Vertical Land Motion Considerations in Environmental Monitoring

Linda Blum[1]
Philippe Hensel[2]
Jessica Flester[1]

[1]Department Environmental Sciences, University of Virginia
[2]NOAA, National Geodetic Survey

Some Definitions:

- **Relative Sea Level (RSL)** height of the ocean surface measured relative to the solid Earth – currently NADV88

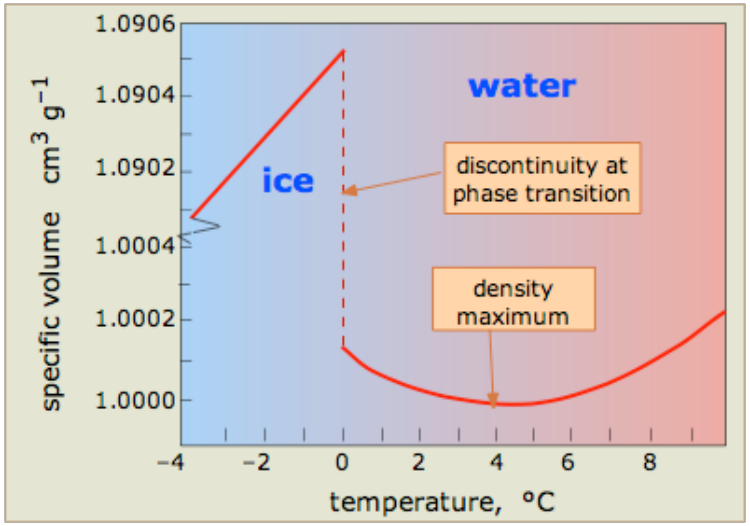
- **Geocentric Sea Level** relates to satellite altimetry and is measured relative to a reference ellipsoid

- **Mean Sea Level (MSL)** is RSL averaged over some period of time to remove variability

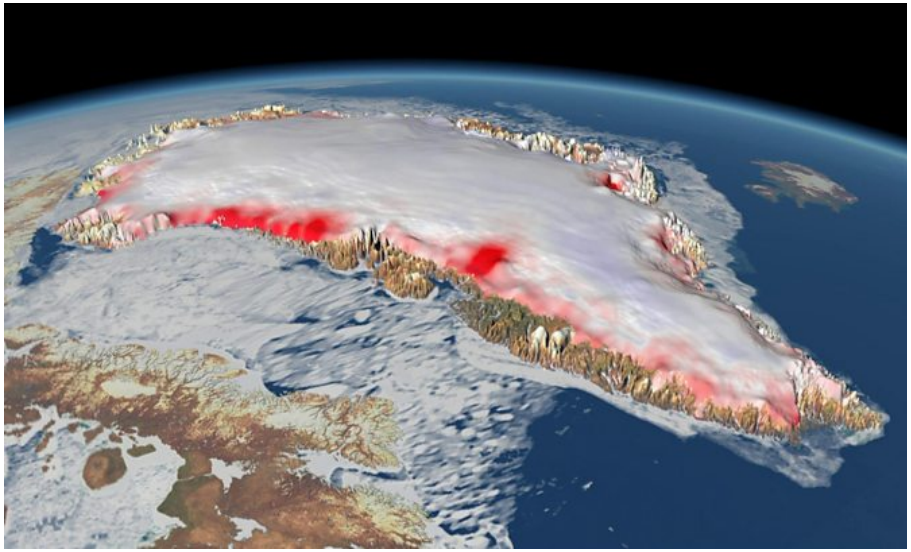
- **Global Mean Sea Level (GMSL)** is MSL averaged spatially/globally

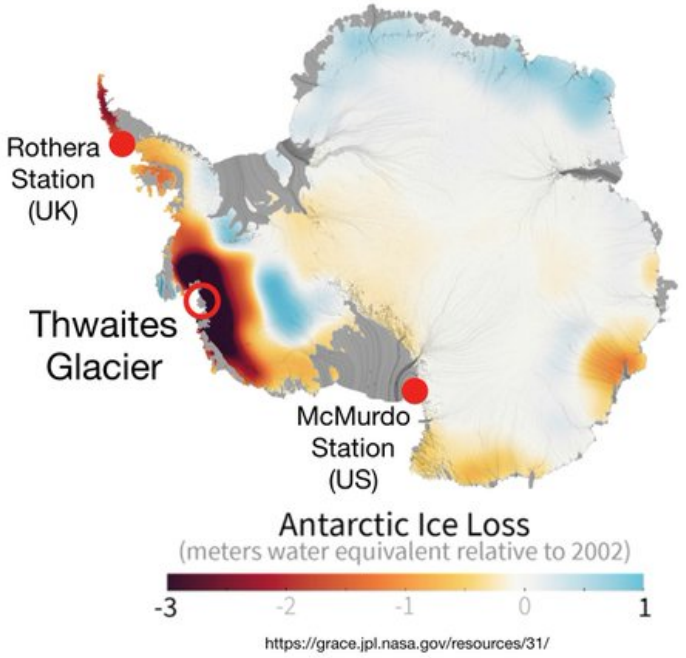
Factors Affecting Sea Level:

Eustatic (Volume) Processes



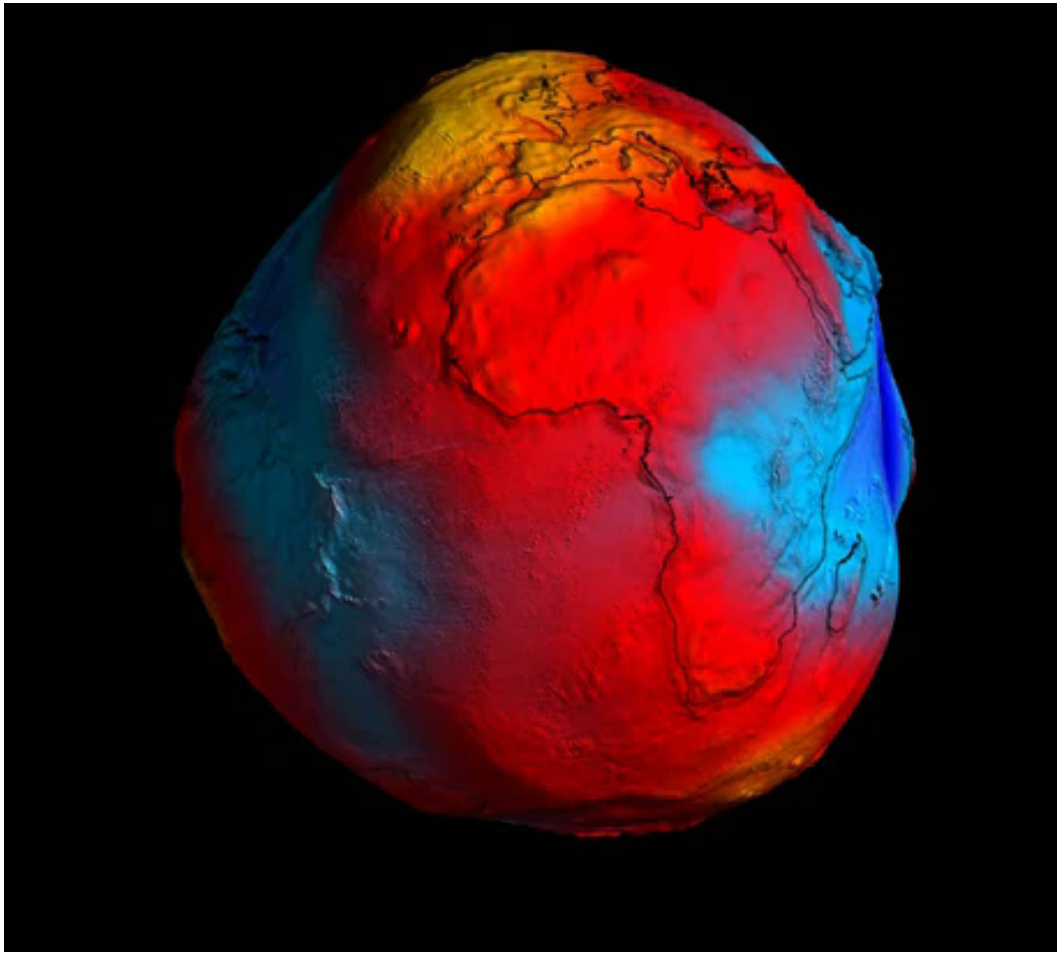
- **Thermal expansion (steric effects)**
- **Inputs of water from glaciers, ice sheets, rivers, and ground water**





Change in the Land Surface:

Isostatic Processes – long term processes related to the mass of the Earth's crust



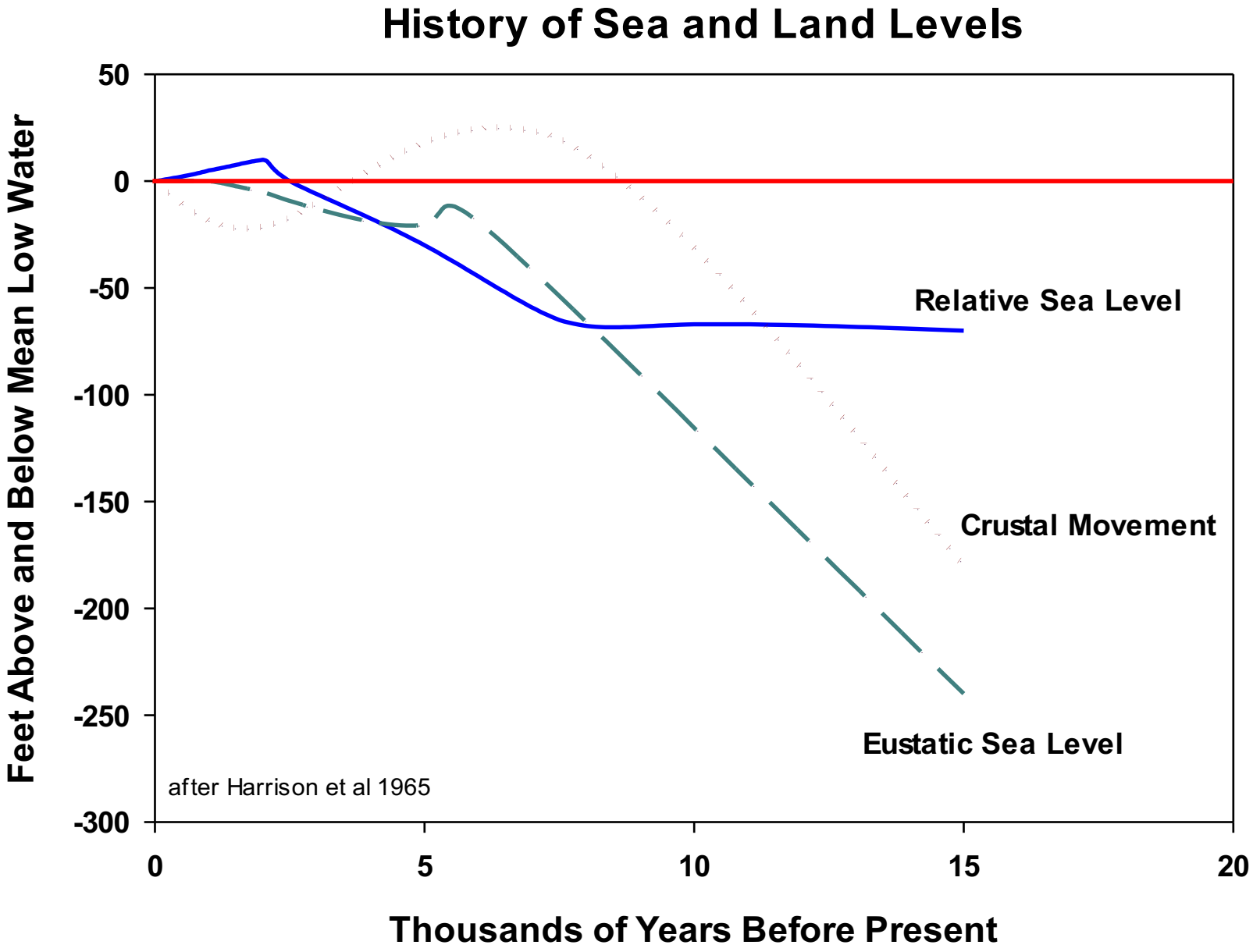
Video courtesy European Space Agency

Processes:

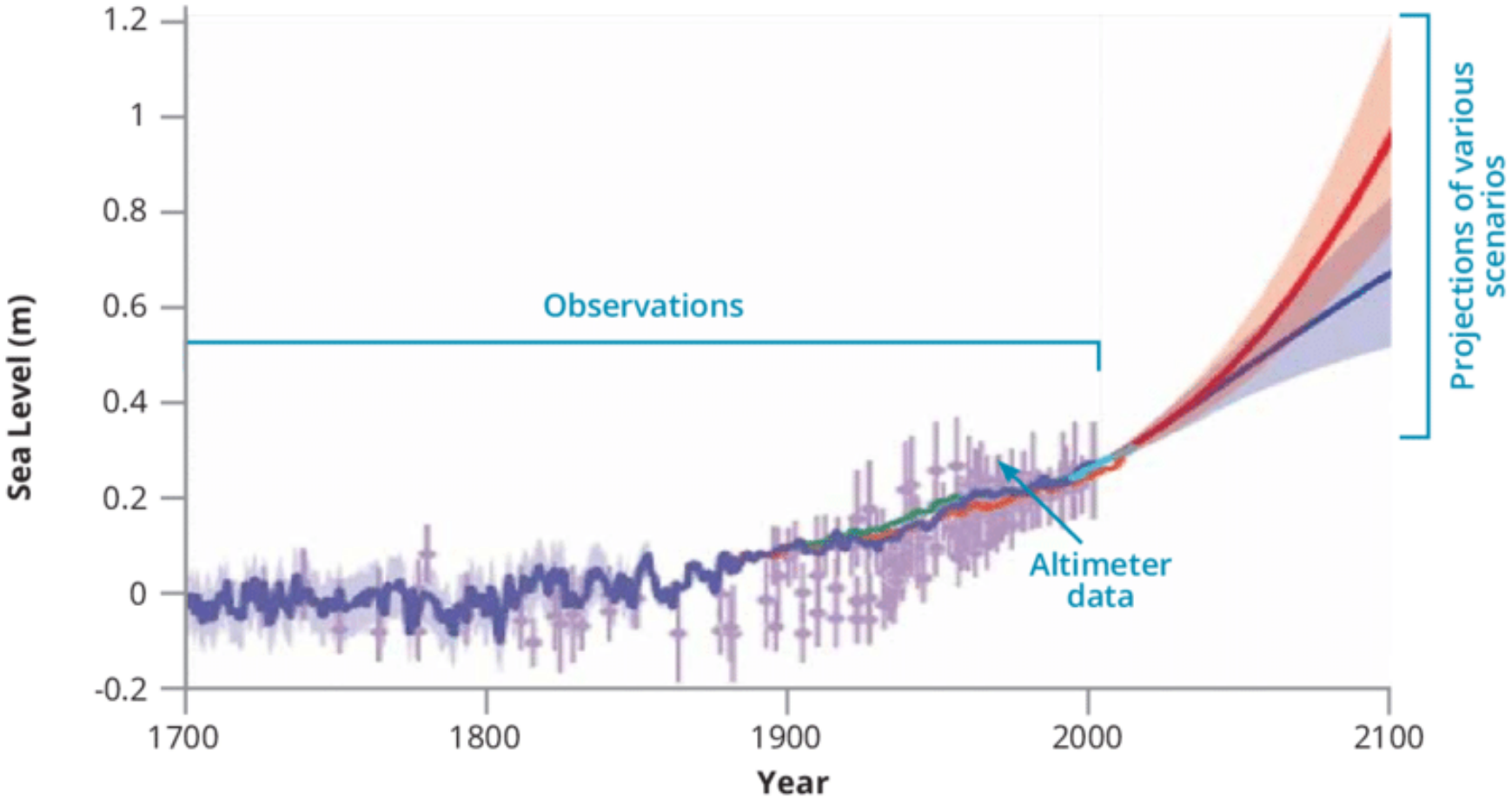
- **Glacio-hydro-isostatic**
- **Sedimentation/erosion**
- **Tectonic activity**

Process contribution to GMSL (1993 – 2013)	mm year^{-1} $\bar{x}$ ± 95% CL
Thermal expansion	1.1 ± 0.3
Glaciers except Greenland and Antarctica	0.76 ± 0.37
Glaciers in Greenland	0.10 ± 0.30
Greenland ice sheet	0.33 ± 0.80
Antarctic ice sheet	0.27 ± 0.11
Land water storage	0.38 ± 0.12
Total GMSL rise	3.2 ± 0.40

Adapted from Church 2013


History of Sea and Land Levels
Feet Above and Below Mean Low Water
50
0
-50
-100
-150
-200
-250
-300
0
5
10
15
20
Thousands of Years Before Present
Relative Sea Level
Crustal Movement
Eustatic Sea Level
after Harrison et al 1965

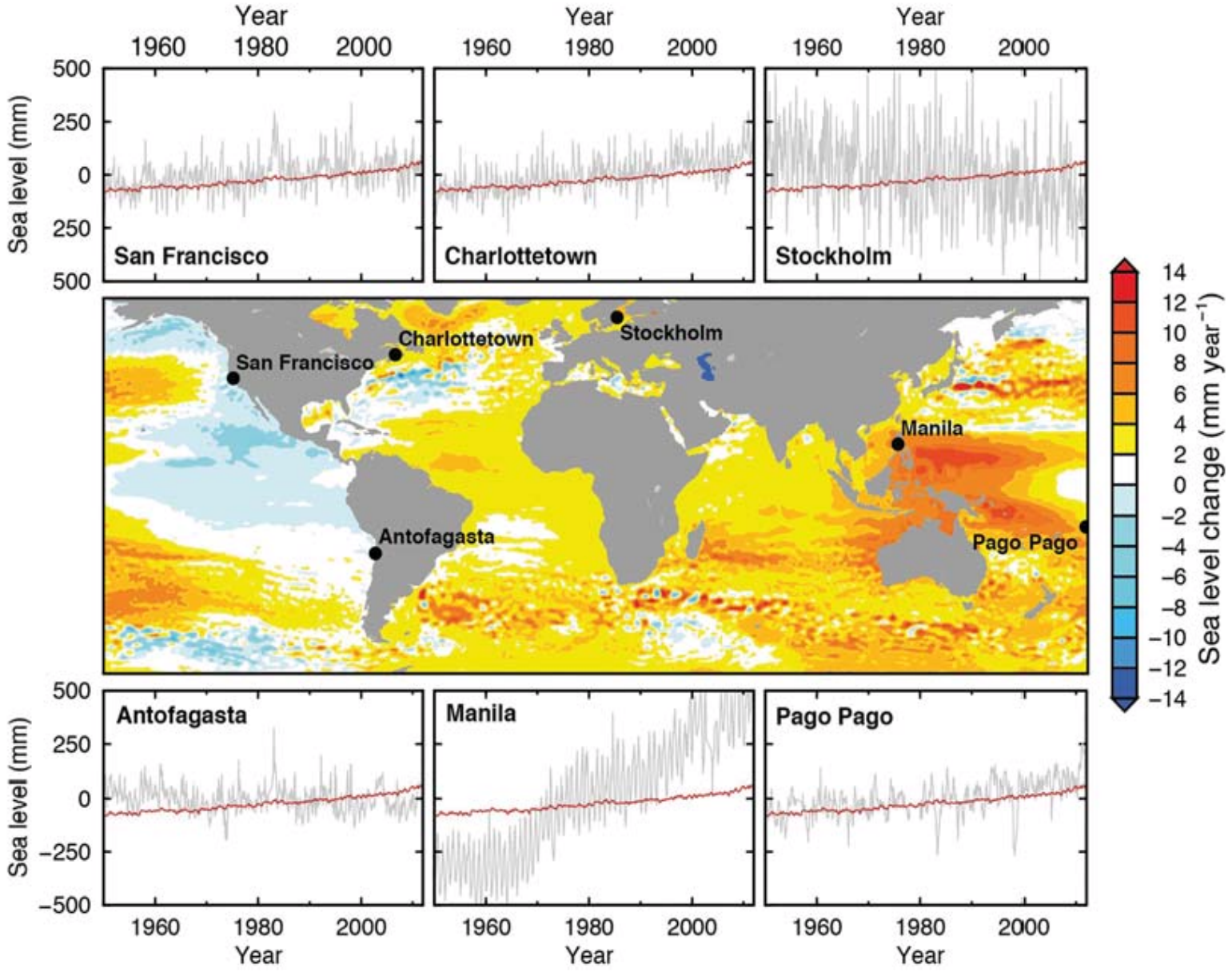
Current Global Eustatic Sea-Level Projections



