Earth and Space Science

Supporting Information for

Lake Modeling on Mars for Atmospheric Reconstructions and Simulations (LakeM^{2}ARS): An intermediate-complexity model for simulating Martian lacustrine environments

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Introduction

Text S1 is a user guide for the LakeMARS Model, including information on the model description, input files, parameters, output files, compilation, and running the model.

Figures S1 to S8 are time series graphs, created in MATLAB, of LakeMARS model outputs for small and large lake systems under various salinity and climate conditions. These data exclude spin-up and show the last two Mars years of the model runs.

Text S1. User Guide for LakeMARS Model

1. Model Description

LakeMARS is adapted from the PRYSM v2.0 Lake Water Energy Balance Model, a one-dimensional lake thermal and hydrological model (Hostetler and Bartlein 1990, Hostetler 1991, Patterson and Hamblin 1988, Small et al. 1999, Morrill et al. 2001, Dee et al. (2018). PRYSM was built to model relationships between climate, lake properties, and paleoclimate proxy data, and LakeMARS is the model to be used in a Martian environment. The model has the ability to simulate lake energy and water balance. Detailed descriptions of the PYRSM model are documented in Dee et al. (2018) and the model can be downloaded from GitHub (https://github.com/sylvia-dee/PRYSM). Adaptations to PRYSM to create LakeMARS are documented in the manuscript.

2. Input file

The lake model requires seven climate input variables including near-surface air temperature (K), near-surface relative humidity (%), downward shortwave radiation (W/m^2), downward longwave radiation (W/m^2), near-surface wind speed (m/s), surface pressure (Pa), precipitation (mm), and basin runoff (mm/day). In this study, the model is configured to Gale crater, Mars, and the input variables are obtained from the Mars Weather Research and Forecasting Global Climate Model.

One climate variable input file is required. It contains all necessary meteorological variables to force the model. In this study, monthly mean climate values were used to drive the model simulations. The input file is in plain text format and can be named as <mars_met_data.txt>. There is no header row in the file. Values in the file follows the structure as below:

Column 1. Year
Column 2. Day of year (accumulative)
Column 3. Air temperature at 5 meters (K)
Column 4. Relative humidity at 5 meters (%)
Column 5. Wind speed at 5 meters (m/s)
Column 6. Surface incident shortwave radiation (W/m^2)
Column 7. Downward longwave radiation (W/m^2)
Column 8. Surface pressure (Pa)
Column 9. Precipitation (mm)
Column 10. Basin runoff (mm per unit area of the drainage basin)

* Columns 1 to 8 are required. Column 9 and 10 are only used when water balance is modeled.

3. Model parameters

Major model parameters are defined in the mars_lake.inc file. It mainly contains lake specific parameters, simulation specific parameters and other fundamental physical and chemical parameters having fixed values.

In the section of lake specific parameters, we specified the Mars' obliquity (degrees), the lake's latitude, longitude, maximum lake depth (meters), the elevation of the basin bottom (meters), the area of the drainage basin when lake depth equals zero (hectares), the neutral drag coefficient (unitless), shortwave extinction coefficient (1/meters), the fraction of advected air in the air mass over the lake (ranges from 0 to 1), albedo of melting and non-melting snow, prescribed or initial lake depth (meters, typically represents mean lake depth), prescribed or initial lake salinity (parts per thousand), and initial lake temperature (ºC).

In the section of simulation specific parameters, we specified the number of years for spinup, and turned on/off the water balance calculations, lake ice, and variable salinity.

In the section of fundamental physical and chemical parameters, we specified Mars' specific heat capacity for dry air, specific gas constant for dry air, longwave emissivity, degrees per day, and gravity.

4. Output files

Two output files are generated from the model. One file is named as <lake_surf.dat>, which contains monthly mean values of the following variables:

Column 1. Day of year (accumulative)
Column 2. Lake surface temperature (degrees Celsius, averaged over top 1 meter)
Column 3. Average mixing depth (m)
Column 4. Lake evaporation (mm/day)
Column 5. Latent heat flux (W/m^2)
Column 6. Sensible heat flux (W/m^2)
Column 7. Shortwave radiation upward (W/m^2)
Column 8. Longwave radiation upward (W/m^2)
Column 9. Ice height (m)
Column 10. Ice fraction (ranges from 0 to 1)
Column 11. Maximum mixed layer depth (m)
Column 12. Lake depth (m)

The other output file is named as <lake_Tprof.dat>, which contains the lake temperature profile from lake surface to the bottom for each meter depth. There are no header rows in either output file.

