Description of a Real-Time Algorithm for Detecting Ionospheric Depletions for SBAS and the Statistics of Depletions in South America During the Peak of the Current Solar Cycle

The Atmosphere and its Effect on GNSS Systems

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Overview

- Background
- Purpose
- Scope
- Description of the proposed algorithm
- Results with two movies
- Summary

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Background

1 of 2

- **Equatorial regions (mag. Equator ±20°) exhibit large Total Electron Content (TEC) values and gradients normally occurring during the afternoon and evening, as well as large TEC depletions in the post-sunset periods**
- **These depletions can be large in absolute value of TEC, while small in geographic east-west extent, and are frequently associated with the onset of plumes of irregularities that produce scintillation effects**
- **The scintillation effects associated with depletions can cause Satellite-Based Augmentation System (SBAS) ground and airborne receivers to lose lock on the GPS signal**

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Background

2 of 2

- **Depletions represent a potentially difficult problem for SBAS systems since they can develop in narrow regions, and therefore may not always be detectable by the ground system if the separation between the reference stations is large, especially in the east-west direction**

- **Risk mitigation techniques will therefore need to be implemented in order to insure the integrity of the SBAS broadcast information**
  - **This may affect the availability and continuity of service for such systems.**

Purpose

- Describe an empirical real-time algorithm for detecting depletions
- Calculate statistics of depletion width and depth

Scope

1 of 2

- **The algorithm, which is still preliminary, could be used in an SBAS airborne receiver and also SBAS ground system**
- **It identifies those lines of sight between SBAS receivers and GPS satellites that are affected by depletions**
- **For the SBAS Ground System**
  - **The location, duration, and depth of depletions can be determined in real-time**
  - **The SBAS ground system could conceptually use this information to raise the error bounds at the appropriate ionospheric grid points (IGPs) in order to protect user aircraft using ionospheric pierce points (IPPs) located in grid cells affected by depletions**

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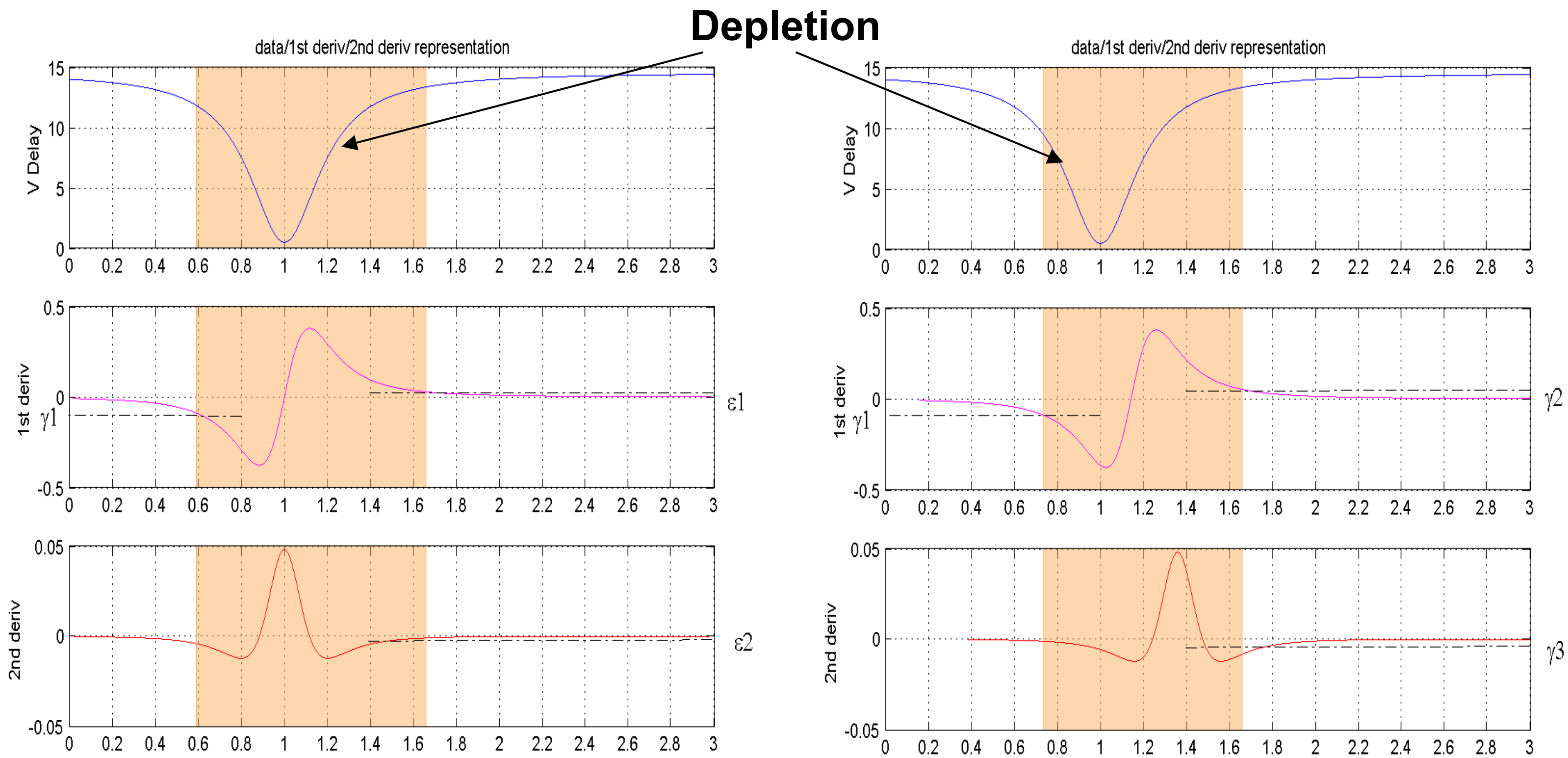
Scope
2 of 2

