NATIONAL WEATHER SERVICE

January 2024: Micronesia Extreme Waves & Inundation

A Meteorological Analysis of the 17-23 January Event & Impacts

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Science & Operations Officer
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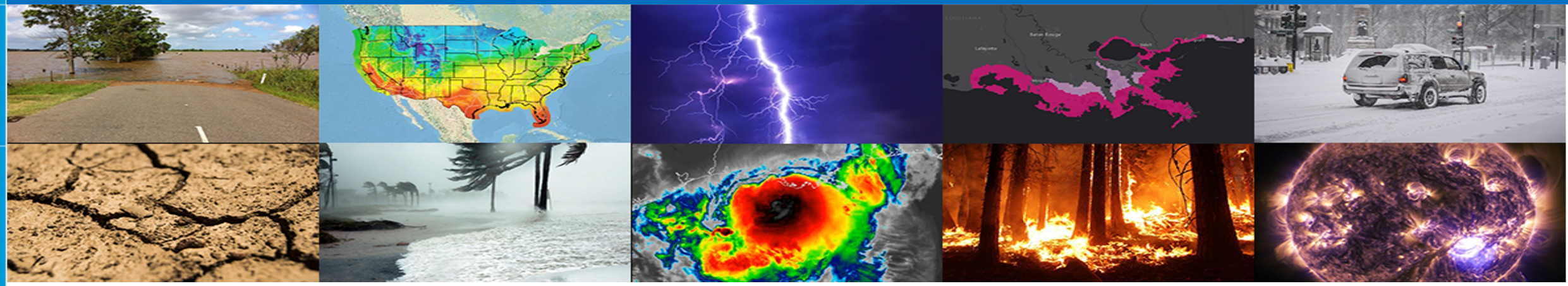

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Acknowledgement & Thanks

NWS Pacific Region HQ

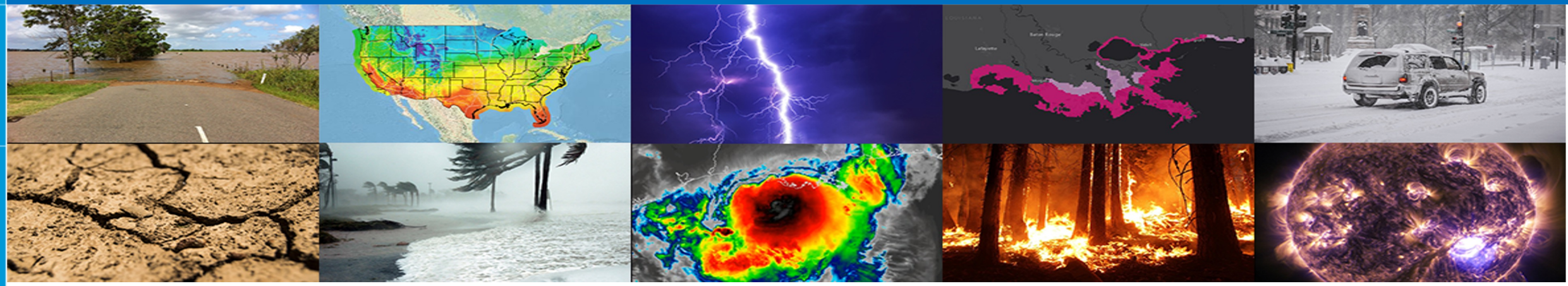
RTS Weather Station

WSOs Majuro, Pohnpei, Chuuk

Ocean Prediction Center

Brandon Bukunt

Joshua Schank



January 20-22, 2024: *Roi-Namur, Kwajalein, RMI*

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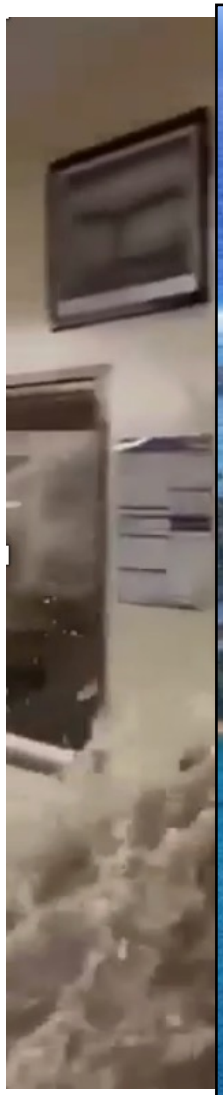
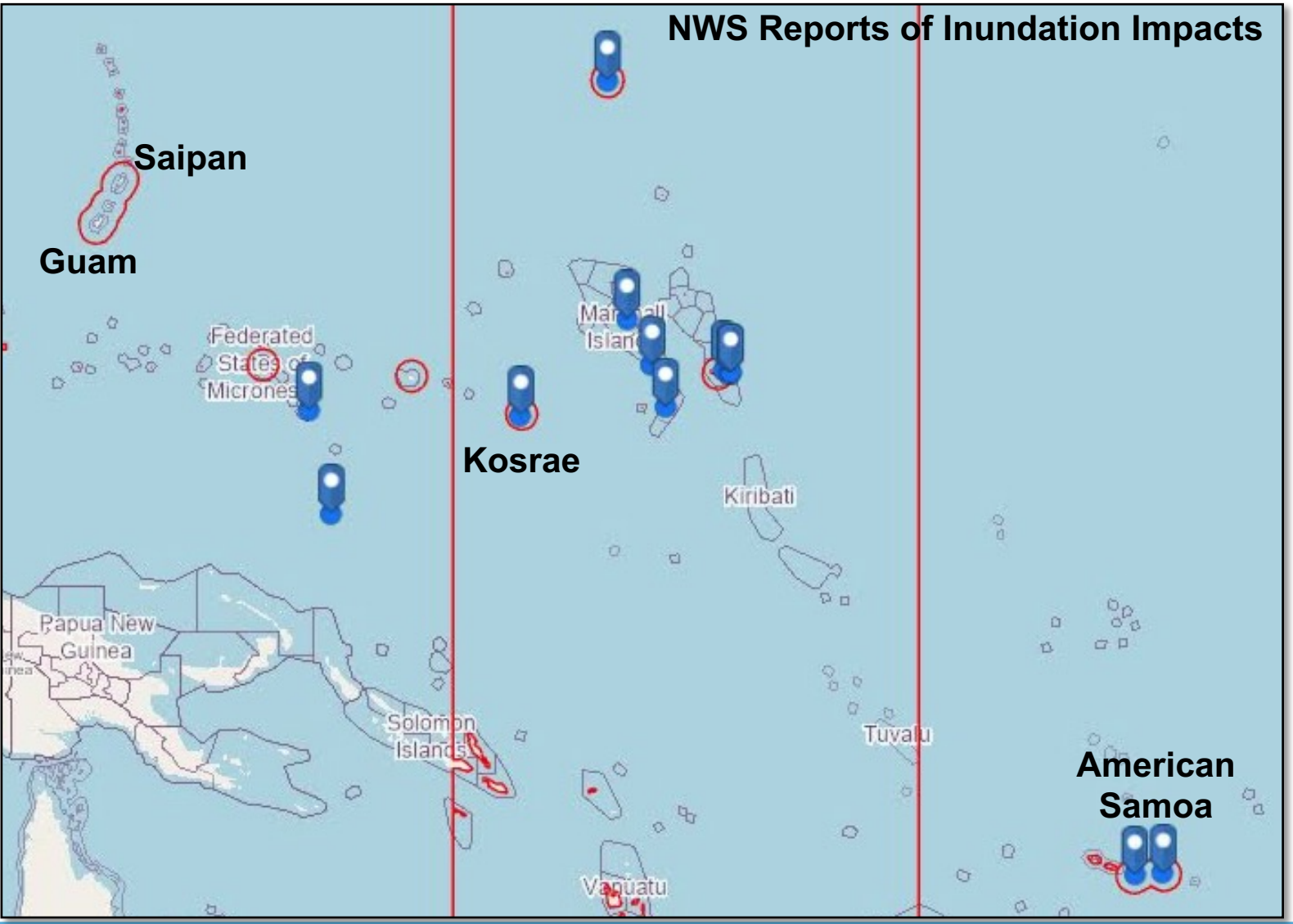


January 20-22, 2024: *FSM & RMI*

"Here is the brief summary of the flood that happened on Lukunoch Island on Monday, January 22, 2024. According to [the] Synoptic Observer [name removed], it started at 09:00 am till 3:00 pm. On that day. He also stated that high surf came from Northeast and East and flooded most of the island that included some of the taro patches." (Courtesy WSO Chuuk)

January 20-22, 2024: *FSM & RMI*



Quick Summary of Regional Impacts

- Massive surf (>15 ft) & large long-period (>15 sec) northerly swell across Micronesia
- Surf-related inundation; at ***most*** islands, seemingly timed around high tide cycles.
- Roi-Namur: Major inundation that occurred only briefly (20-30min from reports); occurred around ***low tide***.
- King Tides & Spring Tides ***were NOT a factor***
- Large surf & inundation also into the southern hemisphere – American Samoa, Kiribati, Solomon Islands, and the Cook Islands

January 21-23, 2024: *Media Coverage*

January 21-23, 2024: *Media Coverage*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Video shows massiv
Army base in Marshall Islands,
causing extensive dam


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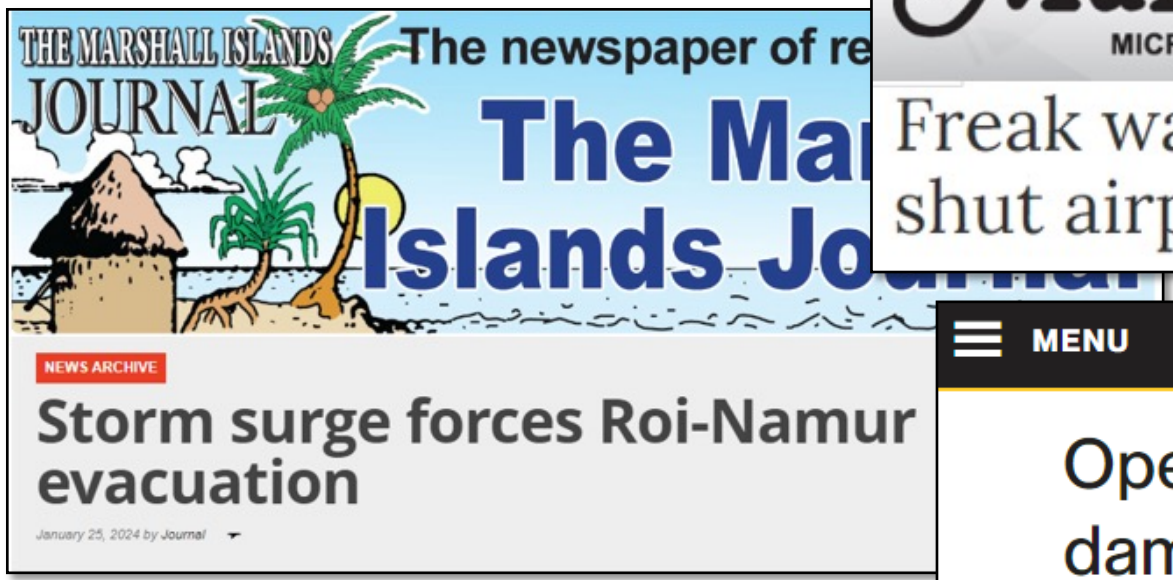
A US military base was pummeled with rogue waves from a storm surge on the Marshall Islands


THE MARSHALL ISLANDS JOURNAL

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NEWS ARCHIVE

Storm surge forces Roi-Namur evacuation

January 25, 2024 by Journal


Marianas Variety News & Views

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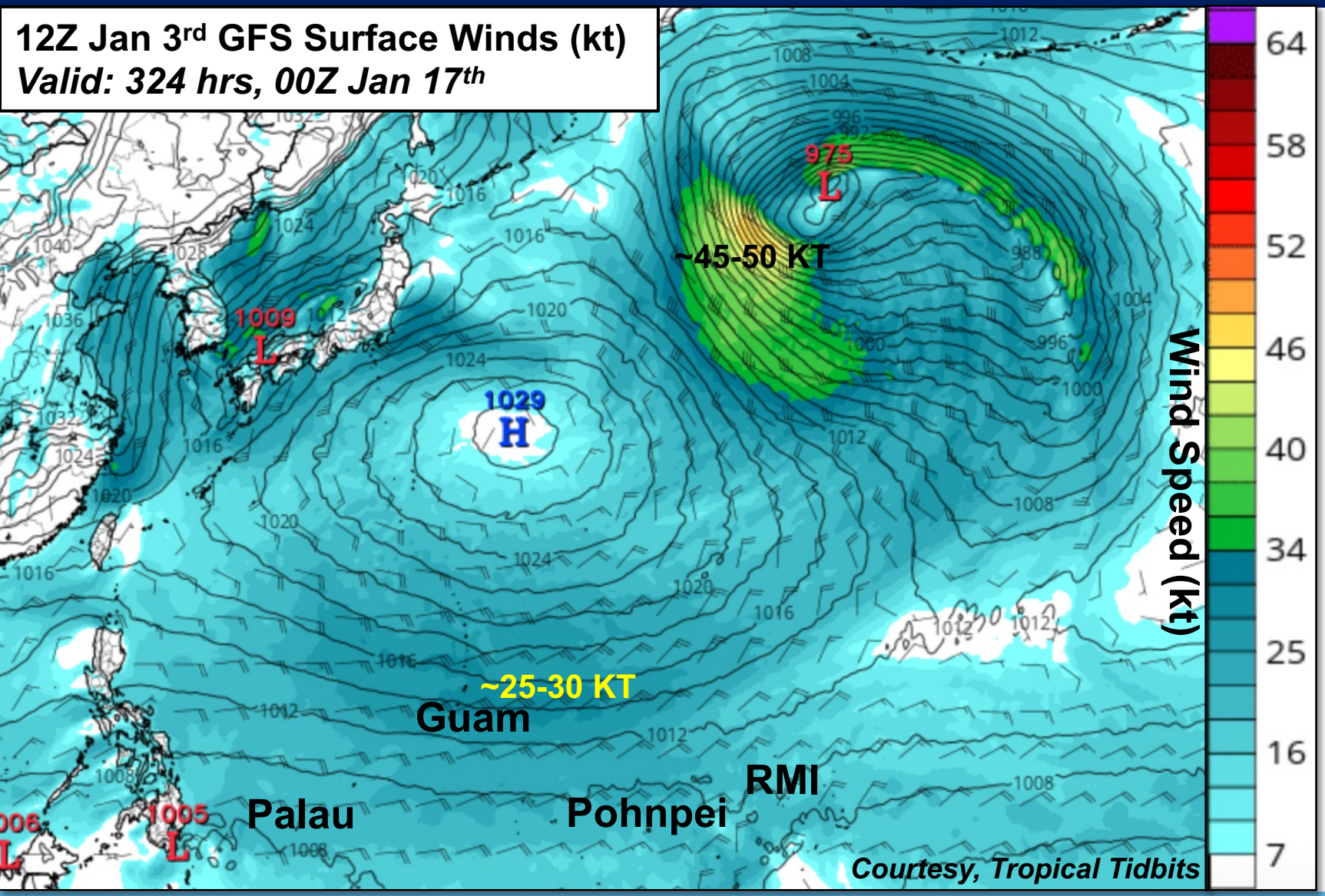
Freak waves cause damage at Army base, shut airports in remote islands


MENU U.S. ARMY SEARCH

Operation Roi Recovery assesses damages to Kwajalein Atoll infrastructure

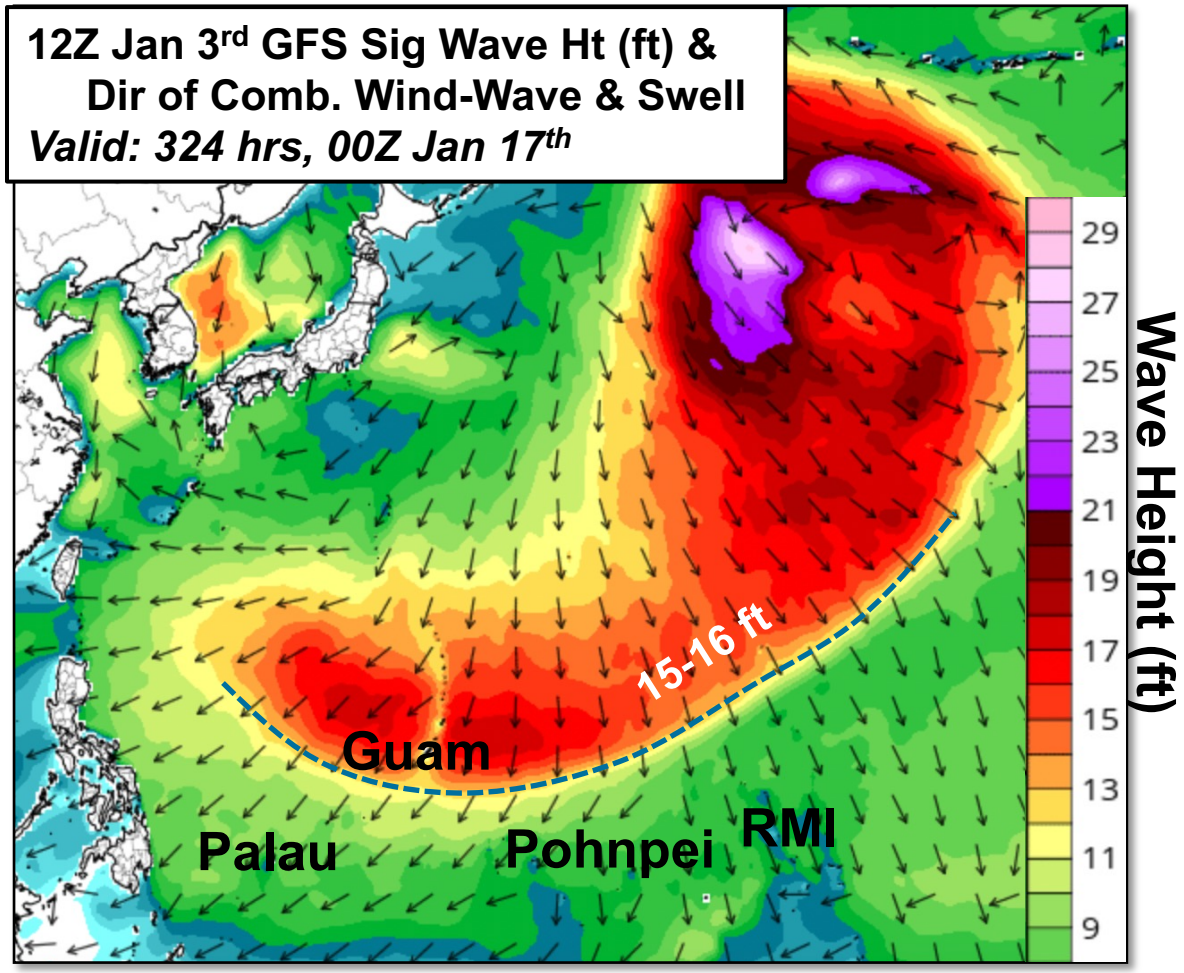
Leading Up to the Event: *Very Long-Range Model Wind Data*



- Typical pattern across the North Pac as low pressure circulations & fronts pushed eastward from Asia; followed by building high pressure areas.
- Around 13d in advance, GFS model began showing a powerful circulation, frontal system, shear line, and strong high pressure to affect the region.
- Forecasts and discussions highlighted shorter-term and mid-range marine (wind, sea, surf) threats.
- Forecasters kept an eye on this system, providing increasing details beginning the week prior as model consensus grew.

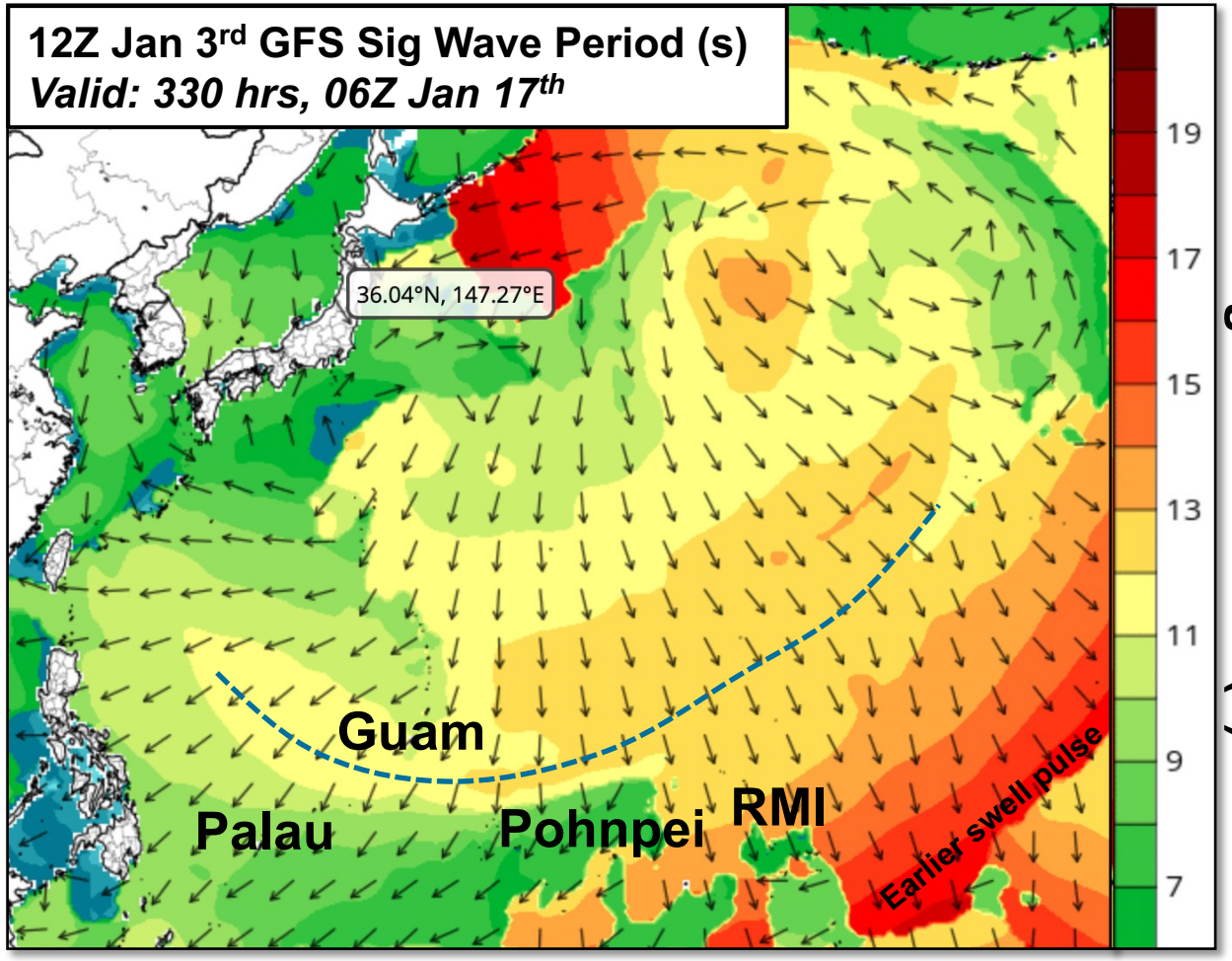
Leading Up to the Event: *Very Long-Range Wave Model Data*

12Z Jan 3rd GFS Sig Wave Ht (ft) & Dir of Comb. Wind-Wave & Swell
Valid: 324 hrs, 00Z Jan 17th