5. Model compilation and running

To install PRYSM v2.0, a user needs to have a working FORTRAN compiler. Gfortran compiler is recommended (https://directory.fsf.org/wiki/Gfortran). In this study, the model was coded in Fortran and compiled using gfortran. All model functions are coded in the prism_env_heatflux.f90 file. Model configurations and parameters are defined in the mars_lake.inc file.

Before compiling the model, a user needs to first adjust all necessary parameter values to the studied lake in the mars_lake.inc file. The mars_lake.inc file should be in the same path of the prism_env_heatflux.f90 file. Moreover, the path for the climate input file should be defined in the mars_lake.inc file by changing the 'datafile' variable. Paths for the two output files can be defined at the 'file_open' subroutine in the prism_env_heatflux.f90 code file.

Once the mars_lake.inc is ready to use, a user can compile the code in terminal (Mac or Linux) or CMD (Windows) using the following command:

```
gfortran -o lakerun prism_env_heatflux.f90
```

*lakerun is the name of the executable file, this is customizable.

Once the executable file 'lakerun' is created, the model can be run using command:

```
./lakerun
```

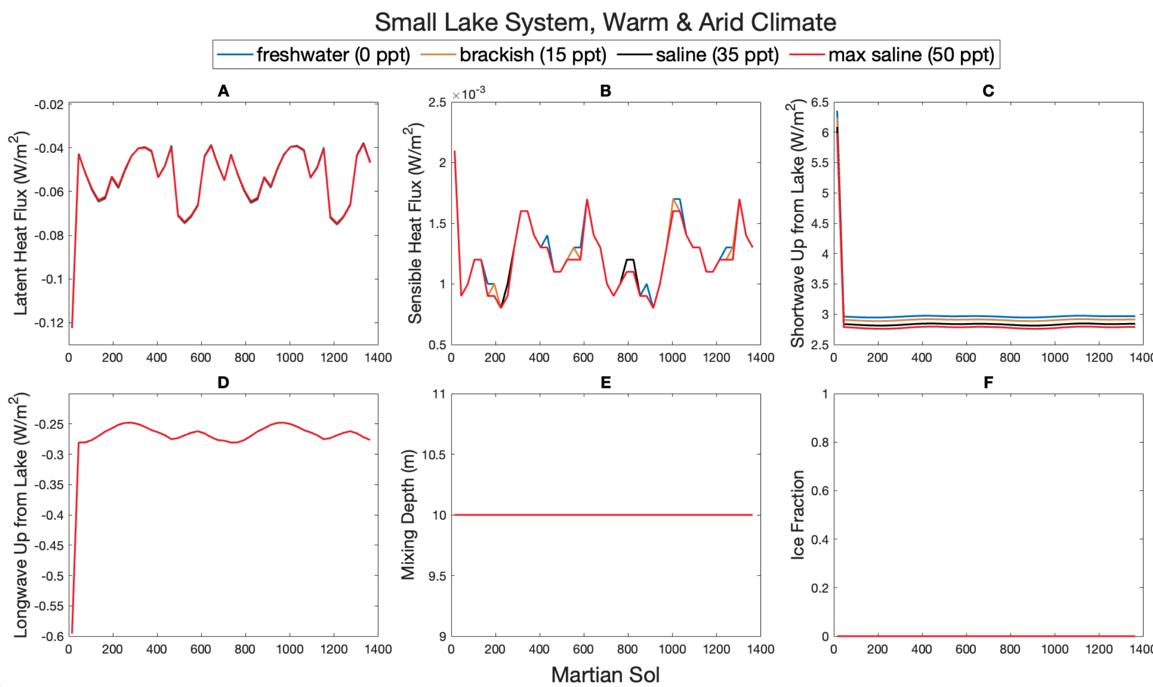

Figure S1. Time series of selected LakeMars outputs not shown in the main text for a small lake system with τ = 5.4 (warm climate), 5% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.

