Comparison of DAWN, Dropsonde, and Aeolus Wind Observations during the April 2019 NASA Aeolus Cal/Val Test Flight Campaign

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100th American Meteorological Society Annual Meeting

16th Annual Symposium on New Generation Operational Environmental Satellite Systems

Boston, MA

January 16, 2020

Airborne DAWN Underflights of Aeolus

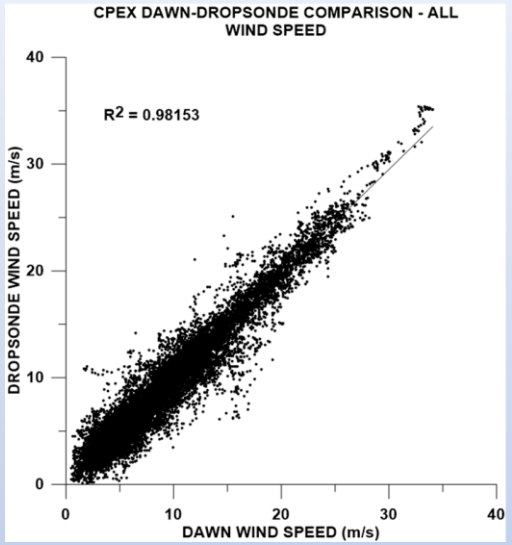
- April 17-30, 2019 NASA Airborne Campaign
- Based out of Palmdale, CA
- Airborne DAWN and YES Dropsonde aboard NASA DC-8
- 5 underpasses of Aeolus in April 2019
- Over the eastern Pacific Ocean
    - Two transects between US west coast and Hawaii
    - **Three missions off west coast of US (30 – 50 N)**
        - **Mostly clear to partly cloudy conditions**
        - **Low and high aerosol segments**

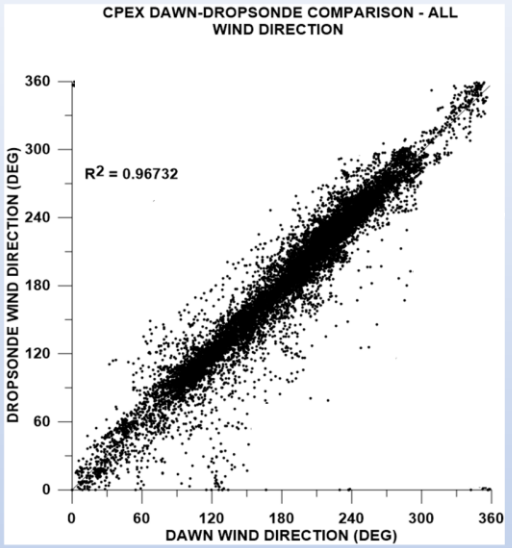
DAWN wind profile

- Presented for 3 DAWN Underflights (April 18, 23 and 30, 2019)
- DAWN wind vector products are low bias (< .25m/s) and good RMSD in comparisons with dropsondes (see next slide)
- 3-d Wind Profiles computed for 5-look DAWN scanning pattern (5 LOS)
  - 4-5km horizontal resolution
  - 75m vertical resolution along LOS
  - 33m resolution for vertical profiles
- U and V of DAWN profile used to compute a DAWN Aeolus projection of HLOS

DAWN data quality

All DAWN – Dropsonde Comparisons from 2017 CPEX
(162 ~ co-located, coincident DAWN and Dropsonde Profiles)





DAWN-Dropsonde comparisons from CPEX 2017
Wind Speed (m/s)

	Number 37m seg	MEAN Z DIFF (m)	BIAS (m/s)	MEAN ABS (ΔWS)	ΔWS RMSD
ALL	15517	3.08	0.09	1.13	1.55
2 LOOK	6921	3.26	0.05	1.28	1.72
5 LOOK	8596	2.93	0.13	1.01	1.39

DAWN-Dropsonde comparisons from CPEX 2017
Wind Direction (degrees)

	Number 37m seg	MEAN Z DIFF (m)	BIAS (deg)	MEAN ABS (ΔWD)	ΔWD RMSD
ALL	15517	3.08	0.62	11.19	20.69
2 LOOK	6921	3.26	0.68	12.66	24.10
5 LOOK	8596	2.93	0.56	10.01	17.44

Aeolus LOS wind product

- **Non-scanning single LOS for Rayleigh and Mie channels**
  - **During April underflights the first laser was operating at nearly 50% of the design optical power**
  - **Not all biases or best calibration data have been accounted for in the preliminary comparison to be shown here.**
- **Rayleigh derives wind from molecular returns**
  - **Baseline horizontal integration: ~85km**
  - **Vertical coverage - ~ 250-500m in PBL to 1km in troposphere**
  - **Rejection – observation error quantifyer > 6.6 m/s (below 200 mb)**
- **Mie derived winds from clouds and aerosols**
  - **Horizontal integration: ~ 10-12 km**
  - **Vertical resolution: in bottom 1km; 500m; 250-400m for 1-4km; 1km > 4km**
  - **Rejection – observation error quantifyer > 4.5 m/s**
- **Using the Aeolus Level 2B Product**
  - **RAYLEIGH CLEAR**
  - **RAYLEIGH CLOUDY**
  - **MIE CLEAR product**
  - **MIE COUDY product**

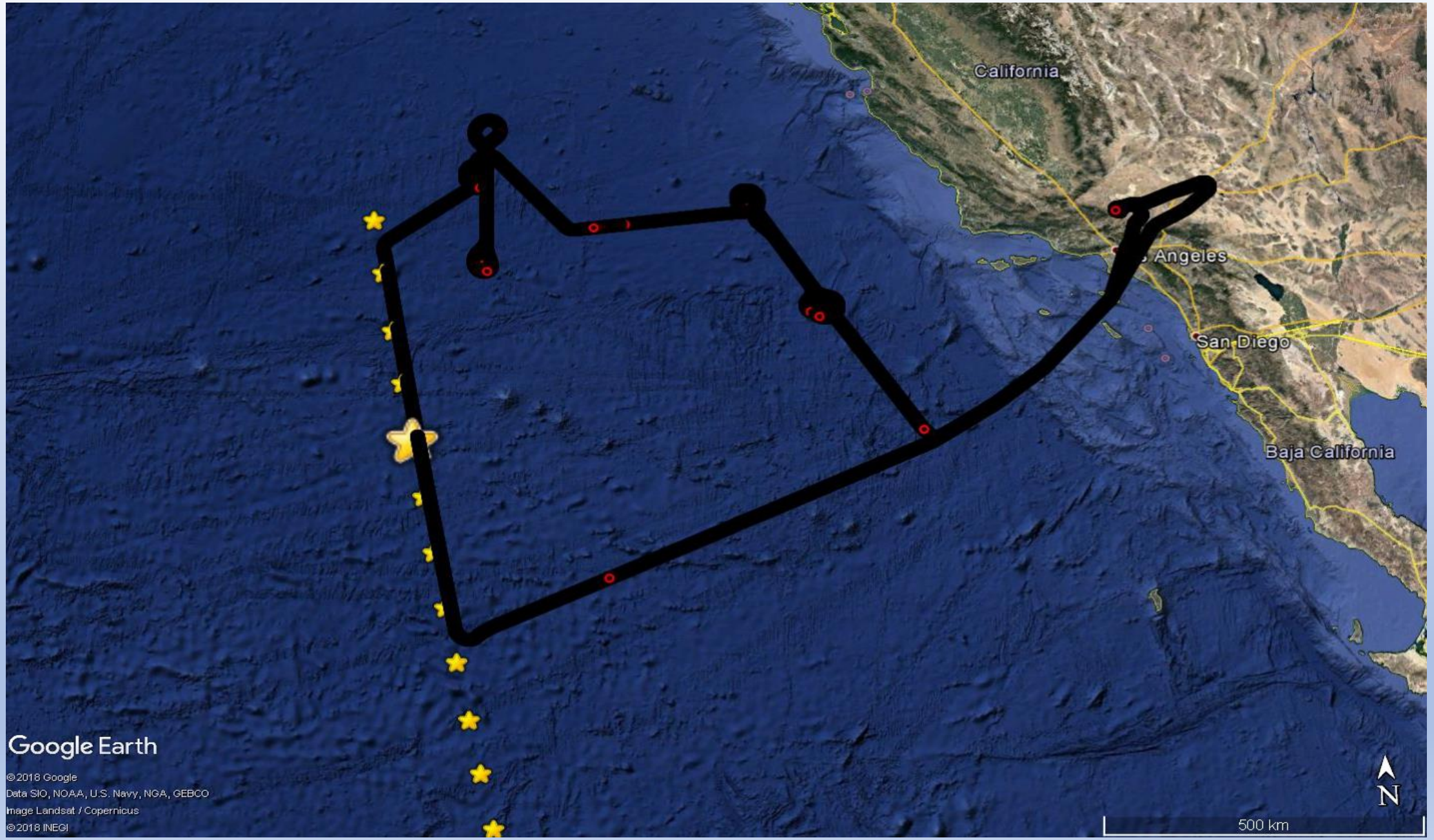
0430 DAWN-AEOLUS HLOS COMPARSIONS

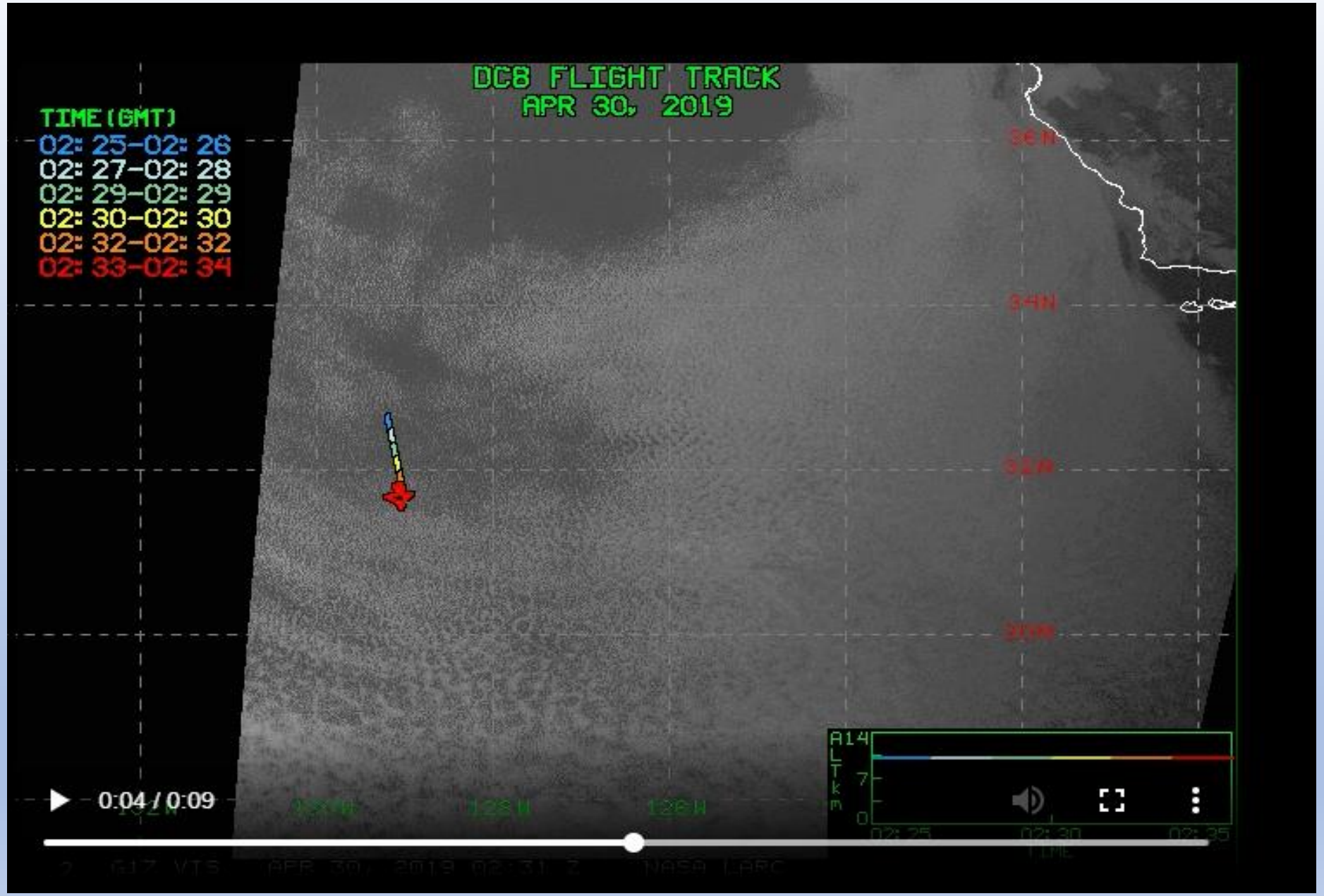
1) AEOLUS S-N 02:27 - 02:29Z
2) DAWN N-S 02:13 – 02:54Z (~ 600 km)
3) DAWN profiles from 5 Looks computed every ~5km
4) 7 AEOLUS profiles along DAWN under-flight track
    - Rayleigh Clear (uses 21-24 winds)
    - Mie Cloudy (uses 1-4 winds)

