

Cloud Observations and Processes in Convection over Central Saudi Arabia

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Middle East Green Initiative

- Inaugurated in 2021 by His Royal Highness Prince Mohammed bin Salman bin Abdulaziz, Crown Prince and Prime Minister, MGI is a first-of-its-kind regional alliance formed to mitigate the specific impacts of climate change on the countries of the Middle East and North Africa.

Middle East Green Initiative

- The MGI will establish collaborations between Middle East neighbors to meet global climate targets. By increasing regional cooperation and creating the infrastructure needed to reduce emissions of greenhouse gases and other environmentally undesirable materials to protect the environment, MGI can amplify impact in the global fight against climate change, whilst creating far-reaching economic opportunities for the region.

Saudi Green Initiative

- Launched in 2021 by His Royal Highness Prince Mohammed bin Salman bin Abdulaziz, Crown Prince and Prime Minister, SGI is a whole-of-society initiative, uniting all sustainability efforts in the country to rapidly scale up the Kingdom's climate action.

SGI supports Saudi Arabia's ambition to reach net zero carbon emissions by 2060 through the Circular Carbon Economy approach and is also accelerating the country's transition to a green economy. Three overarching targets guide SGI's work - emissions reduction, afforestation, and land and sea protection.

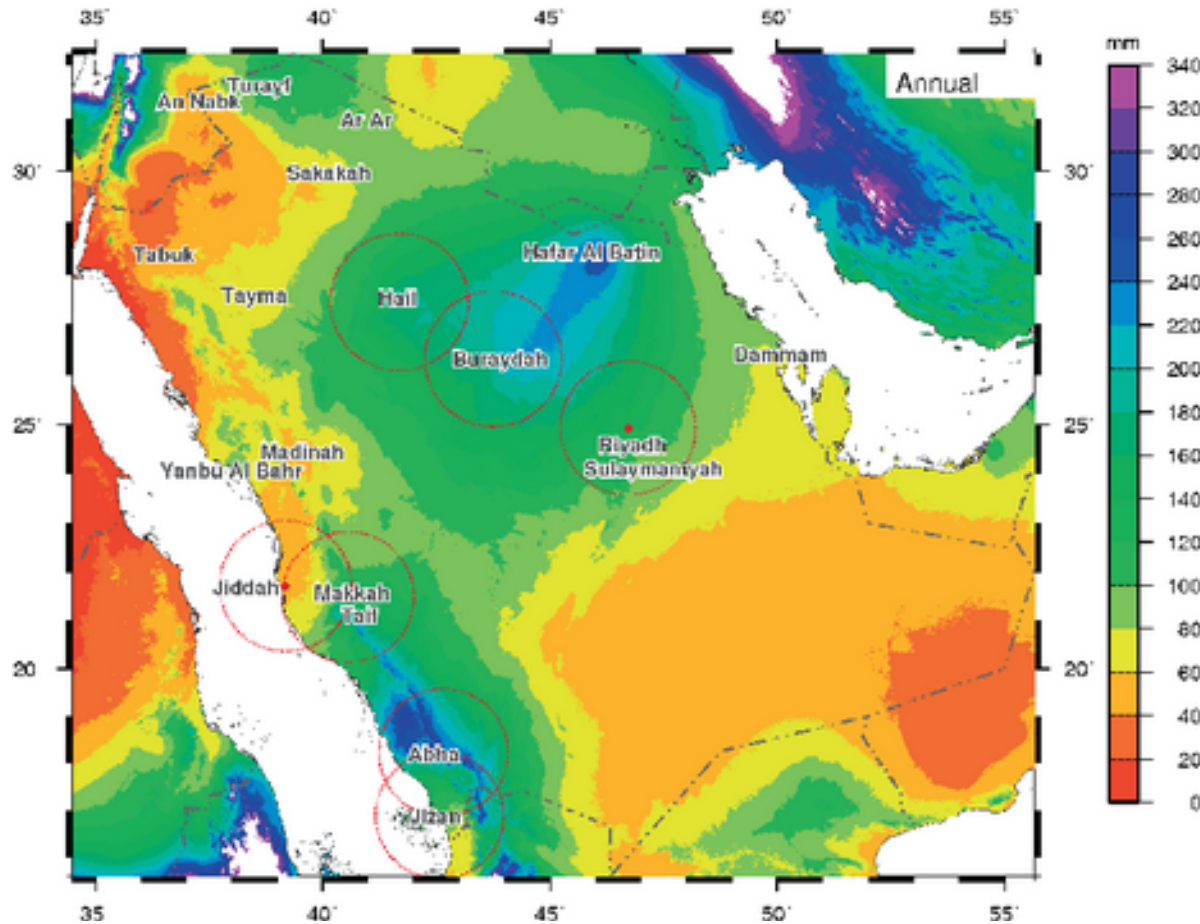
Saudi Green Initiative

- Since SGI's inauguration, 77 initiatives corresponding to the three targets have been activated, representing an investment of more than \$186bn and helping to drive sustainable growth. By bringing together the government and private sector, and fostering collaboration and innovation, the Kingdom's commitments have been turned into tangible action, whilst supporting global goals.
- Among these initiatives is precipitation enhancement by cloud seeding.

Recent weather modification activities in Saudi Arabia

- Assessment of the possibility of enhancing precipitation over Saudi Arabia using cloud seeding began in early 2000's
- Intensive airborne field research was conducted in 2007 – 2010 with international collaborators, including the US National Center for Atmospheric Research
- Operational seeding was conducted for several projects that lasted a year or two at a time
- Over the past couple of years the Saudi National Center for Meteorology has contracted with Weather Modification International to develop infrastructure for operations and research including aircraft, seeding technology, etc.
- The Saudi Aerosol Cloud Precipitation Enhancement Campaign (SARPEC) began in 2023
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Annual Precipitation Pattern in Saudi Arabia



From Kucera et al. 2010

Precipitation growth in Saudi storms

- Kucera et al. (2010) analyzed available observations in storms forming over the Red Sea escarpment along the southeast coast. They try identify the pathways to precipitation in the convective clouds that develop there. They suggest a common pathway is growth of cloud droplets by collision/coalescence, followed by freezing of the larger droplets as they are carried upward, followed by further growth of snow/graupel particles to precipitating sizes through riming and ice-ice aggregation.
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Saudi Aerosol-Cloud-Precipitation Enhancement Campaign (SARPEC)