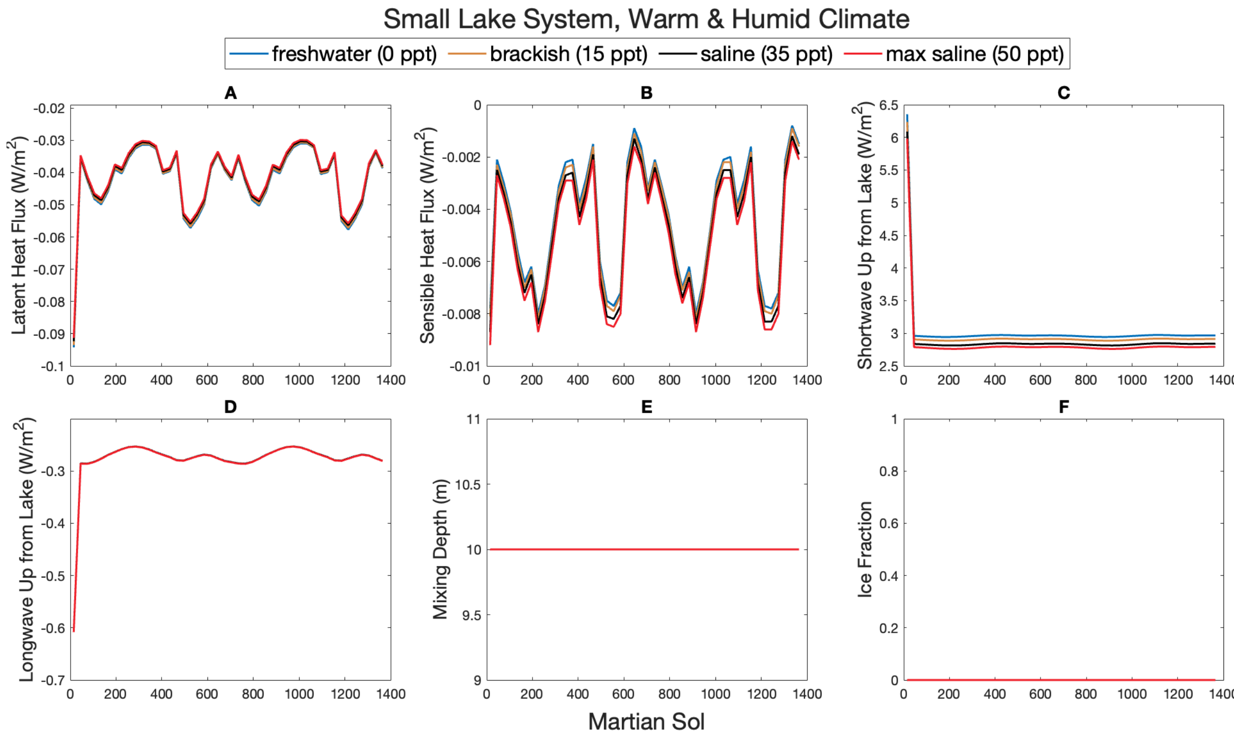

Figure S2. Time series of selected LakeMars outputs not shown in the main text for a small lake system with τ = 5.4 (warm climate), 70% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.

