The Mahali Project: Space weather monitoring everywhere

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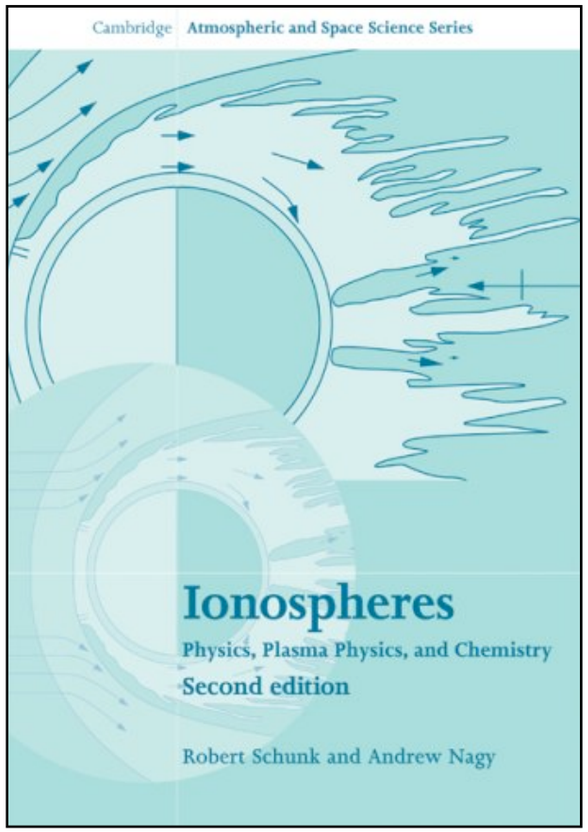
