

AI Generated Briefing: Overview of Climate Science in the Sacramento-San Joaquin Delta

Prepared Using Google NoteBookLM to Inform the Delta Independent Science Board's 2025 Climate Symposium

April 23, 2025

As part of its legislative mandate to provide scientific oversight of adaptive management, the Delta Independent Science Board (Delta ISB) seeks to stay informed on pressing and important topics affecting the Sacramento-San Joaquin Delta system. There is a timely need for Delta ISB members, the scientific community, and public at large to better understand the **rapidly evolving science** of ongoing and anticipated climate change impacts to the Delta region. While there has been a significant amount of research on climate change in the region, it is a quickly changing field so it is important to stay current with the latest developments. To help achieve this, the Delta ISB will host a two-day symposium in the fall of 2025 to explore 1) the current climate projections for the region and related uncertainties, including the compounding and interactive effects of both climatic and non-climate drivers; and 2) how organizations in the Delta are incorporating the current knowledge of climate change into their decision-making and the impact on Delta communities.

The symposium will provide an opportunity for the Delta ISB to learn and review how the current state of climate science is being integrated into decision-making for analysis in the Delta, and how these approaches align with the latest research in the field. In particular, this symposium will help address the questions below.

Current Climate Projections for the region and related uncertainties.

1. What are the important climate drivers for planning under future conditions (e.g., atmospheric rivers, warming, droughts, and wildfires)?
 - a. What changes in these drivers are already being observed?
 - b. What changes in the drivers of regional impacts are expected in the future?

DRAFT (DO NOT CITE)

2. What are state-of-the-science projections for the Delta region based on existing climate scenarios (e.g., sea level rise, precipitation and temperature changes, extreme events), and what are associated ranges of uncertainty?
3. What do we know about the potential for compounding impacts (e.g., extreme precipitation, sea level rise, warming and changing runoff patterns), along with sequential events (e.g., rapid succession of atmospheric river events and mega droughts)?
4. How reliable are current downscaled climate products for regional application in the Delta region?
5. What if anything is missing from this information that needs to be incorporated into existing models used for decision-support (e.g., what are the gaps between projections of climate models and projections needed to drive other models)? How do we address and prioritize what is missing?

How organizations in the Delta are incorporating climate change into their decision making

1. How are organizations in the Delta region integrating climate projections and future impacts of climate drivers into planning?
2. What types of uncertainties and projections are most useful and critical for decision-support? How can understanding of evolving impacts and risks help to build resilience in the region?
3. Are the current and previous efforts to address climate change in the region adequate for enhancing resilience of the Bay Delta system?

As part of the planning process, members of the Delta ISB and the public suggested 50 key references that could help inform the symposium (see Works Cited). This briefing paper was created using NoteBookLM to summarize what might be known related to the above questions using the 50 references. NoteBookLM is an AI-powered research and note-taking tool from Google, designed to simplify complex documents through summaries. **These outputs have not been edited or endorsed by the Delta ISB.** This document is NoteBookLM's interpretation of the publications and not the Delta ISB's perspective.

Current Climate Projections for the Region and Related Uncertainties.

Prompt 1.1: Summarize information from the source documents about the important climate drivers for planning under future conditions (e.g., atmospheric rivers, warming, droughts, and wildfires), what changes in these drivers are already being observed, and what changes in the drivers of regional impacts are expected in the future. Use academic language and approximately 500 words.

Based on the source documents, several important climate drivers are critical for planning under future conditions in regions like the Bay Delta system. These include **warming temperatures altered precipitation patterns influenced by atmospheric rivers, increased frequency and intensity of droughts, and changes in wildfire regimes** [see all sources].

Observed Changes in Climate Drivers:

The sources indicate that **warming is already occurring** in the upper San Francisco Estuary, with an average rate of temperature increase of 0.017°C per year detected. This warming exhibits regional and seasonal variations, with some of the strongest trends overlapping with key life cycle periods of native fish. Globally and nationally, observations show that sea level rise is accelerating. California has already experienced over 0.5°C warming by 2016 relative to a 1986-2005 baseline. Furthermore, the frequency and intensity of heavy precipitation events have increased since the 1950s over most land areas with sufficient observational data. While the role of external forcing in North Atlantic sea surface temperature variability is evolving, understanding long-term climate variability is crucial. Changes in the timing and magnitude of streamflow, particularly in late winter and spring, are also being observed, impacting estuarine hydrodynamics. Wildfire seasons have lengthened, and fire regimes have been transformed globally due to changes in climate.

Expected Future Changes in Climate Drivers:

The **CNRA 2009 California Climate Adaptation Strategy** projects significant future warming in California, with temperatures potentially increasing by 2-5°F by 2050 and 4-9°F by 2100. Precipitation projections for Northern California generally indicate a drier future, with a potential decrease of 12-35% by 2050. Sea level is also projected to rise considerably, with estimates of 12-18 inches by 2050 and 21-55 inches by 2100. The **DSC Delta Adapts Climate Change Vulnerability Assessment 2021** emphasizes that future atmospheric concentrations of

DRAFT (DO NOT CITE)

greenhouse gases will follow a range of pathways, influencing future climate conditions in the Delta. Projections suggest that peak inflows to the Delta's major tributaries may increase substantially by mid- and end-of-century. Warmer storms are anticipated to produce more rainfall in higher elevation watersheds, potentially leading to larger and more frequent high discharge events on the San Joaquin River.

Regarding **atmospheric rivers**, climate change is projected to increase the risk of a megaflood scenario in California. Future warming is likely to bring about even sharper increases in this risk.

The risk of both **agricultural and ecological droughts** is expected to increase in some regions due to human-caused climate change, primarily driven by increased land evapotranspiration. The **Fifth National Climate Assessment Chapter 4 Water** indicates that climate change will continue to cause profound changes in the water cycle, affecting water input volume and movement. The concept of extremes, including drought, is also changing. Some studies suggest that drought assessment has been outpaced by climate change.

Future **wildfire regimes** are subject to considerable uncertainty, partly due to complexities in modeling fine surface fuel accumulation and decomposition. However, the overall trend suggests an increased likelihood of extreme wildfire conditions. Process-based fire regime models are crucial for understanding the feedbacks among climate, fuels, and wildfire under future conditions.