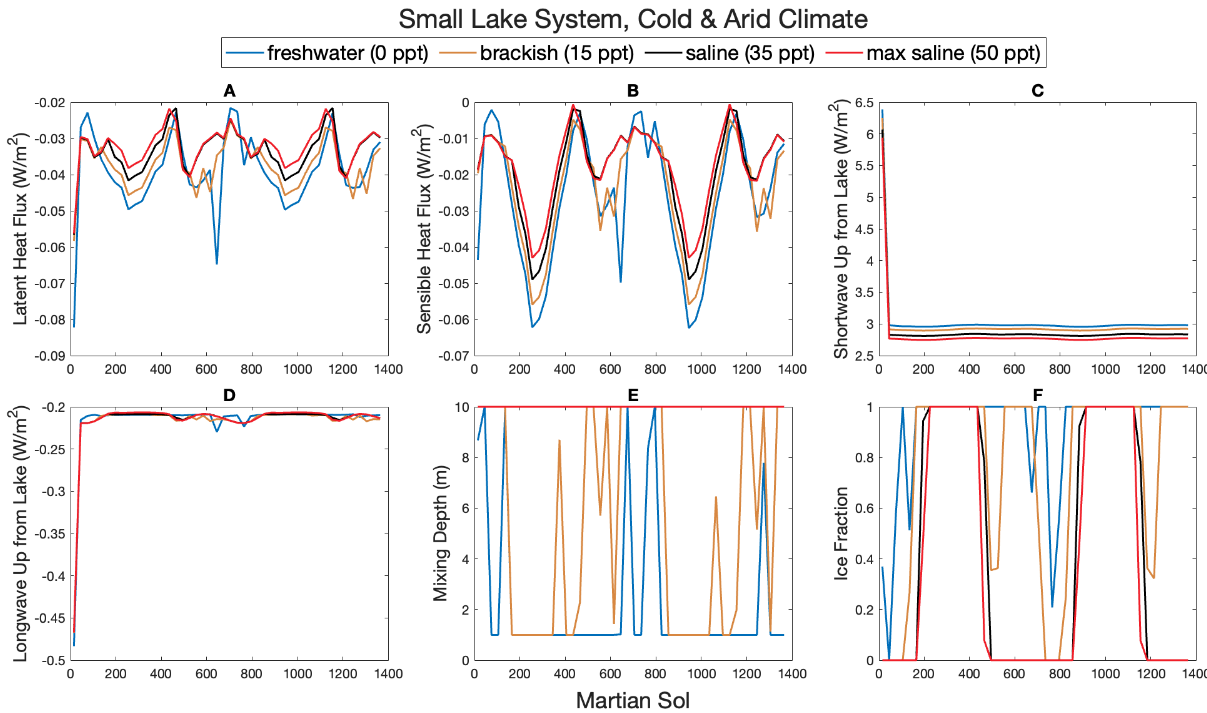

Figure S3. Time series of selected LakeMars outputs not shown in the main text for a small lake system with τ = 3 (cold climate), 5% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.

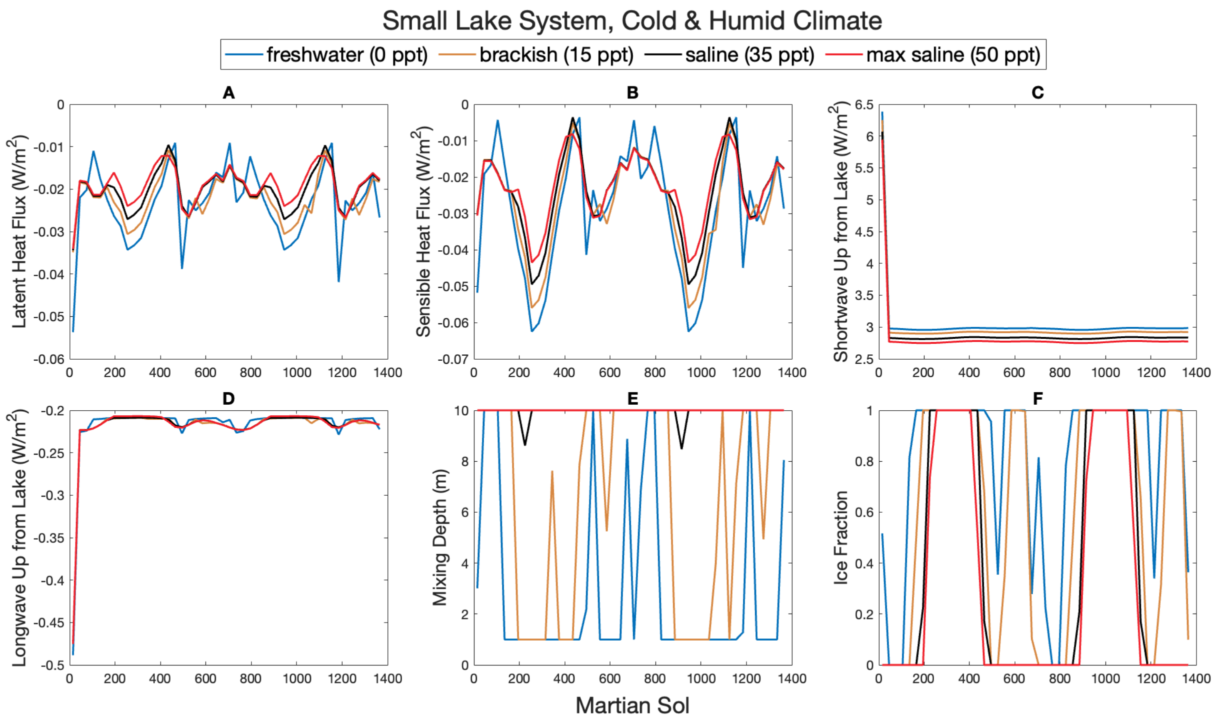

Figure S4. Time series of selected LakeMars outputs not shown in the main text for a small lake system with τ = 3 (cold climate), 70% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.

