Photo credit: John Hannon, Reclamation

Estimating Uncertainty: Sources and Protocol Investigation

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Reclamation

Estimating Uncertainty: Sources Outline

- Peer Review Questions
- Documentation
- Sources of uncertainty
- Uncertainty investigation
- Summary

Peer Review Panel Questions #11

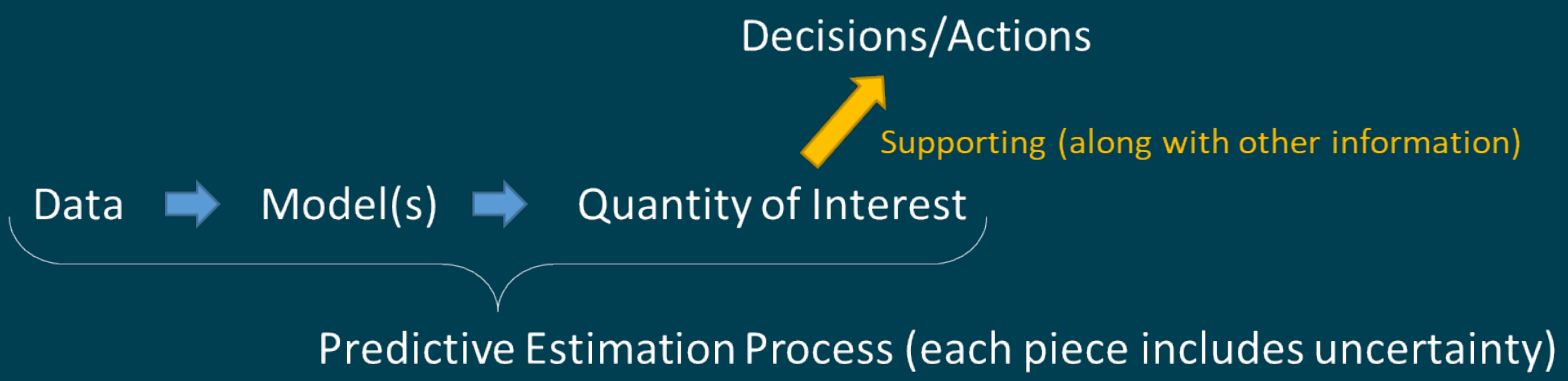
- Are the metrics and methodology for describing and incorporating uncertainty in input data adequate and is model uncertainty described and quantified appropriately?

Estimation of Uncertainty: Sources and Protocols Documentation

- Document Link:
  - Estimation of Uncertainty – Sources
  - Estimation of Uncertainty - Protocols
- Technical Memorandum Status:
  - Final Draft
  - Enhancements since Mid-Term Peer Review:
    - All new material

Reclamation's Perspective: Motivation to Evaluate Uncertainty

- Properly informed decisions/actions require understanding of uncertainty associated with the predicted quantity of interest



What influenced the treatment of Uncertainty?

- Reclamation expressed broad goals to identify sources of uncertainty, but the protocols/treatment were less defined.
- Review of CWEMF Model Development Protocols
- WTMP Solicited Feedback:
  - MTC Meetings #8 and #9
  - WTMP team presented approach at CWEMF
- Summary: WTMP team chose a path forward towards “Protocols” in the absence of specific recommendations.

Uncertainty in the WTMP: Summary

- Considerations when characterizing uncertainty in the WTMP framework
  - WTMP is a tool, not a decision-making body
  - WTMP models represent an approximation of a combination of complex natural processes and built river-reservoir systems
  - Pragmatic for implementation and ability to assess resulting benefits
- Objective: Develop and communicate sources of uncertainty in estimates of water temperature downstream of regulating reservoirs
- Description: Identify potential sources of variability and uncertainty within the modeling approach, particularly significant sources. Explore potential impacts on applications that include forecasting.

Uncertainty in Models

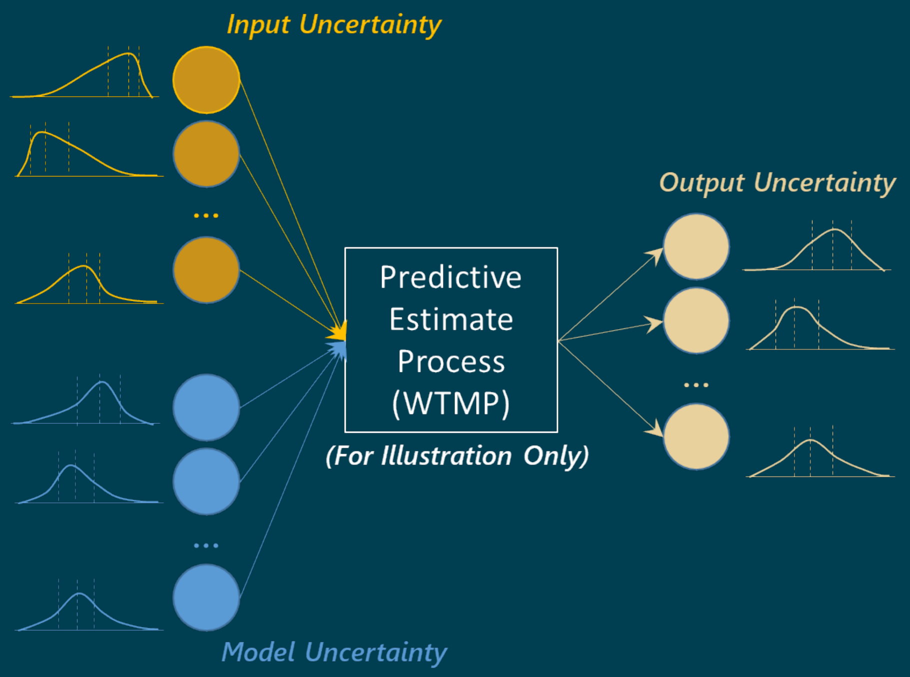
- Model conceptualization
  - Identify key processes and features
- Model development
  - Formulations, process representations error
  - Specific infrastructure representation error (TCD, shutters, curtains)
- Data development
  - Measurement error
  - Forecast error
- Parameter estimation (Calibration)
  - Calibration parameters error (and all other error)

Addressing Model Uncertainty

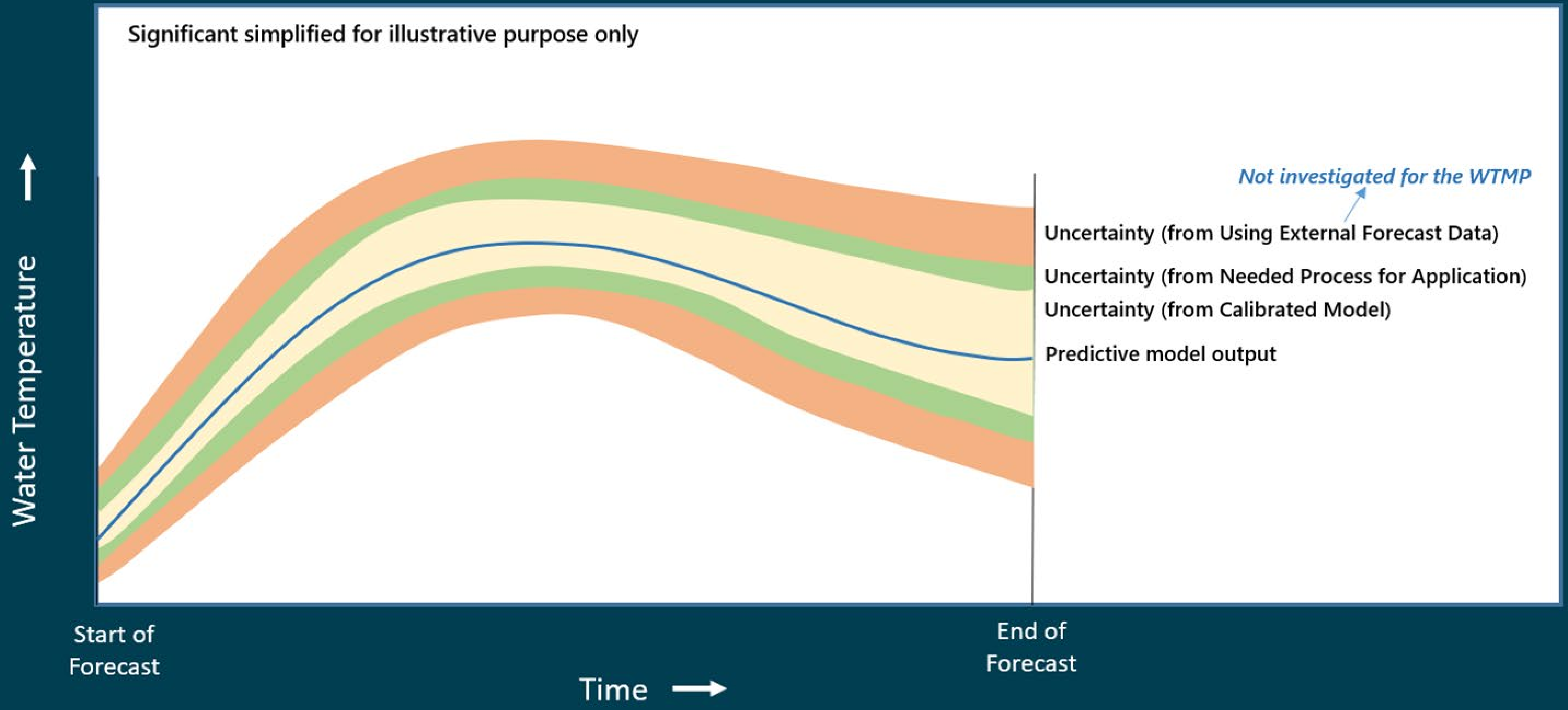
- Build Models and Test Models
  - Calibration Mode
    - Quantification of uncertainty associated with the data and parameter estimation was included in calibration (e.g., calibration parameters)
    - Resulting predictive errors were assessed using model performance metrics to determine the fitness and acceptability of the calibrated model.
    - Encompasses all previous stages (conceptualization, development, data)
- Apply (Calibrated) Models
  - Forecasting Mode
    - Uncertainty of the calibrated model is accepted as is for contributing the overall uncertainty of model results.
    - Initial and boundary conditions (i.e., data) are the focus for examining uncertainty of the predictive/ forecasting processes and estimates

Model Application Uncertainty

- Propagation of Uncertainty
  - Inherited uncertainty from the calibrated model
  - Forecast uncertainty
- Forecast uncertainty
  - Uncertainty in flow and operations, temperature, meteorological forecast
    - External to WTMP (not investigated; may be subject to user preference)
  - Uncertainty in additional necessary processes required for applications to accommodate available input (as currently configurated)
    - Internal for WTMP (investigated; discussed later)



Conceptual Sketch on Accumulation of Uncertainty



Forecasting: Approach to Explore Uncertainties in WTMP Application

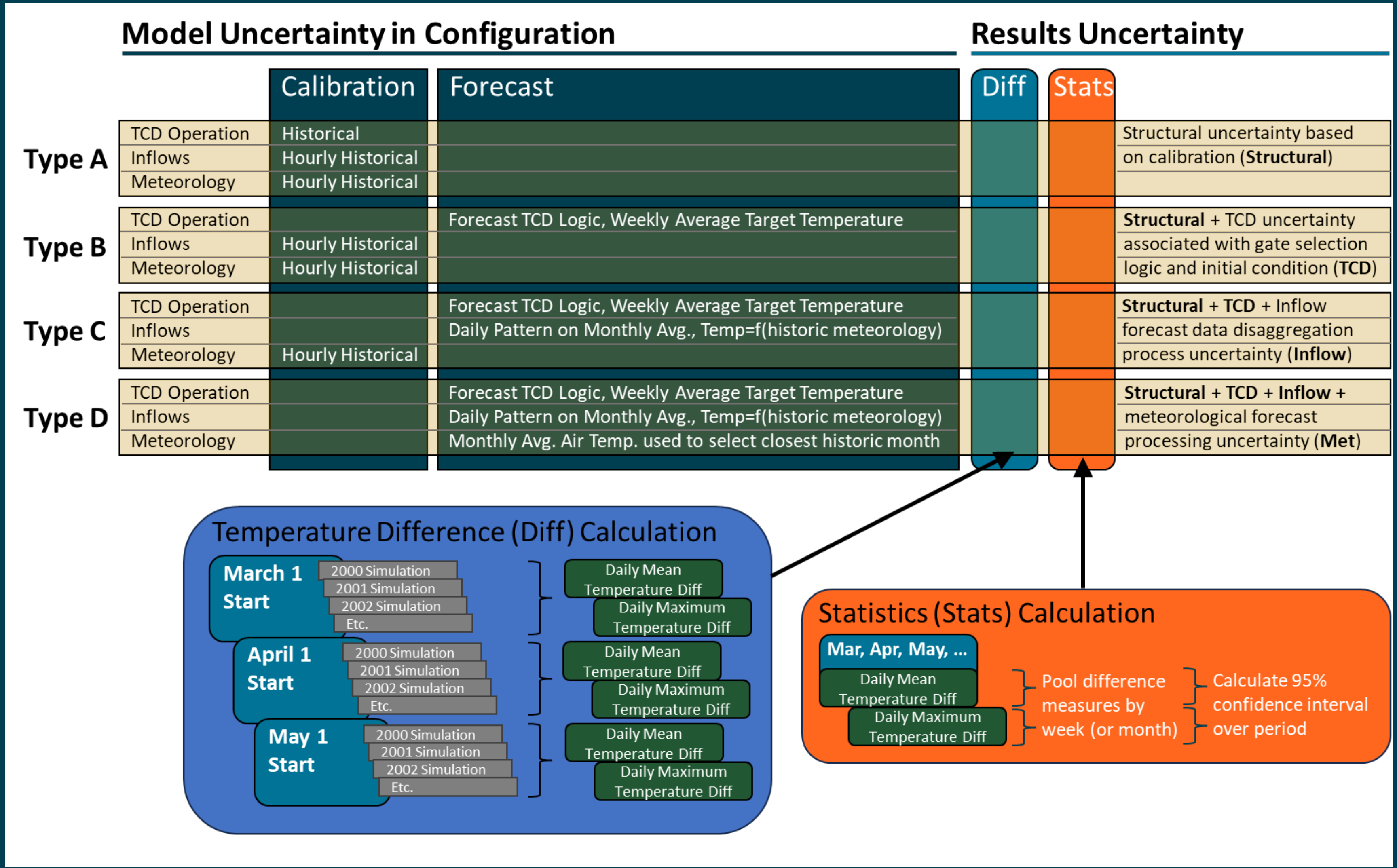
- A range of approaches
  - Position analysis
  - Ensemble analysis
  - Other

Single Scenario Forecast	Selective Scenario Forecasts	Ensemble Forecasts	Multi-Model Ensemble Forecasts
One representative realization of the future scenario (representative, hopefully)	Currently used multiple but selective exceedance points (e.g., 50%, 75%, 90%, 95%, 99%) for hydrologic and meteorological conditions, with paired water temperature boundary conditions. Scenarios are not considered equally possible.	A large number of scenarios with a representative range and probability of hydrologic and meteorological conditions. All scenarios are considered equally possible.	Using different models in the predictive estimation process for ensemble forecast.
Not used as it provides insufficient information for modern decision-making, but implementable in the WTMP	To be implemented in WTMP. Results can be used to bracket possible outcomes with risk consideration, but no formal risk assessment can be done. Not probabilistic.	Could be implemented in WTMP in the future [the platform can accommodate it].	Same as ensemble forecasts. Potential for future inclusion in WTMP driven by the needs and benefits of using different models.

