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Tides & Coastal Flooding Review, Products, & Outlook

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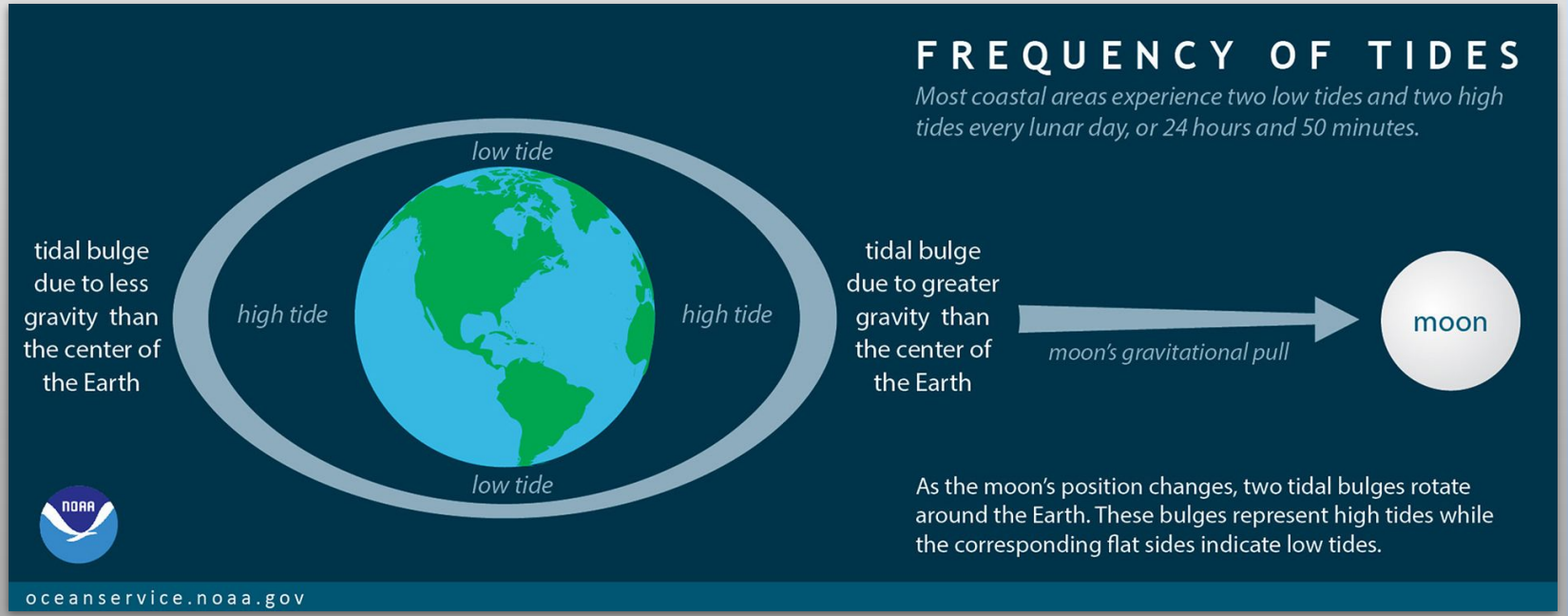
Background & Hazard Information

Tides 101

Astronomical tides are caused by the balance of gravity from the Moon & Sun. Tidal forcing contributions are roughly 2/3rds from the Moon and 1/3rd from the Sun. Therefore overall tides are most strongly tied to the lunar cycle. On the side of the Earth facing the Moon, the Moon's gravity creates a bulge of water. On the opposite side of Earth, inertia and lower lunar gravitational force creates a second bulge. As the earth rotates, it experiences these forces, causing 2 high tides and 2 low tides every 24 hours and 50 minutes. The two high (low) tides each day may not be equal, creating a “high tide” (“low tide”) and a “higher high tide” (“lower low tide”).

Note: Earth’s geography & shape affect the actual tide times at any given location (i.e. high tides do not necessarily occur when the moon is overhead).
More Information



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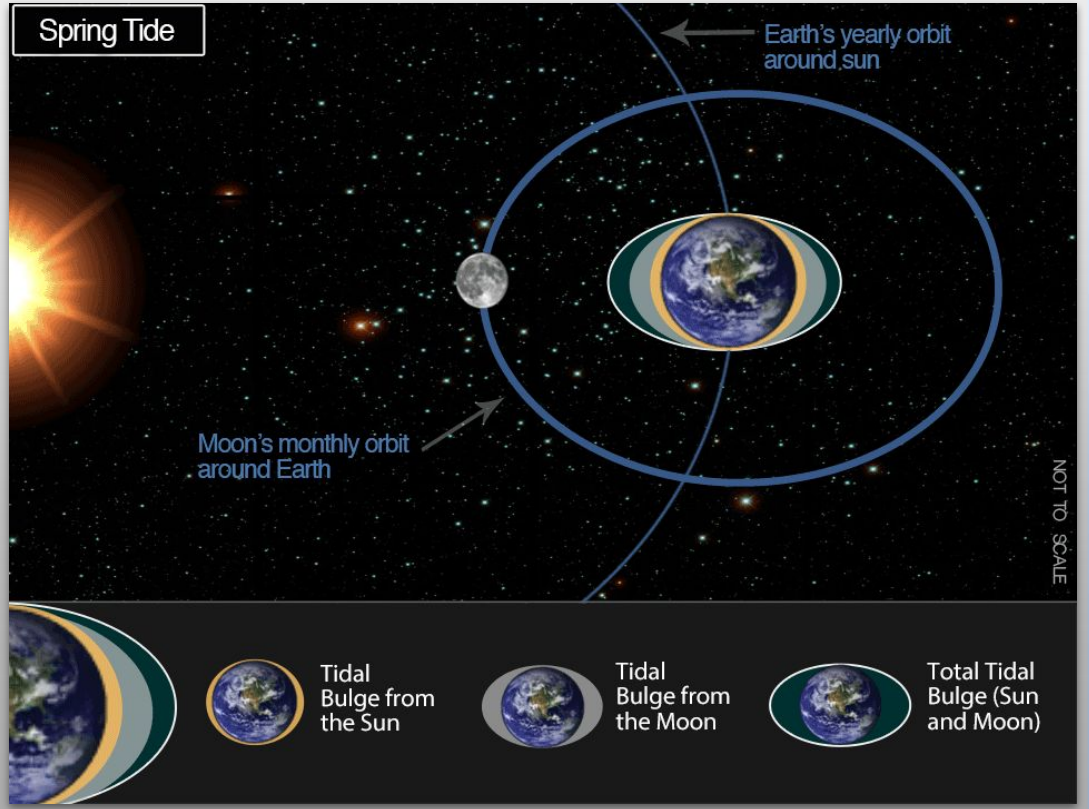
Spring & Neap Tides

King Tide?
"King Tide" is an unofficial term that is loosely used to describe especially high astronomical tides.

Spring Tides
The Moon, Earth, and Sun align (syzygy) resulting in a new or full moon. In this orientation, solar and lunar gravitational forces align resulting in ***higher than average tide levels***. The use of "spring" does not refer to the season, but rather the water "springing forth".

Neap Tides
Moon, Earth, and Sun form a right angle which partially cancels gravitational forces resulting in ***lower than average tide levels***.

Lunar orbit: ~29.5 Days
More Information



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Perigean Spring Tide

When

Occurs when the moon is new or full (spring tide) AND when the moon is closest to earth in its orbit (perigee), resulting in a higher than average lunar gravitational force.

Lunar perigee frequency: every ~28 Days

Typically, 6-8 tide cycles per year have a notable influence from this effect.

