# Multi-fractal turbulence in the ionosphere – IMF clock angle control of intermittency .

Gary Abel, Mervyn Freeman,
and Gareth Chisham
British Antarctic Survey

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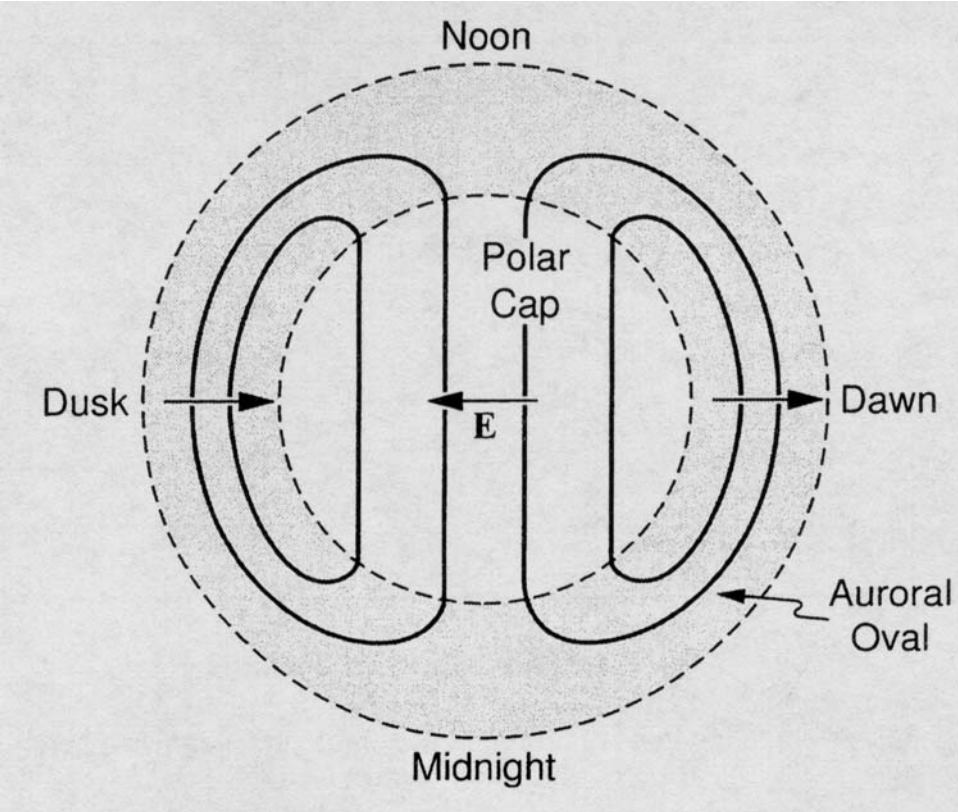
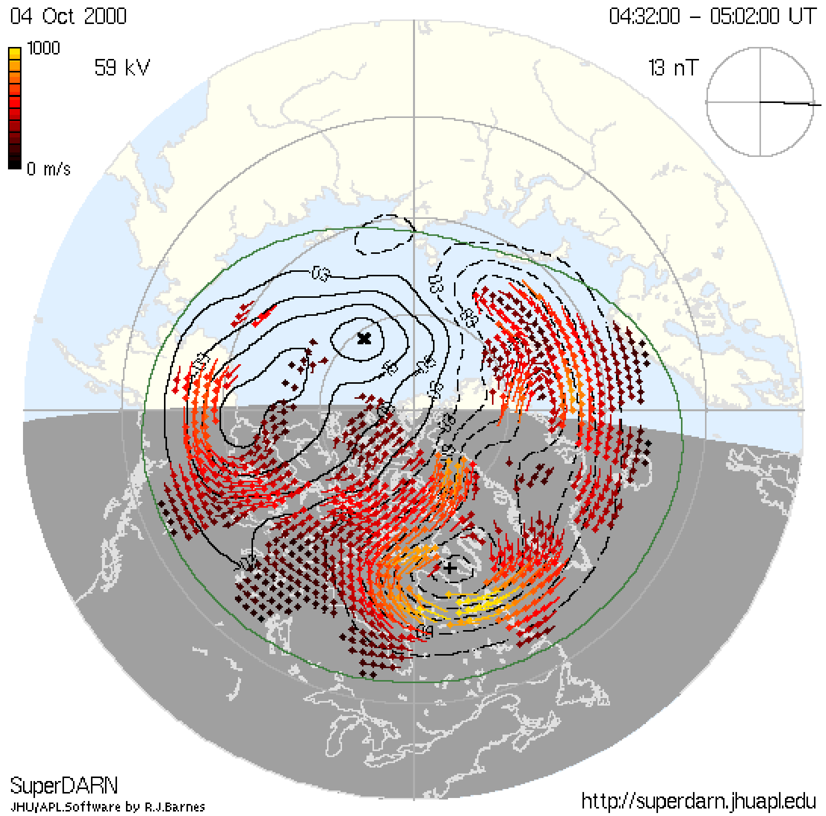
# Dungey convection cycle

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# Turbulence

- Considering turbulence with (fairly) strict definition
- Result of energy cascade
  - Normally from large to small scales
  - Reverse cascade is also possible
- Results in Scale-free distributions of energy, velocity etc.
- "Classic" turbulence models predict mono-fractal phenomenon with Gaussian statistics
- Intermittent models predict multi-fractal phenomenon with non-Gaussian statistics

# Astrophysical Turbulence

- The solar wind is the most explored natural turbulence laboratory
- Predictions from turbulence models are in spatial domain
- Solar wind measurements normally in temporal domain
  - Assumed equivalence under Taylor hypothesis
- SuperDARN measurements of ionospheric velocities are spatially distributed and allow us to probe turbulence without invoking Taylor hypothesis

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# Structure function analysis

- We use all Halley beam 8 data from 1996 – 2003.
- Split data into regions poleward and equatorward of open/closed field line boundary (OCB) and day/nightside
- Locate OCB using SuperDARN spectral width parameter (C-F threshold technique).
- Restrict ourselves to 09-13 MLT and 18-02 MLT

  (i.e. where we know what the spectral width boundaries relate to).
- Condition data by removing fluctuations larger than 3$\sigma$ from calculation

