ACSWA company capabilities building the U.S. Space Weather Enterprise

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ACSWA Executive Committee

Commercial space weather sector can expand O2R with

Data support examples for 5 benchmark SWAP activities

- Induced geo-electric fields
- Ionizing radiation
- Ionospheric disturbances
- Solar radio bursts
- Upper atmosphere expansion

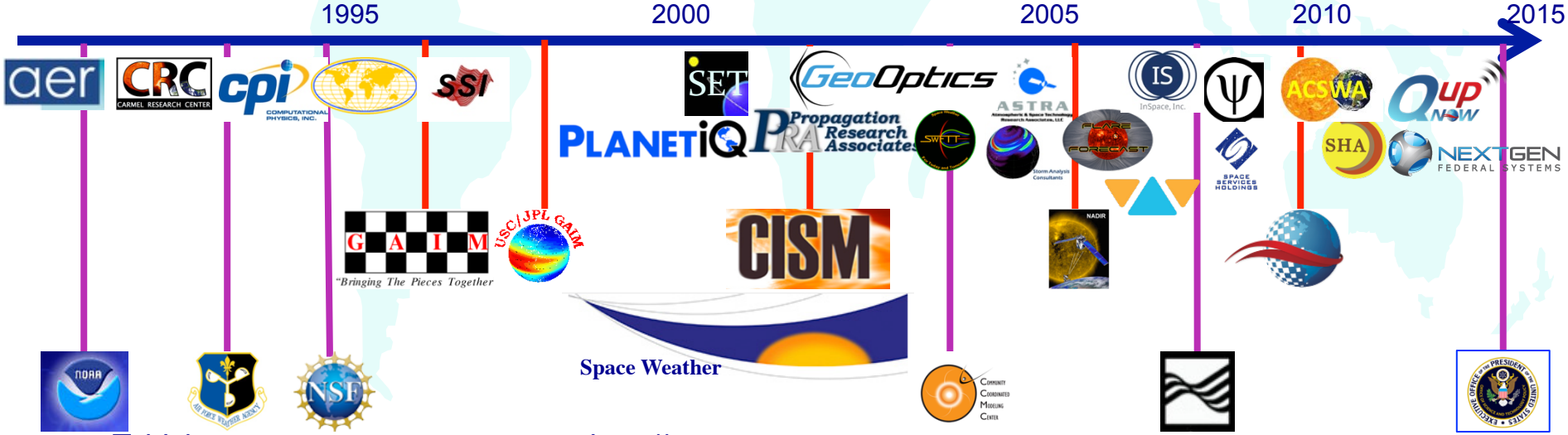
SBIR-developed "low-hanging fruit" data resources

Continuous development through O2R collaborations with agencies, academia, and commercial partners

Data and services products made broadly available to the research community through multiple access portals

Who comprises the national space weather enterprise?

- **National Space Weather Program** (1995,1997,2000,2006,2010,2016)
- **Agencies** (OSTP, NOAA SWPC, AFWA, NSF, NASA CCMC, USGS)
- **Academia** (GAIM MURI, CISM, NADIR MURI, USU SWC)
- **Industry** (19 U.S. companies in ACSWA as of January 1, 2016)



American Commercial Space Weather Association

- **Formed in 2010, 5 Members**
- **Growth to 2017, 19 Members**

AER, ASTRA, CPI, CRC, FF, GO, IS,
PiQ, PRA,PSI, Q-up, SAC, SEC,
SET, SSI, SSH, SA, SWFTT, WA

www.acswa.us

Executive Committee:

G. Crowley (ASTRA) A. Engle (WA)
D. Intriligator (CRC) C. Lautenbacher (GO)
R. Robinson (IS) R. Schunk (SEC)
K. Tobiska (SET)

1. Induced Geo-electric Fields low-hanging fruit

- **Fruit:** *AVERT* real-time magnetic and electric field data for GIC hazard analysis and time series estimates relevant to power utility research, planning and operations
- **Heritage:** NSF grants, federal BPA contracts, IR&D
- **Prime:** Computational Physics, Inc. (CPI)

2. Ionizing Radiation low-hanging fruit (1)

- **Fruit:** *Advanced Weather Simulation and Operational Modeling Effort (AWSOME)* radiation-caused SEE environment provides high-altitude manned aircraft, UAV, and LEO operational planners with an operational CREME96 output based on the current and near-term forecast GCR, SEP, TP, cutoff rigidity environments
- **Heritage:** MDA SBIR Phases I, II
- **Prime:** Space Environment Technologies (SET)

2. Ionizing Radiation low-hanging fruit (2)

- **Fruit:** *Automated Radiation Measurements for Aerospace Safety (ARMAS)* radiation-caused human dose environment provides data products from commercial altitude aircraft that can be used for understanding atmosphere, radiation belt, magnetosphere, solar wind coupling
- **Heritage:** NASA SBIR Phases I, II, IIE, III
- **Prime:** SET

3. Ionosphere Disturbances low-hanging fruit (1)

- **Fruit:** *Space weather based Position error maps for TEC – On-line (Spot-On)* correction maps to improve location and navigation using *Global Assimilation of Ionospheric Measurements (GAIM)* hi-res maps applied to global and regional locations
- **Heritage:** NOAA SBIR Phase I & ONR MURI
- **Prime:** Utah State University (USU), Space Environment Corporation (SEC), and SET

3. Ionosphere disturbances low-hanging fruit (2)

- **Fruit:** *Ionospheric Data Assimilation in 4-D (IDA4D)* Global electron density distribution and TEC using data assimilation. Relevant for communications, navigation and surveillance.
- **Heritage:** AF SBIR Phase I, NASA Phase-1. Various papers published. TRL-9.
- **Prime:** Atmospheric and Space Technology Research Associates (ASTRA)

3. Ionosphere disturbances low-hanging fruit (3)

- **Fruit: *Assimilative Mapping of Ionospheric Dynamics*** *(AMIE).* Provides high-latitude E-field distribution. Useful for driving global full-physics models of the ionosphere and thermosphere. Can provide boundary conditions for magnetospheric models.
- **Heritage:** NASA SBIR Phase-1, NSF grants, NASA grants. Various papers published. TRL-9.
- **Prime:** ASTRA

3. Ionosphere disturbances low-hanging fruit (4)

- **Fruit: CASES and *GAMMA*** hi-res GPS-TEC and scintillation monitors. GAMMA can be used on moving platforms (buoys, ships, aircraft, etc). Data available for purchase from global array.
- **Heritage:** USAF STTR Ph-1&2, SBIR Ph-1&2, AF-Commercialization Readiness Program.

  TRL-9: over 100 units deployed globally.

  Validated performance on moving platforms. Various papers published.
- **Prime:** ASTRA

3. Ionosphere disturbances low-hanging fruit (5)

- **Fruit:** *(TID-MAP)* Mapping of Traveling Ionospheric Disturbances across CONUS. Video progression shows presence, location and propagation of TIDs.

  Can be interrogated to obtain TID parameters
- **Heritage:** USAF SBIR Ph-1&2, AF-Commercialization Readiness Program,

  TRL-9. Various papers published.

  Validated performance.
- **Prime:** ASTRA

3. Ionosphere disturbances low-hanging fruit (6)

- **Fruit:** ***HF Ionospheric Sounders***

  a) TIDDBIT Doppler Sounder

  b) CHIRP sounder

CHIRP measures range (height) as well as Doppler shifts, whereas TIDDBIT only measures Doppler shift. Normally deployed as triangular arrays to measure Traveling Ionospheric Disturbances. Multi-frequency.

- **Heritage:** USAF SBIR Ph-1, Other AF programs, NSF Grant, NASA Grant. papers published. TRL-9.
- **Prime:** ASTRA

3. Ionosphere Disturbances low-hanging fruit (3)

- **Fruit:** *CICERO* hi-coverage and cadence Radio Occultation (RO) TEC acquisition applicable to understanding the ionosphere, atmosphere, magnetosphere coupling
- **Heritage:** USAF contracts
- **Prime:** Geo-Optics (GO)

3. Ionosphere disturbances low-hanging fruit (4)

- **Fruit:** *DICE/DIME **CubeSats*** for characterizing the Ionosphere and measurement of Space Weather impacts. In-situ ionospheric plasma densities; Science and attitude magnetometers; electric field probes
- **Heritage:** DICE Mission – 2011 launch (two – 1.5 U CubeSats) – successful observation of SED & FAC from Cubesat; Follow-on AF SBIR Ph II: DIME (being built)
- **Prime:** ASTRA

3. Ionosphere disturbances low-hanging fruit (5)

- **Fruit:** *SORTIE CubeSat* for characterizing on the distribution of wave-like structures in the plasma density of the ionospheric F-region via a miniaturized Ion Velocity Meter for measuring ion drifts, and a micro-Planar Langmuir Probe for measuring small-scale plasma structures
- **Heritage:** NSF DICE Mission – 2011 launch (two – 1.5 U CubeSats; DIME Phase II SBIR.
- **Prime:** ASTRA

3. Ionosphere disturbances low-hanging fruit (6)

- **Fruit:** *Topside Sounder* - Low power FMCW HF Sounding instrument to make topside measurements of the ionosphere from a 12U CubeSat platform.
- **Heritage:** AF SBIR Phase II Instrument development.
- **Prime:** ASTRA

3. Ionosphere disturbances low-hanging fruit (7)

- **Fruit:** *SIPS* - Scanning Imaging Photometer Systems (UV Imager). Low cost & versatile sensor for UV remote sensing of the ionosphere; nearly continuous monitoring of the night-side ionosphere. Resolves ionospheric structures at 1 vertical TEC unit (better than GPS TEC) via UV detector and Scanning mirror.
- **Heritage:** AF SBIR Phase II, scan mirror
- **Prime:** ASTRA

4. Solar Radio Bursts low-hanging fruit

- **Fruit:** *SPRINTS* solar flare, CME, and proton probabilistic forecasting for improving the timing and magnitude of solar effects at Earth
- **Heritage:** NASA STTR Phase I
- **Prime:** NextGen Federal Systems (NGFS)

4. Solar radio bursts low-hanging fruit

- **Fruit: (***SORBET)* Software Defined Radio for Detection of Solar Radio Bursts. Ground-based system measures solar radio output at a variety of frequency ranges
- **Heritage:** AF, MDA & DARPA SBIRs
- **Prime:** ASTRA

5. Upper Atmosphere Expansion low-hanging fruit

- **Fruit:** The JSpOC *High Accuracy Satellite Drag Model (HASDM)* catalog from 2001 to present is critically needed by the space research community as an accurate atmosphere baseline to improve satellite ops and for improving thermosphere density models
- **Heritage:** NASA LWS TRT & USAF contract
- **Prime:** SET

5. Upper Atmosphere expansion low-hanging fruit (2)

- **Fruit:** ***(****DRAGSTER)* Ensemble assimilation model of thermospheric neutral density. Improves the state of the art in orbit prediction, orbit nowcast, and conjunction analysis for LEO satellites by reducing the errors associated with atmospheric drag modeling.
- **Heritage:** AF SBIR Phases 1, 2, E and RIF. Preparing to transition to JSPOC.
- **Prime:** ASTRA

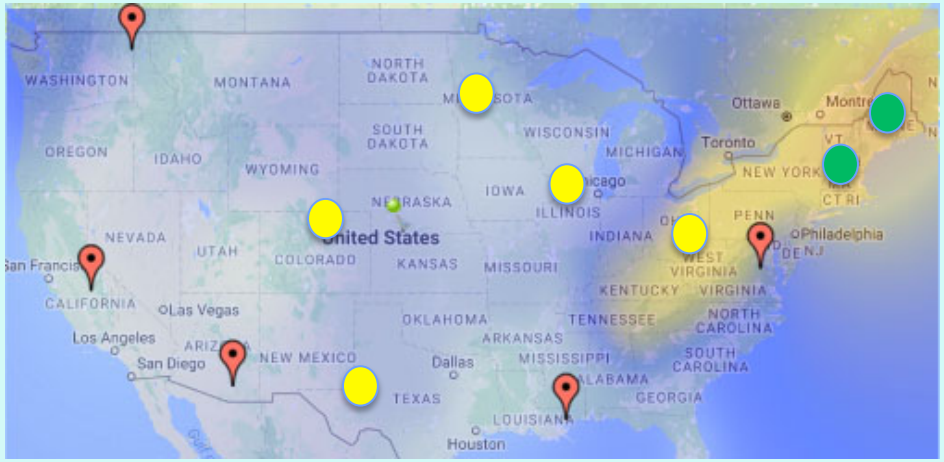
Backup slides

1. AVERT

COMPUTATIONAL PHYSICS, INC.

Local situational awareness of GIC conditions for power utility planning and ops

AVERT real-time induced electric field hazard map: GIC hazard analysis for power utility research, planning and operations



Above: AVERT with SHM sites (existing ; planned 2017)

Space Hazard Monitors (SHM)
Magnetometer installations for monitoring GIC hazard

Designed to meet power industry standards

Remotely deployable and fully autonomous

CONTACT INFORMATION
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gannon@cpi.com

Supported by NSF project EAR-1520864, in partnership with Hennepin County Emergency Management, GIC Magnetics, UIUC, TAMU, and our utility partners.

AVERT – Real time Electric Field model

- Calculates the 1-min geoelectric field over a region or at a specific location (1-sec under development)
- Uses USGS, SHM and commercial magnetometer input
- Data access modes in development in collaboration with power utility partners
- Subscription-based and custom access available
- Web, command line, and Android/iPhone app access

SHMs – Space Hazard Monitors

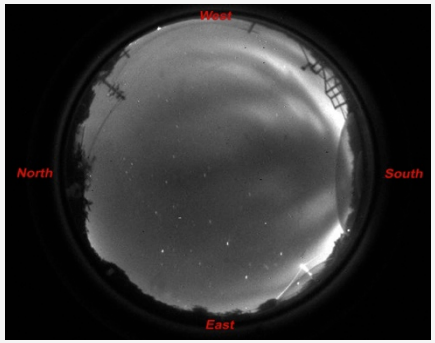
- Magnetic field and optional electric field sensors designed for power utility operations – 7 currently deployed and in operations with power utility and government partners
- 1Hz data rate
- Remotely deployable, fully autonomous
- Subscription-based data access available
- Less than 1 second data latency

COMPUTATIONAL PHYSICS, INC.

Modeling and monitoring the near earth space environment from the ground and space.

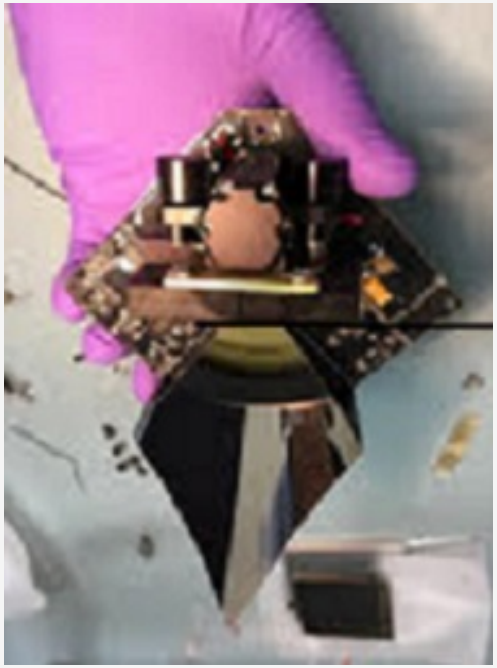
DATA PRODUCTS:
Thermospheric neutral temperatures and Doppler winds at the Arecibo and Millstone Hill Observatories.

MODELS:
AURIC atmospheric radiance model; **B3C** auroral model.



ESF plume imaged at 630 nm over the Arecibo Observatory. Image taken 20 Nov 2014 at 10:30 PM local time. ESF plumes started at about 8:20 PM.

SENSORS &



Small form factor high luminosity optics for space based remote sensing.

Ground based neutral atmosphere sensors, including imagers, spectrographs and Doppler imagers.

Remote, autonomous ground based sensing stations for monitoring TEC and the neutral thermosphere.

CONTACT INFORMATION

http://www.cpi.com
http://www.neutralwinds.com

2. AWSOME

AWSOME SEP spec & f'cast

- Forecast global SEE environment for AFW aircraft support
- Resolution: all single event effects due to GCRs, SEPs, radiation belt particles, and cutoff rigidity changes; 1x1 deg lat/lon bins; surface to LEO; 12 hour forecast
- This would become the definitive SEE operational application for UAV support

AWSOME background

- AWSOME (Advanced Weather Simulation and Operational Modeling Effort) – MDA SBIR Phase IIE project
- Server-based, real-time, operational space weather radiation environment, coupled with operational CREME96 routines that produce spectra for linear energy transfer (LET) of high Z (HZE) particles, protons, and electrons
- Those outputs linked with user-supplied (modular) parts lists and Satellite Tool Kit (STK) trajectories for real-time assessment of single event effects (SEEs) and bit error rates (BERs)
- Specified for volume cells (latitude, longitude, altitude) of a vehicle trajectory
- Capability (Q2 2017) at an Application Readiness Level 7 (ARL, similar to Technology Readiness Level) where functionality has been demonstrated in a prototyping environment and designed to the customer's requirements

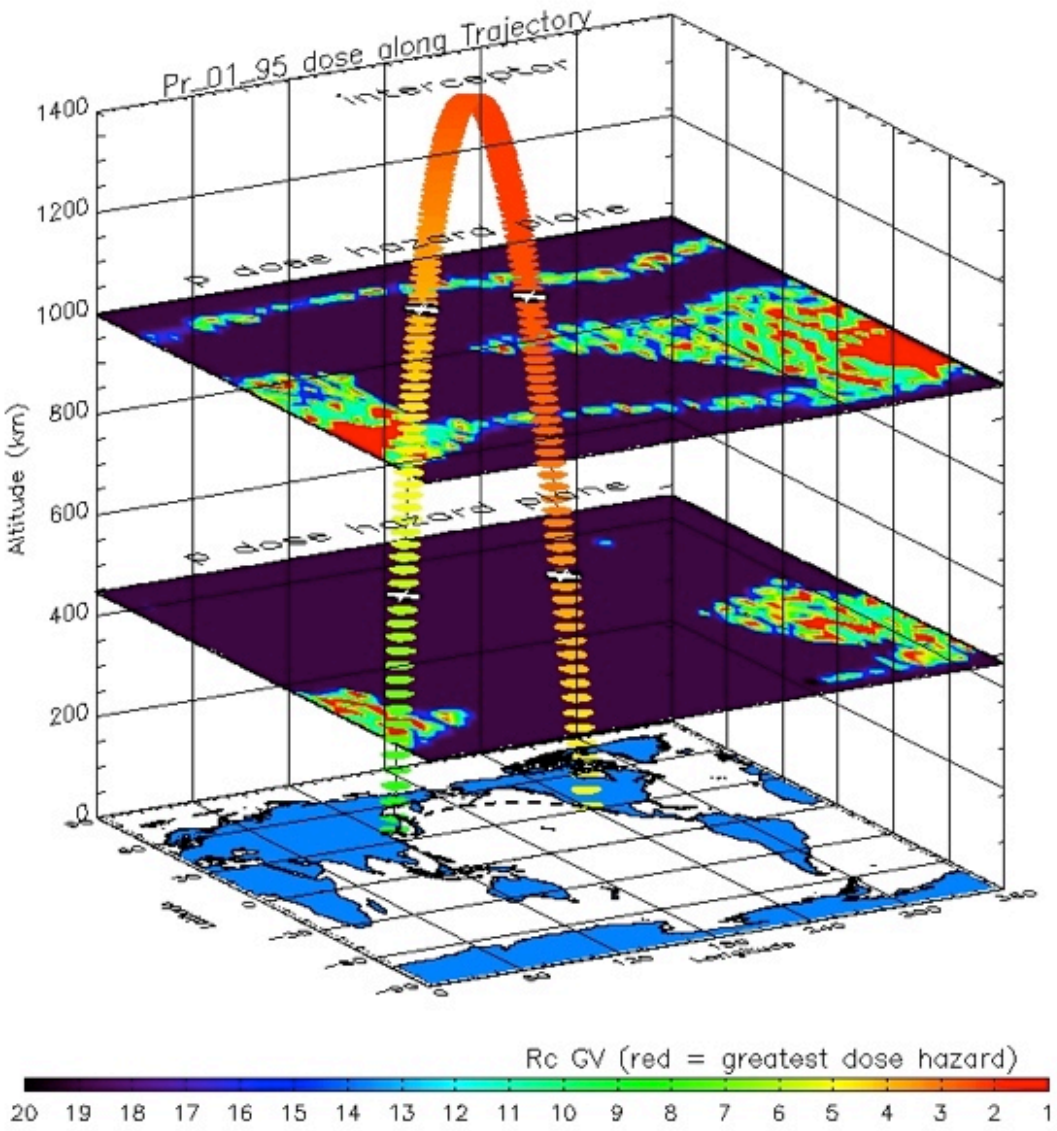
Environments background

- geomagnetic cutoff rigidities (Rc) <20 GV that dynamically specify the magnetic latitudes into which particles with given momentum and charge can enter the atmosphere based on storm or substorm conditions
- galactic cosmic rays' (GCRs) spectra for elements from Z=1 to Z=92 that dynamically change with solar cycle modulation
- solar energetic particles' (SEPs) spectra for elements from Z=1 to Z=92 that dynamically change with solar flare and coronal mass ejection phenomena
- Van Allen radiation belt trapped particles' (TPs) fluxes at multiple energy and altitude levels

SEE background

- Server-produced CREME96 output LET and proton spectra are composites of the GCR, SEP and TP components, modified by the Rc
- These are inputs into the HUP, PUP, and SHIELDOSE2 algorithms that produce SEEs for a user-specified parts list
- The decision-aid tool resulting from the AWSOME system is a real-time, updating, red-yellow-green hazard coded interceptor trajectory, based on a user-specified SEE, dose rate, or BER rate threshold

Dose in parts shown as RYG trajectory that is produced for operations – can just as easily be applied to UAV flight tracks

