Accurate Mean Wave Period from SWIM Instrument On-Board CFOSAT

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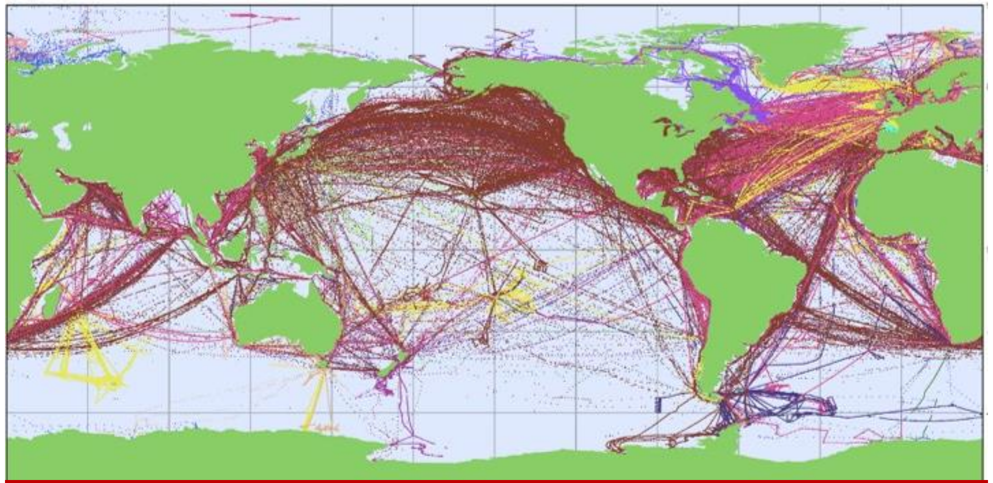
1. Introduction

- **Mean Wave Period (MWP) is a widely used integral wave parameter**
- **Observations MWP are available from several sources:**

Buoys



Voluntary Observing Ships
(Visual Observation)

Remote Sensing
(SAR & Altimeters)

1. Introduction

- **The accuracy of MWP from space**

SAR

RMSE compared to buoys
T_{m02}: > 0.75 s
T_{m01}: > 0.75 s
T_{m-10}:> 0.75 s

using empirical models
e.g.,
Schulz-Stellenfleth et al. 2007

Altimeter

RMSE compared to buoys
T_{m02}: > 0.55 s
T_{m01}: > 0.70 s
T_{m-10}:> 0.95 s

Also empirical models
e.g.,
Mackey et al. 2008

$$T_{m02} = \sqrt{m_0 / m_2}$$

$$T_{m-10} = m_{-1} / m_0$$

$$T_{m01} = m_0 / m_1$$

$$m_n = \int_{f_{dn}}^{f_{up}} f^n E(f)\,\mathrm{d}f$$

- **For wave measurements**

SWIM ≈ Altimeter + "Enhanced SAR"

