

# Turbulence detection on aerial platforms using orientation sensors

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# Motivation

*As would be expected, clouds such as cumulus and cumulonimbus that are definitely the result of convection were found to be accompanied by pronounced bumpiness.*

Meteorological Office Professional Notes, vol. 6, no. 146. *A note on bumpiness at Cranwell, Lincolnshire*, W. H. Pick and G. A. Bull, 1926.

**“Bumpiness” (or turbulence), still remains an aircraft hazard, even at cruising altitudes**

*How can in-situ direct position and orientation sensing can be used to detect turbulence affecting aerial platforms?*

- Investigated using balloon platforms, carrying sensors telemetered by a standard meteorological radiosonde
- Radiosonde orientation varies in turbulent air, as a result of irregular (simple pendulum, conical pendulum, rotation...) motions

# Talk structure

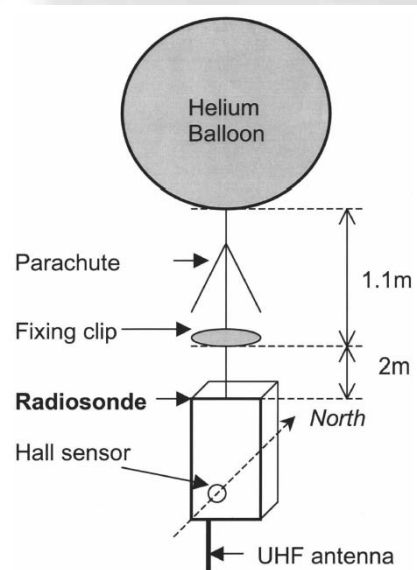
- Geomagnetic sensors to measure orientation
- Orientation variability as a turbulence measure
- Three-dimensional system; sampling strategy
- Results from three flights on 28th October 2006
- Conclusions

# Geomagnetic sensors for orientation sensing

- Sensing of platform orientation is possible using tilt sensors, accelerometers or geomagnetic field measurements (*i.e.* a compass)
- Magnetic position sensing used previously for meteorological applications (*e.g.* UK Met Office Cardington airship work by Lapworth and Mason), as the terrestrial magnetic field is stable (at least on short timescales), hence variability in magnetic field measurements results entirely from probe motions
- modern Hall effect sensors are sensitive and manufactured to close tolerances, providing a cheap way to measure position-induced changes through the geomagnetic field

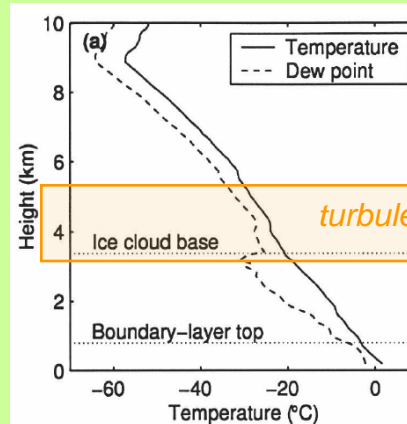
# Preliminary 1-D version

- Hall effect sensor mounted within RS80 radiosonde to detect horizontal field fluctuations
- Hall sensor samples obtained at approximately 3 Hz

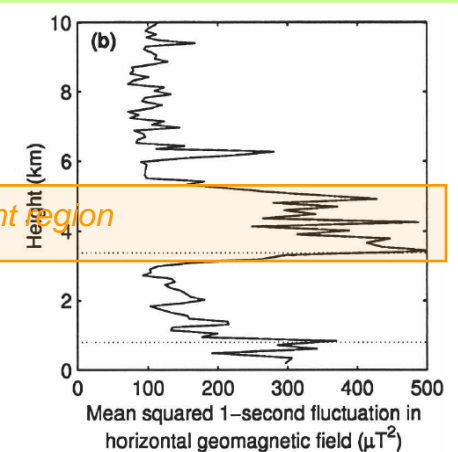


- Honeywell SS495 hall effect sensors have raw sensitivity ( $3.125 \pm 0.125$ ) mV per Gauss (1 Gauss = 100 microTeslas, earth's field is typically  $30 \mu\text{T}$ )
- response amplified by 33, to give overall response of  $\sim 1\text{mV}$  per  $\mu\text{T}$  ( $\sim \pm 30\text{mV}$  on rotation)