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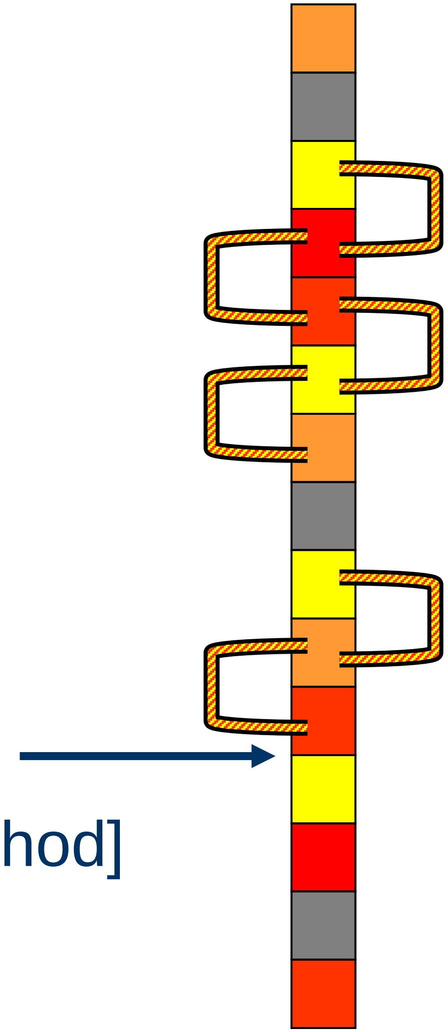
# Structure function analysis

Separation = 1

6 Pairs

Calculate –

- $<|v_{(r+1)}-v_r|>$
- $<|v_{(r+1)}-v_r|^2>$
- $<|v_{(r+1)}-v_r|^3>$



OCB

[C-F method]

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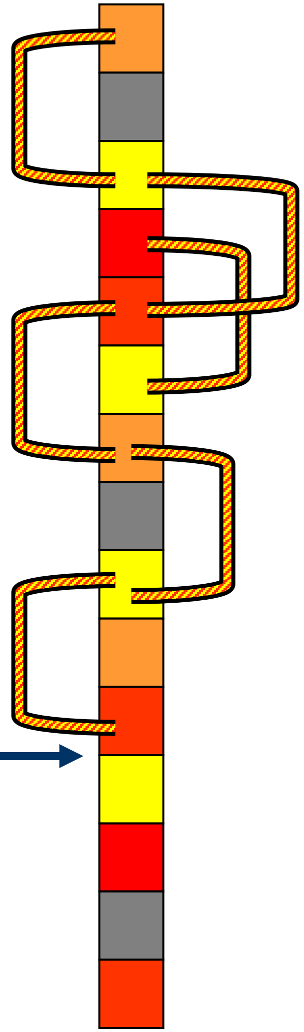
# Structure function analysis

Separation = 2

6 Pairs

Calculate –

- $<|v_{(r+1)}-v_r|>$
- $<|v_{(r+1)}-v_r|^2>$
- $<|v_{(r+1)}-v_r|^3>$



OCB

[C-F method]

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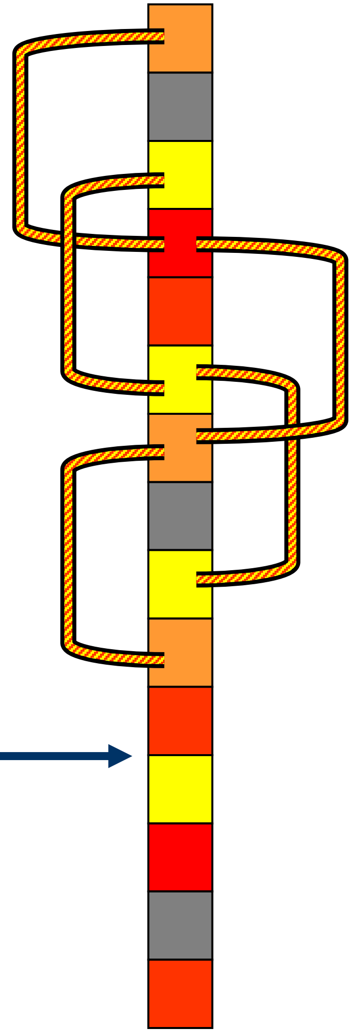
# Structure function analysis

Separation = 3

5 Pairs

Calculate –

- $<|v_{(r+1)}-v_r|>$
- $<|v_{(r+1)}-v_r|^2>$
- $<|v_{(r+1)}-v_r|^3>$



OCB

[C-F method]

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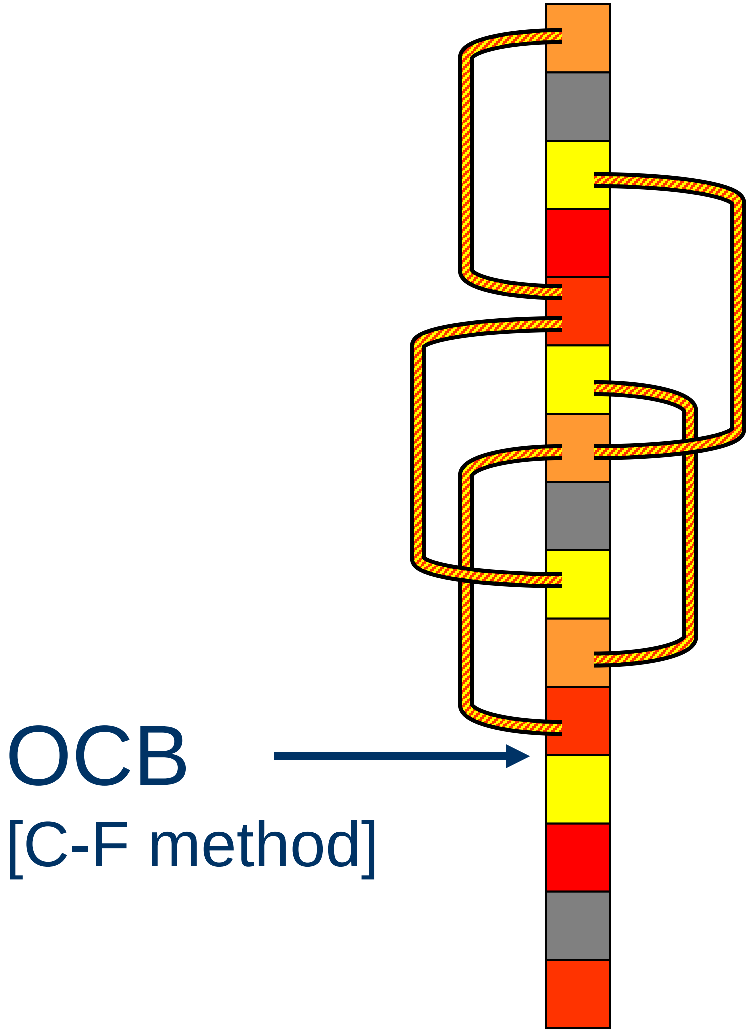
# Structure function analysis

