The Impact of an Active Solar Cycle on DGPS Positioning Performance

Richard Barker
FUGRO CHANCE INC.

Overview

Fugro Chance Services Using GPS

GPS Background

- Autonomous GPS
- GPS Error Sources
- Differential GPS
- GPS Performance Levels
- Impact of the Ionosphere on GPS

Monitor Data

- 1999 African DGPS
- 2000 South America / Africa DGPS
- 2003 South America Scintillations
- 1999 October 22 Event, Gulf of Mexico Performance

Conclusions

Marine Construction Survey

Precision GPS And Communications

Pile Installation

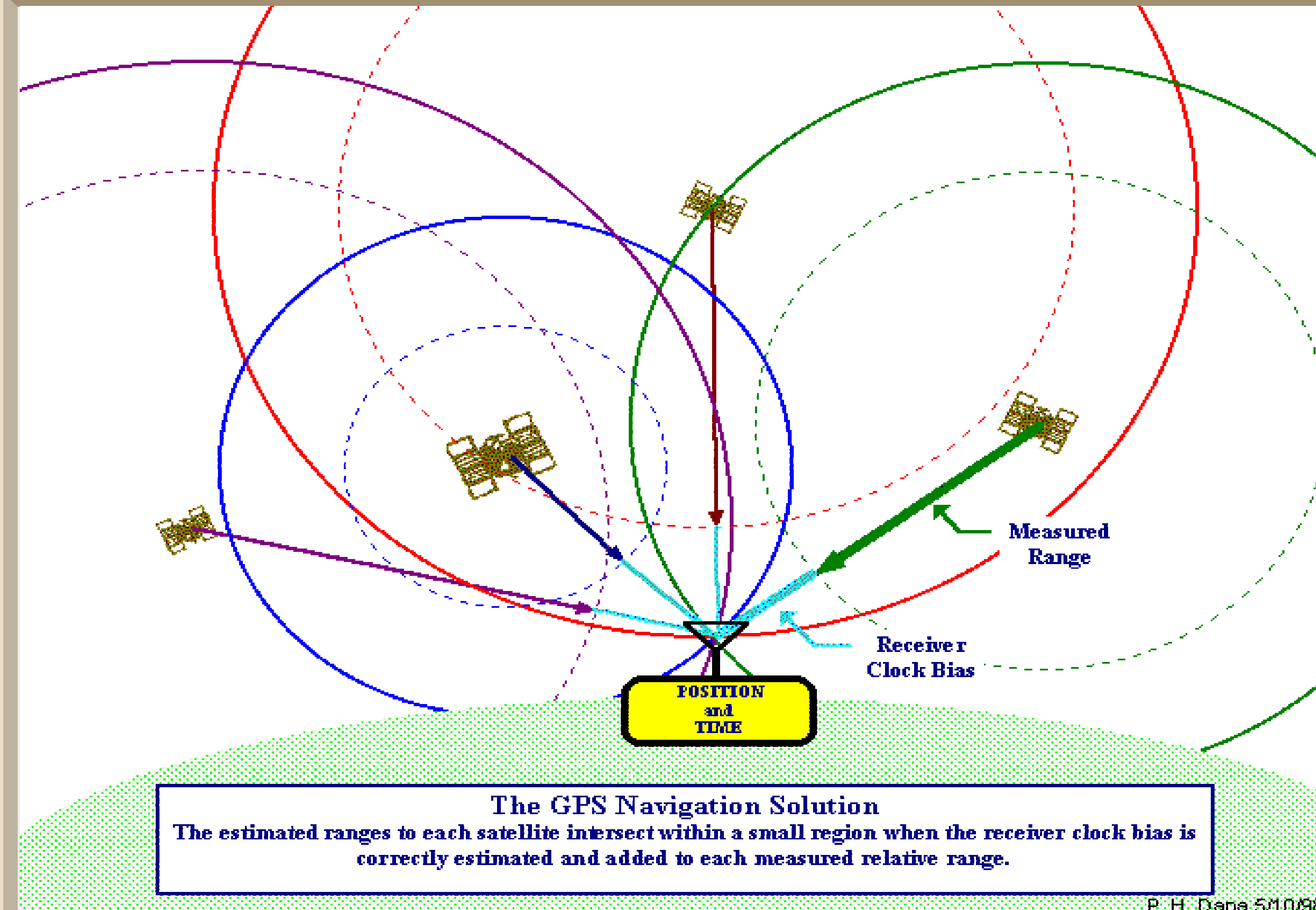
Precision GPS And Communications

Airborne Survey Operations

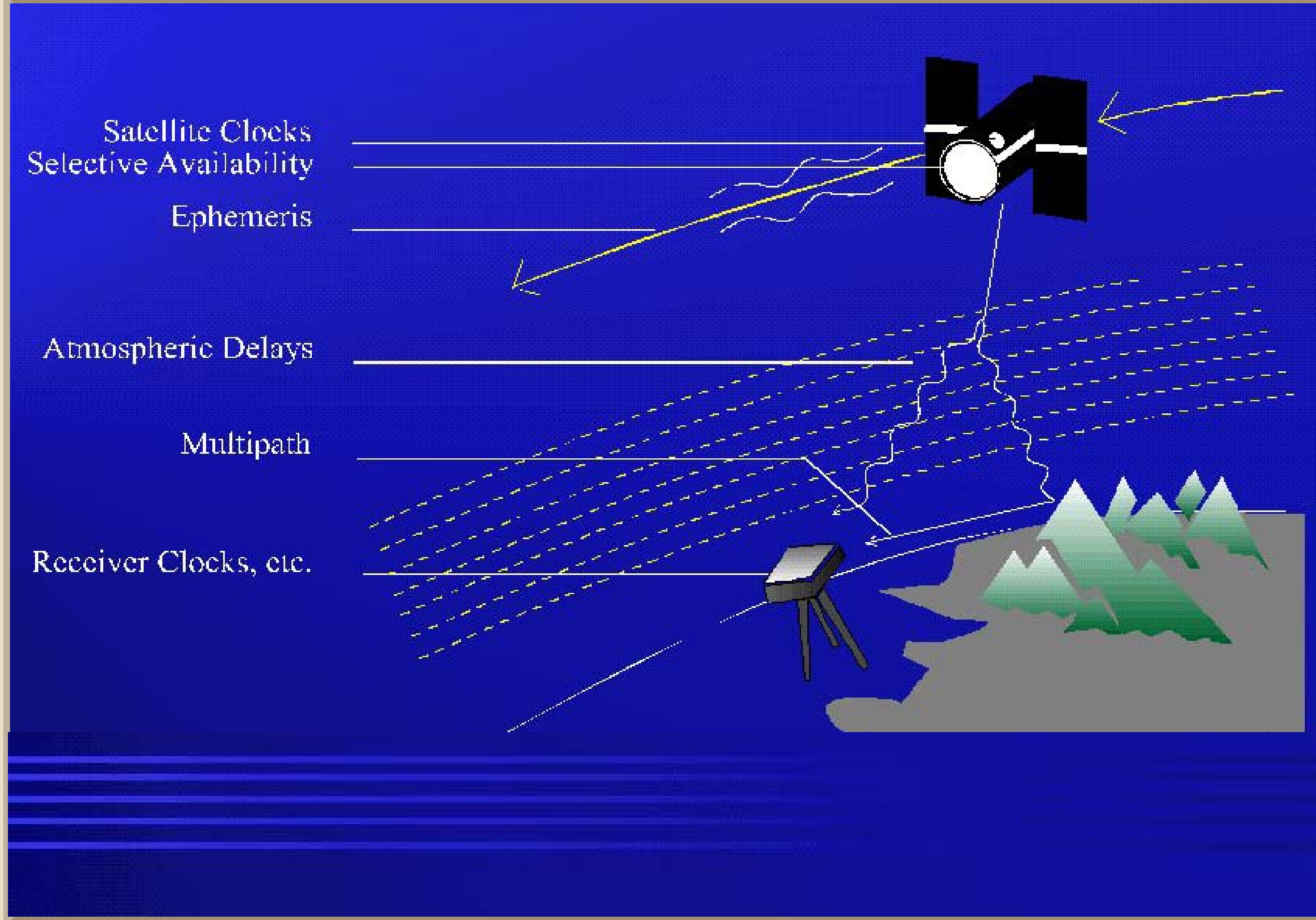
Precision GPS And Communications

Stand Alone GPS Positioning

Space Weather Week
The • Meeting • of • Research • and • Operations



Common GPS Error Sources



Why Differential GPS

Differential GPS – DGPS

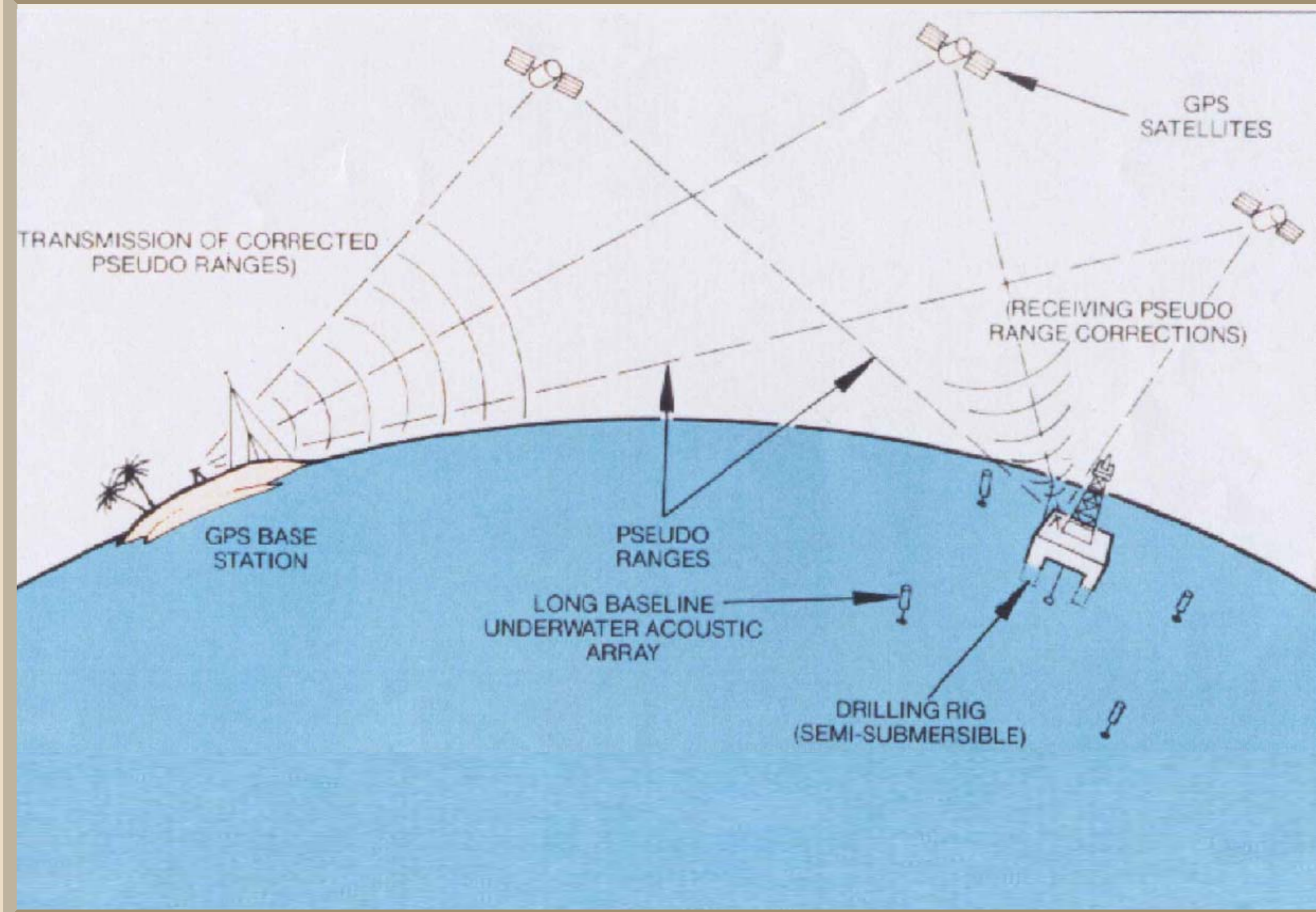
- Increased level of position accuracy over stand alone or autonomous GPS by use of satellite range corrections from a reference receiver at a known location
- Common error sources between reference and remote or user receiver are removed (e.g. iono, tropo, clock)
- Remain subject to spatial (distance) and temporal (time) decorrelation on position (e.g. orbit and S/A)
- .01 to 3 meter positioning possible depending on range and method (Integer RTK, Float RTK or standard DGPS)

Differential GPS Works Because ….

- Modern GPS receivers have high measurement precision and accuracy providing consistency between reference and rover receivers
- At short ranges (< 50 km) most errors are correlated and canceled (Kinematic GPS cm level positioning)
- At long ranges (> 500 km) many errors still can be removed by DGPS providing meter level positioning
- With a ‘GOOD’ GPS constellation the DGPS solution is statistically robust and reliable

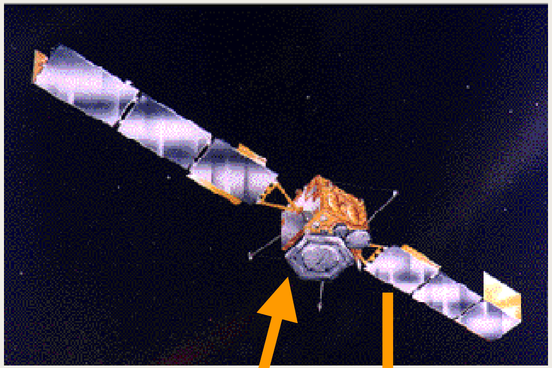
Any changes to the operating environment which adversely impacts the fundamentals will limit operational success.

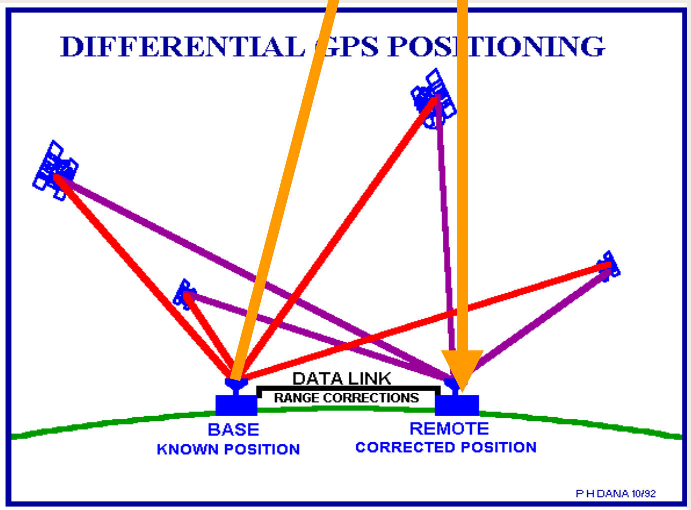
Single Site Differential



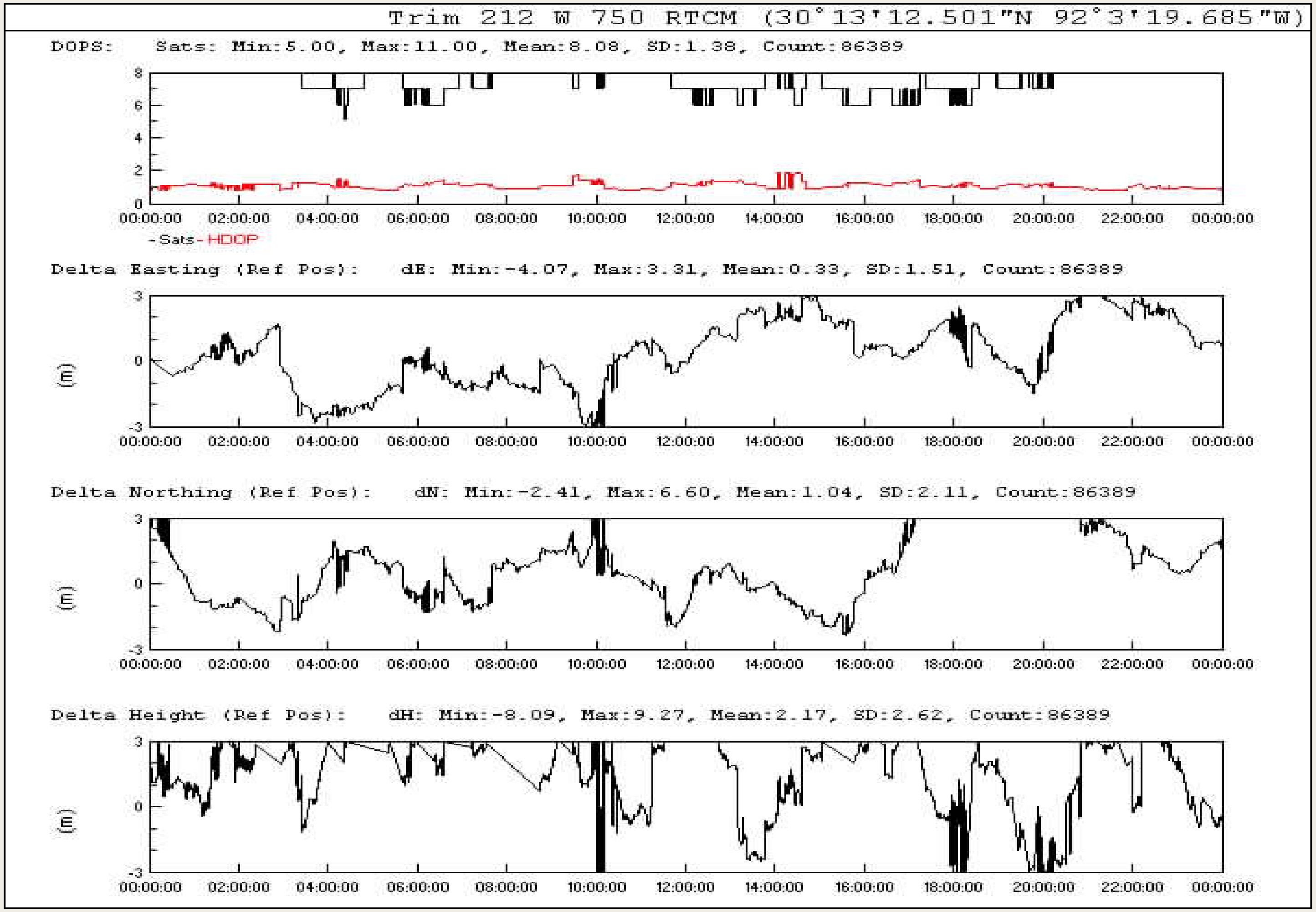
Geostationary Satellites for DGPS Corrections Distribution

3000 LRS Receiver

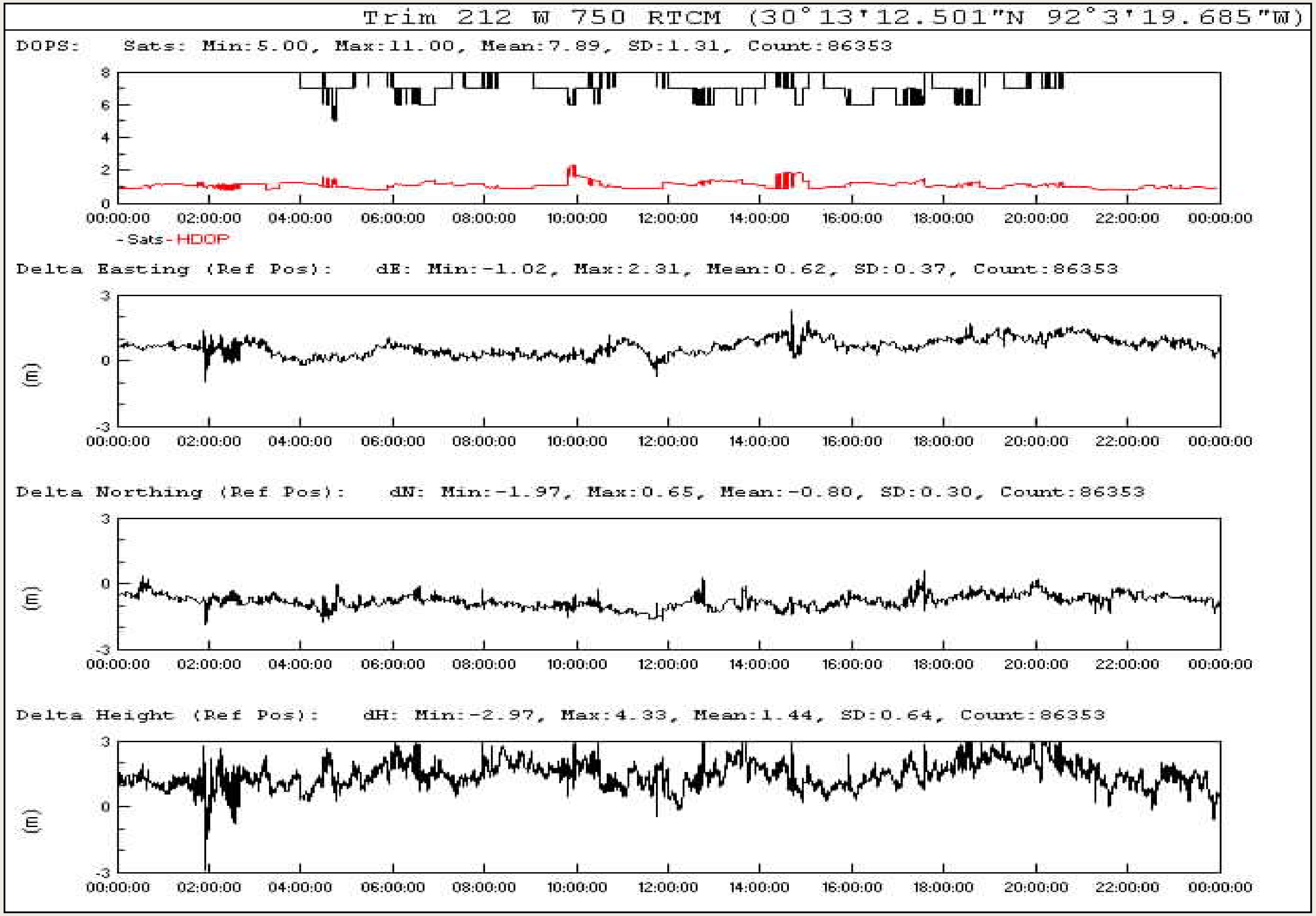




Stand Alone GPS Performance

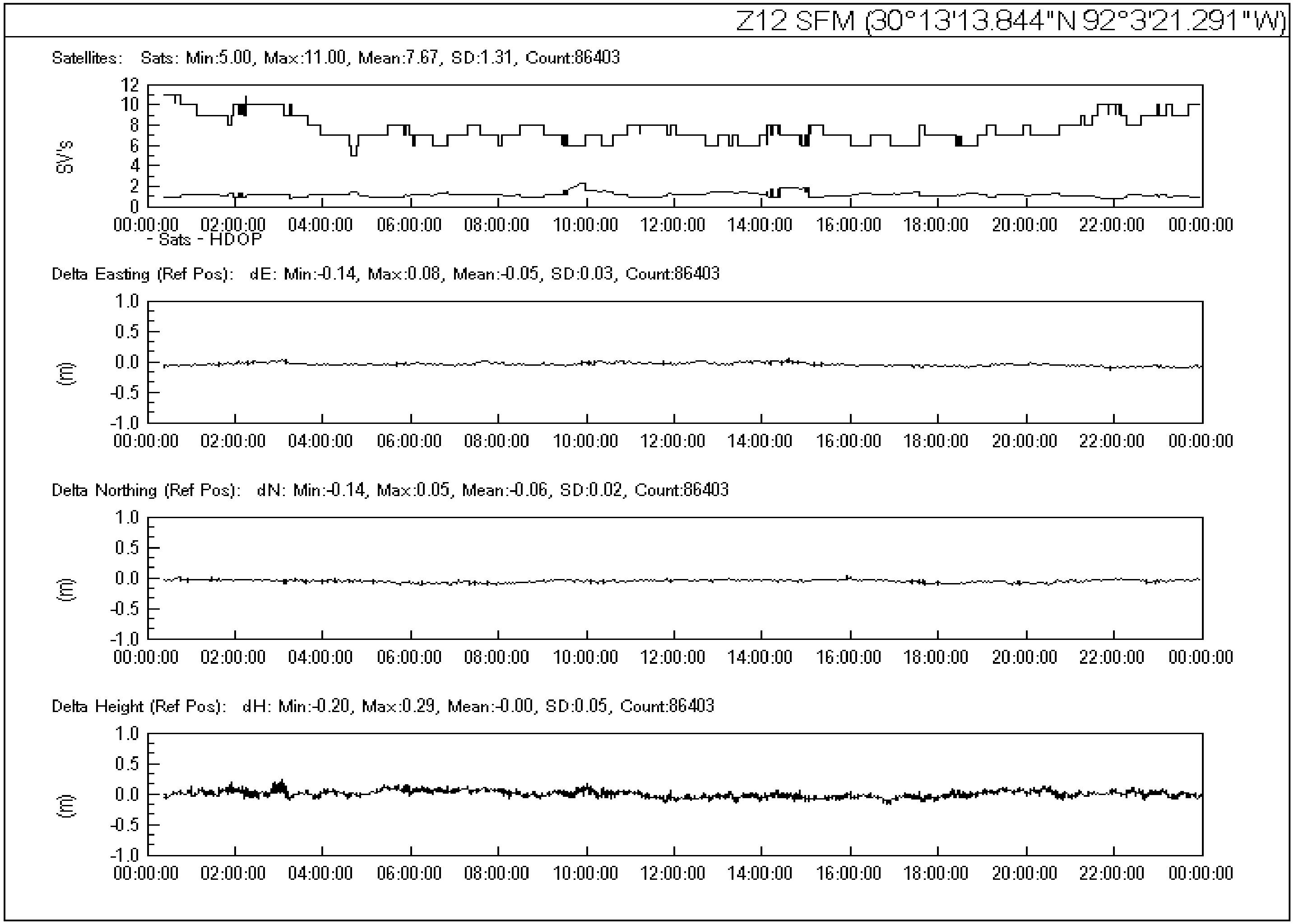


Single Site Differential



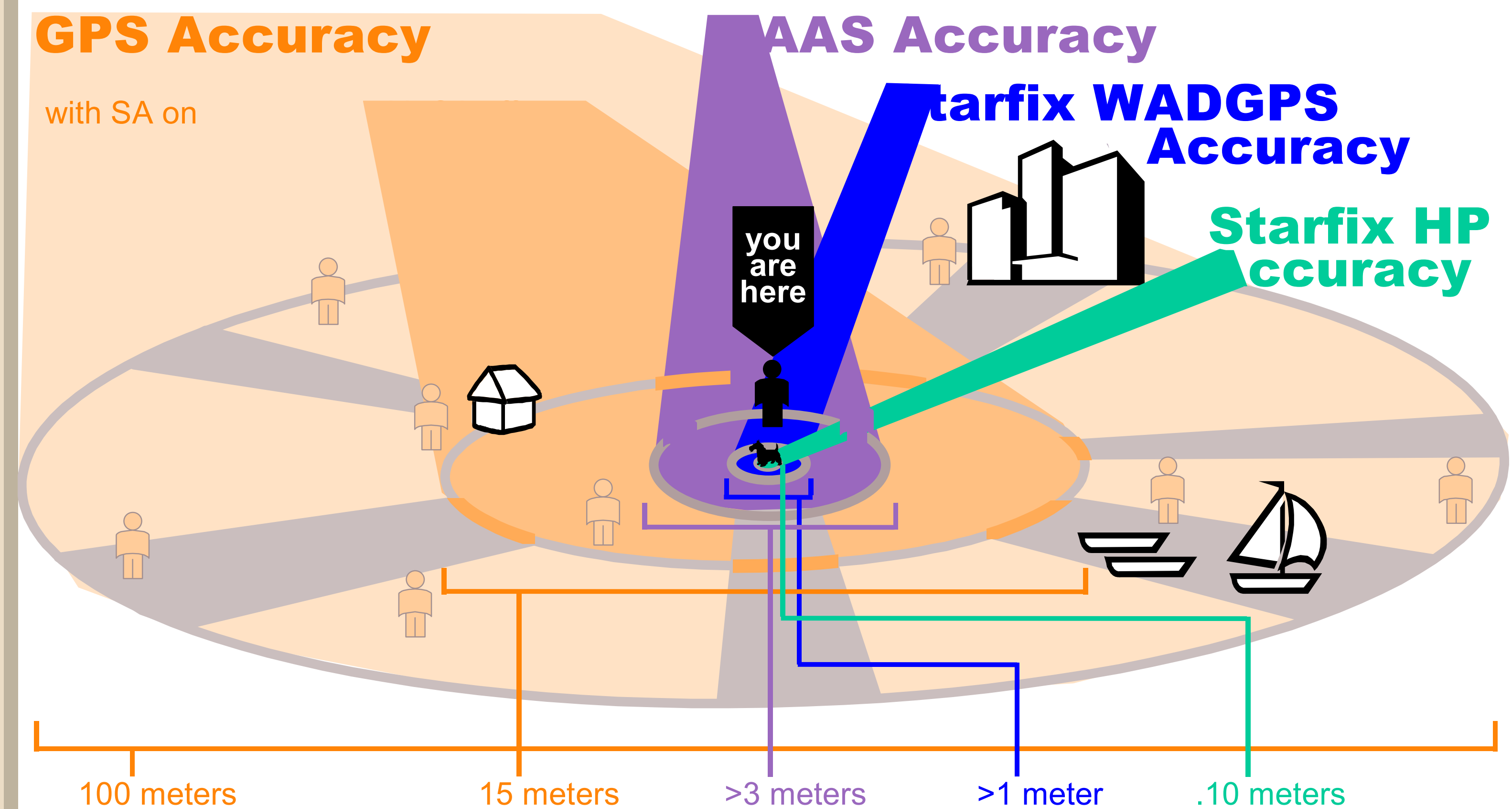
Precision GPS And Communications

High Performance DGPS



Precision GPS And Communications

DGPS Accuracy Comparison



The Ionosphere Is a Major Error Source for GPS Users

- Extreme along the Geomagnetic Equator
  - Greatest impact typically after sundown local time
  - Most severe, commercially, in South America (Brazilian region)
- Can impact in mid latitude regions if extreme
- Average daytime zenith delay at L1 is 5–15 m
  - Up to 36 m at equator during solar maximum
  - Elevation dependent: 5 deg elevation 3 x Zenith delay
- Seasonal variation: November 4 times July
- Sunspot cycle variation (11 yr): Max 4 times minimum

