The Abdus Salam
International Centre for Theoretical Physics

United Nations
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IAEA
International Atomic Energy Agency

2025-18

Satellite Navigation Science and Technology for Africa

23 March - 9 April, 2009

Ionospheric Challenges for Positioning Applications in Africa

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Ionospheric Challenges for Positioning Applications in Africa

S. Skone

Department of Geomatics Engineering,
Schulich School of Engineering, University of Calgary

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Outline

- DGPS & SBAS
- Equatorial anomaly and SED
- Impact on positioning – examples and case studies
- Summary

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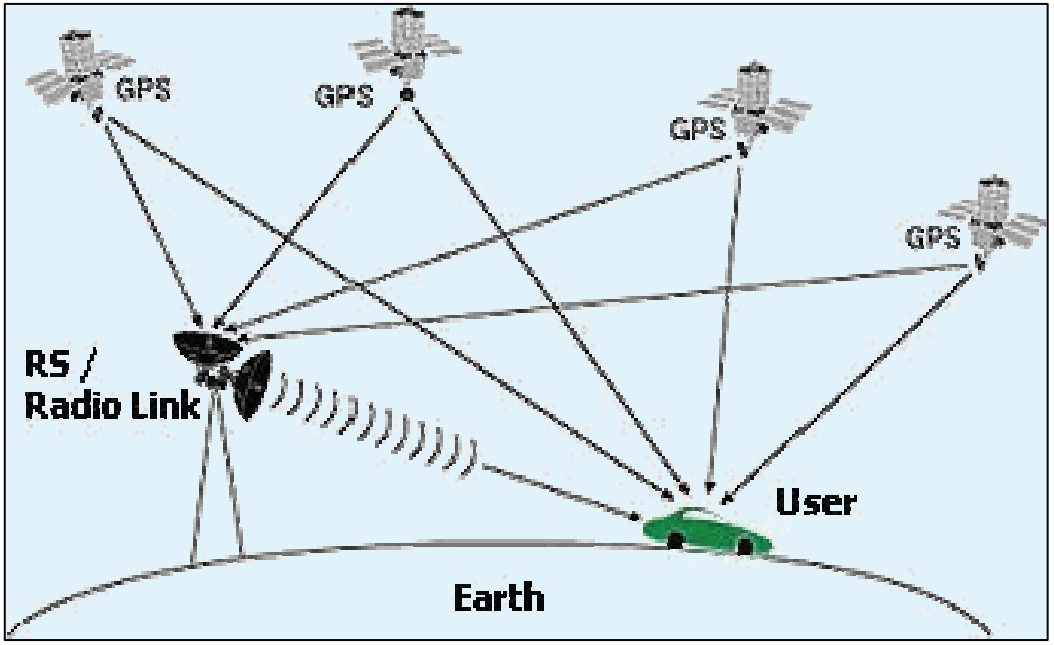
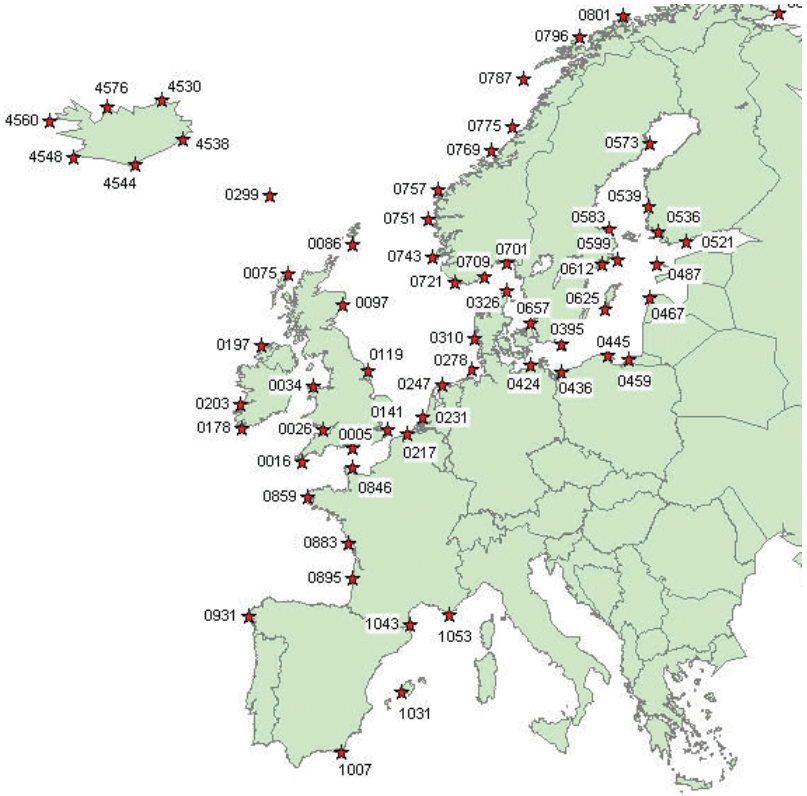
Differential GPS



- Without DGPS… your accuracy is 5-10 metres
- With DGPS…your accuracy improves to 0.5 - 2 metres
- Accuracy degrades with baseline distance

Maritime DGPS

- Many service providers worldwide
- Horizontal positioning accuracies typically 1-2 m



http://www.effective-solutions.co.uk/beacons.html

(Fugro, 2006)

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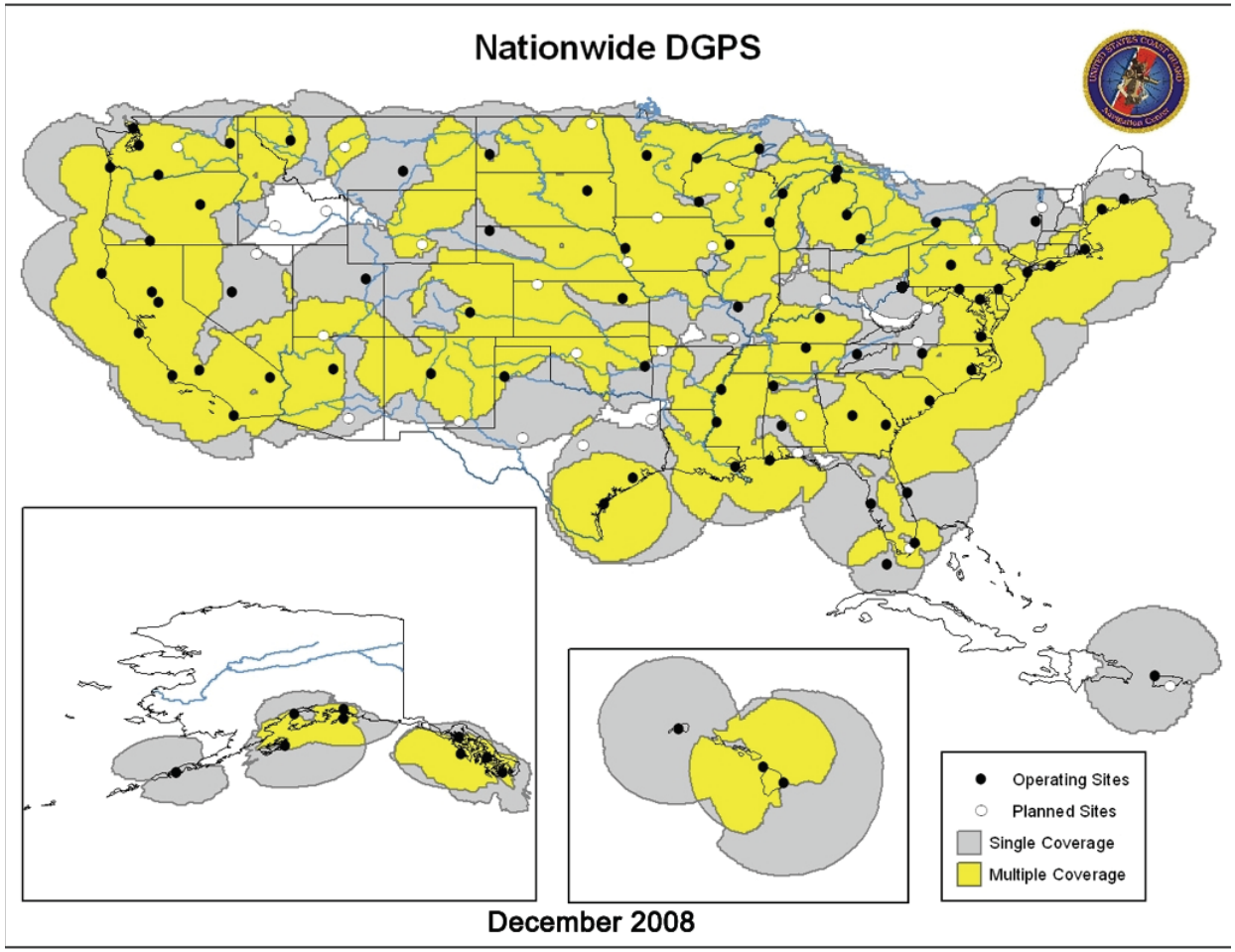
Nationwide DGPS (U.S.)



http://www.navcen.uscg.gov/dgps/coverage/CurrentCoverage.htm

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Applications

- Mapping and surveying, including hydrographic surveying
- Natural resource exploration and management
- Agriculture (seeding and harvesting)
- Environmental monitoring (GIS)
- Transportation – asset management, road construction, train control, and truck routing
- Emergency response

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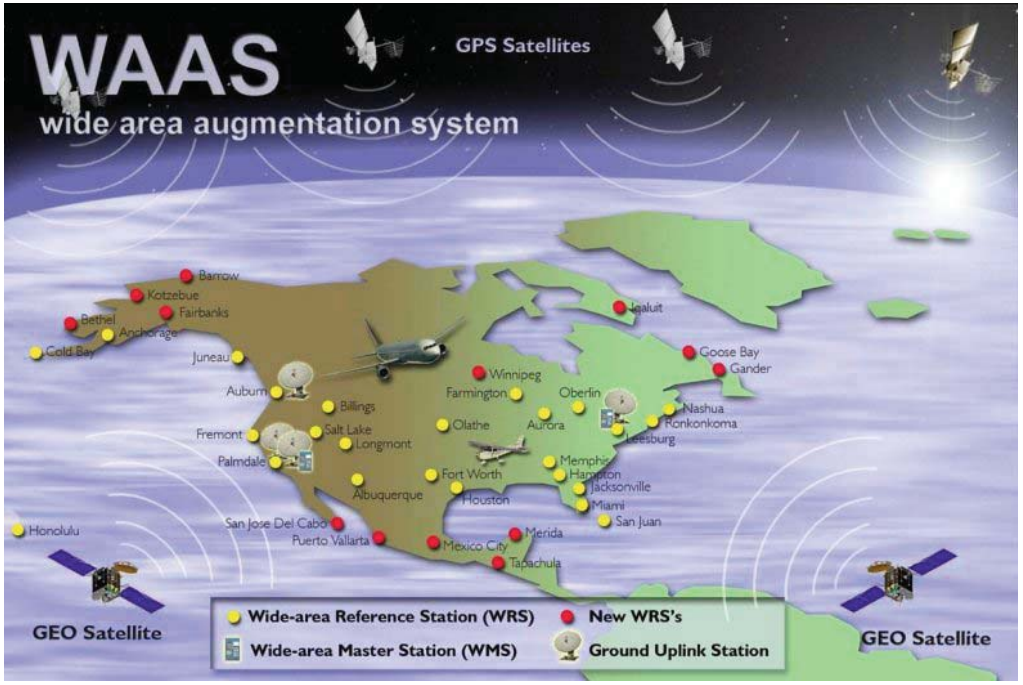
SBAS

- Satellite clock, orbit and ionosphere corrections estimated using dual-frequency reference network
- Ionosphere corrections defined on (typically) 5 deg by 5 deg grid
- Positioning accuracies typically 1-3 m
- WAAS implemented in United States for commercial aviation; EGNOS in Europe; extension to Africa (EGNOS REM)



http://www.nstb.tc.faa.gov/

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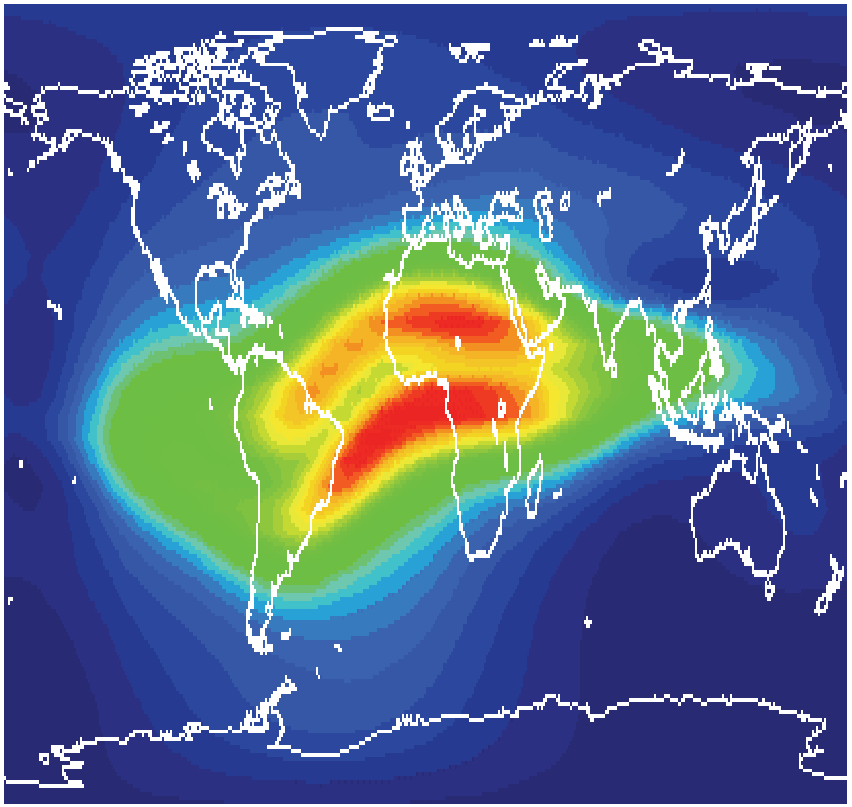
Equatorial Anomaly



- two maxima in TEC (±15° mag)
- primary peak at 1400
- secondary peak at 2100
- large gradients: 30 ppm
- scintillations
- largest peaks observed during equinoxes at solar maximum

