Stochastic perturbation of tropical cyclone initial conditions in the MOGREPS-G ensemble

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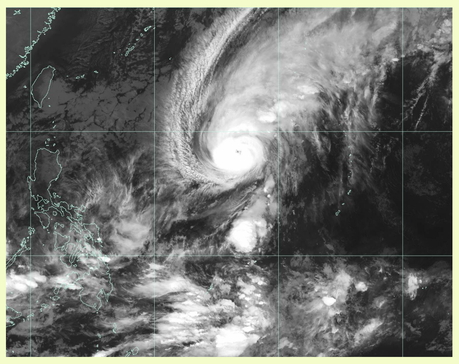
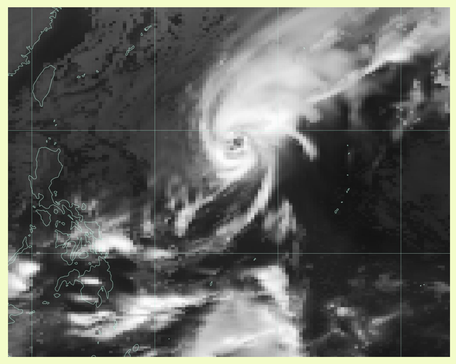
Introduction

At the Met Office, high-resolution global model forecasts of tropical cyclone (TC) intensity have benefited from the assimilation of central pressure observation estimates in the 4dVar deterministic and ensemble of 4d-Ensemble-Var data assimilation schemes (Heming 2016: https://doi.org/10.1175/WAF-D-16-0040.1). Although the ensemble forecasts do have moderate spread for TC track and intensity, these are generally still under-dispersed, particularly for intensity. Thus, to improve ensemble TC forecast spread, we introduce a perturbed observation technique that creates perturbations to the central pressure estimate. These then get passed through a relatively cheap 3dVar system to produce unique analysis increments for each ensemble member. In addition to improving spread in the ensemble, this method targets model underestimated TC intensity and accounts for observations uncertainty in the TC central pressure.



Observed Infra-Red Image: 12Z 2 Dec 2021



Simulated (20km) Infra-Red Image: 12Z 2 Dec 2021

Method

For each ensemble member we take the quality-controlled central pressure estimate and perturb the location and pressure value. Location perturbations are taken from a uniform distribution of random numbers in the range $\in [-0.25, +0.25]$ which corresponds to a maximum displacement of about 25NM independently in the east-west and north-south directions (Fig. 1).

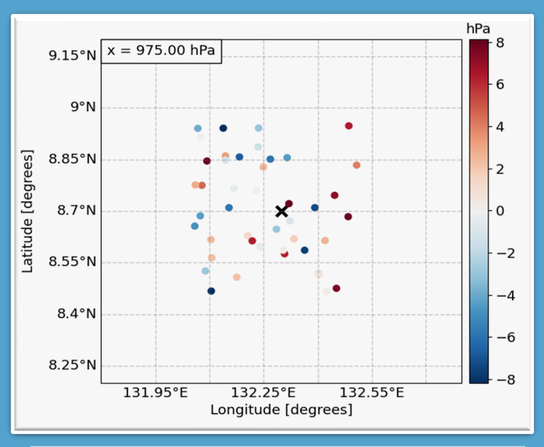


Figure 1: Example of position and pressure perturbations (shaded) to TC central pressure estimate “X”

The central pressure is perturbed similarly in the range $\in [-12.5, +12.5]$ hPa, but the size of the perturbation is also scaled by the depth of the TC. Central pressures lower than 958hPa can be perturbed by this full amount, but this linearly reduces to zero at estimated pressures of 1008hPa. The example in figure 1 has a central pressure of 975hPa, so the maximum pressure perturbation will be capped at ±8.25hPa.

A final scaling step limits perturbations to within 20º of the equator, with a linear reduction from full magnitude at 15º latitude to zero by 20º. This is necessary to prevent perturbations affecting forecast performance in the mid-latitudes.

The 3dVar scheme is able to generate increments to wind, temperature, moisture and pressures with a sensible spatial structure from just the single input pressure observation estimate (Fig. 2 & 3).

A limitation of this scheme is that it will only be able operate when the estimated central pressure observations are available, which typically only occurs once tropical cyclones begin to deepen at model analysis time. It will not be able to influence forecasts of tropical cyclones that are yet to develop.

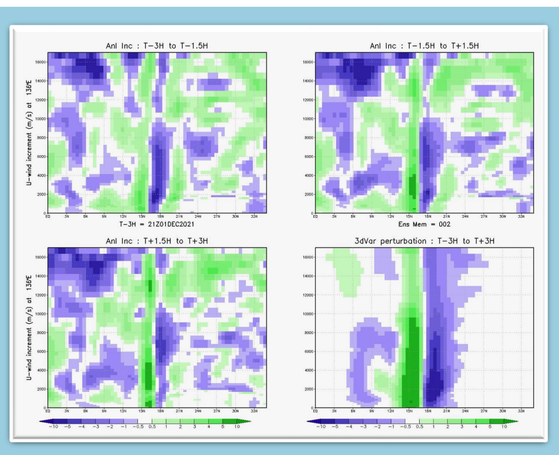


Figure 2: Vertical north-south cross-section of eastward wind increments centred on TC Nyatoh from the ensemble-4dEns-Var scheme for three periods (T-3H top left; T-1.5H top right; T+1.5H bottom left) during the DA window, and the 3dVar increment from the single perturbed central pressure (bottom right), valid for one ensemble member out of 44 at 00Z on 2nd December 2021.

