Sea Surface Temperature Response to Tropical Cyclones

names of project members

Cheng Shukui

Cao Anzhou

Purposes

Tropical Cyclones (TCs) are the most power weather event happening over tropical and subtropical oceans. Each year, TCs cause significant damage to coastal areas due to massive waves, strong winds, heavy rainfall, and other natural disasters, particularly in the Northwest Pacific Ocean, where they are both the strongest and most frequent worldwide.

TCs can cause sea surface temperature cooling (SSTC). Because the formation and maintenance of a TC rely on the continuous transport of vapor and heat from the upper ocean to the atmosphere, TC-induced SSTC also limits its intensity (Schade and Emanuel, 1999). Therefore, sea surface temperature response to TC is an indicator of the intensity of ocean's response to TC and is also a factor in the evolution of TC.

The purposes of the study are to study the TC-induced SSTC process in different Ocean conditions, and investigate the influence of ocean stratification on SSTC .

Methods

Using the Coastal and Regional Ocean Community model (CROCO; https://www.croco-ocean.org), we simulate the ocean's response to TC under various conditions. Given that the average temperature in the mixed layer is essentially equivalent to SST, according to the temperature budget in the mixed layer (Jullien et al., 2012), we can calculate the SST variation as follows:

$$\frac{\partial SST}{\partial t} = -\frac{1}{h}\int_{-h}^{0}\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)dz - \frac{1}{h}\int_{-h}^{0} w\frac{\partial T}{\partial z}dz + \frac{1}{h}\int_{-h}^{0} K_l\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)dz + \left[-K_z\frac{1}{h}\frac{\partial T}{\partial z}(z=-h) - \frac{SST-T(z=-h)}{h}\frac{\partial h}{\partial t}\right] + \frac{Q}{\rho C_p h} \qquad (1)$$

where T is the temperature, t is the time, x and y are zonal and meridional coordinates, z is the depth, u, v, and w are the zonal, meridional, and vertical velocities, respectively, K_l and K_z are horizontal and vertical mixing coefficients, respectively, and they are dependent on shear. Q is net heat flux, ρ is density, C_p is specific heat capacity, and h is time-varying mixed layer depth (MLD). The five terms on the right-hand-side of Equation (1) represent the horizontal advection (Hadv), vertical advection (Vadv), horizontal mixing (Hmix), vertical mixing (Vmix) and heat flux, respectively.

Results

Megi (2010) in October and Linfa (2015) in July are two TCs with similar tracks passing over the SCS Basin from south to north. In our study regions, Megi's maximum wind speed is 50 m/s and Linfa's maximum wind speed is 20-30 m/s. The wind power input (WPI) to near-inertial motions is an important source of near-inertial energy in the ocean. Though Linfa's WPI is one order of magnitude smaller than Megi's (Figure 1), Linfa induced a SSTC about 4.12℃ , which is quite large and is even comparable to that induced by Megi (5.09 ℃) (Figure 2). Through numerical simulation experiments, we reproduce the SSTC processes of the two TCs, and focused on the reason why Linfa can cause such strong SSTC

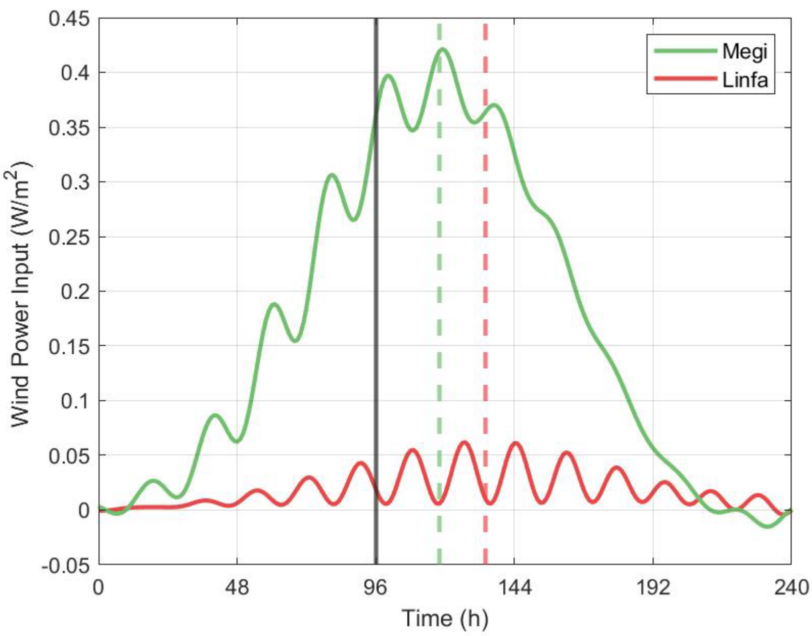

Figure 1 WPI of Linfa and Megi.