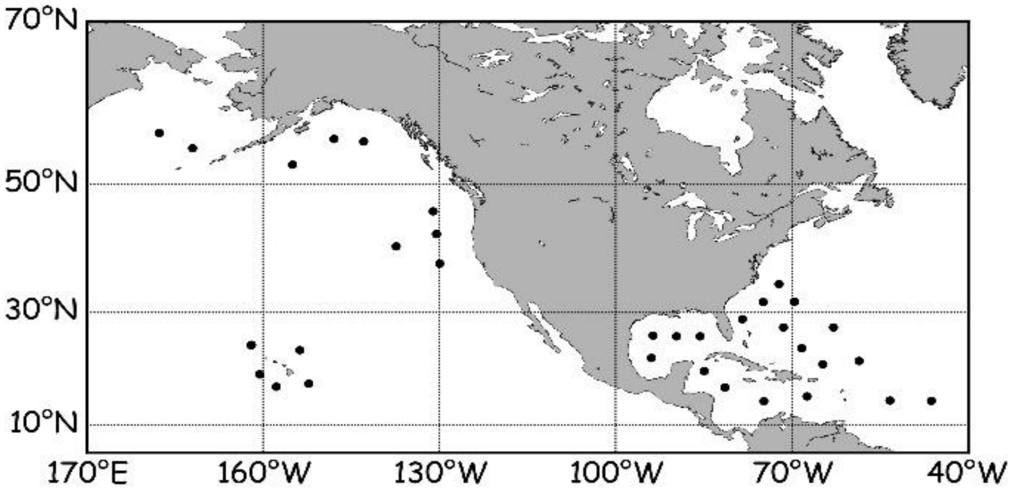
2. Data

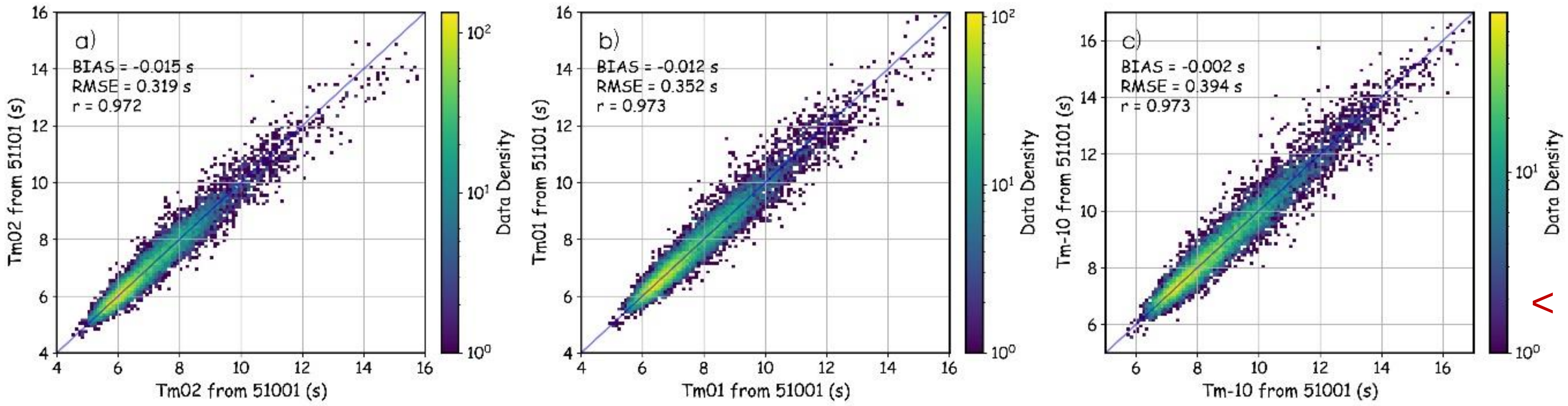
➢ **NDBC buoy data**

- Jan 2011 to Sep 2021
- Wind, SWH and MWP data available
- Offshore distance > 150 km
- Water depth > 200 m
- Precision of buoy's MWP data:

~0.23 s for T_{m02} ~0.25s for T_{m01} ~0.28s for T_{m-10}

37 selected buoys





< 51001 vs 51101 (~13 km away)

2. Data

➢ SWIM data

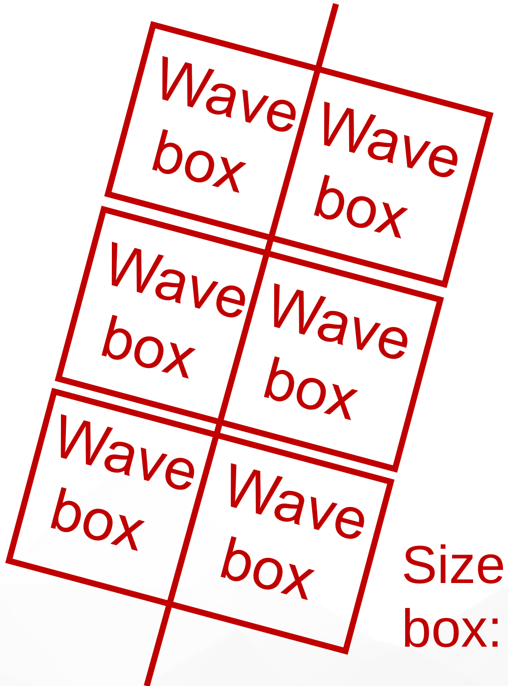
$$\int_{f_1}^{f_2} F(f)df = \int_{k_1}^{k_2} S(k)/k\,dk$$

- Level-2, version 5.1.2
- May 2019 ---- Sep 2021
- Slope spectra are converted to frequency spectra using deep water assumption
- Nadir beam U10 + SWH → regarded as the U10 + SWH in the nearest “wave box”

  (We have checked that the spatial representativeness error is negligible)

➢ ERA5 data

- For dynamic collocation between SWIM and buoy data (presented later)
- 0.5°×0.5°×1h data of T_{m02}, T_{m01} , and T_{m-10}



Size of the wave box: 90 km×70 km

3. Model Establishment

SWIM ≈ Altimeter + “Enhanced SAR”

