Exploration of Approaches to Selection of Storm Events in Wind and Wave Hindcasting

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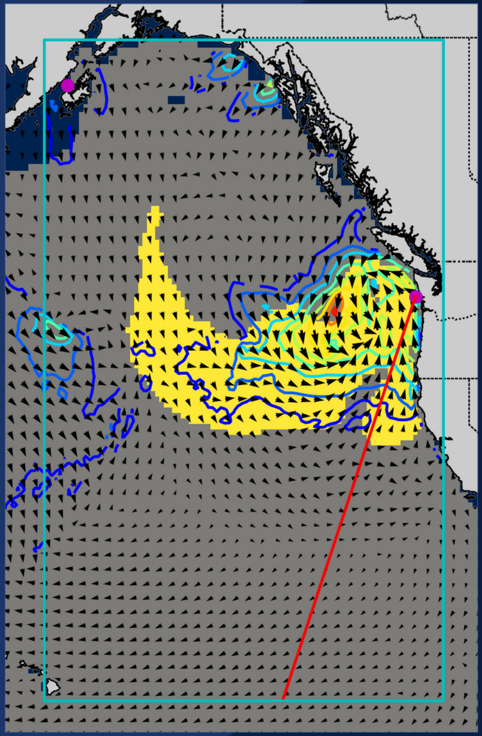
Motivation



- Developing climatological statistics
- Stratification of skill assessment
- Assembling model inputs
- Kinematic analysis
- Storm-specific modeling

Storm Selection?

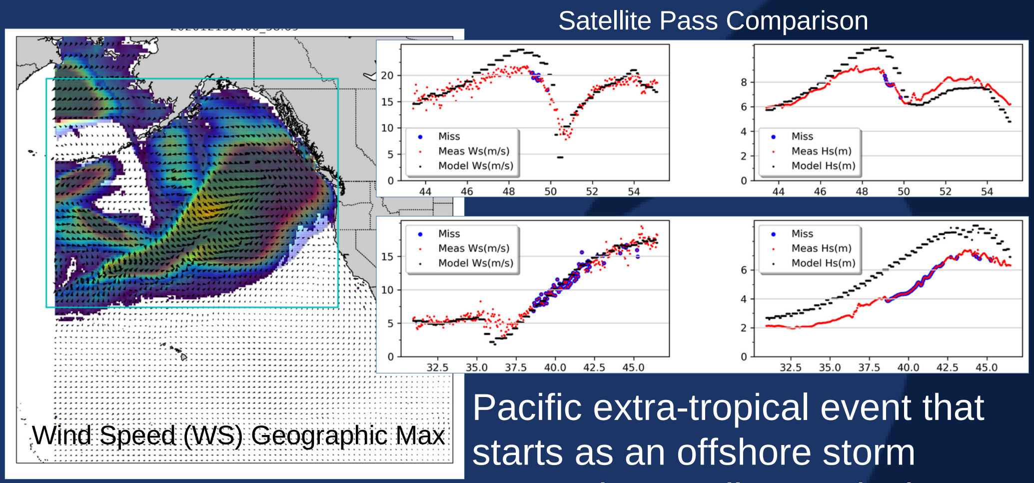
- Inventories of targeted metocean events
- Start/End Dates
- Geographic Extents

Often a need to determine discrete storm events for met-ocean modeling projects including:

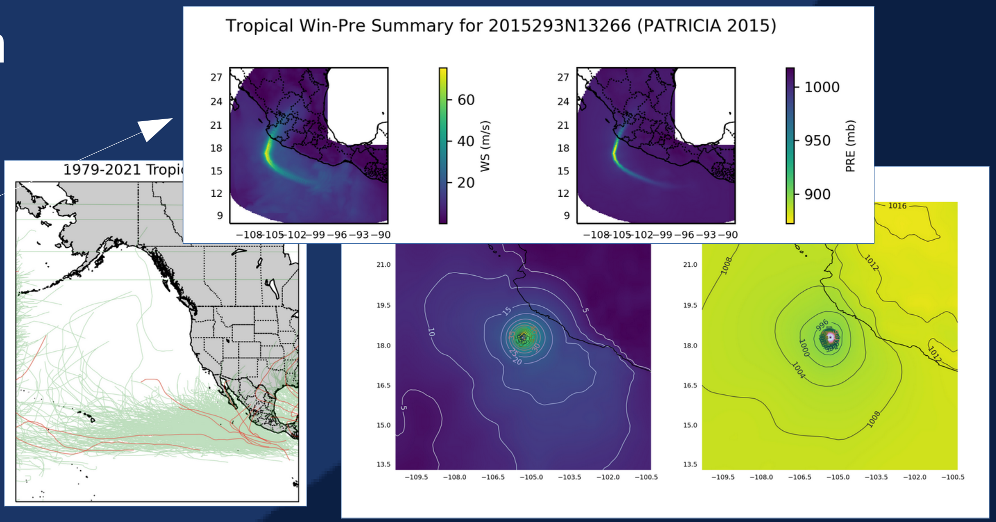
- Atmospheric
- Wave
- Hydrodynamic
- Statistical and kinematic reanalysis of winds/pressures

The Problem

- Extra-tropical storms
  - Large, unorganized
  - Swath of impacts
  - Winds, Waves, Surge
- Coastal storms
  - Tight gradients
  - Short time/space impacts
  - Not well represented in obs/models
- Tropical Storms
  - Well defined in time/space
  - Cataloged
  - Local impacts



Pacific extra-tropical event that starts as an offshore storm generating swell towards the coast, and then moving into the coastal margin.

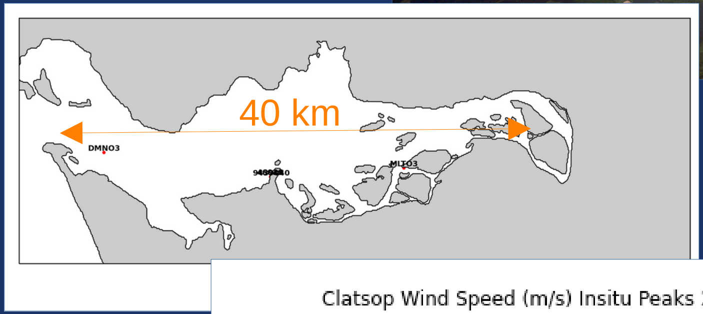


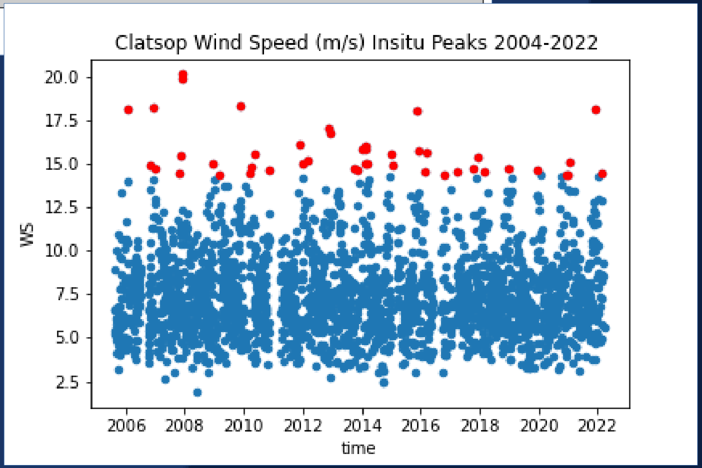
Pacific cyclone Patricia (2015)

