photo credit: Molly Baringer, NOAA/AOML

Measuring global-mean sea level with an array of surface drifting buoys

Concept and preliminary results of a field pilot project

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Field pilot project was supported by NASA's Sentinel-6 project

Concept and Vision

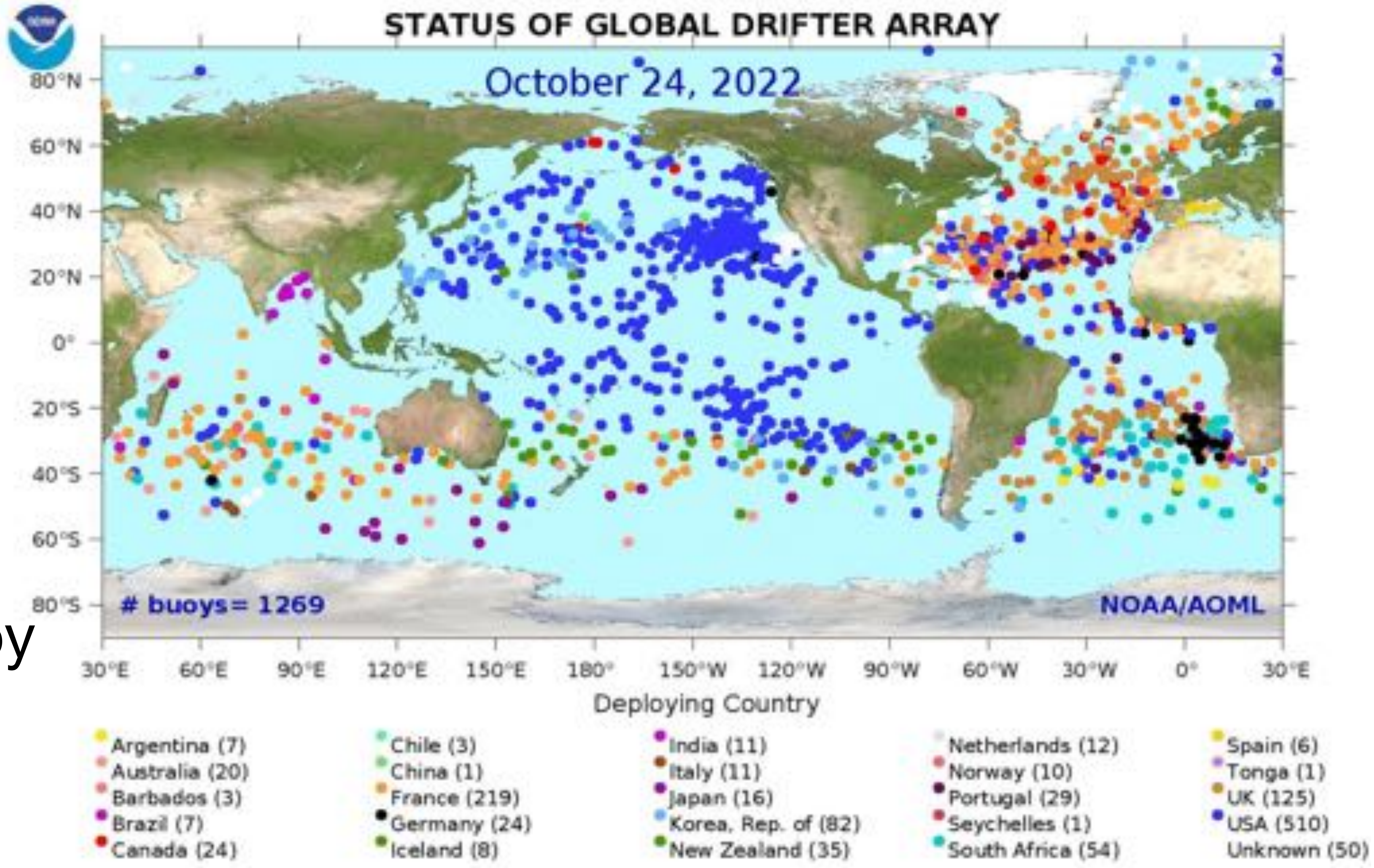
Tristan da Cunha Island (South Atlantic)

- What? Establish a new ocean observing system for monitoring global (and regional) mean sea-level changes.

- Why?