Local sea level rise

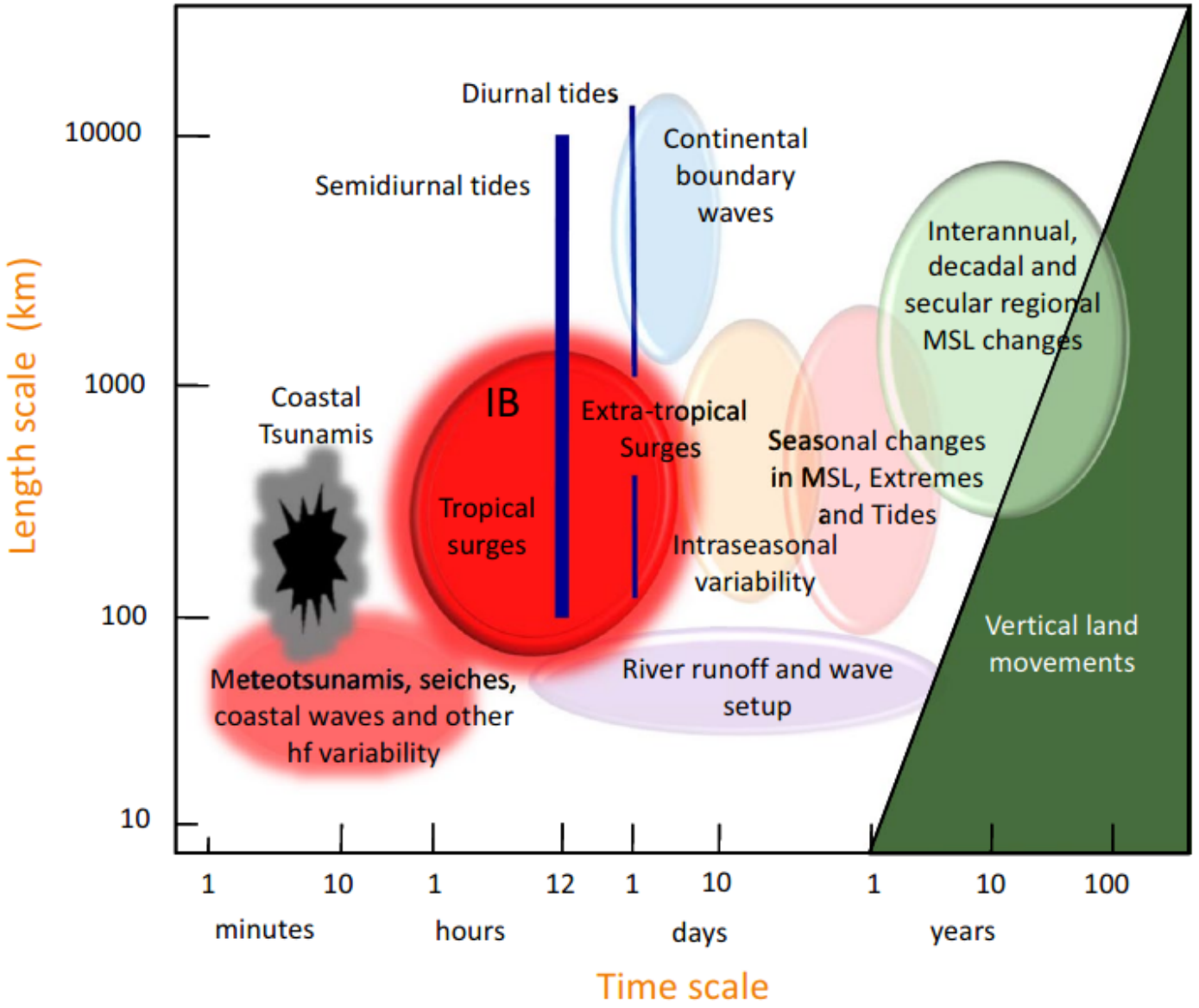
"*Local*" SLR

SLR differs according to location



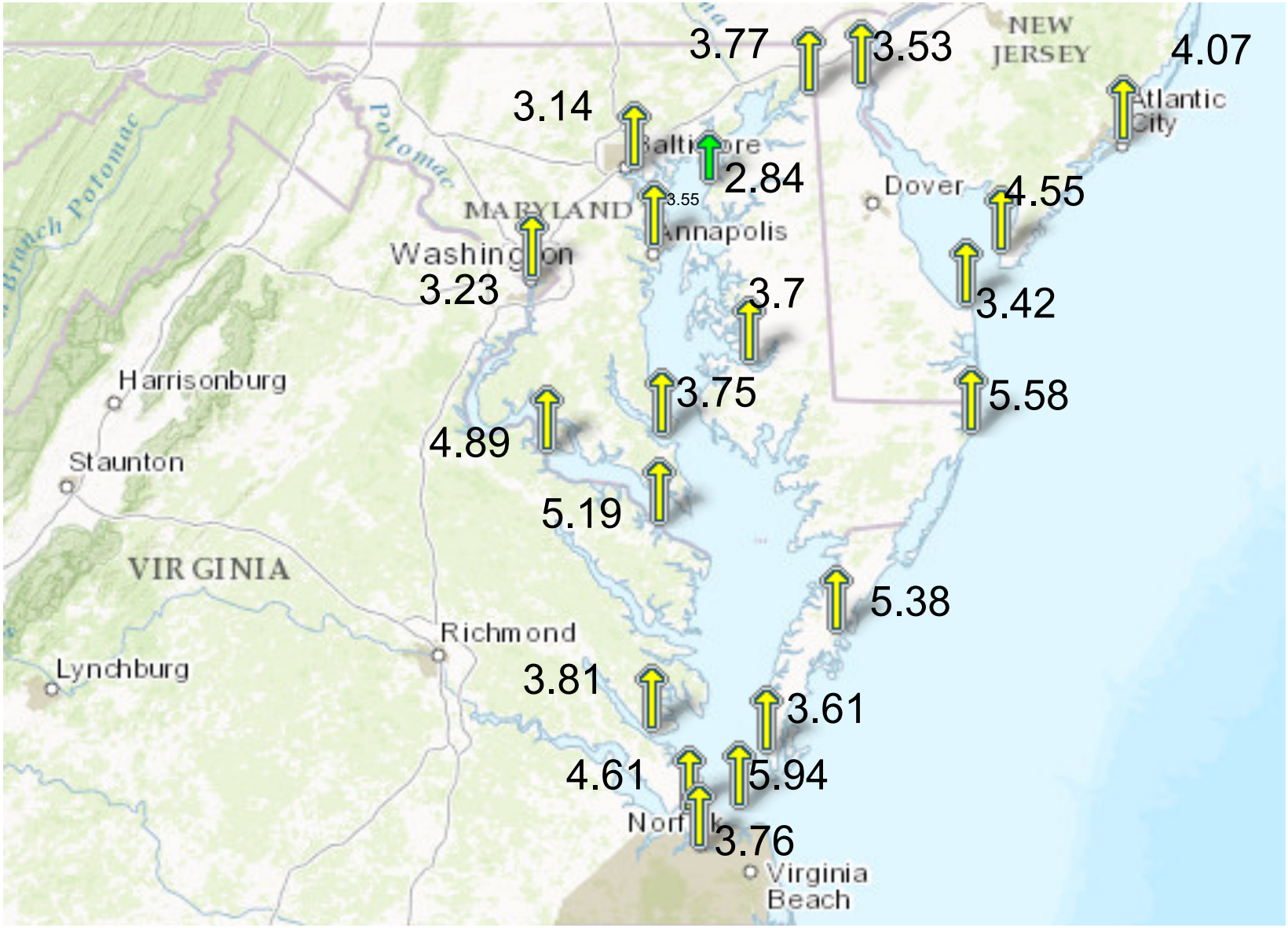
Christian, Blum, et al. 2019

Factors affecting local sea levels



Woodworth et al. 2019 https://doi.org/10.1007/s10712-019-09531-1

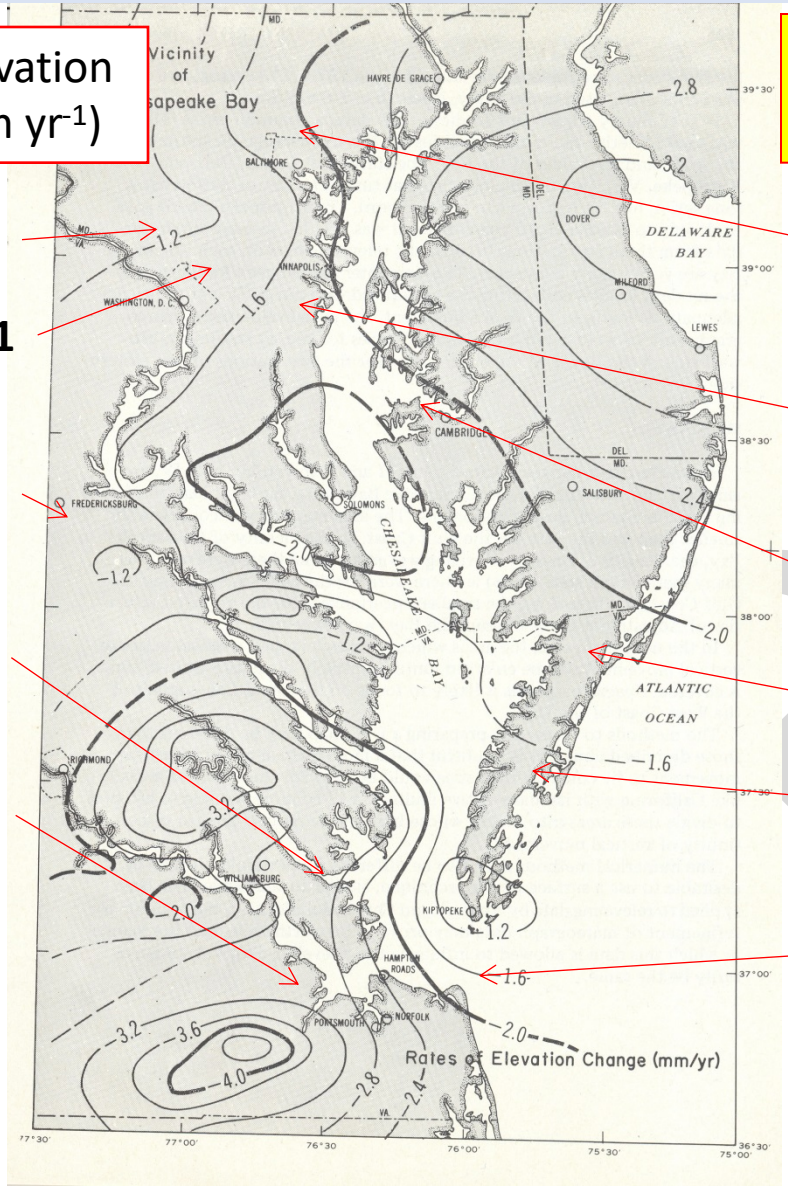
How local is local SLR?



NOAA SLR data

Subsidence: Holdhal & Morrison (1973) compared to CORS vertical velocities (2008)

Rates of Elevation Change (mm yr^{-1})



