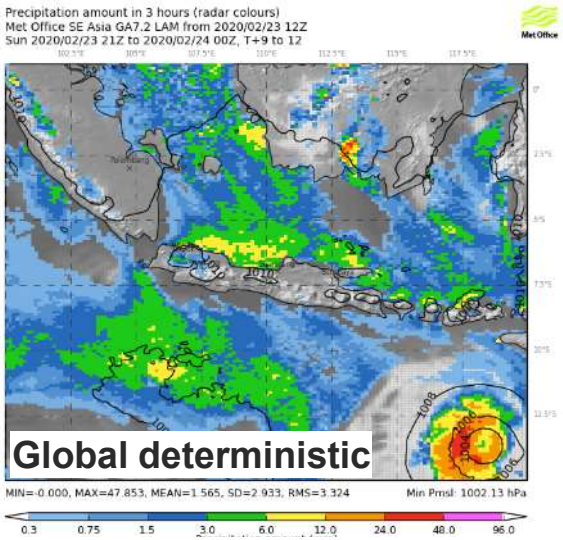
With Chris Short and Melissa Brooks

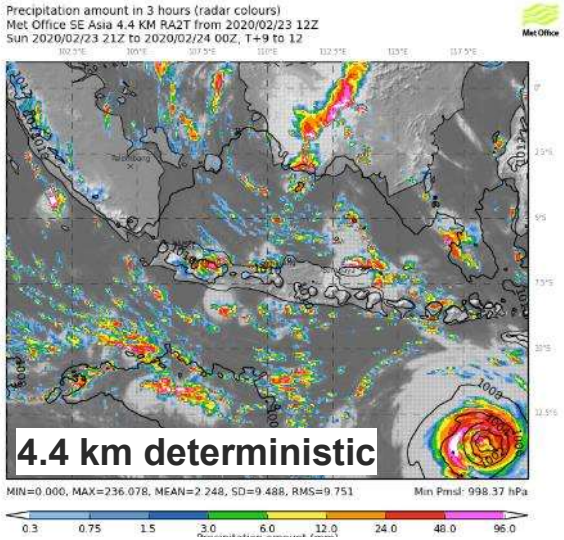
Met Office

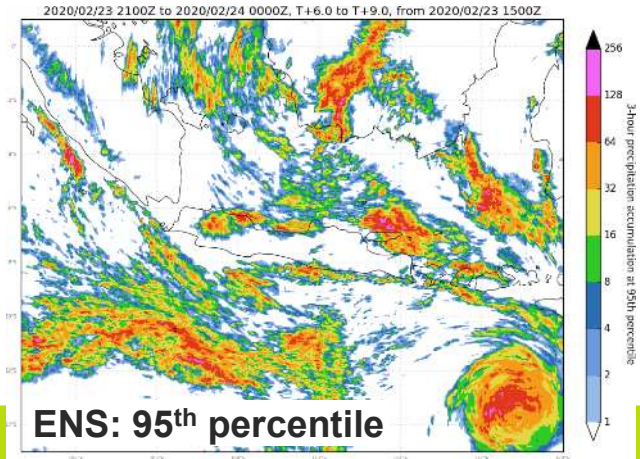
3 hour rainfall accumulations through to 24/2/20 00z T+9 to T+12





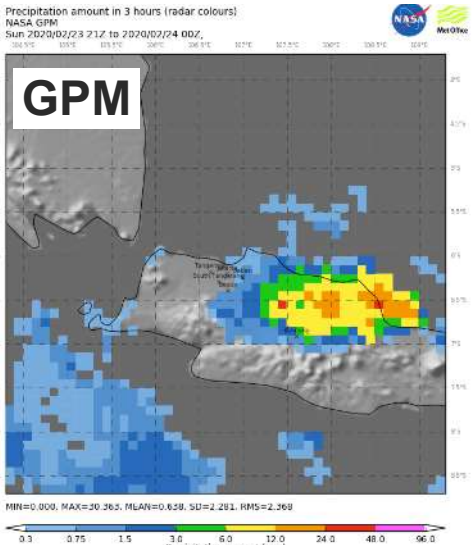


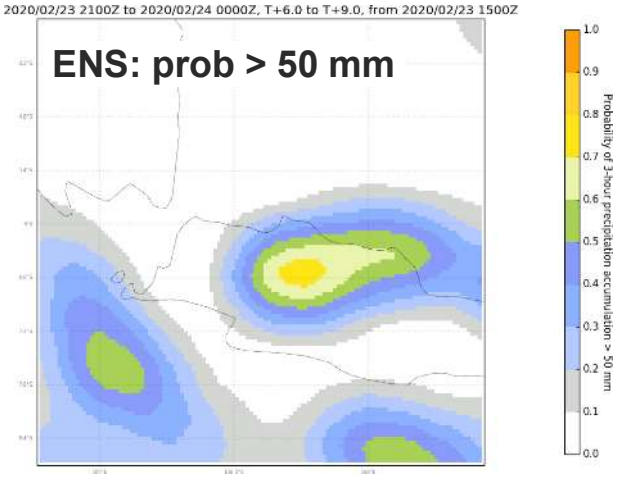


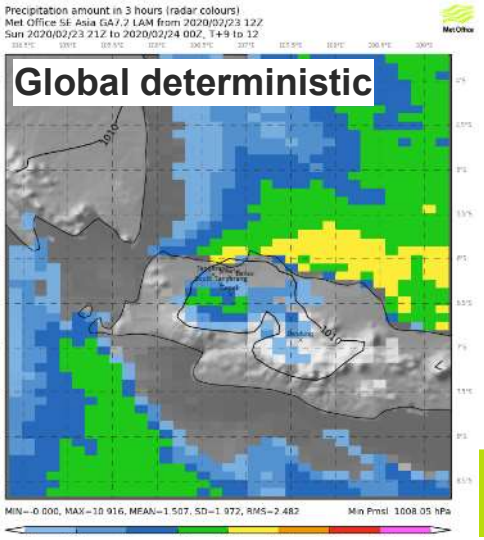


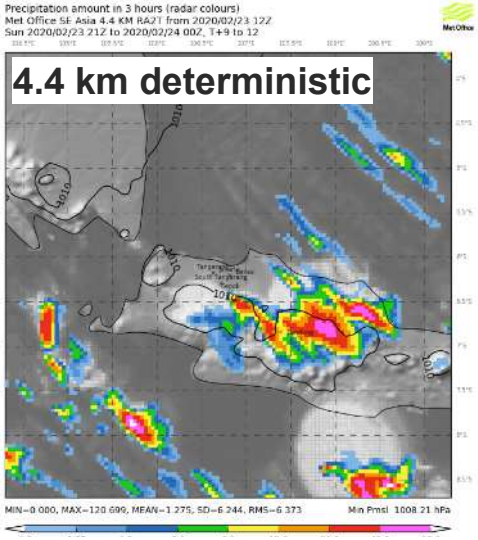
Met Office

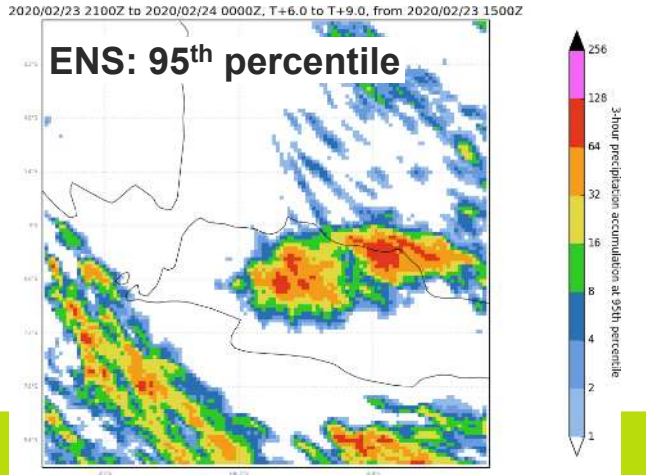
3 hour rainfall accumulations through to 24/2/20 00z T+9 to T+12 ZOOM





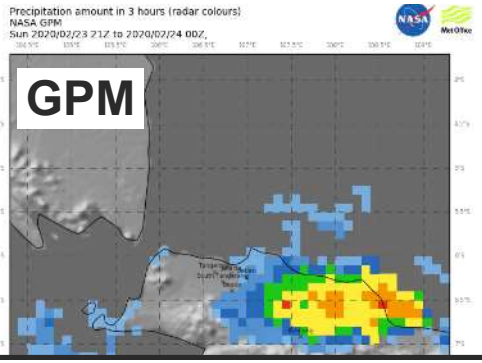


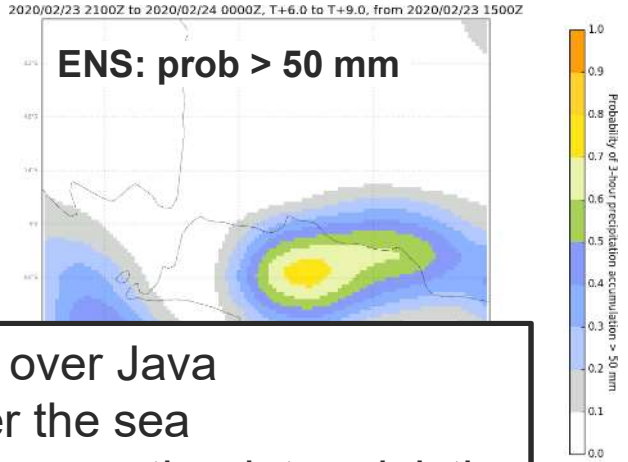




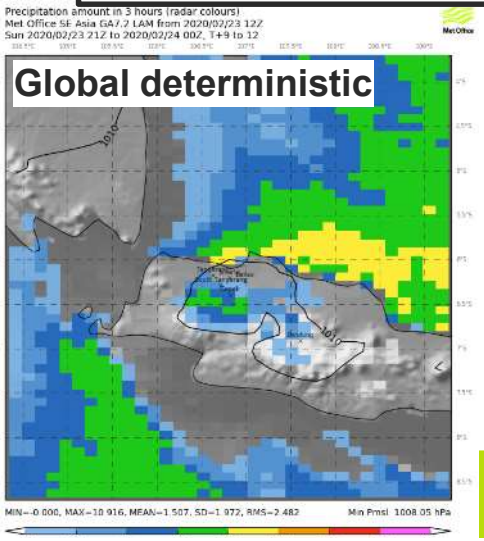
Met Office

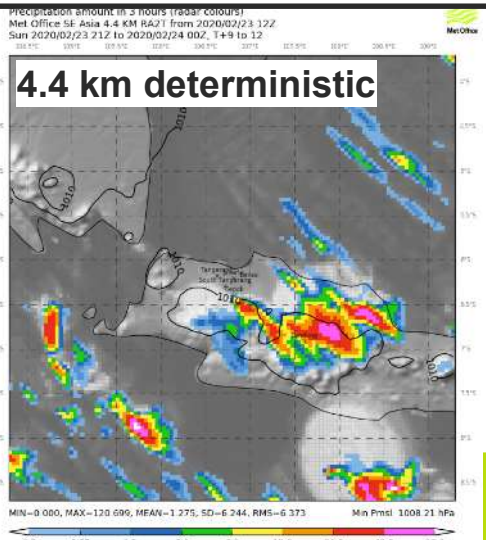
3 hour rainfall accumulations through to 24/2/20 00z

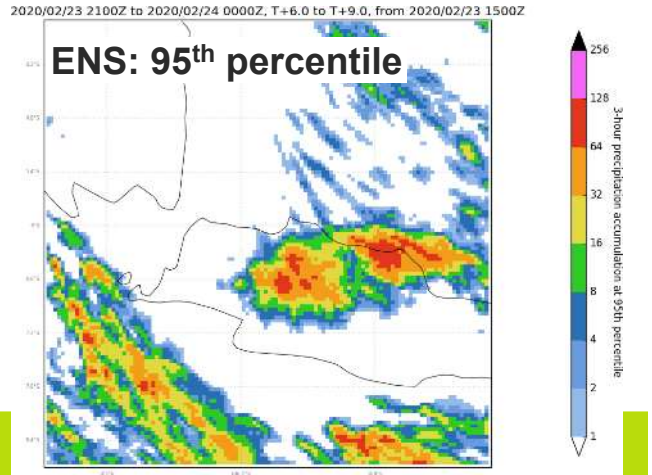




- 4.4 km deterministic captures convective system over Java
- Early evening so global model rainfall mostly over the sea
- Ensemble summary measures highlight same areas as the deterministic

