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Developing a Glacial Surface Model for Greenland to Improve the Projections of Surface Runoff

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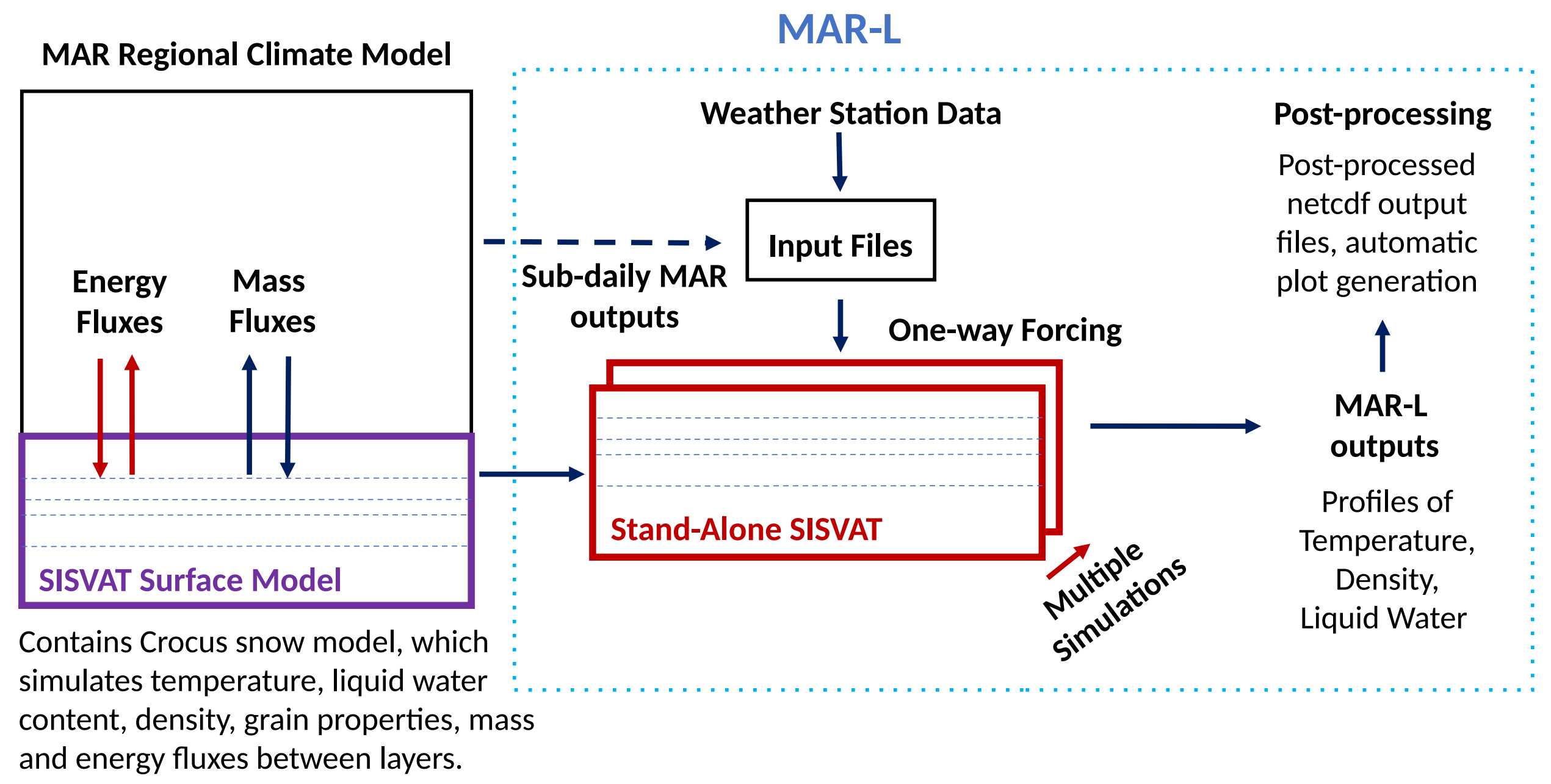
Over the past several decades, the Greenland Ice Sheet has been losing mass through a combination of increased surface runoff and accelerating ice flux to the ocean. Our understanding of the surface component is drawn heavily from satellite observations and climate models. The MAR (Modèle Atmosphère Régional) model is a 3D regional climate model used extensively in Greenland because of its proven record at simulating precipitation and firn and snowpack evolution over glaciated surfaces. Our study focuses on the surface snow and the ice down to 15-meter in depth. A light-weighted surface model for us to integrate the local observation data and force many simulations is needed. Our goal is to develop a surface-only model, derived from MAR, as a tool for understanding the glacial surface components, correlations, and MAR biases to improve projections of surface runoff. This model includes the ability to integrate observations from surface weather stations, translate the data into a model forcing format, force different simulations with various configurations or datasets, visualize model outputs, find key correlations between atmospheric drivers and modeled firn densification.

