The Arctic Carbon Monitoring and Forecasting System: a novel forecasting framework to build new understanding and reduce model uncertainty of the permafrost carbon-climate feedback.

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Abstract

In light of the magnitude and pace of the environmental changes in the northern permafrost zone (NPZ) and their feedbacks to climate, contemporary, accurate and quantitative ecological forecasting has never been so paramount to the development of climate change adaptation and mitigation strategies. Yet, uncertainties associated with carbon (C) projections in the NPZ remain the largest to projections of global C budget and climate. While there are persisting lacks of data documenting important and emerging soil and vegetation dynamics in the NPZ, the volume, variety and accessibility of observational data in the NPZ has grown exponentially over the past decades and significantly improved our understanding of terrestrial C dynamic. Yet, a lag persists between large availability of historical, new and iterative data collections and the capacity of terrestrial biosphere models to fully incorporate this information, limiting advances in reducing the uncertainty of ecological forecasting in the NPZ. In this new project, we are developing the Arctic Carbon Monitoring and Prediction System (ACMPS), a data assimilation system that will use the information from field observations from ecological networks, remote sensing data and ecological modeling to reduce the uncertainty of the terrestrial carbon balance in the NPZ. The ACMPS will be coupling model development and testing, data-assimilation techniques and near-term forecasting capacity to improve the accuracy of historical and future simulations of ecosystem permafrost and C dynamics across the NPZ. We will present the structure and workflow of the ACMPS, as well as preliminary assessment of model sensitivity and uncertainty analysis of soil and vegetation carbon fluxes, using a terrestrial biosphere model specifically developed to represent permafrost, vegetation and carbon dynamics in arctic and boreal ecosystems. Plain-language Summary We are presenting the Arctic Carbon Monitoring and Prediction System, a data assimilation system that uses field observation, remote sensing data and ecological modeling to reduce the uncertainty of the terrestrial carbon balance in the northern permafrost zone, and to better inform development of climate change adaptation and mitigation strategies.

B15A-1409: The Arctic Carbon Monitoring and Prediction System, a data assimilation system to reduce uncertainty of the permafrost-carbon climate feedback.

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Background

Accelerated warming of the Arctic poses a constant threat to vegetation, hydrology, and permafrost. Permafrost contains a significant amount of frozen carbon that could release into atmosphere due to continuous ground warming. Many challenges are associated with predicting permafrost warming and its impact on the Arctic ecosystem and on global climate. Here we take an integrated approach by combining existing in-situ and remotely sensed datasets with the mechanistic model and develop a model-data-assimilation system to better predict anticipated carbon fluxes from thawing permafrost.

