Probabilistic Scenarios of Sea Level Rise (SLR) along the California Coast

a product of the California 4th Climate Assessment

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Thanks:
- California Energy Commission and Guido Franco
- NOAA Office of Global Programs CNAP RISA
- USGS via CASCaDE II and Southwest Climate Science Center
- Robert Kopp, Rutgers University
- SL Expert Panelists: R. Flick, J Severinghaus, H. Fricker, G. Griggs, E. Rignot, T. Pfeffer, R. Kopp

California's Fourth Climate Change Assessment

The Fourth Climate Change Assessment is (the first) inter-agency effort to implement a substantial portion of California's recently released *Climate Change Research Plan, which* articulates near-term climate change research needs to ensure that the state stays on track to meet its climate goals.

The Fourth Assessment builds on the success of three prior assessments to address California-specific policy questions and information needs…. This latest assessment is being supported through two funding sources, one managed by the California Energy Commission (CEC) and another by CNRA. The former focuses on energy-related research needs and the latter on non-energy research needs.

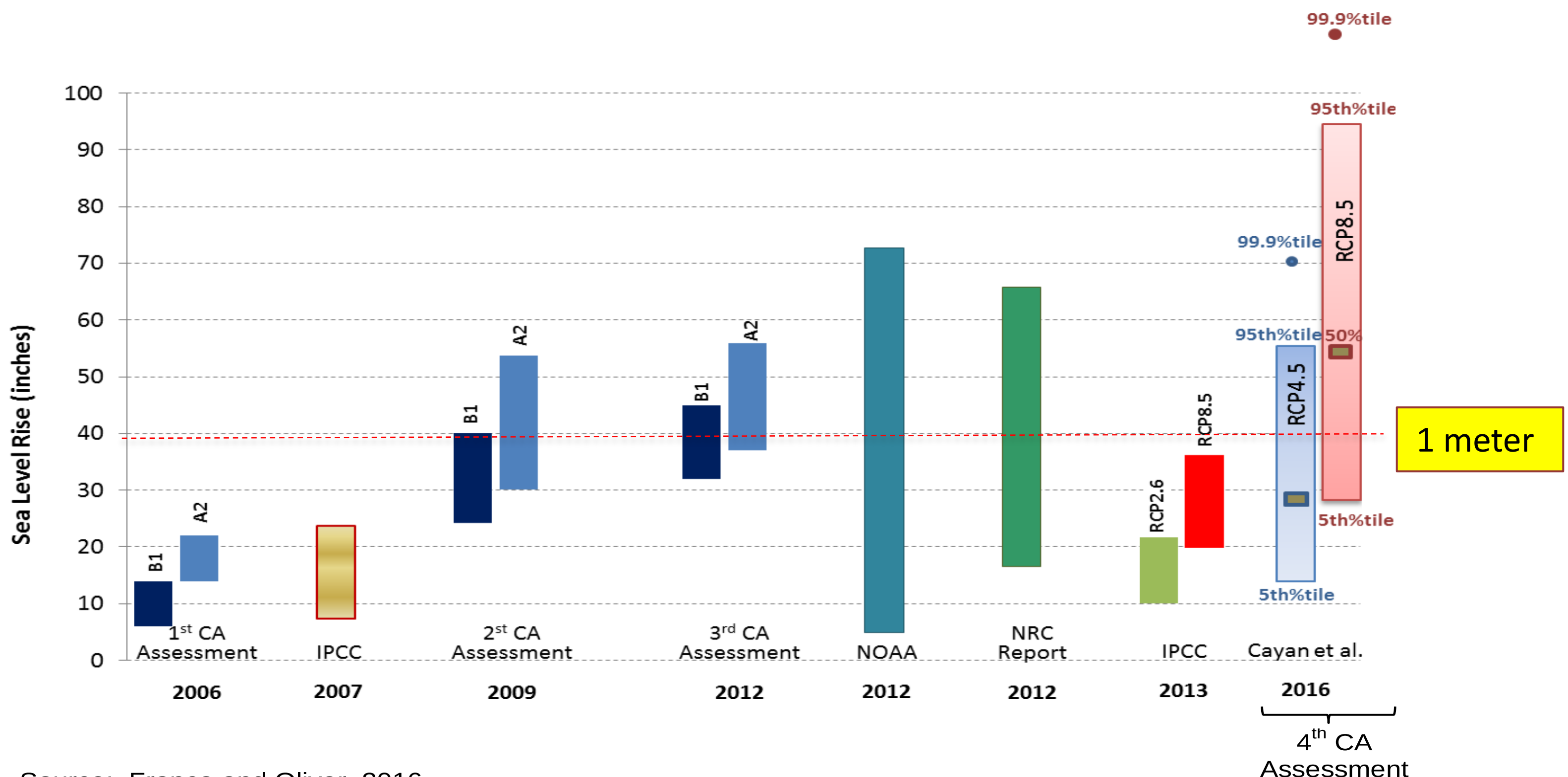
http://resources.ca.gov/climate/fourth/

working figure
Guido Franco, CEC

Sea Level Rise Projected Amounts from ~2000 to 2100

4th Assessment Sea Level Rise Recommendations

Rahmstorf, 2009. If a value representing the 99.9th of the probability distribution would have been used, the upper limit for the 2012 Assessment would have been much larger. In the figure below the filled bar for the values reported by Cayan et al. (2016) represent about the 95th percentile at the top of the bars and the 5th percentile at the bottom. The 99.9th (blue dots) and 50th percentiles (small rectangles) are also included in the Cayan et al. (2016) bars.



