Mutual information as a measure of spatial correlation properties of the turbulent solar wind as seen by WIND and ACE.

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Motivation

Multiple spacecraft measurements are becoming more available, giving us a new insight into the spatial structure of Solar wind turbulence.

Spacecraft give sparse measurements in a continuous field.

Understanding the spatio-temporal structure of turbulence in the solar wind is difficult from this.

Particularly as the study of turbulence requires the correlation structure of these strongly non-linear time series.

Theory

Developed by Shannon in 1949

Mutual information (MI) is a measure of shared entropy between two signals (X and Y)

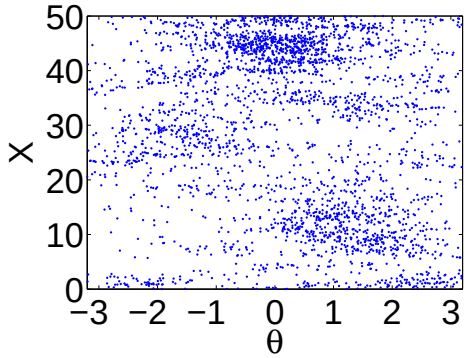
$$I(X;Y) = H(X) + H(Y) - H(X,Y)$$

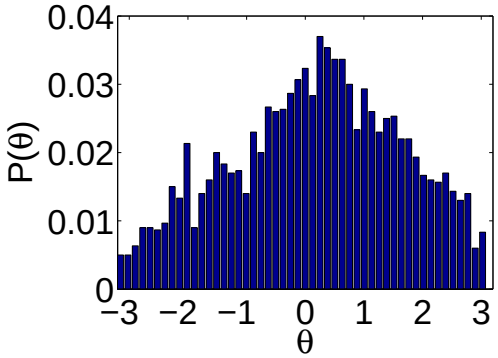
$$H(X) = -\sum_i P(X_i) log_2(P(X_i))$$

Histograms

Probabilities $P(X)$, $P(\Theta)$ and $P(X, \Theta)$ estimated by frequency of occurrence

