



# SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES  
FOR SAFER AVIATION IN ICING ENVIRONMENT

## Short Range Particulate (SRP)

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AC-9C: Aircraft Icing Technology Committee  
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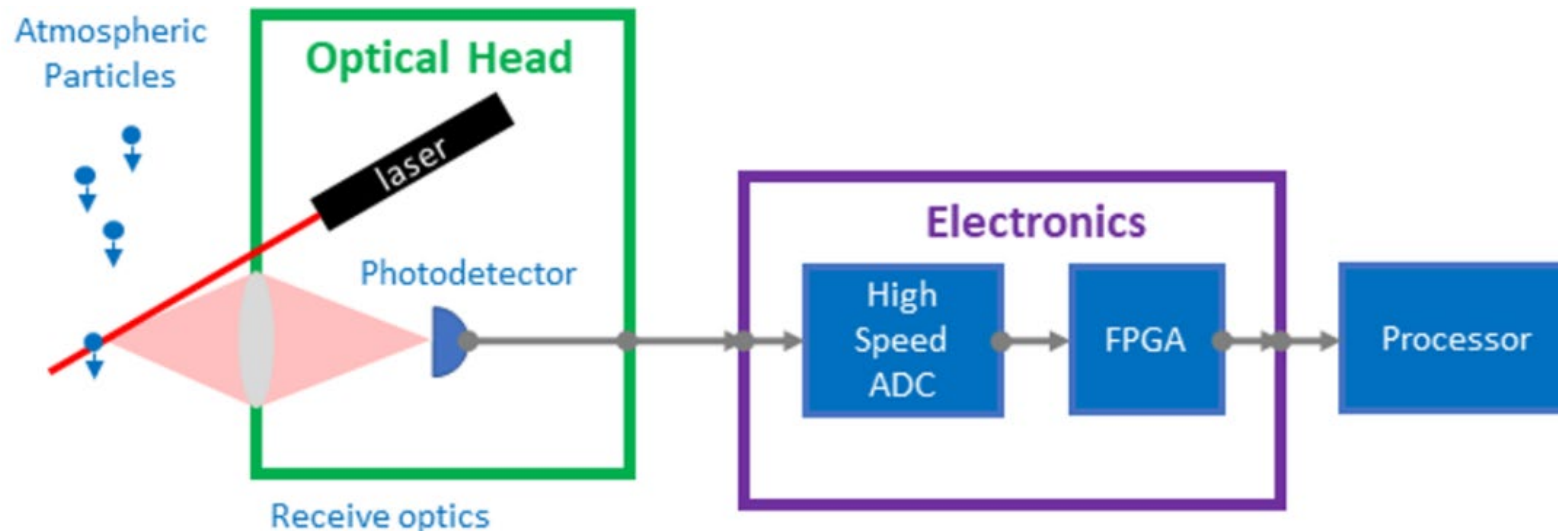
## Sensor Description



# Short Range Particulate - Overview

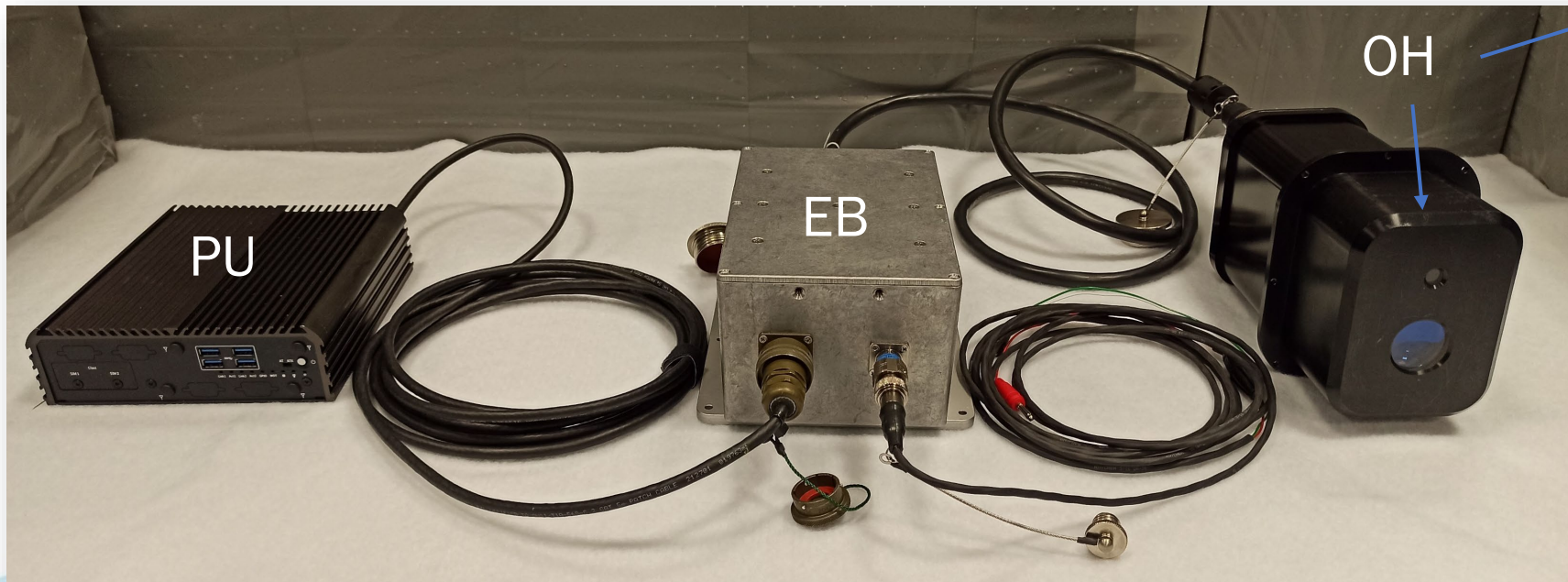
## Optical sensor detecting particles through polarized backscatter

