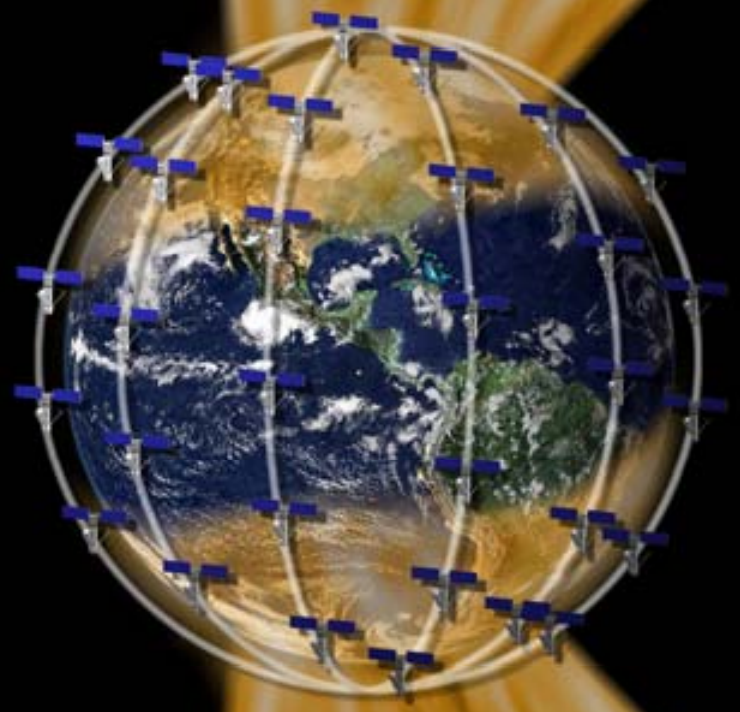
AMPERE



Continuous Global Birkeland Currents from the Active Magnetosphere and Planetary Electrodynamics Response Experiment

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Partners

Sponsor
National Science Foundation

Data provider
Boeing Service Company

Data source
Iridium Satellite LLC

PI Institution, Science Data Center
The Johns Hopkins University
Applied Physics Laboratory

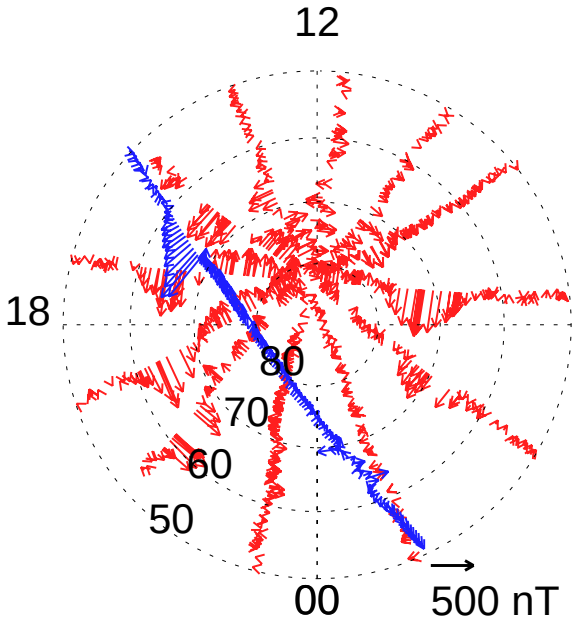
Iridium Constellation for Science

- **Magnetometer on every satellite**
  - **Part of avionics**
  - **30 nT resolution: S/N ~ 10**
- **>70 satellites, 6 orbit planes, ~11 satellites/plane**
- Six orbit planes provide 12 cuts in local time
- 9 minute spacing: re-sampling cadence
- **780 km altitude, circular, polar orbits**
- Polar orbits guarantee coverage of auroral zone
- Global currents never expand equatorward of system