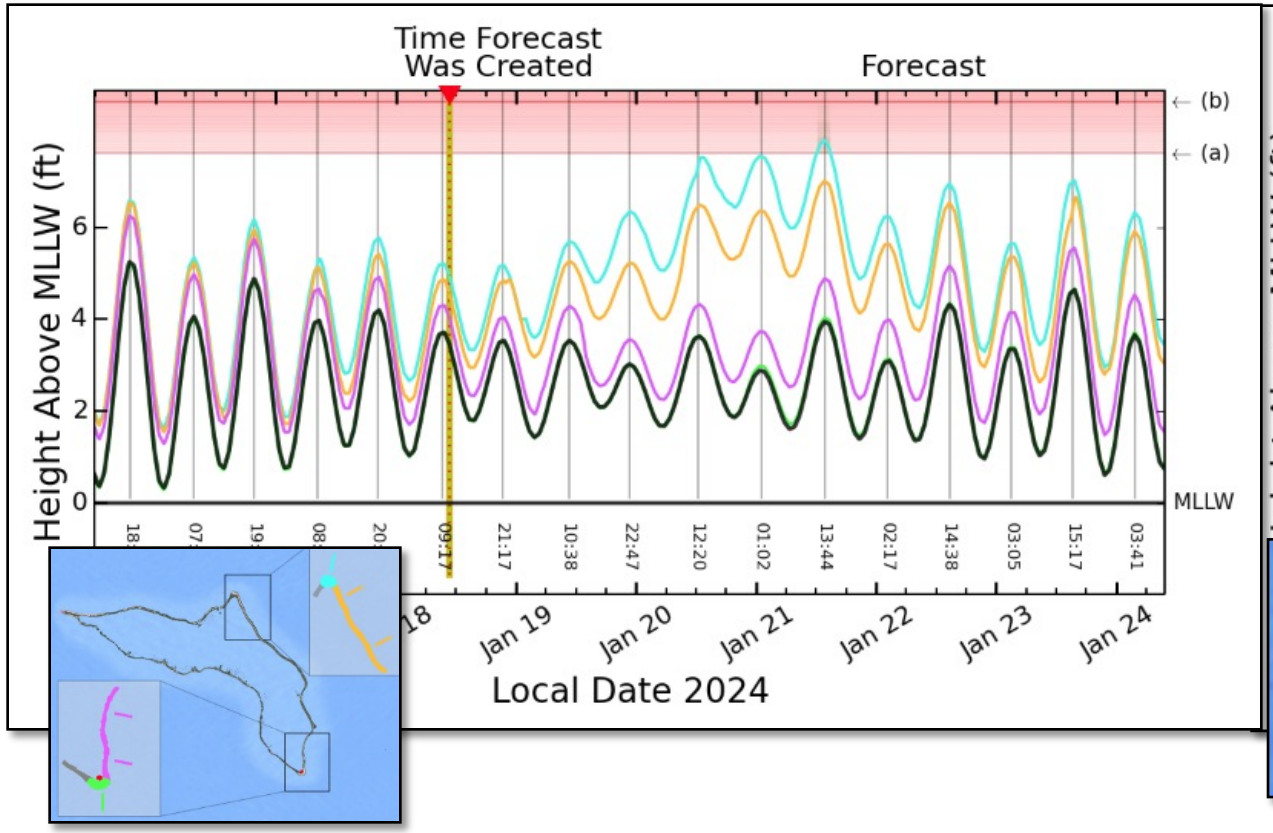


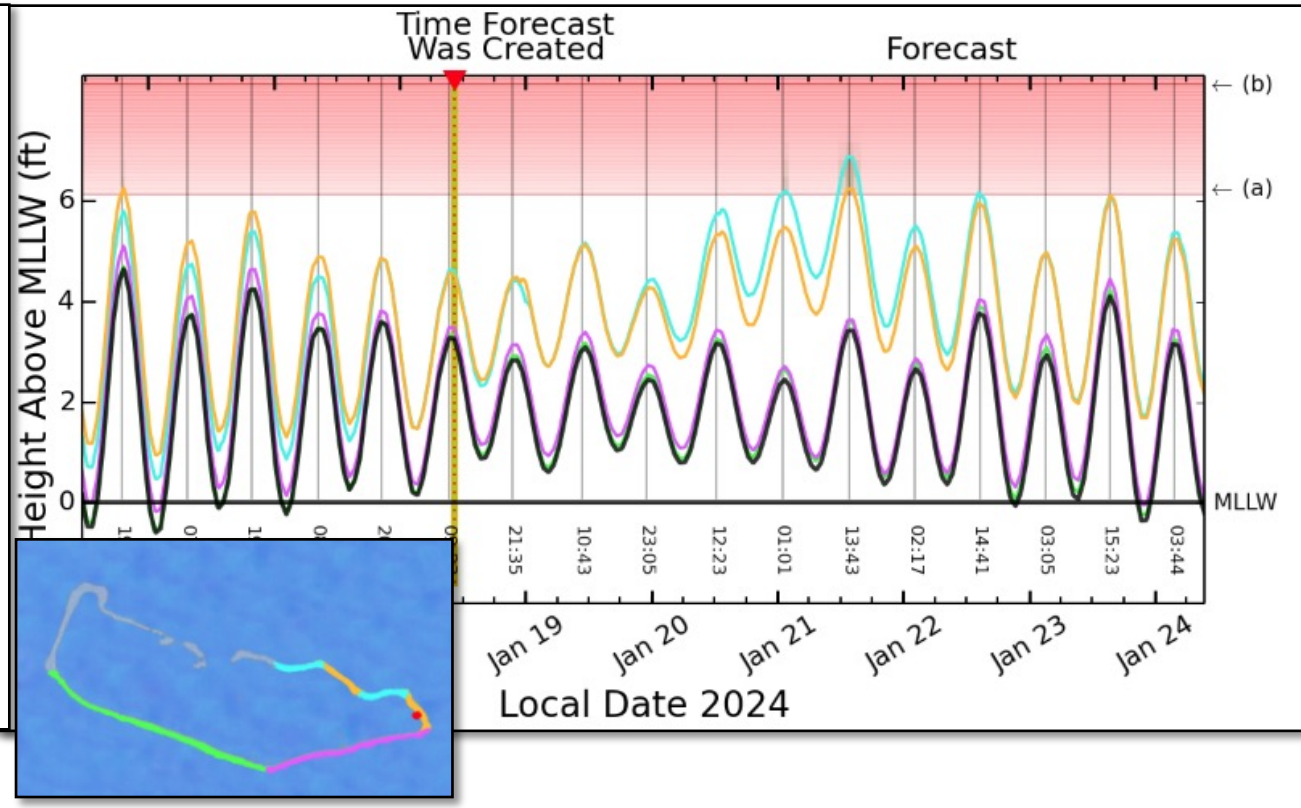
Courtesy, Tropical Tidbits

12Z Jan 3rd GFS Sig Wave Period (s)
Valid: 330 hrs, 06Z Jan 17th



Leading Up to the Event: *PacIOOS Run-Up Guidance*





Four separate color-coded Wave Run-Up Forecasts are provided for the ocean-facing shorelines of the most populous parts of Kwajalein atoll. The **Cyan**, **Orange**, **Magenta**, and **Green** curves show the potential **Inundation Height** for the respective unarmored shorelines due to high tides and/or wind-generated waves. The forecasts are updated hourly.

The **Black Curve** displays the *Observed* and *Forecast Sea Level* at Kwajalein Atoll (Echo Pier) for the previous 3 days and the next 6 days, respectively, relative to Mean Lower Low Water (MLLW, a typical NOAA datum). Grey vertical lines show the associated times of the forecasted high sea level.

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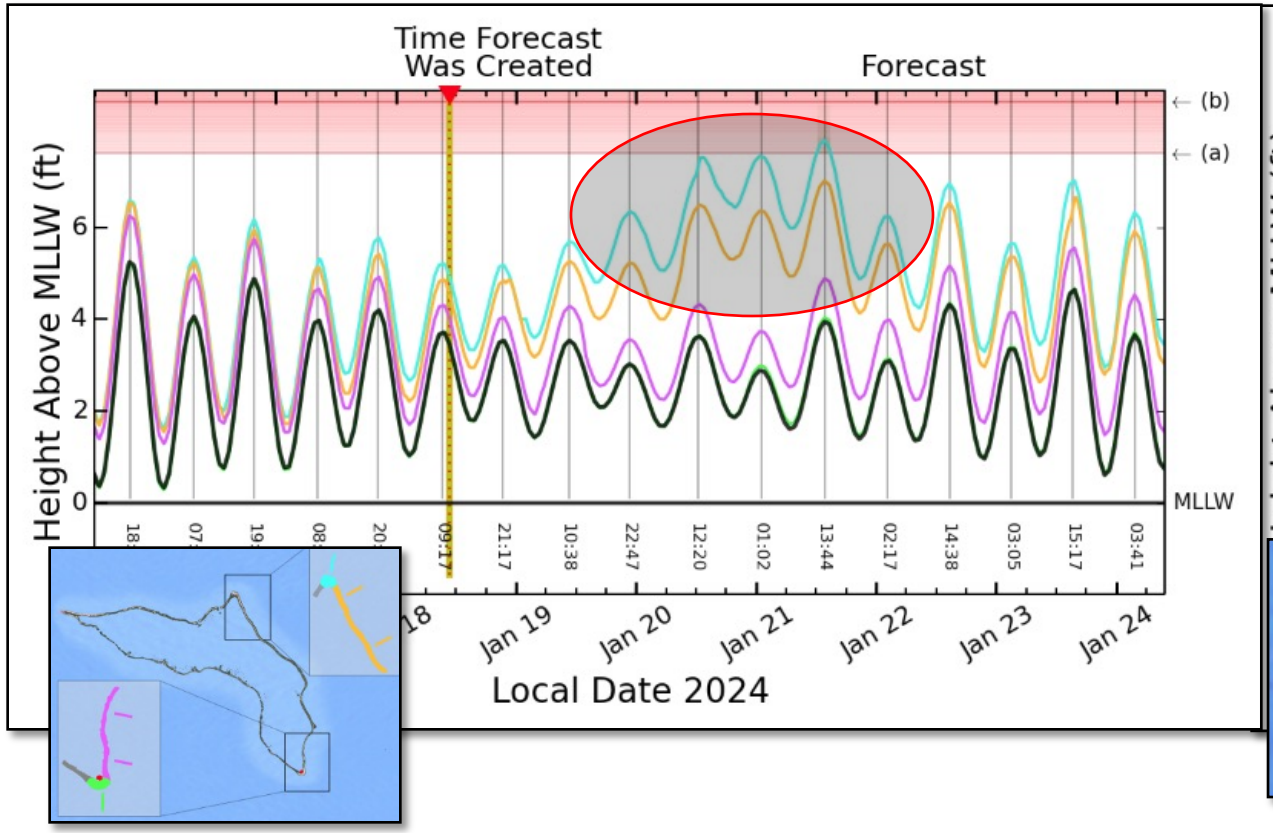

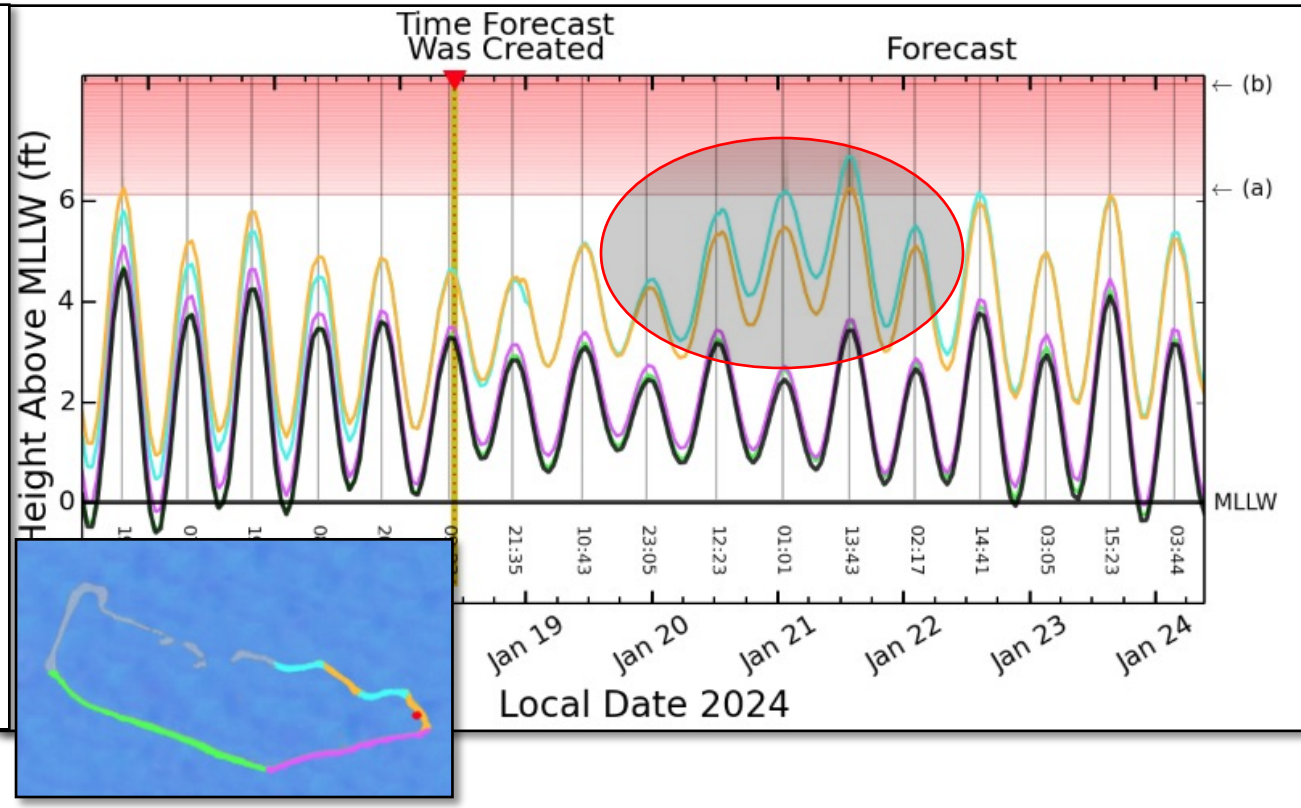

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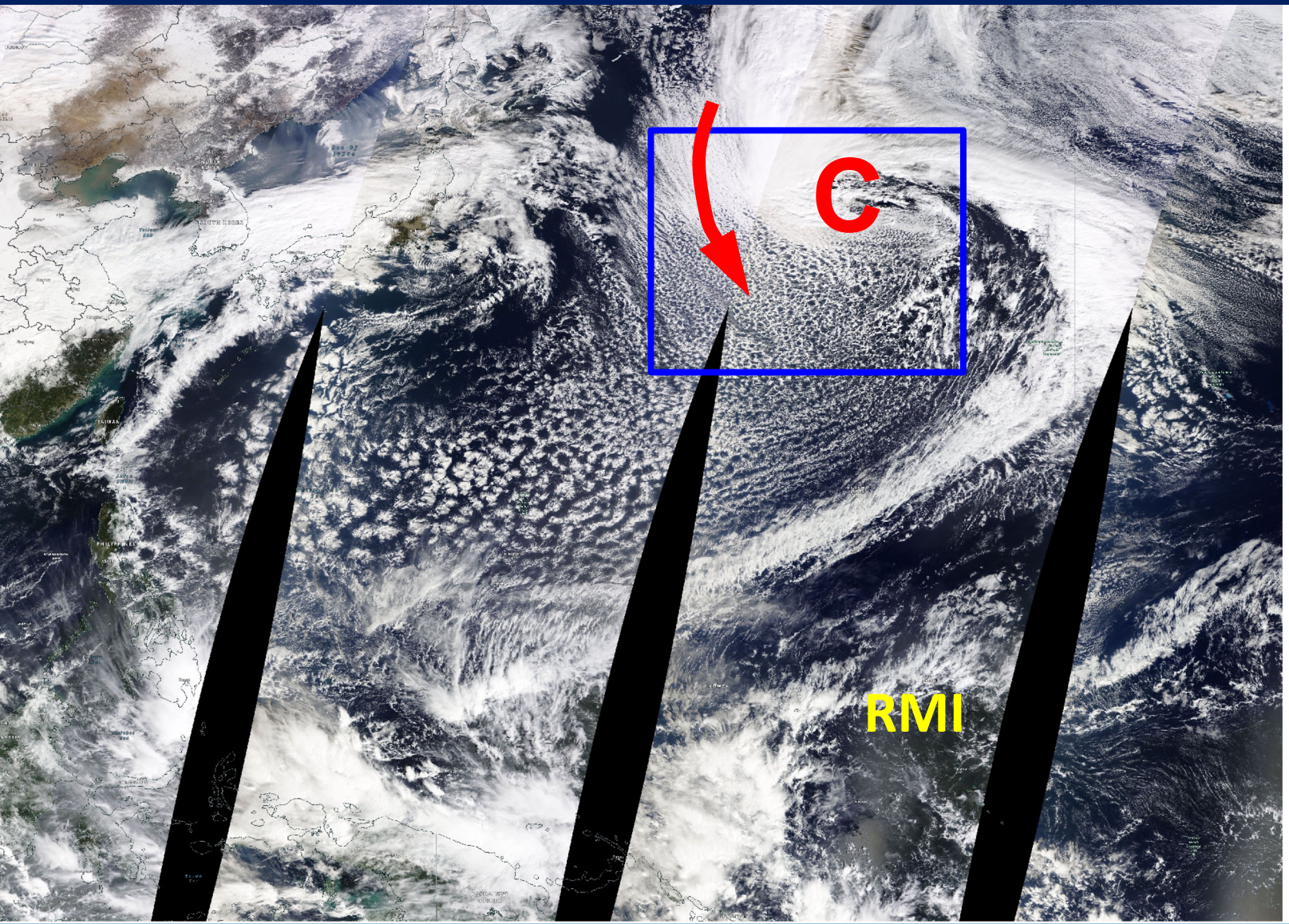
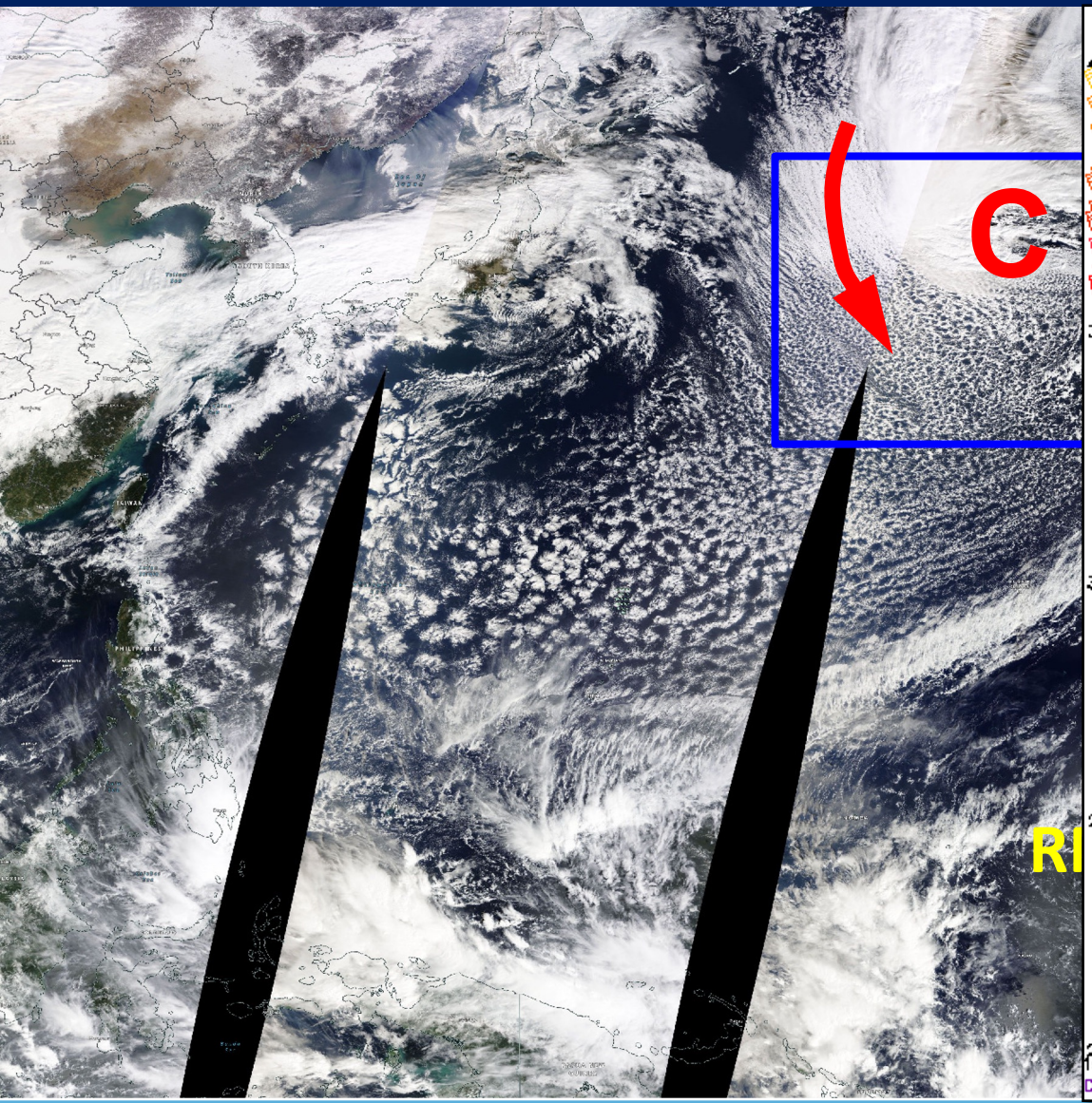
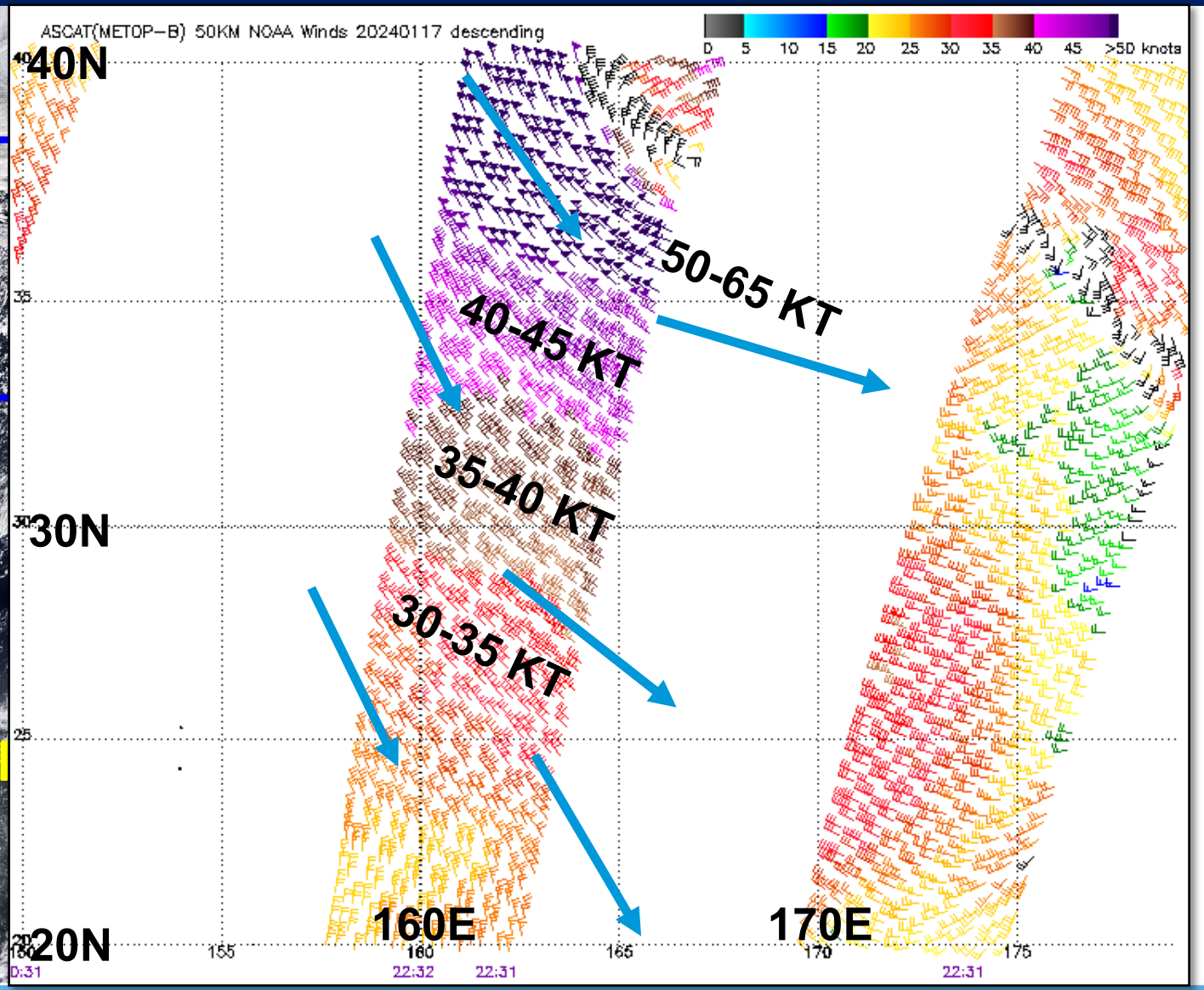
- A significant separation of run-up potential for north-facing shores.
- Level (a) run-up descriptions: some flooding, damage to roads & seawalls; seawater cresting roadway.

What Happened

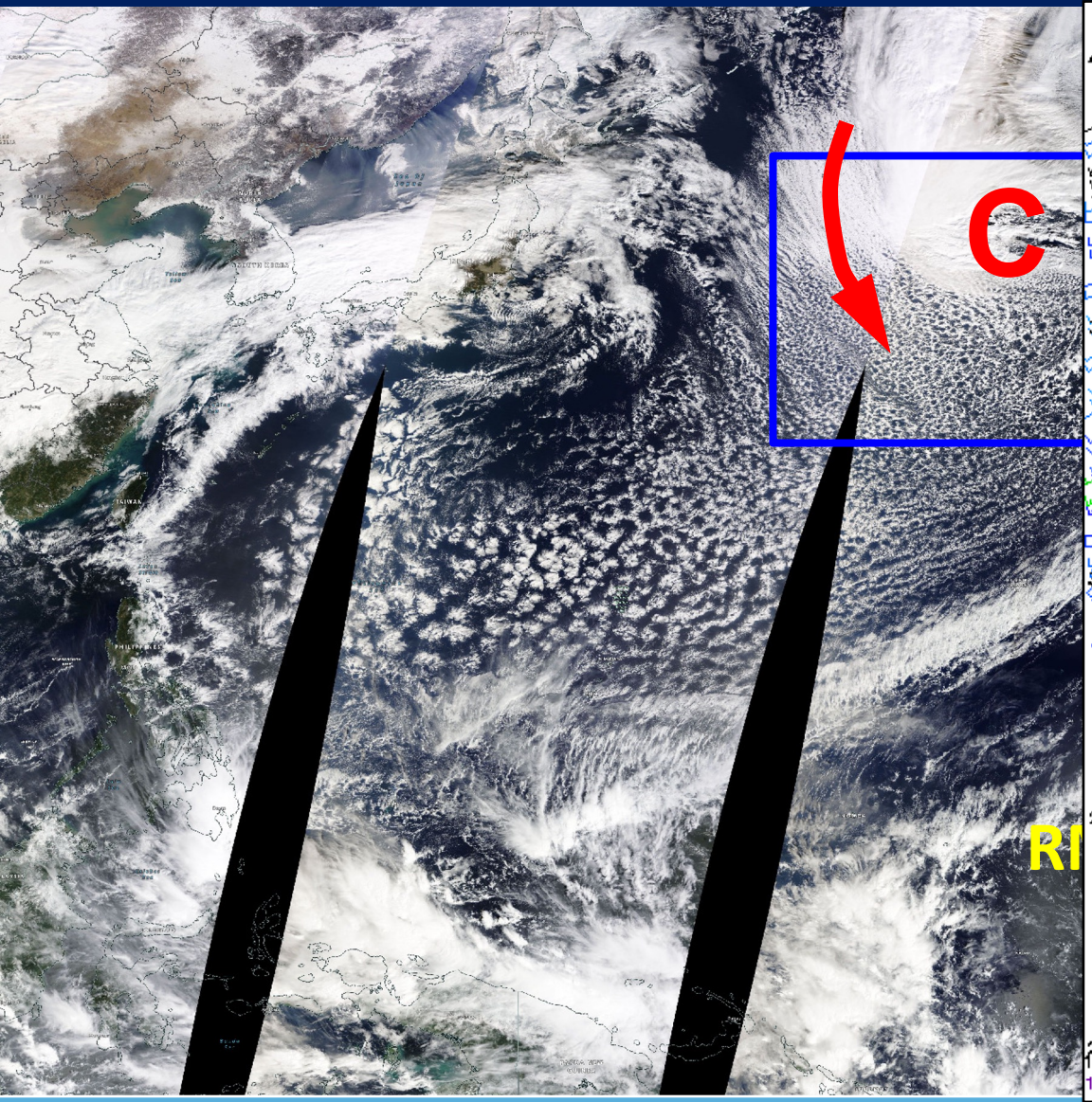


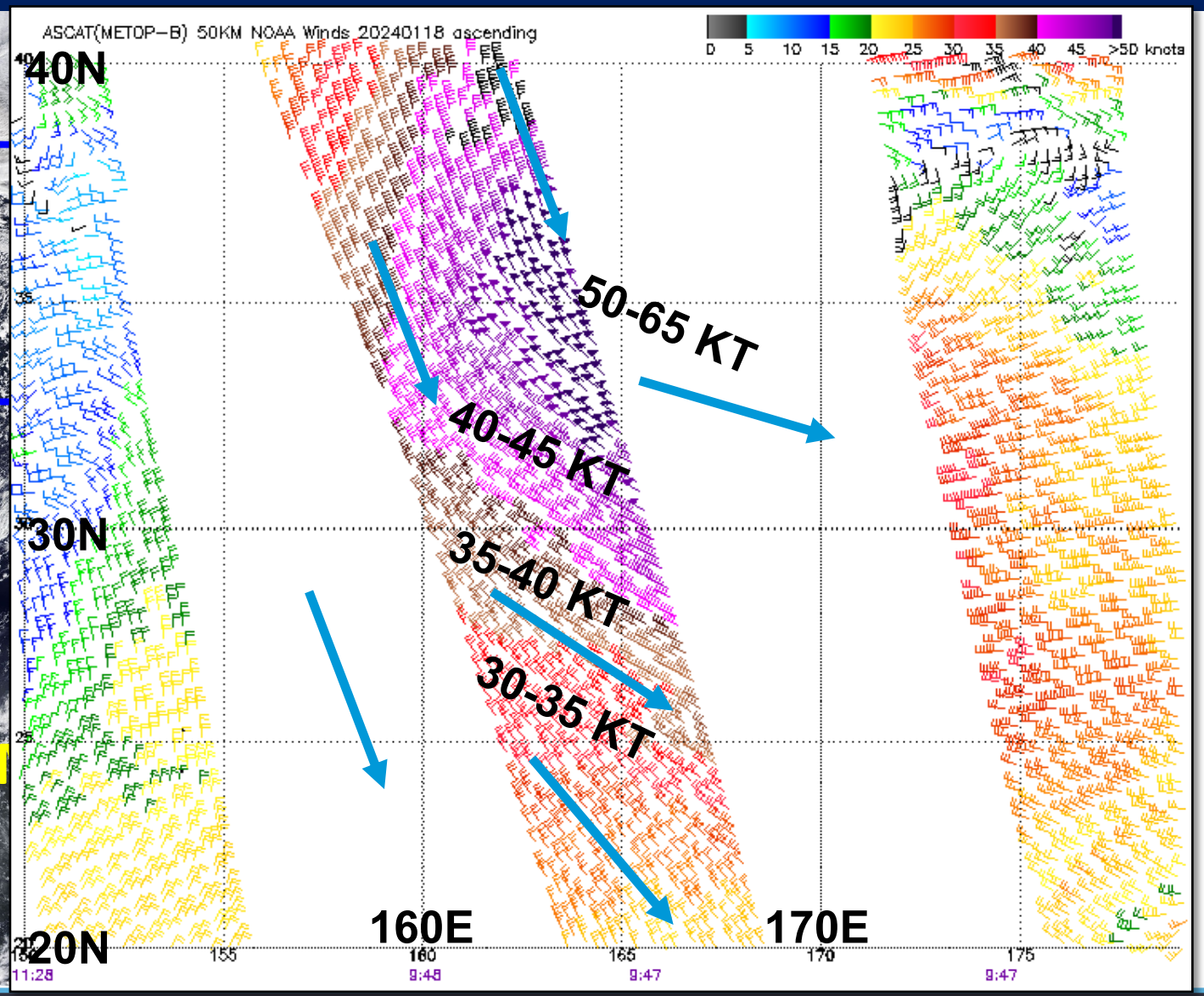
What Happened: *Satellite Scatterometer Wind Data, 17-18 Jan*



