J5.2 UNIVERSITY NAVSTAR CONSORTIUM SUPPORT FOR SUOMINET, A GPS NETWORK FOR ATMOSPHERIC SENSING

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1. ABSTRACT

The University NAVSTAR Consortium (UNAVCO) is a consortium of 100 international universities and laboratories joined to promote the use of the Global Positioning System (GPS) for high-accuracy geosciences research. Traditionally UNAVCO's Boulder Facility provides GPS technology and support to high-accuracy geodetic users via specific project support to investigators funded by the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA). SuomiNet is a university-based, real-time, national GPS network that is being developed for atmospheric research and education (Ware, et al, 2000). SuomiNet is based on a network of GPS receivers located at participating universities that will measure phase delays induced in GPS signals by the ionosphere and neutral atmosphere. These delays can be converted into integrated water vapor (if surface pressure data are available) and total electron content (TEC) along each GPS ray path. Currently UNAVCO provides operational support for SuomiNet by developing receiver specifications, equipment testing, computer operating system configuration, providing data streaming and receiver configuration software compatible with the UNIDATA program, by system packaging, shipping, and configuration, and finally by data routing and backup for geodetic quality stations. SuomiNet provides an opportunity to create a synergy between the solid Earth and atmospheric research communities by providing a single point of contact for all GPS based technology, support, and data management.

2. INTRODUCTION

UNAVCO, in conjunction with the University Corporation for Atmospheric Research's (UCAR's) GPS Science & Technology (GST) and UNIDATA programs, are integrating a GPS receiver and firmware, a meteorological (MET) sensor, data collection software, and data and product distribution software for support of SuomiNet. SuomiNet will demonstrate the innovative concept of a university-based national geophysical instrument providing critical real-time atmospheric data for research and education (Figure 2.1). UNIDATA has a long history of successfully distributing meteorological data to universities. However, SuomiNet is the first application where not only will data be transferred from participants, but quasi real-time products will be returned to investigators, all using the UNIDATA Internet Data Distribution (IDD) model.

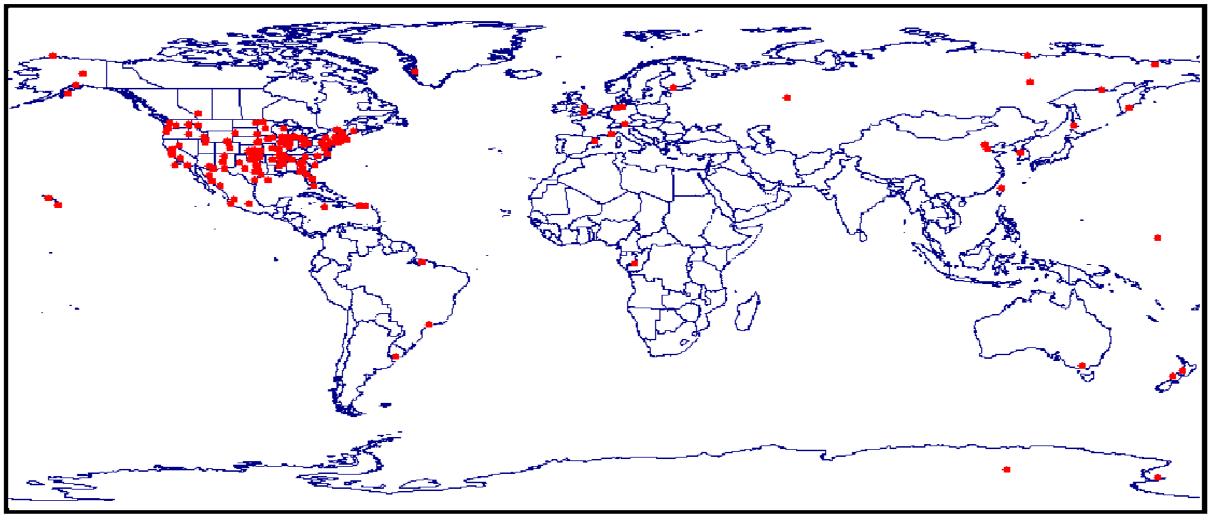

Figure 2.1: SuomiNet sites currently registered. Of the sites registered approximately 60% are registered for both geodetic and atmospheric applications. See http://www.unidata.ucar.edu/suominet for more information and on-line registration.