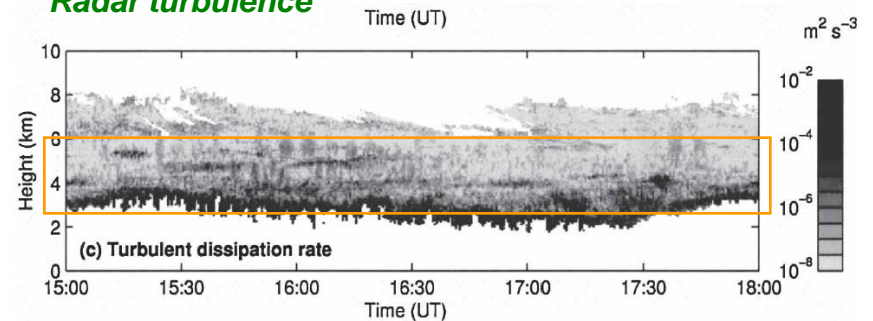
## atmospheric profile



## orientation fluctuations



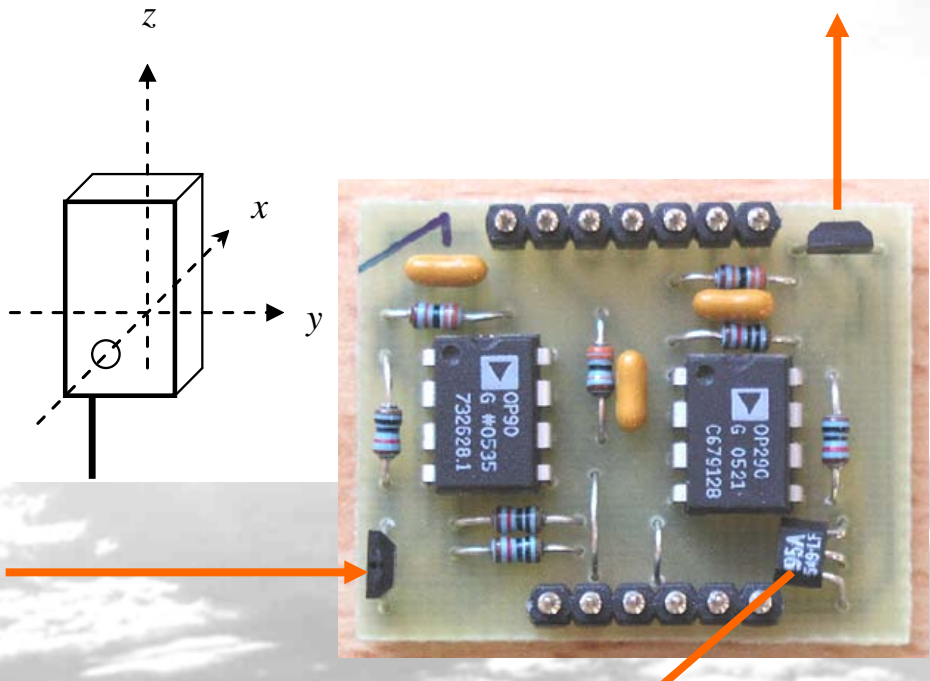
## Radar turbulence



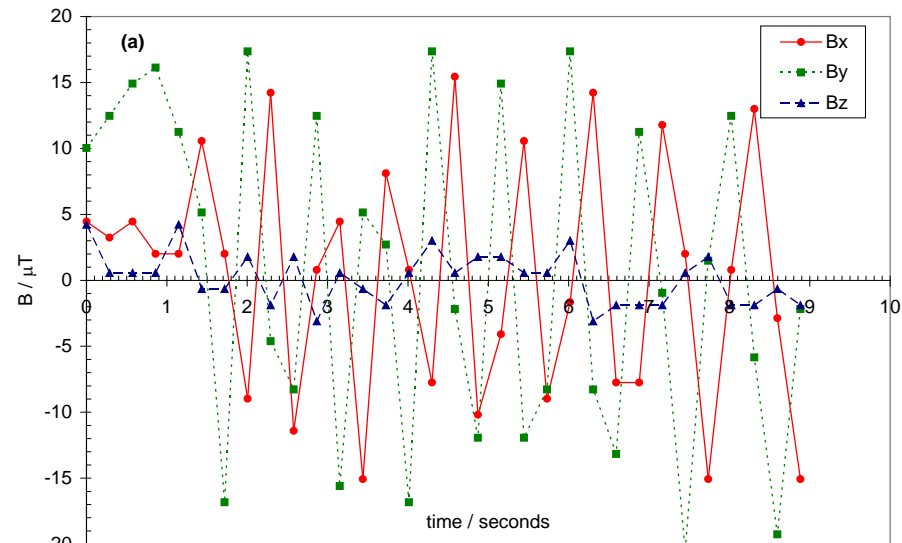
R.G. Harrison and R.J. Hogan (2005), In-situ atmospheric turbulence measurement using the terrestrial magnetic field – a compass for a radiosonde *Journal of Atmospheric and Oceanic Technology* **23**, 3, 517-523.

