# Distributed Arrays for Space Weather Sensing and the SCINDA Network

*International Space Weather Initiative*

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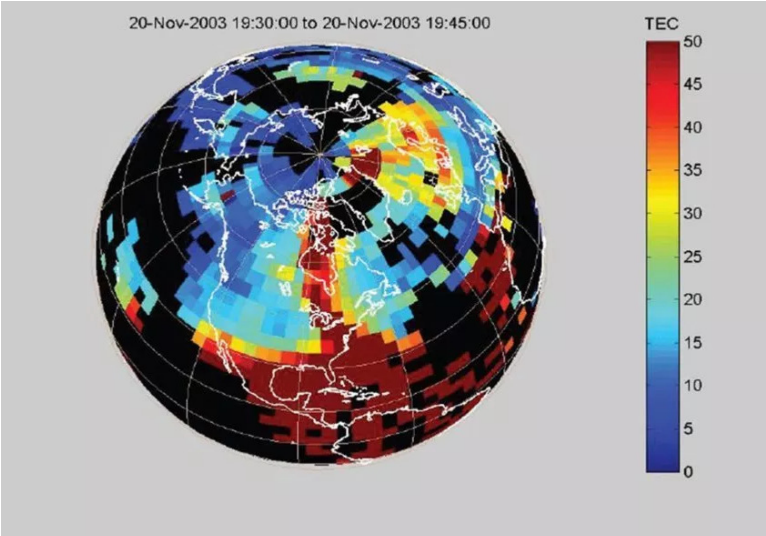
*20-24 May 2019* *ICTP, Trieste, Italy*

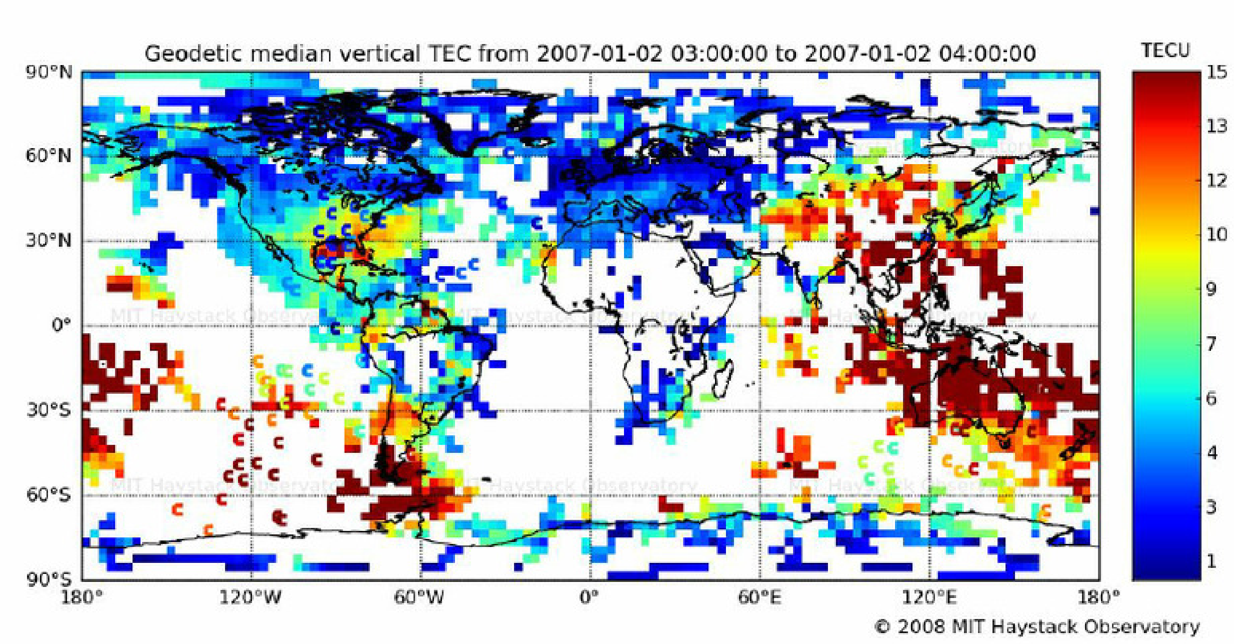
# Outline

- Attributes of Successful Distributed Sensor Networks
  - Some existing networks
- SCINDA Status and Plans
- Exploiting Data from Existing Sensors
- Summary

# GNSS Distributed Networks

- Spatially distributed GPS/GNSS receivers
- Key aspects for success:
  - ✓ Scientific or societal benefit (First "global" scale view of ionospheric dynamics)
  - ✓ Relatively inexpensive sensor deployment & ops
  - ✓ Standardized data format/product*
  - ✓ Data freely and routinely available; latency varies
  - ✓ International (shared resources)
  - ~ Organized community
  - ~ Centralized distribution

