Global Components of Sea Level Rise 1900-2300

Plenary Speaker 1: Dr. Phillip Mote
Director, Oregon Climate Change Research Institute, OSU

Native Americans understand consequences in a spiritual way and I understand things in a quantitative way. Both are important.

Back in 2007 we at the Climate Impacts Group provided a report about sea level rise in Puget Sound. Al Gore’s movie had an image of NY’s 20-foot sea level rise. We then tried to lay out the science of what was happening in Puget Sound.

The next report Mote was instrumental in writing was the Sea-Level Rise for the Coasts of CA, OR, and WA, published in 2012. Internationally, glaciers, ground water and ice sheet and shelf movement contribute to sea level rise. Regionally, atmosphere-ocean interaction, relative sea level, and ocean properties/circulation determine sea level rise.

Even the weak gravitational attraction of ice sheets pulls ocean water towards it: as ice melts, it releases the pull that in addition to melting contributes to sea level rise. In Puget Sound our sea level rise is measurably affected in this way by melting of Alaska glaciers.

Tide gauge table records help tremendously to report long term, sea level rise. Ocean-Atmosphere Circulation Patterns chart shows El Nino effects causing sea level rise. (see Slide #3 on page 2). We need to look at long time periods to detect change. Local sea level rises during warm climate phases like El Nino, and falls during cool climate phases like La Nina.
IPCC Committee Charge: Task 1. Estimate the contributions to global sea level rise and project for 2030, 2050, 2100. Task 2. Estimate contributions to regional sea level rise for CA, OR, and WA for 2030, 2050, and 2100. Task 2a. Examine any changes in storminess and how it would affect regional sea level rise. Task 2b/c examine how sea level rise affects the shoreline and protection provided by habitats and the natural shoreline.

See slides # 5 and 7 for global and regional sea level projections. Global Sea Level Projections. 20 cm of sea level rise (8 inches) by 2030. 2050 a foot rise, 1.5 to 5 foot est. for 2100. The biggest unknown is what will happen to Antarctic Ice Sheet. It is very difficult to predict how its lumpy and irregular contours will melt. (See slides # 5 and 7 page 3 for global and regional sea level projections).

The IPCC 2013 report is up to date science. It predicts a 3 mm of sea level rise/year, since 1993. That is the equivalent to about an inch a decade. Between 1700 and 1900 sea level rise was fairly stable, but once we got to 1900 there was a big increase. There are definite uncertainties in the old measurement data we are using, but the trend is clear.
Mote looks carefully at the evolution of global SLR from 4 perspectives: RCP2.6 (CO2 levels of Paris climate accord); RCP4.5; RCP 6.0, and RCP 8.5 (CO2 levels if no changes
are made). Humans will control what happens in the future by the choices we are making now. 2015 was a turning point because nations negotiated the Paris accord AND we learned that global emissions went down from 2014 totals—a first. It was a hopeful year. RCP8.5 (slide #8) is the path we are currently on if we do not activate the Paris accord. RCP2.6 is the Paris accord. Gray is total sea level rise from all factors. Biggest factor is thermal expansion. As the ocean absorbs heat, it expands and the average ocean depth grows a bit. That is the main factor to date. The path humans chose about emissions makes a huge difference. RCP8.5 has an upward bend to it, which is significant and irreversible for the planet.

Components of global SLR

Components of global SLR (slide 9 above). Looks at thermal expansion, glacier melting, Greenland ice sheet melting, and Antarctica’s mixed signals. We look at keeping CO2 below 500 ppm to help control these effects. According to Mote, thermal expansion is likely to stay below 1 meter forever. Sea level continues to happen even if we stabilize CO2. In high scenarios (more than 700 ppm) the rise is almost 7 meters. There is a HUGE effect of not controlling CO2 if we look to year 2500.

Conclusion: The biggest contribution to date to global sea level rise is thermal expansion and glacier melting. Antarctica is the big unknown. Local factors can have a big effect on global sea level rise. Tectonic factors cause rise like isostatic rebound from continental glaciation or fall of coastlines due to earthquakes.

One of the important things in looking at sea level rise in CA, WA, and OR (Task #2) is understanding plate tectonics. The Pacific plate is descending below North America at the Cascadia Subduction Zone, causing local coastal areas to rise. Pacific and North America plates are sliding past one another along the San Andreas Fault, causing no vertical motion.
Pacific plate sliding over oceanic plate can cause fall of sea level 1-2 meters. The Pacific plate is descending below North America as the Cascadia Subduction zone, causing local coastal areas to rise, observed vertical land movements slide. This is 20 years of data and predicting for next 90 years is very problematic. (see slide 15 above)

