Geosci. Instrum. Method. Data Syst. Discuss., 2, 593–601, 2012
www.geosci-instrum-method-data-syst-discuss.net/2/593/2012/
doi:10.5194/gid-2-593-2012

Discussions
Geoscientific
Instrumentation
Methods and
Data Systems

Comment on “Observing desert dust devils with a pressure logger” by Lorenz (2012)

A. Spiga

Laboratoire de Météorologie Dynamique, UMR8539, CNRS/INSU –
Université Pierre et Marie Curie, Paris, France

Received: 27 July 2012 – Accepted: 13 August 2012 – Published: 20 August 2012

Correspondence to: A. Spiga (aymeric.spiga@upmc.fr)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Lorenz (2012) proposes to use pressure loggers for long-term field measurements in terrestrial deserts. The dataset obtained through this method features both pressure drops (reminiscent of dust devils) and periodic convective signatures. Here we use Large-Eddy Simulations to provide an explanation for those periodic convective signatures and to argue that pressure measurements in deserts have broader applications than monitoring dust devils.

1 Introduction

Desert meteorology has a strong potential for comparative planetology, at least between Mars and the Earth. Intense daytime convection takes place in their Planetary Boundary Layer [PBL] (see Spiga, 2011, for a comparative discussion). Dust devils occur on both Martian and terrestrial deserts (Balme and Greeley, 2006, for a review).

Large-Eddy Simulations [LESs] have showed that dust devils are intimately connected to afternoon PBL convection. LESs are high-resolution numerical integrations of atmospheric fluid dynamics' equations, which resolve the turbulent transport by the largest PBL eddies and plumes (Lilly, 1962). LESs have been carried out for Earth (Kanak et al., 2000) and Mars (Michaels and Rafkin, 2004; Spiga et al., 2010). This high-resolution modeling technique unveils the three-dimensional structure of the convective PBL, which is hardly achieved through measurements.

2 Discussion

Of interest to comment the paper by Lorenz (2012) is the fact that the high-frequency evolution of surface pressure is predicted by LESs. Here we base our discussions on Martian LES modeling described in Spiga et al. (2010). The conclusions we draw from Martian LESs hold for the Earth as well: how daytime PBL convection is organized is qualitatively similar in Martian and arid terrestrial environments (Kanak, 2006). This stems from similar physical cause in both situations: convective turbulent motions arise in the PBL, following unstable temperature gradients which develop near the surface heated by incoming sunlight. The differences between terrestrial and Martian PBL described in Spiga et al. (2010) affect PBL vertical structure and depth, but yield similar horizontal organization in both planets.

The horizontal structure of the afternoon convective PBL on Mars is shown in Fig. 1 for a LES carried out with no background wind (free convection case). The vertical velocity field exhibits polygonal convective cells formed by narrow updrafts and broad downdrafts (see also e.g. Kanak et al., 2000; Michaels and Rafkin, 2004). Those convective cells are associated with fluctuations of surface pressure and horizontal wind (“gustiness”) as is shown in Fig. 1. Local increase in horizontal wind causes in turn enhanced surface-atmosphere heat exchanges, i.e. larger values of sensible heat flux.

The deepest pressure drops are predicted at the edges of convective cells (where strongest updrafts occur) and correspond to convective vortices (Michaels and Rafkin, 2004) which could form dust devils should surface dust be available to be lifted. Pressure drops associated with dust devils have been observed both on Earth (Renno et al., 2004; Lorenz, 2012) and Mars (Schofield et al., 1997; Ellehoj et al., 2010). In fact, the method by Lorenz (2012) is able to capture all convective vortices rather than only dust devils (i.e. the convective vortices which happen to be dusty). In other words we expect pressure loggers as described in Lorenz (2012) to measure a larger number of pressure drops than actual dust devils taking place in the field. This is far from being a limitation: convective vortices are the meteorological phenomena of interest, responsible for PBL transport even if no dust makes those visually apparent. Comparisons between LESs and observations would benefit more from extensive observations of convective vortices than dust devils.