# Three-dimensional implementation

- Three-dimensional system developed to investigate which axis responded most effectively to turbulent motions.
- uses the same signal processing, but with three Hall Sensors (some parts, e.g. the voltage reference, could be made common to the three channels)
- Overall mass 6g, current consumption 20.5mA



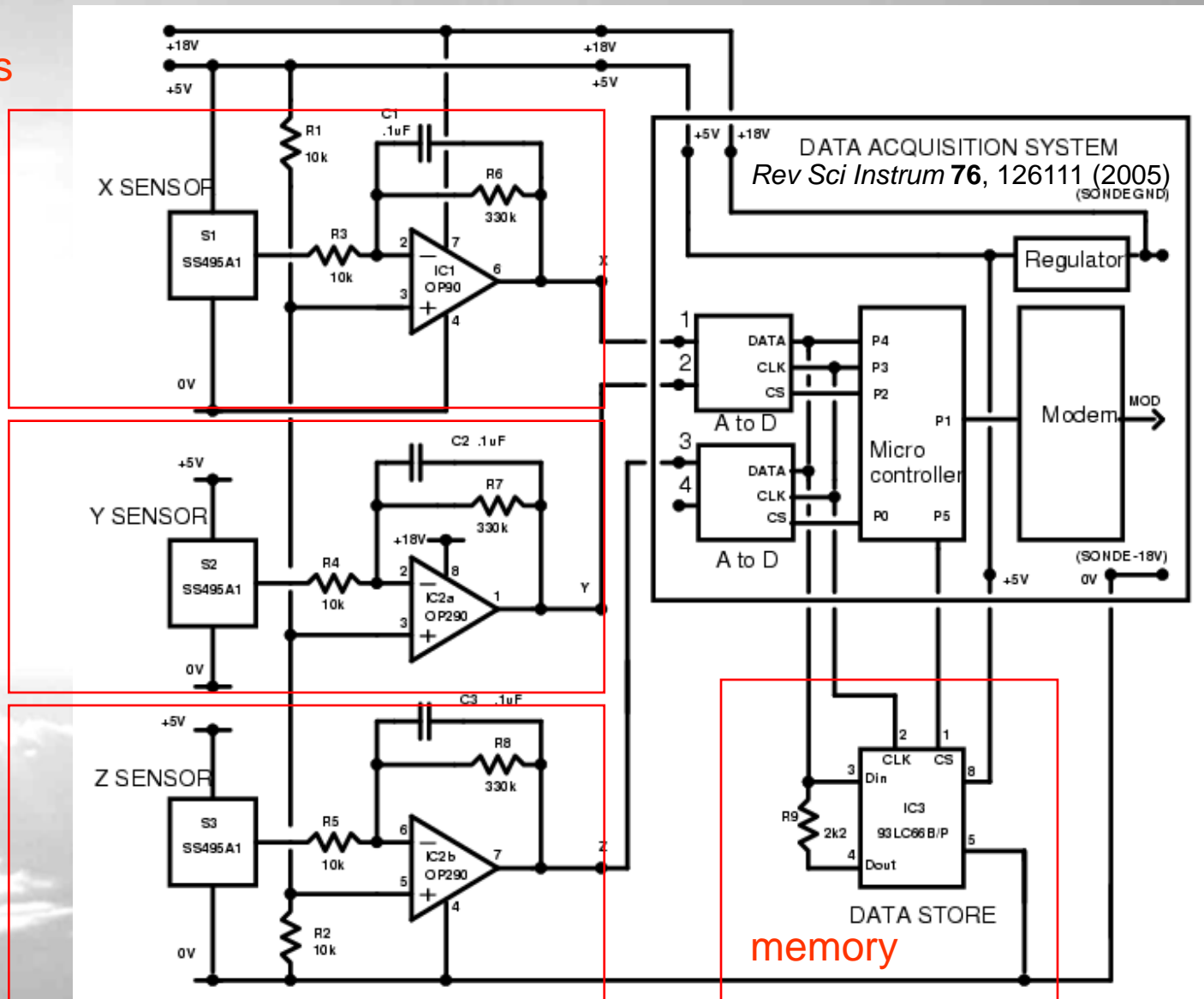
*Spinning*





# Overview of three component system

sensors



Described in *Rev Sci Instrum* 78, 12, 124501(2007) and *Rev Sci Instrum* 76, 126111 (2005)