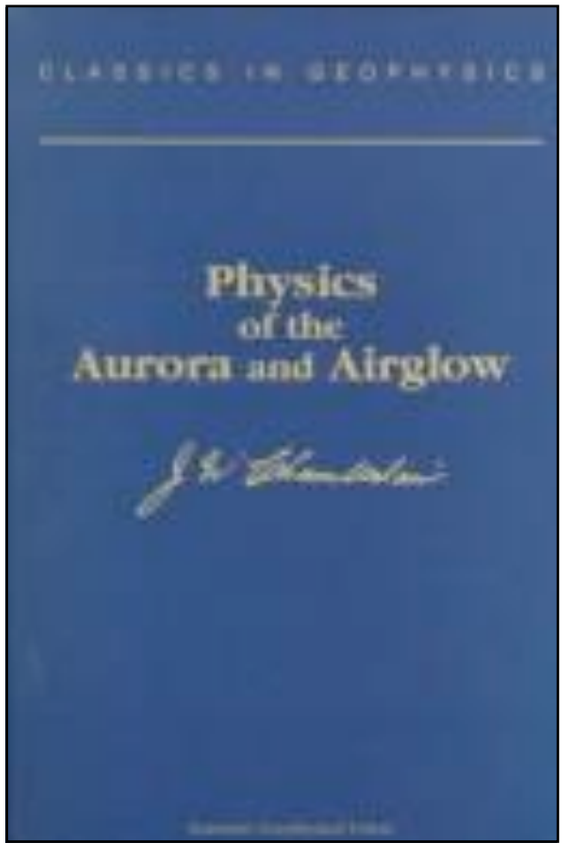
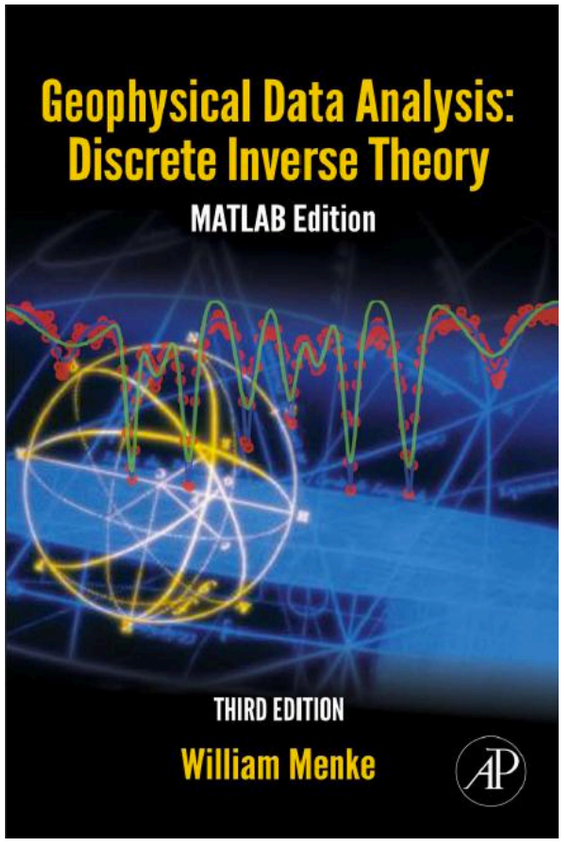
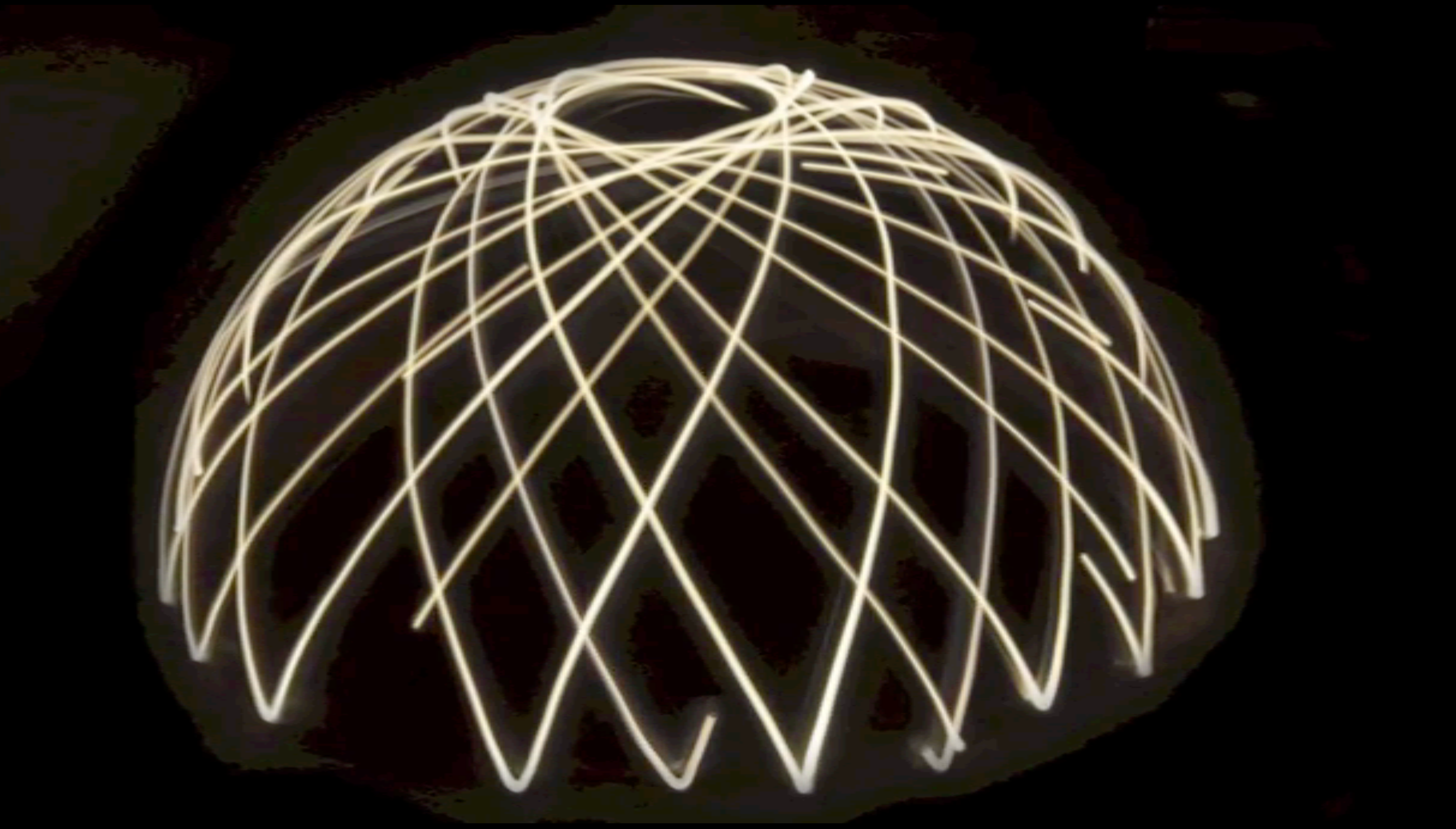
From research to pedagogy to research