**Sea Level Projections and Ranges (cm)**

for West Coast Cities

<table>
<thead>
<tr>
<th>City</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle</td>
<td>7 (-4 to 23)</td>
<td>17 (-3 to 48)</td>
<td>62 (10 to 143)</td>
</tr>
<tr>
<td>Newport</td>
<td>7 (-4 to 23)</td>
<td>17 (-2 to 48)</td>
<td>63 (12 to 142)</td>
</tr>
<tr>
<td>San Francisco</td>
<td>14 (4 to 30)</td>
<td>28 (12 to 61)</td>
<td>92 (42 to 166)</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>15 (5 to 30)</td>
<td>28 (13 to 61)</td>
<td>93 (44 to 167)</td>
</tr>
</tbody>
</table>

Sea level projections and ranges for west coast cities for 2030, 2050, and 2100 are shown above. The large north/south difference is a reflection of the tectonics.

Regional and Global Sea Level Rise: we are a little lower than California because of subduction uplift. We are not rising as much as CA because of AK glacier melts. But if there is an earthquake, that will be a game changer.

Sea level rise will magnify the adverse impact of storm surges and high waves on the coast. (see slide 20 below.)
In closing it is virtually impossible to achieve the two meters of sea level rise in this century predicted by some authors (Hanson et al). It is more likely to have a meter rise.

Questions

#1 Terry Williams: we are all hiring independent contractors to help us understand place-based SLR. How can we organize the data collection more effectively?

Mote: You are talking something akin to an assessment report. That kind of thing is possible. NRC report was part of that. Part of the problem is the desire to control the process and results based on long-term belief.

#2—Is methane contributing to these numbers? Mote: Yes, all these numbers deal with all methane, greenhouse, etc. RCP8.5 does include all of these.

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Local Components of Sea Level Rise in Coastal Washington
Plenary Speaker 2: Dr. Ian Miller
Coastal Hazard Specialist, Washington Sea Grant

My involvement has been in community-scale SLR assessments. First with Jamestown S’Klallam Tribe, then a Climate Change Preparedness Plan for the North Olympic Peninsula, and now I am ready to complete one for Island County.

Sea level change is spatially variable around WA State. Tides and current website for NOAA looking at Seattle where sea level is rising and Neah Bay Sea level is falling.

Why this variability? The global drivers are melting ice as well as changes in terrestrial water storage and water density changes in the ocean. The regional components are gravitational attraction of ice, ocean circulation, and ocean-atmospheric interaction coupled with the local components of uplift and subsidence and glacial isostatic adjustment and groundwater withdrawal.
In general, these local components are small. See Slide #5. There could be a magnitude by 2100 of a maximum of four inches; tectonic component could be up to one foot.

<table>
<thead>
<tr>
<th>Component</th>
<th>Rates (mm/yr)</th>
<th>Magnitude by 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIA (VLM part)</td>
<td>~ 0-1 mm/yr</td>
<td>~10cm / 4 inches</td>
</tr>
<tr>
<td>GIA (SSH part)</td>
<td>~0.2 mm/yr</td>
<td>2 cm / 1 inch</td>
</tr>
<tr>
<td>Tectonics (VLM)</td>
<td>~ -1 to 3 mm/yr</td>
<td>Up to 40 cm / ~ 1 ft</td>
</tr>
<tr>
<td>SLR</td>
<td>1.2 – 3.6 ft (P&gt;.95)</td>
<td></td>
</tr>
</tbody>
</table>

Risk Communication and information needs to be credible (localized). There needs to be a focus on the numbers. Uncertainty must be communicated. We must be there and be transparent. Having this level of local data adds to credibility and accuracy of adaption planning.

The National Research Council published a phenomenal report “Sea Level Rise for the Coasts of CA, Oregon, and WA” Why didn’t it prompt more action? It is really detailed, but hard to digest. How do we develop communication that inspires action.

In our current work we are not changing the numbers, but rather the communication and localizing projections. We have developed a plot for Island County of the historic sea level records for northern Puget Sound. This provides nuanced information, which communities use to make choices. Localizing projections is important. A difference of less than 4mm/year, which equals over one foot over the course of a century. This results in a pretty big difference between Neah Bay and Seattle.
Community relevant information for Neah Bay, Pt. Angeles, and Pt Angeles means localized projections showing specific communities and mean high water levels. For example creating the Sea Level Rise Inundation area map for 2050.
Island County was a little different than the Neah Bay to Pt. Townsend numbers because there is not much spatial variation.

It is not just about average sea level. It is about local extremes that can create coastal flooding. Annual extreme water level projections are available, which include storm surges and El Nino numbers. Slide #13 shows extreme water level predictions for three communities along the Strait of Juan de Fuca for 2030, 2050, and 2100.