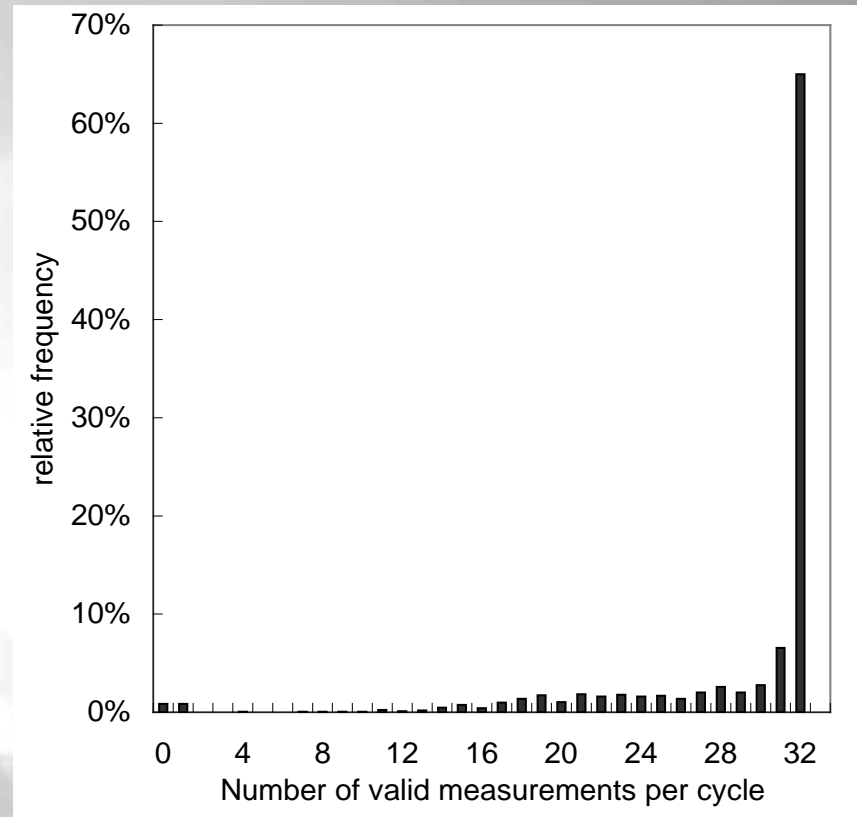
# Burst mode approach

## *Issues*

- Radio telemetry available poor when motions violent or wobbling, probably because of antenna alignment between transmitter and receiver
- Only slow data telemetry available (~30 characters per second),

## *Solution*

- three-component measurements were obtained in rapid bursts, stored in a memory and sent back at the maximum rate available
- This gave high sampling rates, but also increased reliability as the data was often sent back after the turbulence had been encountered

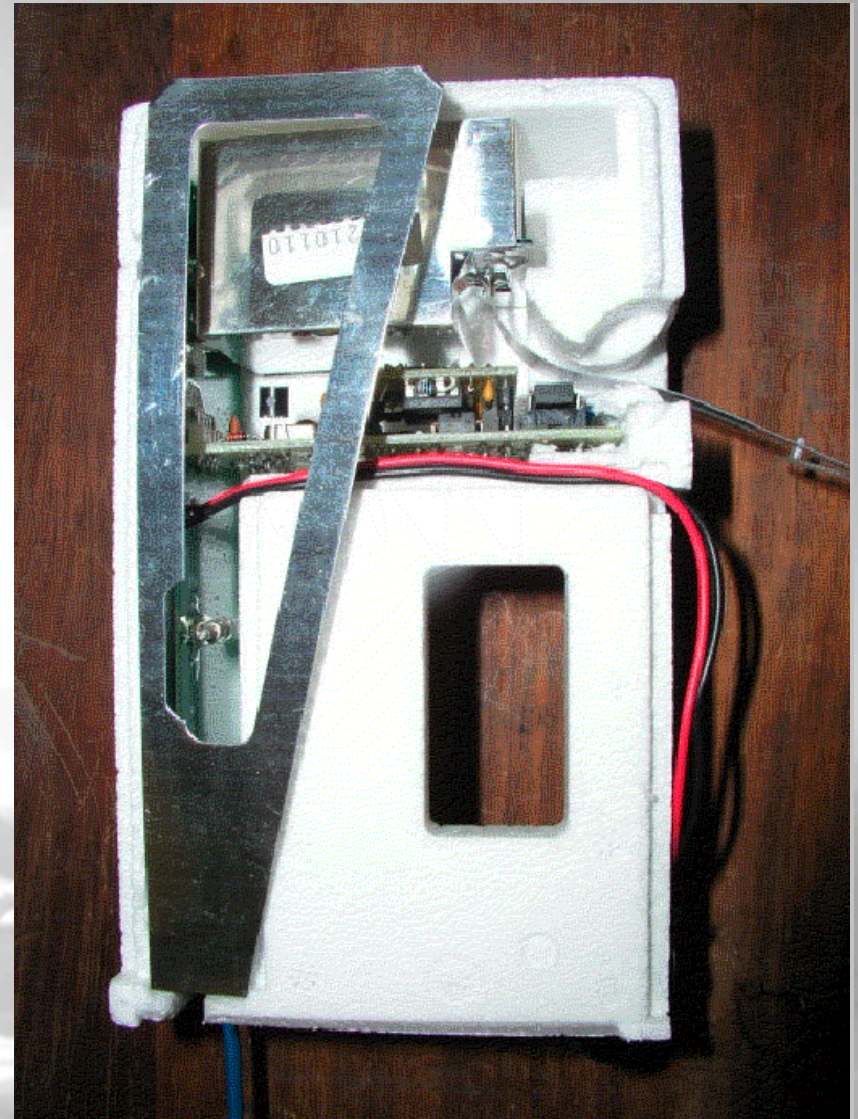
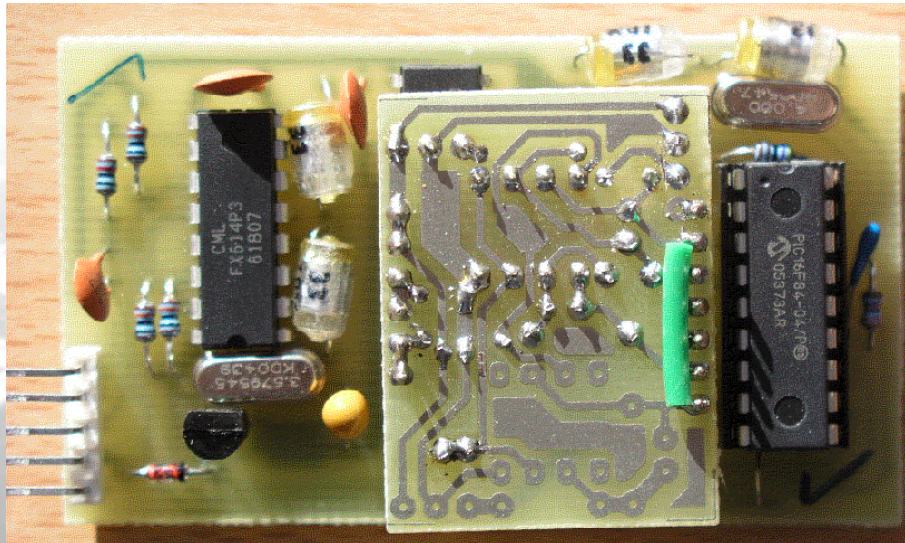