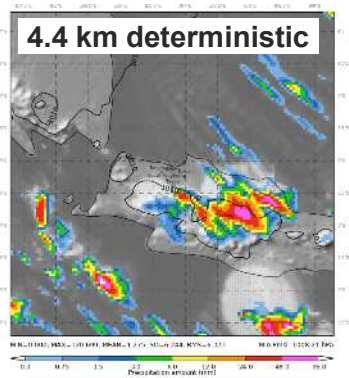




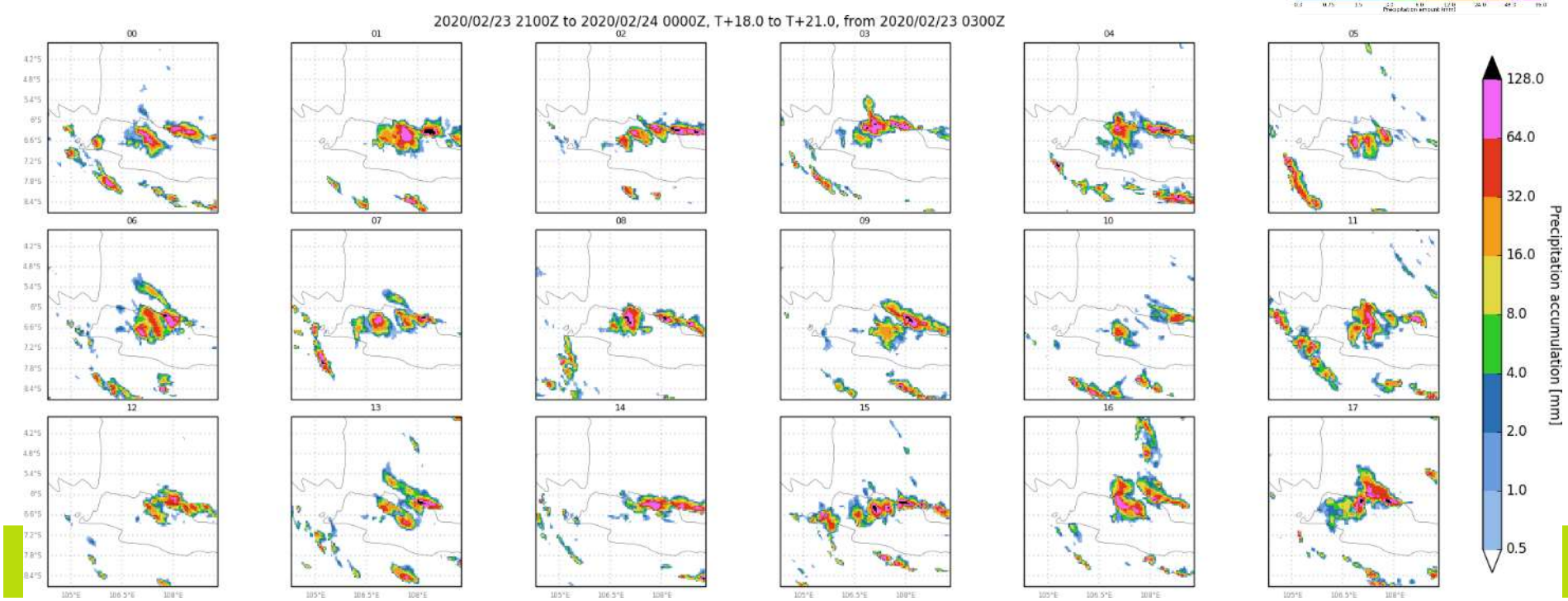


3 hourly rainfall accumulations

through to 24/2/20 00z **T+12**

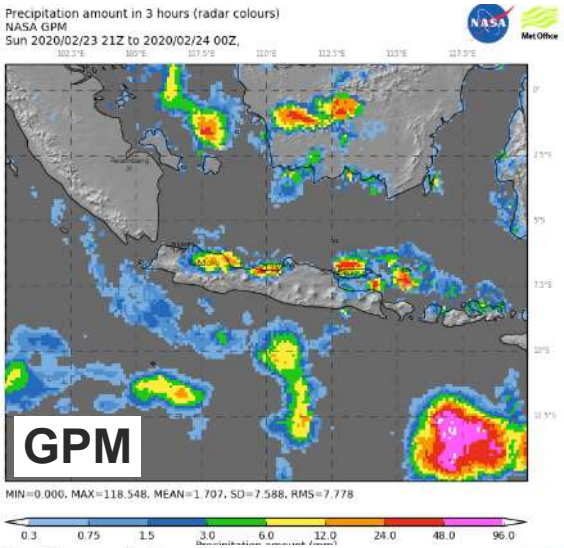


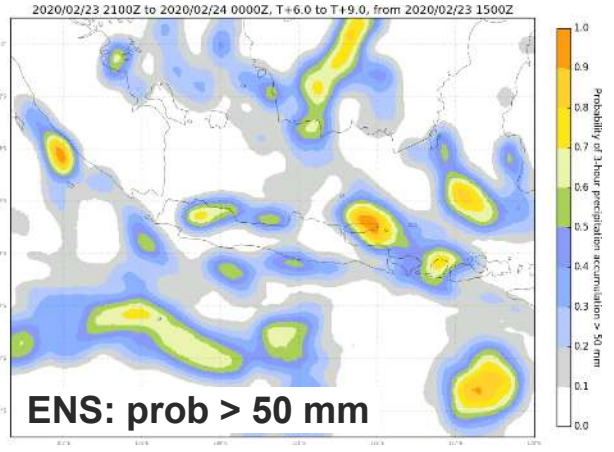
4.5 km ensemble **All 18 members**

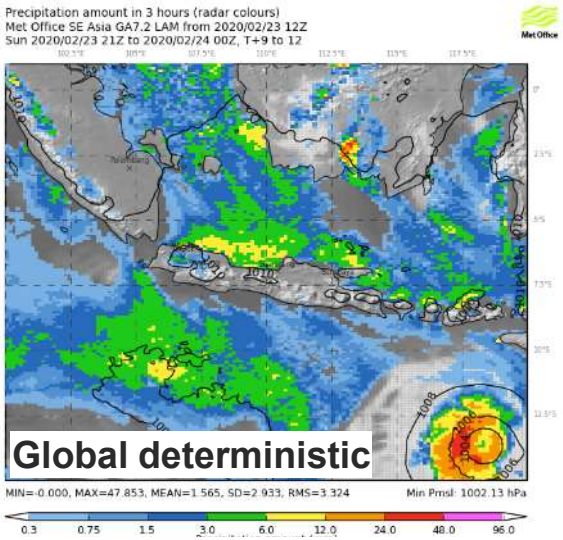


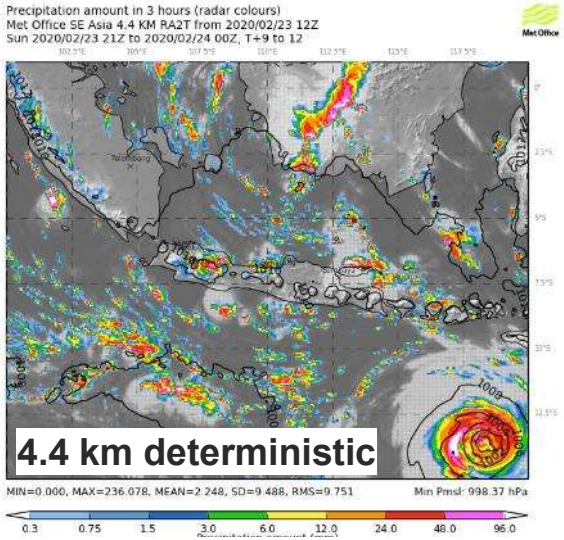
Met Office

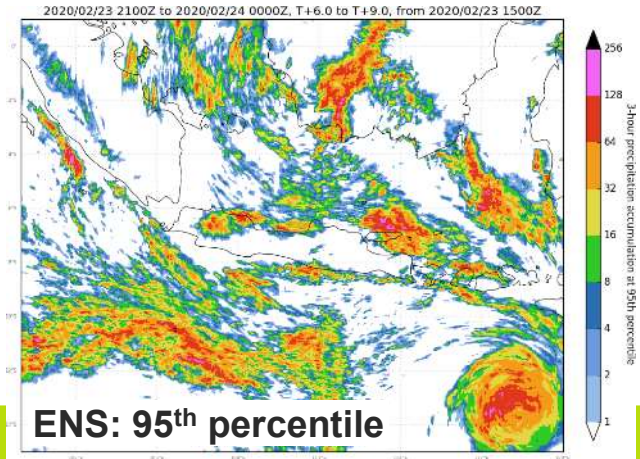
3 hour rainfall accumulations through to 24/2/20 00z T+9 to T+12











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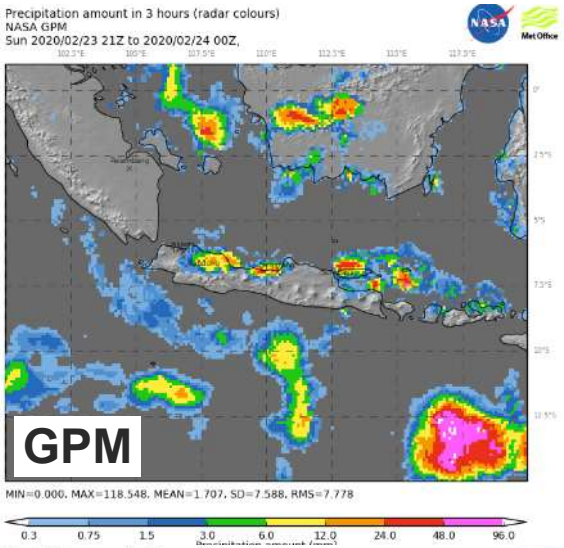
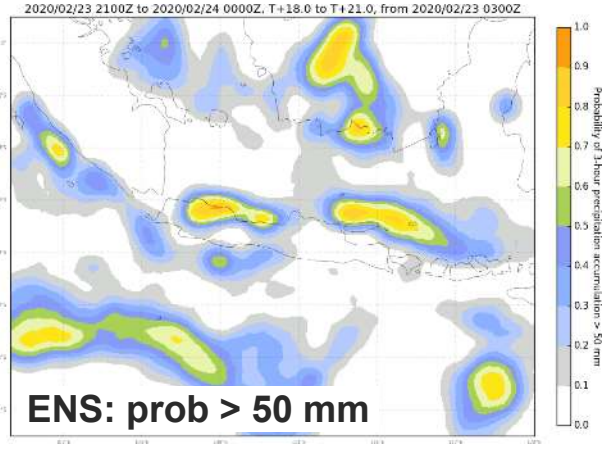
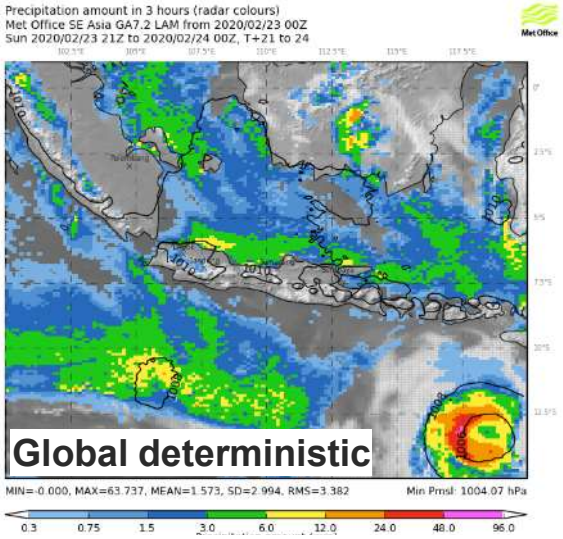
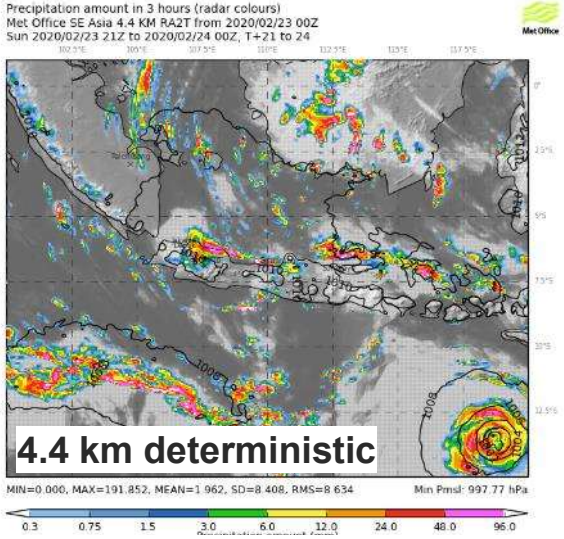
3 hour rainfall accumulations through to 24/2/20 00z T+21 to T+24