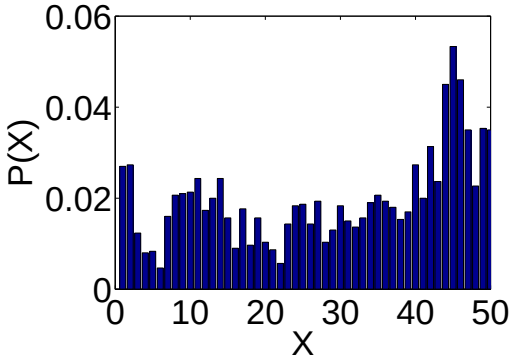
Raw data

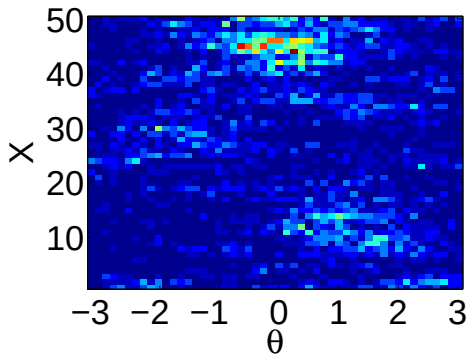




Θ value histogram

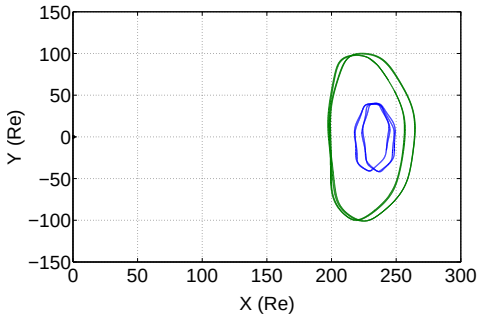
X position histogram

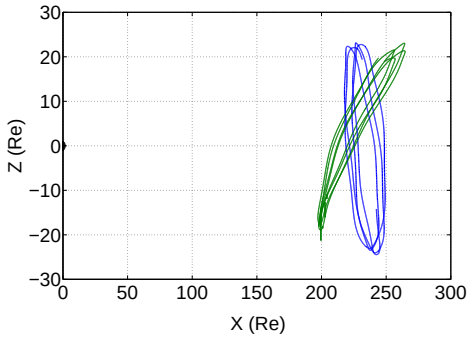


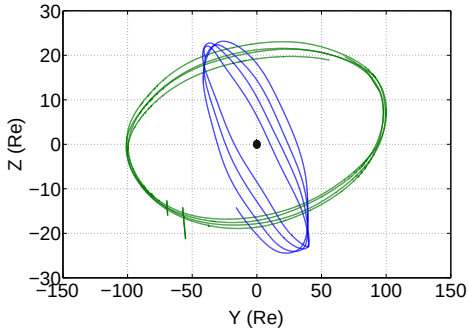


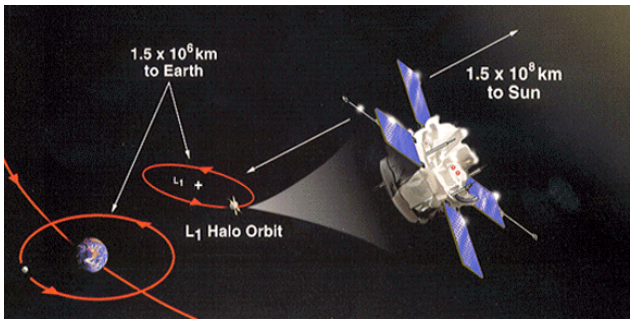
Joint probability distribution $P(X, \Theta)$

ACE and WIND







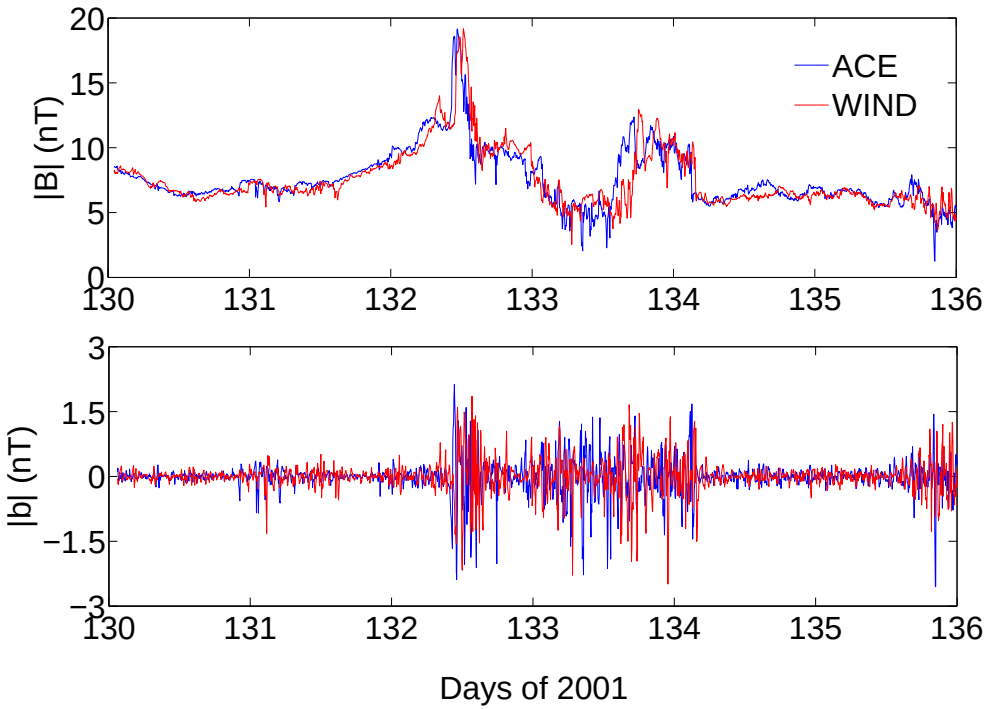


In 2005 and 2006 both ACE and WIND are in halo orbits around L1

This gives a good range of scales and orientations with a large separation (from under 10 Re to over 100 Re)

