

EEMS Demonstration Model Description

DM_Lake_Washington_Thermal_Stratification_SGZ

1 Objective

This demonstration model uses EFDC+ Explorer (EE) and EFDC+ to simulate hydrodynamics and thermal stratification in Lake Washington, Seattle. The model is designed to demonstrate the Sigma-Zed (SGZ) vertical layering option in EFDC+, which is unique to EFDC+ and specifically developed to reduce horizontal pressure gradient errors in vertically stratified systems while remaining computationally efficient.

Two model configurations are included to allow direct comparison of vertical discretization approaches:

- **SGZ model:** Uses the Sigma-Zed (SGZ) vertical grid ($IGRIDV = 1$), which adapts the number of active layers to local bathymetry.
- **Sigma model:** Uses the standard sigma vertical grid ($IGRIDV = 0$), in which all 55 layers are active in every cell regardless of water depth.

Lake Washington is a deep, thermally stratified lake with a maximum depth of approximately 60 m. The large depth range and strong summer thermocline make it a great case for vertical discretization: standard sigma coordinates produce pressure gradient errors in cells where adjacent columns have very different water depths, while z-coordinate grids require many layers to resolve the full depth range. The SGZ approach combines the advantages of both by adapting the vertical layer structure to local bathymetry, as described in Craig (2014).

2 Model Description

The model configuration is summarized in Table 1 and the model domain is shown in Figure 1. The domain covers the full extent of Lake Washington and the connected Lake Union to the northwest, with bottom elevations ranging from -60 m (deep central basin) to $+11$ m (shallow margins). Both model configurations share the same grid, boundary conditions, and forcing; the only difference is the vertical grid type.

Table 1 Model configuration summary

Run Period	Horizontal Cells	Vertical Layers	Activated Modules
2008-06-27 to 2009-06-27	1,183 cells	• 55 layers (SGZ, $IGRIDV = 1$) • 55 layers (Sigma, $IGRIDV = 0$)	• Hydrodynamics • Temperature

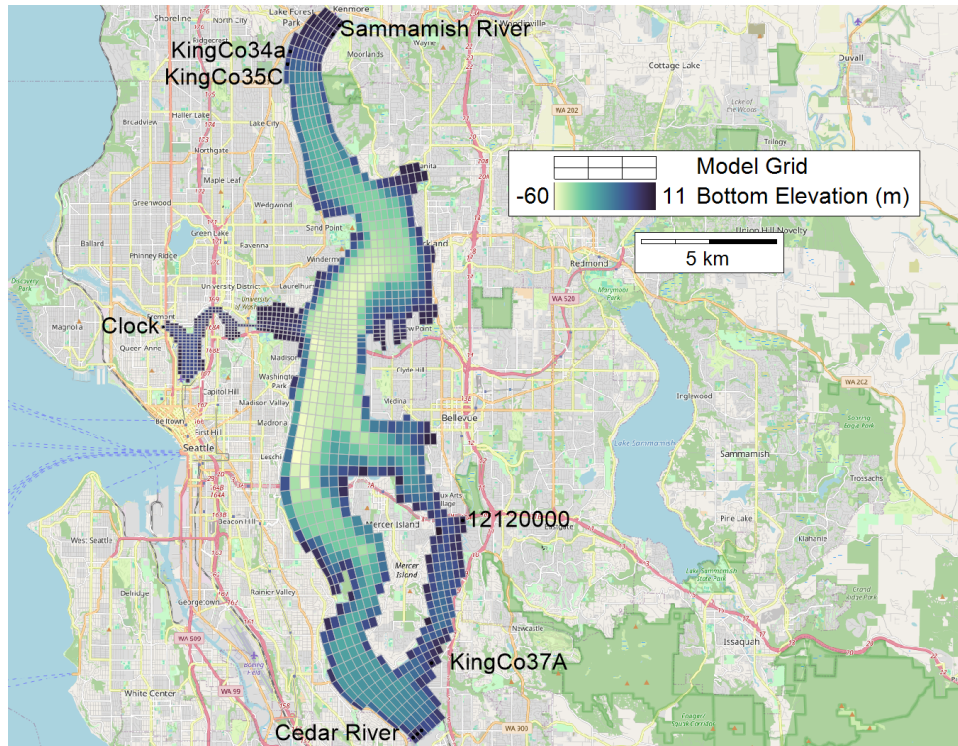


Figure 1 Model domain. The domain encompasses Lake Washington and the connected Lake Union to the northwest.