In the model development, we extract the surface code from the full MAR for the simulations initialized and forced with the following snow and atmospheric fields: snow depth, temperature, density, water volume, and grain size. We then verify that the surface model generates the same outputs as the full MAR does if fetched with the identical data. The bias is checked with snowpack time-depth plots for multiple sites around Greenland, including Summit and Swiss Camp. We have found a very small bias when compared to the fully-coupled MAR. We perform quality control for the data inputs, such as replacing missing data from the station measurements, defining the max and min for each dataset, filtering out the data outliers by statistics standard deviations. As the result, our model software can provide multiple simulations in sequential and concurrent mode with user-friendly interfaces, and run robustly. The model's first release is currently being deployed over different sites across Greenland to understand the importance of atmospheric forcing versus snow model biases in projections of future mass loss due to surface melt.



Contains Crocus snow model, which simulates temperature, liquid water content, density, grain properties, mass and energy fluxes between layers.

Figure-1 Overview of MAR-L and Interfaces with MAR-3D

Integrate Observation Data into the MAR-L Simulation

The data we obtained from the observation stations is the real measure. Taking in the data into the MAR-L model and forcing the data in the simulations, the results show us the reality of the snow and ice surface run-off and melting. Integrating the station data, we need to ensure the station data quality by QC procedures, to do math interpretations to generate a new data set to match the MAR-L data length, and to replace the original MAR simulated data with the new station data set.

