Surface Winds from January 27, 2018
(https://earth.nullschool.net)

THE SEASONAL CYCLE OF SIGNIFICANT WAVE HEIGHT IN THE OCEAN: LOCAL VS. REMOTE FORCING

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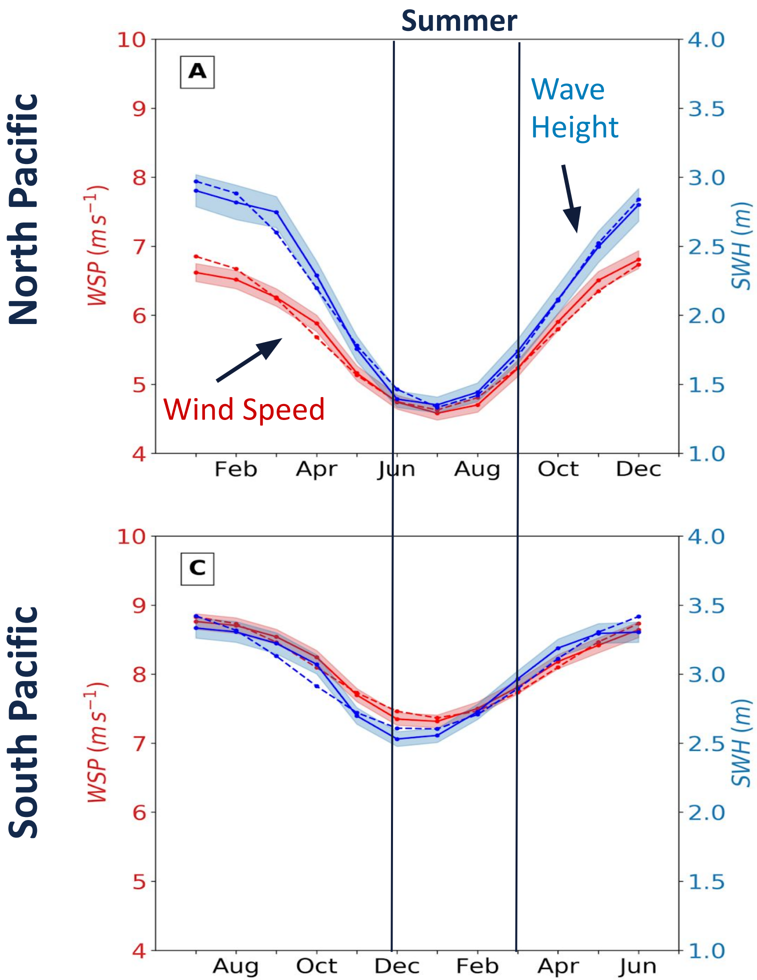
Acknowledgements: NASA, Remote Sensing Systems, IFREMER, Hiestand Scholarship Program

Preprint: *Colosi et. al. submitted to JGR: Oceans.*

Basin-scale Monthly Climatologies



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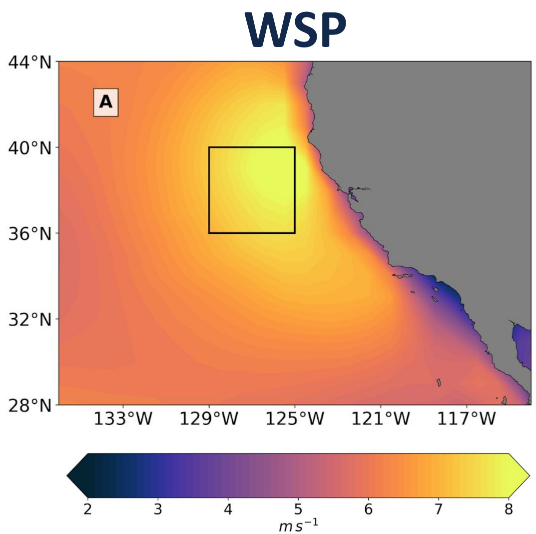
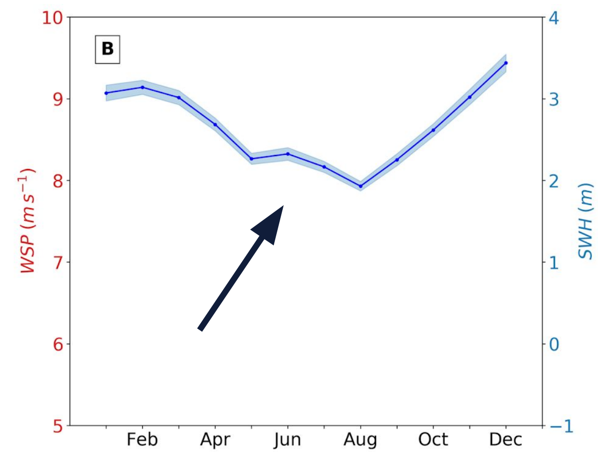
Wind-Wave Climate: Local vs Remote forcing

- At a given location, **surface gravity waves** are a result of locally forced “**wind-sea**” and remotely forced “**swell**” waves.
- High latitude storms generate equatorward propagating swell.
- Wave height of swell undergoes a **seasonal cycle** due to seasonal patterns of storm systems.
- In most world oceans, remotely forced surface waves, generated by storm system, dominate the wave field (Semedo et. al. 2011).

