CFOSAT Wave Field from Wind-Wave Model

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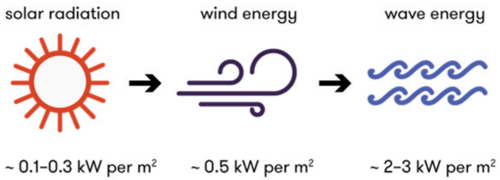
Content

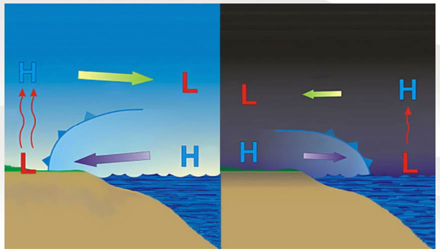
1 Background

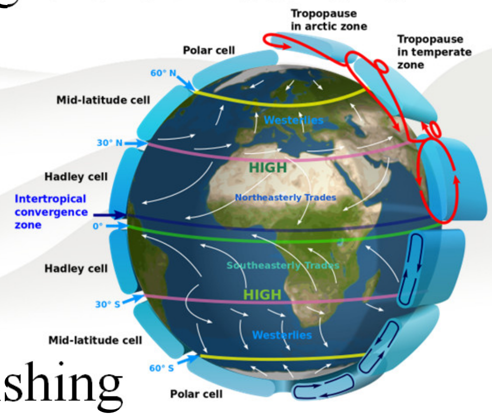
(a)、Wind and waves are the main factors to control the momentum and heat exchanges between the ocean and atmosphere



Solar radiation is converted by wind energy, then to wave energy. The amount of energy per unit volume becomes more concentrated. –Falnes, J.(2007), *Marine Structure20:185-210*

(b)、Wind and waves play critical roles at various scales in regulating the climate and weather system





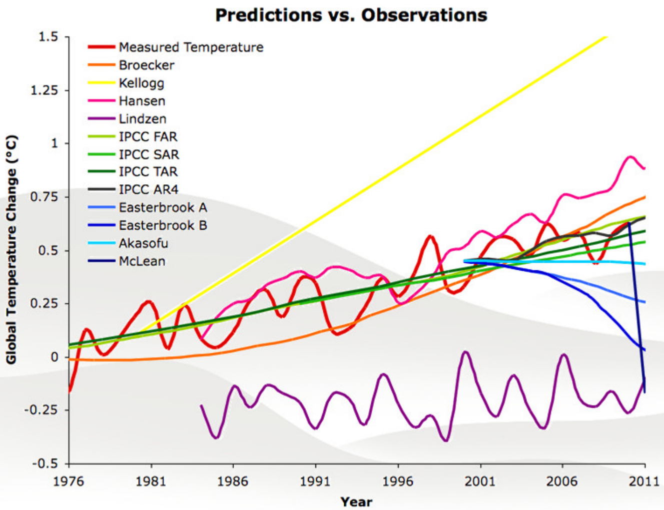
(c)、Wind and waves are crucial information for maritime shipping and fishing

An average of three ships displacing more than 500 tones are sunk every week--European Space Agency

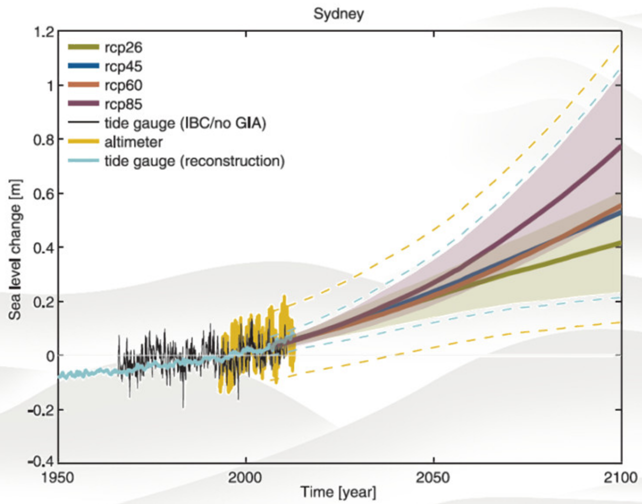
*Figures adopted from web

1 Background

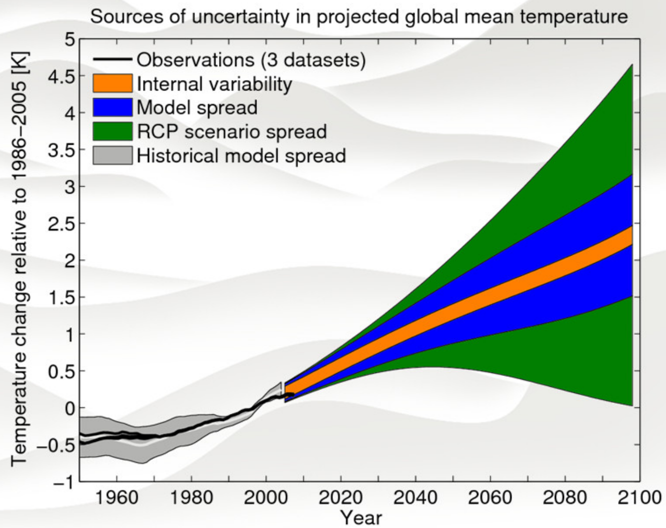
The incomplete knowledge about the air-sea interaction is one of the main sources of the uncertainty of climate models.



Various best estimate global temperature predictions evaluated in the 'Lessons from Past Climate Predictions'. https://skepticalscience.com/search.php?Search=Predictions_150

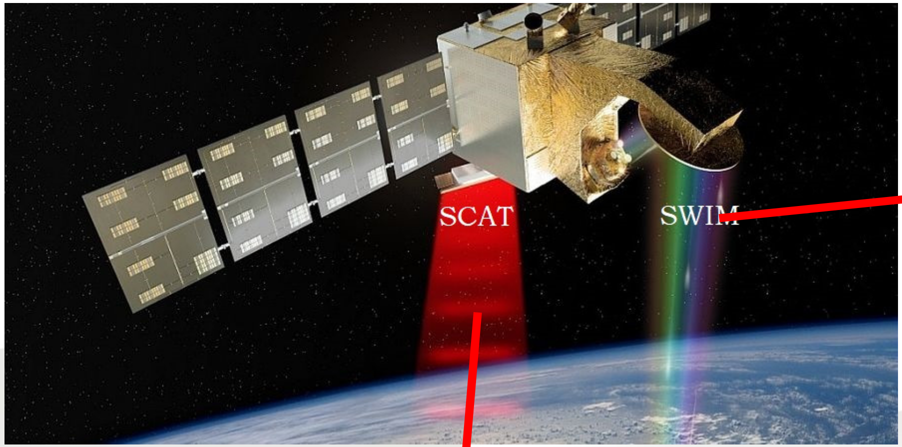


Sea level observed and projected for Sydney. Sourced at Climate Change in Australia, https://www.climatechangeinaustralia.gov.au/en/climateprojections/coastal-marine/marine-explorer/



The sources of uncertainty in global decadal temperature projections, Ed Hawkins, 2013:https://www.climate-lab-book.ac.uk/2013/sources-of-uncertainty/

