The Wide Area Augmentation System (WAAS)

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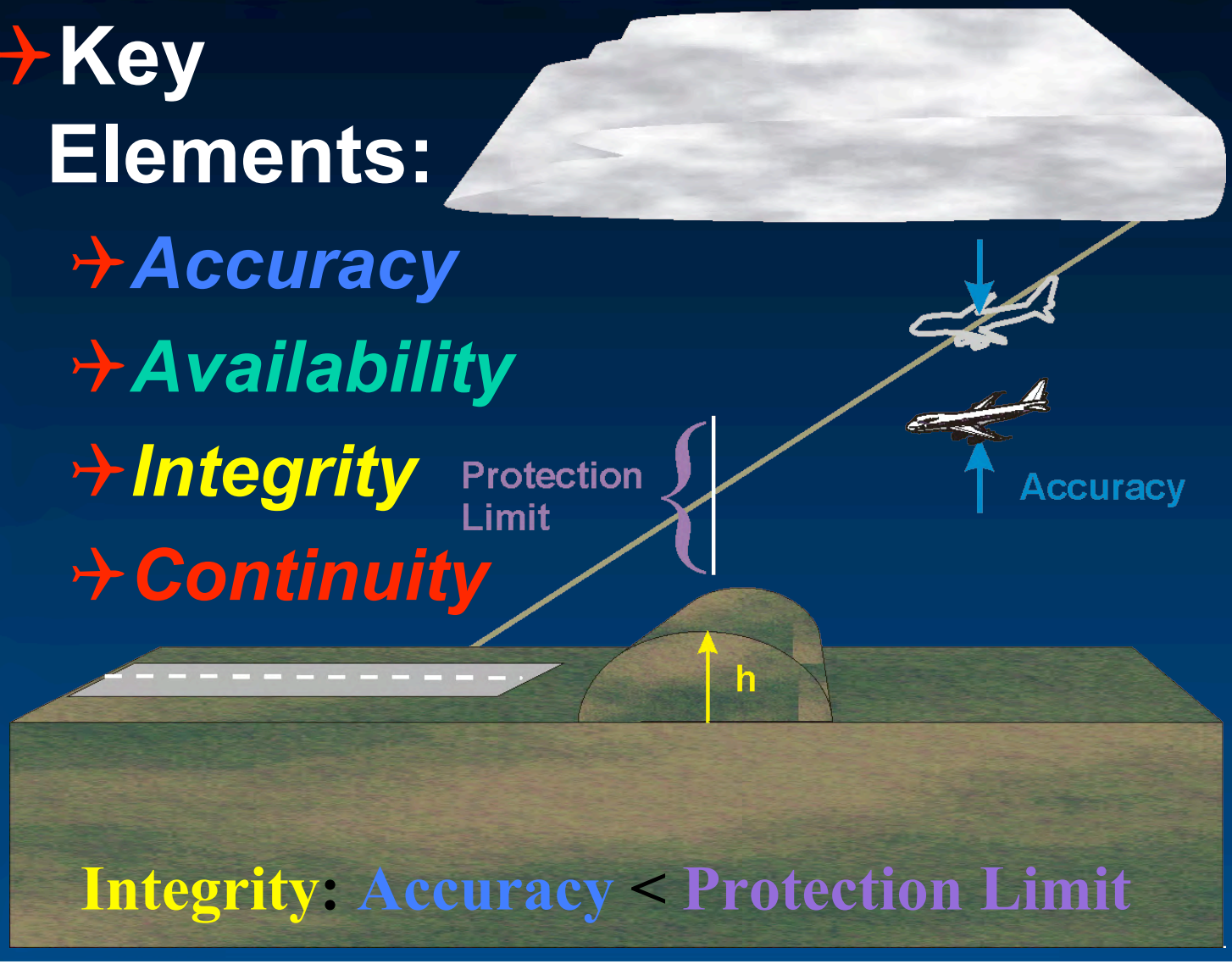
Outline

- Aviation Metrics
- GPS/Aviation Timelines
- The Wide-Area Augmentation System
- Integrity Analyses
- Comparison with Terrestrial Navigational Aids
- Future Directions

Aircraft Guidance Goals

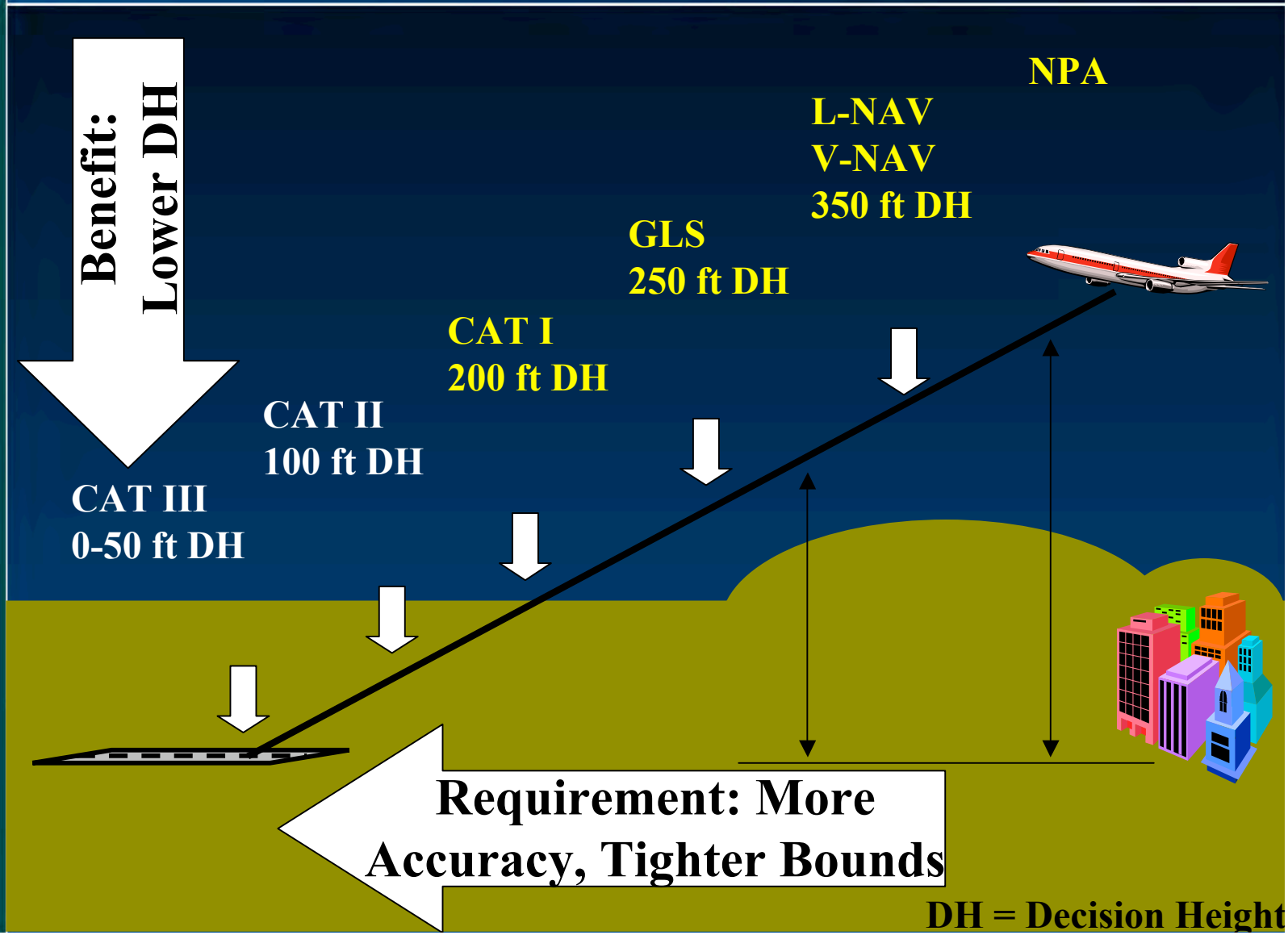
- Key Elements:
  - *Accuracy*
  - *Availability*
  - *Integrity*
  - *Continuity*