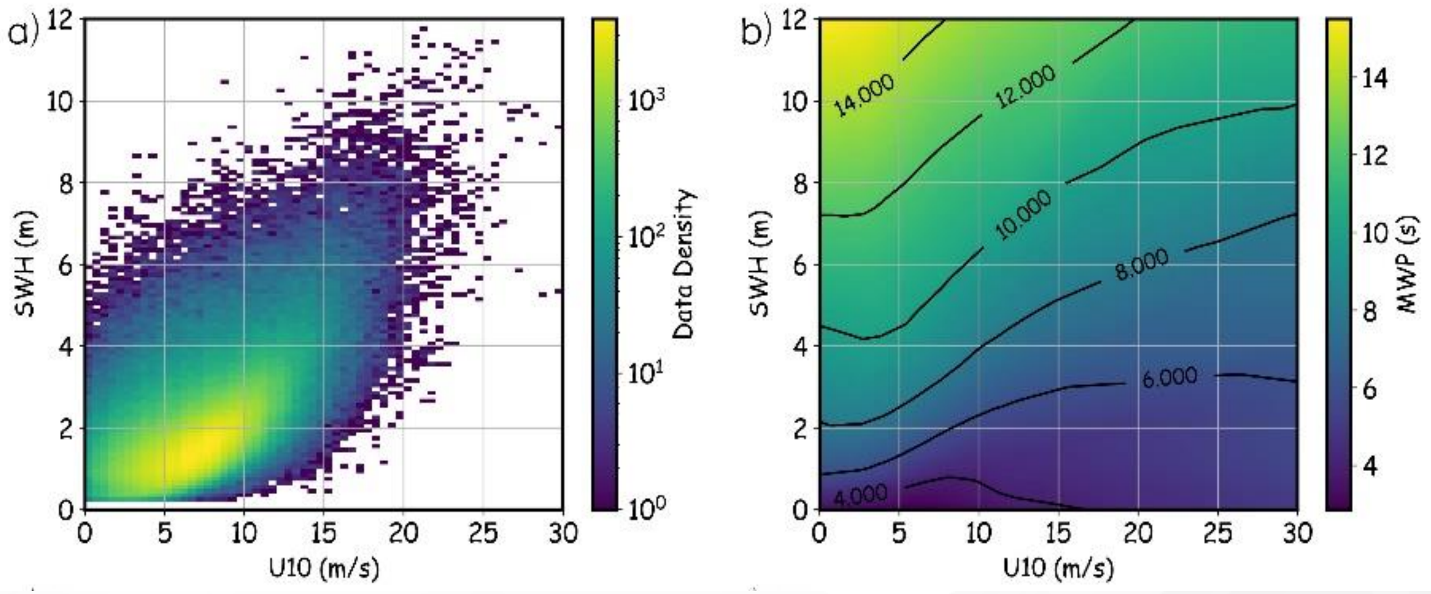
➢ Rationale of MWP from Altimeter

- Under geometrical optics approximation $\mathrm{MWP} \sim T_{m04} = (m_0 / m_4)^{1/4} \sim (\sigma_0 SWH^2)^{1/4}$
- SWH, U10, and MWP follow some statistical relationship during the growth of waves because of the theory of similarity.

$$\mathrm{MWP} = F(SWH, U10) \ or \ F(SWH, \sigma 0)$$

- Using U10 instead of *σ0* :

1. Many high-quality SWH-U10-MWP collocations from buoys, good for empirical algorithm
2. U10 is a standard product of altimeters and are often calibrated, so can be applied to different altimeters (and SWIM)

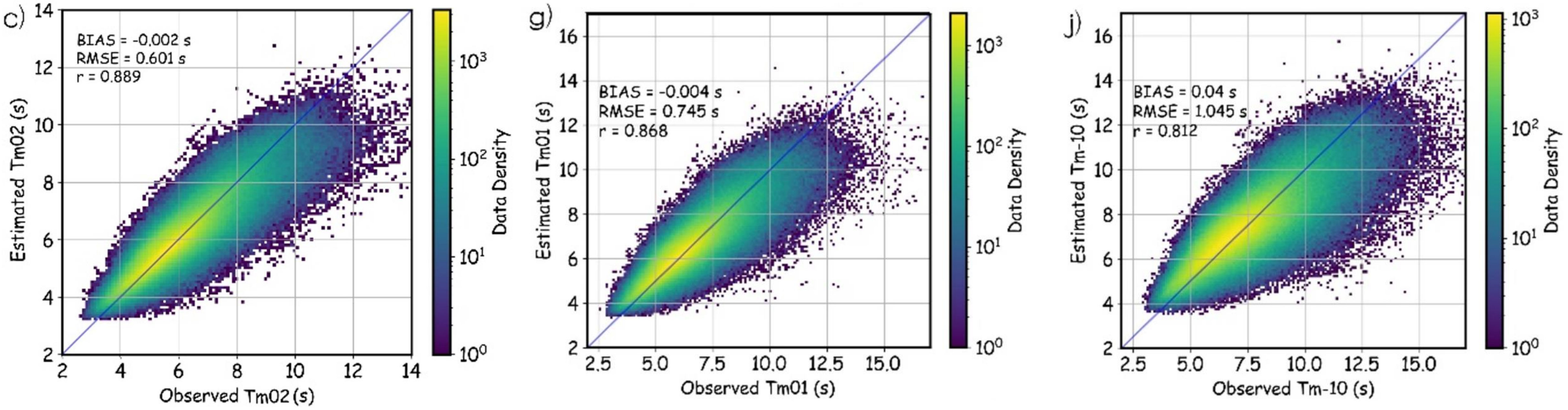


3. Model Establishment

SWIM ≈ Altimeter + “Enhanced SAR”