The Problem

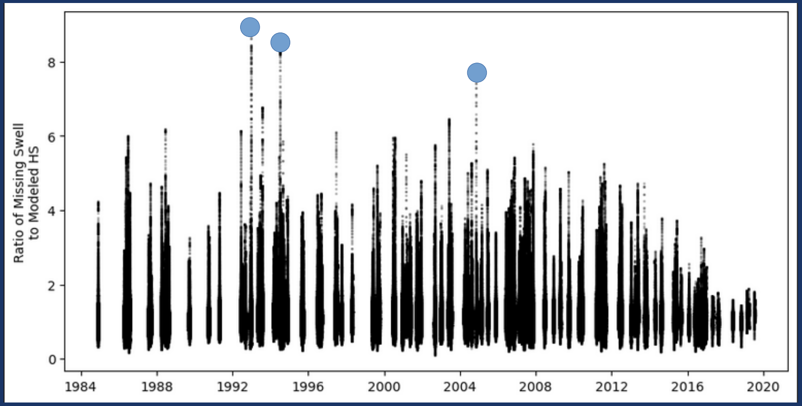
Columbia River Estuary

- Site specific concern
  - Time-series-like
  - Only few obs records or model output
  - Homogeneous within domain





Insitu peak WS magnitude over period of record of NOS stations in Columbia River Estuary

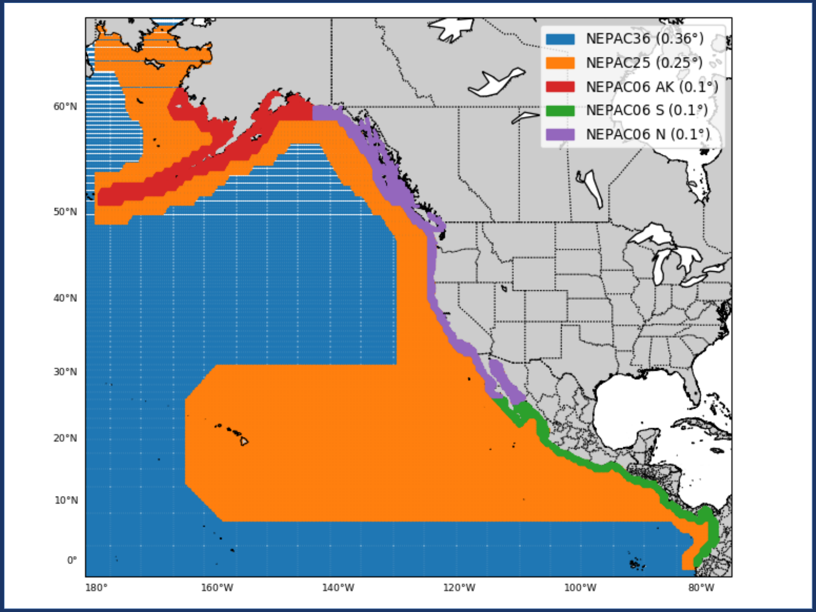


Time-series of strong wave-current interaction causing refraction (South Atlantic western boundary current)

The Problem

- Large coastlines or basins
- Long time periods
- Broadly intended output

- Time-scales
- Spatial-scales
- Locality



Large NEPAC hindcast multi-grid wave model configuration with 0.1 deg. coastal archive (red, green, purple)

- Coastal storms
- Offshore swell storms
- Trends
- Spatial heterogeneity

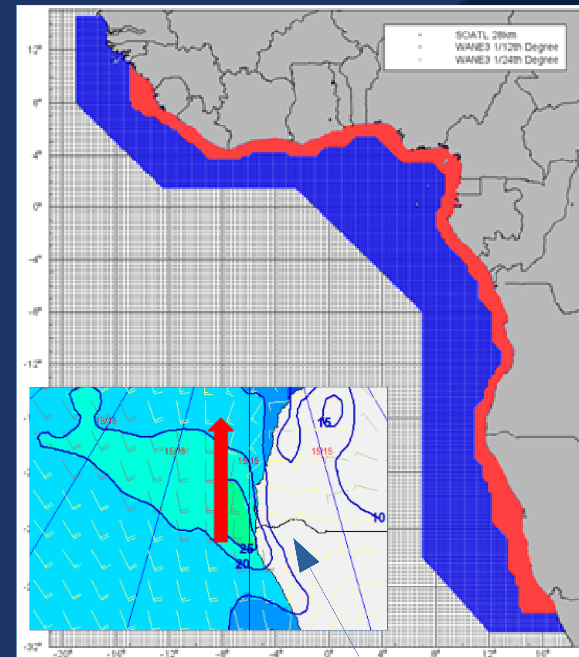
The Problem

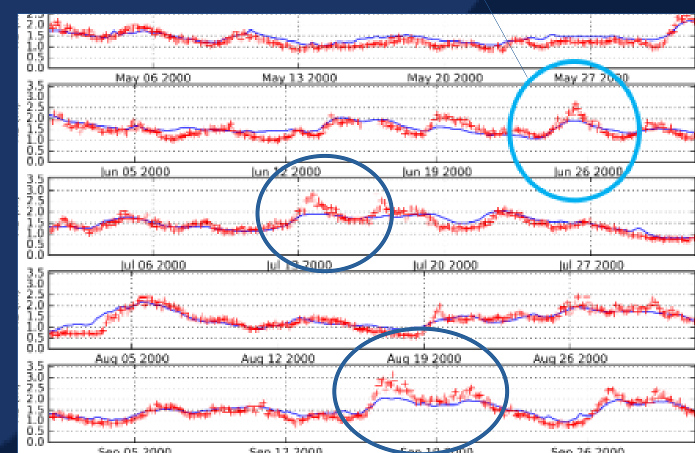
- WANE3 (West Africa Normals and Extremes)
  - South Atlantic basin
  - Long coastal margin

- Offshore VESS storm dataset starting point
- Control points and observations
- Required labor-intensive iterative process that included running the wave models to finalize wind field improvements targeting HS in the nearshore domain(s)

- Important considerations:
  - Trust in a large set of measurements of differing qualities from variety of sources
  - Trust in larger-scale or global model output

Large WANE3 wind and wave domains





HS time-series for important storm events missed in storm selection

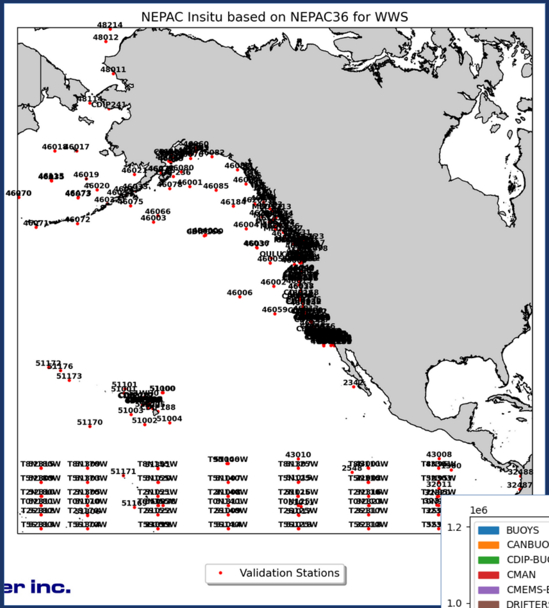
Recent Advances

Seeking improvements in:

