2nd International Workshop on Waves, Storm Surges, and Coastal Hazards
16th International Workshop on Wave Hindcasting and Forecasting
Melbourne, November 2019

# Revised parameterization of wave induced turbulent kinetic energy for upper ocean surface mixing

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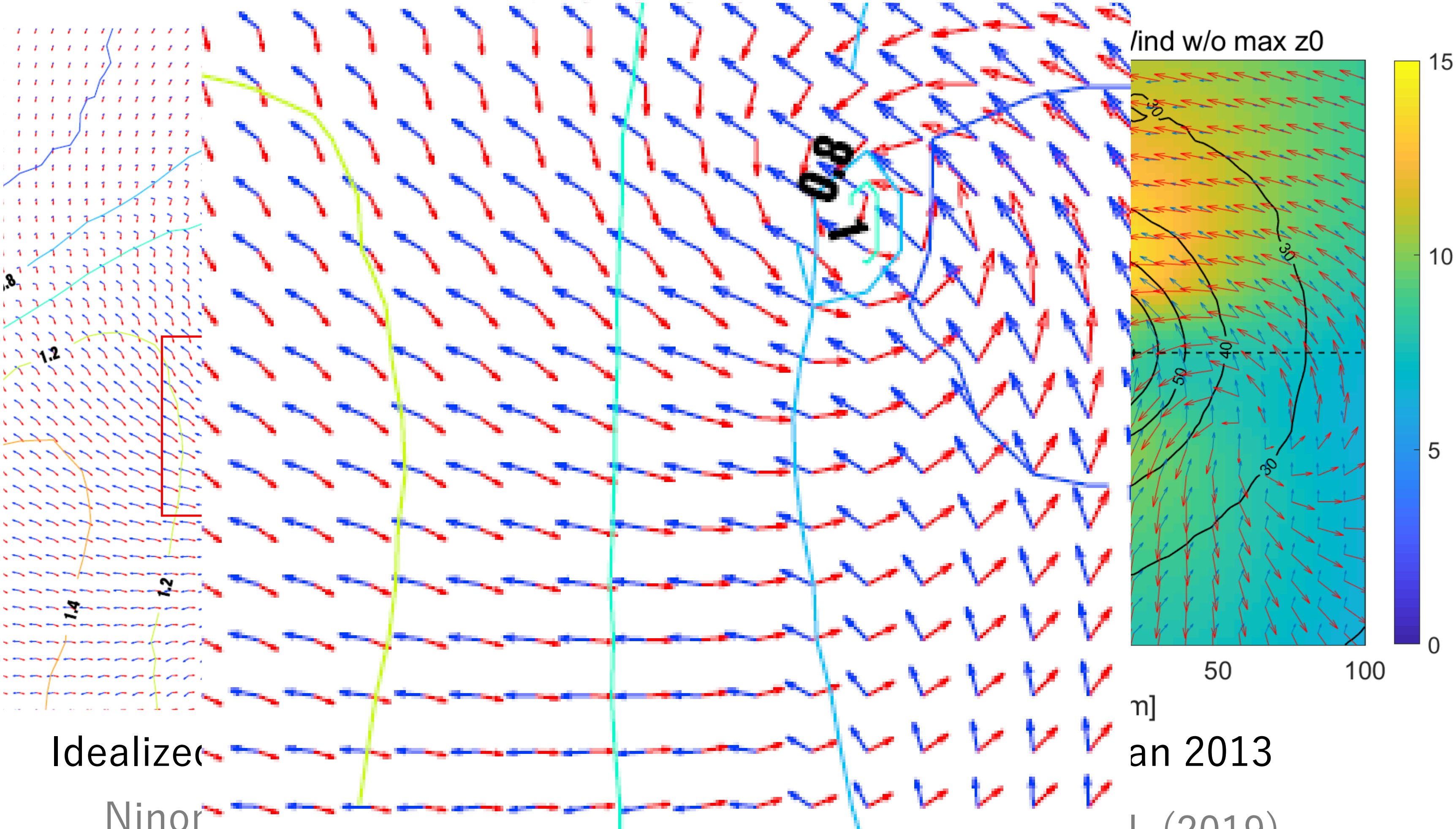
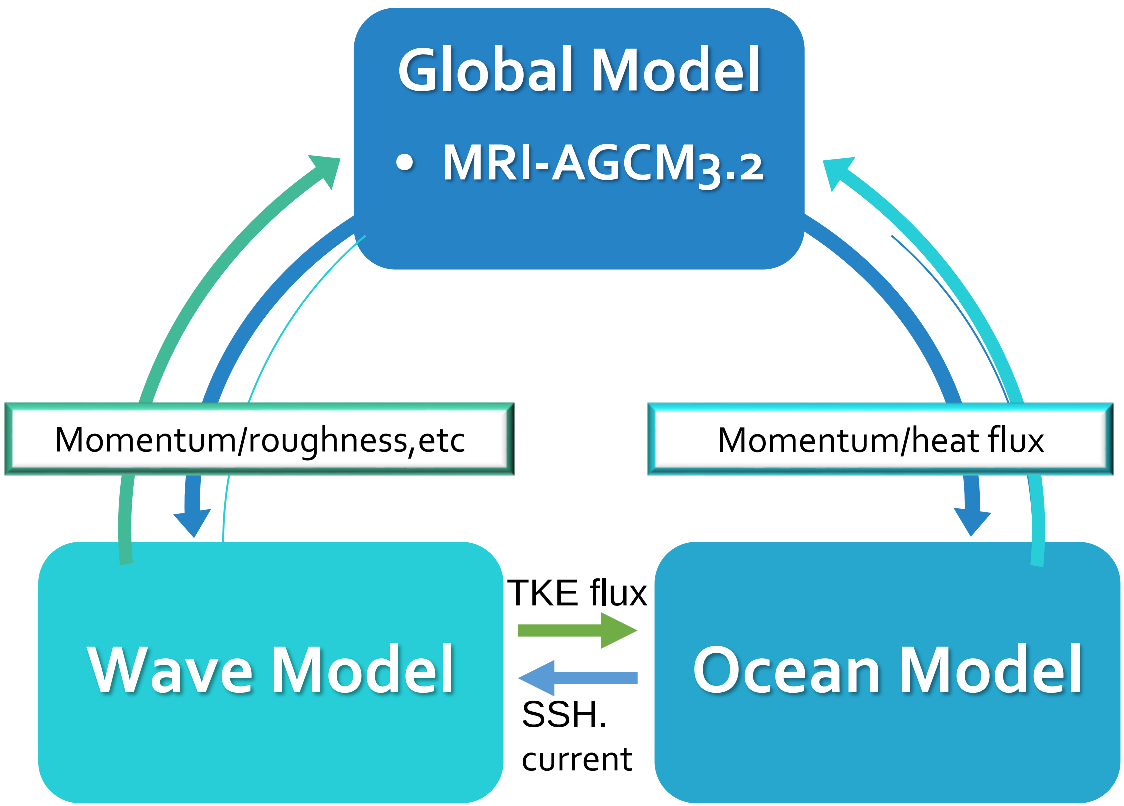
# Wind and wave direction are not same

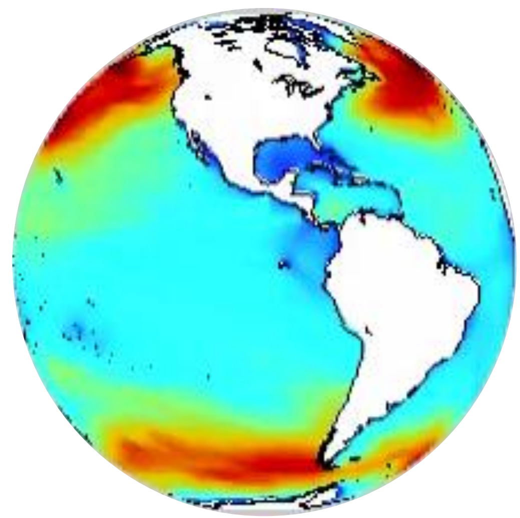



Idealize… …an 2013

Ninor… …Ninomiya et al. (2019)

