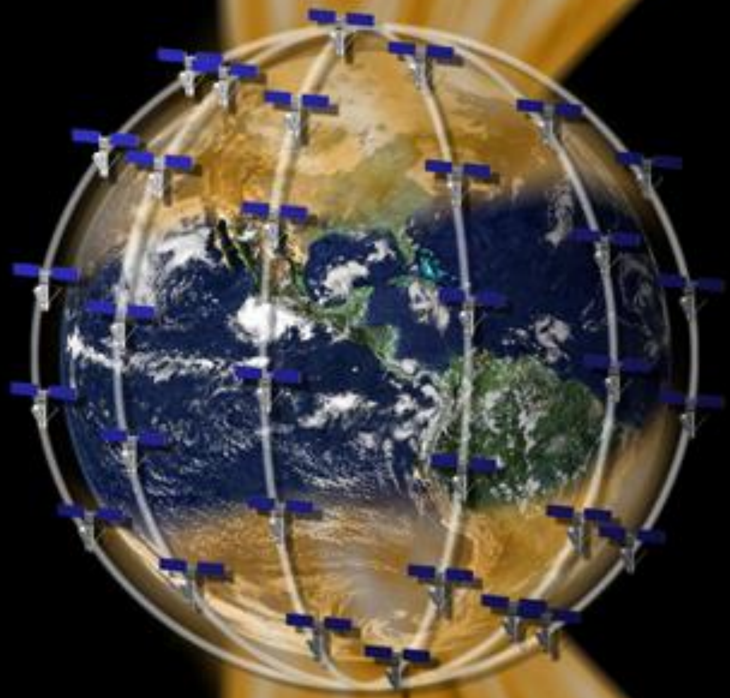
AMPERE



Active
Magnetosphere and
Planetary
Electrodynamics
Response
Experiment

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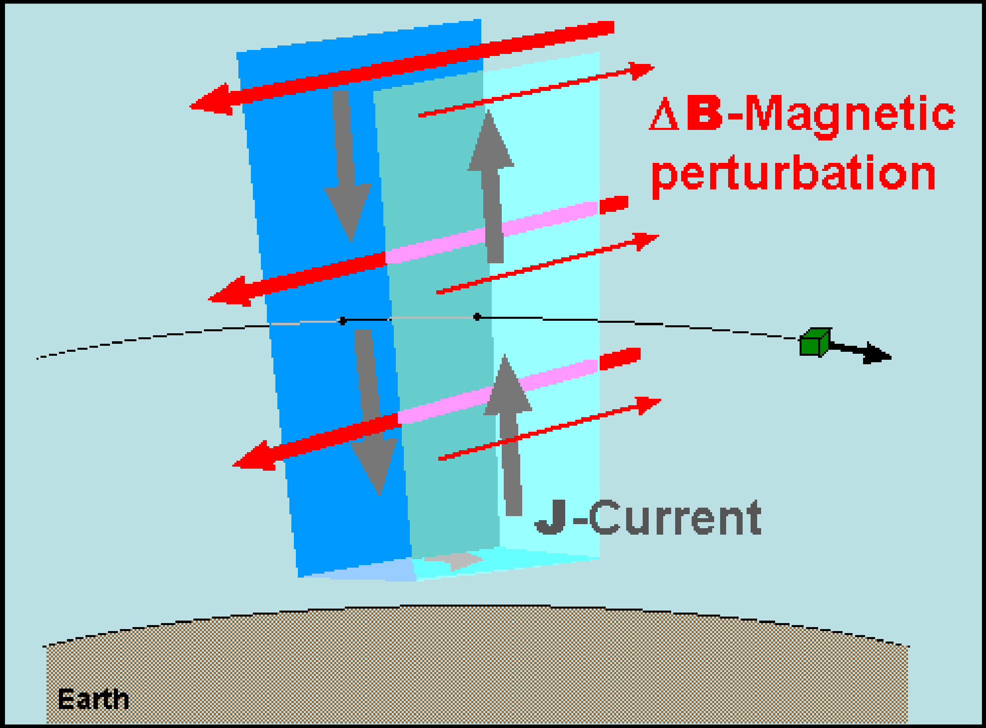
The Johns Hopkins University Applied Physics Laboratory

Jeremy Anderson

Birkeland Current ΔB signatures



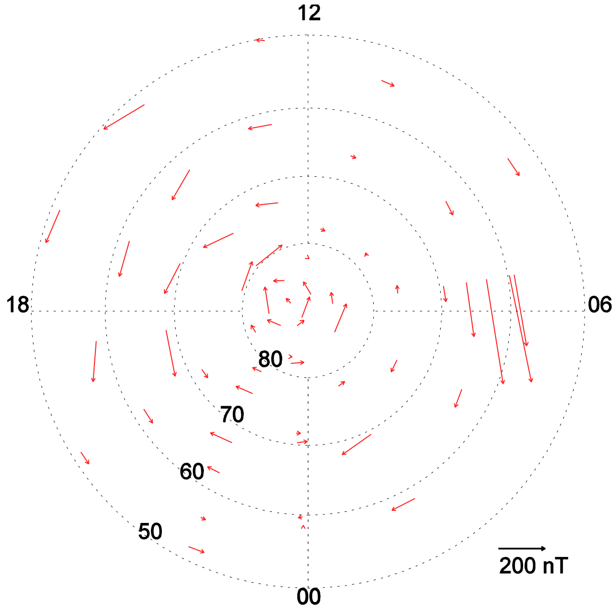
- LEO satellites pass through the Birkeland currents
- Magnetic perturbations are present primarily between sheets of current
- Ionospheric currents shield signatures below

Data Acquisition Implemented

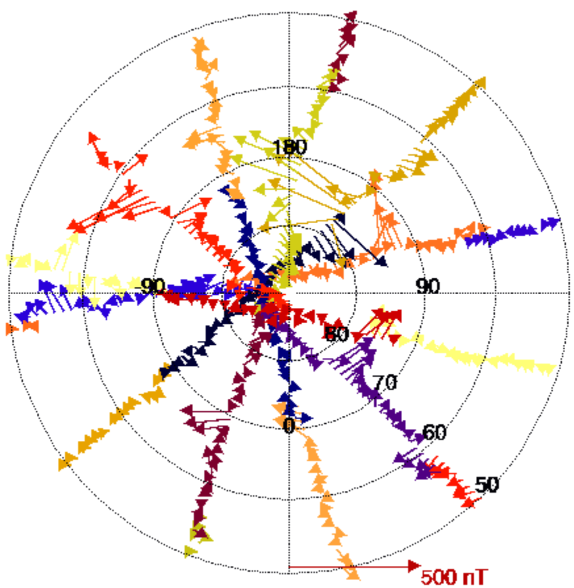
Side-by-side comparison of data acquired in 10 minutes	Old:	~200 s/sample
Standard AMPERE: complete coverage with ~1° lat. res.		19.4 s/sample
High rate AMPERE: ~ 0.1° lat. res.		2.16 s/sample

