Introduction

Modal decomposition or variance reduction methods offer an opportunity for data-driven investigation of thermosphere dynamics and variations and for self-consistent calibration of the thermospheric models. We develop the methodology using the MSIS model and infer oxygen-to-helium transition as a validation by simultaneously assimilating discrete THEMIS/GUVI and CHAMP/GRACE observations [1, 2, 3].

Methodology

We generate hourly model output (snapshots), x, for each input sample generated using a latin-hypercube (FHS) in [60, 250], A_j ∈ [0, 50], DOY ∈ [1, 365] to cover the full range of inputs. We use a total of 365 + 8 (corner samples of the latin-hypercube) = 373 samples. A SVD decomposition is performed on the snapshot matrix X = [x_1, x_2, ..., x_m] to derive the optimal set of basis vectors, U (X = USV^T). For O, He_2, N_2, and He, 60 do we tune N and H under the assumption that the CHAMP and GRACE observations do not contain any signal about the minor species and that the partial pressure of H is negligible. The spatial basis vectors or modes, U, can then be combined with time-dependent coefficients, c, such that x(t, s) = \sum c_i(s) U_i(t), where r is the order or rank of truncation. The first (r = 3) modes for each species captures more than 98% of the total variance. The coefficients, c, are derived by projecting the data, x, onto the spatial modes, U. We model their daily temporal variations using a sum of three cosine terms c(t) = \sum a_{i} \cos(\omega t + \xi) and fit the \omega, \xi for each mode and species using Gaussian Process Regression for prediction at any new set of inputs.

Measurement Intercalibration

Typically, reliable data assimilation requires the observations to be intercalibrated. The CHAMP and GRACE observations are first intercalibrated by multiplying the GRACE densities with a yearly scale factor to match the mean and variance of the observation-to-model ratio.

Oxygen-to-Helium Transition

We use the methodology to infer He density and O-to-He transition. Assimilation shows that the O-to-He transition occurs at significantly lower altitudes, as inferred by Thayer et al. [4] using CHAMP and GRACE observations.

Storm-time Calibration

We also perform storm-time calibration to show that the methodology works effectively even during periods of high variability; we perform assimilation on a 3-hourly timescale.

Conclusion

The developed method can be used for investigation and inference of thermosphere dynamics and variations and calibration of empirical models.

References


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