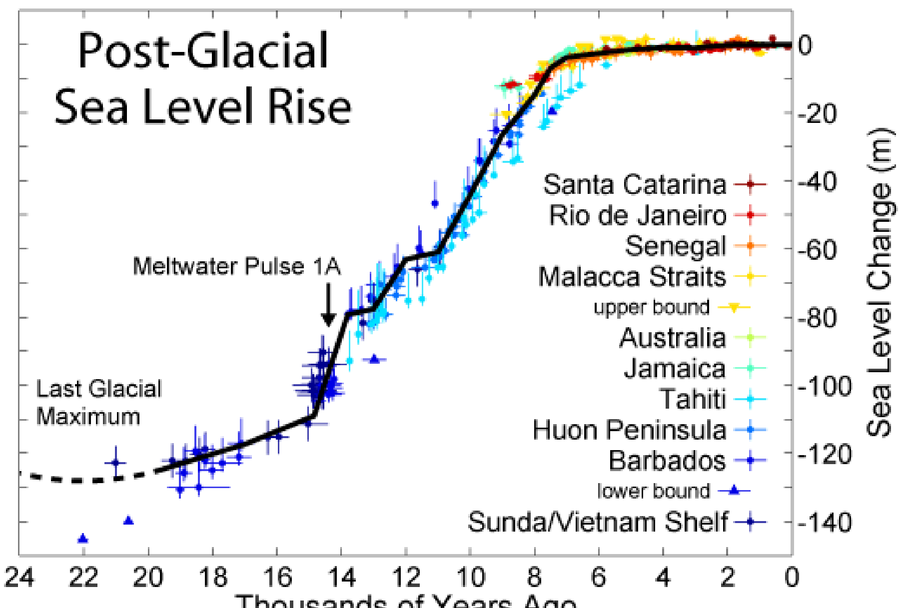
A Projected Sea Level Assessment of Tutuila and Aunu'u Islands, American Samoa

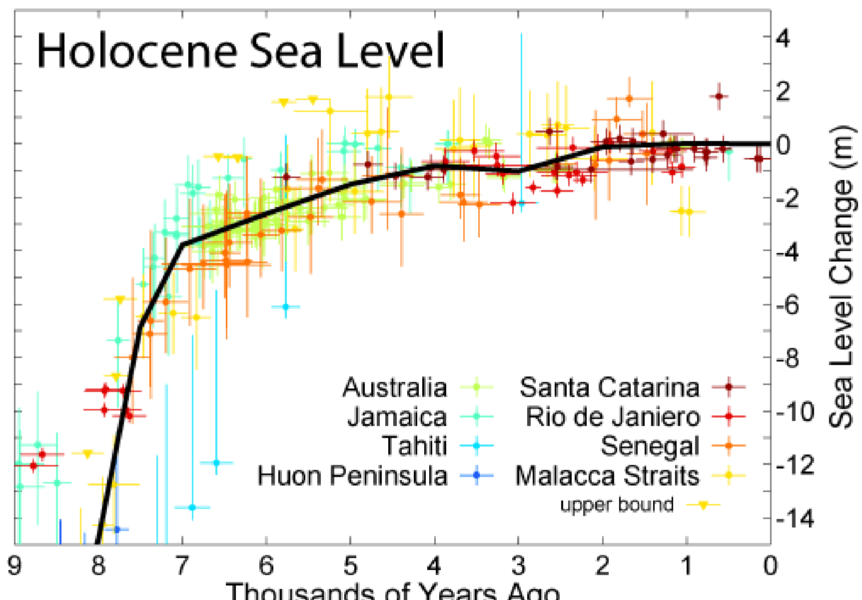
R. Duncan McIntosh
Research Assistant
Pacific Regional Integrated Sciences and Assessments

What do we know about the global mean sea level (GMSL) and how do we know it?

- **The Geological Record** (paleo sea level reconstructions):
  - Since the last glacial maximum (18,000 years BP) GMSL has been rising in pulses of rapid steps (1-10 m) interspersed by periods of relative constancy (Rodriquez et al. 2000)
  - The last rapid pulse occurred ~2,500 years BP and since that time GMSL has been rising slowly (order tenth mm/yr) (Dominquez and Wanless 1991)

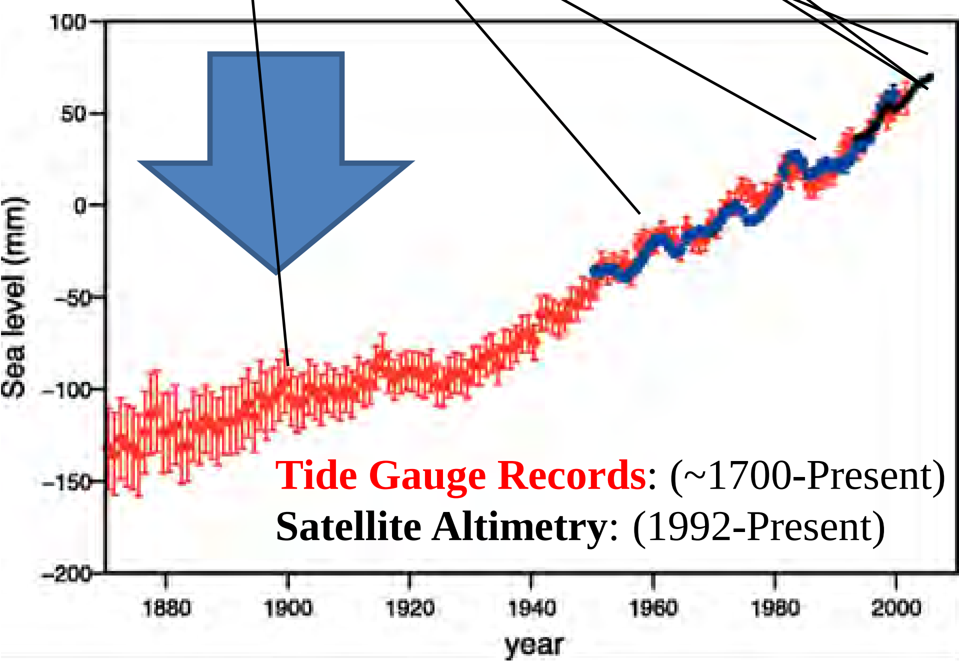
(Graphs: Robert A. Rohde)





What do we know about the global mean sea level (GMSL) and how do we know it?

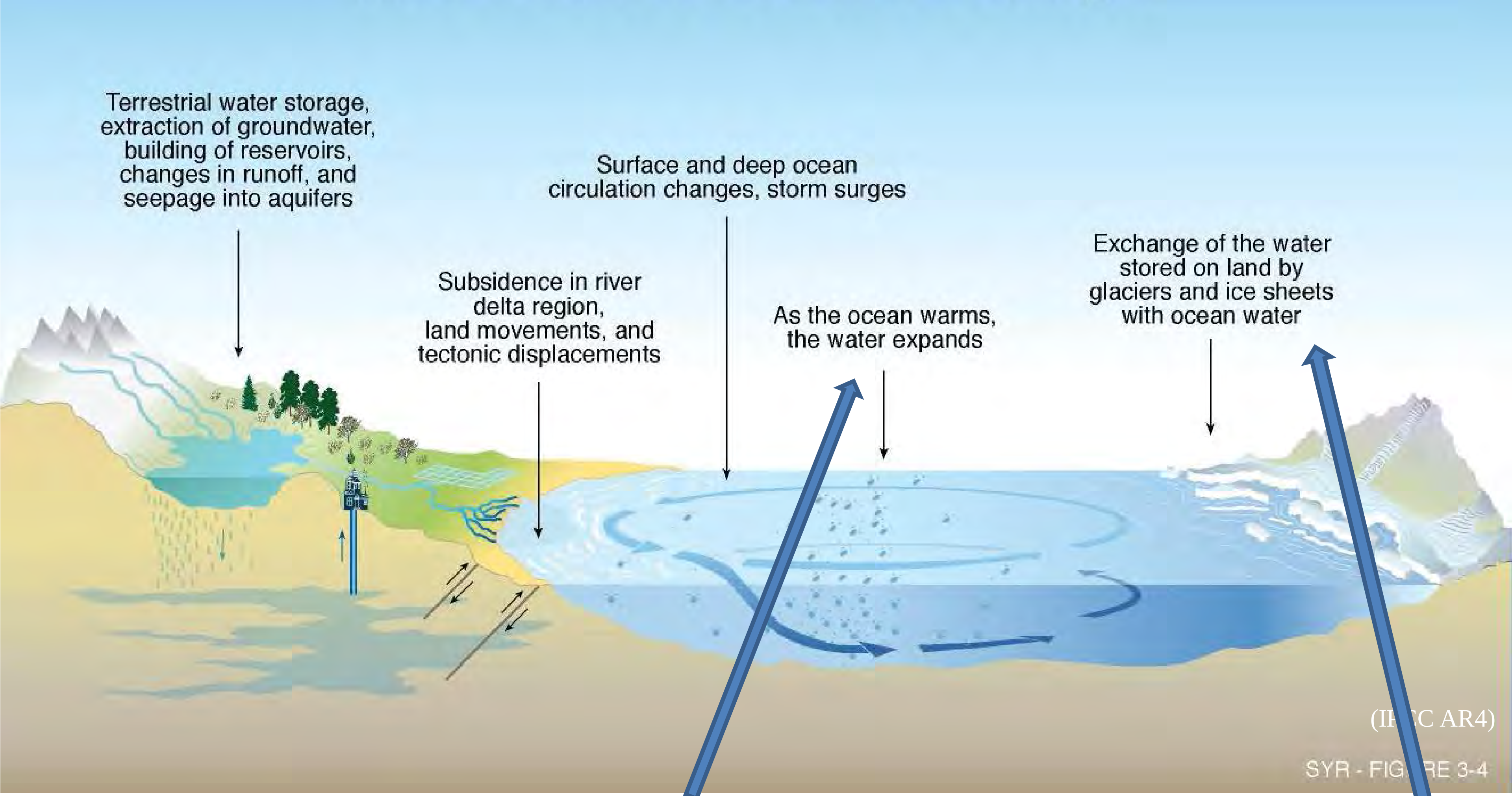
- **The Instrumental Record** (empirical evidence):
  - Sometime between 1840-1920 occurred an acceleration that marks the transition between the relatively low rates (tenths mm/yr) of the late Holocene to modern rates (mm/yr)
  - 1901-2010 GMSL trend = **+1.7** [1.5 to 1.9] **mm/yr** (IPCC AR5)
  - 1971-2010 GMSL trend = **+2.0** [1.7 to 2.3] **mm/yr** (IPCC AR5)
  - 1993-2012 GMSL trend = **+3.2** [2.8 to 3.6] **mm/yr** (IPCC AR5)



The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). (IPCC AR5)

Tide-gauge and satellite altimeter data are consistent regarding the higher rate of the latter period. It is *likely* that similarly high rates occurred between 1920 and 1950. (IPCC AR5)

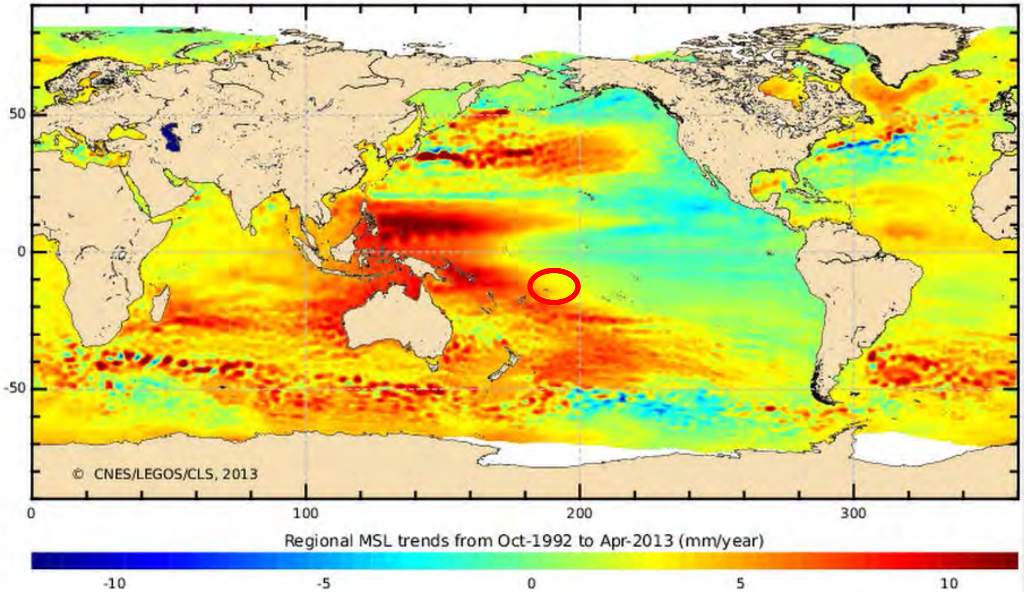
What causes the sea level to change?



- Most of the rise to date has been due to thermal expansion of the ocean (Bindoff et al. 2007)

- During the period 2005-2012, ocean mass transfer was dominant. A shift towards an ice-melt dominant trend could indicate the approach of the next rapid pulse in SLR (Blunden and Arndt 2013)