- Determine effectiveness of operational cloud seeding techniques for rainfall augmentation within the Kingdom of Saudi Arabia
- IOP1 – Summer 2023 – 12 research flights
- IOP2 – Fall 2023 – 22 research flights
- IOP3 – Spring 2024 – currently in the field

North Dakota Citation Research Aircraft

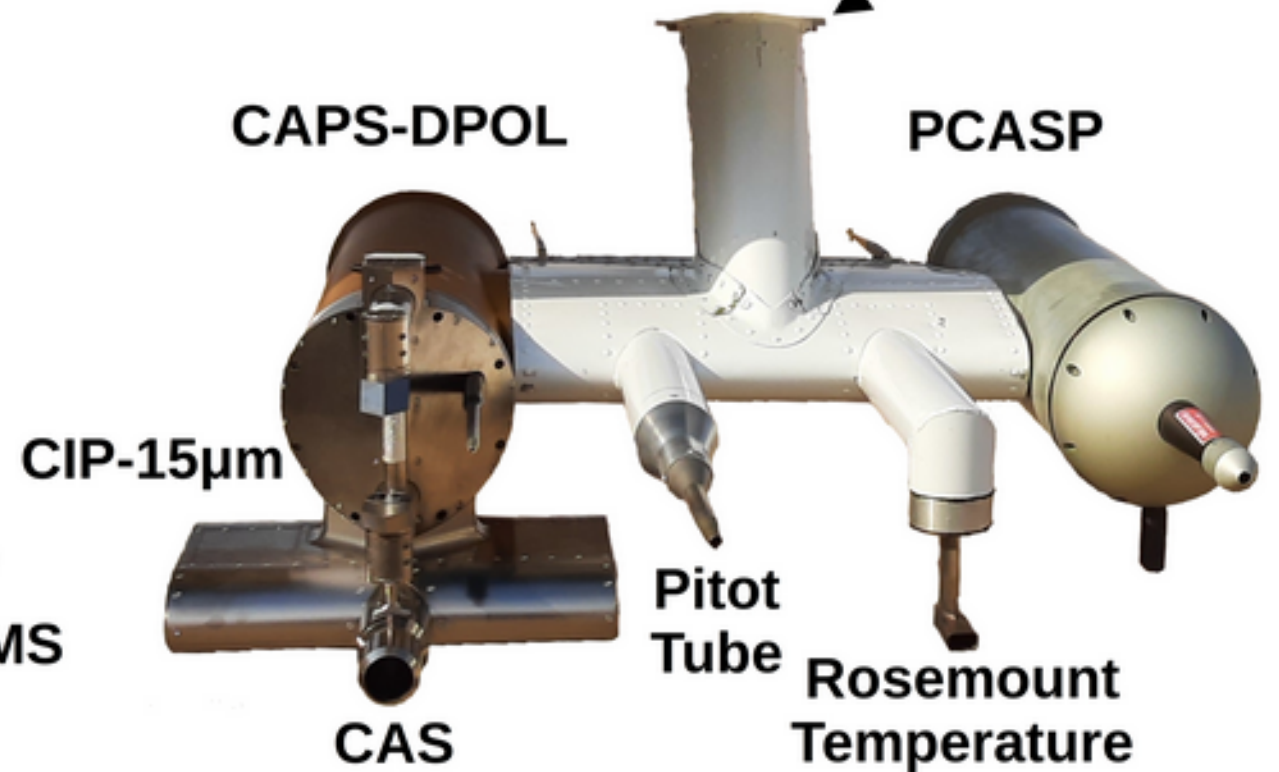
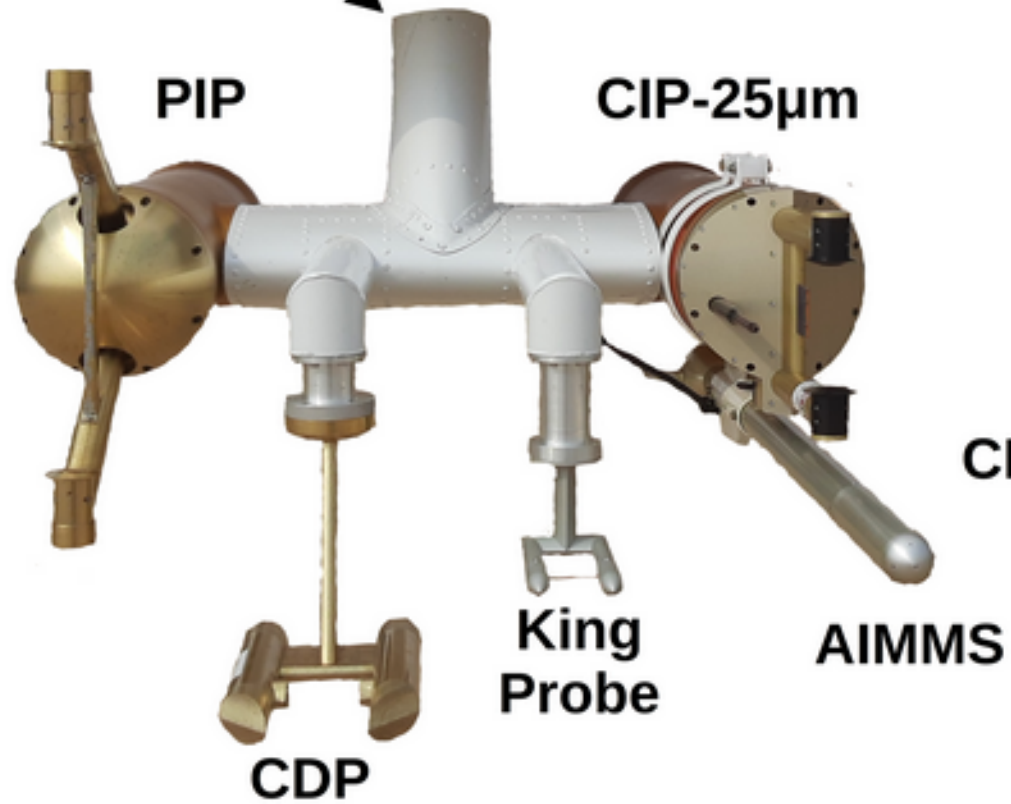
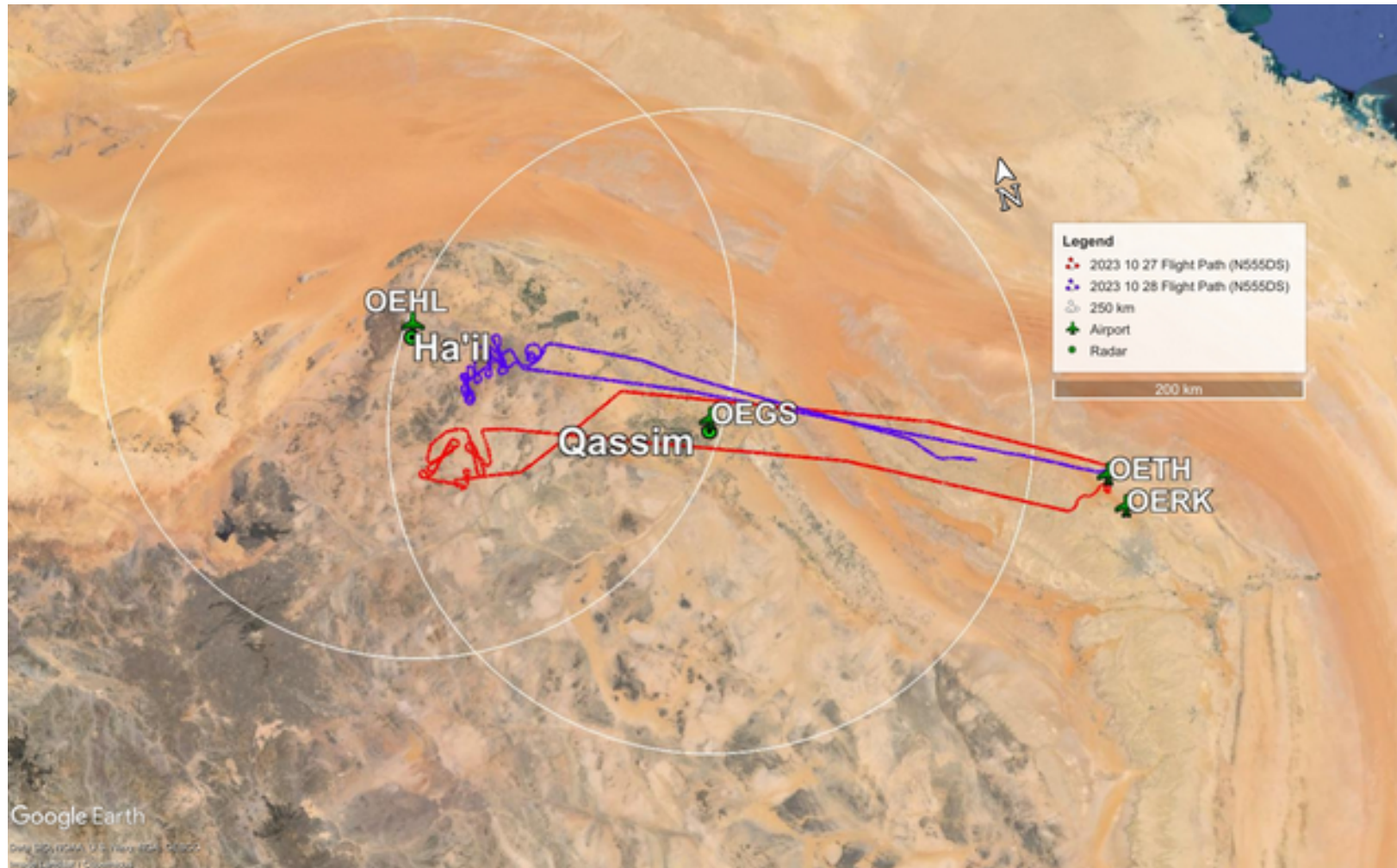