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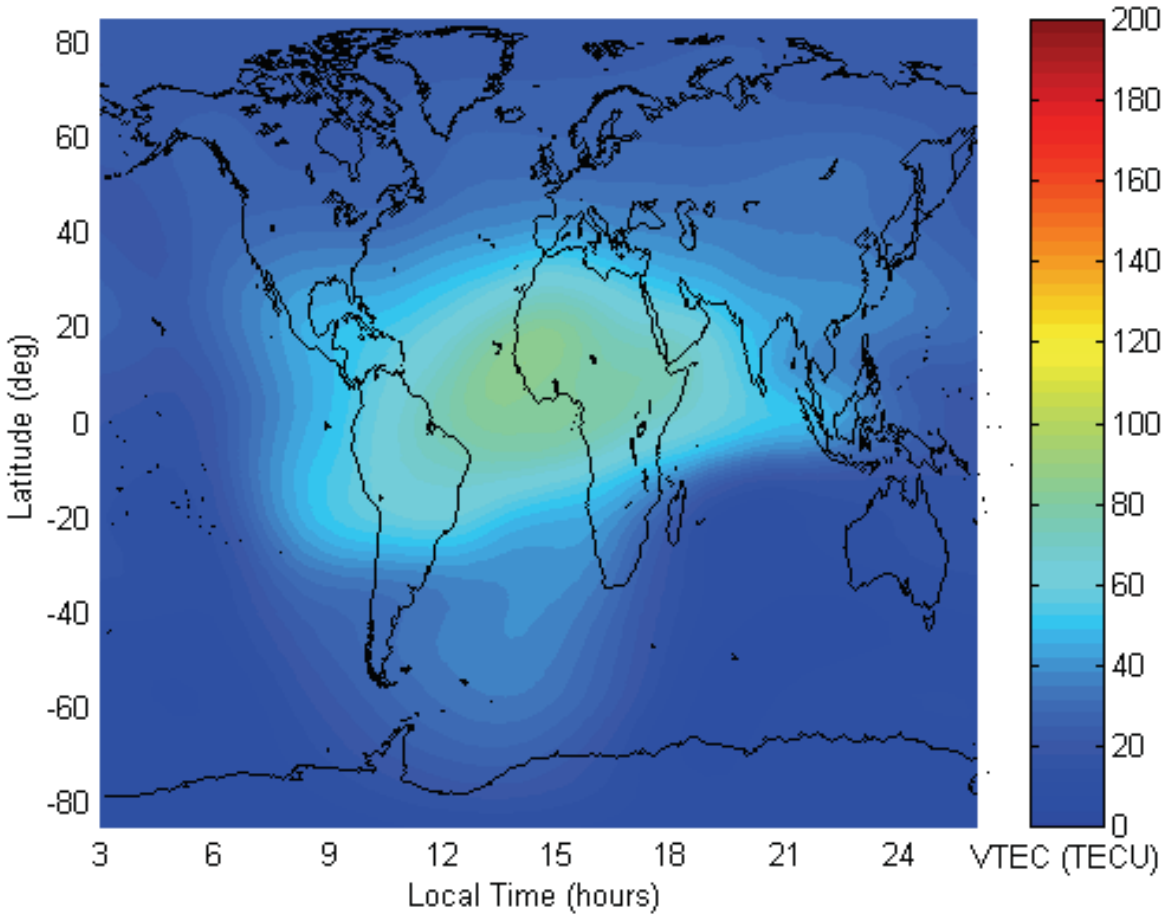
Spatial Distribution of VTEC during Solar Maximum

June 2000



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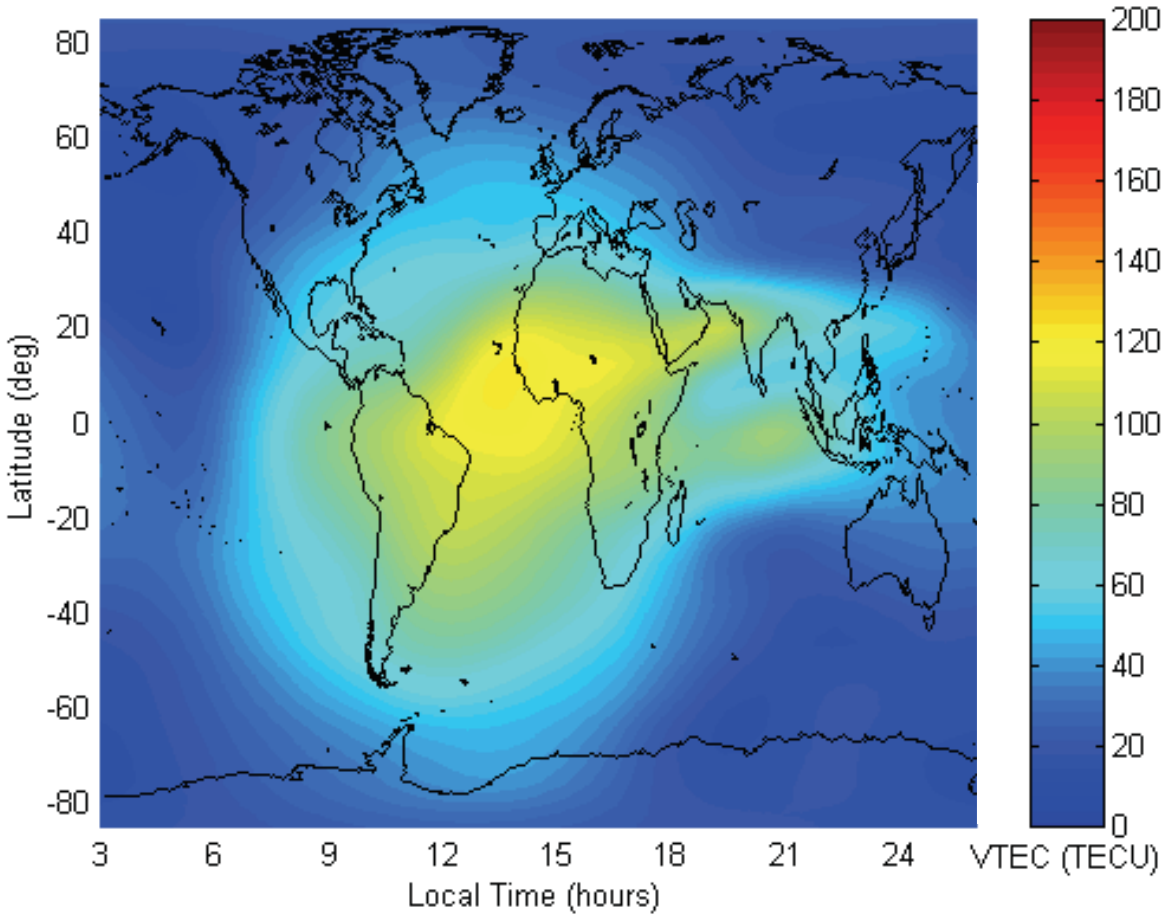
Spatial Distribution of VTEC during Solar Maximum (Equinox)

March 2000



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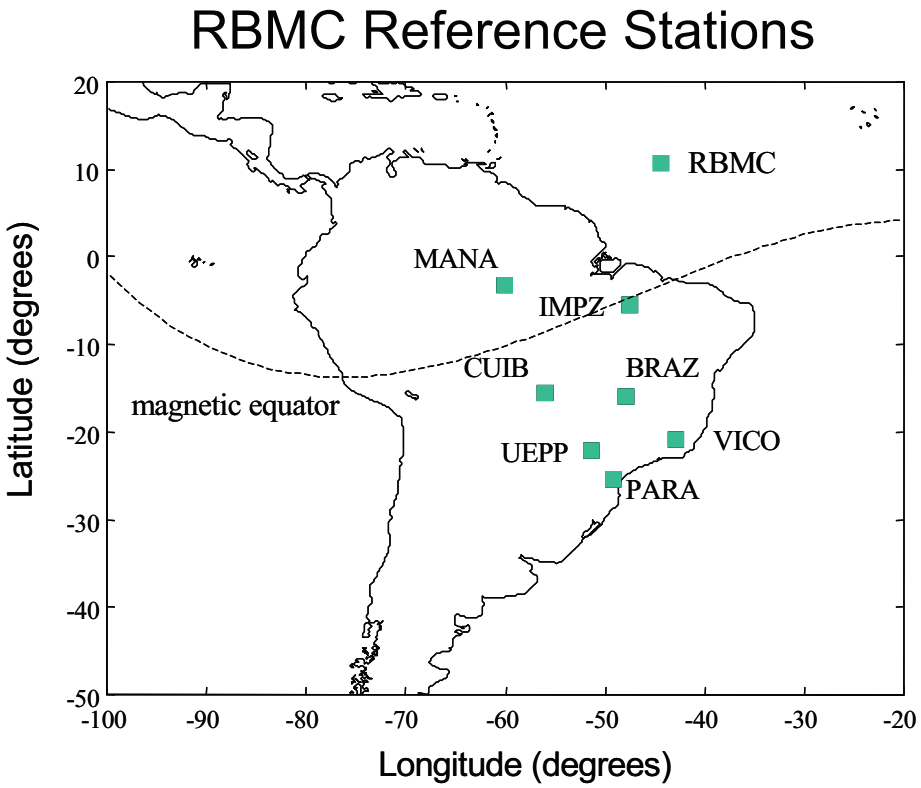
Low Latitude DGPS at Solar Maximum



- DGPS positioning accuracies computed for UEPP-PARA baseline (430 km)

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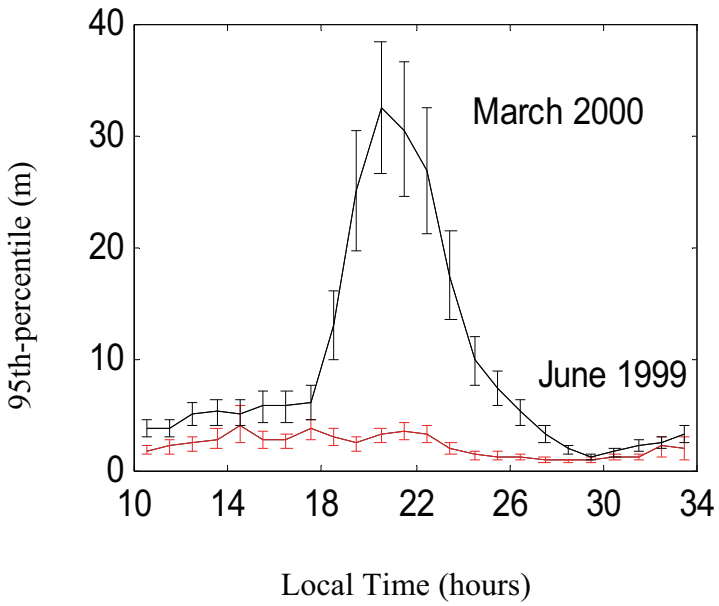
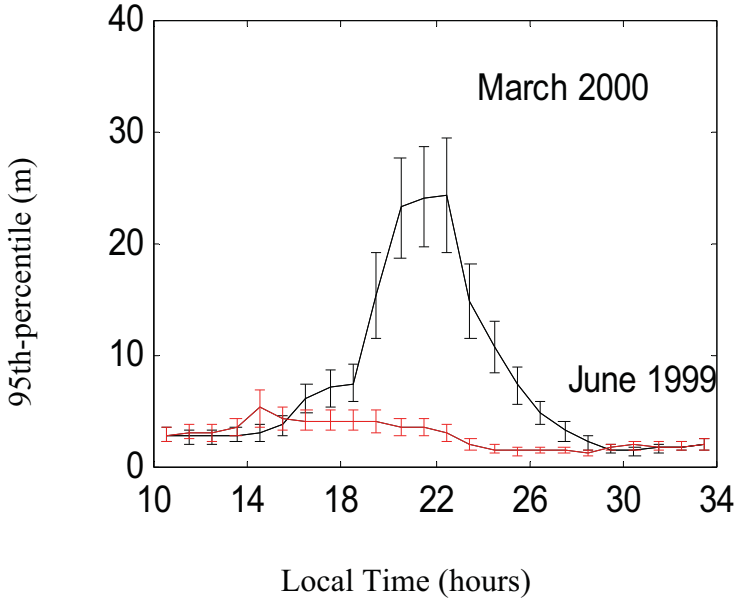
DGPS Positioning Accuracies

Vertical



Horizontal



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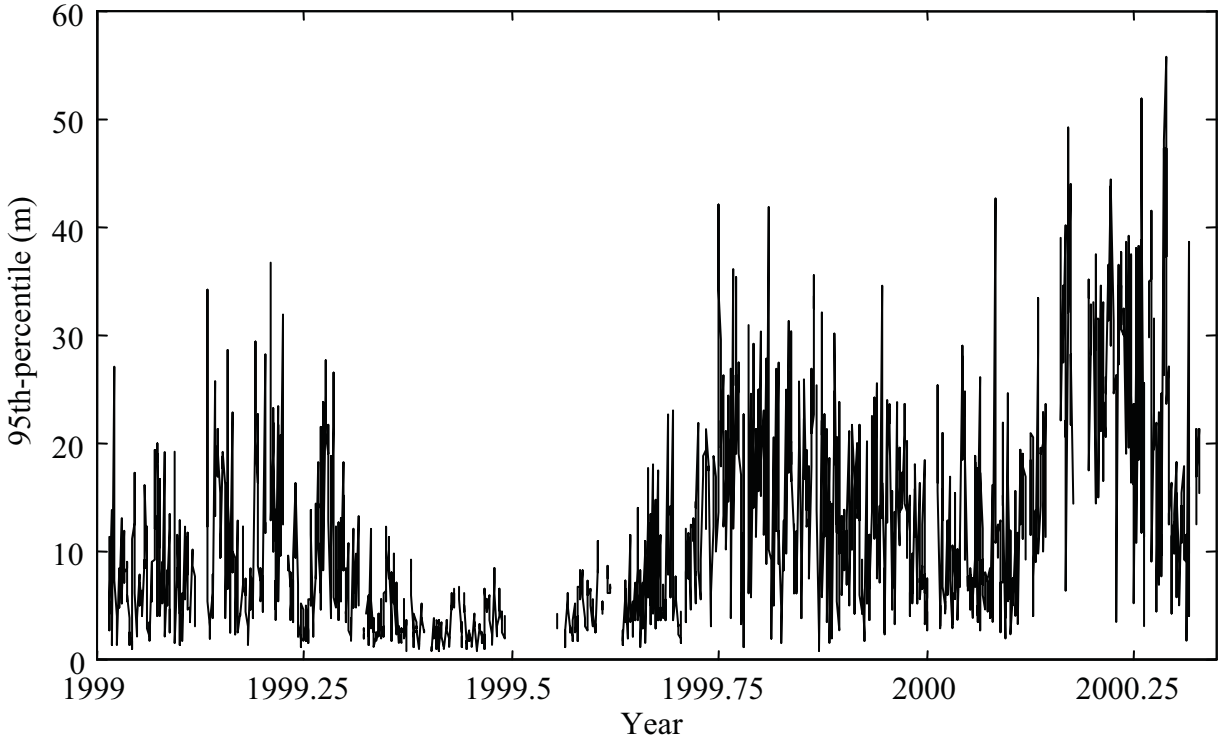
Horizontal DGPS Positioning Accuracies – Evening Sector