Courtesy:
Rich Fuller

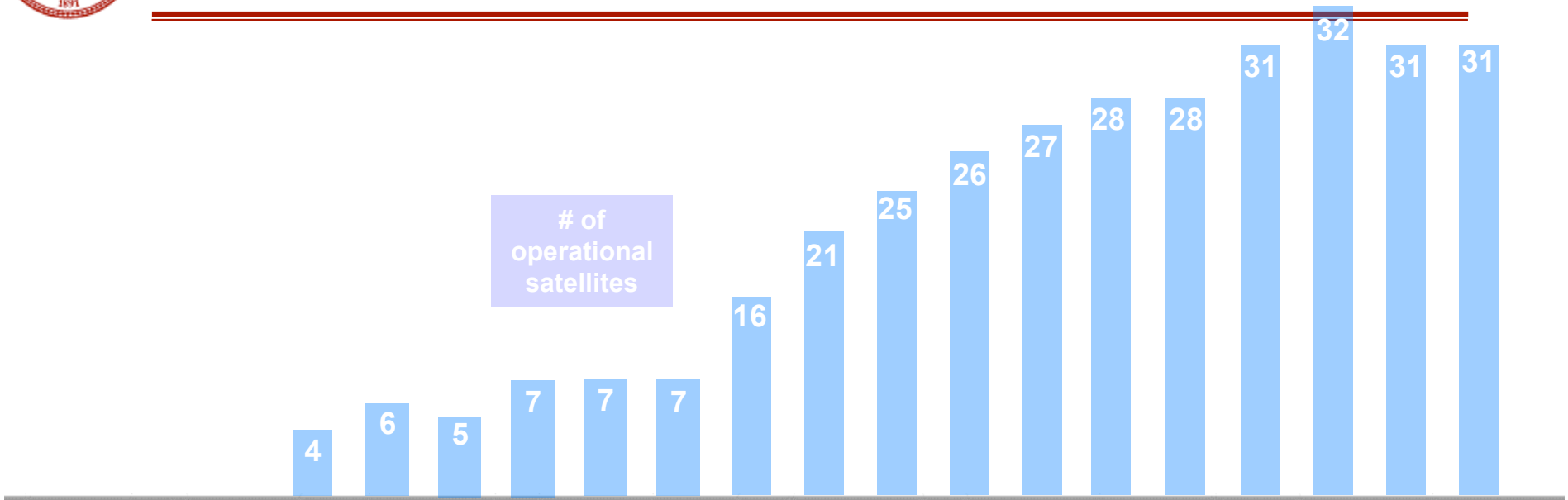
Presented at
University of Calgary

Vertical Guidance



Courtesy:
Sherman Lo

GPS Timeline



DoD development results in approval to proceed with program

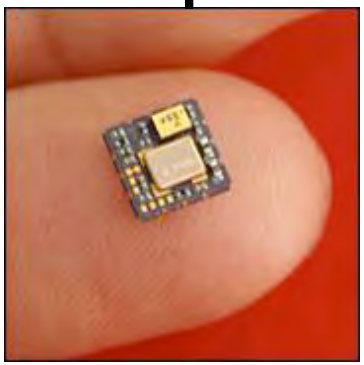
First survey receiver by Trimble

GPS Initial Operating Capability

GPS Final Operating Capability

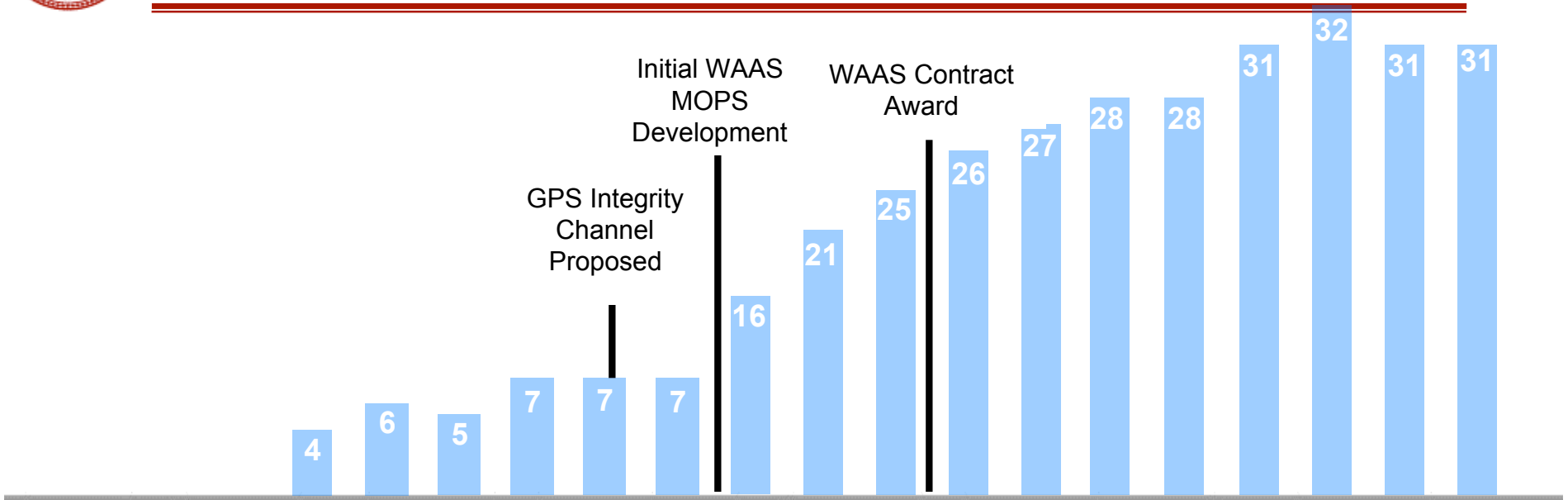
Garmin GPS 45

Turn off Selective Availability



GPS chip sets support over 500 million users

GPS Timeline for Aviation



ICAO notes potential of satellites for aeronautics

ICAO recommends research on aeronautical satellites

KAL 007

ICAO identifies satellite technology as central to air navigation

First aviation receiver

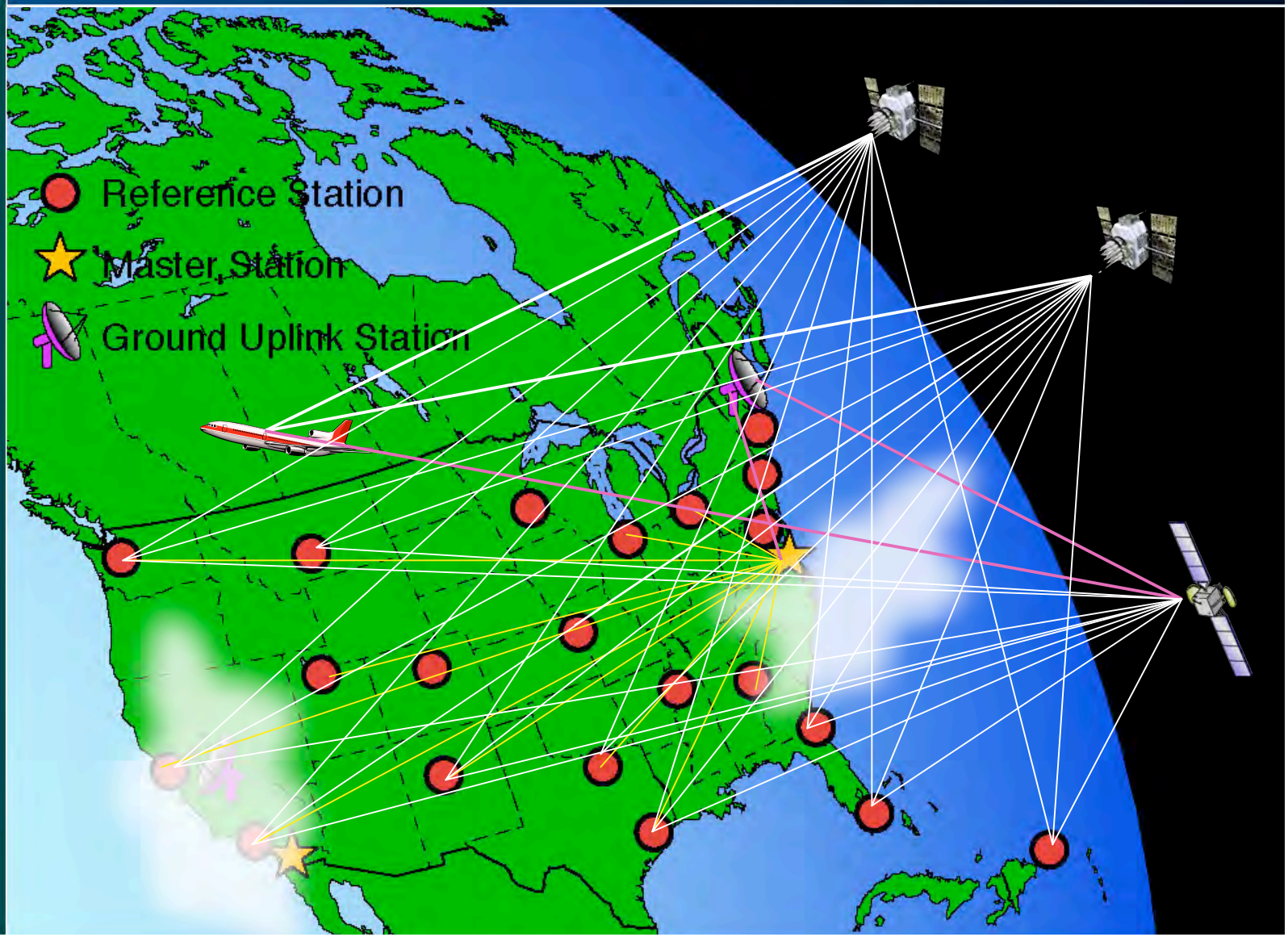
ICAO approves global implementation plan