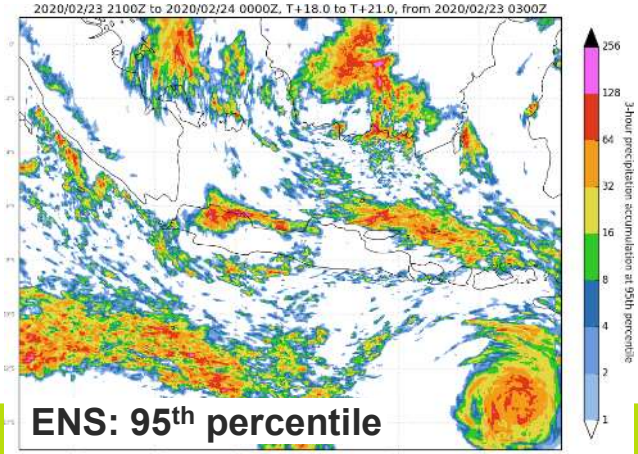
Impact of time lagging





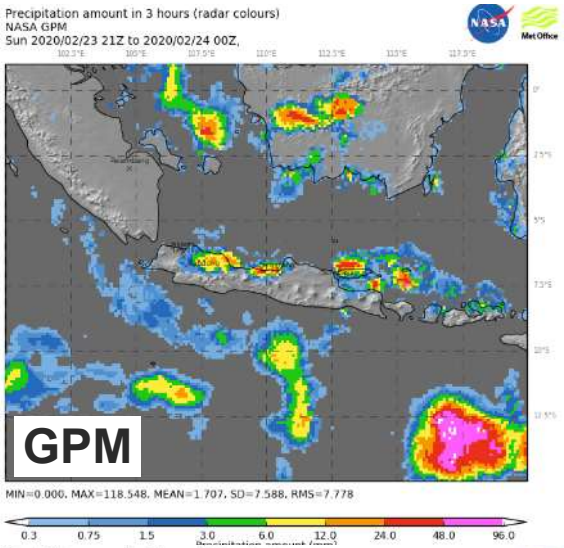


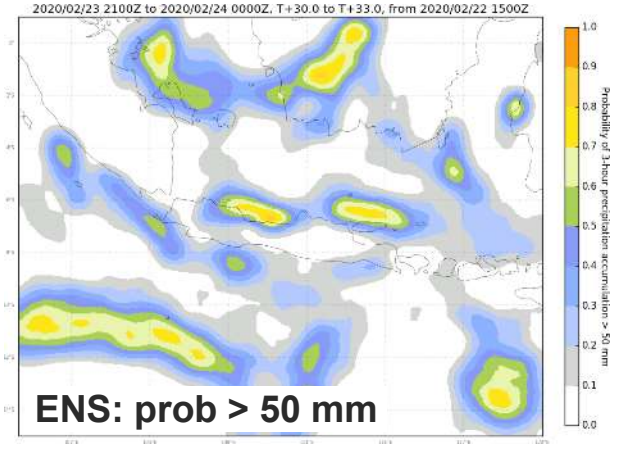


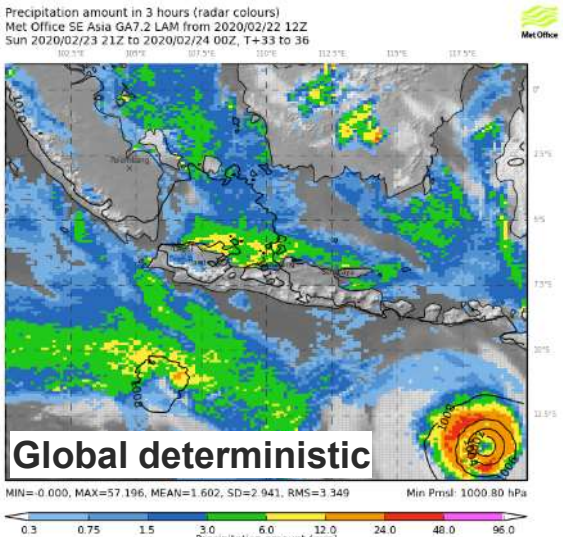


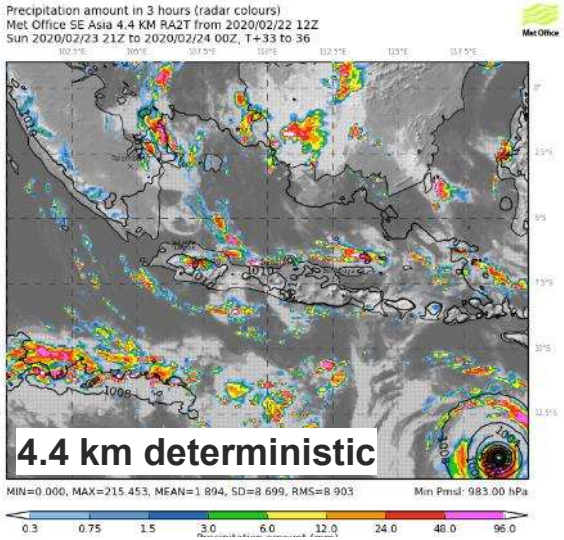
Met Office

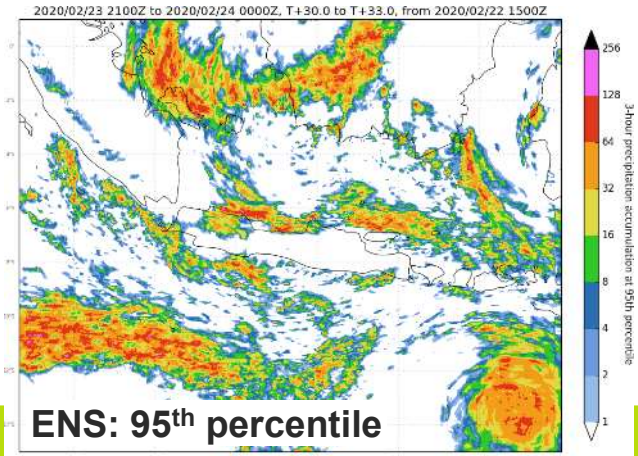
3 hour rainfall accumulations through to 24/2/20 00z T+33 to T+36





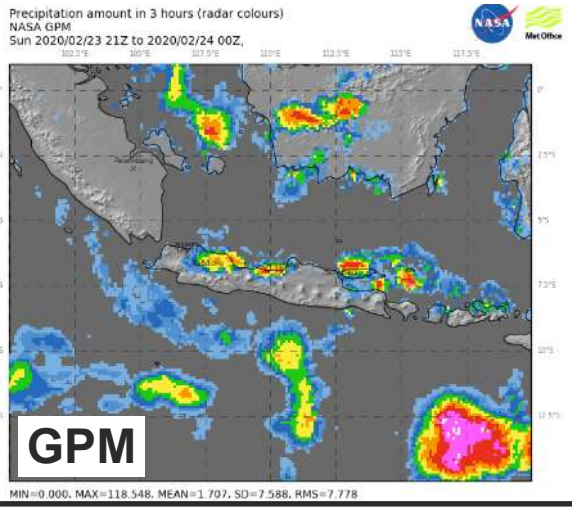


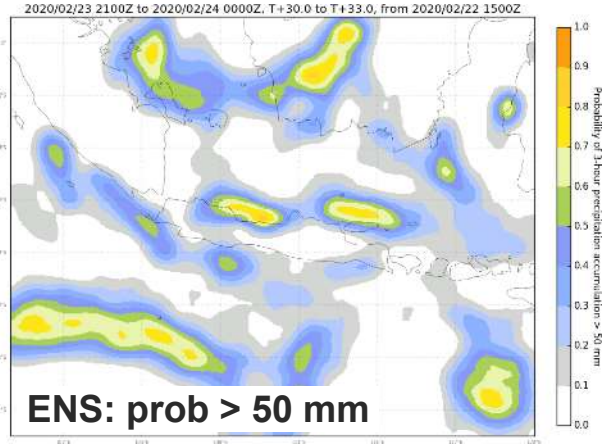




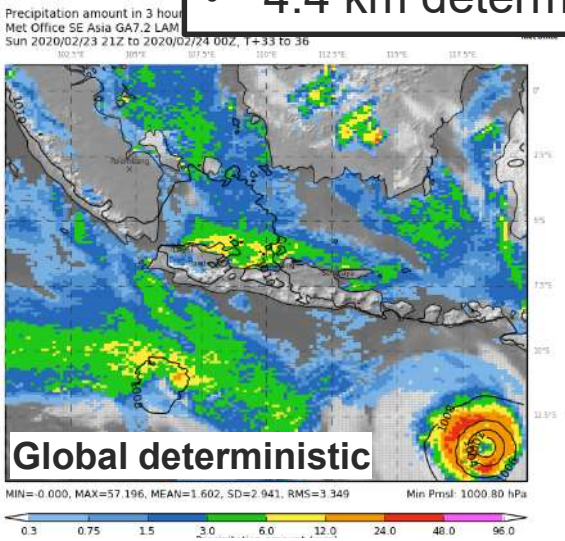
Met Office

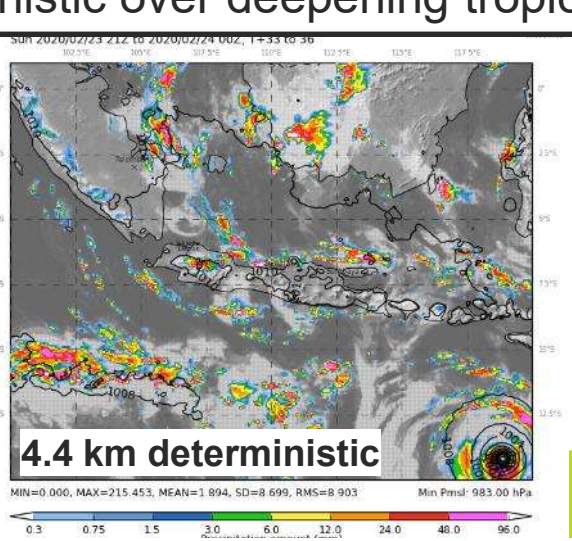
3 hour rainfall accumulations through to 24/2/20 00z T+33 to T+36

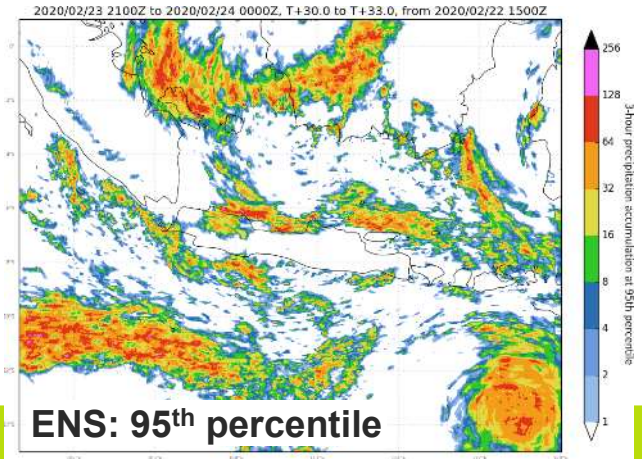




- 4.4 km deterministic over deepening tropical depression

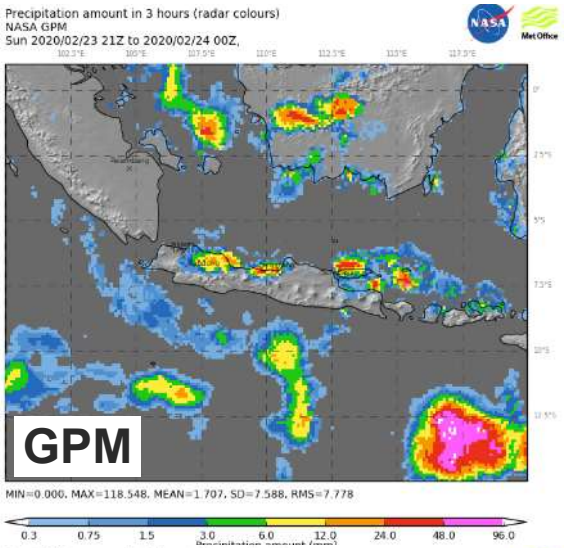


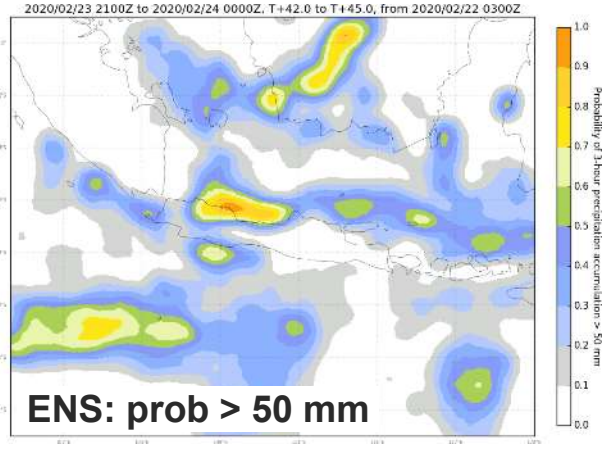


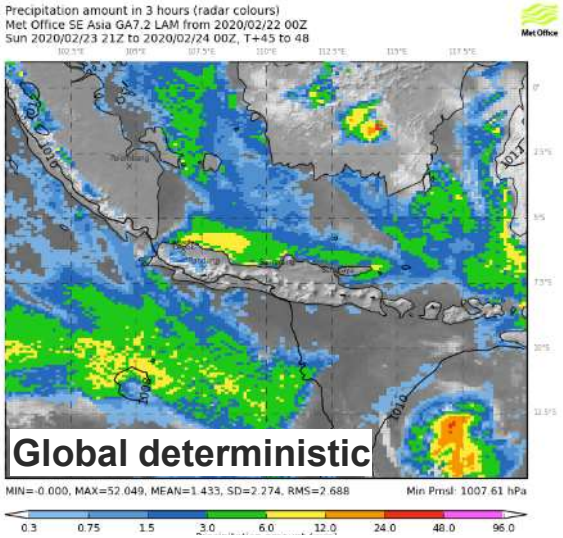


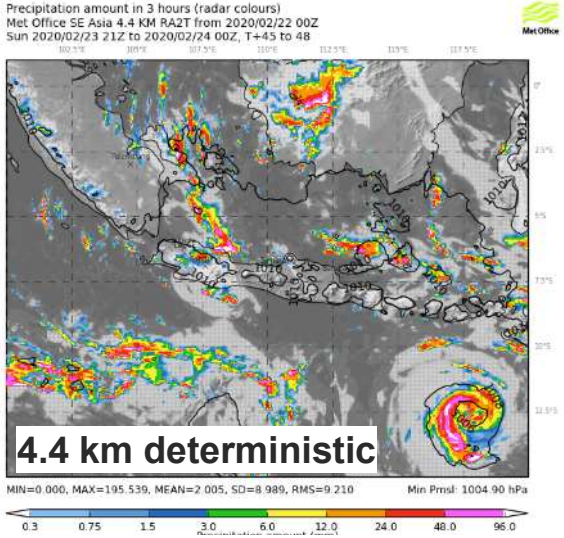
Met Office

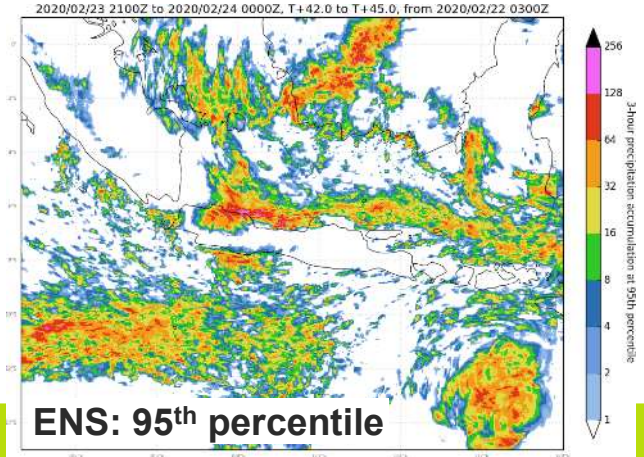
3 hour rainfall accumulations through to 24/2/20 00z T+45 to T+48





