Present and potential global M-I state specification with Iridium

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Or: What can a bunch of attitude mags offer to SWARM?

- The M-I system responds to changes in solar wind/IMF in times as short as tens of minutes
- High precision observations along a single orbital track must be placed in global context.
- The challenge in getting the large-scale view is not precision – it is coverage. The Iridium constellation of >70 satellites does the job. It is proven. It works.
- A dramatically upgraded capability based on Iridium called AMPERE may well be available during the SWARM mission – FREE to SWARM.

Magnetosphere

Ionosphere

Flow

$$\mathbf{E} = -\mathbf{u} \times \mathbf{B}$$

Field lines convey potential

Convection

$$\mathbf{E}_c = -\mathbf{u}_c \times \mathbf{B}_i$$

Momentum

$$\rho \frac{d\mathbf{u}}{dt} = -\nabla P + \mathbf{J} \times \mathbf{B}$$

$$\mathbf{J}_{\perp,\mathrm{m}} = \frac{\mathbf{B} \times \nabla P}{B^2} + \rho \frac{\mathbf{B}}{B^2} \times \frac{d\mathbf{u}_\perp}{dt}$$

Finite conductance - drag

$$\mathbf{J}_{\perp,\mathrm{i}} = \underline{\boldsymbol{\Sigma}} \cdot \mathbf{E}_c = \Sigma_P \mathbf{E}_c + \Sigma_H \mathbf{b} \times \mathbf{E}_c$$

$$J_{\parallel} \propto \int \nabla_\perp \cdot \mathbf{J}_{\perp,\mathrm{m}} ds$$

Currents convey stress

$$J_{\parallel} = \nabla \cdot \mathbf{J}_{\perp,\mathrm{i}} = \nabla \cdot (\underline{\boldsymbol{\Sigma}} \cdot \mathbf{E}_c)$$

FAC intensity is associated with energy deposition for a given electric field

Iridium Satellite Constellation

>70 satellites

6 orbit planes

~11 satellites/plane (9 minute spacing)

