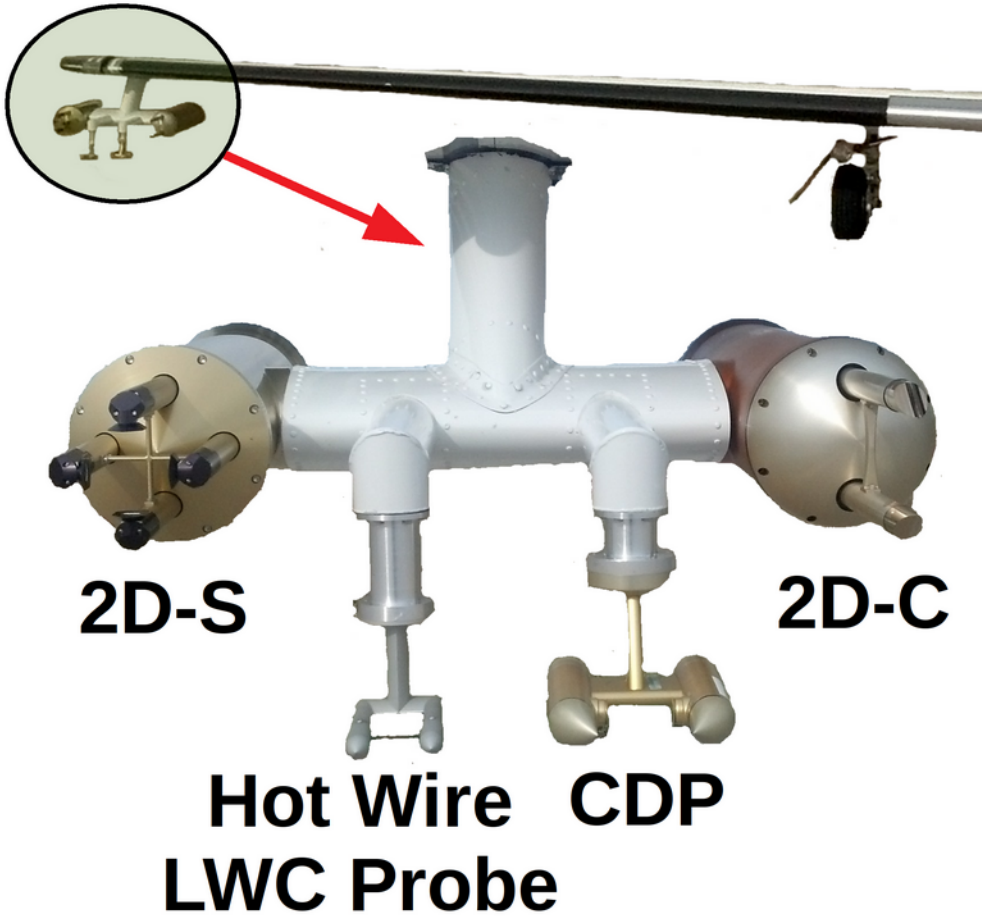
Airborne Measurements

Liquid Water Content

Liquid Water Content (LWC)

- Basic Cloud Parameter
- Icing Studies
- Precipitation Potential
- Comparison with Remote Sensing Measurements
- **Compare Measurements using Different Techniques**



Liquid Water Content (LWC) Calculation

The amount of liquid water in a given volume of air is determined through mass integration of the cloud droplet distribution.

$$LWC = \left(\frac{\pi}{6}\right) \rho_w \sum_{i=1}^{m} N_i d_i^3$$

ρ_w – Density of Water

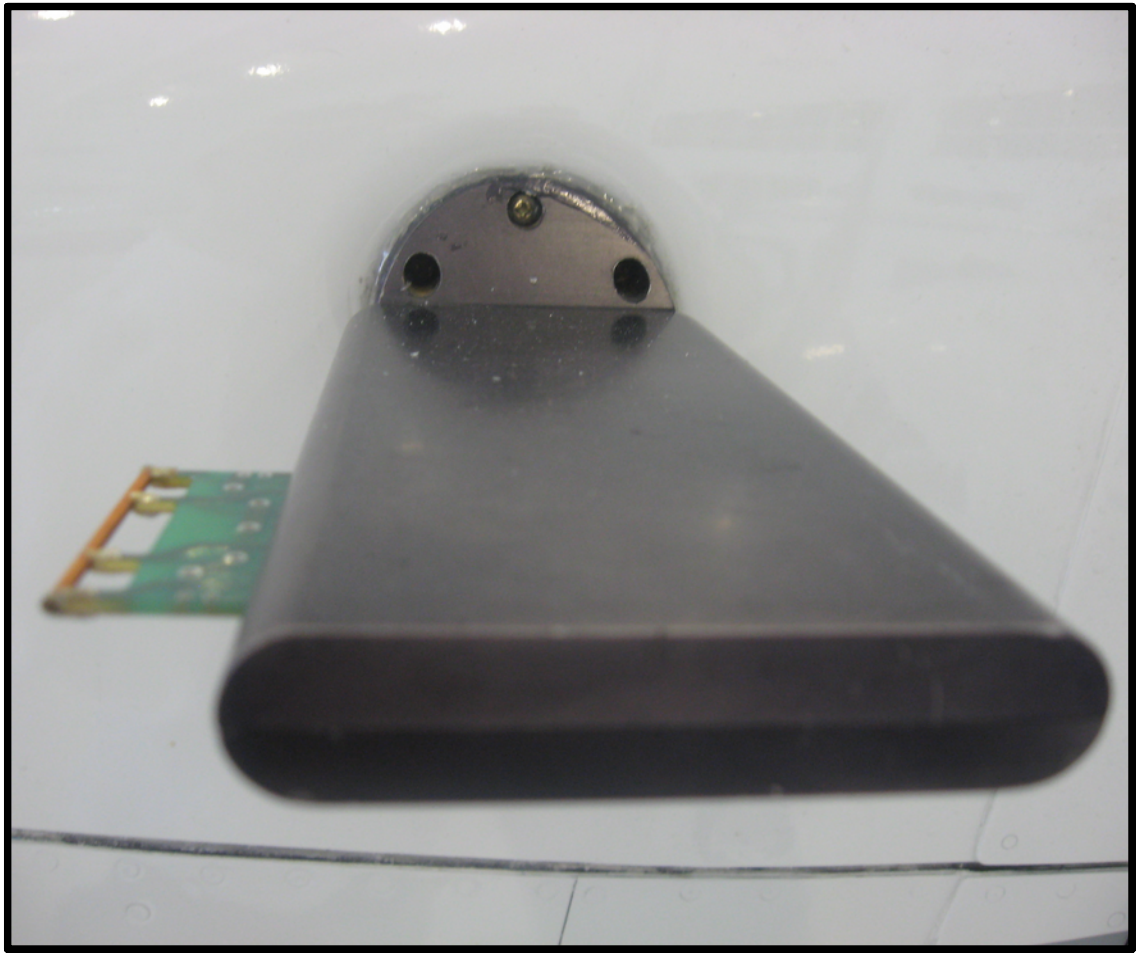
N_i – Concentration of Droplets in Size Channel i

d_i – Droplet Diameter in Size Channel i

m – Total Number of Channels

King Hotwire Probe

DMT Hotwire Probe



King Hot Wire Probe Equations

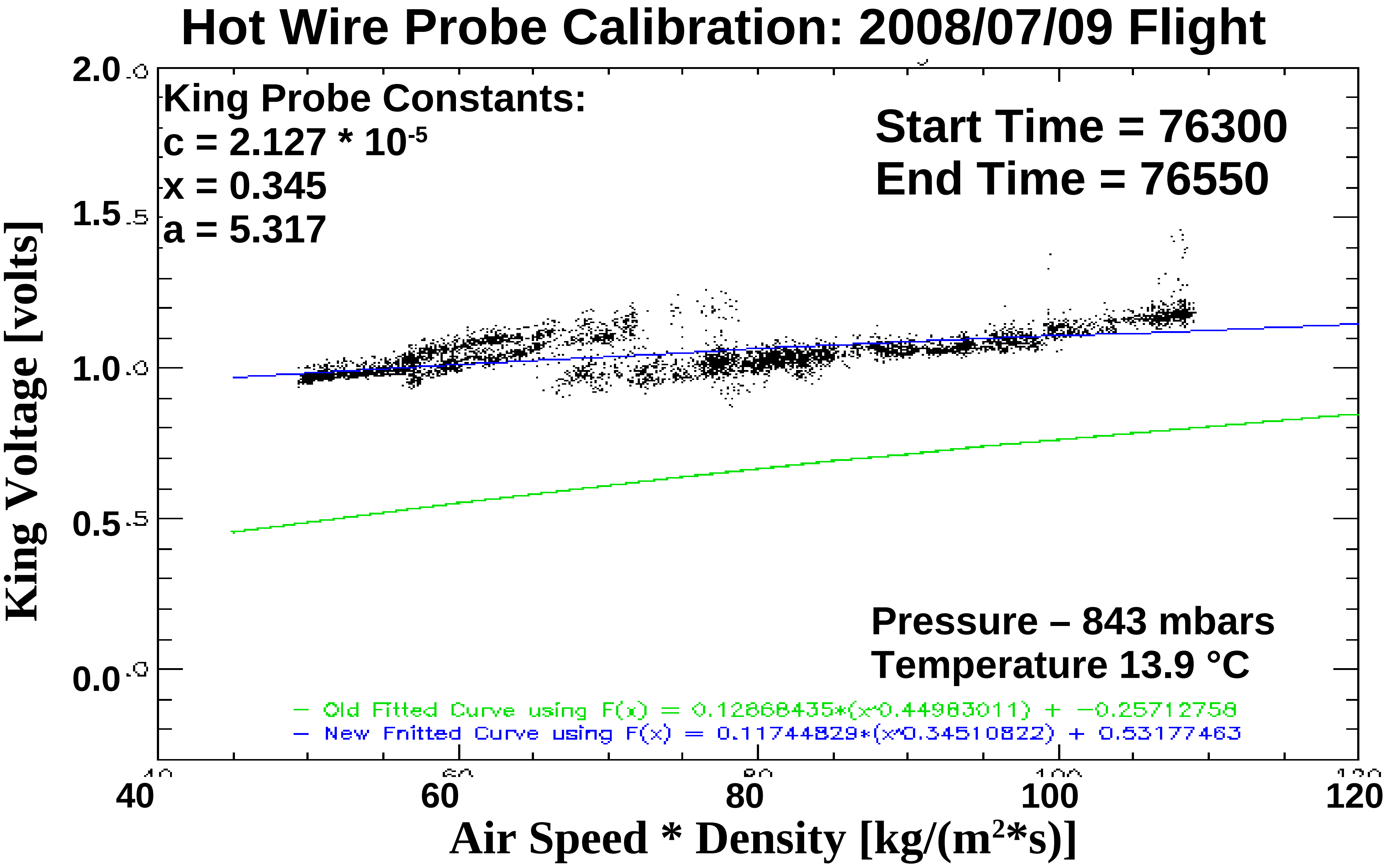
$$P_{Measured} = P_{Dry} + P_{Wet}$$

$$P_{Dry} = C(T_s - T_a) * (\rho v)^x + a$$

$$P_{Wet} = Mldv[L_v + c_w(T_v - T_a)]$$

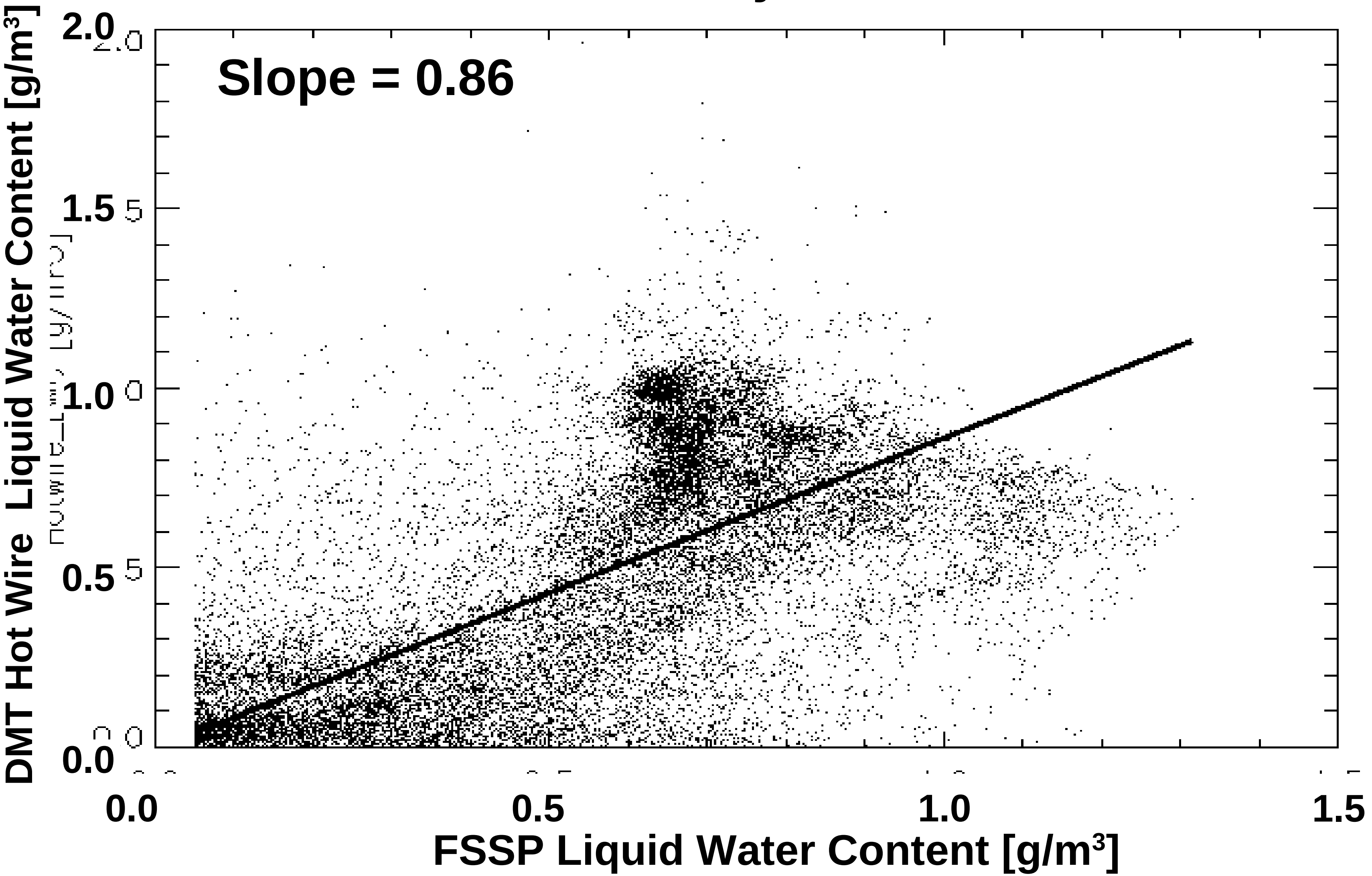
$$M \approx \frac{(P_{measured} - C(T_s - T_a) * (pv)^x)}{(ldv * [L_v + c_w(T_v - T_a)])} + a$$

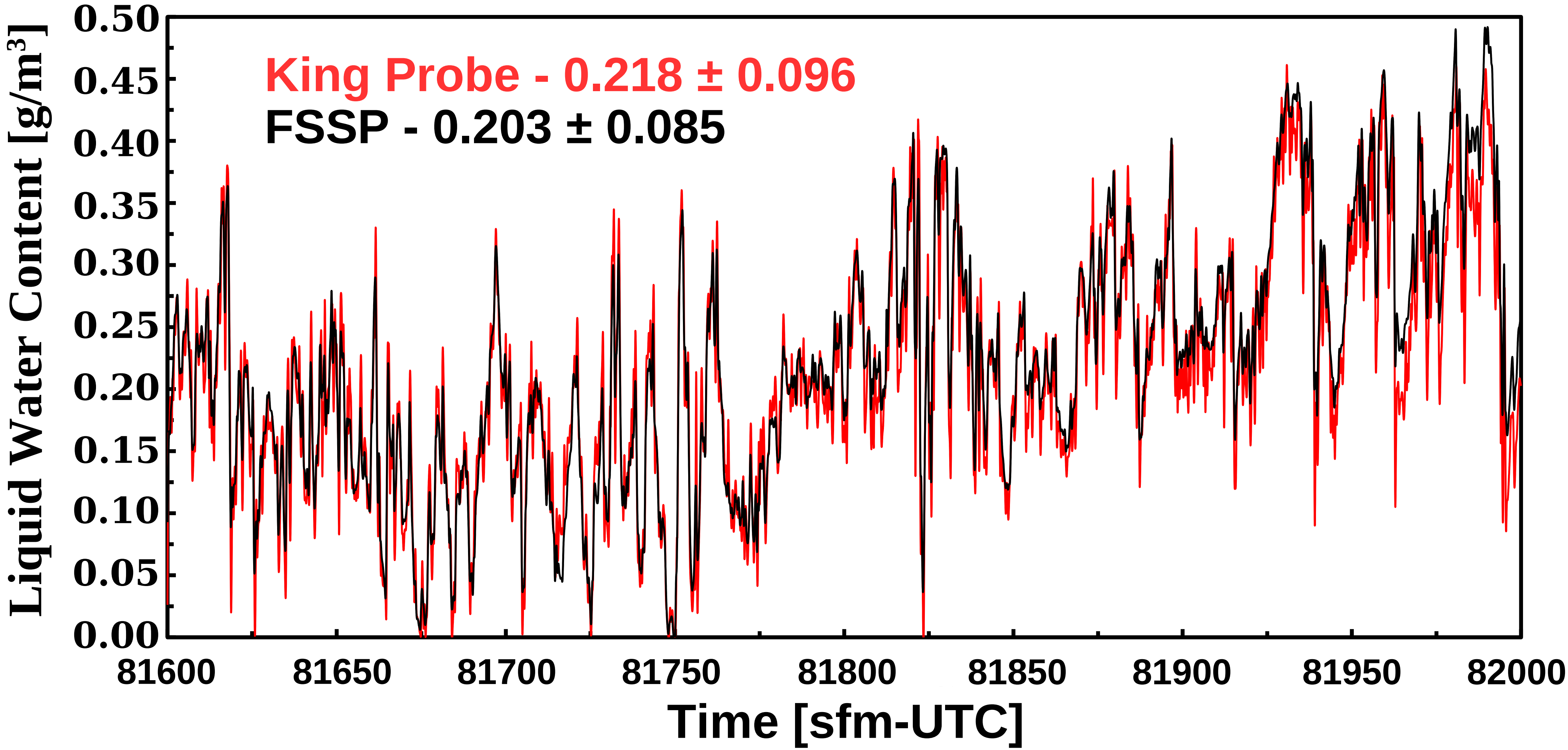
M – Liquid Water Content (LWC)
P – Power
ρ – Density of Air
v – True Air Speed
l – Wire Length
d – Wire Diameter
L_v – Latent Heat of Vaporization
C_w – Specific Heat of Liquid Water
T_s – Temperature of Sensor Wire
T_v – Sensor Water Vaporization
T_a – Air Temperature
C, x, a – Calibration Constants