Interpretation

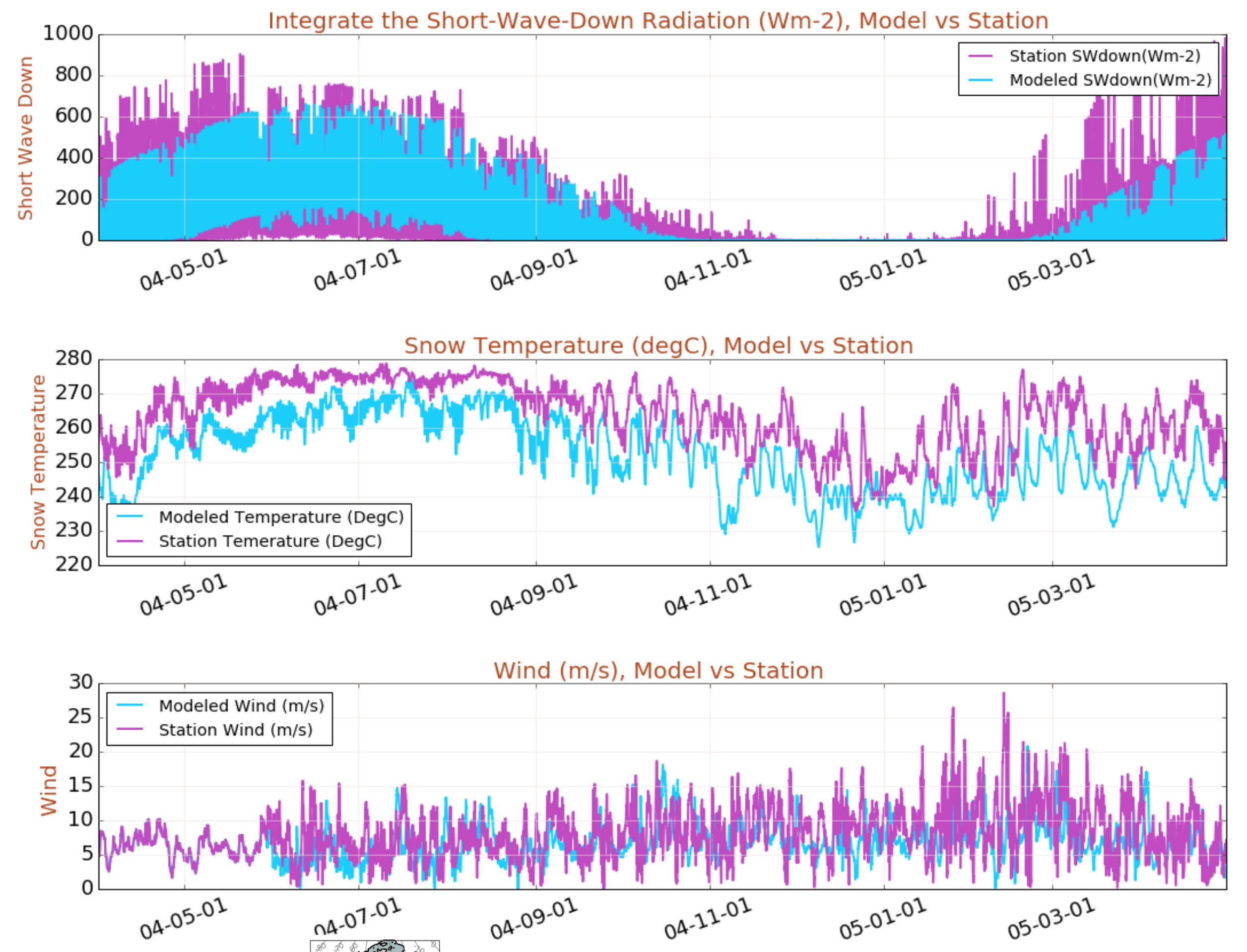
Quality Control
-Missing Values
-Max or Min Limits

Case 1: The station data is measured less frequently than the model data.
*Val = UpVal * (1-n/N) + LowVal * (n/N)*
Where UpVal is the previous station data reading,
'LowVal' is the current station reading data,
'N' is the total number of interpretations,
And the 'n' is the current loop in N.

Case 2: the station data are measured more frequently than model data.
Val = (Val1+Val2+…ValN) / N
Where Val1…ValN are all the measurements,
And N is the total number of values.