- Extract data two ways
  - Direct particle by particle measurements (scattering from a single particle)
  - Aggregate particle scatter through shifts in the background signal
- AS5498B App. C and App. O detection and discrimination
- Measures liquid water content (LWC) and median volume diameter (MVD)



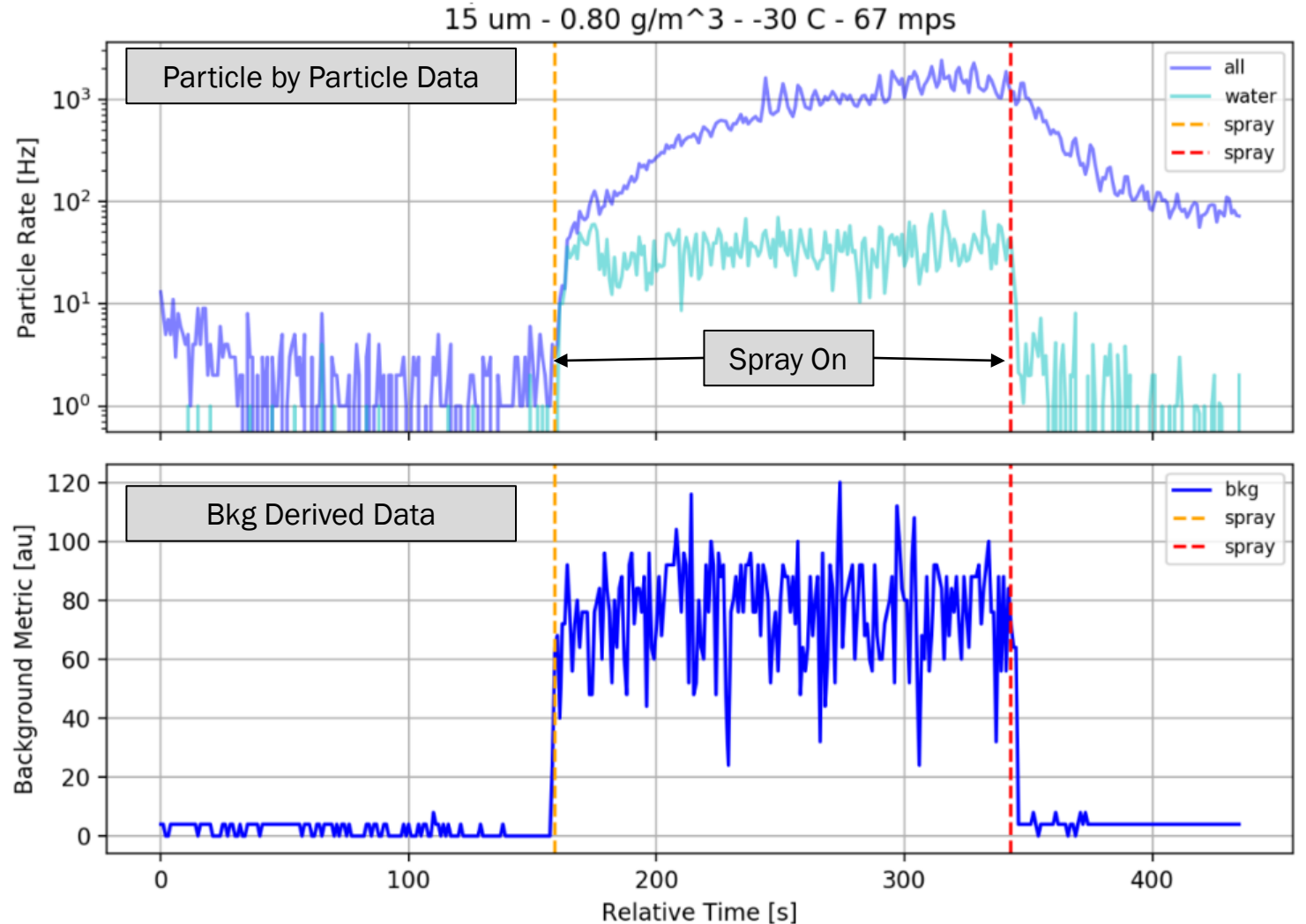
# Short Range Particulate - Overview

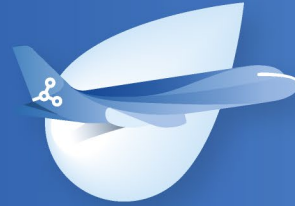
- (OH) Optical Head
- (EB) Digitalization and Pre-processing
- (PU) RCO-3600 Raw data to Icing Parameters



# Short Range Particulate - Overview

- Sample data from icing wind tunnel test (IWT)
- Sensor channels:
  - Direct particle measurements (top) signals large droplets
  - Shifts in background signal (bot) indicate smaller droplets
- Water/Ice discrimination based on polarization discrimination