- Most data packets received with 20 or more samples of up to 32 samples per channel



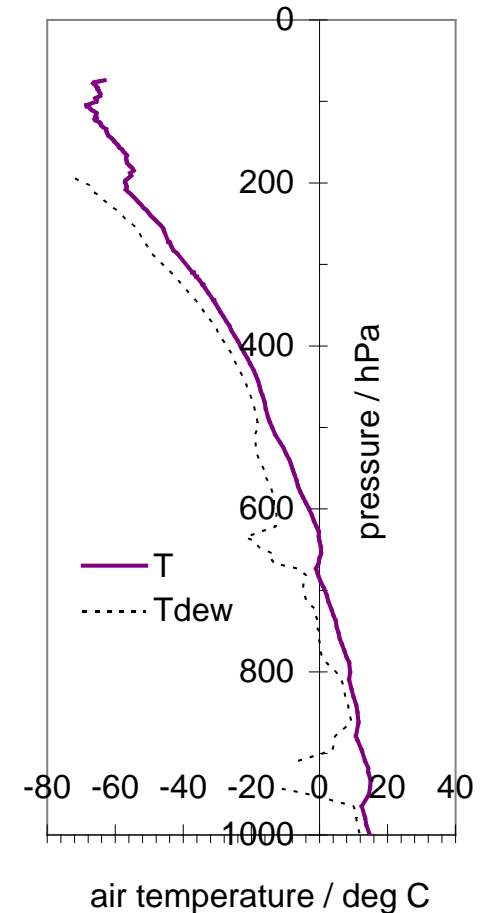
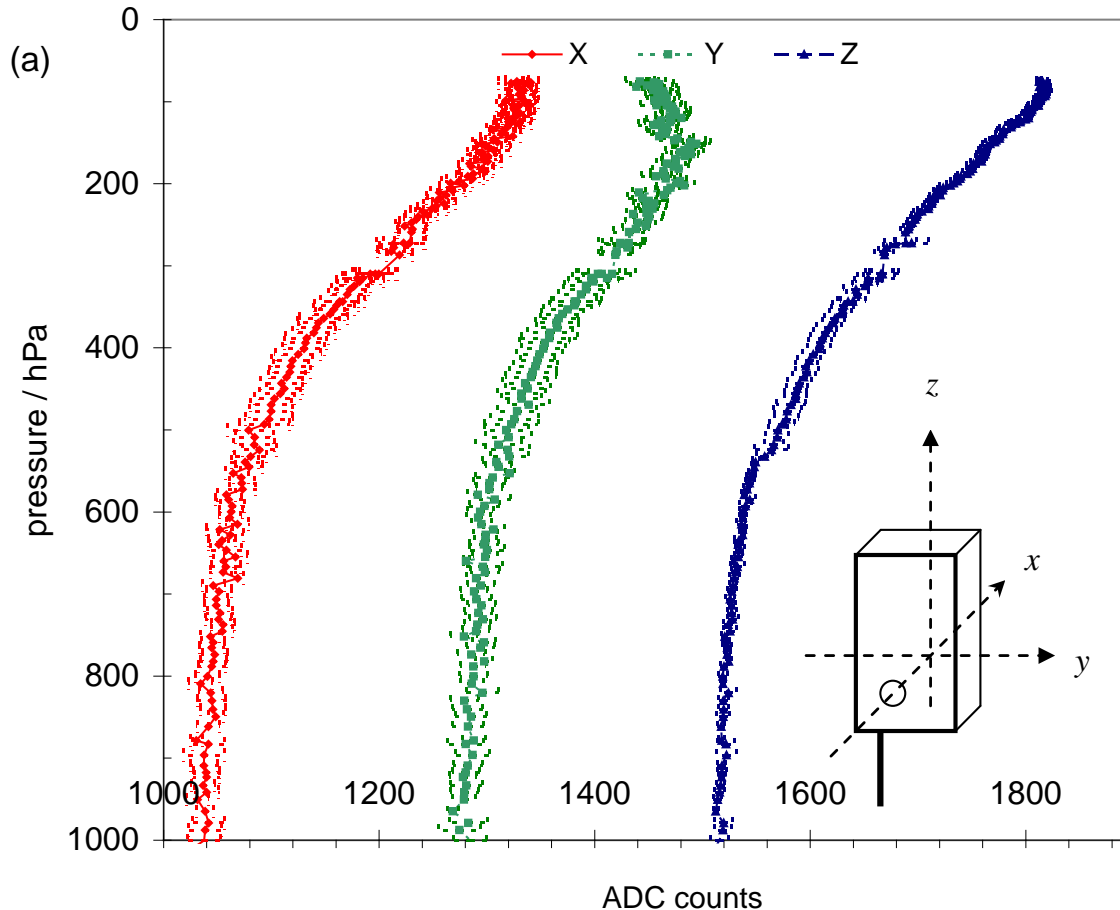
# Sensor integration within a radiosonde