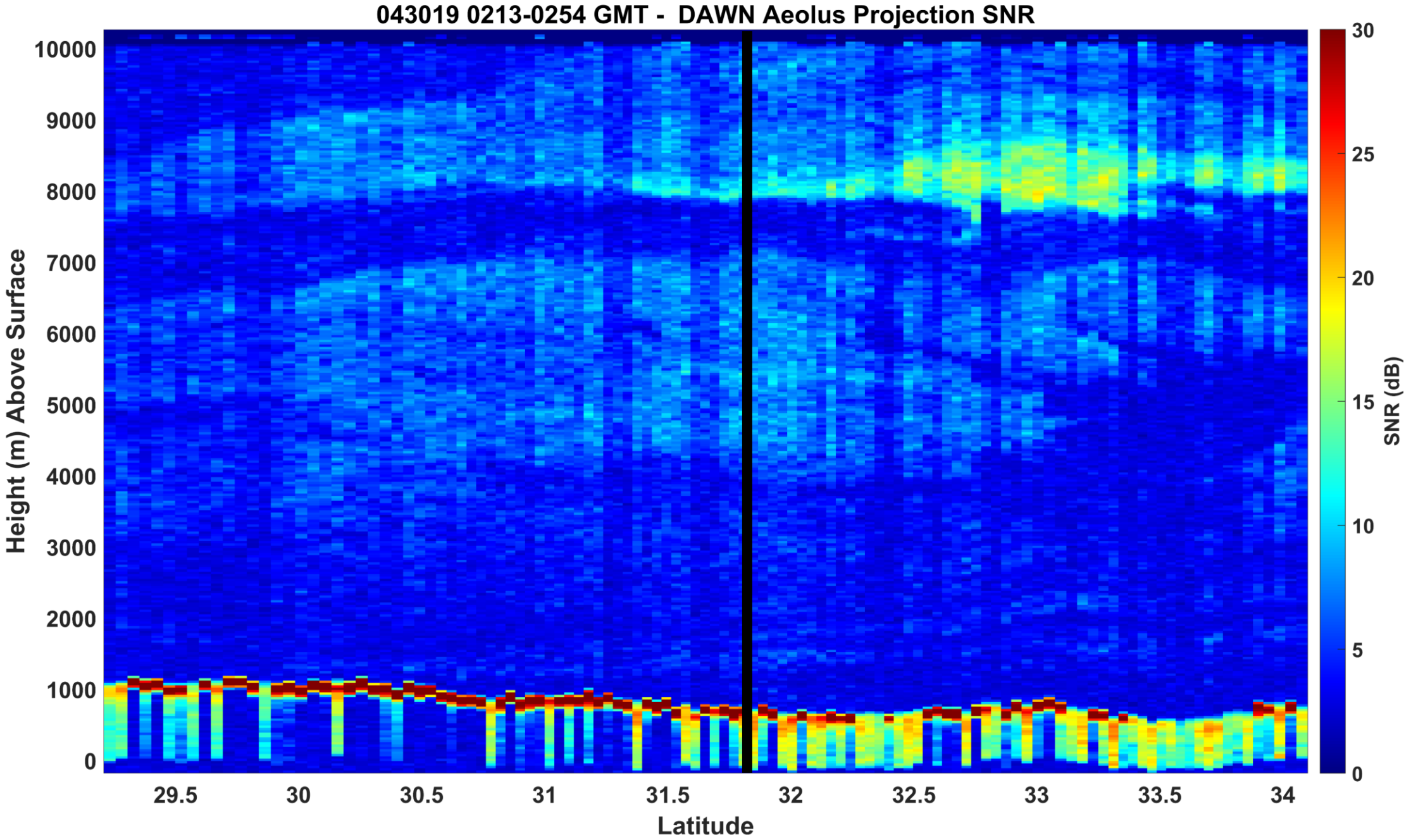
4) DAWN Aeolus projection HLOS shown for 123 DAWN profiles along DAWN underflight

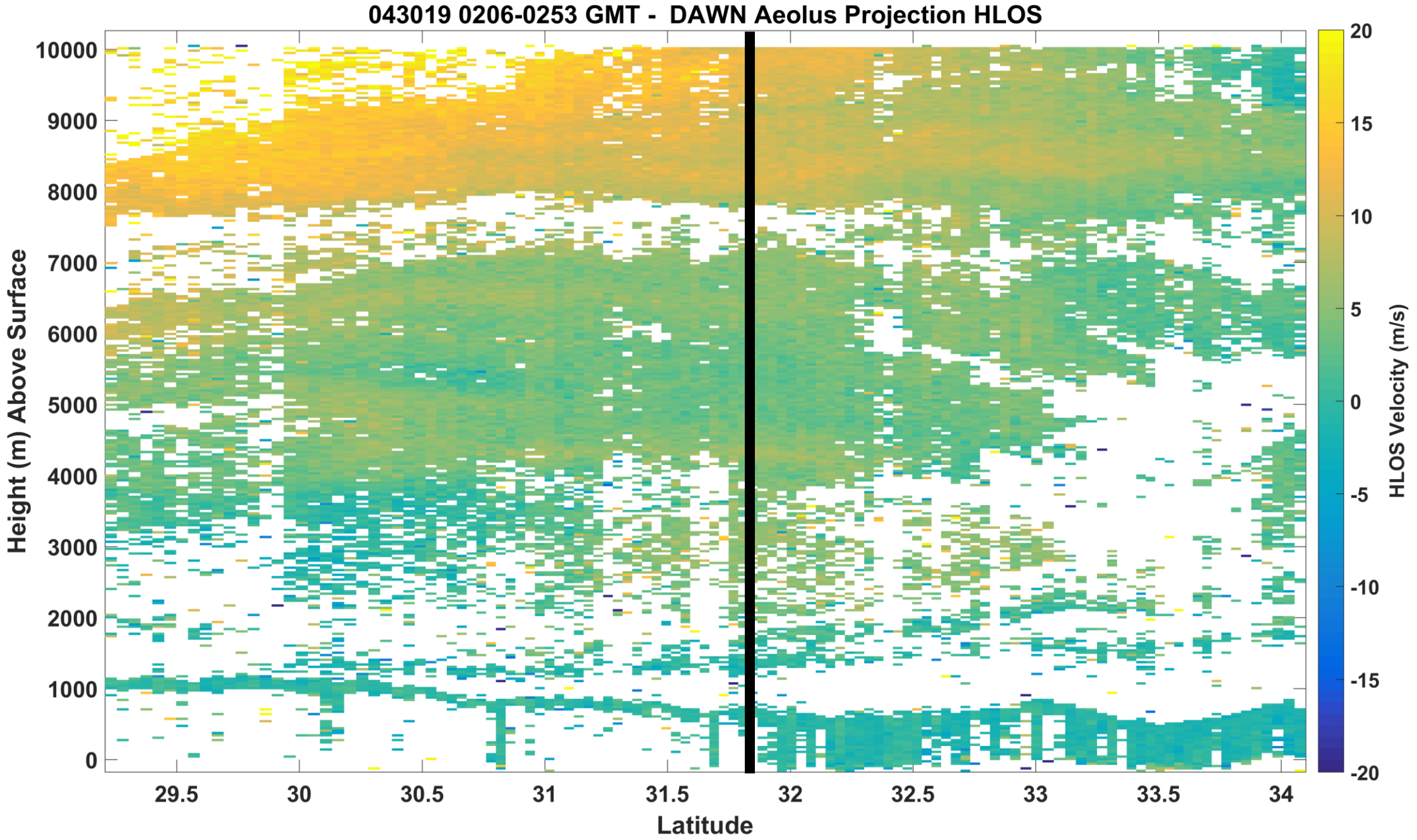
5) 7 DAWN “Integrated” profiles each utilizing 17 individual DAWN profiles

6) Individual comparisons between AEOLUS profile and closest individual DAWN profile