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3. SUOMINET HARDWARE INTEGRATION

Participating SuomiNet sites will have a GPS receiver and antenna, MET sensor, Linux based computer with uninterruptible power supply and ancillary support equipment. The receiver and MET configurations are discussed below. An example of a deployment configuration is shown in Figure 3.1.

3.1 *GPS Receiver and Antenna*

The UNAVCO Facility was tasked with providing a specification for a high quality and price competitive dual-frequency GPS receiver. A specification was developed in consultation with the SuomiNet and the UNAVCO community and opened for bid to GPS manufacturers (see: http://www.unavco.ucar.edu/dev_test/publications/suominetspec/Suominet10-22-99.html).

Unique aspects of the receiver specification were the ability to acquire high rate GPS data for ionosphere scintillation experiments, the ability to disable all GPS receiver multipath mitigation algorithms to avoid filtering out low angle GPS observations important in atmospheric applications, and the ability to stream BINEX (Estey et al., 2000), a binary GPS observable format developed at the Facility. The antenna specification called for a high quality dual-frequency GPS antenna with a well-defined antenna phase center and gain pattern, but not necessarily the Dorne and Margolin choke ring antenna which is a standard with the high precision GPS geodetic community. The reason for breaking with convention on the antenna were:

- The "choke effect" of the Dorne and Margolin choke ring antenna effectively filters out observations at elevation angles lower than ~20° - observations which are very important for atmospheric sensing applications.
- Most manufacturers now market antennas with very stable, consistent, and repeatable phase center/patterns.
- The SuomiNet network will be homogeneous using the same antenna, and thus avoid antenna mixing issues within the network.
- Manufacturers' antennas are much less expensive, often one half to one third the price of the milled choke ring antenna.

GPS manufacturers responded with receivers and antennas that were evaluated based on performance criteria developed for SuomiNet, for example, low elevation tracking performance and GPS carrier phase precision. A report detailing the methodology and results of the receiver and antenna tests can be found at http://www.unavco.ucar.edu/dev_test/publications/