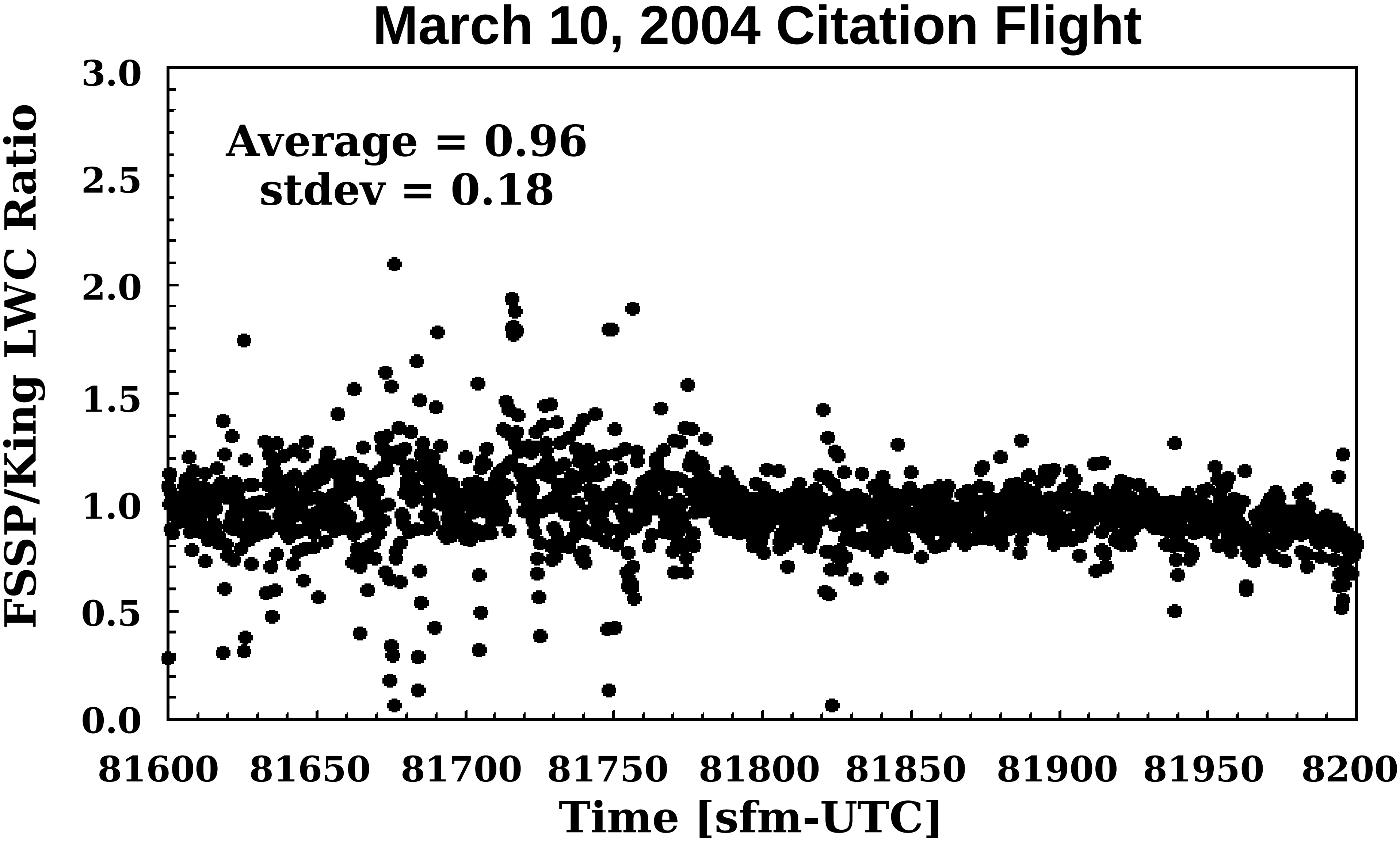
Hot Wire Probe Calibration: 2008/07/09 Flight
King Probe Constants:
c = 2.127 * 10-5
x = 0.345
a = 5.317
Start Time = 76300
End Time = 76550
Pressure – 843 mbars
Temperature 13.9 °C
Old Fitted Curve using F(x) = 0.12868435*(x^0.44983011) + -0.25712758
New Fnitted Curve using F(x) = 0.11744829*(x^0.34510822) + 0.53177463
King Voltage [volts]
Air Speed * Density [kg/(m2*s)]
2.0
1.5
1.0
0.5
0.0
40
60
80
100
120

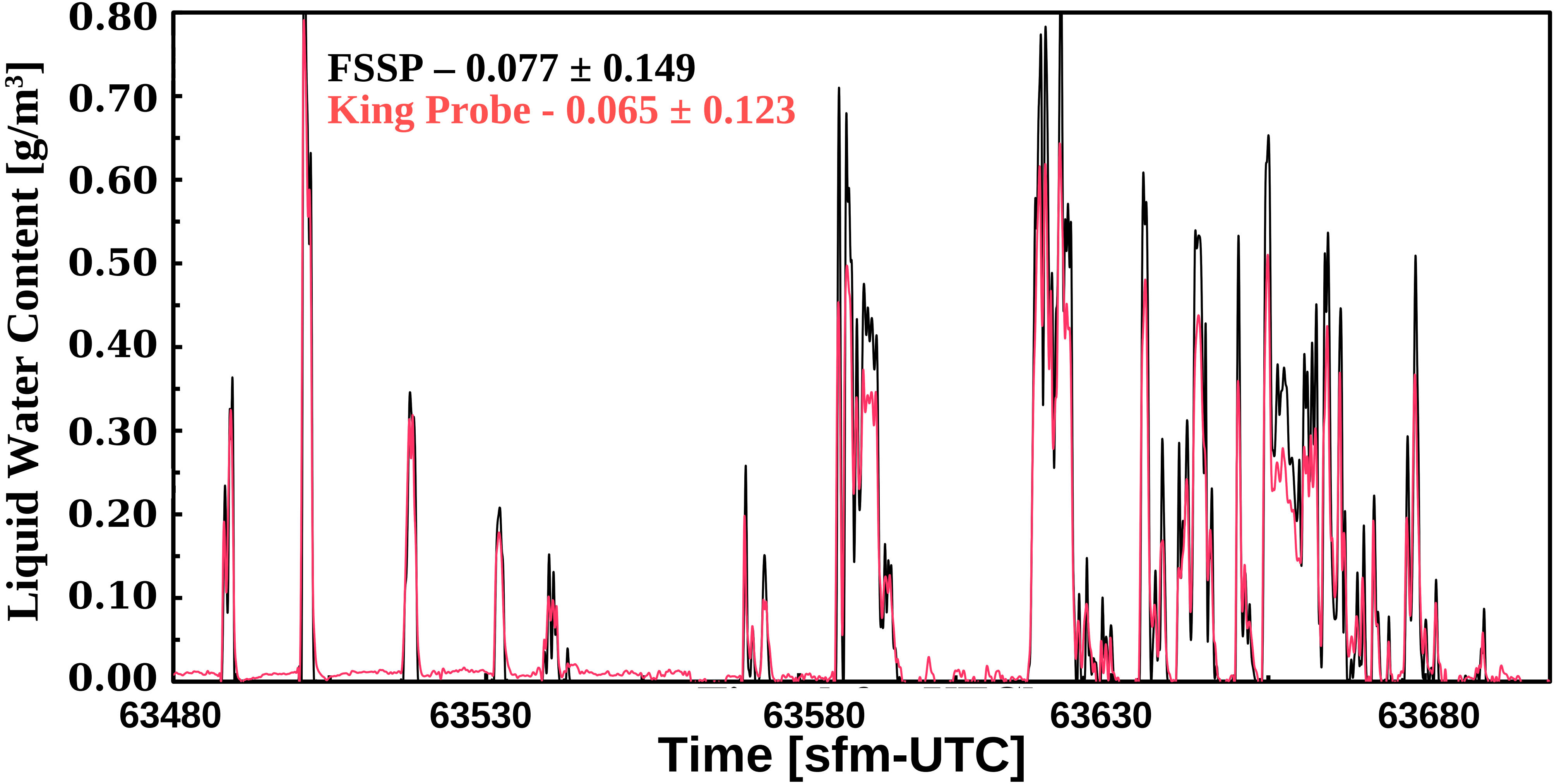
POLCAST2 Field Project: Summer 2008



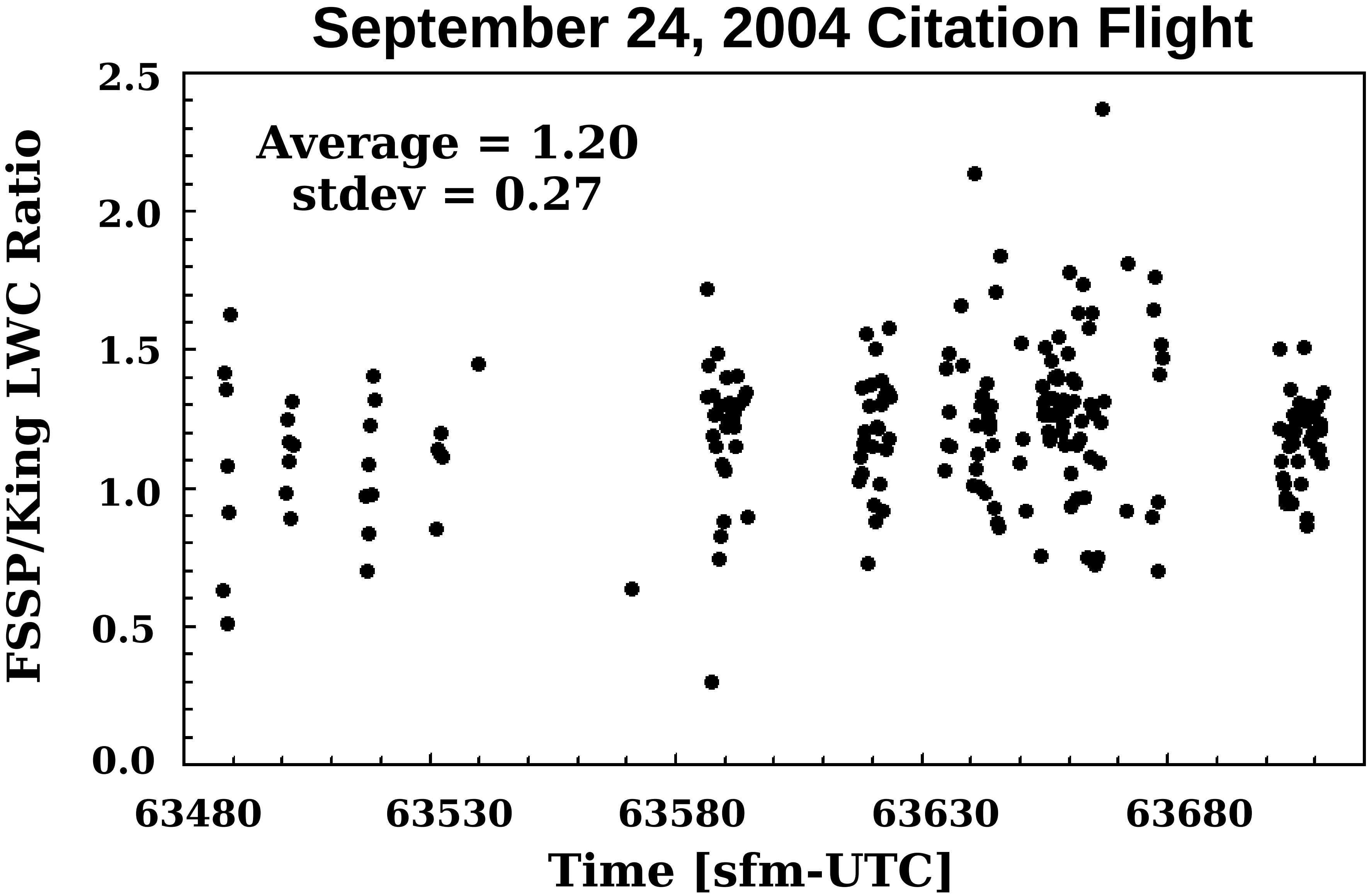


The 4 Hz averaged FSSP (Black line) and King Probe (Red Line) cloud liquid water content data for March 10, 2004 Citation flight.

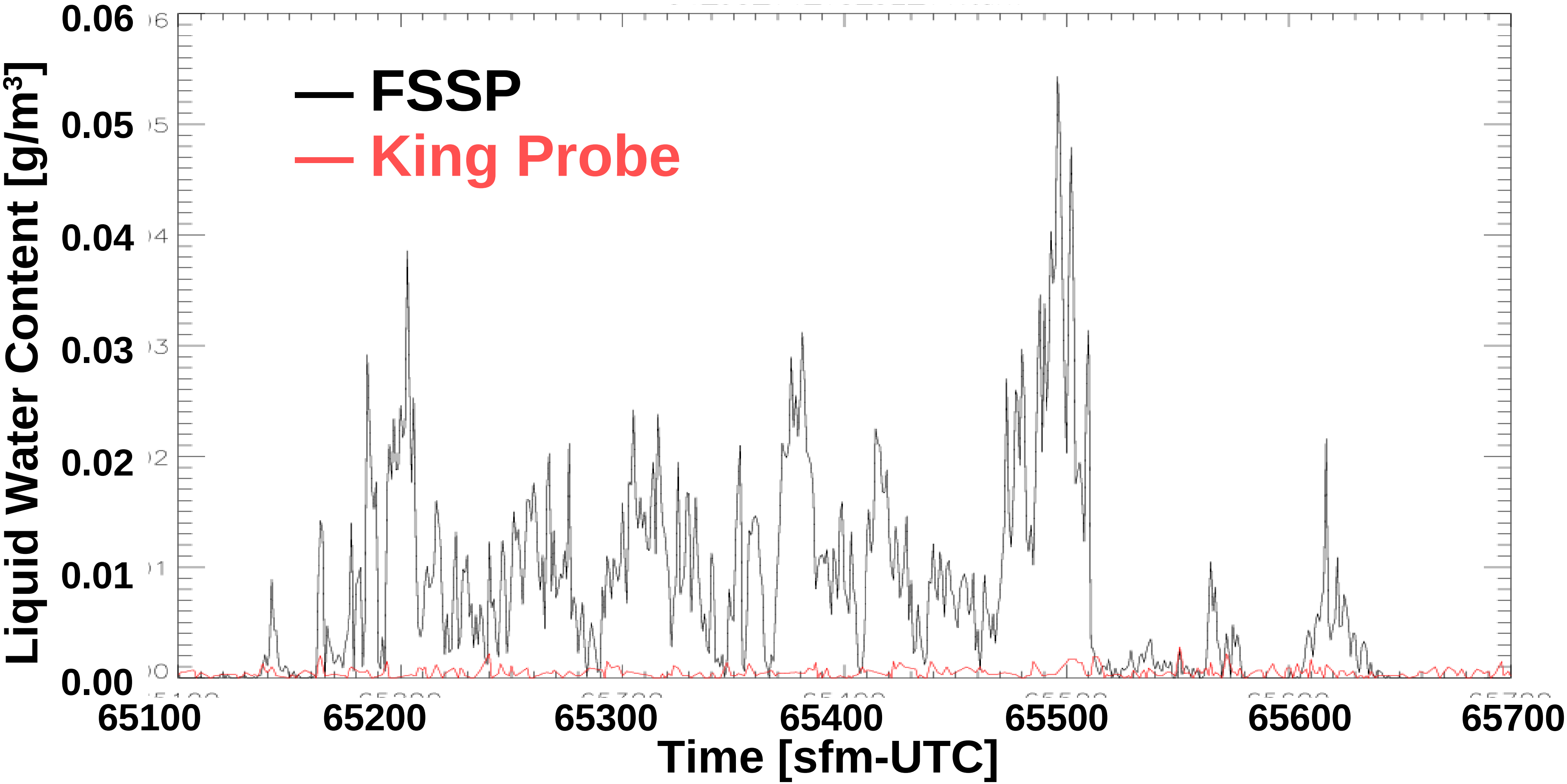

March 10, 2004 Citation Flight
Average = 0.96
stdev = 0.18
FSSP/King LWC Ratio
3.0
2.5
2.0
1.5
1.0
0.5
0.0
81600
81650
81700
81750
81800
81850
81900
81950
8200
Time [sfm-UTC]