Deviations from hemispheric scale seasonal pattern in SWH

- In the California Coast region, a bump in the significant wave height (SWH) monthly climatology is present in boreal spring and summer.





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Deviations from hemispheric scale seasonal pattern in SWH

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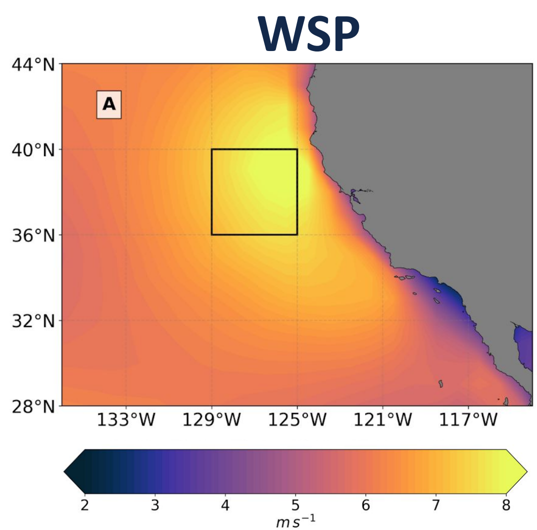
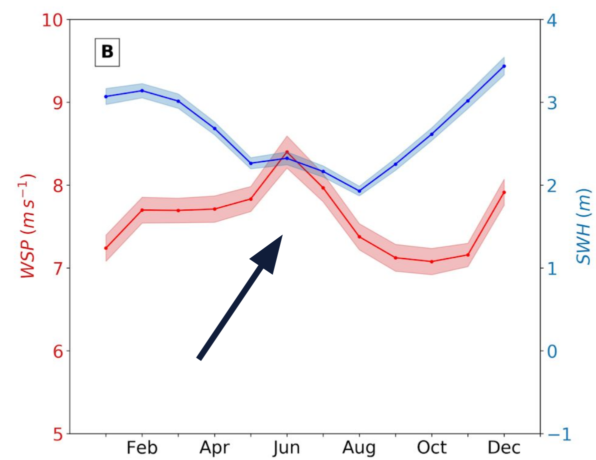
- A corresponding maximum in wind speed (WSP) occurs due to a local wind phenomena, known as Expansion Fan Winds (Winant et. al. 1988).





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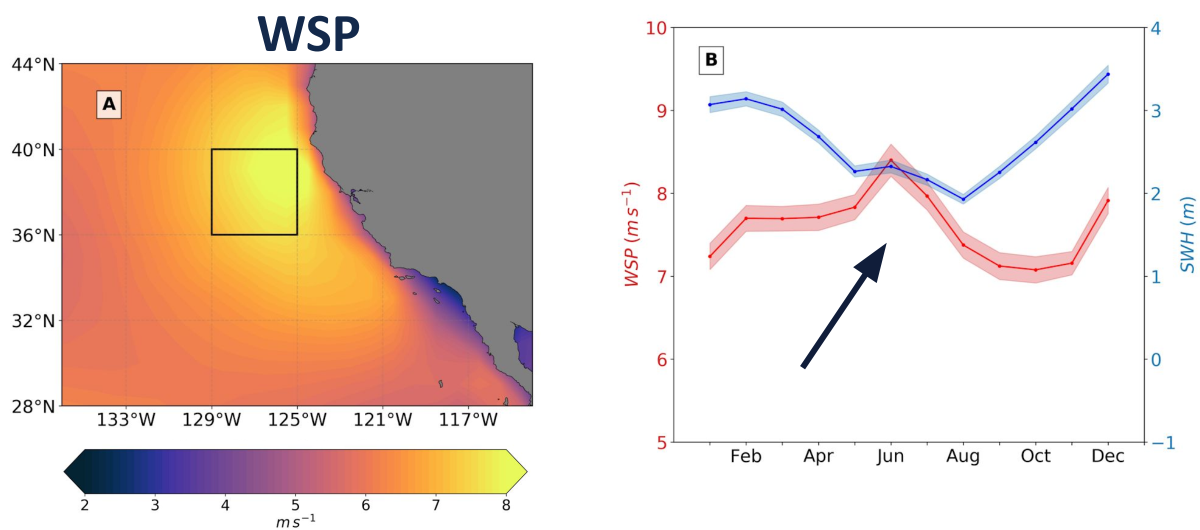
- A corresponding maximum in wind speed (WSP) occurs due to a local wind phenomena, known as Expansion Fan Winds (Winant et. al. 1988).
- This bump in SWH is due to locally forced waves that dominate the wave field up to 50% of the time (Villas Bôas et. al. 2017).