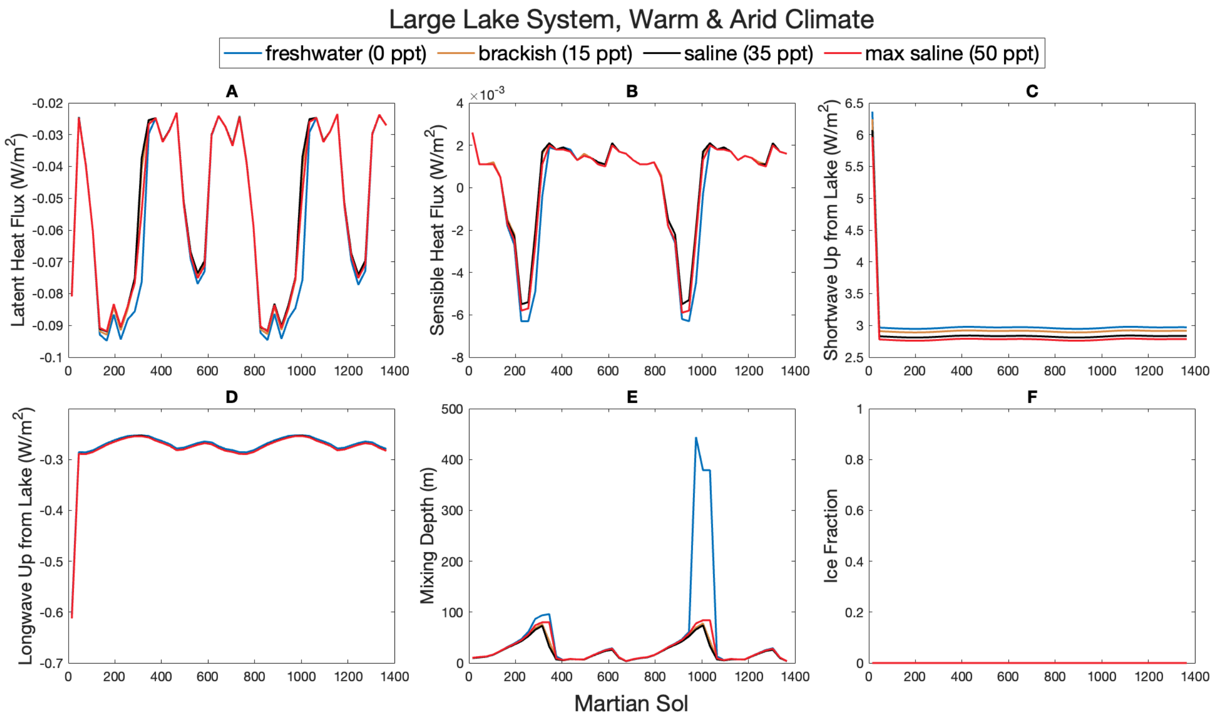

Figure S5. Time series of selected LakeMars outputs not shown in the main text for a large lake system with τ = 5.4 (warm climate), 5% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.