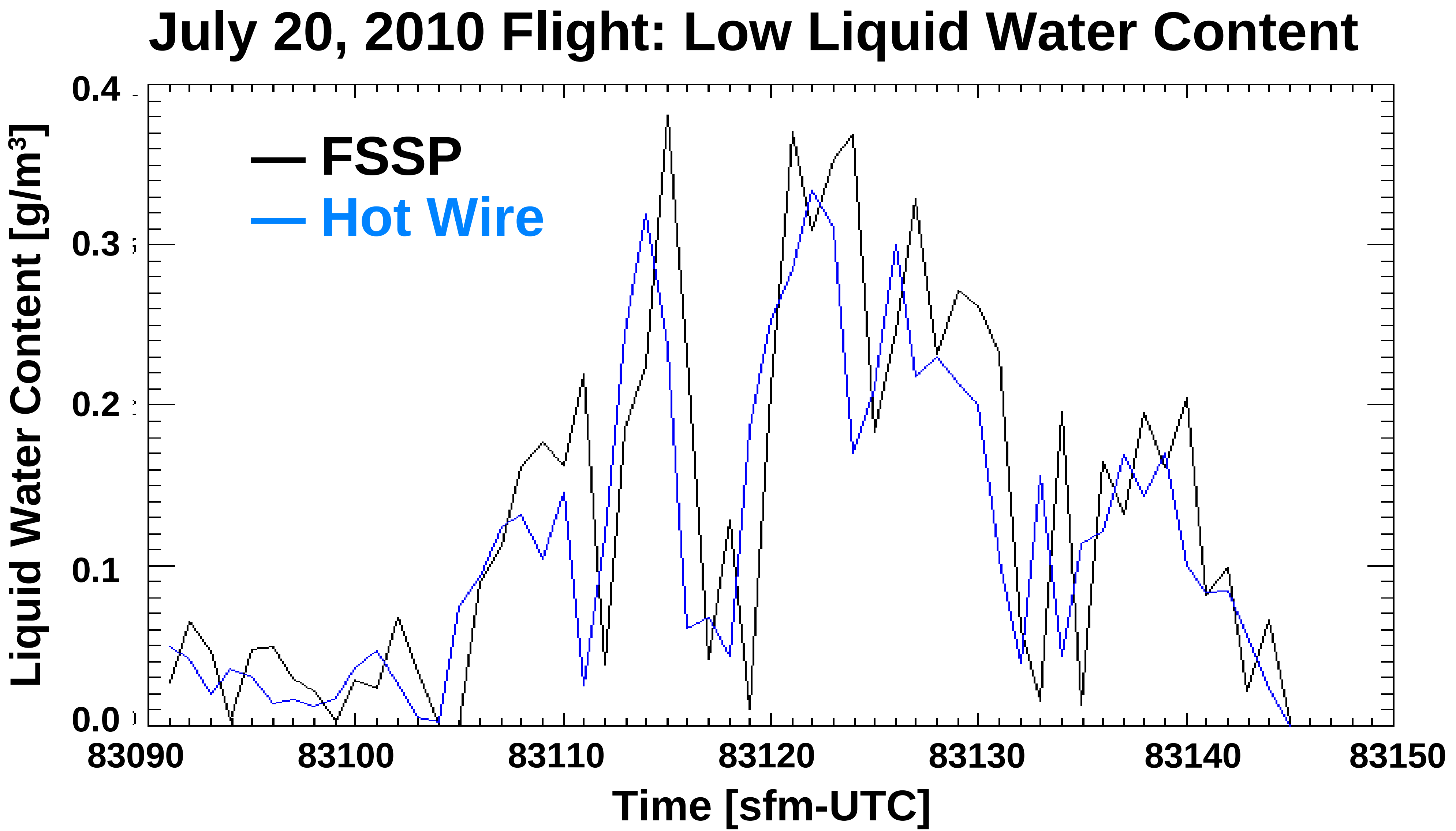
The 4 Hz averaged FSSP (Black line) and King Probe (Red Line) cloud liquid water content data for September 24, 2004 Citation Flight.


September 24, 2004 Citation Flight
Average = 1.20
stdev = 0.27
FSSP/King LWC Ratio
0.0
0.5
1.0
1.5
2.0
2.5
63480
63530
63580
63630
63680
Time [sfm-UTC]

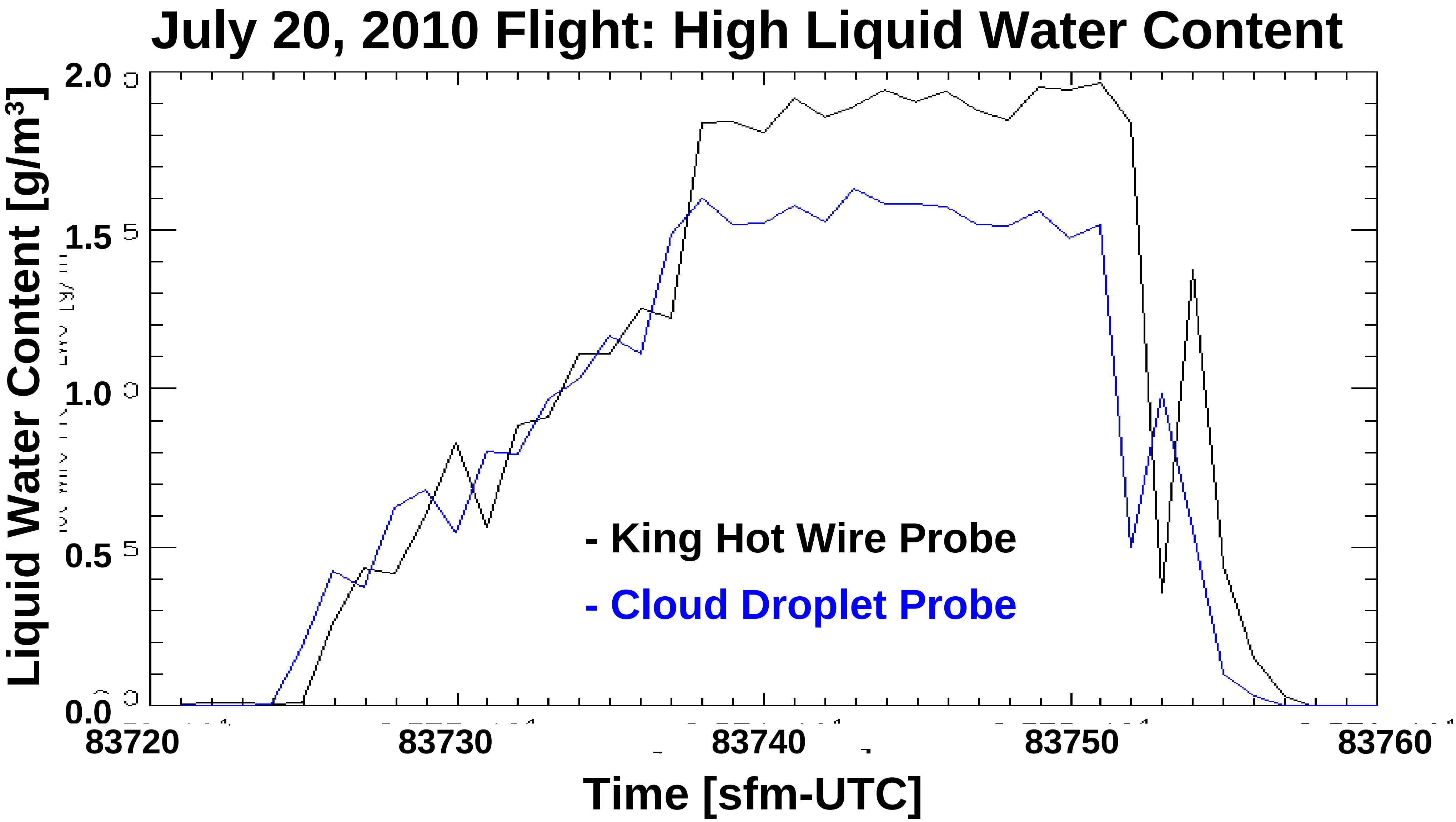
March 14, 2004 Flight

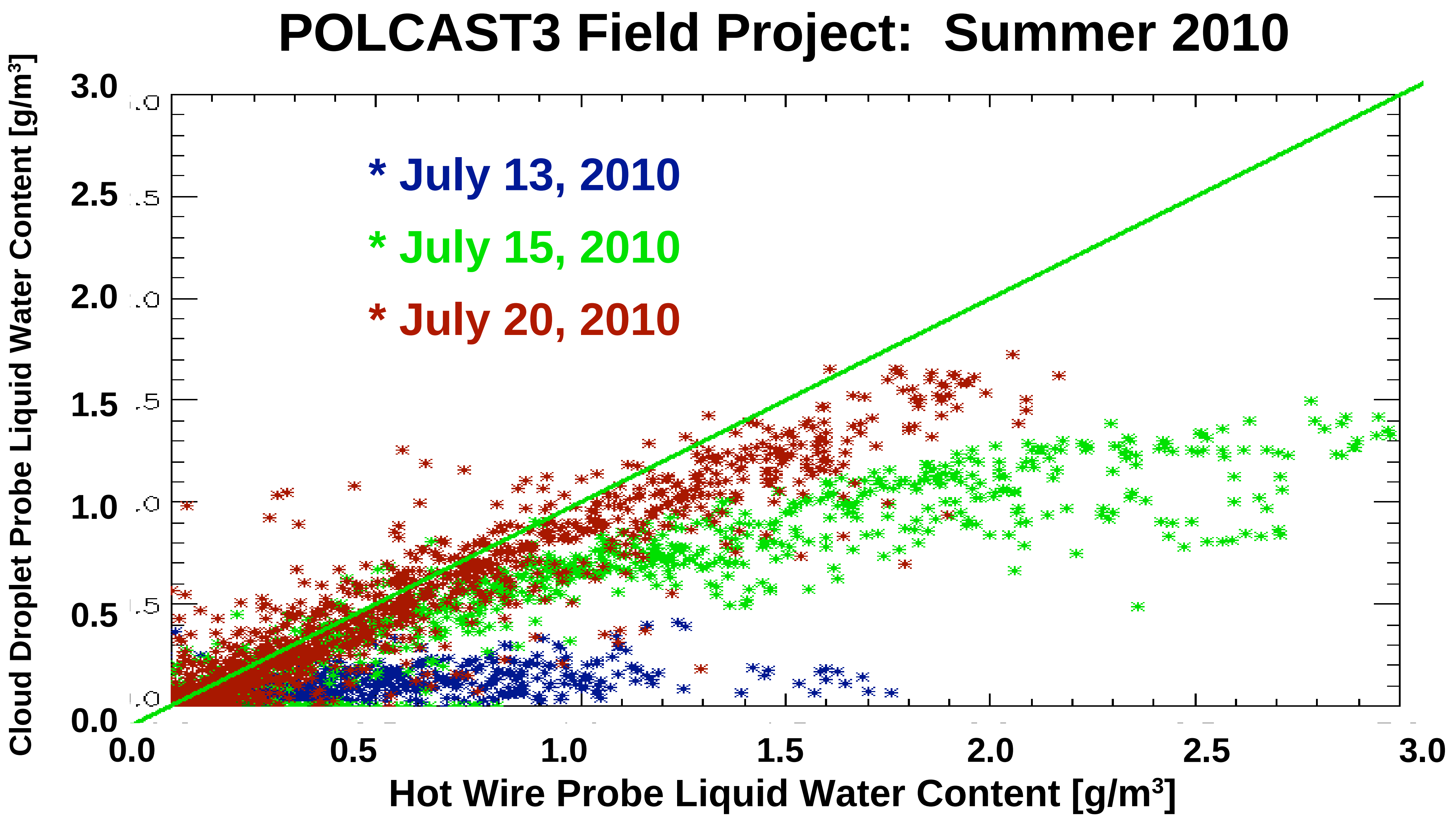


Ice Contamination of the FSSP LWC calculations assume spherical water droplets.