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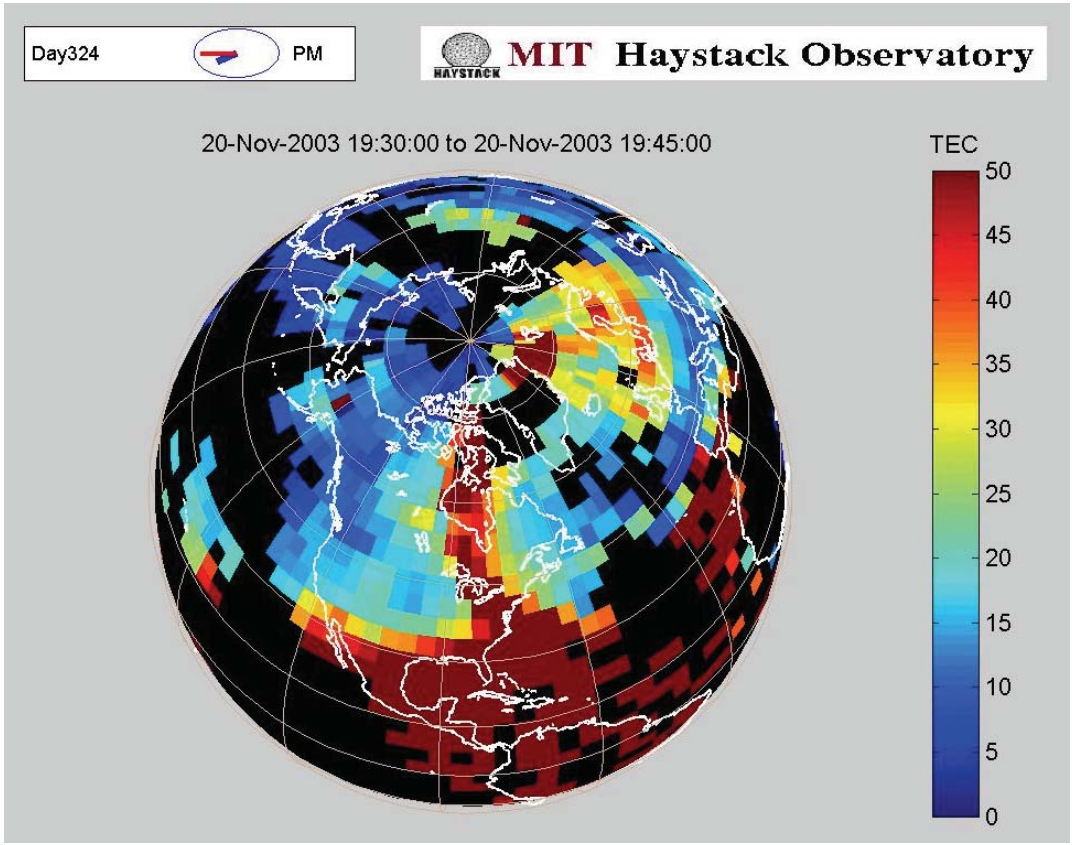
Storm-Enhanced Density

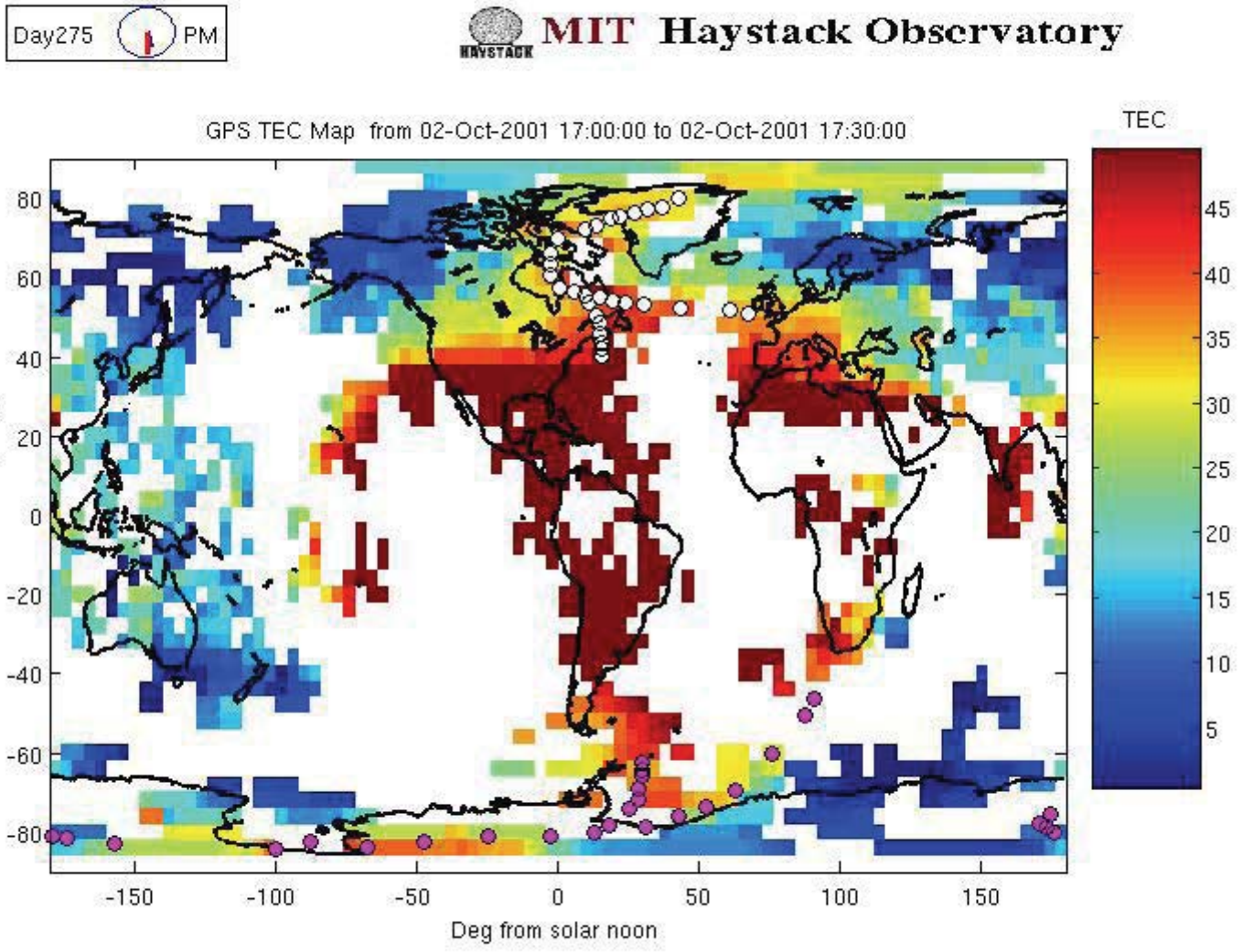


Range Error:

$$I = \pm 40.3 \frac{TEC}{f^2}$$

- Impact on GNSS applications?
- Plume extends 1000 km E-W
- Gradients of 30-50 ppm near edges of plume (E-W) and base of plume (N-S)
- Conjugate effects in northern and southern hemispheres – impact in Africa

Conjugate Effects: 1730 Oct 2, 2001



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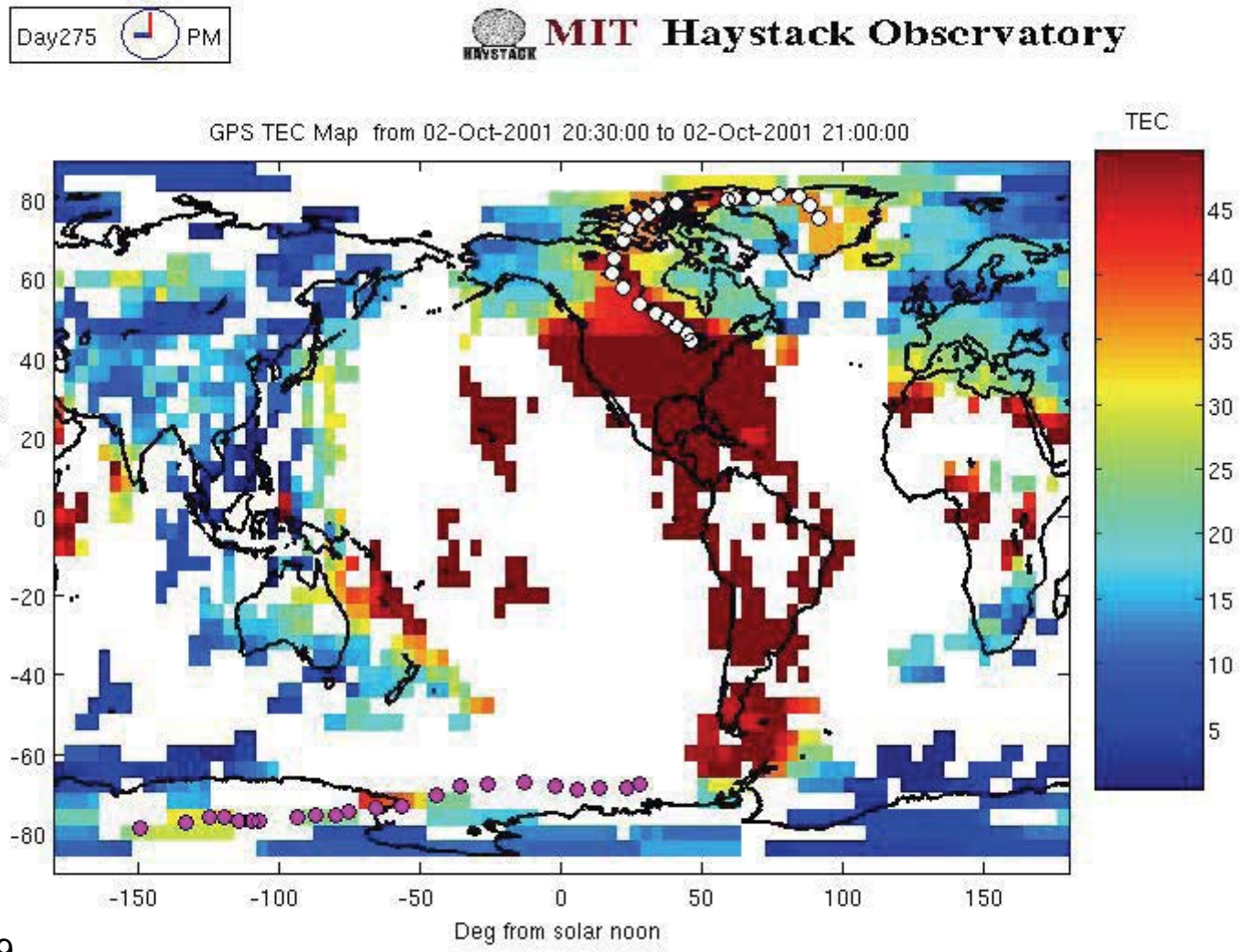
Conjugate Effects: 2100 Oct 2, 2001



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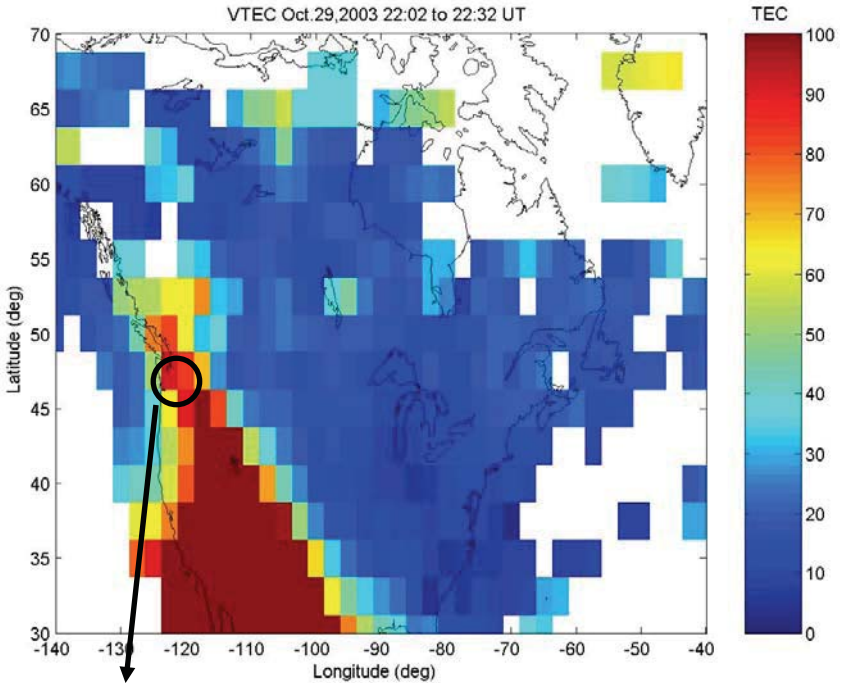
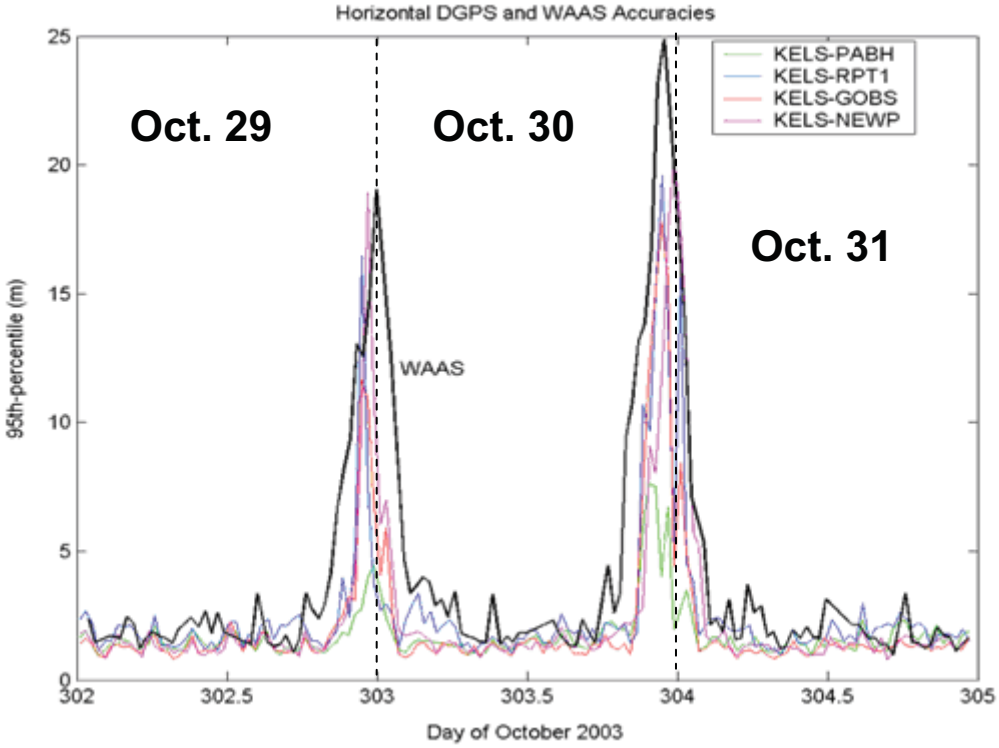
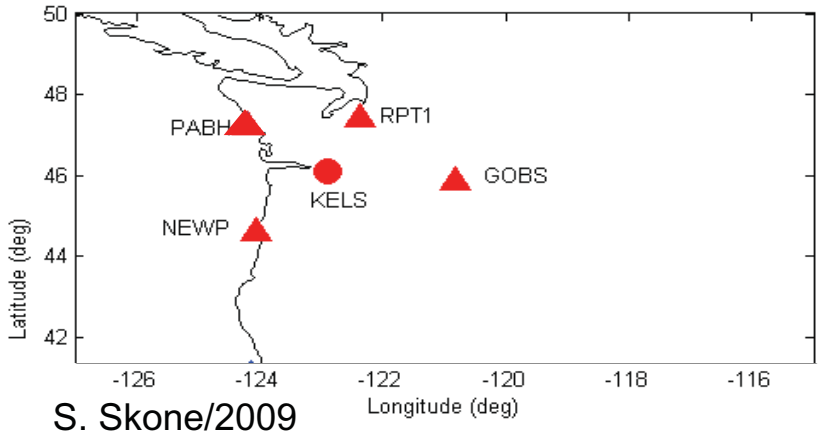
SED Event 29-31 October 2003







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STATION PAIR (USER-REFERENCE)	BASELINE LENGTH (KM)
KELS-PABH	158
KELS-RPT1	147
KELS-GOBS	164
KELS-NEWP	193

