Fast Gaussian Process Emulation of Mars Global Climate Model

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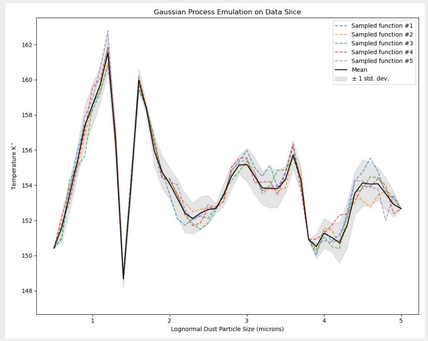
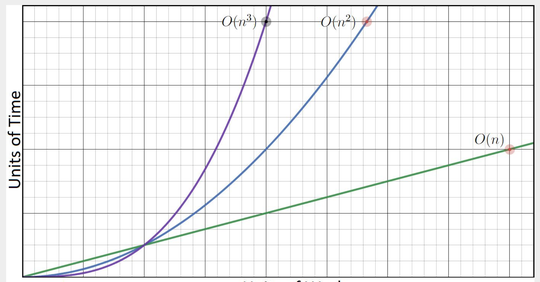
Abstract

The NASA Ames Global Climate Model (GCM) software has been in steady use at NASA for decades and was recently released to the public. This model simulates the complex interactions of various weather cycles that exist on Mars, namely the Dust Cycle, the CO2 Cycle, and the Water cycle. Utilized by NASA, the GCM is used to help understand their empirically observed data through the use of sensitivity studies. However, these sensitivity studies are computationally taxing, requiring weeks to run. To address this issue, we have developed a surrogate model using Gaussian processes (GP) that can emulate the output of this model with relatively small amounts of data in a reduced amount of time (on the order of minutes). We demonstrate the effectiveness of our emulator using backward error analysis.

Gaussian Process Regression

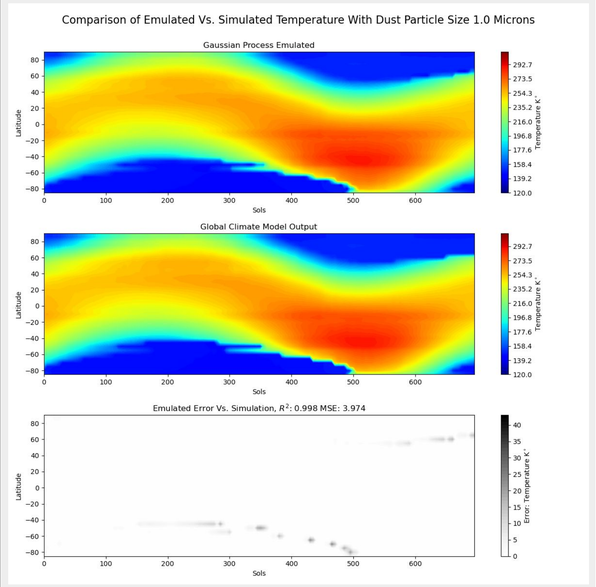


- Learns normal distribution for each data point [4]
- Large changes in behavior based on covariance function

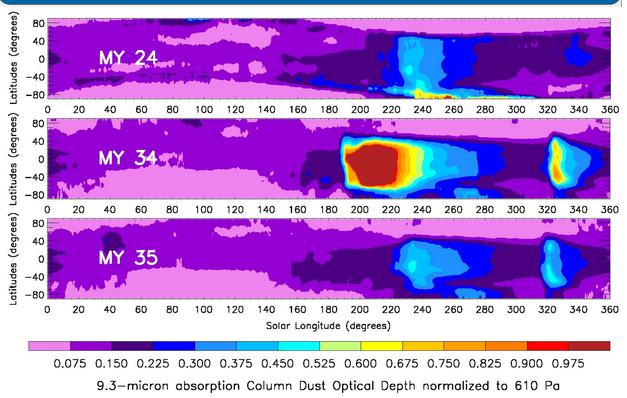


- Cubic time complexity
  - Prohibitively expensive to train on large datasets
  - Mitigated by splitting data

Results

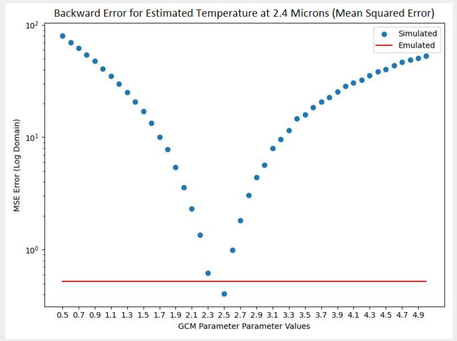


Mars Global Climate Model

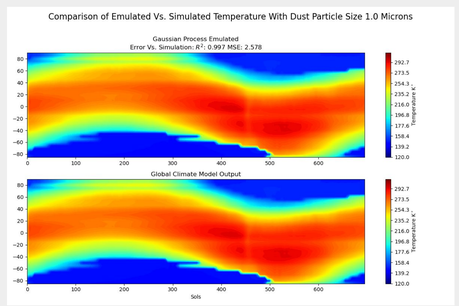


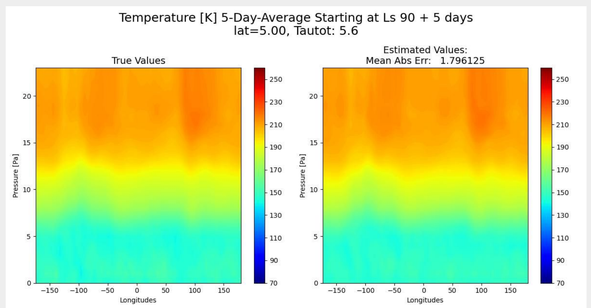
- Numerous input parameters and hundred of thousands of outputs
- Dust Scenarios are derived from empirical data for different years [1, 2]

Emulation Output & Backward Error Analysis



- Emulator is close to simulator with “nearby” parameter values
- Backward error quantifies nearness
- Small backward error -> useful for parameter sensitivity studies





Future Work

- Apply method to remaining Dust Scenarios
- Validate generalizability by applying to model in different domain

References

[1] Image From: http://www-mars.lmd.jussieu.fr/mars/dust_climatology/

[2] Montabone, L., Forget, F., Millour, E., Wilson, R. J., Lewis, S. R., Cantor, B., ... Wolff, M. J. (2015). Eight-year climatology of dust optical depth on Mars. *Icarus*, *251*, 65–95. doi:10.1016/j.icarus.2014.12.034

[3] Wilkinson, J. H. (1971). Modern Error Analysis. *SIAM Review*, *13*(4), 548–568. doi:10.1137/1013095

[4] Kac, M., & Siegert, A. J. F. (1947). An Explicit Representation of a Stationary Gaussian Process. *The Annals of Mathematical Statistics*, *18*(3), 438–442. doi:10.1214/aoms/1177730391