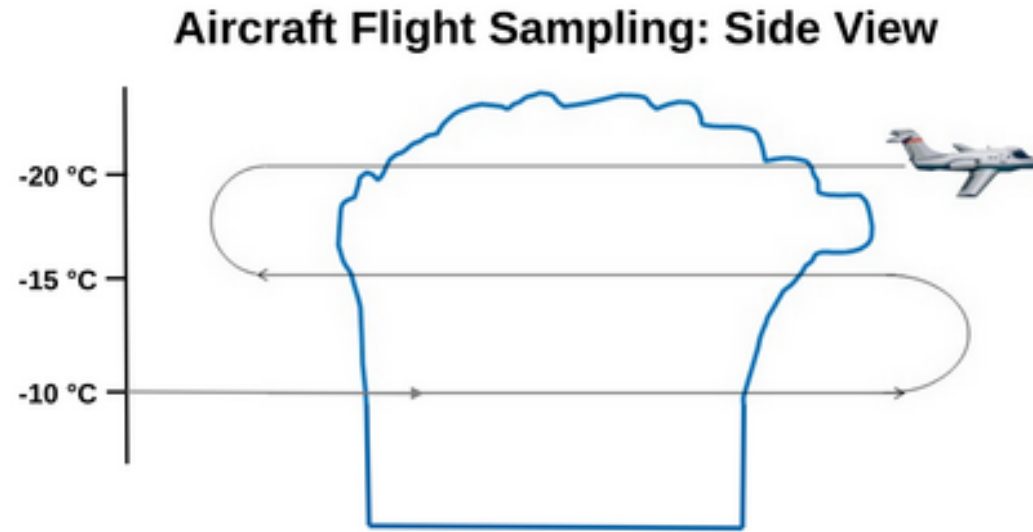
Image showing Saudi Arabia, with national borders given by solid yellow lines. The project is based out of the OETH airport and focuses on measurements near Riyadh; however, clouds in the south-west region are targeted when clouds near Riyadh are not available.

Two example flight tracks from IOP2 initiated from the OETH airport.