Old Data | **AMPERE: Standard** | **AMPERE: High**

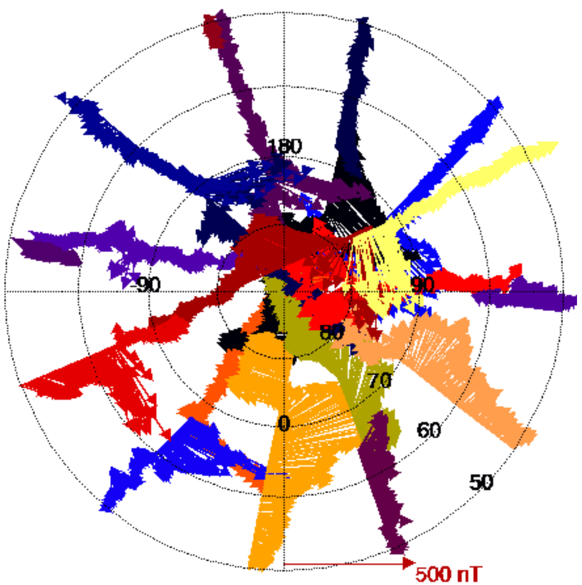
10/01/2002 11:55-12:05



11/25/2009 08:45-08:55



11/24/2009 18:27-18:37

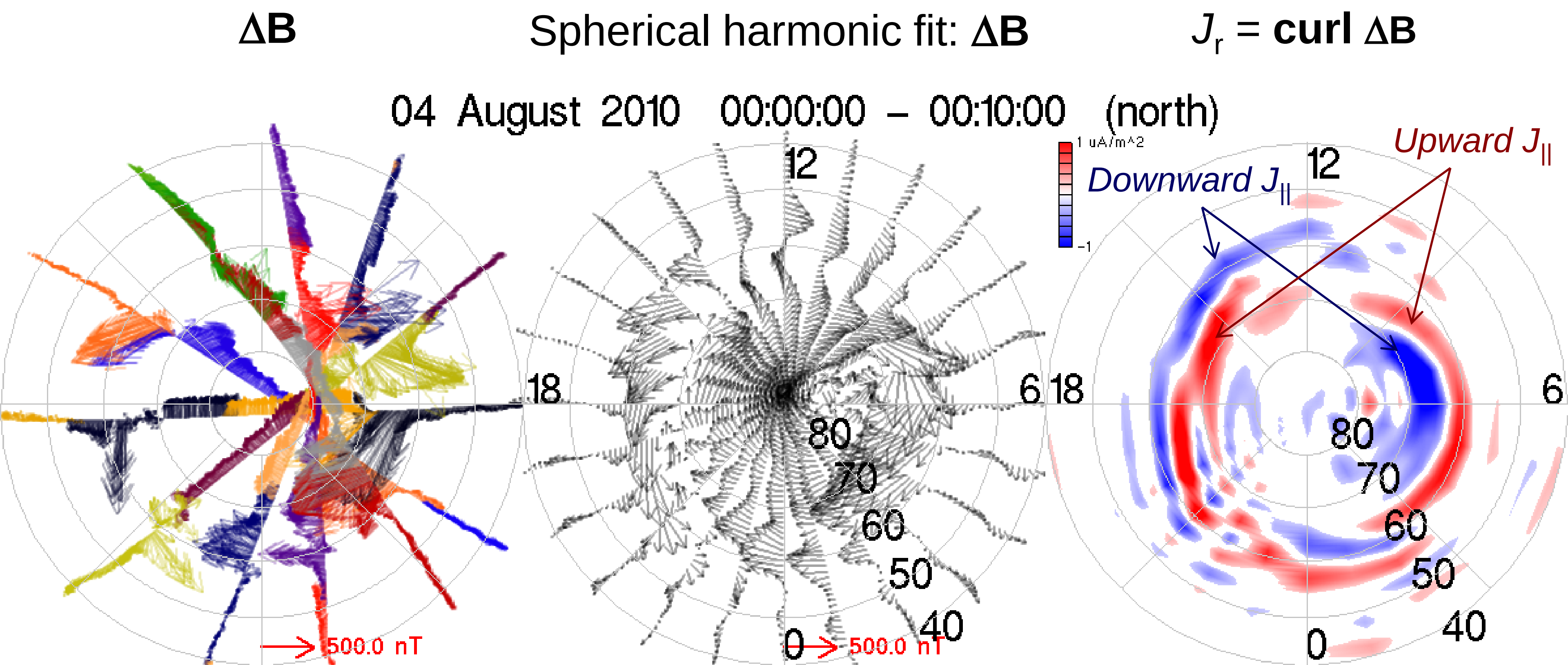


TLM data from all satellites

Different colors denote different satellites

Analysis for ΔB, J_r

- Vector **ΔB**, data, continuous **ΔB** map via SH fit
- J_r from Ampere's law applied to horizontal **ΔB**
- Time cadence: 9 min set by inter-spacecraft separation
- Lat res: 1.15˚ for 19.44s sampling, 0.13˚ for 2.16s sampling



Pre-processing Stages

Read initial hourly files

Spline and filter SC attitude

Rotate IGRF into SC coordinates

Cross calibrate against IGRF: scale factorsLinear regression
$\Delta B_j = a_j + \Sigma c_i * B_i$

Subtract IGRF and Patch model

Fill in data gaps

Filter: T< 120 minutes

Produce Daily files for Final processing

Produce initial survey plots

Step we didn't expect. Only evident in AMPERE data

Since we are only interested in Δ**B,** the accuracy of IGRF is not critical for this

Requires additional analysis using quiet-day data

Identifying gaps and intelligently 'splicing' automatically is not trivial

Eliminating the need for this step is our next big task

Raw data: B_{meas}

Initial main field residuals dB errors ~ 1%

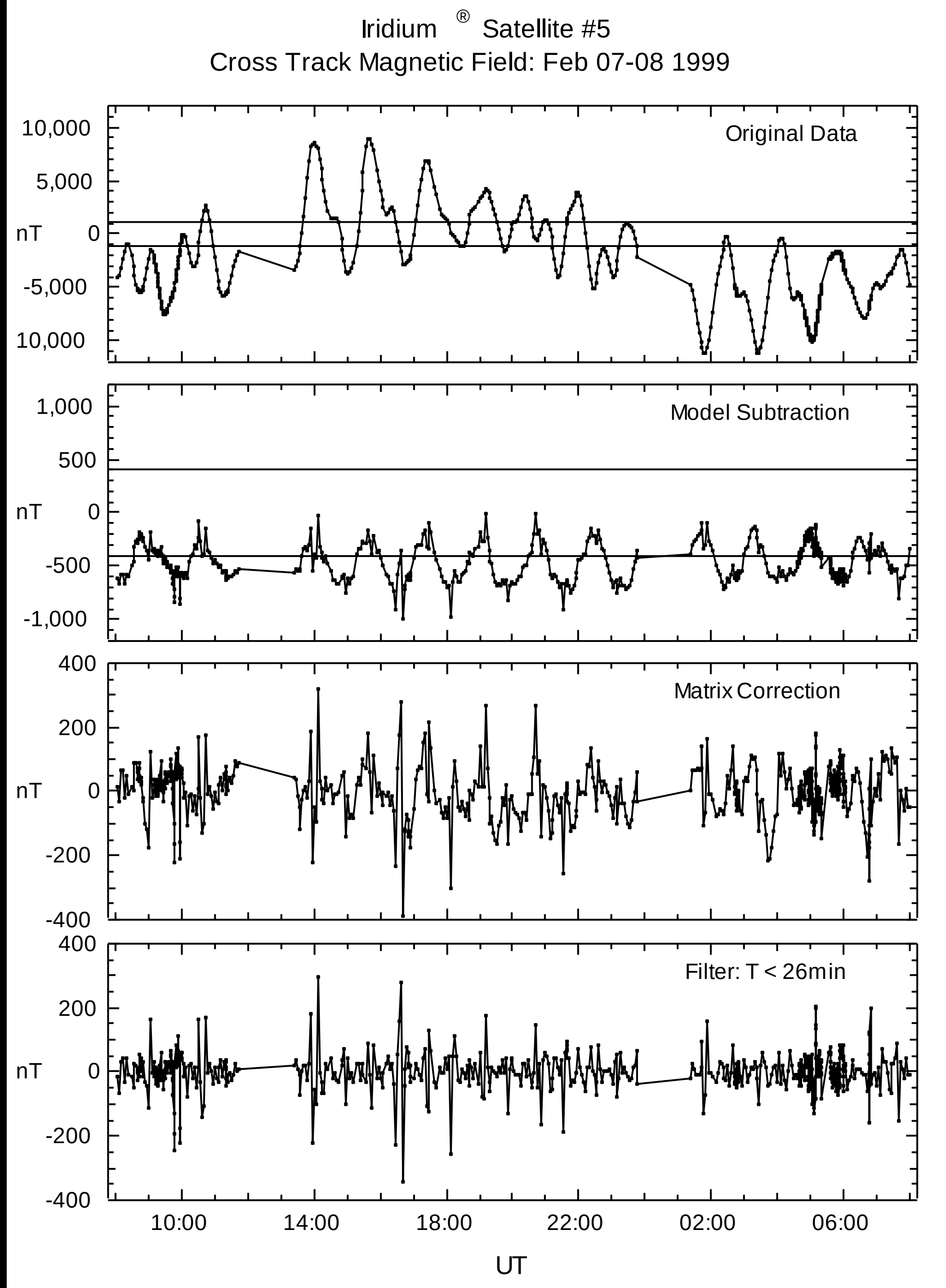
Gain & mag orientation corrections:

dB_{cor} errors ~ 0.4%

Attitude corrections:

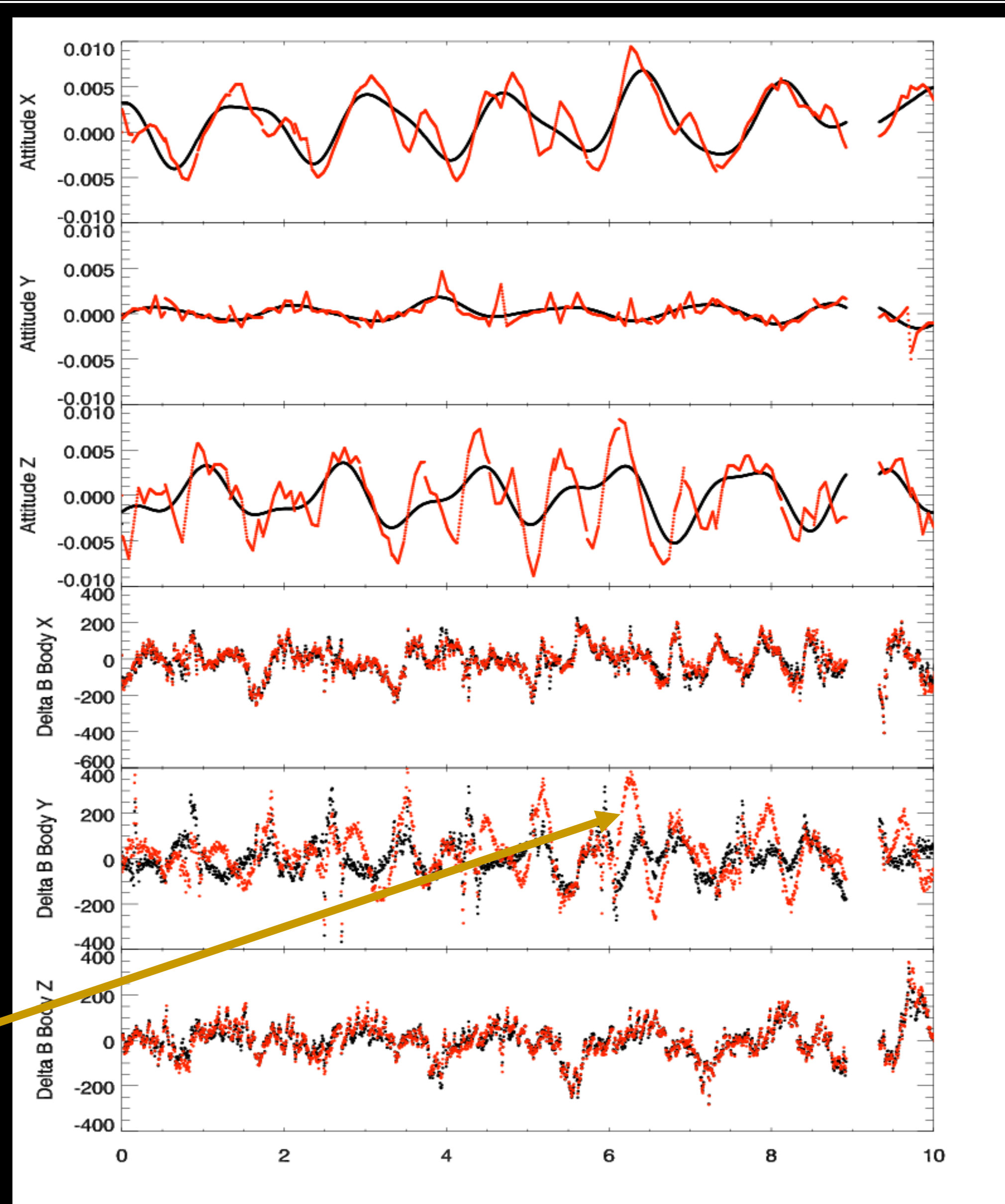
dB_{cor} errors ~ 0.05%

Comparable to 30 nT (12-bit) resolution.



Attitude Data Conditioning

- As-delivered attitude data is noisy and unevenly sampled in time.
- Requires generation of continuous time series filtered to minimize spurious magnetic residuals.