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Objectives: A study of the Surface Wave Climate

- Where in the world ocean are local winds out of phase with hemispheric scale winds?
- Is the seasonality in the California Current region seen in these atypical wind regions?
- What factors determine whether a seasonal augmentation is present in these regions?
- Can locally generated waves be responsible for augmentation?

http://www.looptt.com/content/met-office-rough-choppy-seas-next-24-48-hrs

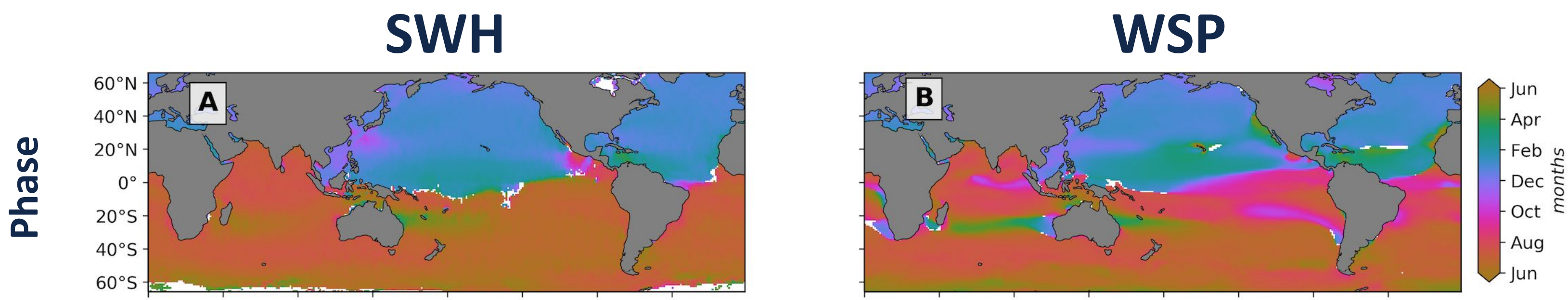
Global Satellite Derived Wave and Sea surface Wind Observations

- Data Sources (time period: 1993 to 2015)
    - **SWH**: Cross calibrated multi-platform satellite altimetry product from the French Research Institute for Exploitation of the Sea
    - **WSP**: Cross calibrated multi-platform wind vector analysis product from Remote Sensing Systems.
- WAVEWATCH III (WW3) hindcast produced by IFREMER is used to complement our analysis.

Analysis of Annual Cycle Variability

- Annual and semi-annual cycle models are least-squares fit to SWH and WSP data.
- Monthly Climatologies are used to analyze mean state of the wave and wind fields

Timing and Magnitude of the Annual cycle



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- Parameters of the annual cycle reveal:
  - Generally, annual cycle is
    - 6 months out of phase between Northern and Southern Hemisphere
    - SWH and WSP are in phase