In summary, planning for the future must account for **significant and interacting changes in** warming, precipitation patterns influenced by atmospheric rivers leading to both increased flooding and altered inflow, a higher likelihood of more intense and prolonged droughts, and altered wildfire regimes. These drivers will have profound impacts on the Bay Delta system's ecosystems, water supply, infrastructure, and communities [see all sources].

Prompt 1.2: Summarize information from the source documents about state-of-the-science projections for the Delta region based on existing climate scenarios (e.g., sea level rise, precipitation and temperature changes, extreme events), and about associated ranges of uncertainty. Use academic language and approximately 500 words.

DRAFT (DO NOT CITE)

State-of-the-science projections for the Sacramento-San Joaquin Delta region indicate significant future climate changes with associated ranges of uncertainty across several key environmental drivers [see all sources]. These projections are crucial for informing adaptation planning and enhancing the resilience of the Delta system.

Sea Level Rise (SLR) is a critical concern for the Delta, with projections based on global models and regional factors. The **Ocean Protection Council (OPC) 2018 Guidance provides** likely ranges for SLR at the San Francisco tide station, considered representative of regional oceanic conditions influencing the Delta. By **2050**, a likely (66% probability) rise of **0.6 to 1.1 feet** is projected, with an upper-range (1-in-200 chance) of **1.9 feet**. By **2100**, the likely range is **1.2 to 3.4 feet**, with an upper range of **6.9 feet**, and an extreme scenario reaching **10.2 feet** considering rapid ice-sheet loss. The **NOAA 2022 report** provides similar scenarios, noting that regional SLR along the U.S. West Coast is expected to be lower than the global average. However, the **Delta Adapts Climate Change Vulnerability Assessment (CCVA) 2021** highlights that local sea level trends in the Delta are further complicated by **regional and local land subsidence**, particularly in diked islands with drained peat soils, which can increase the relative rate of observed SLR. The timing and magnitude of extreme SLR scenarios beyond mid-century carry greater **uncertainty** due to the complex dynamics of ice sheet melt and feedback mechanisms.

Temperature Changes in the Delta and its watershed are projected to be substantial and are characterized by greater consensus among climate models compared to precipitation. The Delta Adapts CCVA indicates **consistent warming trends** throughout the coming century. Spatial variability exists, but overall, average daily maximum temperatures are projected to increase across the Delta. While specific magnitudes vary depending on the emission scenario and timeframe (2030, 2050, 2085), the trend of **increasing temperatures** is robust. This warming is expected to affect water temperatures as well, with observed warming already documented in the upper San Francisco Estuary. **Uncertainty** in temperature projections arises primarily from the specific greenhouse gas emission pathway the world follows.

Precipitation Changes are the **least certain** aspect of climate model projections for the Delta region due to the models' limited ability to resolve fine-scale and complex local interactions. While some models suggest a slight increase in average annual precipitation across the Delta, the magnitude of these changes is small

DRAFT (DO NOT CITE)

relative to typical year-to-year variability. There is **greater consensus** among models that **interannual variability in precipitation** will increase due to climate change. Furthermore, warming air temperatures in the Sierra Nevada watershed are projected to cause a **higher proportion of precipitation to fall as rain rather than snow**, leading to a decrease in annual snowpack and an increase in the frequency and intensity of higher runoff events into the Delta, particularly in late winter and spring. Projections from the CVFPP Update suggest that peak inflows to the Delta's major tributaries may increase significantly by mid- and end-of-century. However, the exact timing and magnitude of these hydrological shifts remain a source of **uncertainty**, influenced by the complexities of atmospheric patterns and watershed processes.

Extreme Events are projected to be exacerbated by climate change in the Delta. Increased peak water levels and flooding are expected due to the combination of sea level rise and changes in watershed hydrology, potentially exposing hundreds of square miles of land to flooding by mid- and end-of-century. The risk of a **megaflood scenario** in California is also projected to increase. The frequency and **intensity of droughts** are also anticipated to rise, driven by increased land evapotranspiration due to warming temperatures. Changes in precipitation patterns, with potentially longer dry periods and more intense wet periods, contribute to this increased drought risk. Future **wildfire regimes** are subject to **considerable uncertainty**, but the overall trend suggests an increased likelihood of extreme wildfire conditions, which can impact air quality and potentially water resources in the Delta. Modeling fine surface fuel accumulation and decomposition contributes to this uncertainty.

In conclusion, state-of-the-science projections indicate a future Delta region characterized by higher temperatures, rising sea levels, and more variable precipitation, leading to an increased risk of extreme events such as floods and droughts. While the direction of these changes is generally consistent across different climate models and scenarios, the precise magnitude and timing, particularly for precipitation and long-term extreme events, remain subject to **significant uncertainty**. These uncertainties underscore the need for adaptive management strategies that can respond to a range of potential future conditions. The Delta Adapts initiative explicitly considers a broad range of climate futures and planning horizons to address these uncertainties. The "State of the Science" Regional Assessments are also intended to provide accessible information on these projections and uncertainties for stakeholders.

DRAFT (DO NOT CITE)

Prompt 1.3: Summarize information from the source documents about the potential for compounding impacts (e.g., extreme precipitation, sea level rise, warming and changing runoff patterns), along with sequential events (e.g., rapid succession of atmospheric river events and mega droughts). Use academic language and approximately 500 words.

The source documents highlight significant potential for **compounding climate impacts** and the occurrence of **sequential extreme events** in regions like California and the Bay Delta, posing substantial challenges for future planning. These interacting hazards can lead to impacts that are greater than the sum of their individual effects, overwhelming natural and human systems.

One critical area of compounding impacts involves the interplay between **sea level rise and extreme precipitation or storm surge**. As average sea levels rise due to climate change, future floods in tidally influenced areas of the lower San Joaquin and Sacramento river watersheds are expected to have increased peak water surface elevations, causing more damage. Even during dry conditions, the frequency and magnitude of emergency response actions are anticipated to increase as a result of sea level rise. Furthermore, the Fifth National Climate Assessment notes that the Atlantic and Gulf Coasts are projected to experience increases in compound flooding from rising sea levels that cause higher storm surge from stronger storms and heavier precipitation. This combination intensifies flood risks, impacting people, ecosystems, and infrastructure along coastlines.

