The Hydrologic Cycle

ES 383

Colby at Bigelow, September 2019

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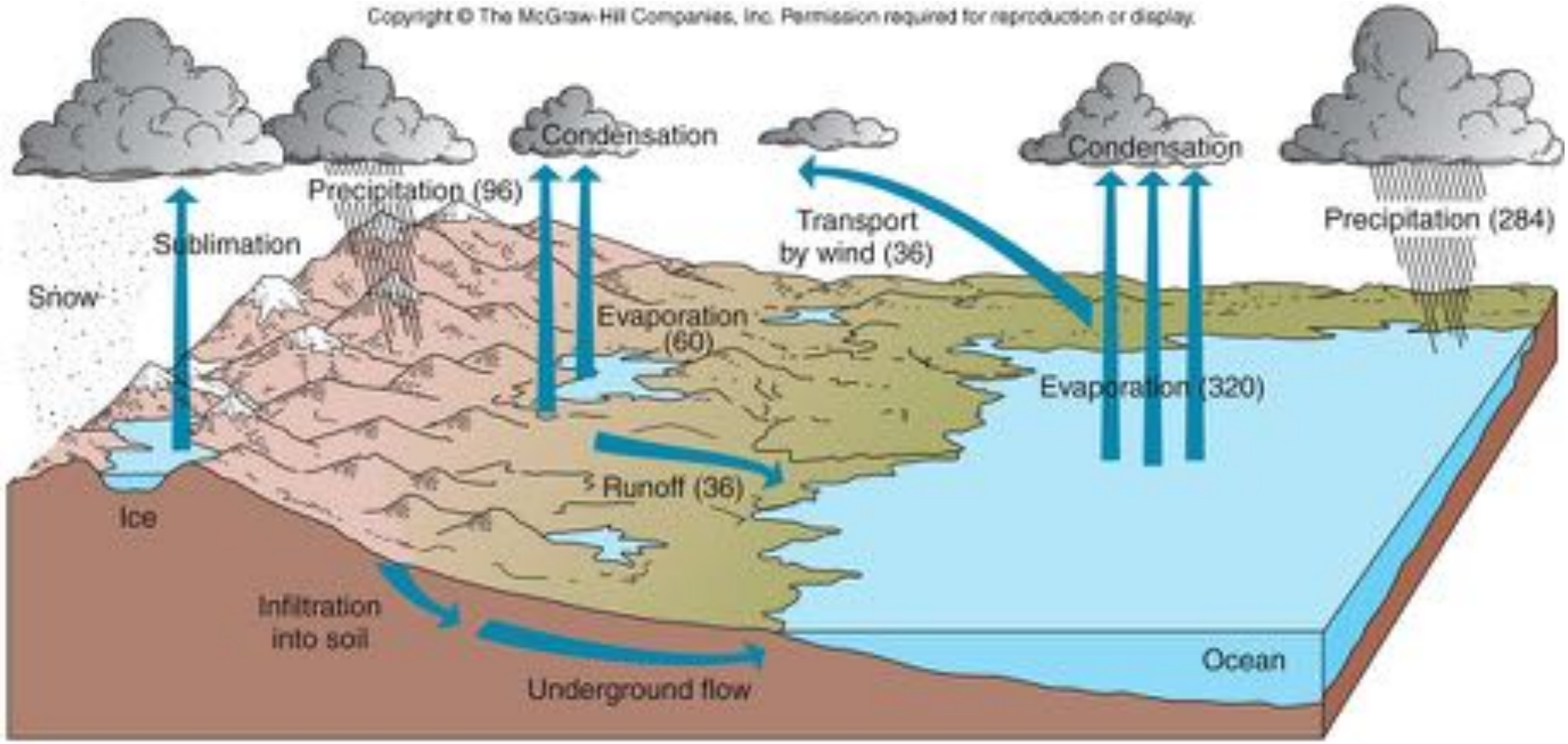
Flows in 10^3 km^3 $year^{-1}$



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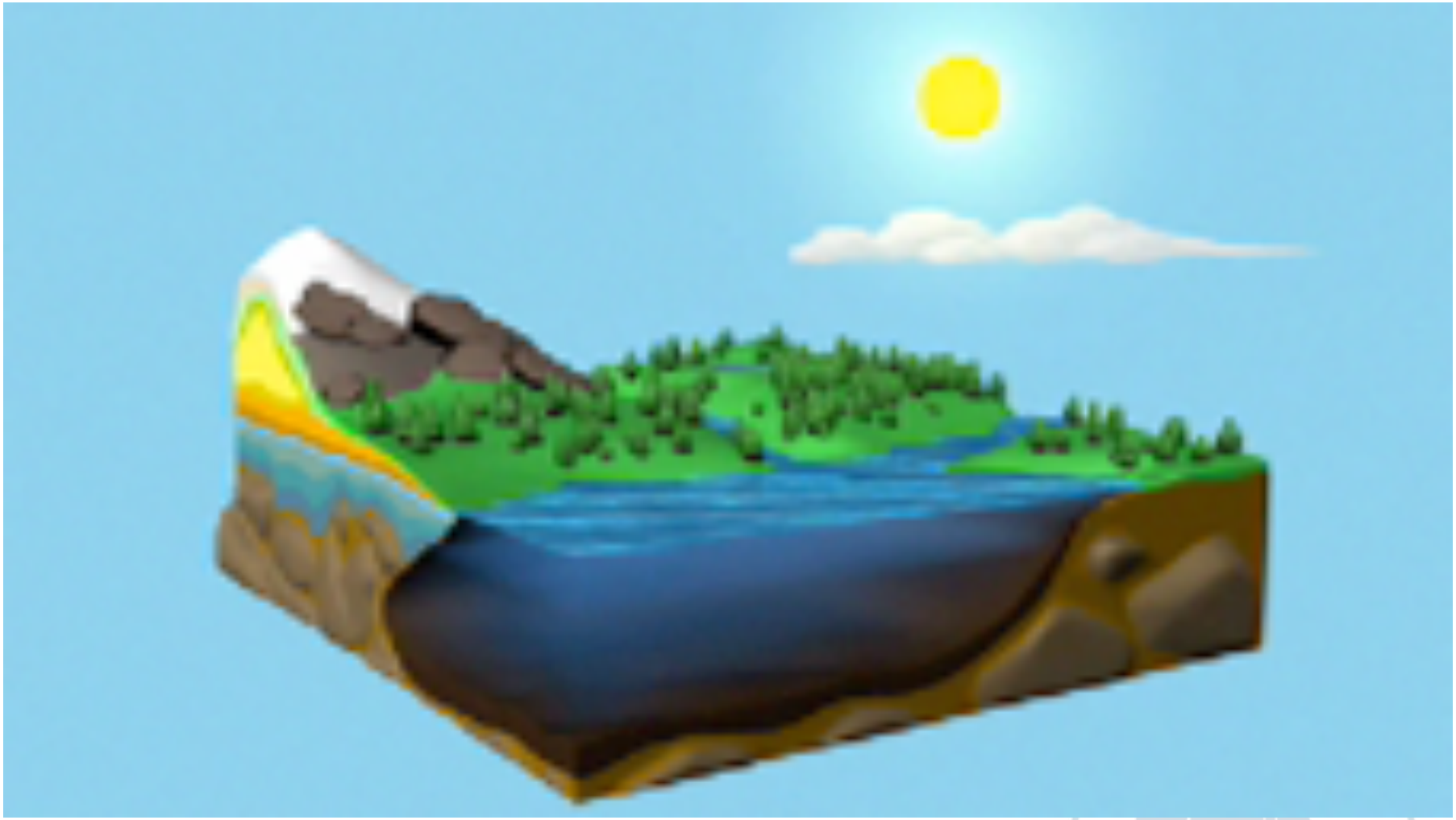


