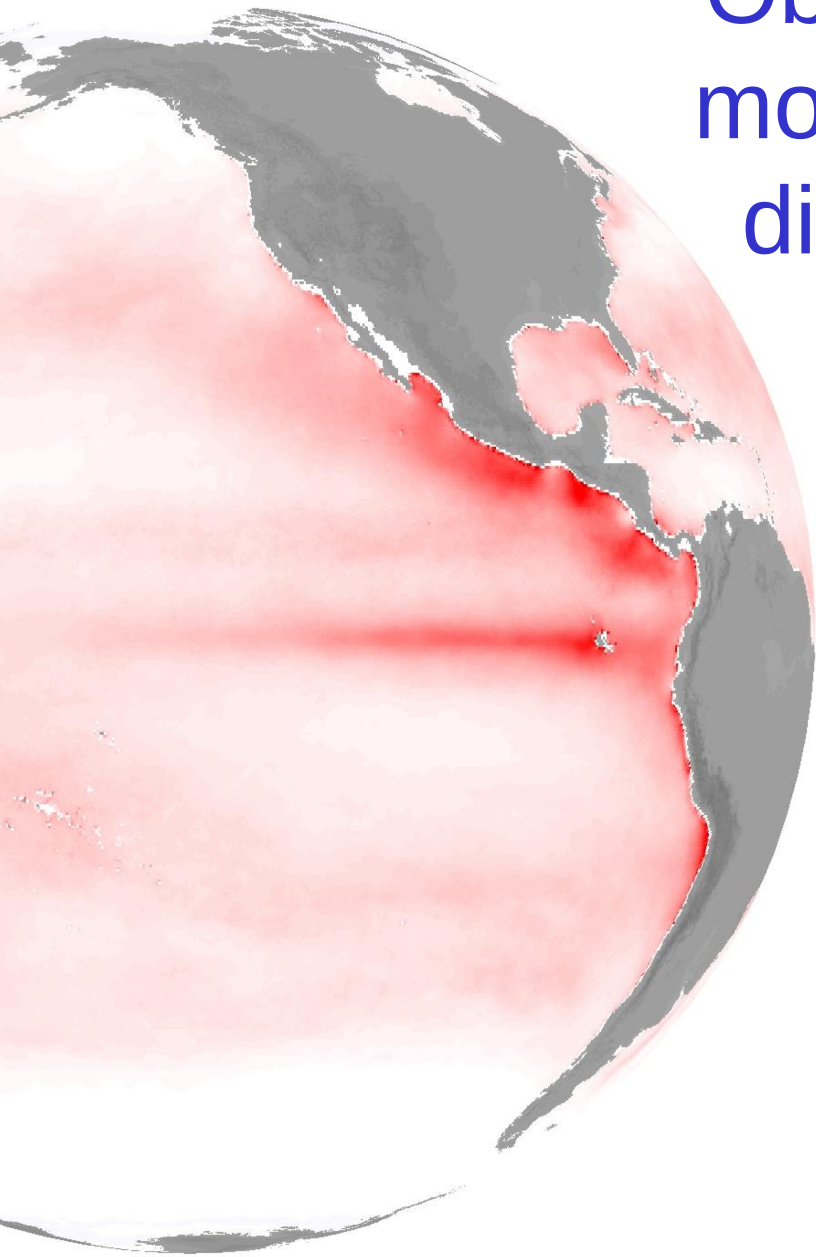

Observations and models of oceanic diurnal warming

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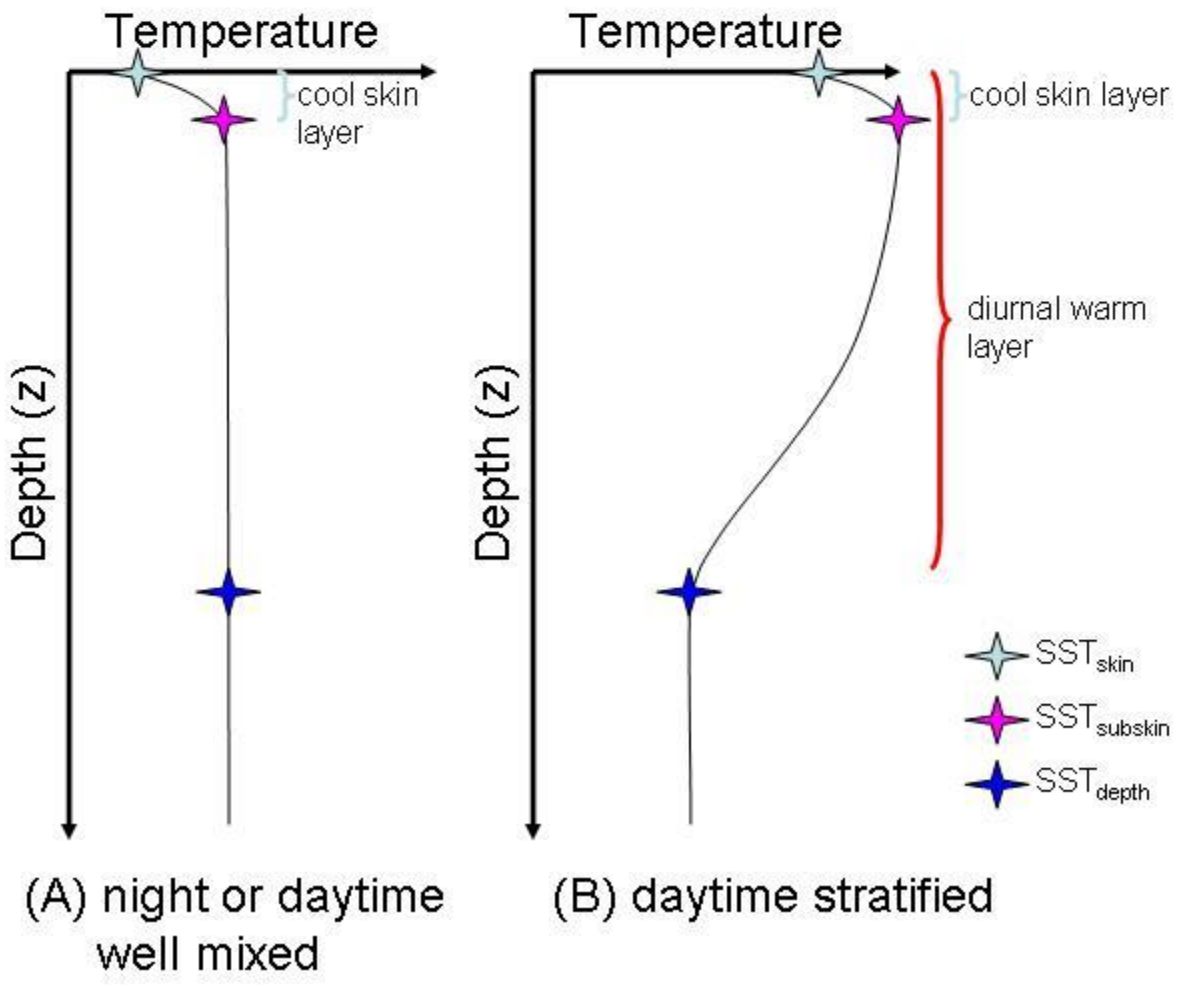
Diurnal warming description