Uncertainty Related to Forecast Data Processing

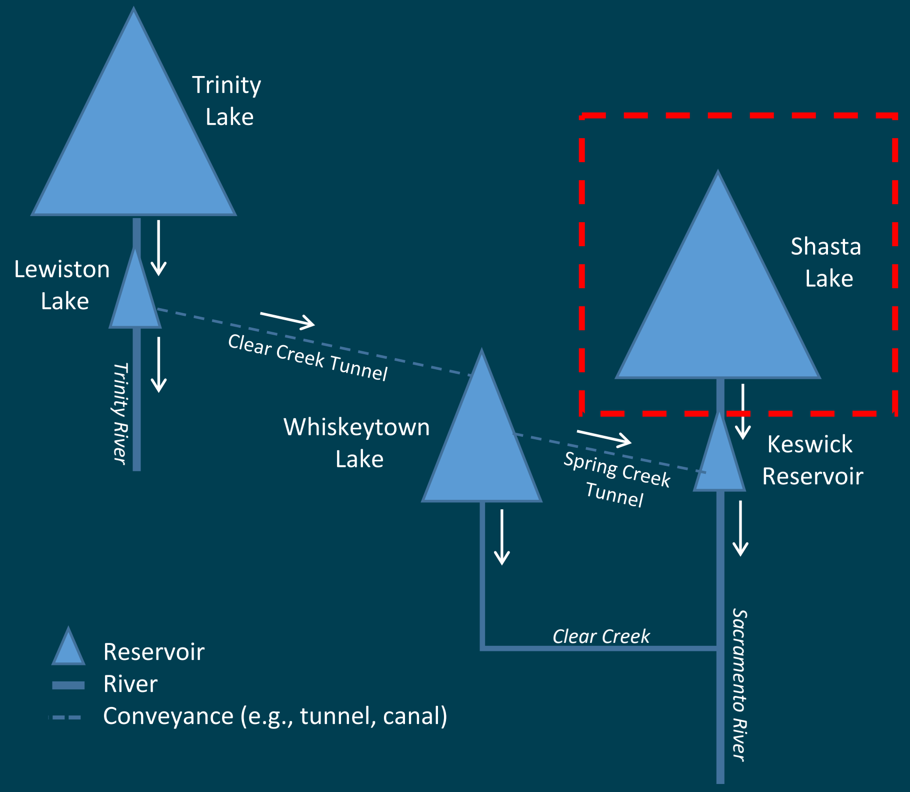
- Models have been carefully calibrated using the best available historical data
- What additional uncertainty is added with data estimation techniques required when performing forecast simulations (based on the current implementation)
  - Operation of TCD and temperature control shutters by model logic
  - Use of monthly average boundary inflows and reservoir releases
  - Estimation of meteorological conditions
  - Estimation of inflow temperatures
- Approach – develop “perfect forecast” boundary conditions from historical data and compare forecast simulation results to historical observations

Simulation Configurations for Uncertainty Attribution



- Note, this is not a forecast skill examination

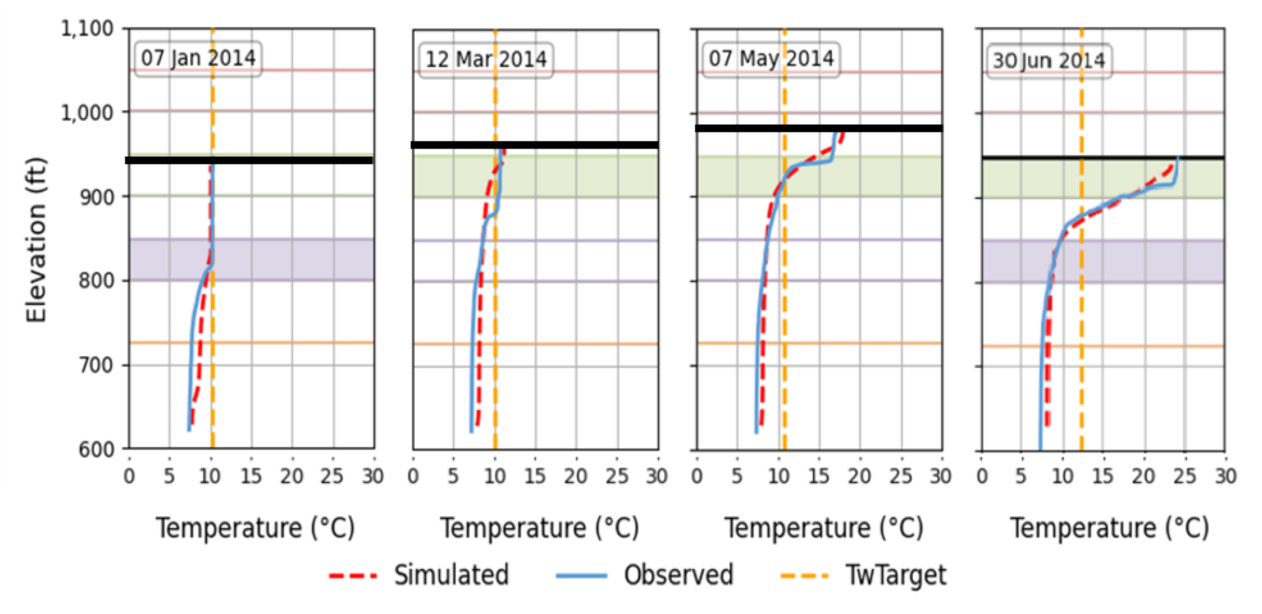
Type A: Structural (Calibration)



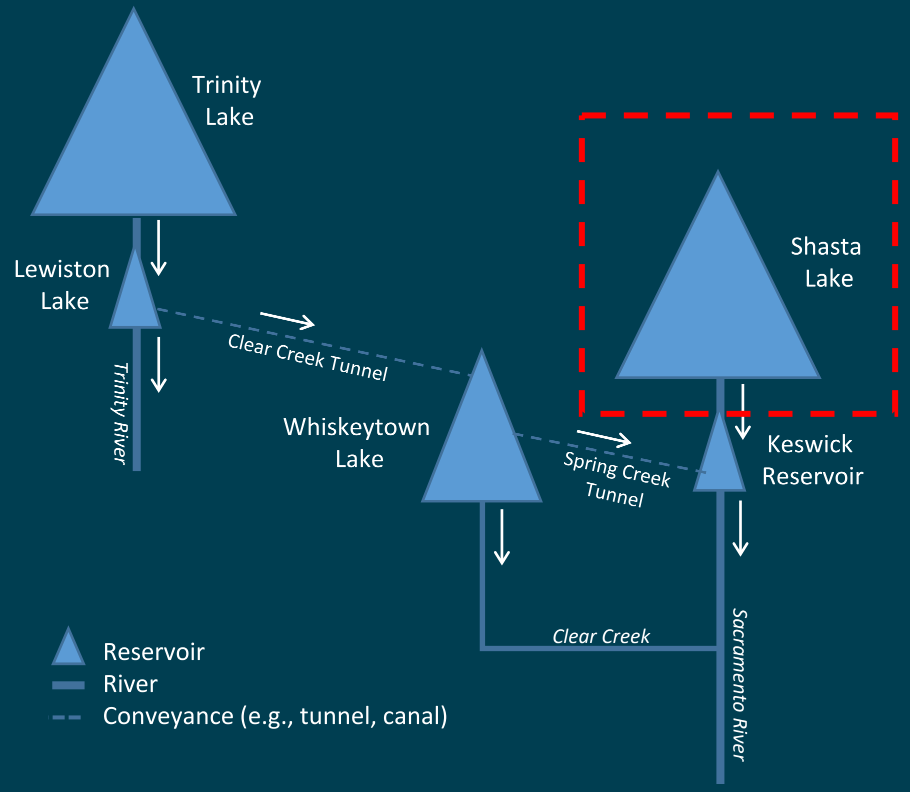
- TCD Operation – Historical
- Inflows – Hourly Historical
- Meteorology – Hourly Historical

Forecast Boundary Condition Processing: Initial Conditions

- Initial Reservoir Storage
  - Historical value at start of simulation
- Initial Reservoir Thermal Profile
  - Start on the date of a valid Shasta profile. If there is a measure profile within 10 days of the Shasta profile, use it. Otherwise, use ResSim calibration model results for initialization
- Initial River Reach Temperature
  - 10 Celsius constant