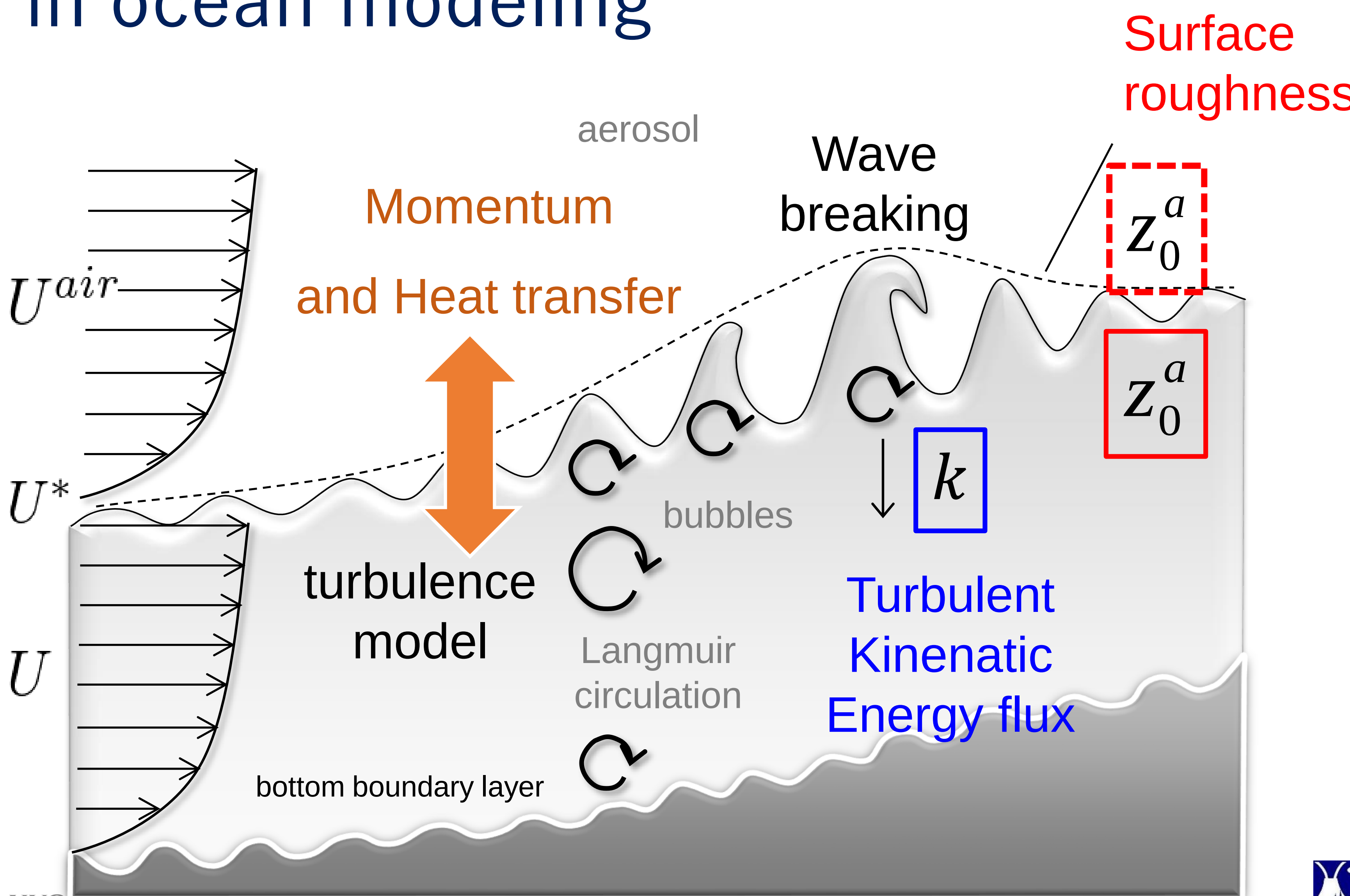
# Wave information is important for coupling models



Coupling model development
ECMWF, NOAA, JMA, CSIRO, Helmholtz-Zentrum Geesthacht and ETC

# Role of air-sea interaction in ocean modeling

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# Wave breaking induced TKE

- 1-D equation for turbulent kinetic energy(TKE) with k-ε model is assumed to be used

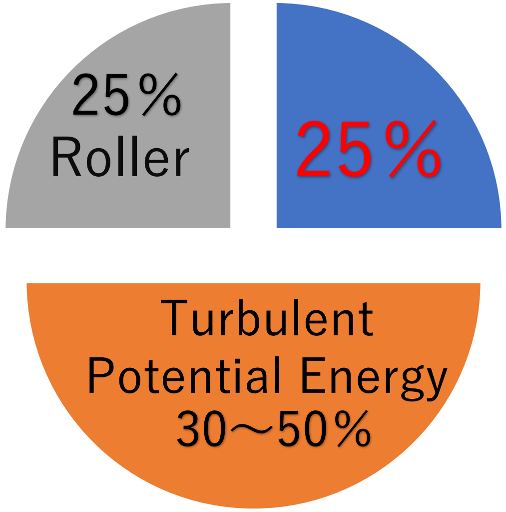
$$\frac{\partial k}{\partial t} = \frac{\partial}{\partial z}\left(\frac{K_v}{\sigma_k}\frac{\partial k}{\partial z}\right) + K_v S^2 - \varepsilon$$

- Boundary condition at MWL is needed to supply $k$
- Feddersen and Trowbridge (2005)

$$\frac{K_v}{\sigma_k}\frac{\partial k}{\partial z} = \alpha\overline{\varepsilon_w} \quad at\, z=0$$

where $\alpha = 1/4$

- Feddersen and Trowbridge (2005) for shallow water breaking study
  - 1/4 of wave breaking dissipation will be used for TKE



# Bulk Formula of Turbulent Kinetic Energy (TKE) flux at water surface

1. Zero

$$K_k \frac{\partial k}{\partial z} = 0$$

2. Craig and Banner (CB) (1994)

$$K_k \frac{\partial k}{\partial z} = \alpha_{CB} u_*^3 \qquad \alpha_{CB} = 100$$

3. Feddersen and Trowbridge (2005)

$$K_k \frac{\partial k}{\partial z} = \alpha_{wdiss} \epsilon_{wdiss} \quad \alpha_{wdiss} = 0.25$$