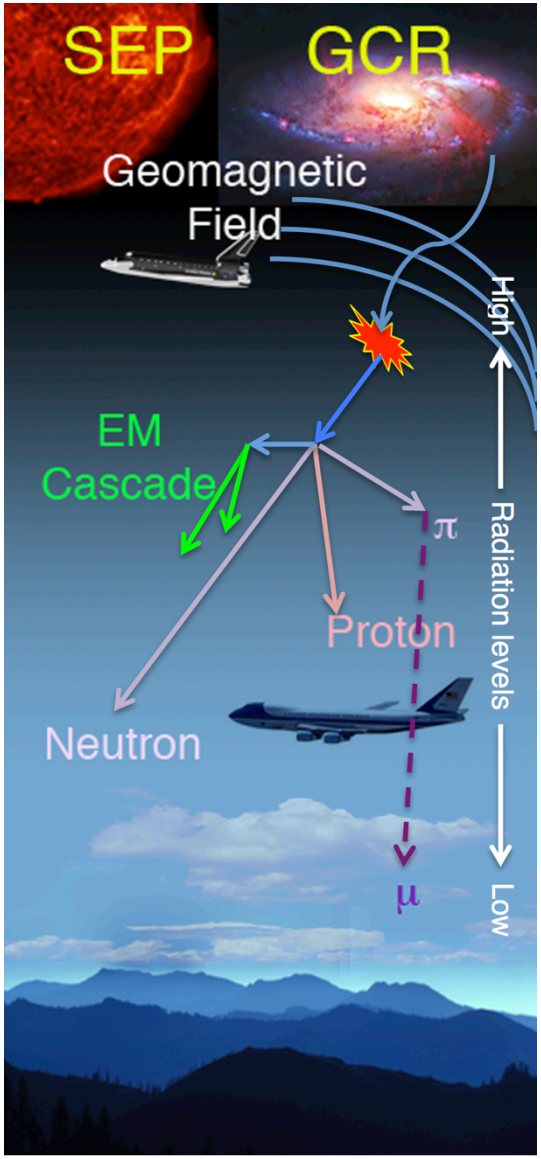


Tobiska

2. ARMAS

Aviation radiation monitoring

- Forecast global human dose environment for AFW aircraft support
- Resolution: 1x1 deg lat/lon bins; surface to LEO; 12 hour forecast
- This would become the definitive pilot and crew operational application for high-altitude (>8 km) aircraft support



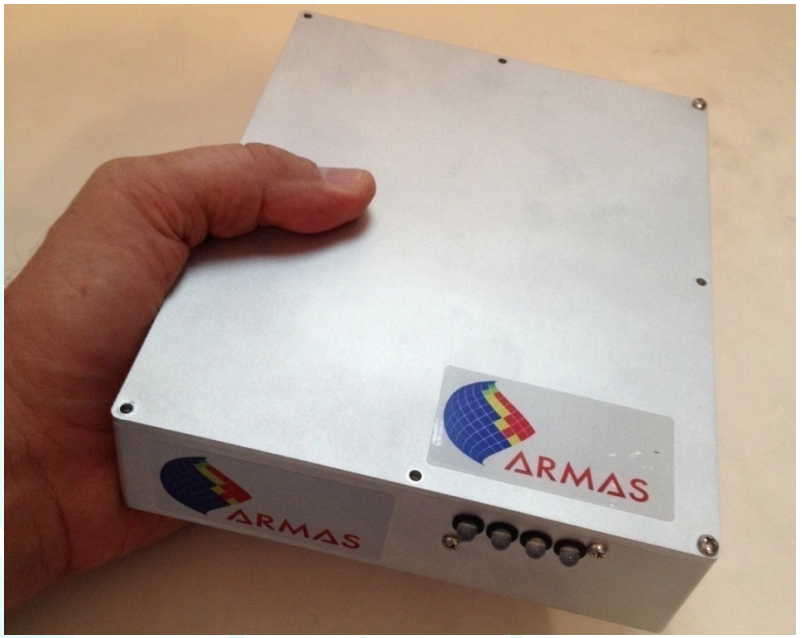
Space weather creates a dynamic radiation environment at aviation altitudes

Aviation radiation exposure can come from

- ✓ **global phenomenon** GCRs (career health issue)
- ✓ **high latitude phenomenon**
  - ✓ **Extended major events** SEPs (fleet operations and aircrew/passenger safety issue)
  - ○ **Possible short-term minor events** precipitating outer radiation belt energetic electrons (career health issue)?

Six ARMAS FM2 units deployed thru 2016

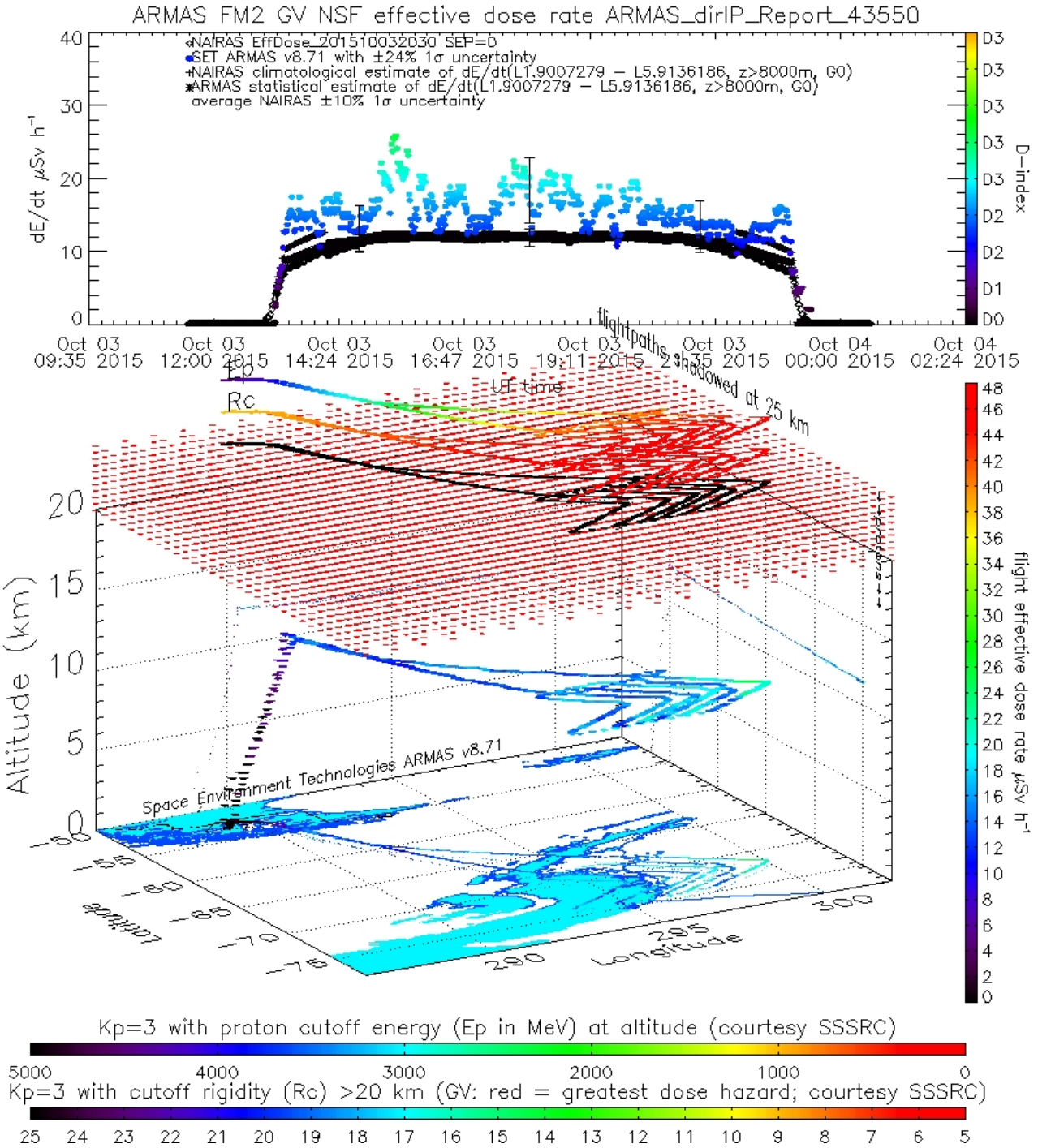
- **Korea Space Weather Center** purchased two FM2s as part of ARMAS Phase IIE
- FMxs were deployed to **NASA** DC-8, **NOAA** G4, **NSF** G5, **NASA** ER-2, **FAA** Bombardier G-5000, **commercial** Boeing and Airbus jets
- Data became available starting June 2013




NSF G5

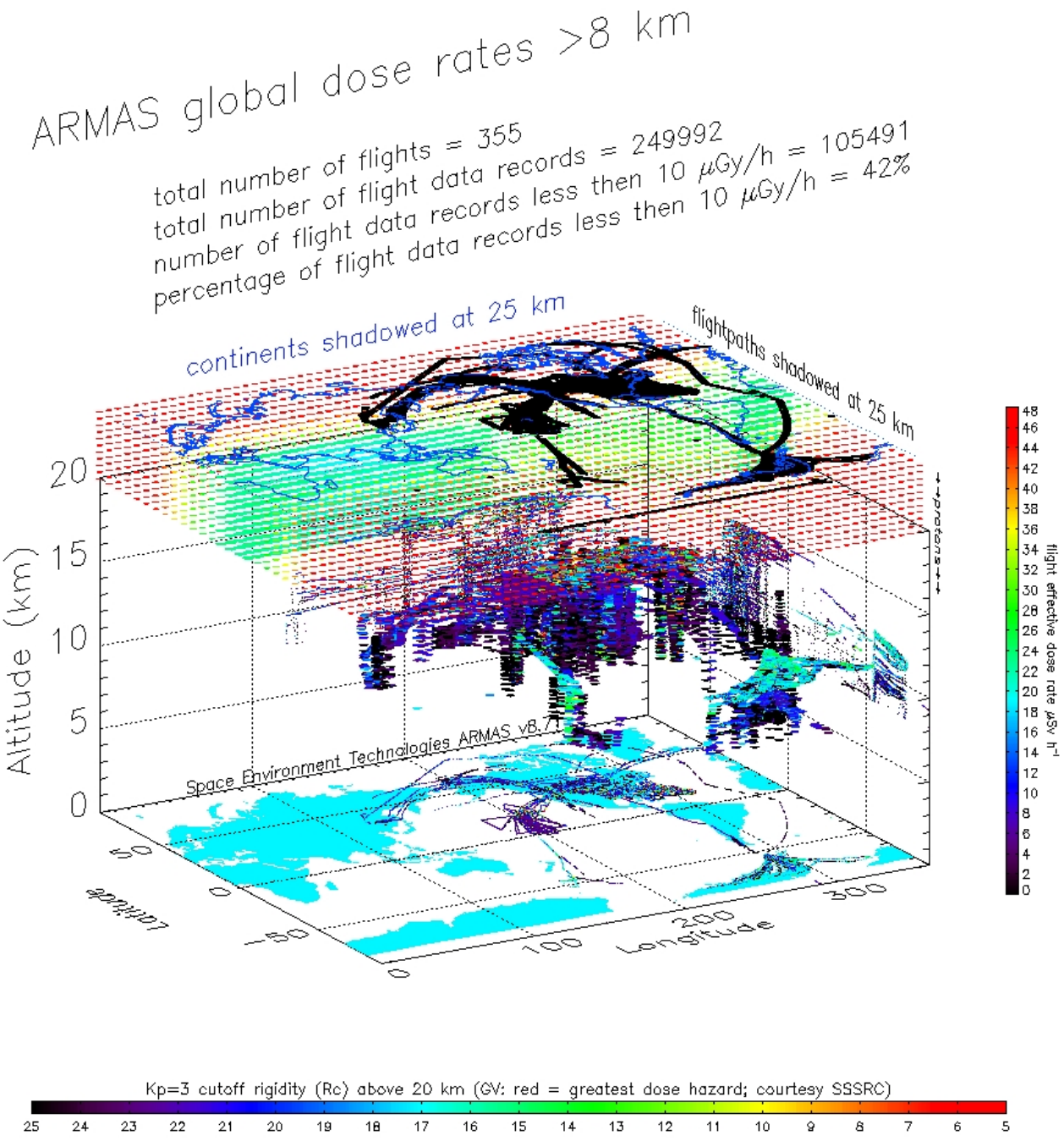

NOAA G4

Example o
October 3
2015 NOA
G5 flight
over
Antarctic



Tobiska

Global ARMAS dose rates above 8 km as of September 2017



Tobiska

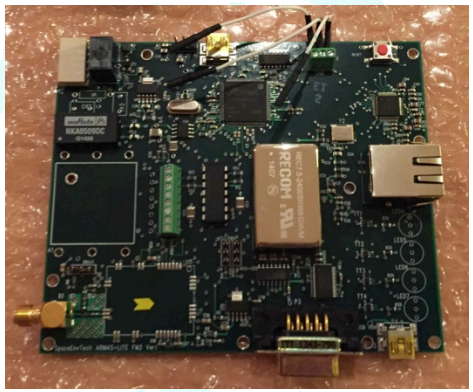
Global and regional loiter and monitor for months

Credit: World View

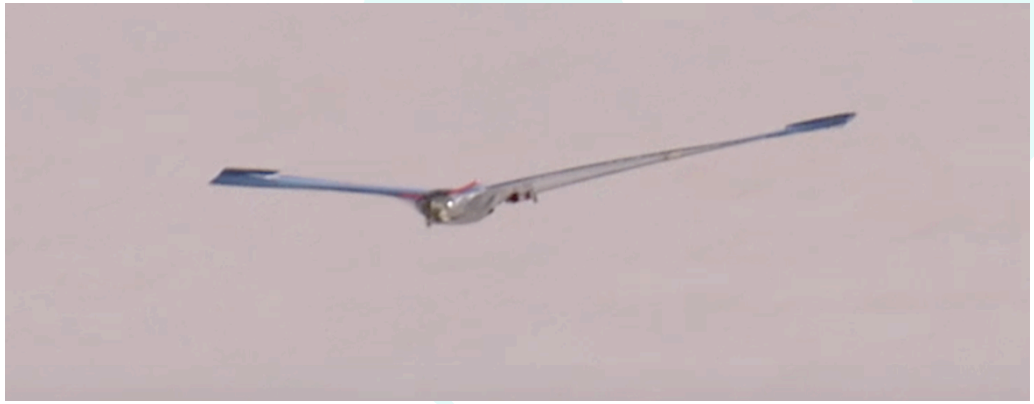
World View deployment

- Stratospheric balloon flight in 2018 under MOU between World View and SET
- Data will be extended to ~40 km as a World View pathfinder payload

High-altitude deploy/monitor with high time and spatial res



NASA WHAATRR Glider deployment



- Data will be captured on balloon ascent to 30 km (100,000 ft.) and on glider descent to Edwards AFB
- Small form-factor

3. Spot-On

GAIM TEC correction maps

- Optimize GAIM overlapping regional and global grids for smooth transition at all scales
- Resolution: ≤15 minutes; 0.7x0.7 deg lat/lon bins; 2m **single frequency** GPS uncertainty
- This would become the definitive data feed for COTS applications with improved location accuracy

GPS error – ionosphere dominates

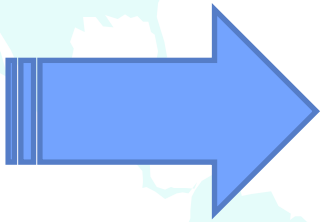
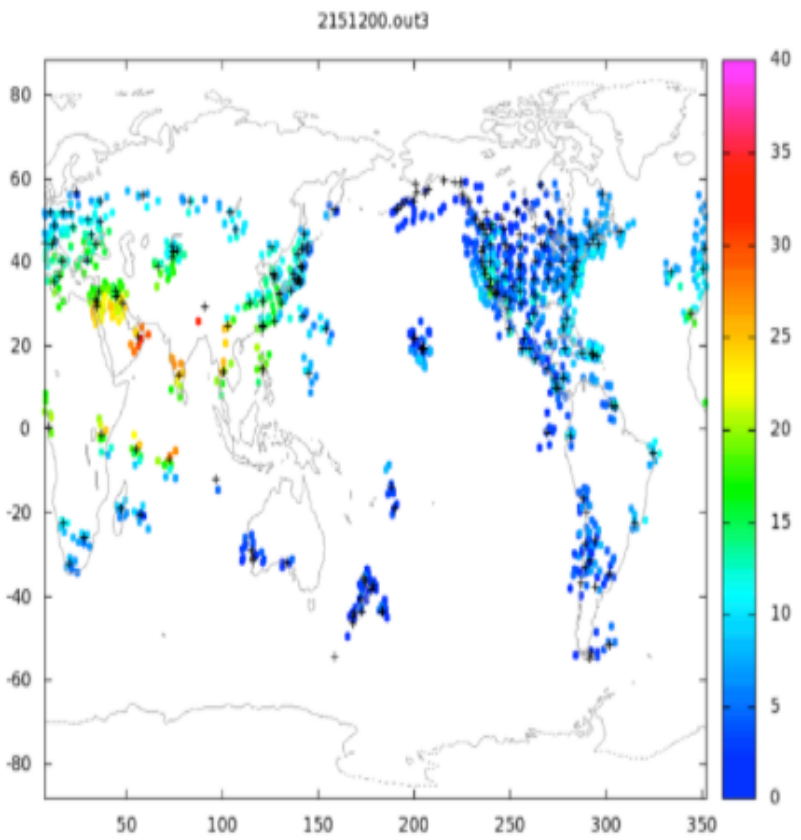


Table 1. GPS error sources/magnitudes

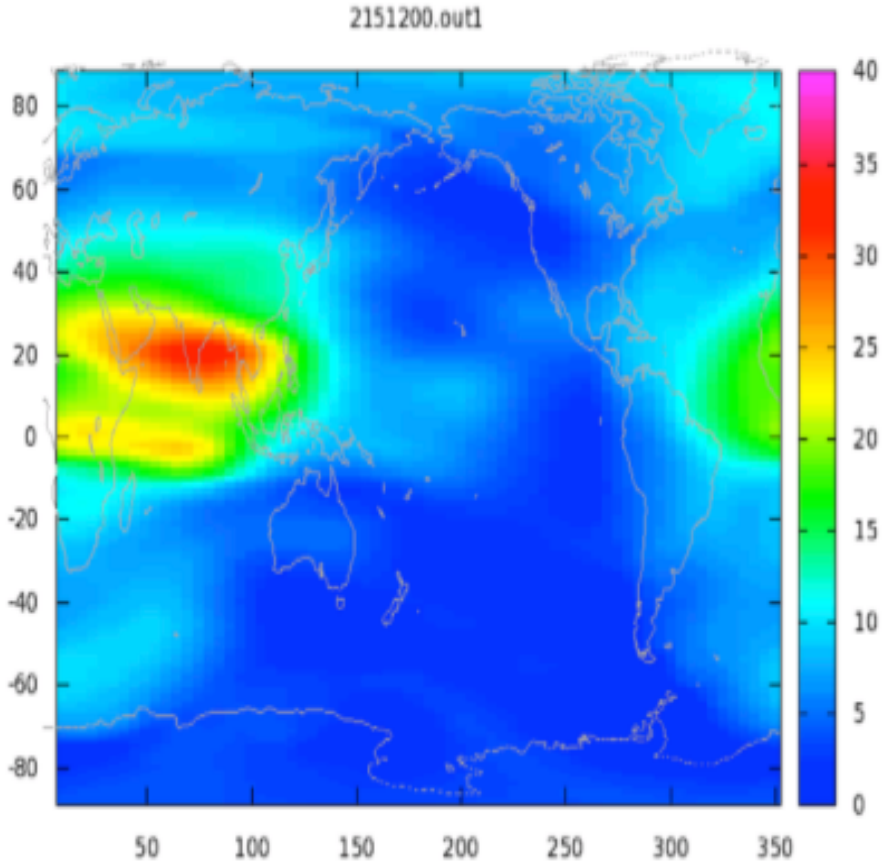
Source	Effect (m)
Ionospheric effects	±5
Signal arrival, C/A code	±3
Ephemeris errors	±2.5
Satellite clock errors	±2
Multipath distortion	±1
Tropospheric effects	±0.5

Ionosphere varies due to space weather and global TEC measurements assimilated into GAIM show that variability