- **Since this algorithm is preliminary, questions on mis-detection and false alarm probabilities of detecting depletions in real-time as well as operational concerns must be addressed before an operational implementation could be considered**
  - **This is beyond the scope of this paper**

MITRE’s Algorithm Parameters (Ref. Conker et al.)

Without a sliding window | With a sliding window



$$\text{if } f'(t) \le \gamma_1 = -0.28\text{m/min, start depletion,}$$

$$\text{if currently in a depletion and}$$

$$\begin{cases} 0 \le f'(t) < \gamma_2 = 0.2\text{m/min and } f''(t) < \gamma_3 = -0.008 m/\min^2, or \\ \sqrt{\frac{\sum_{w_1} (f'(t))^2}{w_1}} < \varepsilon_1 = 0.1 m/\min \text{ and } \sqrt{\frac{\sum_{w_2} (f''(t))^2}{w_2}} < \varepsilon_2 = 0.008 m/\min^2, or \\ f'(t), f'(t-1), \ldots f'(t-n) \text{ cannot be calculated} \end{cases}$$

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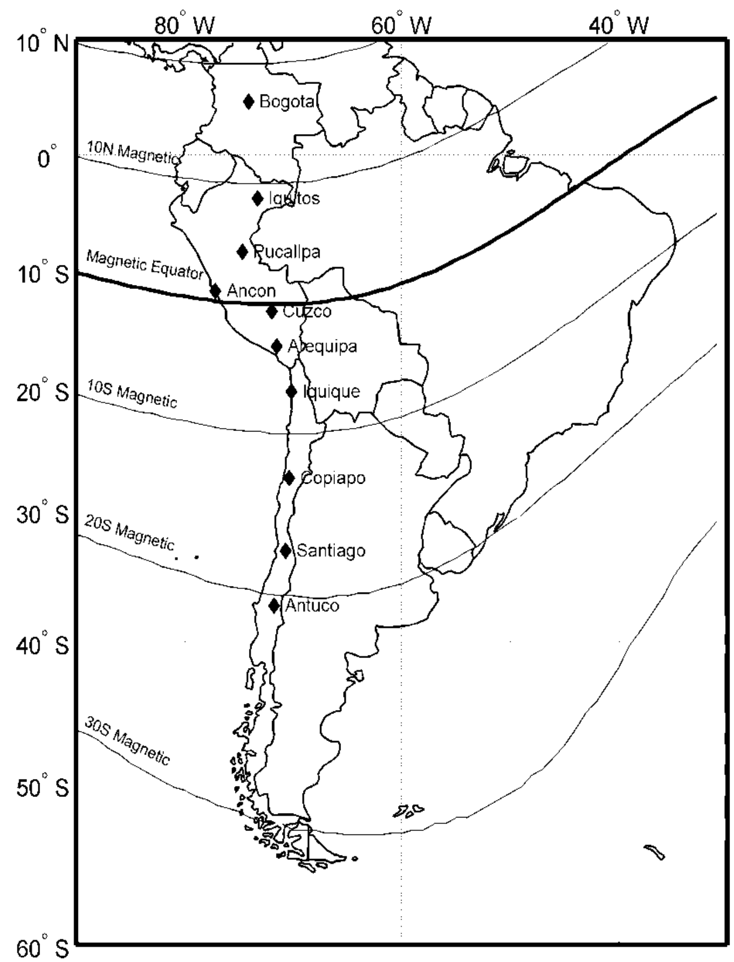
Vertical TEC Data Used in the Analysis and Locations of Sites