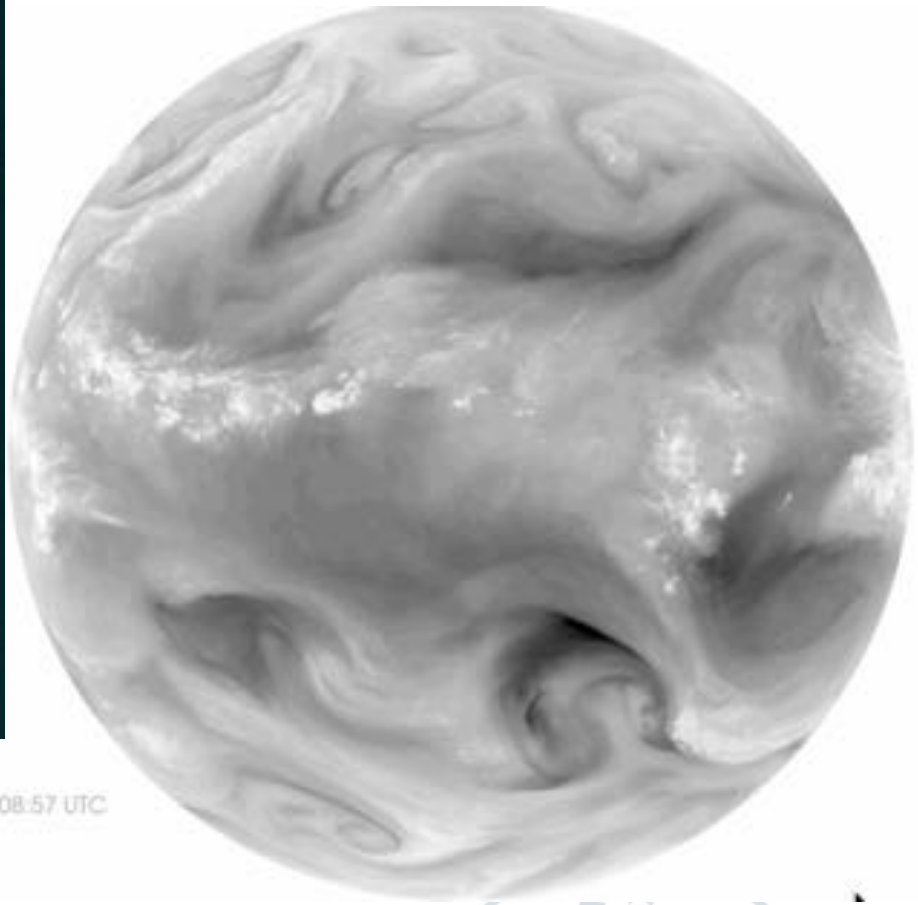
http://svs.gsfc.nasa.gov/goto?10501

Components of the hydrologic cycle (STATE VARIABLE)

- Atmosphere
- Freshwater storage
- Groundwater storage
- Ice and snow
- Oceans
- Springs

Processes (RATE)

- Condensation
- Evaporation
- Evapotranspiration (evaporation + transpiration)
- Groundwater flow
- Infiltration
- Precipitation
- Snowmelt runoff
- Streamflow
- Sublimation
- Surface runoff



White= H_2O vapor; black= dry

9/2/2010 Meteosat-9; over Africa

http://earthobservatory.nasa.gov/Features/GISSTemperature/Images/seviri_water_vapor_720p_best.mov

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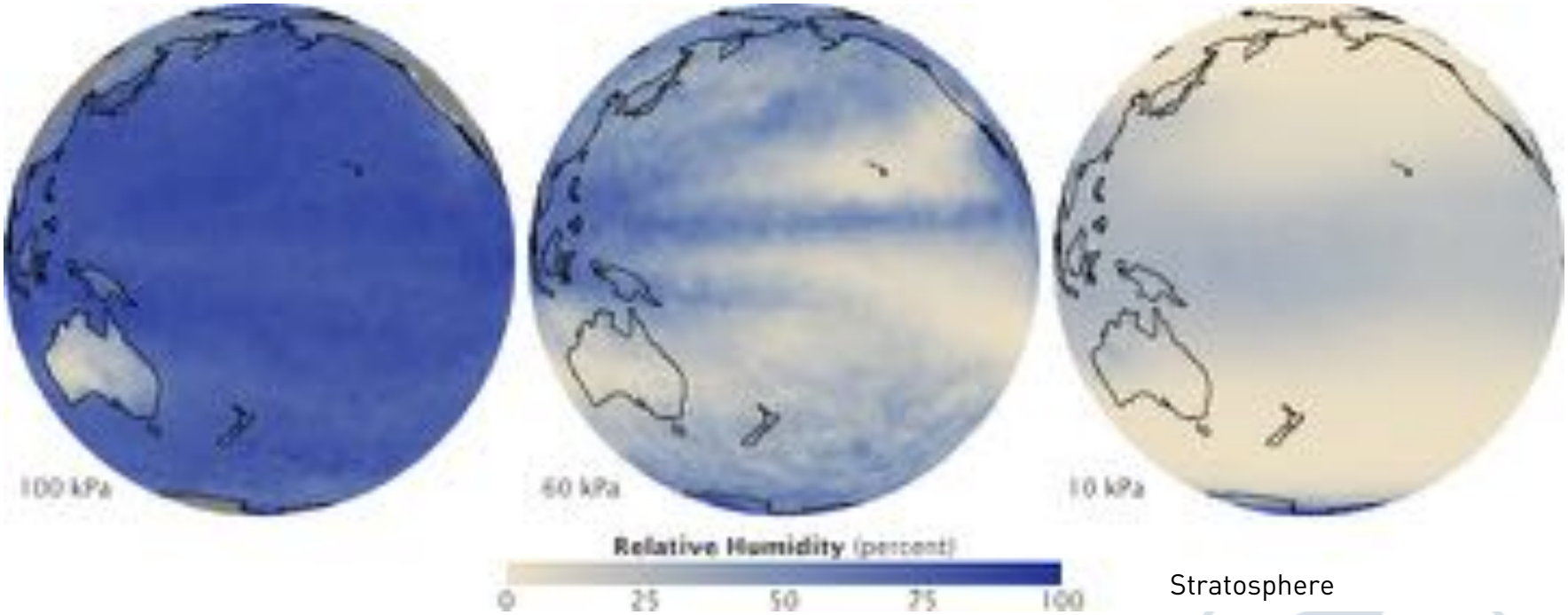
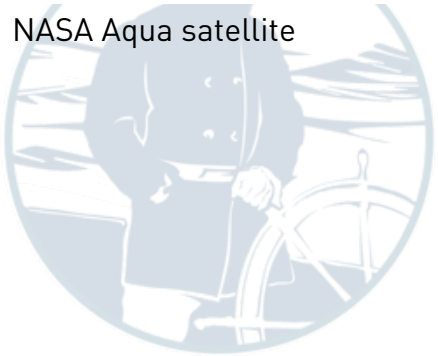
Zooming out



