Automatic Dependent Surveillance–Broadcast (ADS-B) Height Monitoring – United States

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Contents

ASE Technical Interchange Meeting

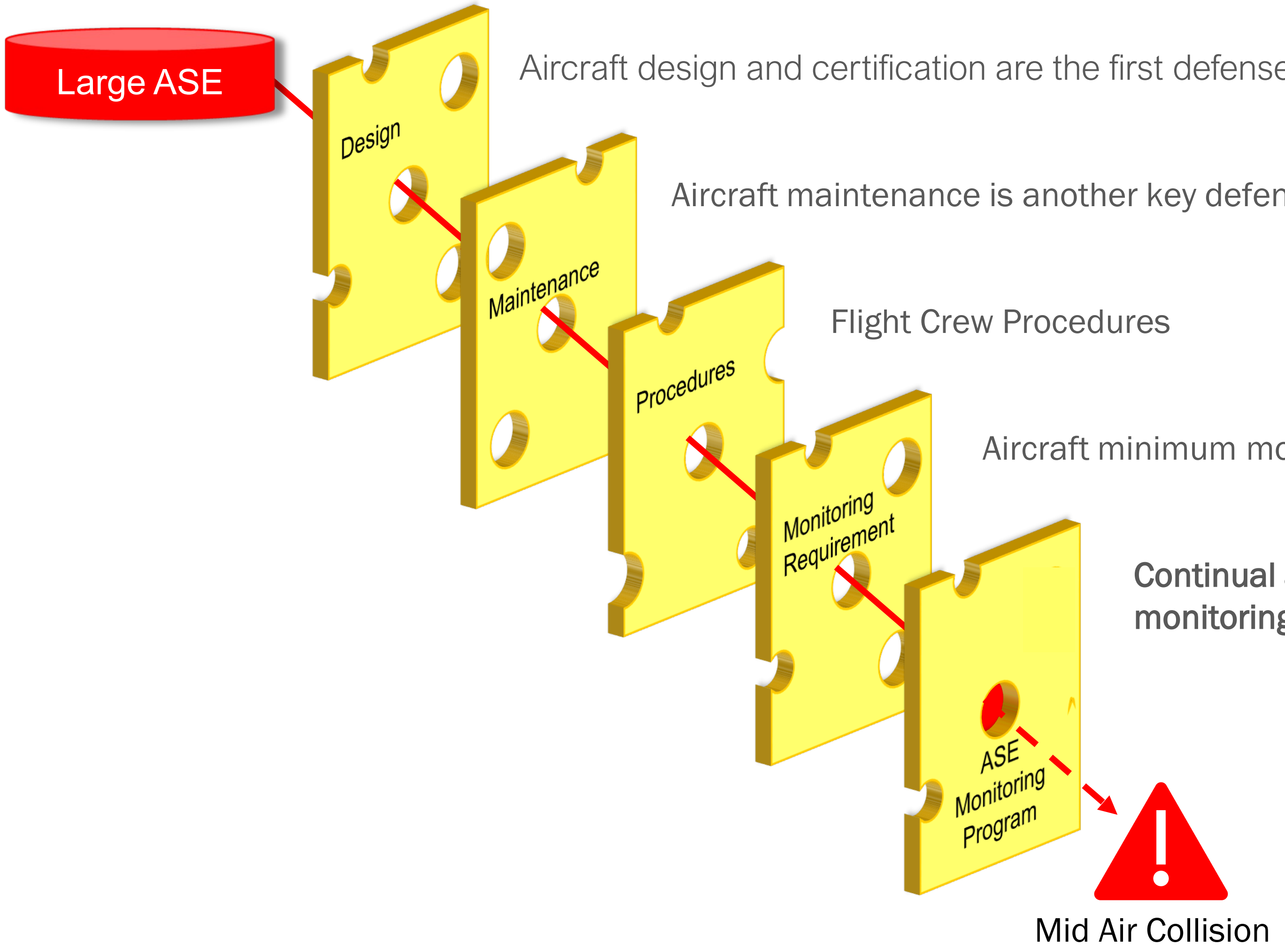
Safety Objectives of the RVSM Monitoring Program

To ensure the continued safe application of RVSM world-wide, standardized safety goals have been established by the International Civil Aviation Organization (ICAO):

- ✓ Verification that the target level of safety will be met upon implementation of RVSM and will continue to be met thereafter
- ✓ Monitoring of the effectiveness of the altimetry system modifications which have been implemented to enable aircraft to meet the required height-keeping performance criteria
- ✓ Evaluation of the stability of altimetry system error (ASE)

ICAO

Ensuring Safe RVSM Operations



Aircraft design and certification are the first defense to large ASE

Aircraft maintenance is another key defense against large ASE

Flight Crew Procedures

Aircraft minimum monitoring requirements

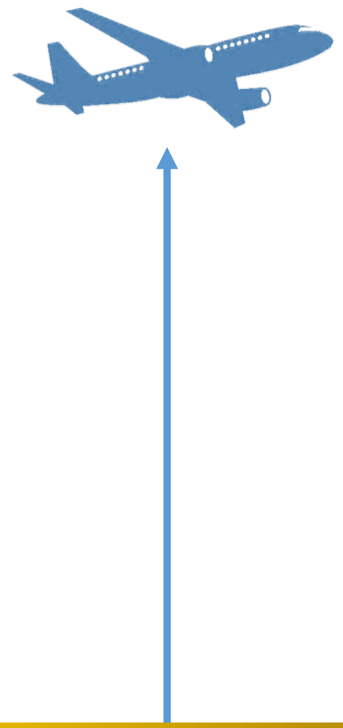
Continual aircraft monitoring and verification that monitoring requirements have been met

Height-Keeping Performance Technical Objectives

Consequently, oversight bodies termed Regional Monitoring Agencies (RMAs), were established world-wide.

A key role of an RMA is to design a height-keeping performance monitoring program to provide ongoing assessment of ASE performance by aircraft-type group so that adverse trends can be identified quickly.

The primary function of the monitoring system is to estimate the ASE of an aircraft by comparing the actual height of the aircraft to the height of the flight level as indicated by the aircraft's own altimetry system.



North American Approvals Registry and Monitoring Organization (NAARMO)

During 2004, through bilateral agreements between the United States, Mexico and Canada, it was agreed that NAARMO shall support the implementation and use of RVSM in North American airspace (Canada, Mexico and the United Sates) and fulfill the role of a regional monitoring agency as specified by ICAO Doc 9574.

In general, RMA duties include:

- **APPROVALS REGISTRY**: Maintain an approvals registry
- **MONITORING**: Perform altimetry system error monitoring
- **AUDITS**: Confirm aircraft RVSM approval status
- **TREND ANALYSIS**: Collect and assess operational errors
- **ASSESS SAFETY**: Perform collision risk calculations

NAARMO has the largest number of RVSM capable aircraft to manage and monitor

Pacific Approvals Registry and Monitoring Organization (PARMO)

In late 1997 during the first meeting of the Pacific RVSM Task Force, States providing air navigation services in the international airspace over the Pacific agreed to pursue implementation of the RVSM.

At the Second Meeting of the Task Force, participating States agreed to establish the Asia/Pacific Approvals Registry and Monitoring Organization (APARMO) to perform the duties and responsibilities of an RMA.