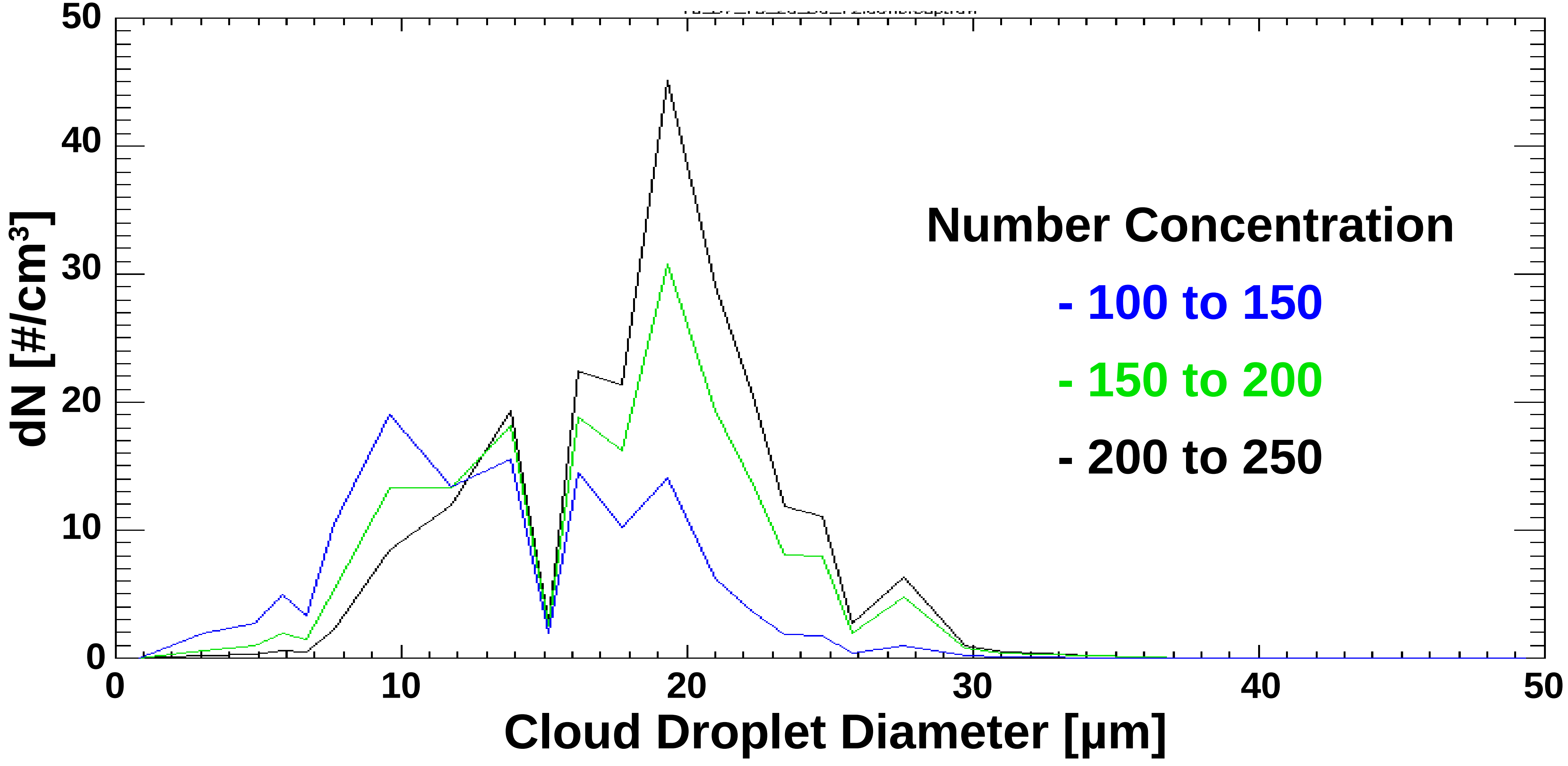


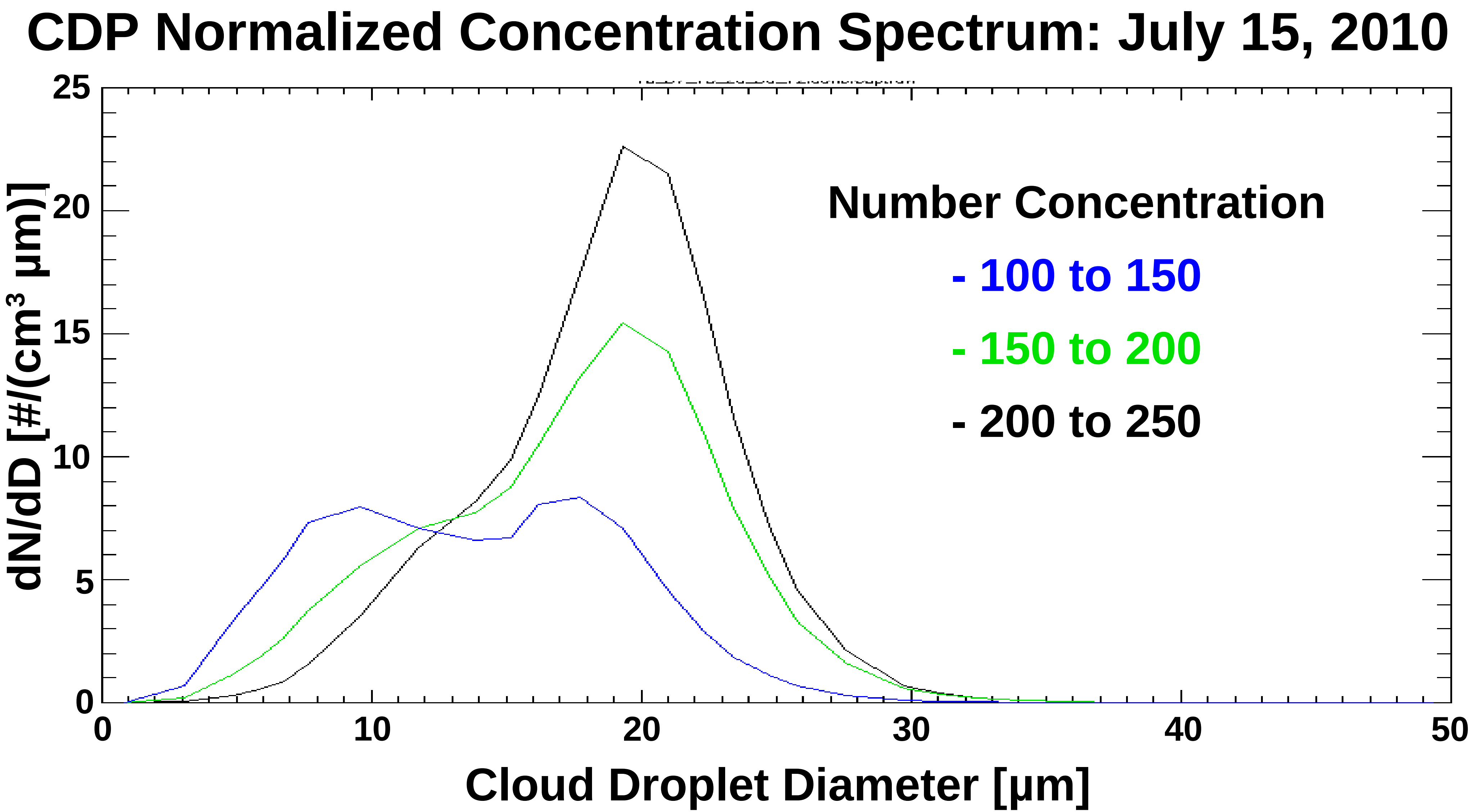
July 20, 2010 Flight: Low Liquid Water Content
Liquid Water Content [g/m³]
Time [sfm-UTC]
FSSP
Hot Wire
0.0
0.1
0.2
0.3
0.4
83090
83100
83110
83120
83130
83140
83150


July 20, 2010 Flight: High Liquid Water Content
Liquid Water Content [g/m3]
2.0
1.5
1.0
0.5
0.0
83720
83730
83740
83750
83760
Time [sfm-UTC]
- King Hot Wire Probe
- Cloud Droplet Probe


POLCAST3 Field Project: Summer 2010
* July 13, 2010
* July 15, 2010
* July 20, 2010
Cloud Droplet Probe Liquid Water Content [g/m³]
Hot Wire Probe Liquid Water Content [g/m³]
0.0
0.5
1.0
1.5
2.0
2.5
3.0

CDP Number Concentration Spectrum: July 15, 2010

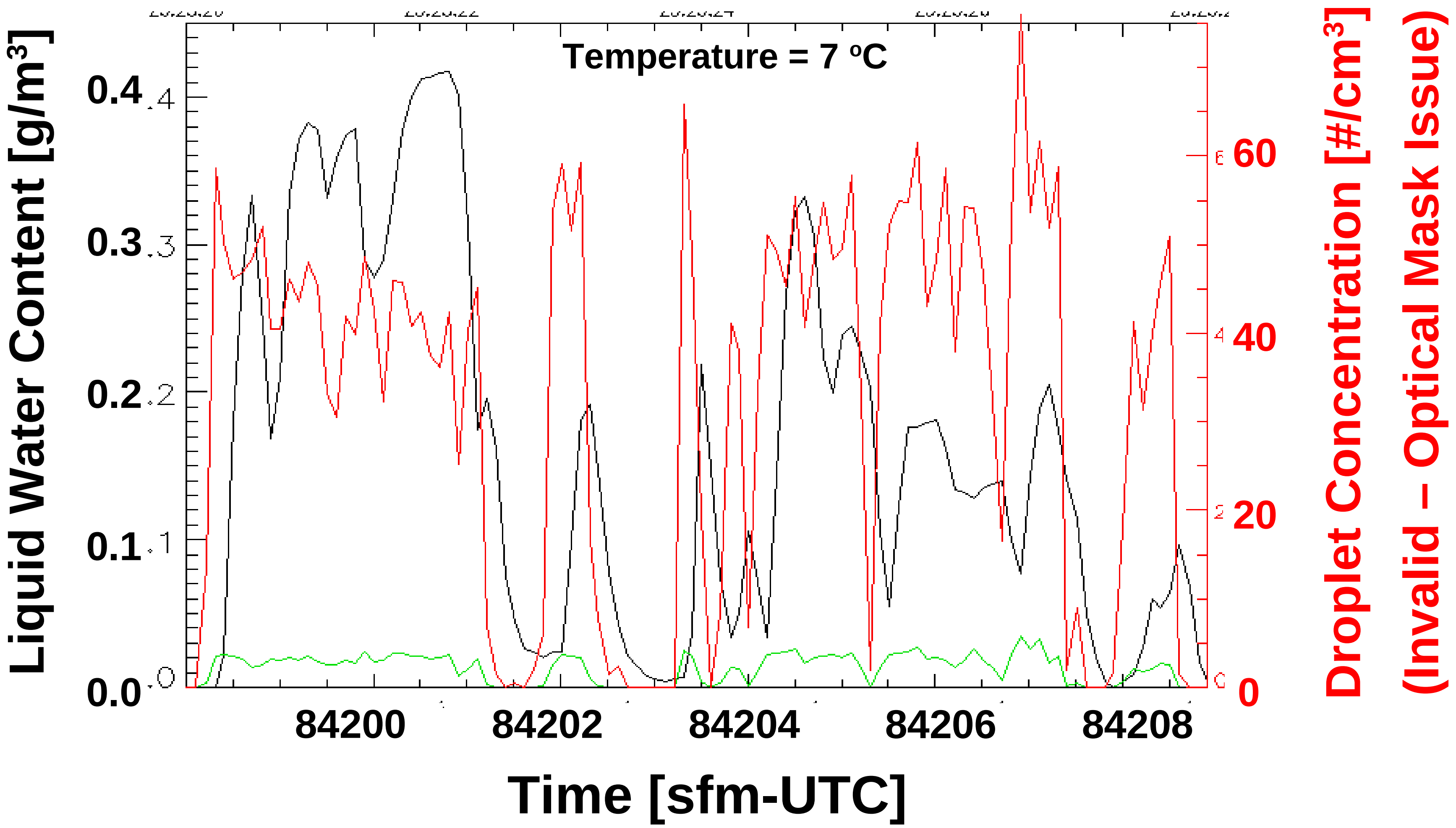




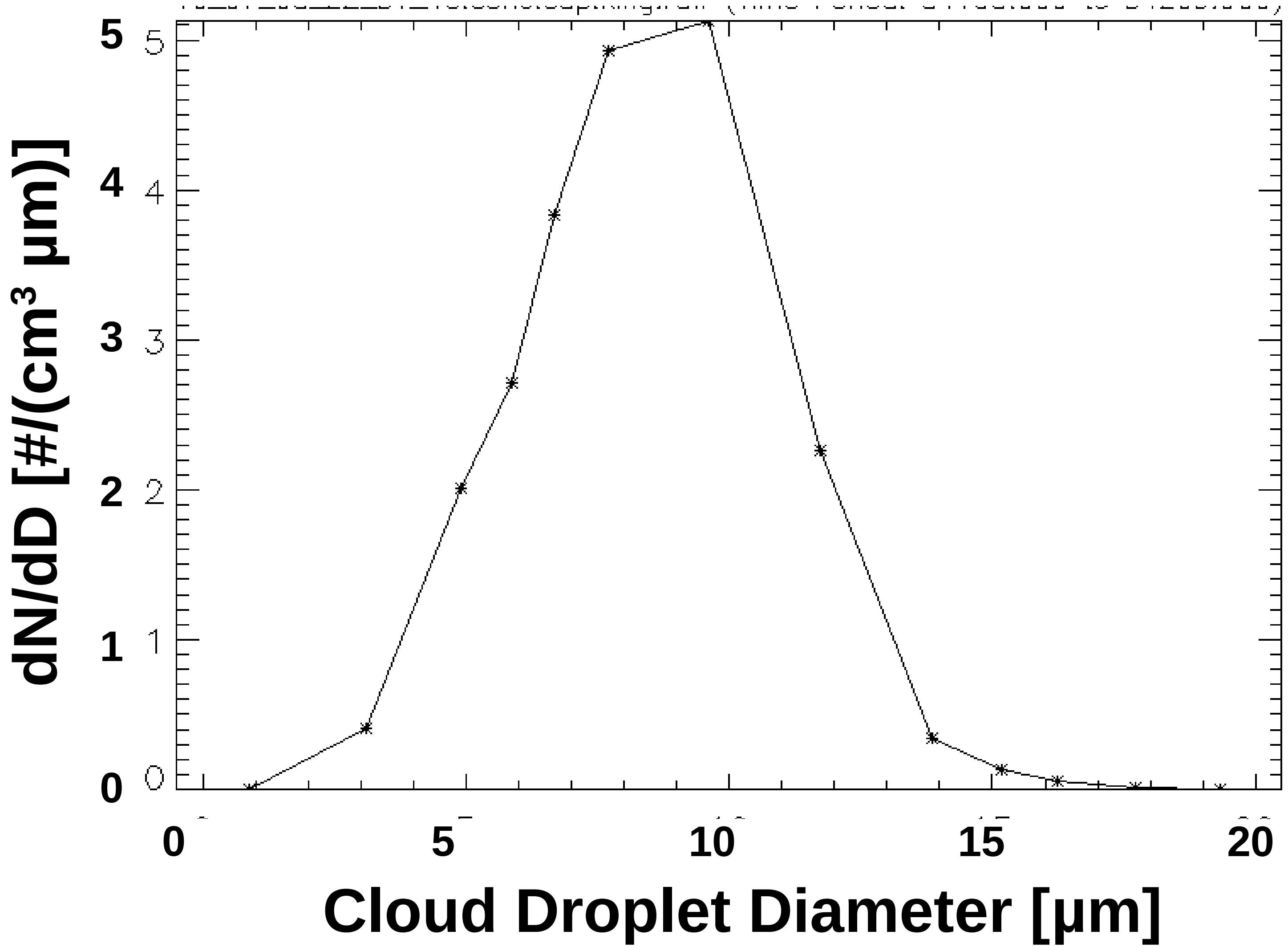
CDP Normalized Concentration Spectrum: July 15, 2010
dN/dD [#/(cm³ μm)]
25
20
15
10
5
0
0
10
20
30
40
50
Cloud Droplet Diameter [μm]
Number Concentration
- 100 to 150
- 150 to 200
- 200 to 250

July 8, 2010 Flight

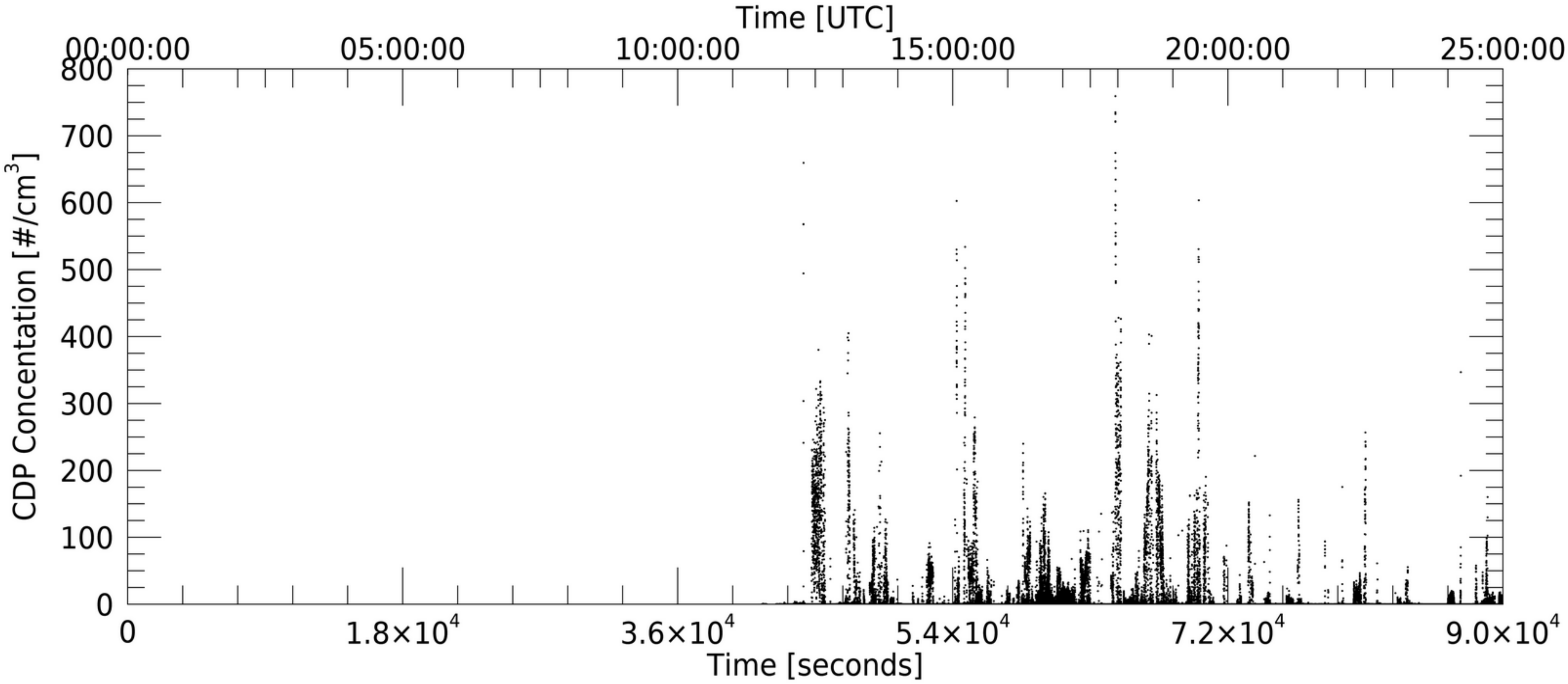
- King Hot Wire LWC - Cloud Droplet Probe LWC - Cloud Droplet Probe Conc.