Source: Franco and Oliver, 2016

Figure 4 Sea Level Rise Projections of Relevance for California Since 2006

Probabilistic SLR Scenarios for California Methodology

Scenarios for California 4th Assessment and CASCADE

these are not the State of California Sea Level Guidance

- Use Global Climate Model results from different climate scenarios (e.g., RCPs INDCs)
- Use contributions from major components from various methods to estimate total SLR:
  (Thermal Expansion, Glaciers and Icecaps, Land water storage change, Greenland, Antarctica).
- Use new ice sheet analyses/modeling of Antarctic contribution to global SLR
  DeConto and Pollard 2016
- Use estimated probabilities from : observational measures, models, expert opinion
  (modern and paleo records, process experiments, GCM projections, and expert opinion as presented, e.g., in (Kopp et al. 2014; Mengel et al 2016)
- Construct hourly Sea Level over 21st Century at selected California coast locations
  GCM weather and short period climate, along with predicted tides to derive hourly projections to be combined with regional SLR trends.

Sea Level Rise Science and Projections--Growing Rapidly

Probabilistic Projections:

•Schaeffer, M., W. Hare, S. Rahmstorf, and M. Vermeer, 2012: Long-term sea-level rise implied by 1.5°C and 2°C warming levels. *Nature Climate Change*, doi: 10.1038/nclimate1584

•Church JA, et al. (2013) Sea level change. Climate Change 2013: The Physical Science Basis, eds Stocker TF, et al. (Cambridge Univ Press, Cambridge, UK), pp 1137–1216. (IPCC AR5 REPORT)

•Kopp RE, et al. (2014) Probabilistic 21st and 22nd century sea-level projections at a global network of tide gauge sites. *Earths Future* 2(8):383–406.

•Horton BP, Rahmstorf S, Engelhart SE, Kemp AC (2014) Expert assessment of sea-level rise by AD 2100 and AD 2300. *Quat Sci Rev* 84:1–6.

•Jevrejeva, S.; Grinsted, A.; Moore, J.C.. 2014 Upper limit for sea level projections by 2100. *Environmental Research Letters*, 9 (10). 104008. 10.1088/1748-9326/9/10/104008

•Kopp, R.E., Kemp, A.C., Bittermann, K., Donnelly, J.P., Gehrels, W.R., Hay, C.C., Mitrovica, J.X., Morrow, R.D., Rahmstorf, S. and Horton, B.P. **(2016).** Temperature-driven global sea level variability in the Common Era. Proceedings of the National Academy of Sciences of the United States of America. doi: 10.1073/pnas.1517056113.

•Mengel, M., Levermann, A., Frieler, K., Robinison, A., Marzeion, B. and Winkelmann, R. **(2016).** Future sea level rise constrained by observations and long-term commitment. *Proceedings of the National Academy of Sciences of the United States of America.*

•DeConto, R.M., and D. Pollard. 2016. Contribution of Antarctica to past and future sea-level rise. Nature, 531, 591-597, doi:10.1038/nature17145. http://www.nature.com/nature/journal/v531/n7596/full/nature17145.html

•Jackson, L. P. and S. Jevrejeva. (2016) A probabilistic approach to 21st century regional sea-level projections using RCP and high-end scenarios., *Global and Planetary Change*. doi: 10.1111/joes.12148

Other Studies

•Alley, K., T. A. Scambos, M R. Siegfried, H. A. Fricker. Impacts of warm water on Antarctic ice shelf stability through basal channel formation. Nature Geoscince **(2016)**

•Kopp, R., C. C. Hay, C. M. Little, J.X. Mitrovica. Geographic Variability of Sea-Level Change. Curr Clim Change Rep **(2015)**.

•Peltier, W.R., Argus, D.F. and Drummund, R. **(2015).** Space geodesy constrains ice age terminal deglaciation: The global ICE-6G_C (VM5a) model. Journal of Geophysical Research – Solid Earth, 120 (1), 450-487. DOI: 10.1002/2014JB011176

•Paolo, F. S., Fricker, H. A. & Padman, L. Volume loss from Antarctic ice shelves is accelerating. Science 348, 899903 (**2015).**

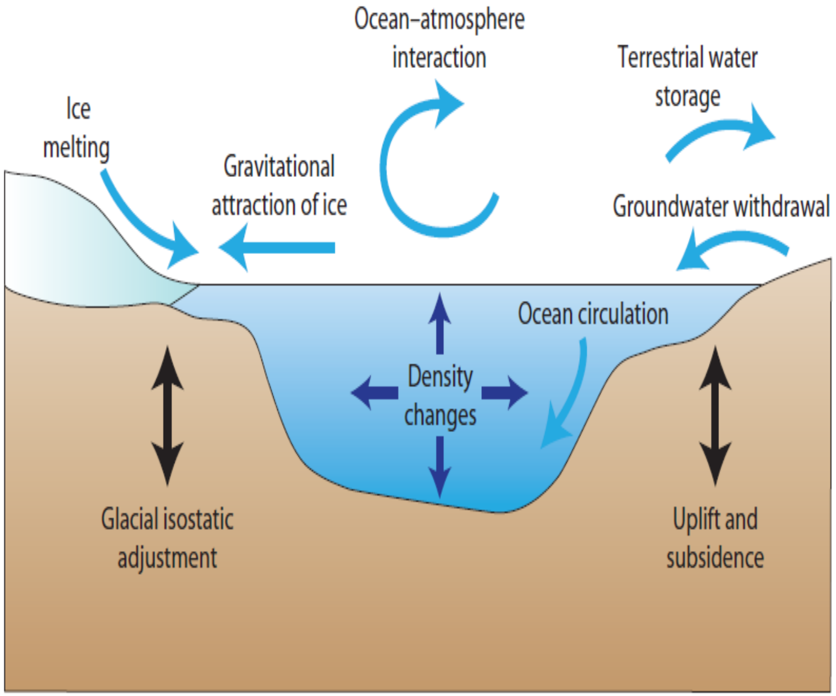
•Marsh, O. J. et al. High basal melt rates forming a channel at the grounding line of Ross Ice Shelf, Antarctica. Geophys. Res. Lett. 43, 250255 (**2015**).