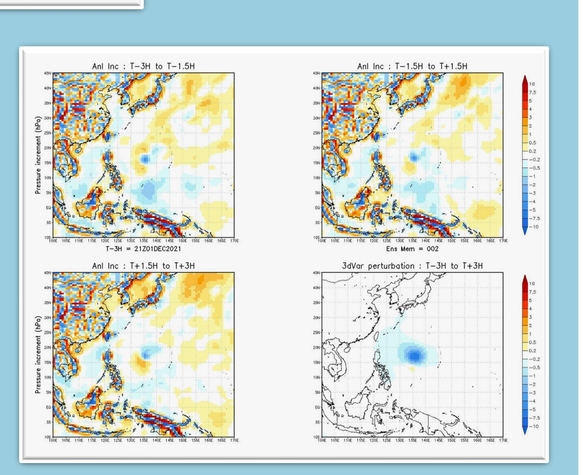


Figure 3: As with figure 2, but showing increments to surface pressure in the SE Asia region with TC Nyatoh in the centre of the plot. Note the pressure increments from the single TC central pressure observation are confined to the region of the TC.

Results

Initial low resolution (60km grid-spacing) and operational resolution (20km) ensemble trials gave encouraging results, with significantly enhanced ensemble spread in the cases of Typhoons Nyatoh and Rai in the North West Pacific in December 2021.

Ensemble spread is strongly dependent on how skilful the model is at forming realistic tropical cyclone intensity in the first place. Weak developments tend to have limited spread regardless of the perturbation scheme used. This can be seen when comparing the forecast performance of the low-resolution 60km model with that of the operational 20km version.

Typhoon Nyatoh started deepening on 30th Nov 2021 near 140ºE 13ºN reaching a deep 925hPa on 3rd December as it headed WNW. It then rapidly dissipated as it tracked NE away from land.

The 20km operational-resolution runs show Nyatoh intensity quite far short of the observed values (Fig. 4).

The ensemble control member (green dashed line) being a direct down-scaler of the 10km deterministic model, is more intense than the ensemble mean in the control simulation, but with the perturbation scheme included the ensemble mean is deepened and intensity spread increased. By this stage in the TC development, track forecasts were already good.

Typhoon Rai started deepening on 13th Dec 2021 and tracked W across the Philippines deepening to 915hPa before and again after landfall, before turning NE and passing to the east of Vietnam. The low-res simulation, although quite poor at intensity shows increased ensemble spread, a general deepening of the simulated TC and improved track at longer lead times (Fig. 5).

These initial trials show how making better use of the central pressure observations has the potential to improve ensemble performance. This of course will need to be trialled with a large sample of TCs to determine a general impact, but so far the concept looks promising.

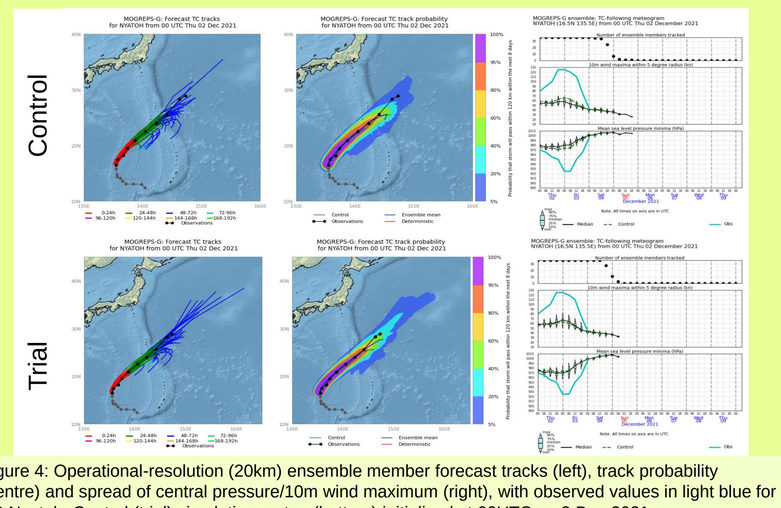


Figure 4: Operational-resolution (20km) ensemble member forecast tracks (left), track probability (centre) and spread of central pressure/10m wind maximum (right), with observed values in light blue for TC Nyatoh. Control (trial) simulation on top (bottom) initialised at 00UTC on 2 Dec 2021.

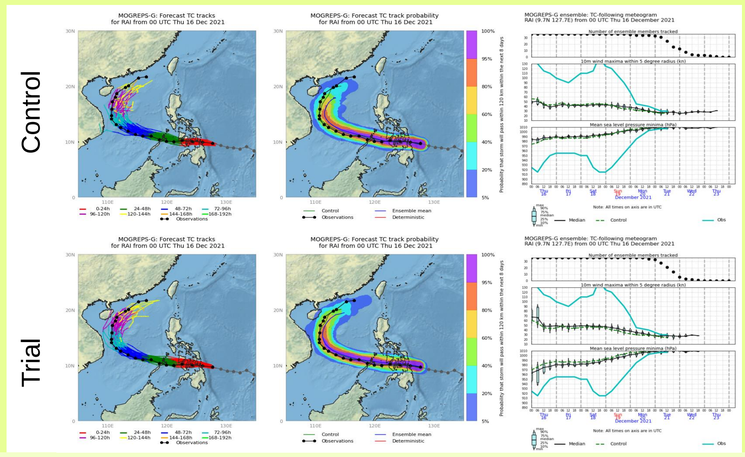


Figure 5: As with figure 4, but with low-resolution (60km) simulations of TC Rai initialised at 00UTC on 16 Dec 2021.

Conclusion

We have shown a positive impact on the MOGREPS-G ensemble spread of tropical cyclone intensity and track by perturbing the central pressure observation estimates and passing these through a cheap 3dVar data assimilation scheme.

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