July 8, 2010 Flight: CDP Spectrum (84198-84209 smf)

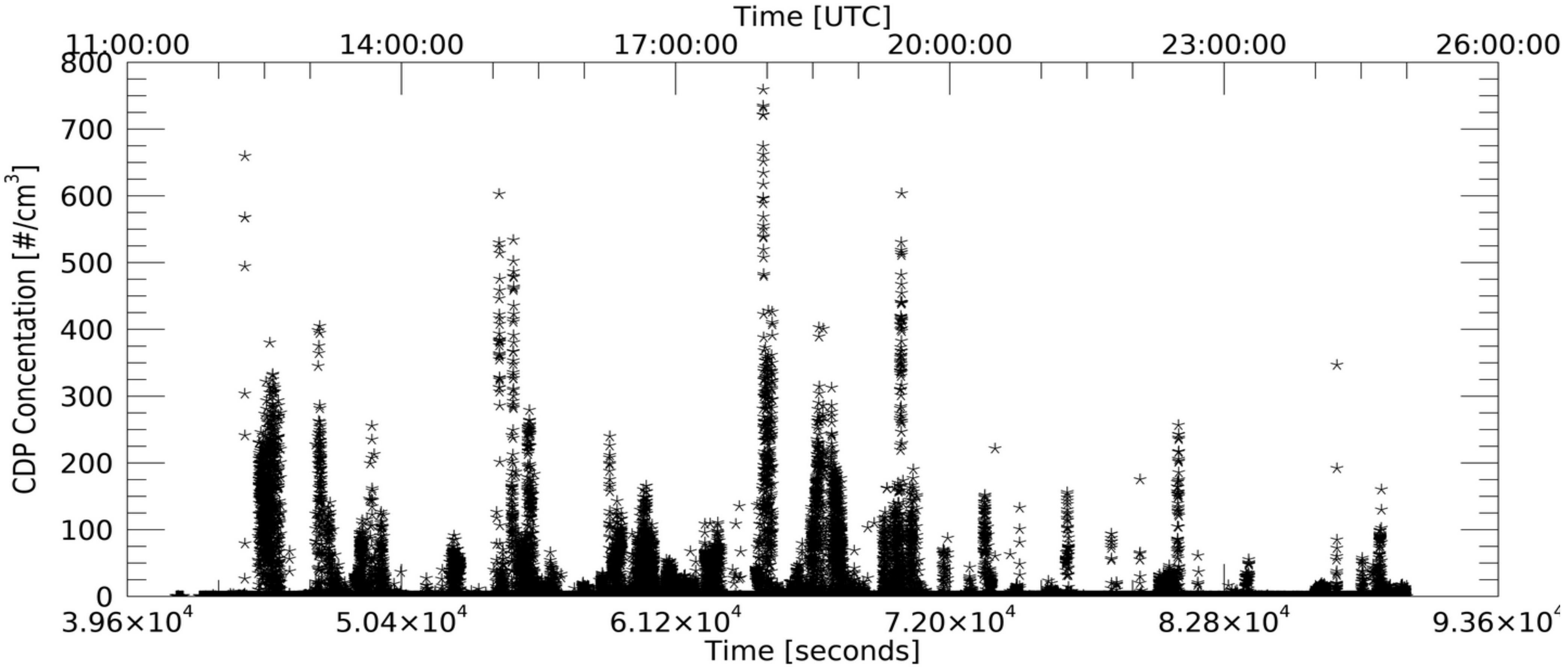


NASA IMPACTS 2022: CDP Total Concentration



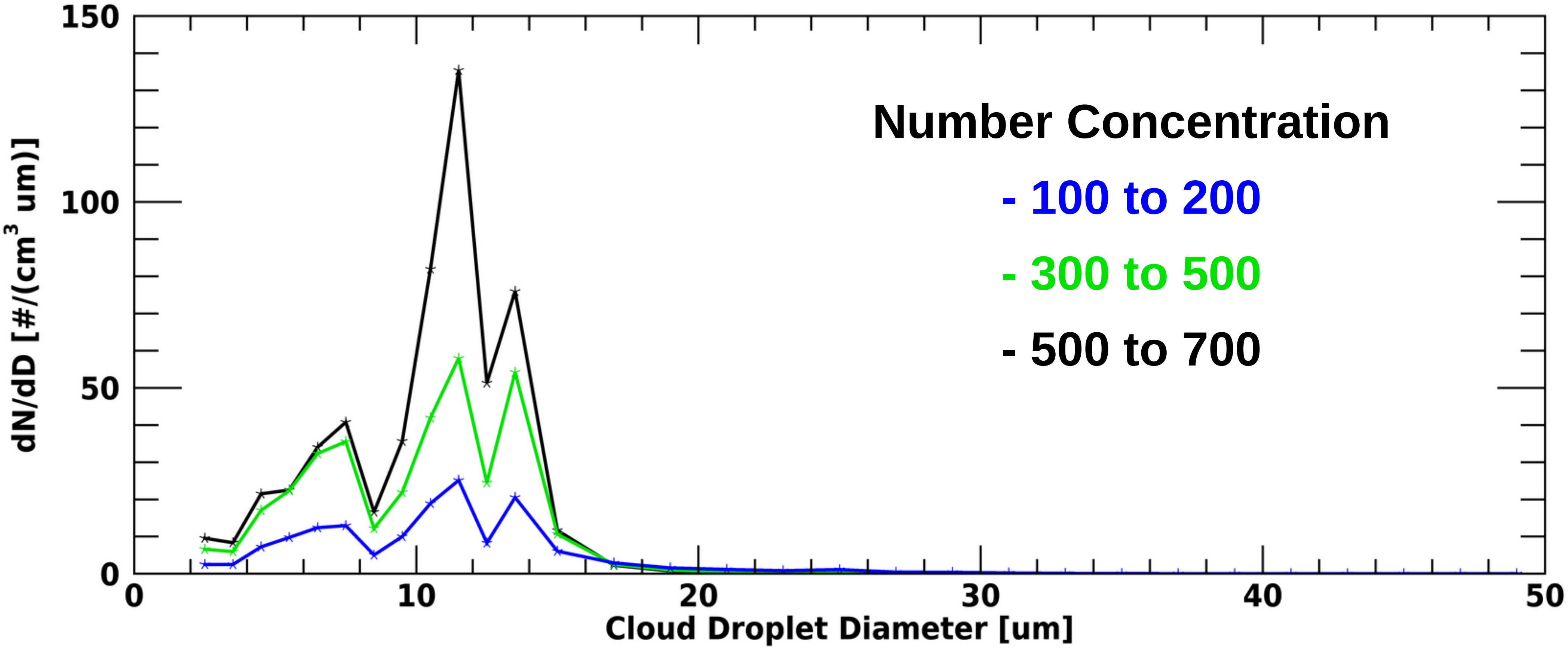
The 1 Hz averaged CDP total droplet concentration for all NASA IMPACTS 2022 flights with data limited from 0-25 hours.

NASA IMPACTS 2022: CDP Total Concentration



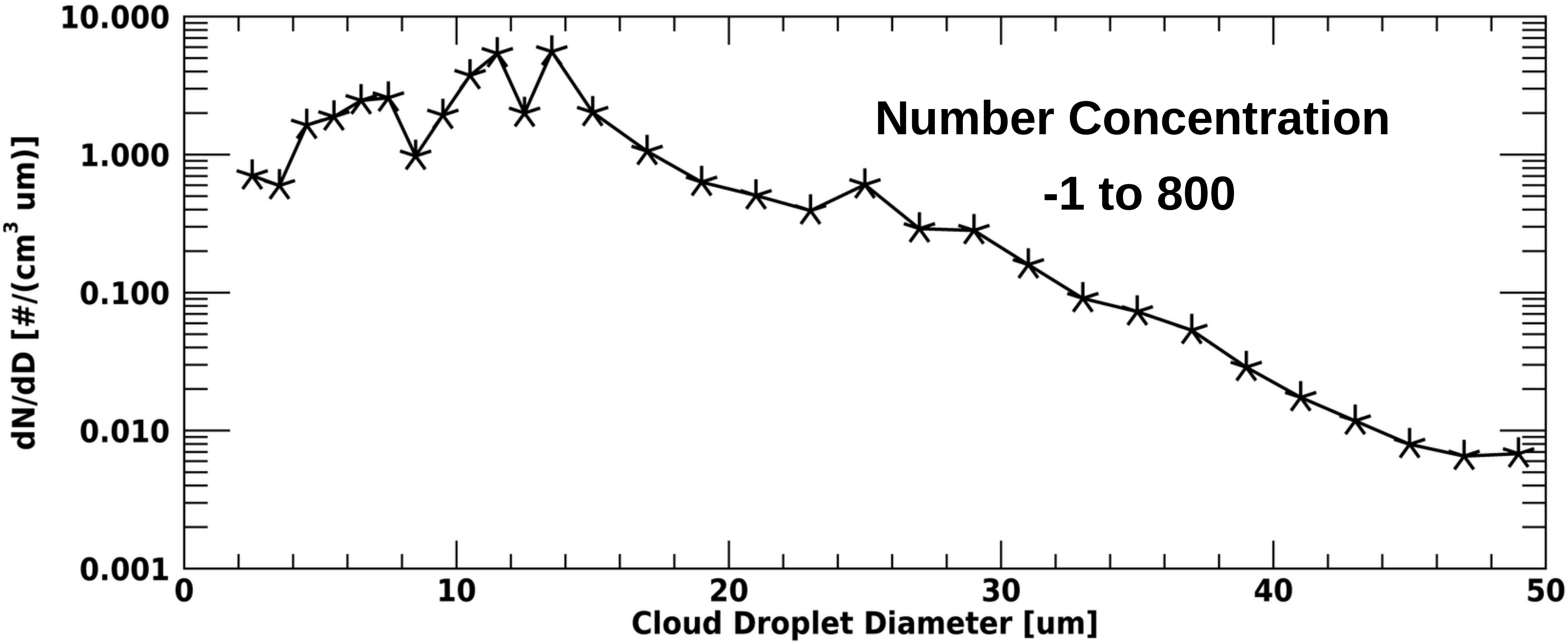
The 1 Hz averaged CDP total droplet concentration for all NASA IMPACTS 2022 flights with data limited from 11-26 hours.

NASA IMPACTS 2022: CDP Normalized Spectrum



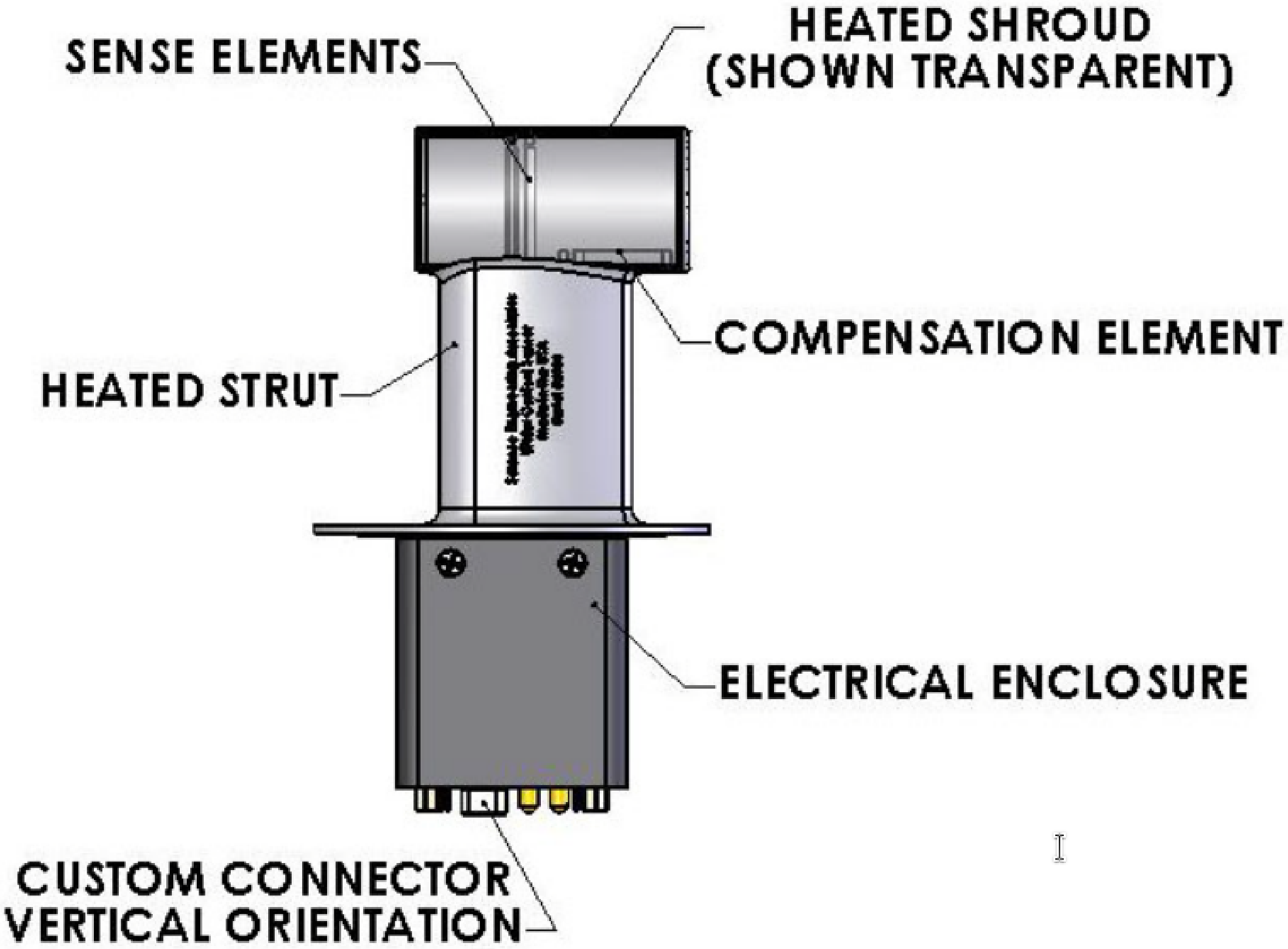
The 1 Hz averaged CDP normalized number spectrum for all NASA IMPACTS 2022 flights with total number concentration limits applied.

NASA IMPACTS 2022: CDP Normalized Spectrum

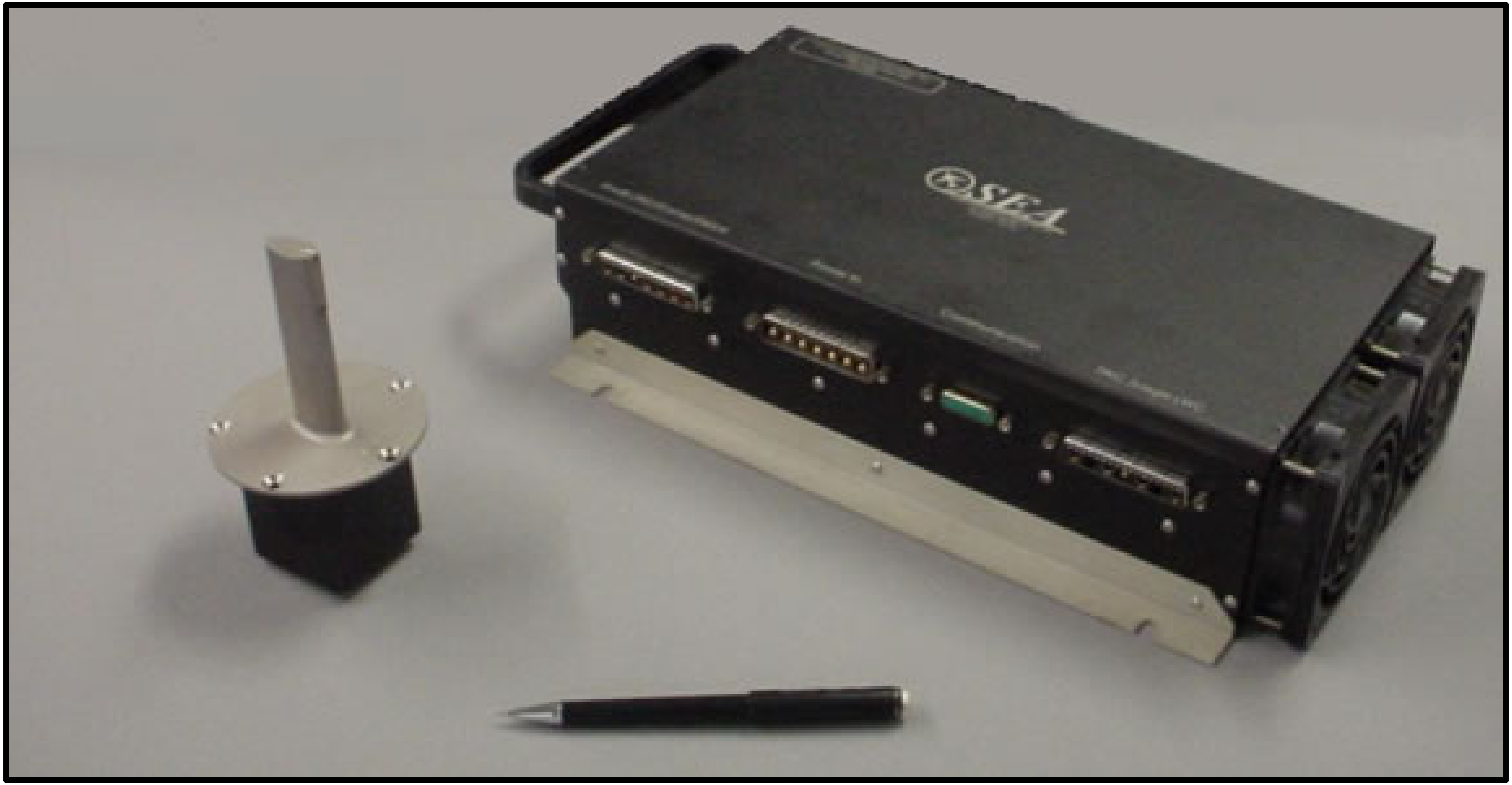


The 1 Hz averaged CDP normalized number spectrum for all NASA IMPACTS 2022 flights with total number concentration limits applied.