While analyzing pressure logger datasets, Lorenz (2012) noticed a pseudoperiodic pressure cycle in the afternoon with a period about 1000 s. We argue this signature is reminiscent of convective cells in Fig. 1 moving along with background (i.e. synoptic or regional) wind. To illustrate this, we carried out LESs in the same typical Martian conditions as in Fig. 1, except we prescribed a background wind of 10 m s^{-1} and 20 m s^{-1} (again, we choose the case of Mars for convenience and proximity to our recent modeling work in Spiga et al. (2010), but conclusions apply in terrestrial deserts too). LESs show that pressure maxima and minima associated with PBL convective cells are advected by background wind. At a given location (for instance, where pressure logger is located in the field), owing to the regular, quasi-periodic, horizontal organization of convective cells, a periodic signal in surface pressure appears, similarly to what Lorenz (2012) observed. This is shown in Fig. 2. This periodic signal would appear as long as convective cells are formed – i.e. in late morning and afternoon conditions when PBL convection takes places – and background wind is of sufficient strength.

The nature of PBL convective cells shown in Fig. 1 implies that periodic fluctuations in horizontal gustiness and sensible heat flux would also be found. This is illustrated by Fig. 3. Fluctuations of sensible heat flux were also observed by Renno et al. (2004) during the MATADOR campaign. Lorenz (2012) points out that pressure and sensible heat flux fluctuate at roughly the same period, which he qualifies as an “intriguing” coincidence. Conversely, we argue those observations are by no means coincidental and stems from PBL convective cells causing fluctuations of both pressure and sensible heat flux. We also conclude that the radiative feedback proposed by Renno et al. (2004) is not necessary to explain those observations.

The predicted order of magnitude for the fluctuation period of surface pressure is consistent with observations. A period of about 800–1000 s (500–700 s) is found for the 10 m s^{-1} (20 m s^{-1}) case. Those values can also be found by a simple calculation. The width of PBL convective cells approximately scales with the PBL depth which is about 5 km in the considered case. Assuming that convective cells are regular and advected at the background wind speed of 10 m s^{-1}, we obtain a period of about 500 s for surface pressure fluctuations. Our simple calculation yields an underestimate, but the aforementioned assumptions are quite strong: for instance background wind would tend to stretch convective cells and modify their width. The same order of magnitude can be found on the Earth where the convective PBL is less deep than on Mars (about 2–3 km in warm arid regions) and background wind perhaps less casually reaching speeds $\geq 10\,\mathrm{m\,s^{-1}}$ than on Mars (Balme et al., 2012). Those estimates are in line with the measured period of about 1000 s measured by Lorenz (2012), which makes it plausible that the recorded pressure fluctuations are caused by PBL convective cells. Further observations with pressure loggers as proposed by Lorenz (2012) will help to better constrain this scenario. For instance, LESs predict that the period of pressure fluctuations decreases when background wind is stronger, which remains to be confirmed by observations.

3 Summary and conclusions

We conclude that pressure measurements proposed by Lorenz (2012) have the potential to broaden the knowledge of convective boundary layer in addition to be suitable for monitoring dust devils. As far as the latter task is concerned, pressure loggers would actually monitor convective vortices, i.e. both dust and “dustless” devils. We also argue that the quasiperiodic pressure fluctuations is a signature of PBL convective cells being advected by background winds and shall be ubiquitous in future pressure logger measurements.

References

Balme, M. and Greeley, R.: Dust devils on Earth and Mars, Rev. Geophys., 44, RG3003, doi:10.1029/2005RG000188, 2006. 594

Balme, M. R., Pathare, A. V., Metzger, S. M., Towner, M. C., Lewis, S. R., Spiga, A., Fenton, L., Renno, N. O., Elliot, H. M., Saca, F. A., Michaels, T., Russell, P., and Verdasca, J. A.: Field measurements of horizontal forward motion velocities of terrestrial dust devils: towards a proxy for ambient winds on Mars and Earth, Icarus, accepted, 2012. 597

Ellehoj, M. D., Gunnlaugsson, H. P., Taylor, P. A., Kahanpää, H., Bean, K. M., Cantor, B. A., Gheynani, B. T., Drube, L., Fisher, D., Harri, A.-M., Holstein-Rathlou, C., Lemmon, M. T., Madsen, M. B., Malin, M. C., Polkko, J., Smith, P. H., Tamppari, L. K., Weng, W., and Whiteway, J.: Convective vortices and dust devils at the Phoenix Mars mission landing site, J. Geophys. Res.-Planet., 115, E00E16, doi:10.1029/2009JE003413, 2010. 595

Kanak, K. M.: On the numerical simulation of dust devil-like vortices in terrestrial and Martian convective boundary layers, Geophys. Res. Lett., 33, L19S05, doi:10.1029/2006GL026207, 2006. 595