Observed diurnal warming

GMAO diurnal model

Conclusions

Upper Ocean Thermal Structure



Foundation SST

Models of DW

- Empirical
  - Variable inputs
  - Derived from data
- Physical
  - GOTM
    - 1D with assumed profile or upper ocean structure
  - Takaya2010 / ZB2005

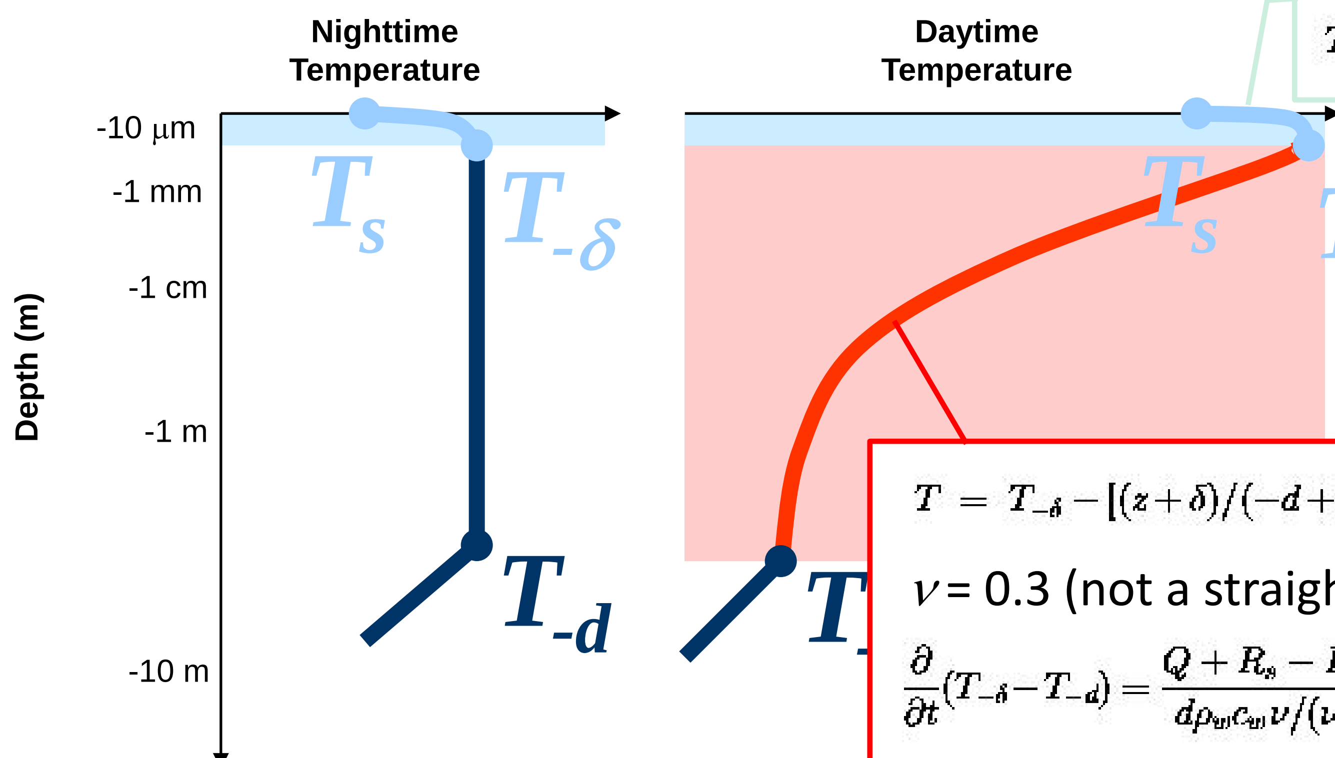
Zeng and Beljaars et al 2005

- Specifically derived for use in NWP, coupled models.
- Developed from 1D heat transfer, prognostic equations predict diurnal variation within cool skin and diurnal warm layer
- Uses Monin-Obukhov vertical mixing parameterization for wind-driven turbulent diffusion
- Assumes diurnal warming normally negligible below 2-4 m, sets fixed diurnal warm layer depth of 3m
- Conserves Heat

Takaya et al 2010

- Refined ZB05
  - Changed stability function in wind-driven turbulent diffusion coefficient
  - Inclusion of mixing effects related to Langmuir circulation during stable conditions

Zeng and Beljaars (2005) scheme



$$T_s - T_{-\delta} = \frac{\delta}{\rho_w c_w k_w}(Q + R_s f_s)$$

$$T = T_{-\delta} - [(z+\delta)/(-d+\delta)]^{\nu}\,(T_{-\delta} - T_{-d})$$

$\nu = 0.3$ (not a straight line)

$$\frac{\partial}{\partial t}(T_{-\delta} - T_{-d}) = \frac{Q + R_s - R(-d)}{d\rho_w c_w \nu/(\nu+1)} - \frac{(\nu+1)k u_{*w}}{d\phi_t(d/L)}(T_{-\delta} - T_{-d})$$