Ionospheric Problems

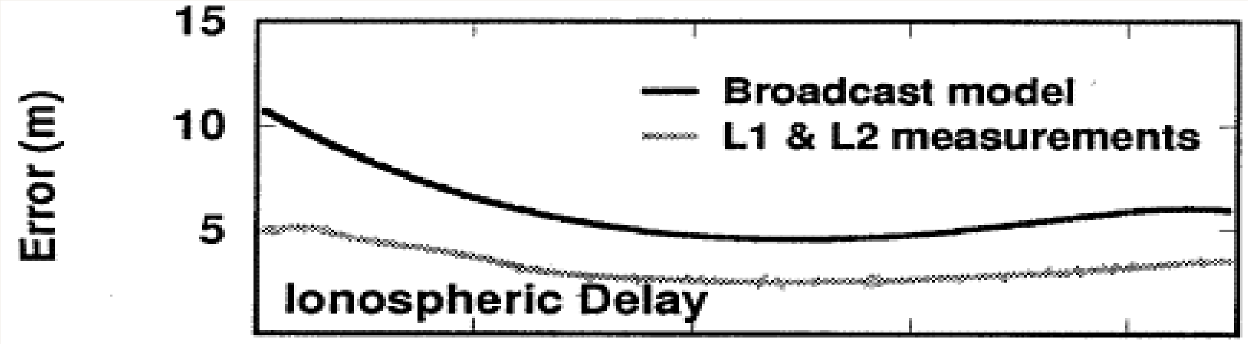
Primary Impact of High Geomagnetic Activity on GPS

- De-correlation of errors between reference and user
  - Impact is greater on Code vs. Carrier measurements
- Most severe in equatorial regions, affecting baselines from a few hundred km, up to 12 or more hours a day, almost daily
- Scintillations
  - Rapid phase and amplitude variations on the GPS signal, causing GPS satellite loss of lock

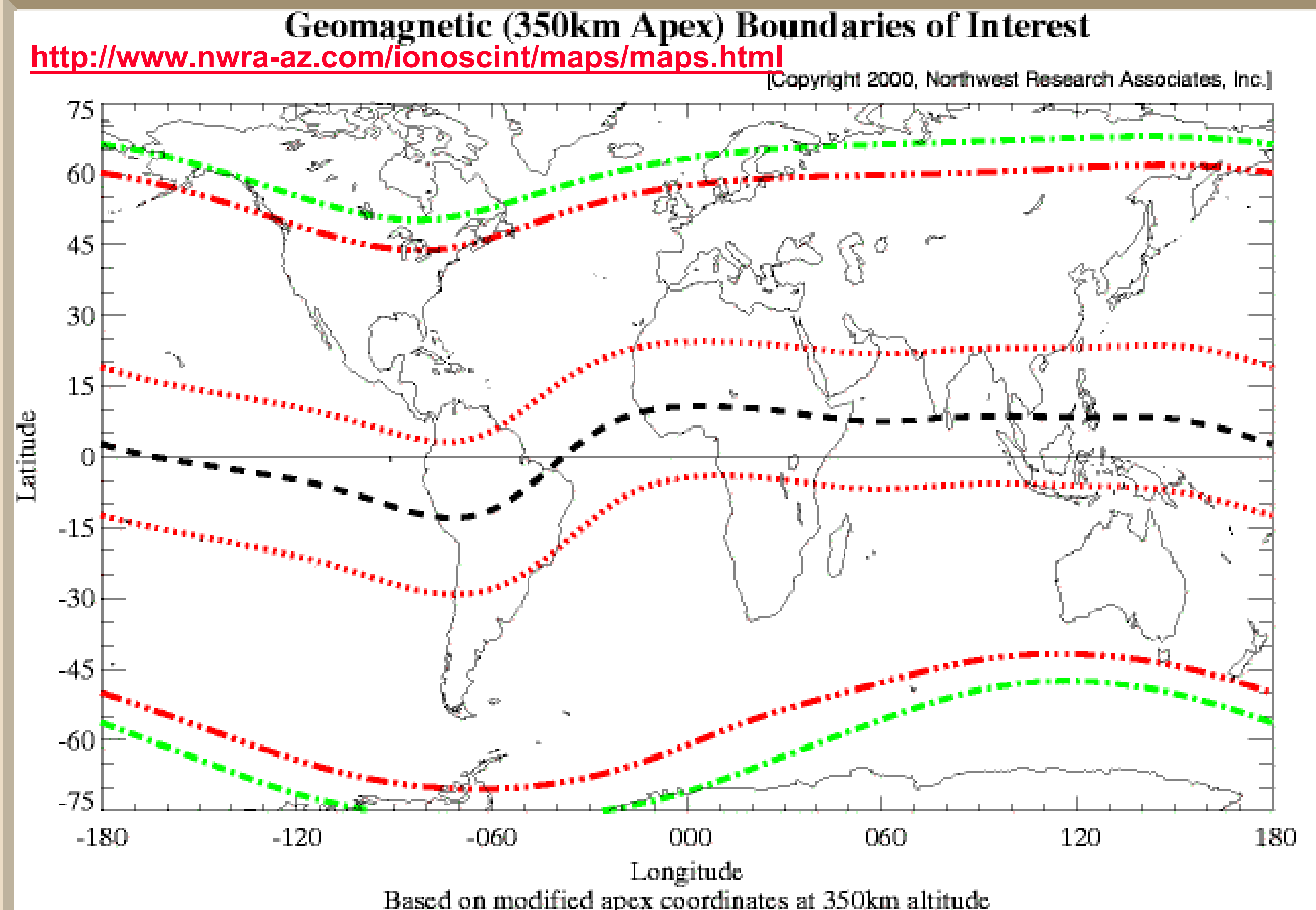
Ionospheric Mitigation Techniques

Ionospheric Delay Can Be Modeled or Measured

- GPS Broadcast model (50% error in TEC)
- IRI-90, Bent, PIM (30% error in TEC). Requires near real-time geophysical information
- Ionospheric Models based on dual-frequency GPS measurements (1-2 m error at L1)
- Direct measurement from dual frequency GPS (PPS)



Regions of High Susceptibility



Ionospheric Models

Standard
GPS Iono
Model

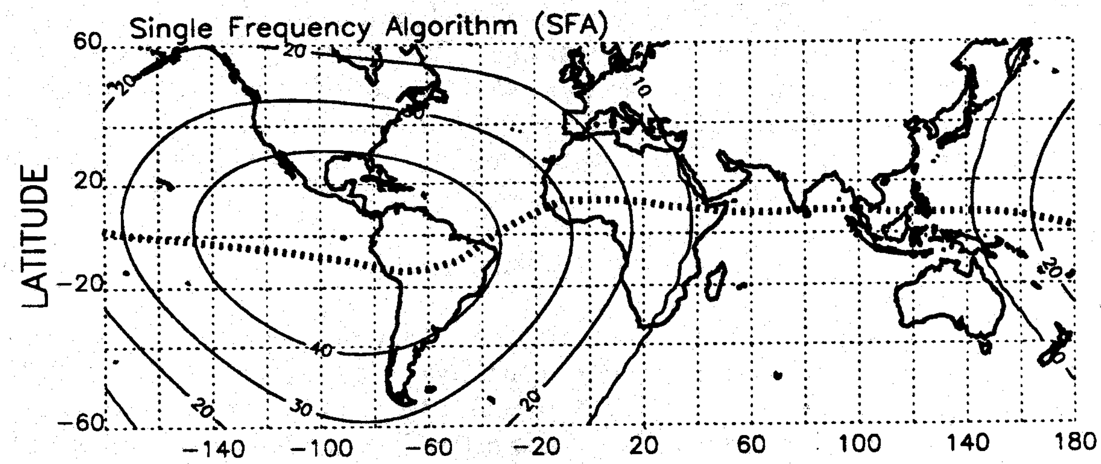


Figure 1) ICA contours of ionospheric TEC for equinoctial solar moderate conditions at 20 hours UT.

Accurate
PIM Iono
Model

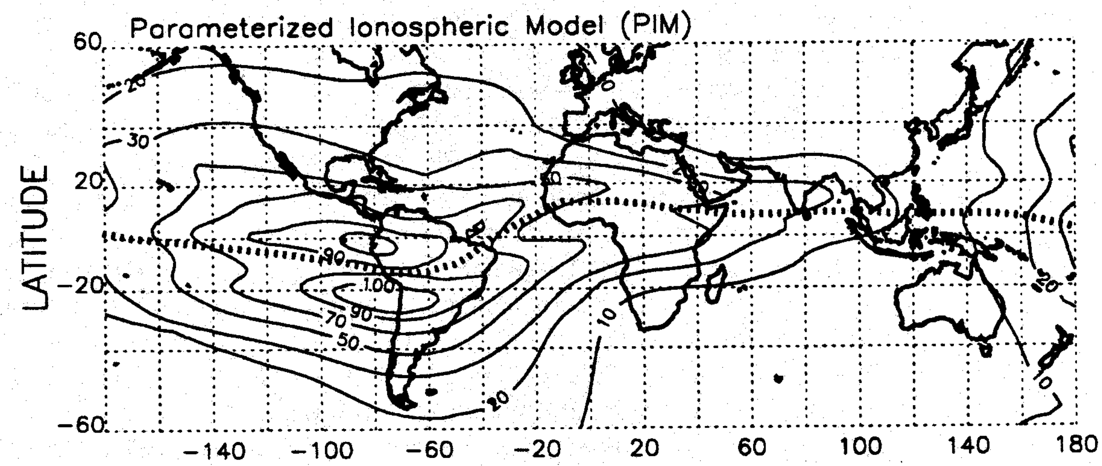
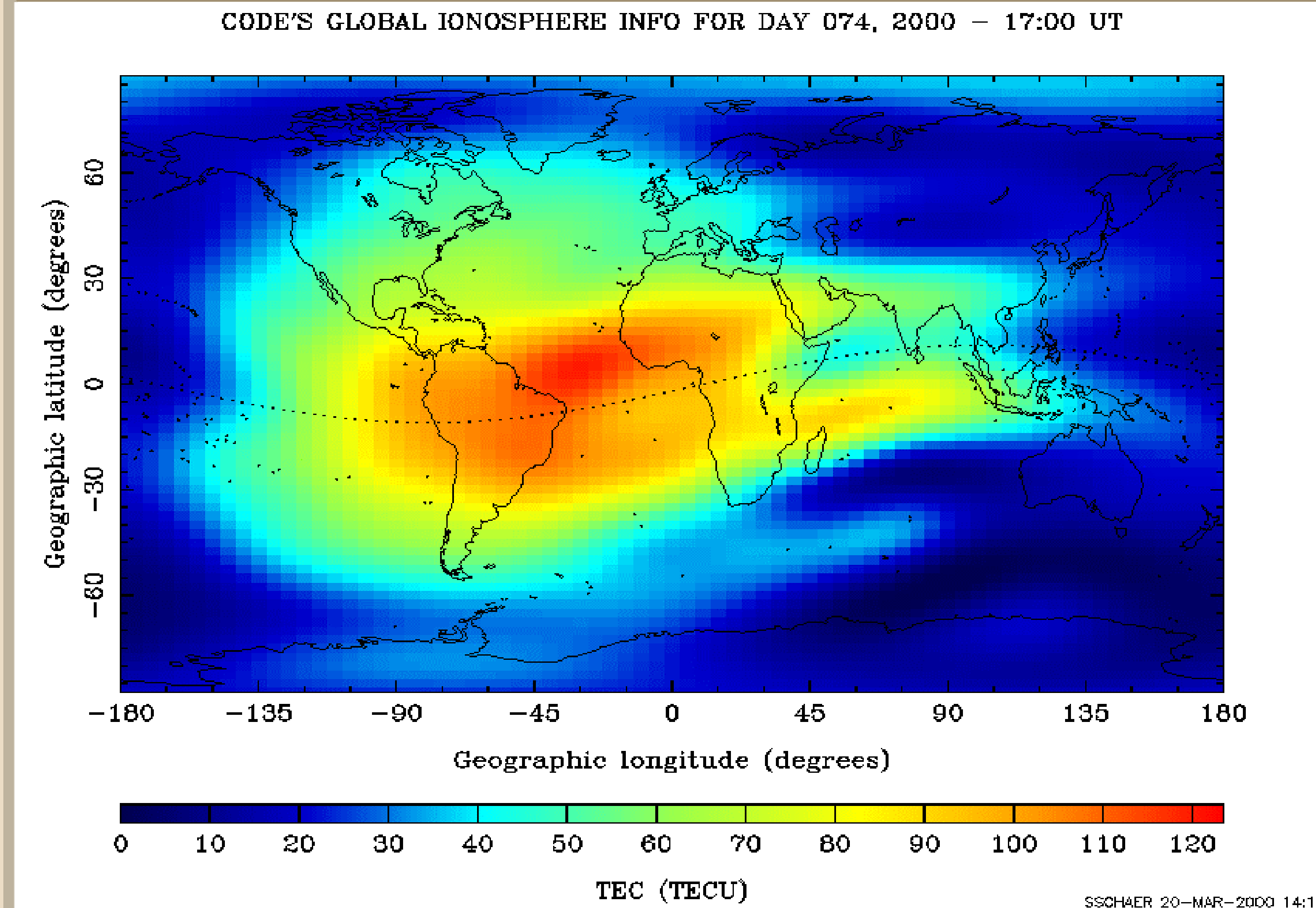


Figure 2) PIM contours of ionospheric TEC for equinoctial solar moderate conditions at 20 hours UT.

1 TECU=0.16 m

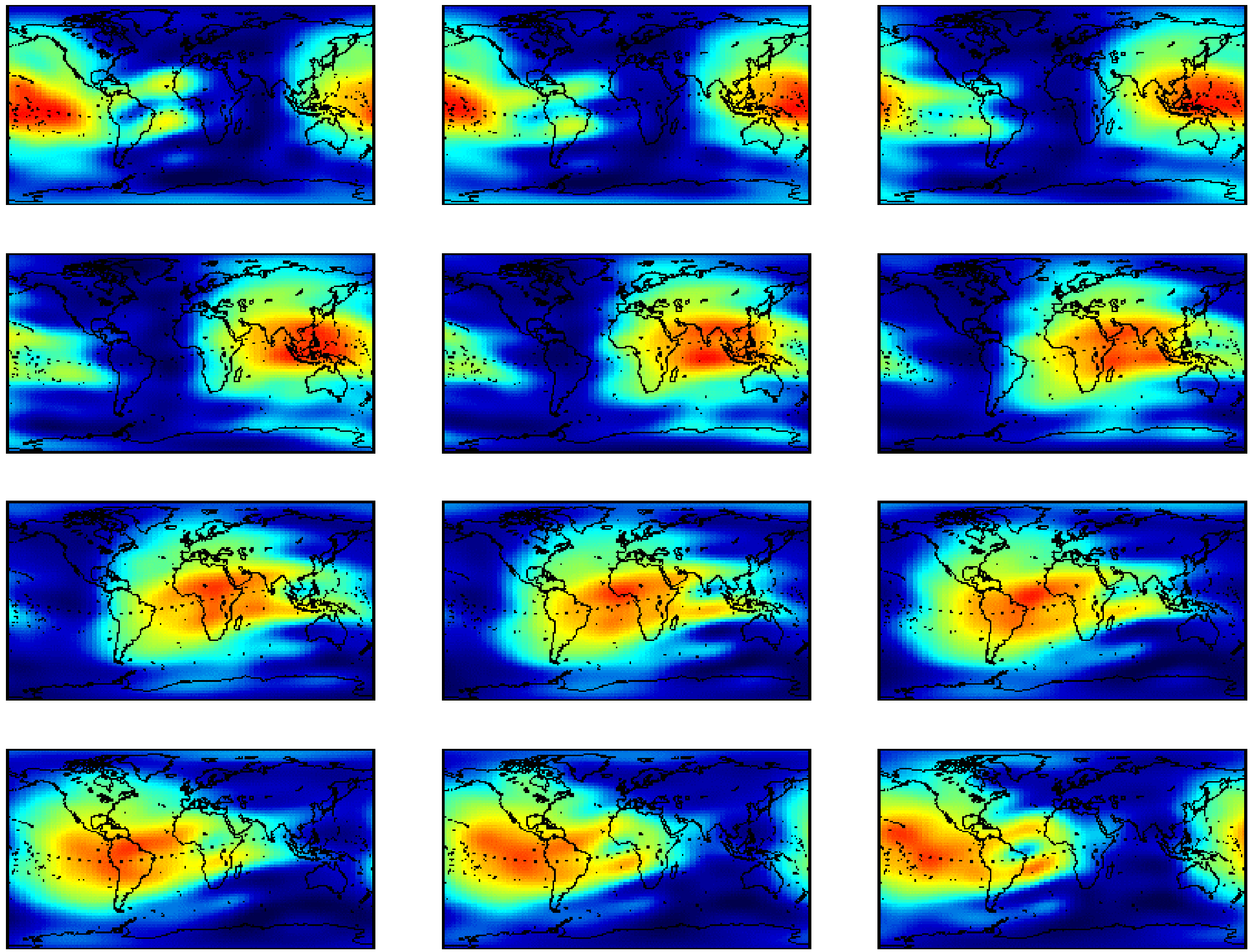
Global Ionosphere
MARCH 14, 2000



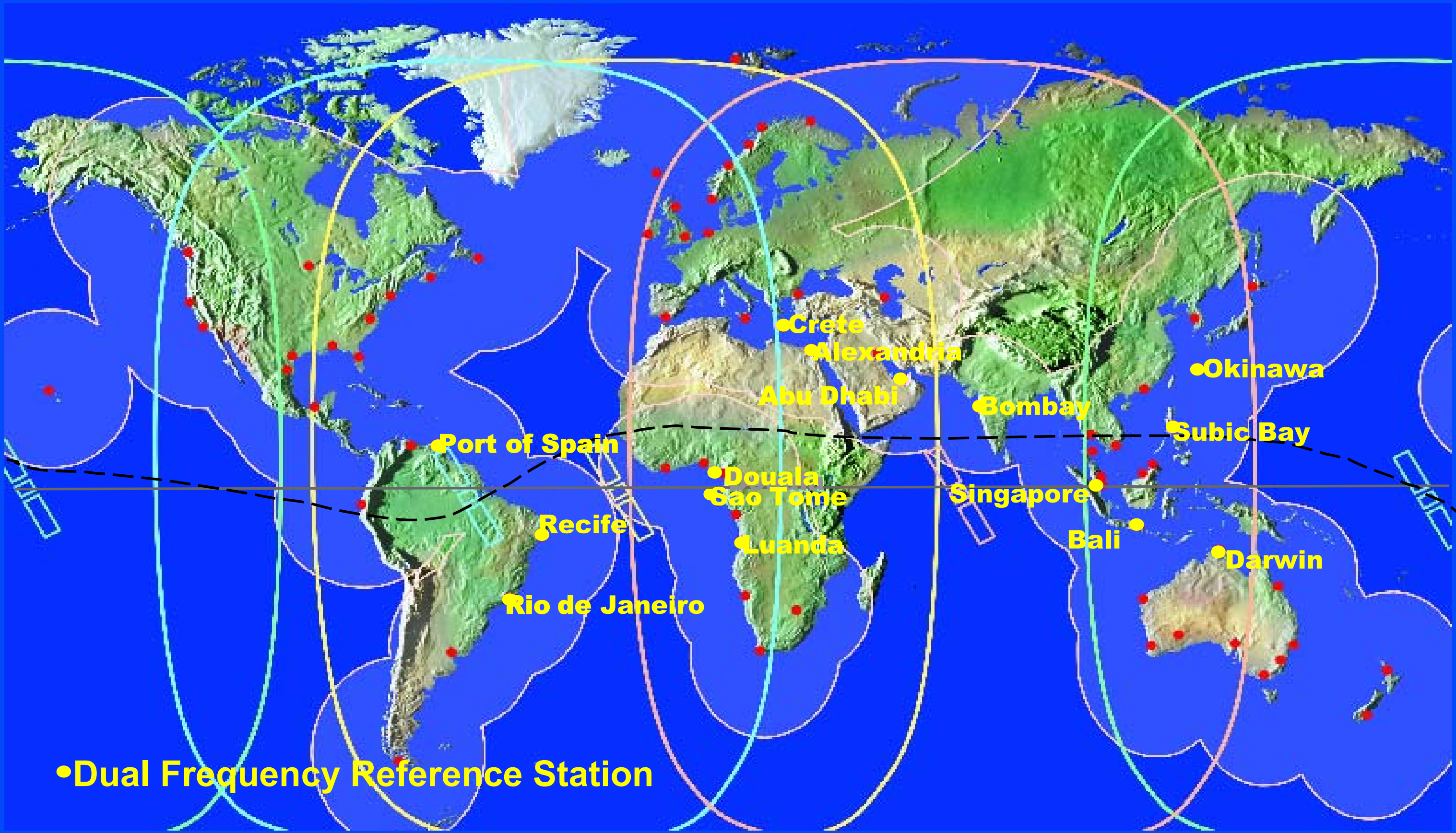
Precision GPS And Communications

Global Ionosphere

MARCH 14, 2000



Reference Network Distribution



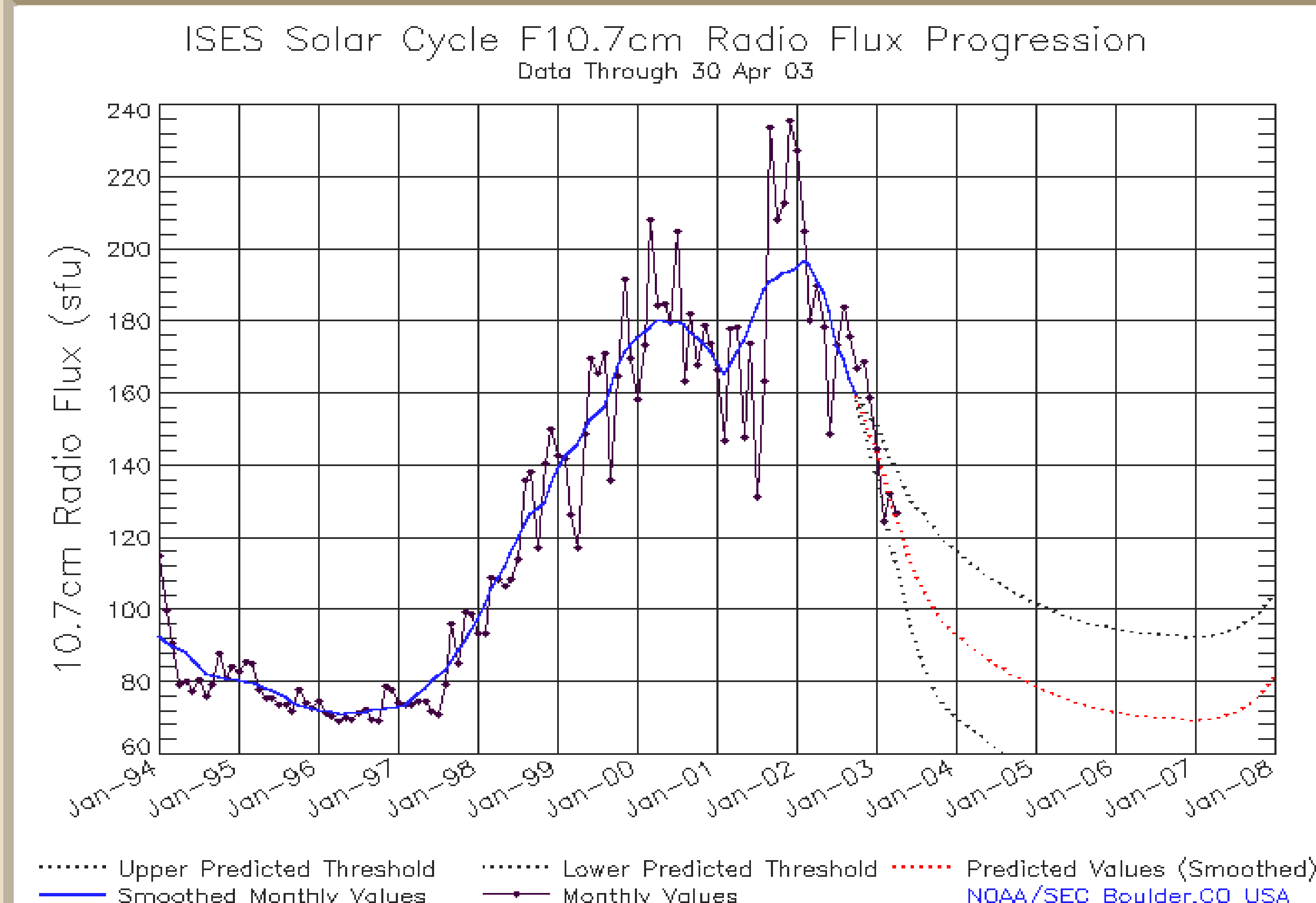
Space Weather Week

THE • MEETING • OF • RESEARCH • AND • OPERATIONS

Users Research Operations

Precision GPS And Communications

Cycle 23 Solar Activity History



Precision GPS And Communications

Impact of Solar Activity On GPS Users

Problems Attributed to Solar Activity Starting in 1998

- Increasing levels of position noise depending on work area
- RTK initialization/re-initialization problems
- Satellite tracking problems caused by scintillations
- In mid latitudes symptoms first appear with Ap >40 and F10.7 flux values >150