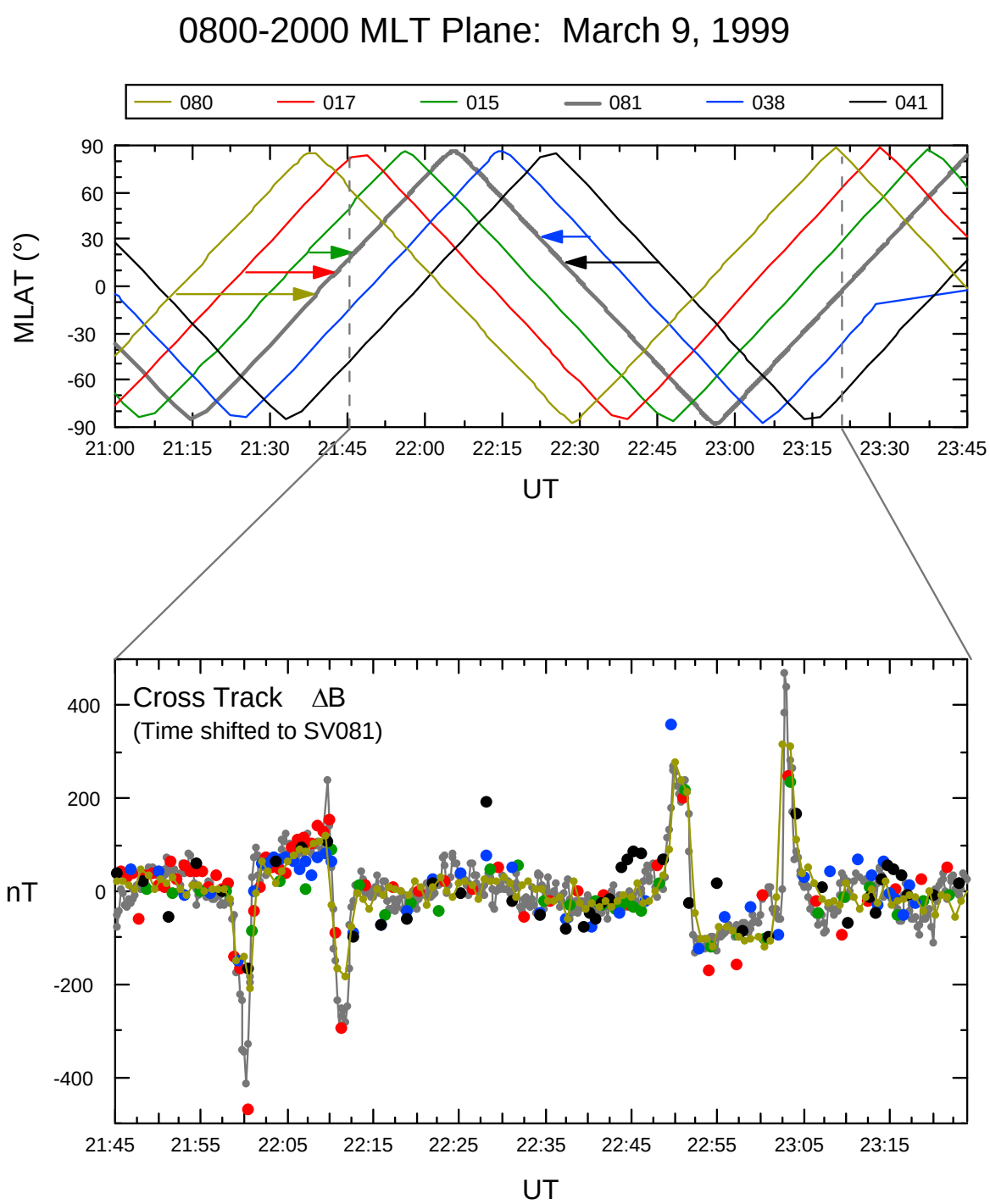
780 km altitude

Circular, polar orbits

Life-time to ~2014

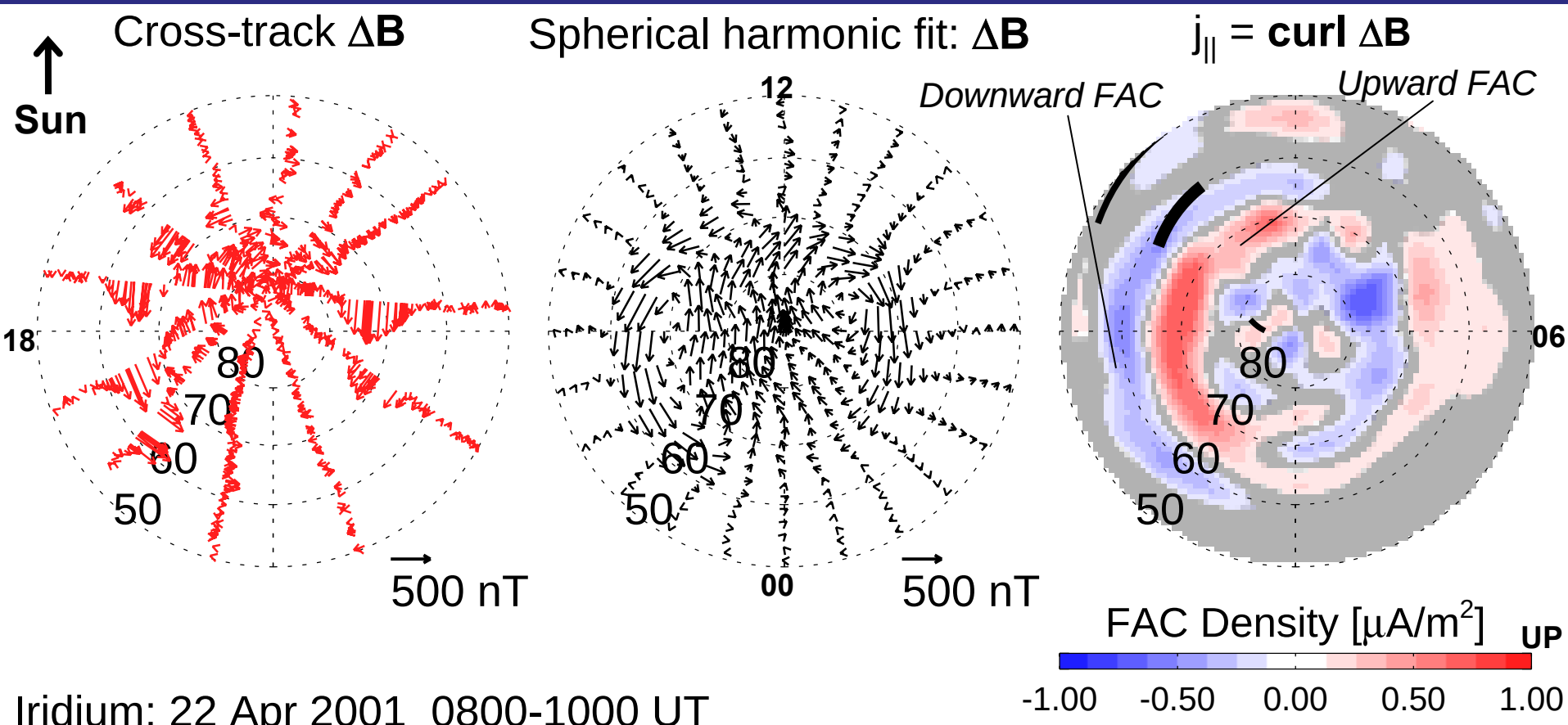
& profitable !!

- Every Iridium satellite carries a vector fluxgate magnetometer
- 12-bit digitization 30 nT resolution: SN ~ 10:1
- SC are clean to this level
- Automated pre-processing developed & proven
- Time sampling:
  - 11/s on board
  - ~200s to ground (on average)



Analysis for ΔB, $j_{||}$ distributions

- Cross track **ΔB**
- **ΔB** map via spherical harmonic fit
- $j_{||}$ from Ampere's law.
- Fit residual 2-sigma ~ 70 nT, ~0.1 to 0.2 μA/m2
- Lat res: ~4˚ for 1-hour accumulation
- Asymmetry is a real feature (HENA)



Iridium: 22 Apr 2001 0800-1000 UT

Derivation of Global ΔB & Field Aligned Current

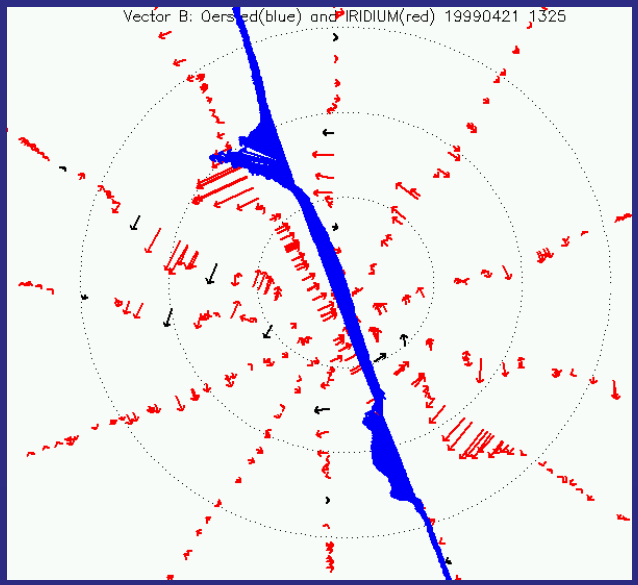
$\nabla \times (\Delta \mathbf{b}) = \mu_0 \mathbf{J}$	Main field is curl free.
$\mathbf{J} = \nabla \cdot \mathbf{I}_P$	$\mathbf{I}_p$ = poloidal ionospheric current $\mathbf{I}_p \neq$ Pedersen current
$\Delta \mathbf{b} = -\mu_0 \mathbf{r}_u \times \mathbf{I}_P$	$\mathbf{r}_u$ is a radial unit vector Approximates FAC as radial **div**$\Delta \mathbf{b}$ = 0 identically.
$\Delta \mathbf{b} = -\mu_0 \mathbf{r}_u \times \nabla \Psi$	$\mathbf{I}_p$ is curl free so use potential formalism.

Potential function and hence **J** determined solely by Δ**b**.
No assumptions about ionospheric conductivities.
No dependence on statistical models.

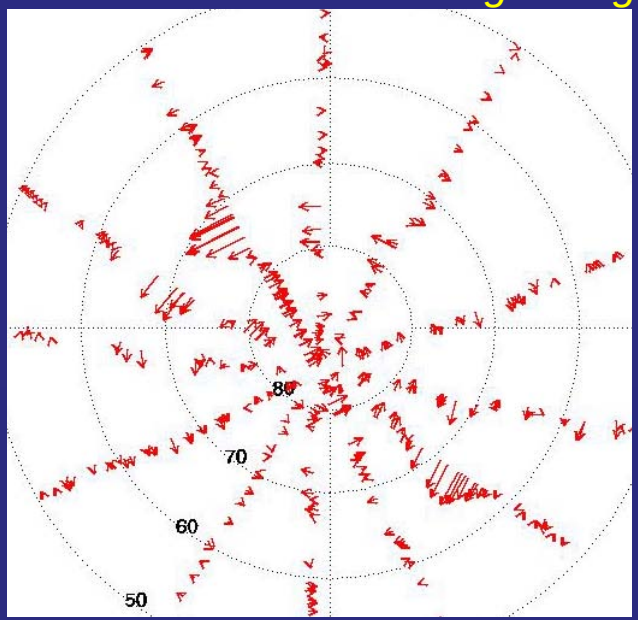
Science potential proven with present Iridium system