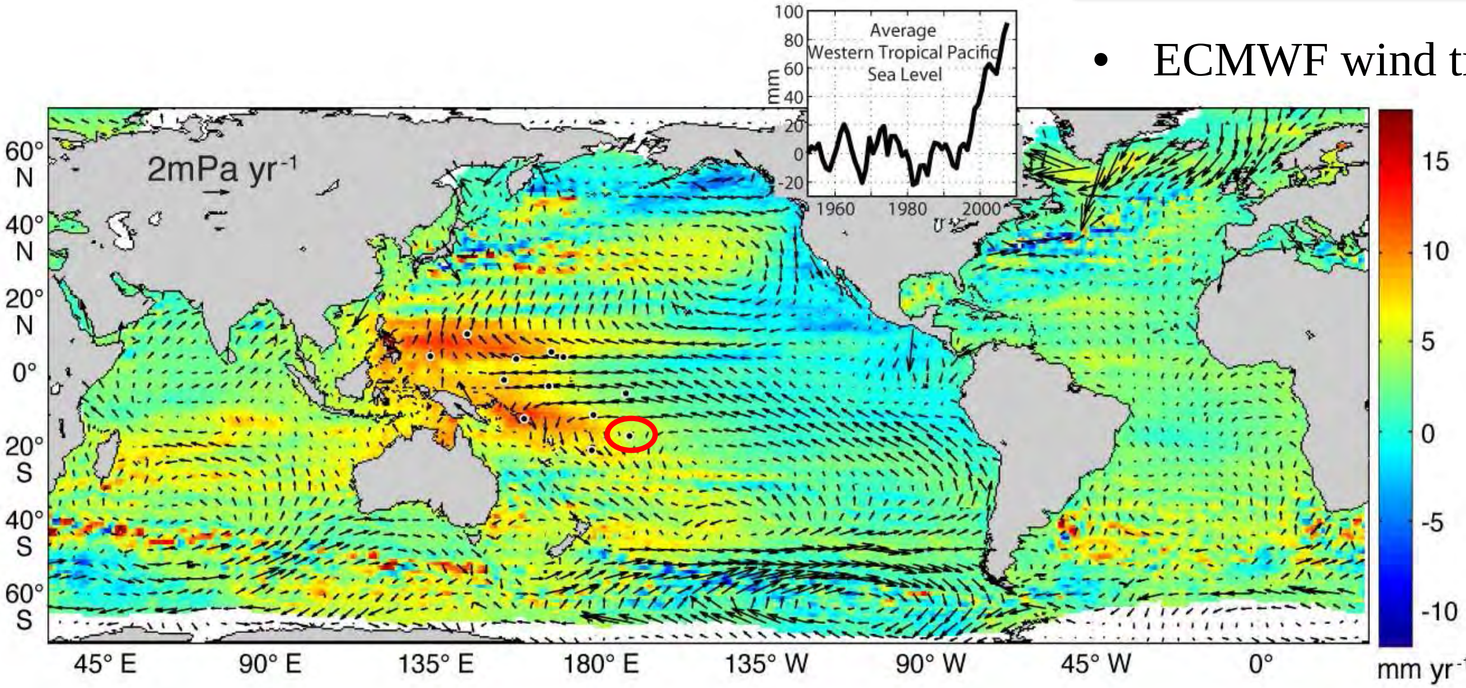
Regional Sea Level Variability



- Interdecadal MSL trends 1992-2013

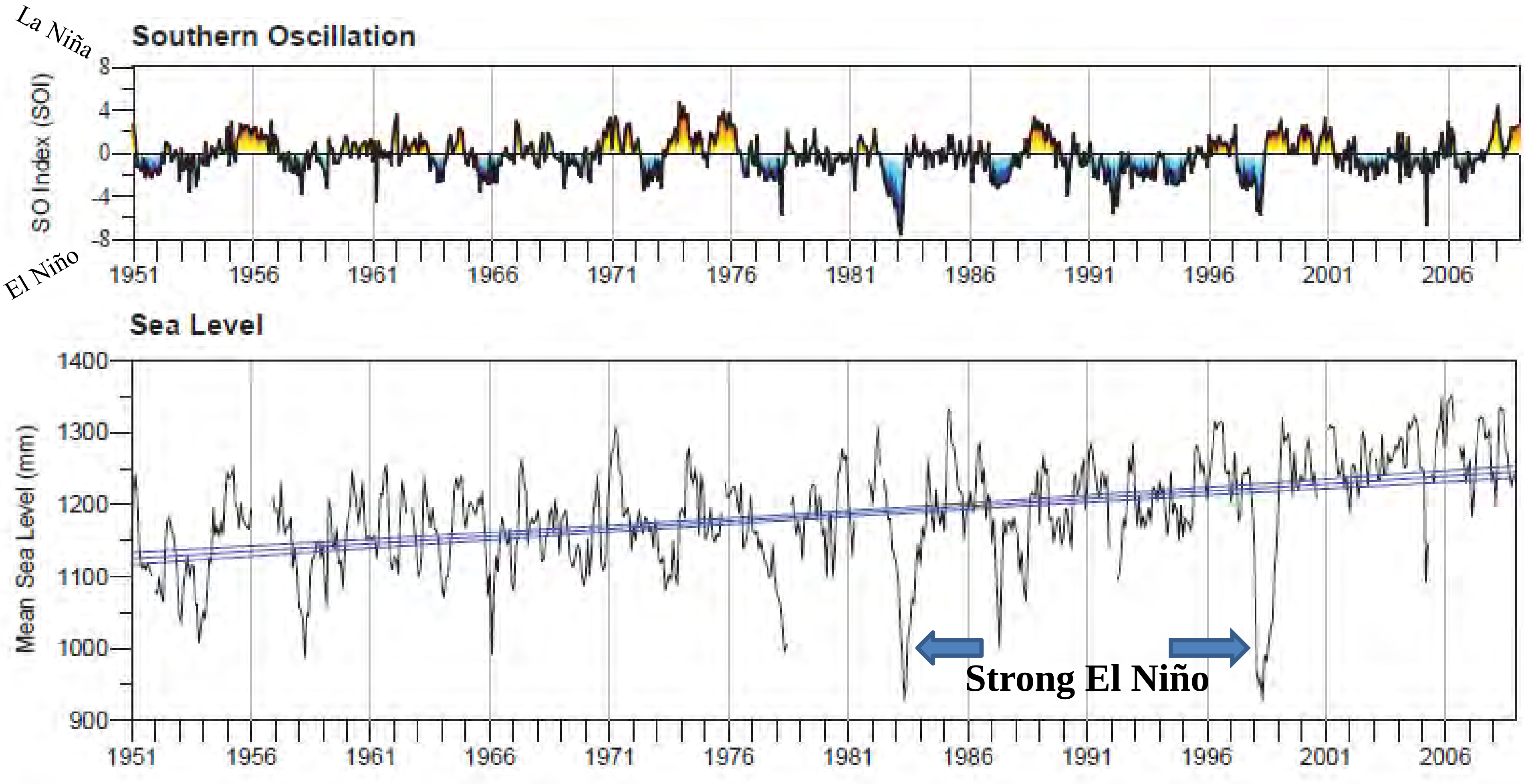
The large rates of sea level rise in the western tropical Pacific and of sea level fall in the central and eastern tropical Pacific over the period 1993-2010 correspond to an increase in the strength of the trade winds in the central and eastern tropical Pacific over the same period. (IPCC AR5)

- ECMWF wind tress trends 1993-2010



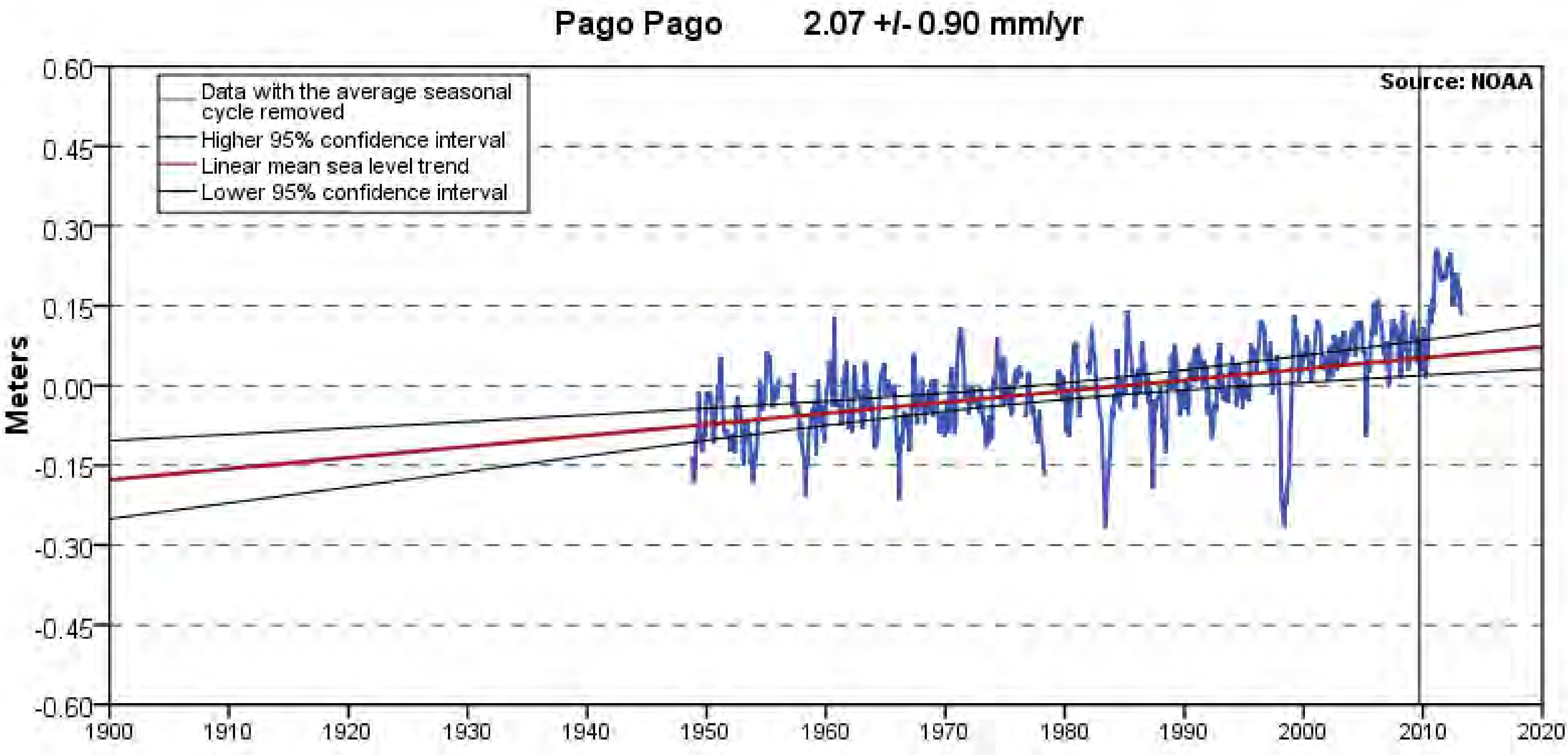
(Merrifield and Maltrud 2011)

Local ENSO Interannual Covariance In Pago Pago, American Samoa



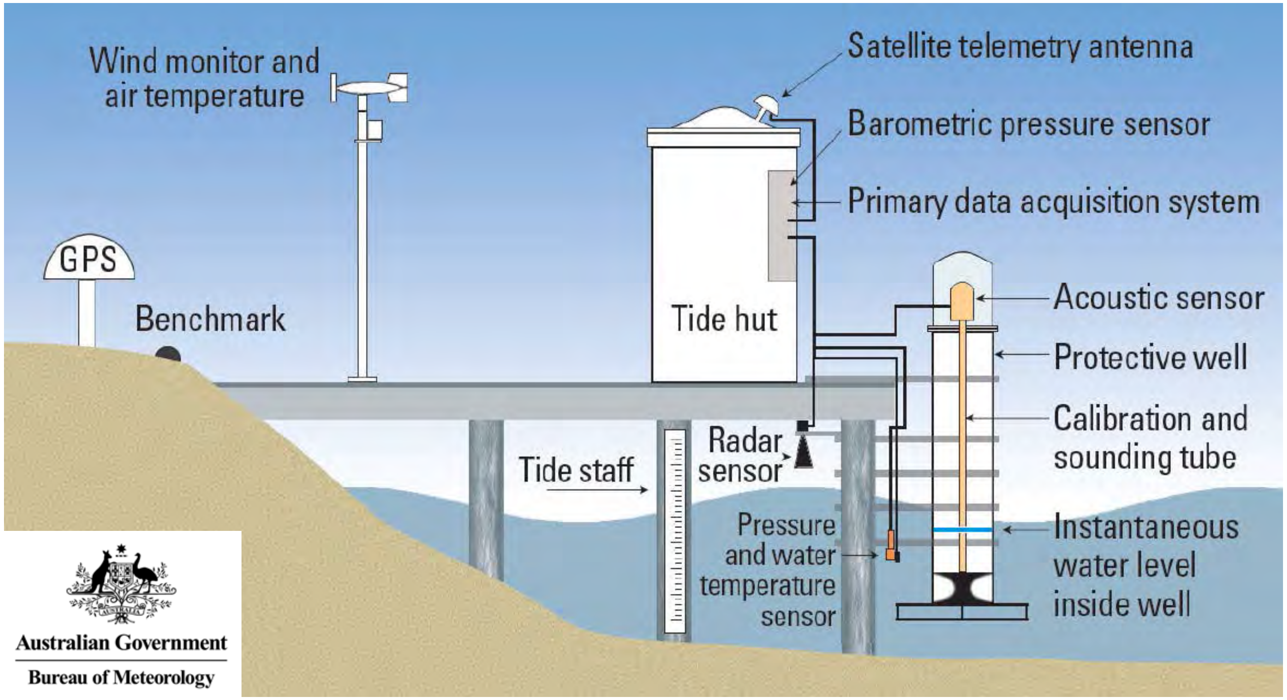
- Sea level values for Pago Pago, American Samoa from 1948 to 2008. Values are monthly averages. Data are from U. Hawaii Sea Level Center/National Oceanographic Data Center Joint Archive for Sea Level. Southern Oscillation Index (SOI) values for the same time period are from NOAA/NWS. El Niño conditions are represented in dark blue with strong negative SOI values. La Niña conditions are represented by orange with strong positive values. (Pirhalla et al. 2011)

Empirical Trend in American Samoa



- The mean sea level trend is **2.07 millimeters/year** with a 95% confidence interval of +/- 0.90 mm/yr based on monthly mean sea level data from **1948 to 2006** (NOAA Tides and Currents 2013)

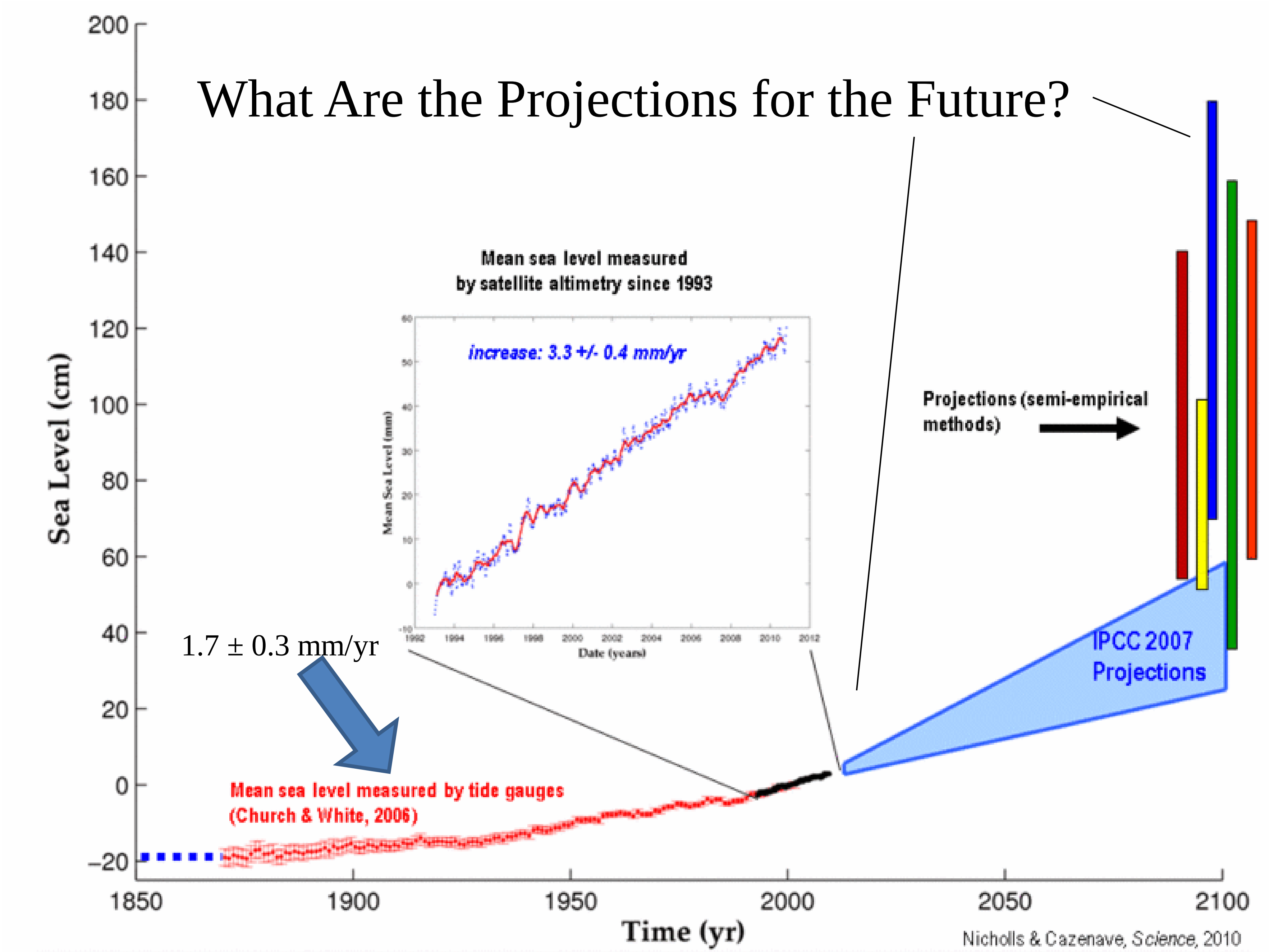
Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) located nearby (Apia, Samoa)



Location	Latitude	Longitude	Date of first data	Rate (mm/yr)	Change in rate from previous month (mm/yr)
Samoa	13°49'36.4"S	171°45'40.7"W	Feb 1993	**+7.7**	+0.1