TEC measurements

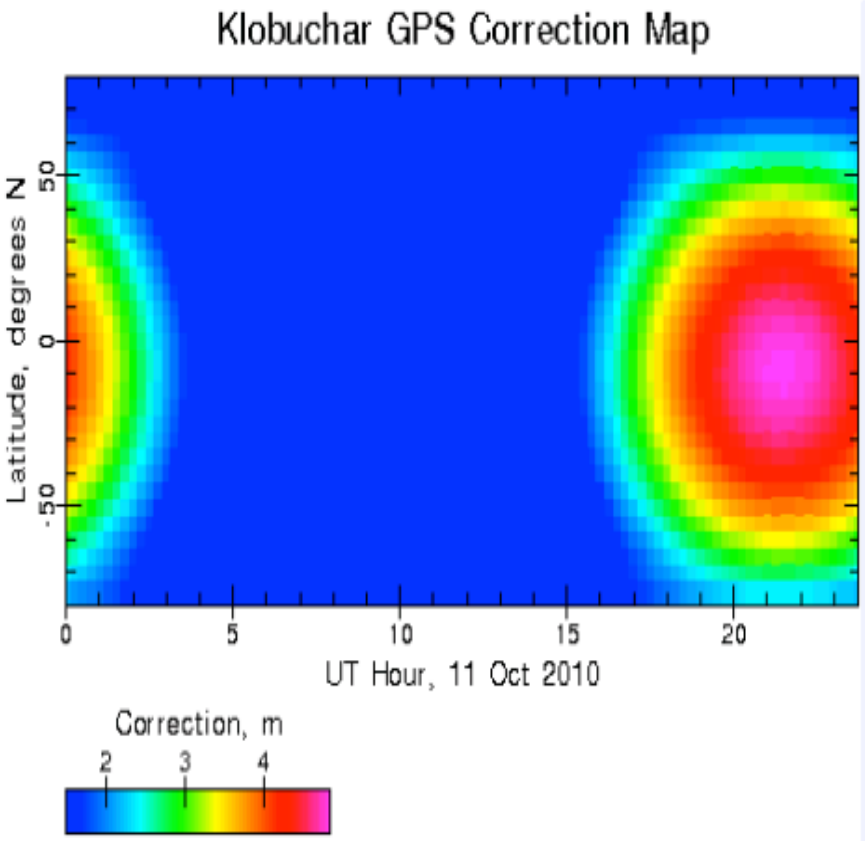


GAIM

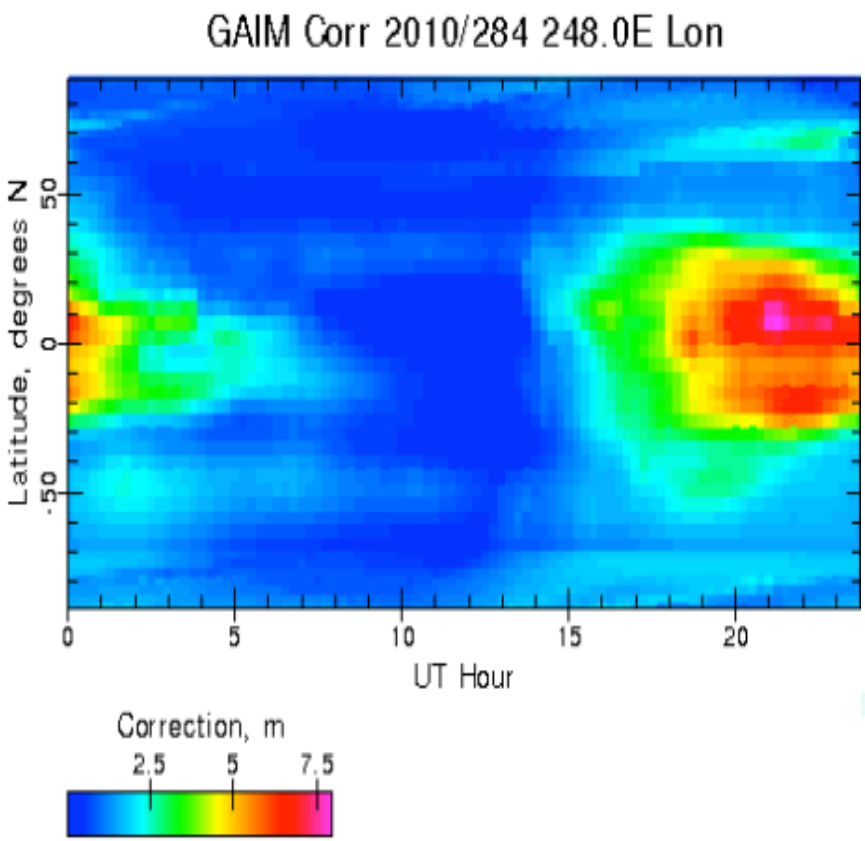


Correction methods to TEC maps for GPS

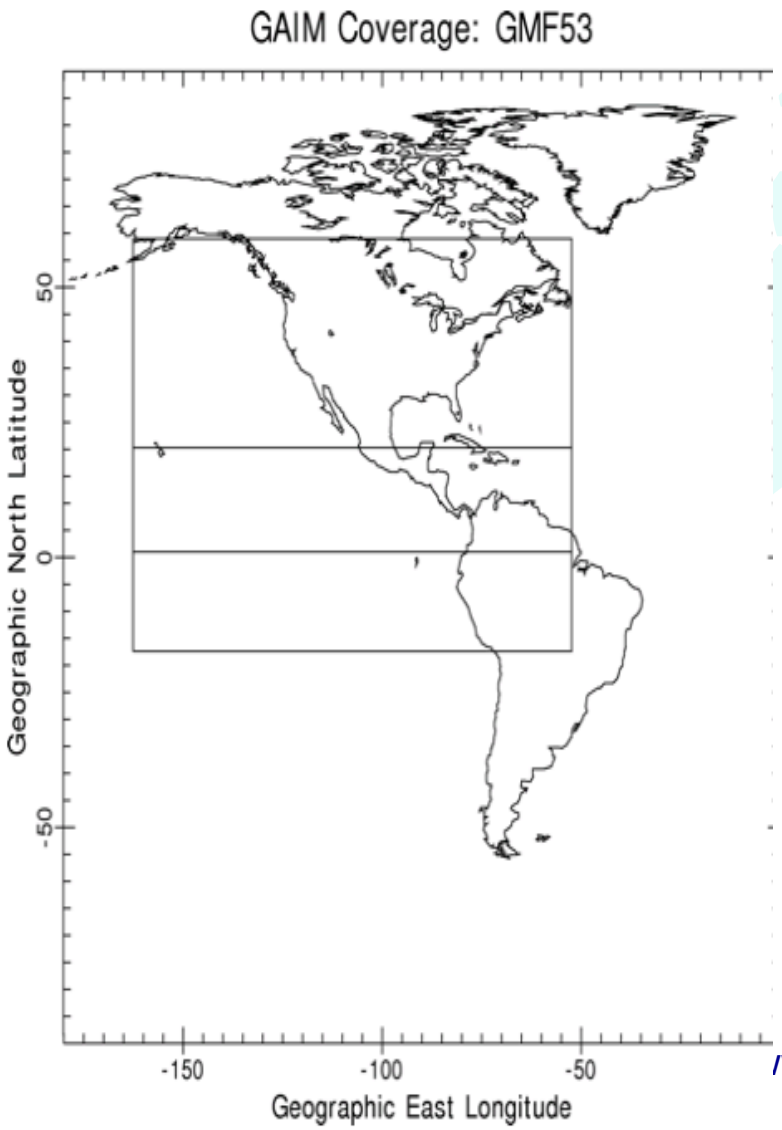
Climatology

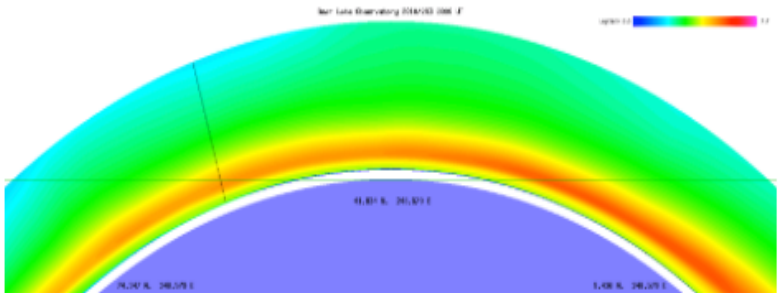


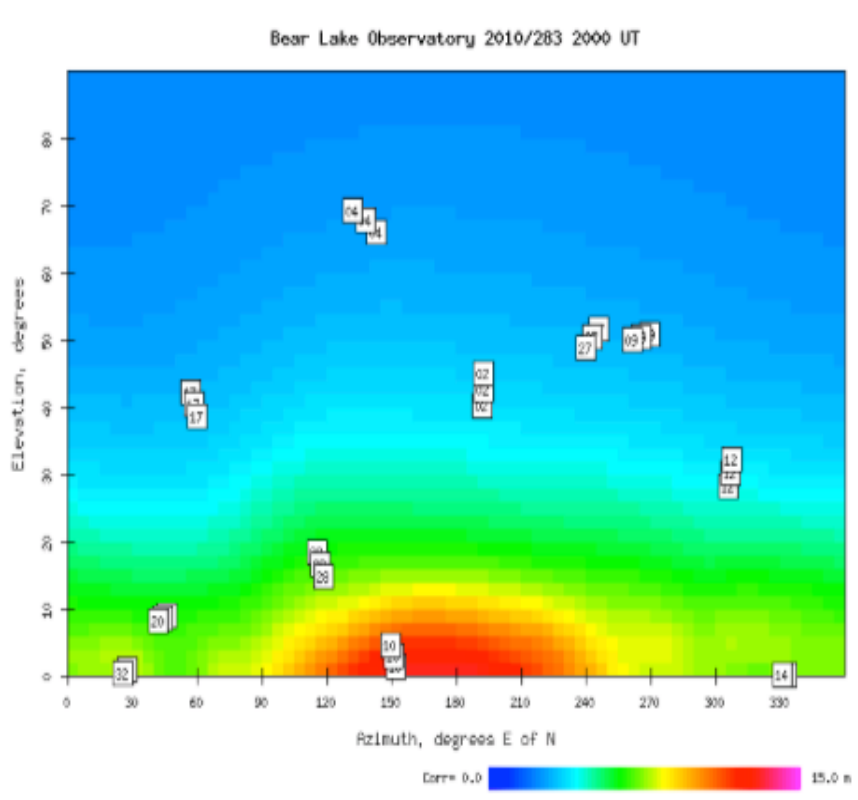
Weather



GAIM TEC geometry applied to GPS correction







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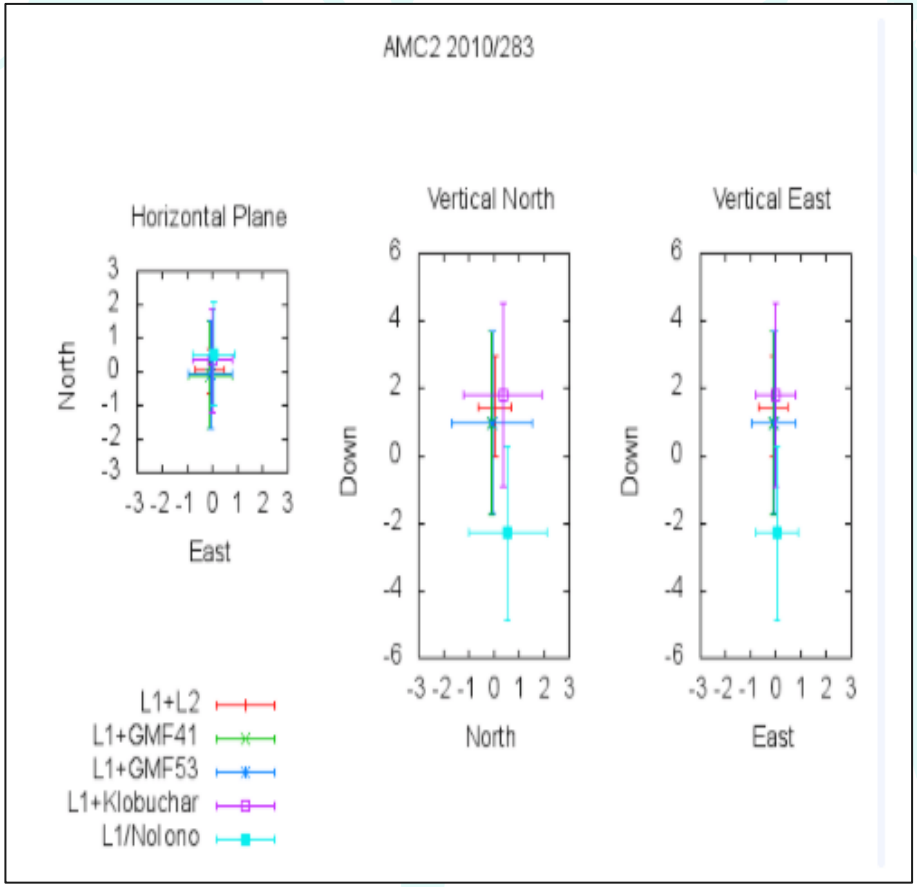
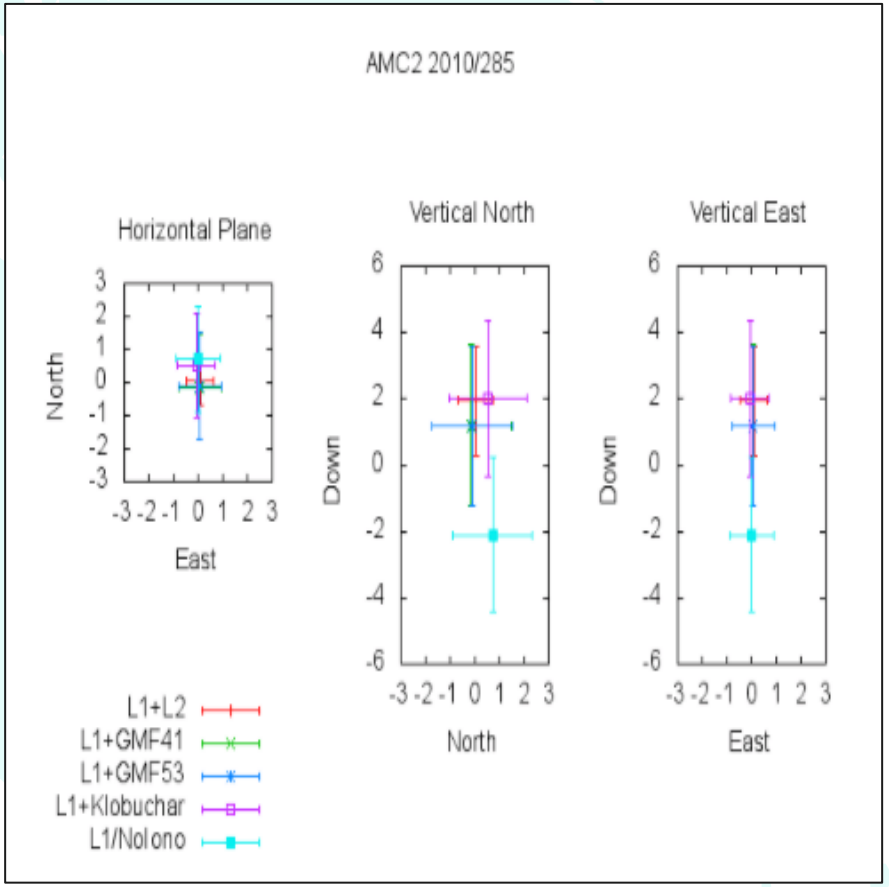
TEC error correction using GAIM



Undisturbed day



Mildly disturbed day

Spot-On results using GAIM for iPhone app

LEFT: Native iPhone accuracy, January 2012 at the Opryland Gaylord Hotel driveway ~7 meters

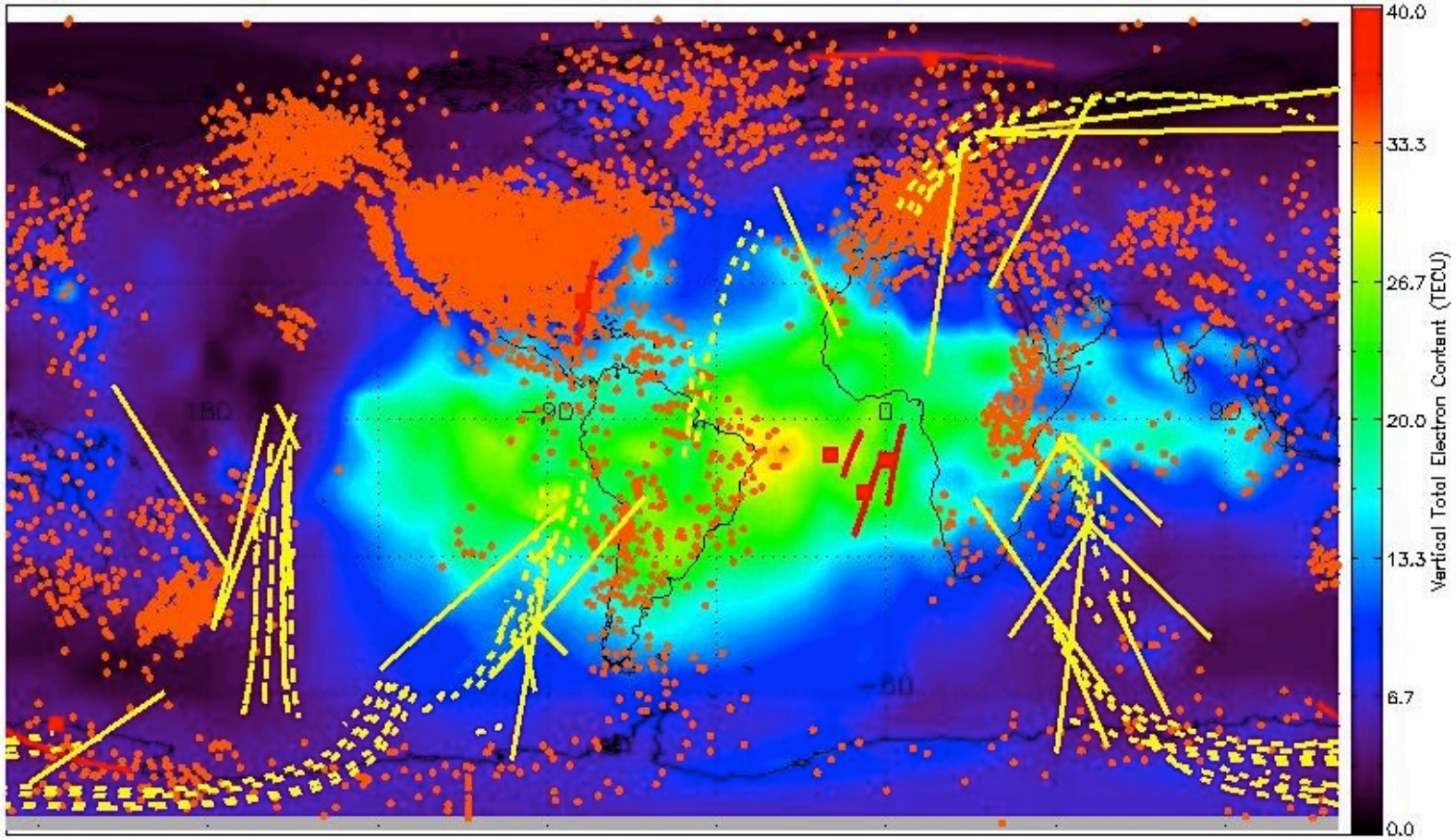
RIGHT: Spot-On corrected iPhone accuracy ~2 meters

3. Ionospheric Data Assimilation in 4-D

IDA4D Electron Density Maps

❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA



Ionosondes | Ground-based TEC | In situ Ne | UV
HF oblique sounders | Over-satellite TEC | GPS Radio Occultation
HF backscatter sounders | Radio Beacon | HF Vertical sounders

3. Assimilative Mapping of Ionospheric Electrodynamics (AMIE)

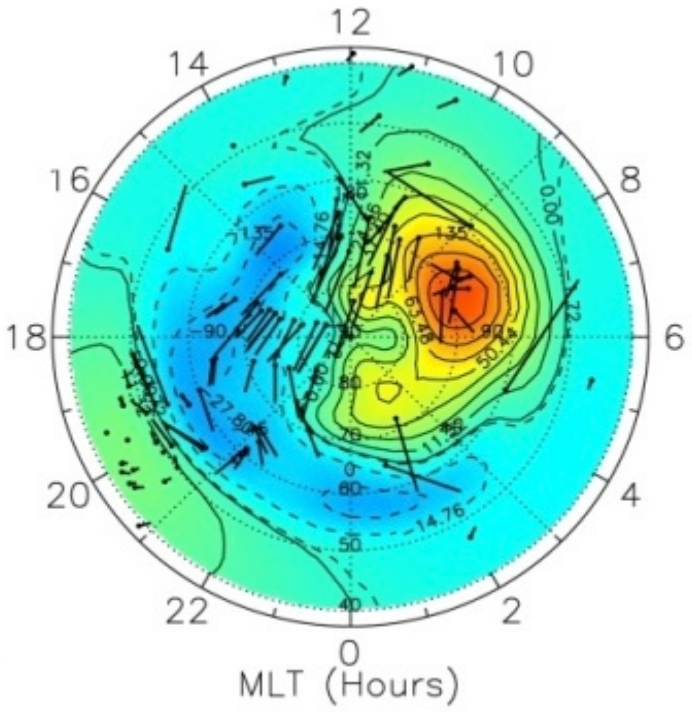
High Latitude Ionospheric Electric Fields

Are IORD requirements being satisfied?

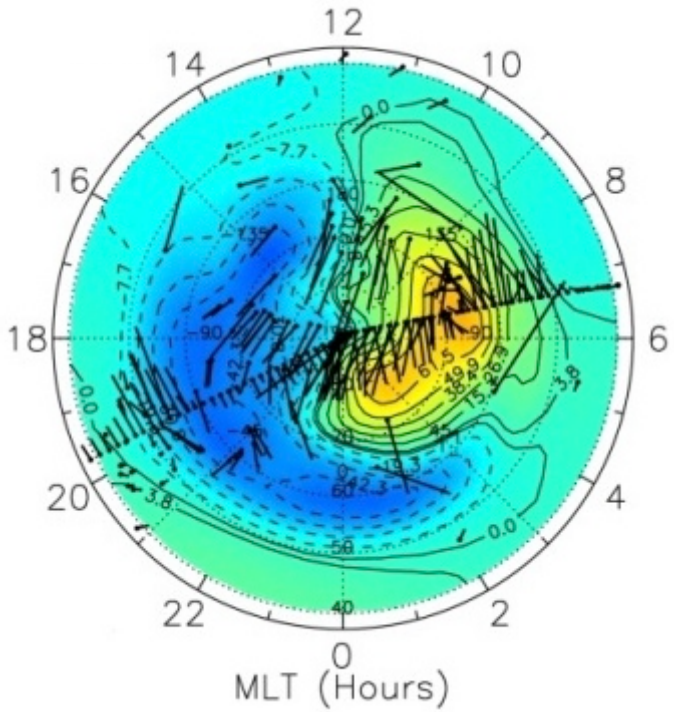
Quantity	Requirement	Goal
Range	0-150 mV/m	0-250 mV/m
Precision	±2 mV/m	±0.1 mV/m
Accuracy	±3 mV/m	±0.1 mV/m
In-track Res.	1.0 km	0.1 km

IORD requirements are not being met globally and temporally

Ground-based data only



DMSP Satellites Added



Model Transition to Operations

Transition of TIMEGCM and AMIE to Realtime Operations

Modeling

Data Assimilation

Data Analysis

TIMEGCM

AMIE

Space Based Data

ACE solar wind

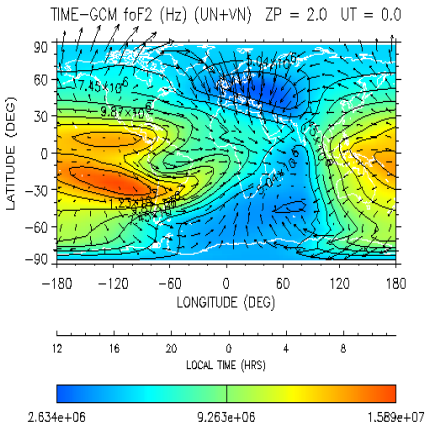
DMSP

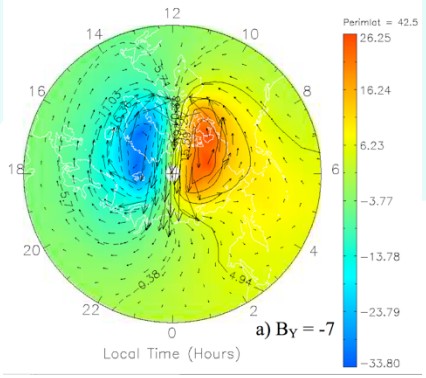
AMPERE FACs

Ground Based Data

magnetometers

SuperDARN





ASTRA works closely with customers to transition research codes to operational status

3. CASES & GAMMA GPS Receivers

ASTRA GPS Receivers

❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

- Superior performance in scintillation
- Standalone system (*internal computer*)
- Low power (2.5W)
- Cost-effective instrument
- Made in the USA
- Remote re-programmability
- Full control of receiver behavior, products
- *Good educational tool (Scales et al., VaTech)*