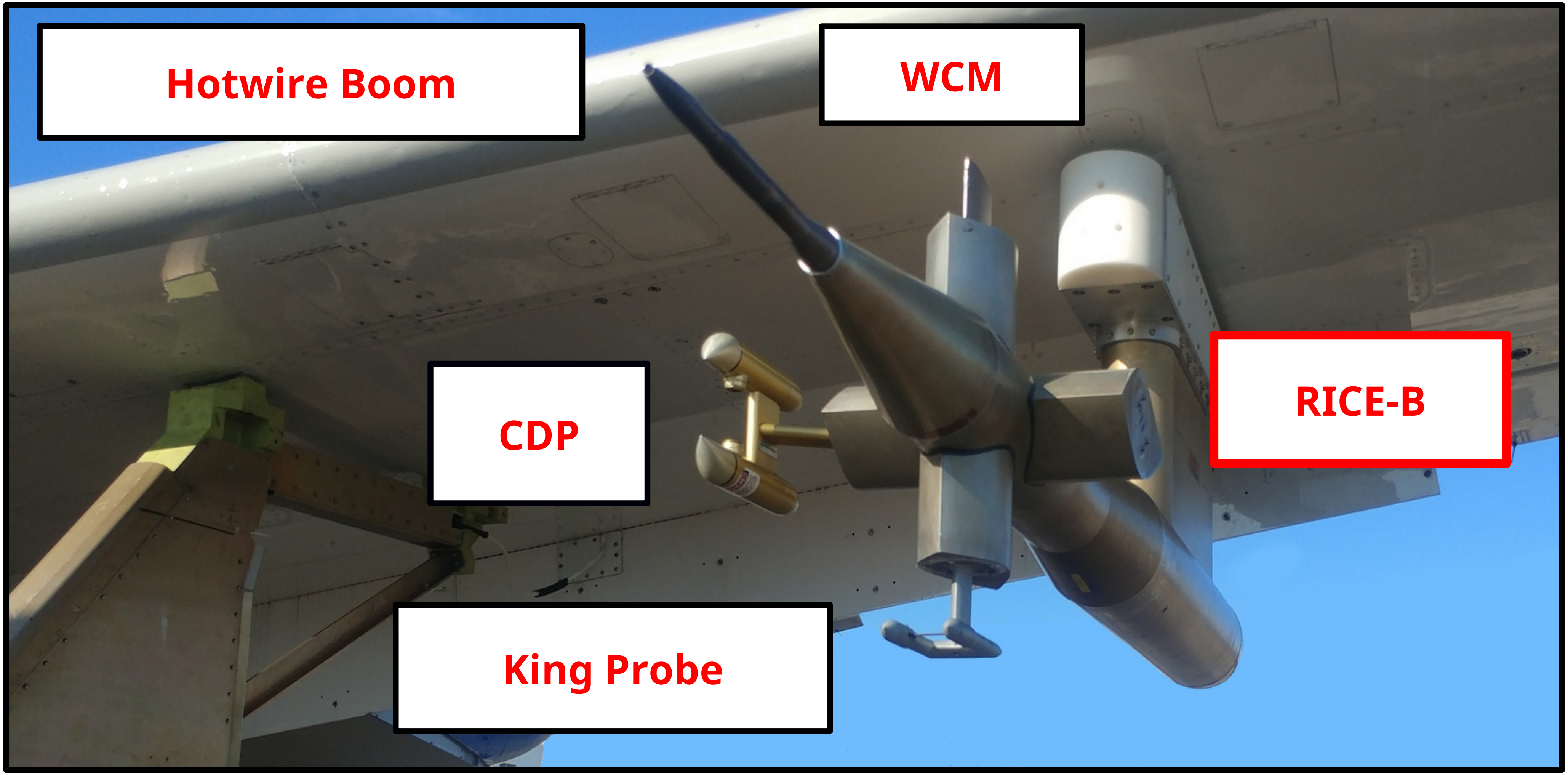
Science Engineering Associates (SEA) Model WCM-2000



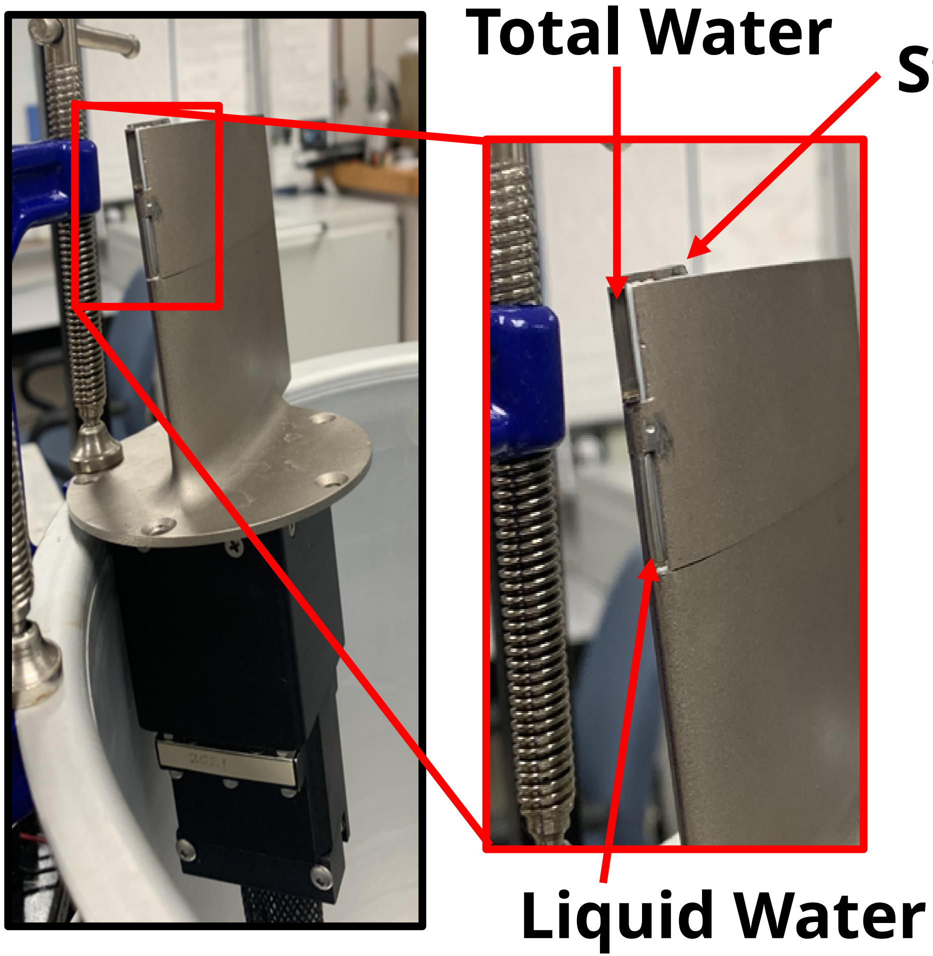
Science Engineering Associates (SEA) Model WCM-3000

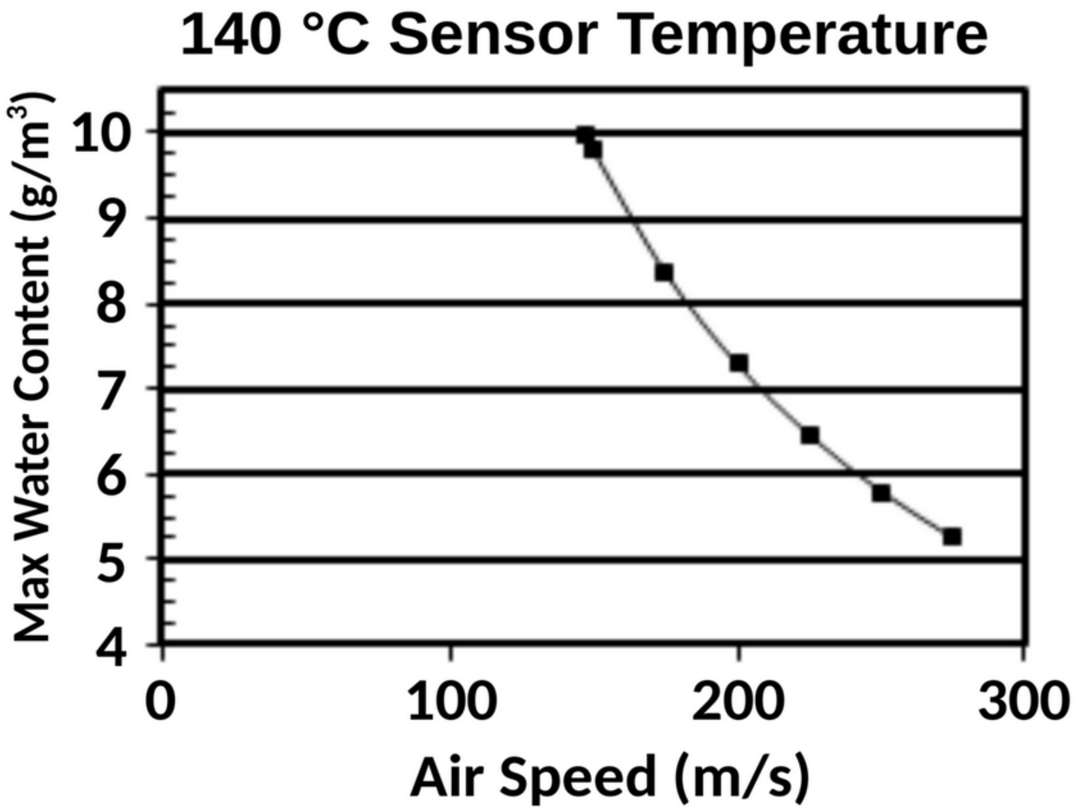


NASA IMPACTS 2022 Field Project

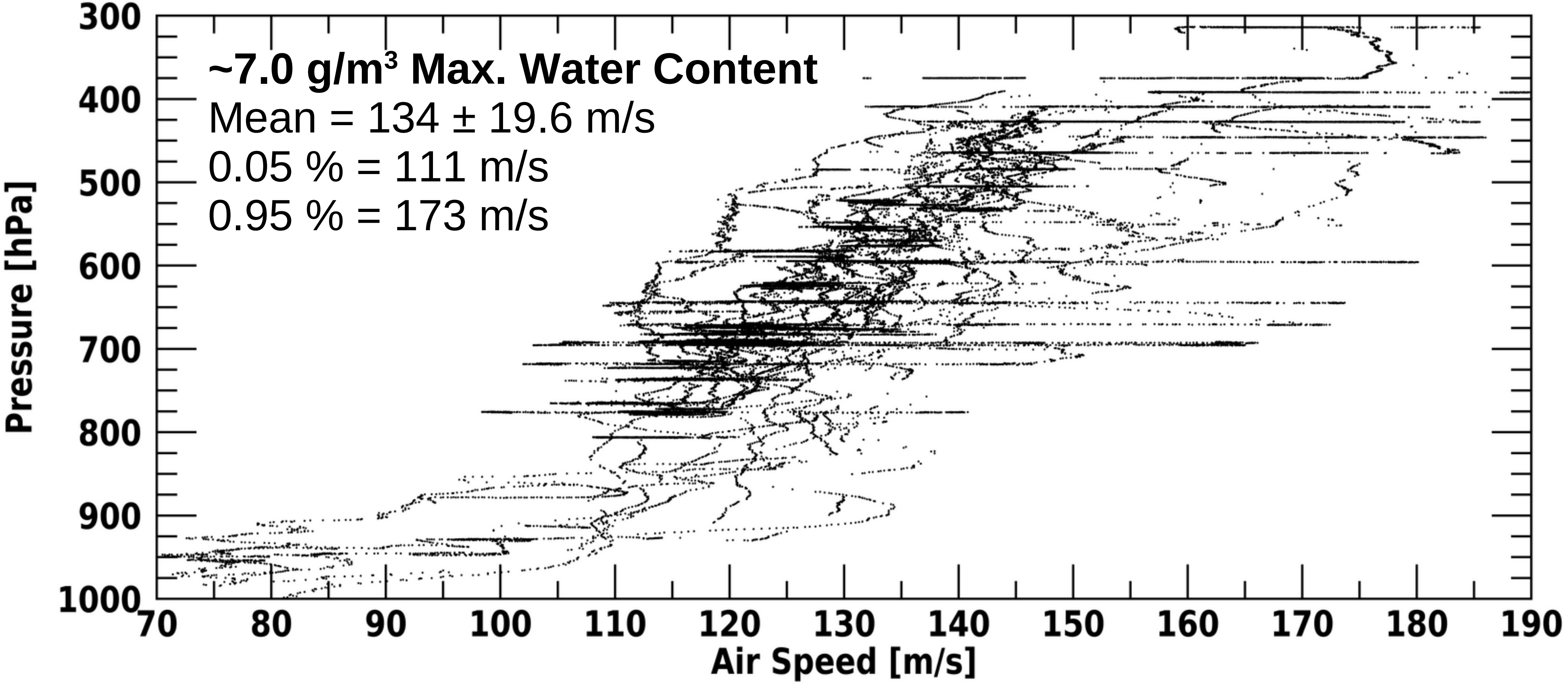


WCM - Total Water Content System
Science Engineering Associates (SEA) Model WCM-3000



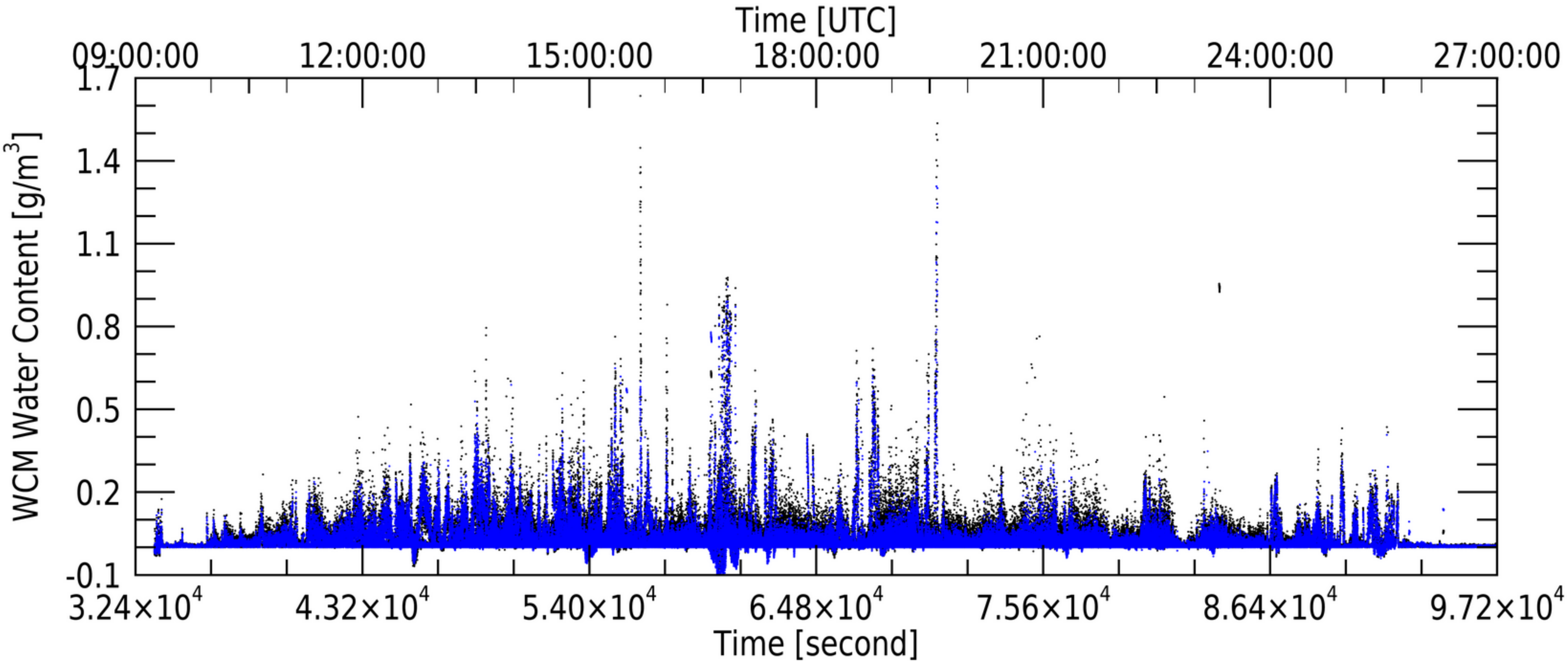


IMPACTS 2022: NASA P-3 Aircraft
Cloud Sampling (TWC_{WCM} > 0.01 g/m^3) Air Speed