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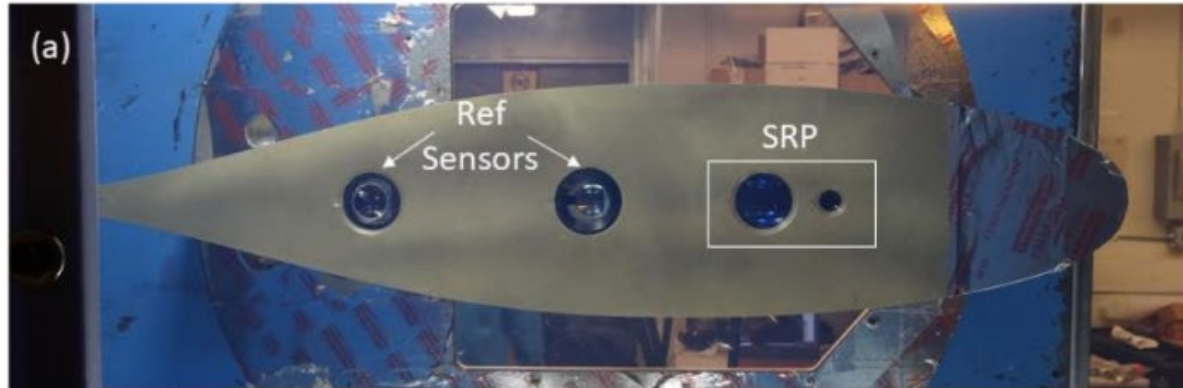
## Icing Wind Tunnel Test





# Installation

- IWT Collins Facility (2021), App. C&O conditions



# Procedure

## Icing Wind Tunnel Test Procedures – Most Points

- Start data recording and record data for 1 min in clear air
- Start the icing cloud
- Run for several minutes with the icing cloud – total exposure varies depending on specific condition being tested
  - In most cases, a minimum of 3 min of icing exposure was tested
- Stop the icing cloud, record minimum of 1 min of data

## Icing Wind Tunnel Test Procedures – Repeat Points

- For a few test conditions, the procedure was repeated three times without de-icing or other intervention





# Performance Summary

- Excellent performance on response time metric across both icing appendices
- Parameter measurement accuracy differed between the two appendices
  - Good match with tunnel values for App. C
  - Higher Error for App. O – discussed in subsequent slide

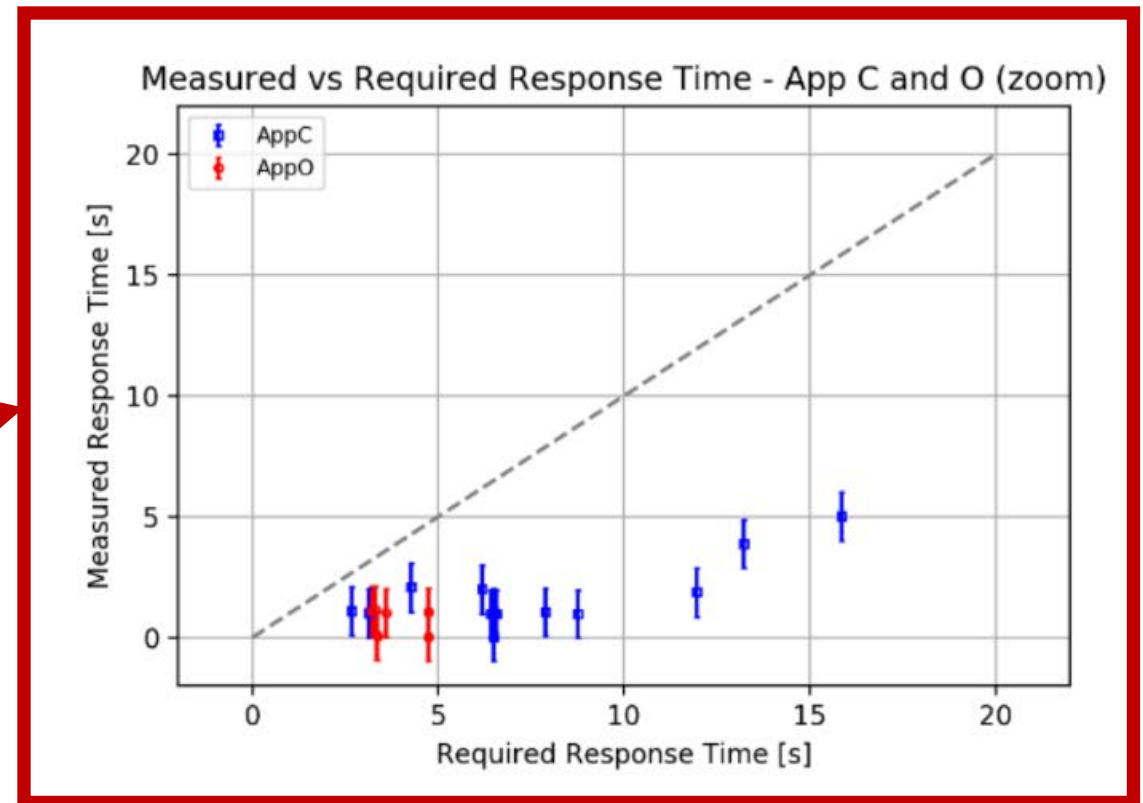
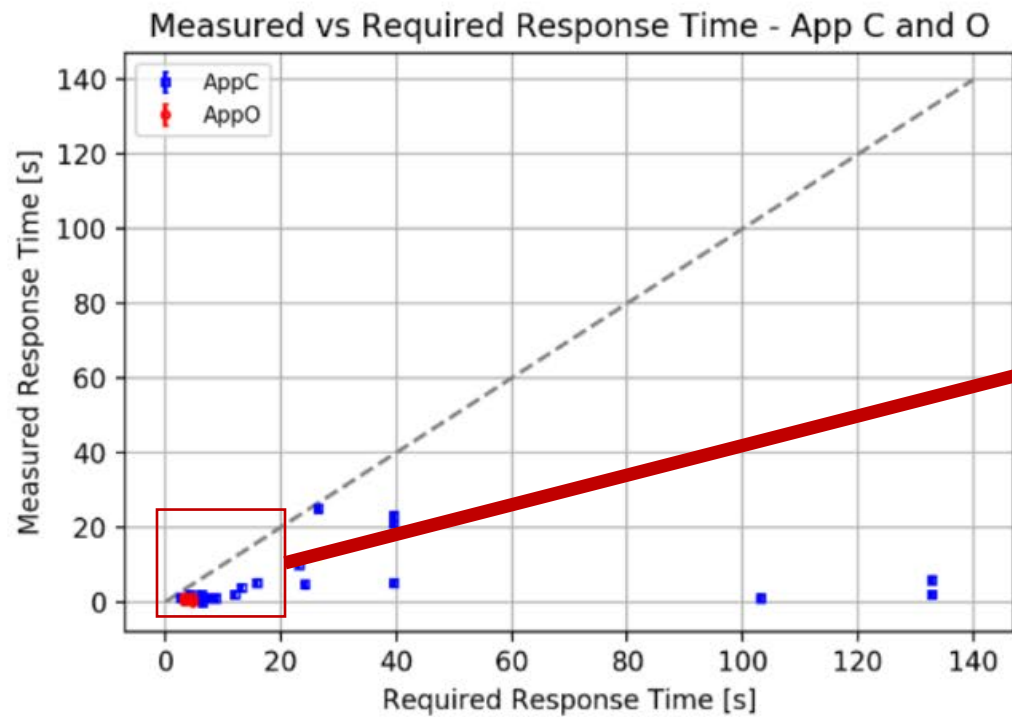
Test	Test Points Detected within Response Time [%]	Average MVD Error [%] *	Average LWC Error [%] *
Appendix C Test Points	100%	14%	28%
Appendix C Repeat Points	100%	15%	27%
Appendix O Test Points	100%	41%	67%
Appendix O Repeat Points	100%	24%	59%