Sea surface

Stratosphere

NASA Aqua satellite



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Residence Time

Average length of time a H_2O molecule (or any other element or compound or water mass) spends in any one reservoir.

$$\text{Water residence time} = \frac{\text{vol. water in reservoir}}{\text{rate at which water is replaced}}$$

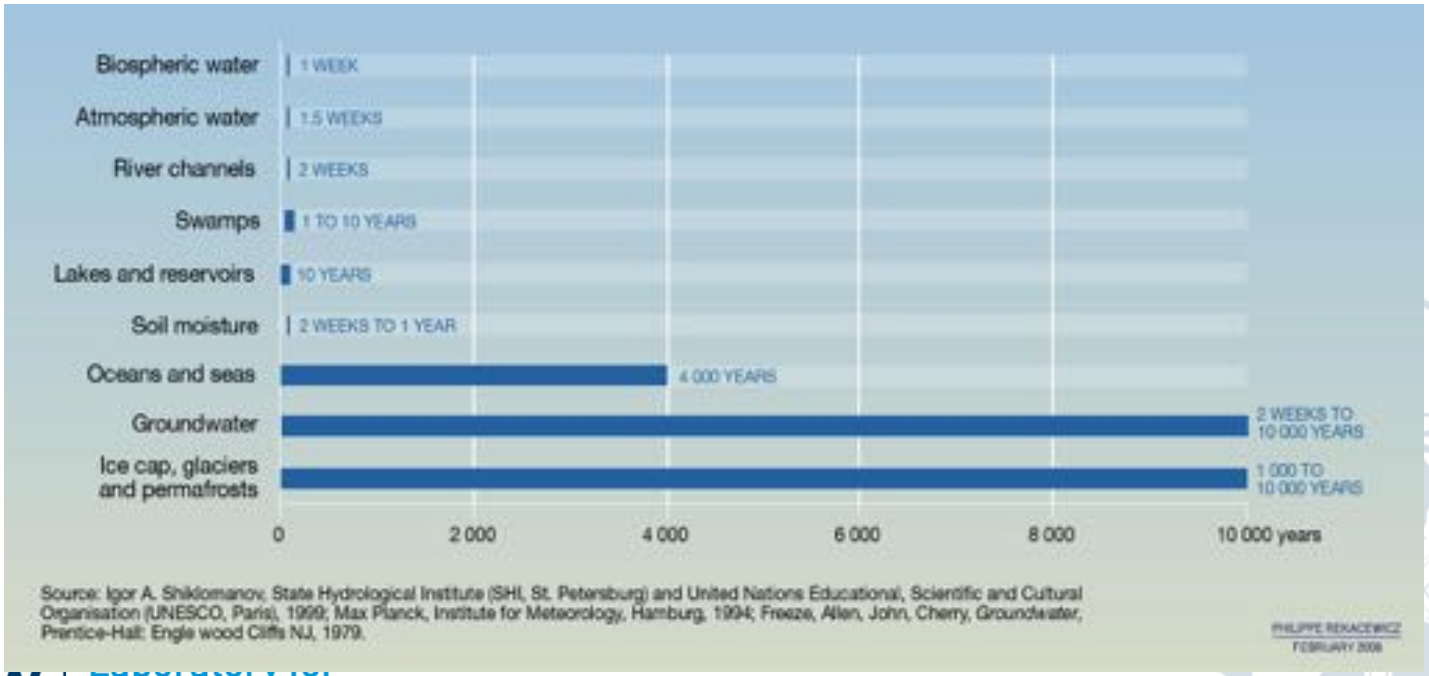

Table 1.3 The Earth's Water Supply

Reservoir	Approximate Water Volume (km^3)	(mi^3)	Approximate Percent of Total Water
Oceans and sea ice	1,338,500,000	320,600,000	97.24
Ice caps and glaciers	29,289,000	7,000,000	2.14
Groundwater	8,368,000	2,000,000	0.61
Freshwater lakes	125,500	30,000	0.009
Saline lakes and inland seas	105,000	25,000	0.008
Soil moisture	67,000	16,000	0.005
Atmosphere	13,000	3,100	0.001
Rivers	1,250	300	0.0001
Total water volume	1,376,468,750	329,674,400	100

Water in the Anthropocene

http://www.igbp.net/multimedia/multimedia/waterintheanthropocenedatavisualization.5.19895cff13e9f675e252f1.html

How the global water cycle is changing as a result of human influence

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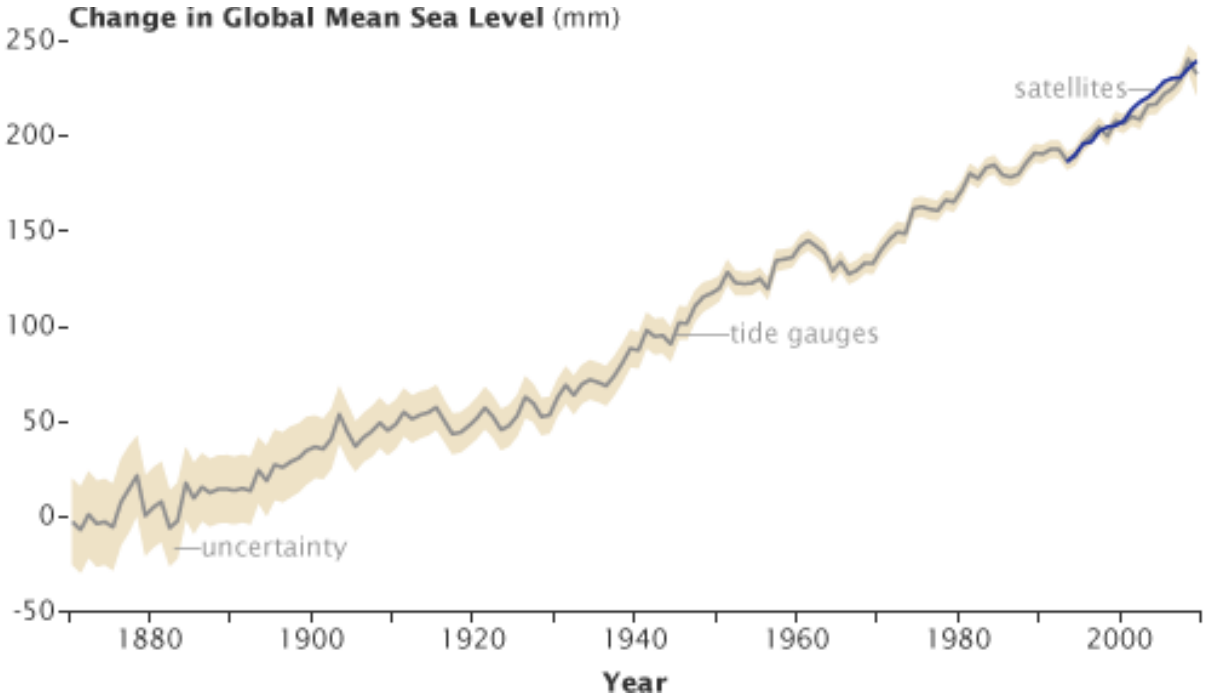

