5TH WORKSHOP ON WAVES AND WAVE-COUPLED PROCESSES

10 April 2024 —— 12 April 2024, ECMWF

Do swells contribute to surface mixing?
Results from machine learning models for SST diurnal warming and cool skin

Haoyu Jiang, Chaoyi Wu

College of Marine Science and Technology,

China University of Geosciences

Haoyujiang@cug.edu.cn

Introduction

Nonbreaking wave induced mixing has been widely accepted

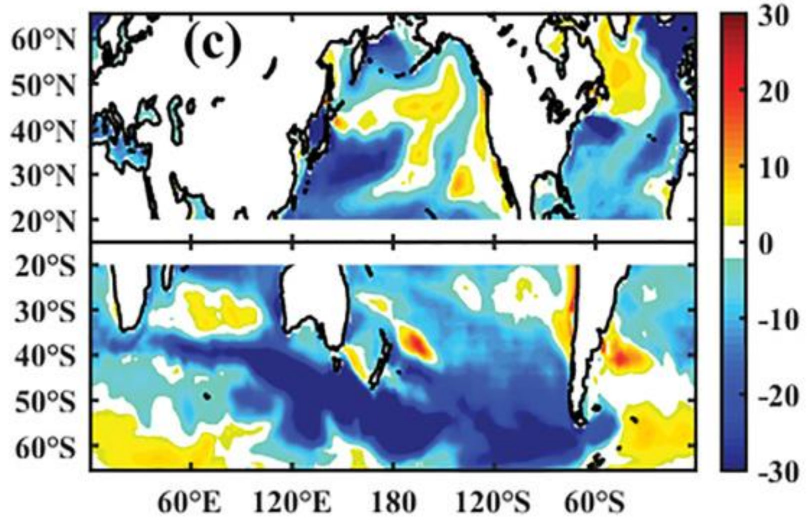
- The knowledge of upper ocean mixing processes is of fundamental importance for ocean circulation models.
- Wave breaking and wave-induced Langmuir circulation processes enhance turbulence and lead to mixing.
- Recently, more attentions have been paid to non-breaking wave induced ocean mixing.
- Non-breaking wave induced ocean mixing has related theoretical basis (e.g., Babanin 2006: Wave Reynolds Number).
- Considering wave-induced mixing can also improve the performance of ocean models and climate models (e.g., Qiao et al. 2004, Qiao et al. 2008, Chen et al. 2018).

$$\mathrm{Re} = \frac{aV}{\nu} = \frac{a^2\omega}{\nu}$$

ω: radian frequency
a: wave amplitude
V = wa :orbital velocity
ν : kinematic viscosity of the water

$Re_{cr} \approx 3000$

Critical Re for the onset of turbulence

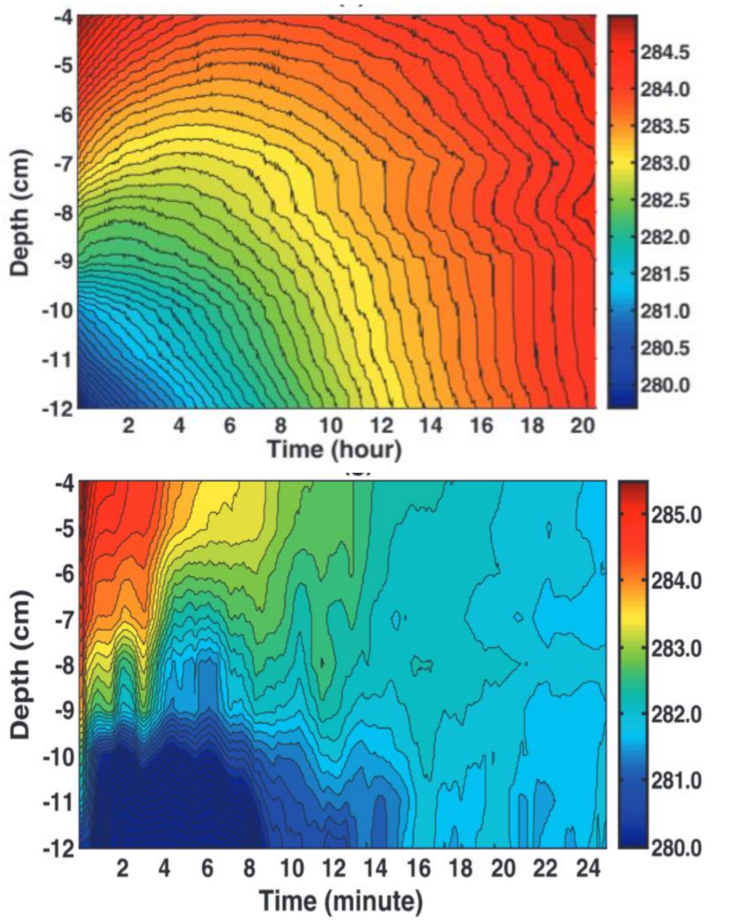


Mean winter MLD difference between the models with and without Bv (Chen et al. 2018)

Introduction

But not much field observational evidence can be found

- However, it seems not much observational evidence can be found on non-breaking wave induced mixing/turbulence.
- In a water tank, sidewalls, bottom, and sometimes even the (contact) sensors, can lead to turbulence, impacting the mixing condition.
- In field experiments, it is difficult to isolate the mixing induced by different factors (including the introduction of contact sensors).