Residual warm layer after sunset:

$$F_d = \begin{cases} g\alpha_w[Q + R_s - R(-d)] \text{ for } T_{-\delta} - T_{-d} \le 0 \\ \left(\frac{g\alpha_w}{5d}\right)^{1/2} \rho_w c_w u_{*_w}^2 (T_s - T_{-d})^{1/2} \text{ for } T_{-\delta} - T_{-d} > 0 \end{cases}$$

(based on Donlon et al. 2002);

Slide from :
https://www.ghrsst.org/files/download.php?m=documents&f=120306053317-BrunkeGHRSSTTWP2012.pptx

NWP diurnal model implementation

- ECMWF, Navy, & NASA coupled models now include ZB05/T10 heat conserving prognostic model
  - ECMWF - Diagnostics for the medium-range forecast interval (0–16 d lead time) indicated that the inclusion of the KPP model improved SST forecast skill at the 10 d lead time and beyond, as well as MJO propagation and Indian monsoon rainfall (Takaya et al., 2010)
  - Navy - Statistically significant gains in forecast performance are seen for all the variables that are analyzed (McLay et al, 2012)

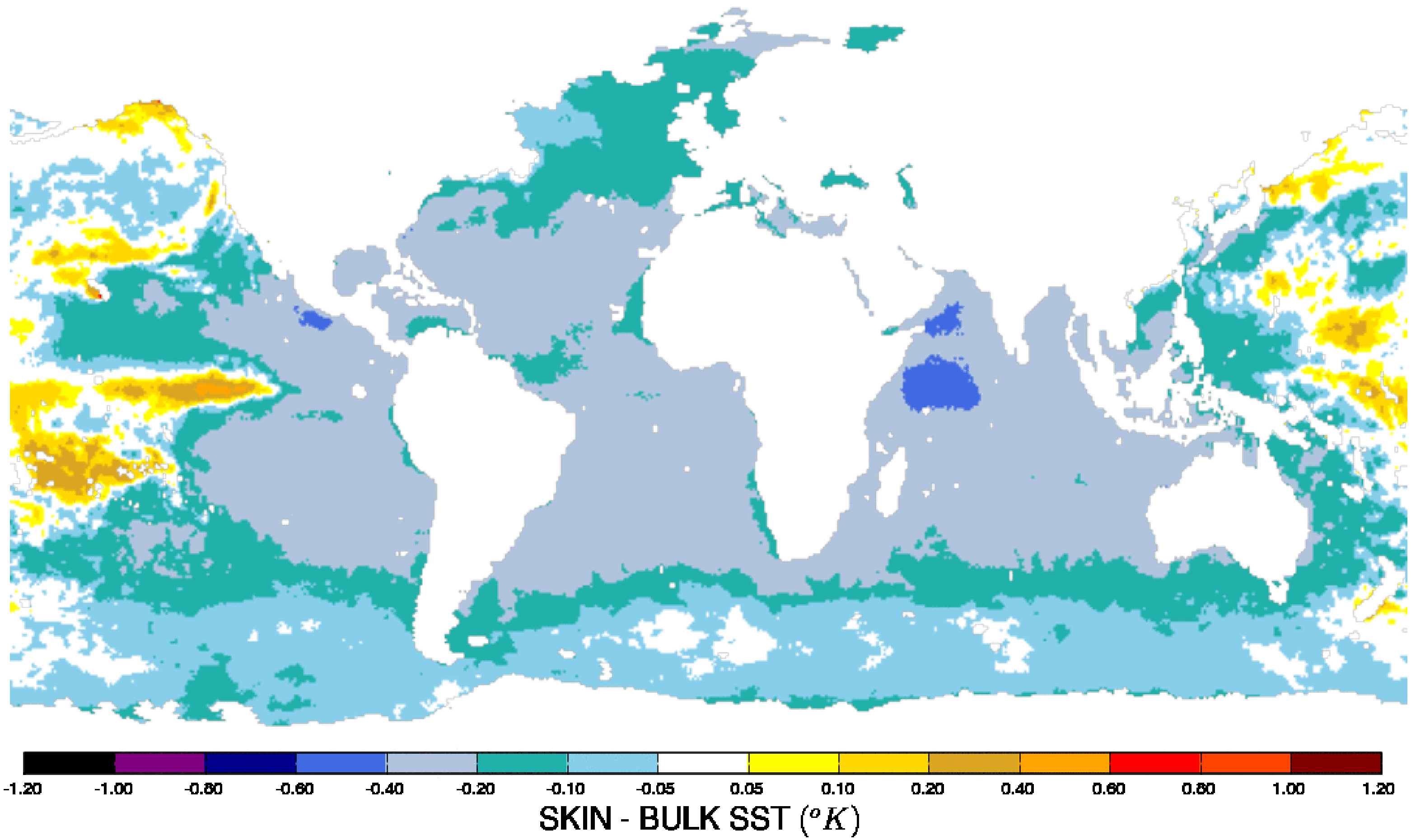
GEOS-5

- The GEOS-5 AOGCM is designed to simulate climate variability on a wide range of time scales, from synoptic time scales to multi-century climate change, and have been tested in coupled simulations and data assimilation mode.
- The main components of the GEOS-5 AOGCM (Fig. 1) are the atmospheric model, the catchment land surface model, both developed by the GMAO (GEOS-5 AGCM, Rienecker *et al.* 2008), and MOM4, the ocean model developed by the Geophysical Fluid Dynamics Laboratory (Griffies *et al.* 2005).
- **These two components exchange fluxes of momentum, heat and fresh water through a "skin layer" interface. The skin layer includes parameterization of the diurnal cycle and a sea ice model (LANL CICE, Hunke and Lipscomb 2008).**
- All components are coupled together using the Earth System Modeling Framework (ESMF) interface. Here we describe the results from a single multi-decade simulation conducted in the latest tuning phase of the AOGCM.