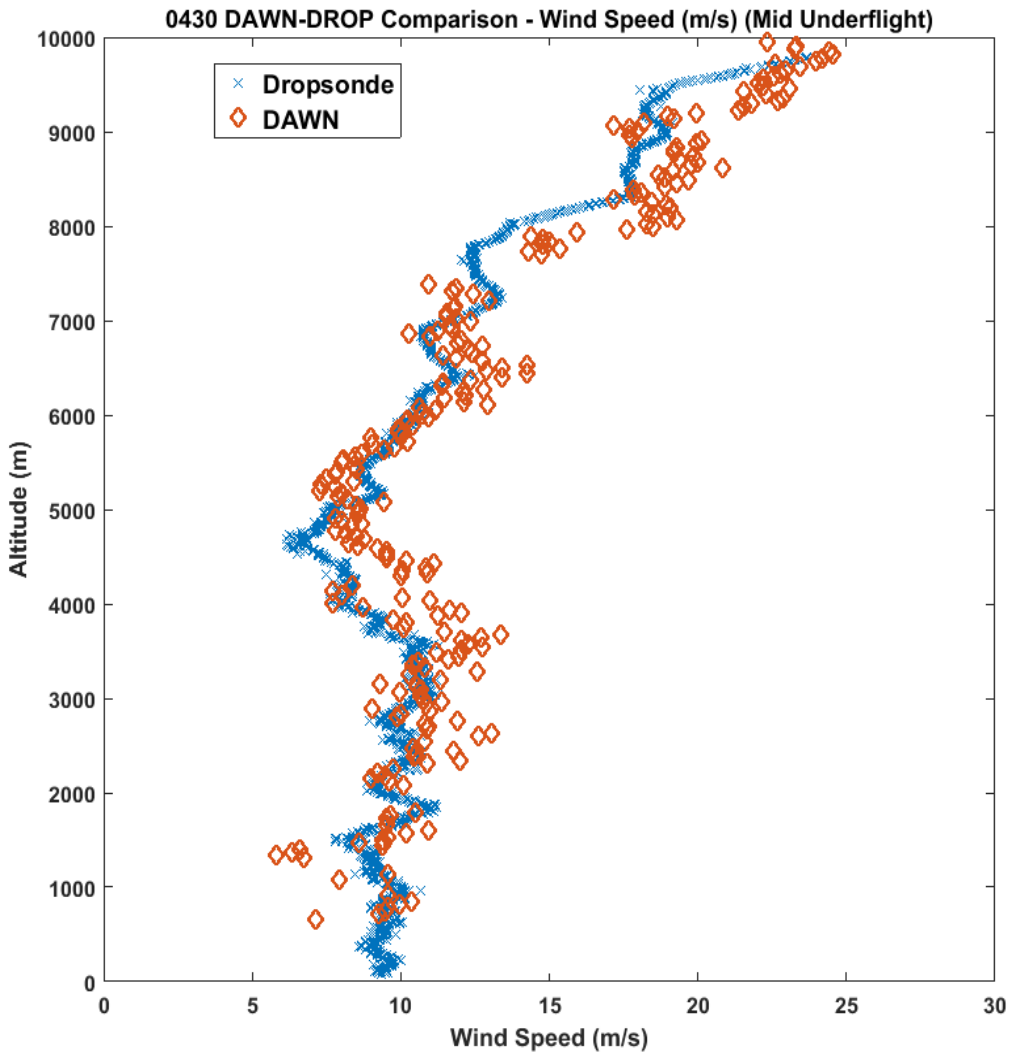

California
Angeles
San Diego
Baja California
Google Earth
©2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
©2018 INEGI
N
500 km

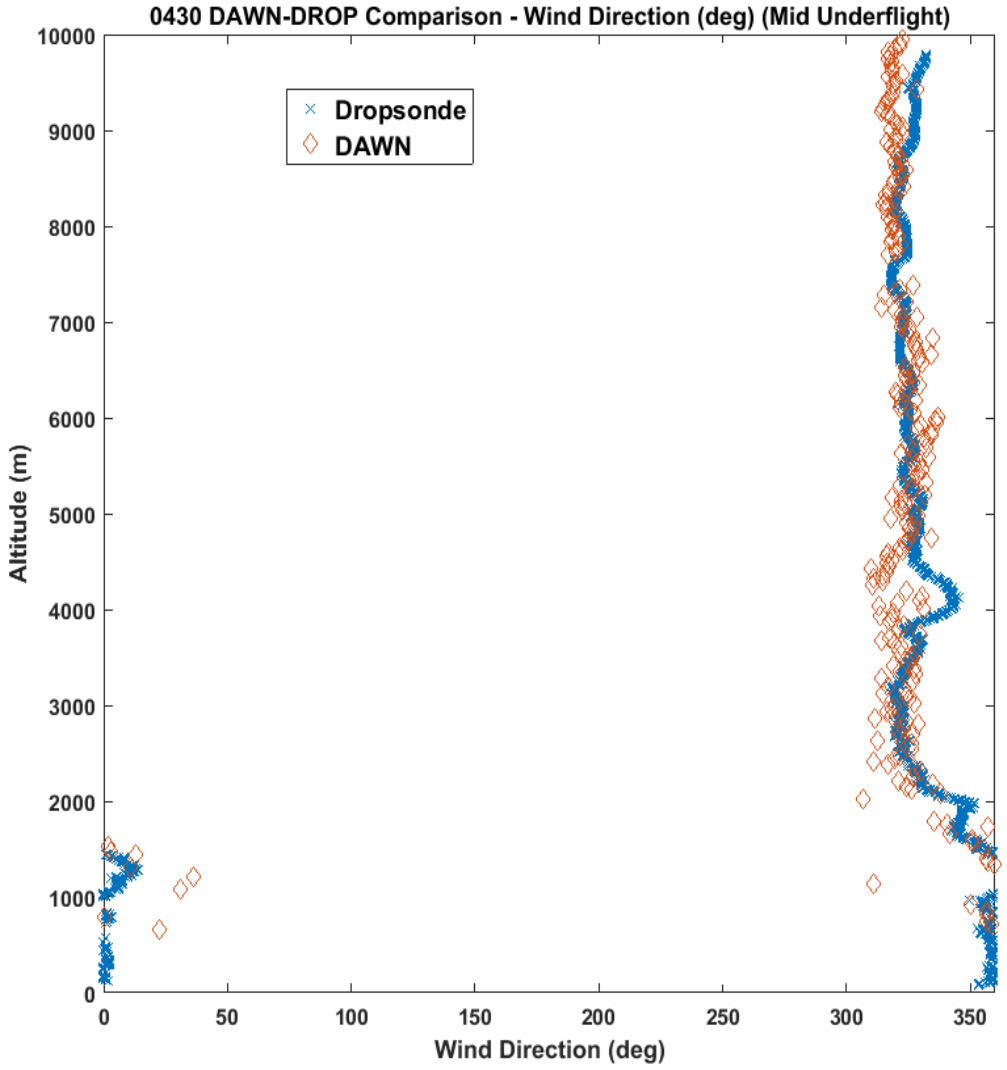

DC8 FLIGHT TRACK
APR 30, 2019
TIME(GMT)
02:25-02:26
02:27-02:28
02:29-02:29
02:30-02:30
02:32-02:32
02:33-02:34
0:04 / 0:09

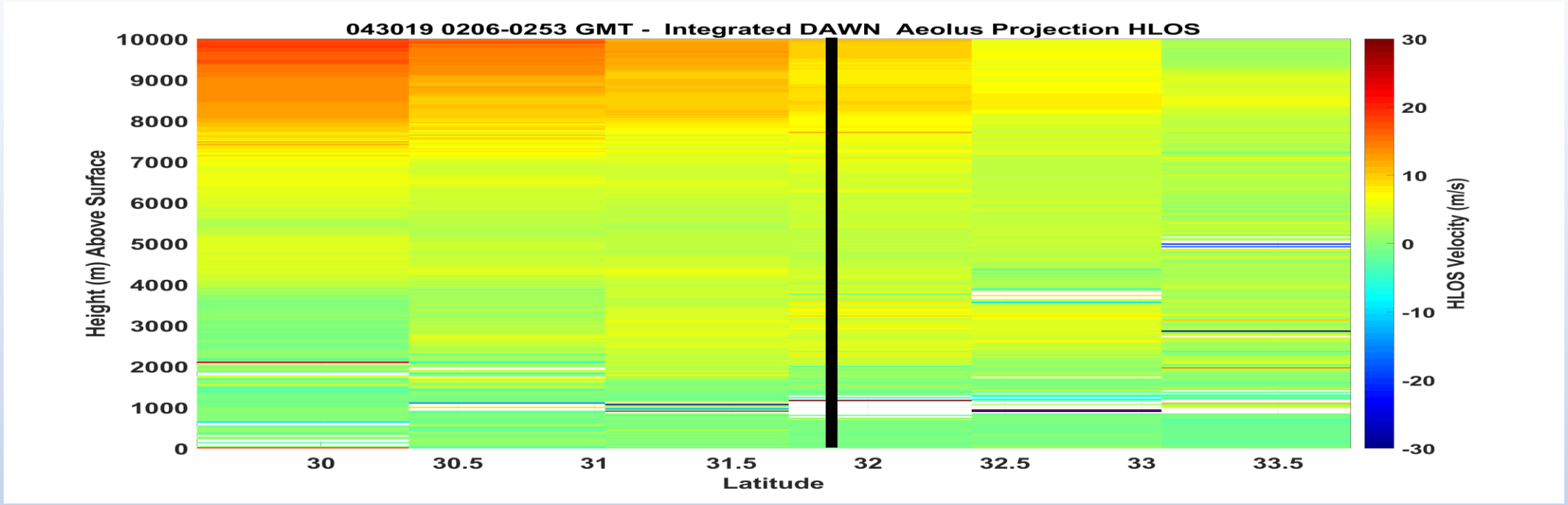

043019 0213-0254 GMT - DAWN Aeolus Projection SNR
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
29.5
30
30.5
31
31.5
32
32.5
33
33.5
34
Latitude
SNR (dB)
30
25
20
15
10
5
0

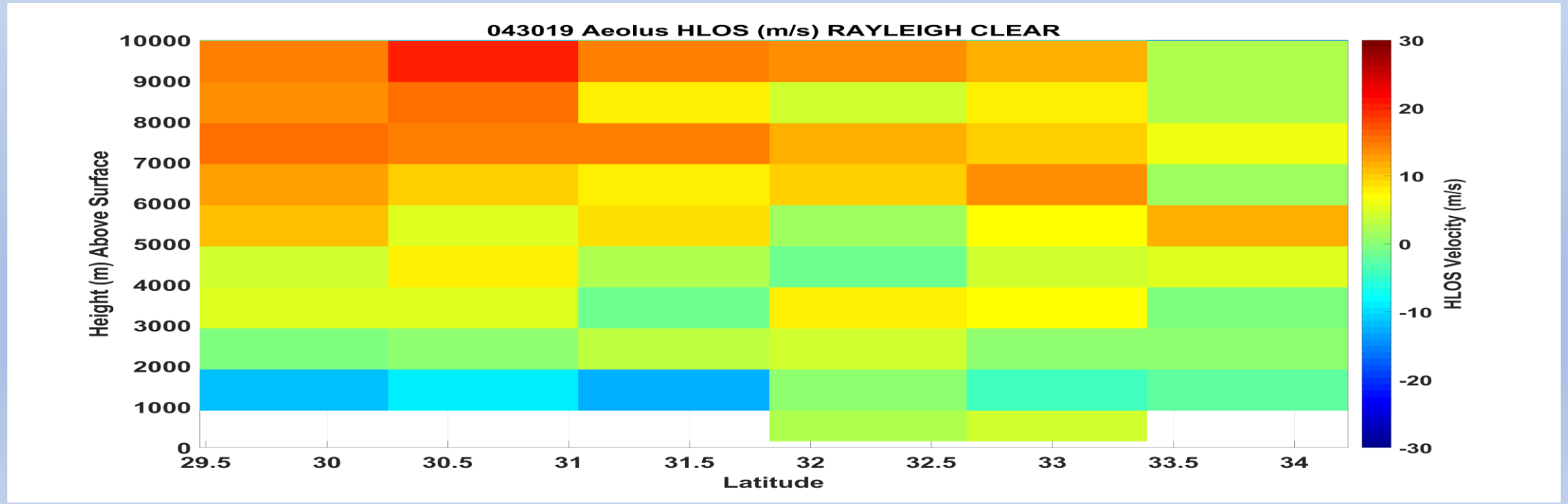

043019 0206-0253 GMT - DAWN Aeolus Projection HLOS
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
29.5
30
30.5
31
31.5
32
32.5
33
33.5
34
Latitude
HLOS Velocity (m/s)
20
15
10
5
0
-5
-10
-15
-20

