Impact of Typhoons on the Western Pacific:
Temporal and horizontal variability of SST cooling
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Long-term Goals/Scientific Background

The long term goal of this research has been to understand those aspects of 1) the ocean's **response** to a tropical cyclone (TC) that impact TC/ocean interaction, and 2) the **relaxation** (or recovery) following a TC passage. This project is now more than a full year past the end of the nominal grant period (plus extension).

The ocean **response** study has sought the development of a physically-based metric of the upper ocean thermal field, dubbed T_{100}, that accounts for the TC-relevant spatial variation of upper ocean temperature gradient, initial mixed-layer depth, etc., that contribute to hurricane-ocean interaction. With this metric and improved understanding we should be in position to make better forecasts of hurricane-ocean interaction, and especially of hurricane intensity (Emanuel et al., 2004; Lin et al., 2013).

This report will emphasize the **relaxation** process of the upper ocean and especially SST. The relaxation of SST can be quite rapid, with a cool anomaly e-folding in a week being fairly typical. What process(es) cause the cool SST in a TC wake to relax back toward warm and quasi-homogeneous pre-TC conditions?

Objectives

A specific objective of ITOP-related research is to test a simple model of the SST relaxation process that was developed during the planning for ITOP (Price, Morzel and Niiler, 2008; PMN08). This model is built around two hypotheses: H1) SST warming of a cool wake is a local process driven by an anomalous air-sea heat flux (anomalous compared to regions outside the cool wake), and the key insight, H2) the trapping depth of this anomalous heat flux is set by the process of diurnal cycling. During instances of fair weather, which often follow TCs, this can result in thin, warm surface layers, O(10 m) being typical.

The two-part hypothesis, combined with a heat budget, leads to a simple solution for the e-folding time of the SST cool anomaly (i.e., the cool wake caused by vertical mixing),

$$\Gamma = C_1 \frac{\tau}{\lambda Q_n^{1/2}}$$

where τ is the wind stress magnitude, λ is known from air-sea transfer formula and is proportional to the anomalous heat flux associated with the cool SST anomaly, and Q_n is the amplitude of the diurnal maximum of the air-sea heat flux. The leading constant, $C_1 = 2.7 \times 10^{10}$ kg$^{1/2}$ m sec$^{-3/2}$ C^{-1} is a product of known thermodynamic constants, a factor involving the latitude, and the drag coefficient. There are no free constants.

Approach

The ITOP field phase observed several remarkable examples of cool wake evolution with far greater detail of *in situ* ocean data than has ever been available before. In particular, the shipboard meteorological data and CTD data acquired by R/V Revelle during a cruise run soon after the passage of Typhoon Fanapi (Chief Scientist Steven Jayne, WHOI, who is collaborating on this research) allow a high quality estimate of the surface heat flux and wind speed required to evaluate the PMN08 wake warming model. The very extensive in situ data acquired from the ITOP field program allow a direct estimate of the trapping depth of the surface warm layer.

Work Completed/Results

The estimated e-folding time of the Fanapi SST cool wake, based upon satellite imagery and in situ data, was about 7 days during the first ten days after Fanapis passage, a period of light winds and fairly strong solar insolation. A CTD section made six days after the passage of Fanapi (Fig. 1) shows that the warming was then trapped within the upper 5 - 15 m of the water column, consistent with H2. Even more striking, the heat content anomaly (Fig. 2) was clearly associated with the cool wake amplitude, consistent with H1. These two observations taken together are strong evidence that the initial warming of SST following Fanapai was due largely to air-sea interaction, i.e., warming by anomalous surface heat fluxes. A direct comparison with the PMN08 model solution is somewhat encouraging for that model, though not

highly precise (Fig. 3).

Impact/Applications

Response   The new ocean thermal field metric referred to in the opening section, T_{100}, has been taken up for operational testing by a number of forecast groups including the East Asian Sea Forecasting System of NRL (Dong-Shan Ko and colleagues), the University of Miami hurricane modeling group (S. Chen and colleagues), by the National Taiwan University remote sensing laboratory (I-I Lin and colleagues). As noted in Lin et al. (2013), it shows considerable promise as a way to represent the ocean within a TC forecast system.

Recovery   The SST e-folding model gives some valuable physical insight into the process of SST recovery. The recovery process is one that will be in common with modern, highly resolved ocean forcecast systems, i.e., NRLs COAMPS (Shouping Wang, personal communication). The practical value is that it shows how the recovery process is likely to yield an anomalous thermal profile; compared to nominal conditions, a warm shallow layer at ambient SST, a cool relic mixed layer, and a warm anomaly in the seasonal thermocline. It also shows explicit parameter dependence, e.g., a sensitive dependence upon wind speed with greater wind speed causing longer e-folding times.

Collaborations

The PI enjoys ongoing collaborations with Dr. Tom Sanford, APL/UW (Sanford et al., 2010), Prof. Shuyi Chen of RSMAS Universitry of Miami, Prof. I-I Lin of National Taiwan University and Dr. Iam-Fei Pun, also of National Taiwan University.