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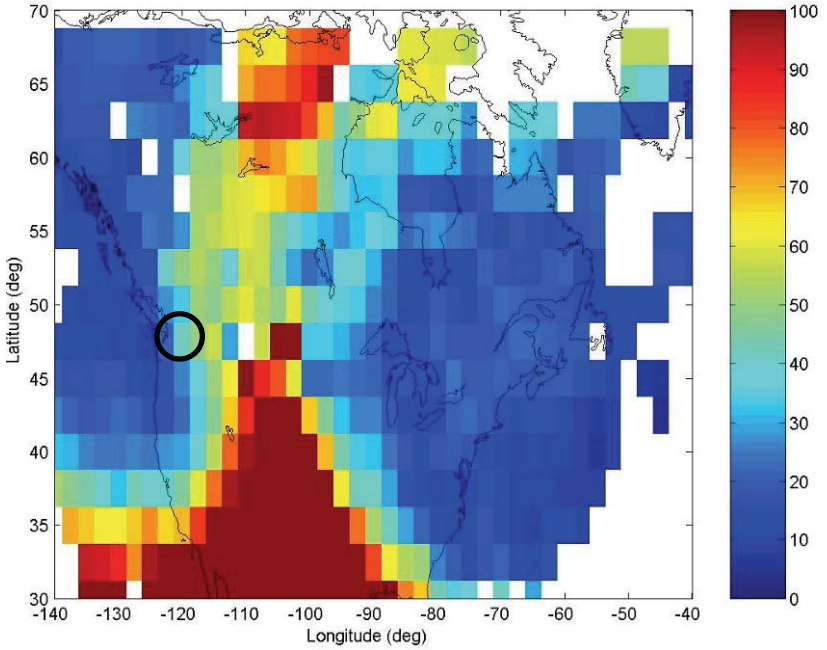
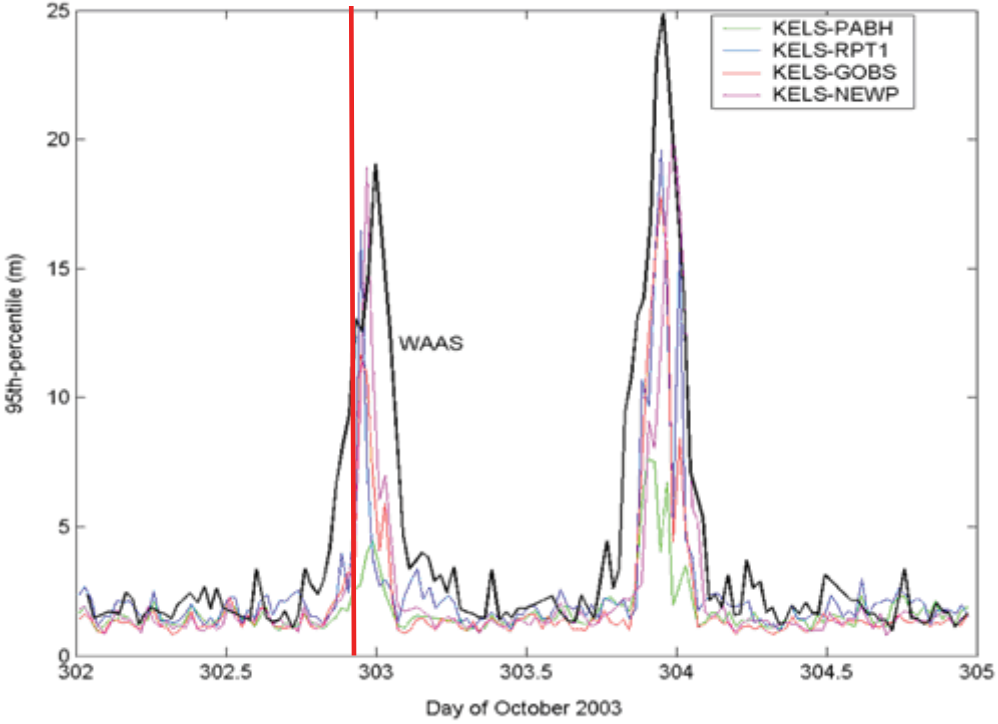
DGPS&WAAS Horizontal Positioning Errors: 29 October 2003

Ionosphere Map: 2130 UT



Horizontal Position Errors



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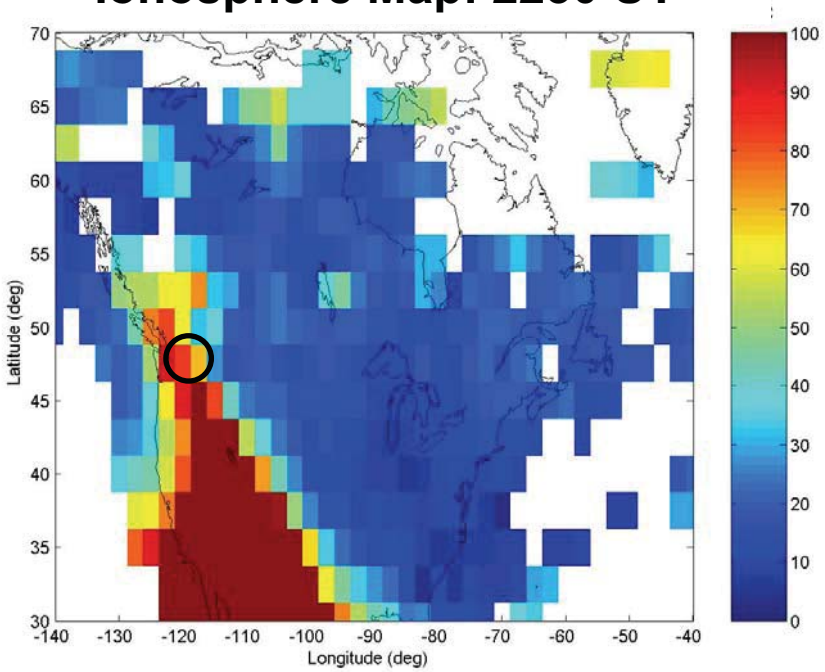
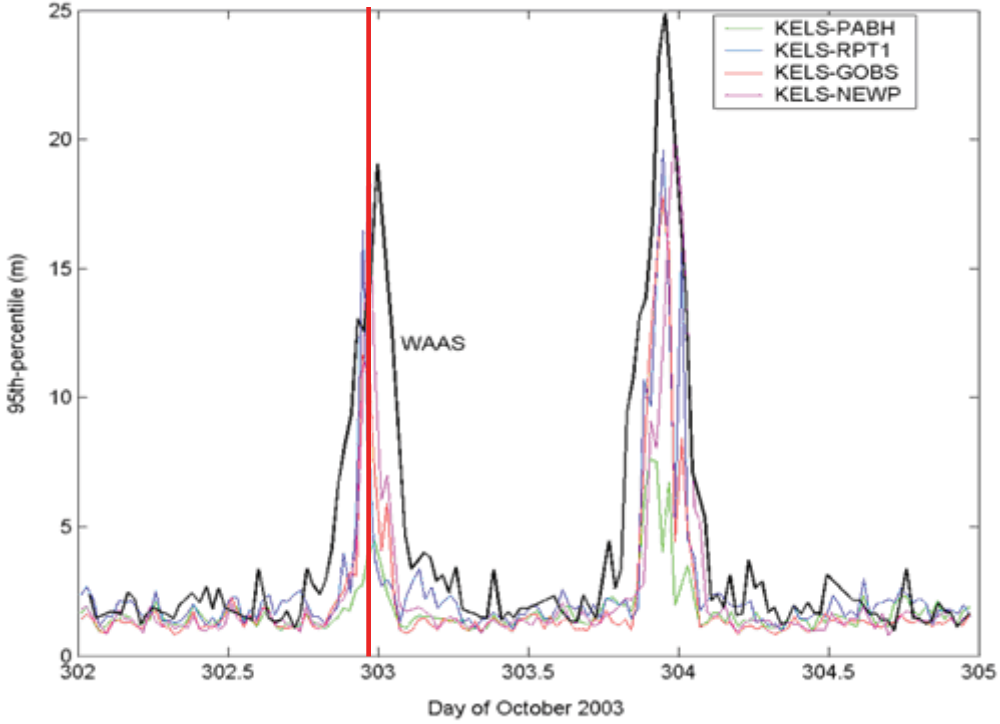
DGPS&WAAS Horizontal Positioning Errors: 29 October 2003

Ionosphere Map: 2230 UT



Horizontal Position Errors



Gradient = 30 ppm

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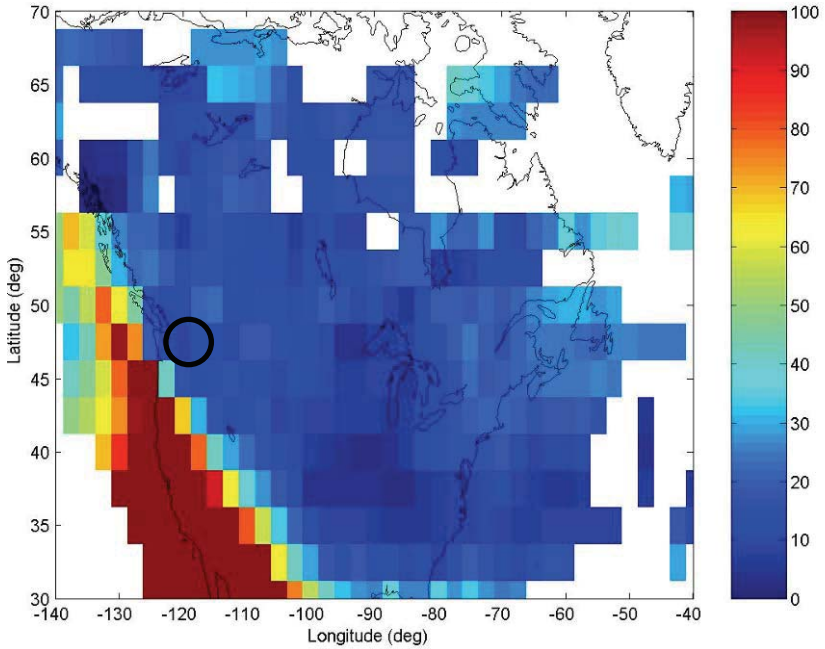
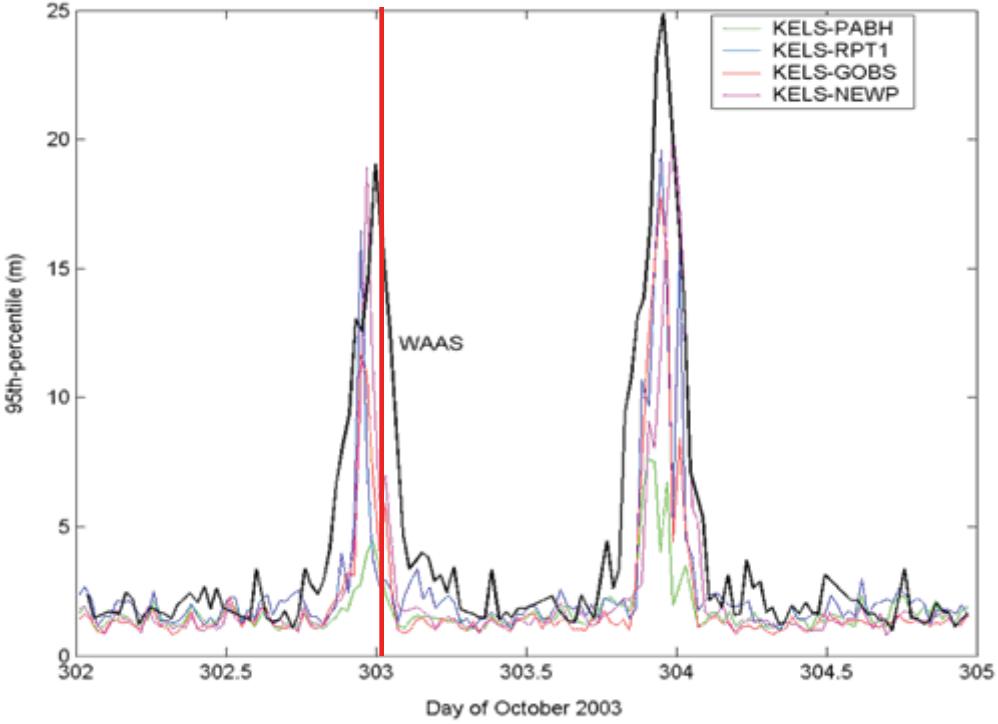
DGPS&WAAS Horizontal Positioning Errors: 29 October 2003

Ionosphere Map: 2330 UT



Horizontal Position Errors



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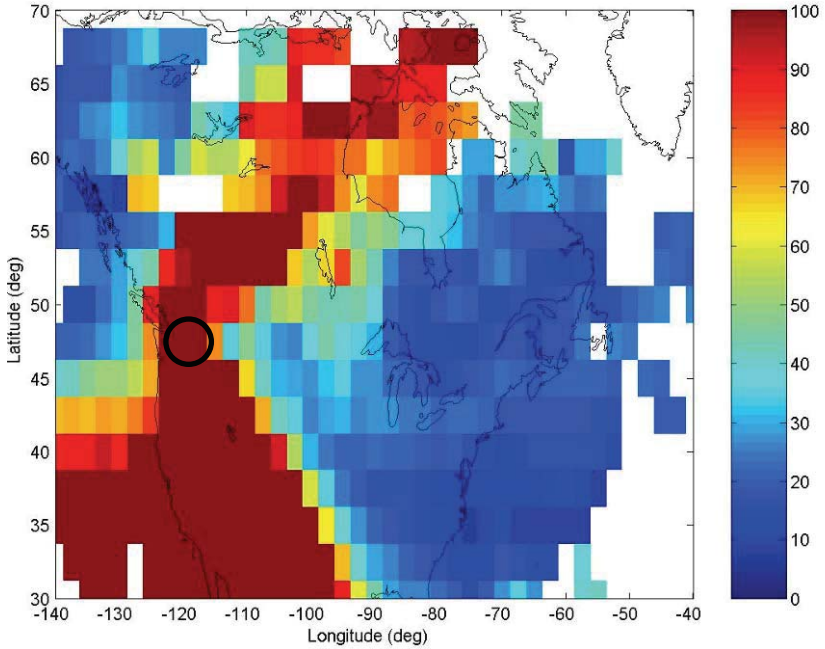
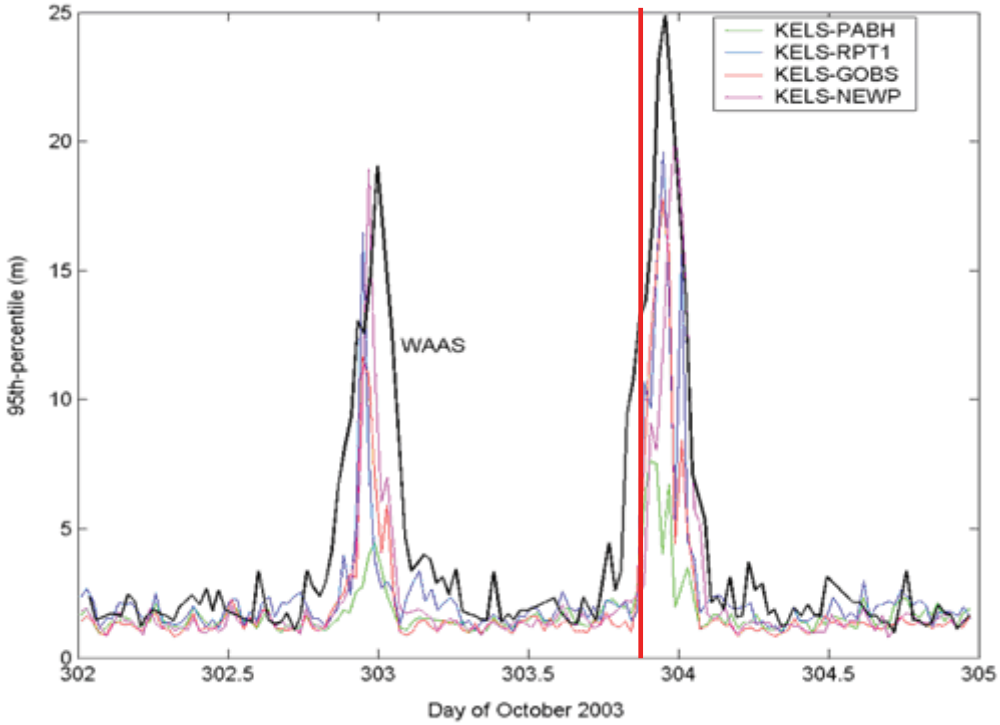
DGPS&WAAS Horizontal Positioning Errors: 29 October 2003