$$* \text{ Error} = 100 * \sqrt{\frac{\sum \left(1 - \frac{\text{meas}}{\text{truth}}\right)^2}{n}}$$



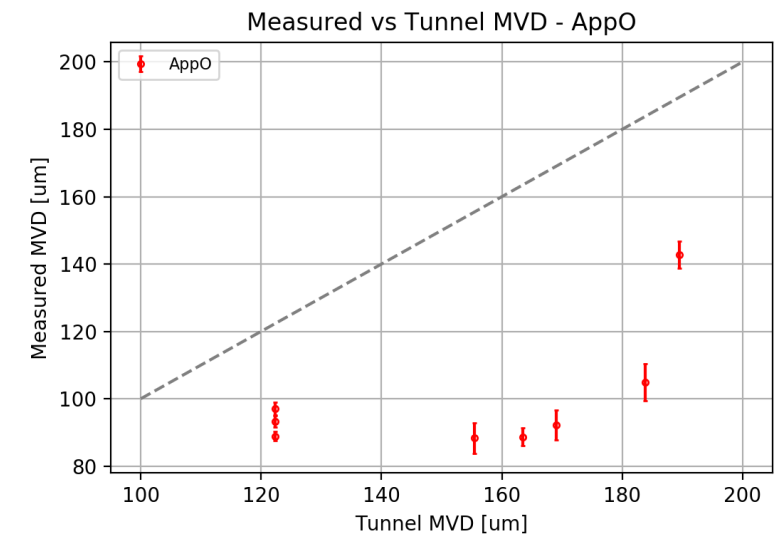
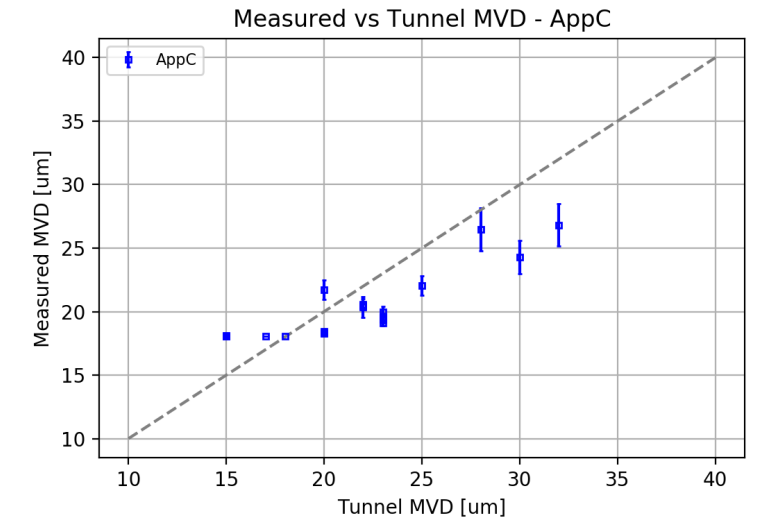
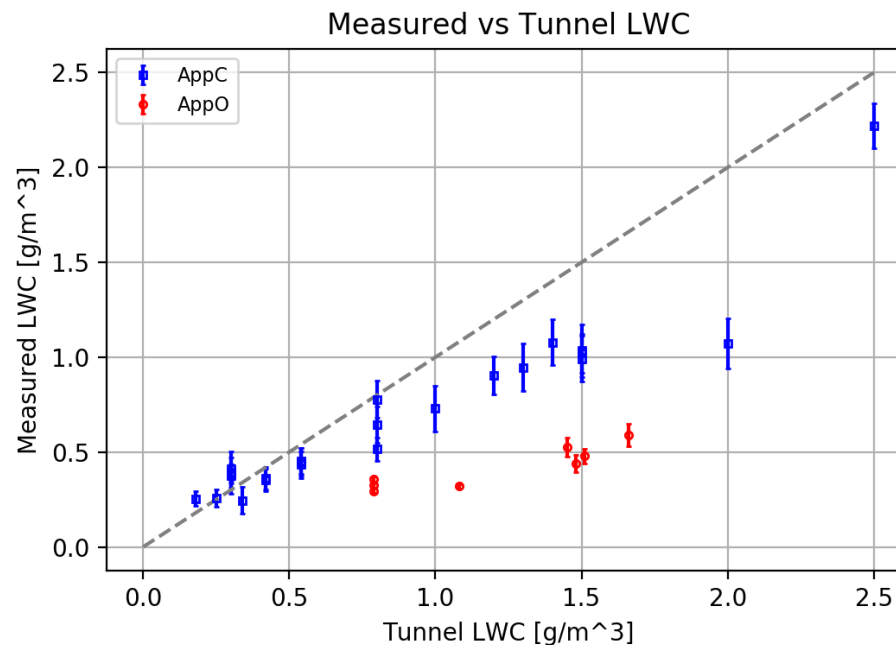
# Response Time