•Bamber J L and Aspinall W 2013 An expert judgement assessment of future sea level rise from the ice sheets Nat. Clim. Change 3 424–7

Components of Global and Regional Sea-Level Rise

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

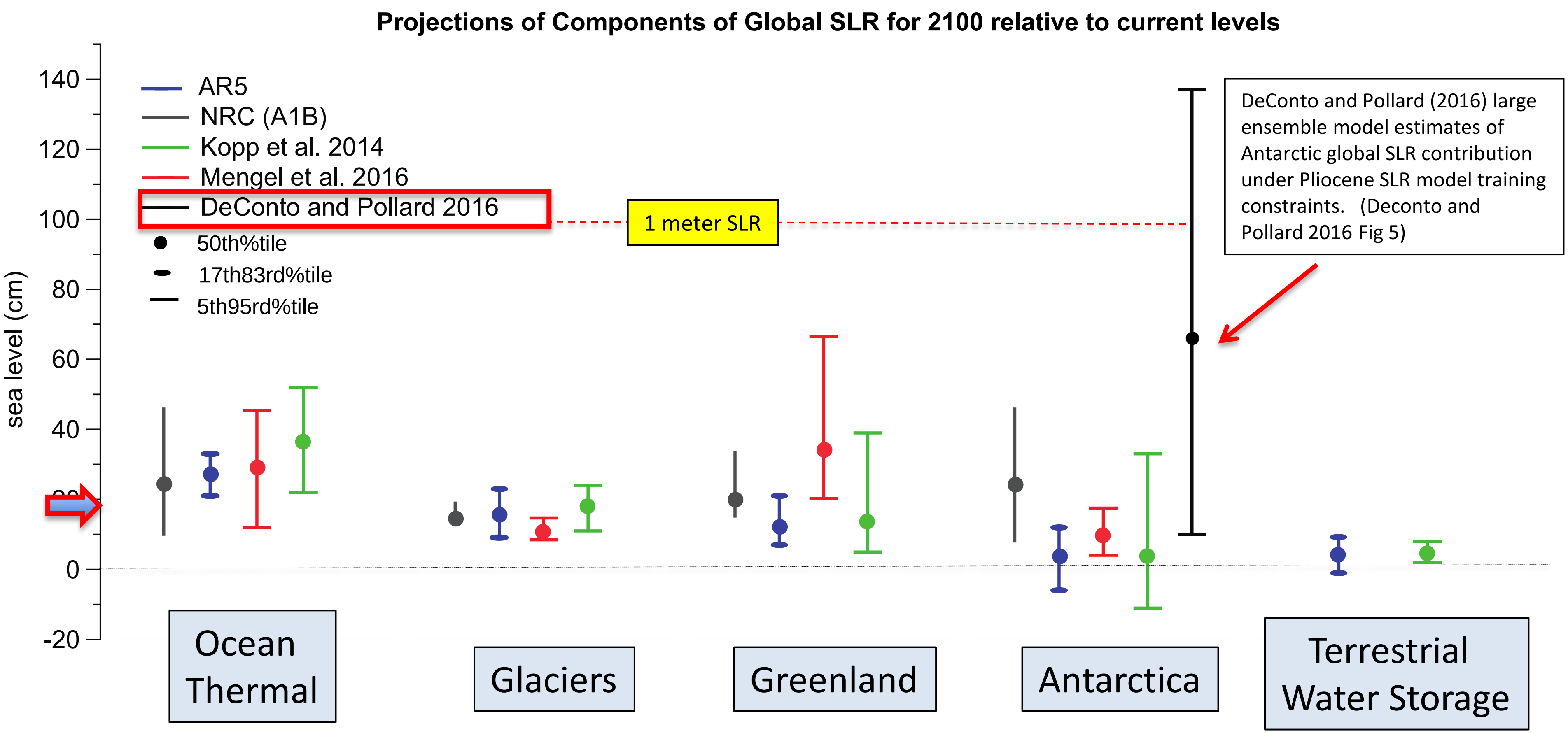
- Global sea-level rise
- Atmosphere-ocean circulation patterns in the Pacific (e.g., El Niño), which affect ocean levels
- Melting of modern and Ice Age glaciers and ice sheets, which affect ocean and land levels
- Tectonics and fluid withdrawal/recharge, which affect land levels