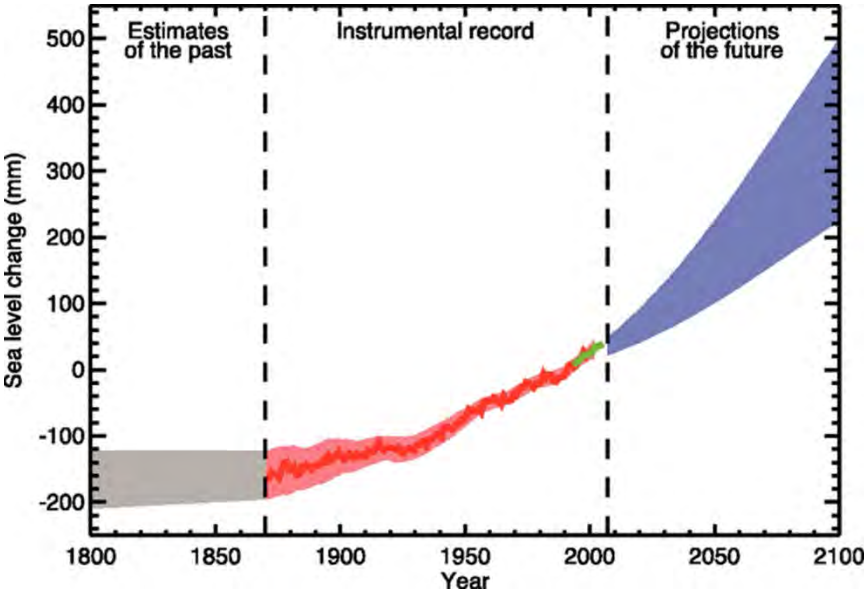
- Updated overall rate of sea level movement based on SEAFRAME data from installation through September, 2013
- Adjusted for the inverted barometric pressure effect and vertical movements in the observing platform relative to the primary tide gauge benchmark
- Indicates acceleration in MSLR = **+7.7 mm/yr**
- **Records are too short (1993 – 2013) to be inferring long-term trends**

Global Mean Sea Level is Rising and Accelerating



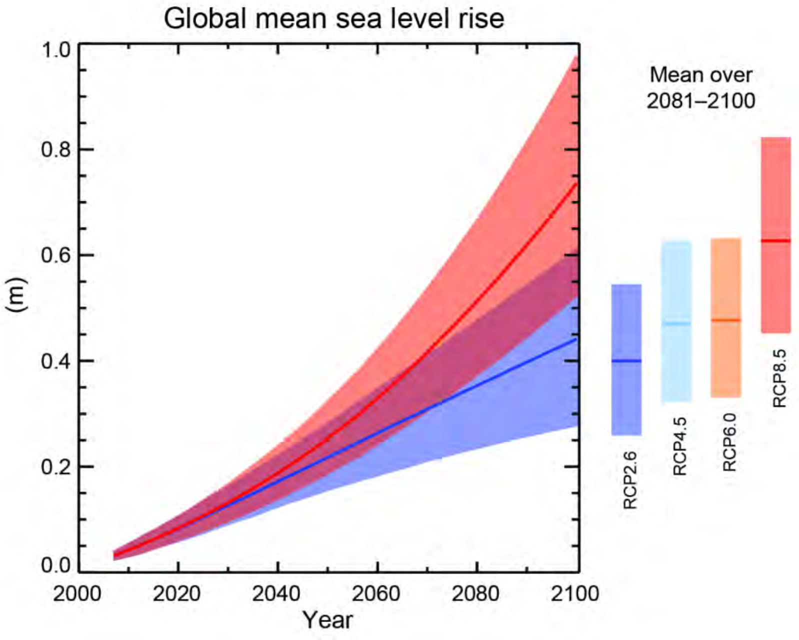
Global MSL Projections for 2100

- **(2007) IPCC AR4**
- + 0.2 – 0.4 m



IPCC AR4

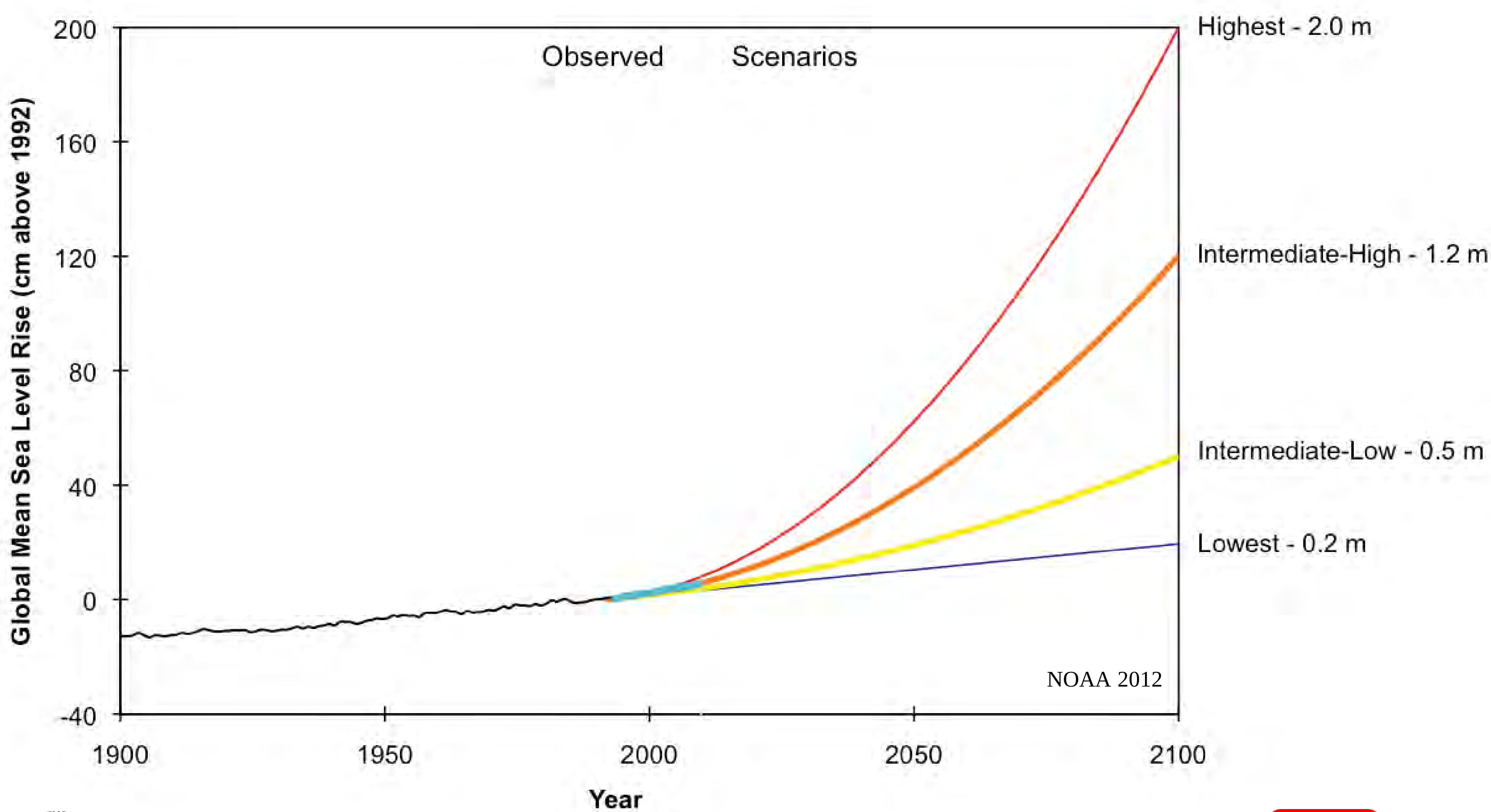
- **(2013) IPCC AR5**
- + 0.2 – 0.8 m



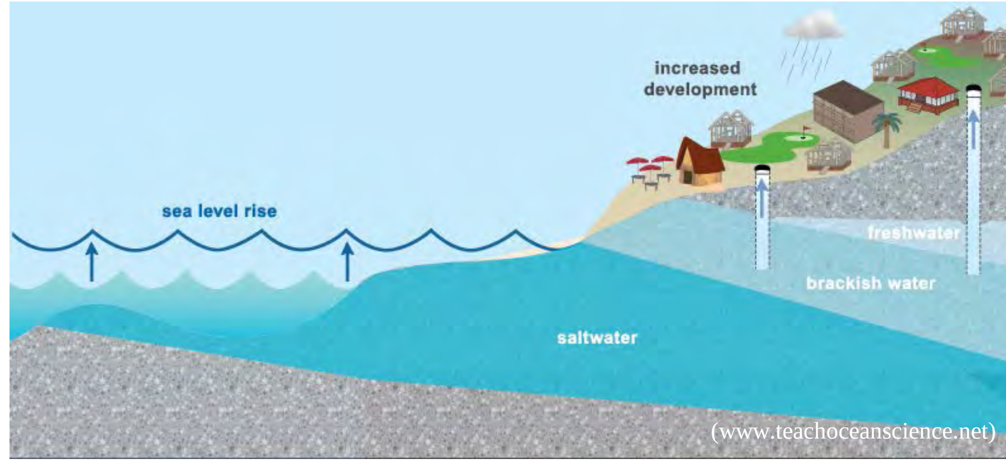
IPCC AR5

INTERGOVERNMENTAL PANEL ON climate change

- **(2012) Global Sea Level Rise Scenarios for the United States National Climate Assessment**
- + 0.2 – 2.0 m



Problems Associated with SLR



- **Inundation**
  - Infrastructure
  - Homes
  - Croplands

- **Saltwater Intrusion of Freshwater Sources**
- **Increased erosion**
  - Narrowing of beaches
  - Exposure/damage to cultural heritage sites
- **Loss of habitat**
  - Mangroves (if landward migration is blocked)
  - Sea turtle and sea bird nesting sites
- **Changes in nearshore light penetration**
  - Stress to coral reefs
- **Drainage Issues**
- **Reduced Return Intervals for Extreme Flooding**

Maps as Management Tools

- Sea level rise maps are useful tools that can:
  - Enable visualization of different scenarios
    - "A picture is worth a thousand words"
  - Provide data for adaptation
    - Highlight vulnerable areas, populations, and infrastructure
  - Be used as a foundation for modeling
  - Guide development of hazard mitigation strategies and technologies
  - Inform climate-aware land-use planning

Caveats of Passive Inundation Maps

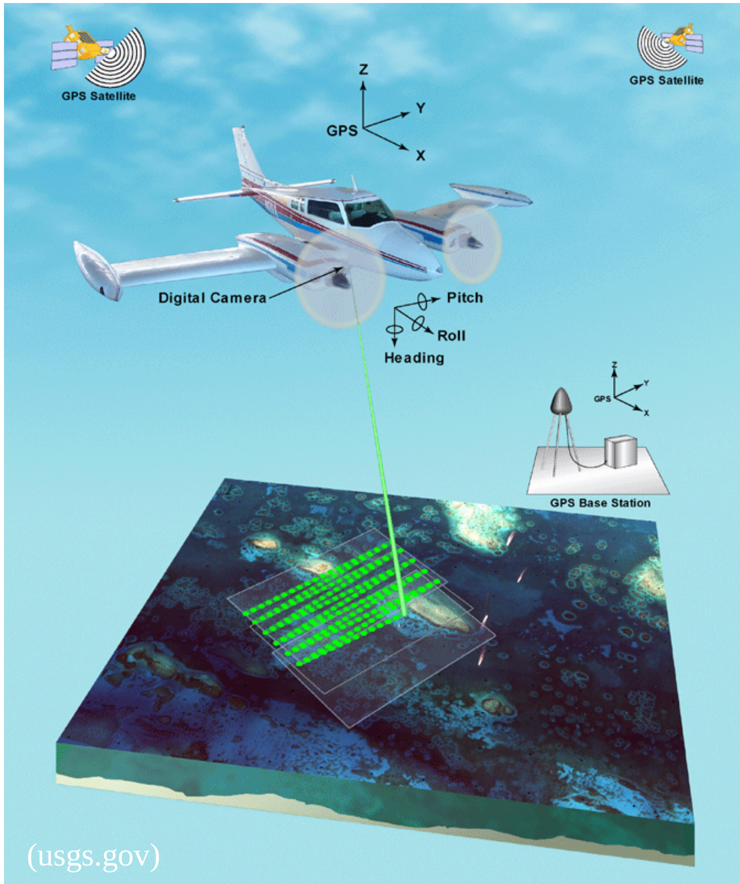
- Only as accurate as the elevation data
  - Remote areas often lack high resolution elevation data
- No hydrology
  - Hydrologically unconnected areas of inundation are still displayed
- Lack coastal dynamics/geomorphology
  - Assumes present land-conditions will persist, which will not be the case.
- Do not include dynamic surge/wave events
- Do not show human responses

Methodology: Elevation Data

- July 2012, NOAA CSC sponsored an airborne LiDAR survey of American Samoa

- August 2013, NOAA PSC began processing the LiDAR data to create a Digital Elevation Model (DEM) for the study area with 1/9 arc-second (3m) resolution

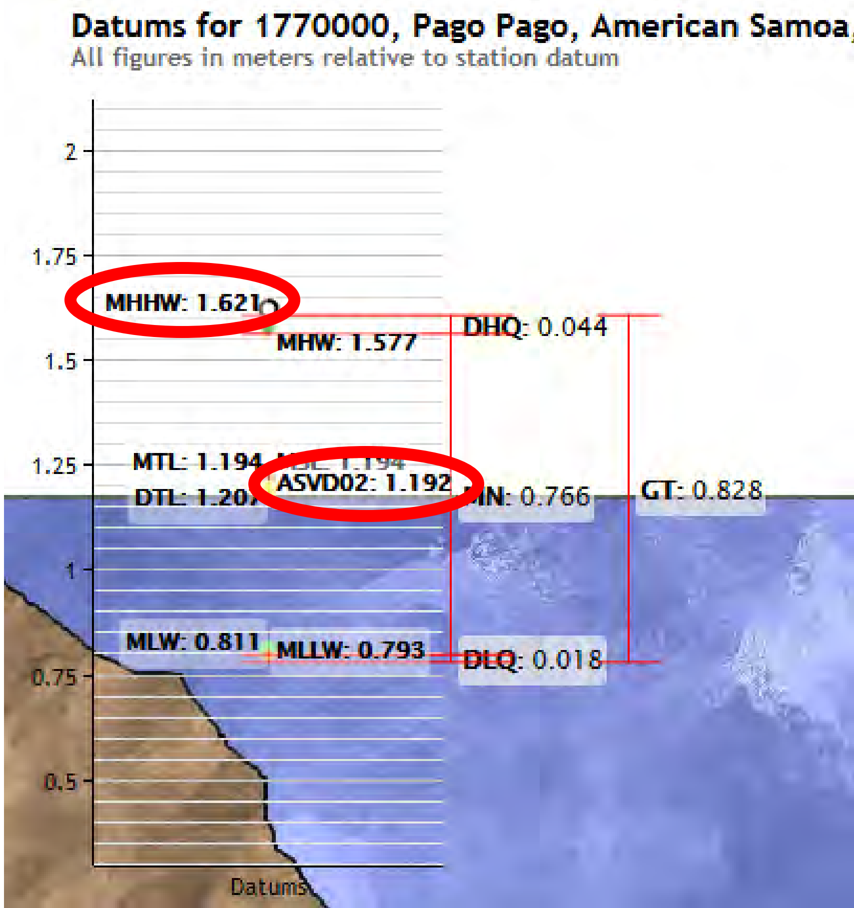
- The first DEM completed for American Samoa is for Tutuila and Aunu’u Islands
  - Manu’a Islands to follow



