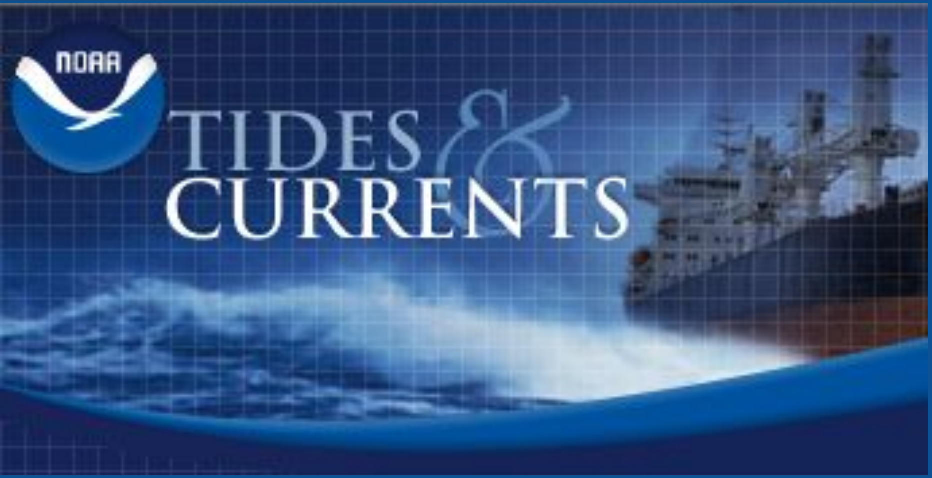
Introduction to Tidal & Geodetic Vertical Datums



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Center for Operational Oceanographic Products and Services

Thursday 13 April 2023

Tidal Theory

Tides

Common Terms

Tide : The alternating rise and fall of water levels with respect to land

Tidal Current : Horizontal motion resulting from rise & fall of water levels

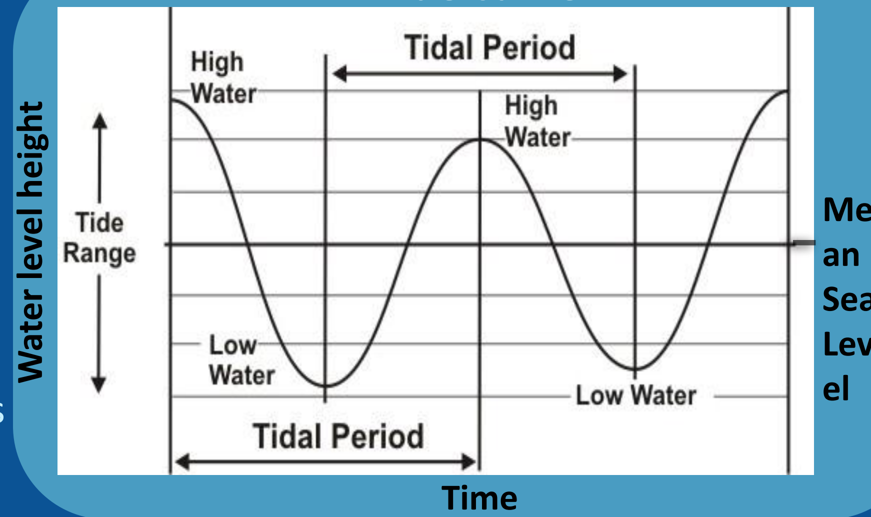
Tide Range : difference in height between highest high & lowest low

Tidal Period : Time between successive lows or highs (Average ~12.4hs)

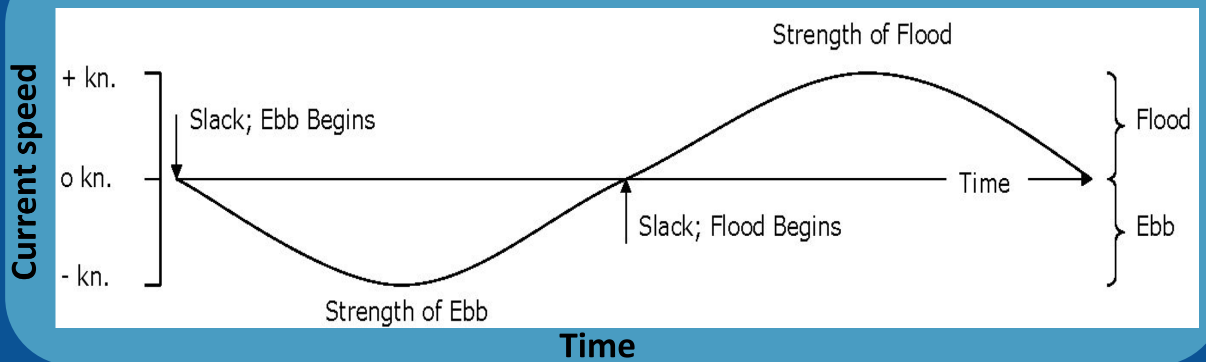
Tidal Frequency : How often 1 tidal period occurs per day (Average ~1.9 cycles per day)

Mean Sea Level : Average height of sea surface

Tide curve



Tidal Current

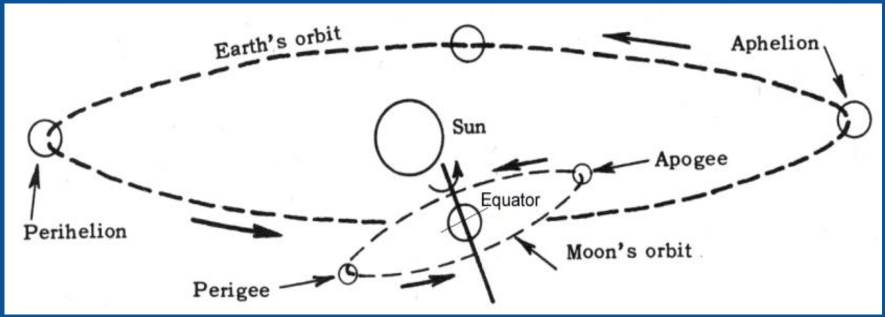


Tide Generating Forces

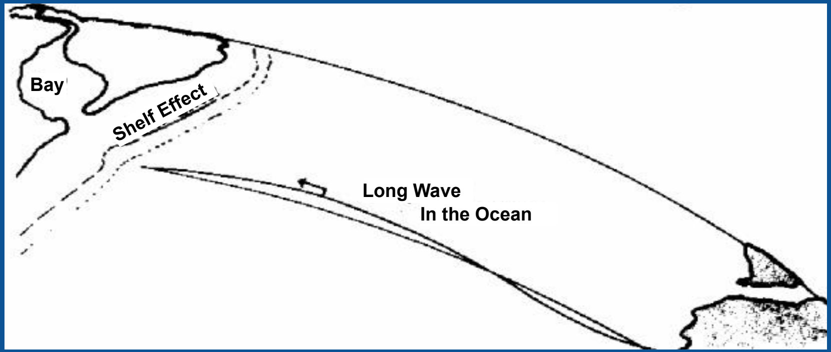
Astronomy & Hydrodynamics

Both the moon & the sun affect the tides (sun's effect is 0.46 times that of the Moon)

Astronomy - Tides are result of the ***gravitational forces*** of the Earth, Moon & Sun & the ***centrifugal forces*** of their rotations

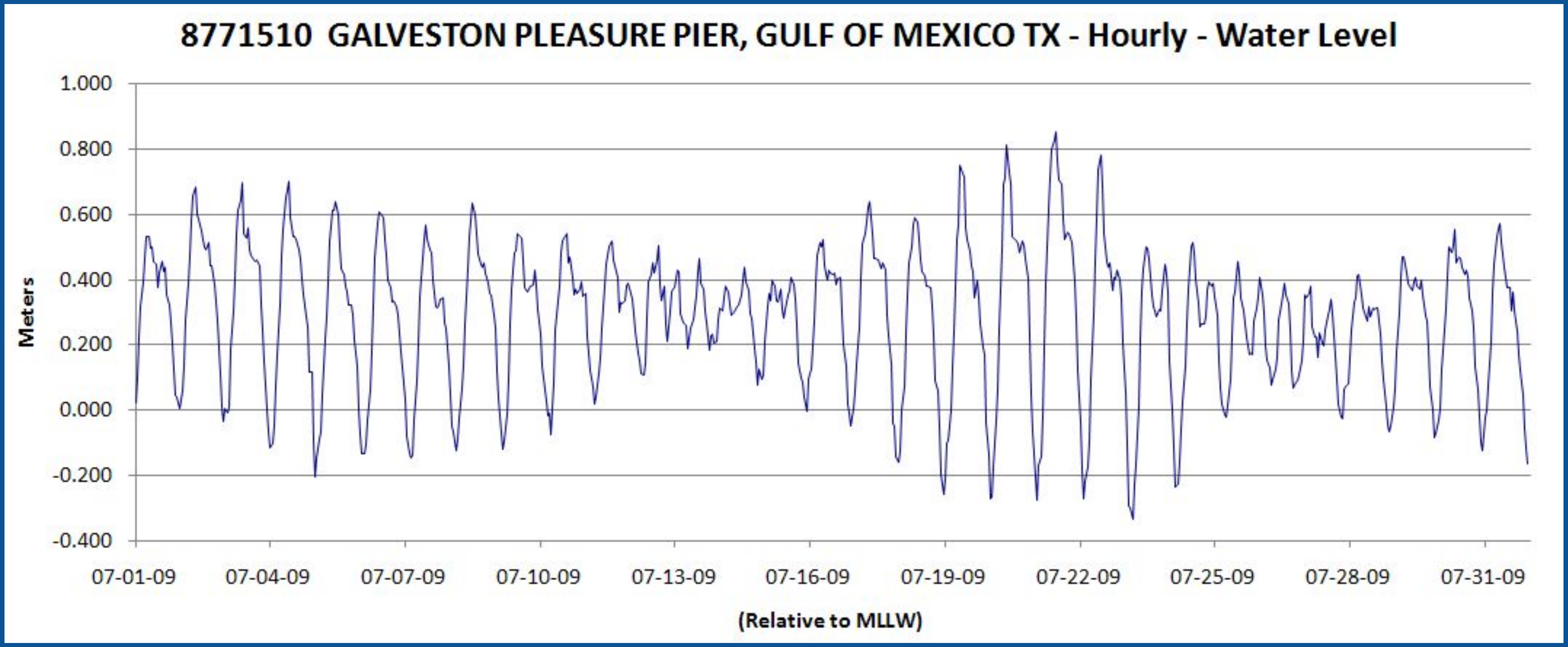


Hydrodynamics - The range & timing of the tide & the speed, direction & timing of the tidal current are also influenced by the configuration of the coastline, bottom topography & local water depth

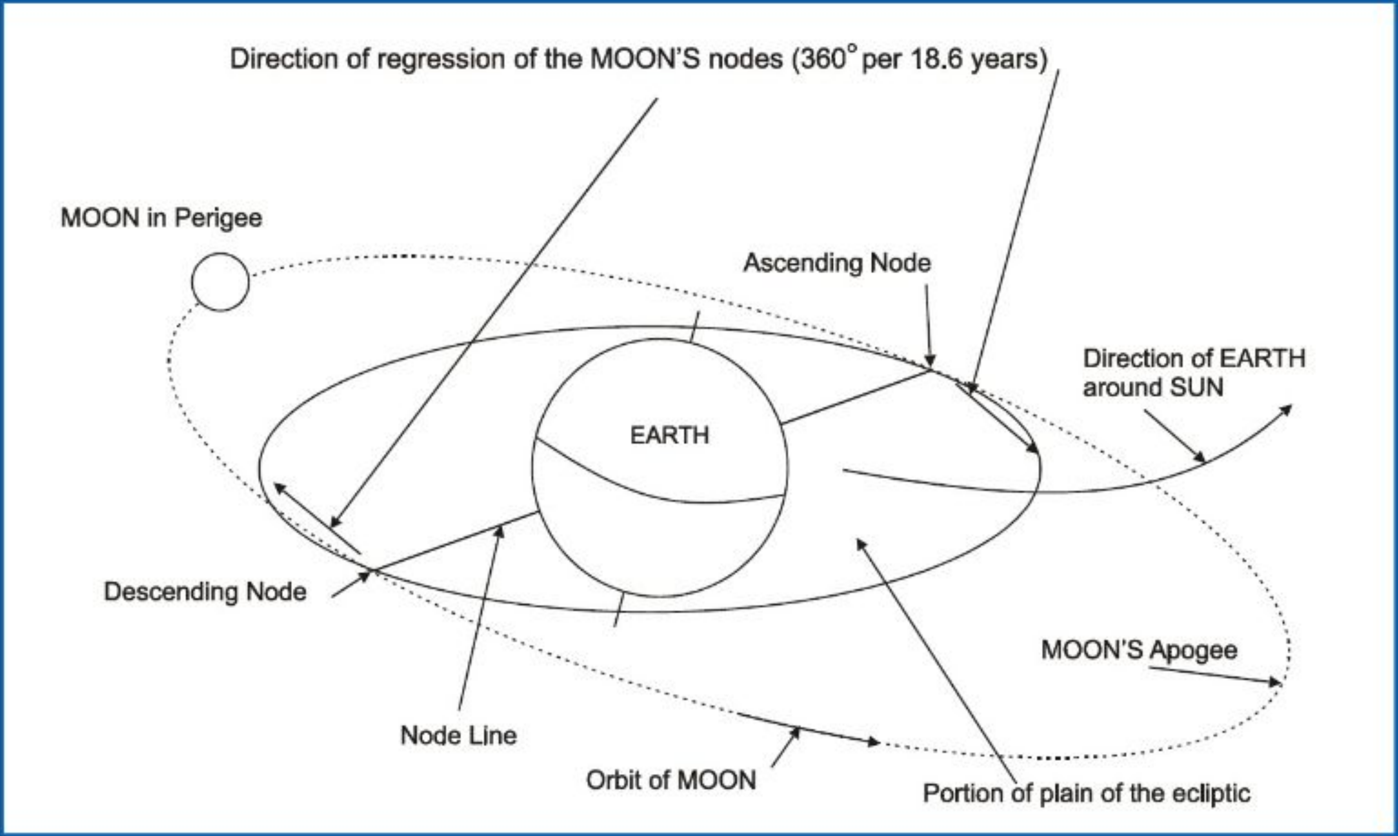


Phase Inequality

Affects the amplitude of the tides (tidal range)



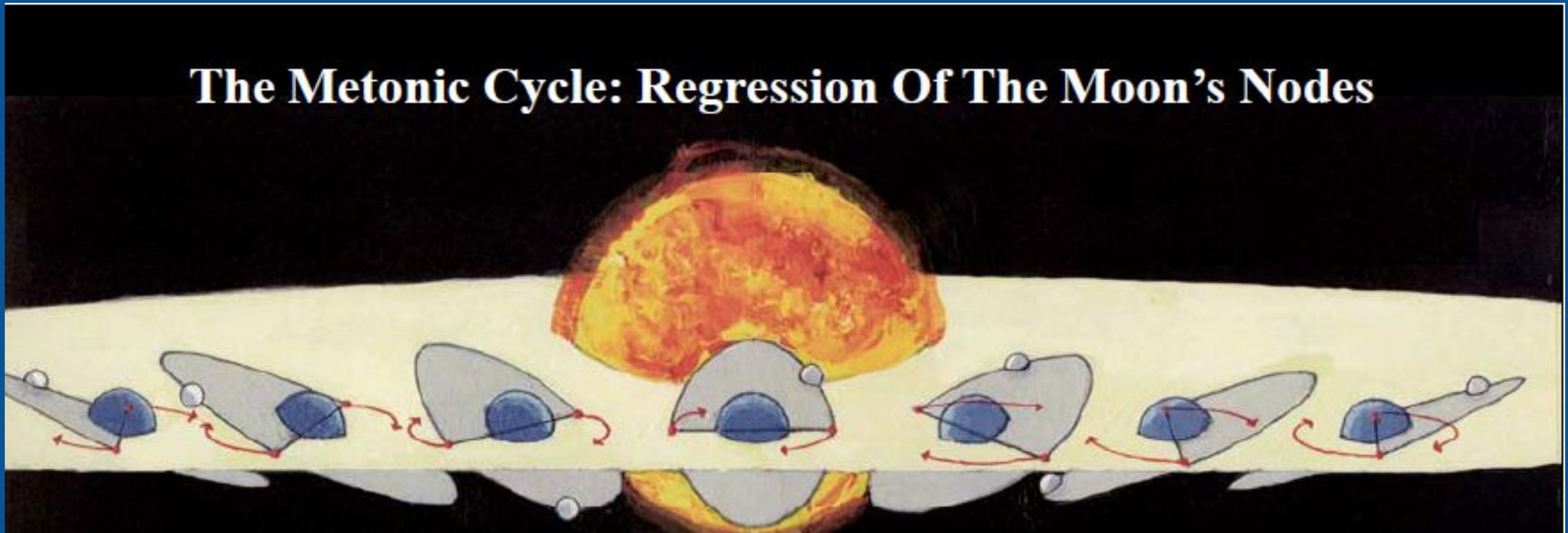
The 18.61 – year Lunar Nodal Cycle – Regression of the moon's nodes



Axis of earth's rotation is inclined 23.452 degrees to the plane of ecliptic;
Plane of the orbit of the moon is inclined 5.145 degrees to the plane of the ecliptic;
Maximum monthly declination of the Moon varies between 28.597 and 18.307 degrees every 18.61 - years

http://tidesandcurrents.noaa.gov/publications/Understanding_Tides_by_Steacy_finalFINAL11_30.pdf

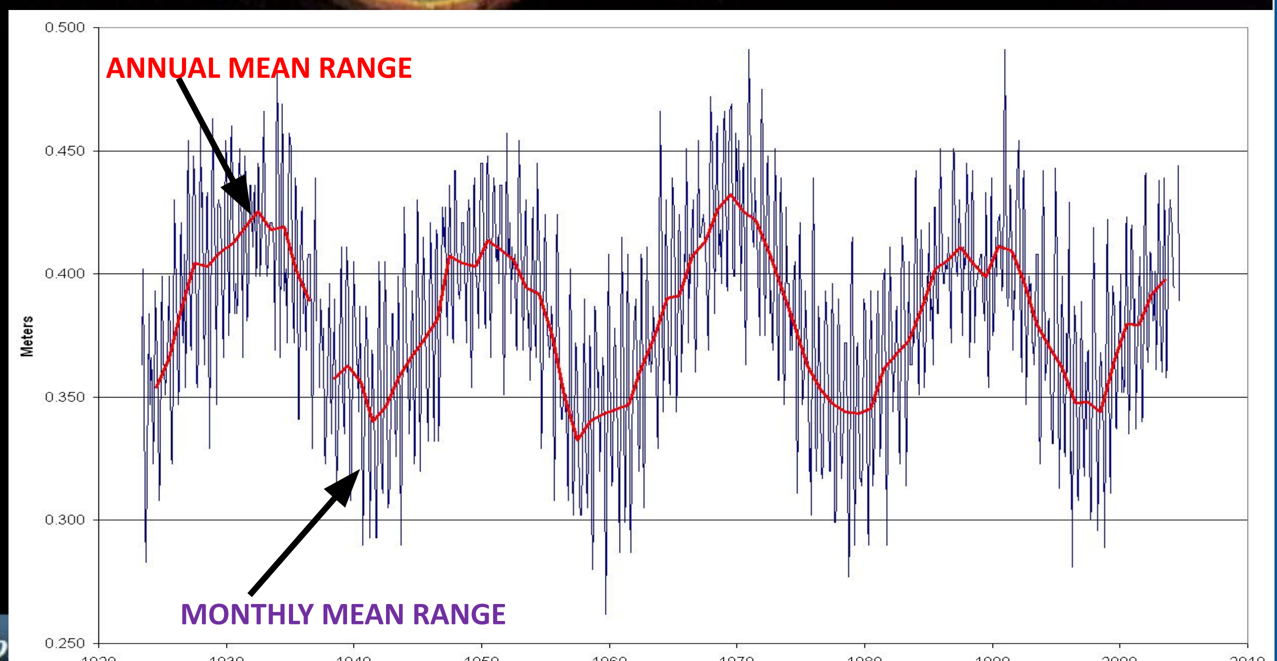
Regression of the Moon's Nodes



The time between peaks is the period of oscillation of the regression (~18.6yrs)

- Basis for defining the National Tidal Datum Epoch (NTDE) as a 19yr period

NOAA's CENTER fo

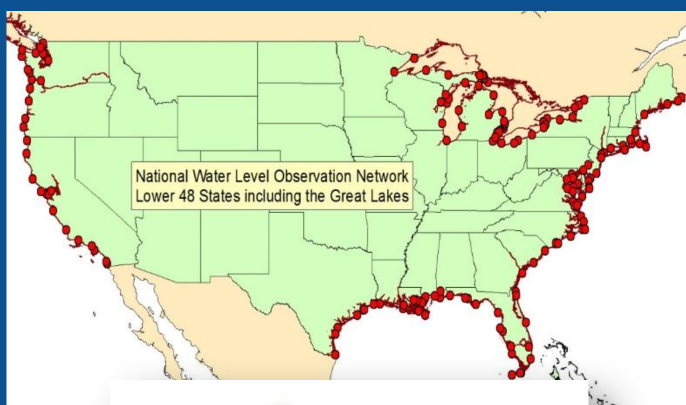


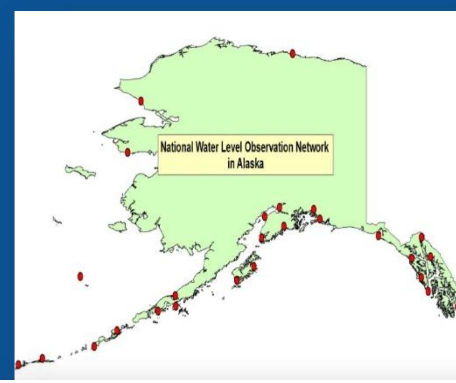
Water Level Gauges

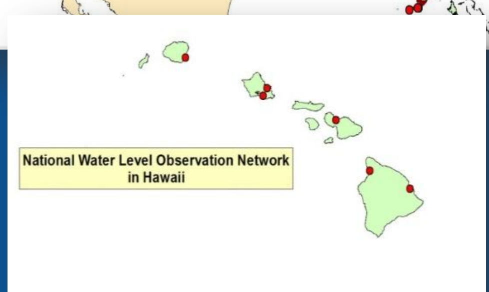
Water Level Station Network

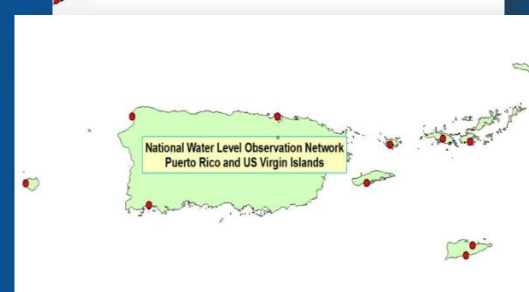
National Water Level Observation Network (NWLON)

- Network of long-term and short-term water level stations
  - 306 coastal stations recording 6-minute data
    - 201 NWLON stations, Includes 53 stations in the Great lakes
    - Includes 61 Short-term stations supporting projects such as storm surge monitoring research, hydro / photo support, and habitat restoration









NWLON Stations

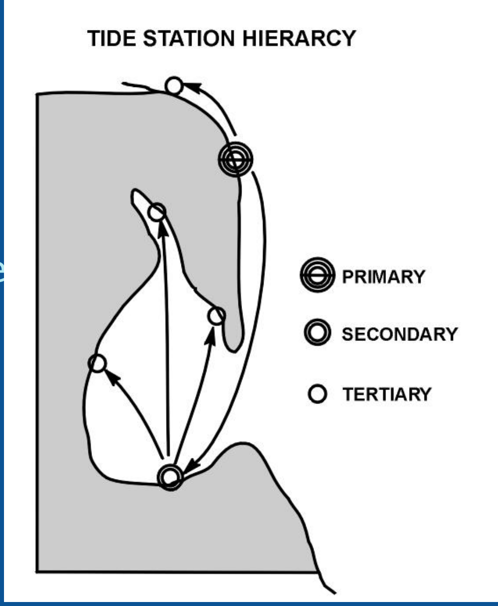
Control stations are operated by NOS and disseminated over the internet

Subordinate stations are usually installed by field teams prior to survey operations and removed after surveys are completed

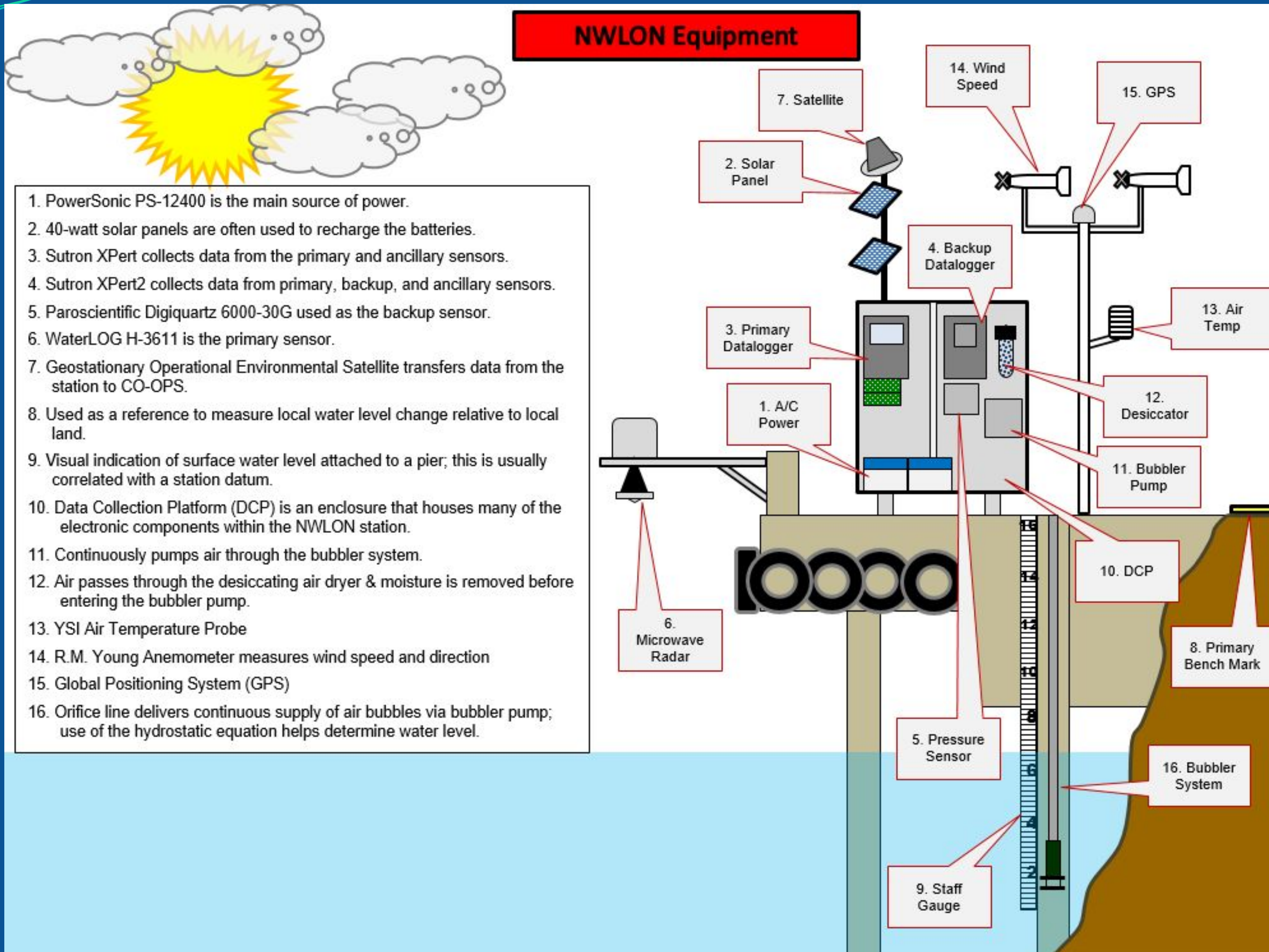
***Primary* Control Tide Station**: Continuous observations over 19 yrs or more & expected to continue
- Data used for determining tidal datums

***Secondary* Control Tide Station**: Subordinate station with continuous observations over at least 1 yr, but less than 19 yrs, and has a planned finite lifetime
- Data must be compared to a suitable control station for determining tidal datums

***Tertiary* Control Tide Station**: Subordinate station with continuous observations over at least 30 days, but less than 1 yr, and has a planned finite lifetime
- Data must be compared to a suitable control station for determining tidal datums

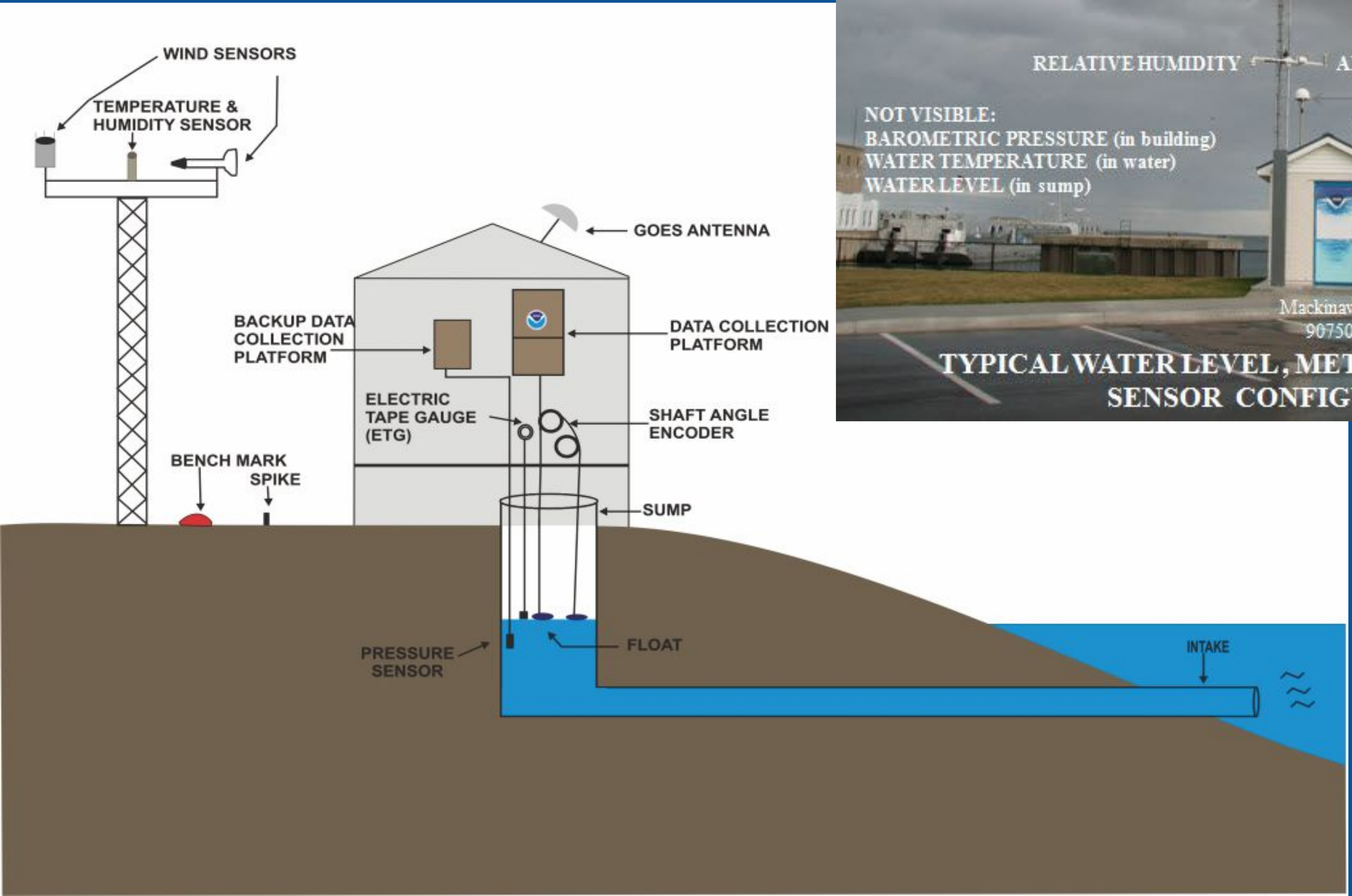


NWLON Tidal Water Level Station



1. PowerSonic PS-12400 is the main source of power.
2. 40-watt solar panels are often used to recharge the batteries.
3. Sutron XPert collects data from the primary and ancillary sensors.
4. Sutron XPert2 collects data from primary, backup, and ancillary sensors.
5. Paroscientific Digiquartz 6000-30G used as the backup sensor.
6. WaterLOG H-3611 is the primary sensor.
7. Geostationary Operational Environmental Satellite transfers data from the station to CO-OPS.
8. Used as a reference to measure local water level change relative to local land.
9. Visual indication of surface water level attached to a pier; this is usually correlated with a station datum.
10. Data Collection Platform (DCP) is an enclosure that houses many of the electronic components within the NWLON station.
11. Continuously pumps air through the bubbler system.
12. Air passes through the desiccating air dryer & moisture is removed before entering the bubbler pump.
13. YSI Air Temperature Probe
14. R.M. Young Anemometer measures wind speed and direction
15. Global Positioning System (GPS)
16. Orifice line delivers continuous supply of air bubbles via bubbler pump; use of the hydrostatic equation helps determine water level.

NWLON Great Lakes Water Level Station



Tertiary (Short-term) Water Level Stations

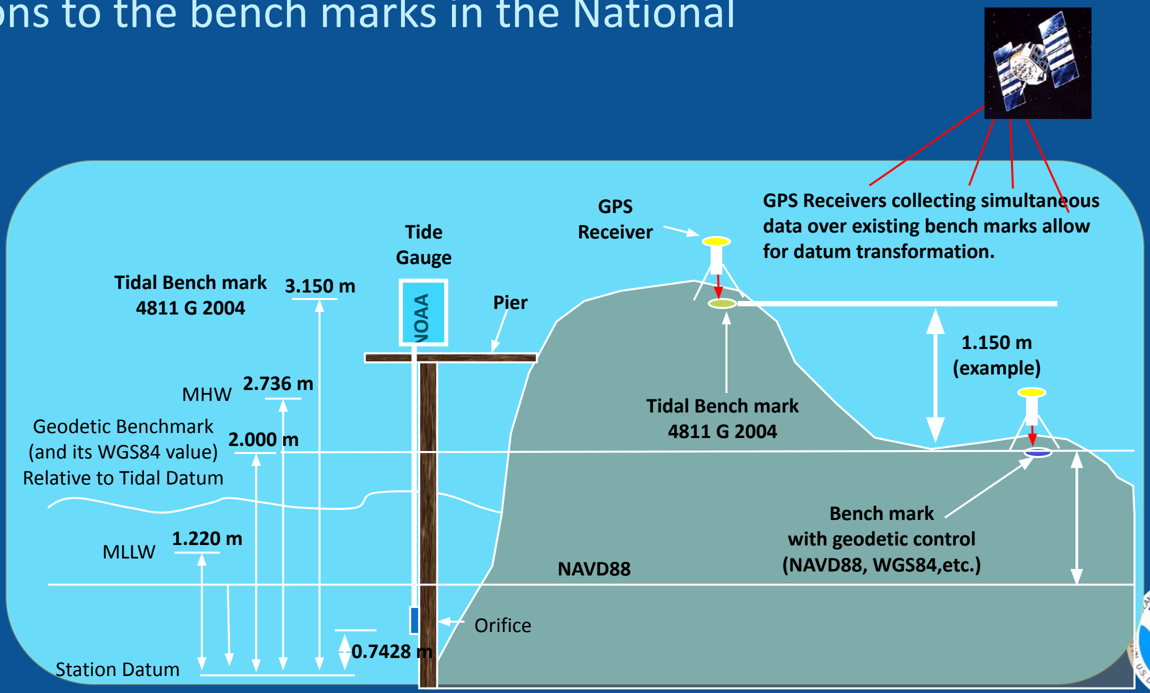
- Data Collection Platform
- Acoustic or pressure sensor
- Solar Panel
- GOES Satellite Transmitter

NWLON Stations

Vertical Datum Reference

Vertical Datum Reference characteristics are:

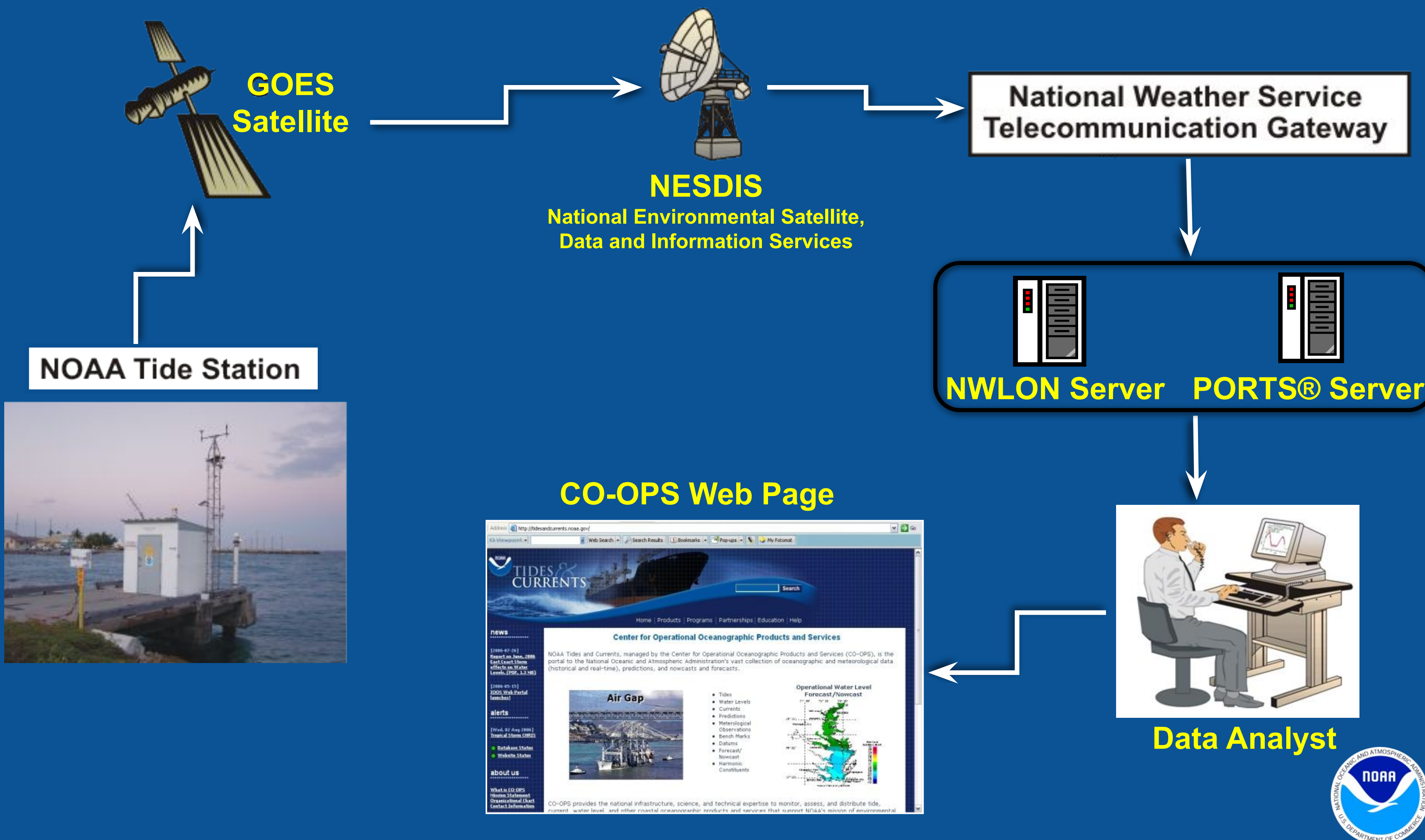
- Water levels accurately known relative to the latest tidal datums on the latest National Tidal Datum Epoch (NTDE)
- Water levels accurately known relative to the land and a local network of recoverable tidal bench marks
- Precise connections to the national geodetic datum (NAVD88) using level connections or GPS connections to the bench marks in the National Spatial Reference System (NSRS)
- NGS Accuracy Standards
  - 2nd Order, Class I for long-term stations
  - 3rd Order for short-term stations
- Annual leveling for NWLON installation and removal levels for short-term stations
- Emergency leveling for storm events



Data

Data Collection

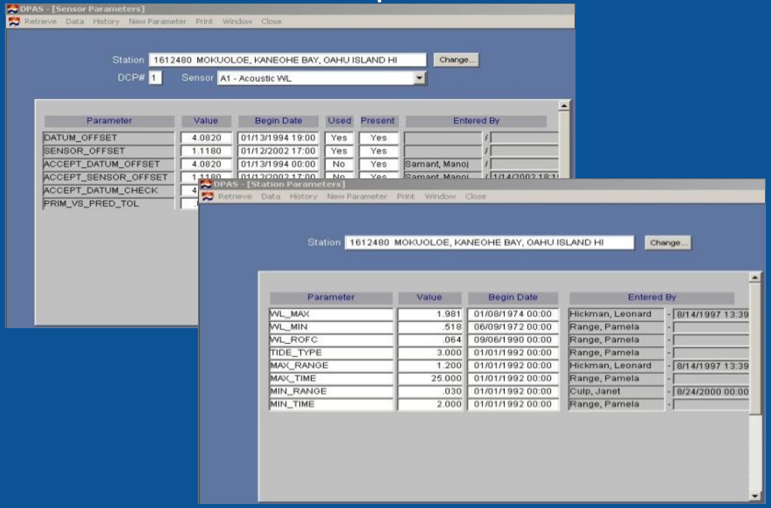
Sent from stations via satellite



Data Processing

Data Processing Procedures

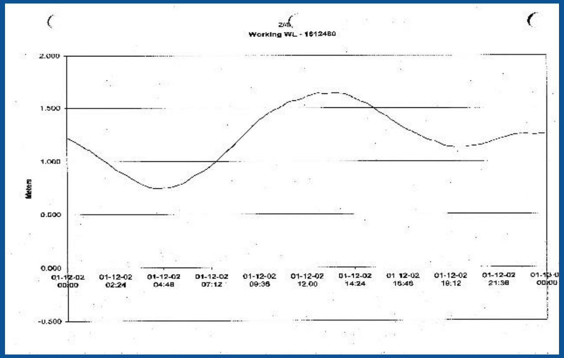
Check station parameters

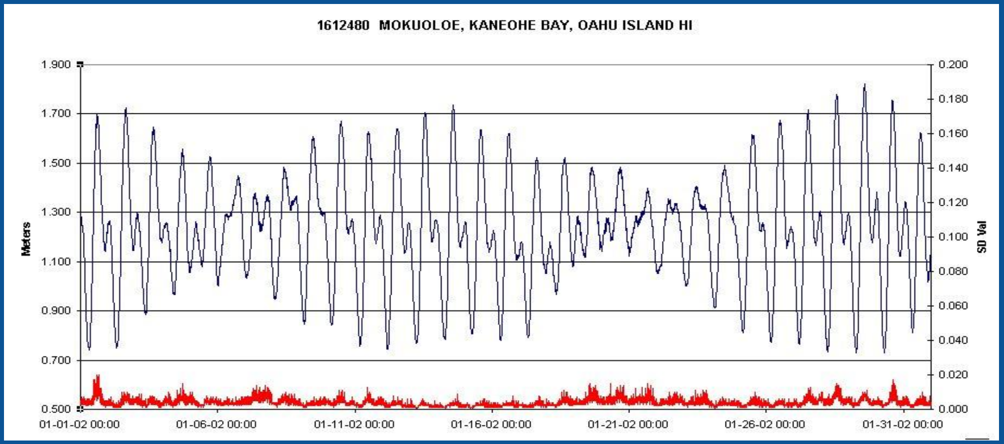


1. Preliminary Analysis

- Check station parameters
- Examine data inventories
- Initialize Working Water Level data
  - Move data from sensor areas into working WL Table
- Review 6-minute Data plots
  - Data Gaps
  - Large standard deviations indicate a problem

Review data plots





Data Processing

Data Processing Procedures

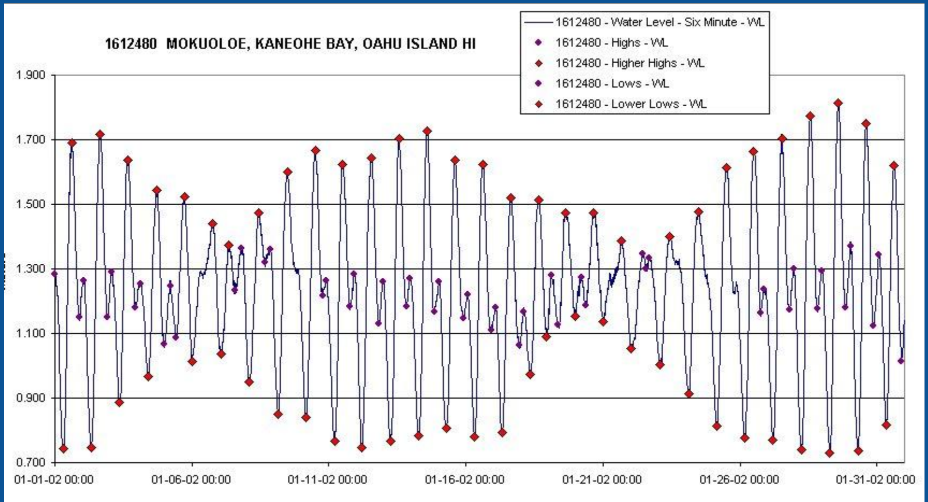
2. Tabulation

- Tabulate High and Low waters
  - Select DIUR or EXHL
  - Tide Check Report – summary & error messages
- Use QC Spreadsheet to edit Hourly Heights and Hi/Lo waters
- Plot WL w/ HI/LO picks and corrections
- Run Hi/Lo check option

Tide Check Report

```
Tide Check      | Apr 11, 2002 15:44

Station:   1612480
DCP:       X
Begin:     20020101 00:00
End:       20020131 23:54
Data Set:  Accepted
Product:   High/Low Checks

Station parameters
   Tide Type:   Mixed Diurnal
   Max Time :          25.00000 hours
   Min Time :           2.00000 hours
   Max Range:           1.20000 meters
   Min Range:           0.03000 meters

Check   High/Low data       (20020101 00:00 - 20020131 23:54)
   Questionable HH or LL:    HH                 20020105 17:12
   Questionable HH or LL:    LL                 20020123 02:06

   Check complete

Tides Summary:
                    Jan
                   2002
   Higher-High       30
   Lower -High       24
   Higher-Low        24
   Lower -Low        30
   Total            108
   Balance          Yes

Tide Check complete
```

Hi-Low Picks



Hi-Low Water

Apr 12 2002 14:26 HIGH/LOW WATER LEVEL DATA January, 2002
National Ocean Service (NOAA)

Station: 1612480 T.M.: 0 W
Name: MOKUOLOE, KANEOHE BAY, OAHU ISLAND, HI Units: Meters
Type: Mixed Diurnal Datum: STND
Note: > Higher-High/Lower-Low [] Inferred Tide Quality: Verified

Day	High Time	High Height	Low Time	Low Height
1	0.0	1.284	> 7.5	0.742
	> 14.8	1.689	21.5	1.149
2	1.3	1.264	> 7.9	0.747
	> 15.7	1.718	22.3	1.149
3	1.7	1.289	> 8.7	0.886
	> 15.8	1.638	22.8	1.181
4	2.9	1.254	> 9.8	0.967
	> 17.3	1.542	23.9	1.067
5	5.0	1.248	10.3	1.086
	> 17.2	1.524		
6			> 0.3	1.015
	> 18.0	1.441		
7	> 8.5	1.373	> 1.2	1.038
	19.8	1.364	13.5	1.234
8	> 10.6	1.474	> 2.3	0.949
	20.5	1.361	15.8	1.320
9	> 11.6	1.601	> 3.7	0.850
10	> 12.0	1.668	> 4.0	0.841
	21.5	1.264	18.4	1.218
11	> 12.0	1.624	> 4.8	0.765
	22.4	1.282	18.6	1.183
12	> 13.2	1.642	> 4.8	0.746
	23.3	1.260	19.9	[1.129]
13	> 13.4	1.702	> 6.0	0.767
	23.2	1.270	19.7	1.185
14			> 6.6	0.784
	> 14.0	1.728	20.1	1.166
15	0.6	1.259	> 6.8	0.806
	> 14.3	1.636	21.5	1.148

Day	High Time	High Height	Low Time	Low Height
16	1.3	1.220	> 7.7	0.780
	> 14.6	1.623	21.9	1.110
17	1.9	1.180	> 7.5	0.792
	> 15.2	1.519	22.9	1.062
18	2.8	1.167	> 8.4	0.974
	> 15.6	1.512	> 22.6	1.091
19	3.0	1.281	9.0	1.126
	> 15.5	1.475	> 23.7	1.155
20	5.2	1.273	8.7	1.188
	> 16.0	1.475		
21			> 0.3	1.136
	> 16.4	1.386		
22	10.9	1.347	> 0.8	1.054
	16.8	1.335	14.0	1.301
23	> 10.7	1.401	> 2.1	1.002
24	> 11.5	1.476	> 3.0	0.913
25			> 3.5	0.813
	> 12.3	1.612		
26	> 12.0	1.664	> 4.1	0.775
	21.4	1.238	18.1	1.164
27	> 12.6	1.702	> 4.9	0.770
	23.0	1.301	19.1	1.172
28	> 13.5	1.774	> 5.7	0.741
	23.8	1.295	19.8	1.176
29			> 6.7	0.731
	> 14.0	1.813	20.5	1.181
30	0.8	1.369	> 7.2	0.737
	> 14.4	1.749	20.9	1.123
31	1.8	1.342	> 8.1	0.816
	> 15.0	1.621	21.6	1.012