National Research Council
West Coast SLR Report, 2015

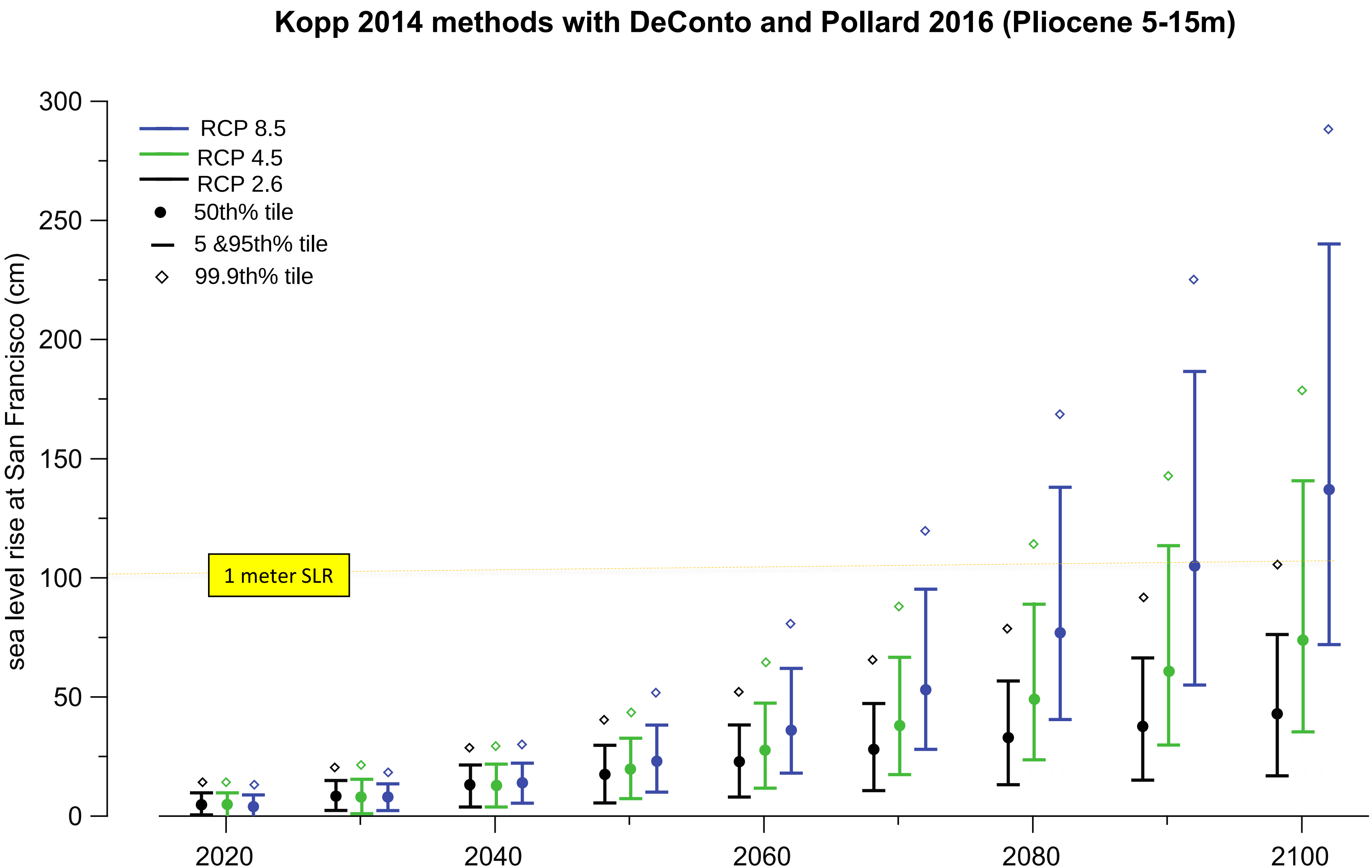
Projected Probabilistic Contributions to Global SLR

for 2100, RCP 8.5 includes DeConto and Pollard 2016 Antarctic model “a/b”