Armed with a physical model, a distributed network of measurements, and the mathematics of inverse theory, the ionosphere-thermosphere system itself becomes a remote sensing diagnostic, providing information about processes above and below that cannot be obtained by any other means.

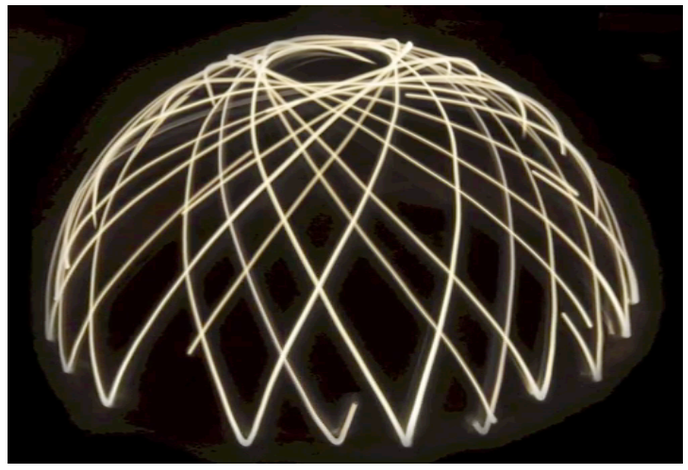


Observational science: inverse theoretic view

Forward **Inverse**

Blurring ⟷ Deconvolution/Interpolation

$$g(s) = \int k(s,t) f(t) dt$$



Projection ⟷ Tomography

$$p_\theta(u) = \int_{-\infty}^{\infty} f(u\cos\theta - v\sin\theta, u\sin\theta + v\cos\theta) dv$$