- How? Use the drifting buoys (drifters) tracked by GPS of the *Global Surface Drifter Array.*

Note: The NOAA *Global Drifter Program* (GDP) is the principle component of the GSDA. The GSDA is a scientific project of the Data Buoy Cooperation Panel (DBCP, WMO/IOC).



https://www.aoml.noaa.gov/phod/gdp/index.php

1. Concept study

Elipot (2020), *Measuring Global Mean Sea Level Changes With Surface Drifting Buoys*, Geophysical Research Letters, doi: 10.1029/2020GL091078:

Observing System Simulation Experiment

1. Simulate individual local MSL measurements in time and space along drifter trajectories …

$$h_{MSL} = h_{GPS} - h_{MSS} + \varepsilon$$

Mean Sea Level

GPS height from drifter

Mean Sea Surface (MSS) = Geoid + Mean Dynamic Topography

SSH variability not relevant for MSL (tides, surface gravity waves)

2. … quantify the associated variance, or uncertainty …

$$\mathrm{Var}(h_{MSL}) = \mathrm{Var}(h_{GPS}) + \mathrm{Var}(h_{MSS}) + \mathrm{Var}(\varepsilon) + 2\mathrm{Cov}(h_{GPS}, \varepsilon)$$

3. … calculate global averages, their uncertainties, and implications for trend estimates.

$$\sigma^2_{\mathrm{GMSL}} = \sigma^2_{\mathrm{S}} + \frac{\sigma^2_{\mathrm{GPS}}}{N} + \sigma^2_{\mathrm{SSH}} + \sigma^2_{\mathrm{I}}$$

Sampling error
(from numerical simulation)

GPS daily error (??)

SSH errors
(from models)

Instrumental error
(from statistical simulation)

How accurately should we observe regional and global MSL?

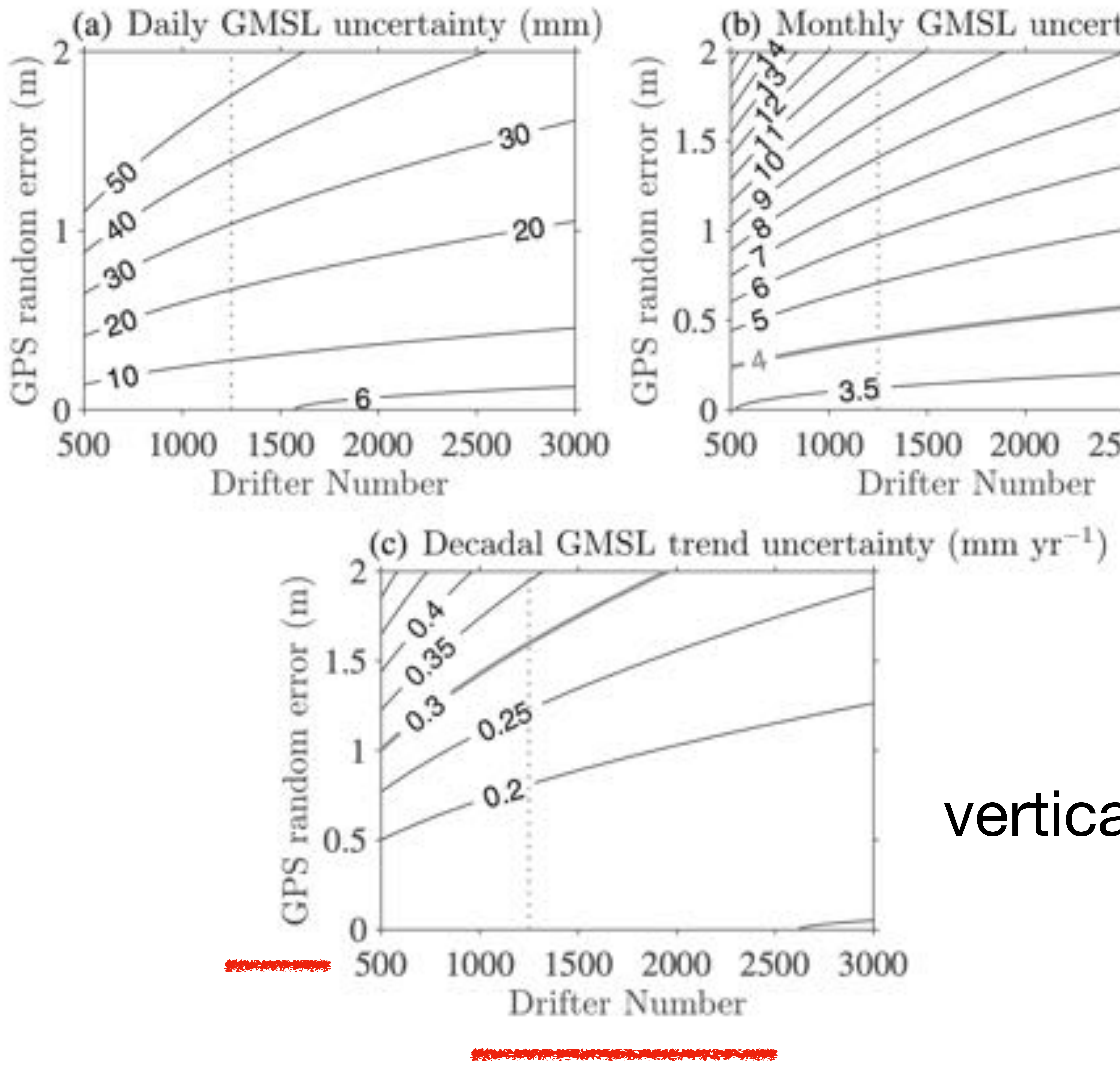
https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