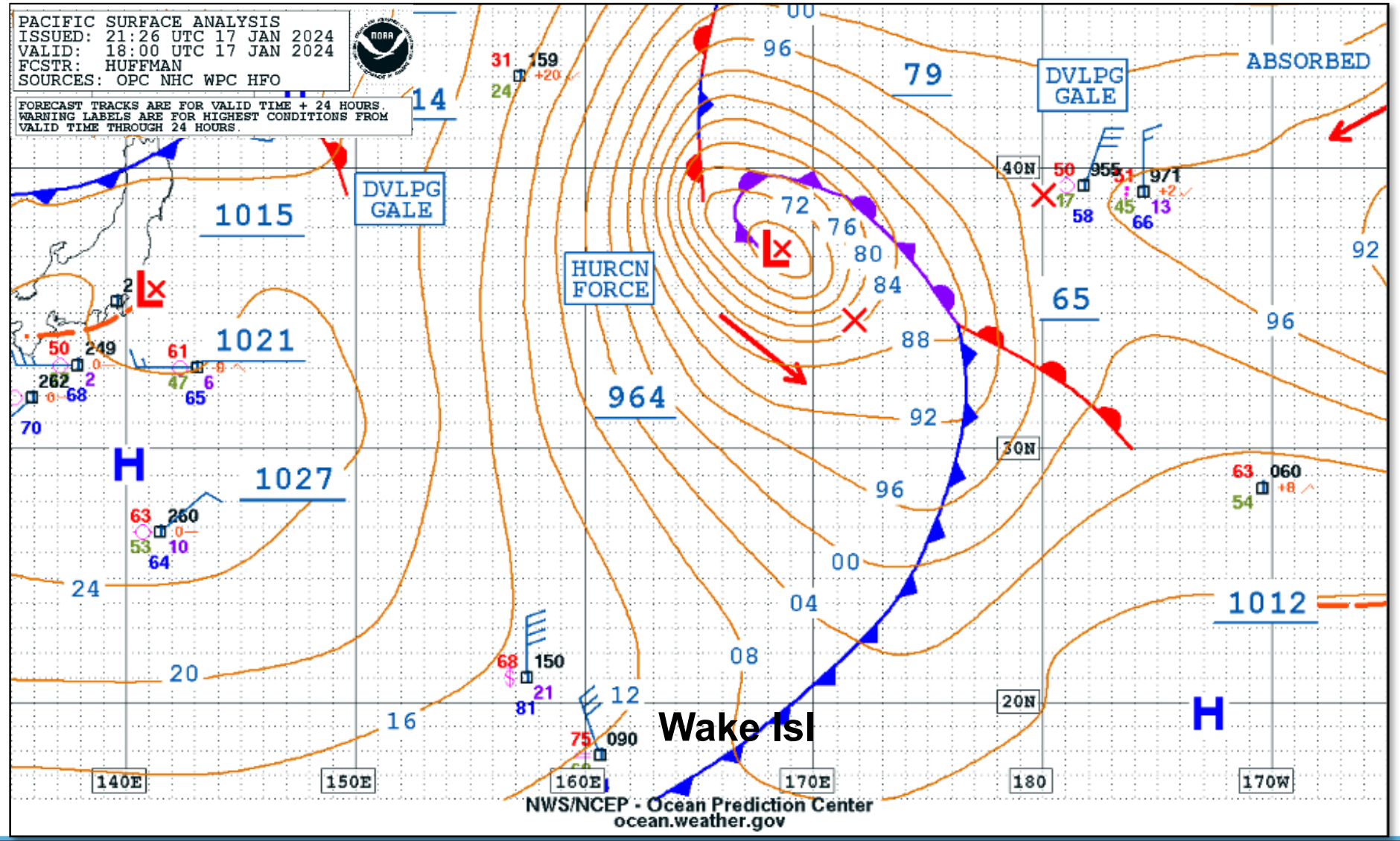


What Happened: *Satellite Scatterometer Wind Data, 18 Jan*





What Happened: *OPC Pacific Analysis, 18Z 17 Jan*



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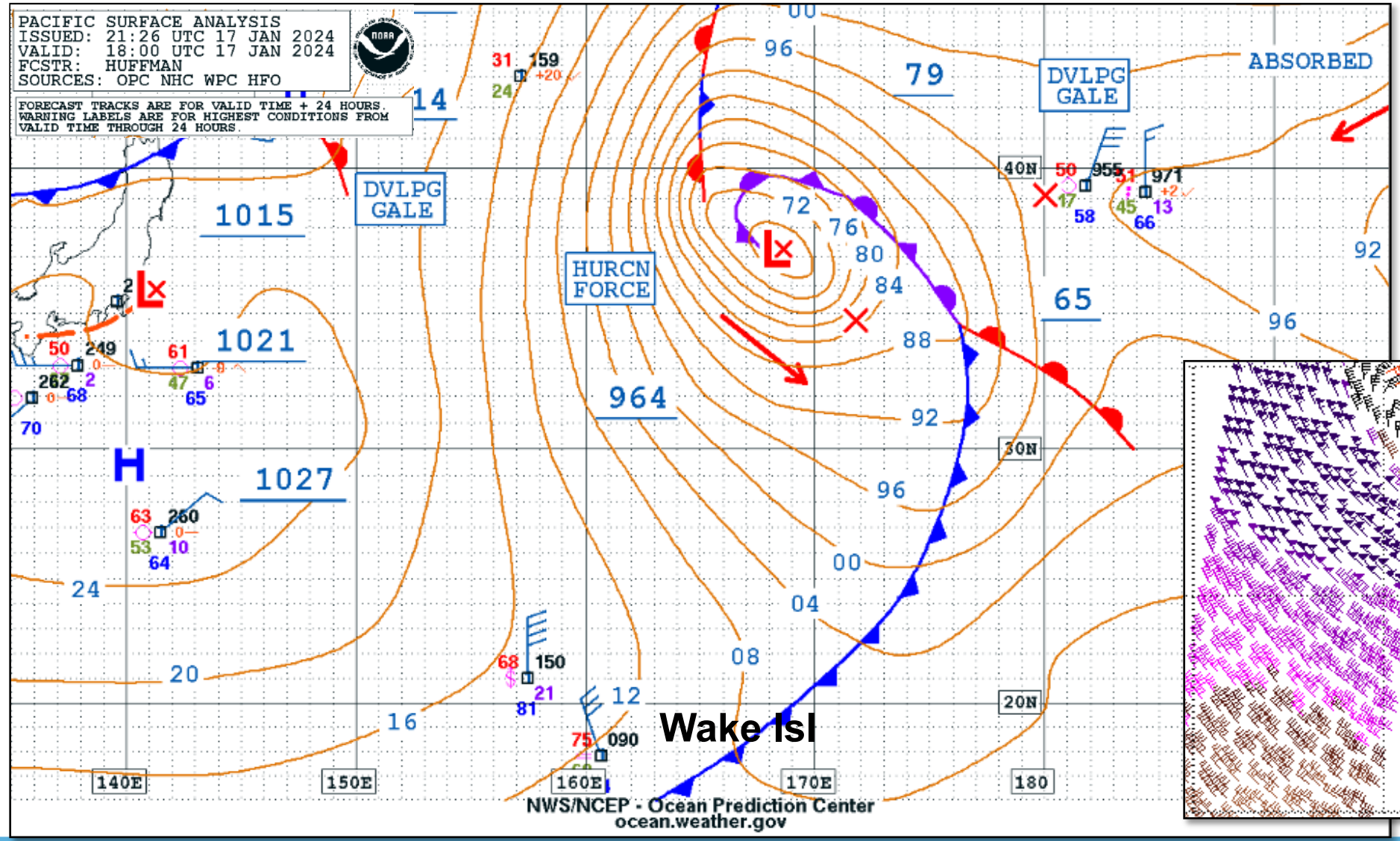

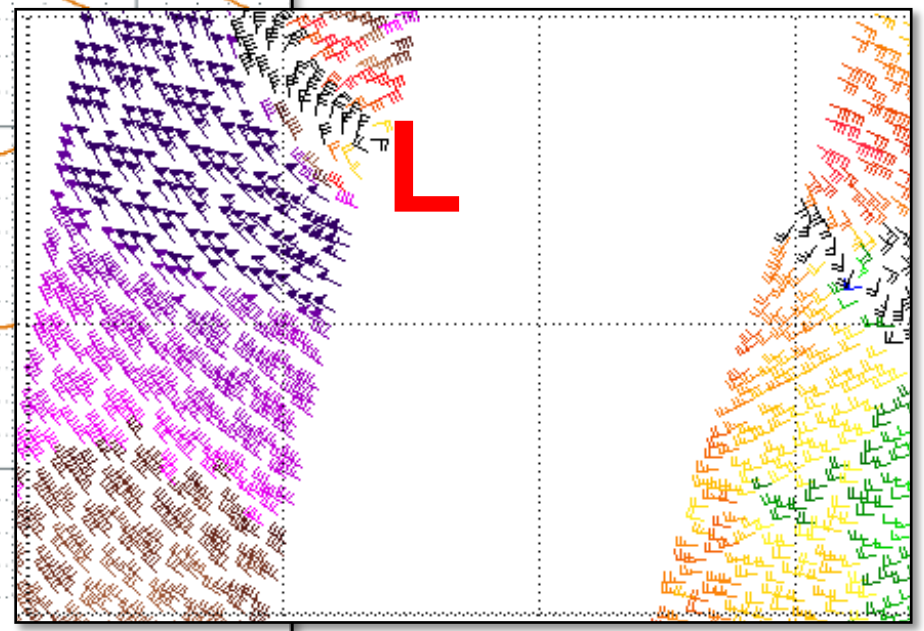

- "Hurricane force" cyclone ***dropping southeast***.
- Wide swath of very strong winds west of the cyclone, ***pointing south-southeast***.

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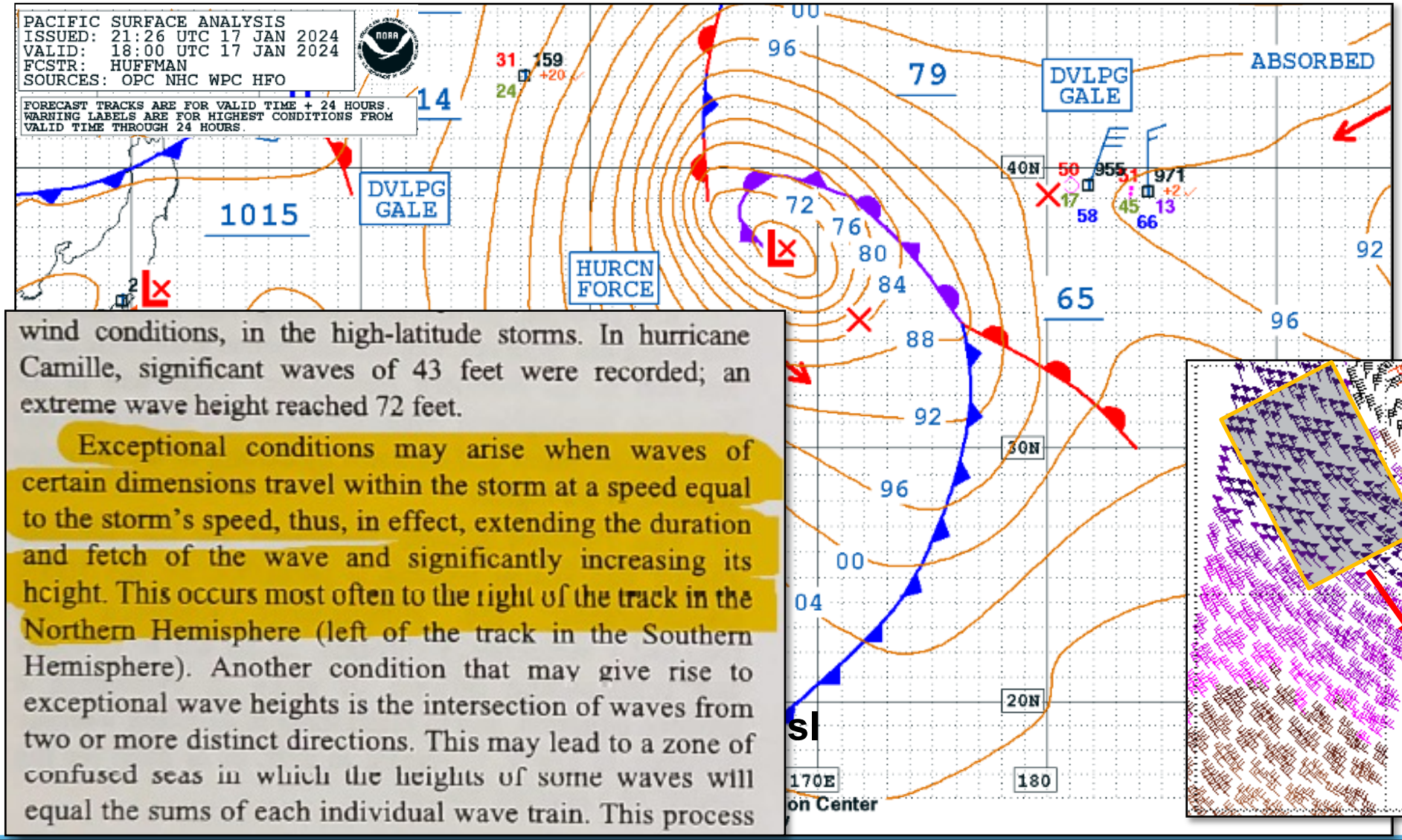
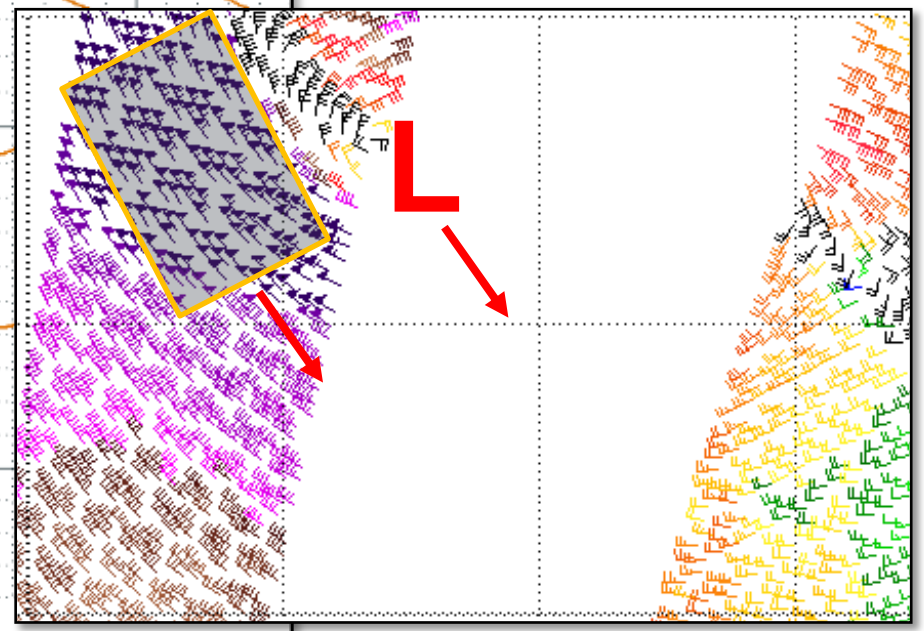


wind conditions, in the high-latitude storms. In hurricane Camille, significant waves of 43 feet were recorded; an extreme wave height reached 72 feet.

Exceptional conditions may arise when waves of certain dimensions travel within the storm at a speed equal to the storm's speed, thus, in effect, extending the duration and fetch of the wave and significantly increasing its height. This occurs most often to the right of the track in the Northern Hemisphere (left of the track in the Southern Hemisphere). Another condition that may give rise to exceptional wave heights is the intersection of waves from two or more distinct directions. This may lead to a zone of confused seas in which the heights of some waves will equal the sums of each individual wave train. This process



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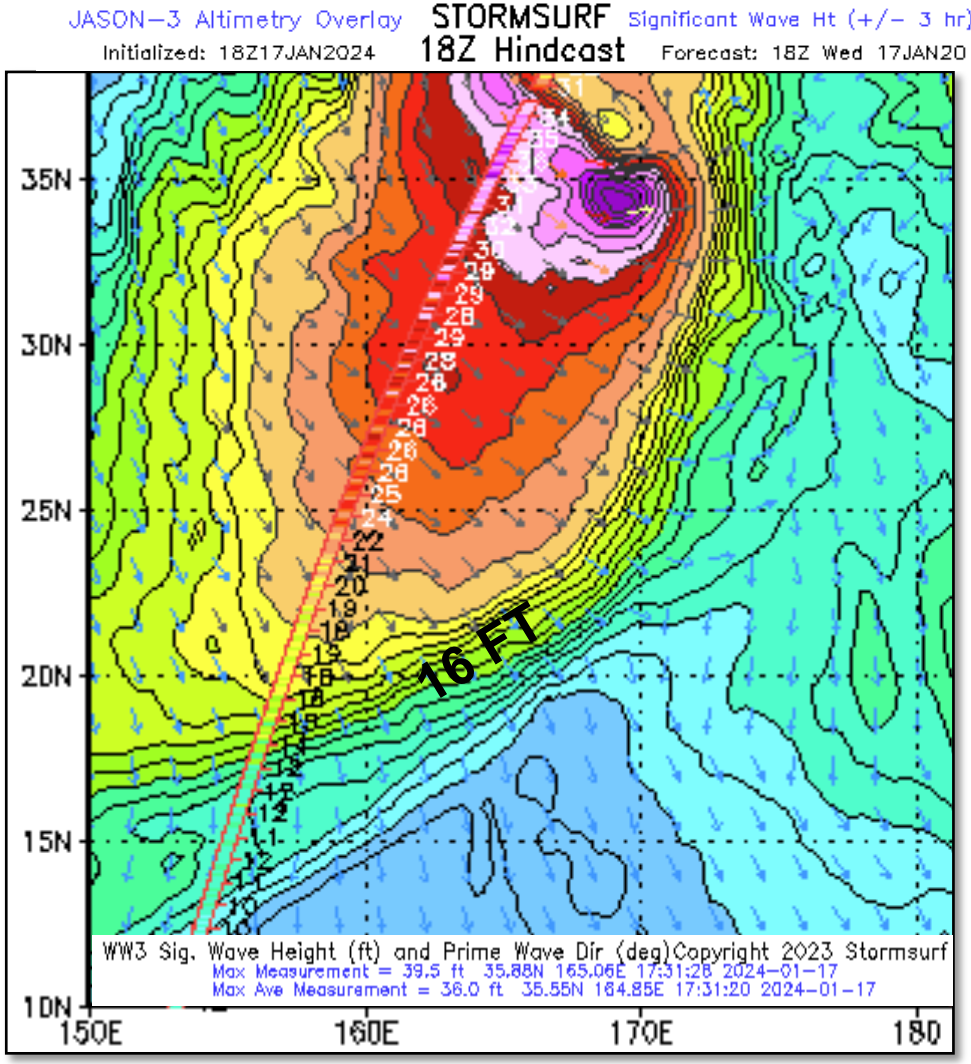
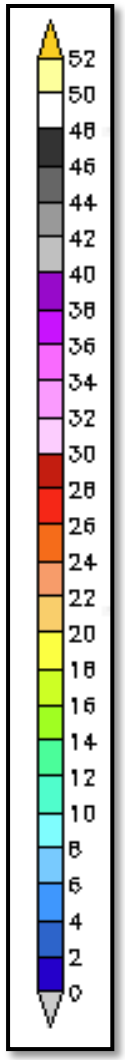
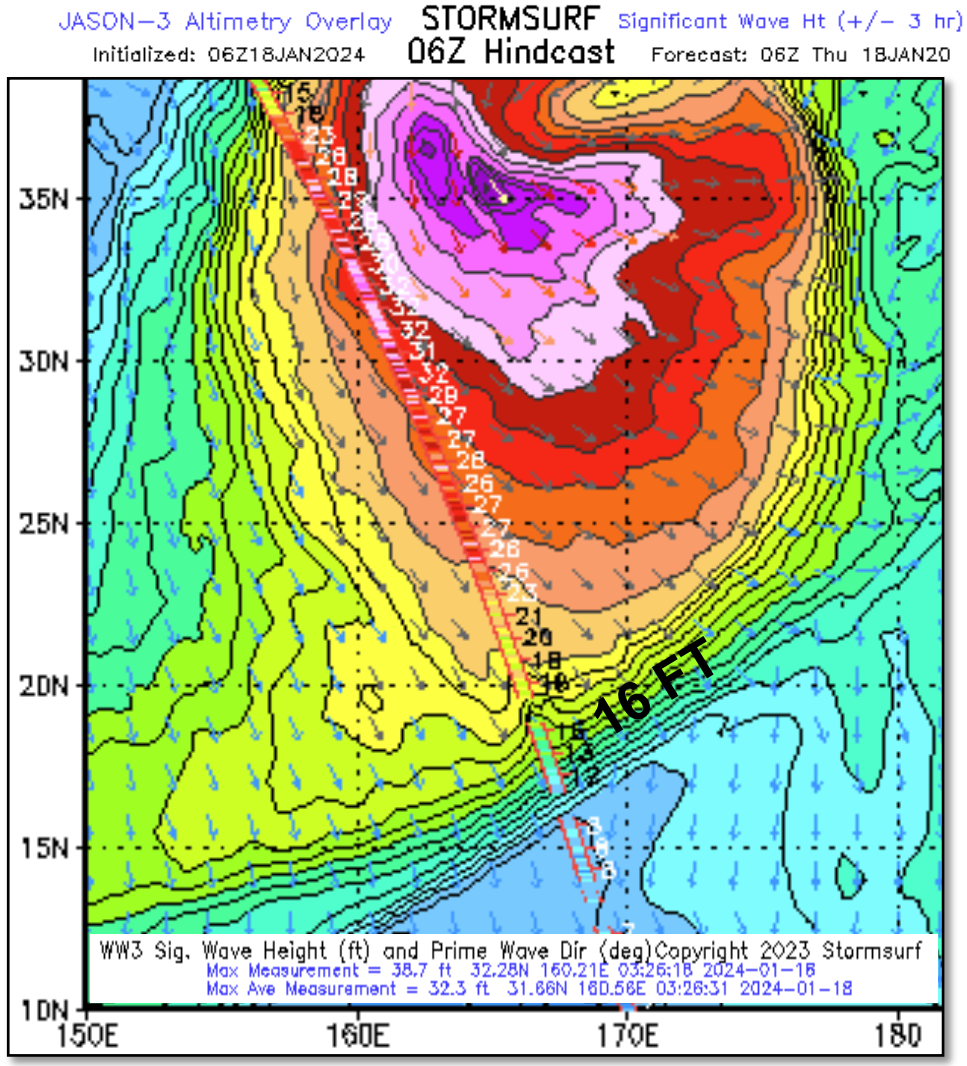
What Happened: *WW3 Model with Satellite Altimetry Data*