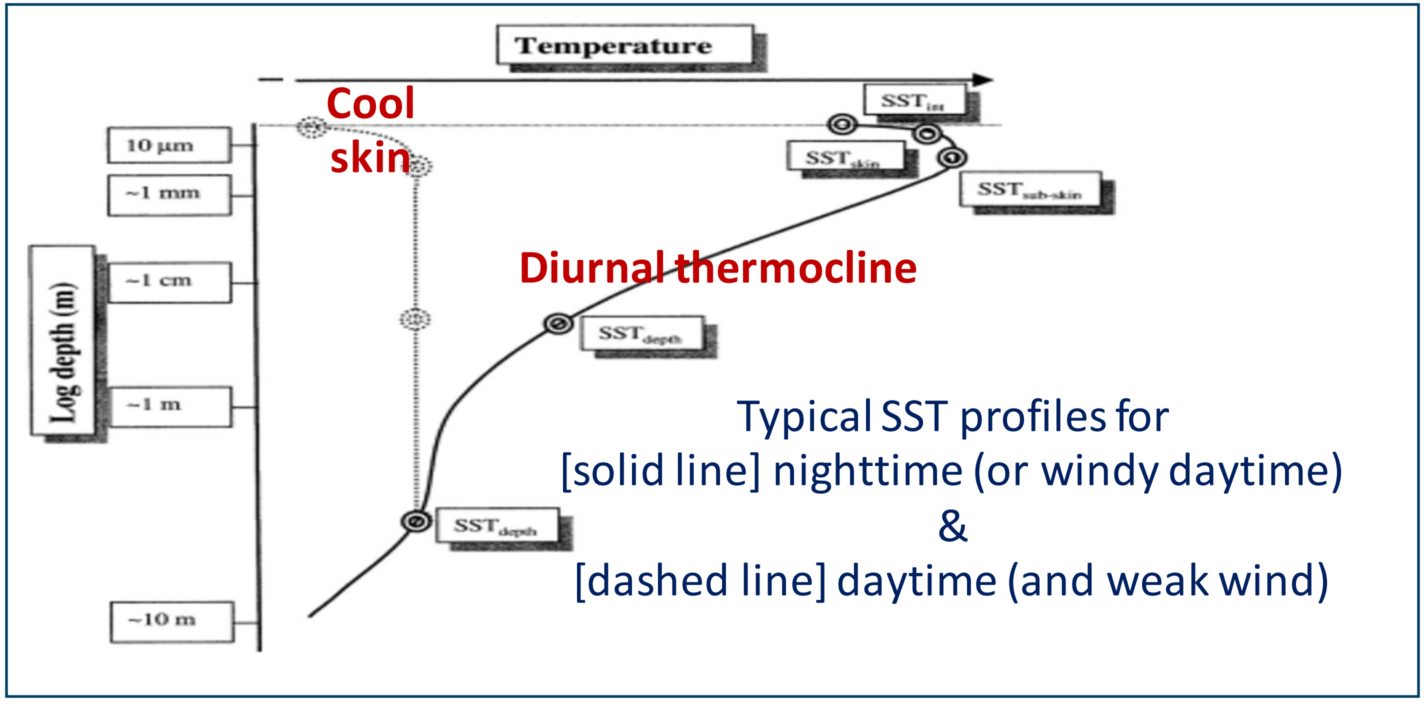


Evolution of the water temperature profile with and without nonbreaking waves (H=3cm/L=75cm) in a water tank (Dai et al. 2010)

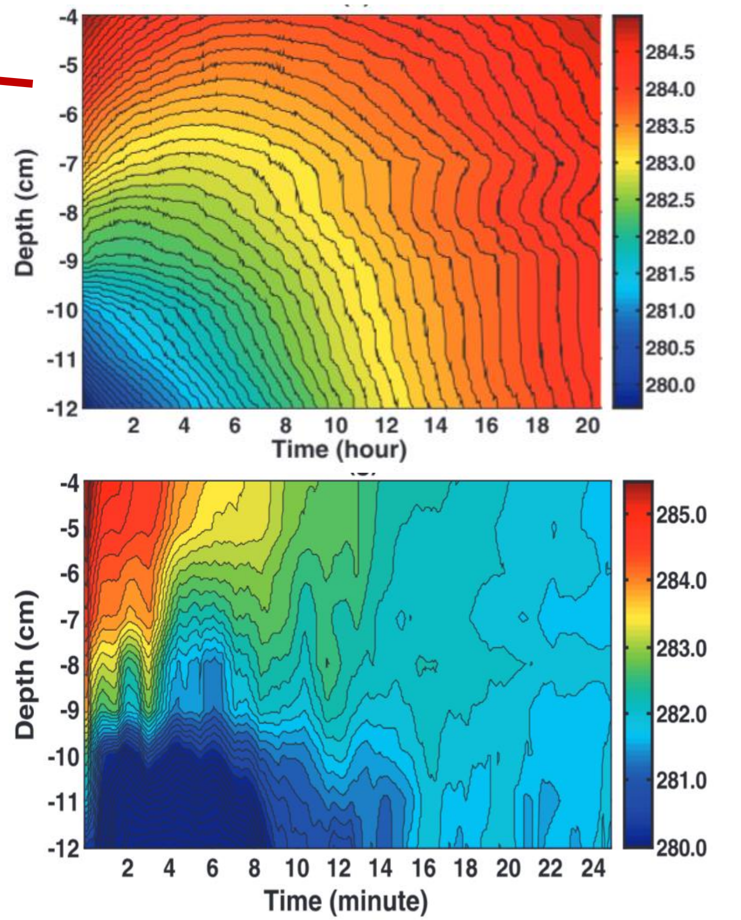
Introduction

Cool skin & diurnal warming as indicator for surface mixing?