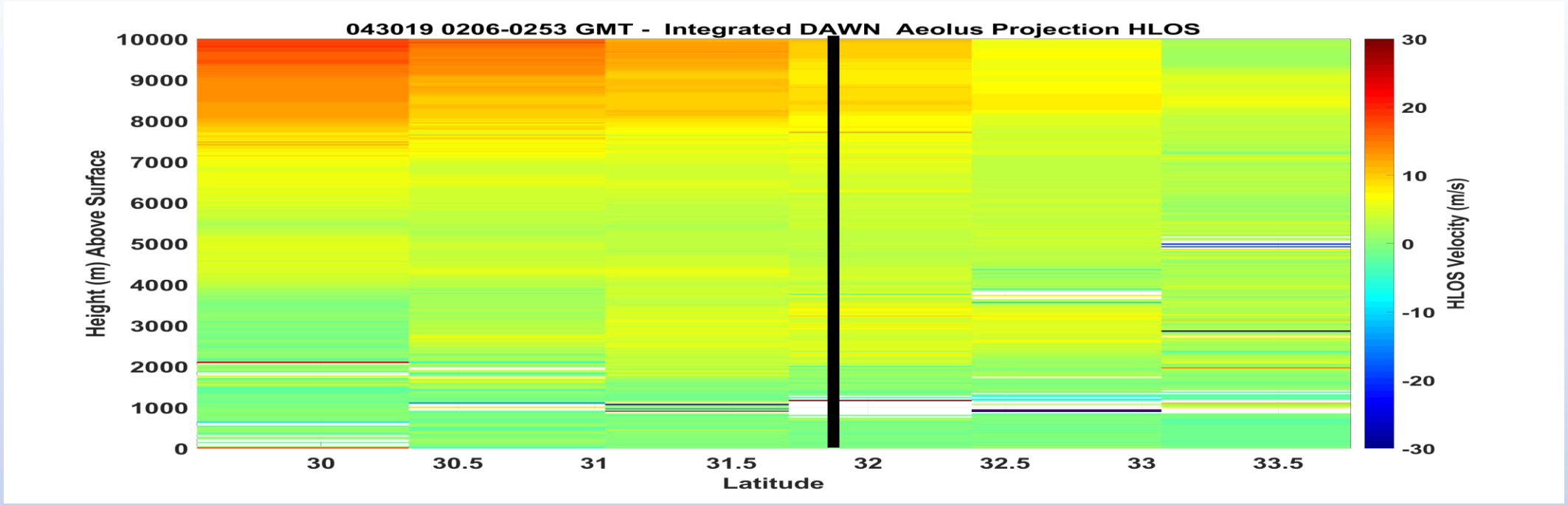
DAWN-DROP COMPARISON
MIDDLE OF UNDERFLIGHT

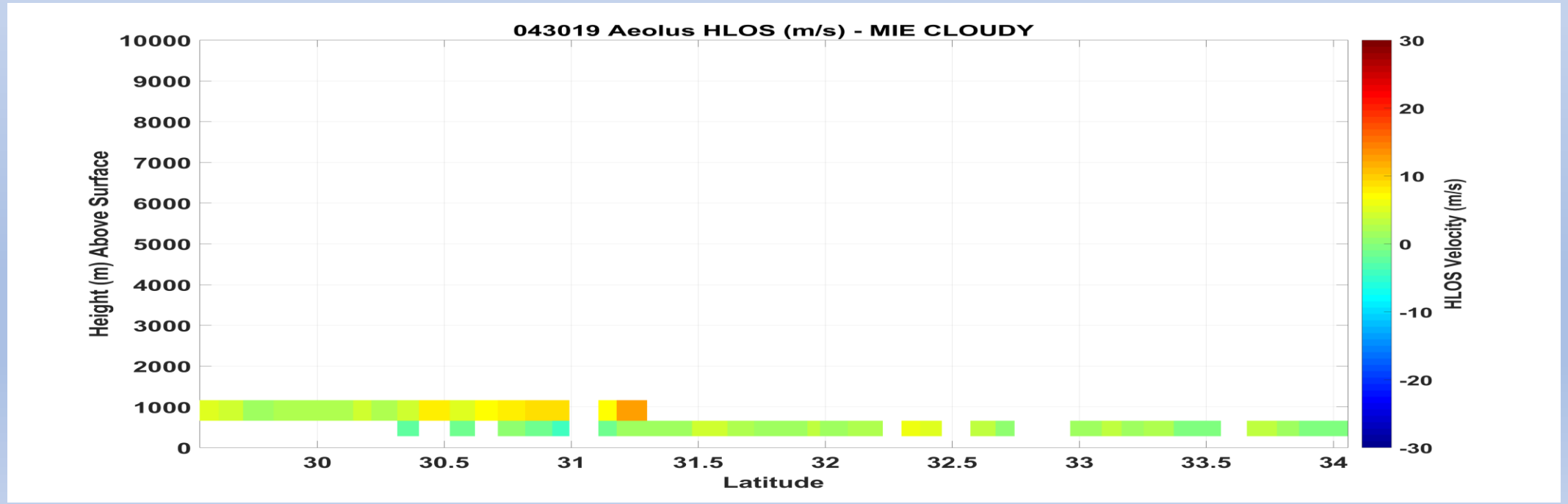

0430 DAWN-DROP Comparison - Wind Speed (m/s) (Mid Underflight)
Dropsonde
DAWN
Altitude (m)
Wind Speed (m/s)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
5
10
15
20
25
30


0430 DAWN-DROP Comparison - Wind Direction (deg) (Mid Underflight)
Dropsonde
DAWN
Altitude (m)
Wind Direction (deg)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
50
100
150
200
250
300
350


043019 0206-0253 GMT - Integrated DAWN Aeolus Projection HLOS
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
30
30.5
31
31.5
32
32.5
33
33.5
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30

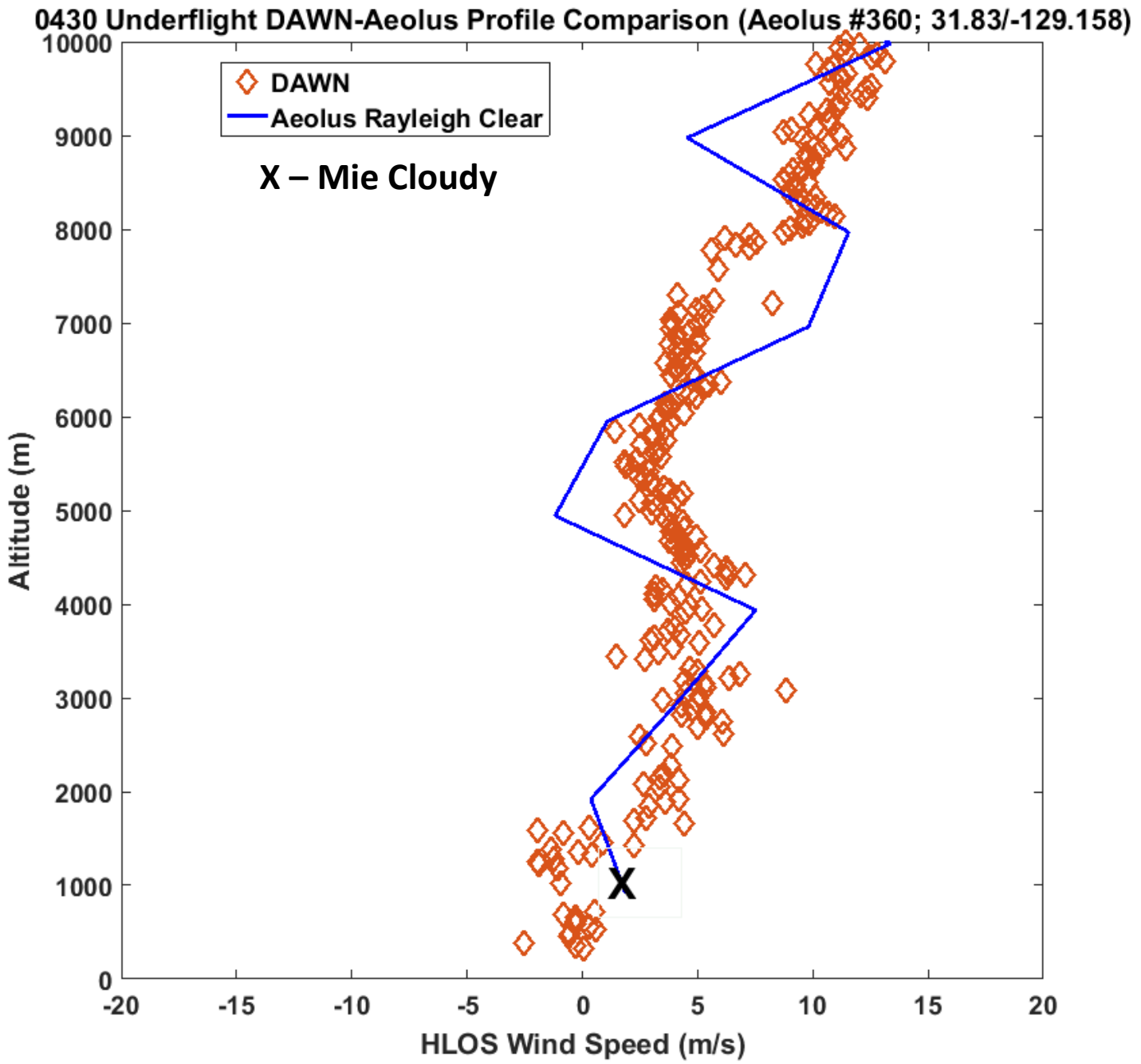

043019 Aeolus HLOS (m/s) RAYLEIGH CLEAR
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
29.5
30
30.5
31
31.5
32
32.5
33
33.5
34
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30