GMAO Warm layer

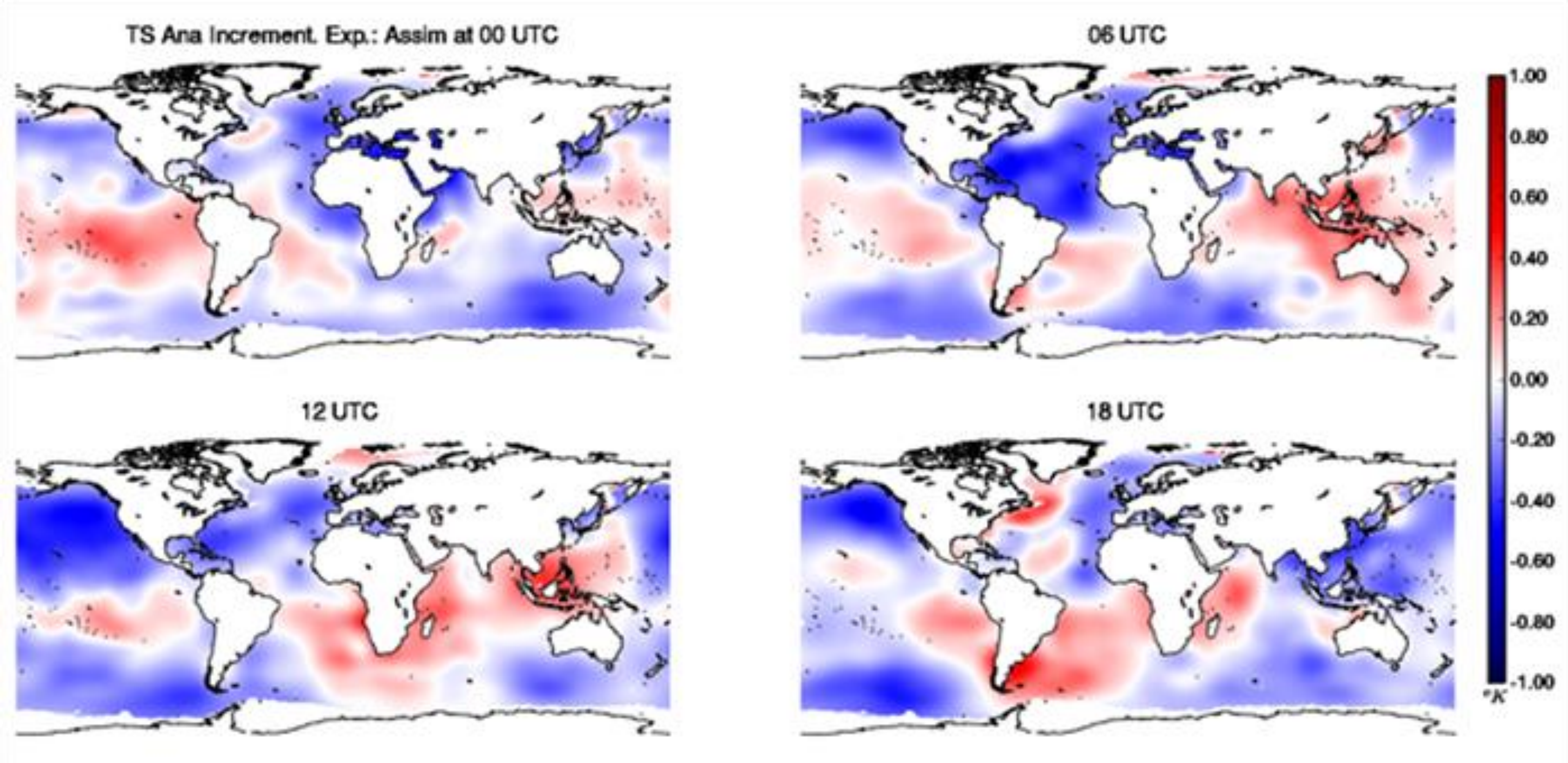
- Takaya et al (2010) & Zeng & Beljaars (2005)
- Interface layer depth = 2m
- υ_s= 0.3 as in T2011 & ZB05
- Foundation SST = GHRSST OSTIA Bulk SST (PO.DAAC / NCEI NODC)
- Includes ocean color climatology
  – Data assimilated initial conditions have a better forecast with the ocean color DW, particularly in the tropics and also extratropics (southern oceans).
  - Physically it make sense that shortwave absorption should depend on turbidity.

00z



-1.20
-1.00
-0.80
-0.60
-0.40
-0.20
-0.10
-0.05
0.05
0.10
0.20
0.40
0.60
0.80
1.00
1.20
SKIN - BULK SST (^oK)

