Stratified Coastal Ocean Interactions with Tropical Cyclones: Irene (2011) & Barry (2007)

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1. Baroclinic coastal ocean mixing processes have been identified in Irene and Barry.

- **Tropical cyclone (TC) intensity forecast improvements currently lag** the progress achieved for tracks
- **TC research has focused on deep ocean**, less to coastal processes despite critical importance to shoreline populations
- High Frequency (HF) radar (Fig. 1-2) and underwater gliders (Fig. 2) observed **wind-forced 2-layer circulation of stratified coastal ocean and resultant shear-induced mixing** across Mid Atlantic continental shelf

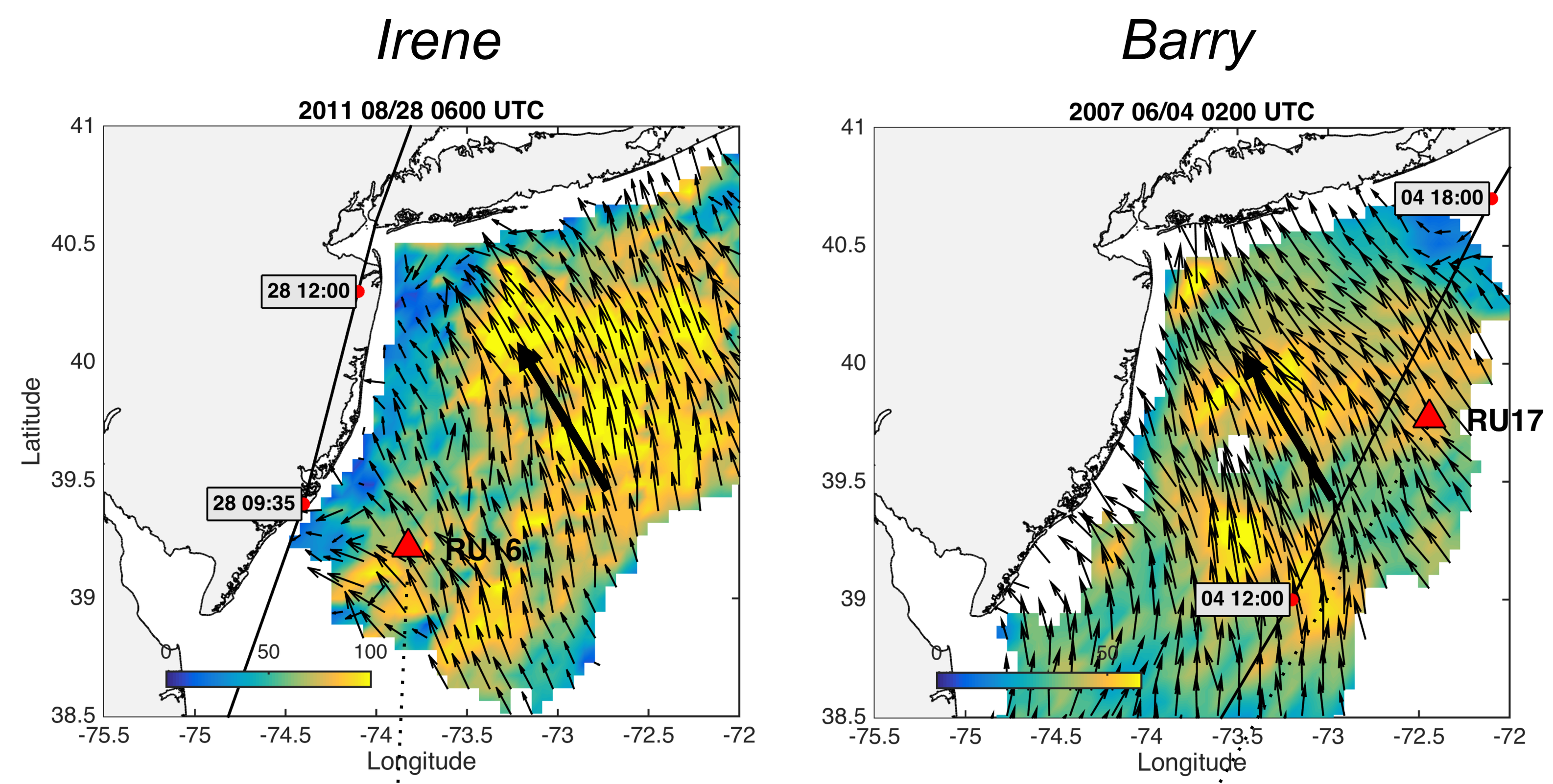


Fig 1. Strong onshore surface ocean currents due to easterly winds ahead of both Irene (left) and Barry (right) were observed by HF radar.