1999 DGPS Performance

African Baselines

- Douala - Luanda 1500 Km
- Pointe-Noire Luanda 469 km

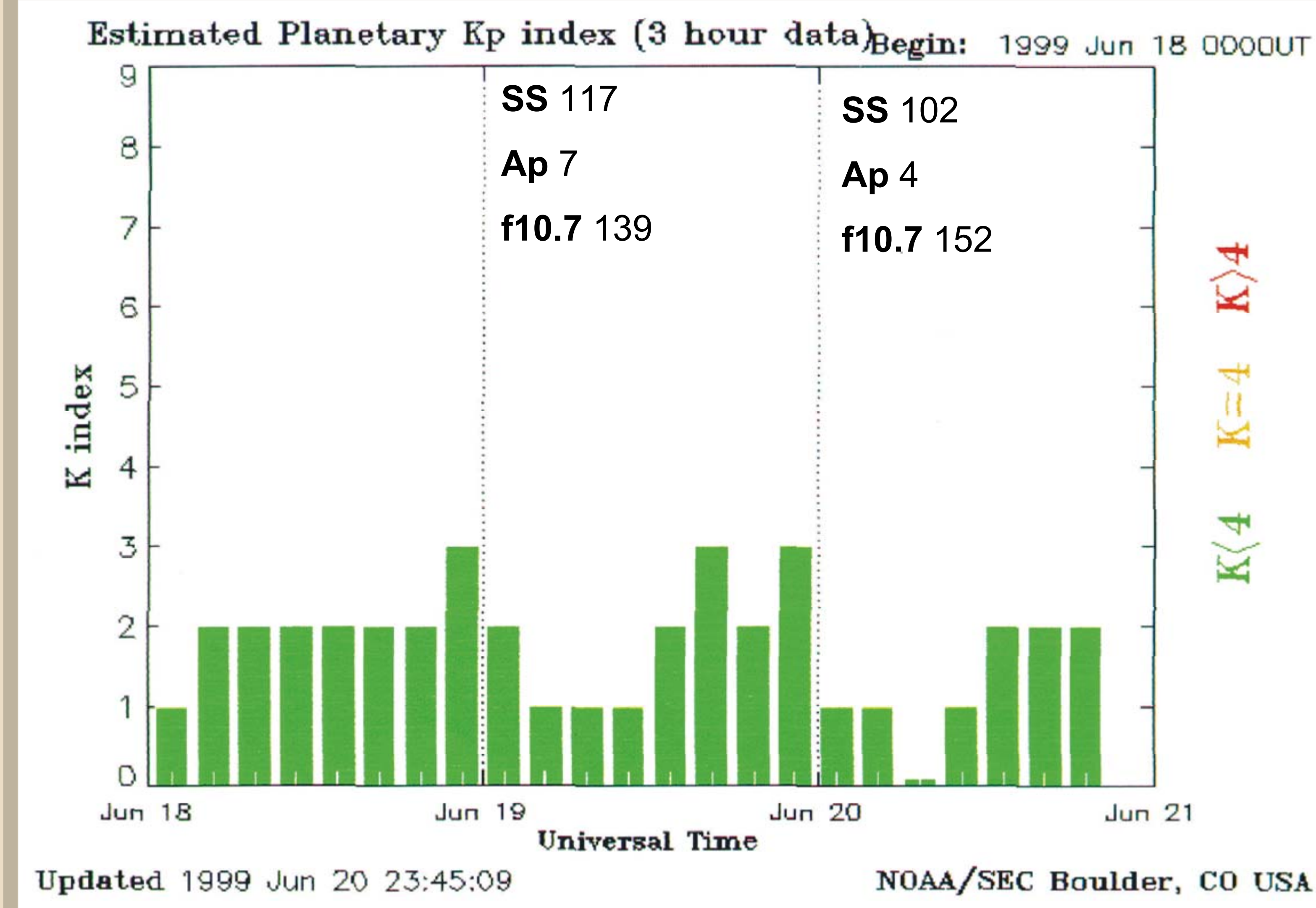
Single Frequency

- Using Klobuchar GPS IONO Model

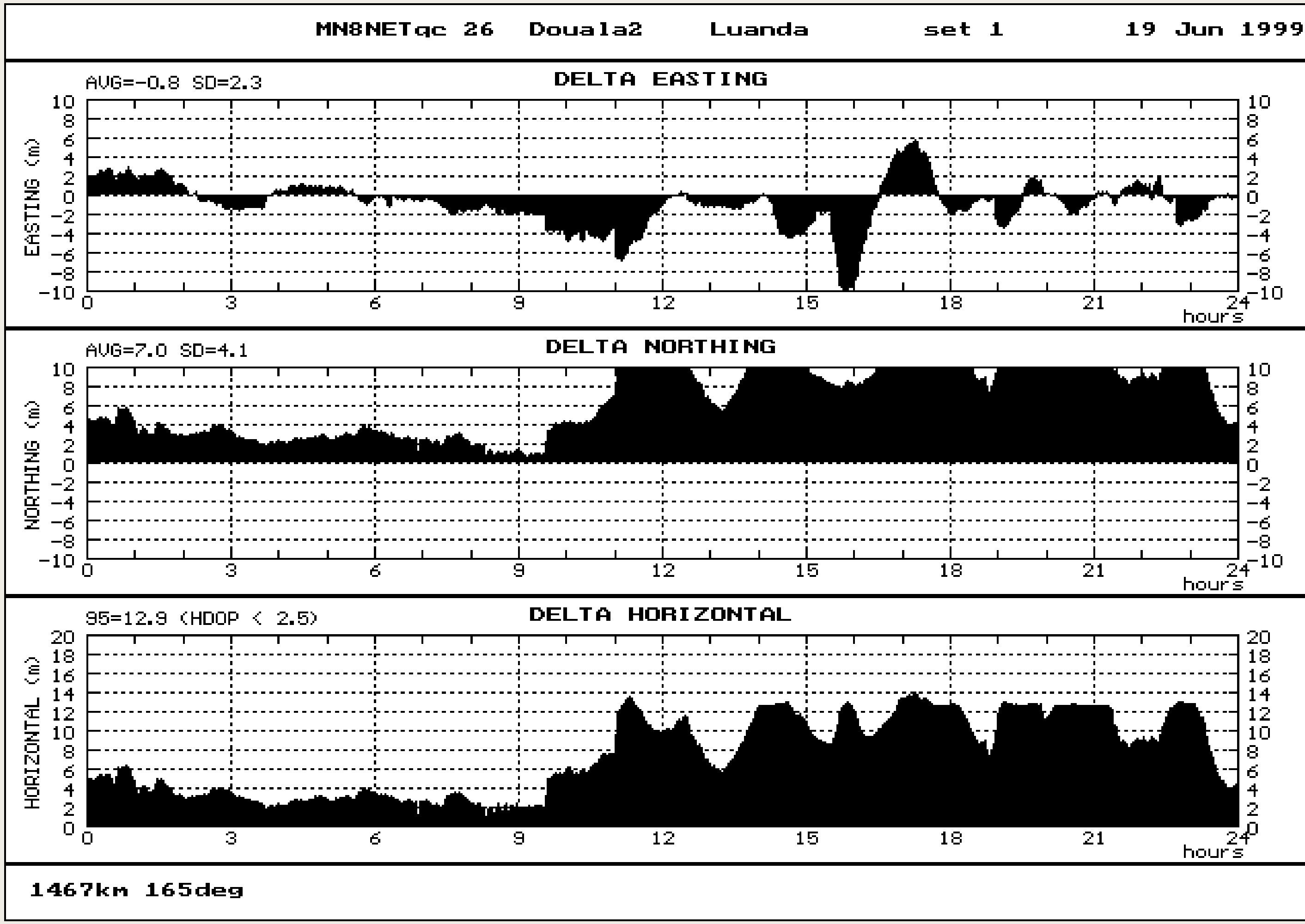
Dual Frequency

- Computing IONO value from measurements

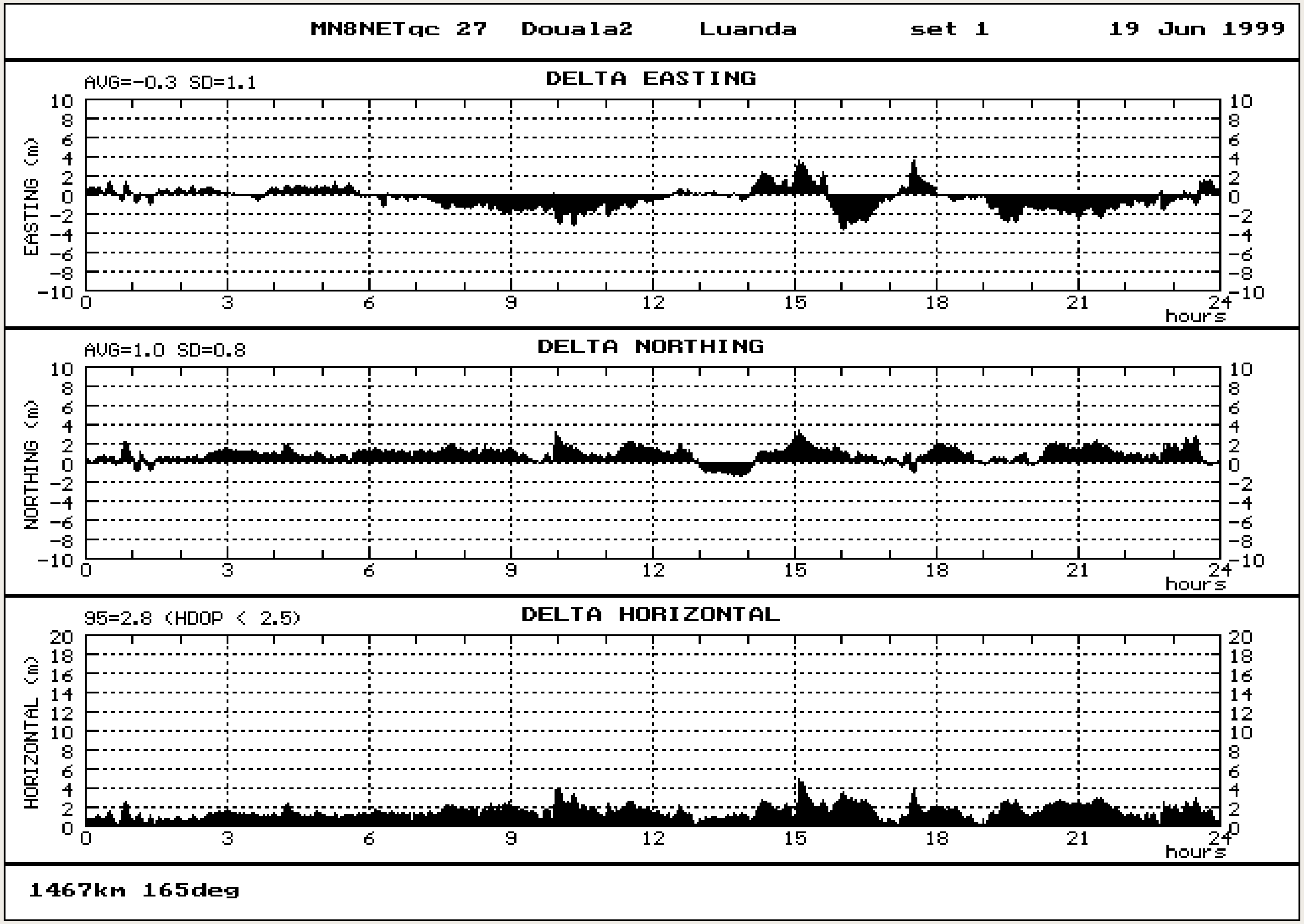
Index Levels
June 18-20, 1999



Single Frequency
Douala - Luanda (1467 km)
June 19, 1999

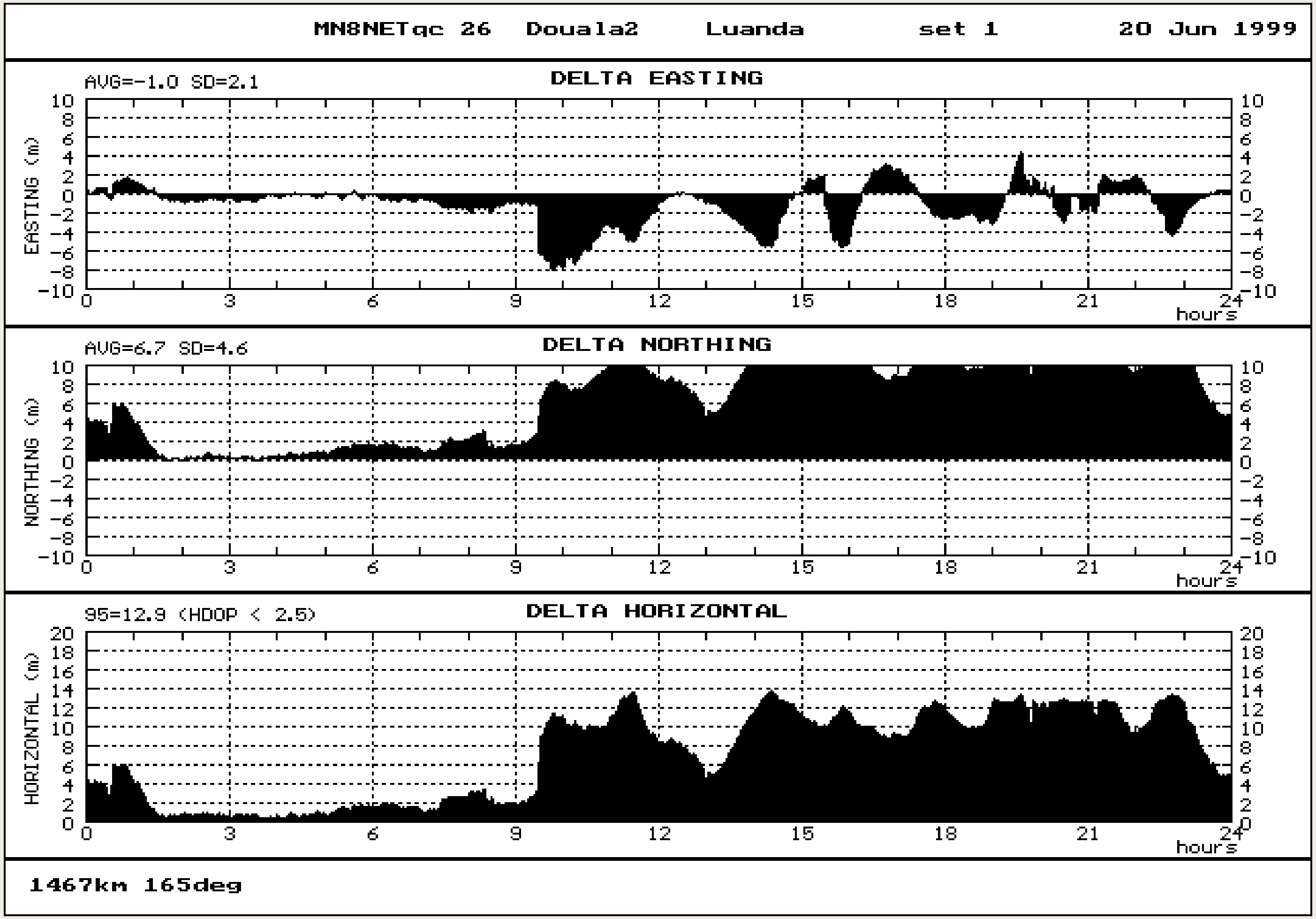


Dual Frequency
Douala - Luanda (1467 km)
June 19, 1999



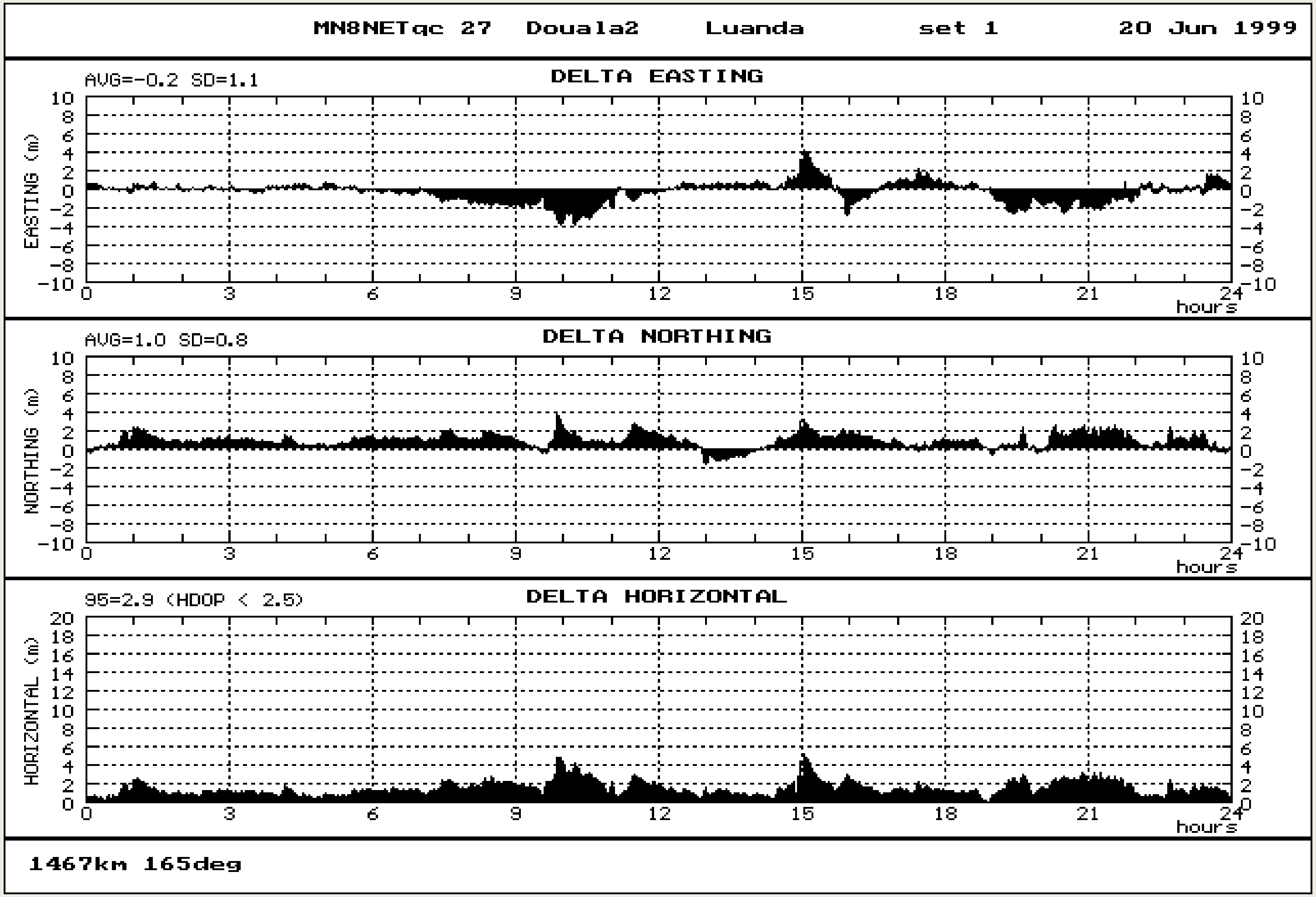
Precision GPS And Communications

Single Frequency
Douala - Luanda (1467 km)
June 20, 1999



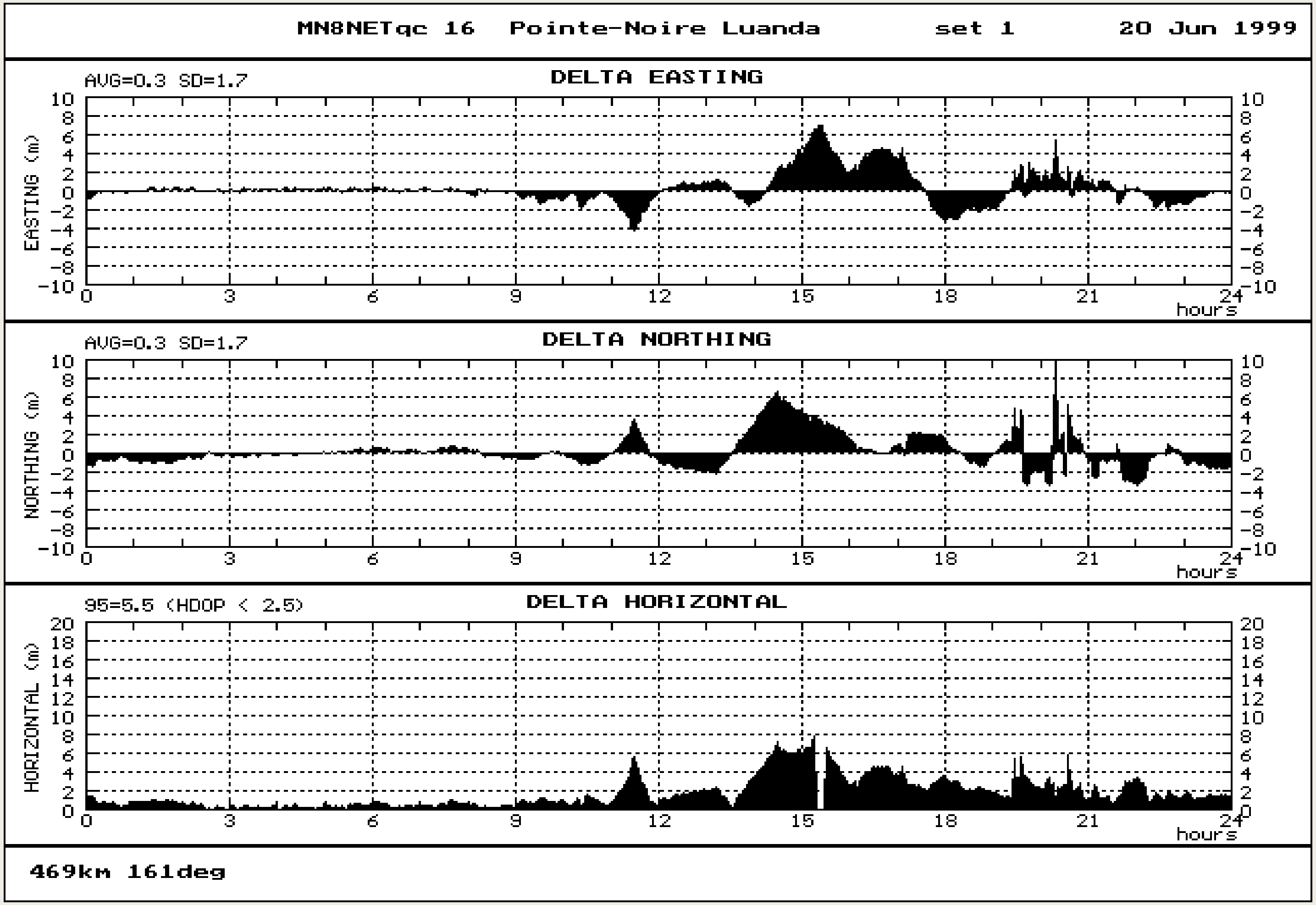
Precision GPS And Communications

Dual Frequency
Douala - Luanda (1467 km)
June 20, 1999

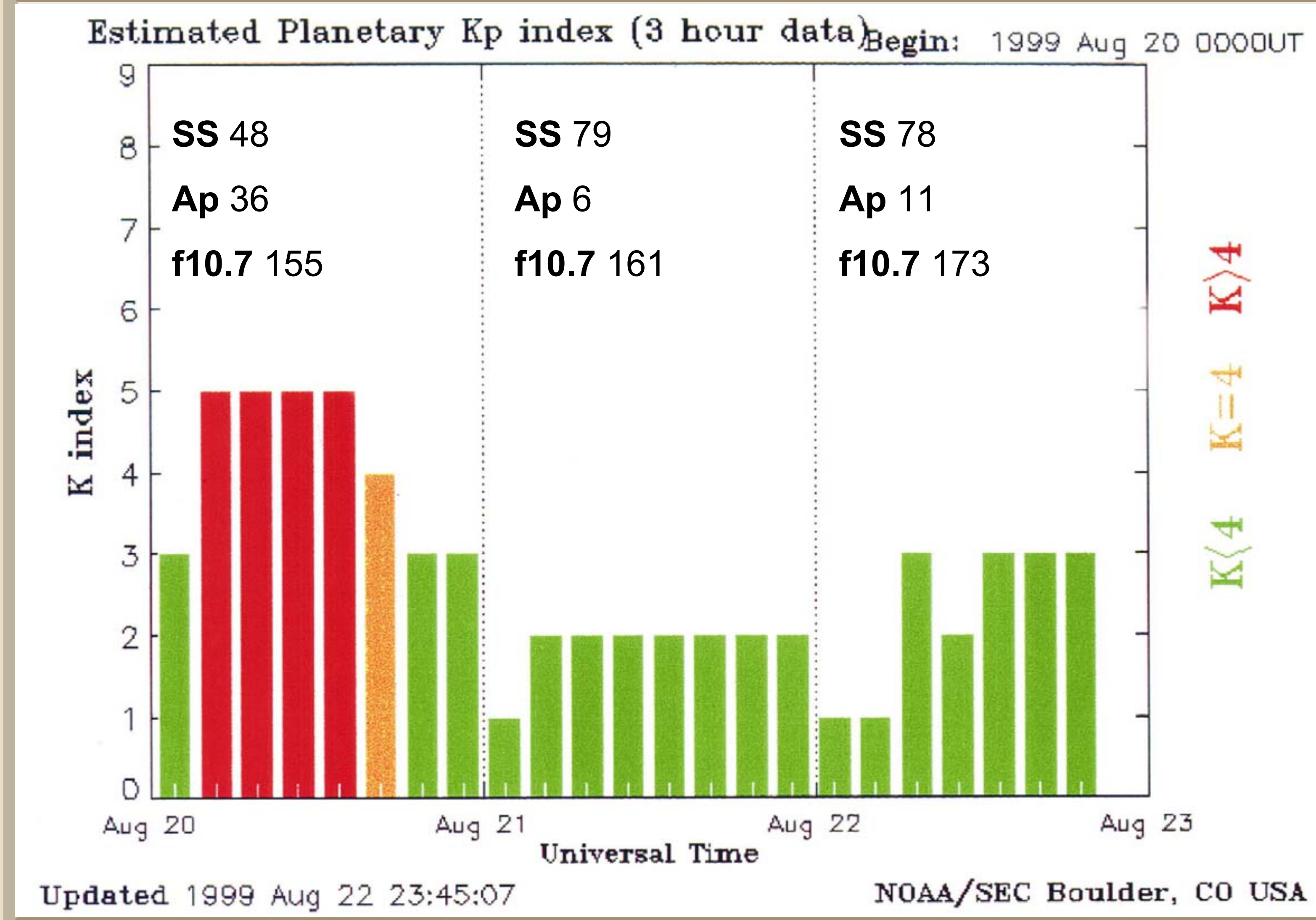


Precision GPS And Communications

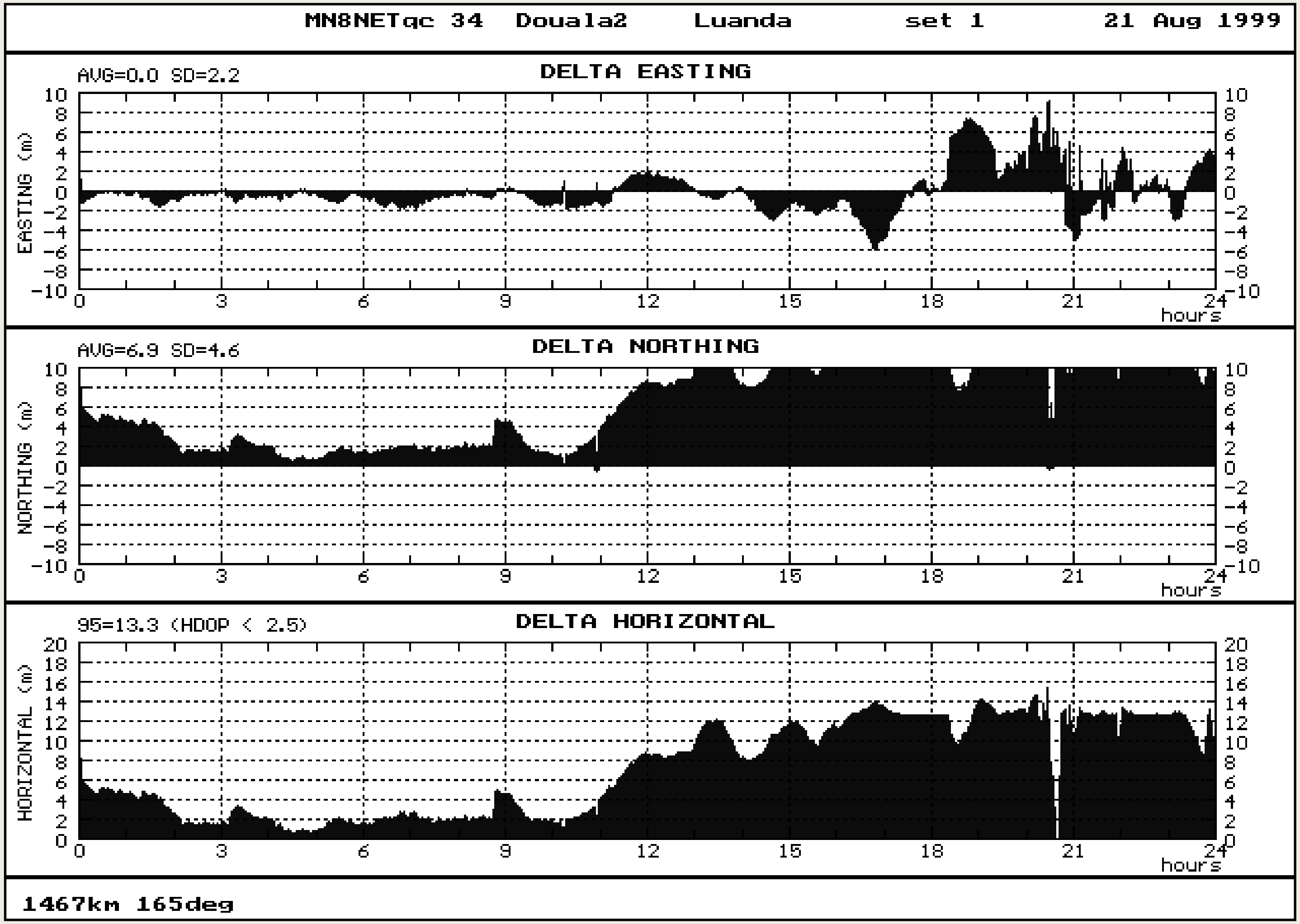
Single Frequency
Pointe-Noire Luanda (469 km)
June 20, 1999