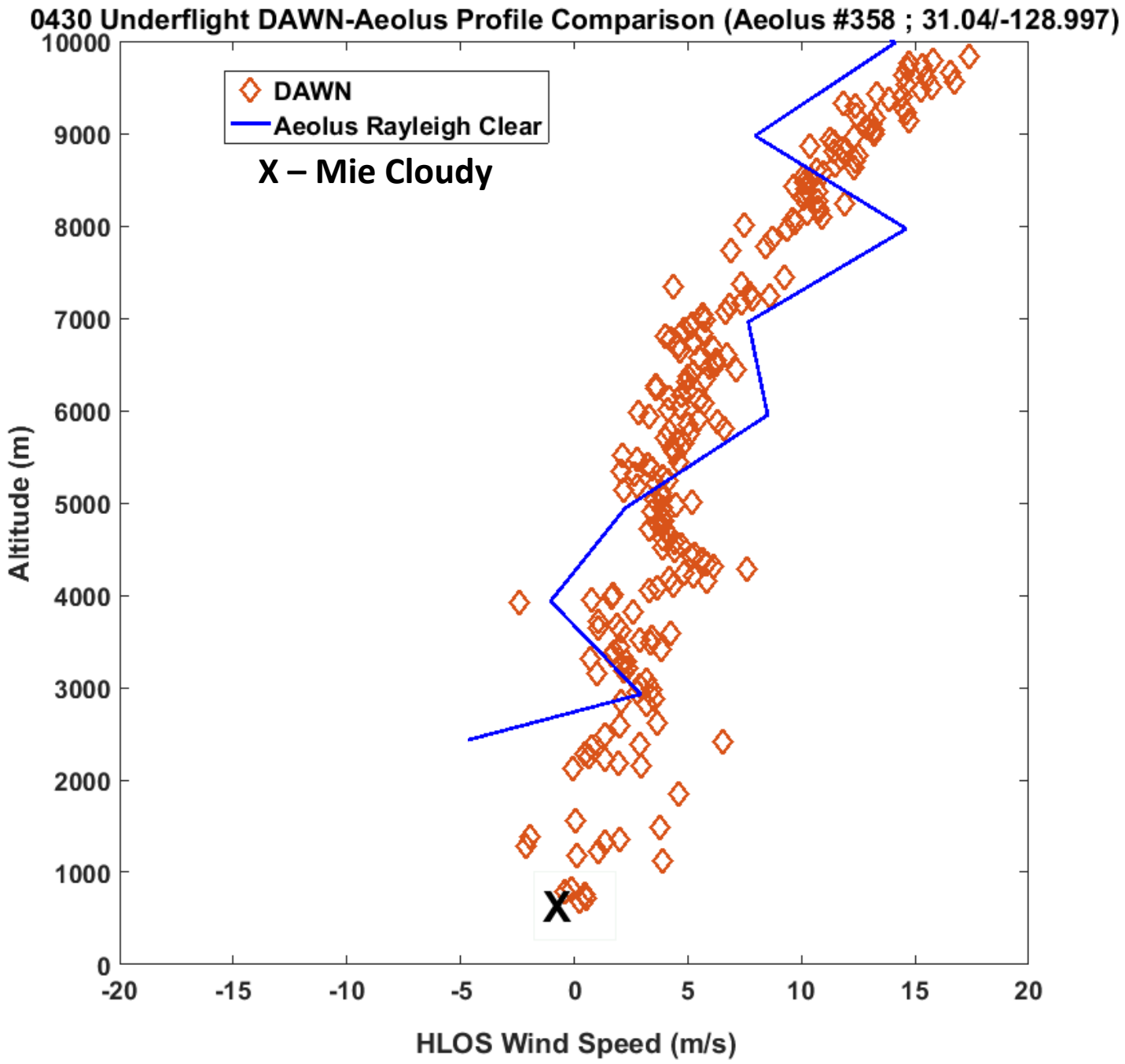

043019 0206-0253 GMT - Integrated DAWN Aeolus Projection HLOS
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
30
30.5
31
31.5
32
32.5
33
33.5
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30


043019 Aeolus HLOS (m/s) - MIE CLOUDY
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
30
30.5
31
31.5
32
32.5
33
33.5
34
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30

INDIVIDUAL PROFILE COMPARISONS

AEOLUS DIRECTLY OVERHEAD




0430 Underflight DAWN-Aeolus Profile Comparison (Aeolus #358 ; 31.04/-128.997)
DAWN
Aeolus Rayleigh Clear
X – Mie Cloudy
Altitude (m)
HLOS Wind Speed (m/s)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-20
-15
-10
-5
0
5
10
15
20
X

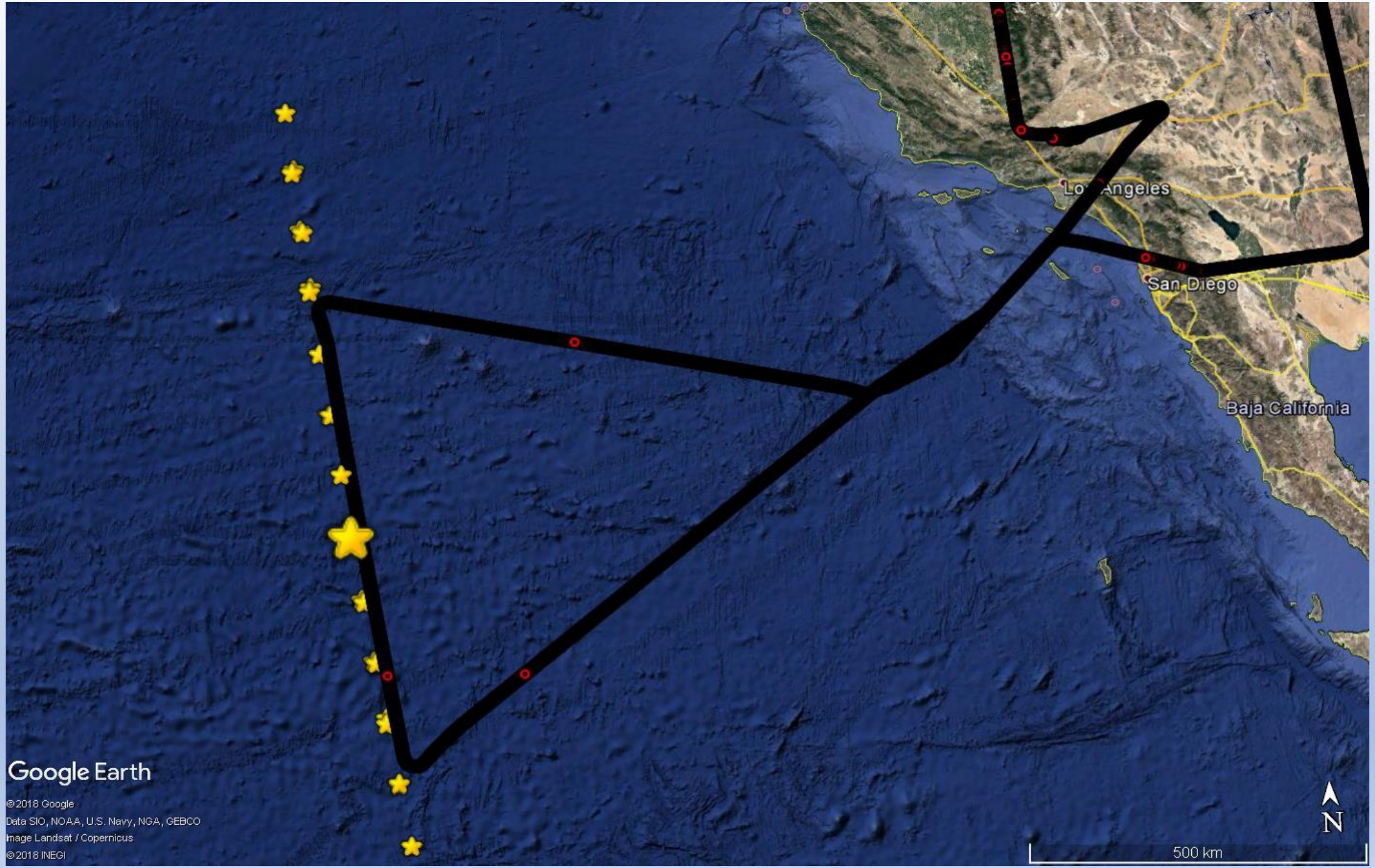
0423 DAWN-AEOLUS HLOS COMPARSIONS

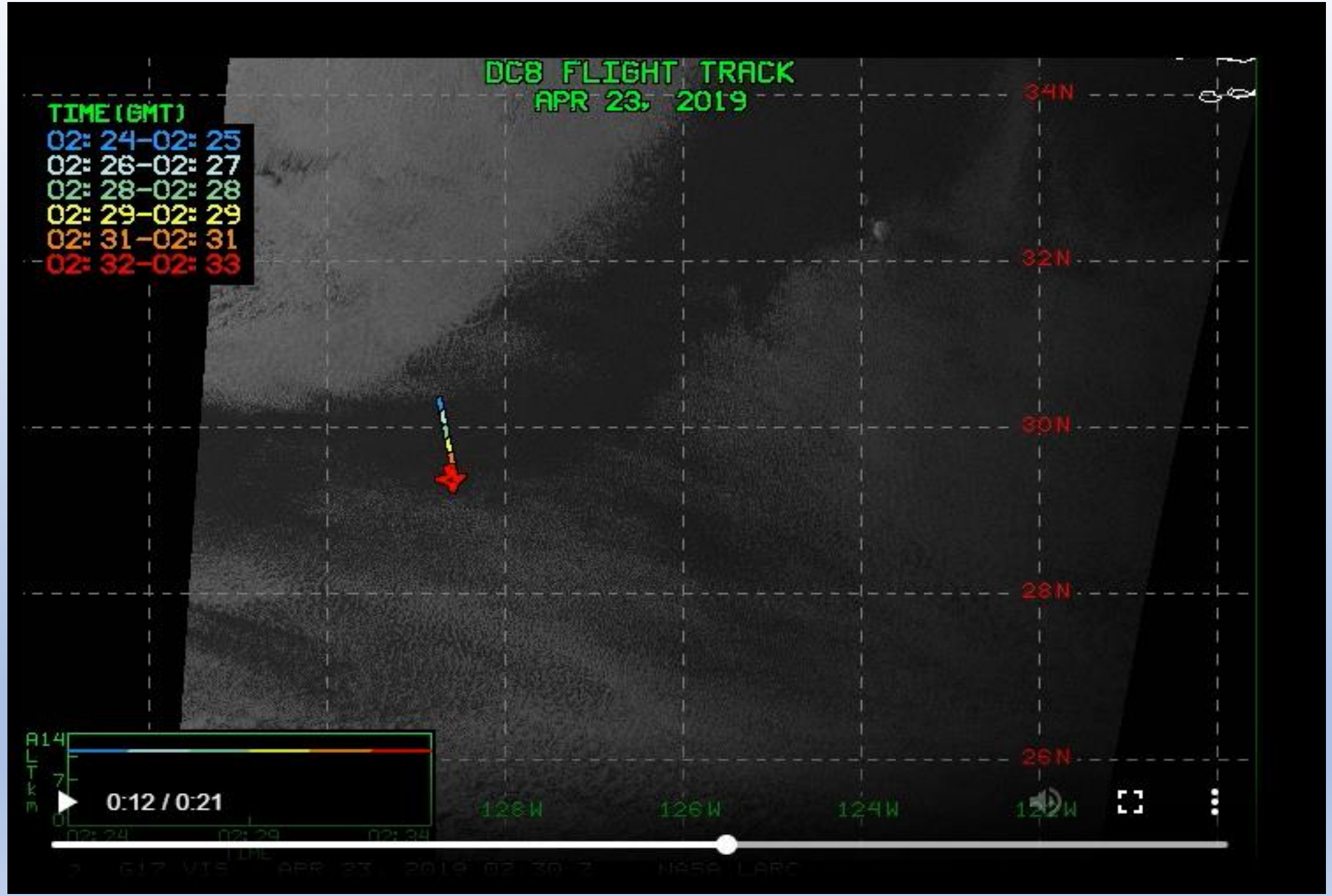
1) AEOLUS S-N 02:28 - 02:29Z
2) DAWN N-S 02:06 – 02:53Z(~ 600 km)
3) DAWN profiles from 5 Looks computed every ~5km (119 profiles)
4) 7 AEOLUS profiles along DAWN under-flight track
    - Rayleigh Clear (21-24 winds used)
    - Mie Cloudy (1-4 winds used)