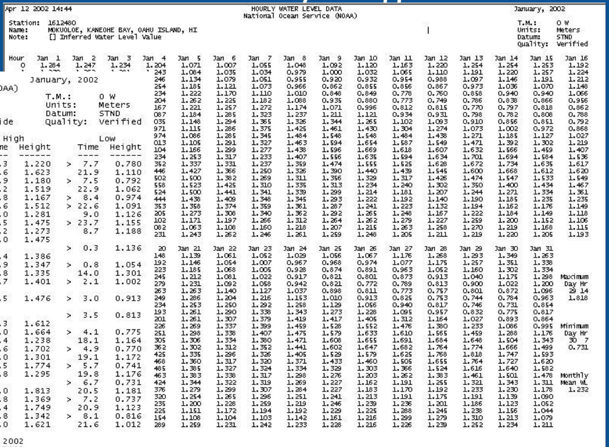
Highest Tide: 1.813 14.0 Hrs Jan 29 2002
Lowest Tide: 0.731 6.7 Hrs Jan 29 2002

Monthly Means:

MHHW	1.593						
MHW	1.455	DHQ	0.138				
MTL	1.228			GT	0.720	HWI	Hrs
DTL	1.233			MN	0.455	LWI	Hrs
MSL	1.232						
MLW	1.000	DLQ	0.127				
MLLW	0.873						

Station #	Sn	PC	Begin Date	End Date	In	COCTT	PID	VID	AID	Data Type
1612480	1	A1	W3	20020101 00:00	20020131 23:54	6	01000	220	206	High/Low

Hourly Heights



Data Processing

Data Processing Procedures

2. Tabulation (Cont'd)

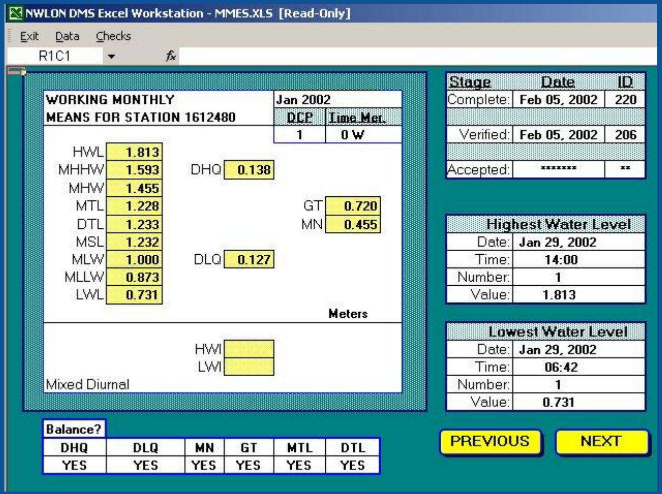
- Compute Monthly Means
- Mark data Complete
- Make output reports
- Final Time Series Check

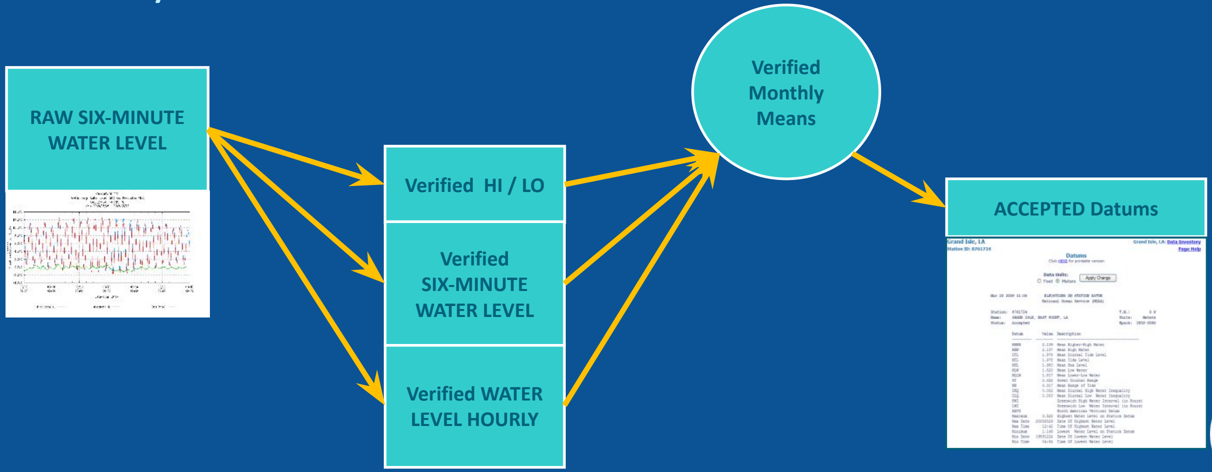
5.Verification

- Check by a senior analyst

6.Compute Datums

Monthly Means





Predictions

Tide Prediction

Tide Analysis & Prediction

- Because we know which frequencies will have tidal energy,

- we can predict the tide or tidal current
- without really knowing anything about the *hydrodynamics*
- *Though,* we can do a better job of prediction, if we ***do*** understand the *hydrodynamics*

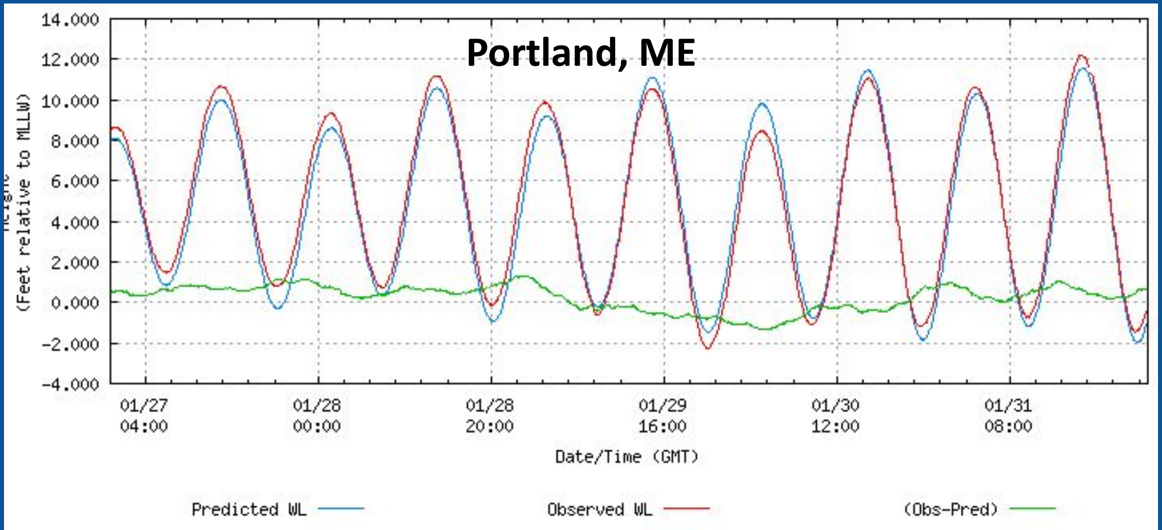
- As long as we have a **long enough data time series** at a location,

•we can analyze that data,

•extracting amplitude and phase information for each tidal frequency,

•and make reasonably good tidal predictions

* *for (only)* ***that specific location*** for anytime in the future or past



Harmonic Constituents

Harmonic Constituents

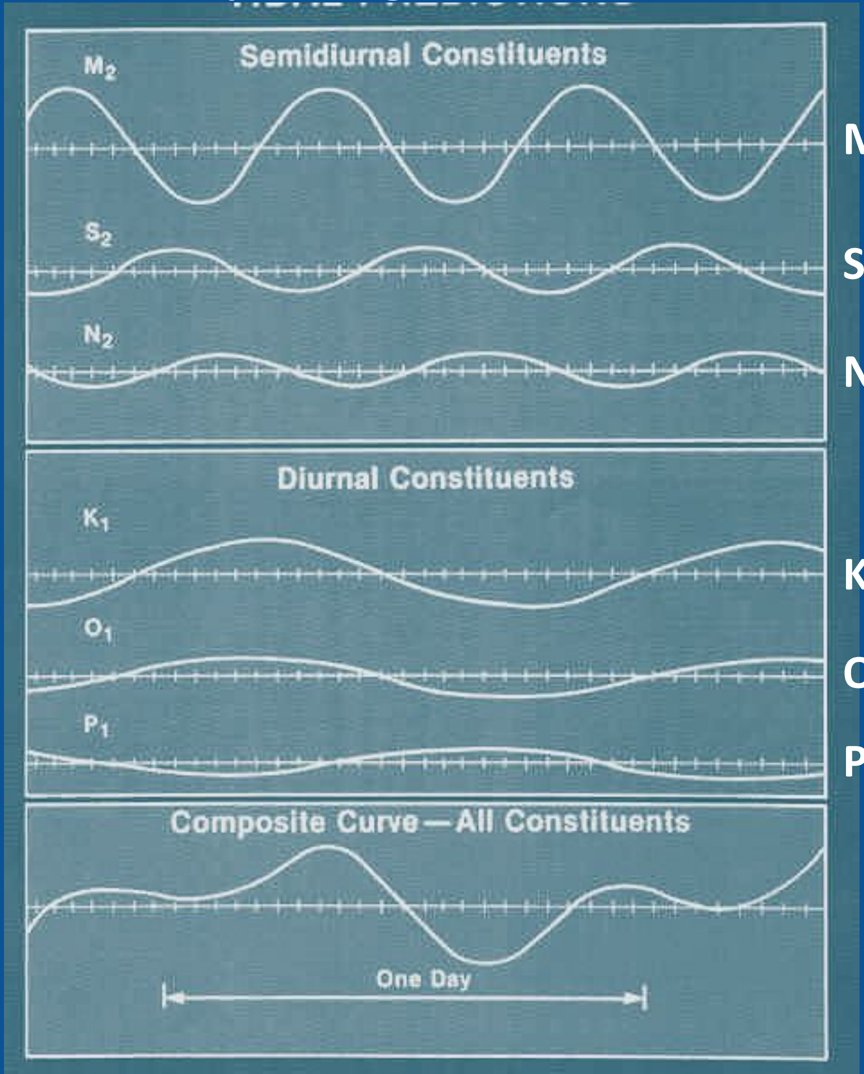
Principal components that make up tide signal, & are used to make tide predictions

More than 1 component from sun & moon

- due to their orbits being elliptical
- and at angles to the plane
- both changing over time

Analysis & Prediction

- Observed tides are analyzed for their constituents
- Constituents are then used to create predicted tides
- $X(t) = H_n \cos(\sigma_n t - g_n)$
- Need observations over a suitable period of time
- 1 – 10yrs depending on constituent to analyze



M_2 - Principal lunar

S_2 - Principal solar

N_2 - Larger lunar elliptic

K_1 - Luni-solar diurnal

O_1 - Principal lunar diurnal

P_1 - Principal solar diurnal

Tide Prediction

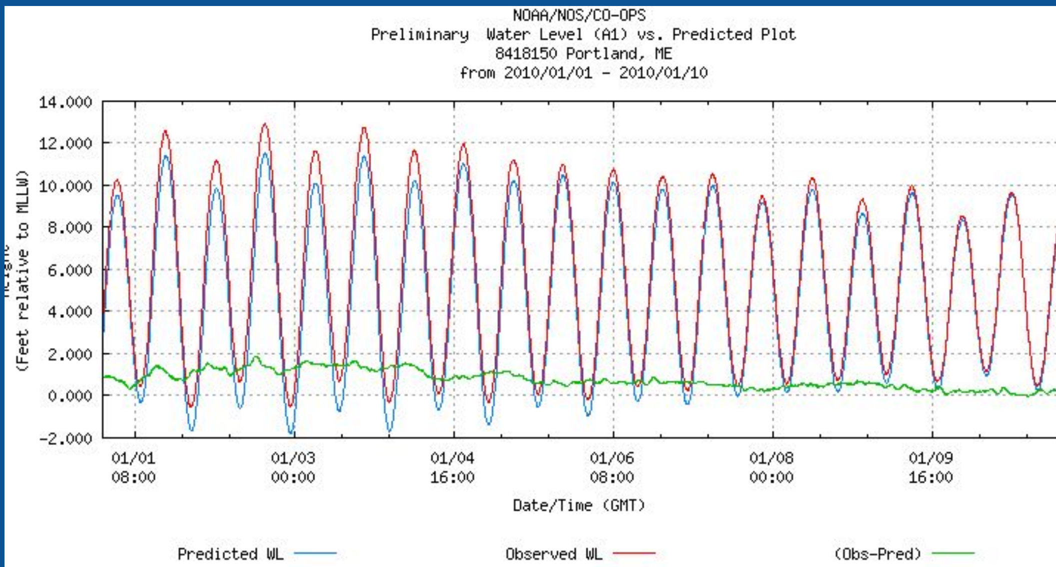
COMPARISON OF TIDAL VS. NON-TIDAL EFFECTS
REDUCTION OF VARIANCE STATISTICS
(FROM ONE-YEAR HARMONIC ANALYSIS)

STATION	TIDAL	NON-TIDAL
BOSTON, MA	98.2%	1.8%
BALTIMORE, MD	44.8%	55.2%
CHARLESTON, SC	91.2%	8.8%
KEY WEST, FL	74.5%	25.5%
PENSACOLA, FL	45.4%	54.6%
GALVESTON, TX	39.5%	60.5%
SAN FRANCISCO, CA	98.6%	1.4%
SEATTLE, WA	98.8%	1.2%

Can Predict Well

Difficult to Predict

Tide Prediction

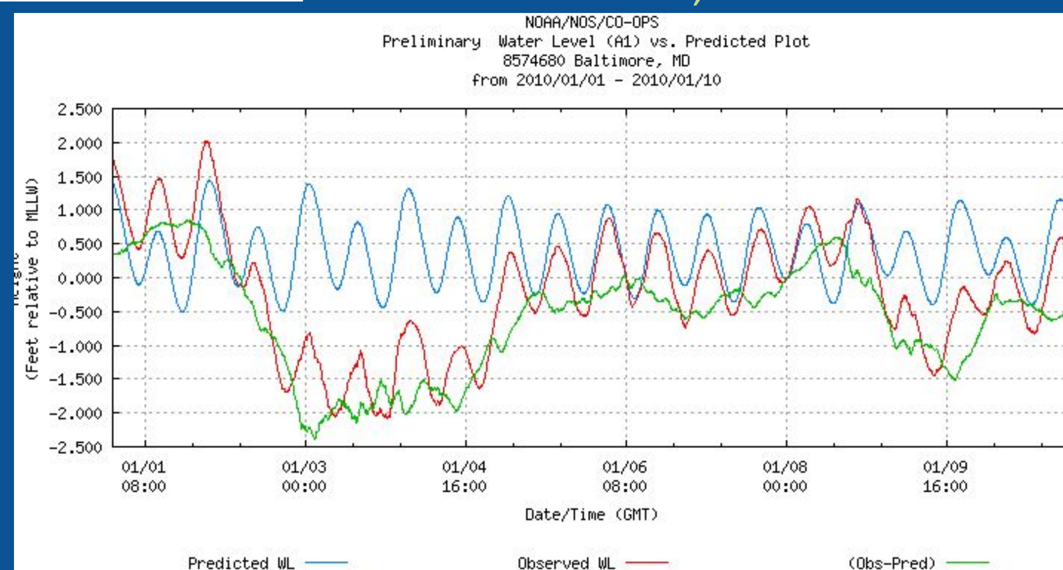


Portland, ME

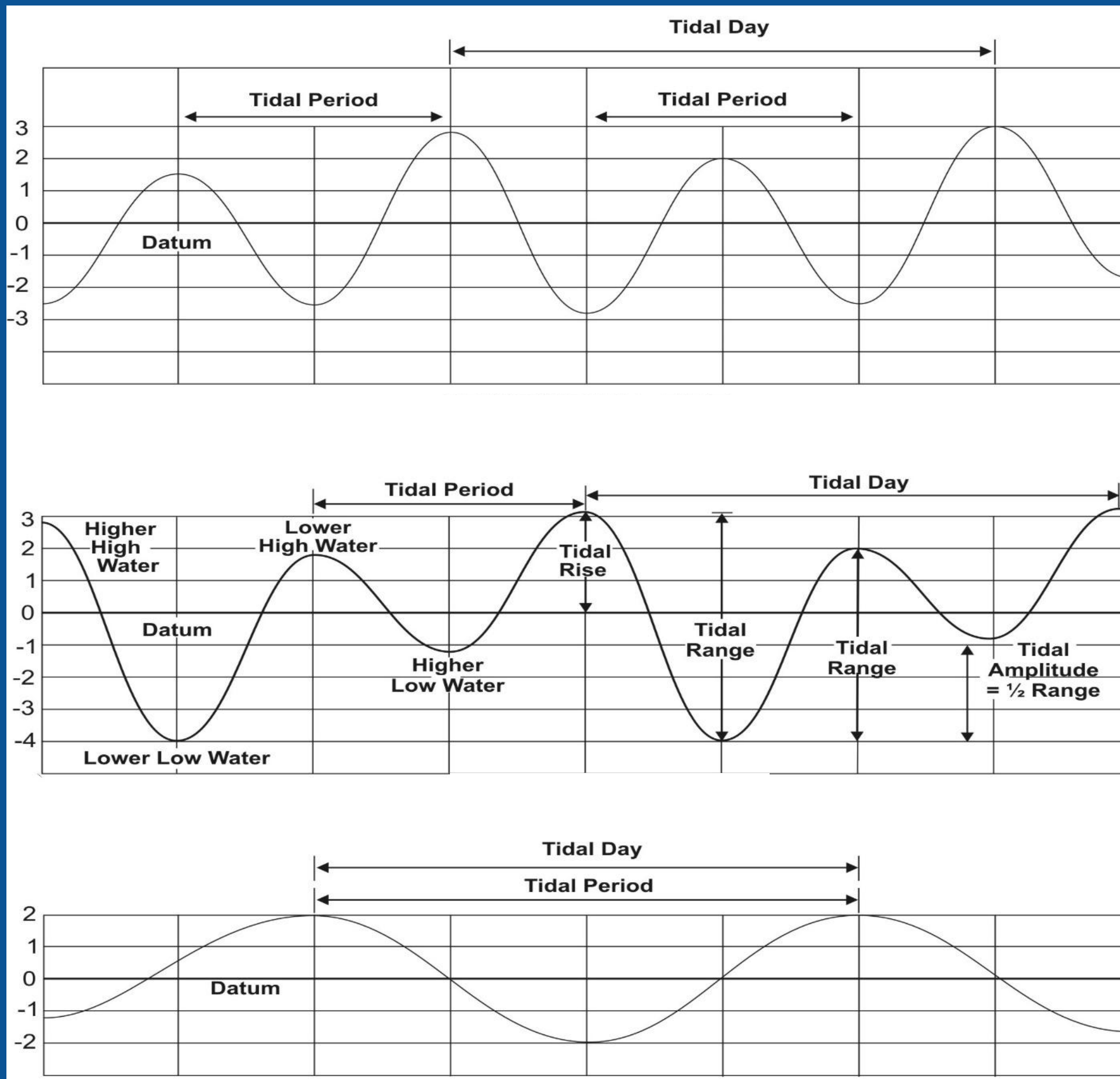
Can Predict Well

Baltimore, MD

Difficult to Predict



Types of Tides



Semidiurnal

two daily highs & lows
~ similar height

Most common

Mixed

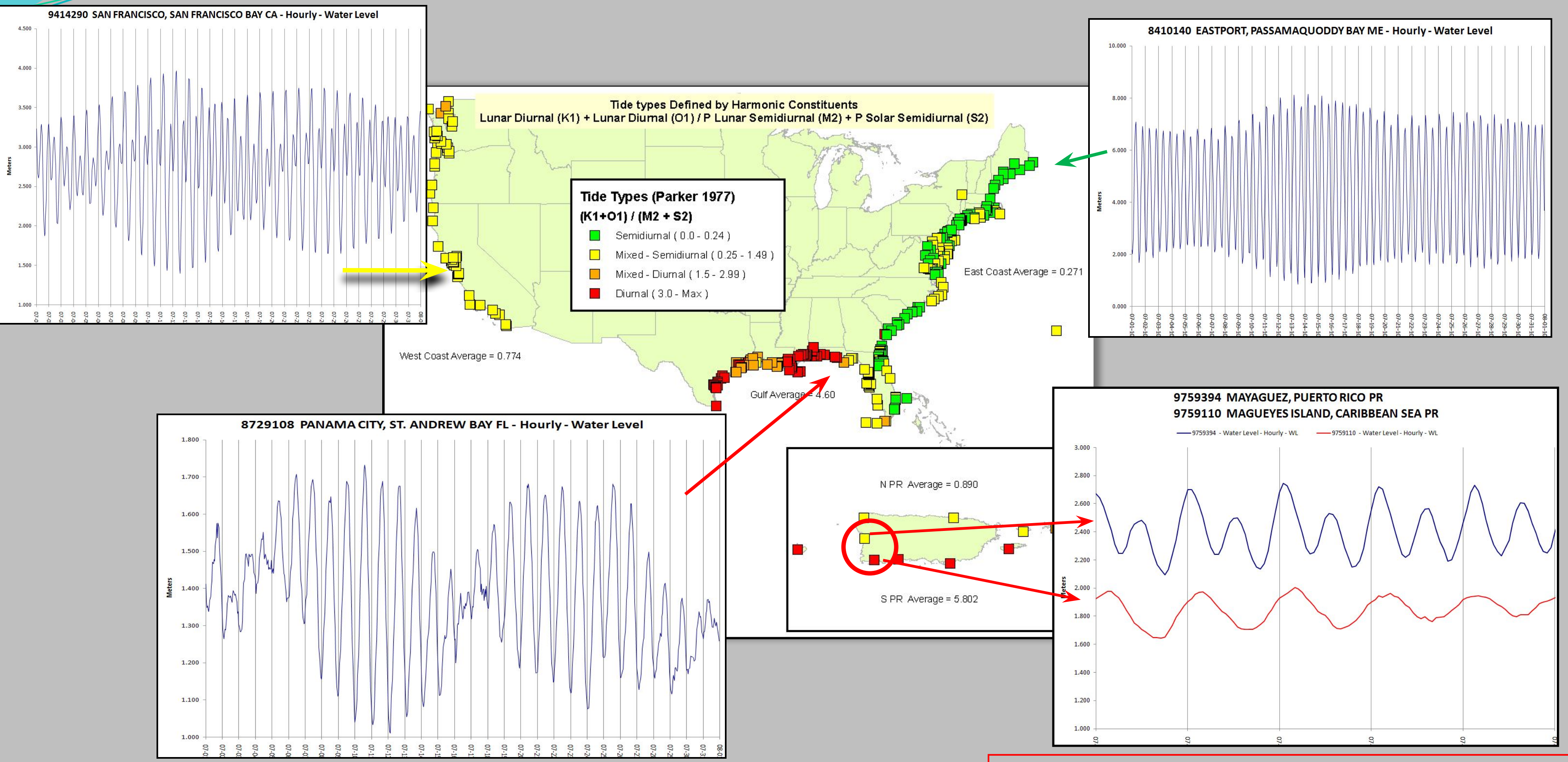
two daily highs & lows
~ not similar height

Diurnal

one daily high & low

Tide Type Considerations

Tide Type Varies by Region due to Local Hydrodynamics



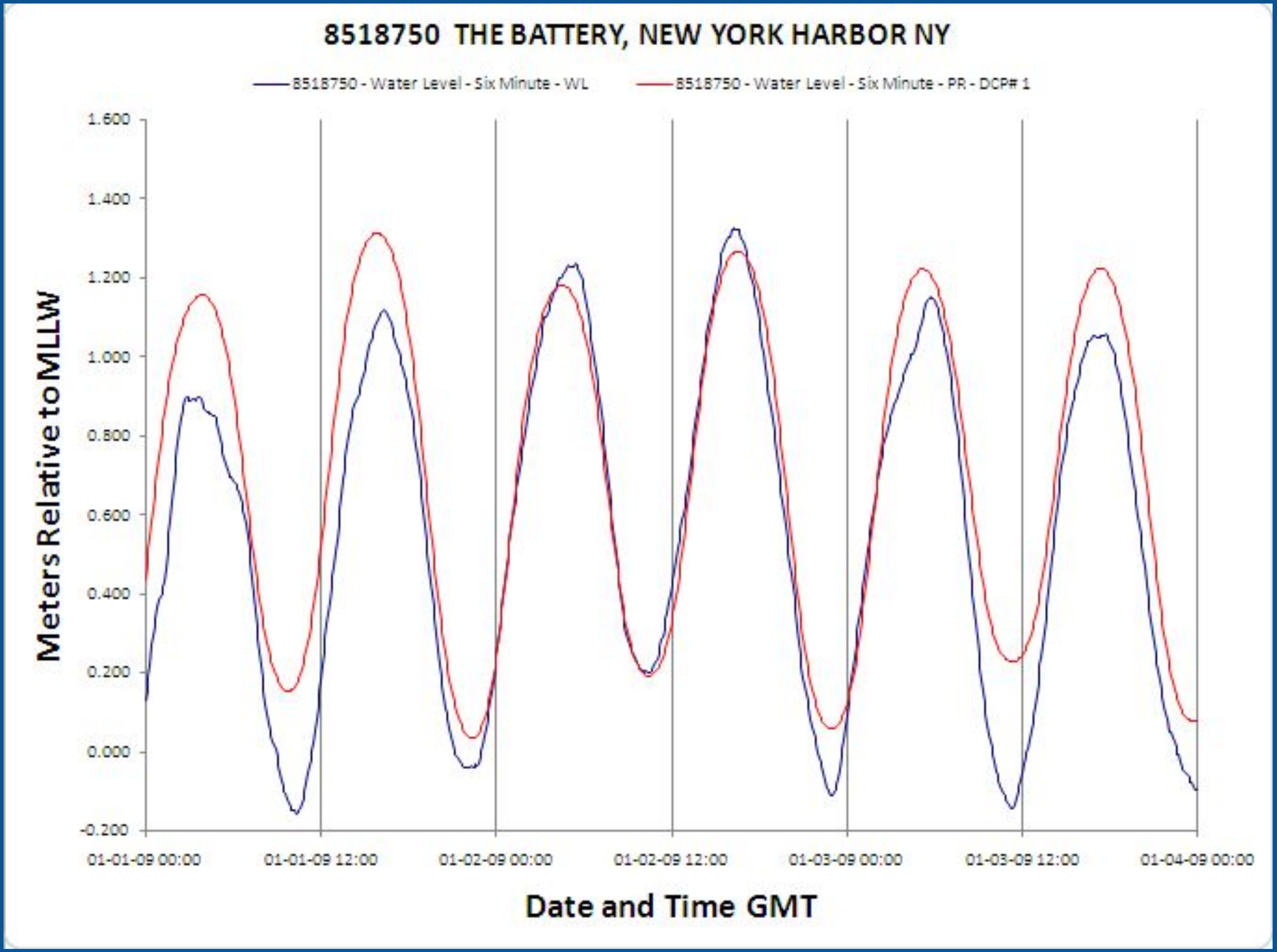
Statute distance between these gauges: 16.5 miles

Tide type does not necessarily transition slowly or smoothly.

Tidal Characteristics

Examples for East Coast

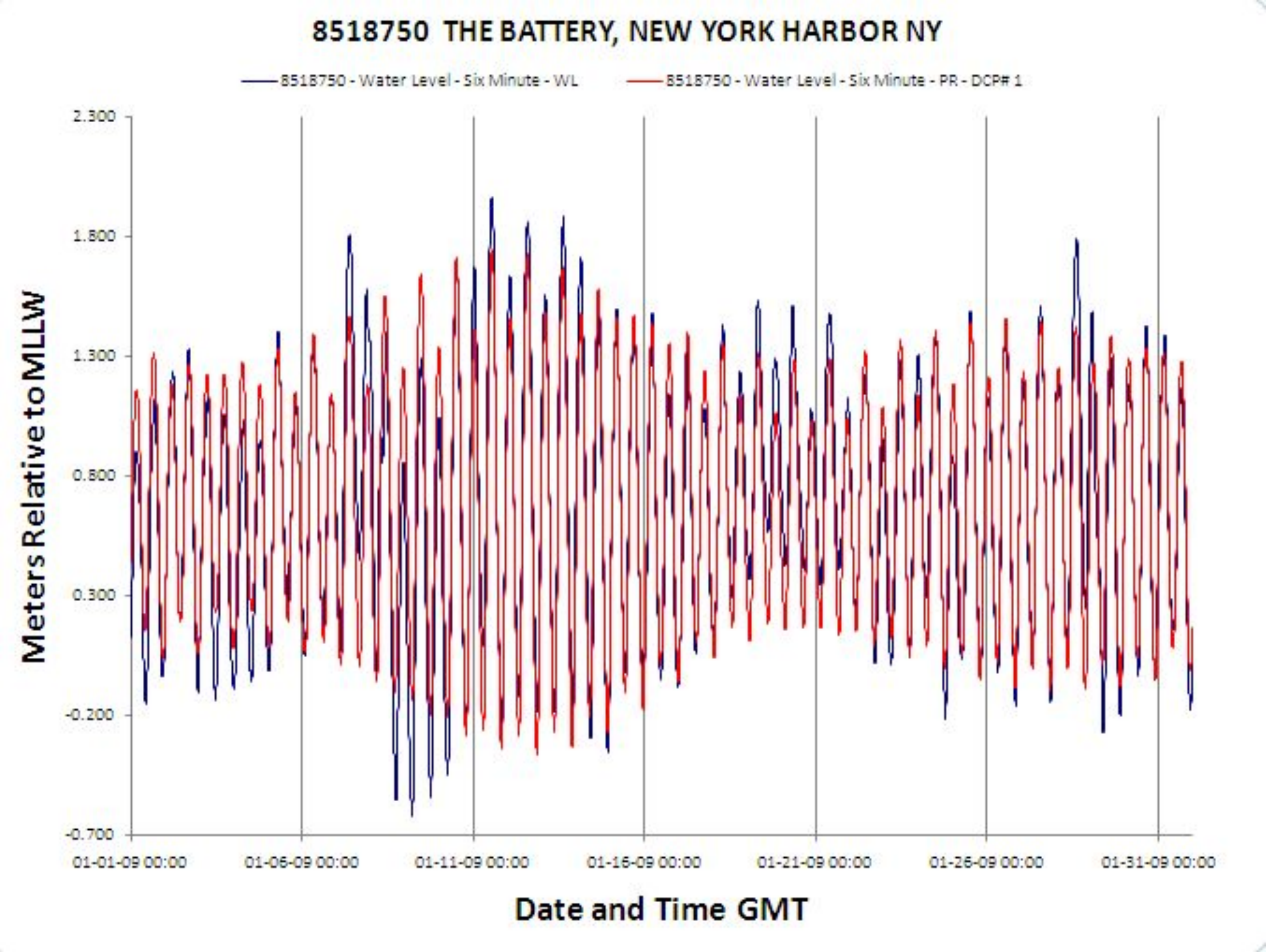
Primarily Semidiurnal



Tidal Characteristics

Examples for East Coast

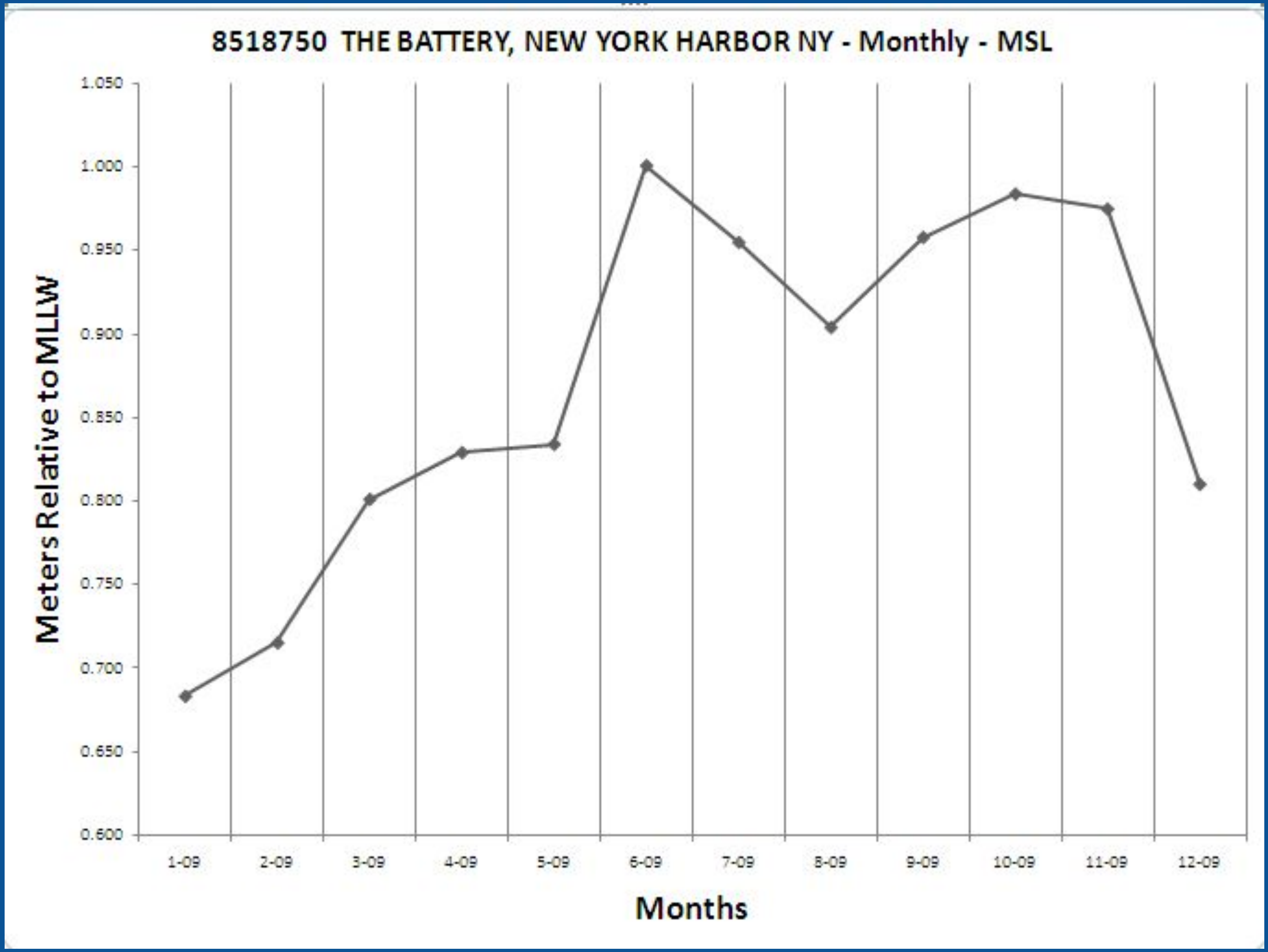
Primarily Semidiurnal



Tidal Characteristics

Examples for East Coast

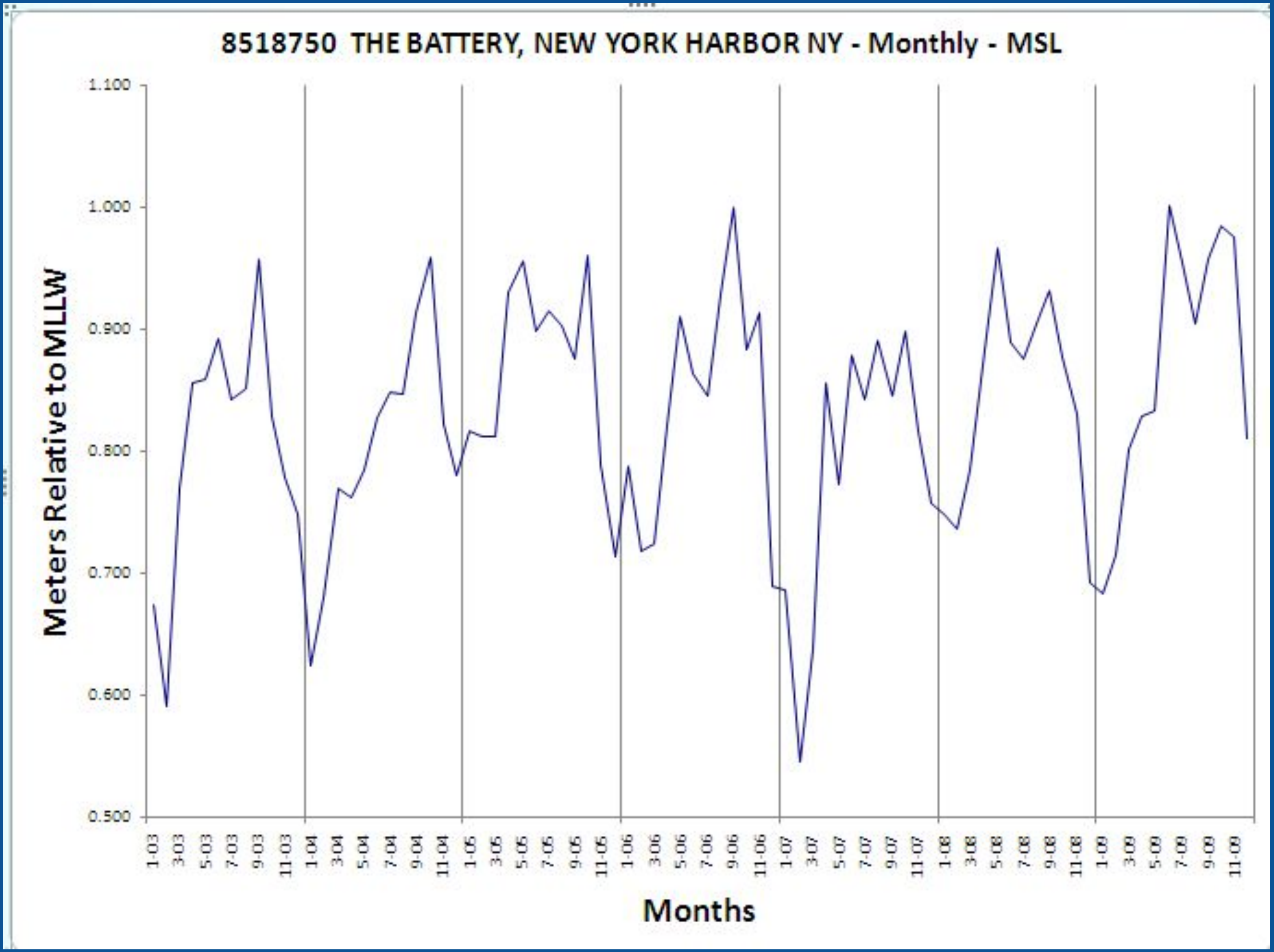
Primarily Semidiurnal



Tidal Characteristics

Examples for East Coast

Primarily Semidiurnal

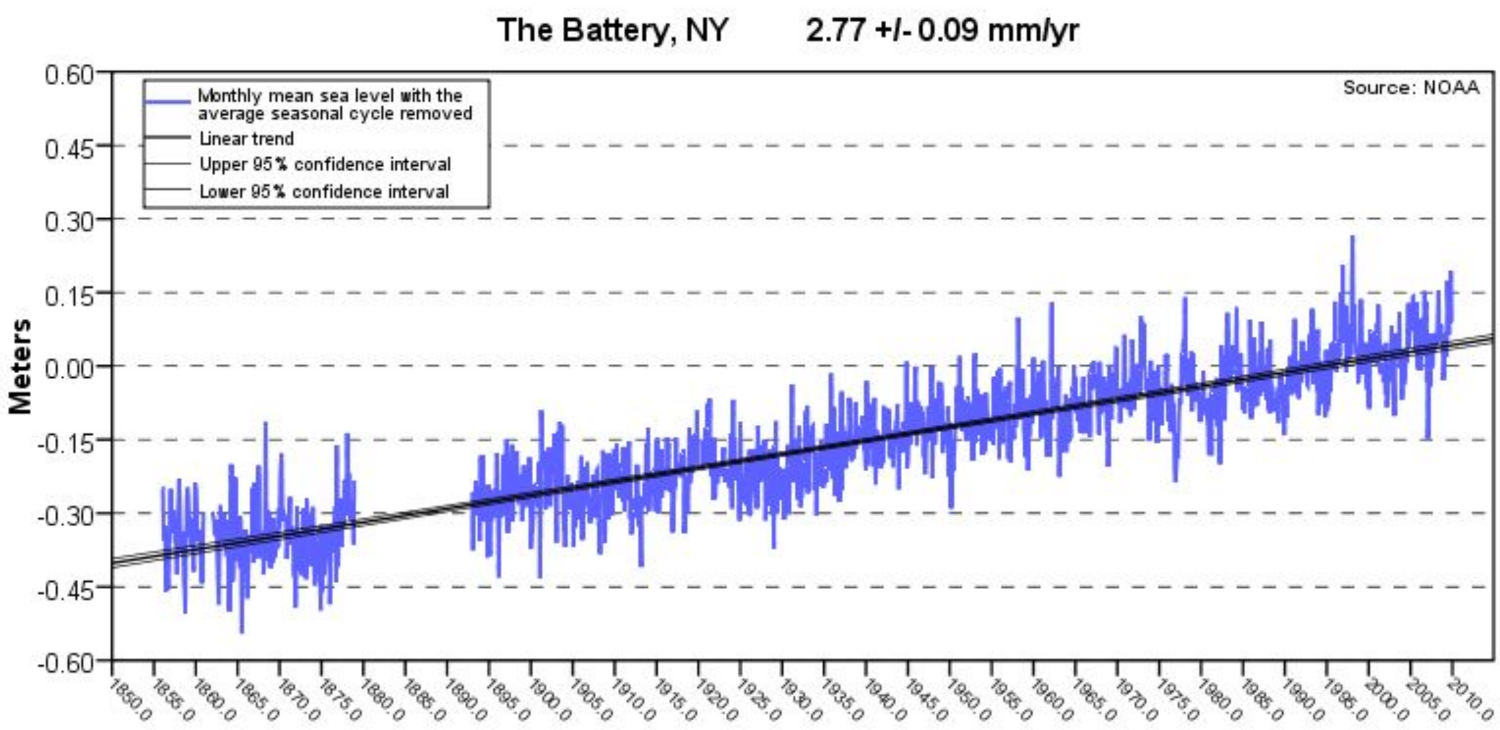


Tidal Characteristics

Examples for East Coast

Primarily Semidiurnal

Mean Sea Level Trend
8518750 The Battery, New York



The mean sea level trend is 2.77 millimeters/year with a 95% confidence interval of +/- 0.09 mm/yr based on monthly mean sea level data from 1856 to 2006 which is equivalent to a change of 0.91 feet in 100 years.

National Tidal Datum Epoch (NTDE)

National Tidal Datum Epoch (NTDE)

A common time period to which tidal datums are referenced

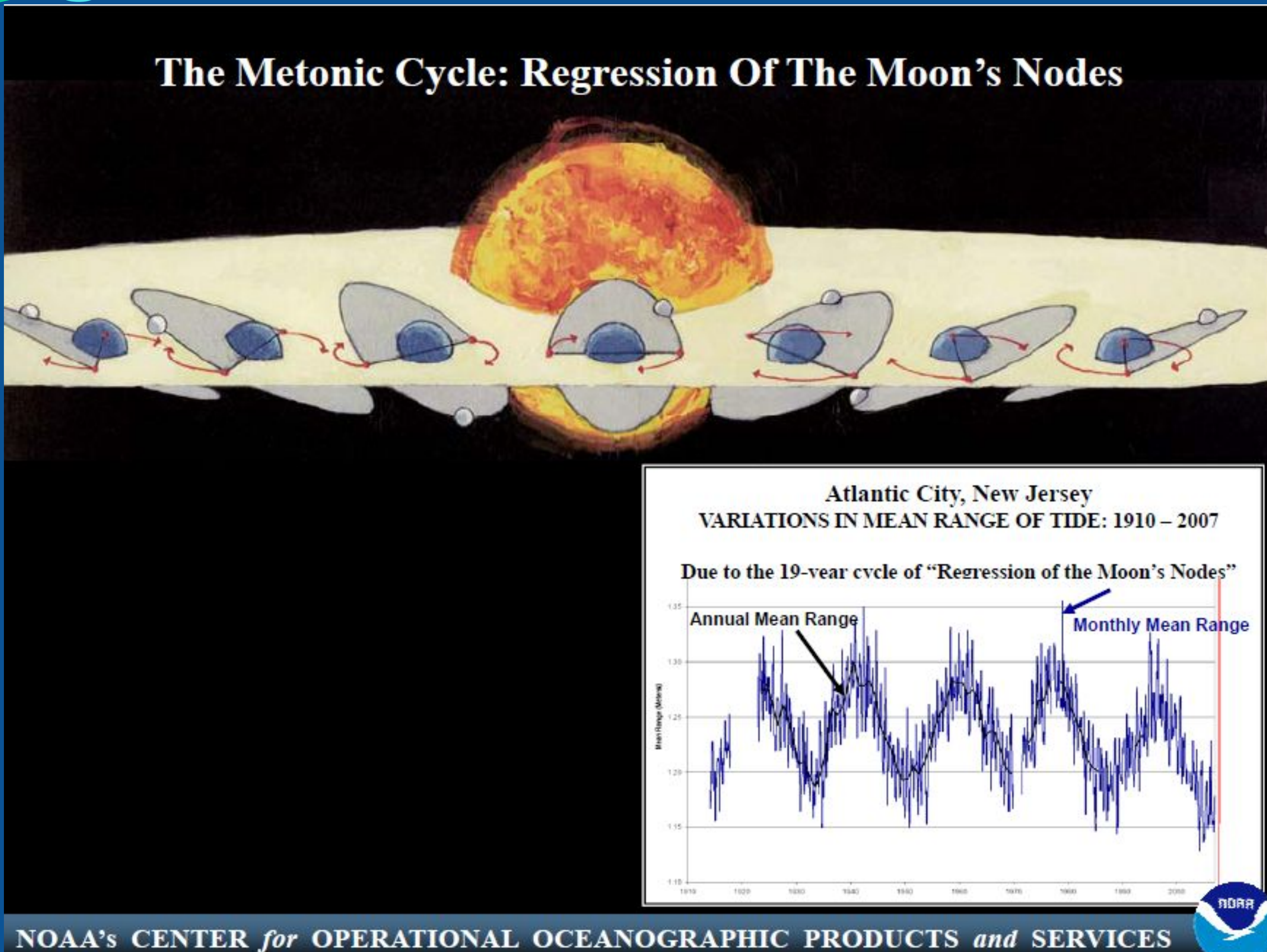
6 A specific 19 year period that includes the longest periodic tidal variations caused by the astronomic tide-producing forces.

6 Averages out long term seasonal meteorological, hydrologic, and oceanographic fluctuations.

6 Provides a nationally consistent tidal datum network (bench marks) by accounting for seasonal and apparent environmental trends in sea level that affects the accuracy of tidal datums.

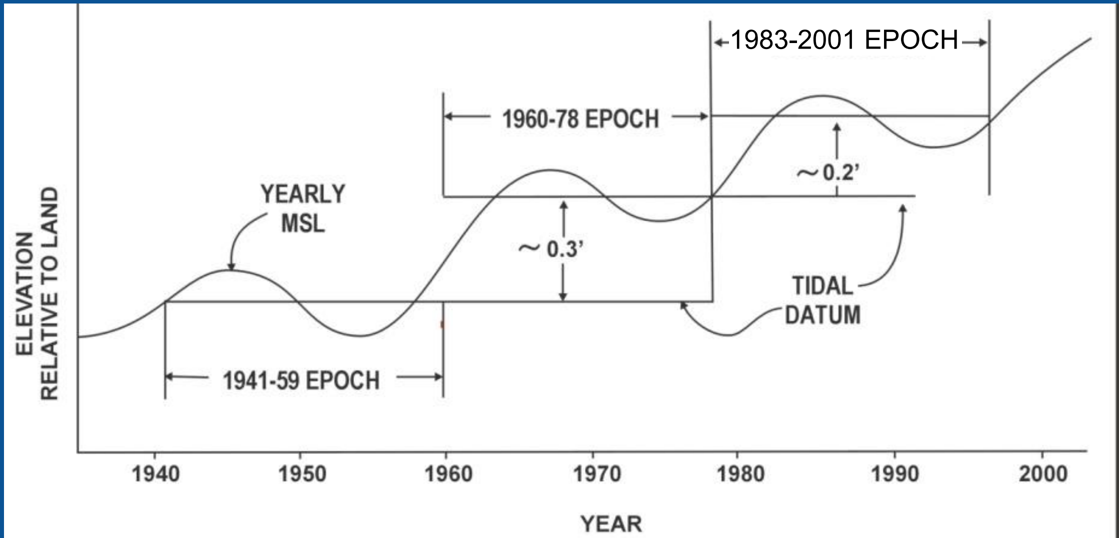
6 The NWLON provides the data required to maintain the epoch and make primary and secondary determinations of tidal datums.