GAIT = - 0.4

GODE = - 1.1

CORB = - 1.0

VAGP = - 2.7

DRV6 = - 3.3

IGS08
Vertical Velocity at Selected CORS

BACO = - 3.2*

ANP6 = - 1.6

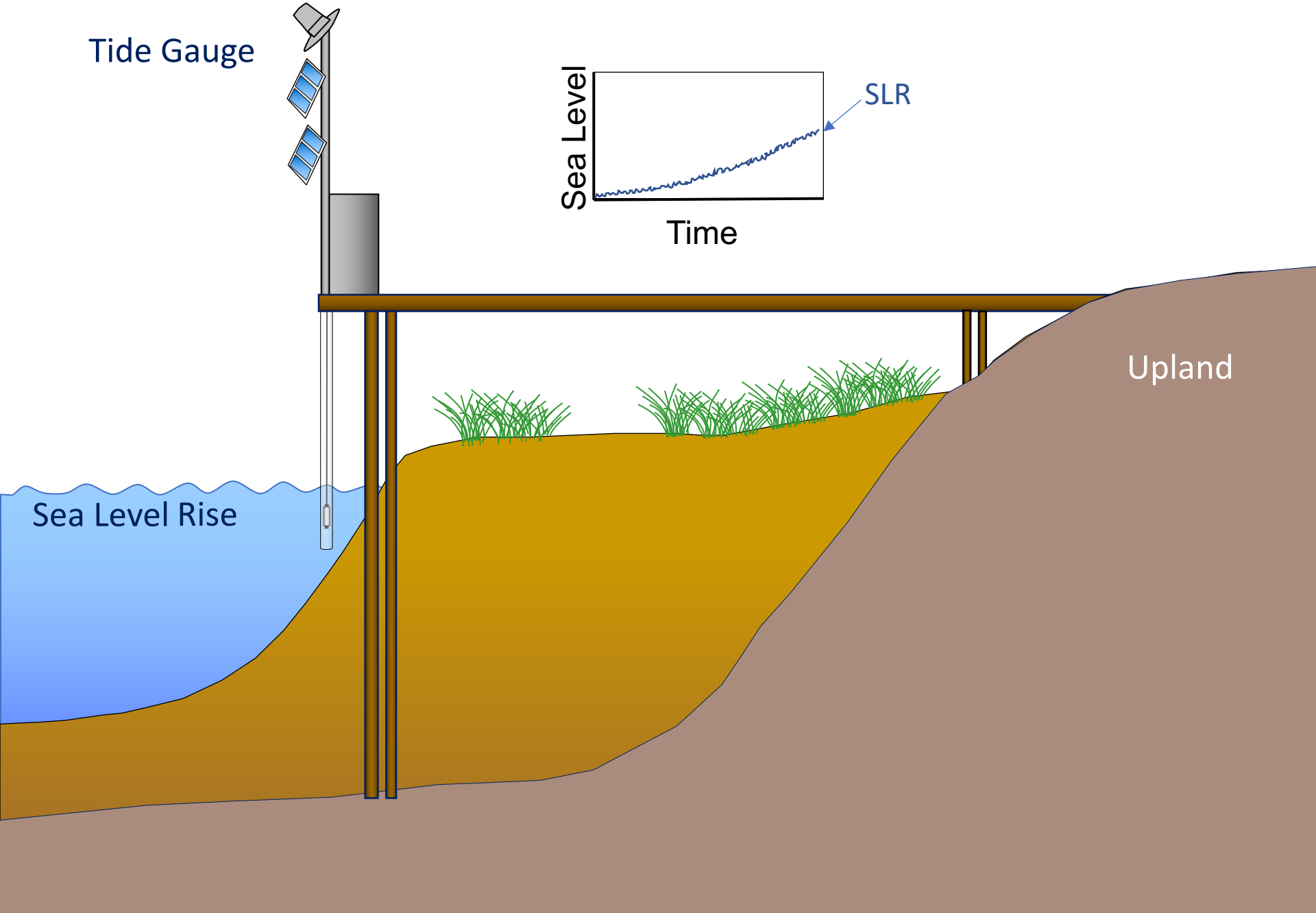
HNPT = - 2.4

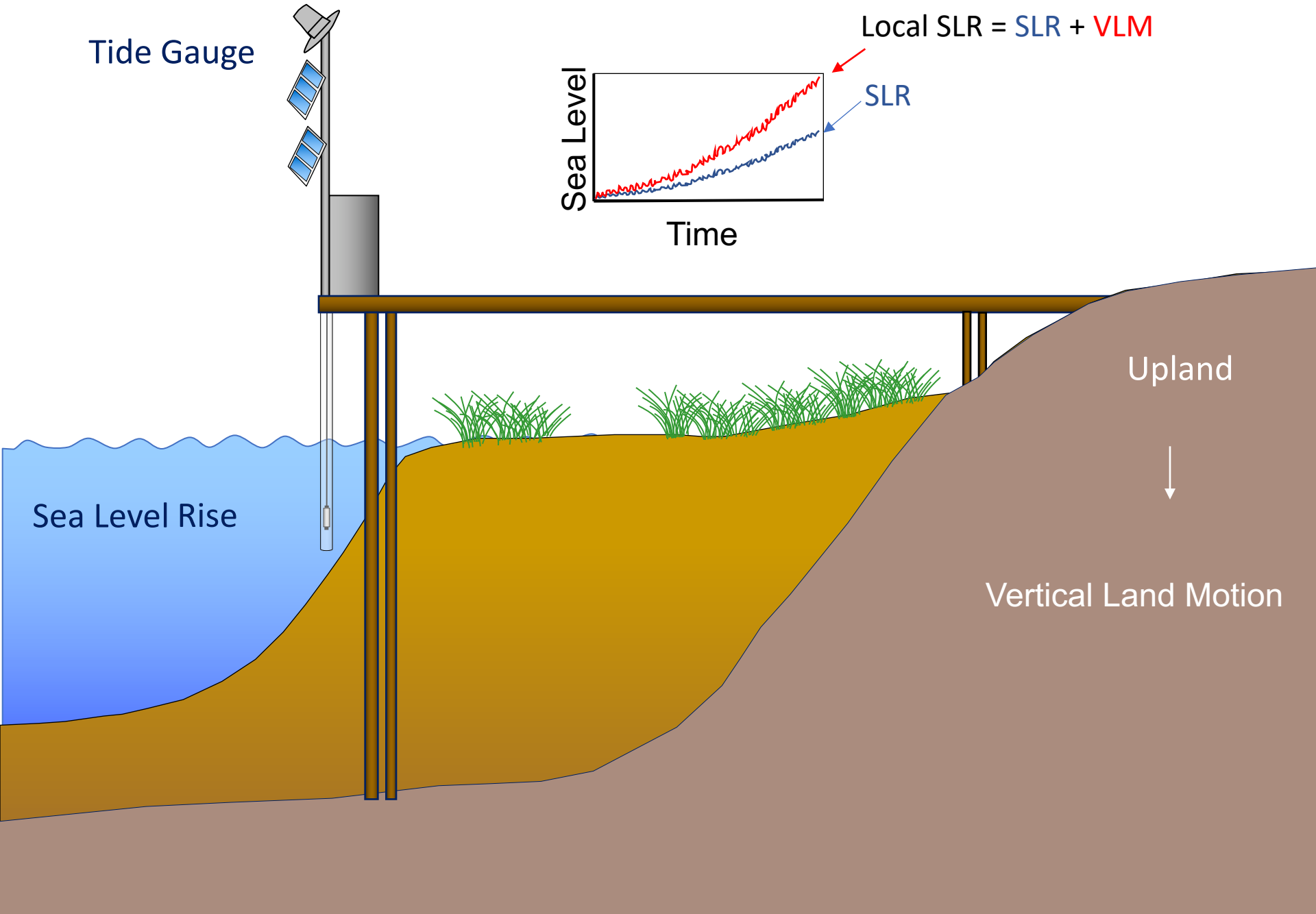
VAWI = - 4.3*

VIMS = - 3.4*

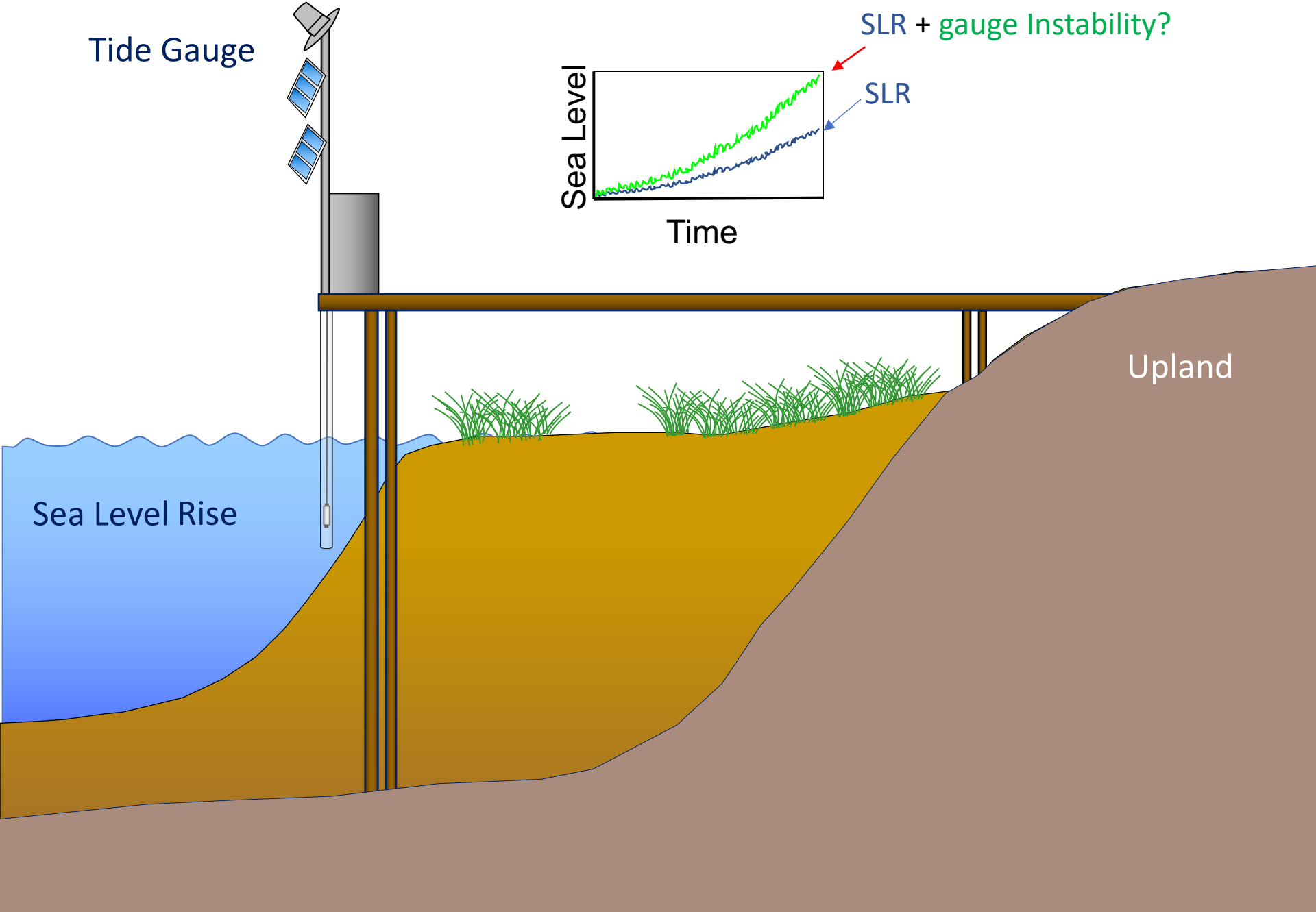
COVX = - 1.6

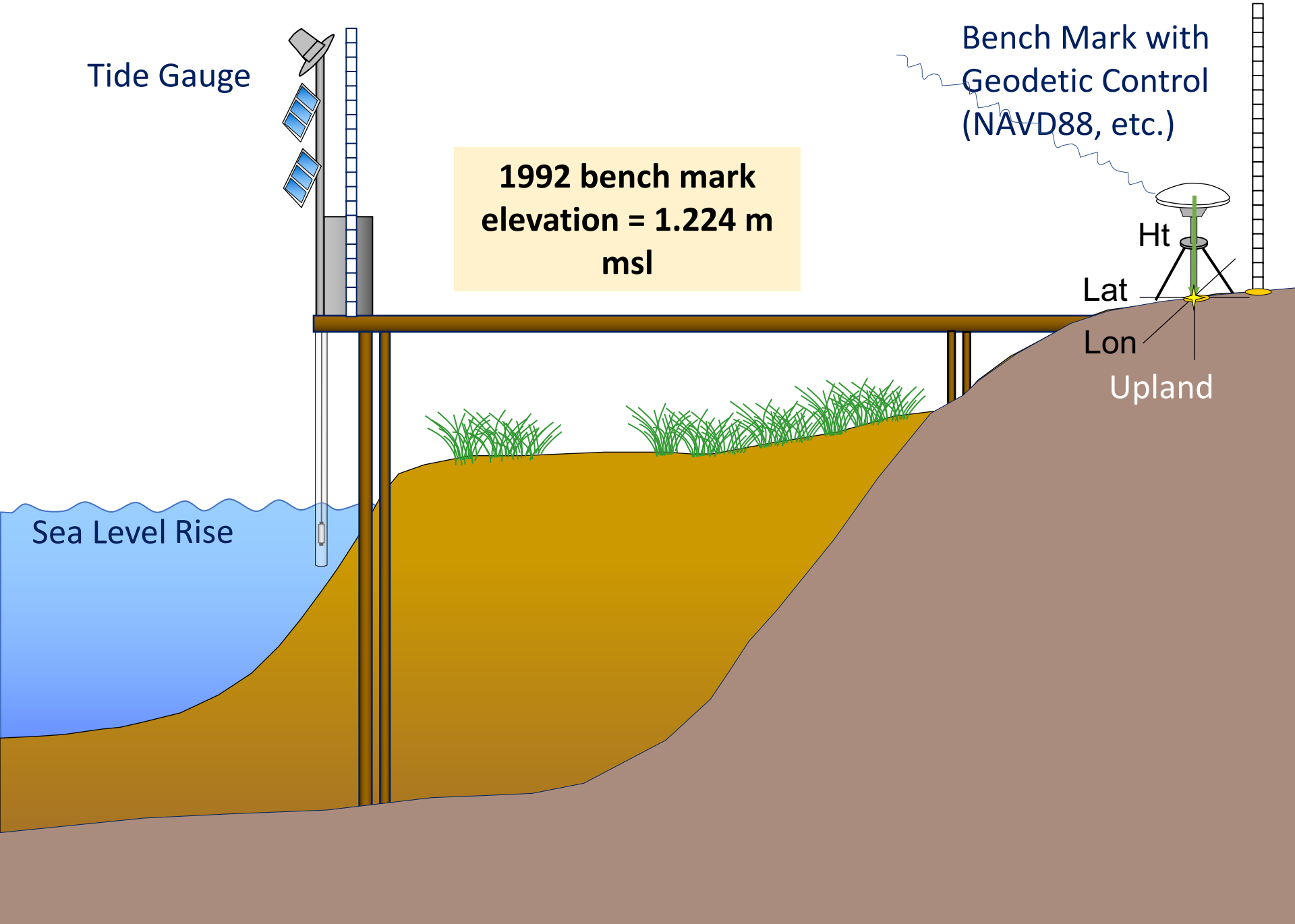
* = Differs by more than 1 mm from 1973 estimates


Tide Gauge
Sea Level
Time
SLR
Upland
Sea Level Rise


Tide Gauge
Local SLR = SLR + VLM
SLR
Sea Level
Time
Upland
Sea Level Rise
Vertical Land Motion

When does VLM matter?

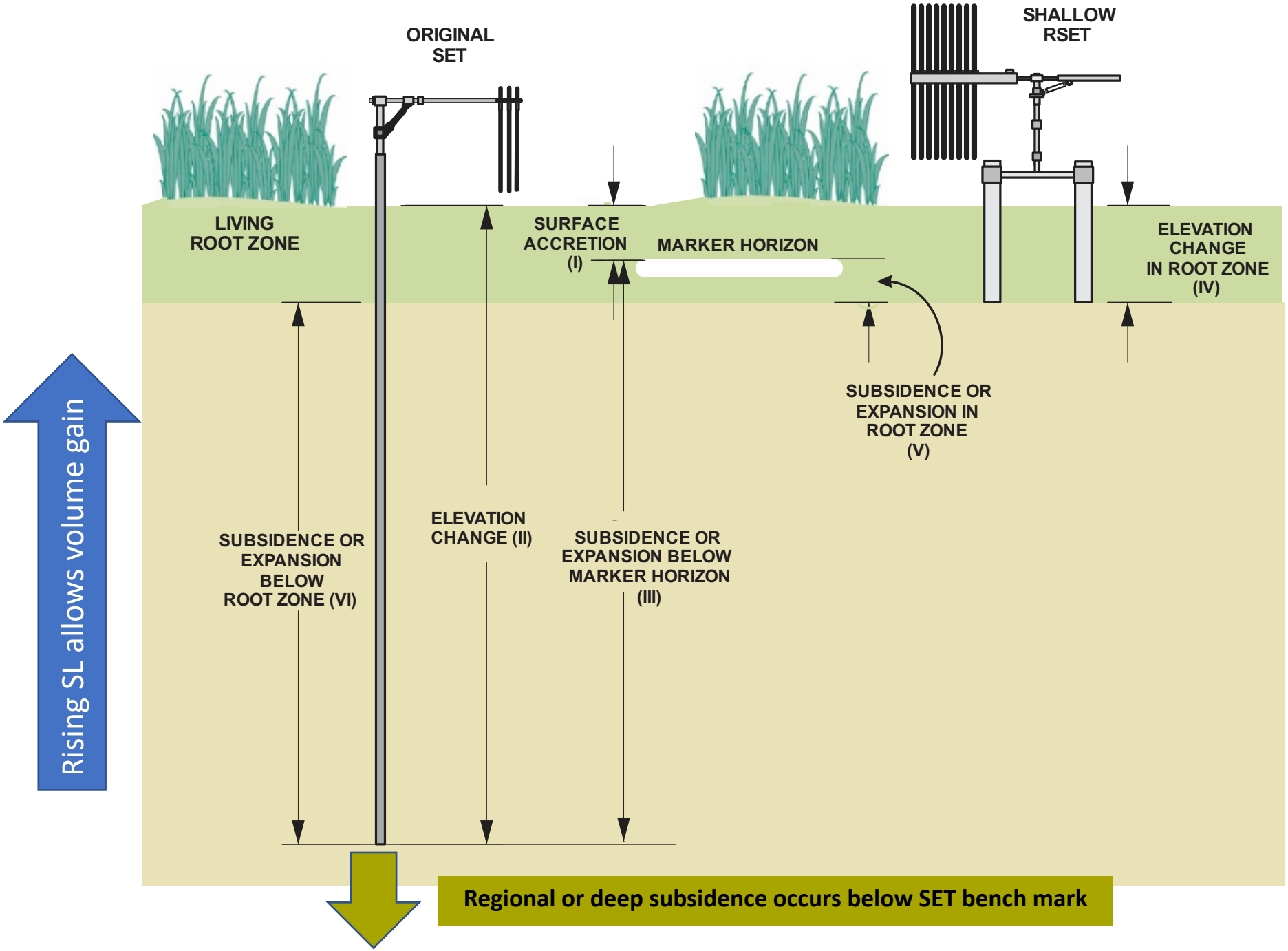



Tide Gauge
Bench Mark with
Geodetic Control
(NAVD88, etc.)
1992 bench mark
elevation = 1.224 m
msl
Ht
Lat
Lon
Upland
Sea Level Rise

Monitoring Wetland Responses to RSLR With Surface Elevation Tables (SET)

Soil volume-based changes:

- **Gain of elevation via**
  - surface deposition
  - belowground production
- **Compaction or loss of**
  - pore space
  - organic matter


ORIGINAL SET
SHALLOW RSET
LIVING ROOT ZONE
SURFACE ACCRETION (I)
MARKER HORIZON
ELEVATION CHANGE IN ROOT ZONE (IV)
SUBSIDENCE OR EXPANSION IN ROOT ZONE (V)
SUBSIDENCE OR EXPANSION BELOW ROOT ZONE (VI)
ELEVATION CHANGE (II)
SUBSIDENCE OR EXPANSION BELOW MARKER HORIZON (III)
Rising SL allows volume gain
Regional or deep subsidence occurs below SET bench mark