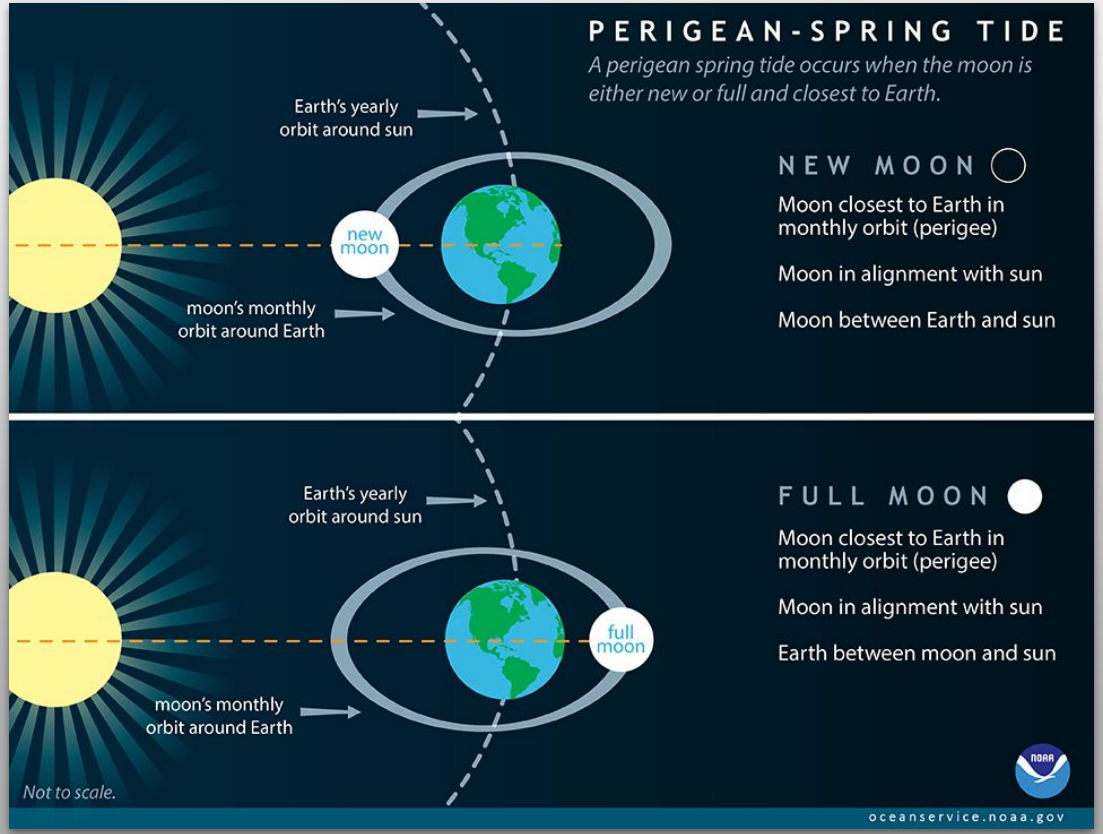
Impacts

Minor coastal/high tide flooding **can** occur with a perigean spring tide.

Major coastal flooding typically occurs in response to a strong onshore winds and low atmospheric pressure.

Impacts are expected to increase over time in areas experiencing sea-level rise.

More Information



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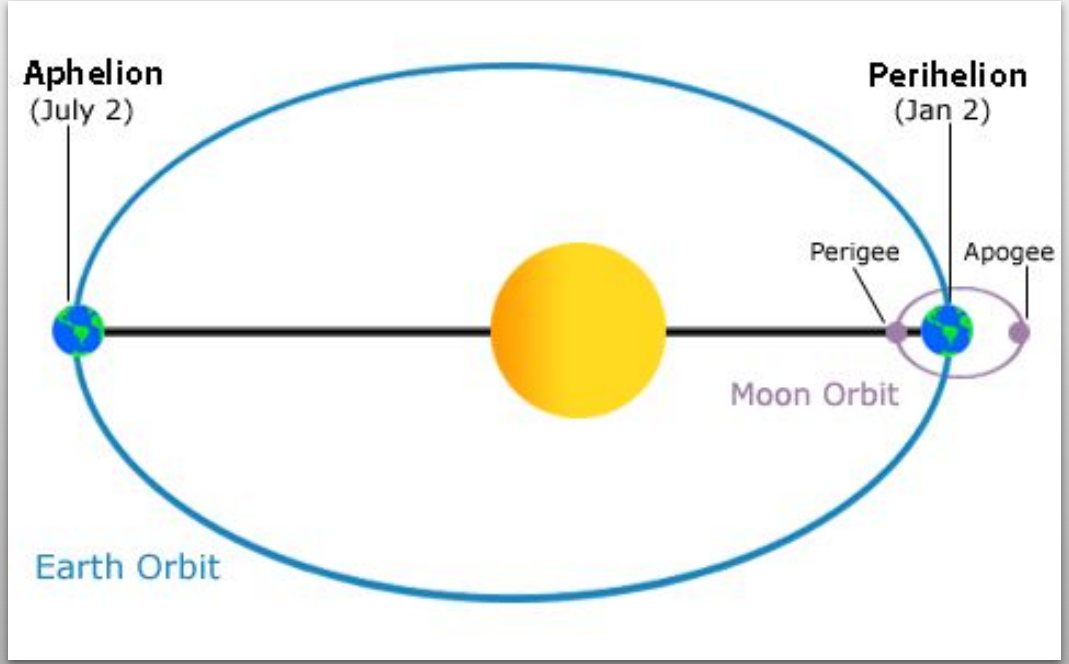
Why Even Higher in Winter?

When
Perihelion is the point at which the Earth is closest the sun in its annual orbit. This typically occurs in early January.

Effect
This results in an increased contribution from the sun to tidal forces (and therefore astronomical tide levels) in the middle of the Northern Hemisphere winter season compared to the rest of the year.

More Information



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Tide Gauges

Official Gauges

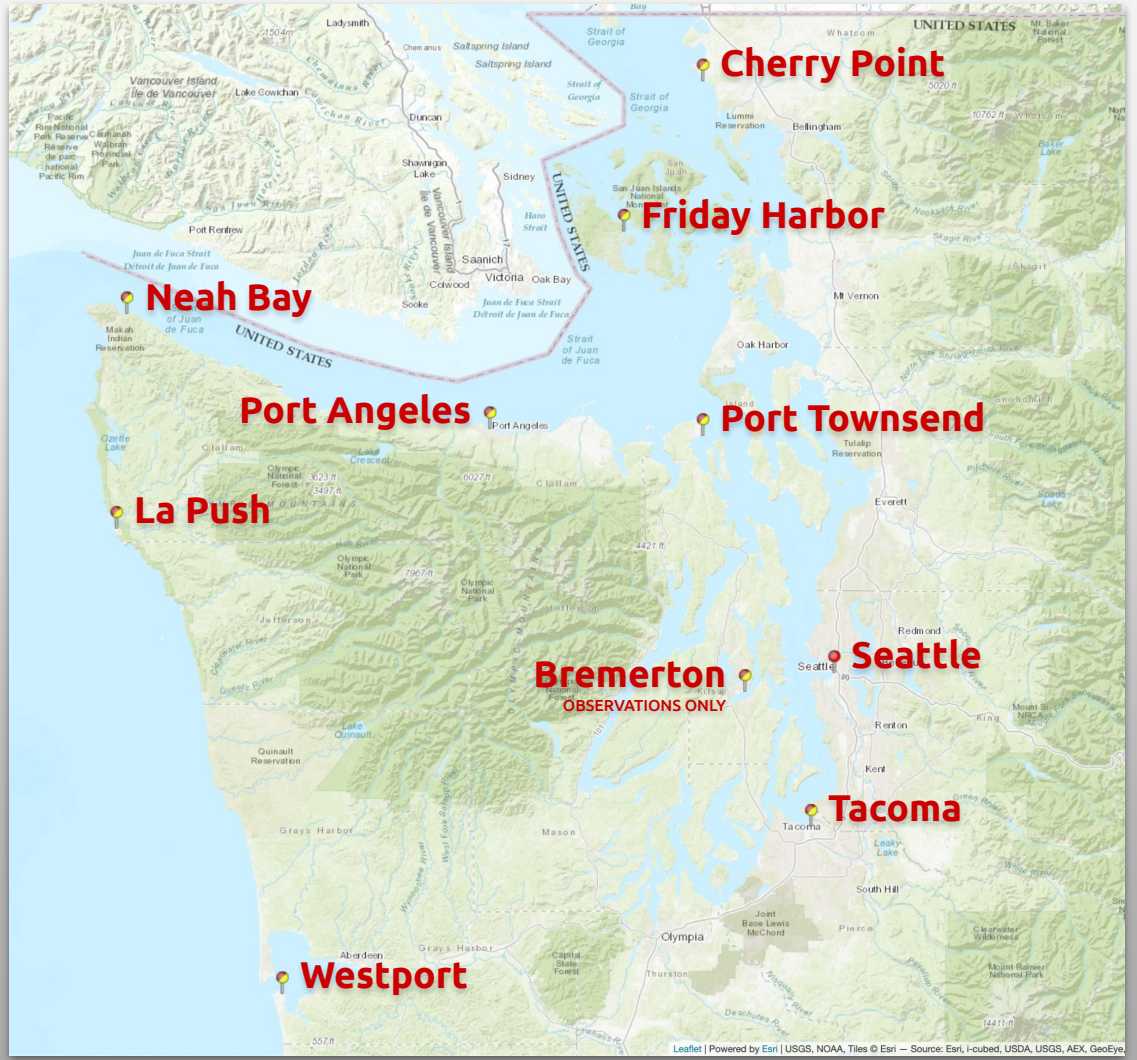
NOAA's National Ocean Service (NOS)

Center for Operational Oceanographic Products and Services (CO-OPS)

NOAA Tides & Currents

- Observations
- Inundation Dashboard

Note: These observations may not represent the full spectrum of impacts (or water levels) in nearby areas.