Ionosphere Map: 2130 UT



Horizontal Position Errors



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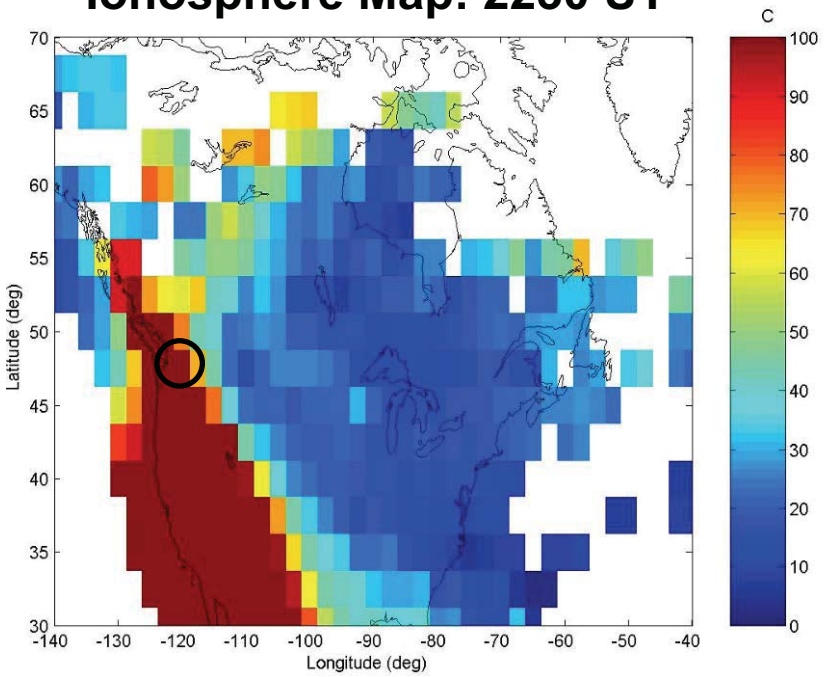
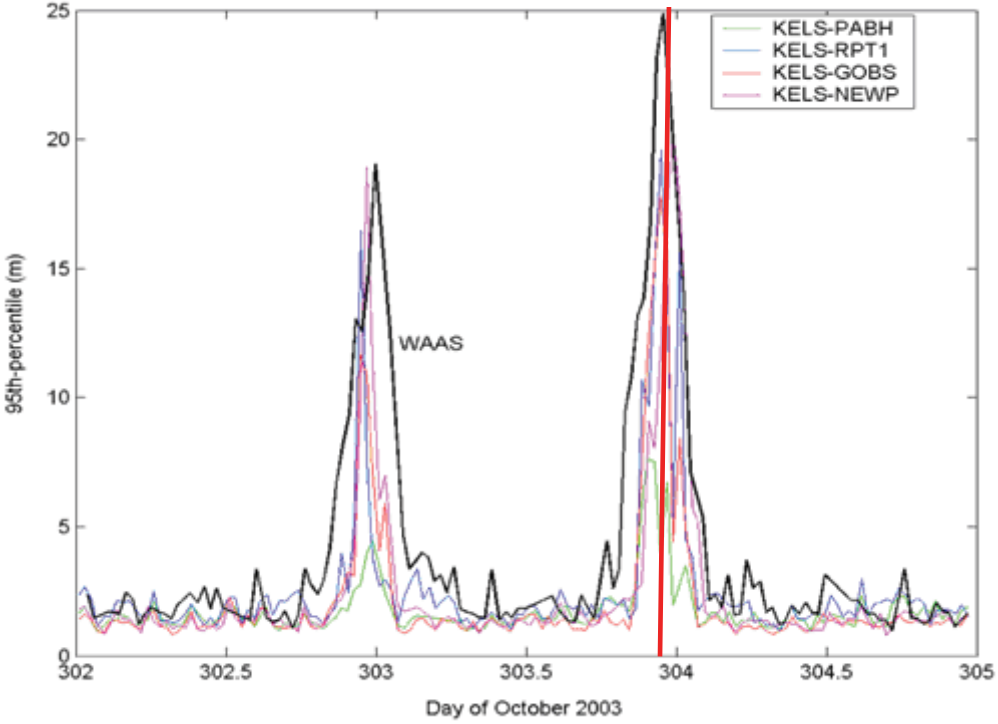
DGPS&WAAS Horizontal Positioning Errors: 29 October 2003

Ionosphere Map: 2230 UT



Horizontal Position Errors



Gradient = 35 ppm

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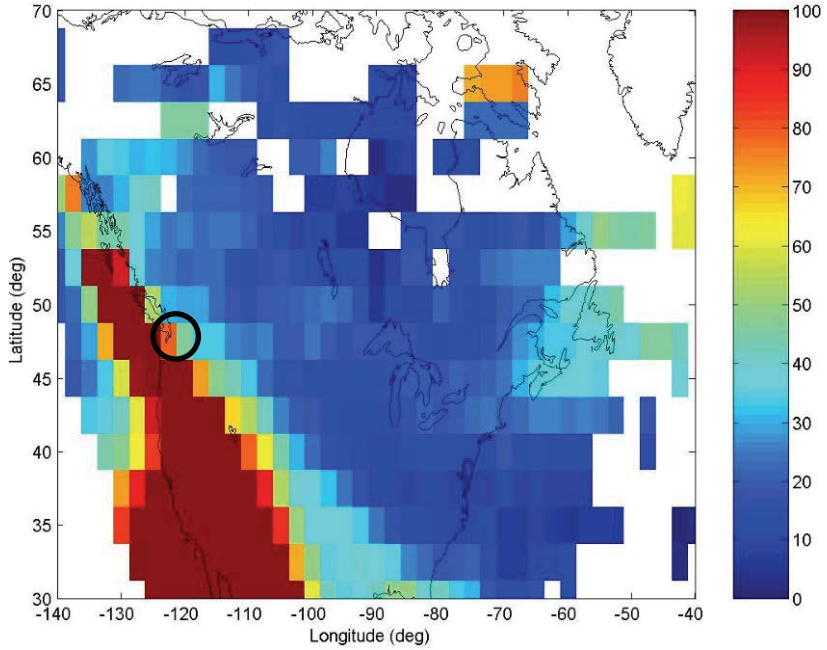
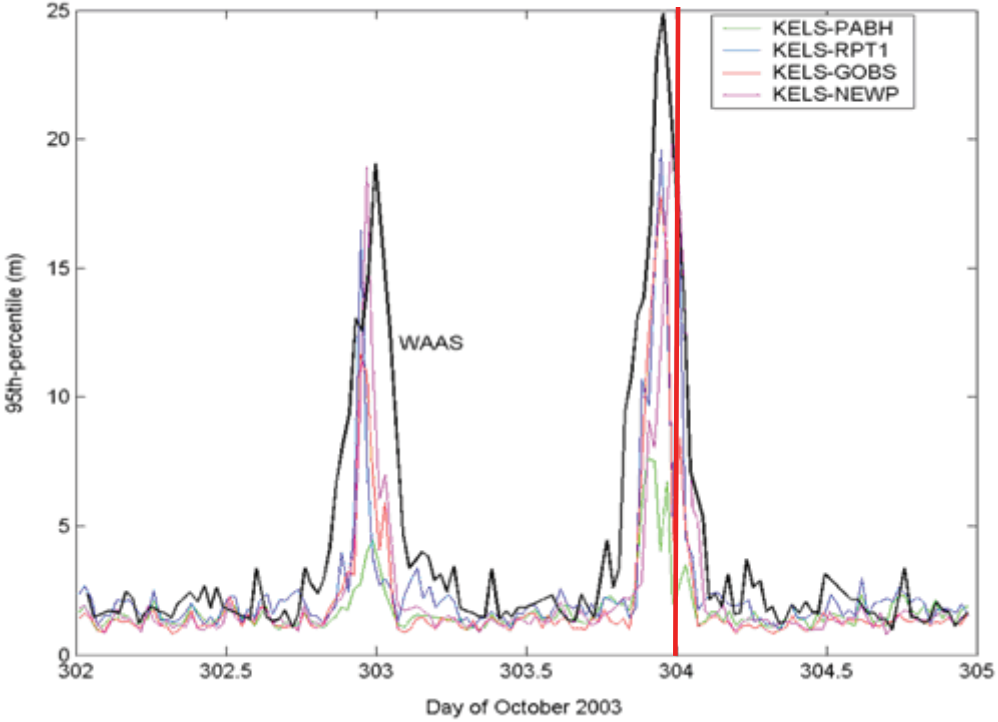
DGPS&WAAS Horizontal Positioning Errors: 29 October 2003

Ionosphere Map: 2330 UT



Horizontal Position Errors



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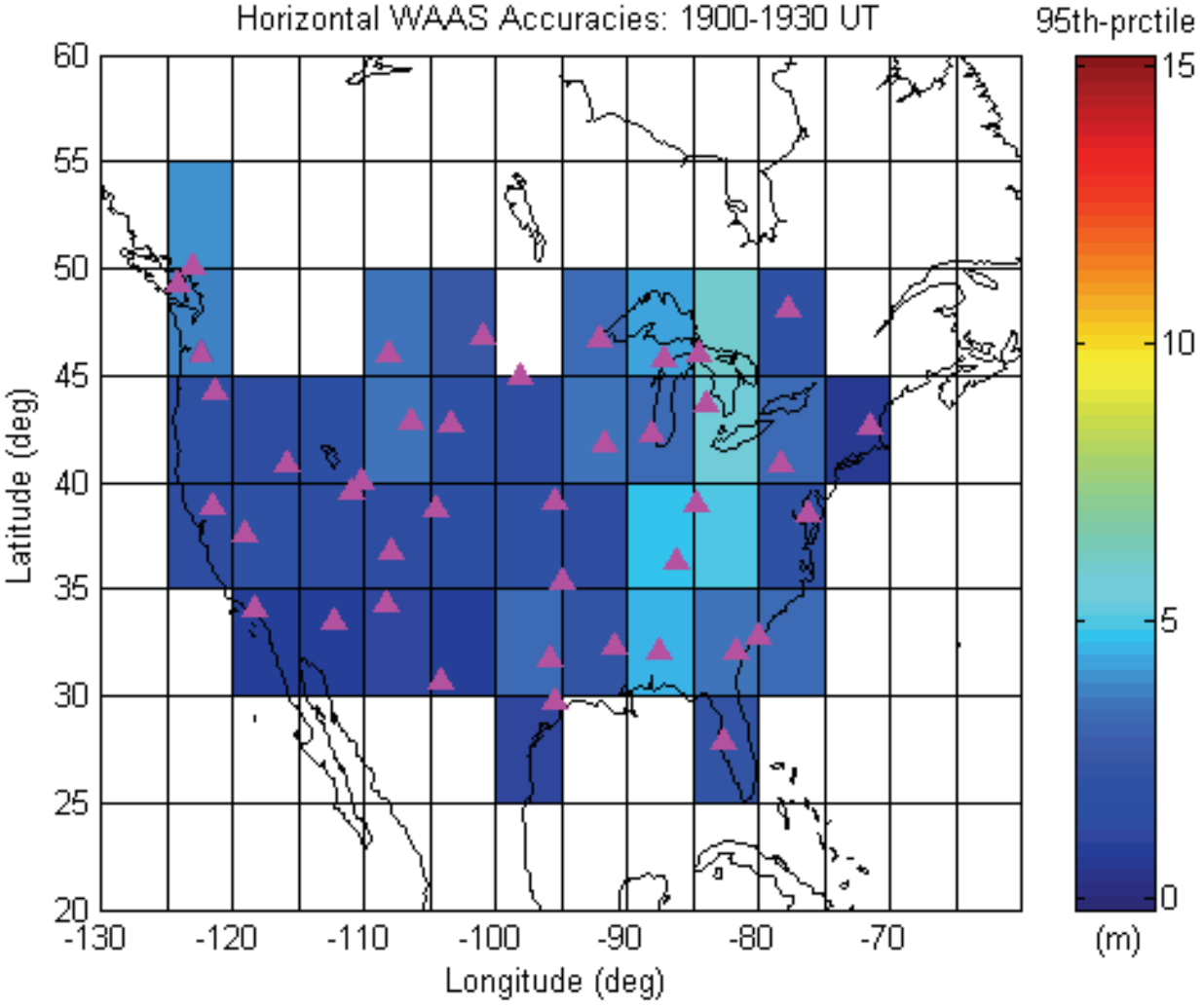
WAAS Analysis



- Positioning accuracies estimated for 40 GPS reference sites
- October 30, 2003

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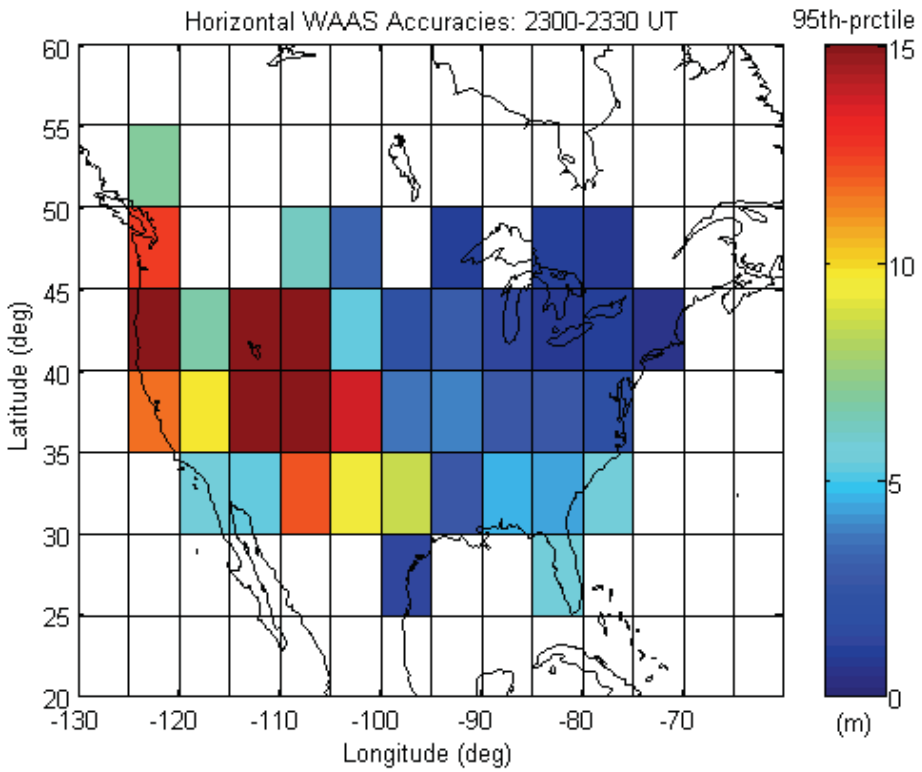
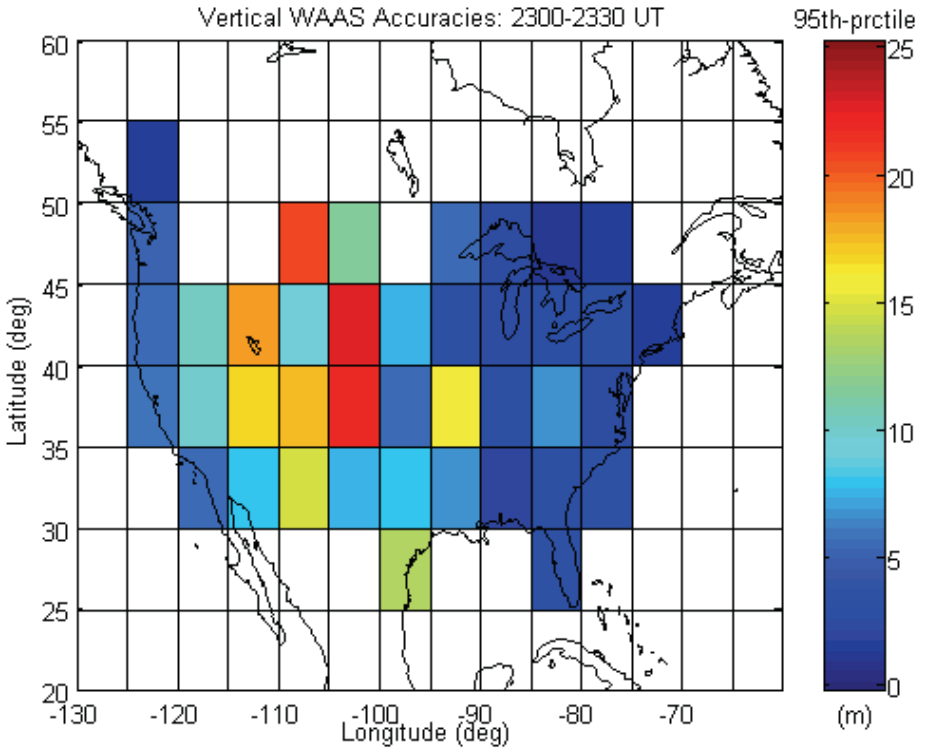
WAAS Positioning Errors