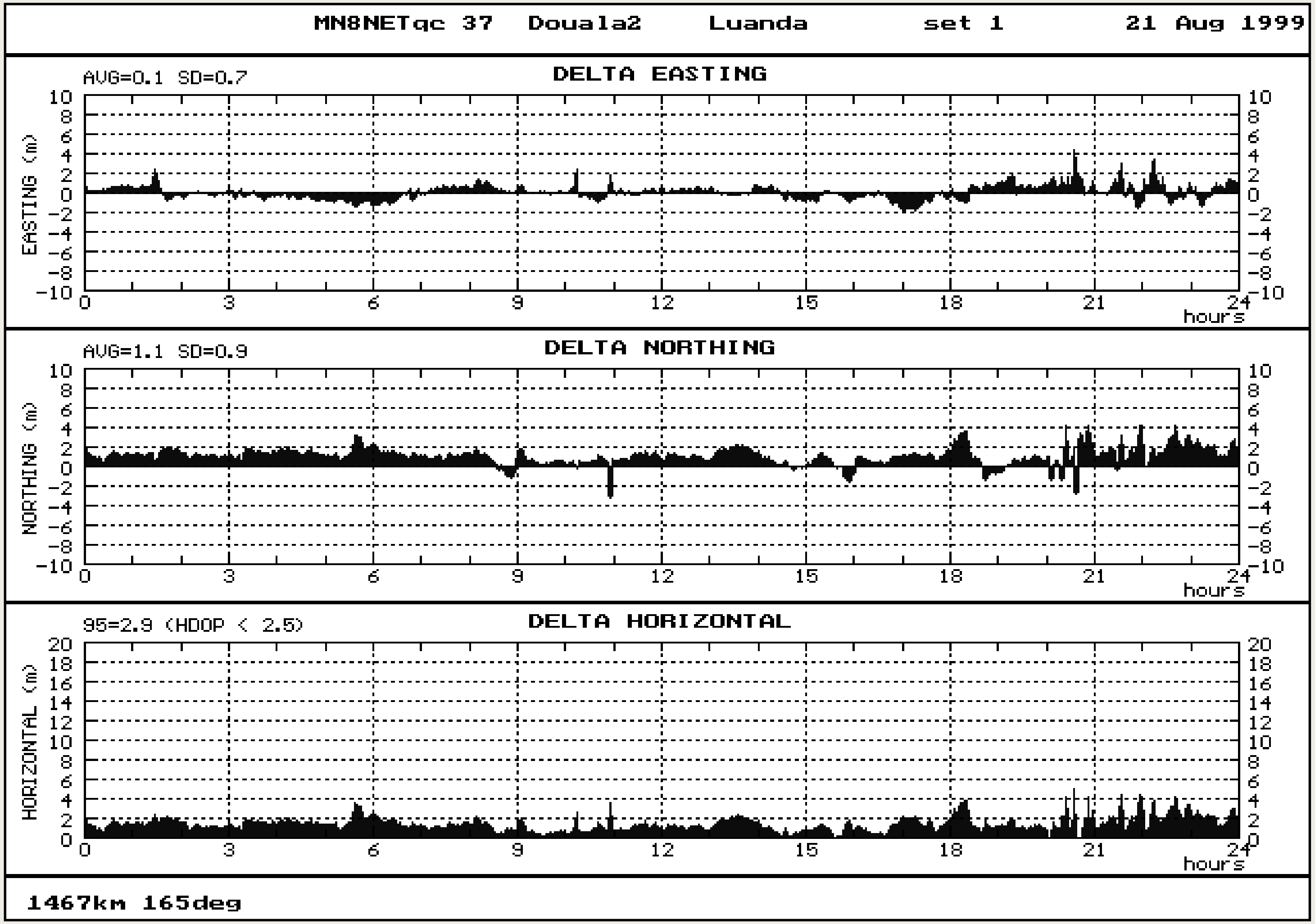
Index Levels
August 20-22, 1999



Single Frequency
Douala - Luanda (1467 km)
August 21, 1999

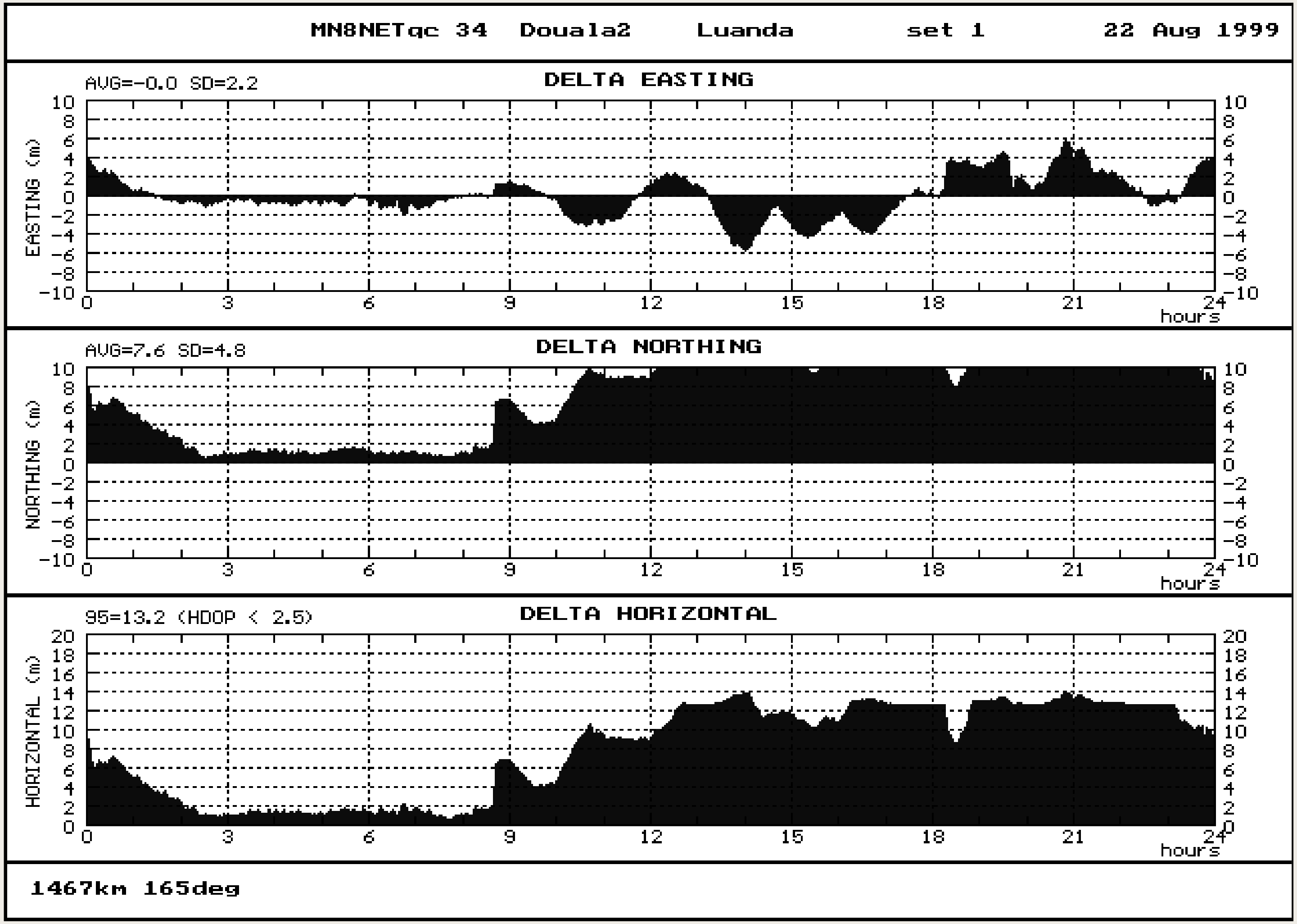


Dual Frequency
Douala - Luanda (1467 km)
August 21, 1999

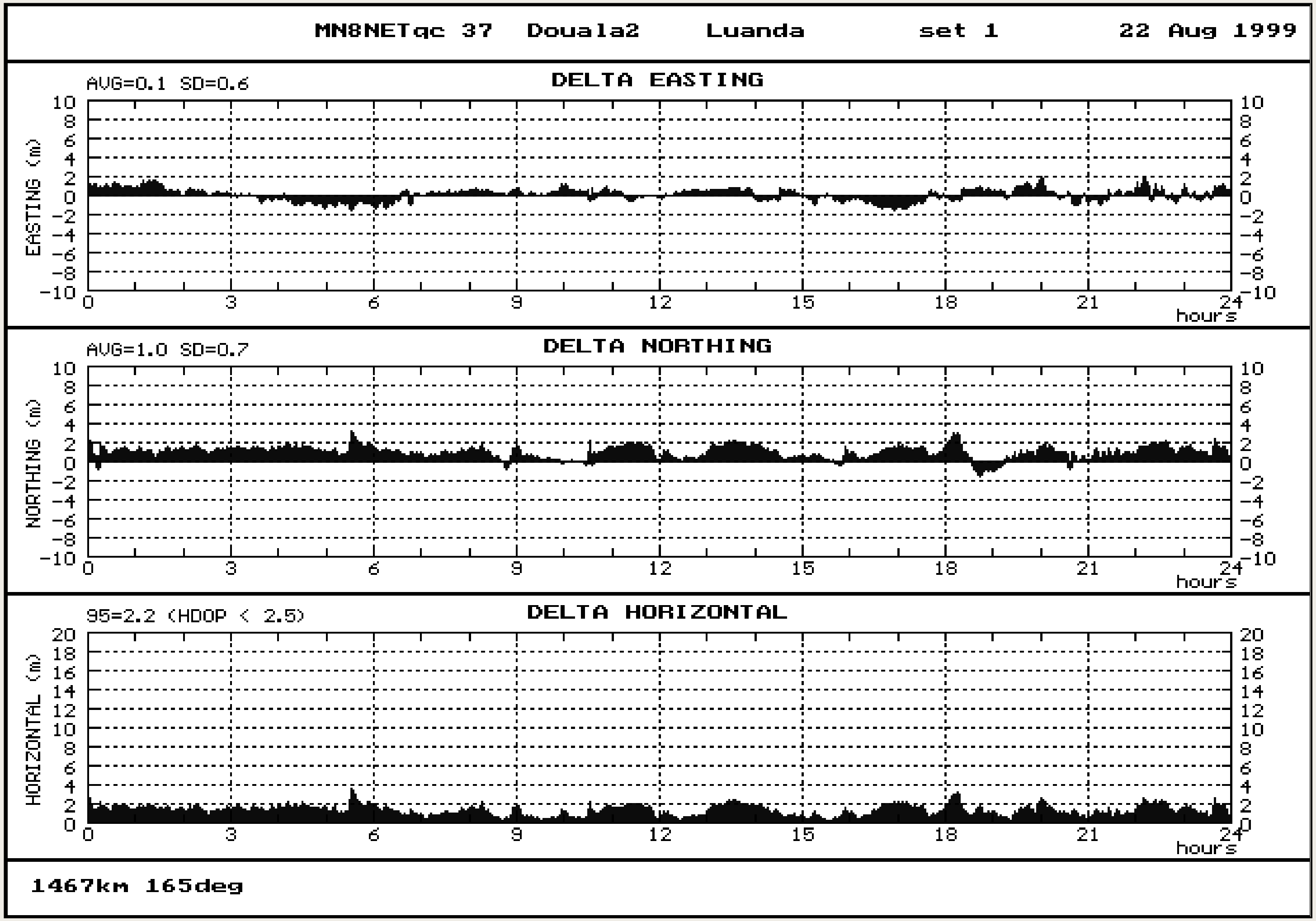


Precision GPS And Communications

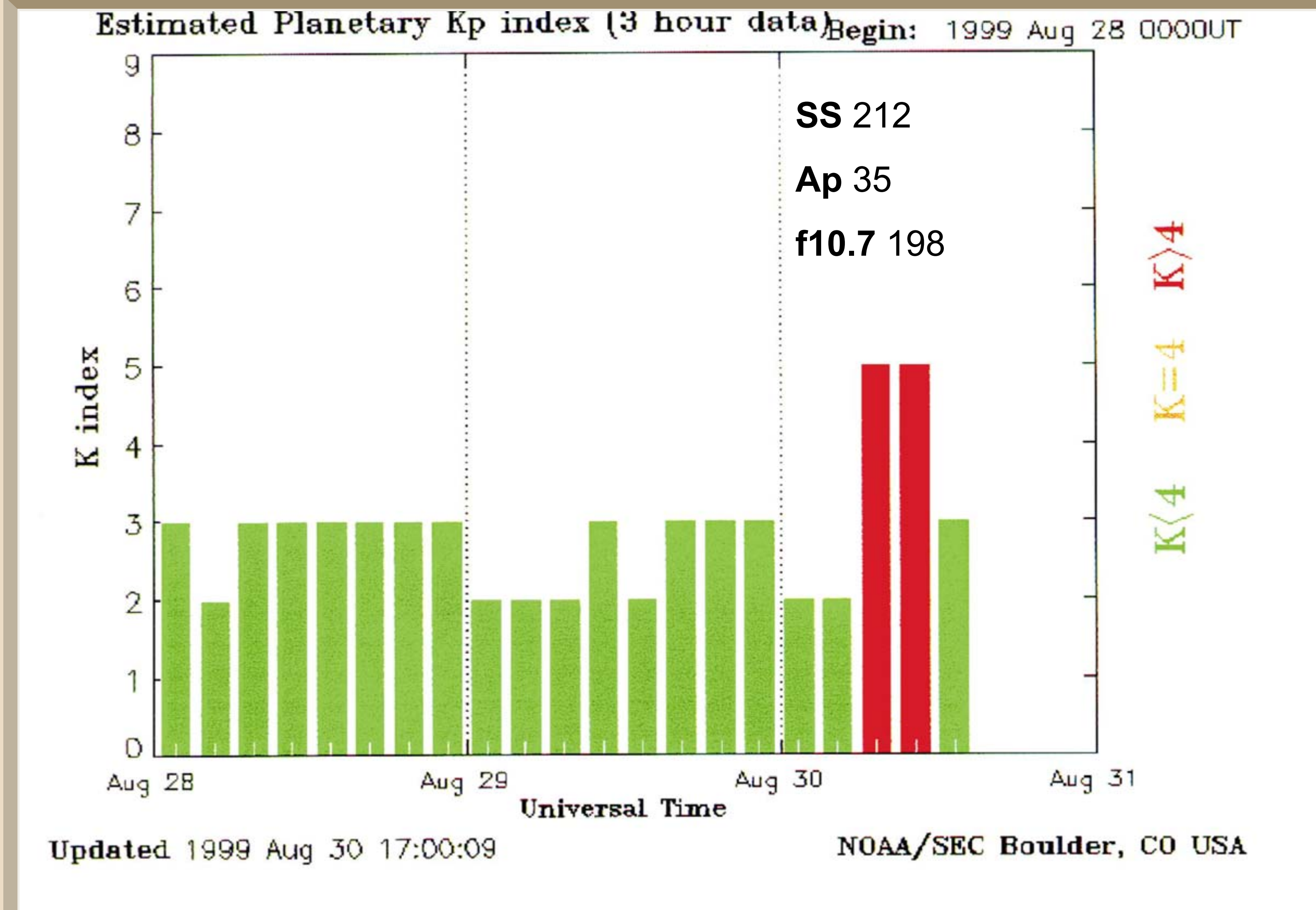
Single Frequency
Douala - Luanda (1467 km)
August 22, 1999



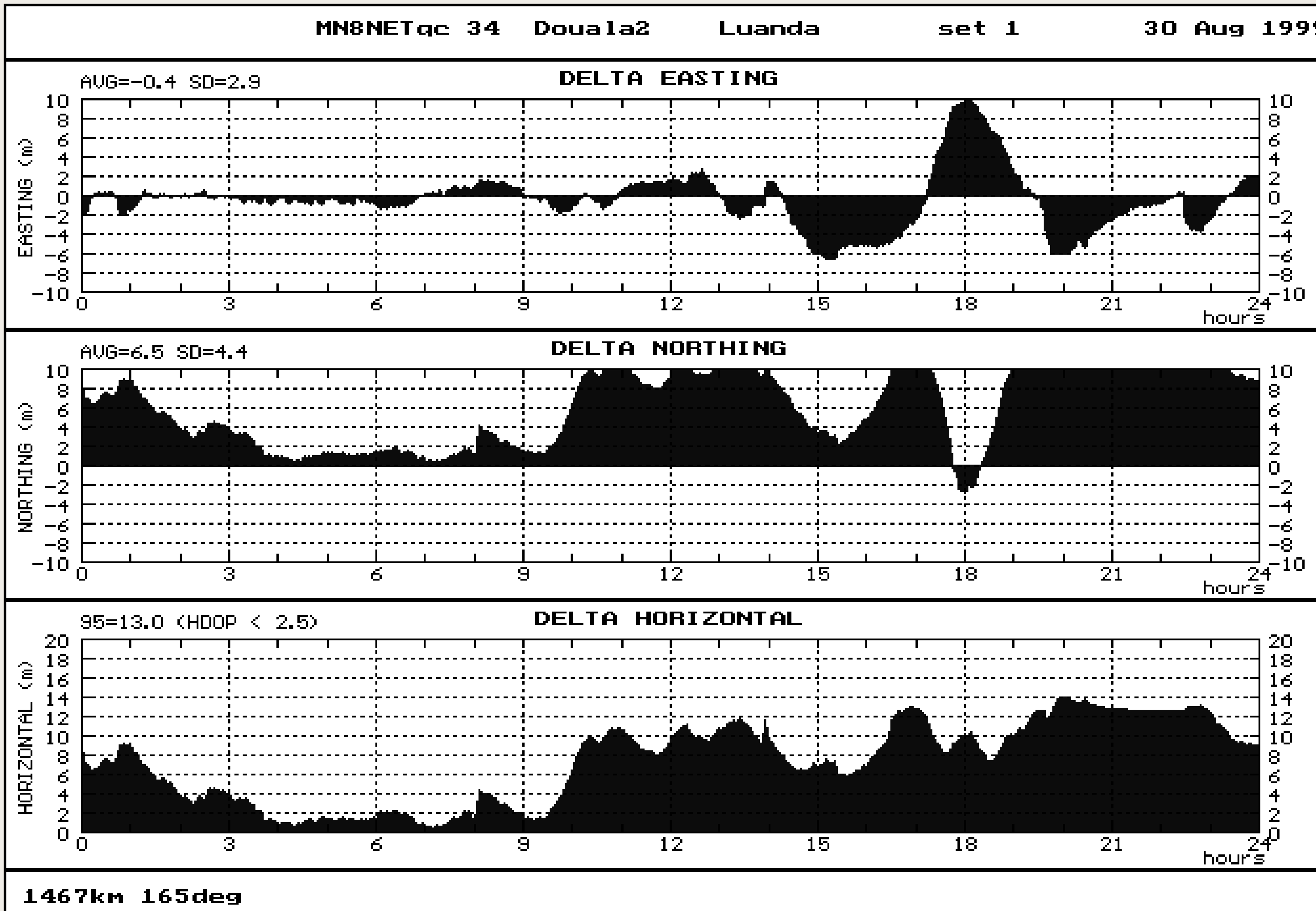
Dual Frequency
Douala - Luanda (1467 km)
August 22, 1999



Index Levels
August 28-30, 1999

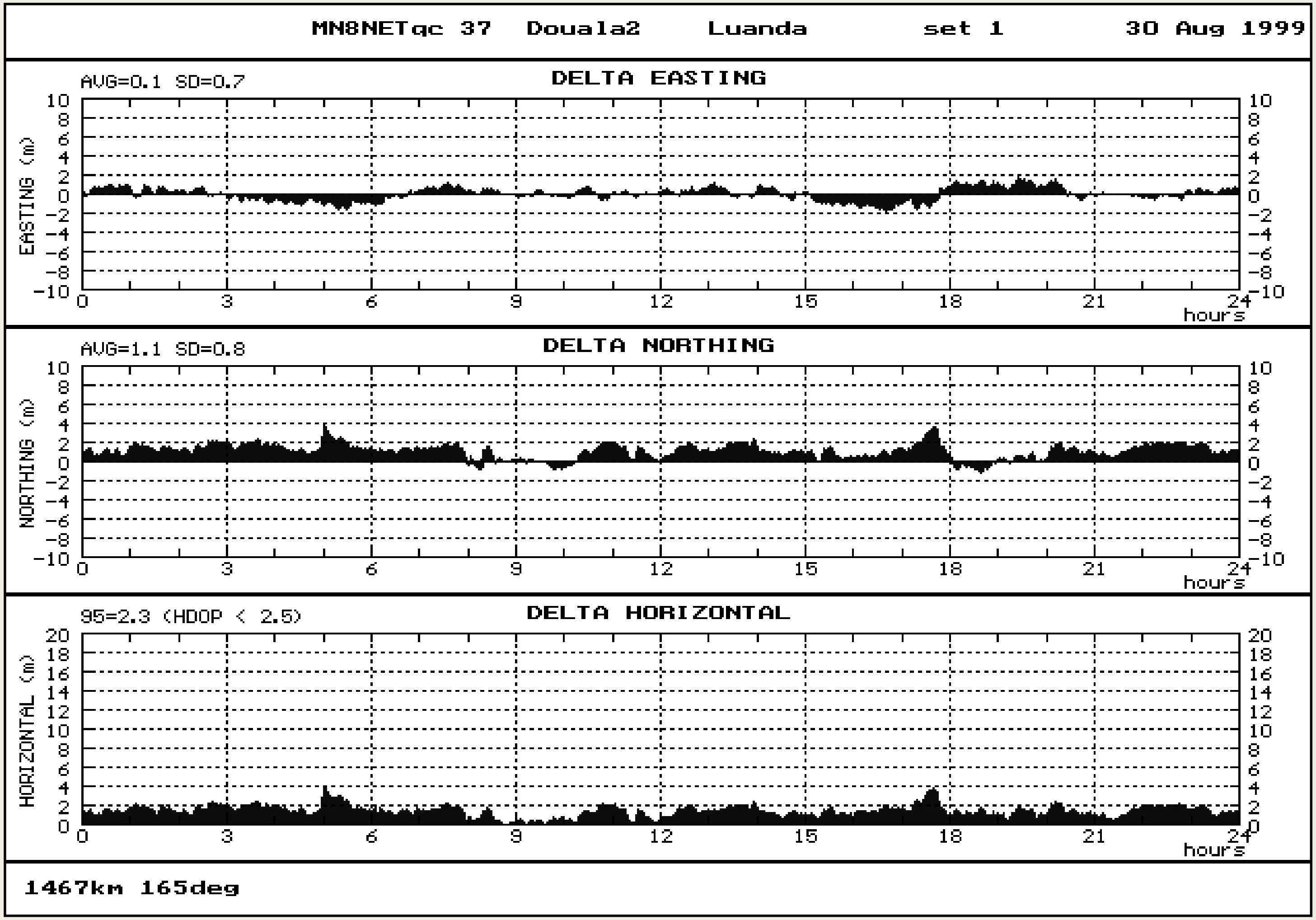


Single Frequency
Douala - Luanda (1467 km)
August 30, 1999



Precision GPS And Communications

Dual Frequency
Douala - Luanda (1467 km)
August 30, 1999



Precision GPS And Communications

2000 DGPS Performance

African Baselines

- Douala - Luanda 1500 Km
- Pointe-Noire Luanda 469 km

South American Baselines

- Rio de Janeiro - Recife 1860 km

Scintillation Problems

Autonomous GPS Positioning

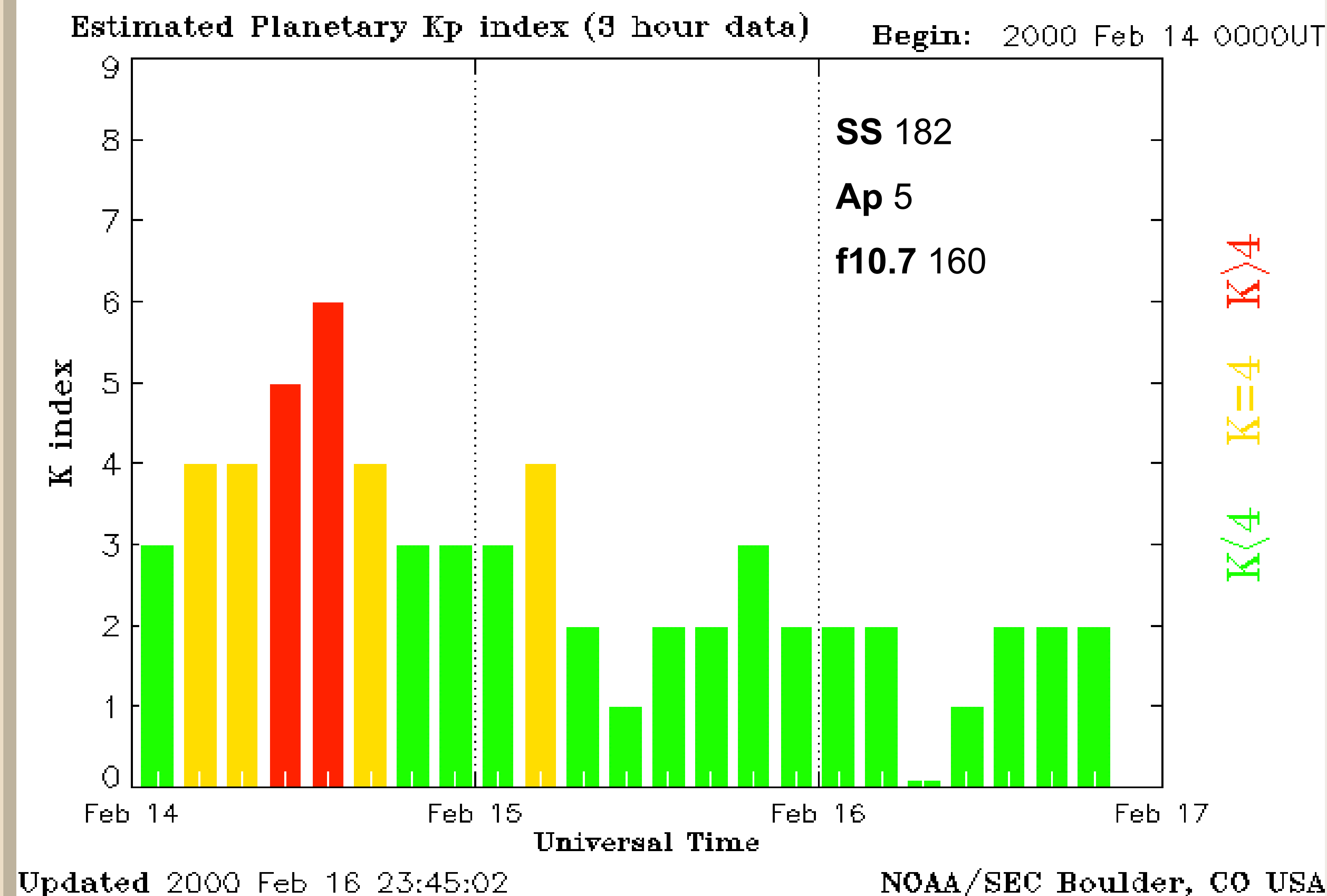
Single Frequency

- Using Klobuchar GPS IONO Model

Dual Frequency

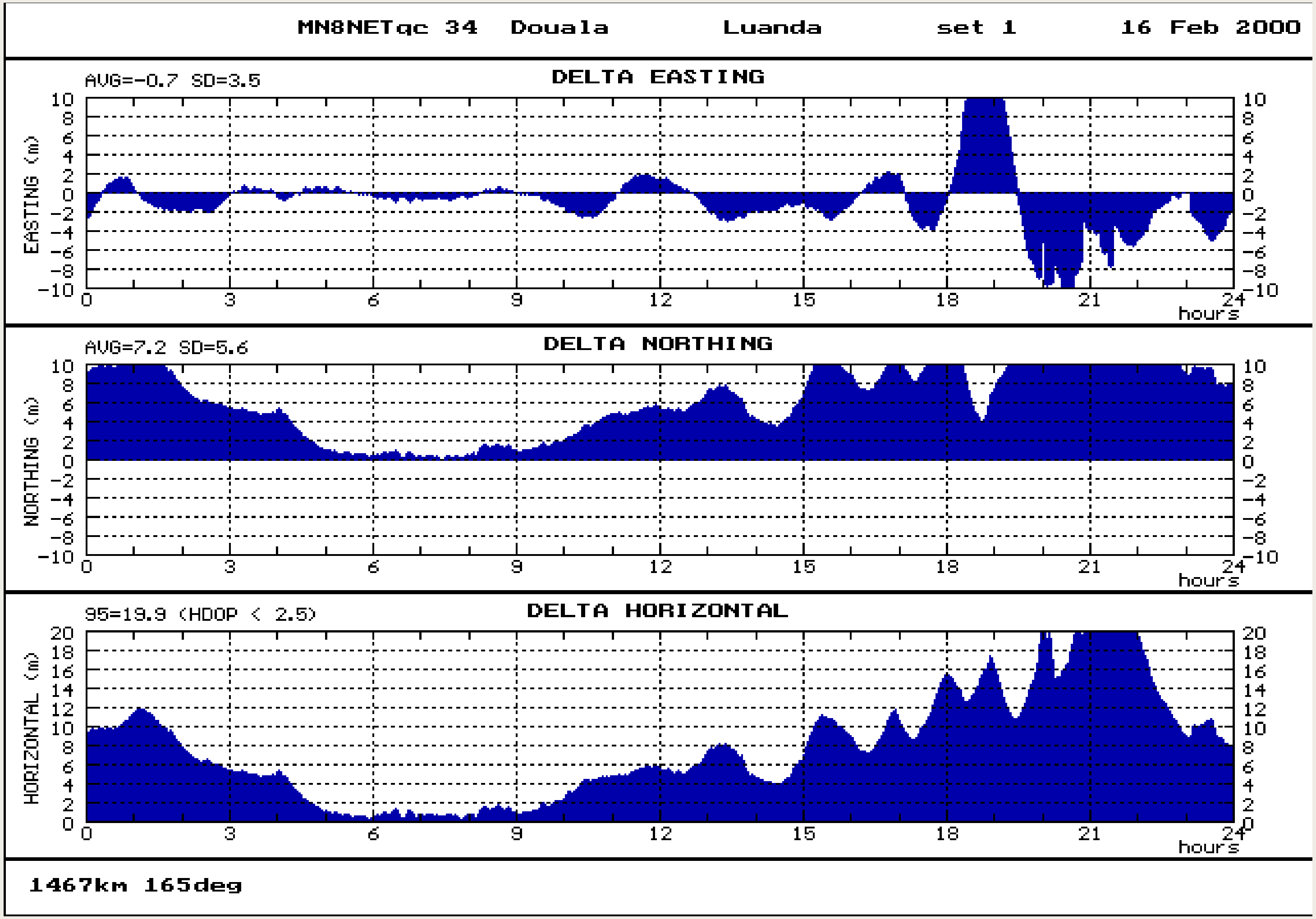
- Computing IONO value from measurements

Index Levels
February 14-16, 2000

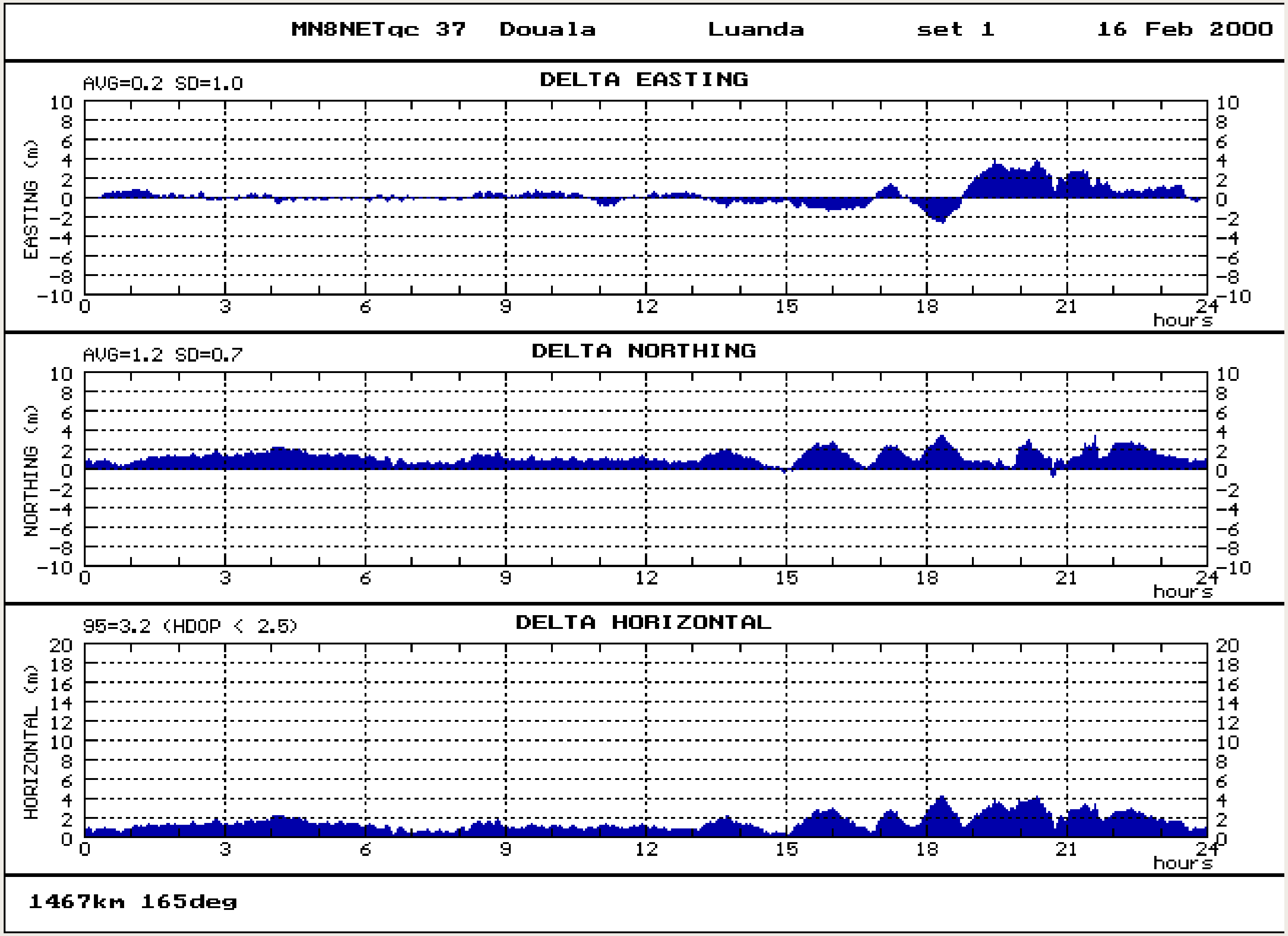


Precision GPS And Communications

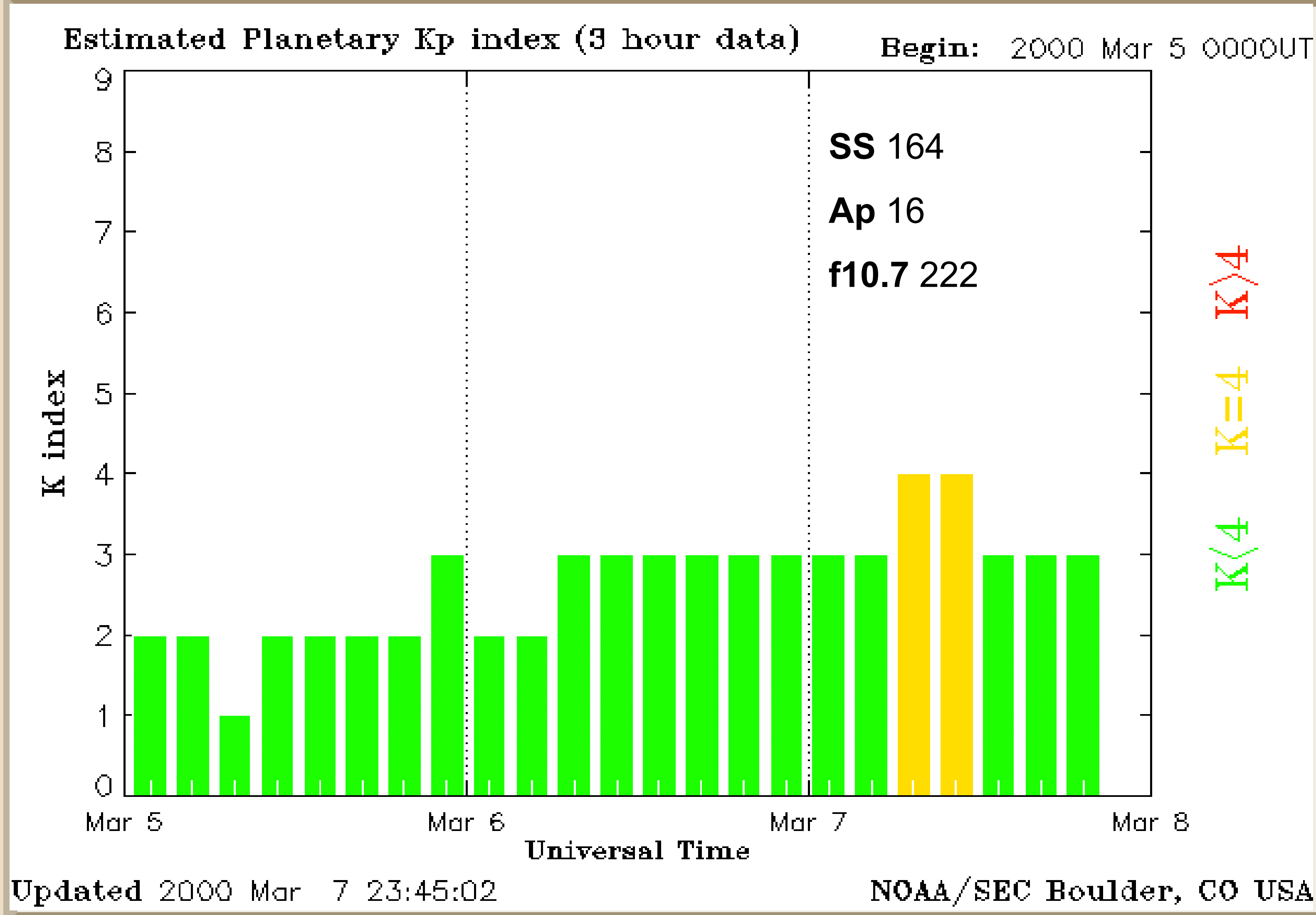
Single Frequency
Douala - Luanda (1467km)
Feb 16, 2000