IFR approval TSO-C129 supplemental

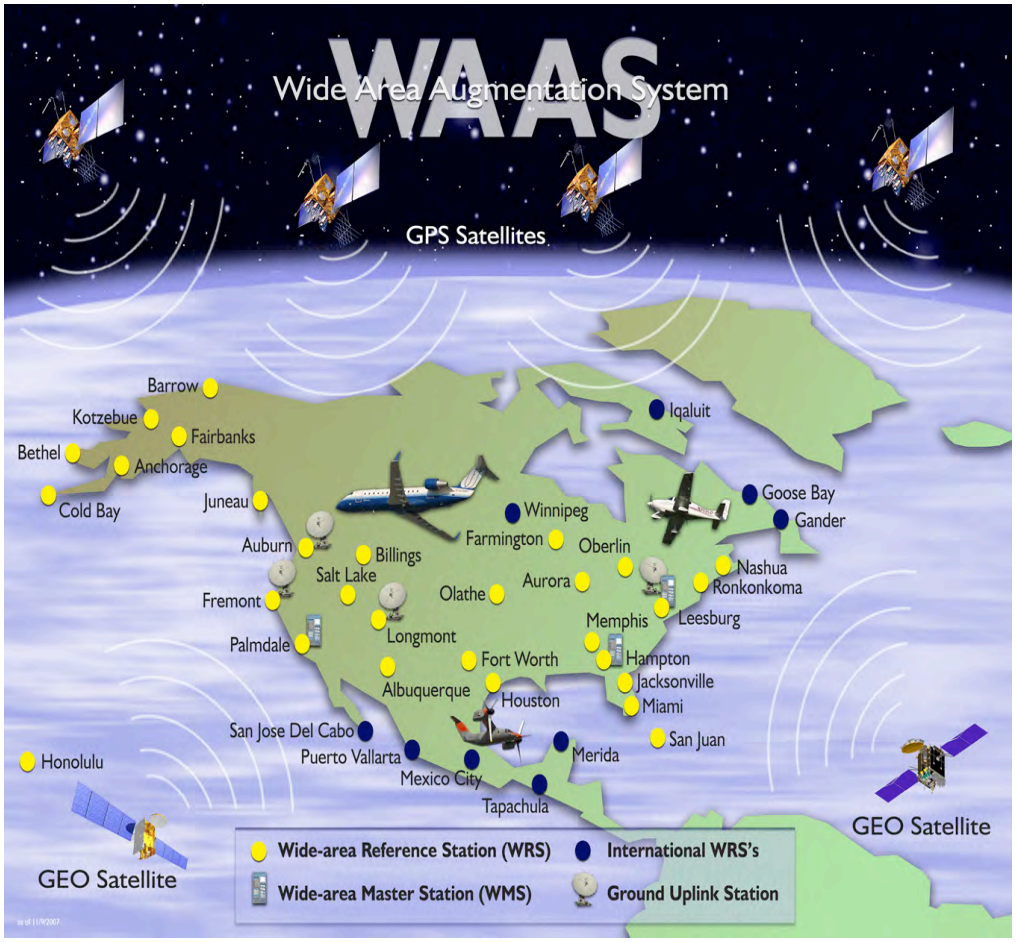
WAAS Approved

SLS-4000 (GBAS) SDA

WAAS



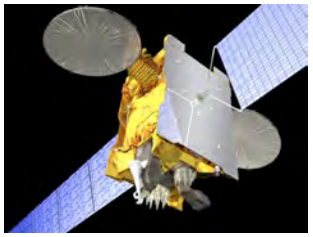
WAAS Architecture



38 Reference Stations

3 Master Stations

4 Ground Earth Stations

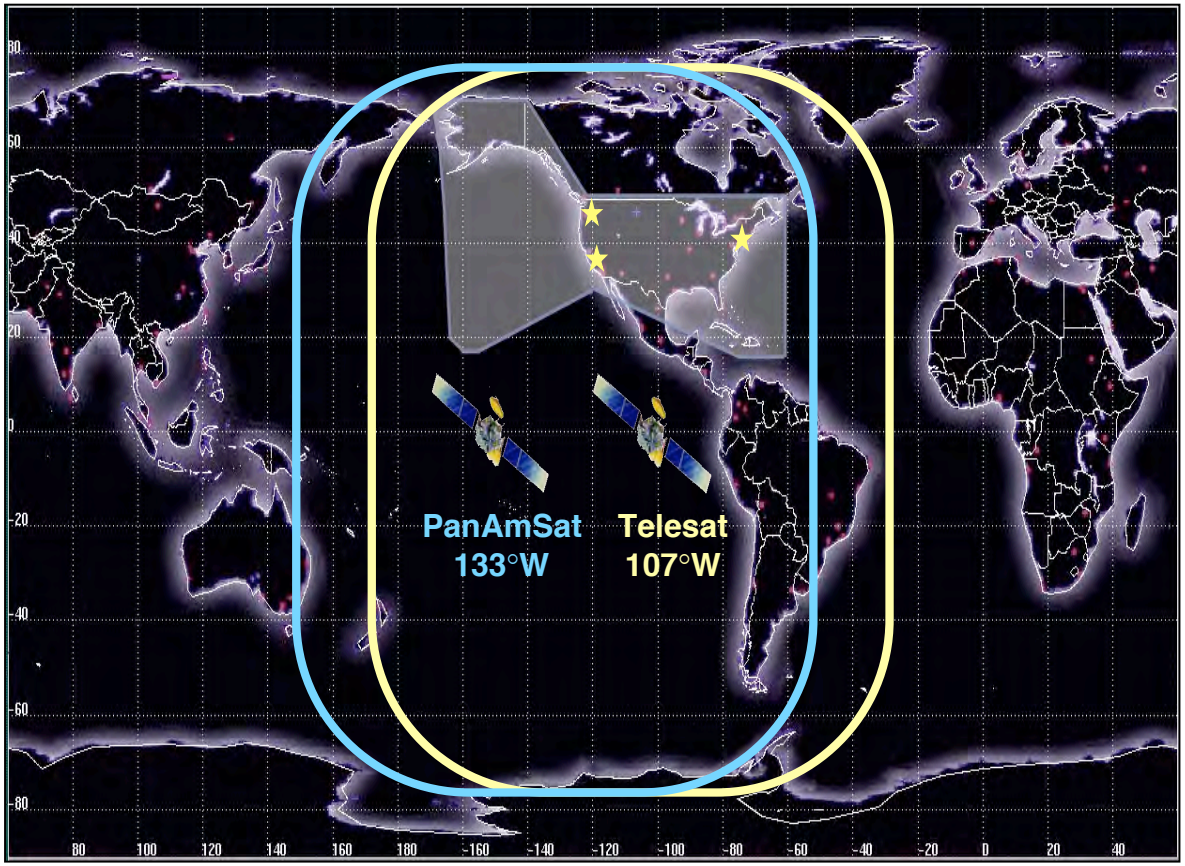


2 Geostationary Satellite Links

2 Operational Control Centers

Courtesy:
Federal Aviation Administration

Geostationary Satellites (GEO)



- **Provides Dual Coverage Over United States**

WAAS LPV and LPV-200 Vertical Position Error Distributions July 2003 to June 2006

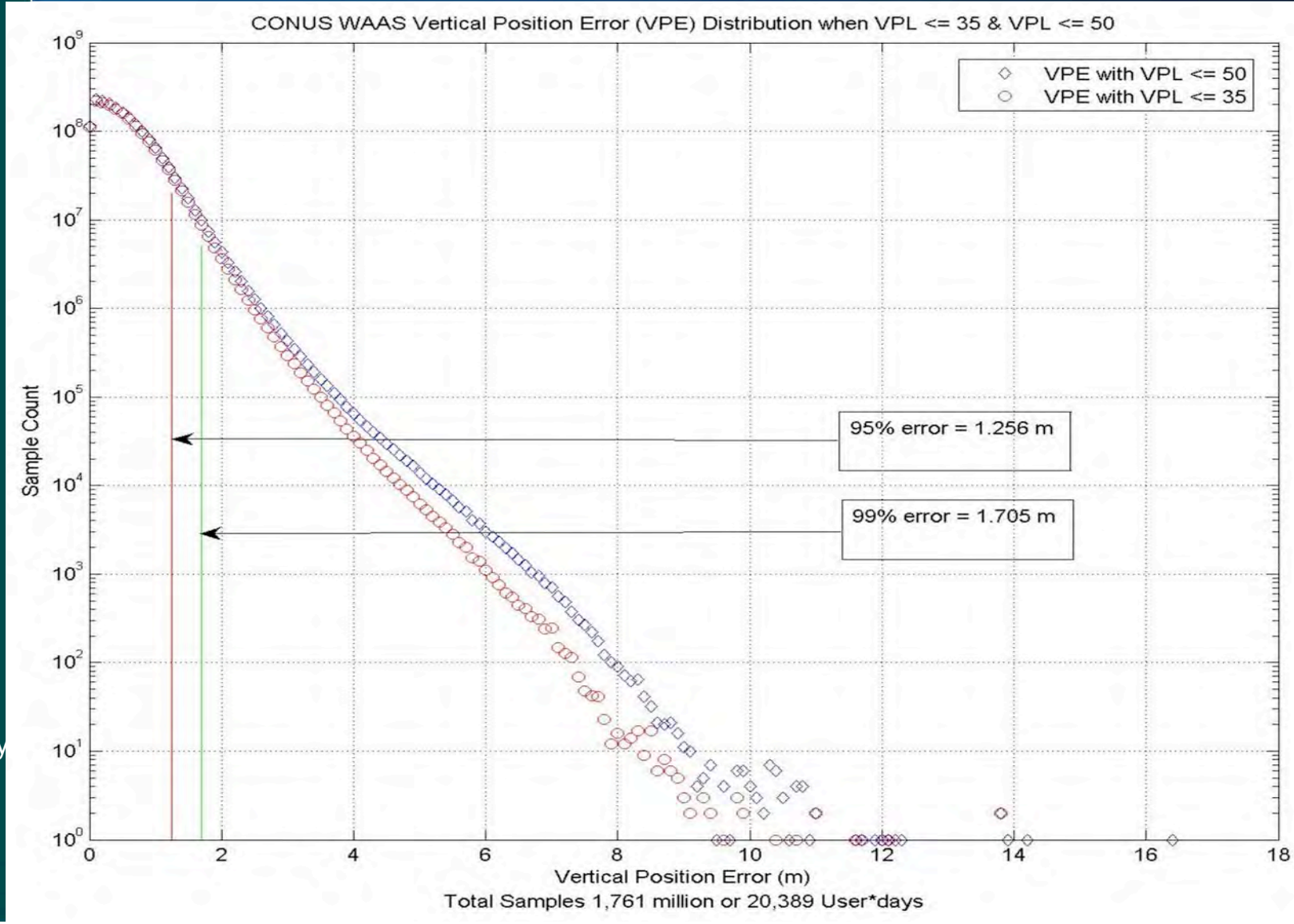
Courtesy:

FAA Technical Center

3 years

20 WRSs

1 Hz data



Integrity Approach

- Aviation integrity operates on a guilty until proven innocent principle
  - *Error bound is the maximum possible value given the measurements*
- This is unlike conventional systems that describe the most likely errors
- Protection level is a 99.99999% bound on worst reasonable conditions
  - *Very different from 95% achieved accuracy*