- Errors of >15 m horizontal and 20-25 m vertical

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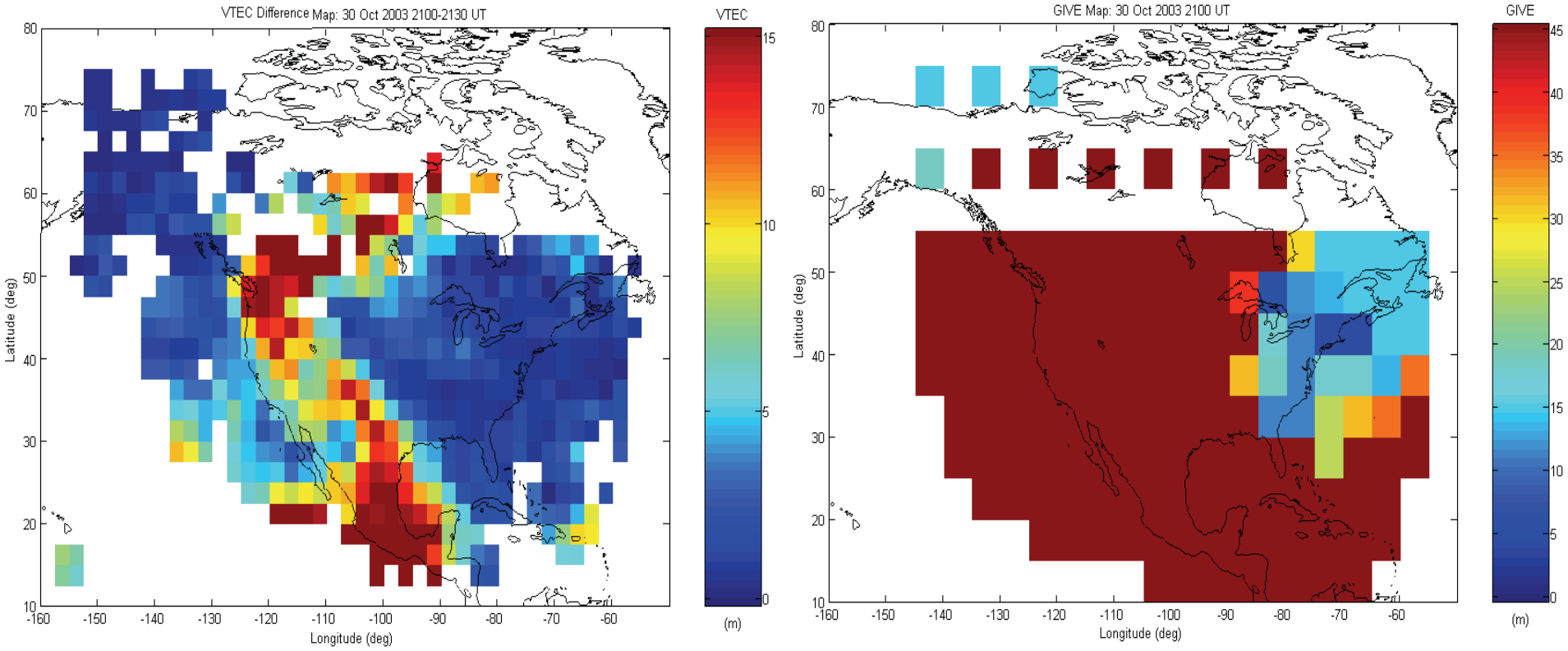
WAAS Iono Model Errors

WAAS Error Oct. 30 **GIVE**



- Errors >15 m in WAAS ionosphere estimates
- Bounded reliably by GIVE values (“do not use”)

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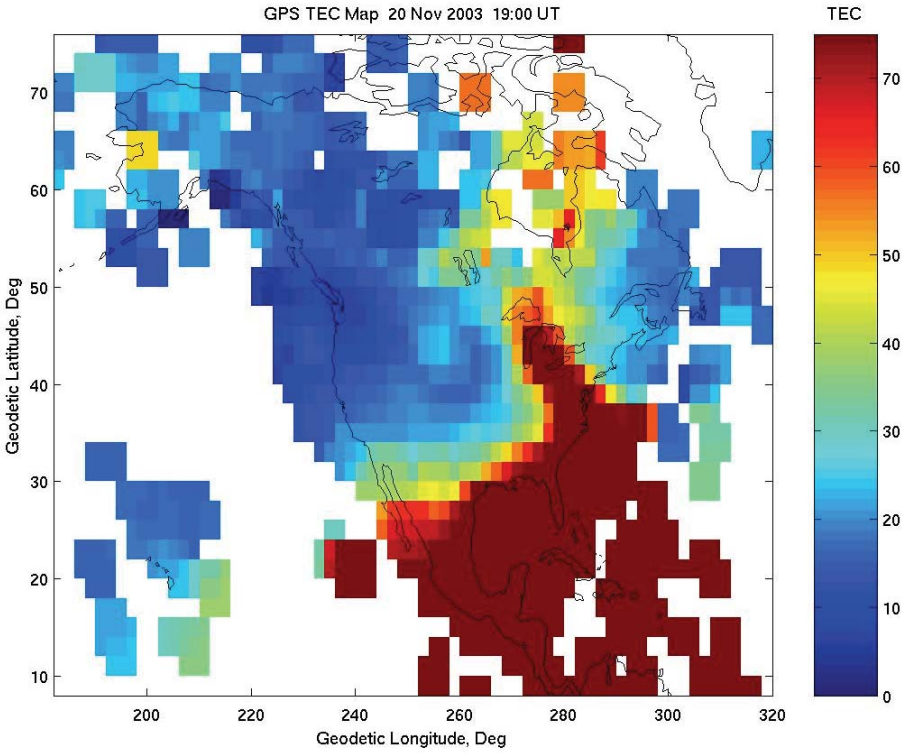
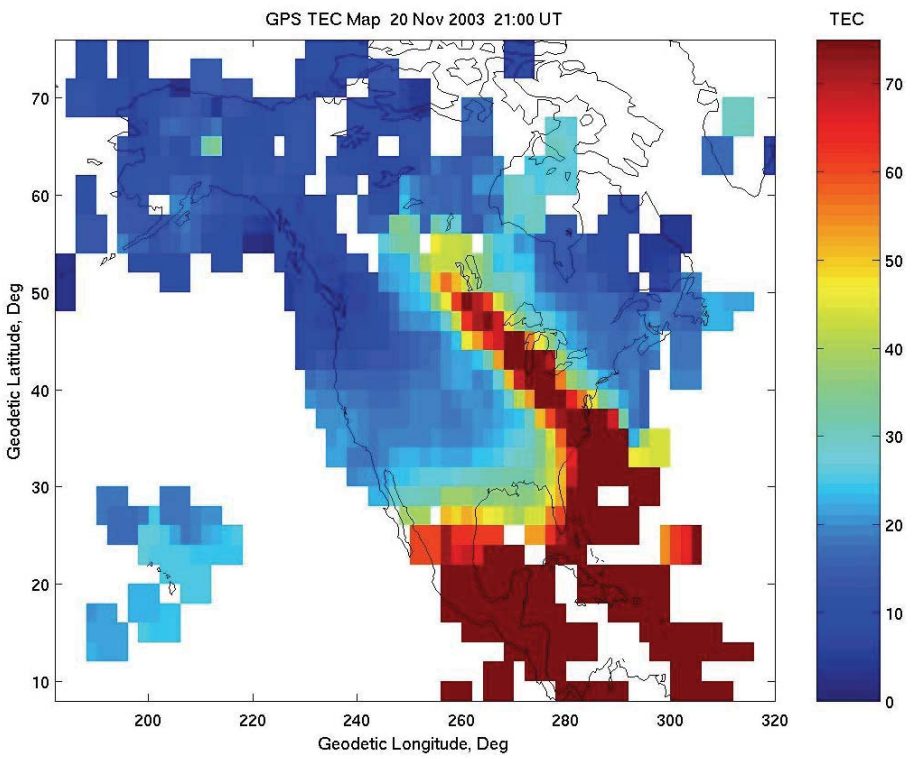
SED Event 20 November 2003

19:00 UT



21:00 UT



- SED develops 18:00 – 22:00 UT
- SED extends north through central Canada
- Impact in eastern and central Canada on DGPS (CCG, USCG, NDGPS) and WAAS

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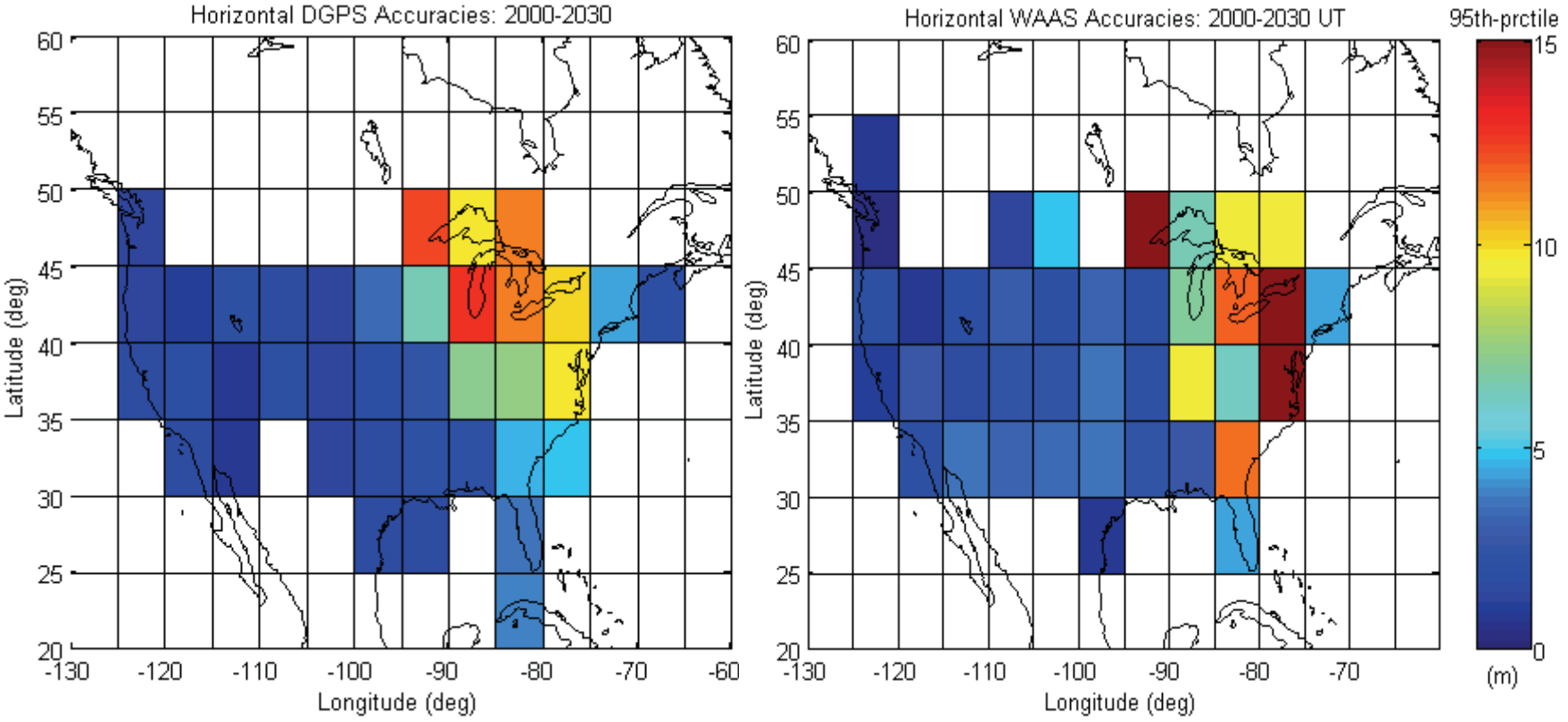
DGPS and WAAS – Horizontal



- DGPS position errors computed for 100-200 km baselines
- Horizontal accuracies of 10-15 m (DGPS) and > 15 m (WAAS) during period 20:00-20:30 UT