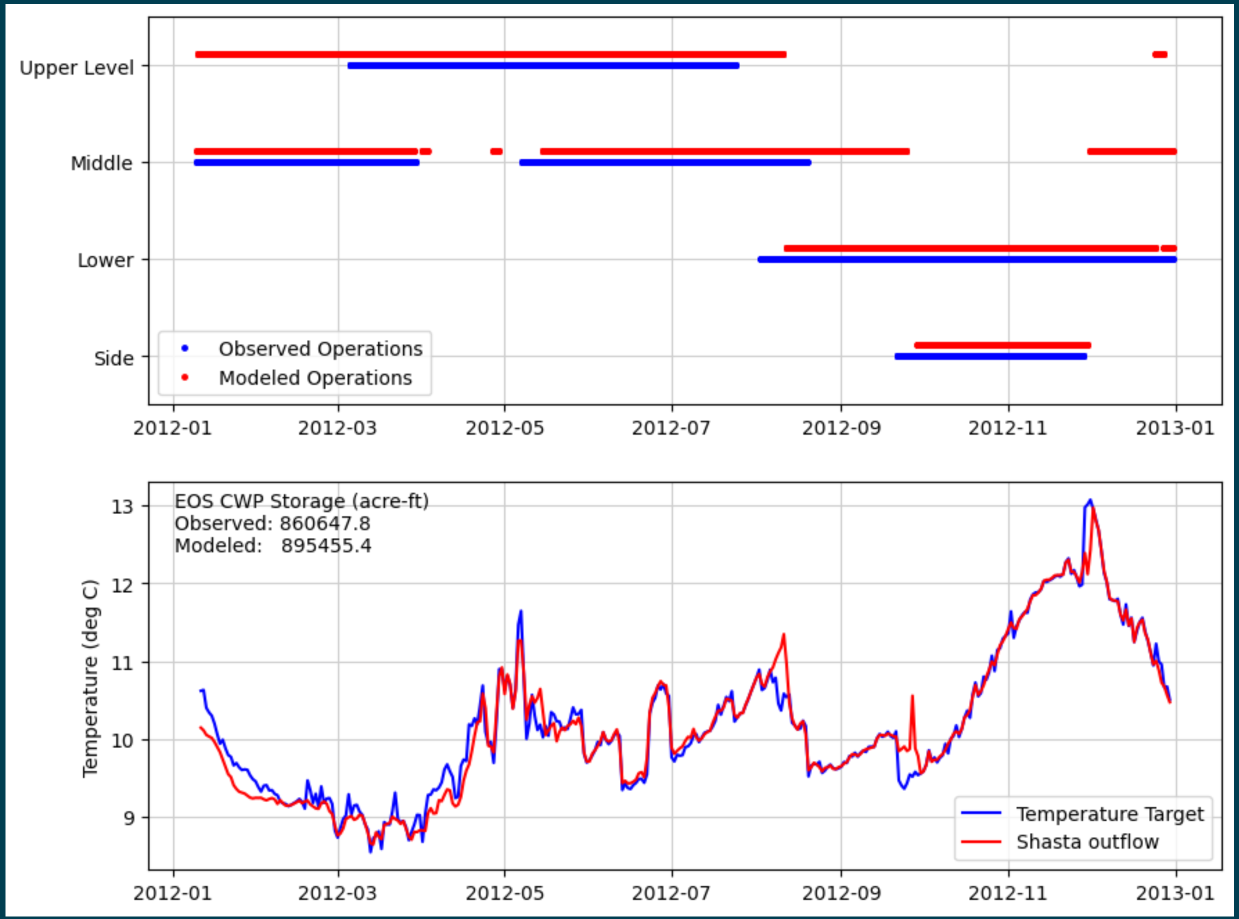
Type B – Structural + TCD Operation



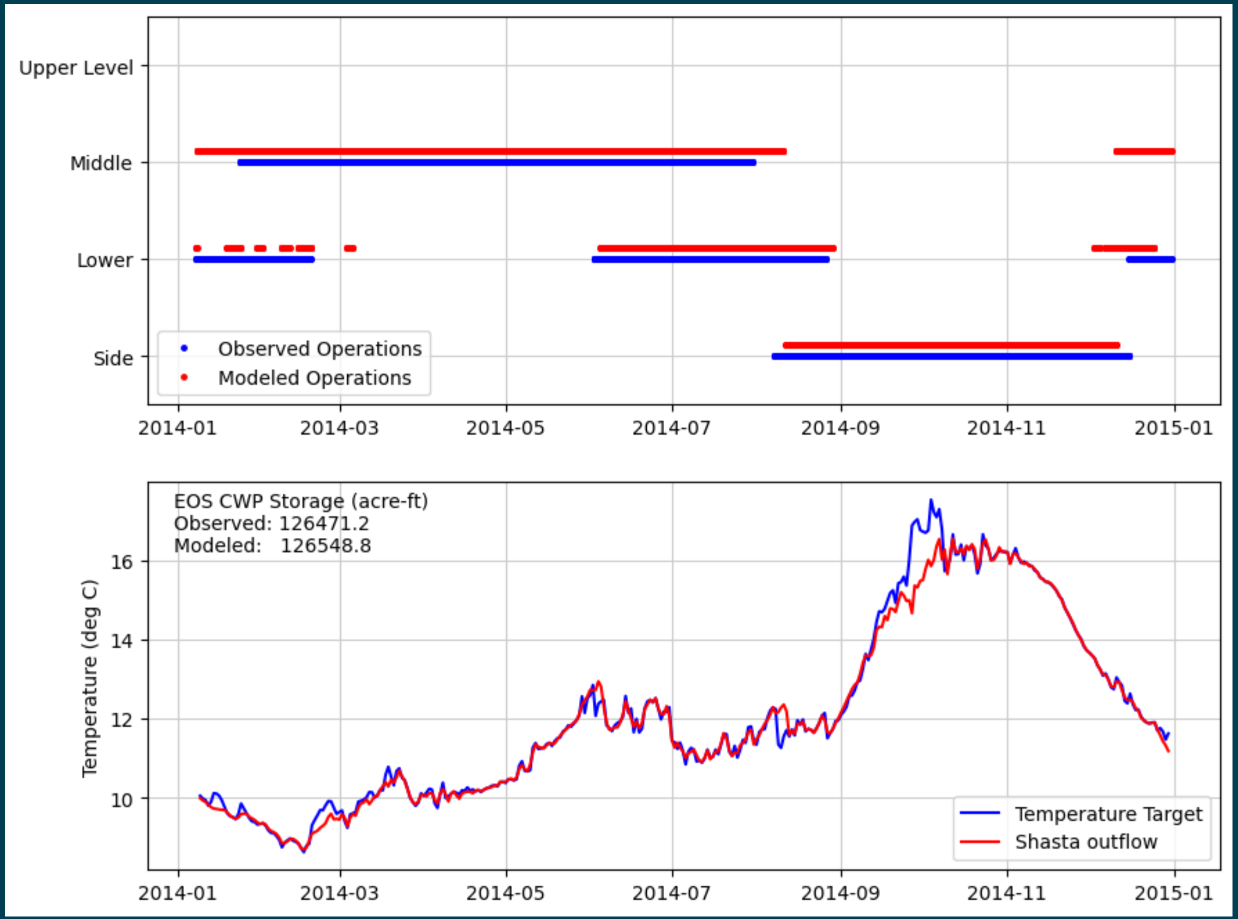
- TCD Operation – Forecasted TCD Logic, Weekly Average Target Temperature
- Inflows – Hourly Historical
- Meteorology – Hourly Historical

Forecast Simulation: TCD Operation Logic

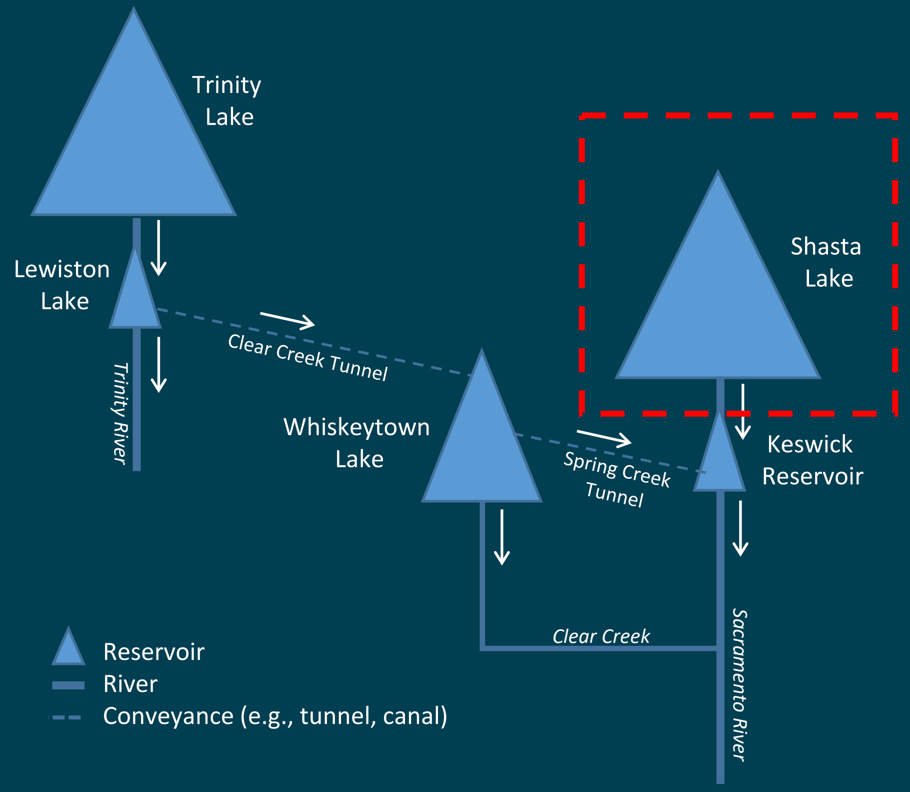
- Example - 2012



- Example - 2014

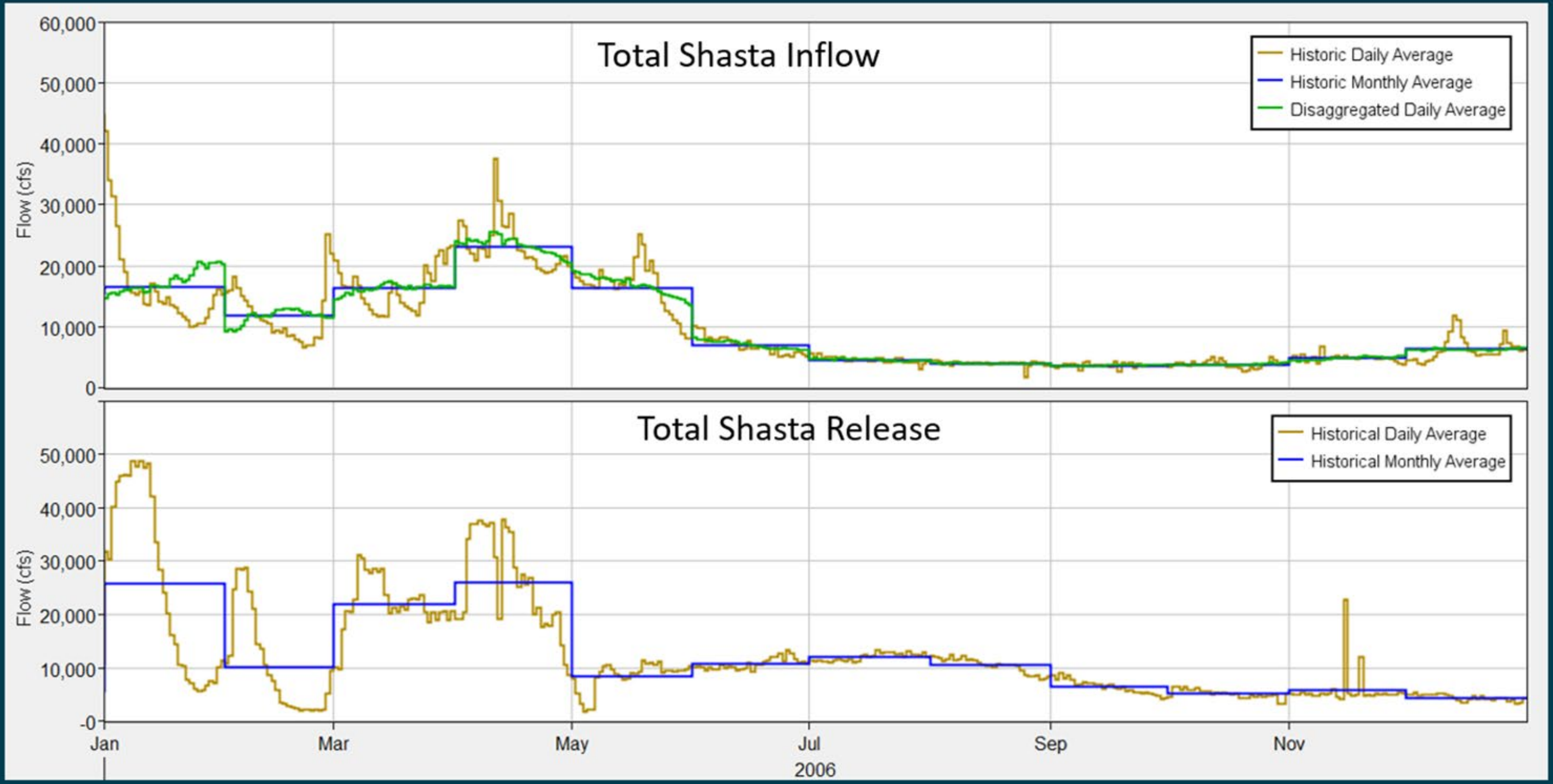


Type C – Structural + TCD Ops + Flow Forecast Pattern /Disaggregation/Inflow temperature



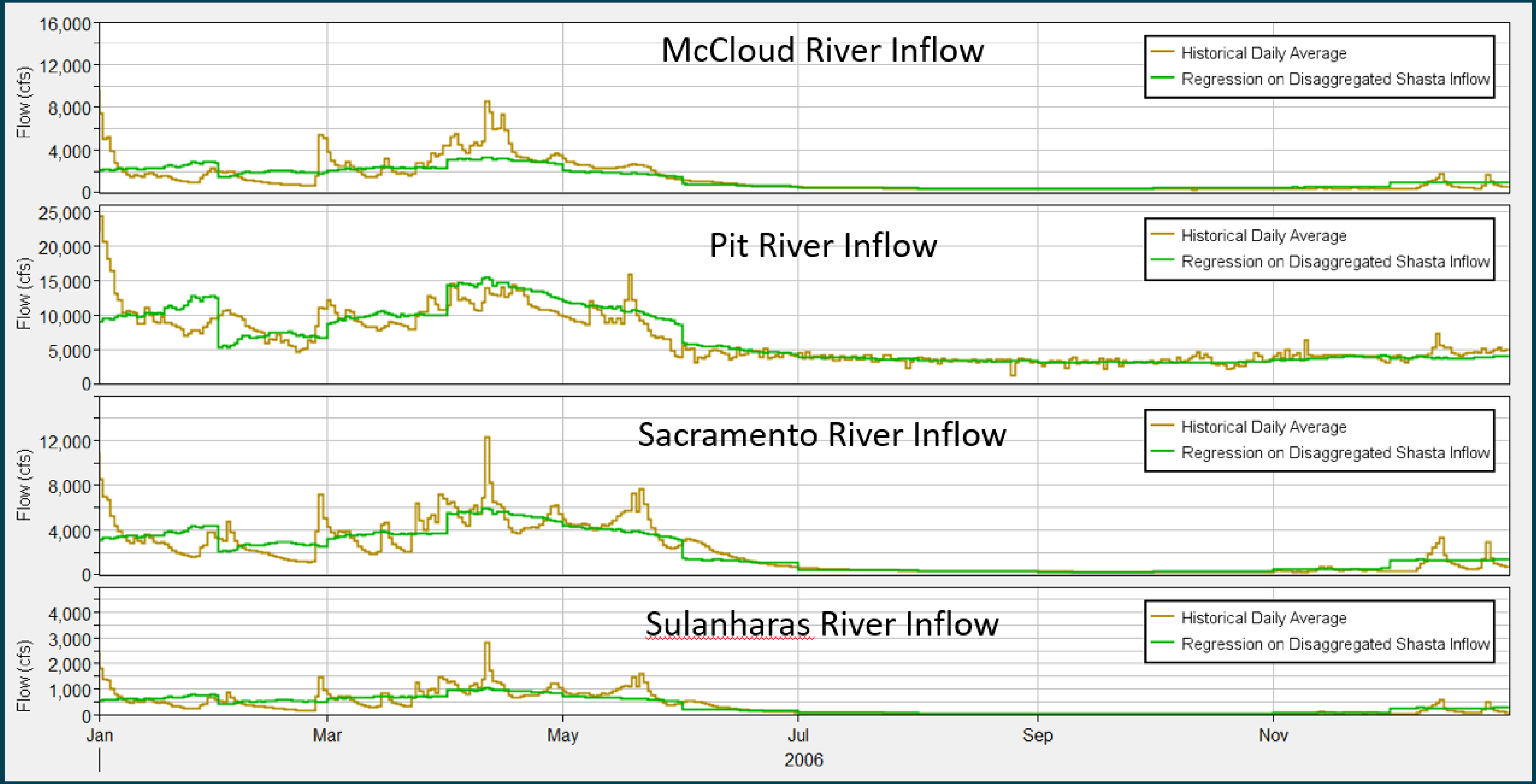
- TCD Operation – Forecasted TCD Logic and Weekly Average Target Temperature
- Inflows – Daily Pattern on Monthly Average, disaggregation, and Inflow temperature a function of historical meteorology
- Meteorology – Hourly Histori

Forecast Boundary Condition Processing: Reservoir Inflow and Release (Example 2006)



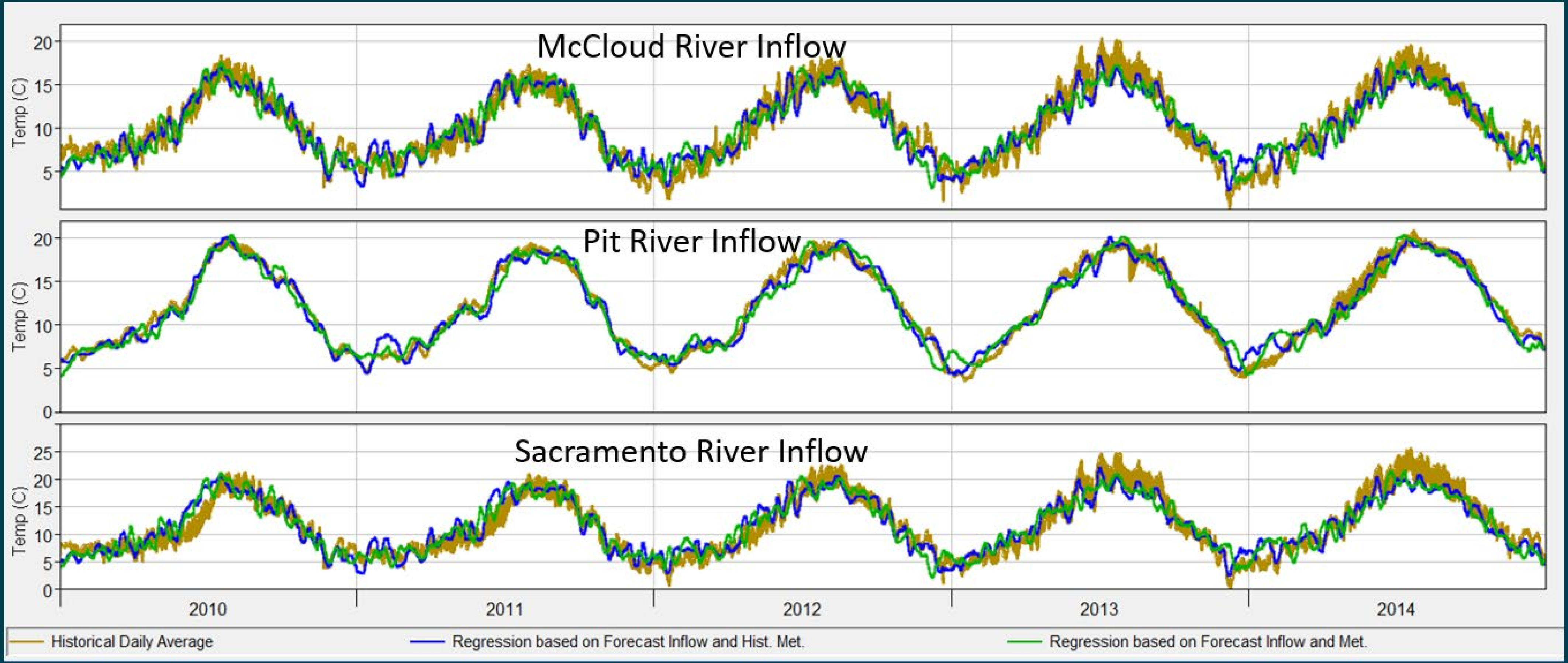
Forecast Boundary Condition Processing: Reservoir Tributary Inflow Distribution (Example 2006)

