PLANETARY WAVE REANALYSIS USING SATELLITE DATA

S. R. Lewis, J. A. Holmes and P. M. Streeter
School of Physical Sciences, The Open University, Milton Keynes MK7 6AA, UK (stephen.lewis@open.ac.uk).

Introduction: A key motivation to use data assimilation for planetary science is in order to recover information about day-to-day atmospheric variability, or 'weather'. Whilst there is no immediate need for a regular weather forecast in most planetary science, data assimilation offers the prospect of a systematic reanalysis of past and present spacecraft data. This is especially valuable when, as is often the case, a planet is being observed from only one or two orbital platforms at any one time and synoptic-scale weather system may translate and change significantly between satellite passes. Observations are often sparse and incomplete. This leads to problems of aliasing and potential ambiguity in a conventional data analysis.

By using a self-consistent atmospheric model, based on the primitive equations of meteorology, data assimilation makes it possible to infer information about variables not directly observed. For example, assimilation can provide a self-consistent set of global temperatures, winds and surface pressure from satellite observations of temperature, combined with the constraint of surface pressure at a handful of points.

Data assimilation can be further extended by using a model able to predict the transport and lifting of dust and other aerosols and the transport, phase changes and chemical reactions of many minor constituents and trace gases. If the model is constrained by observations, it could provide a consistent interpolation to unobserved regions and, in principle, a useful a priori for future retrievals. Any consistent misfit between the model predictions and new observations might be used to identify potentially important physical processes that are missing from the model, including inferring the presence and location of trace gas sources and sinks.

Once sufficient, regularly-sampled, observations of planetary atmospheres become available, it is therefore to be expected that planetary scientists would propose similar analyses to maximize the value of these data sets. For Mars, data assimilation schemes have been proposed since the mid-1990s, e.g. [1]–[10].

This contribution will focus on the reanalysis of large-scale planetary waves in the martian atmosphere. Such waves play a vital role in the horizontal transport of heat and momentum within the climate system, as well as in dust lifting and atmospheric transport of dust and trace species, e.g. [11], [12].

Model and data assimilation scheme: The examples shown here are from the UK version of the LMD Mars global circulation model [13], [14]. Data assimilation was conducted as described in [15].

Thermal tides and other short period waves: Much large-scale variability in the martian atmosphere on timescales of one solar day (sol) and shorter is in the form of various solar-locked and migrating thermal tides [16]. Although sun-synchronous, polar orbiting satellites are not ideal for studying such modes, progress can be made by also assimilating dust opacity, which is intimately linked to the amplitude of the tidal modes through the thermal forcing that results when it absorbs sunlight [17].

Planetary waves: Data assimilation, even from a solitary satellite, is much more powerful in its ability to study planetary waves with periods in the range 1.5–30 sol. Figure 1 shows transient planetary wave behaviour at 25km altitude over the northern hemisphere winter of a typical martian year without a global dust storm. There are strong features around winter solstice (L_S=270°), including a long-period, wavenumber one signal, a displacement of the polar vortex. In contrast, Figure 2 shows the same period in the surface pressure signal, displaying different wavenumbers with periods predominantly of 1–10 sol and peaking in amplitude in both autumn and spring. The 'solsticial pause' of weaker waves near winter solstice is evident [18].

Conclusions: Although data assimilation for other planets has a shorter history than that for the Earth, schemes have both built on established terrestrial techniques and developed new ideas for specific problems. A particular challenge is performance in a relatively data-poor environment compared to Earth, including the lack of a fully-defined climatology and the absence of any observations of some variables for validation, e.g. wind. It should also be noted that data assimilation is not the most suitable tool for all purposes and that much progress can be made with a variety of direct data-model intercomparisons. A specific strength of assimilation lies in its ability to reanalyse transient wave phenomena, as demonstrated here. Some aspects of wave variability, such as the martian solsticial pause, can be captured by assimilating thermal data from a single satellite, even if they are not intrinsic model features.