# Shirahama Tower Kyoto University

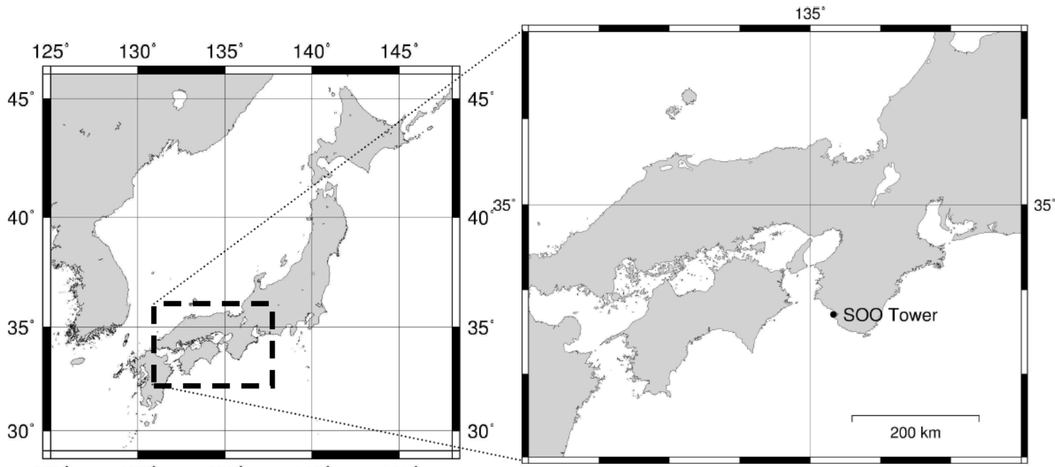
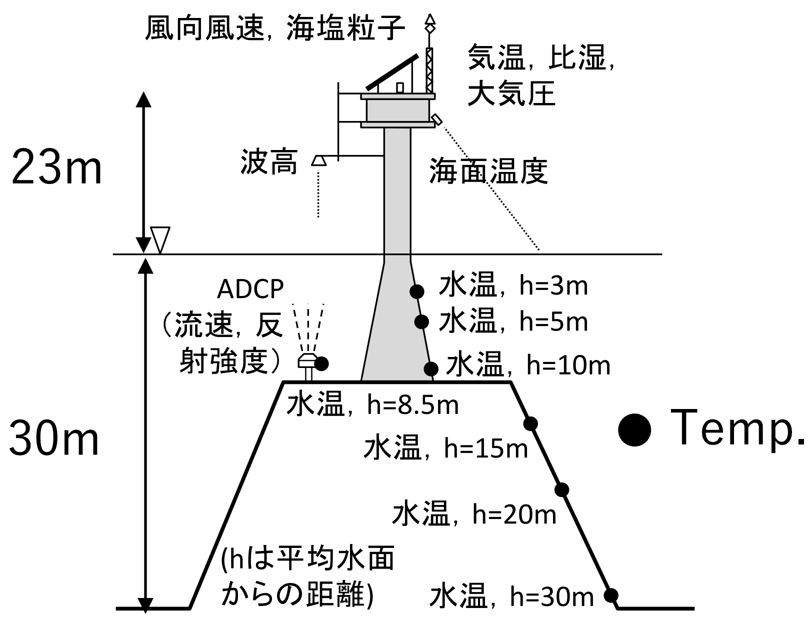
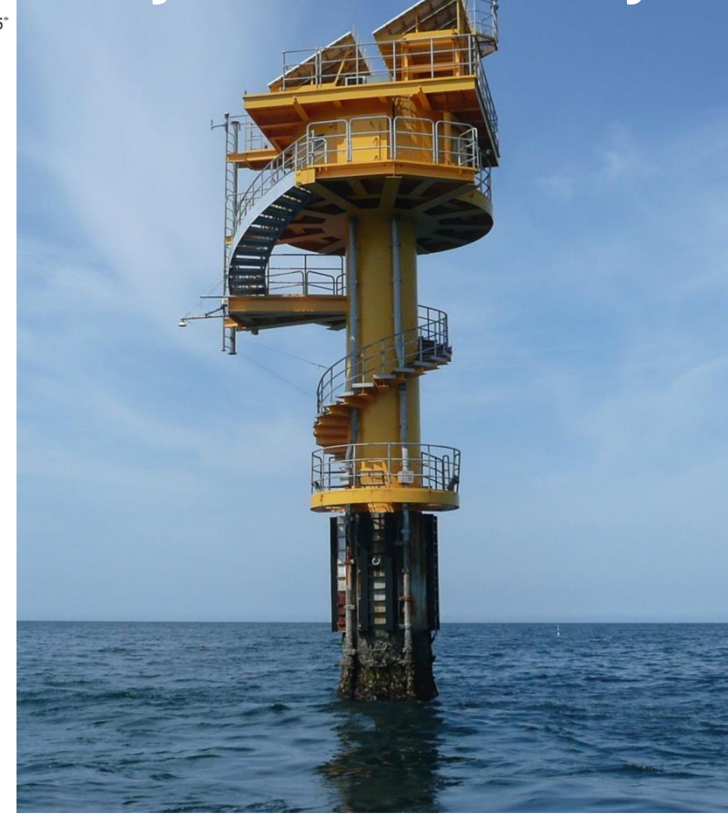
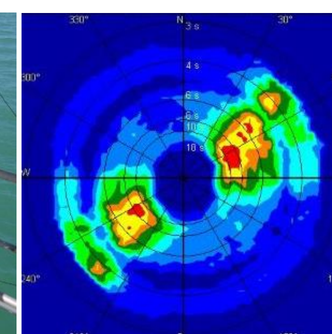



**Figure 1** Shirahama Oceanographic Observatory





Field experiments for typhoons since 2009

# Flow of revising parameterization

Wind speed, direction

Observed data
- Currents

Turbulent components ($u'$)

TKE k

Vertical gradient of TKE $\partial k/\partial z$

Observed data
- Currents

Dissipation ($\varepsilon$)
- Osborn (1980)

$K_v = C_\mu^4 \frac{k^2}{\varepsilon}$

Eddy Viscosity $K_v$

Observed data
- Surface elevation

Wave spectrum

Komen (1984)

Wave dissipation

TKE transport fraction $\alpha$

# Optimization of TKE flux

- Turbulent kinetic energy(TKE)
  - Defining turbulence

$$u_i' = u_i - \bar{u}_i$$

$u_i$: raw current velocity(5 minutes averaged data)

$\bar{u}_i$: mean current velocity (20 minutes averaged data)

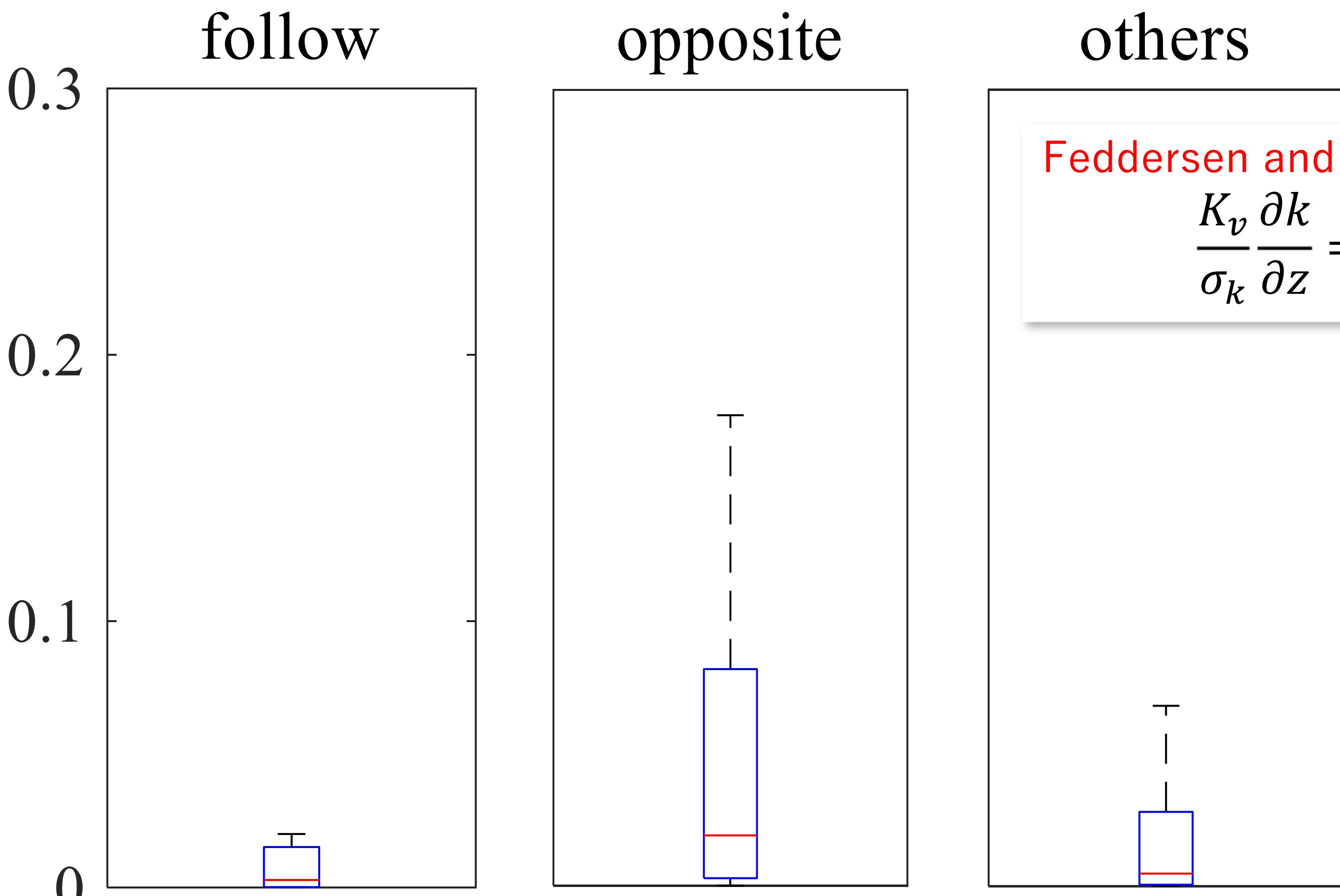
$u_i'$: turbulence velocity

  - Estimation of TKE($k$)