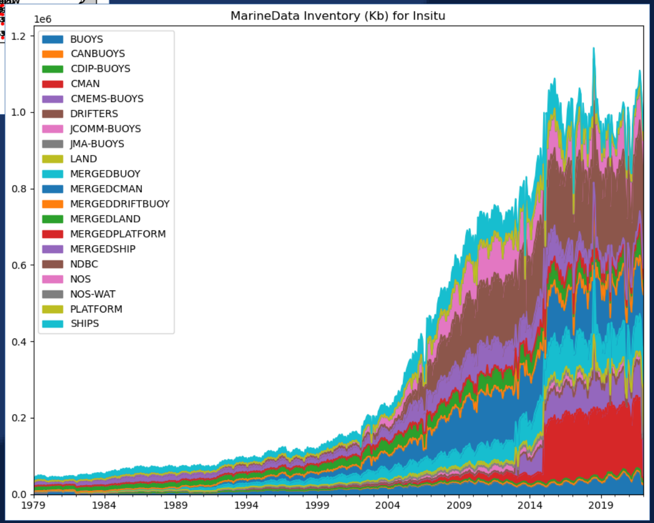
- Spatial/geographic
- Temporal
- Coverage and/or representiveness

With respect to:

- Changes in observations
  - Platforms/Instrumentation
  - Geographic distributions
  - Time-spans
- Climatic changes or cycles
- Geographic scales
- Geographic variations in weather patterns



All available insitu stations in Northeast Pacific (NEPAC) basin



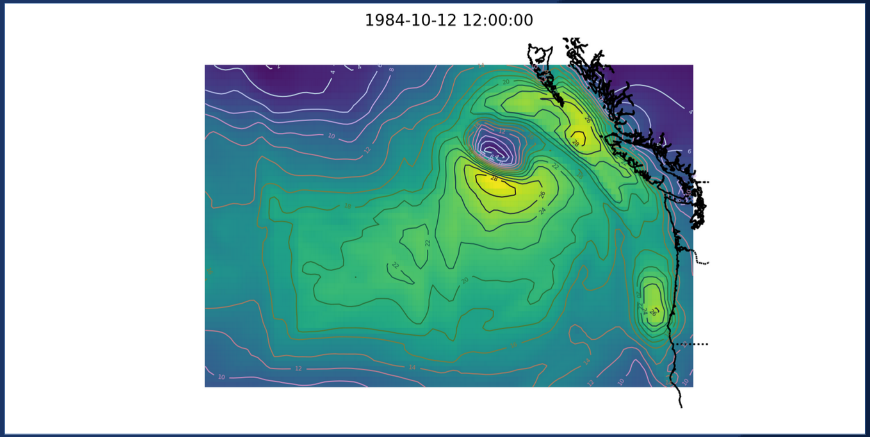
Insitu availability through hindcast period by data source

Recent Advances

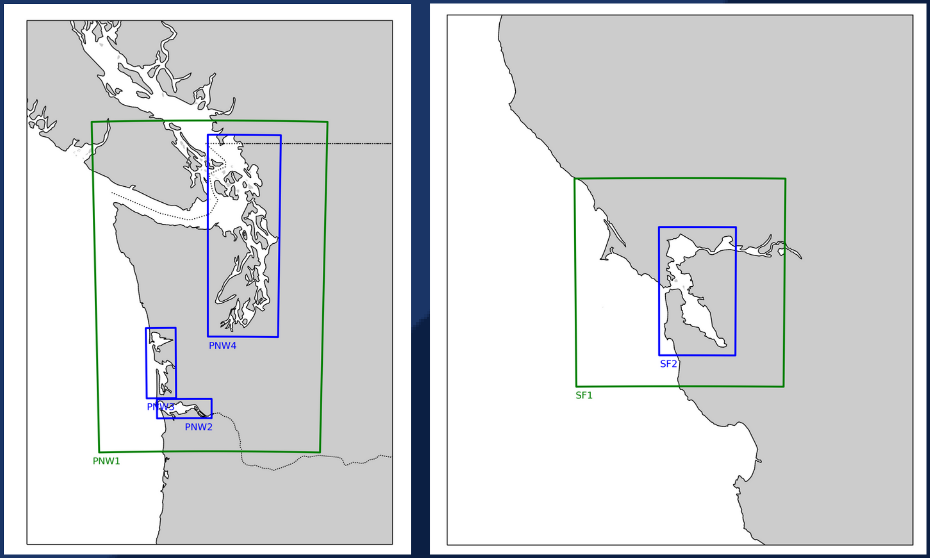
1) Determine storm events for potential kinematic analysis

2) Selection of extremes-driving events for high-resolution modeling

3) Post-modeling attempt to assemble comprehensive inventory of significant events from hindcast project outputs



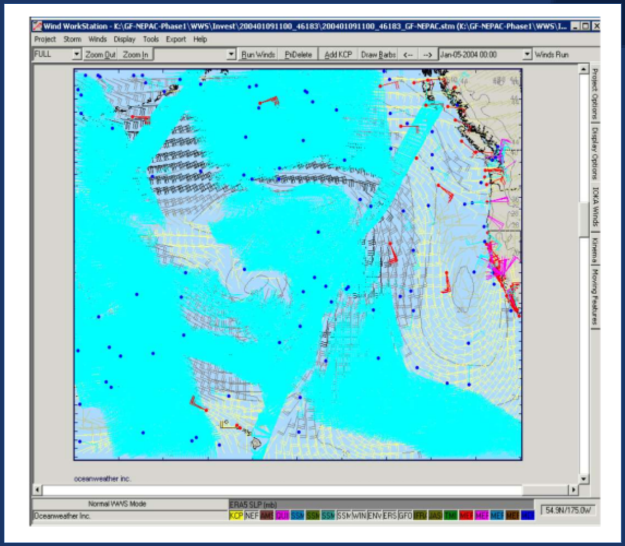
IOKA analysis output WS field in the North-eastern Pacific basin for NEPAC hindcast



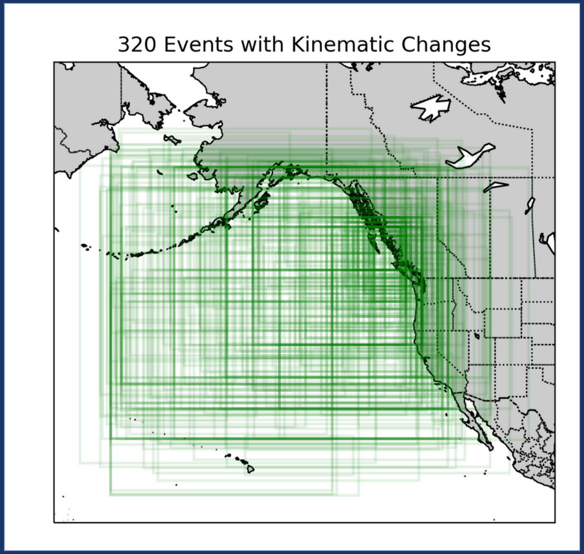
NEPAC WRF model nests for regional extremes and follow-on modeling