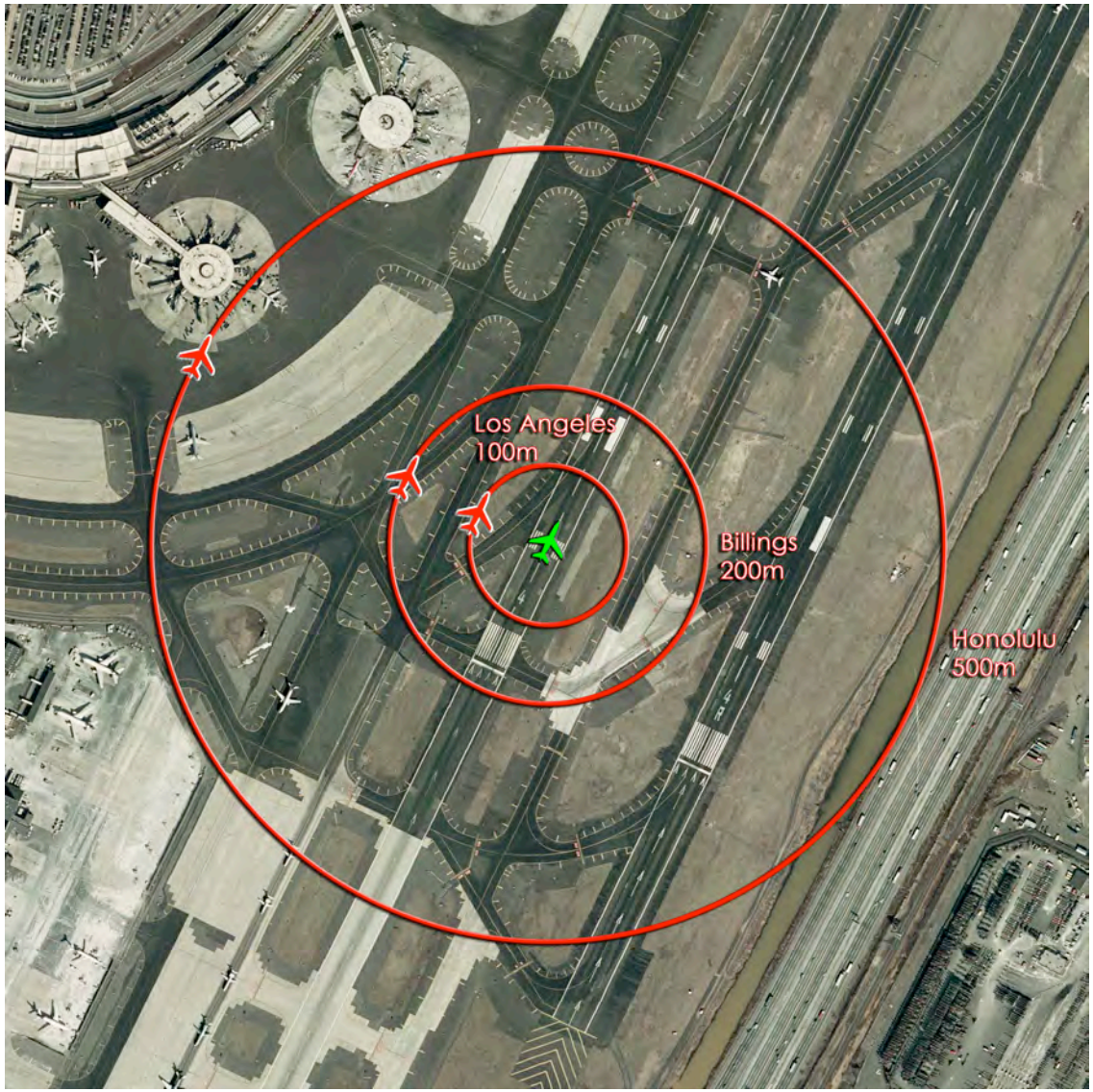
Error Sources

- Satellite errors
  - *Ephemeris*
  - *Clock*
  - *Signal*
- Propagation errors
  - *Ionosphere*
  - *Troposphere*
- Local Errors
  - *Multipath*
  - *Receiver Noise*

GPS Performance (Usually)

On a good day, the red circle encloses 95% of the GPS position fixes.

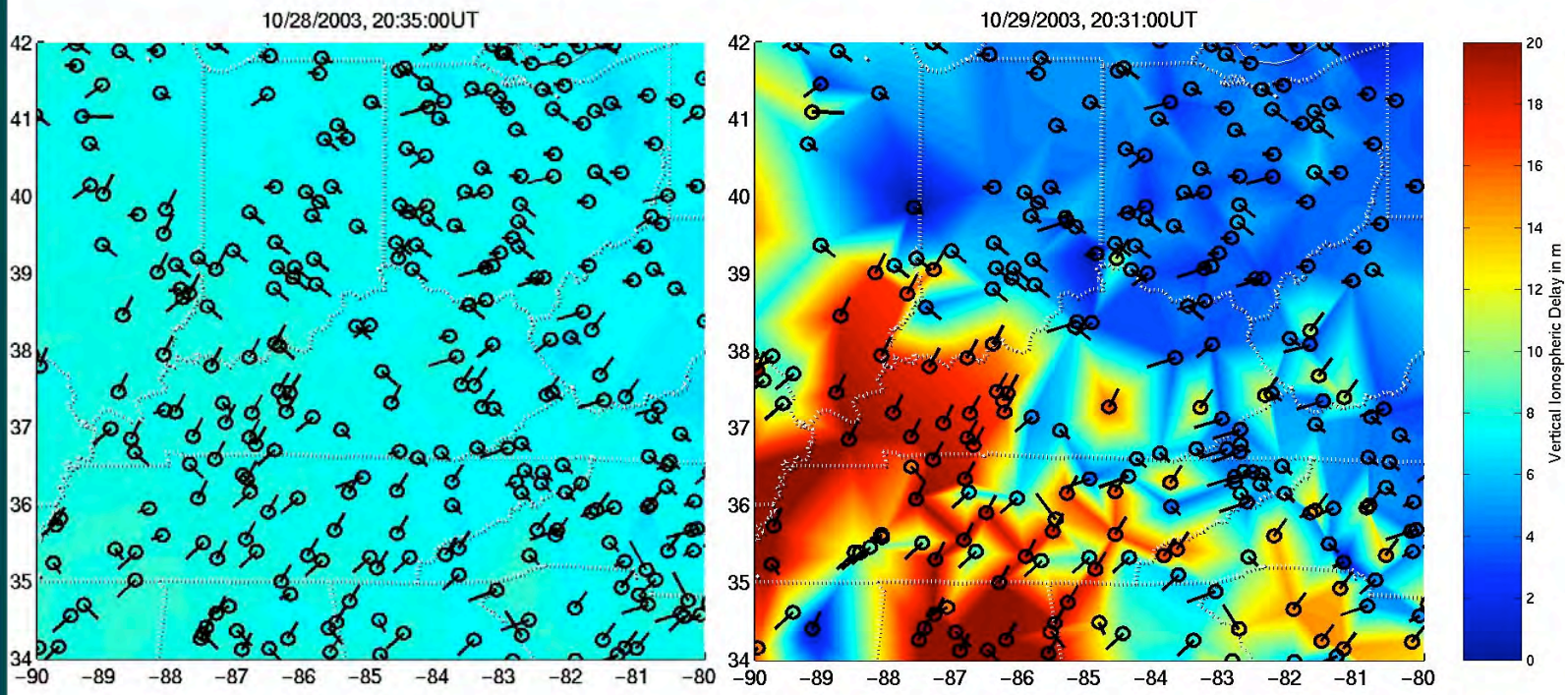
Major GPS Faults About Twice a Year
Example: Ephemeris Failure on April 10, 2007



On a bad day, the GPS errors can be much worse.

WAAS & GBAS eliminate these large errors.