1 Background



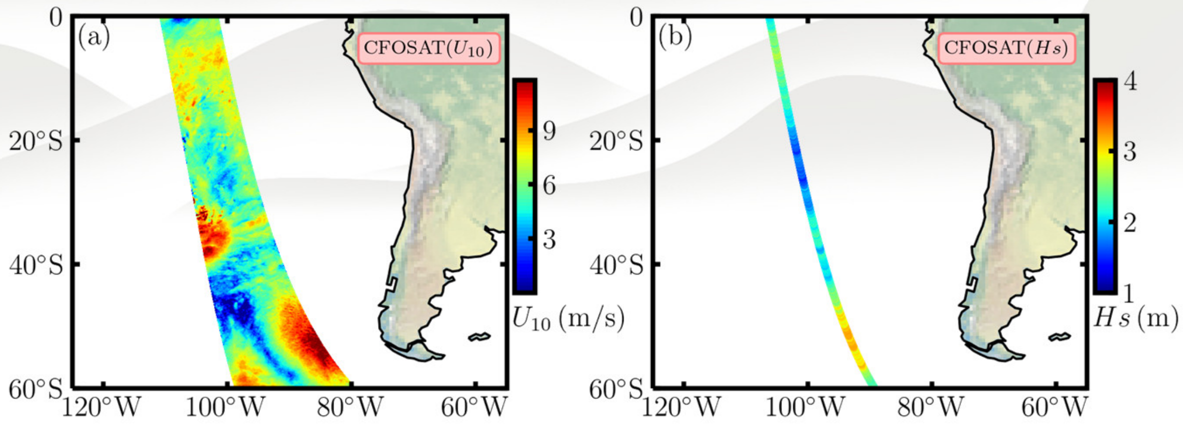
CFOSAT spacecraft in orbit (image credit: CNES)

Significant wave height (*Hs*) provided by the Surface Waves Investigation and Monitoring radar (SWIM)

- 1.5 km resolution for nsec data
- Nadir observation

Wind speed (U_{10}) data collected by the Wind-field SCATterometer (SCAT)

- 12.5 km resolution
- 1000 km swath



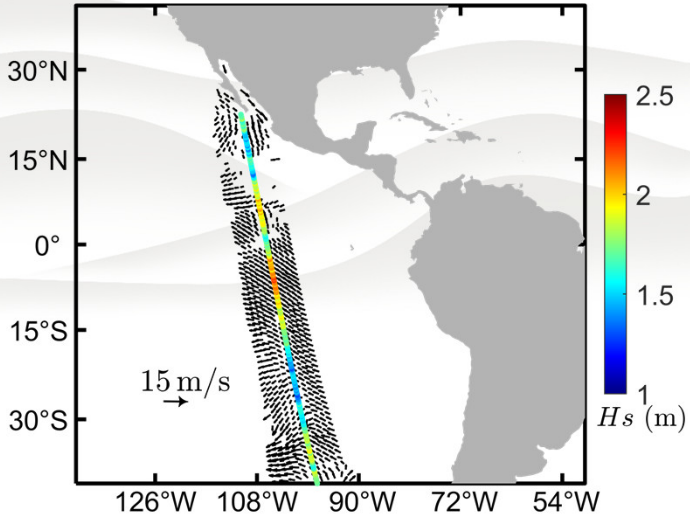
Instantaneously observed (a) wind and (b) wave data by CFOSAT

1 Background

lack of observed *Hs* data → ill-defined wind-wave theories

→ insufficient knowledge of air-sea interaction

→ uncertainty of models

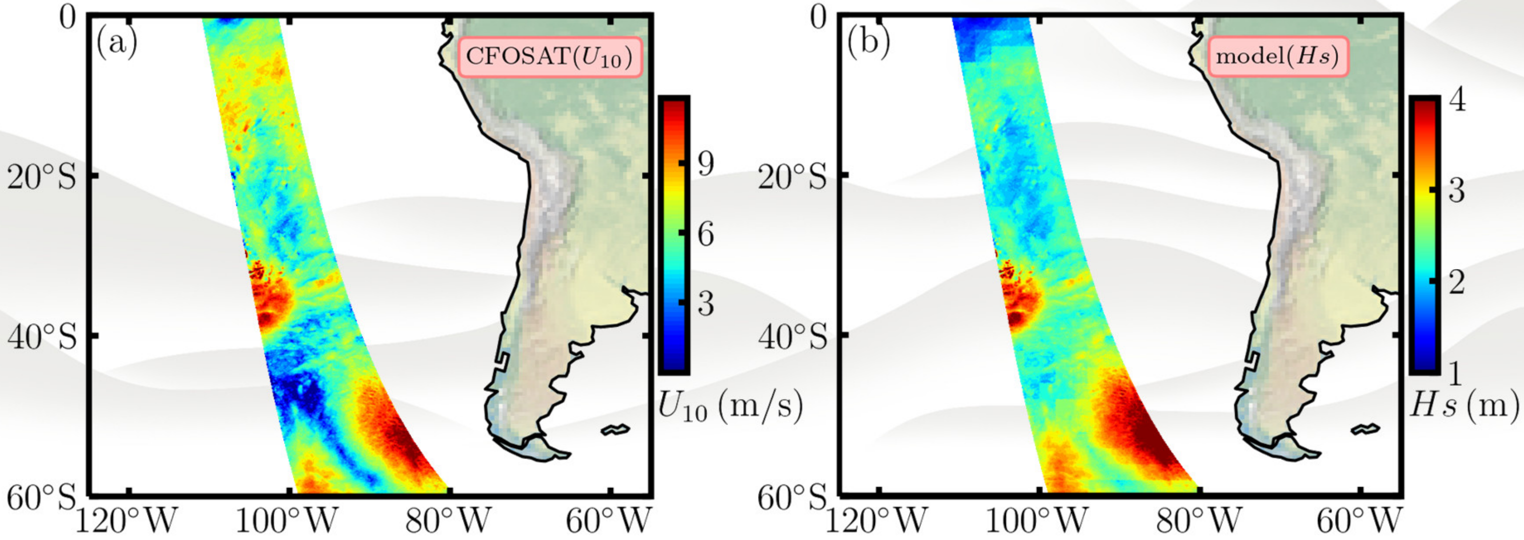


Simultaneously observed wind and wave data by CFOSAT

1 Background

What if we know the relation between wind and waves?

Hs 🔗 U_{10}



CFOSAT observed (a) wind and (b) wind-wave model produced wave field.

1 Background

Previous wind-wave relations

Pierson and Moskowitz (1964)

- fully developed sea
- ignore swell waves

$$E(f) = \alpha g^2 (2\pi)^{-4} f^{-5} e^{-\frac{5}{4}(\frac{f_m}{f})^4}$$

$$Hs \approx 0.0246 {U_{10}}^2$$

Pierson (1922-2003)

Moskowitz (1936-)

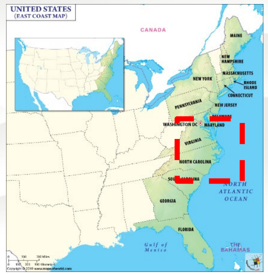
WAM Model (WAMDI Group, 1988)

- fully developed sea
- ignore swell waves

$$Hs = \begin{cases} 1.614 \times 10^{-2} {U_{10}}^2, 0 \le U_{10} \le 7.5\text{m/s} \\ 10^{-2} {U_{10}}^2 + 8.314 \times 10^{-4} {U_{10}}^3, 7.5 \le U_{10} \le 30\text{m/s} \end{cases}$$

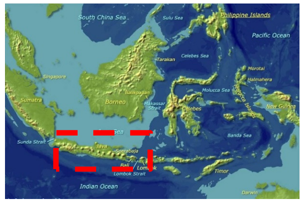
Andreas and Wang, 2007

$$Hs = \begin{cases} C(D), 0 \le U_{10} \le 4\text{m/s} \\ a(D) {U_{10}}^2 + b(D), U_{10} > 4\text{m/s} \end{cases}$$



