ELEVATION AND TIDE GAUGE MODELING TO ASSESS SPATIAL AND TEMPORAL VULNERABILITY TO SEA LEVEL RISE IN HAWAII AND AMERICAN SAMOA

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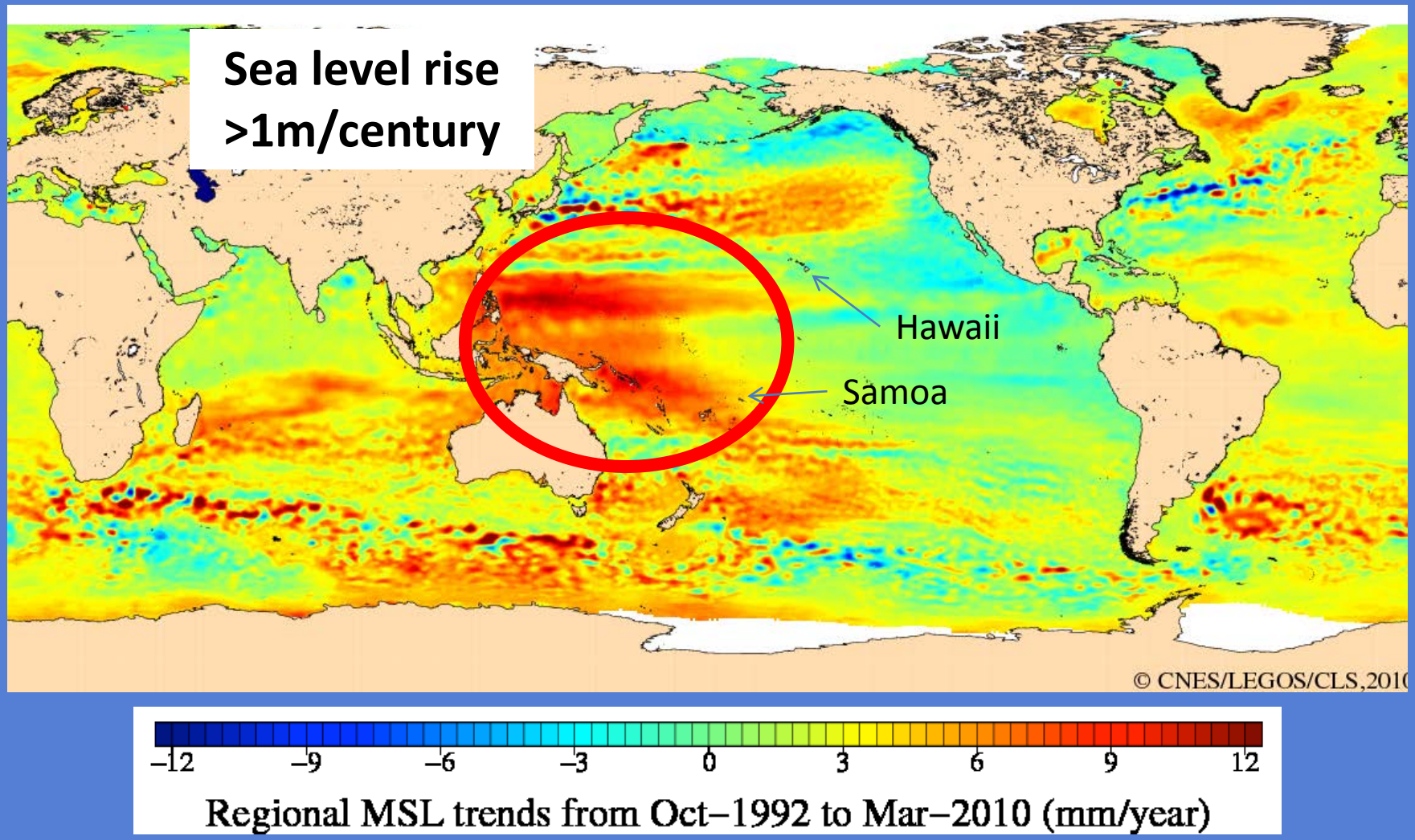
Pacific Island Climate is Changing

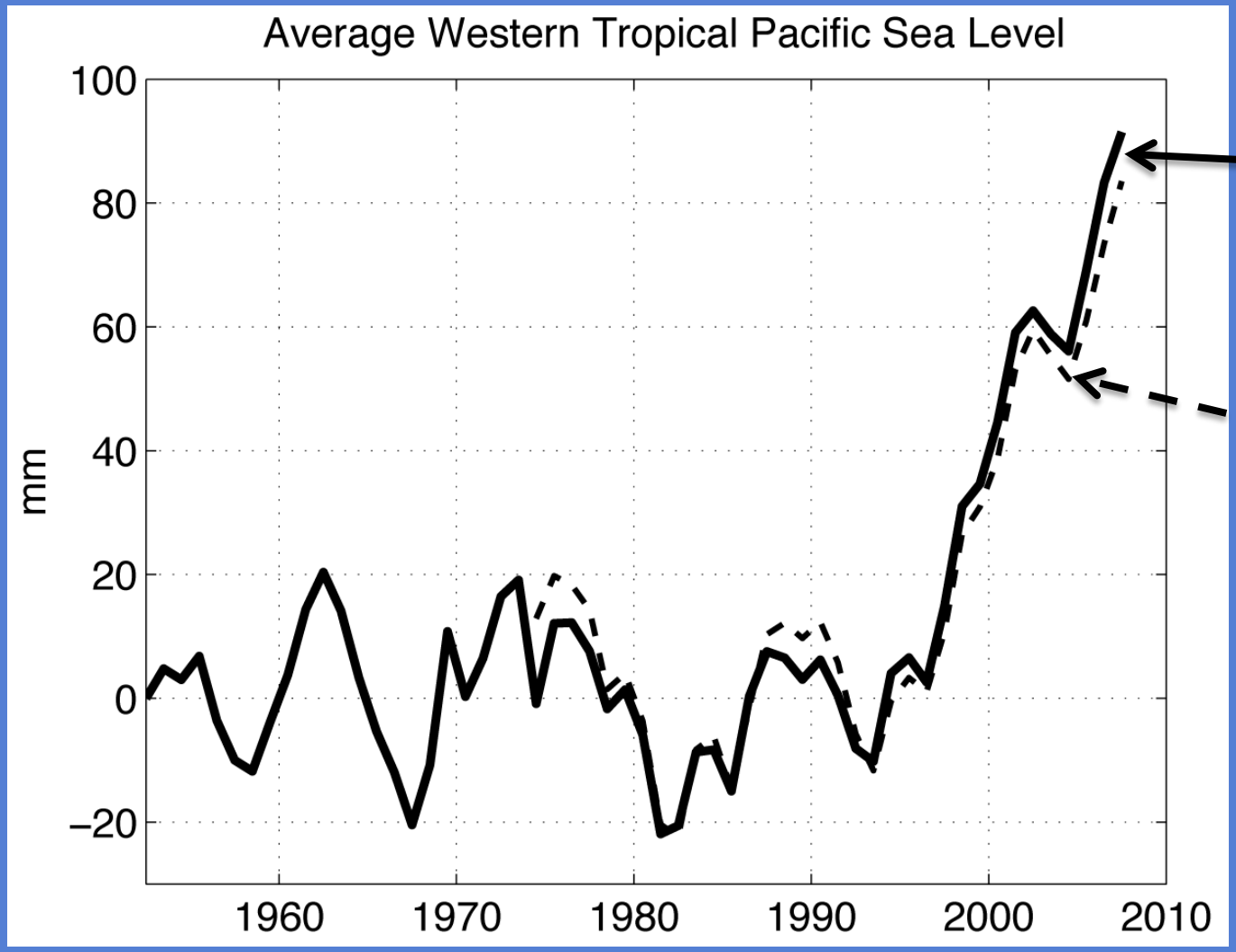
In Hawaii

- Rainfall (-15%) and stream discharge have decreased
- Air temperature is increasing (0.3^{o}F/decade)
- Rainstorm intensity has increased (+12%)
- Ocean has grown more acidic
- Sea surface temperature is rising (0.22^{o}F/decade)
- Sea level is rising