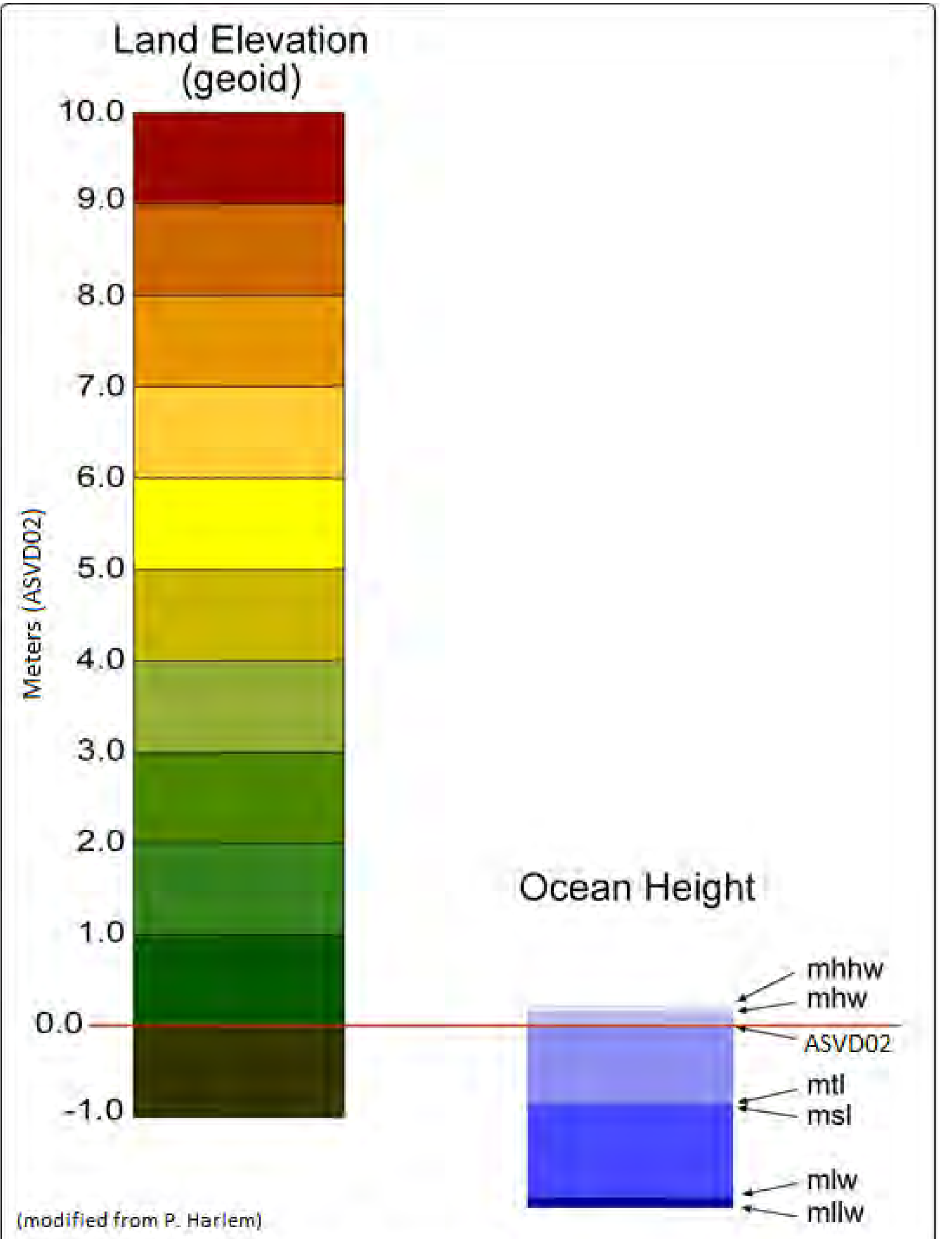
LiDAR: Light Detection and Ranging

Accounting for Tidal Prism

- DEM elevation referenced to American Samoa Vertical Datum of 2002 (ASVD02), a fixed geodetic datum
- ASVD02 consists of a leveling network on the island of Tutuila affixed to a single origin point on the island
- ASVD02 lies within the intertidal zone, however tides will generally exceed this level daily.
- Because of variation in tidal ranges, NOAA recommends describing inundation as it relates to the long-term average of the highest daily tide; Mean Higher High Water (MHHW)



ASVD02 → MHHW



- Mean Higher High Water (MHHW) is the long-term average of the higher high tide of each tidal day
- Per NOAA published tidal datum for Pago Pago, local MHHW equates to ASVD02 + 0.429 m
- DEM elevation is then converted from ASVD02 to MHHW

Methodology

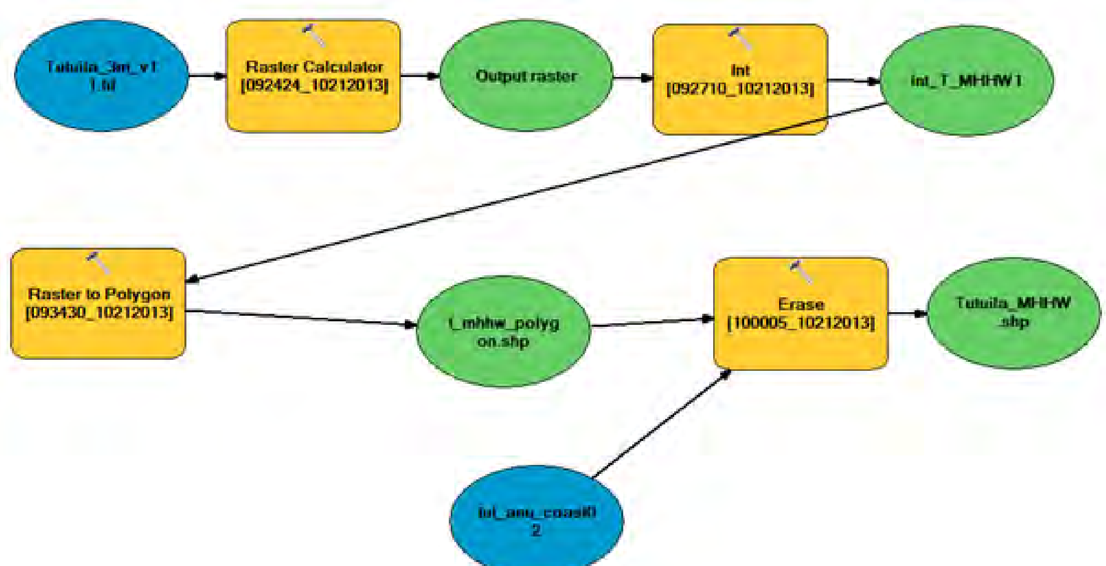
- With the elevation conversion calculated, the DEM can now be used to model any sea level
- Overlay DEM onto basemap
- Symbology
  - 2 Classifications
  - Set first Classification to new “zero” elevation (0.429 m)
    - Change color to blue with desired amount of transparency
  - Set second Class color to “no color”
- This will produce a map showing blue, transparent water at the current MHHW

Methodology

- To model a new sea level, change the classification of the first (lower) class
- In this case, “zero” elevation sea level = ASVD02 + 0.429 m = MHHW
- Therefore, to model 1m sea level rise, set first classification to 1.429 m
- In this way, a series of maps can be produced showing incremental inundation from rising sea level

Spatial Analysis

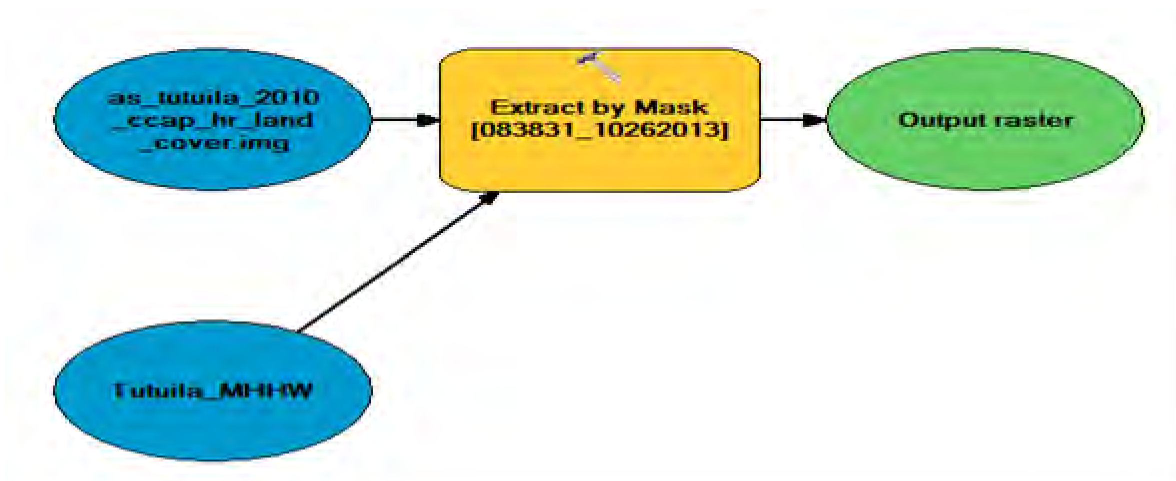
- **Quantification of Land Area Inundated:**
  - Create MHHW shapefile of Tutuila from the original DEM
  - Isolate elevations in the DEM less than or equal to 1 meter of sea level rise above MHHW, i.e. 1.429 m:
    - con ("Tutuila_3m_v11.tif" <= 1.429,"Tutuila_3m_v11.tif")
  - Intersect the resulting SLR polygon with the MHHW polygon
  - Calculate Area of the intersection to yield total area inundated



Model to Create MHHW Polygon of Tutuila

Spatial Analysis

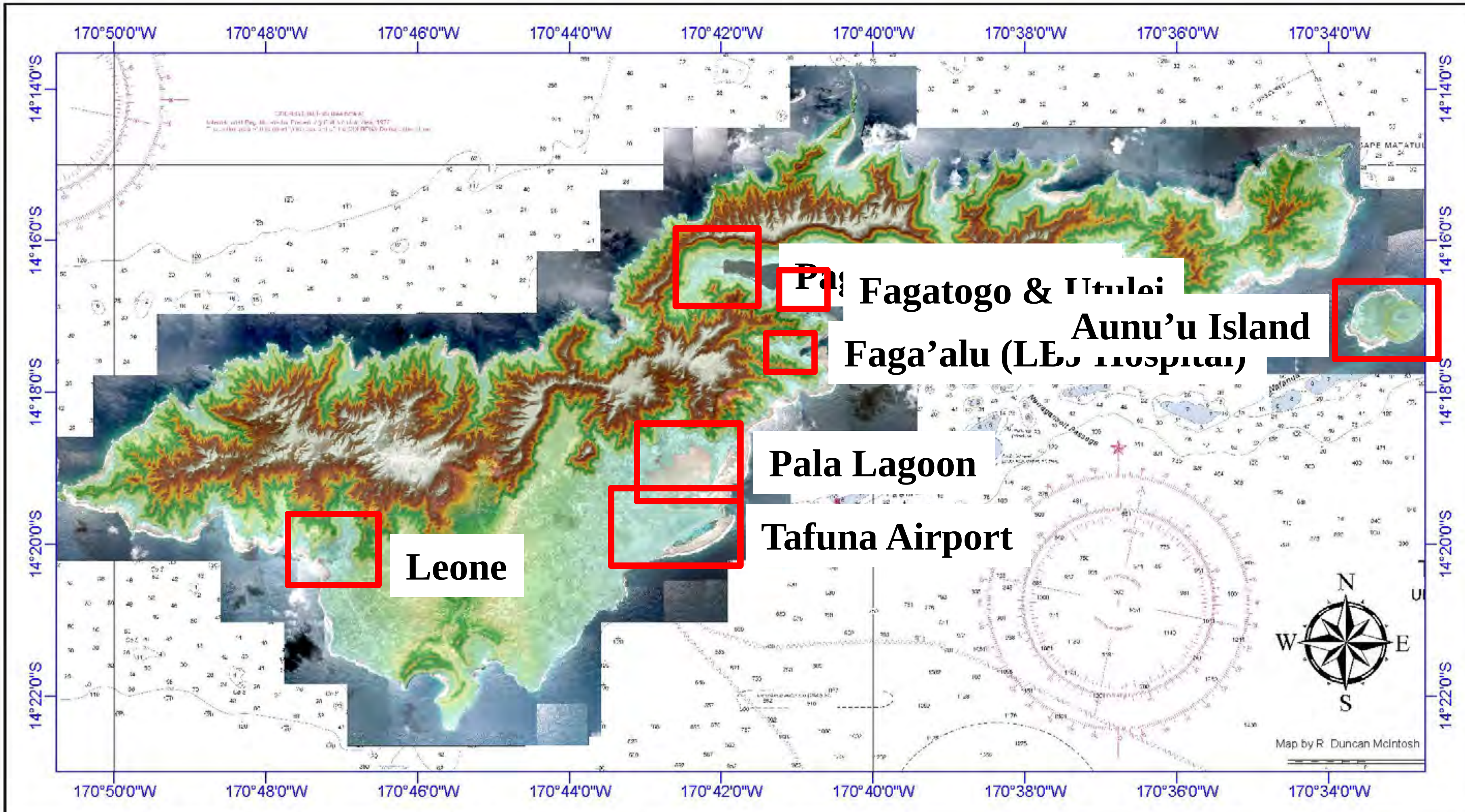
- **Quantification of Land Area Inundated by Land Cover Type:**
  - Clip 2010 Coastal Change Analysis Program (C-CAP) Land Cover rasters, to extract only the values equal to or above MHHW
  - Intersect the resulting C-CAP MHHW raster with the SLR polygons
  - Tabulate Area to yield area of each land cover type inundated under each increment of SLR



Extracting Land Cover Values >= MHHW

Results

- A series of passive-inundation maps was produced for 22 coastal areas of Tutuila and Aunu'u islands depicting:
  - Present Sea Level (MHHW)
  - MHHW + 1 m SLR
  - MHHW + 2 m SLR
- The following maps illustrate seven example locations



Tutuila Elevation

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery over NOAA Nautical Chart 83484

NOT FOR NAVIGATION

Elevation (m)

Value

High : 654.3

Low : -1.1

UTM Projection, Zone 2S, Spheroid: WGS_1984

0 2.5 5 10 Kilometers

Pacific RISA

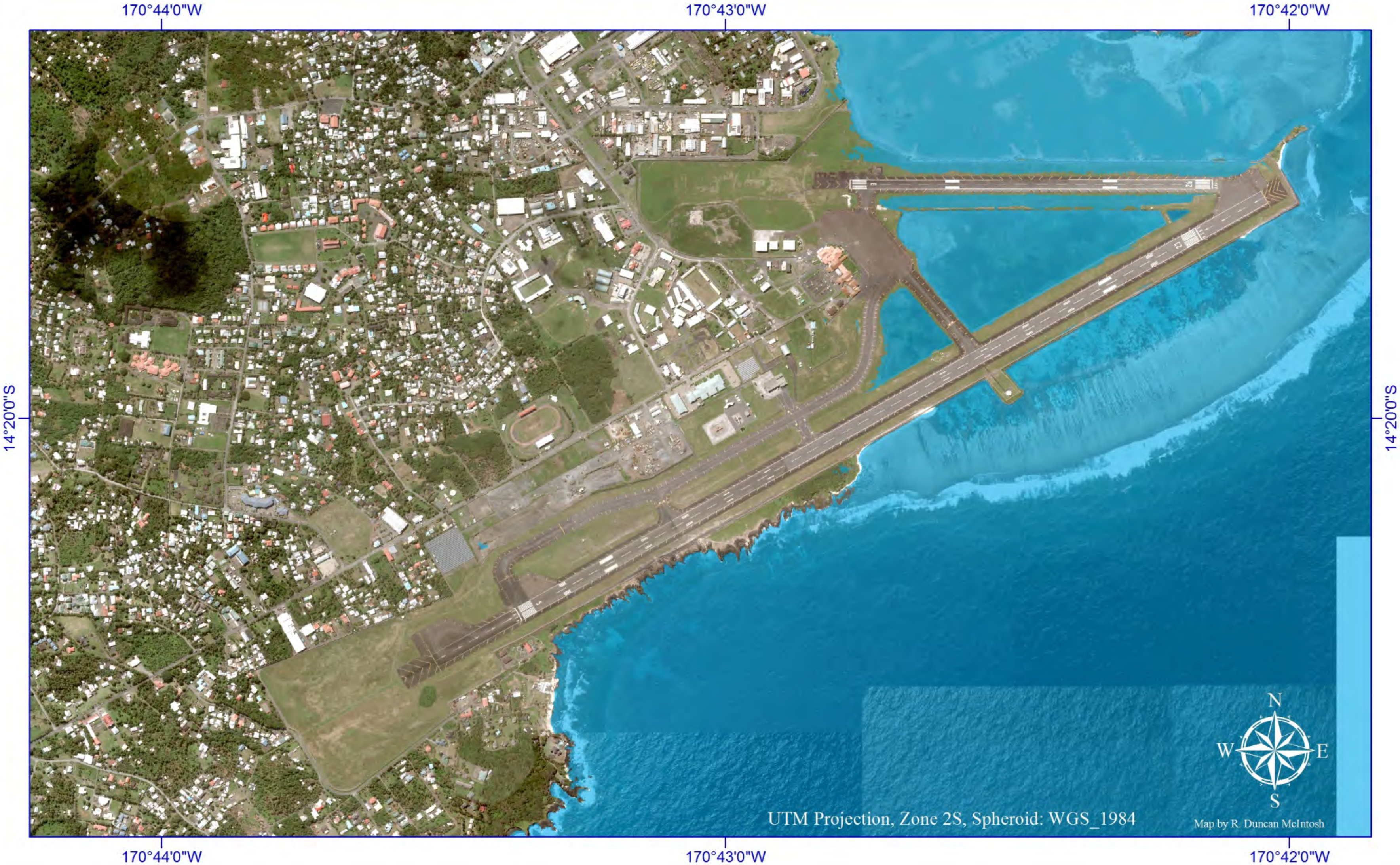
Tafuna Airport
Current Sea Level (MHHW)