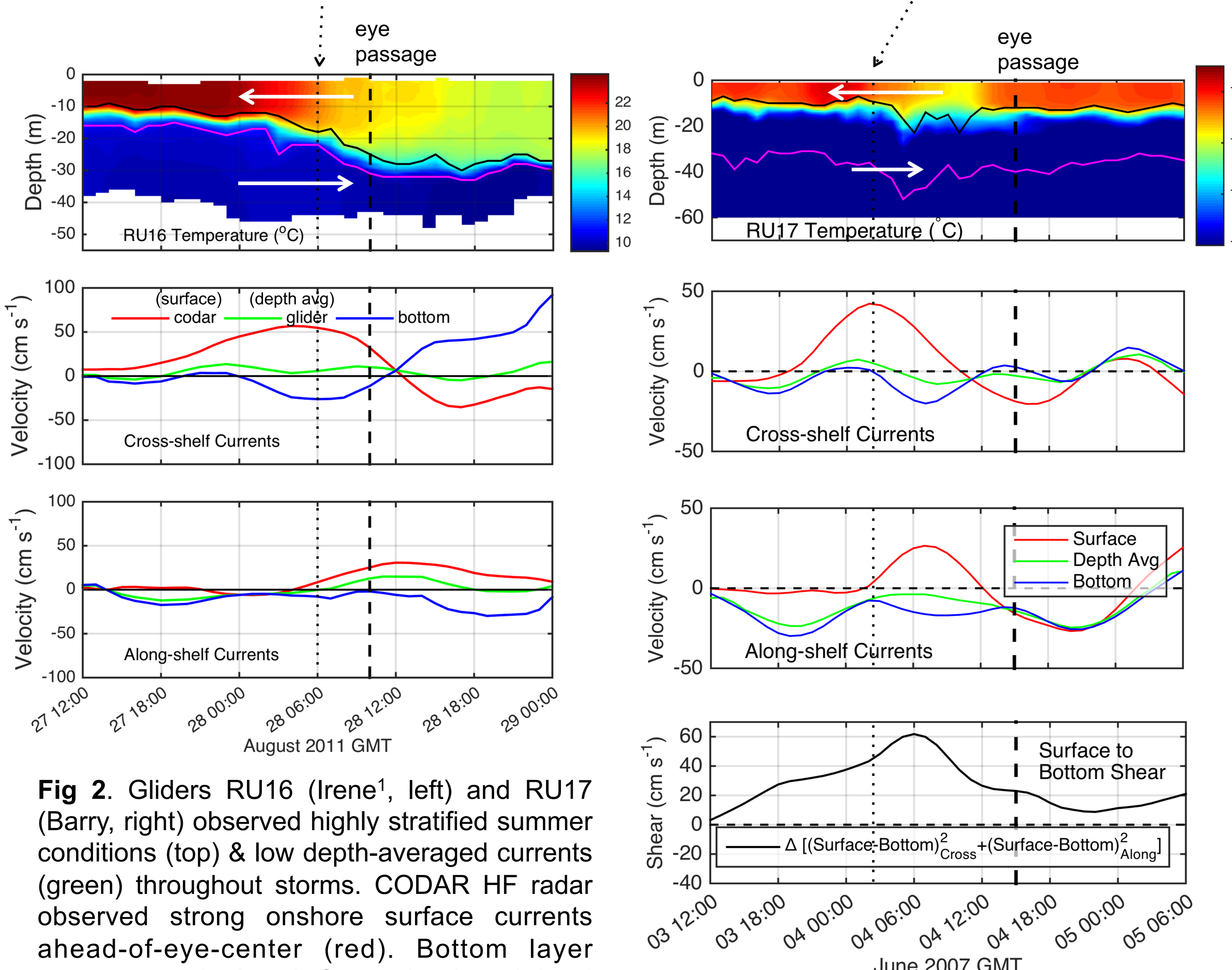


Fig 2. Gliders RU16 (Irene[1], left) and RU17 (Barry, right) observed highly stratified summer conditions (top) & low depth-averaged currents (green) throughout storms. CODAR HF radar observed strong onshore surface currents ahead-of-eye-center (red). Bottom layer currents, calculated from depth-weighted average of the HF radar and glider velocities, were offshore (Irene) and offshore & down-shelf (Barry) ahead-of-eye-center (blue). Irene's dominant depth-averaged momentum balance (not shown) was wind stress opposing pressure gradient (TBD for Barry).