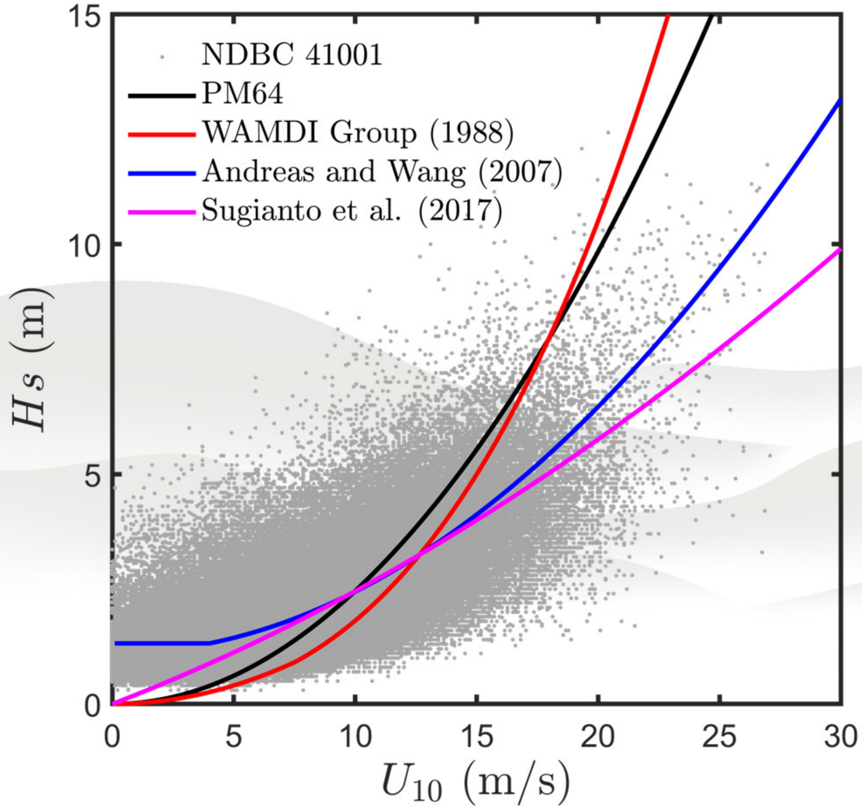
Sugianto et al., 2017

$$Hs = a {U_{10}}^2 + b U_{10}$$



1 Background

Previous wind-wave relations



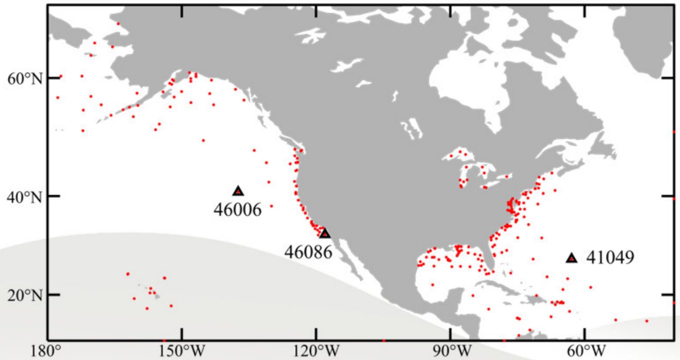
NDBC buoy 41001 observed U_{10} and Hs data, the solid curves are various wind-wave relations.

- Swell waves are ignored by most models
- Fully developed sea assumption
- Spatial limited
- Fixed scaling exponent

Swell identification +variable scaling exponent

2 Data

1、Buoy collected U_{10}, *Hs,* and wave spectra data provided by National Data Buoy Center (NDBC, https://www.ndbc.noaa.gov/)



Locations of NDBC buoys (red dots)

Illustration of a NDBC buoy 46086

Sampling frequency: hourly

Data length: longer than 15 years

Accuracies: 0.55 m/s for U_{10}, 0.2 m for *Hs*

Wind speed transform: a neutral stability logarithmic state of the marine atmospheric boundary layer, $U_{10}=1.084\ U_{4.1}$

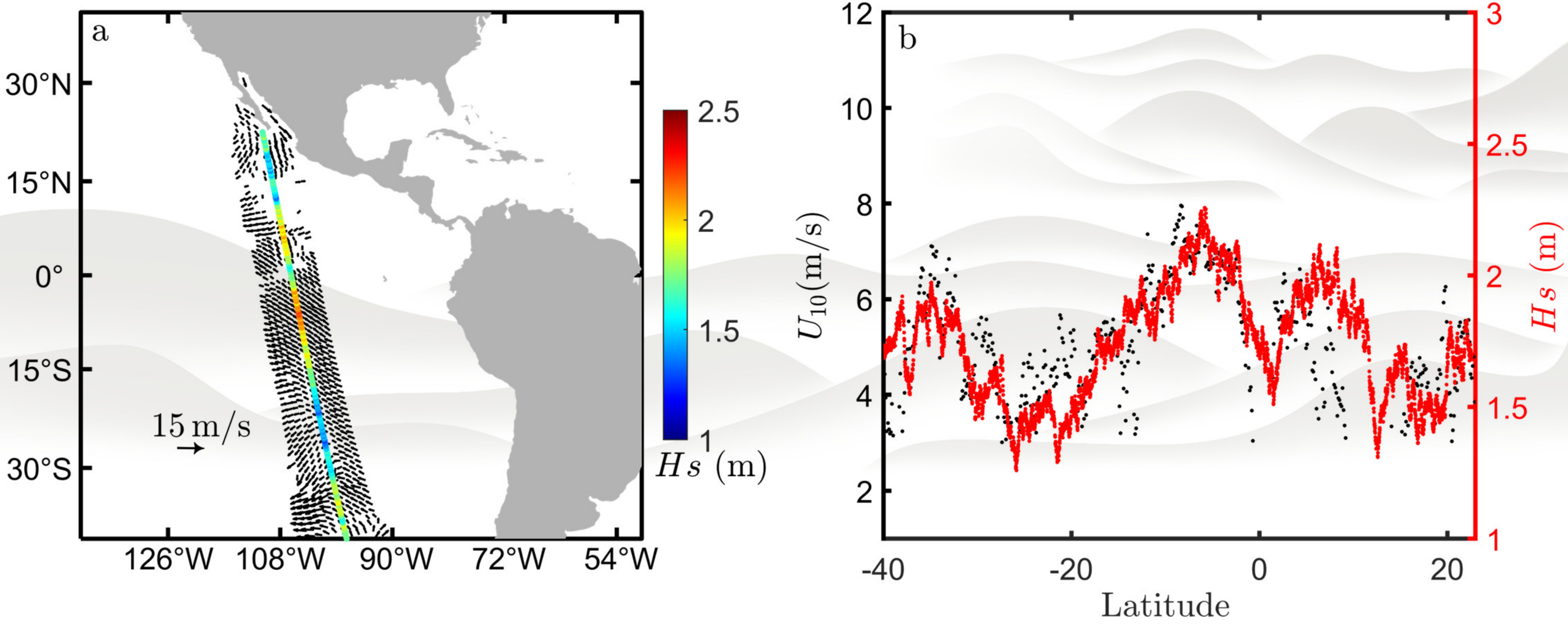
2、17 years of JASON calibrated U_{10} and *Hs* data (Ribal and Young 2019).