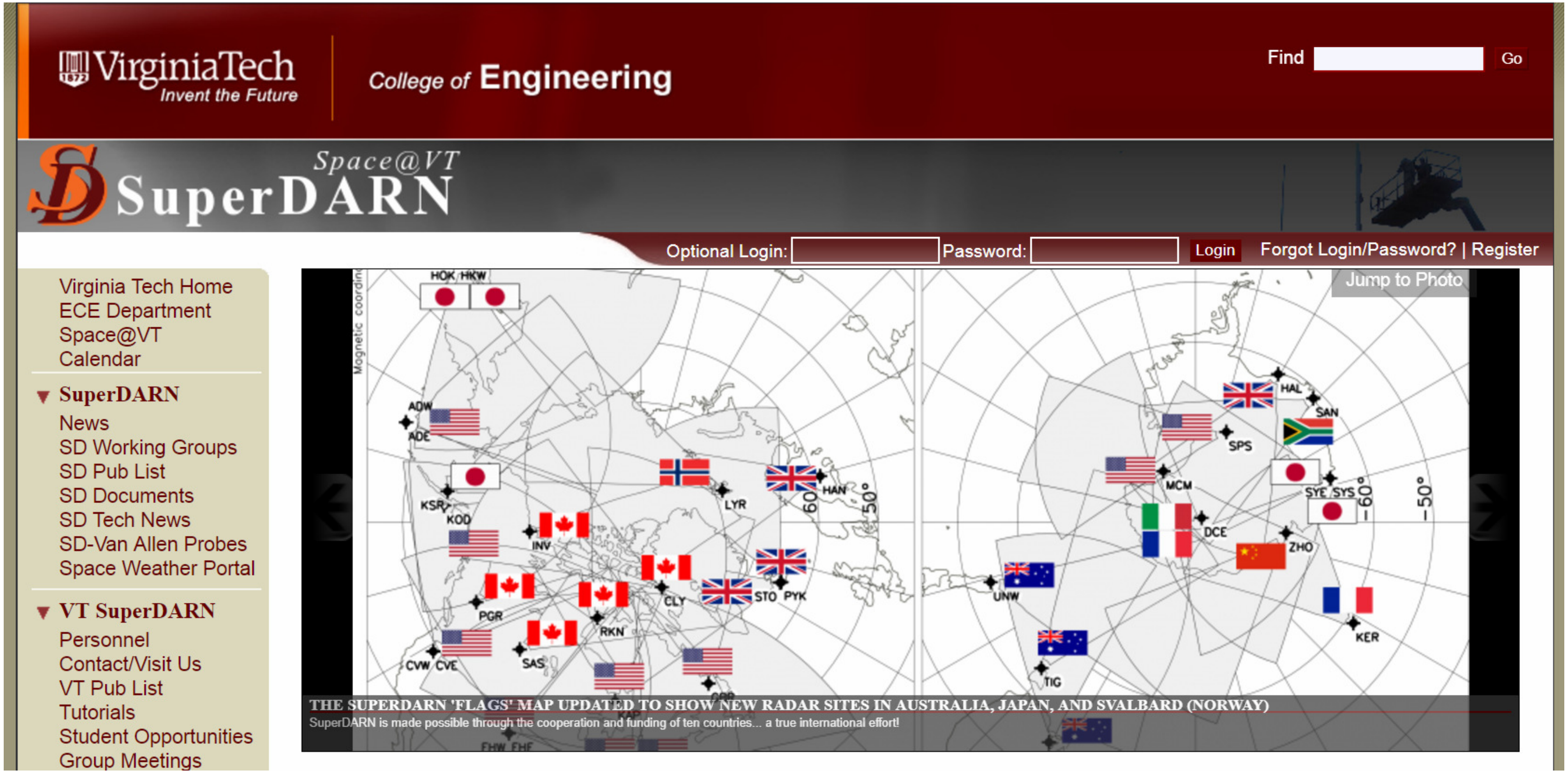



*Rinex, but not TEC

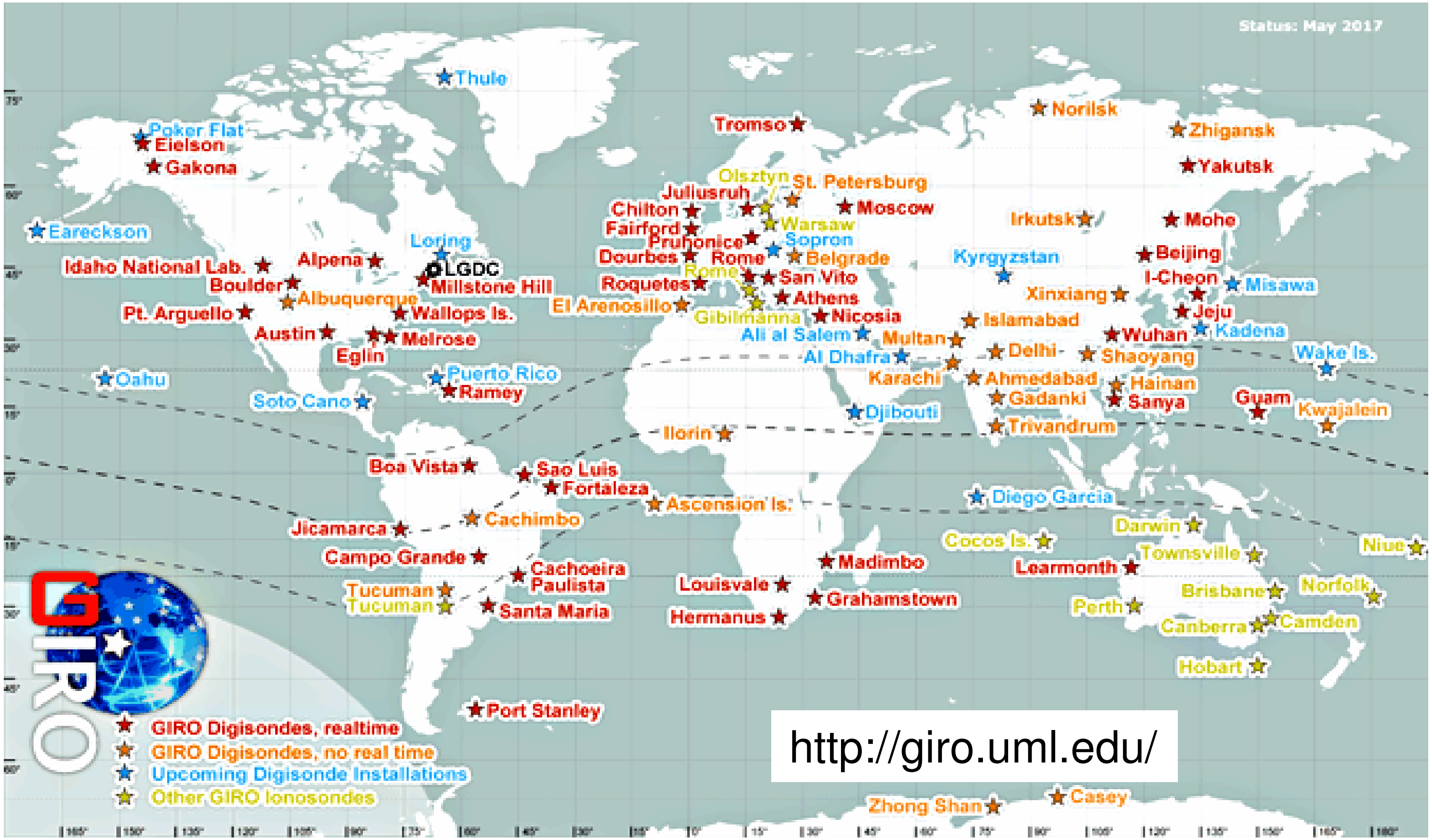
# SuperDARN Radar Network

- Powerful HF coherent backscatter radars (not particularly inexpensive)
- Measures HF backscatter from density irregularities to estimate ionospheric drift velocities; focused on high to mid-latitudes
- International (shared resources), organized community, standardized shared data and fused product, centralized distribution



# Global Ionospheric Radio Observatory
## Ionosonde Network

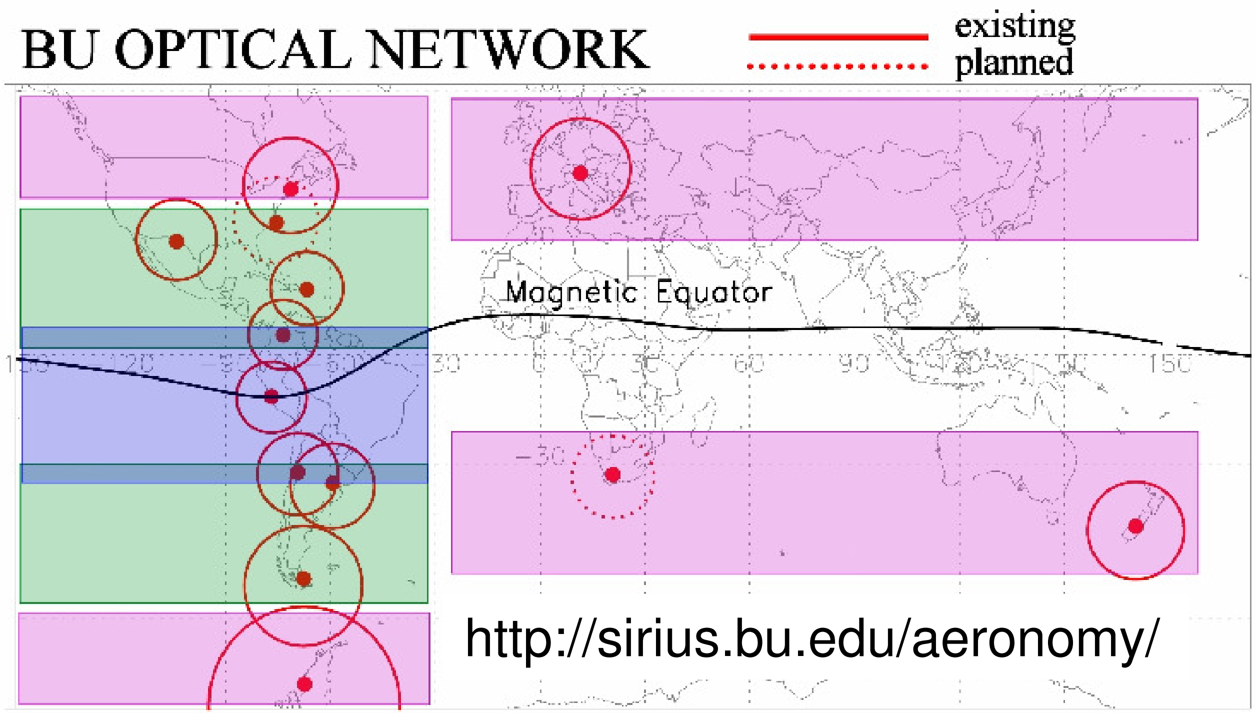
- Recognized benefit, standardized products, readily available, international participation, organized community, centralized distribution



# Radio Signals are not the only data type: All-Sky Imagers

- Boston University has a network of all-sky imagers that forms an American meridional sector chain