- This is somehow similar to the Sea Surface Temperature (SST) profile related to diurnal warming



- **Cool skin & diurnal warming are strongly impacted by surface mixing**
- **Using cool skin & diurnal warming to study whether swells/nonbreaking waves contribute to surface mixing?**

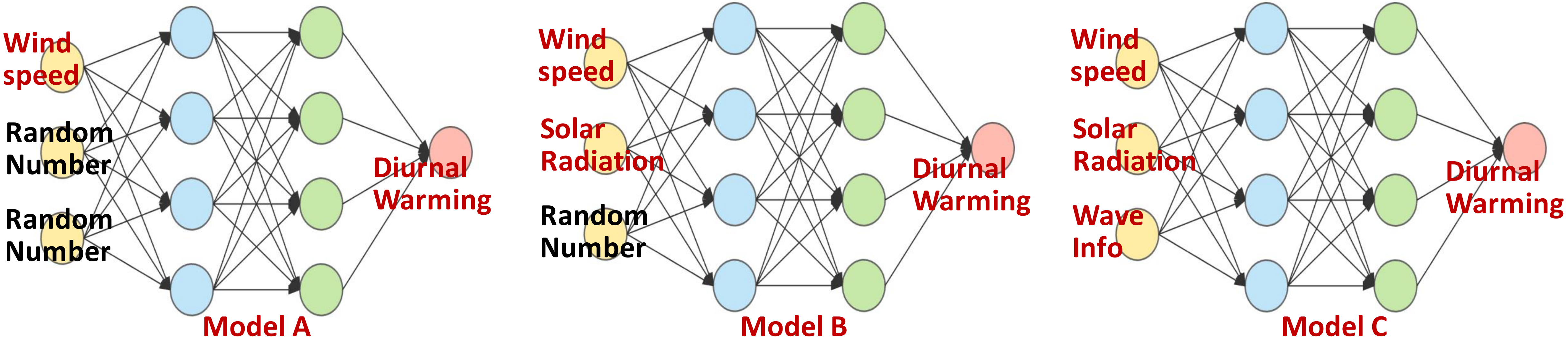


Evolution of the water temperature profile with and without nonbreaking waves (H=3cm/L=75cm) in a water tank (Dai et al. 2010)

Introduction

Separating the contribution of swells from other factors

- However, cool skin & diurnal warming are impacted by many factors (e.g., solar radiation, latent/sensible heat flux, wind speed, etc…)
- How to see whether one factor has contribution?
- **Establishing a machine learning model of cool skin / diurnal warming.**
- If a SWH is important for the prediction of cool skin / diurnal warming, adding SWH to the input term of the model will improve the model performance.
- Vice versa, if adding SWH to the input term of the model cannot improve the model performance, SWH is not important for the prediction of cool skin / diurnal warming, thus, not contributes significantly to surface mixing.



Data & Method

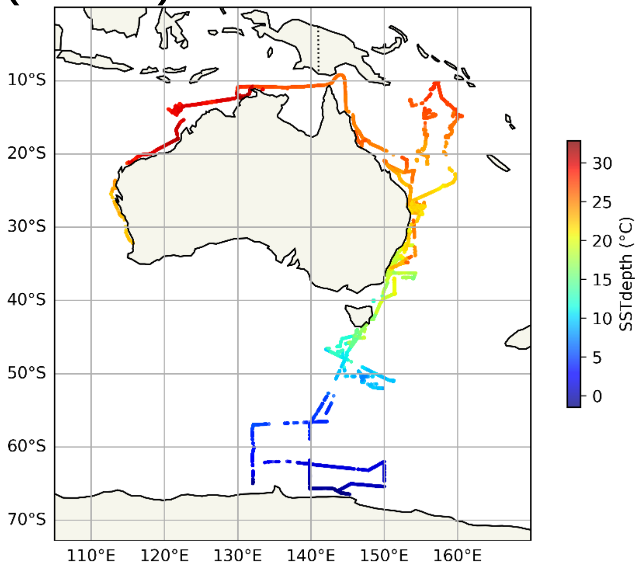
Cool skin data

- ➢ Integrated Marine Observing System (IMOS) R/V
- **Skin Temperature (SSTskin)** from infrared radiometer ISAR-5D
- **SSTdepth** from SeaBird SBE 38 temperature sensor (~7 m depth)
- **10-m wind speed (U10) & Relative Humidity (RH) & LongWave radiation (LW)** from weather station
- Quality controlled using Zhang et al. (2018)

