IMPROVED MEASUREMENTS OF THE SUN'S MERIDIONAL FLOW AND TORSIONAL OSCILLATION FROM CORRELATION TRACKING ON MDI & HMI MAGNETOGRAMS

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Correction for Systematic Offset

1. Assume that the systematic shift, Δ_s, is the same (in m) for all time-lags
2. Assume that the meridional flow speed, **MF** has a baseline profile, **MF*(m/s)**, and time-lag dependent variation, δ(m/s/hr)*time-lag.

Constant error (m)
[DRsyst, Mfsyst]

shift @1^h $\Delta_1(x,y) = (\mathbf{MF(\theta,\phi)}^* + 1\delta(x,y))*1^h + \Delta_s(x,y)$

shift @2^h $\Delta_2 = (\mathbf{MF}^* + 2\delta)*2^h + \Delta_s$

shift @4^h $\Delta_4 = (\mathbf{MF}^* + 4\delta)*4^h + \Delta_s$

Time-lag dependency (m/s/hr)
[deltaDR, deltaMF]

$\delta_{1\text{-}2\text{-}4} = (\Delta_4 - 3\Delta_2 + 2\Delta_1)/6$

$\delta_{2\text{-}4\text{-}8} = (\Delta_8 - 3\Delta_4 + 2\Delta_2)/24$

$\delta_{4\text{-}8\text{-}16} = (\Delta_{16} - 3\Delta_8 + 2\Delta_4)/96$

Baseline flow (m/s)
[BaseDR, BaseMF]

$\mathbf{MF}^*_{1\text{-}2} = (\Delta_2 - \Delta_1)/1 - 3\delta$

$\mathbf{MF}^*_{2\text{-}4} = (\Delta_4 - \Delta_2)/2 - 6\delta$

$\mathbf{MF}^*_{4\text{-}8} = (\Delta_8 - \Delta_4)/4 - 12\delta$

Data Products

- Lev 0` (MDI/HMI) : Raw data

  Correlation arrays for every block(lat, lon*) for every magnetogram (@ hourly cadence)

- Lev 1` (MDI/HMI) : Carrington Rotation Averages

  Carrington Rotation averages of Lev 0

- Lev 2` (MDI/HMI) : Shift decomposition into flow + systematics

  Flows** and systematics in physical units (m, m/s, m/s/hr)

- Lev 3 (combined) : MDI-HMI measurements stacked + calibrated
- Lev 4 (combined) : Legendre fitting coefficients to baseline DR & MF

*All longitudes are Stonyhurst longitudes

**Differential Rotation is in the Carrington Frame of reference

` These lower-level data products are not published, but are available upon request

Data Format (Level 0)

- FeatureMotion***.text: v (Lat, Long, every magnetogram @hourly cadence)

Lat = Latitude (degrees) of first block center

Long = Longitude (degrees) of first block center

x(im) = Horizontal location of block center in disk radius

y(im) = Vertical location of block center in disk radius

DR(fwd) = Horizontal shift detected in number of projected pixels forward in time

MF(fwd) = Vertical shift detected in number of projected pixels forward in time

corr(fwd) = Correlation coefficient of forward shift detection

DR(bkw) = Horizontal shift detected in number of projected pixels backward in time

MF(bkw) = Vertical shift detected in number of projected pixels backward in time

corr(bkw) = Correlation coefficient of backward shift detection

pixels(fwd) = Number of pixels masked in correlation for forward shift detection

pixels(bkw) = Number of masked pixels in correlation for backward shift detection

mask(v1) = Number of pixels that are masked in the reference block

tot(v1) = Total number of pixels in the reference block

- Corrarray, Corrcount: matrices of blocksize give the sum of the correlation array for a particular block. (Optional output)

Data Format (Level 1)

- Carrington Rotation averages of detected shift for every block (lat, long, CR)
- Values beyond 2 sigma filtered out
- Shifts in blocks with less than 100 data points ignored (to avoid small scale statistical errors)

Contents:
Lat, Long, meanDR, errorDR, median DR, meanMF, errorMF, medianMF, medianRcorr, Npoints

Shifts are in units of projected pixel size.

Data Format (Level 2)

- Shifts decomposed into baseline flow and systematic errors for every block (lat, long) for every CR
- All measurements in physical units: m, m/s, m/s/hr
- DR is in Carrington Frame of reference

Contents:
Lat, Long, baseDR, error_baseDR, drsyst, error_drsyst, deltaDR, error_deltaDR, baseMF, error_baseMF, Mfsyst, error_Mfsyst, deltaMF, error_deltaMF

Data Format (Level 3)

- Level 2 measurements from MDI-HMI stacked together in time (calibration details in the published paper)
- Longitudinal average of Level 2 measurements (lat, time)
- Units: m, m/s, m/s/hr

- info.lat.txt marks the latitude gridpoints processed for Carrington rotations in info.CR.txt (1909 to 2232).
- Basemf and error_basemf contain the corrected baseline meridional flow information while basedr and error_basedr contain the corrected baseline rotation rate in the Carrington frame. Unit: m/s.
- MFsyst and DRsyst contain the constant shift error Δ. Unit: meters.
- deltamf and deltadr contain the time-lag dependency parameter δ. Unit: m/s/hr.
- The associated error estimates are included in the same units.

Data Format (Level 4)

- coeff_mf.txt and error_coeff_mf.txt have the Legendre fitting coefficients and the fitting uncertainties respectively for the corrected baseline meridional flow on the same latitude-time grid as Level 3 flow profiles.
- Similar coefficients for solar rotation rate are in coeff_dr.txt and error_coeff_dr.txt.
- These are the coefficients of associated Legendre polynomials with order 1 and degrees 1 to 6 calculated as a function of time. The associated Legendre Polynomials are:

x =sind(info.lat(:,1)); x2=cosd(info.lat(:,1));

- p1 = x2;
- p2 = 2*x.*x2;
- p3 = .726*(5*x.^2-1).*x2 ;
- p4 = 1*(7*x.^3-3*x).*x2 ;
- p5 = .583*(21*x.^4-14*x.^2 +1).*x2 ;
- p6 = .842*(33*x.^5 - 30*x.^3 + 5*x).*x2 ;