Separation = 4

5 Pairs

Calculate –

- $<|v_{(r+1)}-v_r|>$
- $<|v_{(r+1)}-v_r|^2>$
- $<|v_{(r+1)}-v_r|^3>$

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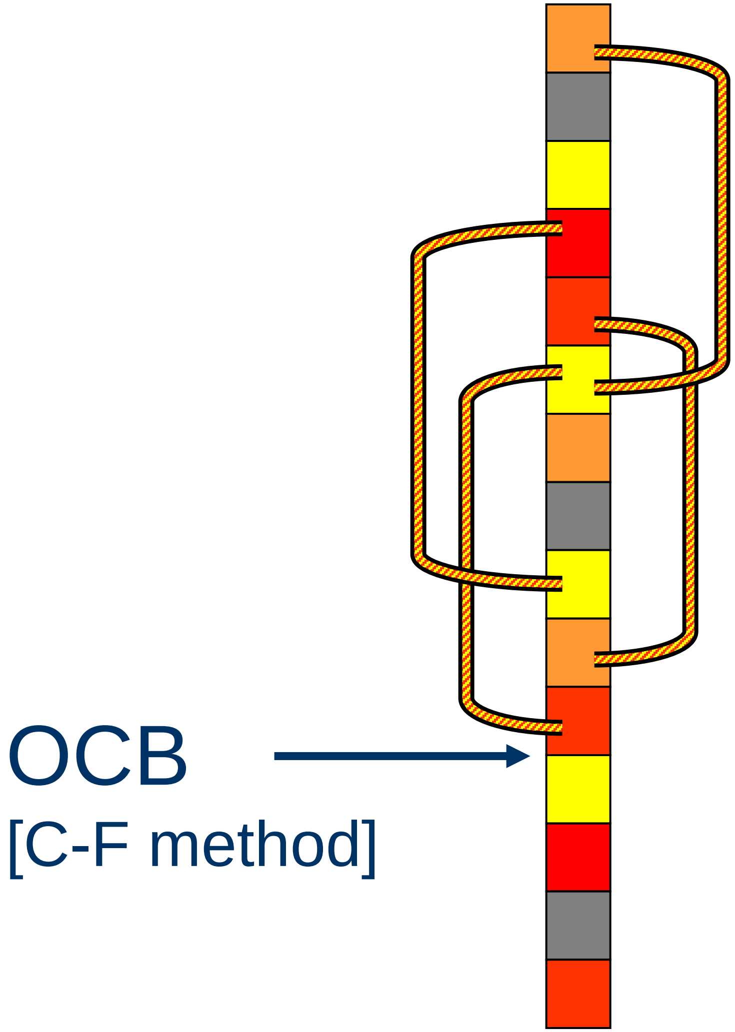
# Structure function analysis

Separation = 5

4 Pairs

Calculate –

- $\langle|v_{(r+1)}-v_r|\rangle$
- $\langle|v_{(r+1)}-v_r|^2\rangle$
- $\langle|v_{(r+1)}-v_r|^3\rangle$

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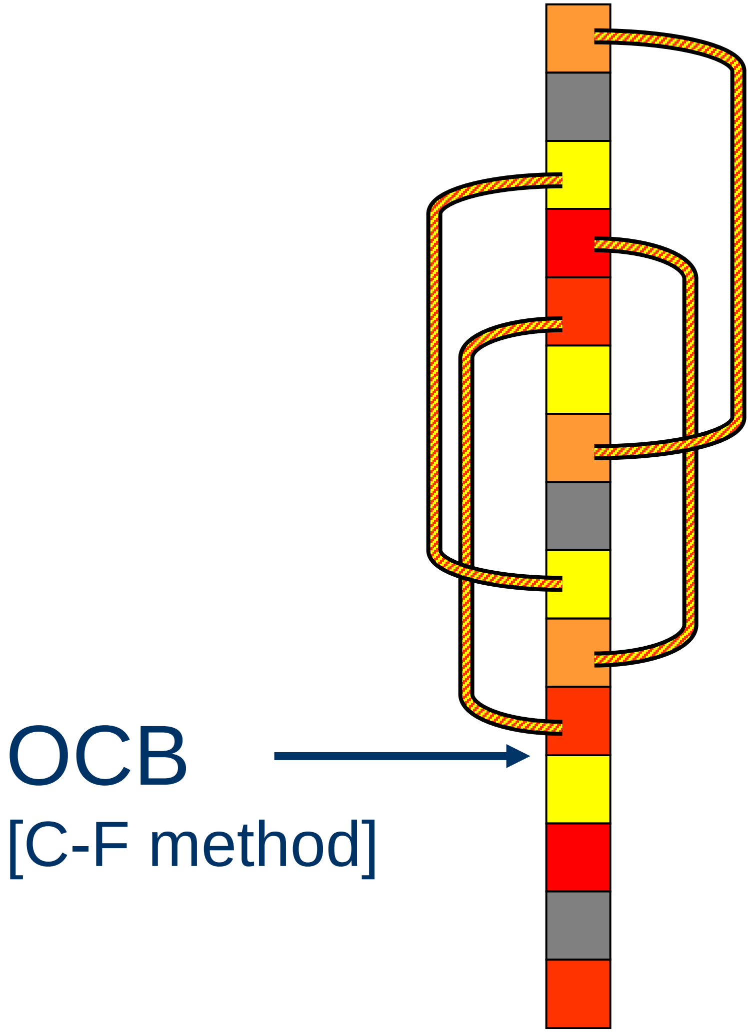
# Structure function analysis

Separation = 6

4 Pairs

Calculate –

- $\langle|v_{(r+1)}-v_r|\rangle$
- $\langle|v_{(r+1)}-v_r|^2\rangle$
- $\langle|v_{(r+1)}-v_r|^3\rangle$

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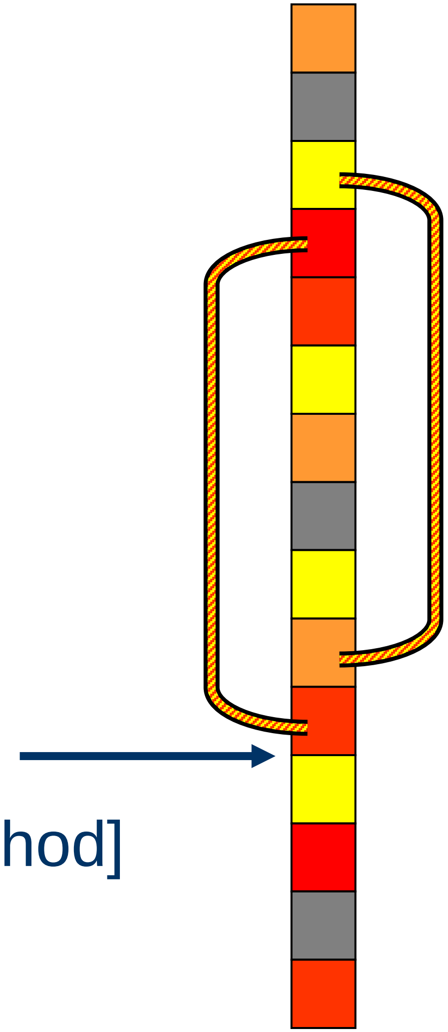
# Structure function analysis