SLR probabilities under 3 different climate scenarios San Francisco, California

Thanks Robert Kopp, Rutgers University

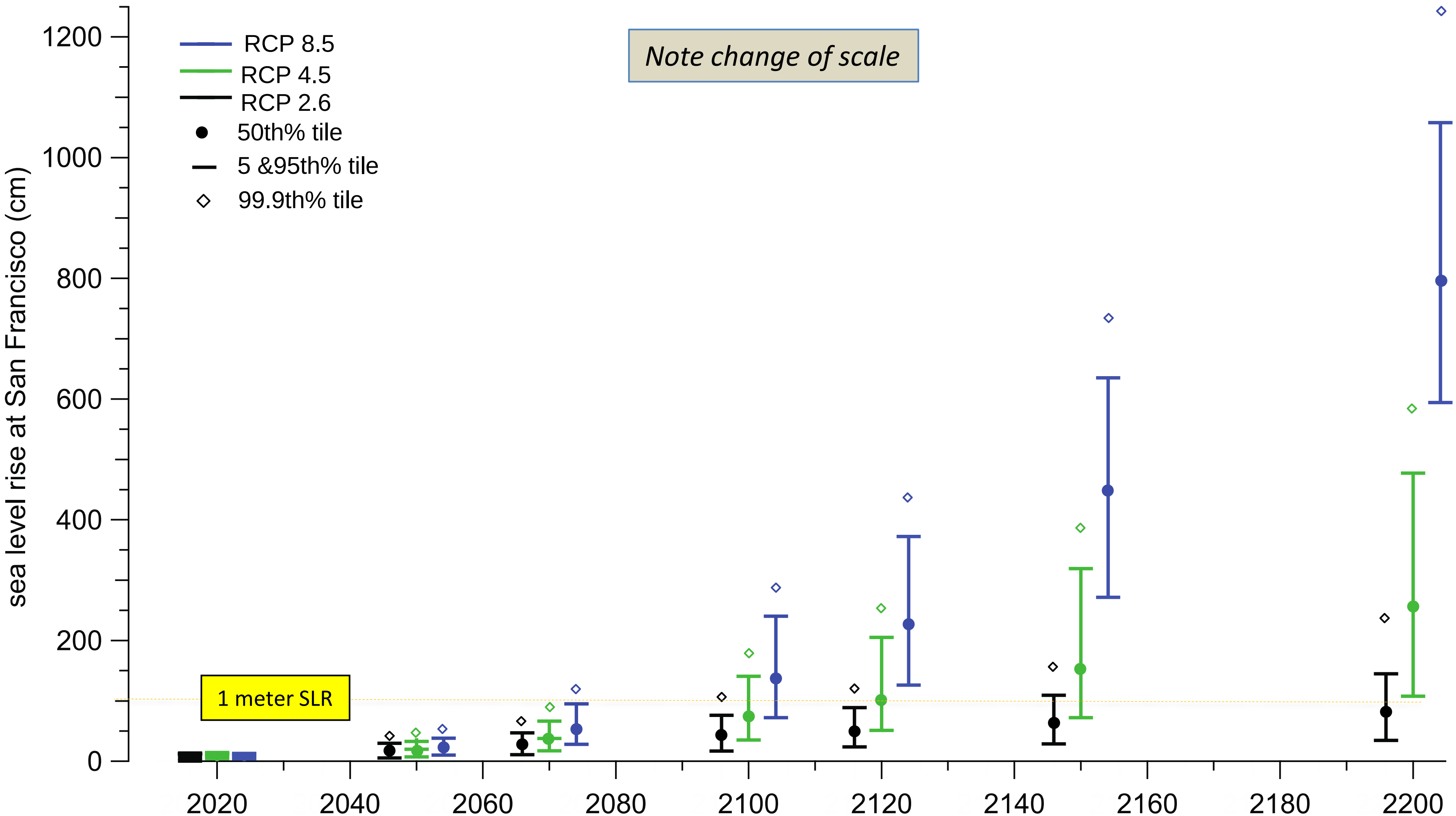


SLR probability envelope from 3 different climate scenarios

Probabilistic Estimates of SLR through 2200 *San Francisco*

Thanks Robert Kopp, Rutgers University

Kopp 2014 methods with DeConto and Pollard 2016 (Pliocene 5-15m)