Warming temperatures also exacerbate other climate-related hazards. Increased temperatures lead to higher evaporative demand, intensifying the severity and duration of **droughts**. The Delta Adapts assessment indicates that wildfire frequency and severity are expected to increase due to increased temperatures and atmospheric aridity, as well as more frequent and severe droughts. Moreover, drought-stressed watersheds become increasingly vulnerable to **wildfires**, leading to synergistic effects such as reduced erosion control and water pollution remediation. The combination of increasing drought risk and extreme precipitation can also elevate the risk of extreme wildfire seasons followed by heavy precipitation, increasing the potential for post-fire hazards like debris flows and landslides.

Changes in precipitation patterns and warming temperatures are also projected to alter **runoff patterns**, compounding flood risks. Warmer storms are anticipated to produce more rainfall in higher elevation watersheds, potentially leading to larger

DRAFT (DO NOT CITE)

and more frequent high discharge events on rivers flowing into the Delta. This can coincide with high tides or storm surges, increasing the likelihood of compound flooding events. The "double whammy effect" describes how increased total precipitation from more intense atmospheric rivers, combined with a decreased snow-to-rain fraction due to warming, can lead to unexpectedly large increases in runoff volume.

The sources also highlight the significance of **sequential extreme events**. The **rapid succession of atmospheric river events** can lead to compound precipitation extremes and significantly increase flood hazard, as demonstrated by scenarios like ARkStorm. Climate change has already increased the risk of such megaflood scenarios in California, and future warming is likely to bring about even sharper risk increases. These multiweek sequences of severe winter storms can result in California-wide average cumulative precipitation representing a considerable fraction of the total annual precipitation, occurring during already anomalously wet water years, further elevating flood risk due to saturated soil conditions.

Furthermore, **mega droughts** followed by extreme floods represent another critical sequential hazard. Prolonged droughts can lead to stress and mortality in riparian vegetation, weakening their ability to stabilize riverbanks. If such droughts are followed by extreme floods, the already weakened species are more likely to succumb to bank erosion, potentially leading to levee failures and catastrophic consequences. The co-occurrence of extreme warm Northeast Pacific ocean conditions (marine heatwaves) and dry California conditions (drought) is also projected to become dramatically more frequent by the end of the 21st century due to anthropogenic warming and drying trends.

Understanding these compounding and sequential climate impacts is crucial for developing effective adaptation strategies and enhancing the resilience of vulnerable regions and communities. The interconnected nature of Delta assets and climate stressors means that cascading or cumulative consequences can threaten the region's economy, health, well-being, and natural environment. Planning and management efforts must therefore consider the complex interactions and sequences of these climate hazards to mitigate their potentially devastating impacts.

Prompt 1.4: Summarize information from the source documents about the degree of reliability of current downscaled climate products for regional application in the Delta region. Use academic language and approximately 500 words.

The source documents indicate that while downscaled climate products are essential for regional climate change vulnerability assessments in the Delta region, they come with inherent limitations and varying degrees of reliability. These limitations arise from the global climate models (GCMs) themselves, the downscaling techniques employed, and the complexities of regional climate processes.

For the Delta region, a common downscaling approach is the **Localized Constructed Analogs (LOCA) technique**. LOCA uses statistical relationships between large-scale climate stressors from GCMs and local, fine-scale physiographical and meteorological features to produce more detailed, place-based projections of climate variables like temperature and precipitation at a resolution of approximately 3.7 miles. The **Delta Adapts** vulnerability assessment heavily relies on LOCA downscaled data from Cal-Adapt, considering projections from multiple GCMs under different Representative Concentration Pathways (RCPs).

Regarding **temperature projections**, the sources suggest a relatively higher degree of confidence. There is a broad consensus among climate models projecting substantial warming trends in the Delta and its watershed throughout the coming century. **Delta Adapts** presents spatial variability of projected temperature changes, noting that while warming is expected across the Delta, localized effects might cause spatial variations. For instance, greater warming inland could potentially enhance cooling Delta breezes, partially offsetting temperature increases within the Delta itself. Bashevkin et al. (2022) also present temperature change rates based on model predictions within their study region, which includes portions of the Delta Plan Hydrologic Regions of Analysis (PHRAs). However, it's important to note that these are still model estimates.

Precipitation projections, on the other hand, are identified as the **least certain aspects of climate models for** the Delta region due to their inability to fully resolve fine-scale and complex local interactions. While some models suggest a slight increase in average annual precipitation across the Delta in the future, the magnitude of these changes is uncertain and small relative to typical year-to-year variability. There is greater consensus among models regarding an increase in

DRAFT (DO NOT CITE)

interannual precipitation variability due to climate change. **Delta Adapts** indicates that localized effects due to topography and proximity to the coast can cause variations in projected precipitation changes across different regions of the Delta.

The uncertainties in precipitation projections directly impact the reliability of **hydrological models** that rely on these projections to simulate runoff and streamflow into the Delta. While models like the one used for the Central Valley Flood Protection Plan (CVFPP) suggest potential increases in peak inflows to the Delta under future climate scenarios, these are acknowledged as areas of active research with limitations that could lead to over- or underestimations of actual future changes. The USGS's CASCaDE2 project also utilizes downscaled precipitation and temperature to model managed flows, but it recognizes limitations in representing the full response of freshwater operations to long-term climate trends. DWR's **Decision Scaling for Hydrological Risk to the State Water Project** employs a decision scaling approach to assess the vulnerability of the Central Valley Water System to a wide range of potential future climate conditions, acknowledging the uncertainties inherent in GCM projections.

Furthermore, the Fifth National Climate Assessment notes general uncertainties in evapotranspiration projections, which are influenced by complex vegetation responses to warming. This uncertainty can affect the accuracy of hydrological models in predicting water availability in the Delta.