- Magnetometer circuit board fitted as a daughter board above the data acquisition system, all of which fitted within a cavity in the RS80 radiosonde
- One connection to the RS80 circuit board
- Additional mass of magnetometer and data system (6g + 17g), and current consumption (20.5mA + 3mA)

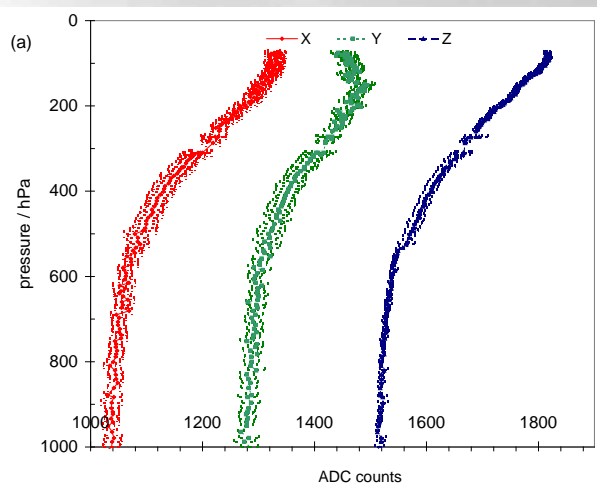


# Measurements during ascent

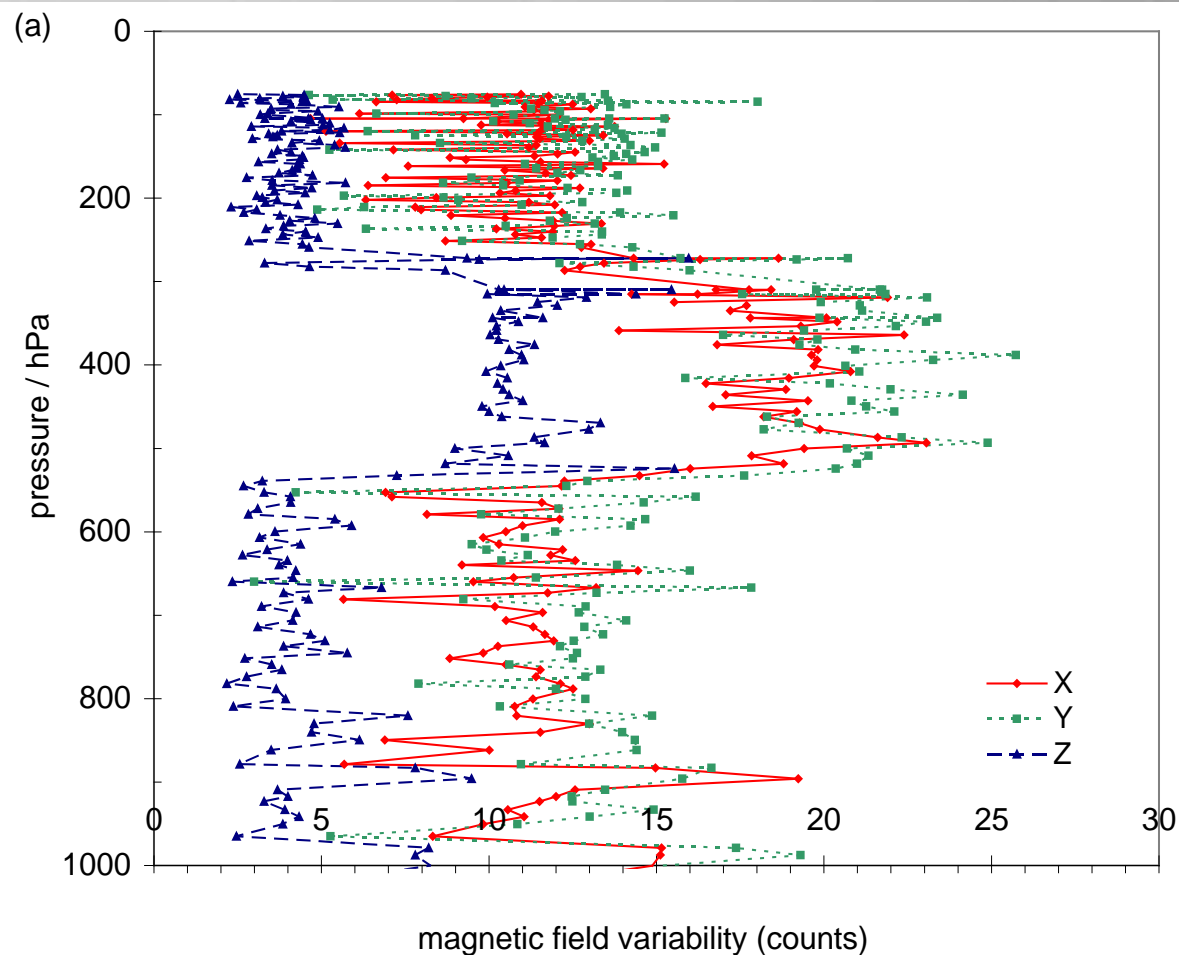
- Slow temperature drift on all three channels
- Variability present in all three channels at a common level (approx. where cloud present)