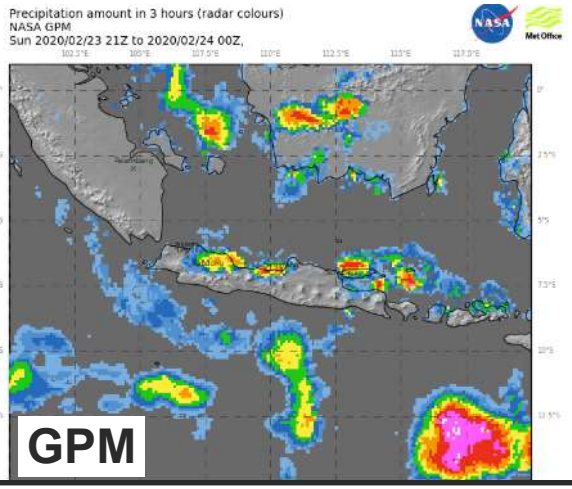


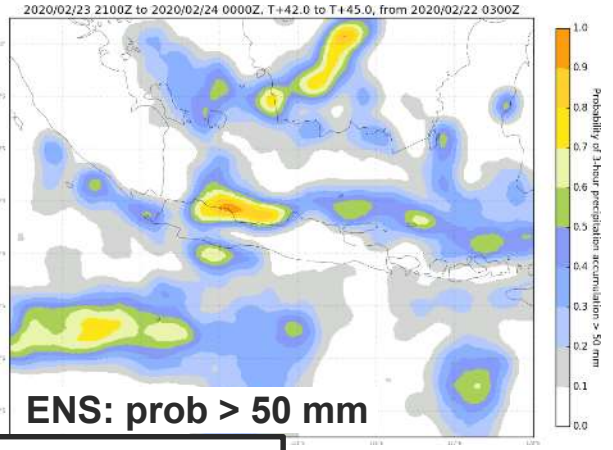




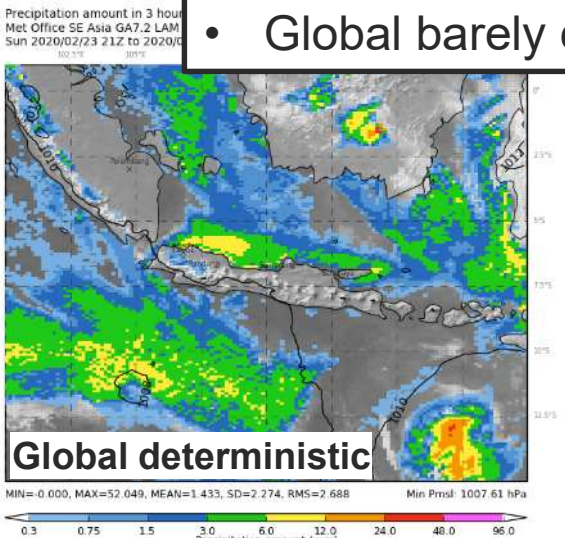
Met Office

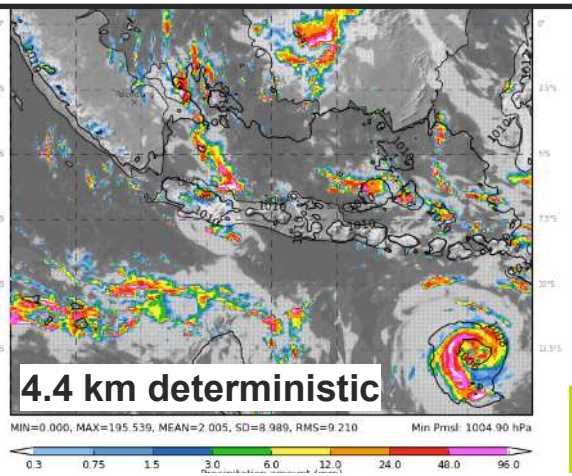
3 hour rainfall accumulations through to 24/2/20 00z T+45 to T+48

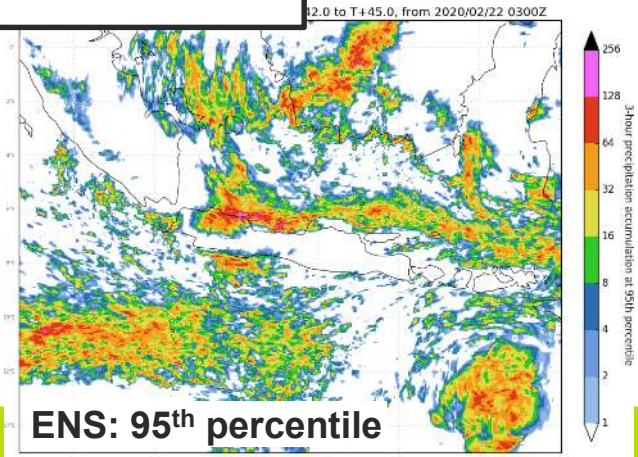




- Now 4.4 km deterministic capturing tropical depression
- Global barely capturing this circulation

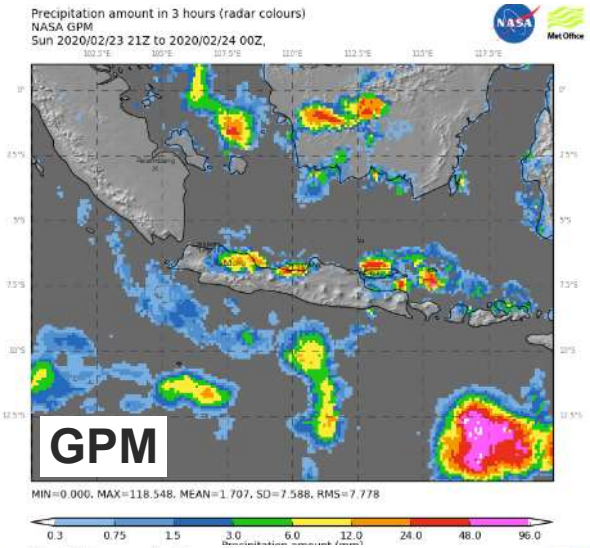


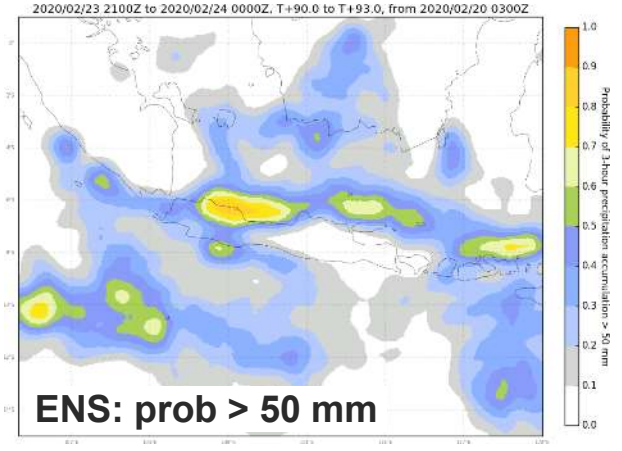


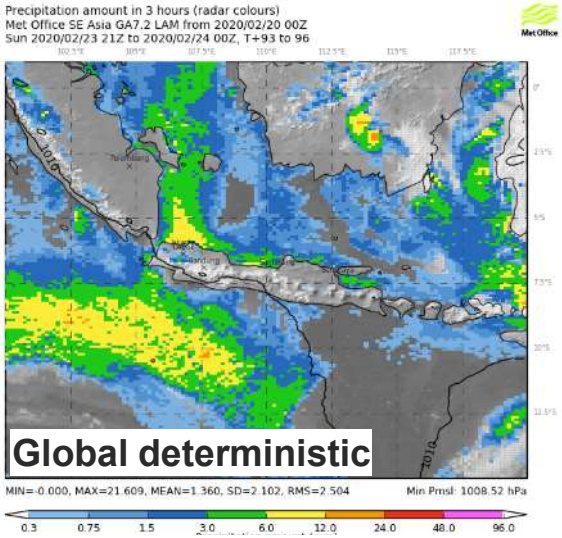


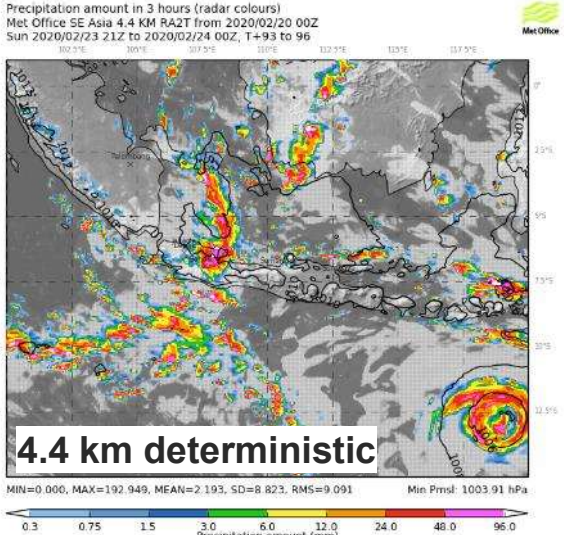
Met Office

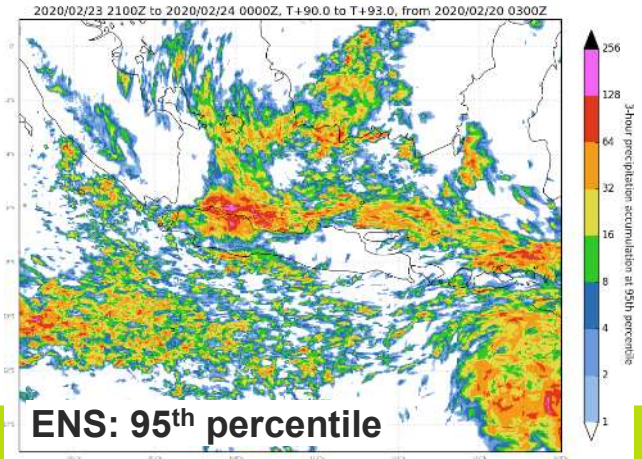
3 hour rainfall accumulations through to 24/2/20 00z T+93 to T+96





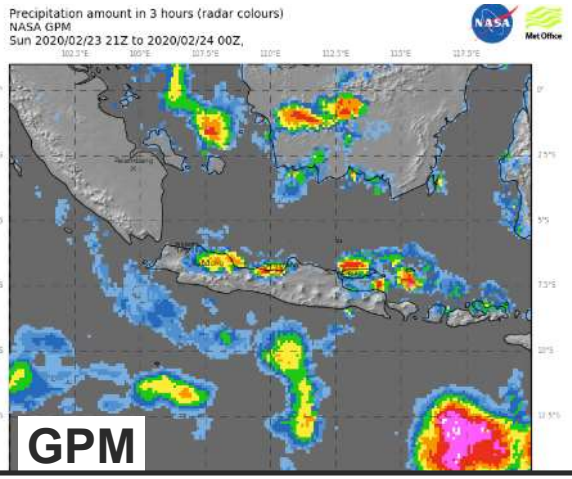


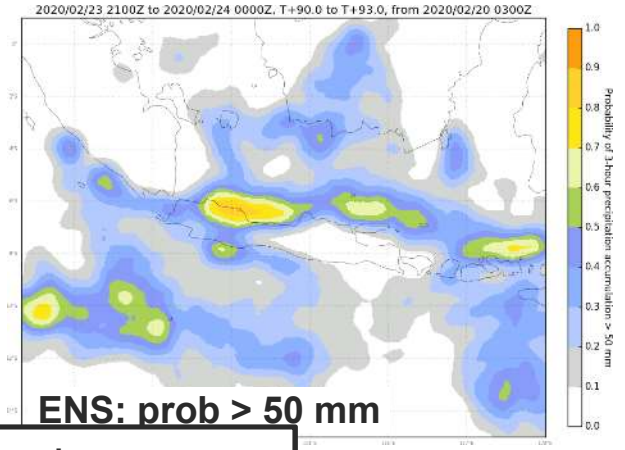




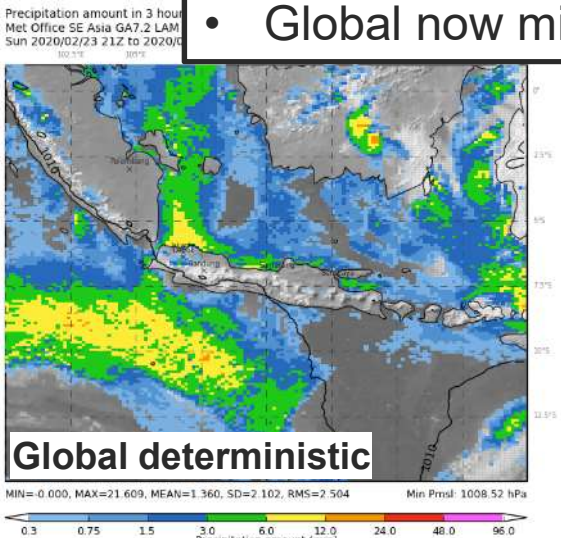
Met Office

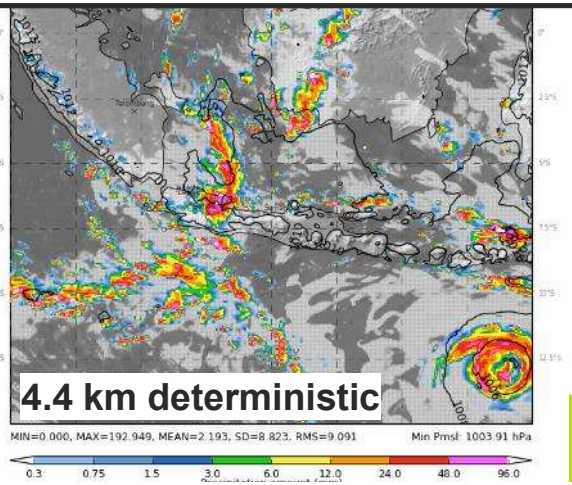
3 hour rainfall accumulations through to 24/2/20 00z T+93 to T+96