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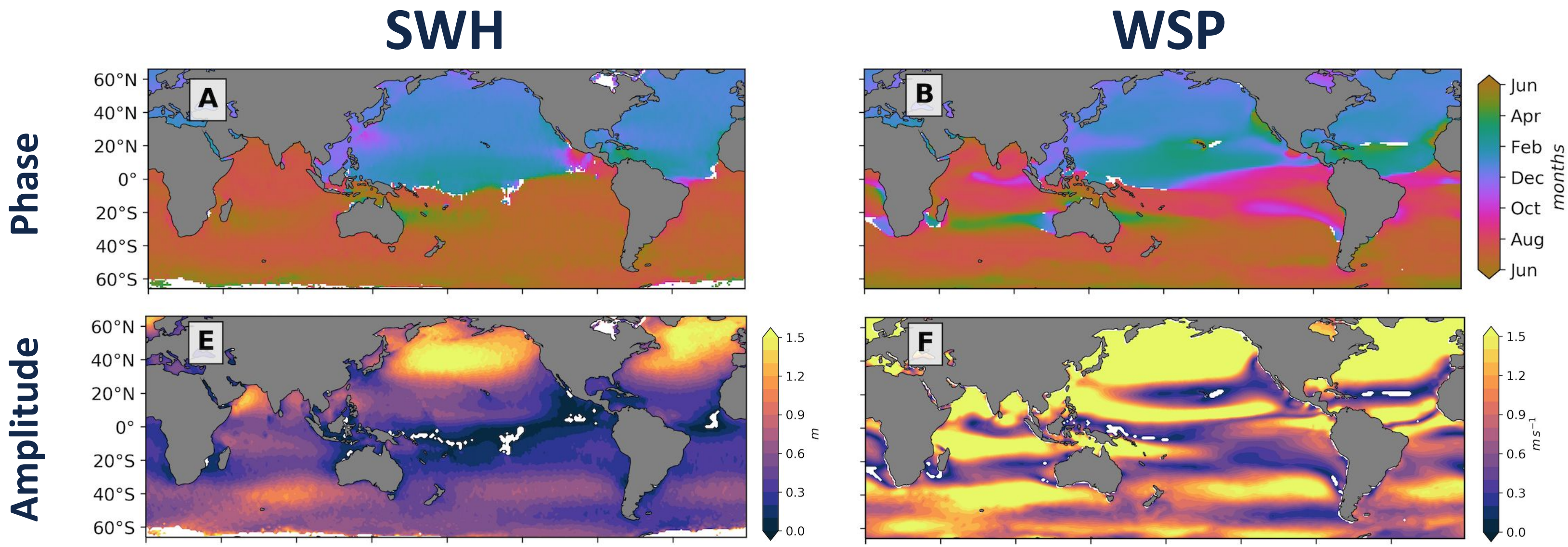

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- Parameters of the annual cycle reveal:
  - Generally, annual cycle is
    - 6 months out of phase between Northern and Southern Hemisphere
    - SWH and WSP are in phase
  - Winds and Waves in the high latitudes of the Northern Hemisphere experience more seasonality than in the Southern hemisphere.

Atypical Winds: Seasonal Wind Anomaly Regions SWARs

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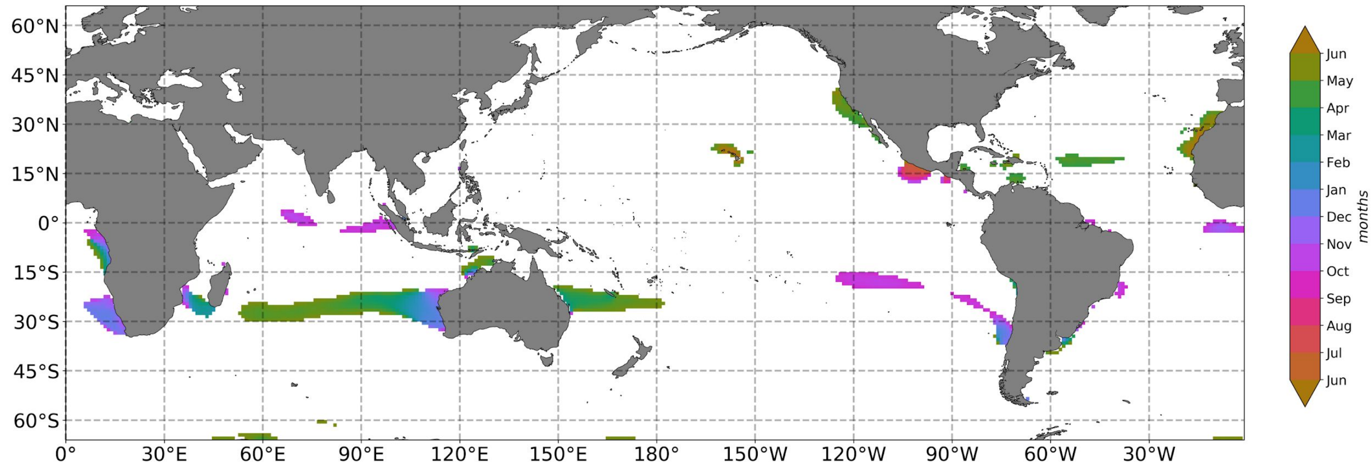

- SWARs identify atypical regions, where local winds are out of phase with hemispheric scale winds.
- Criterion for SWARs: WSP maximum occurs roughly from April through October for the Northern Hemisphere and from October through April for the Southern Hemisphere.
- SWARs are located in:
    - Eastern boundary current regions
    - Monsoon regions
    - Regions significantly sheltered from remotely forced waves