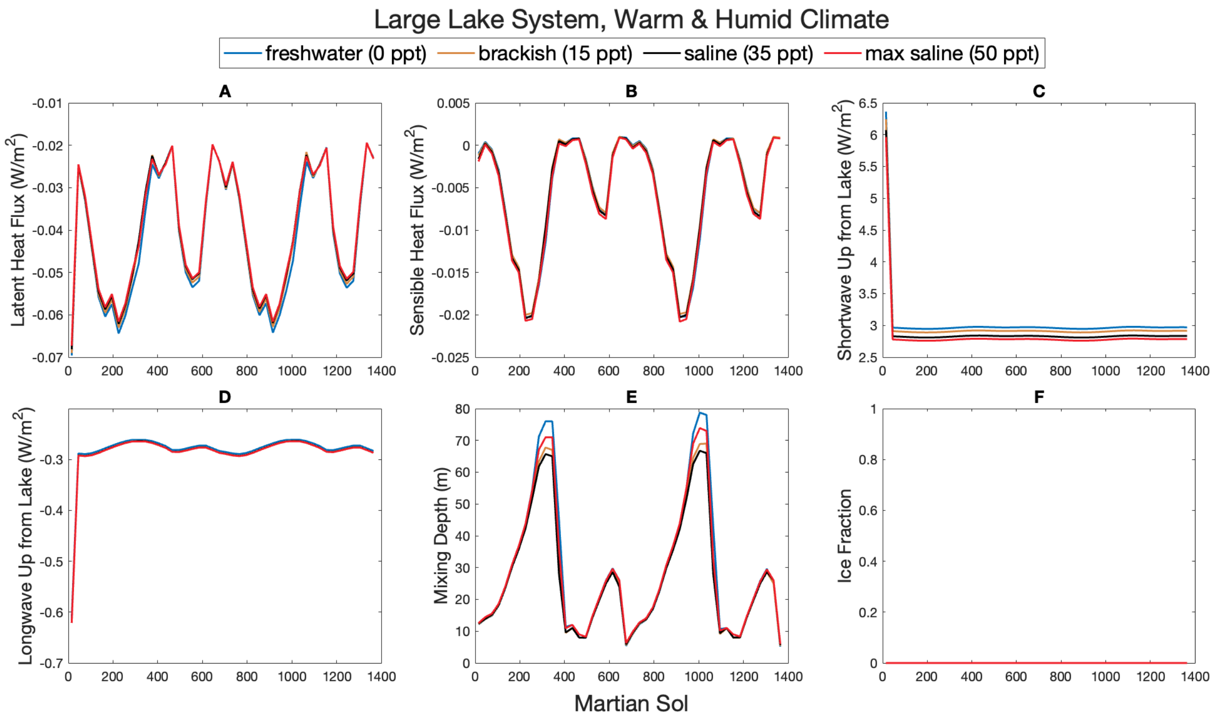

Figure S6. Time series of selected LakeMars outputs not shown in the main text for a large lake system with τ = 5.4 (warm climate), 70% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.