Regression of the Moon's Nodes

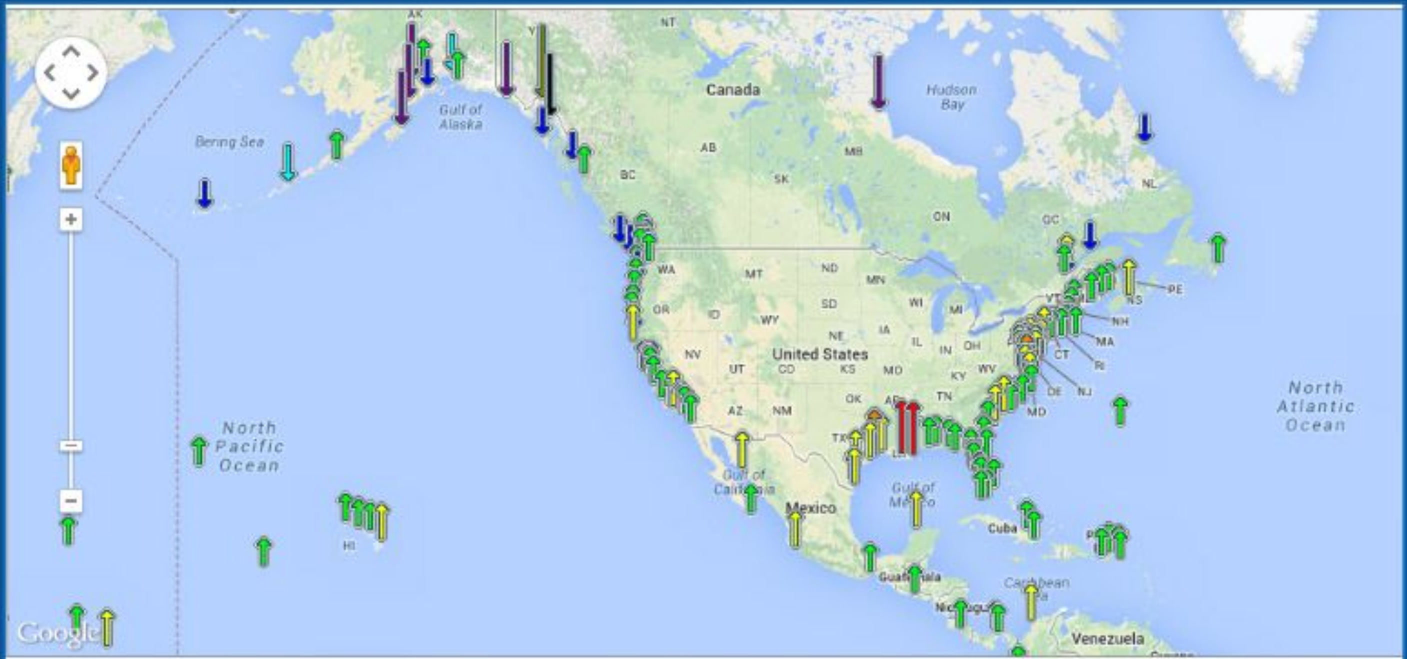


National Tidal Datum Epoch (NTDE)

- Official time period of tidal observations that are used for primary datum calculations
  - Time it takes the Earth, Moon, & Sun to complete an epoch tidal cycle
  - 19 year time period (Current NTDE is 1983-2001)
  - Considered for revision every ~20-25yrs
  - Includes the longest period tidal variations *(18.6 year node cycle)*
  - Averages out seasonal fluctuations
  - Provides a nationally consistent tidal datum network by accounting for seasonal and apparent environmental trends in sea level that affect the accuracy of tidal datums
  - **Next NTDE will be computed on period of 2002-2020**
    - **Anticipated release 2025**
  - **Datum update website: https://tidesandcurrents.noaa.gov/datum-updates/**



Relative Sea Level Trends at National Water Level Observation Network (NWLON) Stations



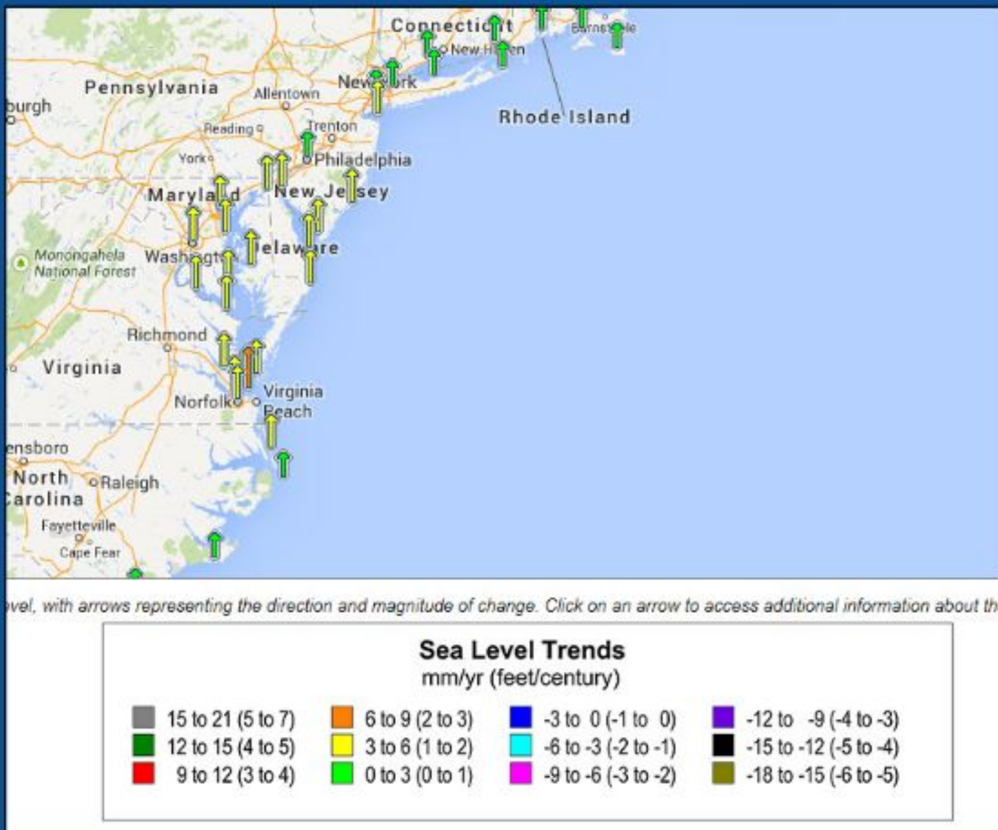
The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional informatio

Sea Level Trends
mm/yr (feet/century)

15 to 21 (5 to 7)	6 to 9 (2 to 3)	-3 to 0 (-1 to 0)	-12 to -9 (-4 to -3)
12 to 15 (4 to 5)	3 to 6 (1 to 2)	-6 to -3 (-2 to -1)	-15 to -12 (-5 to -4)
9 to 12 (3 to 4)	0 to 3 (0 to 1)	-9 to -6 (-3 to -2)	-18 to -15 (-6 to -5)

http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

Effects of Vertical Land Motion and Relative Sea Level Trends



* Tide stations measure sea level variation relative to the local land.

* Sea level variations at any station can be due to global sea level rise from climate change; from shelf and estuarine changes in hydrodynamics and circulation patterns due to decadal climate oscillations; and changes in freshwater flow into estuaries

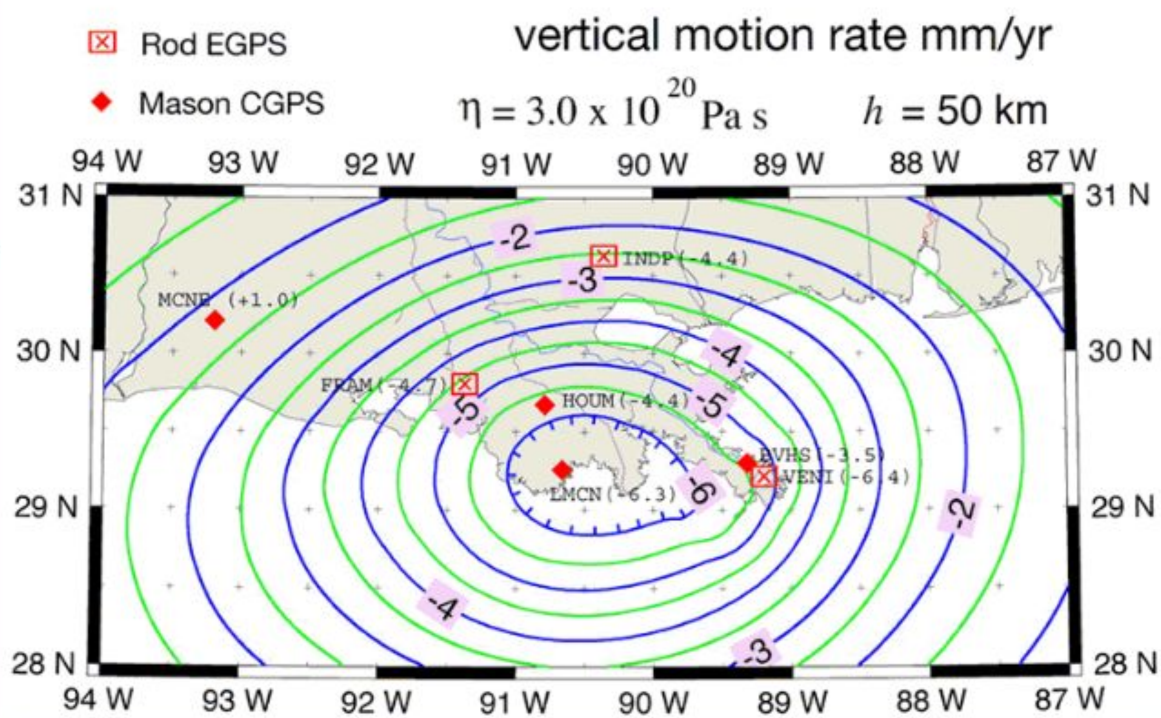
* Long-term sea level variations can also be due to local and regional vertical land movement: either subsidence or uplift

- Tide gauge records do not distinguish as to cause, but simply provide sea level variation relative to the local land – a very important piece of coastal intelligence for decision-making.

http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

Vertical land Motion – Subsidence in Louisiana

greatest, near the center of the Mississippi and Atchafalaya River Delta complexes.

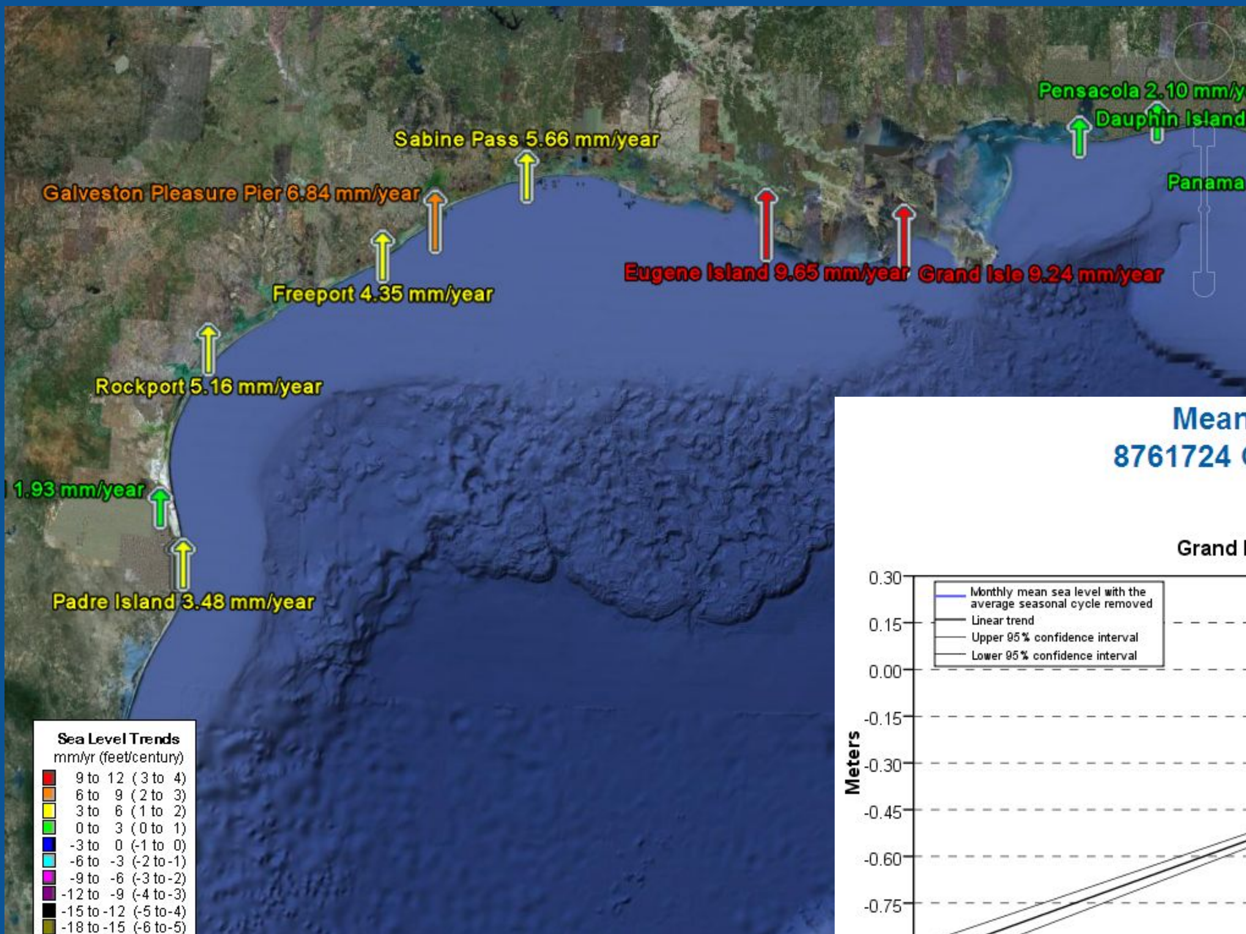


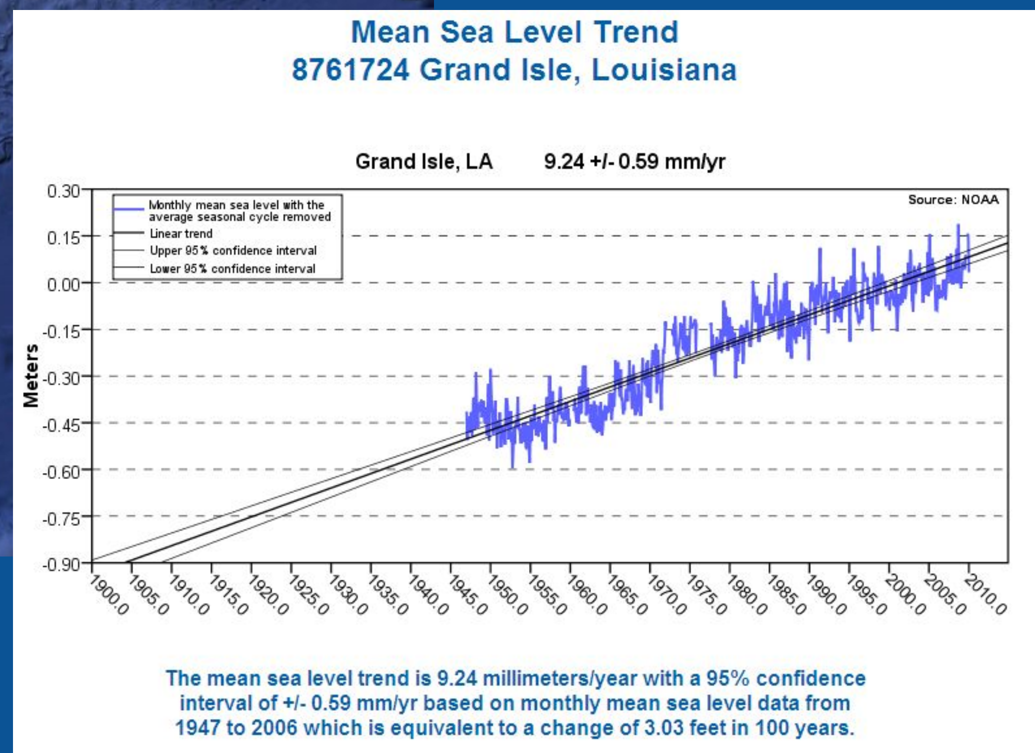
Predicted annual rates of sinking in the Gulf coast region, in millimeters per year, based on a numerical model of Earth deformation resulting from sea level rise and sediment deposits. This model does not include sinking from other sources. Credit: NASA/JPL, Louisiana State University.

Source; NASA, JPL, LSU

Sea Level

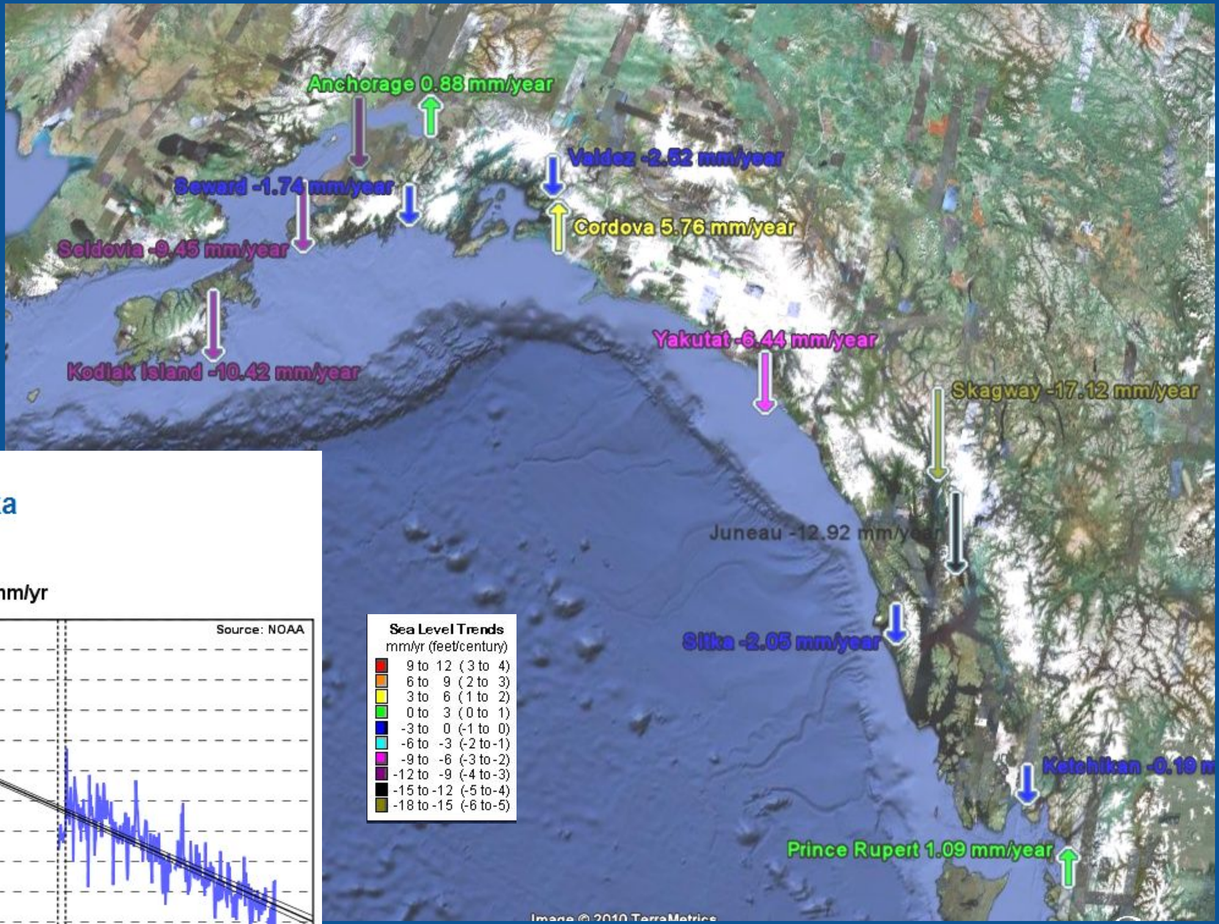
Mean Sea Level Trends

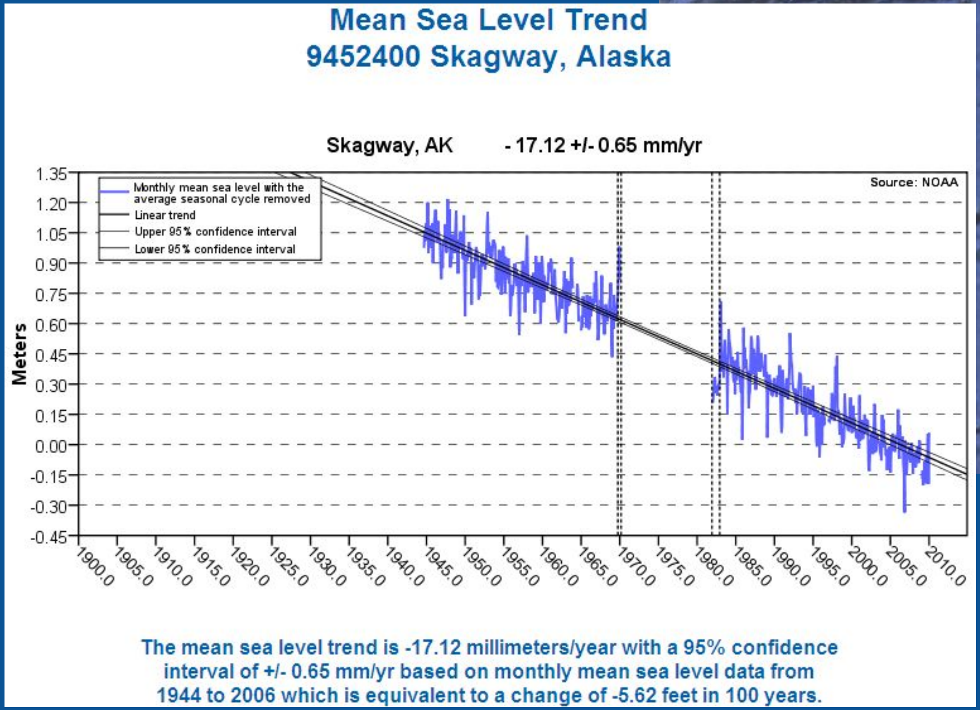




Sea Level

Mean Sea Level Trends

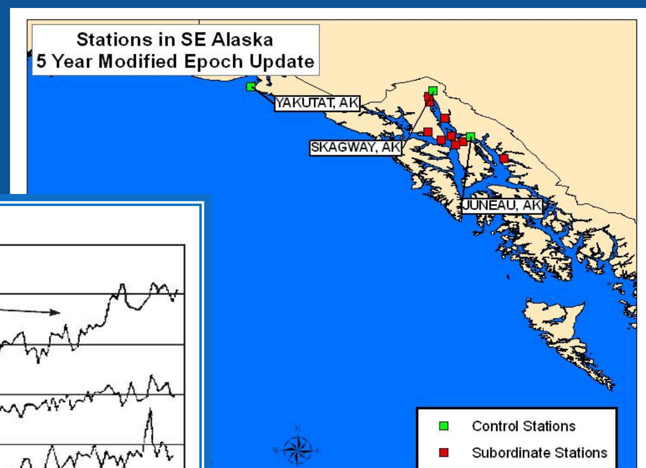


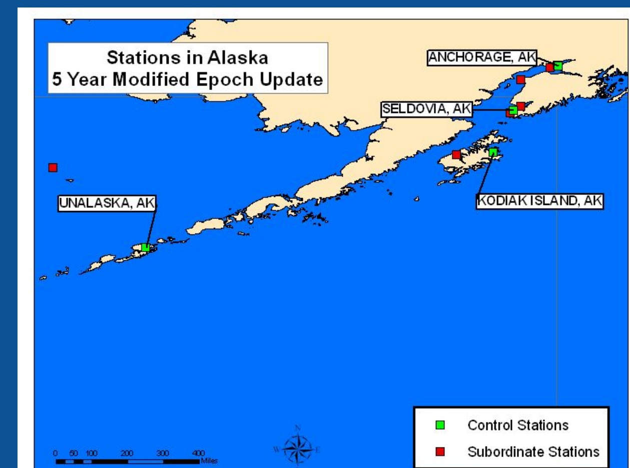


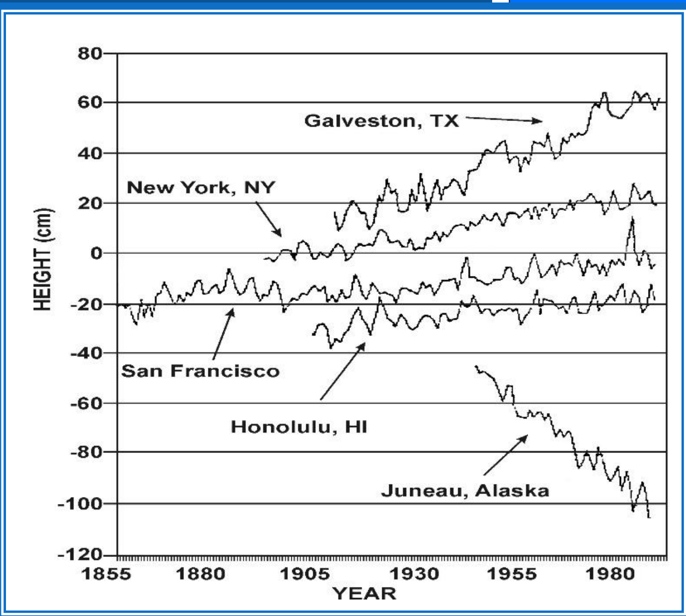
COMPUTING TIDAL DATUMS IN AREAS OF ANOMALOUS SEA LEVEL TRENDS

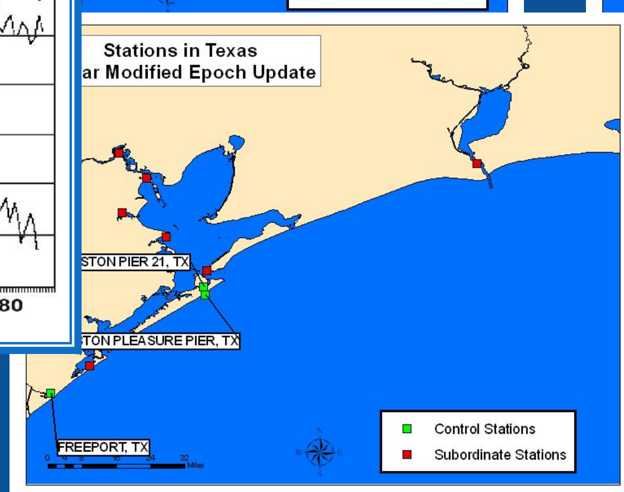
There are areas of Louisiana, Texas, SE Alaska and SW Alaska where there are anomalous sea level trends compared to most other geographic regions of the United States.

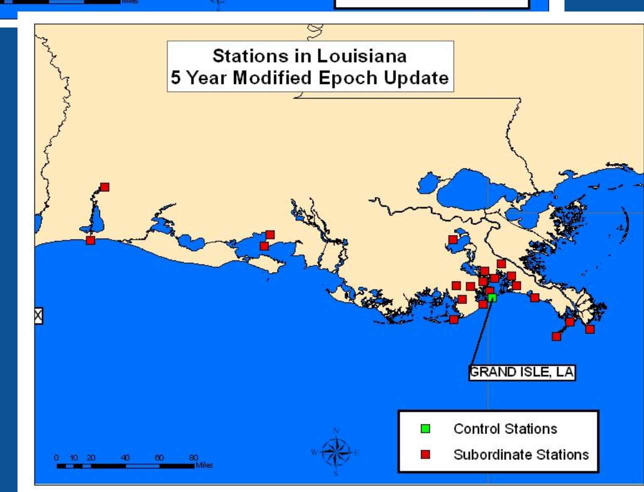
“New Procedures” have been developed to address these regions so that published tidal and geodetic relationships are representative of current conditions









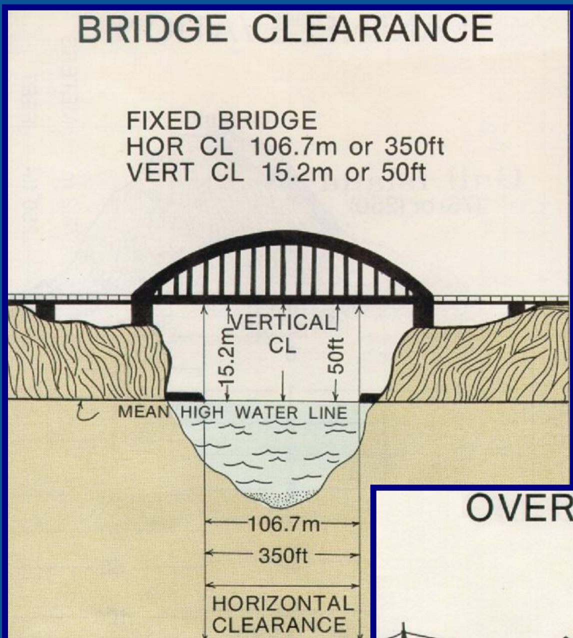


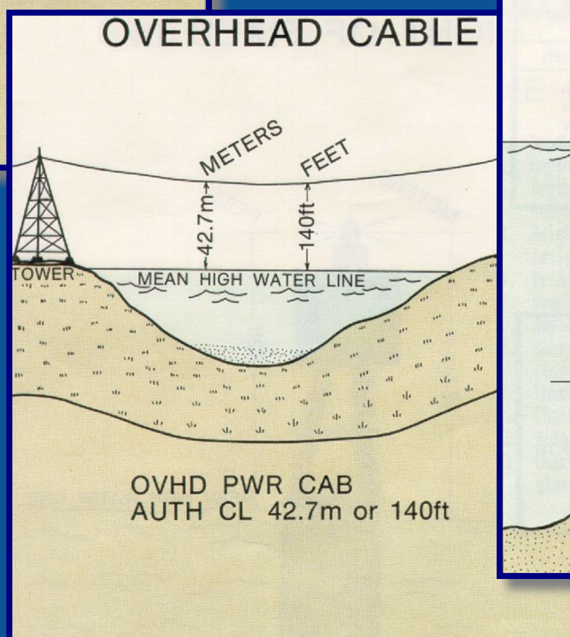
Tidal Datums

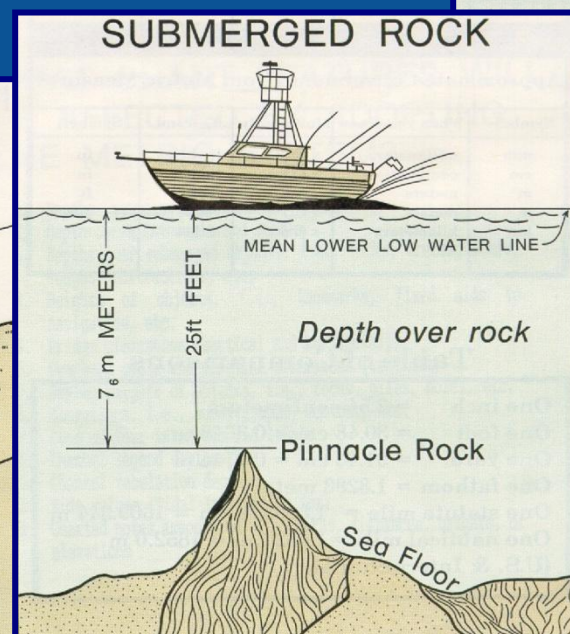
Significance?

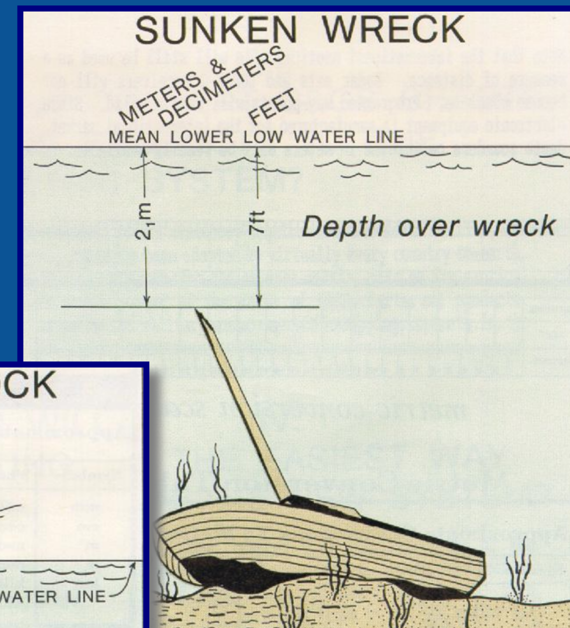
Subsidence and uplift both affect the relationship between the water surface and structures and hazards

This relationship must be monitored and documented









Mean Lower Low Water 1983-2001

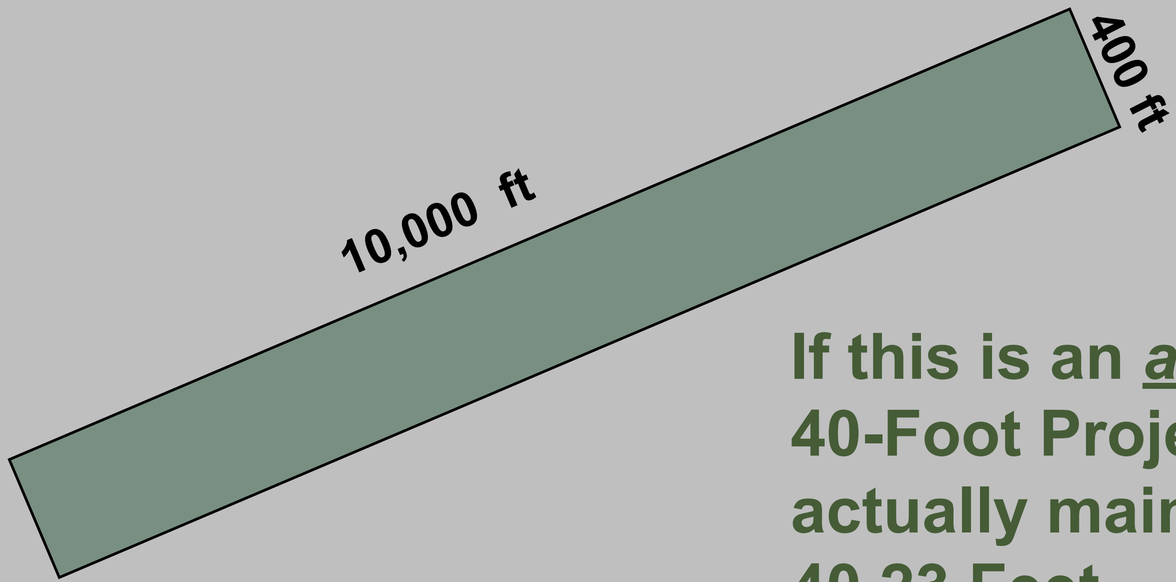
The midpoint of the 1960-1978 was 48 years ago
@ 1.8mm/yr MLLW has risen ~0.086m (0.28ft)

The midpoint of the 1983-2001 was 25 years ago
@ 1.8mm/yr MLLW has risen ~0.045m (0.15ft)

What is Impact of Ignoring a 0.23 ft Tidal Epoch Change?

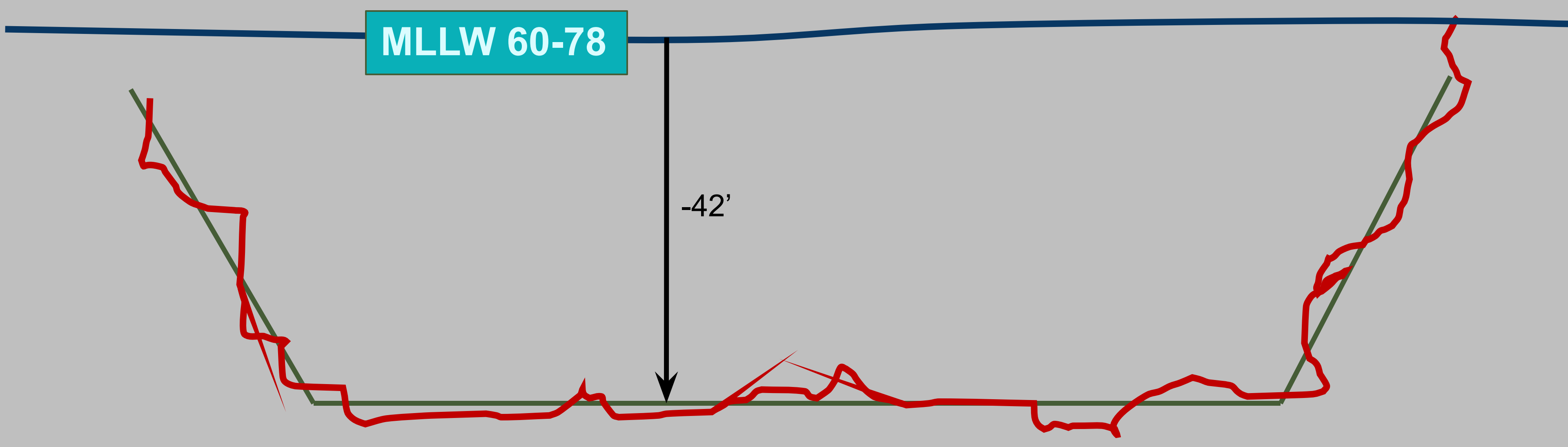
Given, 10,000 ft by 400 ft channel section:

34,000 CY or $340,000 *<u>Overdredging</u>* @ $10/CY



If this is an *<u>authorized</u>* 40-Foot Project, then you are actually maintaining it to 40.23 Feet

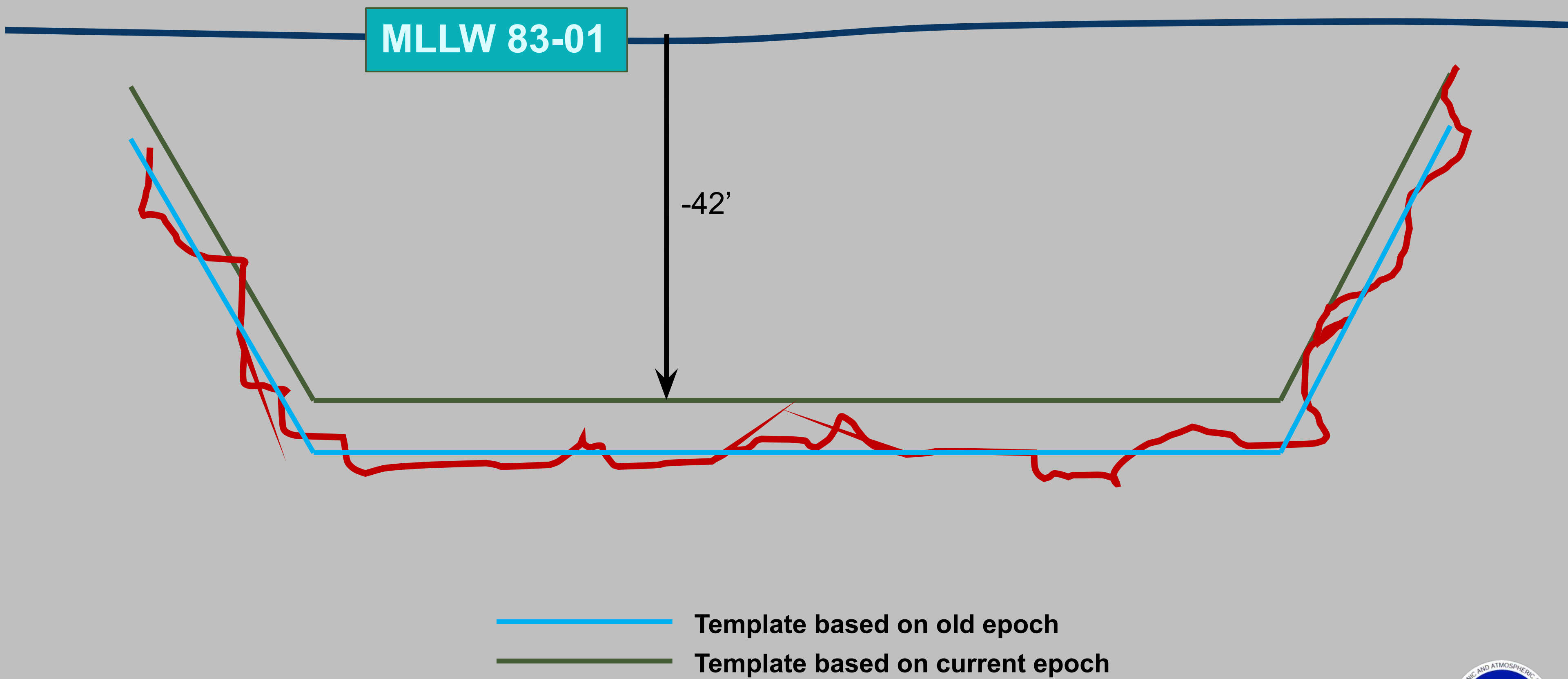
It's Only 0.25'
I Can't Dredge That Close



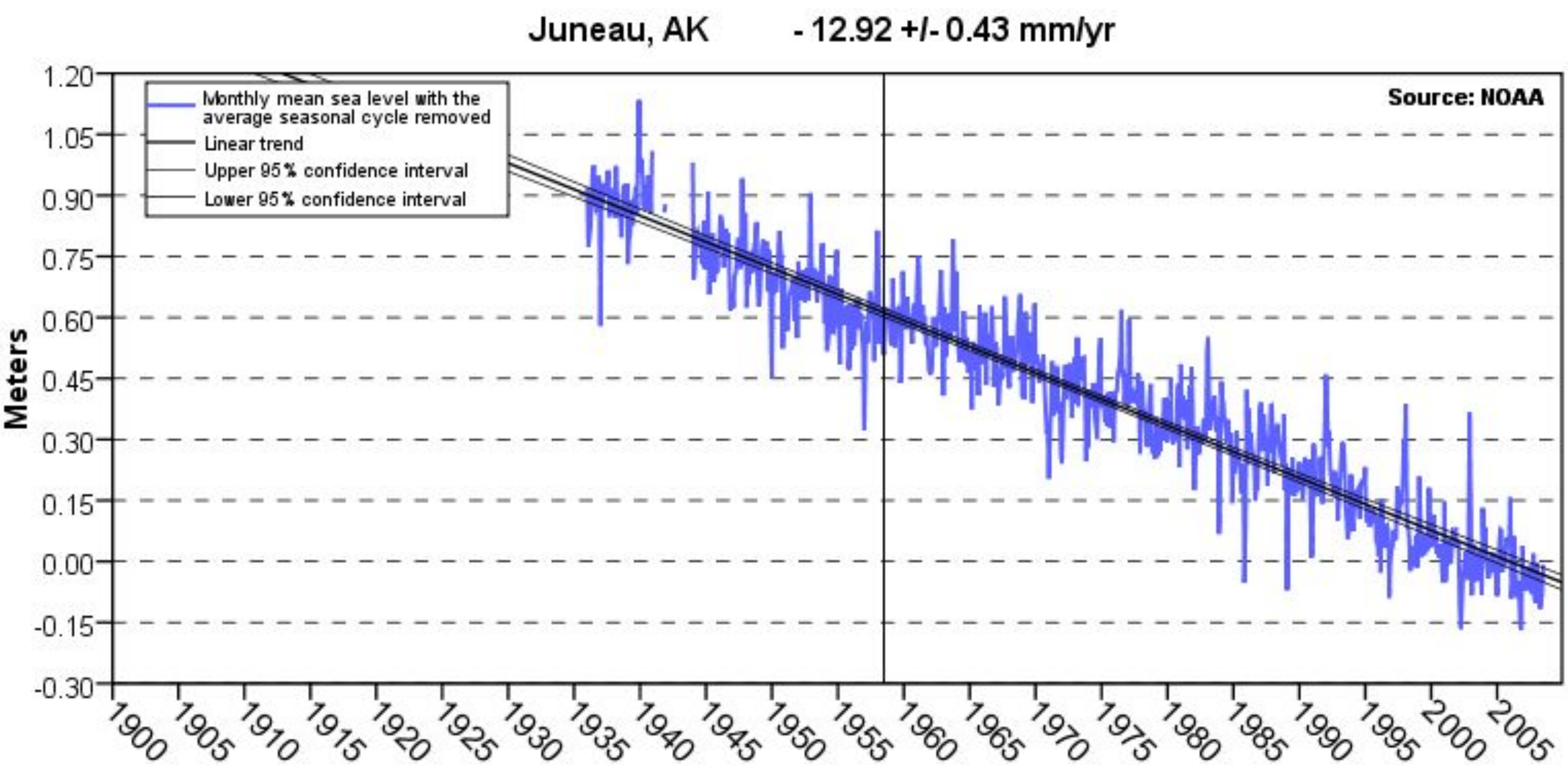
But it is a bias, not a random error

It's Only 0.25'
I Can't Dredge That Close

But it is a bias, not a random error



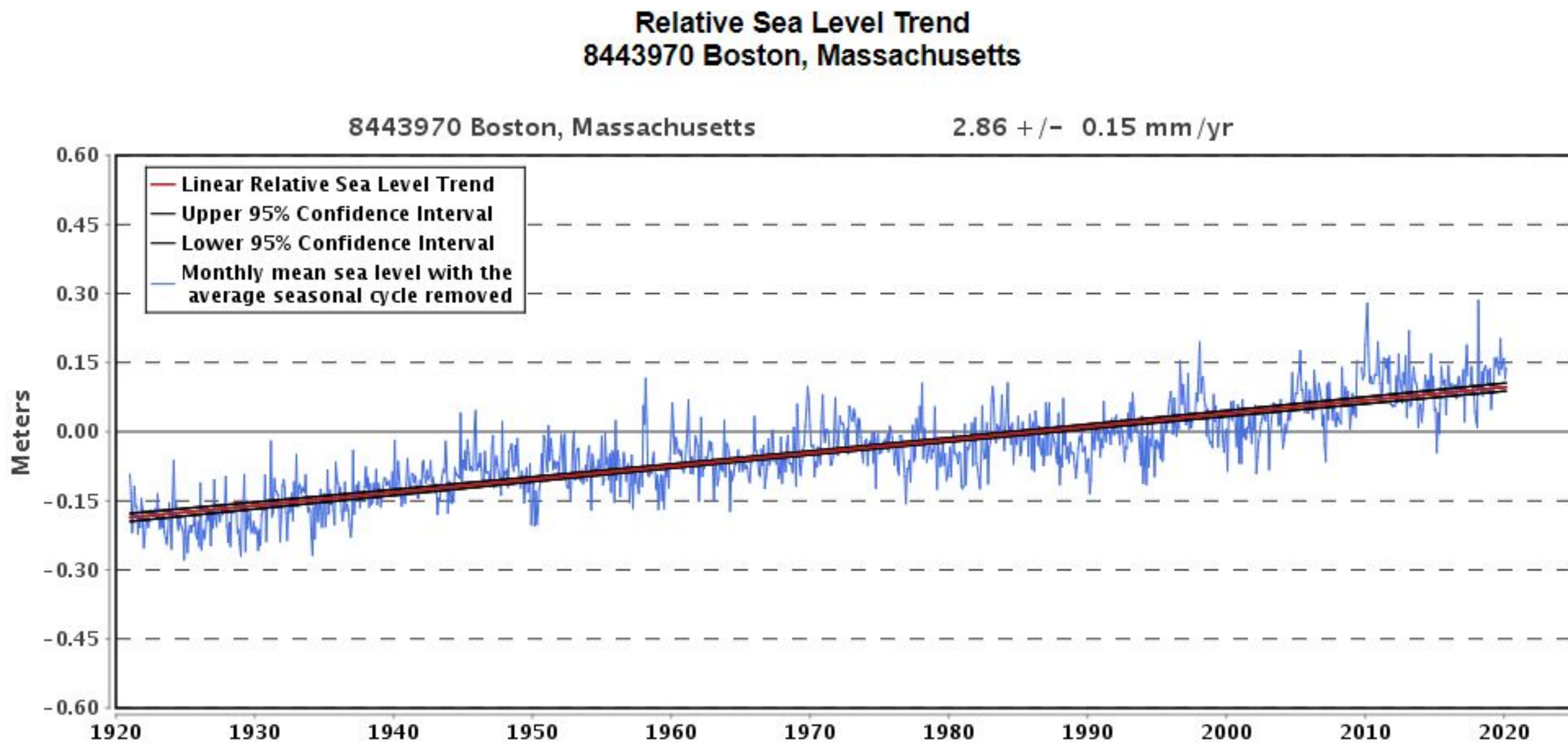
Water depth is reduced as the



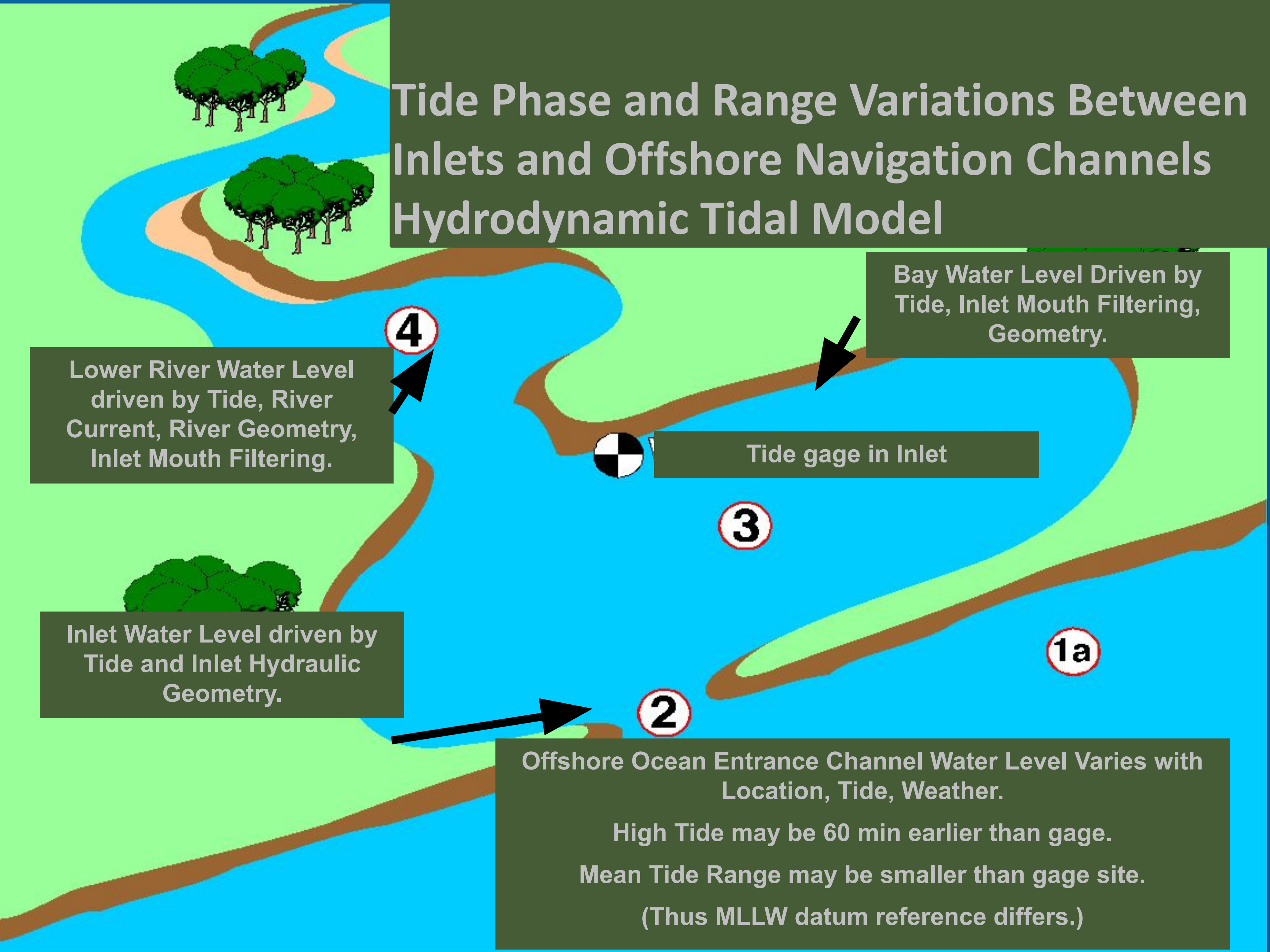
Sea Level Rise

2’+ in 50 years

Subsidence


Relative Sea Level Trend
8443970 Boston, Massachusetts
8443970 Boston, Massachusetts
2.86 +/- 0.15 mm/yr
Linear Relative Sea Level Trend
Upper 95% Confidence Interval
Lower 95% Confidence Interval
Monthly mean sea level with the average seasonal cycle removed
Meters
0.60
0.45
0.30
0.15
0.00
-0.15
-0.30
-0.45
-0.60
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Tide Phase and Range Variations Between Inlets and Offshore Navigation Channels Hydrodynamic Tidal Model



