Comments on "In Situ Atmospheric Turbulence Measurement Using the Terrestrial Magnetic Field—A Compass for a Radiosonde"

RALPH D. LORENZ

Lunar and Planetary Laboratory, The University of Arizona, Tucson, Arizona

(Manuscript received 1 September 2006, in final form 18 December 2006)

In this paper, Harrison and Hogan (2006, hereafter HH06) describe a novel application of an inexpensive Hall effect sensor as a magnetometer and use this to monitor the attitude motions of a radiosonde balloon during ascent to infer the presence of turbulence. I wish here to point out some modifications of their technique, which may offer better results, as well as to offer some further comments on data interpretation and related applications.

First, they mount the sensitive axis of the sensor horizontally, such that it responds to deviations from "North"—their Fig. 2 shows the magnetic field apparently horizontal. In fact, at midlatitudes characteristic of northern Europe and North America, the magnetic field has an appreciably vertical direction (see, e.g., the models at the National Geophysical Data Center available online at http://www.ngdc.noaa.gov/seg/geomag/jsp/struts/calcPointIGRF) and is inclined at some 55°–70° to the horizontal. Thus, the sensor would be more effectively mounted with its sensitive axis along the direction of the tether, that is, nominally vertical. This further makes the sensor exclusively sensitive to swinging motions, rather than the horizontal twisting/untwisting motions whose relevance to atmospheric motion is not obvious.

It is worth noting that while the Hall effect sensor they describe may be a compact and cost-effective solution, it needs some amplification to derive a reasonable angular sensitivity, whereas a variety of small and inexpensive magnetometers (magnetostrictive or fluxgate) are becoming available, produced for automotive, game controller, and mobile robotics applications. Many have amplified analog outputs, such as that used in HH06, although others have pulse frequency-modulated or other digital outputs that are convenient for interfacing to microcontrollers without the additional circuitry whose parts and assembly cost may largely offset the sensor cheapness. As a couple of examples, fluxgate sensors have been used to monitor rapid angular motions on aerospace platforms, including parachute-borne atmospheric probes (Dooley and Lorenz 2005) and recreational flying discs ("Frisbees"; Lorenz 2005). However, it should be underscored that the parameter of interest is turbulence and motion, not the magnetic field per se, and since it would be desired to have a standard sensor suite for use worldwide (where the strength of the magnetic field, and its orientation, can vary substantially) it may be more appropriate to use sensors directly sensitive to motion, such as accelerometers or Micro-Electro-Mechanical Systems (MEMS) gyros (also now very compact, low power, and easy to interface).

HH06 make an important contribution in comparing the history of the attitude motion to independent measurements of the atmospheric motions. This is an important problem in planetary exploration, where probes descending by parachutes through the atmospheres of Venus, Jupiter, or Titan have experienced motions (e.g., Seiff et al. 1999), which are at least partially excited by ambient turbulence; quantitatively recovering the intensity of the turbulence from these dynamics measurements is a problem that has not yet been satisfactorily addressed.

The measurements of HH06 can be considered in this regard. A challenge in this sort of investigation is that turbulence-excited motions are superimposed on various self-excited motions that can occur in perfectly still air, both for ascending balloons and for descending parachutes (although not, of course, on balloons at a steady float altitude). The spectral analysis of motions in HH06 suggests that pendulum motions in particular may be associated with turbulence, for example, at the base of cloud; my own informal observations of parachute motions are consistent with this association.

Corresponding author address: Ralph D. Lorenz, The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723.
E-mail: ralph.lorenz@jhuapl.edu

DOI: 10.1175/JTECH2059.1

The Doppler radar data in HH06 indicate fluctuations of 1–2 m s^{-1} on length scales of a few hundred meters that appear to be associated with the pendulum-type motions of a period of a few seconds, which correspond to mean-squared 1-s differences in the sensed field of 400 μT^2. This corresponds roughly to angular swings of ~40° over 1 s. But how can this be related to the wind?

If a balloon (considered as a point mass sonde suspended under a balloon that provides all the drag area) ascends into a layer with a horizontal velocity V and acts as a heavily damped system, the tether will tilt at an angle θ for a characteristic period δt, while the tilted tether accelerates the sonde up to V such that its relative velocity becomes zero. Instantaneously, the tilt can be considered by resolving forces along the tether, such that $\tan \theta =$ drag_on_balloon/weight_of_sonde or $\tan \theta = 0.5 S \rho C_d \, (V - U)^2 \, \mathrm{mg}^{-1}$, where S is the cross-sectional area of the balloon, ρ is the atmospheric density, C_d is a drag coefficient (typically ~0.4), U is the horizontal velocity of the system, which nominally begins at 0 and asymptotes to V, m is the mass of the gondola, and g is the acceleration due to gravity. The duration δt will depend on these various terms, but an average value simplifies to $\tan \theta = V/g\delta t$. On the other hand, if the system is undamped, then the system will swing as a simple pendulum, with a bottom center velocity $\sim V$. In this case, the amplitude of the swing (for small angles of swing, at least) is $\theta_m = V/(gl)^{0.5}$, with l being the pendulum length and the maximum angular rate is $\omega_m \sim V/l$.

Taking the angular change of ~40° in second increments implies for the undamped situation that $\omega_m \sim 0.7$ rad s^{-1} and thus for $l \sim 3$ m, the largest value of V (which presumably defines the envelope of motion) is ~2 m s^{-1}. Alternatively, in the damped case, successive samples in layers 1 s apart (i.e., ~2.5 m apart) have winds that vary by some ~6 m s^{-1}.

The actual situation lies between these extremes, although one tends to observe that balloon- or parachute-suspended systems damp out their swings after only a handful of cycles, so the damped situation may be a better estimate. The estimated winds above appear somewhat high in comparison with the Doppler data for two reasons. First, the swinging motion was overestimated because HH06's horizontal magnetometer is also sensitive to spurious twisting. Second, the Doppler data may not resolve the smallest scales of turbulence that excite the balloon motion.

Clearly, more sophisticated modeling is needed to enable confident quantitative interpretation of dynamics as turbulence. Such models (in which some progress has been made in the parachute engineering community) should be validated with further experiments that independently characterize the wind environment like that of HH06 (which unfortunately engineering tests tend not to do) and employ slightly improved attitude sensing, such as I describe above. While the exact implementation of the dynamics measurement on a radiosonde might be improved upon from that in HH06 to isolate the relevant motion and to do so in a geographically invariant manner, the concept of making such a measurement is an important and valuable one that deserves vigorous pursuit and offers the prospect of deeper understanding of both our own atmosphere and those of other bodies.

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