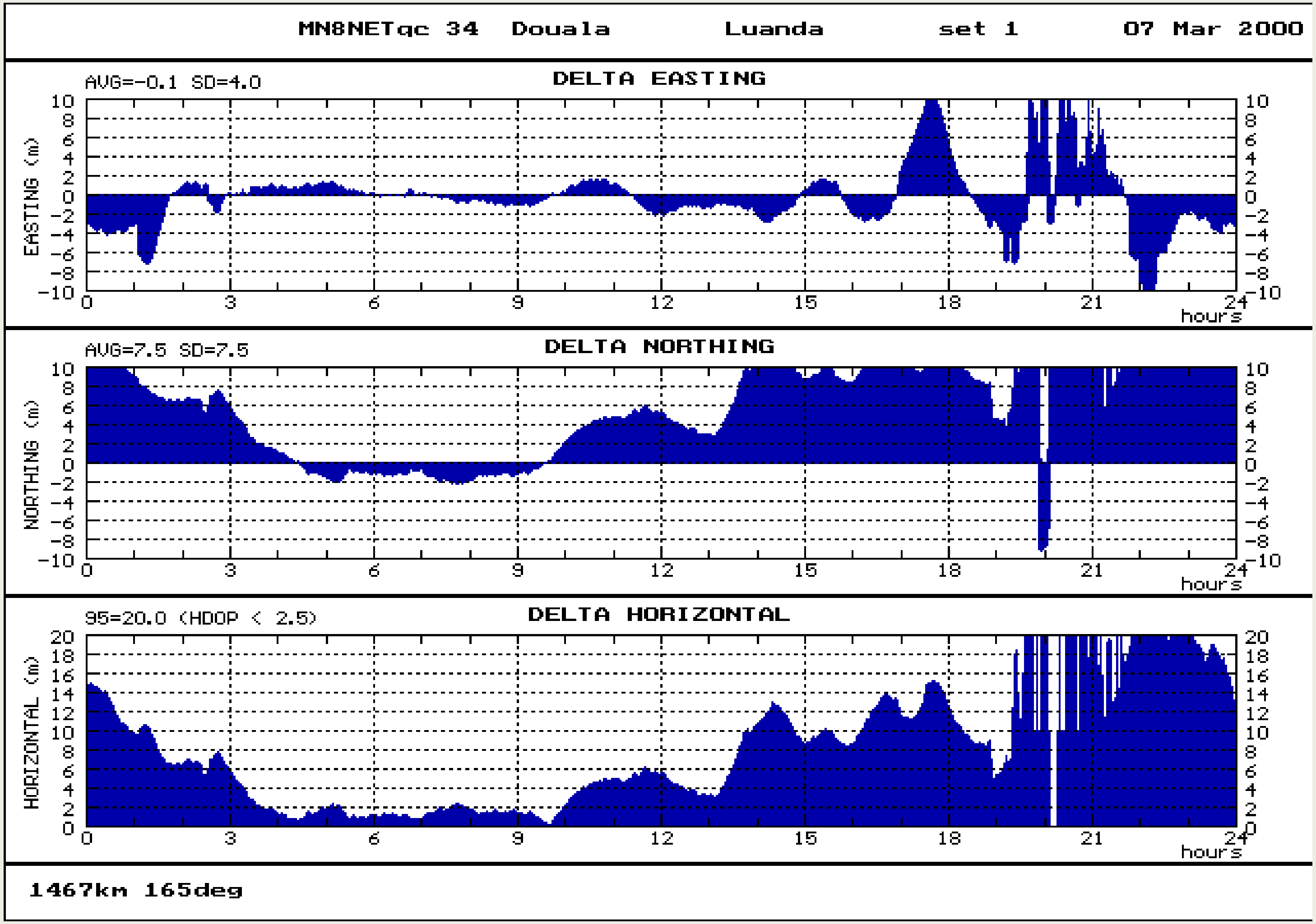
Dual Frequency
Douala - Luanda (1467km)
Feb 16, 2000



Index Levels
March 7, 2000

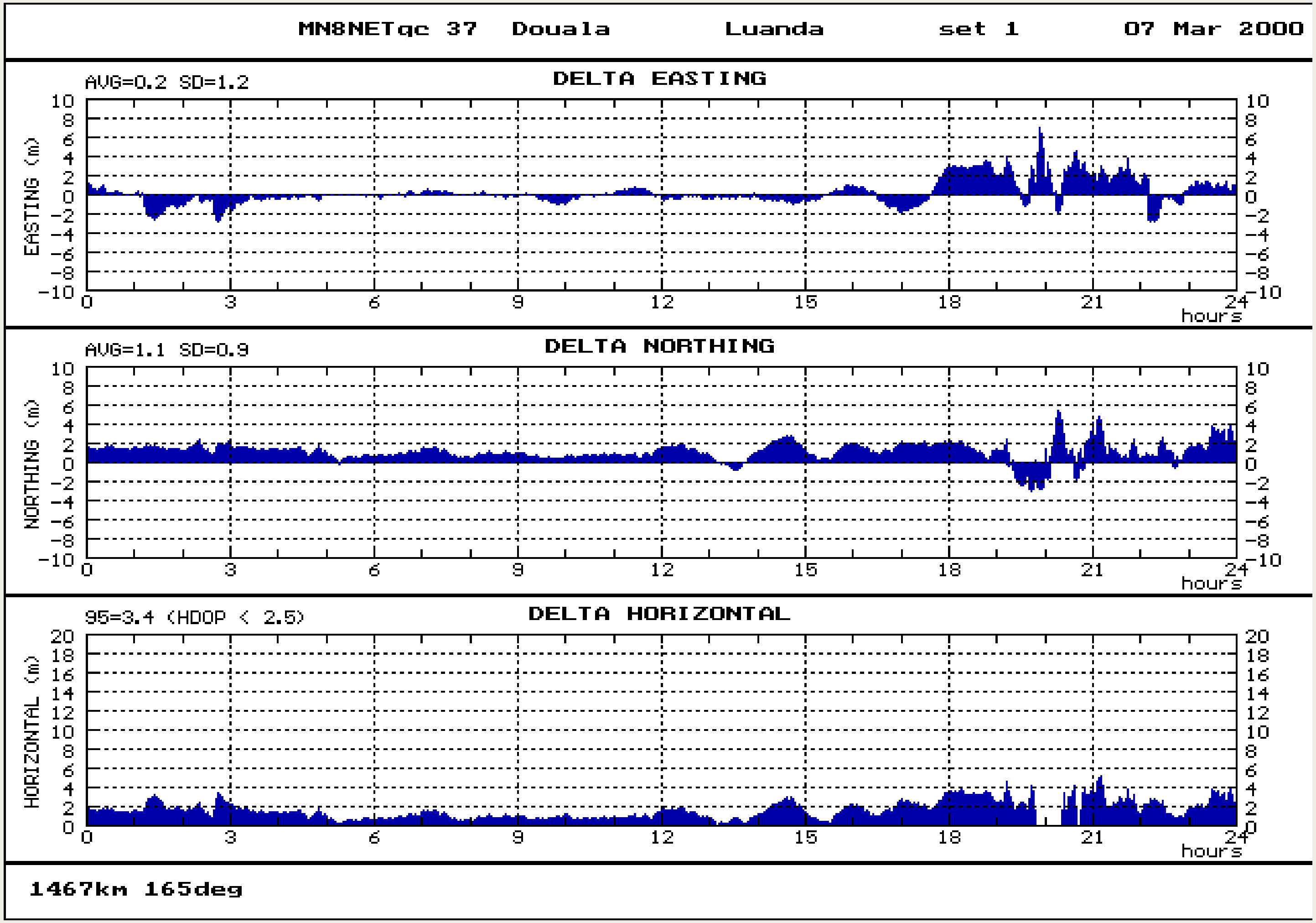


Single Frequency/Scintillations
Douala - Luanda (1467km)
Mar 7, 2000



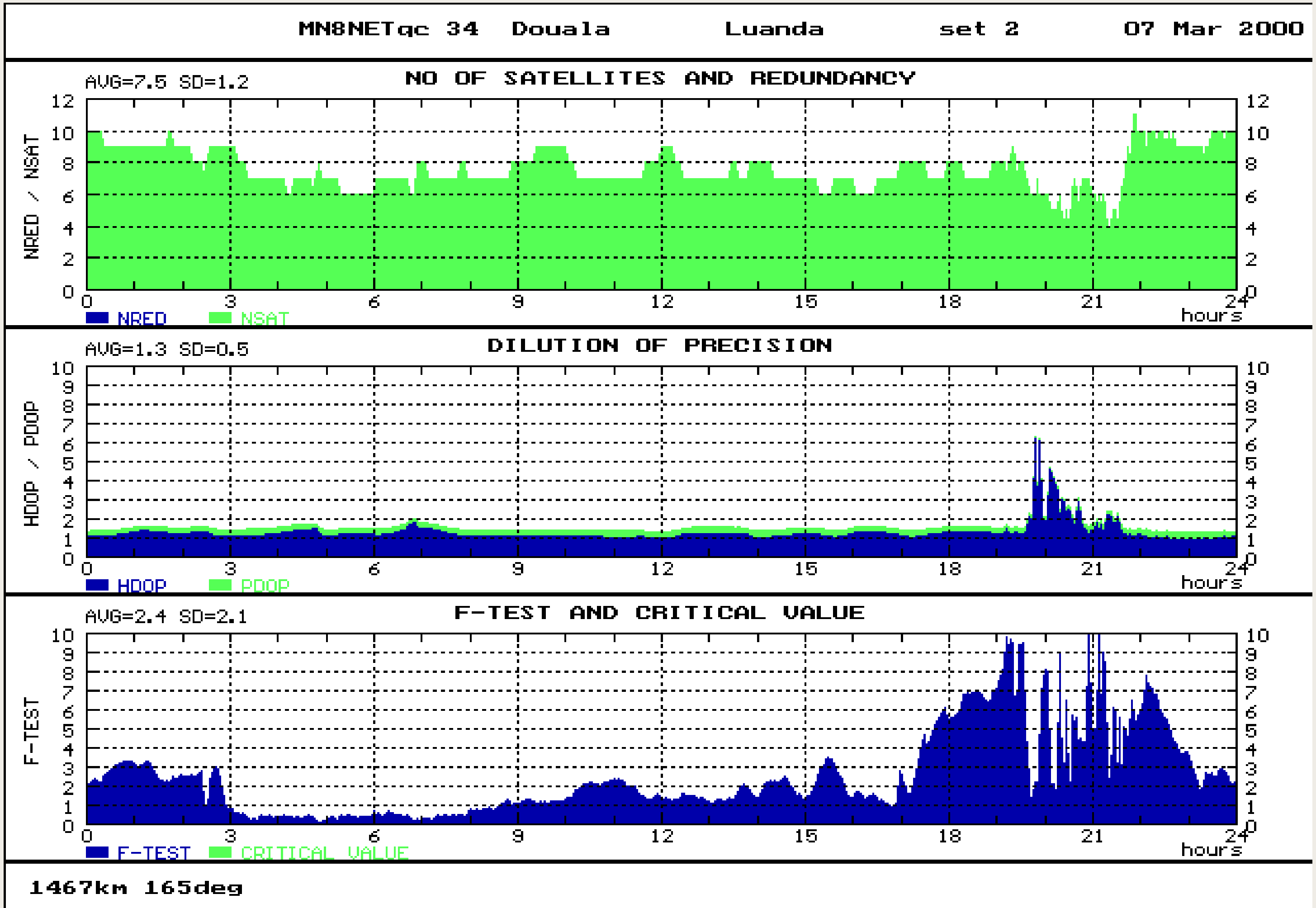
Precision GPS And Communications

Dual Frequency/Scintillations
Douala - Luanda (1467km)
Mar 7, 2000

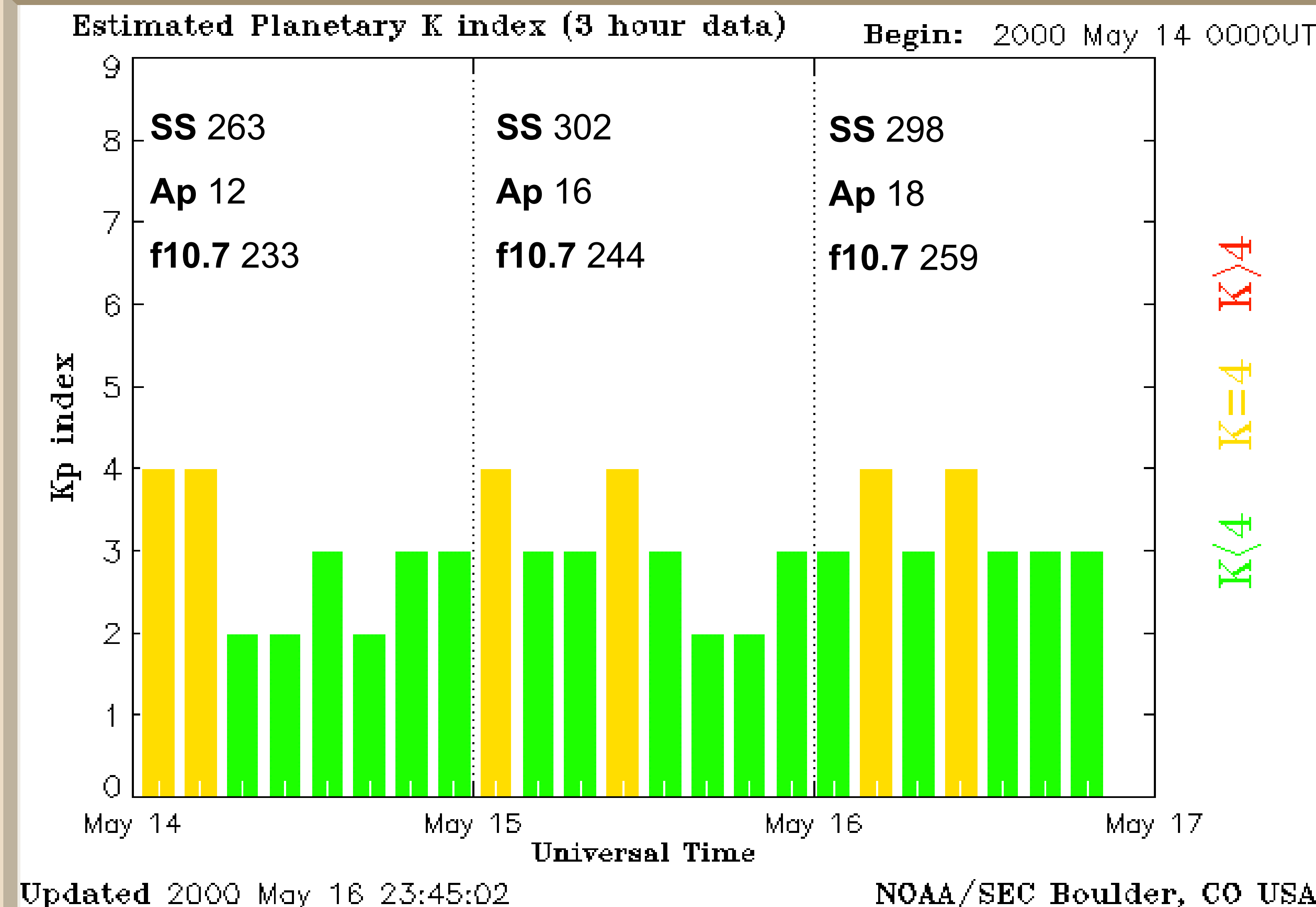


Space Weather Week
THE • MEETING • OF • RESEARCH • AND • OPERATIONS

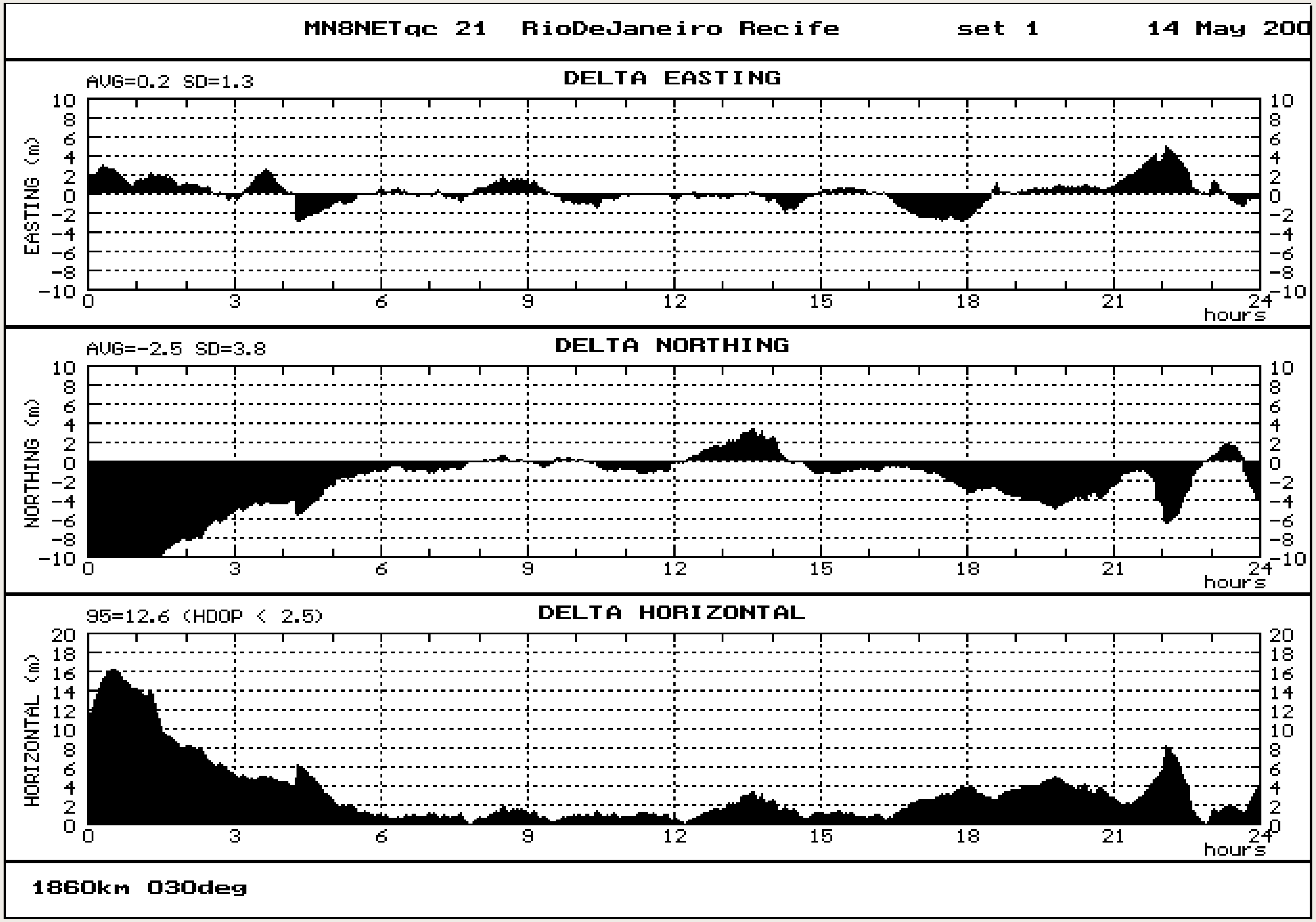
Single Frequency/Scintillations
Douala - Luanda (1467km)
Mar 7, 2000



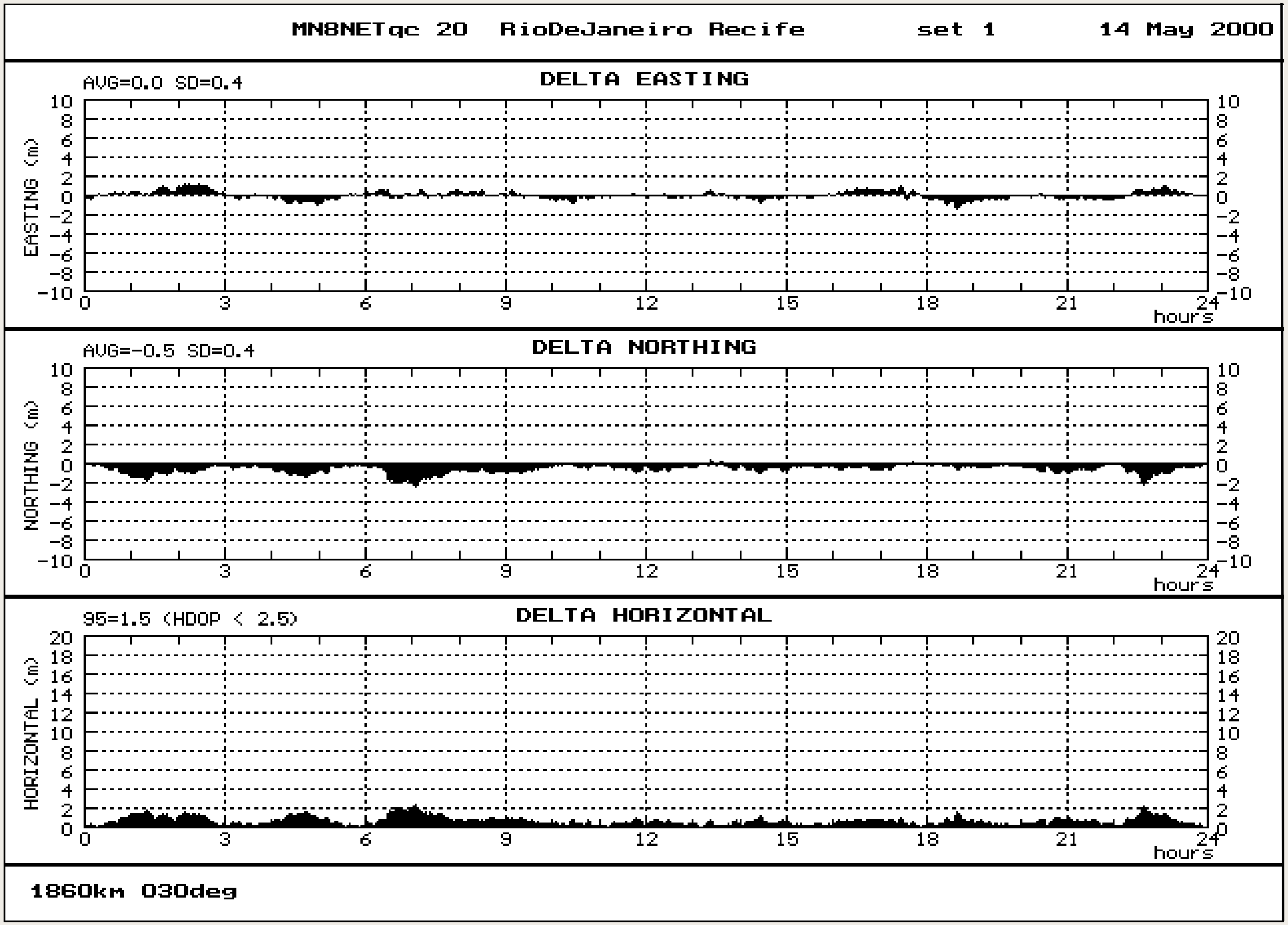
Index Levels
May 14-16, 2000



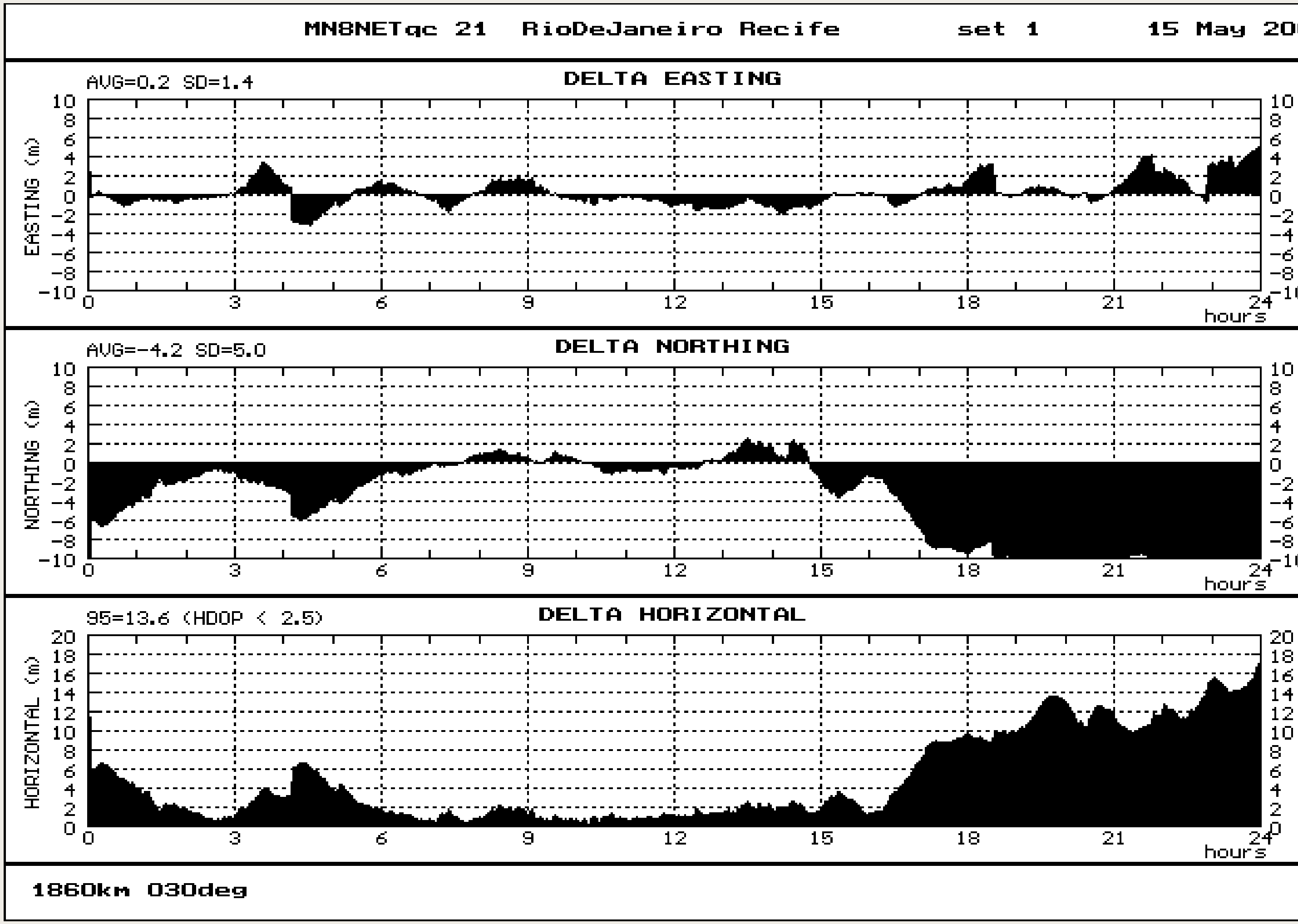
Single Frequency
Rio de Janeiro - Recife 1860km
May 14, 2000