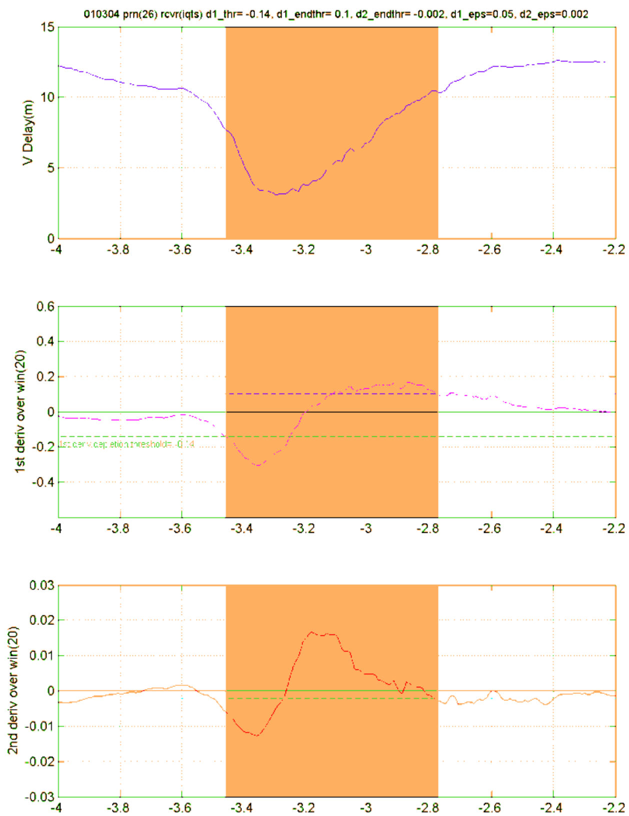
(Provided by Boston College)

- **Two years of TEC data from 10 sites in the western part of South America is provided by Boston College**
- **January 1, 2001 to December 31, 2002**
- **Time interval = 30 seconds**