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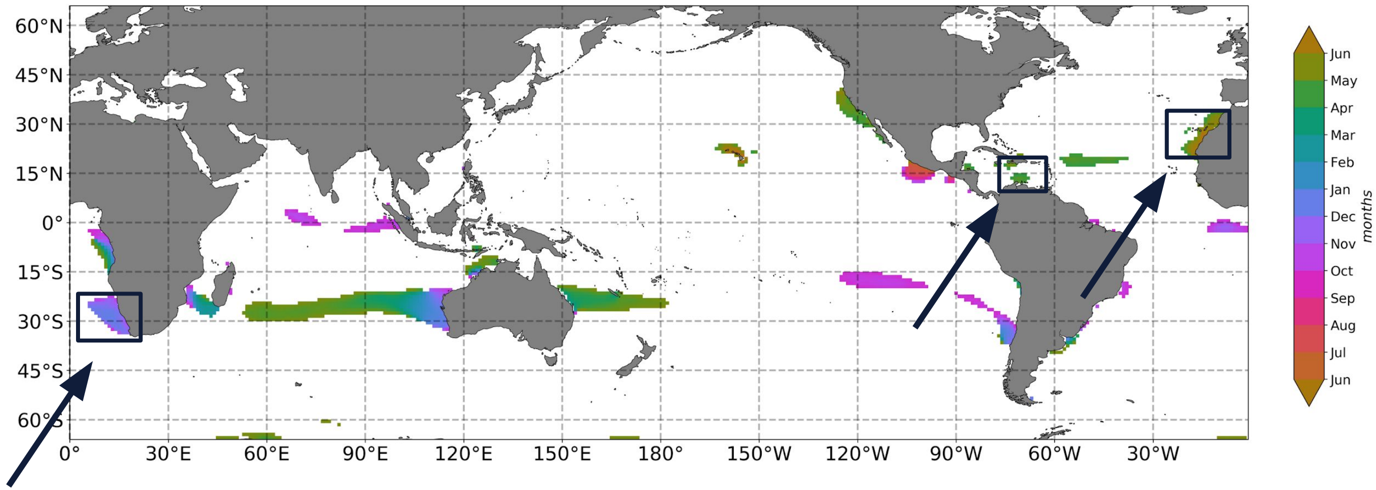

Boxes indicate regions of focus.

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Regional Climatology: Canonical Case

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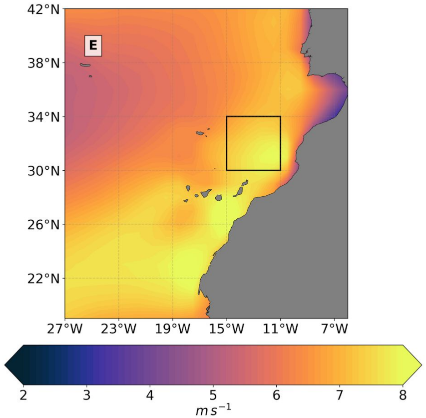
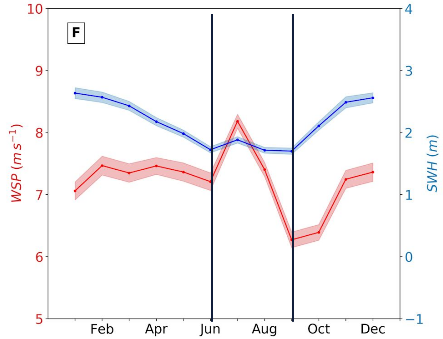
Northwest African Coast





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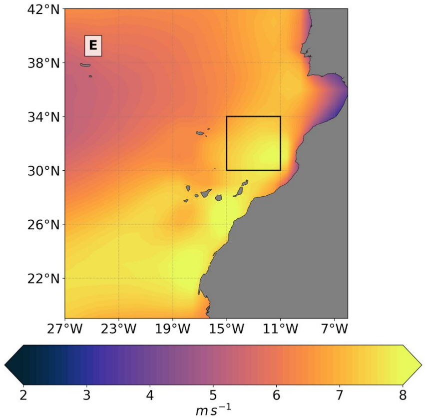
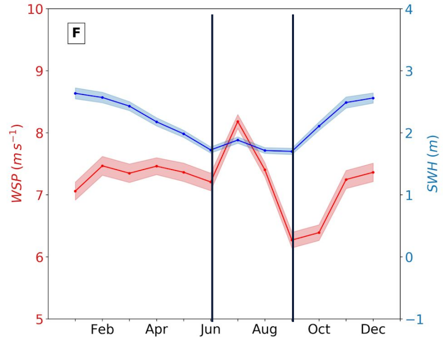
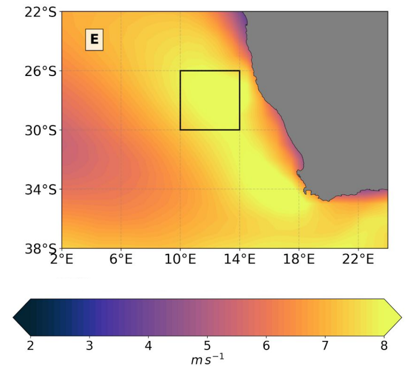


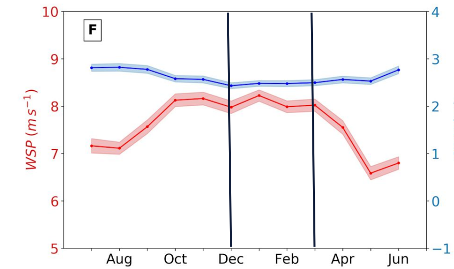


Summer

- Northern Hemisphere SWAR exhibits local maximum in SWH in summer coinciding with local wind maximum.

