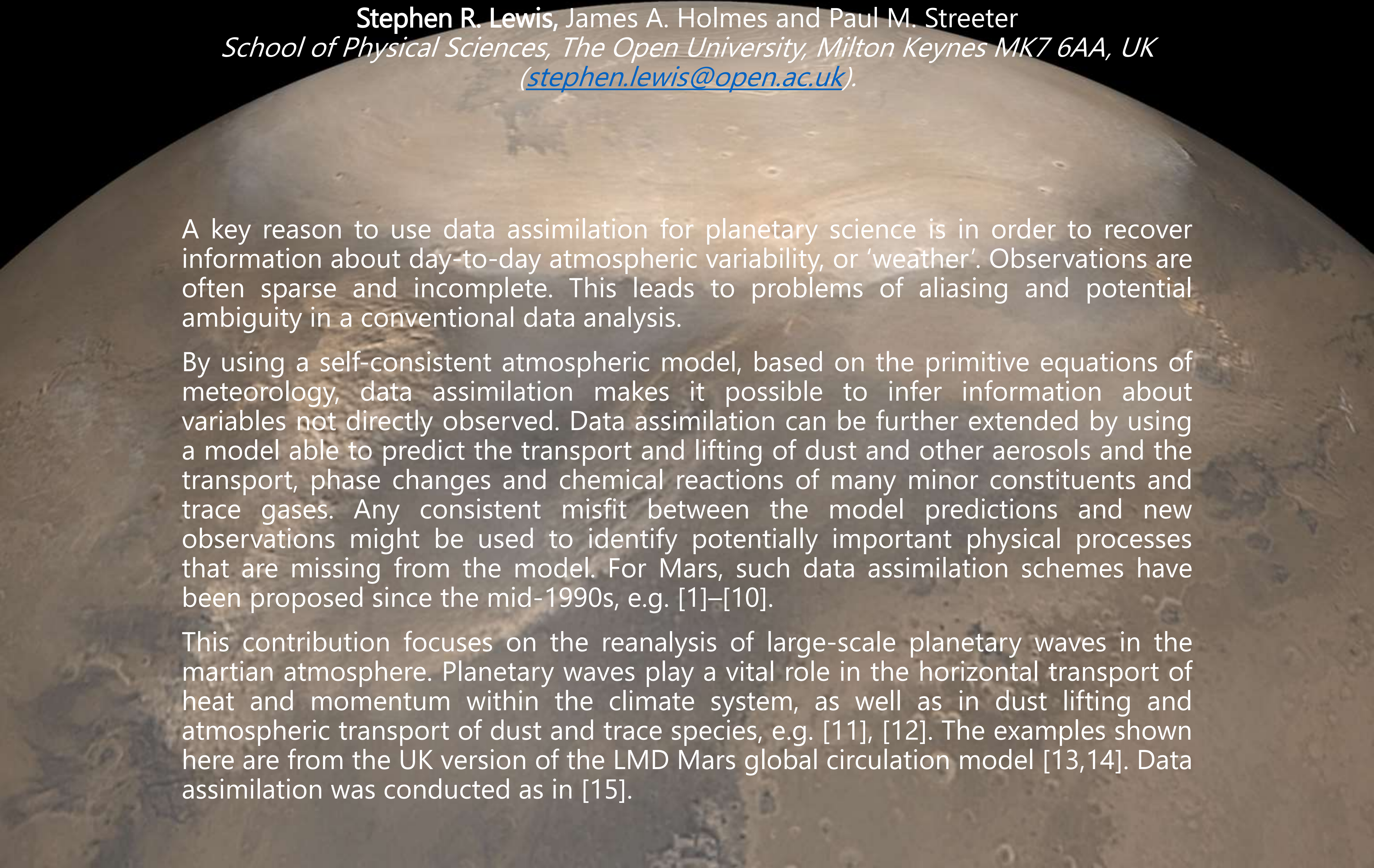
PLANETARY WAVE REANALYSIS USING SATELLITE DATA

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

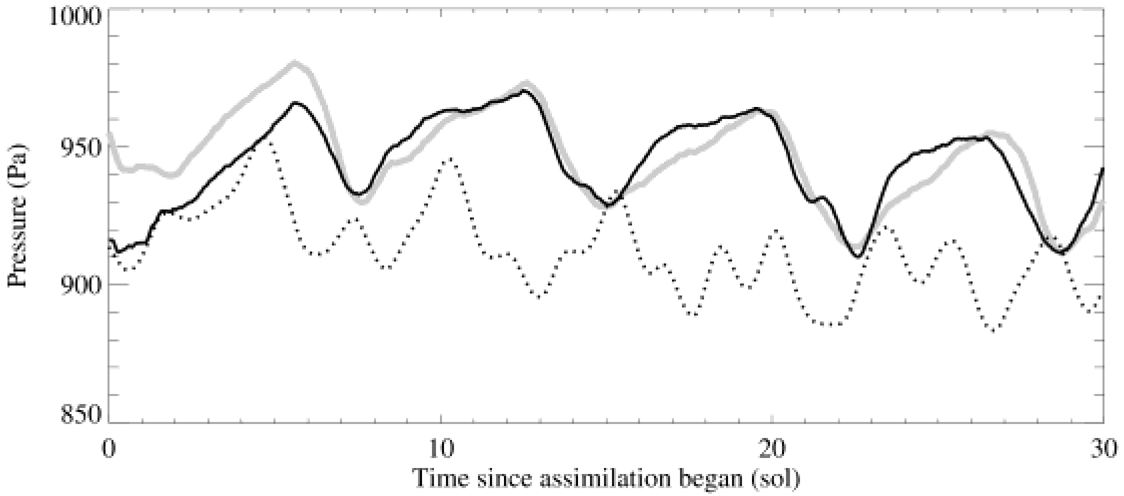


A key reason to use data assimilation for planetary science is in order to recover information about day-to-day atmospheric variability, or 'weather'. Observations are often sparse and incomplete. This leads to problems of aliasing and potential ambiguity in a conventional data analysis.

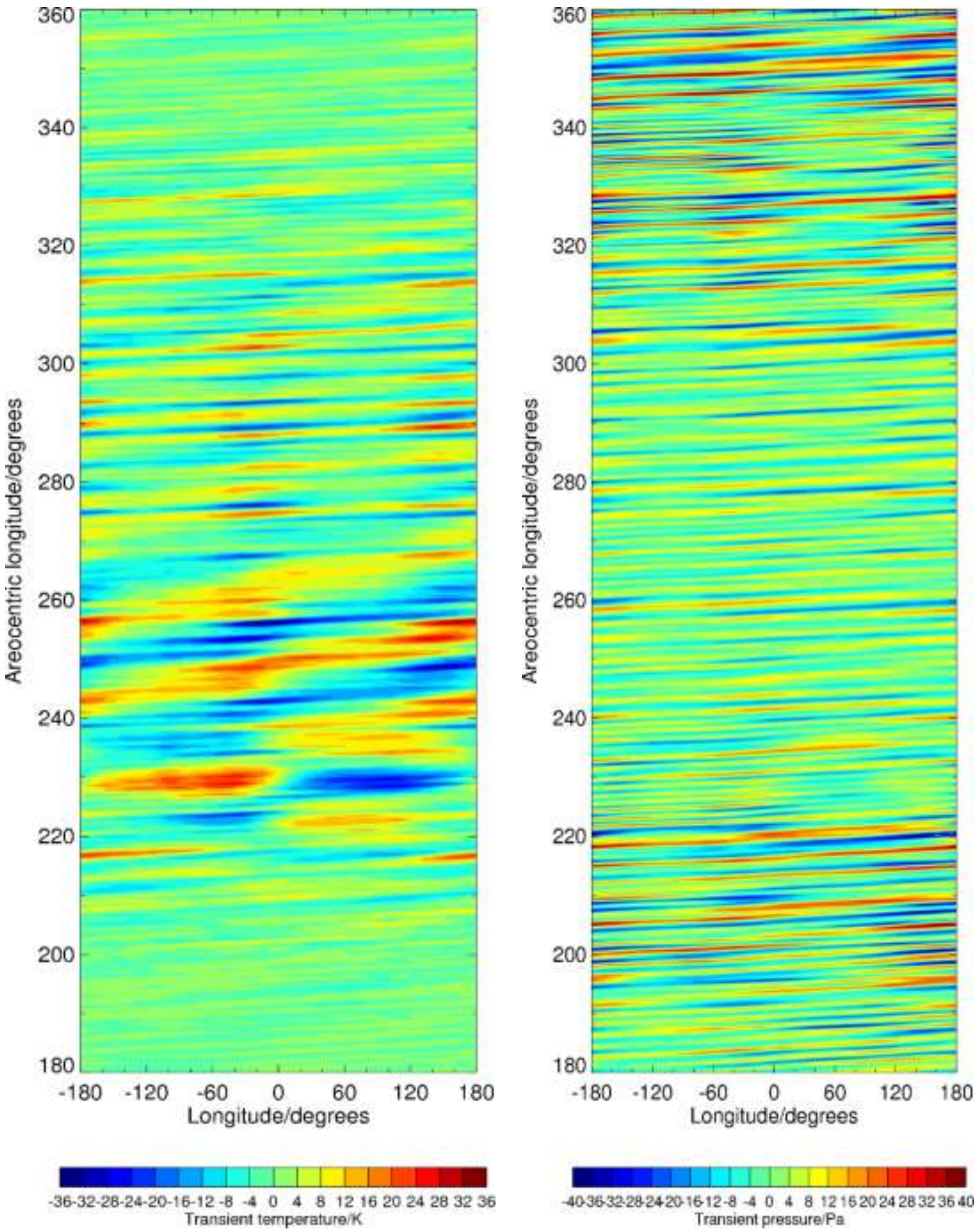
By using a self-consistent atmospheric model, based on the primitive equations of meteorology, data assimilation makes it possible to infer information about variables not directly observed. Data assimilation can be further extended by using a model able to predict the transport and lifting of dust and other aerosols and the transport, phase changes and chemical reactions of many minor constituents and trace gases. 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. For Mars, such data assimilation schemes have been proposed since the mid-1990s, e.g. [1]–[10].