Separation = 7

2 Pairs

Calculate –

- $<|v_{(r+1)}-v_r|>$
- $<|v_{(r+1)}-v_r|^2>$
- $<|v_{(r+1)}-v_r|^3>$



OCB

[C-F method]

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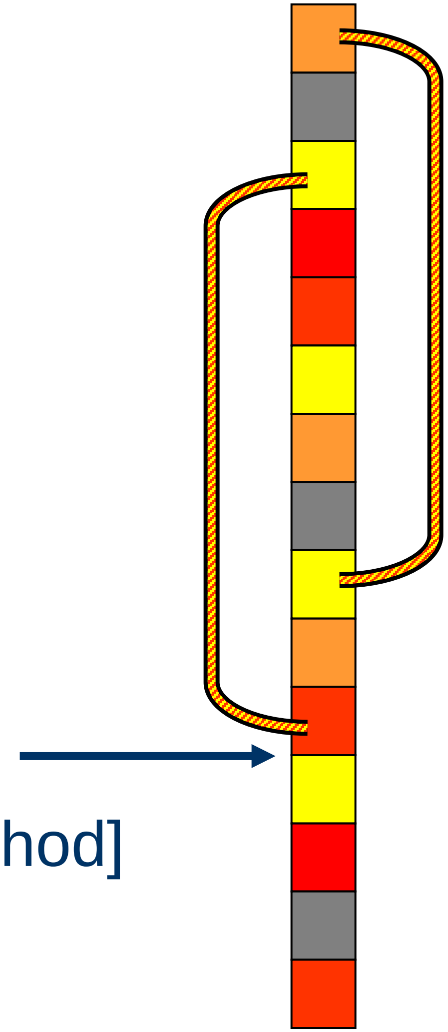
# Structure function analysis

Separation = 8

2 Pairs

Calculate –

- $\langle|v_{(r+1)}-v_r|\rangle$
- $\langle|v_{(r+1)}-v_r|^2\rangle$
- $\langle|v_{(r+1)}-v_r|^3\rangle$



OCB
[C-F method]

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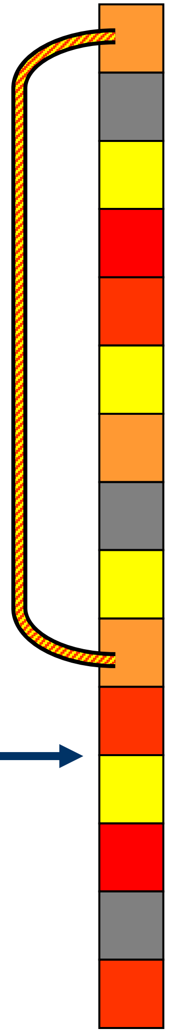
# Structure function analysis

Separation = 9

1 Pair

Calculate –

- $\langle |v_{(r+1)}-v_r| \rangle$
- $\langle |v_{(r+1)}-v_r|^2 \rangle$
- $\langle |v_{(r+1)}-v_r|^3 \rangle$



OCB
[C-F method]

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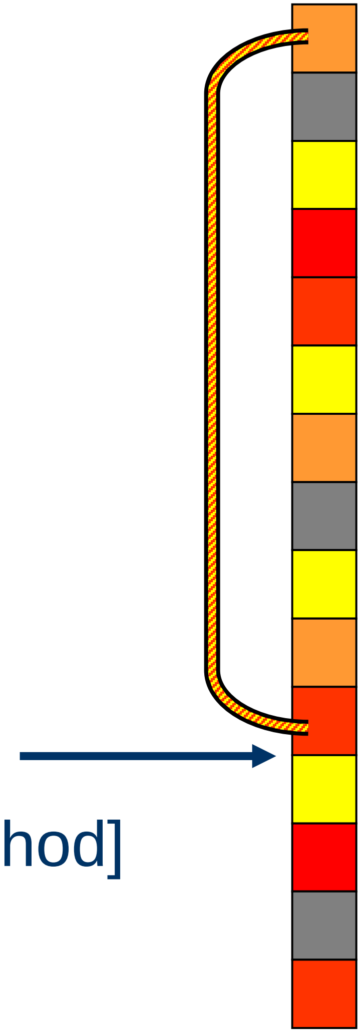
# Structure function analysis

Separation = 10

1 Pair

Calculate –

- $\langle |v_{(r+1)}-v_r| \rangle$
- $\langle |v_{(r+1)}-v_r|^2 \rangle$
- $\langle |v_{(r+1)}-v_r|^3 \rangle$



OCB

[C-F method]

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# Observed Spatial Structure

- Power-law regions seen in 3 out of 4 regions (where statistics are best)
- Different exponents seen poleward and equatorward of OCB
- Similar exponents seen poleward of OCB on day and nightside.
- These are similar to value of 0.32 found for  in solar wind by **Hnat et al., JGR, [2005]**
- Indicates different origin of scale free behaviour in different regions

**[Abel et al., GRL, 2006]**

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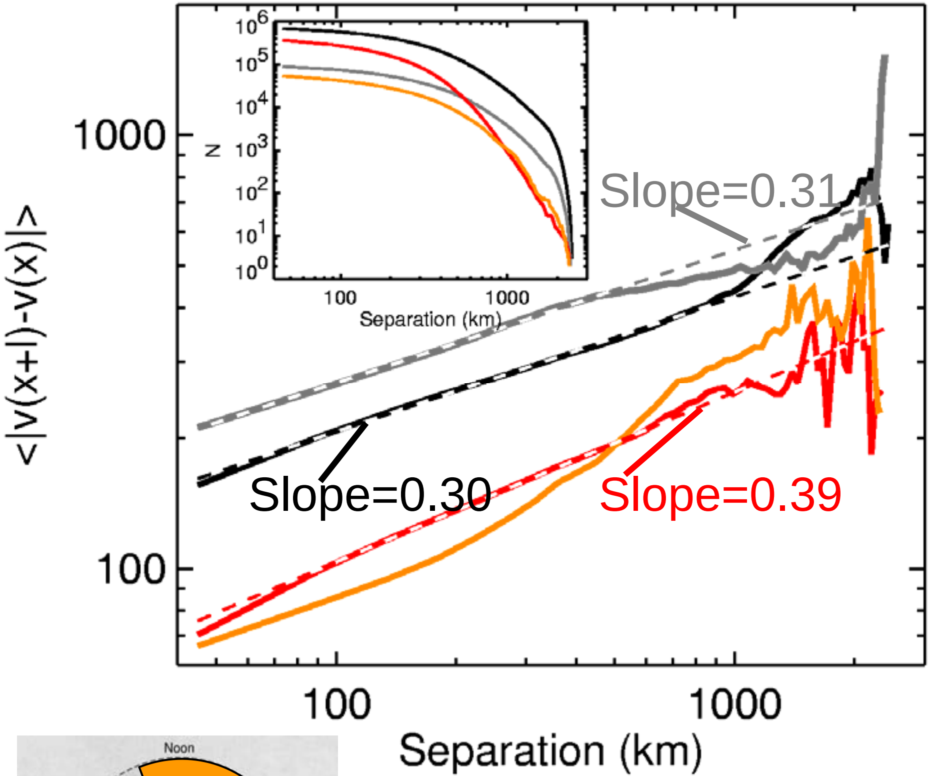
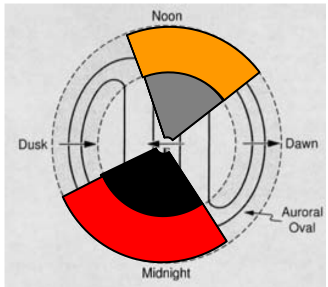