Opposing surface and bottom currents enhanced shear-induced mixing across the thermocline (black) and cooled the surface waters ahead-of-eye-center in both storms. Mixing terms dominated advective terms in Irene's heat balance analysis (not shown, TBD for Barry).

2. Resultant ahead-of-eye-center cooling was present in Irene, Barry, 9 other U.S. Mid Atlantic storms, and Typhoon Muifa in the Yellow Sea.

- The coastal baroclinic processes identified here (Fig. 1-2) occur ahead-of-eye-center (AOEC) due to **onshore winds in front half of storms** that move northward along an eastern coast.
- Buoys show same AOEC cooling signal as gliders (Table 1): **on average, ~73% of in-storm cooling occurred AOEC.**

Storm Name	Buoy	Water Depth (m)	Ahead-of-Eye-Center Cooling (°C)	In-storm Cooling (°C)	% Ahead-of-Eye-Center
Arthur (2014)	44014	48	1.4	2.4	*58%*
Irene (2011)	44009	26	4.5	5.5	*82%*
Barry (2007)	ALSN6	29	5.1	5.1	*100%*
Hermine (2004)	44009	31	0.9	1.1	*82%*
Allison (2001)	CHLV2	14	2.3	2.6	*88%*
Bonnie (1998)	CHLV2	14	4.2	4.2	*100%*
Danny (1997)	44009	31	2.1	3.6	*58%*
Arthur (1996)	44009	31	2.3	3.5	*66%*
Emily (1993)	44014	48	2.3	2.8	*82%*
Bob (1991)	44025	41	2.1	4.6	*46%*
Charley (1986)	44009	31	2.7	5.4	*50%*
Average		**31**	**2.7**	**3.7**	***73%***
Std. Deviation		**11**	**1.3**	**1.4**	***19%***
Irene (2011)	RU16 WRF 1D Air-Sea Flux	37-46	0.0011	0.014	*8%*
	RU16 WRF 1D	37-46	1.0	3.3	*32%*
	RU16 WRF 3D PWP	37-46	5.2	9.2	*56%*
	RU16 Observed	37-46	5.1	6.7	*76%*
Irene (2011)	44065	25	3.8	4.2	*90%*
Irene (2011)	44100	26	6.3	6.4	*98%*
Muifa (2011)	37.045 N 122.66 E	31	4.1	4.8	*85%*

Irene WRF sensitivities show small % AOEC cooling for air-sea fluxes, 1D mixing, and 3D deep ocean processes as compared to observed 76%

Table 1. AOEC cooling (°C), in-storm cooling (°C), and % AOEC cooling observed at nearshore MAB buoys for 11 tropical cyclones that traversed the MAB continental shelf during summer stratified conditions (June-Aug) since 1985[1].

- Satellite maps show **unique cooling patterns for each storm** (Fig 3). Irene: large area of >5°C, up to 11°C. Barry: warming south, cooling north.