GSE coordinates

CME Data

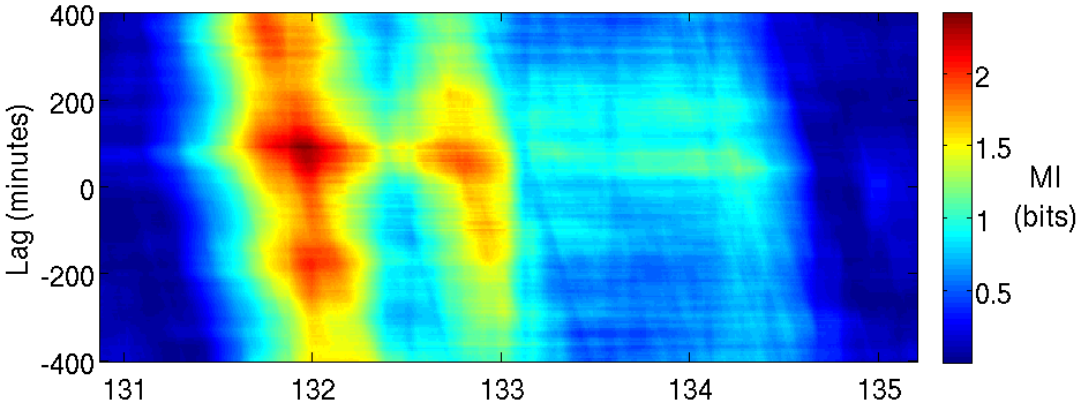


CME as measured by ACE and WIND

$$|b| = |B|_t - \overline{|B|}_{1hour}$$

Note large excursion in $|B|$ and accompanying wave train.

MI of Lagged Timeseries

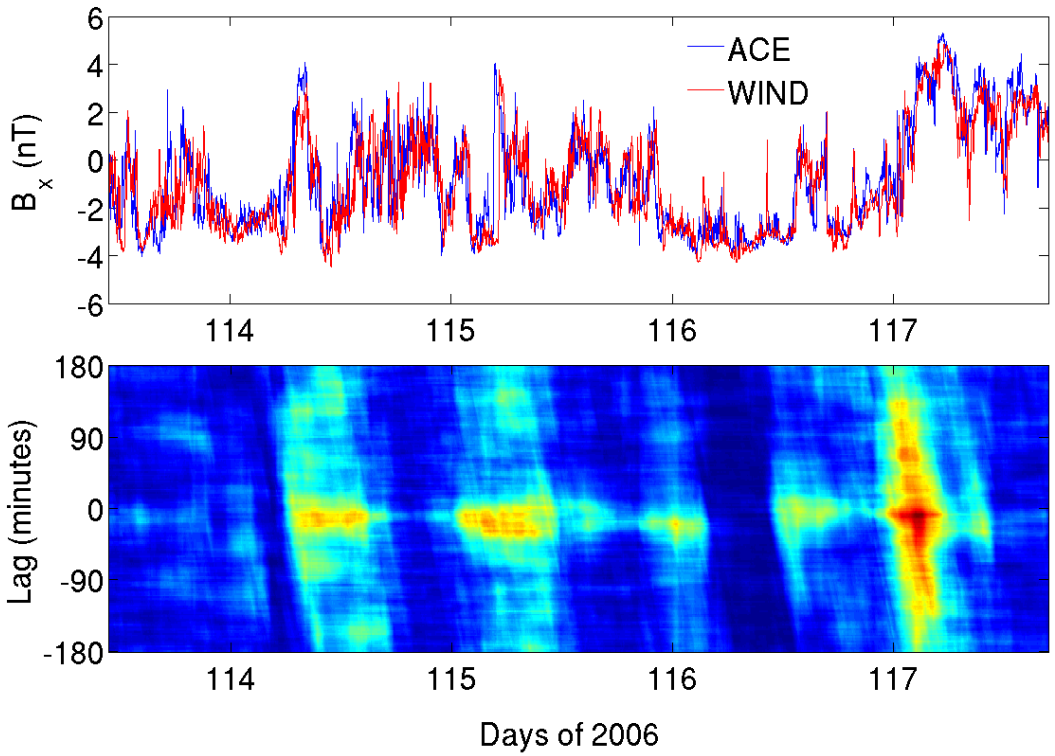


Mutual information of a CME as measured between ACE and WIND

$I(|B|_{ACE}; |B|_{WIND})$

4 minute cadence data, 400 points used for MI ≈ 1.11 days.