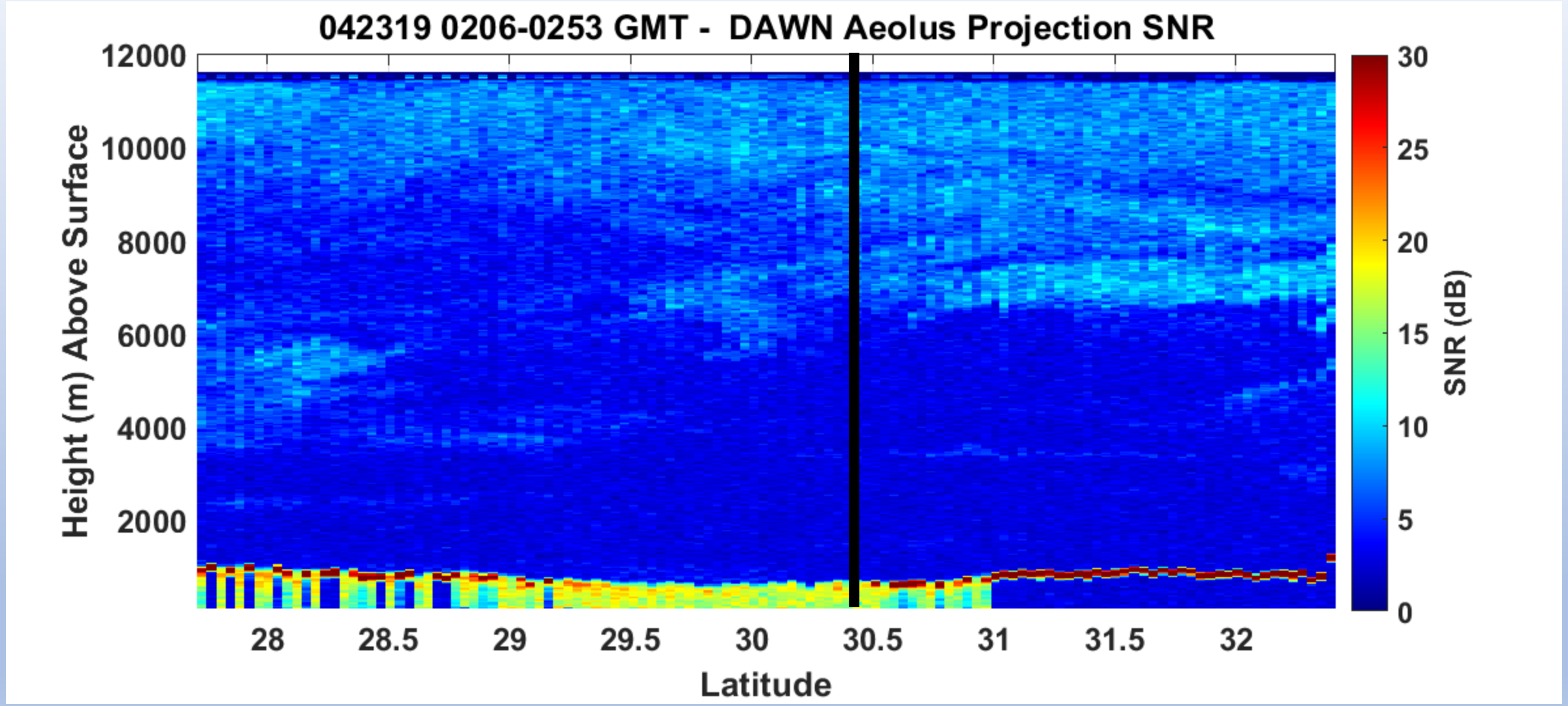
4) DAWN Aeolus projection HLOS shown for 123 DAWN profiles along DAWN underflight

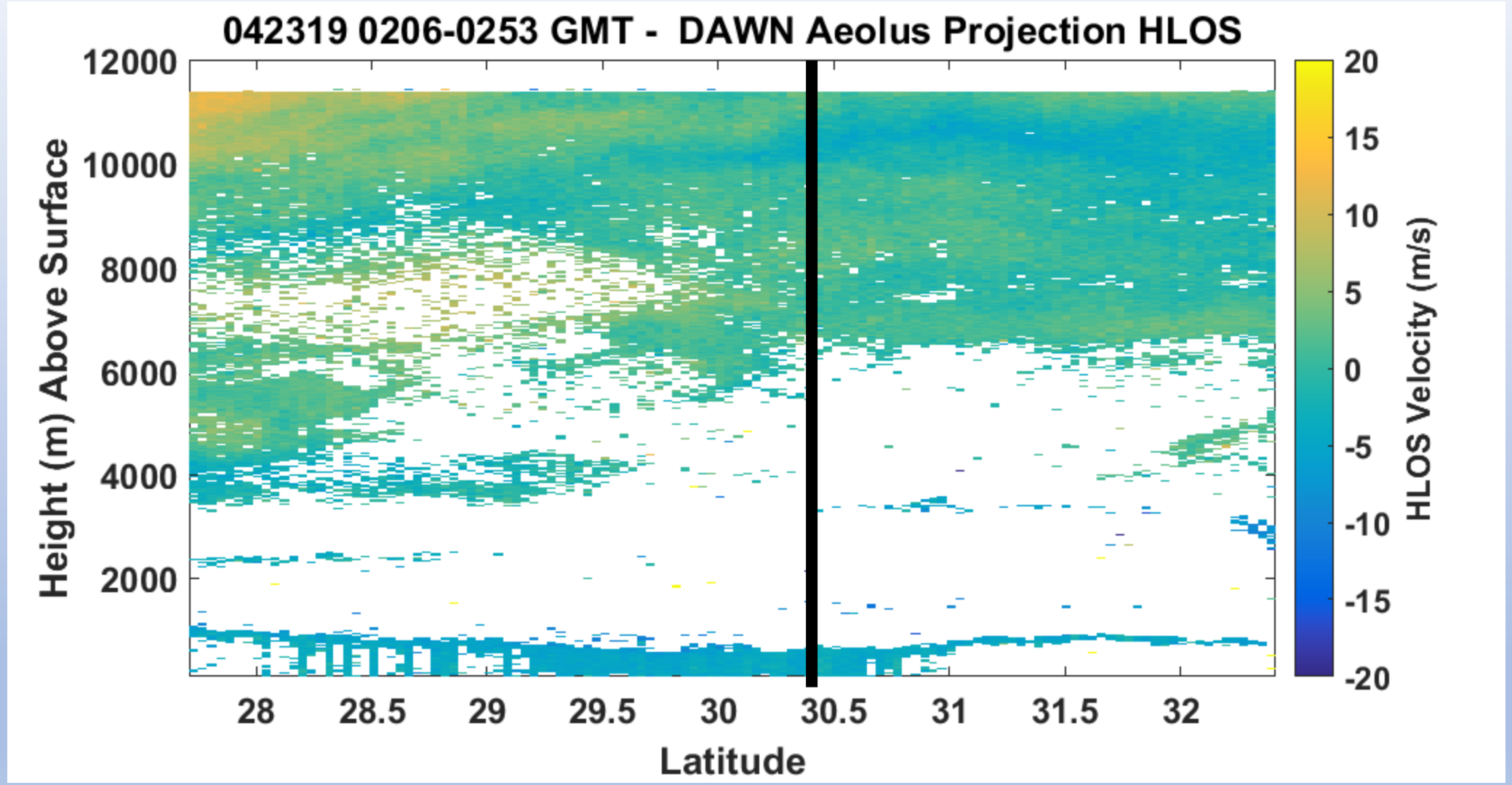
5) 7 DAWN “Integrated” profiles each utilizing 17 individual DAWN profiles

6) Individual comparisons between AEOLUS profile and closest individual DAWN profile

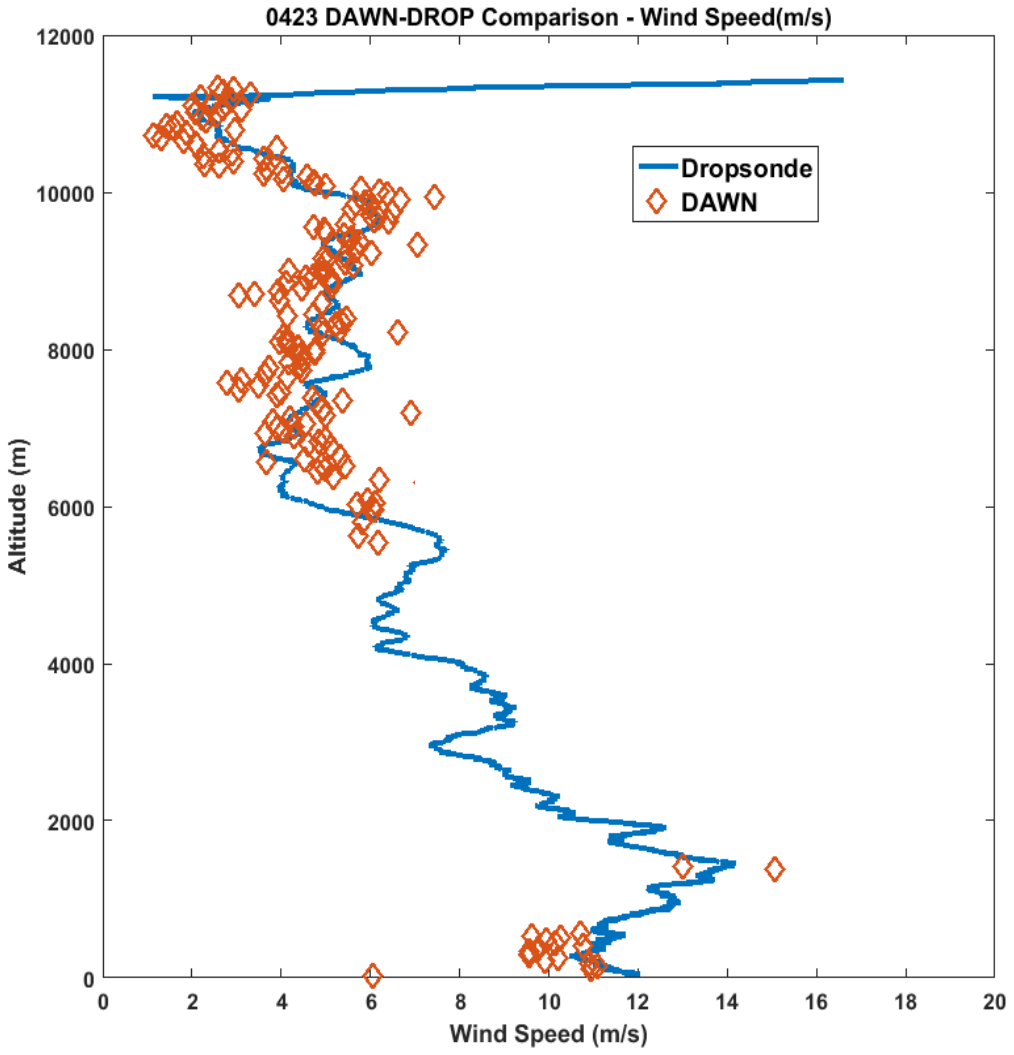

Los Angeles
San Diego
Baja California
Google Earth
© 2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
© 2018 INEGI
N
500 km