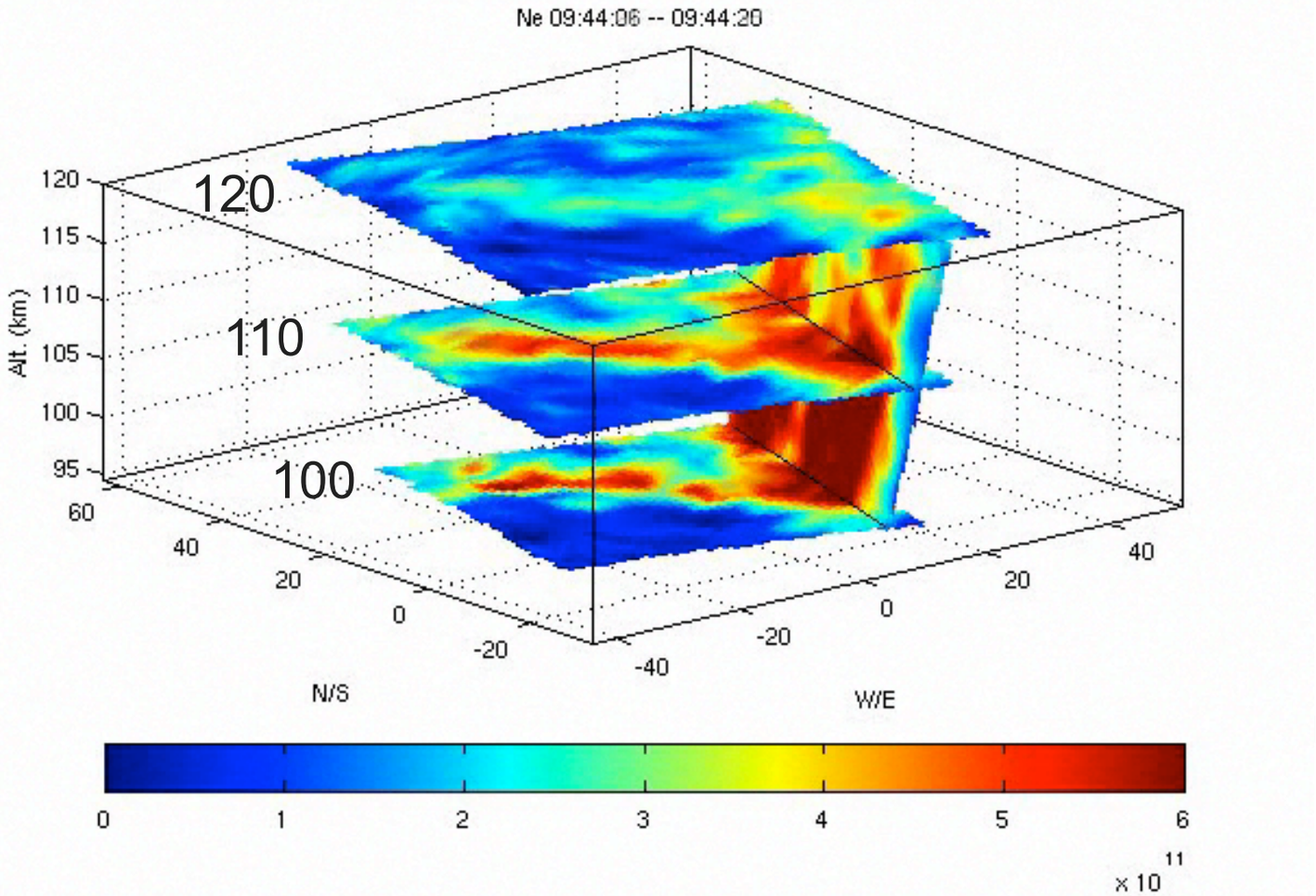
Physical model ⟷ Parameter estimation

$$\widehat{h} = \arg\min_h \left\{ ||L\{h\} - g||_P^2 + ||\alpha K\{f\}||_Q^2 \right\}$$

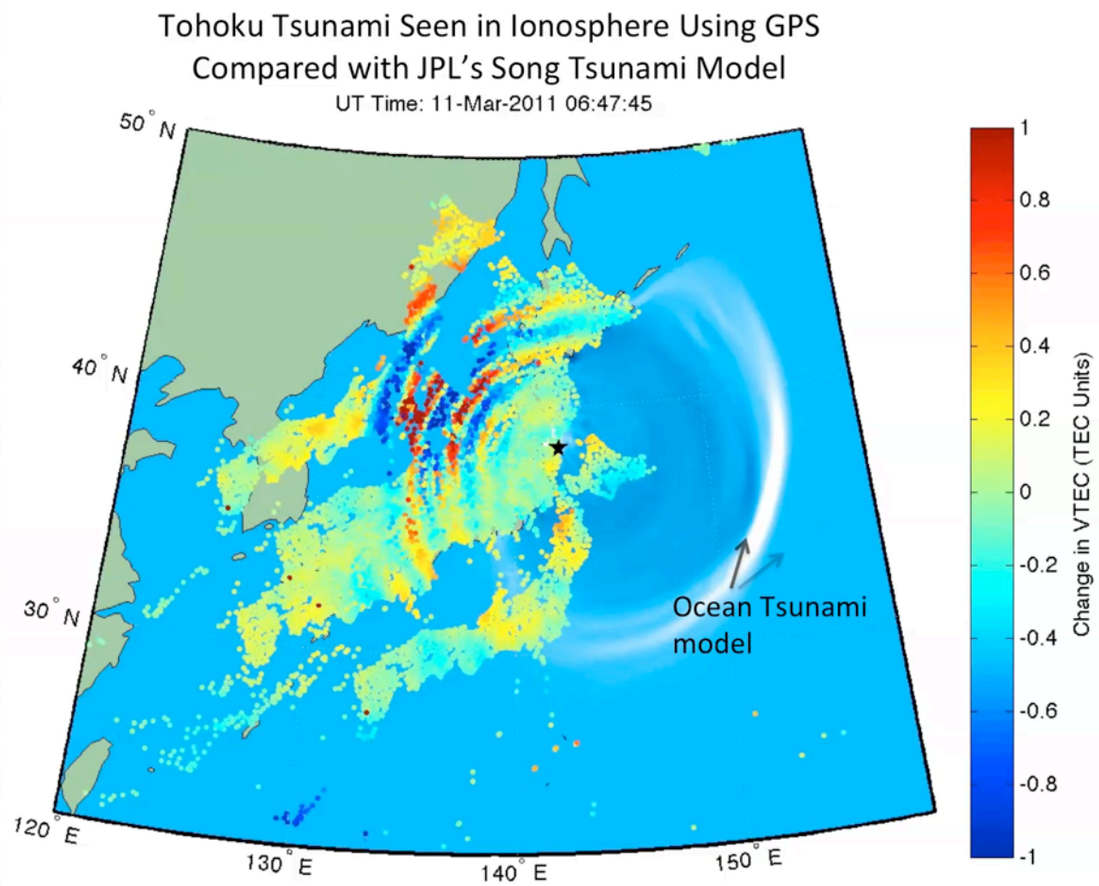
- h: vector of parameters
- L: operator representing physical model and projection
- P: weights (inverse covariance of g)
- K: operator constraining the behavior of the solution
- Q: weights (inverse covariance of h)

The ionosphere as Earth system sensor

Space-time variations in the ionospheric density field provide a projection of dynamics drivers above (left, magnetospheric substorm) and below (right, Tohoku earthquake).