Subsequently, the Asia/Pacific Air Navigation Planning and Implementation Regional Group (APANPIRG), approved APARMO as the RMA.

As RVSM implementation progressed throughout the Asia/Pacific Region, the APARMO's duties and responsibilities were divided among regional monitoring agencies provided by several States.

The original entity was renamed the Pacific Approvals Registry and Monitoring Organization (PARMO).

PARMO States

- ✓ Cook Islands
- ✓ Fiji
- ✓ Kiribati
- ✓ Marshall Islands
- ✓ Micronesia (Federated States of)
- ✓ New Zealand
- ✓ Palau
- ✓ Republic of Korea
- ✓ Samoa
- ✓ Tonga
- ✓ United States and Tahiti Airspace

NAARMO & PARMO RMAs

Separation Standards Analysis Program Performance Monitoring

SEPARATION STANDARD DEVELOPMENT

- ✓ Separation and airspace concepts assessed in analytical and modeled environments to determine the safety of operations, technical and operational performance suitability, and usability.

PERFORMANCE MONITORING

- ✓ Independent ASE RVSM monitoring
- ✓ ADS-B ASE monitoring
- ✓ Post-implementation monitoring of RNP/ RNAV performance-based navigation routes

SAFETY ANALYSIS

- ✓ Safety management system (SMS) oversight & reporting
- ✓ Collision risk modeling
- ✓ Conformance monitoring

RISK ASSESSMENTS

- ✓ Operational data collection and analysis
- ✓ Hazard identification
- ✓ Risk mitigation

MONITORING AGENCIES

- ✓ Operates three monitoring agencies serving the North American and Pacific Regions
- ✓ North American Approvals Registry and Monitoring Organization (NAARMO)
- ✓ Pacific Approvals Registry and Monitoring Agency (PARMO)
- ✓ Pacific Enroute Monitoring Agency (EMA)

FAA Monitoring Methods

GPS-based Monitoring Unit (GMU) – a portable device brought on board and operated by trained technicians. This method uses GPS data to collect the aircraft's position that is then used in the ASE process. **Over 21,000 flights** were monitored using this method from 1995-2025.

Automatic Dependent Surveillance-Broadcast (ADS-B) Height Monitoring System (AHMS) – provides a source of aircraft position data for use in the ASE calculations.

FAA Advisory Circular 91-85B – 01/29/2019*

E.1.4 How Do I Get My Airplanes Monitored?

1. An operator may choose to fly with a trained technician from an FAA-approved RVSM monitoring support provider utilizing a GMU on board the airplanes.

2. An operator may fly an airplane through an established ground-based height-measuring system. Currently, ground-based systems exist in:

   - North America, AGHME (requires Mode S equipment); or approved ground-based height-measuring systems in other regions (e.g., Europe or Japan).

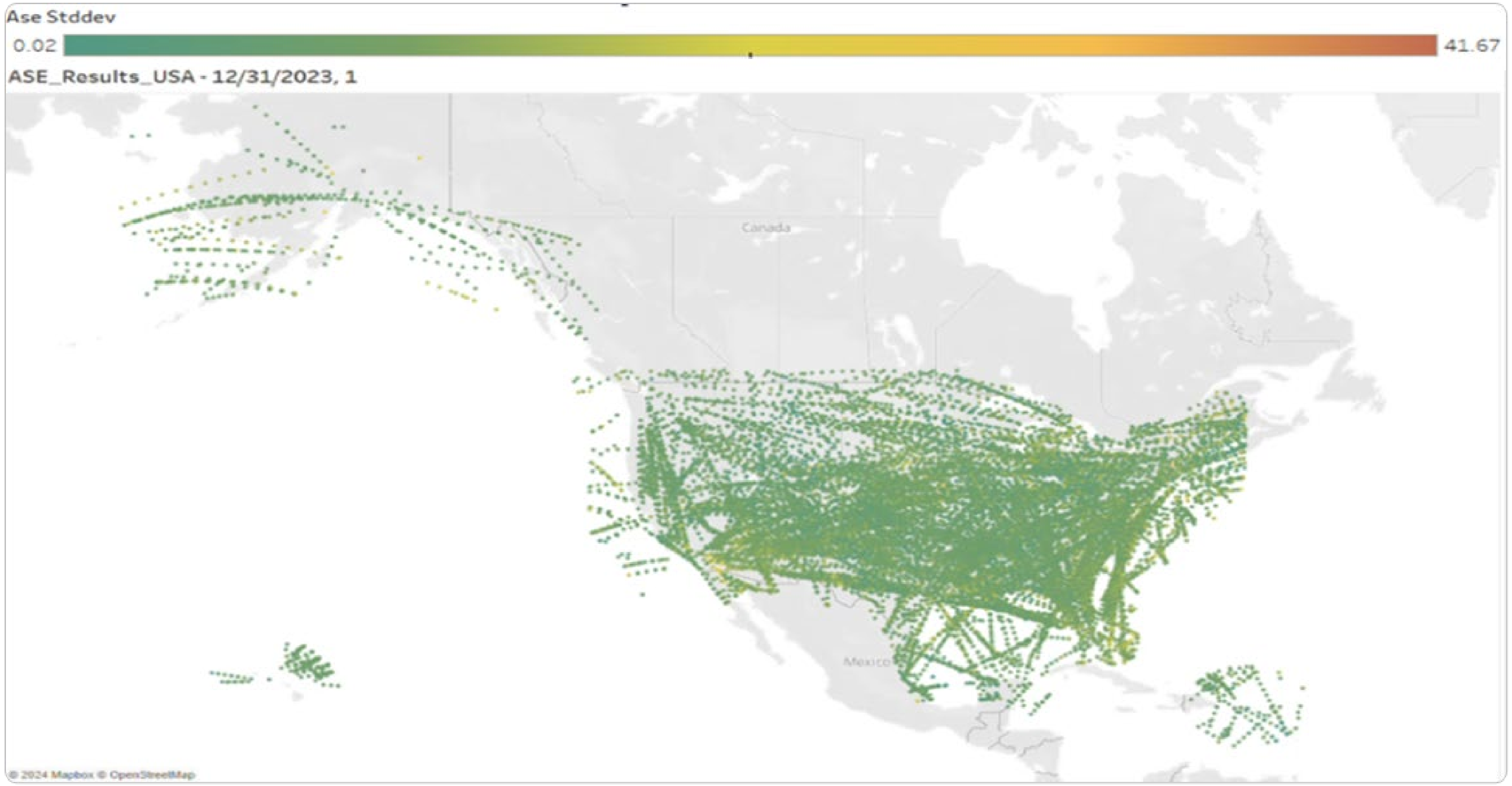
   - An RVSM-authorized aircraft equipped and operating with ADS-B OUT avionics meeting the performance requirements of part 91, § 91.227 at an RVSM altitude where ADS-B height-monitoring is provided.