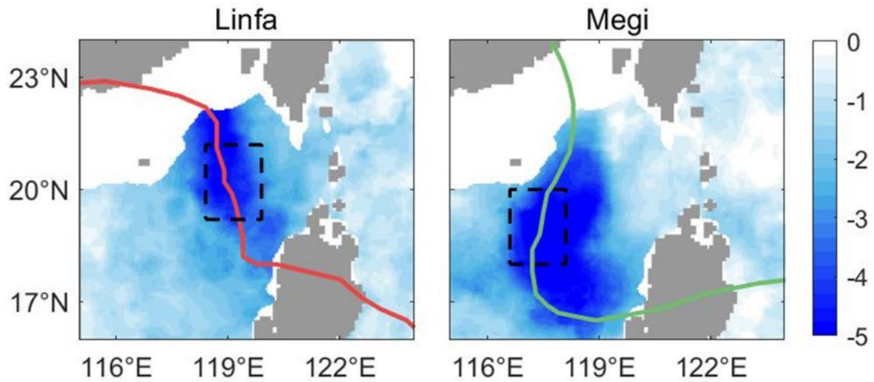

Figure 2 The tracks and SSTC induced by Linfa and Megi.

Analysis of equation (1) indicates that reason why Linfa can cause SSTC comparable to Megi with much weaker intensity is that Vmix of Linfa is similar to that of Megi (Figure 3). According to Equation (1), Vmix is determined by the vertical temperature gradient (*∂T/∂z*), vertical mixing coefficient (Kz), the MLD (*h*), and its variation (*∂h/∂t*):

$$Vmix = -K_z \frac{1}{h}\frac{\partial T}{\partial z}(z=-h) - \frac{SST - T(z=-h)}{h}\frac{\partial h}{\partial t} \tag{2}$$

The first term on the right-hand side of Equation (6) is vertical diffusion at the MLD, and the second term is entrainment (Vincent et al., 2012a; Jullien et al., 2012). As shown in Figure 4, the vertical temperature gradient divided by MLD during Linfa is larger than that during Megi, and the vertical mixing coefficient during Linfa is about one-third that of Megi. The former is due to the ocean stratification of shallower mixed layer and higher SST during Linfa (July) than that during Megi (October).

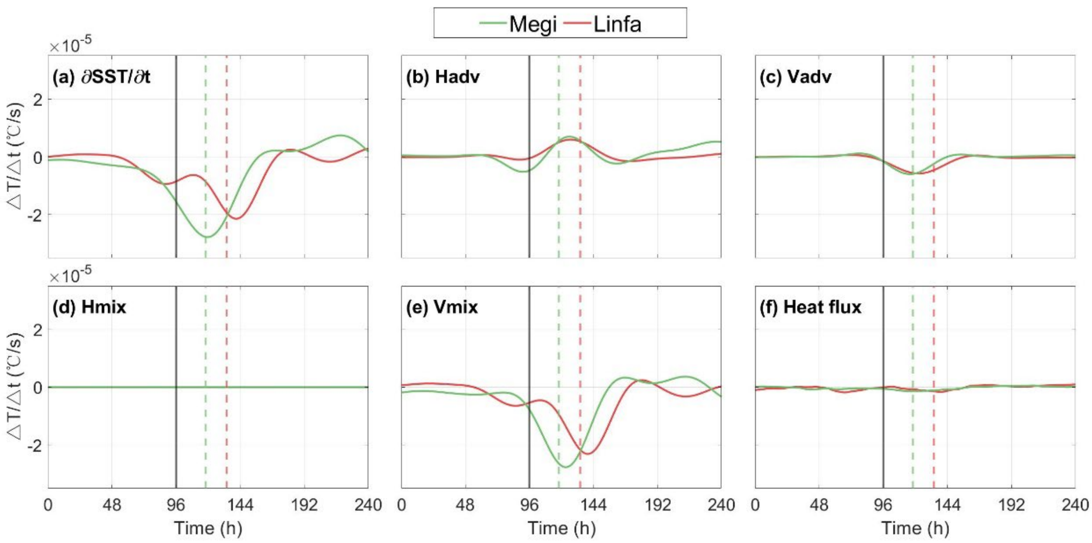

Figure 3 (a) Derivative of SST with respect to time and the contributions of (b) Hadv, (c) Vadv, (d) Hmix, (e) Vmix, and (f) heat flux for Megi (green) and Linfa (red) averaged in the study regions.

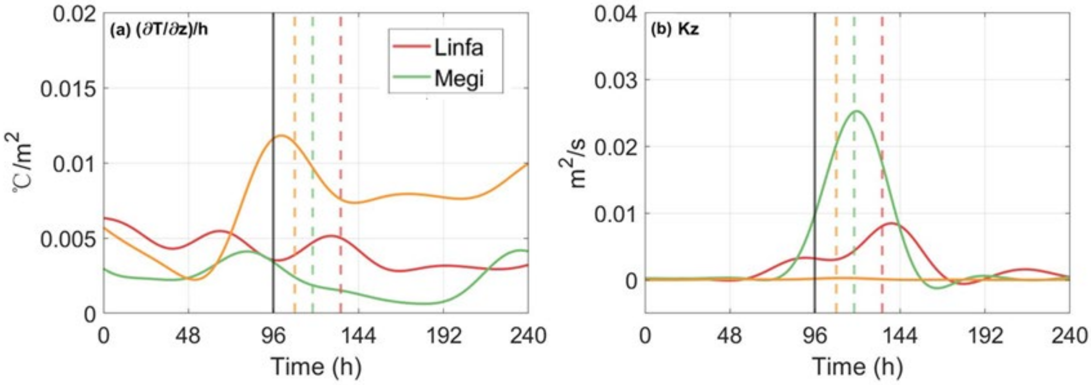

Figure 4 (a) Vertical temperature divided by MLD and (b) vertical mixing coefficient during Linfa and Megi