To Sun

# Comparison with turbulence models

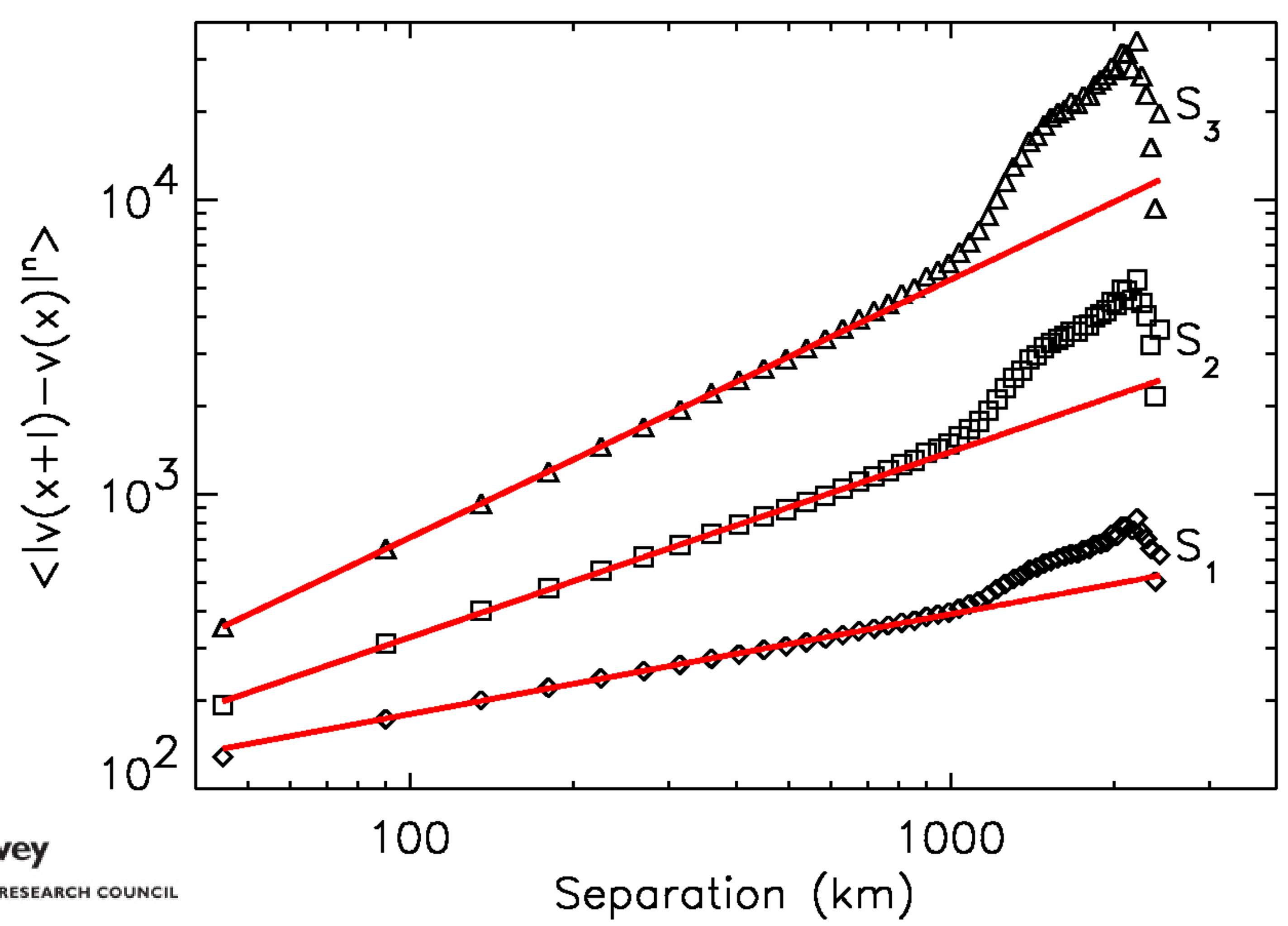
- Values of $\zeta_1$=0.3 and 0.31 on open field lines close to 1/3 predicted for Kolmogorov (K41) turbulence
- Classic Kolmogorov (K41) theory developed from Navier-Stokes equations for hydrodynamic turbulence
  - $\zeta_n = n/3$
- Starting with Magnetohydrodynamic (MHD) equations leads to Kraichnan-Irosnikov (KI65) turbulence
  - $\zeta_n = \mathrm{n}/4$
- K41 and KI65 are mono-fractal models with Guassian fluctuations. Intermittency introduces non-Gaussian fluctuations and implies a multi-fractal
  - We also test 3 multi-fractal models

# Turbulence Models

| | K41 | KI65 |
|---|---|---|
| Classic | $\zeta_n = n/3$ | $\zeta_n = n/4$ |
| P-model | $\zeta_n = 1 - \log_2\left(p^{n/3} + (1-p)^{n/3}\right)$ | $\zeta_n = 1 - \log_2\left(p^{n/4} + (1-p)^{n/4}\right)$ |
| Log-normal | $\zeta_n = \frac{n}{3} + \frac{\mu}{18}(3n - n^2)$ | $\zeta_n = \frac{n}{4} + x(4n - n^2)$ |
| g-infinity | $\zeta_n = \frac{g(\infty)n}{3g(\infty) - 3 + n}$ | $\zeta_n = \frac{g(\infty)n}{4g(\infty) - 4 + n}$ |