Western tropical Pacific – ground zero for sea-level rise



Acceleration ca. 1990

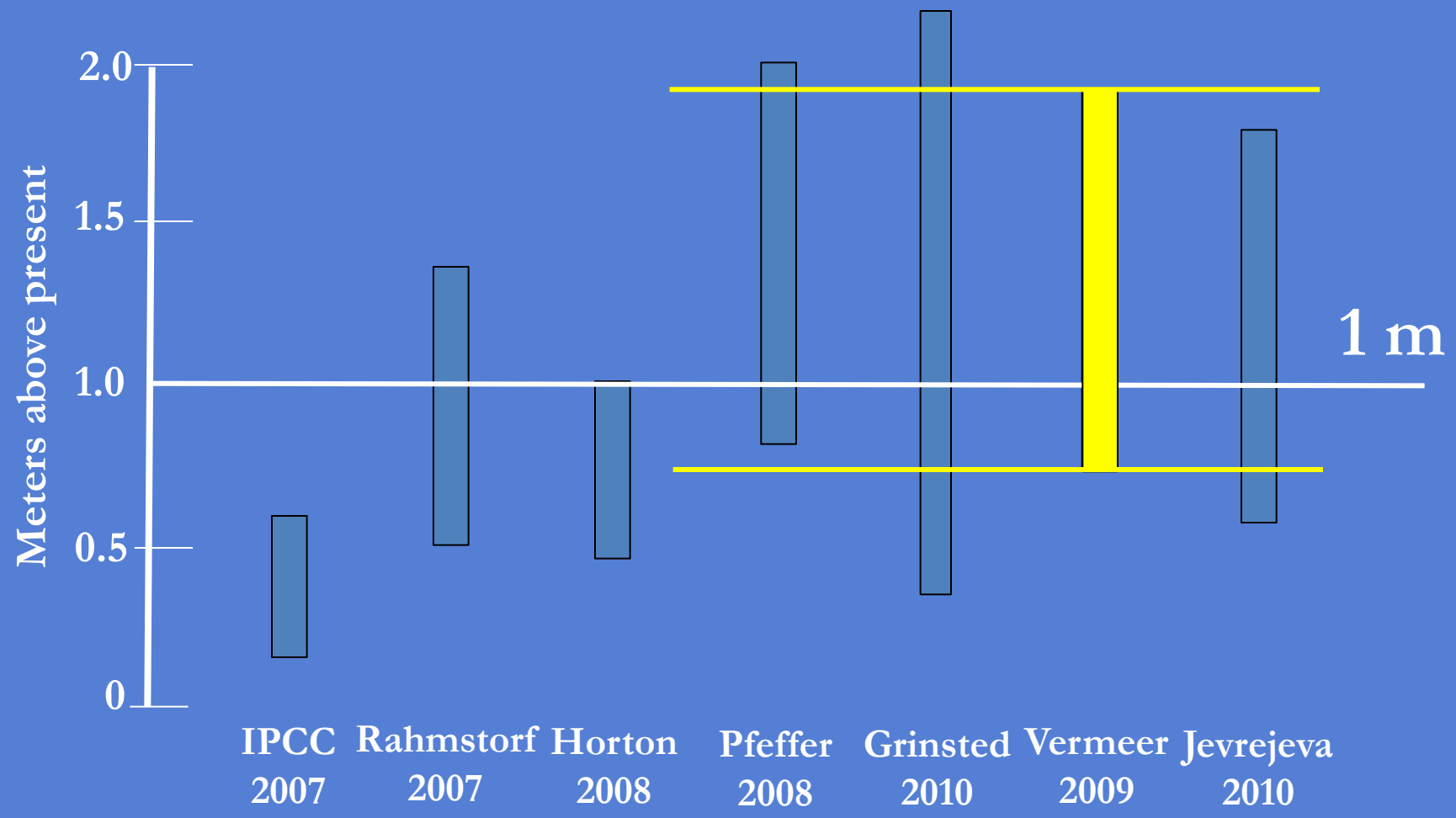


Tide gauge data reveal increase in average sea level

Satellite altimetry Indicate a similar trend

M. Merrifield,
UH Sea Level Center

Sea level Estimates - 2100



Adapting to sea-level rise and inundation

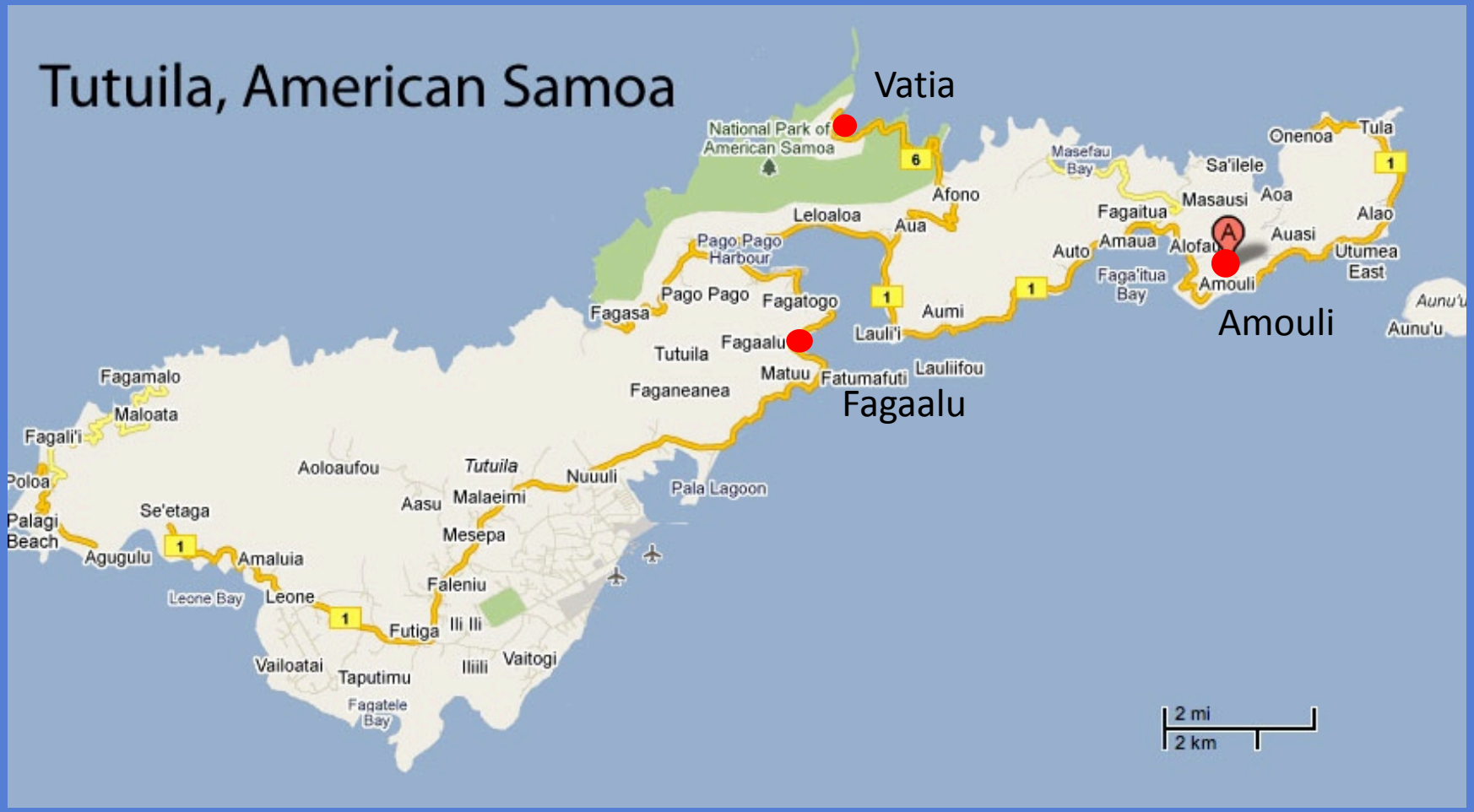
1. Explore the issues of sea level rise with the community to develop a shared vision of what is at risk and the qualities stakeholders want to protect (community-based climate risk management).
2. Map the problem using best and worst case scenarios.
3. Develop adaptation strategies
   a) Building codes
   b) Retreat strategies
   c) Defense strategies
   d) Food, flood, transportation engineering
4. No regrets policy – areas troubled now,
5. Identify funding, create plans, establish
6. Stage activities, apply triage priorities

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

USGS
science for a changing world

American Samoa – June 2010

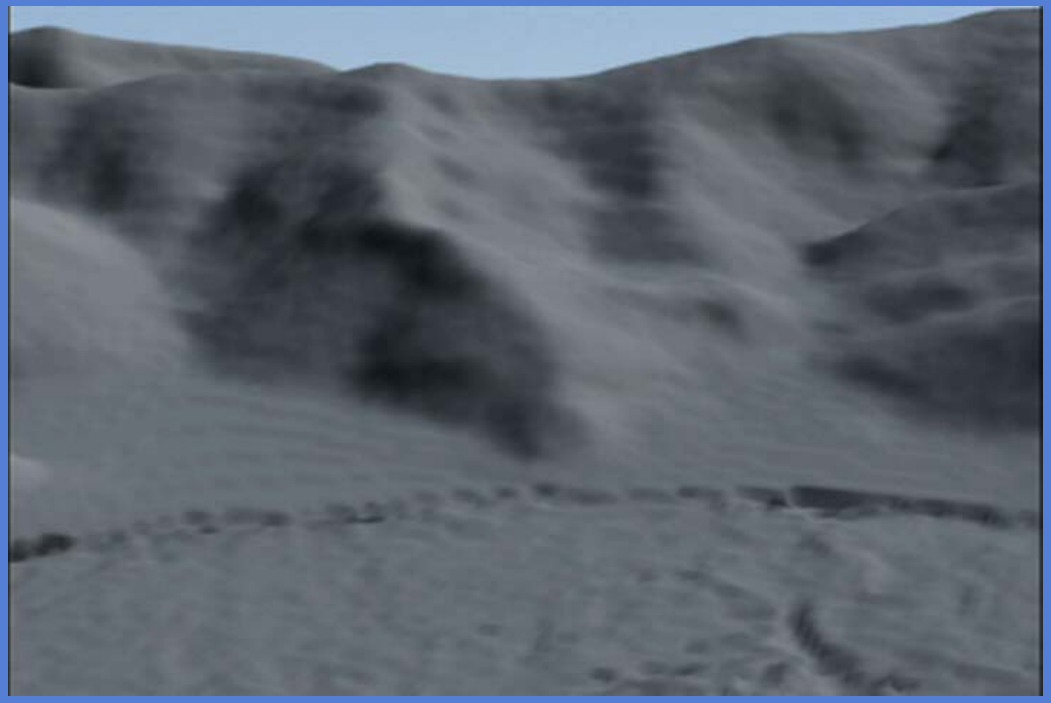
Amouli, Vatia, Fagaalu



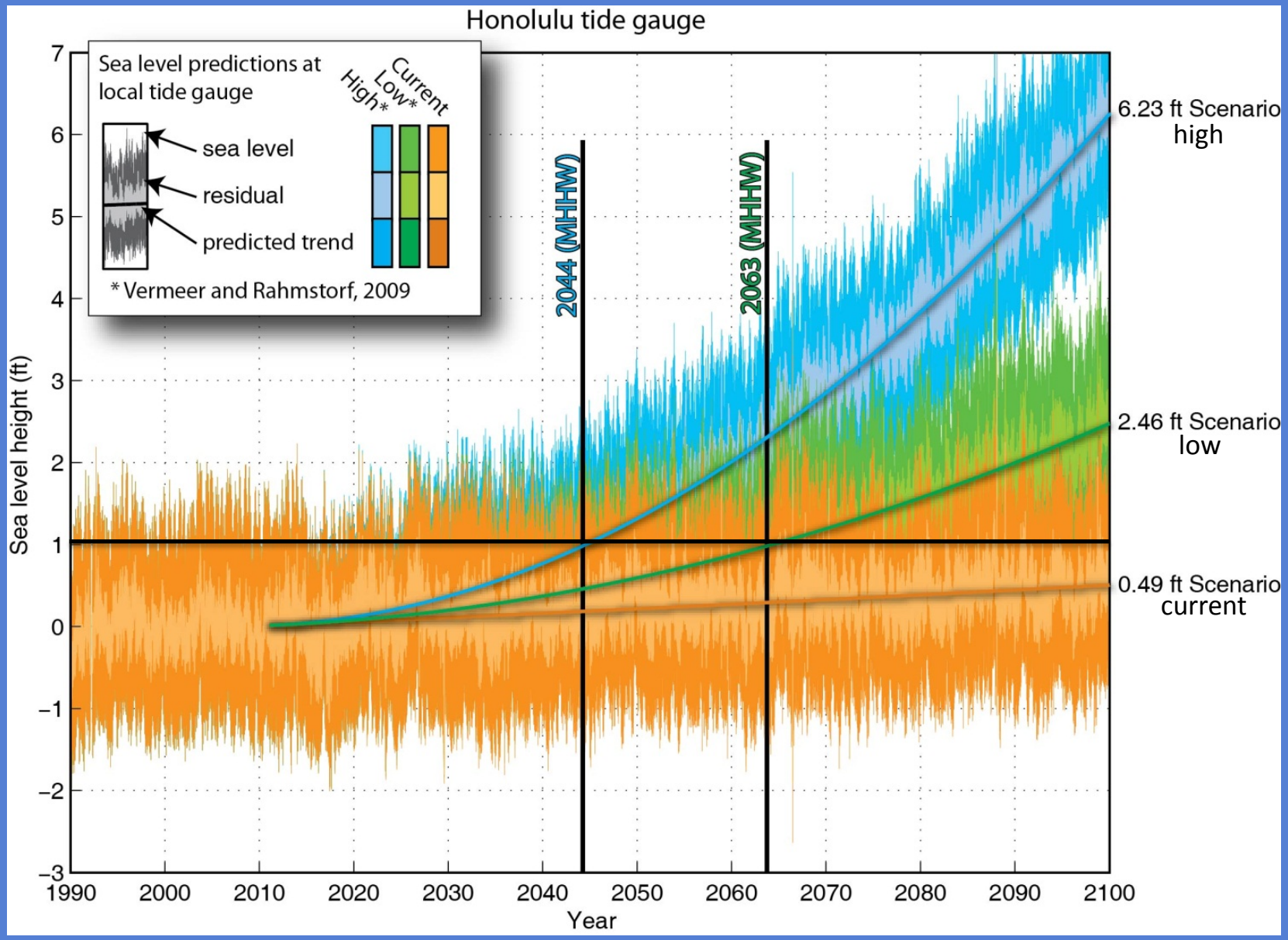
Building a digital elevation model for Amouli