Dual frequency (L1 and L2C)
GAMMA GPS Receiver

Data Type	Per Channel High Rate Data	Per Channel Low Rate Data	Per Channel Scint Params	Other
Default Data Rate	**100 Hz**	**1 Second**	**60 Seconds**	**1 Second**
Configurable Rate?	Yes, 50 or 100 Hz	Yes, >= 1 Second	Yes	Yes, >= 1 Second
Available Parameters	• Integrated Carrier Phase • In-Phase Accumulation • Quadrature Accumulation • GPS Time • Receiver Time	• Pseudorange-based **TEC** • Phase-based delta **TEC** • Pseudorange • Integrated Carrier Phase • GPS Time, Receiver Time • Doppler Frequency • SV Elevation, SV Azimuth • C/N0 • Data Validity Flag, Cycle Slip Flag • Signal Acquisition Status • PRN, SV Health	• S_4 • σ_φ • τ_o • Scint Power Ratio • GPS Time • Reference Channel Status • PRN	• Receiver X/Y/Z Position • Receiver X/Y/Z GPS Time • Receiver Time • Velocity • Receiver Clock Error • Receiver Clock Error Rate • Nav Solution Flag

R2O and O2R in GPS Receivers

❖Science ❖ Technology ❖ Applications

Bringing It All Together

ASTRA

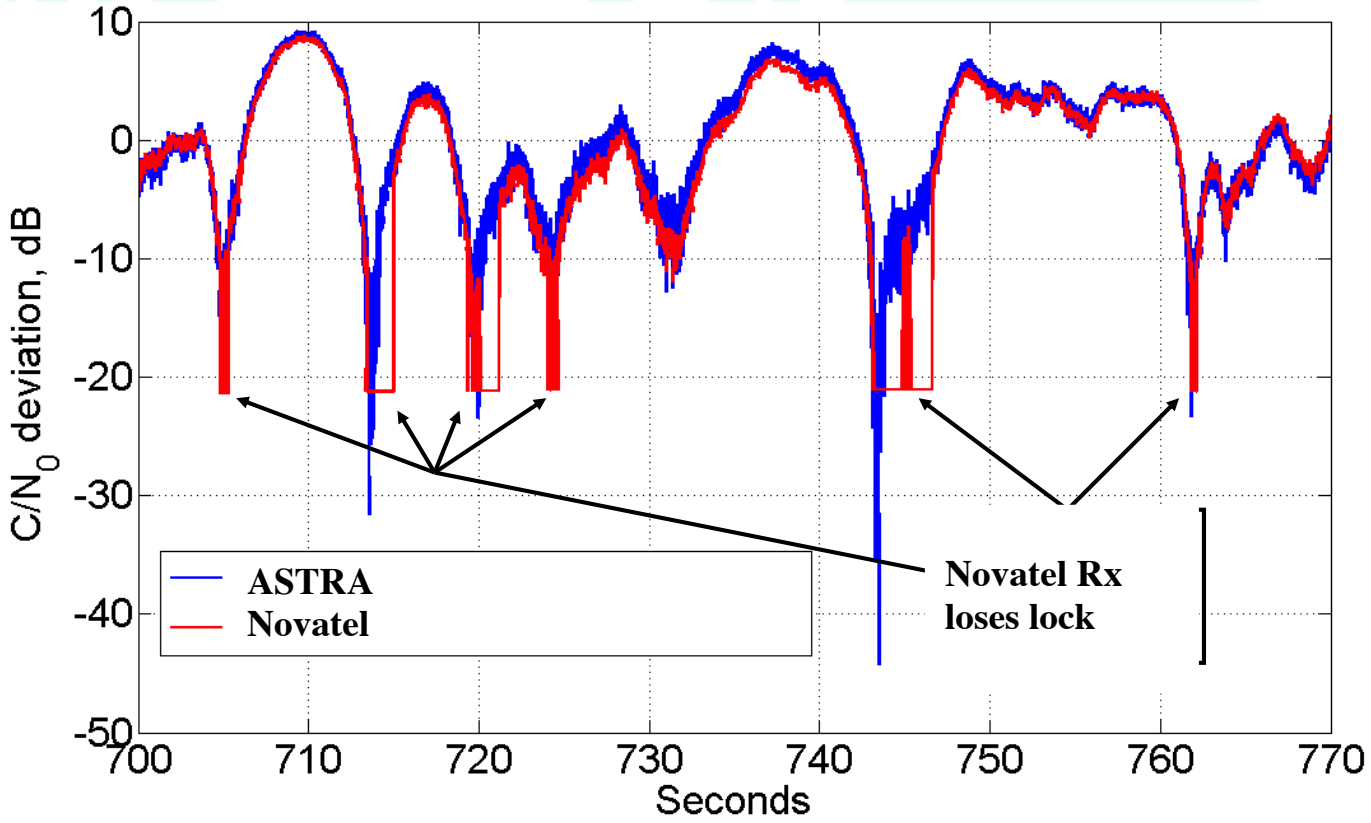
Customer-driven Development

Reduced size, weight, and power

CASES (2009) **2nd Generation**	**CASES SM-211** (2011) **3rd Generation**	**CASES Antarctic** (2013) **4th Generation**	**GAMMA** (2014) **5th Generation**
(TRL-1) TRL-4	TRL-8	TRL-8	TRL-9
15W Prototype	**7.5 W (lower voltage) Commercial Quality**	**Form-factor**	**2.5 W (components) Better computer Motion removal Commercial Quality**

Development funded by AFRL via SBIR Program

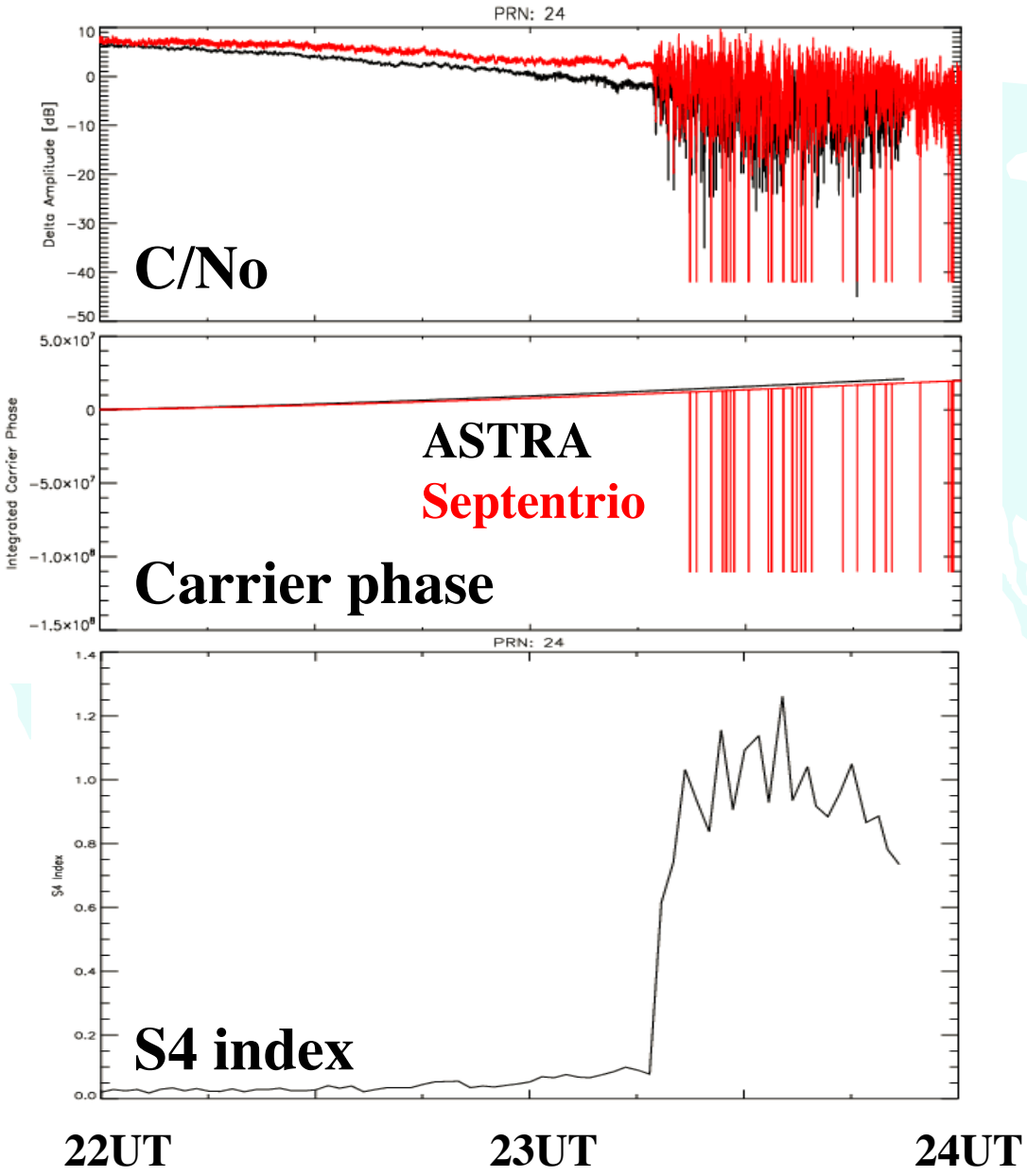
ASTRA vs Novatel Receiver



The CASES specialized tracking loop (blue trace) allows robust tracking during scintillations versus other receivers using fixed bandwidth PLL (red trace) which lose lock.

Data collected from Jicamarca, Peru at magnetic equator.

ASTRA vs Septentrio PolaRxS



Data collected in Brazil

Tracking Loops Performance

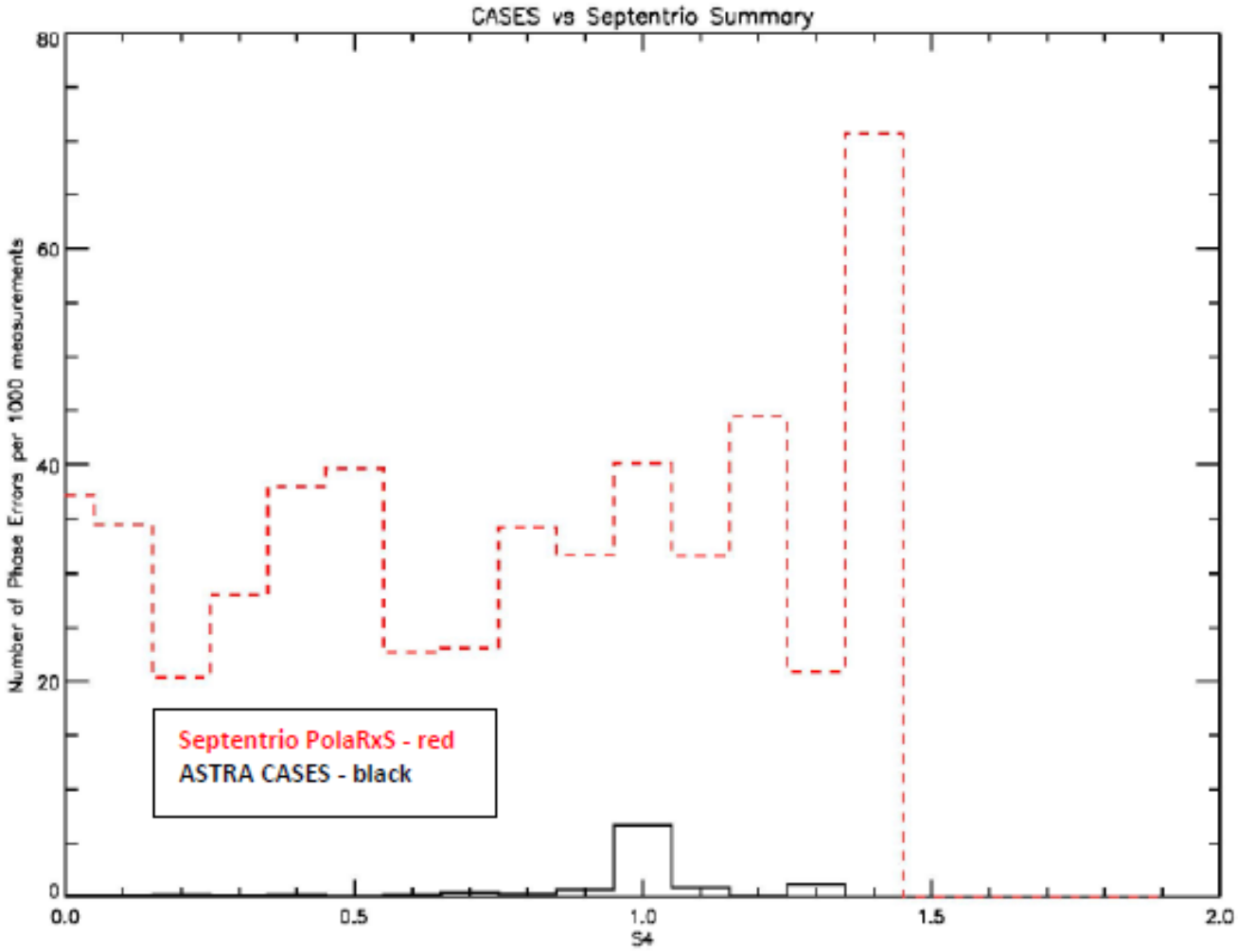
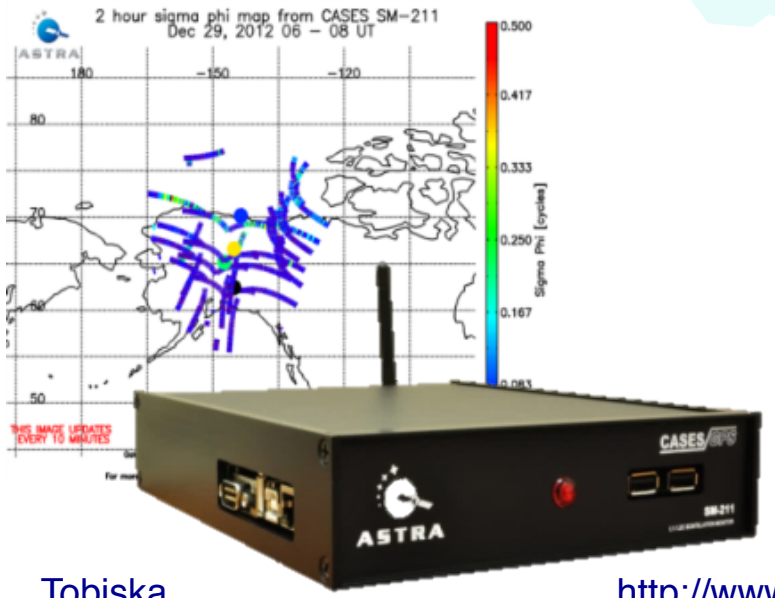


Figure A-2. Number of Phase Errors per 1000 measurements vs. Amplitude scintillation index (S4) demonstrating the tracking performances of the CASES and PolaRxS receivers over six month period.

Realtime Scintillation Monitoring

Array of CASES receivers deployed in Alaska:

- Kaktovik (70.1° N, 143.6° W)
- Toolik (68.6° N, 149.6° W)
- Fort Yukon (66.6° N, 145.2° W)
- Poker Flat (65.1° N, 147.4° W)
- Eagle (64.8° N, 141.2° W)
- Gakona (62.4° N, 145.2° W)

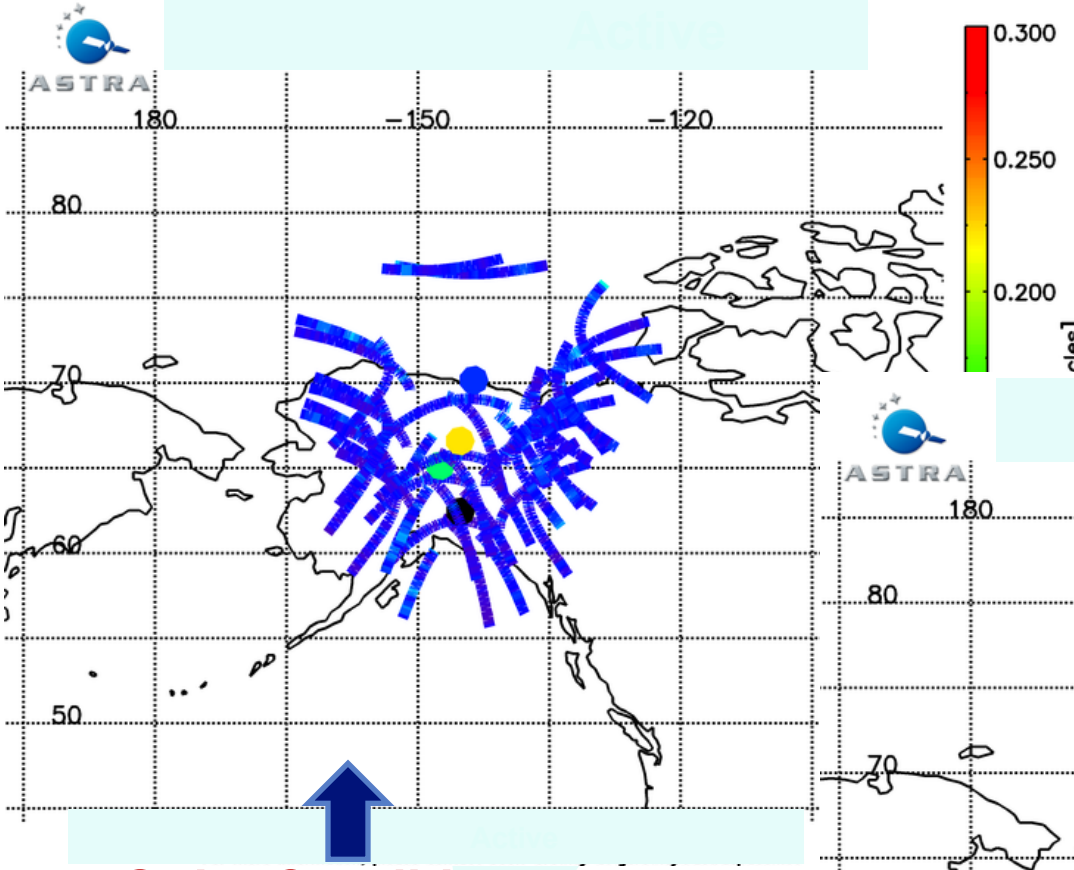


Unattended operation in remote locations since 2012

Realtime Scintillation Monitoring

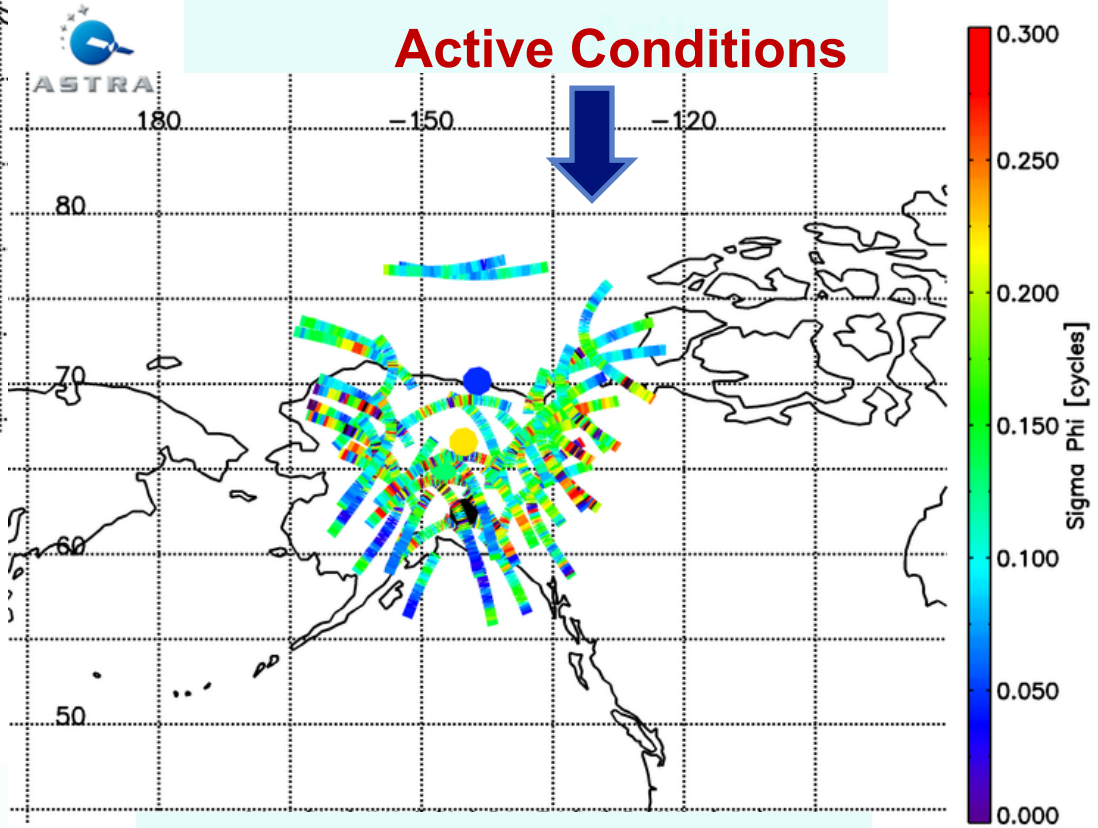
❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA