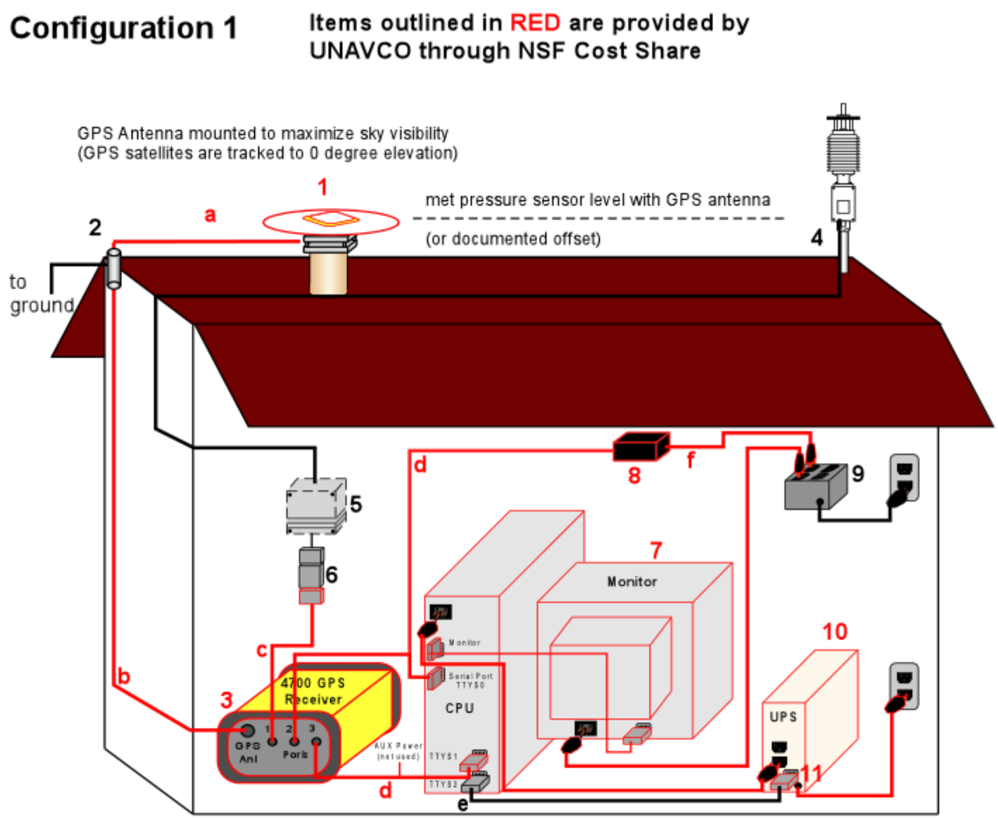

Figure 3.1: Possible SuomiNet deployment configuration showing a GPS receiver and antenna (1 and 3), MET sensor (4), and system computer (7). See http://www.unavco.ucar.edu/equipment/suominet/configurations.html for color figure and more details.

suominetreportv_4.pdf. The SuomiNet project selected the Trimble 4700 receiver with the Trimble Microcentered antenna (Figure 3.2).

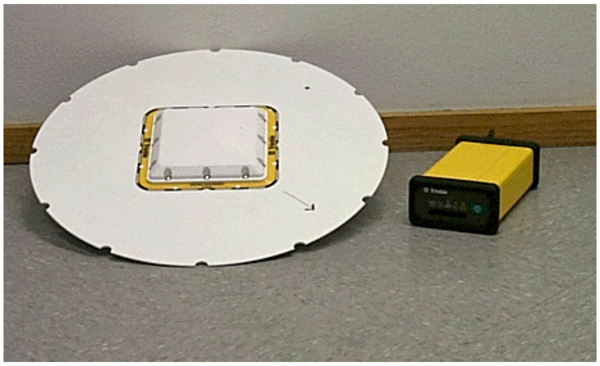

Figure 3.2: The Trimble 4700 GPS receiver and Microcentered antenna.

The receiver will use special firmware which is specifically configured for atmospheric applications. For example, the receiver phase bandwidth can be optimized for low-elevation and high dynamic tracking (Figure 3.3). Receiver multipath mitigation can be disabled, as can all smoothing of pseudorange observations.

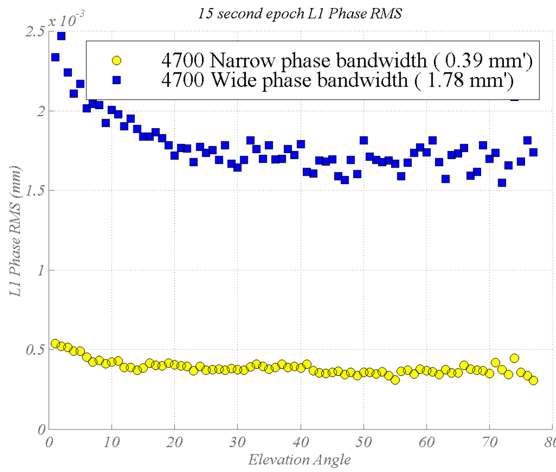

Figure 3.3: 4700 zero-baseline double difference residuals for receivers with narrow (~1 Hz) and wide (~5 Hz) phase tracking bandwidth. For dynamic applications (ionosphere scintillation) a wide tracking bandwidth should be used. For low-dynamic, very high precision phase applications a narrow tracking bandwidth should be used.

Another unique requirement of the SuomiNet GPS receiver system was it needed to stream GPS observables in the BINEX format. The benefits of using BINEX are:

- Robust error correction for streaming applications.
- Scalable and easily extendable format
- Data Compression (~2-6X better than other binary formats)
- BINEX translator built into the UNAVCO translate, Edit, and Quality Check (TEQC) program
- CA, P1, and P2 pseudoranges to 0.001 meter resolution (same as in RINEX)
- L1 (CA), L1 (P1), and L2 (P2) phase values to 0.0001 cycle (one order of magnitude better than RINEX)
- Includes signal-to-noise values for L1 and L2
- Manufacturer specific error flags for each satellite
- Observable records for MET and geophysical data
- Format adopted by several major GPS receiver manufacturers

