WAAS Technical Report
William J. Hughes Technical Center
Pomona, New Jersey
5/15/2024

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DR 158: Iono Activity
May 10-12, 2024
W2313D5 to W2314D0

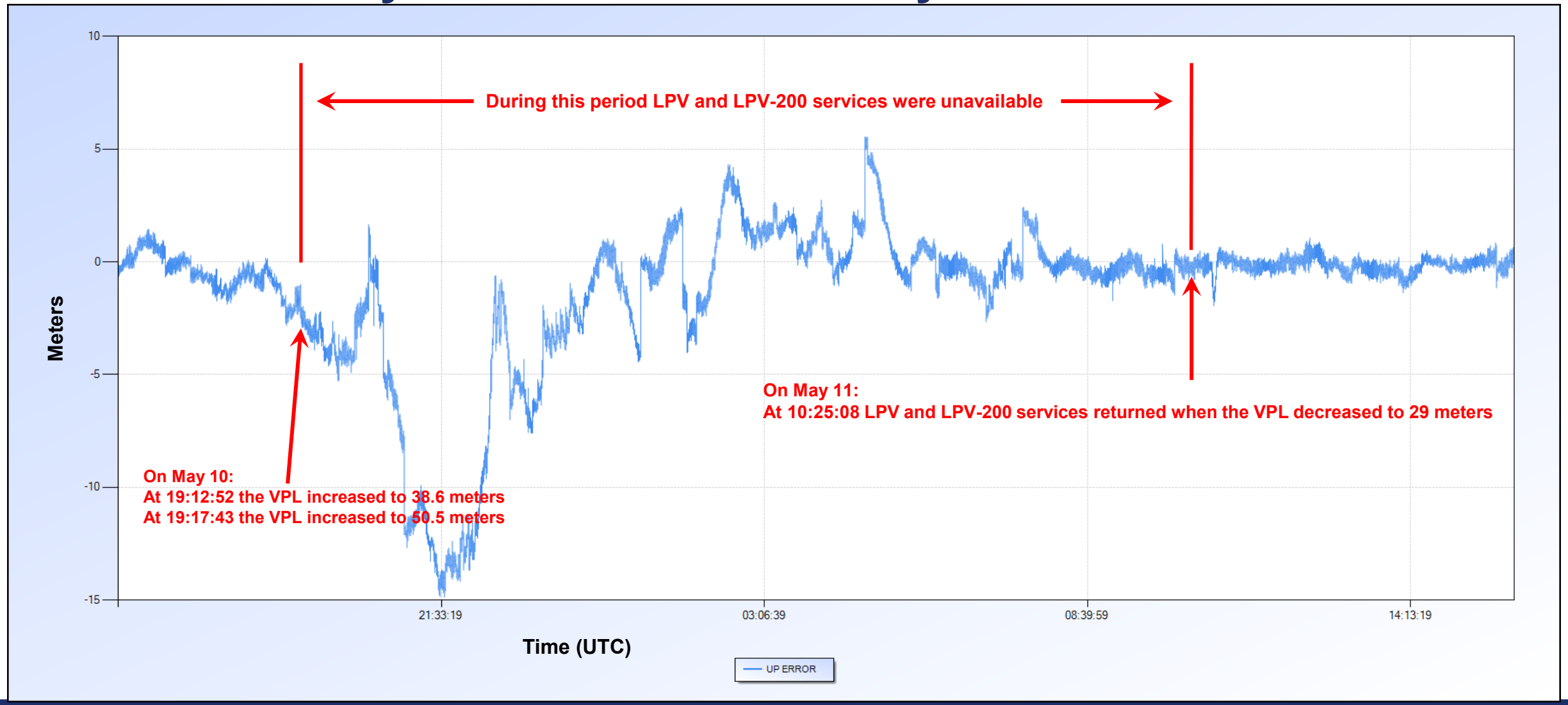
Introduction

- **On May 10-12, 2024, there was a loss of LP, LPV, and LPV-200 WAAS service in CONUS and Alaska**
  - The WAAS Extreme Storm Detector (ESD) tripped on May 10, causing an extended loss of vertical service by WAAS over the entire WAAS service volume
- **WAAS NPA coverage (at RNP 0.1 and RNP 0.3 levels of service) was not impacted**
- **Based on the number of airports with an LPV/LPV-200 outage and the length of the outages, this event is considered 'significant' for CONUS**
  - Categories are based on metrics established by the WAAS Test Team at the Tech Center
  - Iono events are categorized as either 'minor,' 'moderate,' or 'significant'
- **WAAS corrected, SPS, and dual frequency SPS (L1/L2) accuracy was examined at selected WRSs**
  - Albuquerque, Bethel, and Boston
- **Kp > 9 on May 10 and 11. Kp > 7 on May 12**

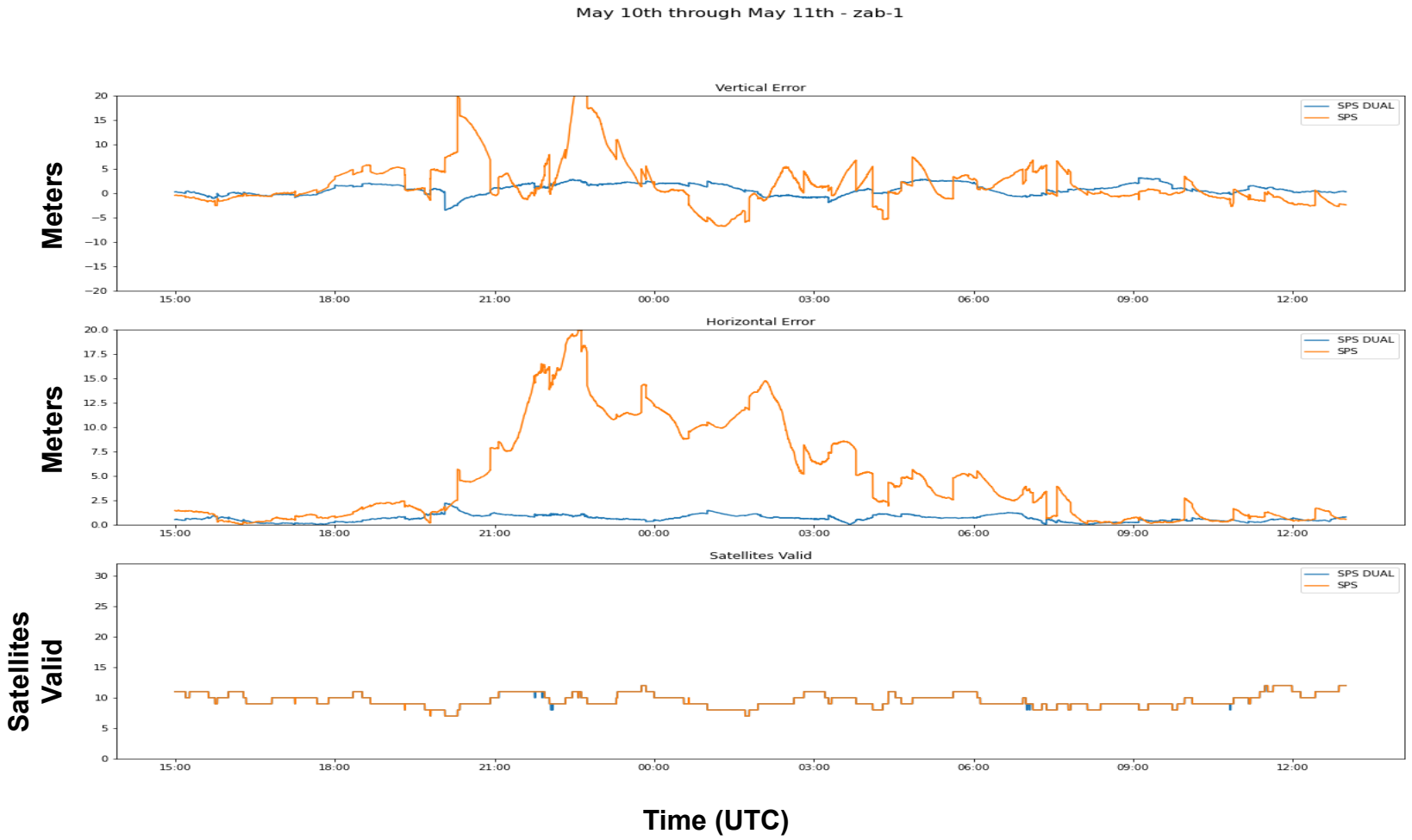
Position Accuracy May 10-11, 2024

- **The next few slides show position accuracy as calculated at the Albuquerque, Bethel, and Boston WRSs**
- **Vertical position error is shown with WAAS corrections, GPS only, and GPS only using a dual frequency (L1 and L2 codeless)**
  - The GPS and dual frequency are shown on the same plot for comparison
  - The GPS and dual frequency plots also show horizontal error and the number of satellites used in the solution
- **Also shown is the difference in the number of satellites used in the position solution on May 9 and May 10/11**
  - This difference is shown to see if the iono event caused satellite tracking to be affected

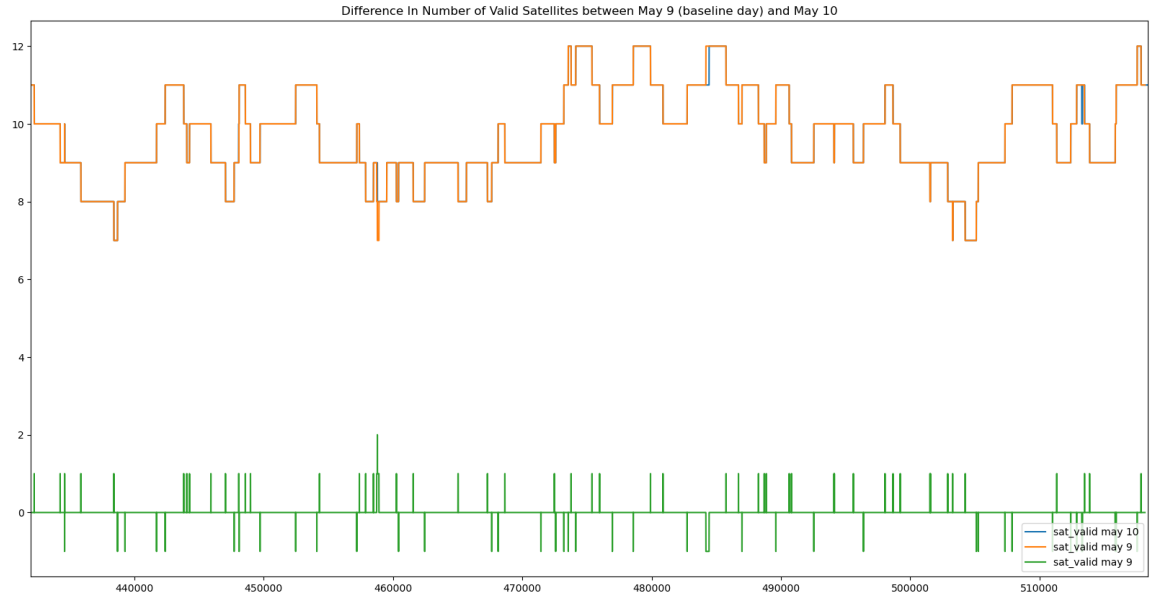
Vertical Position Errors at Albuquerque from May 10 at 16:00 UTC to May 11 at 16:00 UTC