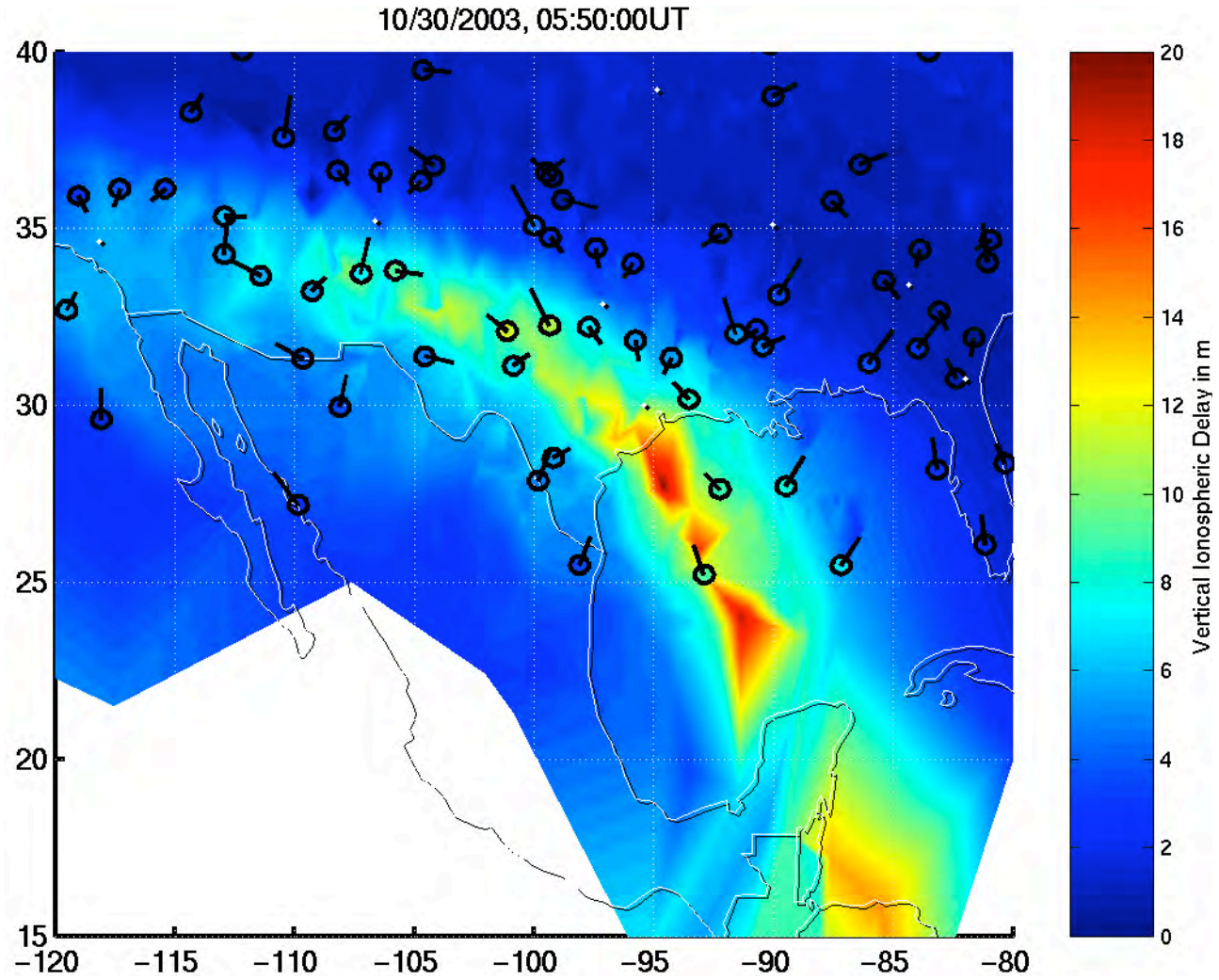
Failure of Thin Shell Model



Quiet Day

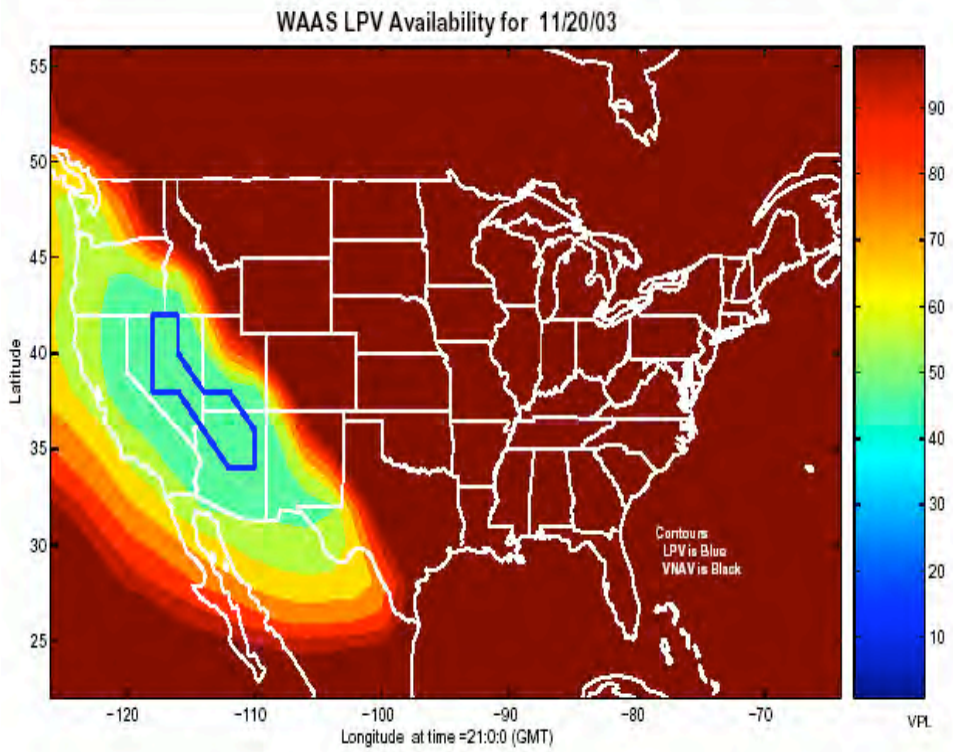
Disturbed Day

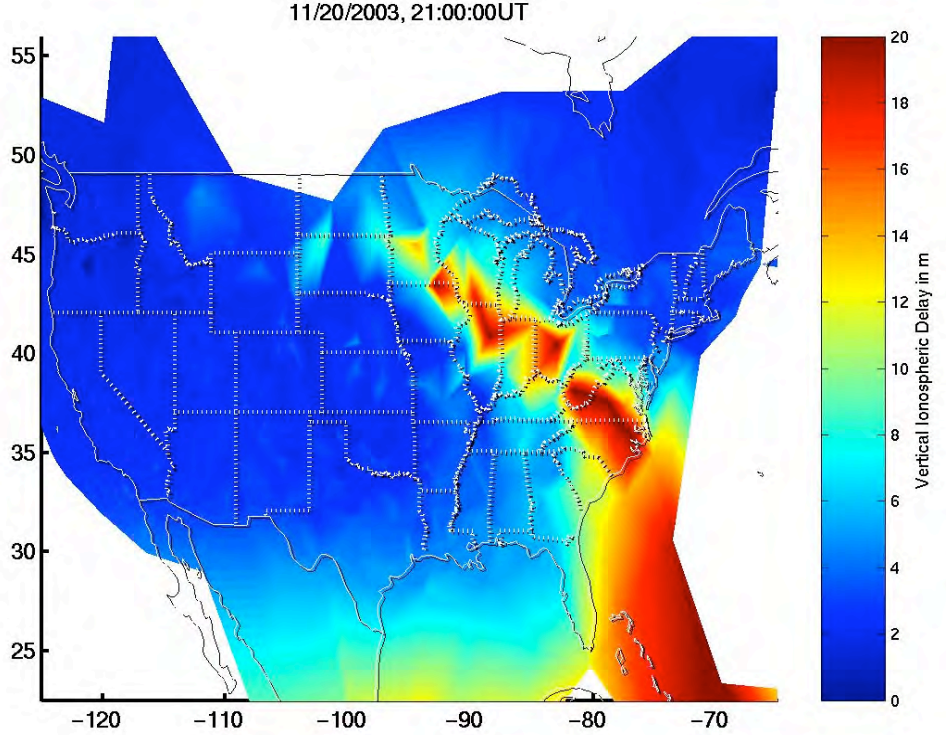
Undersampled Condition



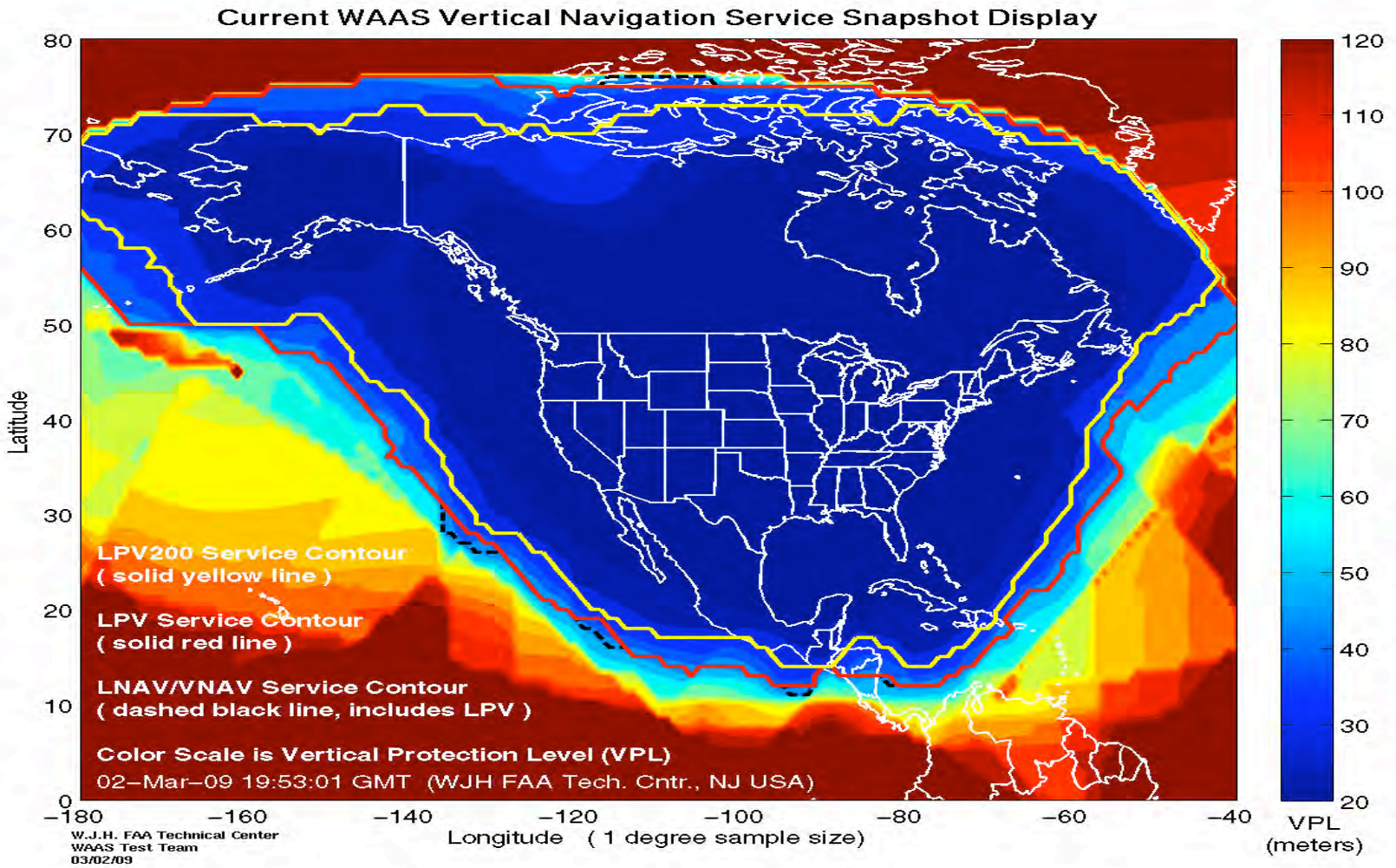
Courtesy:
Seebany
Datta-Barua

11/20/2004
21:00:00 GMT



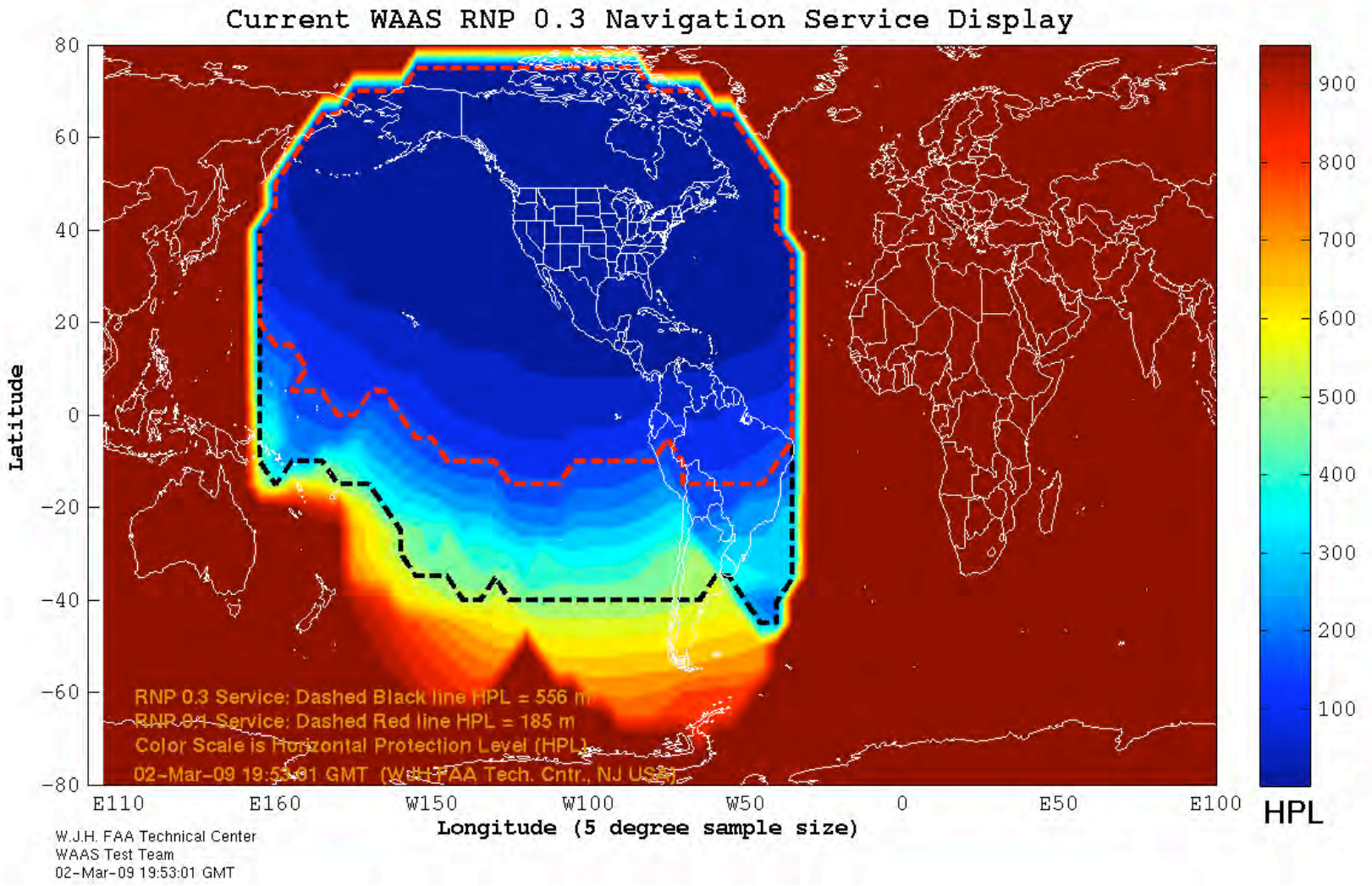