$$k = \sum_i \frac{\overline{u_i'^2}}{2}$$

  - If the vertical gradient of TKE on sea surface is negative value, the data is removed as abnormal data

# Result of tuning parameter $\alpha$




Feddersen and Trowbridge

$$\frac{K_v}{\sigma_k}\frac{\partial k}{\partial z} = \alpha\overline{\varepsilon_w}$$

follow<others<opposite

In case “follow”, the correlation coefficient between **the inverse number of wave steepness** and $\alpha$ is 0.45

-->weak dependency on wave steepness

# Impact of wave-induced turbulence on tropical cyclone(TC)

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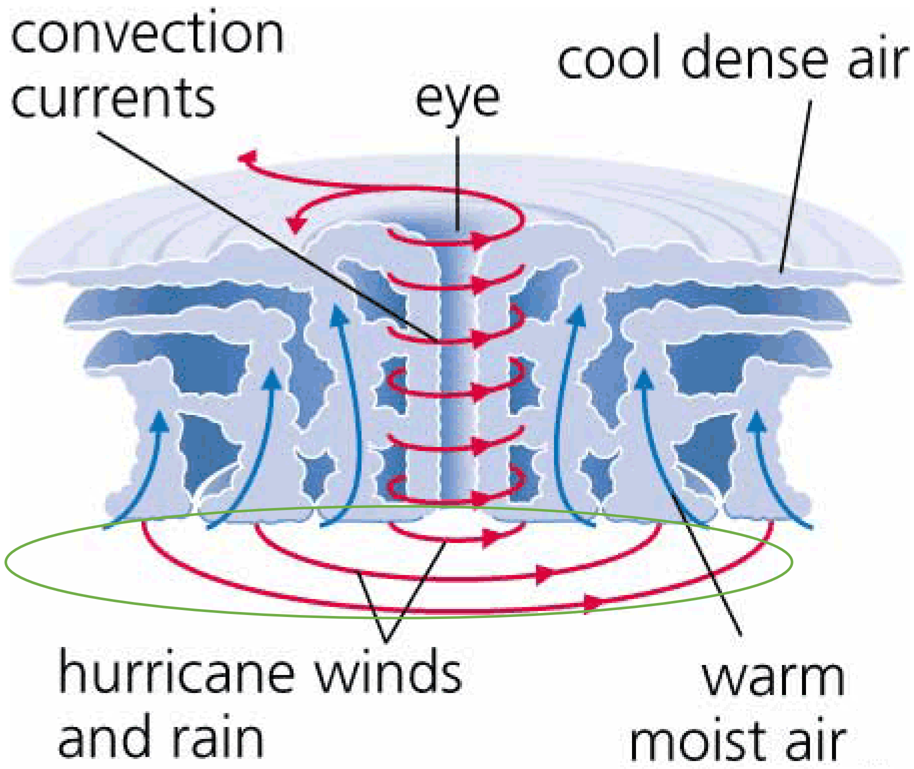
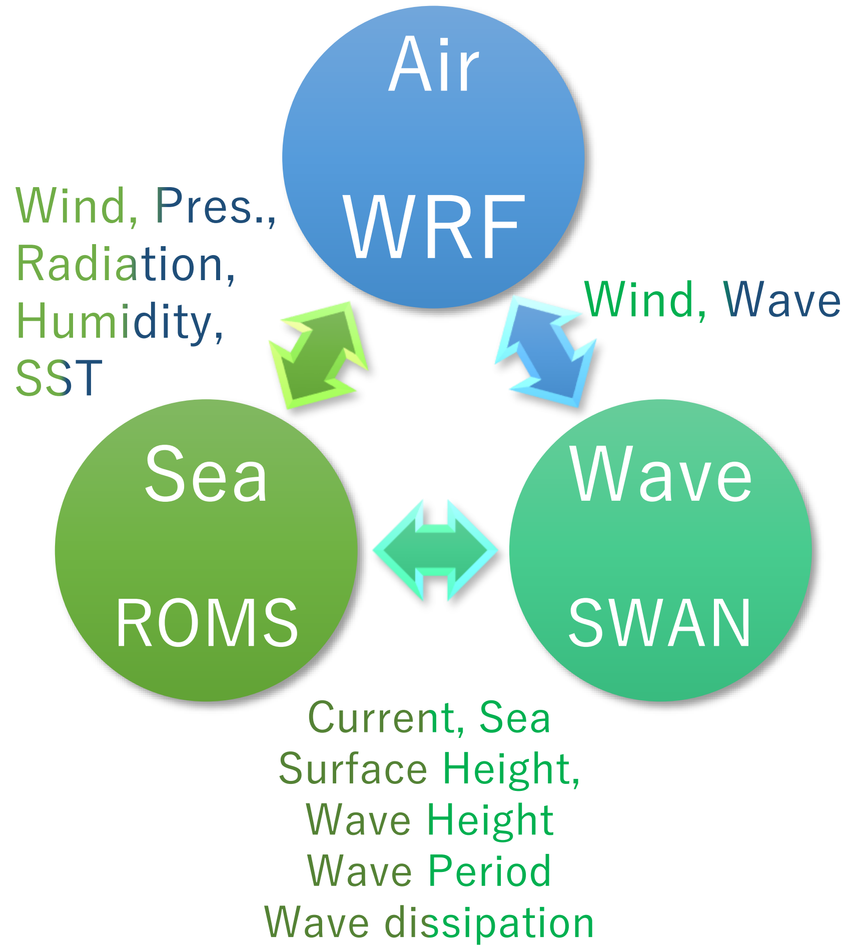
# Model Setup




