The Seasonal Cycle of Significant Wave Height in the Ocean: Local vs Remote Forcing

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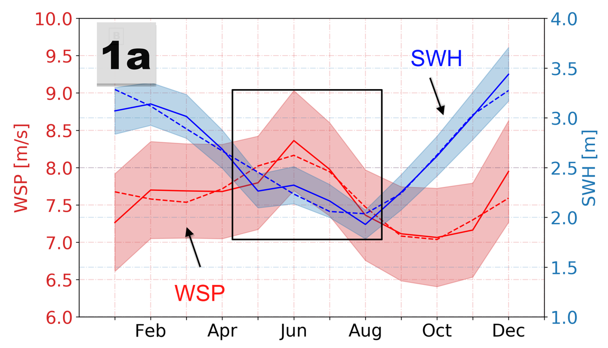
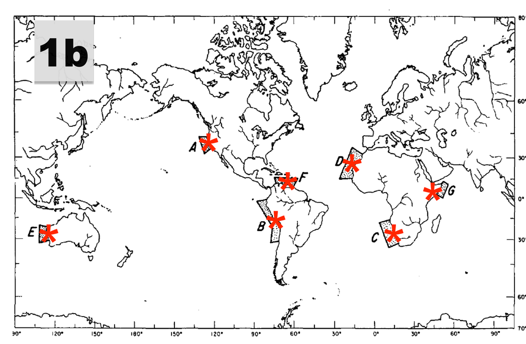
Motivation

Wind generated **surface gravity waves** are fundamental to our understanding of the **interactions** between the ocean and atmosphere. An appropriate metric for expressing **quantitatively** this interaction is **significant wave height** (SWH). **Remotely forced** wind waves, generated by storm systems, dominate the wave field[5].

SWH of wind waves undergoes a sinusoidal **annual cycle** due to seasonal patterns in storm. However, local wind events can cause deviations from this annual cycle. Villas Bôas et al. analyzed a particular **deviation** from SWH's annual cycle off the California coast[1] due to the local wind event called **expansion fan winds**[2] (EFWs). EFWs are identified by high wind speed (WSP) along shore winds and this deviation is characterized by an **increase** in SWH during the late spring to early summer months. This SWH anomaly has been linked to EFWs[2].



Regional Climatology of SWH (solid blue) and WSP (solid red) in 4x4 degree box off the coast of California



Winant et al. 1988 hypothesized expansion fan wind regions in eastern boundary regions of ocean basins

Similar local wind events has been hypothesized by Winant et al. to be present in other regions with similar coastal topography and atmospheric conditions as California (hereon referred as local wind anomaly regions (LWARs)). In the present work, we **assess**:

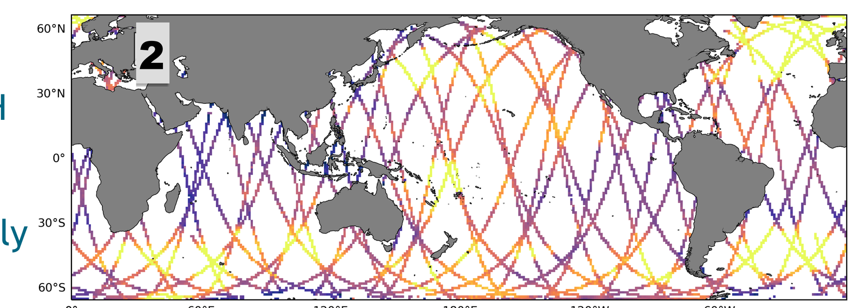
- Are deviations from the SWH annual cycle **present** in other LWARs?
- Is there a corresponding **maximum** in WSP climatology correlated with the SWH deviation?

Data and methods

Satellites measures SWH and WSP **globally** over large time periods. We used data from January 1st, 1993 to December 31st, 2015.

IFREMER SWH Satellite Altimetry Data

IFREMER's **along track** cross calibrated SWH altimetry data was collected from multiple near polar non-sun synchronous satellites binned to global 1x1 degree spatial and daily temporal **resolution**



January 1st, 1993 IFREMER SWH along track data

Cross-Calibrated Multi-platform version 2 Wind Vector Product

CCMP2 is a **gridded** wind vector product consisting of a mixture of satellite remote sensed, in situ buoy, and modeled **wind velocity** data with global 0.25x0.25 degree spatial and 6 hourly temporal resolution

All analysis between IFREMER SWH and CCMP2 WSP is implemented with **monthly averaged** 1x1 degree spatial resolution data.

