Effect of Wave Boundary Layer on Sea-to-Air Dimethylsulfide (DMS) Transfer Velocity during Typhoon Passage

Peter C Chu, and Kuofeng Cheng

Naval Ocean-Atmospheric Prediction Laboratory
Department of Oceanography
Naval Postgraduate School
Monterey, California, USA
pcchu@nps.edu
http://www.oc.nps.navy.mil/~chu

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References

- Chu, P.C., and K.F. Cheng, 2006: Effect of wave boundary layer on the sea-to-air dimethylsulfide transfer velocity during typhoon passage. Journal of Marine Systems, in press.

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The dominant natural source of sulfur to the atmosphere is the oceanic DMS

(Bates et al., 1992; Gondwe et al., 2003).

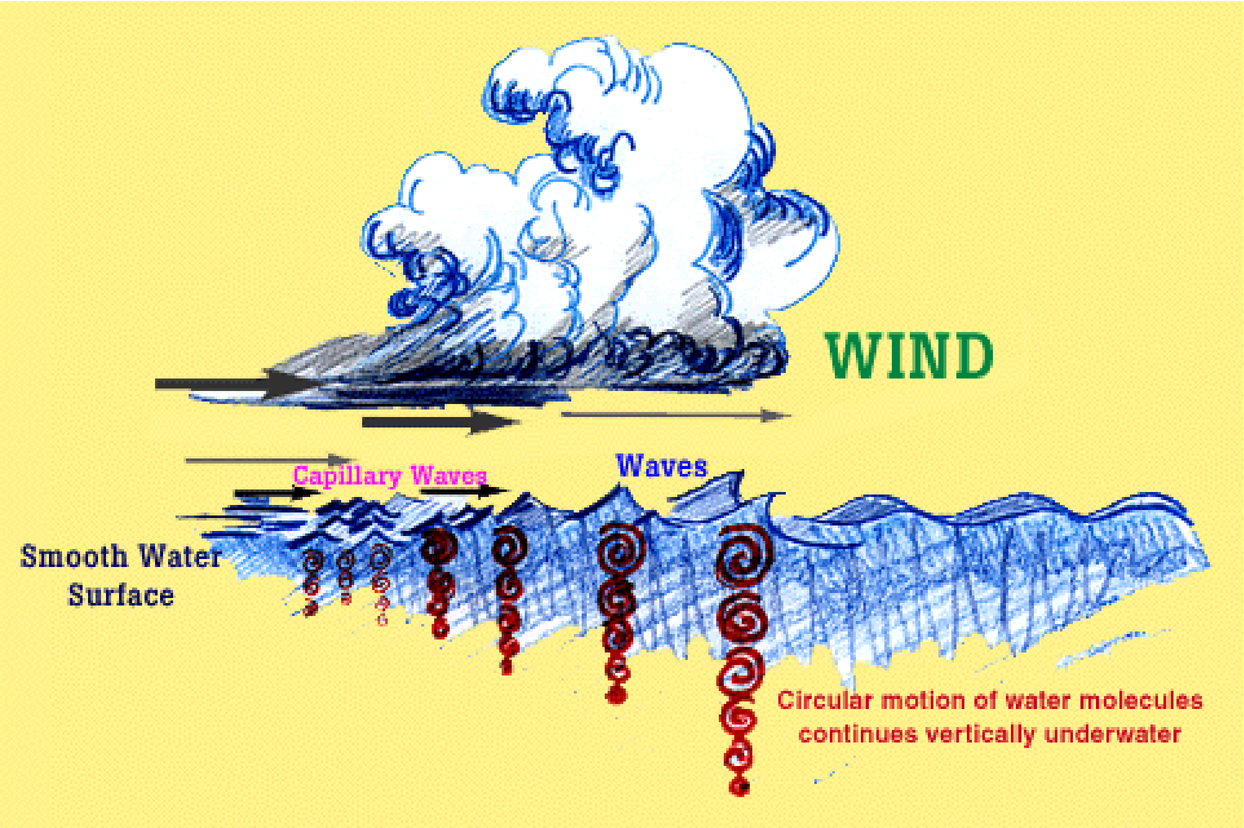
DMS changes the radiation budget in the atmosphere and in turn changes the climate.

Flux Parameterization Issues (Fairall el al. 2005)

- Representation in GCM
  - Most observations are point time averages
  - Concept of gustiness sufficient?
  - Mesoscale variable? Precip, convective mass flux, …
- Strong winds
  - General question of turbulent fluxes, flow separation, wave momentum input
  - Sea spray influence
- Waves
  - Stress vector vs wind vector (2-D wave spectrum)
  - z_o vs wave age & wave height
- Breaking waves
  - Gas and particle fluxes
  - Distribution of stress and TKE in ocean mixed layer
- Gas fluxes
  - Bubbles
  - Surfactants (physical vs chemical effects)
  - Extend models to chemical reactions

What is the effect of the wave boundary layer (WBL) on the sea-to-air DMS transfer?