Data integration

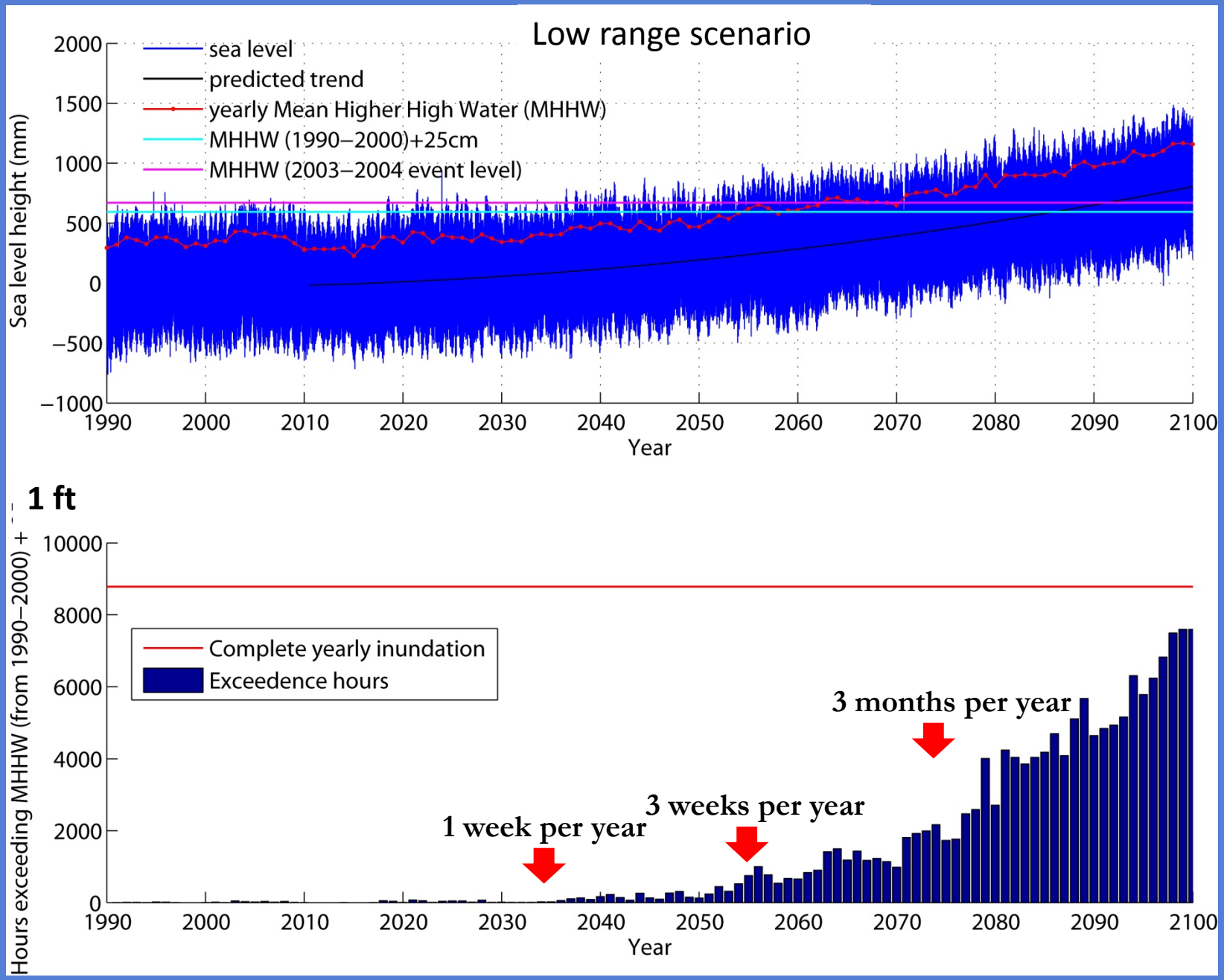
- Field collected kinematic GPS survey used to anchor total station elevation survey (1100 points in low elevations with multiple setups)
- Ground level photographs of the survey area within the village
- Combined existing GIS layers and survey data with digitized village structures and geomorphic features from ground-level photographs and satellite imagery



Scheduling



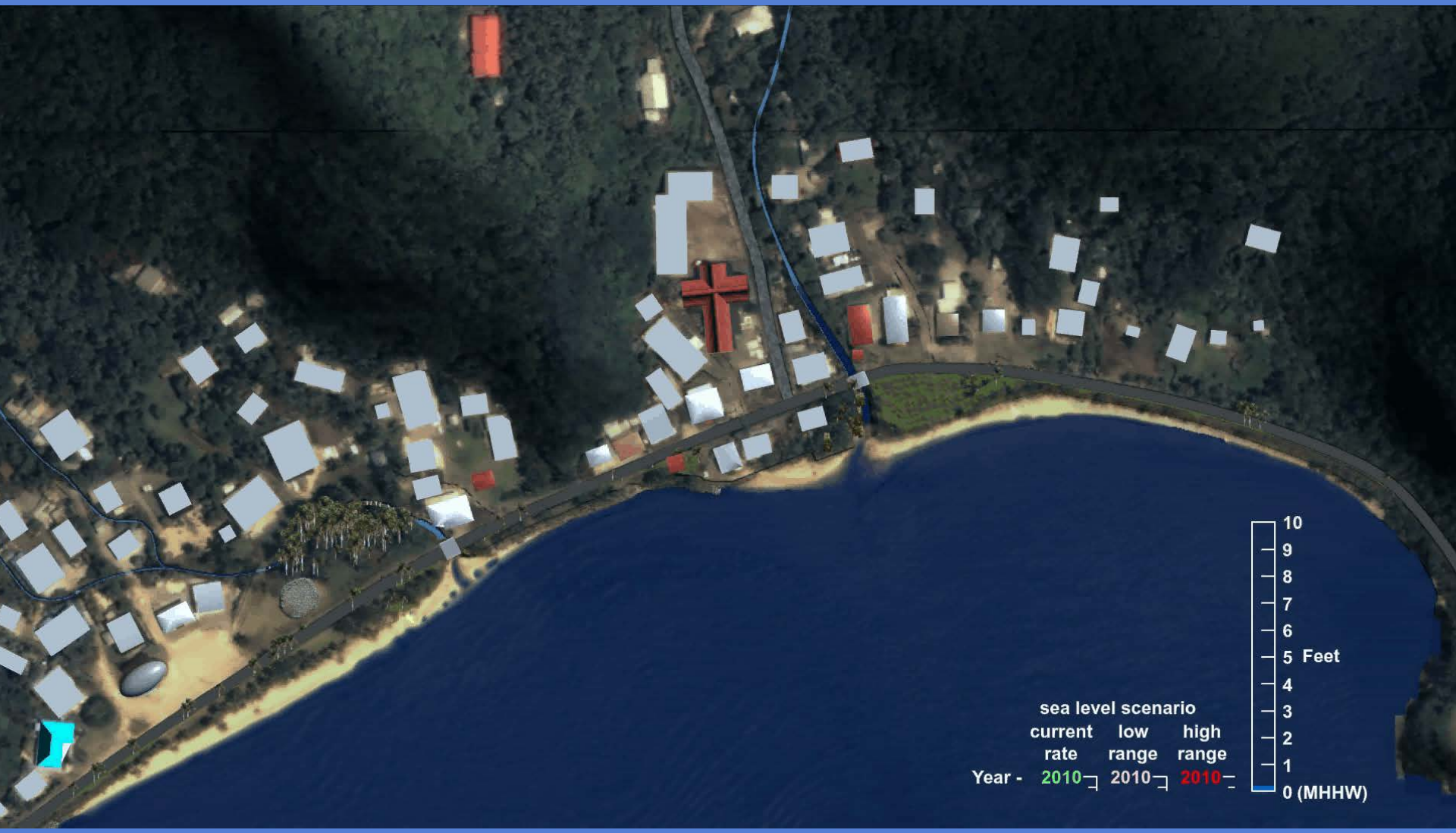
(Vermeer and Rahmstorf, 2009)


Low range scenario
sea level
predicted trend
yearly Mean Higher High Water (MHHW)
MHHW (1990–2000)+25cm
MHHW (2003–2004 event level)
Sea level height (mm)
2000
1500
1000
500
0
−500
−1000
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
1 ft
Hours exceeding MHHW (from 1990–2000) +
10000
8000
6000
4000
2000
0
Complete yearly inundation
Exceedence hours
3 months per year
3 weeks per year
1 week per year
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year

Amouli

10
9
8
7
6
5 Feet
4
3
2
1
0 (MHHW)
sea level scenario
current rate
low range
high range
Year - 2010
2010
2010

