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Statistical Analysis of Seasonal Changes and Temporal Variability in Atmospheres of Jupiter and Saturn

P. A. Yanamandra-Fisher[1] and A. A. Simon-Miller[2]
(1) Space Science Institute (padma@spacescience.org), (2) NASA/GSFC

Abstract

Jupiter and Saturn have exhibited dramatic atmospheric changes in the past few years. and highlight the importance of placing them in the context of various timescales (seasonal, periodic or episodic) that represent changes in various inherent physical parameters that govern albedo, composition and thermal fields of both global axisymmetic and local discrete features. The underlying basis for these changes may be a common driver of atmospheric disturbances in Jovian planets.

1. Introduction

Given the wealth of observations of Jupiter and Saturn since Galileo's first telescopic observations, there are still important unanswered questions about their atmospheres and the dynamics of various processes that are still not understood. Yet, access to these data sets is not sufficient to develop unique models of various physical and chemical processes that govern planetary atmospheres. Dramatic changes in their atmospheres from discrete localized features to global regions and impacts (as in the case of Jupiter); availability of large telescopes (higher spatial andspectral data), requires a new paradigm of rapid exploratory data mining that can be corroborated or validated with standard physical and theoretical models.

2. PCA Analysis

Principal Component Analysis (PCA) is a mathematical technique that utilizes an orthogonal transformation of a set of data or observations of possibly correlated variables into a smaller set of uncorrelated parameters, or principal components (PCs), that are linear combinations of the variables. The results of PCA determine trends in temporally and spectrally changing systems [1]. The first PC captures the most variance in the data set (accounting for as much of the variability of the system as possible); with each subsequent PC capturing the highest variance possible, subject to the constraint that it be orthogonal to (uncorrelated with) the preceding PCs. We also can reconstruct the original data with respect to a particular PC. This allows insight into the influence of the variables on the behavior of a particular PC, and thus to a broader trend in the data set. PCA is not biased by the data, which is desirable; however, it means that PCA works best on highly correlated sets of data. Both false correlation and false variation in the data should be avoided. False correlation can be introduced in the form of "black space" (zero pixel) values, in images or by the improper geometric registration of the images. The advantage of the PCA is that it yields a new data set that is smaller in dimensions than the original data, while capturing all the information of the original data set, enabling rapid data exploration to identify patterns in the data. PCA analysis has been performed on the spatial variation of phosphine in Saturn's troposphere [1,2]; Jupiter's Great Red Spot and one white oval [3]; Saturn's clouds and hazes [4]; and Jupiter's Oval BA after its color change from white to red in 2006 [5]. We report on our efforts to develop a flexible approach to the application of PCA to temporally changing features on Jupiter and Saturn.

2.1. Jupiter

Since 2005, nearly every belt/zone region on Jupiter is experiencing changes - the most pressing question is: what processes in the atmosphere are drivers for these changes? With access to an enormous amount of multi-spectral multi-variate data, we applied PCA method to identify trends amongst varrious parameters to identify temporal variability in specific parameters that influence the observed changes. Some recent examples that we applied PCA are: (i) The North Temperate Belt disturbance (NTBs), at latitude of 22 degrees north, identified in late March 2007, appeared suddenly as a bright feature high in the atmosphere, encircled the planet in about two months and dissipated within days. An enhancement of ammonia ice was detected, similar to the spectra of ammonia clouds identified observed by Galileo, with the strength of the ammonia ice features varying from the localized "head" of the feature along the length of the plume (i.e., longitude). (ii) Interactions of giant vortices, the Great Red Spot (GRS) and white oval(s) from 1997 to 2008, highlight common trends such as the increase in overall cloudiness, and changes in ammonia humidity [6]. We will present the results of PCA applied to other recent changes on Jupiter, namely, the recent South Equatorial Belt (SEB) "fade/revival", which occurs aperiodically (the last such dramatic occurrence was in 1989-1990) [7].

2.2. Saturn

Since seasons on a planet are caused by its obliquity. Saturn's large obliquity of 26.7 degrees means it uniquely is able to experience seasonal variability, enhanced by its ring shadow. Latitudes, shadowed by the rings, displayed a rapid response to direct insolation and warmed-up to their pre-emergence levels upon their emergence from the ring shadow. Temporal PCA of Saturn's southern hemisphere, post-1995, identified the first PC was associated with the annual (or temporal) increase in the brightness temperatures from equator to its south pole, during the southern hemisphere summer and converge at northern latitudes where the planet is obscured by the rings; whereas the second PC was associated with the expansion of the various belts and zones in latitude and occurs on a smaller spatial scale [8]. Similar trends were identified in Hubble Space Telescope data, over a similar time span [4]. Other variable features exhibited by Saturn include stratospheric temperature oscillations, with a period of half a Saturnian year, suggesting the influence of seasonal forcing (equatorial oscillations of temperatures on Earth and Jupiter), planetary scale waves [9]. The current dramatic Great White Storm (GWS), which broke out in December 2010, is an example of a possible 30-year (one Saturnian year) occurrence of great storms in Saturn's atmosphere. We will discuss the results of our ongoing PCA analysis of these phenomena.

3. Summary and Conclusions

Rapid data exploratory techniques are needed to distill the behavior of the latent physical parameters characteristic of atmospheric state of Jupiter and Saturn. Traditional retrieval methods, based on physical models, are sometimes cumbersome, time consuming, yet a focused approach that provides a standard model to compare observations. Statistical models, like PCA and empirical orthogonal analysis, provides an unbiased rapid examination of data and identification of key trends in the latent variables that influence the state of the atmosphere. Application to Jupiter's GRS-Oval(s) periodic interactions, and seasonal changes in the brightness temperatures on Saturn, showcase its versatility for rapid retrieval.

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