2.1 Sigma-Zed Vertical Grid

The SGZ vertical grid is activated, with specifying the minimum number of active vertical layers in the shallowest cells to 2 layers. The maximum of 55 layers applies in the deepest cells of the domain (≈ 60 m), providing a vertical resolution of approximately 1 m near the thermocline. In shallower areas, the SGZ algorithm collapses unused layers to maintain numerical efficiency without distorting the pressure gradient calculation.

The SGZ approach is particularly valuable for Lake Washington because the 60 m maximum depth combined with strong summer stratification requires fine near-surface resolution to resolve the thermocline, while the pressure gradient errors that would arise in a standard sigma grid between deep and shallow cells are eliminated by the layer-collapsing mechanism (Craig, 2014).

2.2 Standard Sigma Vertical Grid

The sigma model configuration uses the standard sigma vertical grid ($IGRIDV = 0$), in which all 55 layers are distributed uniformly through the water column at every cell. The layer thickness fractions are uniform, with each layer assigned a fractional thickness of approximately 0.018 (i.e., $1/55$ of the local water depth). Unlike the SGZ configuration, the sigma grid does not collapse layers in shallow cells, which can introduce horizontal pressure gradient errors where adjacent cells have significantly different depths.

2.3 Forcing and Boundary Conditions

The model is forced by wind and atmospheric heat exchange, with a simplified internal heat balance. Dynamic time-stepping is used with a base timestep of 0.06 s and a maximum of 100 s. Seven inflow/outflow boundaries are configured across 10 cells, as summarized in Table 2. The two major tributaries including Cedar River (southern end) and Sammamish River (northern end) carry temperature time series; the remaining boundaries use 0°C .

Table 2 Flow boundary conditions

Boundary	Flow Series	Temperature
Cedar River	0804	Time series (0831)
Sammamish River	KingCo51T	Time series (0804)
KingCo34a	KingCo34a	Constant (0°C)
KingCo35C	KingCo35c	Constant (0°C)
12120000	Lock01	Constant (0°C)
Clock	Lock02	Constant (0°C)
KingCo37A	KingCo37a	Constant (0°C)

3 Folder Structure

The model package contains the following components:

- **Model:** The complete EFDC+ model project directory, loadable directly in EFDC+ Explorer for pre- and post-processing.
- **Data:** Contains three subfolders:
 - *Bathymetry:* `Bathymetry.dat`
 - *Boundaries:* time series files for all inflow, outflow, wind, and atmospheric boundary conditions
 - *Calibration:* measured water level and water temperature data for comparison with model output
- **Grid:** `LW Grid.gpc` (GridPlus format for EE) and `LW Grid.kml` (viewable in Google Earth).
- **Maps-Images/:** Geo-referenced imagery (`Lake Washington.jpg/.jgw`).

4 Model Results

Figures 2 and 3 show modelled versus measured vertical temperature profiles at the Buoy station ($I = 48$, $J = 37$) for two dates: 2008-09-09 (peak summer stratification) and 2009-05-01 (developing spring stratification), for the SGZ and standard sigma configurations respectively. Figure 4 shows the plan-view depth-averaged temperature at 2009-04-28 19:30.

SGZ Model — Vertical Temperature Profiles

At both dates the SGZ model closely reproduces the observed profile. On 2008-09-09, it captures the full 7–20°C summer range, the sharp thermocline between –5 and –15 m, and the cold isothermal hypolimnion, with only a minor near-surface overshoot. On 2009-05-01 it tracks the developing spring thermocline and cold hypolimnion ($\approx 7^\circ\text{C}$ below –25 m) equally well throughout the water column.