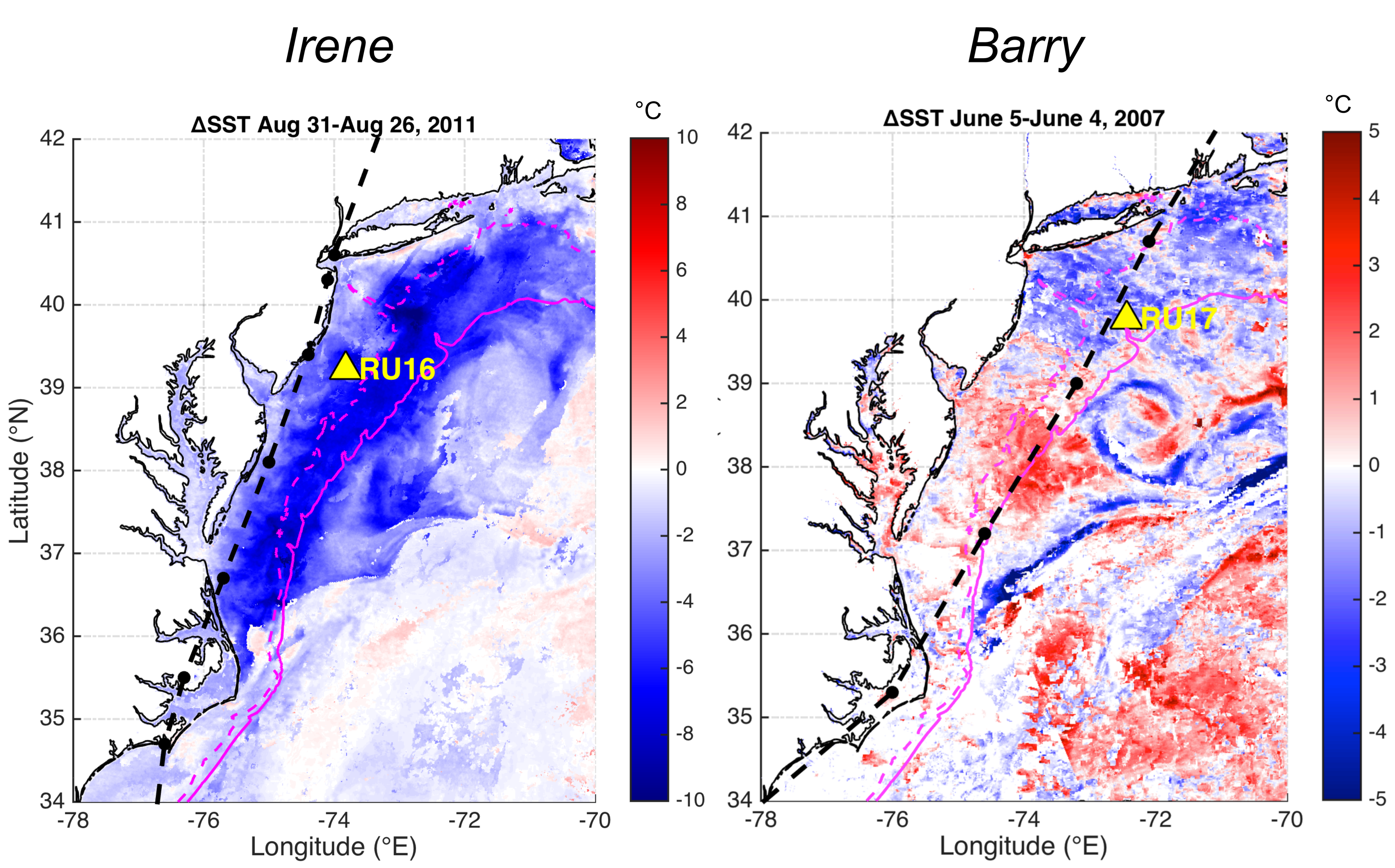


Fig 3. Satellite maps of cooling for Irene[1] and Barry, obtained by differencing pre- and post-storm SST composites. Note uniform cooling for Irene and more complex cooling/warming patterns for Barry.

3. Cooling has large impact on storm intensity and should be included in TC forecast models.

- >140 Irene WRF simulations (Fig. 4) show **largest sensitivity to AOEC cooling** (fixed pre-storm vs. fixed post-storm SST, as in Fig. 3).