- Different regions are characterized by different physical processes
- Other organizations are developing similar concepts
- Centrally funded
- Data sharing through collaboration
- Standardization?

Example Distributed Sensor Network




**1. Equatorial and low latitude Ionosphere** (from magnetic equator to the crests of the Appleton Anomaly). *ESF and MSTIDs, effects on trans-ionospheric radio signals using GPS and optical diagnosis.*

**2. Mid latitude Ionosphere** (poleward from Anomaly crests to ~ ± 40 mag lat). *Nighttime MSTIDs, E and F region coupling.*

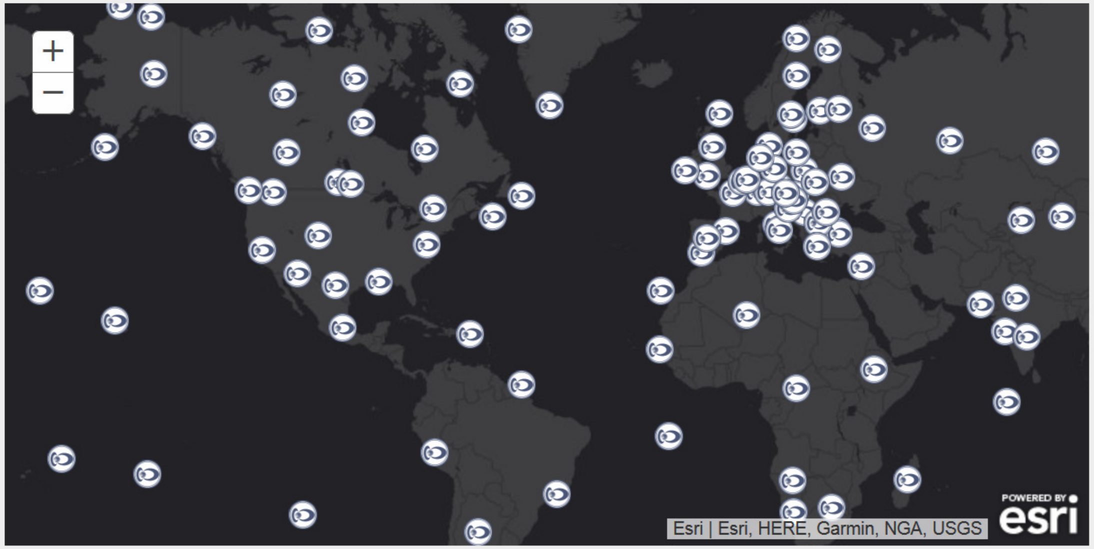
**3. Sub-auroral Ionosphere** (latitudes below auroral ovals). *Stable auroral red (SAR) arcs (magnetic activity effects that transfer magnetospheric ring current energy into the I-T system)*