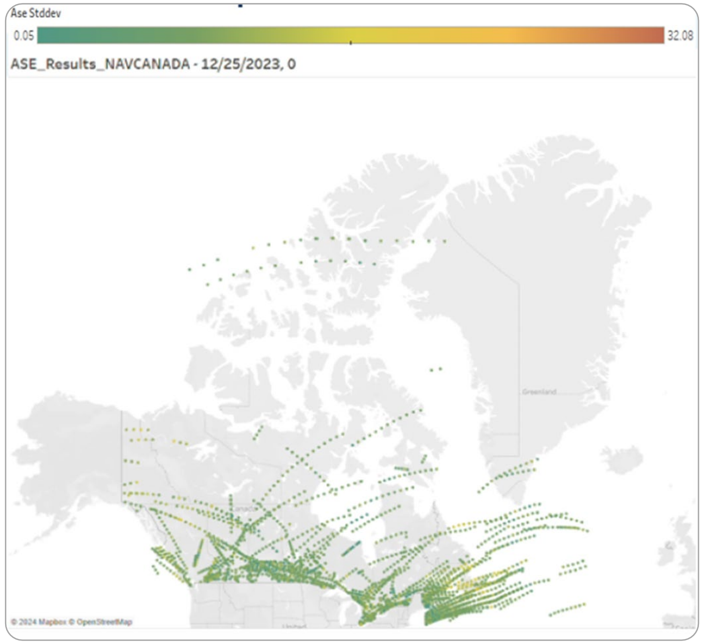
* ADS-B ASE monitoring was included in AC 91-85A 07/21/16

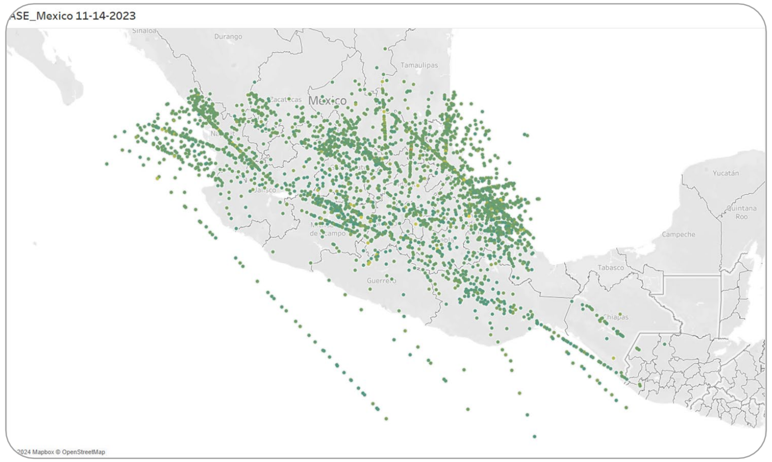
Aircraft ASE Monitoring with ADS-B OUT

Daily processing in US Airspace using ADS-B OUT data

- Canada and Mexico ADS-B OUT data processed weekly





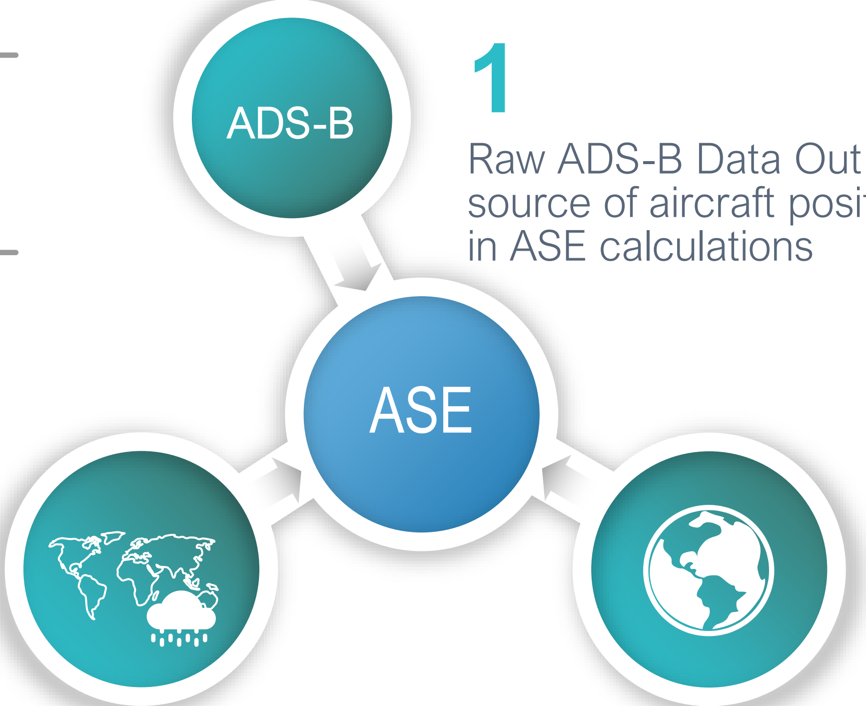


ASE Calculation Details

- ASE is determined by comparing the geometric height of the aircraft and the geometric height of the barometric pressure surface associated with the altimetry measurement.
  - Automatic Dependent Surveillance- Broadcast (ADS-B) Out provides a source of aircraft position data for use in ASE calculations
  - Necessary Meteorological (MET) data is downloaded daily from the US National Oceanic and Atmospheric Administration (NOAA) and the National Centers for Environmental Prediction (NCEP) website

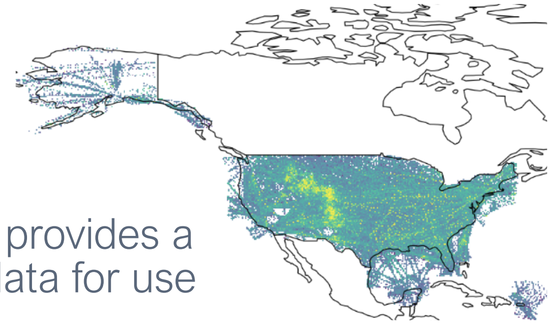
Calculating ASE – Data Sources

3 Three sources of data are used to calculate ASE.



1

Raw ADS-B Data Out data provides a source of aircraft position data for use in ASE calculations



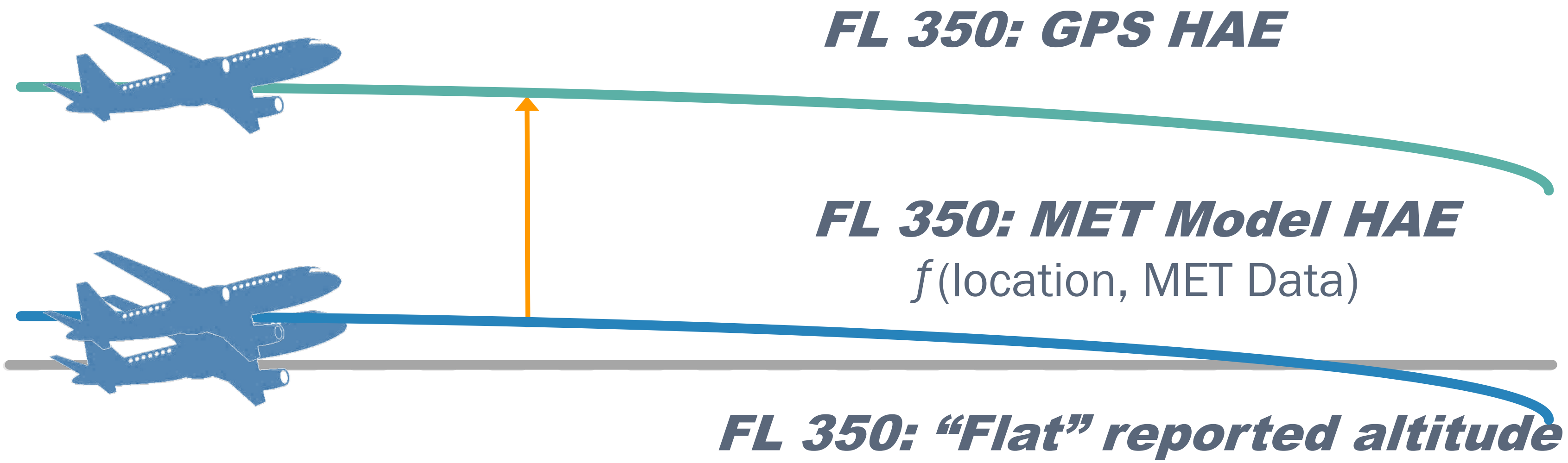
2

Meteorological (MET) Data - downloaded daily from the US National Oceanic and Atmospheric Administration (NOAA) and the National Centers for Environmental Prediction (NCEP)