decadal trend

Sea Level	Global Mean Sea Level	Weekly to monthly	10-100 km	2-4 mm (global mean); 1 cm over a grid mesh	< 0.3 mm/yr (global mean)
	Regional Sea Level	Hourly to weekly	10 km	1 cm (over grid mesh of 50-100 km)	< 1 mm/yr (for grid mesh of 50-100 km)

Note: GMSL decadal linear trend uncertainty from altimeter data varies between 1 and 0.5 mm yr^{-1} (90% confidence limit, Ablain et al., 2019).

Calibrating expectations:



Target :
vertical uncertainty < 1.6 m

Elipot (2020), *Measuring Global Mean Sea Level Changes With Surface Drifting Buoys*, Geophysical Research Letters, doi: 10.1029/2020GL091078

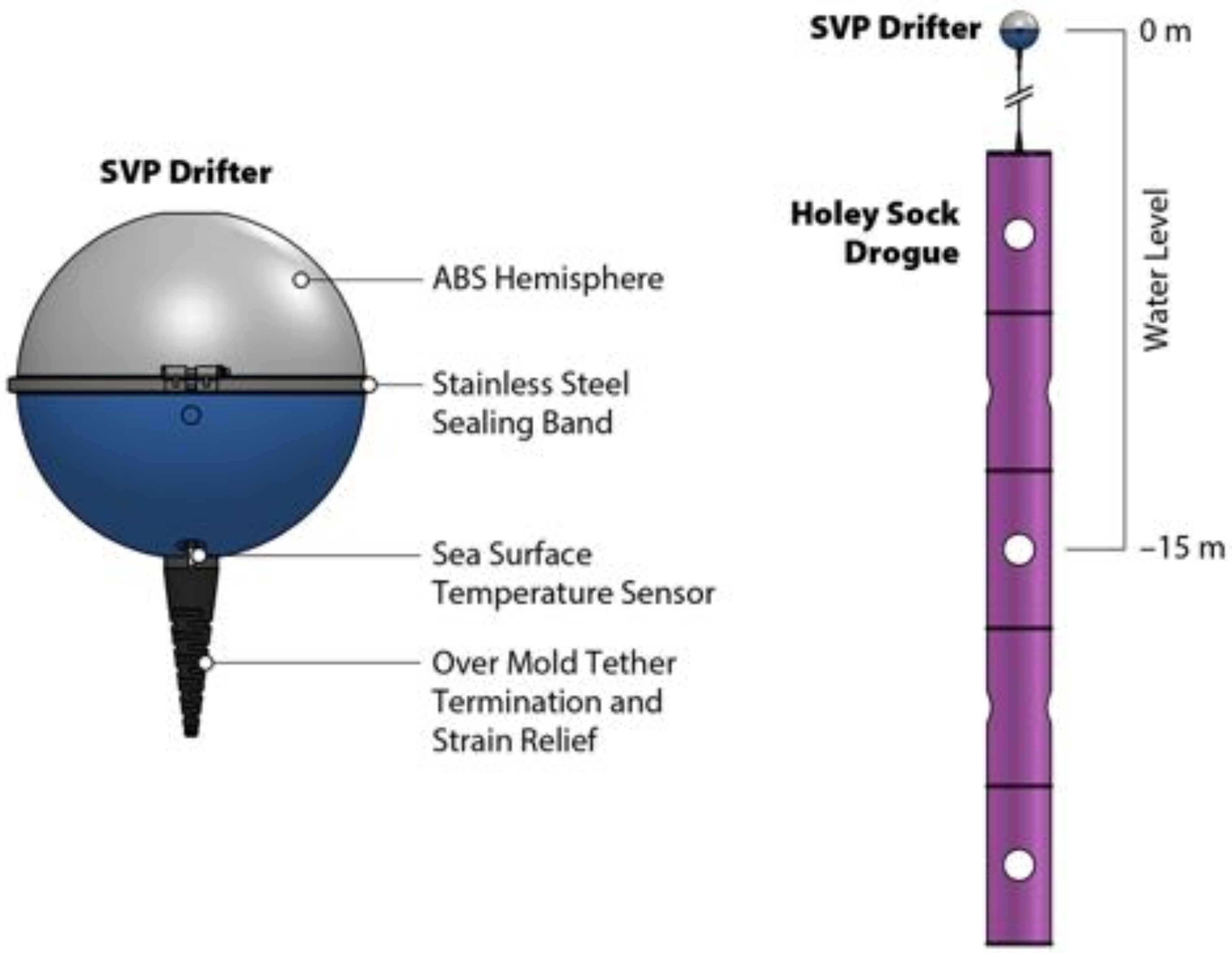
Why another GMSL observing system?