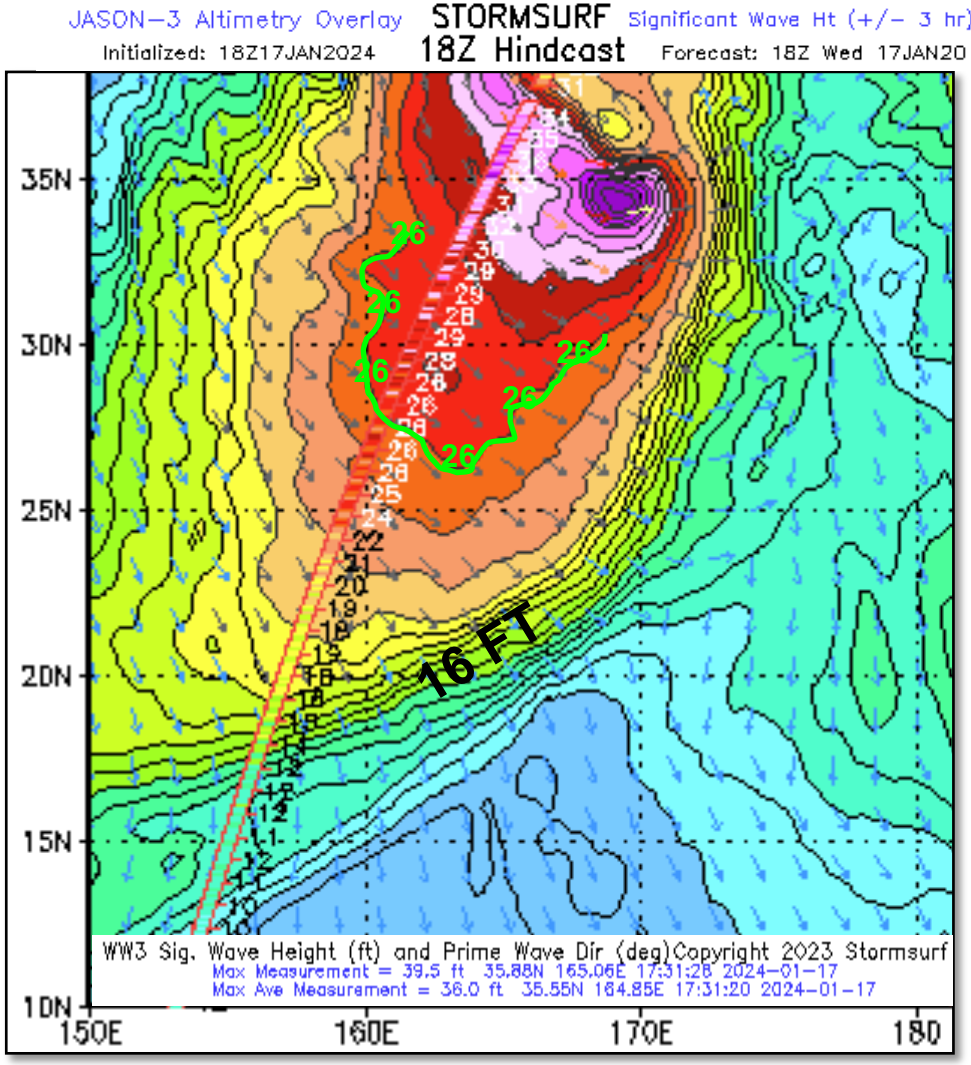


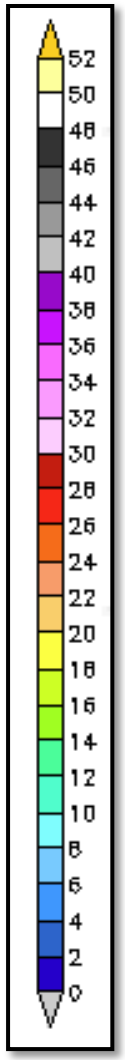


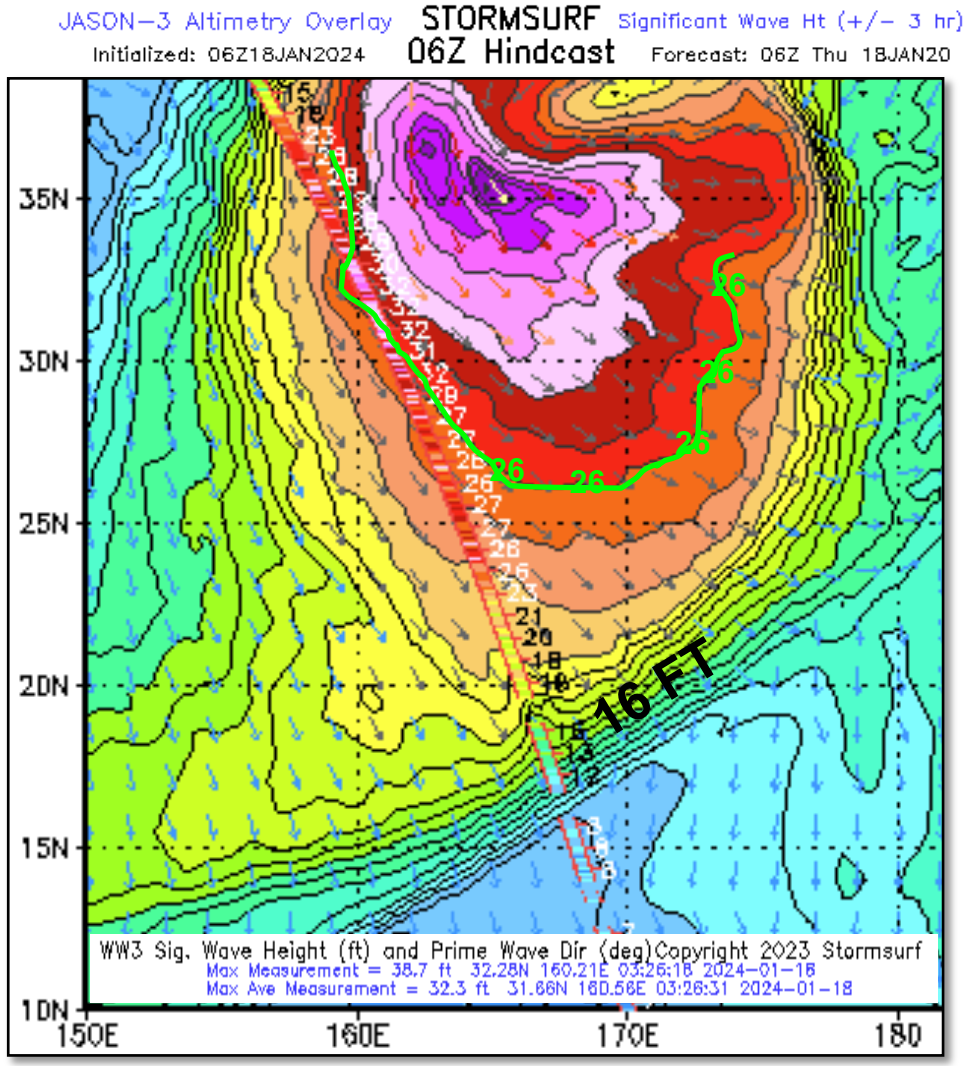


Courtesy, Mark Sponsler at Storm Surf

What Happened: *WW3 Model with Satellite Altimetry Data*







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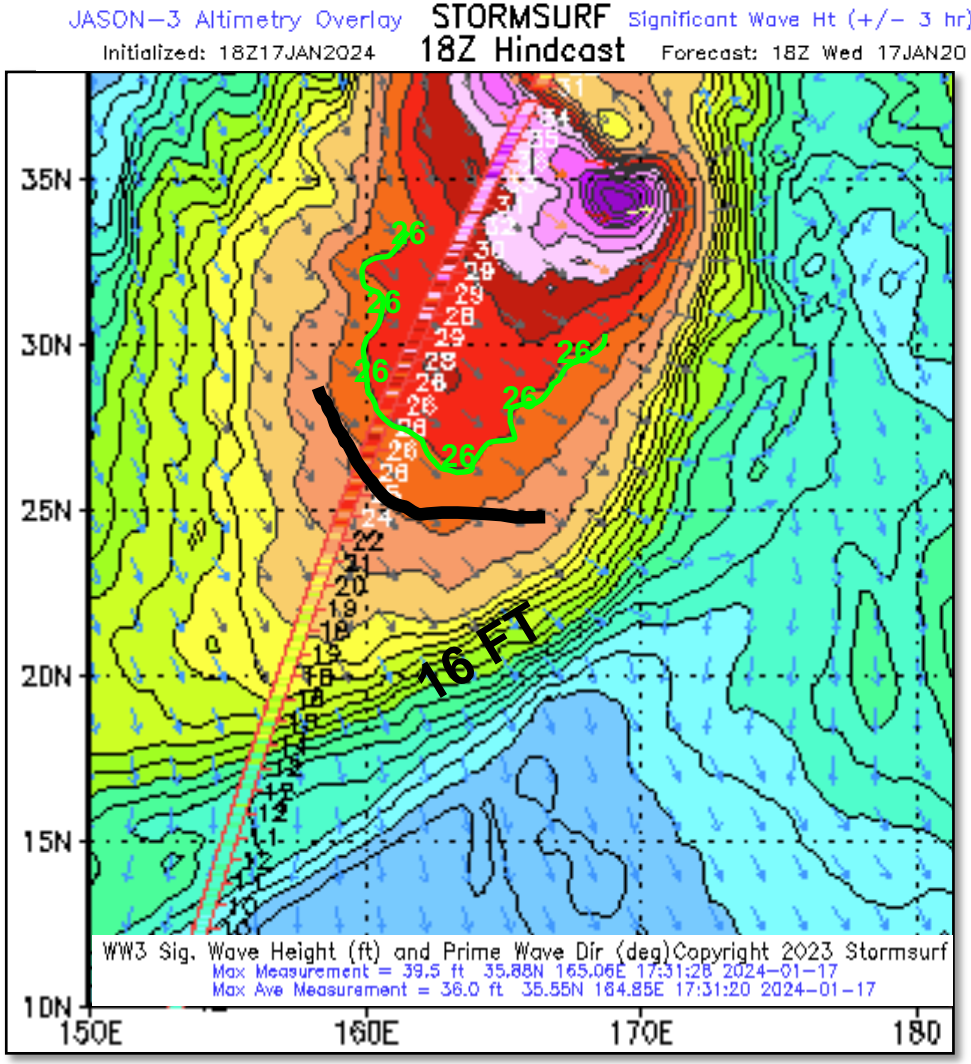

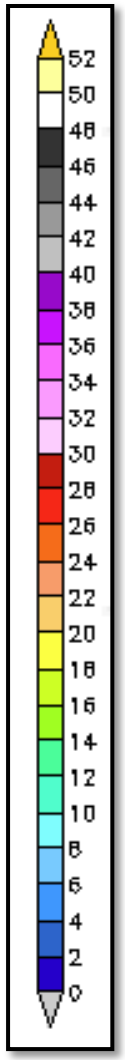

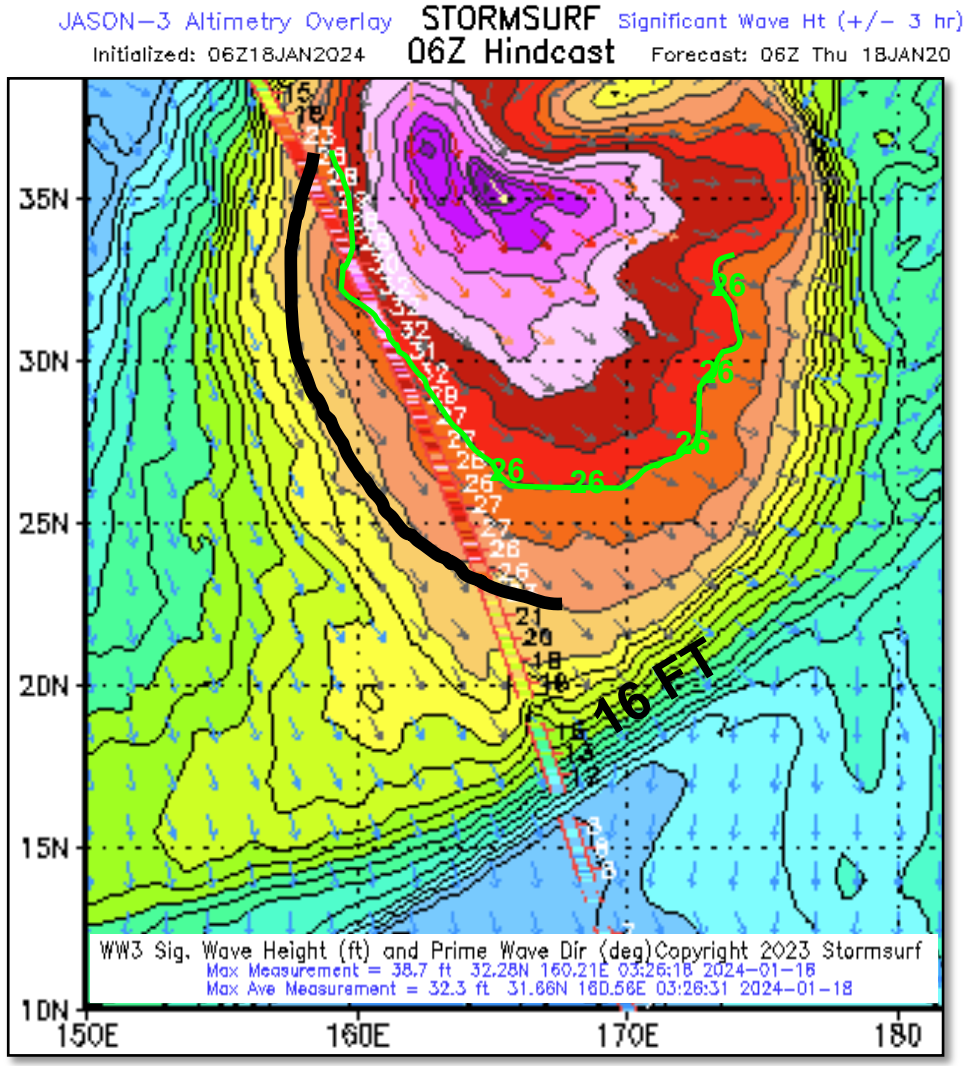

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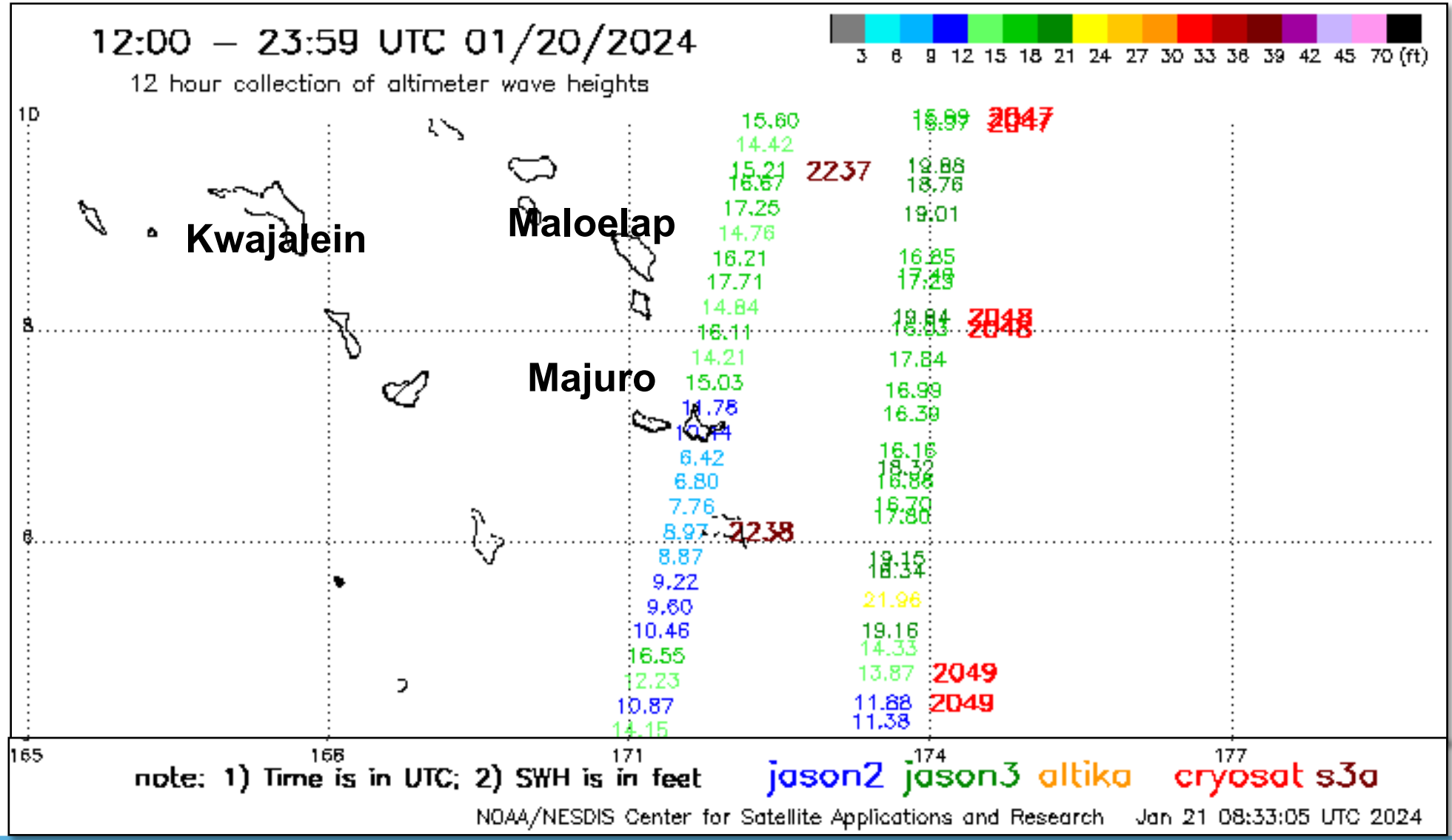
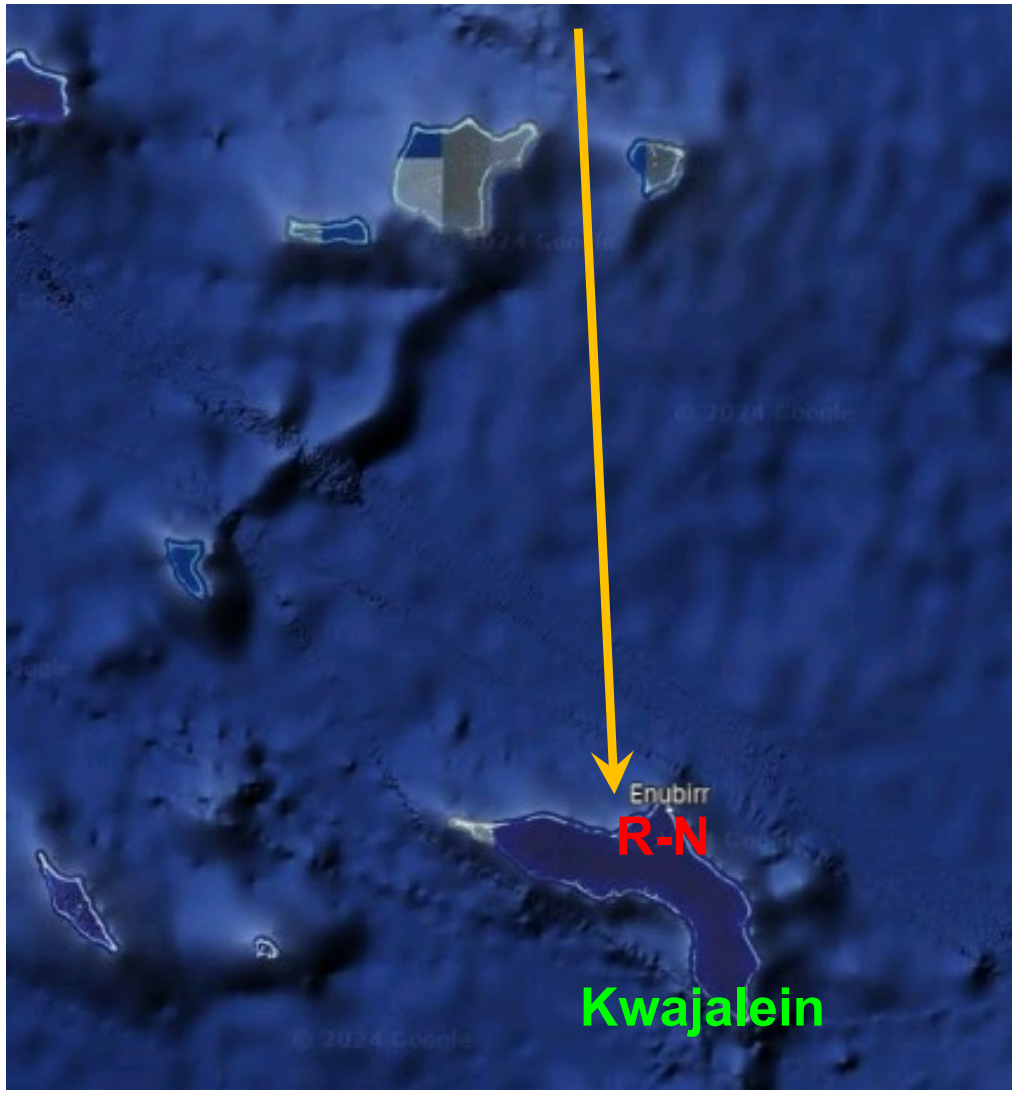
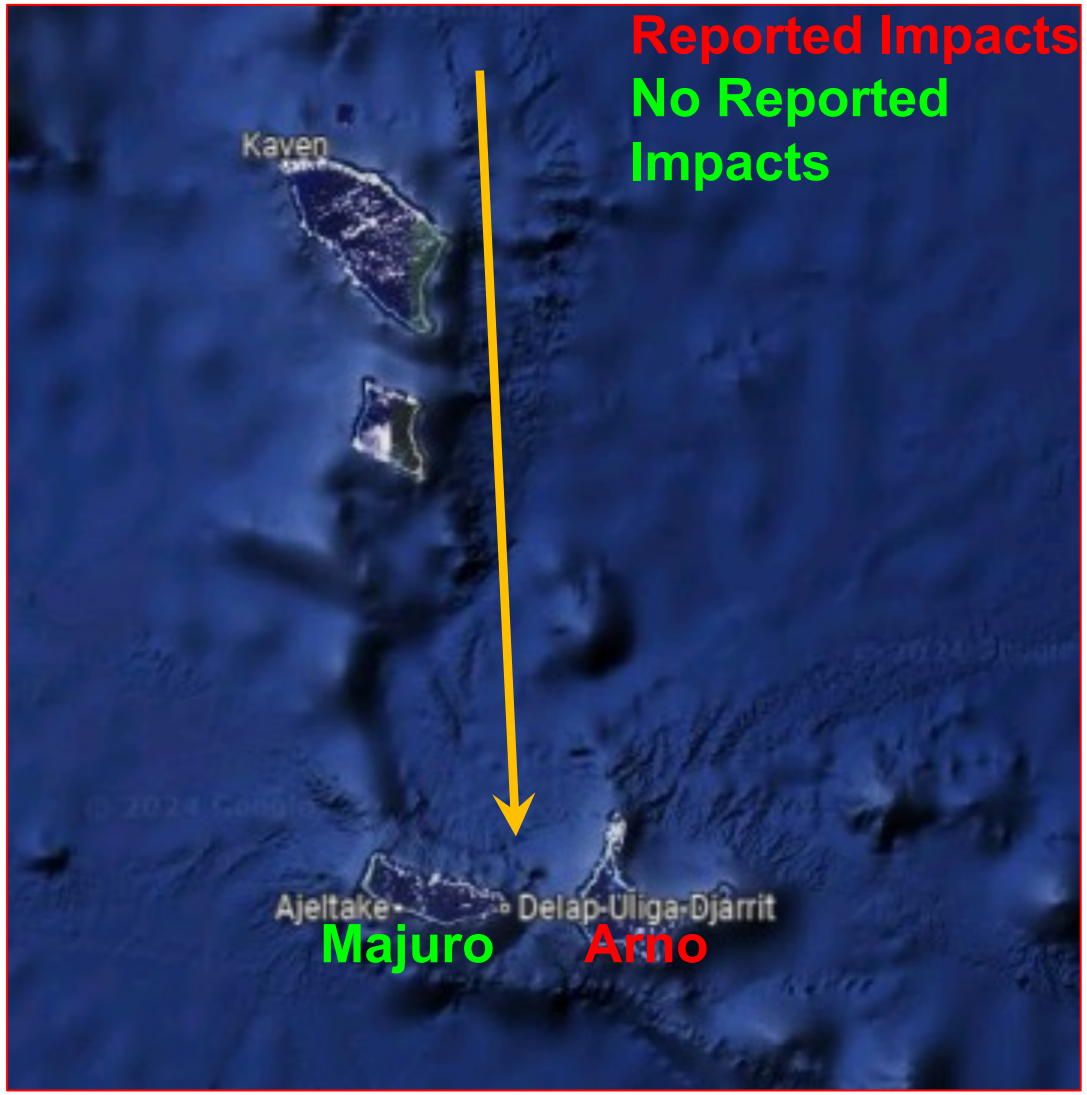
What Happened: *Satellite Altimetry, 12-24Z 20 Jan*