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Intro to Datums

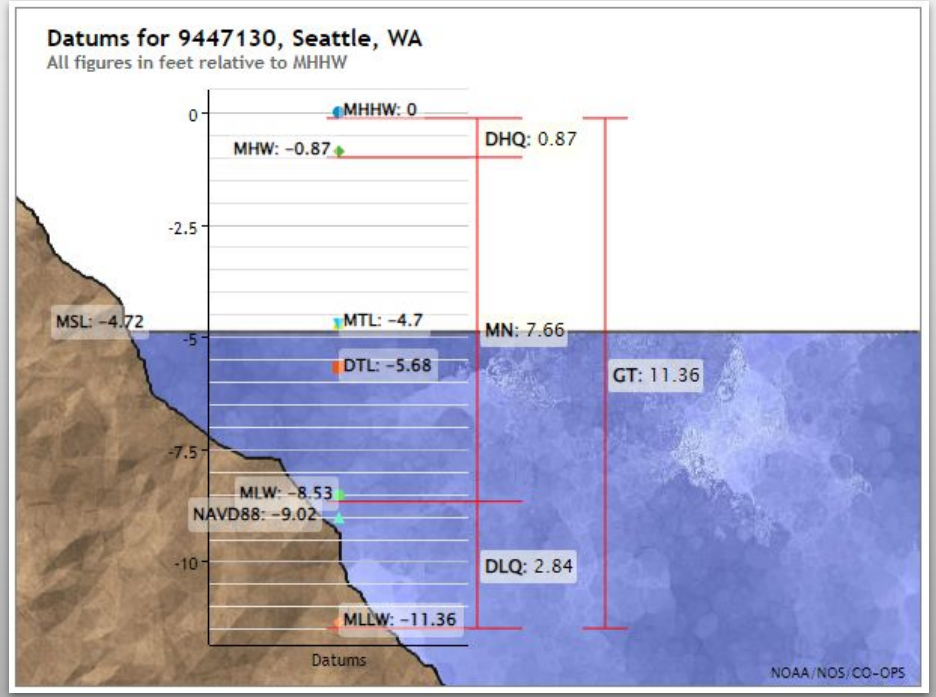
National Tidal Datum Epoch (NTDE)

19-Year period of observed tides used to define tidal datum levels (more detail on next slide). NTDE is updated every 20-25 years.

Current NTDE Period: 1983-2001
Next Update: Release Est. in 2025 and will include observations from 2002-2020

North American Vertical Datum 1988 (NAVD88)

Commonly used as a reference datum for engineering and other applications. NAVD88 is a fixed reference for elevations determined by geodetic leveling. NAVD 88 should not be used as Mean Sea Level. NOAA tidal datums can be converted to NAVD88 for each station. Gravity for the Redefinition of the American Vertical Datum (GRAV-D) is being developed to replace NAVD88.



[More on datums]

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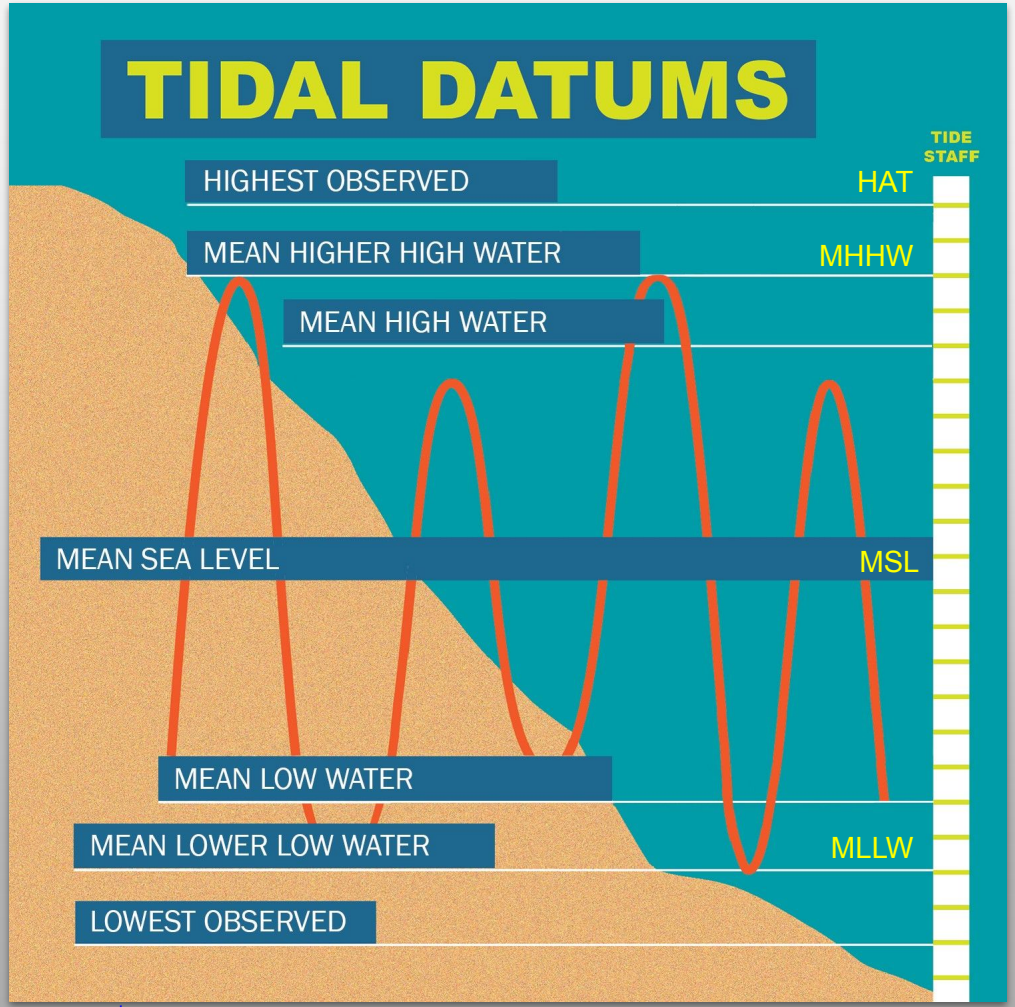

More on datums

Highest Astronomical Tide (HAT)

The elevation of the highest predicted astronomical tide expected over the time period of 40 years.

Application: Currently used as minor flood threshold when other thresholds are undefined.

Mean Higher High Water (MHHW)

The average of the higher high water height of each tidal day over NTDE.

Application: Used as "ground level" reference point in official NWS coastal flood products. Often used as a reference datum in model guidance.

Mean Sea Level (MSL)

The mean of hourly heights over the NTDE.

Application: Sometimes available as a reference datum in model guidance.

Mean Lower Low Water (MLLW)

The average of the lower low water height of each tidal day over the NTDE.

Application: Sometimes available as a reference datum in model guidance. Typically used as the reference datum for astronomical tide predictions (tide tables), bench marks, and nautical charts.