Semeter, J., T. Butler, C. Heinselman, M. Nicolls, J. Kelly, and D. Hampton, Volumetric imaging of the auroral ionosphere: Initial results from PFISR, J. Atmos. Sol. Terr. Phys., 71, 738–743. doi: 10.1016/j.jastp.2008.08.014, 2009.

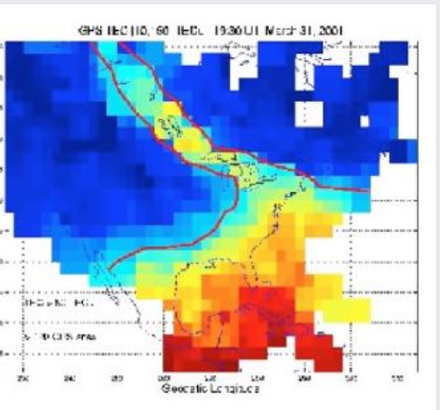


Song, Y. T., et al (2007), Detecting tsunami genesis and scales directly from coastal GPS stations, Geophys. Res. Lett., 34, L19,602, 10.1029/2007GL031681.

Space weather monitoring using GNSS signals

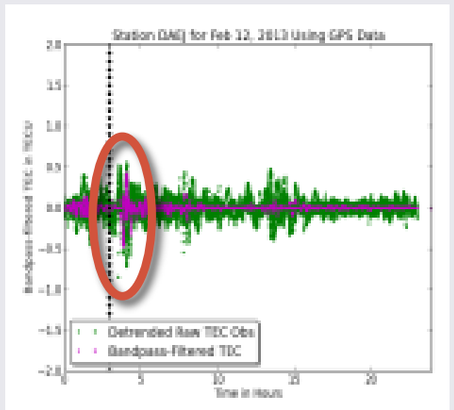
- **Our goal: Leverage entire ionosphere as a sensor** for
  - Space-based phenomena (e.g., Solar wind)
  - Earth-based phenomena (e.g,. Earthquakes, Tsunamis; Song et al. 2007; Galvan et al. 2011; Komjathy et al. 2013)

Storm Enhanced Density feature

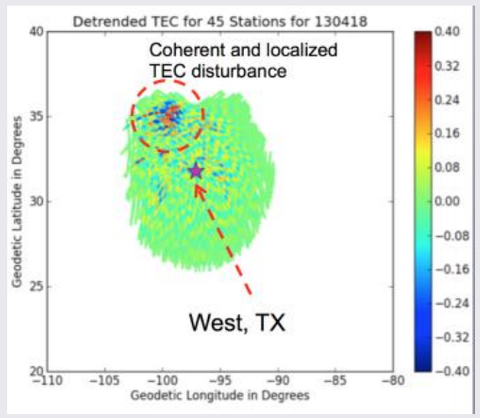


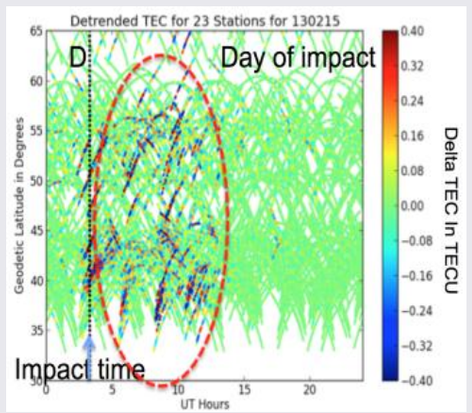
(Rideout & Coster 2006)