What Happened: *Swell Direction & Impacts?*





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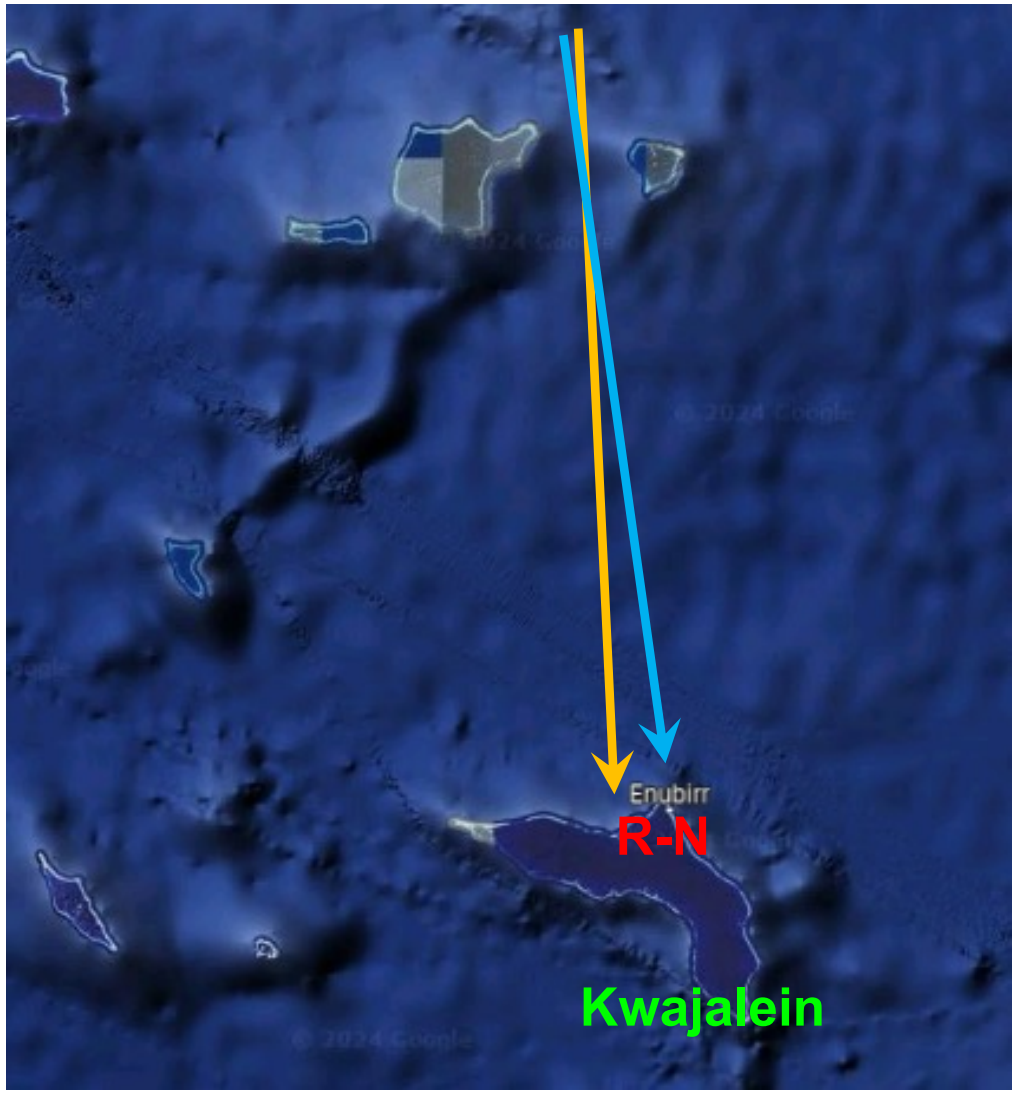

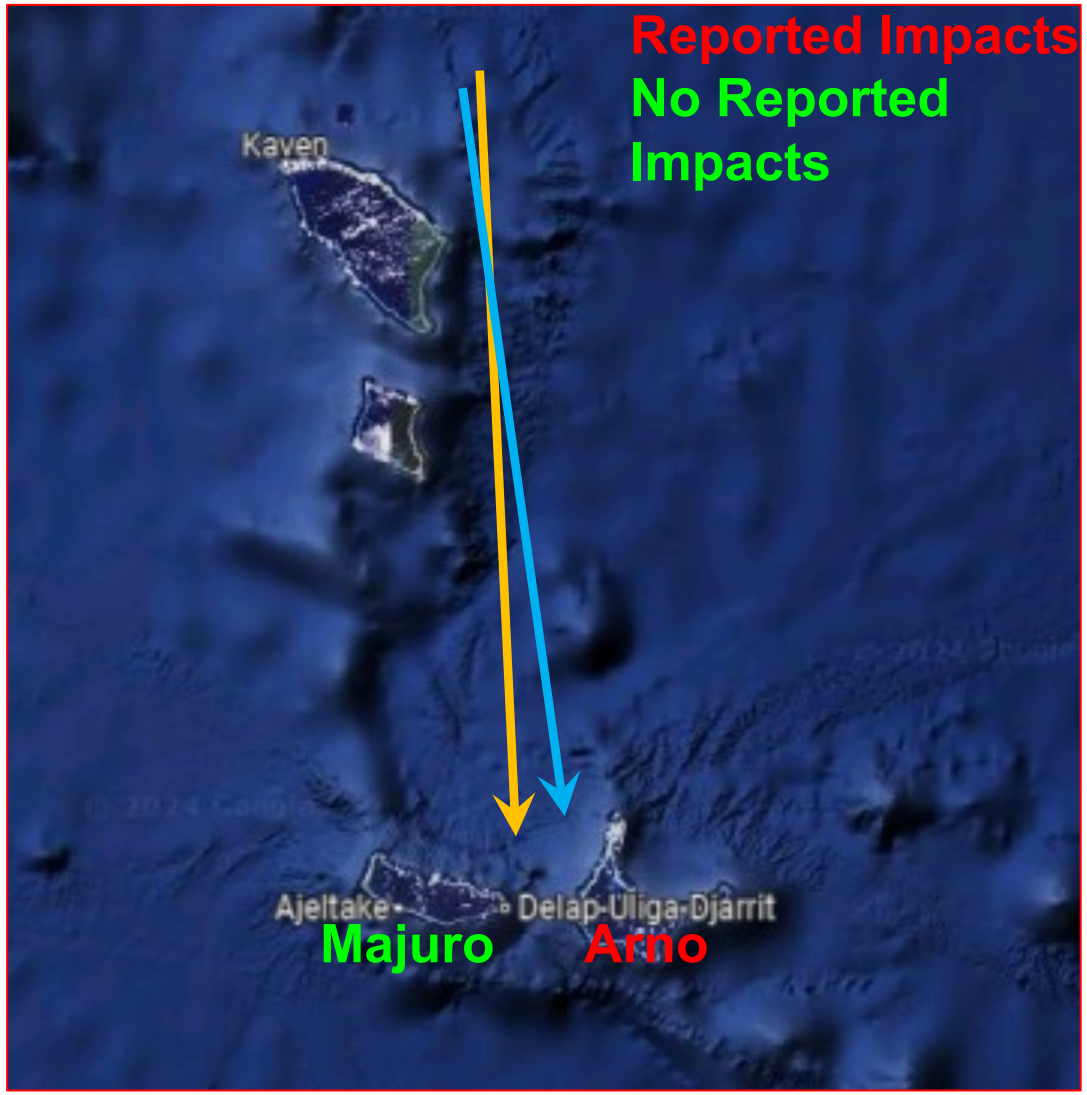

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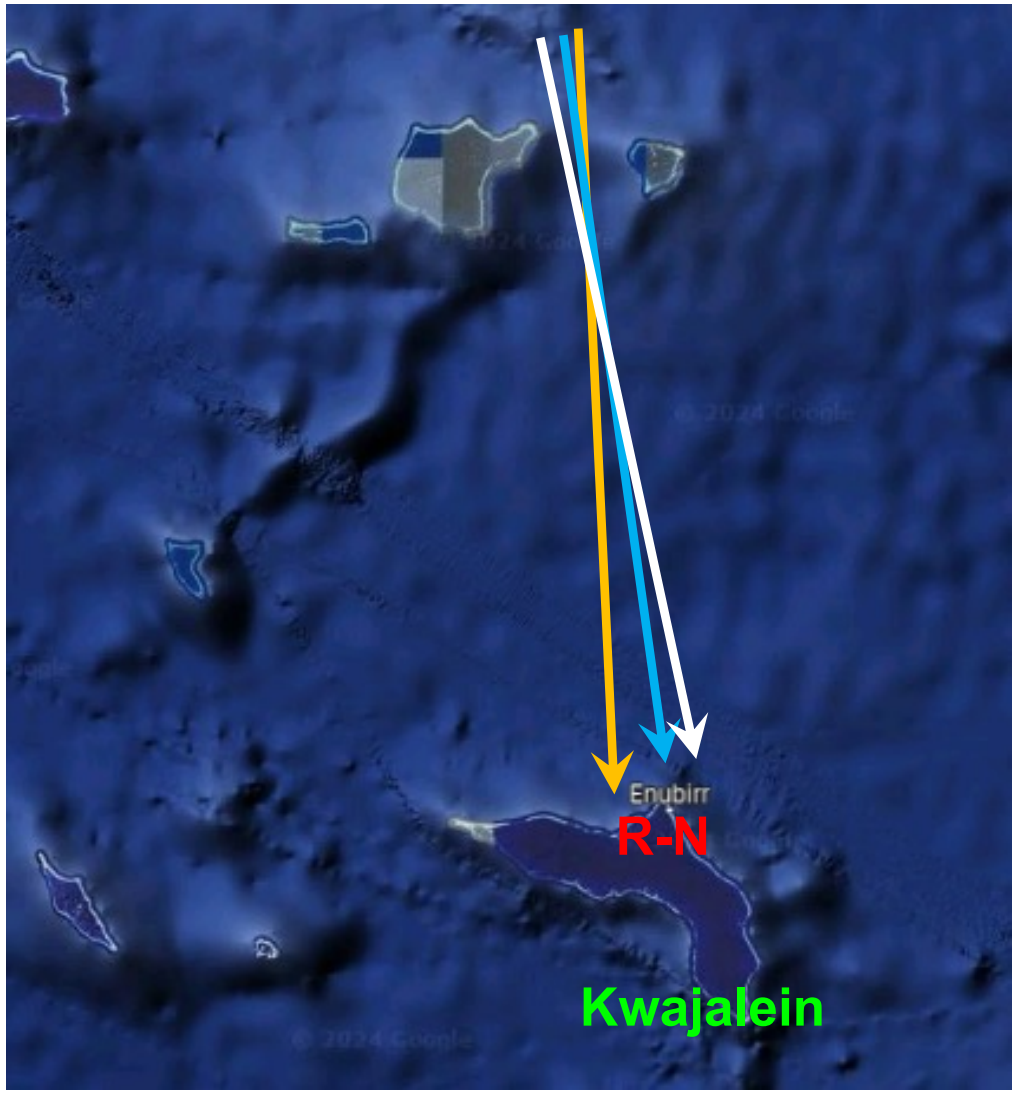
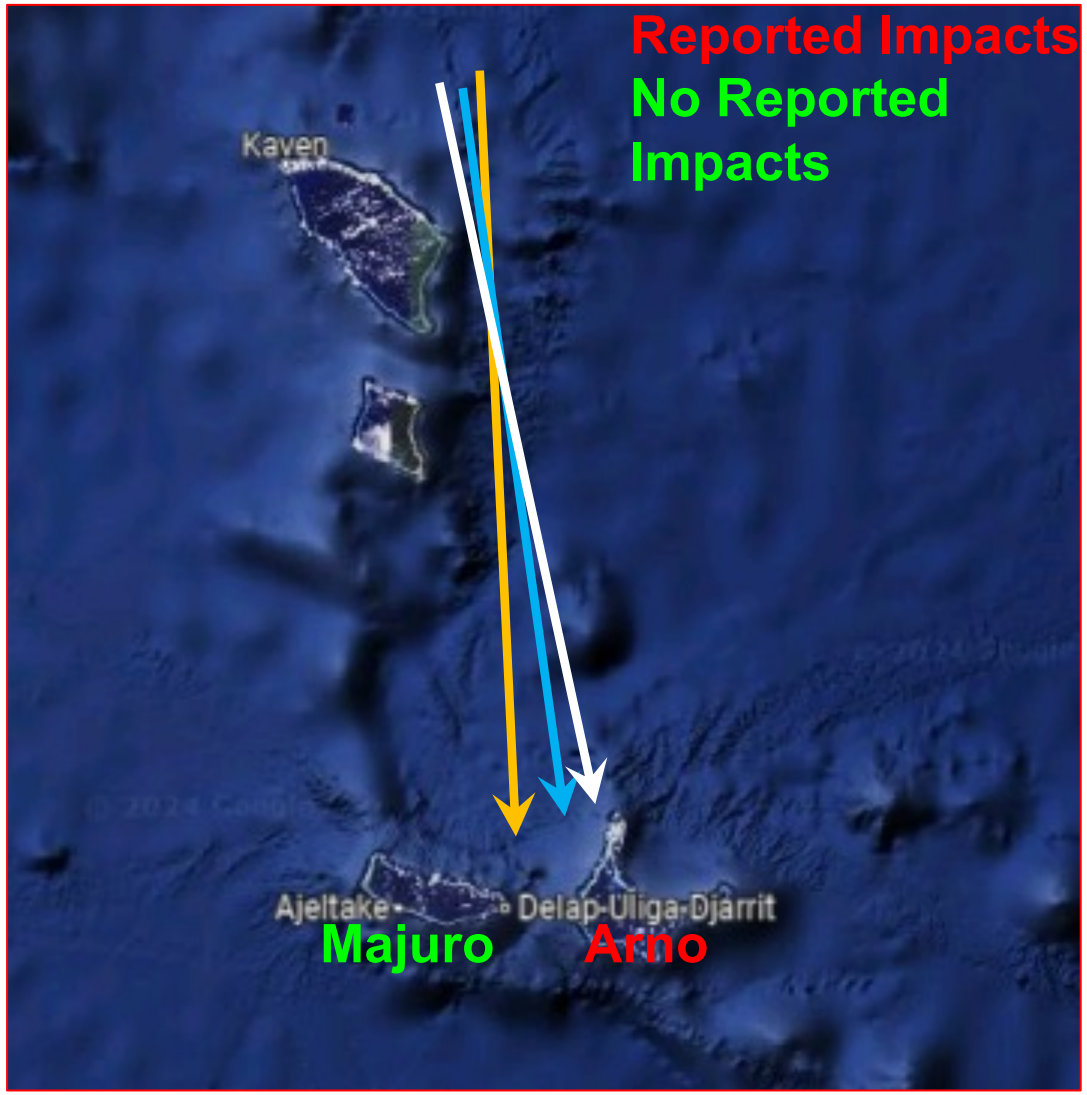




What Happened: *Other Possible Factors/Contributions*

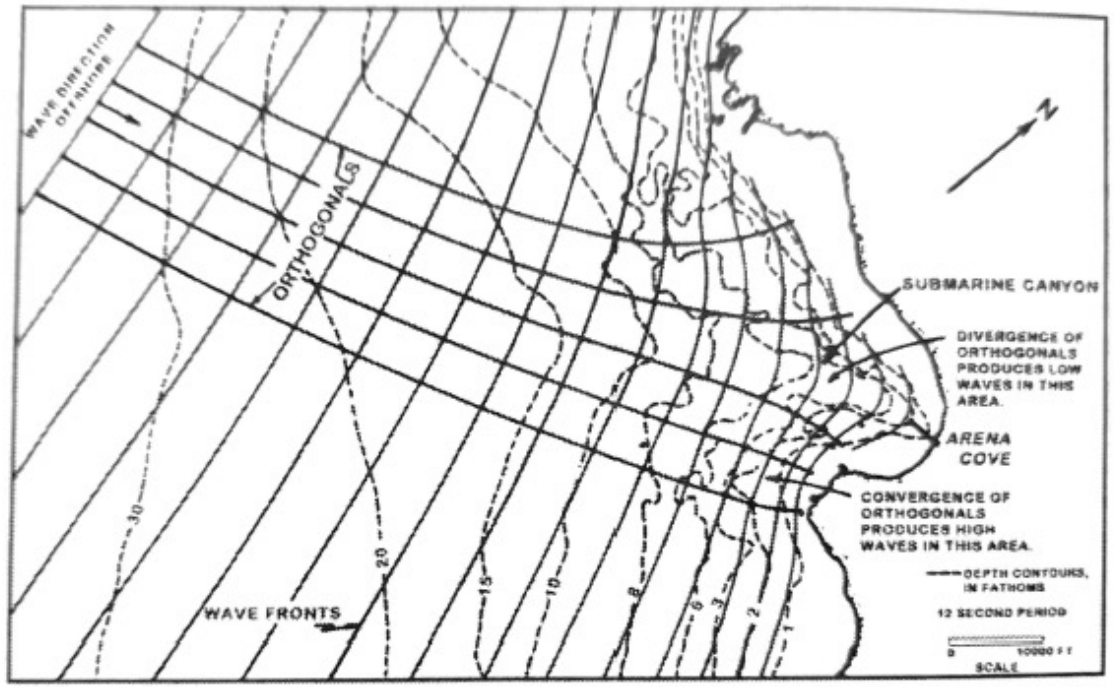
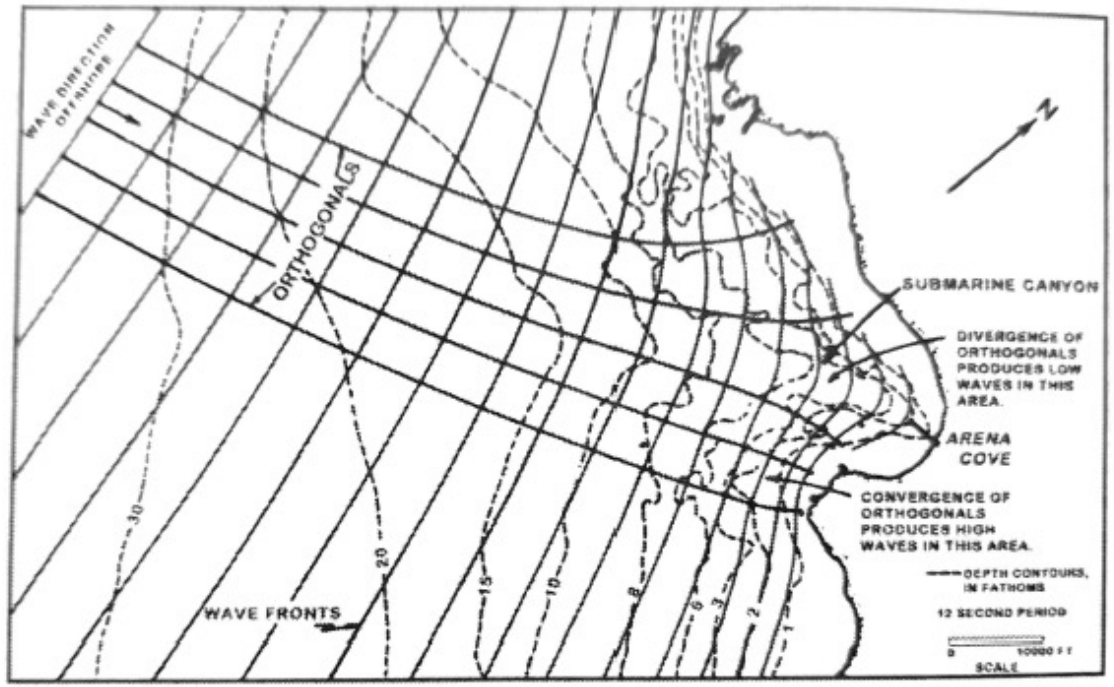


Figure 3215. The effect of bottom topography in causing wave convergence and wave divergence. Courtesy of Robert L. Wiegel, Council on Wave Research, University of California.

What Happened: *Other Possible Factors/Contributions*



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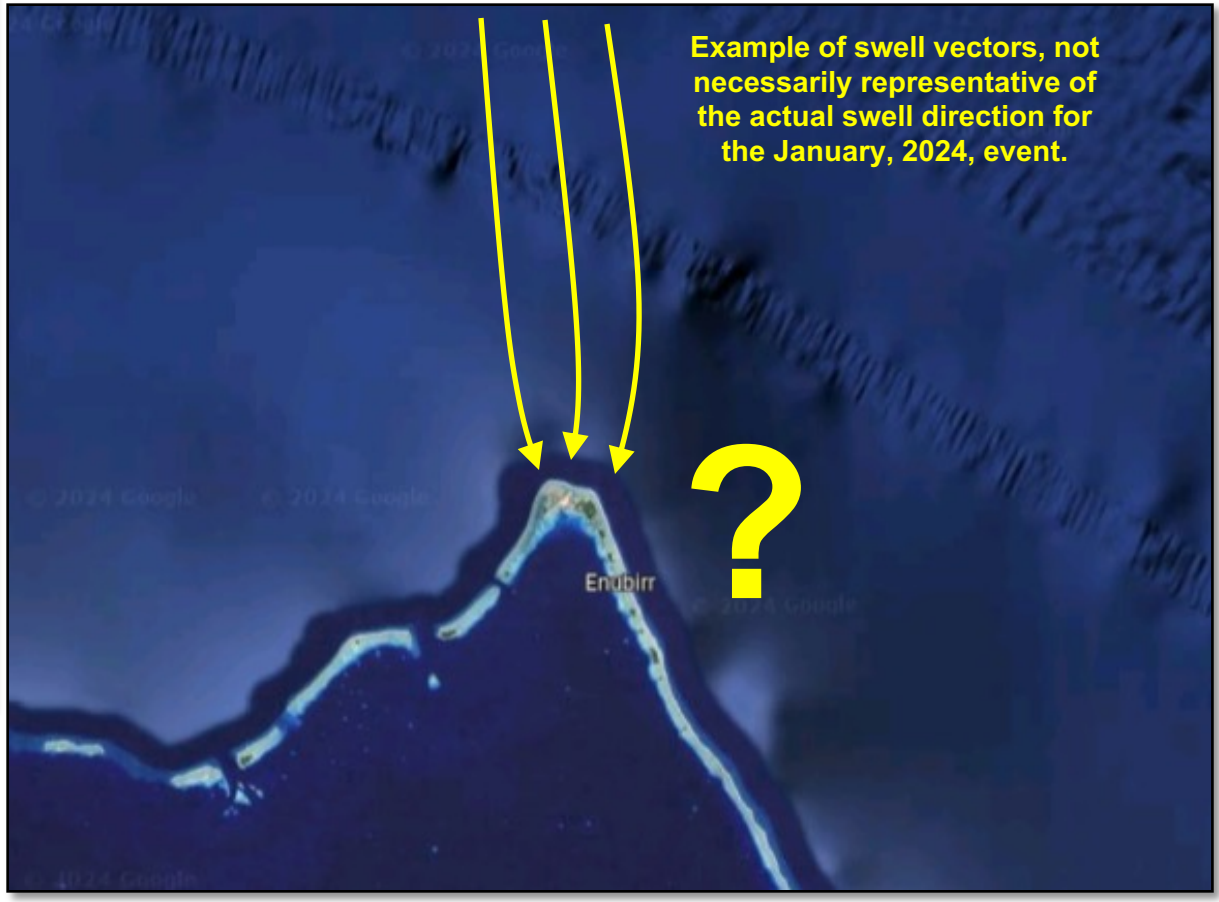

A Unique Event?

A Unique Event? *December, 2008 – Similar Roi-Namur Impacts*

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Widespread inundation of Pacific islands triggered by distant-source wind-waves

Ron K. Hoeke [a,*], Kathleen L. McInnes [a], Jens C. Kruger [b], Rebecca J. McNaught [c], John R. Hunter [d,f], Scott G. Smithers [e]

[a] CSIRO Marine and Atmospheric Research, Australia
[b] SPC Applied Geoscience and Technology Division, Fiji
[c] Red Cross/Red Crescent Climate Centre, Vanuatu
[d] Antarctic Climate & Ecosystems Cooperative Research Centre, Australia
[e] James Cook University, Australia
[f] University of Tasmania, Australia