Albuquerque WRS GPS and Dual Frequency GPS Position Error

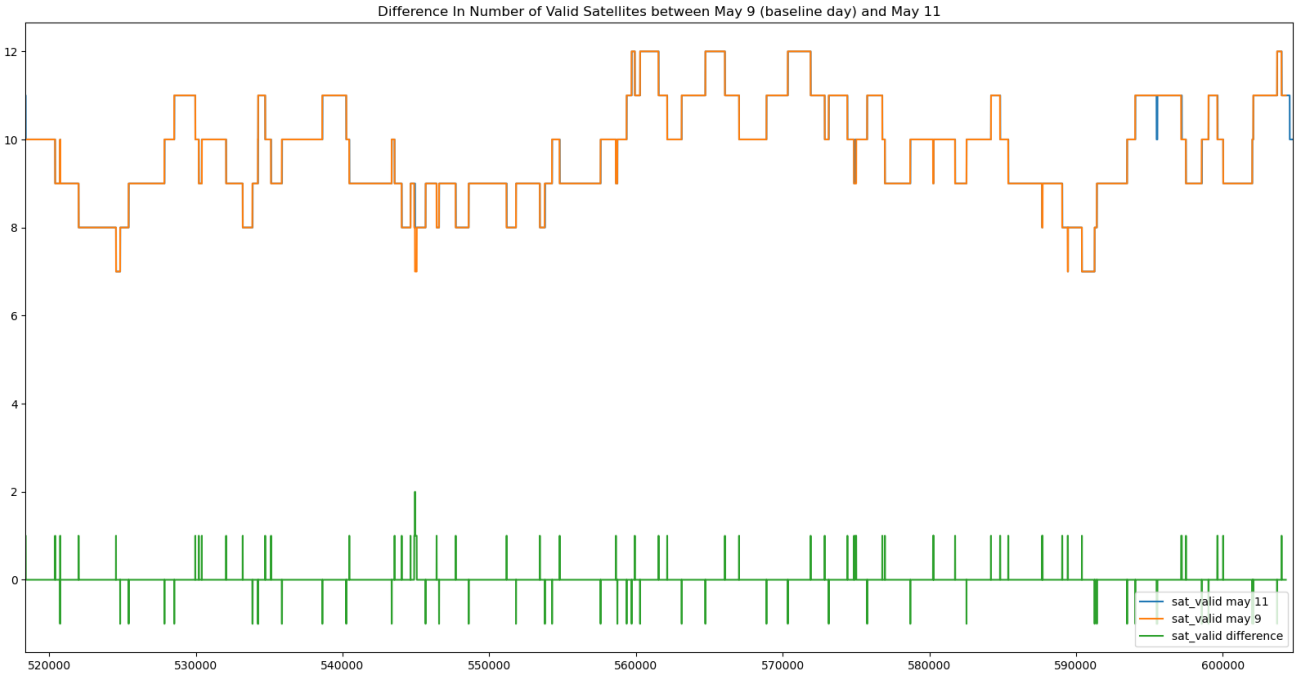


Difference in Number of Satellites Used – Albuquerque



May 9 vs. May 10

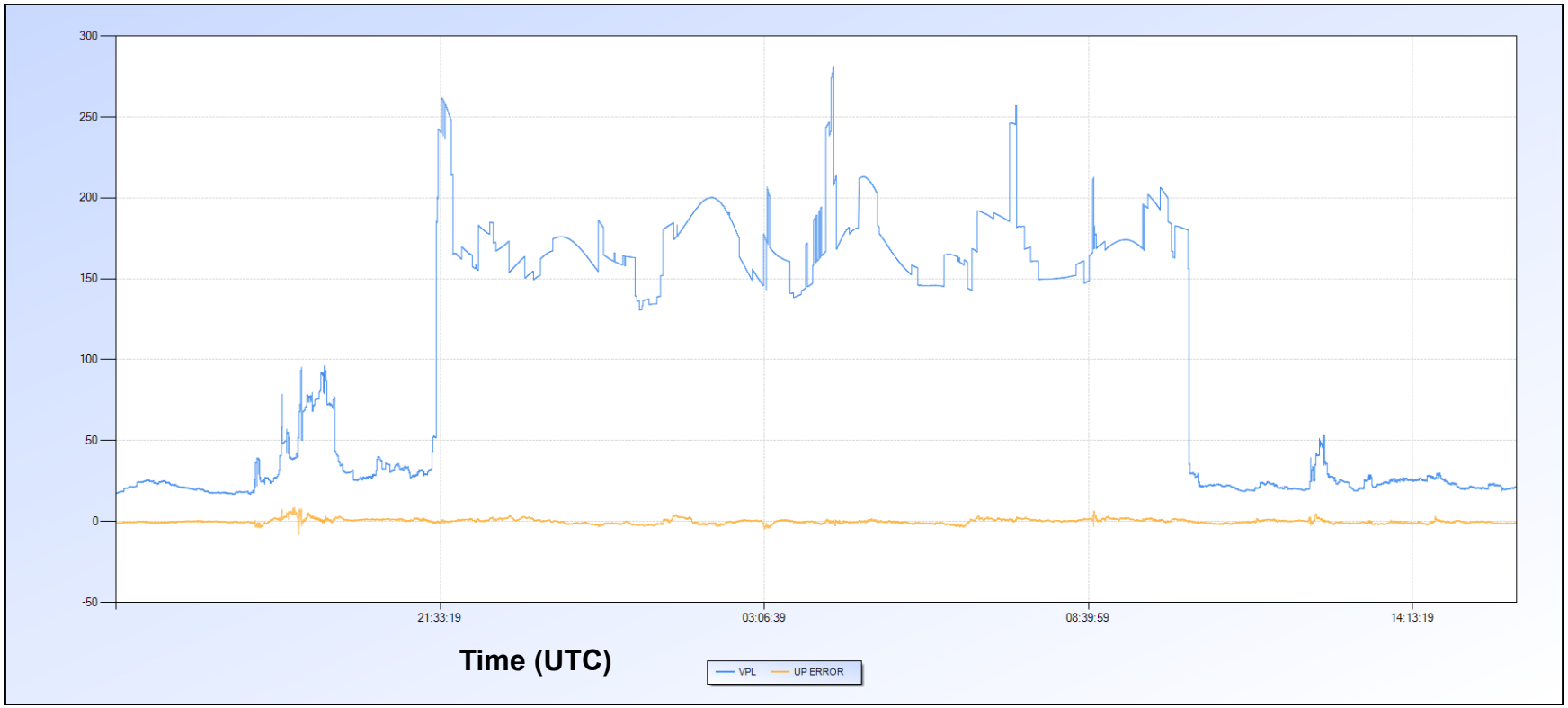
The number of satellites used in the user position solution is shown in orange. The difference for May 10 and 11 compared to May 9 is shown in green. A difference on one or two satellites is not significant since that difference could be because of satellites rising or setting at a slightly different time each day.



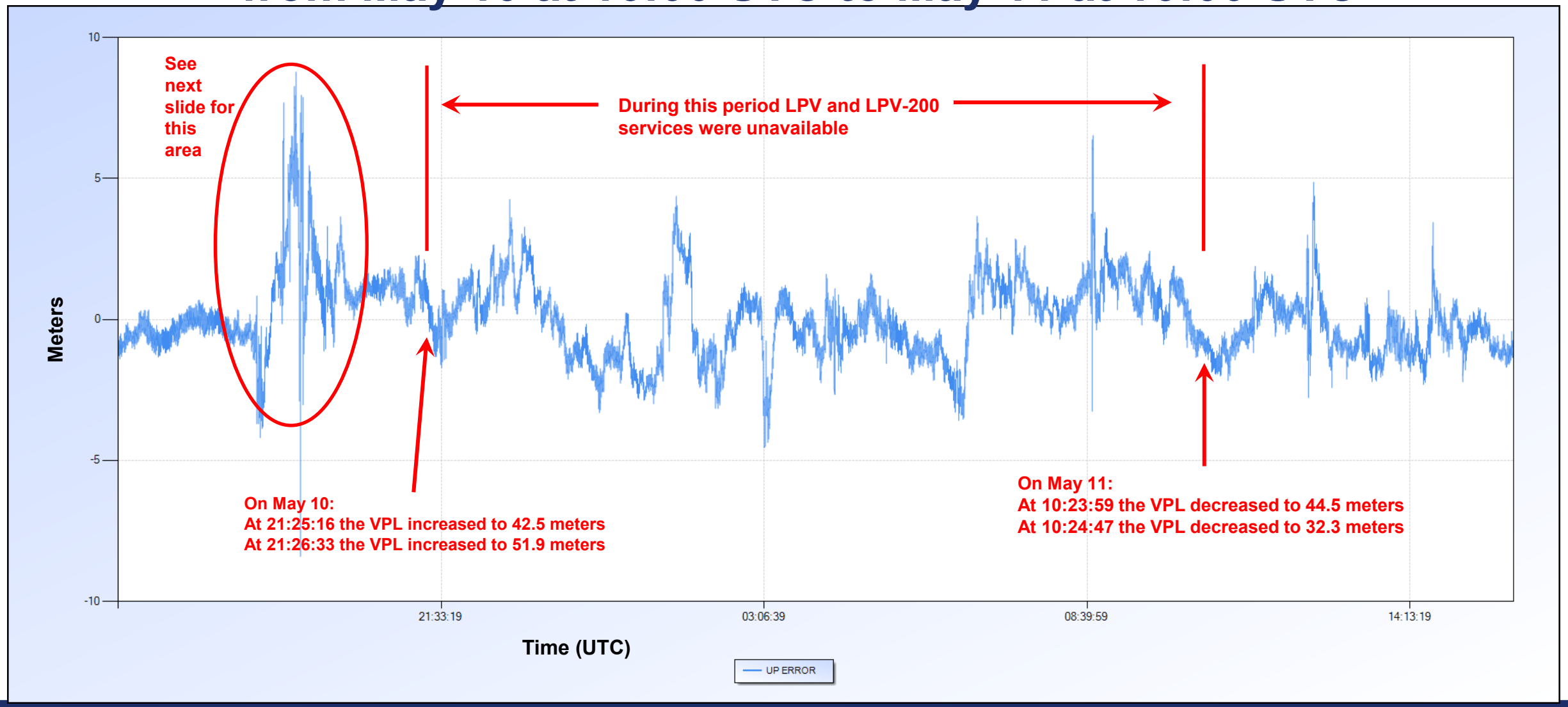
May 9 vs. May 11

Vertical Protection Level at Bethel from May 10 at 16:00 UTC to May 11 at 16:00 UTC

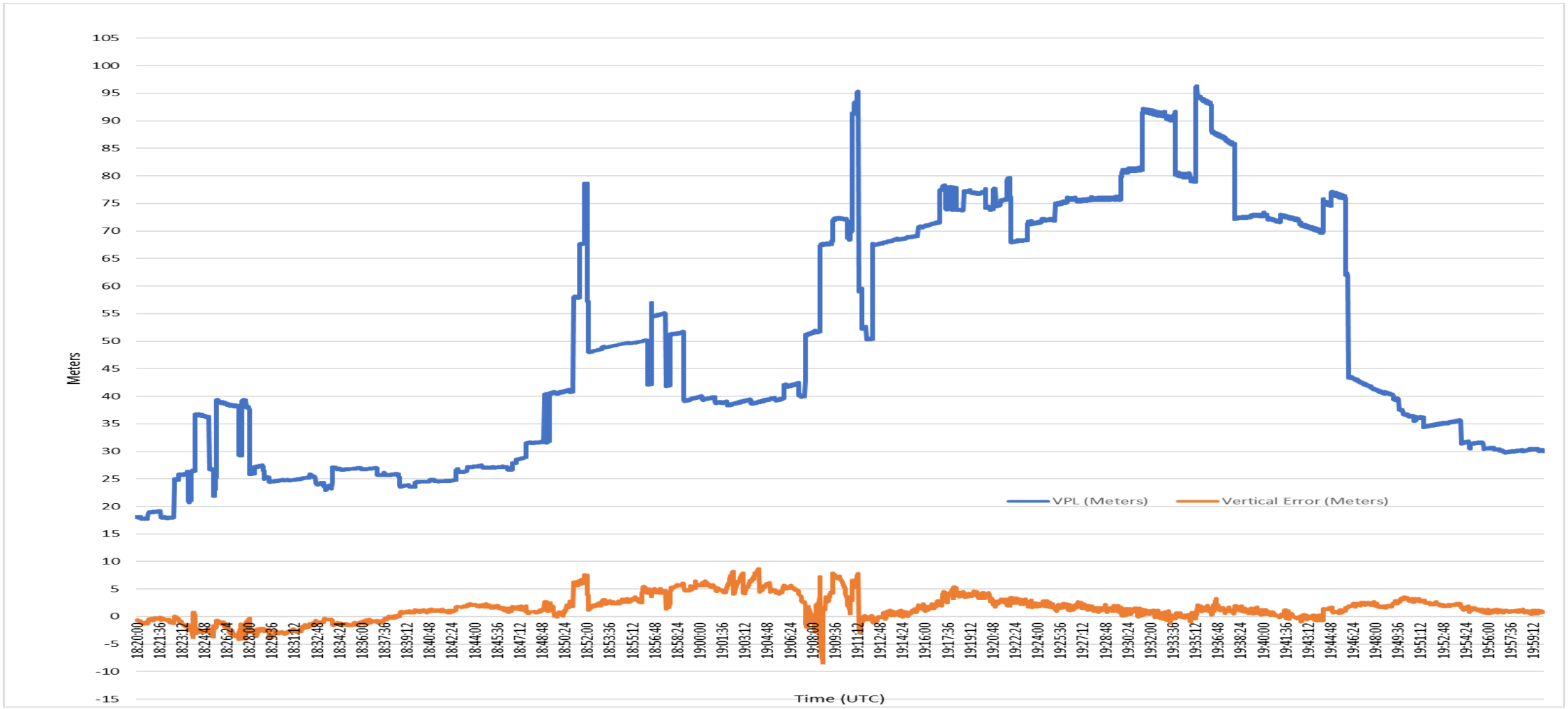
- **The VPL as calculated at the Bethel WRS had a different signature than other WRSs shown in this presentation**
  - As shown below there are periods of VPLs > 35 and 50 meters before and after the primary period of high VPLs
  - The next slide shows times for the primary period of high VPLs



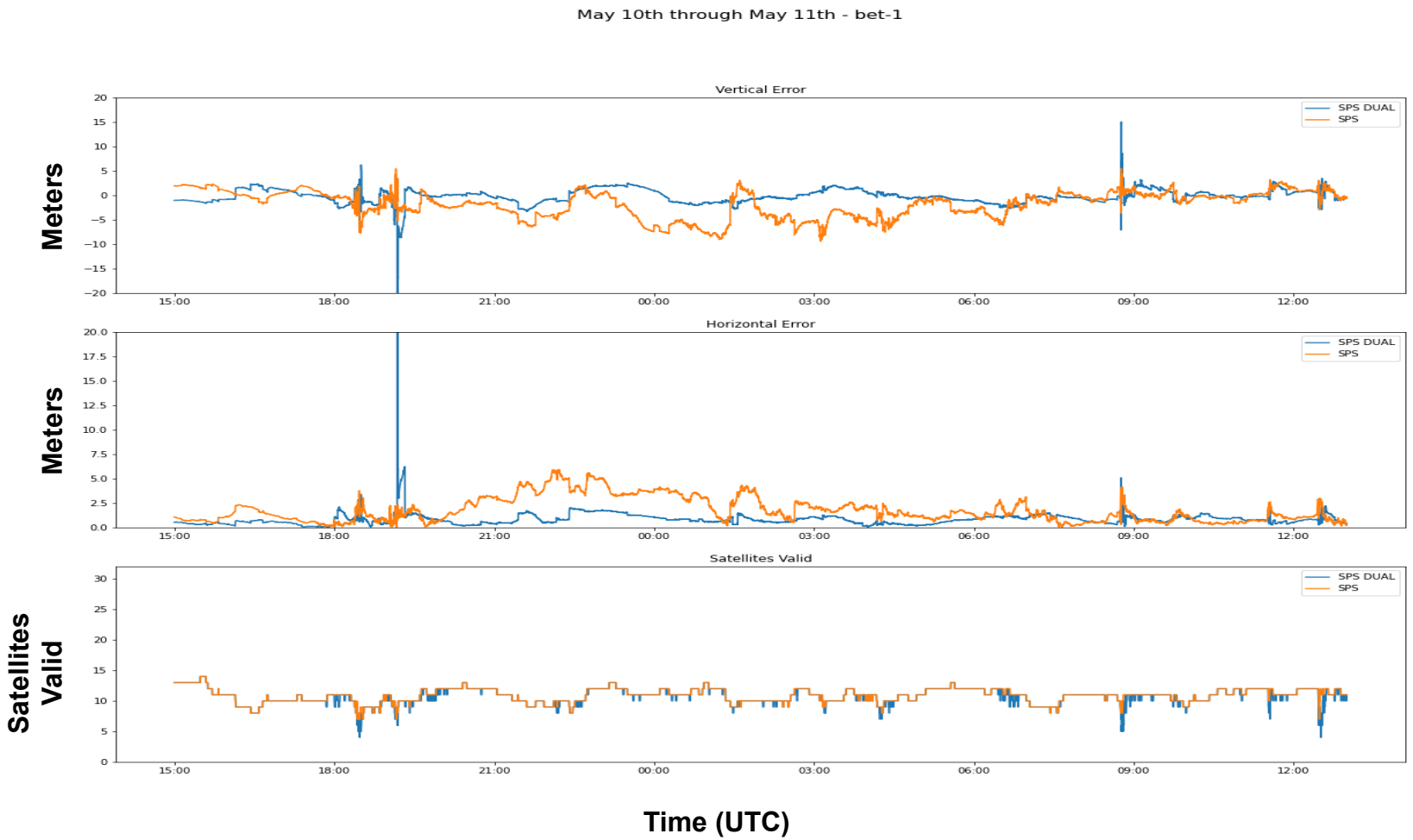
Vertical Position Errors at Bethel from May 10 at 16:00 UTC to May 11 at 16:00 UTC