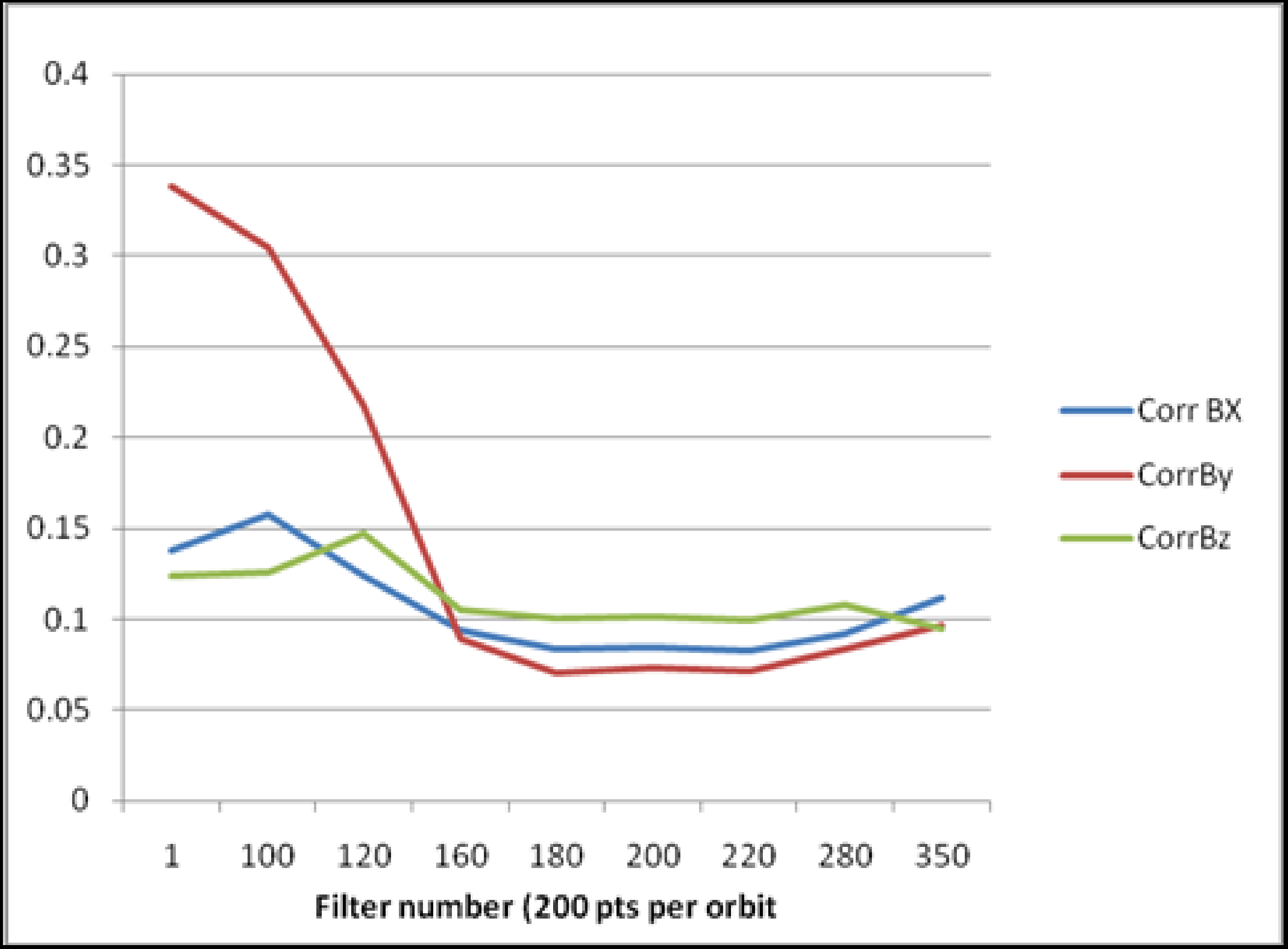


RED – Original attitude

BLACK– Splined and Filtered attitude

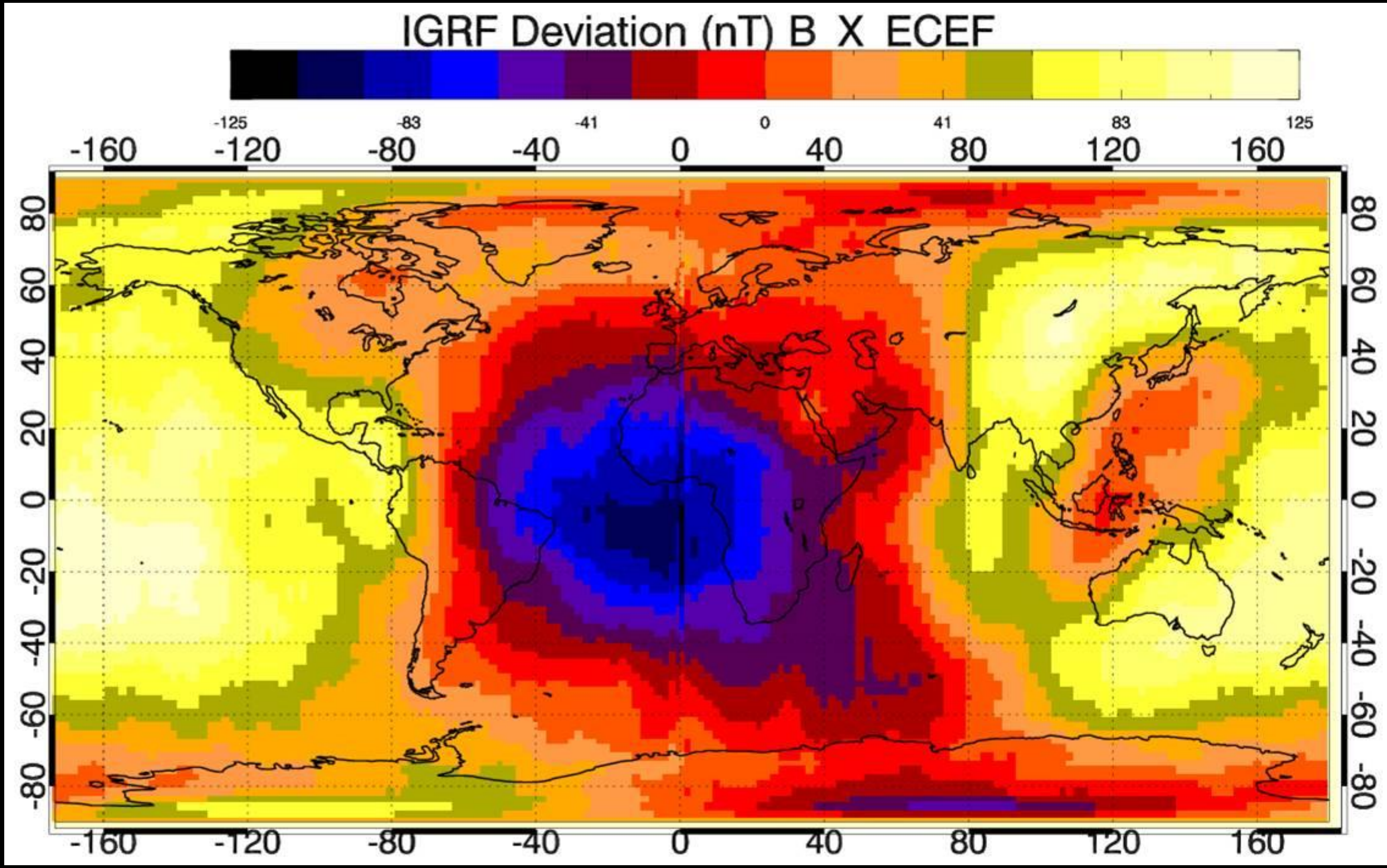
Note the reduction in residuals for the **By** component when using the filtered attitude.

Attitude Conditioning



- Attitude data conditioning filter determined by reducing correlation between attitude and magnetic residuals.

Main Field Adjustment



- Capability to adjust IGRF implemented and needed.
- Yields correction to <10 nT with a few days of AMPERE quiet-time data.

Inversion Steps: Cap Inversions

- Data Preparation:
  - For each 10 minute segment N and S separately
  - Sort by track and by slot within each track.
  - Convert to AACGM, positions and vector data (two options since AACGM is not an orthonormal system).
  - Track overlap conditioning.
  - Nyquist condition checks and regularization.

- Basis Set Computation:
  - Must be orthonormal set: required for curl computation (fitting data using a re-defined polar angle in standard Y_l^m is not sufficient).
  - Given latitude range, latitude order and longitude order: compute cap inversion basis functions.
  - Non-integral Legendre functions derived from series of hypergeometric functions).

- Design Matrix Inversion
  - Compute design matrix convolution of cap functions and measurement locations.
  - Matrix inversion.
  - Gridded output: dB, Jr and uncertainties.

Formal Inversion Problem

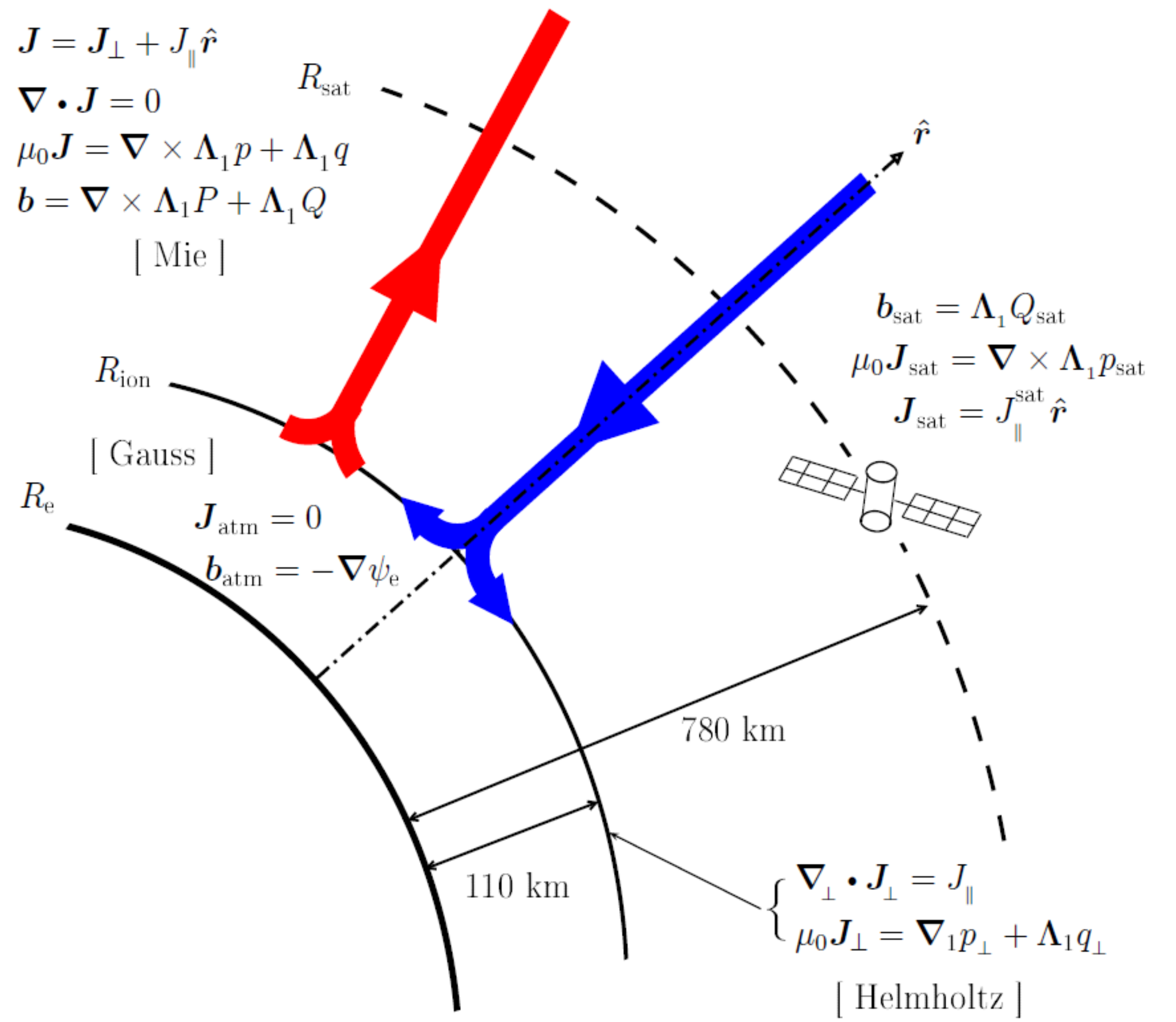
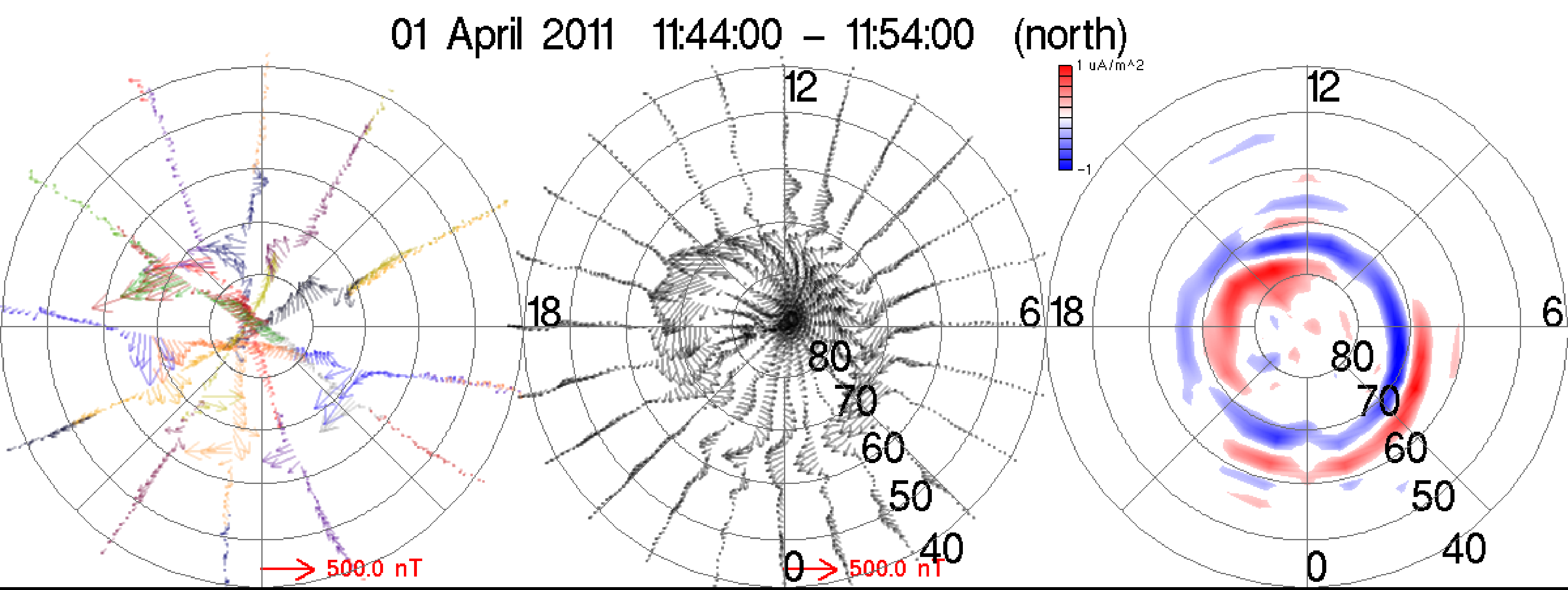


Fig. 1 Magnetic fields and currents and relevant mathematics below, in and above the ionosphere. The surface curl operator $\Lambda_1 = \mathbf{r} \times \nabla$ (Green 2006).