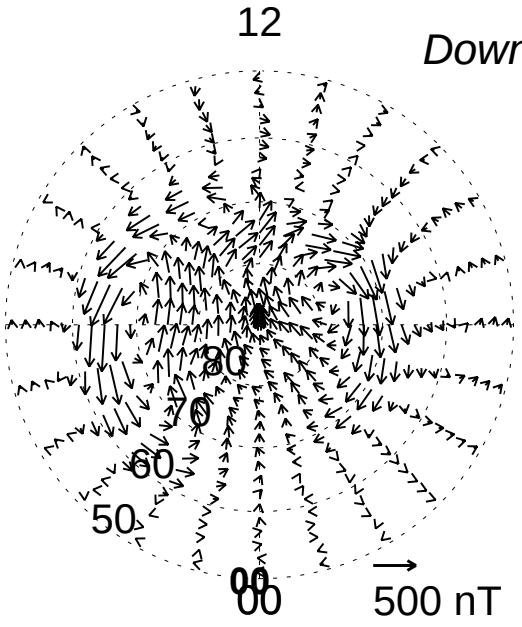
Analysis for ΔB, $j_{||}$

- Cross track ΔB, vector **ΔB** map via spherical harmonic fit
- $j_{||}$ from Ampere's law (arbitrary geometry, no stats or cond.)
- Fit residual 2-sigma ~ 70 nT, ~0.1 to 0.2 $\mu A/m^2$
- Lat res: ~4˚ for 1-hour accumulation

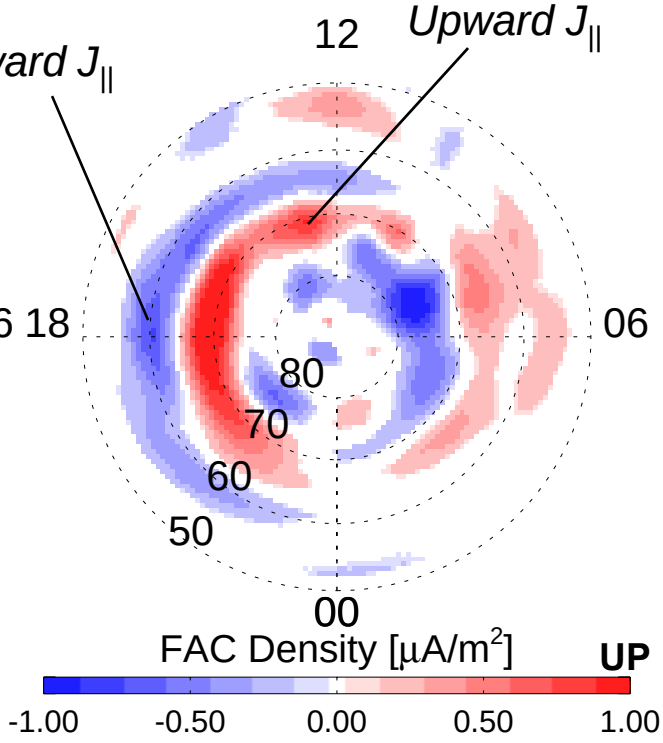
Cross-track Δ**B**



Spherical harmonic fit: Δ**B**



$j_{||}$ = **curl** Δ**B**



Iridium: 22 Apr 2001 0800-1000 UT

The Ionospheric electrodynamics view

Convection $\mathbf{E}_C = -\mathbf{V}_C \times \mathbf{B}$ $\mathbf{E}_c = -\nabla\varphi$

Horizontal currents $\mathbf{J}_{\perp,\mathrm{i}} = \underline{\boldsymbol{\Sigma}} \cdot \mathbf{E}_\mathrm{C} = \Sigma_\mathrm{P}\mathbf{E}_\mathrm{C} + \Sigma_\mathrm{H}\mathbf{b} \times \mathbf{E}_\mathrm{C}$

ψ = equivalent current potential

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

Electrodynamics equations: 2 eqs, 5 unknowns

$$\nabla^2\psi = \Sigma_\mathrm{H}\nabla^2\varphi + \nabla\Sigma_\mathrm{H} \cdot \nabla\varphi + \hat{\mathbf{r}} \cdot (\nabla\Sigma_\mathrm{P} \times \nabla\varphi)$$

$$J_{\parallel} = -\Sigma_\mathrm{P}\nabla^2\varphi - \nabla\Sigma_\mathrm{P} \cdot \nabla\varphi + \hat{\mathbf{r}} \cdot (\nabla\Sigma_\mathrm{H} \times \nabla\varphi)$$