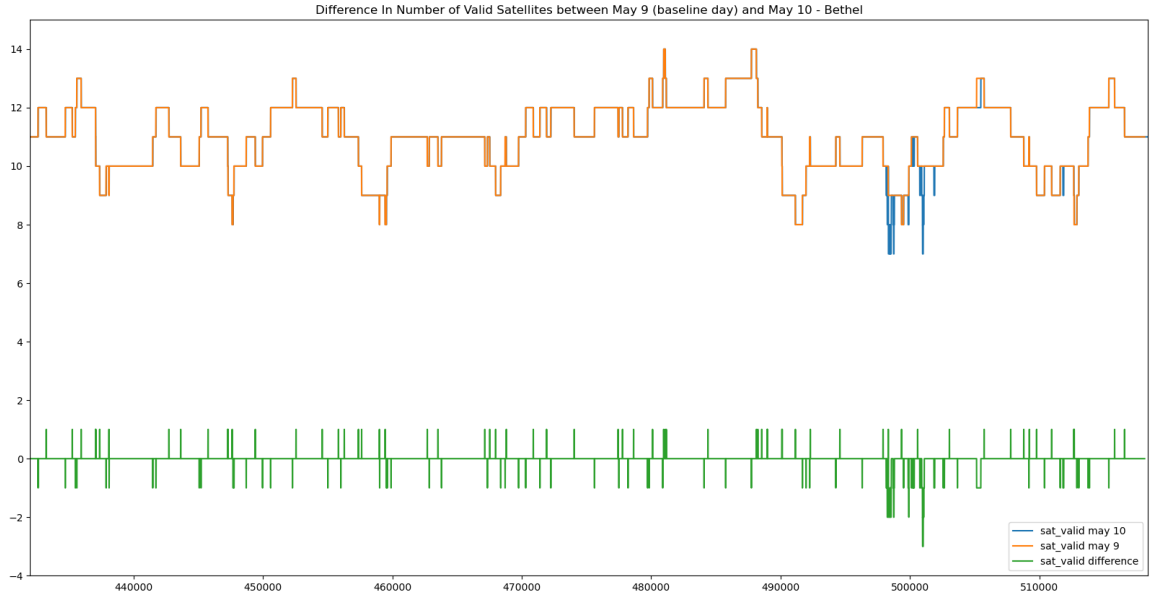
Bethel VPL and Vertical Error on May 10 from 18:20 to 20:00 UTC



Bethel WRS GPS and Dual Frequency GPS Position Error



Difference in Number of Satellites Used – Bethel



May 9 vs. May 10

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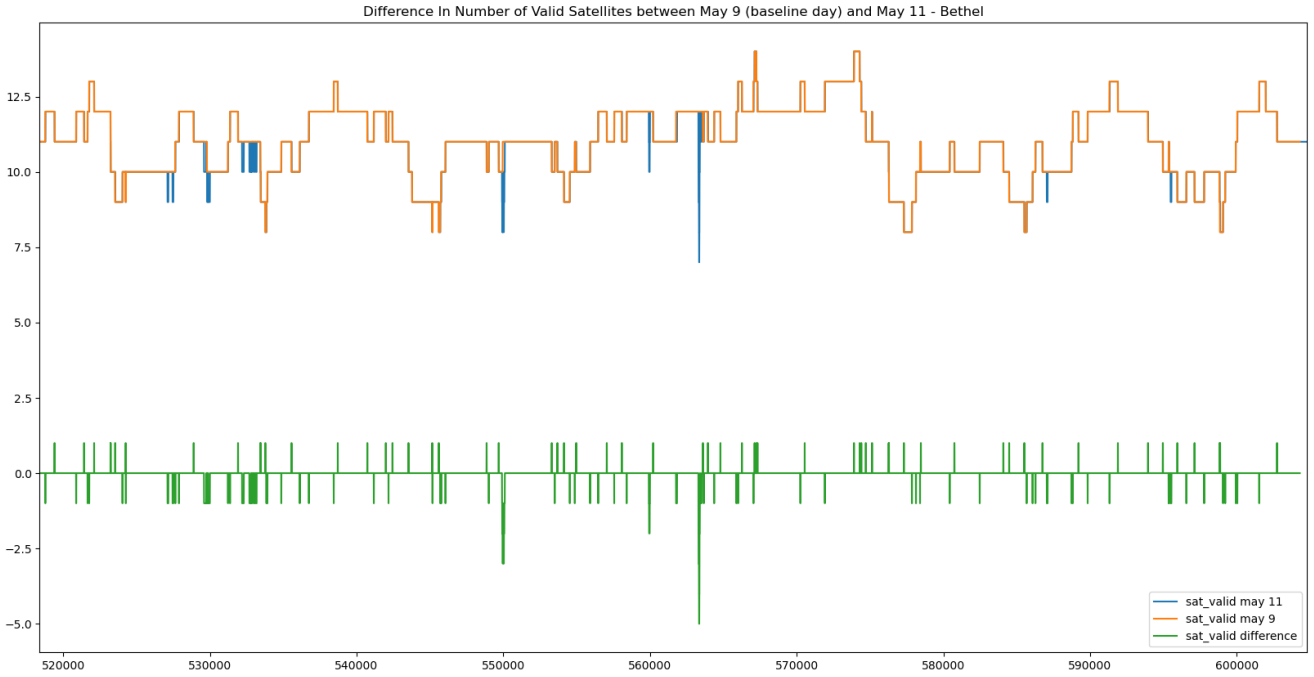
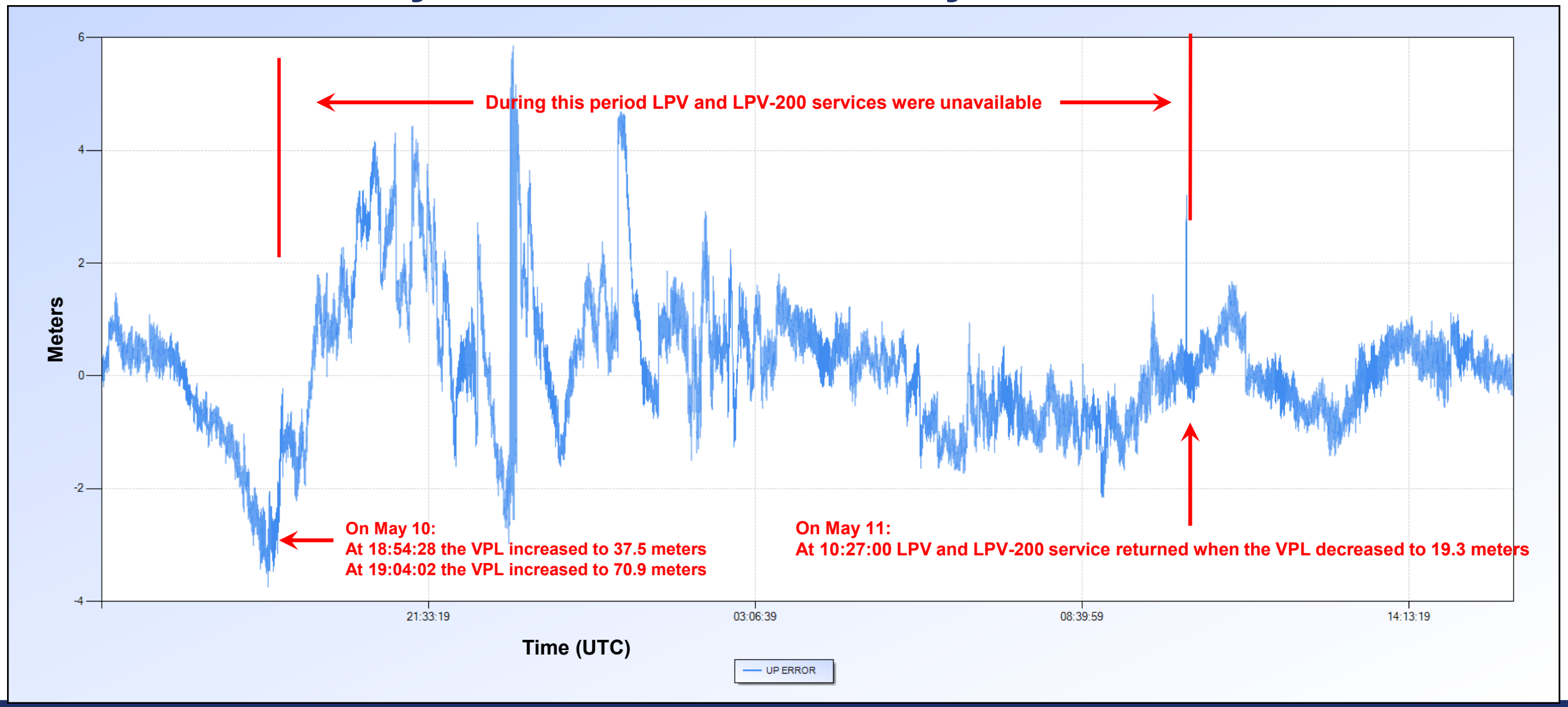
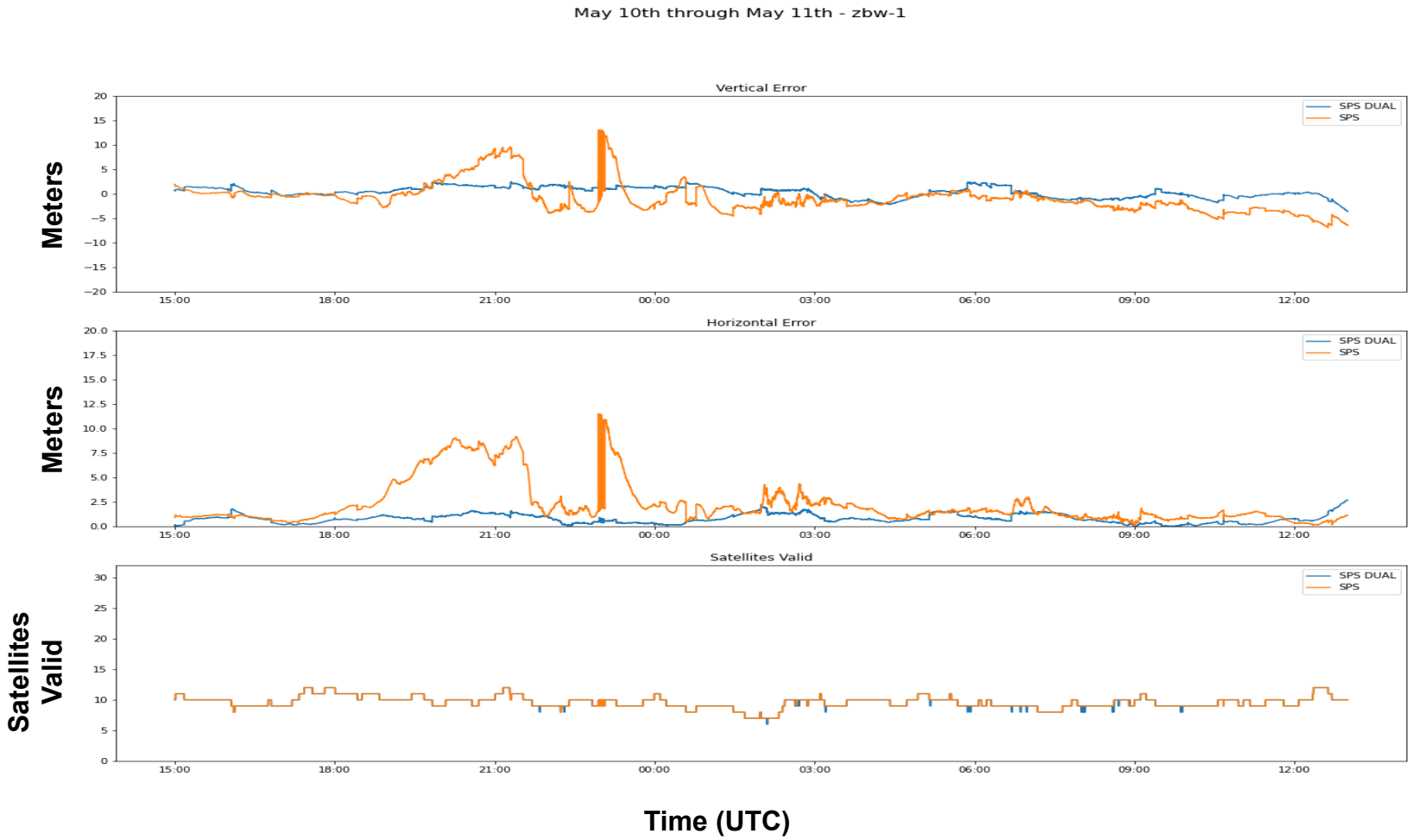


May 9 vs. May 11

Vertical Position Errors at Boston from May 10 at 16:00 UTC to May 11 at 16:00 UTC



Boston WRS GPS and Dual Frequency GPS Position Error



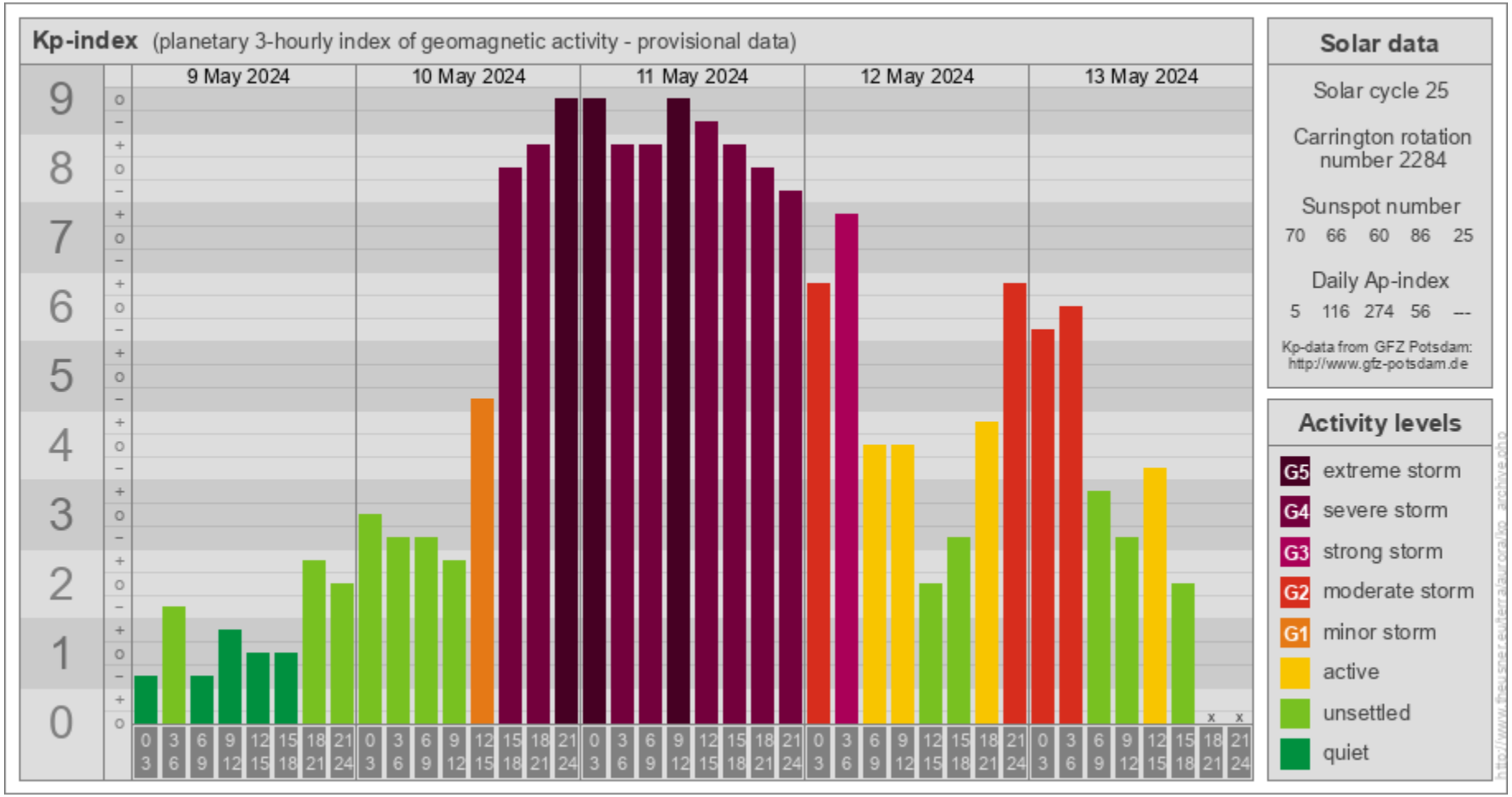
Airport Outages May 10-11, 2024

- **The next slide shows number of airports that had LPV and/or LPV-200 service outages**
- **Number of airports with an LPV outage are the number of airports that have a published LPV approach (this is both LPV and LPV-200 approaches)**
- **Number of airports with LPV-200 outages is showing the smaller subset of the LPV airports with a published LPV-200 approach that experienced an LPV-200 service outage**
- **The Outage Duration Range column shows the duration of the shortest and longest consecutive service outage with a 15-minute threshold between 2 or more service outages counting towards a single outage**
  - The time duration (in seconds) between 2 or more service outages within 15 minutes of each other is included in the duration