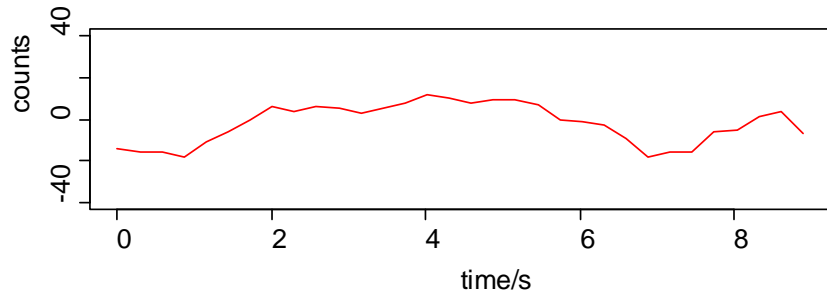
# Variability to measure orientation change



- Temperature drift is readily removed, as mean level of Hall sensor output not required
- Standard deviation (independent of the mean value) was calculated for each channel in each measurement burst

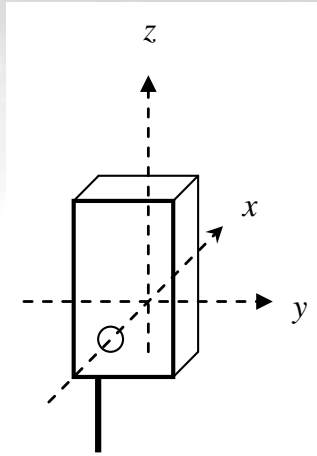


# Example of single measurement bursts



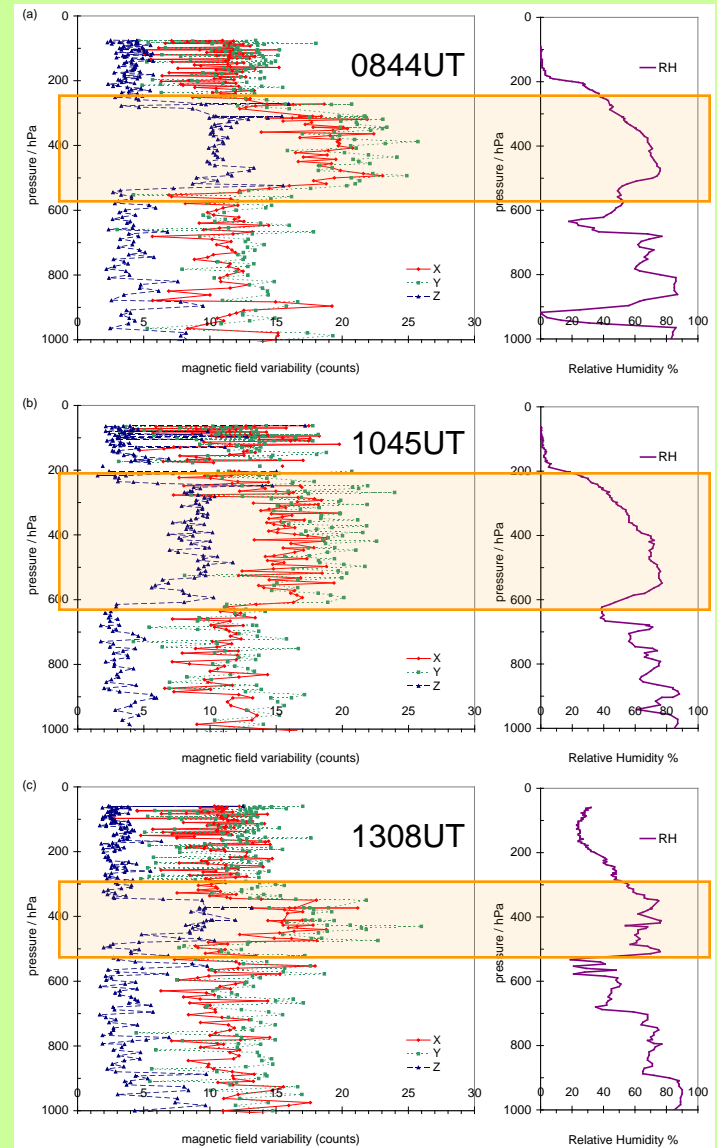


# Repeated soundings



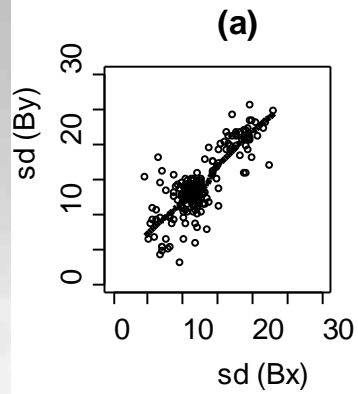
- In launches from the south coast of the UK on 28th October 2006, carrying three-dimensional magnetometers, consistent regions of variability were identified

- These show some association with Relative Humidity (and cloud) boundaries



R.G. Harrison, G.W. Rogers, and R.J. Hogan, (2007) A three-dimensional magnetometer for motion sensing of a balloon-carried atmospheric measurement package *Review of Scientific Instruments* 78, 12, 124501 DOI: 10.1063/1.2815349

# Variability in X,Y,Z sensors





# Aerial platforms: planetary applications

Descent to Titan

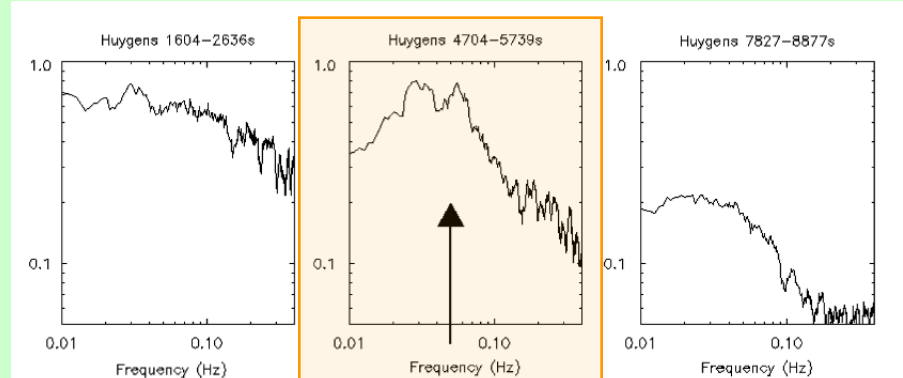


- During the Cassini-Huygens probe descent to Titan (January 2005), irregular motions were encountered within a region of methane cloud