Kanak, K. M., Lilly, D. K., and Snow, J. T.: The formation of vertical Vortices in the convective boundary layer, Q. J. Roy. Meteor. Soc., 126, 2789–2810, doi:10.1256/smsqj.56909, 2000. 594, 595

Lilly, D. K.: On the numerical simulation of buoyant convection, Tellus, 14, 148–172, 1962. 594

Lorenz, R. D.: Observing desert dust devils with a pressure logger, Geosci. Instrum. Method. Data Syst. Discuss., 2, 477–505, doi:10.5194/gid-2-477-2012, 2012. 594, 595, 596, 597

Michaels, T. I. and Rafkin, S. C. R.: Large eddy simulation of atmospheric convection on Mars, Q. J. Roy. Meteorol. Soc., 130, 1251–1274, doi:10.1256/qj.02.169, 2004. 594, 595

Renno, N. O., Abreu, V. J., Koch, J., Smith, P. H., Hartogensis, O. K., De Bruin, H. A. R., Burose, D., Delory, G. T., Farrell, W. M., Watts, C. J., Garatuza, J., Parker, M., and Carswell, A.: MATADOR 2002: A pilot field experiment on convective plumes and dust devils, J. Geophys. Res., 109, 7001, doi:10.1029/2003JE002219, 2004. 595, 596

Schofield, J. T., Crisp, D., Barnes, J. R., Haberle, R. M., Magalhaães, J. A., Murphy, J. R., Seiff, A., Larsen, S., and Wilson, G.: The Mars Pathfinder Atmospheric Structure Investigation/Meteorology (ASI/MET) experiment, Science, 278, 1752–1757, 1997. 595

Spiga, A.: Elements of comparison between Martian and terrestrial mesoscale meteorological phenomena: Katabatic winds and boundary layer convection, Planet. Space Sci., 59, 915–922, 2011. 594

Spiga, A., Forget, F., Lewis, S. R., and Hinson, D. P.: Structure and Dynamics of the Convective Boundary Layer on Mars as Inferred from Large-Eddy Simulations and Remote-Sensing Measurements, Q. J. Roy. Meteor. Soc., 136, 414–428, 2010. 594, 595, 596

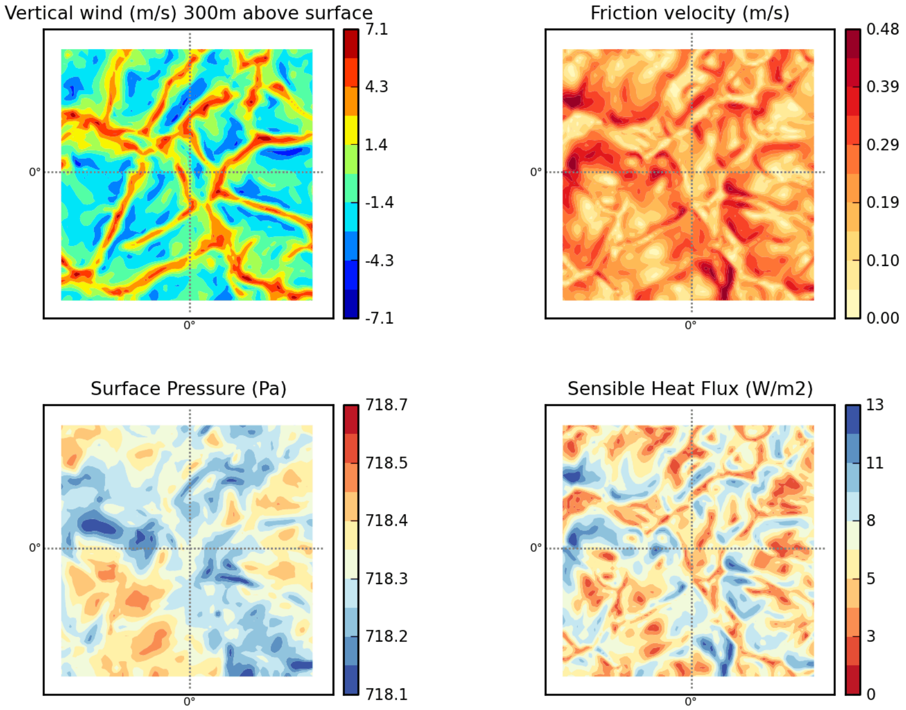

Fig. 1. Convective cells in daytime convective PBL. Results are obtained through Large-Eddy Simulations in the Martian environment. Similar organization is observed for the daytime convective boundary layer in terrestrial arid regions. The dimension of the simulation domain is ∼ 10 km. Results are shown at local time 1200.