Ecosystem Modeling

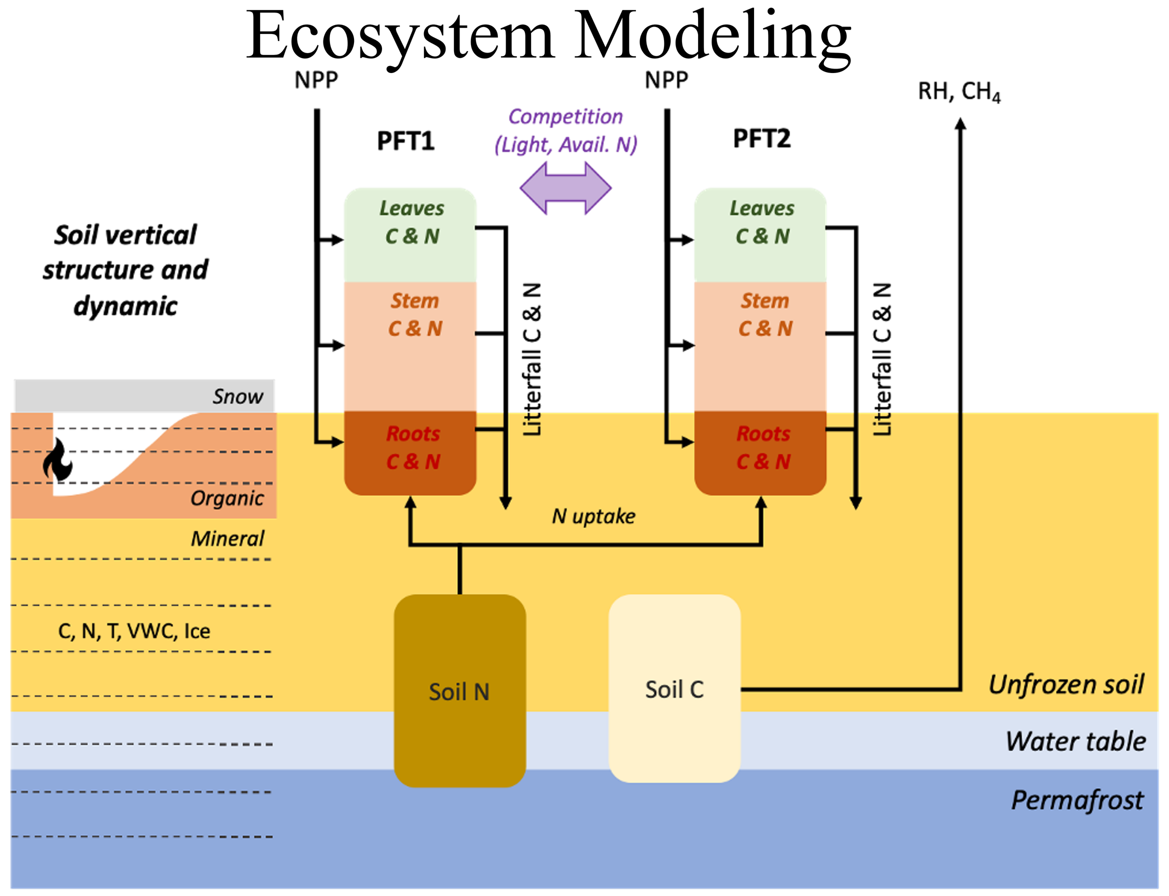


Figure 1. A schematical representation of the DVM-DOS-TEM model features.

What is DVM-DOS-TEM?

The DVM-DOS-TEM is a process-based biosphere model that couples a dynamic vegetation model, a dynamic organic soil model and a terrestrial ecosystem model. The model has been specifically developed and parameterized to represent biophysical and biogeochemical processes at play in the main land cover types of boreal forest, arctic tundra and wetland ecosystems.

The DVM-DOS-TEM input data.

The model is driven by forcing of climate, wildfire and atmospheric CO_2 time series, land cover distribution, soil texture and physiography. Wildfire disturbances are affecting carbon and nitrogen dynamics by burning the vegetation and the organic layer at a ratio related to fire severity. By burning the organic layer, wildfire is also affecting soil thermal and hydrological regimes.

Available Data

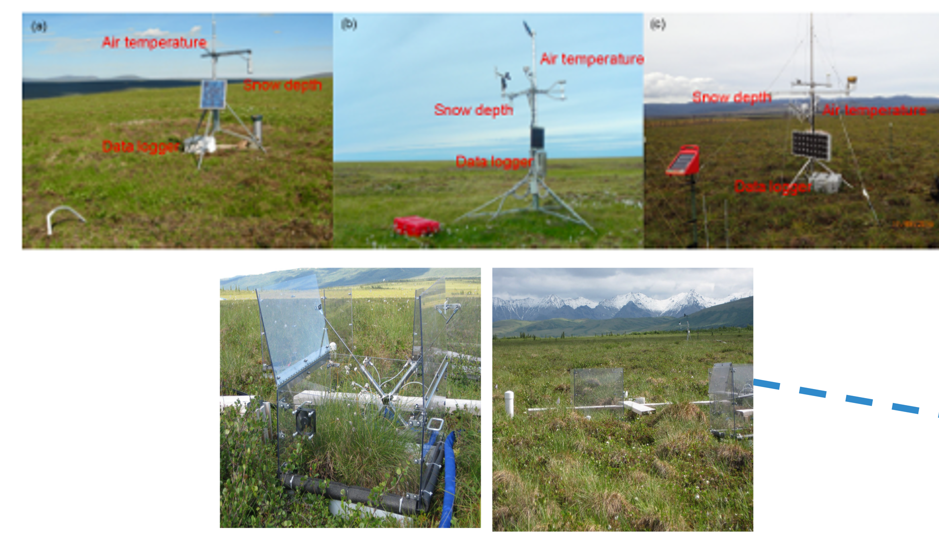


Figure 2. Photos of permafrost monitoring stations and in-situ soil carbon flux monitoring stations.