Chesapeake Bay Sentinel Site Cooperative Partners

Marsh Elevation Change Measurements

- 13 sites, > 425 SETs
- some increasing, some decreasing

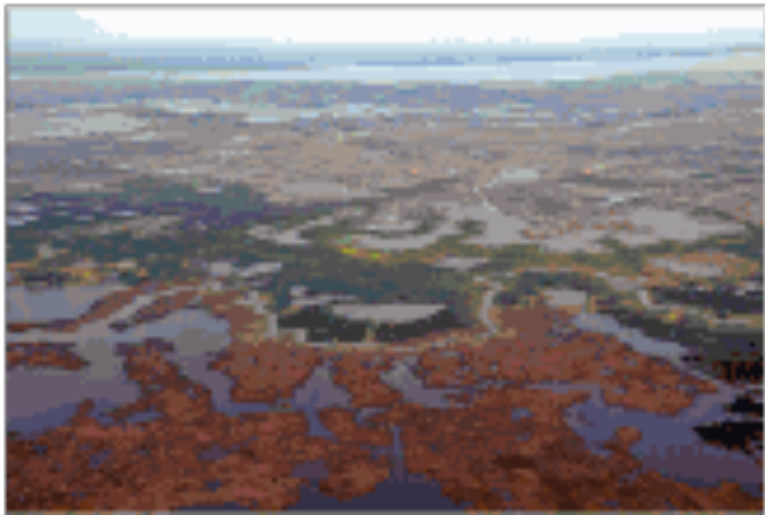
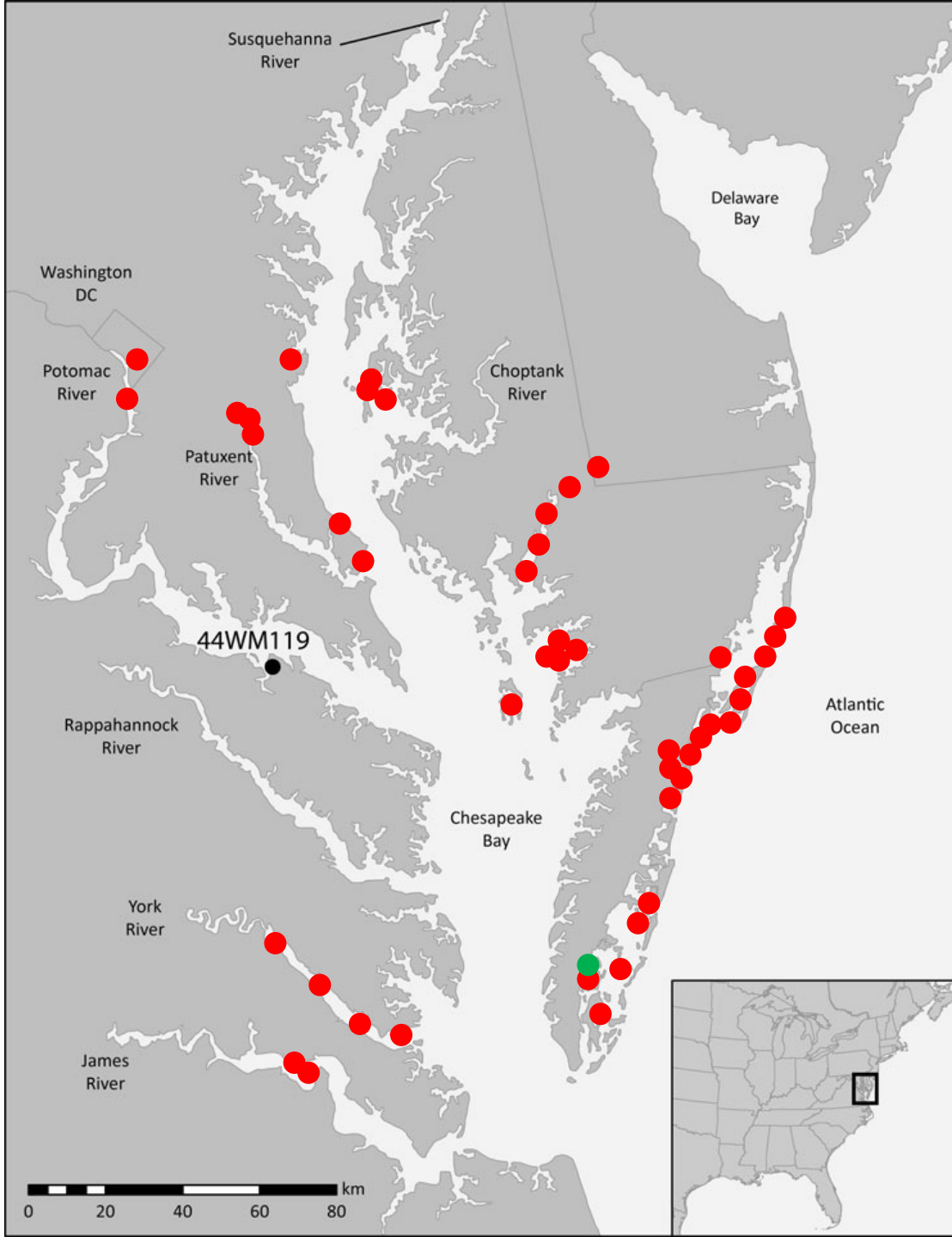
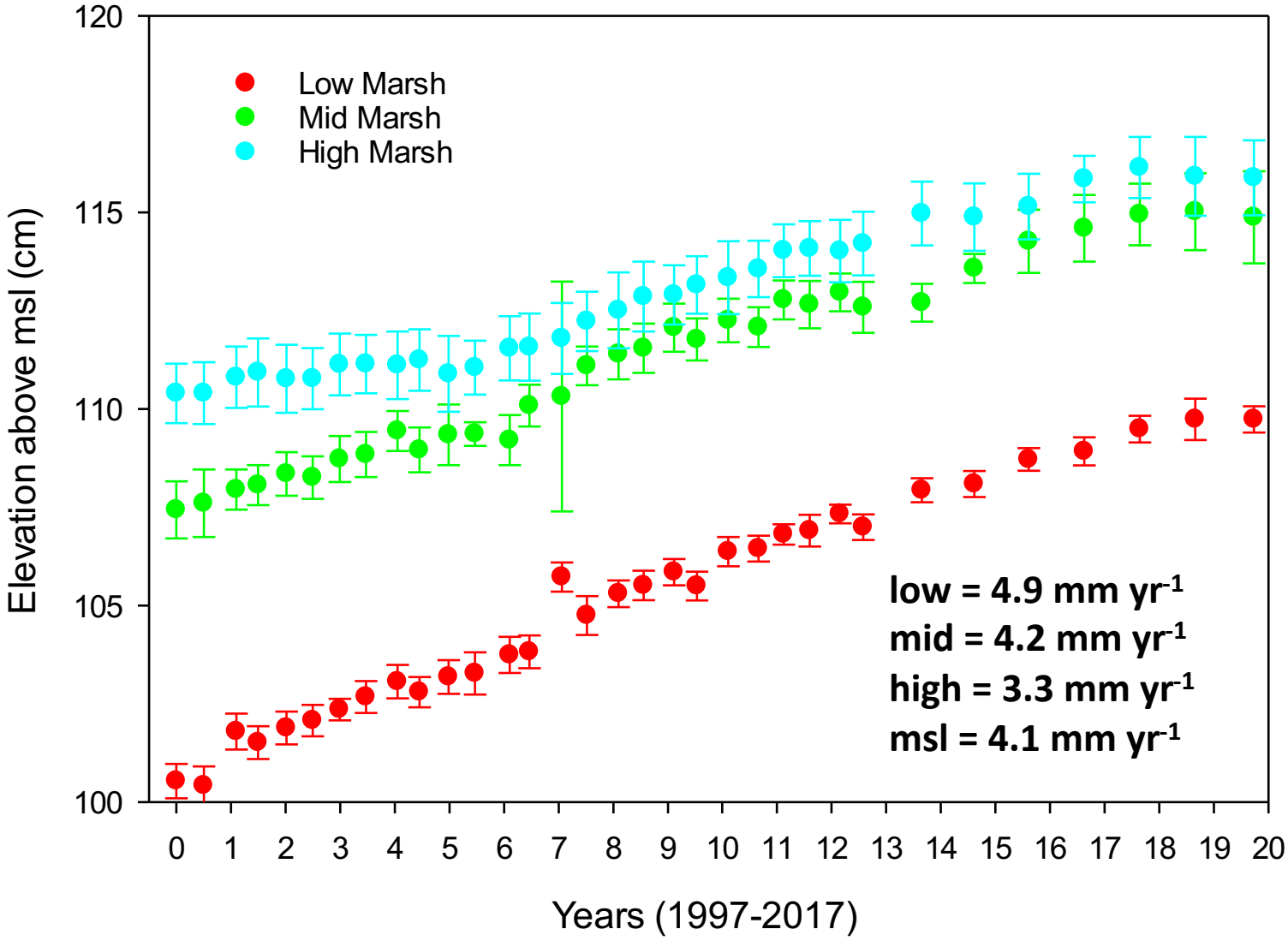


Photo: by Jane Thomas. Blackwater National Wildlife Refuge, June 2006. green= healthy; brown = dead



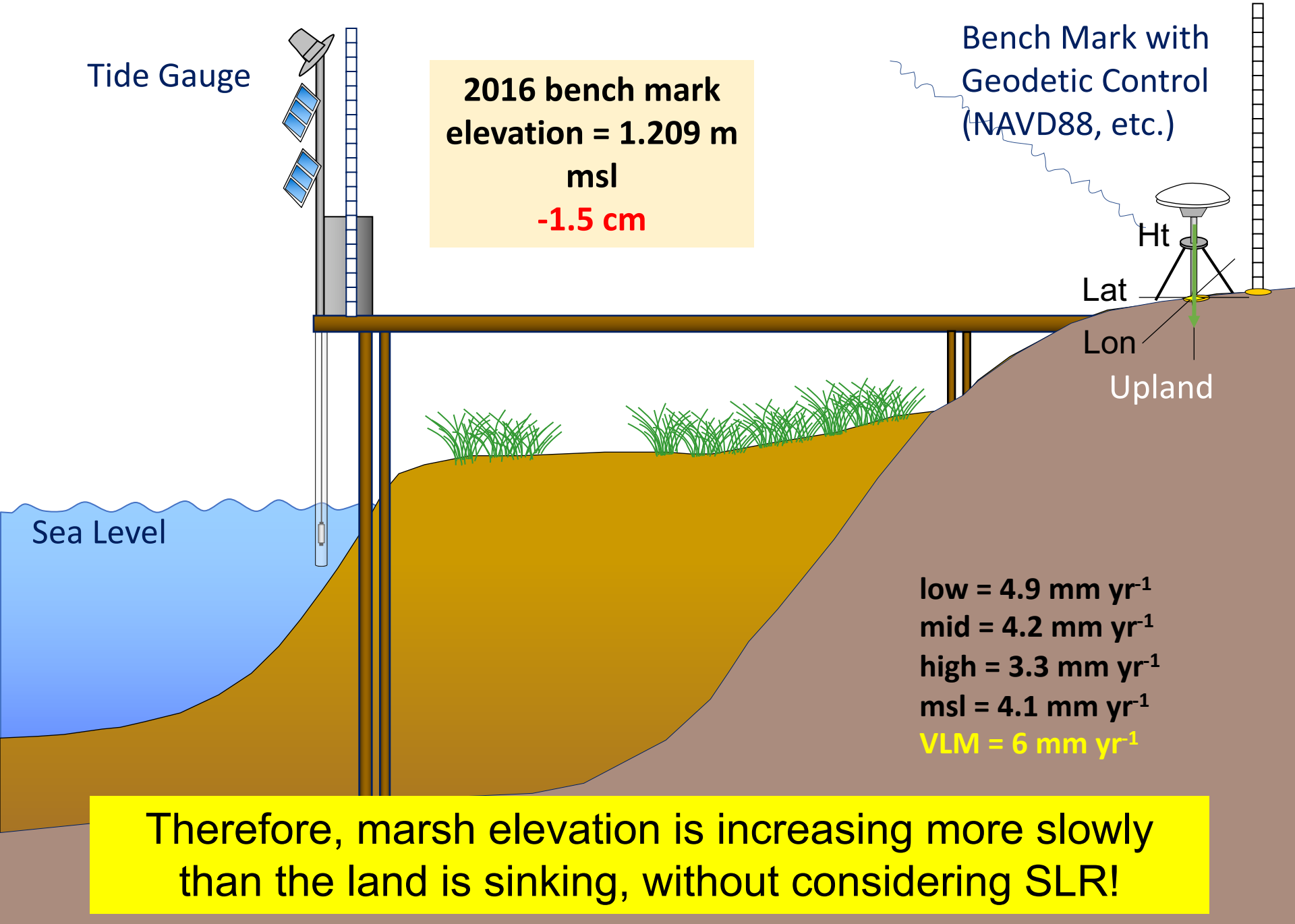
How do 1997 SET Marsh Elevations Compare to 2018?




But what we observe increased ponding of water in the high marsh and collapse of the surface……


…. and ultimately conversion to marsh ponds ….


…. or low marsh,
which suggests marsh is not keeping up with SLR


Tide Gauge
2016 bench mark elevation = 1.209 m msl
-1.5 cm
Bench Mark with Geodetic Control (NAVD88, etc.)
Ht
Lat
Lon
Upland
Sea Level
low = 4.9 mm yr-1
mid = 4.2 mm yr-1
high = 3.3 mm yr-1
msl = 4.1 mm yr-1
VLM = 6 mm yr-1
Therefore, marsh elevation is increasing more slowly than the land is sinking, without considering SLR!