- JASON-1: January 2002 to June 2013
- JASON-2: July 2008 to July 2018
- JASON-3: February 2016 to July 2018

→ reassigned in 2°x2° boxes

2 Data

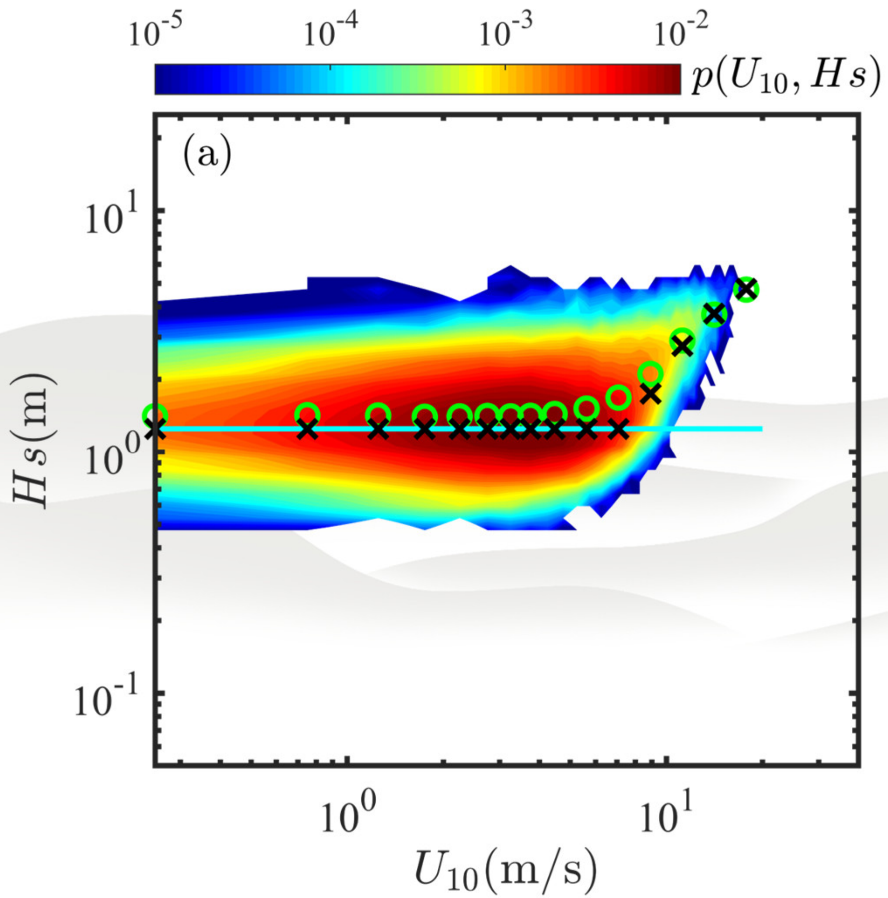
3、CFOSAT observed L2 wind and wave data (https://www.aviso.altimetry.fr/)



Simultaneously observed wind and wave data by CFOSAT

3 Generalized Wind-Wave Relation

➢ Swell wave



Joint probability density function for NDBC buoy 46086 collected U_{10} and Hs data

○ conditional mean $\overline{H}s$

× maximum probability of $\overline{H}s_0$

Assumption: swell wave dominates during the small winds

Swell significant wave height: Hs_{sw}

$Hs_{sw}(U_{10}) = \overline{H}s_0$, $U_{10} \leq U_{cr}$ (U_{cr} = 4 m/s)

when $p(U_{10}, Hs_0) = \max\{p(U_{10}, Hs_0)\}$

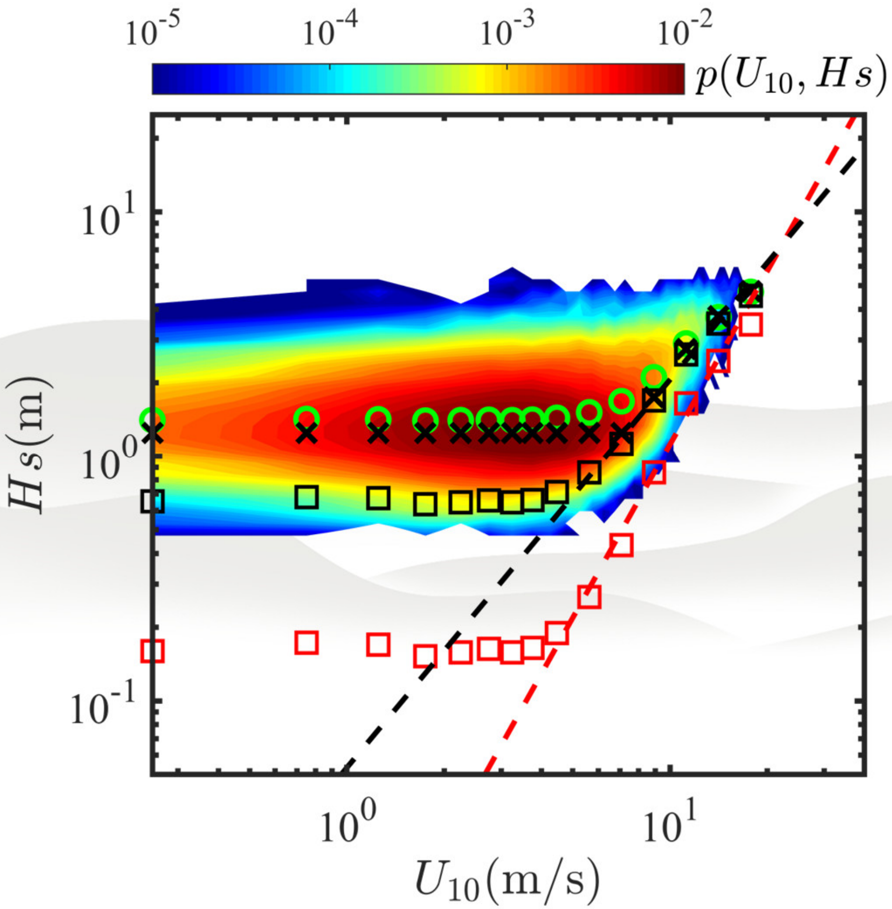
consequently：

$\overline{H}s_{sw} = \langle Hs_{sw}(U_{10}) \rangle_{U_{10} \leq U_{cr}}$=1.25 m

—— swell significant wave height

3 Generalized Wind-Wave Relation

- Local wind wave



Joint probability density function for NDBC buoy 46086 collected U_{10} and Hs data

□ Linear decomposition (Pandey et al.,1986;Chen et al., 2002; Andreas & Wang, 2007)

$$\overline{H}s_{Ll}=\overline{H}s-\overline{H}s_{sw}$$

□ Energy conserved decomposition (Bouws et al., 1998):