Localizer Performance Vertical (LPV) Coverage



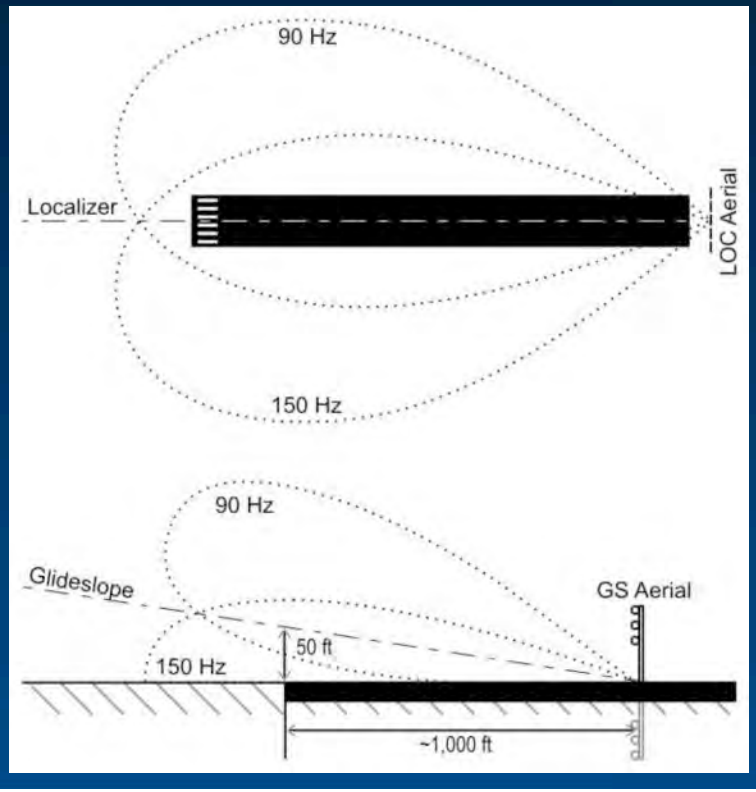
Courtesy:
Federal Aviation Administration

WAAS RNP 0.3 Current Coverage

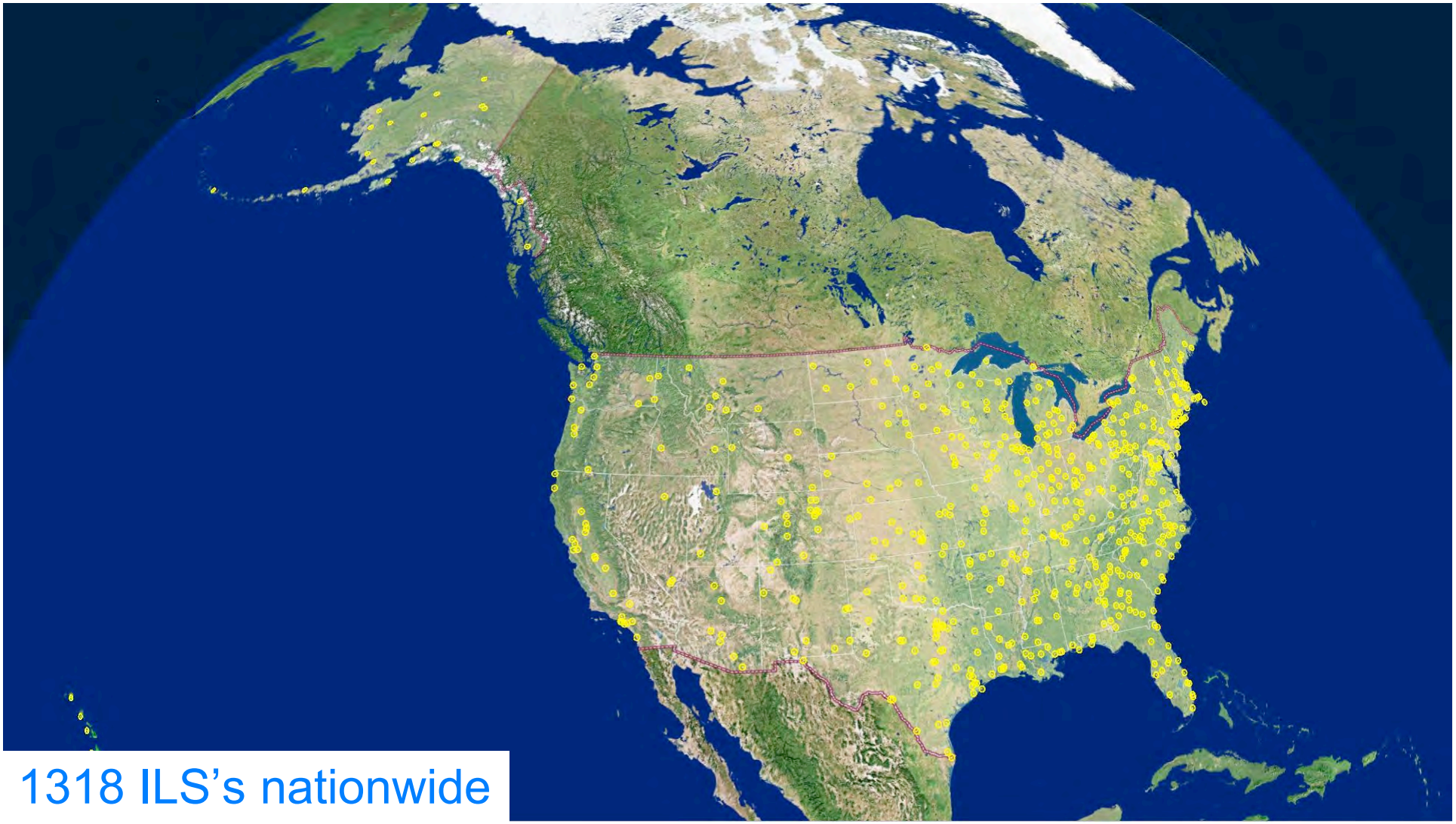


Navigational Aids

- Instrument Landing System (ILS)
  - *Glideslope antenna for vertical*
  - *Localizer for horizontal*