A Unique Event? *December, 2008 – Similar Roi-Namur Impacts*

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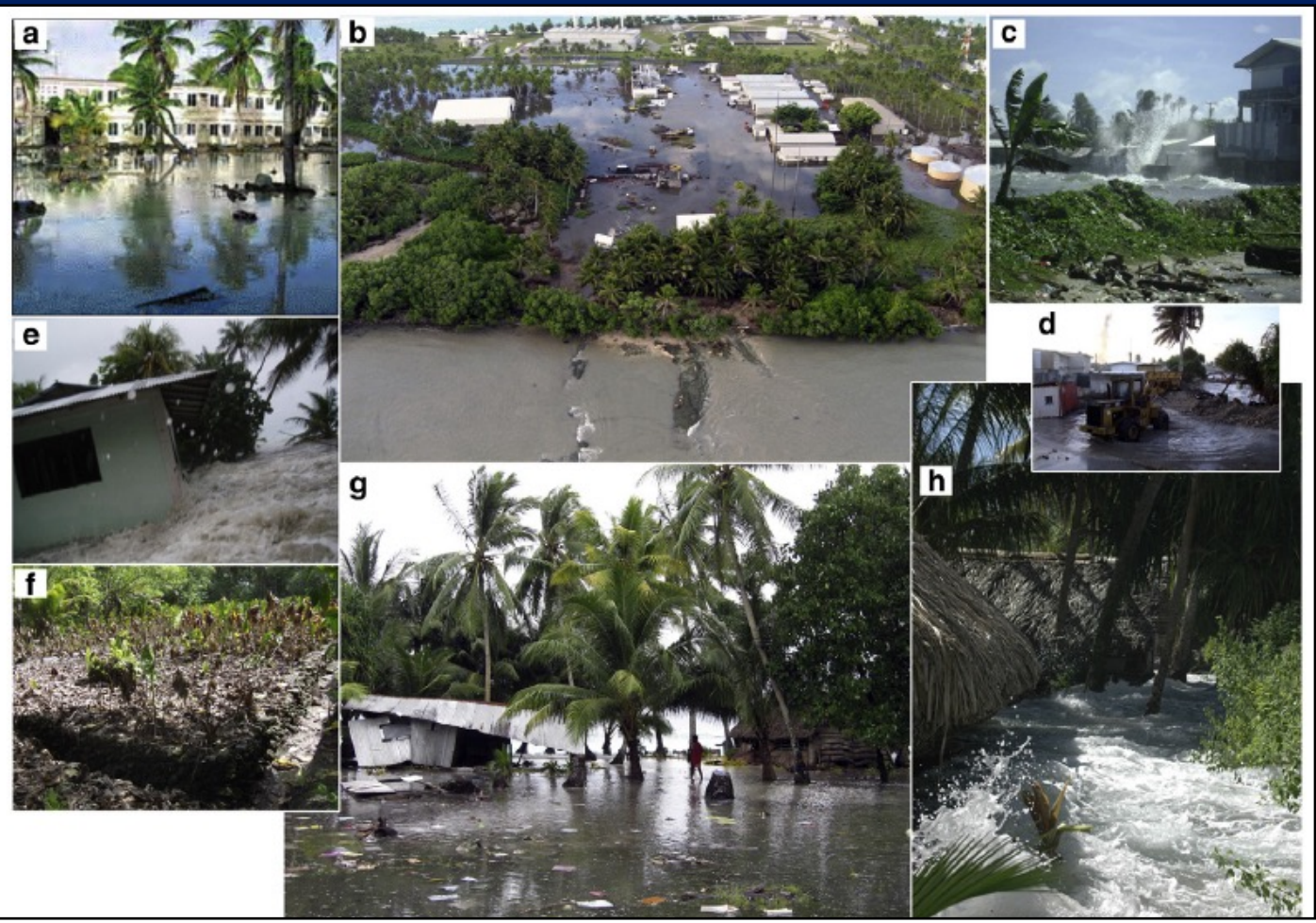
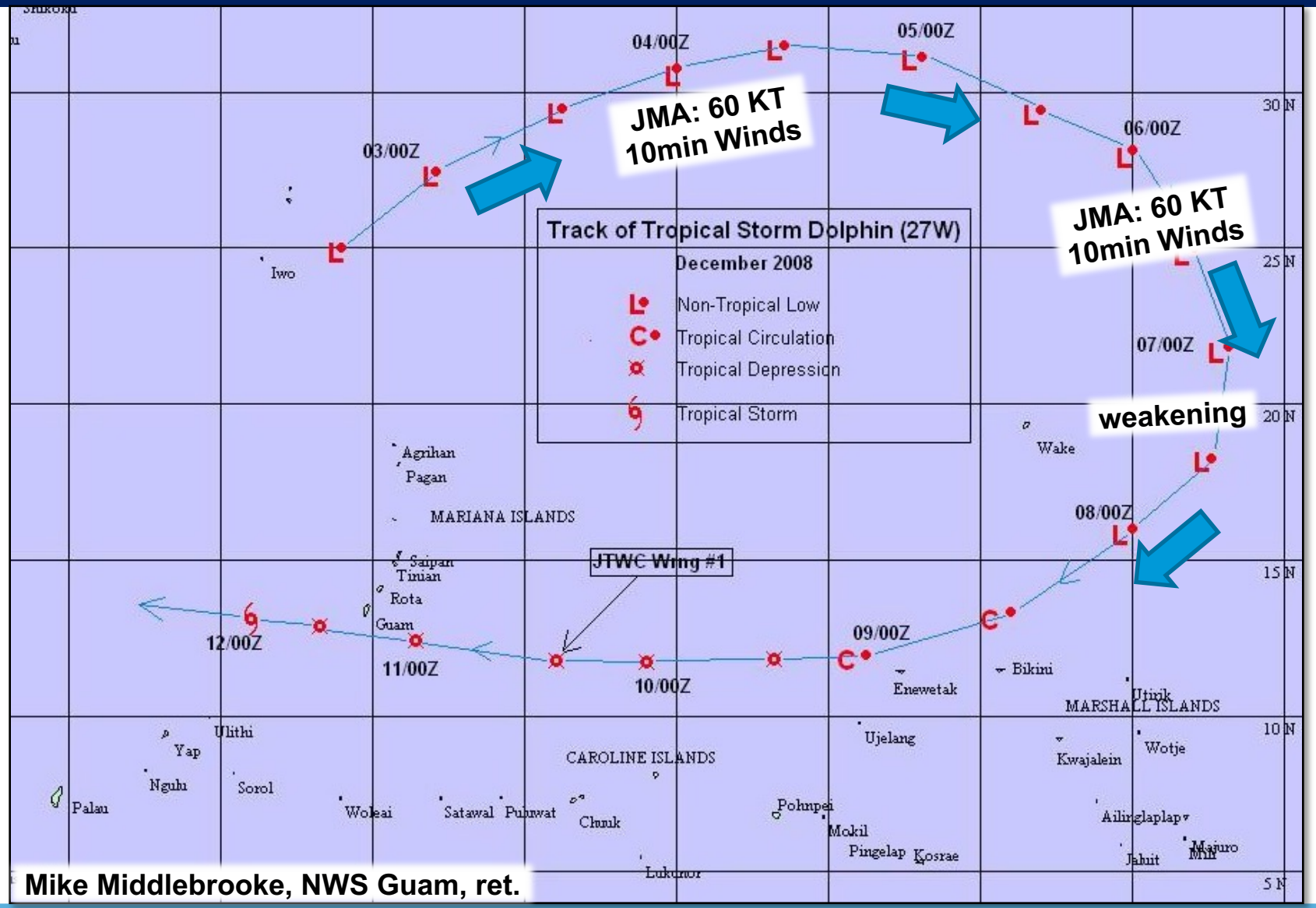


Fig. 1. Examples of the inundation events of the western Pacific during December 2008: flooded military infrastructure at (a) Wake Atoll (photo credit: Hickam Kukini/Honolulu Advertiser) and (b) Roi-Namur, Kwajalein Atoll, Marshall Islands on December 7 (photo credit: Neil Schwanitz); (c) impacts to houses (photo credit: Reginald White) and (d) emergency shoreline remediation (photo credit: Marshall Islands Journal) at Delap, Majuro Atoll, Marshall Islands on December 7; (e) wave run-up impacting houses in Kosrae State on December 8 and (f) saltwater-damaged taro crops resulting from December inundation in Chuuk State, Federated States of Micronesia (photo credit: Kosrae Resource Management Agency); (g) destroyed structures (photo credit: Scott Smithers) and (h) waves washing through the village (photo credit: Jeffrey Holdaway) at Nukutoa, Takuu Atoll, Papua New Guinea on December 10.

A Unique Event? *December, 2008, Dolphin (27W)*



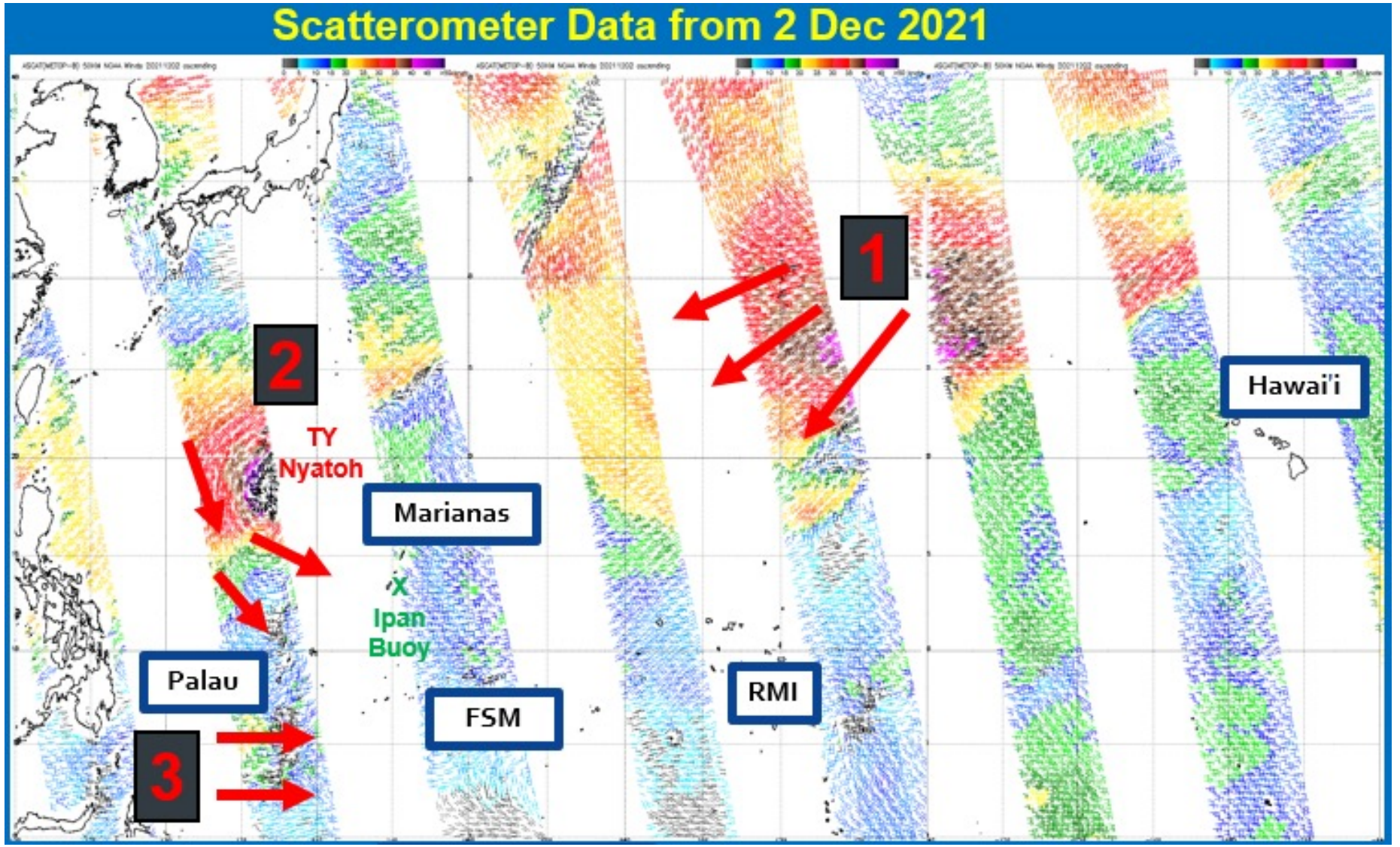
Mike Middlebrooke, NWS Guam, ret.

A Unique Event? *Early December, 2021 – King Tide + Large Swell*

Background: *The December, 2021, King Tide Impacts Across Micronesia*

The King Tide cycle of 3-7 Dec 2021 coincided with the arrival of large swell from several different weather systems. Damage reports from the islands reported inundation up to 40 ft inland with major erosion among the north through east facing reefs of many, if not most, islands. Islands suffered infrastructure, agricultural and residential damage. One island in Pohnpei State was about 85% covered in salt water.

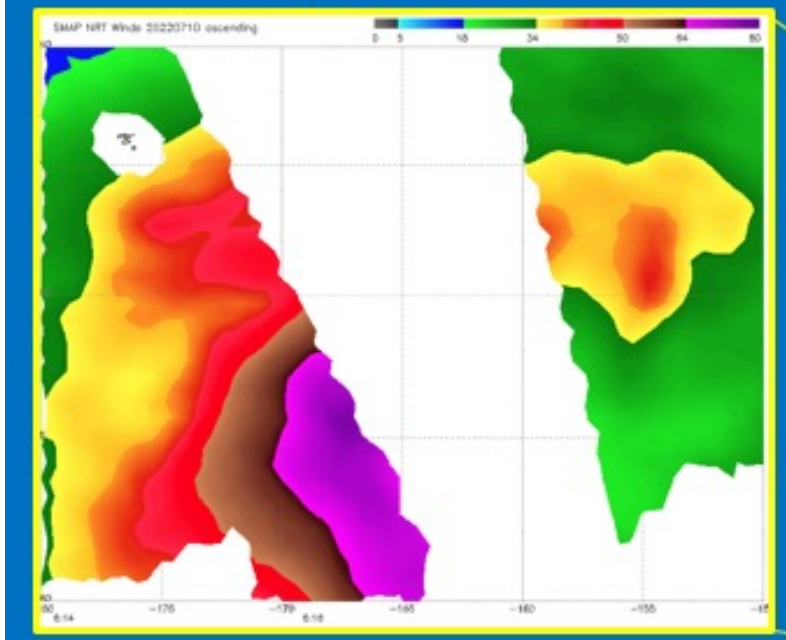
A Unique Event? *Early December, 2021 – King Tide + Large Swell*

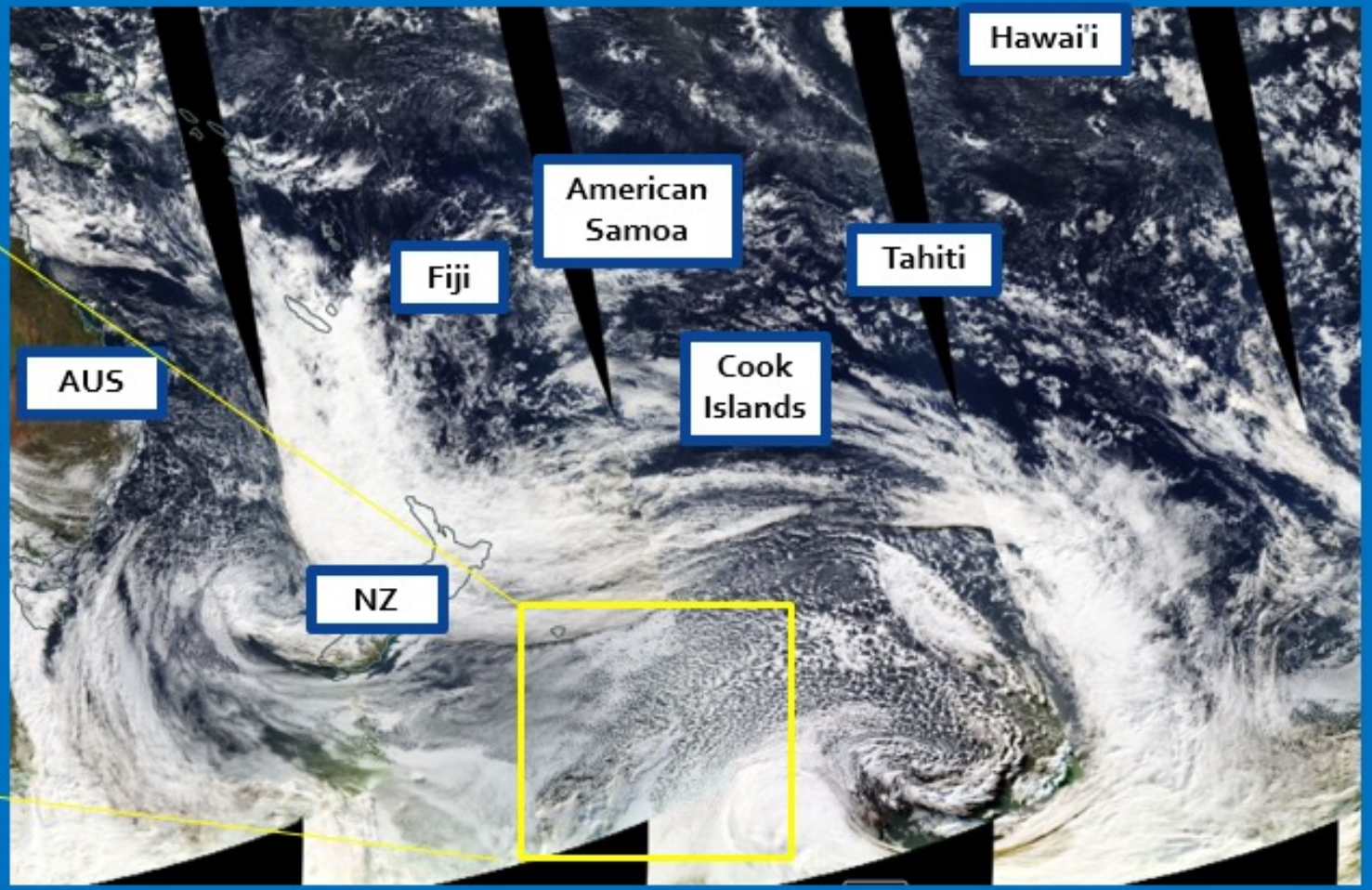


A Unique Event? *Mid July, 2022 – King Tide + Large Swell*

Widespread Coastal Flooding Across Islands of the South Pacific

65+ kt winds





A Unique Event? *Mid July, 2022 – King Tide + Large Swell*

A Few Images & Reports from American Samoa

State of Emergency

Via WFO Pago Pago…Considerable damage to coastlines of Tutuila, Aunu'u and Manu'a Islands. Pago Pago airport shut down due to waves reaching the runway

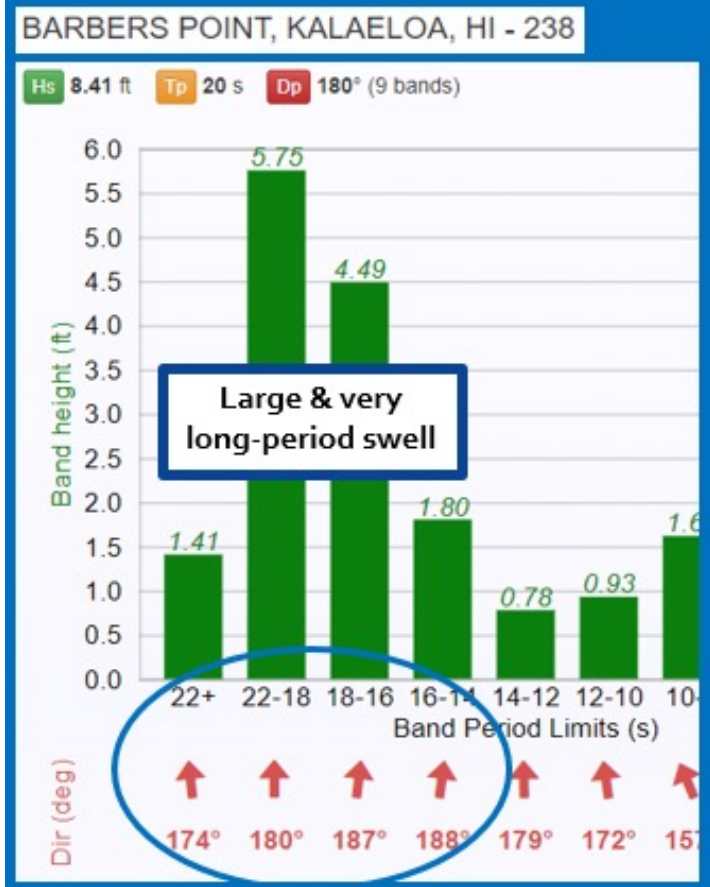
Diane F. (Facebook)

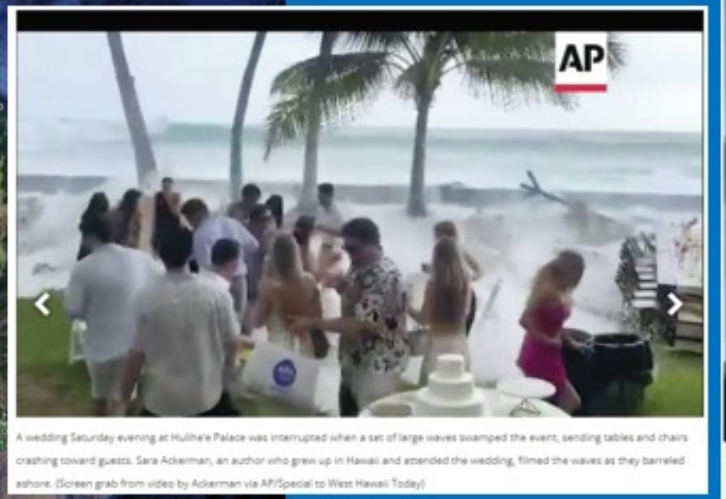
Tony B. (Facebook)

Vaoto Lodge (Facebook)

A Unique Event? *Mid July, 2022 – King Tide + Large Swell*

3 Days Later…Historic Southern Hemi South Swell for Hawai‘i





A wedding Saturday evening at Hulihe'e Palace was interrupted when a set of large waves swamped the event, sending tables and chairs crashing toward guests. Sara Ackerman, an author who grew up in Hawaii and attended the wedding, filmed the waves as they barreled ashore. (Screen grab from video by Ackerman via AP/Special to West Hawaii Today)

Via Associated Press and West Hawaii Today (July 19 2022)

Image captured from video provided by Isabella Sloan of a large swell hitting Kona Surf and Racquet Club in Keauhou on Saturday, July 16, 2022.

Big Island Now (July 19 2022)

Recap of Jan, 2024, and Other Recent Events

3 large & widespread inundation events in 3 years

- Dec, 2021 – King Tide + Distant Weather
- July, 2022 – King Tide + Distant Weather
- Jan, 2024 – Distant Weather
  - Dramatic impacts at Roi-Namur, akin to Dec, 2008

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Large storm systems ANYWHERE in the ocean basic must be watched:

- wind field
- direction of system motion
- Constructive interference / dynamic fetch potential?

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Large storm systems ANYWHERE in the ocean basic must be watched:

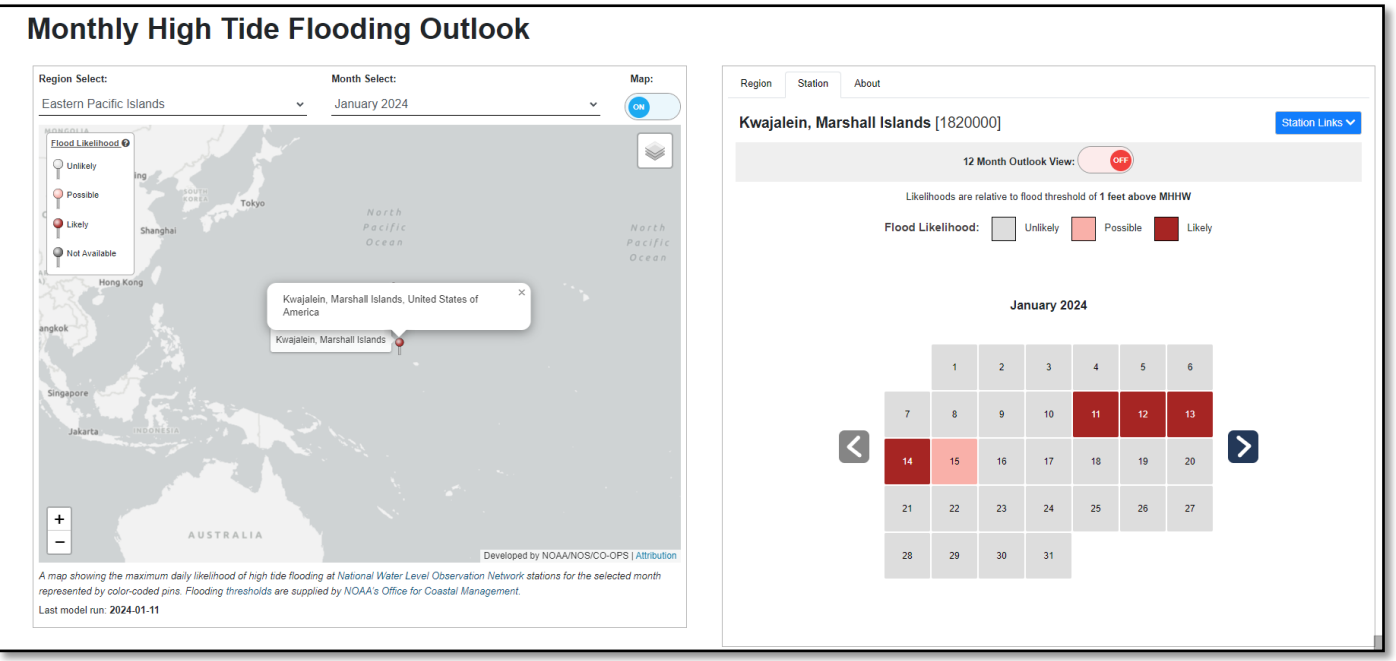
- wind field
- direction of system motion
- Constructive interference / dynamic fetch potential?

Even outside of King Tides and high tide cycles:

- ~warning level swell (15ft, NWS Guam) will bring saltwater onto normally dry ground in vulnerable low-lying areas susceptible to those swell directions
- Increasing threat of significant impacts with longer wavelength (period ~15+ sec)

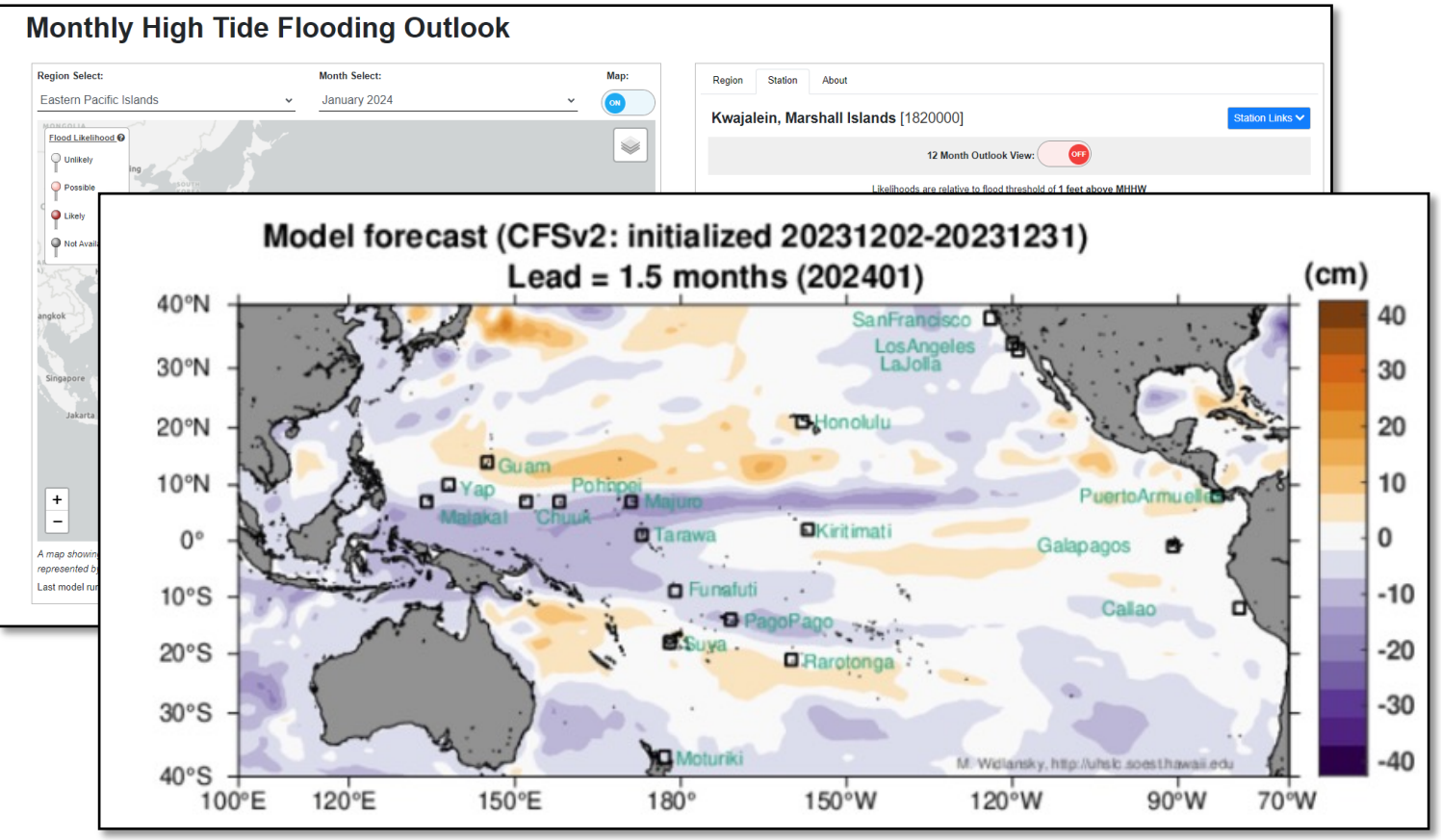
Predicting & Understanding Future Events