ΔSST = SSTskin - SSTdepth

- ➢ Only nighttime data (sun zenith angle>110°) was used to avoid the impact of diurnal warming

- ➢ ERA5 data (0.5deg)
- **Significant Wave Height (SWH)**

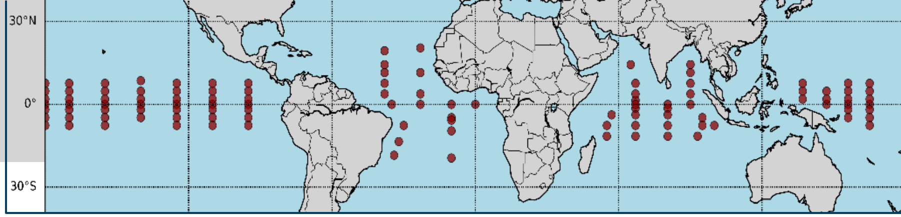


Ship route and corresponding SSTdepth

ISAR on the ship

Data & Method

Diurnal warming data



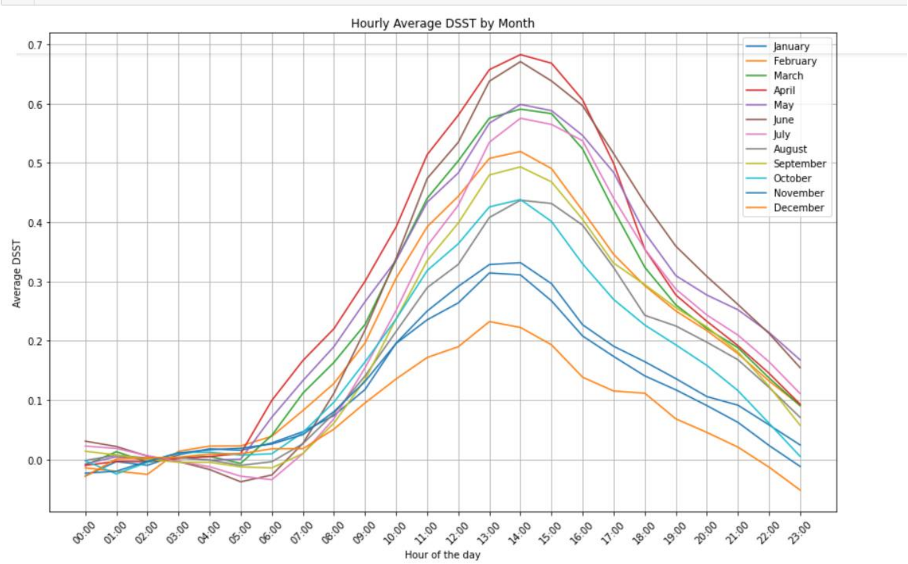
Locations of TOGA buoys

- ➢ Tropical Ocean Global Atmosphere (TOGA) buoys
- **SST** from temperature sensors
- **10-m wind speed (U10)** & **ShortWave radiation (SW)** from weather station

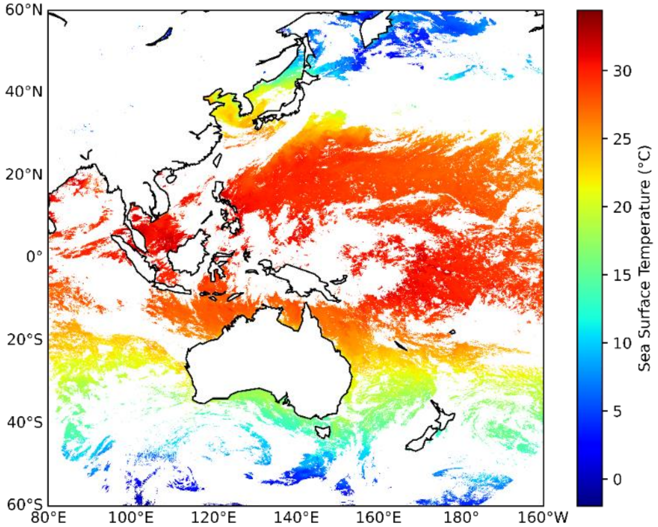
- ➢ Geostationary satellite Himawari-9 remote sensing data (L3 version 2.1)
- **SST:** 1-h × 0.02° → 1-h × 0.2° (reducing random noise)

- ➢ ERA5 data (0.5deg)
- **SWH U10 SW**

DW= SST(13:00~15:00)
– SST (1:00~5:00)