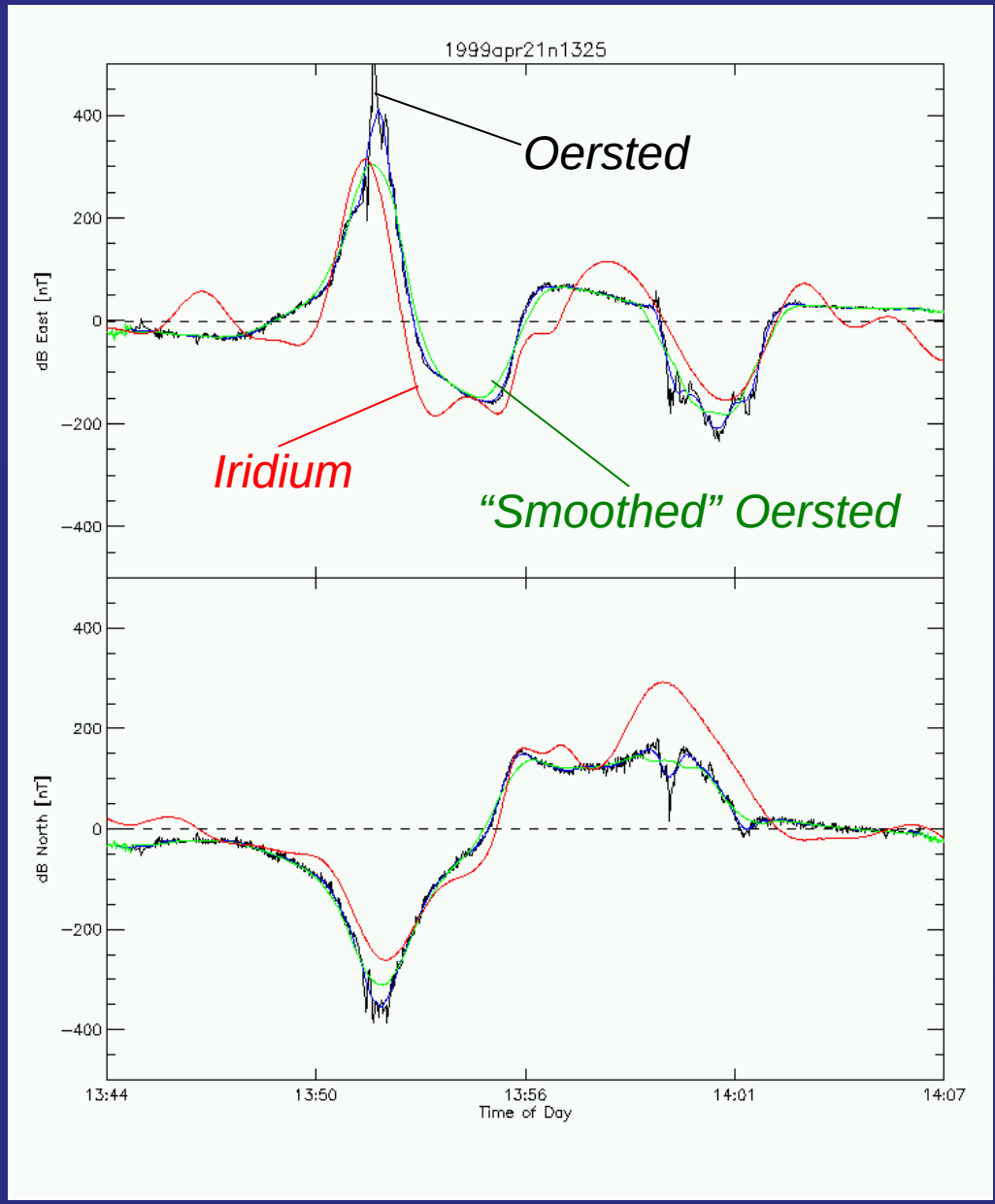
- Techniques to derive Birkeland currents w/o geometry or modeling assumptions
- Comparison with Oersted
- Comparison with auroral imaging
- High quality science even with present system