➢ **Evaluation of MWP from Altimeter**

T_{m02} RMSE=0.60 s　　*T_{m01} RMSE=0.75 s*　　*T_{m-10} RMSE=1.05 s*



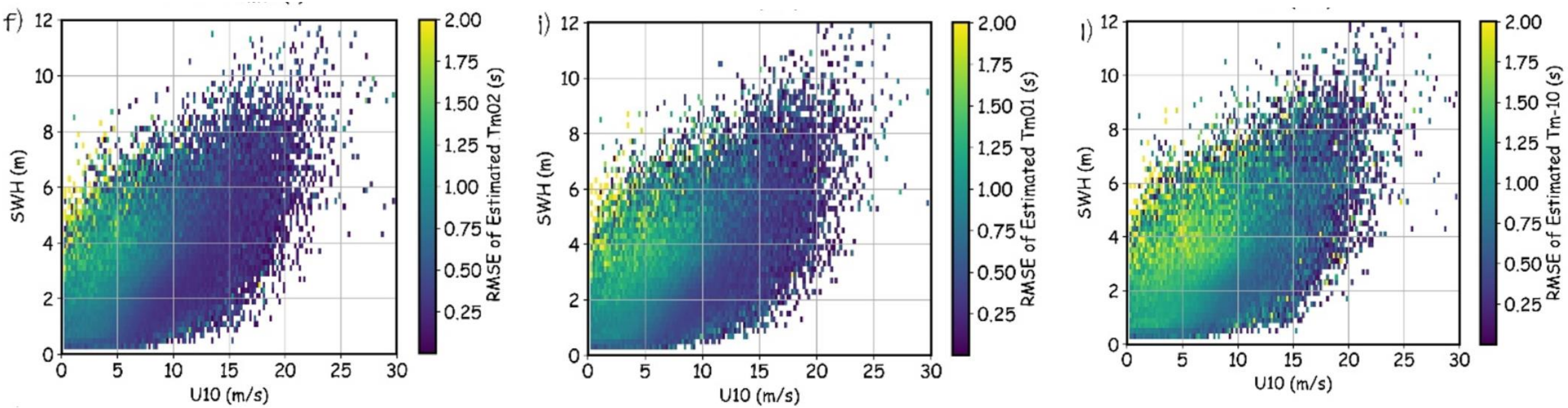
- The models all tend to overestimate short MWPs and underestimate long MWPs
- We also applied the model to altimeter data (the dataset of Ribal and Young 2019), and the RMSEs do not significantly changed.

3. Model Establishment

SWIM ≈ Altimeter + "Enhanced SAR"