# INTERMAGNET Magnetic Observatories

- INTERMAGNET originated in the late 1980s to address the lack of connectivity between existing magnetic observatories around the world
- The data has numerous applications, including the study of solar events
- The website lists more than 140 participating observatories

- International and voluntary participation funds sensors
- INTERMAGNET established strict guidelines for acceptable data & formats that must be adopted by participants
- Managed by international committee, connection to IAGA scientific organization
- Data downloadable, minimal overhead

**Magnetic Observatories (Map)**



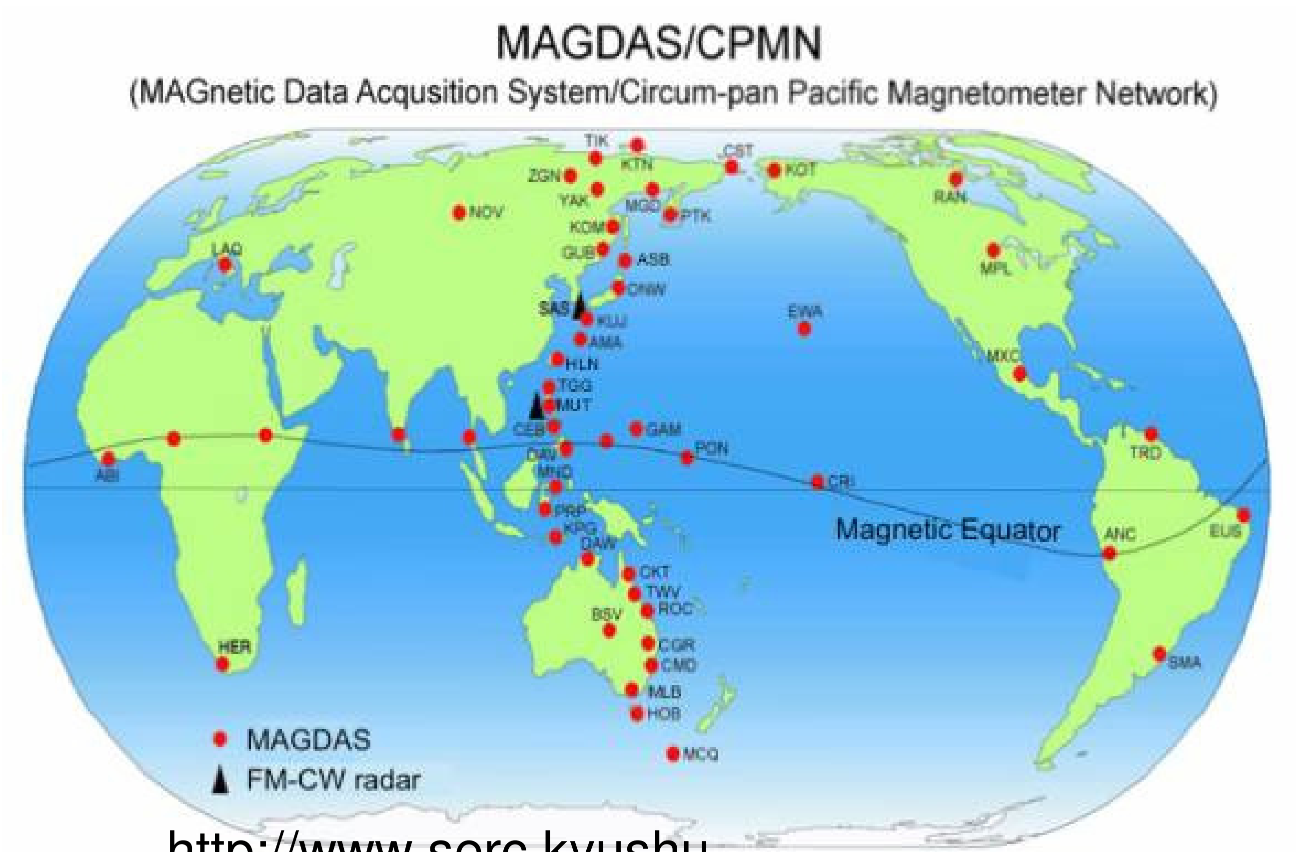

A large number of geomagnetic observatories throughout the world are members of INTERMAGNET. All these observatories send their data to Geomagnetic Information Nodes. In order to become an INTERMAGNET observatory (IMO) a strict set of conditions must be met. These conditions are described in the INTERMAGNET Technical Manual. Go to List of IMOs to follow the links to individual observatories. Details on location, instrumentation, type of data, and more are given in the pages for the individual observatories.