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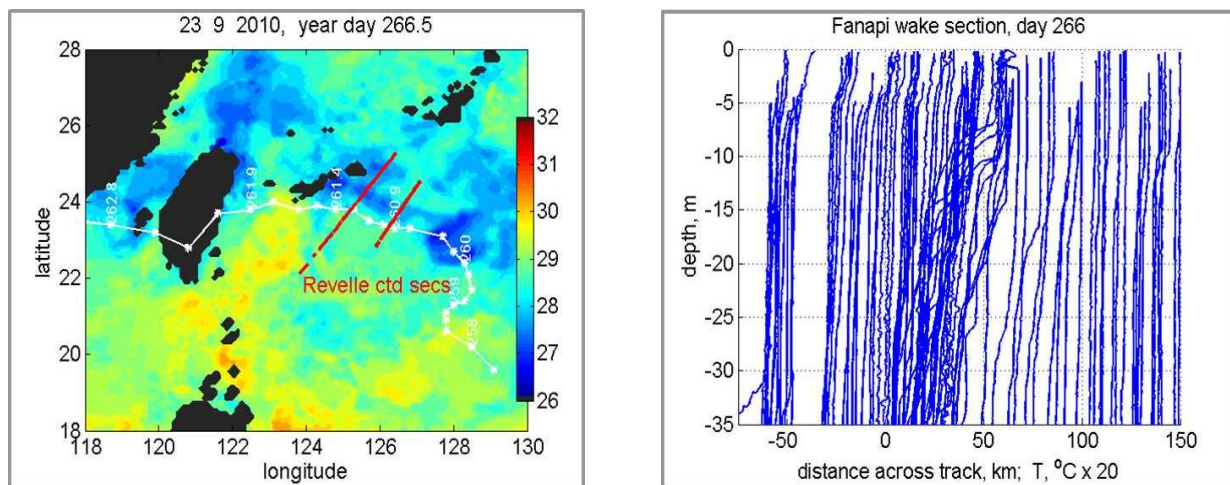
Figures

Figure 1: (left) An SST image of the western North Pacific and the track of typhoon Fanapi. The R/V Revelle ran two CTD sections across the track and the cool wake on days 264 and 266, six days after the passage of Fanapi. (right) Temperature profiles across the track on day 266. The cool wake occupied the middle third of this section centered on across track distance = 50 km. Note the thin, warm surface layer found above the cool wake.
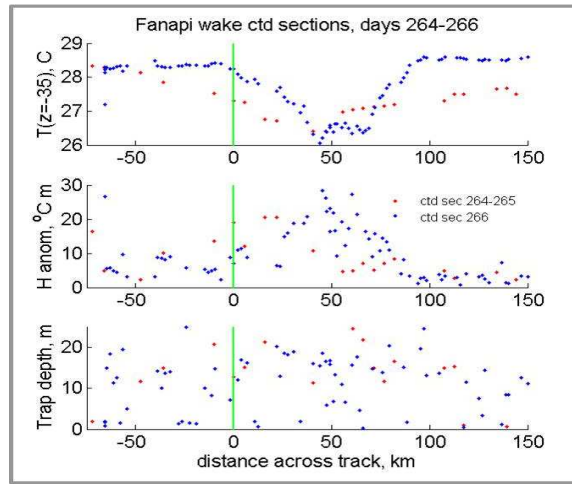
Figure 2: Temperature profile properties from the ctd sections across the track of Fanapi. (upper) The 35 m temperature on 264 and 266 (red and blue dots). The cool wake is clearly evident as the cool anomaly centered about 50 km to the right of the track, marked by the vertical green line. (middle) The heat content anomaly with respect to 35 m depth. Notice that the anomaly is very clearly associated with the cool wake. This is consistent with H1 of the PMN08 model. (lower) The trapping depth (heat content anomaly divided by the surface temperature anomaly). This depth shows quite a lot of variability, about 5 to 15 m over the coolest part of the wake, and roughly consistent with the expectations of diurnal cycle variability.
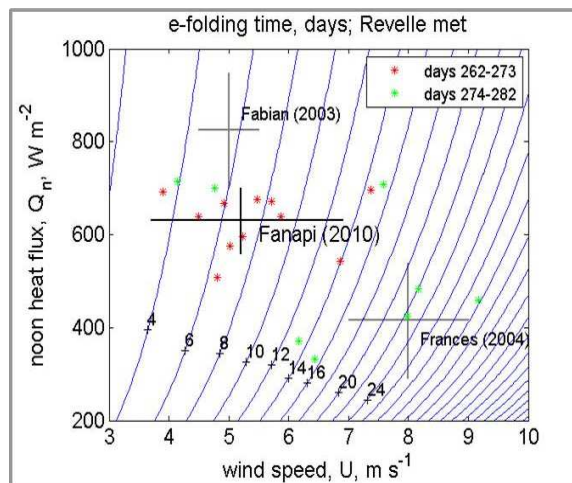

Figure 3: The hypotheses H1 plus H2 combined with a heat budget leads to the PMN08 solution for the e-folding time of an SST cool anomaly, the contour lines labeled in days, and which is a function of wind speed and noon heat flux. The estimated e-folding time for Fanapis cool wake SST was about one week. The PMN08 model evaluated for the first ten days following Fanapi gives the red dots, which are reasonably consistent with the initial, observed e-folding of the Fanapi cool wake. The next ten days were characterized by unsettled weather — greater cloud cover and higher though still moderate winds — and yield the green dots, most of which indicate much slower (or no) SST warming, consistent with in situ observations.