Amouli


sea level scenario
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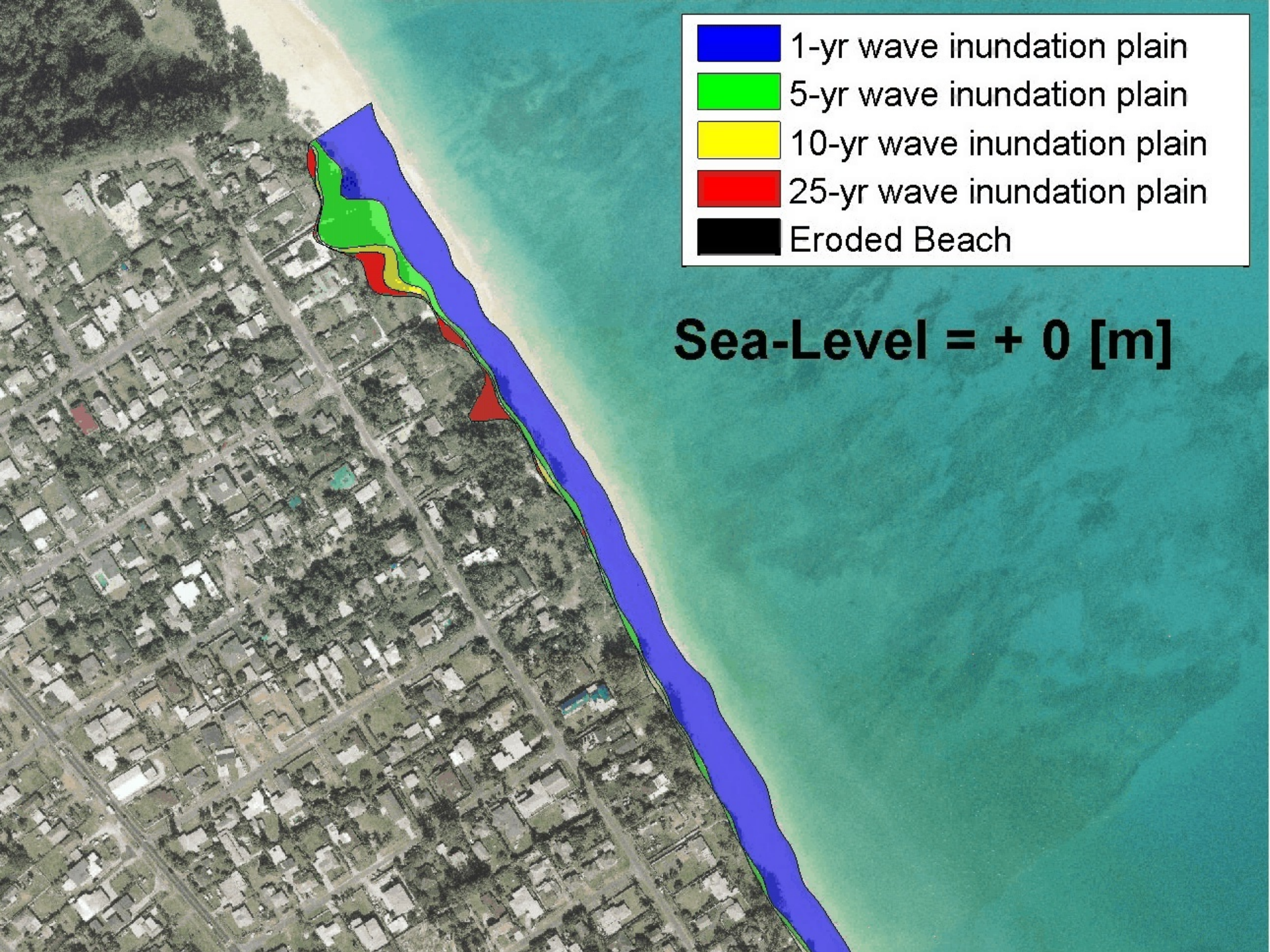
low range
high range
Year -
2010
2010
2010
10
9
8
7
6
5 Feet
4
3
2
1
0 (MHHW)

Hawaii

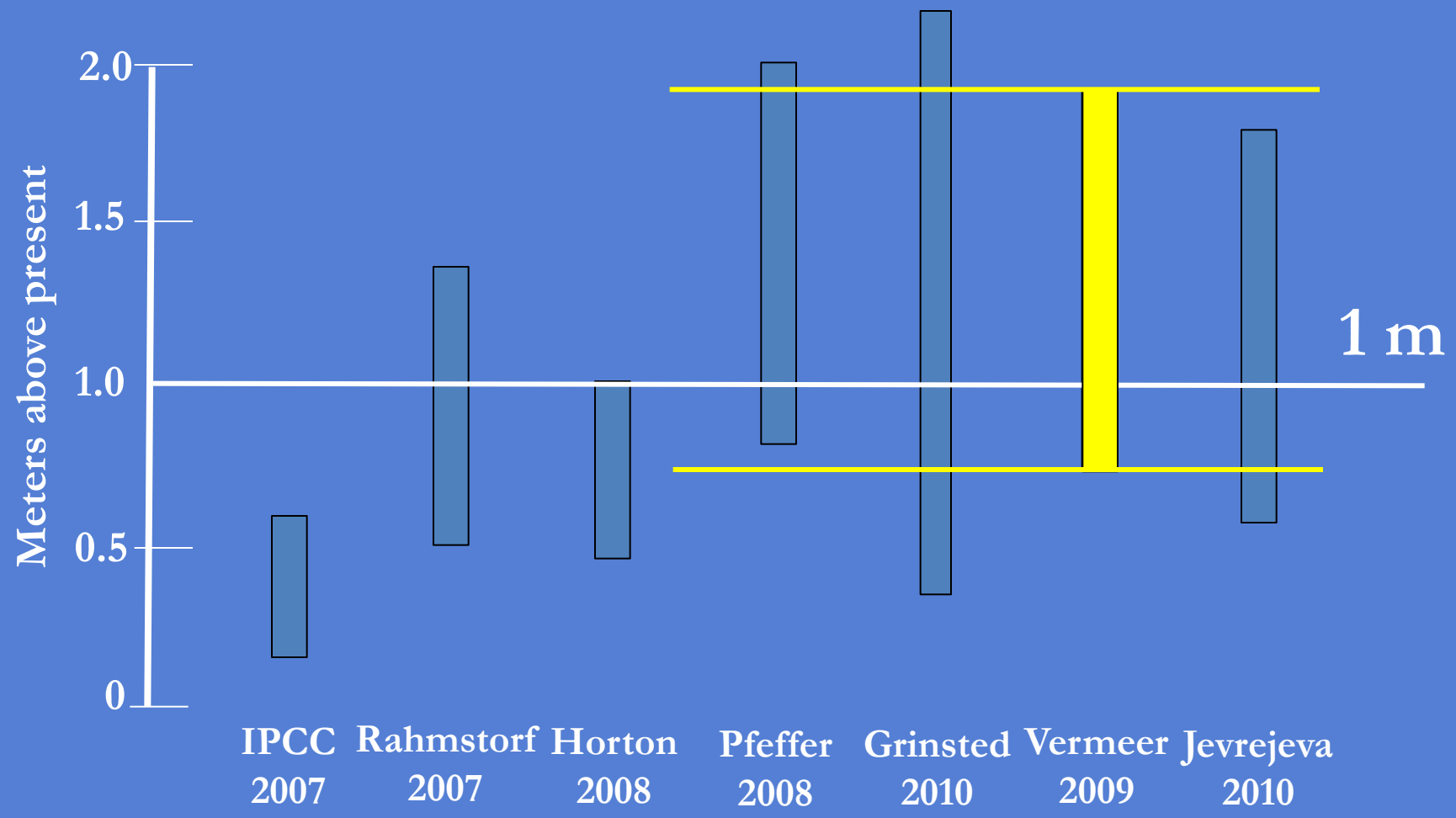
- 2 approaches
  1. Modeling
     - Buoy wave data transformed and run up using increase in sea level


1-yr wave inundation plain
5-yr wave inundation plain
10-yr wave inundation plain
25-yr wave inundation plain
Eroded Beach
Sea-Level = + 0 [m]

Hawaii

- 2 approaches
  1. Modeling
     - Buoy wave data transformed and run up using increase in sea level
  2. Predictive
     - Using Vermeer and Rahmstorf, 2009 sea level rise predictions on existing tide station data
     - Visualize increased water heights on tidal DEM
- Both require a DEM with Tide related elevations

Sea level Estimates - 2100



Methods: Orthometric hts → Tidal DEM

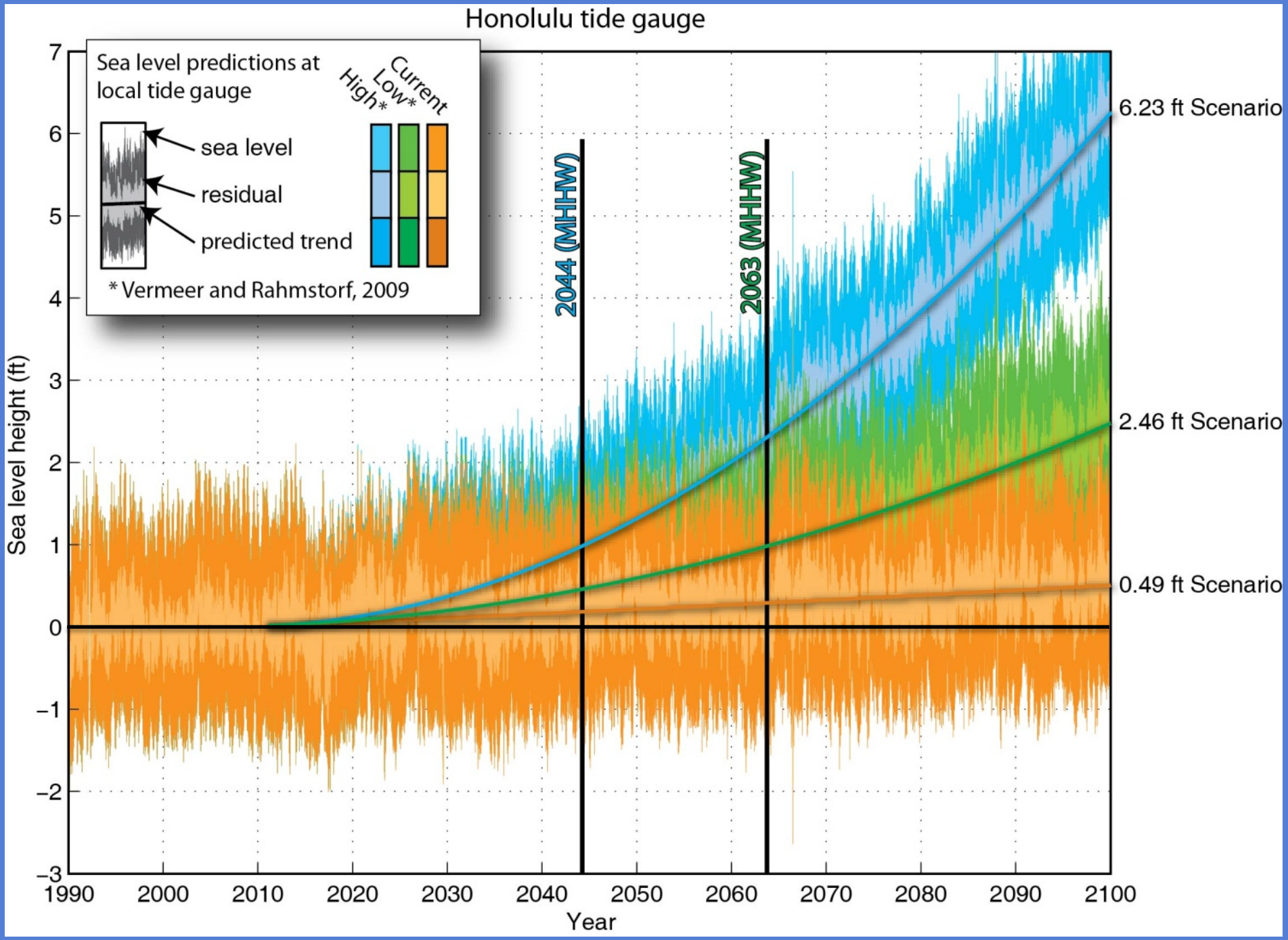
- Hawaii has many definitions of zero elevation
  - msl (tide station), msl (NAVD88), mllw (multiple tide stations), mhhw, ltd, Ellipsoid height (GRS 80, WGS 84 interations), etc.
- Integrating data can become a puzzle of figuring out what transformations have been done to each dataset and what steps need to be taken to relate the data to a common and relevant datum (tidal is our choice)