Feb 12, 2013 North Korea Nuclear Test



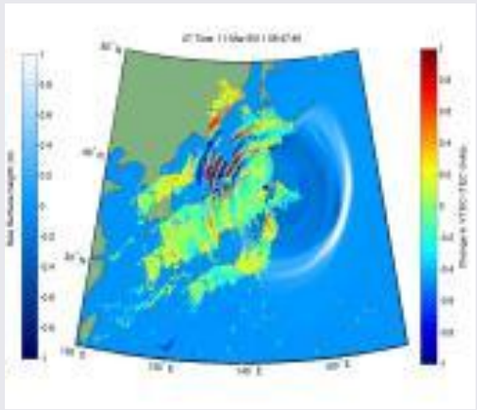
Texas Fertilizer Plant Explosion Apr 18





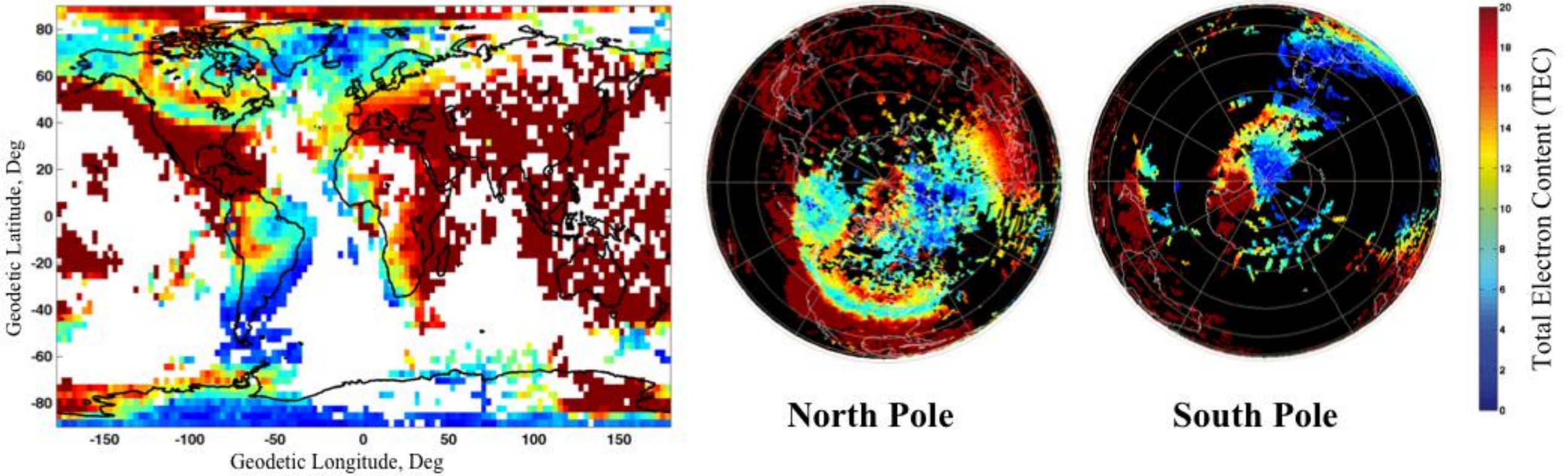
(Komjathy, Yang, Butala, Ijima, Mannucci. Beacon Satellite Symp. 2013)

Chelyabinsk Meteor and Tsunami



(NASA JPL Photojournal PIA14430/Caltech, 2012)

Problem: Sensor sparsity



Solution: Technology trends

Top500 Supercomputers, 1993

CM-5 Los Alamos

- 1024 processors
- 59.7 GFLOPS

[1 GFLOP = 10^9 floating point ops]

http://www.top500.org/timeline/

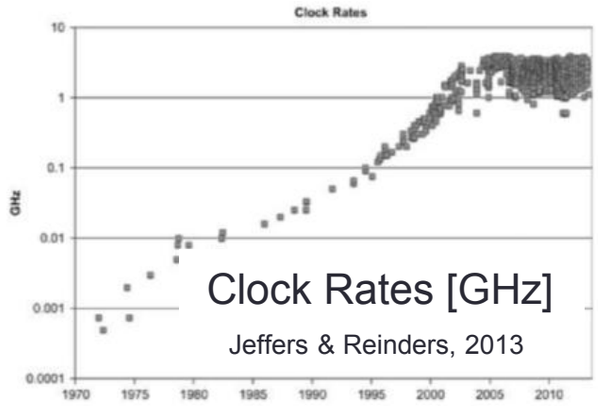
2013

iPhone 5S (A7 64 Bit)
76.8 GFLOPS (GPU@300MHz)

iPad3
38.4 GFLOPS (GPU@300MHz)

[Source: AnandTech.com]

Processor Trends



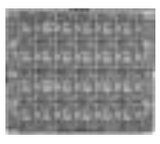
Clock Rates [GHz]

Jeffers & Reinders, 2013

General-Purpose

60 Cores

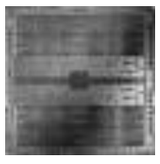
48 Cores



2 - 16 Cores

Special-Purpose

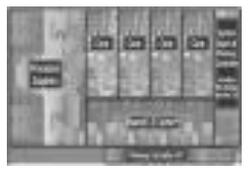
Thousands of Cores (GPUs)