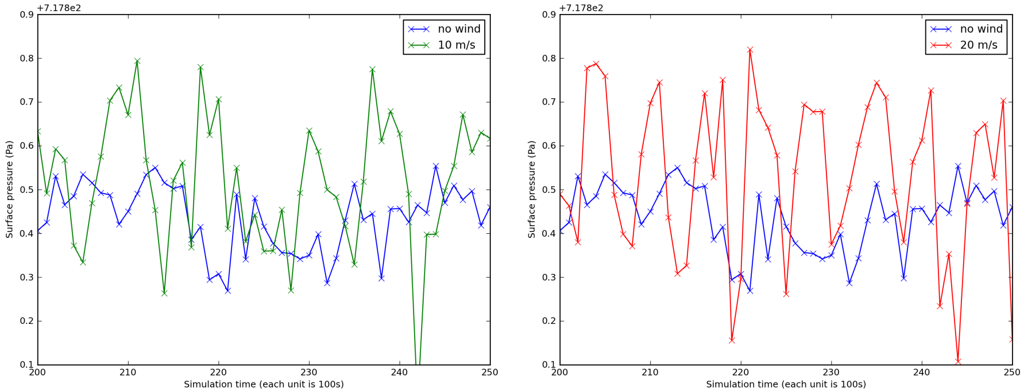

Fig. 2. Fluctuations of surface pressure with time at the central grid point of a Martian LES. On the left (right), a case with background wind of 10 m s^{-1} (20 m s^{-1}) is compared to a case with no background wind. Instantaneous model outputs are shown every 100 s between approximately local times 1200 and 1300 (LES integration timestep is 1.5 s). Higher frequency outputs show similar periodic patterns except for the added "noise" of lesser amplitude which corresponds to turbulent eddies of smaller scale than convective cells shown in Fig. 1.

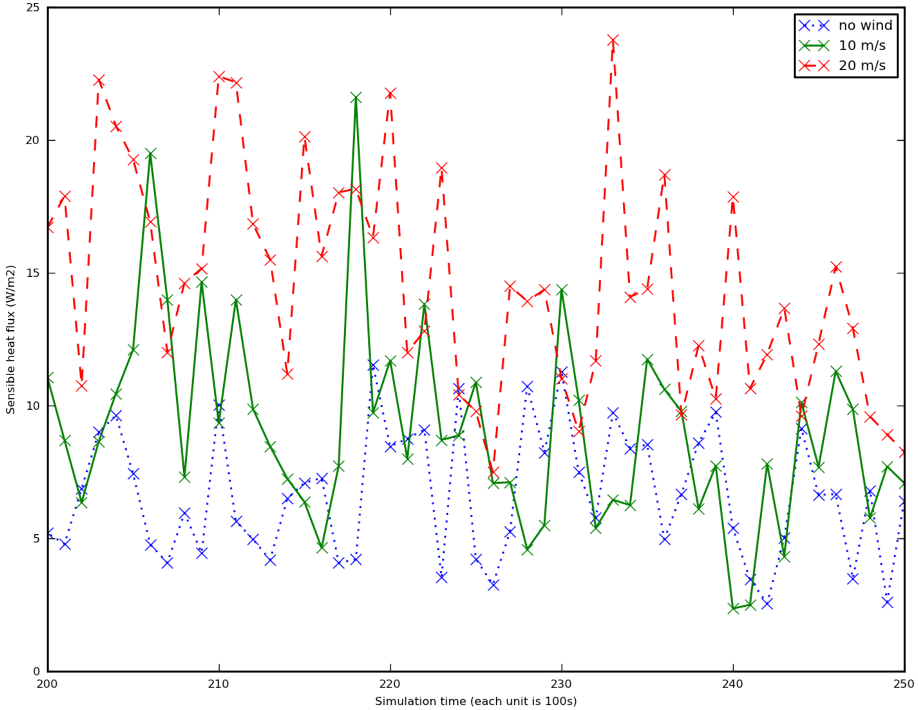

Fig. 3. Fluctuations of sensible heat flux with time. Cases with a 0 m s^{-1} (blue), 10 m s^{-1} (green) and 20 m s^{-1} (red) background wind are displayed.