Airports with WAAS LPV/LPV-200 Service Outages
May 10-11, 2024

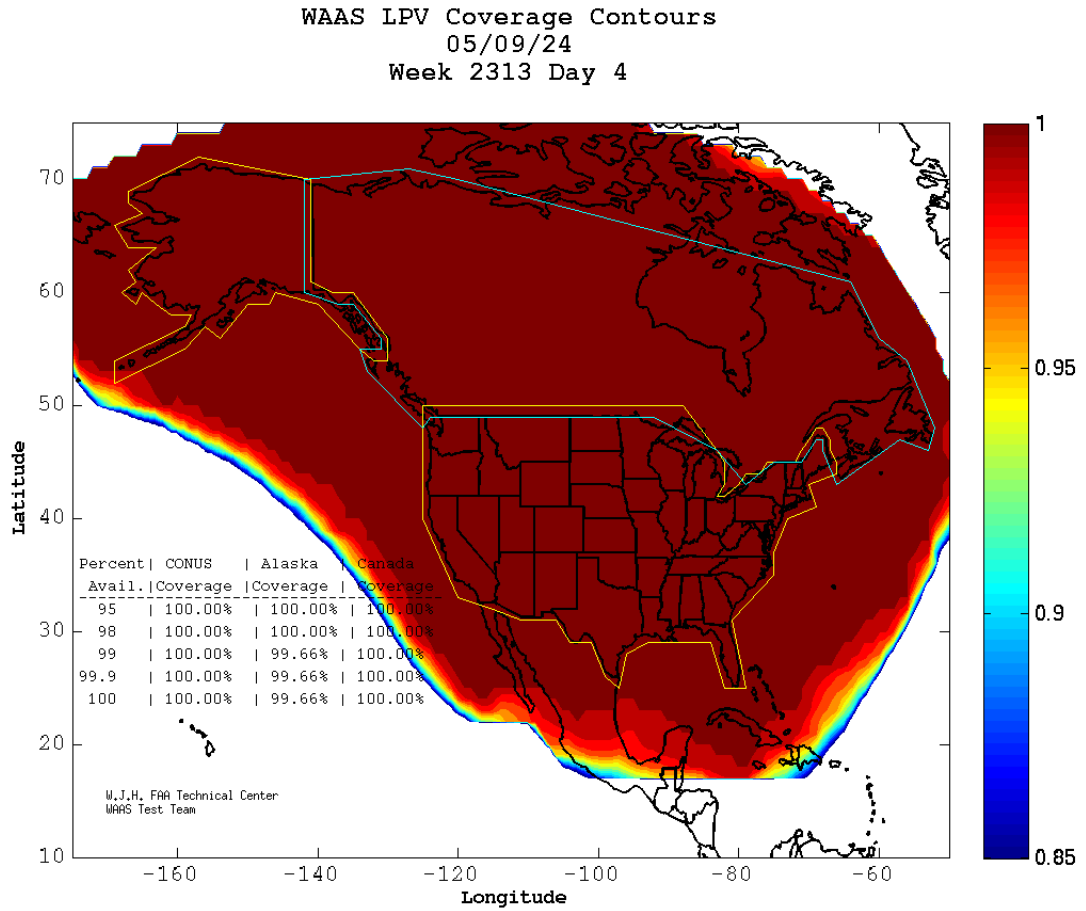
Area/Service Level	Number of Airports with Outage (5/10/24 – 5/11/24)	Number of Airports with Outages greater than or equal to 15 minutes (5/10/24 – 5/11/24)	Outage Duration Range (5/10/24 – 5/11/24) + There were CONUS LPV200 outages on May 10 in MS, LA, AL, TX and on May 11 in NM, TX, AZ that were <20 minutes, but these are repeatable daily outages and not during the time of the iono event. ++ There was Alaska LPV and LPV200 outages on May 11 between 1 – 34 minutes after the end of the main iono event.
CONUS/LPV	May 10: 1921 May 11: 1921 Combined: 1921	May 10: 1921 May 11: 1921 Combined: 1921	May 10: 269 – 312 minutes May 11: 626 – 640 minutes Combined: 896 – 938 minutes
CONUS/LPV-200	May 10: 614 May 11: 614 Combined: 614	May 10: 614 May 11: 614 Combined: 614	May 10: 276 – 322 minutes+ May 11: 626 – 640 minutes+ Combined: 903 – 961 minutes
Alaska/LPV	May 10: 60 May 11: 60 Combined: 60	May 10: 60 May 11: 60 Combined: 60	May 10: 1 – 328 minutes May 11: 625 – 629 minutes++ Combined: 819 – 951 minutes
Alaska/LPV-200	May 10: 10 May 11: 10 Combined: 10	May 10: 10 May 11: 10 Combined: 10	May 10: 5 – 327 minutes May 11: 625 – 635 minutes++ Combined: 880 – 962 minutes

Kp Index for May 9 – May 13, 2024

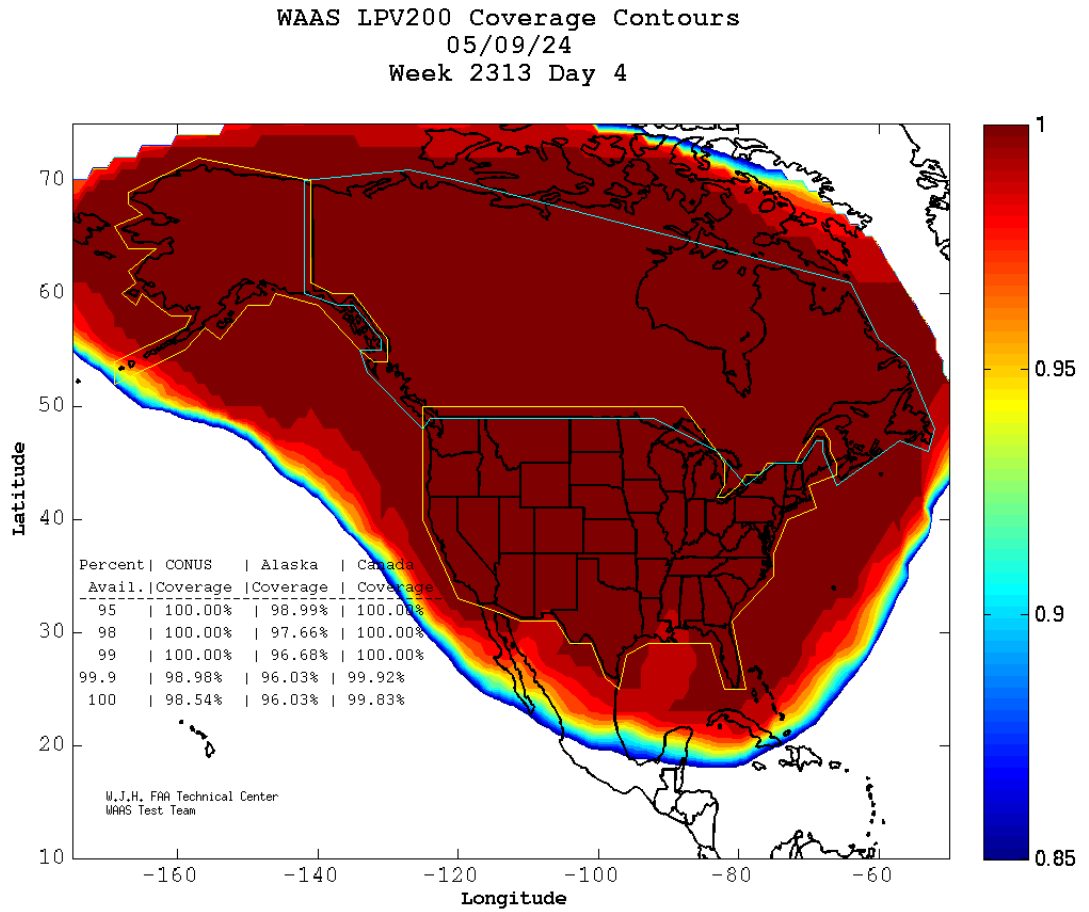


Retrieved from [Kp- and Kpa-index archive - Homepage of Michael Theusner]