Namibian coast





Summer

- Southern Hemisphere SWAR exhibits no local maximum in SWH in summer.

Regional Climatology: Canonical Case

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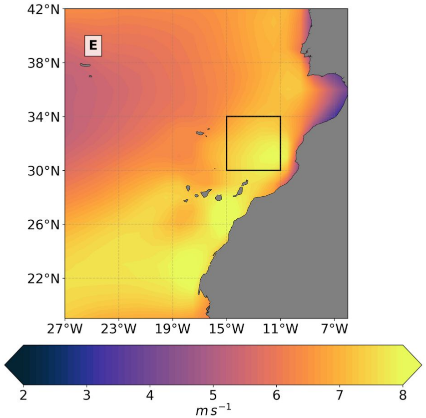
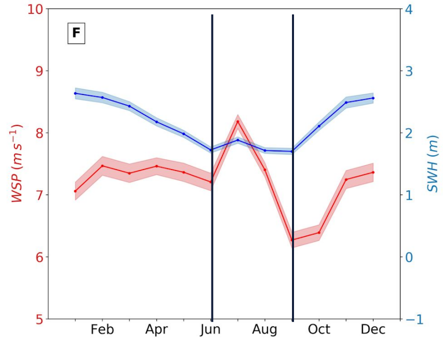
Northwest African Coast





Summer

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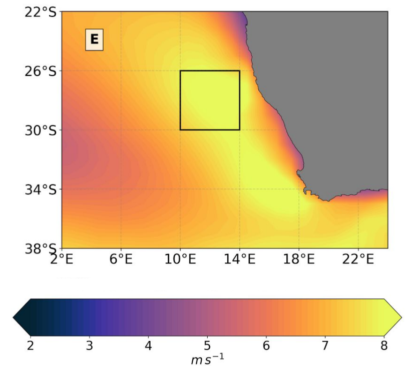
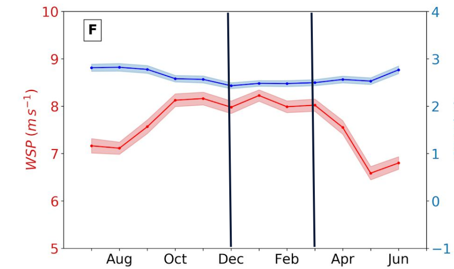




Summer

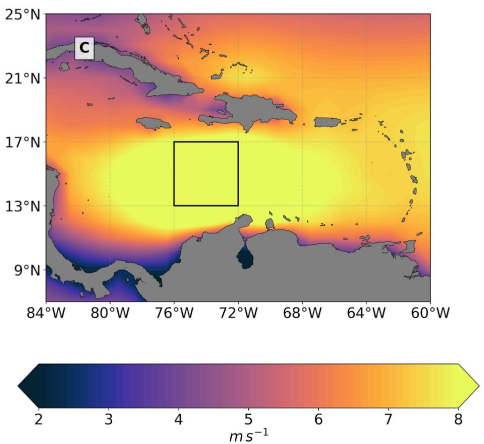
- Northern Hemisphere SWAR exhibits local maximum in SWH in summer coinciding with local wind maximum.
- Southern Hemisphere SWAR exhibits no local maximum in SWH in summer.

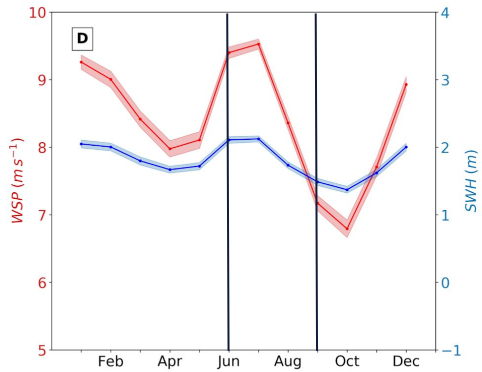
➔ There are other factors than local winds that determining whether a seasonal augmentation is present. Factors may include:

- ◆ Exposure to swell generated in the high-latitude
- ◆ Swell's annual cycle amplitude
- ◆ Strength of local winds