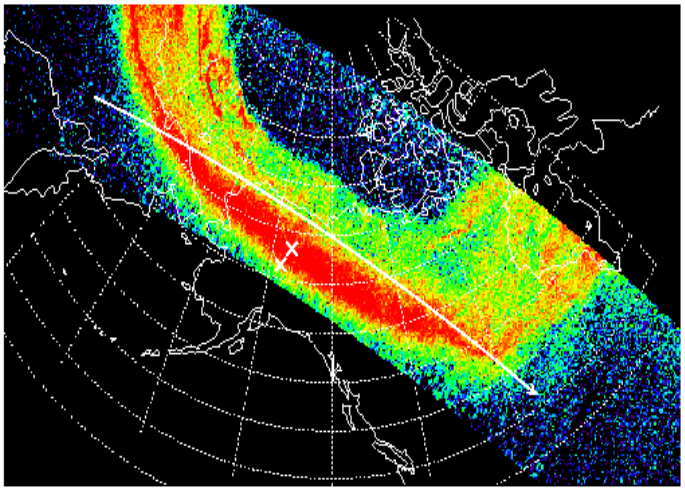
Quiet Conditions

Active Conditions

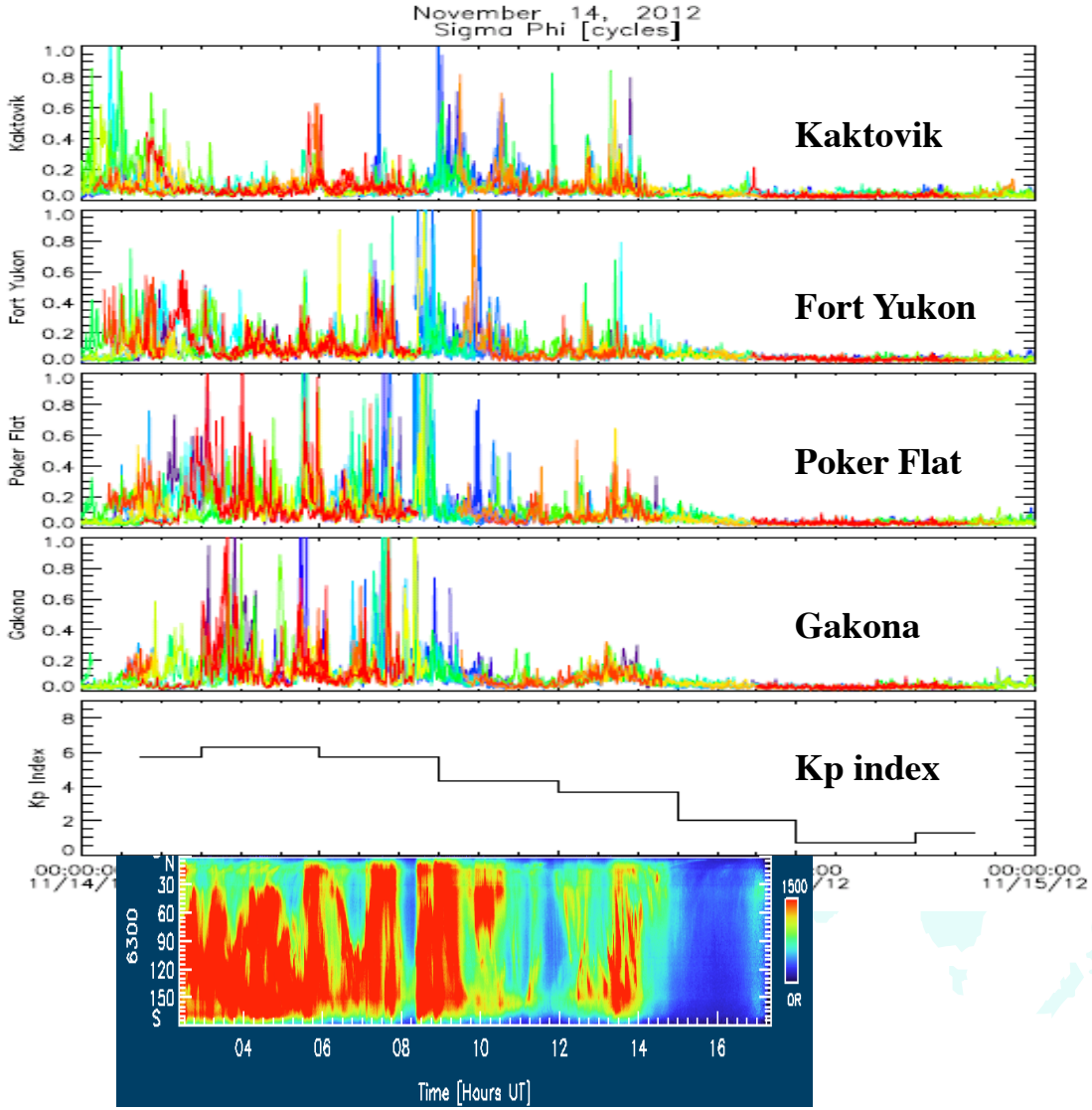


http://cases.astraspace.net

Realtime Scintillation Monitoring



Aurora over Alaska every night



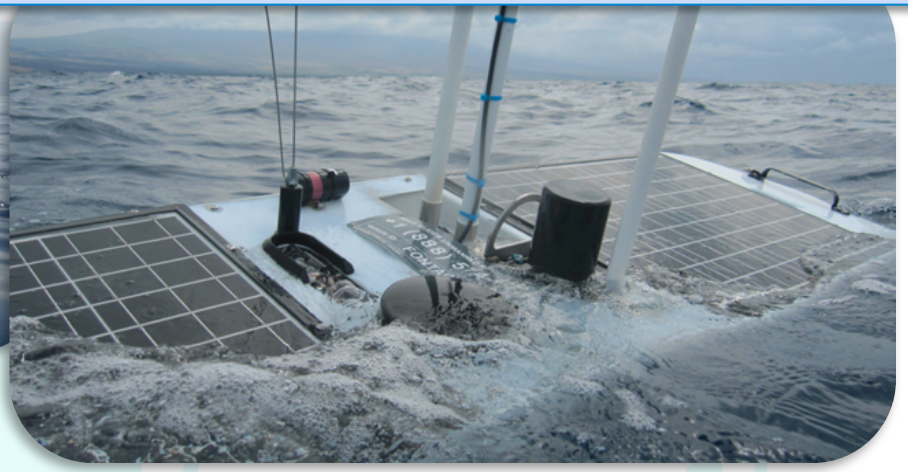
ASTRA 'CASES' Receiver

Ionospheric Monitoring from Moving Platforms

❖ Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

> ***"No one else in the World has done this…"***
> – recent quote from Technical Director of a multi-Billion dollar International Commercial Services company that provides marine data services



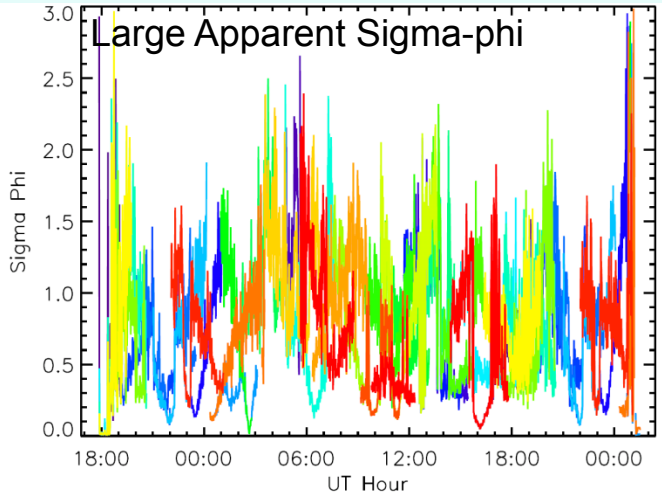
- Near real-time ionospheric data from moving platform
- Patented technique
- Data Products: TEC, scintillation data products, and system status
- Ground link via Iridium or cell towers
- Programmable data latency (Nominal 5 minutes)

Validation of Motion Removal Against Land-based Receivers

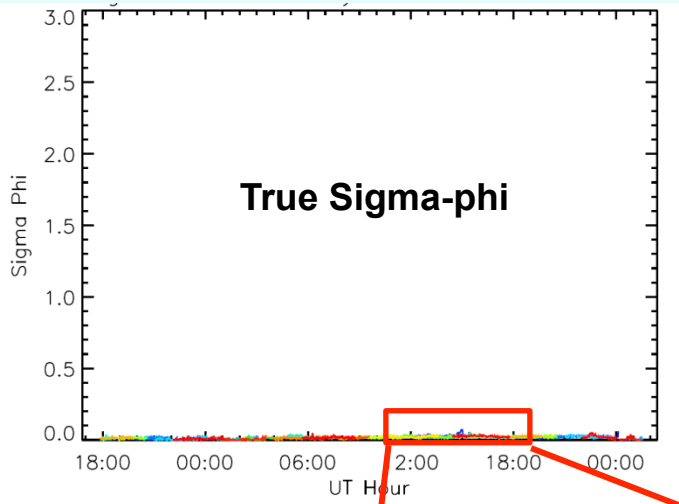
❖ Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

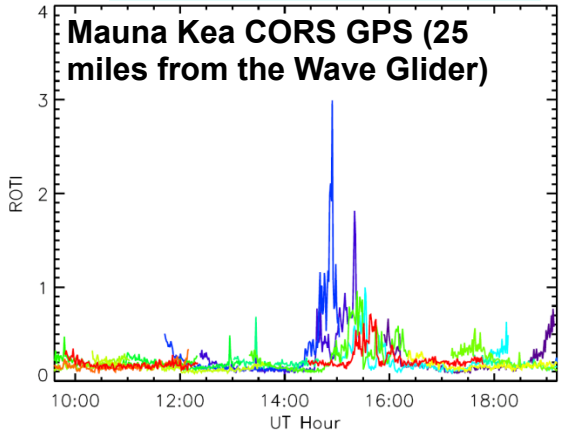
Without Motion Correction



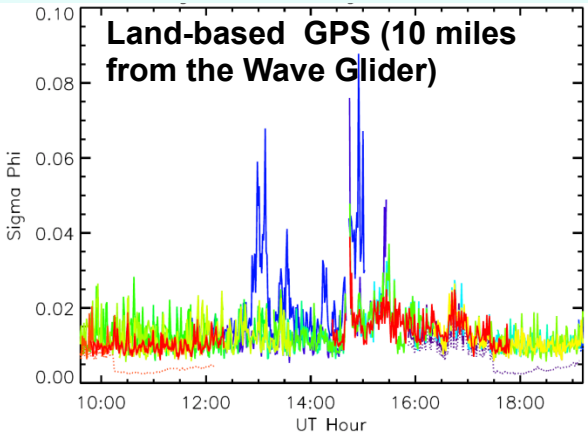
With Motion Correction



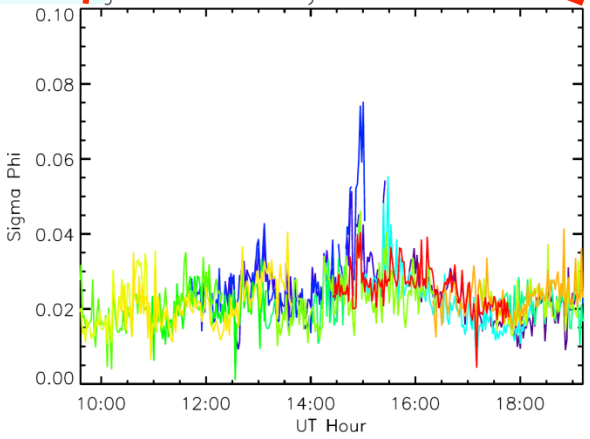
MKEA ROTI



Sigma_phi from nearby ASTRA Rx



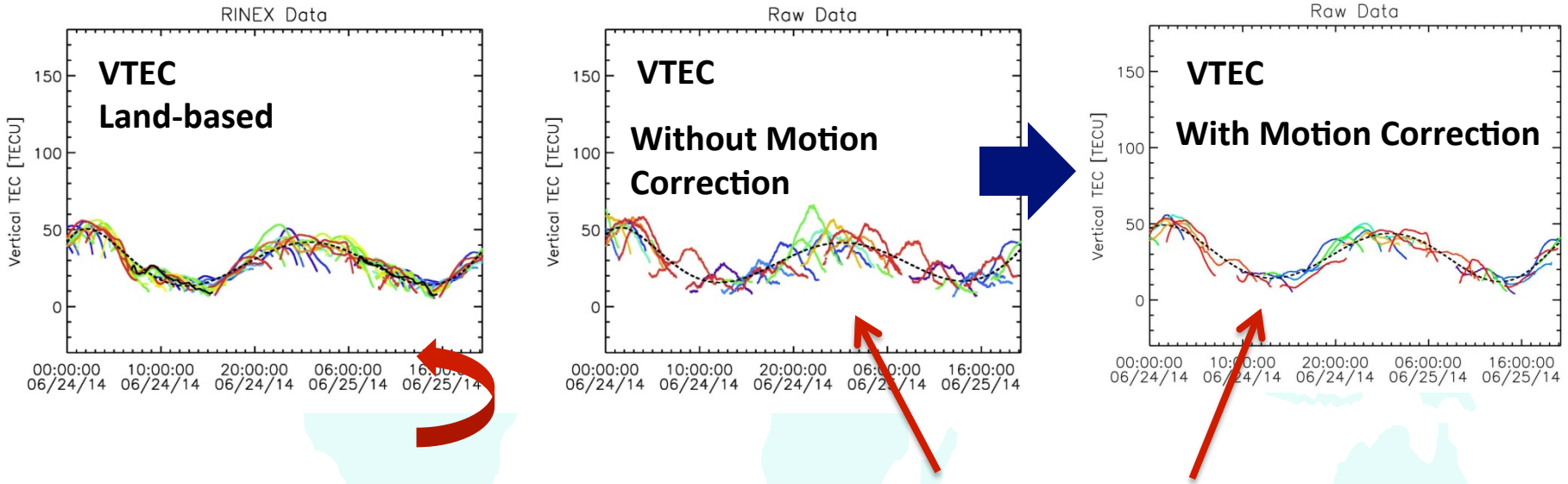
With Motion Correction



VTEC from a Buoy (Hawaii)

Land Based Measurement:
Mauna Kea CORS GPS (25 miles from the Wave Glider)

GAMMA GPS receiver on the ocean

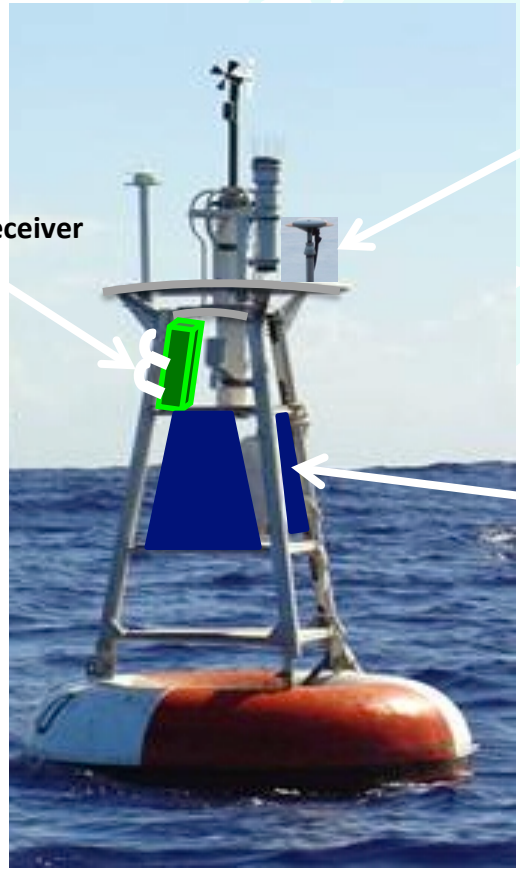


Vertical TEC from the CORS receiver at Mauna Kea.

Vertical TEC from GAMMA on the Wave Glider.

- Accurate TEC measurements are critical for extraction of TID signals.
- GAMMA GPS receiver provides accurate TEC measurements enabling TID characterization from moving platforms

Installation on NOAA Buoys



Any Moving Platform!

❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

NASA DC-8 (over 50 flights)

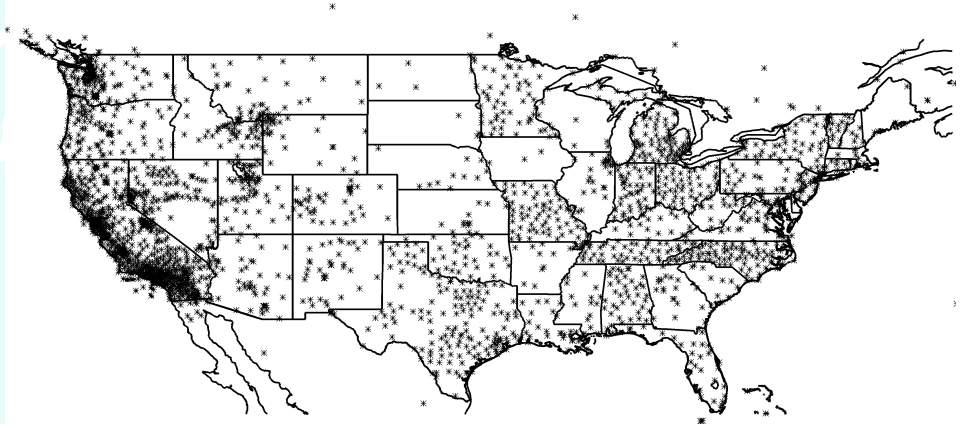
Navy Twin Otter (several flights)

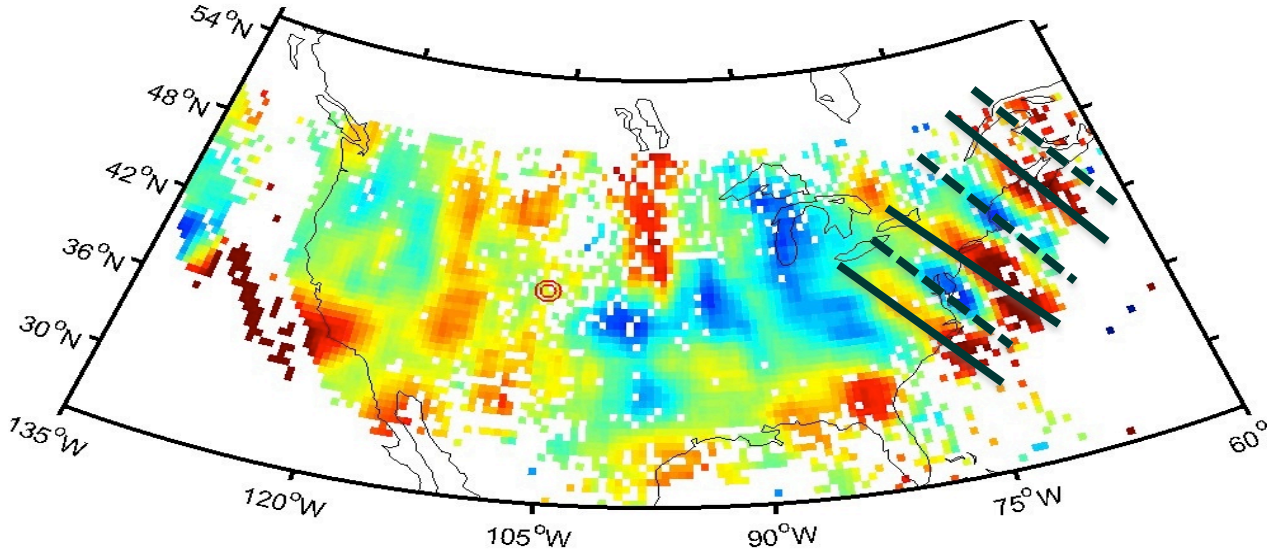
3. TID-MAP

GPS-Derived Traveling Ionospheric Disturbances (TIDs)

❖Science
❖ Technology
❖ Applications
Bringing It All Together

- ASTRA is using CORS and other GPS data for analysis of TIDs
- ~3,800 GPS receivers in the US
- 10-100 km horizontal spacing
- 30-sec sampling (decimated)