- Can further validate and calibrate the existing observing systems (tide gauges and reference altimetry); scalable to region, basin, or coastal areas.
- Redundancy in case of failure of the existing systems (🤞🏻)
- Synoptic GMSL estimates at daily time step.
- BUT currently not achievable because of the anticipated limitation of the GPS receivers equipping the drifters of the global array (GPS altitude is not even transmitted as part of drifter sensor transmission). So what is the current drifter GPS vertical accuracy? How good can it get?

2. Pilot project (preliminary results)

Surface Velocity Program (SVP) Drifter

Standard SVP drifters (SST sensor, geolocated by GPS)



Source: SIO Lagrangian Drifter Laboratory (https://gdp.ucsd.edu/ldl/svp/)

Modified SVP drifters for moored configuration

Two experiment sites

Scripps Institution of Oceanography (SIO) La Jolla, CA

January 2022, ~25 m depth

NOAA tide gauges

University of Miami, Rosenstiel School, Miami, FL

December 2021, ~1-2 m depth

Drifter Configurations

“SVP”

Hirschmann
antenna

Ublox GPS Neo6Q (hourly)
(single frequency)

~$1800
Life expectancy: 450 days

“GEO”

Tallysman TW7972
Triple band antenna

u-blox GPS (1Hz)
(single frequency)

Septentrio AsterX
M3 Pro+ GPS
(Dual frequency, 1Hz)

> $1800+$1000
Life: 8 days

“RAW”

Hirschmann
antenna

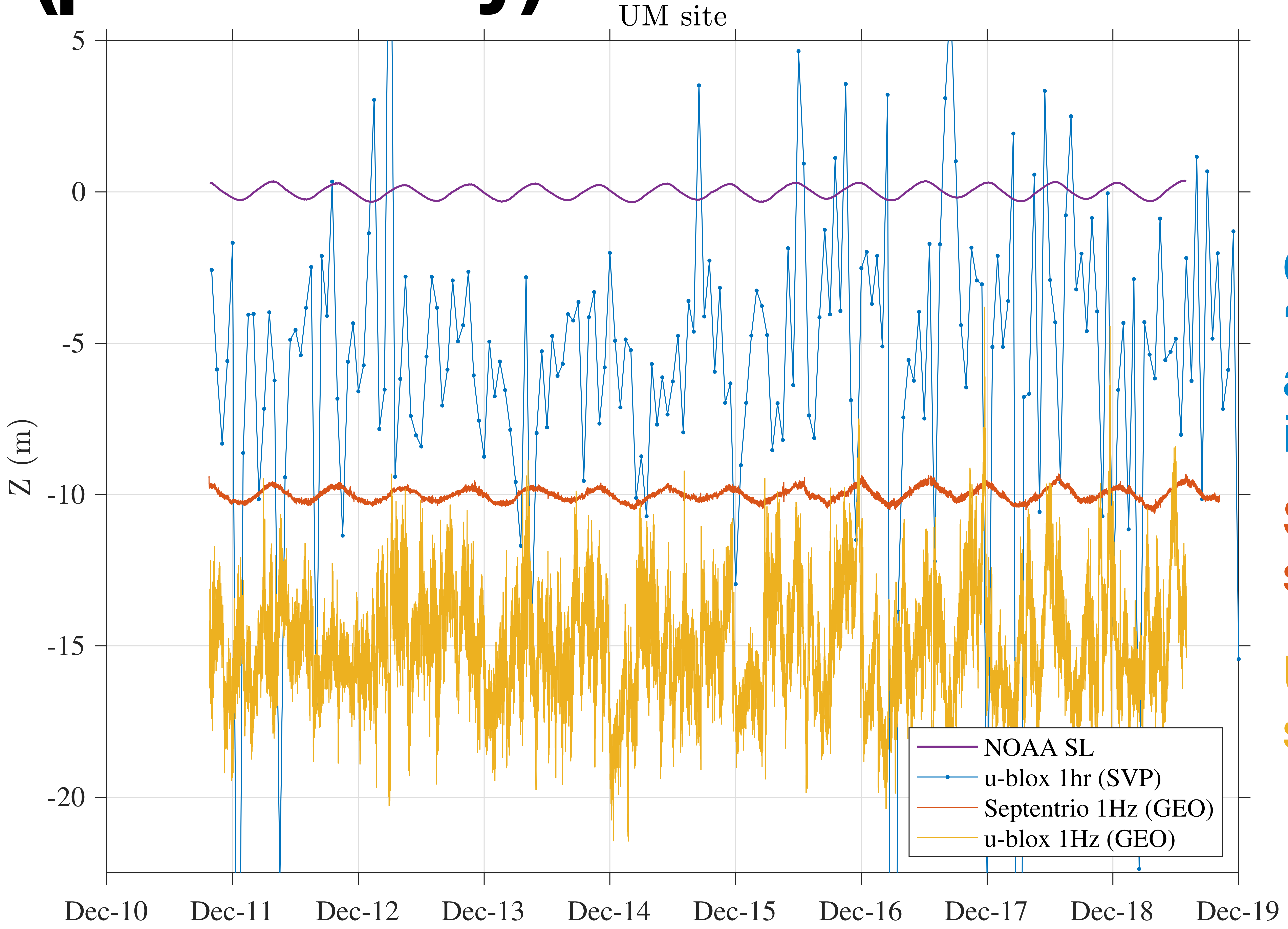
u-blox GPS Neo6P
raw tracking (1Hz)
(single frequency)