# Analysis of conditioned data

- $\zeta_1$=0.34
- $\zeta_2$=0.63
- $\zeta_3$=0.88

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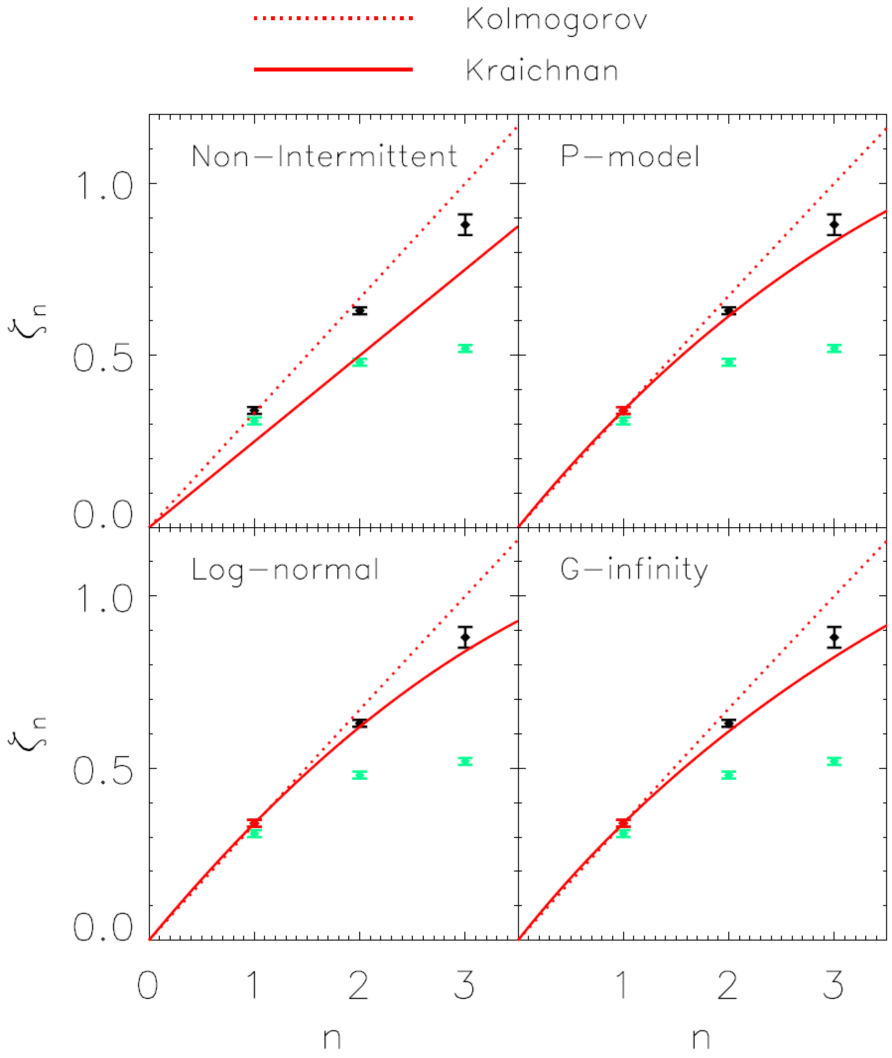
# Comparison with turbulence models

- Model free parameters determined from $\zeta_1$
- Kolmogorov type models close to non-intermittent and give good fit to $\zeta_1$, and $\zeta_2$
- Intermittent Kraichnan type models give better fit to $\zeta_1$, $\zeta_2$ and $\zeta_3$ - log-normal best fit

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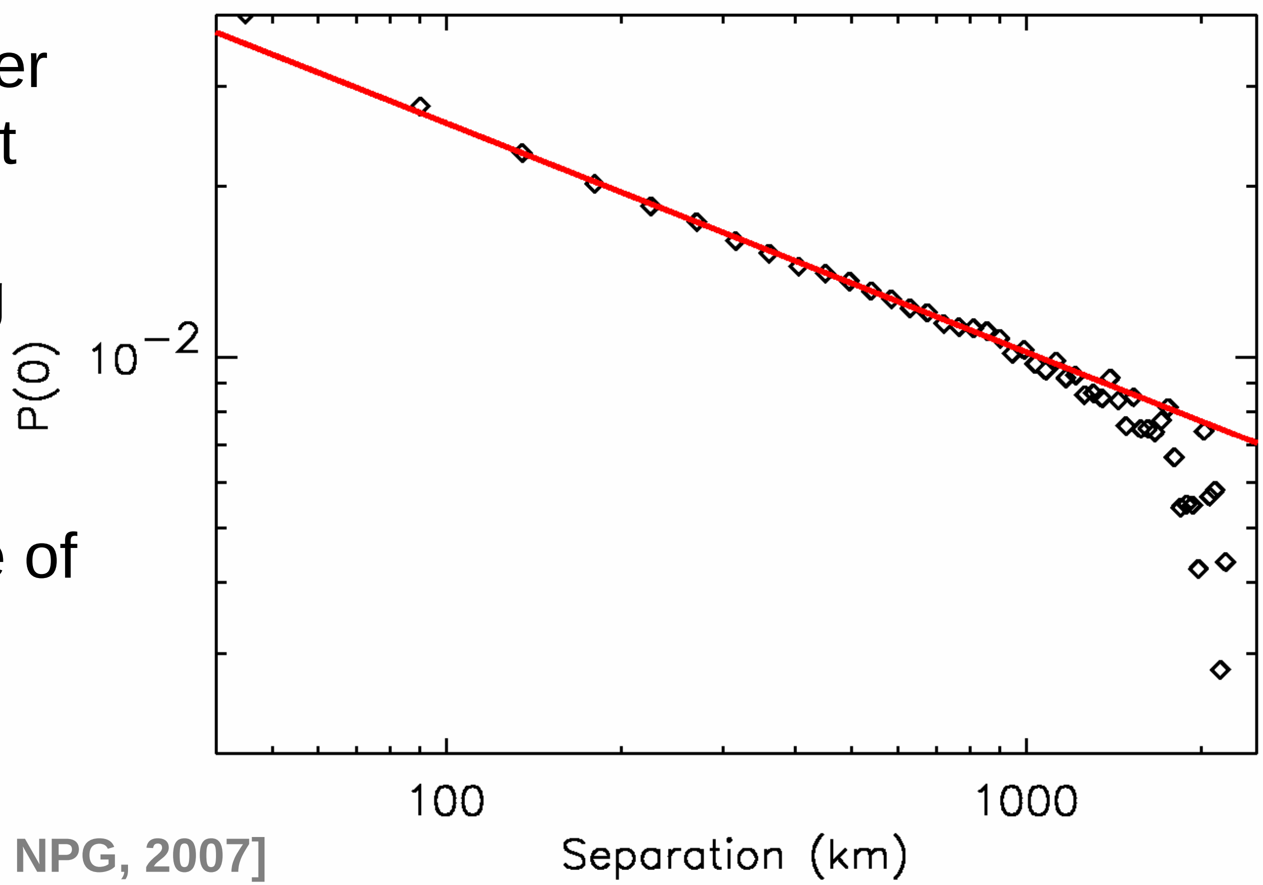
# *P(0)* Scaling