3

Earth Gravitational Model Data

ASE Calculation



ASE = GPS HAE – MET Model HAE

HAE = Height above ellipsoid

Calculating ASE - Pre-Process Meteorological & Geoid Data

Download meteorological (MET) data from NOAA

- ✓ Convert millibar (mb) levels to flight levels (FL 180 – FL 670).

Convert geopotential heights to height above ellipsoid (HAE) for the MET data

- ✓ Verify that the current Gravitational Earth Model is correct.
- ✓ Source location for the geoid: NGA - Office of Geomatics Home Page

Interpolate the MET data with respect to the Date, Time, Latitude, Longitude, and Pressure Altitude of the aircraft to be assessed.

- ✓ The MET data altitude is converted from meters to feet.
- ✓ This process creates the input file (TB2, TB3, or TB3H file for US-supplied GDAS MET files) for the production code.

Calculating ASE – Data Processing

1

Identify vertical track level segments

Group ADS-B flight data into two-minute segments.

Determine if the segment represents a level flight.

(Binary classification model)

2

Join all consecutive level flight segments

Join all consecutive level flight segments into a final "inferred flight level" track, counting all tracks per flight.

3

Divide flight tracks

Divide all flight tracks into five-minute sample periods.

4

Interpolate the MET data

Interpolate MET data to HAE of the pressure measurement based on the aircraft location.

This is done via function f that maps (Date, Time, Latitude, Longitude, and Pressure Altitude) to HAE.

5

Identify the number of ADS-B points

Identify the number of ADS-B points available in each 5-minute period.

300 1-hz updates are expected; however, gaps can occur.

6

Calculate the mid-point of each segment

Calculate the mid-point of each segment (Lat, Lon) for ASE position analysis.

Calculating ASE – Data Processing (cont.)

7

Calculate the ASE at every point

Calculate the ASE at every point by subtracting the GPS altitude from the converted MET pressure HAE.

Calculate the average and standard deviation of the ASE for each sample.

8

Calculate the Assigned Altitude Deviation (AAD) at every point

Calculate the Assigned Altitude Deviation (AAD) at every point by subtracting the reported pressure altitude from the track inferred flight level.

9

Remove Samples

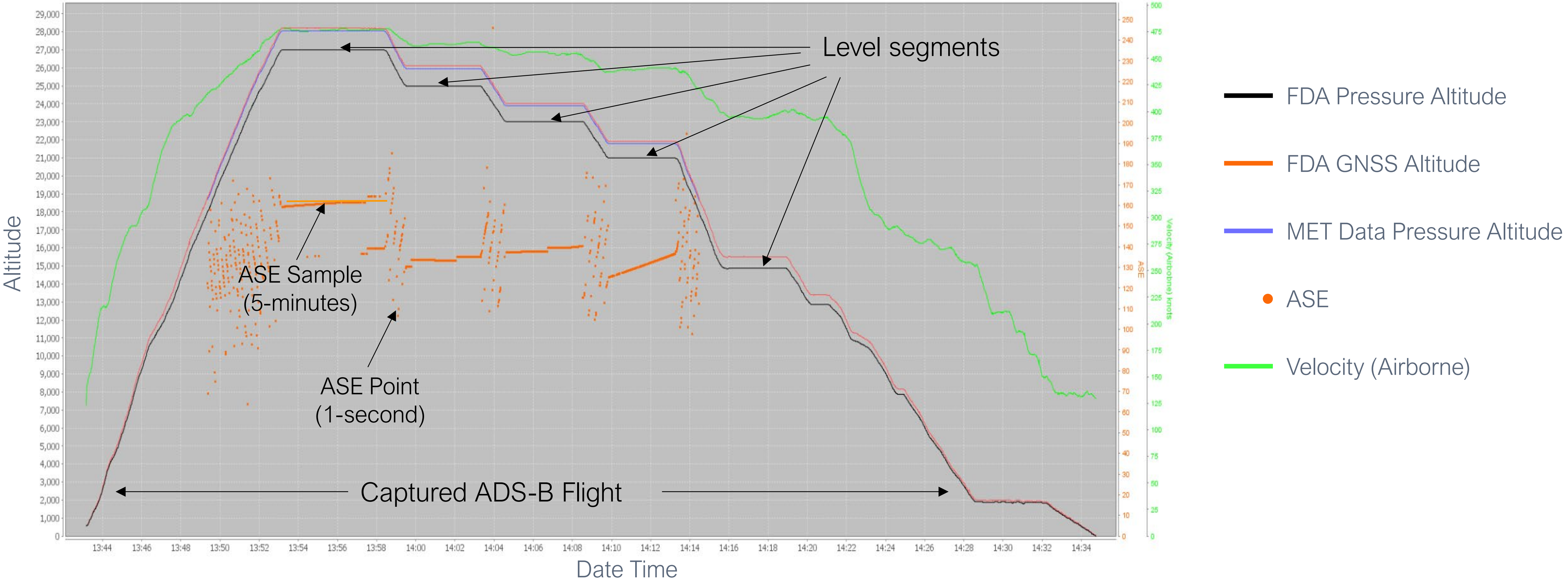
Remove samples with N<60, NIC <8, or very high ASE Std Dev (>30ft).