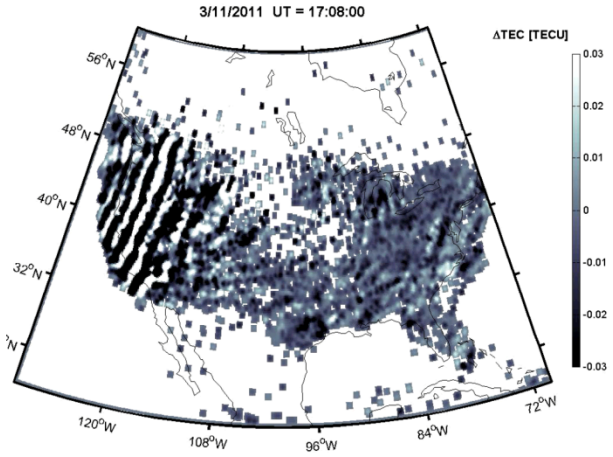


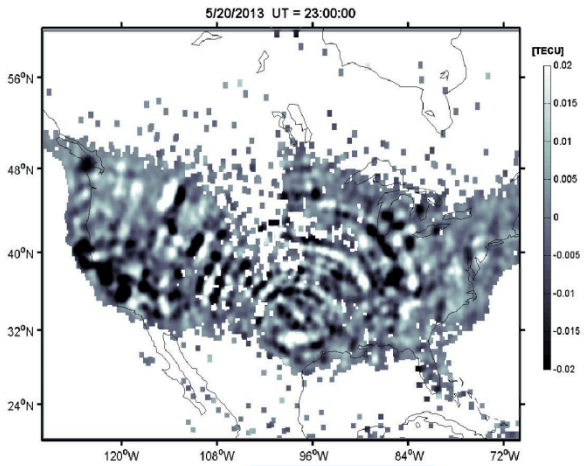
Tobiska

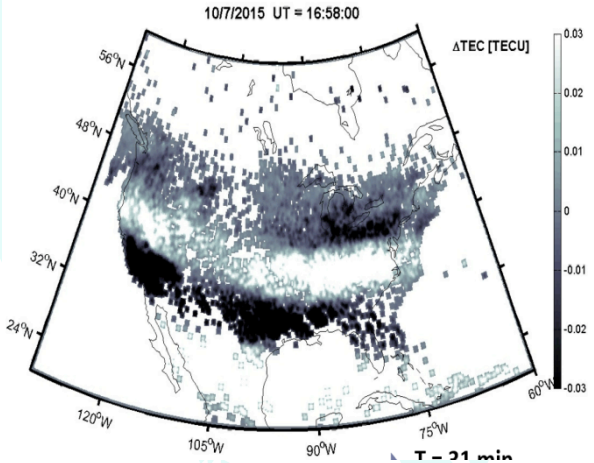
Examples from GPS TID-MAP

❖Science
❖Technology
❖ Applications
Bringing It All Together

ASTRA







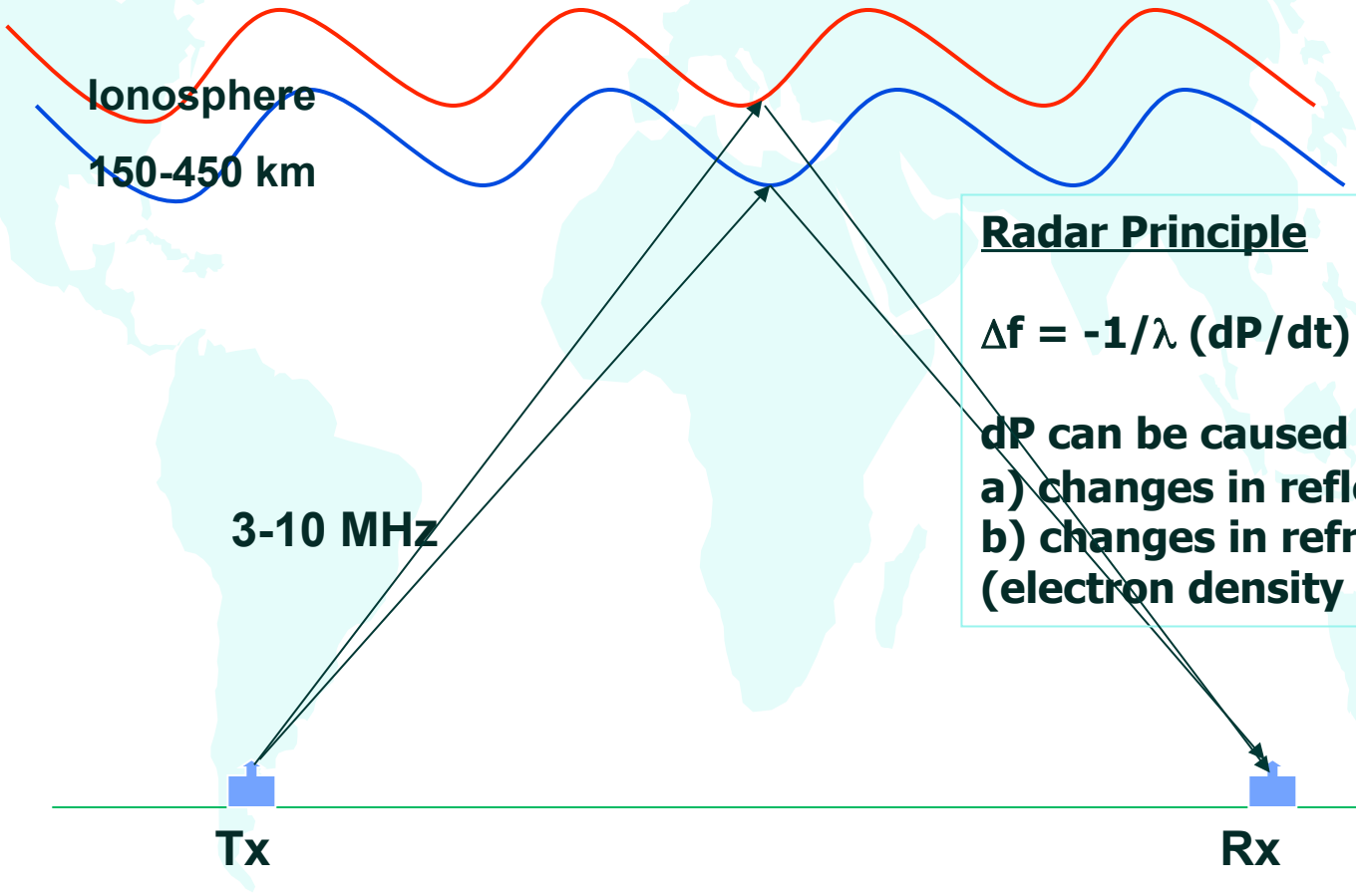
Tsunami

Thunderstorm

Auroral Source

3. TIDDBIT & CHIRP HF SOUNDERS

TIDDBIT & CHIRP HF Sounders



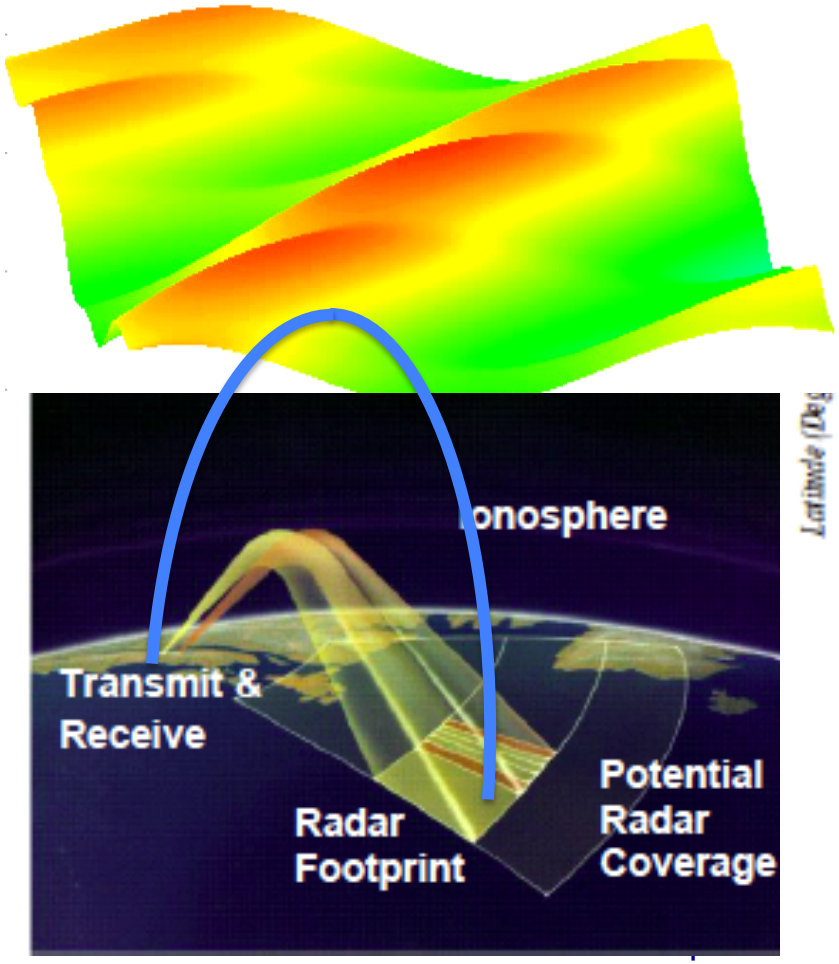
Radar Principle

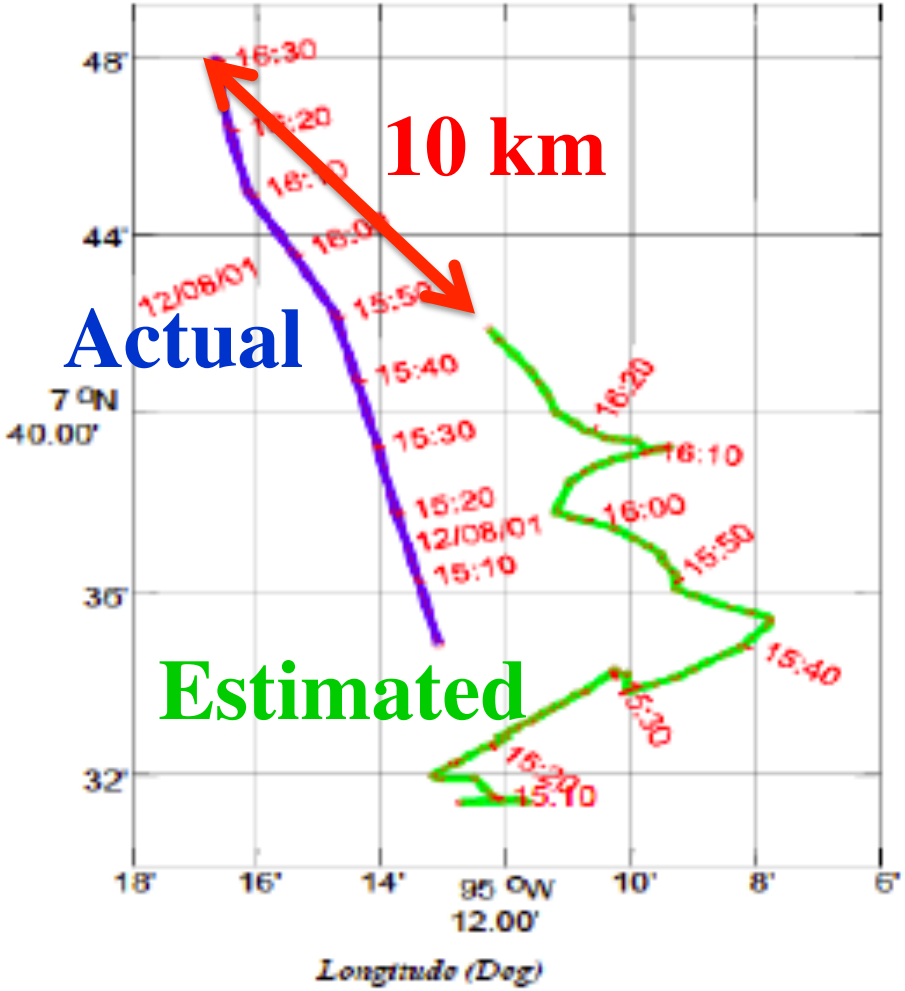
$\Delta f = -1/\lambda \, (dP/dt)$

dP can be caused by:
a) changes in reflection height
b) changes in refractive index (electron density profile)

Applications

OTH-Radar + TIDs
= Coordinate Registration Problem





TIDDBIT & CHIRP TID Mappers

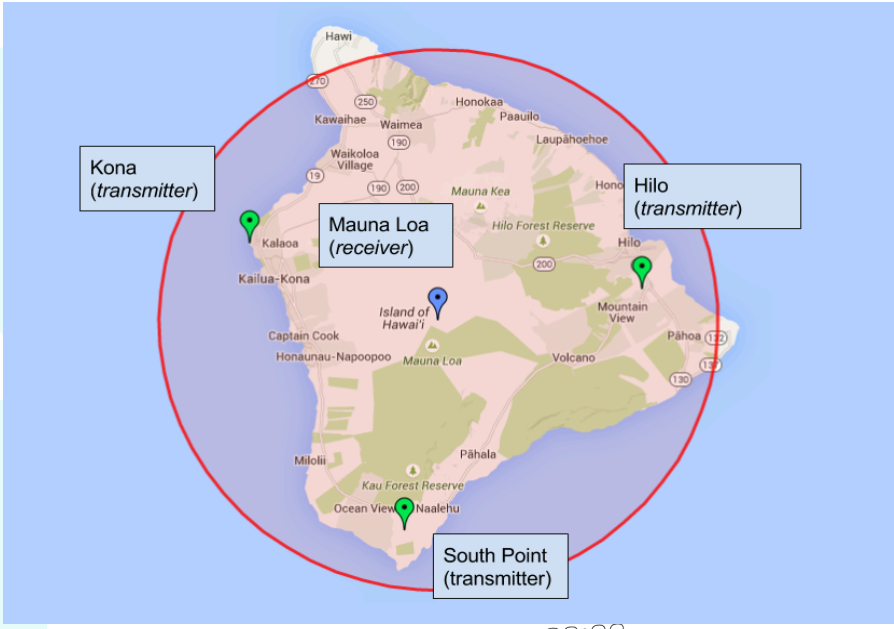
❖Science ❖ Technology ❖ Applications

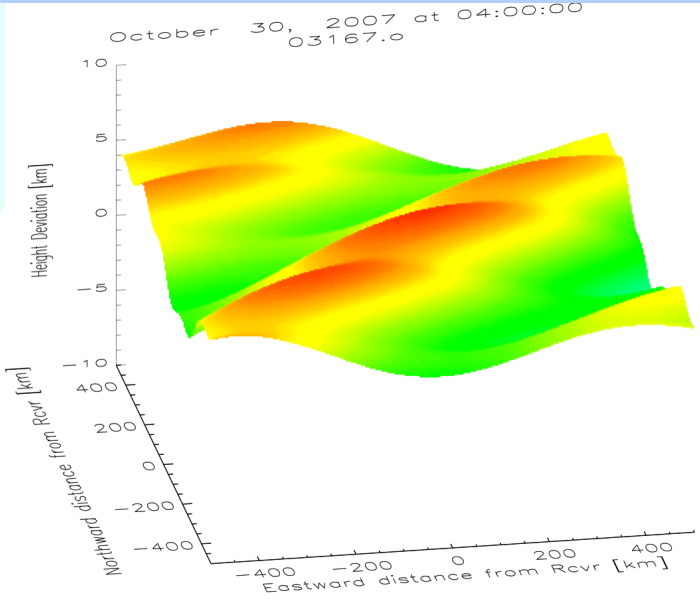
Bringing It All Together

ASTRA

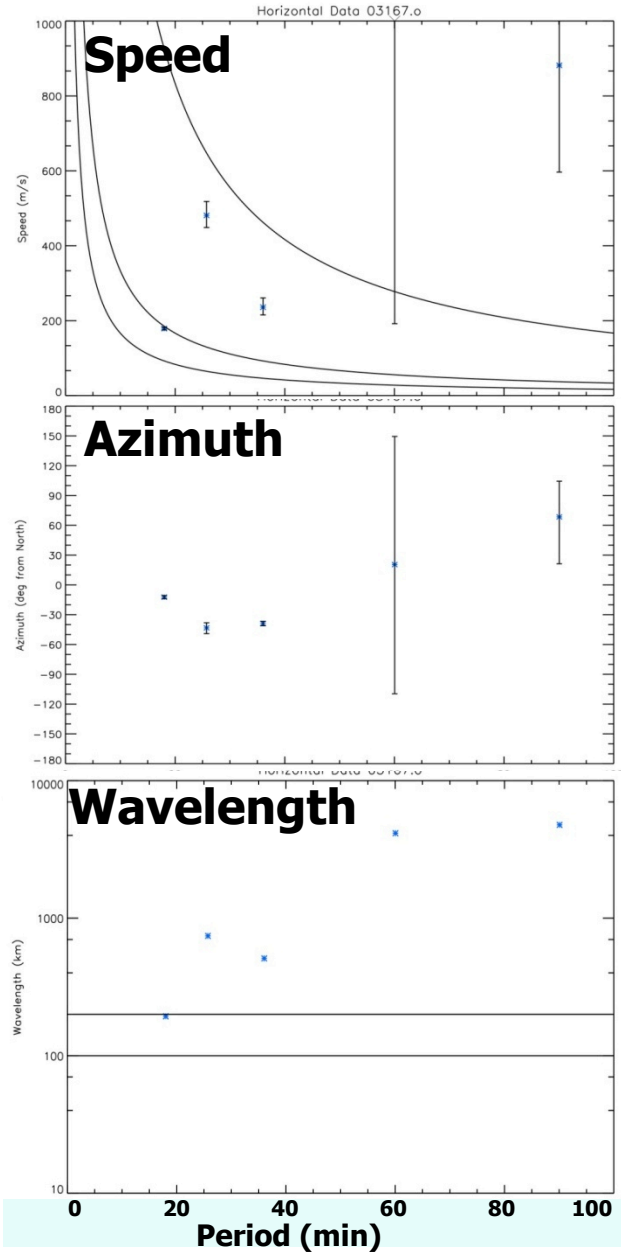
ASTRA's TIDDBIT & CHIRP Systems

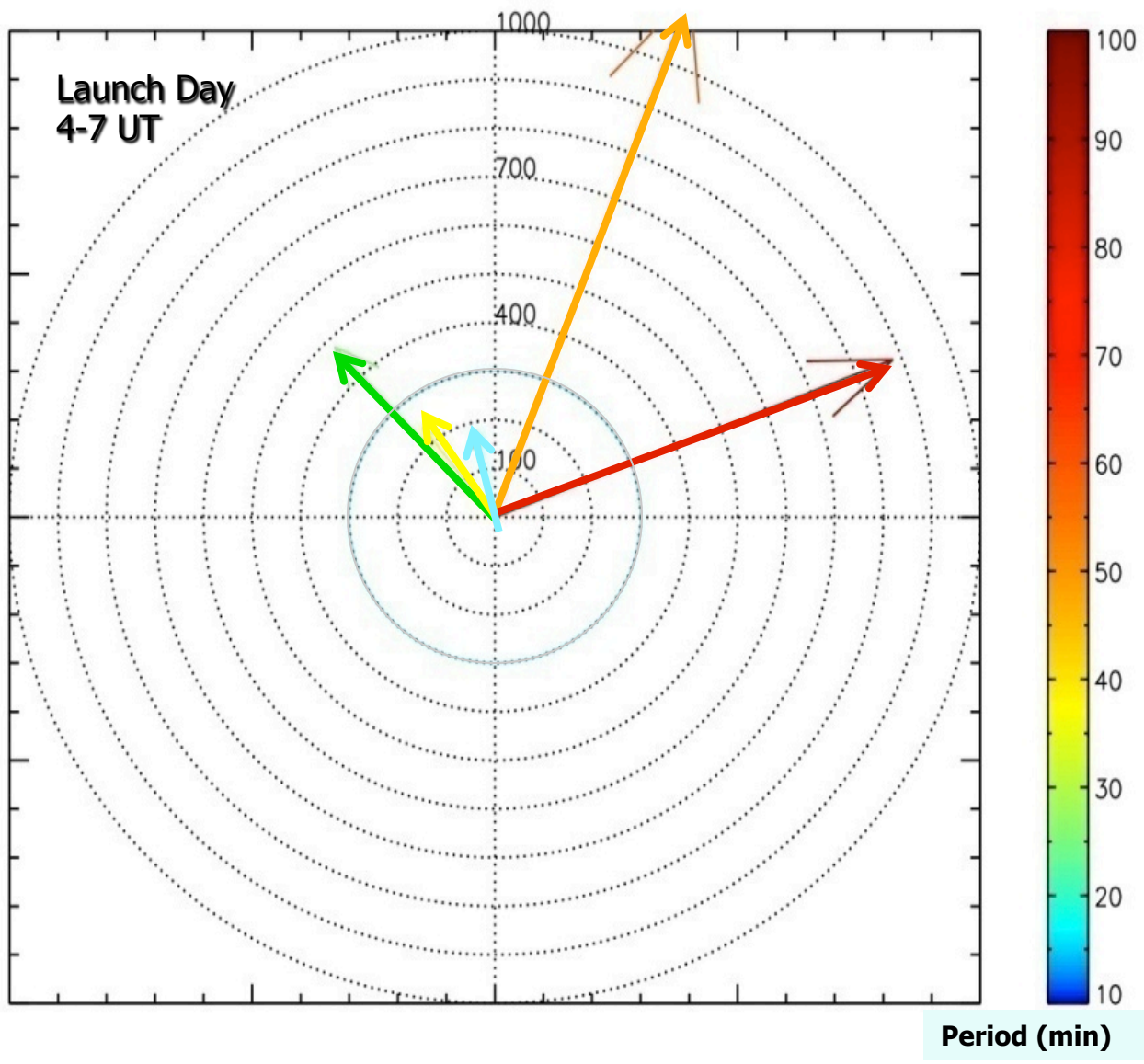
- HF Transmitter/Receiver system to detect waves in the ionosphere (150-450 km altitude)
- Recent installations in Peru, Florida, and Hawaii
- Hardware and signal processing software
- CHIRP is an advancement over TIDDBIT by measuring range as well as Doppler shifts





TIDDBIT/CHIRP TID Velocity Analysis





3. CICERO

GeoOptics

C I C E R O

CICERO

- Nano Satellites
- 6 → 12 → 24 → 48 → ?
- Cion Receiver
- Ground Command & Control
- Data Processing
- Products
  - High Resolution Atmospheric Profiles
    - Bending Angle
    - Refractivity
    - Density
    - Pressure
    - Temperature/Moisture
    - Absolute Measurement Heights
  - Ionospheric Electron Density
  - Global Temporal & Spatial avgs
  - Global pressure contours, gradients & geostrophic winds
- Replenishment & Updating

Radio Occultation (RO)

COSMIC I

- Fully Successful RO Test
- Rapidly Reaching End of Life

COSMIC II

- Limited Satellite Number (12)
- Specified Lifetime
- CICERO data Interchangeable
  - Ground Processing
  - Distribution
  - NWP Use

4. SPRINTS

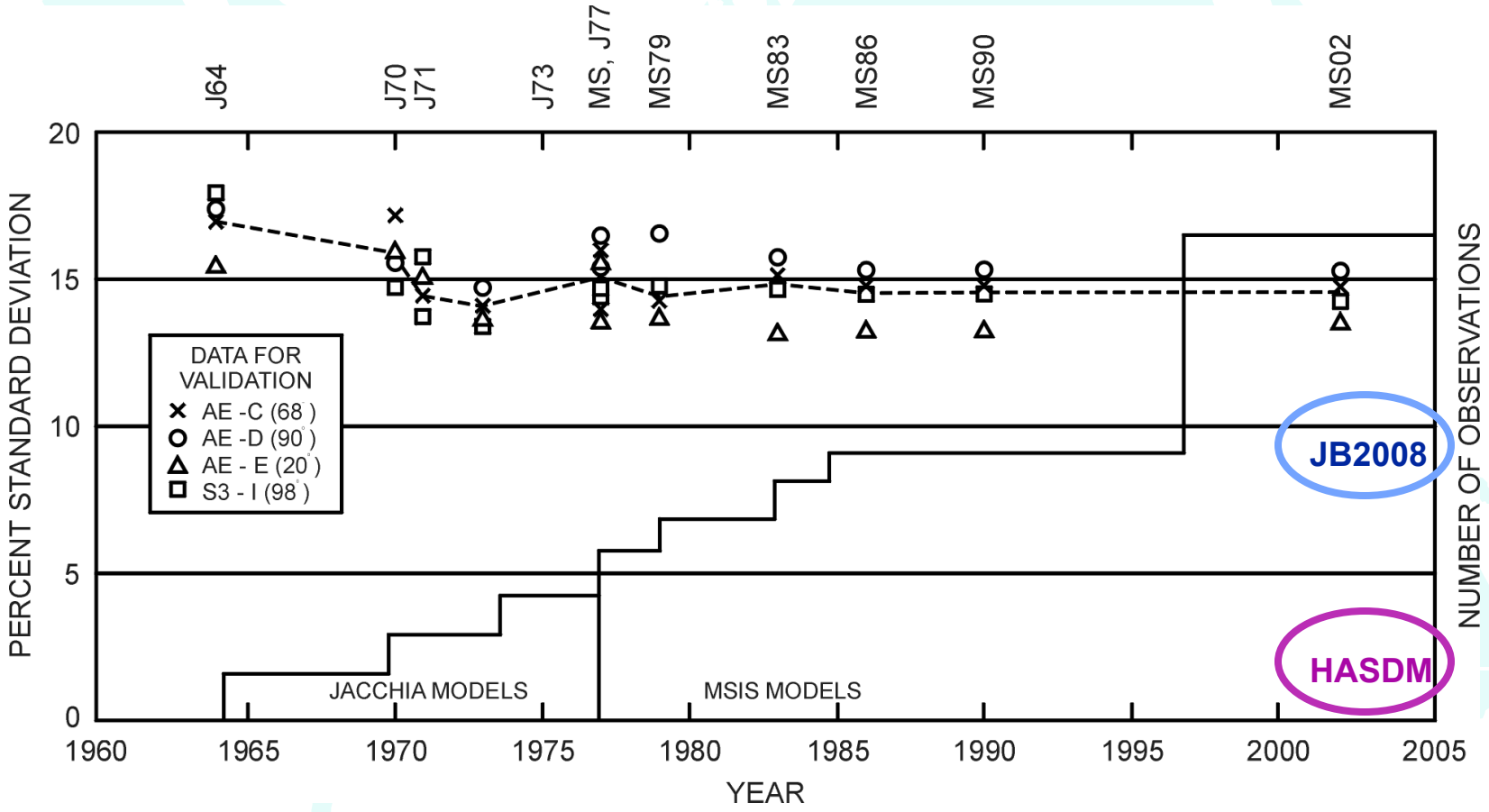

SPRINTS
Historical
Near-Real Time
<
19891019
>
Variables
Input Data
Plot
Display Forecasts
Forecast Models
Radio Blackout,
4-Day Forecasts
G07 X-Rays .1-.8 nm Wm^-2
Gs0 Protons cm^-2 s^-1 sr^-1
G07 Bz/Bt Magnetic Fields nT
NextGen Federal
Input Data
Add a space weather event
flare
SEP
CME
HSS
Start Date
00:00:00 YYYYMMDD
End Date
00:00:00 YYYYMMDD
ID
SOLyyyy-mm-ddThh:mm:ssLdddCdddRnnn.f
Event Parameter
Peak flux (10 MeV)
Value
XXXX pfu
Add a space weather impact
Start Date
00:00:00 YYYYMMDD
End Date
00:00:00 YYYYMMDD
Lat
Lon
Alt
ID
IMPyyyy-mm-ddThh:mm:ssLdddCdddRnnn.f
Display Plot
SEP
Cancel
Create Event
10/19
10/20
10/21
10/22
10/23
10/24
10/25
10/26
10/27
10/28