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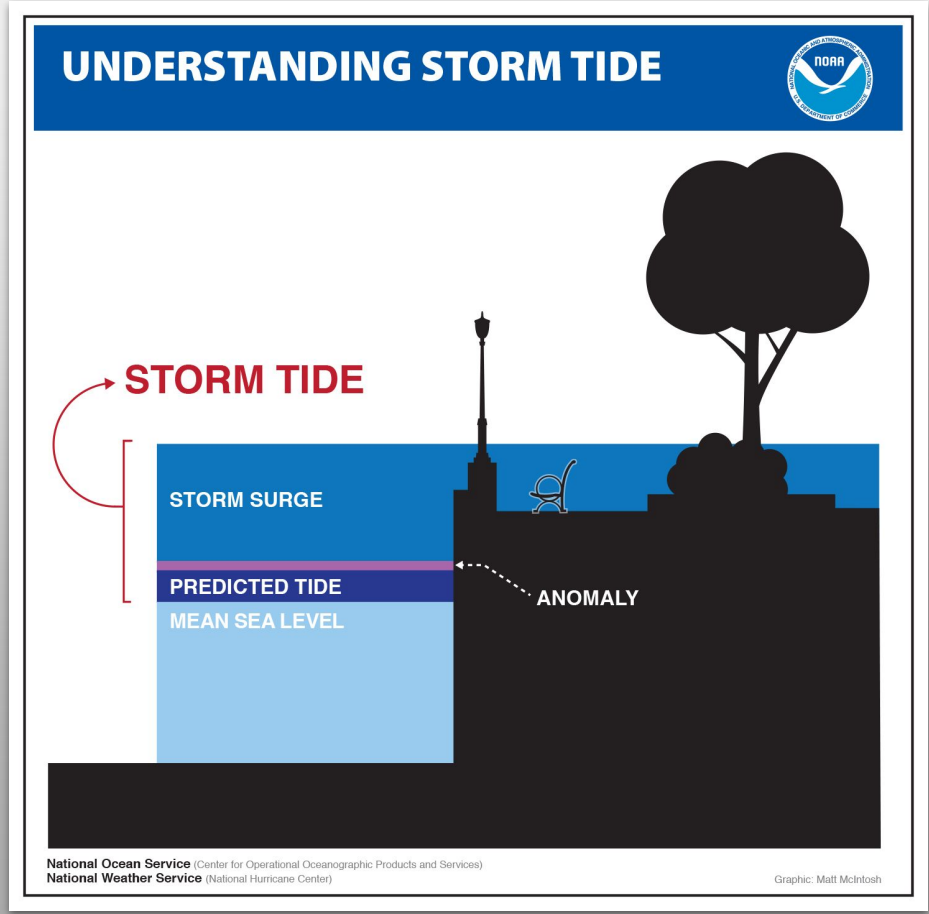
Definitions

Astronomical Tide
The alternating rise and fall in sea level with respect to the land, produced by the gravitational attraction of the moon and the sun. Expressed as height above a datum.

Storm Surge
Abnormal rise of waters generated by a storm, over and above the normal astronomical tide levels. Expressed in height above predicted tide levels.

Storm Tide
Water level due to a combination of storm surge and astronomical tide. Expressed as height above a datum. Does NOT account for wave run-up.

Inundation
Total water level above normally dry ground as a result of the storm tide, expressed in feet above ground level. MHHW is used as a proxy for ground level in NWS products.



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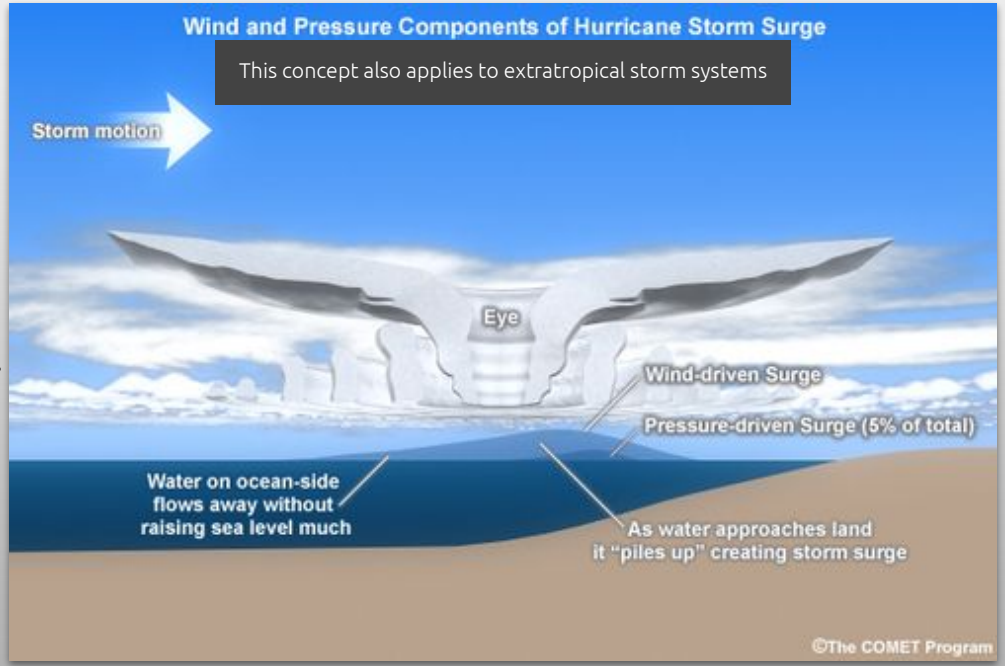
Storm Surge Contributors

Onshore Wind

In short, strong surface winds causes water to “pile up” along coastlines.

Atmospheric Pressure

Low pressure allows the water to bulge upward, resulting in higher water levels. This effect is estimated at a 10 mm (0.39 in) increase in sea level for every millibar (hPa) drop in atmospheric pressure, though this varies.



Orientation/Depth of Water Body

A narrow shelf, with deep water relatively close to the shoreline, tends to produce a lower surge but higher and more powerful waves. A wide shelf, with shallower water, tends to produce a higher storm surge with relatively smaller waves.

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Compound Flooding

Occurs when coastal flooding is combined with other inland flood factors to inundate coastal regions.

Examples of contributions to compound flooding:

- Storm Surge (pressure & wind effects)
- River Flooding
- Heavy Rain
- Snowmelt

Compound flooding is an active area of research. There are currently no models serving the Western U.S. Coast that capture all contributing factors.