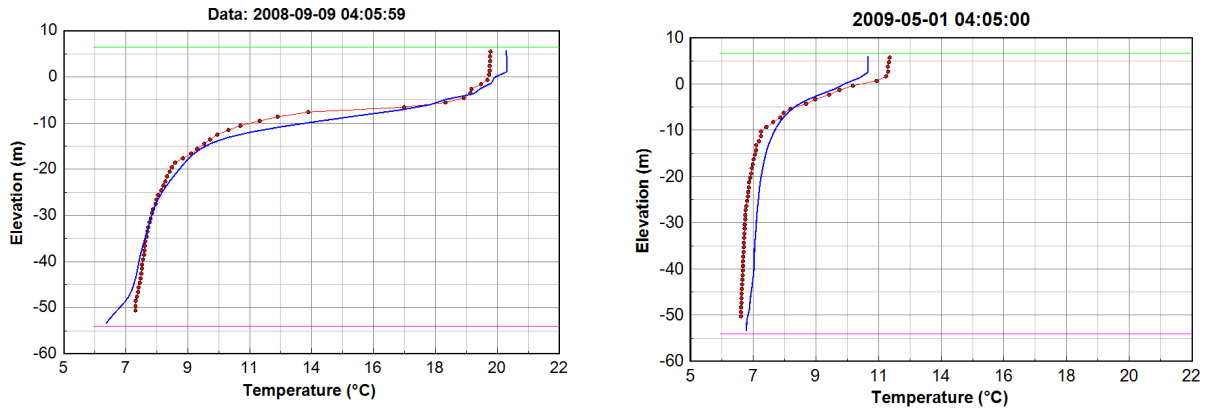


Figure 2 Modeled versus measured vertical temperature profiles at the Buoy station using the SGZ model *Left: 2008-09-09 Right: 2009-05-01*

Standard Sigma Model — Vertical Temperature Profiles

On 2008-09-09 the sigma model substantially underpredicts the warm epilimnion, reaching only $\approx 17\text{--}18^\circ\text{C}$ at the surface versus the observed $\approx 20^\circ\text{C}$, and fails to resolve the sharp thermocline. Horizontal pressure gradient errors from the uniform sigma discretization generate spurious mixing that overwhelms the stratification signal. On 2009-05-01, where stratification is weaker, the sigma model performs reasonably well, demonstrating that its limitation is most pronounced under strong summer conditions.

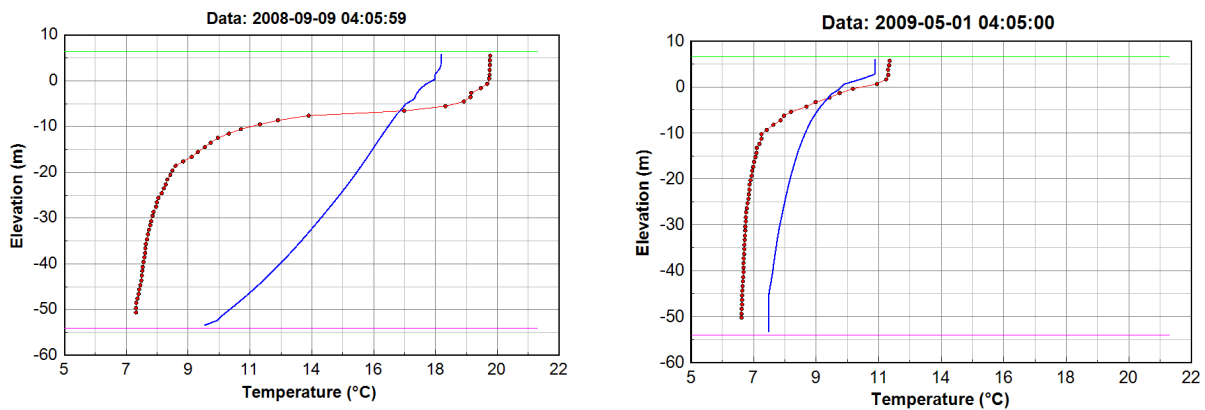


Figure 3 Modeled versus measured vertical temperature profiles at the Buoy station using the standard sigma-stretch model. *Left: 2008-09-09 Right: 2009-05-01*

Plan-View Temperature Distribution

Figure 4 shows the depth-averaged temperature field at 2009-04-28 19:30. Temperatures range from approximately 8°C to 11°C . The spatial pattern reveals a clear temperature gradient between the deep central basin of Lake Washington and the shallower northern arm and Lake Union connection.

