

A Tale of Two Rapidly Intensifying Supertyphoons

Hagibis (2019) and Haiyan (2013)

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Supplementary to results

3DPWP results. PERIOD 1 (P1). Four sensitive experiments were conducted to elucidate the different impacts from individual parameters. As in Fig. ES8a and Table ES1, the cooling effect of Hagibis's observed run was ~0.57°C (blue dashed profile), but the cooling of the size sensitivity run was ~0.29°C (green dashed profile). This means that if Hagibis's size was to be smaller, i.e., of similar size as Haiyan, the cooling effect would be 0.29°C (and not the 0.57°C in the observed run). Figure ES8b compares the results of the Uh sensitivity run (orange dashed profile) and Hagibis's observed run (blue dashed profile). Because there was little difference in the translation speed (Uh) of the two supertyphoons (STYs) during P1, there was also little difference in the cooling results (i.e., orange and blue dashed profiles almost overlap). Similar results are in Fig. ES8d, i.e., the salinity sensitivity run. As for Fig. ES8a) and not the Uh impact (i.e., Fig. ES8b).

3DPWP results. PERIOD 2 (P2). The sensitivity test results of P2 are in Fig. ES7 and Table ES3. It can be seen that both size and Uh are differentiating factors between the 2 STYs during P2, and both have contributions to cooling. Therefore the combined size + Uh impact is the most evident (Fig. ES7c). Similar to P1, salinity was not a key differentiating factor between the two STYs and the difference was minimal.

Tropical cyclone size. In addition to Figs. 4a and 4b (RMW and R34), the complete size information from the JTWC best track, i.e., including also R50 and R64, is shown in Fig. ES6. ASCAT ocean surface wind data are also included for additional size information (Fig. 11).

Argo profiles. Two during–tropical cyclone (TC) Argo profiles were found. According to the nearest 6-hourly track location, details are given below:

- Haiyan P2 (green profile 1 in Fig. 0d of the main text): Nearest TC track location: 1107:00 UTC; TC size (D50): 213 km; Uh: 8.5 m s⁻¹; transit time = 7 h; Argo_time: 1107:07 UTC.
- Haiyan P2 (green profile 2 in Fig. 9d of the main text): Nearest TC track location: 1107:12 UTC; TC size (D50): 232 km; Uh: 11 m s⁻¹; transit time = 5.8 (6) h; Argo_time: 1107:18 UTC.

Equivalent OHC estimation. When comparing the pre-TC ocean heat content (OHC) with the eastern North Pacific TC, e.g., Hurricane Patricia in 2015, in addition to the regular OHC, "equivalent" OHC (E-OHC; as proposed by Shay and Brewster 2010), was also calculated. This is because eastern North Pacific has high upper-ocean stratification. Thus, Shay and Brewster (2010) proposed the calculation of the E-OHC, to factor in the stratification effect. Using method from Shay and Brewster (2010), we generated two maps of the stratification (S) parameter (S factor), one for October climatology and the other for November climatology (Figs. ES9 and ES10). Indeed, the eastern North Pacific is featured by very high S factor, as compared to the western North Pacific. Pre-TC E-OHC for the three super TCs, i.e., Hagibis, Haiyan, and Patricia, was also calculated and compared. As in Table ES5, the original OHC for Patricia was slightly lower than the two western North Pacific cases, i.e., Haiyan and Hagibis. With consideration of the S factor, the E-OHC of the three cases are similar and comparable.

Table ES1. Three-dimensional PWP results for P1. Because there are five 6-hourly points for each case (i.e., 1200 UTC 6 Oct to 1200 UTC 7 Oct for Hagibis and 0000 UTC 5 Nov to 0000 UTC 6 Nov for Haiyan), for each experiment, the values are the average over the five points. Results of the two observed (obs.) runs are in the top section, while the results of the four sensitivity (sens.) runs are in the bottom section.

	Input TC size in D50 (km)	Input TC Uh (m s ⁻¹)	SST _{preTC} (°C) (from Argo)	SST _{duringTC} (°C) (3DPWP output)	Cooling (°C)
Obs. run					
Hagibis obs. run	266.8 ± 91.2	7.7 ± 0.6	30.33 ± 0.20 (4 Argo)	29.76 ± 0.30	0.57 ± 0.30
Haiyan obs. run	157.4 ± 53.2	7.8 ± 0.5	29.05 ± 0.59 (3 Argo)	28.94 ± 0.05	0.11 ± 0.05
Sens. run					
Size sens. run	157.4 ± 53.2	7.7 ± 0.6	30.33 ± 0.20 (4 Argo)	30.03 ± 0.06	0.29 ± 0.06
Uh sens. run	266.8 ± 91.2	7.8 ± 0.5	30.33 ± 0.20 (4 Argo)	29.77 ± 0.30	0.56 ± 0.30
Size + Uh sens. run	157.4 ± 53.2	7.8 ± 0.5	30.33 ± 0.20 (4 Argo)	30.04 ± 0.06	0.29 ± 0.06
Salinity sens. run	266.8 ± 91.2	7.7 ± 0.6	30.33 ± 0.20 (4 Argo)	29.78 ± 0.28	0.54 ± 0.28

Table ES2. As in Table ES1, but for the corresponding flux results for P1. $\Delta T = T_s - T_a$ and $\Delta q = q_s - q_a$, T_s is during-TC SST. See also Appendix C.