Map provided in collaboration with *Geophysical Center of Russian Academy of Science*

http://www.intermagnet.org

# MAGnetic Data Acquisition System (MAGDAS)

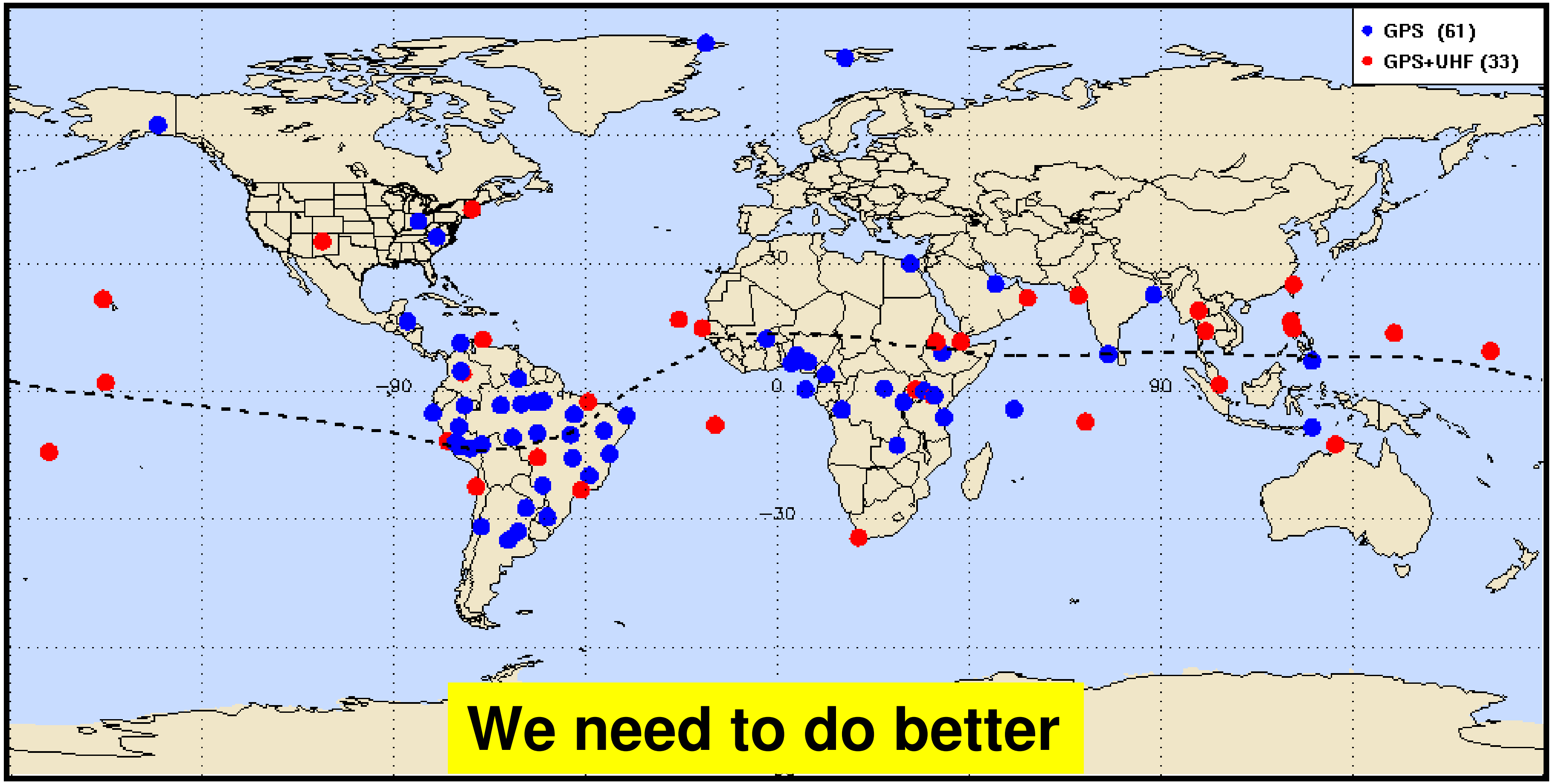
- Originally a meridional chain, MAGDAS has been expanding to other longitudes at low latitudes through **ISWI**
- The goal of MAGDAS is to become the most comprehensive ground-based monitoring system of the earth's magnetic field (to study solar events)
- Standardized data types, inexpensive sensors, international participation
- Single-source funded for sensors; international partners for siting
- Data available through contact/collaboration




http://www.serc.kyushu-u.ac.jp/magdas/MAGDAS_Project.htm

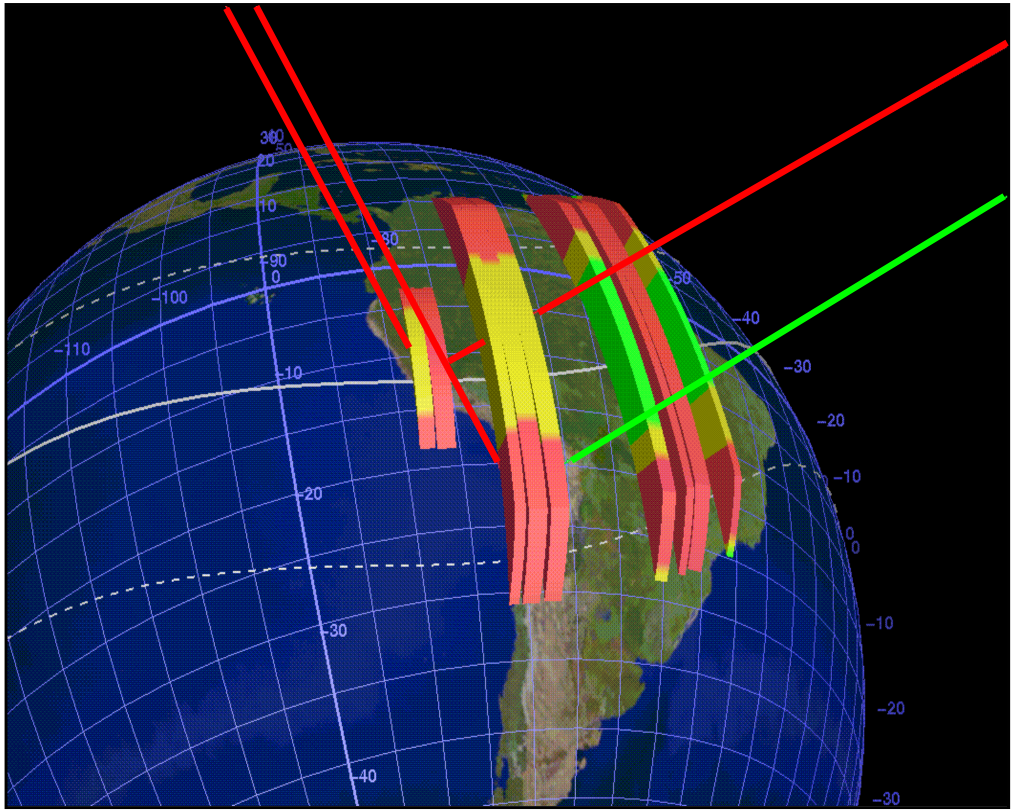
# Scintillation Network Decision Aid (SCINDA)