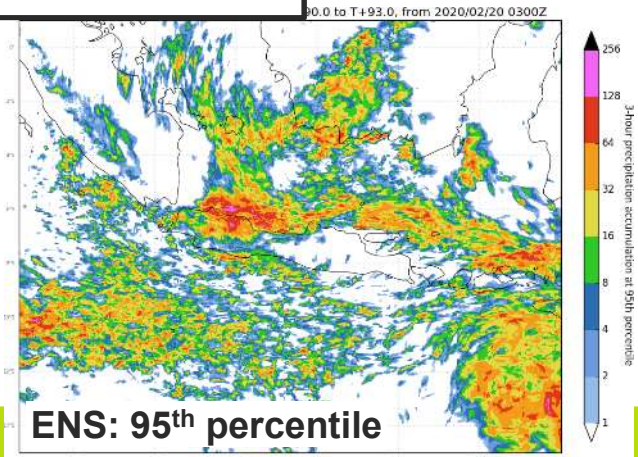




- 4.4 km deterministic capturing tropical depression
- Global now missing it completely

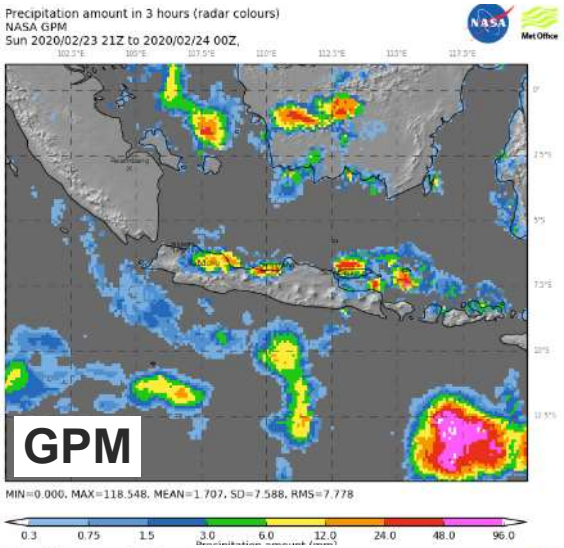


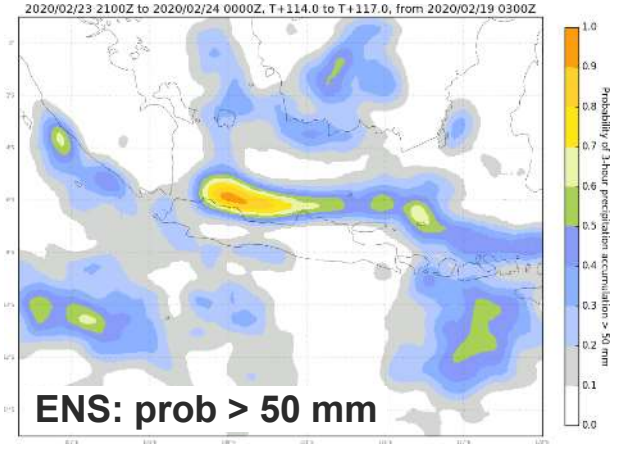


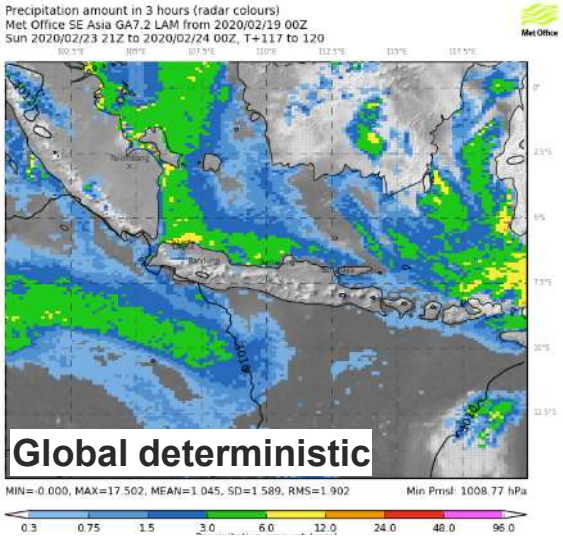


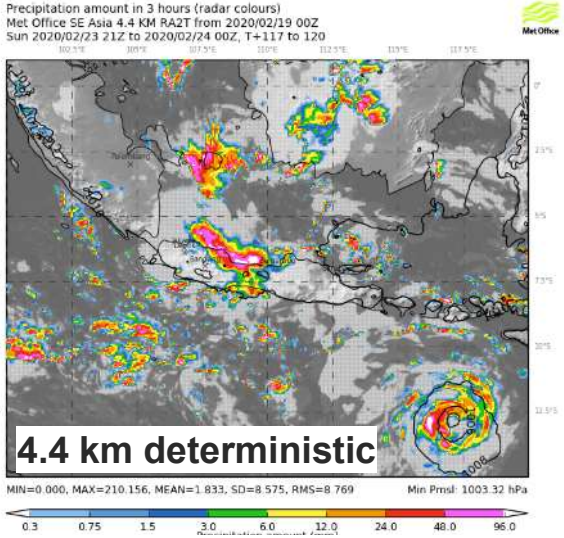
Met Office

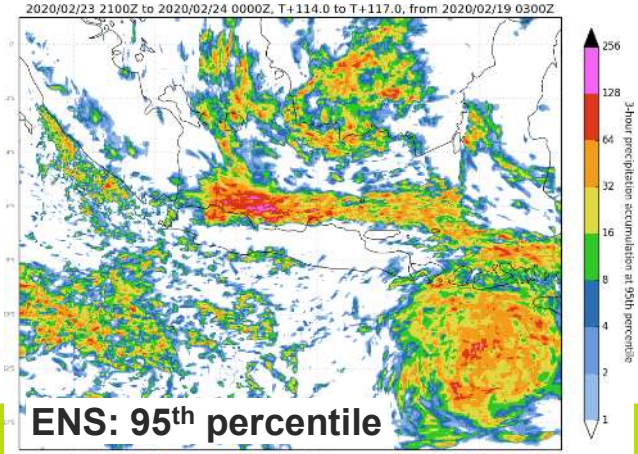
3 hour rainfall accumulations through to 24/2/20 00z T+117 to T+120





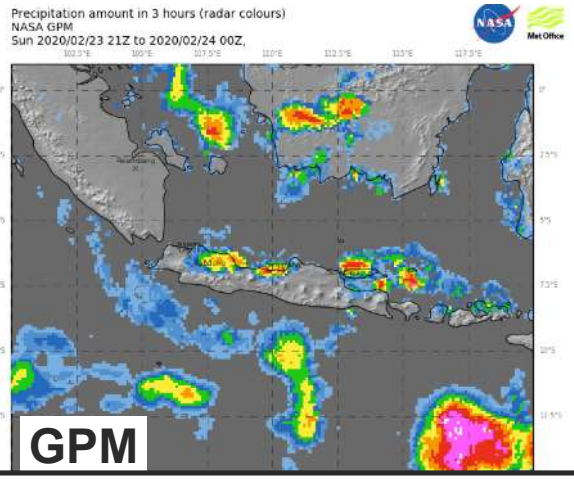




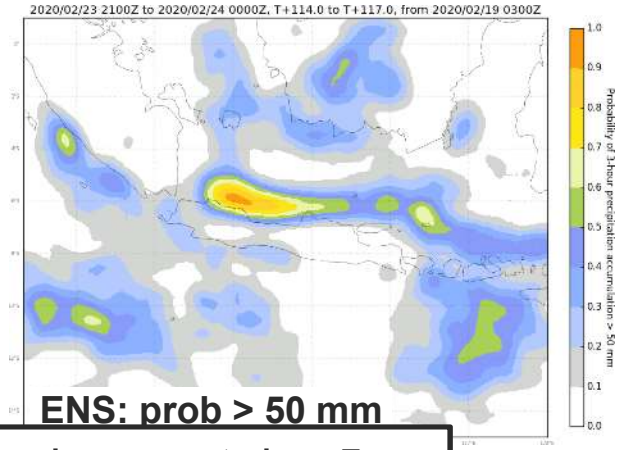


Met Office

3 hour rainfall accumulations through to 24/2/20 00z T+117 to T+120

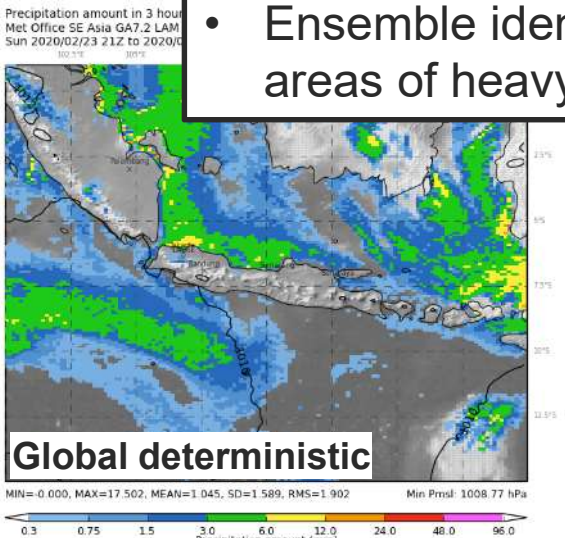


GPM

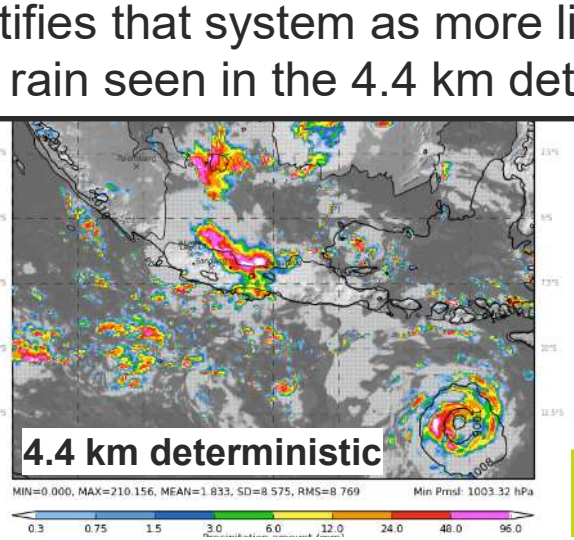


ENS: prob > 50 mm

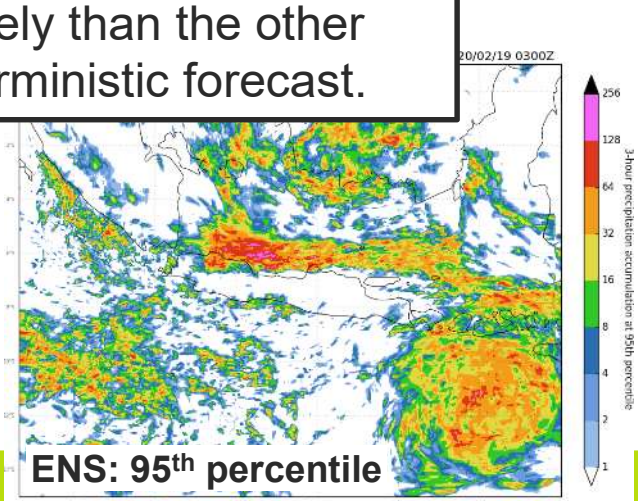
- Heavy rain over Java reasonably well captured even at day 5.
- Ensemble identifies that system as more likely than the other areas of heavy rain seen in the 4.4 km deterministic forecast.