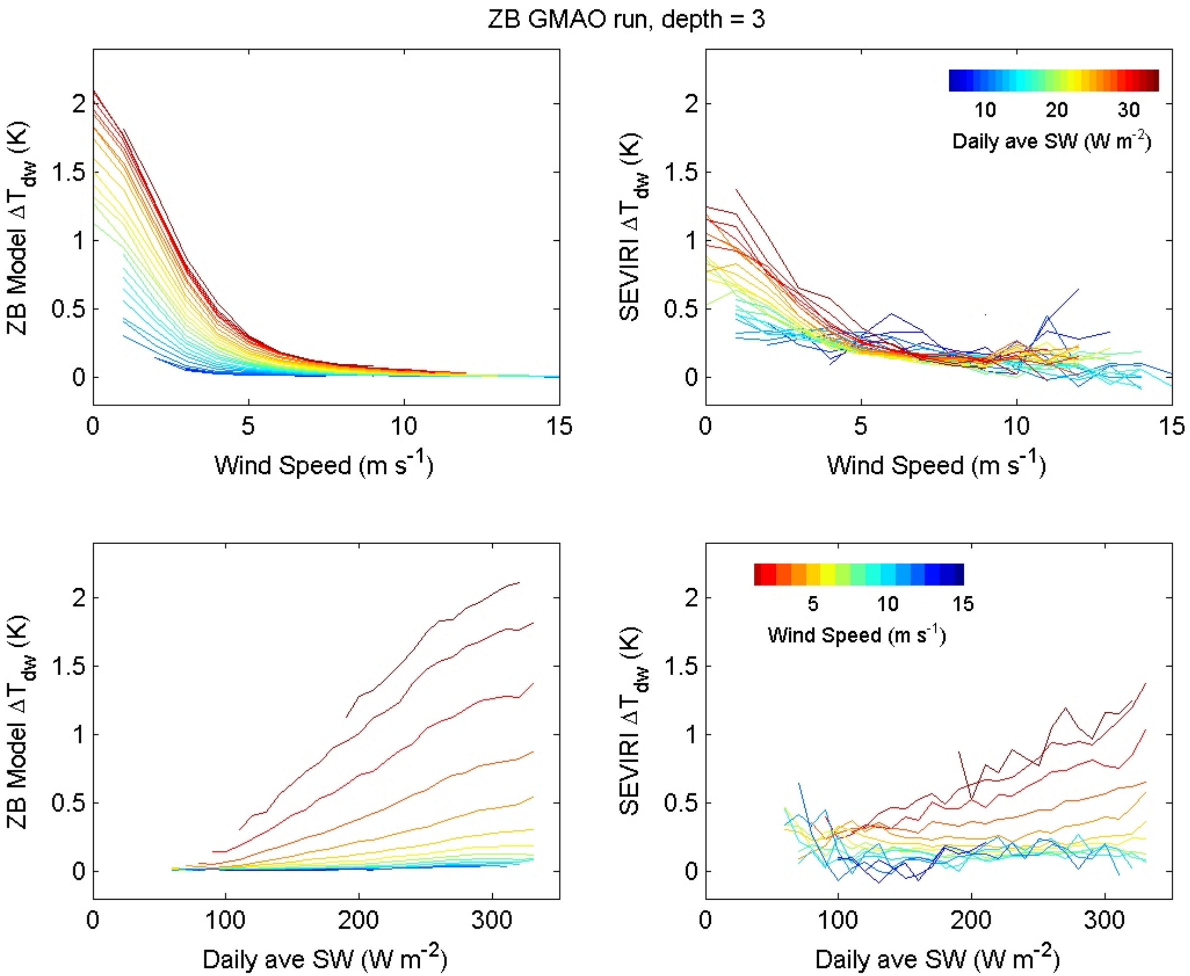
Monthly ave warming



Compare to SEVIRI

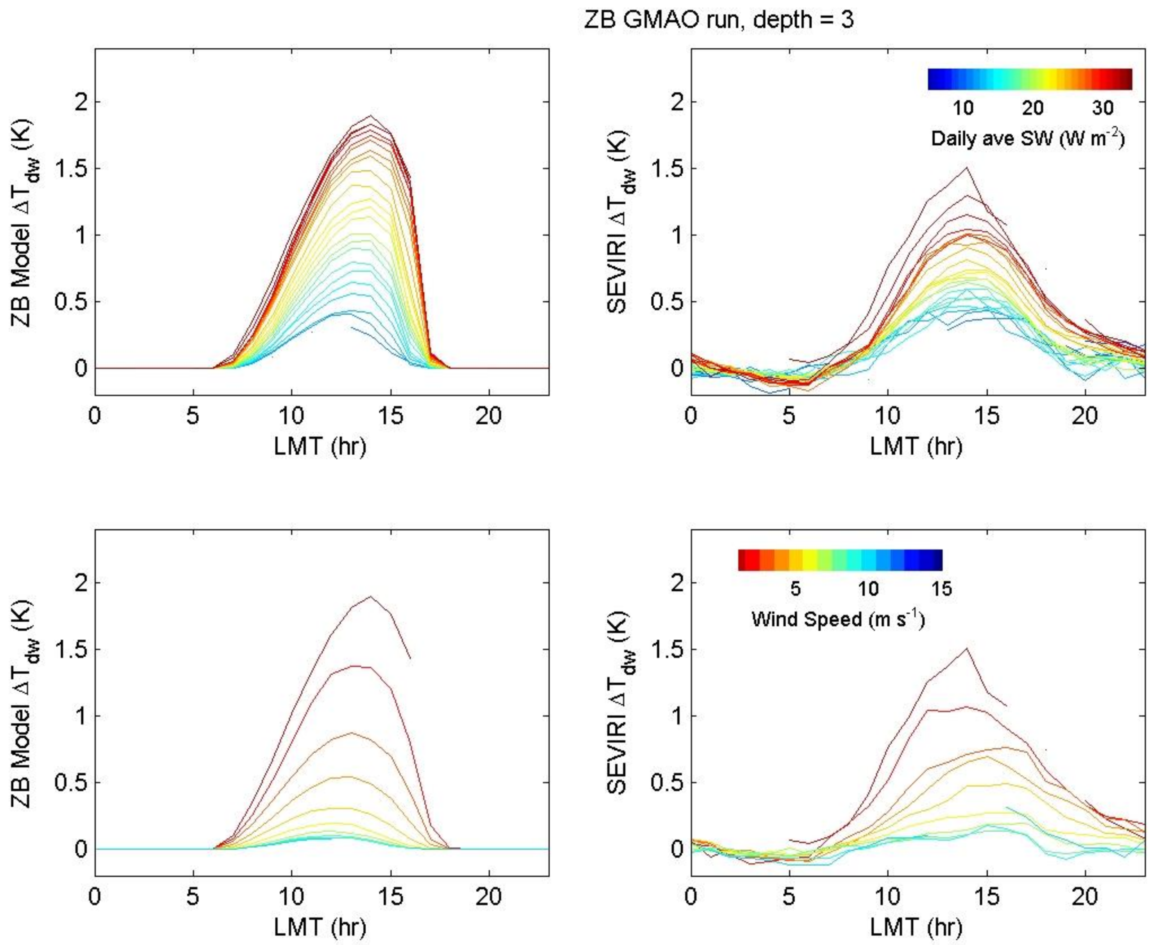
- SEVIRI 15 minute 4km data
- Averaged to GEOS-5 hourly grid
- Night time data used for foundation SST
- DW = SEVIRI – Foundation SST

GEOS-5 model vs SEVIRI



April 2012
Amplitude too large at low wind speeds

Local Time



ZB cools too fast in afternoon

(others found same result, known issue)