- Sites containing SCINDA (and LISN) hardware as noted in the legend
- The status of individual sites is not indicated; several are not healthy or real-time
- Standardized data types, inexpensive sensors, international participation but single-source funded, data not freely available, community somewhat organized



# Motivation for SCINDA

A *regional nowcasting system* to support research and users of space-based communication and navigation systems



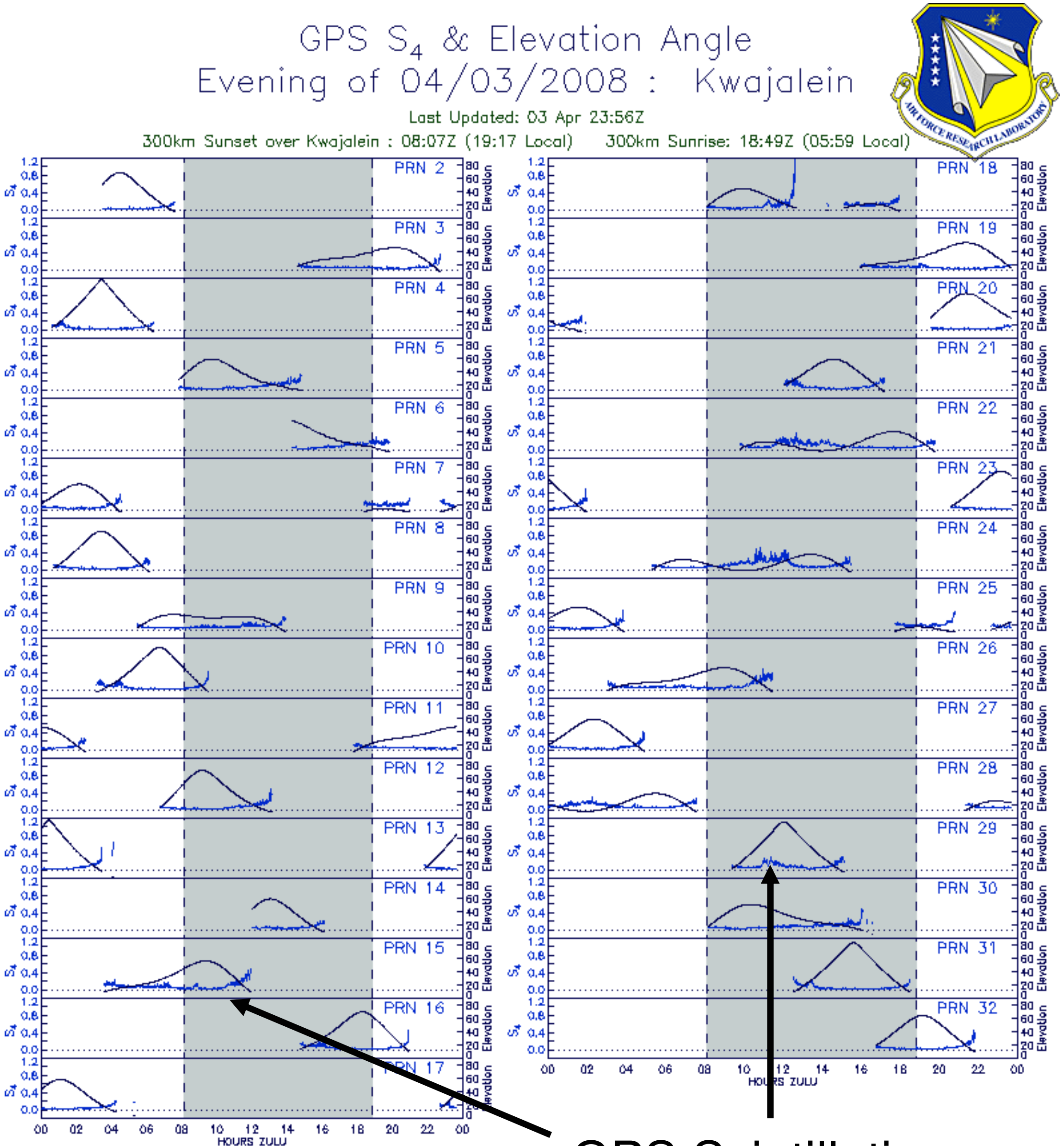
- Ground-based sensor network
  - Passive UHF / L-band /GPS scintillation receivers
  - Measures scintillation intensity, eastward drift velocity, and TEC
  - Automated real-time data retrieval via internet
- Data supports research and space weather users
  - Understand on-set, evolution and dynamics of large-scale ionospheric disturbances
  - Empirical model provides simplified visualizations of scintillation regions in real-time