Dual Frequency
Rio de Janeiro - Recife 1860km
May 14, 2000

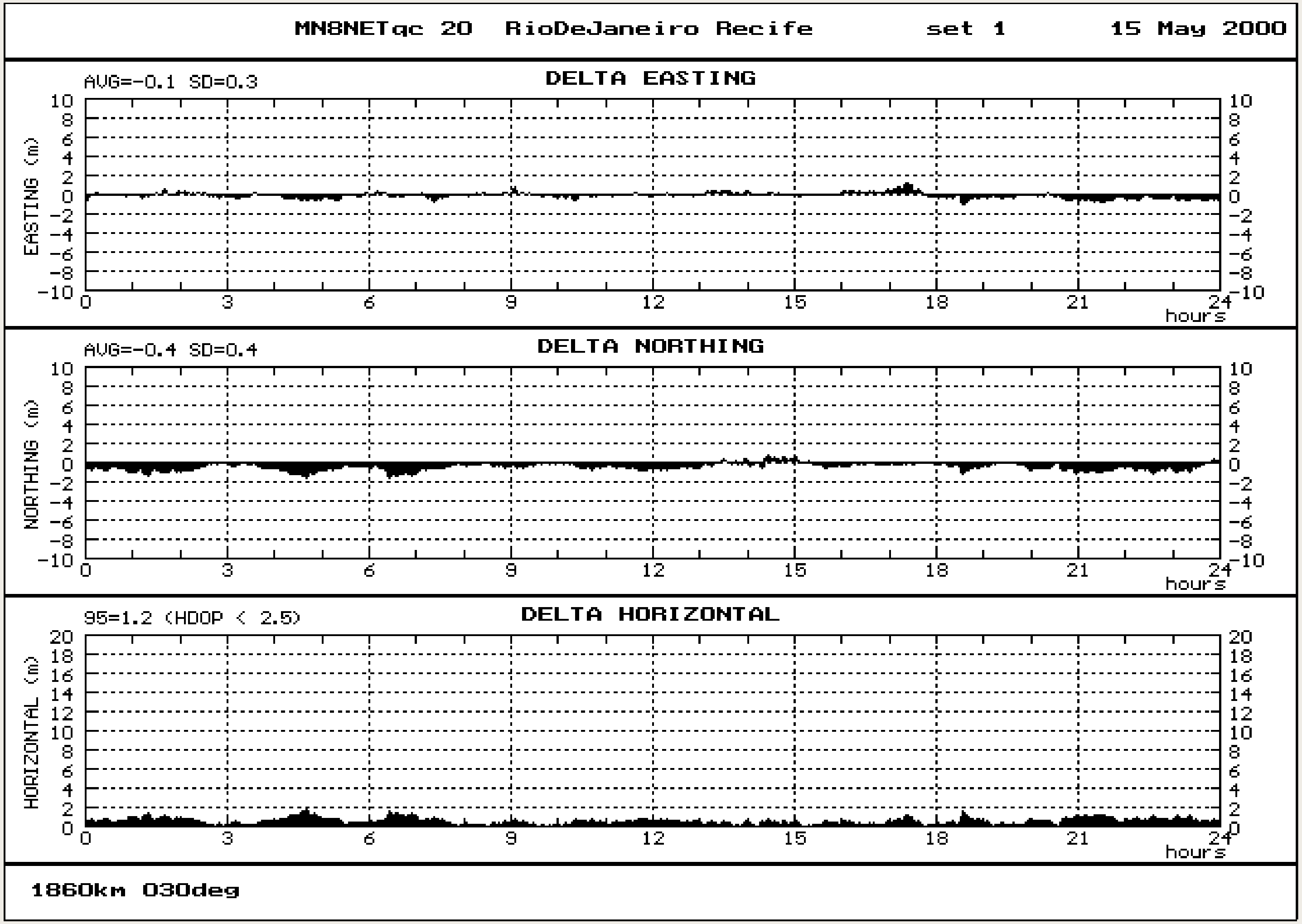


Single Frequency
Rio de Janeiro - Recife 1860km
May 15, 2000



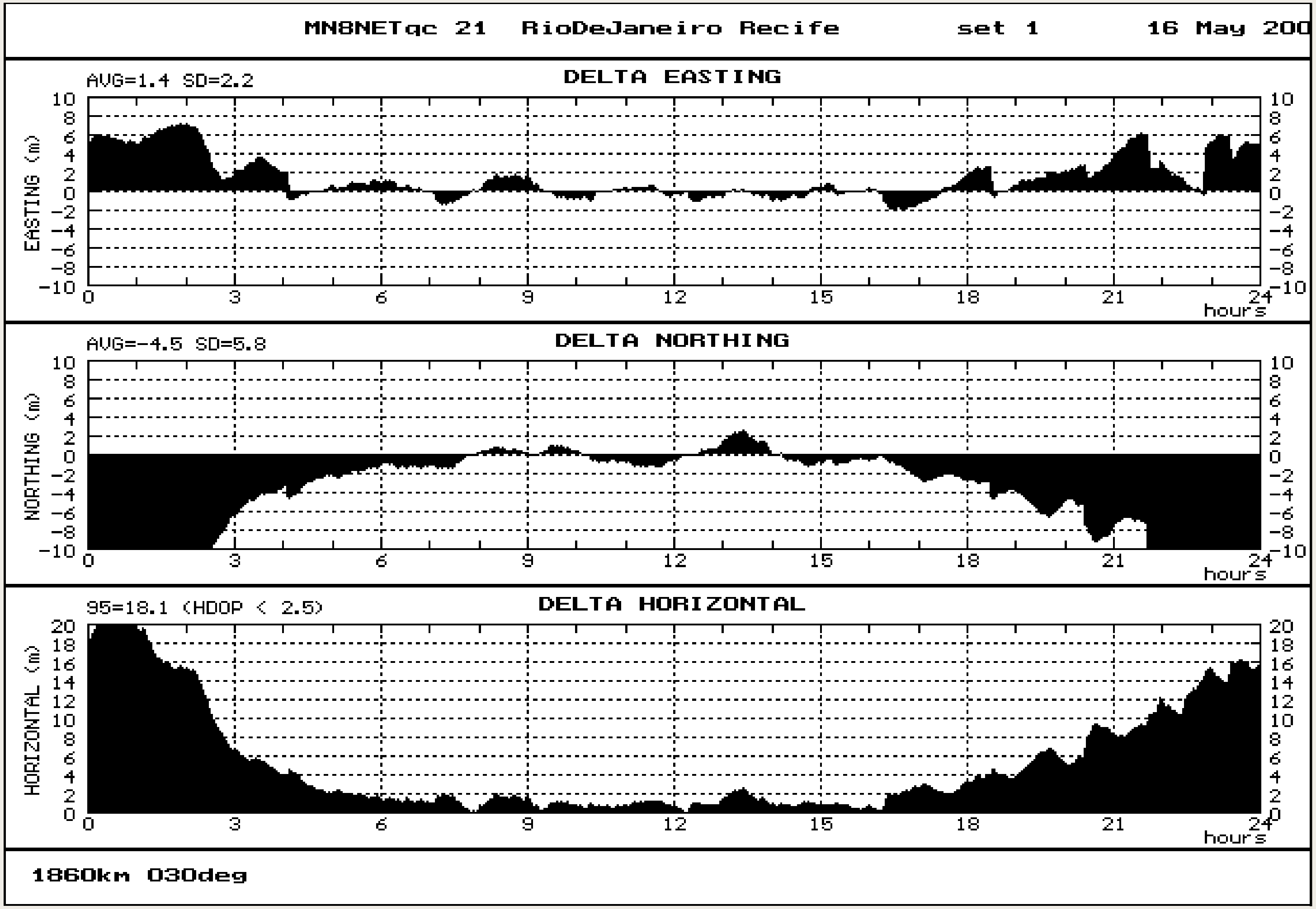
Precision GPS And Communications

Dual Frequency
Rio de Janeiro - Recife 1860km
May 15, 2000



Precision GPS And Communications

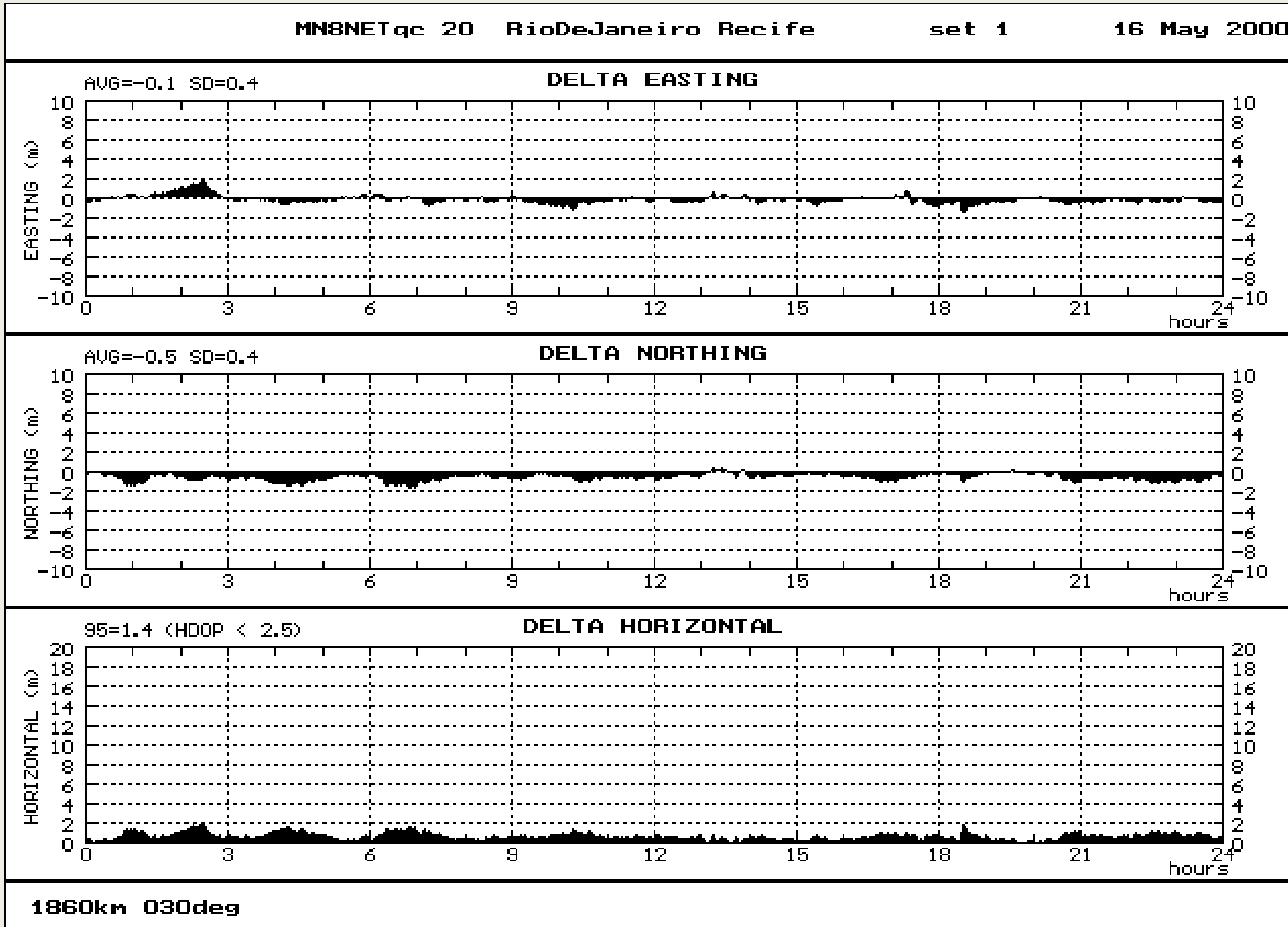
Single Frequency Baseline
Rio de Janeiro - Recife 1860km
May 16, 2000



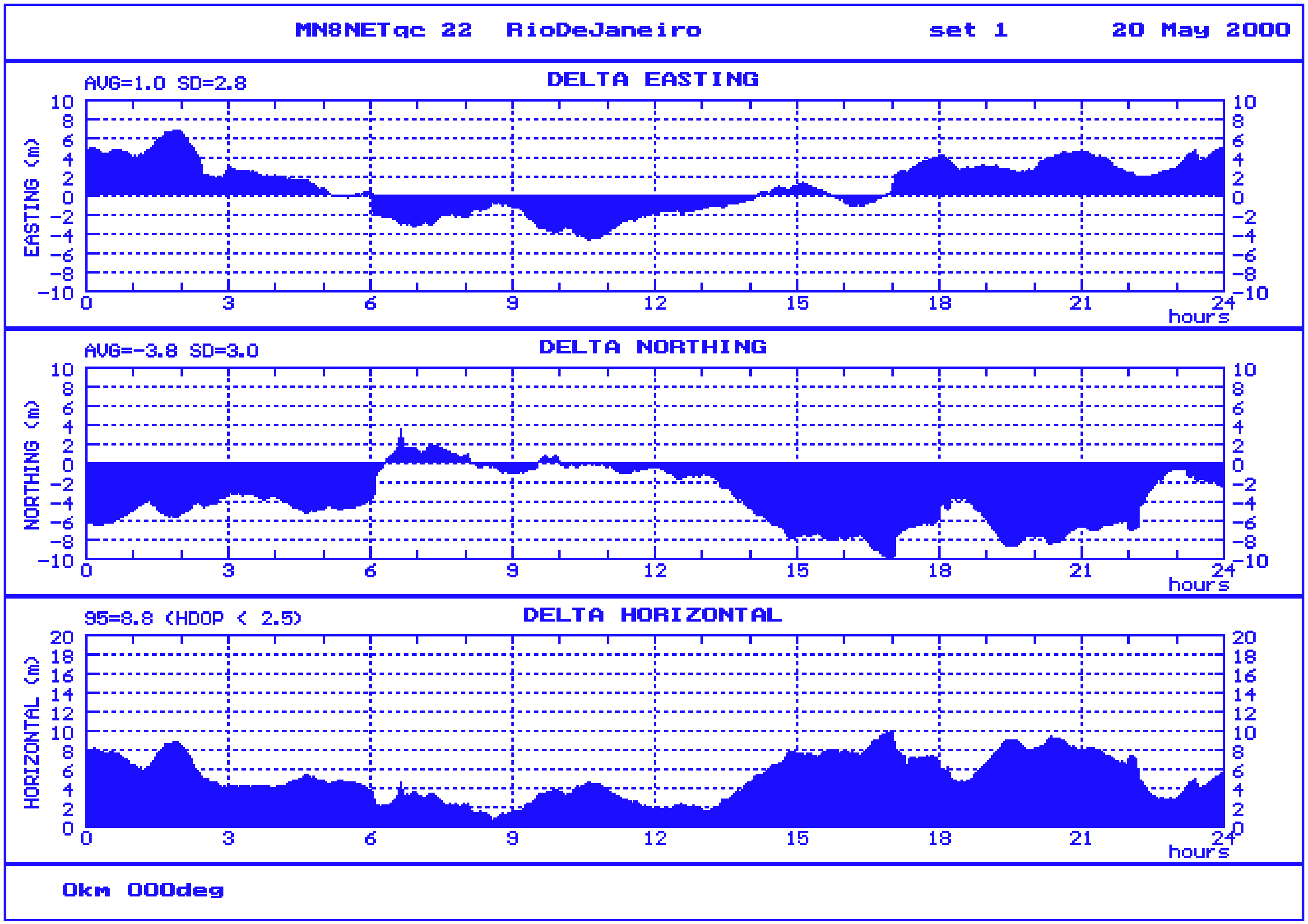
Space Weather Week

THE • MEETING • OF • RESEARCH • AND • OPERATIONS

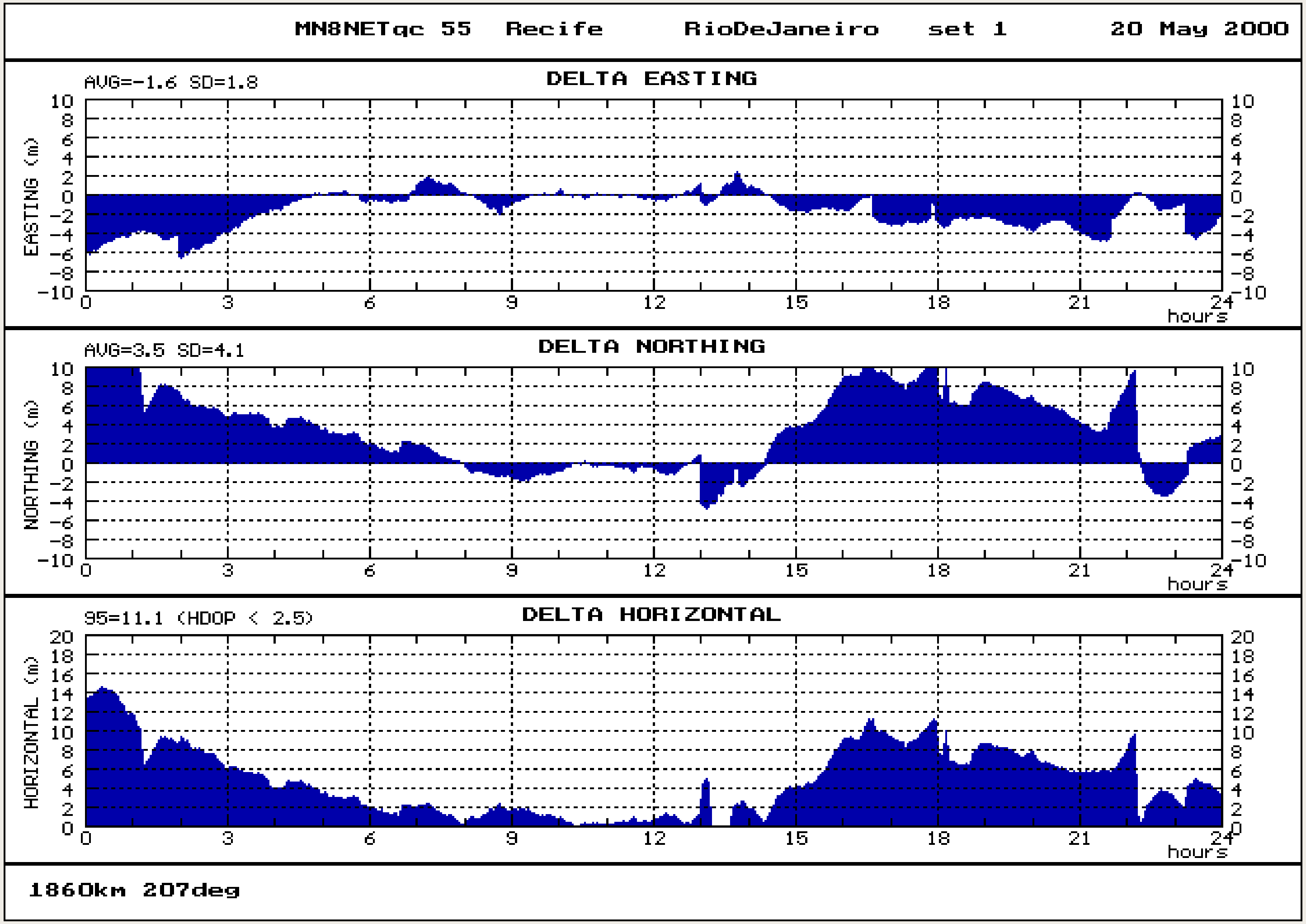
Dual Frequency Baseline
Rio de Janeiro - Recife 1860km
May 16, 2000



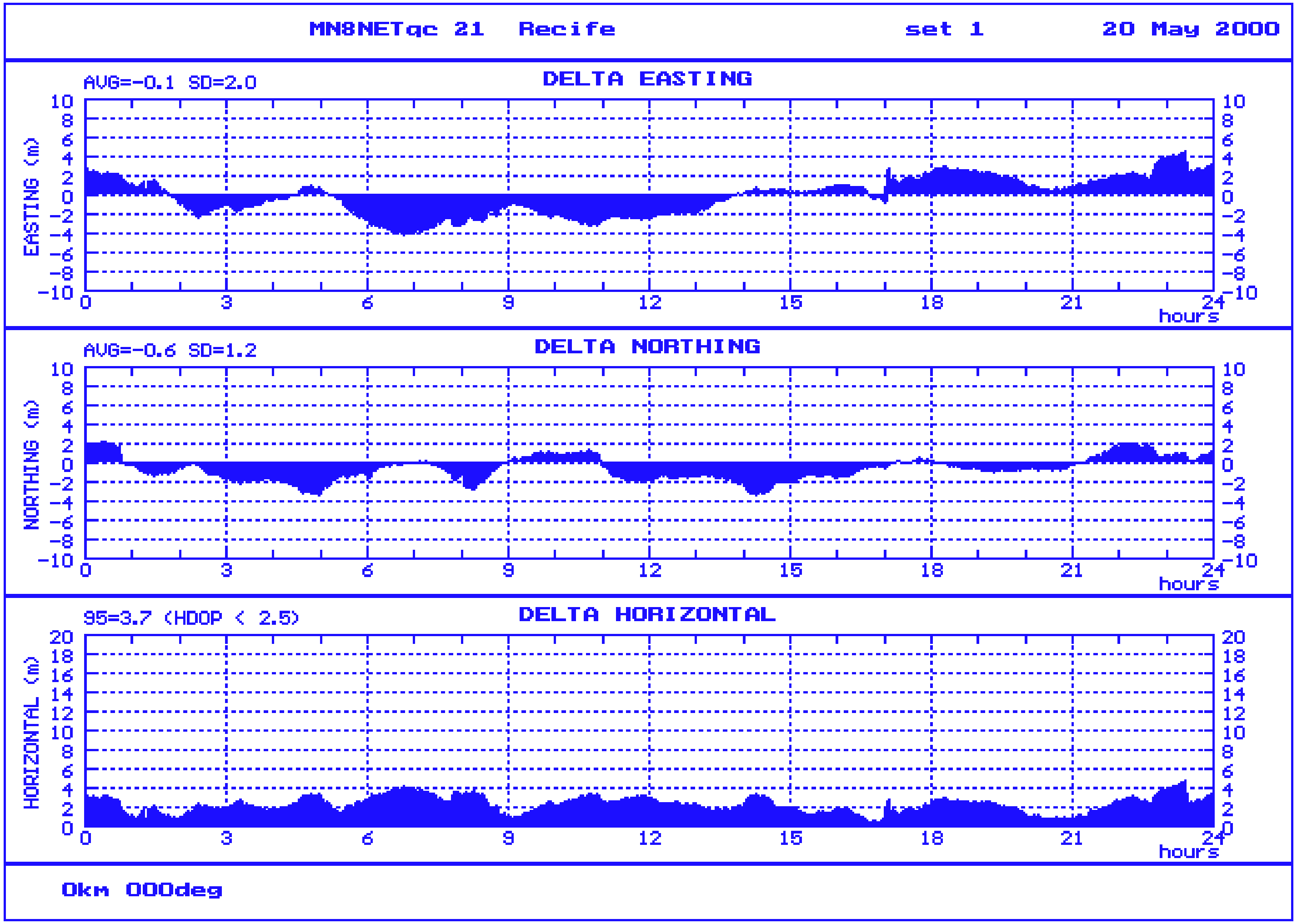
Single Frequency Autonomous
Rio de Janeiro
May 20, 2000



Single Frequency (DGPS)
Rio de Janeiro-Recife (1860km)
May 20, 2000

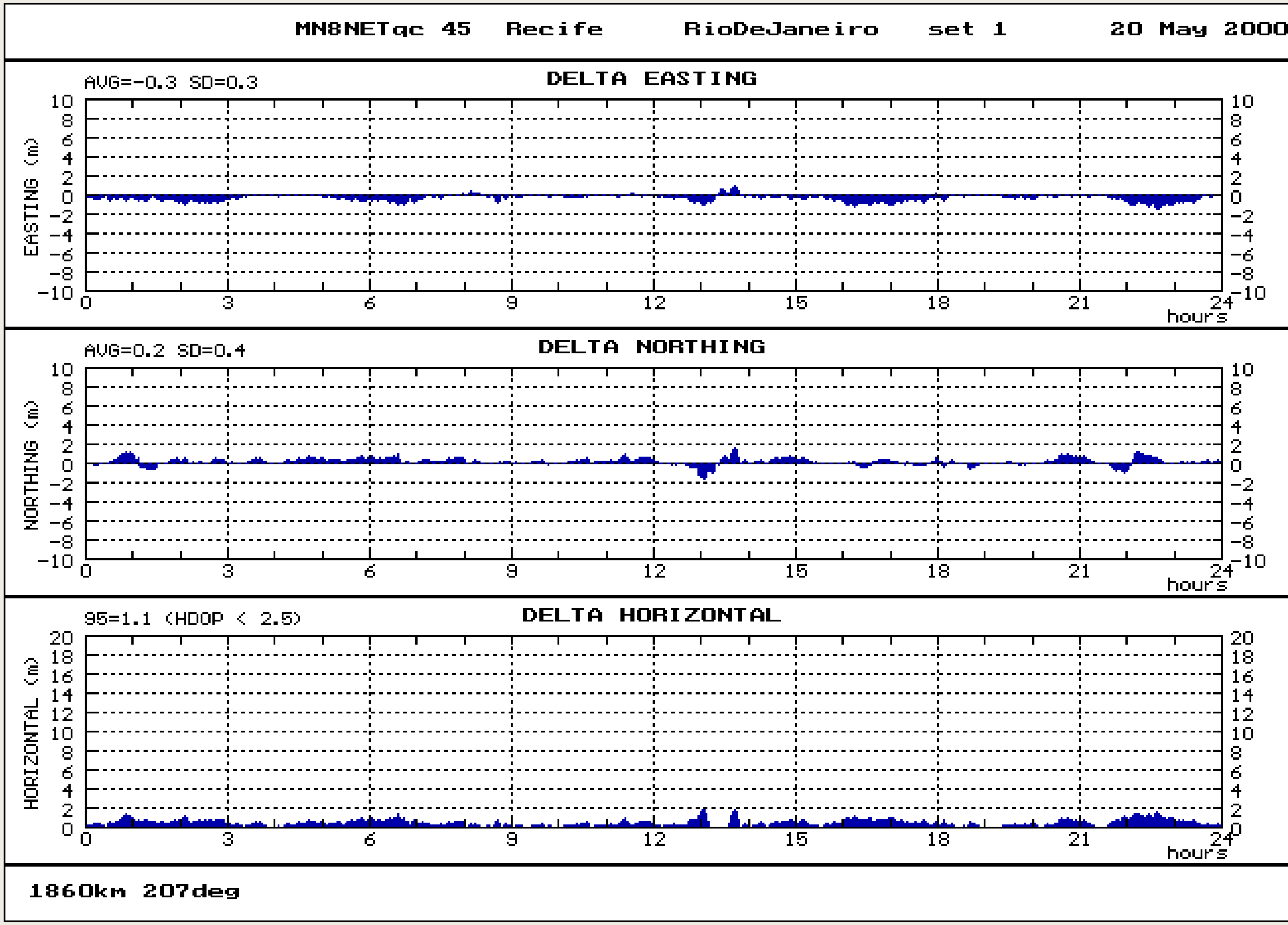


Dual Frequency Autonomous Recife
May 20, 2000



Precision GPS And Communications

Dual Frequency (DGPS)
Rio de Janeiro-Recife (1860km)
May 20, 2000



2003 DGPS Performance

South American Baselines

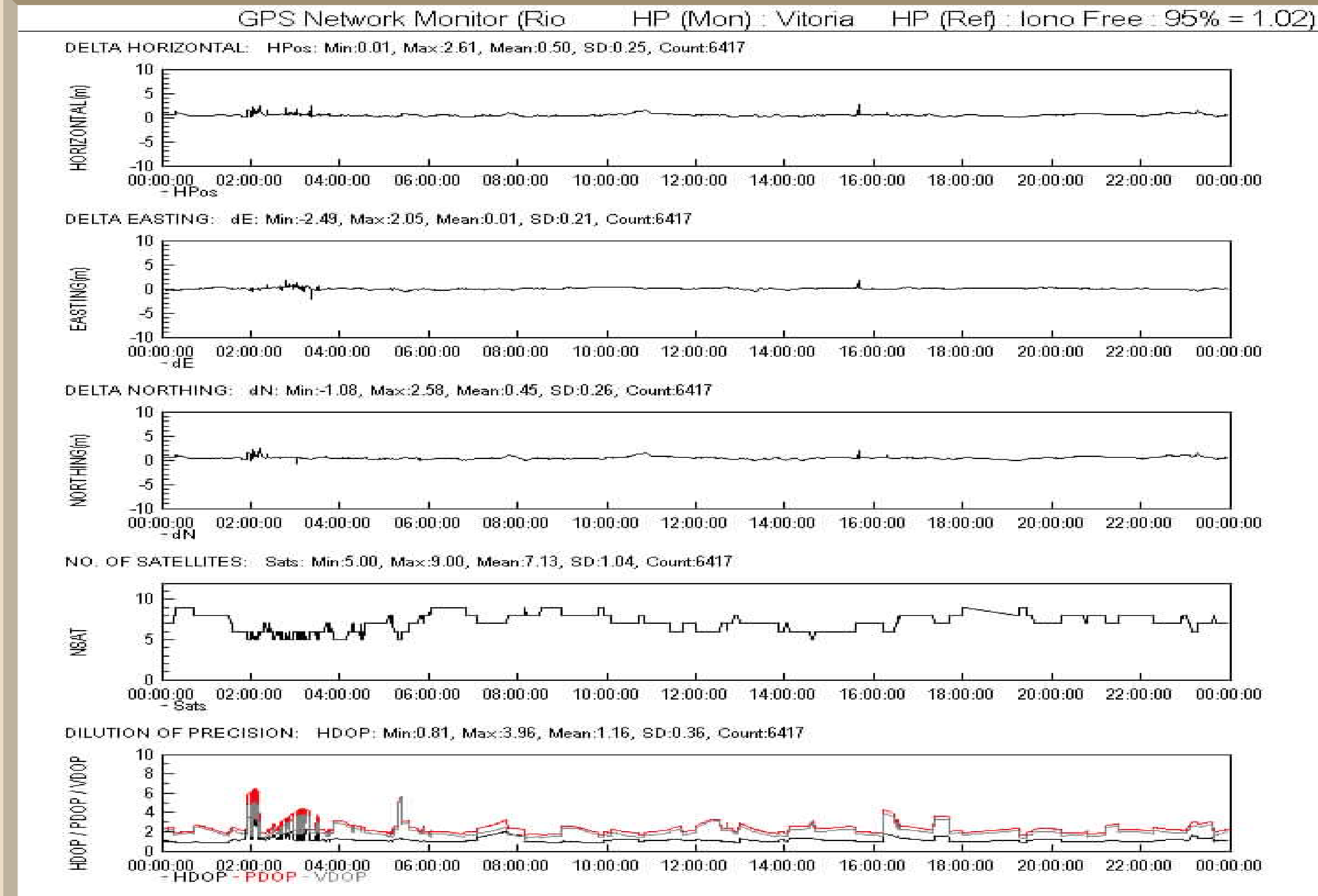
- Rio de Janeiro – Vitoria 420 km

Scintillation Problems

Dual Frequency Data

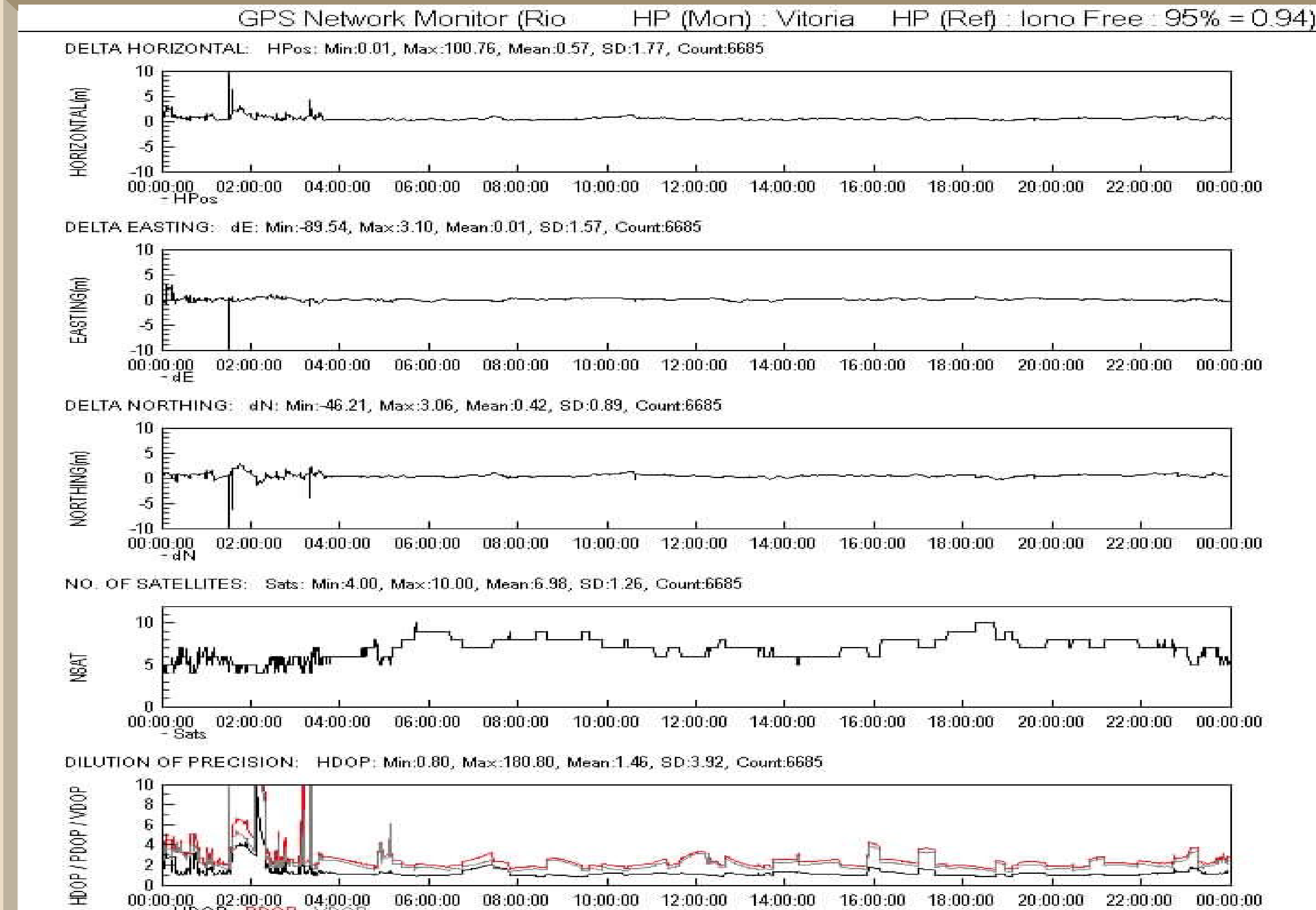
- Computing IONO value from measurements