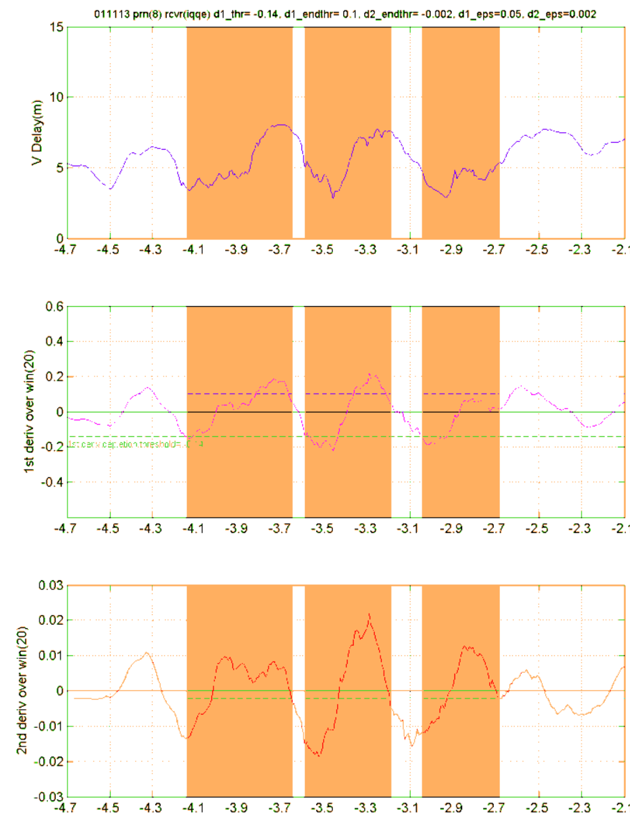


Summary of Results

Examples of Detecting A Single Depletion and Three Depletions

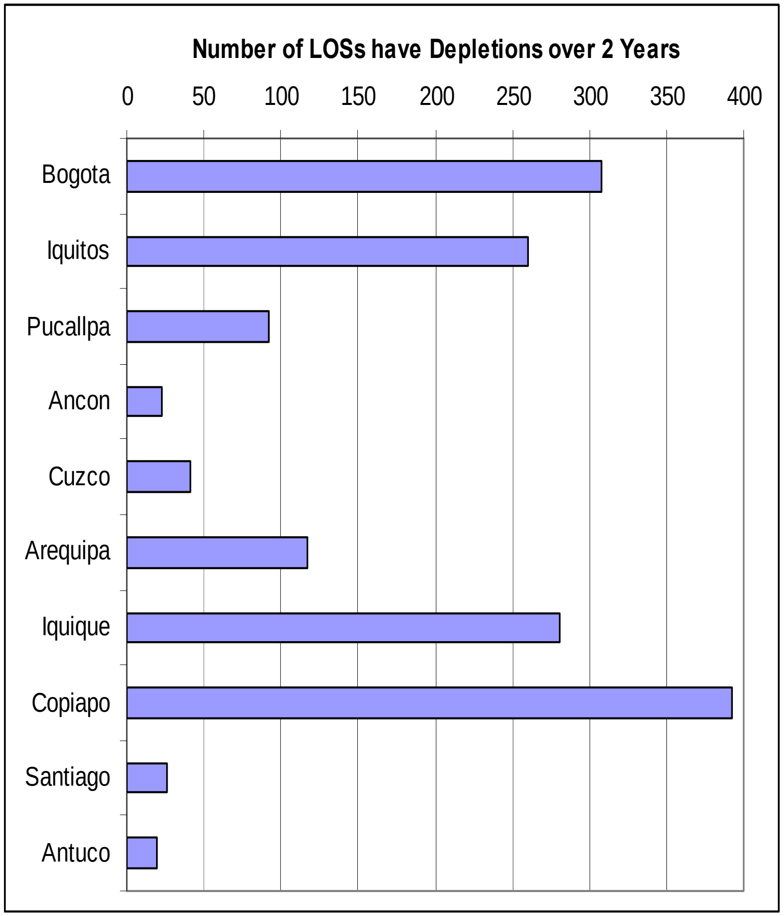


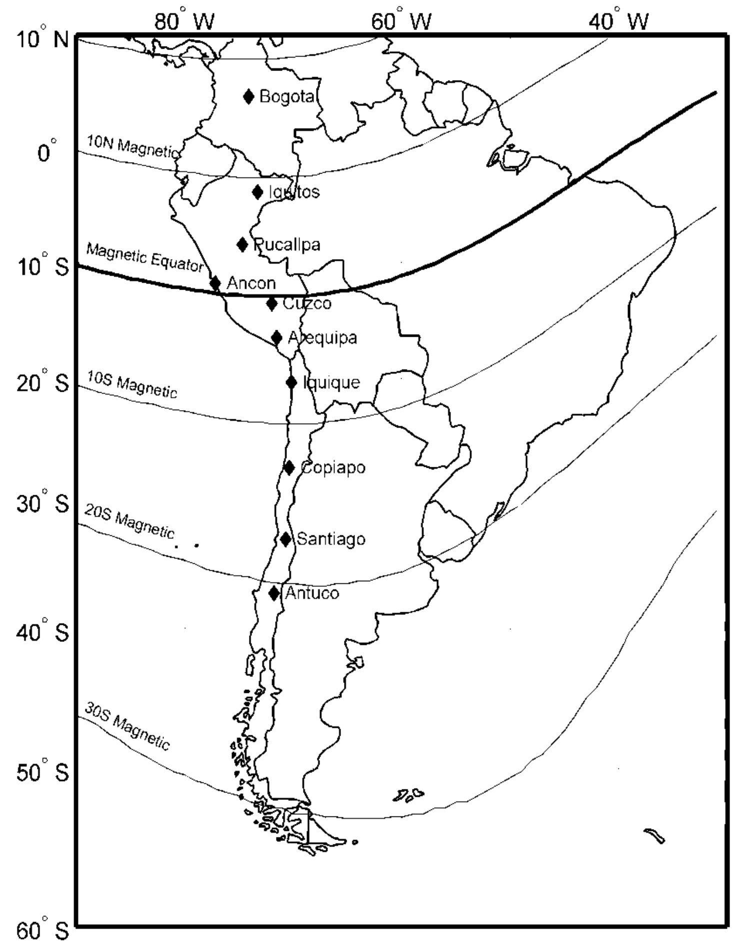
PRN 26 at Iquitos, Peru, March 4, 2001



PRN 8 at Iquique, Chile, November 13, 2001

Number of Line of Sights per Station Which Have Depletions Over Two Years