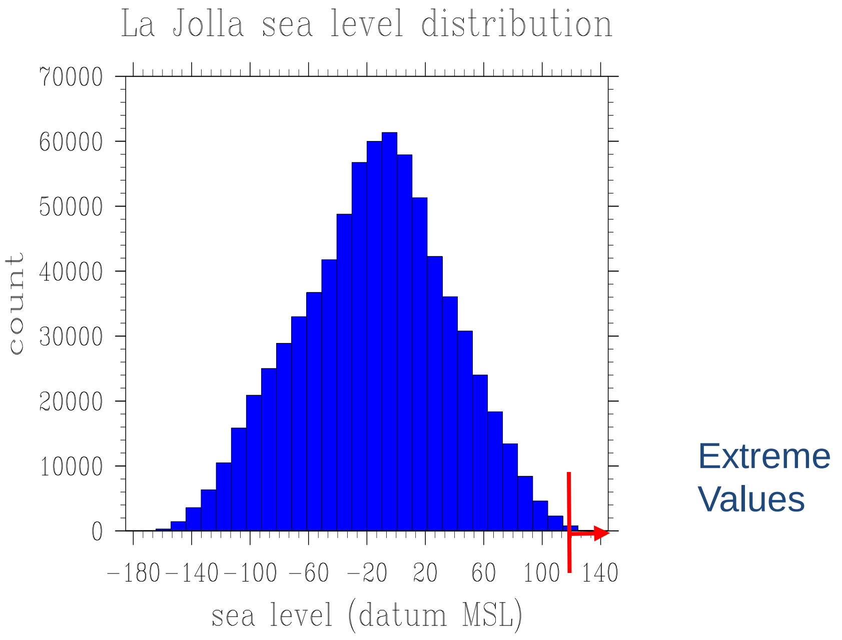
Extreme tail of sea level distribution

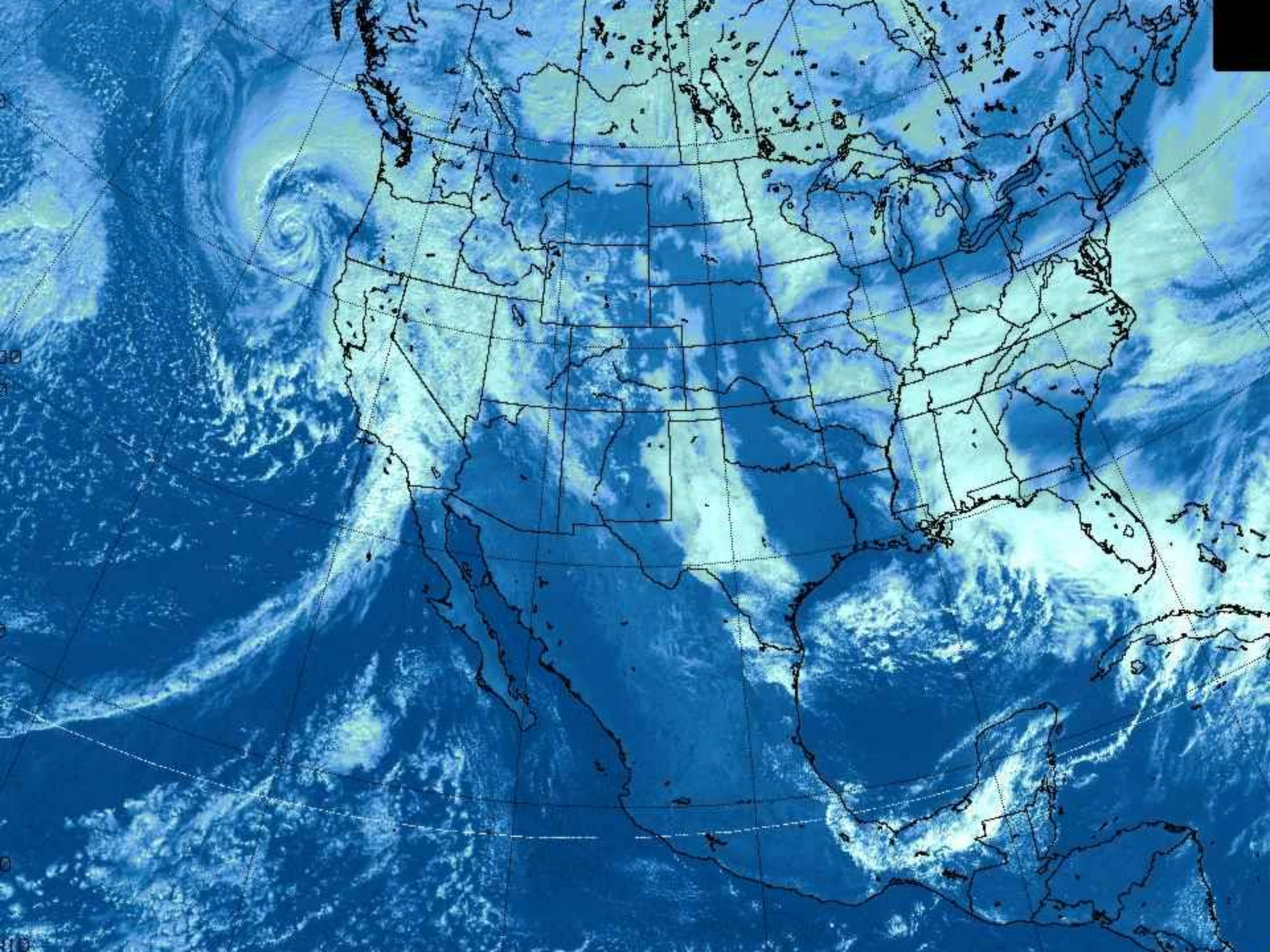
range of Sea Level ~3m
during the last 4 decades

very highest SL's >1.2m above mean

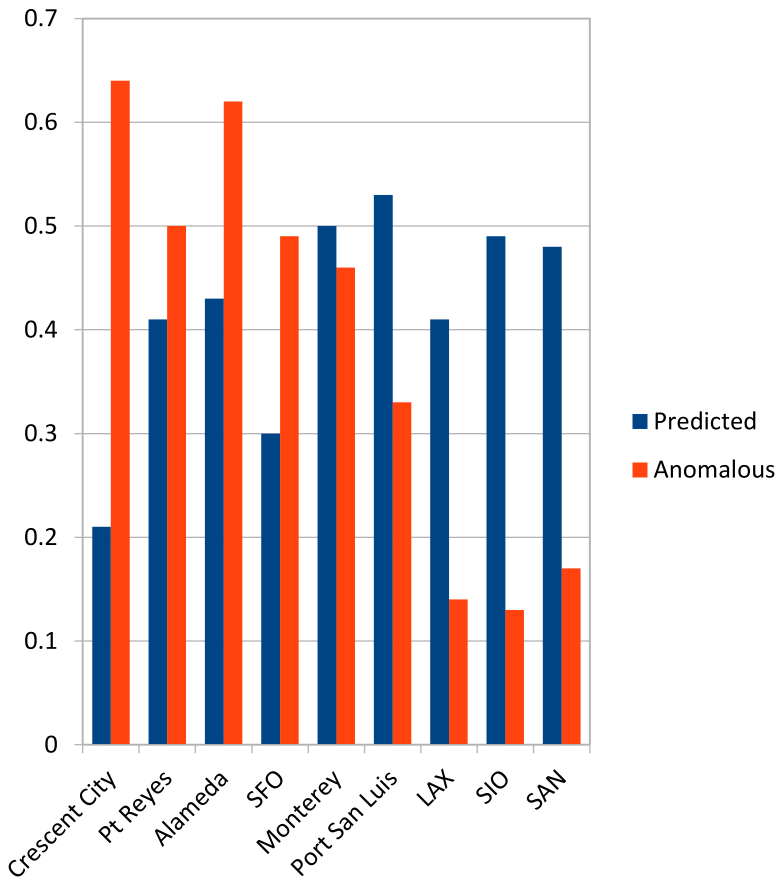
-top 0.01% of all hourly values (either absolute or anomalous)