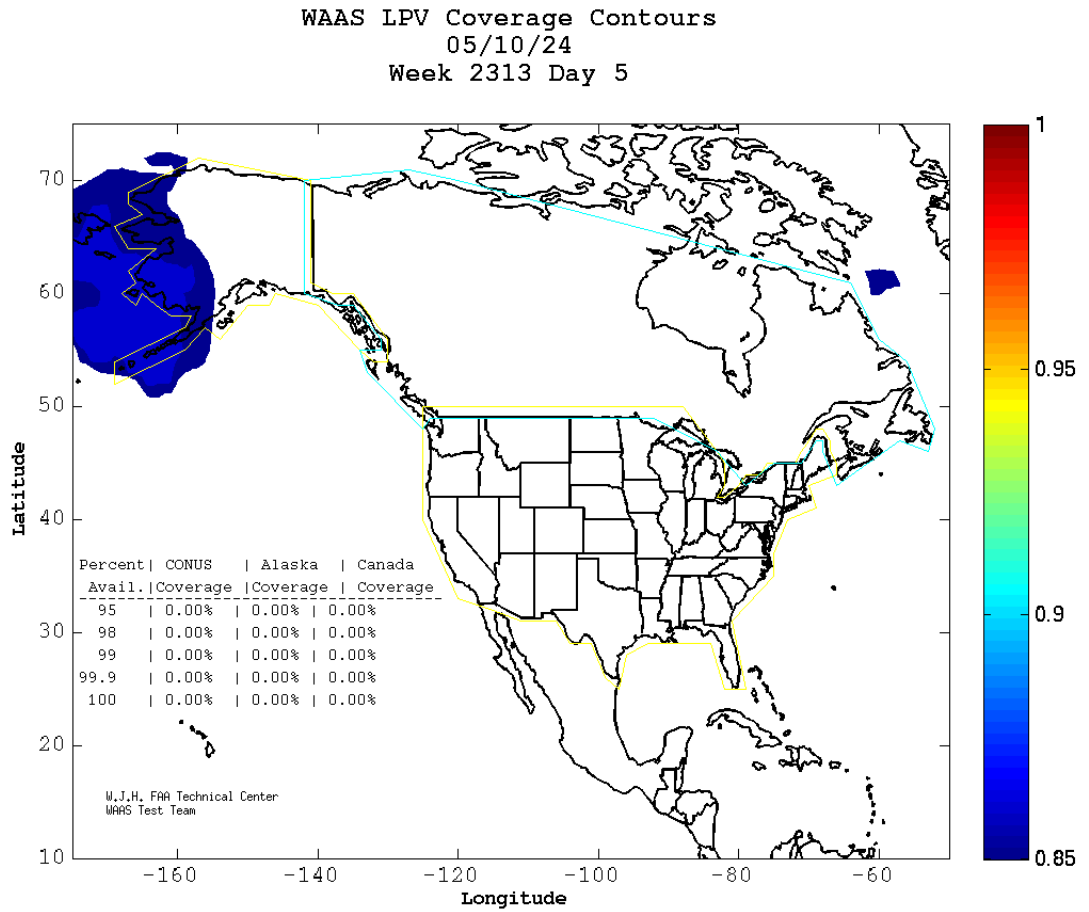
LPV Coverage Plot for May 9, 2024



LPV-200 Coverage Plot for May 9, 2024

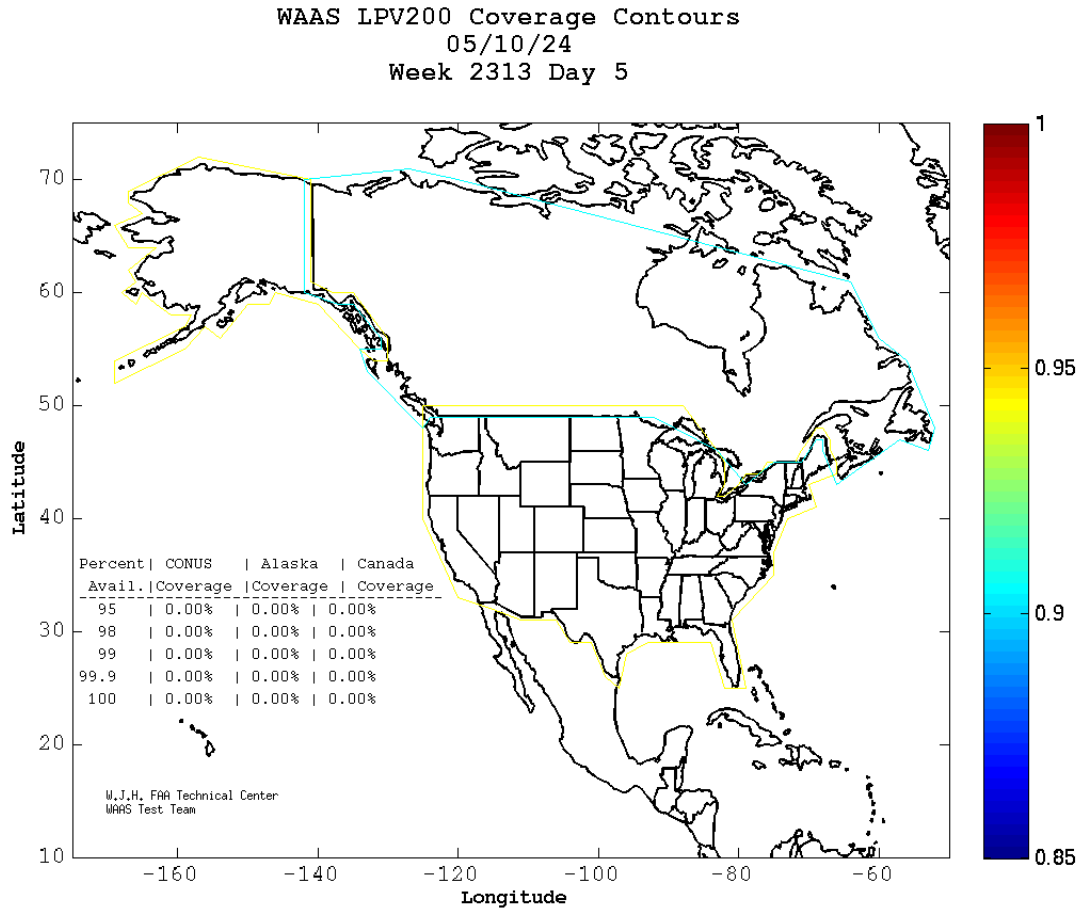


LPV Coverage Plot for May 10, 2024



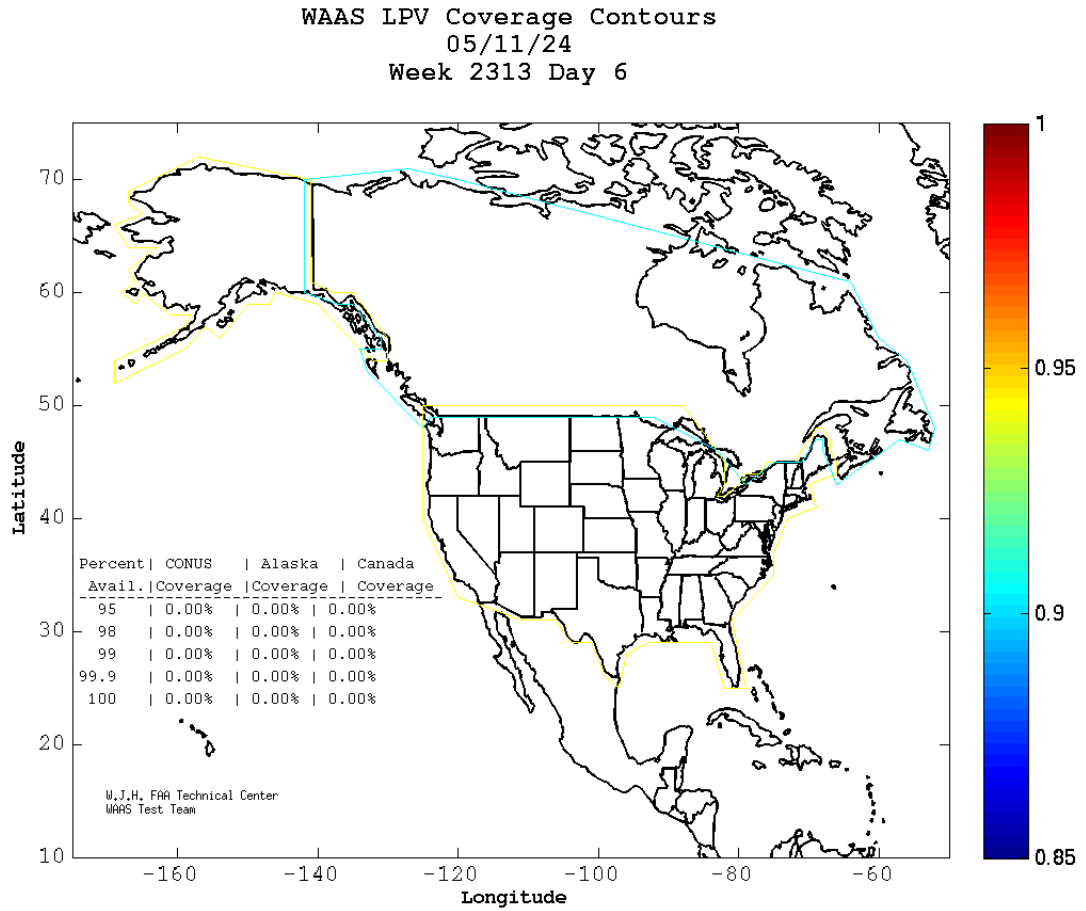
NOTE: All white means the availability is less than 85%

LPV-200 Coverage Plot for May 10, 2024



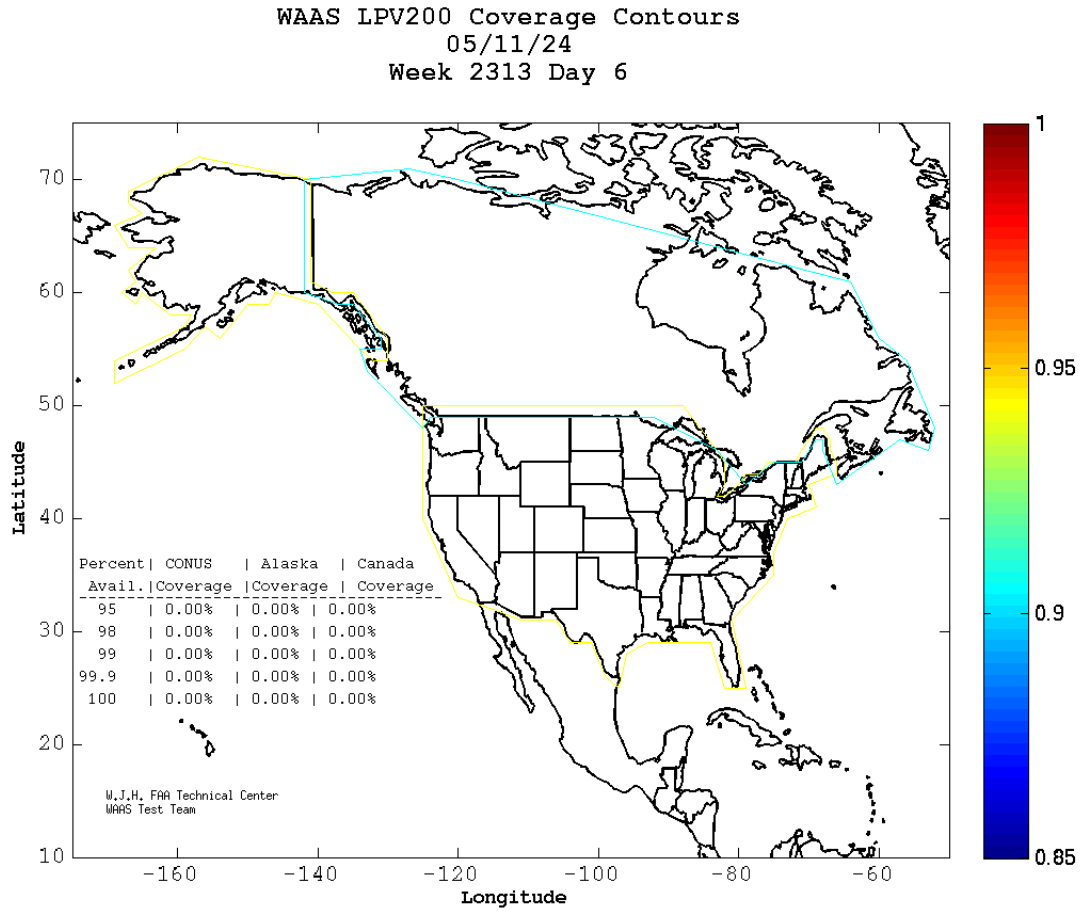
NOTE: All white means the availability is less than 85%

LPV Coverage Plot for May 11, 2024



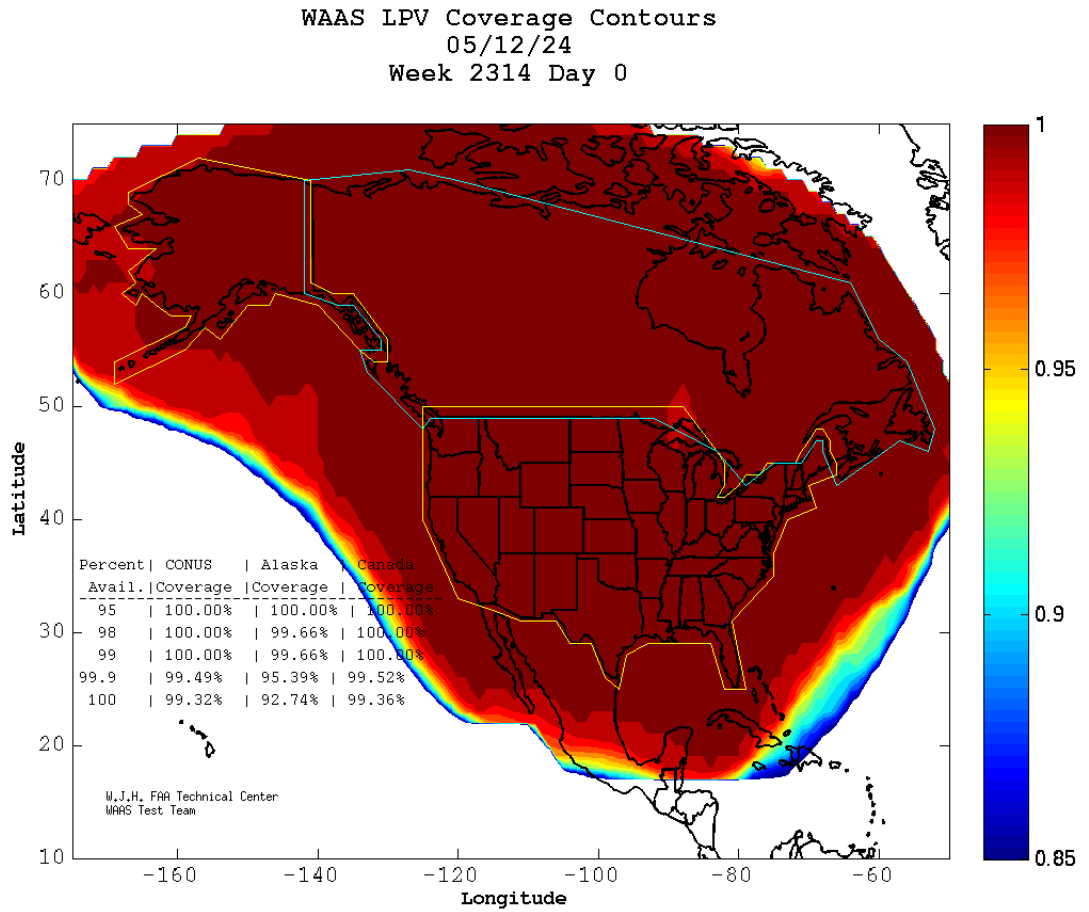
NOTE: All white means the availability is less than 85%