	SST _{duringTC} (°C) (3DPWP)	<i>T_a</i> (°C) (CFS)	<i>q₅</i> (g kg ⁻¹) (SST _{duringTC})	<i>q</i> _a (g kg⁻¹) (CFS)	Δ 7 (°C)	∆ <i>q</i> (g kg⁻¹)	SHF (W m ⁻²)	LHF (W m ⁻²)	Total flux (W m ⁻²)
Obs. run									
Hagibis obs. run	29.76 ± 0.30	28.42 ± 0.35	25.74 ± 0.31	19.33 ± 0.28	1.34 ± 0.60	6.42 ± 0.25	82 ± 23	1,169 ± 433	1,250 ± 433
Haiyan obs. run	28.94 ± 0.05	27.78 ± 1.11	24.61 ± 0.16	19.37 ± 0.23	1.15 ± 1.10	5.24 ± 0.09	69 ± 65	853 ± 212	923 ± 240
Sens. run									
Size sens. run	30.03 ± 0.06	28.42 ± 0.35	26.15 ± 0.08	19.33 ± 0.28	1.62 ± 0.40	6.82 ± 0.30	106 ± 33	1,264 ± 529	1,370 ± 554
Uh sens. run	29.77 ± 0.30	28.42 ± 0.35	25.75 ± 0.30	19.33 ± 0.28	1.35 ± 0.57	6.43 ± 0.28	82 ± 19	1,171 ± 435	1,253 ± 435
Size + Uh sens. run	30.04 ± 0.06	28.42 ± 0.35	26.16 ± 0.08	19.33 ± 0.28	1.62 ± 0.39	6.83 ± 0.30	106 ± 32	1,266 ± 530	1,372 ± 554
Salinity sens. run	29.78 ± 0.28	28.42 ± 0.35	25.78 ± 0.28	19.33 ± 0.28	1.36 ± 0.58	6.45 ± 0.24	83 ± 23	1,176 ± 440	1,260 ± 442

Table ES3. As in Ta	ble ES1, but for	period 2 (P2,	the post-RI period)
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	Input TC size in D50 (km)	Input TC Uh (m s ⁻¹)	SST _{preTC} (°C) (from Argo)	SST _{duringTC} (°C) (3DPWP output)	Cooling (°C)
Obs. run					
Hagibis obs. run	447.2 ± 45.4	4.5 ± 1.1	29.62 ± 0.10 (10 Argo)	28.34 ± 0.26	1.29 ± 0.26
Haiyan obs. run	231.6 ± 25.6	9.5 ± 0.9	29.24 ± 0.23 (20 Argo)	29.06 ± 0.01	0.18 ± 0.01
Sens. run					
Size sens. run	231.6 ± 25.6	4.5 ± 1.1	29.62 ± 0.10 (10 Argo)	28.96 ± 0.17	0.66 ± 0.17
Uh sens. run	447.2 ± 45.4	9.5 ± 0.9	29.62 ± 0.10 (10 Argo)	29.00 ± 0.02	0.62 ± 0.02
Size + Uh sens. run	231.6 ± 25.6	9.5 ± 0.9	29.62 ± 0.10 (10 Argo)	29.34 ± 0.01	0.28 ± 0.01
Salinity sens. run	447.2 ± 45.4	4.5 ± 1.1	29.62 ± 0.10 (10 Argo)	28.39 ± 0.25	1.24 ± 0.25

Table ES4. As in Table ES2, but for the flux results for P2.