Replace with the Selected Measurement Parameters of MAR-L Simulations

SWdown LWdown Wind Temp. Humid. Pressure Precip. Ph. SWabs Tsurf Cld



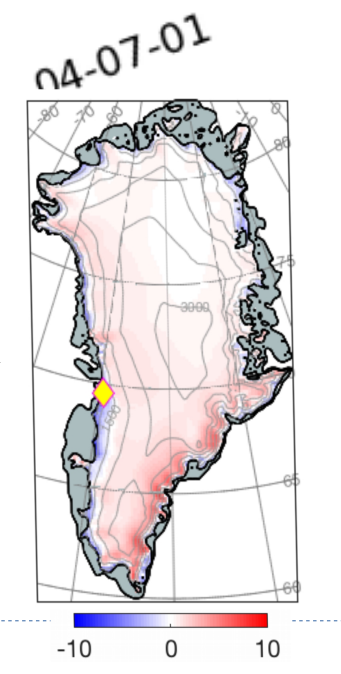
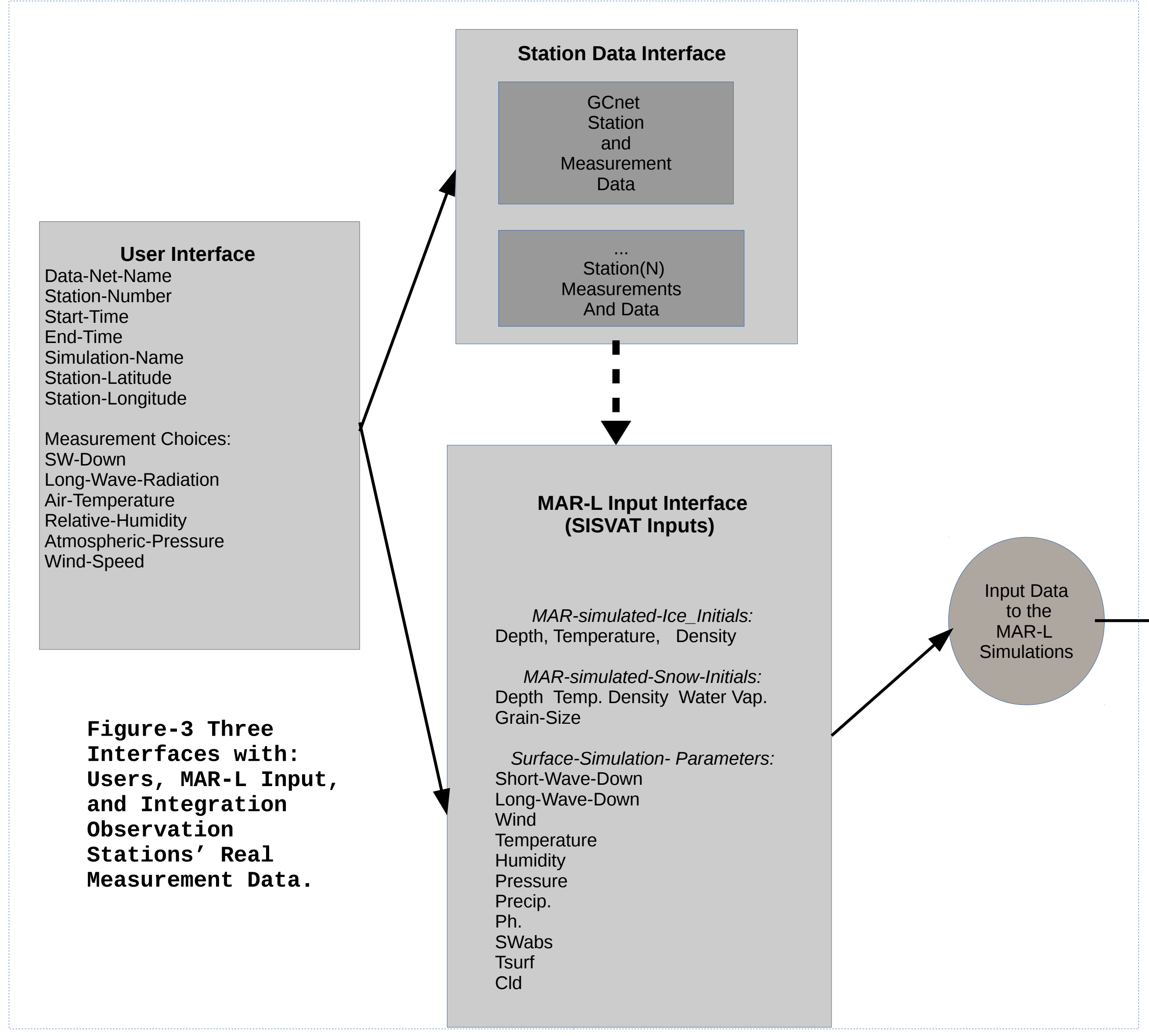


Figure A: GC-Net JAR1 Station and Average MAR SMB (1980-2017)

Figure-2 Shows the Data Comparisons of Short-Wave-Down Radiation, Snow Temperature, and Wind Speed from the MAR-Model and Summit-Station in GreenLand, from April 1, 2004 to April 30, 2005

MAR-L Interfaces

Interfacing with users for the choices of the simulation parameters, taking the MAR output as its own input, and integrating the stations' real measurements in the input, MAR-L thus forces these parameters and their data into the simulation, in generating the ice-surface data and then information for our exploring.