5. HASDM

HASDM density catalog

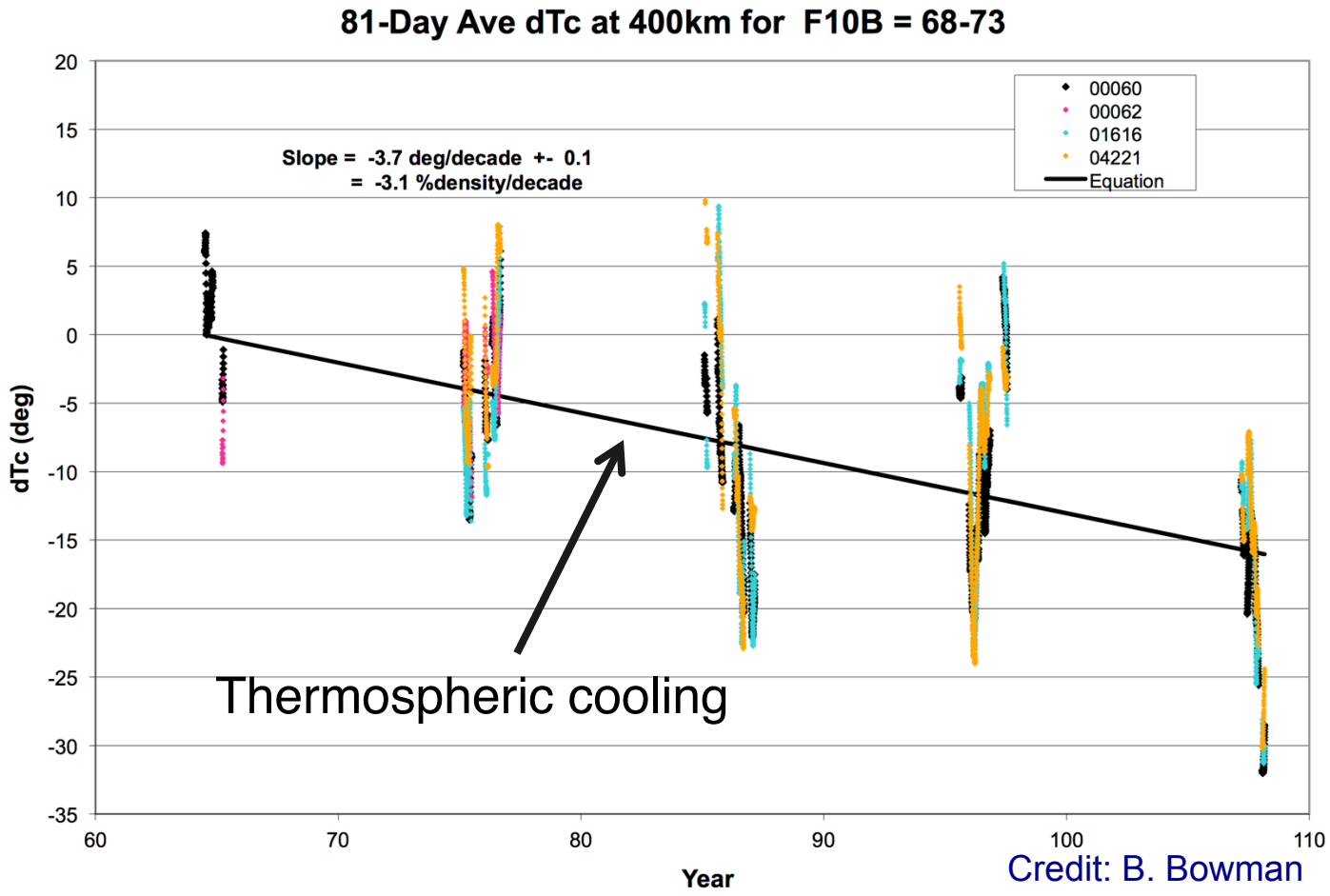
- Process HASDM coefficients into neutral atmosphere densities and temperatures
- Resolution: 3 hours; 2001 through current epoch; 200–1500 km; 15x15 deg lat/lon bins; 10 km steps; ~1–3% uncertainty at epoch
- This would become the definitive reference thermosphere

What we started with – historical density model errors at 350 km (1-σ)



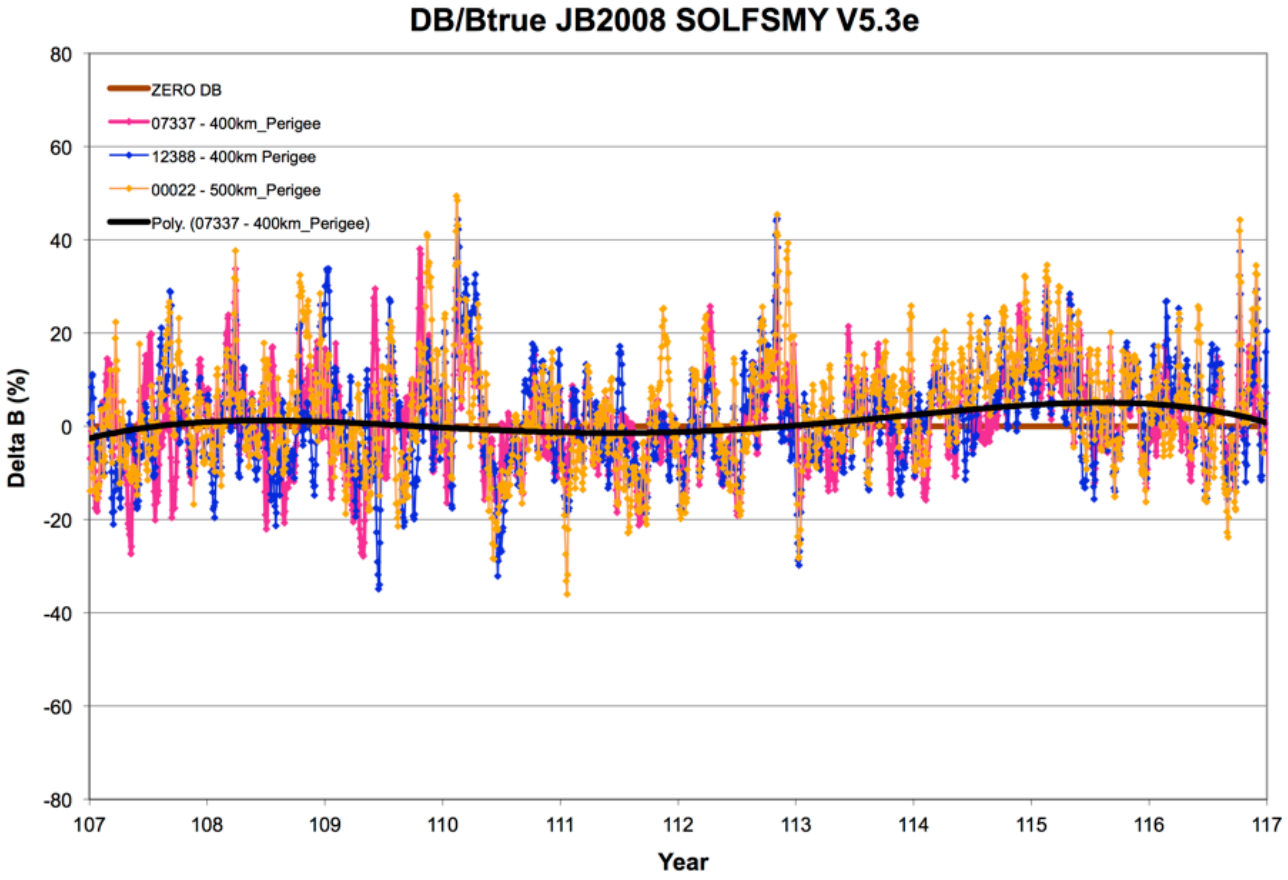
Credit: F. Marcos

Four solar cycles of decreasing temperatures at 400 km



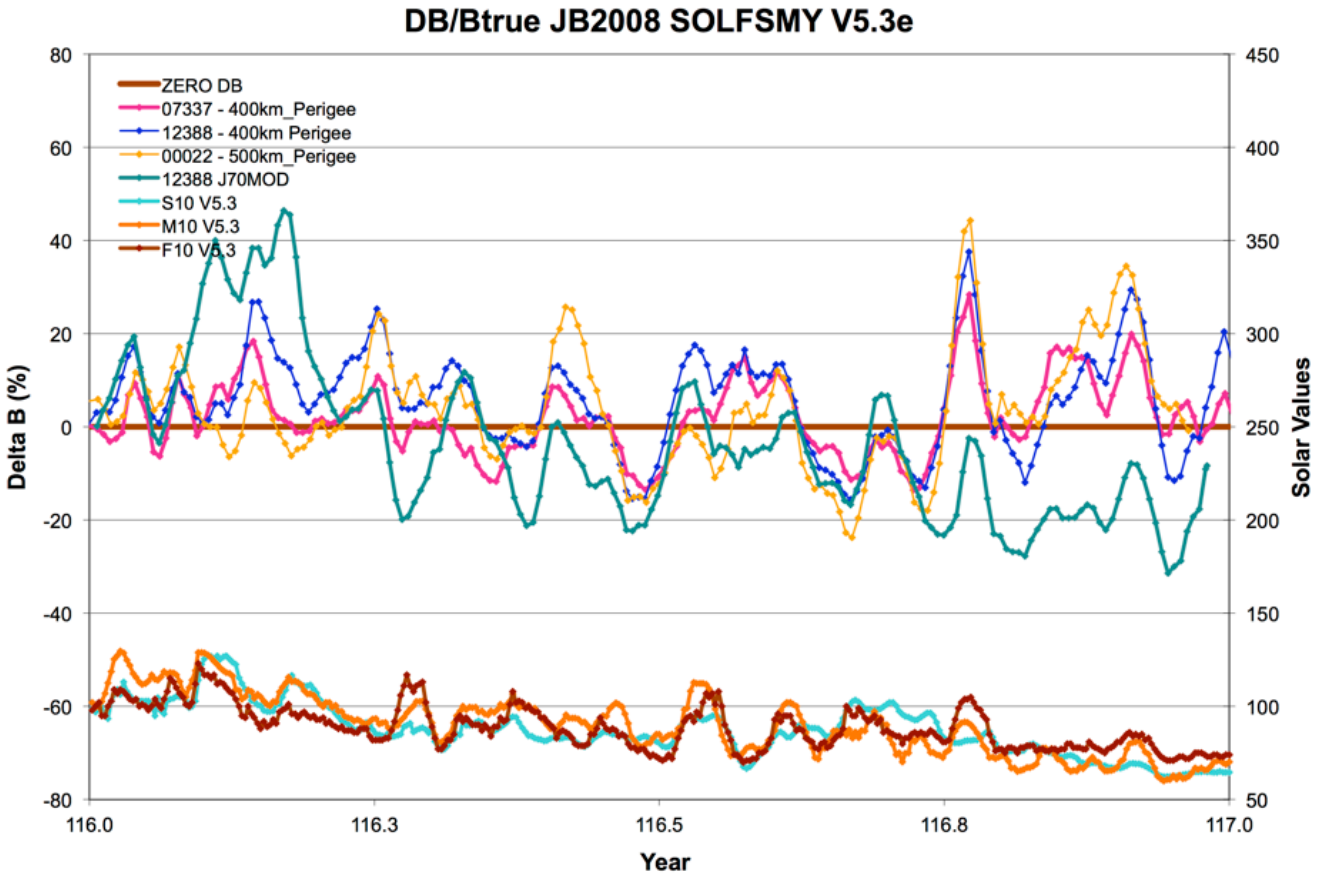
Credit: B. Bowman

One solar cycle JB2008 density error



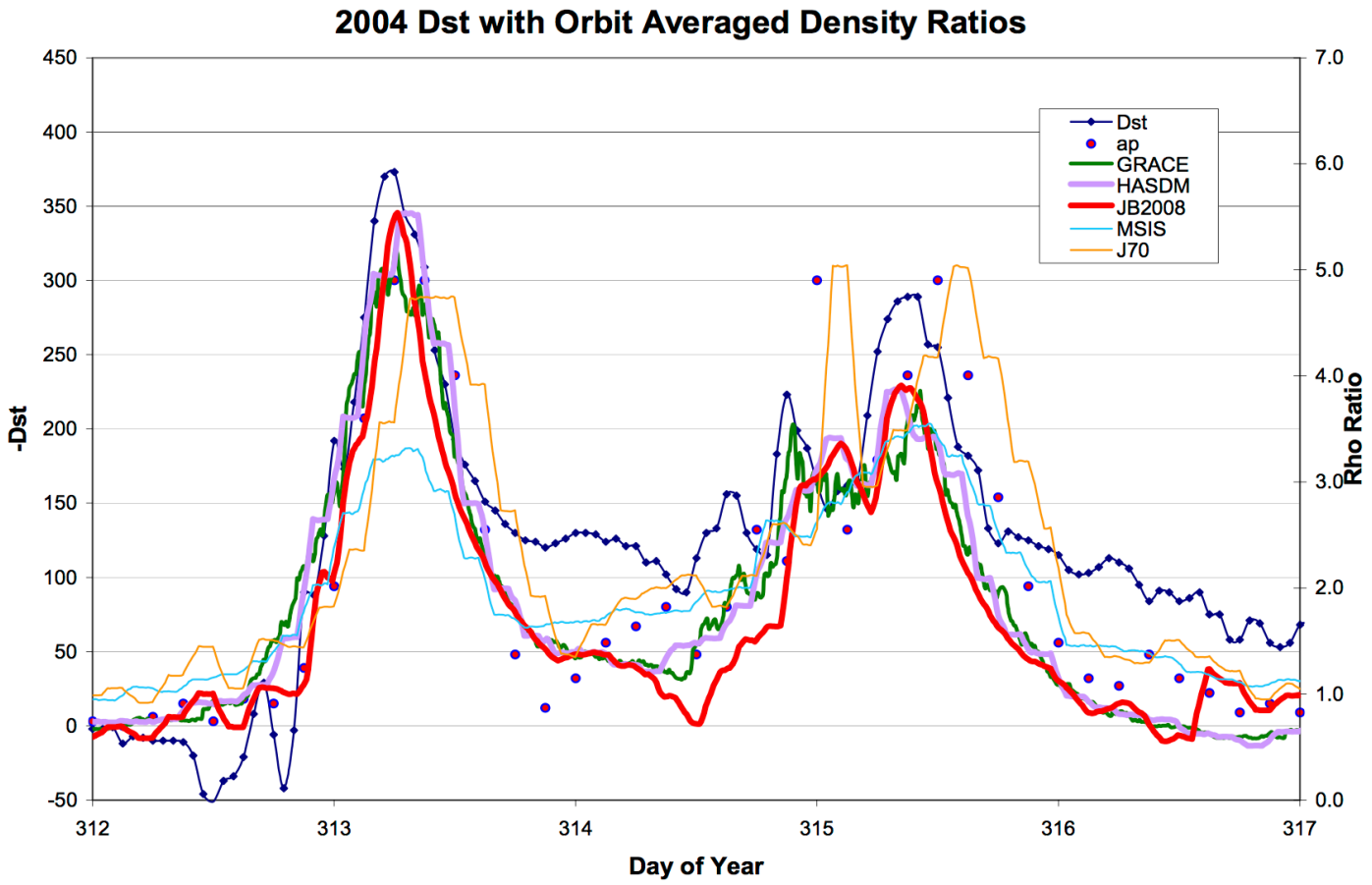
Credit: B. Bowman

One-year JB2008 density error comparison



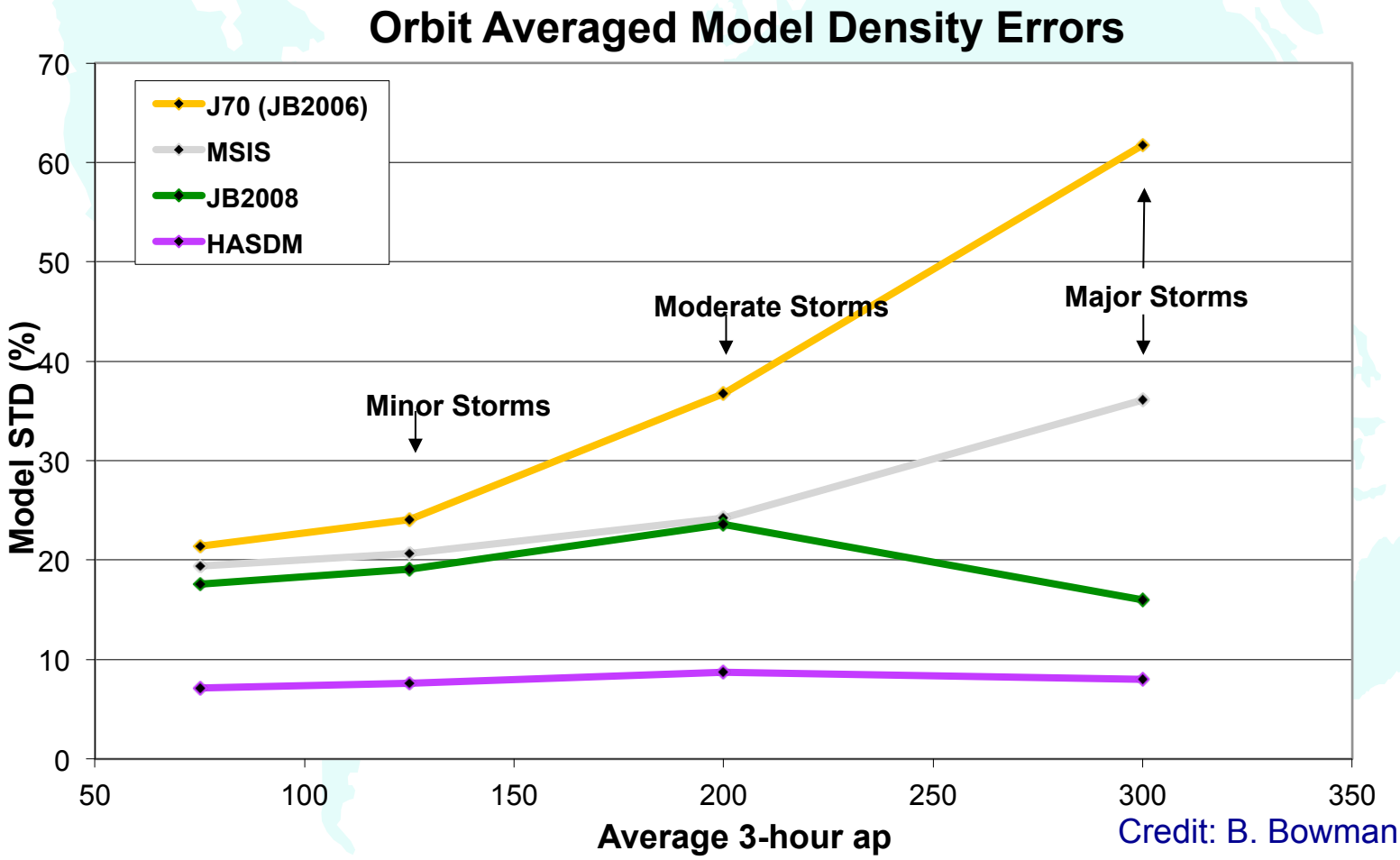
Credit: B. Bowman

Orbit Average Density ratios for Geomagnetic Storms



Credit: B. Bowman

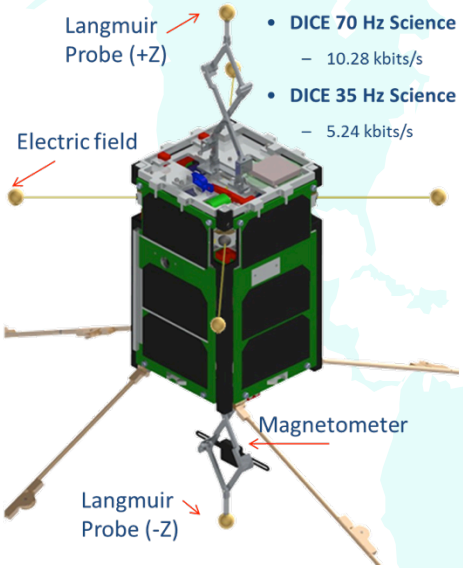
Orbit Average Density Error for Geomagnetic Storms