- We can get further information about the intermittency from *P(0)* scaling
- Exponent is 0.4 while $\zeta_1$=0.34
- Implies presence of intermittency




[Abel et al., NPG, 2007]

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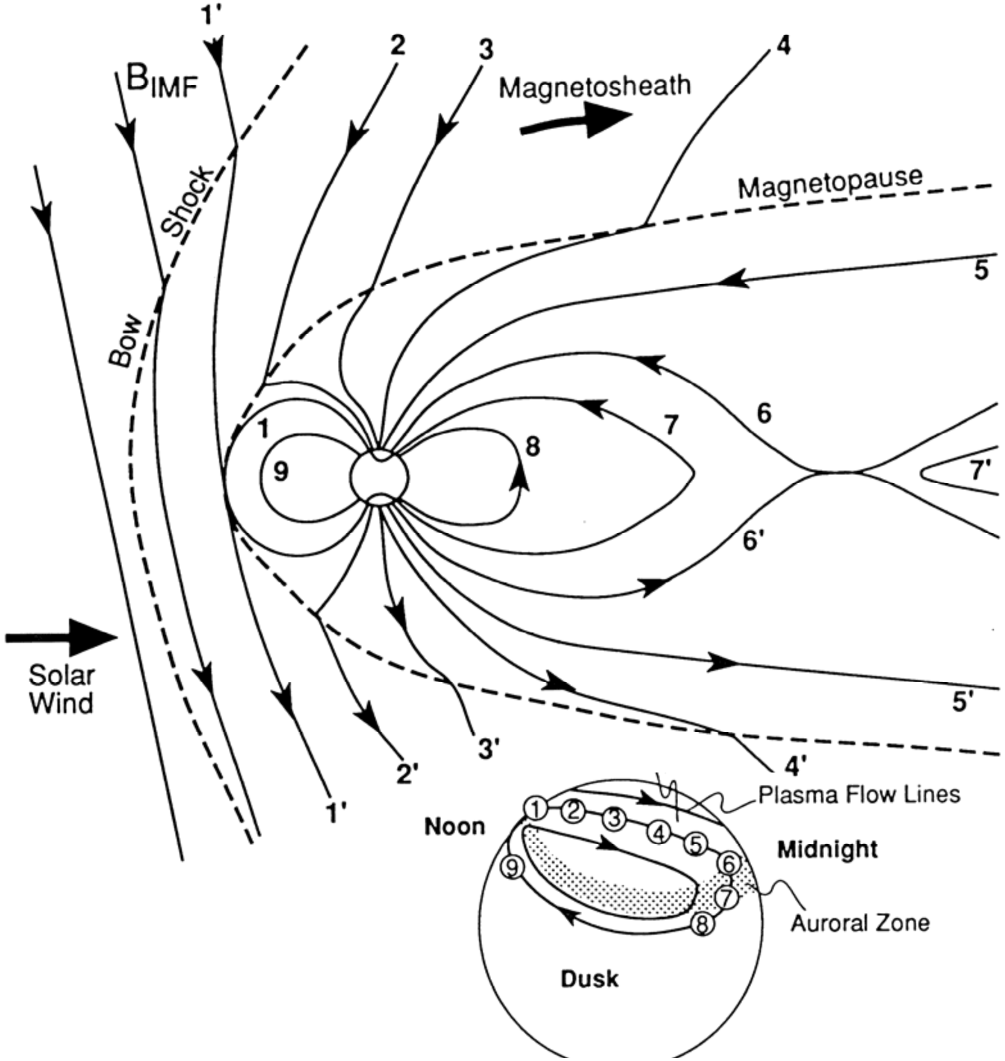
# Does IMF clock angle matter?

- Under southward IMF conditions reconnection at the dayside magnetopause allows solar wind to drive the polar ionosphere.
- Under northward IMF conditions this driving effectively stops.
- How does this affect turbulence?

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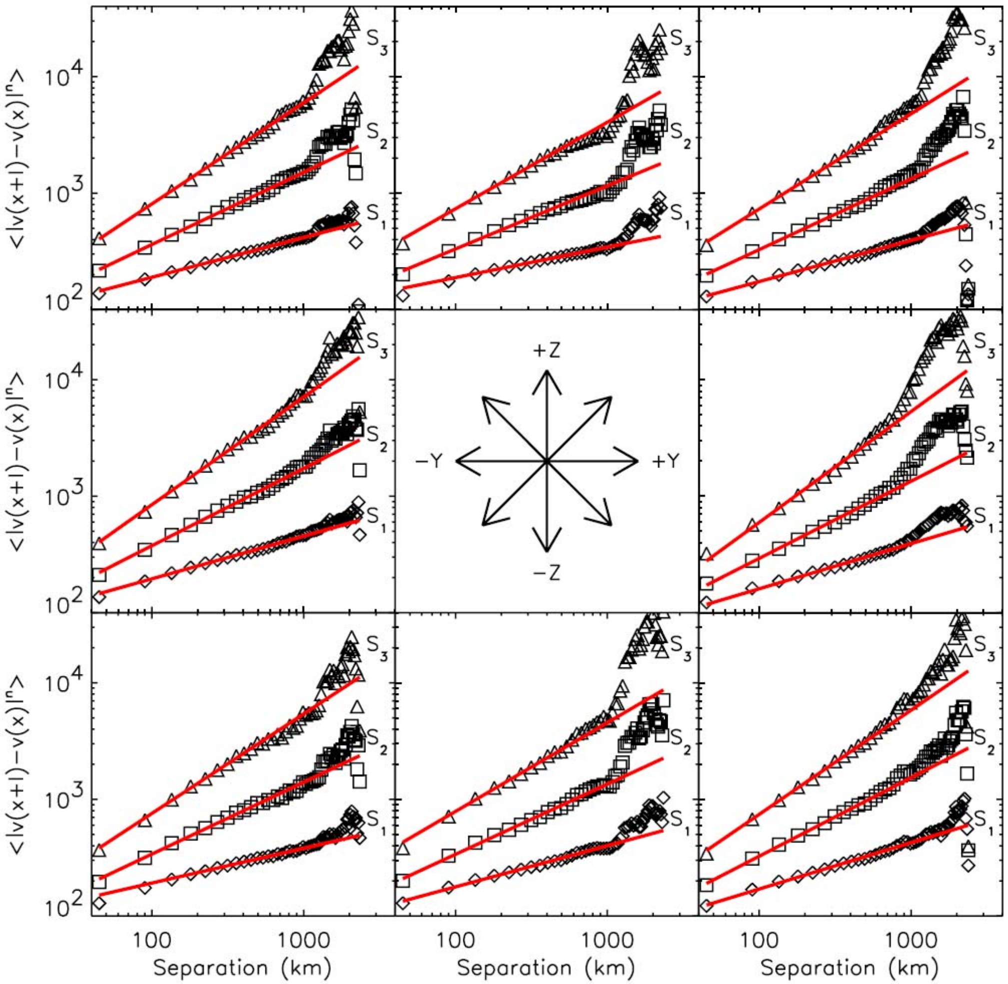
# Results