Shasta Lake Tributary Inflows

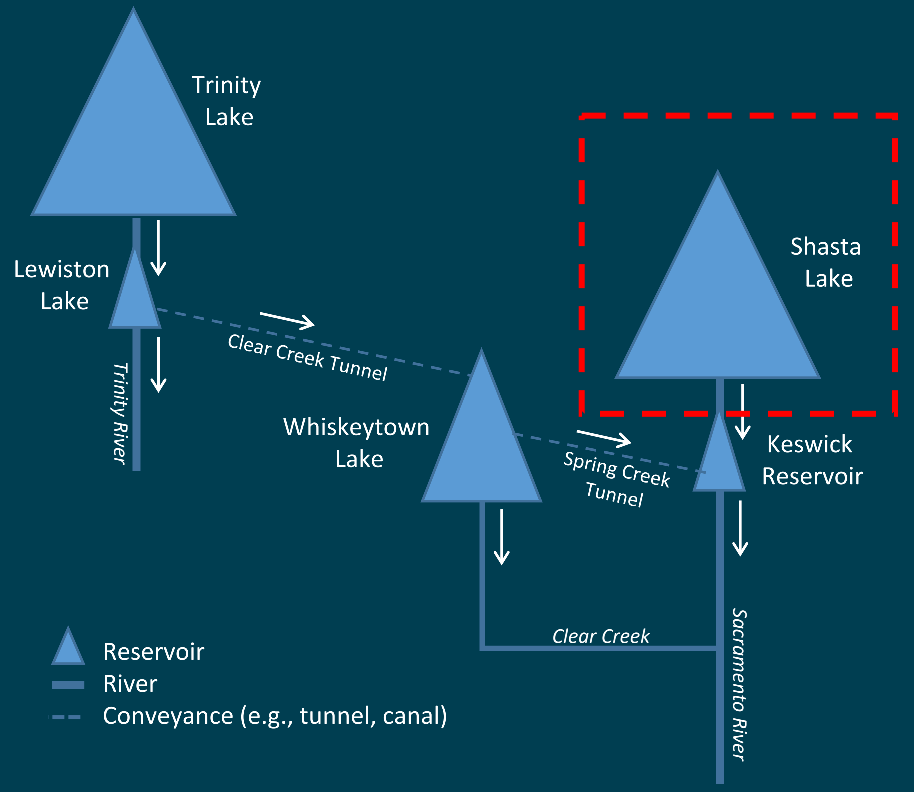


Forecast Boundary Condition Processing: Estimation of Inflow Temperature (Example 2010 to 2014)

Shasta Lake Tributary Inflows



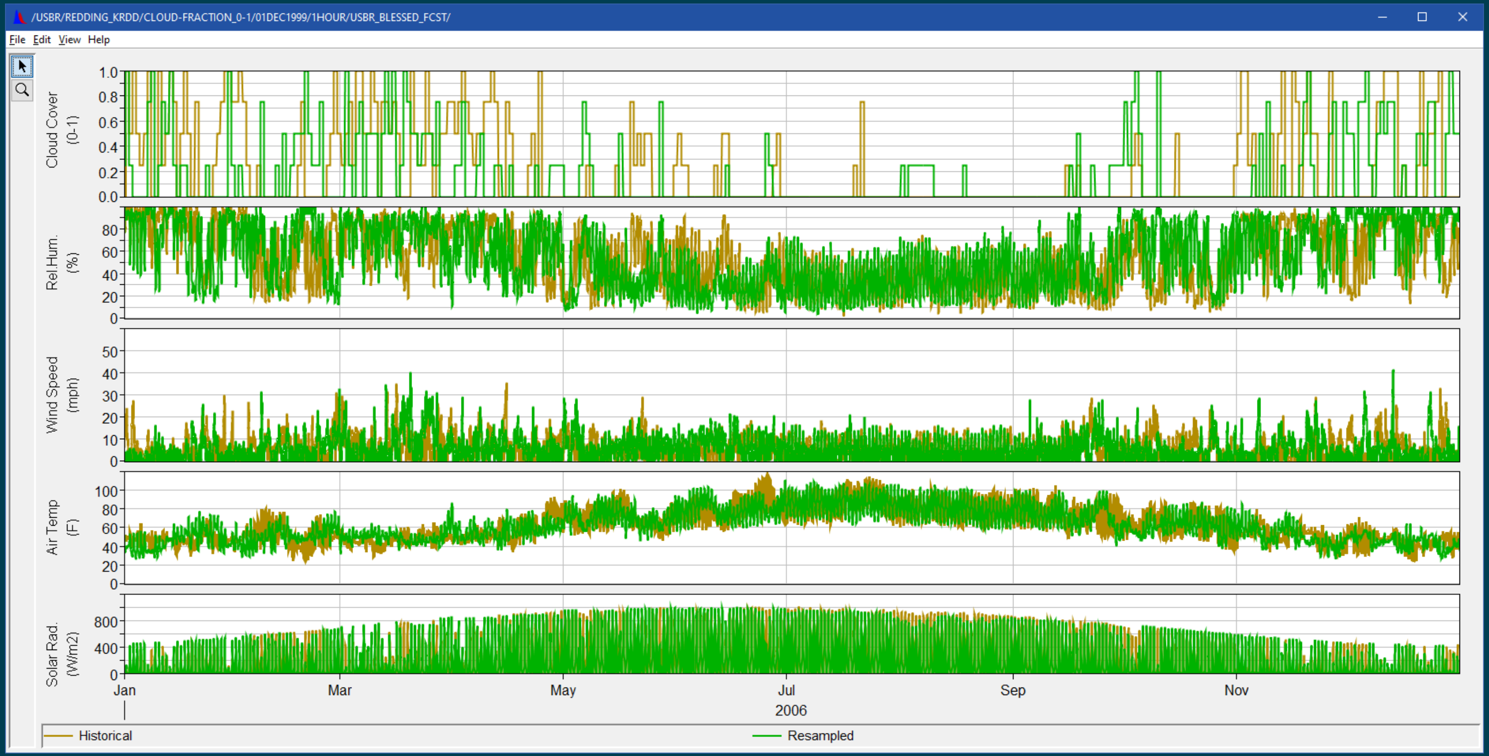
Type D – Structural + TCD Ops + Flow + Meteorological Forecast Processing



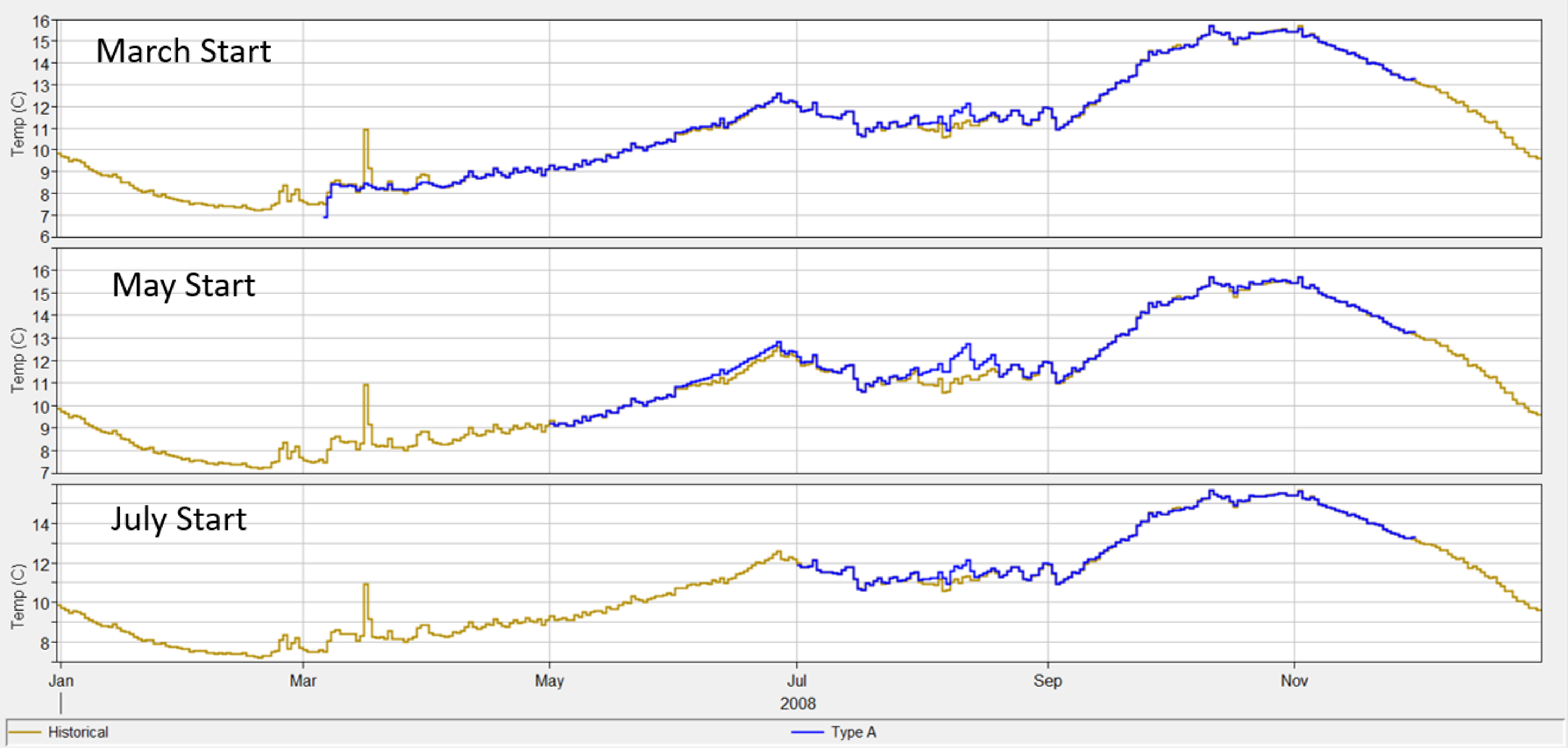
- TCD Operation – Forecasted TCD Logic and Weekly Average Target Temperature
- Inflows – Daily Pattern on Monthly Average, Temperature a function of historical meteorology
- Meteorology – Monthly average air temperature used to select closest historical month

Forecast Boundary Condition Processing: Meteorologic Data (Example 2006)

- Resampled based on Monthly Average Air Temperature
  - For each month:
    - Find closest match from same month of another historical year base on monthly average air temperature
    - Copy all met data records from the identified month/year to forecast met data input

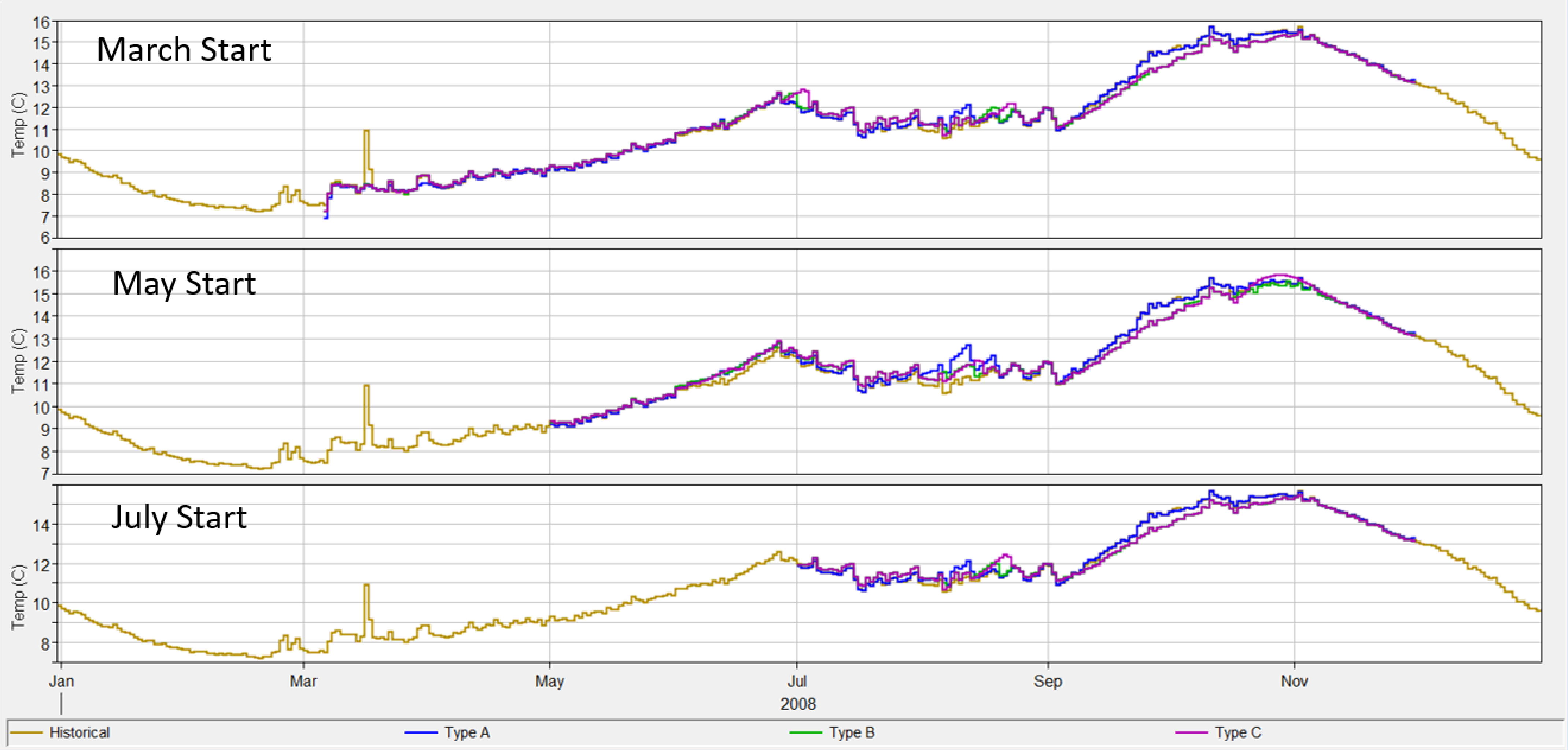


Example Simulation Result: Type A Shasta Outflow Temperature (2008)