➢ **Evaluation of MWP from Altimeter**

RMSE as a function of U10 and SWH for T_{m02} / T_{m01} / T_{m-10}

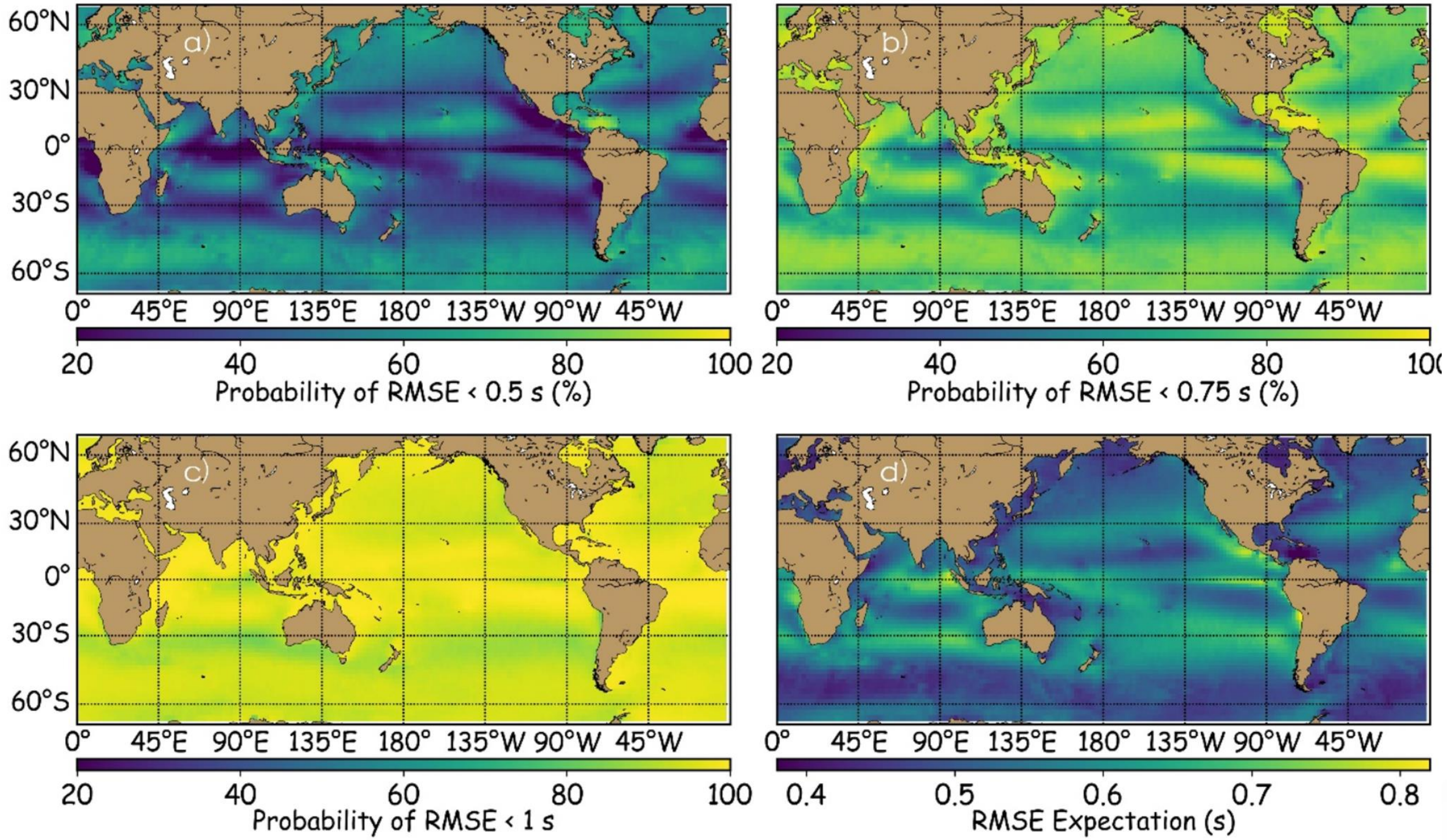


- Relatively good/bad performance of the models in wind-sea/swell-dominated cases

3. Model Establishment

SWIM ≈ **Altimeter** + “Enhanced SAR”

➢ Evaluation of MWP from Altimeter



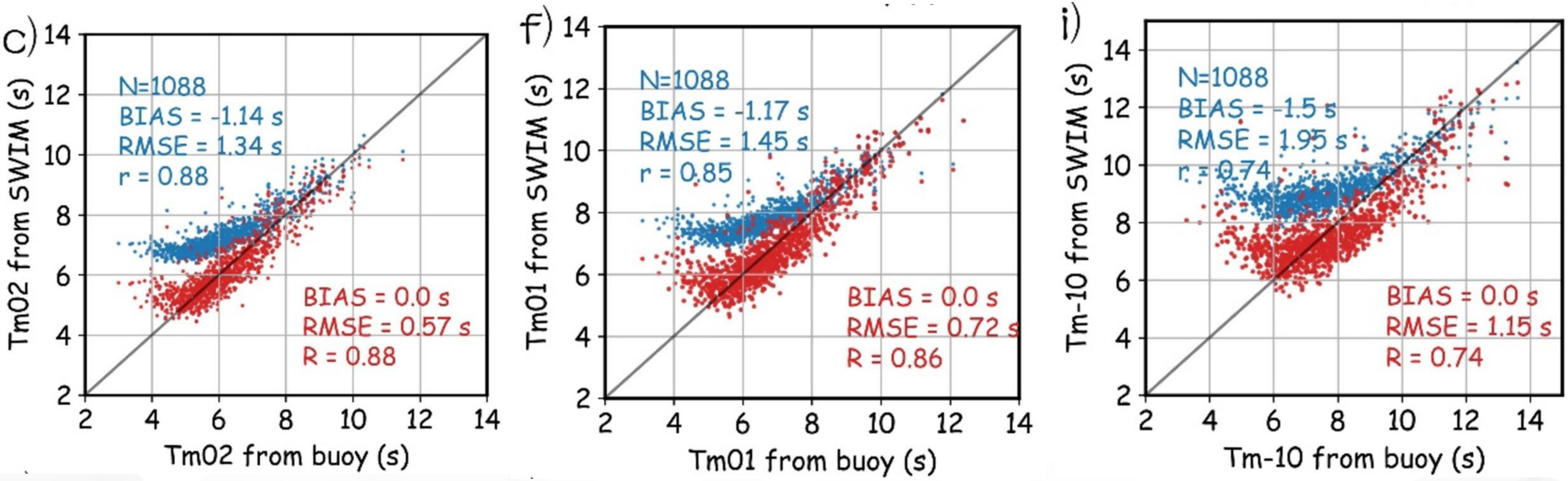
Global distributions of the error properties of the *Tm02* look-up table model and the altimeter U10 and SWH data from altimeter. (a)-(c) The global distributions of probabilities for RMSE being less than 0.5 s (a), 0.75 s (b), and 1 s (c). (d) The global distribution of mean estimated RMSE.

3. Model Establishment

SWIM ≈ Altimeter + "Enhanced SAR"

➢ Evaluation of MWP from SWIM spectra

- The overall accuracy is similar to the altimeter MWP model.
- Better performance for long waves than short waves.