Waves


WIND
Capillary Waves
Waves
Smooth Water Surface
Circular motion of water molecules continues vertically underwater

Drag Coefficient and Roughness Length

$$u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

$$z_0 = z_r \exp\left(-\frac{\kappa}{\sqrt{C_D}}\right)$$

$z_r = 10$ m

$$C_D = u_*^2 / u_r^2$$

Nondimensional Roughness Length

$$z_{0*} = z_0 g / u_*^2$$

Effect of WBL on Momentum Transfer

- Without WBL: Charnock (1955) parameter

$$z_{0*} = 0.0144$$

- With WBL: Chalikov (1995) parameterization

$$C_D = \kappa^2 \left[R - \ln C_D \right]^2$$

$$R = \ln\left(\frac{z_r g}{\gamma_r \sqrt{\mu_p}\, u_r} \right)$$

$$\mu_p = 0.57 \left(\frac{u_*}{c_p} \right)^{3/2}$$

C_p is the peak phase speed.

WBL Effects

- Waves $\rightarrow$ z_0 $\rightarrow$ $C_D \rightarrow k_a$
- Waves $\rightarrow$ z_0 $\rightarrow$ $(Re, Sc) \rightarrow k_w$
- WaveWatch-3 for the South China Sea as an example

NOAA WaveWatch-3 Third Generation Wave Model (Tolman 1999)

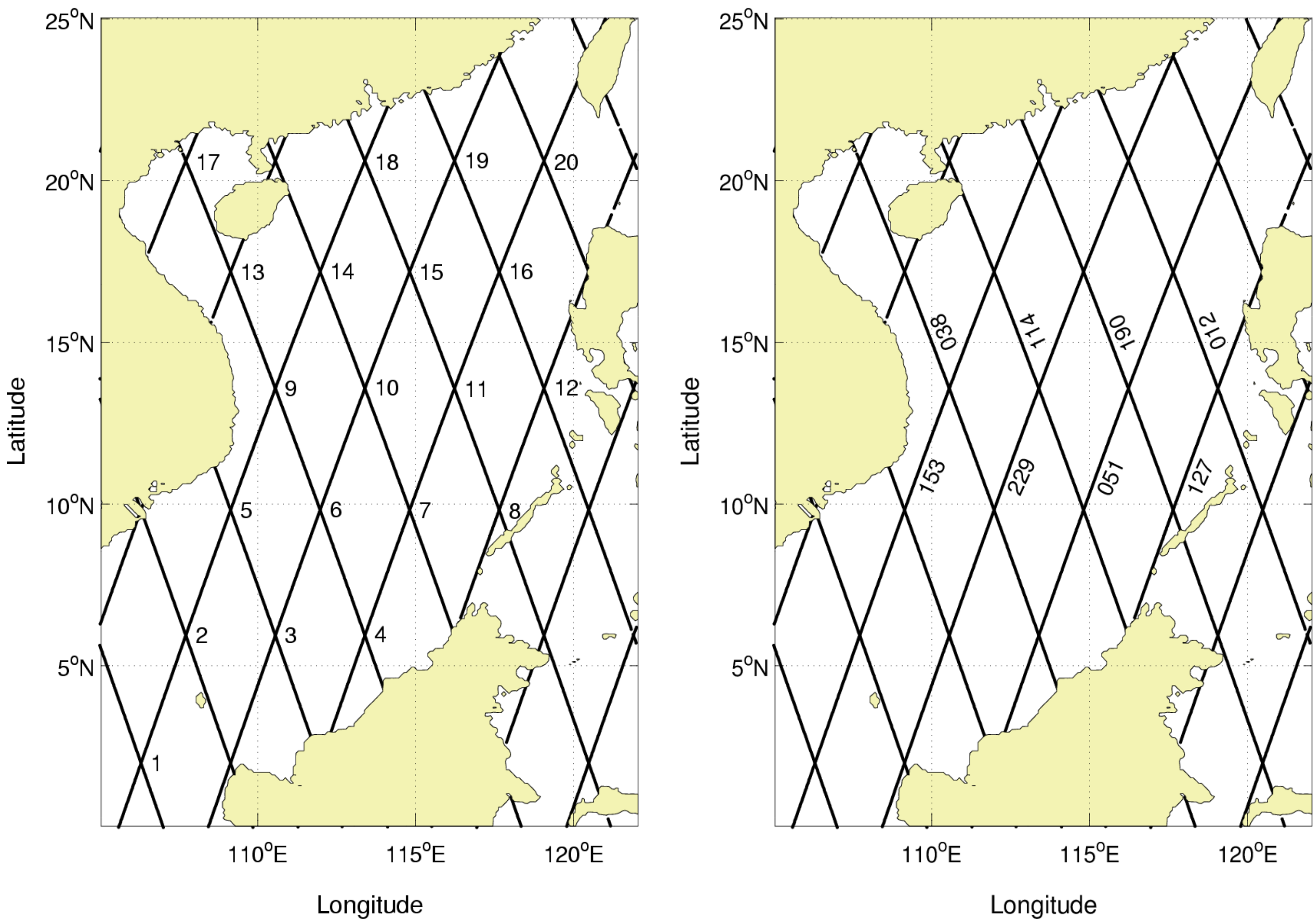
$$\frac{\partial N}{\partial t} + \frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\dot{\phi}N\cos\theta + \frac{\partial}{\partial\lambda}\dot{\lambda}N + \frac{\partial}{\partial k}\dot{k}N + \frac{\partial}{\partial\theta}\dot{\theta}_g N = \frac{S}{\sigma}$$