Example Simulation Result: Type A and B Shasta Outflow Temperature (2008)

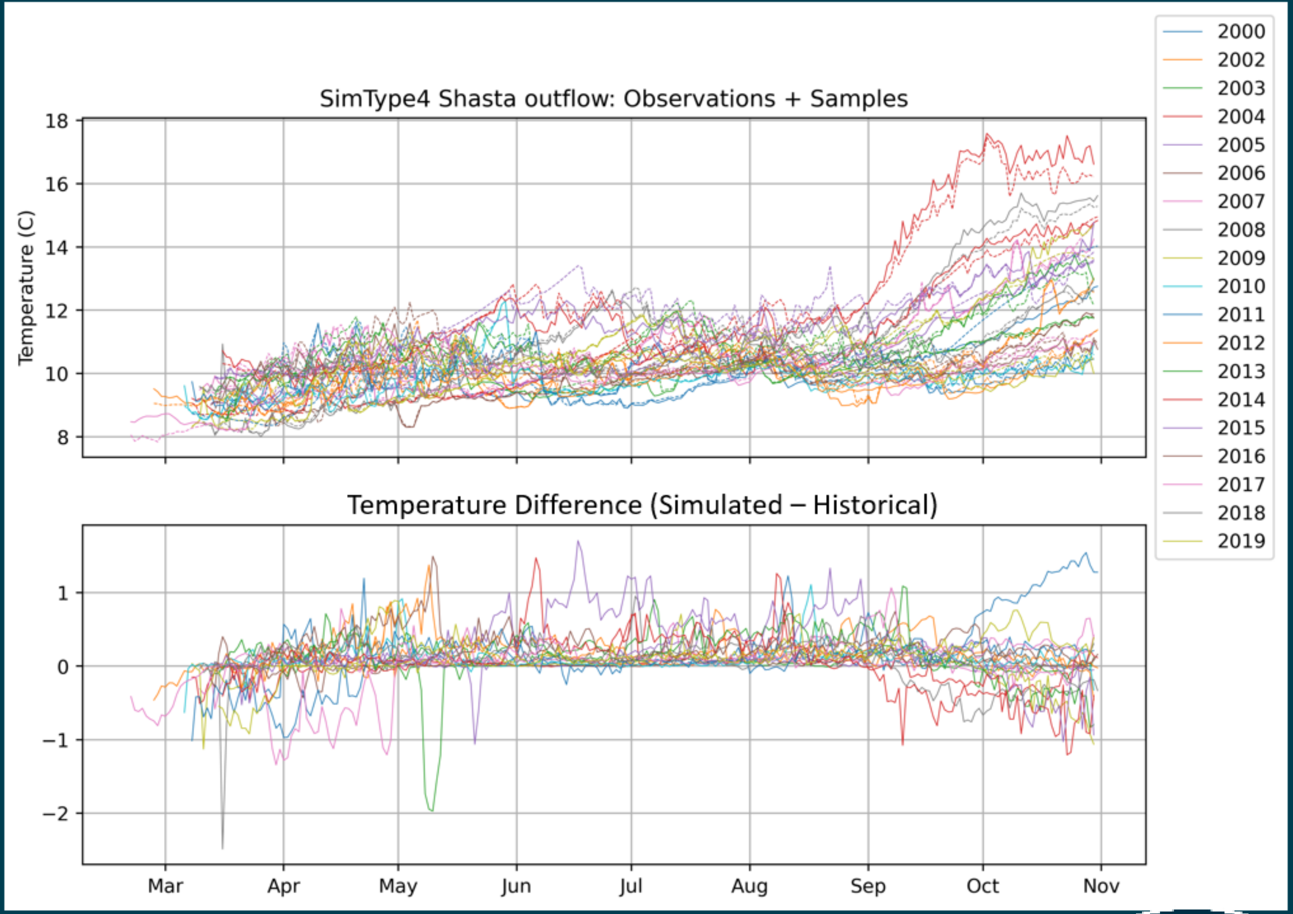
Example Simulation Result: Type A, B, and C Shasta Outflow Temperature (2008)



Example Simulation Result: Type A, B, C, and D Shasta Outflow Temperature (2008)

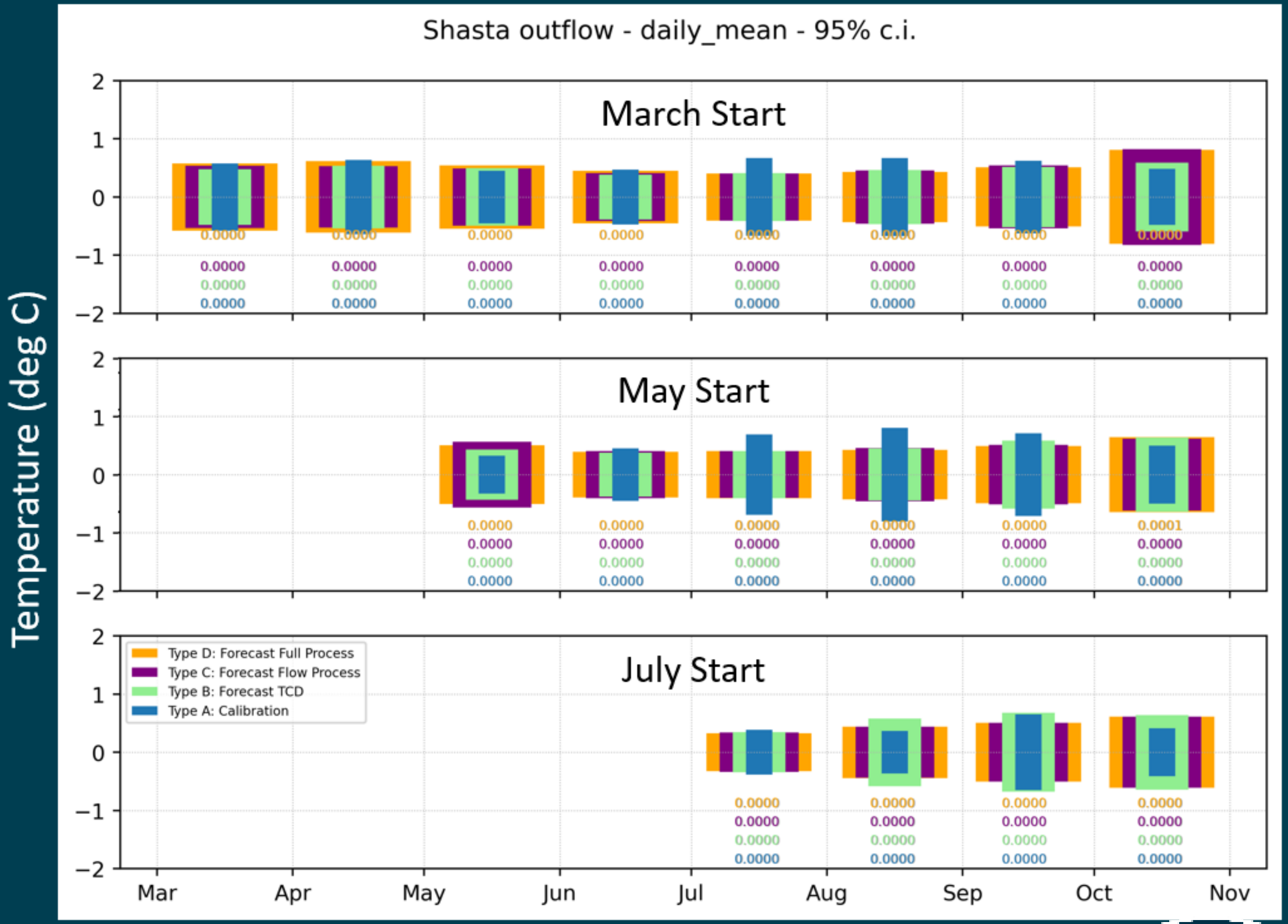
Shasta Outflow Temperature Type D Simulation Results, 2000-2019 March Start

- Top panel: Historical (solid) and Modeled (dashed) daily mean temperatures
- Bottom panel: Difference in daily mean temperature, Simulated – Historical
- Differences before May and in late Fall are often due to profile differences
- In May through September outflow temperature differences are mostly associated with TCD operations



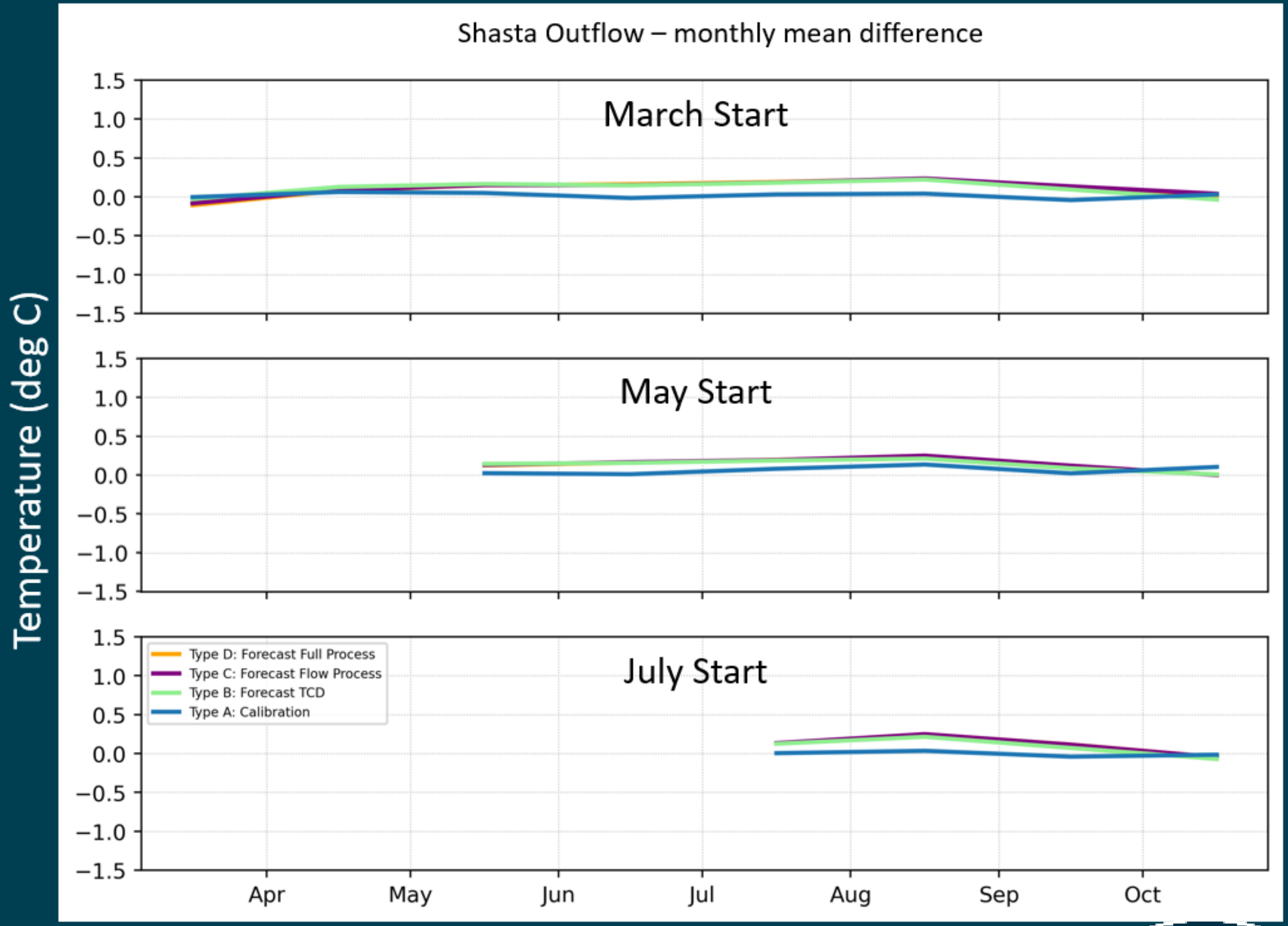
Forecast Process Uncertainty Estimate: Shasta Outflow Temperature

- Vertical height of monthly box = 95% confidence interval
- Numbers below box show p-value of normality test
- Samples are the simulated daily mean temperature minus historical daily mean
- Calibration = Type A
- Forecast TCD = Type B
- Forecast Flow Process = Type C
- Forecast Full Process = Type D