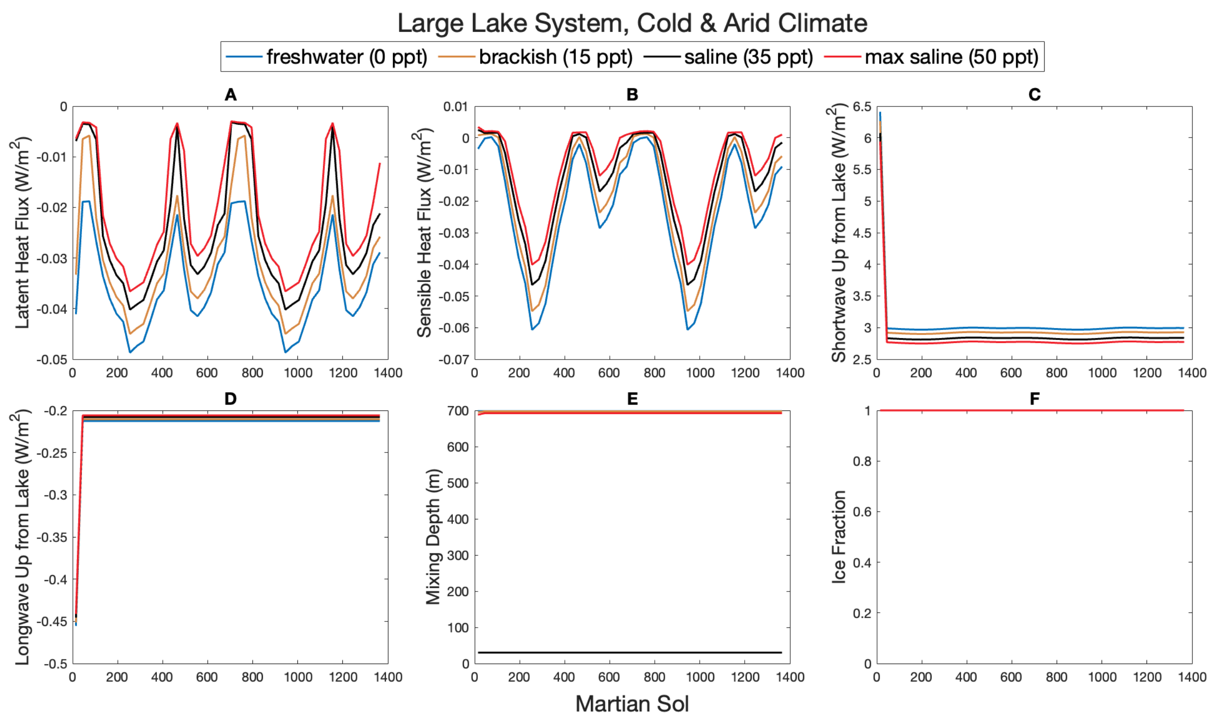

Figure S7. Time series of selected LakeMars outputs not shown in the main text for a large lake system with τ = 3 (cold climate), 5% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.

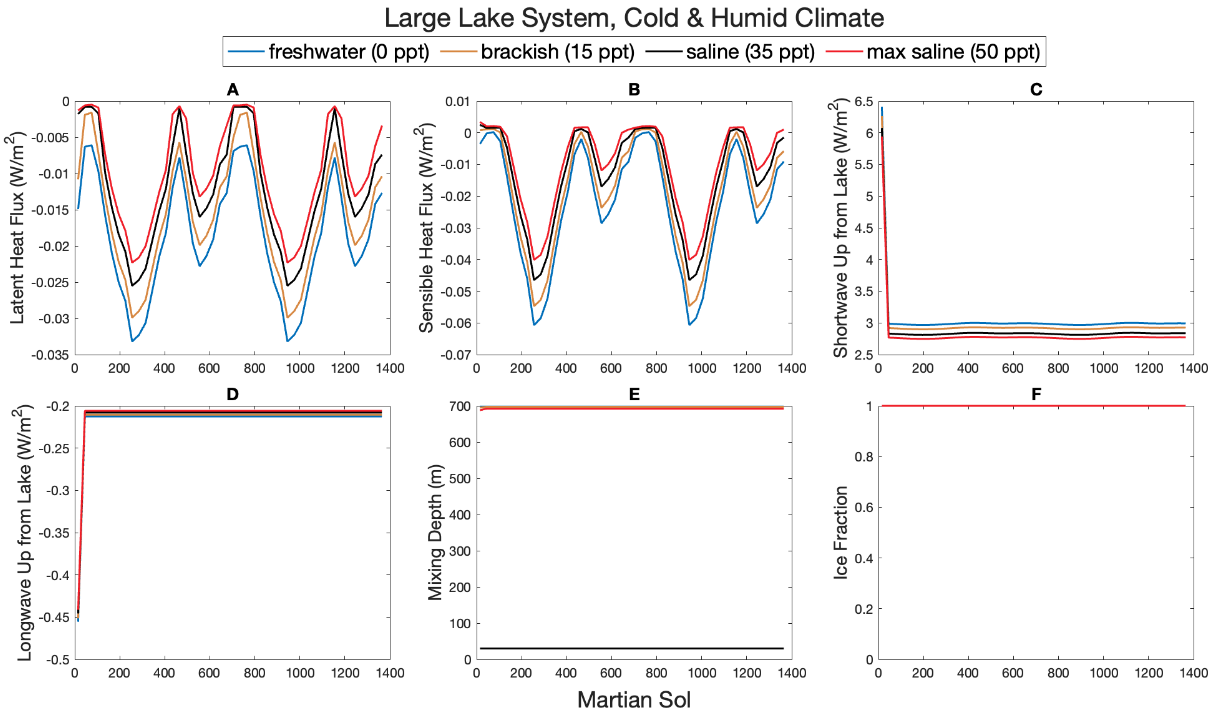

Figure S8. Time series of selected LakeMars outputs not shown in the main text for a large lake system with τ = 3 (cold climate), 70% constant humidity, and variable salinity. A) Latent heat flux (W/m^2), B) Sensible heat flux (W/m^2), C) Shortwave up from the lake (W/m^2), D) Longwave radiation up from the lake (W/m^2), E) Maximum mixing depth of the lake (m), and F) Ice fraction, or fraction of the lake covered with ice. For lone lines, other colors aren't visible because they overlap.