Deriving and integrating elevation datasets

- GOAL: Define a relationship between available terrain datasets and tide gauge sea levels
  - Between LiDAR sets with apparent vertical offset (Maui)
    - Series of checkpoints located on planar surfaces
  - Between the integrated LiDAR data and the local tide station (Oahu and Maui)
    - Using Tidal Benchmark locations

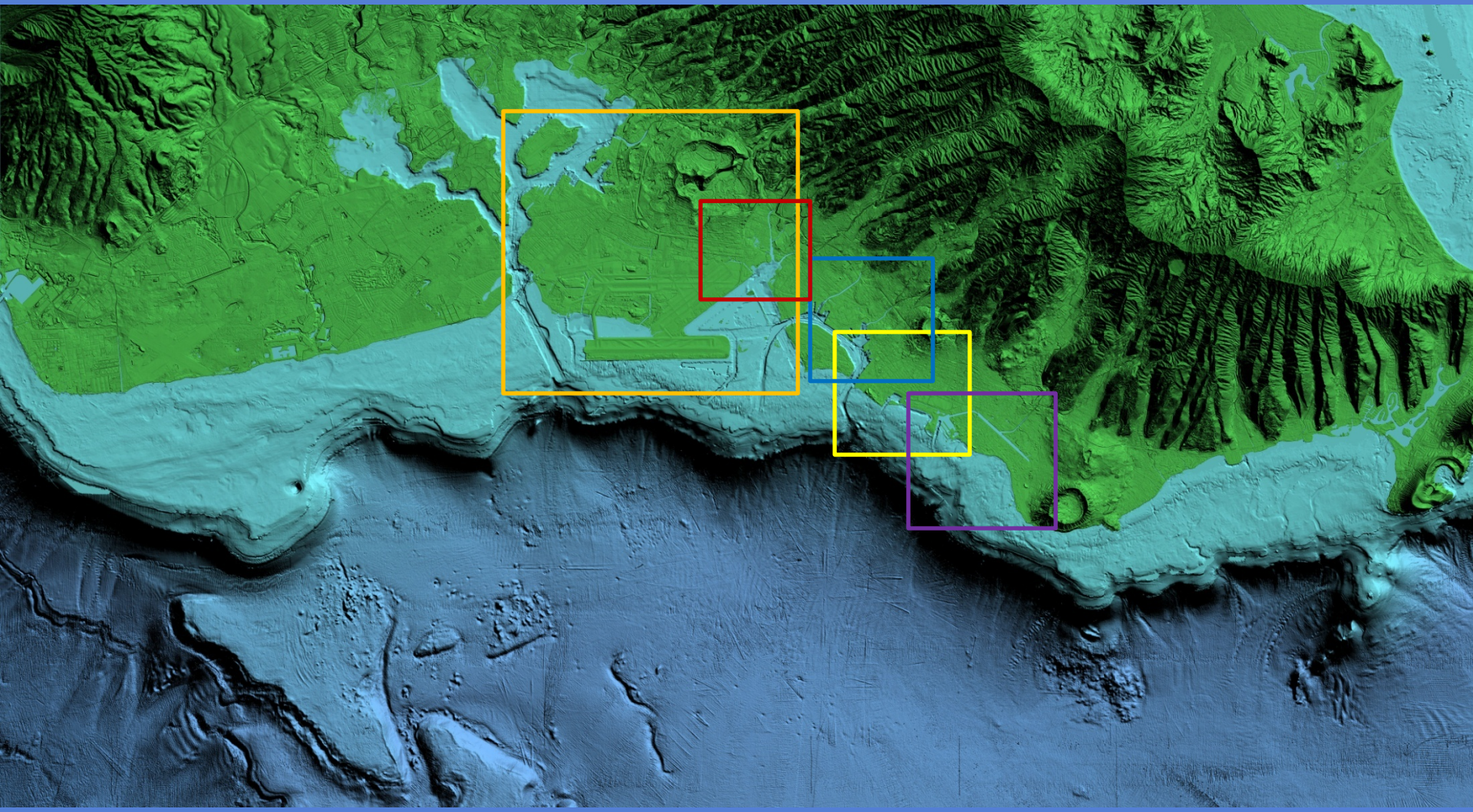
Oahu

- NGA LiDAR covers the entire south shore of Oahu
  - Qualitative analysis:
    - Pearl Harbor water elevations > 0
    - Datum reported to be NAVD88 (there is no NAVD88 datum for Hawaii yet…)
  - Quantitative analysis:
    - Only a DEM is available – no point data
    - Vertical offset between benchmark location elevations and DEM = - 0.162 ± 0.096 m
      - Applied to water level height calculations (+ 0.162 m)

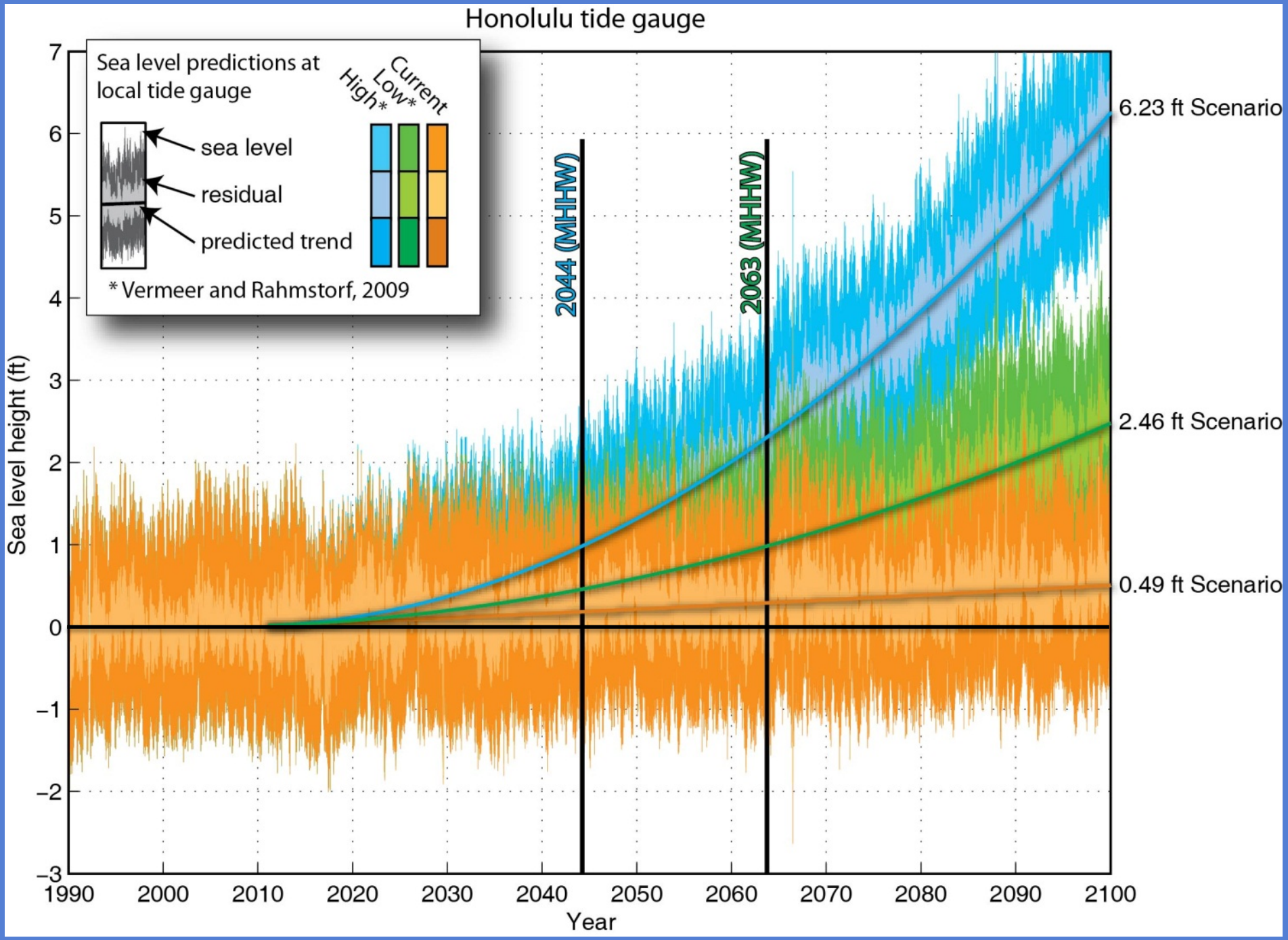

Honolulu tide gauge
Sea level predictions at local tide gauge
Current
Low*
High*
sea level
residual
predicted trend
* Vermeer and Rahmstorf, 2009
2044 (MHHW)
2063 (MHHW)
6.23 ft Scenario
2.46 ft Scenario
0.49 ft Scenario
Sea level height (ft)
Year
7
6
5
4
3
2
1
0
−1
−2
−3
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