Annual and Semi-annual SWH and WSP Model

In order to analyze the seasonal cycle of SWH and WSP, we least-squares fitted SWH and WSP with annual and semi-annual sinusoidal cycles:

$$f(t) = a_0 + a_1 * \cos\frac{2\pi t}{T} + a_2 * \sin\frac{2\pi t}{T} + a_3 * \cos\frac{4\pi t}{T} + a_4 * \sin\frac{4\pi t}{T}$$

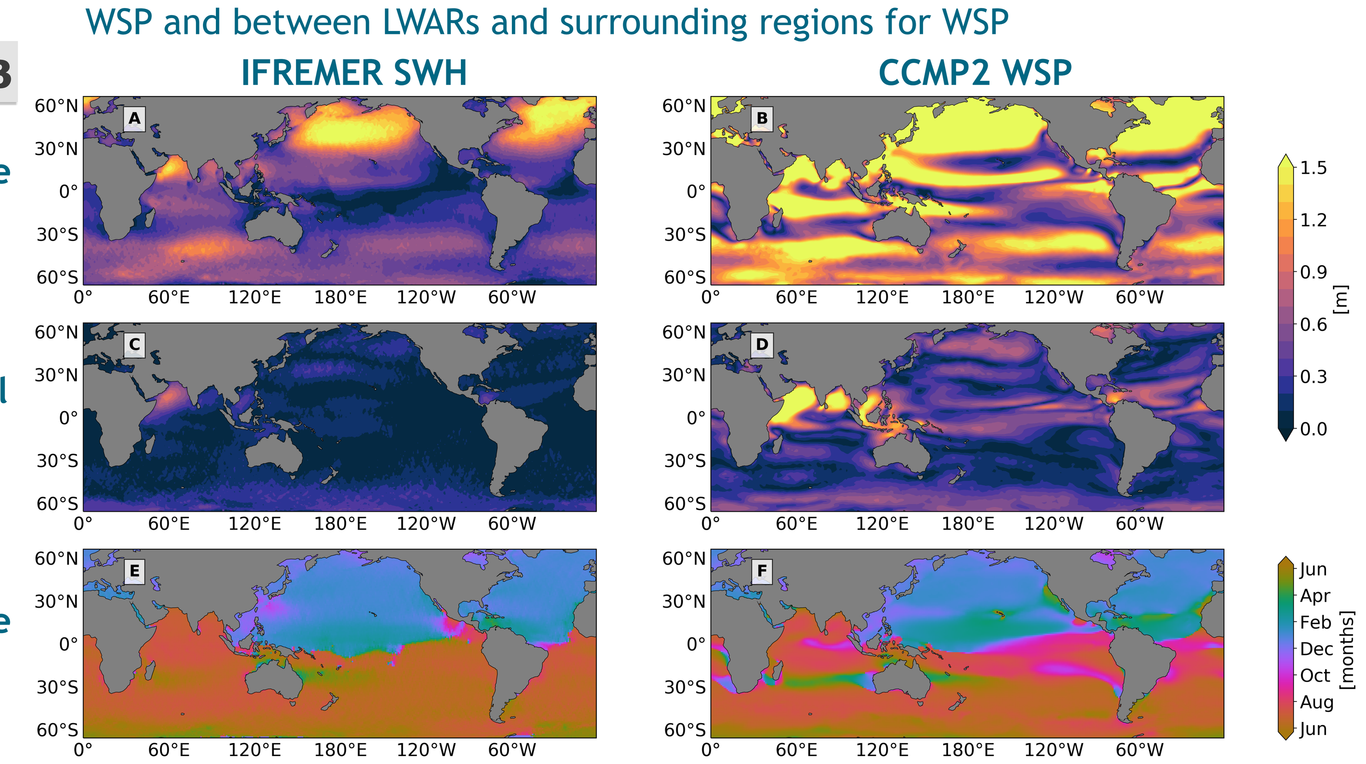
By fitting the regression curve along time series at each grid point across the globe for SWH and WSP data, the **parameters** of each annual cycle could be compared **geographically**.