~$1800
Life: ~31 days

NOAA CO-OPS
Water Level from
tide gauge

Acoustic (UM)
Microwave (SIO)
6-min from 1Hz

Results (preliminary): UM site



Tide gauge:
6-min interval

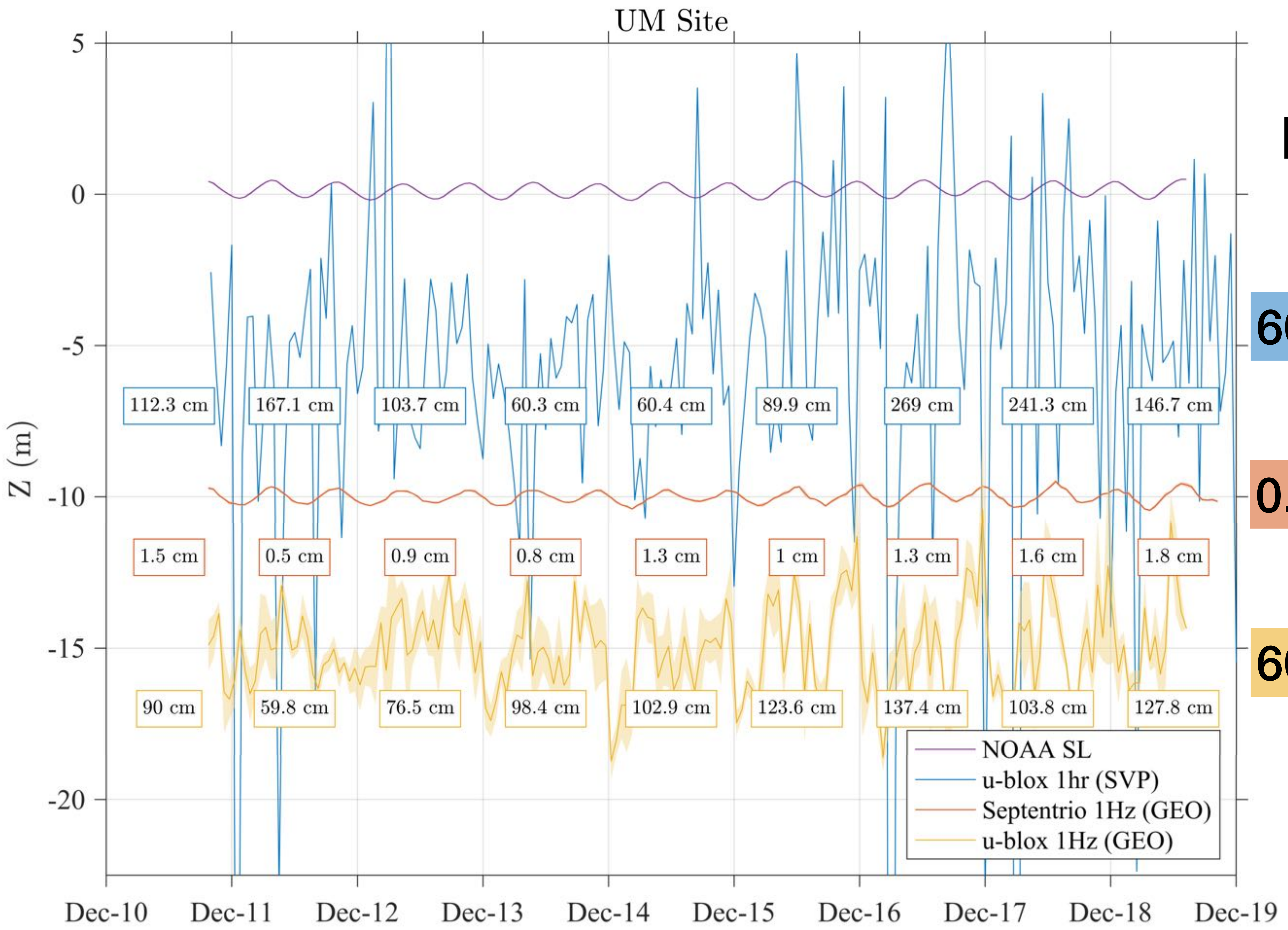
Control SVP:
“Instantaneous” at hourly intervals