Full-Sphere Inversions

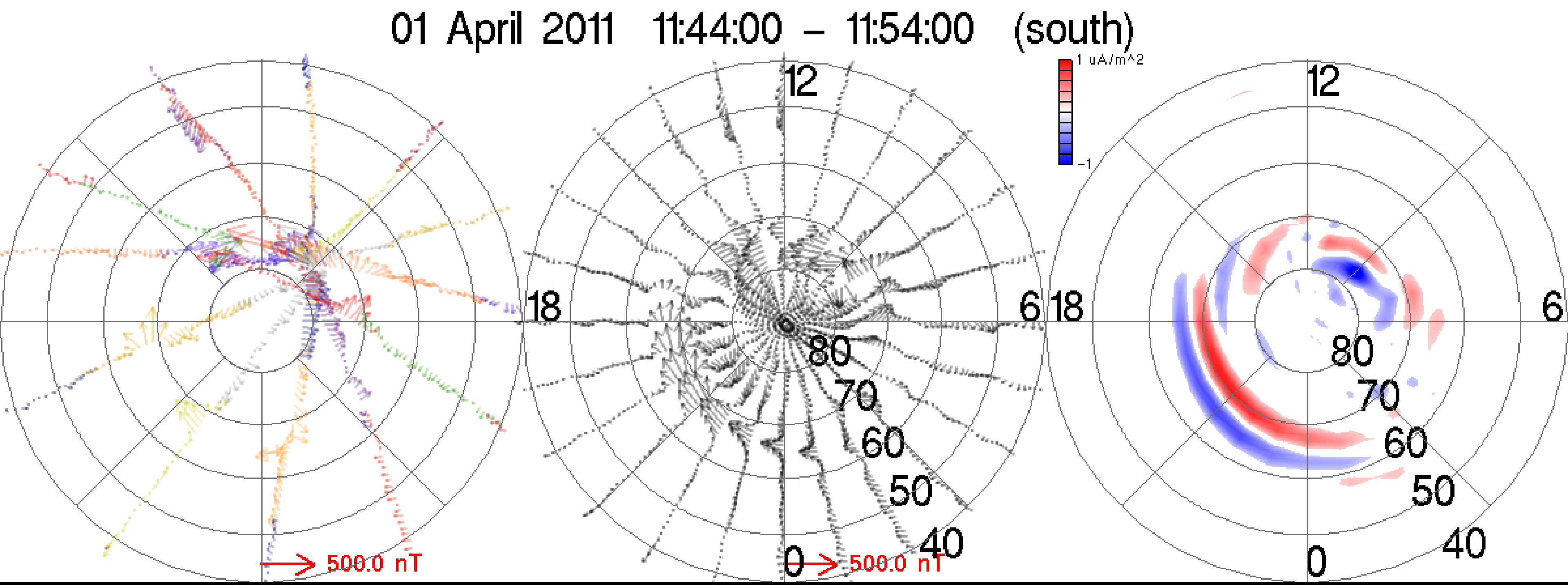
- Advantages: clear
  - Uses full coverage provided by Iridium orbits.
  - Fits northern and southern hemisphere in same inversion.
  - Direct application of integer spherical harmonic functions.
- Disadvantages: not obvious but serious
  - Fundamental disparity between basis functions and physical system – especially in southern hemisphere.
  - Disparity between latitude (<0.5º) and longitude (30º) resolution introduces severe artifacts.
  - Locked into origin given by orbit crossing point in both hemispheres: exacerbates both of these problems.

Full-Sphere Inversion (North)



- Orbit crossing point happens to nearly coincide with AACGM north pole.
- Inversion seems well behaved.

Full-Sphere Inversion (South)

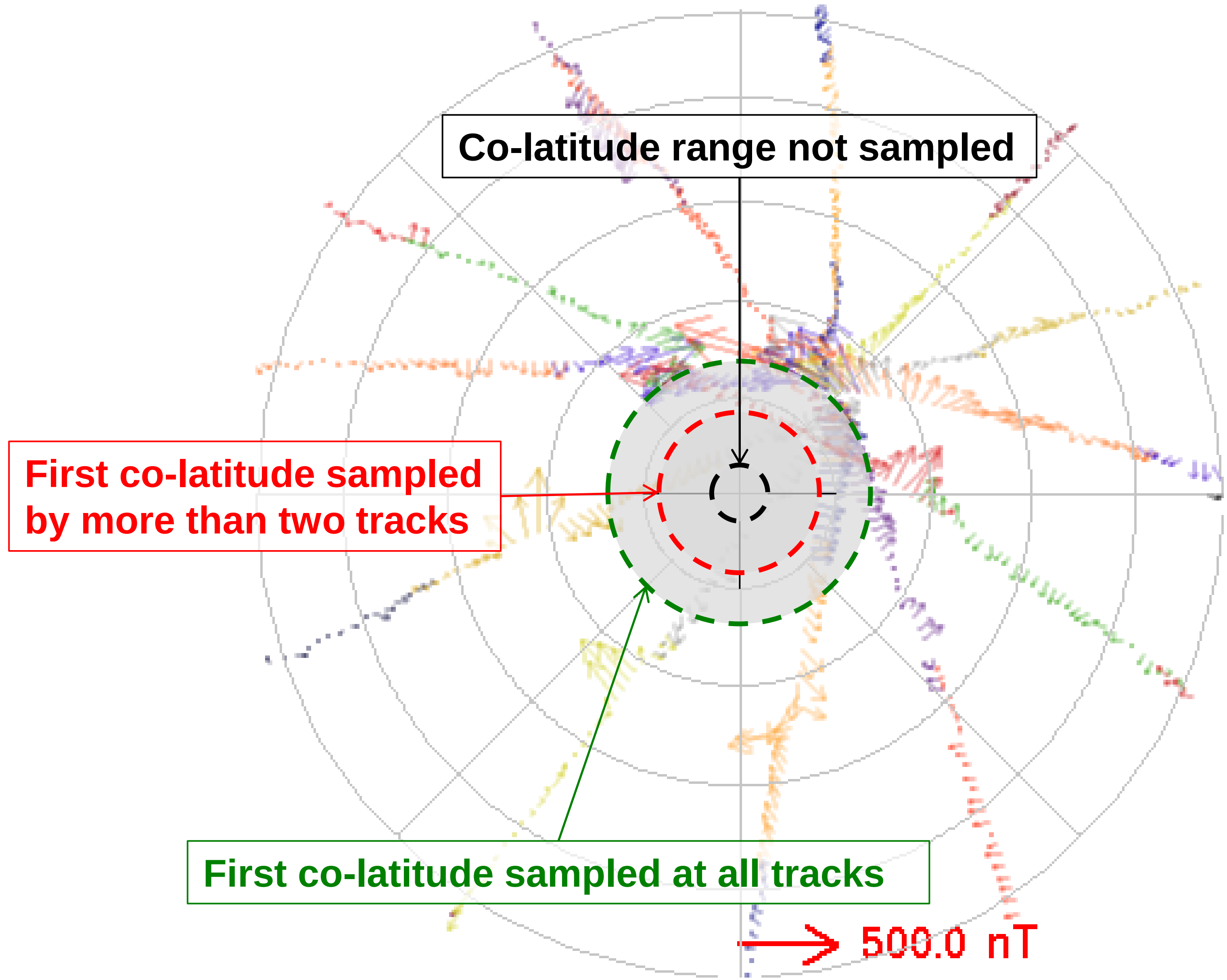


- In South the orbit crossing point is slightly equatorward of the currents.
- Basis functions cannot follow auroral oval resulting in piecewise arc segmentation.