Summing Up

- Elevation increases approximate local sea-level rise increases
- Rapid regional subsidence rates
  - consistent with field observations
  - consume elevation capital
- VLM matters!
- Change in practice – SET+ SLR + VLM

Acknowledgements

- Graduate Students:
  Laura Barr
  Jessica Kastler
  Mindy May
  Patricia Willis
- Virginia Coast Reserve Long Term Ecological Research Program
- National Science Foundation
- The Nature Conservancy
- Chesapeake Bay Sentinel Site Cooperative
- Numerous volunteers assisting with elevation and accretion measurements

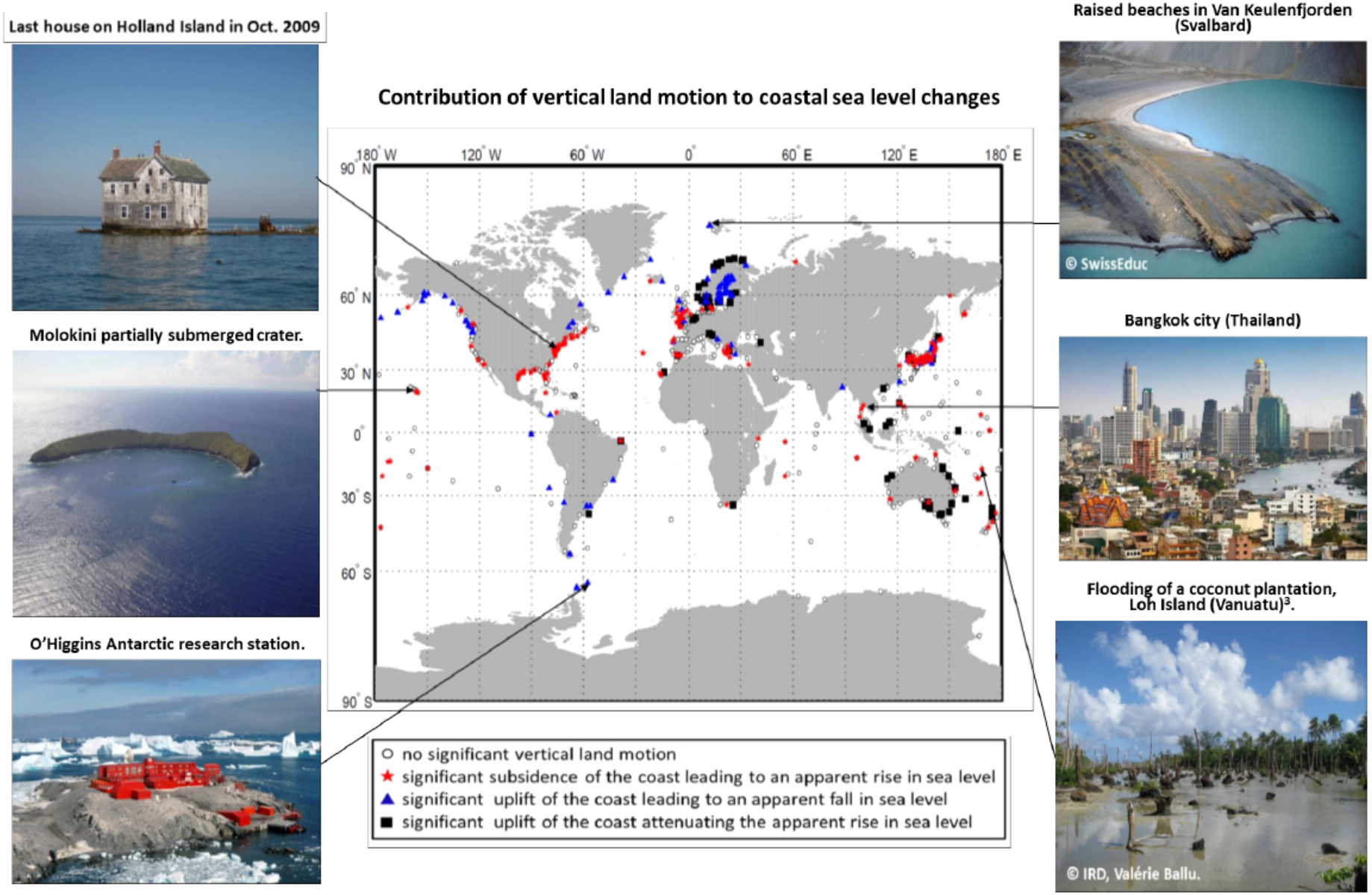
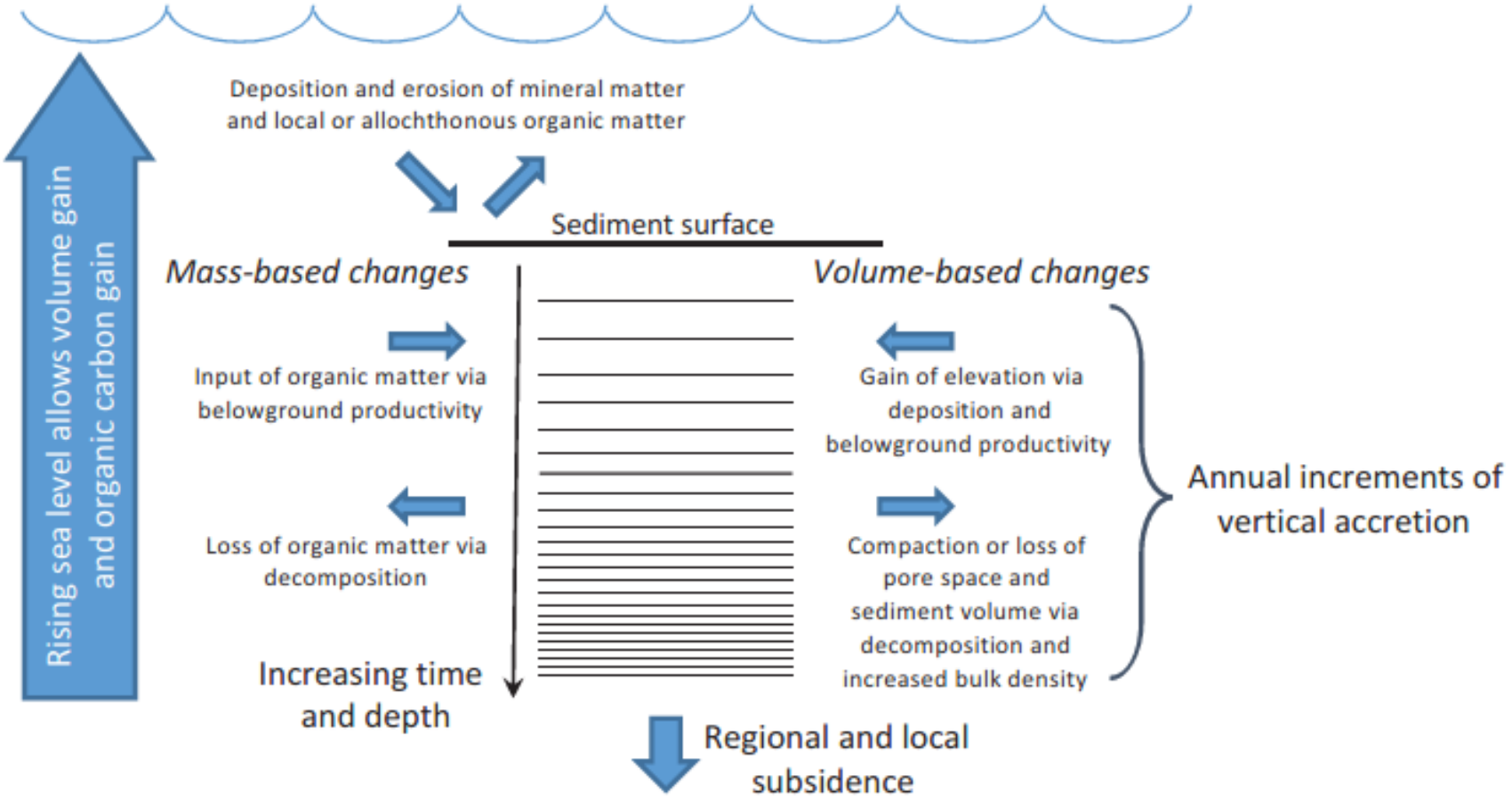
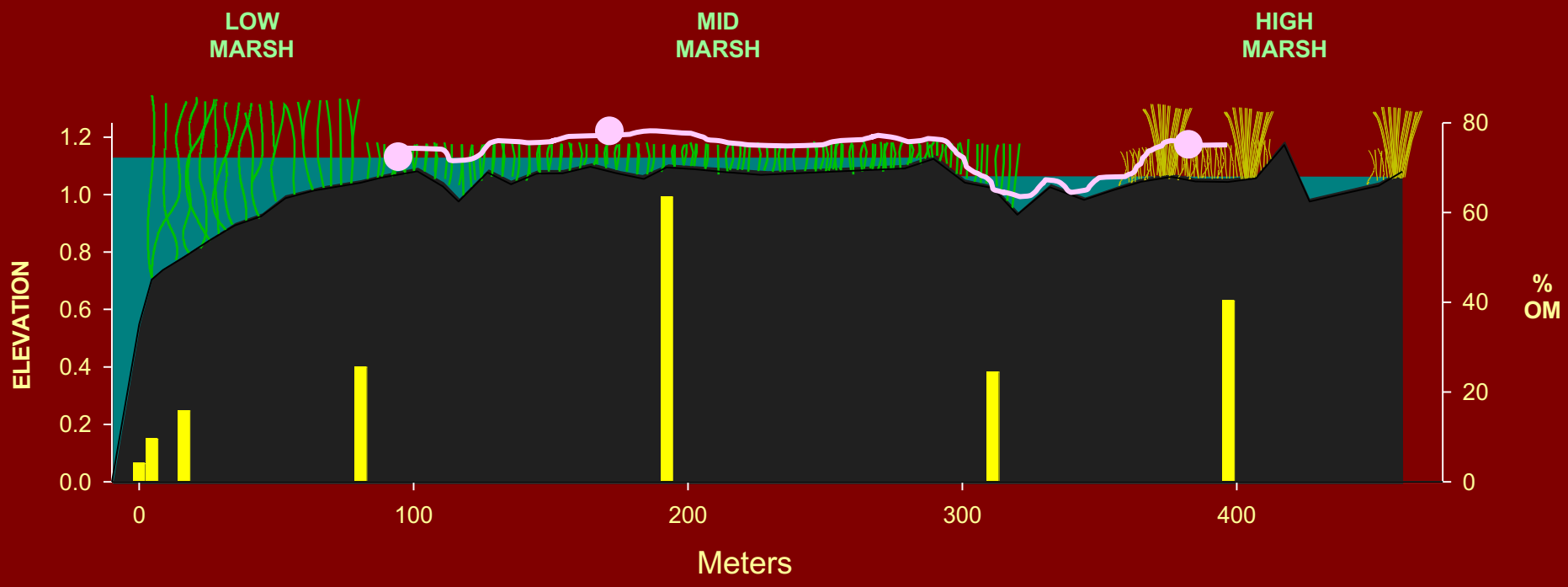
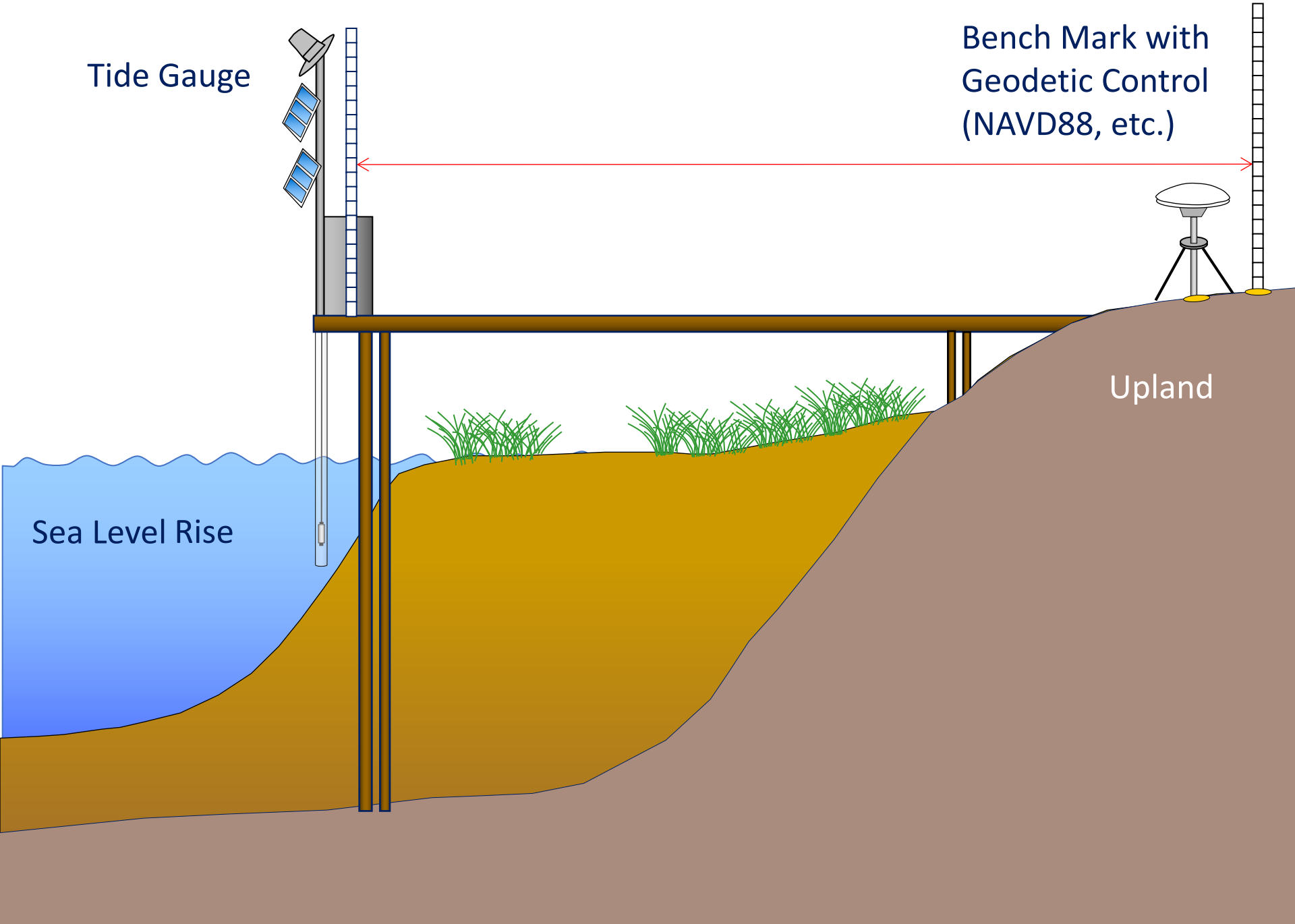