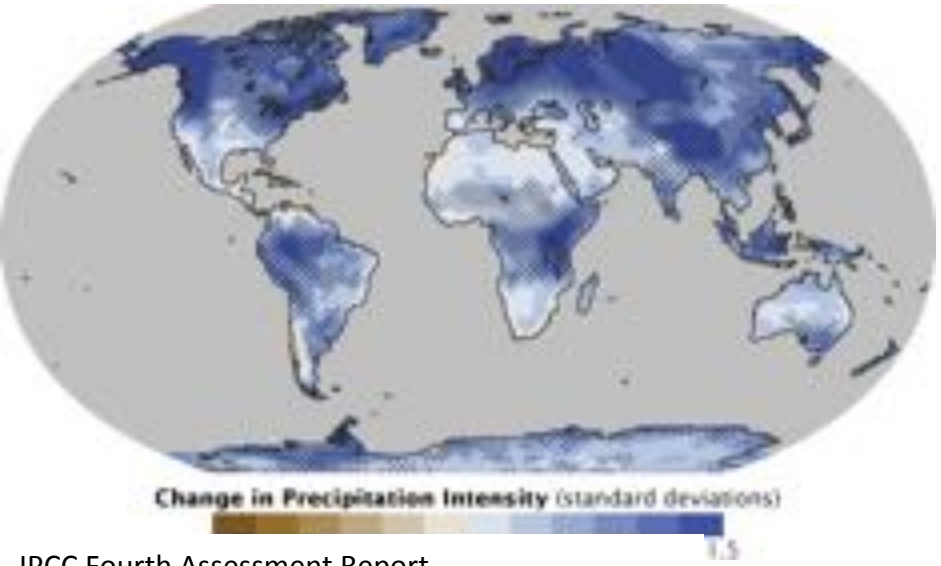

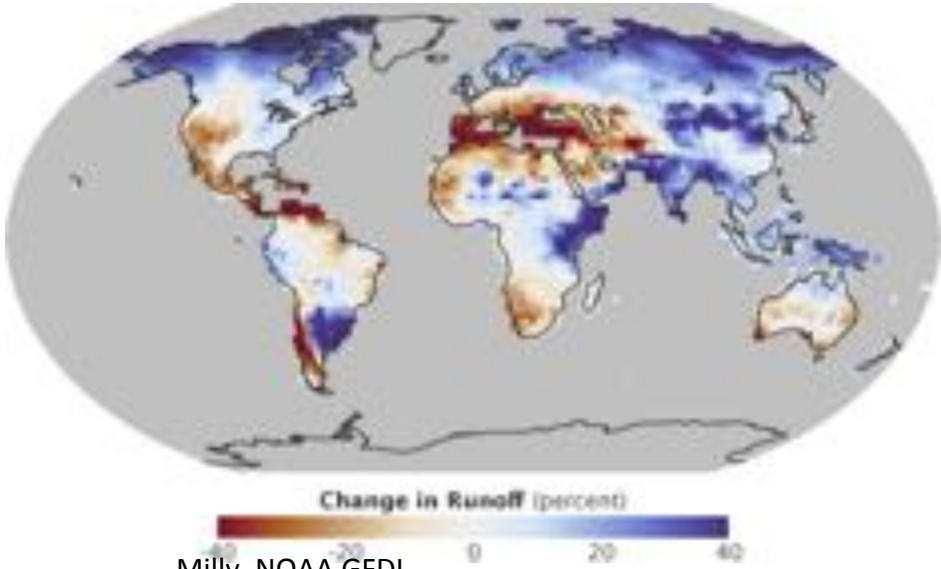

IPCC Fourth Assessment Report

Milly, NOAA GFDL

Oroville Dam reservoir, north of Sacramento.
Photo Credit: California Department of Water Resources.

Aral Sea: The world's 4th largest lake

Aral Sea: The world's 4th largest lake

Rivers diverted for irrigation

Shrunk to <10% of size

Then basin completely dried up

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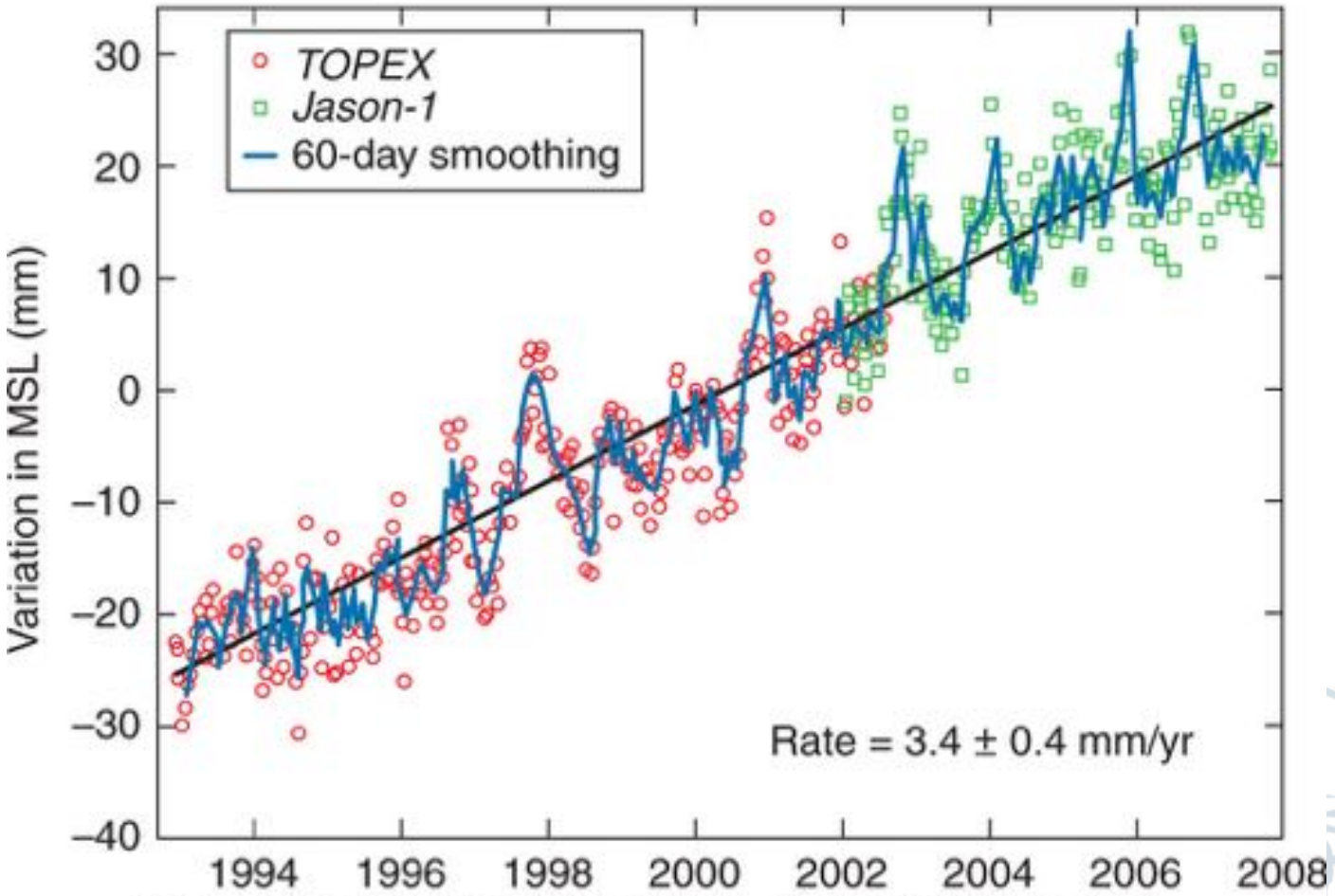
Rising sea level