Climatology of SST diurnal variation in different month from Himawari-9 data



An example of Himawari-9 SST on 15 June 2023

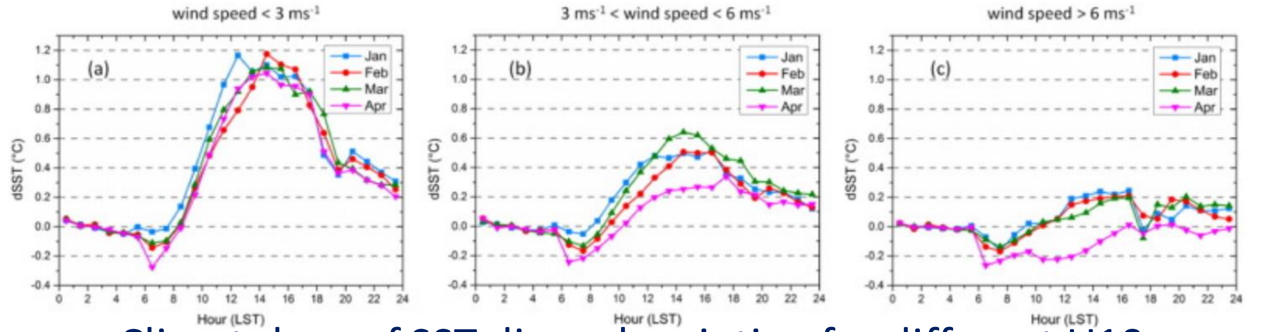
Data & Method

Machine Learning Models

- Two types of models (tree model: XGBoost / neural network: ANN) were used to predict cool skin & diurnal warming. [No significant difference between them]
- 50% training / 50% validation
- Previous studies have shown that cool skin is dependent on U10, RH, & LW,

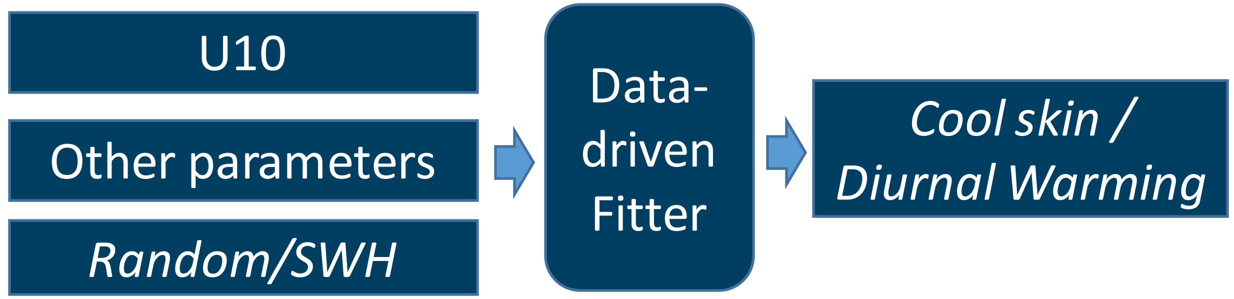
  and diurnal warming is dependent on U10 & SW
- U10 is related to breaking waves so we further test if introduce SWH can help the prediction.

• Low wind high SWH: Strong swells
• Low wind low SWH: Weak swells



Climatology of SST diurnal variation for different U10

< 3 m/s)   3~6m/s   >6m/s



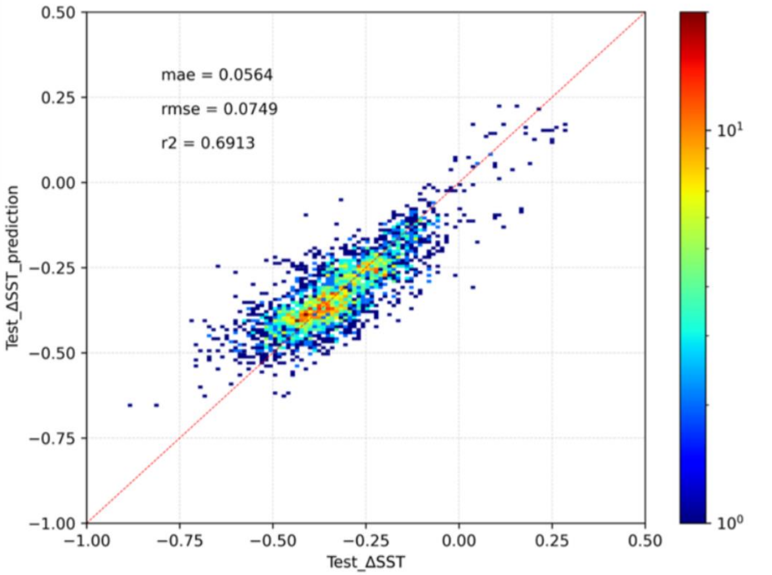
Schematic of the machine learning model used in this study