## AOW Model

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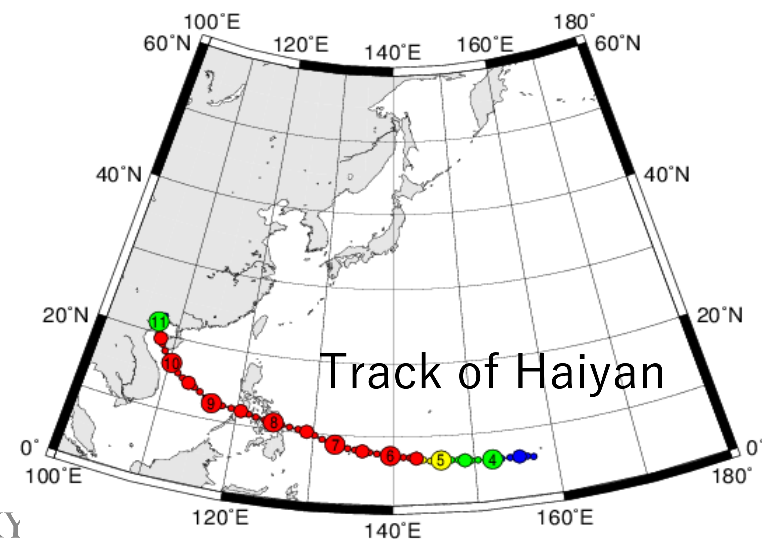
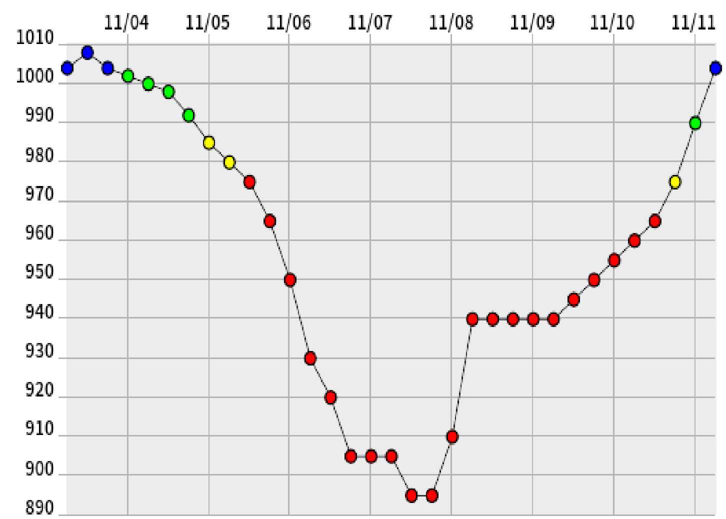
COAWST Warner et al.(2009)

# Analysis of the impact on TC

- Simulation model：COAWST (Atmosphere-ocean-wave coupled model)
  - Regional weather model：　WRF （444×222×56）
  - Ocean model：　ROMS （444×222×20）
  - Wave model：　SWAN （444×222）
  - Horizontal resolution is 9km
- Target: Haiyan (2013, No.30)
- Simulation period：2013/11/5～11/9




Track of Haiyan




Minimum sea level pressure

# Numerical tests

Feddersen and Trowbridge

$$\frac{K_v}{\sigma_k}\frac{\partial k}{\partial z} = \alpha\overline{\varepsilon_w}$$

Case 1. $\frac{K_v}{\sigma_k}\frac{\partial k}{\partial z} = \mathrm{func(wind\ speed)}$ （CB94）

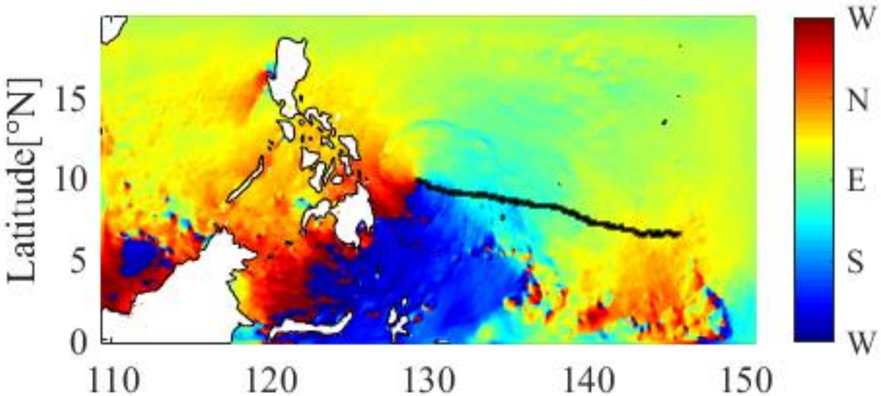
Case 2. $\alpha = \mathrm{constant}$ （FT05）

Case 3. $\alpha = \mathrm{func(wind\ direction, wave\ direction)}$ （Wdir）

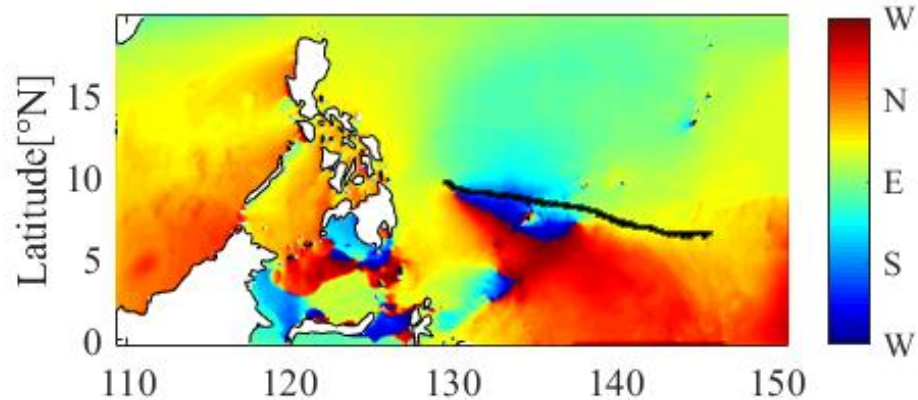
Case 4. $\alpha = \mathrm{func(wind\ dir., wave\ dir., wave\ steepness)}$ （Wstp）

Blue existing parameterization
Red revised

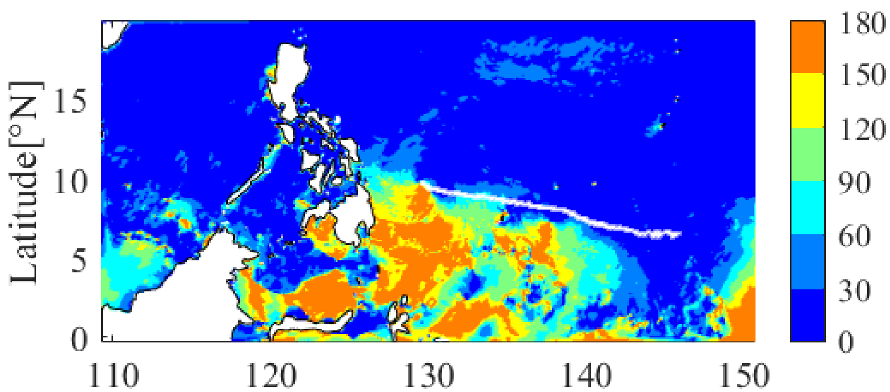
# Snapshot of parameters directions, steepness