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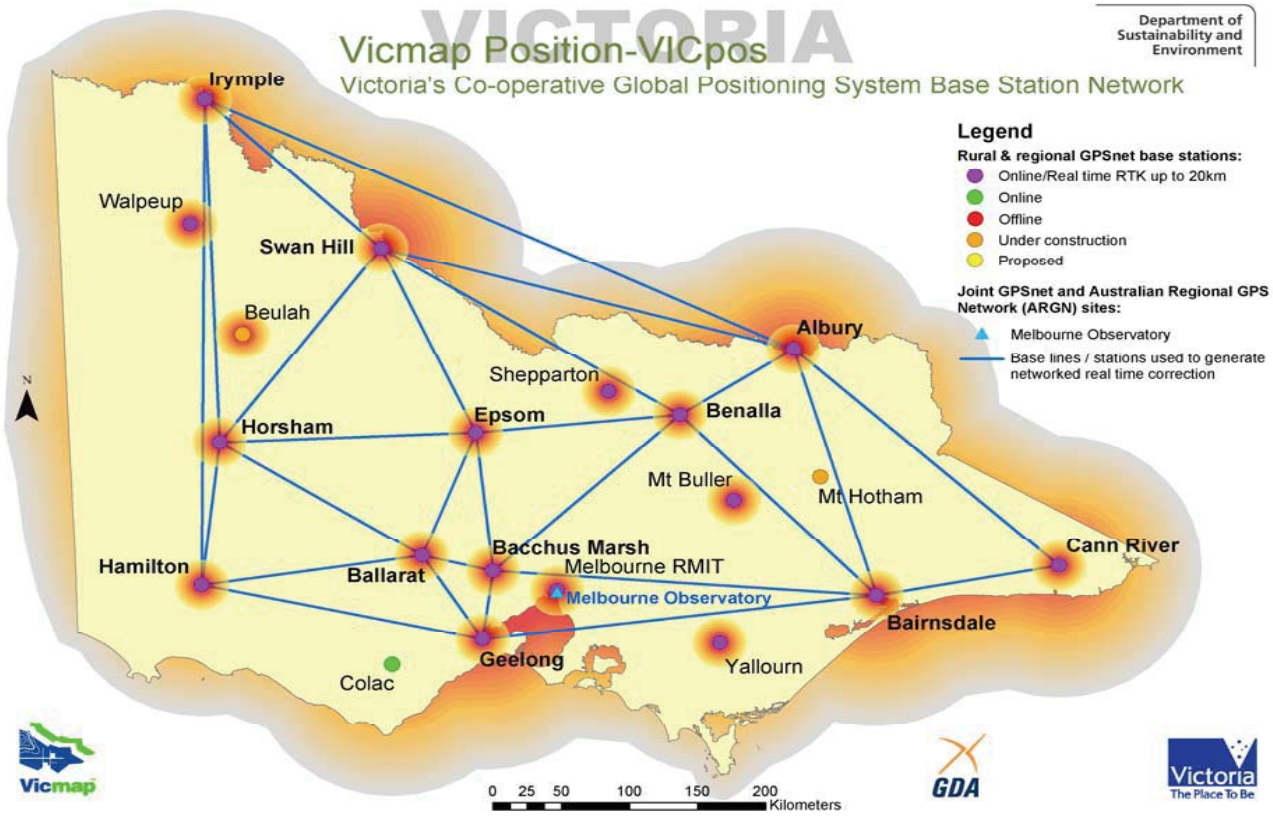
Vicmap Position (Australia) GPS and WAAS – Horizontal

- GPSnet™ operational in 2004 for sub-metre positioning in southeastern Australia
- Reference station spacings of 100-200 km
- Applications in agriculture, GIS, navigation, forestry, surveying, emergency response, mining and transportation



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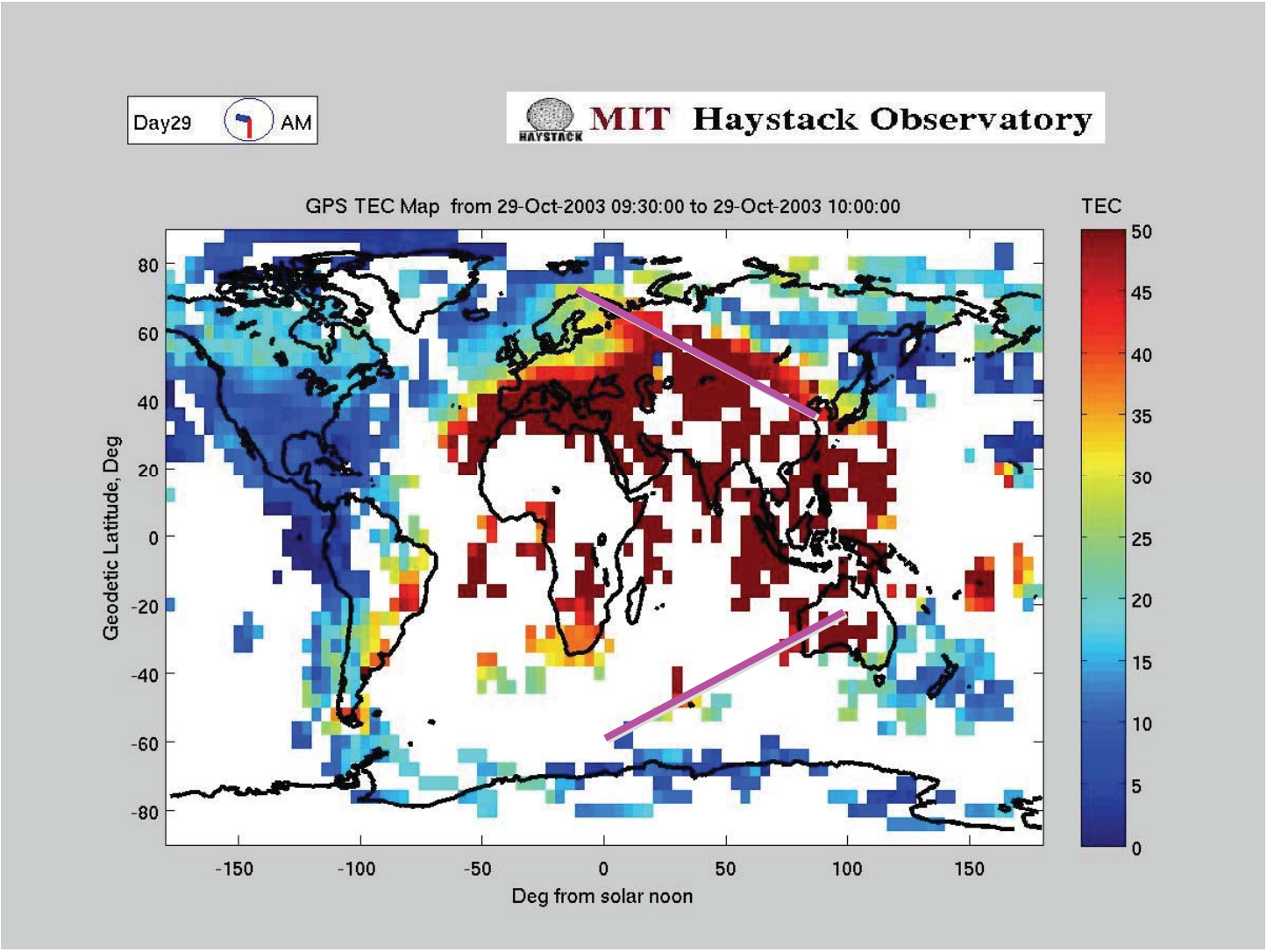
10:00 UT 29 October 2003



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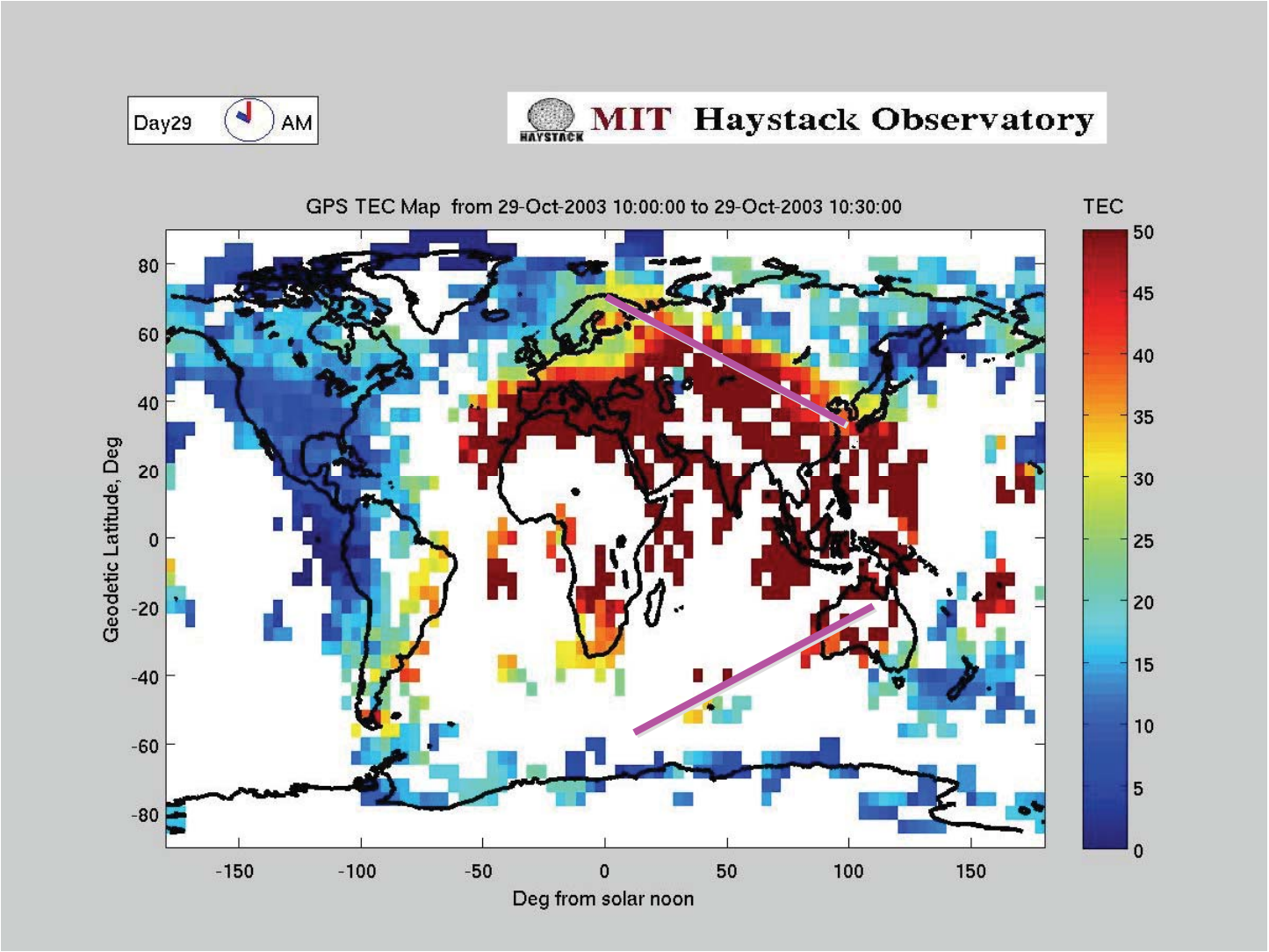
10:30 UT 29 October 2003



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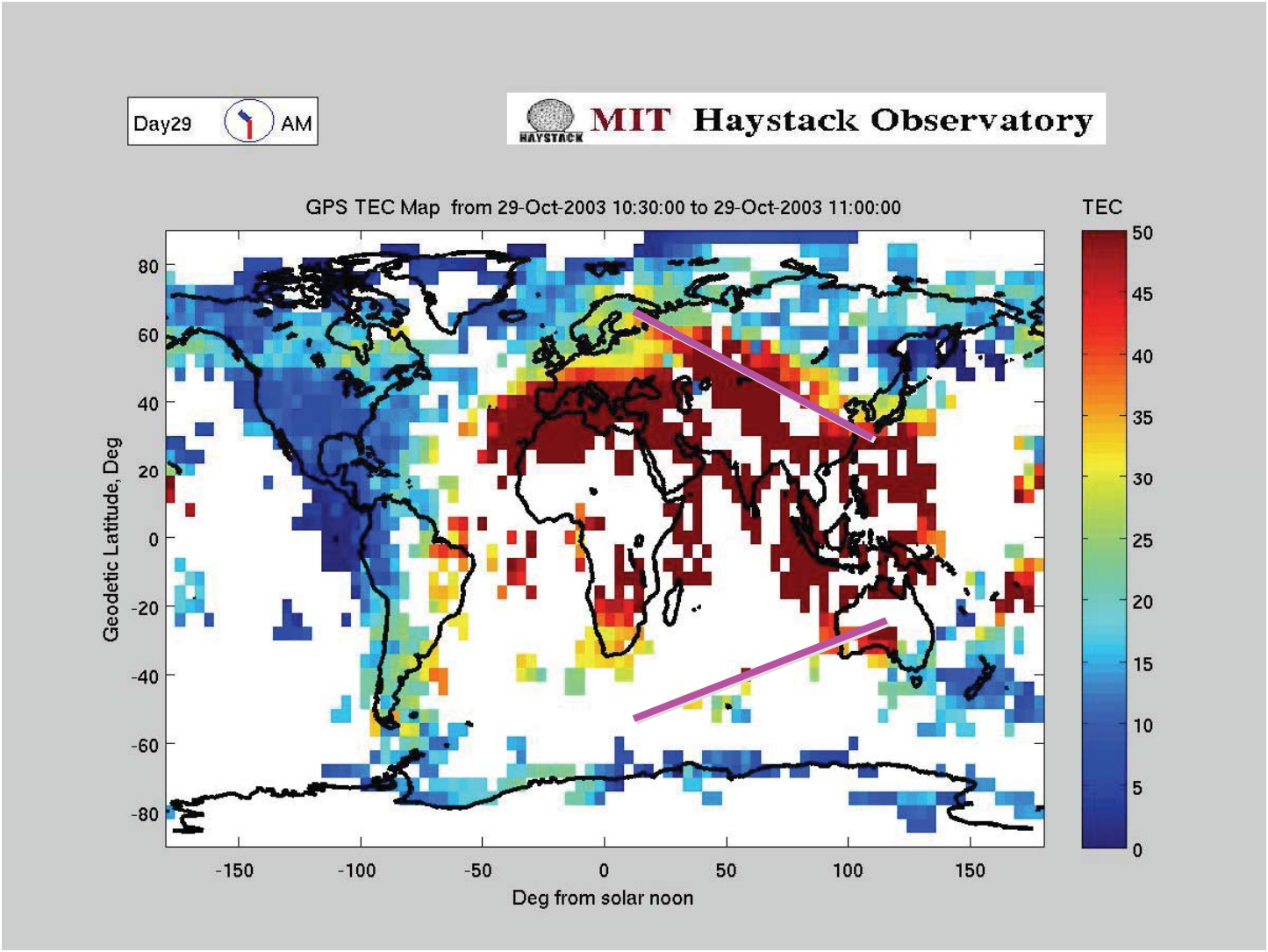
11:00 UT 29 October 2003