From Leuliette, E. W., R. S. Nerem, and G. T. Mitchum, 2004: Calibration of TOPEX/Poseidon and Jason altimeter data to construct a continuous record of mean sea level change. Marine Geodesy, 27(1–2), 79–94. http://sealevel.colorado.edu. Reprinted with permission from the Colorado Center for Astrodynamics Research.

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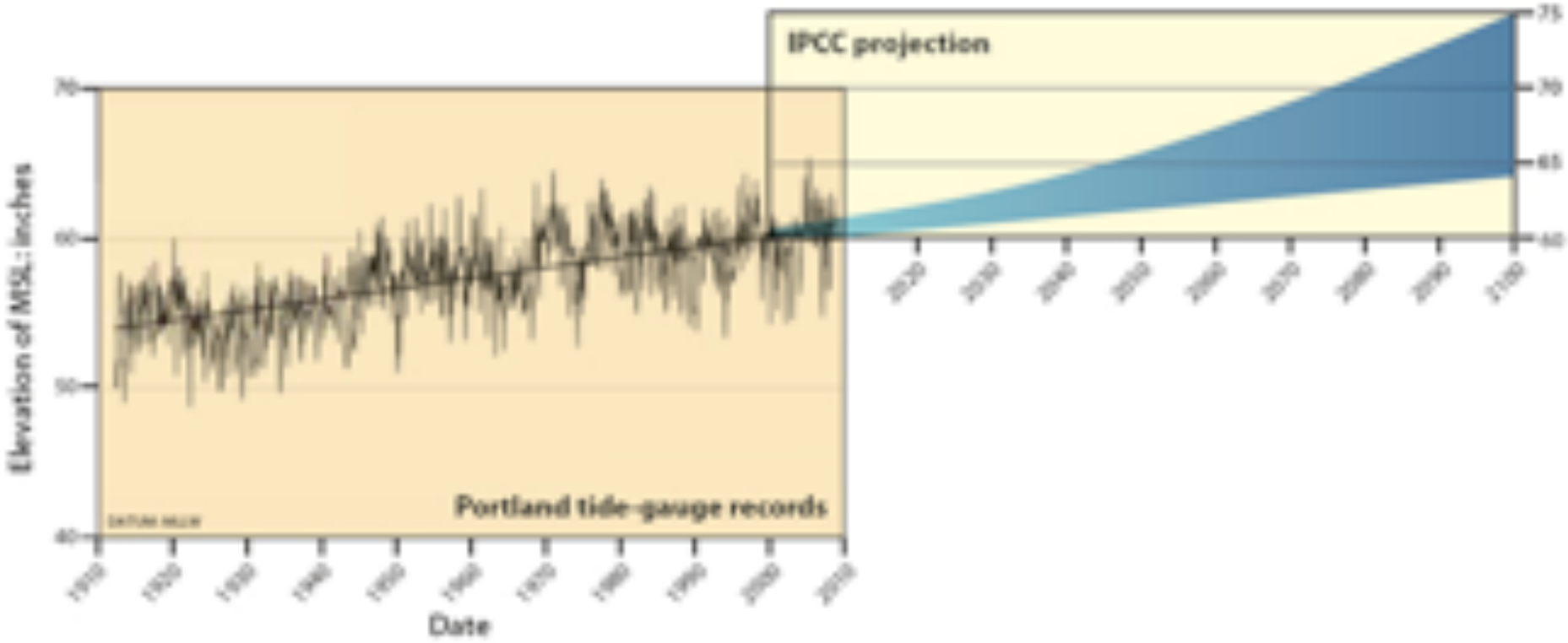

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Sea level- regional variability
Nicholls et al. 2011