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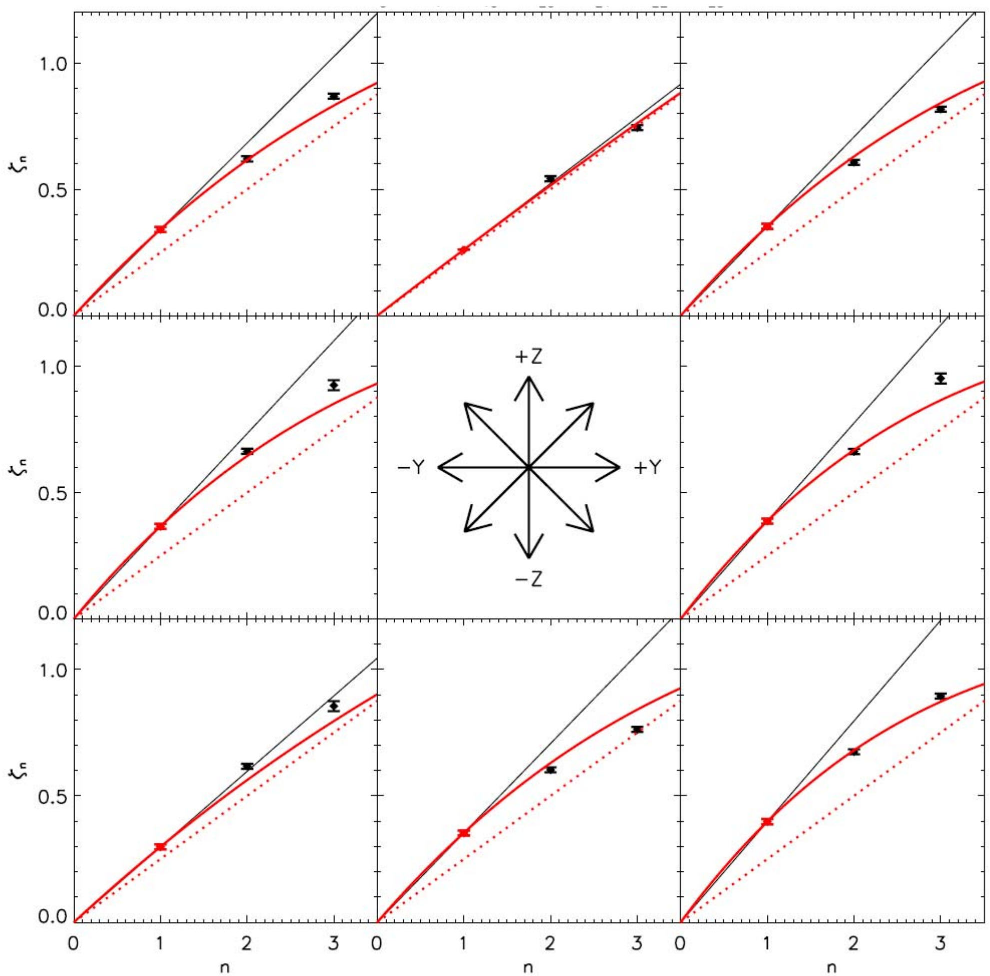
# Results

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# Why?

- Intermittency inherited from solar wind
  - When driven we see intermittent turbulence
  - When not driven we see “classic” turbulence
- Intermittency evolves away over time
  - long field line between ionosphere and solar wind
  - Ionosphere has time to evolve since being driven
- Intermittency asymmetric relative to flow
  - When driven we are looking mainly along the flow direction
  - When not driven no dominant flow direction present

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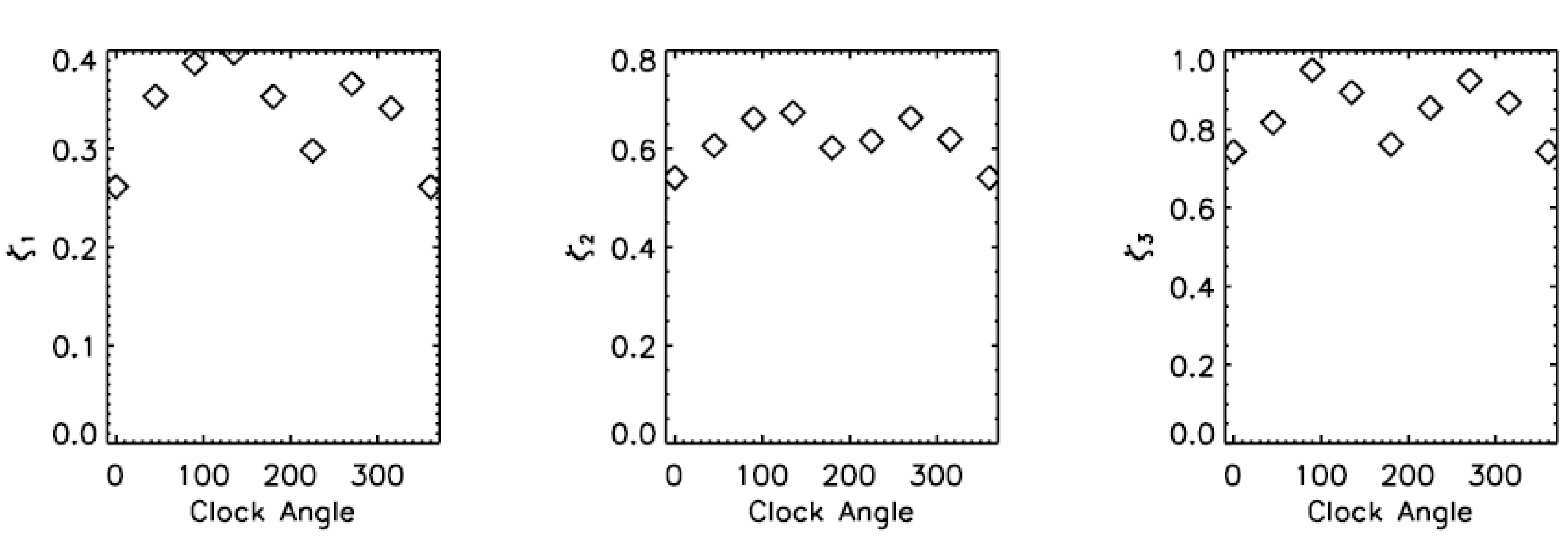
# Results

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