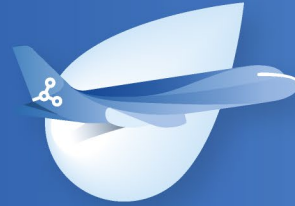
- Sensor meets SAE AS5498B (or equivalently ED-103B from EUROCAE) requirements on response time



# MVD/LWC Measurements

- Appendix C tracks well for both MVD and LWC
- Larger errors in Appendix O resulting from loss of signal in IWT vs lab calibration
  - Believe window fogging to be core issue – mitigations being developed





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## Flight Test Campaign



# Preparations

- Flight test campaign executed late Feb - early Mar in North America
- Prior to flight test, sensor went through flight worthiness
  - Qualified against a subset of DO-160G tests, including temperature, vibration / shock, power input, lightning, and ESD





# Flight test execution

## Embraer's Phenom 300 optical sensor integration

- Communication issue between sensor & aircraft was resolved without any impact on the campaign

## Flight Test Campaign

- Eight flights for which reference data were successfully measured
- Appendix C and Appendix O conditions encountered multiple times
- Optical sensor data collection successful

## Sensor data analysis and preliminary results

- Performance compared with reference data provided by DLR
- Good results for events in which particulate MVD > 25 microns
- Sensor underestimates TWC for events in which particulate MVD < 15-20 microns
- Detailed results provided for flights 1476 and 1481



*1<sup>st</sup> gen. optical sensor  
direct ptcl. sensing: 2 - 42 um*

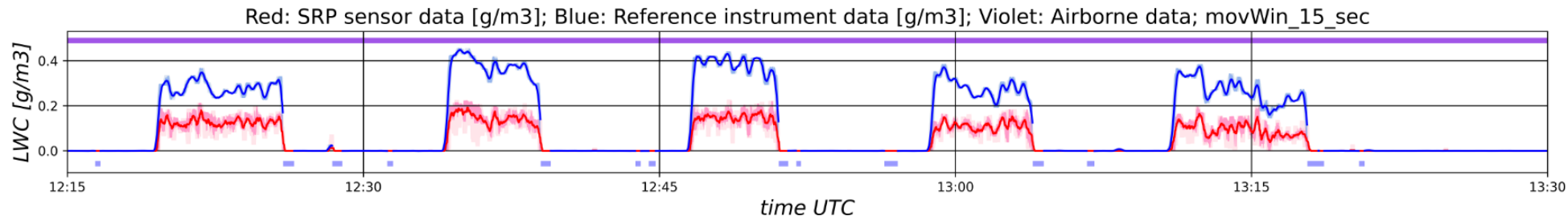


*2<sup>nd</sup> gen. optical sensor  
direct ptcl. sensing: 50 - 1000 um  
background signal sensing: 5 – 50 um*