South American Scintillations
February 2, 2003

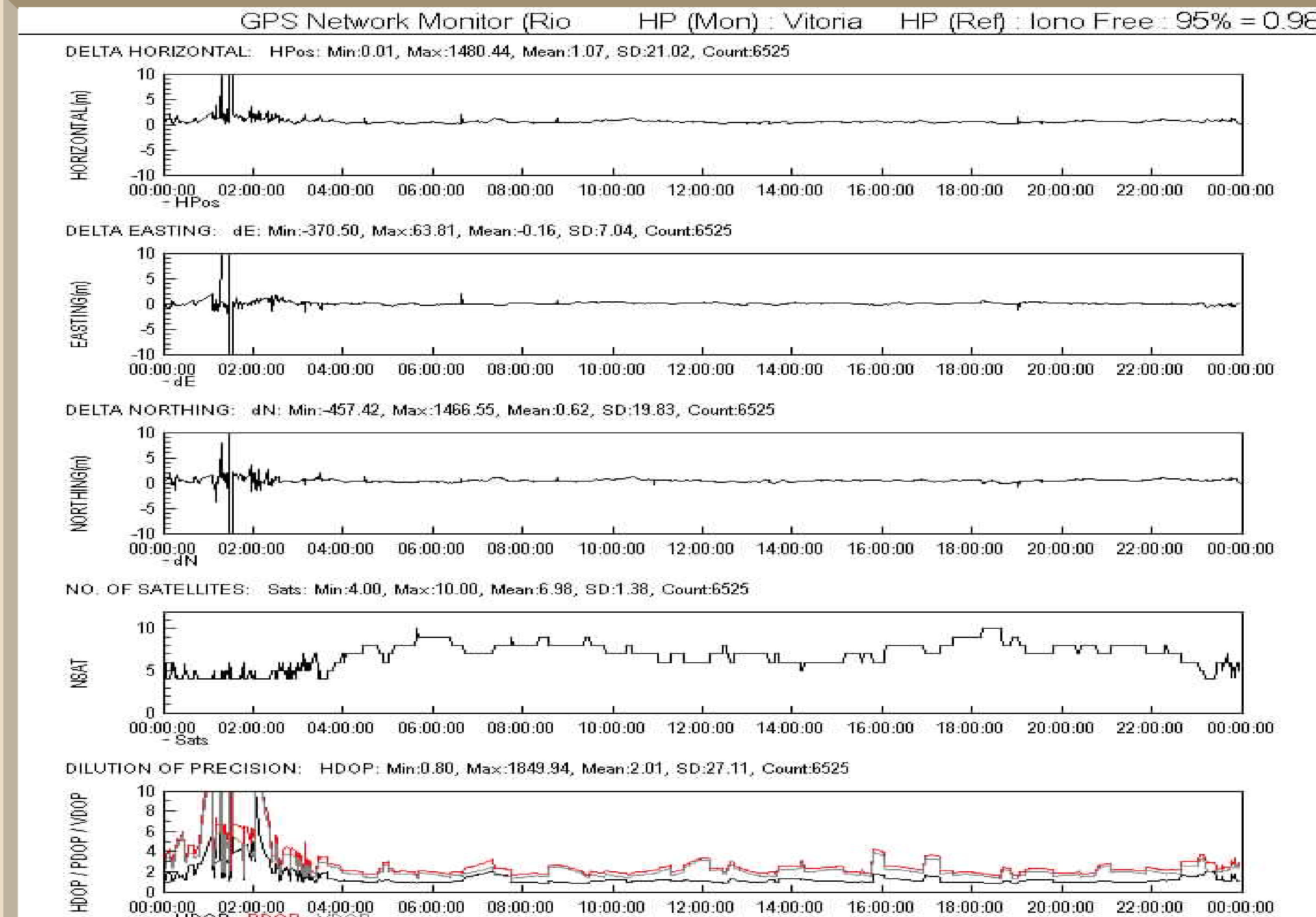


Precision GPS And Communications

South American Scintillations
February 11, 2003

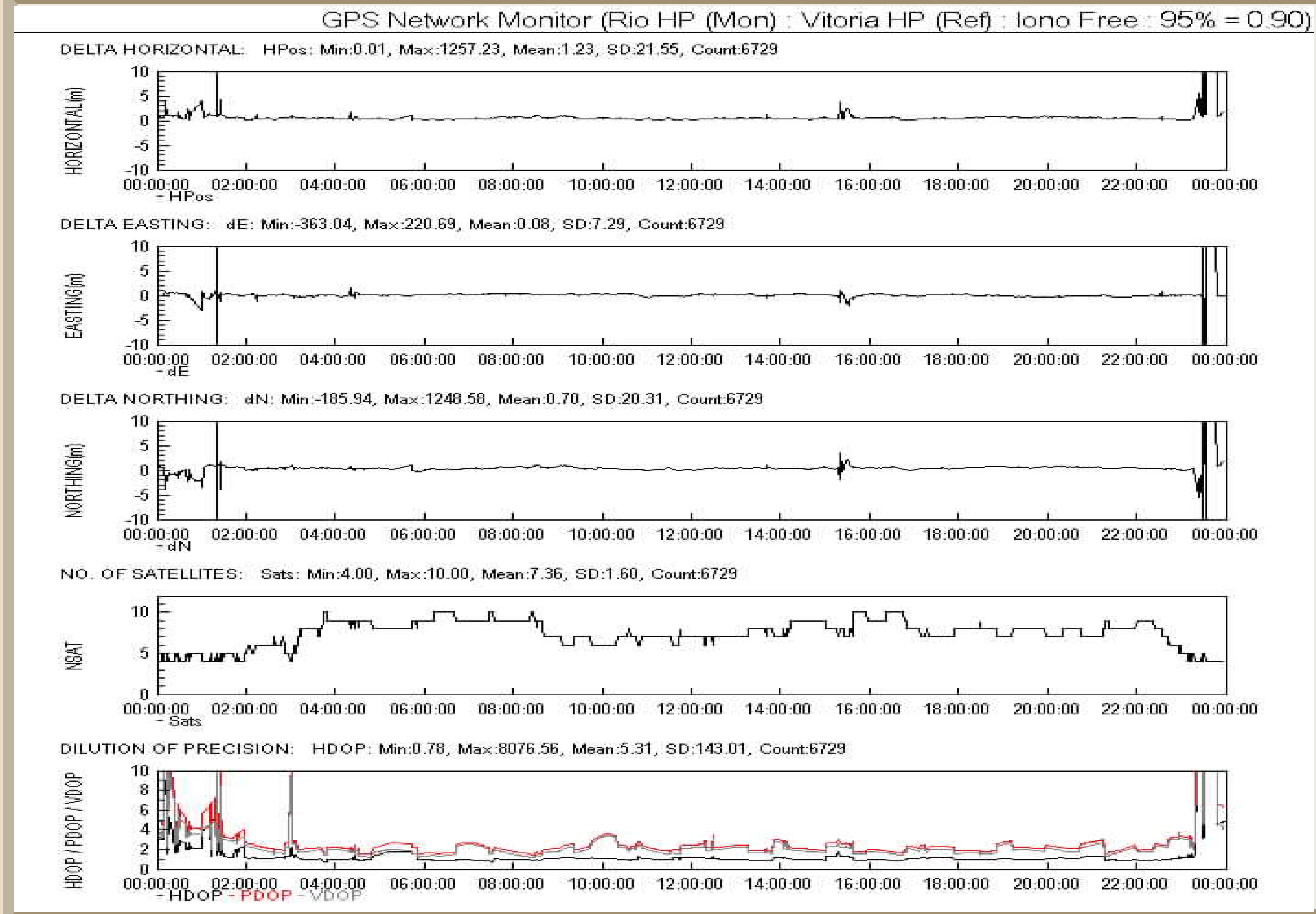


South American Scintillations
February 12, 2003



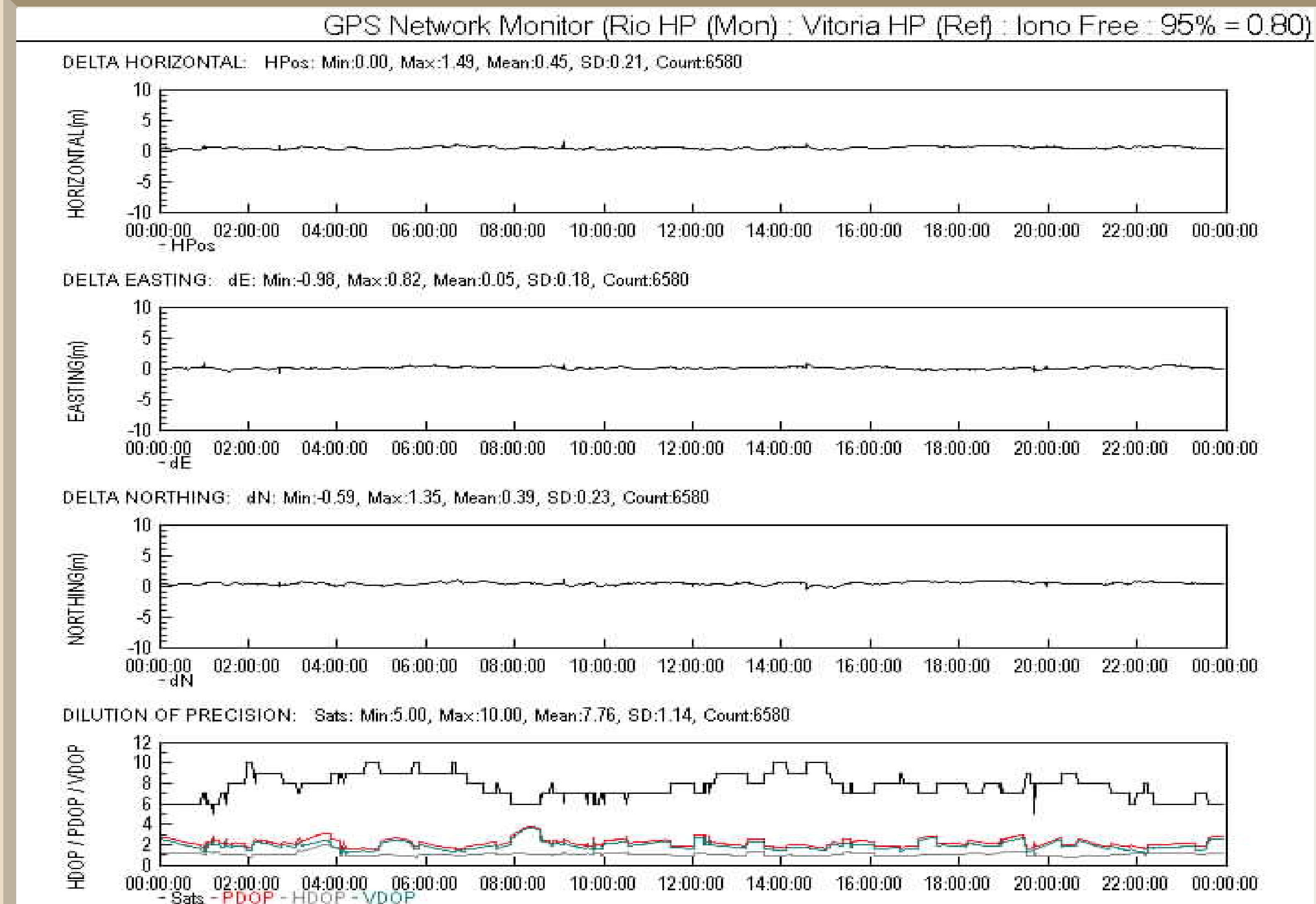
Precision GPS And Communications

South American Scintillations
March 12, 2003

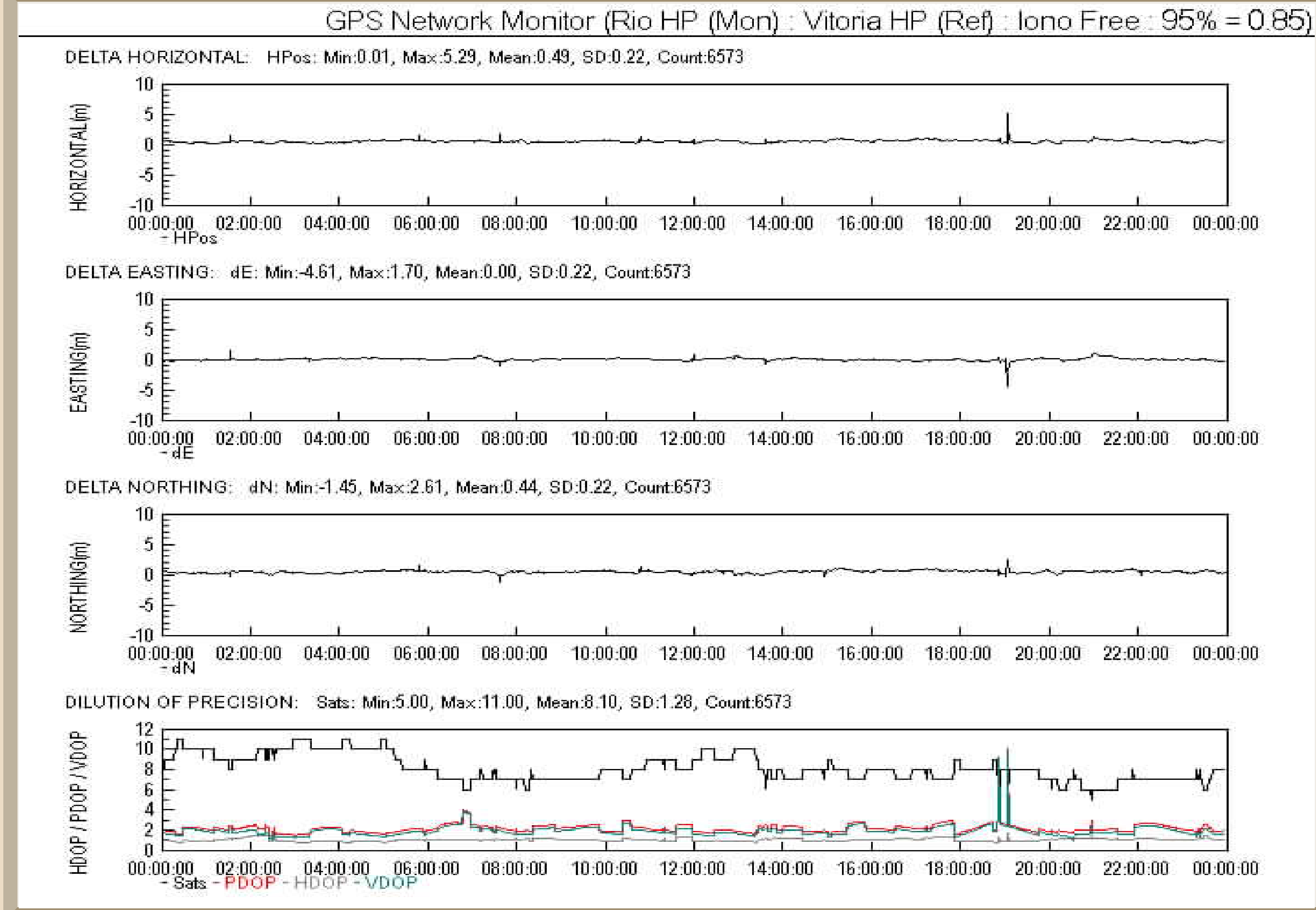


Precision GPS And Communications

South American Scintillations
April 7, 2003



South American Scintillations
May 1, 2003



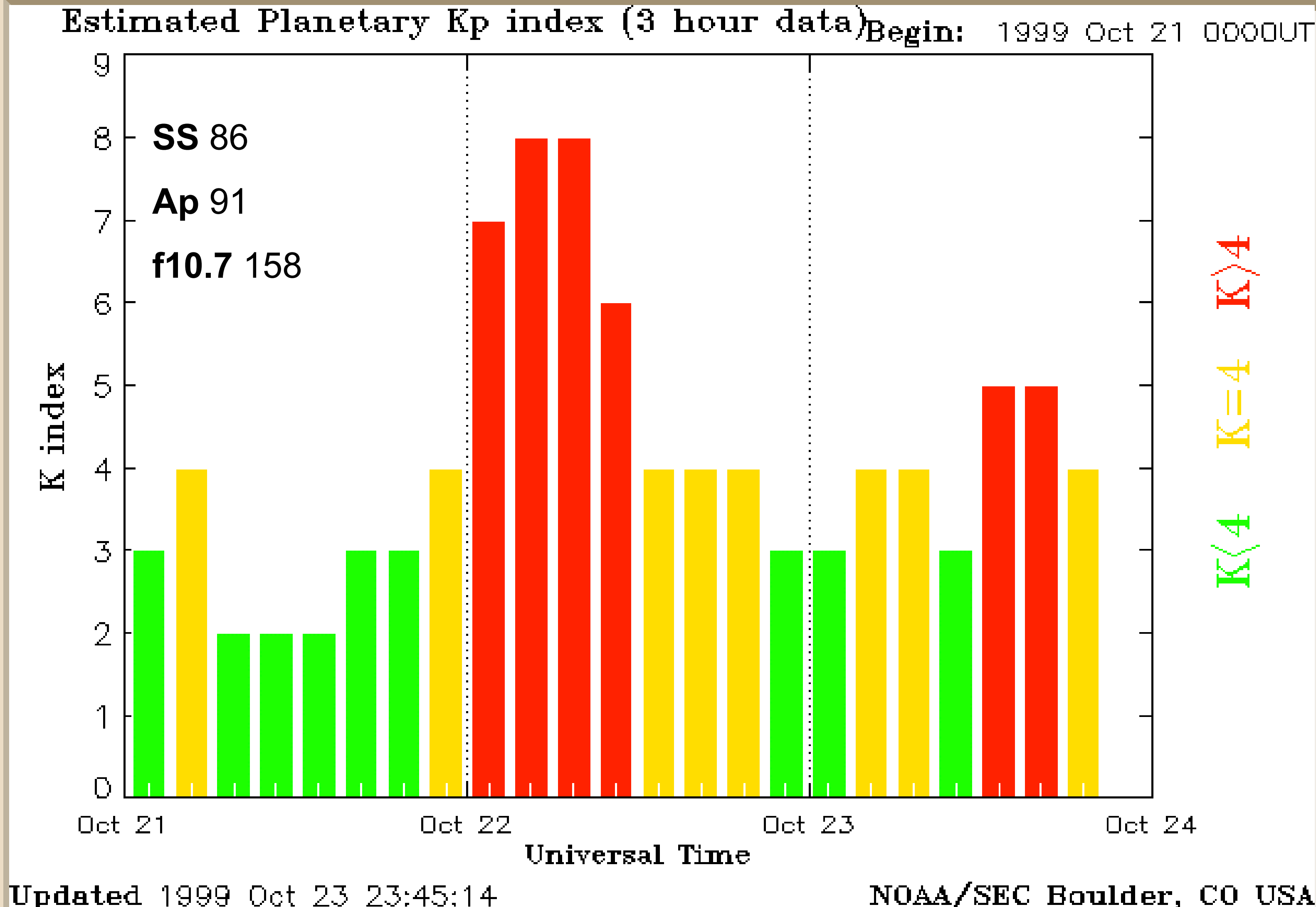
Precision GPS And Communications

Effects of Solar Activity In GOM

The following slides show the effects on GPS performance of a CME originating October 18, 1999, striking the earth's magnetosphere on October 22, 1999.

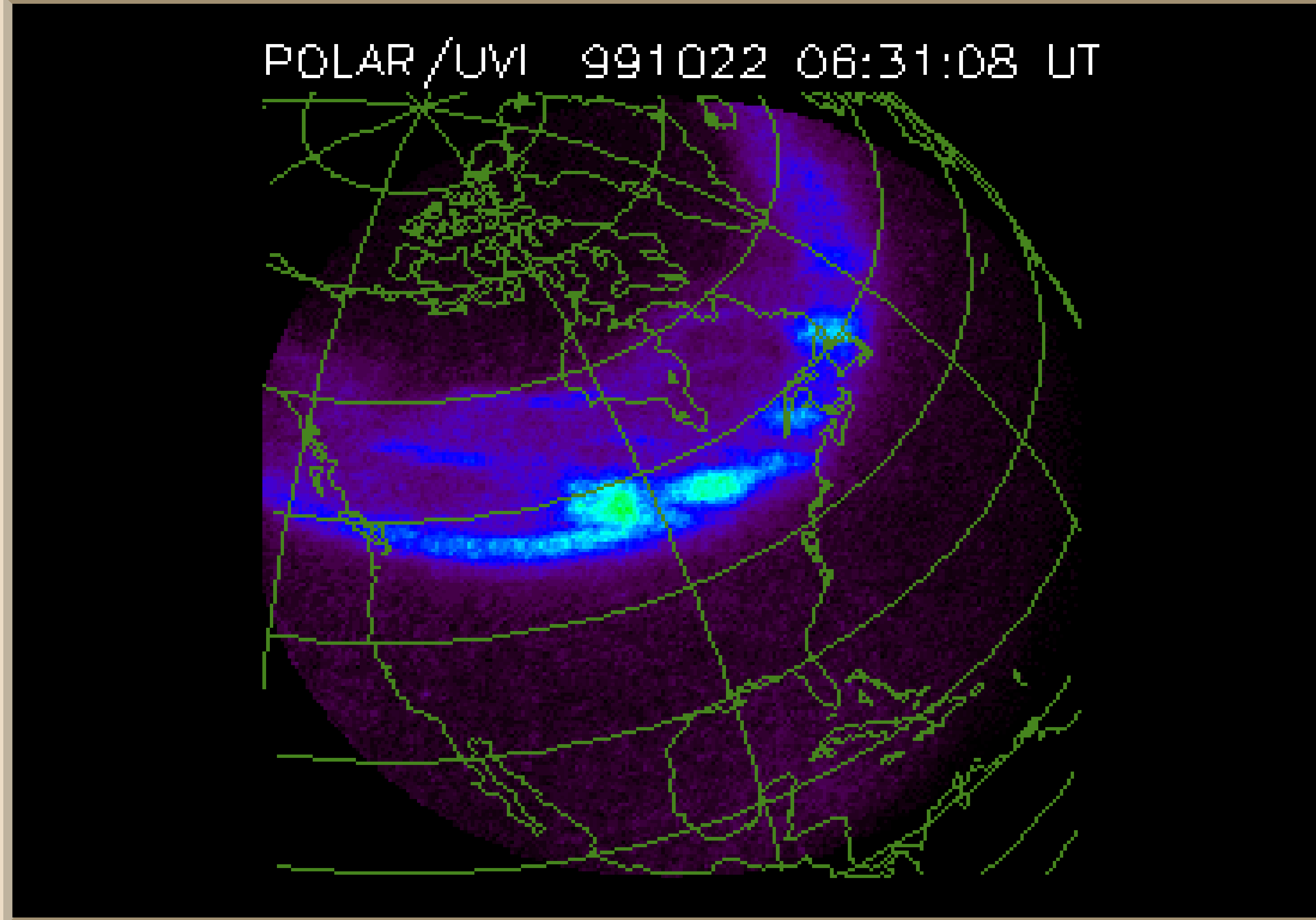
- Indices
- High Performance (L1) GPS Results
- WASS Results
- DGPS Results