Global deterministic



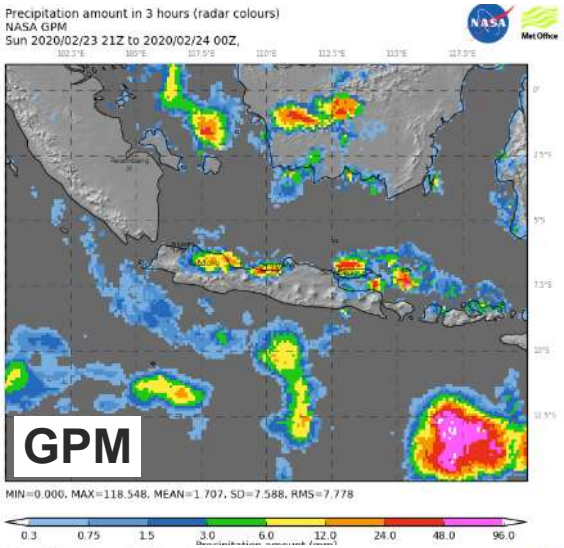
4.4 km deterministic

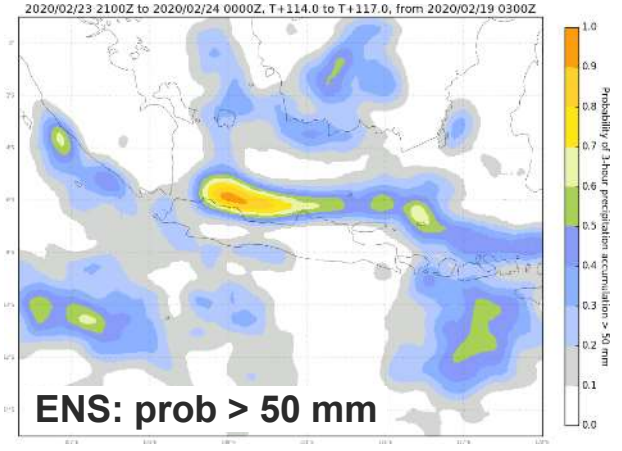


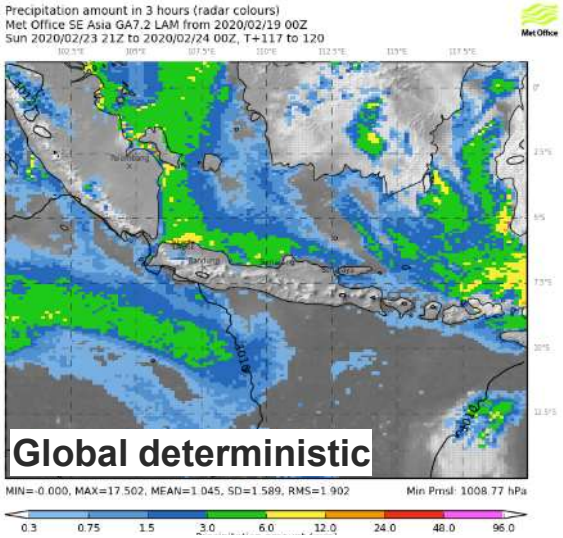
ENS: 95th percentile

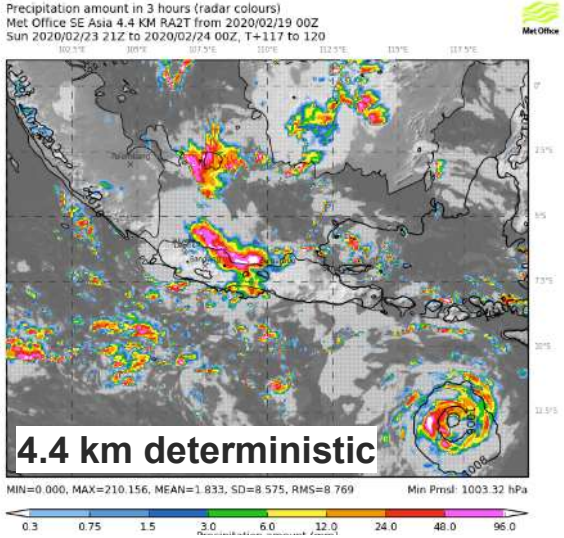
Met Office

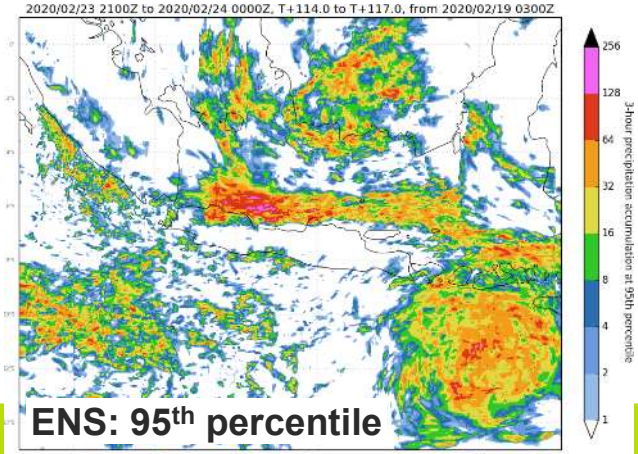
3 hour rainfall accumulations through to 24/2/20 00z T+117 to T+120







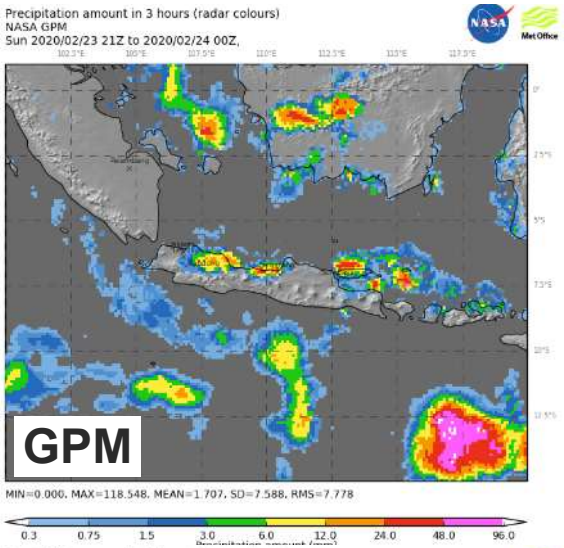


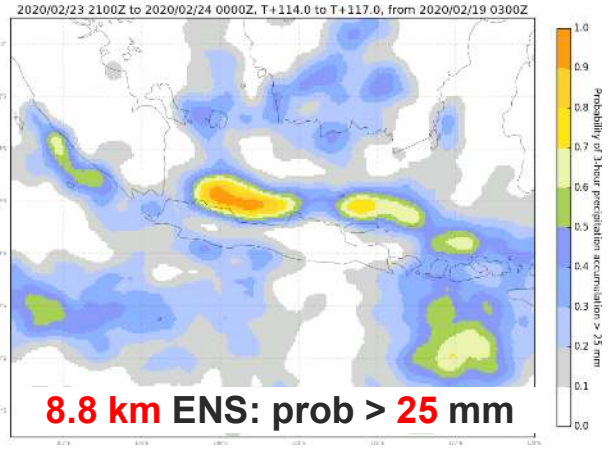


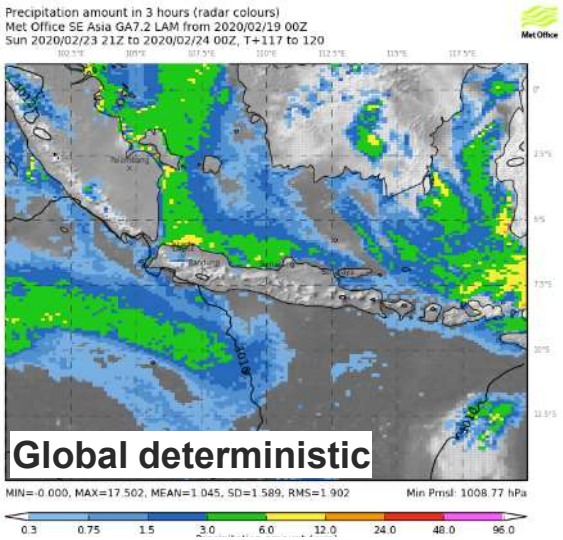
Met Office

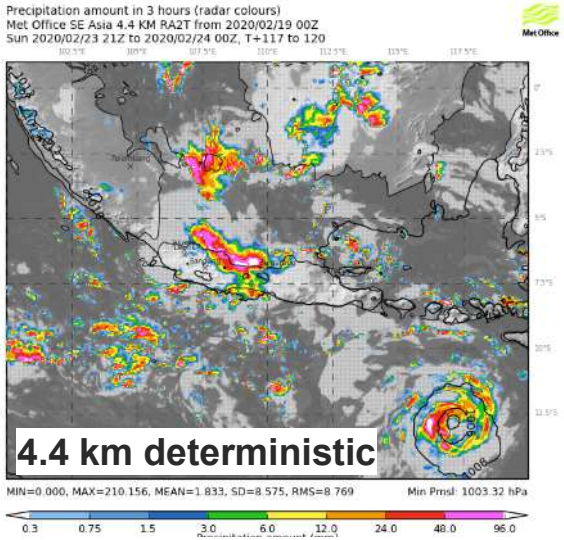
3 hour rainfall accumulations through to 24/2/20 00z T+117 to T+120