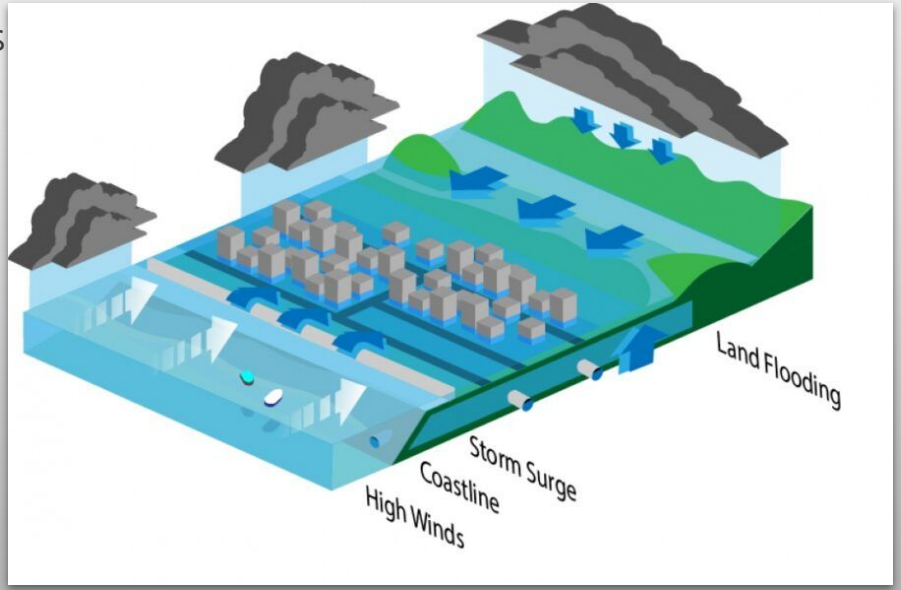

Image Courtesy: University of Texas at Austin

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December 27, 2022 Event

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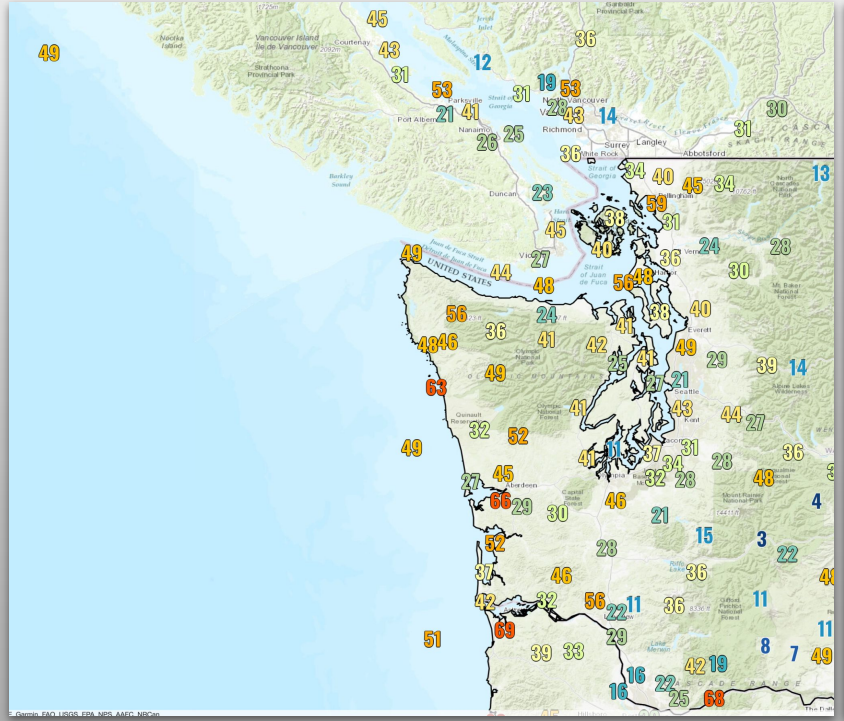
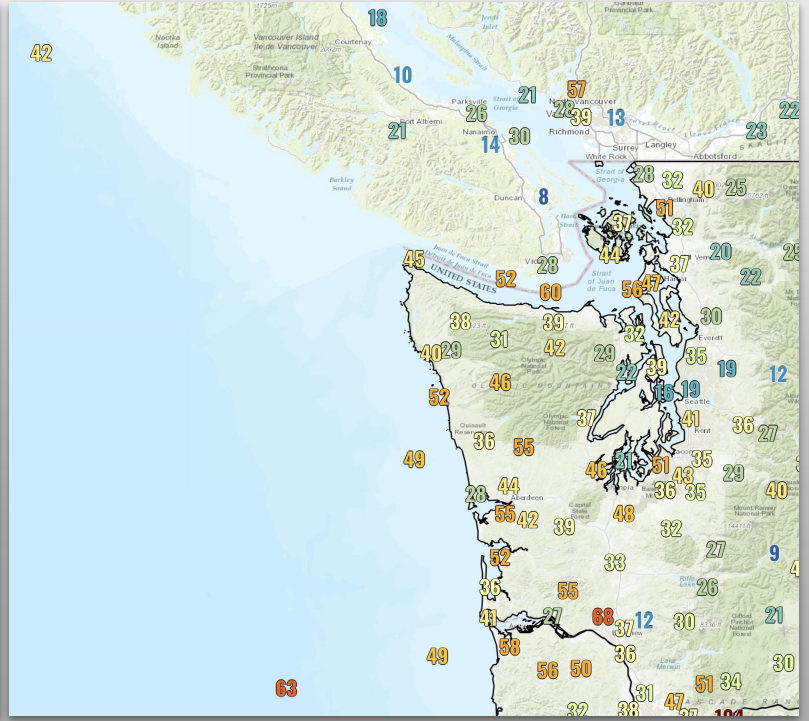
Strong Winds

December 26, 2022



December 27, 2022



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Atmospheric Pressure

December 27, 2022

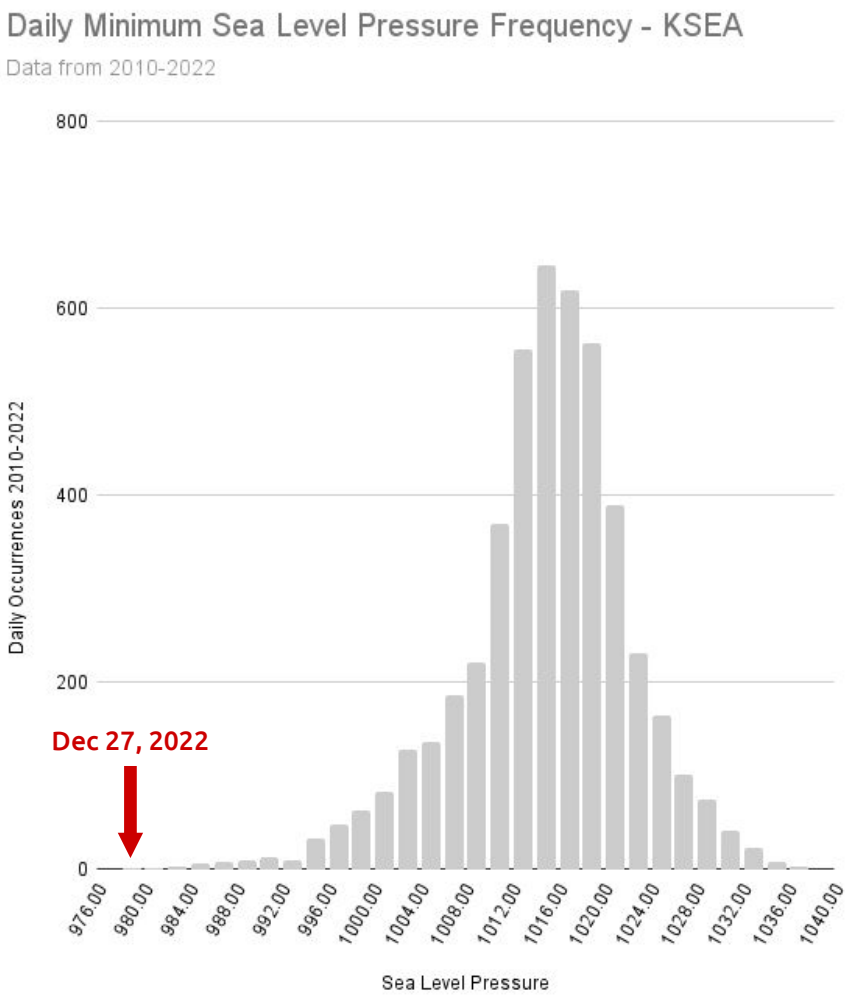
Sea-Tac observed minimum sea level pressure was **978.3 mb which is the 7th lowest on record** and reached a minimum at high tide.

- Global average sea level pressure is 1013.25mb

This pressure alone is estimated to have contributed ~**13.6" of surge**

- *(Avg SLP - Observed SLP) x (0.39" surge/1 mb SLP)*

Unofficial Sea-Tac Sea Level Pressure Records		
Ranking	**Date**	**Sea Level Pressure**
1	1995-12-12	970.2
2	1980-01-12	973.9
3	2008-01-04	975.2
4	1980-01-11	975.8
5	1950-10-27	978.0
-	1952-12-07	978.0
7	2022-12-27	978.3
8	1961-12-17	978.7
9	1950-10-26	979.0
10	1952-12-06	979.3
-	1958-02-25	979.3