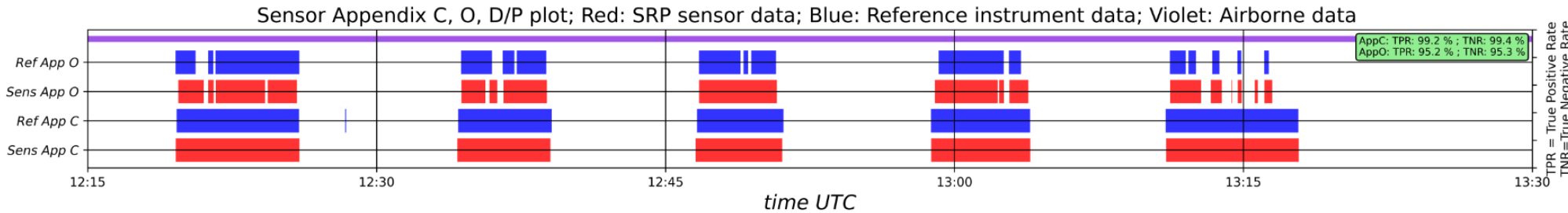


# Optical sensor data analysis: Flight 1476

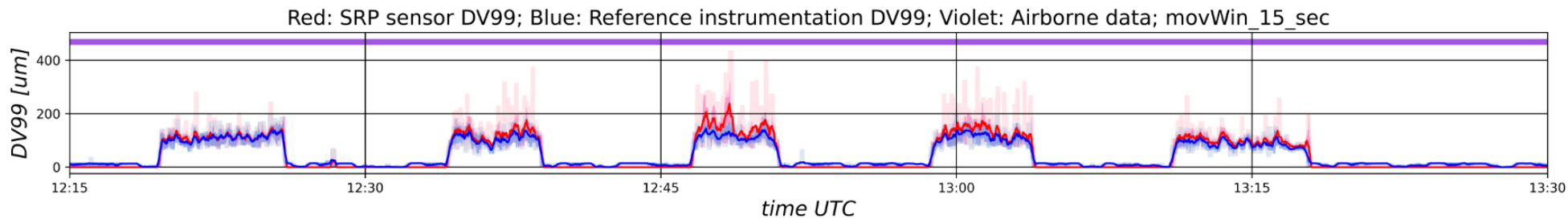
No collection efficiency corrections applied, sensor non-linearities corrections not applied, better results are expected



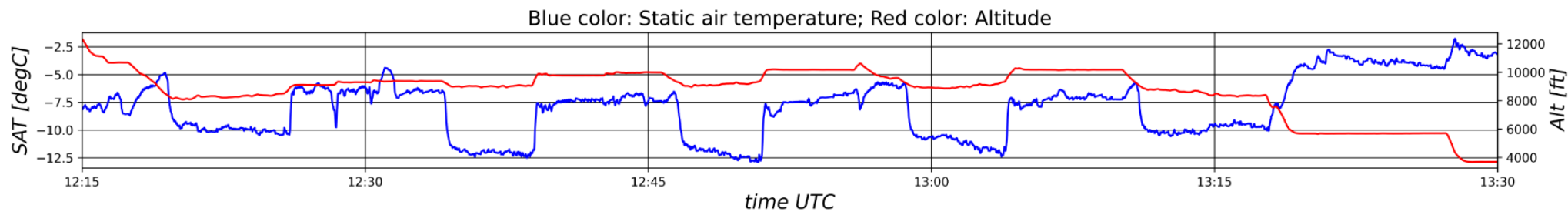
High correlation between reference and optical sensor data