Summary of GEOS-5

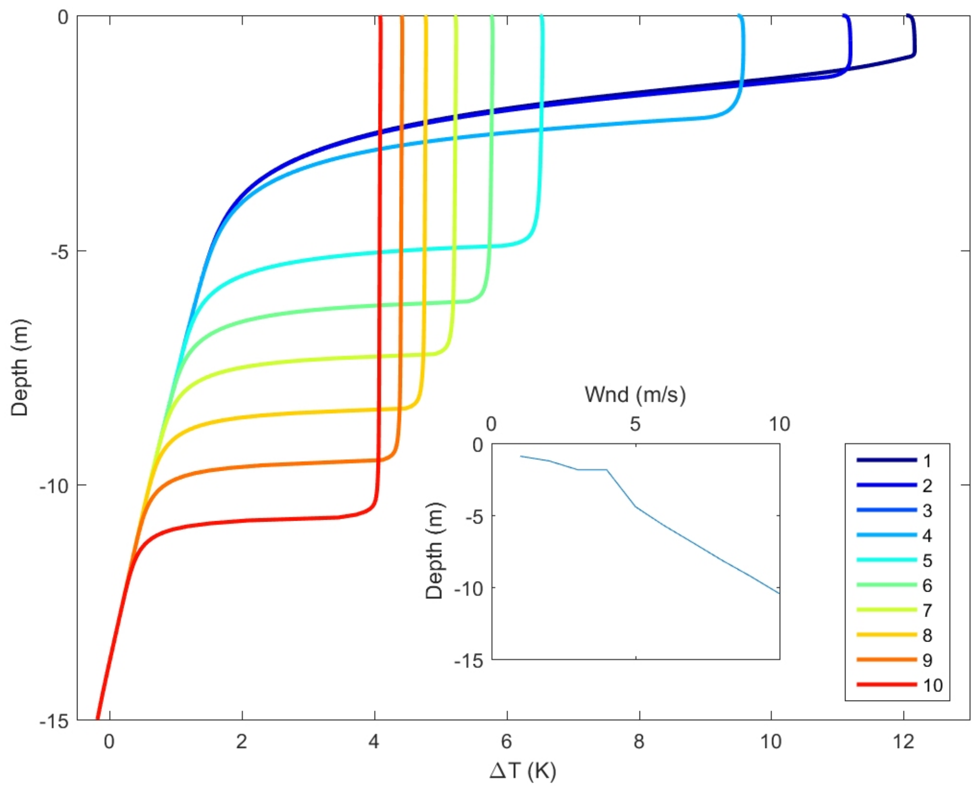
- Too large amplitude
- Afternoon cools too rapidly

- Work on improved wind speed dependence by introducing a wind speed dependent empirical depth dependence
- Examine ocean color

GOTM modeling

- 1D turbulence model (GOTM)
- Radiative transfer model (Paulson & Simplon, 1977), modified to split the visible into the red and the ‘rest’
- WASPARC (WArm SPot Dataset for the ARCtic, Météo-France)

GOTM warming wind dependence



GOTM model results for day 8 diurnal peak, different wind speeds shown by color. Depth of warm layer shown in interior plot.

GOTM run for constant wind speed (1-10m/s)

Depth of warm layer has almost linear dependence on wind speed

Impact of phytoplankton on DW

- Surface chlorophyll-a concentration well measured by multiple satellites
- Phytoplankton distribution nonlinear with depth (dependent on nitracline)
- Chlorophyll-a reflects and absorbs shortwave radiation and can increase diurnal warming stratification

Absorption

$$I(z) = I_o\left(A e^{\frac{z}{\eta_1}} + (1-A) e^{\frac{z}{\eta_2}}\right)\beta_z$$

Paulson&Simpson, 1977

Damping term due to bioturbidity

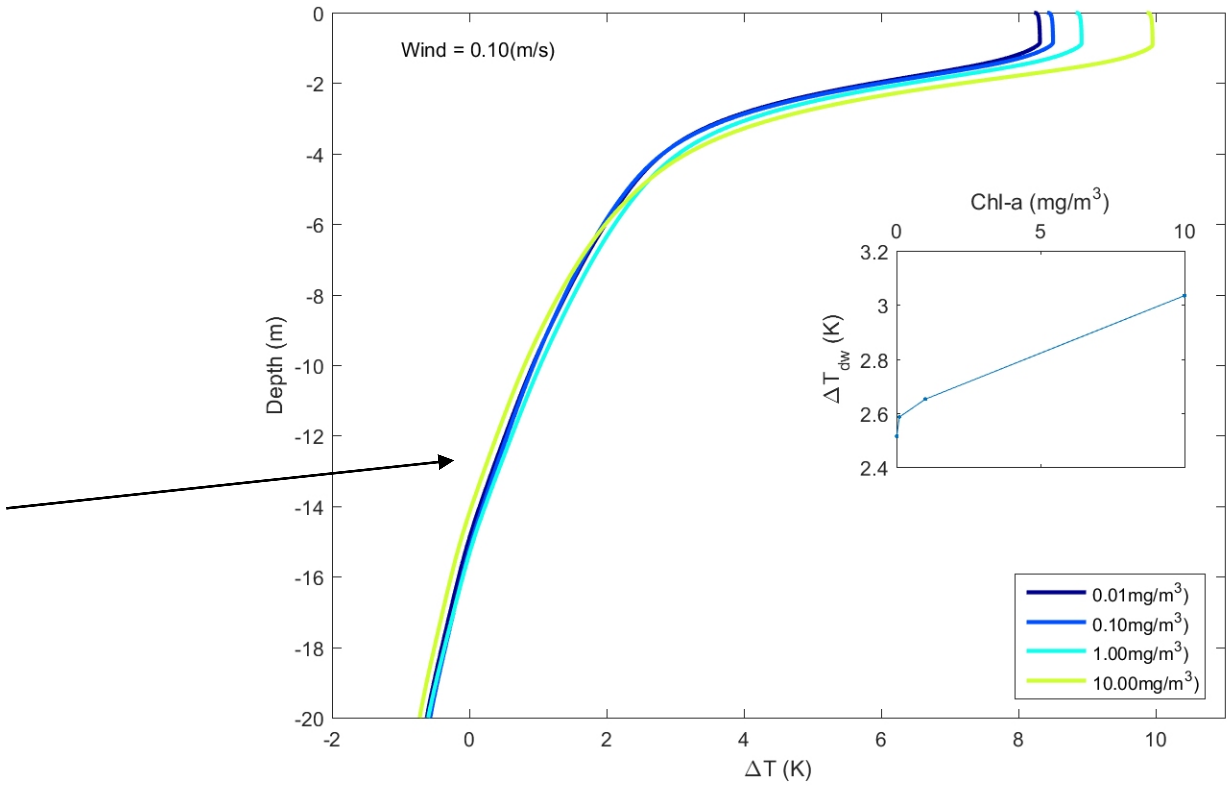
A and absorption coefficients depend on water type

$$I(z) = I_o\left(A e^{\frac{z}{\eta_1}} + (1-A)\left(\beta e^{\frac{z}{k_1}} + (1-B) e^{\frac{z}{k_2}}\right)\right)$$