Funding was provided by URS Summer Research program under the Hiestand Research Scholarship with additional support through NASA

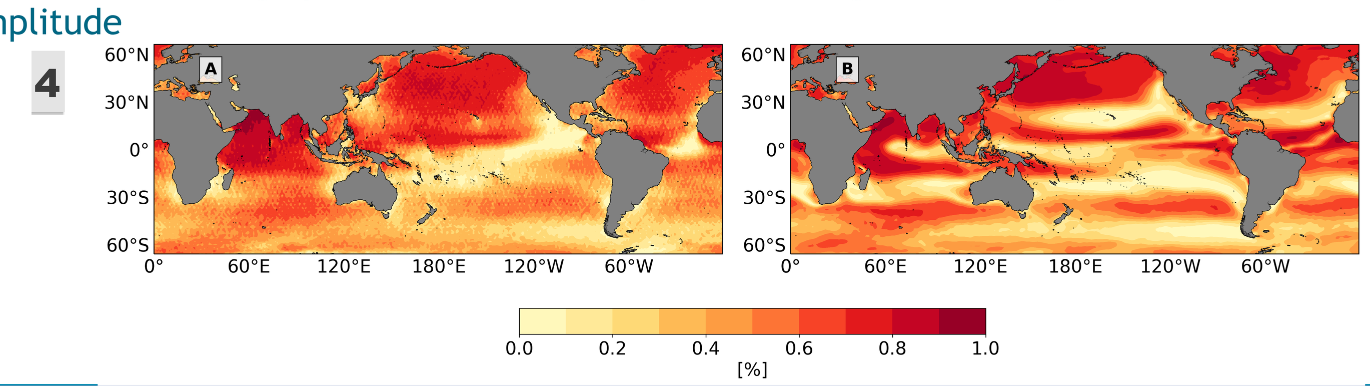
Parameters of Annual and Semi-annual Model

The **parameters** of the annual and semi-annual model reveal:

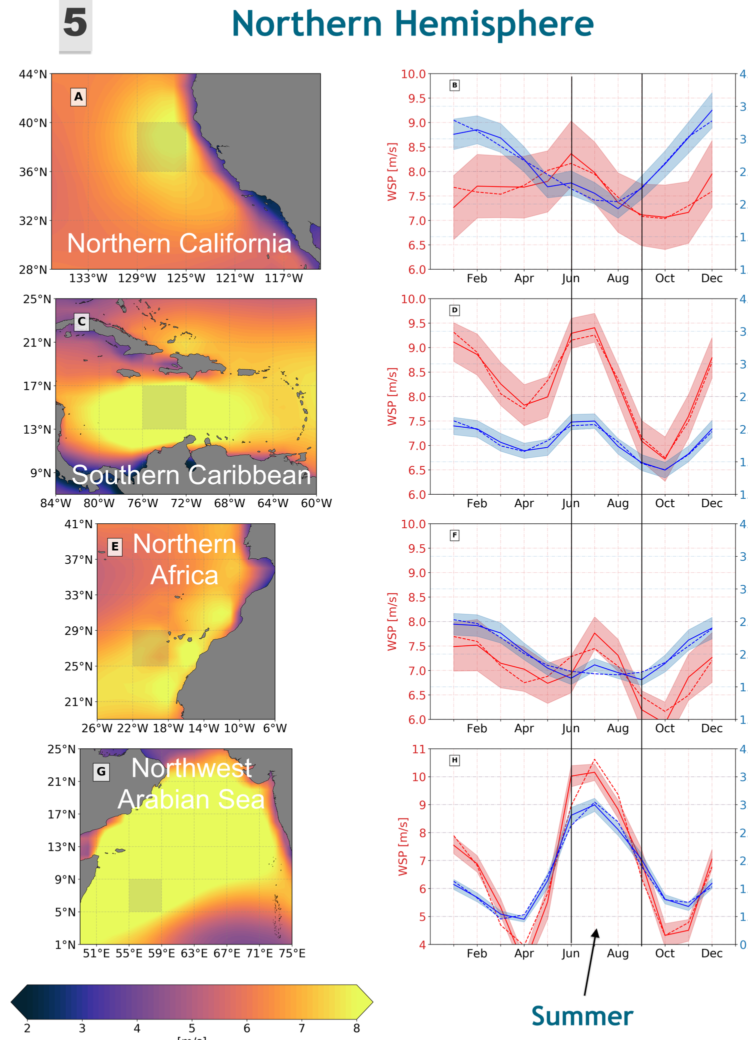
- High annual cycle **amplitude** in high latitudes of northern hemisphere
- High semi-annual cycle amplitude in monsoon and some LWAR regions
- **Anti-correlation** between northern and southern hemisphere for SWH and WSP and between LWARs and surrounding regions for WSP