- Red track is from a flight on 10/27/2024
- Purple track is from a flight on 10/28/2024

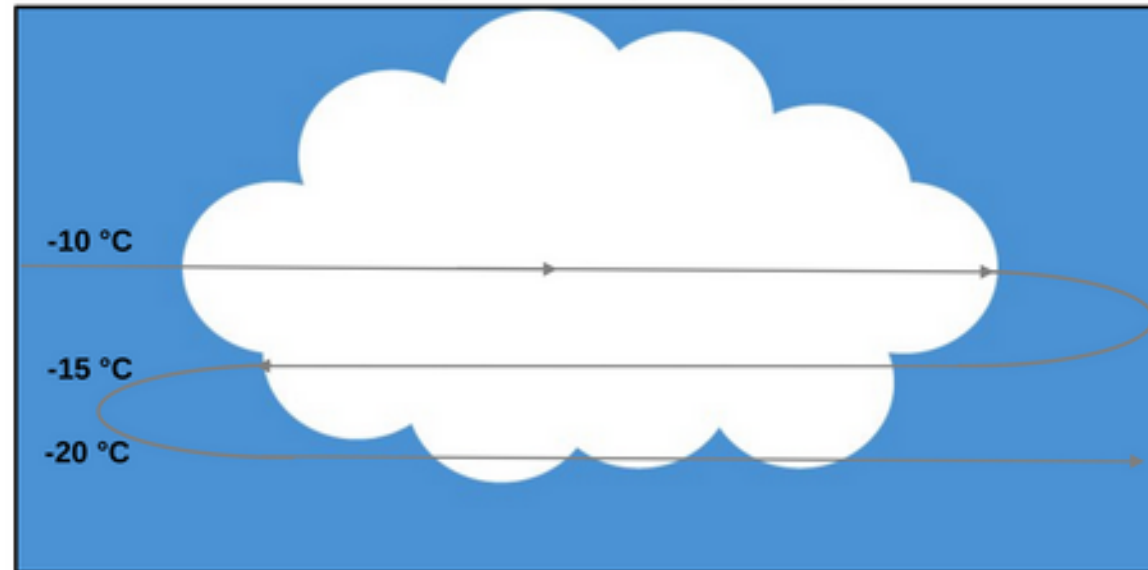


Example of Observations from IOP 3 in Spring 2024



Example of Research Observations from IOP 3 in Spring 2024

Aircraft Flight Sampling: Top View





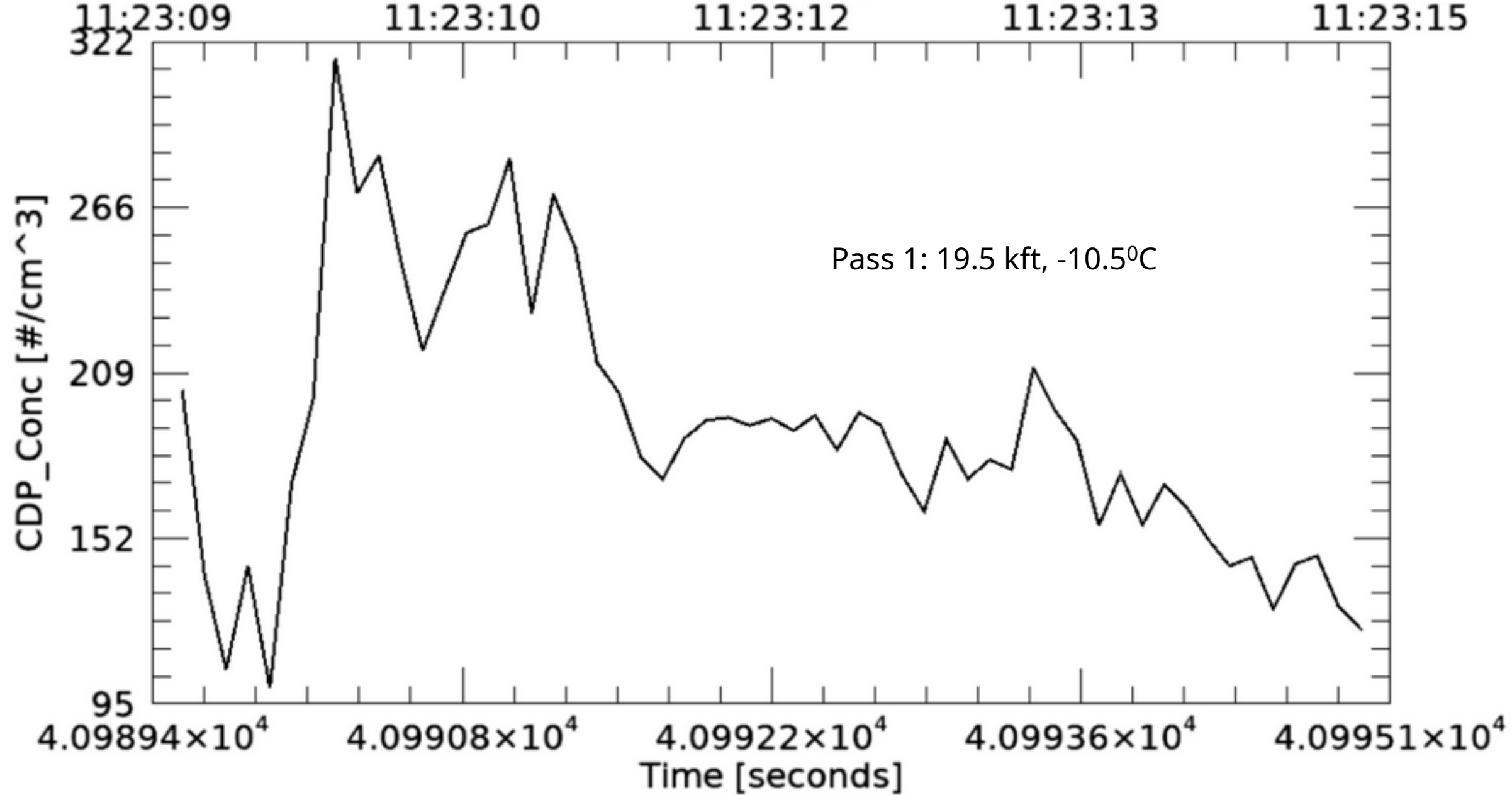
Cloud sampled on SARPEC
mission on October 27, 2023