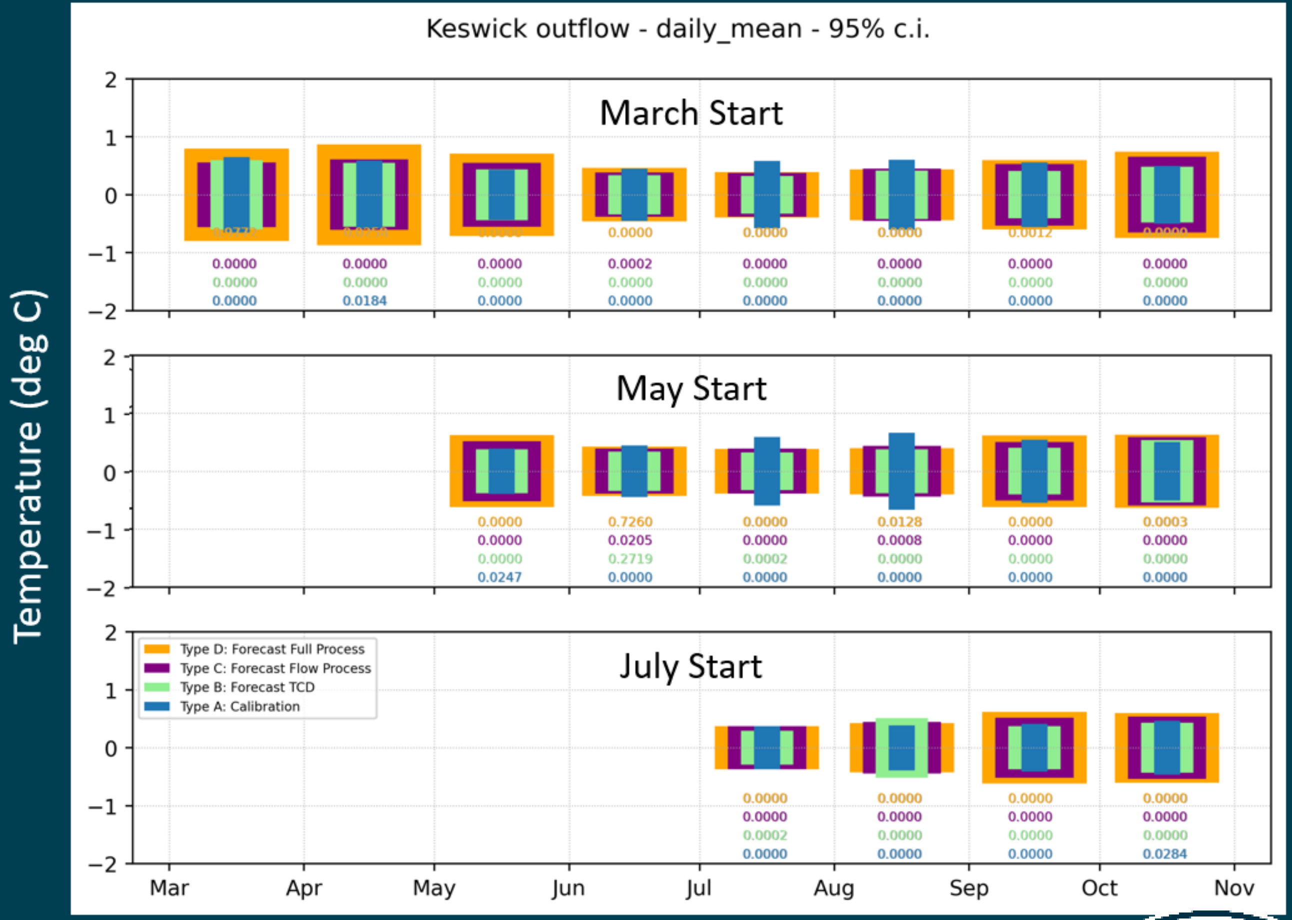
Forecast Process Mean Difference Estimate: Shasta Outflow Temperature

- Samples are the simulated daily mean temperature minus historical daily mean
- Mean difference is calculated as the average of all samples within each month grouped by forecast start
- Calibration = Type A
- Forecast TCD = Type B
- Forecast Flow Process = Type C
- Forecast Full Process = Type D



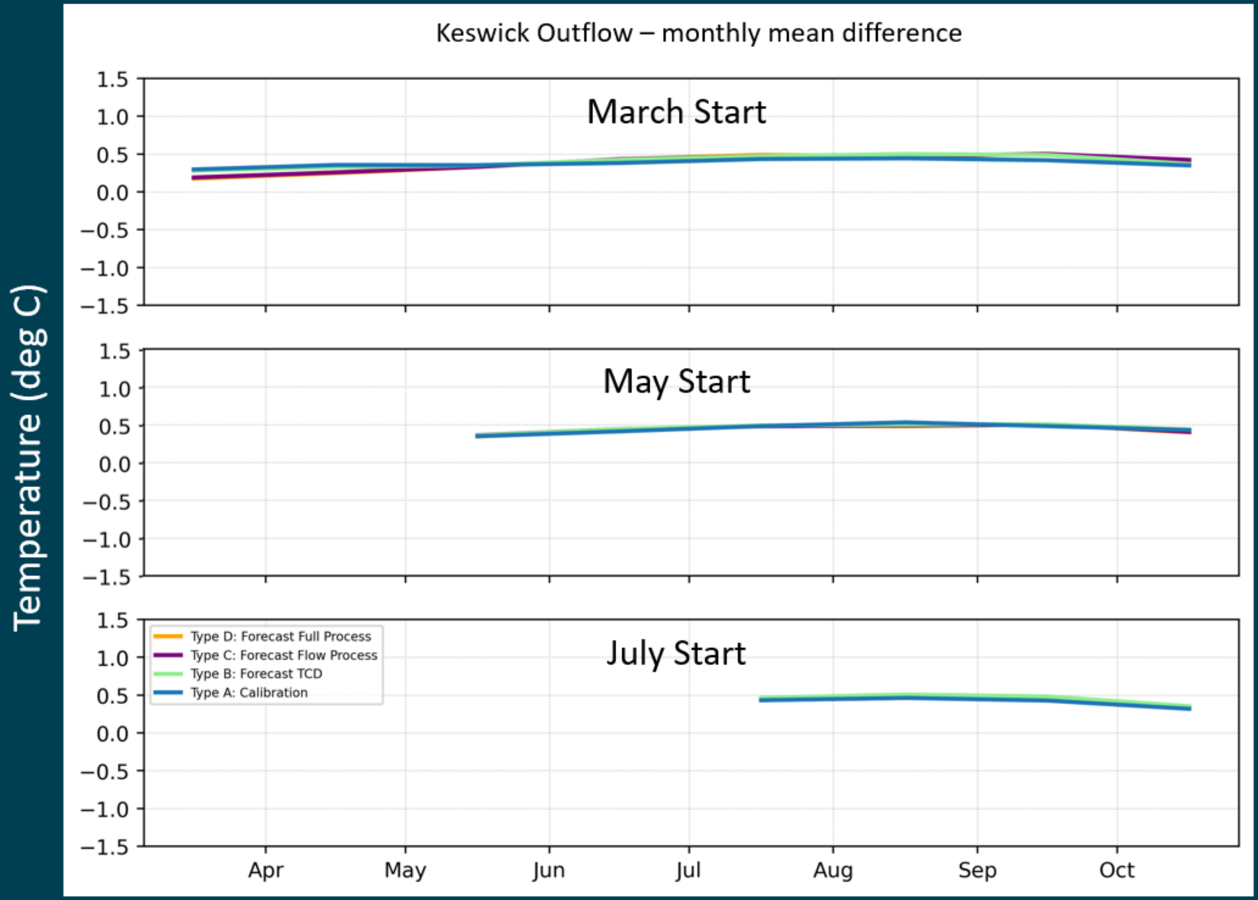
Forecast Process Uncertainty Estimate: Keswick Outflow Temperature

- Vertical height of monthly box = 95% confidence interval
- Numbers below box show p-value of normality test
- Samples are the simulated daily mean temperature minus historical daily mean
- Calibration = Type A
- Forecast TCD = Type B
- Forecast Flow Process = Type C
- Forecast Full Process = Type D



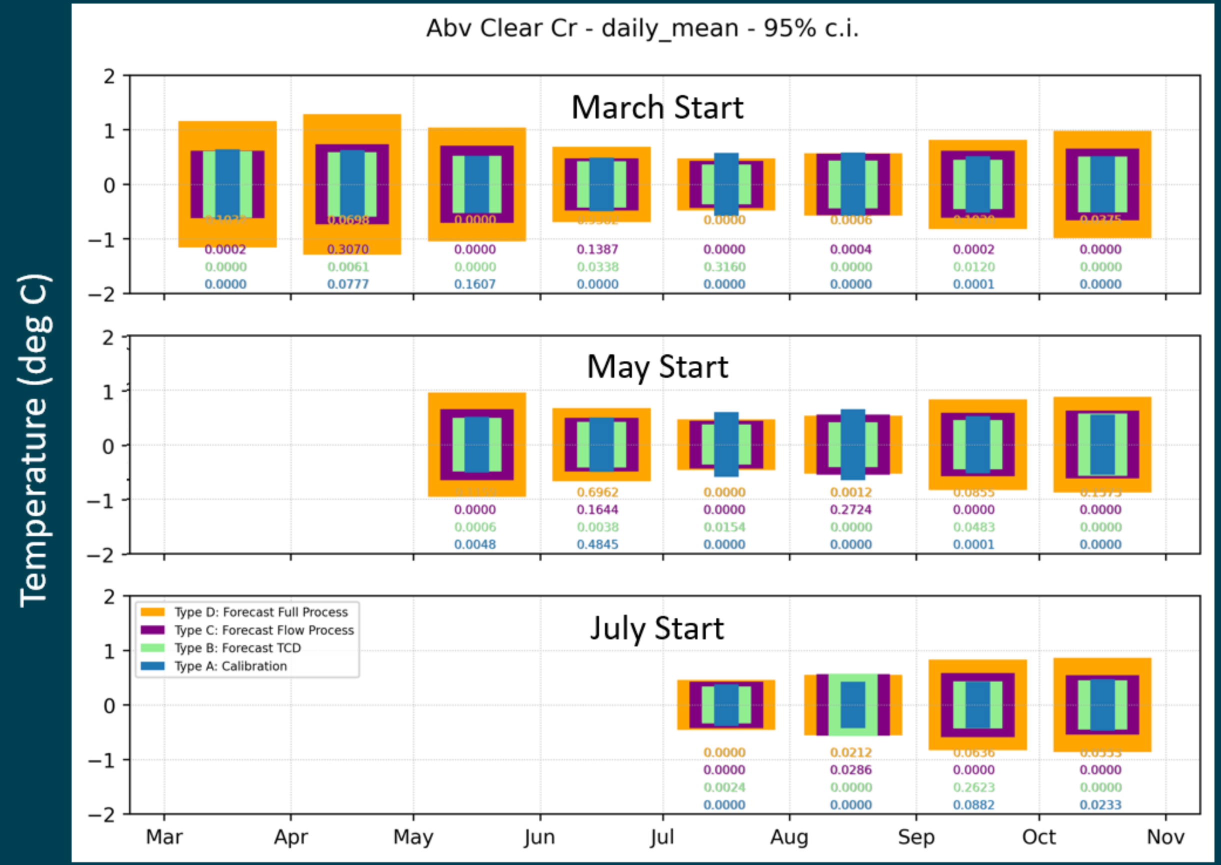
Forecast Process Mean Difference Estimate: Keswick Outflow Temperature

- Samples are the simulated daily mean temperature minus historical daily mean
- Mean difference is calculated as the average of all samples within each month grouped by forecast start
- Calibration = Type A
- Forecast TCD = Type B
- Forecast Flow Process = Type C
- Forecast Full Process = Type D



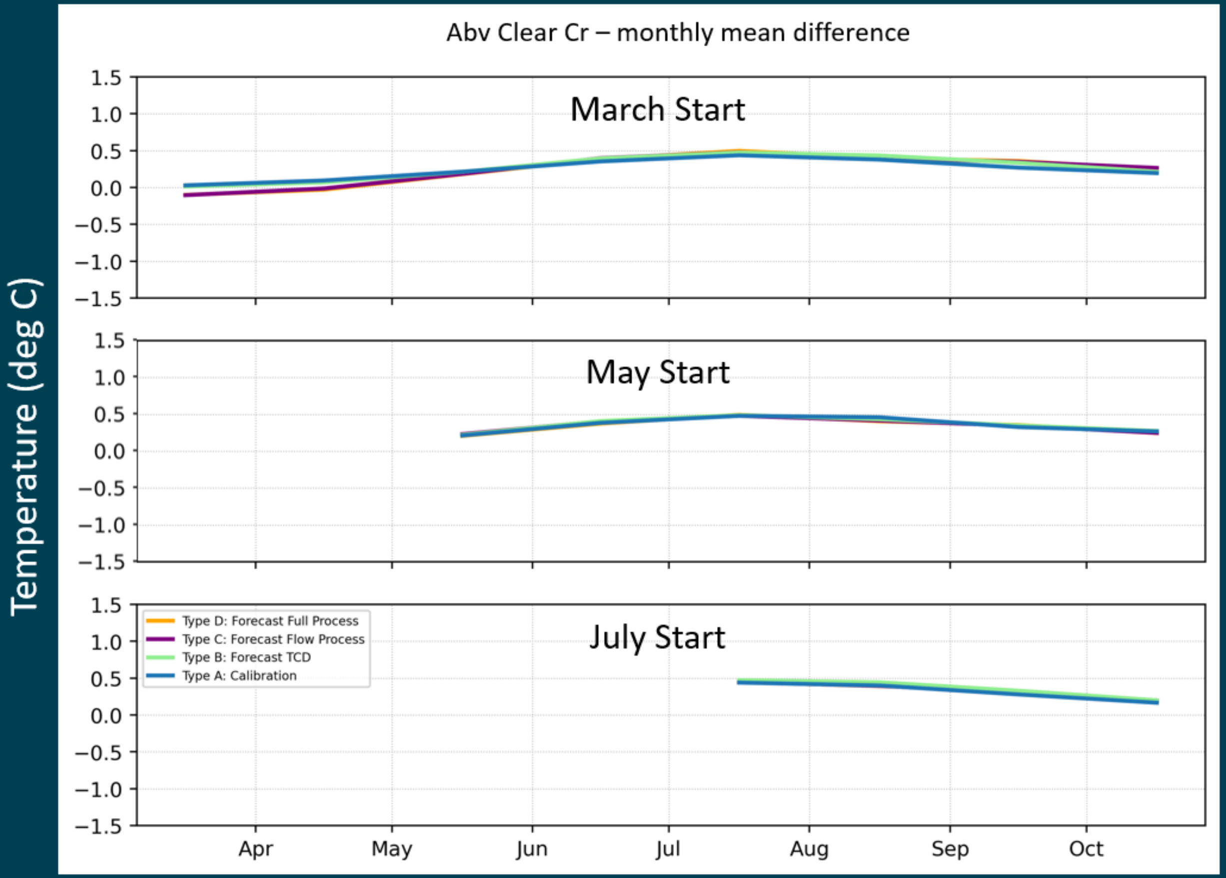
Forecast Process Uncertainty Estimate: Sacramento River above Clear Creek

- Vertical height of monthly box = 95% confidence interval
- Numbers below box show p-value of normality test
- Samples are the simulated daily mean temperature minus historical daily mean
- Calibration = Type A
- Forecast TCD = Type B
- Forecast Flow Process = Type C
- Forecast Full Process = Type D