Oersted Comparison



Vector arrows are even the right length





Northern IMF interval following the Bastille day storms

16 July 2000: 1600-1700 UT **1700-1800 UT** **1800-1900 UT**

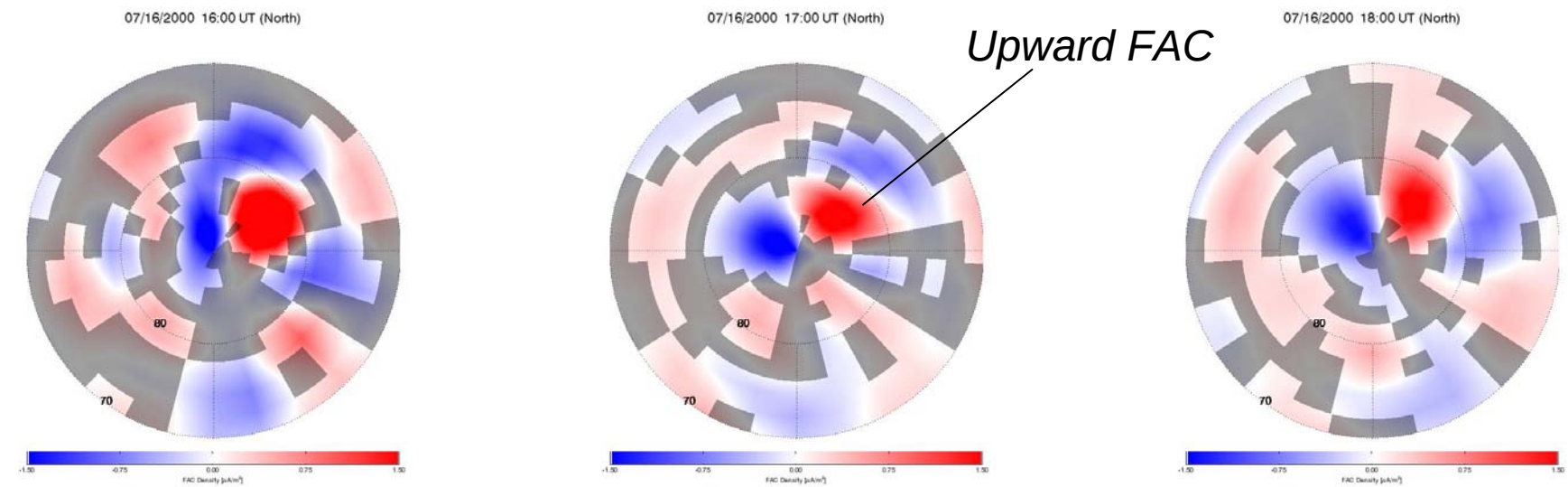
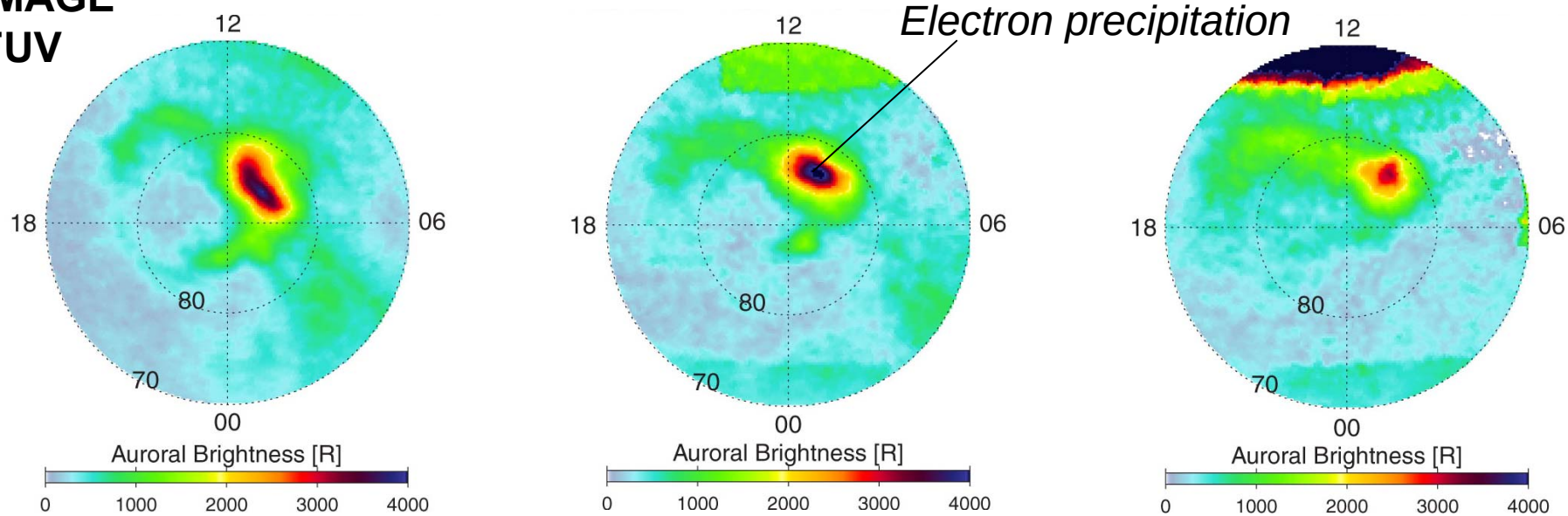
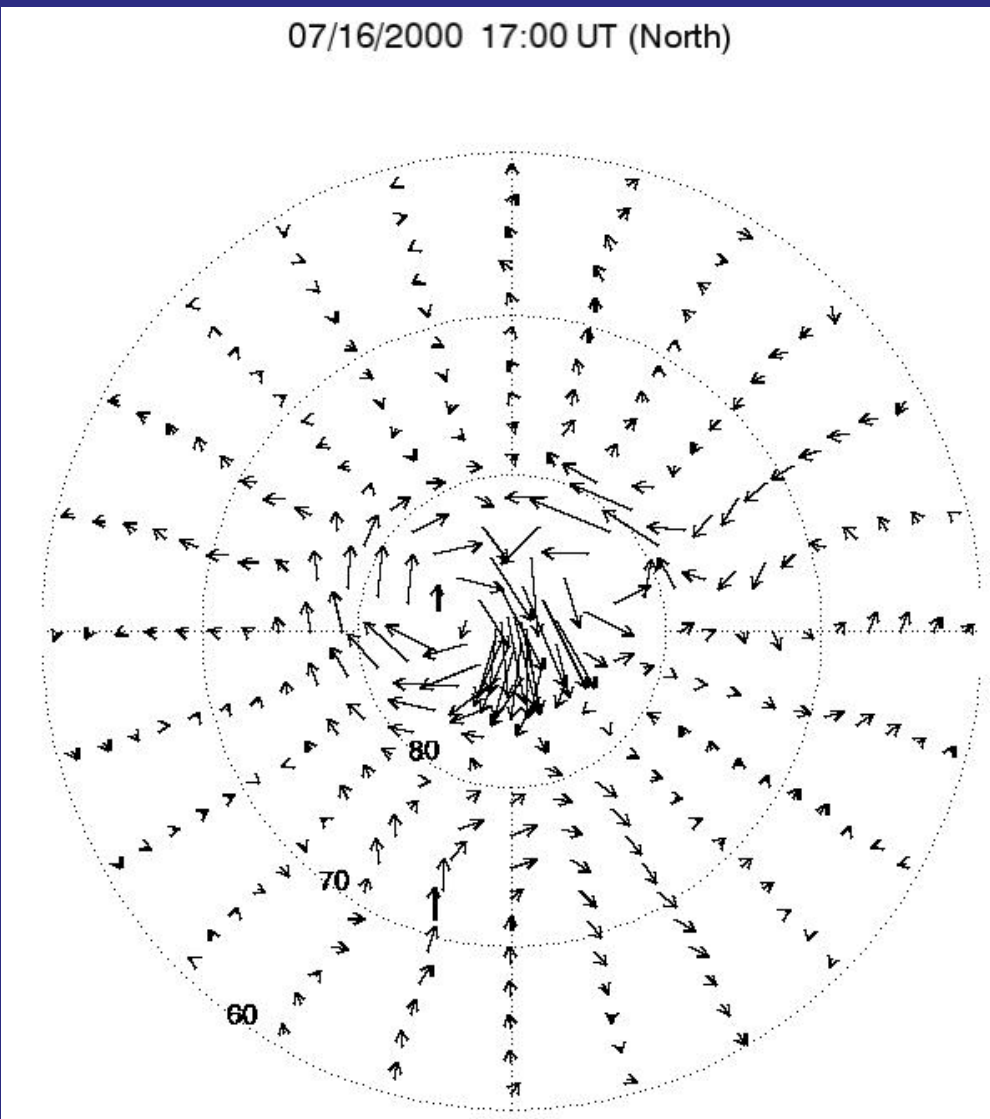
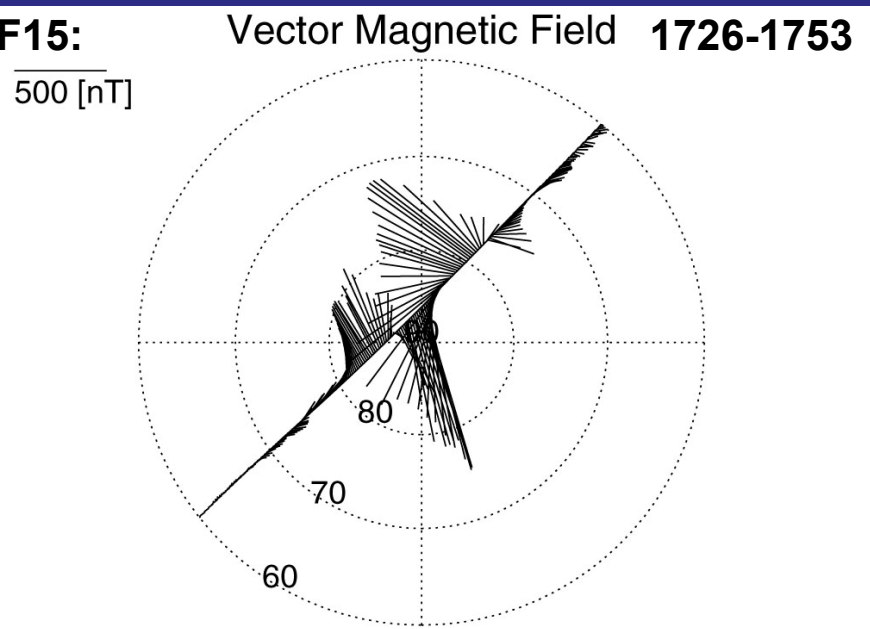