App. C and App. O flags are well matched with reference instrumentation data

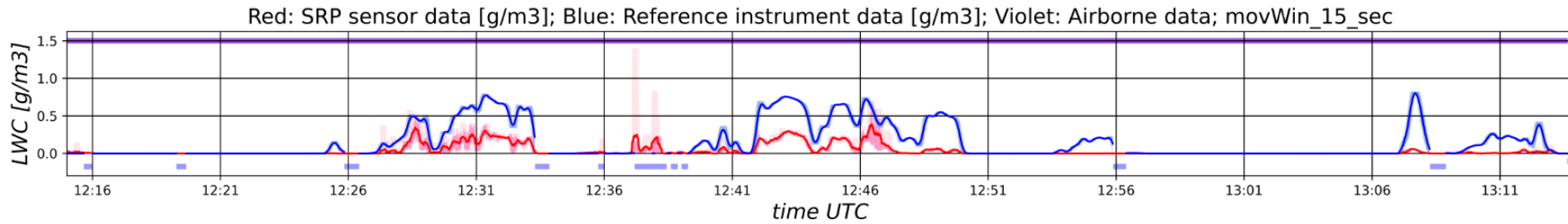


DV99 values are well matched with reference instrumentation data

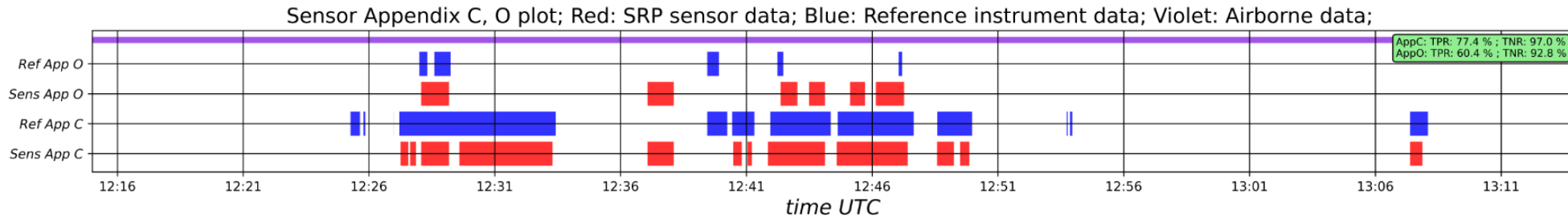


# Optical sensor data analysis: Flight 1481

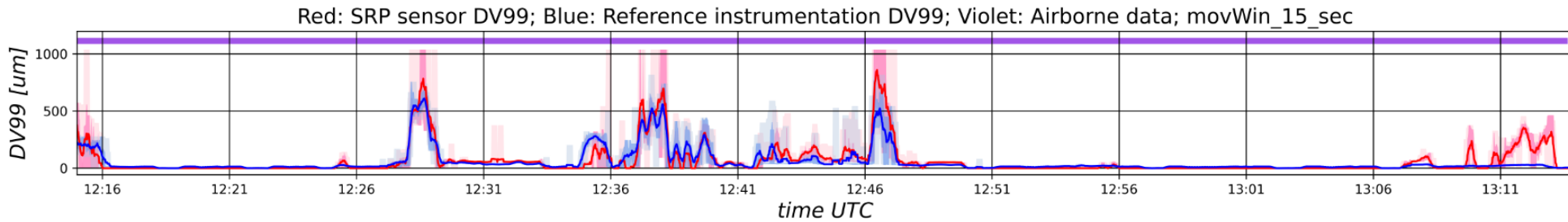
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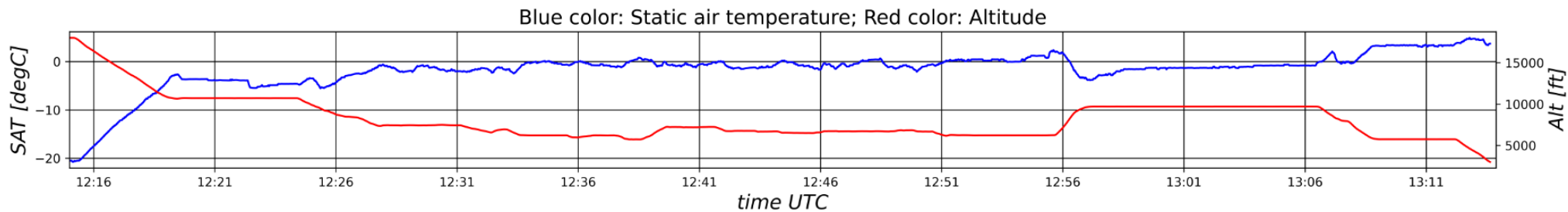
High correlation between reference and optical sensor data



App. C flag is well matched with reference instrumentation data. False alarm presence in App. O flag estimation



DV90 values are well matched with reference instrumentation data



# Conclusions & Next Steps

## Conclusions

- High measurement performance for events in which particulate MVD > 25 microns
- Small particulate detection successfully evaluated under previous program (1<sup>st</sup> gen. optical head)

## Next gen. optical sensor development

- Design single sensor covering icing appendixes C, D, O
- Develop ash / dust / sand sensing functionality

## Use-cases

- Safety, autonomy, situation awareness
- Reduce fuel consumption, reduce CO<sub>2</sub> emissions
- Predictive health maintenance



## Acknowledgment

- Thank you to Embraer, DLR and all SENS4ICE partners for US flight test preparations and execution

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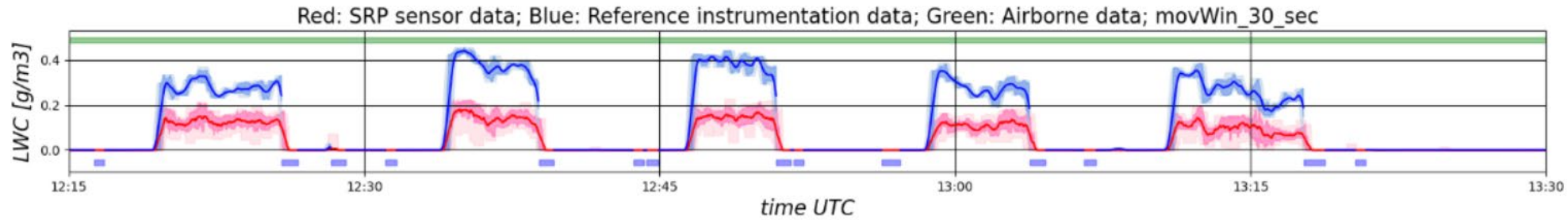
Visit our website [www.sens4ice-project.eu](http://www.sens4ice-project.eu)  
and LinkedIn [#sens4iceproject](#)