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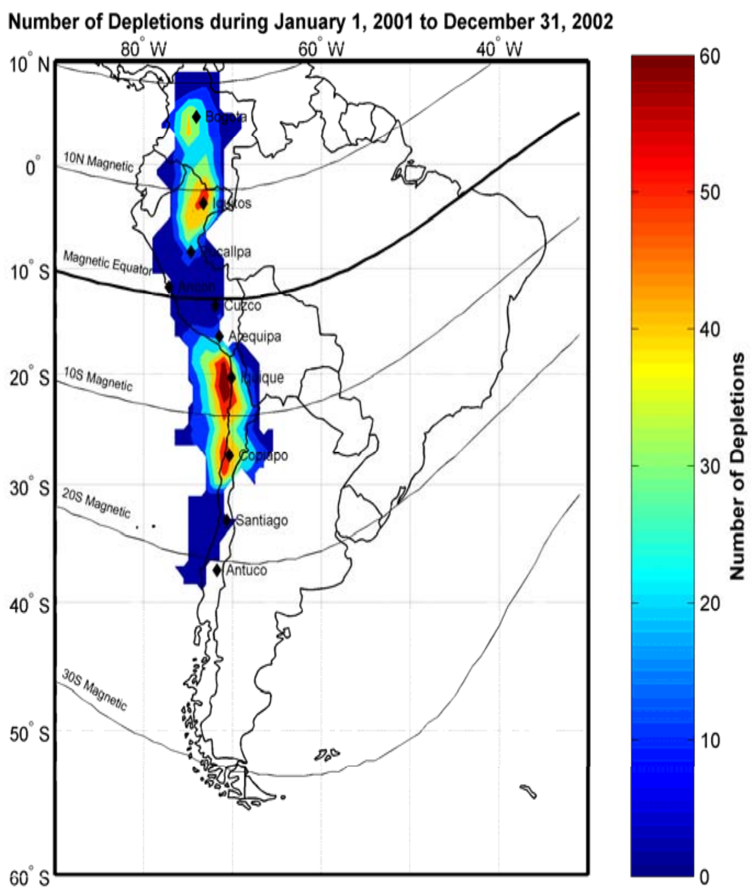
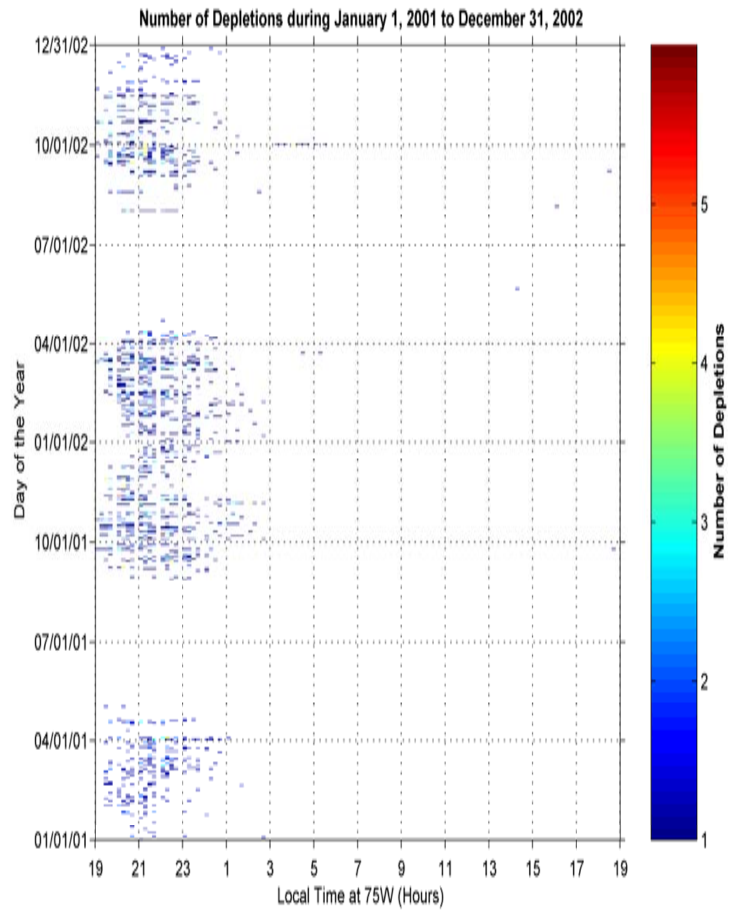
Location and Frequency of Depletions for Two Years of Data





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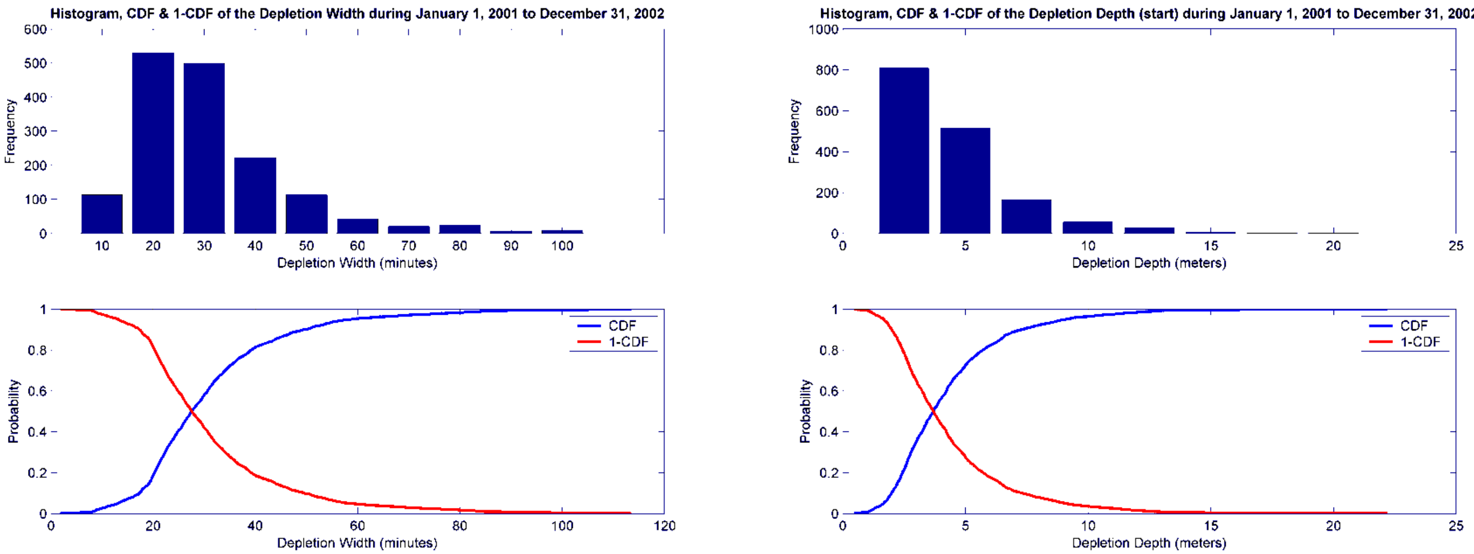
Statistics of Depletion Width and Depth Over Two Years of Data