Tides

Tidal Phase Differences

Flood Tide

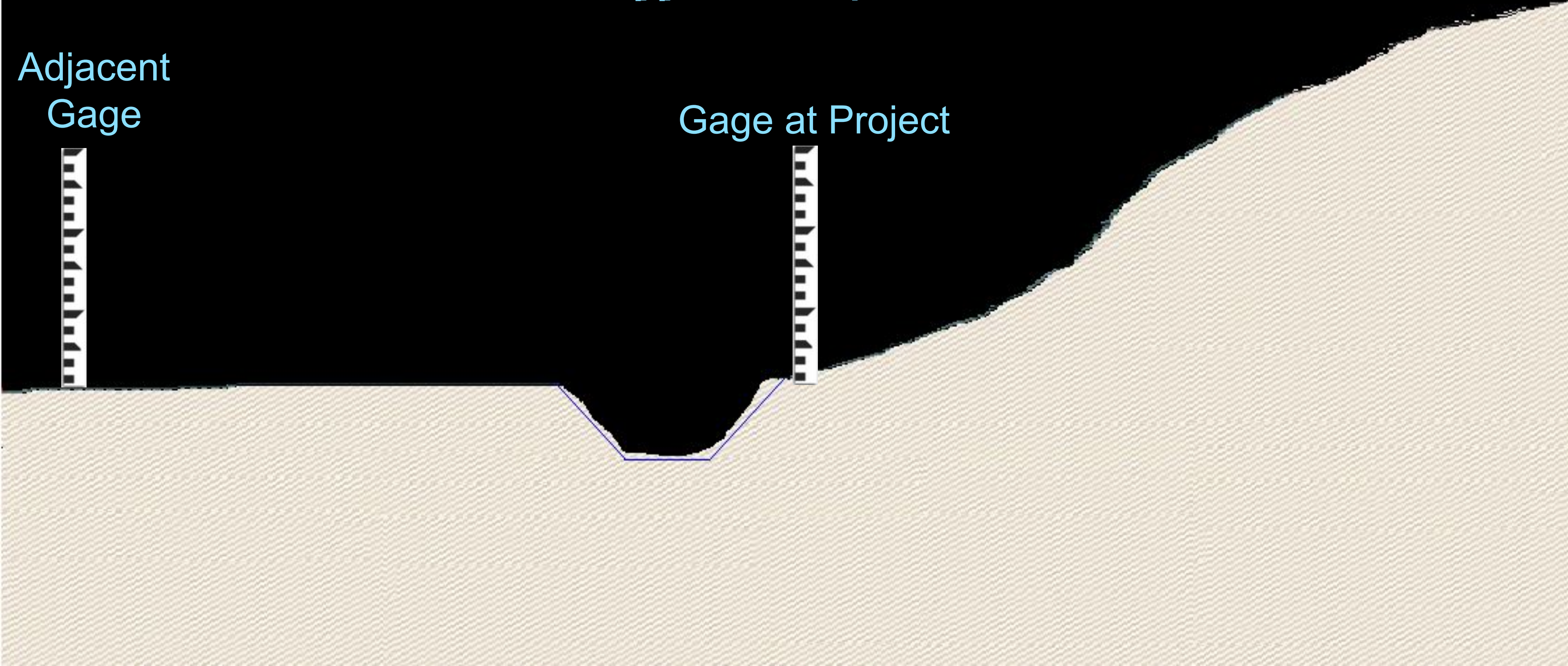
Ebb Tide

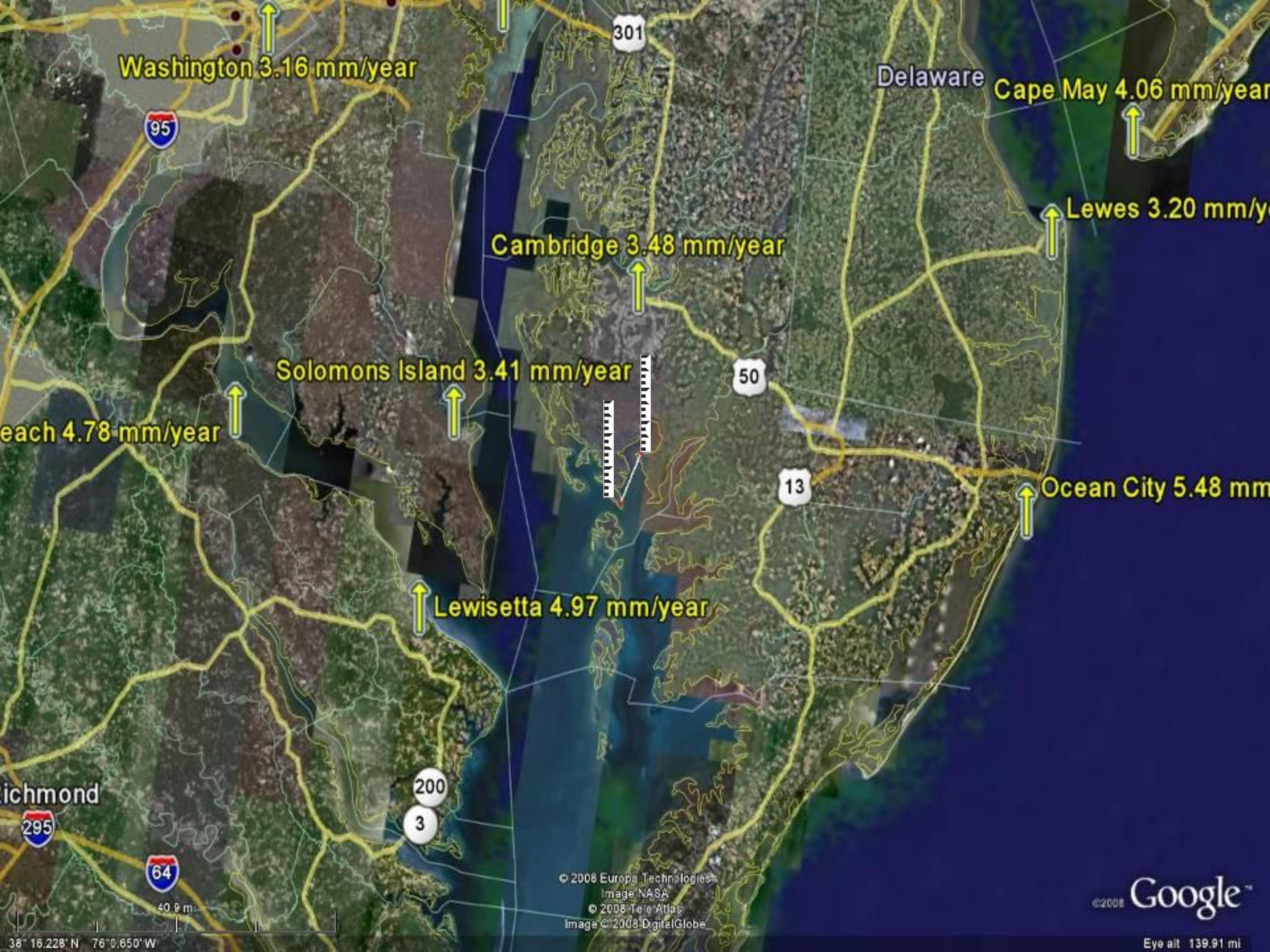
Slope on the Water

Delta in Gage Readings

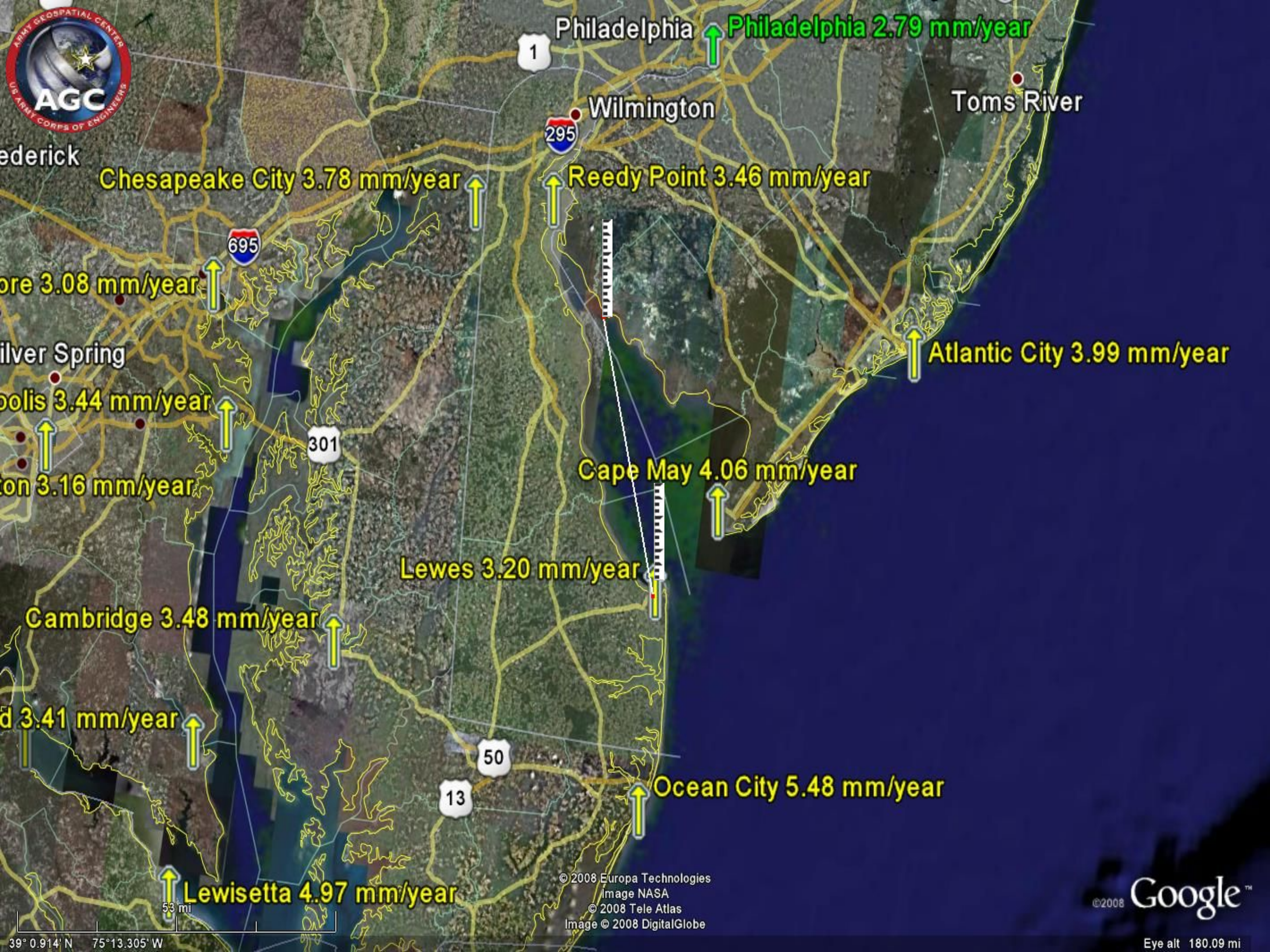
Appears Shallower

Appears Deeper





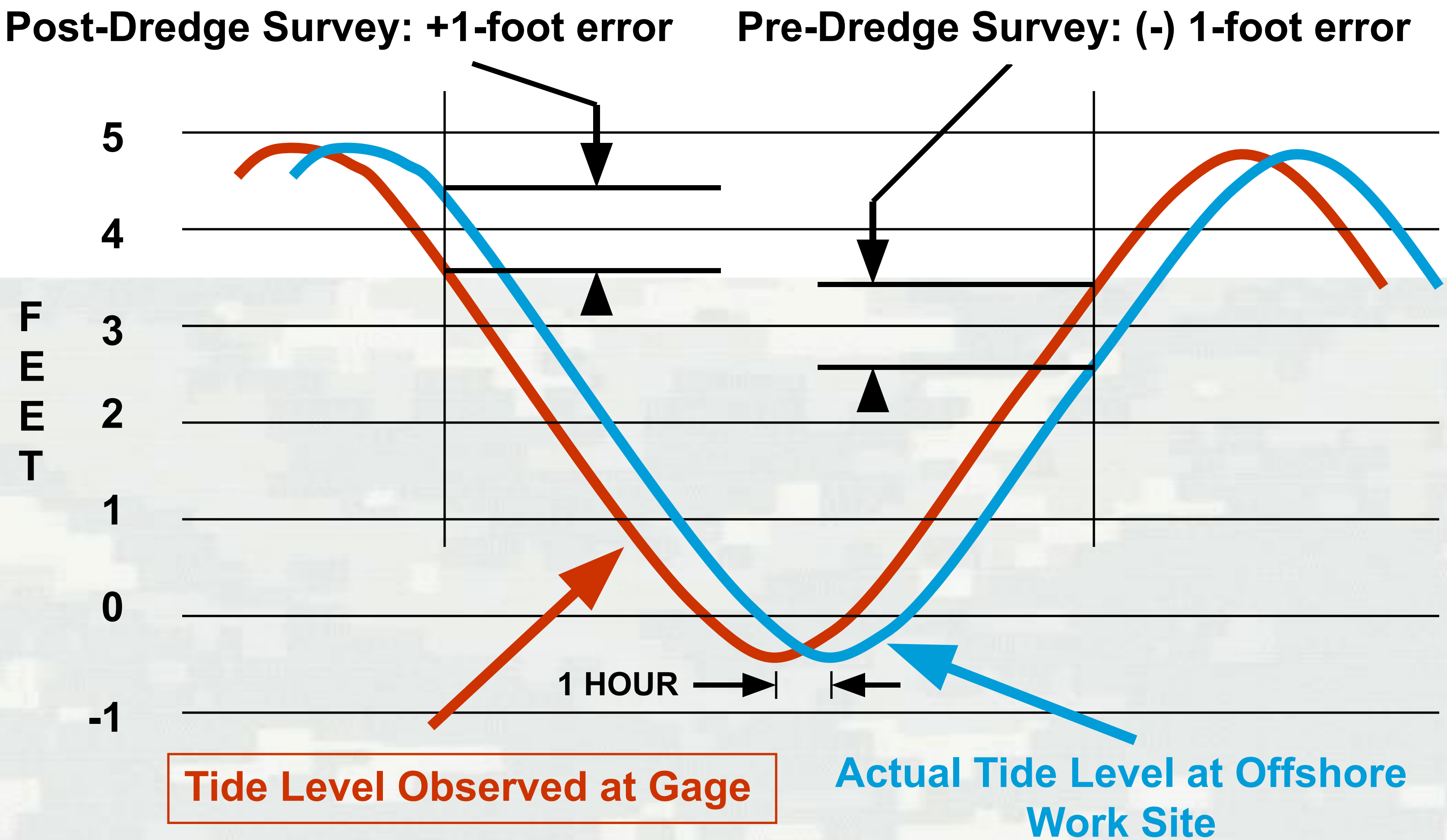
Washington 3.16 mm/year
Delaware
Cape May 4.06 mm/year
Lewes 3.20 mm/y
Cambridge 3.48 mm/year
Solomons Island 3.41 mm/year
each 4.78 mm/year
Ocean City 5.48 mm
Lewisetta 4.97 mm/year
ichmond
301
95
50
13
200
3
295
64
© 2008 Europa Technologies
Image NASA
© 2008 Tele Atlas
Image © 2008 DigitalGlobe
Google
38° 16.228' N 76°0.650' W
Eye alt 139.91 mi



AGC
ARMY GEOSPATIAL CENTER
US ARMY CORPS OF ENGINEERS
Philadelphia
Philadelphia 2.79 mm/year
Wilmington
Toms River
ederick
Chesapeake City 3.78 mm/year
Reedy Point 3.46 mm/year
ore 3.08 mm/year
ilver Spring
Atlantic City 3.99 mm/year
polis 3.44 mm/year
ton 3.16 mm/year
Cape May 4.06 mm/year
Lewes 3.20 mm/year
Cambridge 3.48 mm/year
d 3.41 mm/year
Ocean City 5.48 mm/year
Lewisetta 4.97 mm/year
1
295
695
301
50
13
53 mi
© 2008 Europa Technologies
Image NASA
© 2008 Tele Atlas
Image © 2008 DigitalGlobe
©2008 Google
39° 0.914' N 75°13.305' W
Eye alt 180.09 mi

Error Due to Uncertain (Unmodeled) Tides

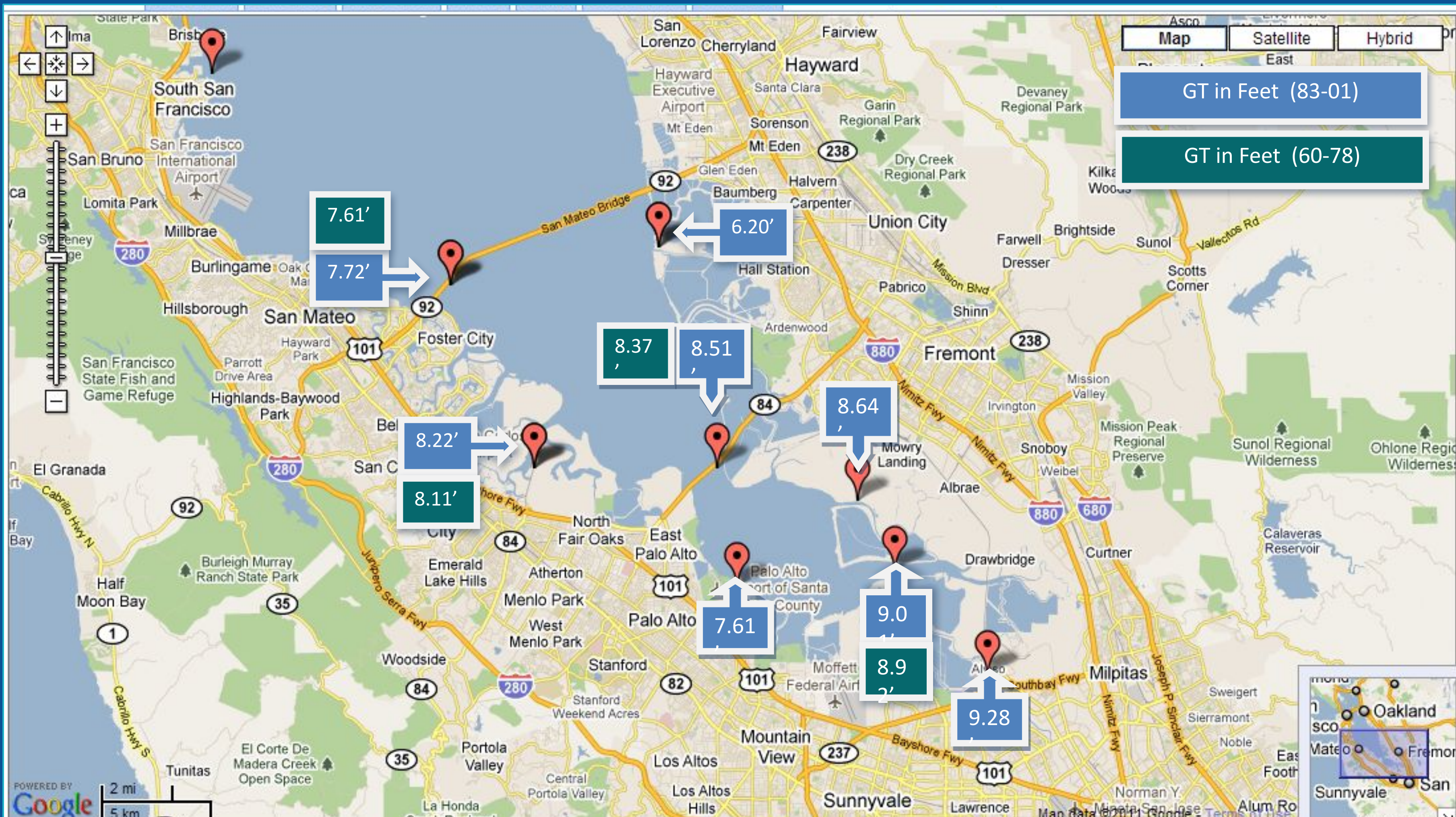
Pre-Dredge on Flood ... Post-Dredge on Ebb Tide

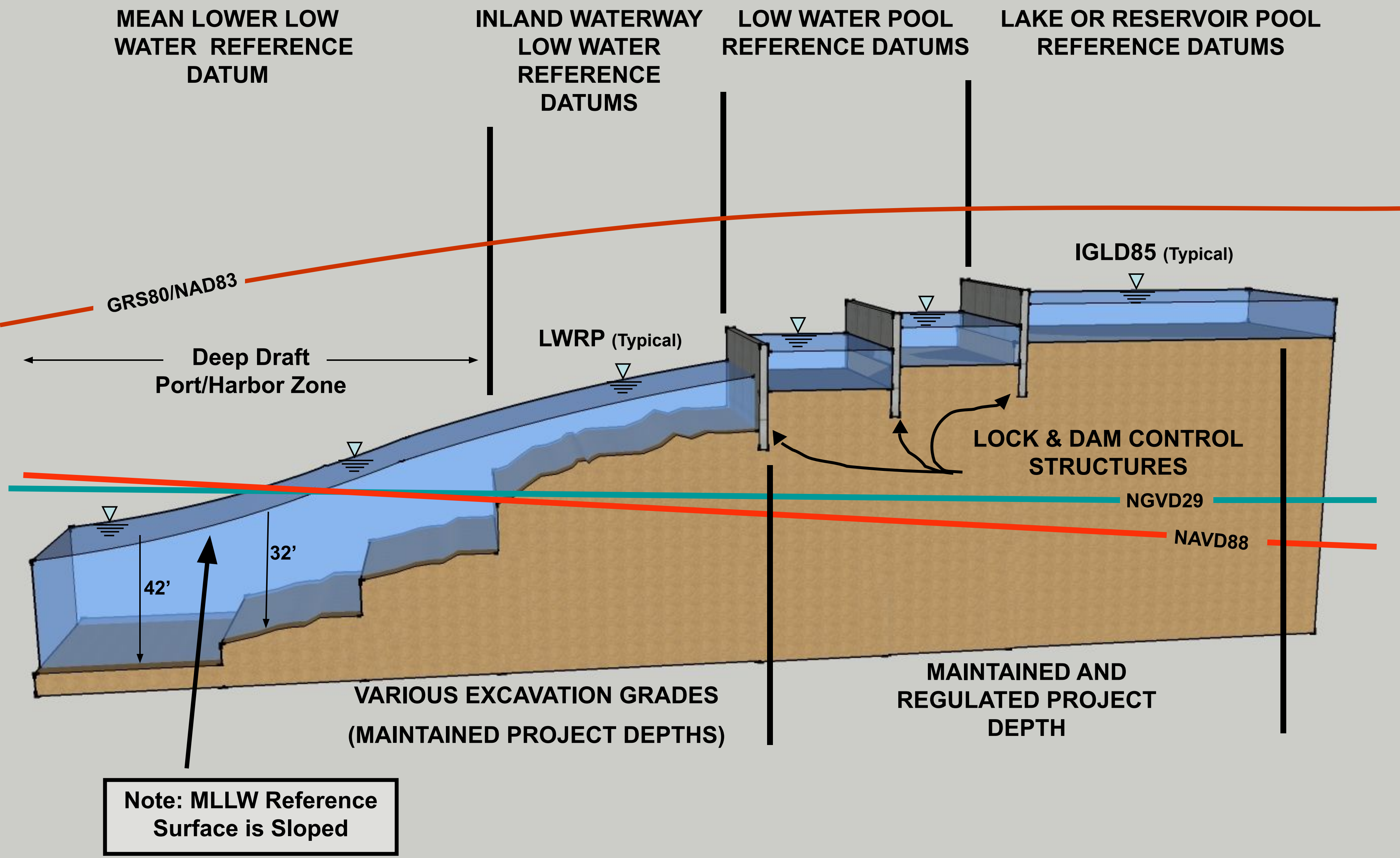


COMBINED ERROR = 2 FT ... GROSS OVERPAYMENT TO CONTRACTOR

(If Pre & Post surveys are reversed, then Underpayment)

Variations in Tidal Range

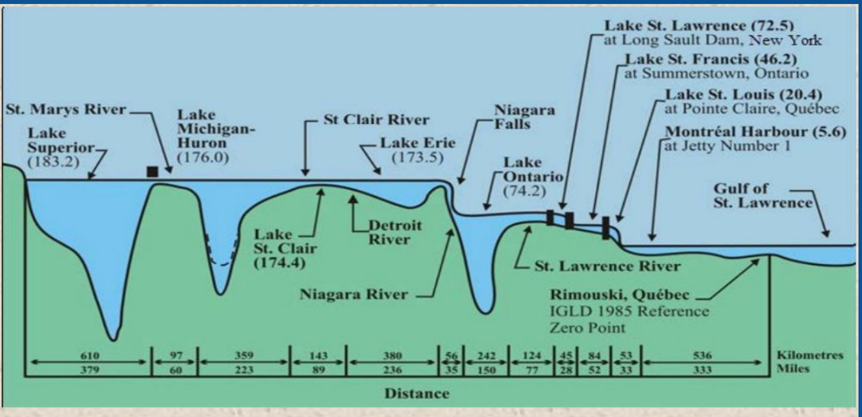




MEAN LOWER LOW WATER REFERENCE DATUM
INLAND WATERWAY LOW WATER REFERENCE DATUMS
LOW WATER POOL REFERENCE DATUMS
LAKE OR RESERVOIR POOL REFERENCE DATUMS
GRS80/NAD83
IGLD85 (Typical)
LWRP (Typical)
Deep Draft Port/Harbor Zone
LOCK & DAM CONTROL STRUCTURES
NGVD29
NAVD88
32'
42'
VARIOUS EXCAVATION GRADES
(MAINTAINED PROJECT DEPTHS)
MAINTAINED AND REGULATED PROJECT DEPTH
Note: MLLW Reference Surface is Sloped

International Great Lakes Datum (IGLD)

- Official time period of water level observations that are used for primary datum calculations
  - 7 year time period (Current IGLD is IGLD85 data period centered on 1985)
  - Considered for revision every ~25-30yrs to account for vertical movement due to glacial isostatic adjustment
  - Averages out seasonal fluctuations
  - The difference between IGLD 85 and NAVD88 is that NAVD88 uses orthometric heights and IGLD uses dynamic heights
  - Provides an international consistent water level datum network used for navigation, regulations, and modeling
  - **Next IGLD will be computed on period of 2017-2023 named IGLD2020**
    - **Anticipated release in 2025**
  - **Datum update website: https://tidesandcurrents.noaa.gov/datum-updates/**



IGLD 85 Heights (m) of LWD/Chart Datum for the Great lakes – St. Lawrence River System.

Tidal Datums

Tidal Datums

Base reference elevation from which *local* water levels are measured

Vertical Datum: Base elevation used as a reference from which to reckon heights or depths

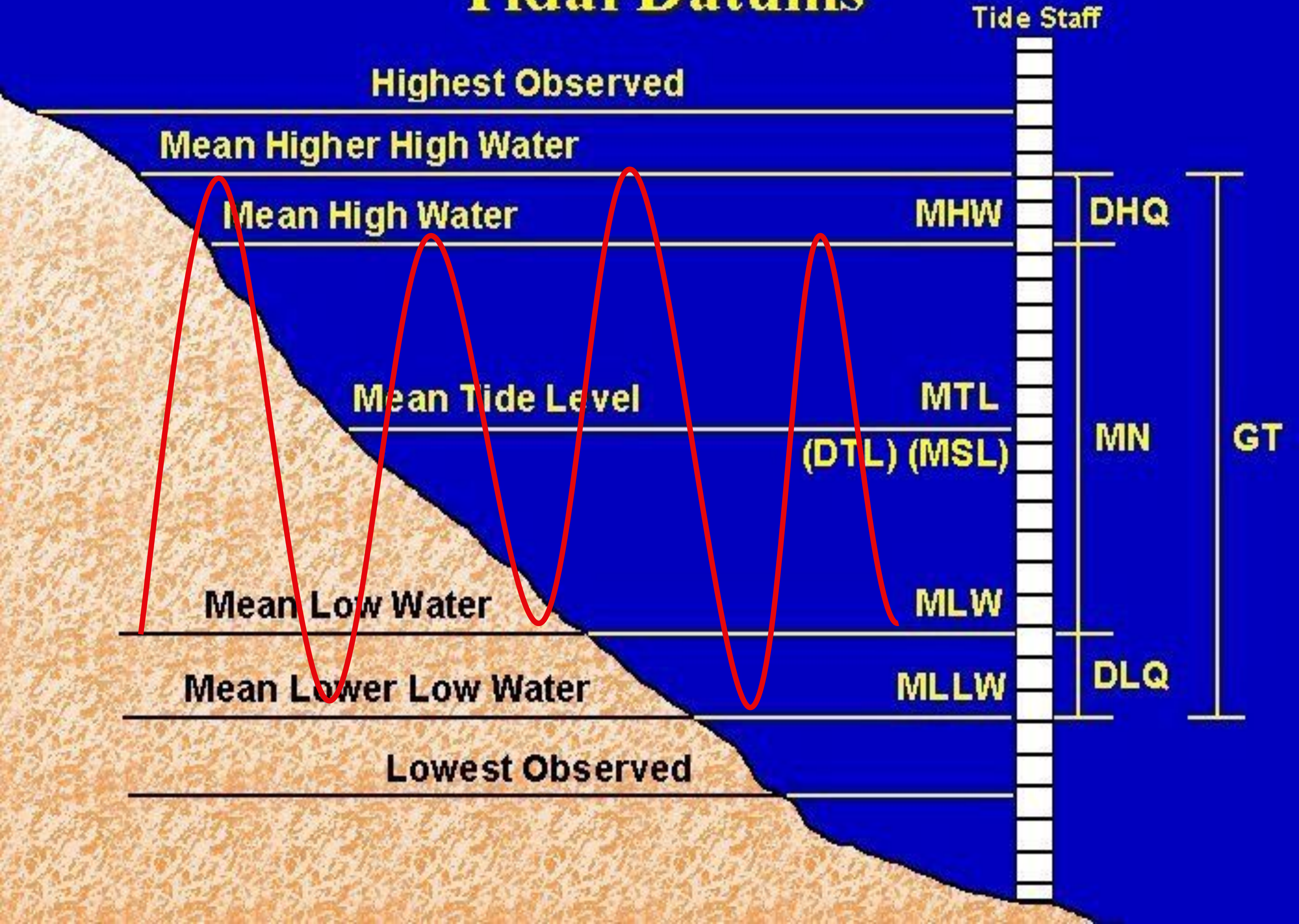
Tidal Datum : Local standard elevation defined by a certain phase of the tide from observed data *(i.e. MLW, MHW, MSL)*

- Derived from continuous observations over time at specific tide stations
- Are referenced to fixed and stable points on land *(Bench Marks)*
- Are local references and should not be extended into areas with different oceanographic characteristics
- Are also used as a basis for establishing legal boundaries and regulations

Chart Datum : Water level datum to which nautical chart soundings are referred

- USA chart datum is *Mean Lower Low Water (MLLW)* for tidal areas, or a *Low Water Datum (LWD)* for non-tidal areas

Tidal Datums



Tidal Datums

Principal tidal datums related to a beach profile

The intersection of tidal datums with land define marine boundaries

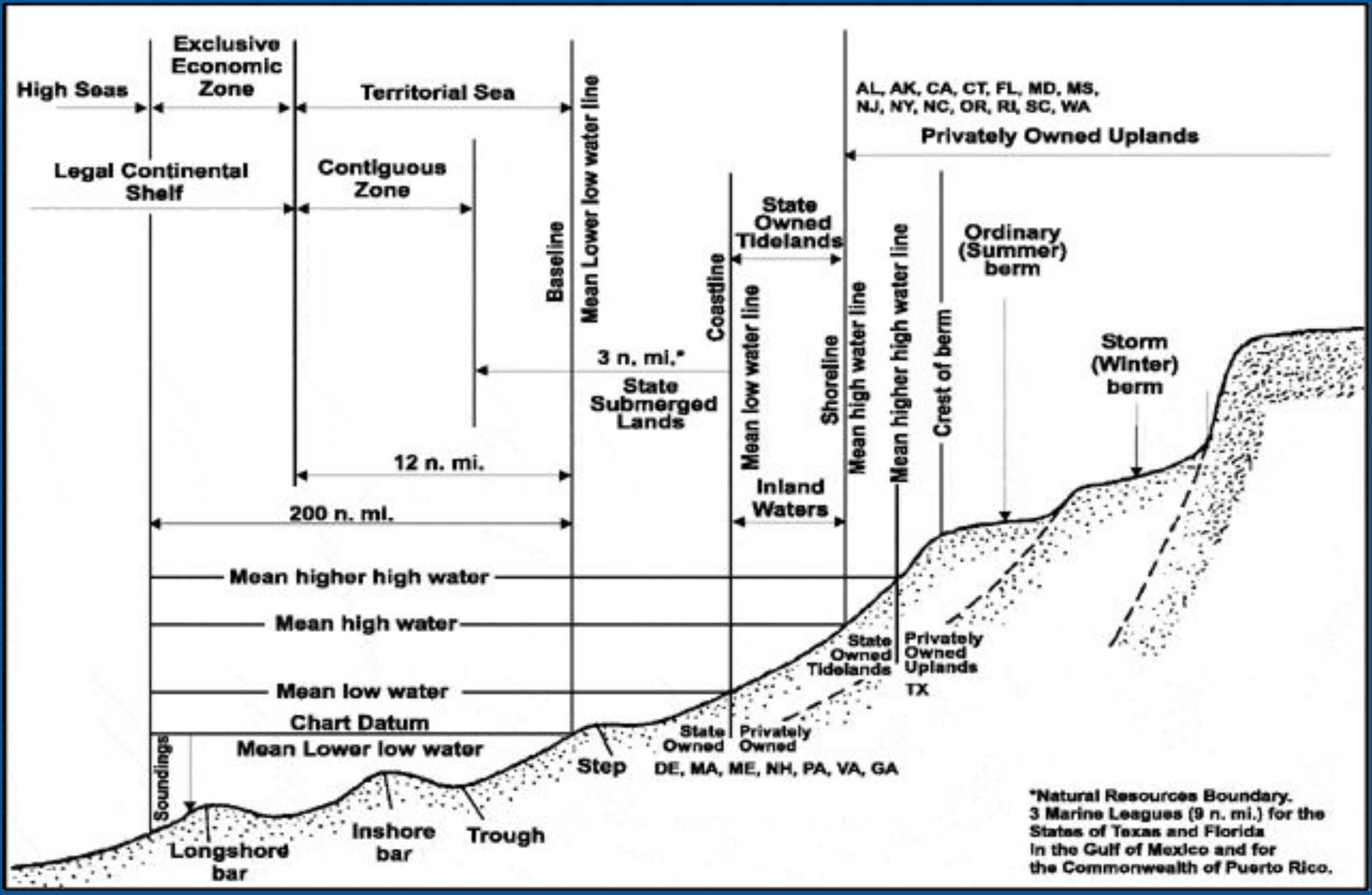


Chart Datum

The chart datum is the level of water that charted depths displayed on nautical charts are measured from. The chart datum is generally a tidal datum; that is, a datum derived from some phase of the tide. Common chart datums are lowest astronomical tide and mean lower low water.

Mean Lower Low Water

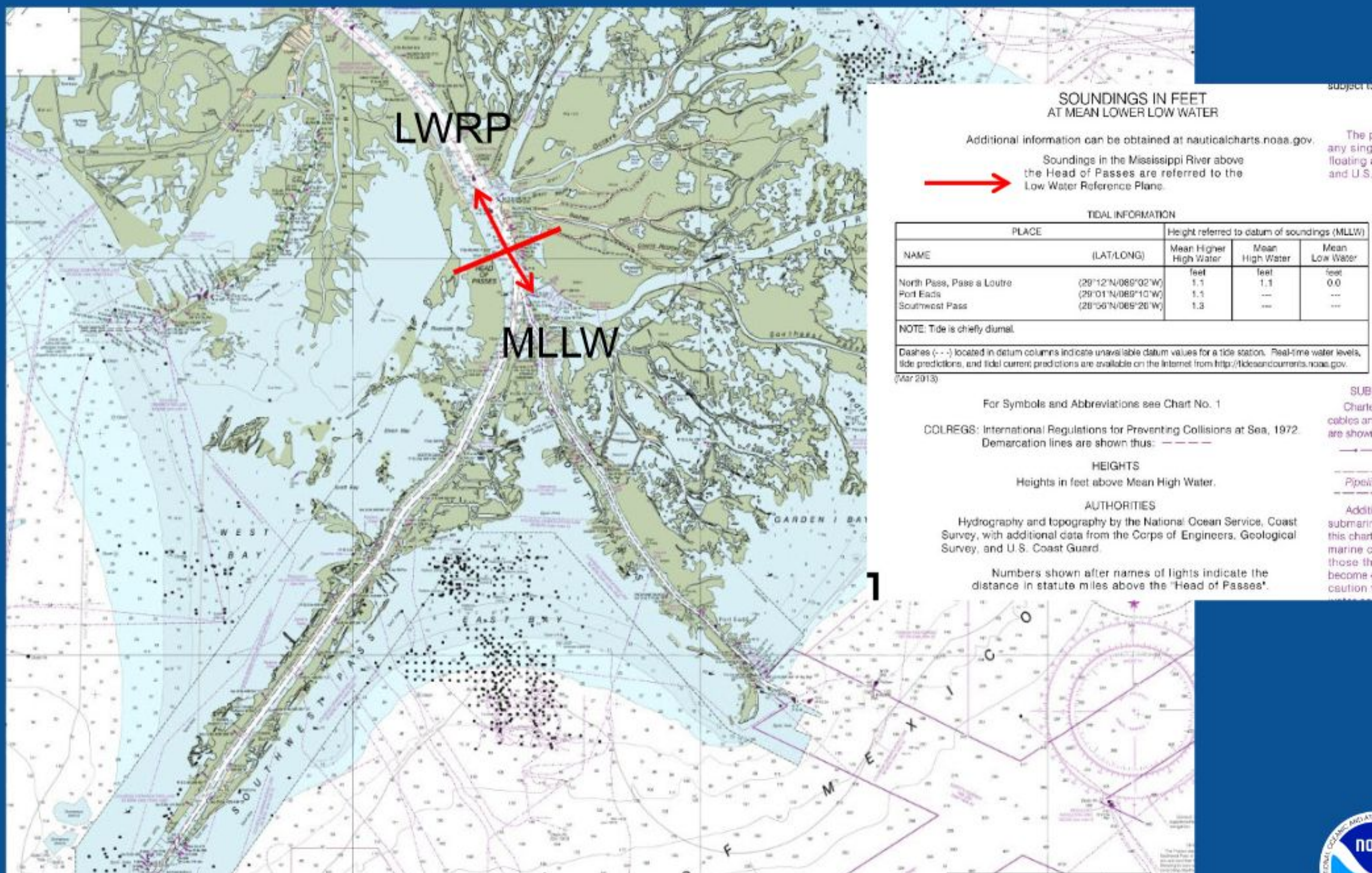
The United States' National Oceanic and Atmospheric Administration uses mean lower low water (MLLW), which is the average of the lowest tide recorded at a tide station each day during the recording period. MLLW is generally located above LAT and therefore some tidal states may have negative heights. The advantage of using Mean Lower Low Water is avoiding the costs and confusion that moving to LAT would involve.

Lowest Astronomical Tide

Many national charting agencies, including the United Kingdom Hydrographic Office and other hydrographic services, such as those of Canada and Australia, that originated with the British Admiralty use the Lowest astronomical tide (LAT), the height of the water at the lowest possible theoretical tide, as chart datum. The advantage of using LAT is that all tidal heights must then be positive (or zero) avoiding possible ambiguity and the need to explicitly state sign. Calculation of the LAT only allows for gravitational effects so lower tides may occur in practice due to other factors (e.g. meteorological effects such as high pressure systems).

Special Datums

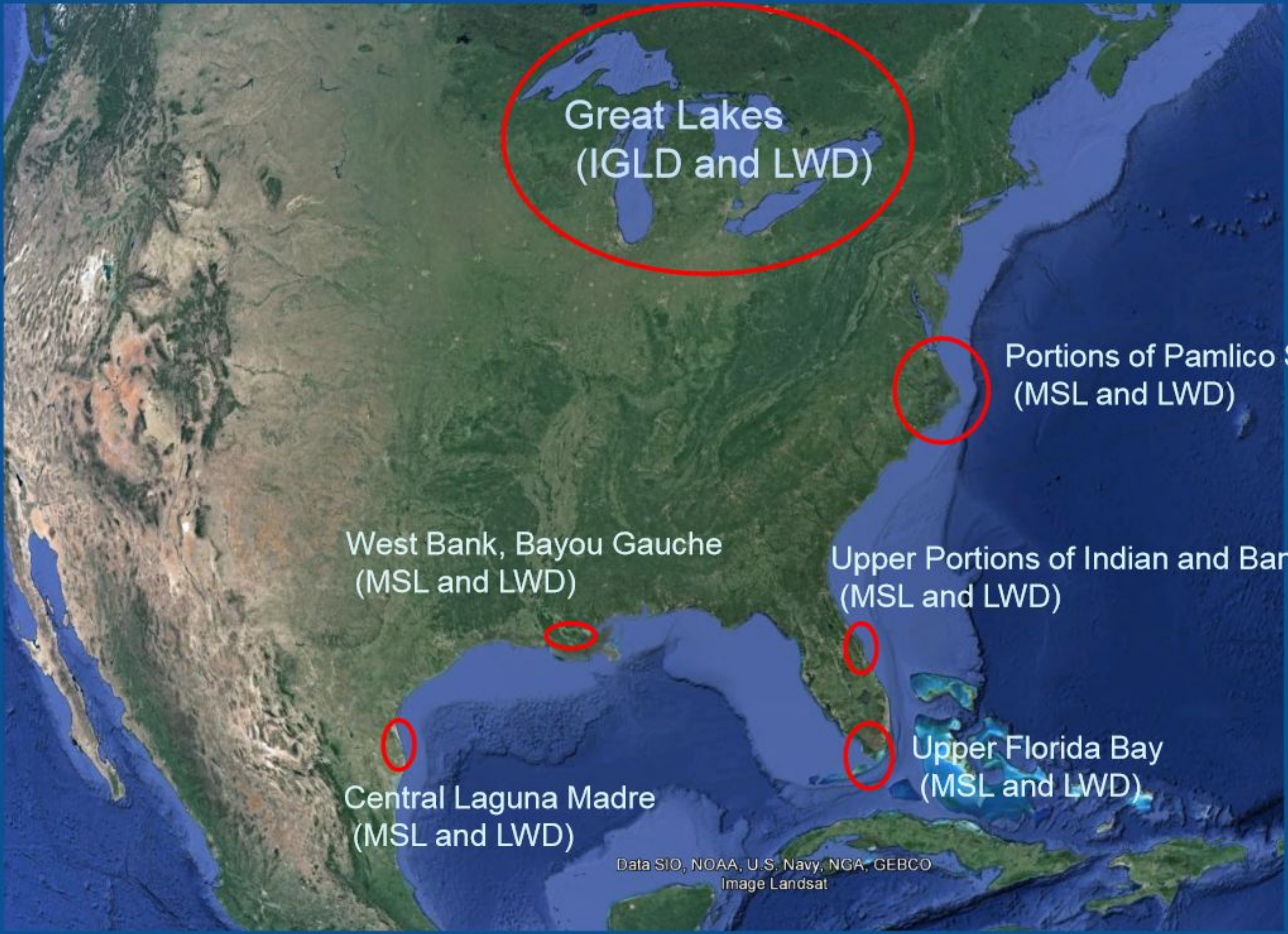
Lower Mississippi River – Transition from MLLW to USCOE-Determined Datum of Low Water Reference Plane (LWRP)



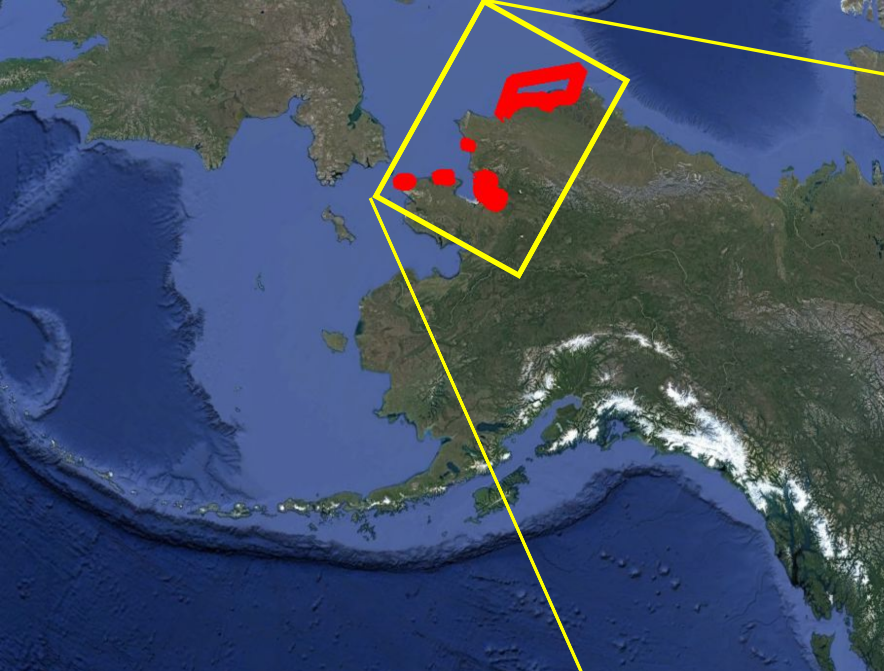
Datums in Non-Tidal Regions

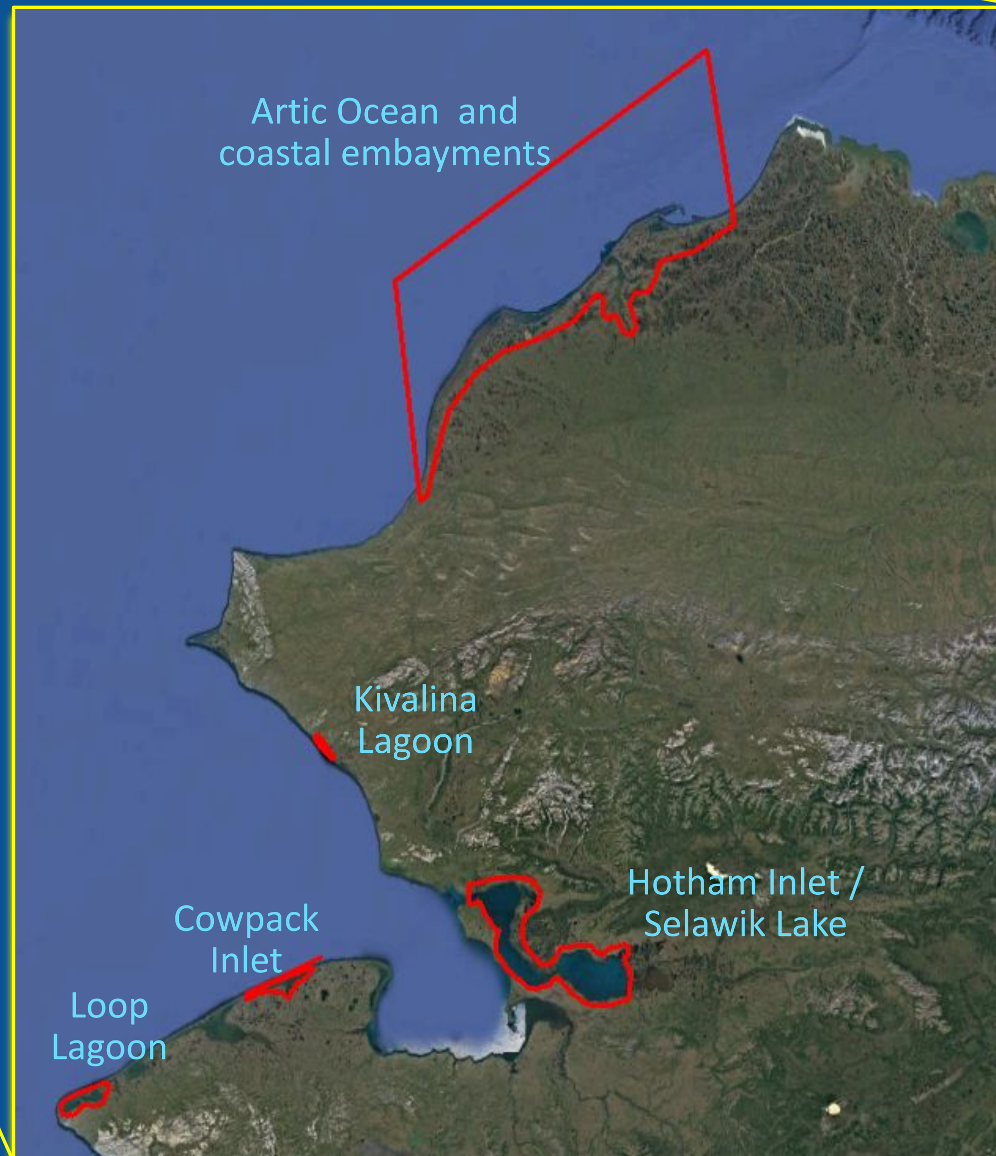
- "The plane of reference for depth measurements in the Atlantic Ocean is Mean Lower Low Water (MLLW), a tidal datum. In the sounds and rivers shown on this chart, except near the ocean inlets, a periodic tide is negligible or has a mean range of less than one half foot. In these areas, the plane of reference for depth measurements is Low Water Datum (LWD). LWD is determined by subtracting one half foot from the observed Mean Water Level (MWL) in the area. MWL is determined from the average of the observed hourly heights adjusted to a common 19-year period. This 19-year period corresponds to the same 19-year period for which tidal datums, including MLLW, are based and is referred to as the National Tidal Datum Epoch (NTDE)"