Forecast Process Mean Difference Estimate: Sacramento River above Clear Creek

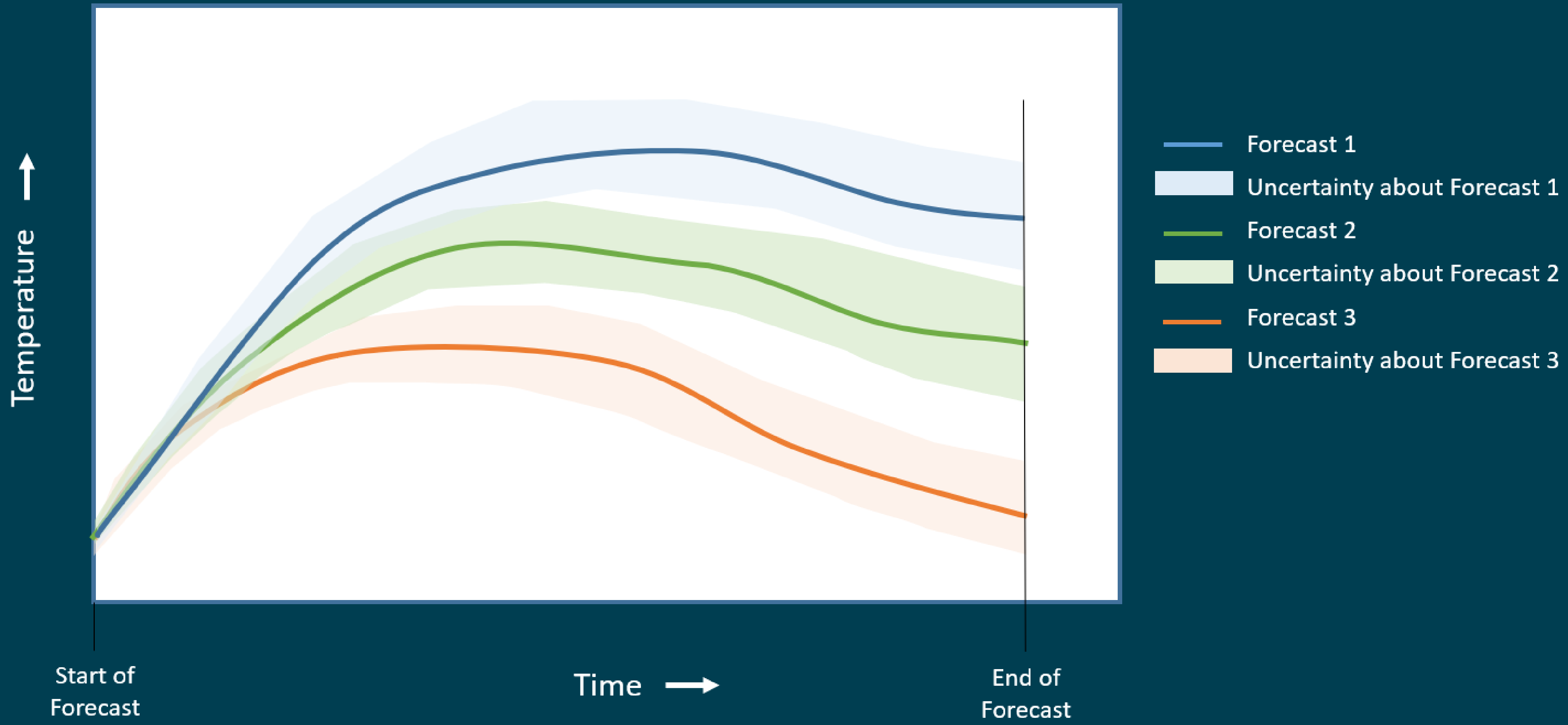
- Samples are the simulated daily mean temperature minus historical daily mean
- Mean difference is calculated as the average of all samples within each month grouped by forecast start
- Calibration = Type A
- Forecast TCD = Type B
- Forecast Flow Process = Type C
- Forecast Full Process = Type D



Summary of Forecast Process Uncertainty Results

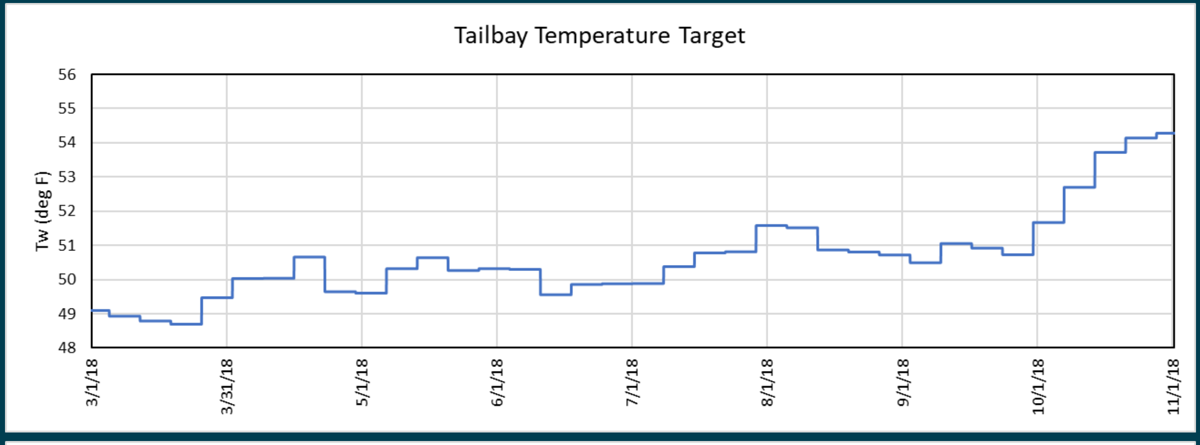
- Early forecasts tend to have moderately greater uncertainty in late fall predictions
- When the model is allowed to operate the TCD to meet target temperatures, error is typically reduced mid-year but possibly at the expense of missing targets later in the year
- Estimation of meteorologic data has a relatively greater impact on downstream locations
- The "structural" uncertainty of the calibrated model as measured by 95% confidence interface is generally on the order 0.5 deg C
- Considering all aspects of the forecast data processing, the 95% confidence interval at the Sacramento River above Clear Creek Station increases to approximately 1 deg C, not an excessive increase

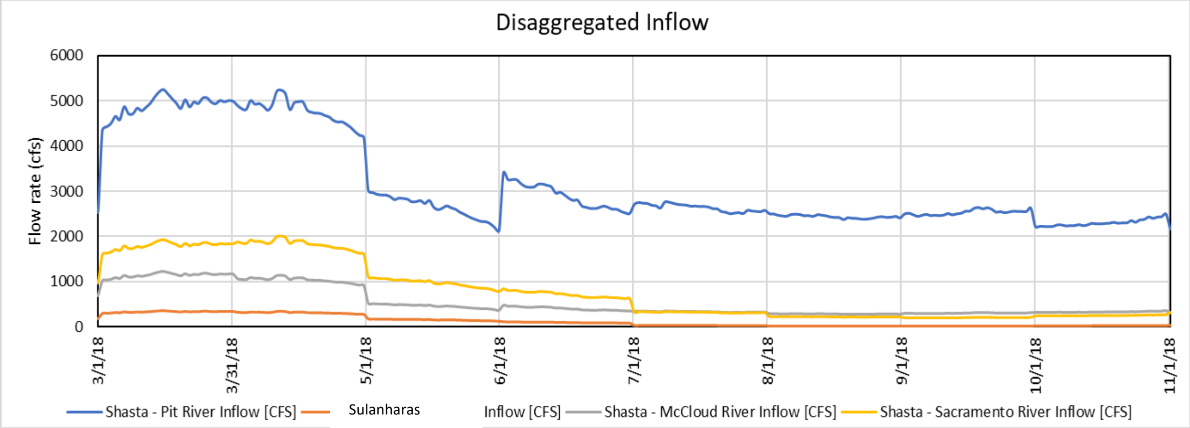
Rough Sketch suggesting application of forecast process uncertainty onto individual forecast traces



Shasta Lake –CE-QUAL- W2

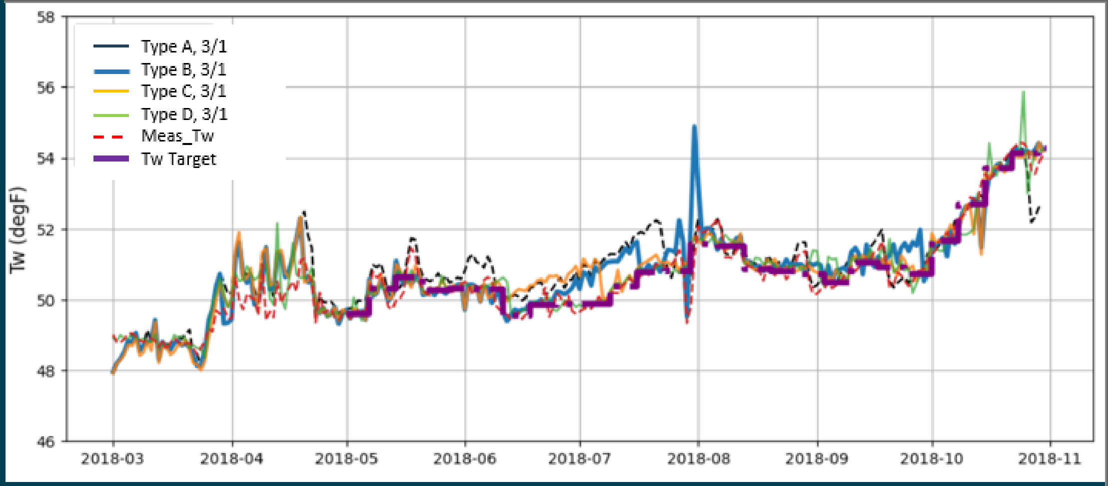
- Single year (no distribution)
- Similar assumptions for Type A-D
  - A: Calibration
  - B: TCD gate operations logic (weekly)
  - C: Flow disaggregation/tributary
  - D: Meteorology (and water temperature)
- Results
  - Shasta Only
  - March 1 and May 1 start dates
  - Time series results

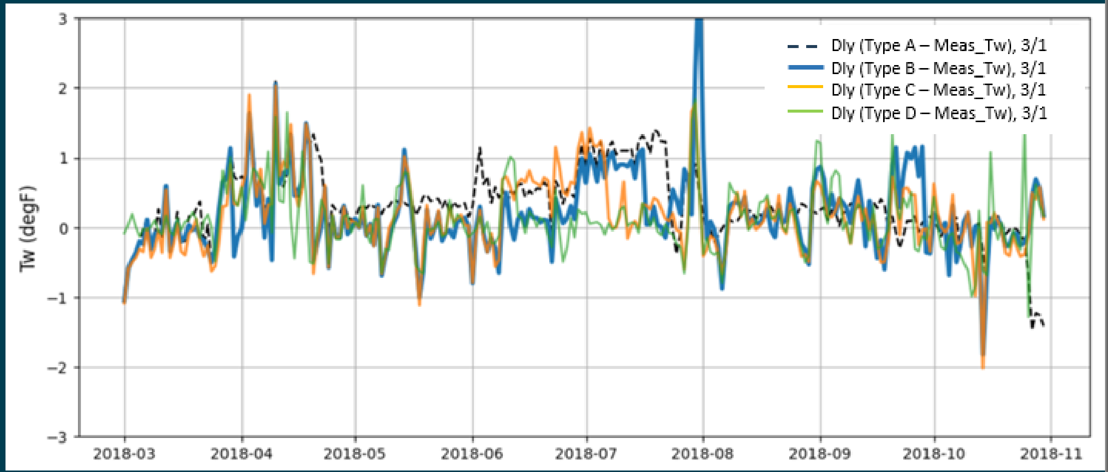


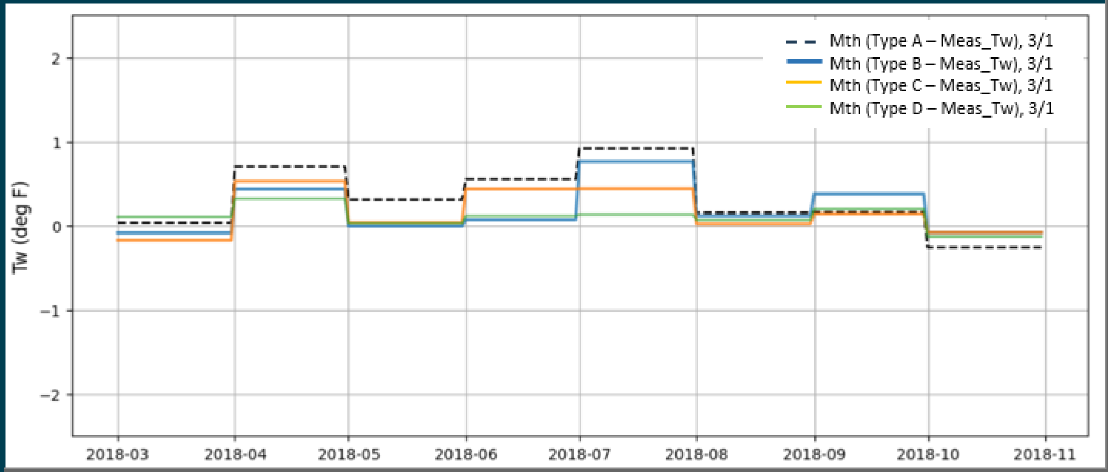


Results: March 1

- Simulated Shasta Dam release temperature (top)
- Difference between Simulated Shasta Dam release temperature and measured
  - Daily average (middle)
  - Monthly average (bottom)
- Forecasts uncertainty response varies
  - Maximum Type A (1.0F)
  - Maximum Type D (0.3F)