10

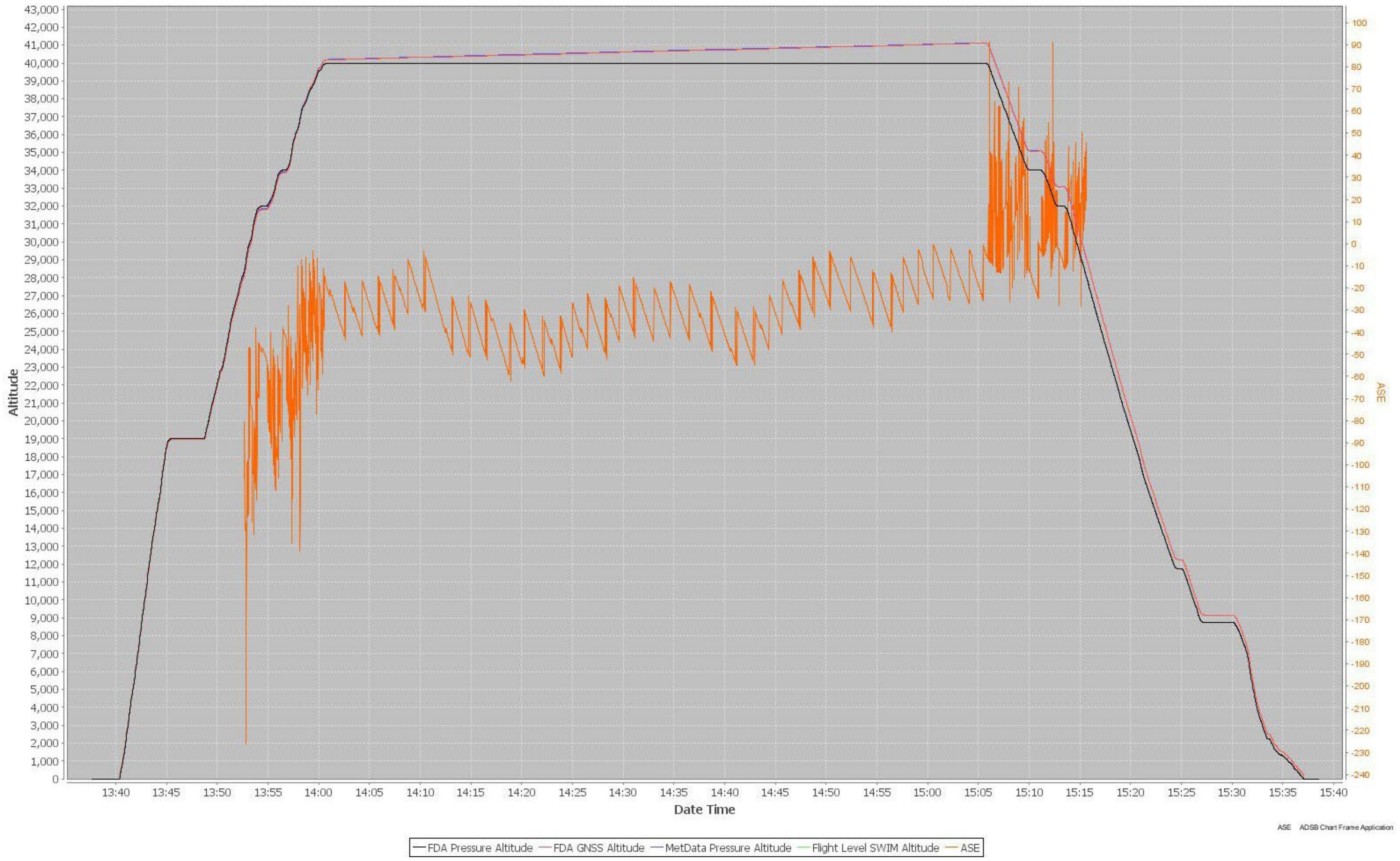
Create Output Data

Create output data file for including in the database.

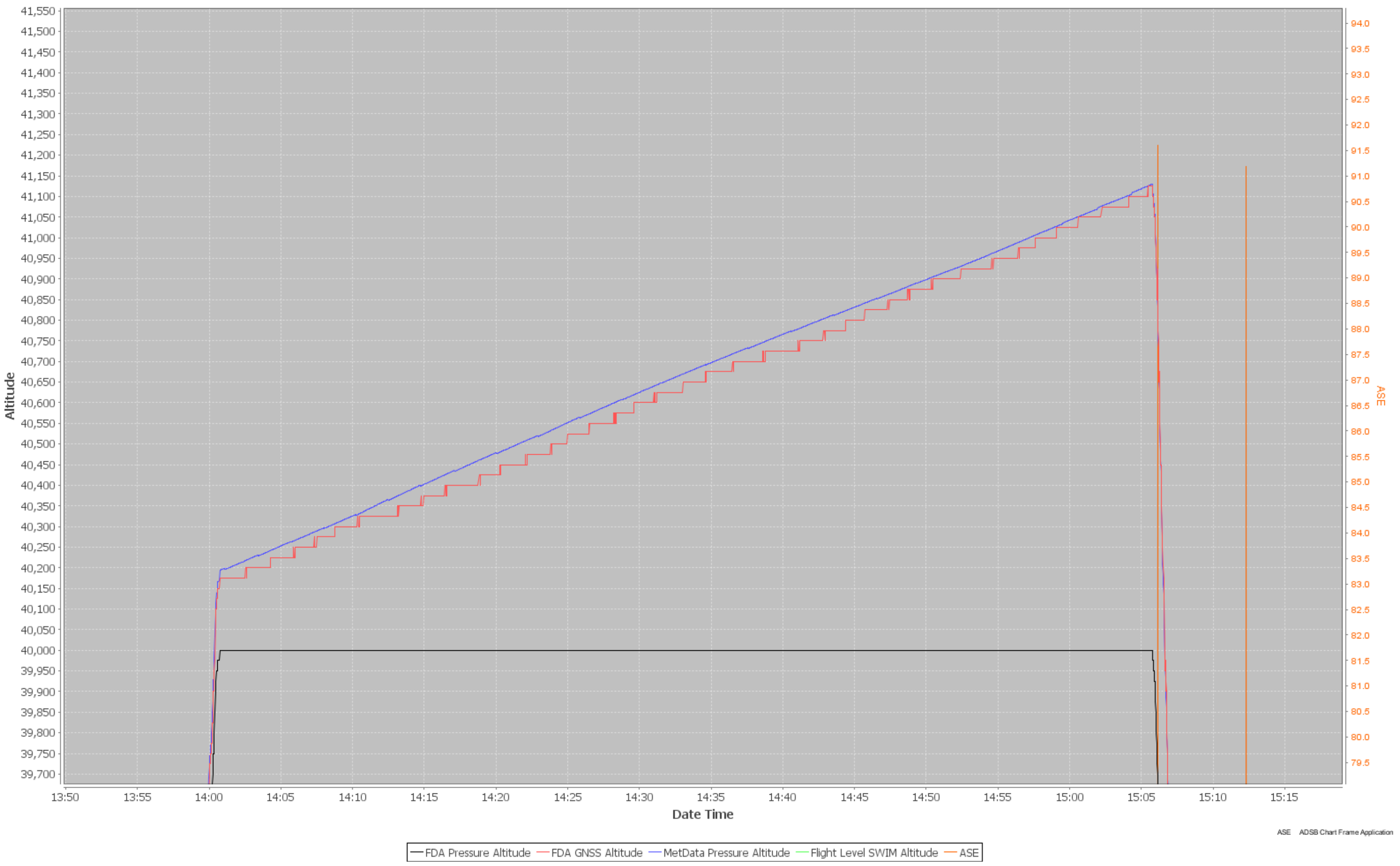
Vertical Track Profile



Data Visualization – Full Flight



Data Visualization – Zoom to Altitude Data



This graph depicts aircraft altitude- keeping information using ADS-B Out.

- The aircraft is maintaining FL400 (reported pressure altitude) (black line, left scale
- The blue line is the modeled meteorological data
- The red line is the GPS reported altitude

This aircraft is on its cleared flight level.