Turbulent Data

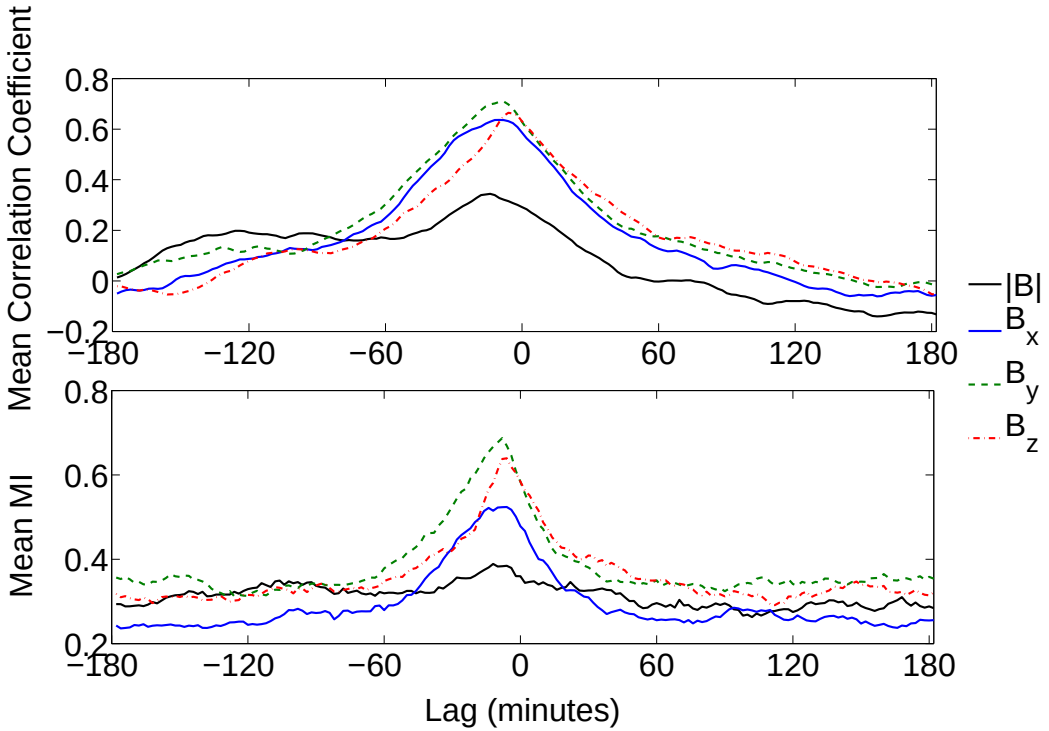


ACE and WIND data

MI calculated with lag
Min MI 0.0001
Max MI 1.42

MI gives indication of typical coherence length within solar wind

Mean Correlation

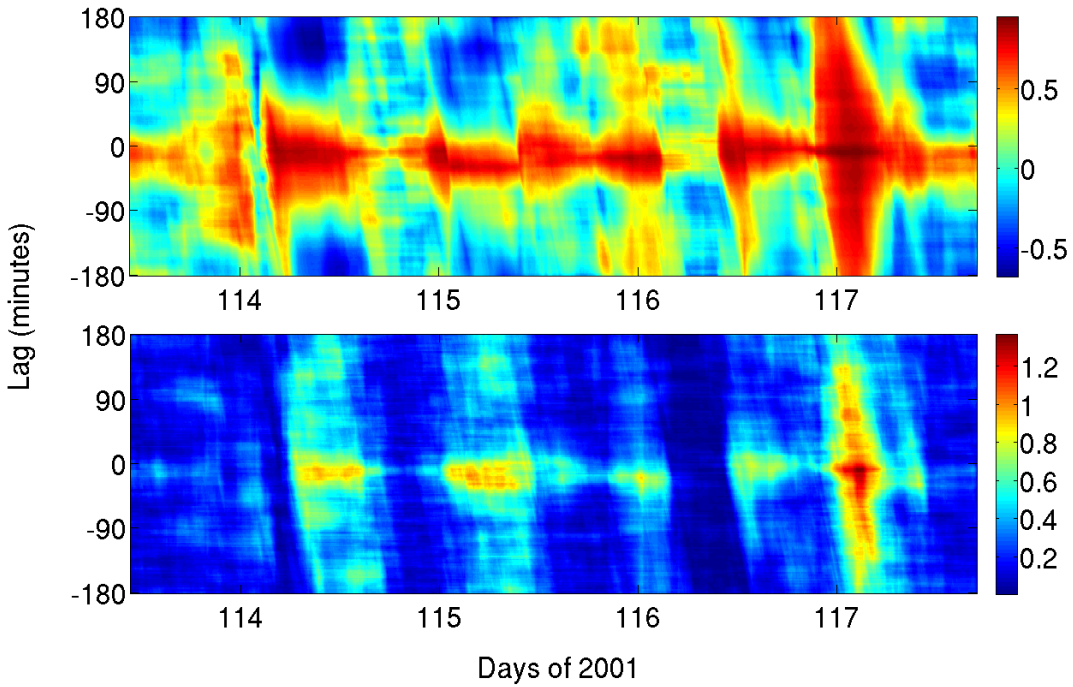


$|B|$ peak smaller than components $\rightarrow$ Alfvénic turbulence?