192 Cores (Networking)

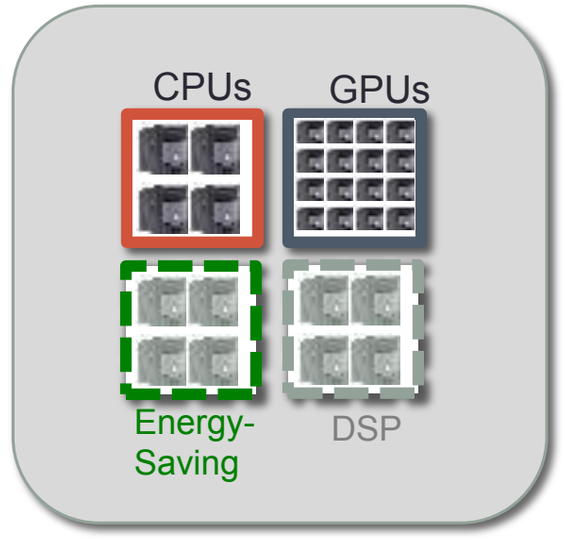
Hybrids

4 CPU + **16** GPU (Ivy Bridge)



2 CPU + **4** GPU (ARM A6X)

Mobile Processors

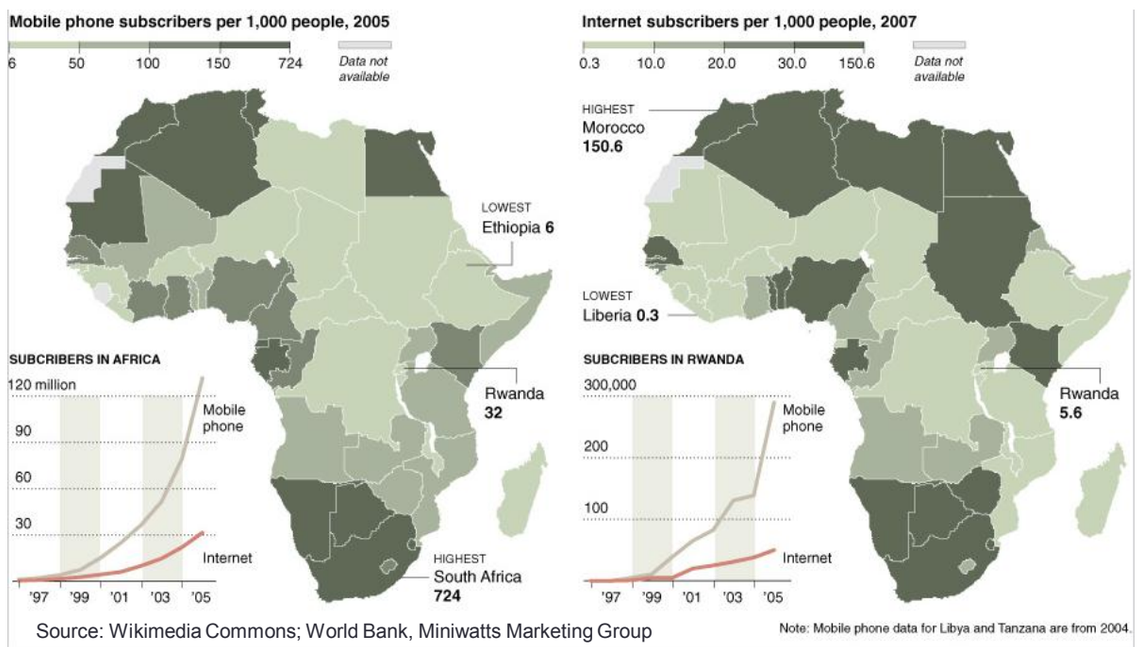


Solution: Technology trends

Mobile Devices

- Parallel computers
- Network connections (cell, WiFi, Bluetooth, USB)
  → "Last Mile Data Transmission Problem"
- Local storage (GB)
  → asynchronous data collection; GPS is time-tagged
- Low cost; software productivity; COTS hardware
- Extensibility (sensors, hardware, software)
- Adaptable intelligent behavior (e.g., profiles for battery / power, network type, etc.)
- Ubiquity: CEO Ericsson: ~6.4 billion devices in 2013, ~9.3 billion in 2018