-on average, that's about 1 hour every 14 months





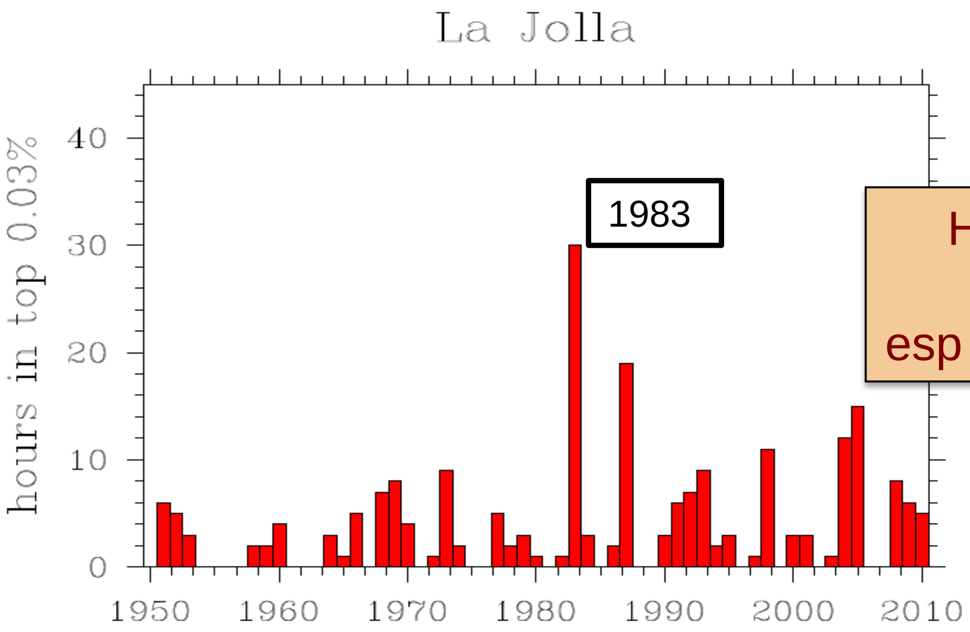
Extreme high sea levels often, but not always coincide with extreme high astronomical tide



- Along southern California coast, most extreme sea levels occur during peak astronomical tides.
- But along northern California coast, extreme sea levels are often *not* during peak astronomical tides. *In other words, heavy weather conditions drive the majority of extreme sea level events in the north.*

Extreme sea level occurrences La Jolla

observed at or above 99.99% historical hourly threshold 1.41m above mean



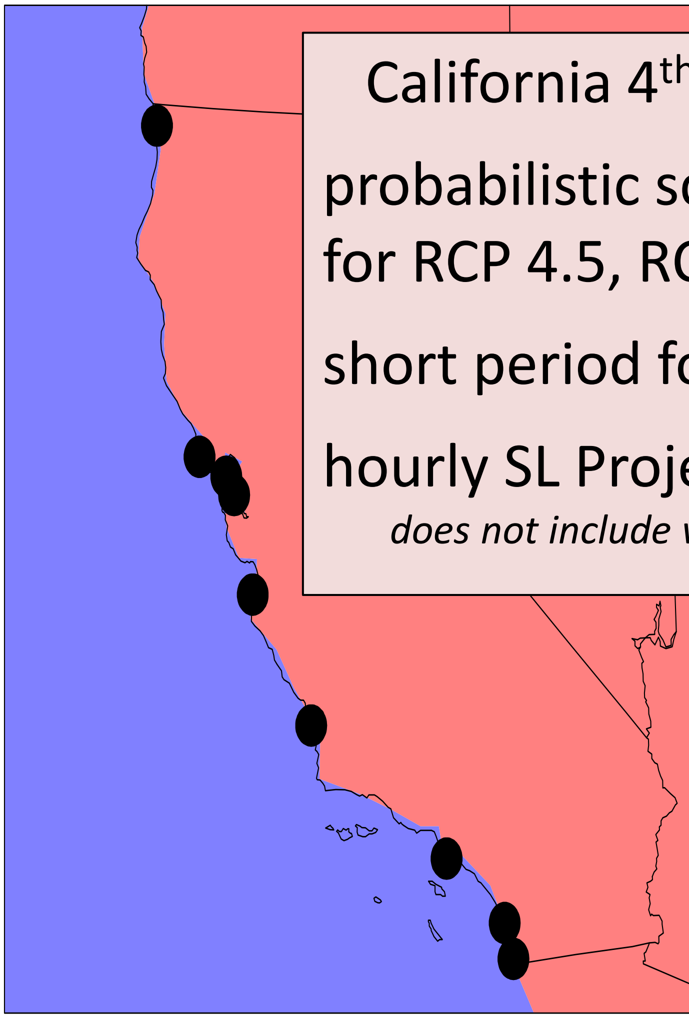
Highest sea levels have mainly occurred in just a few years, esp large El Niños (e.g., 1983)

Projections of Hourly Sea Level Height at California Tide Gage sites

Combination of:

- Astronomical Tide
  - well known and easily obtained
  - assume same constituents as today
- Global Sea Level Rise (SLR)
  - use range of assumed SLR trends based on recent studies
- Include Regional SLR effects
  - Vertical land motion
  - -gravitiy.
- Oceanic/Atmospheric Contribution (storms, El Nino, regional climate)
  - use climate model projections of atmospheric and oceanic conditions (2 emission scenarios RCP4.5 and RCP8.5)
  - in synch with GCM weather
  - relate to sea level using historical observations