Non – Tidal Regions for Lower 48 States



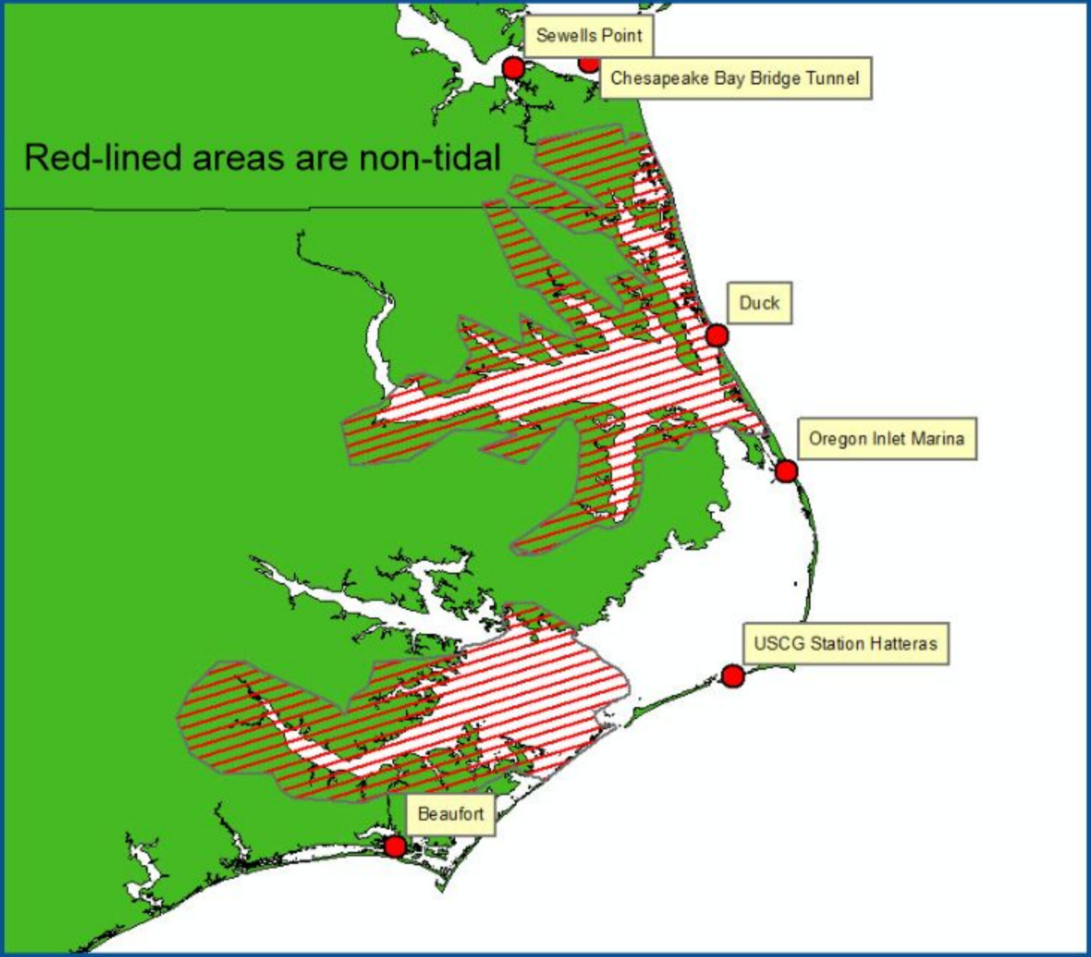
Non-Tidal Regions for Alaska





Non-Tidal Areas – Pamlico Sound, NC

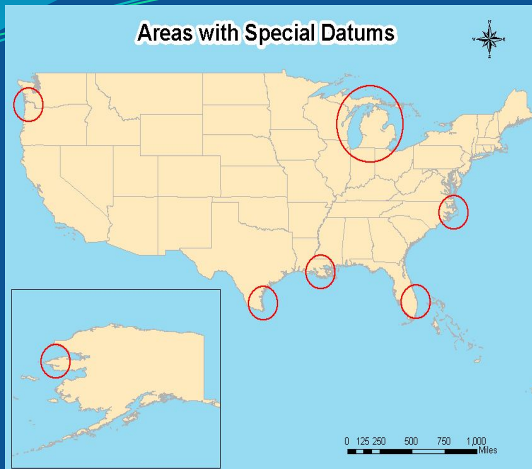
Classified by Observations and Delineated using Vdatum Tidal Model



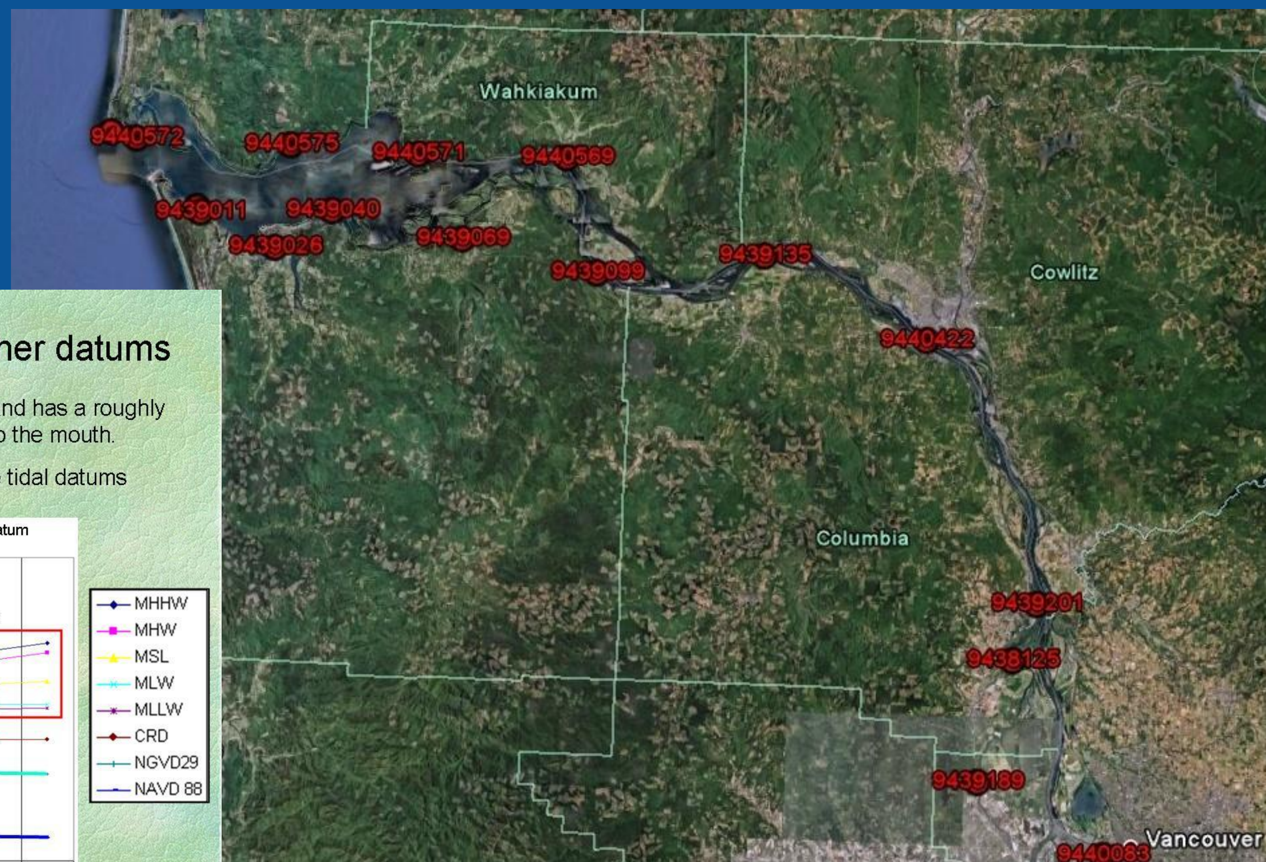
Datums

Special Datums

(Non-Tidal Regions)

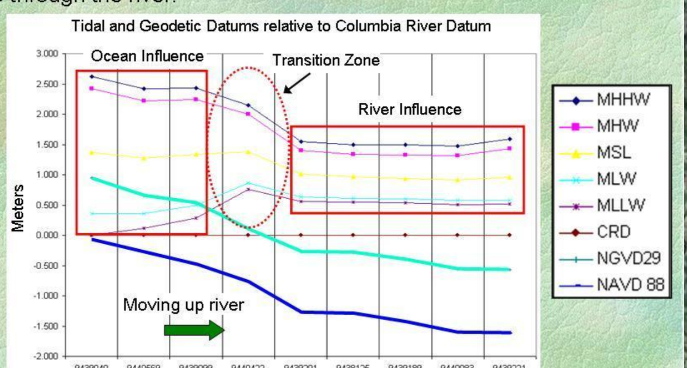


Columbia River, OR & WA



What makes CRD unique from other datums

- CRD is tied to geodetic datums through NGVD29 and has a roughly linear trend with a downward slope from Portland to the mouth.
- Changes in tidal characteristics can be seen as the tidal datums step through the river.

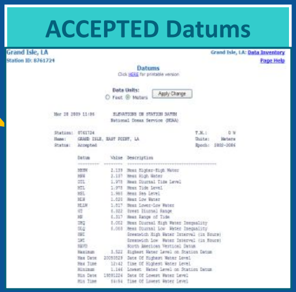


Datum Computation

Datum Methods

Datum Computation

Verified Monthly Means



1. Make observations (NWLON Stations)
2. Tabulate the tides (Data Processing)

3. **Compute tidal datums**

A. Control Stations - Stations with ***over*** 19 years data

Primary determination (NTDE Tidal Datums)

Method: *First Reduction* or Arithmetic mean

= Average of observations over a 19-year National Tidal Datum Epoch (NTDE)

B. Subordinate Stations - Stations with ***less than*** 19 years data

Secondary determination (NTDE *Equivalent* Tidal Datums)

Method: *Simultaneous comparison* - Subordinate Station with Control Station

3 Methods for Simultaneous Comparison: (Depending on tide type)

- Standard Method
- Modified-Range Ratio Method
- Direct Method

Datum Methods

Datum Computation

A. Control Stations – ***Primary determination*** using ***First Reduction***

```
Station ID: 8557380                                  PUBLICATION DATE:  04/21/2003
Name:        LEWES, FT. MILES
             DELAWARE
NOAA Chart: 12216                                    Latitude:          38° 46.9' N
USGS Quad:  CAPE HENLOPEN                            Longitude:         75°  7.2' W

                          T I D A L   D A T U M S

Tidal datums at LEWES, FT. MILES based on:

     LENGTH OF SERIES:       19 Years
     TIME PERIOD:            January 1983 - December 2001
     TIDAL EPOCH:            1983-2001
     CONTROL TIDE STATION:

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

     HIGHEST OBSERVED WATER LEVEL (03/06/1962)     =  2.810
     MEAN HIGHER HIGH WATER (MHHW)                 =  1.418
     MEAN HIGH WATER (MHW)                         =  1.290
     NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)     =  0.801
     MEAN SEA LEVEL (MSL)                          =  0.680
     MEAN TIDE LEVEL (MTL)                         =  0.669
     MEAN LOW WATER (MLW)                          =  0.048
     MEAN LOWER LOW WATER (MLLW)                   =  0.000
     LOWEST  OBSERVED WATER LEVEL (01/10/1978)     = -1.284

National Geodetic Vertical Datum (NGVD 29)

Bench Mark Elevation Information              In METERS above:

     Stamping or Designation                  MLLW        MHW

     NO 20 1975                                3.142      1.852
     7380 B 1979                               2.564      1.274
     37 1947                                   3.252      1.962
     7380 D 1986                               2.904      1.614
     7380 E 1986                               1.955      0.665
     GPS S-5 1990                             12.784     11.494
     GPS S-5A 1990                             3.192      1.902
     7380 F 1997                               1.883      0.593
     7380 G 1997                               2.015      0.725
```

- ***Average*** of observations over a 19-year National Tidal Datum Epoch (NTDE)
- Mean of all tidal heights for a particular phase (ie HW or LW) over the epoch time period
- Accepted NTDE datum values for that station
- Available online at CO-OPS Tides & Currents Website
- Used as a reference for converting elevations taken in that area to a common datum
  (i.e. hydro survey depths to MLLW for charting)

Datum Methods

Datum Computation

B. **Subordinate Stations - *Secondary determination*** using ***<u>Simultaneous Comparison</u>***

Method of Comparison of Simultaneous Observations is a two-step process:

1. Compute the differences and/or ratios in the tidal parameters and differences in mean values between short-term and control stations over the period of simultaneous comparison.

2. Apply the differences and ratios computed above to the NTDE Accepted Values at the control station. This provides equivalent NTDE values for the short-term station.

Datum Methods

Methods for Subordinate Stations

Simultaneous Comparison – compare monthly means between control & subordinate station

1. Choose an appropriate **control station** to compare with
2. Choose an appropriate **computation method** for the tide type
3. **Compare values to the control stations** to correct to NTDE equivalent

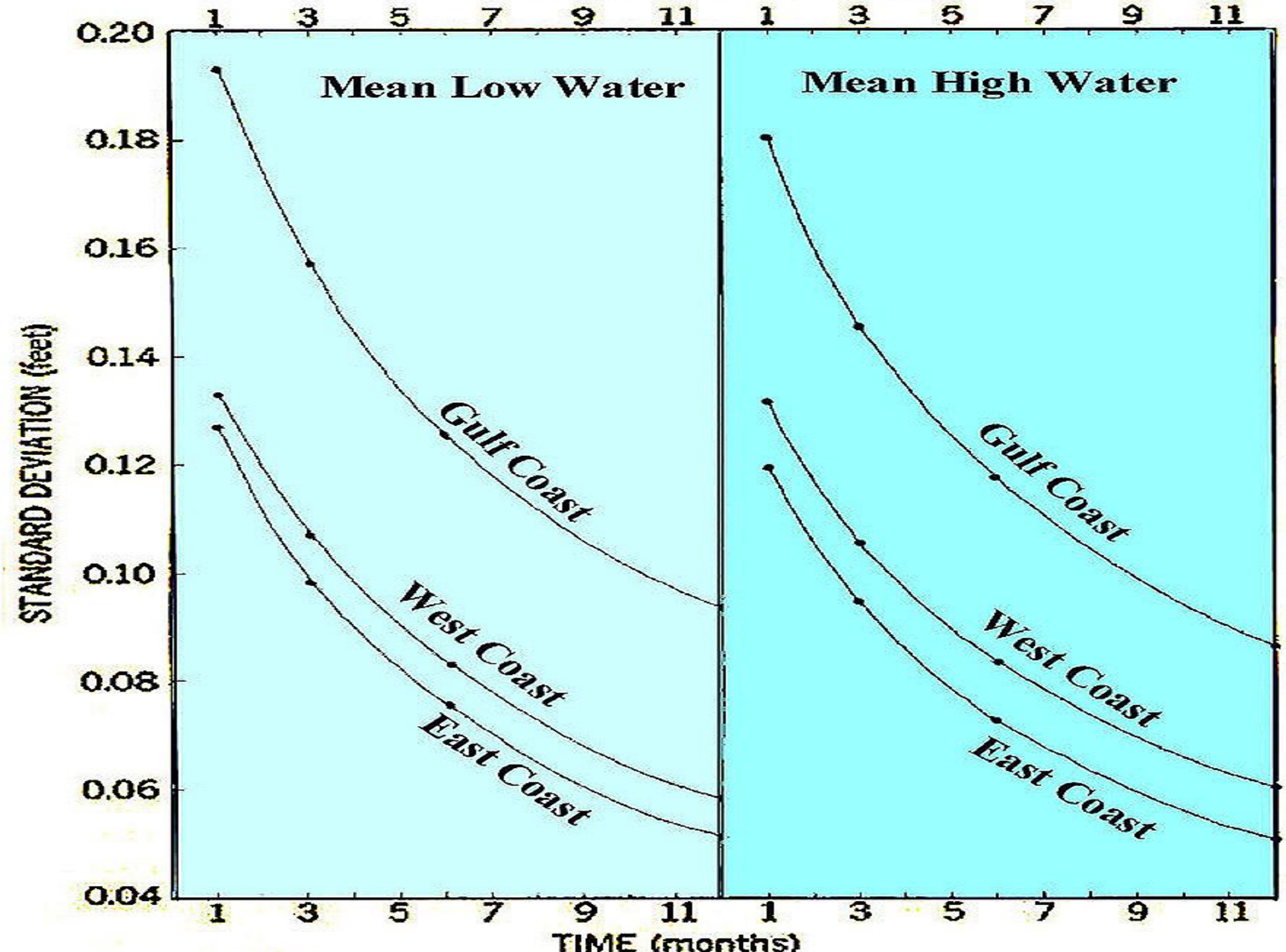
***Standard Method*:** (mixed tide types) **West Coast & Pacific Islands**

***Modified-Range Ratio Method*:** (semidiurnal & diurnal) **East Coast, Gulf Coast, & Caribbean**

***Direct Method*:** Generally used when a full range of tidal values are not available

Datums determined by direct comparison with appropriate control station

Error Bounds



R. L. SWANSON – GENERALIZED ACCURACIES OF TIDAL DATUMS

Table 1. Generalized accuracy of tidal datums from short series of observation; based on one standard deviation (one-sigma) uncertainty level (from Swanson 1974).

Series Length (months)	East Coast	Gulf Coast	West Coast
1	0.13 ft	0.18 ft	0.13 ft
2	0.10 ft	0.15 ft	0.11 ft
3	0.07ft	0.12 ft	0.08 ft
4	0.05 ft	0.09 ft	0.06 ft

Use of First-Reduction Procedure for Subordinate Stations

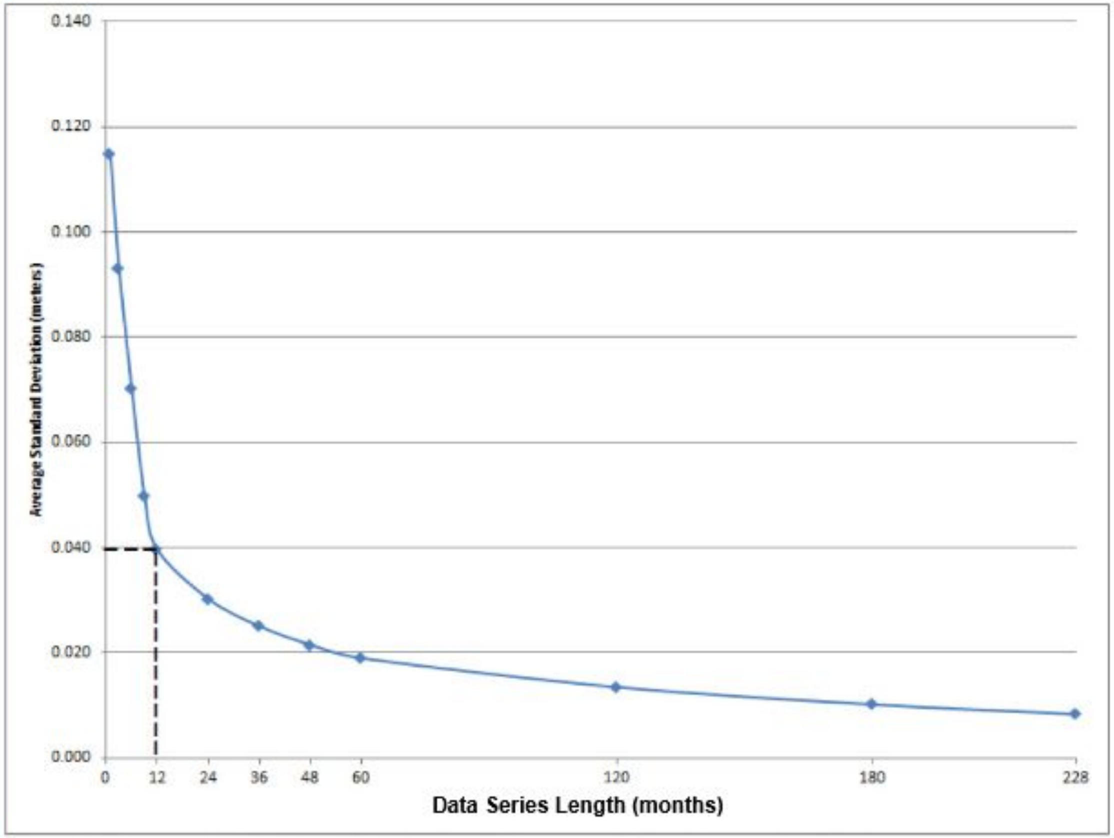


Figure 4. Average standard deviation (FRED datum error) along the coast of Alaska.

http://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_070.pdf

Tidal Analysis Datum Calculator

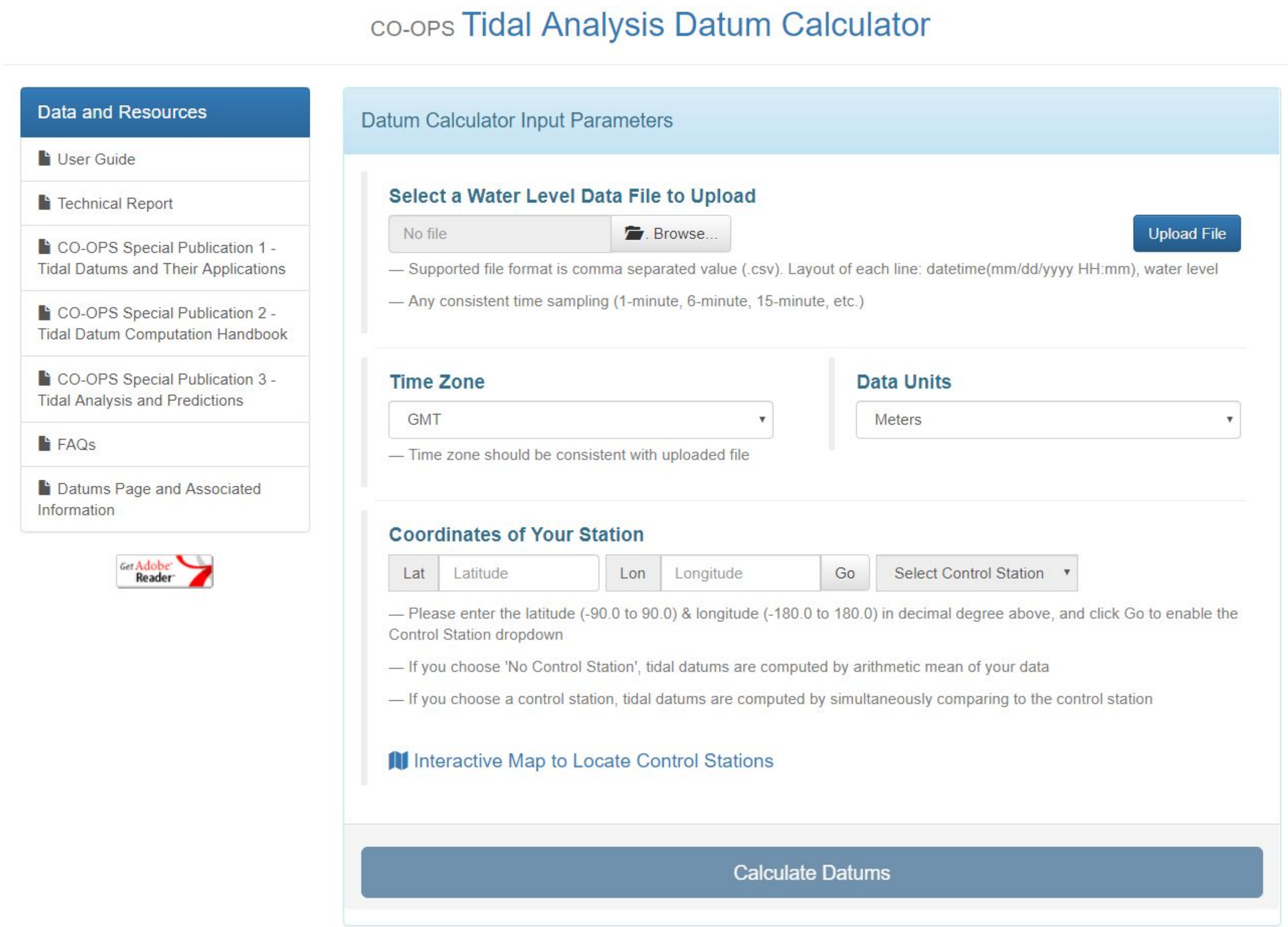
Tidal Analysis Datum Calculator

Tidal Datum Calculator Access:

https://access.co-ops.nos.noaa.gov/datumcalc/index.jsp

WE LOVE YOUR FEEDBACK!

Tidal Analysis Datum Calculator



What TAD does for you:

First Reduction Tidal Datums (FRED) – Method 1

If data is >= 18.6 years

To obtain NTDE tidal datums

Monthly Mean Simultaneous Comparison (MMSC) – Method 2

If data is >= 1 month and < 18.6 years

To obtain NTDE **equivalent** tidal datums

Tide By Tide Comparison (TBYT) – Method 3

If data is <1 month

To obtain NTDE **equivalent** tidal datums

Why to Tie or Not to Tie to NTDE:

Pros:

Generates a long term equivalent datum.

Short term effects (meteorological, seasonal, etc.) are factored out when compared to a long term Control Station.

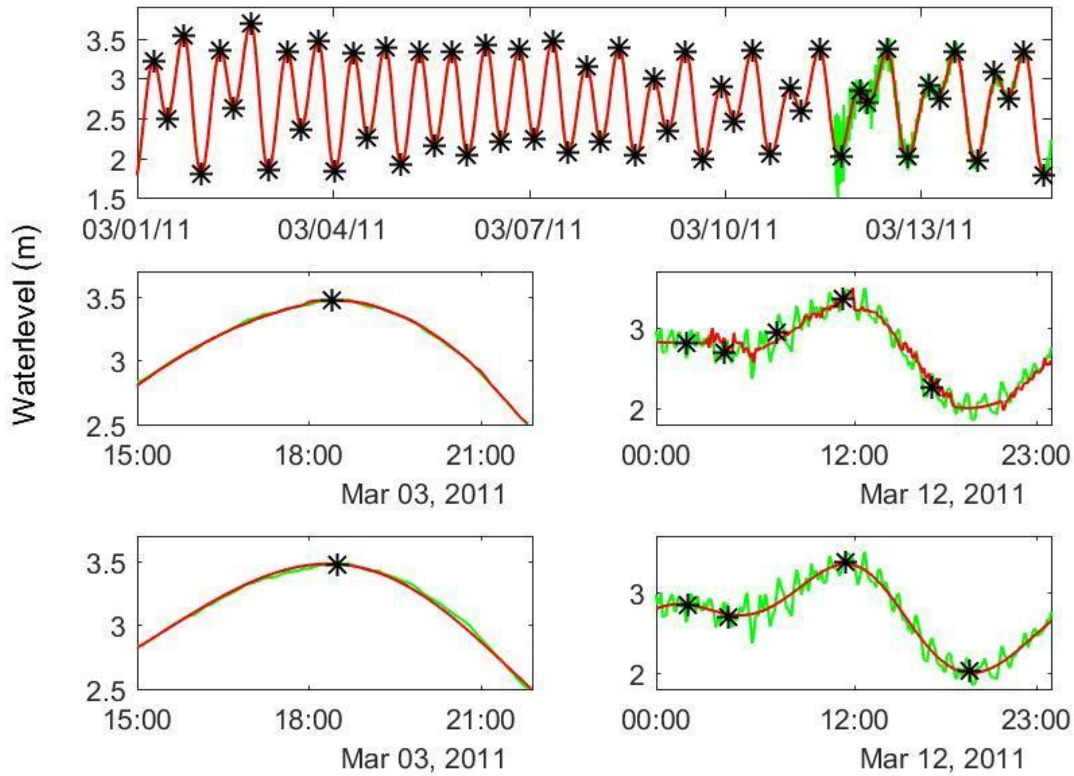
Cons:

Requires a reasonable Control Station that is already tied to the NTDE.

Generates datums that reflect a long time period as opposed to shorter, more seasonal or local situations.

What the TAD does for you:

Tide Picking in the Datum Calculator



Technical Report https://access.co-ops.nos.noaa.gov/datumcalc/docs/TechnicalReport.pdf

Why or Why not to Choose a Control Station?

FRED, Or MMSC TBYT

FRED Datums: *Average* of observations over the Observed time period

- Not tied to an epoch

    - Better reflect current sea level condition

    - Risk of time segments in an anomalous oceanographic and meteorological period

83-01 NTDE Equivalent Datums (MMSC or TBYT):

    - Tied to an epoch

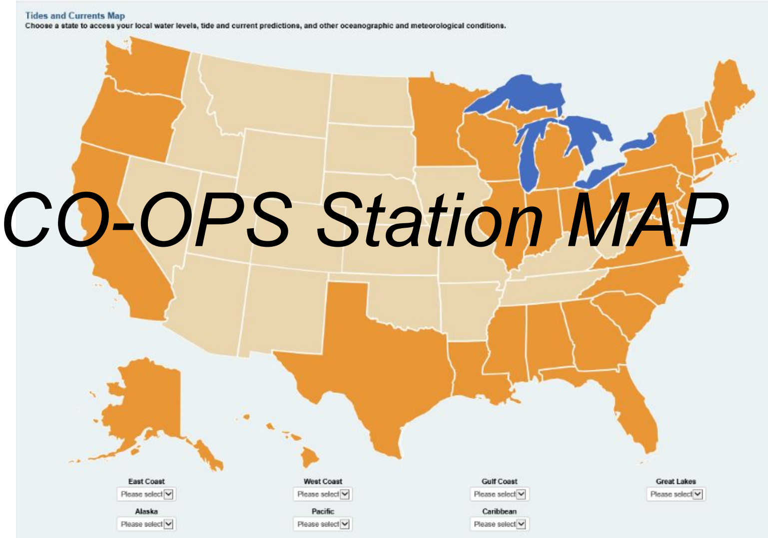
    - Reflect historical sea level condition in 1992

    - Average out short-term oceanographic and meteorological fluctuations

Tidal Analysis Datum Calculator

Choose a Control Station

- Use the CO-OPS Station Map to see where the control stations are located
- Simultaneous water level data plot between control and subordinate
- https://tidesandcurrents.noaa.gov/map/

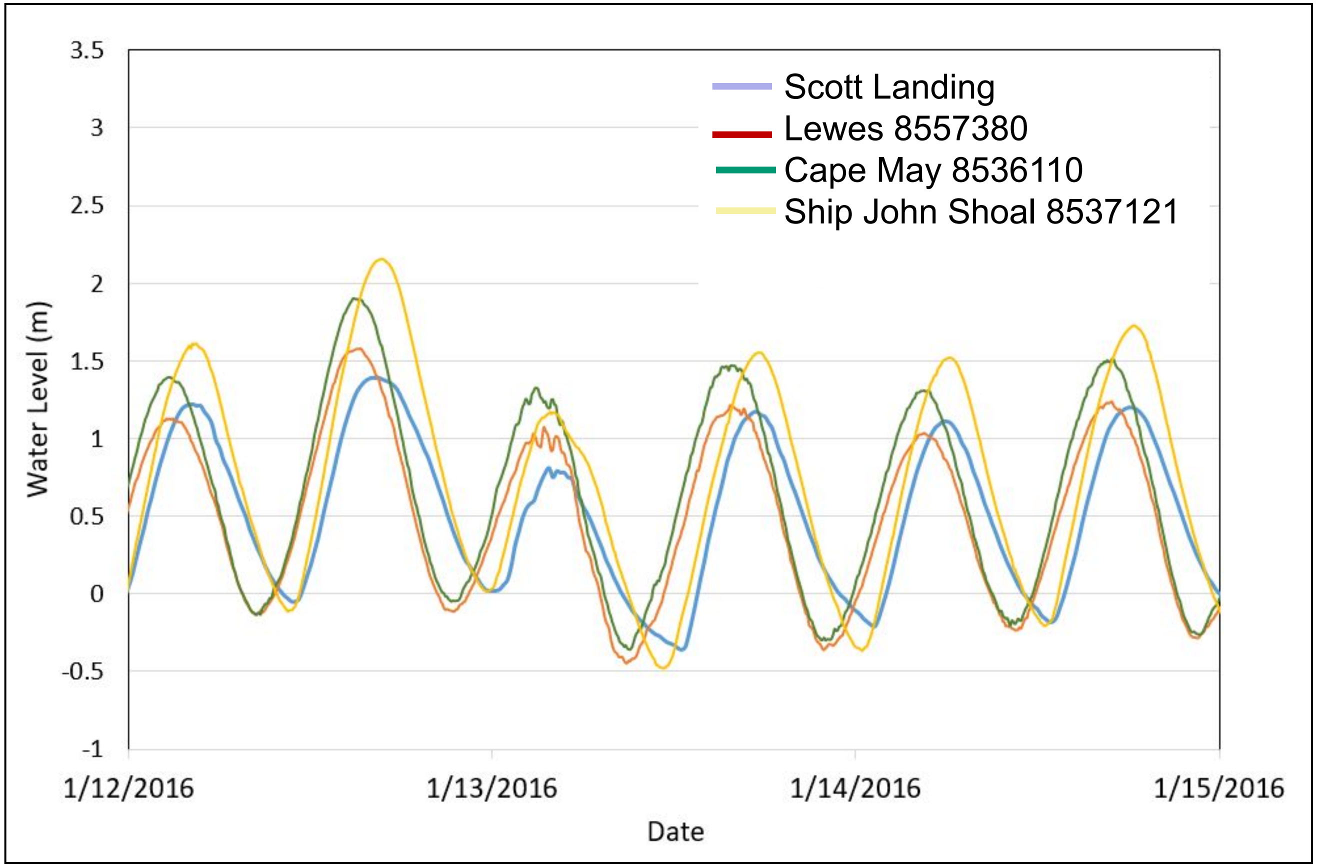


Tidal Analysis Datum Calculator

Plot and compare your station data to potential control stations

Select data for 4-5 day period for all stations with date and time then insert a plot

What to look for:
- Tide type
- Tidal Curve Time off sets
- Meteorological effects
- Shallow water effects



Tidal Analysis Datum Calculator

User Guide Document and FAQs

NOAA Tidal Analysis Datums Calculator Users Guide

The Tidal Analysis Datums Calculator (TAD) allows users to load in a file of water level data to quickly generate a simple suite of tidal datums. This tool is built on a foundation of simplified algorithms that already exist in various National Ocean Service (NOS) products but there is no requirements for users to enter information such as benchmark diagrams, sensor specifications and station metadata. The tool will help public and private users to analyze and understand water level data in their areas of interest by calculating preliminary datums from user data.

Use the tool to compute datums:

Step #1: Browse your data file

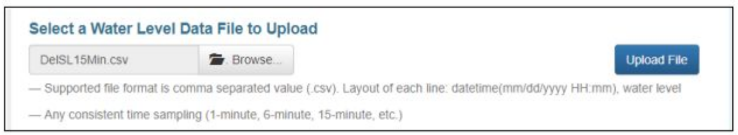


Figure 1. Browse and upload your file

Select the water level data file by clicking "**Browse**" button and then navigate to the file on your PC (Figure 1). The tool supports .csv data format. Once you select a file, click "**Upload File**". The file should only contain two columns, time stamp and water level data (Figure 2). Delete any extra columns. Below are the requirements for input files:

- Date format: .csv file in the format of timestamp, water level (mm/dd/yyyy HH:MM, xxx.xxx or mm-dd-yyyy HH:MM, xxx.xxx)
- Header: a single line of header or no headers
- Time sampling: any consistent time intervals
- Gaps: no more than 3 hours. The datum calculator will fill in all gaps less than 3 hours. For any gaps more than 3 hours, the datum calculator treat them as separated time segments and only compute tidal datums for the longest continuous time segment.
- Data length: maximum file size of 50 MB. There is no limitation for the minimum data length. However, it is strongly recommended that your date length is at least 2 weeks long because that is about the period of the major harmonic constituent M2. Otherwise, the error associated with the computed datums will be so high and there is no meaning

NOAA Tidal Analysis Datums Calculator FAQs

Frequently Asked Questions

1. First Reduction (FRED) or 19-year equivalent datum by MMSC or TBYT? Why or Why not?
2. How to choose a control station?
3. What are the uncertainties associated with tidal datums?
4. What if my data file contains gaps? Any QA/QC tips for my data?

1. First Reduction (FRED) or 19-year equivalent datum by MMSC or TBYT? Why or Why not?

A 19-year equivalent datum provides the user with the historic perspective of your data associate with the last 19 years. For instance, if tidal datums at a short-term station are computed by simultaneously comparing to a control station on 1983-2001 National Tidal Datum Epoch (NTDE), tidal datums at the short-term station are tied to the sea level condition in the middle of 1983 and 2001, which is 1992.

Keeping your data independent from NTDE will generate a different result from 19-year equivalent datums. However, uncoupling your data from NTDE may give you a better picture of more recent conditions verses what has happened over the last two decades. It should be noted that depending on how long your data record, short term episodic events like storms can have a significant effect on the computed sea level. Tying your data to the NTDE will average out short-term meteorological, hydrologic and oceanographic fluctuations.

Looking at both results may be the best option, when trying to gain perspective on how your site has responded to past and recent tidal and meteorological conditions.

2. How to choose a control station?

In order to choose the best control station for a short-term station, a comparison of tidal characteristics between several potential controls and the short-term station is recommended. Generally, the best control station will have tidal characteristics such as number of tides per day, range of tide, time of highs and lows, etc., that most closely resemble the subordinates characteristics, including during periods of greater non-tidal influences such as weather events. Control stations nearby that are within the same bay, inlet, or similar geographic and hydrodynamic environments as the short-term station (i.e., having the same parcels of water

https://access.co-ops.nos.noaa.gov/datumcalc/index.jsp

Tidal Analysis Datum Calculator

Comparison of TAD Vs. CO-OPS Standard Products

Station		HWL	MHHW	MHW	MSL	MLW	MLLW	LWL
Portland (1/1996-6/2007)	CO-OPS	6.619	5.651	5.516	4.130	2.724	2.617	1.631
	TAD	6.619	5.649	5.516	4.130	2.724	2.615	1.630
	Diff	0	0.002	0	0	0	0.002	0.001
CBBT (1/1995 - 12/2013)	CO-OPS	10.008	8.653	8.582	8.200	7.807	7.770	6.955
	TAD	9.993	8.652	8.582	8.201	7.808	7.770	6.952
	Diff	0.015	0.001	0	-0.001	-0.001	0	0.003
Oregon Inlet Marina (1/1997 -12/2011)	CO-OPS	3.073	1.197	1.152	1.014	0.879	0.840	0.285
	TAD	3.063	1.198	1.154	1.014	0.878	0.838	0.283
	Diff	0.01	-0.001	-0.002	0	0.001	0.002	0.002
Pensacola (8/2008 - 02/2012)	CO-OPS	3.882	3.009	3.001	2.813	2.633	2.624	2.062
	TAD	3.883	3.012	3.004	2.814	2.633	2.626	2.063
	Diff	-0.001	-0.003	-0.003	-0.001	0	-0.002	-0.001
Rockport (1/1997 - 10/2015)	CO-OPS	2.883	2.086	2.086	2.032	1.973	1.972	1.407
	TAD	2.888	2.088	2.089	2.032	1.968	1.967	1.407
	Diff	-0.005	-0.002	-0.003	0	0.005	0.005	0
San Francisco (1/1997 - 7/2012)	CO-OPS	4.376	3.601	3.414	2.773	2.174	1.818	1.078
	TAD	4.383	3.601	3.414	2.773	2.174	1.818	1.079
	Diff	-0.007	0	0	0	0	0	-0.001
Seattle (1/1997 - 10/2015)	CO-OPS	6.833	5.902	5.639	4.461	3.298	2.433	1.030
	TAD	6.834	5.900	5.639	4.461	3.297	2.432	1.027
	Diff	-0.001	0.002	0	0	0.001	0.001	0.003
Ketchikan (1/1997 - 10/2015)	CO-OPS	8.115	6.579	6.303	4.325	2.346	1.866	0.282
	TAD	8.116	6.579	6.303	4.326	2.346	1.866	0.281
	Diff	-0.001	0	0	-0.001	0	0	0.001

Tidal Analysis Datum Calculator

Time Sampling Testing Results – from a partner product

Comparison of published tidal datums to datums computed using the original water level data resampled at different intervals and only 7 days of data from the original data series. Shown as a percentage of stations within each category. ***Total sample size of 429***.

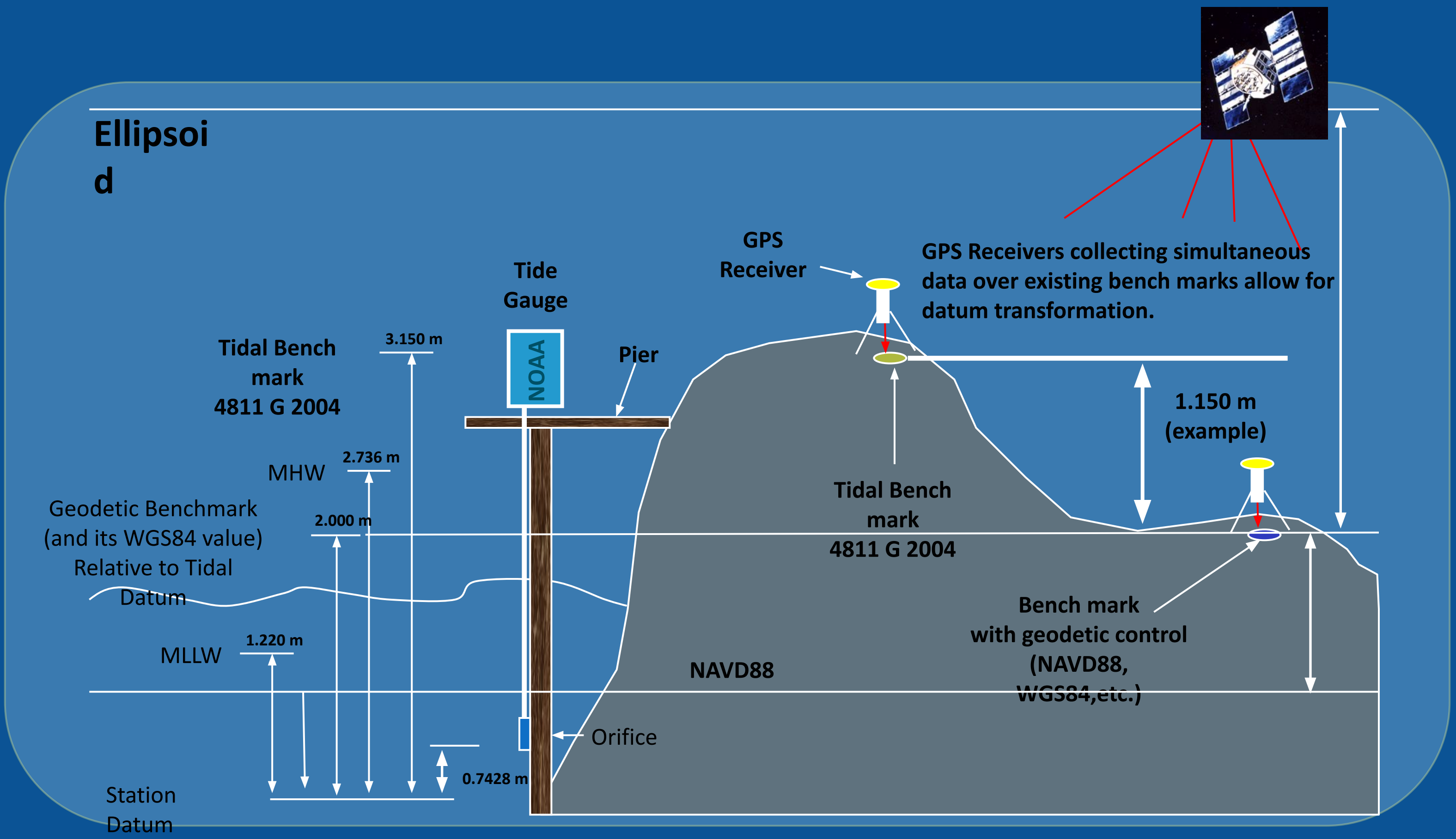
RMS of Diff btw Published and TIDELAB	Sample Rate					Data Series Length
	6 min	10 min	15 min	30 min	60 min	7 days
Less than 5 mm	51.7%	54.8%	53.4%	43.8%	14.2%	4.3%
Less than 5 cm	74.5%	76.4%	75.7%	71.9%	33.2%	20.9%
Less than 10 cm	99.8%	99.8%	99.8%	99.8%	82.9%	93.8%
Greater than 10 cm	0.2%	0.2%	0.2%	0.2%	3.4%	5.8%
N failed	0	0	0	0	57	2

Tidal and Geodetic

Geodetic Ties at NWLON Stations

GPS Connections Between Benchmarks

- GPS-derived orthometric heights can be used for datum transfers (**H = h – N**)
- Not as limited as line of sight leveling for making benchmark connections
- Allows for connections over greater distances



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

Station ID: 8461490 PUBLICATION DATE: 04/21/2003
Name: NEW LONDON, THAMES RIVER
CT
NOAA Chart: 13213 Latitude: 41° 21.3' N (41.35500)
USGS Quad: NEW LONDON Longitude: 72° 5.2' W (-72.08670)

T I D A L D A T U M S

Tidal datums at NEW LONDON, THAMES RIVER based on:

LENGTH OF SERIES:	19 Years
TIME PERIOD:	January 1983 - December 2001
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (09/21/1938)		=	3.224
MEAN HIGHER HIGH WATER	MHHW	=	0.930
MEAN HIGH WATER	MHW	=	0.840
North American Vertical Datum	NAVD88	=	0.560
MEAN SEA LEVEL	MSL	=	0.468
MEAN TIDE LEVEL	MTL	=	0.449
MEAN LOW WATER	MLW	=	0.059
MEAN LOWER LOW WATER	MLLW	=	0.000
LOWEST OBSERVED WATER LEVEL (02/02/1976)		=	-1.220

North American Vertical Datum (NAVD88)

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
15 1947	3.806	2.966
1490 K 1979	9.398	8.558
1490 M 1990	2.476	1.636

- CO-OPS Published benchmark sheet
  - Elevations of individual BM relative to tidal datums.
  - Can identify the relative elevation differences between individual BM
  - Note the elevations are based on a series (2 or more) of levels.
  - BM identified as unstable based on elevations relationships determined by leveling will not be included.
  - Individual CO-OPS tidal benchmarks with NGS IDB PID will be hyperlinked to the data sheets.

PRIMARY BENCH MARK STAMPING: 15 1947
DESIGNATION: 846 1490 TIDAL 15

MONUMENTATION: Tidal Station disk VM#: 239
AGENCY: US Coast and Geodetic Survey (USC&GS) IDB PID#: LX0157
SETTING CLASSIFICATION: Retaining wall OPUS PID:
LATITUDE: 41° 21.6' N (41.36028) LONGITUDE: 72° 5.5' W (-72.09169)

The primary bench mark is a disk set on the concrete retaining wall along the west side of the ramp leading to the Connecticut State Pier from Winthrop Street, 225.9 m (741 ft) south along the ramp from Winthrop Street, 6.86 m (22.5 ft) north of the south end of the retaining wall, 4.27 m (14.0 ft) west of the center line of ramp, and 0.15 m (0.5 ft) above the ramp.