Extreme storm flooded areas can be mapped to local geography to make data relevant. Such as map of Crescent Harbor and Oak Harbor.
The new Regional Resilience Project will:

- Support an updated sea level rise and storm surge assessment for coastal Washington
- Build climate resilience principles into state agency processes and plans
- Look for resilience benefit from ecological restoration investments in Puget Sound
- Create outreach tools, including “Resilience Ambassadors”, to facilitate implementation of resilience projects and plans

Questions

1) Are there any papers or science on extreme low pressure and onshore winds and how they affect coastal communities? Miller: For communities without a tide gauge we have to check historic records. Regional resilience grant will allow some modeling for extreme scenarios to help find communities vulnerable to storm surges.

2) Look for resilient benefits . . . are there benefits to estuary and potential for armoring. Are you also looking at human behavior like armoring? Miller: We are not monitoring human behavior. We are trying to remove armoring, even though we know that sea level rise may encourage shoreline property owners to increase armoring. I am trained as a shoreline geomorphologist. We don’t know how the different types of armor respond to sea level rise.

3) Question about getting storm water data from county departments? Miller: Don’t have much info on surging seas and high winds, but this is something we need to look at.
In 2003 California Governor Schwarzenegger said they should plan for sea level rise. The report did not come out until 2012 and cities are now beginning to use those reports. Clallam County just passed a climate change resolution but did not define a certain level of sea level rise.

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Assessing coastal impacts where people and ecosystems are being squeezed by climate change

Plenary Speaker 3: Dr. Eric Grossman
Research Scientist, U.S. Geological Survey, Pacific Coastal and Marine Science Center

Dec. 17, 2012 Storm surge in Whatcom County photos
March 10, 2016 Storm photos

Coastal squeeze is happening from storm surge waves, bluff erosion and littoral sediment, and over wash erosion and landward migration.

Coastal and estuary squeeze is happening because of more rain, less snow, intense/frequent floods, longer flood seasons, more sediment, and lower summer flows, more high tide events, storm surge/waves, sediment trapping, lower flow conveyance, groundwater rising, salt water intrusion.

We are seeing these extreme events more frequently. This causes humans to want to armor the shore but that action potentially makes us more vulnerable. We may have 3-6 times increase in sediment from more rain, less snow, intense/frequent floods, longer flood season, more sediment, lower summer flow.
Talk outline:

1) Context—Land Use Change
2) Climate Impact Pathways
   2a. Estuaries and wetlands (salmon rearing)
   2b. Beaches & Nearshore (shellfish, forage fish)
   2c. Floodplains (Coordinated investments for fish, farms, flood risk)
3) Information Needs

Risk zone mapping tools and sea level rise and coastal flooding impact zones are useful but maybe not at individual parcel level.

The Fate of Sediment slide, shows how moving sediment supply, shoreline armoring, vertical land movement, and sea level rise come together to affect our coasts. Historically in the Skagit river delta we have really altered the wetlands. In 100 years we have rerouted the river with levees and dikes. This has created a loss of 80 percent of salmon wetlands. 90 percent of sediment is bypassing the system and doing a lot of damage. In the 1900s we were doing a lot of dredging, but in the 1960s we had to stop because of marsh erosion.

We have been involved in a CHIPS Large River Delta Project addressing 750 proposed restoration actions on more than 50,000 acres affecting half a million residents. We are looking at Nooksack, Skagit, Stillaguamish, Snohomish, Nisqually, Skykomish and Elwah looking at amount of sediment loads. Scaled by area's potential to receive marshes. Stilly and Nisqually are receiving very little sediment to marshes. Skagit is receiving huge amounts of sediment.
Sediment export in the Skokomish Delta at about 10 times higher than the Holocene period. This represents lost resource for deltas to keep pace with sea level rise. This greatly disrupts salmon recovery goals, shellfish, and water quality.

One hundred years of sediment from the Skagit are causing a loss of eel grass. In 2014, 70 percent of the flow and sediment out of the Skagit was settling out to cover eel grass beds.

We have been mapping a lot with sonar and Lidar looking at metrics of sediment aggradation. The Skagit River channel, which has never been mapped in a continuous way, is currently being mapped with detail. Comparing 30 transects across Skagit.
the entire complex since 1975 we are seeing steady aggrading by as much as 10 feet in a few places. By and large the whole system is starting to aggrade. This results in lost marsh for salmon and coastal flood risk protection.

Port Susan Bay of the Stillaguamish, Slide #13, shows sediment obstruction and restoration and how this creates lost marsh for salmon and coastal flood risk protection. The first observed storm surge overwash of levee occurred in 2006.

We thought we knew that the Feb. 8, 2006 storm was the 100-year storm. March 10, 2016 was far worse. We are now developing a coastal storm modeling system (CoSMoS) to look 48 hours in advance at tides, atmospheric pressure, winds, stream flow, storm surge barometer readings, and wave heights to better be able to predict these things. We do have some storm surge models and are now developing them for all of Puget Sound. Meteorological forcing-barometric tide table predictions are part of the model.