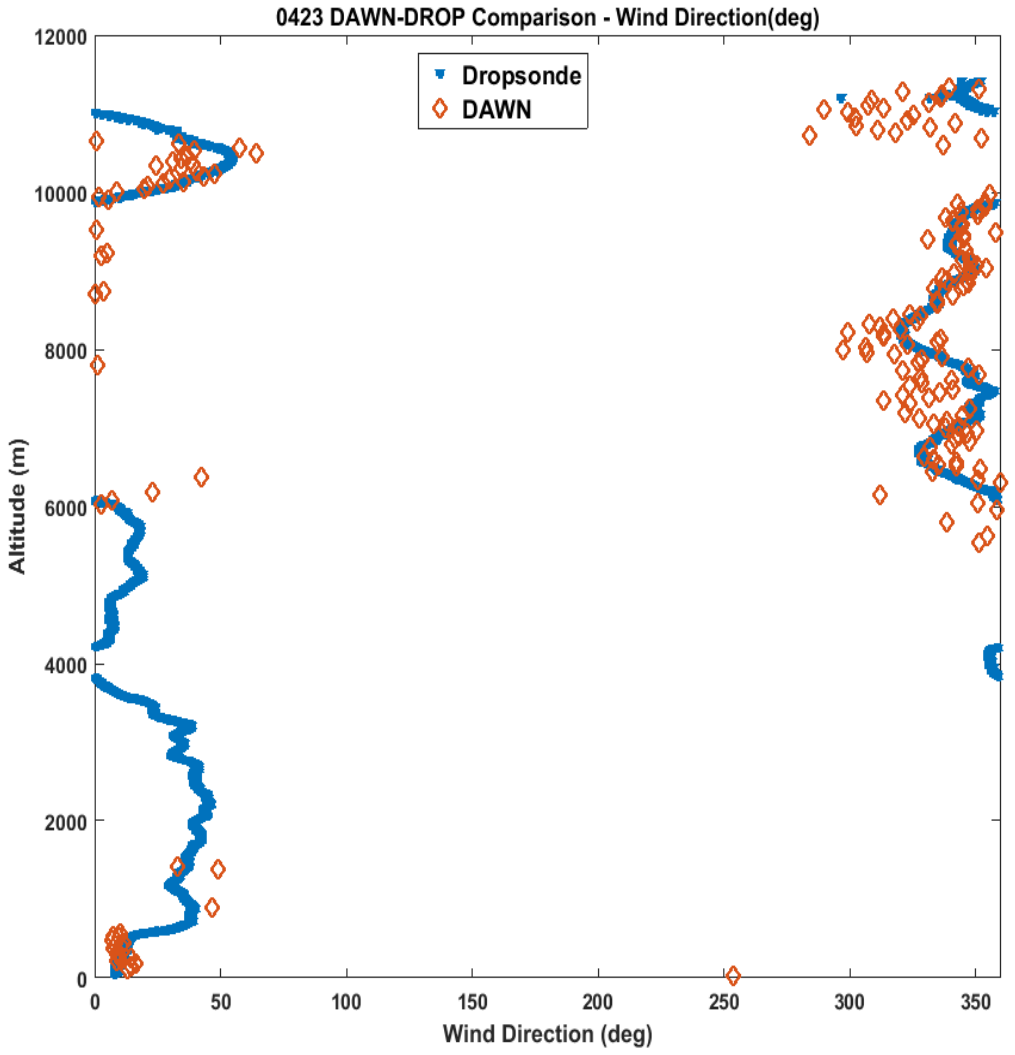

DC8 FLIGHT TRACK
APR 23, 2019
TIME(GMT)
02:24-02:25
02:26-02:27
02:28-02:28
02:29-02:29
02:31-02:31
02:32-02:33
34N
32N
30N
28N
26N
128W
126W
124W
122W
A14
ALT km
0:12 / 0:21

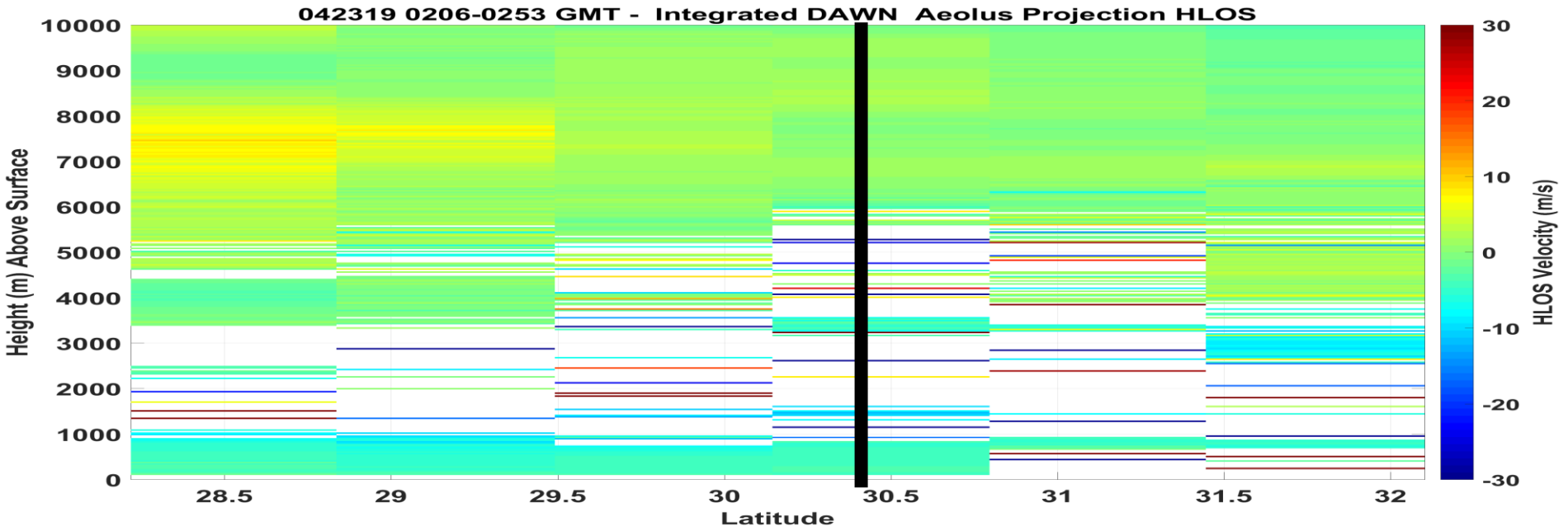

042319 0206-0253 GMT - DAWN Aeolus Projection SNR
Height (m) Above Surface
12000
10000
8000
6000
4000
2000
28
28.5
29
29.5
30
30.5
31
31.5
32
Latitude
30
25
20
15
10
5
0
SNR (dB)

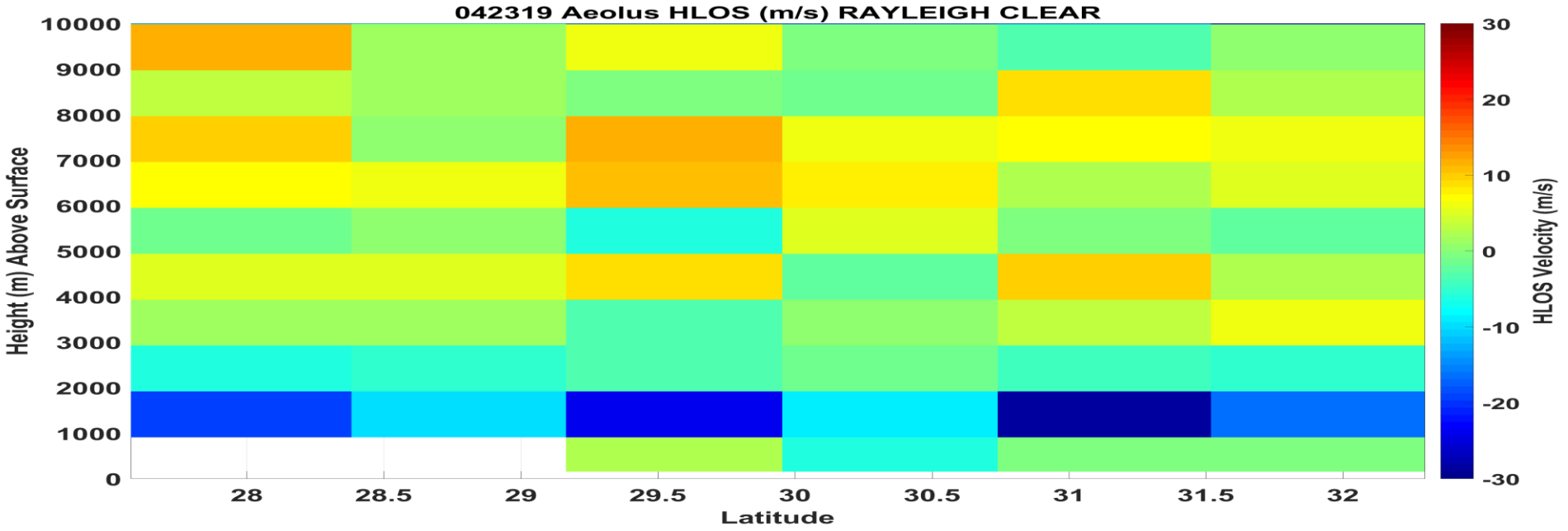

042319 0206-0253 GMT - DAWN Aeolus Projection HLOS
Height (m) Above Surface
12000
10000
8000
6000
4000
2000
28
28.5
29
29.5
30
30.5
31
31.5
32
Latitude
20
15
10
5
0
-5
-10
-15
-20
HLOS Velocity (m/s)