Removing ADS-B Resolution Noise

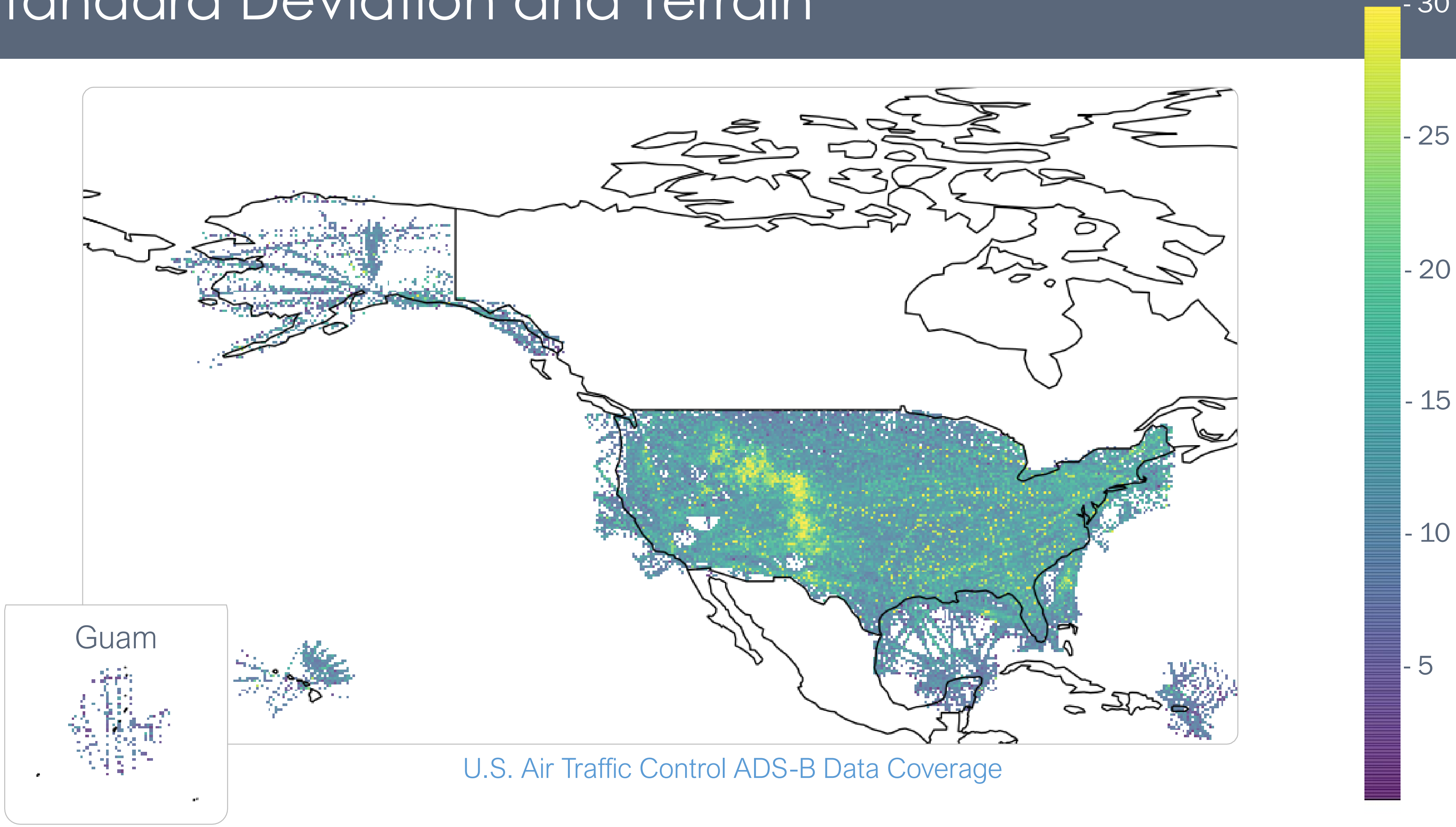
- Both Mode-S pressure altitude and GPS altitude are rounded to the nearest 25ft in the ADS-B broadcast
  - Altimetry systems attempt to maintain a constant FL while the actual height above the ground changes
    - Constant pressure data fed into the MET model produces a smooth function
  - Quantized GPS height data creates a saw tooth function in the ASE profile
- ASE is averaged over 5-minute segment to determine one ASE sample

Quality Control

- Quality Control of the ASE input data includes:
  - GPS solution accuracy parameters
    - ADS-B provides several GPS solution quality factors representative of horizontal solution quality that can be used for removing suspected poor GPS data
    - Geographic performance plots can also provide an indication of poor solution quality