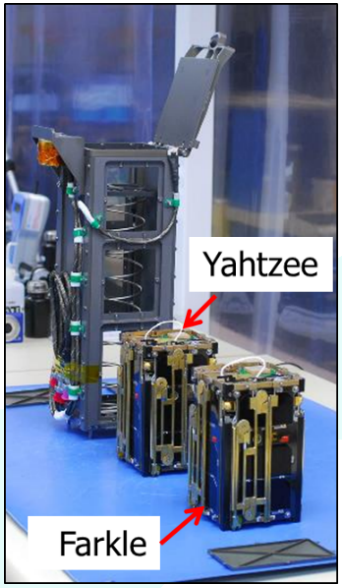


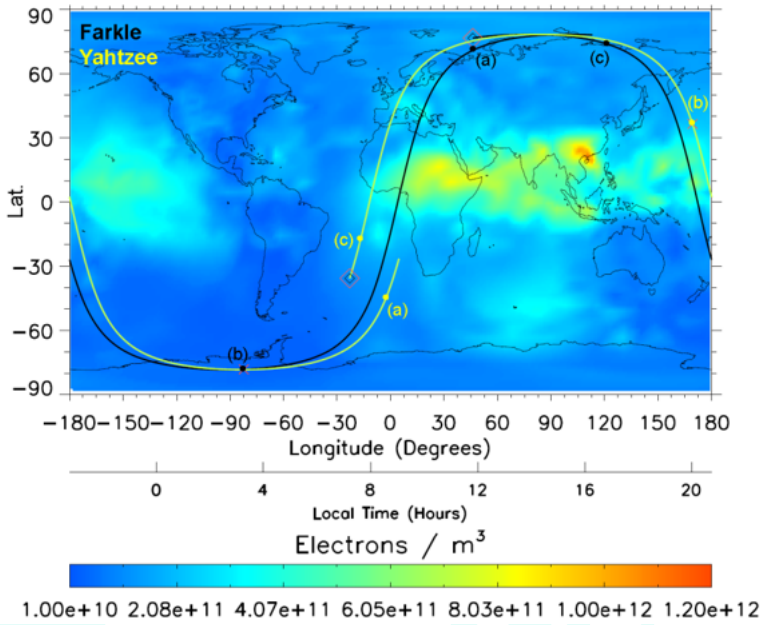
Credit: B. Bowman

5. ASTRA CUBESATS

Instrumentation: LP/E-FIELD/Mag
Observations: E, B, N_e, N_i, T_e

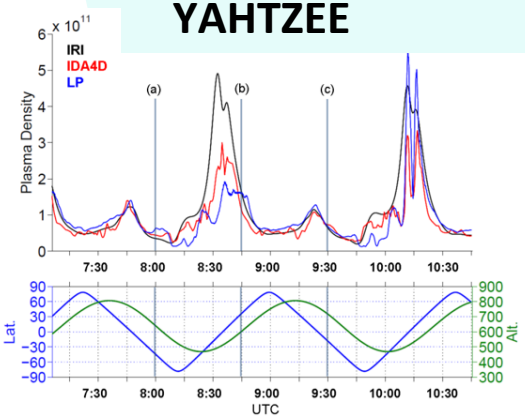




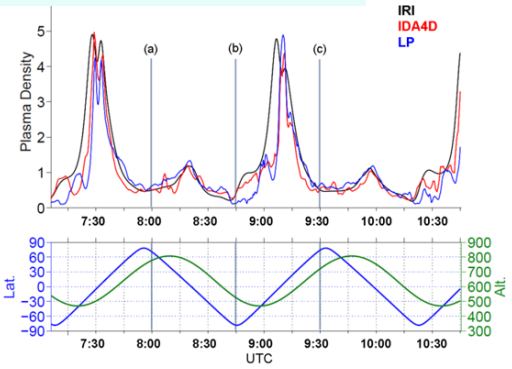


Sensor SWaP	
Volume (U)	0.4
Mass (g)	350
Power (mWDC)	520

YAHTZEE



FARKLE



Currently being built for the Air Force

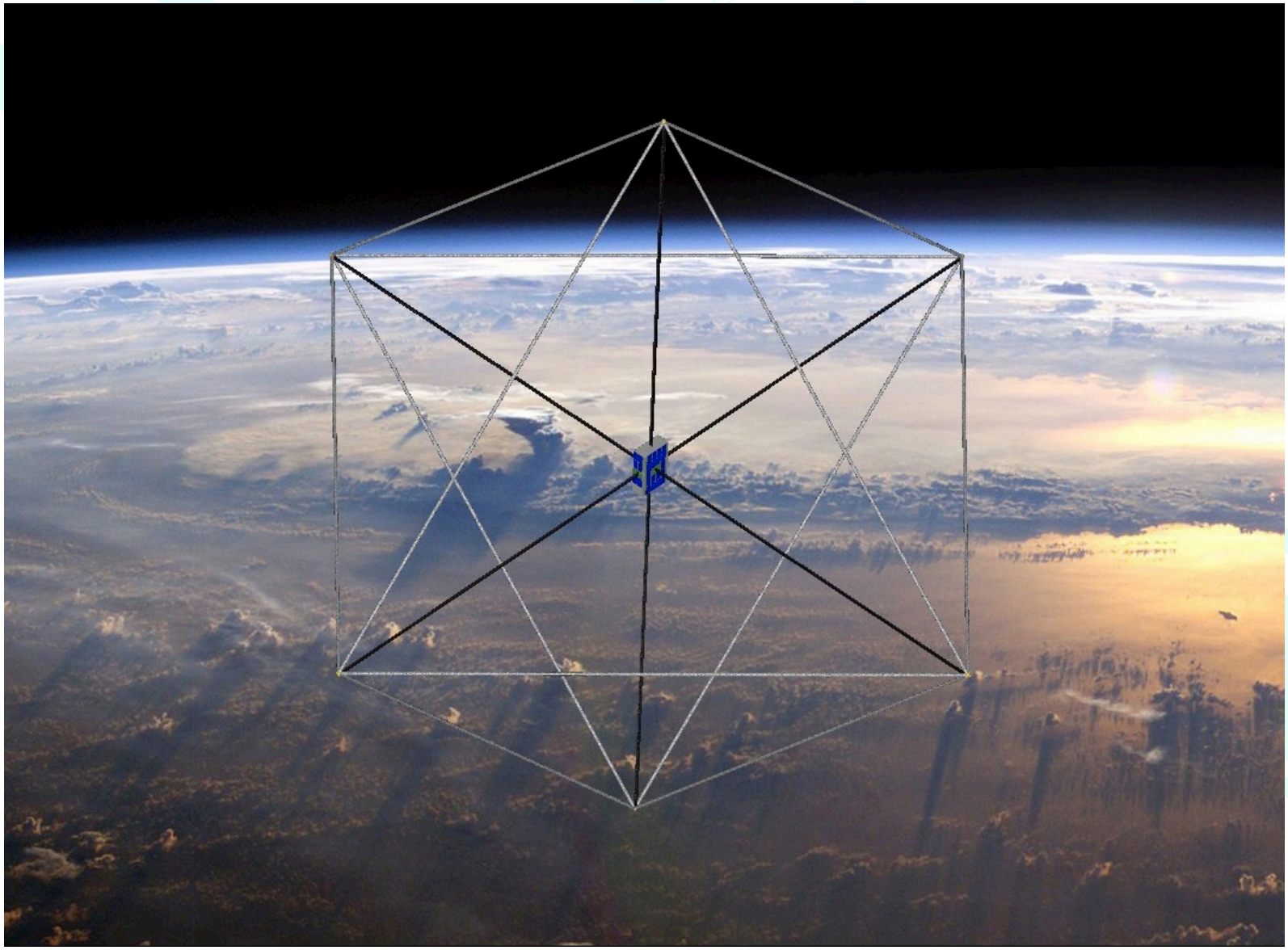
DIMESat is a Constellation pathfinder mission for monitoring electric fields in Low-Earth Orbit implementing lessons-learned from on-orbit experience with DICE.

DICE Heritage Instrumentation:

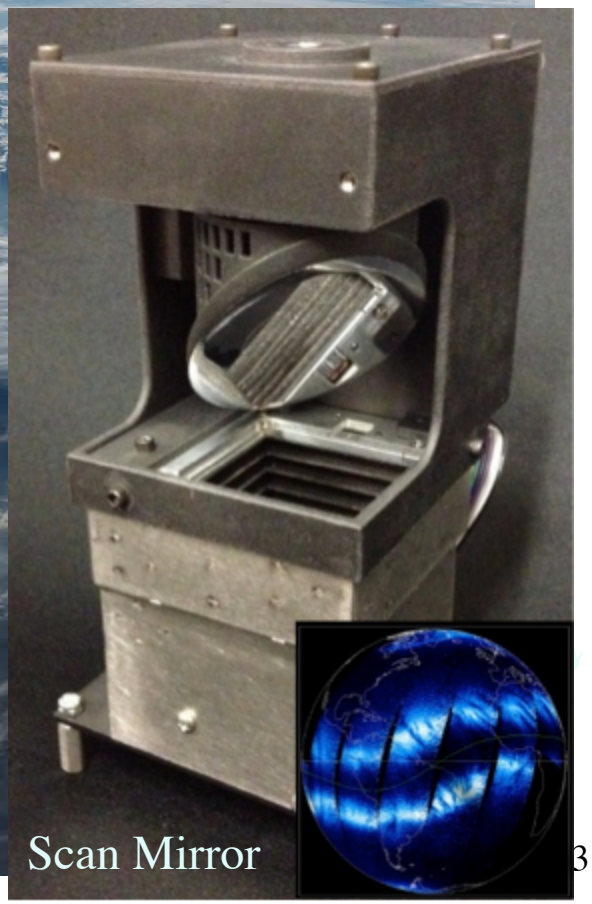
1. **Langmuir Probes (deployable)**
2. **E-FIELD Probes (deployable)**
3. **Magnetometers (Science & Attitude)**

Observations: E, B, N_e, N_i, T_e

Sensor SWaP	
Volume (U)	0.4
Mass (g)	350
Power (mWDC)	520



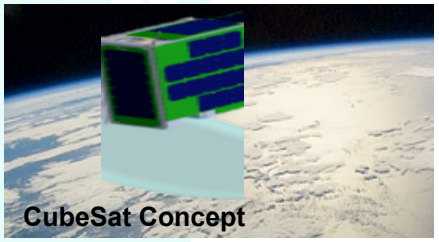
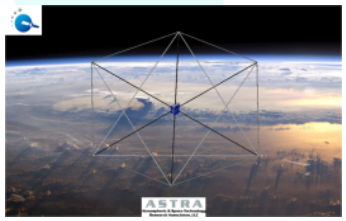
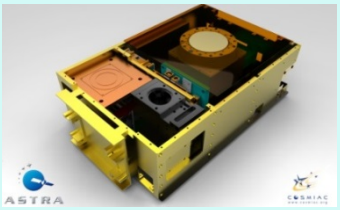
Satellite Concept (6U)



ASTRA*space*
Selected Missions & Instruments

❖Science ❖ Technology ❖ Applications
Bringing It All Together

ASTRA

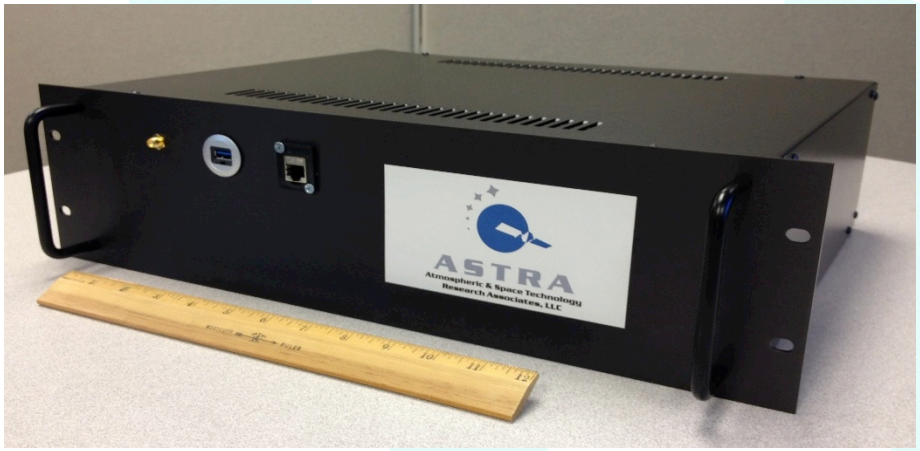
Mission	Description	Instruments	Other: Plug-n-Play Avionics
DICE (NSF)  **Form: Two 1.5U CubeSats**	**2011 launch** ***Flown* – first successful observations of SED's and FAC's from a CubeSat** Fastest comm. rates achieved by scientific CubeSat	• **Two Langmuir probes** to measure in-situ ionospheric plasma densities. • Science and attitude **magnetometers** • **Four electric field probes** on 5-meter cable booms	**SIPS** **Scanning Imaging Photometer Systems (UV Imager)**  **CubeSat Concept** **Form: 6U** • **UV Detector (photometer)** • **Scanning mirror**
DIME (Air Force) 	DIME… pathfinde… monitoring ele… Low-Earth Orb… implementing… learned from… experience…	**Other Instruments:** • Scanning UV Photometer (SIP… RF Remote Se… …ounder …Wind Profiler GPS-based …pa… Weather M…	**Topside Sounder** 
SORTIE (NASA)  **Form: 6U**	**Est. launch 2018** **NASA LCAS**. SORTIE will provide information on the distribution of wave-like structures in the plasma density of the ionospheric F-region.	• **Miniaturized Ion Velocity Meter** for measuring ion drifts • **micro-Planar Langmuir Probe** for measuring small-scale plasma structures	

5. SORBET

SORBET (SDR)

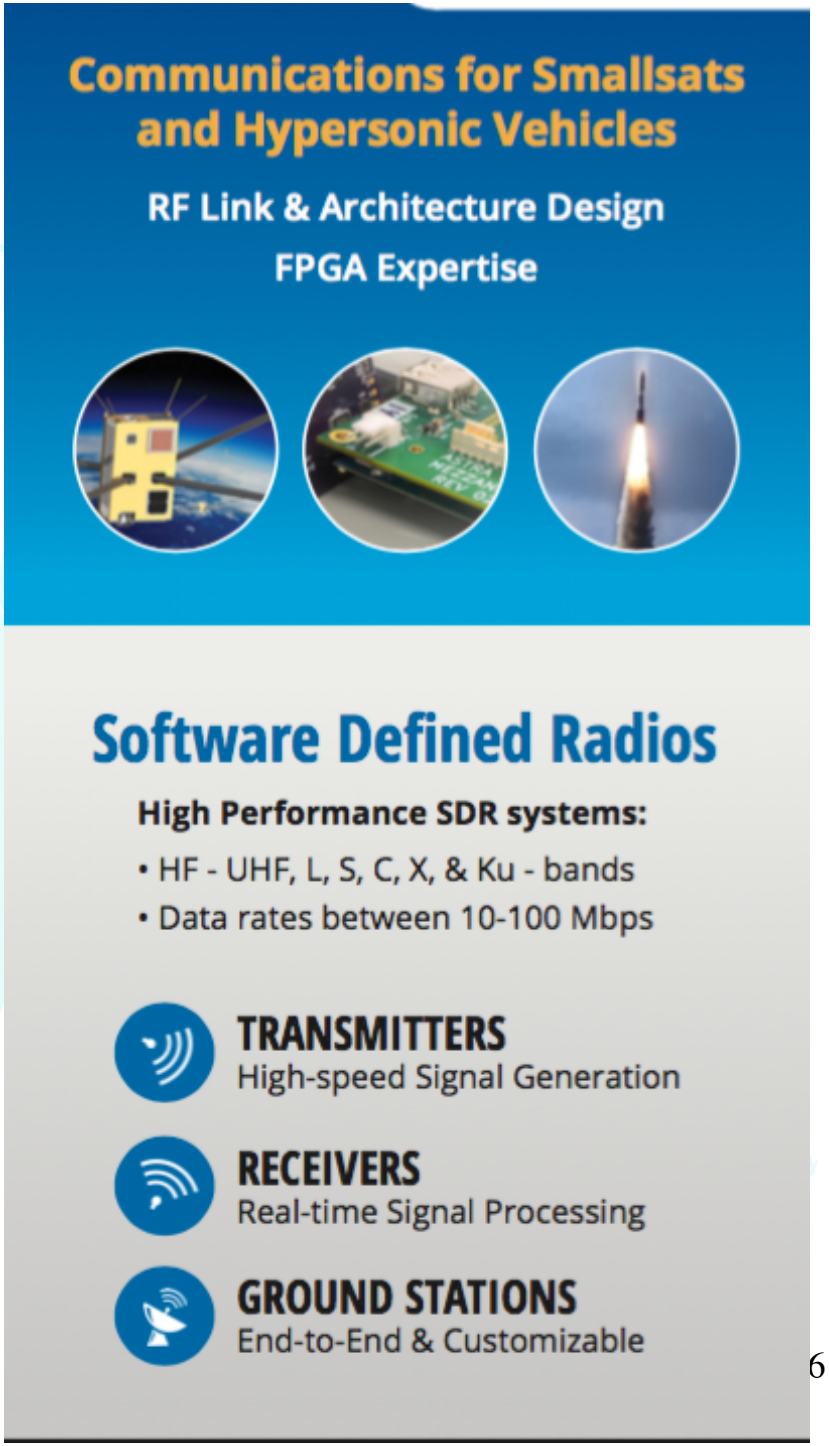
High Performance Hardware

- DC - 14 GHz
- Sampling rates from 10 – 100 Mbps



Other Applications:

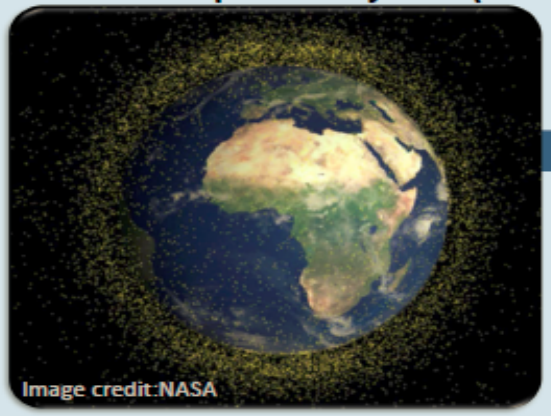
- Satellite ground-station
- Cubesat transmitter



5. DRAGSTER

Dragster Design Overview

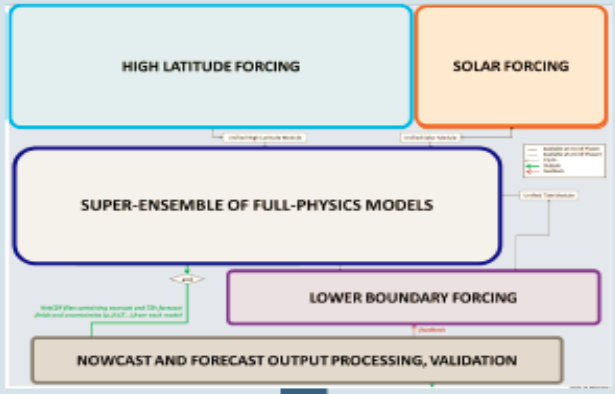
Resident Space Objects (LEO)



satellite drag and density observations

- ***Orbit observations***
- *GPS*
- *Accelerometers*
- *O/N_2*
- *Mass Spectrometer*

Dragster Architecture



orbital analysis

Dragster

conjunction analysis

Super-Ensemble Approach

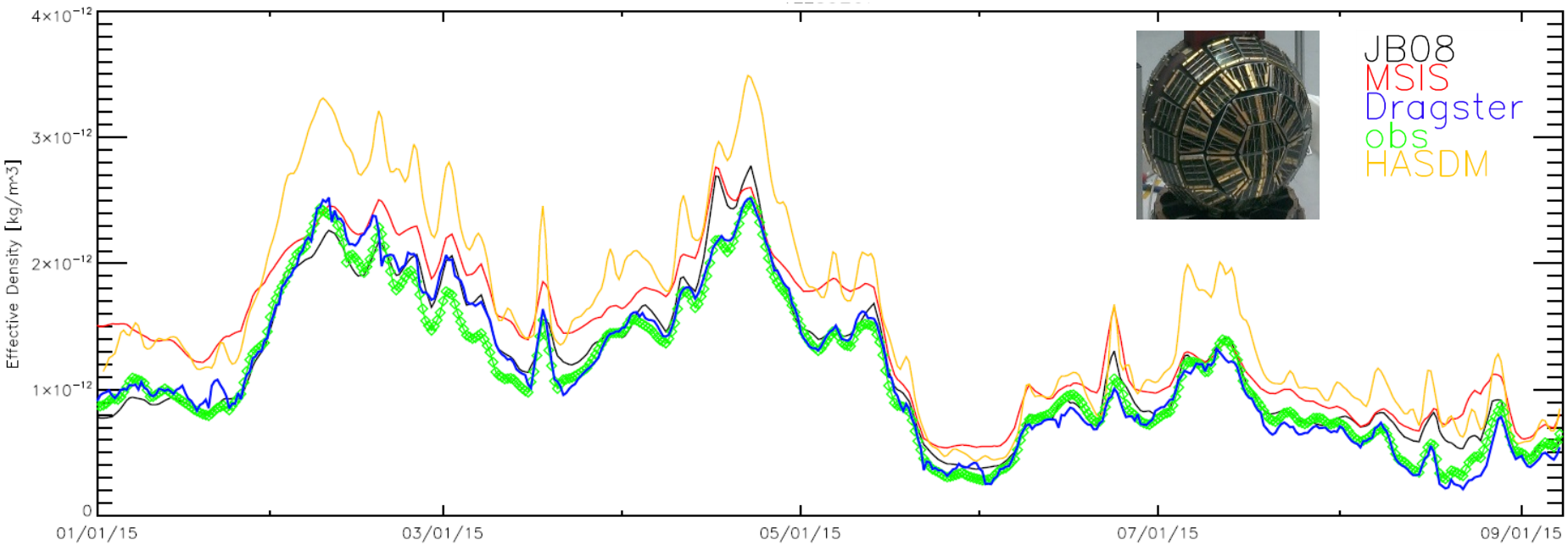
Image credit: TerraMetrics, Google

Output information feeds into existing orbit prediction and determination tools

Results

- Improved satellite orbit nowcast and 72h forecast
  - Improvements over HASDM and JB08
  - Up to three-fold improvement during storms and solar minimum
- Densities, winds, and composition outputs
- Covers altitudes from 30 km to 1500 km
- Improved performance during geomagnetic storms

Density Validation versus DANDE, 2015



DANDE (#39267) satellite effective densities (bright green) as a function of time. Model effective densities from NRLMSIS-00 (red), JB08 (black), HASDM (gold), and Dragster (blue) are also plotted. DANDE is in an 81° elliptical orbit (~ 330x1420 km)

Satellite	Perigee Altitude [km]	MSIS Standard Deviation	JB08 Standard Deviation	HASDM Standard Deviation	*Dragster* Standard Deviation
DANDE (39267)	338	29.3%	17.3%	18.8%	10.9%

Forcing Estimates, 2015