LPV-200 Coverage Plot for May 11, 2024

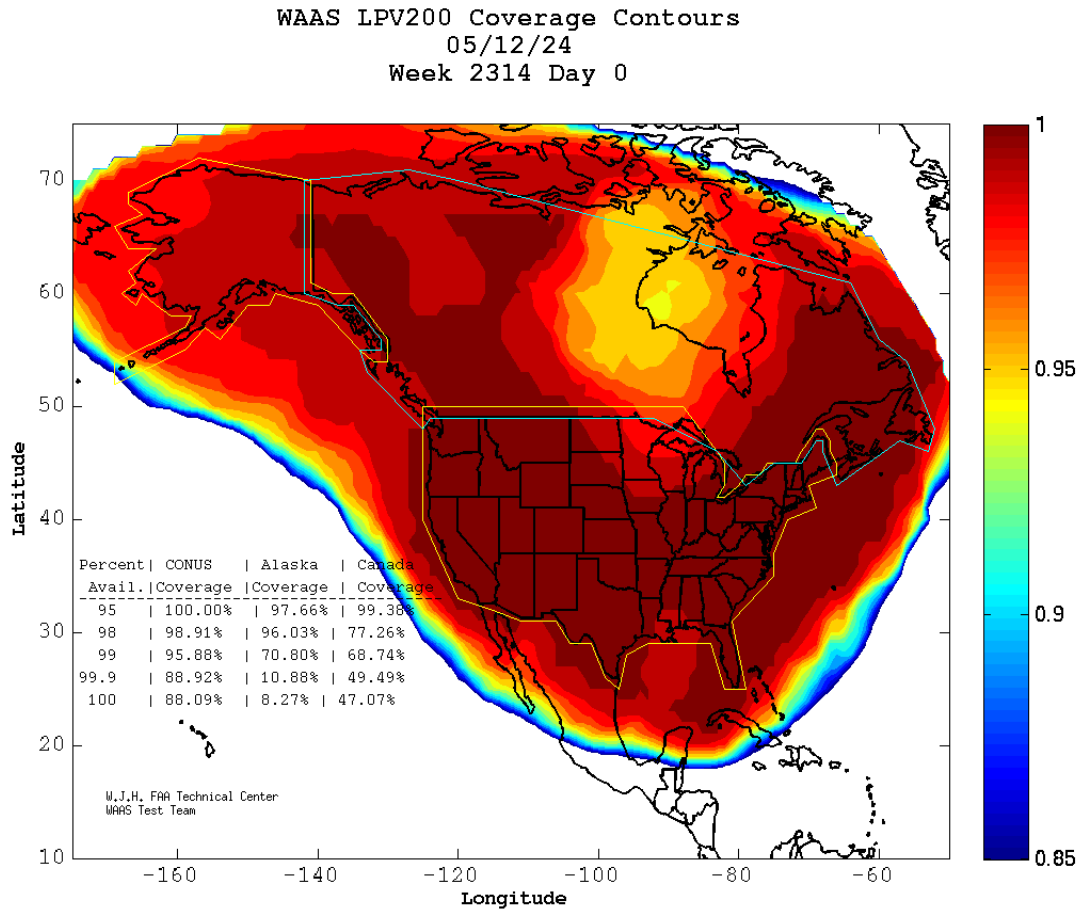


NOTE: All white means the availability is less than 85%

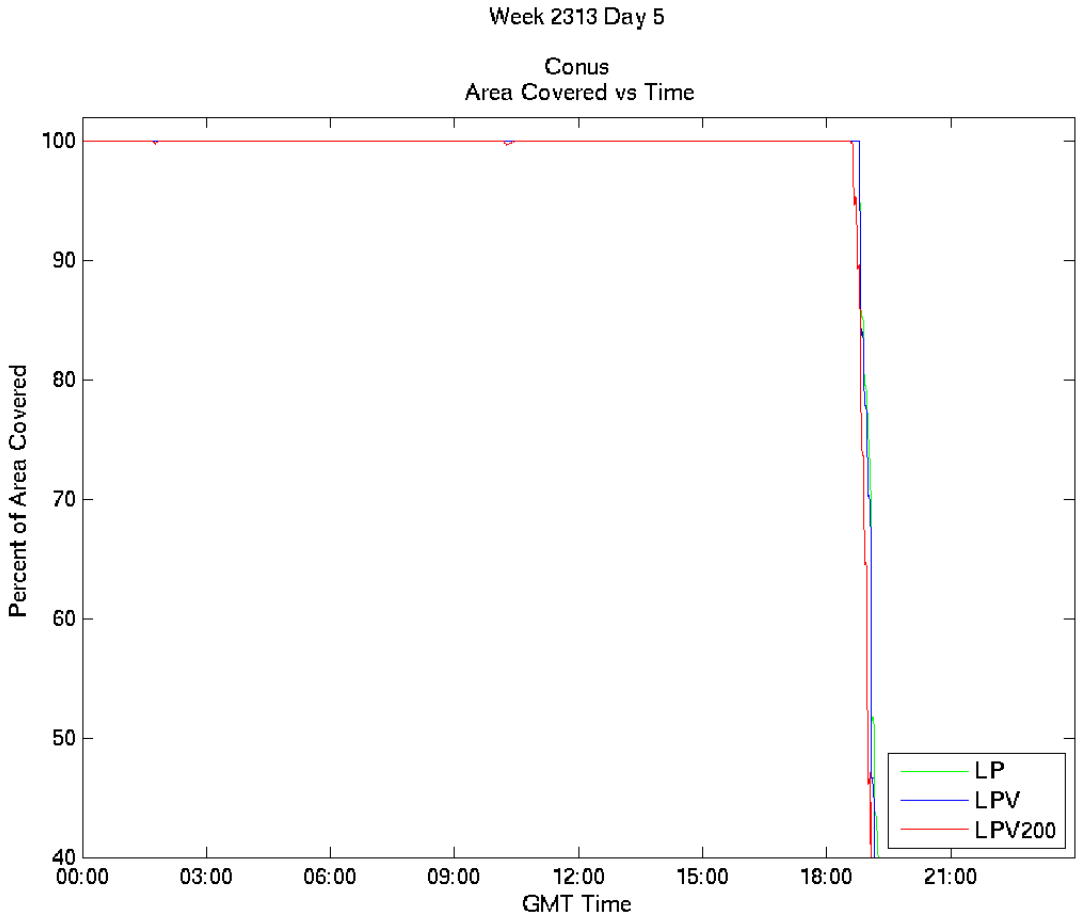
LPV Coverage Plot for May 12, 2024



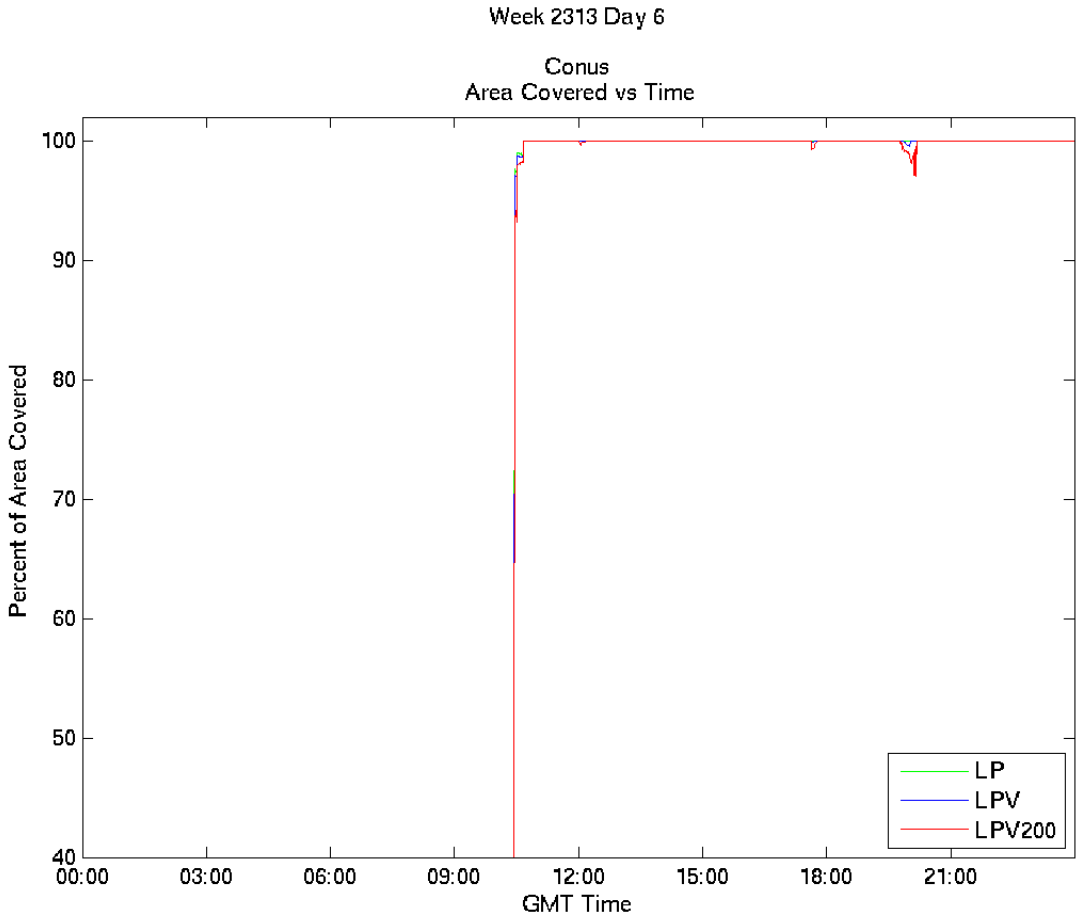
LPV-200 Coverage Plot for May 12, 2024



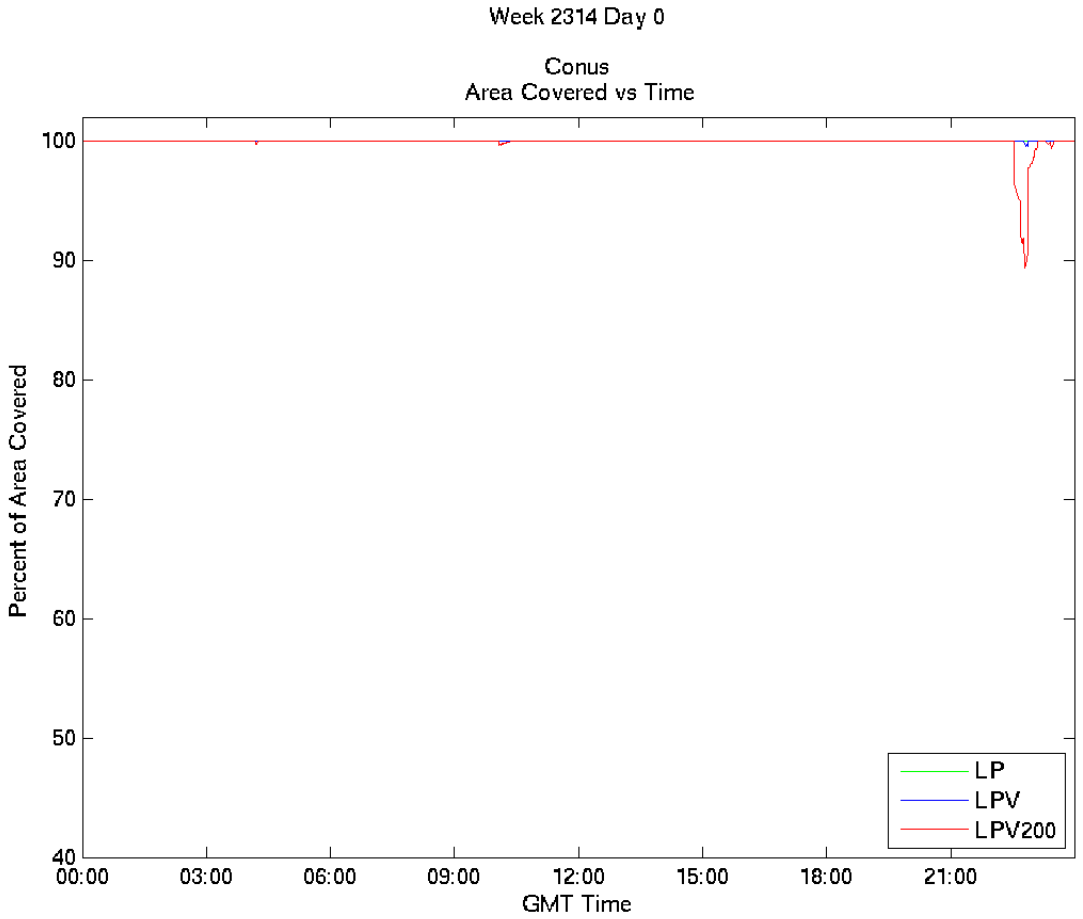
Coverage vs. Time on May 10, 2024



Coverage vs. Time on May 11, 2024



Coverage vs. Time on May 12, 2024



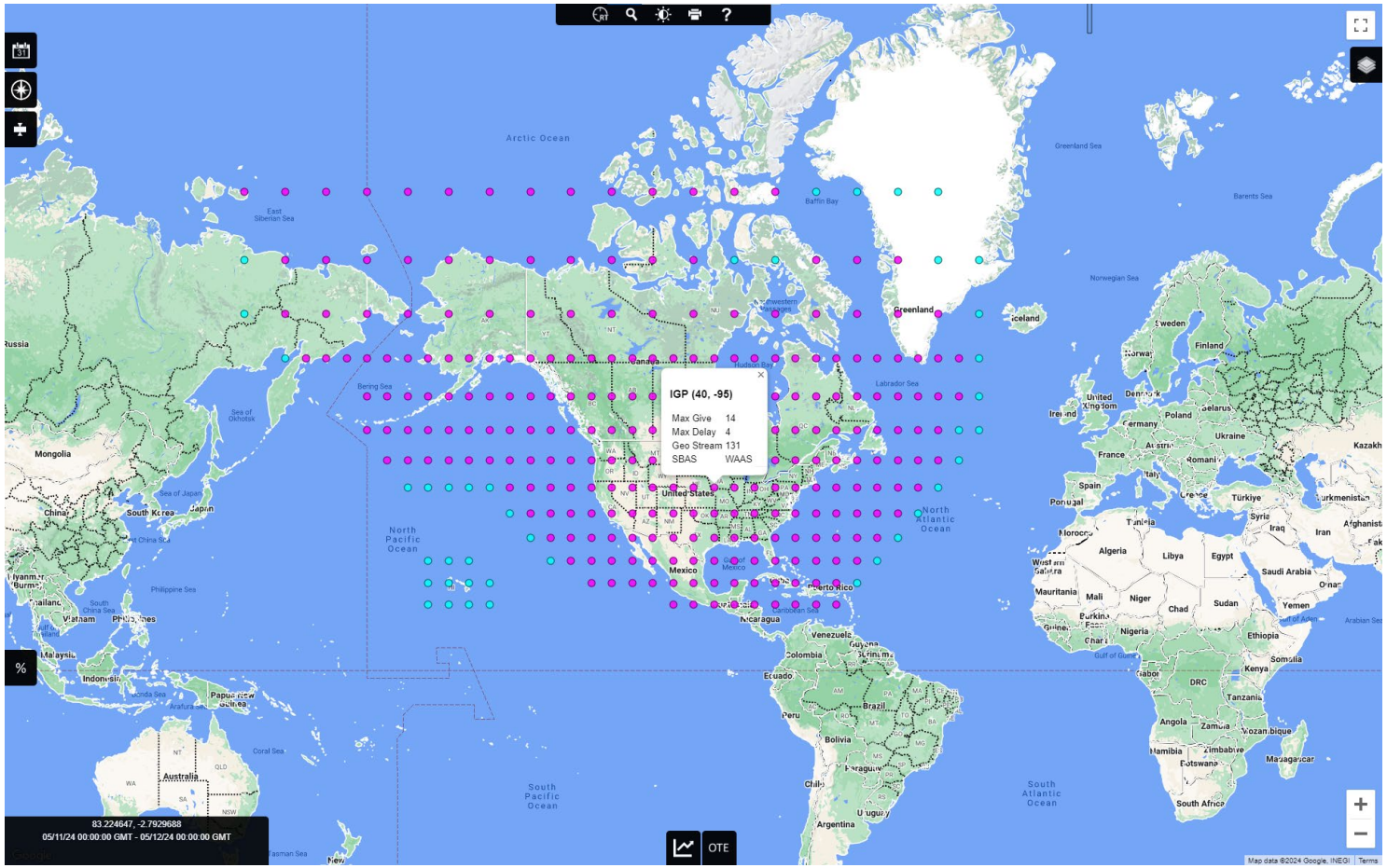
Extreme Storm Detector

- **WAAS has functionality to protect the users from large-scale ionospheric storms that impact a large portion of the service volume (>50%) for an extended period (>1 hour)**
  - This functionality is the Extreme Storm Detector (ESD)
- **ESD is a system-wide protection**
- **Before tripping, the ESD goes into an 'onset' state**
- **If in the onset state for 1 hour, then the ESD trips**
  - When an ESD trip occurs all IGPs have their GIVE set to 45 meters for 8 hours
    - This causes the vertical service of WAAS to be disabled
    - After 8 hours WAAS tests to determine if the system can exit the ESD state
  - Note that WAAS is operating as designed in this state to keep aviation users safe in the unstable ionosphere environment

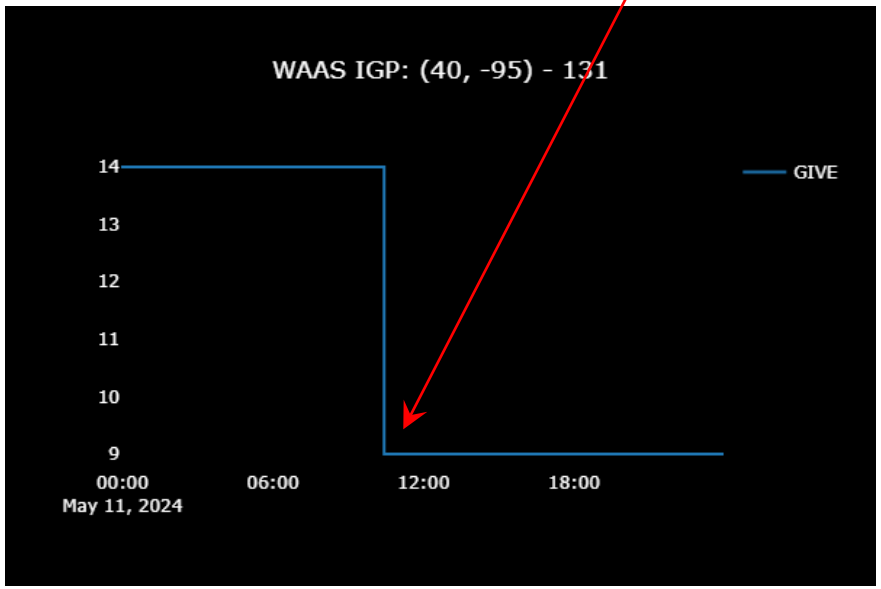
Extreme Storm Detector

- **On May 10, ESD went into ‘onset’ state at 20:55 UTC**
- **The ESD state cleared on May 11 at 10:22 UTC**
- **When the ESD cleared, the GIVEs went to a ‘normal’ level**
- **The next two slides show examples of the GIVE for two different IGPs going from 45 meters to an expected GIVE**
  - Note that even though ESD trip state cleared at 10:22 UTC it takes several minutes for the IGP GIVEs to be updated
    - The update follows the WAAS message scheduler that continues to run throughout the entire event
    - The message scheduler sends out the new GIVEs according to the band and block numbers for the IGPs. Several messages are needed before the user obtains all GIVE information.
  - IGP at 40 degrees latitude/ -95 degrees longitude (center of CONUS)
    - GIVE index (GIVEi) is at 14 (45 meters) and drops to GIVEi = 9 (3 meters) at 10:25:53 UTC
  - IGP at 65 degrees latitude/ -150 degrees longitude (Alaska)
    - GIVEi is at 14 (45 meters) and drops to GIVEi = 9 (3 meters) at 10:27:47 UTC