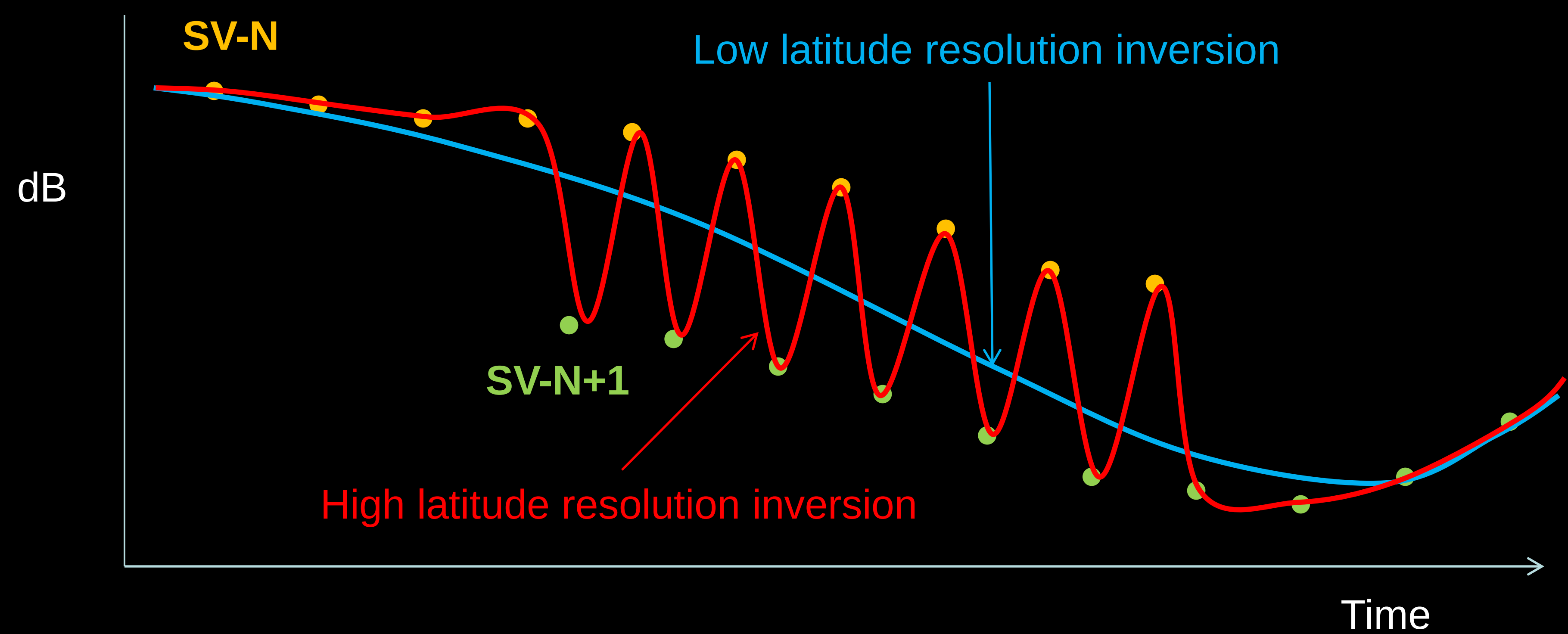
Spherical Cap Inversion

- Allows choice of coordinate system centered on AACGM pole in each hemisphere.
- Results in violation of Nyquist condition in longitude in some latitude ranges (esp. near AACGM pole).
- Requires imposing inversion constraints (e.g. interpolated ‘ghost’ data).
- Basis functions are non-standard (no longer integer Legendre functions).

AACGM Nyquist condition violation



Extracting High Latitude Resolution



Baselines between SVs are generally somewhat different.

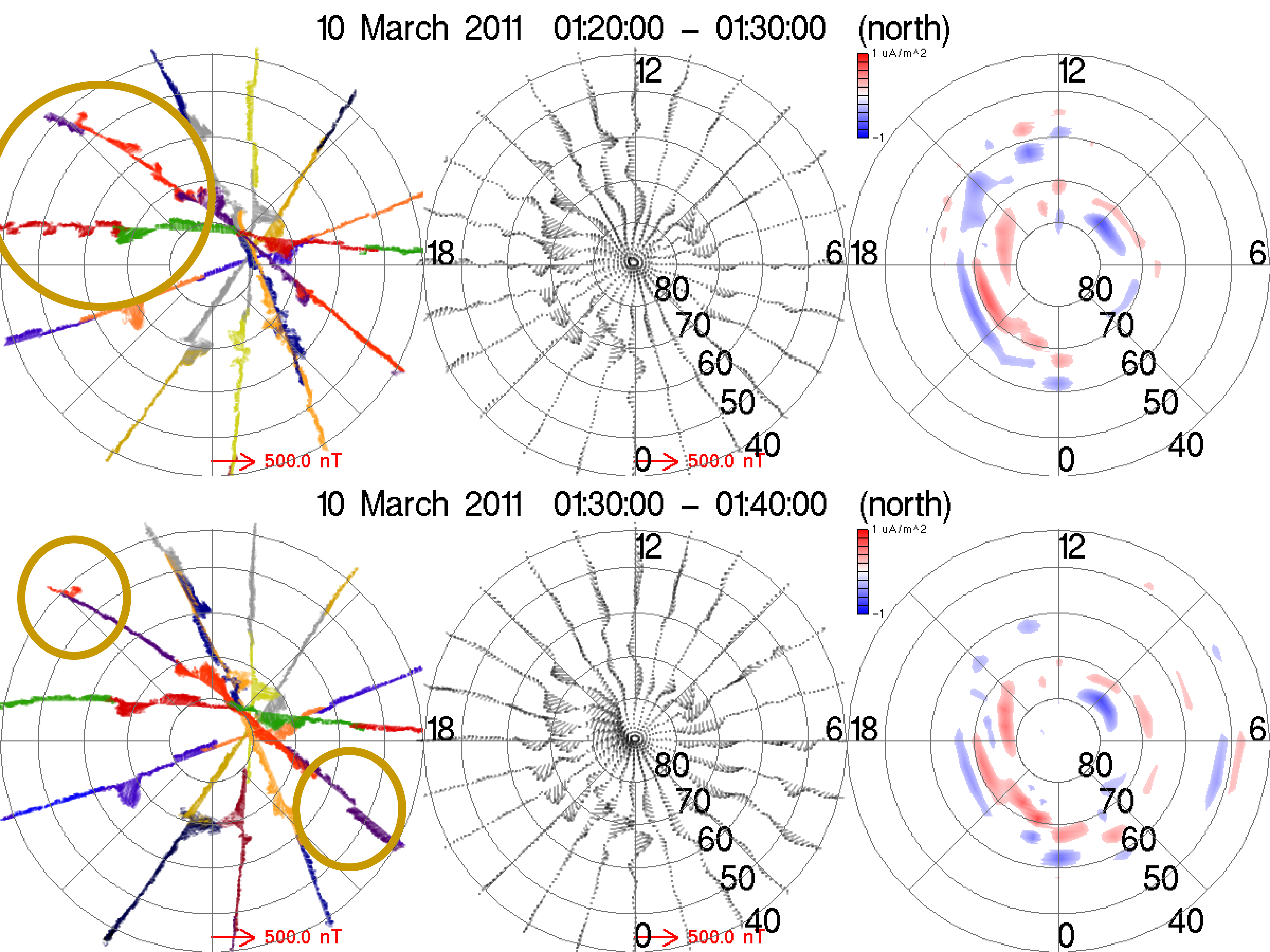
Causes moderate phantom signals in low latitude resolution fits.

Overlap in track segments causes severe corruption in high latitude resolution fits.