	Depletion Width (Minutes)	Depletion Depth (meters)	Depletion Depth (TECU)
Mean	31.14	4.29	26.38
Standard Deviation	14.96	2.44	15.02
50th Percentile	27.55	3.7	22.73
95th Percentile	58.48	9.11	56.03
99th Percentile	84.6	12.69	78.05
99.9th Percentile	107.57	18.62	114.52

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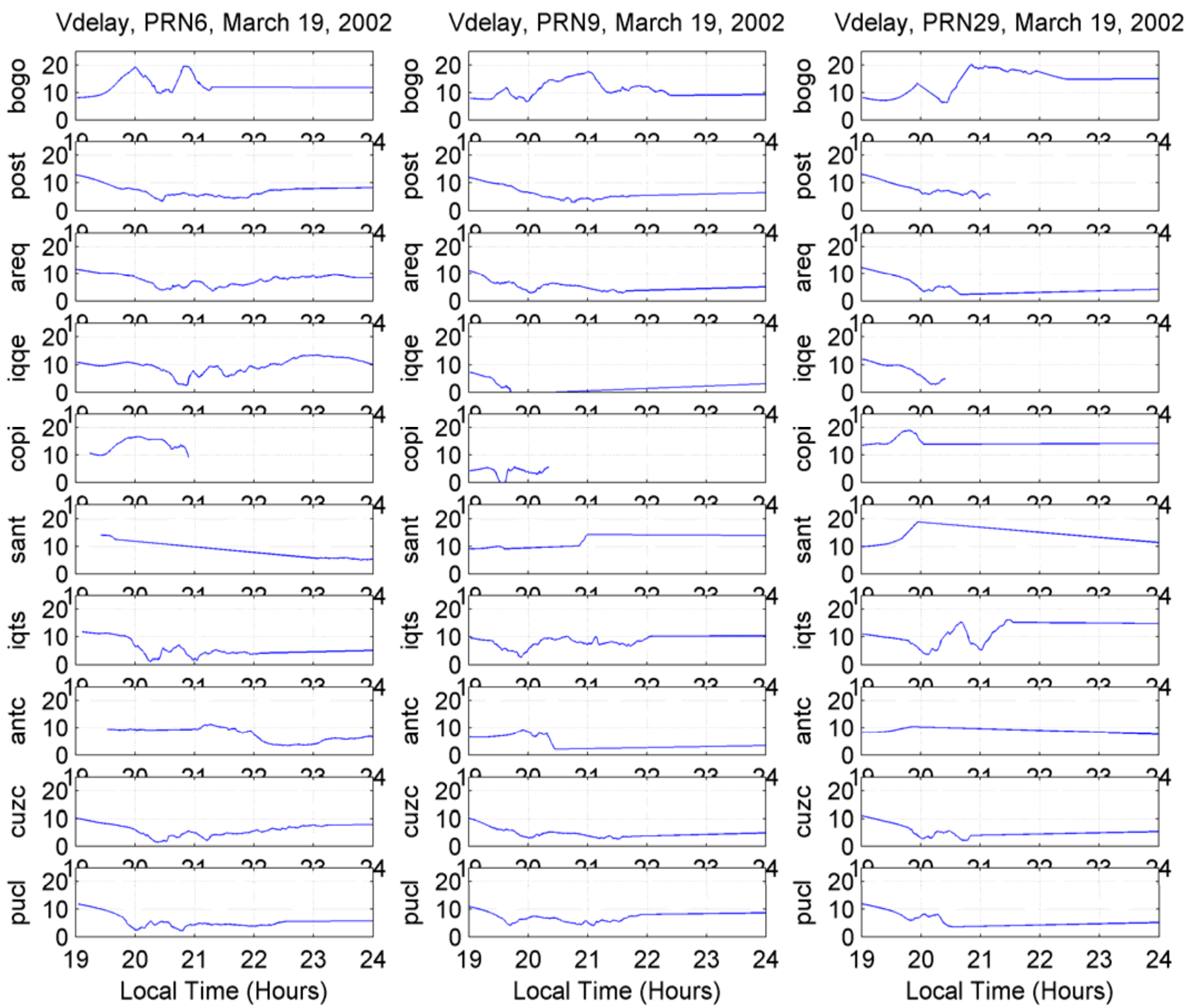
Vertical Ionospheric Delay (meters)