Potential Kinematic Analysis

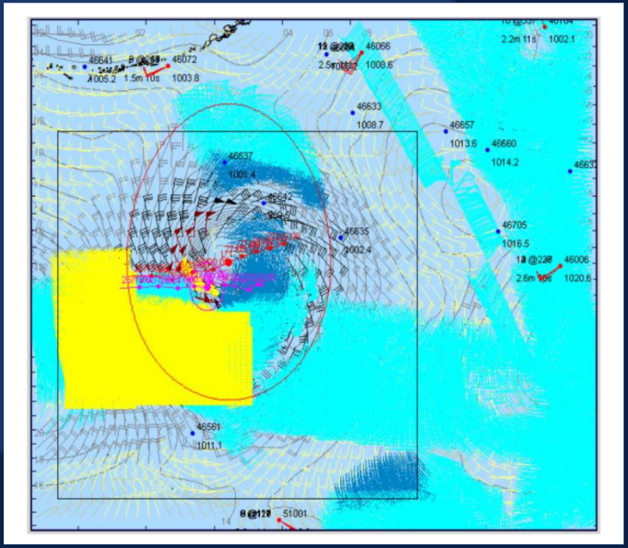
- Needs for “kinematic” storms in NEPAC hindcast
  1) Deficient input wind fields
  2) Impacts distributed throughout domain/time-period
  3) Analyses worth the manual effort required
  4) Identify event start/end and bbox



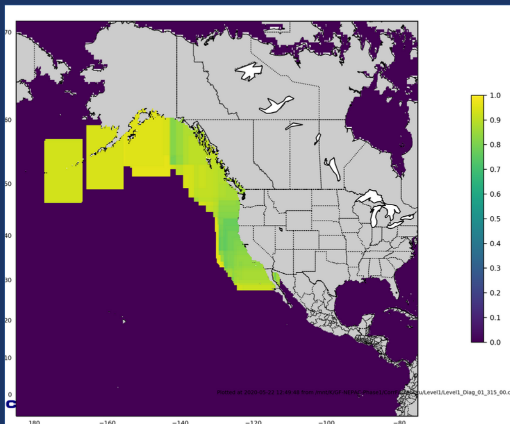
IOKA kinematic analysis for NEPAC showing feature tracking, assimilation, measurements, and manual adjustments using the WWS



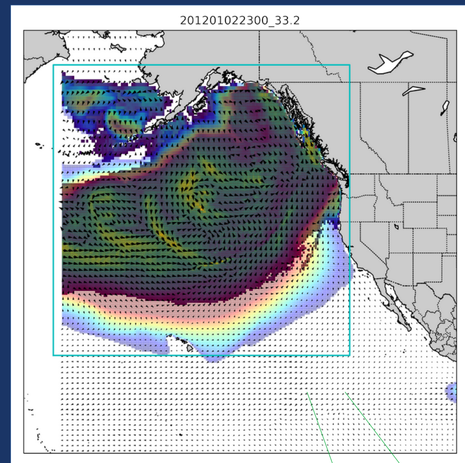
Final population of kinematic analysis modification extents



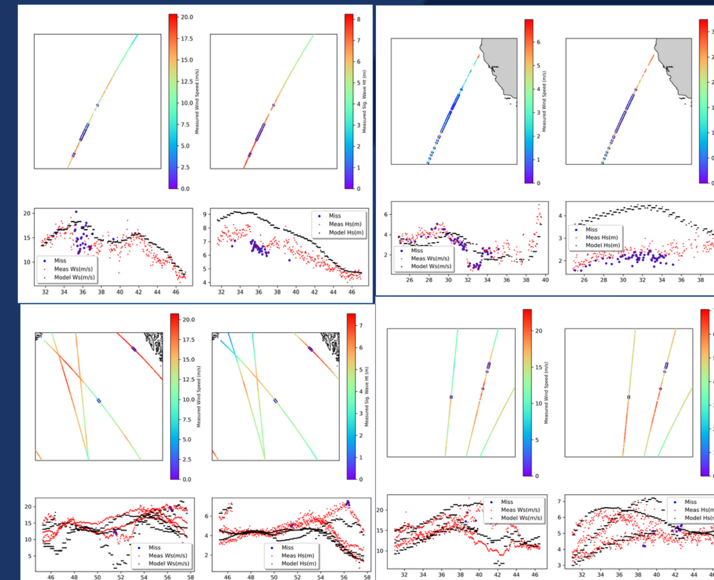
Potential Kinematic Analysis



Spatial map of overall model WS correlation to insitu measurements

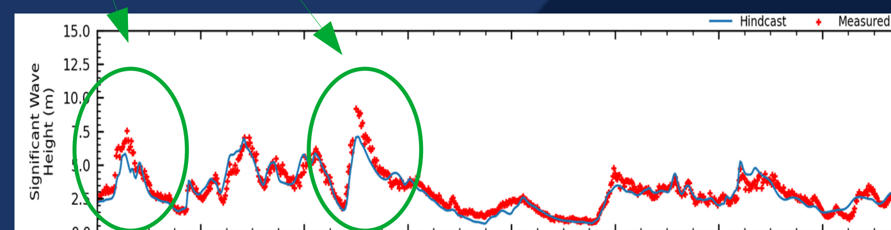


WS/HS max for January 2012 event identified in both satellite and insitu observations



Satellite altimeter comparisons to model of WS/HS in January 2012

- Approach guided by
  - Background wind field statistically good near coast
  - Regular wind/wave “misses” during intense offshore storms
  - Signatures found in insitu wave measurements along the coast in the target archive domain(s)



Coastal insitu buoy HS time-series comparison showing impact of deficient offshore wind fields for January 2012 events

Potential Kinematic Analysis

On yearly basis, and for all overlapping insitu wave observation stations:

1) Time/space match model to insitu
2) Remove insitu stations > 10km

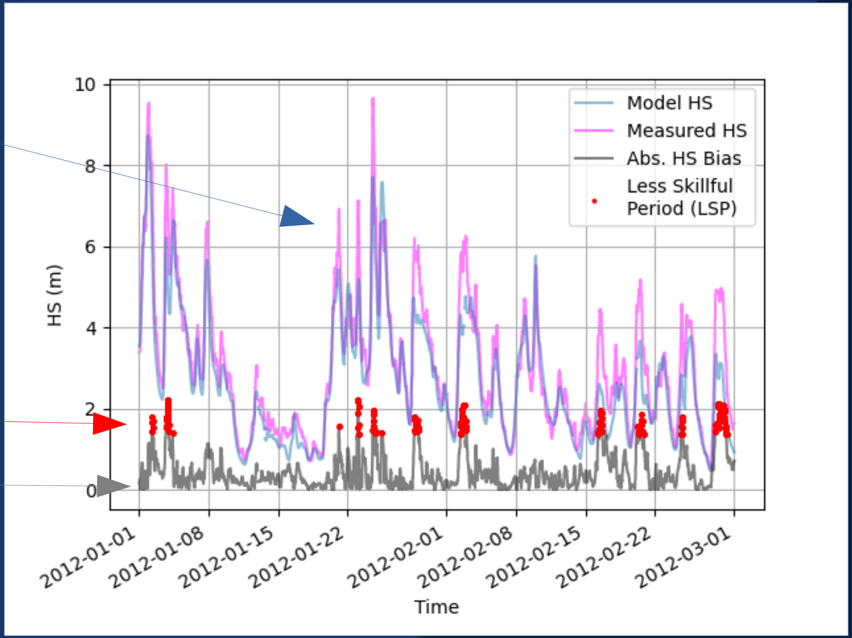
   Assuming failure or maintenance
3) Remove individual comparison samples BIAS > 4xSTDDEV

   Assuming bad observation or comparison location
4) HS bias comparison time-series smoothed w/ 3-hour mean

   Sustained (correctable?) modeling error
5) 1.35 m (smoothed) bias threshold determined less skillful periods (LSP, red)

   Arbitrary threshold
6) Overlapping LSP from different stations concatenated

   Total combined LSP determined event



Steps 4 and 5 applied for NDBC 46185 for the first quarter of 2012

Potential Kinematic Analysis

7) Buffer time added to start/end

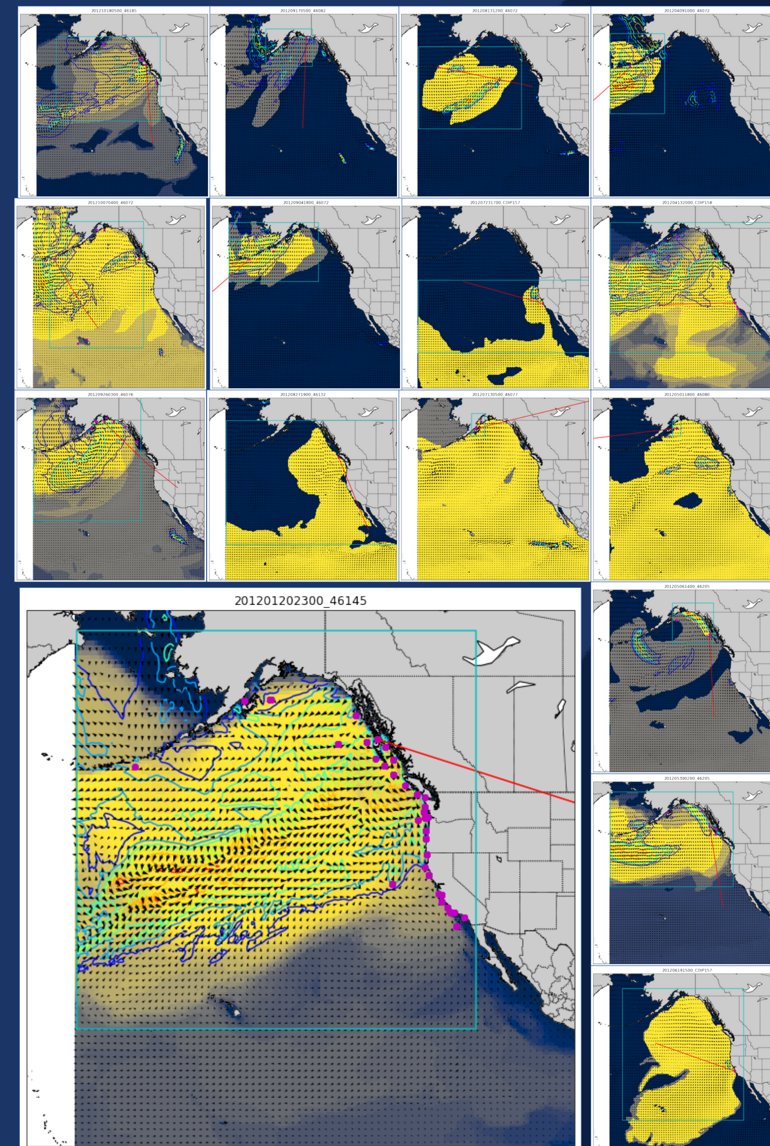
   Swell travel time

8) Impose maximum time limits around non-smoothed maximum absolute bias in given event

   Technological constraints and potential for long-term model bias exceedances/LSP

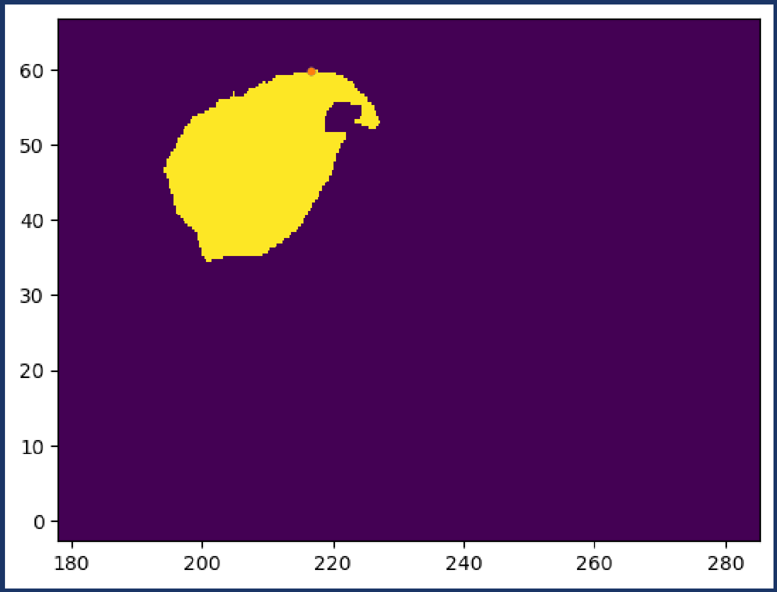
9) Iterative approach to determine spatial extents for IOKA WWS software for each potential storm event

   Considering LSP on coastal wave grids may be due to local wind-sea or swell produced offshore



2012 storm event max WS/HS plots as identified for potential kinematic analysis with associated insitu stations in pink

Potential Kinematic Analysis



Area above threshold (yellow) at t <= bias peak for individual station (orange circle near top)

1) Flood basin grid area based on HS threshold using insitu station as seed

$$HS_{basin} \geq HS_{station}^{t=bias\ peak}$$

2) For each timestep between peak bias and event start: flood basin grid exceeding threshold using any previously flooded grid points as seeds

3) Compile flooded regions for all stations and compute probability of flooding from above for basin grid points across stations associated with event

4) Determine Lat/Lon extent of the region with >60% probability within event
   - **Local storm:** set extent to encompass only stations if number of >60% flooded points larger than half the total grid points with model