Predicting & Understanding Future Similar Events: *Tying the Data Together*



- NOAA's High Tide Flooding Outlook

Predicting & Understanding Future Similar Events: *Tying the Data Together*



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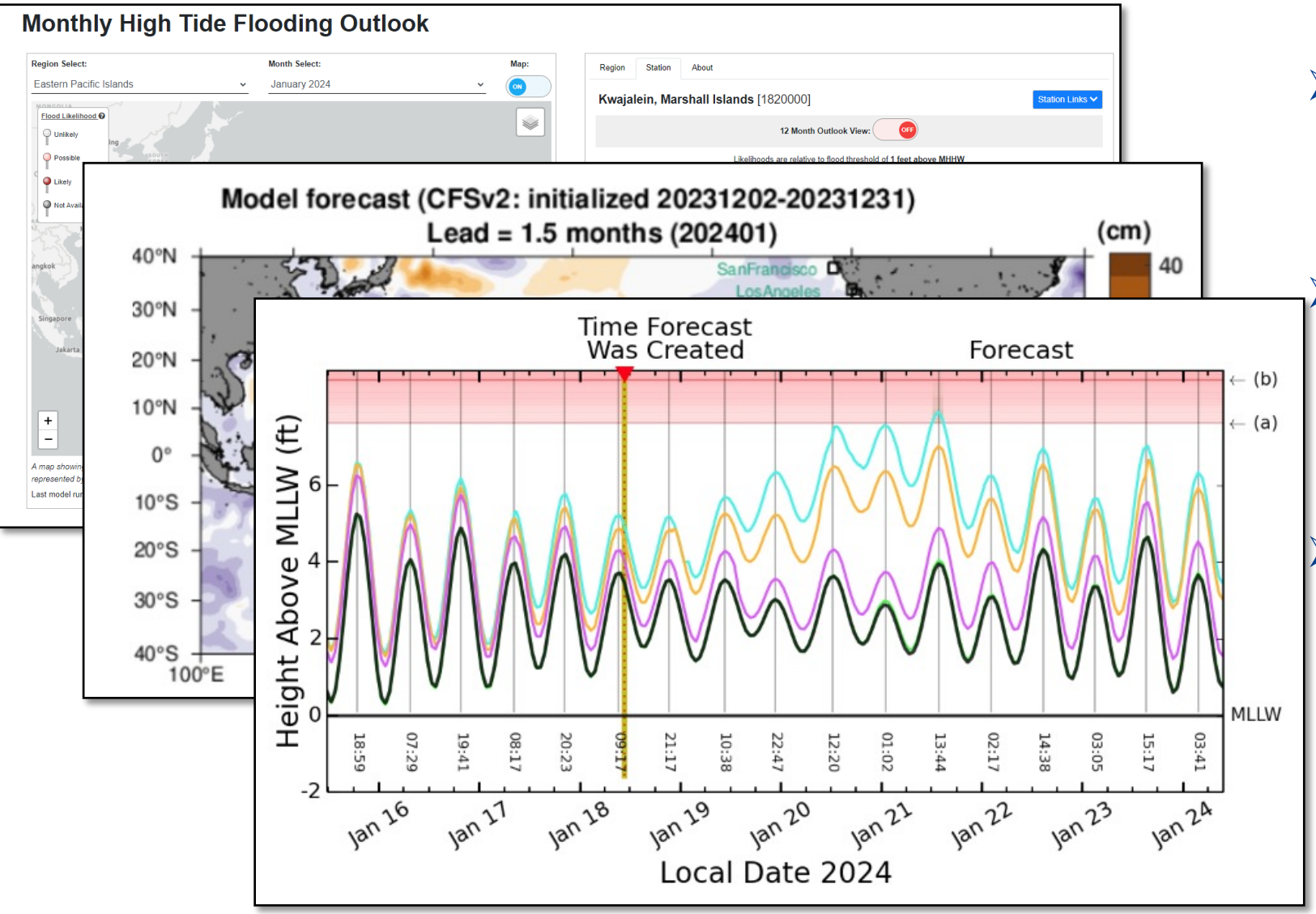

- NOAA's High Tide Flooding Outlook
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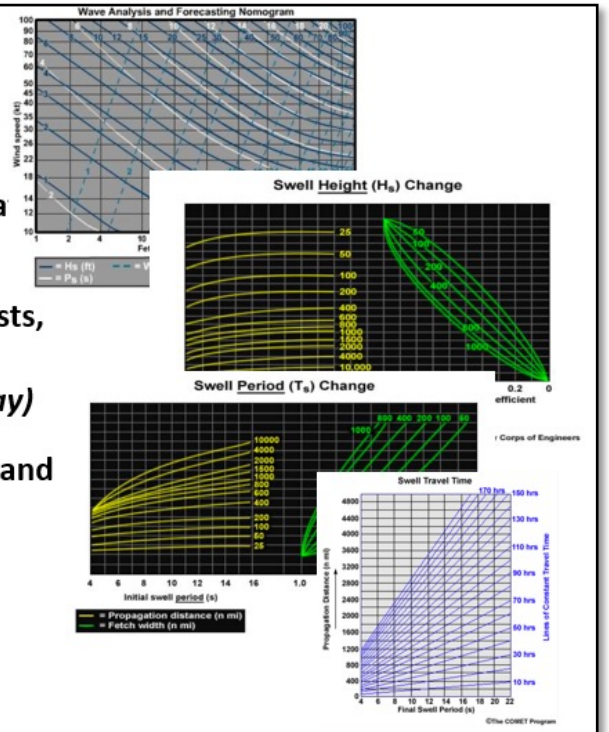
- PacIOOS shoreline impacts and run-up guidance

Predicting & Understanding Future Similar Events: *Real-Time Analyses*

- The process reinforces & offers improved understanding and insight into wave development & travel;
- Global wave models have their own weaknesses & biases tha we MUST be aware of & factor into our forecasts;
- Forgetting where models perform poorly leads to bad forecasts, sometimes with devastating consequences *(i.e., a 3-5 ft surf forecast later being updated to a HSW of 15 ft in the same day)*
- Nomograms provide the extra insight on wave development and arrival times giving forecasters useful data to compare with model guidance



Why Nomograms? They're Tedious… (Forecaster Meeting 2/21/2023)

From WFO Guam training…

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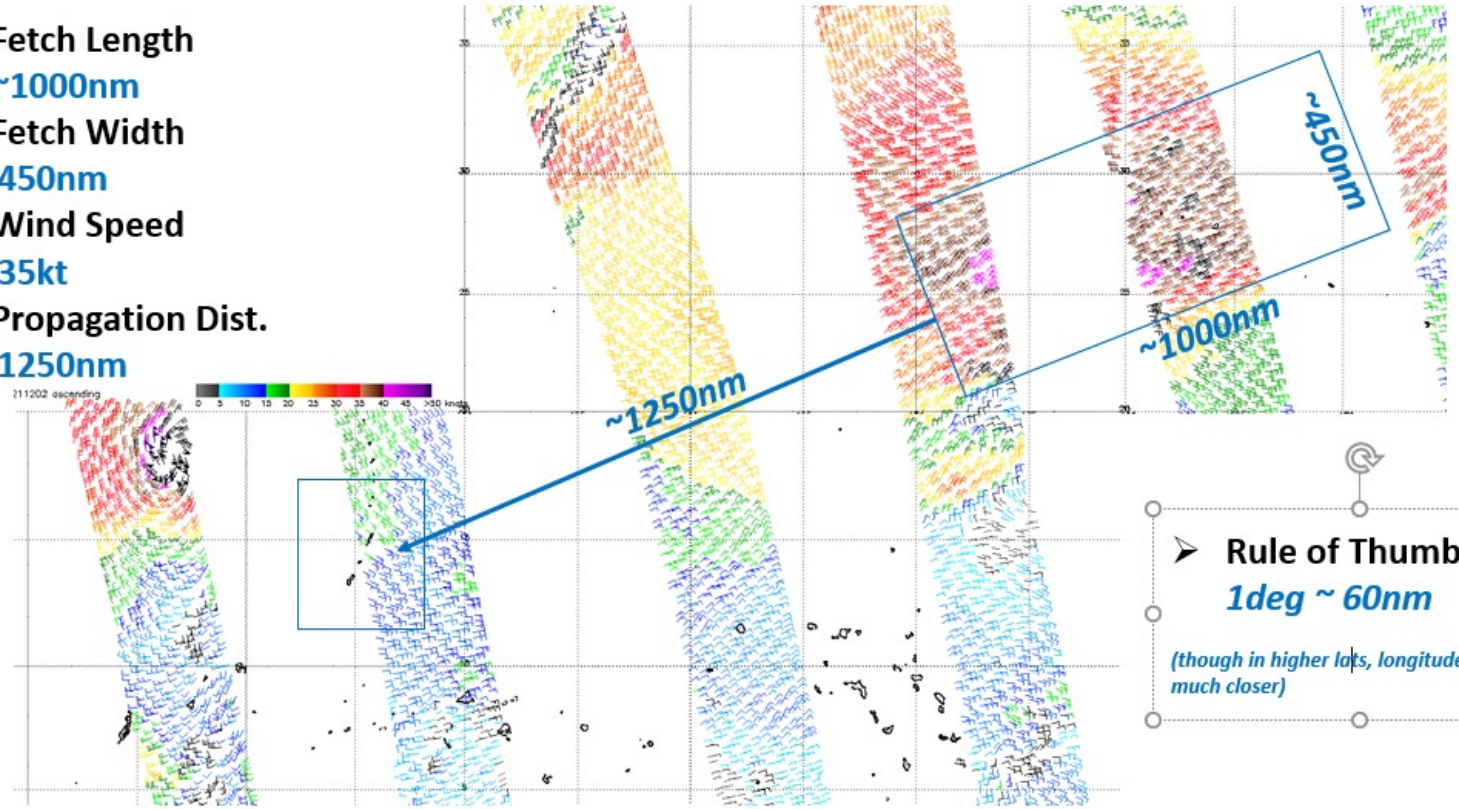
Why Nomograms? They're Ted

1. Fetch Length
   ~1000nm
2. Fetch Width
   ~450nm
3. Wind Speed
   ~35kt
4. Propagation Dist.
   ~1250nm



- Rule of Thumb: *use 1deg ~ 60nm*

(though in higher lats, longitude lines get much closer)

How to do a Nomogram Analysis (Forecaster Meeting 2/21/2023)

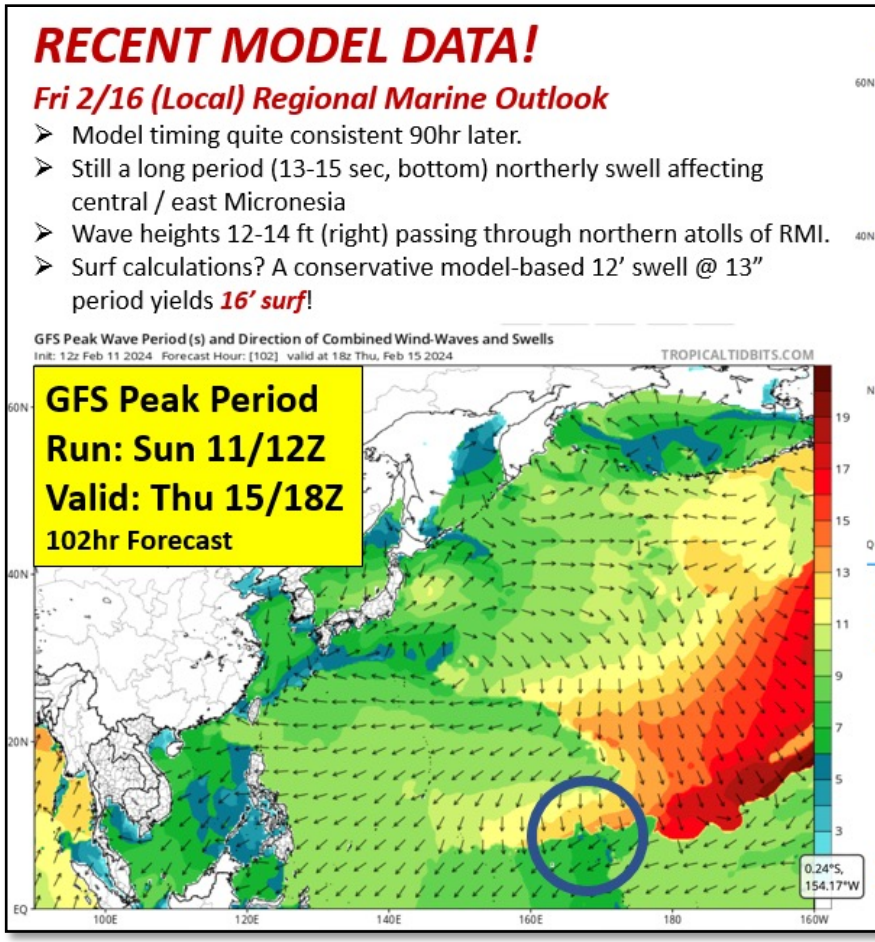
From WFO Guam training…

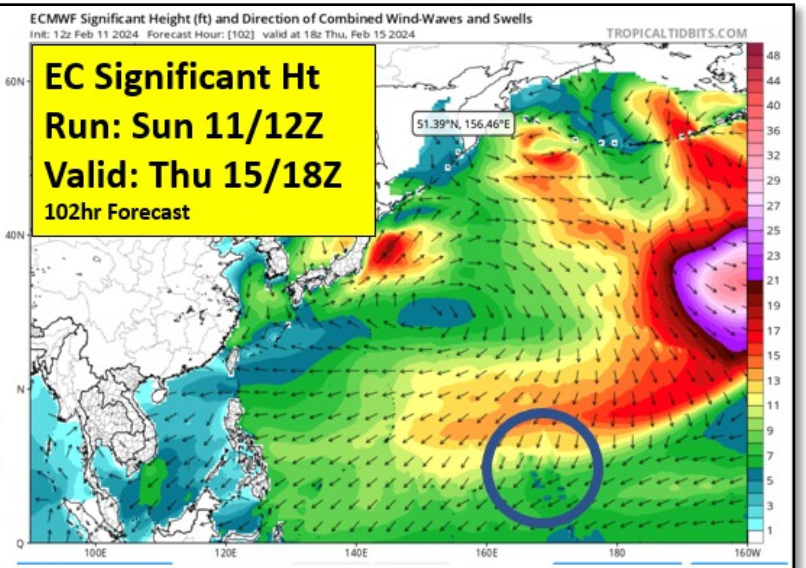
Predicting Future Similar Events: *Understanding Model Tendencies*

RECENT MODEL DATA!

Fri 2/16 (Local) Regional Marine Outlook

- Model timing quite consistent 90hr later.
- Still a long period (13-15 sec, bottom) northerly swell affecting central / east Micronesia
- Wave heights 12-14 ft (right) passing through northern atolls of RMI.
- Surf calculations? A conservative model-based 12' swell @ 13" period yields ***16' surf***!





Things to Note:

- Note how the wave models show the northerly swell penetrating into the northern & central RMI through the atolls!
  - This is how Roi-Namur got its waves in January (powerful 80kt-ish cyclone to the north that briefly moved SE), and
  - ALSO in Dec, 2008, as developing TS Dolphin moved southward near Wake Island.
- Model trends in 4 days? ***Perhaps*** a little lower in wave height potential.

From WFO Guam training…

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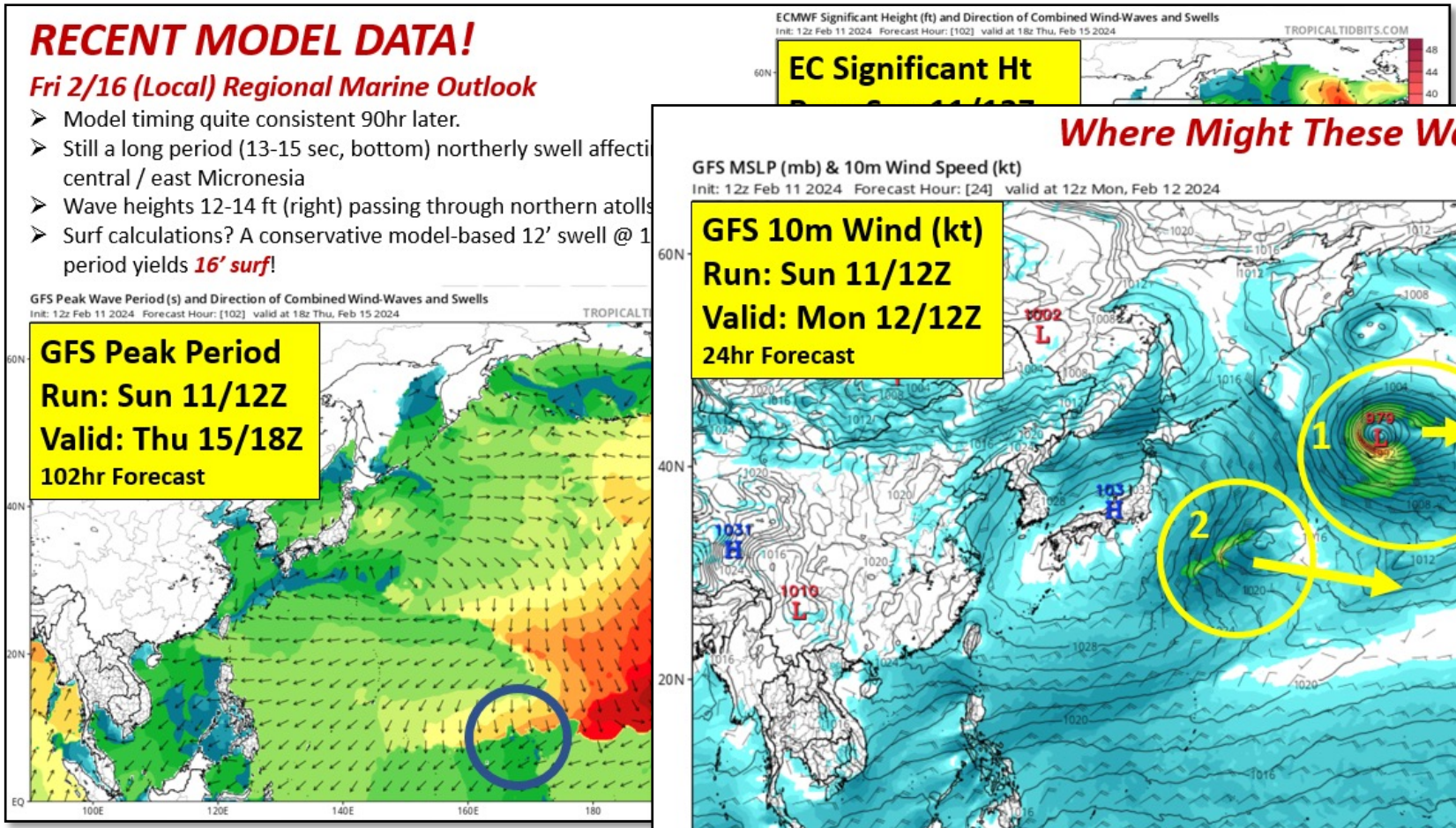
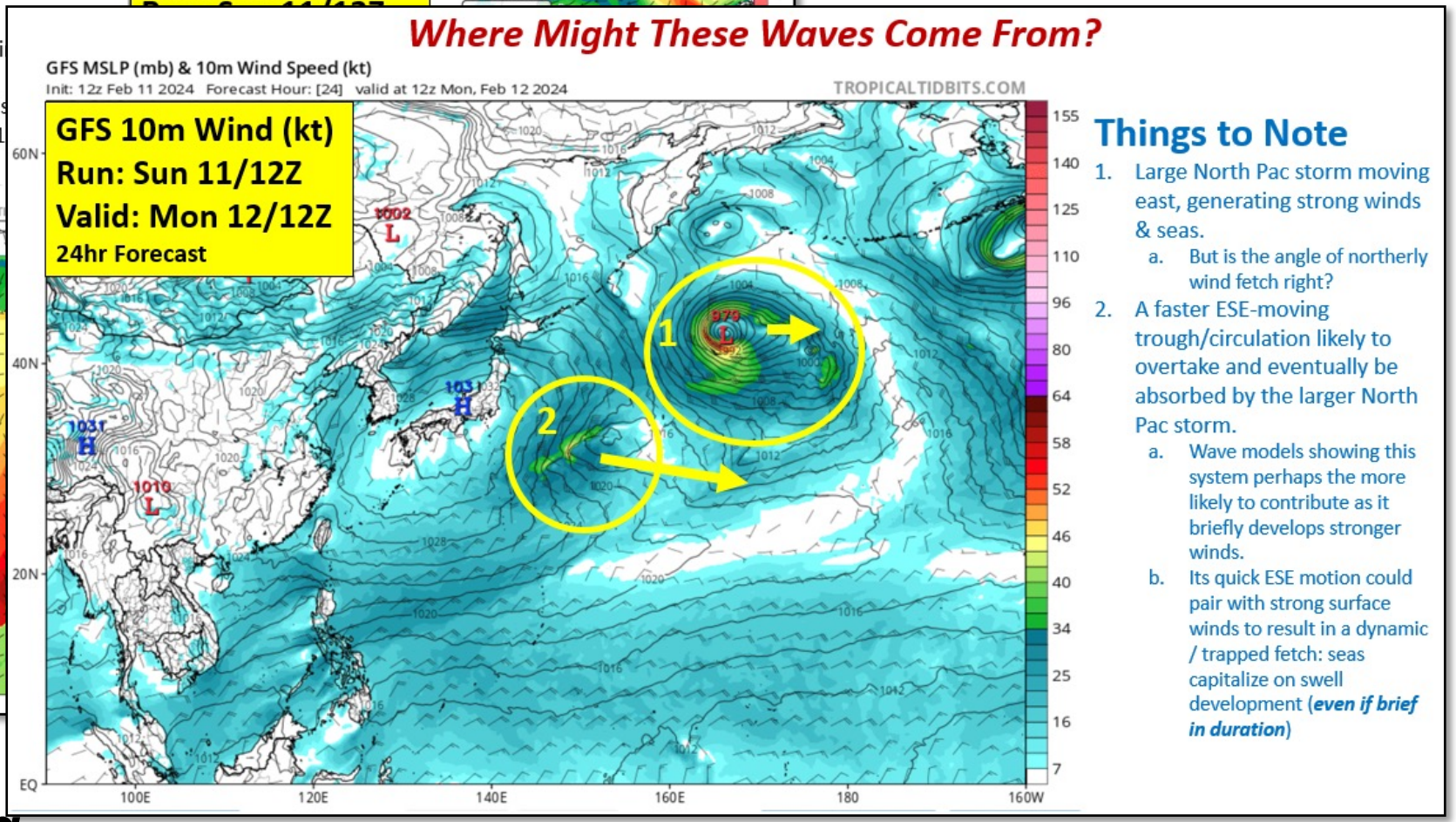


Where Might These Waves Come From?

