CLIMATE CHANGE and SEA-LEVEL RISE

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The world’s 7.3 billion people, and California’s 39 million people, are struggling to solve a high-stakes, three-fold problem:

1. Satisfy a growing appetite for food, water and energy
2. Preserve a livable natural environment
3. Build resilience to natural extremes & climate change
Climate changes have been recorded in:

- Deep-sea sediment cores
- Ice cores from Greenland and Antarctica
- Corals from tropical oceans
- Tree rings- dendrochronology
- Pollen records in lake sediments
Variations in the Earth’s orbit around the Sun played a major role in causing past climate change and Ice Ages.

Three Orbital Cycles & Periods

1. Shape of orbit-100,000 years
2. Tilt of axis of rotation ~41,000 years
3. Wobble of Earth’s axis- ~26,000 years
Antarctic ice cores 11,500 feet deep extend back 850,000 years and contain air bubbles, which record atmospheric carbon dioxide content. 402 ppm 2015 – 34% increase
THE KEELING CURVE

Atmospheric CO₂ at Mauna Loa Observatory

Charles Keeling

Ralph Keeling
Where humanity’s CO₂ comes from

- 91% 33.4 billion metric tonnes
  - Fossil Fuels & Cement 2010
- 9% 3.3 billion metric tonnes
  - Land Use Change 2010

Where humanity’s CO₂ goes

- 50% 18.4 billion metric tonnes
  - Atmosphere 2010
- 26% 9.5 billion metric tonnes
  - Land 2010
- 24% 8.8 billion metric tonnes
  - Oceans 2010

2010 data updated from:
Le Quéré et al. 2009, Nature Geoscience
Canadell et al. 2007, PNAS
In the next hour the world will use about 150 million gallons of oil, 15 billion cubic feet of natural gas, and a million tons of coal, which all produce carbon dioxide.

We’re not running out of fossil fuels, we’re running out of atmosphere.
Likely local climate change effects based on historic patterns and climate models

1] higher temperatures

2] summer water shortages and longer droughts

3] increase in wild land fires

4] more concentrated winter rainfall and more flooding

5] sea-level rise with increased rates of coastal inundation and shoreline retreat

These will not be new events, but will likely occur more frequently and be more intense than in the past.
New FEMA maps show more of East Palo Alto at risk of flooding

By Peninsula Press on December 12, 2015 at 6:27 AM
Changes in sea level are driven primarily by global temperature. As the Earth has warmed and cooled, sea level has risen and fallen, in response to 1) melting or expansion of glaciers and ice sheets, and 2) expansion and contraction of sea water.

375,000 years of sea level fluctuations
Components of Global and Regional Sea-Level Rise

Sea-level rise at a particular place can be higher or lower than the global mean due to regional effects.
Sea Level

Ice Age ended

- Rapid Rise: 11mm/yr (1/2 inch) 45”/100 yrs
- Very rapid rise: >20mm/yr (3/4 inch) 6.5 ft/100 yrs
- Very slow rise/Little change: <1mm/yr
- Present Rate: 3.2mm/yr (12”/100 yrs)
SEA LEVEL WAS ESSENTIALLY CONSTANT OVER THE ENTIRE HISTORY OF HUMAN CIVILIZATION
And they are still being built
Rising waters

Sea levels going up 60 percent faster than previous UN climate panel forecasts, scientists report Wednesday

Largest cities exposed to risk by 2070
Most vulnerable to surge-induced events, by projected population

Millions

- New York: 2.9
- Miami: 4.8
- Alexandria: 4.4
- Abidjan: 3.1
- Lagos: 3.2
- Kolkata: 11.1
- Khulna: 3.6
- Chittagong: 2.9
- Ho Chi Minh City: 9.2
- Bangkok: 5.1
- Tianjin: 3.8
- Ningbo: 3.3
- Yangon: 5.0
- Shanghai: 5.5
- Tokyo: 2.5
- Hai Phong: 4.7
- Jakarta: 2.2
- Guangzhou: 10.3

Value of exposed assets
$ billion
- 1.5 - 3.5
- 0.5 - 1.5
- less than 0.5

Source: OECD

108 million people in just 20 cities
The rate of global sea-level rise was measured from tide gages historically and satellites since 1993.