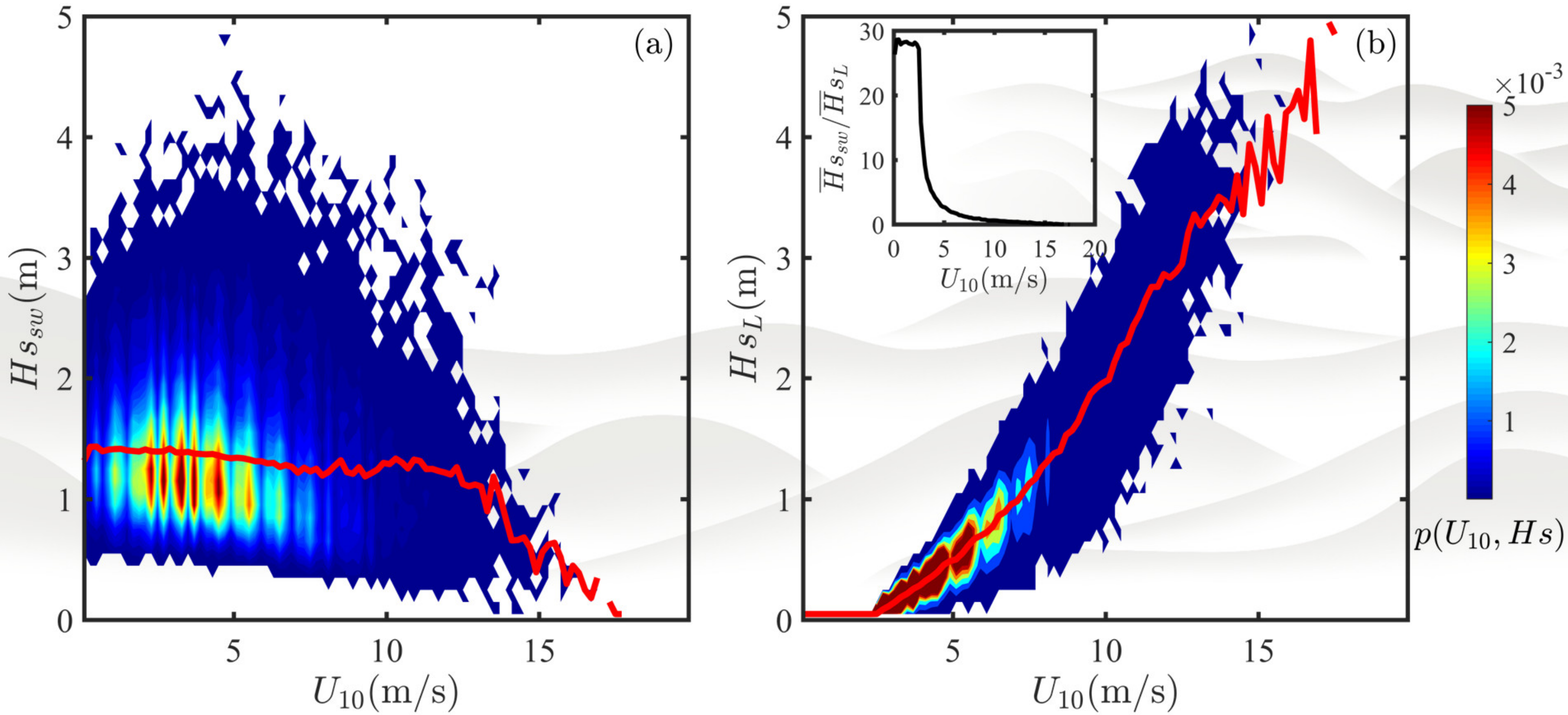
$$\overline{H}s_{Le}=\sqrt{\overline{H}s^{2}-\overline{H}s_{sw}^{2}}$$

- - - $\overline{H}s_{Ll}=\alpha_l U_{10}^{\eta_l}$

- - - $\overline{H}s_{Le}=\alpha_e U_{10}^{\eta_e}$

3 Generalized Wind-Wave Relation

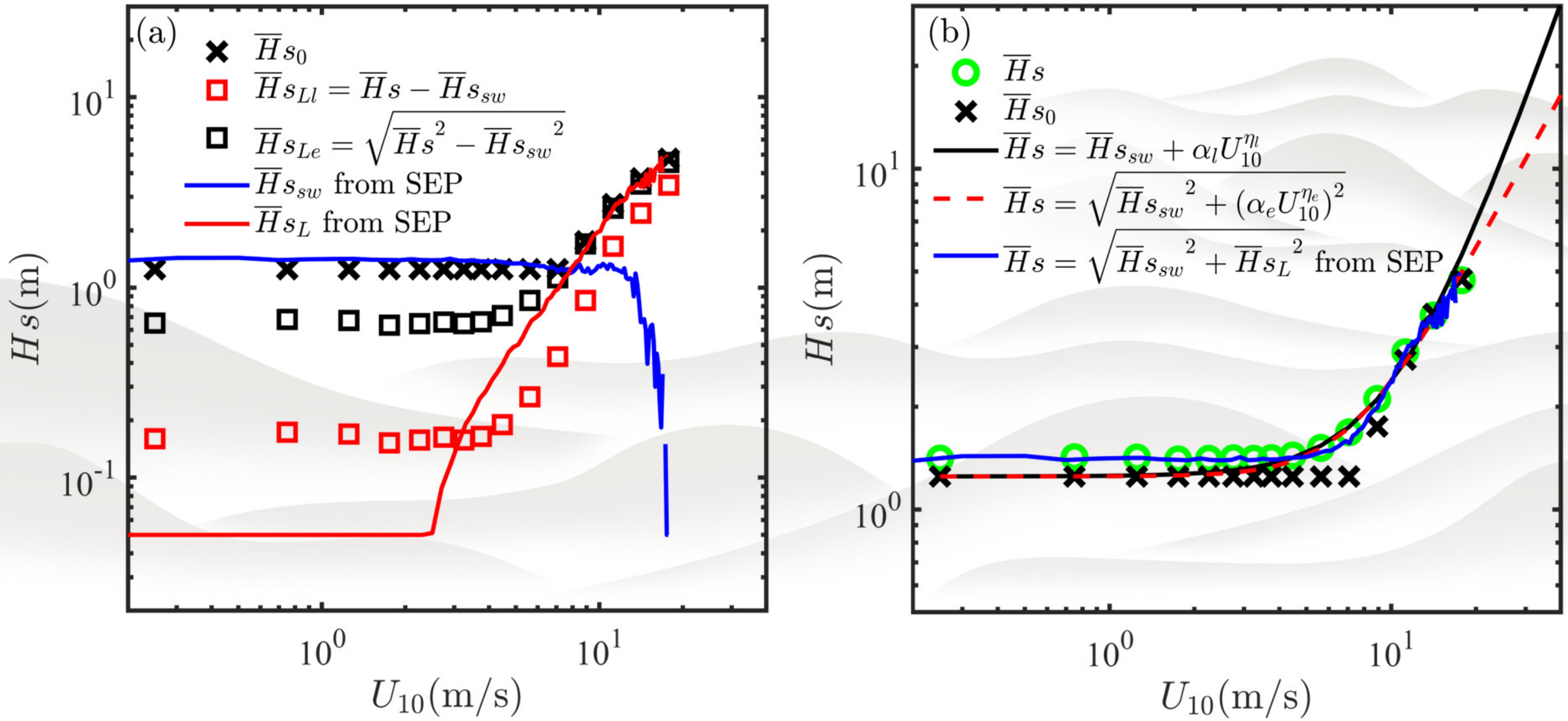
➢ Validation of the decomposition via spectral energy partitioning (SEP) analysis



Measured joint PDFs of (a) U_{10} and Hs_{sw}, (b) U_{10} and Hs_L extracted from the data provided by NDBC buoy 46086 with SEP analysis. The solid curves are the conditional average Hs. The inset in (b) shows the ratio between $\overline{H}s_{sw}$ and $\overline{H}s_L$ at various wind speeds.