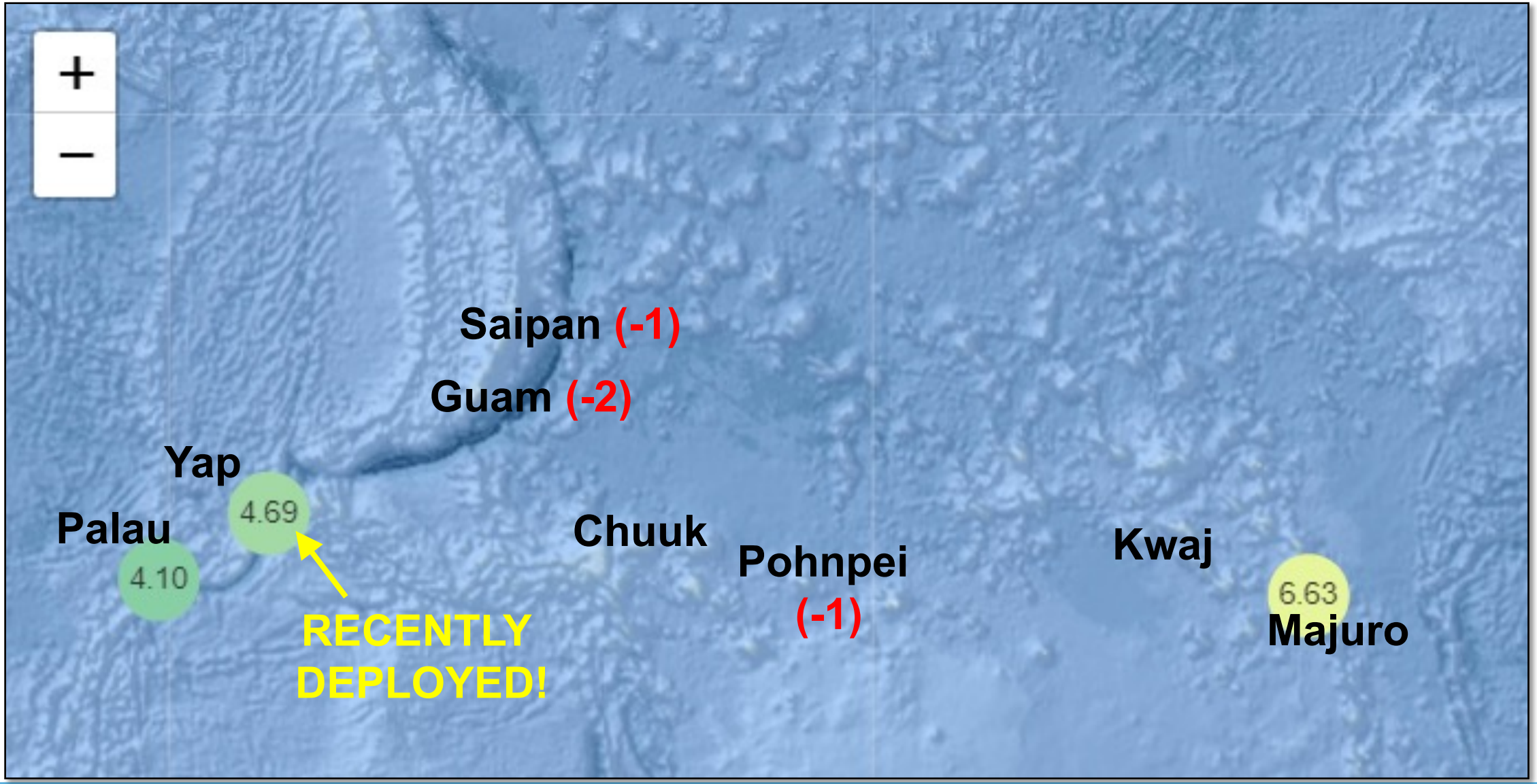


Things to Note

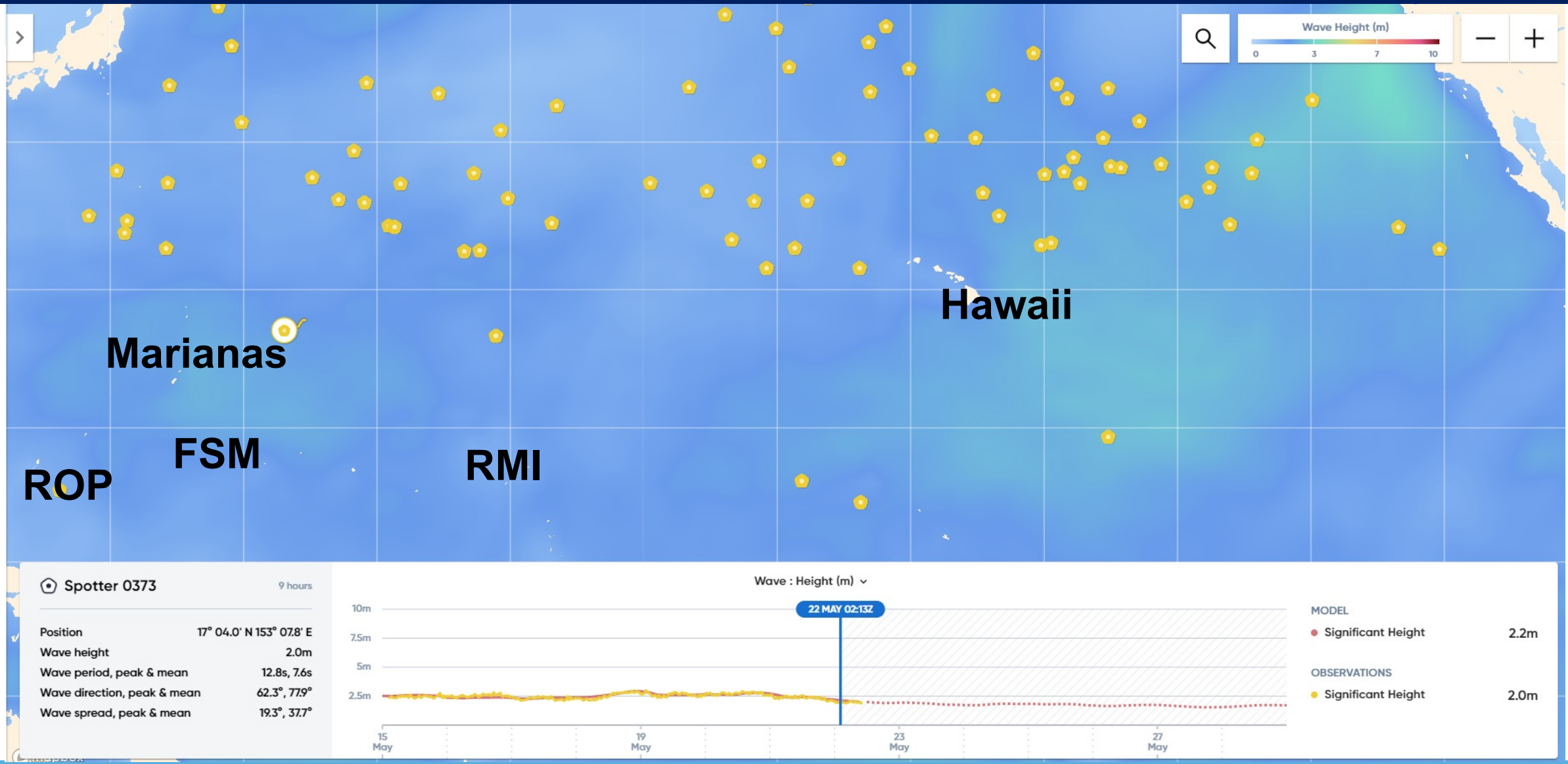
1. Large North Pac storm moving east, generating strong winds & seas.
   a. But is the angle of northerly wind fetch right?
2. A faster ESE-moving trough/circulation likely to overtake and eventually be absorbed by the larger North Pac storm.
   a. Wave models showing this system perhaps the more likely to contribute as it briefly develops stronger winds.
   b. Its quick ESE motion could pair with strong surface winds to result in a dynamic / trapped fetch: seas capitalize on swell development (***even if brief in duration***)

From WFO Guam training…

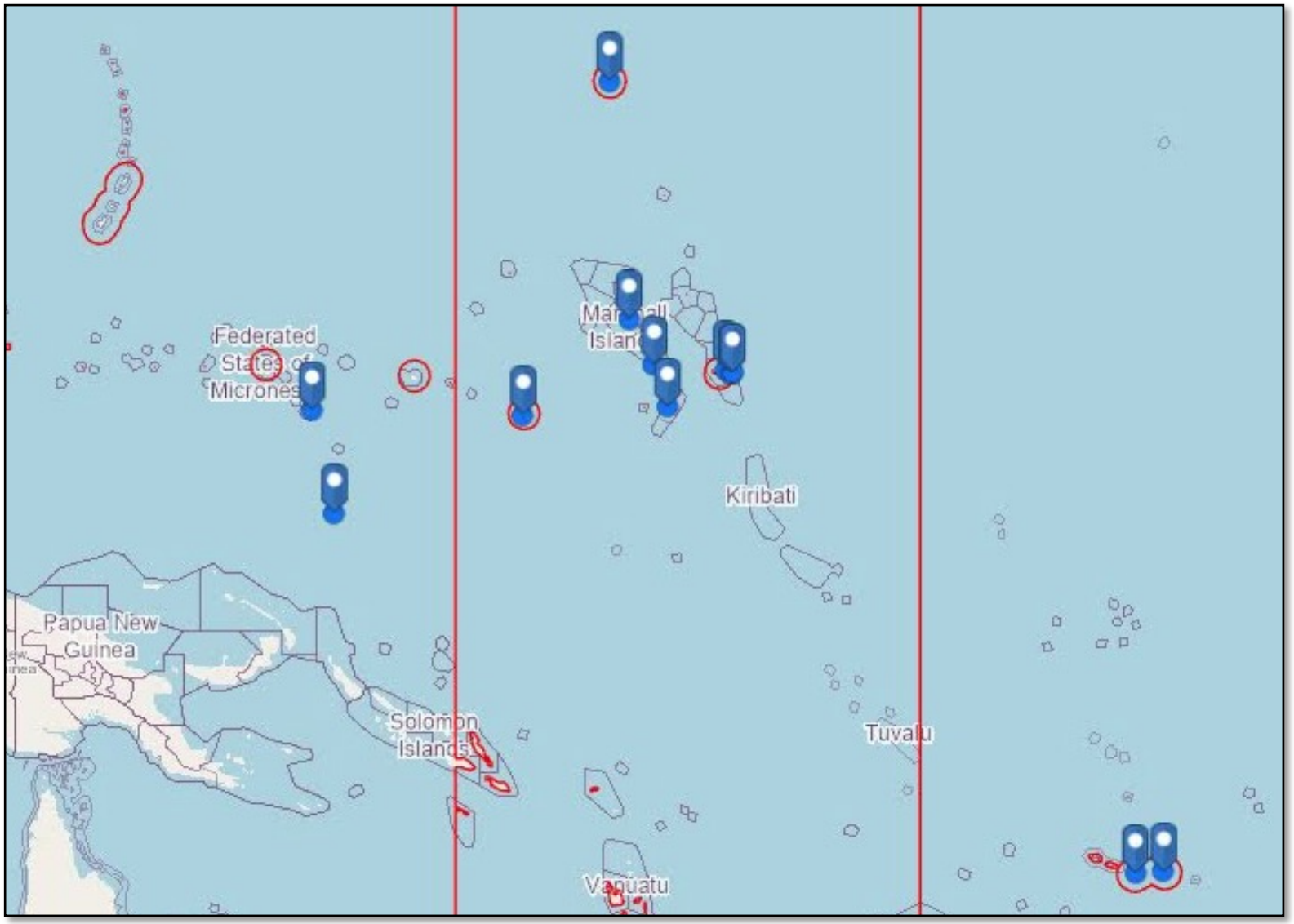
Observing & Understanding Future Similar Events: *PacIOOS Waverider Buoys*



Observing & Understanding Future Similar Events: *Drifting Buoys - SOFAR*



Observing & Understanding Future Similar Events: *Real-time Reports*



- **Reports are critical for awareness and improved understanding of impacts**
- **Reports of NO IMPACTS *<u>are just as valuable</u>* when impacts are anticipated but do not occur.**

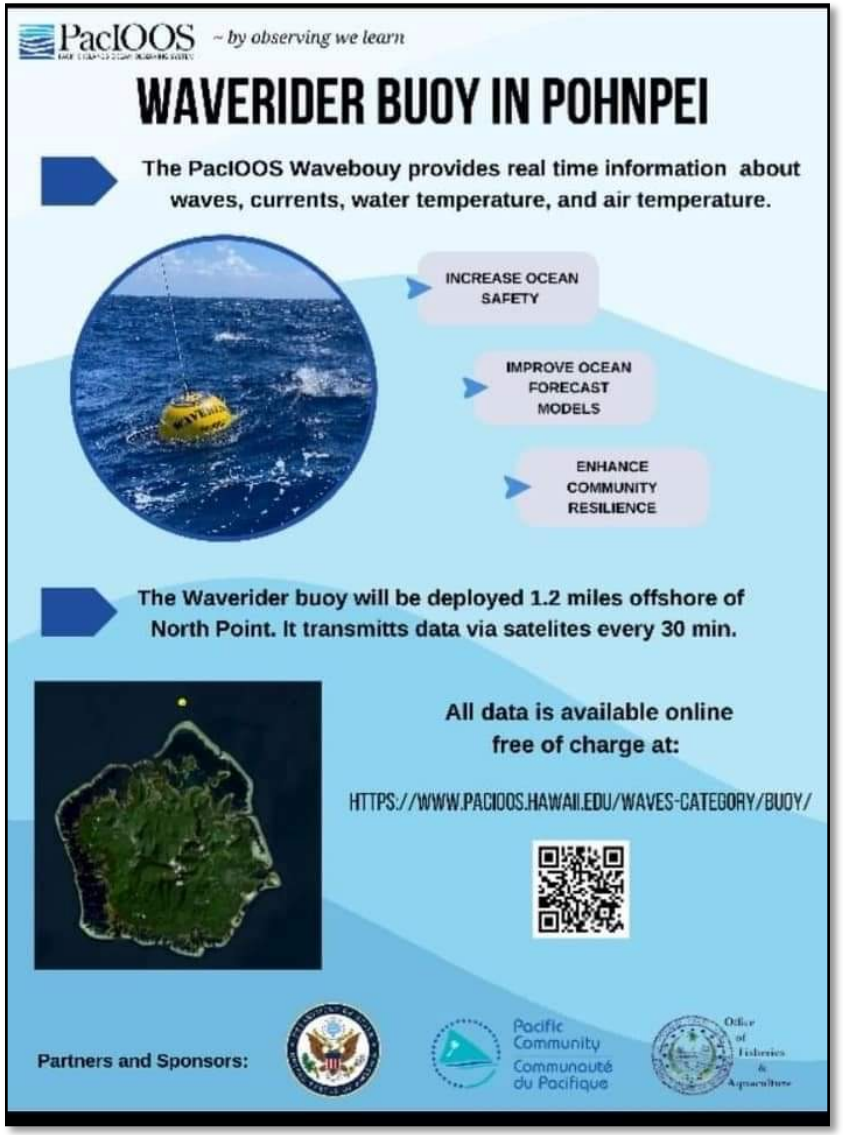
Observing Future Similar Events: *PacIOOS Waverider Buoys*

US Embassy Kolonia
Jan 3 ·

We all work together to better understand our ocean. It's been reported a new wave buoy off the northern shore of Pohnpei was cut from its anchor on December 28 just two weeks after installation and will take several months to reinstall. This buoy was part of the Pacific Islands Ocean Observing System (PacIOOS) network and was funded by the U.S. Department of State through the U.S. National Oceanic and Atmospheric Administration. It provided information on wave height, period and direction, current speed, current direction, sea surface temperature, and air temperature, which anyone could look up at https://www.pacioos.hawaii.edu/regions/fsm/ and https://cdip.ucsd.edu/m/stn_table/.

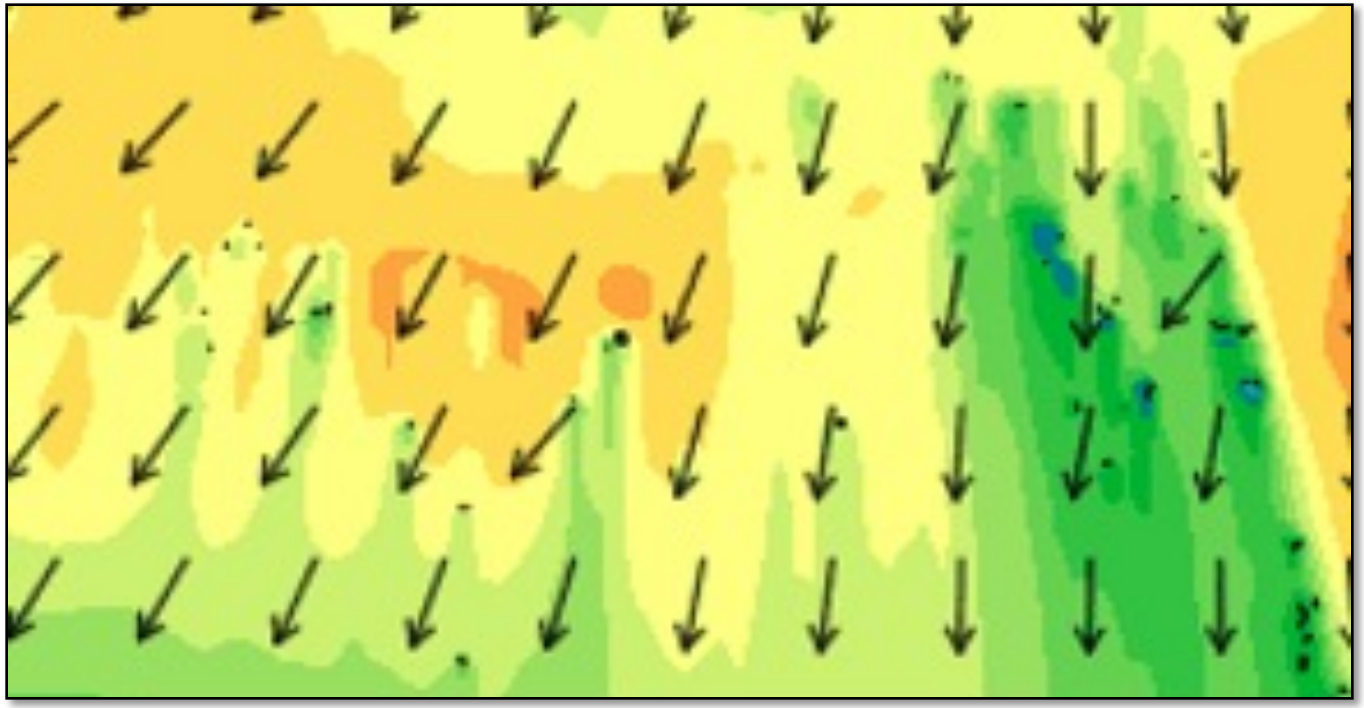
Damaging oceanic equipment means costly, difficult repairs for operators and disrupted service for people who rely on it. This buoy benefits everyone who is part of the ocean community, here is how the data it generates is used:

- Pohnpei residents can check ocean conditions before fishing, sailing, or swimming and add to their local knowledge.
- Local agencies like the weather office can generate forecasts and make public safety advisories.
- Companies and local authorities can monitor temperature and current changes that affect fisheries more easily.
- The FSM government and its partners can plan for the future with better insight on long-term ocean and weather trends.
- Environmental organizations can better understand how extreme events and climate change are impacting Pohnpei's coast.



Shortfalls, Gaps in Understanding, etc.

- Model resolution
  - Atolls/islands and swell dissipation / interaction
    - High resolution analyses & studies needed



Model Wave Heights encountering atolls/islands of FSM & RMI.

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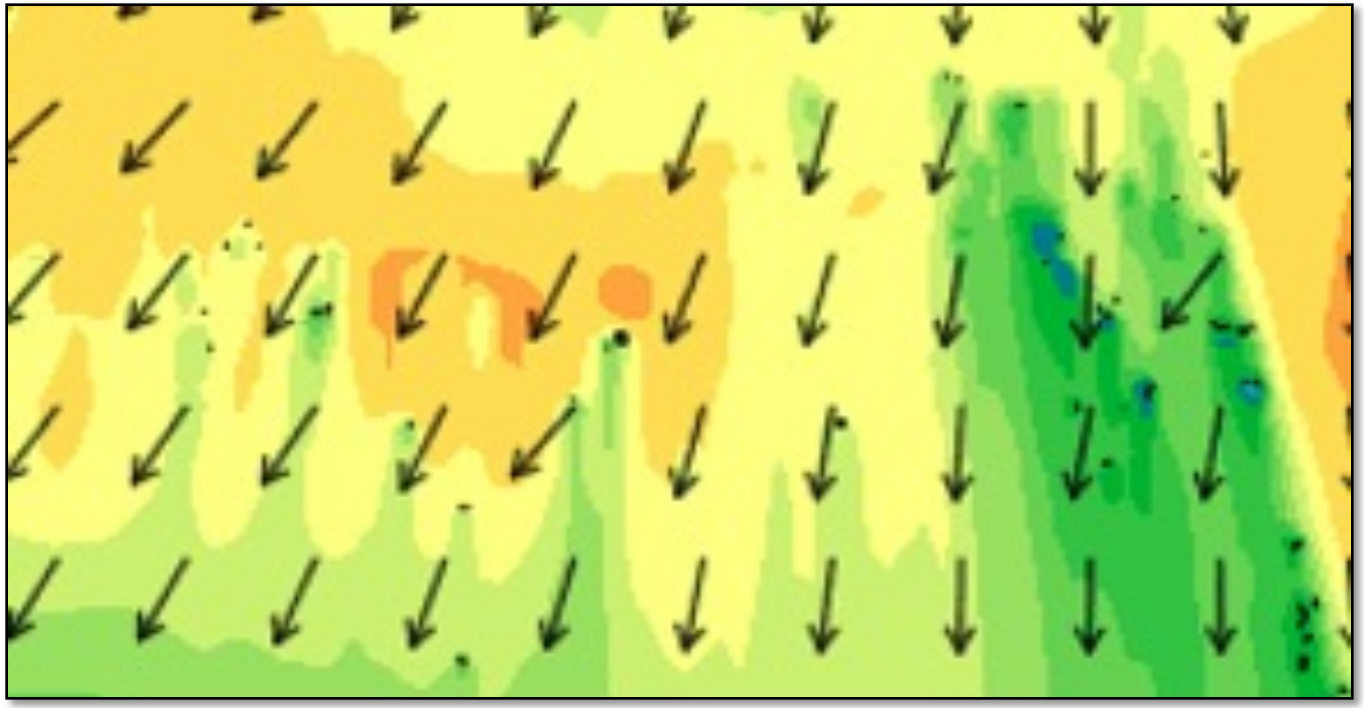

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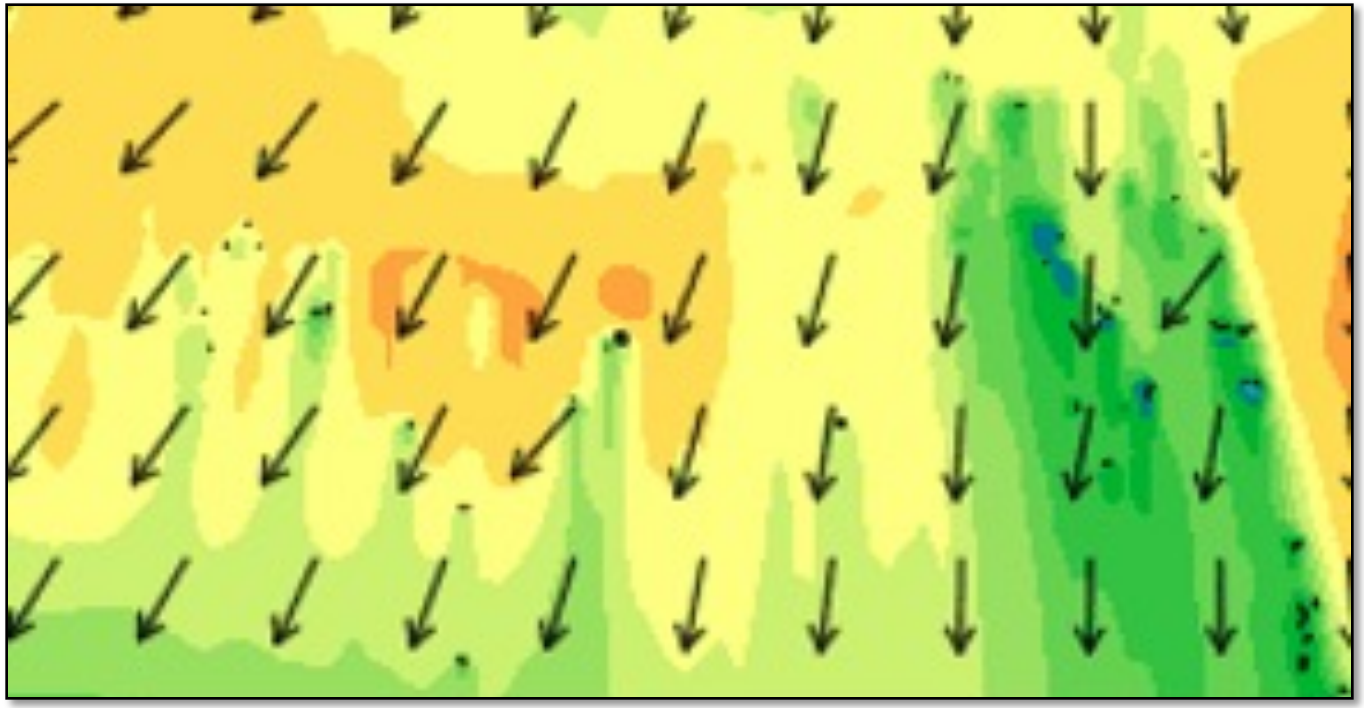

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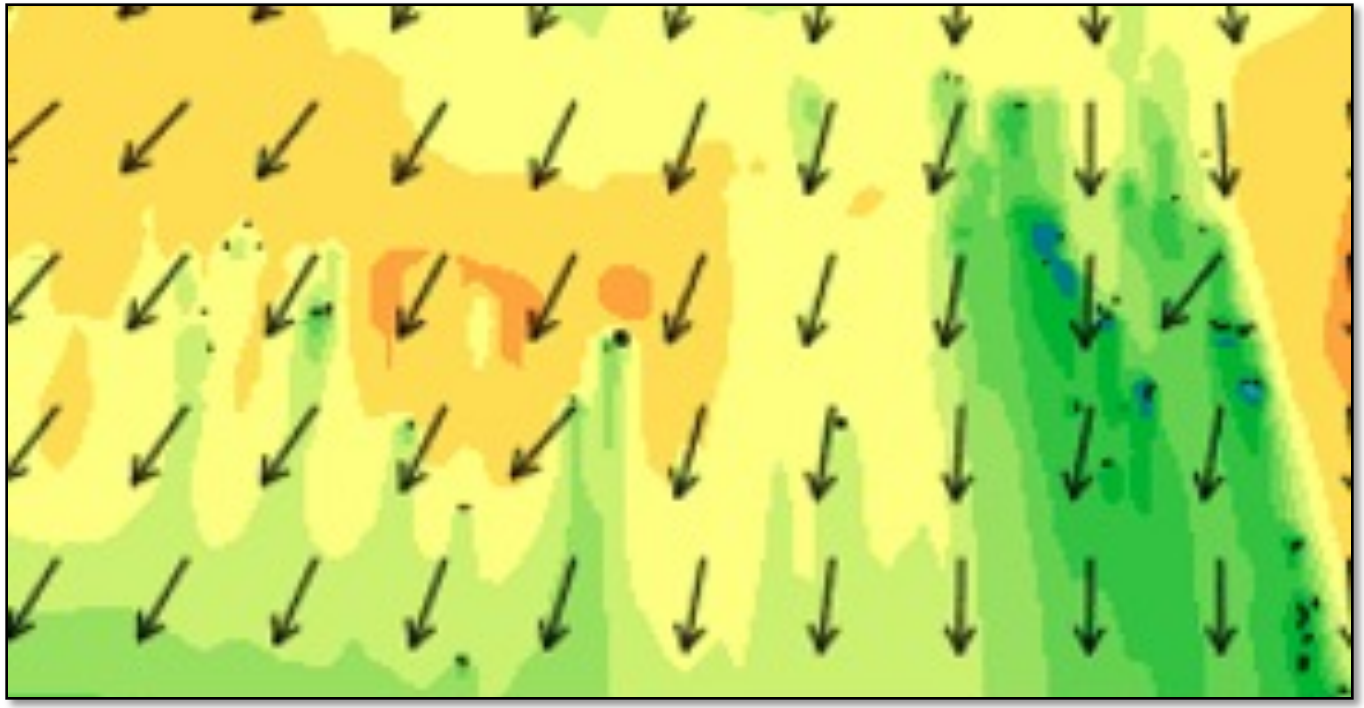
  - Improved understanding of wave / surf / inundation behavior and potential
- Tools to predict the magnitude of such coastal impacts as what happened at Roi-Namur



Model Wave Heights encountering atolls/islands of FSM & RMI.

Predicting Future Similar Events: *A Forecaster's Framework*

Data to Assess

NOAA HTF guidance.

Sea level anomalies (ENSO variability).

Regional tide gauges for water level deviations.

1-2 week model guidance for large, strong wind systems / swell generators.

Inundation / run-up guidance from PacIOOS.

Scatterometry wind fields for manual analyses.

Altimetry data for swell tracking & model verification.

Actions to Consider

Review internal procedures for operational readiness.

Internal discussion about long-range 'stage-setting' (astronomical, sea levels).

Long-range outlook & discussion of potential event with outside partners.

Increase communications with outside partners and social media engagement.

Communicate increasingly more specific details on timing and impacts of the event.

Issue the appropriate watches / warnings / advisories

Questions?

January 2024: Micronesia Extreme Waves & Inundation

A Meteorological Analysis of the 17-23 January Event & Impacts

NATIONAL WEATHER SERVICE

William Brandon Aydlett

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