Datum Information on the BM Sheet

Epoch, Series & Control Station

Tidal Datums Relative to MLLW

Benchmarks Relative to MLLW and MHW

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

Page 5 of 6

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U.S. DEPARTMENT OF COMMERCE
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North American Vertical Datum (NAVD88)

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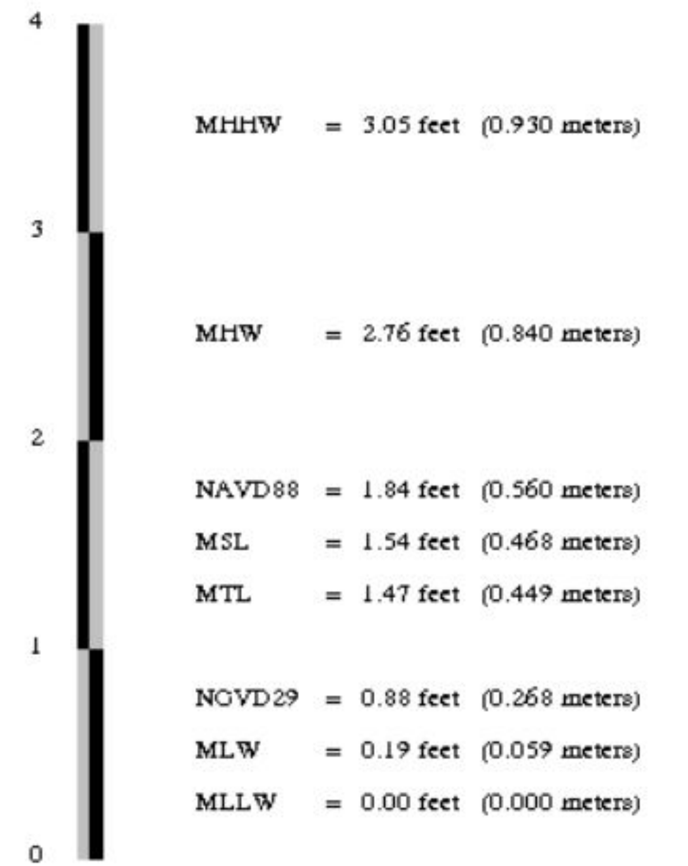
1490 M 1990	2.476	1.636

ELEVATION INFORMATION

PID:	LX0157
VM:	239
STATION ID:	8461490
EPOCH:	1983-2001
DATE:	Monday, October 19, 2020 2:35:50 PM EDT

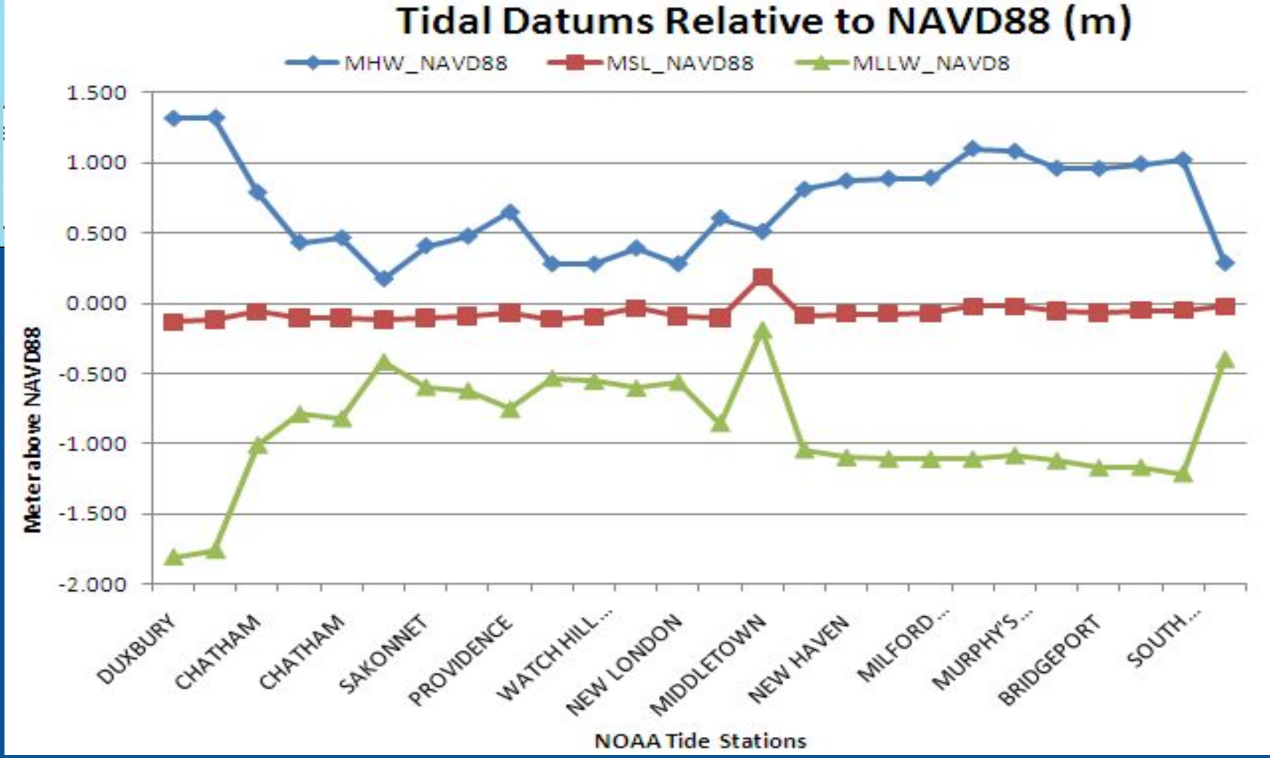


The NAVD 88 and the NGVD 29 elevations related to MLLW were computed from Bench Mark, 846 1490 TIDAL 15, at the station. Displayed tidal datums are Mean Higher High Water(MHHW), Mean High Water (MHW), Mean Tide Level(MTL), Mean Sea Level (MSL), Mean Low Water(MLW), and Mean Lower Low Water(MLLW) referenced on 1983-2001 Epoch.

Regional variation

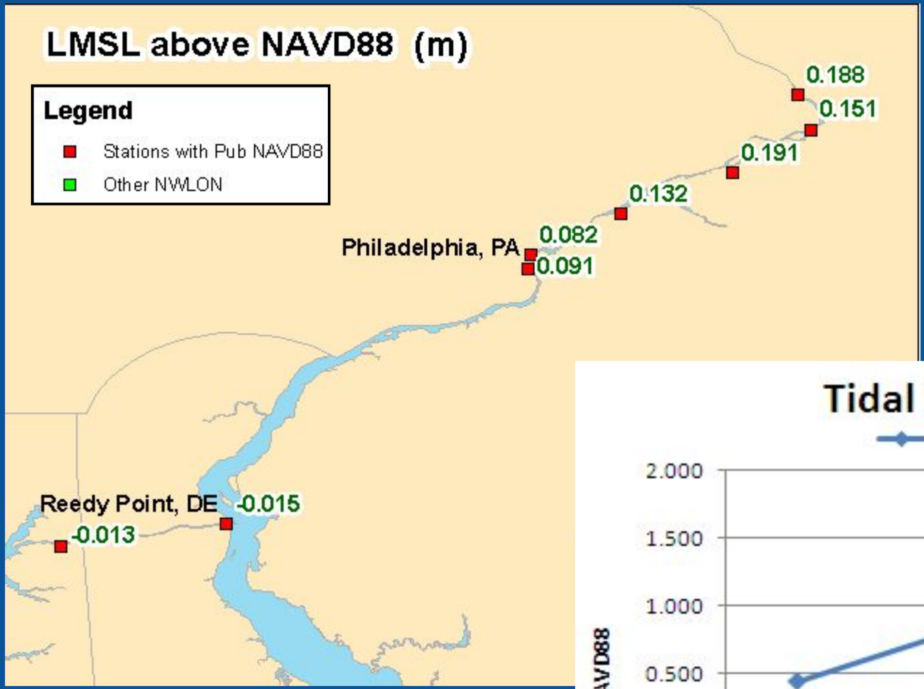
Vertical Datums

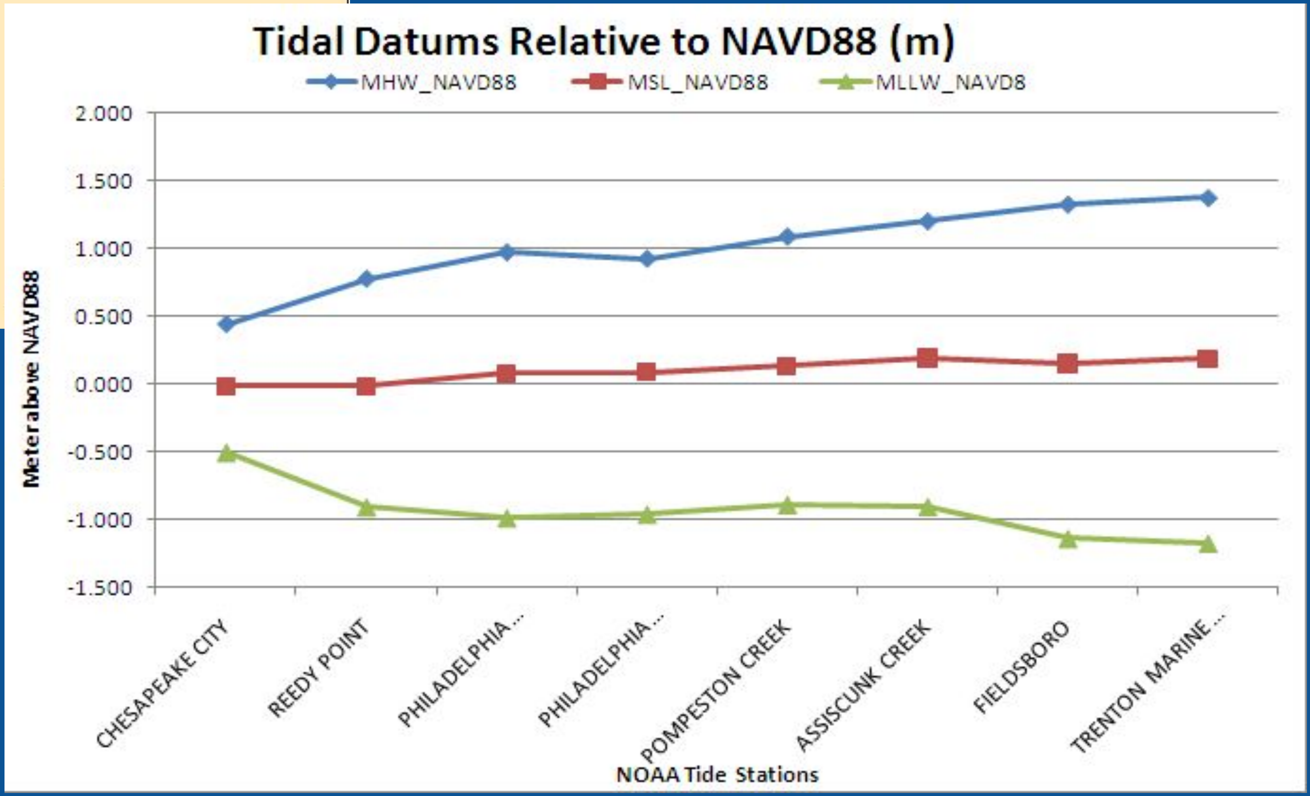
Tidal Datums Relative to Geodetic Datum NAVD88



Vertical Datums

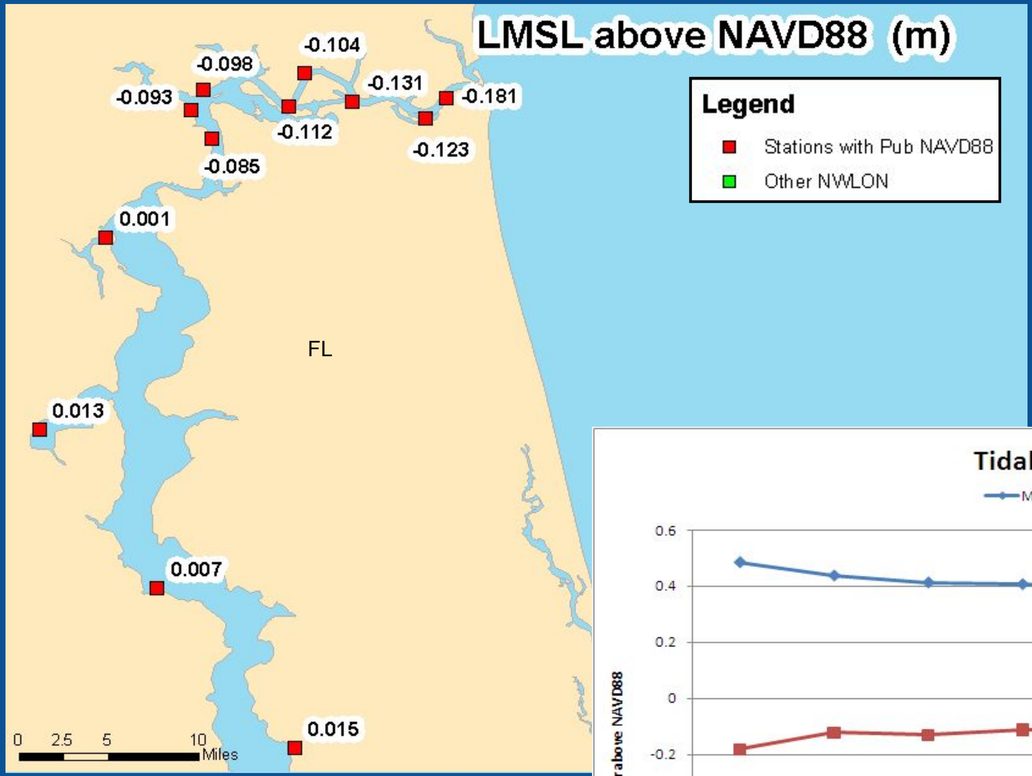
Tidal Datums Relative to Geodetic Datum NAVD88

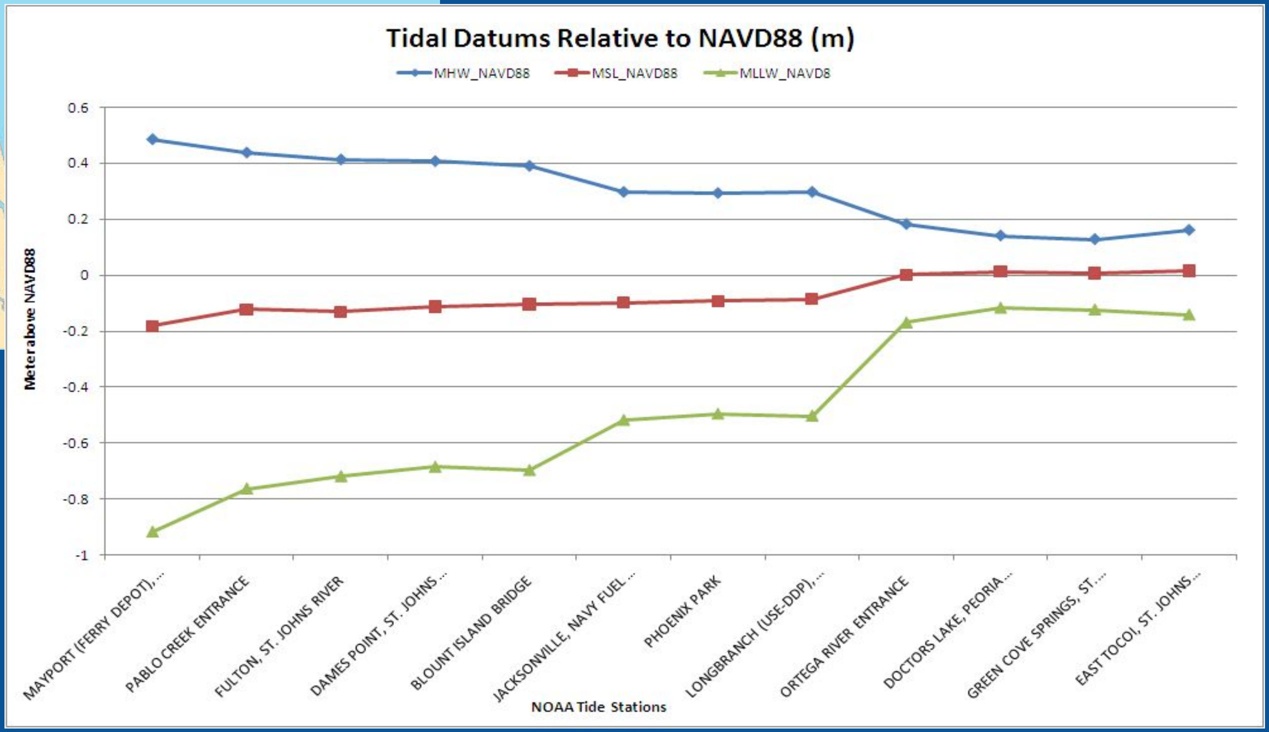




Vertical Datums

Tidal Datums Relative to Geodetic Datum NAVD88





VDatum

All elevation data is referenced to a vertical datum.

BUT *there are a many different vertical datums in use around the nation*

Relationship of vertical datums for Tampa Bay:

86.39 ft	WGS 84 (G873)	26.33 m
81.33 ft	NAD 83 (86)	24.79 m
0.792 ft	MHHW	0.241 m
0.409 ft	MHW	0.125 m
0.0 ft	NAVD 88	0.0 m
-0.535 ft	LMSL	-0.163 m
-0.850 ft	NGVD 29	-0.259 m
-1.495 ft	MLW	-0.456 m
-1.919 ft	MLLW	-0.585 m

For elevation data sets to be blended together they must be referenced to ***same*** *vertical datum.*

Ellipsoid Datums

18 3-D Datums

WGS 84, NAD 83 (NSRS), 17 others

Orthometric Datums

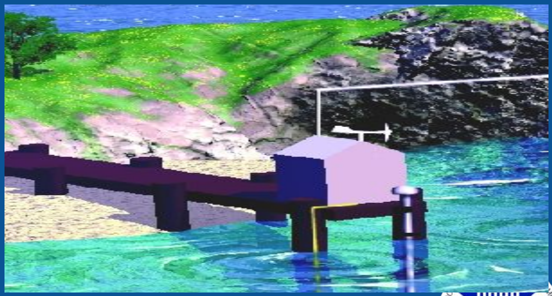
Geodetic Datums

NAVD 88, NGVD 29

Tidal Datums

7 Tidal Datums

MHHW, MHW, MTL, DTL, LMSL, MLW, MLLW



CO-OPS

(Observational Data Assessment & Complete List)

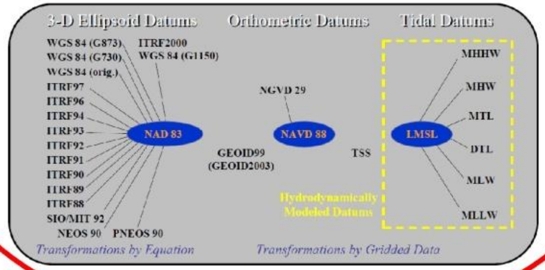
1) Tidal, Geodetic, Ellipsoidal datum assessments at NWLON and historic WL stations. (VDatum work list).
2) New gauge installations w/ geodetic surveys.
3) Current Epoch tidal datums and harmonic constituents.
4) Published tidal and geodetic relationships.
5) VDatum complete list.

NGS

(Observational Data, NSRS, Gravity, Geoid, & TSS)

1) Collect and publish gravity, ellipsoidal, and orthometric elevations.
2) Development and maintenance of NSRS.
3) Develop GPS processing (OPUS DB)
4) Shoreline data collection.
5) Geoid Model (ellipsoidal – orthometric conversions)
6) Topography of the Sea Model (TSS).
7) Maintenance of VDatum tool on the web.

VDatum
Transtormation Tool

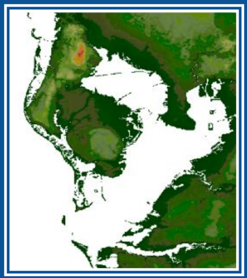


OCS

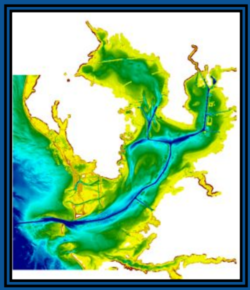
(Hydrodynamic Model Development & Update)

1) Development of new hydrodynamic models (ADCIRC).
2) Update of VDatum model (model maintenance).
3) Collection and use of Bathymetry data.
4) Use of shoreline data.
5) VDatum error analysis.

VDatum and Creation of Digital Elevation Models

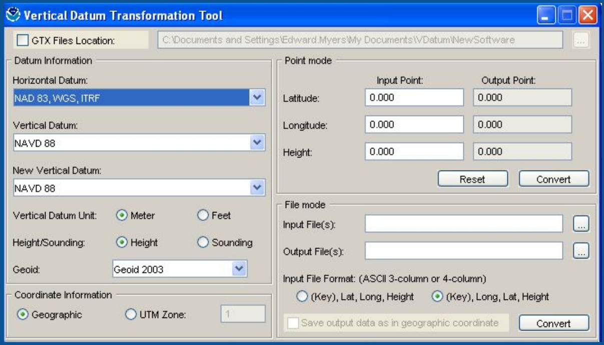


Topography

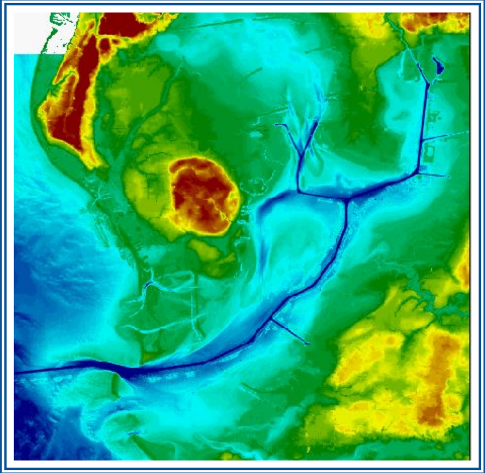


Bathymetry

VDatum



Bathy/Topo
Digital Elevation Model



Applications for Seamless Bathy/Topo Datasets:

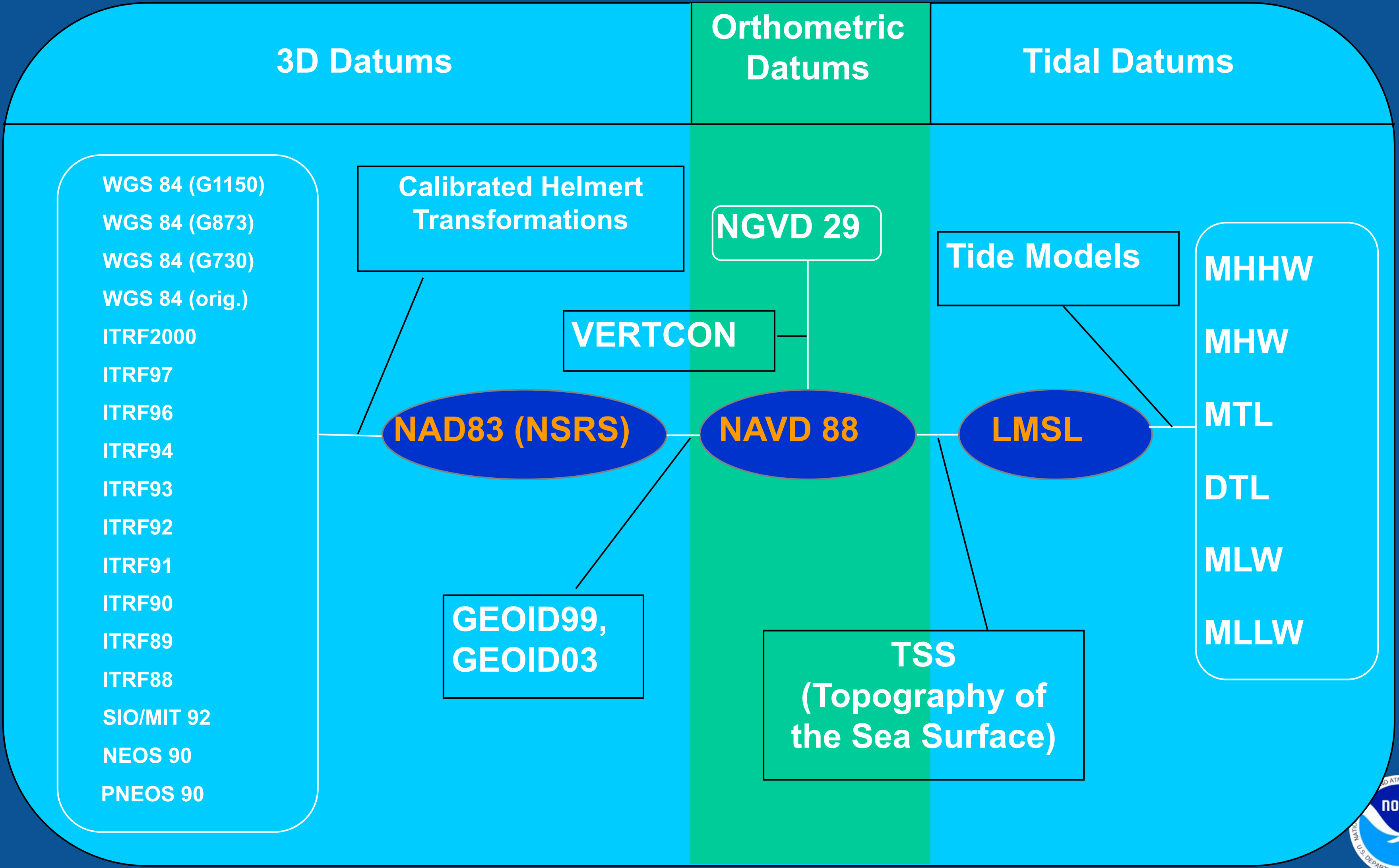
- Inundation modeling from storm surge, tsunamis, and sea level rise.
- Erosion, accretion, renourishment
- Analyzing storm impacts
- Determining setback lines
- Determining local, state, and national boundaries
- Navigation Products and Services
- Habitat restoration
- Shoreline Change Analysis
- Analyzing environmental and natural resources
- Permitting

3 Categories of Vertical Datums:

- **3D / Ellipsoidal Datums:**
  - **Realized through space-based systems such as GPS**
- **Orthometric Datums:**
  - **Based on a form of mean sea level**
- **Tidal Datums:**
  - **Based on tidally-derived surfaces such as high or low water.**

Transformations Between Datums

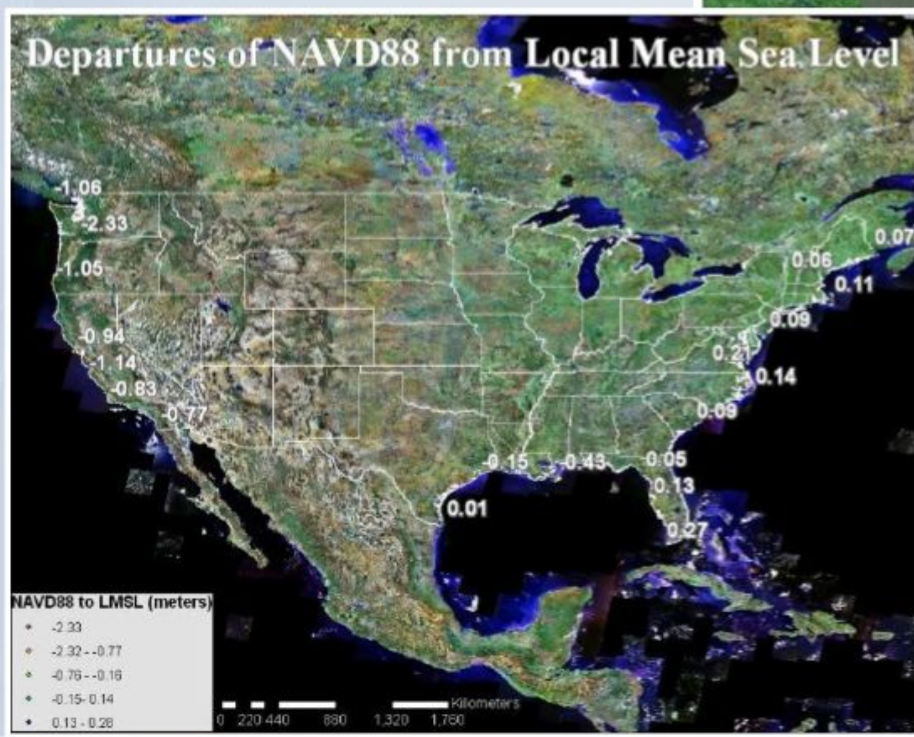
Vertical Datum Transformation "Roadmap"



Topography of the Sea Surface

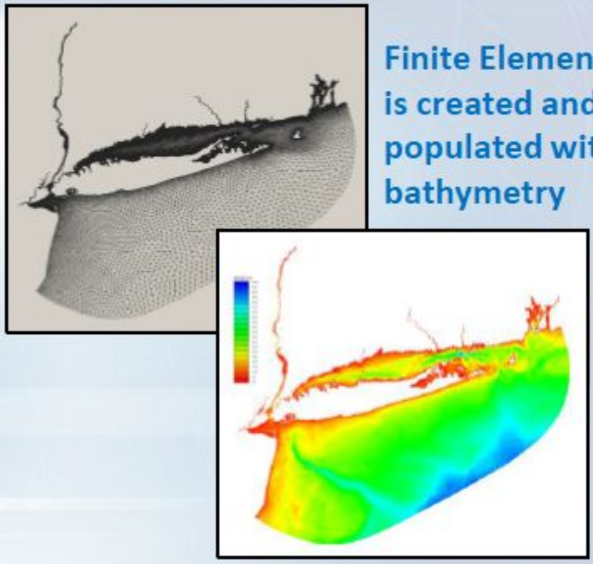
The Topography of the Sea Surface (TSS) is defined as the elevation of the North American Vertical Datum of 1988 (NAVD88) relative to local mean sea level (LMSL).

- This grid provides compensation for the local variations between a mean sea level surface and the NAVD88 geopotential surface.
- A positive value specifies that the NAVD88 reference value is further from the center of the Earth than the local mean sea level surface.

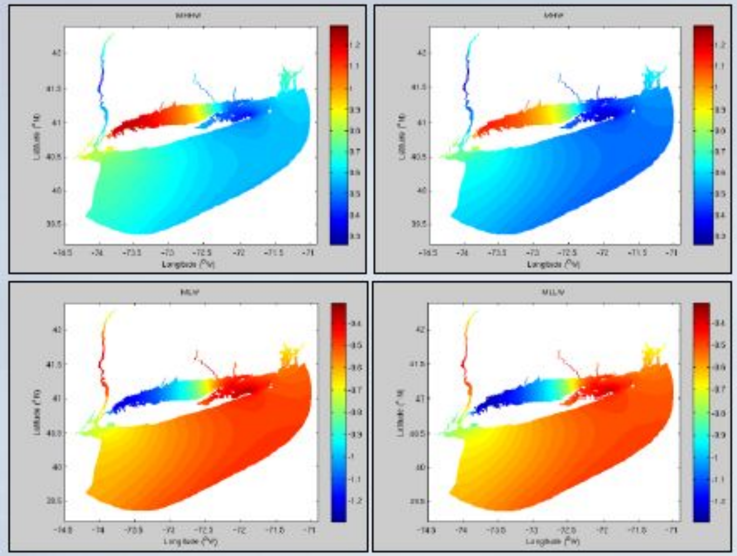


bilinear interpolation

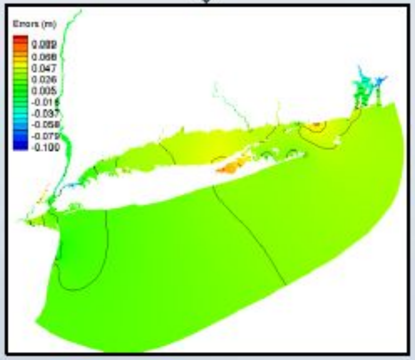
Tidal Datums and Hydrodynamic Modeling



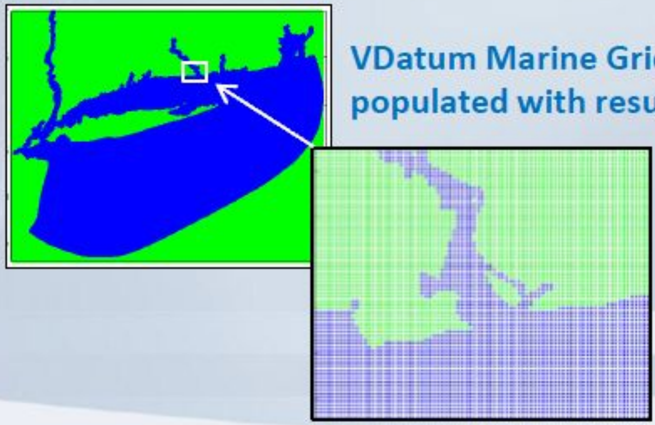
Finite Element grid is created and populated with bathymetry



Tidal Datum fields are derived from ADCIRC (Advanced Circulation) Model, simulations are made on cluster computers at NOAA's Earth System Research Laboratory



Correct results by spatially interpolating errors with TCARI (Tidal Constituent and Residual Interpolation)

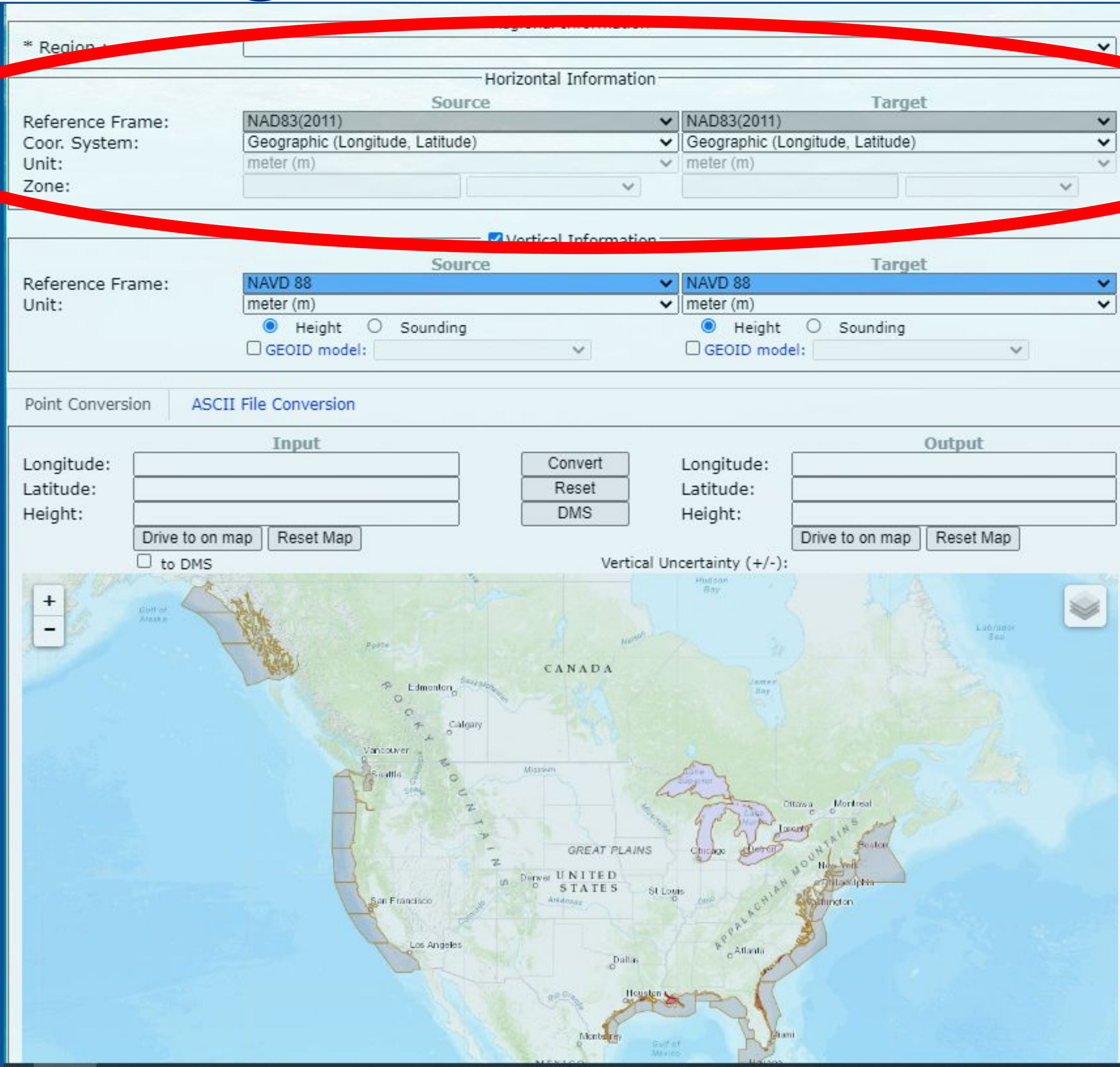


VDatum Marine Grid is populated with results

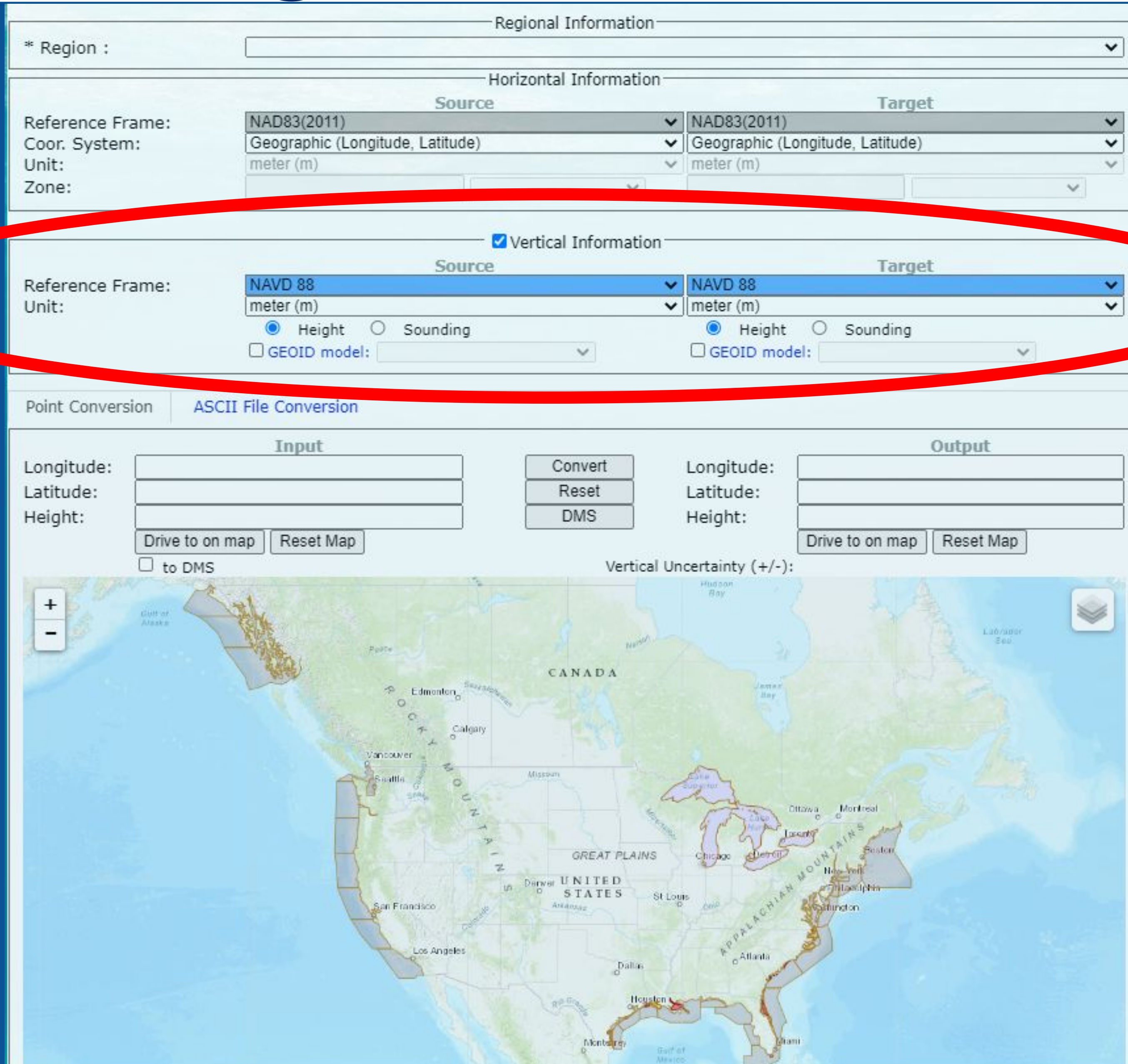
bilinear interpolation

National Oceanic and Atmospheric Administration

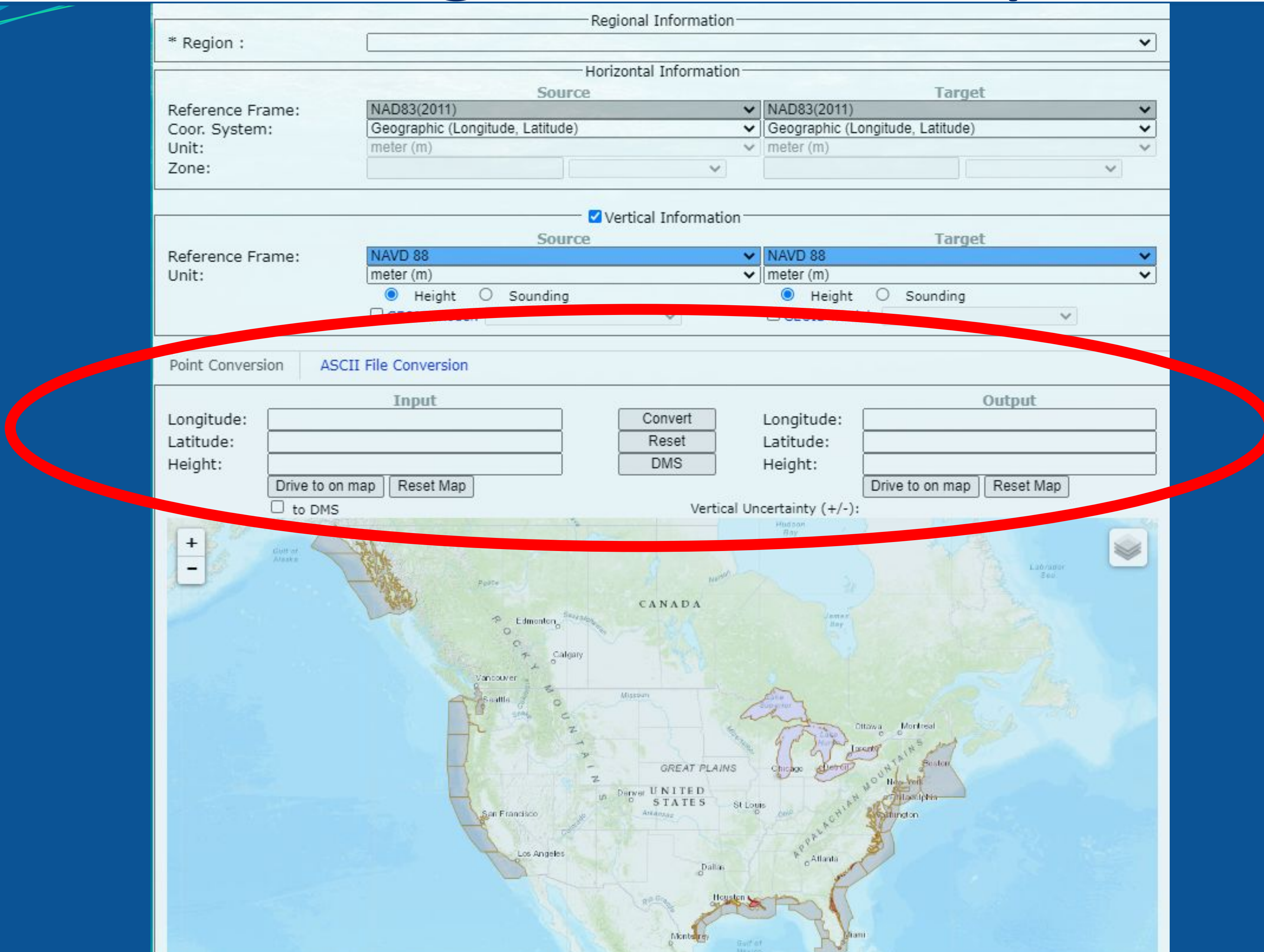
Utilizing VDatum: Horizontal

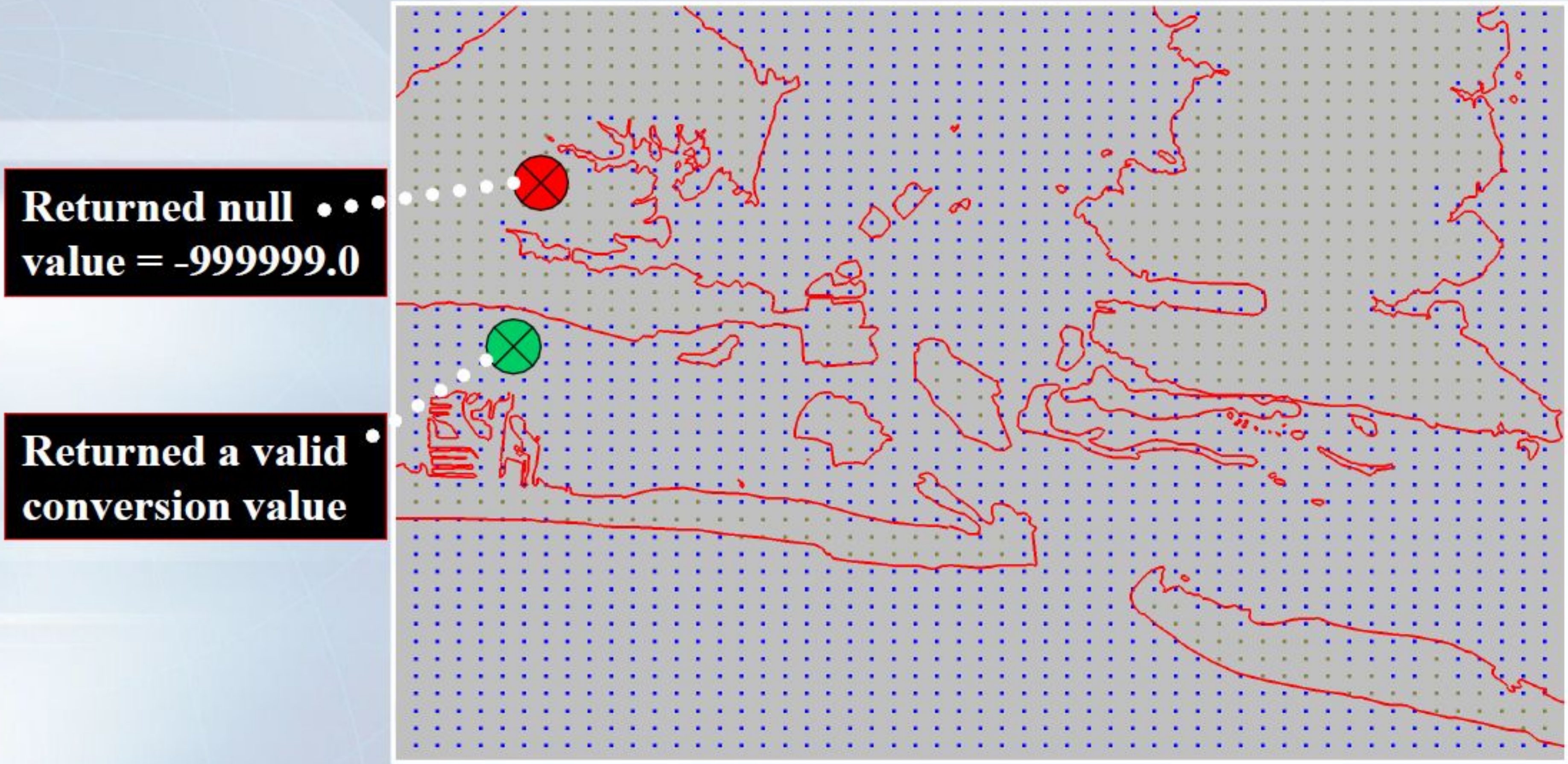


Utilizing VDatum: Vertical



Utilizing VDatum: Input

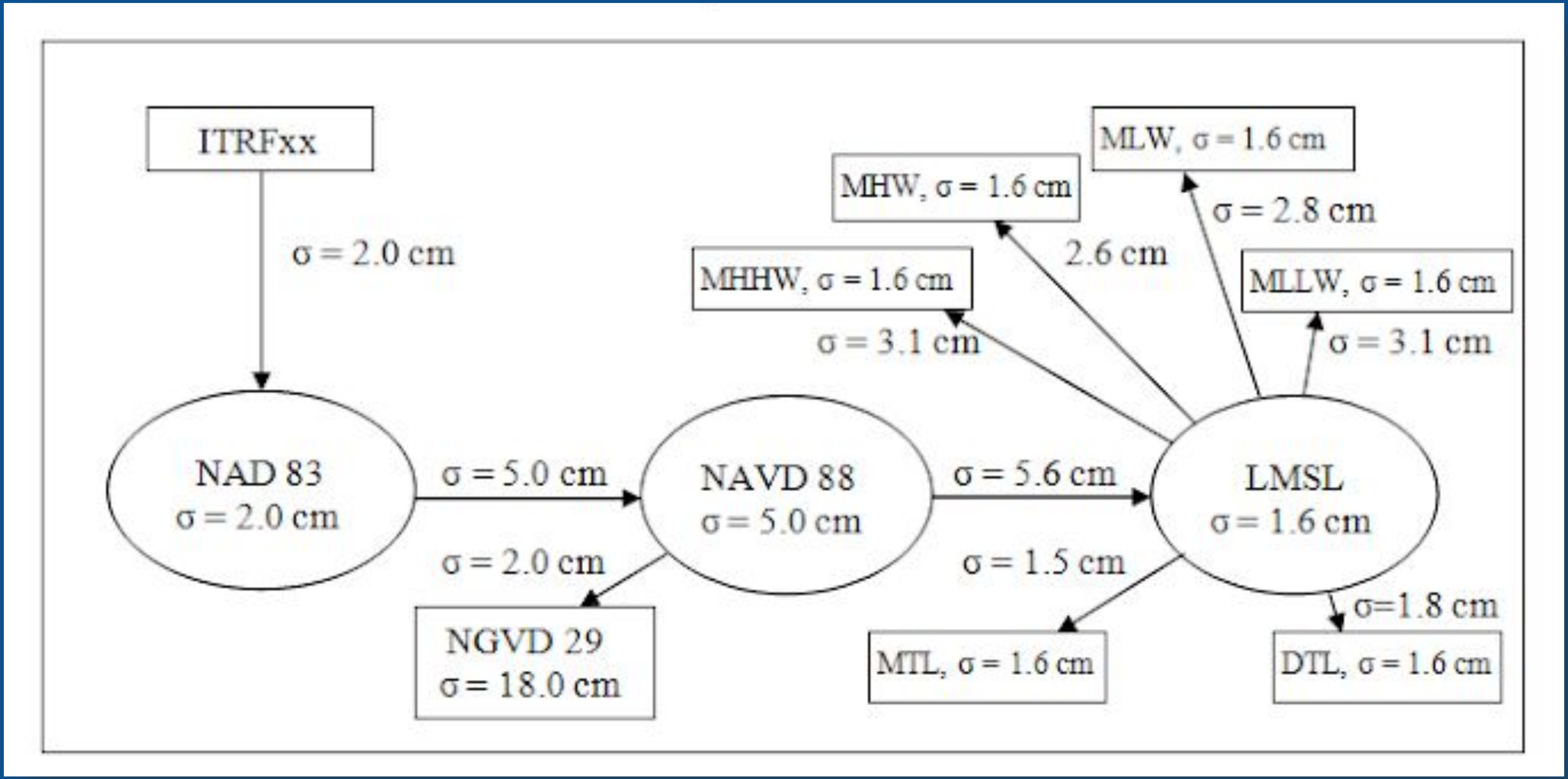




- With exception of small buffer region near coastline, user-input points falling on “land” side of MHW shoreline are assigned a null value.
- Orthometric and ellipsoidal conversions may still be made at land points, as only conversions involving tidal datums will be invalid inland of the buffer zone along coastline.