In summary, while downscaled climate products like those generated using the LOCA technique provide valuable information for assessing climate change vulnerability in the Delta region, their reliability varies depending on the climate variable. Temperature projections exhibit greater consensus and thus higher confidence, while precipitation projections remain highly uncertain. These uncertainties propagate through hydrological models, impacting the reliability of projections for runoff, streamflow, and ultimately, water supply reliability and flood risk assessments in the Delta. Therefore, decision-makers should consider the inherent uncertainties associated with these downscaled products and utilize a range of scenarios and approaches, such as decision scaling, to inform robust adaptation strategies. The **Delta Adapts** assessment itself emphasizes that its results are based on modeling efforts and should guide the development of an adaptation strategy that involves input from diverse stakeholders.

DRAFT (DO NOT CITE)

Prompt 1.5: Summarize information from the source documents about what if anything is missing from the information included in the previous prompts that needs to be incorporated into existing models used for decision-support (e.g., gaps between projections of climate models and projections needed to drive other models), and how the missing pieces should be addressed and prioritized. Use academic language and approximately 500 words.

Drawing upon the provided sources and our previous discussions, several critical information gaps necessitate incorporation into existing models used for decision support concerning climate change impacts, particularly within the Sacramento-San Joaquin Delta region and California's broader natural and working lands. Addressing these deficiencies is paramount for enhancing the efficacy of these models in guiding robust adaptation strategies.

One significant omission pertains to the **detailed representation of ecological processes and their interplay with climate stressors, especially in off-channel habitats**. While temperature monitoring data exists for areas like Suisun Marsh and the Yolo Bypass floodplain, it has not been comprehensively integrated into local and regional modeling frameworks. This lack of integration limits our ability to accurately project climate change impacts on interconnected aquatic ecosystems and the diverse species they support. To address this, a prioritized effort should focus on **incorporating existing and future data from these off-channel habitats into relevant temperature and ecological models**. Furthermore, research should prioritize **monitoring keystone species, selected species, and species interactions** under changing abiotic conditions to better inform adaptive management. Understanding how zooplankton taxa interact with salinity and drought, as highlighted by Barros et al. (2024) and Hartman et al. (in prep), is crucial for informing fish release strategies and managing food web dynamics during drought.

A second critical gap lies in the **modeling of fuel dynamics within wildfire regimes**. Current land surface fire regime models often exhibit significant uncertainty in parameterizing and representing fine fuel decomposition, which can substantially affect projections of future wildfire under climate warming. To address this, **more empirical research focused on the mechanisms controlling decomposition is essential** to refine model development and reduce parameter uncertainty. Transparency regarding model choices and associated uncertainties in fuel accumulation processes is also needed. Moreover, the scope of fuel modeling

DRAFT (DO NOT CITE)

should be expanded to include understory and canopy fuel dynamics, which also drive extreme wildfire behavior.

The integration of groundwater and surface water interactions represents another crucial missing piece in some decision-support models, such as those used for the State Water Project. Decision scaling evaluations have identified the need for integrated groundwater-surface water modeling to provide a more detailed understanding of climate change risks and to explore the benefits of enhanced groundwater storage and recovery. Efforts should be prioritized to **develop and incorporate these integrated modeling capabilities** into existing water management tools.

Furthermore, many models may not adequately capture the complexities of **compounding and sequential extreme events**. The interaction of hazards like sea level rise with extreme precipitation can lead to impacts exceeding those of individual events [see previous prompts]. Future model development should prioritize the **incorporation of mechanisms that allow for the simulation and analysis of these interacting and sequential events to** provide a more realistic assessment of future risks.

From a broader perspective, there is a need to **improve the application of scientific information to policy and planning instruments** and enhance coordination across jurisdictional boundaries. Grant program guidelines should incorporate impactful climate adaptation criteria. Supporting essential data collection and information sharing is also crucial for performing and updating vulnerability assessments. This includes establishing baseline climate change data and common modeling assumptions across agencies, as well as centralizing database management. For instance, creating a complete and digitized inventory of managed lands with accompanying habitat information, as noted in the DWR Climate Change Vulnerability Assessment (2019), would significantly enhance vulnerability assessments of DWR properties.

Finally, **uncertainty in climate projections and model outputs needs to be communicated more effectively** to decision-makers. This involves clearly distinguishing between variability and uncertainty, acknowledging model limitations, and potentially using alternative methods like ember plots to represent unmodeled risks. Incorporating recommendations from independent climate change review panels into future CVFPP updates, as suggested in the 2022 CVFPP Update, is also vital for ensuring the scientific rigor of these models.

Prioritization of these missing pieces should be guided by the **potential impact on critical decision-making processes and the vulnerability of the Delta region and California's natural resources to specific climate change impacts**. Given the Delta's exposure to sea level rise, flooding, and water scarcity, improving the modeling of compound flooding events and the integration of groundwater-surface water interactions are likely high priorities. Enhancing the representation of ecological responses and wildfire risks are also crucial for long-term ecosystem health and safety. Implementing focused studies to address key data gaps identified in the 2022 Conservation Strategy Update should be prioritized within the next five years. Addressing the valuation of ecosystem services through research and estimating funding gaps for nature-based solutions are also important for effective policy and investment decisions. Underpinning all these efforts is the fundamental need for improved data collection, management, sharing, and the effective communication of uncertainties to inform robust and adaptive management strategies.

How organizations in the Delta are incorporating climate change into their decision making

Prompt 2.1: Summarize information from the source documents about how organizations in the Delta region are integrating climate projections and future impacts of climate drivers into planning. Use academic language and approximately 500 words.

Several organizations in the Delta region are actively integrating climate projections and anticipated future impacts of climate drivers into their planning frameworks, recognizing the profound implications for the region's ecosystems, water management, infrastructure, and communities. The Delta Stewardship Council (Council) plays a central role in this integration through its **Delta Adapts** initiative, a comprehensive, regional approach to climate resiliency. This two-phased effort includes a climate change vulnerability assessment (CCVA) completed in 2021, which characterized the Delta's vulnerabilities to climate stressors and hazards like changing temperatures, precipitation patterns, sea level rise, and extreme events. The subsequent **Adaptation Plan**, a public review draft from November 2024, proposes strategies to address these vulnerabilities across various sectors, including flood risk reduction, ecosystems, agriculture, and water supply reliability.

DRAFT (DO NOT CITE)

Delta Adapts explicitly considers a broad range of climate futures and utilizes downscaled climate data. The Council aims to inform its own future work, provide tools for local governments, and integrate climate change into state prioritization and investments.