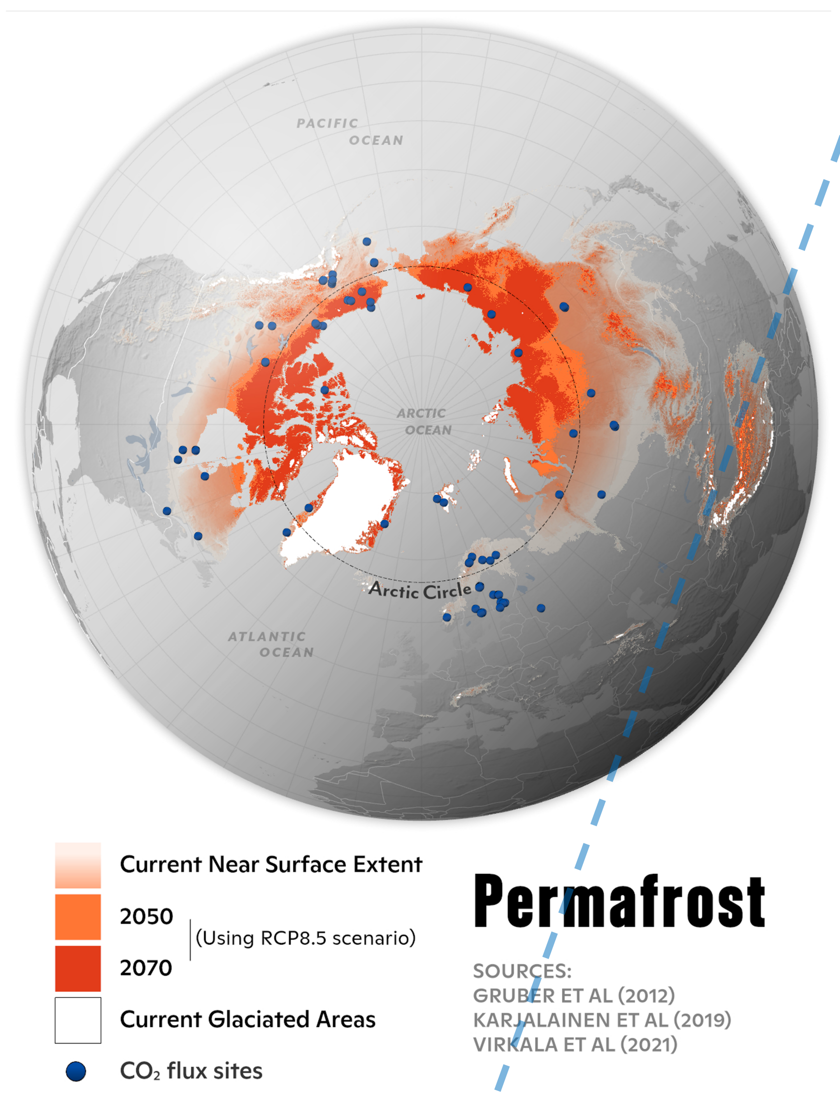


Figure 3. Flux Tower Station Network and projected permafrost conditions.