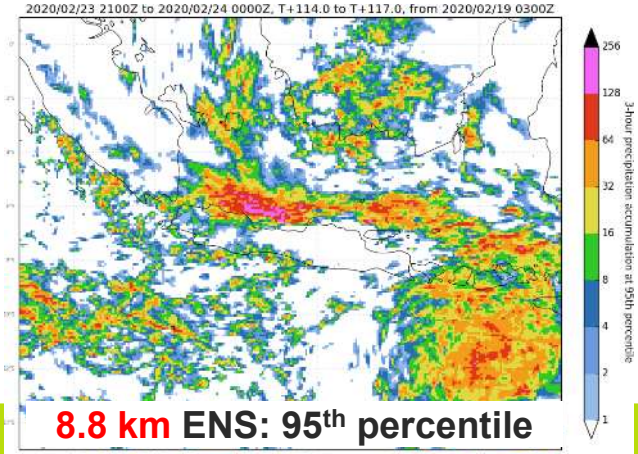
8.8 km ensemble







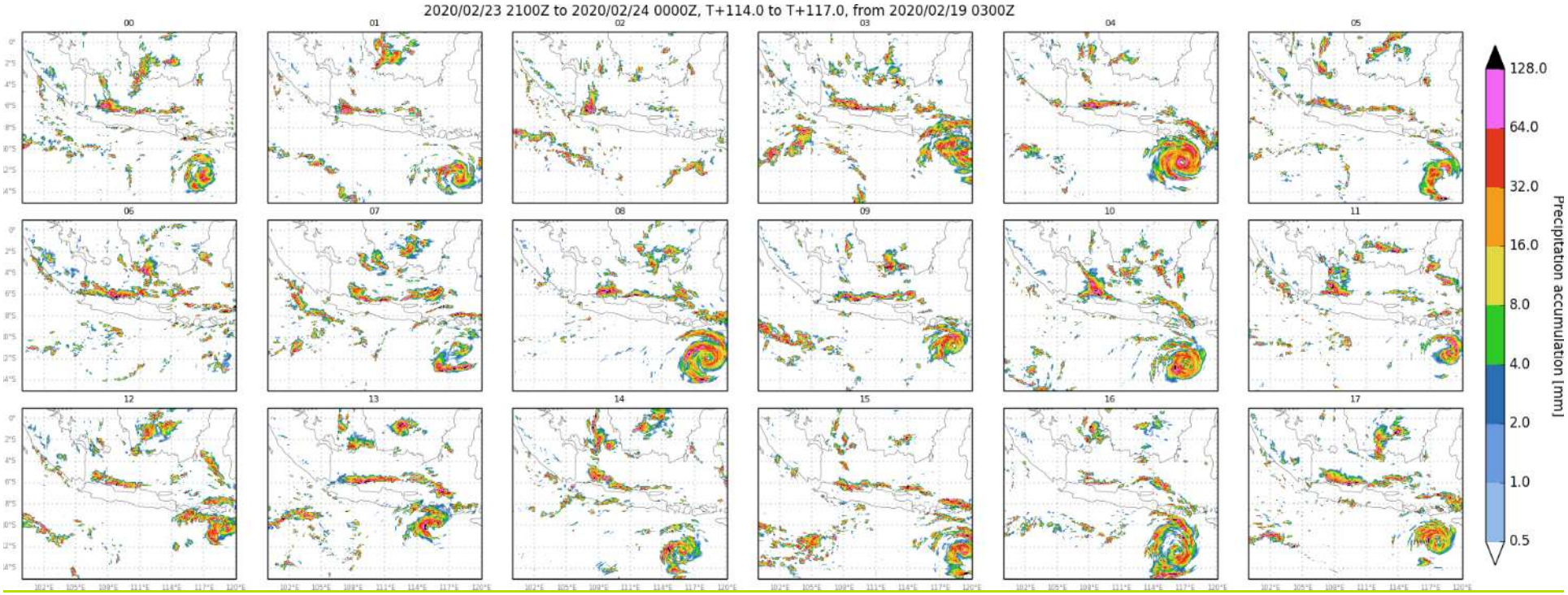




Met Office

3 hourly rainfall accumulations
through to 24/2/20 00z **T+120**

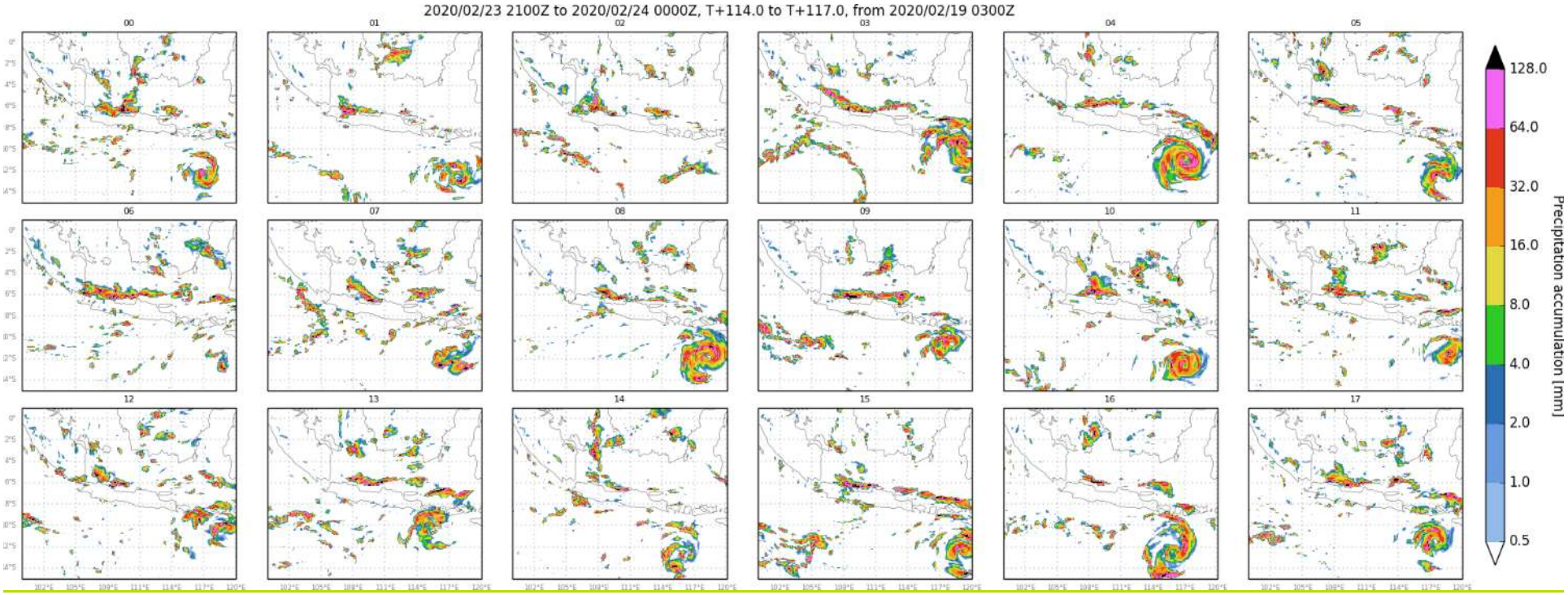
4.5 km ensemble **All 18 members**



Met Office

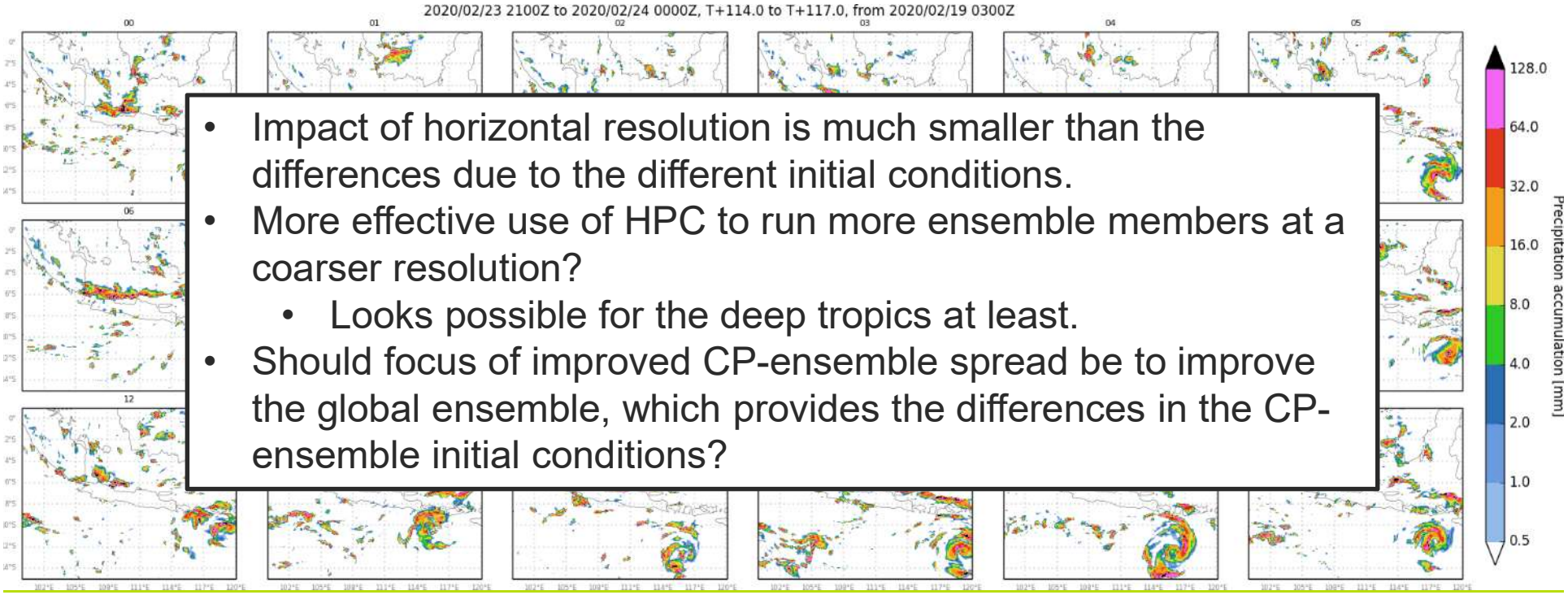
3 hourly rainfall accumulations
through to 24/2/20 00z **T+120**

8.8 km ensemble **All 18 members**



3 hourly rainfall accumulations
through to 24/2/20 00z **T+120**

8.8 km ensemble **All 18 members**



- Impact of horizontal resolution is much smaller than the differences due to the different initial conditions.
- More effective use of HPC to run more ensemble members at a coarser resolution?
  - Looks possible for the deep tropics at least.
- Should focus of improved CP-ensemble spread be to improve the global ensemble, which provides the differences in the CP-ensemble initial conditions?

Outline

- MOGREPS-UK
  - Currently the only MO ensemble system centred on a convective-scale DA analysis.
- Met Office Spread Process Evaluation Group (PEG)
- Hazardous Weather Testbed
- WCSSP SE Asia
- GCRF Africa-SWIFT
- Atlantic Tropical Cyclones
- Summary

Outline

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GCRF *African* SWIFT - Science for Weather Information and Forecasting Techniques

Convection-permitting ensembles rainfall forecasts for Tropical East Africa: a preliminary analysis

Carlo Cafaro, Caroline Bain, Cathryn Birch, Samantha Clarke, Andrew Hartley, Peter Hill, Thorwald Stein, Stuart Webster, Beth Woodhams

GCRF UKRI UK Research and Innovation

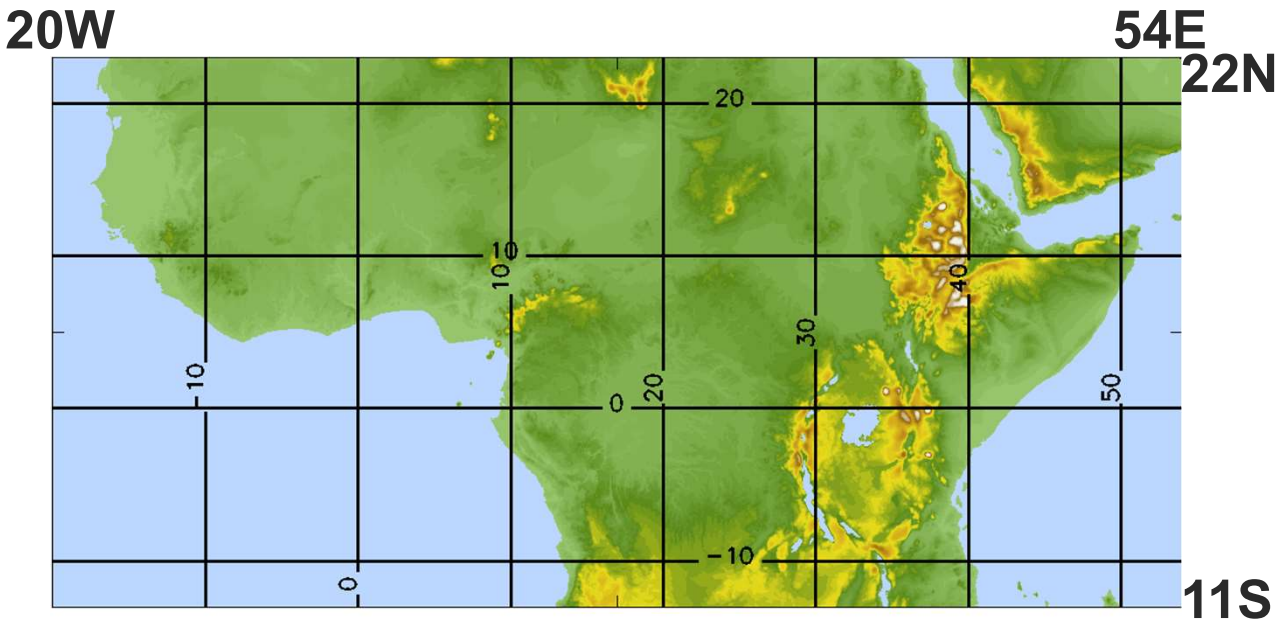
https://africanswift.org/

GCRF African SWIFT

Testbed 1B: 20/4/19 to 6/5/19

Tropical Africa Ensemble Forecasts

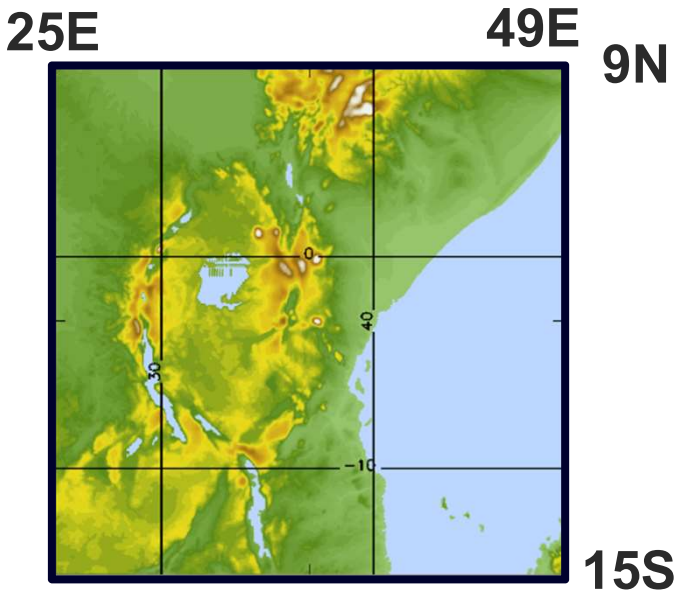
- **8.8 km**, dt=150 s
- RA1T
- 930 x 450 points
- L80, 38.5km lid
- Runs to T+72.
- ICs + LBCs from latest 18 members of operational ensemble N640 global (MOGREPS-G)
- Initialised at 00Z and 12Z each day



Testbed 1B: 20/4/19 to 6/5/19

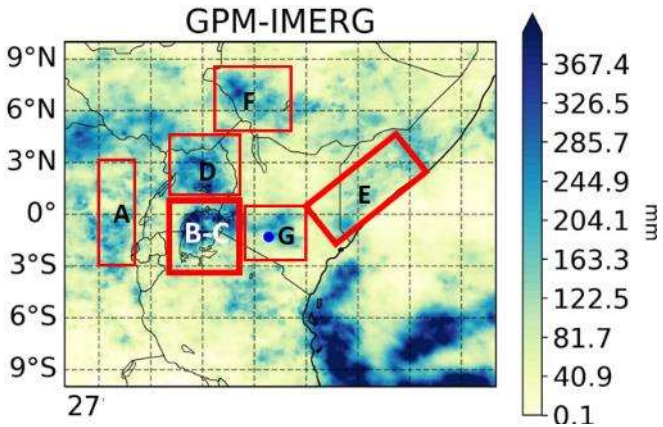
East Africa Ensemble Forecasts

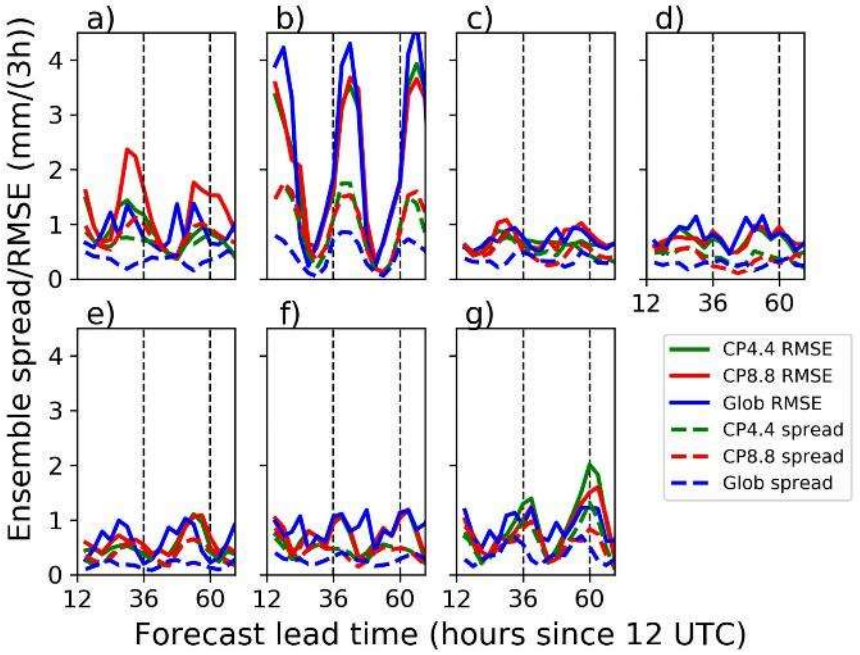
- 4.4 km, dt=120 s
- RA1T
- 600 x 600 points
- L80, 38.5km lid
- Runs to T+72.
- ICs + LBCs from latest 18 members of operational ensemble N640 global (MOGREPS-G)
- Initialised at 00Z, 06Z, 12Z and 18Z each day



Same cost as 8.8 km Tropical Africa ensemble

Spread and RMSE for 3h rainfall accumulation





All three ensembles are underspread over all sub-regions.