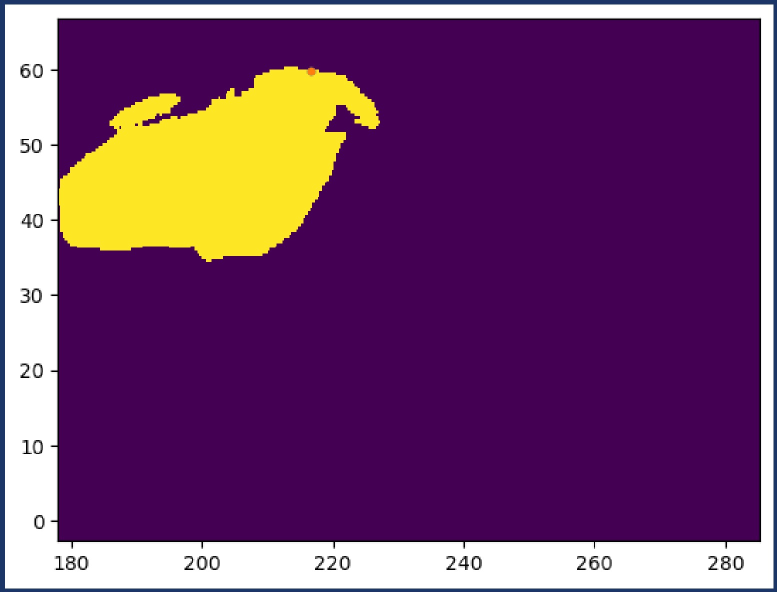
     $$TP_{station}^{t=bias\ peak} > 13\ s$$

   - **Offshore/basin storm:** use combined extent encompassing stations and the >60% probability region

5) Tropical cyclone within event's time period and geographic extent, flag for tropical analysis

For each station with LSP in event
Iterate through time steps from peak bias to start of event in reverse

Potential Kinematic Analysis



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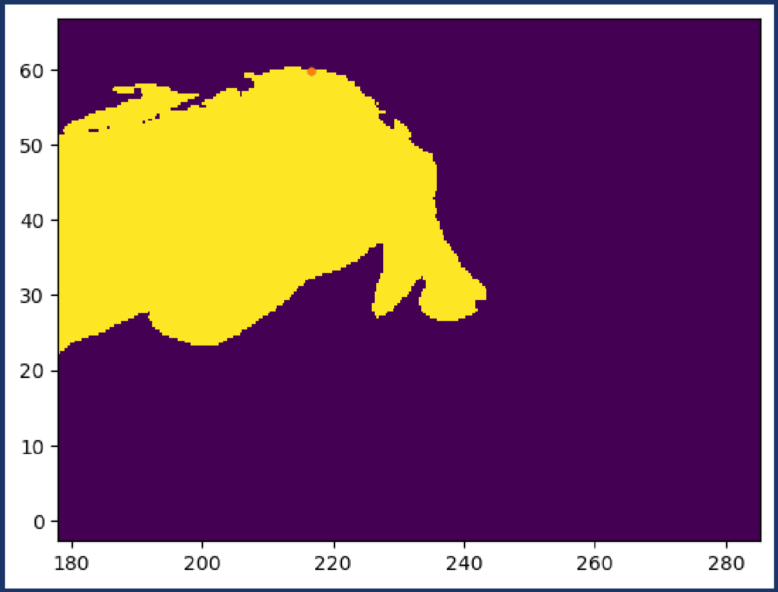

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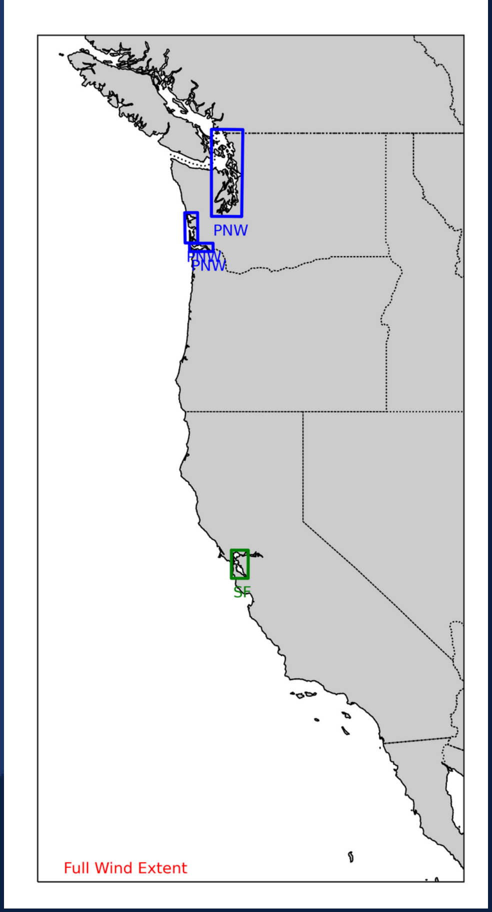
Selection of Extremes-Driving Events

Case:

- High-resolution atmospheric modeling (WRF) coastal water bodies not resolved by global reanalyses
- Wave and/or Hydrodynamics run with WRF inputs at later date by USACE

Conditions:

- Need storms defining extreme distributions for wind and coastal waterway response
- Applicable and extensible to multiple bays and estuaries along West Coast
- Not concerned with incoming offshore swell events

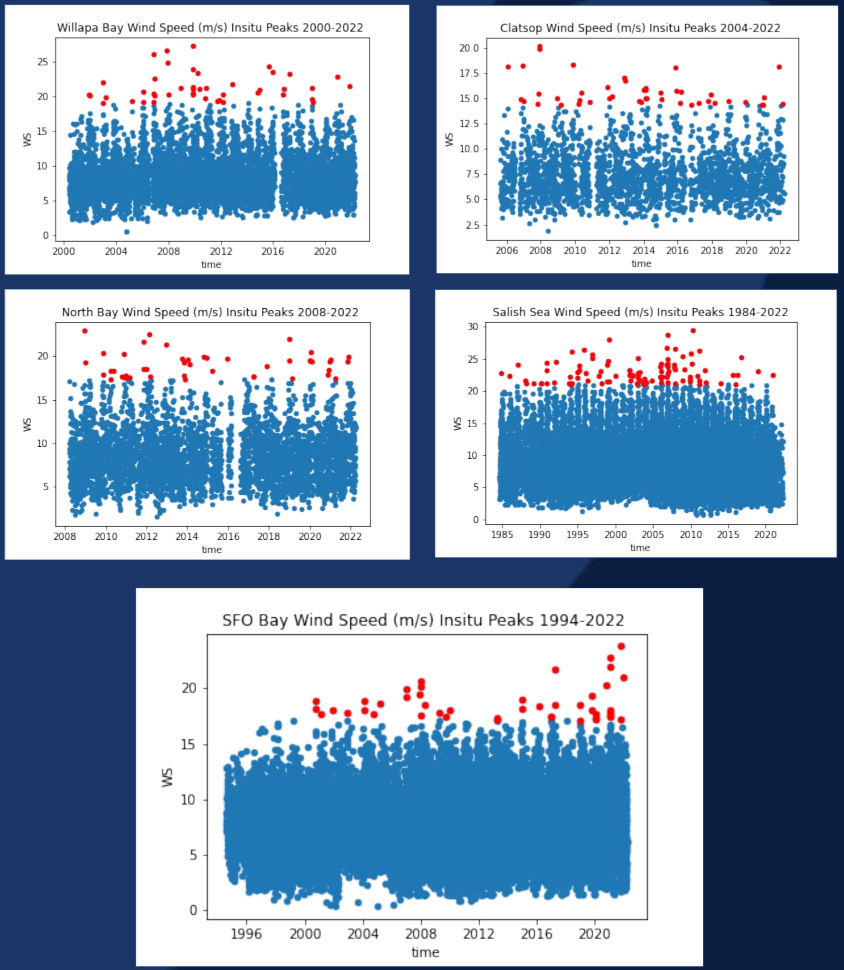


Domains for storm selection: PNW-1, PNW-2 and SFO (3)