An example of parsed GPS observables as recorded in the BINEX format are shown in Figure 3.4. More information on the BINEX format can be found at http://www.unavco.ucar.edu/software/binex.html.

```
Binex Record[5]: id=7F  len=244
Subtype 0x02: Trimble Binex Observables Record
  GPSmin:10919817 Weekms:15000  [GPSWeek:1083
TUE 04:57:15.000]
  Number of satellites: 9 - PRNs=
7,9,8,4,20,24,2,5,26
  Clock offset bit flags : 0x04
  Clock Offset : 169029 nsec
  First ObsPresent is 7A - lsb is 0
    Using for all observables groups
  PRN:7  Obs:7A chn:00  SNR(L1/L2):52.5/44.8
A/S:1  LOL:L1-0 L2-0
      C/A range  20776040.592
    CA-P2 range        10.178
       CA phase -15669335.9239
    L1-L2 phase    -14326.4530
     L1 doppler     -1320.918
  PRN:9  Obs:7A chn:01  SNR(L1/L2):51.0/40.5
A/S:1  LOL:L1-0 L2-0
      C/A range  22146124.861
    CA-P2 range         9.260
       CA phase -13077827.3443
    L1-L2 phase    -19791.8514
     L1 doppler      1012.017
```

Figure 3.4: An ASCII representation of the BINEX (7Fh) GPS observable record for satellites PRN 7 and 9. Note the inclusion of L1 and L2 Signal to Noise (SNR) values as part of the observable records.

3.2 *MET Sensor*

Each SuomiNet site will have a dedicated meteorological measurement package (MET package) recording temperature, barometric pressure, and relative humidity controlled by UNAVCO developed software (described later). MET observations will be stored directly in the GPS stream in BINEX format. Examples of parsed MET observables as recorded in the BINEX format are shown in Figure 3.5.

```
Binex Record[4]: id=7E  len=15
Subtype 0x00 - Ancillary Site data (MET data)
  GPSmin:10919817 Weekms:3577  [GPSWeek:1083
TUE 04:57:03.577]
  Observables = 0x07
  Pressure = 836.819 millibars
  Temp = 23.99 degrees C
  Humidity = 28.2 %
Simple Checksum: 39(rcvd)   39(calc)
```

Figure 3.5: An ASCII representation of the Binex (7Eh) MET observable record containing Pressure (mbar), Temperature (C), and Relative Humidity (%).

The Facility has recommended use of either the Paros MET 3/3a or Vaisala PTU-GPS, which differ primarily in price and dynamic range for barometric pressure observations. Both systems have highly stable pressure sensors requiring infrequent calibration.

4. SUOMINET DATA MANAGEMENT

Each SuomiNet site will have a dedicated computer system to capture GPS and MET observables, allow real-time configuration of the GPS and MET sensors, shunt data into the IDD data distribution queue, and act as a short term (~30 day) site data backup system. The computer will run the Linux operating system networked to the Internet. A Java-based program called JStream (Jackson et al., 2000) will configure the receiver and MET sensor using a site property file, accept the data stream, and package the observables into files. Once files are written to disk, a separate Perl-based program will move the files into the data distribution queue where the Unidata IDD program will pick up the files for distribution. Figure 4.1 outlines the proposed data management implementation.