Quantity	Technique	Strengths	Operational Considerations
Ψ Equivalent currents	Ground magnetometers	Excellent time resolution; continuous data; coverage improving in latitude, density and southern hemisphere	Non-uniform coverage (oceans, concentration at nominal auroral latitudes, local time gaps)
φ Potential convection	**SuperDARN:** mid-latitudes	Broad field of regard; continuous operation; both hemispheres; 2-min cadence; 10s km resolution	Requires irregularities; D-region absorption (mitigated somewhat by mid-latitude radars)
	IS radars	Indep. of conditions	Focussed (limited) coverage (few sites)
	LEO ion drift	Direct ion drift observations	100 minute revisit time Restricted local time cuts (4)
Σ_P, Σ_H	IS radars	Accurate density meas.	Focussed (limited) coverage (few sites)
	UV imaging	Hemispheric image	Significant uncertainties Not operational routinely
$J_{\parallel}$ Birkeland currents	LEO mags	Direct signature of currents	Iridium: long accumulation times (>2 hrs) Other: ~3 satellites, 100 minute revisit time, Requires geometrical assumptions
	AMPERE	Direct signature of currents >70 satellites 9 minute revisit time 12 local time cuts	30 nT resolution – S:N ~ 10:1 Latitude resolution: 1º nominal Event driven sub-degree sampling