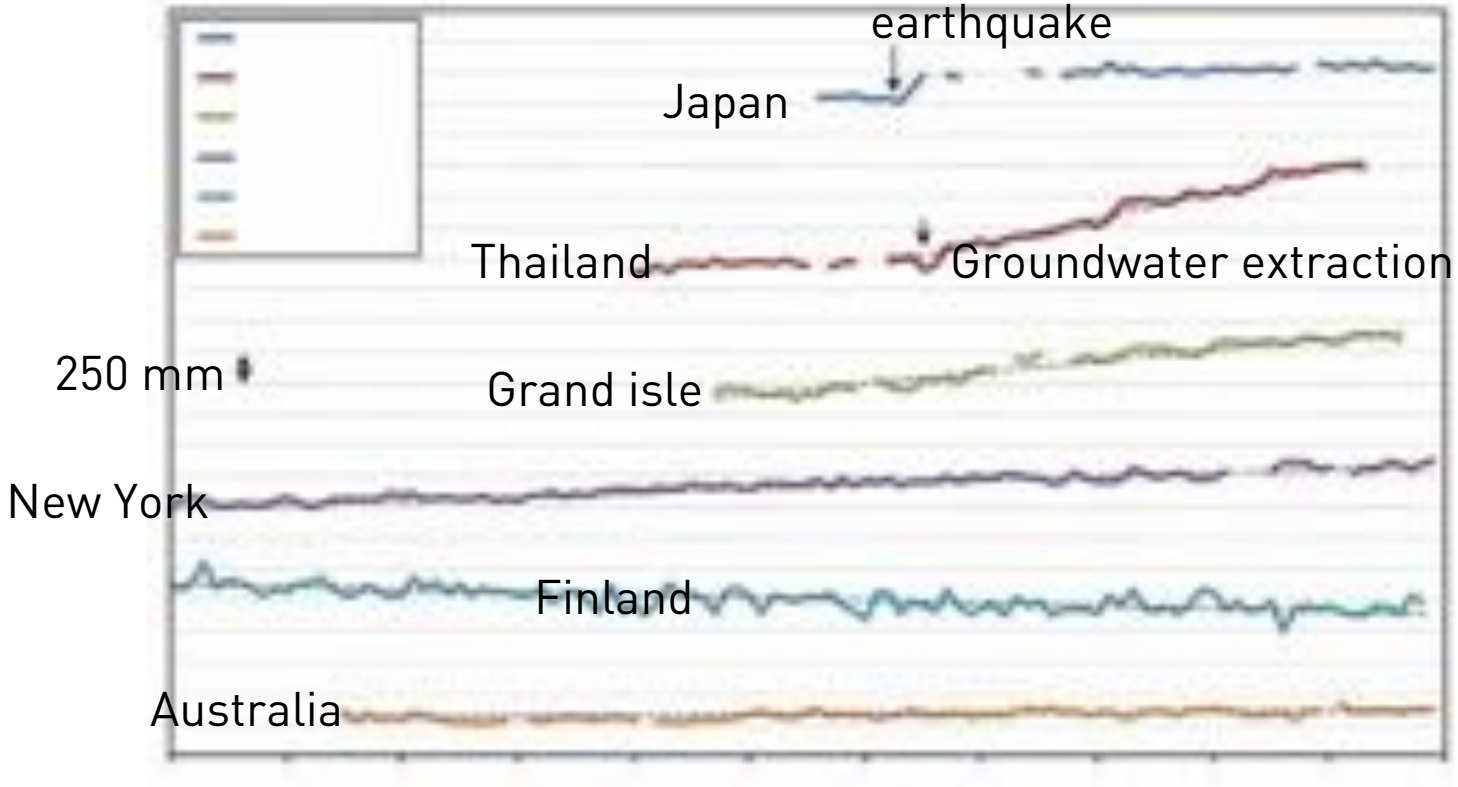

Figure 1. Selected relative sea level observations since 1900. Helsinki shows a falling trend (-2.0 mm yr–1), Sydney shows a gradual rise (0.9 mm yr–1), New York is subsiding slowly (3.0 mm yr–1), Grand Isle is on a subsiding delta (9.3 mm yr–1), Bangkok includes the effects of human-induced subsidence (20.7 mm yr–1 from 1962 to 2003), and Nezugaseki shows an abrupt rise due to the 1964 Niigata earthquake.

Effects of sea level rise and adaptations

NATURAL SYSTEM EFFECT		POSSIBLE INTERACTING FACTORS		POSSIBLE ADAPTATION APPROACHES
		Climate	Non-climate	
1) Inundation / flooding	**a) Surge (from sea)**	Wave/storm climate, erosion, sediment supply	Sediment supply, flood management, erosion, land reclamation	Dikes, surge barriers, closure dams, dune construction, building codes, flood-proof buildings, land use planning, hazard mapping, flood warnings
	b) Backwater (from rivers)	Runoff	Catchment management, land use	
2) Wetland loss (and change)		CO2 fertilization, sediment supply, migration space	Sediment supply, migration space, land reclamation	Nourishment, land use planning
3) Erosion of soft morphology		Sediment supply, wave/storm climate	Sediment supply	Coast defenses/seawalls, land claim, nourishment, building setbacks
4) Saltwater intrusion	**a) Surface waters**	Runoff	Catchment management, land use	Saltwater intrusion barriers, changewater extraction
	b) Groundwater	Rainfall	Land use, aquifer use	Freshwater injection, change water extraction
5) Impeded drainage, higher water table		Rainfall, runoff	Land use, aquifer use, catchment management	Drainage systems, land use change, land use planning, hazard deliniation

What will happen as sea level rises?

What will happen as sea level rises?

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Maine's moving coastline

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1992

1996

Google Earth
(now?)

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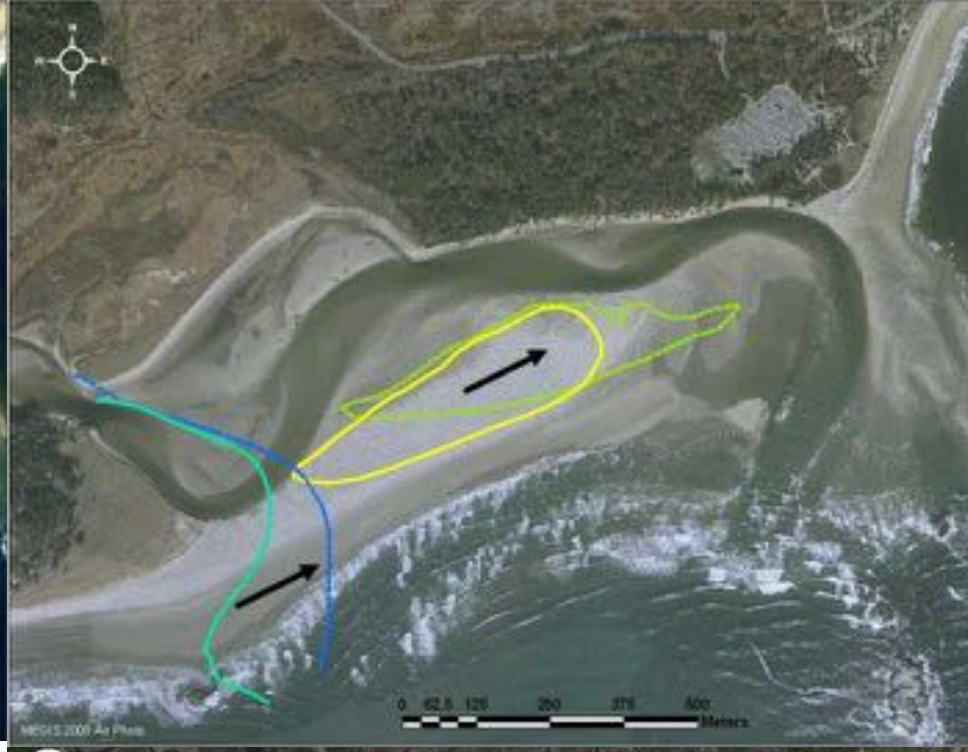

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How do we address the changing coastline?