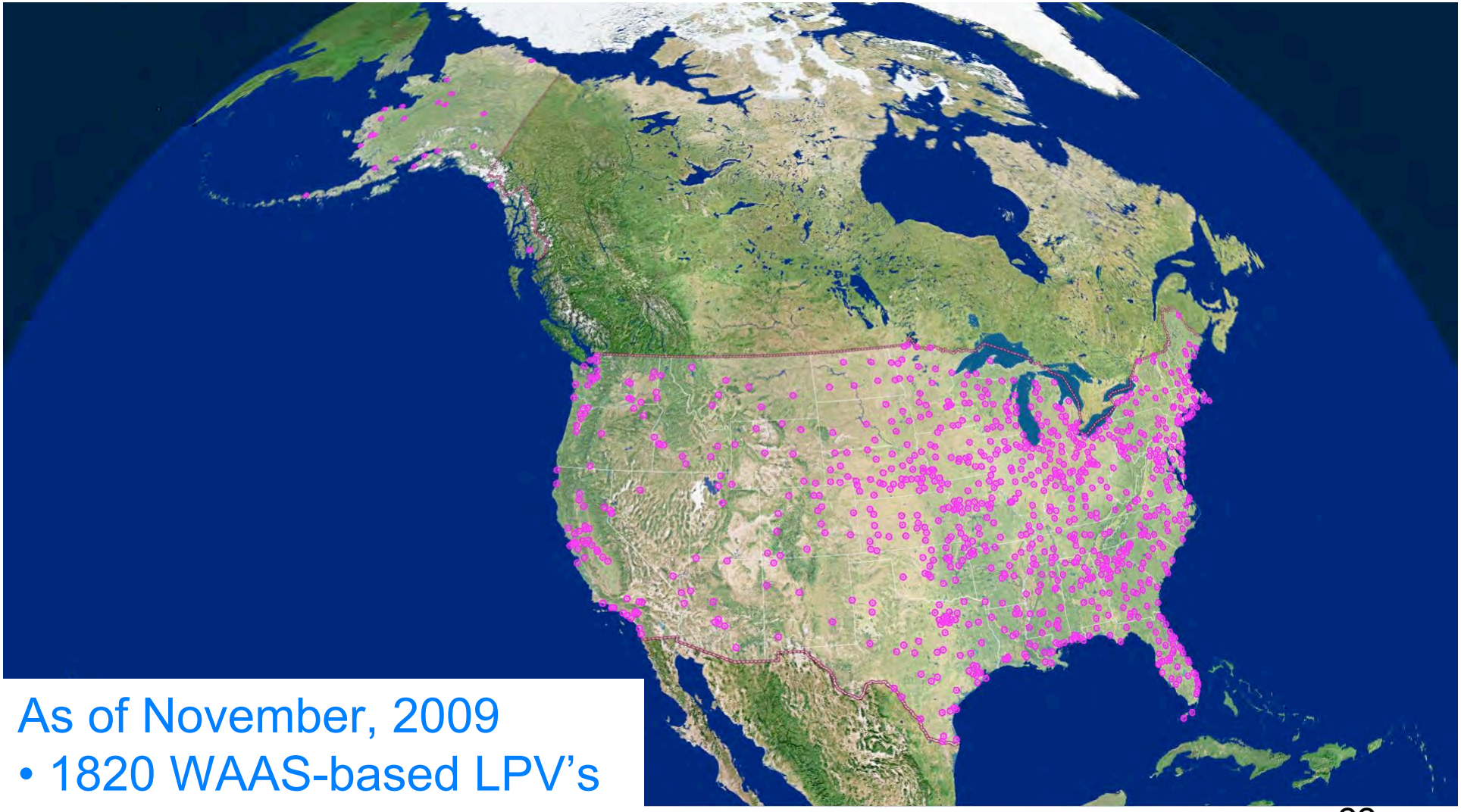


ILS Installations: Each Runway End Requires At Least Two Transmitters



1318 ILS's nationwide

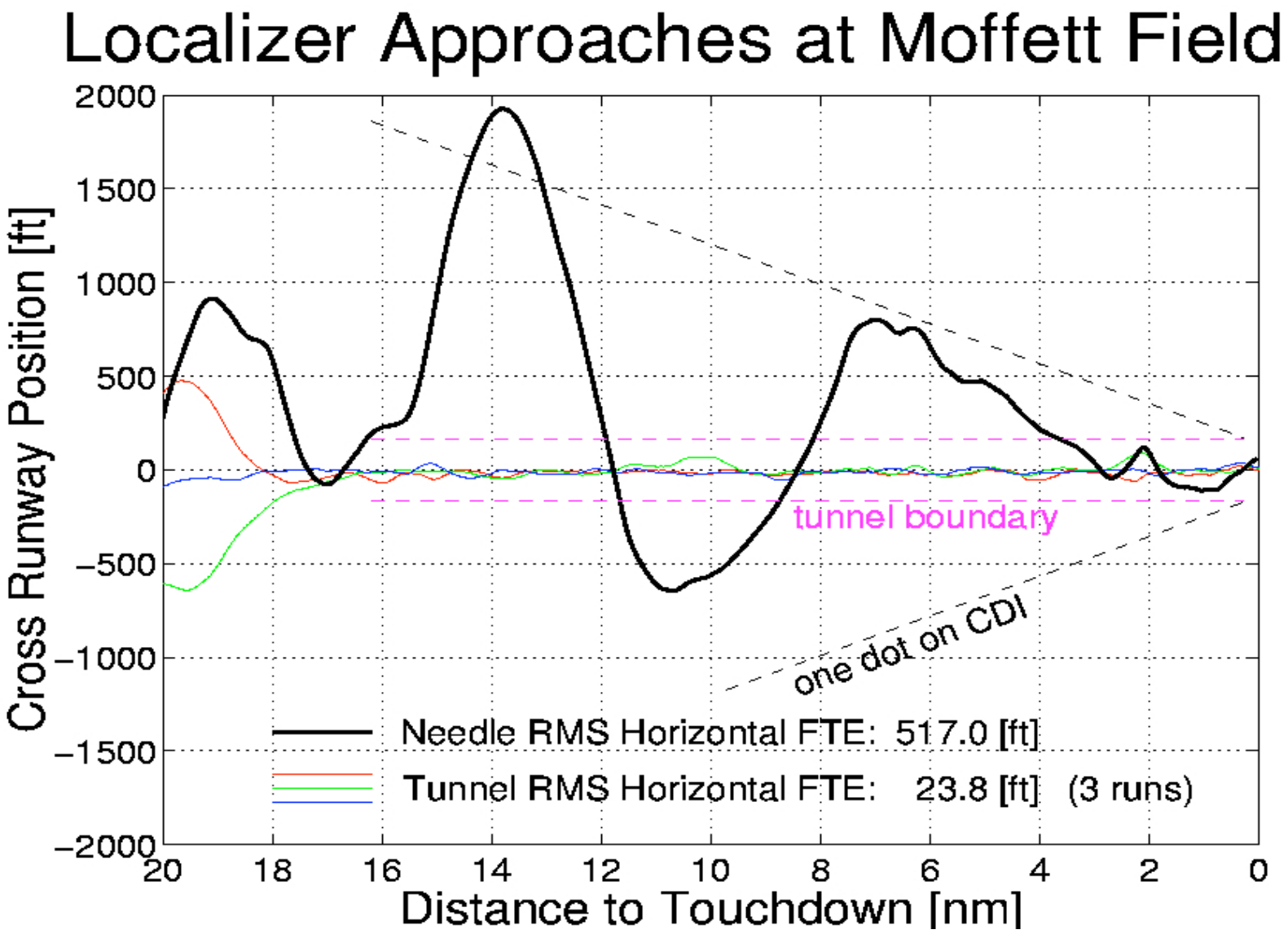
No GPS Equipment Required at Airport
50 Pieces of WAAS Equipment Serve the Continent