- **YES→Swells contribute to mixing**

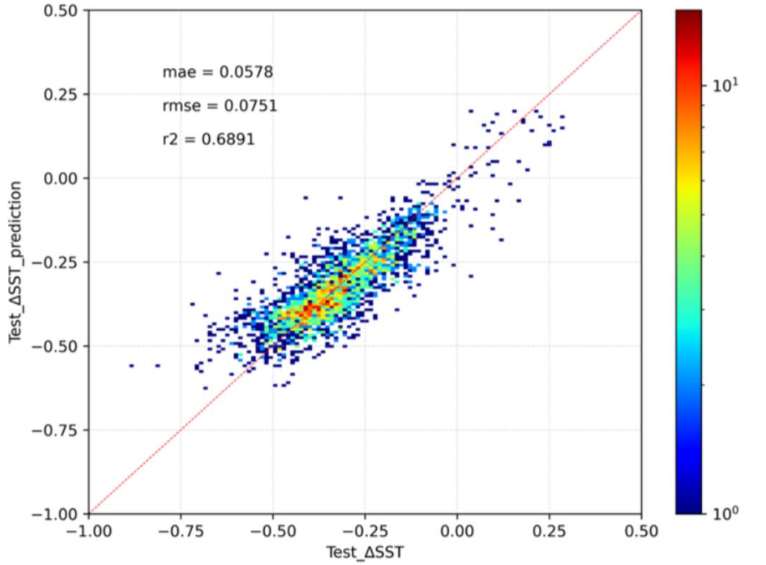
NO→Swells not contribute to mixing

Results

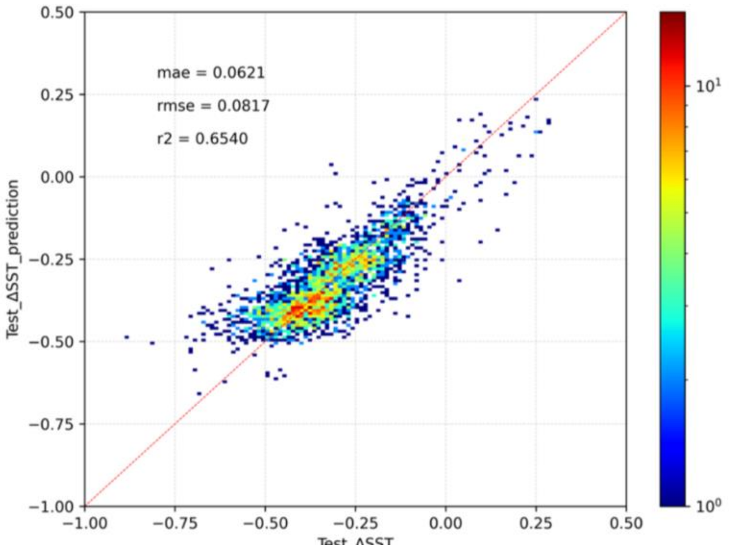
Model Evaluation —— Cool Skin



INPUT: U10 + RH + LW
RMSE = 0.075℃ R= 0.83



INPUT: U10 + RH + LW**+SWH**
RMSE = 0.075℃ R= 0.83

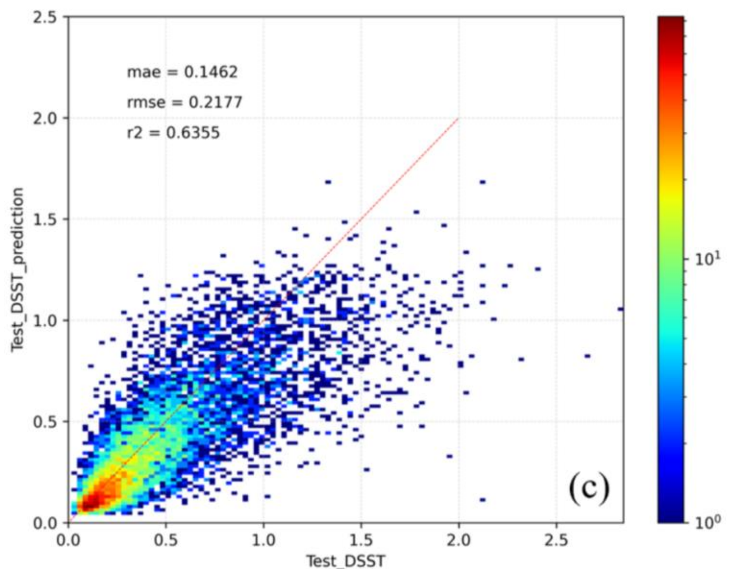


INPUT: RH + LW **(-U10)**
RMSE = 0.082℃ R= 0.81

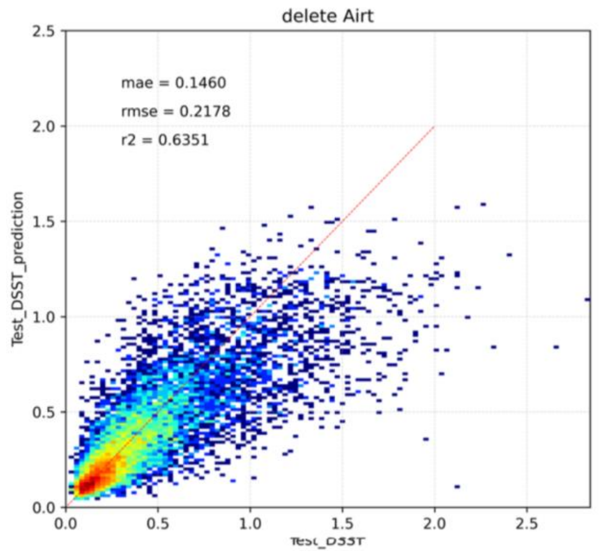
- Adding SWH seems not to be helpful for the prediction of cool skin.
- This dataset cannot support the contribution of swells in surface mixing.
- Data coverage is short, the inter-dependence between different parameters might be too strong. [Even removing U10 slightly (but significantly) impacts the prediction]
- Maybe also because the formation of cool skin is too fast? (within seconds)