Significant Terrain Features in the United States

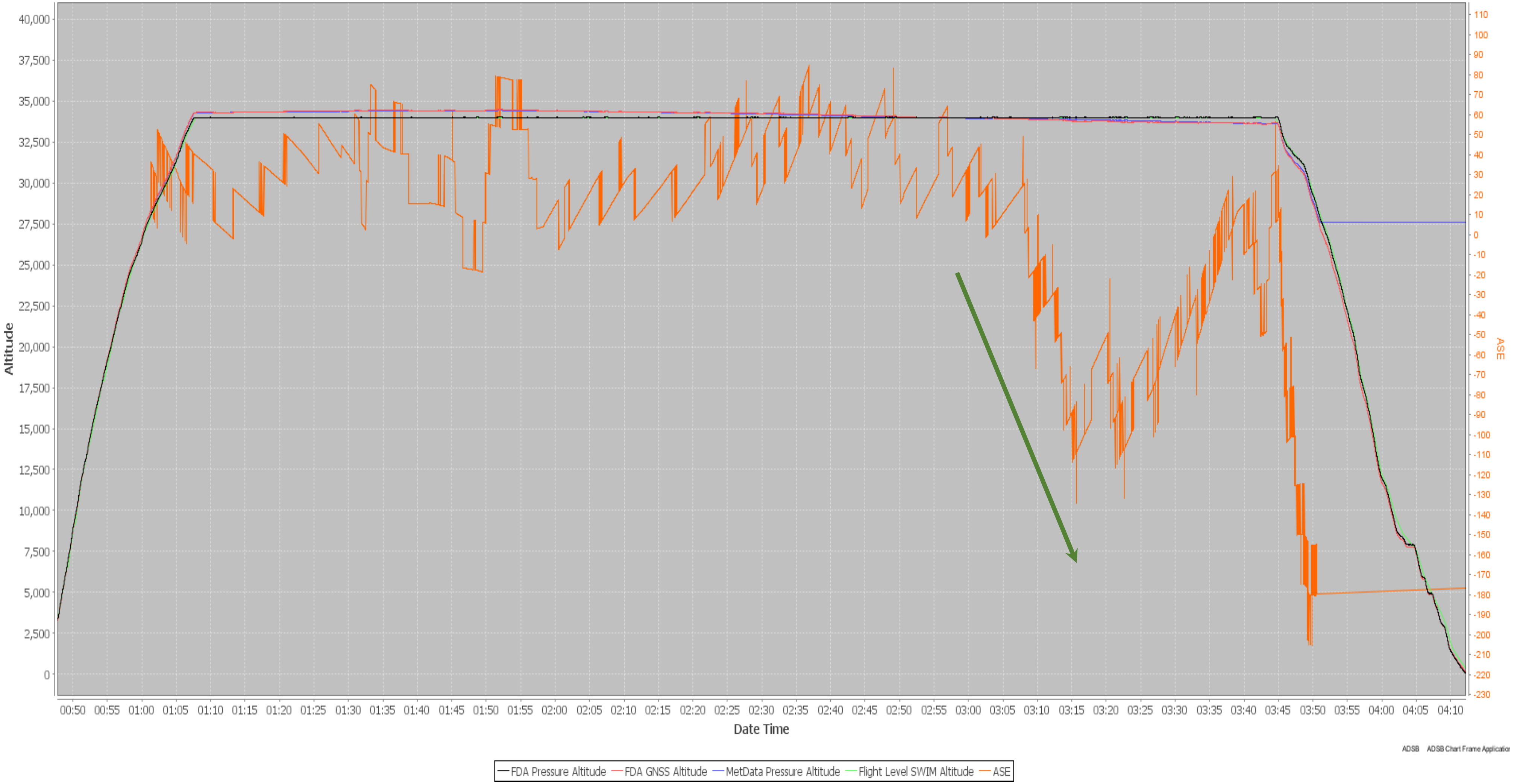
ASE Standard Deviation and Terrain



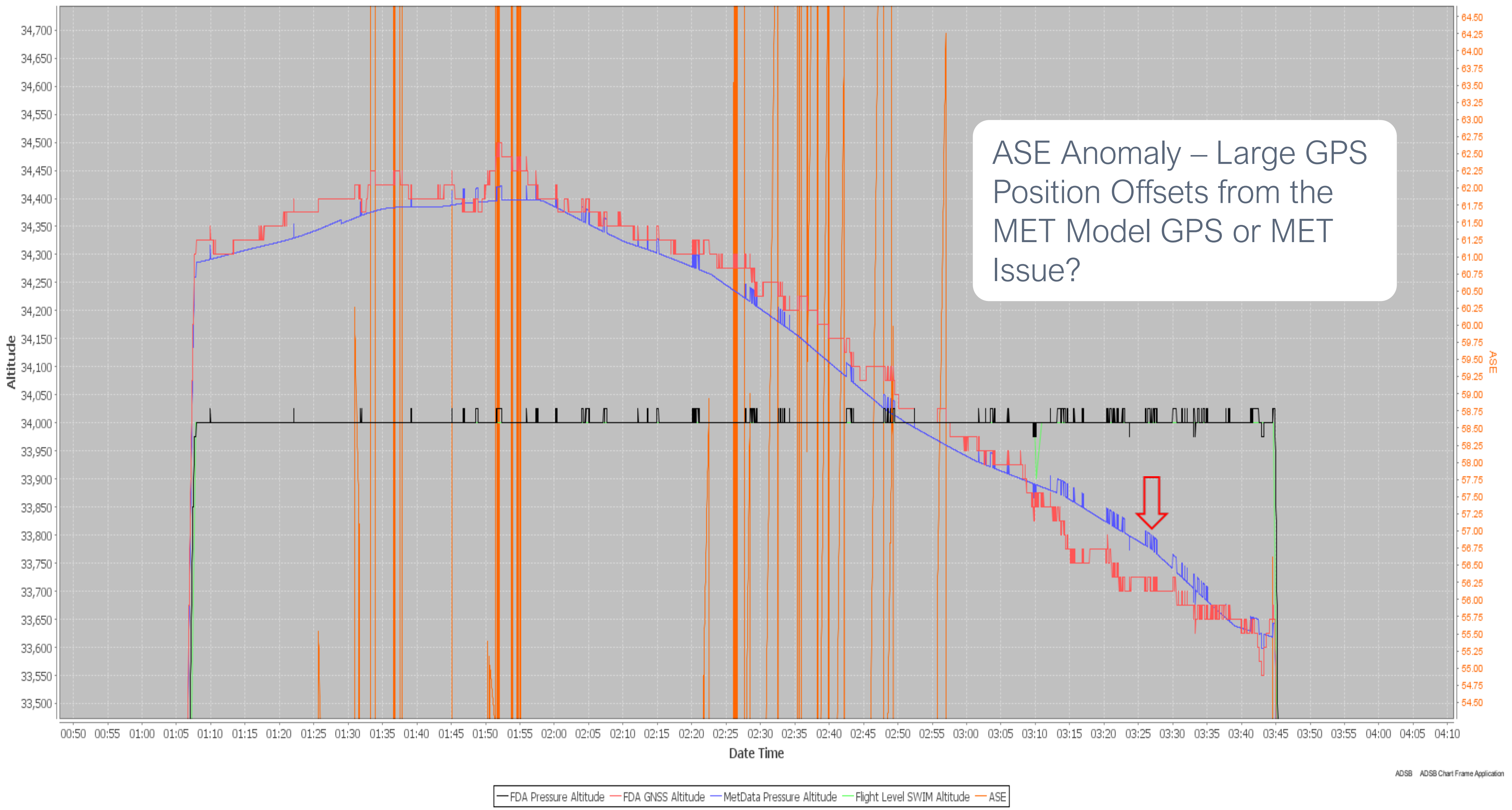
U.S. Air Traffic Control ADS-B Data Coverage