Septentrio:
solution at 1Hz

U-blox:
solution at 1Hz

Form hourly estimates and calculate standard error of the mean: “1-σ” uncertainty

Results (preliminary): UM site



Daily uncertainty:

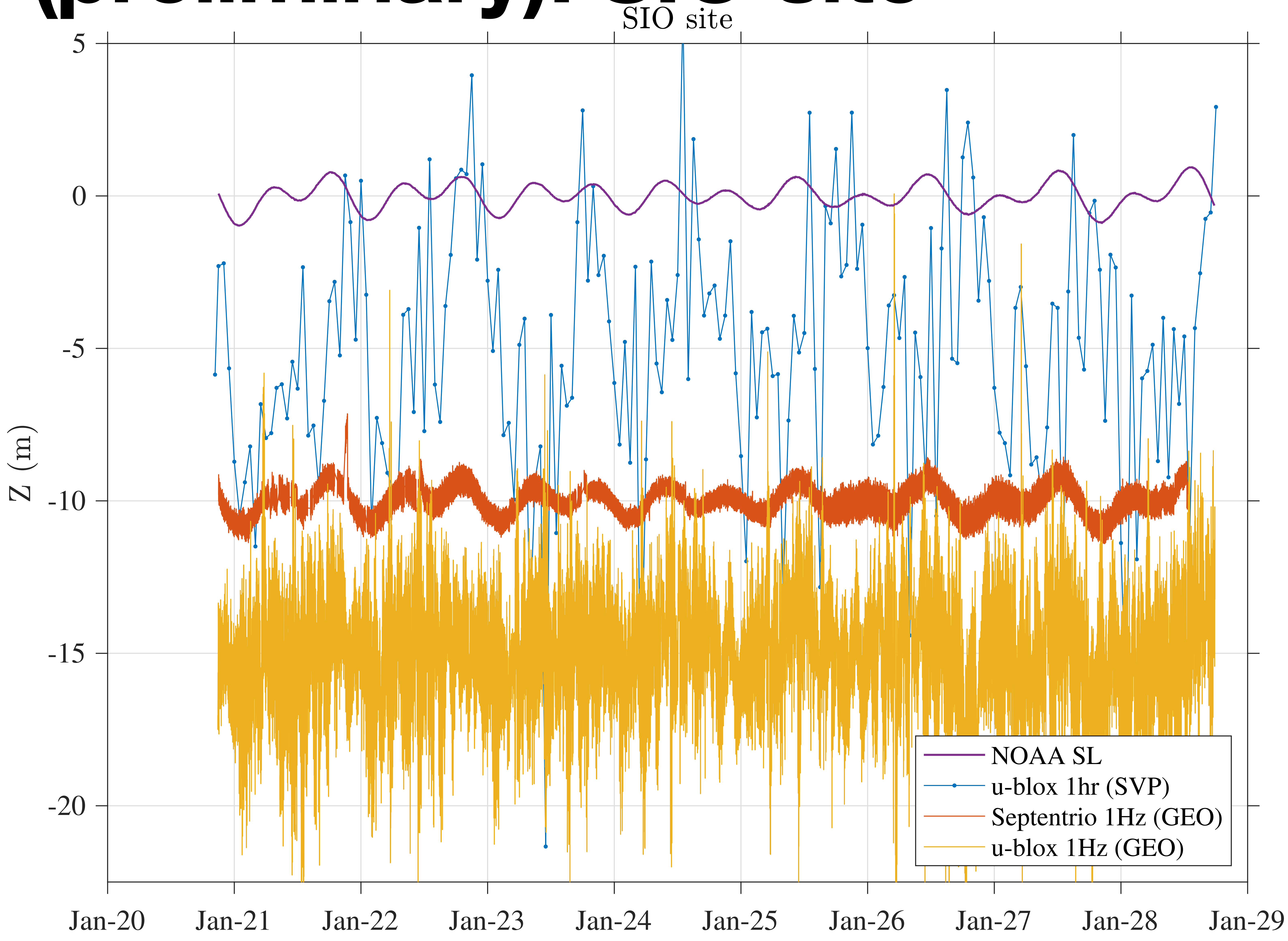
60 cm < $|\sigma|$ < 240 cm ?