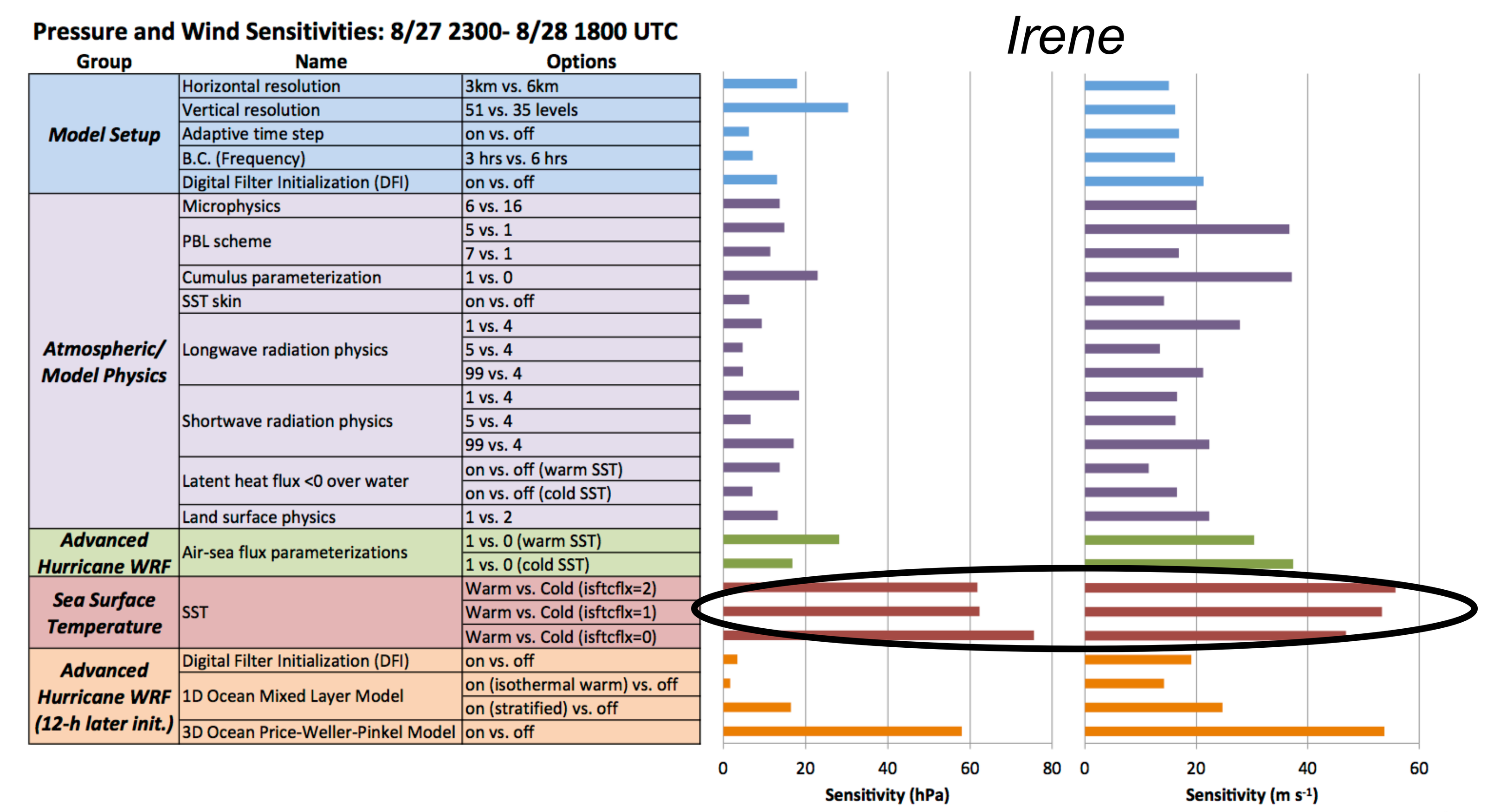
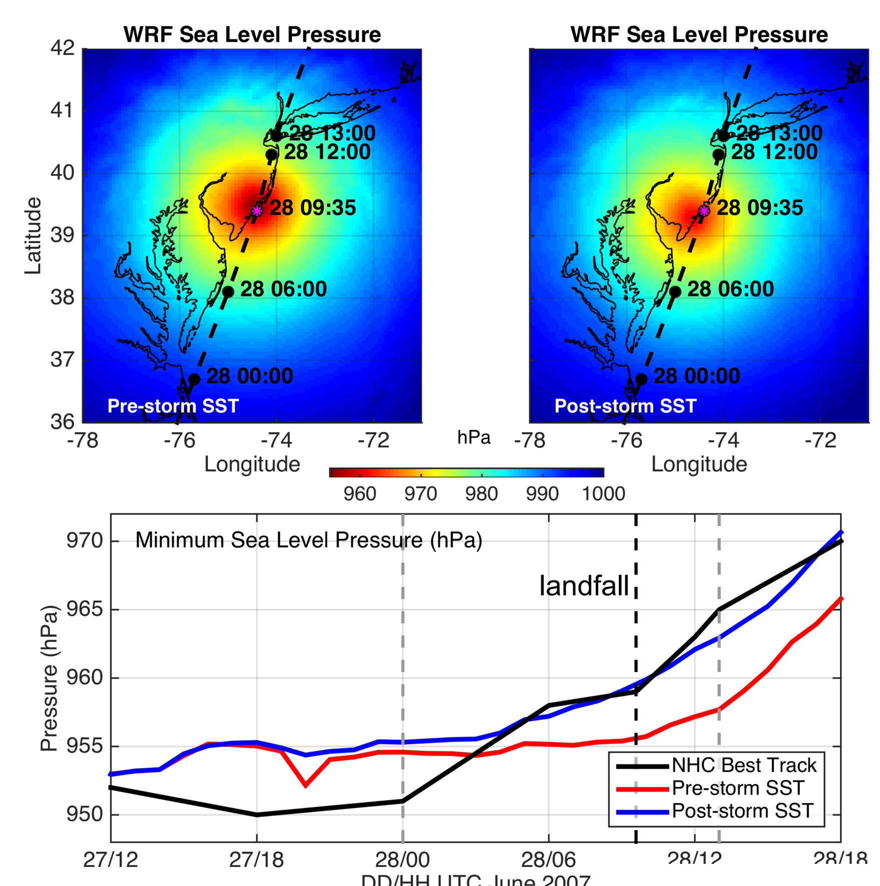
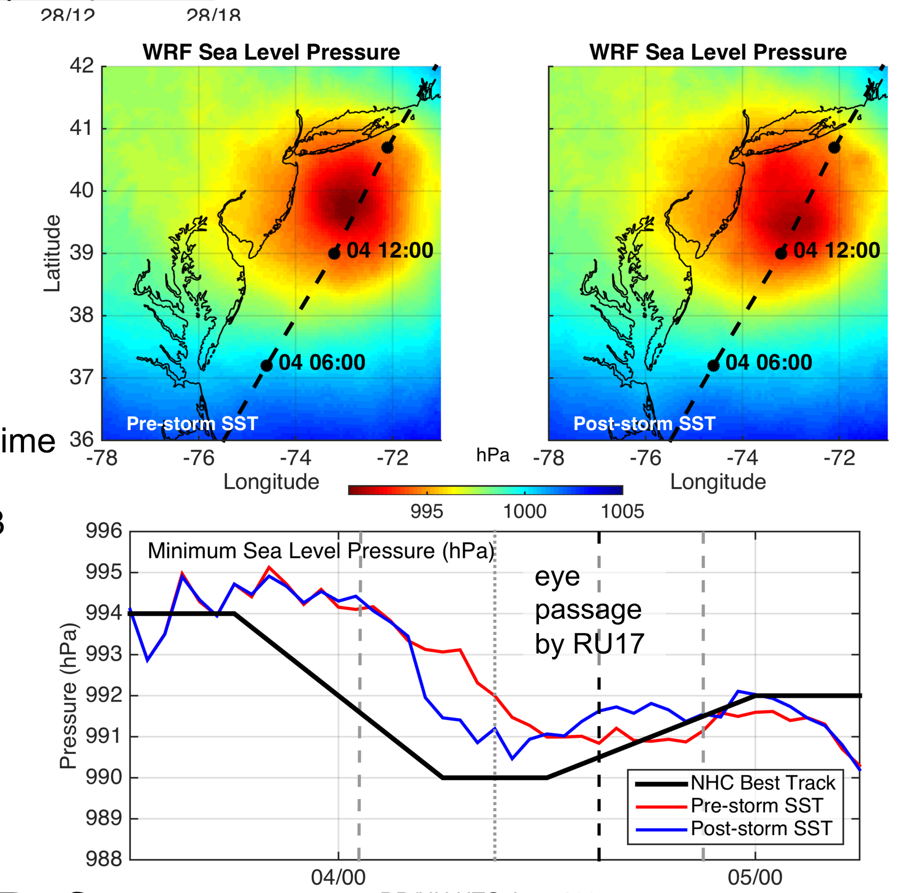


Fig 4. Irene WRF cumulative sensitivity results in both min sea level pressure (SLP) & max 10m wind.[2]



Irene

Fig 5. Irene WRF landfall SLP maps for pre-storm and post-storm SST simulations, and SLP time-series comparison to NHC Best Track.[1]



Barry

Fig 6. Same as Fig. 5 but for Barry at time of eye passage by RU17. Note that for Barry, more simplified SSTs than Fig. 3 were used for WRF simulations.

References

[1]Glenn, S. M. *et al.* Stratified coastal ocean interactions with tropical cyclones. *Nat. Commun.* 7:10887 doi: 10.1038/ncomms10887 (2016).

[2]Seroka, G. N. *et al.* Hurricane Irene Sensitivity to Stratified Coastal Ocean Cooling, *Mon. Wea. Rev., In Review* (2016).

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