PRN 6, 9, 29 on March 19, 2002



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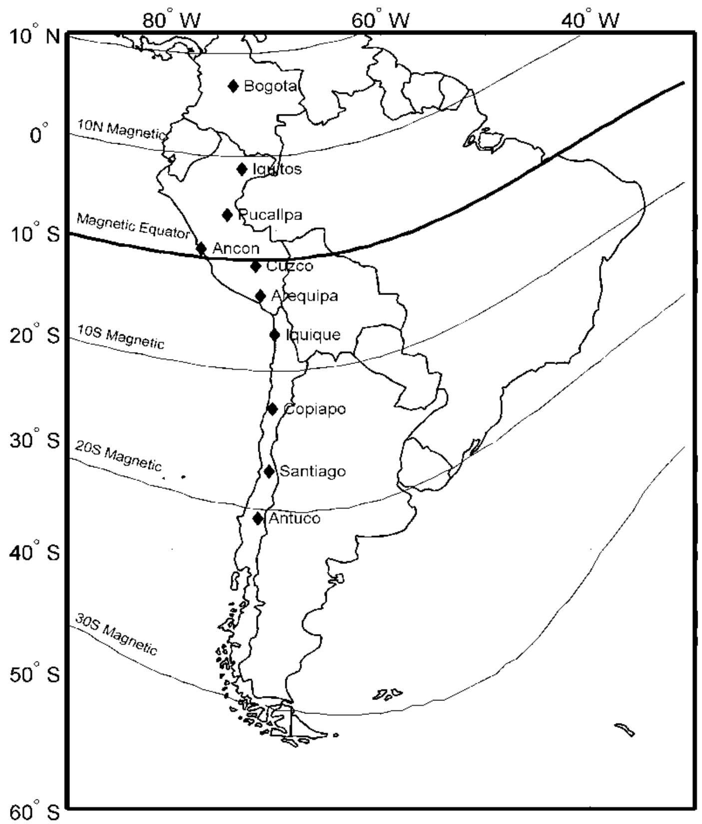
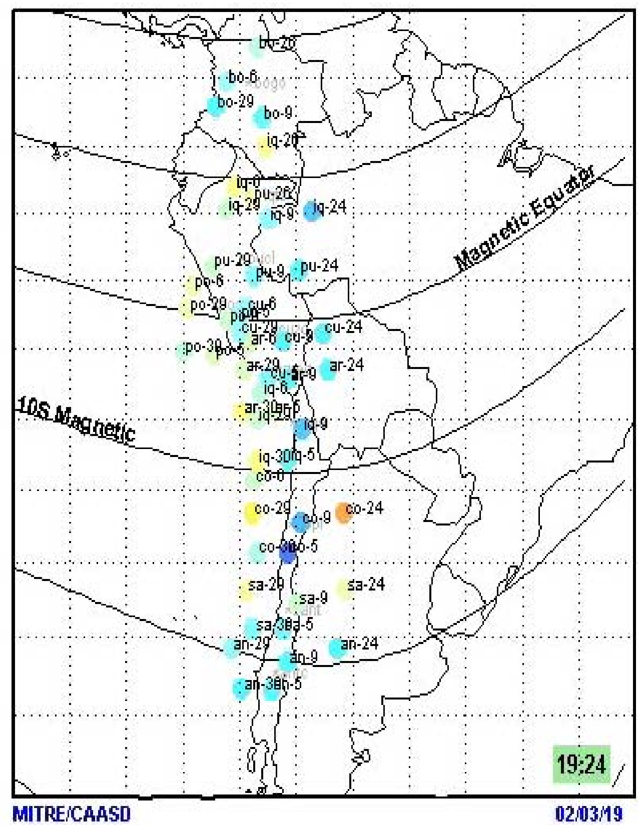
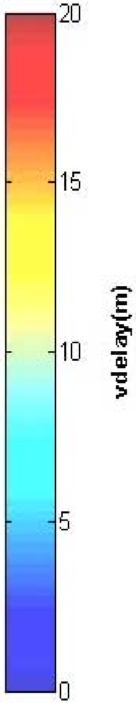
Example 1