The **Delta Plan**, adopted by the Delta Stewardship Council, mandates the consideration of "the future impact of climate change and sea level rise" in restoration planning, with a planning horizon of 2100. The Delta Plan and the Central Valley Flood Protection Plan (CVFPP) share goals related to ecosystem support and flood risk reduction in the Delta. DWR coordinates with the DSC on the development of Delta Adapts, ensuring consistent data is used for technical analyses, particularly concerning flood risk. The CVFPP itself is being updated to account for the projected impacts of climate change, especially in the San Joaquin River Basin where precipitation is expected to shift from snow to rain, increasing peak flows. The 2022 CVFPP Update emphasizes climate resilience as a key theme and commits to consulting tools like the Delta Social Vulnerability Index developed as part of Delta Adapts. The CVFPP also aims to define and quantify opportunities to adapt to a changing climate.

State agencies like the **California Natural Resources Agency (CNRA)** and the **Department of Water Resources (DWR)** are also integrating climate considerations into their planning efforts. The 2009 California Climate Adaptation Strategy by CNRA included a strategy to "Fix Delta Water Supply, Quality and Ecosystem Conditions," explicitly encouraging the incorporation of adaptive responses to climate change in Delta-related efforts. The Safeguarding California Plan 2017 Update by CNRA further recommends strengthening the climate adaptation component of conservation planning efforts at multiple scales, including plans relevant to the Delta such as Natural Community Conservation Plans and the 2017 Delta Conservation Framework. DWR is actively involved in the Delta Adapts process and is developing its own climate adaptation plan. DWR also utilizes a "decision scaling" approach to assess the State Water Project's hydrological risk under a wide range of potential future climate conditions, acknowledging the uncertainties inherent in GCM projections. Furthermore, DWR coordinates with the DSC to ensure consistent data on flood risk within the Delta Adapts initiative.

Regional and local agencies also play a role. For instance, the Delta Protection Commission (DPC) has prepared reports such as "The State of Delta Agriculture: Economic Impact, Conservation and Trends" (2020), which likely considers the implications of climate change for the agricultural sector. The San Francisco Bay

DRAFT (DO NOT CITE)

Conservation and Development Commission (BCDC) is also mentioned in the context of its ART (Adapting to Rising Tides) program, the lessons from which are being applied to Delta Adapts. Local agencies within the Delta are at varying stages of incorporating climate change and sea level rise considerations into their policy frameworks, as noted in the Delta Adapts CCVA.

The **Delta Conservancy** has developed a Climate Change Policy (2017 Update) to guide its actions in promoting the Delta's resilience to climate change effects, focusing on ecosystem restoration and the economic well-being of Delta residents. The Conservancy collaborates with various partners to develop and implement mitigation and adaptation strategies and provides up-to-date climate change information relevant to the Delta.

Overall, a multi-faceted and collaborative approach is evident, with the Delta Stewardship Council's Delta Adapts initiative serving as a central coordinating framework for integrating climate projections and anticipated impacts into planning across various levels of governance and sectors within the Delta region. This includes vulnerability assessments, adaptation strategy development, and the consideration of equity and socially vulnerable communities. The emphasis is on using the best available science and fostering collaboration among numerous stakeholders.

Prompt 2.2: Summarize information from the source documents about the types of uncertainties and projections that are most useful and critical for decision-support, and how understanding of evolving impacts and risks can help to build resilience in the region. Use academic language and approximately 500 words.

Climate change decision-support relies critically on specific types of projections and a nuanced understanding of their inherent uncertainties to foster effective resilience-building. The sources emphasize a shift towards **vulnerability-based assessments** that quantify the probability of consequences under various climate scenarios and identify resulting vulnerabilities, moving beyond limited hazard-based approaches. This evolution allows for a more integrated understanding of risk, encompassing hazard, exposure, and the sensitivity and adaptive capacity of human and natural systems.

Decision scaling is highlighted as a particularly useful approach, as it evaluates system performance by stress-testing against a range of climate stressors, such as

DRAFT (DO NOT CITE)

temperature and precipitation changes, thereby revealing critical sensitivities. This method allows for the use of diverse climate information sources and frames risk as a function of both impact and likelihood, aiding investment decisions. While downscaled climate model data provides valuable inputs, decision-makers often grapple with selecting projections due to inherent uncertainties. Thus, frameworks that facilitate the translation of global climate model projections to regional and local actionable scales are crucial.

Understanding the various types of **uncertainty** is paramount. These include **scenario uncertainty**, arising from different potential future emissions pathways; **model uncertainty**, stemming from the approximations and limitations in climate and impact models; **parameter uncertainty**, related to the estimation of model parameters; and **trajectory uncertainty**, influenced by both initial conditions and large-scale features of the climate system. While parameter uncertainty can be reduced through empirical studies, model uncertainty is more complex, and trajectory uncertainty has both irreducible and potentially reducible components. Acknowledging **model inadequacy**—the known and unknown limitations in representing real-world processes—is also essential for informed policy decisions. Effective communication of these uncertainties to policymakers is vital, enabling them to make decisions in a context of increasing climate change uncertainty.

Furthermore, decision support must incorporate projections of **compound and cascading extreme events**, where the interaction of multiple hazards can lead to more severe impacts than individual events alone. Improved understanding and modeling of such events are critical for robust risk assessment and adaptation planning. For coastal regions, **sea-level rise projections**, including local and regional variations and the potential for acceleration due to ice sheet dynamics, are particularly critical for long-term planning, infrastructure investment, and ecosystem management.

Building resilience necessitates the effective utilization of these projections and the comprehension of evolving impacts and risks. By understanding the **vulnerabilities** of specific regions, communities, and ecosystems to identified climate stressors and hazards, targeted adaptation strategies can be developed and prioritized. The **Central Valley Flood Protection Plan (CVFPP) Update** and the **Delta Adapts initiative** exemplify efforts to integrate climate resilience into planning by utilizing updated risk assessments, climate change analyses, and innovative tools. The **DWR Climate Adaptation Plan** employs a decision scaling

DRAFT (DO NOT CITE)

approach to quantify risks to the State Water Project and formulate adaptation objectives.