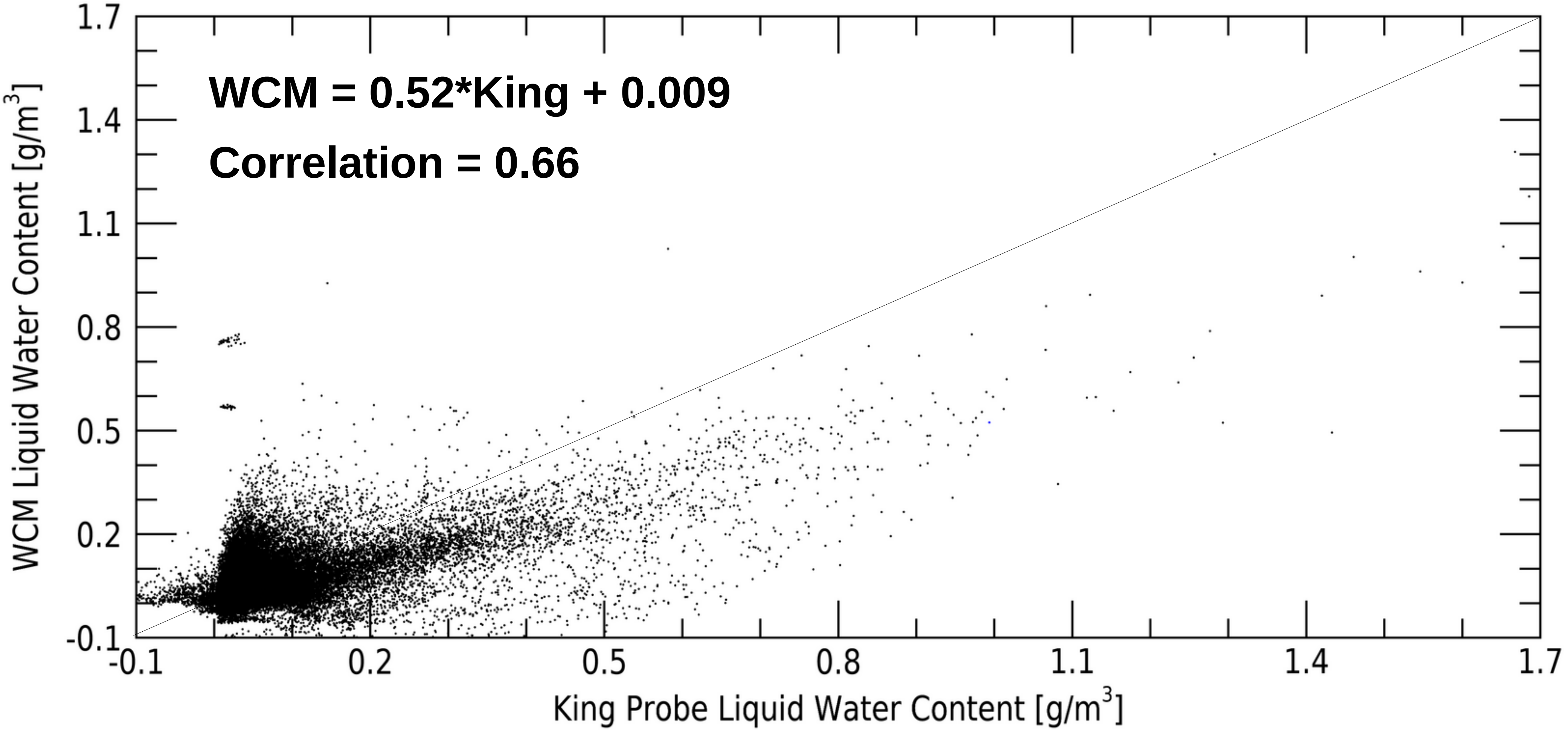


IMPACTS 2022: NASA P-3 Aircraft

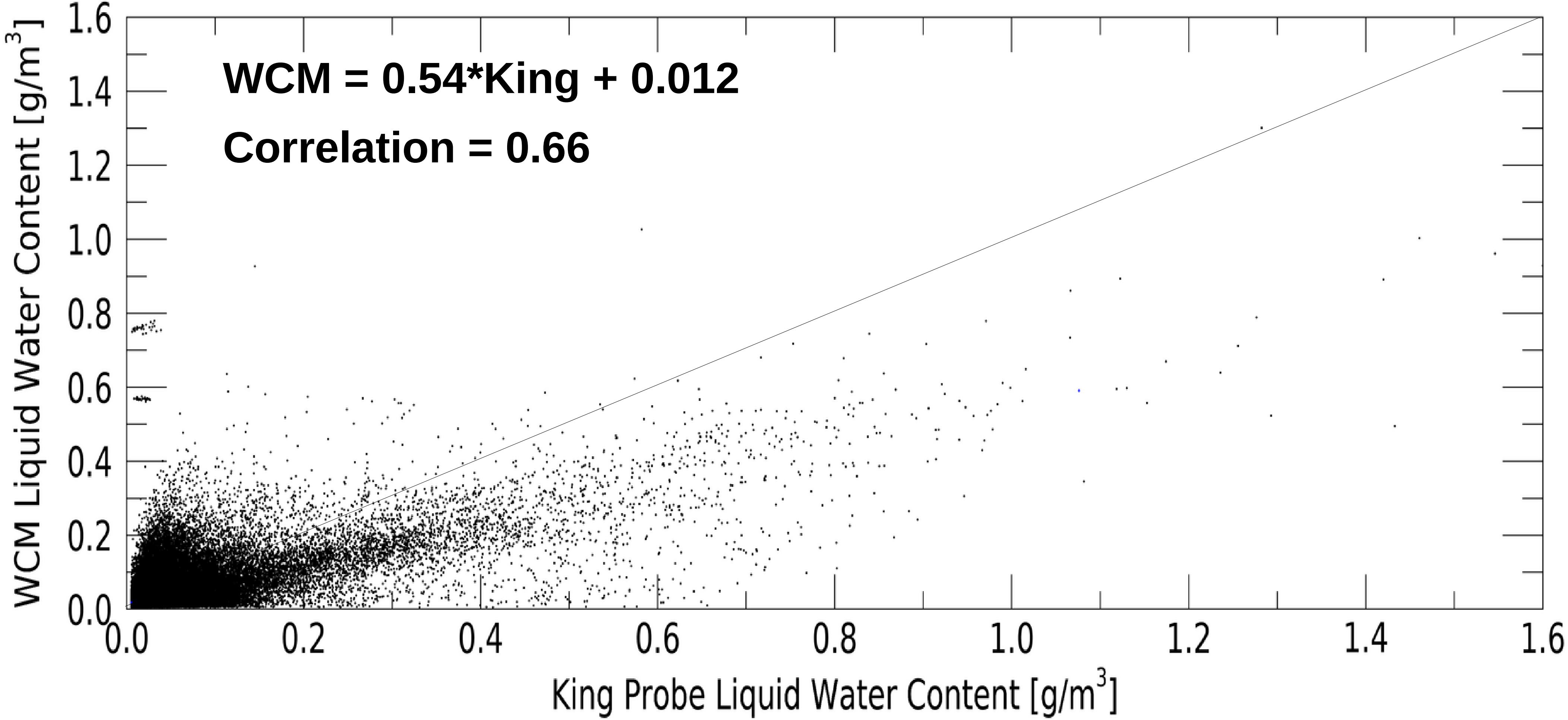
● Total Water Content ● Liquid Water Content



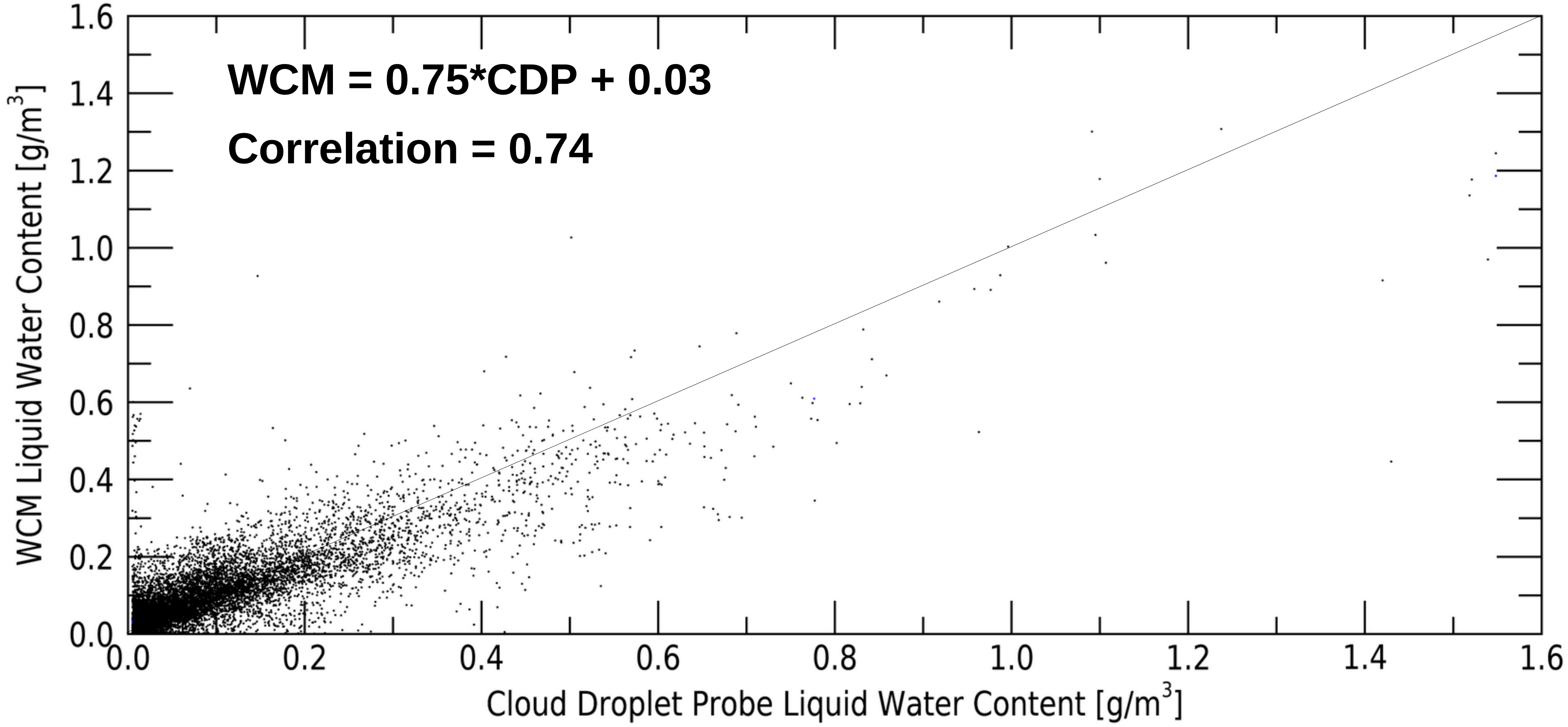
IMPACTS 2022: WCM vs. King Probe Comparison



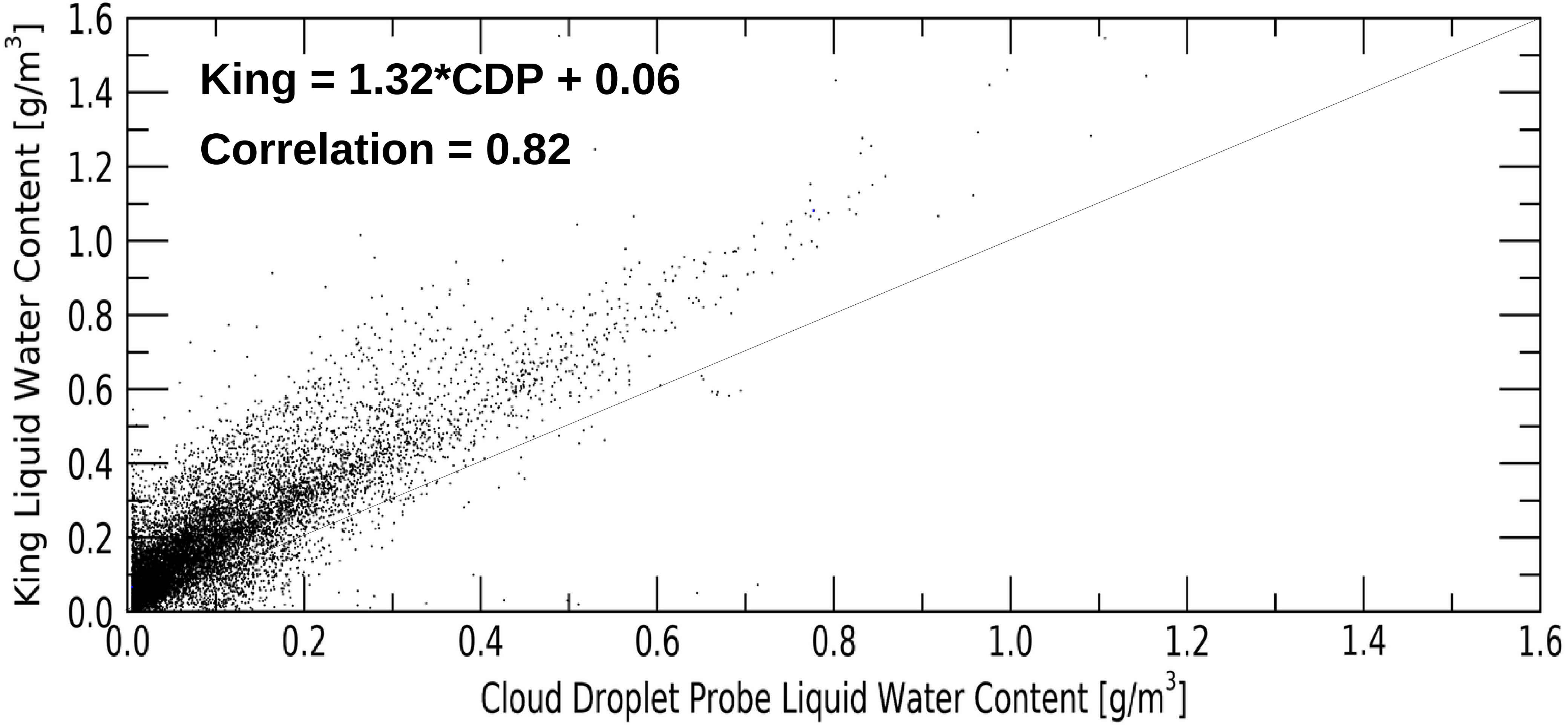
IMPACTS 2022: WCM (>0.005 g/m³) vs. CDP (>0.005 g/m³)



IMPACTS 2022: WCM vs. CDP (>0.005 g/m³) Comparison



IMPACTS 2022: King vs. CDP (>0.005 g/m³) Comparison



WCM Basic Equations

$$P_{Total} = P_{Dry} + P_{Wet}$$

$$P_{Wet} = P_{Total} - P_{Dry}$$

The actual magnitudes of the wet and dry terms depend on airspeed, air density, ambient temperature and sense element geometry.

WCM Equations Using Comp. Power

- WCM has a *sense* elements and *comp*ensation element.
- Compensation element is not sensitive to water content.

$$P_{Sense,Wet} = P_{Sense,Total} - P_{Sense,Dry}$$

$$P_{Comp,Wet} = P_{Comp,Total} - P_{Comp}$$

- Compensation element is highly correlated to dry power.

$$P_{Sense,Wet} = P_{Sense,Total} - (offset + slope) * P_{Comp}$$

- The WCM3000 does not have a compensation element.

WCM Equations Using Calculated Power

$$P_{Sense,Dry} = K_1 * (T_{Sense} - T_{ambient}) * (P_{Ambient} * TAS)^{K_2}$$

T_{Sense} = Sense Element Operating Temperature (Typically 140 °C)

$T_{Ambient}$ = Ambient Temperature of the Air Stream

$P_{Ambient}$ = Ambient (Static) Air Pressure

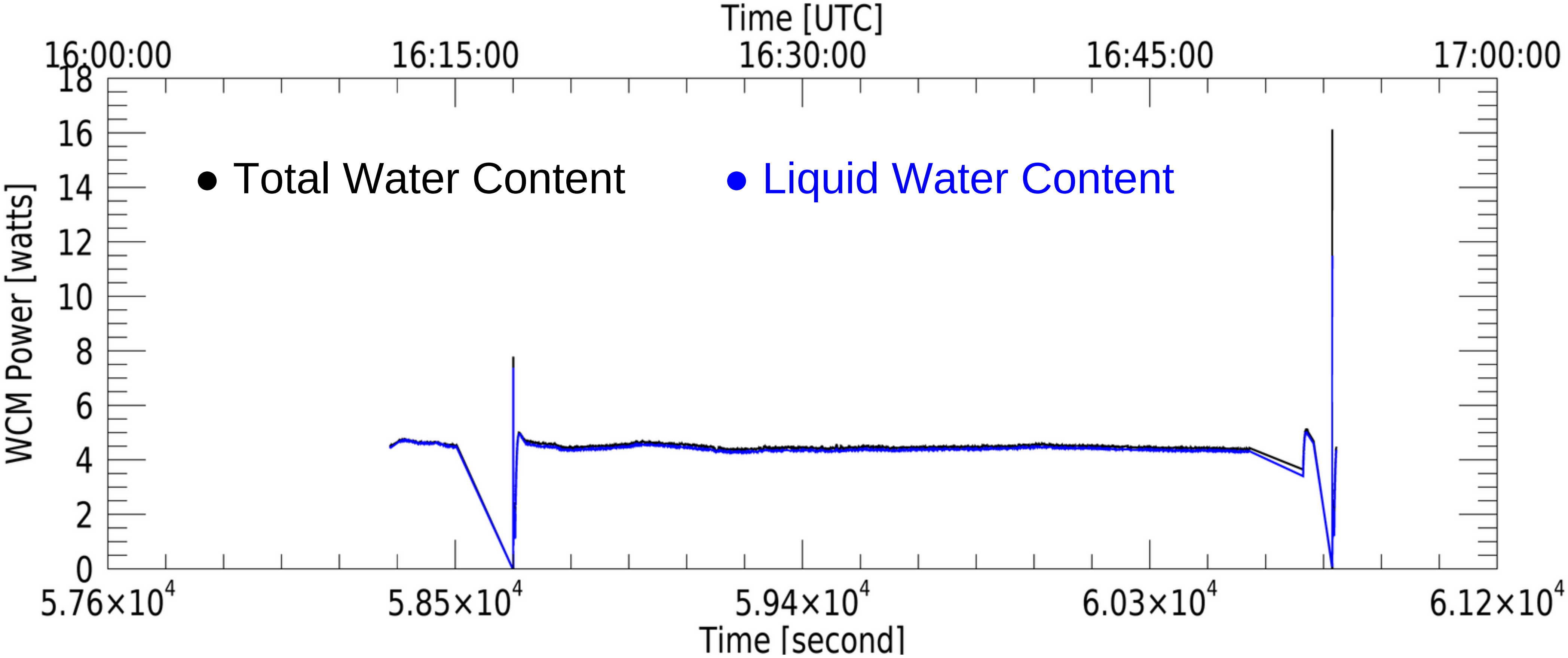
TAS = True Air Speed

K_1 = Constant

K_2 = Constant (Generally in the Range of 0.5)