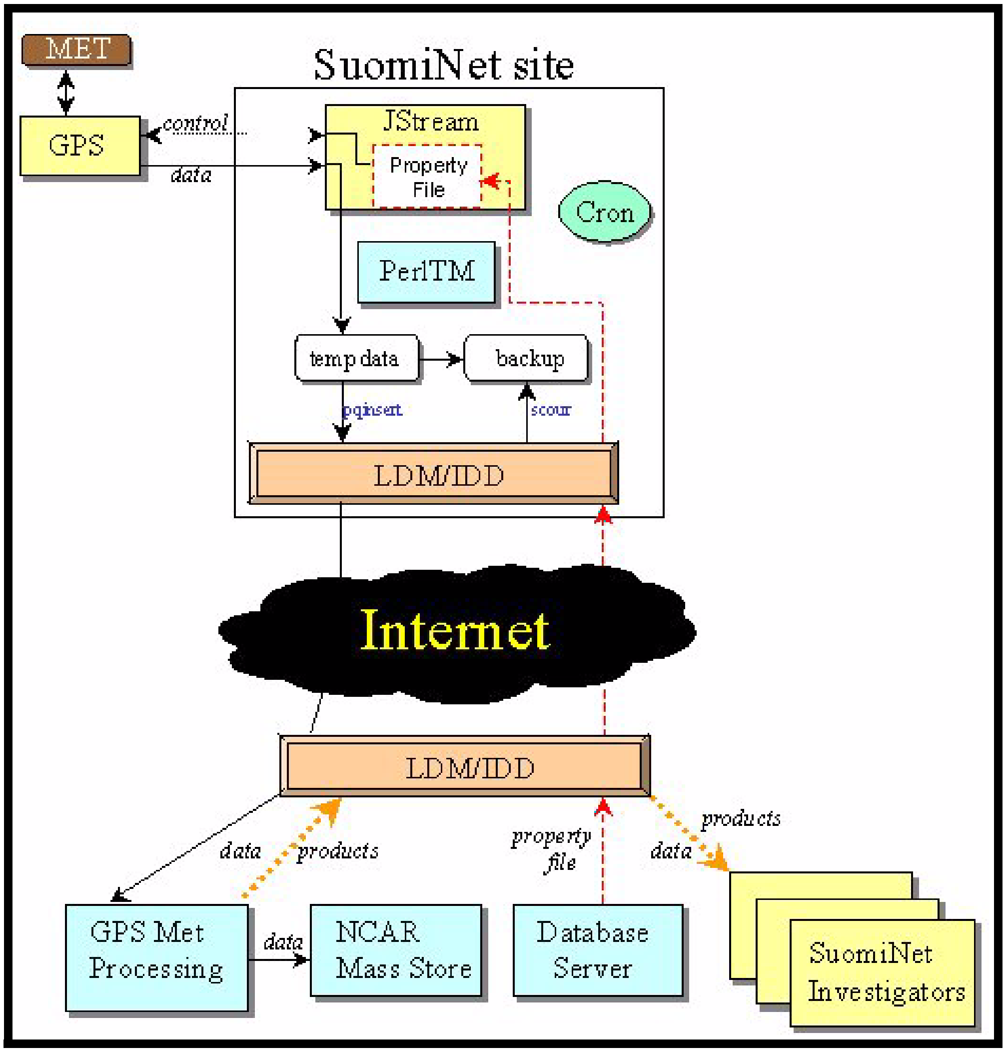

Figure 4.1: Proposed data management scheme for SuomiNet.

As illustrated in Figure 4.1, a MET sensor plugs directly into the Trimble 4700 which streams BINEX GPS and MET observables into the Linux data collection and transfer computer. JStream collects the raw data into time-binned files in a temporary directory. A PERL program (PerlTM) will use the LDM pqinsert program to put the raw observable file into the LDM queue which will transport the data via the Internet to the UCAR/GST LDM data manager/data processing server. PerlTM will then move the file into a longer term backup storage directory where it can be removed after 30 days by the LDM "Scrubber" command. The UCAR/GST LDM Server will push the data to NCAR's Scientific Computing Division mass storage system for long term archiving. GST will process the data into troposphere and ionospheric products (zenith delay, slant delay, TEC) that will be distributed via IDD to the University user and atmospheric research community (see http://www.gst.ucar.edu/gpsrg/ for more details).

The UNAVCO Facility will pull a subset of the data of interest to the solid Earth community and make it available to investigators via anonymous ftp.

5. JSTREAM SOFTWARE

At the heart of the data management system is JStream, a Java software tool developed to configure and stream GPS and meteorological observables, create data files, and deliver data to a client (in this case LDM data manager/data processing server) (Jackson et al., 2000). JStream for SuomiNet operates on a receiver property file which is used to configure the receiver and set the observable file size. The program monitors the data stream by reading individual data records and buffers the data so that back-to-back files are created with no loss of data or cycle-slips.

Site metadata and complete configuration information are stored in a SuomiNet Network database at the UNAVCO Facility. These data include antenna height and receiver configuration information including tracking elevation, epoch interval, and custom receiver settings. The database can create a site property file (Figure 5.1) for each SuomiNet station. The property file includes all information needed to configure the receiver and bin data into files.