Recognizing the inherent uncertainties should not lead to inaction. The principle of following **corridors of clarity**—focusing on direct and well-supported links between policy decisions and desired outcomes—can help overcome uncertainty paralysis. Prioritizing **no-regrets policies**, which offer benefits regardless of the exact climate trajectory, is another strategy for decision-making under uncertainty. In situations where plausible risks with potentially severe consequences exist, even with scientific uncertainty, the **precautionary principle** suggests a responsible policy reaction to protect against harm. Continuous updating of projections and vulnerability assessments, aligned with climate change assessment cycles, is also crucial for adaptive management. By embracing a dynamic and iterative approach to understanding climate risks and implementing adaptation measures, informed by the best available science and acknowledging its uncertainties, the region can build greater resilience to the evolving impacts of climate change.

Prompt 2.3: Summarize conclusions from the source documents about whether the current and previous efforts to address climate change in the region are adequate for enhancing resilience of the Bay Delta system. Use academic language and approximately 500 words.

The source documents suggest that while significant efforts have been undertaken to address climate change in the Bay-Delta region, **current and previous efforts are generally considered insufficient to fully enhance the resilience of the system in the face of projected future impacts**. These efforts provide a crucial foundation and have increased understanding of vulnerabilities, but the scale and pace of implementation need to be accelerated and expanded to meet the growing challenges.

The **Delta Adapts initiative** by the Delta Stewardship Council (DSC) is a comprehensive regional approach that includes a Climate Change Vulnerability Assessment (CCVA) and a subsequent Adaptation Plan. The CCVA characterized the Delta's vulnerabilities to various climate stressors and hazards, considering different planning horizons and emission scenarios. The Adaptation Plan proposes strategies across sectors like flood risk reduction, ecosystems, agriculture, and water supply reliability. Delta Adapts aims to inform the Council's future work, provide tools for local governments, and integrate climate change into state

priorities. However, the Adaptation Plan itself is a public review draft, indicating that the implementation phase is still developing. Furthermore, the CCVA identified significant opportunities to improve the application of scientific information to policy and planning instruments and to enhance coordination across jurisdictional boundaries.

Similarly, the **Central Valley Flood Protection Plan (CVFPP) Update 2022** acknowledges the increasing risks due to climate change and includes projections of these impacts on ecological conditions and flood management. It emphasizes climate resilience as a key theme and highlights the urgency for increased investment in flood management at all levels. The CVFPP Update also coordinates with the DSC's Delta Adapts initiative to ensure consistent data use for flood risk analysis. Despite these advancements, the document notes that without increased investment, the effects of climate change may outpace our ability to adapt and respond.

State agencies like the **Department of Water Resources (DWR)** and the **California Natural Resources Agency (CNRA)** have also integrated climate considerations into their planning. DWR has developed its own Climate Adaptation Plan and utilizes a "decision scaling" approach to assess hydrological risks to the State Water Project (SWP) under various climate futures. The Safeguarding California Plan 2017 Update recommends strengthening climate adaptation in conservation planning efforts relevant to the Delta. These efforts demonstrate a commitment to understanding and addressing climate impacts. However, the DWR's analysis of SWP vulnerability indicates potential performance losses under future climate conditions, suggesting that adaptation strategies need further development and implementation.

The **Delta Conservancy** has a Climate Change Policy to promote resilience. Local and regional agencies are also in varying stages of incorporating climate change into their frameworks. This decentralized approach, while valuable, highlights the need for better coordination and leveraging of efforts, a gap that Delta Adapts aims to address.

Several sources explicitly point to the **insufficiency of current funding** for the scale of adaptation required. The Delta Adapts Draft Adaptation Plan estimates that implementing levee improvements and ecosystem restoration strategies alone will cost billions of dollars over the next 30 years, exceeding historical allocation levels. This funding gap is a significant impediment to enhancing resilience.

Furthermore, the **IEP Climate Change Management Analysis and Synthesis Team Report 2022** emphasizes that climate change is the gravest threat facing the estuary and necessitates a fundamental rethinking of how the estuary is managed and studied. The **Delta Adapts CCVA** also concludes that climate change will continue to affect the Delta, and a broad set of key findings necessitates future adaptation planning efforts. The assessment of flood hazards in the Delta Adapts report projects increasing exposure to flooding under future scenarios, indicating that current flood management infrastructure may become increasingly stressed.

In conclusion, while prior and ongoing efforts such as Delta Adapts, CVFPP updates, and state agency climate plans represent critical steps in understanding and planning for climate change in the Bay-Delta region, the source documents suggest that these efforts are **not yet adequate** to ensure the system's long-term resilience. Key challenges include the need for more effective application of science to policy, better coordination across governance levels, accelerated implementation of adaptation strategies, and significantly increased financial investment to address the scale of the projected impacts. Continuous monitoring, adaptive management, and a holistic, systemic approach involving all stakeholders are crucial for building a truly climate-resilient Delta.

Works Cited

- Alessi, M. J., & Rugenstein, M. (2024). Potential near-term wetting of the Southwestern United States if the eastern and central Pacific Cooling Trend reverses. *Geophysical Research Letters*, 51(13).
<https://doi.org/10.1029/2024GL108292>
- Barros, A., Hartman, R., Bashevkin, S. M., Burdi, C. E. (2024). Years of Drought and Salt: Decreasing Flows Determine the Distribution of Zooplankton Resources in the San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 22(1). <https://doi.org/10.15447/sfew.s.2024v22iss1art3>
- Bashevkin, S. M., Mahardja, B., Brown, L. R. (2022) Warming in the upper San Francisco Estuary: Patterns of water temperature change from five decades of data. *Limnology and Oceanography*, 67(5). 1065-1080.
<https://doi.org/10.1002/lno.12057>

DRAFT (DO NOT CITE)