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.375 0.75 1.5 Kilometers

Pacific RISA



Tafuna Airport +1 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.375 0.75 1.5 Kilometers

Pacific RISA

Tafuna Airport
+2 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.375 0.75 1.5 Kilometers

Pacific RISA

Pago Pago Harbor
Current Sea Level (MHHW)

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.125 0.25 0.5 Kilometers

Pacific RISA

Pago Pago Harbor
+1 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.125 0.25 0.5 Kilometers

Pacific RISA

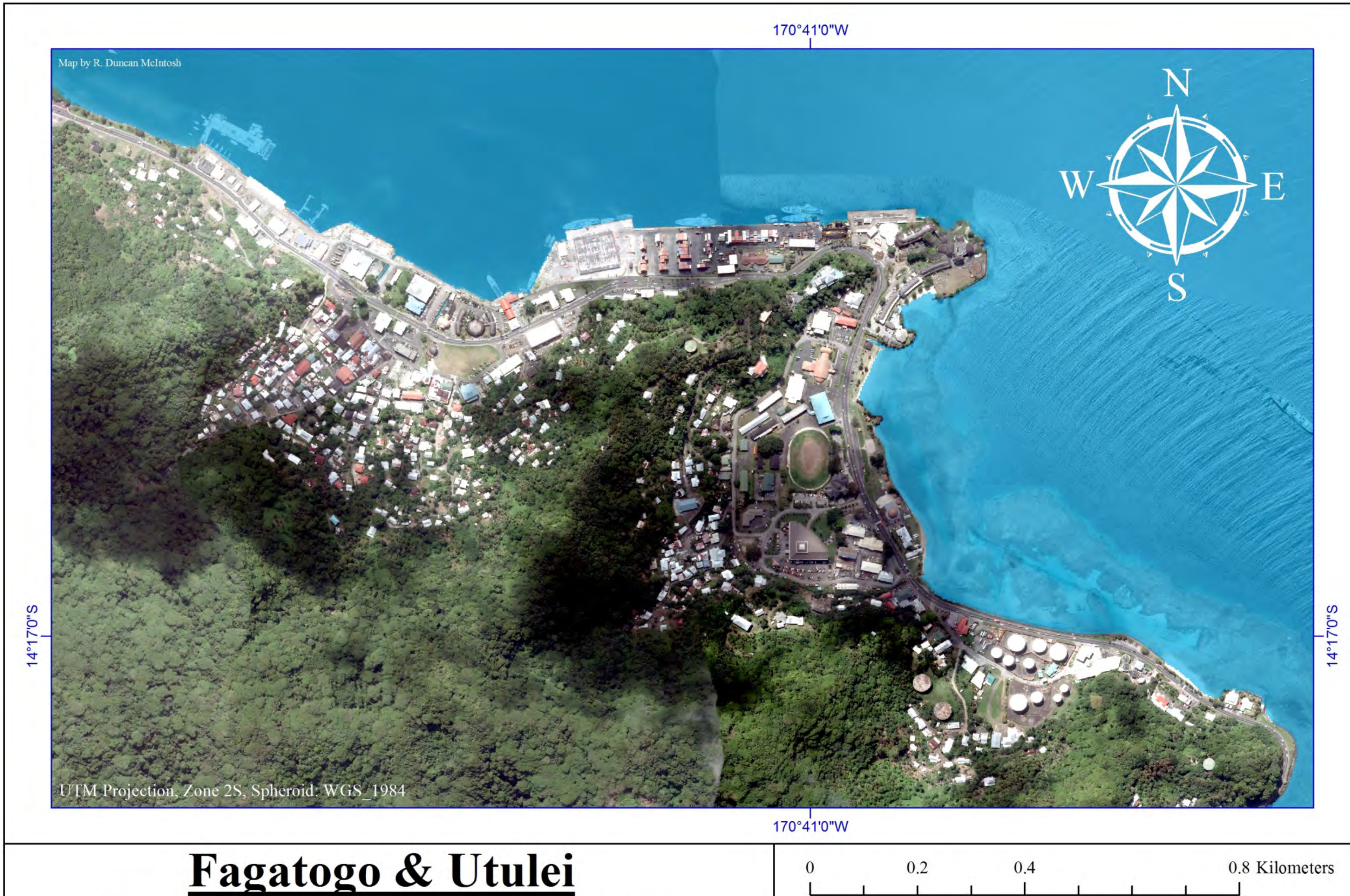
Pago Pago Harbor
+2 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.125 0.25 0.5 Kilometers

Pacific RISA

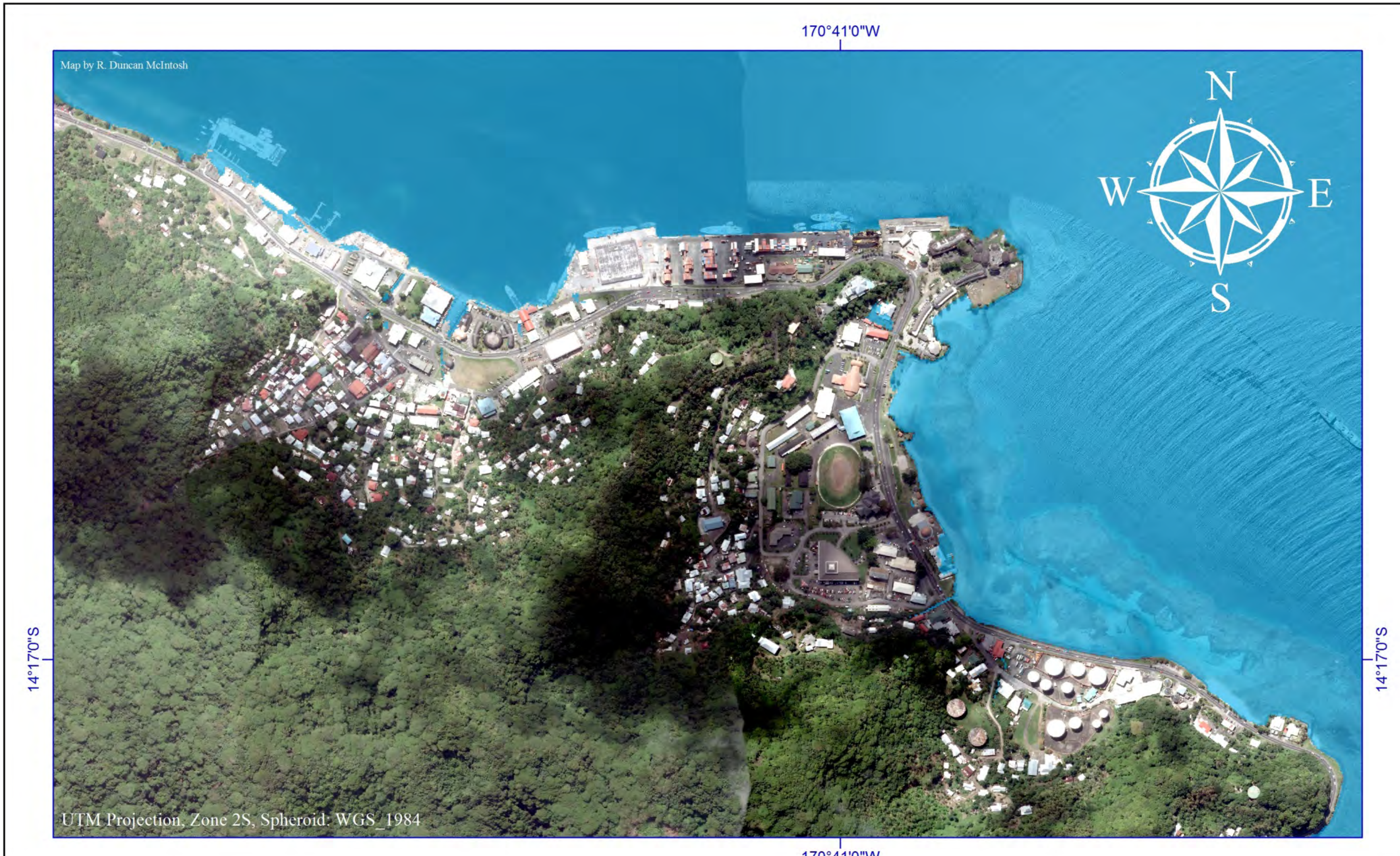


Fagatogo & Utulei Current Sea Level (MHHW)

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

Pacific RISA



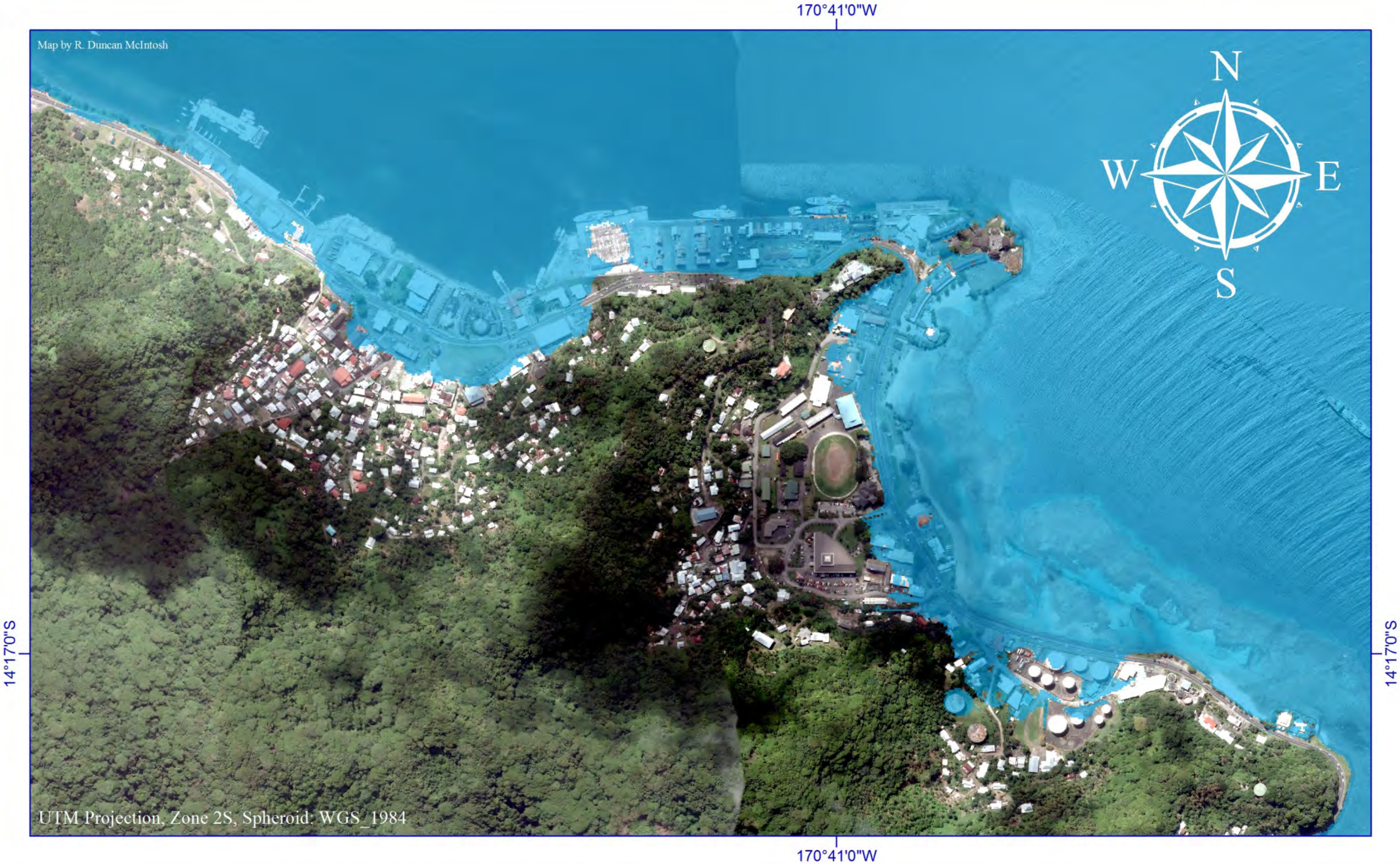
Fagatogo & Utulei
+1 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.2 0.4 0.8 Kilometers

Pacific RISA



Fagatogo & Utulei
+2 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

Pacific RISA

Faga'alu

Current Sea Level (MHHW)

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

Pacific RISA

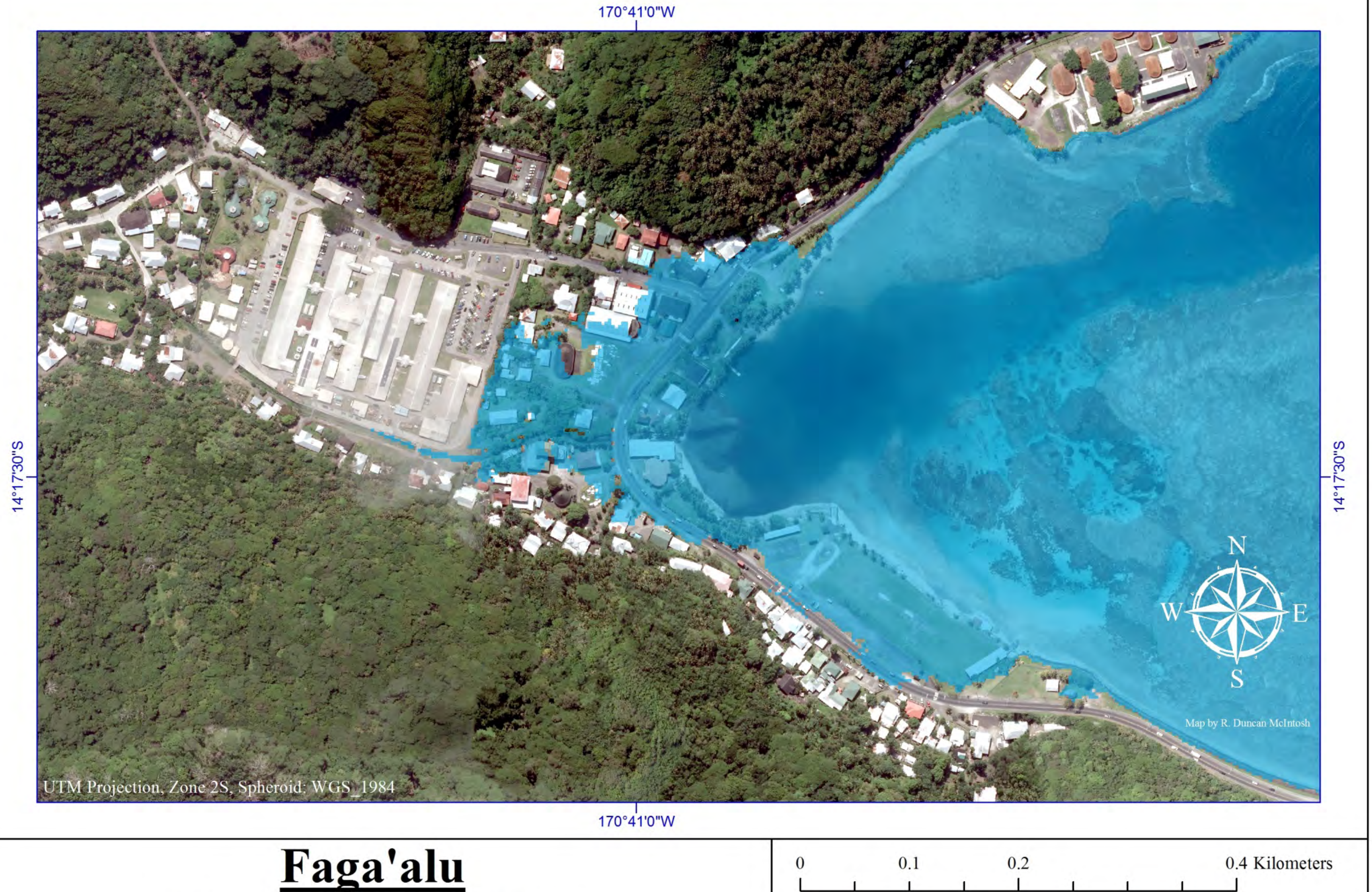
Faga'alu
+1 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.1 0.2 0.4 Kilometers