Using Data from 10 Sites in the Western Side of South America, March 19, 2002

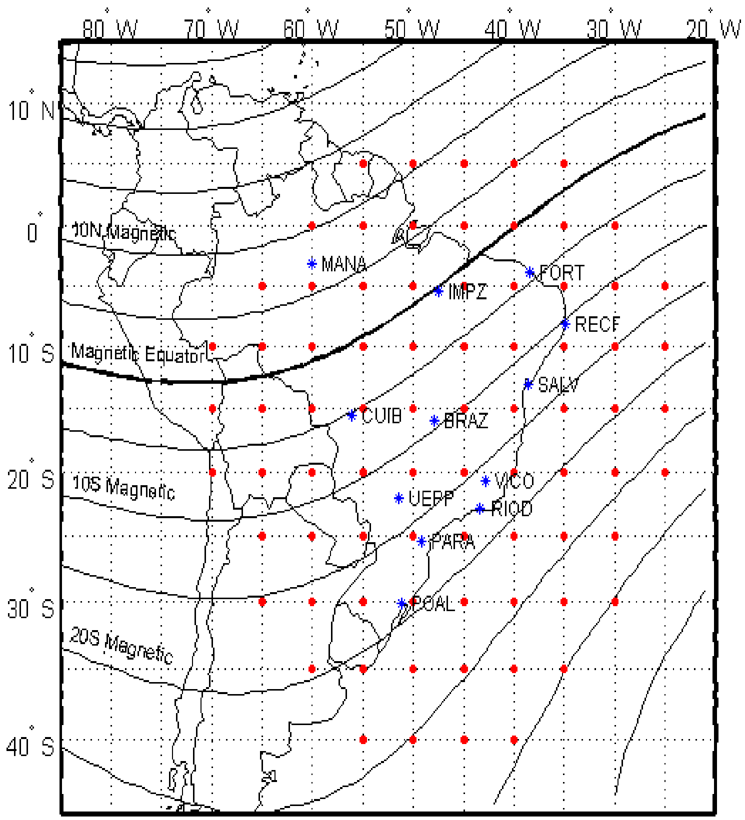


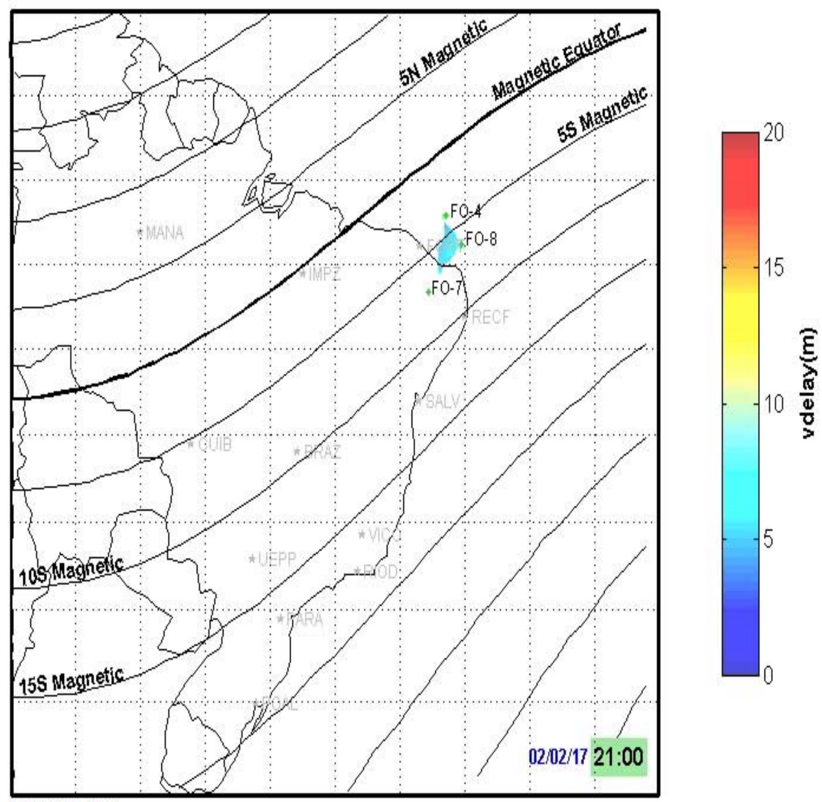




Example 2

Using Data from 12 Sites in Brazil on February 17, 2002 (Data Provided by INPE, Brazil and Processed by JPL)





Summary of Results

- **Using this algorithm, the location, duration, and depth statistics of depletions in the western side of South America were calculated over a 2-year period (2000-2002) during the peak of the current solar cycle**
- **Recorded data from 10 sites approximately located on the same longitude was used for the analysis**
- **Preliminary results show that most depletions occur in small areas around 10 degrees North and also between 5 and 15 degrees South magnetic latitudes, which are located in the northern and southern anomalies**
- **Median values for the duration and depth of the depletions have been estimated to be 27.55 minutes and 22.73 vertical TEC Units (3.70 meters of vertical delay at L1 GPS frequency), respectively**

Future Work

- **Apply similar algorithm in a single-frequency SBAS airborne receiver using code-minus-carrier (CMC)**
- **Estimate miss detection and false alarm probabilities for the ground and airborne receivers**
- **Estimate the impact of occurrence of depletions on availability of SBAS in the Equatorial Region**
  - **Note: There is no guarantee of useable APV availability in South America using L1 (single frequency), even with this algorithm**

Acknowledgements

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- JPL, Pasadena, California for processing Brazilian data