Transformations Between Datums

Uncertainty has been calculated for transformations across the full process…



Ellipsoid **Orthometric** **Tidal**

VDatum Uncertainty Modeling (cm)

(ITRFxx to the tidal datum, the transformation with the greatest uncertainty)

VDATUM REGION	MAXIMUM CUMULATIVE UNCERTAINTY
California - Southern California from Morro Bay south to US/Mexico border	8.1
California - Monterey Bay to Morro Bay	8.0
California - San Francisco Bay Vicinity	9.8
Oregon/ California – Punta Gorda to Cape Blanco	13.1

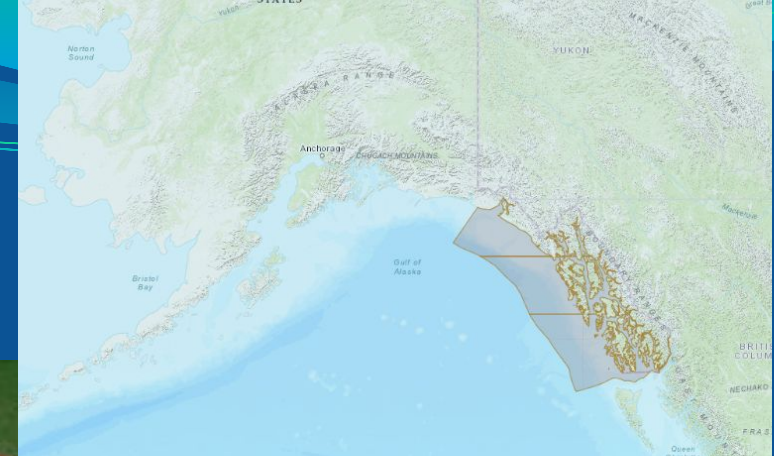
Uncertainties that are constant for all VDatum regions of the U.S.

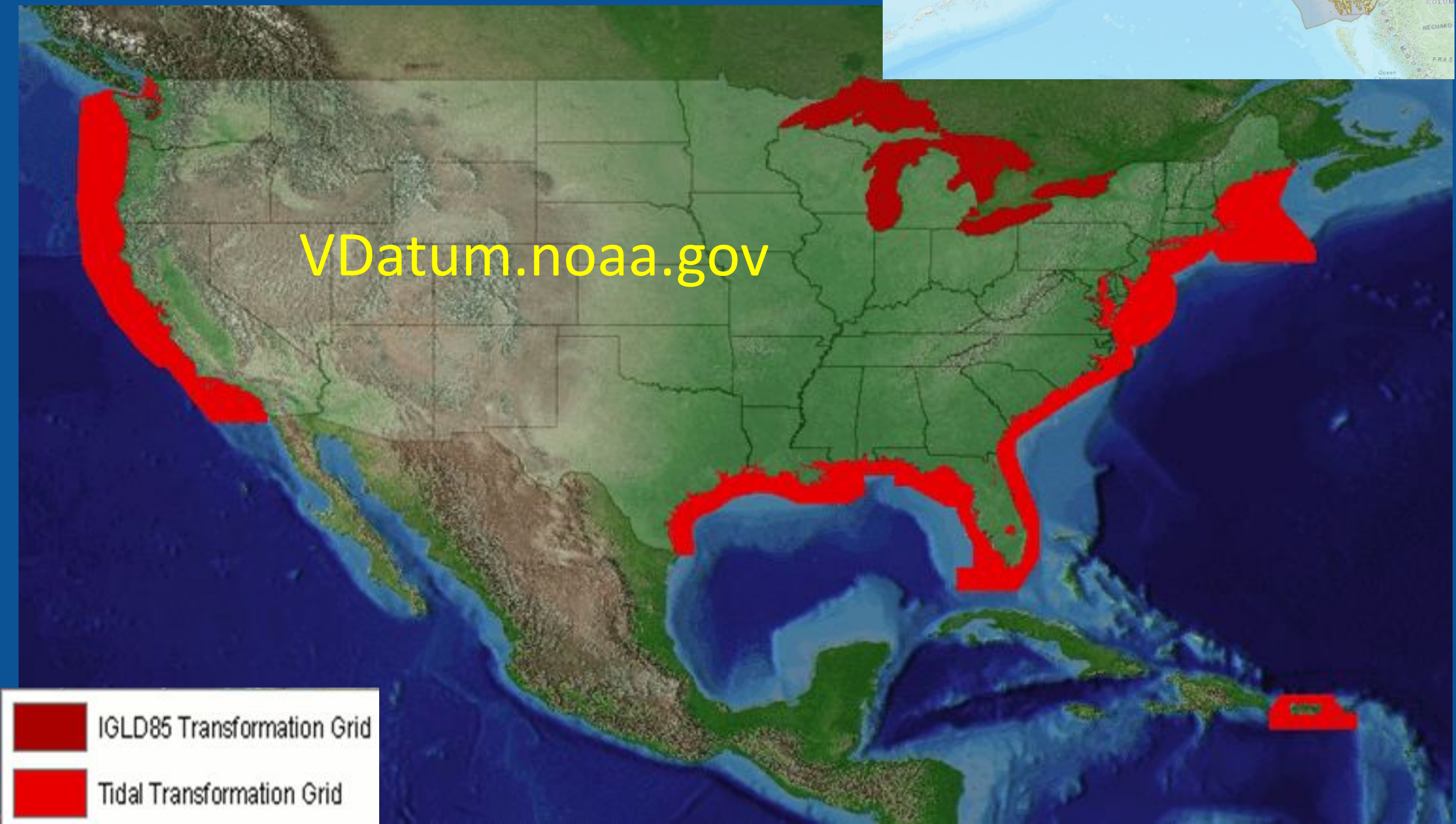
TRANSFORMATION			SOURCE DATA		
ITRFx to NAD83	NAD83 to NAVD88	NAVD88 to NGVD29	NAD83	NAVD88	NGVD29
2.0	5.0	2.0	2.0	5.0	18.0

REGION	TRANSFORMATION							SOURCE DATA	MCU
	NAVD88 to MSL	MSL to MHHW	MSL to MHW	MSL to MTL	MSL to DTL	MSL to MLW	MSL to MLLW	All Tidal Datums	
California - Southern California from Morro Bay south to US/Mexico border	1.6	1.4	0.9	0.1	0.4	0.8	0.9	1.3	8.1
California - Monterey Bay to Morro Bay	1.1	0.8	1	0.7	1	0.9	1.7	1.1	8
California - San Francisco Bay Vicinity	0.1	3.7	4.5	2	2.5	4.2	5.8	1.4	9.8
Oregon/ California – Punta Gorda to Cape Blanco	4.4	2	1.6	2.5	4.4	5.7	9.5	1.2	13.1

Transformations Between Datums

Current VDatum Availability





VDatum.noaa.gov

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

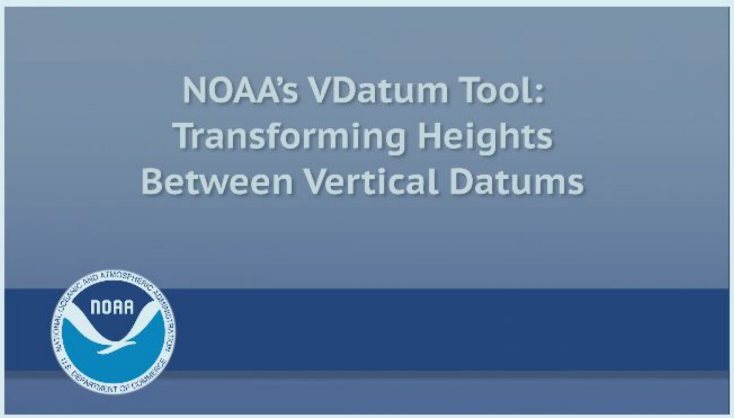
VERTICAL DATUM TRANSFORMATION
INTERGRATING AMERICA'S ELEVATION DATA

Home | About VDatum | Download | Online | Docs & Support | Contact Us

Welcome to VDatum!

VDatum is a free software tool being developed jointly by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS). VDatum is designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums - allowing users to convert their data from different horizontal/vertical references into a common system and enabling the fusion of diverse geospatial data in desired reference levels.

Important: Transformation Uncertainties in the 'Louisiana/Mississippi - Eastern Louisiana to Mississippi Sound' Regional Model, have been found to range from 20 to 50 cm in particular locations from the Mississippi River Delta north to Lake Pontchartrain. These issues most likely can be attributed to subsidence, newly established datums, and changes to the understanding of NAVD88 based on new versions of the GEOID. The VDatum Team is currently looking at resolving these uncertainties.

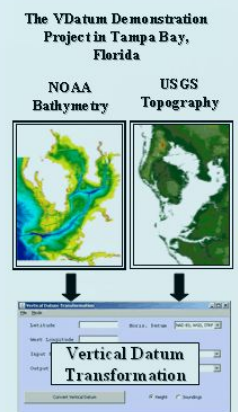


Download

Download the newest VDatum (v3.6.1) and its datasets.

Animated tutorial!

One-Pager



on Mac OS X, Unix, VMP, and Windows.

shed, VDatum supports the conversions among

M, State Plane Coordinates (SPC), and geocentric

986), and NAD83(HARN); and ellipsoidal datums
rializations

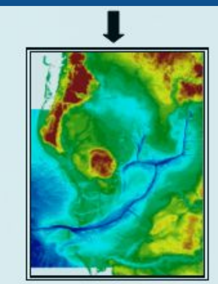
S84, ITRF88, ITRF89, ITRF90, NEOS 90, PNEOS 90,
93, ITRF94, ITRF96, ITRF97, IGS97, ITRF2000,
ITRF2008, IGS08, WGS84(transit), WGS84(G730),
WGS84(G1674), NAD83(PACP00), NAD83(MARP00)

, NGVD29, PRVD02, VIVD09, ASVD02, GUVD04,
1996, and EGM1984

Tidal Datums: MLLW, MLW, LMSL, DTL, MTL, MHW, LWD, and MHHW

- IGLD85

- **GEOID models:** GEOID12B, GEOID12A, GEOID09, GEOID06 (Alaska only), GEOID03, GEOID99, and GEOID96
- **EGM models:** EGM2008, EGM1996, and EGM1984
- **Supported file format:** text(ASCII), LiDAR(.LAS) version 1.0 to 1.2, ESRI ASCII Raster(.ASC), and ESRI 3D shapefile



Integrated Bathy/Topo DEM

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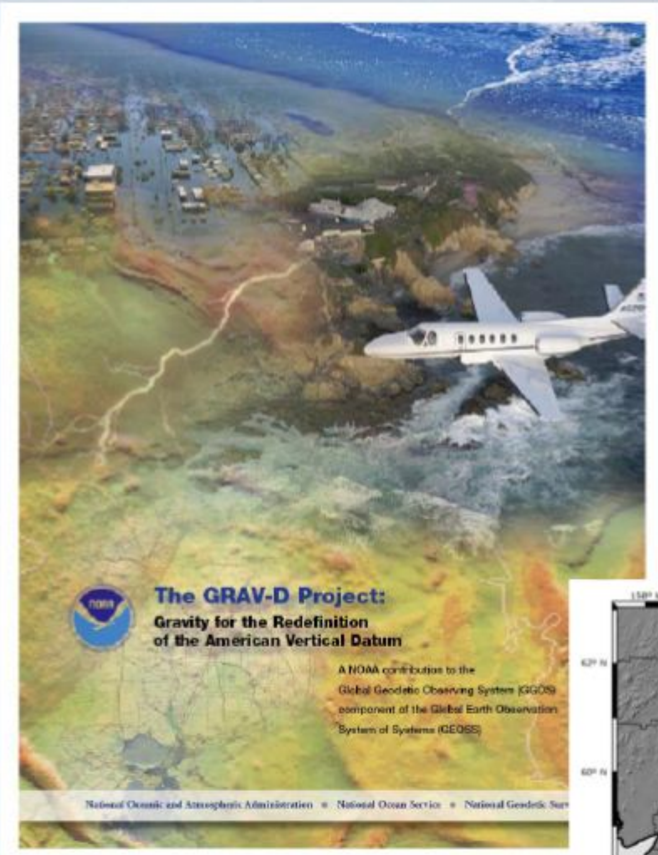
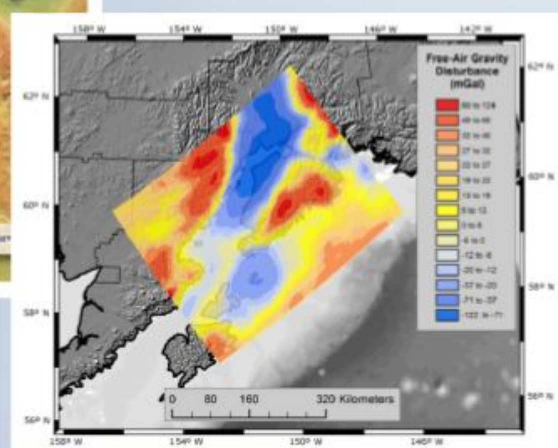
Web site owner: National Ocean Service | NOAA | Department of Commerce

Last modified: Dec 08 2016

GRAV-D: (**G**ravity for the **R**edefinition of the **A**merican* **V**ertical **D**atum)



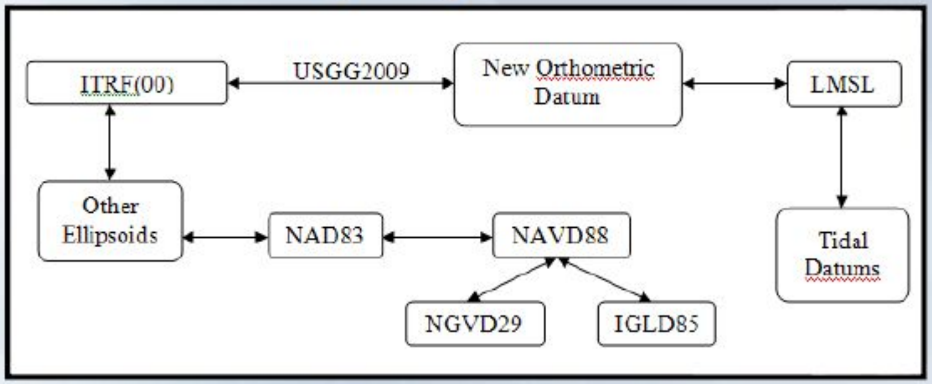
- An NGS project whose target is to redefine the official civilian vertical datum as the geoid, realized through the use of GNSS technology and a gravimetric geoid model over at least the United States and its territories
- *Official NGS policy as of Nov 14, 2007*
- *Re-define the Vertical Datum of the USA by 2022 (at current funding levels)*
- *Part of the NGS 10 year plan (2013-2023)*
- *Target: <u>2 cm accuracy</u> orthometric heights from GNSS and a geoid model*

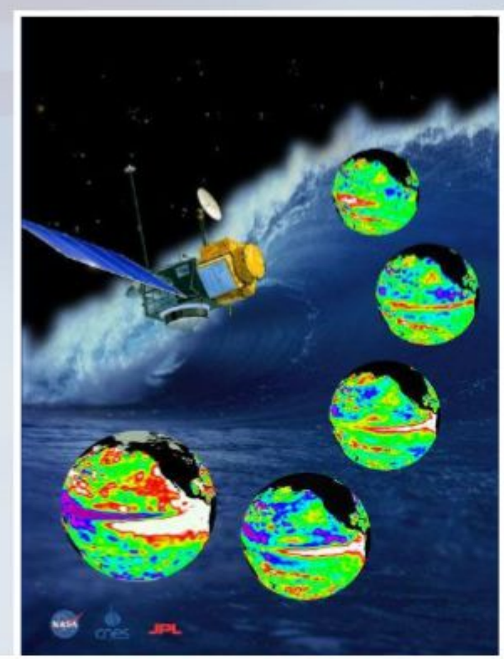


National Oceanic and Atmospheric Administration

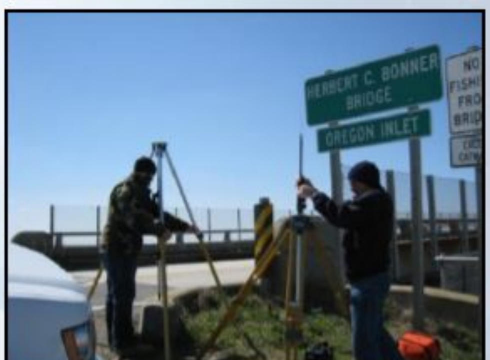
Future Enhancements: Next Generation TSS Development

New Proposed Transformation Roadmap based on a purely Gravimetric GEOID

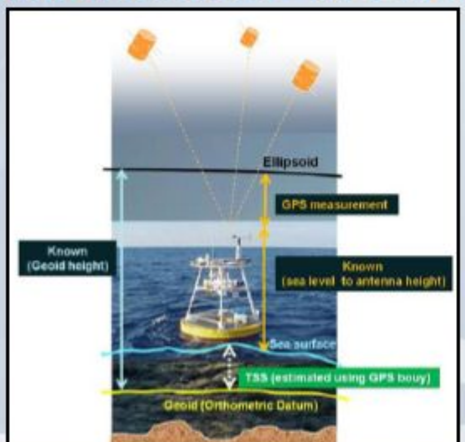


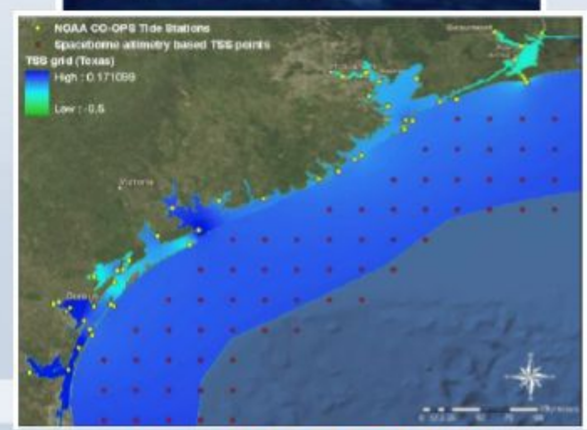


A Must: GPS Campaign on benchmarks to determine new relationships



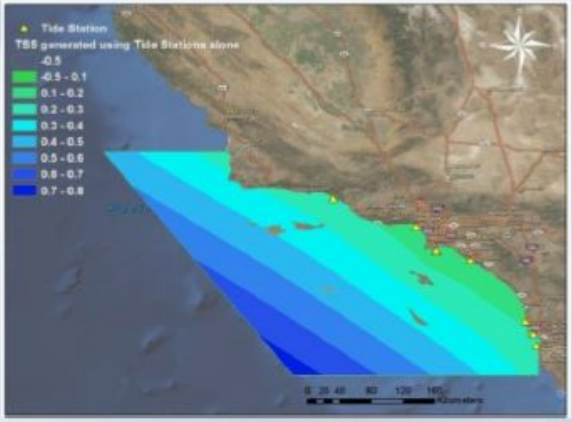
Wish List: GPS tide buoys to be utilized for data input, validation, and calibration inshore and offshore



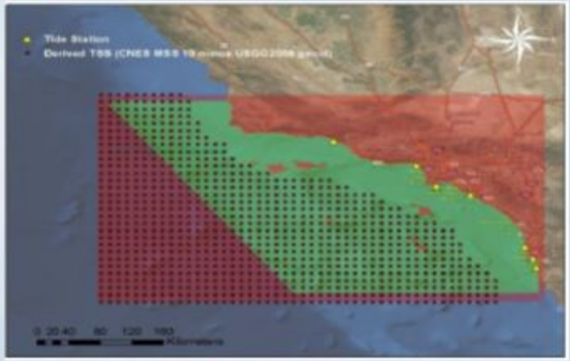


Utilization of Satellite Altimetry/Derived Products to better understand offshore Sea Surface Topography

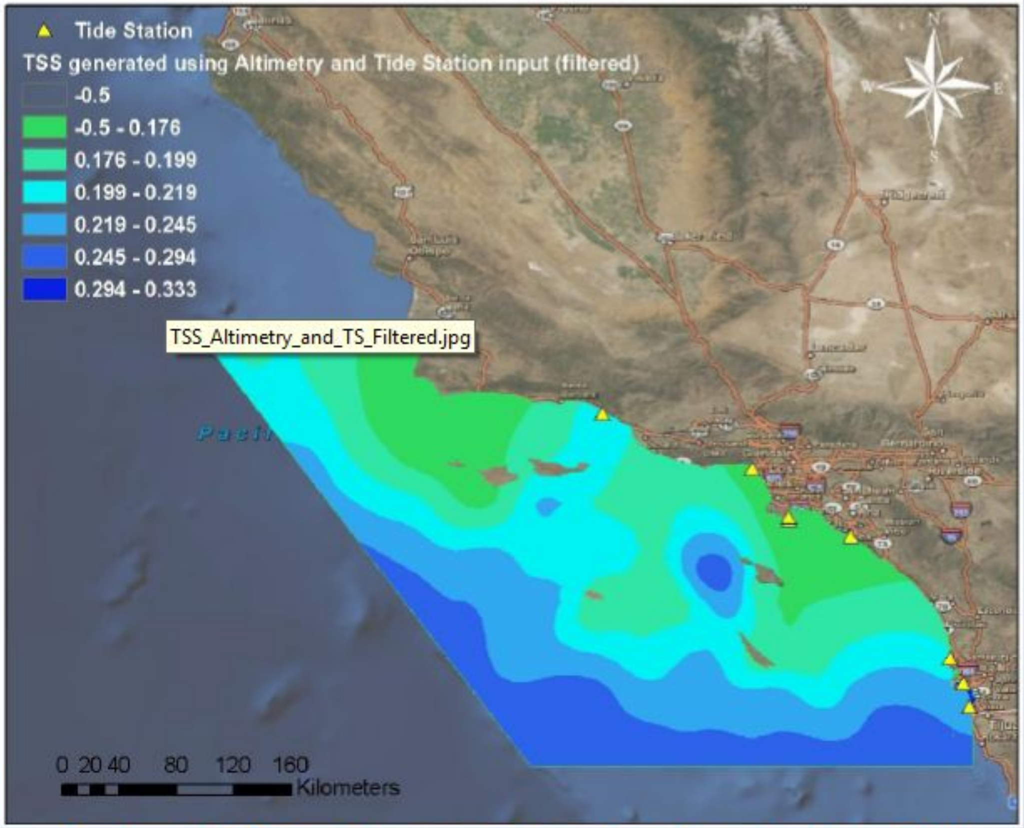
Future Enhancements: Next Generation TSS Development



TSS generated with only the 8 tide stations



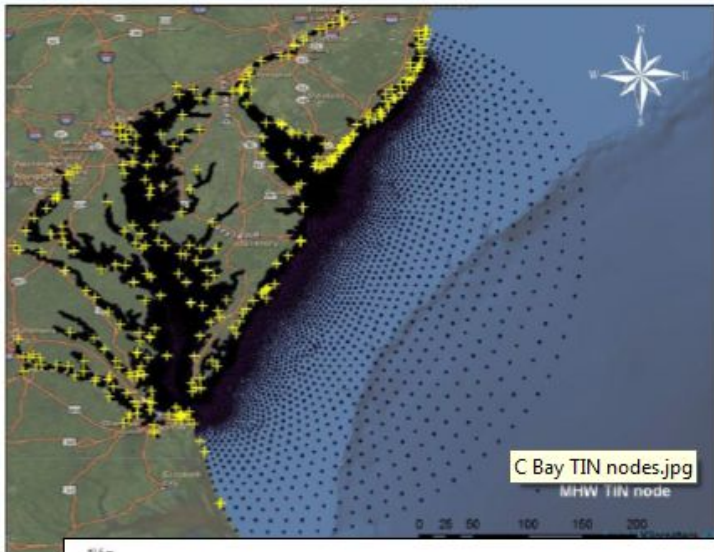
TSS points derived at the location of tide stations (yellow triangle) and CNES MSS points (red dots). These TSS points are the input for TSS grid (0.001 degree spacing) creation.

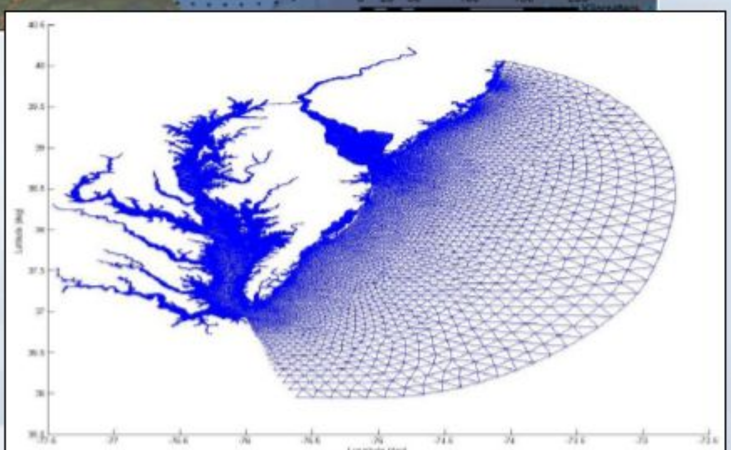


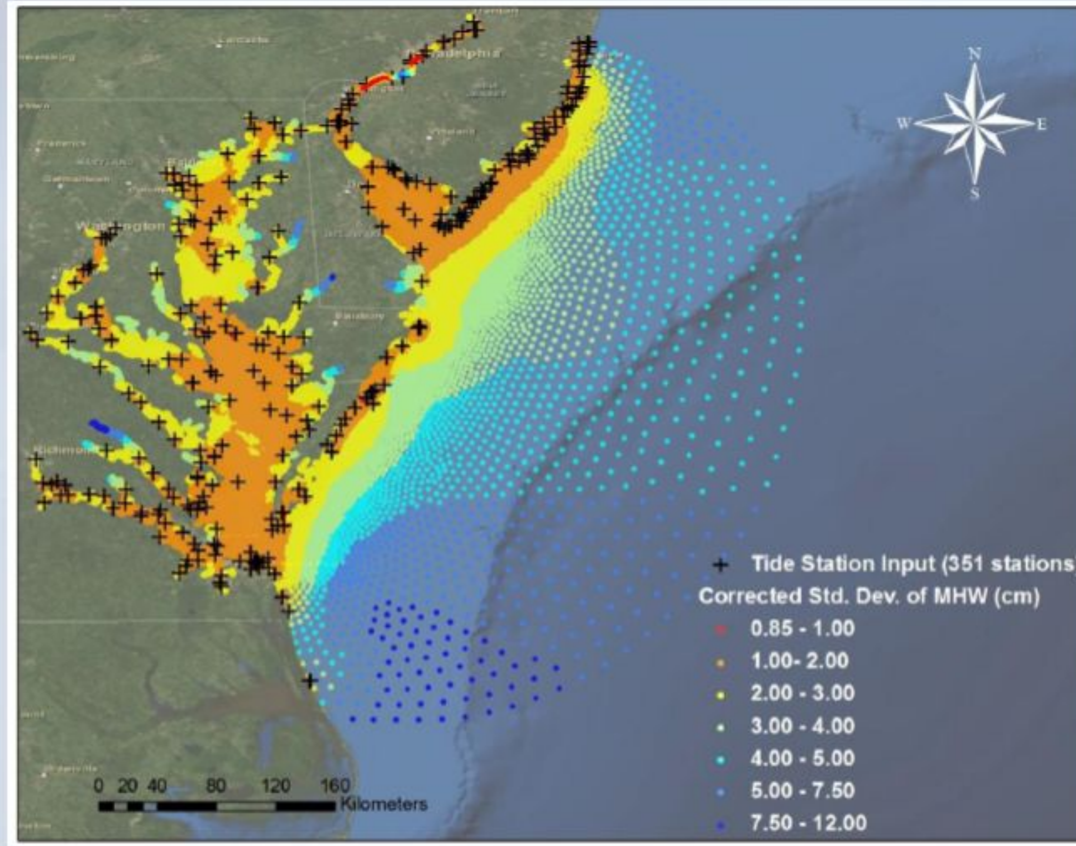
Refined TSS grid created using the derived TSS points at CNES MSS points (Gaussian filtered), and newly determined geodetic relationships at tide stations

Future Enhancements: Spatially Variable Uncertainty Estimation

- **Test Area:** Chesapeake Bay area and Delaware Bay area. 351 tide stations in this region



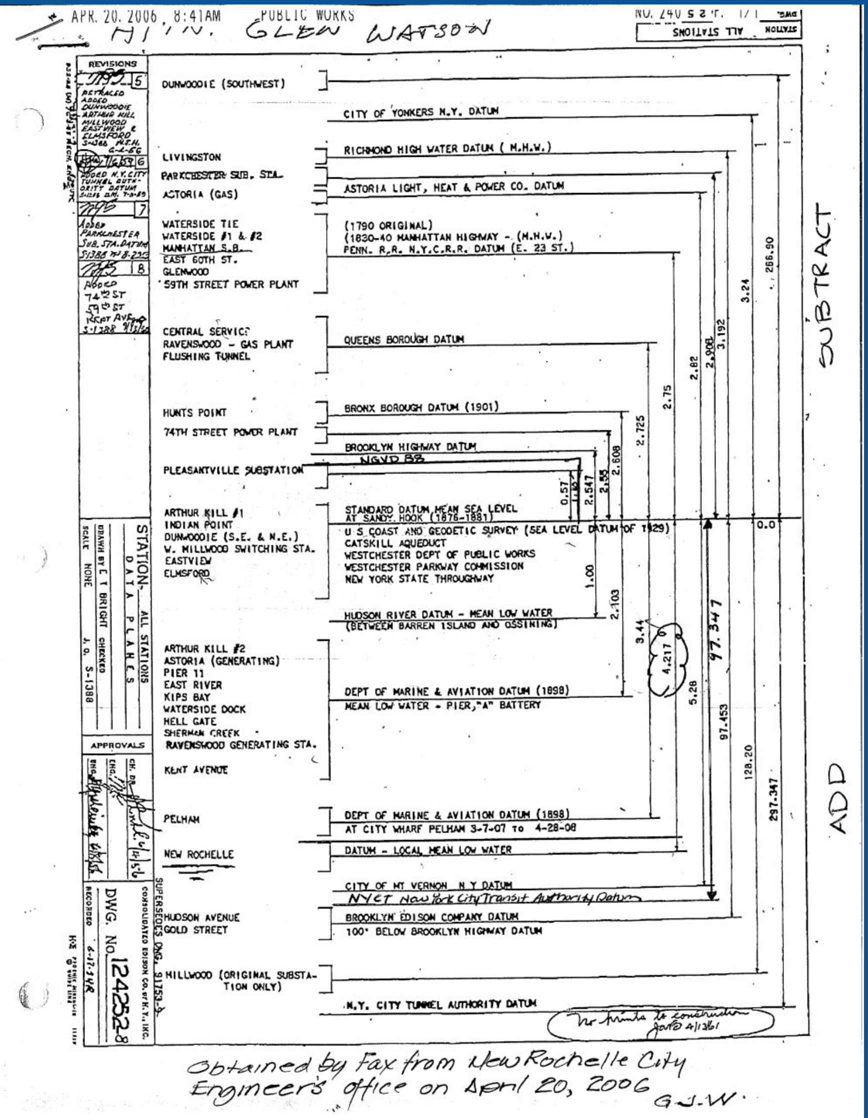


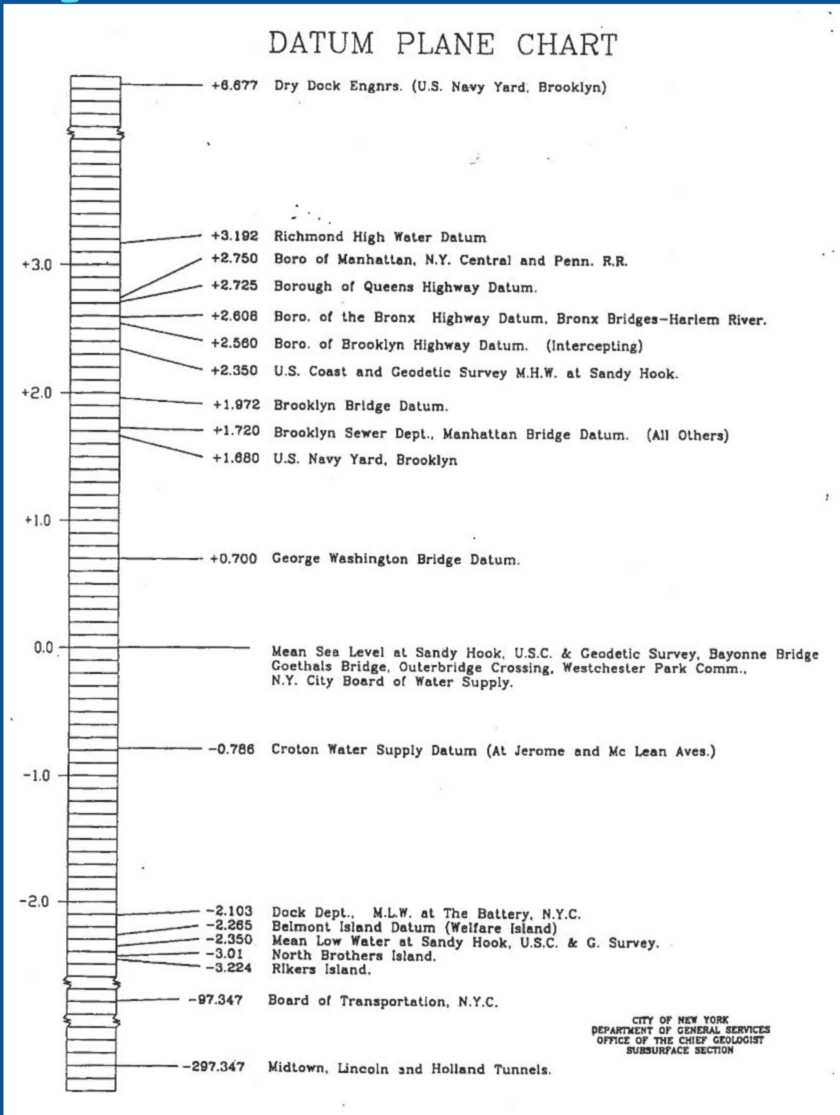


National Oceanic and Atmospheric Administration

Importance of datums and correct metadata

Datums Datums every where but not as easy as you think



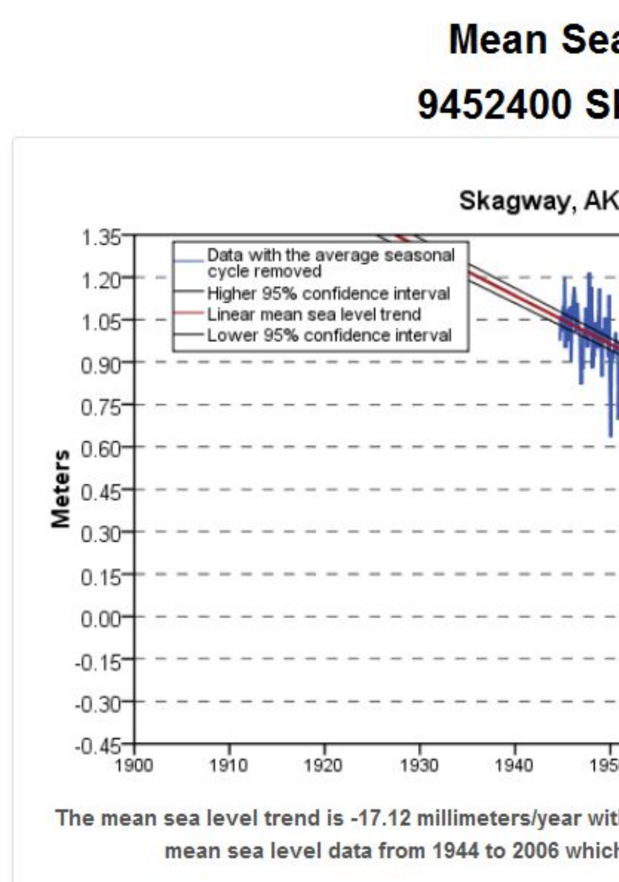


Construction company A started building the western side of the bridge using NAD83 (North American Datums of 1983) for its horizontal positioning

Construction company B started building the eastern side of the bridge using ITRF00 (International Terrestrial Reference Frame 2000) for its horizontal positioning

Well when they meet in the middle there was a huge problem

- A family on vacation in South East Alaska decided to save some cash and use a nautical chart that was published in 1950.
- Sea level change in this area of AK changes by -17.12 mm / year
- In the 60 years this means a chance of 1027.2mm
- Charted clearance said they had room under keel at mid tide
- They learned the hard way metadata maters.

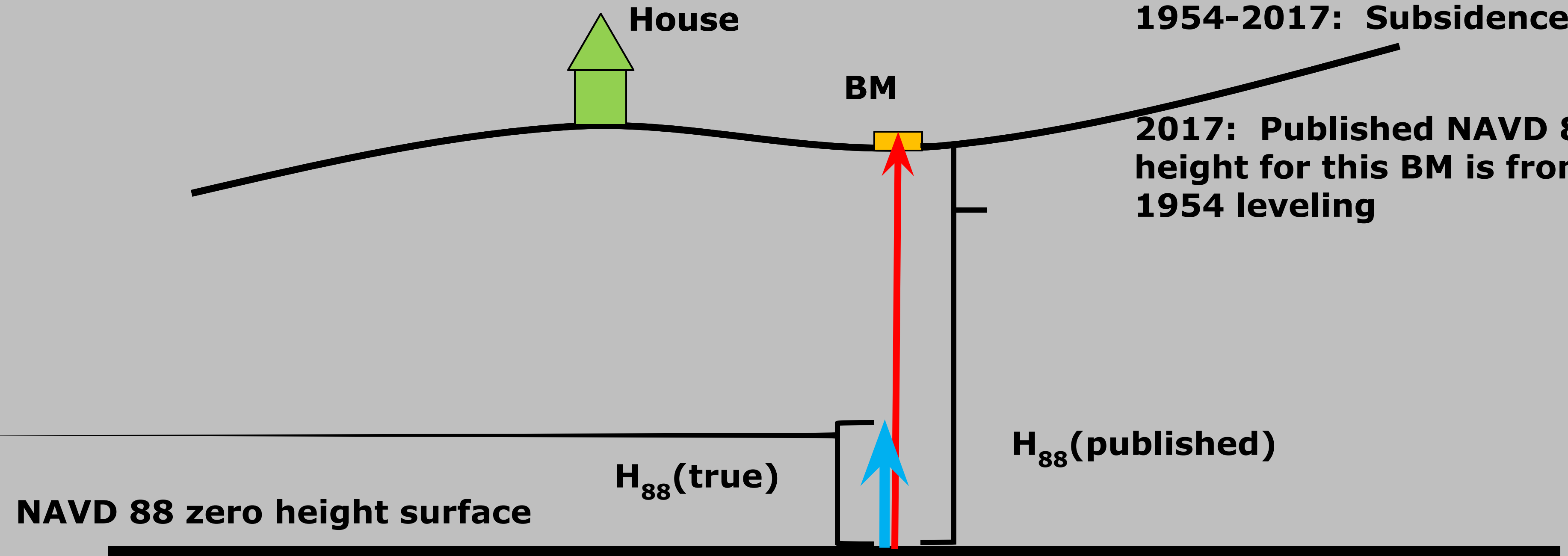


Subsidence and Bench Mark Height

1954: Leveling Performed to bench mark

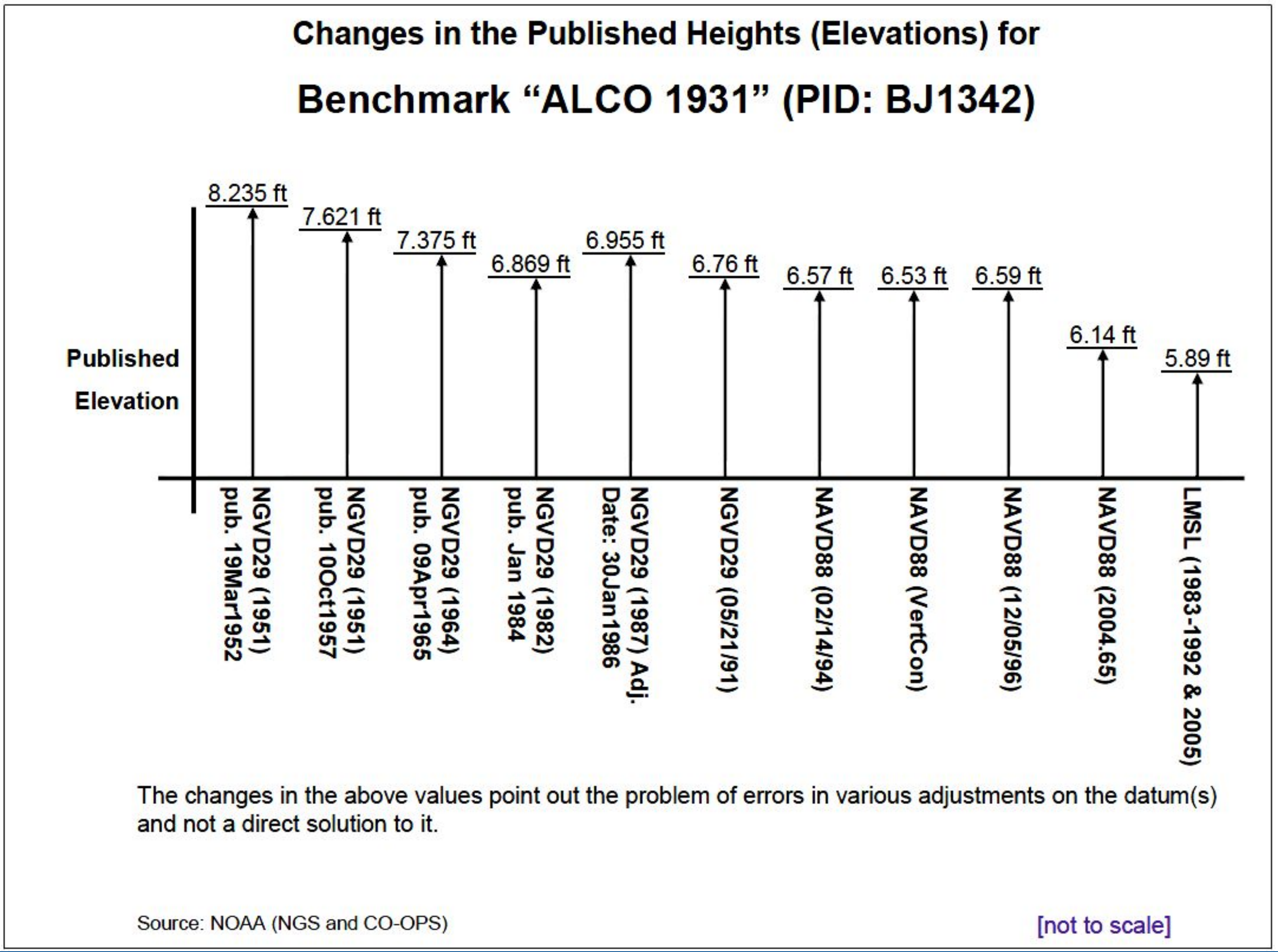
1954-2017: Subsidence

2017: Published NAVD 88 height for this BM is from 1954 leveling

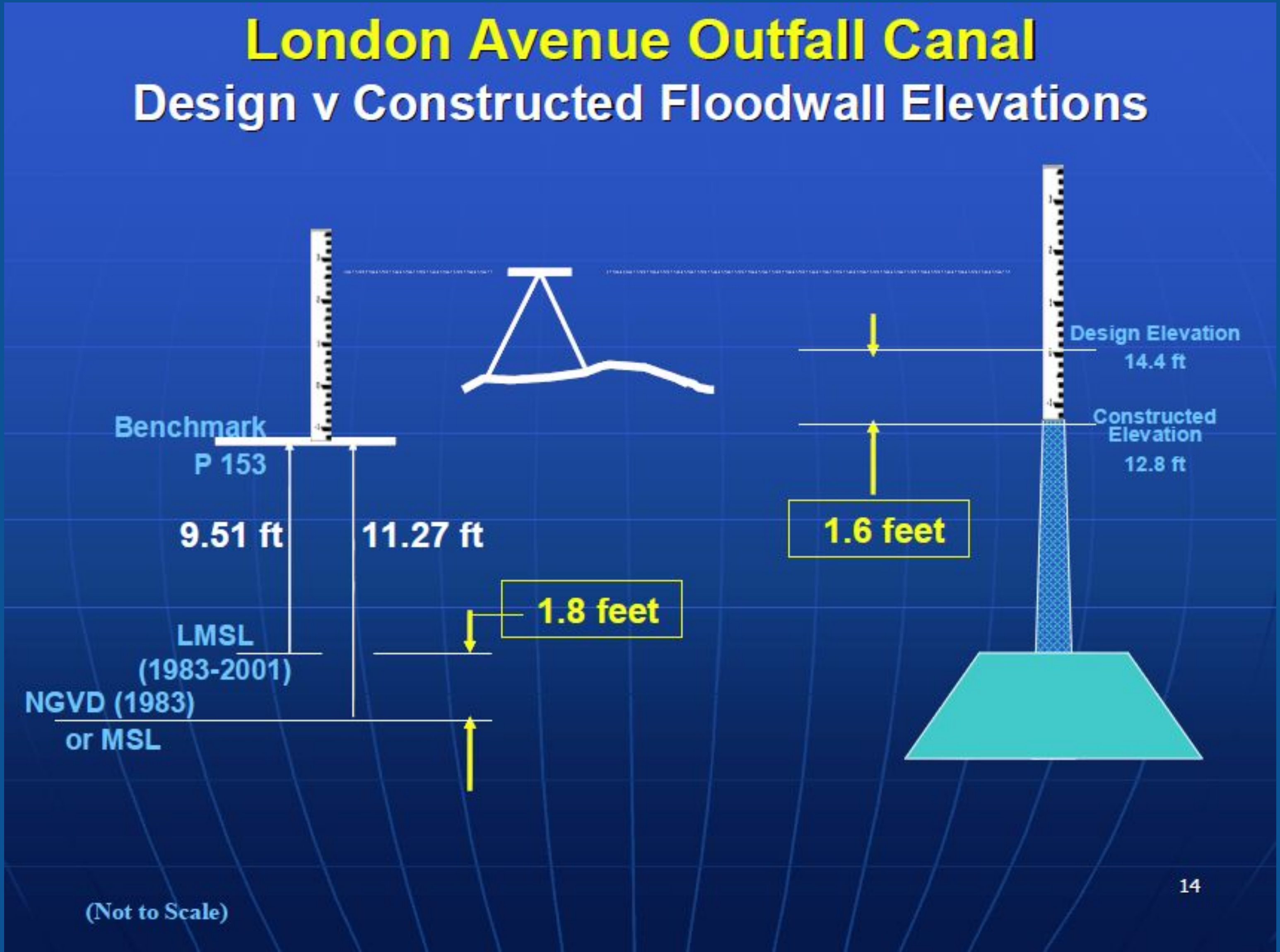


The published NAVD 88 height is no longer the true height for this BM

Its not only datum but metadata that is key



Impact of using NGVD elevation instead of LMSL elevation for construction stakeout of London Ave. Outfall Canal floodwall construction.