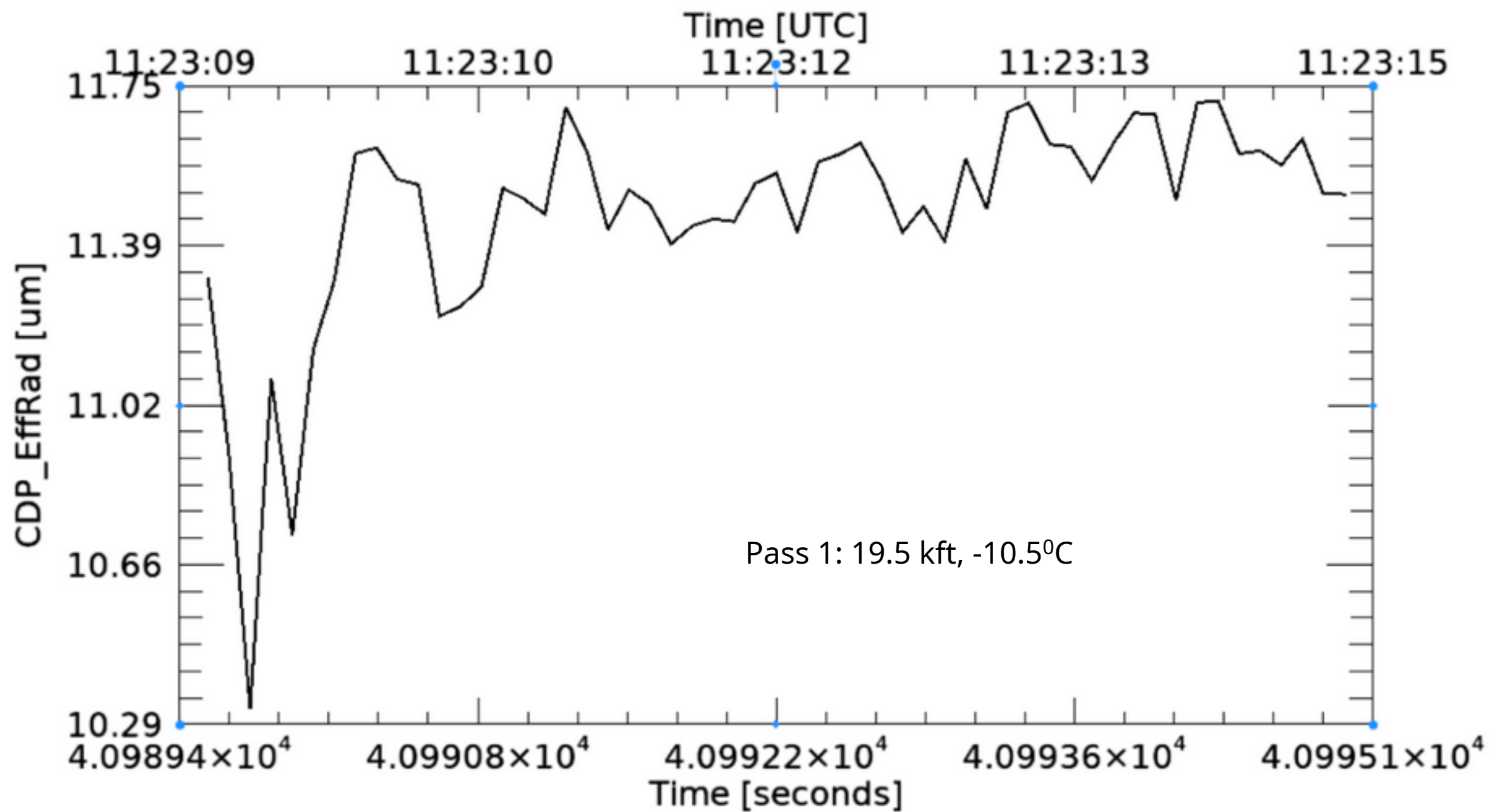
Cloud sampled on SARPEC mission on October 27,
2023