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Outline

- MOGREPS-UK
  - Currently the only MO ensemble system centred on a convective-scale DA analysis.
- Met Office Spread Process Evaluation Group (PEG)
- Hazardous Weather Testbed
- WCSSP SE Asia
- GCRF Africa-SWIFT
- Atlantic Tropical Cyclones
- Summary

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Atlantic Tropical Cyclones 2018

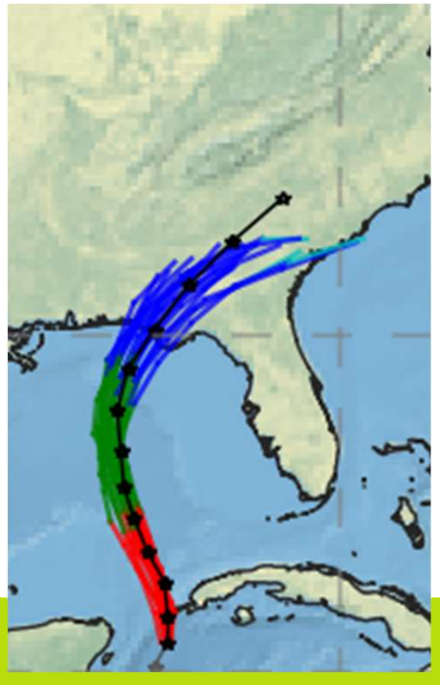
- Ran real-time 4.4 km ensemble for storms potentially affecting British Overseas Territories.
- Run “on demand” out to T+120 twice daily.
- Relocatable domain, which was manually chosen based on the forecast tracks of the previous MOGREPS-G run.
  - Ensured domain big enough that TC circulation is wholly contained wholly within it.
- Nesting inside latest 18 members of MOGREPS-G.
- Using “RA1T+”
  - RA1T **and additionally** reduced drag at high wind speeds, which is part of RA2 package.
  - Change only affects tropical cyclones, and improves the TC wind-pressure relationship,
- Most interesting cases:- Michael and Florence.

Hurricane Michael

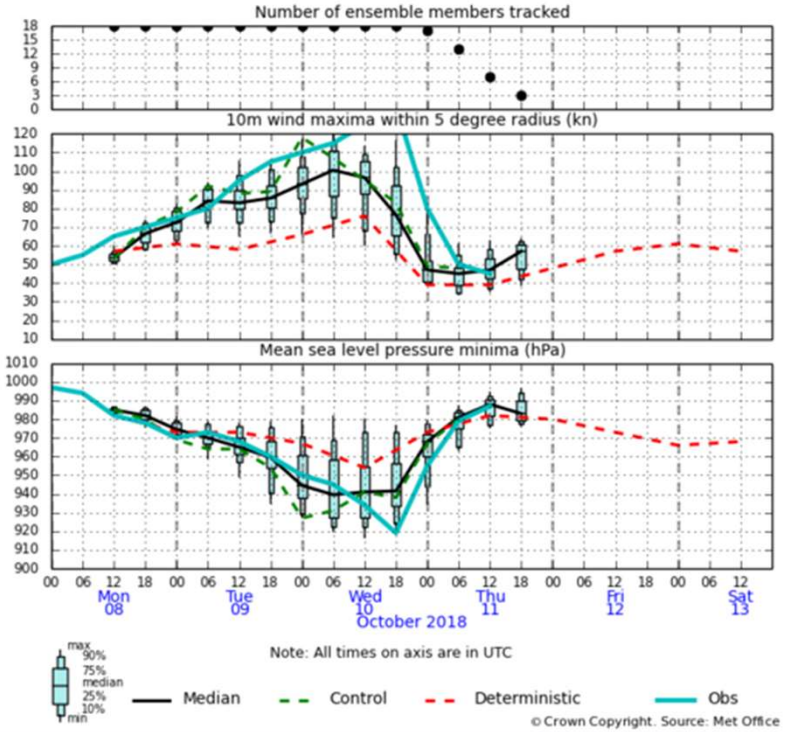
- First forecast run 8th October 12Z = 60 hours before landfall.

- Rapid deepening well captured by 4.4 km ensemble.
- Large spread in central pressure – 920 hPa to 975 hPa around landfall.
- c.f. observed 919 hPa.

MOGREPS-4p4: Forecast tropical storm tracks for MICHAEL from 12UTC 08/10/2018



MOGREPS 4.4km ensemble: Tropical Cyclone storm-following meteogram
MICHAEL (20.9N 85.1W) from 12UTC 08 October 2018



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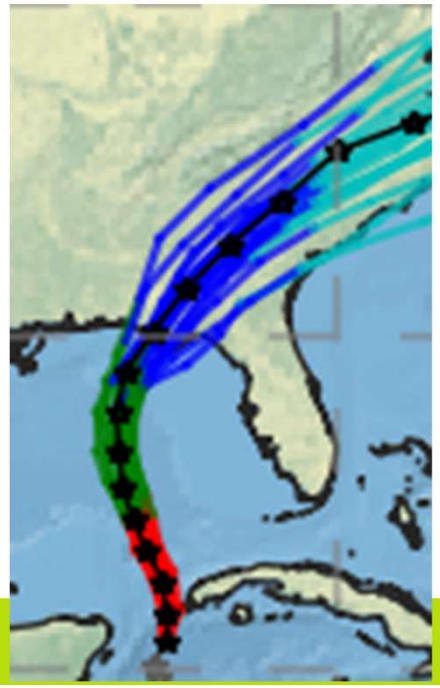
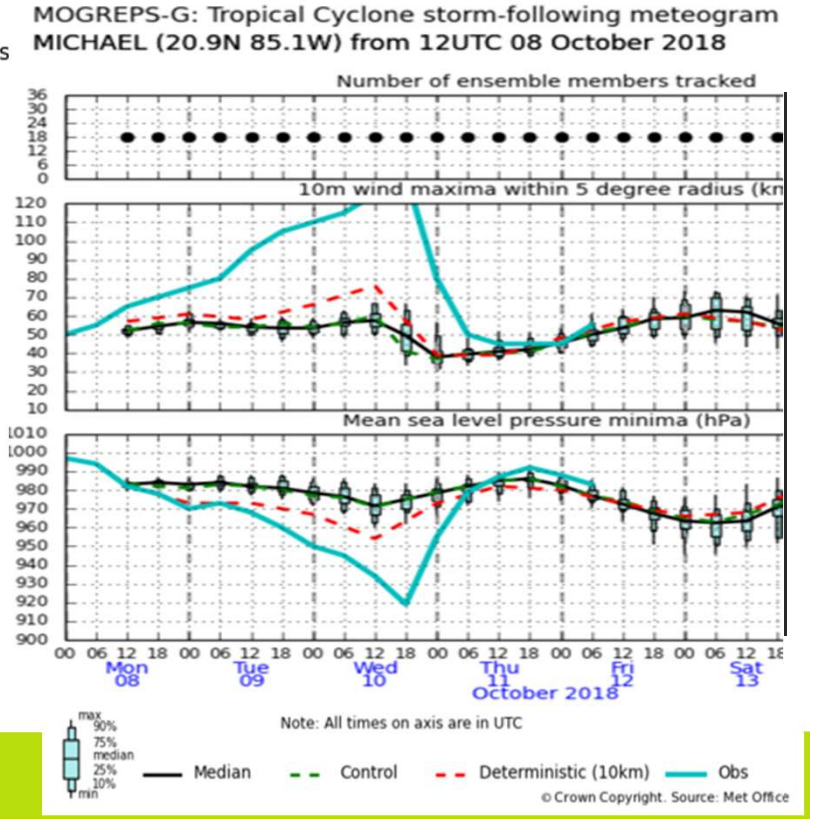
Hurricane Michael

- First forecast run 8th October 12Z = 60 hours before landfall.

- Rapid deepening not captured by MOGREPS-G.
- Central pressures – 965 hPa to 980 hPa around landfall.
- c.f. observed 919 hPa.

MOGREPS-G-18: Forecast tropical storm tracks for MICHAEL from 12UTC 08/10/2018





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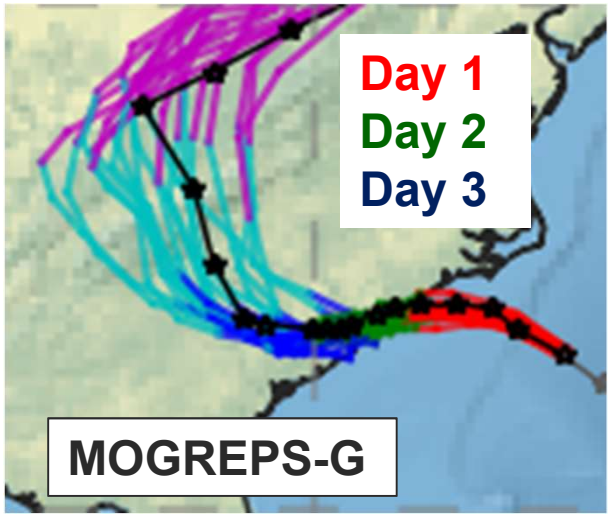
Met Office Hurricane Florence

- Ran forecasts from 3rd September through to landfall on 14th September.
- Florence traversed most of the Atlantic – so used 7 separate domains
  - smaller domains = cheaper and more timely output.
- Florence stalled at landfall, leading to ~1000 mm rainfall accumulations.
- 4.4 km ensemble offers potential for quantitatively more accurate rainfall forecasts in these situations.
- And, indeed, 4.4 km tracks were very different to MOGREPS-G.
- Plot to right shows MOGREPS-G tracks from 13th September 12Z…



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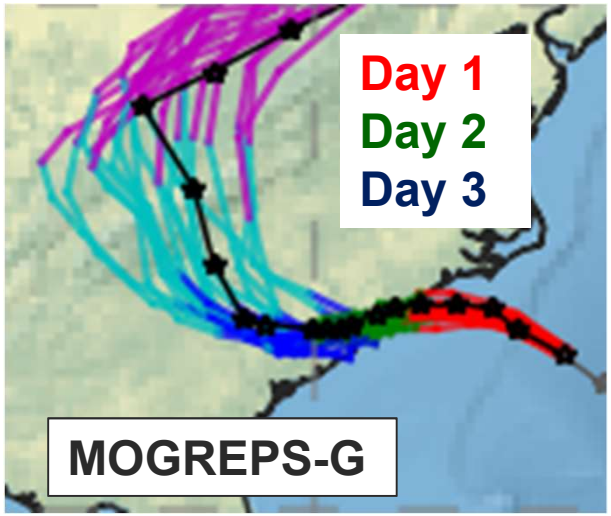
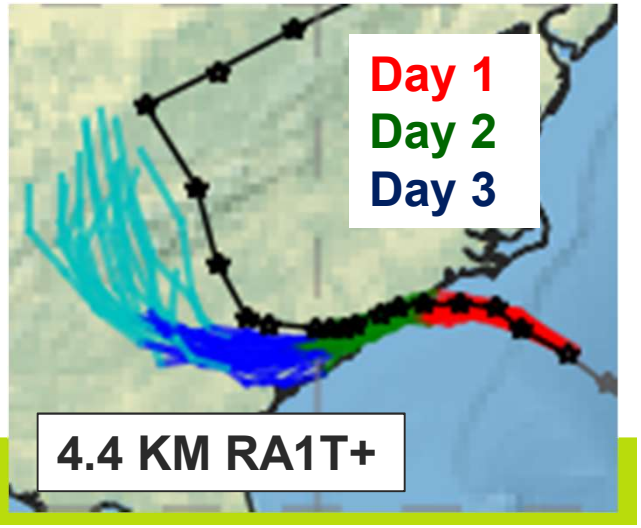
Met Office Hurricane Florence

- Plot to right shows tracks from 13th September 12Z.
- MOGREPS-G forecasts do stall.
- 4.4 km ensemble does not stall:-
  - Moves too rapidly – compare **day 2 track lengths**
  - "Overshoots" actual and MOGREPS-G tracks.
  - **Peak rainfall accumulations ~500 mm rather than the ~1000 mm observed.**

- **Understanding cases like this, with large differences between global and regional ensembles, is currently being investigated as part of WCSSP SE Asia**





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Summary

- Top priority for UK-based ensembles development is to improve spread.
- Same issue is being seen for other regions.
  - HWT and SWIFT, and likely over SE Asia too.
- No obvious improvement in CP-ensemble spread from changing ETKF to Ens4DEnsVar in MOGREPS-G.
- Ongoing work to improve spread:-
  - Assessing the impact of the driving model ensemble (e.g. using ECMWF EPS).
  - More intelligent stochastic physics perturbations.
    - Most parameters chosen to maximise spread in fog forecasts – not “optimum” for deep convection !
- UM tropics specific thoughts:-
  - Potentially useful ensemble forecasts out to at least day 5.
  - Running with explicit convection at ~9 km resolution produces forecasts almost as good as at 4.5 km resolution.
    - c.f. ~9 km forecasts run with parametrized convection (not shown).