Sea Level Rise and Coastal Flood Risk

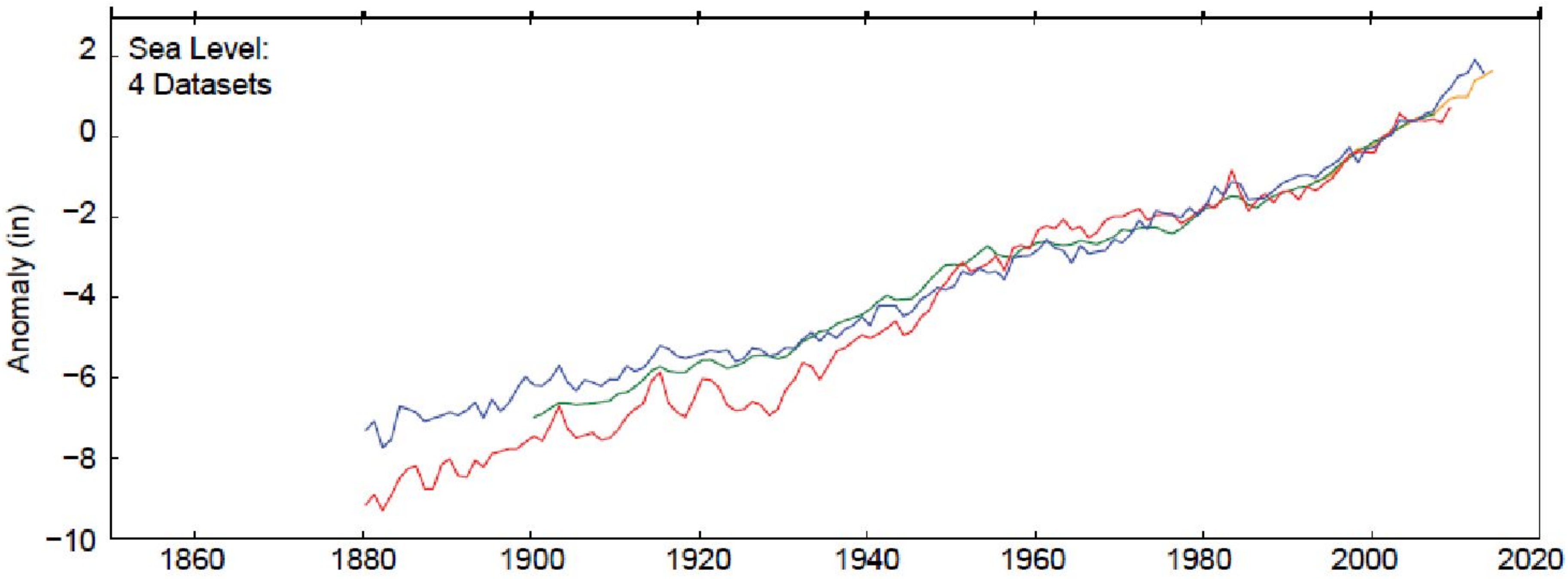
U.S. 4th National Climate Assessment (NCA4)
Climate Science Special Report (CSSR)

This presentation was created by

Dr. William Sweet

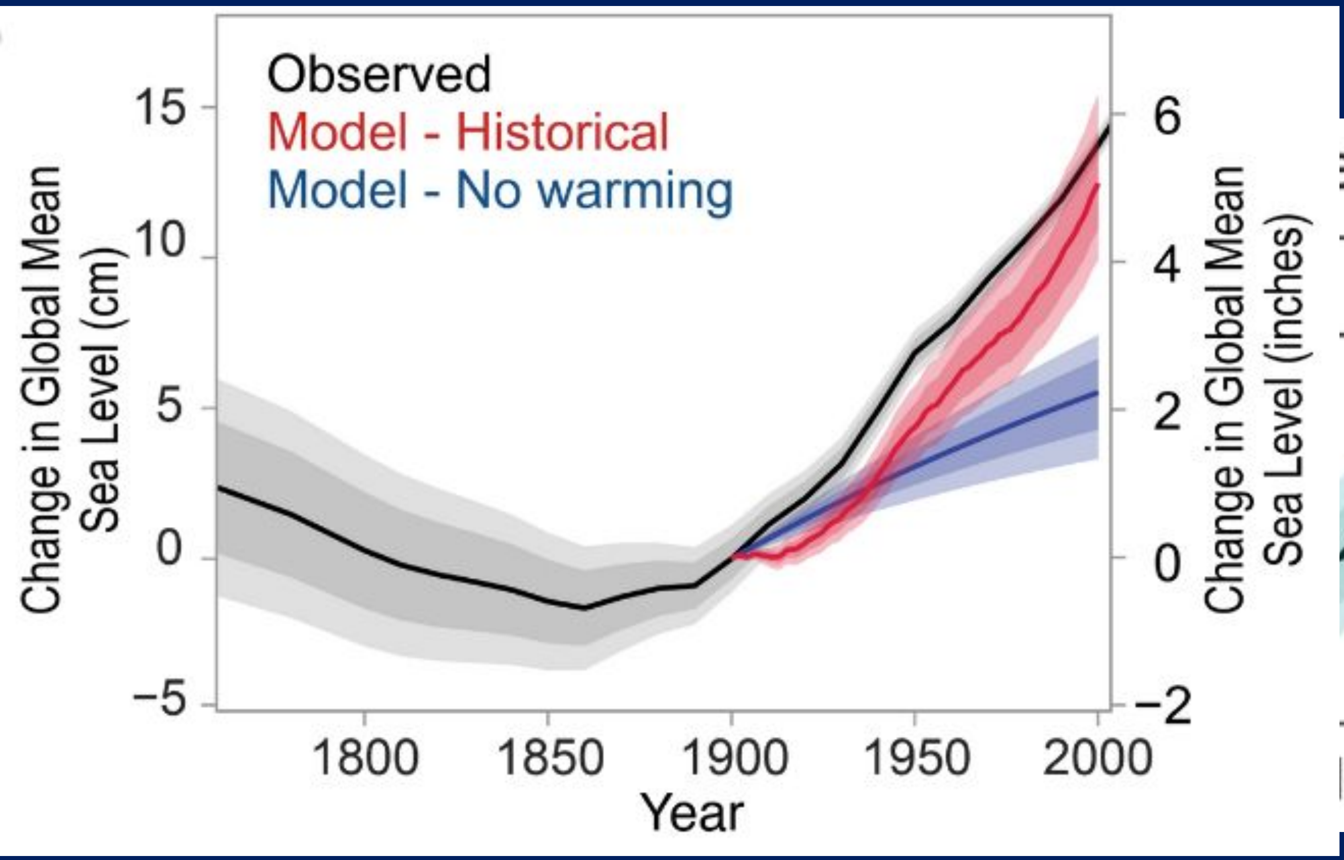
NOAA CO-OPS

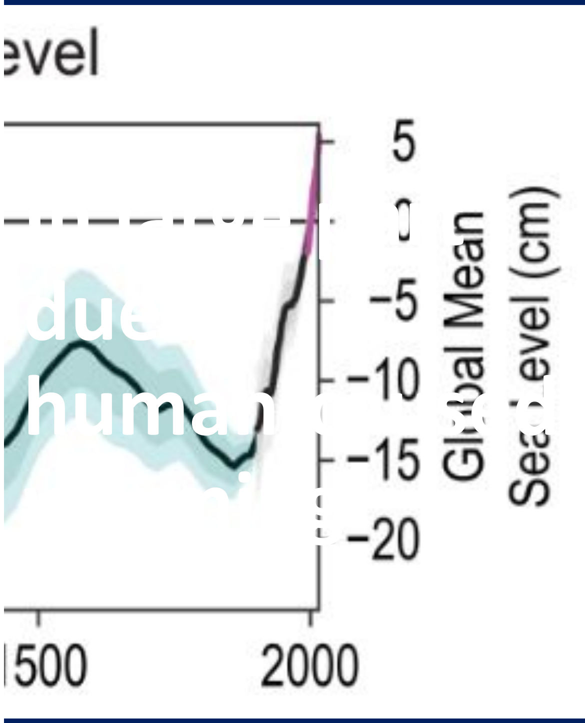
Global mean sea level has risen by about 16-21 cm (7-8 in) since 1900, with about 7 cm (3 in) occurring since 1993.



Wuebbles et al. (2017): CSSR Chapter 1

The rate of rise since 1900 is faster than during any preceding century in at least 2,800 years.

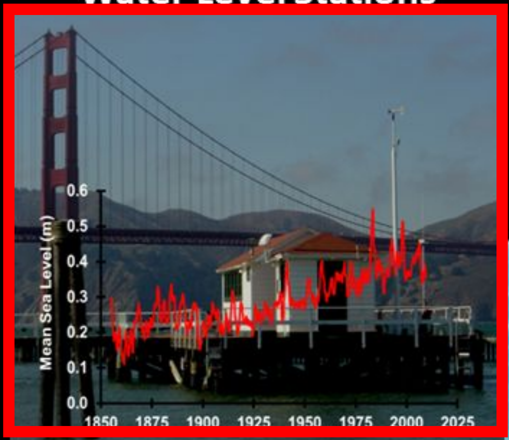




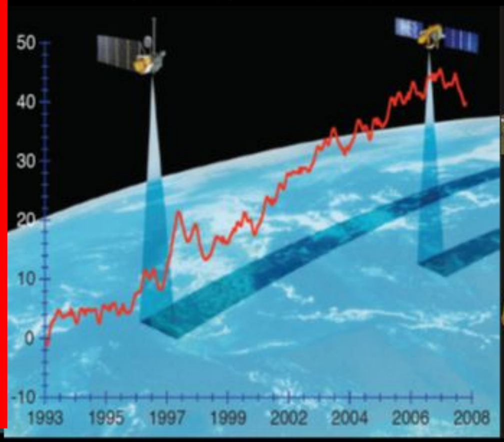
Sweet et al. (2017): CSSR Chapter 12

Global & Local Relative Sea Level Rise (SLR)

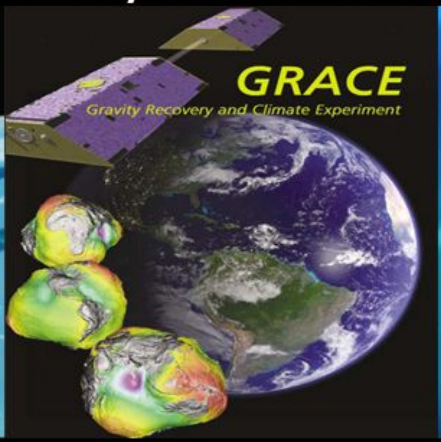
Water Level Stations



Satellite Altimeter



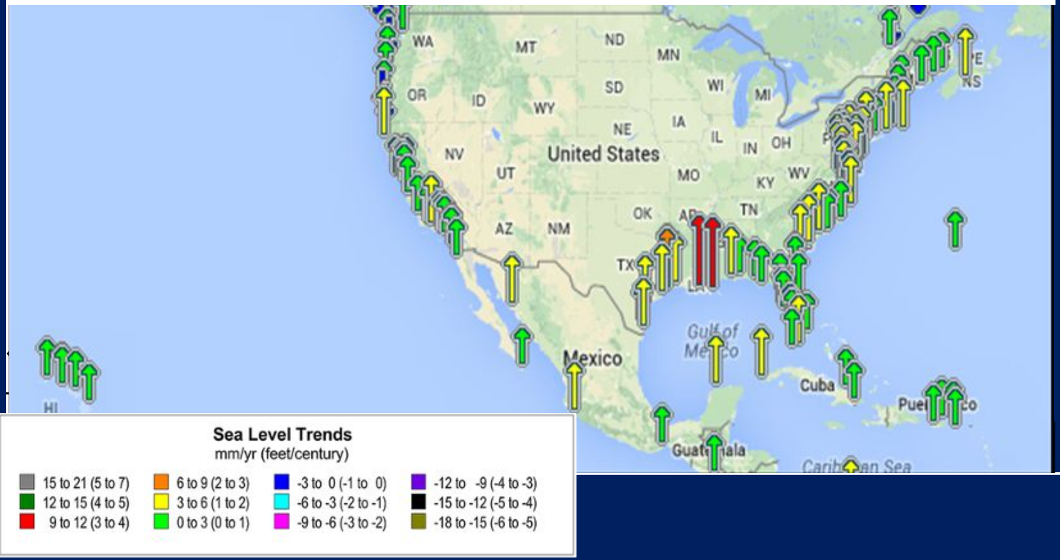
Gravity Measurements



ARGO Profilers

NOAA Relative Sea Level Trends

Historical trends are not considered future guidance for risk planning purposes!!!



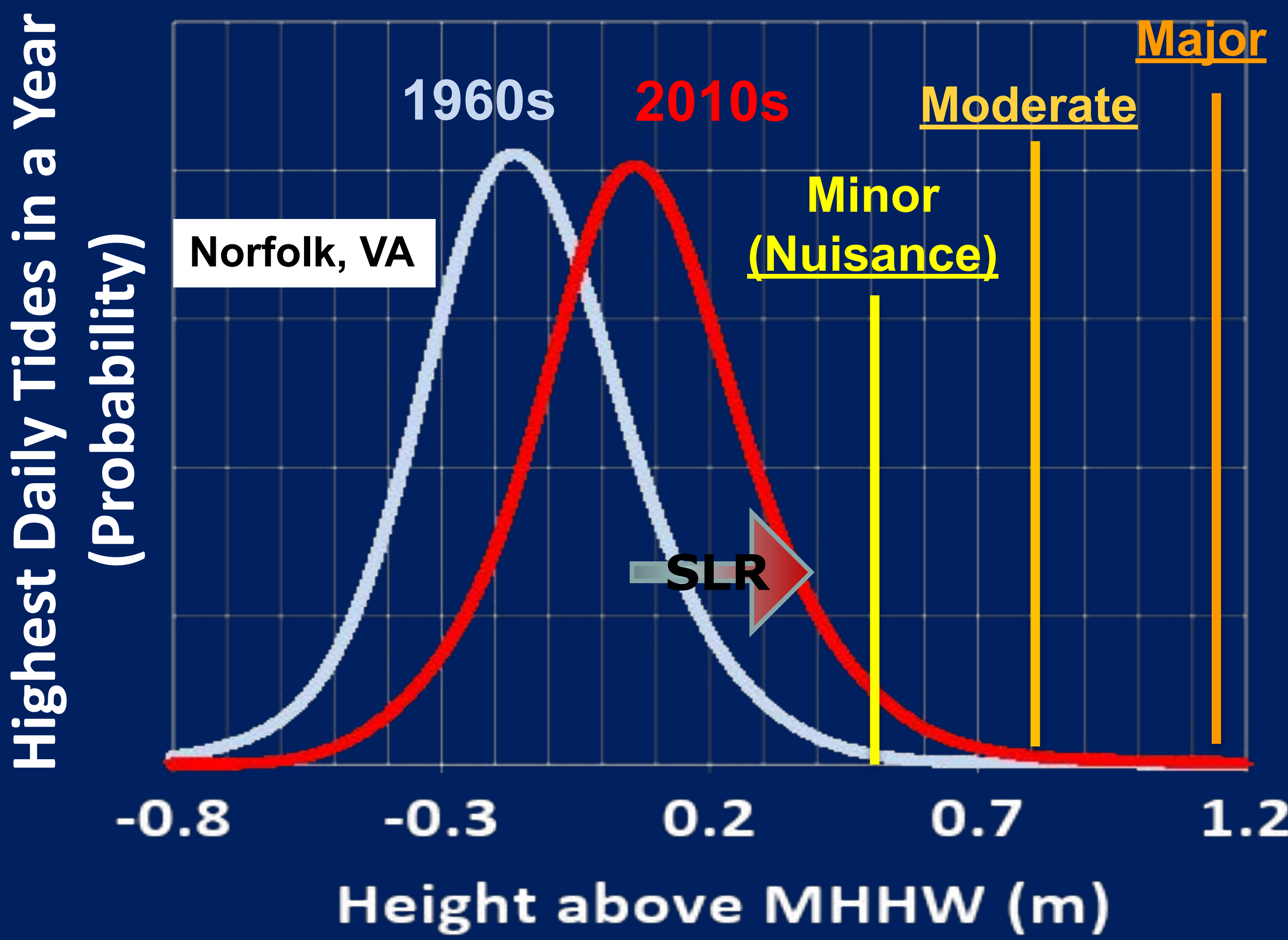
Relative SLR =

Δ Ocean Height

–

Vertical Land Motion

The Accelerating Threat of Tidal Flooding



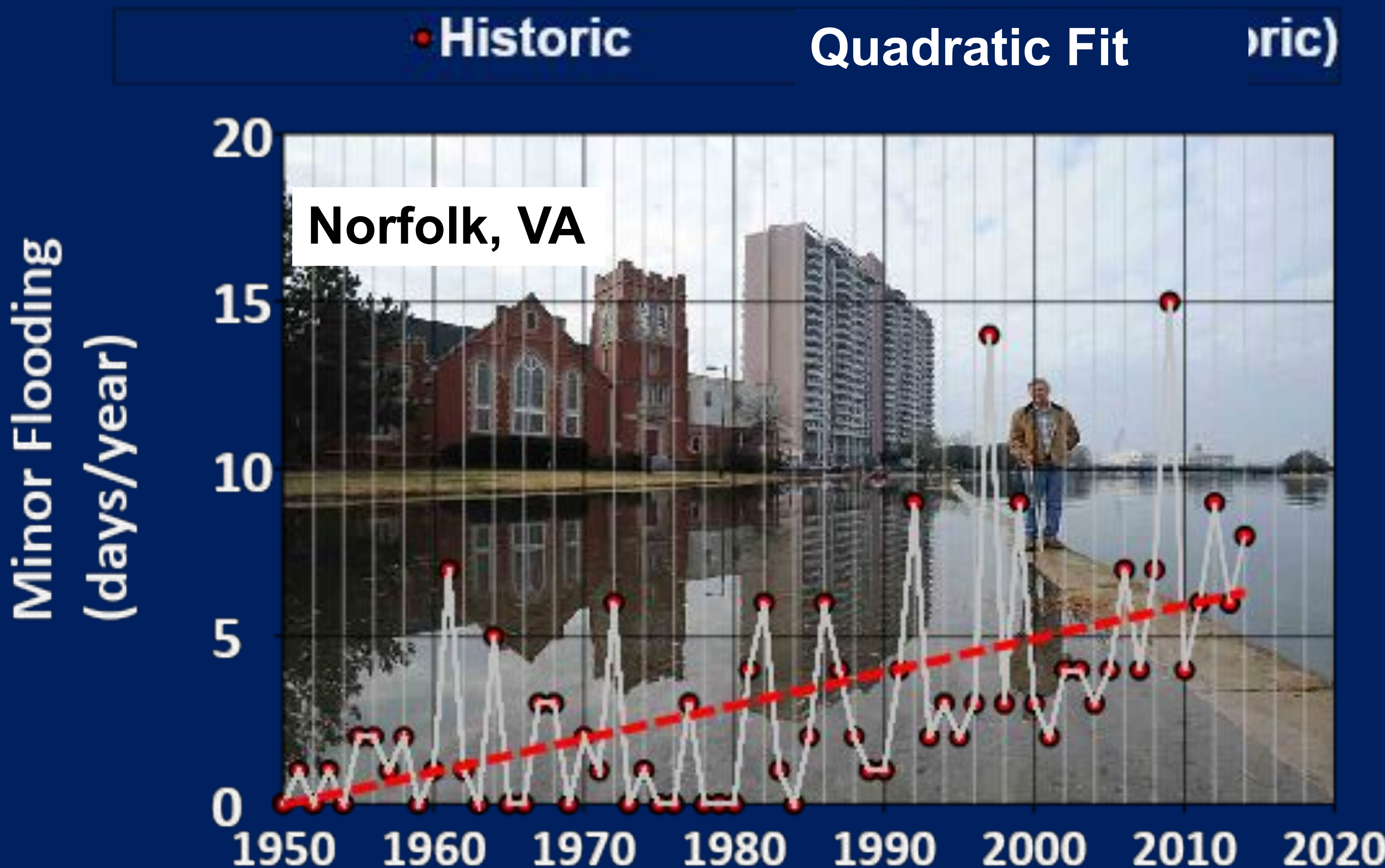
Communicating Flood Severity and NOAA Forecasts

Coastal Flooding Thresholds

National Weather Service Wakefield, Virginia

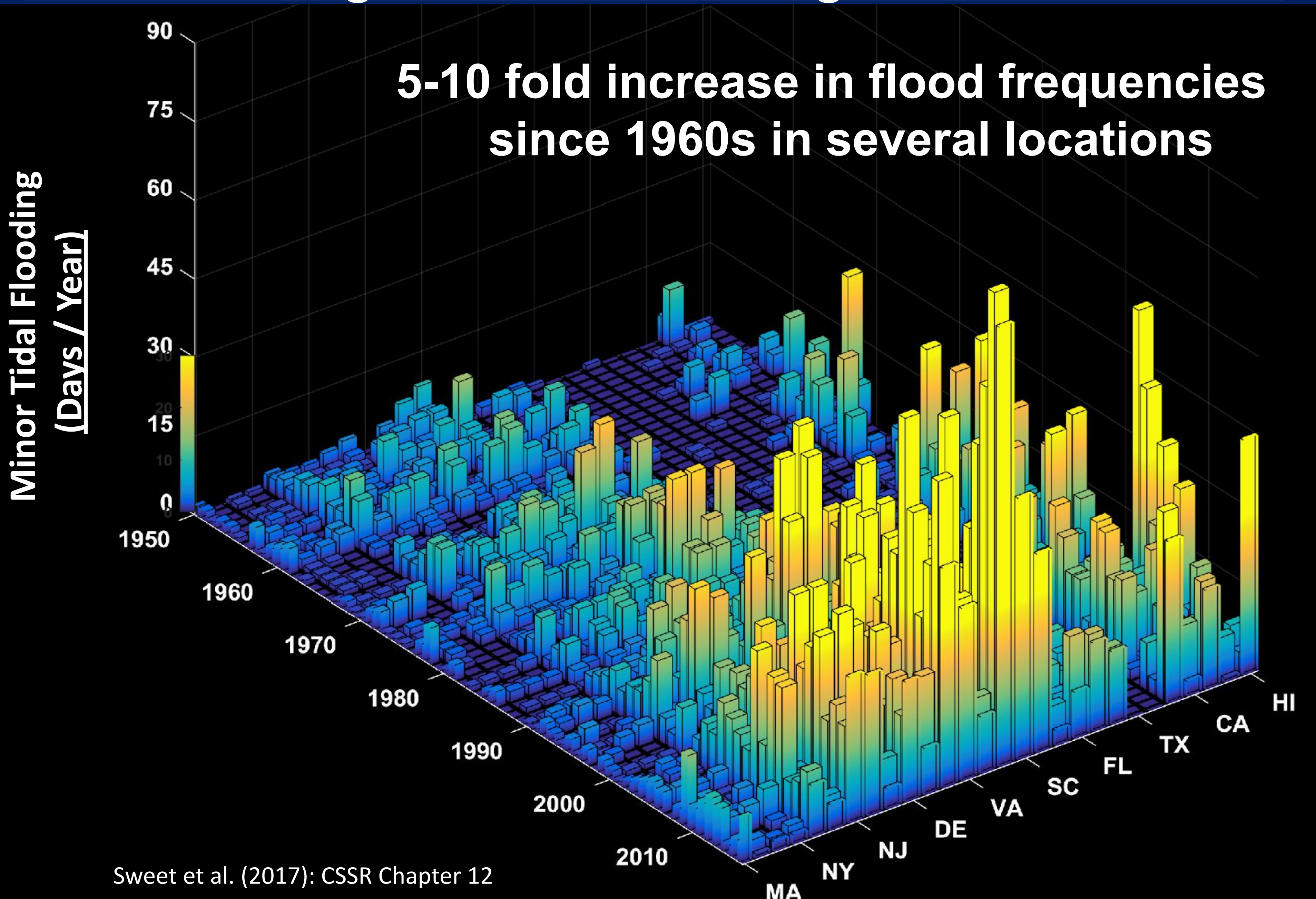
	Minor (High Tide Flooding)	Moderate	Major
Picture	Coastal Flood 'Advisory' 	Coastal Flood 'Warning' 	Coastal Flood 'Warning' 
Hazard	➢ **Shallow flooding** in the most vulnerable locations near the waterfront and shoreline resulting in a **low threat of property damage.** ➢ **Up to 1 foot of inundation** in shoreline and vulnerable areas.	➢ **Widespread flooding** of vulnerable areas will result in an **elevated threat of property damage.** ➢ **1 to 2 feet of inundation** primarily in shoreline and vulnerable areas.	➢ **Severe flooding** will cause extensive inundation and flooding of numerous roads and buildings resulting in a **significant threat to property and life.** ➢ **2 to 3 feet or more of inundation.**
Impact	➢ A few shoreline and vulnerable roadways and adjacent properties will experience shallow flooding. ➢ Minor beach erosion with possible erosion to the front of vulnerable dune structures.	➢ Inundation of roads and low lying property near the waterfront. ➢ Flooding will extend along tidal rivers and creeks resulting in some road closures, flooding of vehicles, and some property. ➢ Severe beach erosion and considerable erosion of dunes, especially during long duration events.	➢ Numerous roads will be impassable, with many unprotected cars submerged. ➢ Evacuations will be necessary for the most vulnerable areas. ➢ Flood waters may extend well inland. ➢ Substantial coastal damage and severe erosion of dunes.

An Accelerating Trend of Tidal Flooding



Sweet and Park (2014)

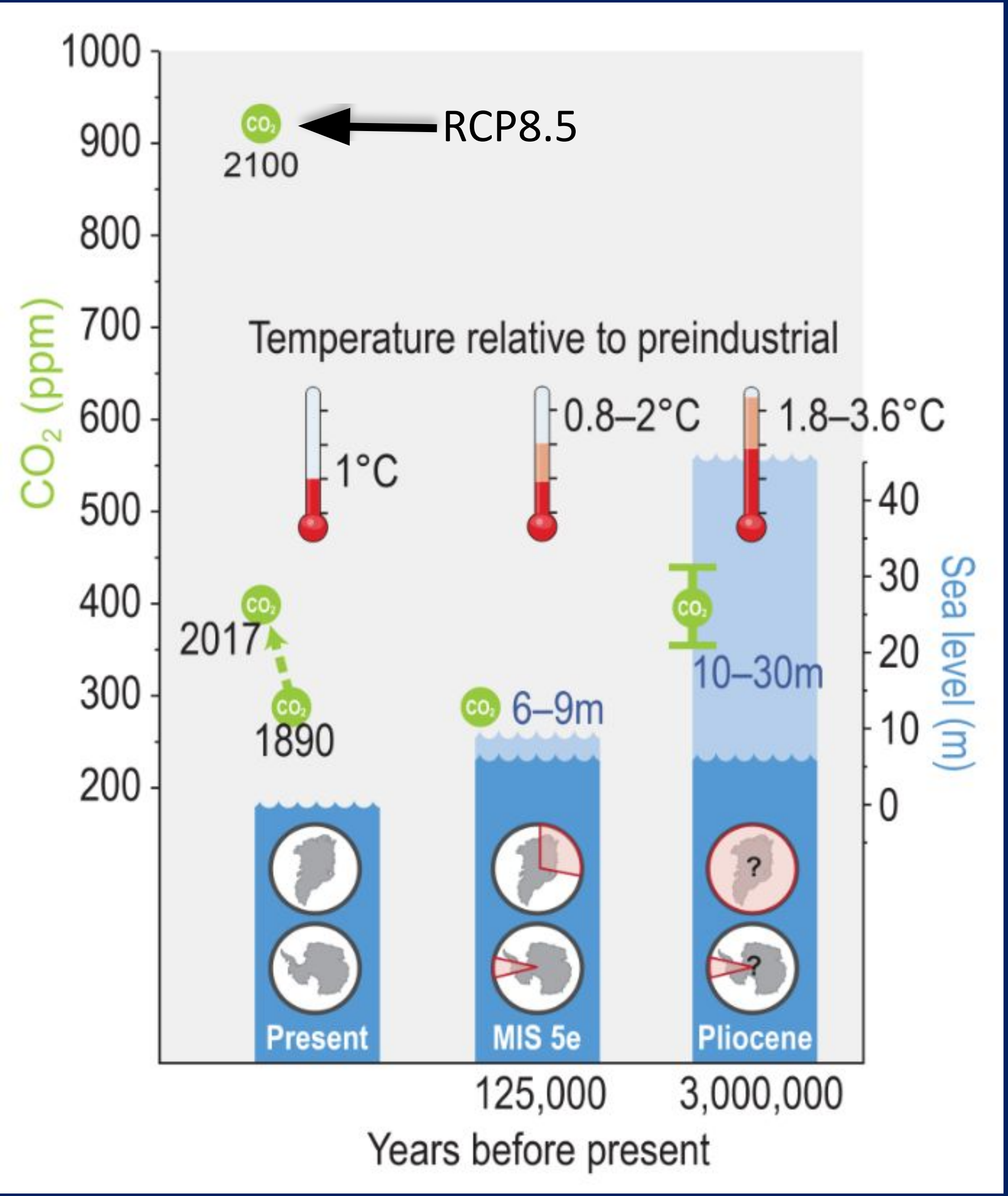
Tidal Flooding Trends: A Growing National Problem



Sweet et al. (2017): CSSR Chapter 12

What does the Future Hold? Future Possible SLR

Global sea level reconstructions of 6-9 m during the Last Interglacial is possible long-term response to the minimum temperature change projected for this century.



Sweet et al. (2017): CSSR Chapter 12

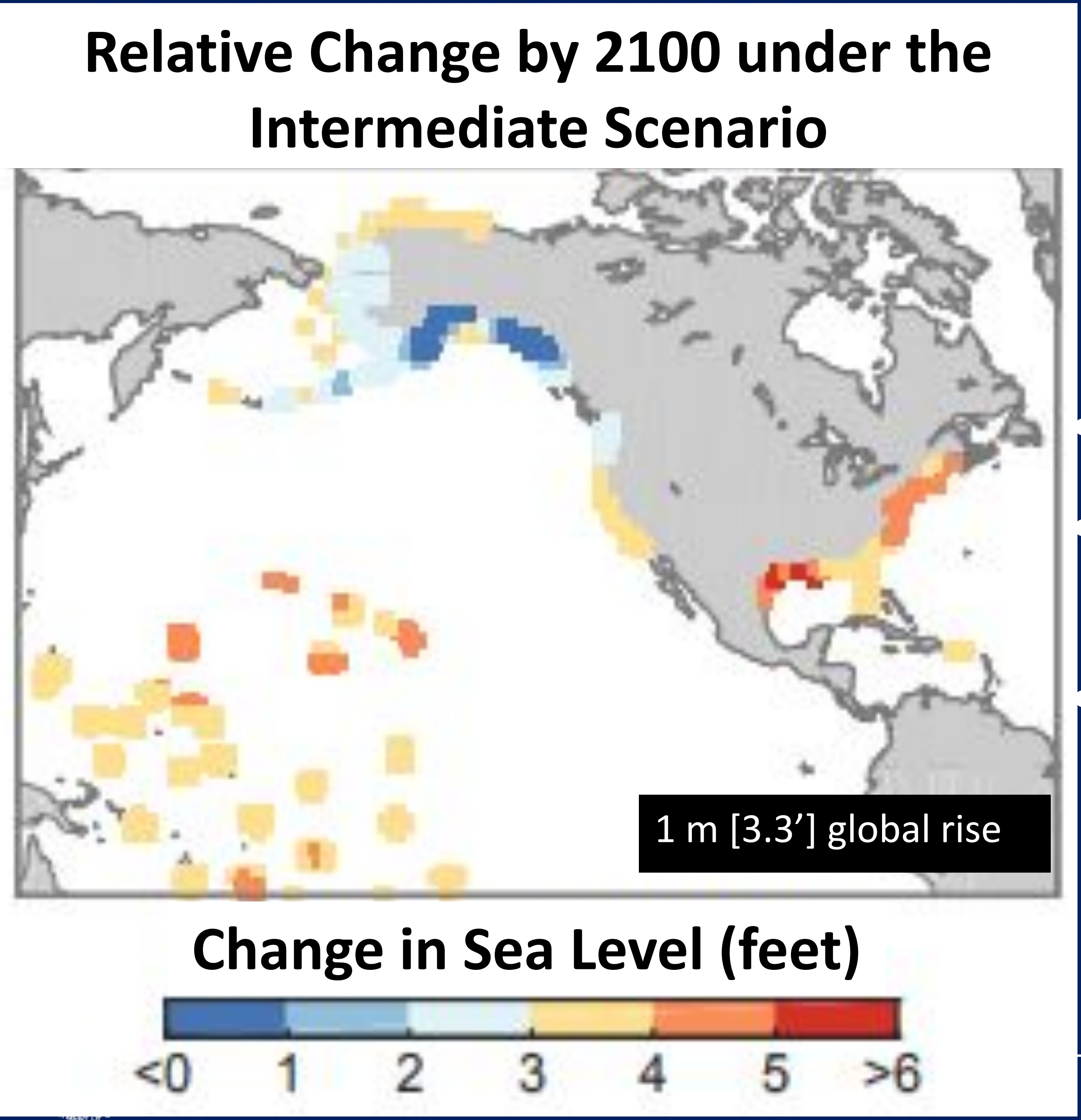
Table 12.3. Interpretations of the Interagency GMSL rise scenarios

Scenario	Interpretation
Low	Continuing current rate of GMSL rise, as calculated since 1993 Low end of *very likely* range under RCP2.6
Intermediate-Low	Modest increase in rate Middle of *likely* range under RCP2.6 Low end of *likely* range under RCP4.5 Low end of *very likely* range under RCP8.5
Intermediate	High end of *very likely* range under RCP4.5 High end of *likely* range under RCP8.5 Middle of *likely* range under RCP4.5 when accounting for possible ice cliff instabilities
Intermediate-High	Slightly above high end of *very likely* range under RCP8.5 Middle of *likely* range under RCP8.5 when accounting for possible ice cliff instabilities
High	High end of *very likely* range under RCP8.5 when accounting for possible ice cliff instabilities
Extreme	Consistent with estimates of physically possible "worst case"

The SLR scenarios contextualized in terms of probabilistic projections of Kopp et al., 2014

Sweet et al. (2017): CSSR Chapter 12

NCA4 SLR scenarios localized to 1° grids for the U.S. coastline



Includes changes in:

- Ocean circulation
- Earth’s gravitational field & rotation
- Vertical land motion

Sweet et al. (2017): CSSR Chapter 12

Today's 'Freeboard' and NCA4 SLR Scenarios

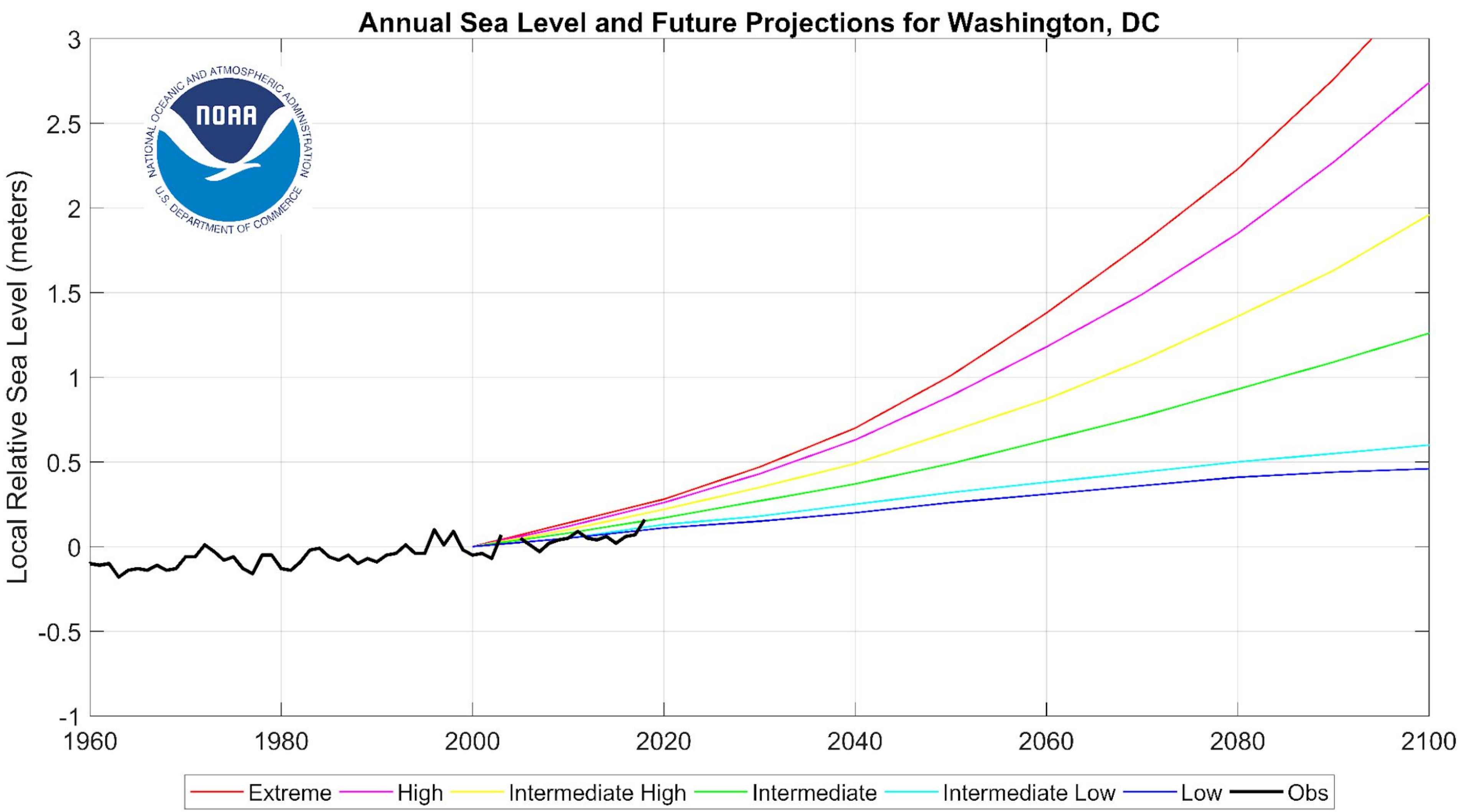
Norfolk, VA

Intermediate-Low Intermediate

High Extreme

5/year

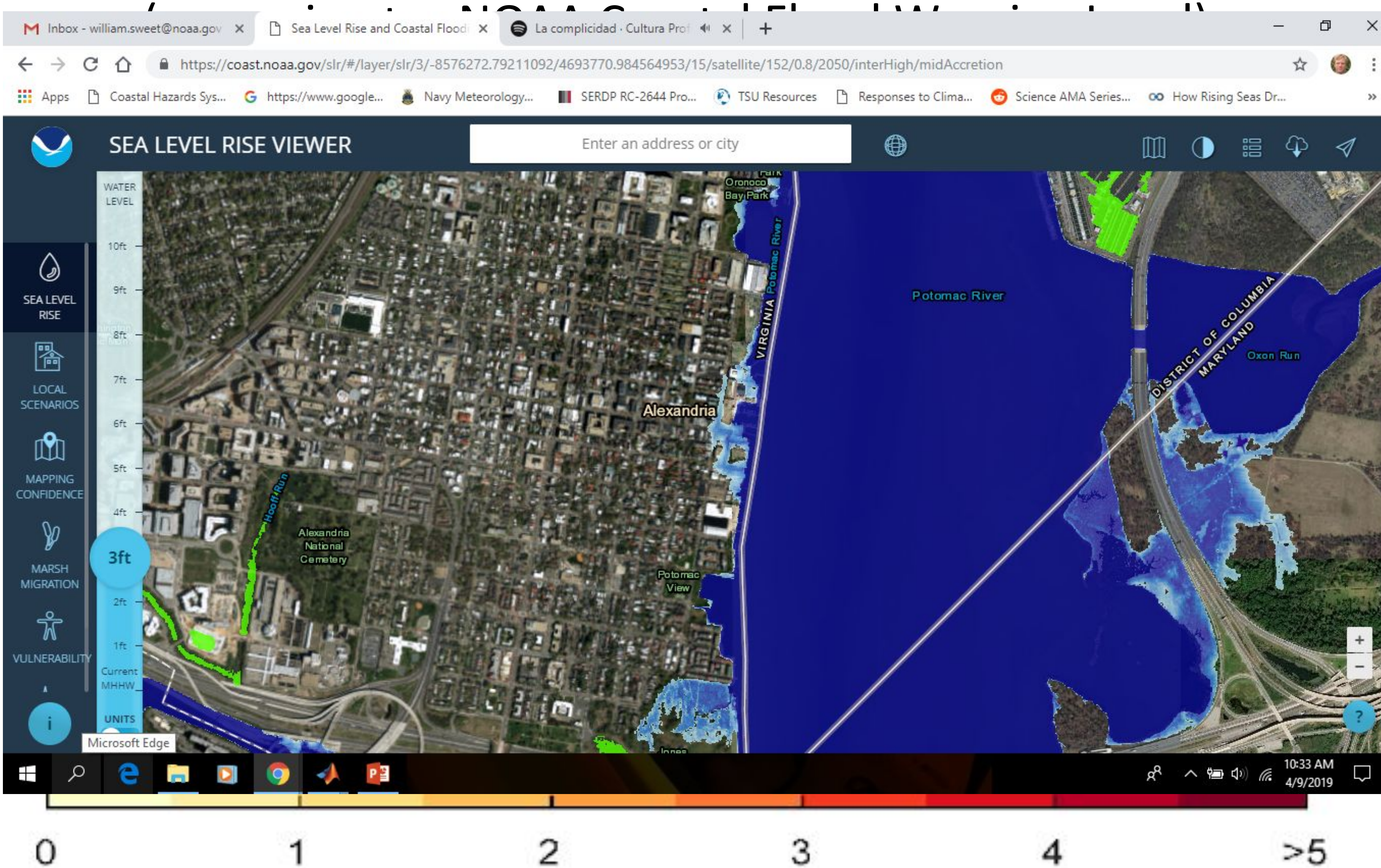
5-year



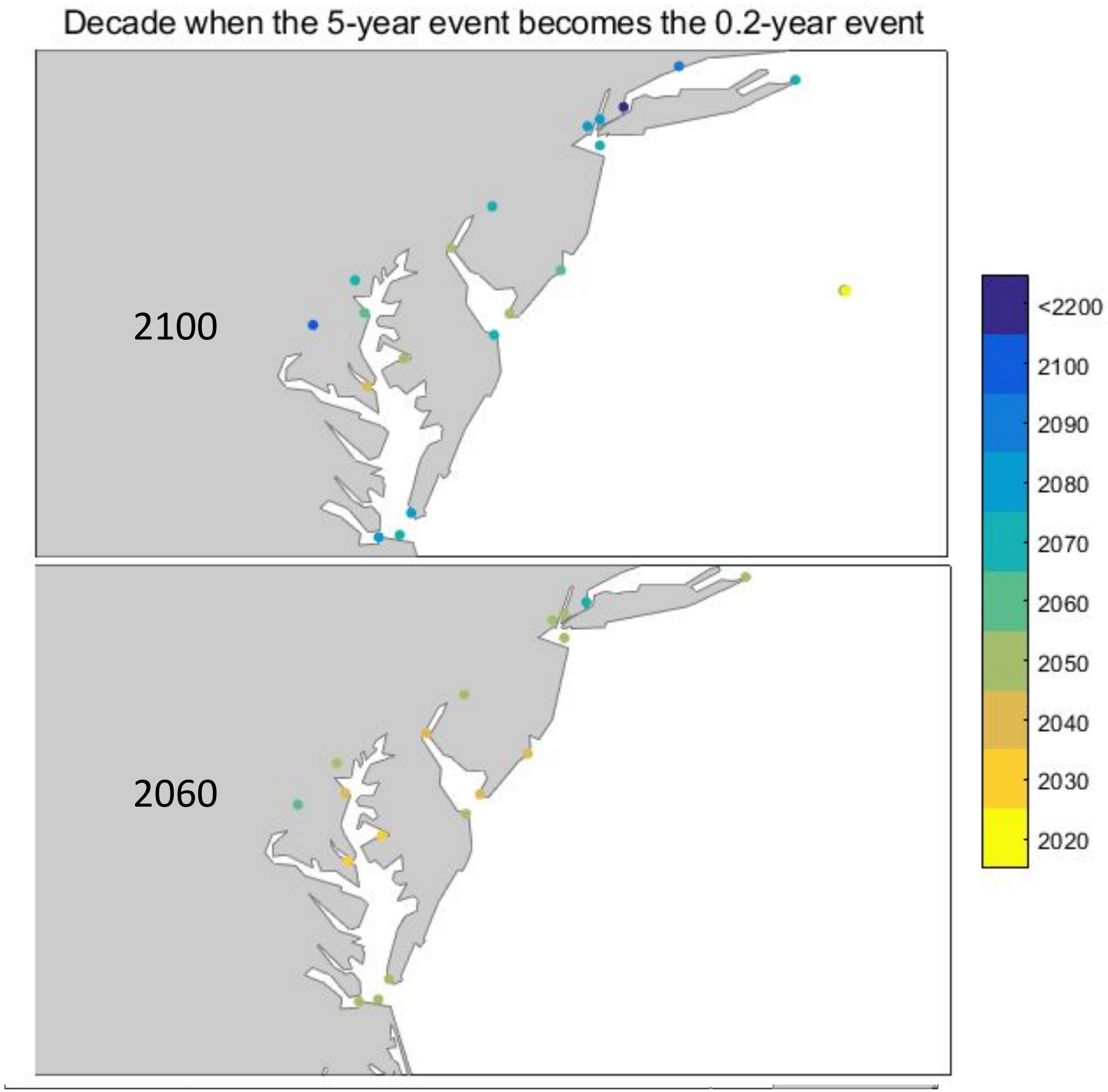
Sweet et al. (2017): CSSR Chapter 12

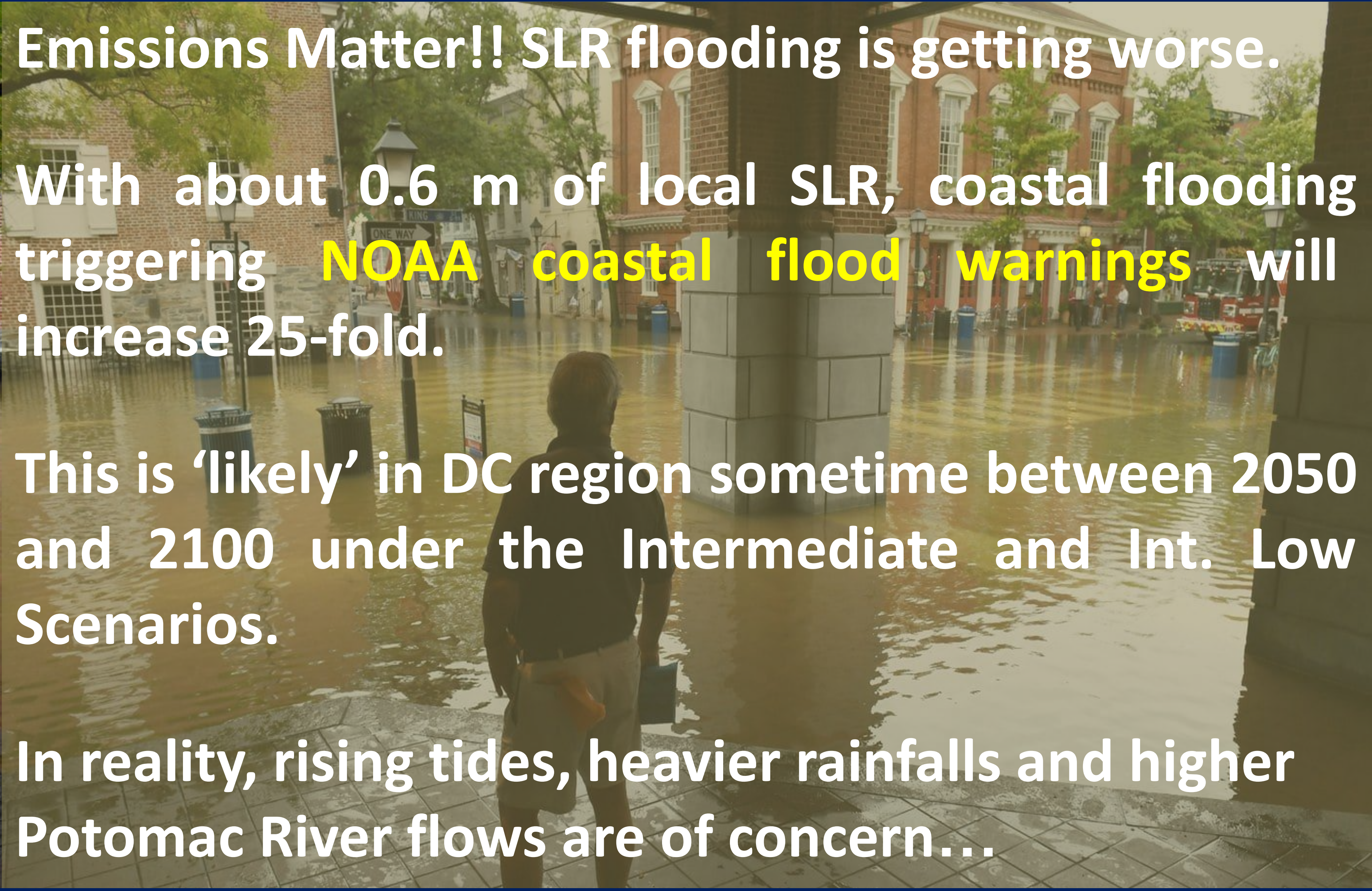
SLR Time Horizon for Impending Impacts

Moderate Flooding has a ~5-year Recurrence Interval



SLR Time Horizon for Impending Impacts





Emissions Matter!! SLR flooding is getting worse.

With about 0.6 m of local SLR, coastal flooding triggering NOAA coastal flood warnings will increase 25-fold.

This is ‘likely’ in DC region sometime between 2050 and 2100 under the Intermediate and Int. Low Scenarios.

In reality, rising tides, heavier rainfalls and higher Potomac River flows are of concern…


Questions?