Selection of Extremes-Driving Events

Approach

1) Coastal water bodies divided into 3 inner-nest WRF domains (42 events/nest)
2) Manual culling from marine, coastal and land-based insitu WS measurement records (record length, uncertainty…)
3) Identify WS peaks and rank by magnitude in each station's record
4) Remove duplicate peak periods between stations

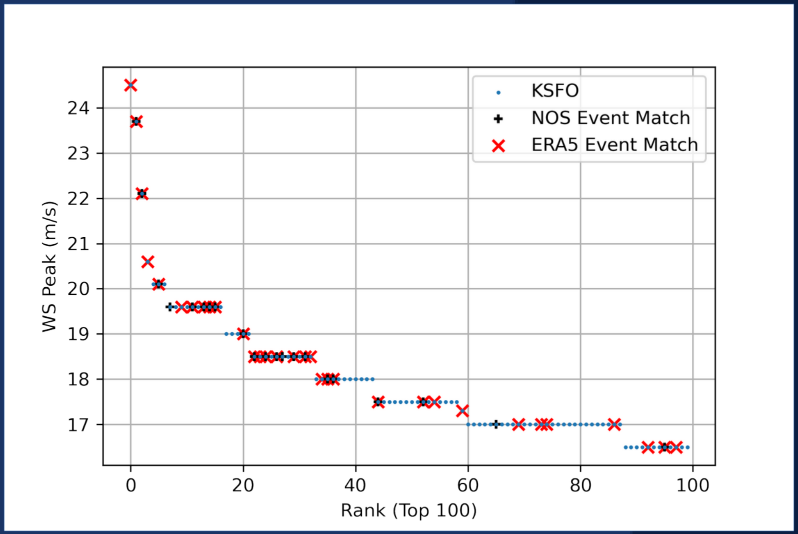


Peaks found in coastal waterway WS observations

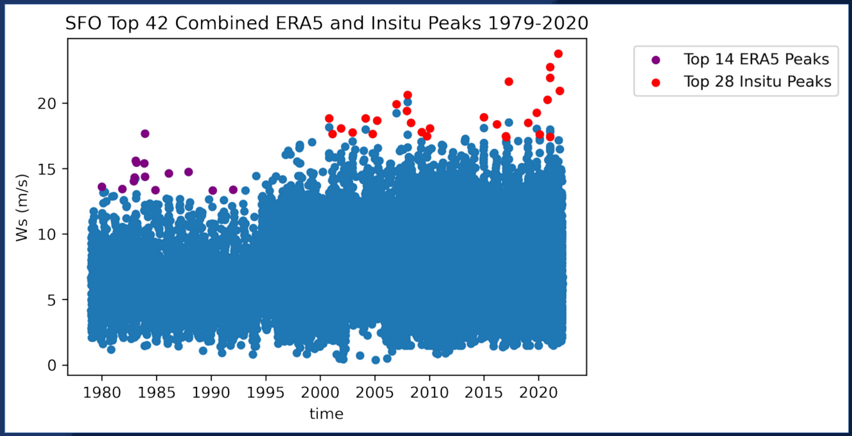
Selection of Extremes-Driving Events

5) ERA5 used as proxy to extend search outside of insitu coverage

- WS magnitude not comparable
- Reanalysis not resolving the small scale air/sea T or topography in study
- KSFO analysis indicated ERA5 can provide a statistically similar event population

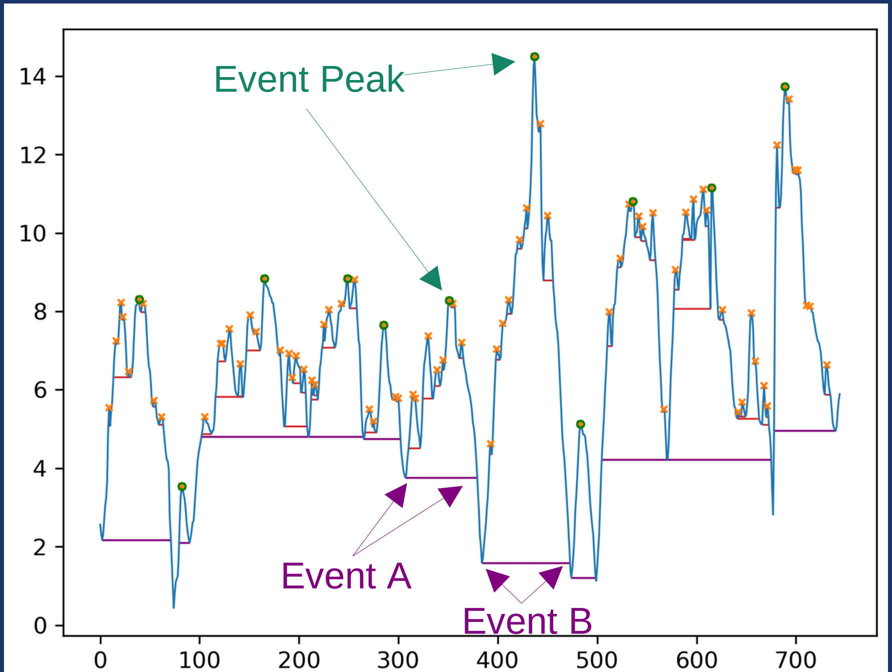


KSFO WS events found in ERA5 and NOS top 100 ranked peaks



San Fran WS events extended by ERA5 proxy

Post-Hindcast Catalog of Storms



Relative prominence approach to isolating events (periods with purple horizontal lines) from time-series with example events A and B called out.

Peaks associated with events A and B indicated by green arrows.