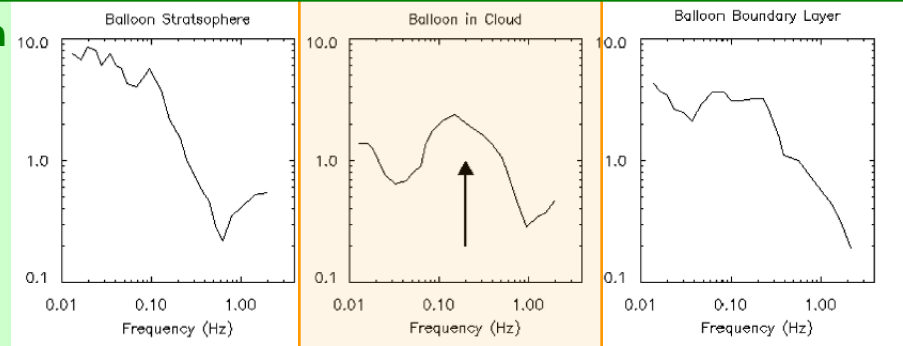
- Lorenz et al (2007) reported that the 2005 Harrison and Hogan radiosonde magnetometer results showed spectral similarities with the Titan measurements, suggesting turbulence in Titan's clouds

## Power spectrum of probe motions

Titan



Earth



From R. D. Lorenz, J. C. Zarnecki, M. C. Towner, M. R. Leese, A. J. Ball, B. Hathi, A. Hagermann, N.A.L. Ghafoor, *Planetary and Space Science*. 55, 1936, (2007)

[http://www.nasa.gov/mission\\_pages/cassini/media/cassinif-20070828.html](http://www.nasa.gov/mission_pages/cassini/media/cassinif-20070828.html)

# Conclusions

- Turbulence detected by measuring orientation fluctuations on an aerial platform
- Geomagnetic sensors provide rapid, sensitive measurements of orientation fluctuations
- Two sensors (one vertical and one horizontal) provide an optimal system
- Using temperature drift correction and a burst sampling approach, regions of atmospheric variability can be consistently detected

## **Acknowledgement:**

*This work was supported by the Royal Society through their Paul Instrument Fund*