Oahu

Data Source: NGA LiDAR
Tidal Datum: MHHW
1 ft interval scenarios



Airport Area MHHW + 3 ft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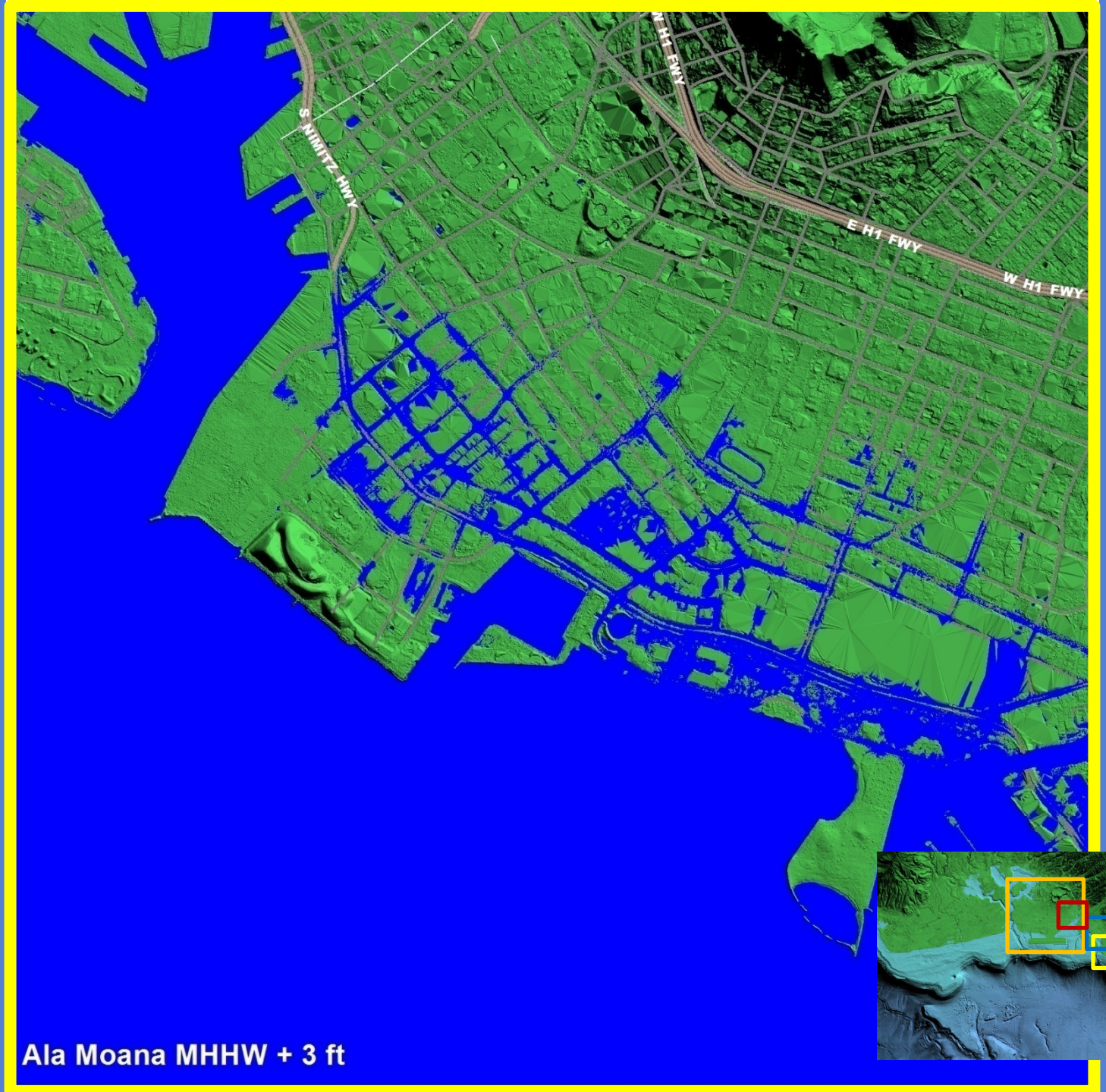
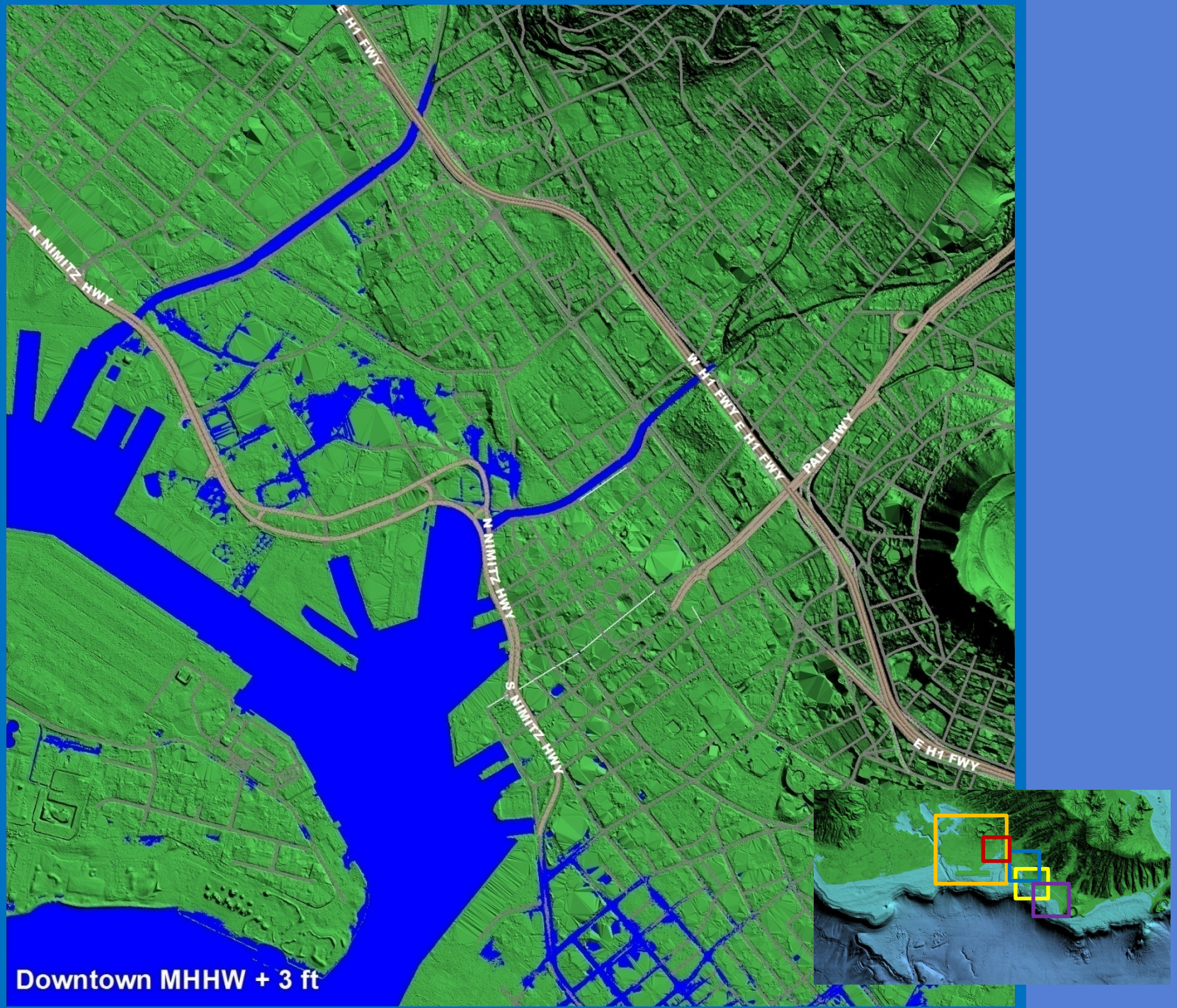
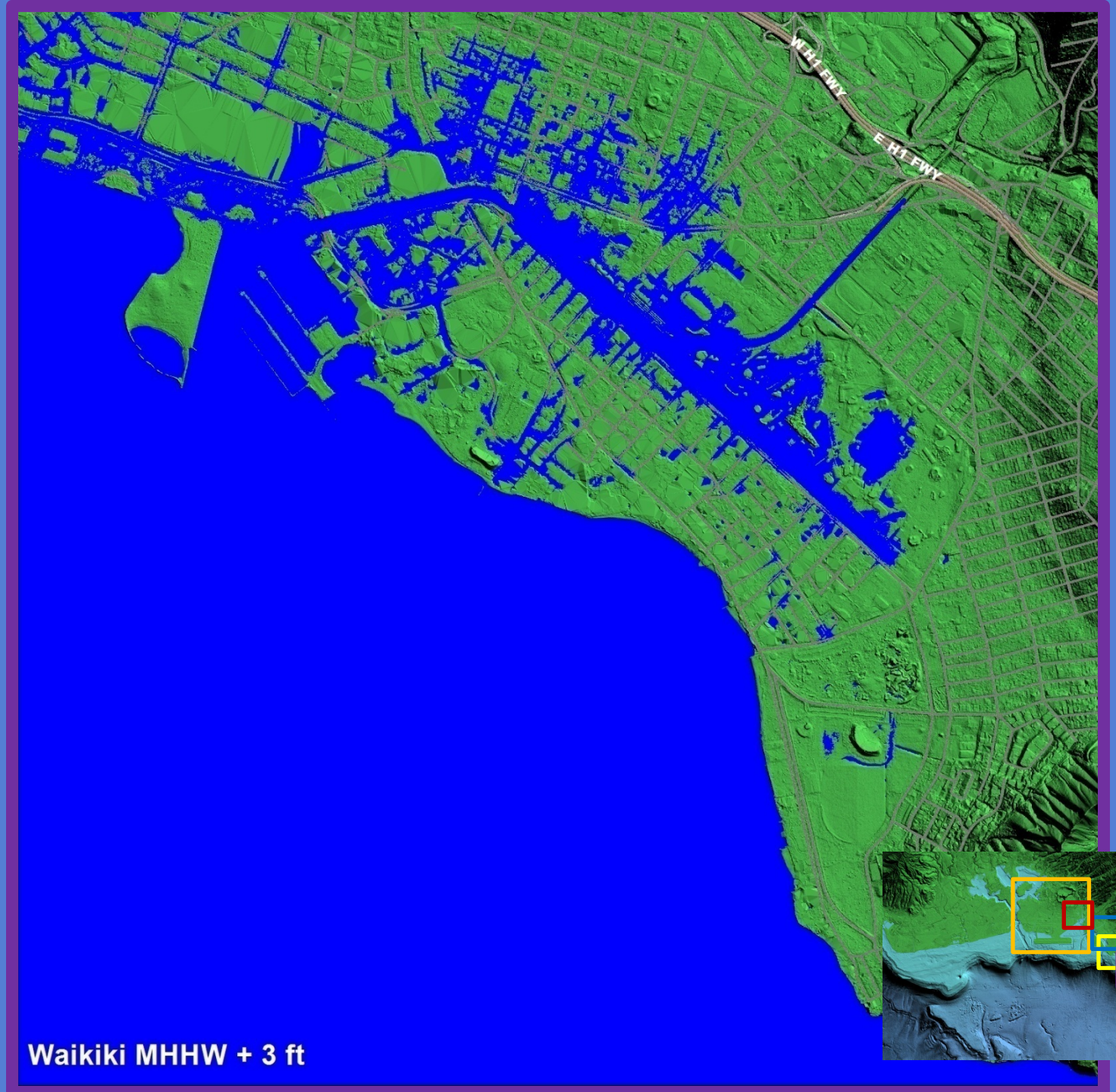
Year
7
6
5
4
3
2
1
0
−1
−2
−3
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