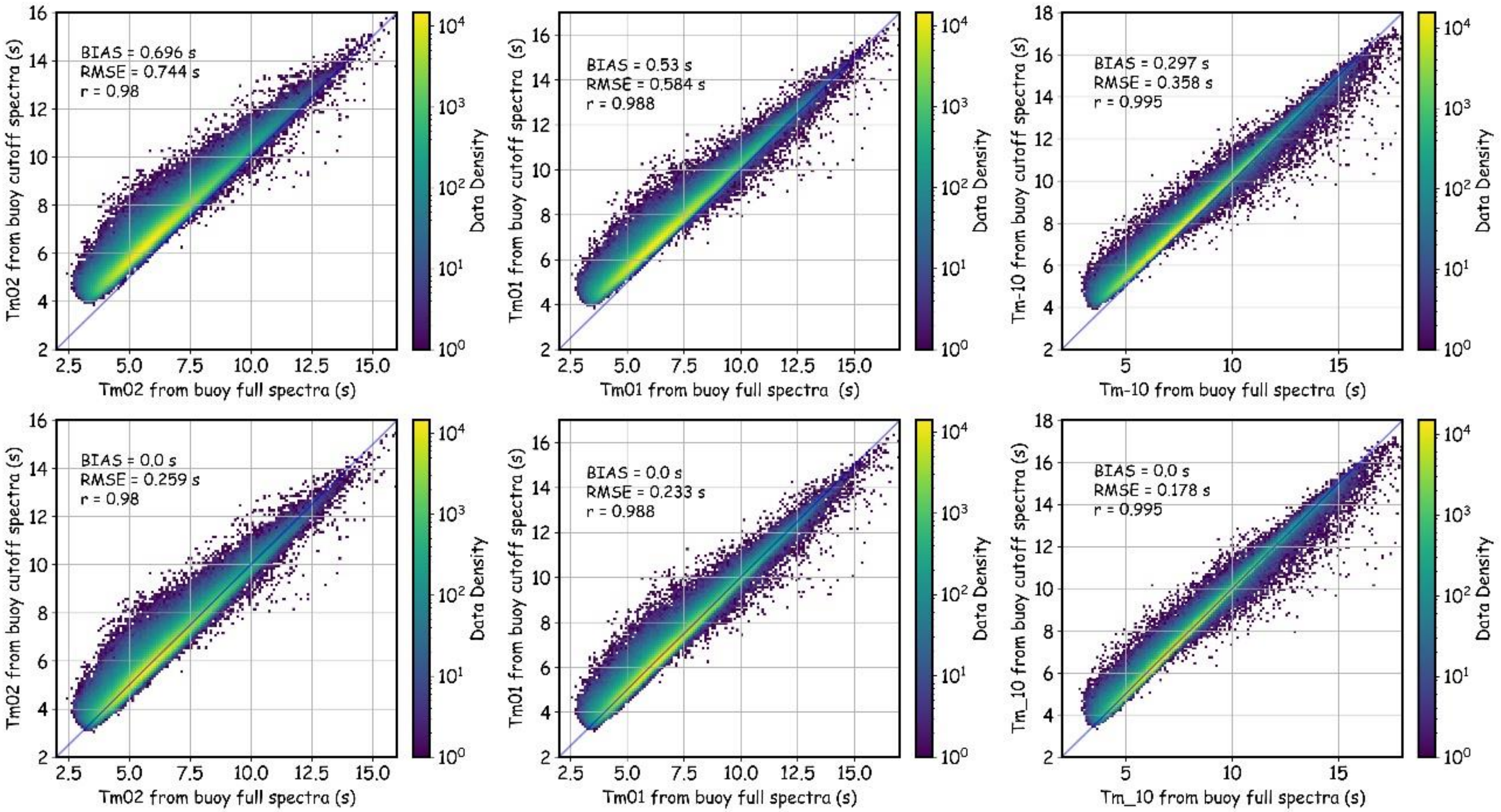


Scatterplots of MWPs directly computed from SWIM wave spectra against MWPs from buoys using a 50km-30min window, before (blue) and after (red) a quadratic polynomial correction.

3. Model Establishment

SWIM ≈ Altimeter + "Enhanced SAR"