1) Identify (all) peaks for each main parameter (WS, HS…) on each hindcast archive grid point
2) Peaks of conditional params associated with each identified event (per grid point)

Repeat for each point

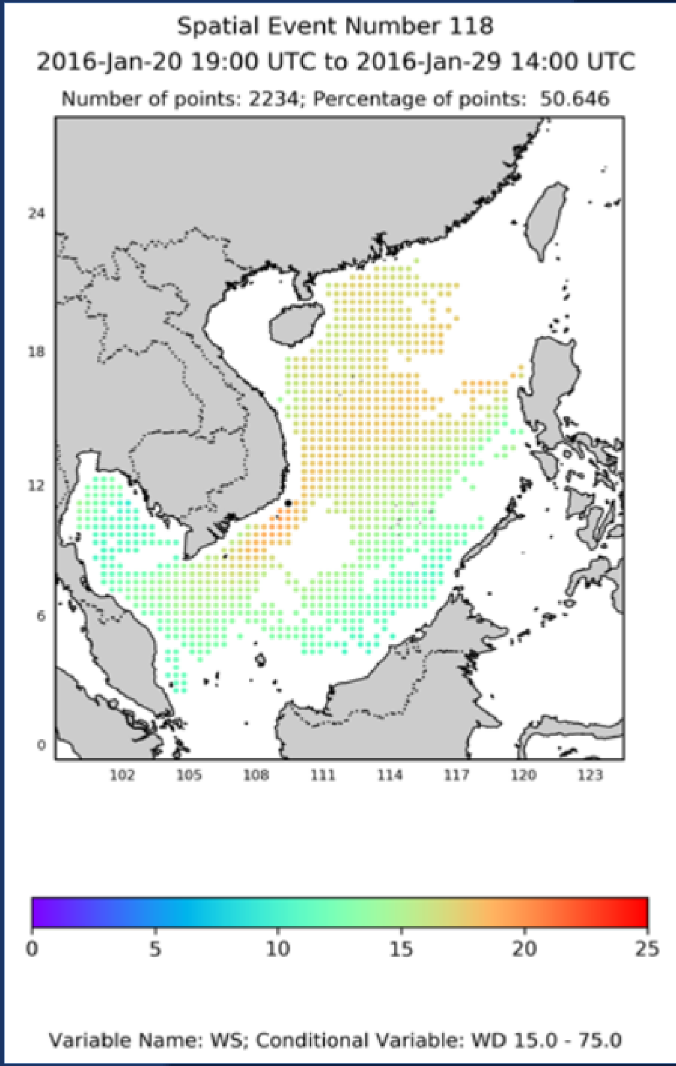
3) Group overlapping events among adjacent grid points
4) Rank peaks events by magnitude for

– or –

5) Rank by event area

Overall, by-grid-point and within conditional facets

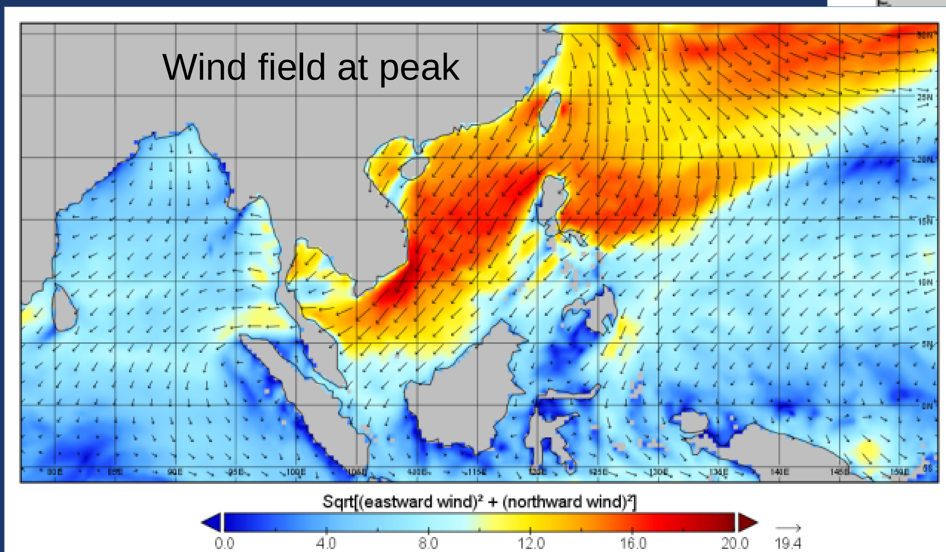
Post-Hindcast Catalog of Storms



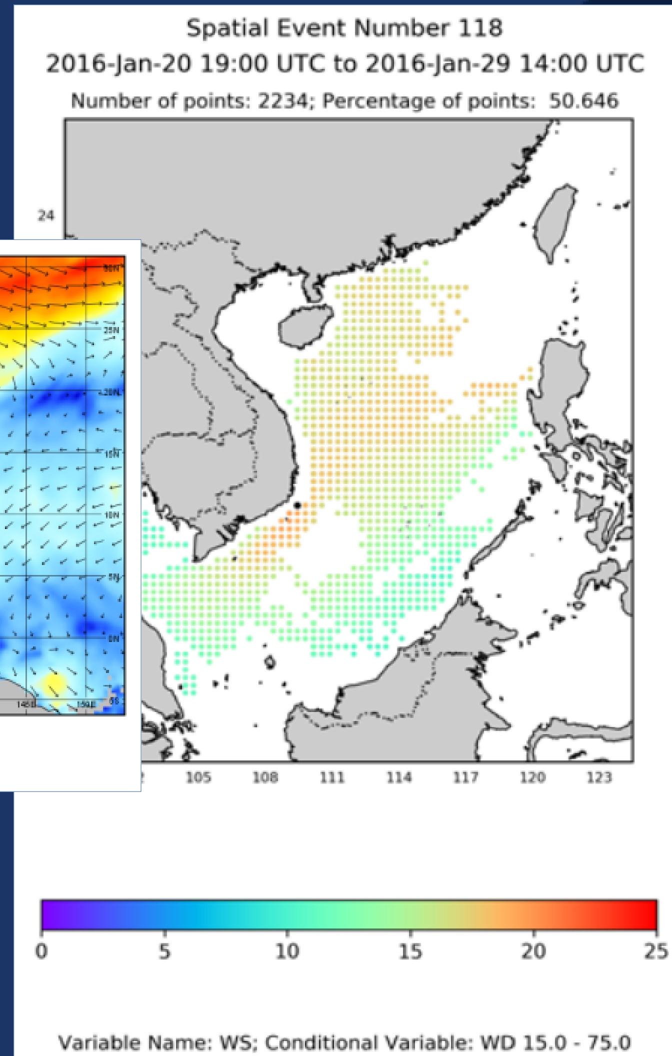
SEAFINE3 Grid points with peaks in event #118 from directional facet

Wind Speed from Wind Direction 15-75 deg.

Post-Hindcast Catalog of Storms



North-easterly monsoon weather pattern



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Summary

– Identifying events for potential storm reanalysis in NEPAC wind/wave hindcast

– WS extremes for high-resolution NEPAC WRF modeling and follow-on response modeling

– Inventory and classification of all significant storm events in SEAFINE3 South China Sea wind/wave hindcast

- Storm/event meaning subjective
- Helpful to combine obs/model output
- Key components:
  – Peak identification
  – Time/space grouping
- Movement towards:
  – Approaches self-characterized by data/scales/events contained in data
  – Conditional facets for corner-cases
  – Reproducible and update-able
  – Future requirements and concerns

- Future uses?
  – Surrogate modeling
  – ML training
  – Comparison of hindcasts or odels
  – Quantifying and qualifying climatic changes to storms