As of November, 2009

- 1820 WAAS-based LPV's
- ~1000 for non ILS runways

Localizer Approaches at Moffett Field

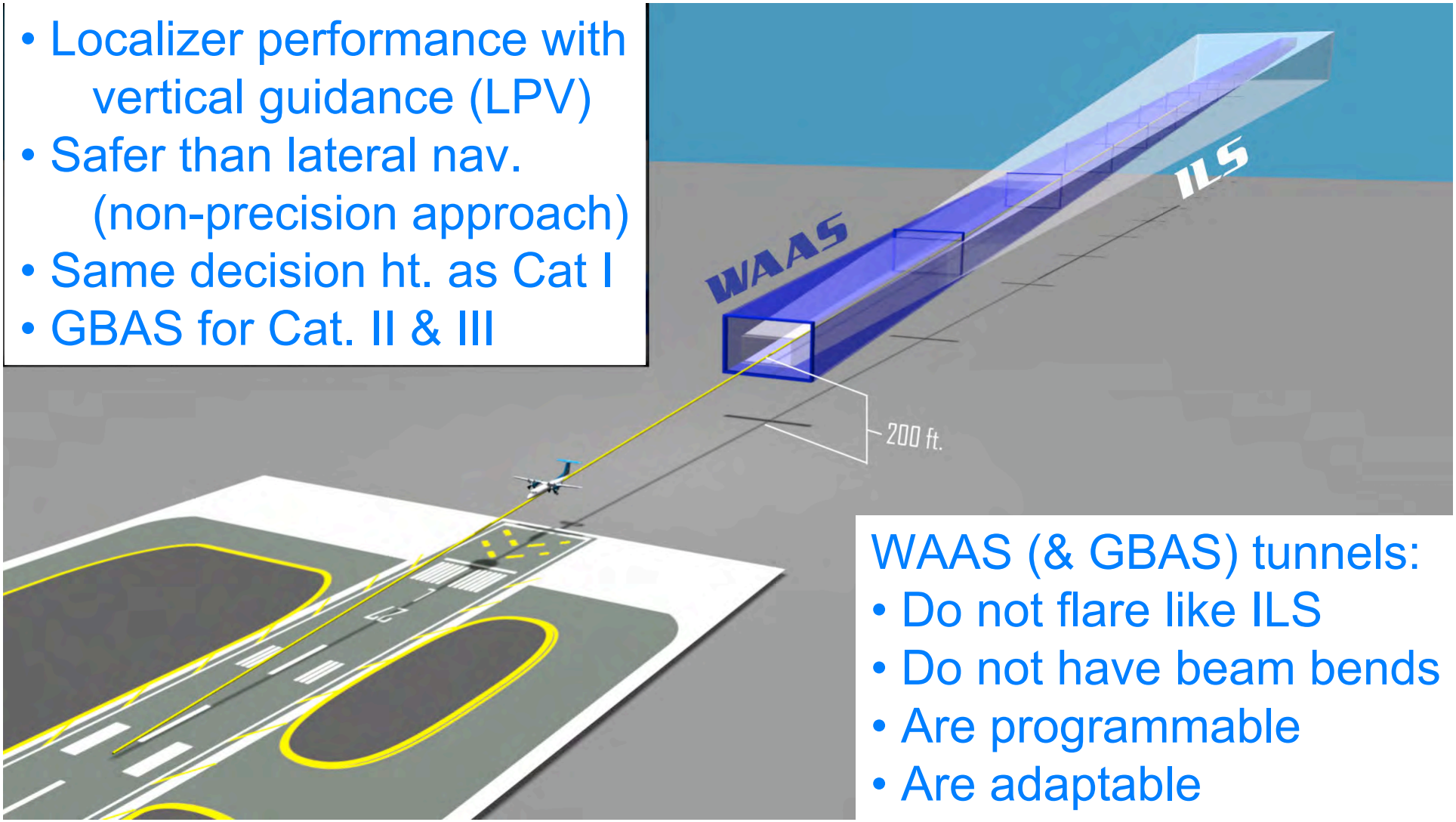


Courtesy:
Sharon Houck

Presented at
University of Calgary

Utility of Protected Accuracy from WAAS

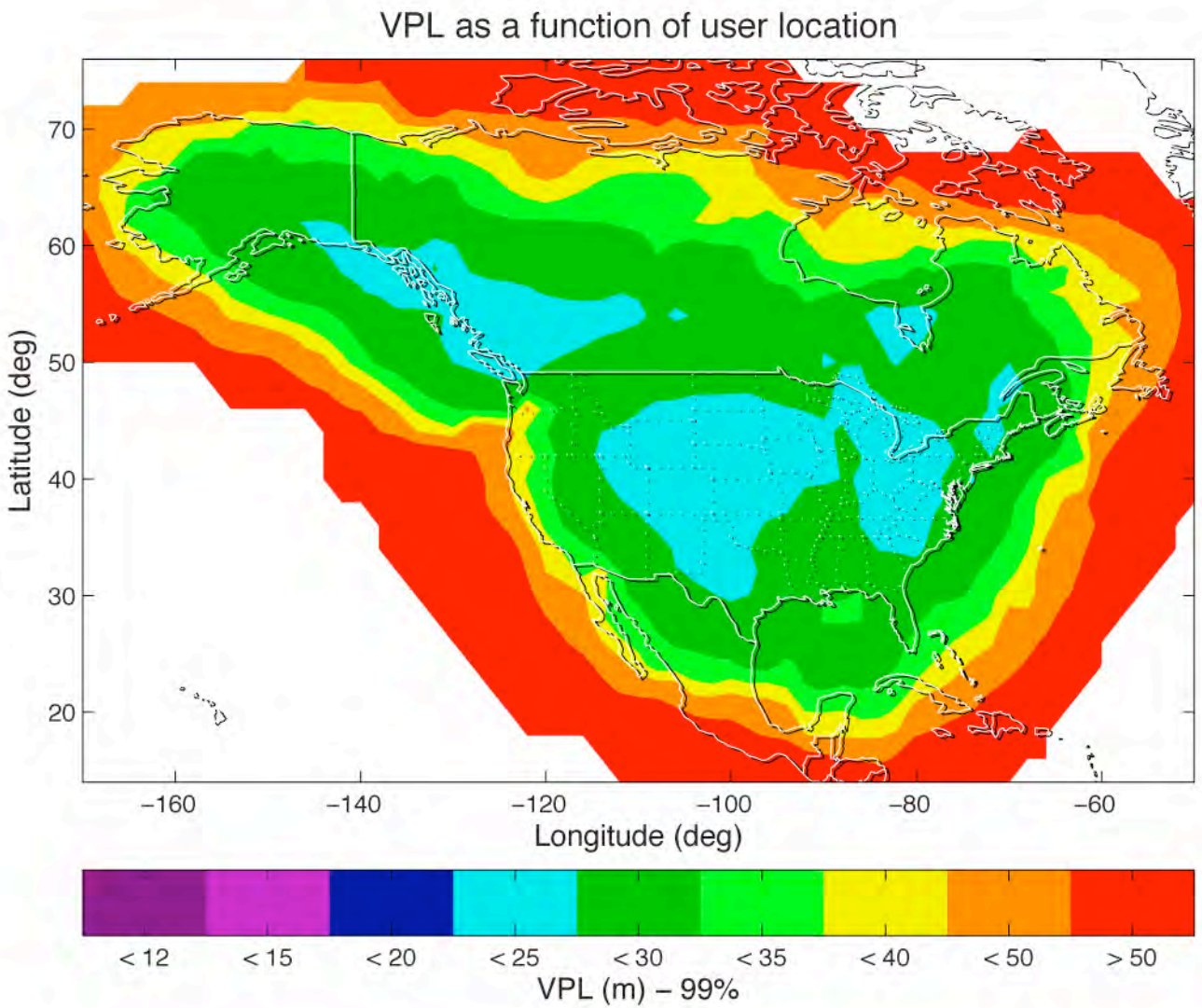
- Localizer performance with vertical guidance (LPV)
- Safer than lateral nav. (non-precision approach)
- Same decision ht. as Cat I
- GBAS for Cat. II & III



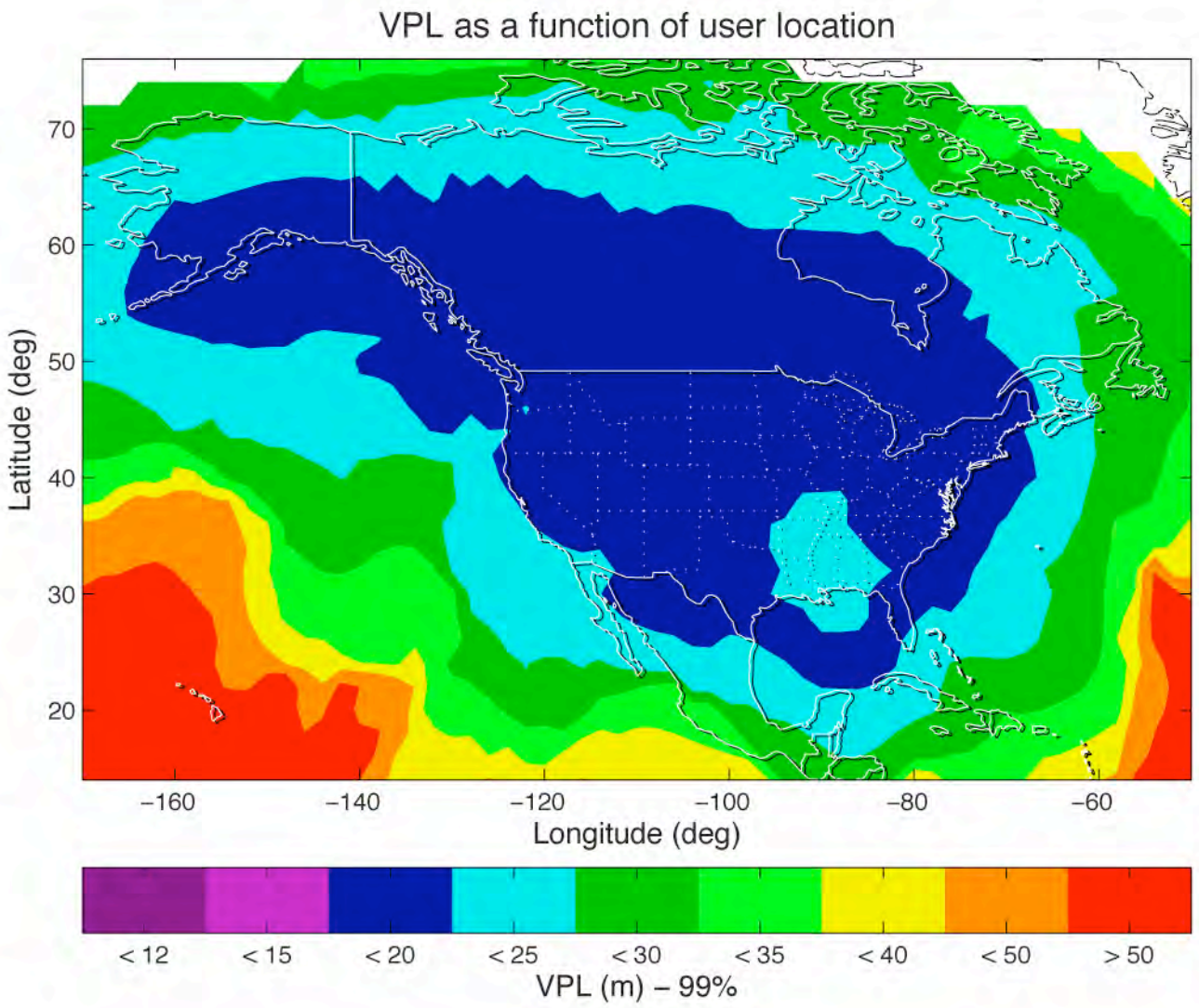
WAAS (& GBAS) tunnels:

- Do not flare like ILS
- Do not have beam bends
- Are programmable
- Are adaptable

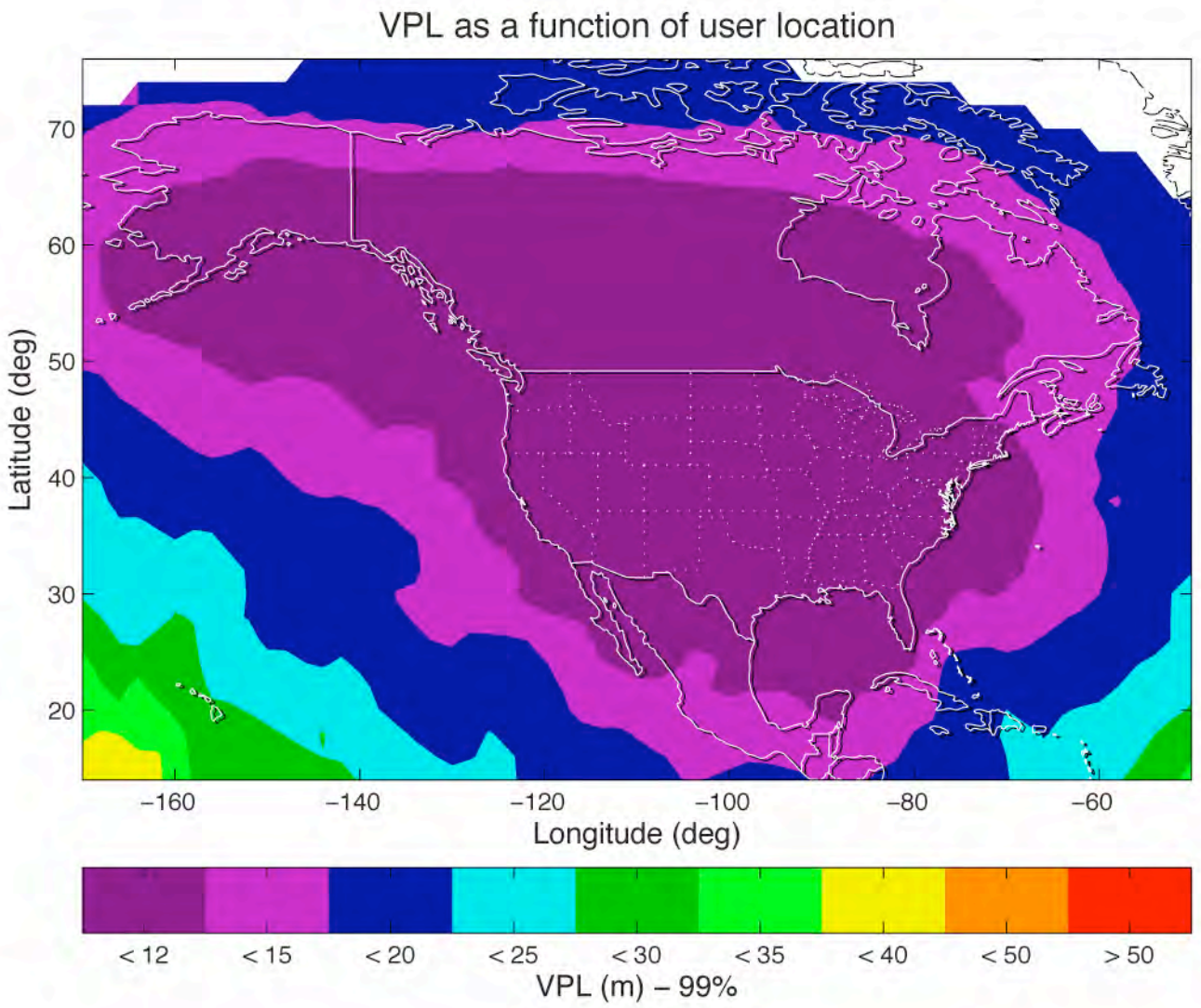
Current WAAS Performance



Future L1/L5 Performance



Potential of L1/L5 GPS/Galileo Performance



Conclusions

- WAAS is used to provide aircraft navigation from enroute through vertically guided approach
- Integrity was and is the key challenge
  - *Important to understand what can go wrong and how to protect users*
  - *Careful analysis of feasible threats*
- New civil frequencies and additional constellations may further improve performance