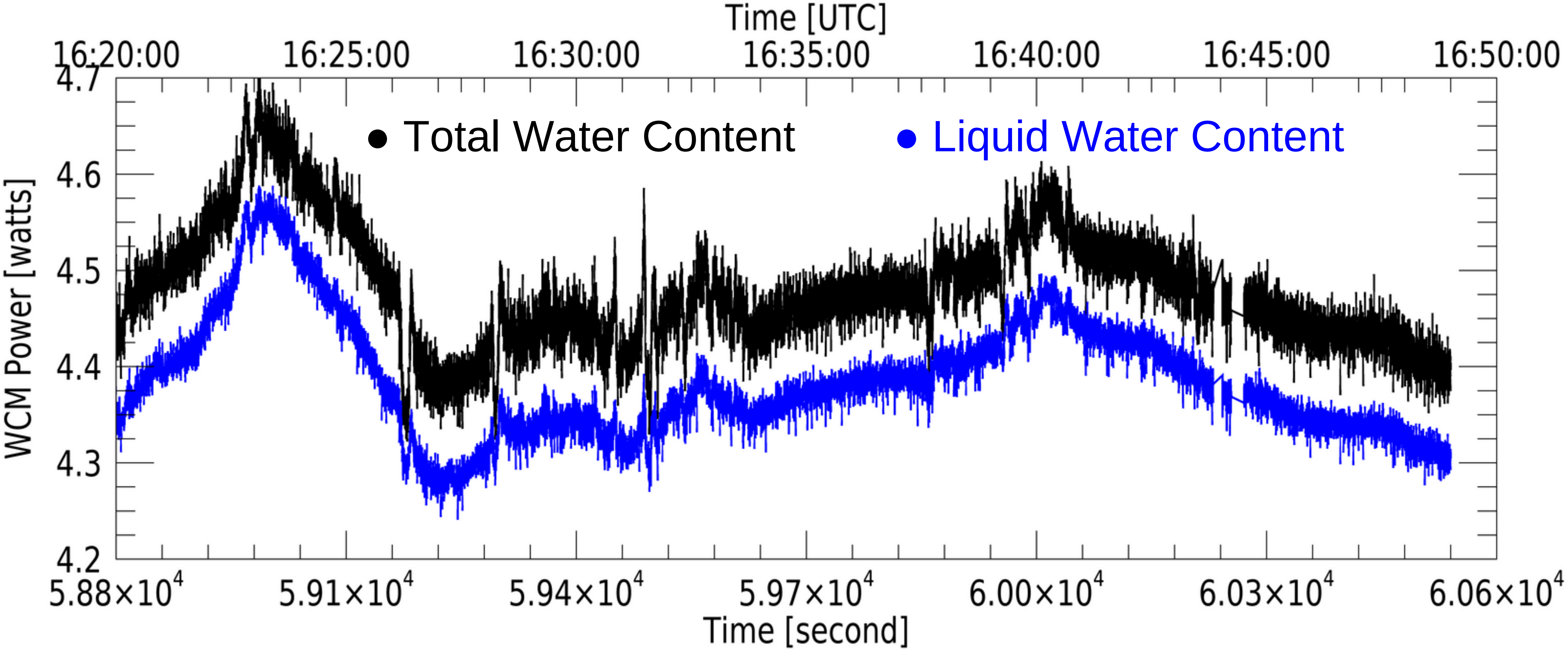
A more correct approach from a units standpoint is to use ambient air density instead of ambient air pressure in the above equation. However, experience has shown that a more usable prediction achieved using ambient pressure rather than ambient density, in spite of the mixed units.

WCM3000 Total and Liquid Power (Dry Air)



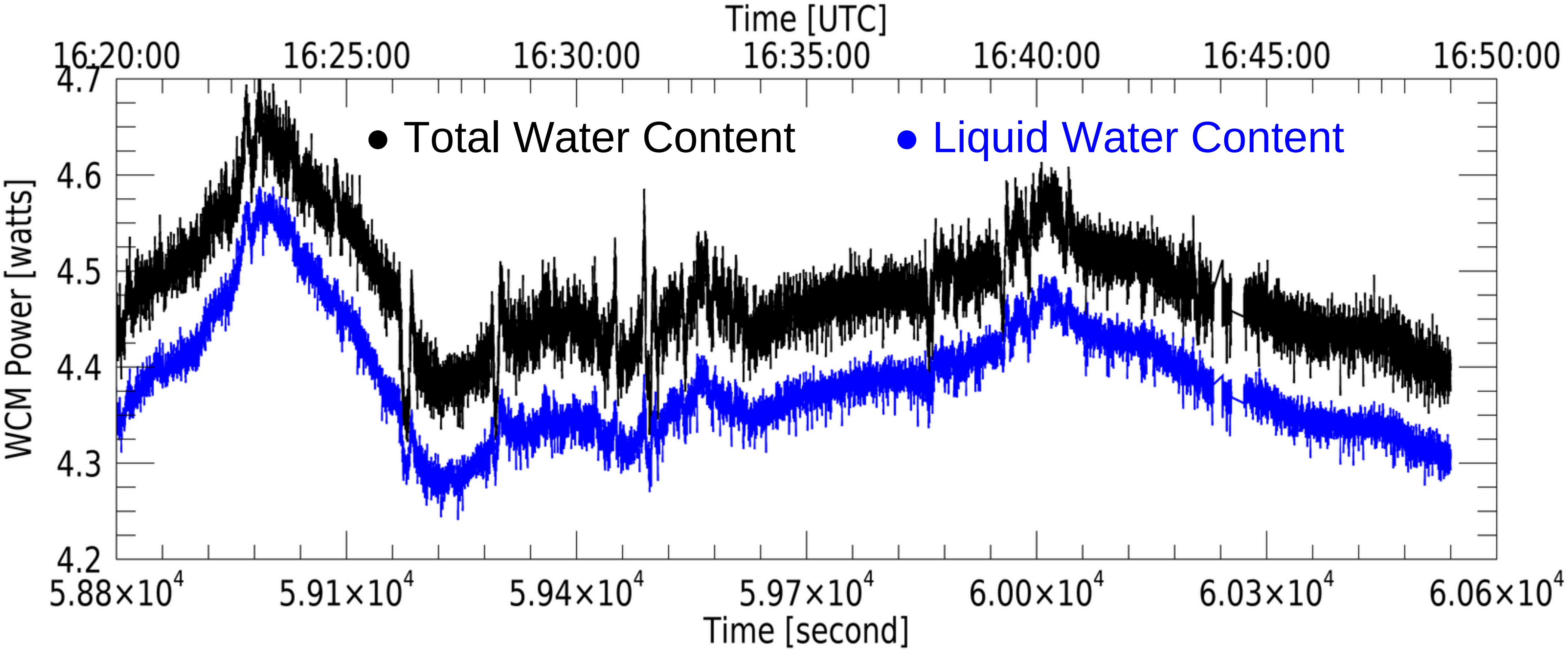
Plot showing the WCM 3000 power on January 6, 2022 IMPACTS flight.

WCM3000 Total and Liquid Power (Dry Air)

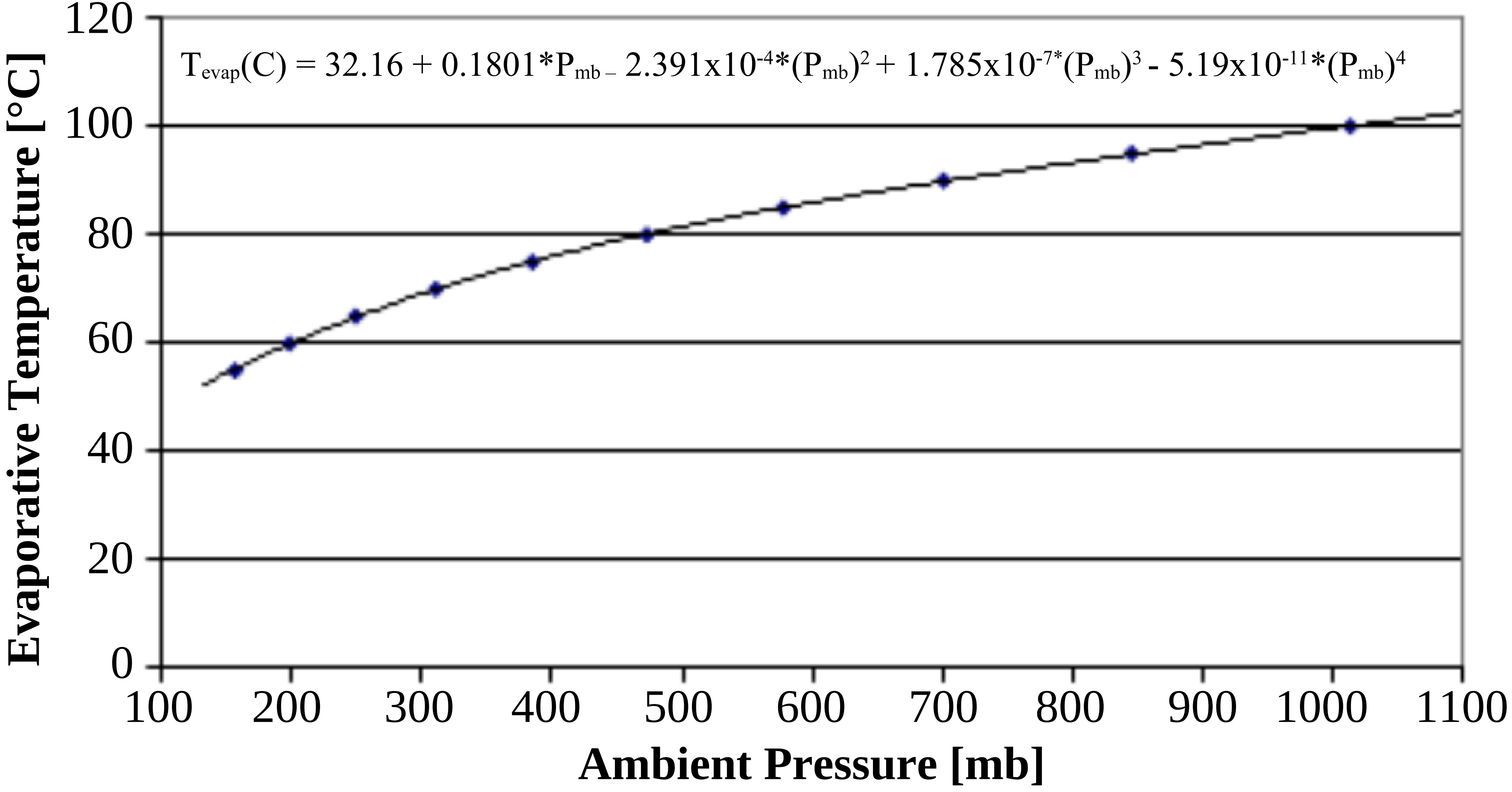


Plot showing the WCM 3000 power on January 6, 2022 IMPACTS flight during the middle of the out of cloud flight.

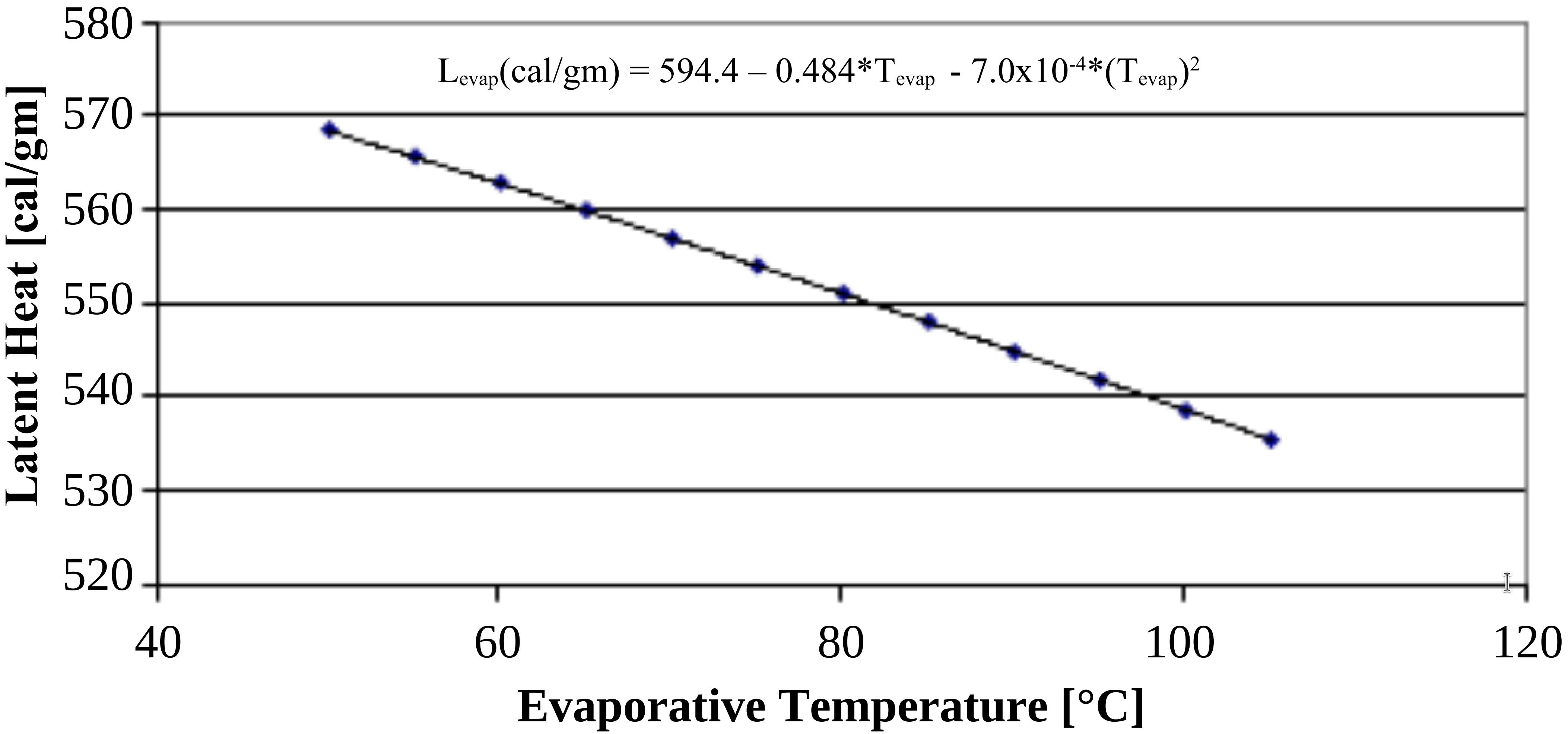
WCM3000 Total and Liquid Power (Dry Air)



Plot showing the WCM 3000 power on January 6, 2022 IMPACTS flight during the middle of the out of cloud flight.



Plot (WCM3000 manual) showing where a droplet begins to rapidly evaporate.



Plot (WCM3000 manual) showing that lower evaporative temperature takes a larger amount of heat to evaporate a droplet.

WCM Sample Volume

$$S_{Vol} = L_{Sense} * W_{Semse} * TAS$$

S_{Vol} = Volume of Air Sample per Unit Time

L_{Sense} = Length of the Sense Element

W_{Sense} = Width of the Sense Element

TAS = True Air Speed

Data from the WCM300 C0 stream.

l – Length (mm): TWC →

l =10.0080 mm, w = 2.4380 mm

w – width (mm): LWC →

l = 10.0080, w = 2.3880 mm

Sample Volume Comparison

NASA P-3 IMPACTS → 134 m/s

- WCM

  $S_{TWC} = 0.010008*0.0024380*134 = 0.00327\ m^3/s$

  $S_{LWC} = 0.010008*0.0023880*134 = 0.00320\ m^3/s$

- CDP

  $S_{Area} = 0.2400\ mm^2 = 2.4e\text{-}7\ m^2$

  $S_{Vol} = 2.4e\text{-}7\ m^2 * 134\ m/s = 3.216^{-5}\ m^3/s$

WCM = $3.2*10^{-3}\ m^3/s$ compared to $3.2*10^{-5}$ for CDP

Conclusions

The Forward Scattering Spectrum Probe (FSSP) and Cloud Droplet Probe have different optical systems that give different comparison to hot wire probes.

- The FSSP liquid water content agrees with the King Probe LWC in ice free conditions. Cases from two different field programs found FSSP to King ratios of 0.96 and 1.20.

- The cloud droplet probe uses different optical system than the FSSP. The July 20 POLCAST3 flights show CDP Liquid Water Content measurements 20% low compared to King Hot Wire probe measurements; however, other flights are worst.

Any Questions?