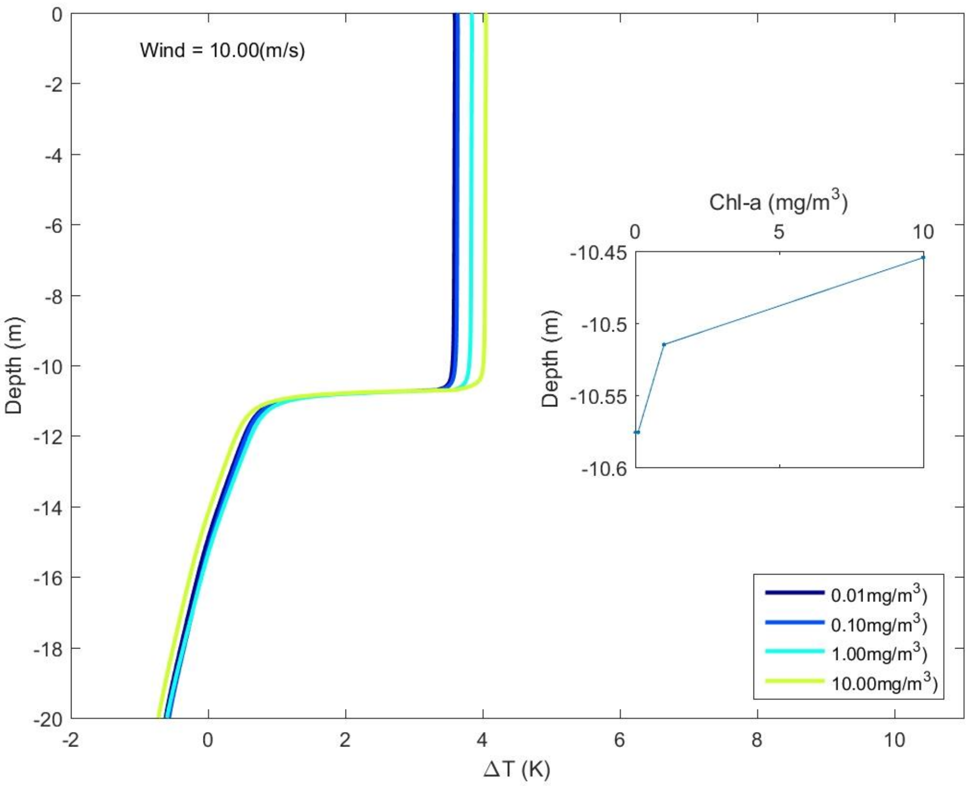
Constant partitioning visible light in spectrum

η, k_1, k_2 calculated suing Sathyendranath&Platt 1988

Impact of Chl-a at low winds



Impact of Chl-a at high winds

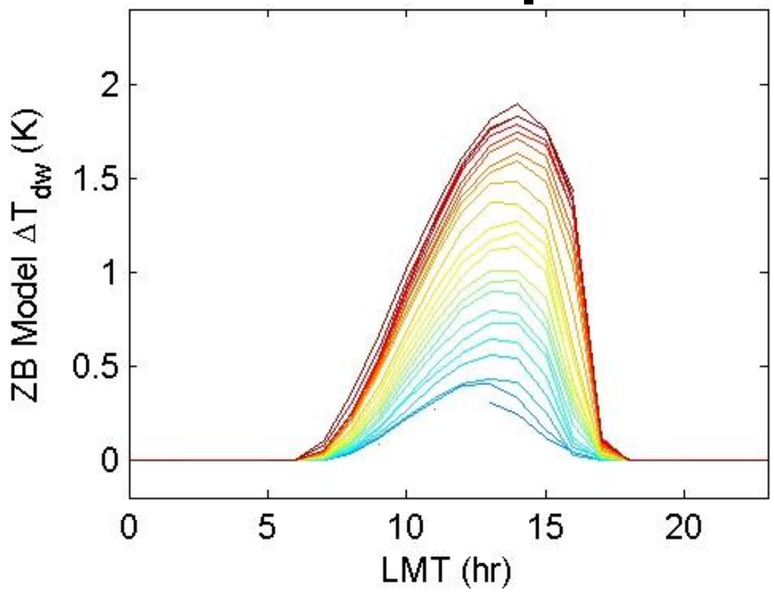


GOTM results

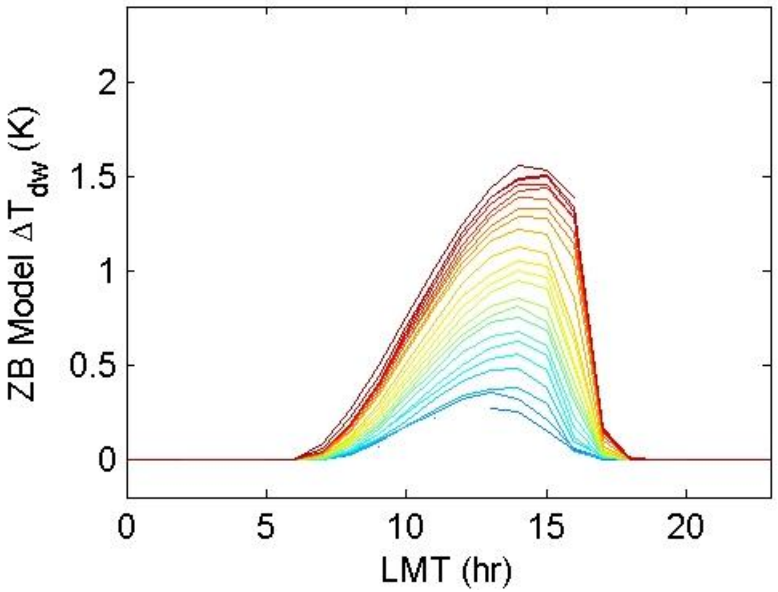
- Diurnal layer depth varies ~linearly for increasing wind speeds
- Chlorophyll-a concentration impacts DW more at low-medium wind speeds