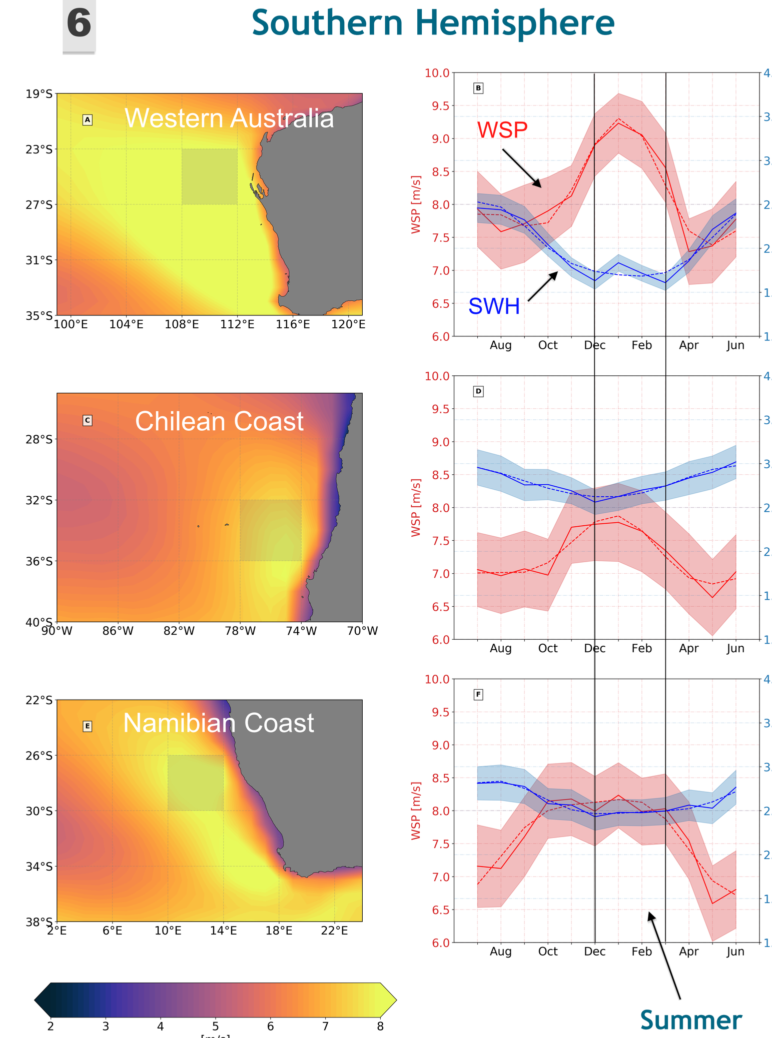
Goodness of fit of the five parameter least square fit model, quantified by the coefficient of determination, shows high **percent variance explained** in regions with high annual or semi-annual cycle amplitude



Regional Climatology Analysis



Deviations from SWH annual cycle in the northern hemisphere LWARs are clearly **observed** and occur during a **maximum** in WSP climatology



Deviations from SWH annual cycle in the southern hemisphere LWARs are **less pronounced** or not present at all

Dashed Blue: SWH model
Dashed Red: WSP model
Contour map NH: JJA mean WSP
Contour map SH: DJF mean WSP

The magnitude of the deviation from the SWH cycle is determined by the local conditions and characteristics of the wave field within the region

Probability of Swell: Consistency between Metrics

Wave Age

In order to justify that SWH during the spring months in these LWARs are **locally forced**, wave age can be used for **separating** growing seas from **fully developed** seas by quantifying the stage of **development** of the wave through the ratio criterion:

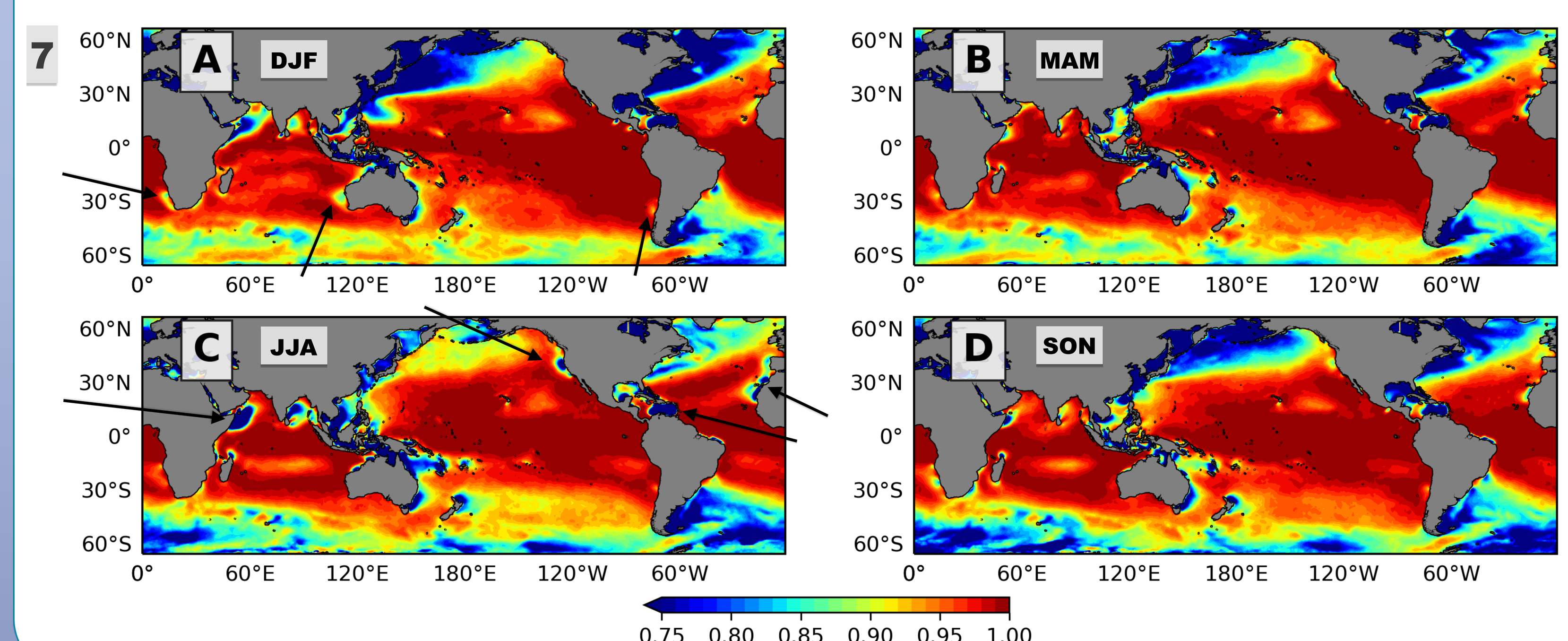
$$A = \frac{c_p}{U_{10}} \quad \text{where} \quad A > 1.2 \rightarrow \text{Remotely Forced Wave (Swell)}, \quad A \leq 1.2 \rightarrow \text{Locally Forced Wave (Wind-seas)}$$

Probability of Swell

Probability of swell quantifies the faction of **number of swell events** (N_{swell}) to total number of wave events (N_{total}) over a time period using wave age as the **separation criterion** for wind-seas and swell events:

$$P_s = \frac{N_{swell}}{N_{total}} \quad \text{where} \quad N_{total} = N_{swell} + N_{wind}$$

In global **seasonal** progression maps of probability of swell below, LWARs contained waves that are categorized as **locally forced** during the spring and summer months for the respective hemisphere. In the southern hemisphere, this **decrease** in probability of swell is less than the northern hemisphere.



Final Remarks

- **Deviations** in the SWH seasonal cycle are **present** with high **magnitude** in the northern hemisphere and with low to near zero magnitude in the southern hemisphere due to close **proximity** to large southern ocean swells overwhelming locally forced waves
- Using **wave age**, probability of swell **decreases** significantly in all LWARs during the spring and summer months implying an **increase** in the amount of locally forced waves in LWAR. This is consistent with our hypothesis of local forced wave **causing** the deviation from the SWH annual cycle
- **Future** assessments will focus on using **spectral data** from WW3 to **partition** the wave field into swell and wind seas and plot regional climatologies of SWH for these partitions in order to further understand the dynamics between swell and wind-sea waves influencing the magnitude of the SWH deviation
- **Understanding** SWH climatology globally can help obtain **realistic high-resolution ocean wave models.**

References

[1] Villas Bôas, Ana B., et al. "Characterization of the deep water surface wave variability in the California Current region." *Journal of Geophysical Research: Oceans* 122.11 (2017): 8753-8769.

[2] Winant, C. D., et al. "The marine layer off northern California: An example of supercritical channel flow." *Journal of the Atmospheric Sciences* 45.23 (1988): 3588-3605.

[3] Stopa, Justin E., and Kwok Fai Cheung. "Intercomparison of wind and wave data from the ECMWF Reanalysis Interim and the NCEP Climate Forecast System Reanalysis." *Ocean Modelling* 75 (2014): 65-83.

[4] Hanson, Jeffrey L., et al. "Pacific hindcast performance of three numerical wave models." *Journal of Atmospheric and Oceanic Technology* 26.8 (2009): 1614-1633.

[5]Semedo, Alvaro, et al. "A global view on the wind sea and swell climate and variability from ERA-40." *Journal of Climate*24.5 (2011): 1461-1479.