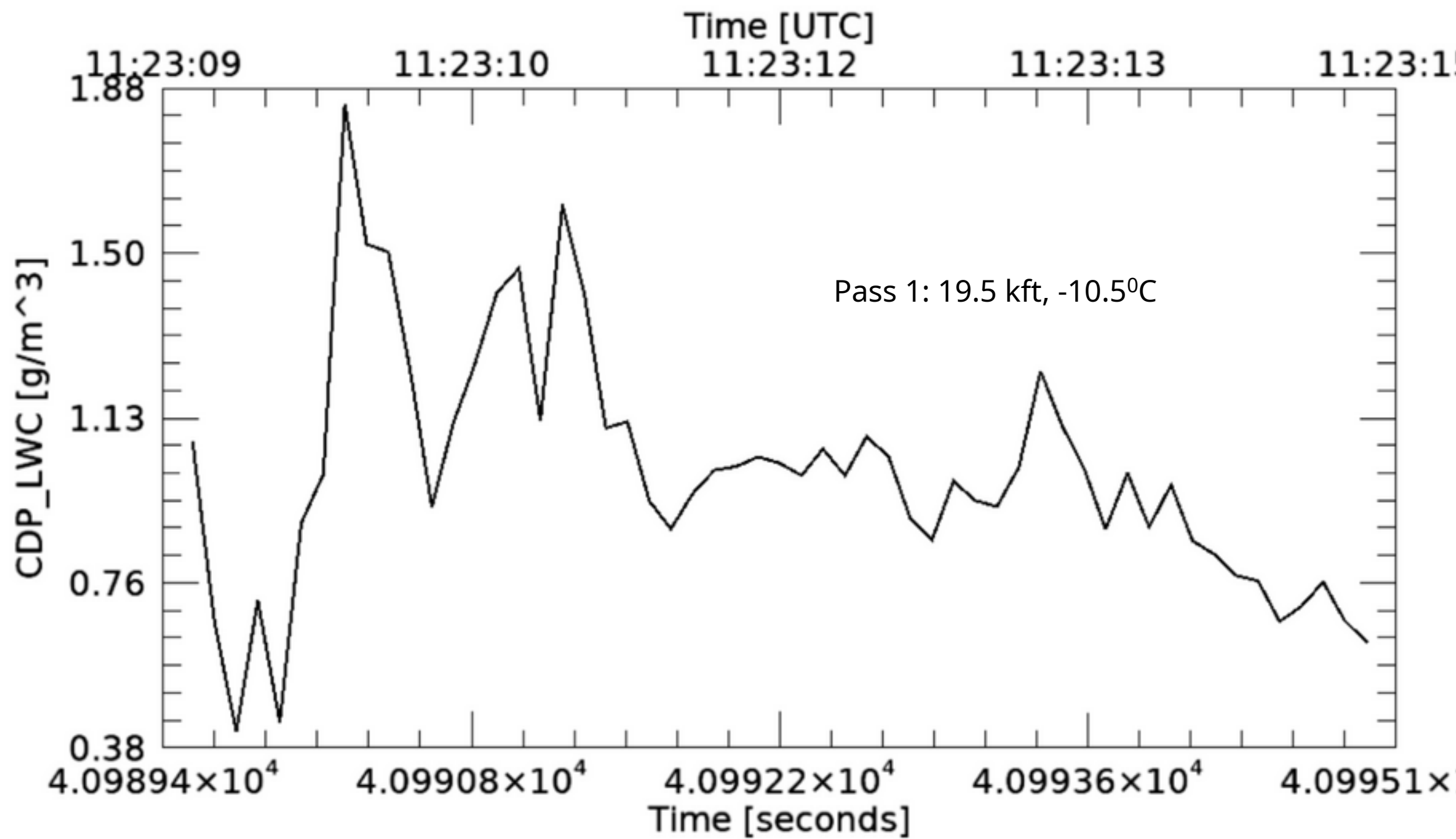




Cloud sampled on
SARPEC mission
October 27, 2023







Pass 1: 19.5 kft, -10.5°C
Precipitation particle images from Droplet Measurement Technology PIP optical
array probe

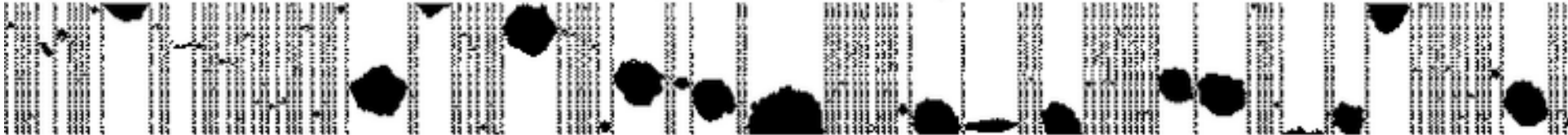
Volume sampling rate ~160 l/sec

10/27/23 Start: 40991.4300(11:23:11.4300) End: 40991.7099(11:23:11.7099) Delta: 0.27990000 [s] TAS: 115.41 [m/s]



6.2 mm

10/27/23 Start: 40991.7099(11:23:11.7099) End: 40991.9700(11:23:11.9700) Delta: 0.26010000 [s] TAS: 115.41 [m/s]