ASE Quality Control

Large ASE Anomaly – Change of 180ft in 25 minutes

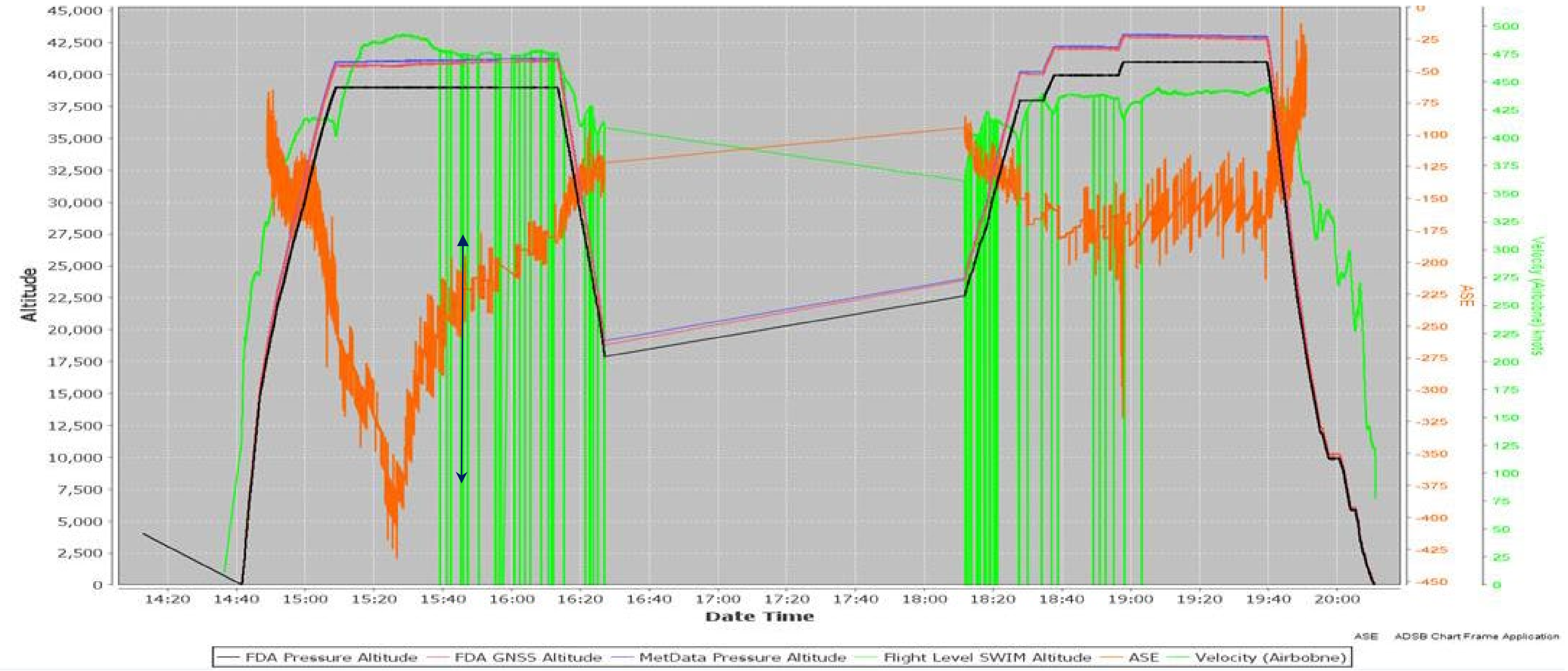


ASE Quality Control

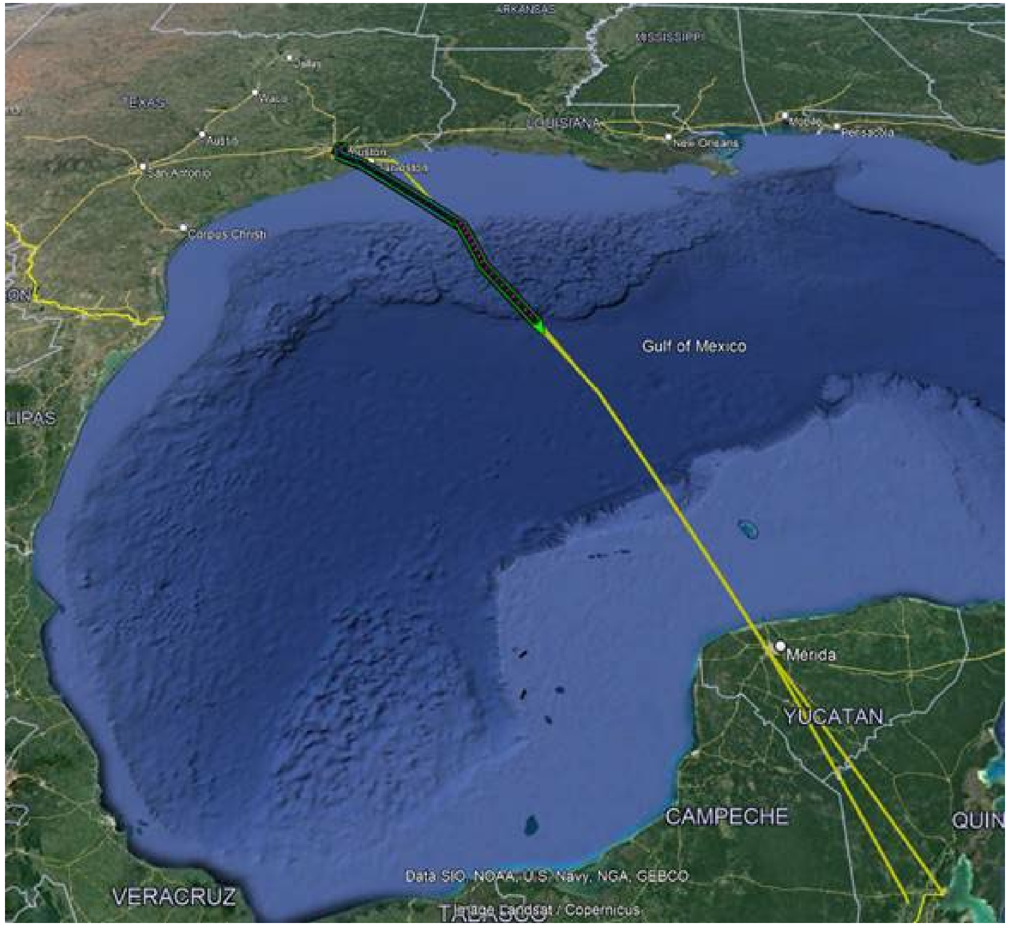


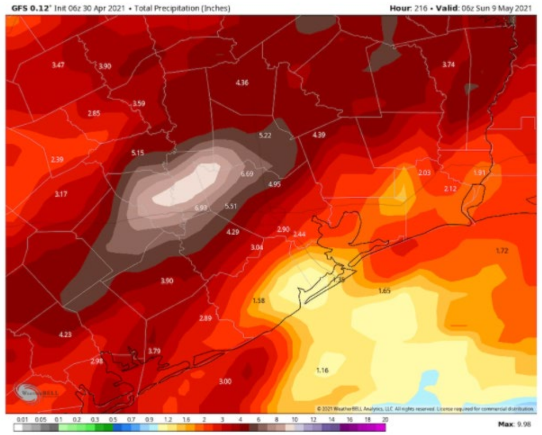
ASE Quality Control
Position of the anomaly suggests Mountain Wave Effects

MET Anomaly Caused by a Storm



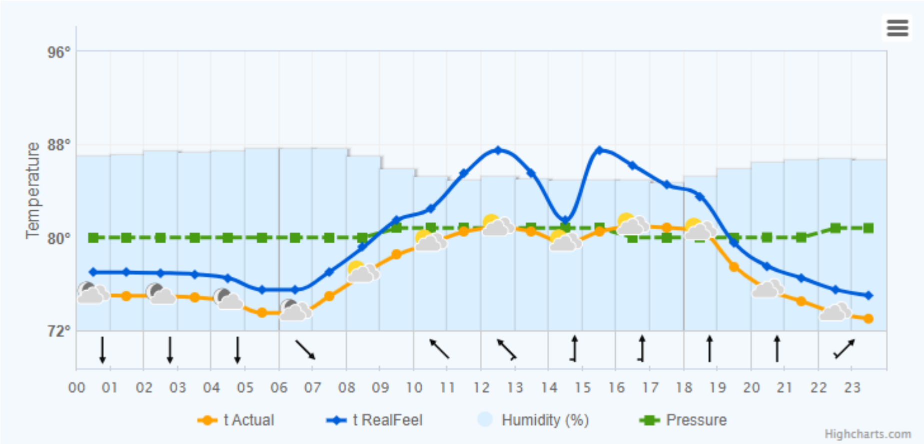
Ground Track of Flight and MET





The American GFS model simulates rainfall in Houston through Sunday. (WeatherBell)

Hourly forecast for 30.04.2021



ASE Monitoring Accuracy

- ASE is calculated from independent GPS and MET model data
- The overall accuracy of the ASE measurement can be estimated from the expected accuracy of each component
- GPS and MET data are derived from separate sources and can be considered independent
- The accuracy of the ASE measurement can be best characterized by the Root Sum Square (RSS) of the individual component accuracy

Benefits of Frequent Monitoring

- Daily monitoring of all flights within US airspace supports any flights required for Section 9 operators to be initially monitored
- Uncertainty in the ASE estimates due to observed errors in the current MET data are averaged over time. More ASE observations reduce uncertainty in the ASE average
- Minimum monitoring requirements are easily met with regular ADS-B ASE processing
    - Detection of faulted aircraft is simplified with more observations

Sample Database Output: Operator Report with Poor Performer

Summary

- Availability of aircraft position data in ADS-B messages provides an unpresented ability to observe ASE
- Accuracy of ADS-B ASE processing will be improved with additional work to identify contributing factors
- Data quality control is an essential part of the any aircraft analysis to be sure the ASE is a true measure of the system performance