- Bosworth, D. H, Bashevkin, S. M, Bouma–Gregson, K., Hartman, R., & Stumpner, E. B. (2024). The Anatomy of a Drought in the Upper San Francisco Estuary: Water Quality and Lower-Trophic Responses to Multi-Year Droughts Over a Long-Term Record (1975-2021). *San Francisco Estuary and Watershed Science*, 22(1). <https://doi.org/10.15447/sfews.2024v22iss1art1>
- Bouma–Gregson, K., Bosworth, D. H, Flynn, T. M, Maguire, A., Rinde, J., & Hartman, R. (2024). Delta Blue(green)s: The Effect of Drought and Drought-Management Actions on Microcystis in the Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 22(1). <https://doi.org/10.15447/sfews.2024v22iss1art2>
- CNRA, California Natural Resources Agency (2009). 2009 California climate adaptation strategy: a report to the governor of the state of California in response to executive order S-13-2008. Available from: https://resources.ca.gov/CNRALegacyFiles/docs/climate/Statewide_Adaptation_Strategy.pdf
- CNRA, California Natural Resources Agency (2017). Safeguarding California Plan: 2017 Update California’s Climate Adaptation Strategy. May 2017. Available from: <https://resources.ca.gov/CNRALegacyFiles/wp-content/uploads/2017/05/DRAFT-Safeguarding-California-Plan-2017-Update.pdf>
- CVFPP, Central Valley Flood Protection Plan (2022). Update 2022. Available from: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-Planning-and-Studies/Central-Valley-Flood-Protection-Plan/Files/CVFPP-Updates/2022/Central_Valley_Flood_Protection_Plan_Update_2022_ADOPTED.pdf
- Delta Conservancy (2017). Climate Change Policy - 2017 Update. Available from: https://deltaconservancy.ca.gov/wp-content/uploads/2019/12/Climate-Change-Policy-2017-Update_10-15-19.pdf

DRAFT (DO NOT CITE)

- DSC, Delta Stewardship Council (2021). Delta Adapts: Creating a Climate Resilient Future Sacramento-San Joaquin Delta Climate Change Vulnerability Assessment. June 2021. Available from: <https://deltacouncil.ca.gov/pdf/delta-plan/2021-06-25-delta-adapts-vulnerability-assessment.pdf>
- DSC, Delta Stewardship Council (2025) Delta Adapts: Creating a Climate Resilient Future Adaptation Plan. November 2024. Available from: <https://deltacouncil.ca.gov/pdf/delta-plan/2024-11-18-delta-adapts-draft-adaptation-plan.pdf>
- Dettinger, M., & Cayan, D. R. (2014). Drought and the California Delta—A Matter of Extremes. *San Francisco Estuary and Watershed Science*, 12(2). <https://doi.org/10.15447/sfews.2014v12iss2art4>
- DWR, California Department of Water Resources (2020). Climate Action Plan Phase III: Climate Change Adaptation Plan. July 2020. Available from: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan/Files/Adaptation_Plan.pdf
- DWR, California Department of Water Resources (2019). Climate Action Plan Phase III: Climate Change Vulnerability Assessment. February 2019. Available from: <https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan/Files/CAP-III-Vulnerability-Assessment.pdf>
- DWR, California Department of Water Resources (2019). Decision Scaling Evaluation of Climate Change Driven Hydrologic Risk to the State Water Project. May 2019. Available from: <https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan/Files/CAP-III-Decision-Scaling-Vulnerability-Assessment.pdf>
- EPA, Environmental Protection Agency (2021). Climate Change and Social Vulnerability in the United States: A focus on six Impacts. September 2021. Available from: <https://www.epa.gov/cira/social-vulnerability-report>

DRAFT (DO NOT CITE)

- Gartrell G. (2016). Will Increasing Outflow In the Summer Increase Delta Smelt Survival. California State Water Resources Control Board. Dec 2015. Available from:
https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/comments121616/docs/greg_gartrell.pdf
- Hanan, E. J., Maureen, K. C., Ren, J., Johnson, M. C., Smith, A. M. S. (2022). Missing Climate Feedbacks in Fire Models: Limitations and Uncertainties in Fuel Loadings and the Role of Decomposition in Fine Fuel Accumulation. *Journal of Advances in Modeling Earth Systems*, 14(3).
<https://doi.org/10.1029/2021MS002818>
- Hardiman, S.C., Dunstone, N.J., Scaife, A.A., Smith, D. M., Comer, R., Nie, Y., Ren, H. (2022). Missing eddy feedback may explain weak signal-to-noise ratios in climate predictions. *npj Climate Atmospheric Science* 5(57).
<https://doi.org/10.1038/s41612-022-00280-4>
- Hartman, R., Stumpner, E. B, Bosworth, D. H, Maguire, A., Burdi, C. E, & Drought Synthesis Team, I. (2024). Dry Me a River: Ecological Effects of Drought in the Upper San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 22(1). <https://doi.org/10.15447/sfews.2024v22iss1art5>
- Hartman, R., Twardochleb, L., Burdi, C. E, & Wells, E. H. (2024). Amazing Graze: Shifts in Jellyfish and Clam Distributions During Dry Years in the San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 22(1).
<https://doi.org/10.15447/sfews.2024v22iss1art4>
- He, C., Clement, A.C., Kramer, S. M., Cane, M. A., Klavans J. M., Fenske, T. M. Murphy, L. N. (2023). Tropical Atlantic multidecadal variability is dominated by external forcing. *Nature* 622, 521–527. <https://doi.org/10.1038/s41586-023-06489-4>
- Herbold, B., Bush, E., Castillo, G., Colombano, D., Hartman, R., Lehman, P. Mahardja, B., Sommer, T. (2022). Climate Change Impacts on San Francisco Estuary Aquatic Ecosystems: A Review. *San Francisco Estuary and Watershed Science*, 20(2). <https://doi.org/10.15447/sfews.2022v20iss2art1>

DRAFT (DO NOT CITE)