Impact of depth on amplitude

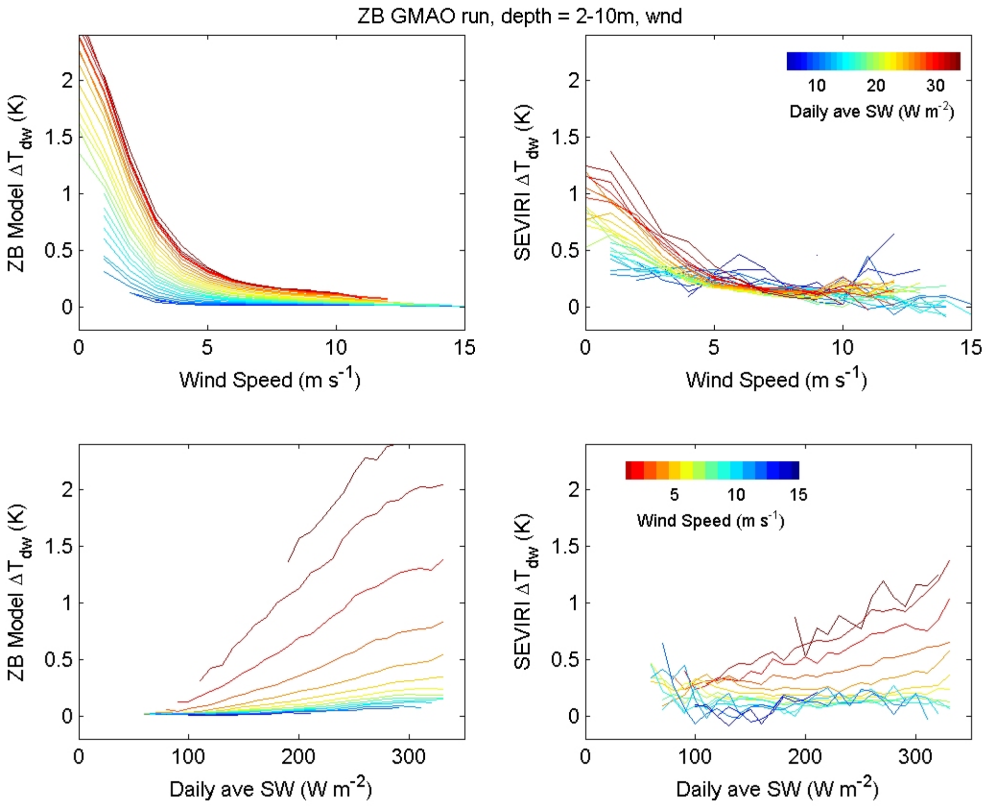
3m depth



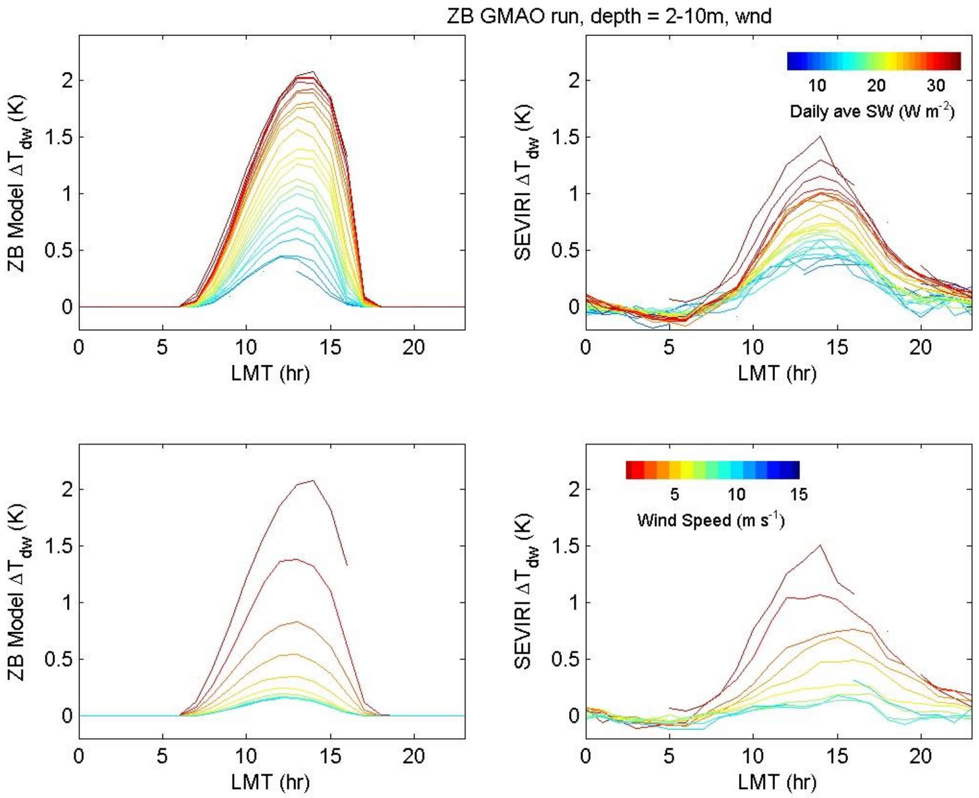
5m depth



Depth dependent on wind



Depth dependent on wind



Conclusions

- Changing depth shifts warming later in day
- Changing shape of warming profile (v) sensible, but needs to be carefully done
- Decrease in warming still not correct
- Working to implement GOTM model derived (v) profile with changes in depth simultaneously