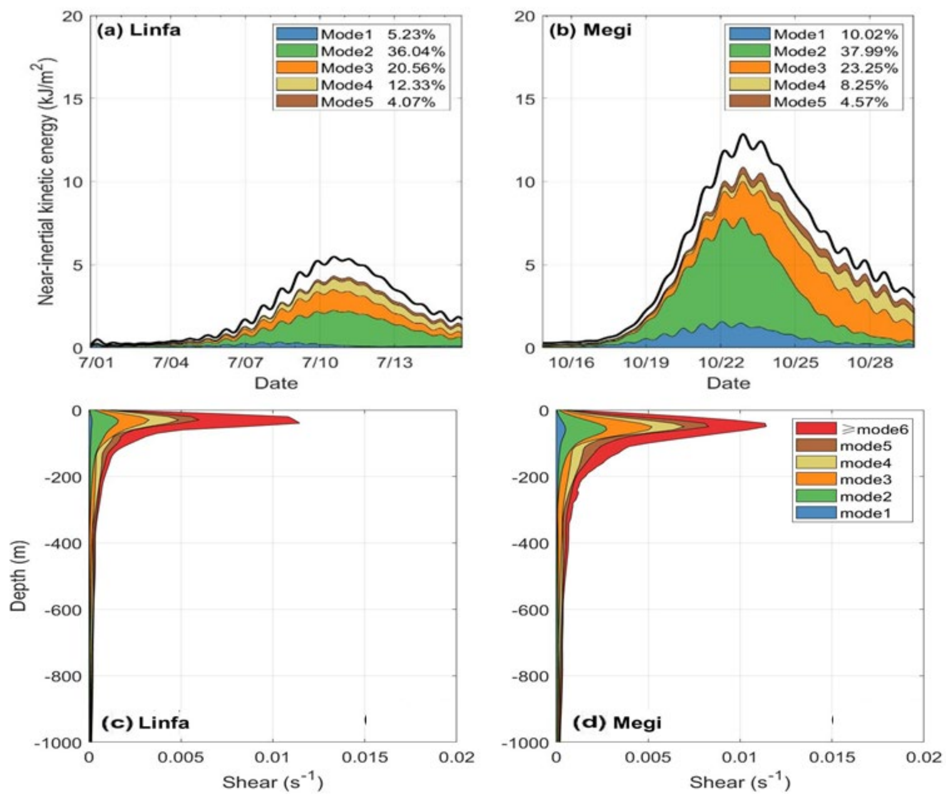

Figure 5 Near-inertial kinetic energy during (a) Linfa and (b) Megi in different mode, and near-inertial vertical shear during (c) Linfa and (d) Megi

Because Linfa's WPI is much smaller than Megi's, the vertical mixing coefficient during Linfa reaches one-third that of Megi is unexpected. This is because the ocean stratification results in larger proportion of high-mode NIWs during Linfa than that during Megi, and higher-mode NIWs contribute more to upper ocean vertical shear (Alford et al., 2016，Cao et al.,). Therefore, Linfa induces relatively strong near-inertial shear with relatively weak near-inertial kinetic energy.

Future challenges

In addition to ocean stratification, many other ocean conditions also influence sea surface temperature response to TC. These factors and their interactions processed still need further researches.

Reference

Schade, L. R., and K. A. Emanuel (1999), The Ocean's Effect on the Intensity of Tropical Cyclones: Results from a Simple Coupled Atmosphere–Ocean Model. J ATMOS SCI, 56(4), 642-651.

Jullien, S., et al. (2012), Impact of Tropical Cyclones on the Heat Budget of the South Pacific Ocean. J PHYS OCEANOGR, 42, 1882-1906.

Vincent, E. M., et al. (2012), Processes setting the characteristics of sea surface cooling induced by tropical cyclones. J Geophys Res: Oceans 117(C2).

Cao, A., et al. (2023), Modal content of typhoon-induced near-inertial waves around the East China Sea, CONT SHELF RES, 264, 105055.

Cheng, S., et al. (2023), Numerical study on the influence of internal tides on tropical-cyclone-induced sea surface temperature cooling in the South China Sea. OCEAN DYNAM, 73(7), 449-461.

Alford, M. H., et al. (2016), Near-Inertial Internal Gravity Waves in the Ocean. Annual Review of Marine Science, 8(Volume 8, 2016), 95-123.