IMAGE FUV



DMSP F13 and F15 have excellent passes through NBZ region





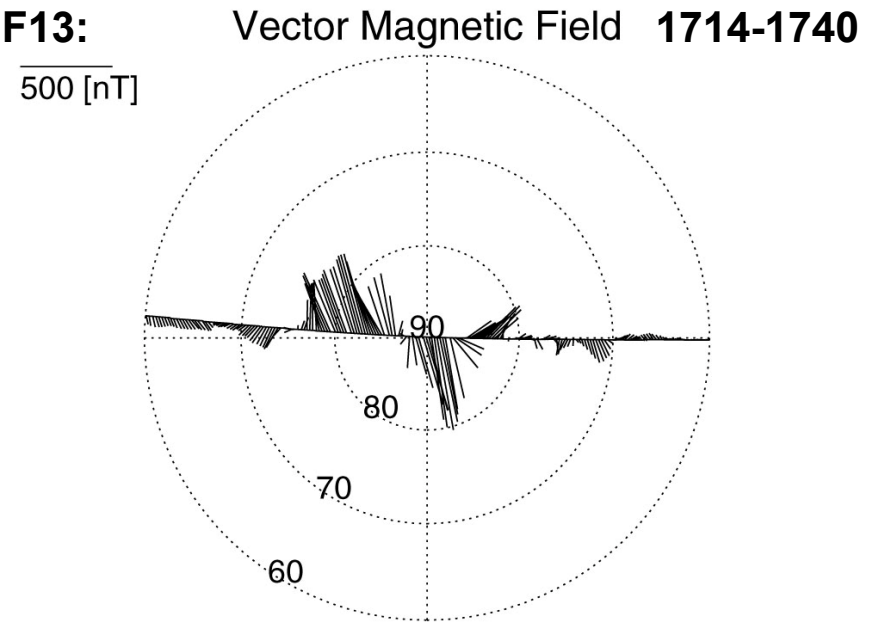
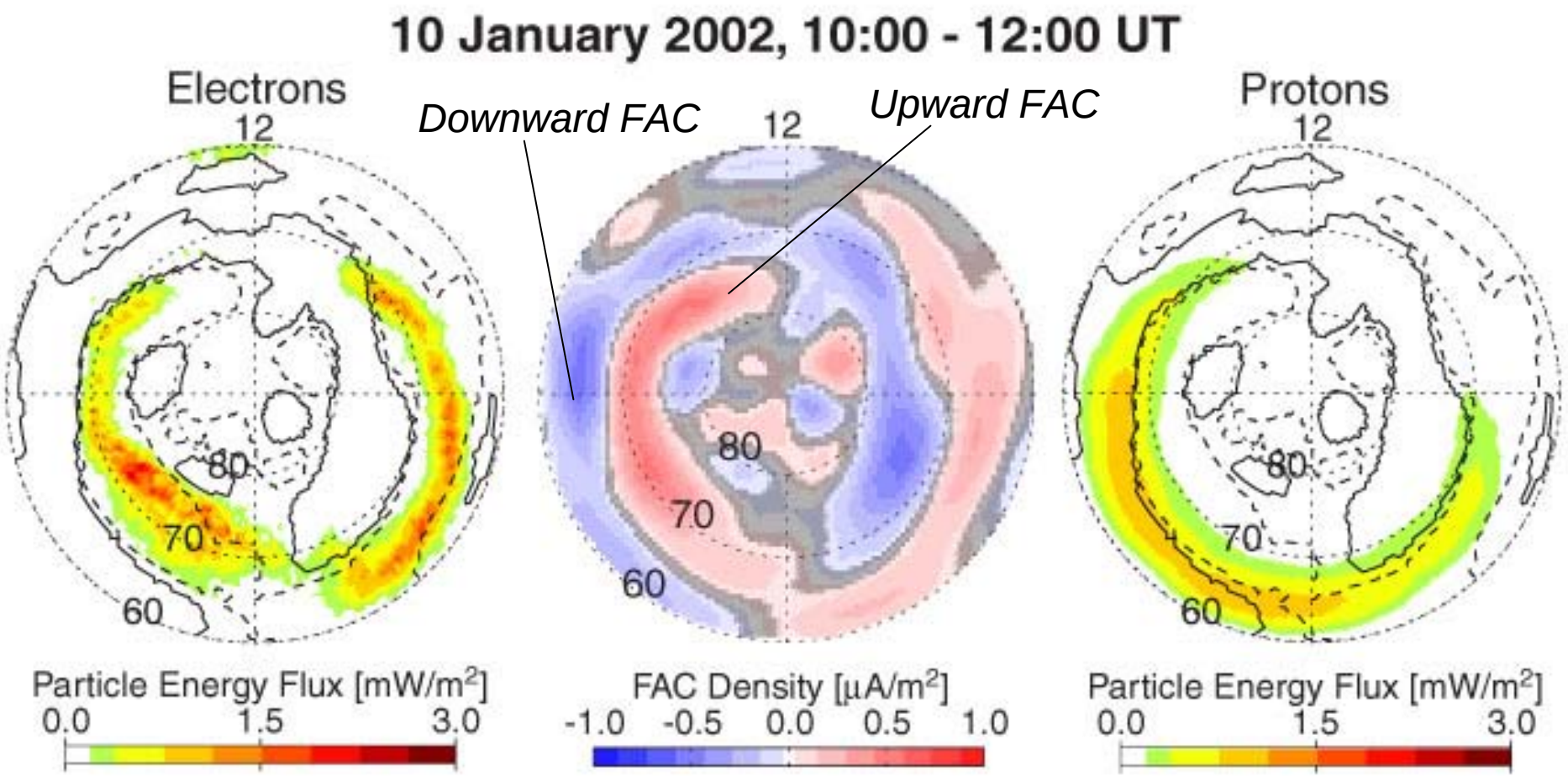