# What's Happening with SCINDA?
## AFRL Reorganization

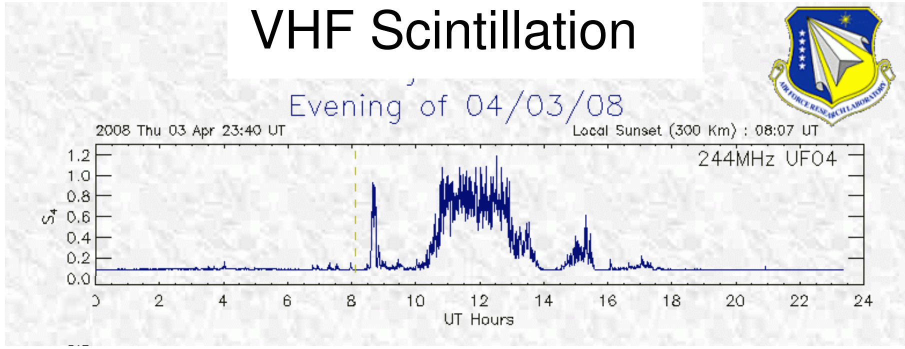
- AFRL officially relocated from the Boston area to Albuquerque, New Mexico at the end of July 2011
- Following a (lengthy) period of space weather mission and management reorganization, the AF intends to resume support of SCINDA network data collection through Boston College
- Some programmatic issues <u>remain to be resolved</u>

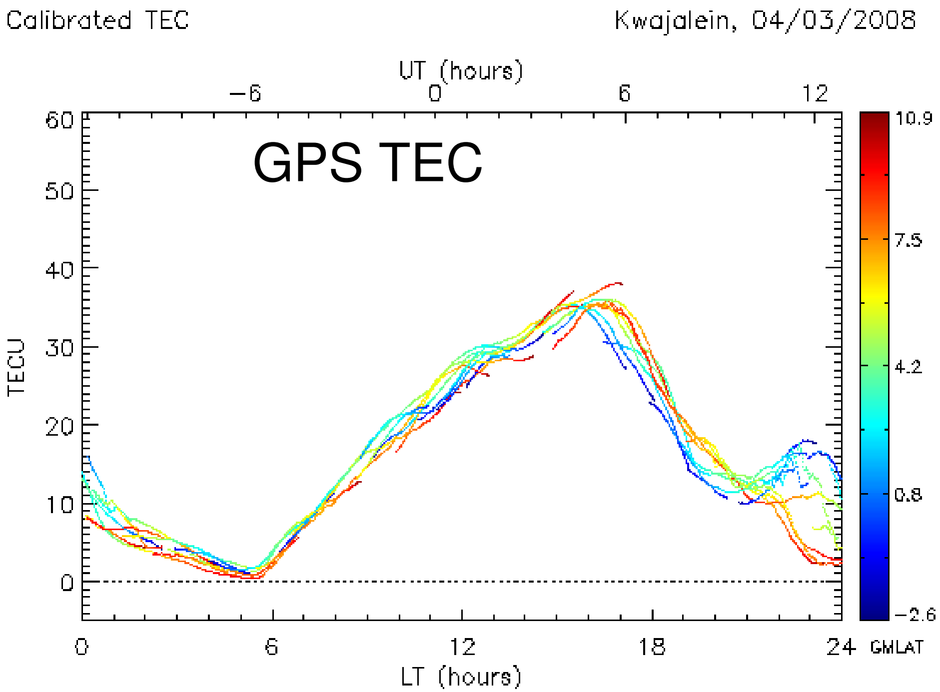
- Immediate focus will be on restoring high priority sites and updating sensors (existing GPS & VHF sensors both obsolete)
- Future looks bright, BUT the key to continued success will be consistent data acquisition

# SCINDA has a Space Wx Focus: Scintillation Severity & Drift




GPS Scintillation




Requires high-rate data sampling and signal processing

# Upcoming Developments for SCINDA

NEAR-TERM

•Sensor upgrades: GNSS and new VHF

MID-TERM

•Increased attention on site robustness, reliability and real-time data

- Development of solar power & cellular data transer capabilities
- Improved operator and site support (training, operating costs, etc)

•Make entire scintillation and TEC data archive > 6 months old publicly available (real-time data available to participants and/or through collaboration with P.I.s)