- Hill, P. G., Holloway, C. E., Byrne M. P., Lambert, F. H., Webb, M. J. (2023). Climate Models Underestimate Dynamic Cloud Feedbacks in the Tropics. *Geophysical Research Letters*, 50(15). <https://doi.org/10.1029/2023GL104573>
- Huang, X., & Swaine D. L. (2022). Climate change is increasing the risk of a California megaflood. *Sci Adv*, 8. <https://doi.org/10.1126/sciadv.abq0995>
- Hwang, Y., Xie, S., Chen, P., Tseng, H. & Deser, C. (2024) Contribution of anthropogenic aerosols to persistent La Niña-like conditions in the early 21st century, *Proc. Natl. Acad. Sci.* 121(5). <https://doi.org/10.1073/pnas.2315124121>.
- IEP, Interagency Ecological Program (2022). Ecological Impacts of Drought on the Sacramento-San Joaquin Delta with special attention to the extreme drought of 2020-2021. Preliminary Report. Feb 2022. Available from: https://www.waterboards.ca.gov/drought/tucp/docs/2021/20220201_report_cond7.pdf
- IEP, Interagency Ecological Program (2023). Ecological Impacts of Drought on the Sacramento-San Joaquin Delta with special attention to the extreme drought of 2020-2022. IEP Technical Report #100. Available from: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=211225&inline>
- IEP, Interagency Ecological Program (2023). Synthesis of data and studies related to the effect of climate change on the ecosystems and biota of the Upper San Francisco Estuary Year 2022. IEP Technical Report #99. Available from: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=204625&inline>
- IPCC (2023) Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647.
- Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., Stouffer, R. J. (2008). Stationarity Is Dead: Whither Water Management? *319*(5863). <https://doi.org/10.1126/science.1151915>

DRAFT (DO NOT CITE)

- Natural and Working Lands Climate Smart Strategy (2021). Available From:
https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Expanding-Nature-Based-Solutions/FINAL_DesignDraft_NWL_100821_508-opt.pdf
- NCR, National Climate Change Assessment (2023). Ch. 2. Climate trends. In: Fifth National Climate Assessment. Crimmins. U.S. Global Change Research Program, Washington, DC, USA. <https://doi.org/10.7930/NCA5.2023.CH2>
- NCR, National Climate Change Assessment, (2023). Ch. 4. Water. In: Fifth National Climate Assessment. Crimmins, Washington, DC, USA.
<https://doi.org/10.7930/NCA5.2023.CH4>
- NCR, National Climate Change Assessment, (2023). Ch. 9. Coastal effects. In: Fifth National Climate Assessment. U.S. Global Change Research Program, Washington, DC, USA. <https://doi.org/10.7930/NCA5.2023.CH9>
- NCR, National Climate Change Assessment, (2023). Focus on compound events. In: Fifth National Climate Assessment. U.S. Global Change Research Program, Washington, DC, USA. <https://doi.org/10.7930/NCA5.2023.F1>
- NOAA, National Oceanic and Atmospheric Administration (2022) Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Ocean Service, Silver Spring, MD, 111 pp. <https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf>
- OPC, Ocean Protection Council (2017). Rising Seas In California: An update on Sea-level Rise Science. April 2017. Available from:
<https://opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf>
- Polasky, S., Crépin, A., Biggs R., Carpenter, S. R., Folke, C., Peterson, G., Scheffer, M., Barrett, S., Daily, G., Ehrlich, P., Howarth, R. B., Hughes, T., Levin, S. A., Shogren, J. F., Troell, M., Walker, B., Xepapadeas, A. (2020). Corridors of Clarity: Four Principles to Overcome Uncertainty Paralysis in the

DRAFT (DO NOT CITE)

Anthropocene, *BioScience*, 70(12), 1139–1144,
<https://doi.org/10.1093/biosci/biaa115>

PPIC, Public Policy Institute of California (2024). PPIC Water Policy Center Priorities for California's Water: Are we ready for Climate Change? November 2024. Available from: <https://www.ppic.org/wp-content/uploads/priorities-for-californias-water-november-2024.pdf>

Rising, J., Tedesco, M., Piontek, F., Stainforth, D. A. (2022). The missing risks of climate change. *Nature*, 610, 643–651. <https://doi.org/10.1038/s41586-022-05243-6>

Shi, H., García-Reyes, M., Jacox, M. G., Rykaczewski, R. R., Black, B. A., Bograd, S. J., Sydeman, W. J. (2021). Co-occurrence of California drought and northeast Pacific marine heatwaves under climate change. *Geophysical Research Letters*, 48(17). <https://doi.org/10.1029/2021GL092765>

Stevens B., & Bony, S. (2013). What Are Climate Models Missing? *Science*, 340(6136). 1053-1054. <https://doi.org/10.1126/science.1237554>

Rahmstorf, S. (2024). Is the Atlantic Overturning Circulation Approaching a Tipping Point? *Oceanography*, 37(3), 16–29. <https://www.jstor.org/stable/27333920>

Robinson, A., Lehmann, J., Barriopedro, D., Coumou, D. (2021). Increasing heat and rainfall extremes now far outside the historical climate. *Clim Atmos Sci* 4(45). <https://doi.org/10.1038/s41612-021-00202-w>

Rugenstein, M., Zelinka, M., Karlsruh, K. B., Ceppi, P., and Andrews, T. (2023), Patterns of surface warming matter for climate sensitivity, *Eos*, 104, . Published on 31 October 2023.

Stuivenvolt-Allen, J., Wang, S.-Y. S., Johnson, Z., Chikamoto, Y. (2021). Atmospheric rivers impacting Northern California exhibit a quasi-decadal frequency. *Journal of Geophysical Research: Atmospheres*, 126(15), <https://doi.org/10.1029/2020JD034196>

PPIC, Public Policy Institute of California (2024). PPIC Water Policy Center Priorities for California's Water: Are we ready for Climate Change? November 2024.

DRAFT (DO NOT CITE)

Available from: <https://www.ppic.org/wp-content/uploads/priorities-for-californias-water-november-2024.pdf>

USGS, US Geological Survey (2018). Modeling Managed Flows in the Sacramento/San Joaquin Watershed, California, Under Scenarios of Future Change for CASCade2. Available from: <https://doi.org/10.3133/ofr20181101>

Whicker-Clarke, C. A., Antwerpen, R., Flanner, M. G., Schneider, A., Tedesco, M., Zender, C. S. (2024). The effect of physically based ice radiative processes on Greenland ice sheet albedo and surface mass balance in E3SM. *Journal of Geophysical Research: Atmospheres*, 129(7), <https://doi.org/10.1029/2023JD040241>

Wills, R. C., Schneider, T., Wallace, J. M., Battisti, D. S., Hartmann, D. L. (2018). Disentangling global warming, multidecadal variability, and El Niño in Pacific temperatures. *Geophysical Research Letters*, 45(5), 2487–2496. <https://doi.org/10.1002/2017GL076327>