Results

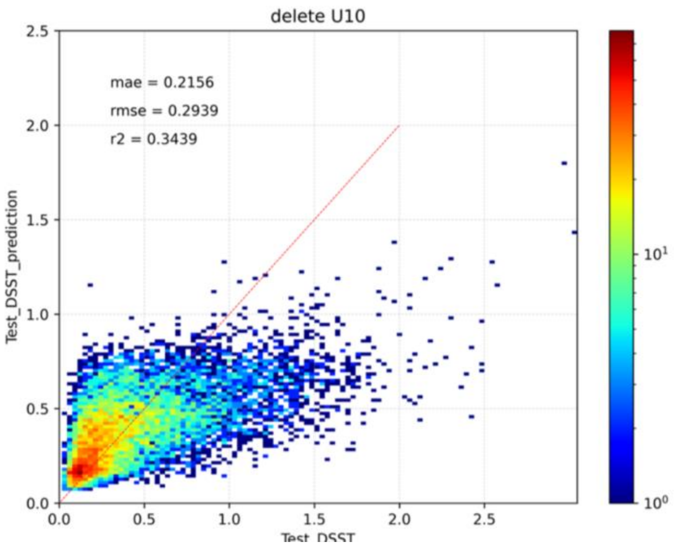
Model Evaluation —— Diurnal Warming



INPUT: U10 + SW (TOGA)
RMSE = 0.22℃ R= 0.80



INPUT: U10 + SW **+ SWH** (TOGA)
RMSE = 0.22℃ R= 0.80

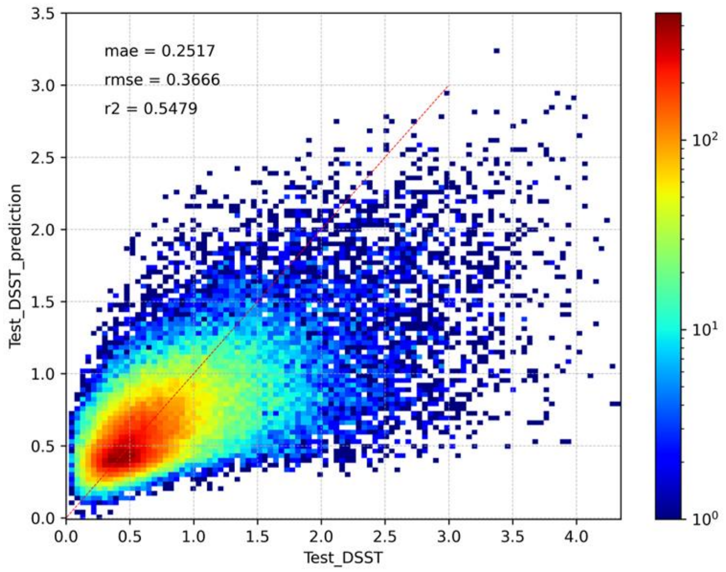


INPUT: SW **(-U10)** (TOGA)
RMSE = 0.29℃ R= 0.59

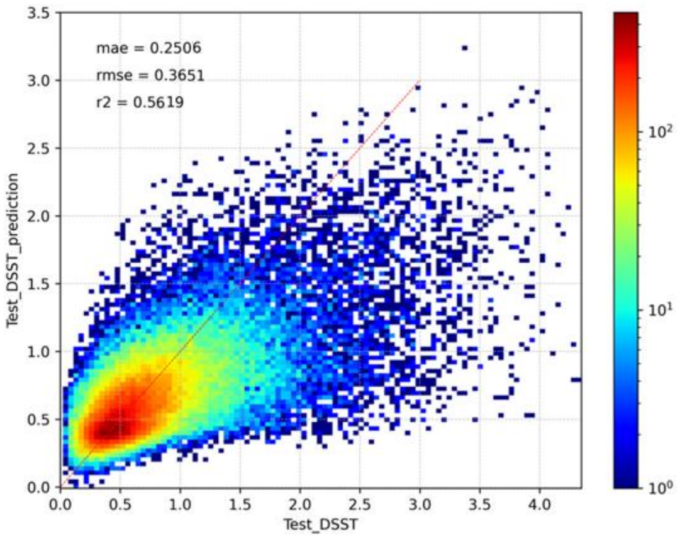
- Adding SWH also seems not to be helpful for the prediction of diurnal warming.
- Again, the result cannot support the contribution of swells in surface mixing.
- Different locations and long span, almost no over-fitting issue [Removing U10 largely impacts the prediction]