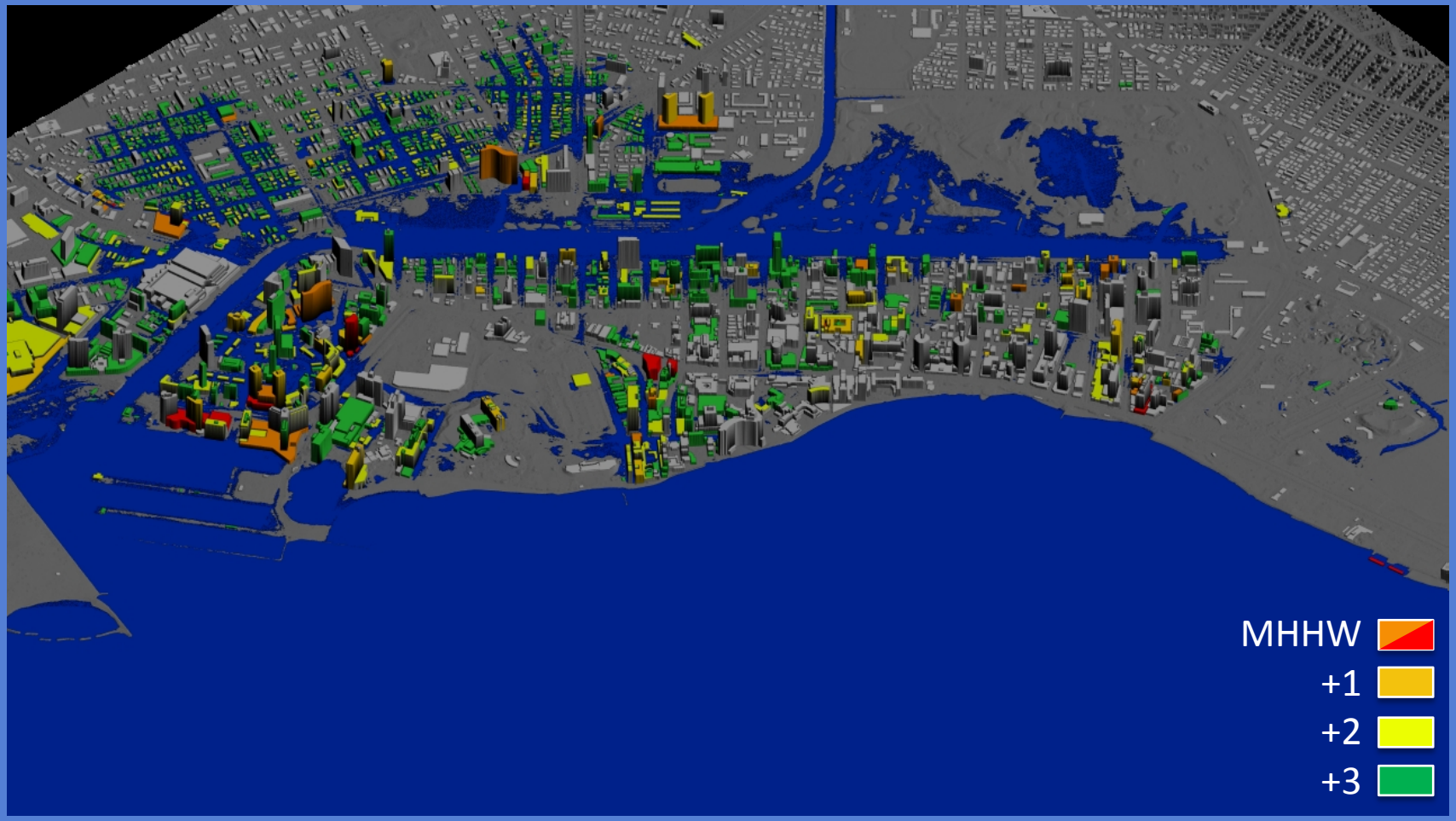
E MOANALUA FWY
E H1 FWY
N NIMITZ HWY
KAM HWY
E H1 FWY
W H1 FWY
E H1 FWY
N NIMITZ HWY
Mapunapuna MHHW + 3 ft


S NIMITZ HWY
W H1 FWY
E H1 FWY
W H1 FWY
Ala Moana MHHW + 3 ft


E H1 FWY
N NIMITZ HWY
W H1 FWY
E H1 FWY
PALI HWY
N NIMITZ HWY
S NIMITZ HWY
E H1 FWY
Downtown MHHW + 3 ft


W H1 FWY
E H1 FWY
Waikiki MHHW + 3 ft

Waikiki affected structures



Maui

- Multiple LiDAR datasets
  - USACE, NOAA, FEMA, Maui County
- Apparent offset in overlapping areas
- Varying levels of detail in metadata. Specifically concerning vertical datum calculation
- Referenced to NAVD88 using between 1 and 6 control points. Different GPS control for each survey.

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Integrating LiDAR datasets using planar surfaces (< 2° slope)

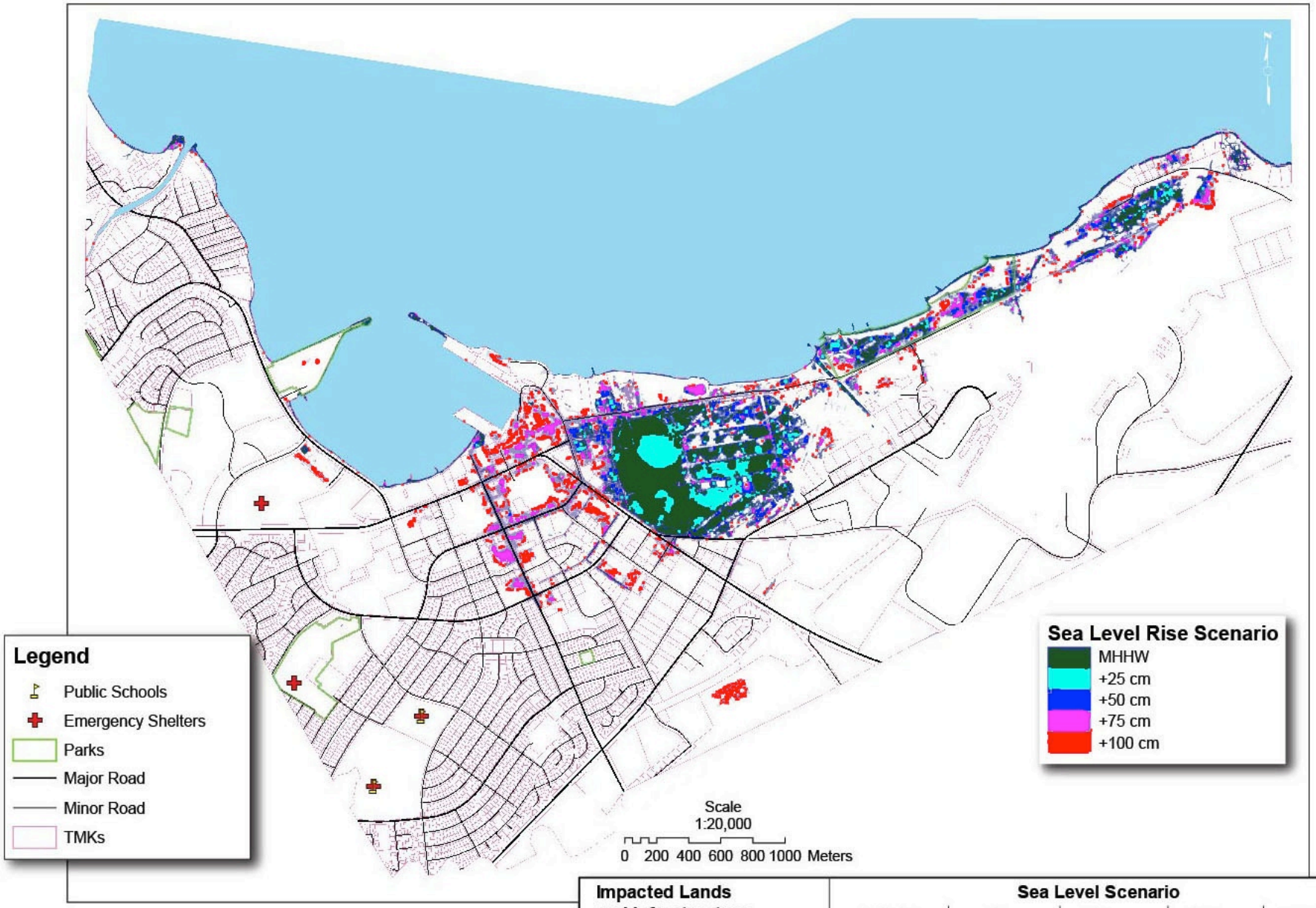
		Z_{NOAA} (m)			Z_{USACE} (m)			
Description	Location (m)	μ	σ	n	μ	σ	n	Δ_μ
Basketball court	744,014E, 2,324,251N	13.81	0.04	67	13.58	0.04	288	0.23
Parking lot	745,401E, 2,324,650N	72.16	0.06	15	71.76	0.10	80	0.4
Road 1	742,909E, 2,324,005N	32.13	0.13	34	31.91	0.16	260	0.22
Road 2	744,475E, 2,324,740N	18.00	0.12	40	17.59	0.10	126	0.41
Road 3	746,284E, 2,326,341N	57.06	0.09	27	56.47	0.10	117	0.59
Road 4	743,170E, 2,324,064N	50.97	0.07	19	50.65	0.09	68	0.32
Road 5	745,393E, 2,325,407N	21.91	0.2	51	21.45	0.20	67	0.46
Tennis court 1	743,491E, 2,324,279N	19.91	0.03	29	19.53	0.06	116	0.38
Tennis court 2	742,733E, 2,323,622N	13.53	0.04	72	13.15	0.03	112	0.38
Tennis court 3	745,081E, 2,324,552N	48.16	0.06	35	47.73	0.05	64	0.43
					Mean			0.38
					Stdev			0.10