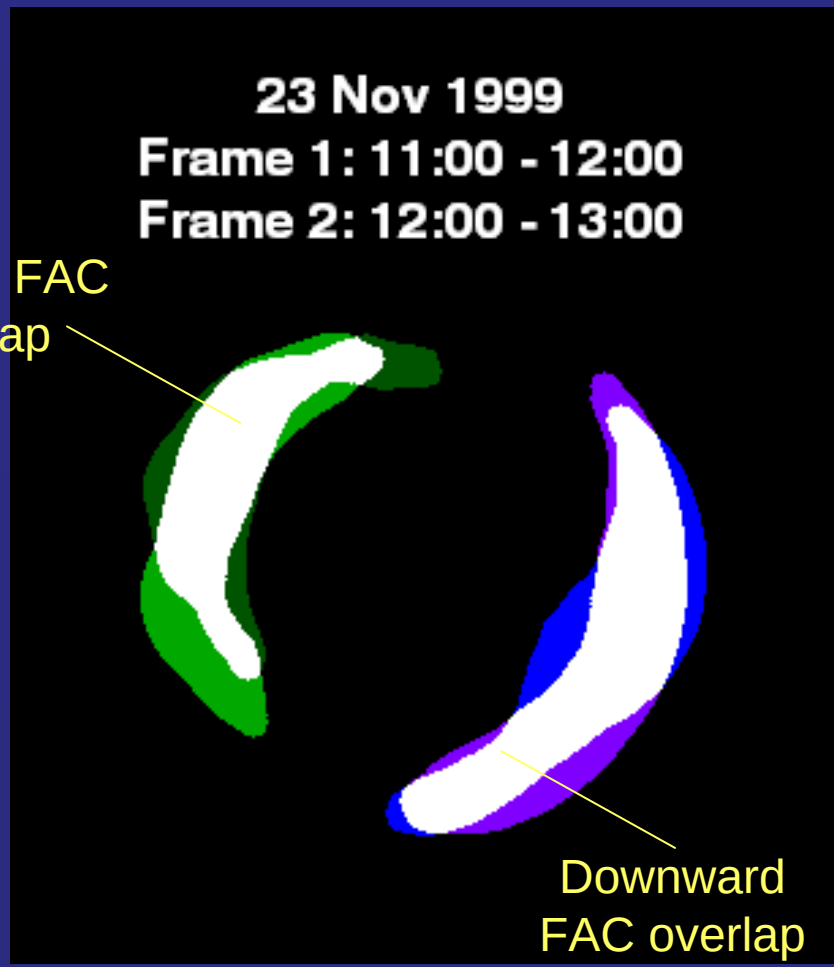
IMAGE Particle Energy Flux & $J_{||}$

- **Total hemispheric particle energy flux: 12 GW**
- **Electron energy flux coincides with upward Birkeland current**



Iridium Statistical FAC Model

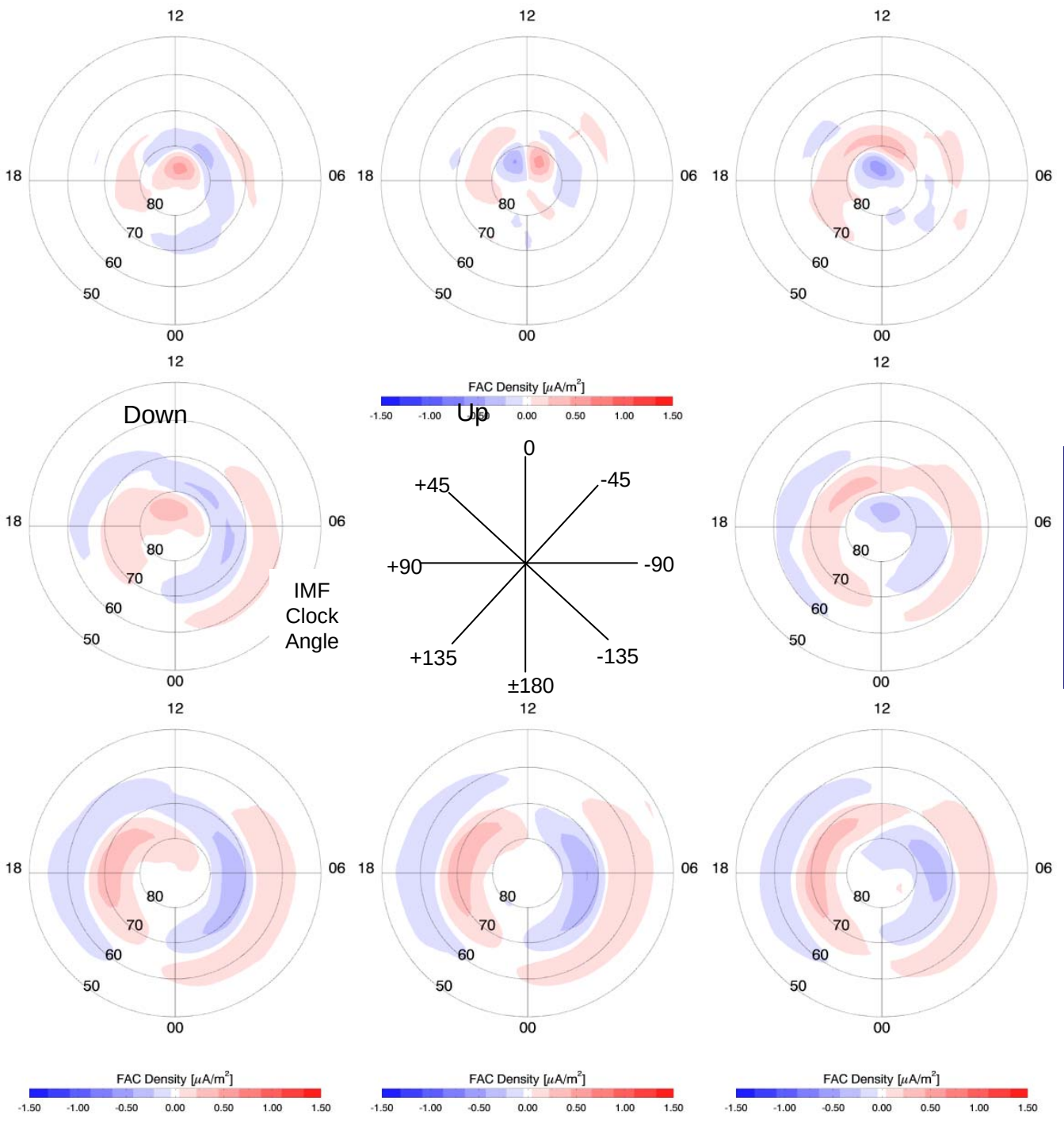
- Database:
  - 7 years of data: 1999 – 2005.
  - 60,000 independent 1-hour FAC snapshots.
- Data Processing Steps:
  - Compute 1-hour FAC distributions for 1999-2005.
  - Determine overlap of adjacent FAC distributions.
  - Discard events with overlap <45%
  - Identify solar wind and IMF parameters.
  - Bin FAC distributions by clock angle and average.



⇨ 3000 stable 1-hour frames, 5% of total intervals!