User Interface
Data-Net-Name
Station-Number
Start-Time
End-Time
Simulation-Name
Station-Latitude
Station-Longitude

Measurement Choices:
SW-Down
Long-Wave-Radiation
Air-Temperature
Relative-Humidity
Atmospheric-Pressure
Wind-Speed

Station Data Interface
GCnet Station and Measurement Data
…
Station(N) Measurements And Data

MAR-L Input Interface (SISVAT Inputs)

MAR-simulated-Ice_Initials:
Depth, Temperature, Density

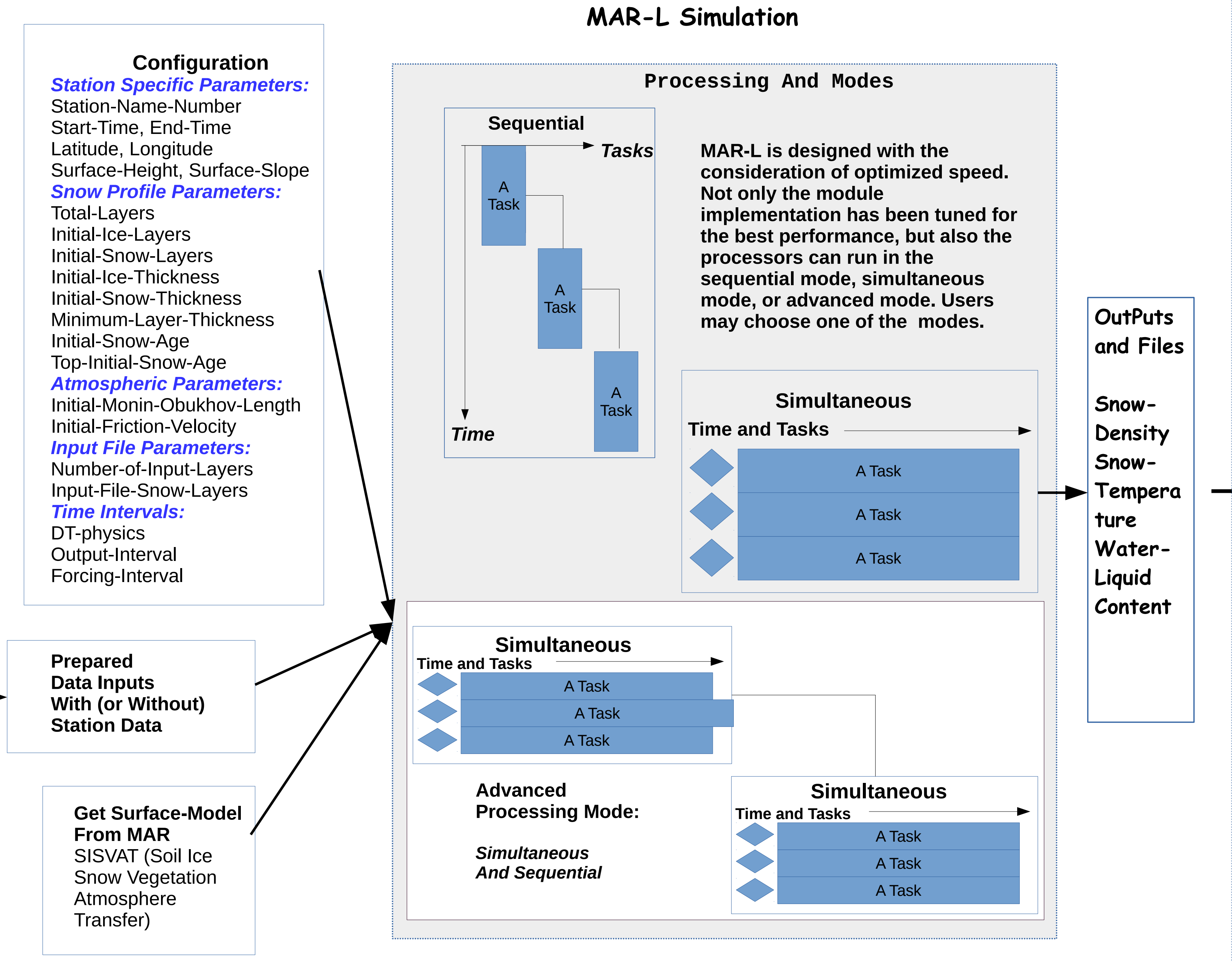
MAR-simulated-Snow-Initials:
Depth Temp. Density Water Vap. Grain-Size