➢ Evaluation of MWP from SWIM spectra

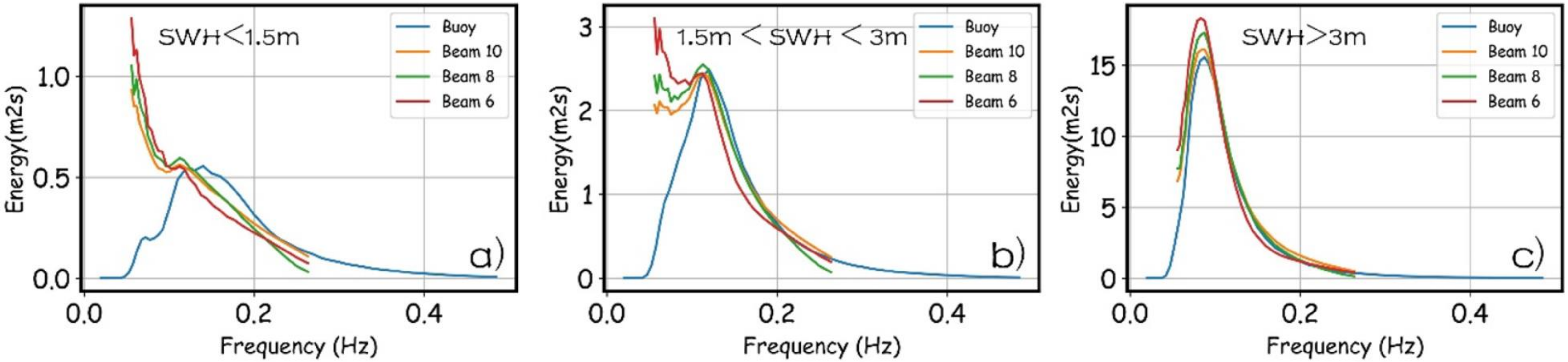


Scatterplots for the comparison of (a) T_{m02}, (b) T_{m01}, and (c) $T_{m\text{-}10}$ between those computed from the original buoy spectra and those computed from the cutoff buoy spectra from 0.055-0.265 Hz (25-500 m). (d-f) is the same as (a-c), but after a linear correction.

3. Model Establishment

SWIM ≈ Altimeter + “**Enhanced SAR**”

- **Evaluation of MWP from SWIM spectra**
  - A large part of the errors comes from the low-frequency spurious peaks (noise floor).
  - Noise amplified when turning F(k) to S(k)



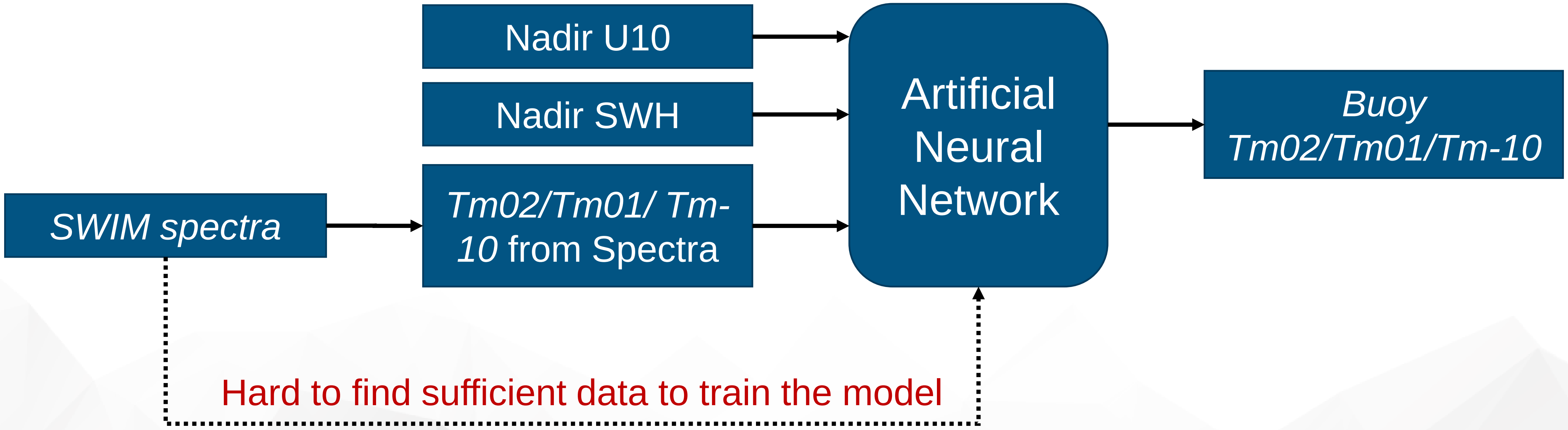
Comparison between the mean omni-directional spectra from buoys and from SWIM for the collocated data pair for different SWHs.

3. Model Establishment

SWIM ≈ Altimeter + "Enhanced SAR"

- **Merged retrieval model (Model selection)**
  - Nearly independent measurements (nadir beam + beam 10°)
  - Nadir beam: better for short waves
  - Beam 10°: better for large waves

Merging? Yes.



3. Model Establishment

SWIM ≈ Altimeter + "Enhanced SAR"

➢ Merged retrieval model (Dynamic collocation)

- The 1088 collocations from the 50-km spatial window might be insufficient.
- A "dynamic collocation" method is used to obtain more collocations.

- **Dynamic collocation:** Using the spatial difference from model output to partly compensate for the real spatial difference between RS and buoy location.

$$O_{RS} \quad \text{V.S.} \quad (O_{Buoy} - M_{Buoy} + M_{RS})$$

$$O: observation \qquad M: Model$$

- Using objective analysis to estimate the MWP near buoy locations.
- 8730 collocations obtained with a 150-km window without increasing RSME.

$$F_{Cref}(\phi,\lambda,t) = F_b(\phi,\lambda,t) + \sum_{i=1}^{N_{ref}} w_i \bullet \left[O_i(t) - F_i(t)\right]$$

$$w_i = \exp\left[-d_i^2(\phi,\lambda)/2R^2\right] / \sum_{i=1}^{N_{ref}} \exp\left[-d_i^2(\phi,\lambda)/2R^2\right]$$

$$R = \min\left[d_i(\phi,\lambda)\right] \quad \left(i = 1,2,3,\ldots,N_{ref}\right)$$