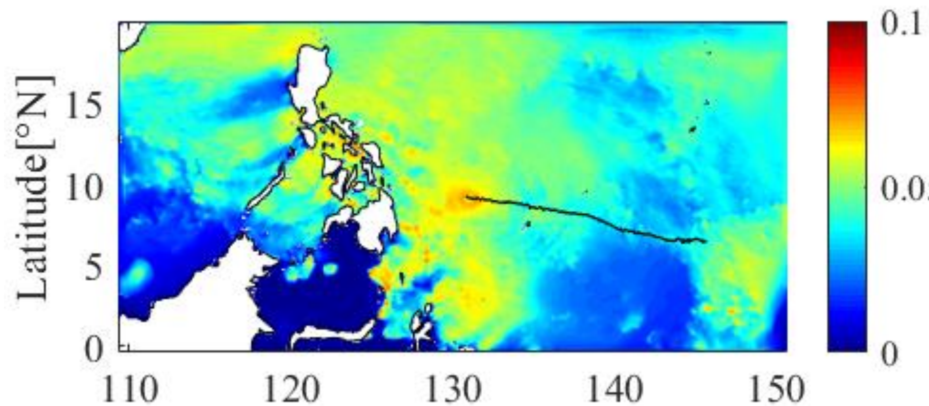

Wind direction




Wave direction

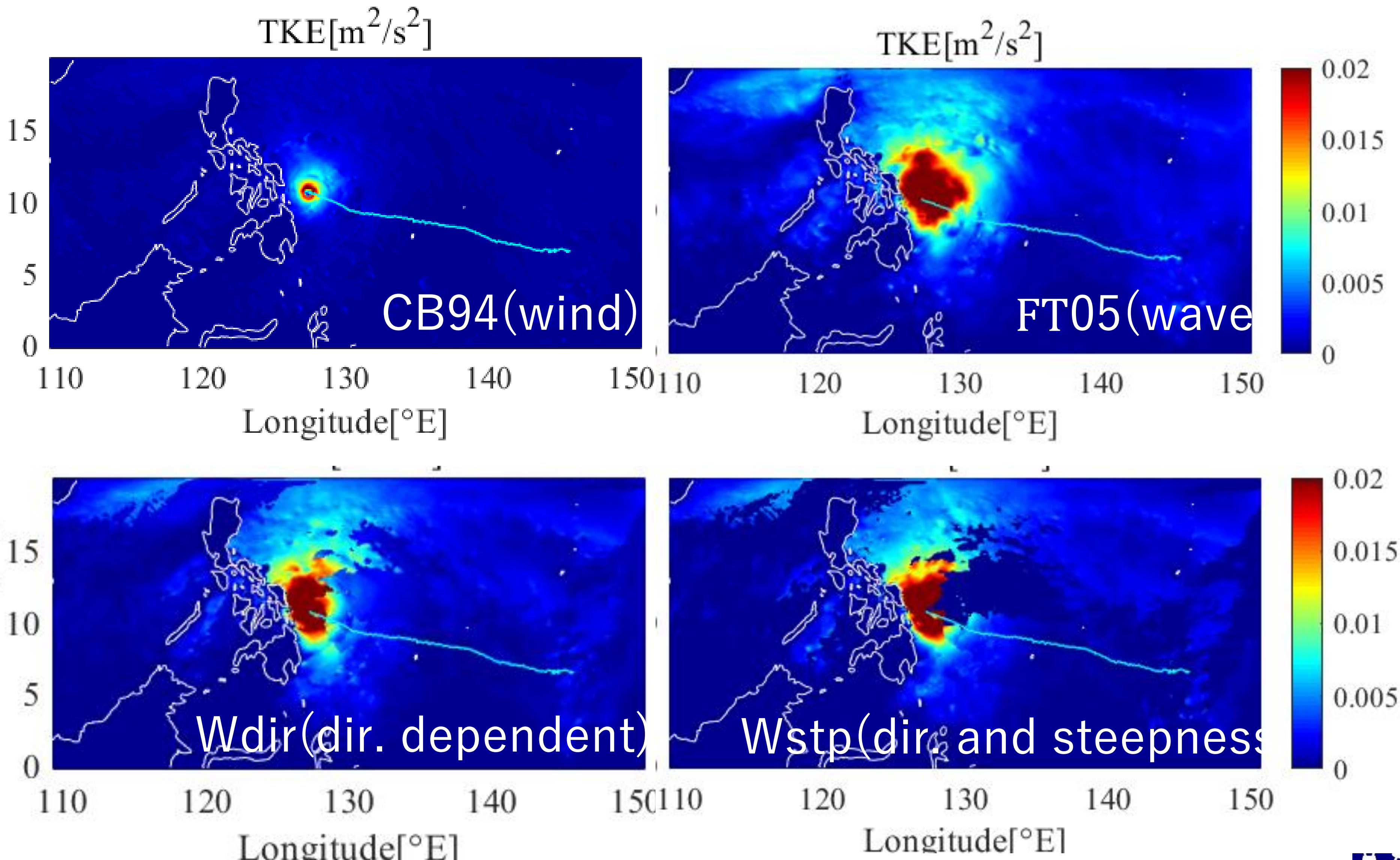



Difference of wind and wave direction

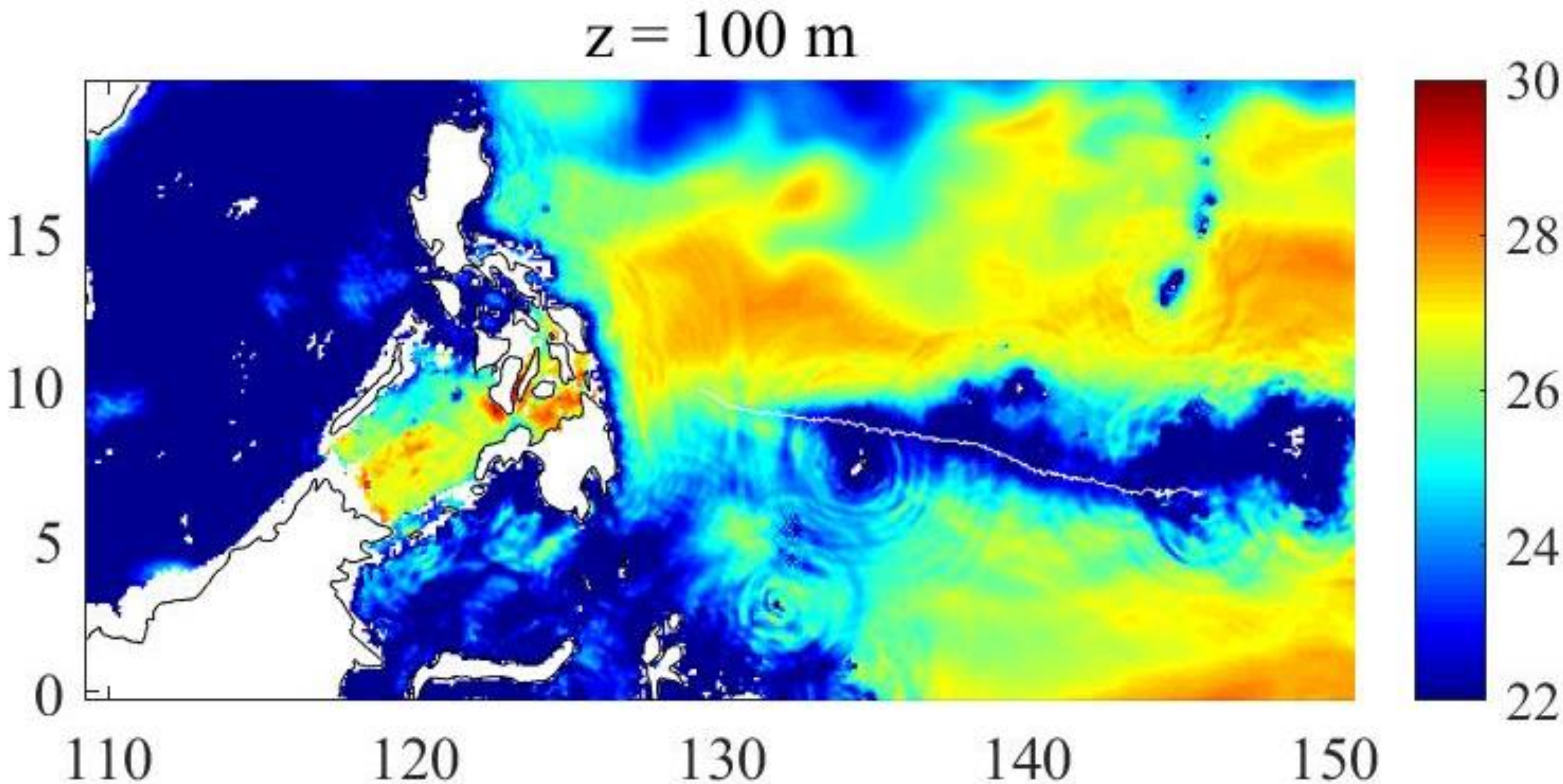



wave steepness

# Snapshot of TKE

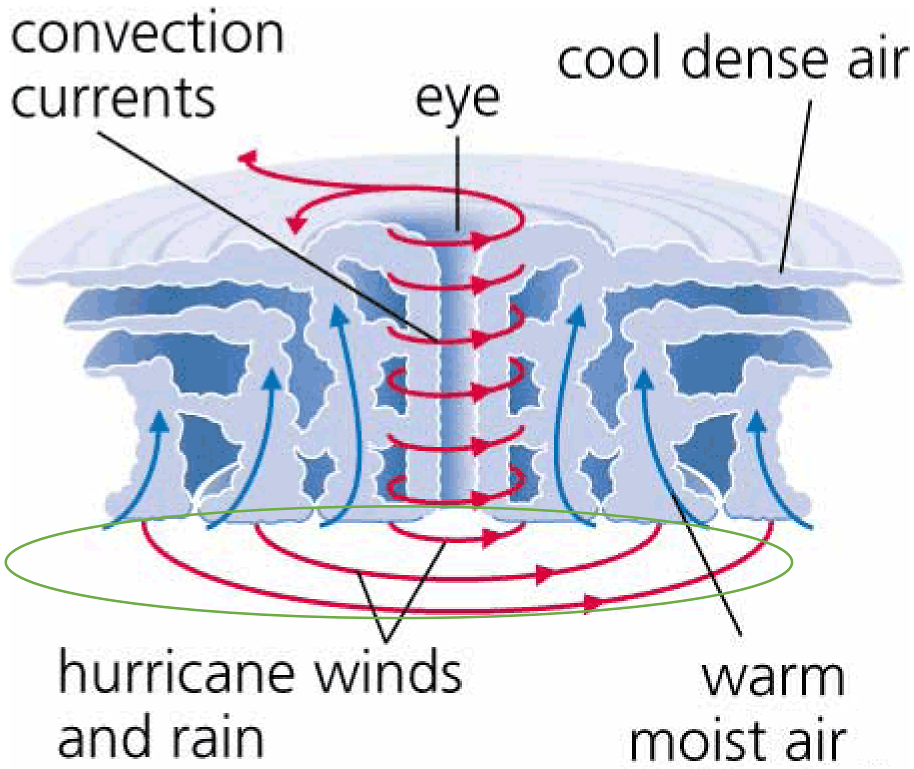


# Changes of temperature at h=100m TC Haiyan 2013

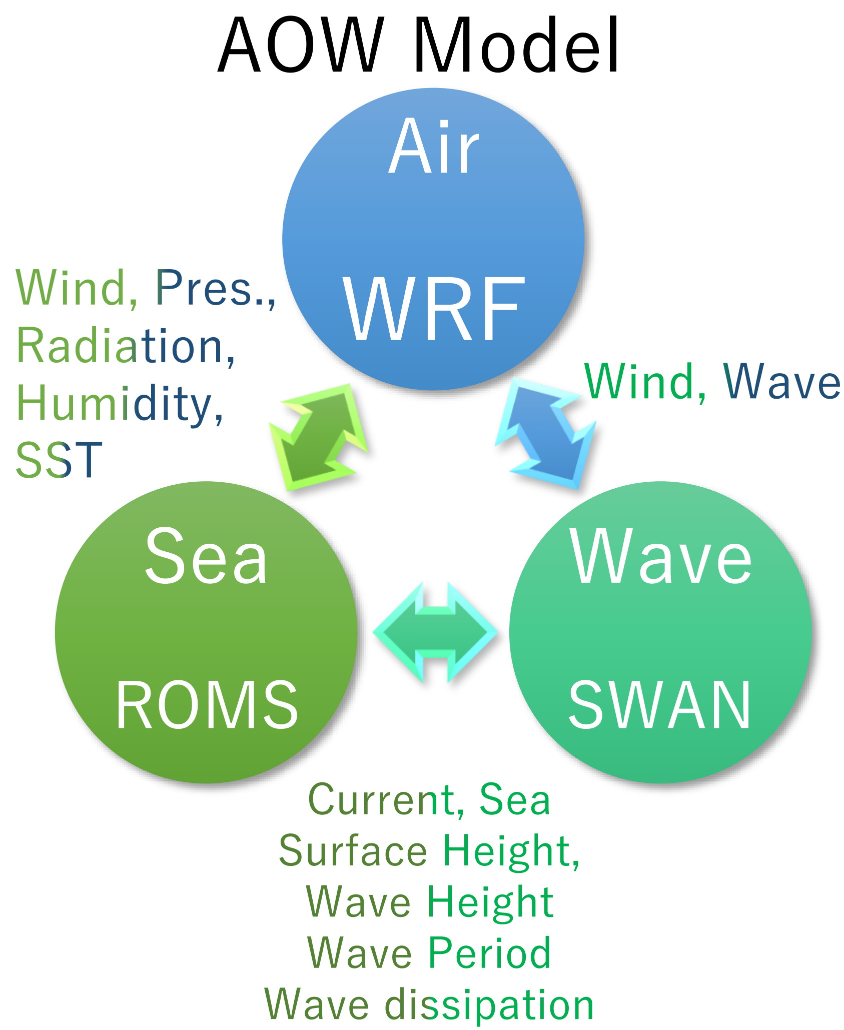



7 Novemver UTC12:00

# Conclusion

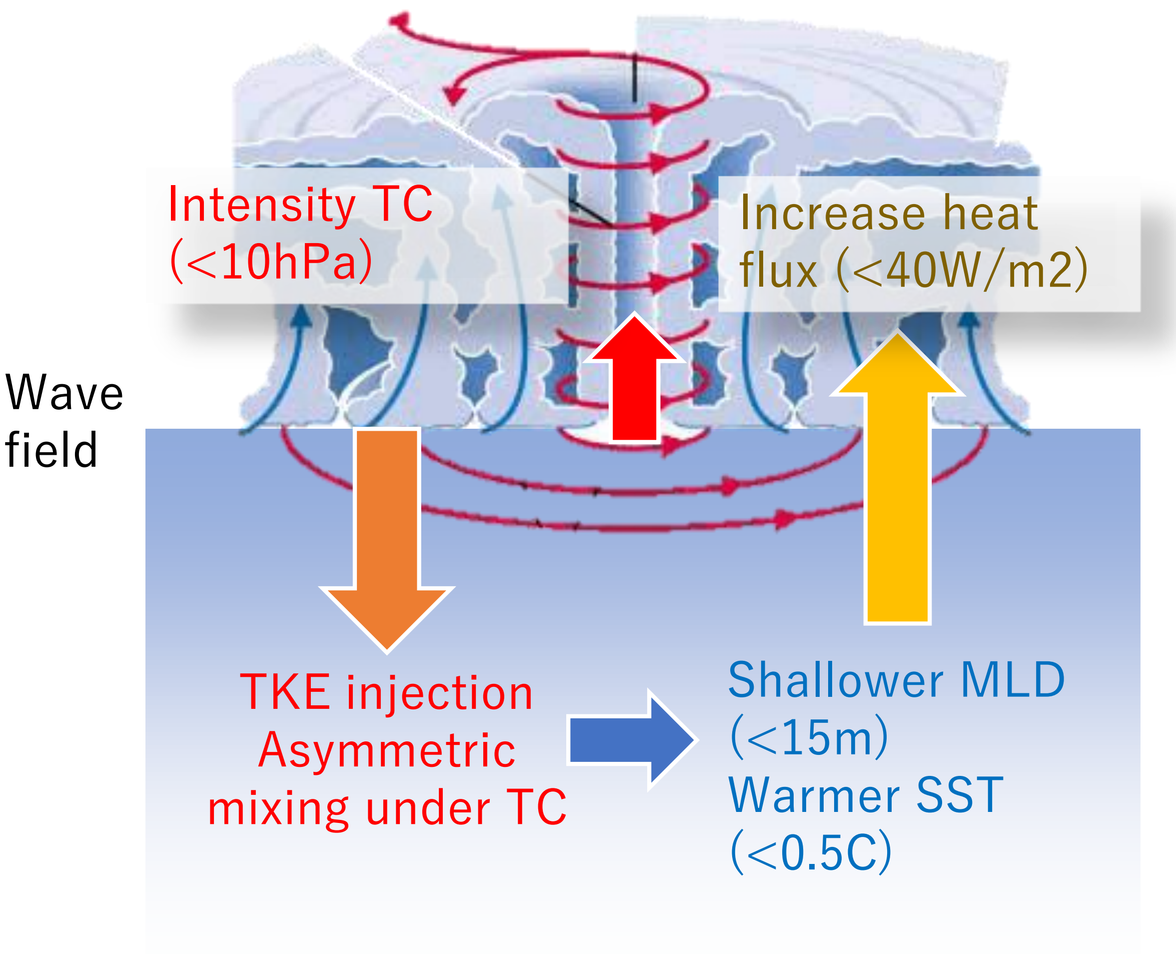


convection
currents
eye
cool dense air
hurricane winds
and rain
warm
moist air

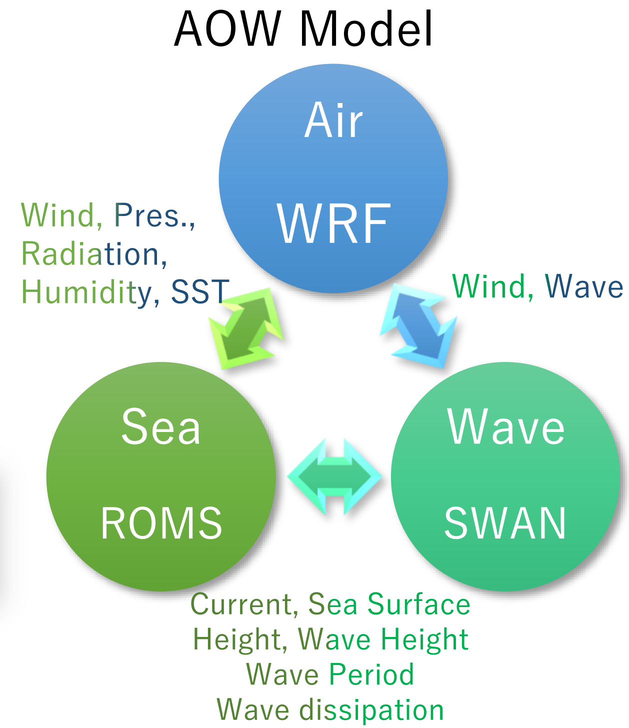



AOW Model
Air
WRF
Wind, Pres.,