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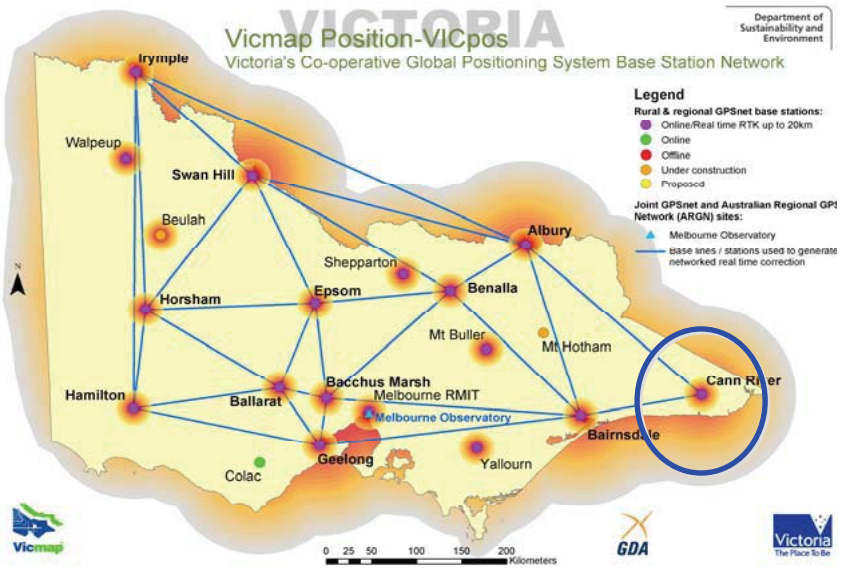
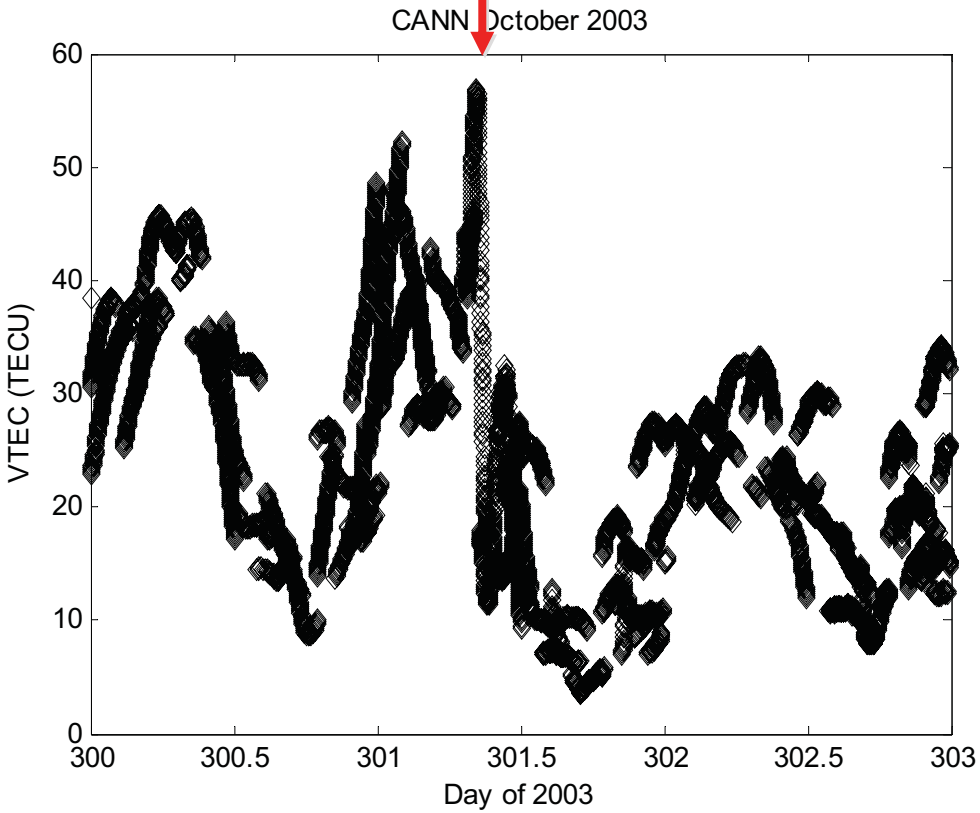
VTEC: Reference Station CANN





Large TEC variations observed approx. 10:00 UT on October 29 (day 301)

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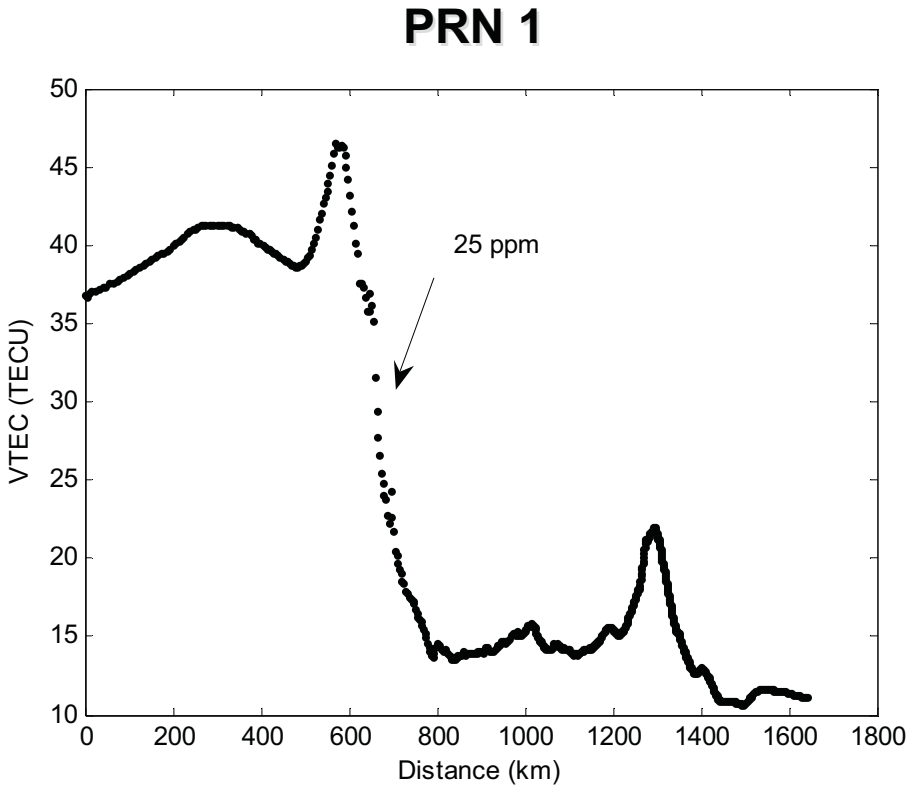
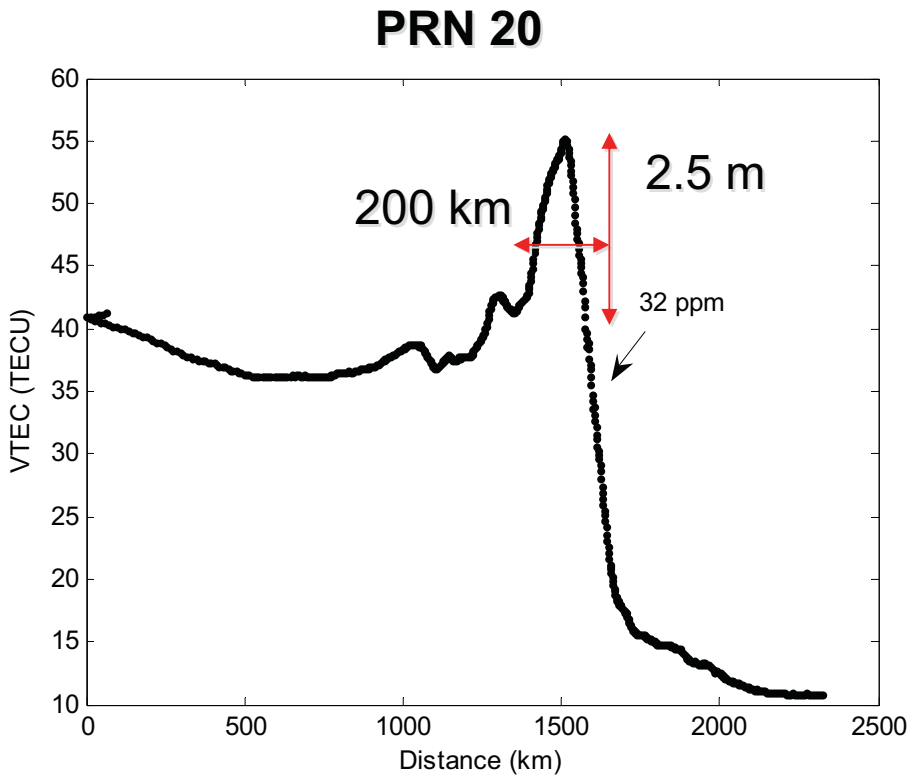
CANN: Gradients





- Gradients of 25-30 ppm over distances of 200 km
- Differential ionosphere range delay of 2 to 3 m for 100 km baseline
- DGPS positioning errors of 6-7 m

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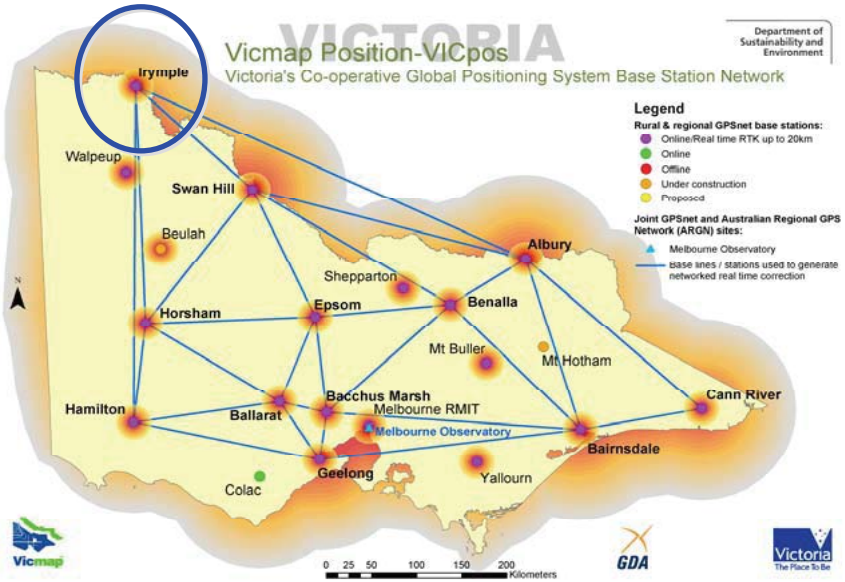
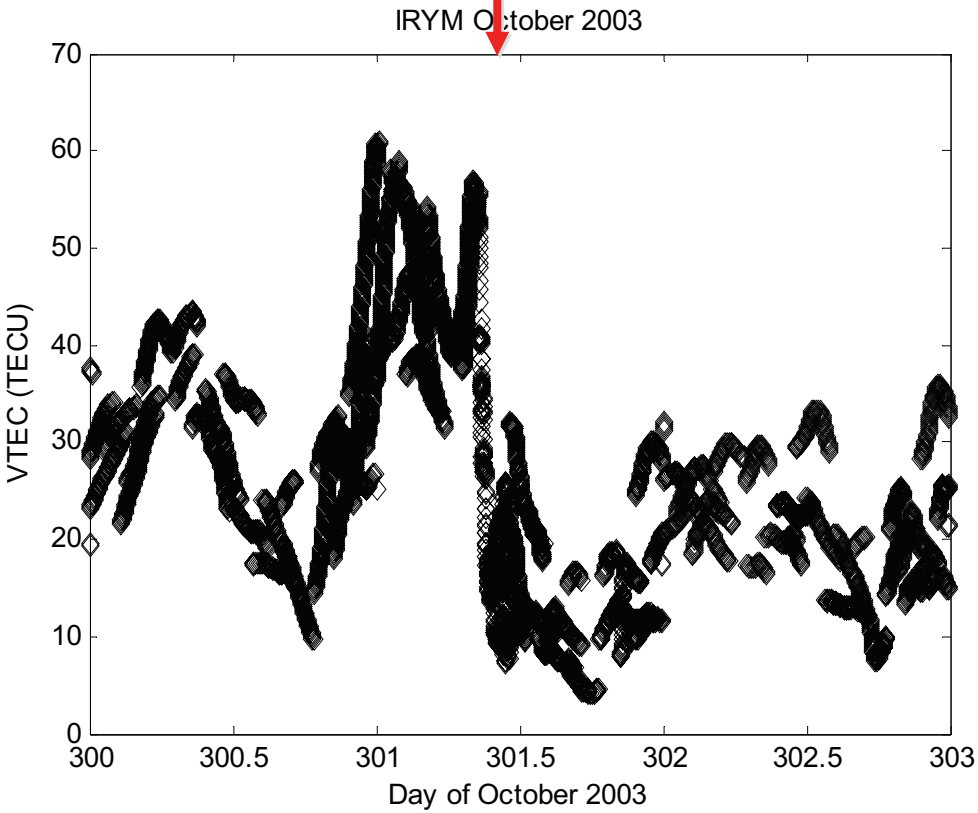
VTEC: Reference Station IRYM





Large TEC variations observed approx. 10:00 UT on October 29 (day 301)

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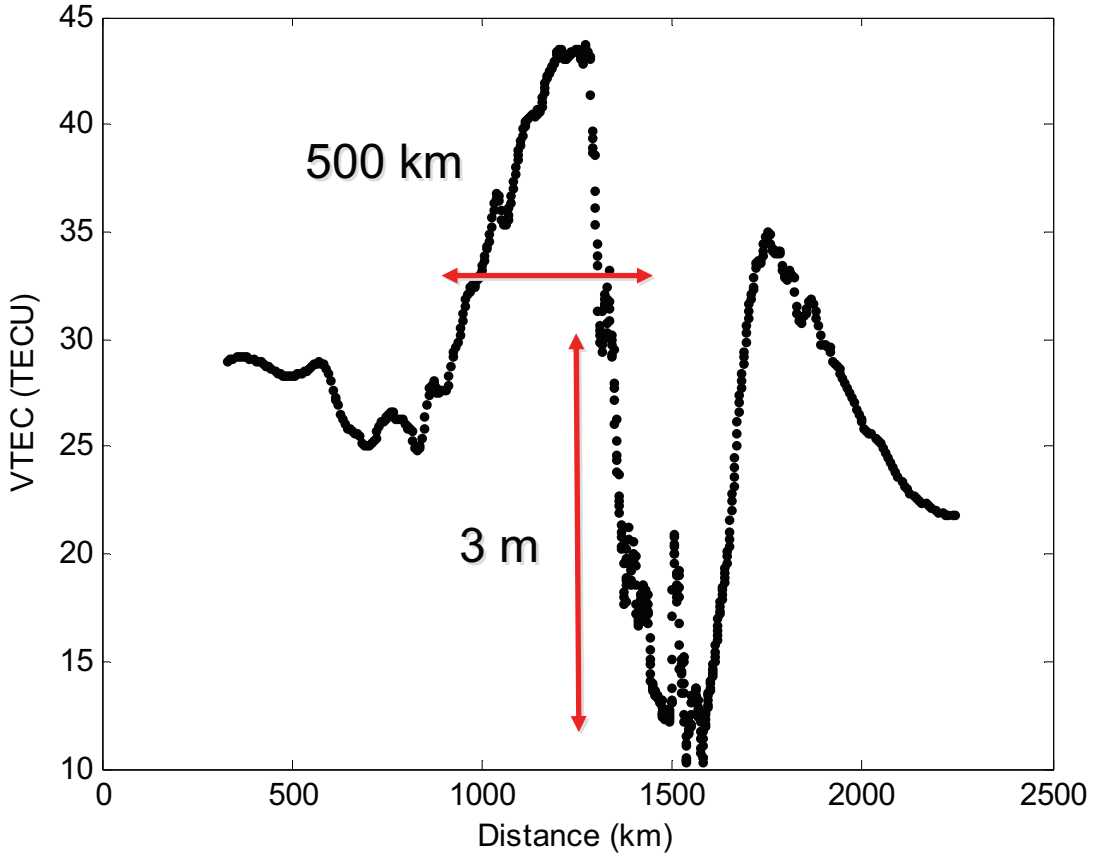
IRYM: PRN 16



Structure with amplitudes of 2-3 m and scale size of 500 km

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Summary

- DGPS method supports many practical applications
- Enhanced equatorial anomaly and SED effects observed during solar maximum
- Large ionospheric gradients of 30-40 ppm observed near equatorial anomaly and 10-35 ppm observed near SED
- DGPS positioning errors of 20-30 m (95%) near anomaly
- SBAS such as WAAS with 5 deg by 5 deg grid spacing do not fully resolve gradients
- DGPS positioning errors of 2-10 m (95%) during SED events
- SBAS (WAAS) positioning errors of 8-12 m (95%) during SED events
- Conjugate effects observed in southern hemisphere