$$S = S_{in} + S_{nl} + S_{ds} + S_{bot}$$

$$\dot{\phi} = \frac{c_g\cos\theta + U_\phi}{R} \qquad \dot{\lambda} = \frac{c_g\sin\theta + U_\phi}{R\cos\phi}$$

$$\dot{\theta}_g = \dot{\theta} - \frac{c_g\tan\phi\cos\theta}{R}$$

WaveWatch-3 was evaluated using T/P (a) crossover points and (b) tracks in the SCS (Chu et al., 2003, JTECH)



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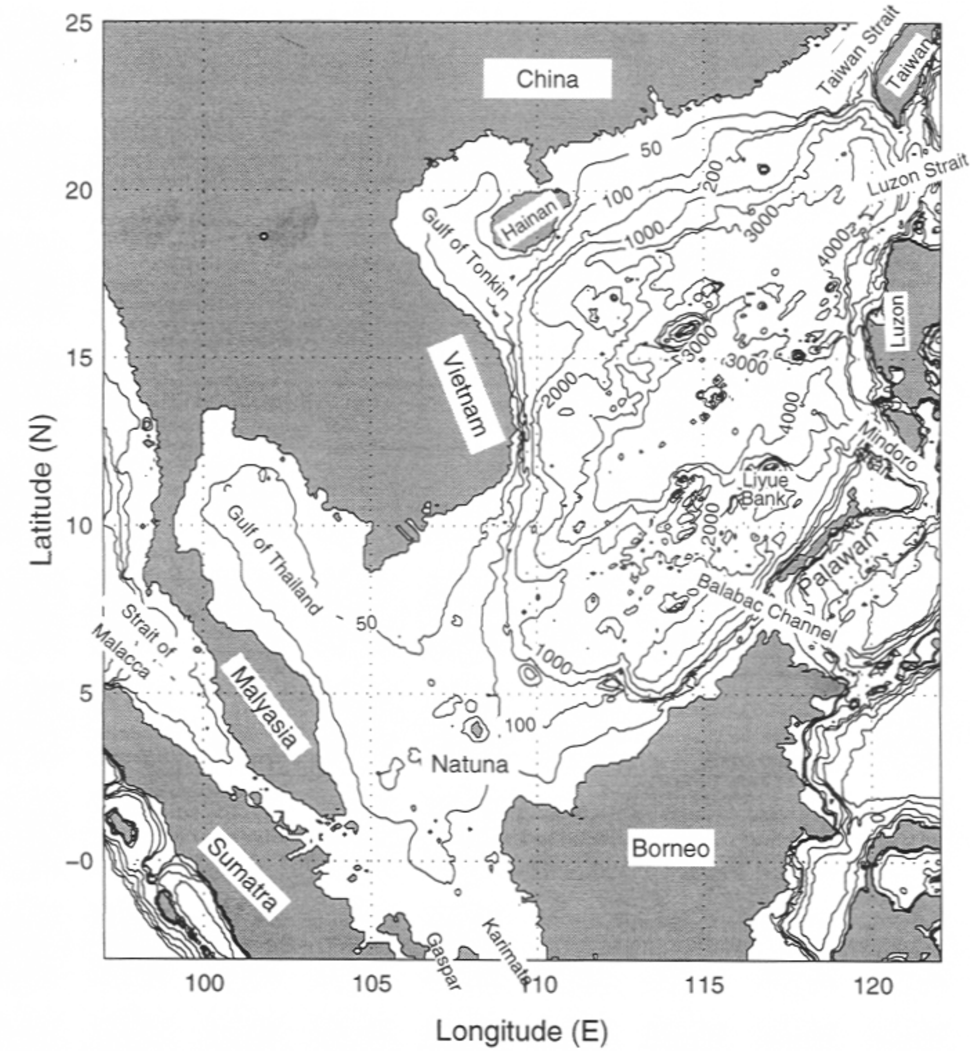
South China Sea