Other applications

E-M Energy Flux

No δB, no S_z

$|\delta\mathbf{B}|$ locates regions of S_z

$$S_z = \frac{1}{\mu_0}\mathbf{E}_C \times \delta\mathbf{B}$$

Useful for assimilation

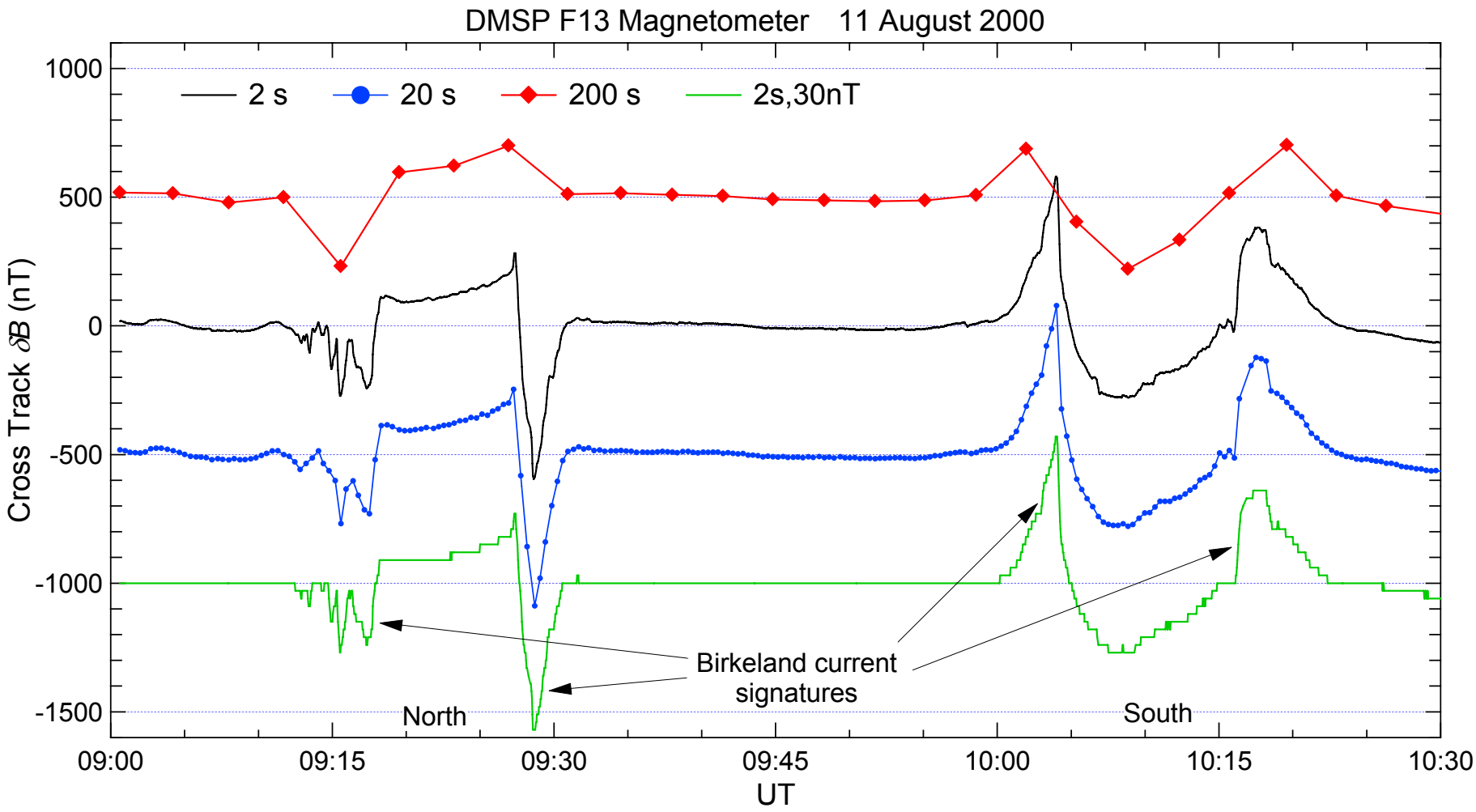
Global and 'uniformly' distributed

Fundamental physical quantity: $\delta\mathbf{B}$ or $j_{||}$

Relevant to multiple efforts

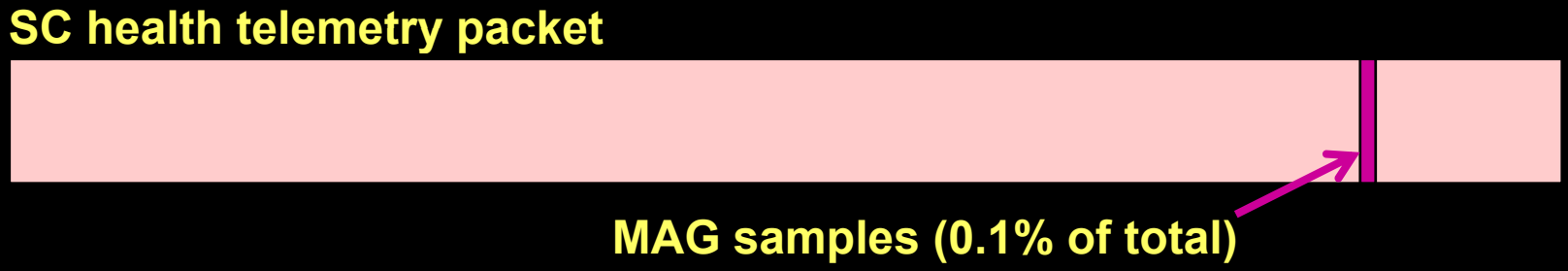
Ongoing: AMIE, GAIM

Potential: RCM, MHD



- **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 is sufficient**

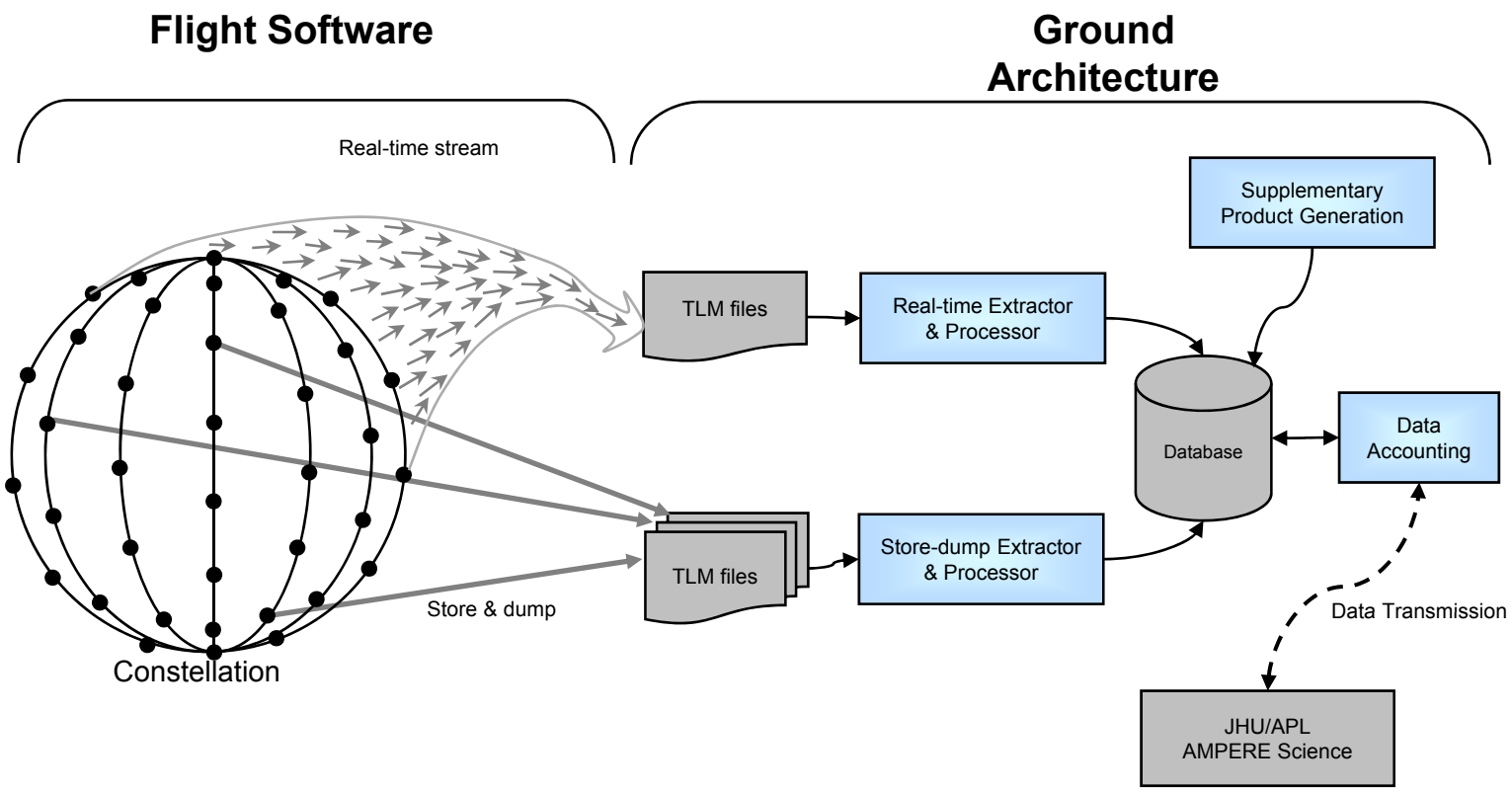
Telemetry Issue & Solution



- Existing system:
  - Magnetometer data embedded in satellite engineering data packet
  - Enormous quantity of engineering data: voltages, currents, temperatures, other attitude sensors, RF system (rec'd intensities), power system (arrays/batteries), computer/memory monitors …
- Modification:
  - Use alternate path: event message. Designed for satellite to report 'event' of interest to operators
  - New software to query magnetic field from attitude system processor
  - Pack set of magnetic samples (~10 to 100) in an event message.
  - Event messages delivered in continuously, sequentially (SV001, 002 …) using satellite network to ground station in true real-time

AMPERE: Boeing/Iridium - Data Provider

- Iridium system upgrade: concept in place and ready
  - satellite constellation flight software
  - ground system development
- Real-time data stream
- Store & dump data: fill any gaps; definitive orbit/attitude



AMPERE Development Effort

- Space software upgrade and installation
- Ground data system to extract and archive data at Iridium operations center
- Data exchange to Science Data Center at JHU/APL
- AMPERE Science Data Center: capability to ingest real-time, 24/7 data and process data products
- Promotion to highest rate:
  - 2 s on all satellites (normally ~20 s)
  - 36-hour promotion span
  - 16 per year
  - Effected in ~1 hour

Development Timeline

Release of upgraded ‘historical’ data (1999-present)	Fall 2009
First ‘light’	Dec 2009
Testing and validation	CY 2010
Real-time development	CY 2011
‘Burst’ promotion	CY 2012
Completion	May 2013

- Release of products will occur during development as they are ready