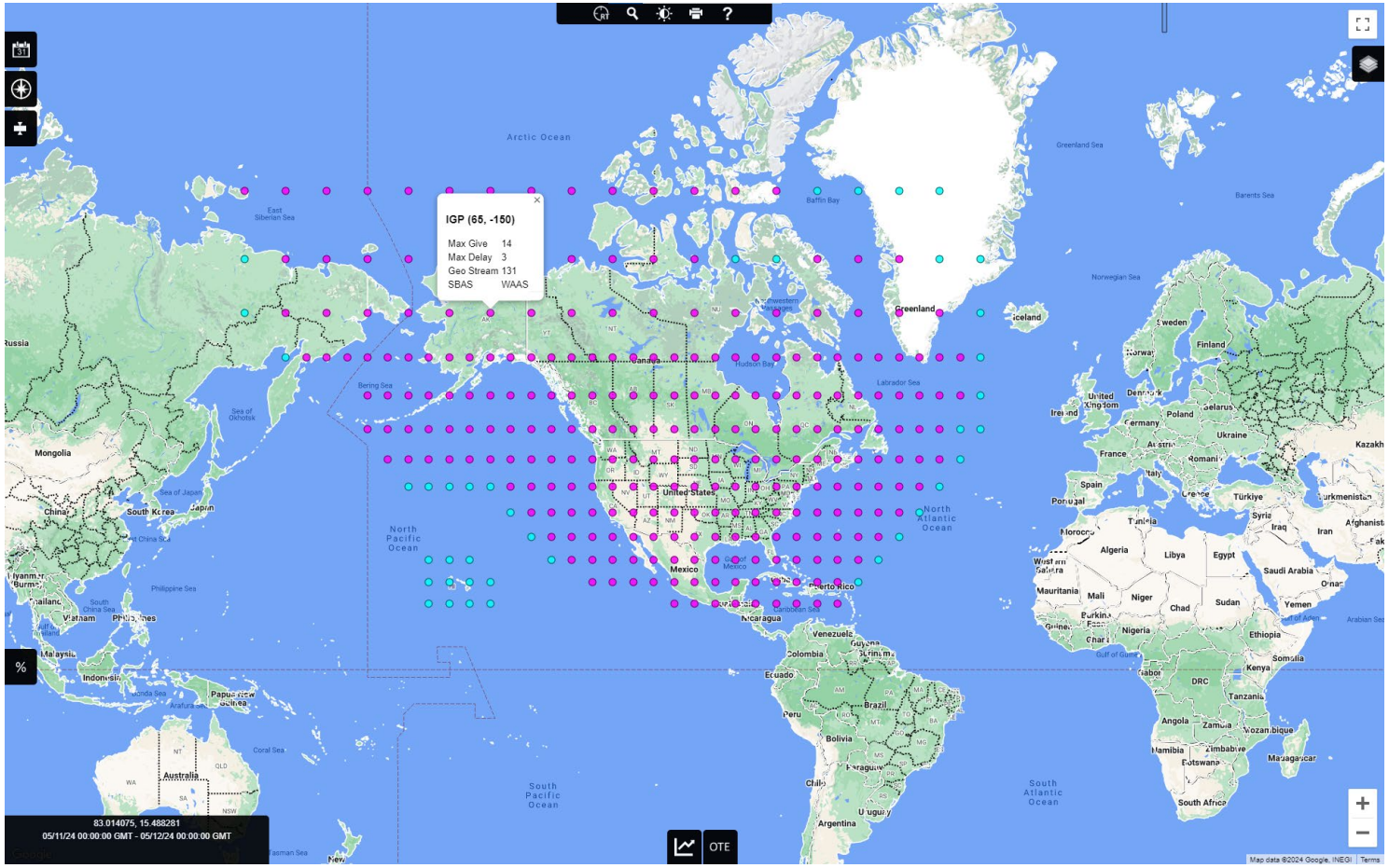
GIVE at the IGP at 40/-95



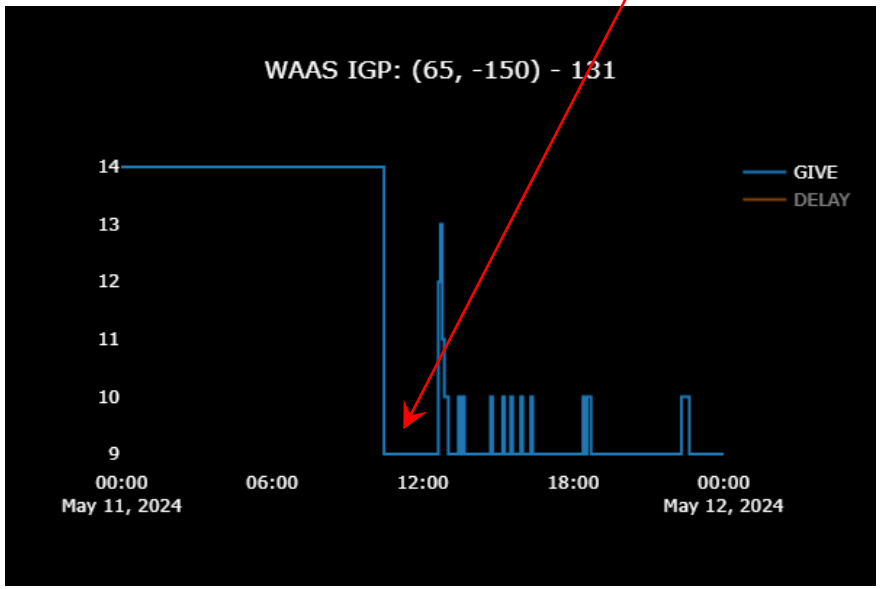
GIVEi at this IGP drops to 9 at 10:25:53



GIVE at the IGP at 65/-150

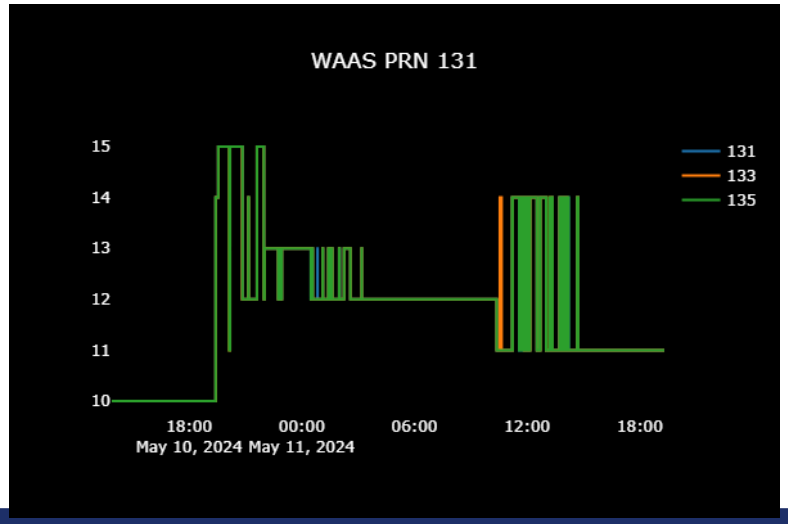


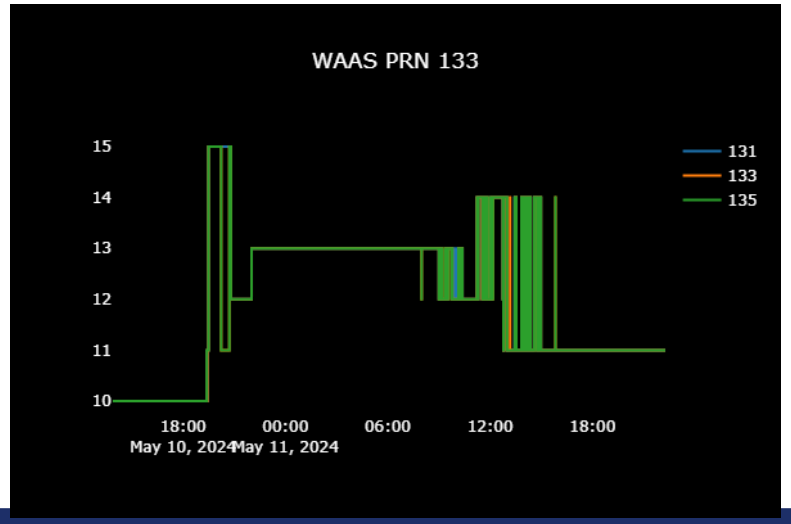
GIVEi at this IGP drops to 9 at 10:27:47

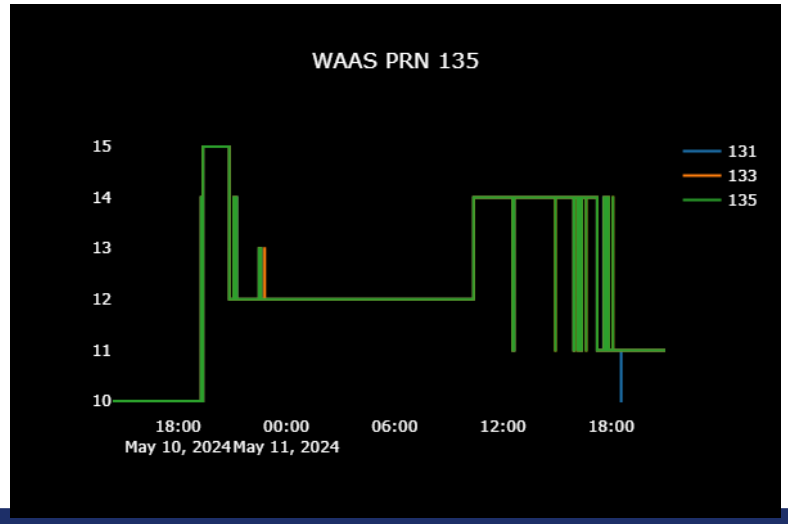


Code Carrier Coherence (CCC) Monitor Trip on WAAS GEOs

- **The purpose of the CCC monitor is to detect satellite failures that cause the code phase and carrier phase of the GPS or GEO signal to be incoherent**
  - Since the MOPS user equipment uses carrier phase measurements to smooth the code phase (pseudorange) measurements, this is a potential source of user error
- **On May 10 each of the three WAAS GEOs had a UDRE of Do Not Use (DNU) since they each tripped the CCC Monitor**
- **Below are the UDREi plots for each of the three GEOs**
  - During the time when the UDREi was DNU (UDREi = 15), the CCC monitor tripped for the GEO satellites







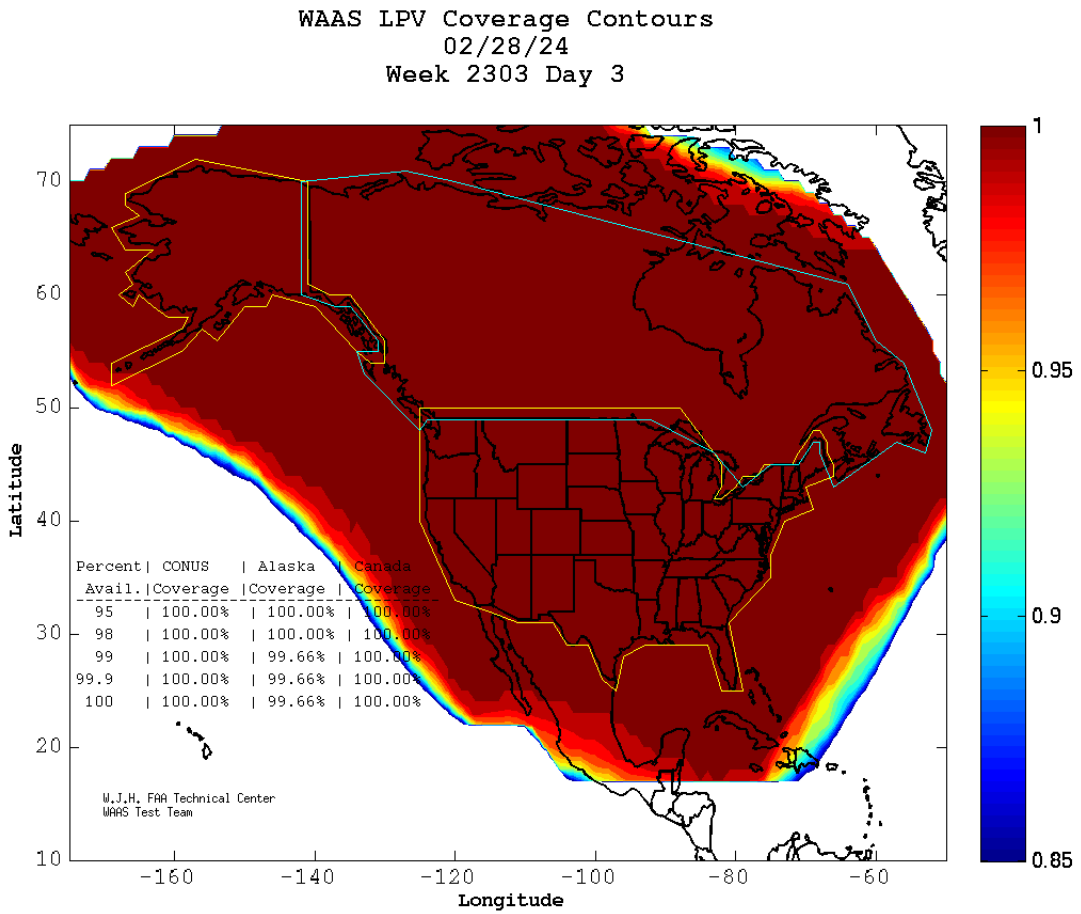
Days in 2024 with Iono Activity

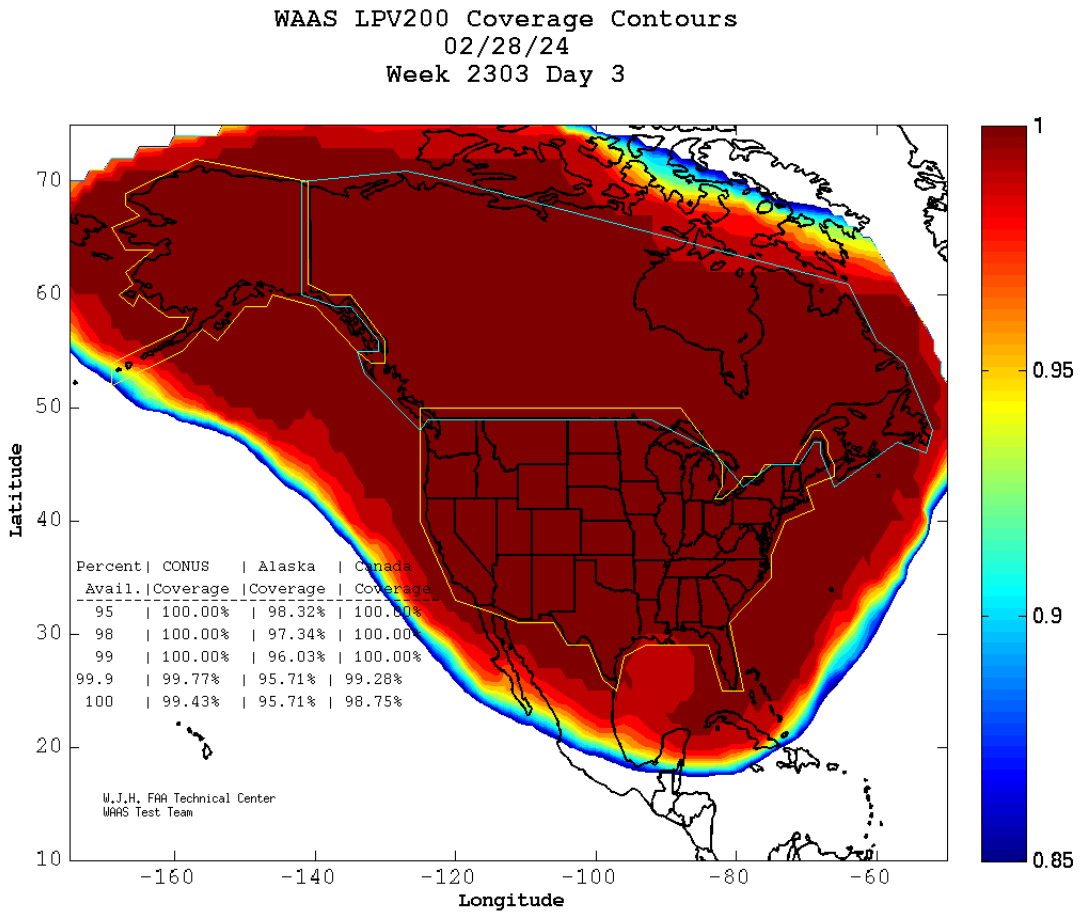
- **The following slides show days in which iono activity caused impact in CONUS**
  - This is a running list of days that had impact on LPV or LPV-200 service in CONUS due to iono
  - Presentations on the impact for these days were provided previously and are available on request
  - Note that these days are not necessarily the same as the ‘Iono Days of Interest’ that are tracked by the WAAS program for the offline monitoring that supports the assertions made in the WAAS HMI document
- **LPV and LPV-200 coverage plots are shown for each day**