# BACKUP SLIDES

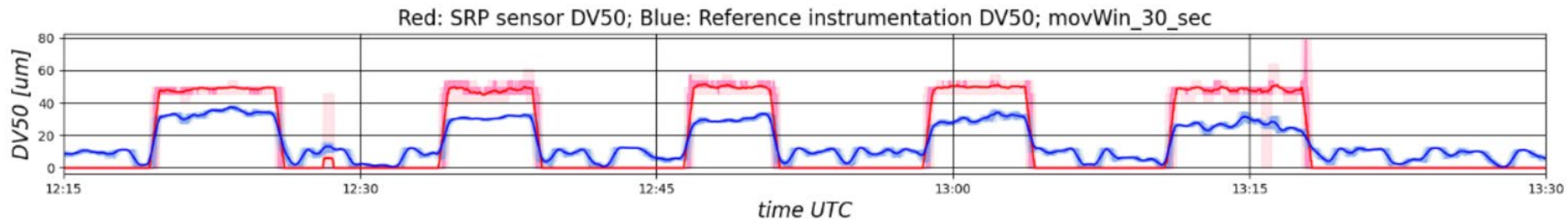


# Optical sensor data analysis: Flight 1476

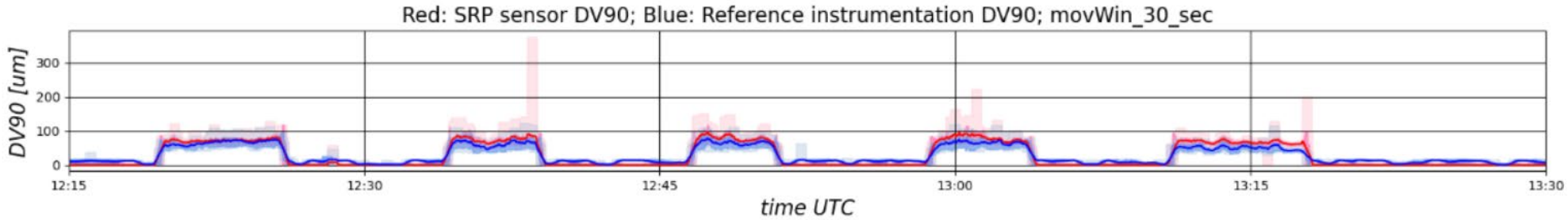
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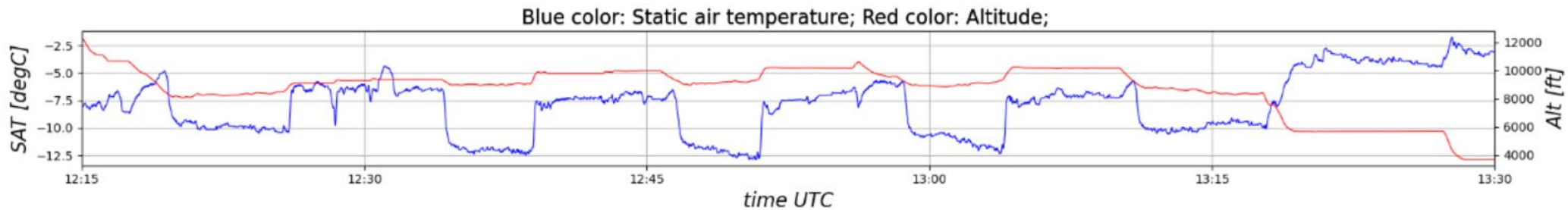
High correlation between reference and optical sensor data



Optical sensor underestimates volume/mass of small particles

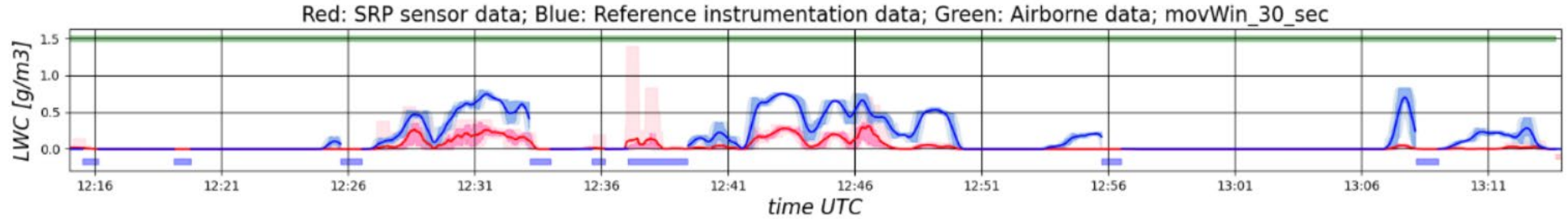


DV90 values are well matched with reference instrumentation data

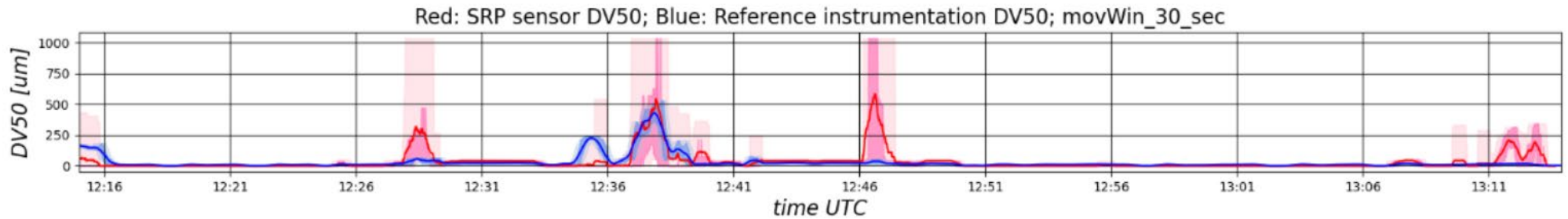


# Optical sensor data analysis: Flight 1481

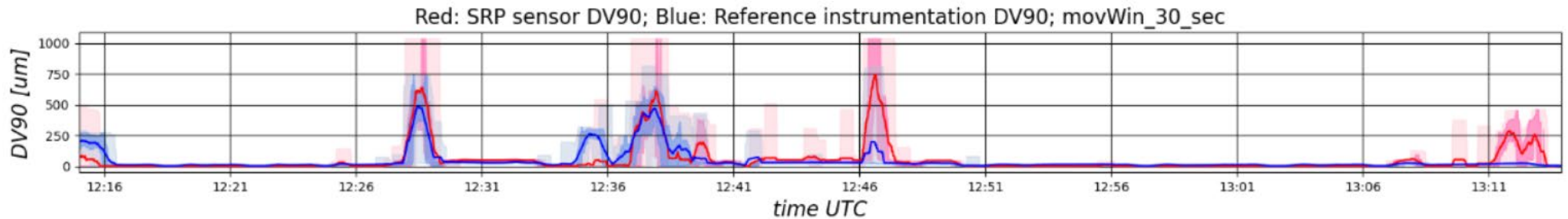
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High correlation between reference and optical sensor data



Optical sensor underestimates volume/mass of small particles



DV90 values are well matched with reference instrumentation data