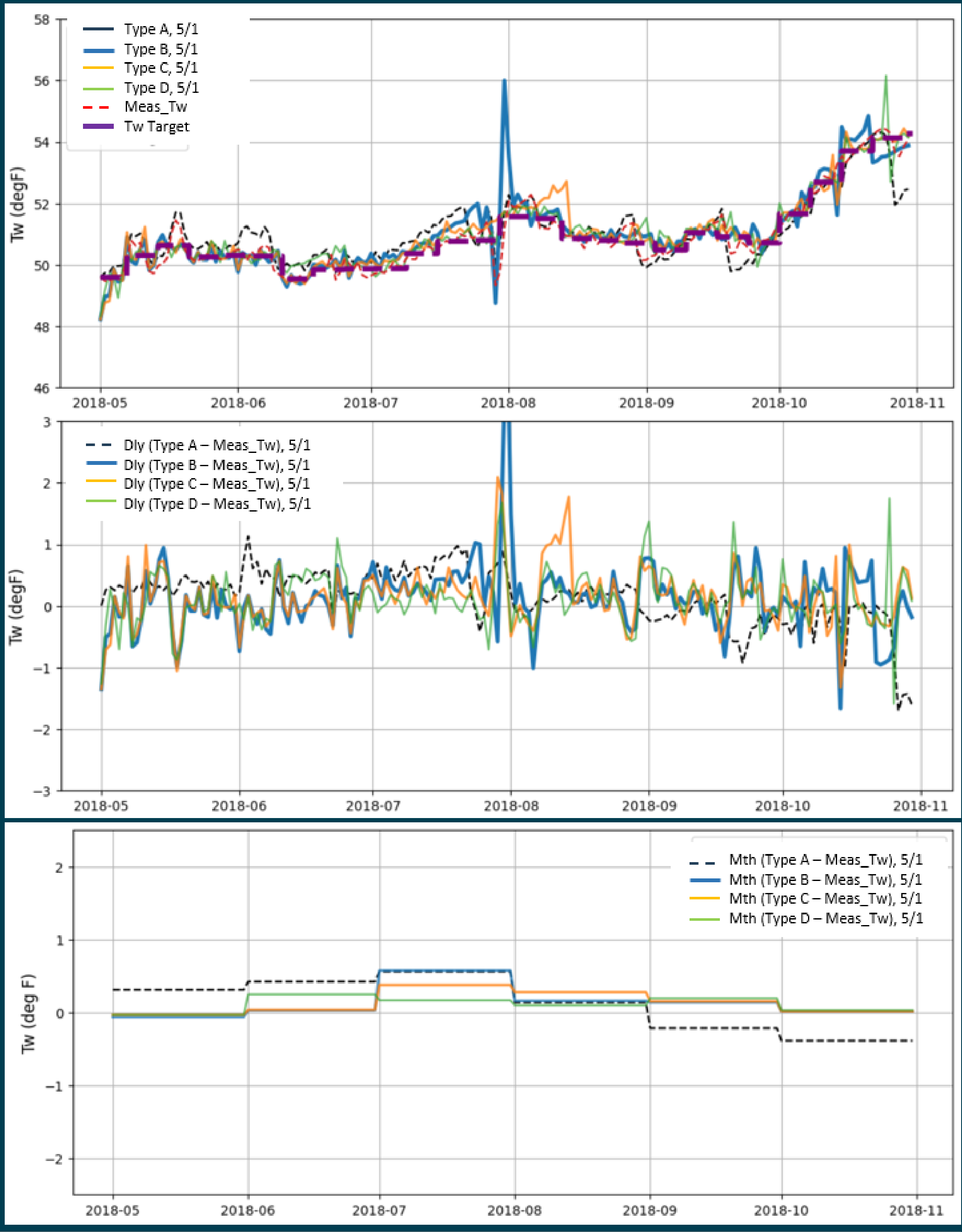






Results: May 1

- Simulated Shasta Dam release temperature (top)
- Difference between Simulated Shasta Dam release temperature and measured
  - Daily average (middle)
  - Monthly average (bottom)
- Forecasts uncertainty response varies
  - Maximum Type A (0.6F)
  - Maximum Type D (0.2F)



Uncertainty Estimation Summary (Part I)

- Generally, forecasts starting in May avoid uncertainty in March and April (lower average difference)
- Forecast runs often had results with lower error in tailbay target temperature than the calibration runs because automatic TCD gate selection
- While tailbay temperatures are largely similar, in-reservoir conditions change under different simulations (B, C, D)
- Exploring metrics to assess these in-reservoir differences

Uncertainty: Linked and Unlinked Modeling

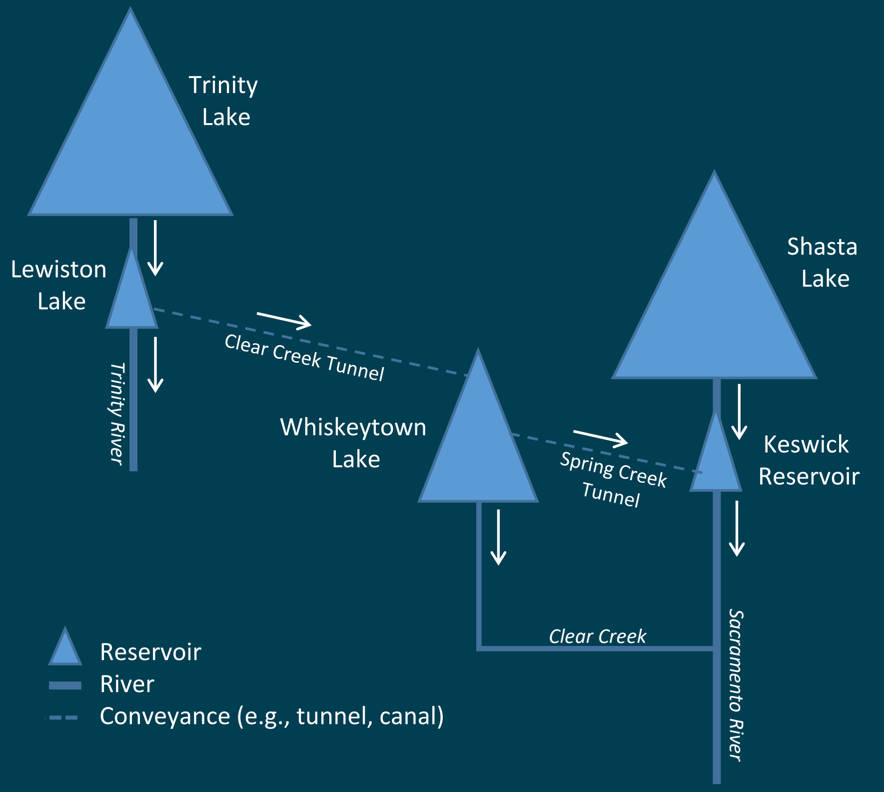
- Based on recent clarification by the Peer Review Panel:
  - Exploration examined linked and unlinked CE-QUAL-W2 models of the Shasta/Trinity basins
  - Preliminary Results (pending documentation)

CE-QUAL-W2 Model Assessment: Shasta/Trinity System

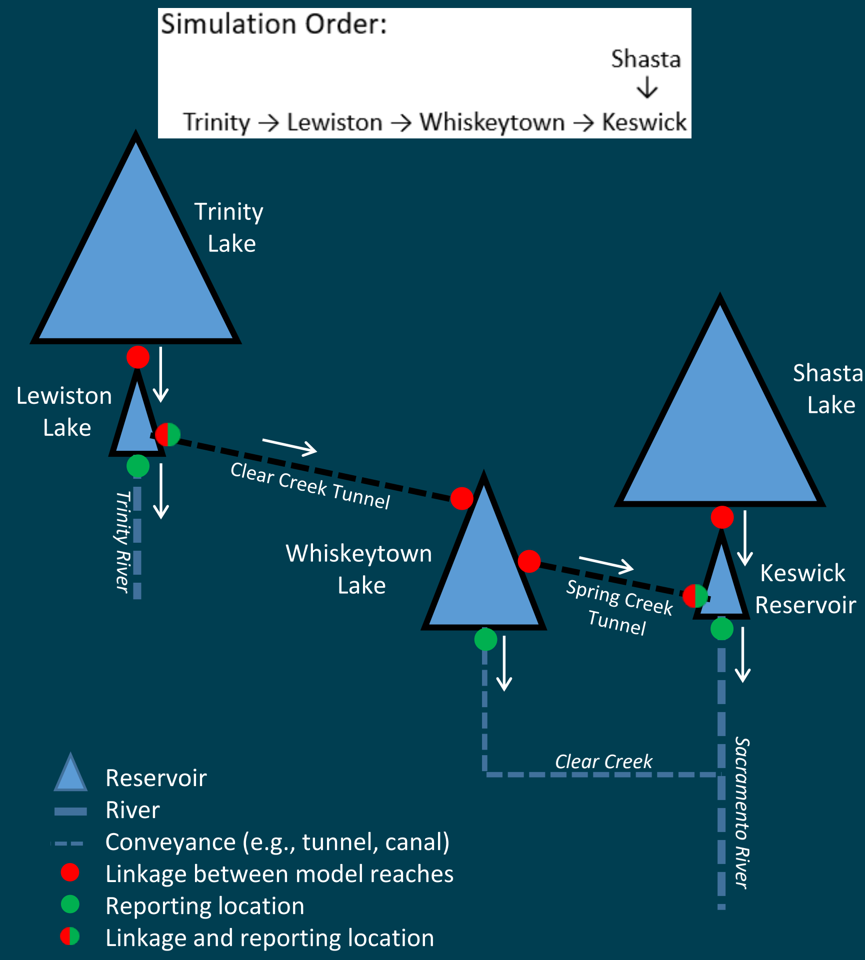
- Objective: assess propagation of model uncertainty
- Approach:
  - Compare model performance
    - Unlinked (calibrated) models: upstream water temperature (Tw) boundary conditions is measured
    - Linked models: Linked – upstream Tw boundary conditions is simulated
    - Equivalent flow and operations, meteorology, initial conditions
- Period of analysis: 2016-2019 (period of globally available data)
- Summary:
  - **Linked and unlinked CE-QUAL-W2 model simulation do not exhibit remarkable differences.**
  - **Results are consistent with the calibration performance**
  - **Useful insight into year-round temperature dynamics.**

CE-QUAL-W2 Model Assessment: Linked and Unlinked Systems

Unlinked: Shasta-Trinity System
Discrete CE-QUAL-W2 Models (2016-2019)



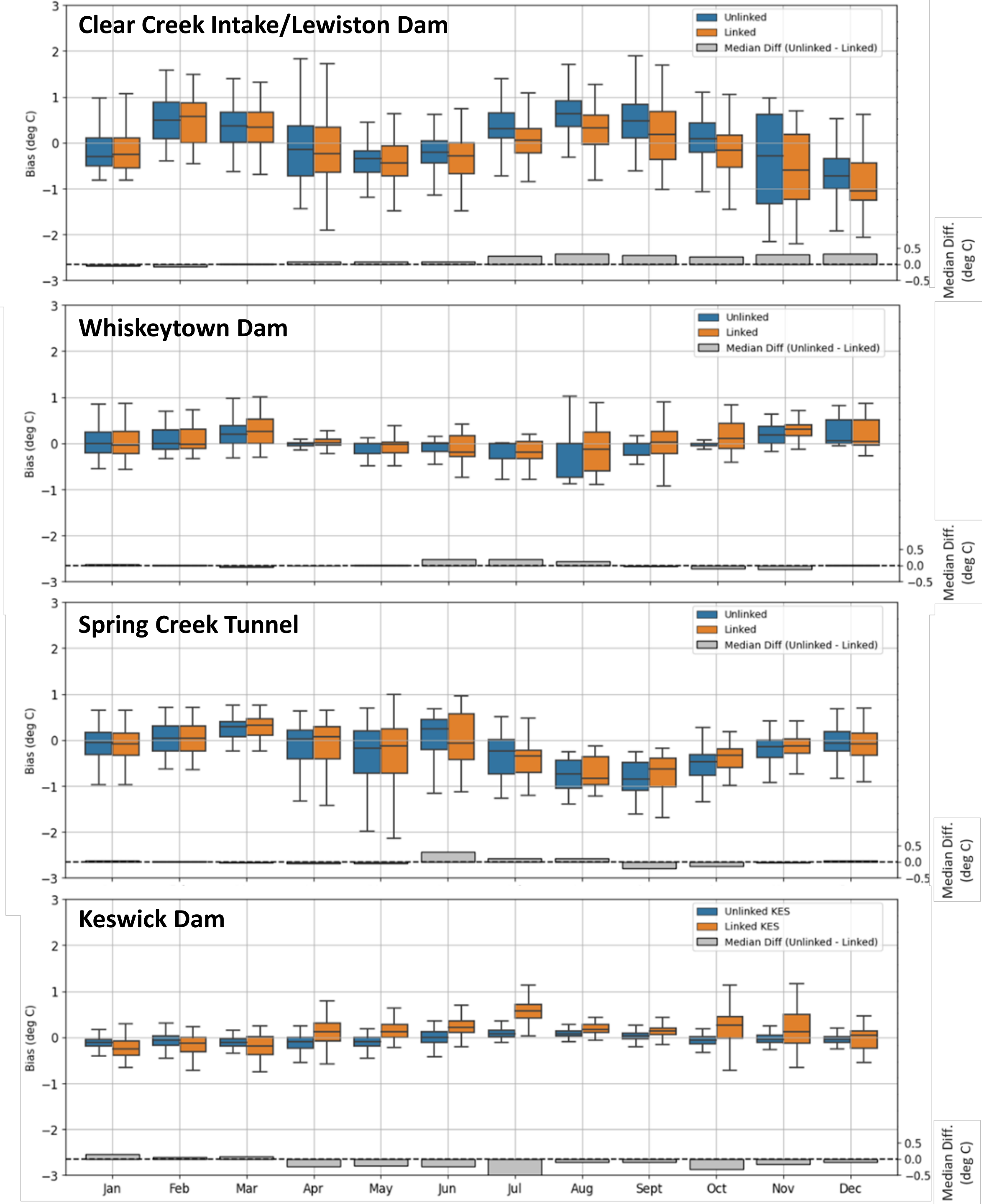
Linked: Shasta-Trinity System
CE-QUAL-W2 Models (2016-2019)



Un/Linked Results

- **Trinity-Lewiston:**
  - Minimal changes at Lewiston Dam. Exceptions include high flow conditions (short residence time) when bias from simulated Trinity Lake Dam release temperatures are evident at Lewiston Dam.
- **Whiskeytown Lake:**
  - Moderates Trinity Basin diversions, with minimal differences at Whiskeytown Dam.
  - Variability at Spring Creek Powerhouse is similar to calibrated model
- **Keswick Dam:**
  - Deviations at Keswick Dam are associated with simulated Shasta Dam releases.
  - Short residence time in Keswick Reservoir results in bias from simulated Shasta Dam release temperatures being conveyed to Keswick Dam, overwhelming the modest uncertainty associated with inputs from Spring Creek Tunnel

(Figures utilize 2016-2019 data)



Uncertainty Estimation Summary (II)

- Achievement:
  - WTMP project demonstrated identifying sources of uncertainty, employed a method of quantifying uncertainty, and explored uncertainty with linked and unlinked models (documentation pending).
- Assessment:
  - CE-QUAL-W2 and ResSim evaluation, findings, and preliminary information suggests uncertainty introduced is of similar magnitude as calibration error and presents suitability to apply models in real-time/seasonal or long-term planning modes.