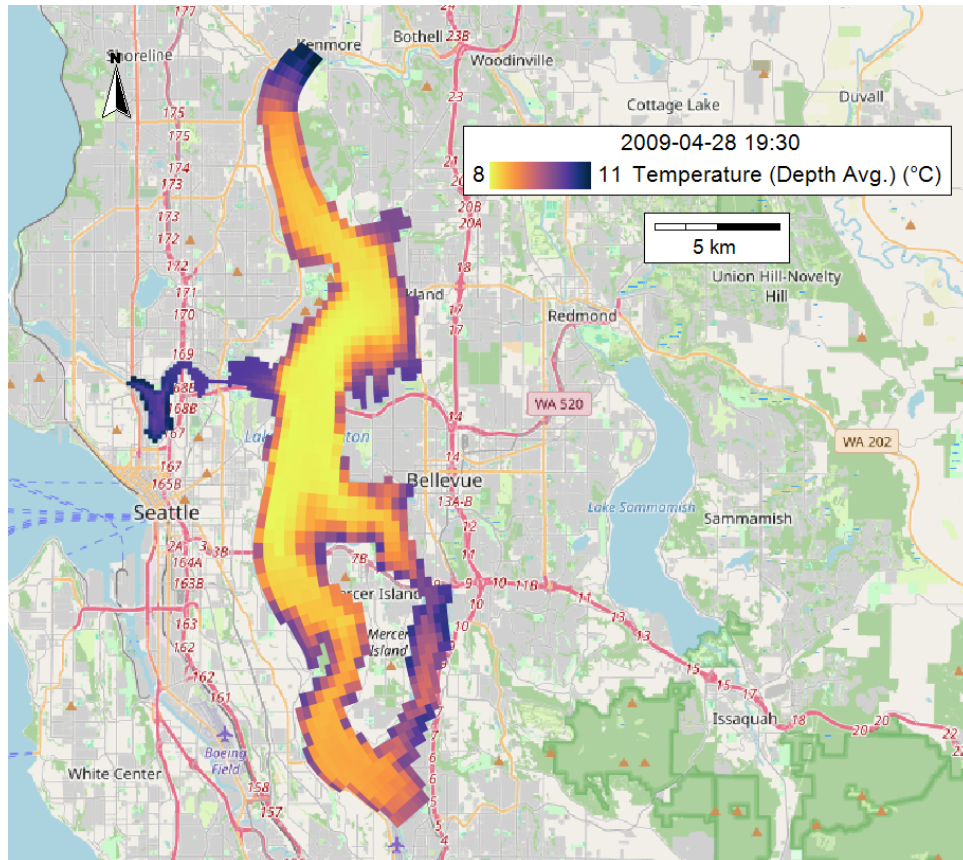


Figure 4 2DH depth-averaged temperature at 2009-04-28 19:30

5 References

- Craig, Paul M. (2014). Sigma-Zed: A Computationally Efficient Approach to Reduce the Horizontal Gradient Error in the EFDC's Vertical Sigma Grid. *Proceedings of the 11th International Conference on Hydrodynamics (ICHD 2014)*, October 19–24, 2014, Singapore.

6 Notes

6.1 Disclaimer

This model is provided to demonstrate that EFDC+ Explorer and EFDC+ can be used to build and analyze this type of models. The simulation results are consistent with expected behavior; however, the model should not be considered a final or validated product. Users are encouraged to review, modify, and refine model parameters to obtain results appropriate for their specific application.

6.2 EEMS Demo Mode

In Demo mode, the model is validated against a set of predefined signatures, including grid size, domain area, center coordinates, transport count, and module configuration. While certain parameter values may be adjusted, the grid cannot be modified, transports cannot be added, and the prescribed module setup cannot be altered. Any deviation from these conditions results in the model no longer being considered a valid demo model.

6.3 Support

For technical support, additional documentation, or to obtain the latest version of EFDC+ Explorer, please visit: www.eemodelingsystem.com