3 Generalized Wind-Wave Relation

- Validation of the decomposition via spectral energy partitioning (SEP) analysis

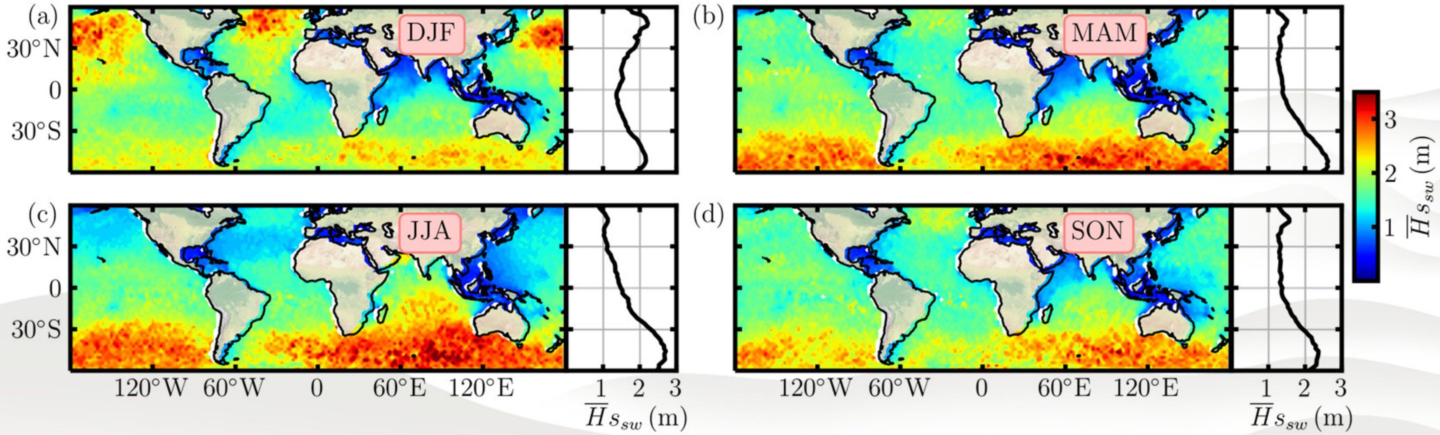


$\overline{H}s_{sw}$ from SEP is 1.35 m, slightly larger than the one from probability analysis (1.25 m) .

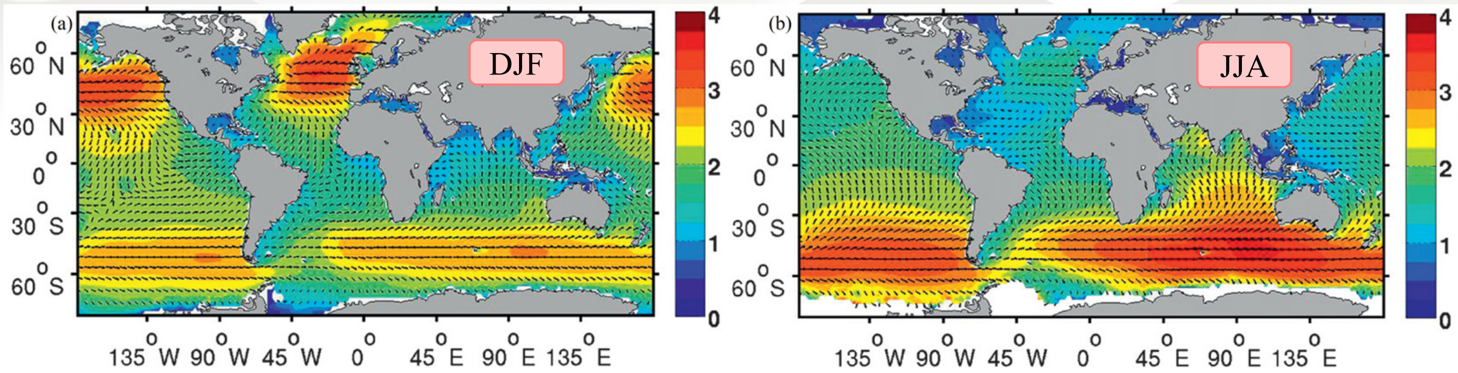
Reconstred $\overline{H}s$ are close to each other when $U_{10} \geq U_{cr}$.

4 Global Wind-Wave Relation

- Identified $\bar{H}s_{sw}$ from 17 years JASON data



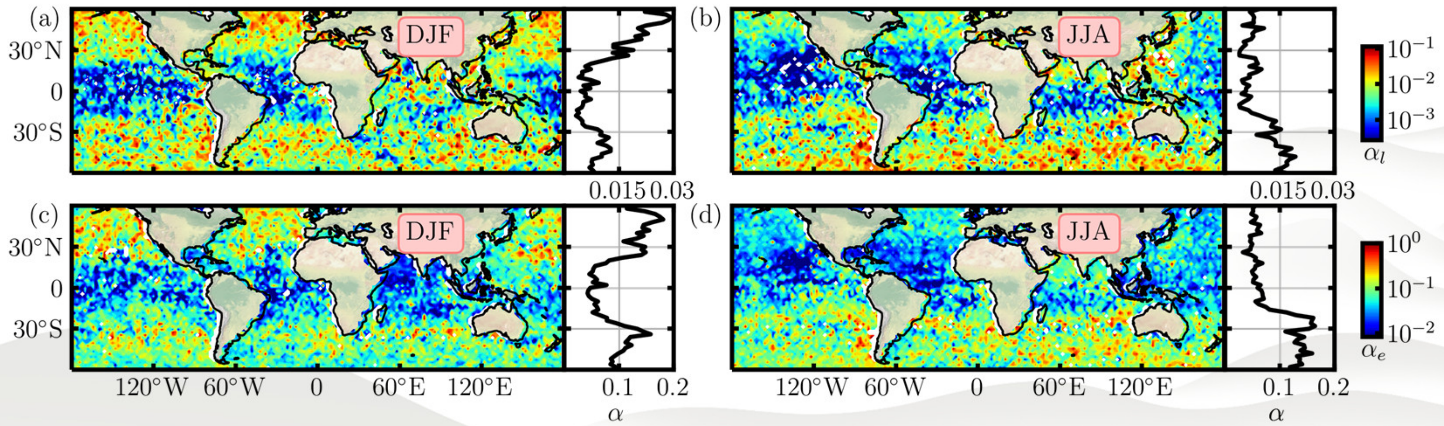
Global distributions of extracted $\bar{H}s_{sw}$ in (a) DJF and (b) MAM, (c) JJA, and (d) SON.



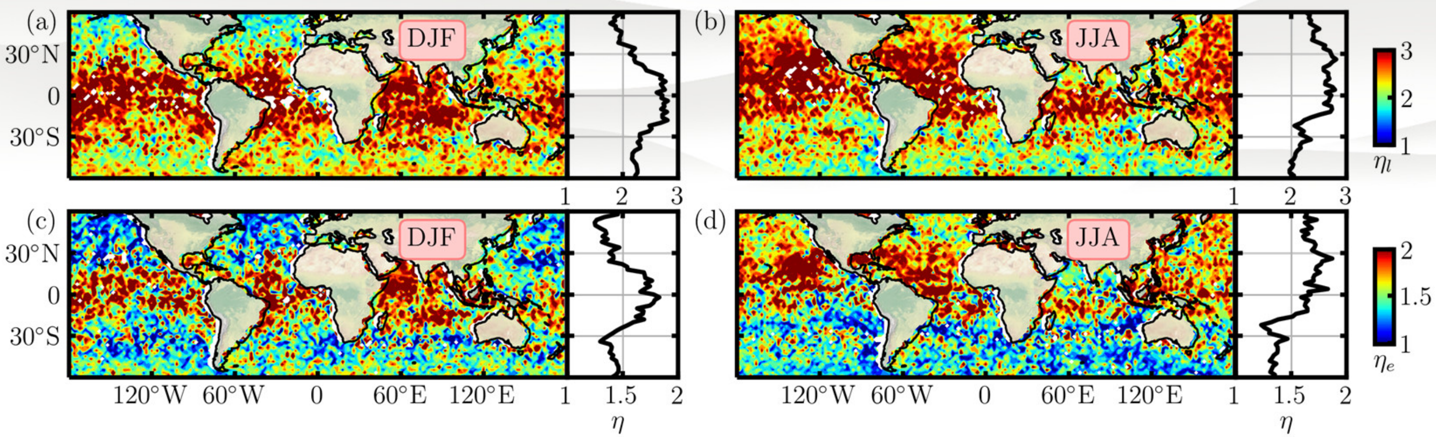
The global distributions of $\bar{H}s_{sw}$ separated by SEP analysis in (a) DJF and (b) JJA (Semedo et al., 2011).