MI peaks sharper than linear correlation.

MI and linear correlation agree on time lag and ordering of the data.

Detailed Correlation



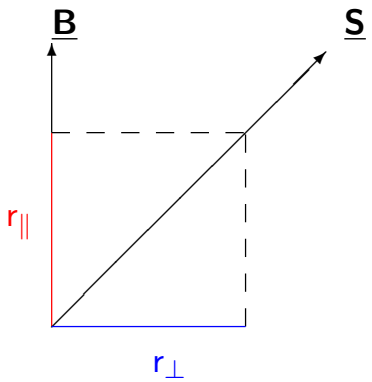
Linear Correlation identifies the convecting structures.

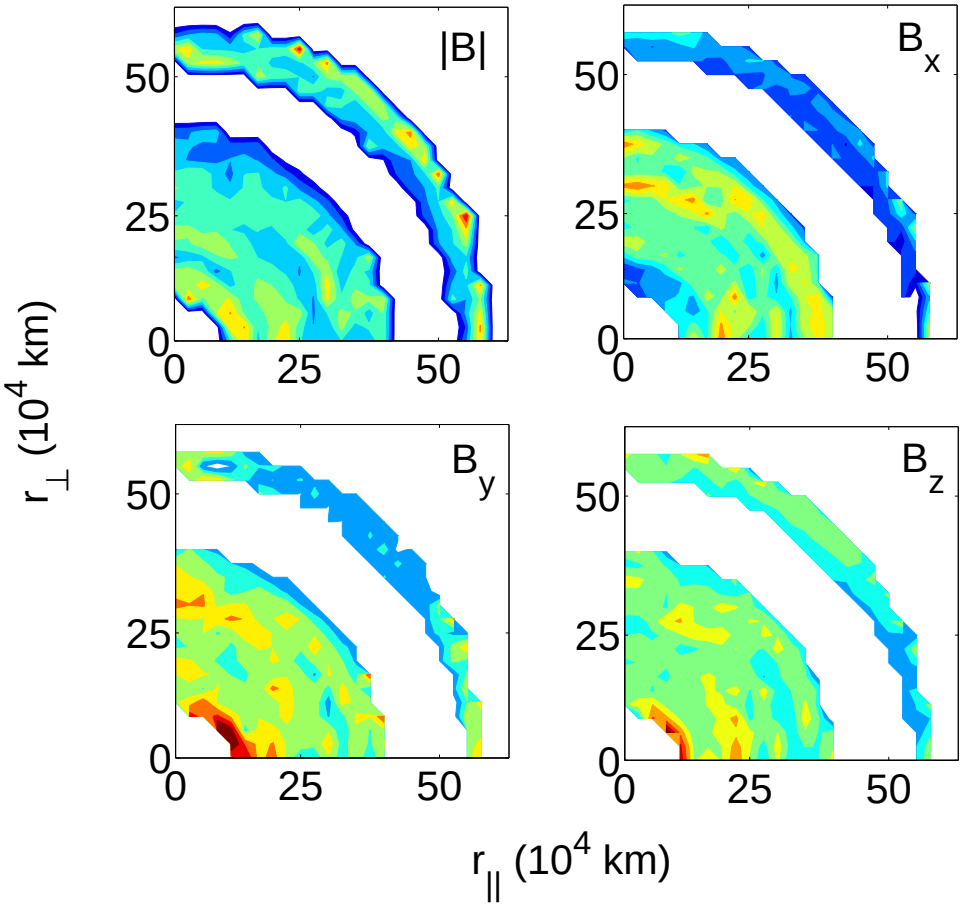
Distinct signature in MI.

Anisotropy

All components show anisotropy. Anisotropic

peak in MI most clearly seen in B_y and B_z.





- Data from two spacecraft, ACE and WIND, has been analysed using mutual information for the first time.
- Mutual information has been demonstrated on large scale structures (CMEs) that convect past both spacecraft.
- On average both MI and linear correlation find large scale convecting structures, although MI is more precise.
- When viewed in more detail, MI reveals distinct fine scale structure, reflecting nonlinear structure/dynamics.
- Preliminary results on vector information suggest anisotropy (anisotropic SW turbulence?).