Breakwaters and jetties

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Drakes Island
Image © 2012 TerraMetrics

Seawalls

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Saco, ME

Other Solutions

Other Solutions

Sea level rise in Maine

Portland high tide (photo credit A. Pershing)

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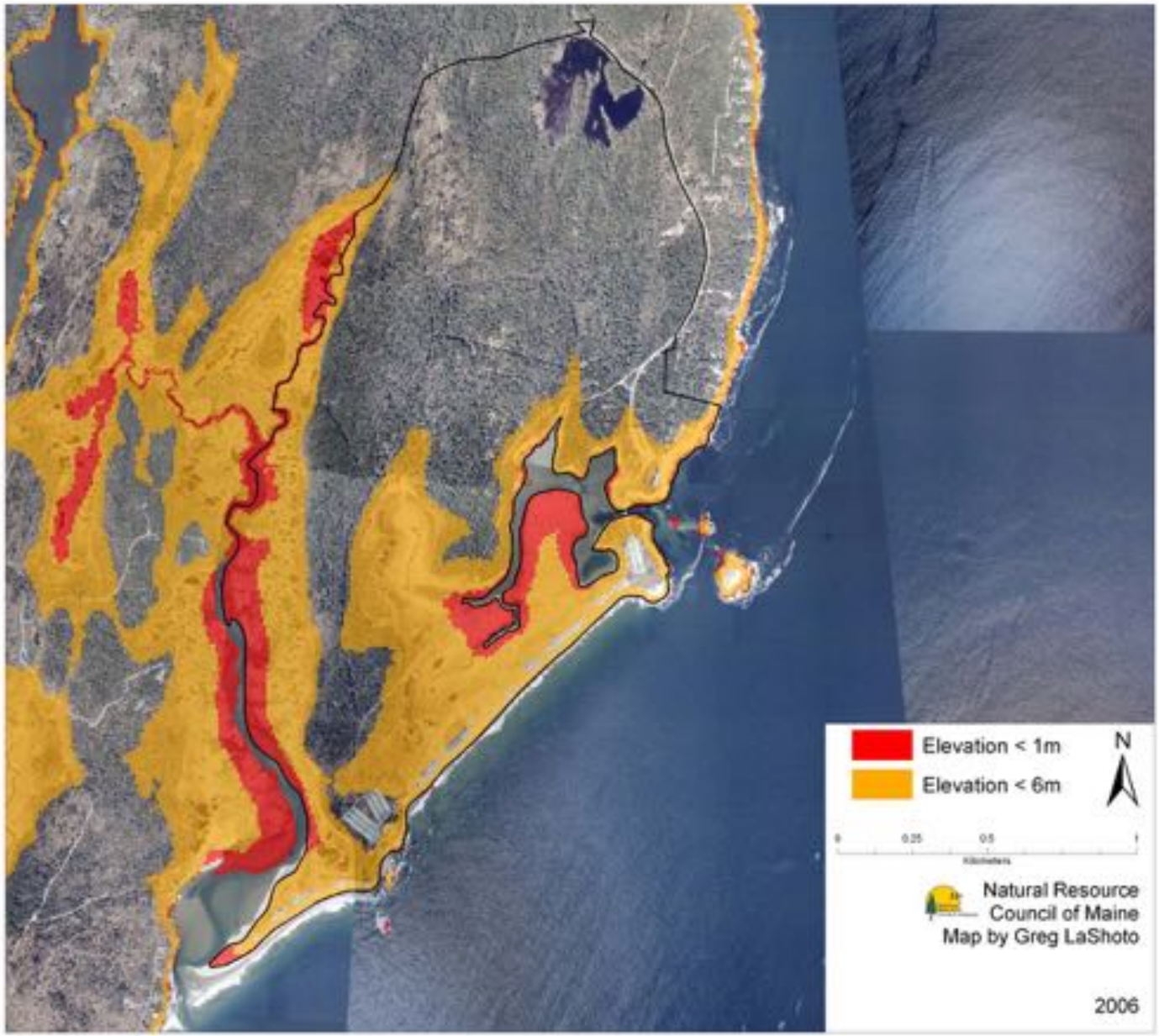
Impact of Sea Level Rise on Reid State Park, Georgetown, Maine