0.5 cm < $|\sigma|$ < 1.6 cm ✅

60 cm < $|\sigma|$ < 138 cm ✅

Target: < 160 cm

Results (preliminary): SIO site



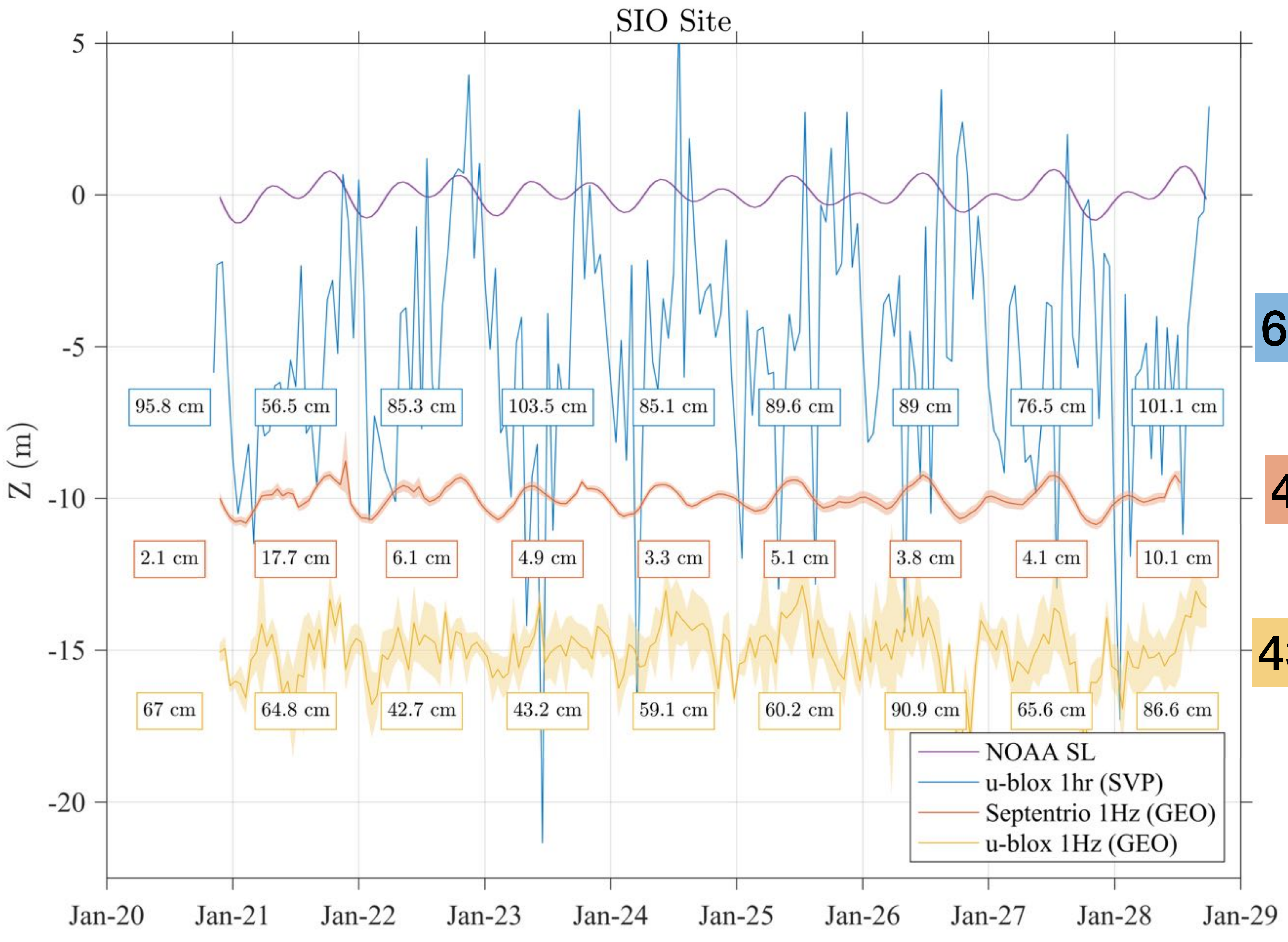
Tide gauge: 6-min interval

Control SVP "Instantaneous" at hourly intervals

Septentrio solution at 1Hz

U-blox solution at 1Hz

Results (preliminary): SIO site



Daily uncertainty:

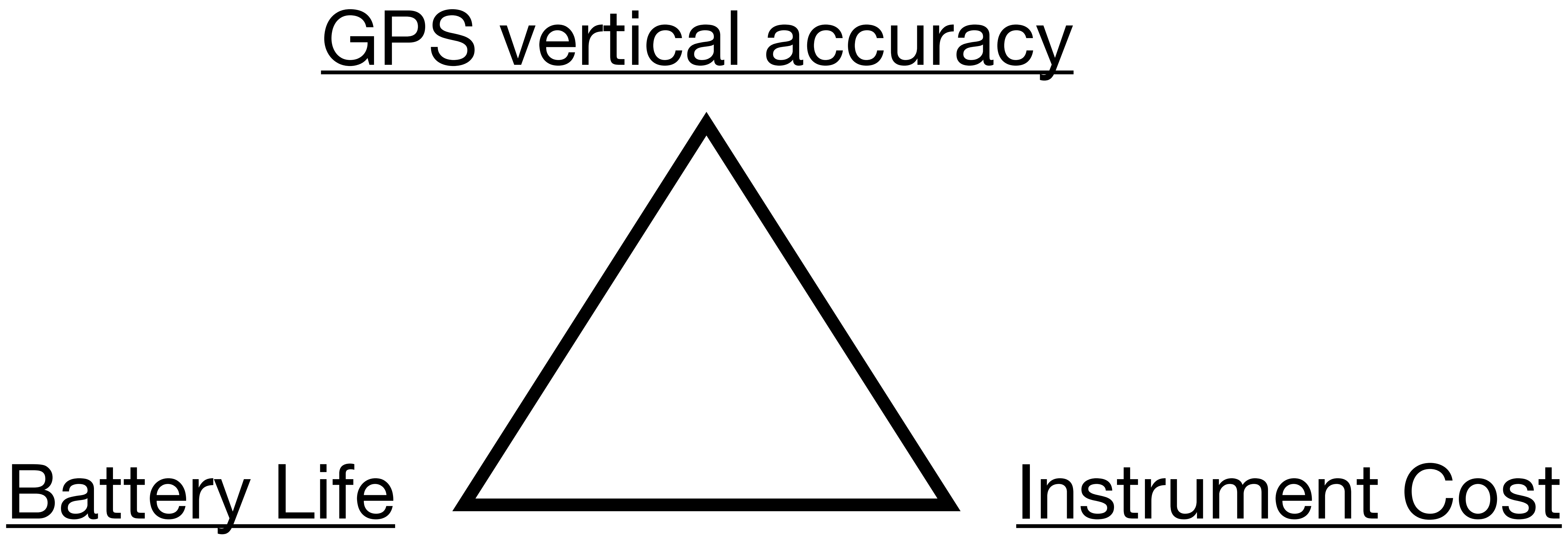
60 cm < $|\sigma|$ < 104 cm ✅

4 cm < $|\sigma|$ < 18 cm ✅

43 cm < $|\sigma|$ < 91 cm ✅

Target: < 160 cm

Conclusion & Next steps?



- It CAN work! But more tests are needed! Devise new instrumental setup to conduct field tests in drifting conditions with data transmission.
- The implementation of this vision would provide an independent, resilient, sustainable, and economical observational system to quantify natural and anthropogenic regional and global sea-level changes, augmenting and validating the existing satellites and tide gauge observing systems.

GSDA: ~$2M/year (instrument only)
Current Argo: ~$40M/year
OneArgo: ~$120M/year
Sentinel 6A & 6B: ~$1B for 10 year = $100M/year

photo credit: Molly Baringer, NOAA/AOML

Thank you! Questions?

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