Regional Climatology: Sheltering Case

South Caribbean Sea





Summer

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- Wind and wave climates are distinctly different than Eastern Boundary current Regions:
  - Strong semi-annual cycles for winds and waves
  - Almost no annual cycle for waves
  - In-phase wind and waves
- Lack of an annual cycle for waves suggests SWH is forced entirely by local winds
- Antilles archipelago shelters SWAR from waves propagating from high latitudes

Wave Age: A Separation Criterion for Sea State

- **Hypothesis**: SWH seasonal augmentations are caused by local wind events if locally forced waves in SWARs dominate the wave field during summer months.
- We use wave age to separate growing seas from fully developed seas (Donelan et. al. 1992):

$$A = \frac{c_p}{U_{10}}$$ where

$A > 1.2 \longrightarrow$ Remotely Forced Waves (swell)

$A \leq 1.2 \longrightarrow$ Locally Forced Waves (wind-seas)

where c_p is peak phase speed and U_{10} is wind speed 10 meters above the ocean surface.

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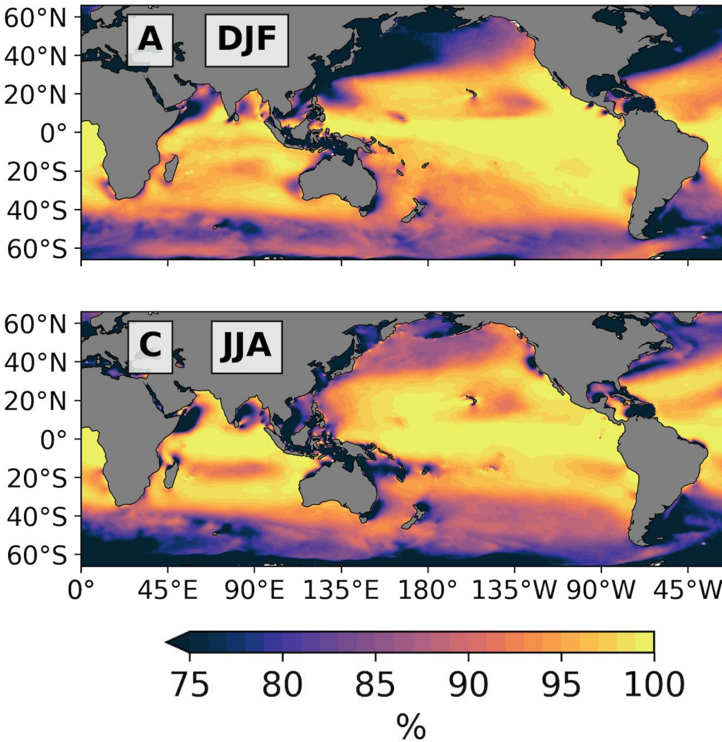
where c_p is peak phase speed and U_{10} is wind speed 10 meters above the ocean surface.

- **Probability of Swell** (Chen et. al. 2002) quantifies the number of swell events (N_{swell}) relative to total number of wave events (N_{total}) over a time period:

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

- Probability of swell provides the fraction of time that the wave field is swell-dominated.

Probability of Swell



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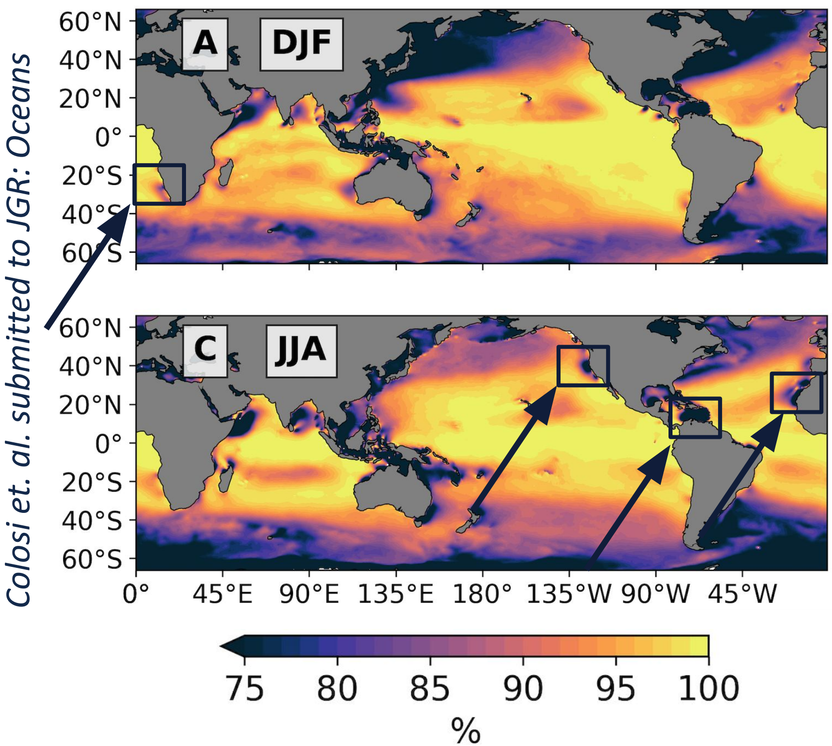
- Seasonal probability of swell is calculated using Climate Forecast System Reanalysis (CFSR) winds and WW3 peak frequency.