Surface-Simulation- Parameters:
Short-Wave-Down
Long-Wave-Down
Wind
Temperature
Humidity
Pressure
Precip.
Ph.
SWabs
Tsurf
Cld

Input Data to the MAR-L Simulations

Figure-3 Three Interfaces with: Users, MAR-L Input, and Integration Observation Stations' Real Measurement Data.

MAR-L Simulation



Configuration
Station Specific Parameters:
Station-Name-Number
Start-Time, End-Time
Latitude, Longitude
Surface-Height, Surface-Slope
Snow Profile Parameters:
Total-Layers
Initial-Ice-Layers
Initial-Snow-Layers
Initial-Ice-Thickness
Initial-Snow-Thickness
Minimum-Layer-Thickness
Initial-Snow-Age
Top-Initial-Snow-Age
Atmospheric Parameters:
Initial-Monin-Obukhov-Length
Initial-Friction-Velocity
Input File Parameters:
Number-of-Input-Layers
Input-File-Snow-Layers
Time Intervals:
DT-physics
Output-Interval
Forcing-Interval

Prepared Data Inputs With (or Without) Station Data

Get Surface-Model From MAR
SISVAT (Soil Ice Snow Vegetation Atmosphere Transfer)

Processing And Modes

MAR-L is designed with the consideration of optimized speed. Not only the module implementation has been tuned for the best performance, but also the processors can run in the sequential mode, simultaneous mode, or advanced mode. Users may choose one of the modes.

Advanced Processing Mode:

Simultaneous And Sequential

OutPuts and Files

Snow-Density
Snow-Temperature
Water-Liquid Content

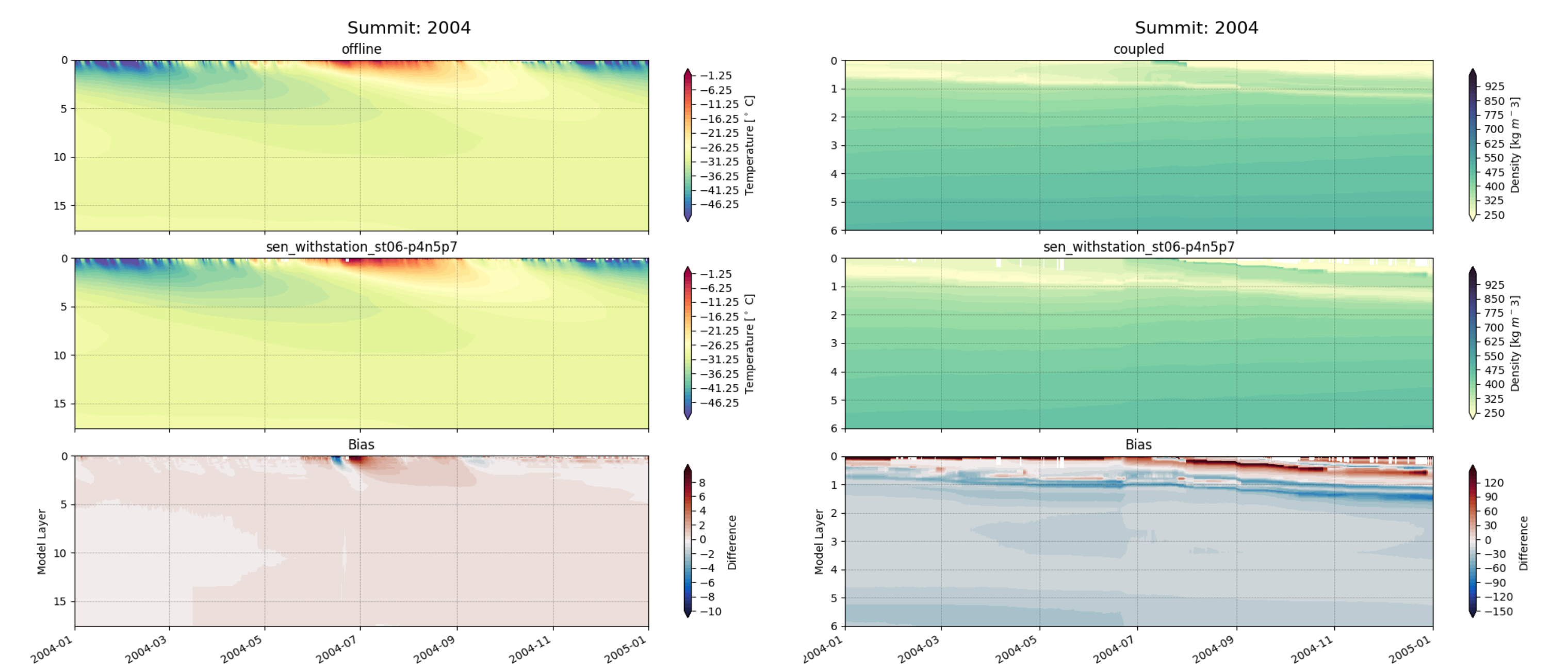
Figure-4 MAR-L Simulation. Configuration, Inputs, Surface Module, Simulation-Run-Types