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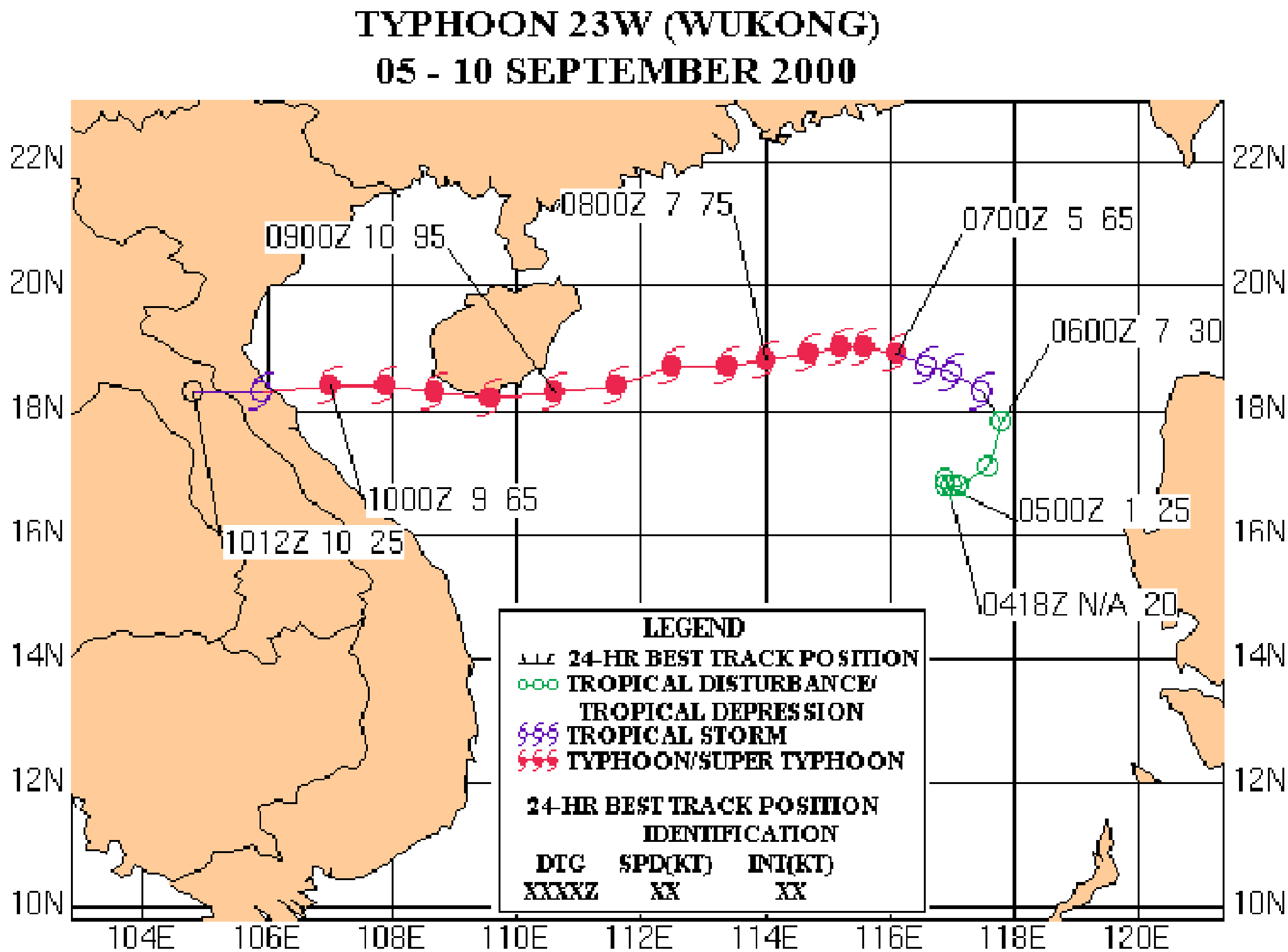
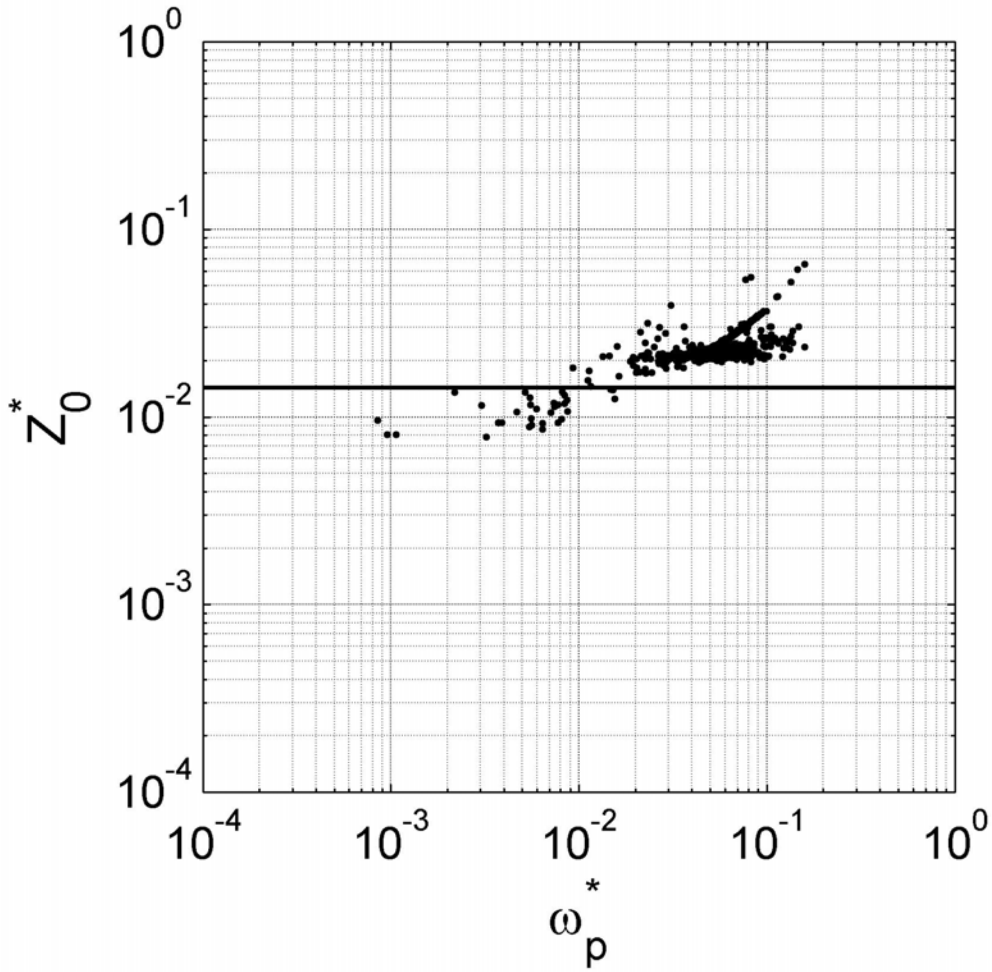
Typhoon 23W (Wukong) Sept 5-11, 2000
Maximum Sustained Wind: 38 m/s