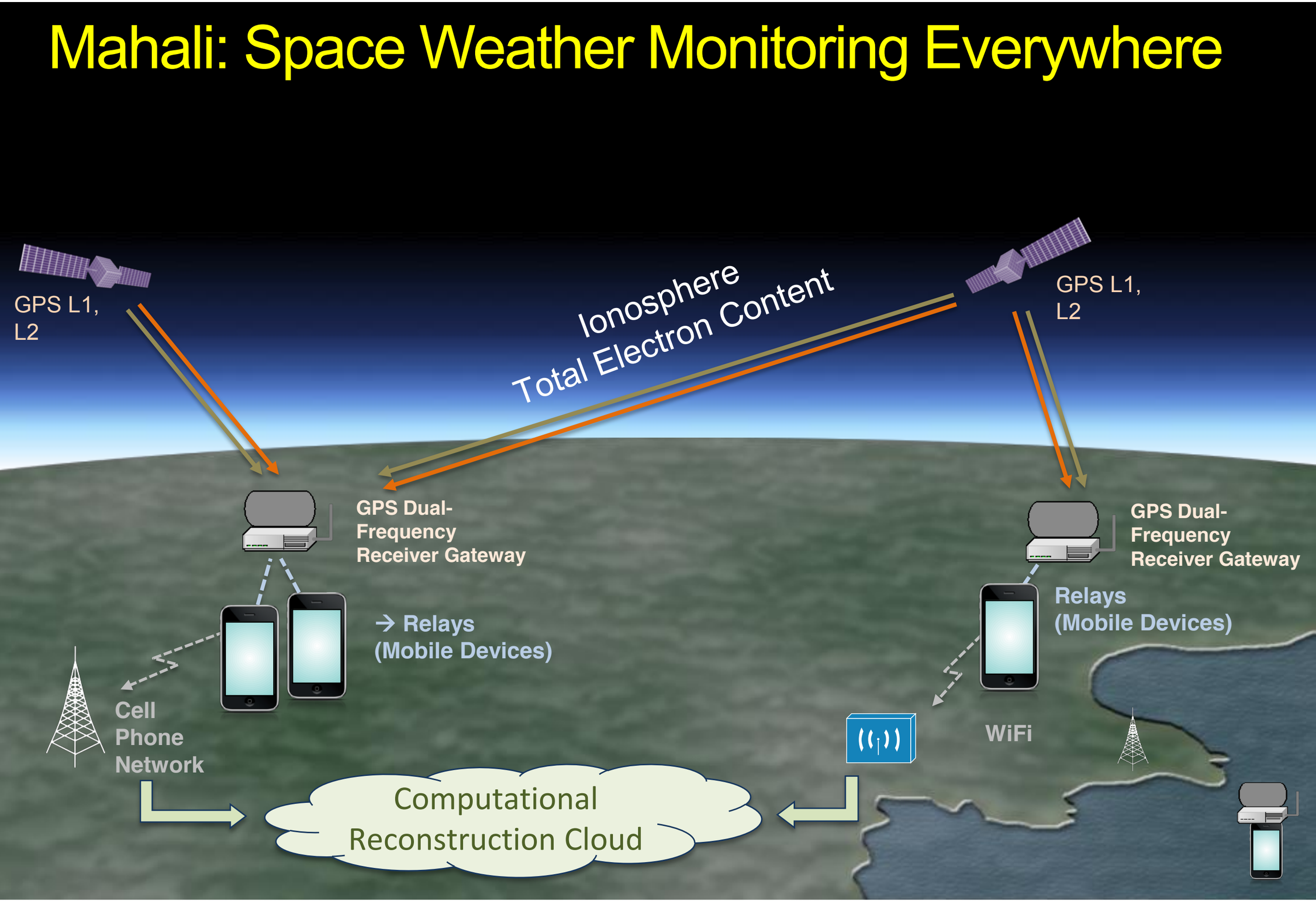
Rural Gambia; Source: Wikipedia



Source: Wikimedia Commons; World Bank, Miniwatts Marketing Group

Note: Mobile phone data for Libya and Tanzana are from 2004.

Mahali: Space Weather Monitoring Everywhere



Conclusions

- Mobile technology is a game changer for observatories
  - Range, variety of networks for data transport
  - Pervasive use
  - Processing power: Local parallel computing on multicore processors, cloud connectivity for more complex tasks
  - Local storage
  - Expecting dual-frequency GPS in every device (e.g., for precise navigation)
  - Synchronous & asynchronous data processing
- Long-term goal: Leverage entire ionosphere as sensor for ground-based and space-based phenomena