FAC patterns averaged by IMF clock angle – using only 5% of data

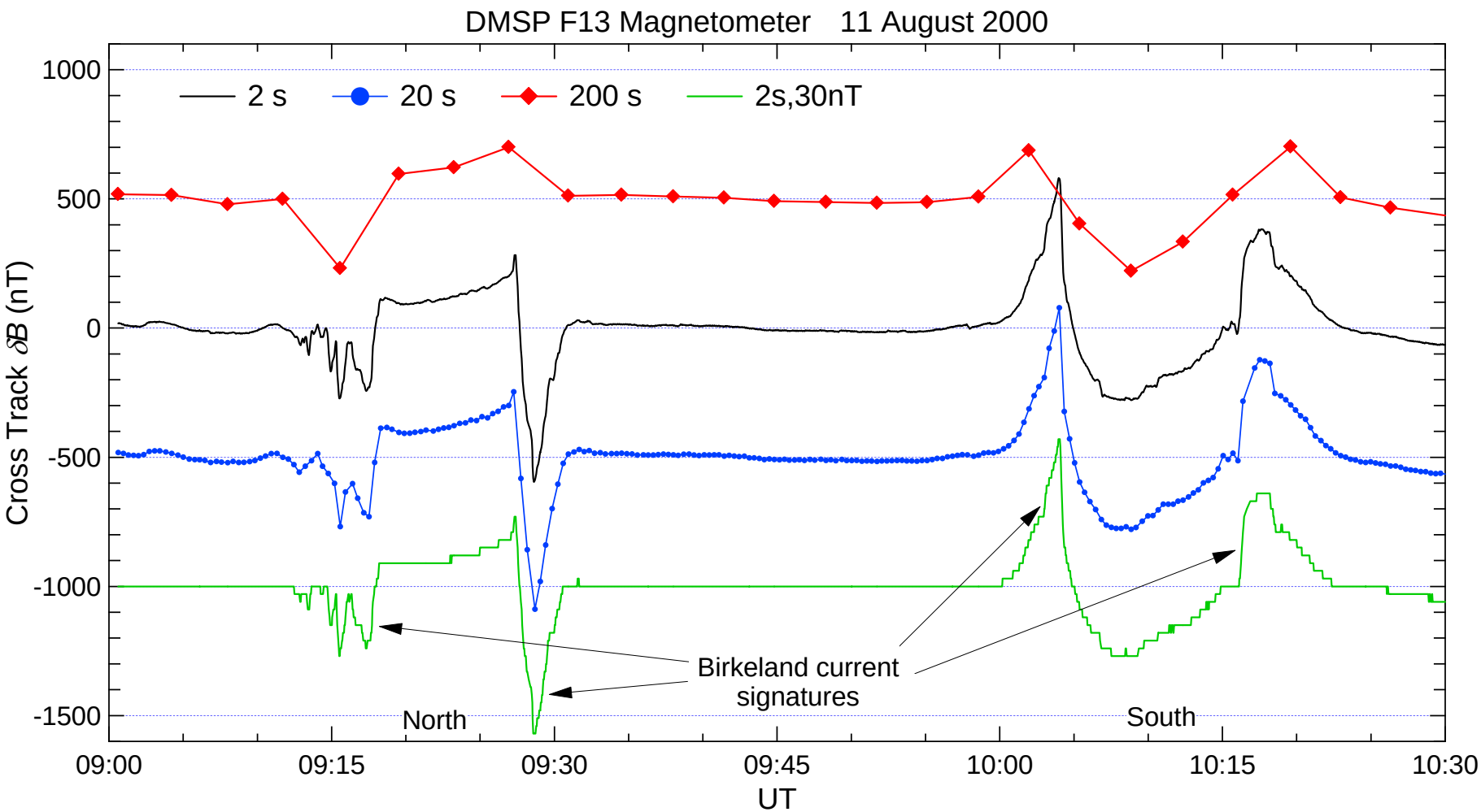
Other currents are often seen in FAC maps. These are probably due to dynamics in the system and are "super-imposed" (or time aliased)



Limiting Factor: Data Rate

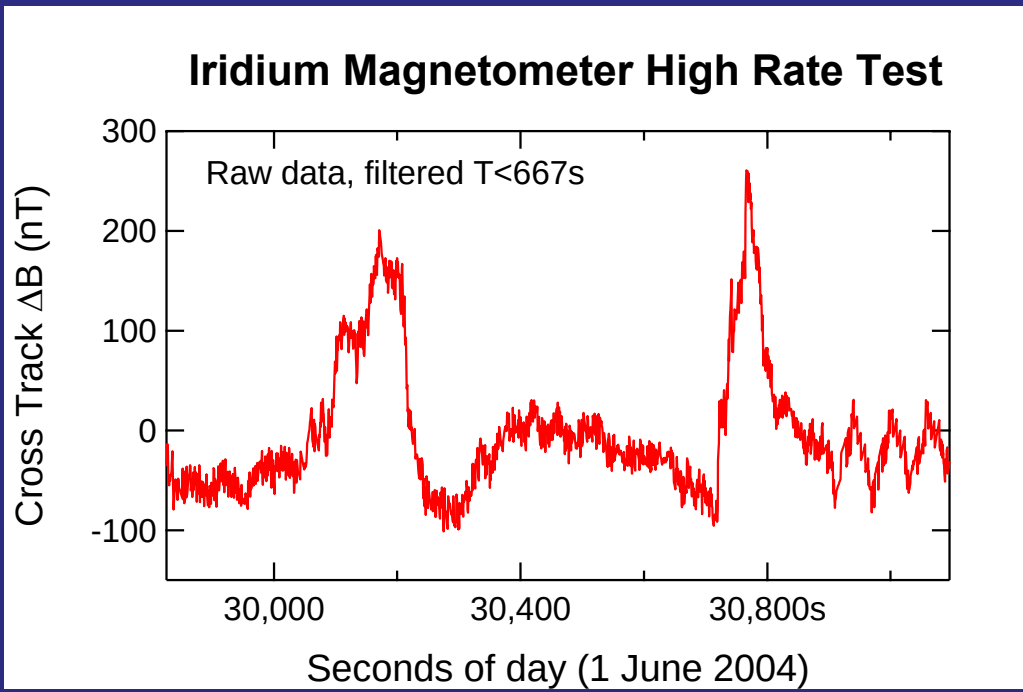
- Present data capability
  - ~200 sec / magnetometer vector sample
  - ~14° latitude between samples
- Creates *severe* analysis limitations
  - One hour data accumulations required
    - **can only study stable conditions**
    - **shorter time scales very difficult to study**
  - Analysis cannot resolve along track component
    - **limited to cross track component**
    - **compromised fit results: polar cap, convection throats**
  - Data holes/low point density is *THE* factor limiting science

- **Existing 200-s sampling often misses signatures**
- **2-s sampling captures small-scale features**
- **20-s sampling captures all large scale currents**
- **30-nT resolution does a good job!**