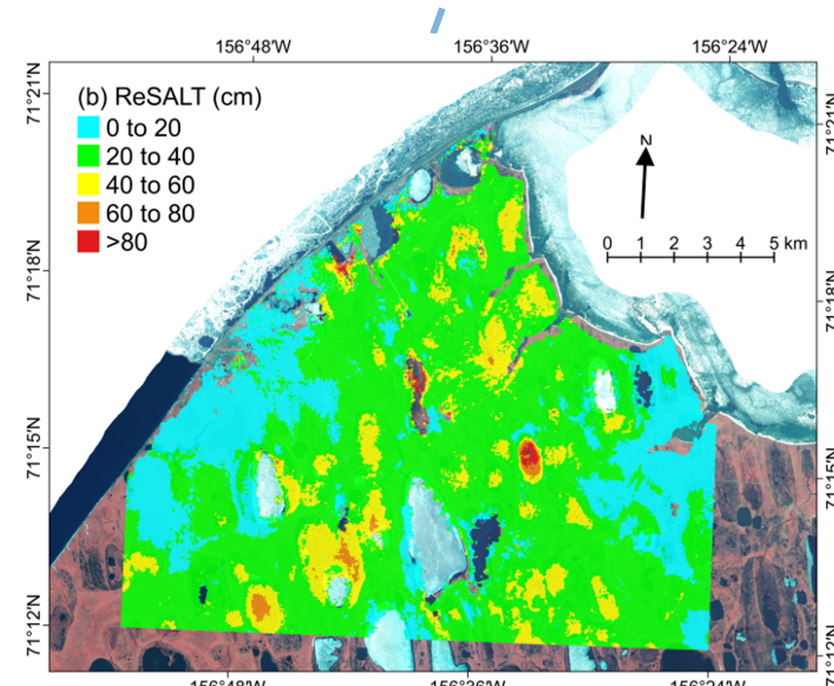
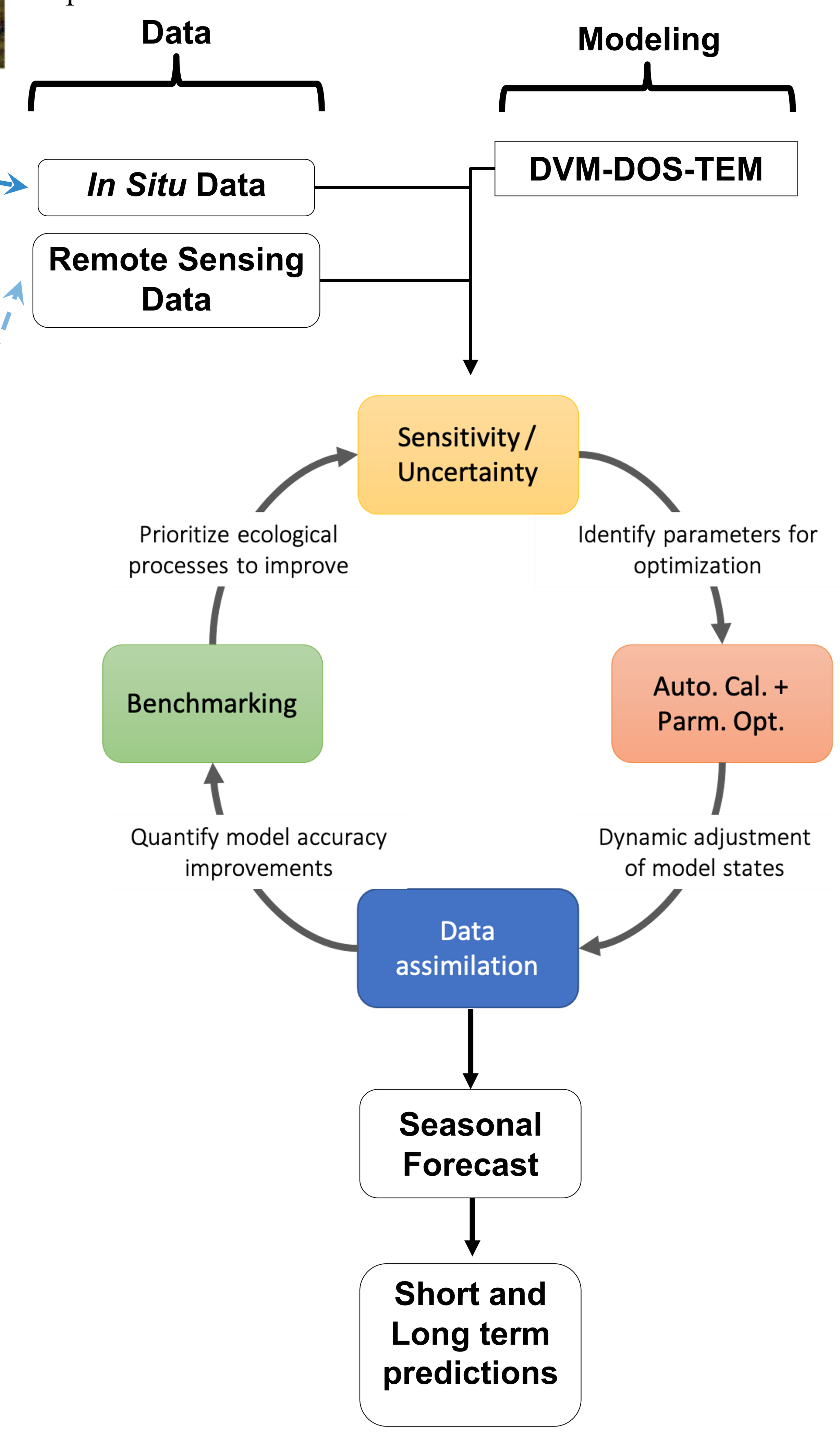