1.7 mm/yr  3.2 mm/yr
Uncertainty

There are the known knowns, there are the known unknowns, and there are the unknown unknowns.

- Natural variations in climate
- Future greenhouse gas emissions
- Release of carbon from thawing of permafrost
- Rate of melting of Greenland ice cap
- Acceleration of flow rate of Antarctic glaciers into ocean

“There are the known knowns, there are the known unknowns, and there are the unknown unknowns”.
Juneau, Alaska: -4.3 ft./100 years, -½ inch/year

Grand Isle, Louisiana: +3 feet/100 years, +1/3 inch/year
Greenland ~22 feet of SLR

Mountain Glaciers ~ 2 feet of SLR

Potential future sea-level rise is very large (~225 feet total), but uncertainties in rate of rise.

Antarctica ~200 feet of SLR

“HOW ON EARTH DO WE TURN IT OFF?”
Height in Inches

2030
San Francisco International Airport and Oracle with a 16-inch rise in sea level.
Not an acceptable long-term solution
BCDC
sea-level rise
inundation
map for city of Palo Alto
Temporal Differences in Sea Level Change

**LONG-TERM: LOW RATE OF CHANGE**
- Ice melt and thermal expansion of ocean: mm/year but hundreds of feet over thousands of years
- Plate tectonics and changing volume of ocean basins: hundreds of feet over millions of years

**SHORT-TERM: HIGH RATE OF CHANGE (California)**
- Tsunamis: up to 20 feet or more over minutes
- Storm Surges: up to 3 feet over hours
- El Niño: 1-2 feet over months
- Tides: 8-12 feet over hours, including King Tides
Sea level is rising and the bathtub is slowly overflowing, but....
The extreme events are going to be of greater concern in the near term.
Short-term events have had greater impacts than sea-level rise over the past century, and this will likely continue until at least 2050, except perhaps in very low lying areas.

SAN FRANCISCO: 1.9 mm/yr. (7.4”/100 years)
A nearly 20 year hiatus in sea-level rise along the west coast...
global mean sea level
seasonal signals removed
trend: 2.9 ± 0.4 mm/year
Global average sea level has increased 8 inches since 1880. Sea levels along the U.S. East Coast and Gulf of Mexico are rising much faster.

Local Sea Level Rise
1880-Present

The rate of local sea level rise varies depending on both global and local factors, including currents, ocean floor topography, variations in ocean density, and land uplift or subsidence due to geological reasons or human activities.

Washington D.C.
El Niño 1997-98 - Elevated Water Levels

REDWOOD CITY
2 ft. above predicted
Seacliff State Beach - El Niño Winter 1983
SEAWALL DESTROYED FOR THE 8TH TIME TWO MONTHS AFTER BEING REBUILT
TIDES
King of the tides

Once or twice a year, coasts are visited by king tides: higher high tides and lower low tides than normal. The royal visit happens when the Earth is closest to the moon or sun, or as in today’s case, both celestial bodies.

Tidal: As the Earth orbits the sun, and as the moon orbits the Earth, the distance between the objects changes. This change, however slight, translates into more or less gravitational pull and thus, more radical or conservative high and low tide cycles. Within each 29-day moon orbit of the Earth the distance changes and, once a year, the two become closer than ever. The sun and Earth are furthest apart July 2 and closest together Jan. 2.

King tide 7.1 ft.  Mean tide 2-5 ft.  Sea level

Sources: National Oceanic and Atmospheric Administration, Orange County Coastkeeper, International Astronomical Union, NASA
King tides rolling into the Bay Area

Here is a look at the high tides forecast for the Bay Area on Thursday and Friday. Tides will be highest in the cul-de-sac of the South Bay, where water “piles up” in the tight confines.