Radiation,
Humidity,
SST
Wind, Wave
Sea
ROMS
Wave
SWAN
Current, Sea
Surface Height,
Wave Height
Wave Period
Wave dissipation

# Conclusion

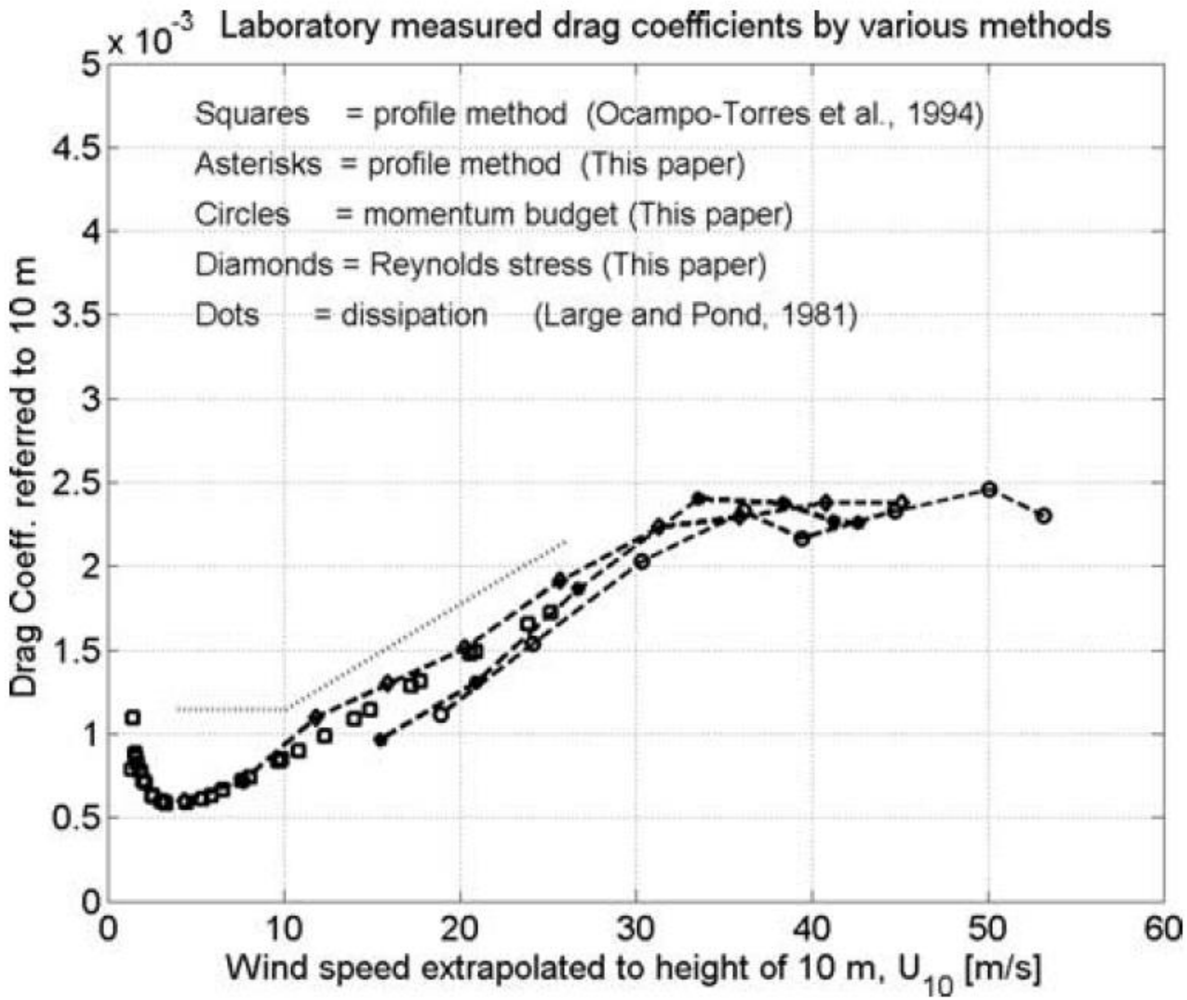


Intensity TC
(<10hPa)
Increase heat
flux (<40W/m2)
Wave
field
TKE injection
Asymmetric
mixing under TC
Shallower MLD
(<15m)
Warmer SST
(<0.5C)

AOW Model
Air
WRF
Wind, Pres.,
Radiation,
Humidity, SST
Wind, Wave
Sea
ROMS
Wave
SWAN
Current, Sea Surface
Height, Wave Height
Wave Period
Wave dissipation

# Donelan et al. (2004) GRL



# Wave related parameterizations need to be revised/improved

Momentum roughness length:

$$z_{0_m} = \underbrace{\frac{0.11\nu}{u_*}}_{\text{Viscous term}} + \underbrace{\frac{\alpha}{g}u_*^2}_{\text{Wave term}}$$

$$C_d = \left(\frac{u_*}{U_z}\right)^2 = \left(\frac{\kappa}{\Phi_m(L, z + z_{0_m}, z_{0_m})}\right)^2$$

$$\tau_{tot} = \rho_a C_d U_z^2$$

$$z_{0_h} = f(z_{0_m},\ u_*)$$

$$C_H = \frac{\kappa^2}{\Phi_m(L, z + z_{0_m}, z_{0_m})\Phi_h(L, z + z_{0_m}, z_{0_h})}$$

$$\frac{H}{\rho c_p} = -C_H \frac{u_*}{\sqrt{C_D}}\left(\Delta T + \frac{g}{c_p}(z + z_{0_m} - z_{0_h})\right)$$

- Taylor and Yelland (2001)：Wave Slope
- Oost (2002)：Wave age, Wave length
- Drennan (2003)：Wave age, Wave height

# Questions?