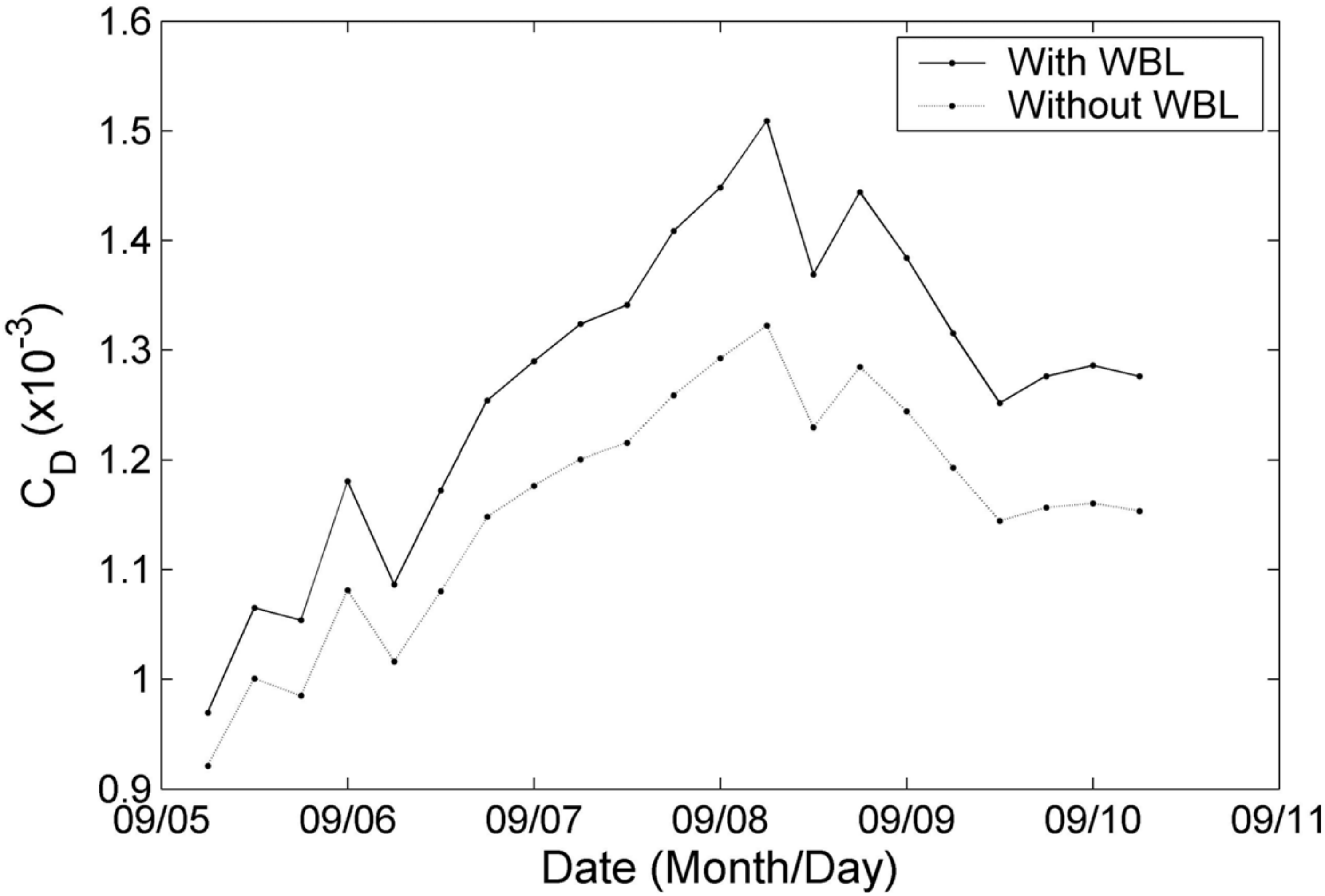
Effect of WBL on z_{0*}

Nondimensional Peak Wave Frequency

$$\omega_{p*} \equiv \omega_p u_* / g$$

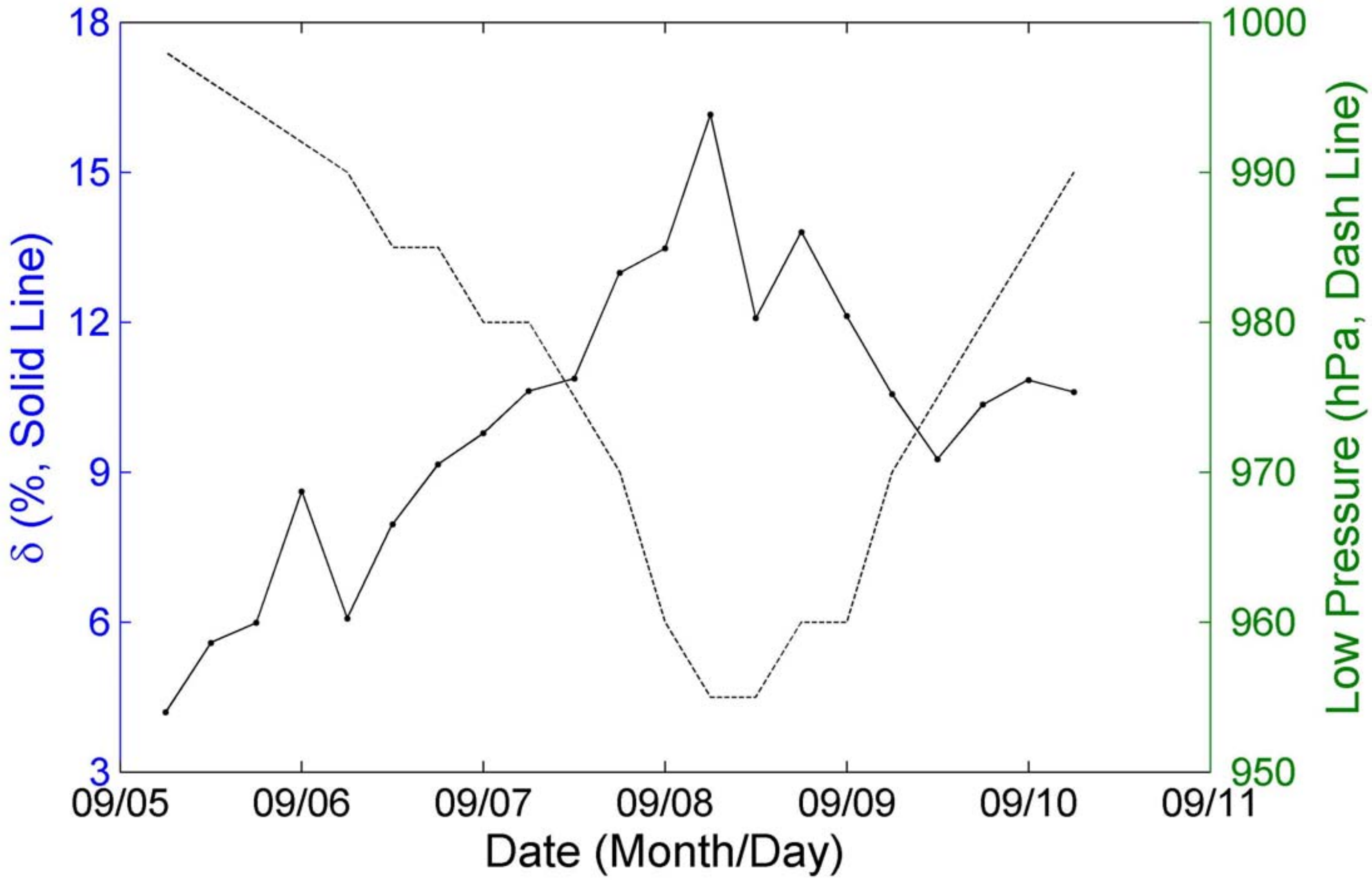


Effect of WBL on C_D



Relative Difference of C_D

$$\delta = \frac{\sum_i \sum_j \left[C_D^{(w)}(i,j) - C_D^{(n)}(i,j) \right]}{\sum_i \sum_j C_D^{(n)}(i,j)}$$