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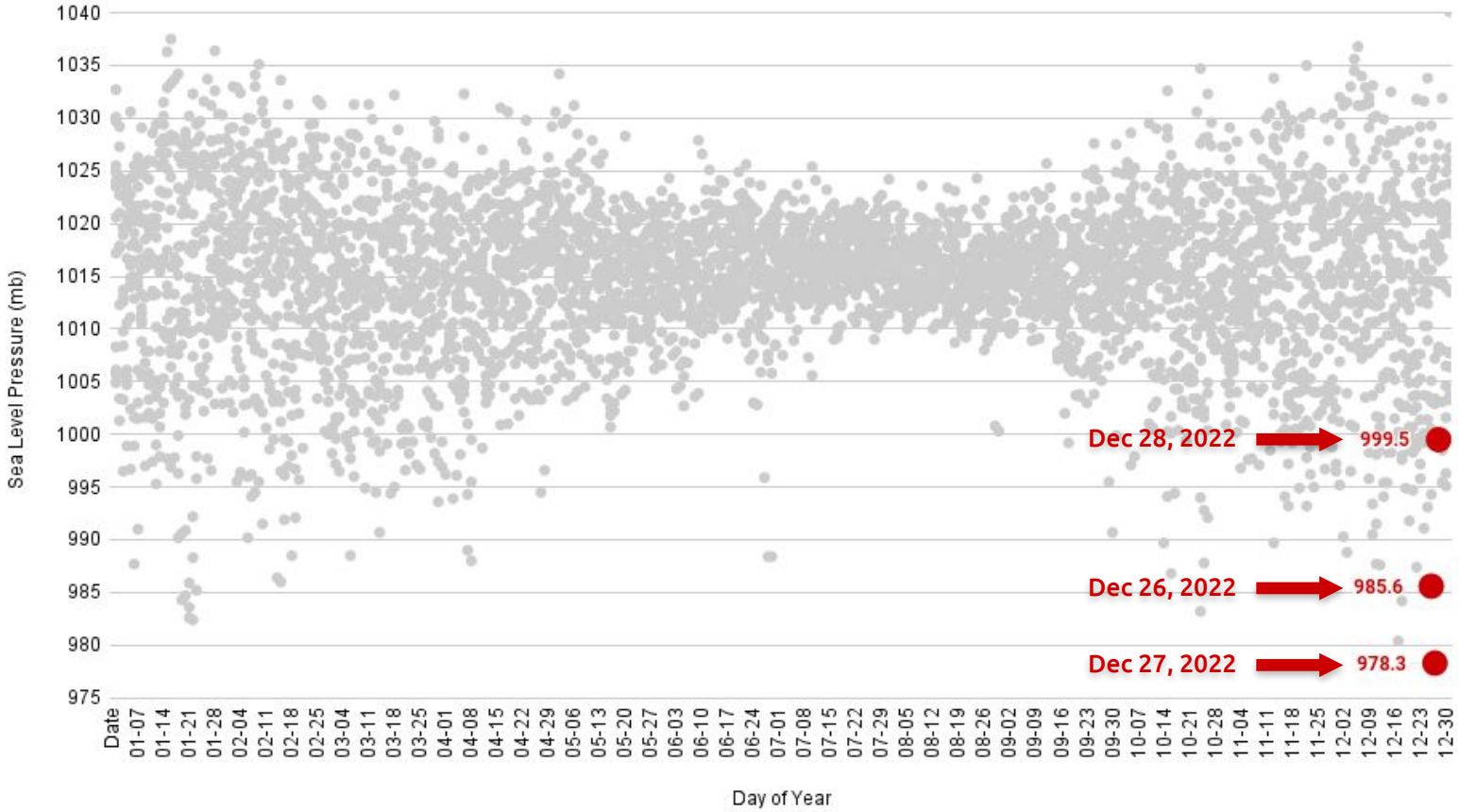
Daily Minimum Sea Level Pressure - KSEA

Data From 2010-2022



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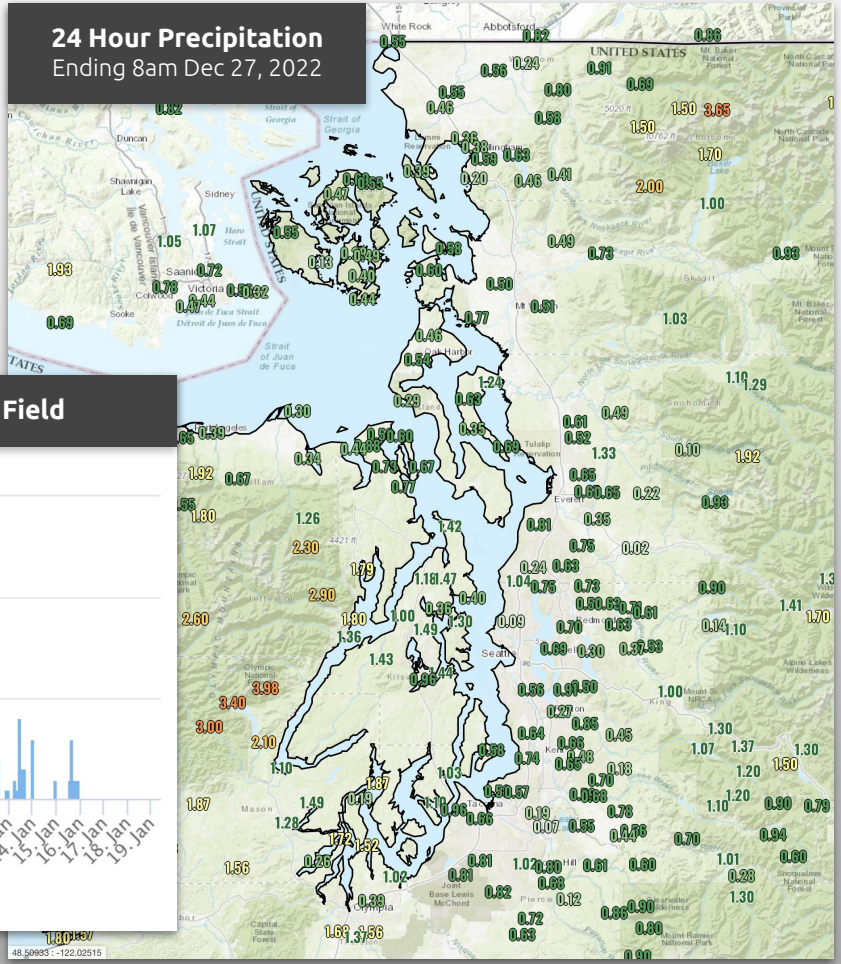
Heavy Rain?

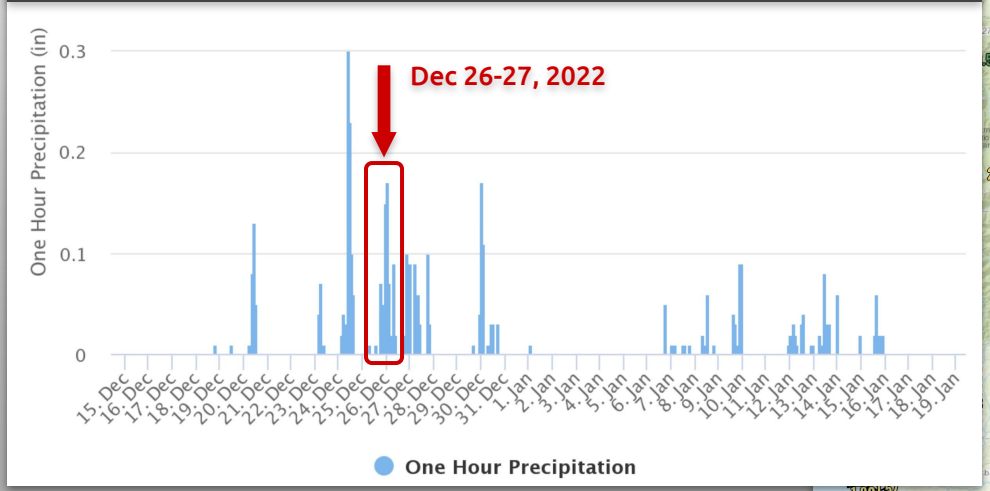
Rainfall Summary

Modest 24 hour rainfall totals and rainfall rates, not enough to cause flooding on their own.

24 Hour Precipitation
Ending 8am Dec 27, 2022



30-Day History of 1 Hour Precipitation Totals - Boeing Field



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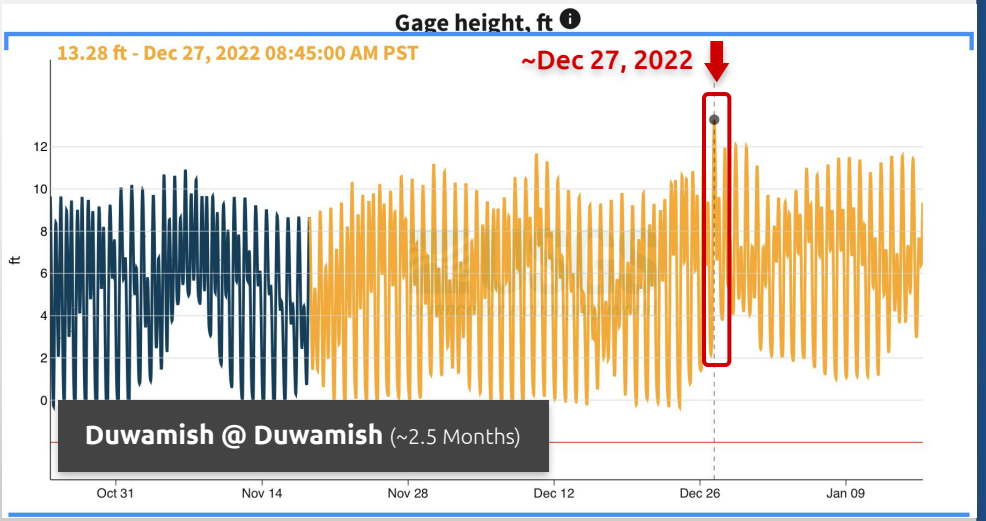
River Levels?

River Summary

Rivers were running high due to rainfall, but upstream gauges were below action and flood stages. Gauges near river outlets are often tidally influenced.



