Severe Storms and California's Fragile Delta—Historical Impacts and a New Monitoring Network

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Problem: Over the past century, California's Sacramento-San Joaquin Delta has been re-engineered to be an important center for water supplies, utilities and transportation, and agriculture. As important and engineered as it is, the Delta is also an increasingly fragile system with aging levees, subsiding land surfaces, declining ecosystems, and many invading species. Severe storms and floods pose great risks to the levees and other infrastructures in the Delta, but have necessary roles in biogeomorphological processes that will need to be restored if ecosystems are to be protected and restored. Of particular concern are severe storms associated with atmospheric rivers (ARs) that, since 1950, have caused 80% of major floods, 76% of inundations of the Yolo Bypass floodplain, and 81% of levee breaks in the Central Valley.

Approach: Because of the critical role of severe storms and especially ARs in the Delta, a new severe-storm monitoring network is being implemented across the Delta catchment and much of California by the Department of Water Resources, NOAA, and Scripps Institution of Oceanography. The network is intended to provide more precise now-casting of critical but previously under-monitored storm characteristics, like rapidly evolving snowlines, barrier jets, and patterns of moisture transport into the State, characteristics that will enable enhanced storm- and flood-forecasts.

Results: The network is now nearly complete, and relies on new radar, sounder, and GPS technologies installed strategically throughout the State. The network has room for additional technological extensions, including some being demonstrated in upcoming field campaigns flying research aircraft offshore into the hearts of approaching ARs.

Conclusions: The network–especially in the context of a new science center at Scripps focusing on extreme weather and water events--constitutes a major step toward enhancing California's ability to anticipate and manage both flood benefits and flood risks in the Delta and its watershed.

Keywords: storms, monitoring, floods, levees, climate
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The Next Generation of 21st Century Coastal Flood Maps for San Francisco Bay

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Climate change over the course of the 21st century and beyond will have significant physical and socioeconomic impacts on the low-lying San Francisco Bay margin due to sea level rise (SLR) and the potential variability in storminess and tributary discharge. Most studies of coastal flooding vulnerability in the region consider sea level rise only, typically applying a bath-tub type approach, which omits several key physical-forcing factors that elevate flood levels, such as in-Bay generated waves and fluvial discharge. Here we present a new modeling approach that considers all the relevant factors that contribute to San Francisco Bay flood extents during the 21st century, and highlight areas of the Bay that are highly susceptible to present and future flooding.

The Coastal Storm Modeling System (CoSMoS) is a numerical modeling system developed to predict coastal flooding due to both SLR and plausible 21st century storms. CoSMoS applies a predominantly deterministic framework that encompasses large geographic scales (100s to 1000s of kilometers) yet reduces flood extents to fine-scale local resolution (2 m) so that storm related changes in water levels at the shore can be resolved. Several important processes contribute to total water levels within the Bay. Specifically, efforts were made to incorporate water level fluctuations in response to trapped coastal waves, low pressure systems, ocean swell energy penetrating through the Golden Gate, breaking of locally wind-generated waves, and backflow induced by river discharge. The end product is a web-based tool (www.prbo.org/ocof) where users can assess variations in flood extent, maximum flood depth, maximum current velocities and wave heights in response to a number of potential SLR and storm combinations.

Keywords: climate change, flooding, modeling, San Francisco Bay, waves
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The Diminishing Odds of 'Normal' Snow Packs as California Warms

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A substantial portion of the inflow to the San Francisco Bay and Delta derives from mountain snowmelt, but California snow packs vary considerably from year to year. Year-to-year values of spring snow water content has varied, historically, by a factor of nearly 10 (as estimated from VIC hydrological model simulations). This variation has been due mostly to interannual precipitation fluctuations, and only incrementally from temperature fluctuations. However, this mix of precipitation and temperature influences is projected to shift. As climate warms, which is very likely as atmospheric greenhouse gas concentrations increase, the spring and early summer snowpack will decline substantially. The effects of projected climate changes on the odds of various snow pack volumes is being explored using an ensemble of downscaled climate-change projections under two emissions scenarios. With this ensemble, we can address important questions like: *a)* How do the odds of obtaining spring snow-water volumes that meet or exceed the historical median change with time or, as usefully, with level of warming? *b)* And even more pressingly, what are the odds that the snow pack is very small in any given year? Among the projections included in this ensemble, warmings range from +1°C to more than +3°C by 2100. Projected precipitation shows the "normal" high level of year-to-year variability over the region with very modest trend, much like the historical record. Although precipitation fluctuations continue to contribute strongly, the temperature influence in diminishing spring snowpack becomes increasingly strong as the 21st Century unfolds. Notably, the simulated dependence of California-wide spring snow water content on seasonal temperature change is nearly linear over the range of changes represented in the ensemble, and a rule of thumb that emerges is that California loses about 25% of present-day spring snow pack for each 1°C of warming.