Results

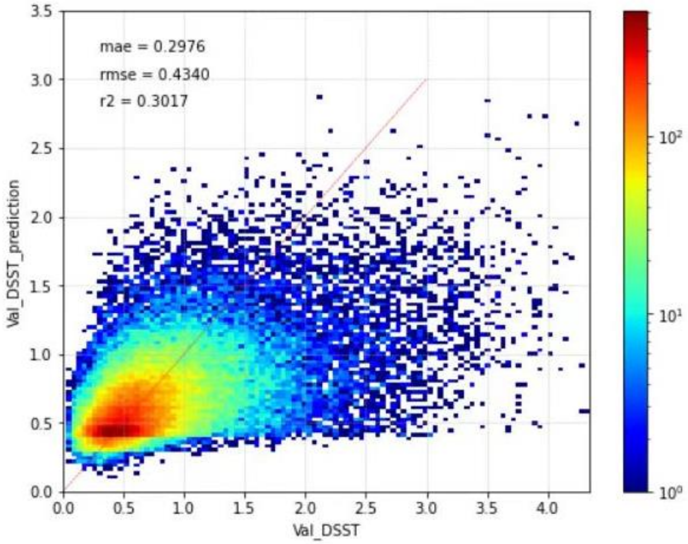
Model Evaluation —— Diurnal Warming



INPUT: U10 + SW (Hiwamari-9)
RMSE = 0.37℃ R= 0.74



INPUT: U10 + SW **+ SWH** (Hiwamari-9)
RMSE = 0.37℃ R= 0.75



INPUT: U10 **(- SW)** (Hiwamari-9)
RMSE = 0.43℃ R= 0.55

- The satellite data shows a similar result.

Summary

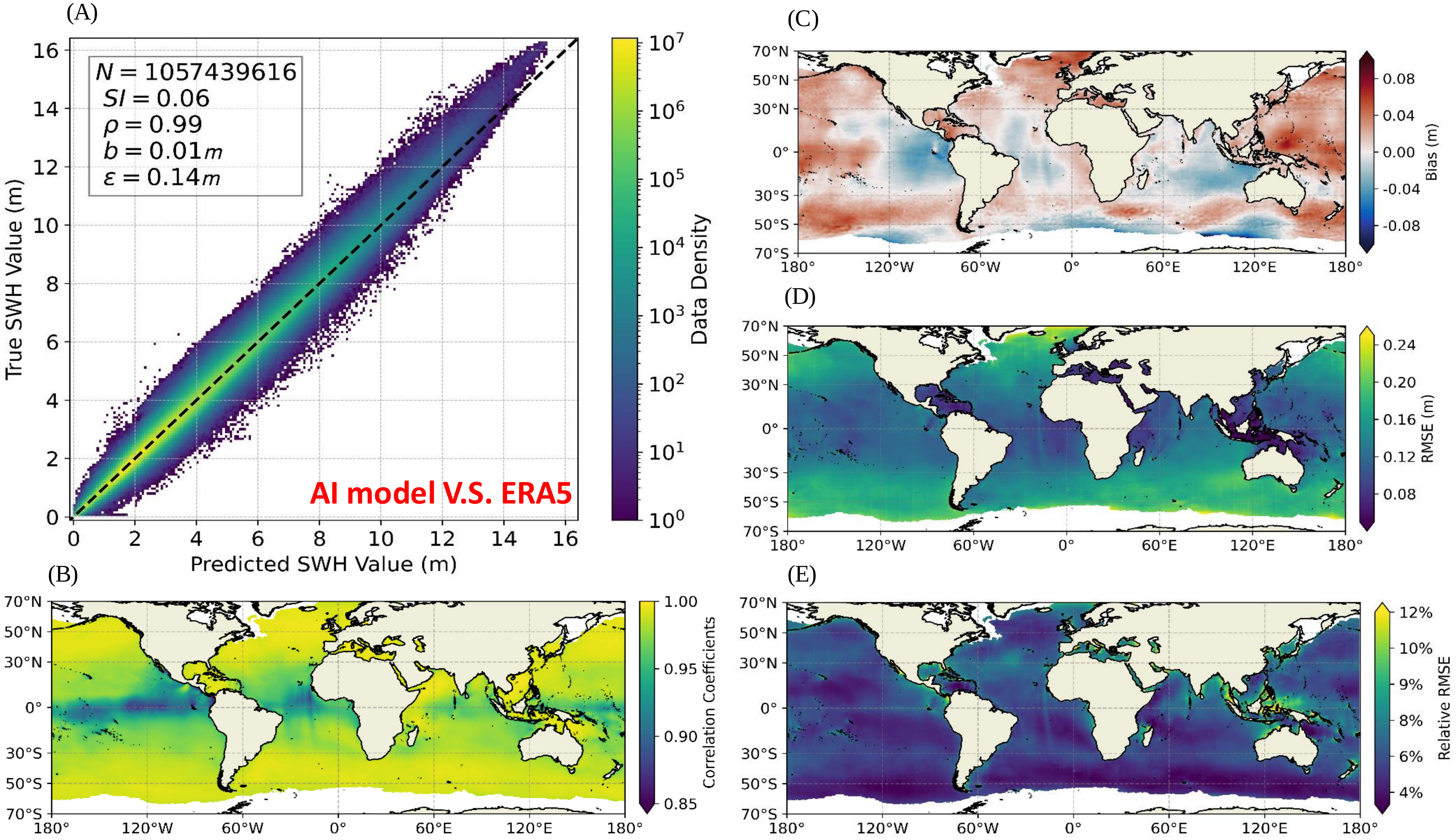
- Data-driven models were trained to predict the magnitude of cool skin and diurnal warming.
- We tried to used U10 and U10+SWH as the input of the model during model training.
- Adding SWH as input is not helpful for a better prediction.

- Does it mean swells do not contribute to surface mixing?
- Maybe it is because something is wrong with my understanding to this issue but I failed to realize.

Criticism is welcome!

Thank you!

Haoyujiang@cug.edu.cn



0.5 hour for 1-yr (0.5 deg 3h) modelling on a PC