Pacific RISA

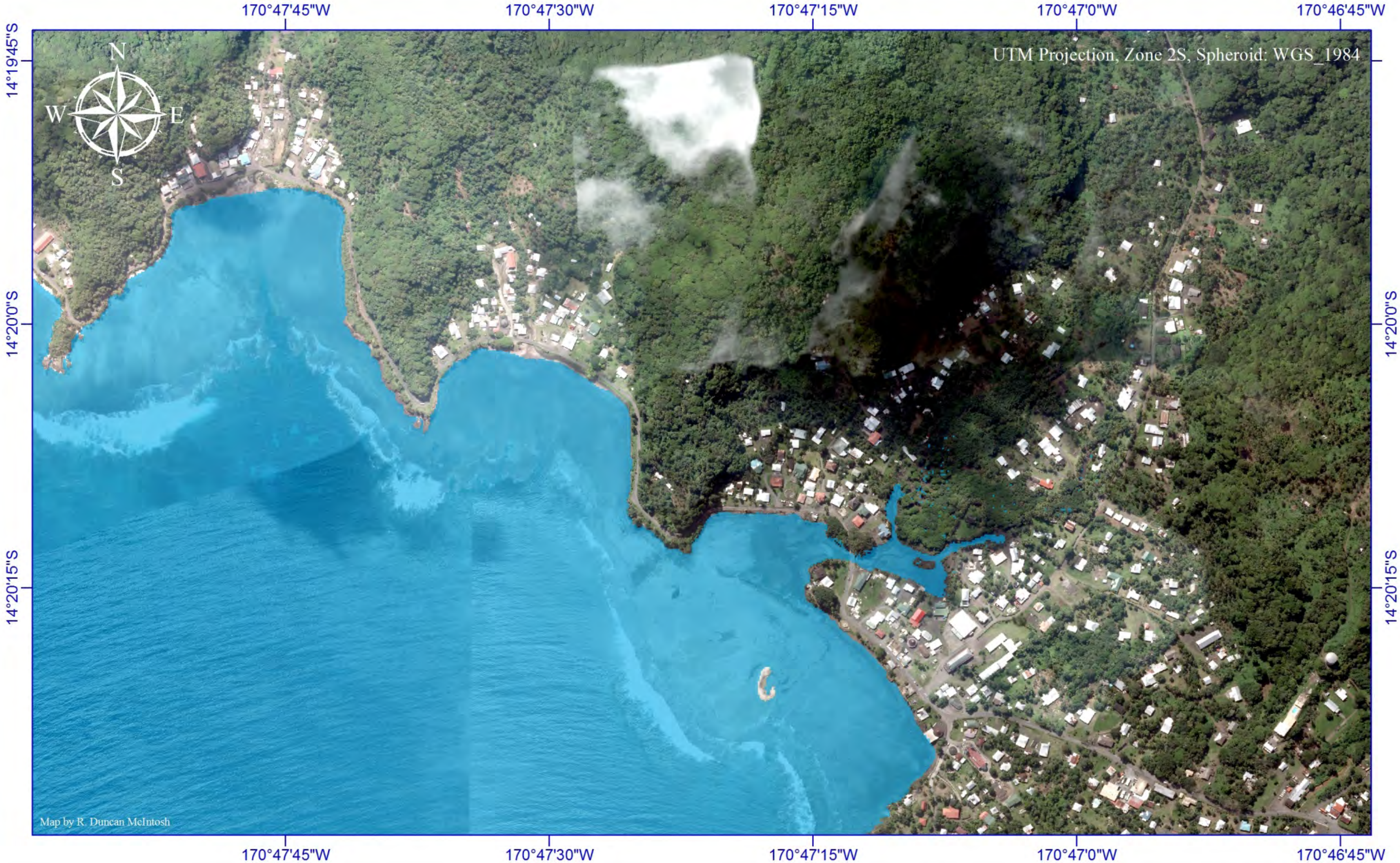


Faga'alu
+2 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

Pacific RISA



Leone

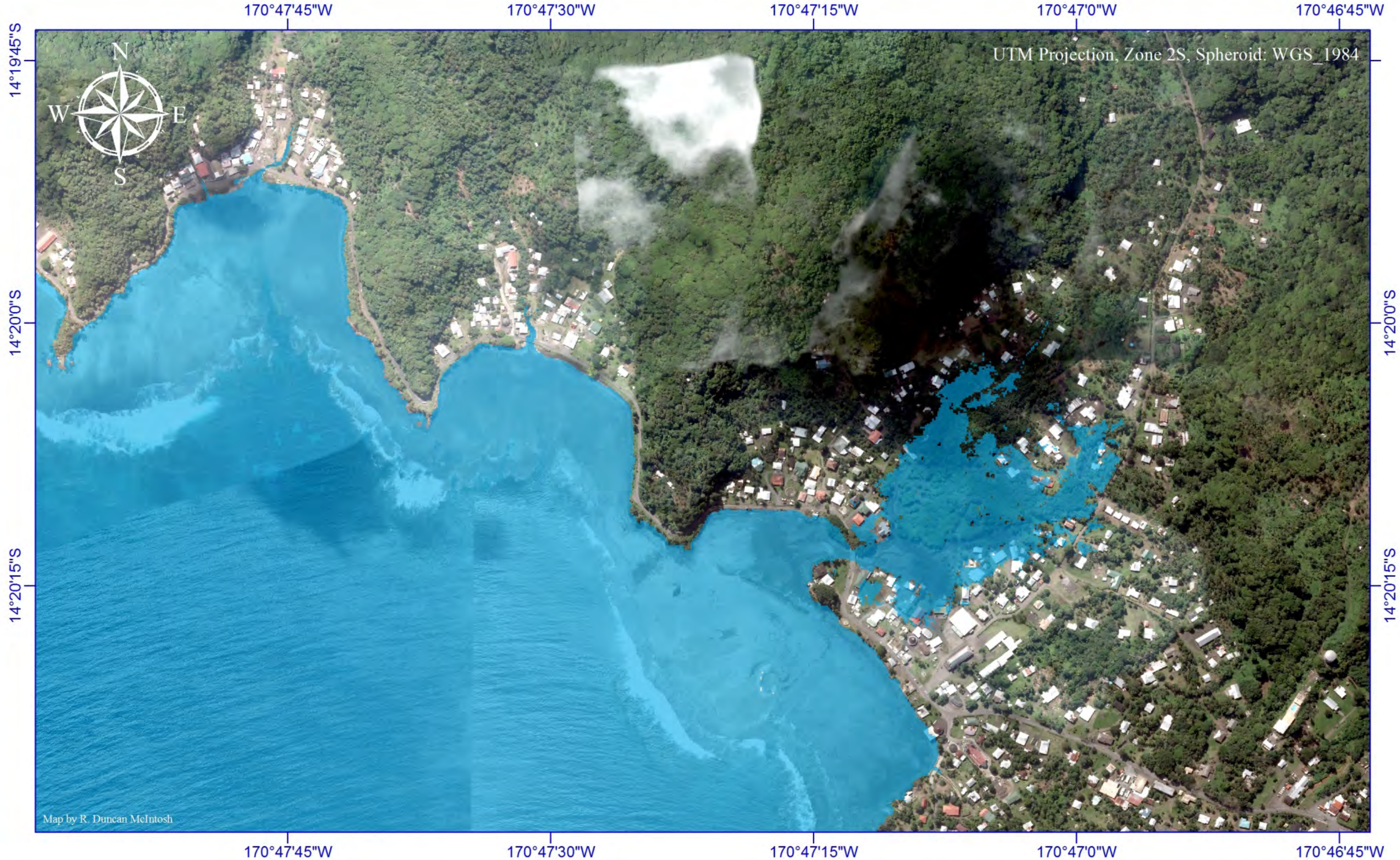
Current Sea Level (MHHW)

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.15 0.3 0.6 Kilometers

Pacific RISA



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+1 m Sea Level Rise

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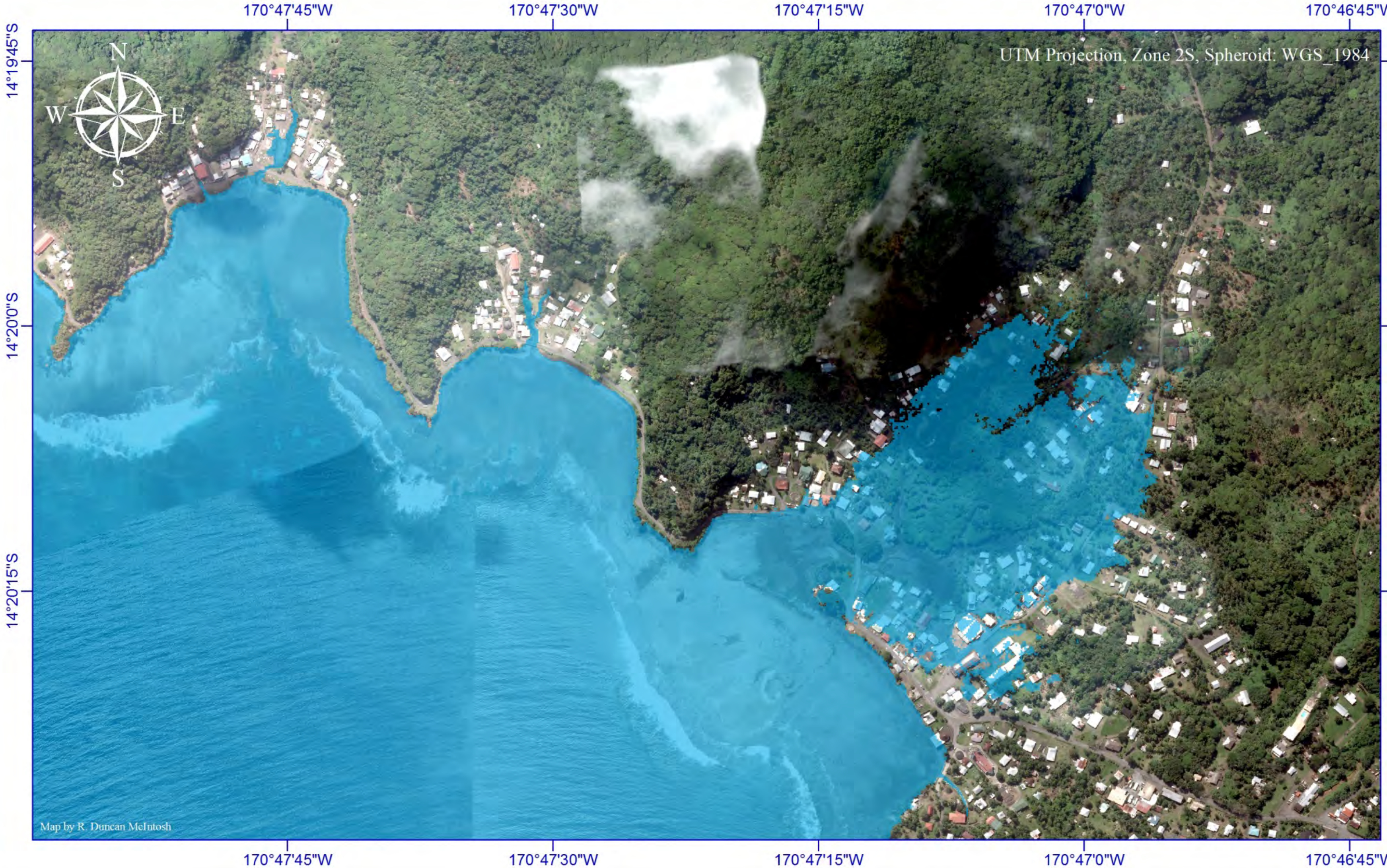
Pacific RISA



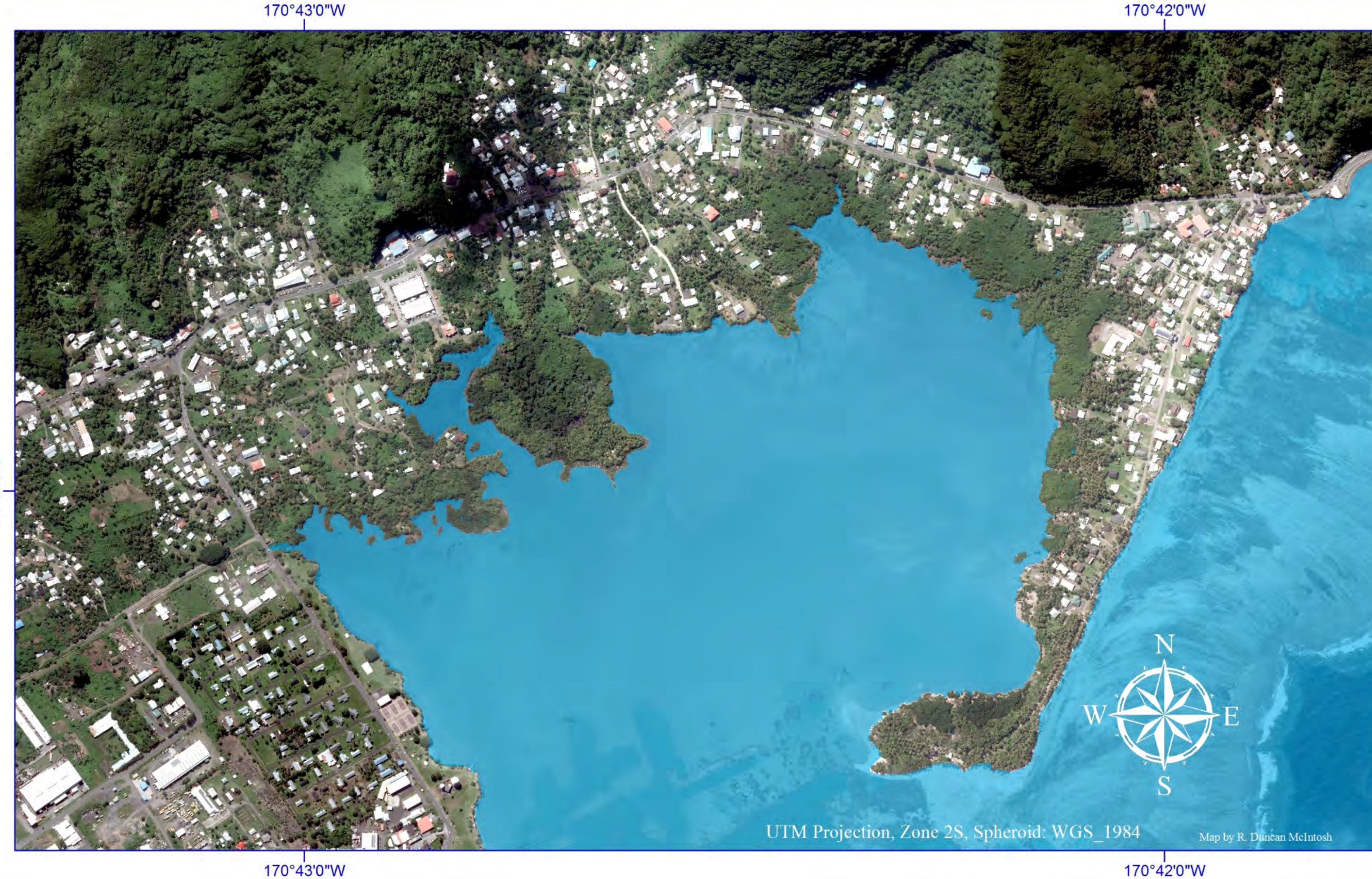
Leone
+2 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.15 0.3 0.6 Kilometers