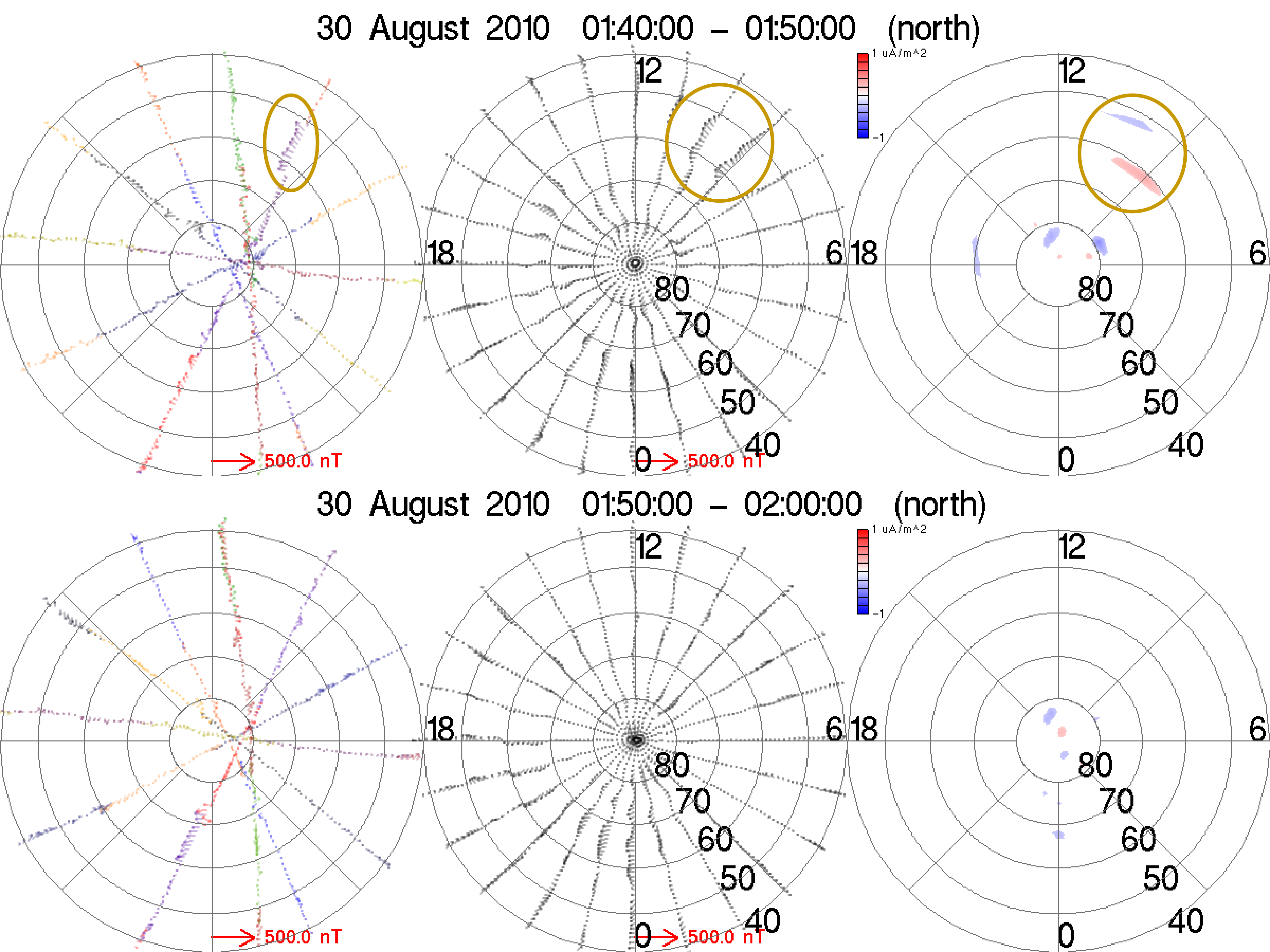
Step-like artifacts in δB

- Advisory #1: Some step-like features are present which are on the list to investigate and mitigate

- Advisory #2 (3-4 Aug 2010): Implementation of spherical harmonic fitting is subject to unphysical ‘ringing’ which is evident for strong currents. Regularizing the inversion is in the works.



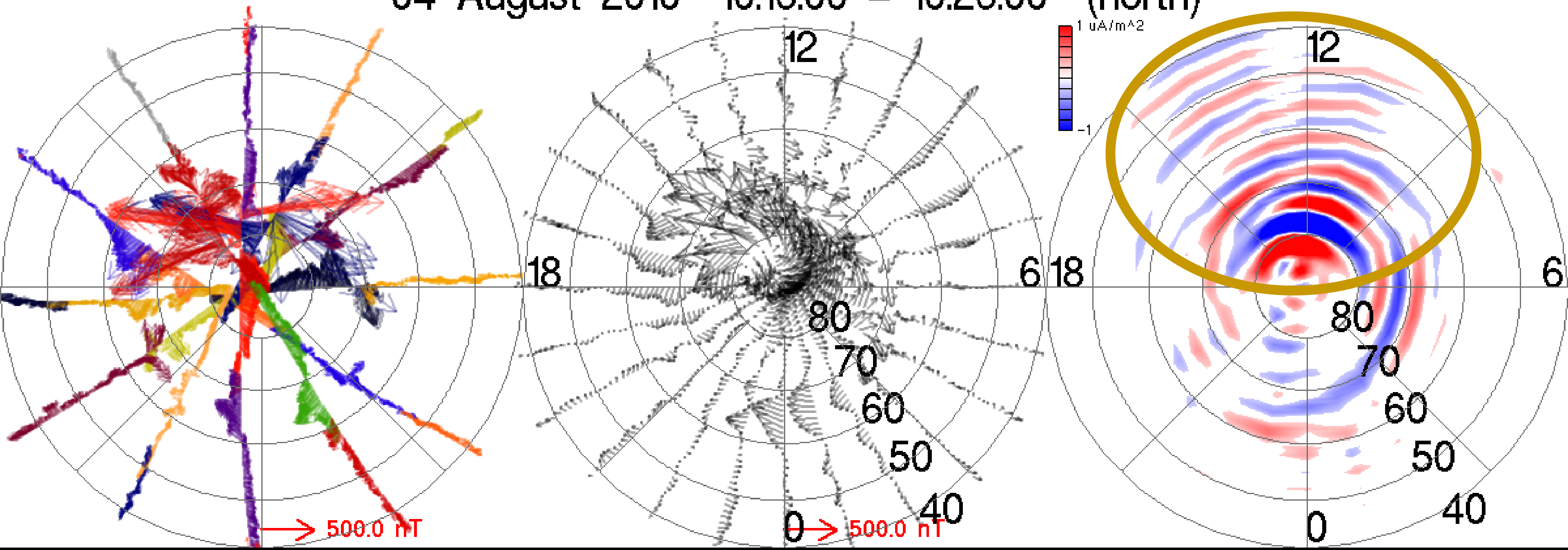
10 March 2011 01:20:00 – 01:30:00 (north)
500.0 nT
12
18
6
80
70
60
50
40
0
500.0 nT
1 uA/m^2
-1
12
18
6
80
70
60
50
40
0
10 March 2011 01:30:00 – 01:40:00 (north)
500.0 nT
12
18
6
80
70
60
50
40
0
500.0 nT
1 uA/m^2
-1
12
18
6
80
70
60
50
40
0


30 August 2010 01:40:00 – 01:50:00 (north)
12
18
6
0
80
70
60
50
40
500.0 nT
1 uA/m^2
-1
30 August 2010 01:50:00 – 02:00:00 (north)

Limitation of fits: ringing

- Advisory #2 (3-4 Aug 2010): Implementation of spherical harmonic fitting is subject to unphysical ‘ringing’ which is evident for strong currents. Regularizing the inversion is in the works.
- Simple result of truncating the latitude harmonic series: analogous to Fourier transform response to a delta function. Without an infinite series one is left with a ‘ringing’ at the highest frequency used.

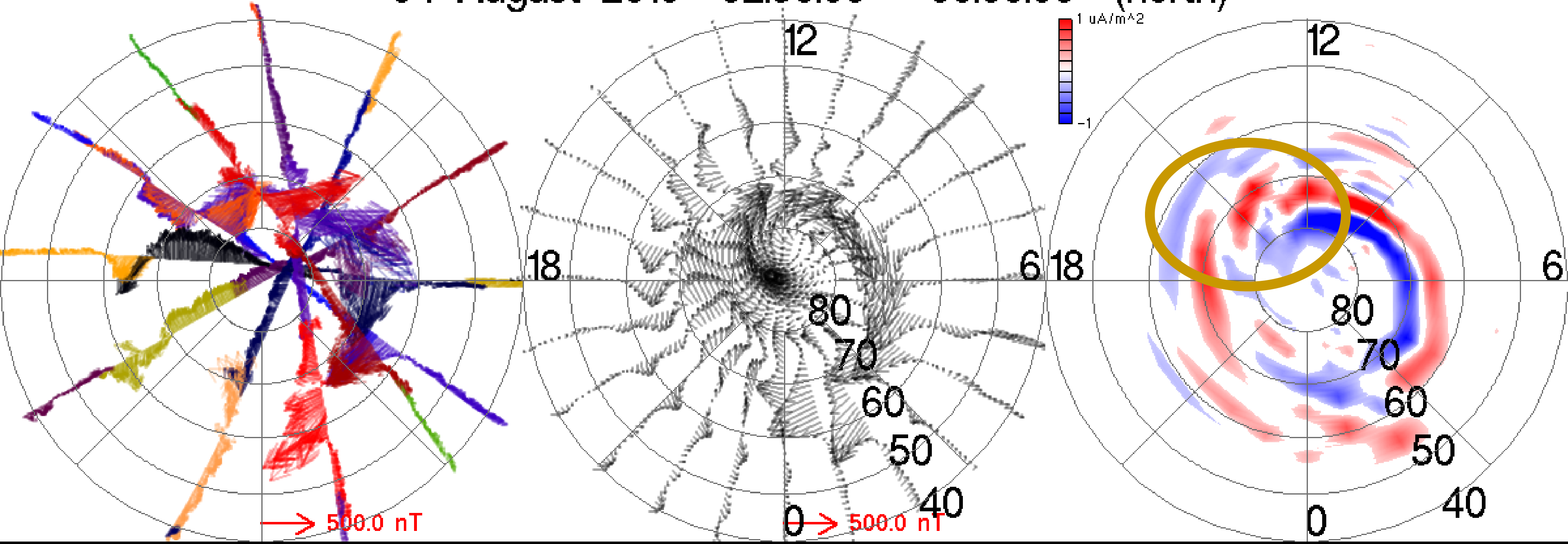
04 August 2010 10:16:00 – 10:26:00 (north)



~10x disparity in lat/lon res.