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Observed Water Levels

Outer Coast

Minimal impacts reported.

Inner Coast

Record water levels for most interior locations.

Primary contributors to coastal flooding were likely wind/waves and pressure (storm surge), with minor localized enhancements from precipitation and/or river levels.

Tide Gauge	Observed **MHHW** | MSL | MLLW	Top 10 Rank
Westport	2.74 | 7.01 | 11.88	-
La Push	3.06 | 7.01 | 11.58	-
Neah Bay	2.13 | 5.77 | 10.09	-
Port Angeles	2.68 | 5.49 | 9.74	-
Port Townsend	3.54 | 7.07 | 12.06	1st
Tacoma	3.90 | 8.84 | 15.68	1st
Seattle	3.76 | 8.48 | 15.12	1st
Cherry Point	3.39 | 7.25 | 12.54	2nd
Friday Harbor	3.60 | 6.80 | 11.35	1st
Bremerton *Forecasts Not Currently Available*	3.80 | 8.71 | 15.51	N/A

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Forecast Tools & Situational Awareness (SA)

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Storm Surge Models

ETSS Extratropical Storm Surge Model	**P-ETSS** Probabilistic Extratropical Storm Surge Model	**STOFS** Surge and Tide Operational Forecast System
Guidance	Guidance	Guidance
102 Hour Forecasts (4 days)	102 Hour Forecasts (4 Days)	180 Hour Forecasts (~7 Days)
Datum: Customizable	Datum: Customizable	Datum: MSL
GFS Wind/Pressure	GEFS / NAEFS Wind/Pressure	GFS Wind/Pressure
Initialized with Observed Tides	Initialized with Observed Tides	Initialized with Model Tides/Astronomical Tides
5-Day Bias Correction *Can assist when compound flooding is occurring*	5-Day Bias Correction *Can assist when compound flooding is occurring*	No Bias Correction *Bias correction algorithm is currently being evaluated.*
Lower Resolution	Lower Resolution	Higher Resolution
Surge Model: SLOSH	Surge Model: SLOSH	Surge Model: ADCIRC
		Notes: Active development. Atlantic Basin evaluating 3D components that take river hydrology and precipitation into consideration.

No models are currently available that forecast compound flooding over the U.S. West Coast.

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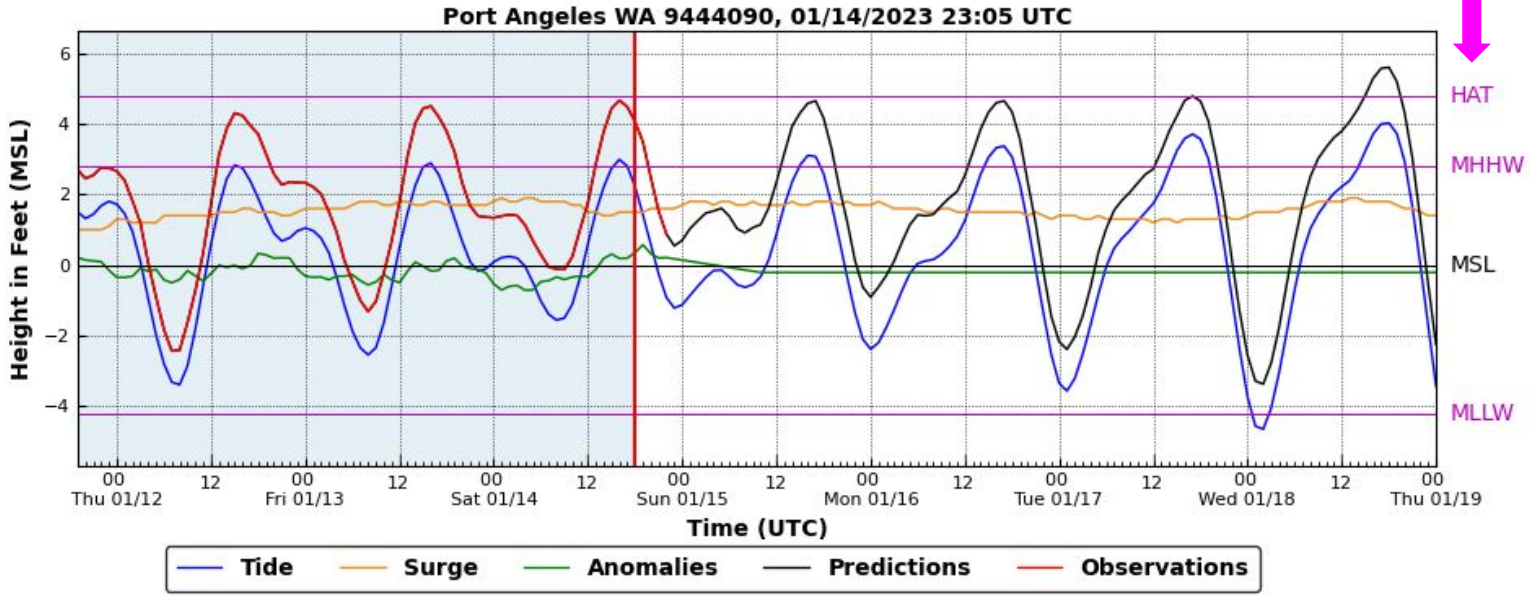
NOAA/NWS Coastal Flood Guidance

ETSS - Example

User selectable datums



Tide
(i.e. Astronomical Tide)
Basic tides available in tide charts years in advance.

Surge
(i.e. Storm Surge)
Additional water resulting from weather systems.

Anomalies
Difference between prediction & observations.
5-Day average used in predictions as bias correction.

Predictions
(i.e. Forecast)
Astronomical Tide + Storm Surge + Average Anomaly.

Observations
Observed tide level.

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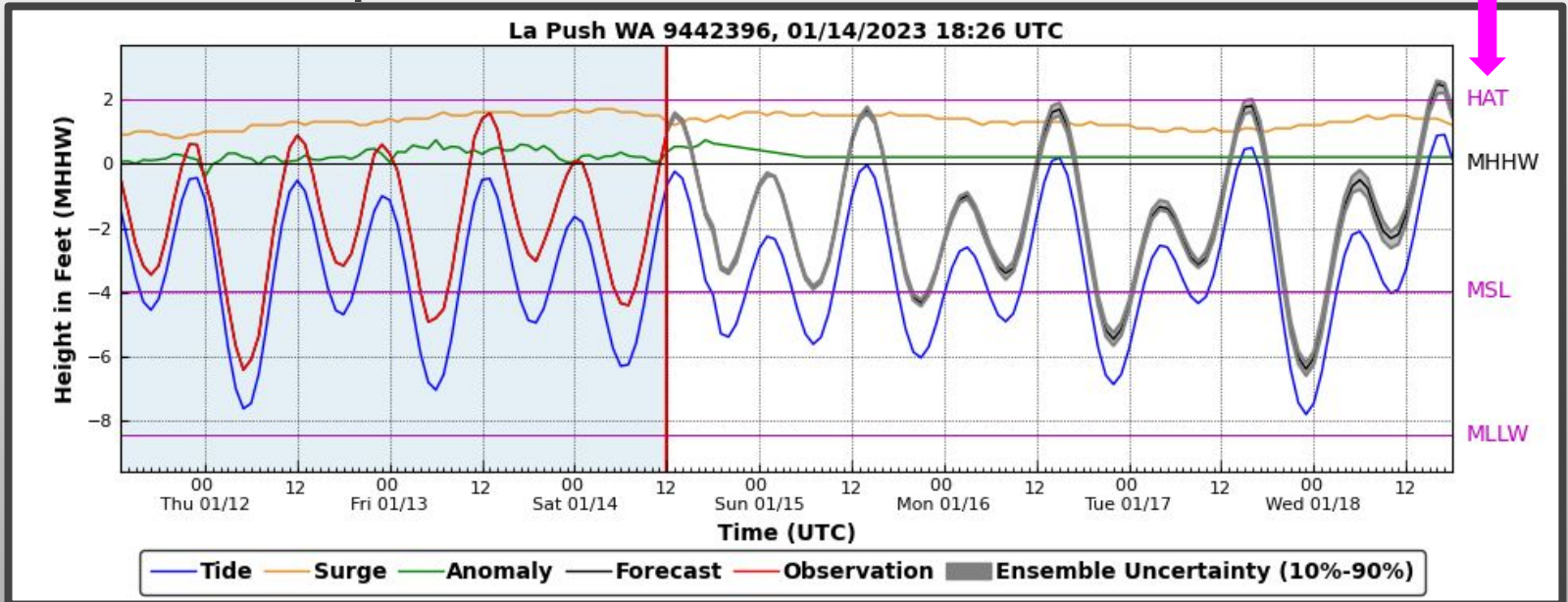
NOAA/NWS Coastal Flood Guidance

P-ETSS - Example

User selectable datums



Tide
(i.e. Astronomical Tide)
Basic tides available in tide charts years in advance.