Pacific RISA



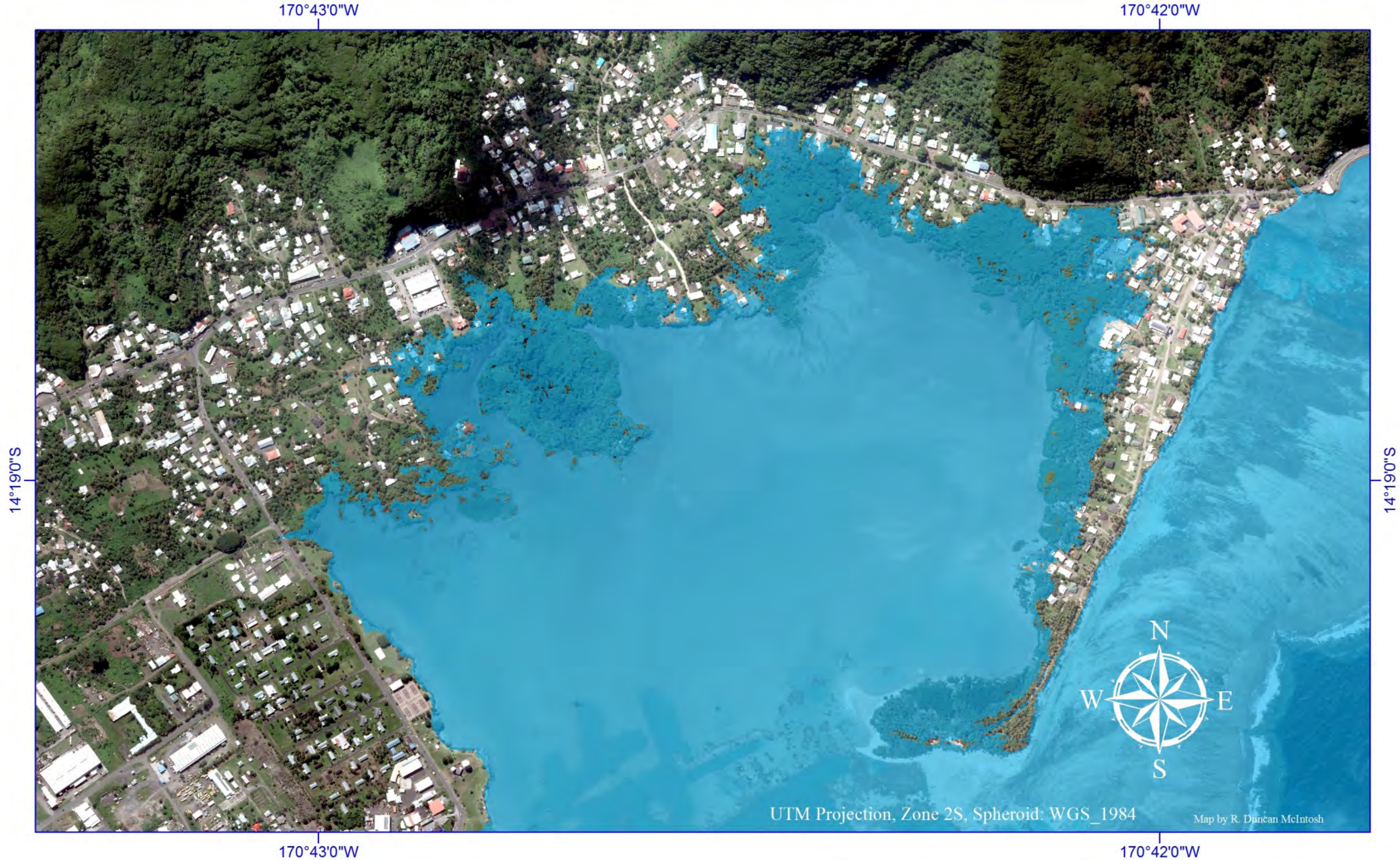
Pala Lagoon
Current Sea Level (MHHW)

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.25 0.5 1 Kilometers

Pacific RISA



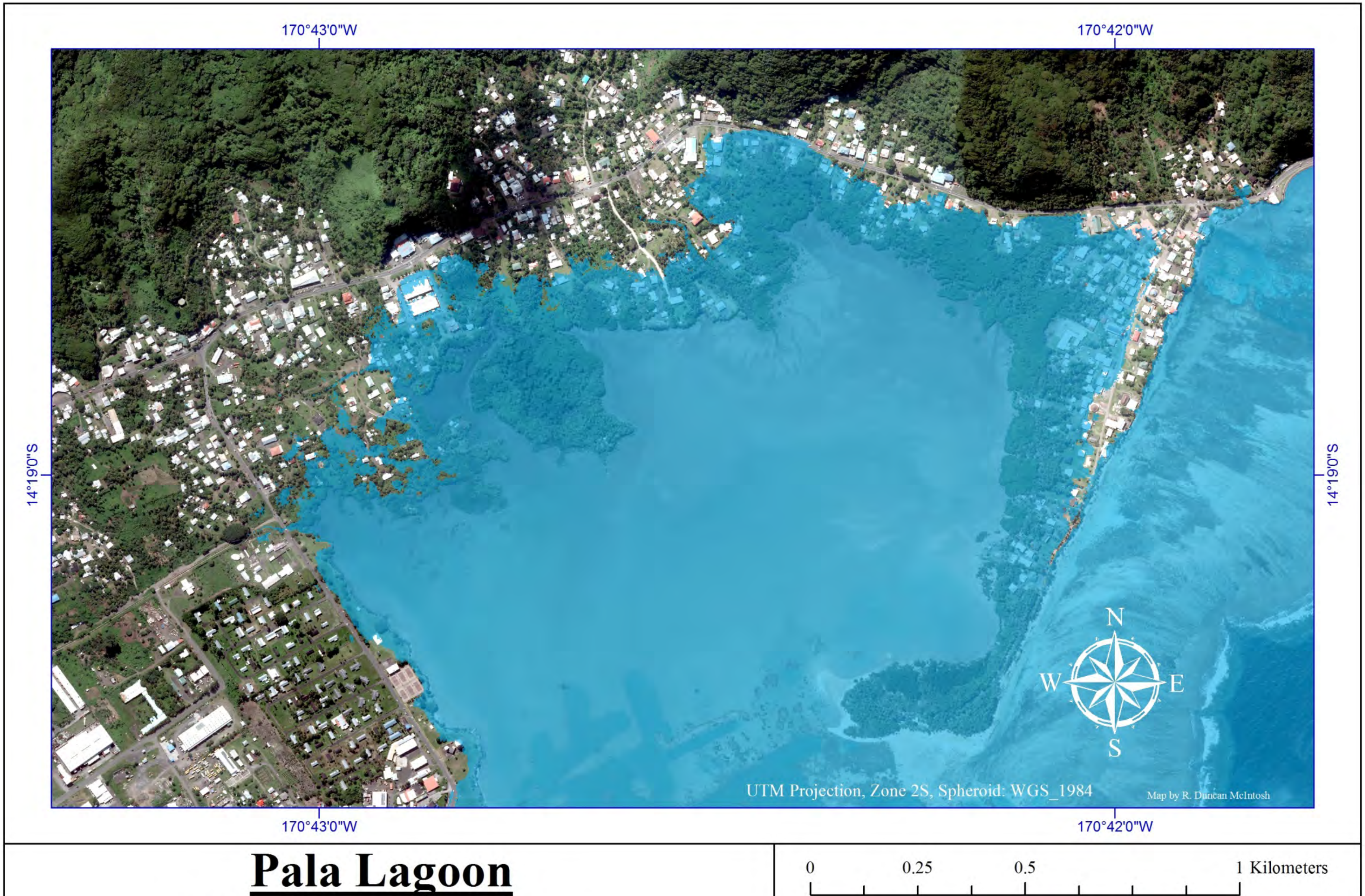
Pala Lagoon
+1 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.25 0.5 1 Kilometers

Pacific RISA

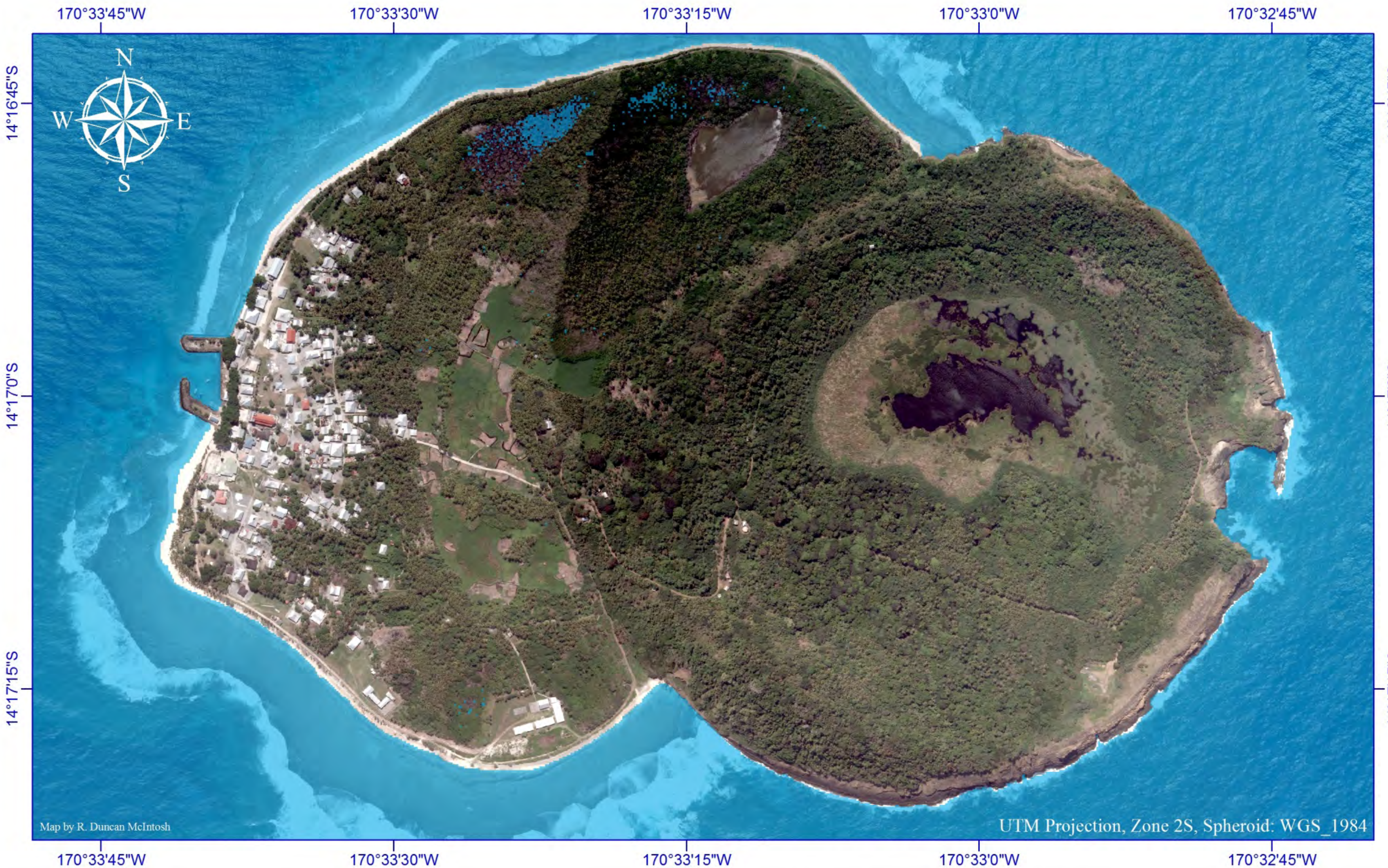


Pala Lagoon
+2 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

Pacific RISA



Aunu'u

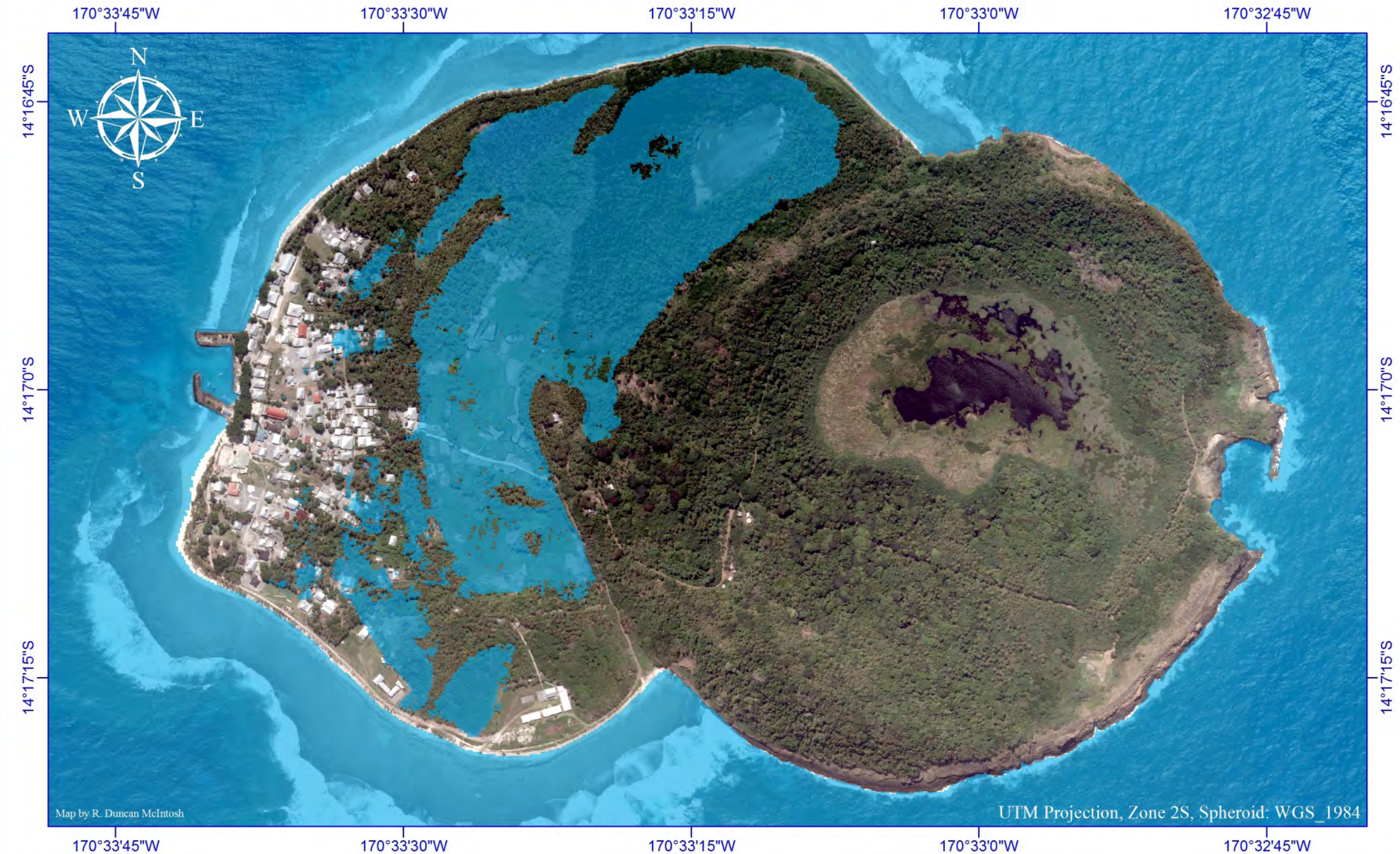
Current Sea Level (MHHW)