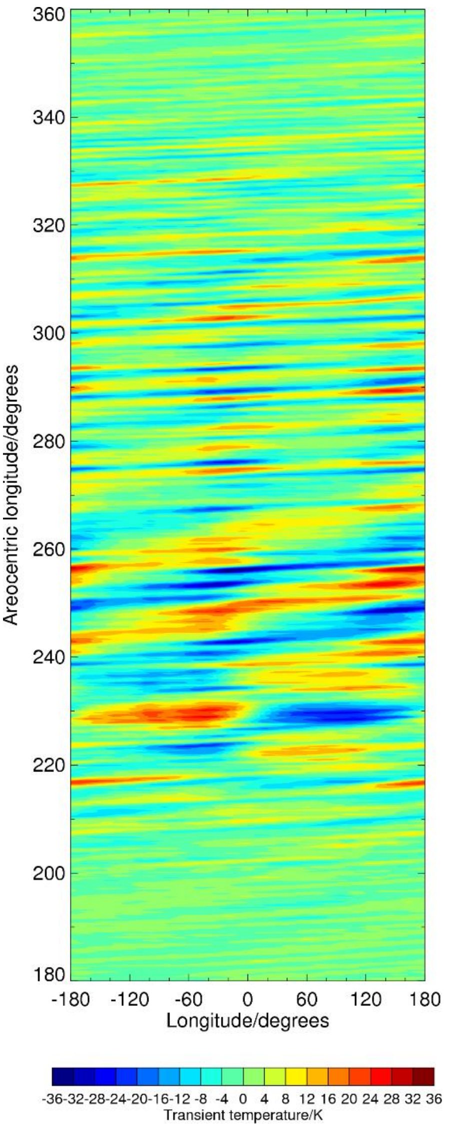

Figure 1: Transient temperature on the 50 Pa pressure surface (~25 km altitude) at 62.5°N over the period, L_S=180°–360° (northern autumnal to vernal equinox), of MY 24.

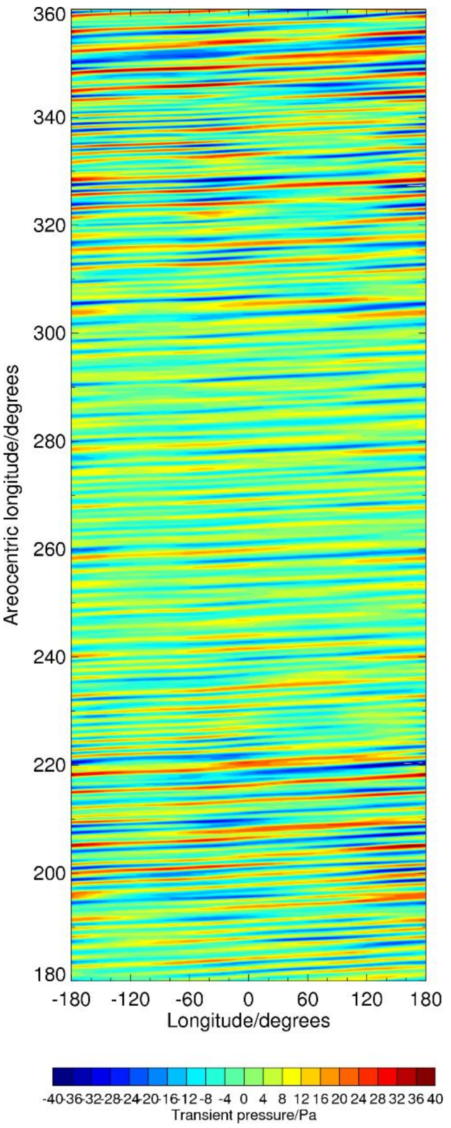

Figure 2: Transient mean zero datum-level pressure, over the same latitude and time range as Fig. 1.

References:
[1] D. Banfield, A. P. Ingersoll, and C. L. Keppenne, *JAS* **52,** 737–753, 1995. [2] S. R. Lewis and P. L. Read, *Adv. Space Res.* **16,** 9–13, 1995. [3] S. R. Lewis, M. Collins, and P. L. Read, *Adv. Space Res.* **19,** 1267–1270, 1997. [4] S. R. Lewis, P. L. Read, and M. Collins, *Planet. Space Sci.* **44,** 1395–1409, 1996. [5] H. Houben, *Adv. Space Res.* **23,** 1899–1902, 1999. [6] D. M. Kass, Ph.D. Thesis, CalTech, 1999. [7] K. Q. Zhang *et al.*, *JGR* **106,** 32863–32877, 2001. [8] M. J. Hoffman *et al.*, *Icarus* **209,** 470–481, 2010. [9] S. J. Greybush *et al.*, *JGR* **117,** E11008, 2012. [10] T. Navarro *et al.*, *GRL* **41,** 6620–6626, 2014. [11] P. L. Read and S. R. Lewis, *The Martian climate revisited: atmosphere and environment of a desert planet*. Springer, 2004. [12] R. M. Haberle *et al.*, *The atmosphere and climate of Mars*. Cambridge University Press, 2017. [13] F. Forget *et al.*, *JGR* **104,** 24155–24175, 1999. [14] S. R. Lewis *et al.*, *JGR* **104,** 24177–24194, 1999. [15] S. R. Lewis *et al.*, *Icarus* **192,** 327–347, 2007. [16] R. J. Wilson and K. Hamilton, *JAS* **53,** 1290–1326, 1996. [17] S. R. Lewis and P. R. Barker, *Adv. Space Res.* **36,** 2162–2168, 2005. [18] S. R. Lewis *et al.*, *Icarus* **264,** 456–464, 2016.