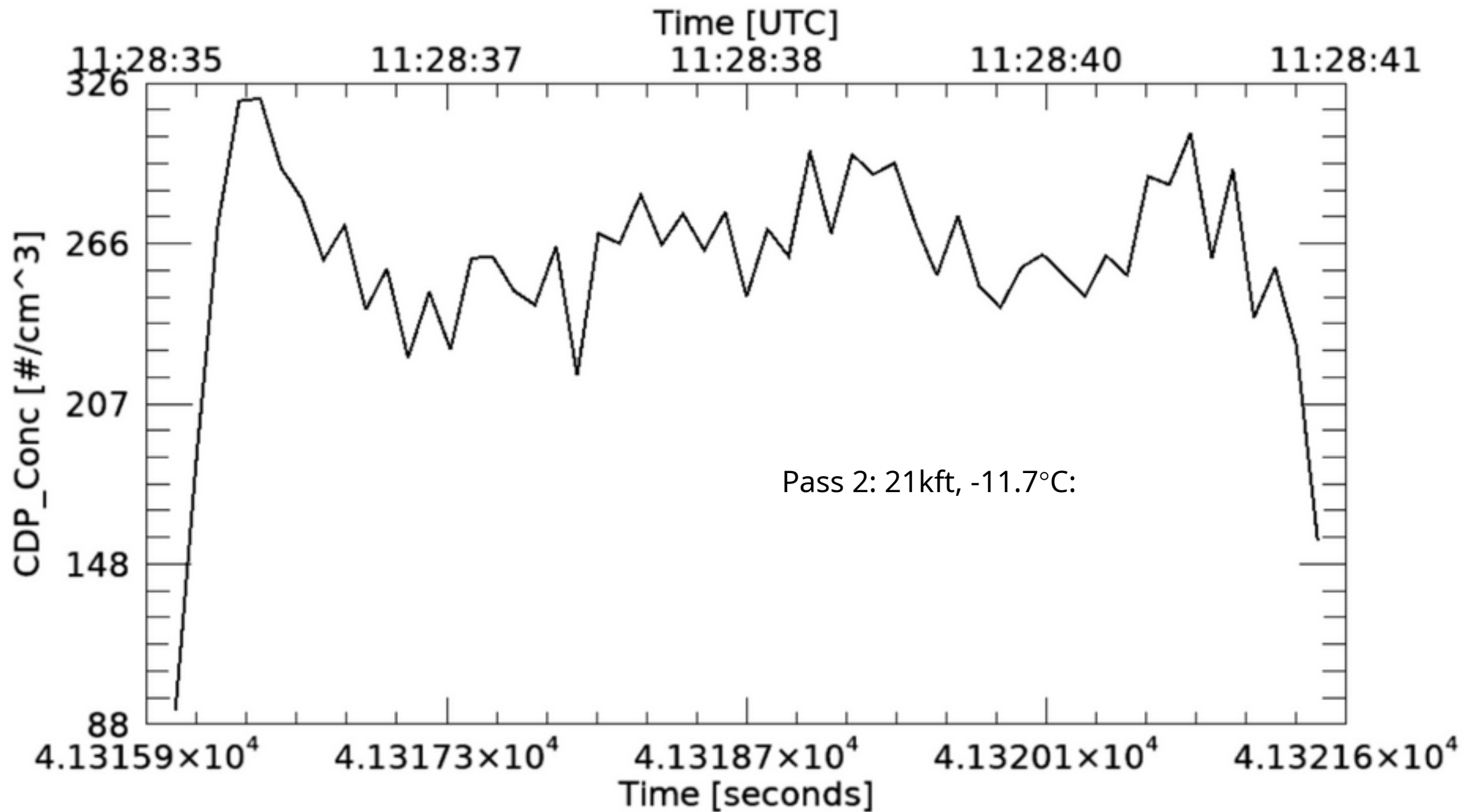


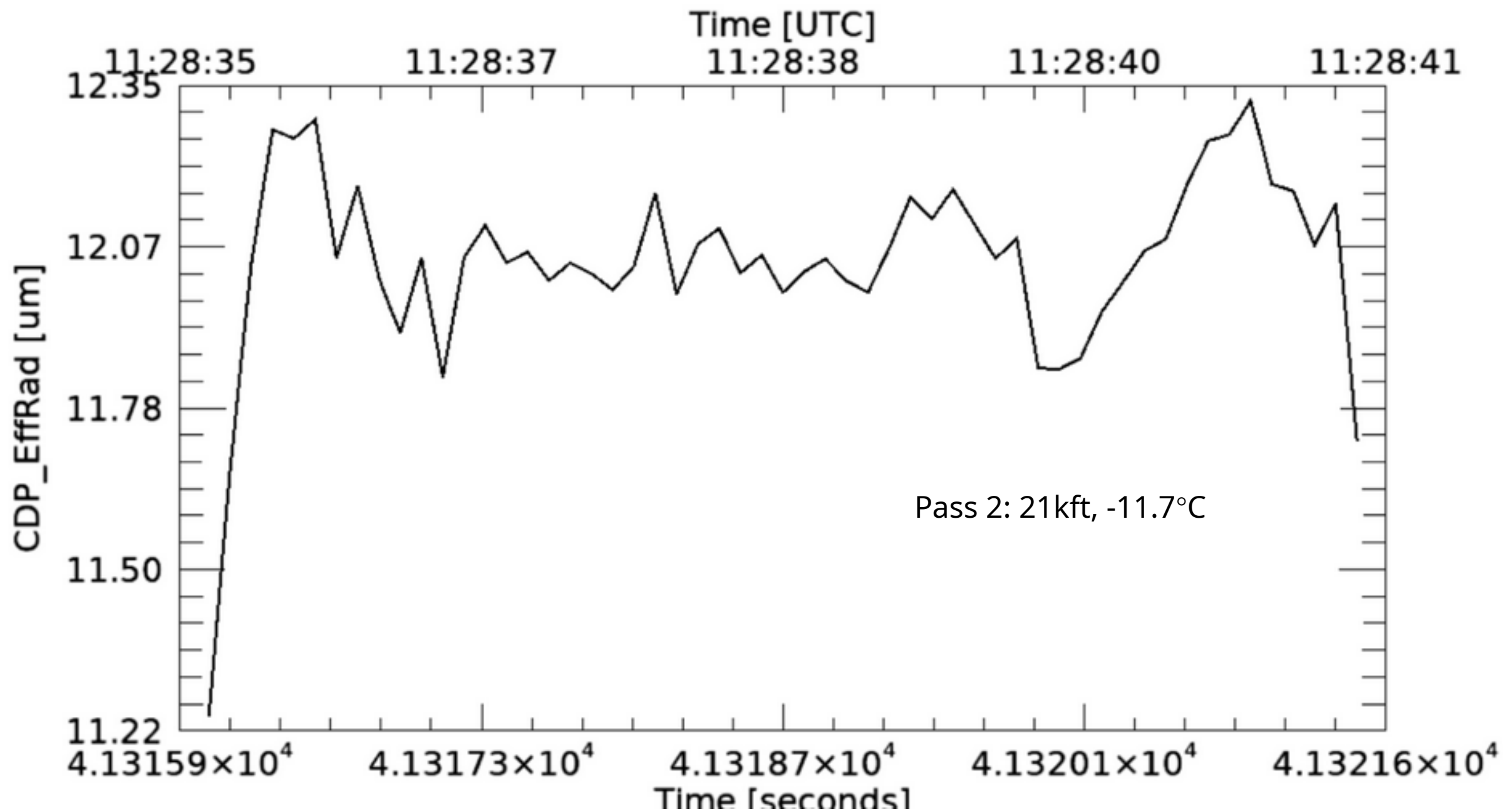
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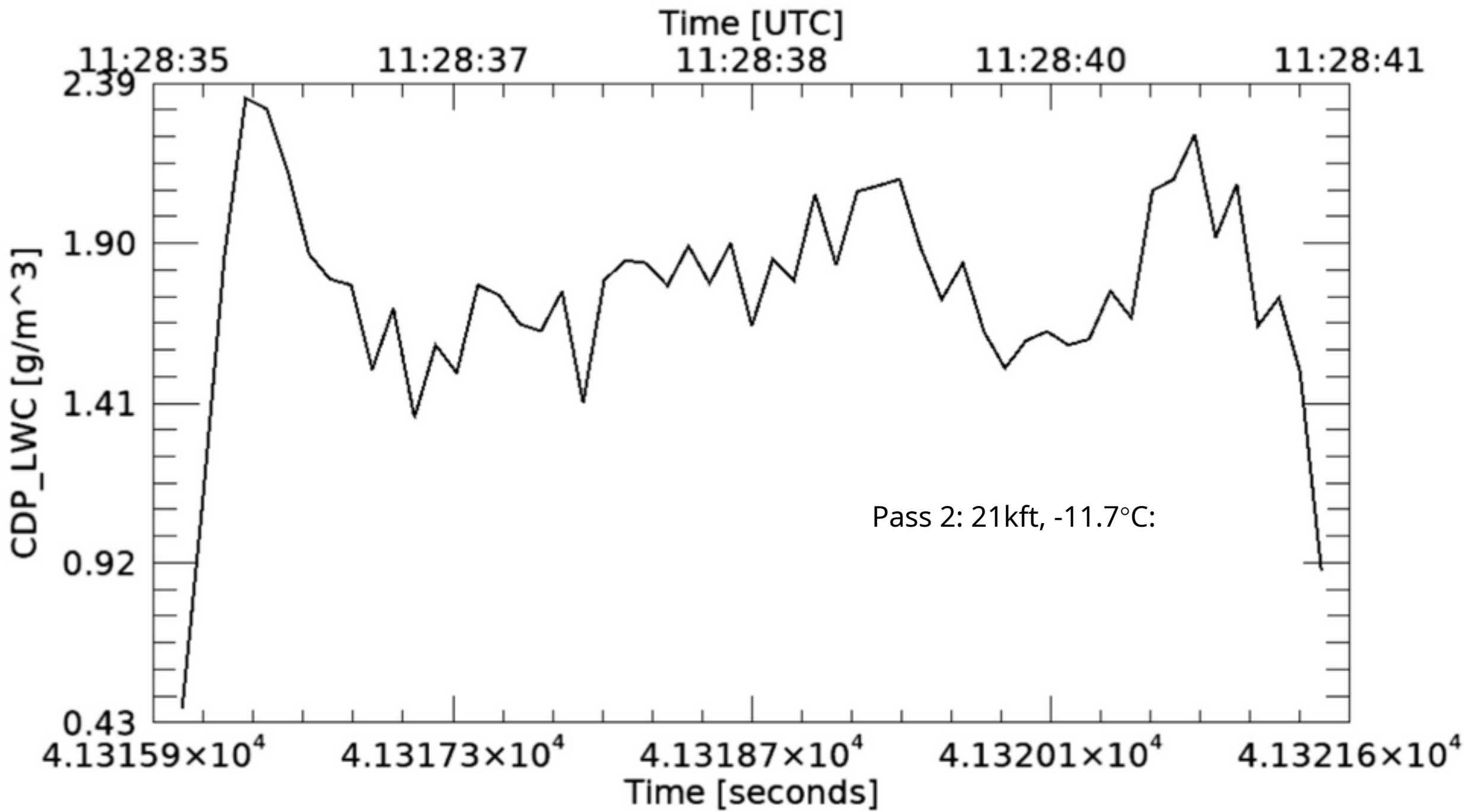