Speed and Performance Improvement in the Module Implementation

Our design of MAR-L concerns the quality and the performance. Not only we consider that the model's science, math, and physics are implemented correctly, but also the modeling speed.
In station data integration, the module has been designed 3 times in 3 different approaches. The results are unbelievable: the time needed to integrate one year station data into the MAR-L input changes from 520 seconds to 5 seconds; it's 100 times faster!
From speeding a small portion of code to the simultaneous simulations, fast speed is the high-light of our MAR-L model.

Prove the Reliability of the MAR-L Model

MAR-L is the surface subset of the MAR which has been well recognized in the cold region area because of its super performance. To make sure that MAR-L is reliable at the beginning of its development, we need to prove that MAR-L can produce and same simulation as MAR when feed with the same inputs.
We studied the snow depth at summit in Greenland in 2004, and the temperatures, by analyzing the data from MAR and MAR-L, and compared them to verify that the bias is small enough and in the tolerable rate. The biggest temperature bias is 5%, while the max snow depth bias is 2.7%, both at the top surface and affecting a small region.
The images below show our results and proofs of the MAR-L accountability.



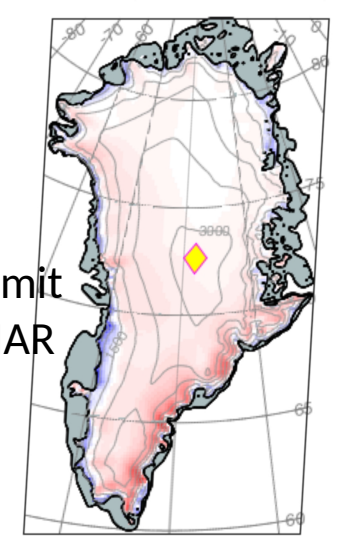


Figure B: GC-Net Summit Station and Average MAR SMB (1980-2017)

Figure-6 Bias Analysis. Compare the Outputs from MAR and MAR-L for Temperature, and Snow Density Based on the Data of Year 2004.

Plots of Outputs

The output plots will be generated in the production stream automatically for the studies in the visualized images. MAR-L model plans to perform data integration, QC, simulations, and data visualization in a run.