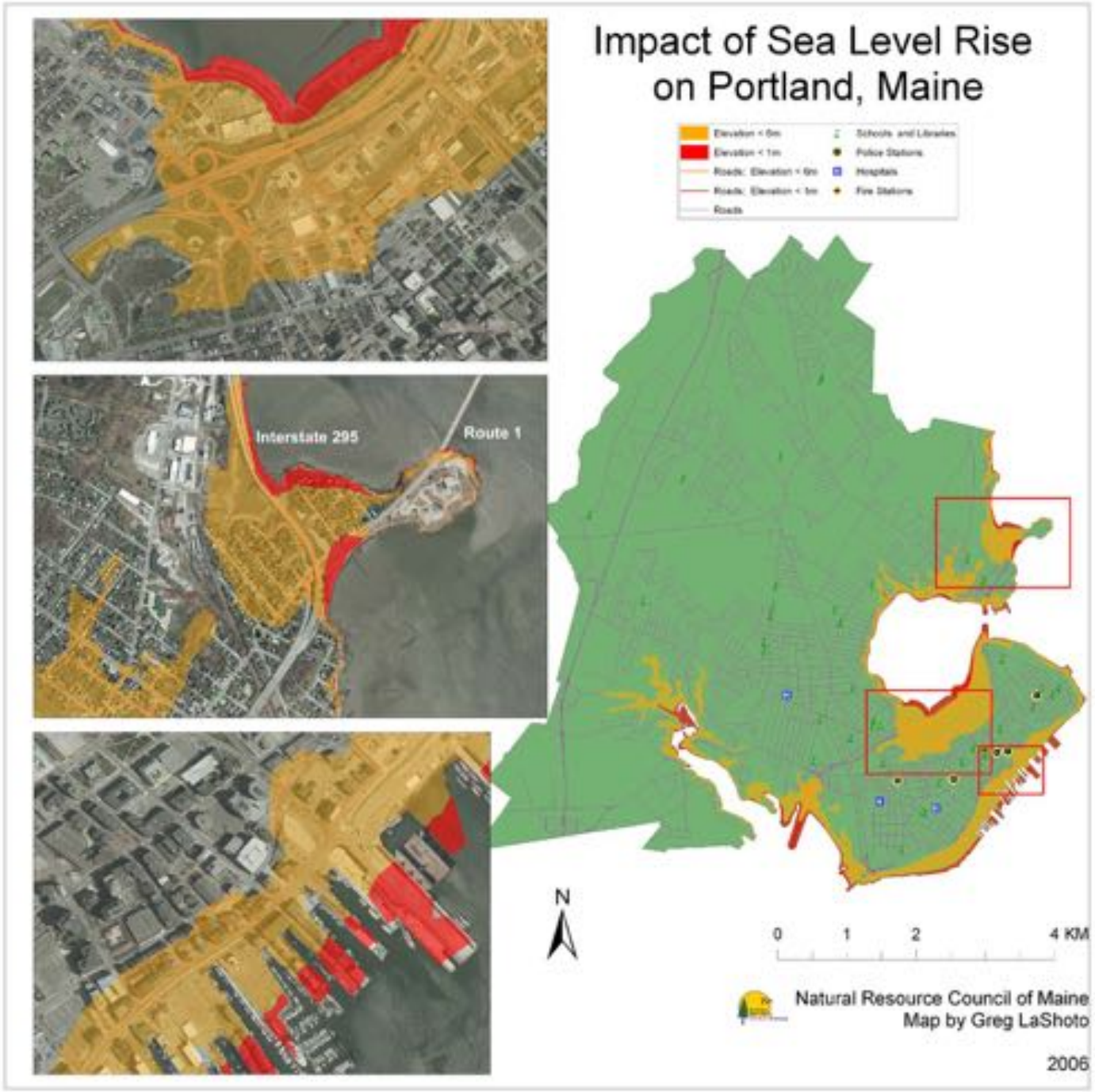
Natural Resources Council of Maine

Impacts of Sea Level Rise on Bath, Maine

Natural Resource Council of Maine
Map by Greg LaShoto

2006

Natural Resources Council of Maine



Natural Resources
Council of Maine

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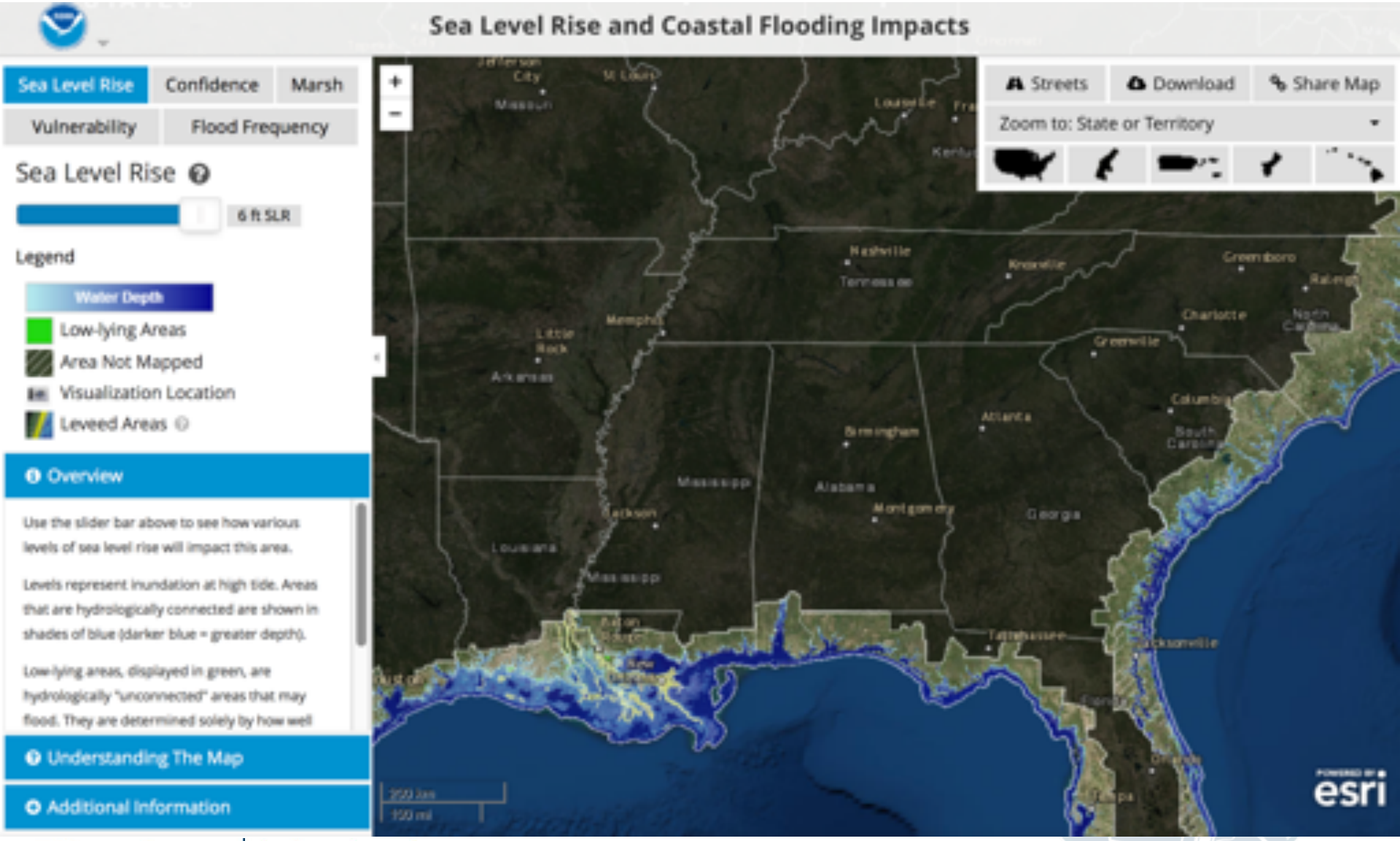
Natural Resources Council of Maine

Impact of Sea Level Rise on Walker's Point

Natural Resources Council of Maine, 2006

Natural Resources
Council of Maine

US sea level rise visualizer: https://coast.noaa.gov/slr/



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Scientific Papers

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Scientific Papers

"*Probably what you should learn…is not a large number of facts, especially if they are in books, but what the important problems are, and to sense which experiments, work that has been done, probably aren't quite right.*"

- James Watson (of Watson & Crick)

- Before reading an article, ask yourself: *What am I looking for in this article?*

- **AUTHORS**
  - Where and with whom are they working?
  - What is their expertise?

- **TITLE**
  - Read and digest the title.
  - Is the "take-home message" in the title?

- **ABSTRACT**
  - Read carefully and try to understand it. Take some time here.
  - Does the abstract align with your expectations for the article?
  - Take-home message(s)

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Scientific Papers

- **FIGURES, TABLES, LEGENDS**
  - What does each figure show?
  - Reference the methods where necessary.

- **INTRODUCTION**
  - In the first few paragraphs, the objective should be clear.
  - What gap does this study fill? *Is it transformative or incremental?*
  - Look for assumptions
  - Generally, the Intro and Literature Cited sections go hand-in-hand.

- **RESULTS**
  - Should align with figures

- **DISCUSSION**
  - Authors should explain WHY they saw what they saw
  - Beware of unfounded speculation
  - …though new hypotheses are okay
  - Look for caveats to "take-home messages"

Scientific Papers

- **HYPOTHESIS**
  - Is there a hypothesis?
  - Some types of hypothesis

    Simple: cause → effect

    eg: smoking leads to cancer

    Complex: multiple cause → multiple effect

    Null hypothesis: no relationship

    H0: There is no relationship between atmospheric CO_2 and global temperature.

    Alternative hypothesis: an alternative to a discounted (usually null) hypothesis

    H1: Increasing atmospheric CO_2 leads to increasing global temperature by trapping heat.

    Statistical hypothesis: validated statistically