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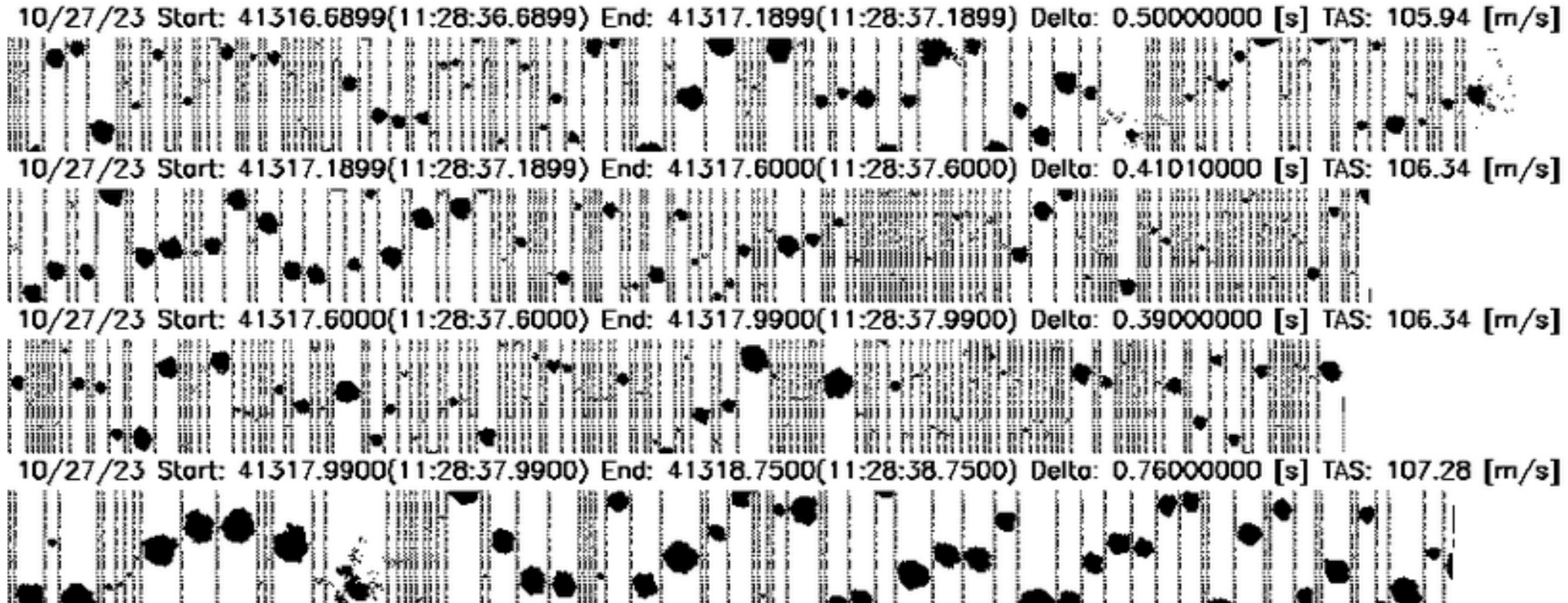








Precipitation particle images from Droplet Measurement Technology PIP optical array probe
Volume sampling rate ~160 l/sec



6.2 mm

Pass 3: 22 kft, -15.9⁰C

- Cloud glaciated
- Negligible supercooled cloud water
- Aircraft could have missed the center of the cloud core

Summary

- Saudi Arabian precipitation producing processes are complex
- Small convective clouds initiate and grow quickly.
- In the example shown ice particles are found at the -10 C level at concentrations of $<\sim 1$ per liter.
- In the example shown cloud liquid water concentrations are of the order of 2 g m^{-3} . This is substantial.
- It is possible glaciogenic seeding might accelerate precipitation development in these conditions

Summary (cont'd)

- Many more observations are needed, including more extensive observations of precipitation development in more clouds
- SARPEC observations are providing additional insights into how to best utilize cloud seeding to further accelerate production and increase total precipitation on the ground
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References

- Features of the Weather Modification Assessment Project in Southwest Region of Saudi Arabia. (2010). *The Journal of Weather Modification*, 42(1), 78-103.
<https://doi.org/10.54782/jwm.v42i1.162>

Acknowledgements

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