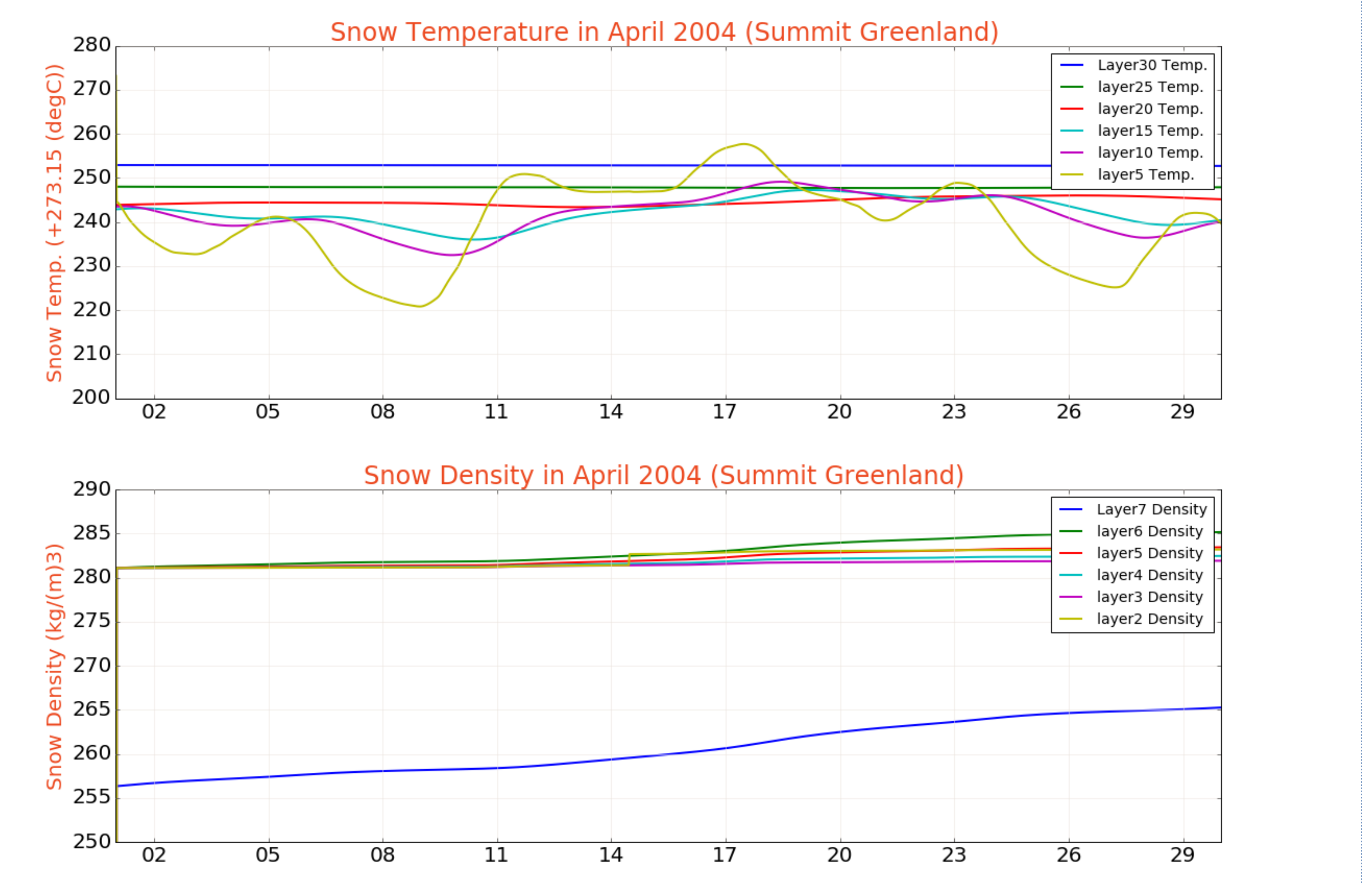


Figure-5 Generating Output Plots of Snow Density and Snow Temperature. Data Is from Summit Station in Greenland, April, 2004.

References:

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