High tides around the Bay Area

1. Mare Island
   Thursday: 7.0 ft., 12:00 a.m.
   Friday: 6.9 ft., 12:50 p.m.

2. Port Chicago
   Thursday: 5.9 ft., 12:53 p.m.
   Friday: 5.8 ft., 1:44 p.m.

3. Richmond
   Thursday: 7.5 ft., 10:50 a.m.
   Friday: 7.4 ft., 11:41 a.m.

4. San Francisco
   Thursday: 7.2 ft., 10:34 a.m.
   Friday: 7.0 ft., 11:24 a.m.

5. Rincon Point
   Thursday: 7.56 ft., 10:52 a.m.
   Friday: 7.44 ft., 11:42 a.m.

6. Alameda
   Thursday: 7.9 ft., 11:03 a.m.
   Friday: 7.8 ft., 11:54 a.m.

7. Hunter’s Point
   Thursday: 8.1 ft., 11:01 a.m.
   Friday: 8.0 ft., 11:53 a.m.

8. San Leandro Marina
   Thursday: 8.9 ft., 11:28 a.m.
   Friday: 8.7 ft., 12:19 p.m.

9. San Mateo Bridge
   Thursday: 9.1 ft., 11:25 a.m.
   Friday: 9.0 ft., 12:16 p.m.

10. Princeton, Half Moon Bay
    Thursday: 6.9 ft., 9:28 a.m.
    Friday: 6.7 ft., 10:18 p.m.

11. Redwood City
    Thursday: 9.6 ft., 10:44 a.m.
    Friday: 9.5 ft., 12:27 p.m.

12. Dumbarton Bridge
    Thursday: 10.1 ft., 11:44 a.m.
    Friday: 10.0 ft., 12:36 p.m.

13. Coyote Creek
    Thursday: 10.5 ft., 11:50 a.m.
    Friday: 10.3 ft., 12:41 p.m.

14. Santa Cruz
    Thursday: 6.7 ft., 9:12 a.m.
    Friday: 6.5 ft., 10:01 a.m.

Source: California King Tides Initiative
King Tide 2012
The Embarcadero
San Francisco
IMPACTS OF SHORT (AND LONG) TERM SEA-LEVEL RISE

Twin Lakes-Flooded Roadways

Capitola-Flooded park facilities

Aptos Seascape-Damaged oceanfront homes

Pacifica-Cliff retreat
Components of Total Water Level Predictions

- Stinson Beach
- 50 cm SLR
- SLR only
- SLR + a annual storm

Hbr: H decreases rapidly due to breaking in height towards the breaking zone (shoaling)

breaks:
- hR
- hwv
- hss
- hse
- htide

- Sea level rise
- Tide difference
- Seasonal effects
- Storm surge
- Wave run-up
- Wave set-up

1 m
2 m
0.3 m
1.0 m
1.7 m
2 m +
VENICE HAS BEEN DEALING WITH HIGH WATER FOR YEARS
MIAMI DURING HURRICANES HAS HIGH WATER
Giraffes...Check.
Elephants...Check.
Florida Homeowners...Check.

Flood Insurance Rates
NEW ORLEANS AND KATRINA
NEW YORK AND NEW JERSEY AND SUPERSTORM SANDY
What Next? Options for the future
ADAPTATION OR RESPONSES TO SEA-LEVEL RISE AND EXTREME EVENTS

1. IGNORE SEA-LEVEL RISE
2. BUILD FLOATING CITIES
3. BUILD BARRIERS: SEAWALLS
4. PLAN FOR MANAGED RETREAT
We need to inventory those coastal areas that are subject to short and long-term sea-level rise, assess vulnerabilities and risks, and develop responses.
Which of these future projections should we be using?

What is the sea-level rise rate from closest tide gauge?

What is the cost or value of the proposed project or infrastructure?

What is the lifespan of the proposed project or infrastructure?

What is the impact of damage to or loss of facility or infrastructure?
Adapting to Sea Level Rise: A Guide for California’s Coastal Communities

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We have exactly enough time if we start now.

It’s real.
It’s us.
It’s bad.
Scientists agree.
There’s hope.
POST-PARIS CLIMATE CHANGE SUMMIT

GOOD NEWS!

WE FINALLY HAVE A BINDING INTERNATIONAL AGREEMENT TO CONTROL GREENHOUSE GASES!

CLIMATE-CHANGE SUMMIT 2040

MT. EVEREST
GOOD NEWS! AT THE CURRENT RATE OF GLOBAL WARMING WE SHOULD BE ABLE TO JUST SWIM OVER THERE AND EAT HIM IN UNDER FIVE YEARS...!