Figure 4. An example of the remotely sensed data that can be used in the Prediction System. The active layer thickness estimated from from Interferometric Synthetic Aperture Radar (Schaefer et al., 2015).

Schaefer, K.; Liu, L.; Parsekian, A.; Jafarov, E.; Chen, A.; Zhang, T.; Gusmeroli, A.; Panda, S.; Zebker, H.A.; Schaefer, T. Remotely Sensed Active Layer Thickness (ReSALT) at Barrow, Alaska Using Interferometric Synthetic Aperture Radar. *Remote Sens.* **2015**, 7, 3735-3759. https://doi.org/10.3390/rs70403735

Elements of a Prediction System

The system would consist of data and a model combined using data assimilation to produce a permafrost short- and long-term predictions.



Current progress

The system will include four major components:

1) Sensitivity Analysis (testing)
2) Uncertainty Quantification (developing)
3) Model-data calibration
4) Data Assimilation

Sensitivity Analysis

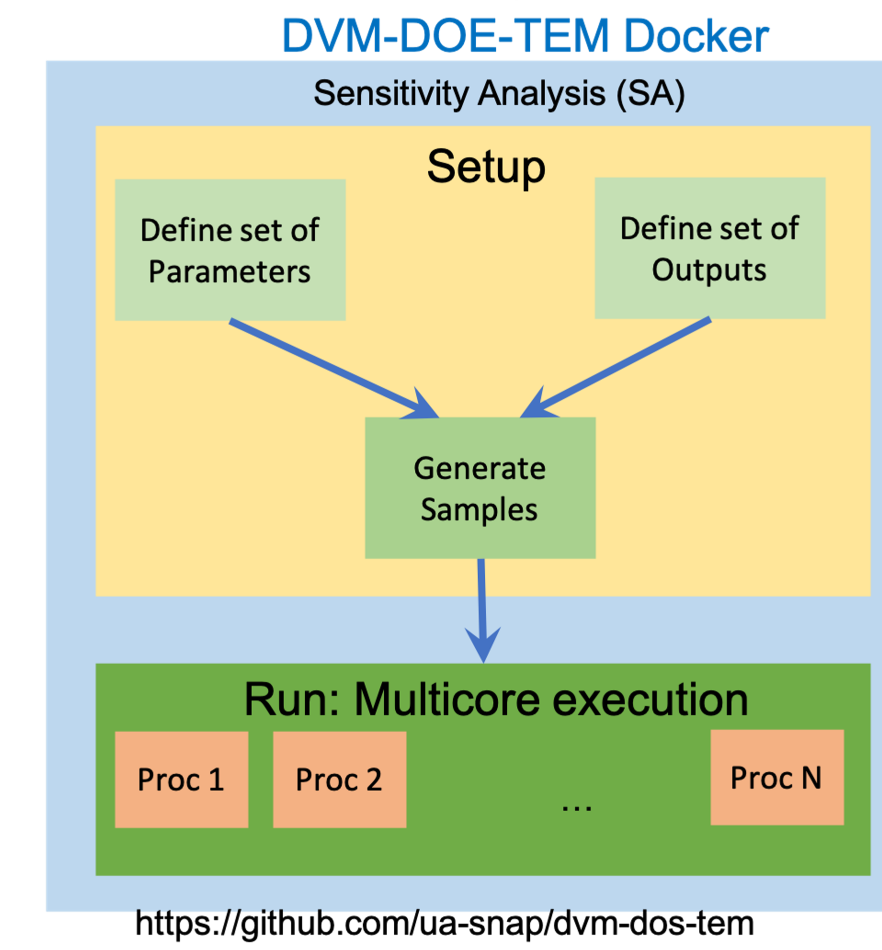