Sea-to-Air DMS Flux (McGillis et al., 2000)

- Air transfer velocity k_a
- Water transfer velocity k_w
- DMS concentrations at airside (C_a)
- DMS concentrations at waterside (C_w)

$$H = \frac{k_w}{1 + \alpha k_w / k_a} (C_w - \alpha C_a)$$

$$\alpha = \exp\left[\frac{3525}{T} - 9.464\right]$$

$$k_a = k_{H_2O} (M / M_{H_2O})^{-1/2}$$

$$k_{H_2O} = 659\ u_r$$

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Waterside DMS Transfer Velocity (Jahne et al., 1987; McGillis et al., 2000)

- Waterside transfer velocity ($n = 0.58$)

$$k_w = \sqrt{\rho_a / \rho_w}\,\beta^{-1}\mathrm{Sc}^{-n}u_*$$

- Schmidt Number = 720 (DMS at 300 K)

$$\mathrm{Sc} \equiv \nu / D$$

- DMS Diffusion coefficient (Saltzman et al., 1993)

$$D = 1.1\times 10^{-2} \exp\left[-\frac{1896}{T}\right] \quad \text{(unit: cm}^2\text{/s)}$$

$$\beta = 0.55\,\mathrm{Re}_r^{1/4}$$

Roughness Reynolds Number

$$\mathrm{Re}_r \equiv u_* z_0 / \nu$$

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WBL Effects

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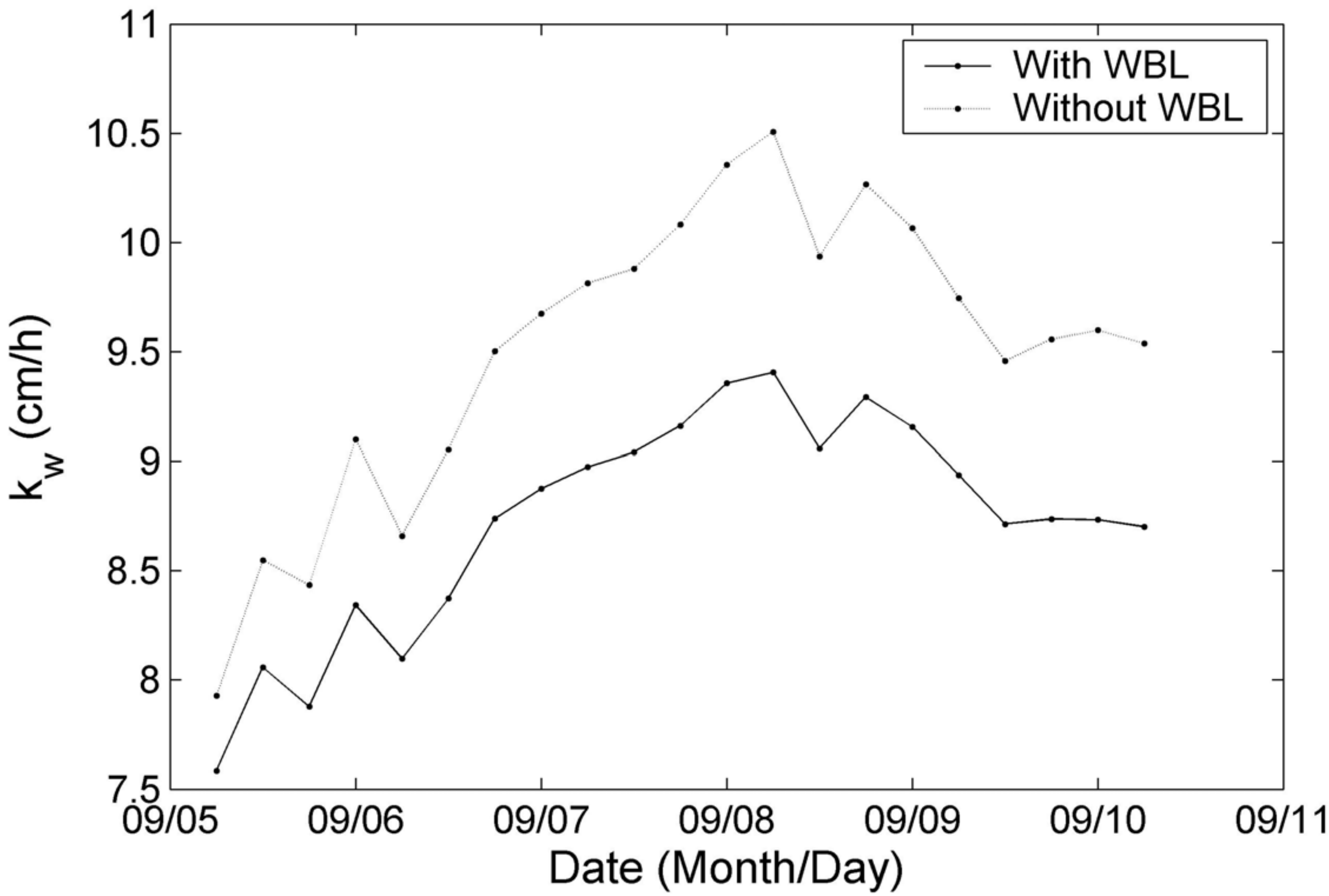
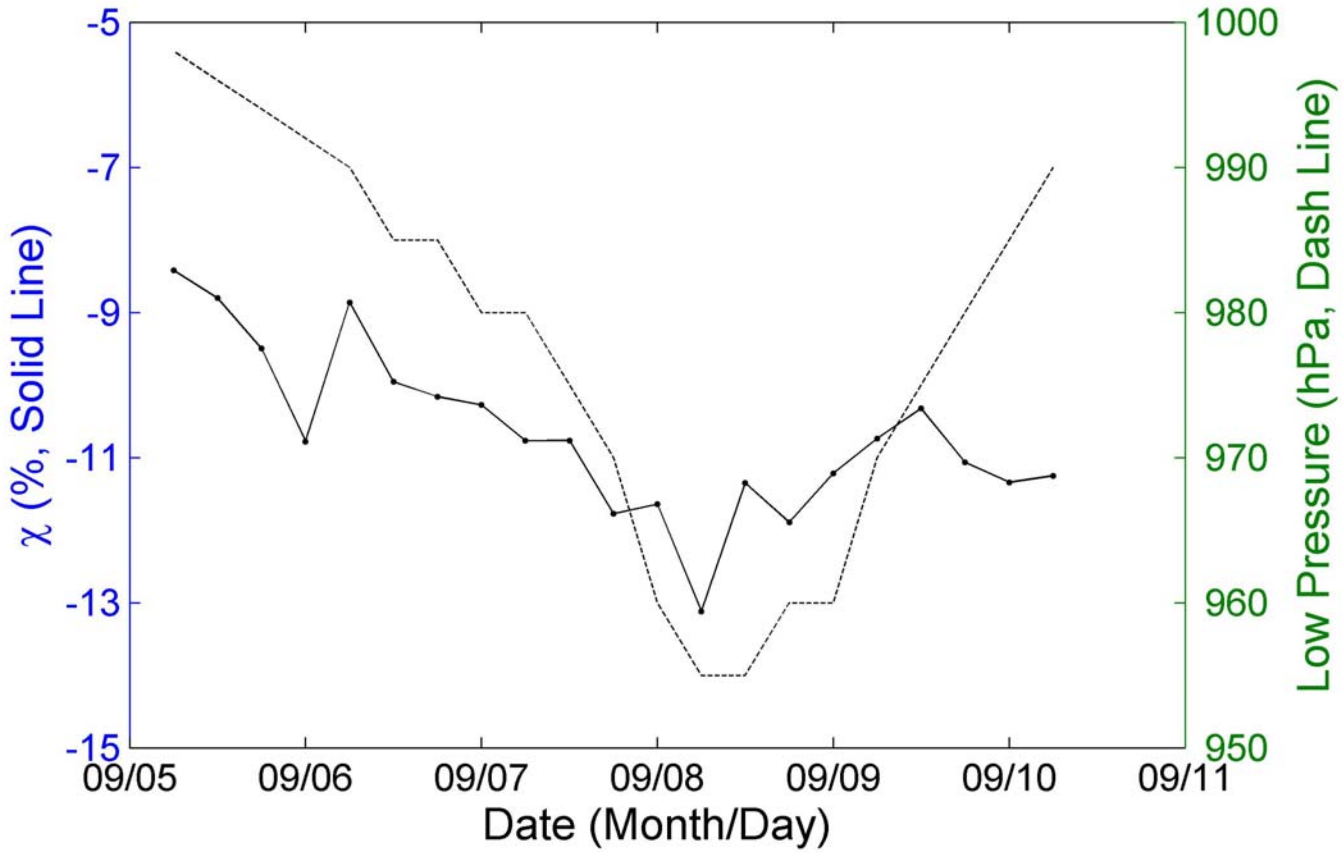
Effect of WBL on k_w



Relative Difference of k_w

$$\chi = \frac{\sum_i \sum_j \left[k_w^{(w)}(i,j) - k_w^{(n)}(i,j) \right]}{\sum_i \sum_j k_w^{(n)}(i,j)}$$



Conclusions

- (1) WBL increases C_D and in turn enhances the momentum flux.
- (2) WBL decreases k_w and in turn weakens the sea-to-air DMS transfer.
- (3) Such opposite WBL effects are evident for minor typhoon (Wukong, max wind ~ 38 m/s)
- (4) Such opposite WBL effects on the climate should be further investigated.

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