- Advisory #3: artifacts of ‘sawtooth’ structure in currents.
- Longitude resolution is ~30 deg, latitude resolution is at least 10x higher.
- Origin for fit is centered near orbit crossing point
- Fit cannot represent an oblique current sheet – it splits it into a series of ‘teeth’
- Solution requires polar cap fitting (non-integral basis functions) in AACGM coordinates (data fill procedures to regularize fit): implemented.

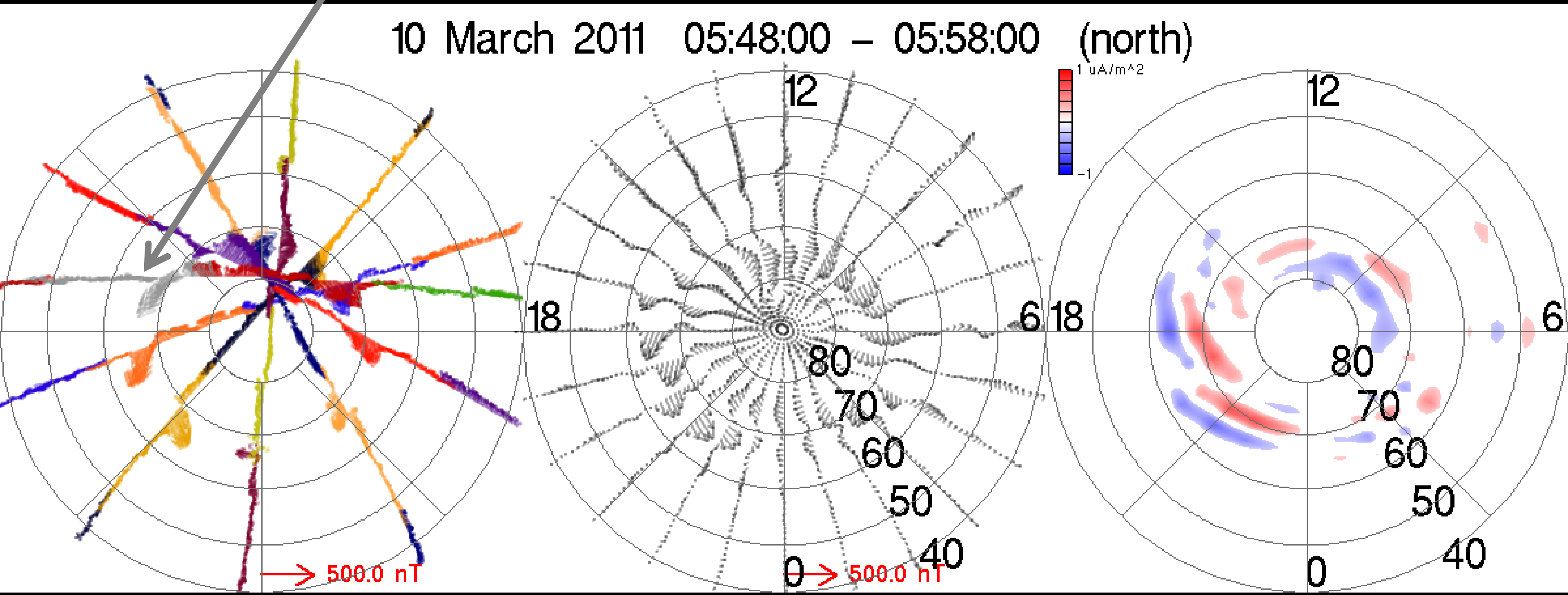
04 August 2010 02:50:00 – 03:00:00 (north)



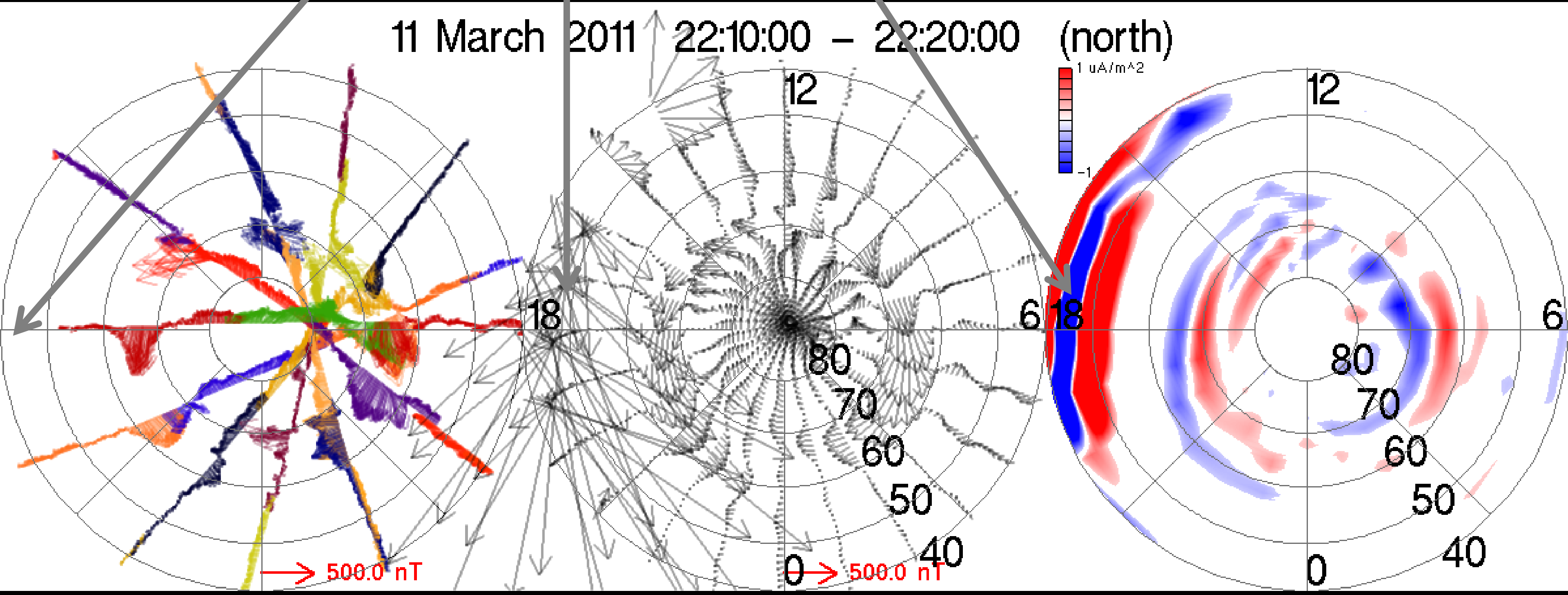
Data splicing

- Gaps in composite tracks occur:
  - Real data gaps from a given satellite (common before 12 June 2010)
  - Satellites with ‘bad atittudes’ whose data are generally not usable
- Data splicing:
  - In each 10-min window replace ‘bad/missing’ data with interpolation of data from ahead and behind satellites
  - Spliced data flagged and color plotted as grey
- Fits often explode w/o splicing

Replaced data in grey



Not replacing is much worse!



Inversion Status

- Cap inversion code using AACGM separate N and S fits developed: FORTRAN code with uncertainty estimates implemented.
- Track overlap ‘oscillation’ problem resolved: apply a smooth transition between SVs.
- Investigations underway into step functions on individual SVs and differences in baselines (correlate with SV housekeeping).

AMPERE-NEXT

- AMPERE-II concept:
  - AMPERE-Continuation: on Iridium (Block-1)
  - AMPERE-NEXT: on Iridium NEXT (Block-2)
  - Replacement launches begin in 2015.
- AMPERE-NEXT:
  - Iridium-NEXT satellites do have magnetometers.
  - AMPERE on NEXT will be different but superior.
  - Same orbital configuration: 6 orbit planes with 11 SVs equally spaced in each plane.
  - Time sampling will be fixed but return more than twice as much data as the present AMPERE standard rate: <0.5° latitude resolution 24/7.
  - Attitude knowledge: ~10x greater accuracy. Higher quality **δB** data, more stable baselines (cf. Knipp et al., 2014).