4 Global Wind-Wave Relation

$$\bar{H}s_L=\alpha U_{10}{}^{\eta}$$



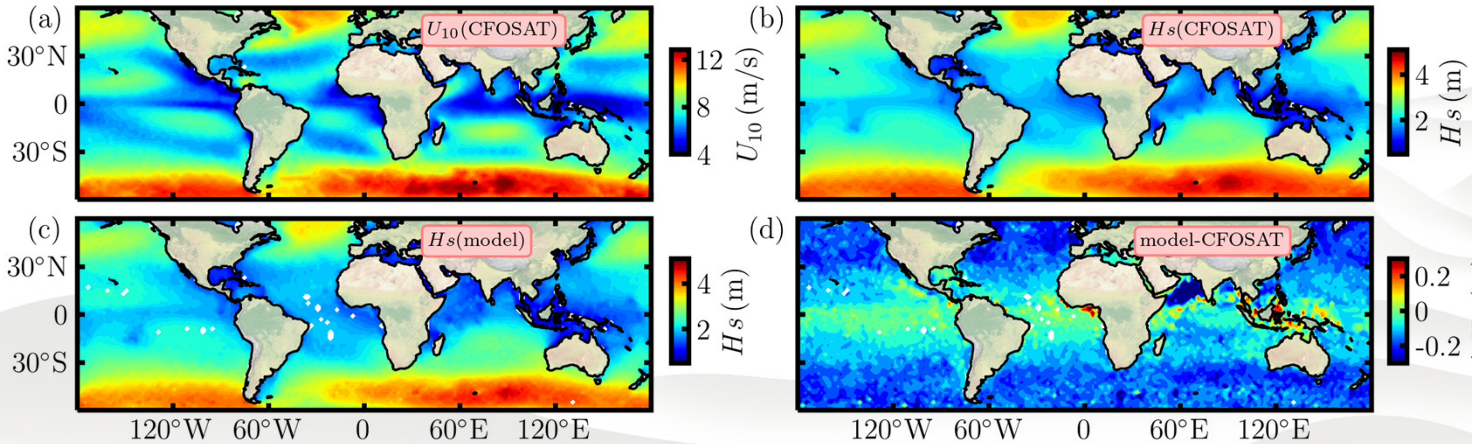
The global distributions of extracted α_l from $\bar{H}s_{Ll}$ in (a) DJF and (b) JJA . (c) and (d) are the α_e measured from $\bar{H}s_{Le}$ in DJF and JJA, respectively.



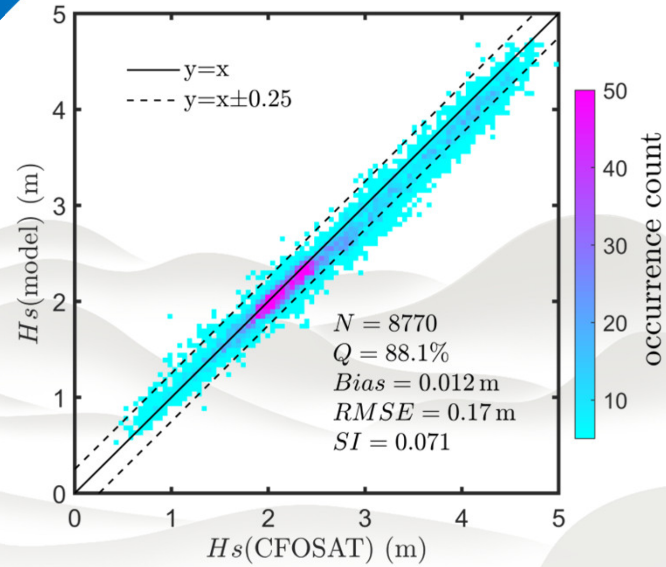
The global distributions of extracted η_l from $\bar{H}s_{Ll}$ in (a) DJF and (b) JJA. (c) and (d) are the η_e measured from $\bar{H}s_{Le}$ in DJF and JJA, respectively.

5 Wave Field from Wind-Wave Model

➢ CFOSAT wind+wind-wave relation model ➔ *Hs*



CFOSAT observed annually average (a)U_{10} and (b)Hs. (c) Hs generated by wind-wave relation. (d)The differences between model and observations.



Comparisons of *Hs* between model result and CFOSAT observation. The solid and dashed lines are given as references.

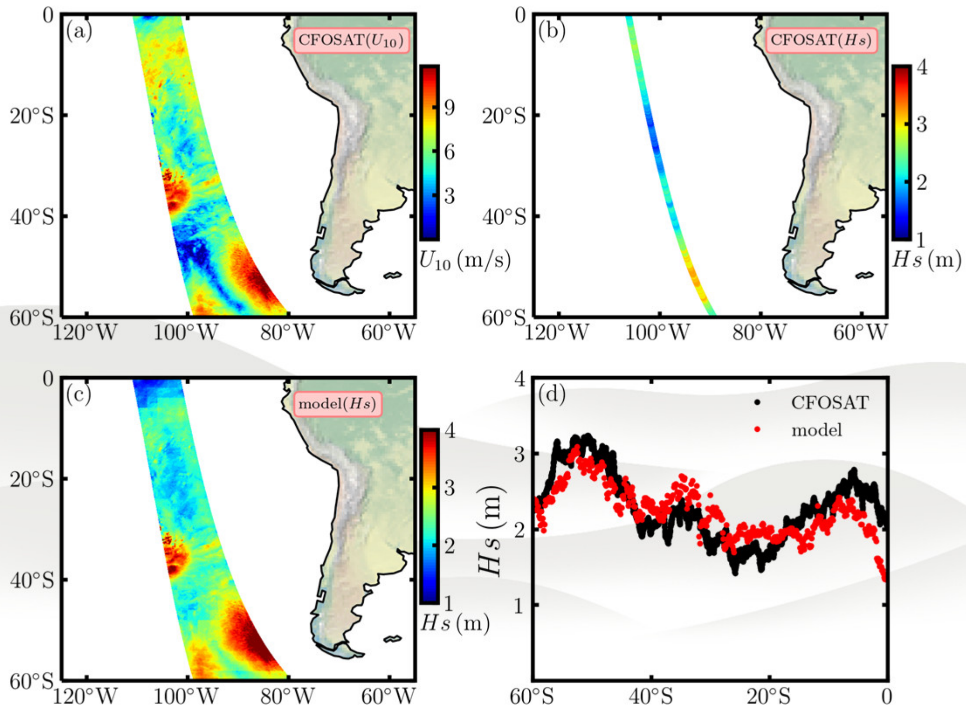
$$Q = \frac{Nq}{N} \times 100\%,\quad Bias = \frac{1}{N}\sum_{i=1}^{N}(M_i - O_i),\quad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)^2},$$

$$SI = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i - Bias)^2}}{\frac{1}{N}\sum_{i=1}^{N} O_i}$$