Station Locations



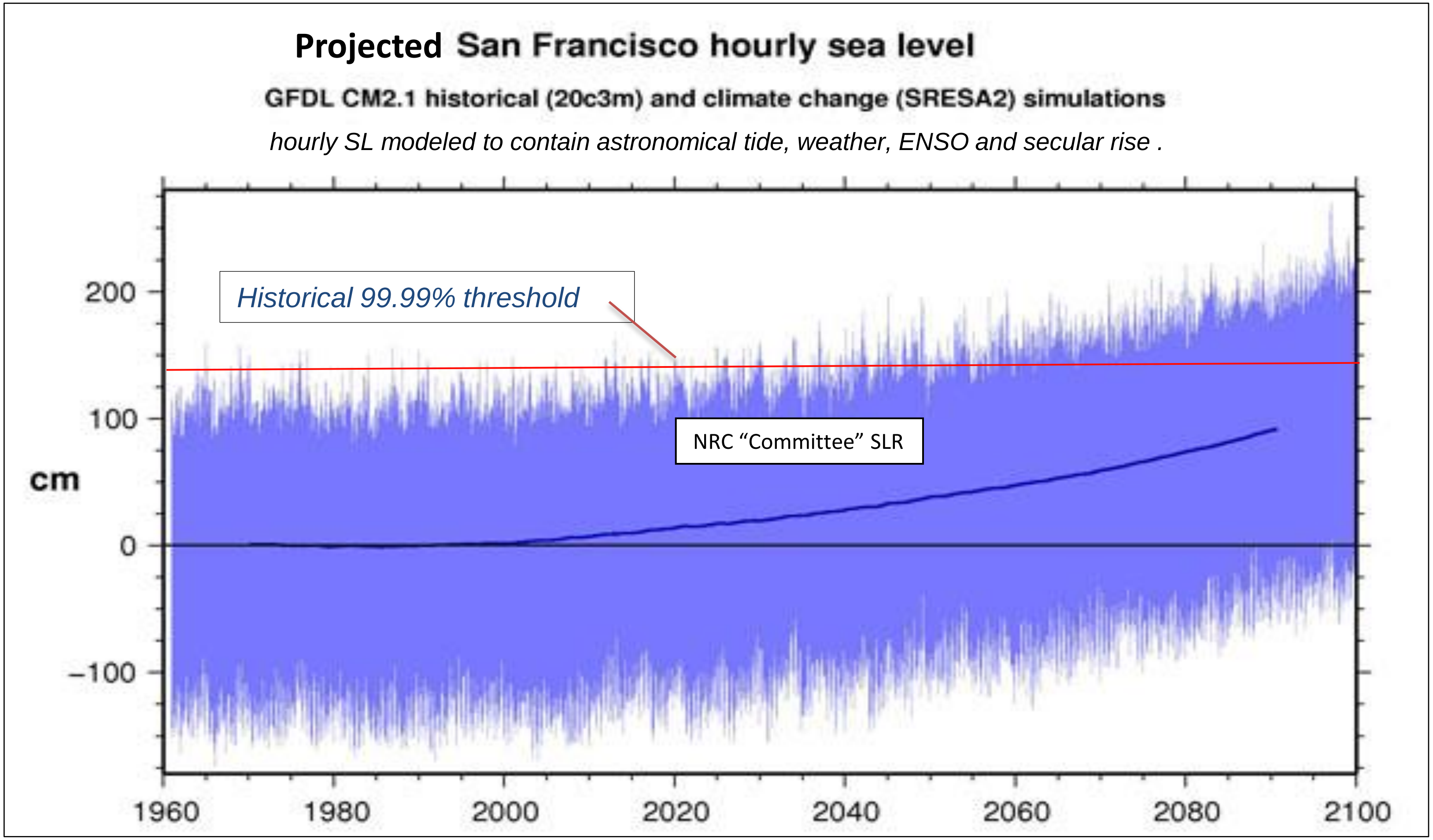
California 4th Climate Change Assessment and CASCaDE

probabilistic scenarios of SLR: 50th, 95th, 99.9th %ile SLR for RCP 4.5, RCP 8.5

short period forcing from 8 GCMs

hourly SL Projections 1950-2100 9 sites

does not include wave height or wave run- up



NRC Committee scenario:
SL rises ~1m during 2000-2100

hourly extremes increase along with mean sea level.

Cayan, D.R., P.D. Bromirski, K. Hayhoe, M. Tyree, M..D. Dettinger and R.E. Flick 2008: Climate change projections of sea level extremes along the California coast. *Climatic Change*, **87**, (Suppl 1):S57-S73,

Key Points

- Scenarios for California 4th Assessment and CASCaDE, "probabilistic", dependent upon global emissions pathway, aligned with GCM simulations, hourly 1950-2100

  These Scenarios do not replace the State of California Sea Level Guidance

  SL projections will be available on Cal-Adapt or contact Cayan or Kalansky

- Sea-level in California (south of Cape Mendocino) expected to rise considerably by 2100, about the same as global sea-level rise. Considerable variability across weather-multi-decade time scales in addition to secular GHG-forced rise

- SLR literature and findings are rapidly evolving ==> *uncertainty* in forcings, processes, rates

- In short range, greatest problems when large winter storm coincides with high tide. Historically, highest sea level and wave events have happened preferentially in El Niño years. SLR will magnify the adverse impact of storm surges and high waves.

- SLR uncertainty grows in future, especially the upper tail. But earth is committed to SLR , probably for many centuries.

- There are a wide range of projected SLR (1' to more than 6' by 2100) , so an adaptive strategy for preparation seems prudent.