The benefit of storing this information in a database is that it allows for the creation of property files with the exact configuration for all or part of the network. For example, a subset of 20 SuomiNet sites may want to change tracking parameters simultaneously to collect GPS observations during an ionospheric scintillation event. The database would generate a property file for each station that increases the observation interval to 5Hz, opens the phase tracking bandwidth, and reduces the elevation tracking mask to zero. The property files are then distributed to the respective SuomiNet site computers using the IDD model, and JStream applies the configuration upon receipt. The JStream property file and database concept in concert with the real time delivery offered by IDD means that the SuomiNet network can act as a cohesive large aperture instrument to capture ionospheric and atmospheric events.

```
###########################################
# streamed data out receiver port 3 into '/
dev/ttyS1'
###########################################
comm.3port.device= COMP_Rx
comm.3port.dfdirection= IN
comm.3port.name= /dev/ttyS1
comm.3port.baud= 38400
comm.3port.parity= 0
comm.3port.flctrl= NONE
comm.3port.recname= 3
###########################################
# data stream parameters
###########################################
data.in.stream.PDOPmask= 7
data.in.stream.ElevationMask= 0
data.in.stream.TrackingMode= STATIC
data.in.stream.Smoothing= OFF
data.in.stream.MultipathMitigation= OFF
data.in.stream.streamType= BINEX
data.in.stream.StreamInterval= 1
data.in.stream.METInterval= 1
data.in.stream.file.size= 15
###########################################
# METADATA
###########################################
site.id= UNAV
site.monument_id= UNAV
site.computer_id= GSTX117
file.length= minutes
env.downloadpath=/home/gpsops/javaprojects/
Data/temp
```

Figure 5.1: A portion of the JStream property file used for receiver configuration. In this example port 3 of the GPS receiver is configured and targeted to /dev/ttyS1 on the computer, the GPS data logging rate is set to 1 sec, MET data are recorded every minute, and files are stored every 15 minutes.

6. SYSTEM DEPLOYMENT AND SETUP SUPPORT

The UNAVCO Facility will provide SuomiNet investigators with a single point of focus for system deployment and installation support. The Facility will configure and ship equipment to SuomiNet investigators, offer advice on monumentation and set up configurations, and provide limited on-going support and troubleshooting for SuomiNet sites. Initial station deployment information can be found at [http://www.unavco.ucar.edu/equipment/suominet.](http://www.unavco.ucar.edu/equipment/suominet) Once a SuomiNet station is registered the procedure for getting the station installed is:

- Verify that the registered SuomiNet site is included in the list of approved sites.
- Determine the site configuration.
- Determine the antenna cable length.
- Install atmospheric or geodetic GPS antenna monument.

- Purchase the required university cost-share equipment.
- Complete and send the Cost Share Confirmation letter to UCAR.
- Submit the required site information to UNAVCO.
- Submit GPS and computer request to UNAVCO

After completing the above steps, UNAVCO will ship a Linux based computer configured with the investigator's site IP information, a GPS receiver/antenna system, and associated ancillary equipment (for example see: http://www.unidata.ucar.edu/suominet). Phone and Web-based support is available for installation, and if necessary, an engineer site visit can be scheduled.

7. CONCLUSIONS

SuomiNet provides a unique opportunity for the UNAVCO Facility to provide support simultaneously to both the atmospheric and solid Earth GPS communities. The synergy in this relationship lies in the Facility's ability to shorten the GPS technology learning curve for atmospheric science investigators, encouraging the solid Earth community to adopt innovative techniques of sharing data developed and widely applied by the atmospheric community, applying the SuomiNet model of a simultaneously configurable, large aperture network to solid Earth initiatives, and most important in sharing the cost of collection and availability of data from stations with both atmospheric and solid Earth interest. The Facility is ready to provide support to both the solid Earth and atmospheric research communities by providing a single point of contact for all GPS based technology, support, and data management.

8. REFERENCES

Estey, L. C., Meertens, and D. Hunt, 2000: Application of BINEX and TEQC for Real-Time Data Management, Paper presented at the International GPS Service Network Workshop 2000, Oslo, Norway.

Jackson, M. C. Meertens and C. Rocken, 2000: Real-time Data Streaming from GPS Networks, Paper presented at the International GPS Service Network Workshop 2000, Oslo, Norway.

Ware, R H., Fulker, D., Stein S., Anderson, D., Avery, S, Clark, R, Droegemeier, K., Kuettner, J., Minster, B., and Sorooshian, S., 2000: SuomiNet: A Real-Time National GPS Network for Atmospheric Research and Education. Bull. Am. Meteor. Soc. 77, 5-18.