This contribution focuses on the reanalysis of large-scale planetary waves in the martian atmosphere. Planetary 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]. The examples shown here are from the UK version of the LMD Mars global circulation model [13,14]. Data assimilation was conducted as in [15].

Data assimilation, even from a solitary satellite, is powerful in its ability to study planetary waves with periods in the range 1.5–30 sol. The figures illustrate 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, the same period in the surface pressure signal, displays 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].



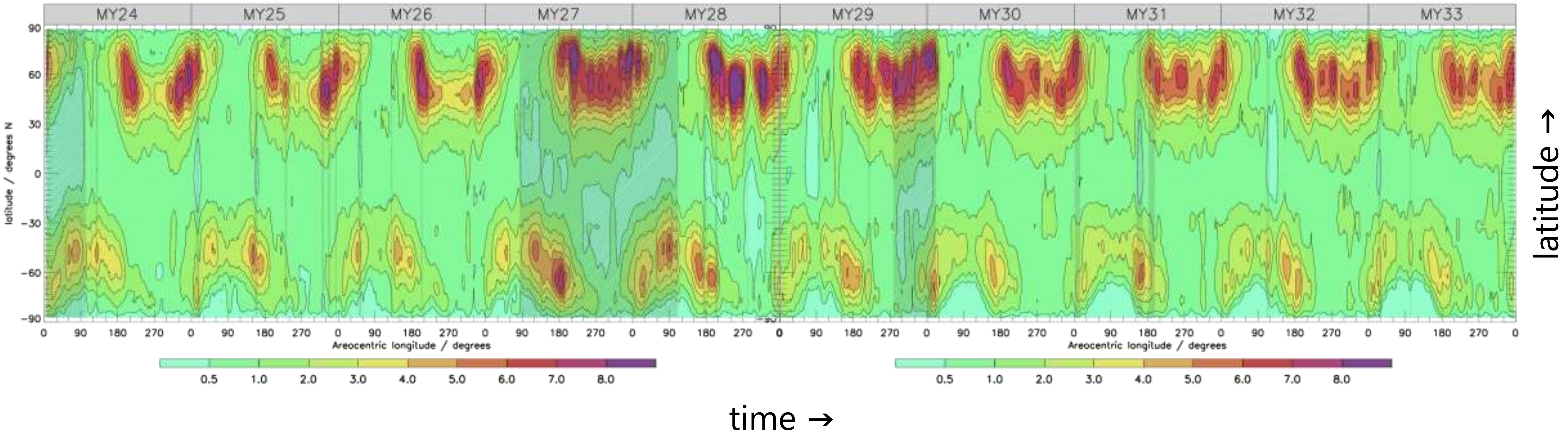
This figure demonstrates the ability of a non-twin model to recover the correct wavenumber and phase during a non-twin model experiment from [3], showing surface pressure at the Viking Lander 2 site (134° E, 48° N) over a 30 sol assimilation. The thicker grey line shows the true (τ=1.0) curve, the dotted line the control (τ=0.2) experiment and the solid black line the assimilation result using the control parameters. Note that surface pressure was not observed, only air temperature from simulated retrievals.