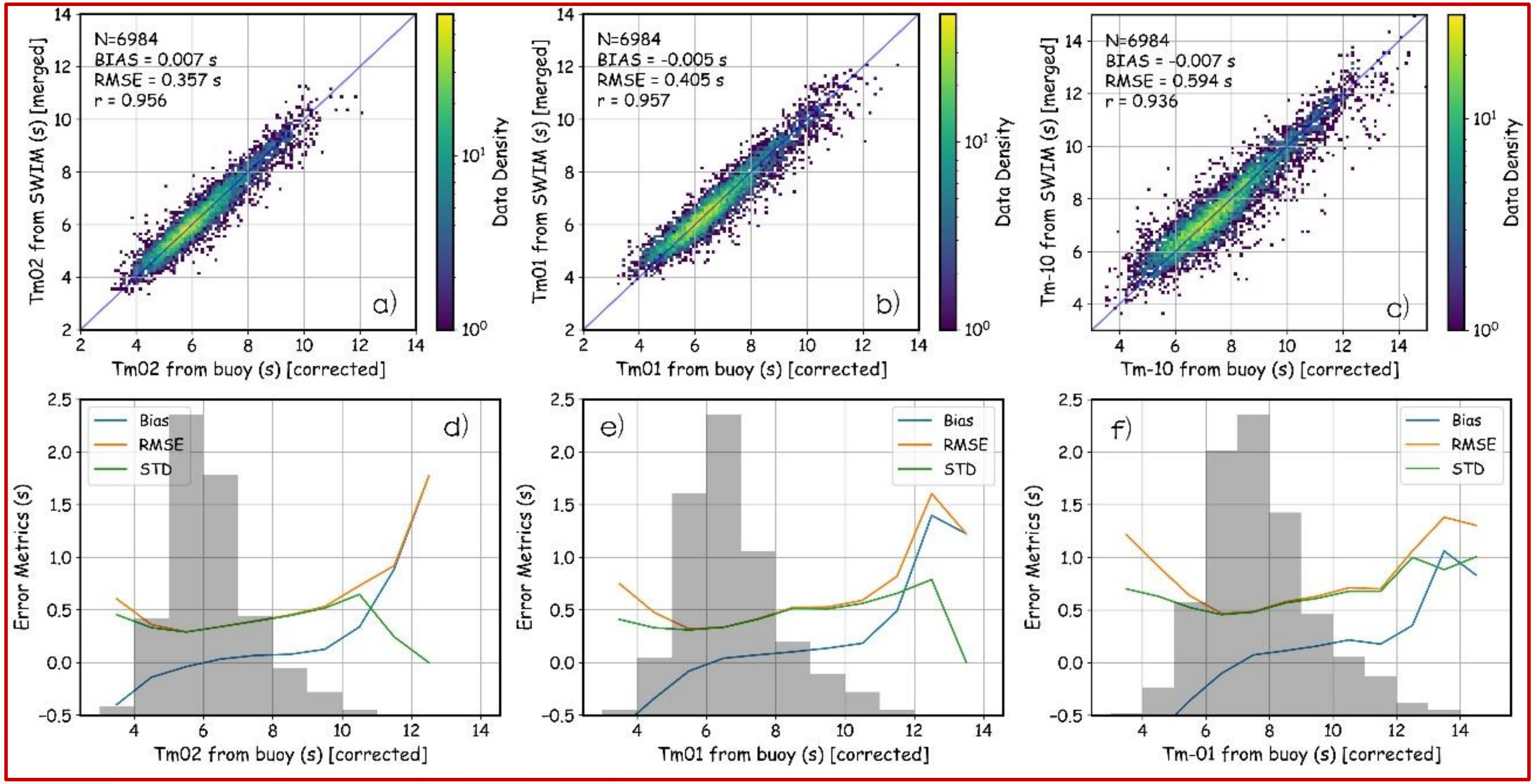
Training: 20% data

Validation: 80% data

3. Model Establishment

SWIM ≈ Altimeter + “Enhanced SAR”

- **Model training and validation**



This performance is close to the accuracy of buoys

(for *Tm02* and *Tm01*)

Model explanation: Just a weighted average of the two sources.

4. Summary

- SWIM onboard CFOSAT can estimate MWP using two methods:

  1. Nadir SWH + U10 & 2. Directly from off-nadir spectra
- Both of them have their limitations but merging the two methods can minimize these limitations.
- Using a simple ANN, an empirical merged model is presented, obtaining good accuracy of MWP. (RMSE: 0.36 s/0.41 s/0.60 s for T_{m02}/T_{m01}/T_{m-10})

- **Future directions:**
  - NDBC buoy network from which the data is only available in limited areas. E.g., Spotter?
  - Estimation of wind-sea/swell SWH using a similar idea
  - Global distribution & wave climate of MWP

- **As an operational data product of SWIM?**

THANKS!

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