Exceptional Solar Event
October 22, 1999



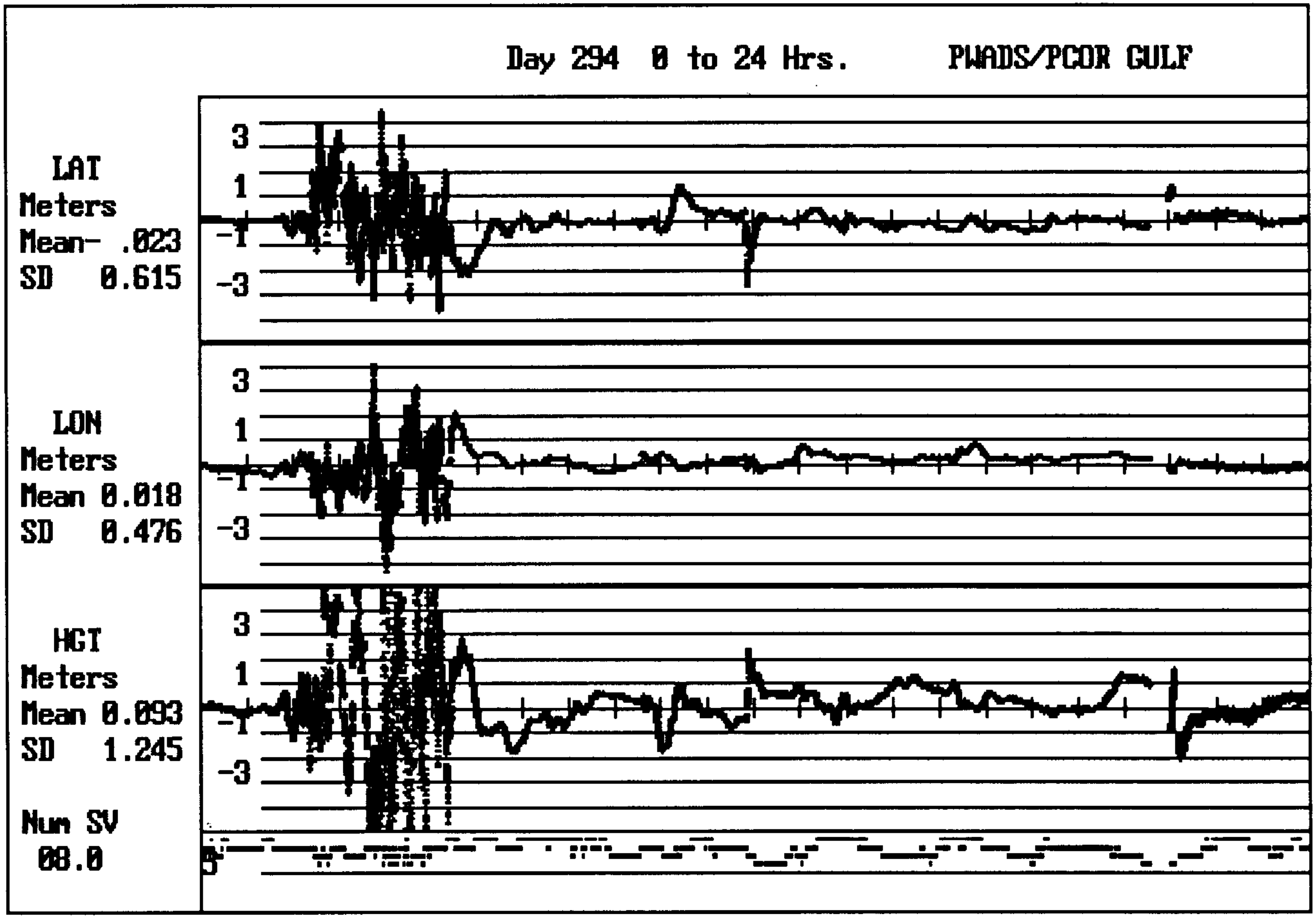
UV Image of Aurora

October 22, 1999

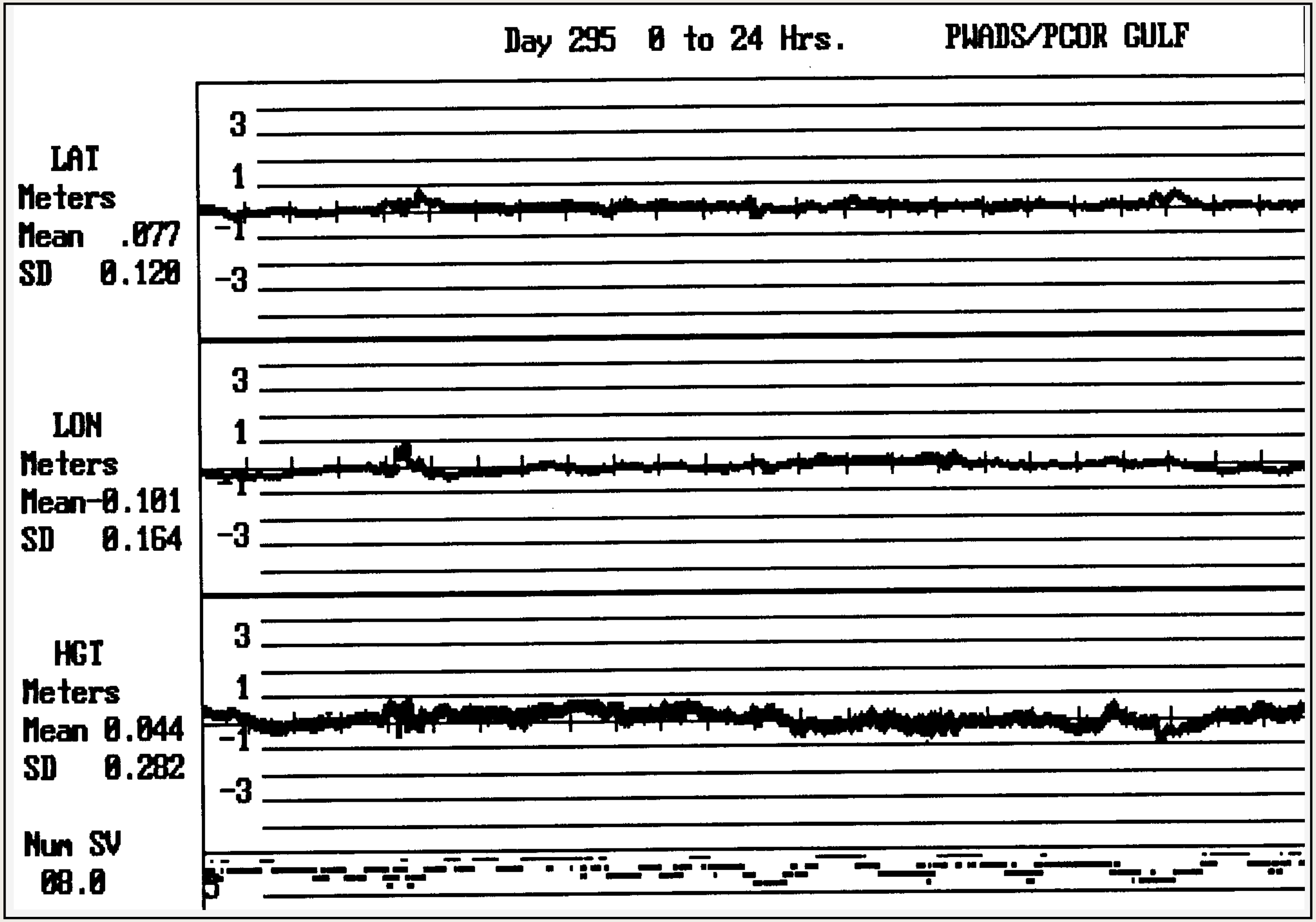


Precision GPS And Communications

Single Frequency High Performance GPS

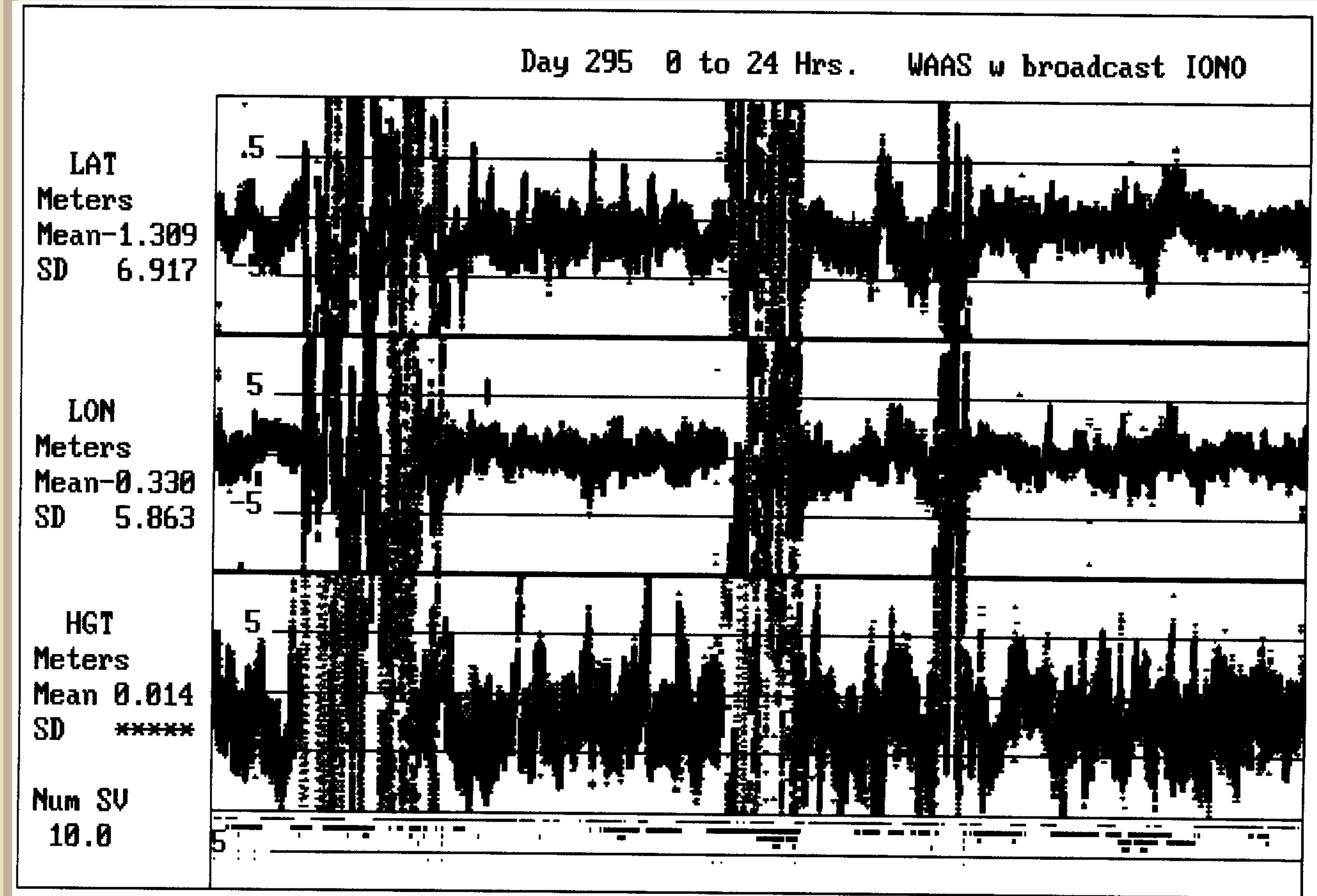


Day Following Solar Event

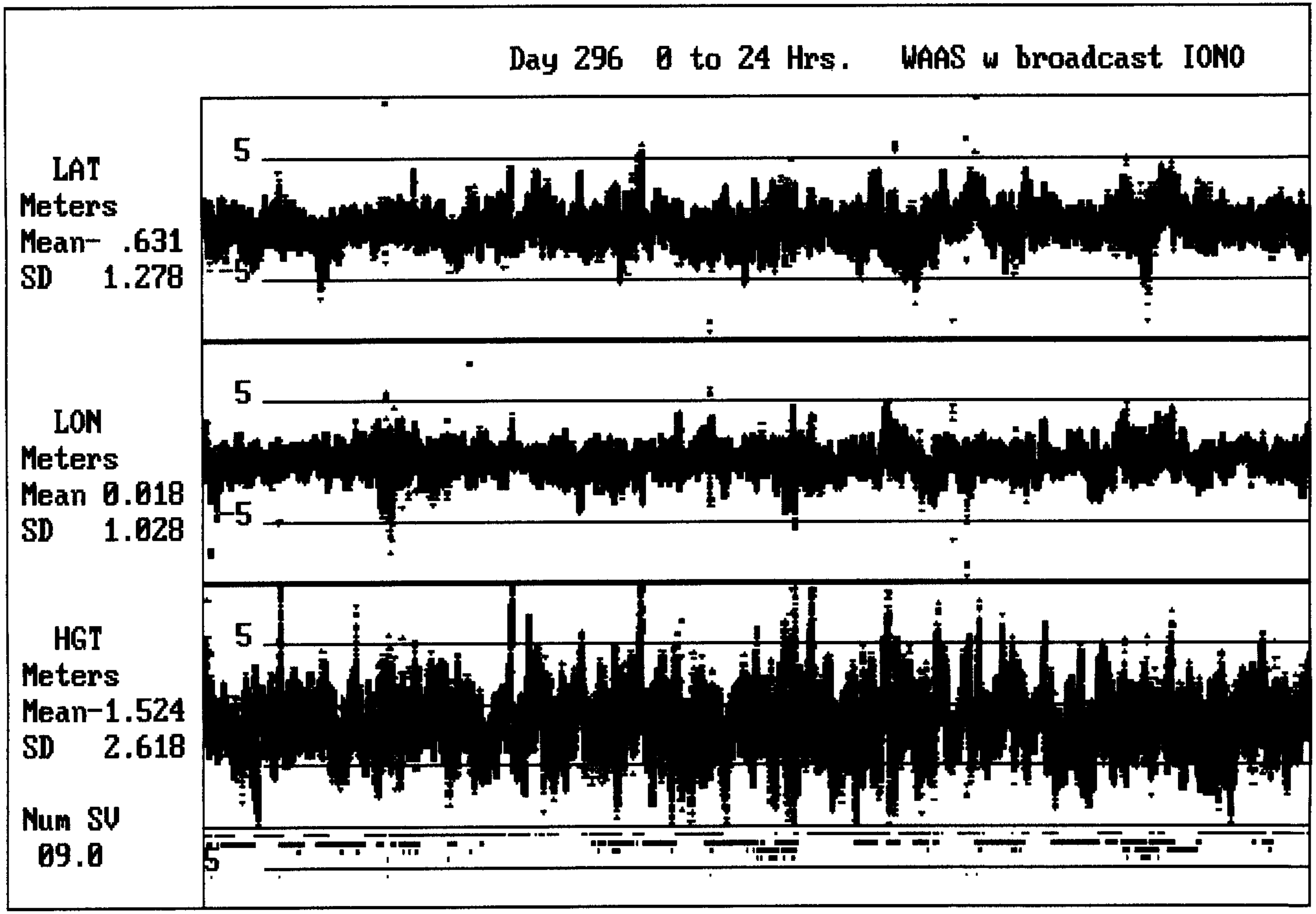


Precision GPS And Communications

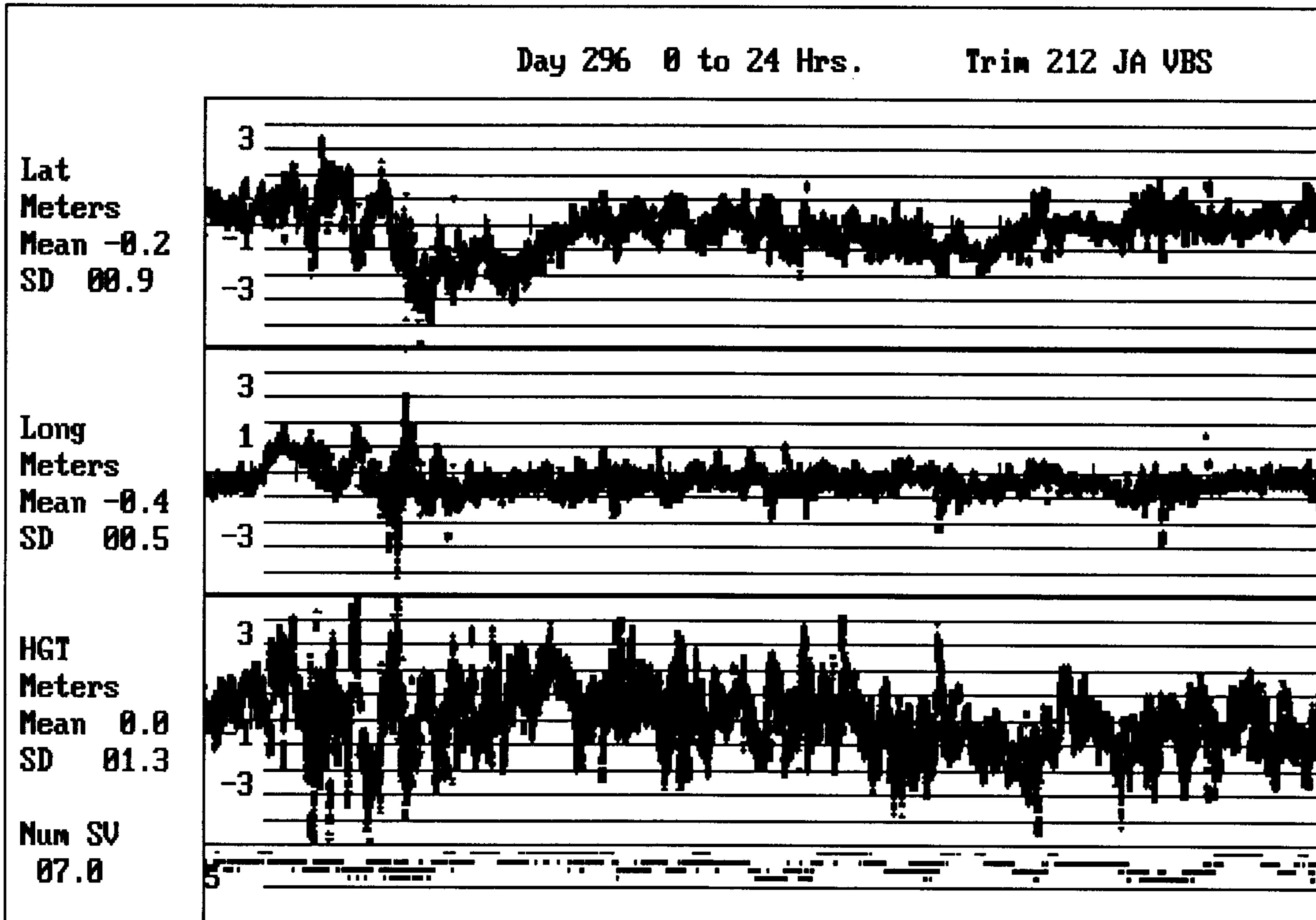
Solar Event Effect on WAAS Results



Day Following Solar Event

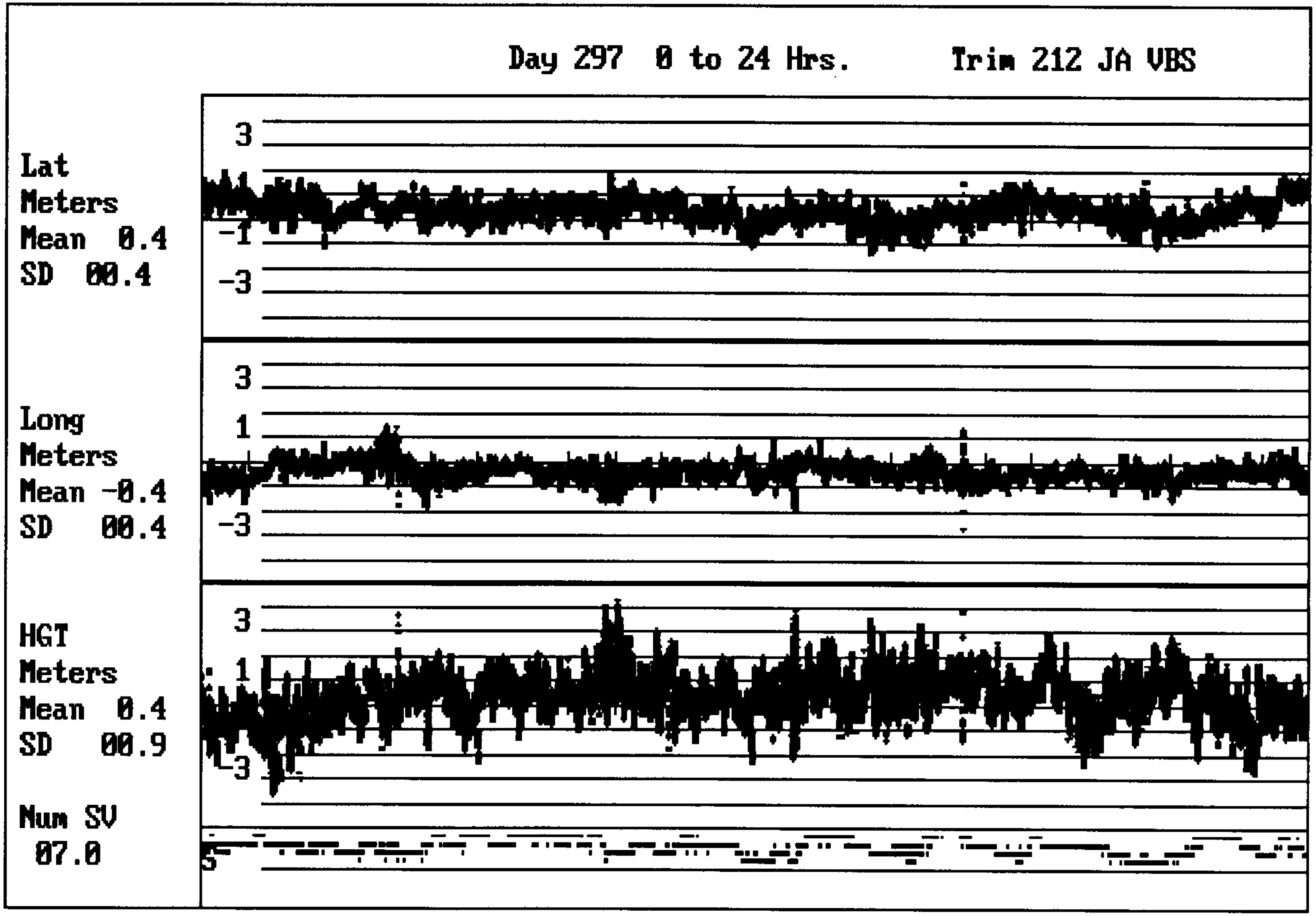


Solar Event Effect on Multi Ref DGPS



Precision GPS And Communications

Day Following Solar Event



Other Reported Problem Areas

- Offshore Alaska (Bering Sea)
- Guam
- Indian West Coast (Arabian Sea)
- Trinidad
- Southern Florida / Bahamas

Conclusions

At the height of solar cycle 23 there was considerable impact on DGPS performance due to the active Ionosphere.

Along the geomagnetic equator the performance degradation has generally followed the F10.7 flux levels.

Since the peak of the cycle the problem has decreased in most areas but there remain "hot spots".

In the mid latitude regions, DGPS performance degradation is limited to periods of geomagnetic activity at the Major Storm level
(Ap >40 and F10.7 flux >150).

When the GPS constellation is degraded the impact of an active ionosphere on GPS performance is increased due to lack of satellite redundancy.

Reporting of possible upcoming solar events (Significant CME impacts and high speed coronal streams) has allowed us to better manage our resources to reduce activities during high geomagnetic storm levels.

Additional Slides

Sample Satellite/IONO Status Report

How does the GPS Control Segment Select the Broadcast IONO Parameters

How the GPS Constellation Impacts GPS Positioning Performance

Typical GPS Error Magnitudes

Referenced Web Sites and Contact Information

Sample Satellite Space Weather Update

Satellite Status / Space Weather Update May 9, 2003

Satellite Status:

28 healthy GPS Satellites. SVN/PRN 22 remains unhealthy.

GPS Launch Status:

The third and final launch of the year is scheduled for July 24th (originally July 18).

Satellite Maintenance:

No outstanding satellite maintenance: SVN/PRN 26 was set healthy early this morning.

ONO Status:

We have been under active to minor storm conditions for the last three days due to multiple coronal streams and a possible CME impact: the solar wind peaked at over 800 km/sec early this morning. Fortunately the solar flux has been low, limiting the impact on GPS positioning in active areas. I am seeing little scintillation impact in South America or Africa over this period.

Current Solar Conditions:

Solar wind speed, 780 km/sec; Sunspot number, 33; F10.7cm; flux, 101; Kp, 5; Ap, 33 (minor storm); IMF is South.

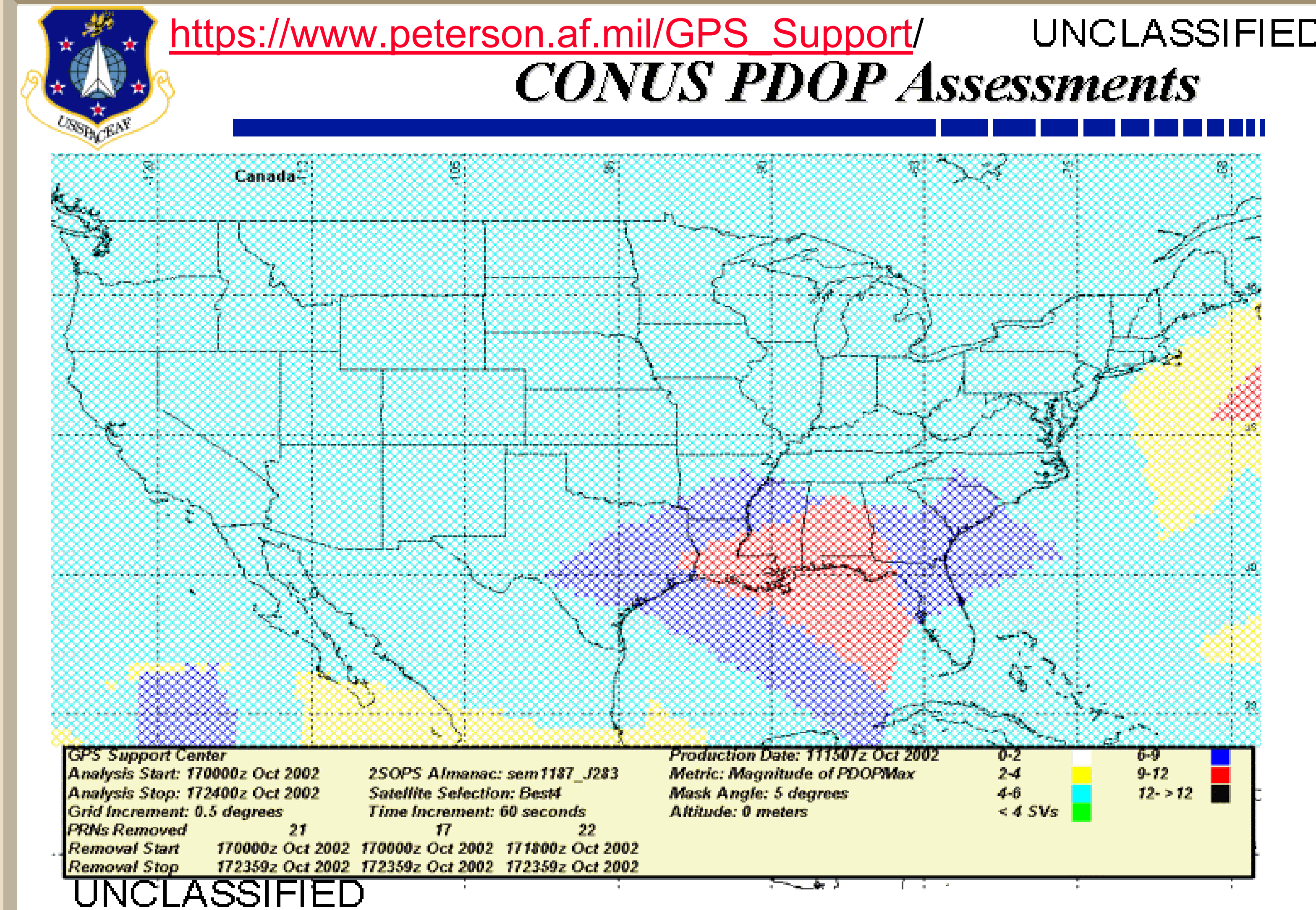
Geomagnetic Forecast:

Expect the geomagnetic field to be unsettled to minor storm through May 12th due to high speed coronal stream.

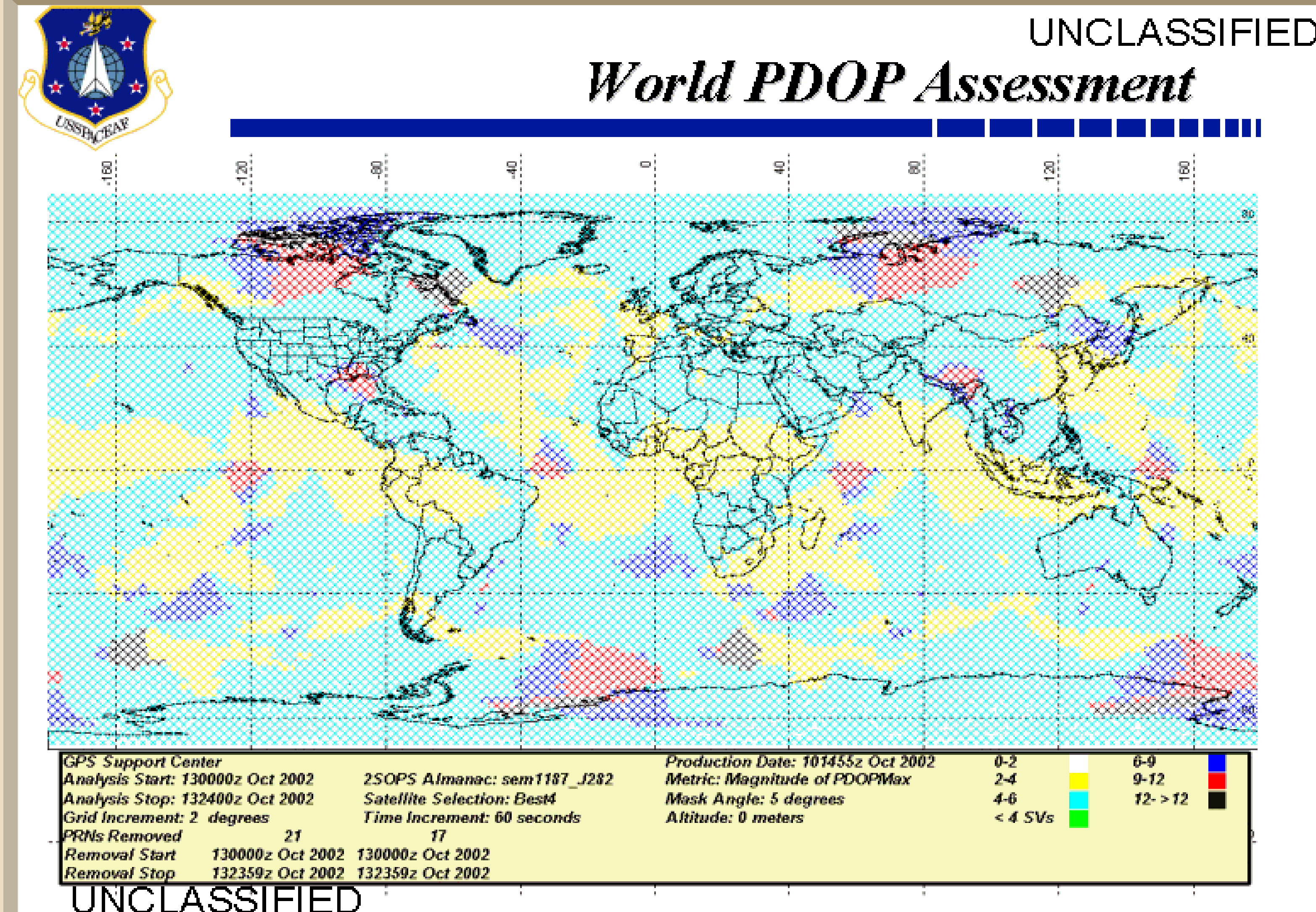
How Are the GPS IONO Parameters Selected

The GPS control segment is reported to use the running mean of the previous five-day solar radio flux at the 10.7 cm wavelength, called F10.7, to choose among ten sets of ionospheric coefficients.

The Satellite Constellation Matters
Maximum DOP - 5° Mask in October



World Constellation DOP Peaks - October



Space Weather Week

The • Meeting • of • Research • and • Operations

Typical GPS Error Magnitude

• Clock	1 m
• Ephemeris (orbit)	1 m
• Selective Availability (S/A)	10 -100 m
• Troposphere	2-20 m
• Ionosphere	5-45 m
• Pseudo Range Noise	.1-1 m
• Receiver Noise	.2-1 m
• Multipath (reflections)	.5 m

Referenced Web Sites
Contact Information

Current Kp Index http://www.sec.noaa.gov/rt_plots/kp_3d.html

Geomagnetic Equator Plot http://www.nwra-az.com/ionoscint/maps/maps.html

Solar Cycle Status http://www.sec.noaa.gov/SolarCycle/

GPS Interference http://www.uscg.mil/hq/gm/moa/docs/11-02.htm

GPS Interruptions http://www.navcen.uscg.gov/gps/gpsnotices/default.htm

DOP Plots https://www.peterson.af.mil/GPS_Support/

Planning http://www.trimble.com/planningsoftware_ts.asp?Nav=Collection-8425

GPS NANU Subscriptions http://www.navcen.uscg.gov/gps/subscribe.htm

Richard Barker
Fugro Chance Inc.
200 Dulles Drive
Lafayette, LA 70506
(337) 268-3372
rbarker@fugrochance.com
http://www.fugro.com