- Requires website development
- Includes free distribution of SCINDA software

LONGER-TERM

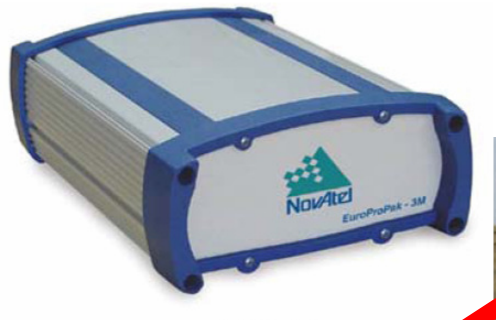
•Grow the network

•Exploit available TEC data sources

# SCINDA Sensors

Single channel VHF Receiver


USRP 8-channel VHF Receiver



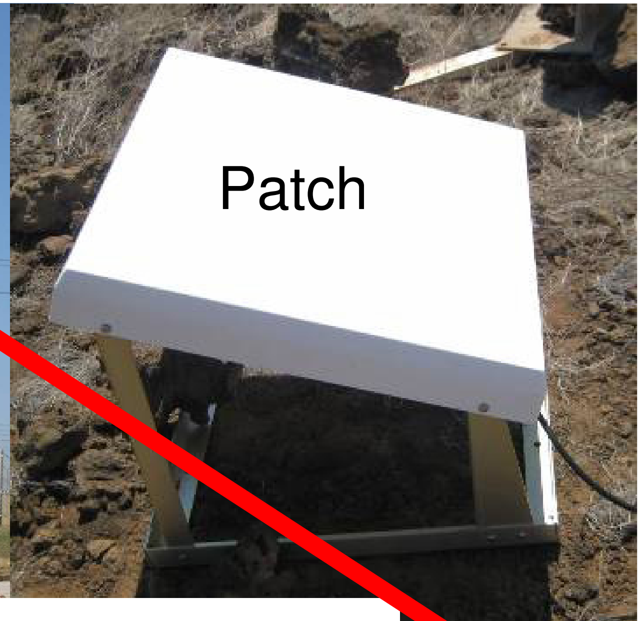

GSV4004B

GPS Receiver

GPS Antenna

Yagi

Patch



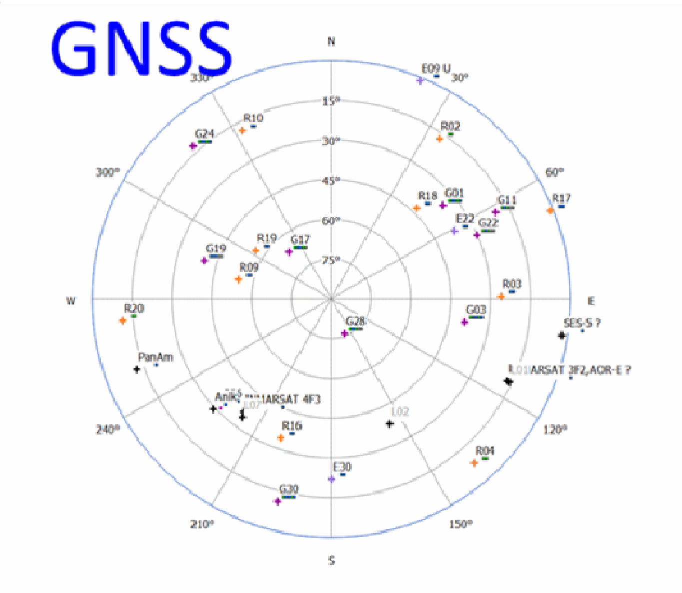
VHF Antenna

# Expand Use of Modern GNSS Sensors

## GPS Rx Replacement

### Existing GPS receivers are obsolete; replacement hardware will be fully GNSS


- Multi-frequency L1/L2/L5/E5abAltBoc code/carrier tracking of GPS, GLONASS and GALILEO signals


GNSS approximately doubles available number of measurement links; validation needed

# Upgrades to Improve System Reliability

## Availability and real-time are still important!

- Autonomous SCINDA system upgrades:
  - Low power computer (6-8 Watts)
  - Deep cycle UPS (with optional solar panel addition)
  - 3G cellular USB modem (to augment network connection)
  - Solar powered option

Low power, compact Fit-PC

Goal is to establish a “get-well” plan for each existing site and implement it efficiently

# Relationships Between Scintillation Parameters

(Carrano et al., *Radio Sci.*, 2016; Carrano et al., *JGR Space Phys.*, 2019)

## Amplitude Parameters

**Amplitude scintillation**

**Decor-relation time**

$$\tau_I \sim \rho_F / V_{eff} \ \text{(weak)}$$

$$\tau_I = [C_p G F_\tau(p)]^{-1(p-1)} / V_{eff} \ \text{(strong)}$$

## Phase Parameters

**Phase scintillation**

$$\sigma_\varphi^2 = C_p G F_\sigma(p) \left[ V_{eff} \tau_c \right]^{p-1}$$

**TEC rate of change index**

$$ROTI^2 = C_p G F_R(p) \frac{c^2}{\delta t^2} \left[ V_{eff} \delta t \right]^{p-1}$$

- Phase perturbation $C_p$ depends on irregularity strength as $C_p = r_e^2 \lambda^2 \sec\theta \left(2\pi / 1000\right)^{p+1} C_k L$
- $S_4$, $\sigma_\varphi$, and *ROTI* share same dependence on irregularity strength, any of them can measure $C_k L$.
- $S_4$ depends on the distance to the irregularities through the Fresnel parameter. It scales with wavelength as $S_4 \propto \lambda^{(p+3)/4}$. It saturates in very strong scatter.
- $\sigma_\varphi$ and *ROTI* depend on the irregularity drift through the effective scan velocity. In weak scatter they are proportional to wavelength $\sigma_\varphi \propto \lambda$, and $ROTI \propto \lambda$ (and simply related to each other!)
- $\tau_I$ changes with irregularity strength in strong scatter, also depends on $V_{eff}$.

# Relationships Between Scintillation Parameters

(Carrano et al., *Radio Sci.*, 2016; Carrano et al., *JGR Space Phys.*, 2019)

## Implication:

- If ROTI is sampled sufficiently fast and drift velocity is known, it is possible to estimate CkL (i.e., scintillation parameters)
- Necessary sampling rate determined by environment: well within the outer scale (~10 km?)
- Potentially unlocks thousands of TEC sites for scintillation monitoring

*Table of Symbols*

$C_p$ – phase spectral strength due to irregularities
$p$ – phase spectral index
$k$ – signal wavenumber
$\theta$ – propagation (nadir) angle
$z$ – vertical propagation distance past screen
$\rho_F$ – Fresnel scale = $[z \sec \theta / k]^{1/2}$
$\wp(p)$ – combined geometry and propagation factor
$G$ – phase geometry enhancement factor
$F_s(p)$, $F_\sigma(p)$, $F_R(p)$ – functions of $p$ only
$V_{eff}$ – effective scan velocity
$\tau_c$ – time constant of the phase detrend filter
$\delta t$ – TEC sampling rate

References:


– Carrano, C., K. Groves, C. Rino, and P. Doherty (2016), A Technique for Inferring Zonal Irregularity Drift from Single-Station GNSS Measurements of Intensity (S4) and Phase (σφ) Scintillations, *Radio Sci.*, 51, 8, 1263-1277, doi:10.1002/2015RS005864

– Carrano C., K. Groves, and C. Rino (2019), On the relationship between the rate of change of total electron content index (ROTI), irregularity strength (CkL) and the scintillation index (S4), *JGR Space Physics*.

# Summary

- Numerous distributed networks exist and will likely continue to expand as long as they address a compelling scientific or societal need
- Successful networks share a number of key attributes that can provide guidance for the development of additional networks in the future
- SCINDA has been unsupported since mid-2014, but has nearly turned the corner for renewed sponsorship
- The network is in serious need of capability restoration—reliability and real-time data transfer will be emphasized
- Additionally, in many cases we may be able to exploit ROTI observations for scintillation estimates
- New opportunities for participation, sensor deployment, operation and data analysis for the ISWI community

# First SCINDA Workshop

## Sal, Cape Verde 10-14 July 2006