Integrated LiDAR data and tide stations

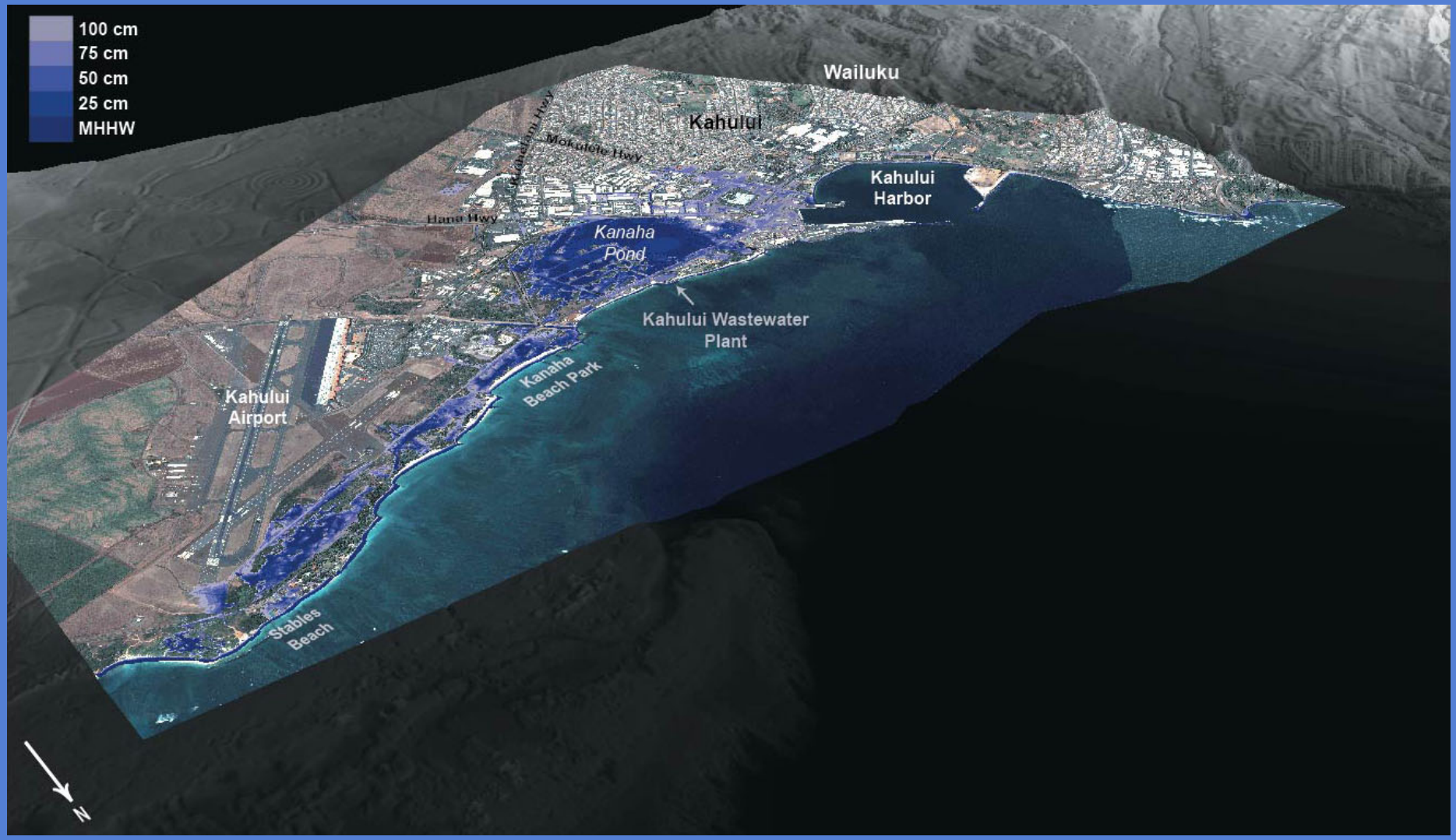
Using Tidal Benchmark locations, LiDAR points and interpolated DEM (for comparison)

Benchmark	n	Z_{min}	Z_{max}	Z_{σ}	Z_{μ}	Z_{DEM}	Z_{BM}	Δ_{pts}	Δ_{DEM}
161 5680 A	1	2.15	2.15	0.00	2.15	2.11	1.93	0.22	0.18
161 5680 C TIDAL	6	1.65	1.85	0.07	1.77	1.76	1.46	0.31	0.3
161 5680 TIDAL 11	9	2.02	2.11	0.03	2.05	2.06	2.11	-0.06	-0.05
161 5680 TIDAL 12	8	1.68	1.81	0.04	1.75	1.76	1.37	0.38	0.39
161 5680 TIDAL 2	12	2.15	2.23	0.03	2.19	2.2	2.50	-0.31	-0.3
161 5680 TIDAL 5	12	2.05	2.18	0.04	2.11	2.11	1.86	0.25	0.25
161 5680 TIDAL 6	3	2.58	2.61	0.02	2.59	2.58	2.41	0.18	0.17
161 5680 TIDAL 8	5	2.64	2.71	0.03	2.67	2.67	2.80	-0.13	-0.13
161 5680 TIDAL 9	7	2.50	2.66	0.06	2.56	2.54	2.58	-0.02	-0.04
							Δ_{μ}	0.09	0.09
					RMSE	0.23 m	Δ_{σ}	0.23	0.23

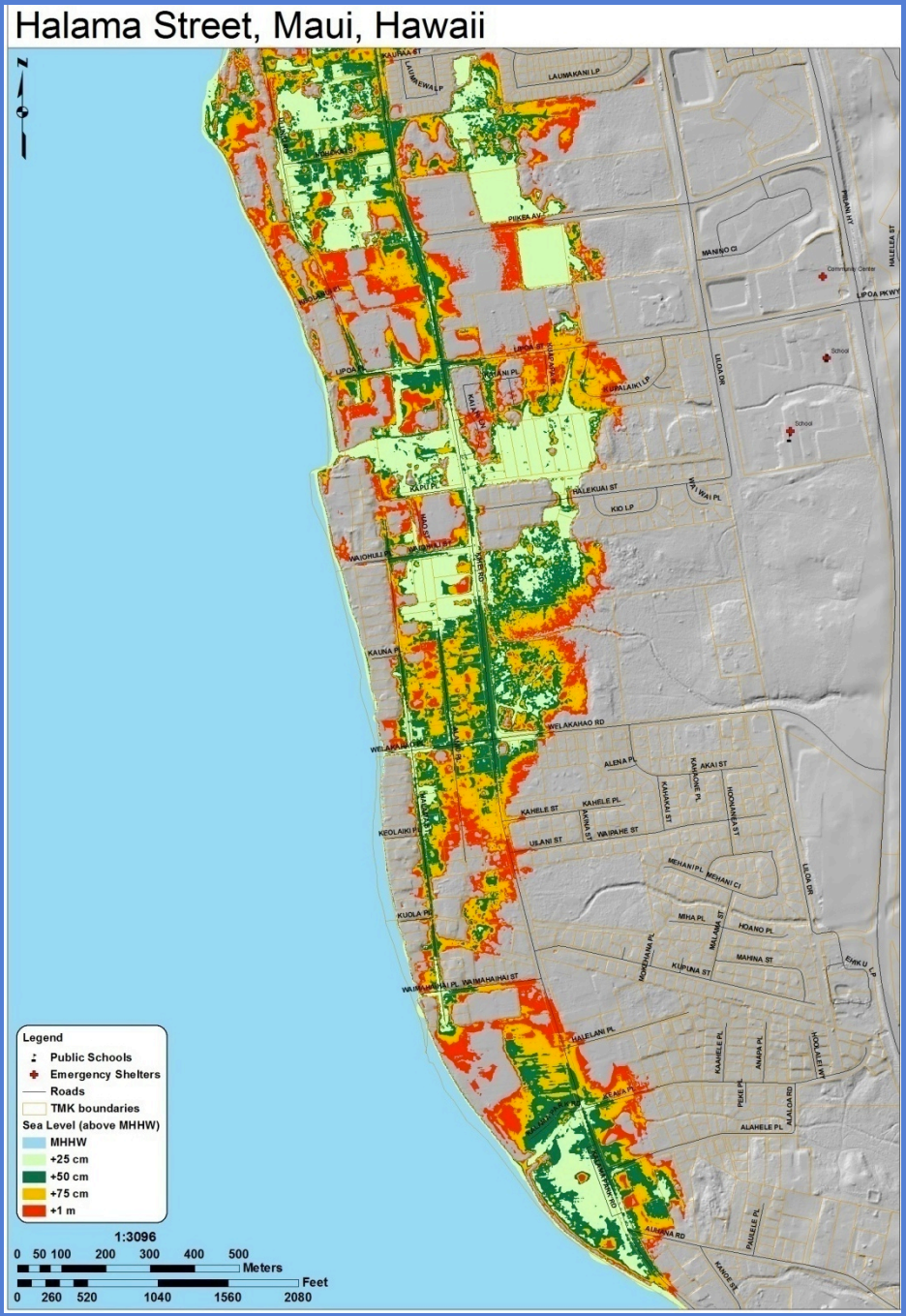
Kahului Harbor, Maui: Bare earth USACE LiDAR points (n) within a 2 m radius of NGS tidal benchmarks



Impacted Lands and Infrastructure	Sea Level Scenario				
	MHHW	+25 cm	+50 cm	+75 cm	+100 cm
Total Land Area (km^2)	0.49	0.88	1.16	1.62	2.21
Roads (km)	0	0.01	0.88	4.21	8.65
Land Parcels (quantity)	93	130	177	236	309


100 cm
75 cm
50 cm
25 cm
MHHW
Wailuku
Kahului
Mokulele Hwy
Hana Hwy
Kahului Harbor
Kanaha Pond
Kahului Wastewater Plant
Kanaha Beach Park
Kahului Airport
Stables Beach
N

Sea Level Risk and Vulnerability



Questions?

Thank You