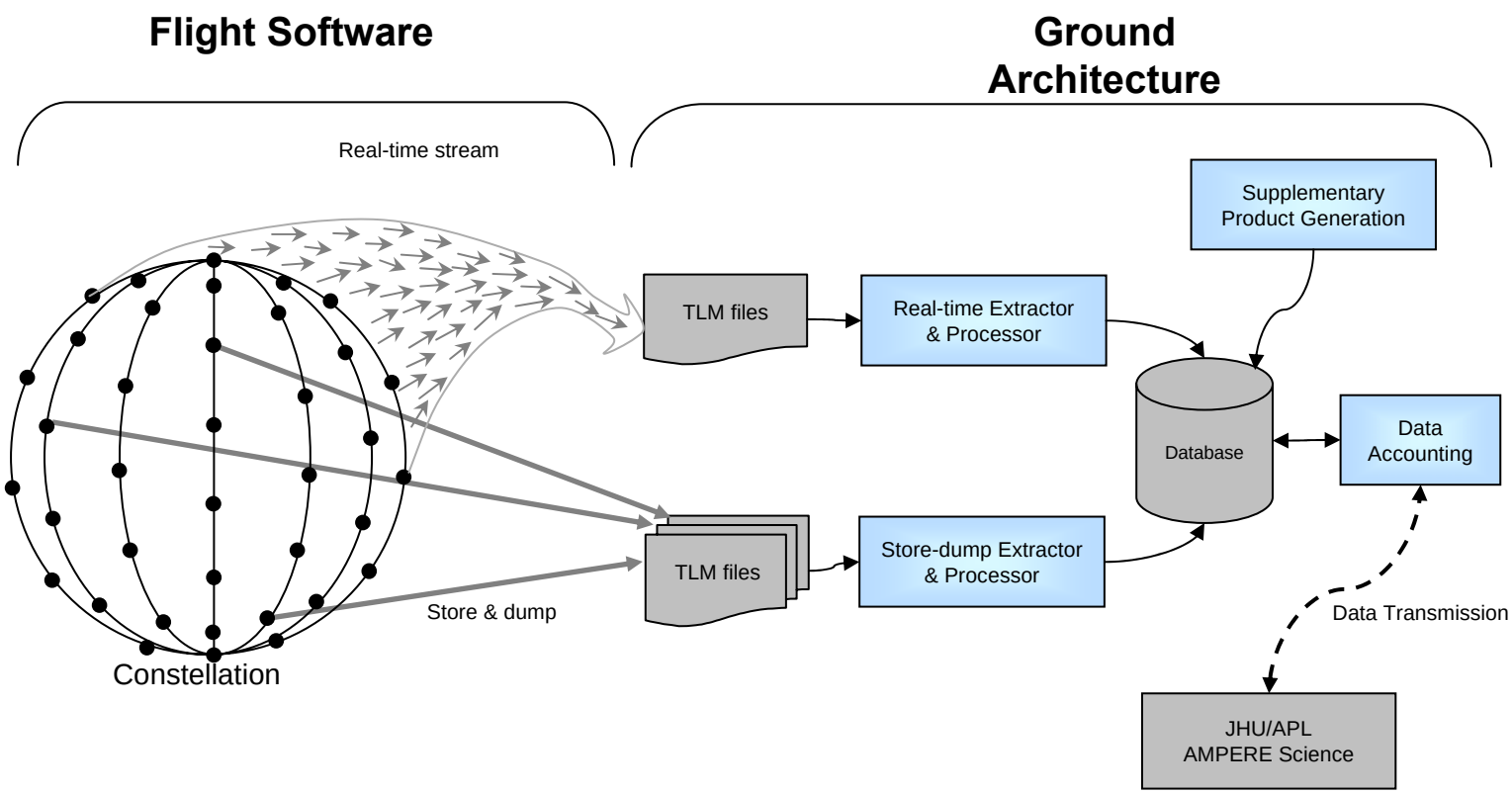
Higher Rate Data Tested

- Special high rate data experiment done
  - one satellite to verify that Iridium magnetometer noise is low enough to meet higher cadence science requirements
- 200 nT Birkeland current signatures clearly observed are low relative to storm time (>1000 nT)
- Structures in cross-track field are clearly visible
- Data shows noise is low, relative to the current signatures
  - No surprise high frequency noise features hiding in data
- High time resolution data are of high quality and will successfully fill in current time gaps



AMPERE: Active Magnetosphere and Planetary Electrodynamics Experiment

- Iridium system upgrade: concept in place and ready
  - satellite constellation flight software
  - ground system development
- Global, continuous, real-time observation of large-scale Birkeland currents: 9 minute cadence

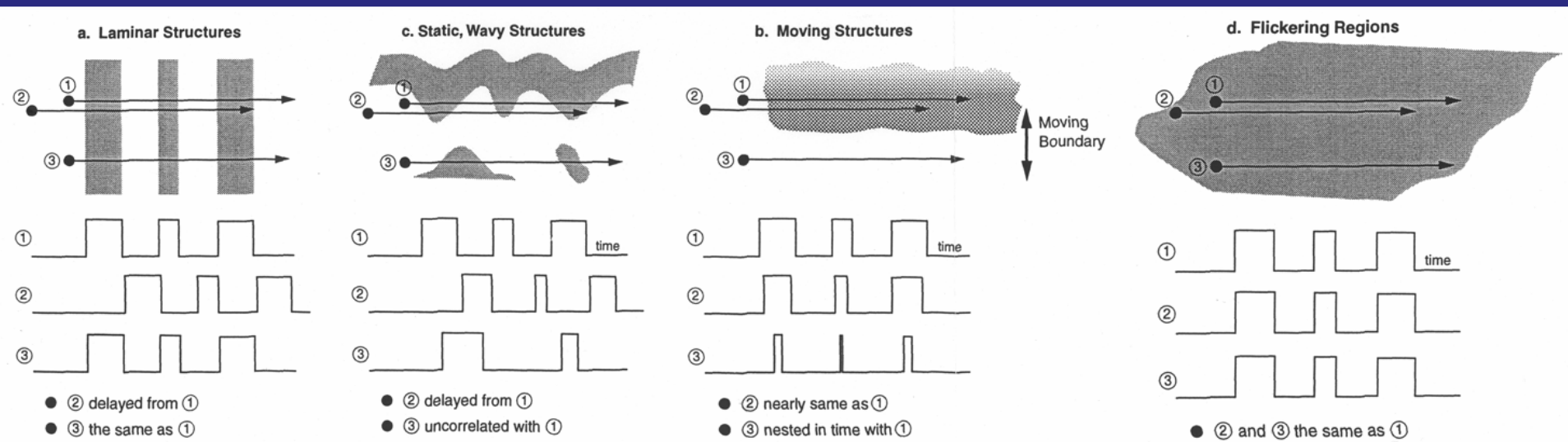


Making AMPERE a reality

- Appropriate for both NASA and NSF
  - Fits within NASA mission of opportunity class
  - Fits within NSF facility line
  - Both being pursued
  - Implementation in 2008 not impossible
  - Iridium satellite life-time: to 2014 at least.

Where is the best place for the third SWARM satellite?

- Global state specification:
  - Does not require ultra-high precision
  - Likely to be available prior to SWARM implementation and through mission from AMPERE
  - Why do something marginally that is already being done better?
- Resolving space-time ambiguity in smaller scale M-I coupling physics & phenomena
  - Requires three closely spaced SC with high-precision instrumentation
  - New frontier for fundamental science
  - Ideal fit to SWARM capabilities



Keeping options open: AMPERE-SWARM synergy.

- By allowing the option to use AMPERE to provide the large-scale context SWARM can
  - Free all of your resources and unique capabilities to focus on the science that SWARM is best suited to solve.
  - Resolve fundamental space-time ambiguities that require multiple closely spaced satellites IN THE SAME TRACK.
- This synergy is an opportunity to significantly enhance SWARM science.