Figure 5. A schematic representation of the newly developed sensitivity analysis tool for the DVM-DOS-TEM model.

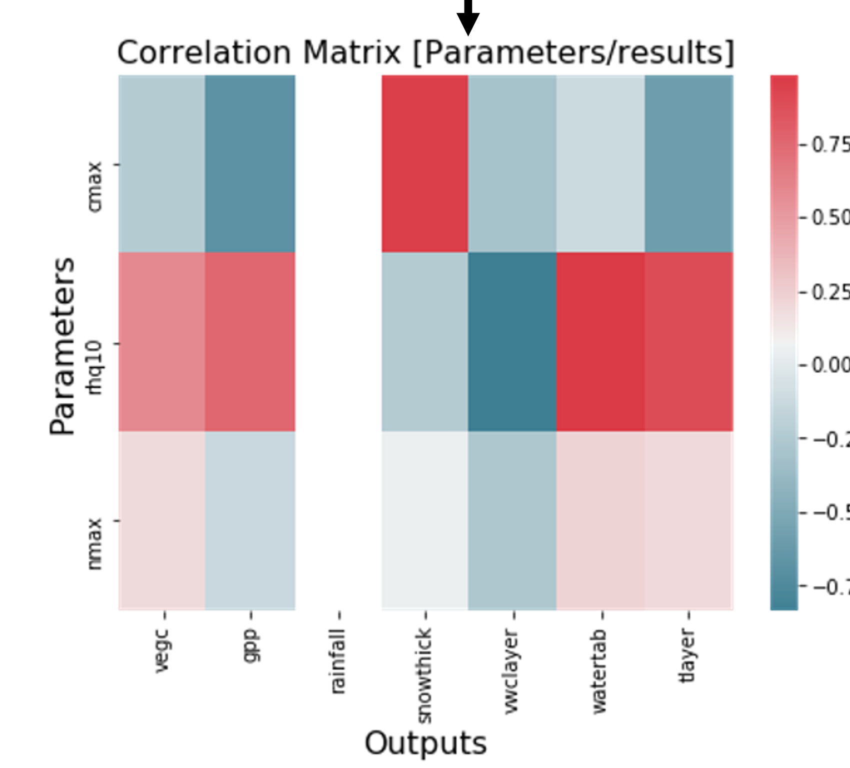


Figure 6. An example of the parameter-output correlation matrix produced as a result of the sensitivity analysis run

Functional benchmarking will be used to identify processes that would gain the most from data assimilation. Benchmarking will also help quantifying the gain of model performance in response to data assimilation.

Sensitivity / Uncertainty analysis will be use to identify the model parameters that will become the targets of the data assimilation.

Automated calibration and parameter optimization will help reducing model uncertainty by producing new parameterization that reflect better ecosystem spatial heterogeneity.

Data assimilation and model adjustment module using ensemble Kalman filter will be developed to sequentially adjust the model states.