List of Days with Iono Impact in CONUS during 2024

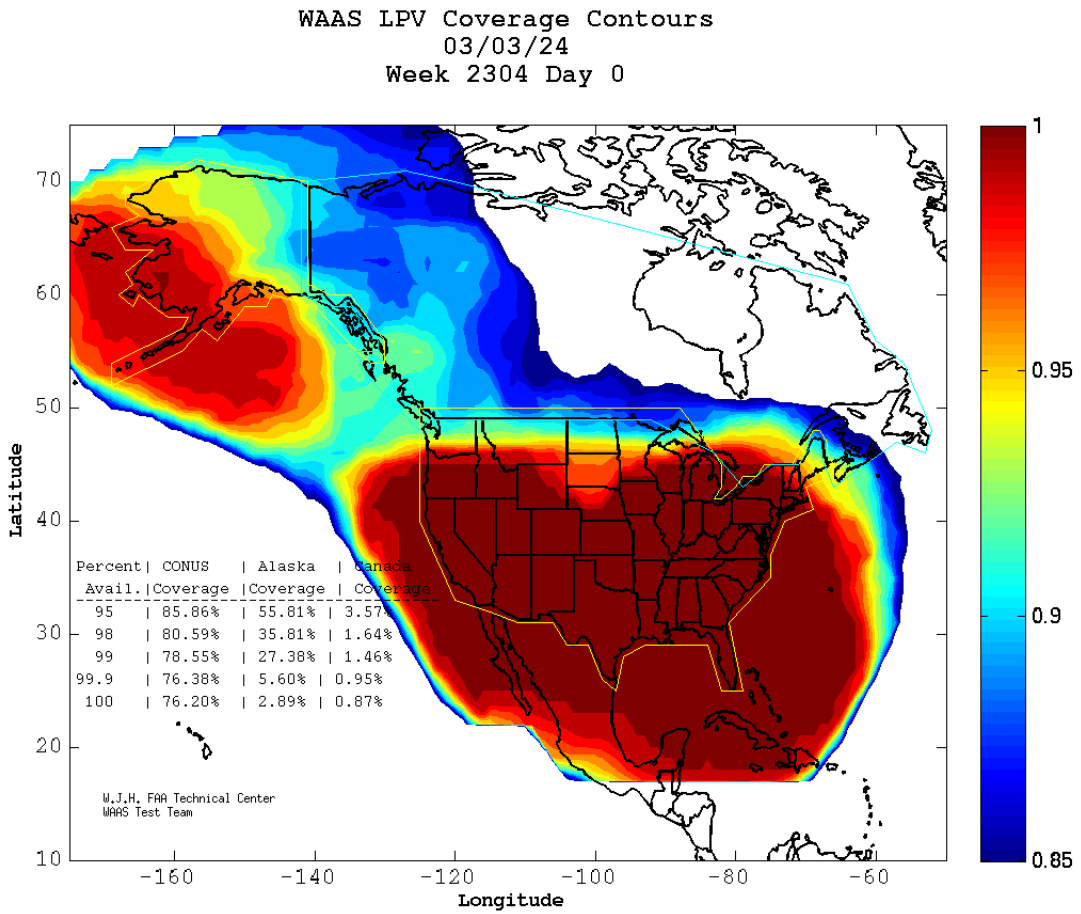
- **March 3 - 4, 2024**
- **May 2, 2024**
- **For comparison, a normal day (February 28, 2024) is the first LPV and LPV-200 plot shown**
  - A normal day means there were no anomalies that impacted WAAS coverage

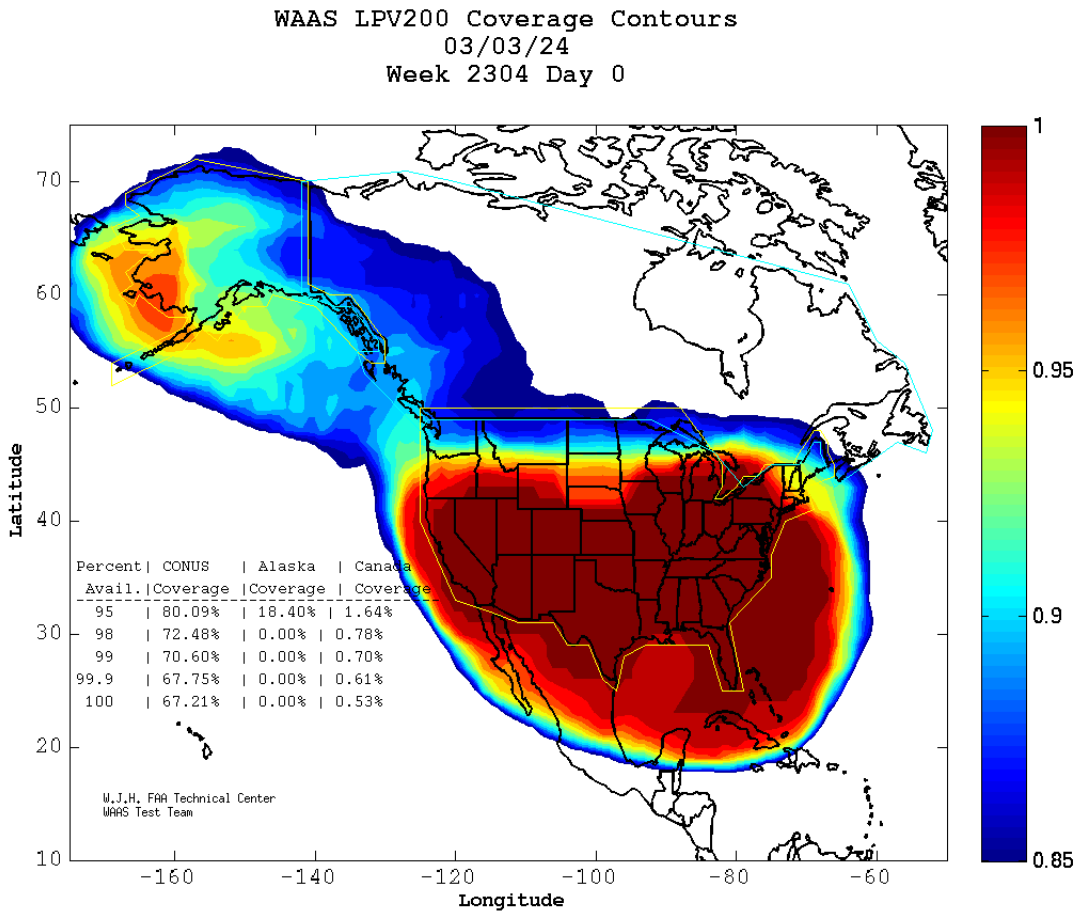
February 28, 2024 – LPV and LPV-200 Coverage on a Normal Day



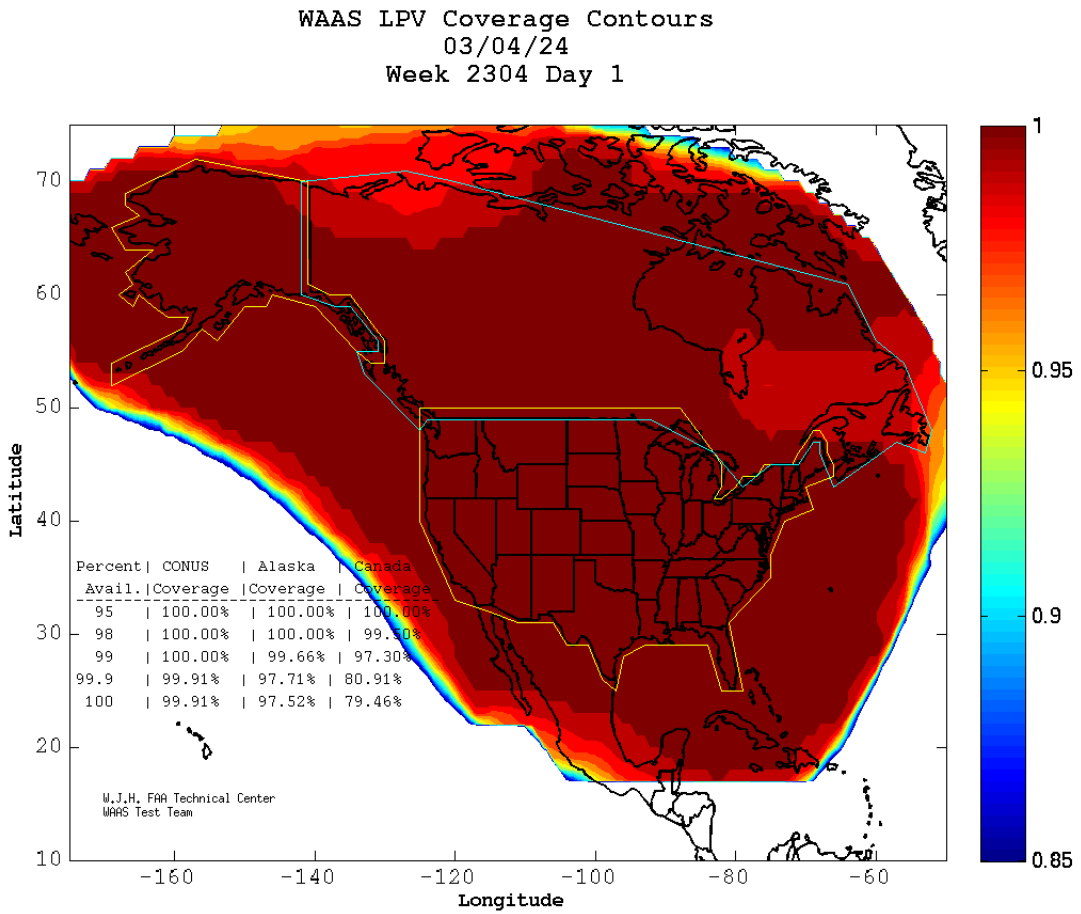


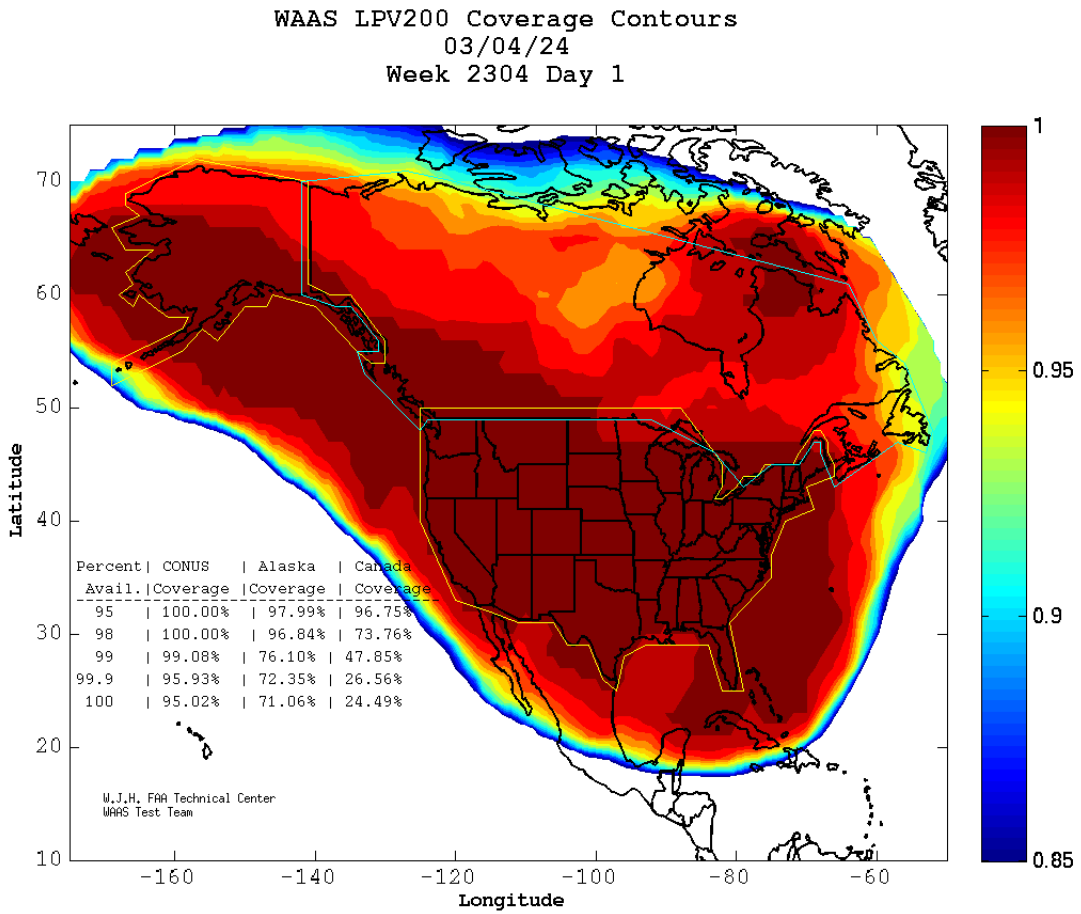
WAAS LPV and LPV-200 Coverage on March 3, 2024





WAAS LPV and LPV-200 Coverage on March 4, 2024





WAAS LPV and LPV-200 Coverage on May 2, 2024