Surge
(i.e. Storm Surge)
Additional water resulting from weather systems.

Anomalies
Difference between prediction & observations.
5-Day average used in predictions as bias correction.

Predictions
(i.e. Forecast)
Astronomical Tide + Storm Surge + Average Anomaly.

Observations
Observed tide level.

Ensemble Uncertainty
10th-90th percentile range based on wind & pressure uncertainty.

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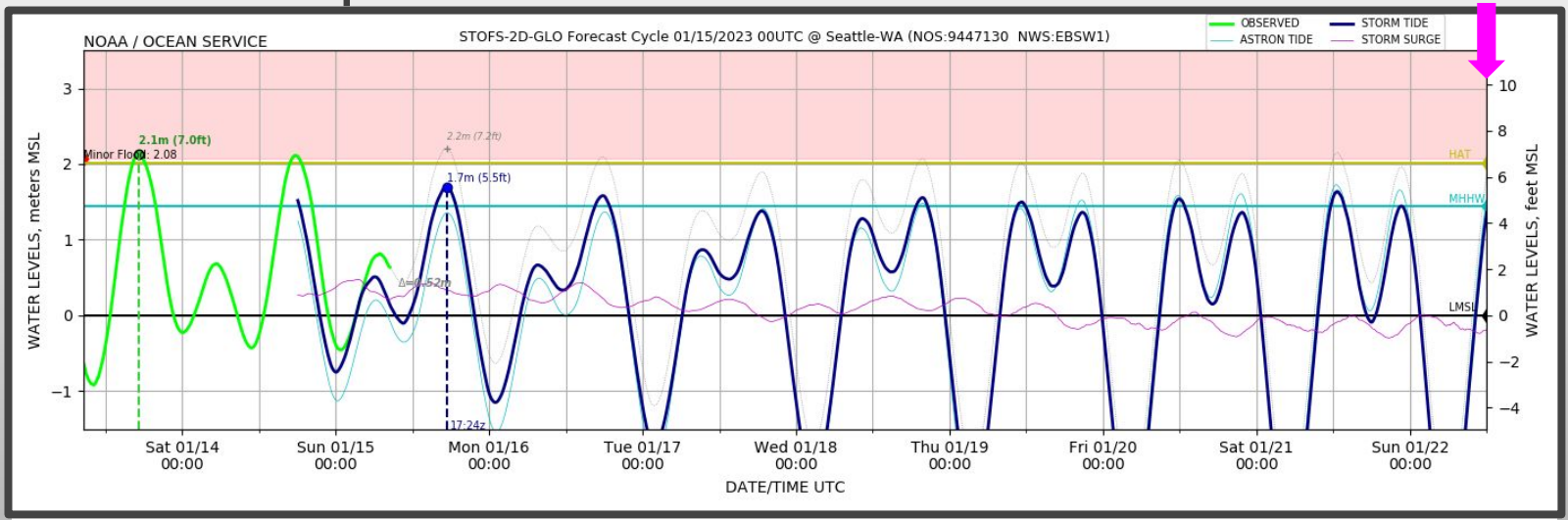
NOAA/NWS Coastal Flood Guidance

STOFS - Example

Reference to MSL datum only. Feet on right, meters on left.



Tide
(i.e. Astronomical Tide)
Basic tides available in tide charts years in advance.

Surge
(i.e. Storm Surge)
Additional water resulting from weather systems.

Anomaly
Difference between current prediction & observation.
Extrapolated through 7-day forecast.

Predictions
(i.e. Forecast)
Astronomical Tide + Storm Surge.

Observations
Observed tide level.

Flood Levels
When available, flood levels are displayed.

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Surge Model Resources

ETSS/P-ETSS

- ETSS Hydrographs
- ETSS Maps
- P-ETSS (GEFS) Hydrographs
- P-ETSS (NAEFS) Hydrographs

STOFS

- STOFS Hydrographs
- STOFS Maps

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Watch/Warning/Advisory (WWA) Products

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WWA Products

TYPE	DEFINITION	THREAT	ACTION
WARNING	Hazard is occurring, imminent, or very likely	Threat to life & property	Take protective action
WATCH	Conditions are favorable for hazard to occur	Threat to life & property	Have a plan of action
ADVISORY	Hazard is occurring, imminent, or very likely	Threat of significant inconvenience	Use caution

Normal Fire Department / Facebook

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WWA Products

Watch, Warning, & Advisory products are each associated with a minimum confidence threshold.

Note: Tsunami WWA products do not use confidence thresholds.

Watch Threshold

Conditions are expected to be favorable for hazard to occur.
Hazard occurrence confidence is >= 50%

Warning Threshold

or

Advisory Threshold

Hazard is imminent or occurring.
Hazard occurrence confidence is >= 80%

Idealized Example

Note: times, confidence path varies for each event. (e.g confidence grows much earlier for heat events than for snow events)

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WWA Criteria

Coastal Flood Advisory

Impacts Criteria

Minor flooding (e.g. minor tidal overflow) along the coast that can cause impacts to roadways, buildings, etc.

Numerical Criteria

Minor flood level. Criteria varies by location. Other factors such as winds and wave run-up will also be considered.

Important Note: NWS Coastal Flood products reference water levels above "ground level". MHHW is used as a proxy for "ground level".

Tide Gauge	Minor MHHW | MSL | MLLW	Moderate MHHW | MSL | MLLW	Major MHHW | MSL | MLLW
Westport	2.25 | 6.52 | 11.39	3.25 | 7.52 | 12.39 *Preliminary*	
La Push	2.59 | 6.53 | 11.11 *HAT/Preliminary*		
Neah Bay	2.62 | 6.26 | 10.58 *HAT/Preliminary*		
Port Angeles	2.10 | 4.92 | 9.16 *HAT/Preliminary*		
Port Townsend	3.00 | 6.52 | 11.52		
Tacoma	1.87 | 6.81 | 13.65 *HAT/Preliminary*		
Seattle	2.10 | 6.82 | 13.46	3.14 | 7.86 | 14.50 *Preliminary*	
Cherry Point	1.85 | 5.72 | 11.00	2.85 | 6.72 | 12.00	3.85 | 7.72 | 13.00
Friday Harbor	1.75 | 4.96 | 9.51	2.25 | 5.46 | 10.01	2.75 | 5.96 | 10.51
Bremerton *Forecasts Not Currently Available*	2.36 | 7.27 | 14.06 *HAT/Preliminary*		

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WWA Criteria

Coastal Flood Warning & Watch

Impacts Criteria

Moderate to severe coastal flooding that poses a serious threat to life and property, including beach erosion, damage to homes/businesses/roads, etc.

Numerical Criteria

Moderate or major flood level. Criteria varies by location. Other factors such as winds and wave run-up will also be considered.

Important Note: NWS Coastal Flood products reference water levels above "ground level". MHHW is used as a proxy for "ground level".

Tide Gauge	Minor MHHW | MSL | MLLW	Moderate MHHW | MSL | MLLW	Major MHHW | MSL | MLLW
Westport	2.25 | 6.52 | 11.39	3.25 | 7.52 | 12.39 *Preliminary*	
La Push	2.59 | 6.53 | 11.11 *HAT/Preliminary*		
Neah Bay	2.62 | 6.26 | 10.58 *HAT/Preliminary*		
Port Angeles	2.10 | 4.92 | 9.16 *HAT/Preliminary*		
Port Townsend	3.00 | 6.52 | 11.52		
Tacoma	1.87 | 6.81 | 13.65 *HAT/Preliminary*		
Seattle	2.10 | 6.82 | 13.46	3.14 | 7.86 | 14.50 *Preliminary*	
Cherry Point	1.85 | 5.72 | 11.00	2.85 | 6.72 | 12.00	3.85 | 7.72 | 13.00
Friday Harbor	1.75 | 4.96 | 9.51	2.25 | 5.46 | 10.01	2.75 | 5.96 | 10.51
Bremerton *Forecasts Not Currently Available*	2.36 | 7.27 | 14.06 *HAT/Preliminary*		

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Thank You

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