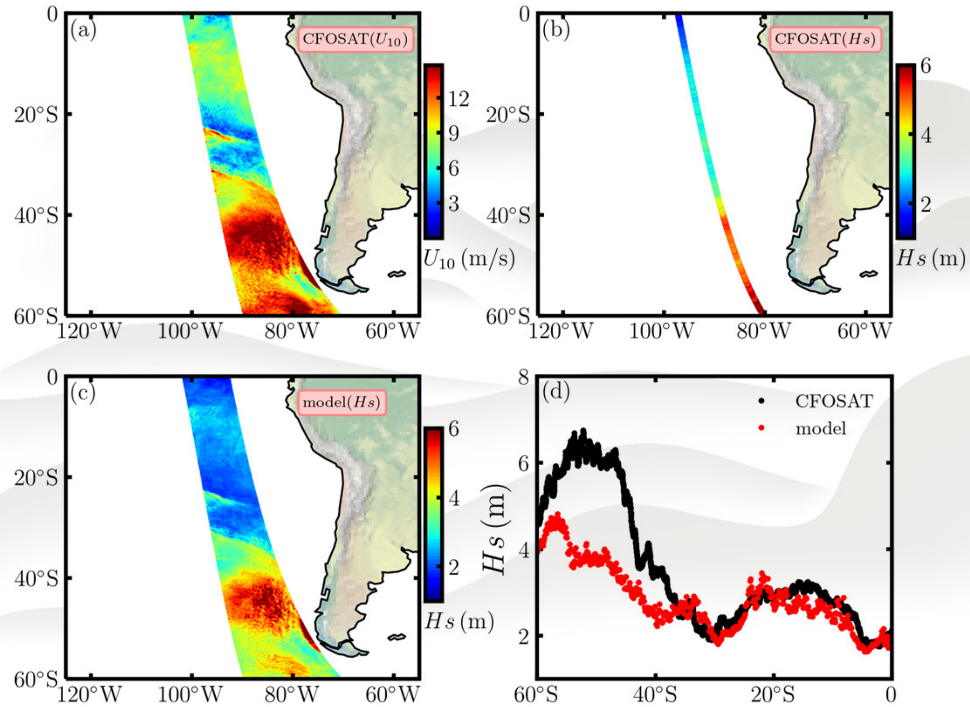
Where N and Nq means the number of model-observation pairs, and the pairs which hold the differences less than 0.25m, respectively.

5 Wave Field from Wind-Wave Model

➢ CFOSAT wind+wind-wave relation model ➔ *Hs*



Simultaneously observed (a) U_{10} and (b) *Hs* by CFOSAT on January 16, 2022. (c) Wind-wave power-law model predicted Hs. (d) The meridional variations for CFOSAT along-track Hs (black dots) and the corresponding model predicted Hs (red dots).

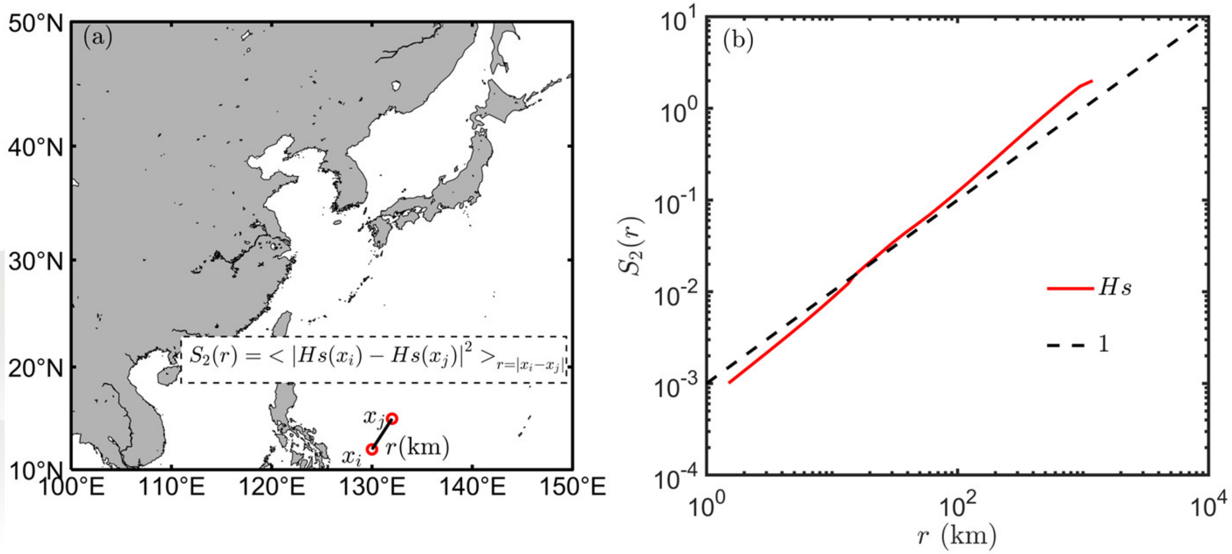


The same as the left figure, but with the data collected in July 1, 2021

6 Perspective

Physics-informed machine learning

1) Second-order structure function (scaling features)

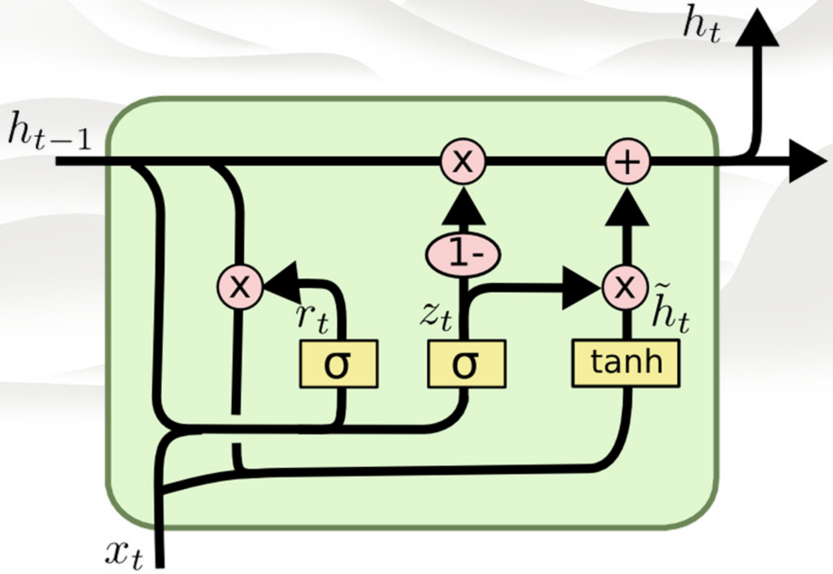


$$S_2(r) =< |Hs(x_i) - Hs(x_j)|^2 >_{r=|x_i-x_j|}$$

2) Generalized wind-wave power-law relation

$$\overline{H}s = \overline{H}s_{sw} + \alpha U_{10}{}^{\eta}$$

3) Long Short-Term Memory Network



7 Conclusion

- ✓ A probability based swell identification is proposed.
- ✓ A generalized wind-wave power-law relation model is established.
- ✓ CFOSAT wave field could be extracted from the proposed wind-wave model.
- ✓ Physics-informed machine learning will be considered to enhance the accuracy of model predicted wave data.

Thanks!