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

NOT FOR NAVIGATION

0 0.15 0.3 0.6 Kilometers

Pacific RISA



Aunu'u

+1 m Sea Level Rise

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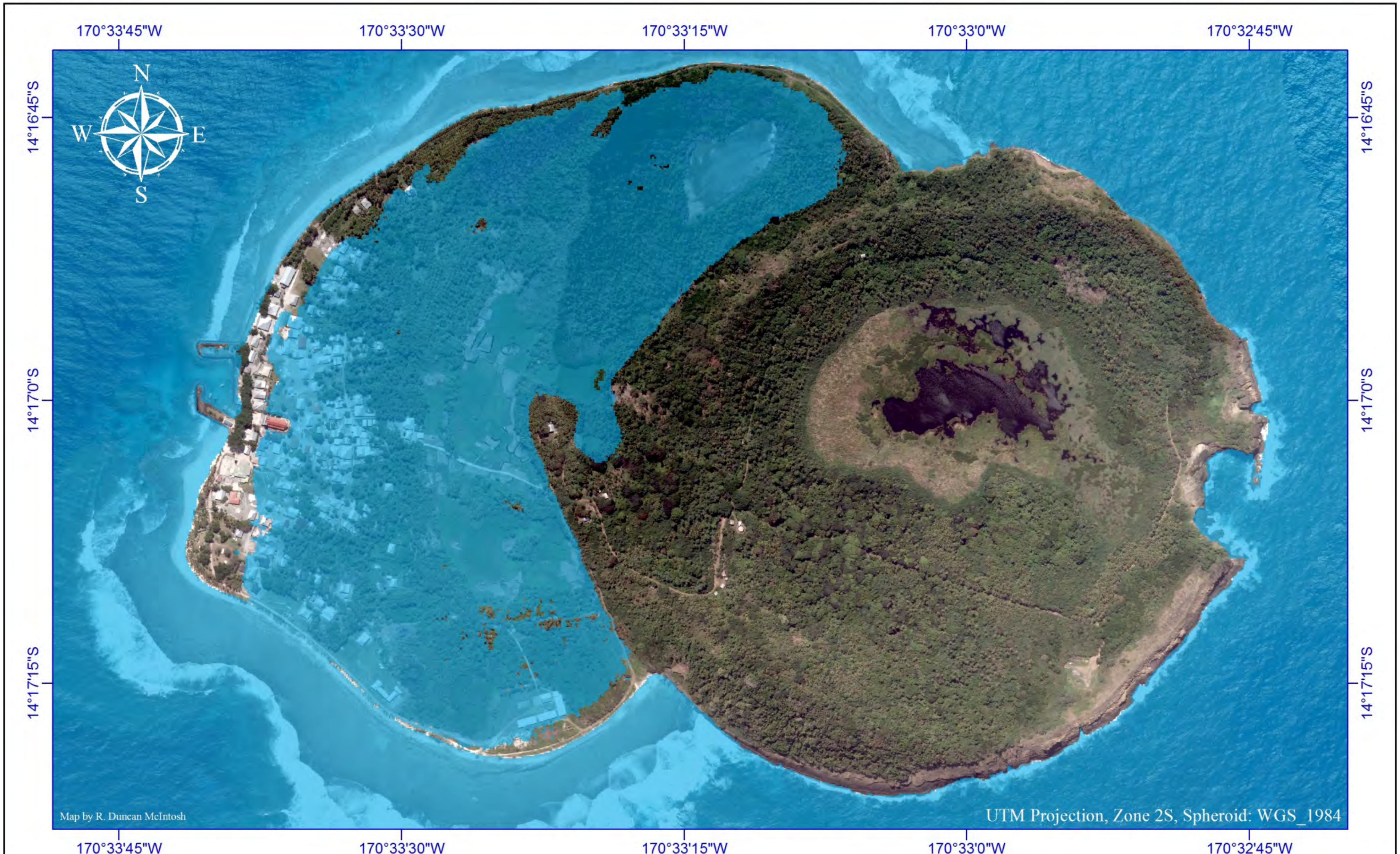
Pacific RISA



Aunu'u
+2 m Sea Level Rise

2013 NOAA Digital Elevation Model over 2012 USGS Multispectral Digital Orthoimagery

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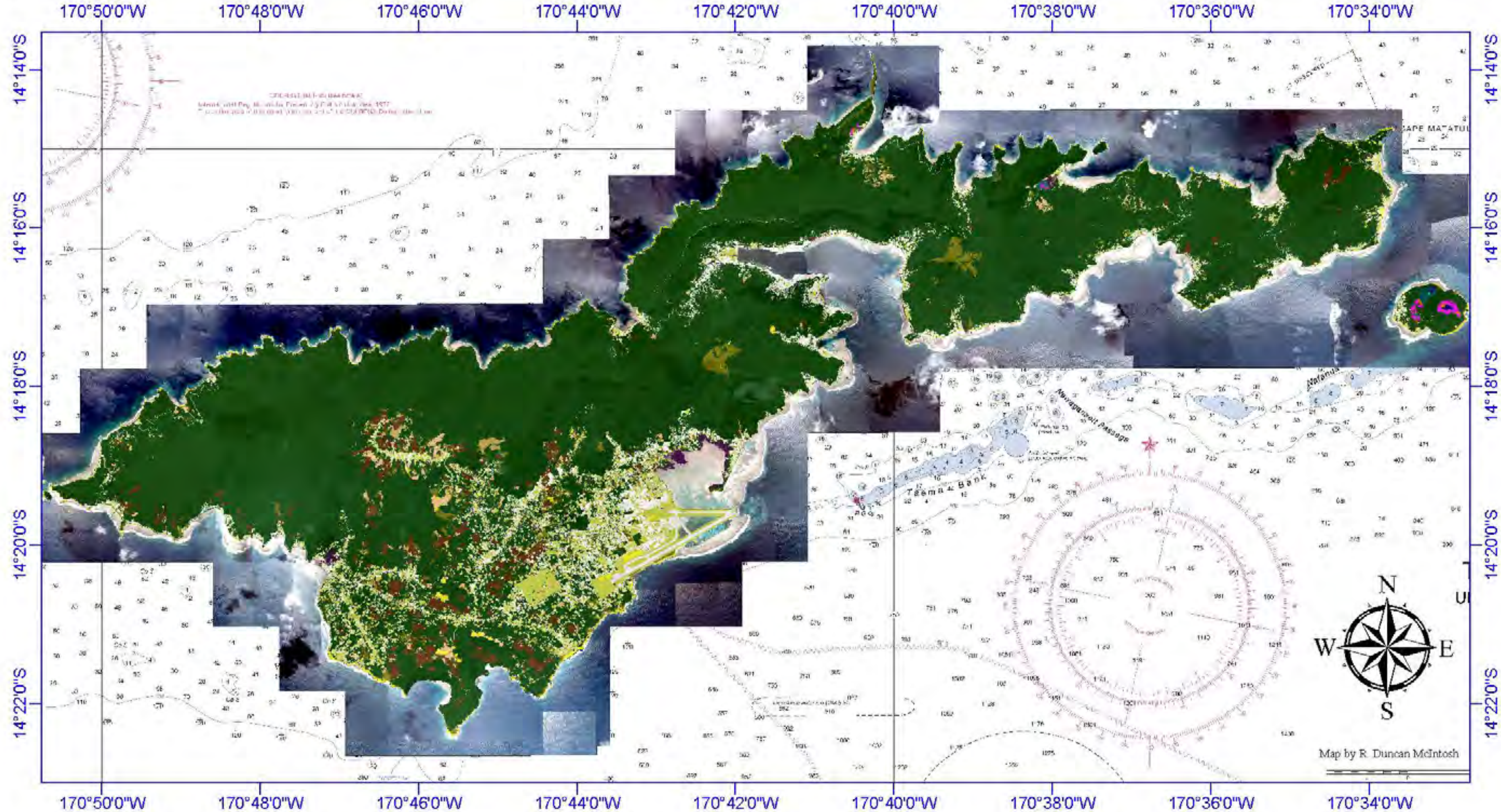
Pacific RISA



Tutuila Land Cover

Bare Land	Impervious Surface
Cultivated	Palustrine Emergent Wetland
Developed Open Space	Palustrine Forested Wetland
Estuarine Emergent Wetland	Palustrine Scrub/Shrub Wetland
Estuarine Forested Wetland	Pasture/Hay
Estuarine Scrub/Shrub Wetland	Scrub/Shrub
Evergreen Forest	Unconsolidated Shore
Grassland	Water

2010 NOAA C-CAP Land Cover
over 2012 USGS Multispectral
Digital Orthoimagery
over NOAA Nautical Chart 83484

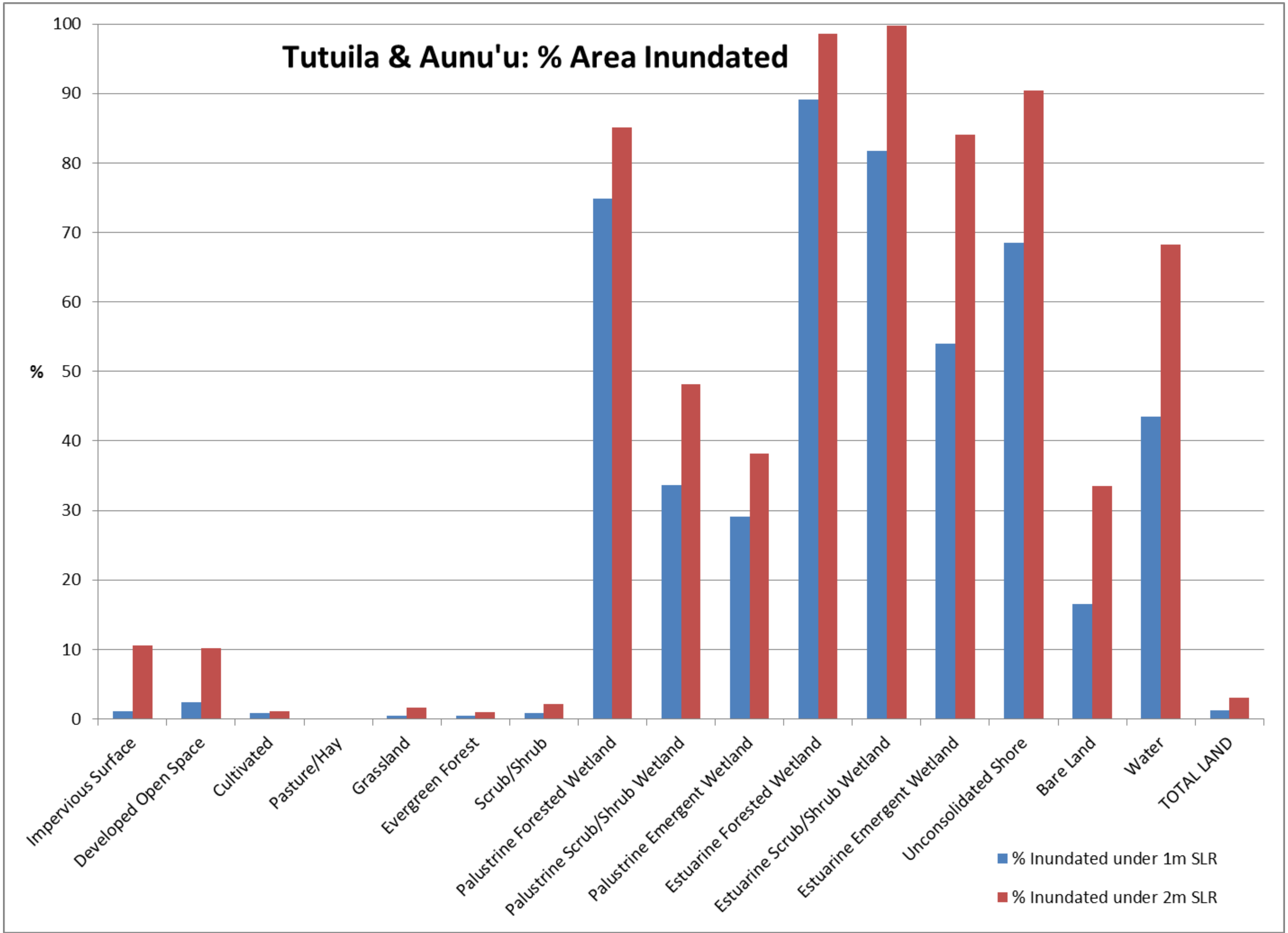
NOT FOR NAVIGATION

UTM Projection, Zone 2S, Spheroid: WGS_1984

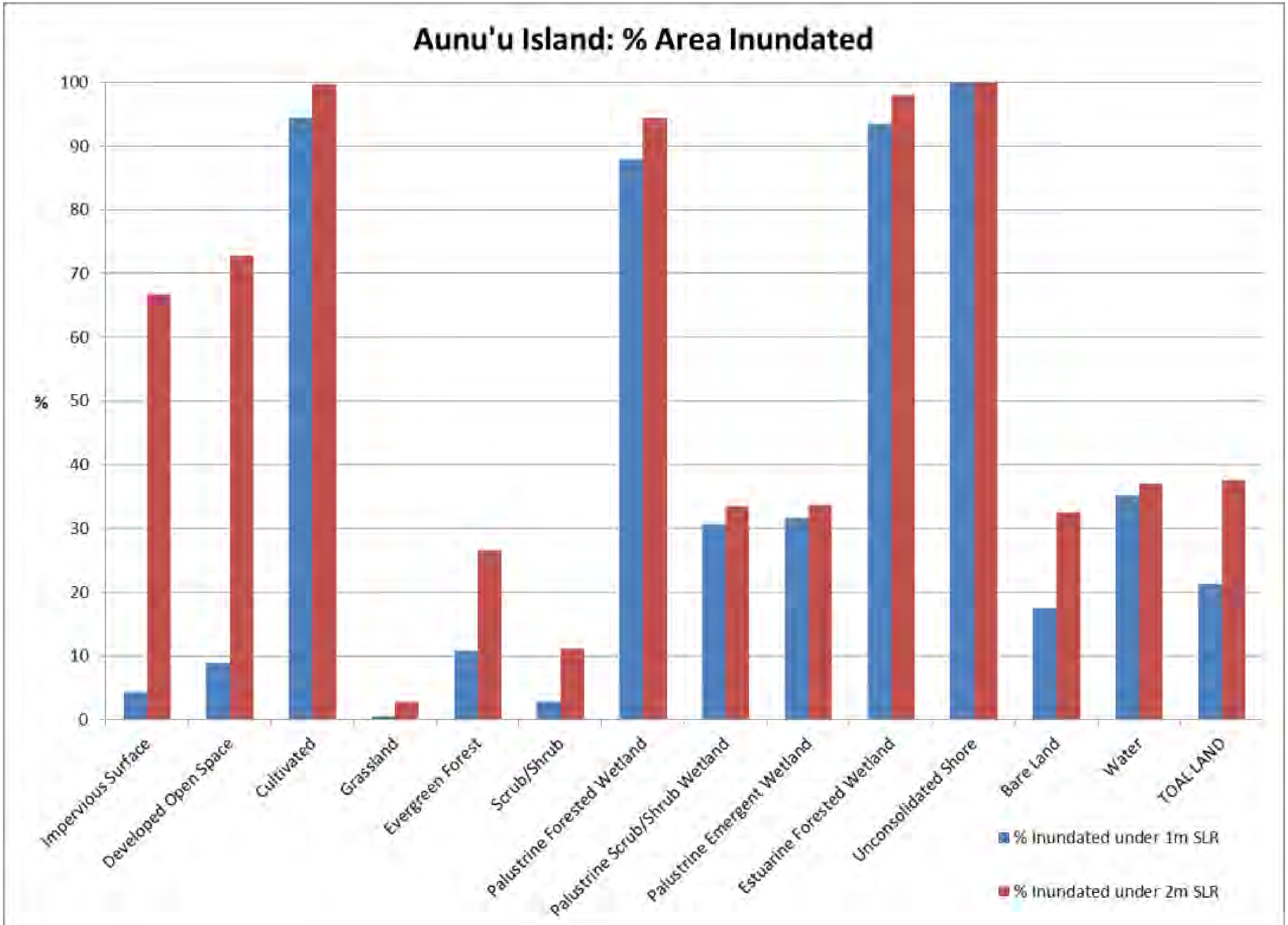
0 2.5 5 10 Kilometers

Pacific RISA

Analysis


Tutuila & Aunu'u: % Area Inundated
%
100
90
80
70
60
50
40
30
20
10
0
Impervious Surface
Developed Open Space
Cultivated
Pasture/Hay
Grassland
Evergreen Forest
Scrub/Shrub
Palustrine Forested Wetland
Palustrine Scrub/Shrub Wetland
Palustrine Emergent Wetland
Estuarine Forested Wetland
Estuarine Scrub/Shrub Wetland
Estuarine Emergent Wetland
Unconsolidated Shore
Bare Land
Water
TOTAL LAND
% Inundated under 1m SLR
% Inundated under 2m SLR

Analysis



Aunu'u Island: % Area Inundated
100
90
80
70
60
50
40
30
20
10
0
%
Impervious Surface
Developed Open Space
Cultivated
Grassland
Evergreen Forest
Scrub/Shrub
Palustrine Forested Wetland
Palustrine Scrub/Shrub Wetland
Palustrine Emergent Wetland
Estuarine Forested Wetland
Unconsolidated Shore
Bare Land
Water
TOAL LAND
% Inundated under 1m SLR
% Inundated under 2m SLR

Conclusions

- Sea level rise maps can be valuable tools for coastal adaptation to climate change
- LiDAR based DEM data must be properly processed to be utilized
- Elevation datum of the DEM must be reconciled with local tidal prism
- Spatial analysis can inform climate aware land use planning
- Limitations of static maps must be assumed
  - Maps do not account for hydrology, geomorphology, storm surge

(Joel Pett, Cartoon Arts International)

Fa'afetai lava

Ofu Beach, National Park American Samoa. Photo (c) Michael Anderson