Keywords: snow, runoff, climate change
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Implications of Water Temperatures from Climate Change Projections for Delta Smelt in the Sacramento-San Joaquin Delta, California

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We assessed the possible effects on Delta Smelt *Hypomesus transpacificus* of water temperatures calculated from four 100-year scenarios of climate change at nine locations in the Sacramento-San Joaquin Delta. Results from two regional climate models at two levels of greenhouse gas emissions were used to calculate water temperatures, using location-specific regression models. We compared modeled daily maximum water temperatures to recently derived laboratory measurements of thermal maxima for four life stages of Delta Smelt: larvae (March-June), juveniles (June-December), adults (December-March), and spawning adults (March-May). We also compared modeled average daily water temperatures to 25°C, a temperature beyond which few Delta Smelt are captured in surveys. The juvenile life stage was the most vulnerable to climate change because of high summer water temperatures particularly in July and August. The upper San Joaquin River upstream of Stockton was the most unfavorable area for juveniles with temperatures exceeding the chronic lethal thermal maximum (CLTmax) for 50 percent mortality (27°C) under even the mildest climate change scenario. The Sacramento River corridor was more favorable but water temperatures still exceeded the threshold at times. The CLTmax for 95 percent mortality (28°C) and the critical thermal maximum (CTM; acute mortality) (29°C) were rarely exceeded except in the upper San Joaquin River. For the most severe scenario, beyond 2060, the CLTmax for 95 percent mortality or critical thermal maximum of juveniles was regularly exceeded for several days per year at all sites, except in Suisun Bay. Exceedances of the 25°C threshold were more common than exceedances of lethal temperatures, suggesting the 25°C threshold may be an indicator of behavioral avoidance of areas likely to become lethal. Our results suggest that climate change is likely to reduce available habitat for Delta Smelt.

Keywords: Delta Smelt, climate change, water temperature, thermal tolerance
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Water Temperatures in the North Delta: What Does the Future Hold for Delta Smelt?

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The Northern Sacramento-San Joaquin Delta is a vital confluence for the endangered Delta smelt *Hypomesus transpacificus*, associated habitat restoration proposals, and potential future hydrologic changes related to climate change and water management proposals. Current climate change forecasts indicate potential changes in habitat parameters including sediment, turbidity, and water temperature. These climate change forecasts, coupled with physiological limits for sensitive species such as the Delta smelt, suggest decreasing habitat into the future. The forecasts thus far, however, are spatially limited and do not consider potential thermal refugia. Additionally, water temperature at a particular location is controlled by atmospheric conditions, tidal dispersion, and riverine flows, but current water temperature forecast models do not consider freshwater flow as a variable. Given the climate forecasts for reduced snowmelt and more frequent, longer duration drought conditions, the effects of low freshwater flows on North Delta water temperatures should be considered. This presentation will discuss the water temperature characteristics from multiple continuous monitoring locations in the North Delta specifically from 2011 (a wet year) and 2014 (a critically dry year) while connecting potential implications of future management proposals and comparing water temperature models to observed conditions. Cooler, favorable water temperatures in 2011 were a result of higher flows. In contrast, during 2014, in Miner Slough, water exceeded the favorable temperature threshold for Delta smelt as early as April and exceeded 20^{o}C and pushed 24 ^{o}C as early as May. Daily average water temperature data exceeded the temperature model forecasts for the most extreme climate scenarios in upstream locations such as in Upper Cache Slough and Miner Slough, indicating the importance of low freshwater flows (not considered by the models). Vertical water quality profile data collection efforts from April to September 2014 will also be discussed in regards to potential thermal refugia during spring and summer months.

Keywords: water temperatures, North Delta, Delta smelt habitat
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