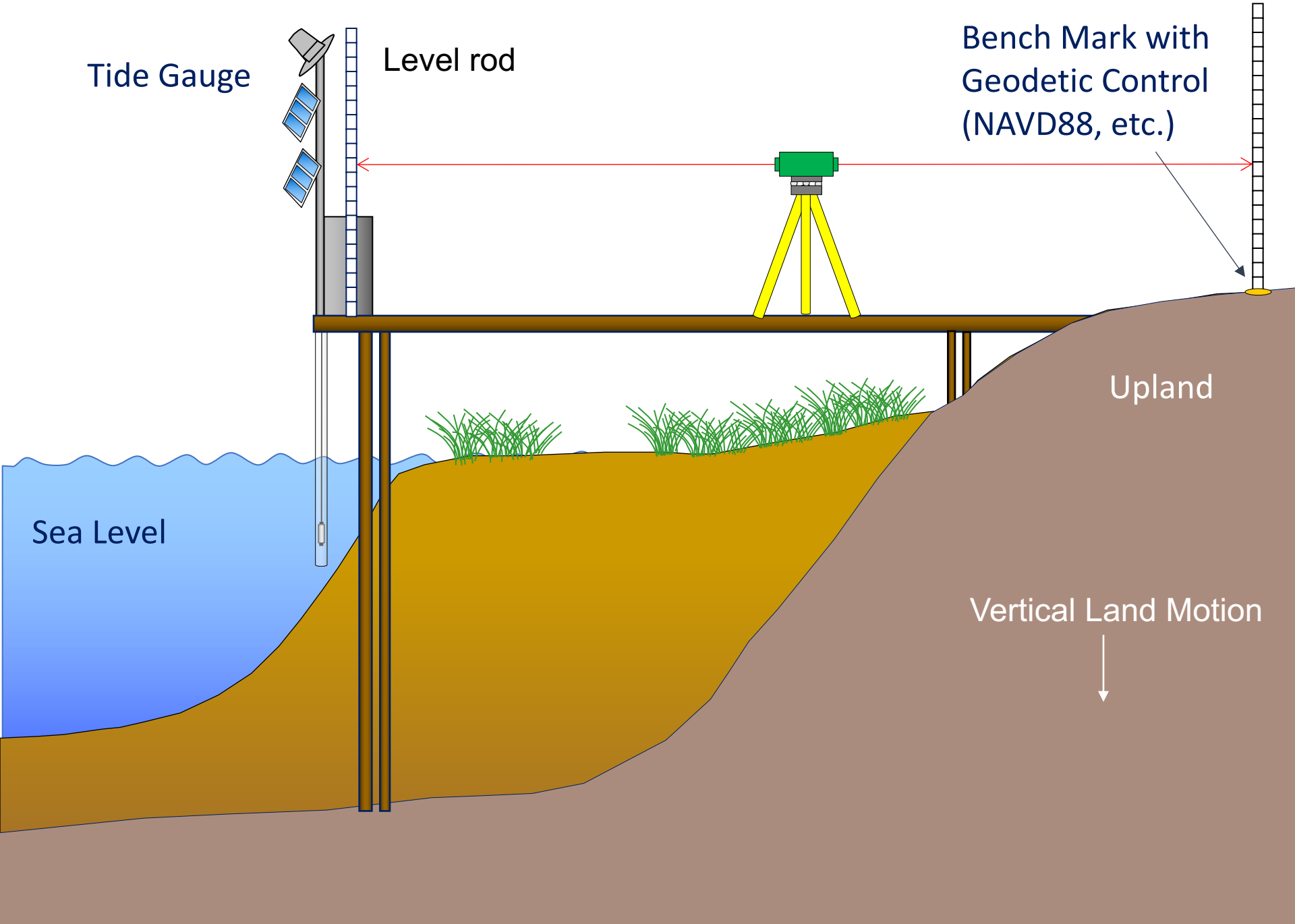
Figure from poster by Pfeffer, J., P. Allemand, and G. Spada. 2016. Contribution of vertical land motions to coastal sea level variations: A global synthesis of multisatellite radar altimetry, tide gauge and GPS measurements. European Geosciences Union.

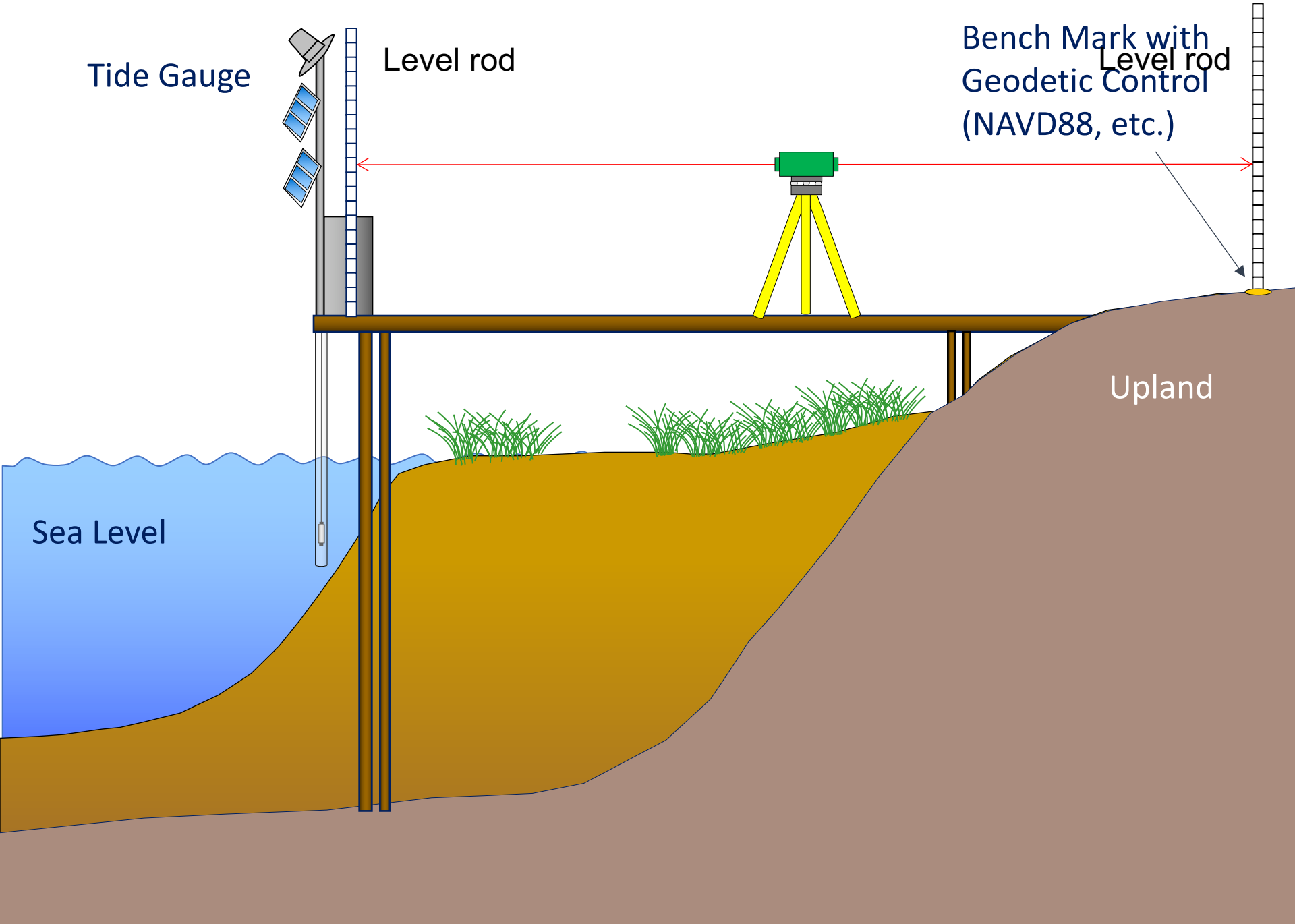

Rising sea level allows volume gain and organic carbon gain
Deposition and erosion of mineral matter and local or allochthonous organic matter
Sediment surface
Mass-based changes
Volume-based changes
Input of organic matter via belowground productivity
Loss of organic matter via decomposition
Gain of elevation via deposition and belowground productivity
Compaction or loss of pore space and sediment volume via decomposition and increased bulk density
Annual increments of vertical accretion
Increasing time and depth
Regional and local subsidence

Within Marsh Response to Local Sea-Level Rise after 20 Years




Tide Gauge
Bench Mark with
Geodetic Control
(NAVD88, etc.)
Upland
Sea Level Rise


Tide Gauge
Level rod
Bench Mark with
Geodetic Control
(NAVD88, etc.)
Upland
Sea Level
Vertical Land Motion


Tide Gauge
Level rod
Bench Mark with
Geodetic Control
(NAVD88, etc.)
Level rod
Upland
Sea Level