	SST _{duringTC} (°C) (3DPWP)	<i>T_a</i> (°C) (CFS)	<i>q₅</i> (g kg⁻¹) (SST _{duringTC})	<i>q</i> _a (g kg⁻¹) (CFS)	Δ <i>Τ</i> (°C)	∆ <i>q</i> (g kg⁻¹)	SHF (W m ⁻²)	LHF (W m ⁻²)	Total flux (W m ⁻²)
Obs. run									
Hagibis obs. run	28.34 ± 0.26	29.29 ± 0.33	25.62 ± 0.52	21.25 ± 0.45	-0.95 ± 0.58	4.37 ± 0.96	-81 ± 51	957 ± 163	876 ± 213
Haiyan obs. run	29.06 ± 0.01	27.65 ± 0.77	25.73 ± 0.40	19.15 ± 0.87	1.41 ± 0.78	6.57 ± 1.07	138 ± 78	1,689 ± 364	1,827 ± 416
Sens. run									
Size sens. run	28.96 ± 0.17	29.29 ± 0.33	26.56 ± 0.40	21.25 ± 0.45	-0.32 ± 0.49	5.31 ± 0.81	-28 ± 41	1,166 ± 124	1,138 ± 164
Uh sens. run	29.00 v±0.02	29.29 ± 0.33	26.62 ± 0.21	21.25 ± 0.45	-0.29 ± 0.34	5.37 ± 0.62	-25 ± 29	1,180 ± 81	1,155 ± 107
Size + Uh sens. run	29.34 ± 0.01	29.29 ± 0.33	27.15 ± 0.19	21.25 ± 0.45	0.06 ± 0.34	5.90 ± 0.62	4 ± 28	1,297 ± 75	1,301 ± 100
Salinity sens. run	28.39 ± 0.25	29.29 ± 0.33	25.69 ± 0.52	21.25 ± 0.45	-0.90 ± 0.58	4.44 ± 0.95	-77 ± 51	973 ± 162	896 ± 211

Table ES5. OHC, S-factor, and equivalent OHC (i.e., E-OHC) comparison of the three TCs. The S factor in the table is the averaged value from the S-factor values extracted along the RI track locations of each TC in Figs. ES9 and ES10.

	Hagibis	Haiyan	Patricia
OHC (kJ cm ⁻²)	121–150	93–121	90–104
	Estimated based on Argo pre-TC profiles and satellite measurements in this work	Estimated based on Argo pre-TC profiles and satellite measurements in this work, and Huang et al. (2017)	From Rogers et al. (2017) (satellite measurements) and Huang et al. (2017) (Argo in situ pre-TC profiles)
S factor	1.8	2.1	2.5
E-OHC (kJ cm ⁻²)	218–270	195–254	225–260



Fig. ES1. Converting (left) T_a and (right) q_a from the NCEP sigma 995 level (i.e., ~40 m) to 10 m altitude, based on in situ observed relationship of historical TC inner-core dropsonde observations (Zhang et al. 2013, 2020) over category-4 and category-5 TCs of the North Atlantic.



Fig. ES2. As in Figs. 1c and 1d, but for RH at midlevel.



Fig. ES3. Observation of TC structure and ERC from the NRL microwave imagery for Hagibis between 0506 UTC 6 Oct and 0359 UTC 11 Oct 2019 (see Fig. ES4). These images are after quality control. The images with poor quality or missing the primary features of Hagibis are discarded. Data source: 85 GHz-H archive from www.nrlmry.navy.mil/TC.html.





Fig. ES5. As in Figs. 2c and 2d, but also showing the cold ocean eddy (COE) location. (left) Pre-TC ocean heat content (OHC). (right) Pre-TC sea surface height anomaly (SSHA).



Fig. ES6. As in Figs. 4a and 4b, but for the complete TC size information from the JTWC.



Fig. ES7. Three-dimensional PWP results during P2. (a) Size sensitivity run (green dashed profile) vs Hagibis's observed run (blue dashed profile). (b) As in (a), but for Uh sensitivity run (orange dashed profile). (c) As in (a), but for size + Uh sensitivity run (purple dashed profile). (d) As in (a), but for salinity run (pink dashed profile).



Fig. ES8. As in Fig. ES7, but for P1.

WOA13_1015_PAC.bvf



Fig. ES9. *S*-factor map [based on method in Shay and Brewster (2010)] for October climatology, with Hagibis's and Patricia's tracks depicted. The ocean temperature and salinity profiles used in the *S*-factor calculation is from the *World Ocean Atlas* (*WOA*) 13.

WOA13_1115_PAC.bvf









Fig. ES12. Time series to objectively identify the convection evolution of the two storms: (a) Hagibis and (b) Haiyan. Both the IR brightness temperature (Tb) ring determined by the advanced Dvorak technique (ADT) and the Automated Rotational Center Hurricane Eye Retrieval (ARCHER) ring scores are measures of the convective organization (presence of a ring) and magnitude of the convection. Objective measures of RMW (from Kossin et al. 2007) are also provided to complement Fig. 4 that shows JTWC best track RMW and to provide more detail on the inner-core structure change. Of note during P2 (6–7 Nov 2013) is that Haiyan IR Tbs continue to cool up to landfall consistent with the increase in intensity. ARCHER scores also reach a peak during this period. By contrast the Hagibis IR Tb values during P2 (9 Oct 2019) was weaker than Haiyan's during P2. While these values are proxies for TC intensity, they show some detail of the convection response during the two periods of interest.

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