Probability of Swell



- Seasonal probability of swell is calculated using Climate Forecast System Reanalysis (CFSR) winds and WW3 peak frequency.

- In Northern Hemisphere SWARs, the wave field is dominated by wind-seas a higher percentage of time than it is in surrounding regions.
- In Southern Hemisphere SWARs, probability of swell is not as low as in Northern Hemisphere SWARs.
- Results suggest:
  - Seasonal augmentations in SWH result from locally forced wave contributions to SWH.
  - Southern Hemisphere SWARs are less likely to be dominated by locally forced waves.

Conclusions

- Atypical WSP seasonal cycles, out of phase with hemispheric-scale winds, are identified as SWARs.
- Anomalous patterns of wind variability do not necessarily drive anomalous patterns of wave climatology.
- Statistics that define the coastal California SWAR are not universal because the fraction of wave variability attributed to local wind events varies depending on regional and wave field characteristics.
- We present a method to evaluate the relative importance of wind-sea and swell from mean behavior of the wave field without the need for directional wave spectra.
- Global observations of directional wave spectra from remote sensing platforms such as Chinese-French Oceanography Satellite (CFOSAT) or other proposed Doppler oceanography missions have the potential to further our understanding of the effects of local winds on the wave climate:
  - Concurrent observations of wind and waves.
  - Distinguish the roles of swell, wind-seas, and mixed seas in determining wave conditions.

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Resources

Preprint for *Colosi et. al. submitted to JGR:Oceans 2021:* https://www.essoar.org/doi/10.1002/essoar.10506029.1

Source Code: https://doi.org/10.5281/zenodo.4505581

Preliminary Data Repository: https://drive.google.com/drive/folders/1fxhS00Oz8CSbYIUxcDfann2s65t3m5-B?usp=sharing

Github Repository: https://github.com/lcolosi/WaveClimatology.

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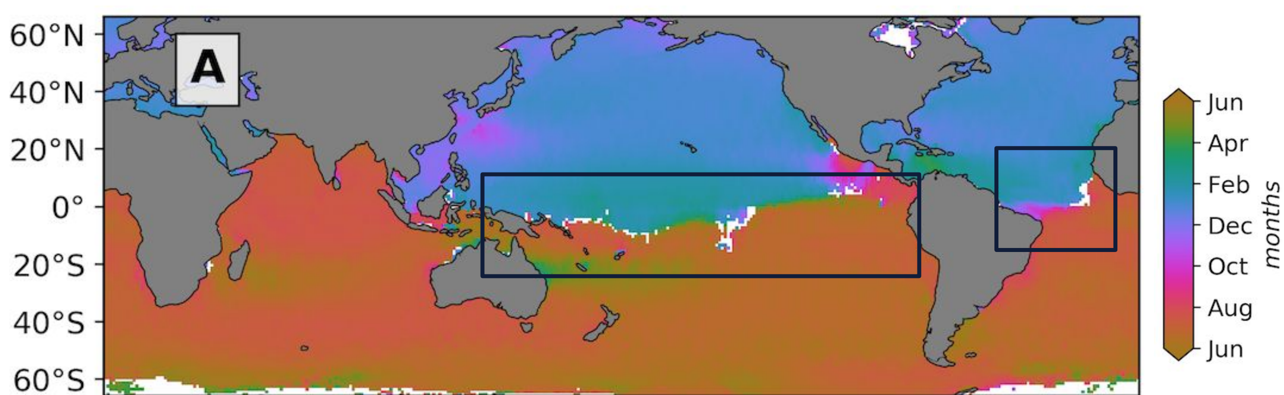
SUPPLEMENTARY SLIDES

SWH Phase: Discontinuity along the Equator

- SWH displays a sharp phase discontinuity off the equator in the Pacific and Atlantic.
- This discontinuity identifies the transition between regions with swell originating primarily in the Northern Hemisphere and swell primarily from the Southern Hemisphere.
    - We refer to this transition as the **swell phase discontinuity**.
- The swell phase discontinuity coincides geographically with **swell fronts** defined based on mean wave direction (Young 1999; Semedo et. al. 2011; Jiang et. al. 2013).
- Here, we provide a new method for characterizing swell fronts without directional information.



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