Was March 10, 2016 a new 100-year event? 7 a.m. was the peak of the storm. Models in blue predicted what would happen on the Swinomish Reservation.
This redefined the 100-year storm. Sheer pressure mobilized coarse sand.

These storms have a tendency to erode what is needed for clams. Pocket estuaries are being affected/shrinking. What we are seeing is lost clam resources and shellfish in general. Wave modeling aides previous estimates of storm damage.

According to the Puget Sound Coastal resilience tool, which brings in more physical modeling, today’s storm surges raise tides over 13% of the time. This will increase 5-25% by 2050 and 2100.

We have measurements up to Mt. Vernon and Sedro-Woolley. High tides are reducing velocities of the river flows and causing sedimentation in unusual places.
Higher sea level rise and flooding projections are used as a planning tool. These high storm surges occur about 13% of the year, which adds to flooding, will occur 5-10 percent more often with sea level rise.

What will this do to groundwater? Vulnerability will occur to increased ponding, drainage, and saltwater intrusion. Three feet of storm surges on top of sea level rise will dramatically affect this. The elephant in the room is how are we going to respond when the water just cannot drain?

Sediments play a huge role in the Pacific Northwest because there is so much coming into a small basin. For example, there is five times more sediment power than in Chesapeake Bay.

Questions
How much have you taken population growth, sea level rise, and storm surges into account? Grossman: I acknowledge that many things are happening, but we are not yet in the position to bring in non-stationary, non-linear events.
Tribal Perspectives on Sea Level Rise
Plenary Speaker 4: Mr. Larry Campbell
Tribal Elder and Cultural Specialist, Swinomish Indian Tribal Community

My education is in my spiritual tradition and my traditional teachings. Went to WWU in political science. My degree is therefore in the social sciences. We need to bring our social scientists into these conversations. We need to bring PEOPLE into all this data.

Scientists often work in a bubble. It is important to get tribal issues into the studies so we don’t have to do competing studies. Asking the right questions is very important. Our people have a lot of knowledge. There is an opportunity to go into our community and see what our people are thinking.

Elected leadership decided that when climate change started hitting news we would not get into argument about whether it is or not happening. We focused on how to mitigate what is coming. We noticed 100-year storms happening every 5 years. What is happening is truly mind opening.

It has taken us 15 years to get to the point of delineating health indicators. Our goal is to take our ideas into action. A healthy community from a tribal viewpoint starts and ends with our families—tribal relationships and tribal priorities. This includes physical, social, mental, and spiritual health on individual, familial and community levels, as well as relations between people, the environment, and natural resources.

*We are still a fishing, hunting, and gathering society.* This is difficult because we are on reservations. We are grateful for fishing that enables us to extend our reservation boundaries. If the environment is sick, tribal people are going to be sick.

**Concepts important to our people:**
1) Community connection (work, sharing, relations),
2) Education (the teachings elders, youth),
3) Cultural use (respect and stewardship, sense of place, practice),
4) Natural resource security (quality, access, safety),
5) Self-determination (healing and restoration, development, trust),

The federal government tried to make farmers of us, even though we are fishermen. It is a long slow process, but we have continuity for a long time of elected leaders. Lot of intergenerational pain we are trying to overcome. Trying to develop trust within our community and around us. We are starting to make our presence felt. In 1974 because of the Boldt Decision the State of Washington *had* to consult with the tribes and we then had to develop our scientific capabilities to step up to that consultation.
There is so much teaching—take what you need and leave the rest for your brothers. All of the tribes right now are preparing for the first salmon ceremonies to show that we still have respect for salmon people.

If we do our ceremonies and follow those ancient ways of life, we will do OK. We as tribal peoples are not going away. We are dedicated to our land and our families. 85% of the Swinomish live within a short distance (one and a half hours) of our reservation. We want to help our young people be strong.

We must have access to our natural resources. It irritates us to have to get federal and state land managers to get things like cedar bark collection permits, etc. It makes us stronger to follow the ways of our ancestors so we do this, but it is irritating. We will be successful no matter what we do if we stay tied to our ancestral roots. Our community needs to work with scientists to take care of our resources and all of North America. Extinction is not an option.

**Natural Resources Security**

We wouldn’t be who we are without natural resources. Salmon, deer, elk, clams and oysters are major. These offer food and economic support. But more than that, it’s our culture. My heart feels right gathering seafoods during the right seasons.

If the Health Department puts out a warning not to eat the clams, our spirit is as important as our body. We will eat the clams anyway.

**Question**

How do we keep the tribes involved in the process?

Campbell: Each tribal community is different. Pinpoint each of their concerns and they will buy into that process. We will buy into the scientific process. It is our hope that science, including the social scientists, keep sight of our work.

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