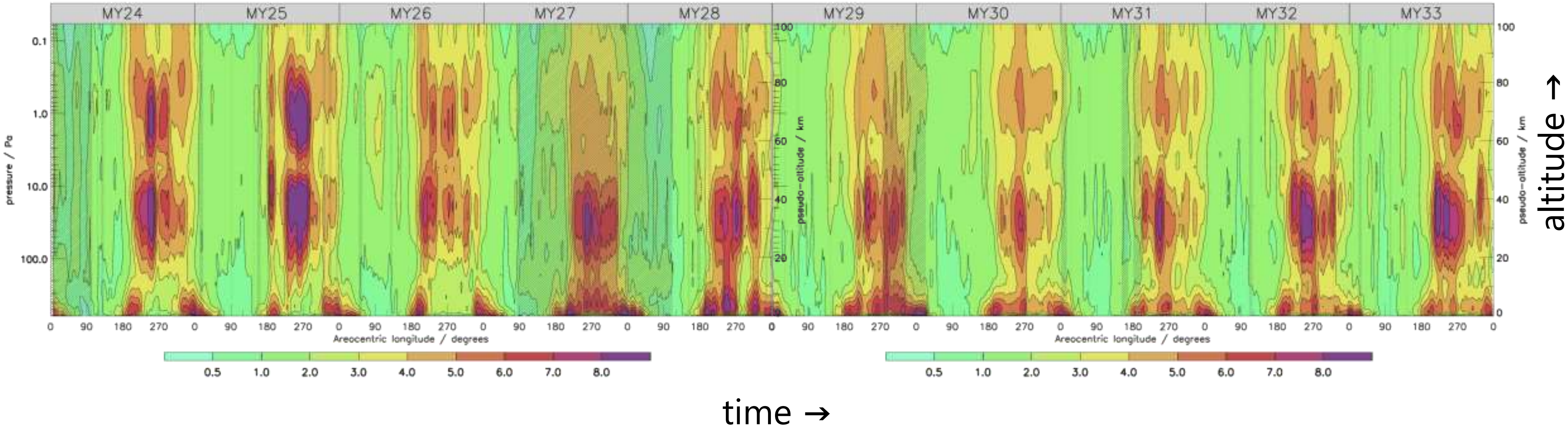
Left: Transient temperature on the 50 Pa pressure surface (~25 km altitude) at 62.5°N over the period, L_S=180°–360° (northern autumnal to vernal equinox), of MY 24.

Right: Transient mean zero datum-level pressure, over the same latitude and time range.

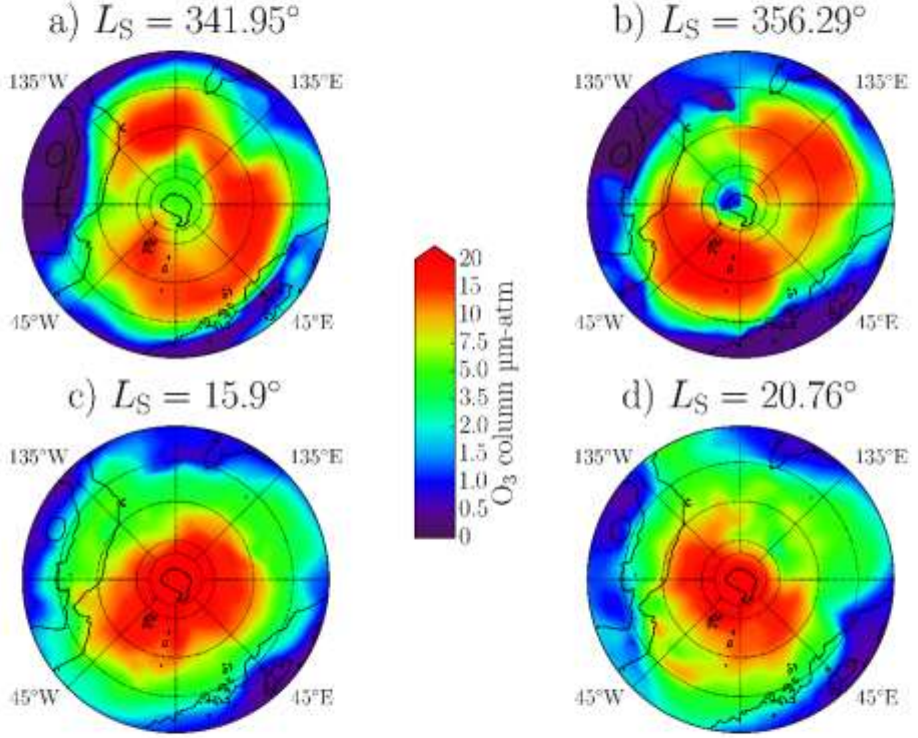
The martian ‘solsticial pause’ in planetary wave activity, re-analysed using data assimilation



Horizontal cross-section of temperature variability (rms) at 2.5 km altitude from the ten-year assimilation, band-pass filtered to periods of 1.5–30 sols and with a 20-sol running mean applied. Hatching indicates no data.



Vertical cross-section of temperature variability (rms) at 50°–70° N from the ten-year assimilation, band-pass filtered to periods of 1.5–30 sols and with a 20-sol running mean applied. Hatching indicates no data.



Planetary waves are important for their role in atmospheric transport, in particular of heat, momentum and constituents, such as trace gas species. Assimilation of ozone is able to highlight transient variations in the structure of the martian polar vortex, especially around its edge.

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.

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.