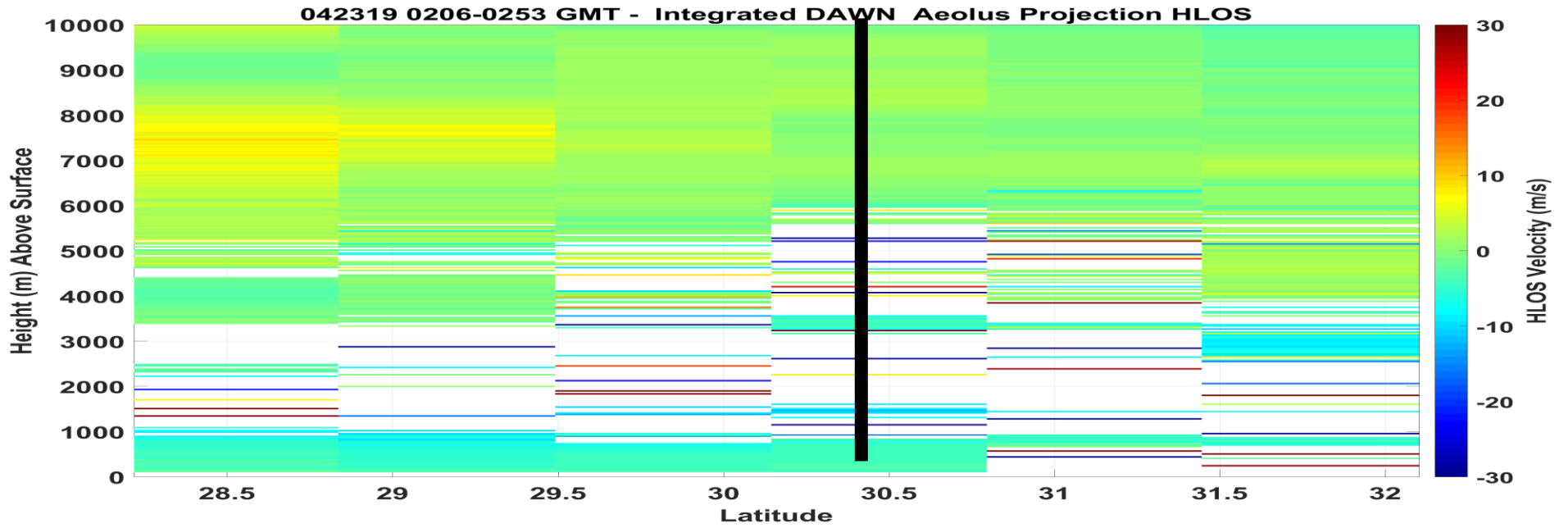
DAWN-DROP COMPARISON
MIDDLE OF UNDERFLIGHT

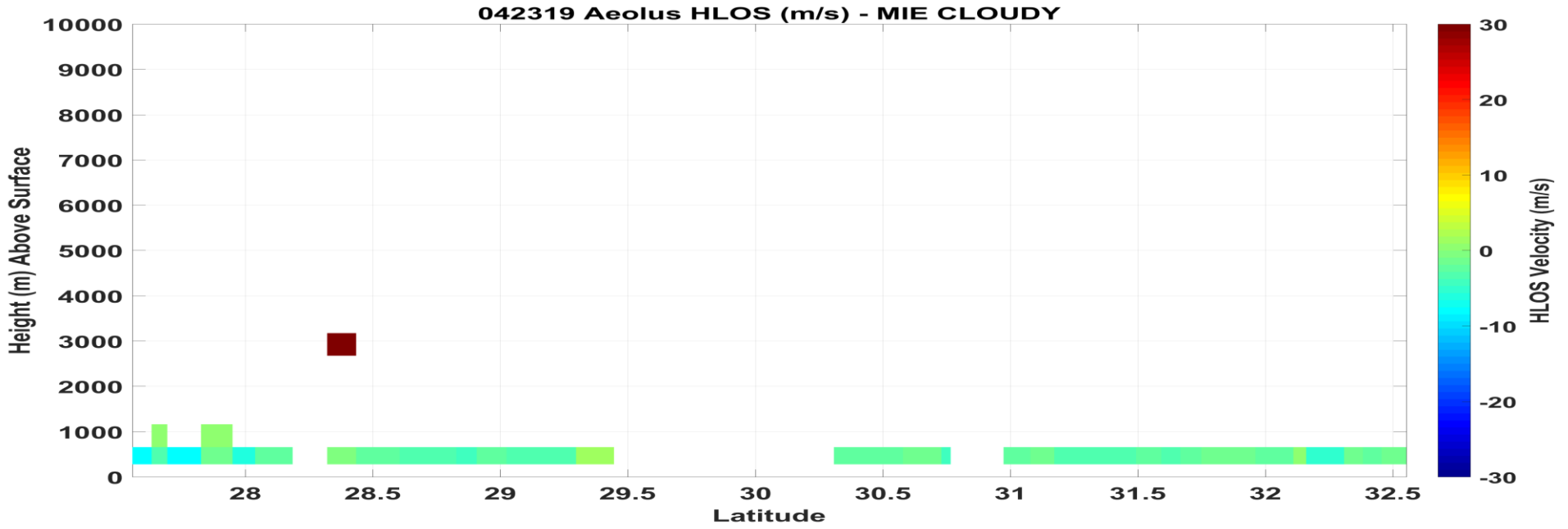

0423 DAWN-DROP Comparison - Wind Speed(m/s)
Dropsonde
DAWN
Altitude (m)
Wind Speed (m/s)
0
2000
4000
6000
8000
10000
12000
0
2
4
6
8
10
12
14
16
18
20


0423 DAWN-DROP Comparison - Wind Direction(deg)
Dropsonde
DAWN
Altitude (m)
Wind Direction (deg)
0
2000
4000
6000
8000
10000
12000
0
50
100
150
200
250
300
350

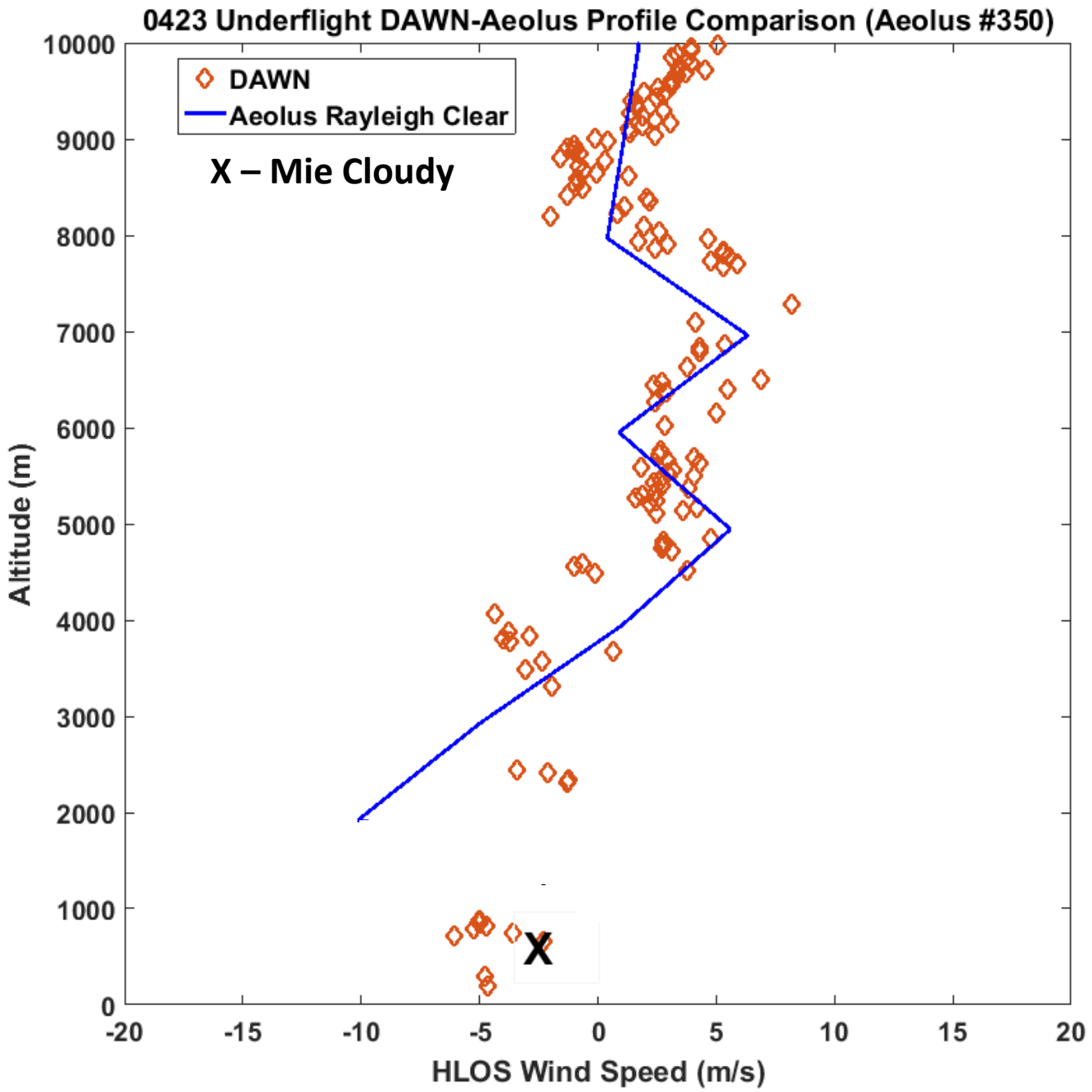

042319 0206-0253 GMT - Integrated DAWN Aeolus Projection HLOS
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
28.5
29
29.5
30
30.5
31
31.5
32
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30


042319 Aeolus HLOS (m/s) RAYLEIGH CLEAR
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
28
28.5
29
29.5
30
30.5
31
31.5
32
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30

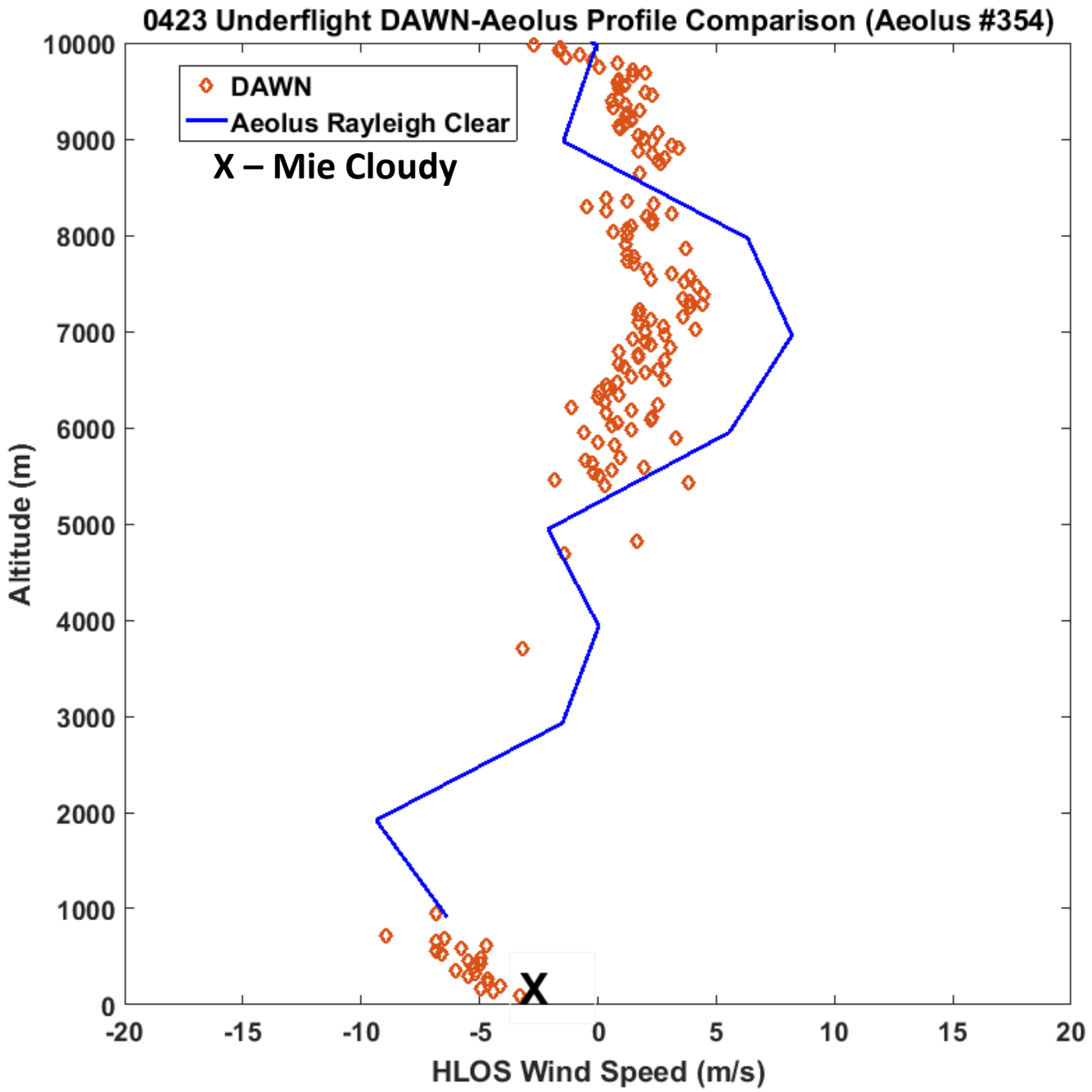

042319 0206-0253 GMT - Integrated DAWN Aeolus Projection HLOS
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
28.5
29
29.5
30
30.5
31
31.5
32
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30


042319 Aeolus HLOS (m/s) - MIE CLOUDY
Height (m) Above Surface
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
28
28.5
29
29.5
30
30.5
31
31.5
32
32.5
Latitude
HLOS Velocity (m/s)
30
20
10
0
-10
-20
-30

INDIVIDUAL PROFILE COMPARISONS

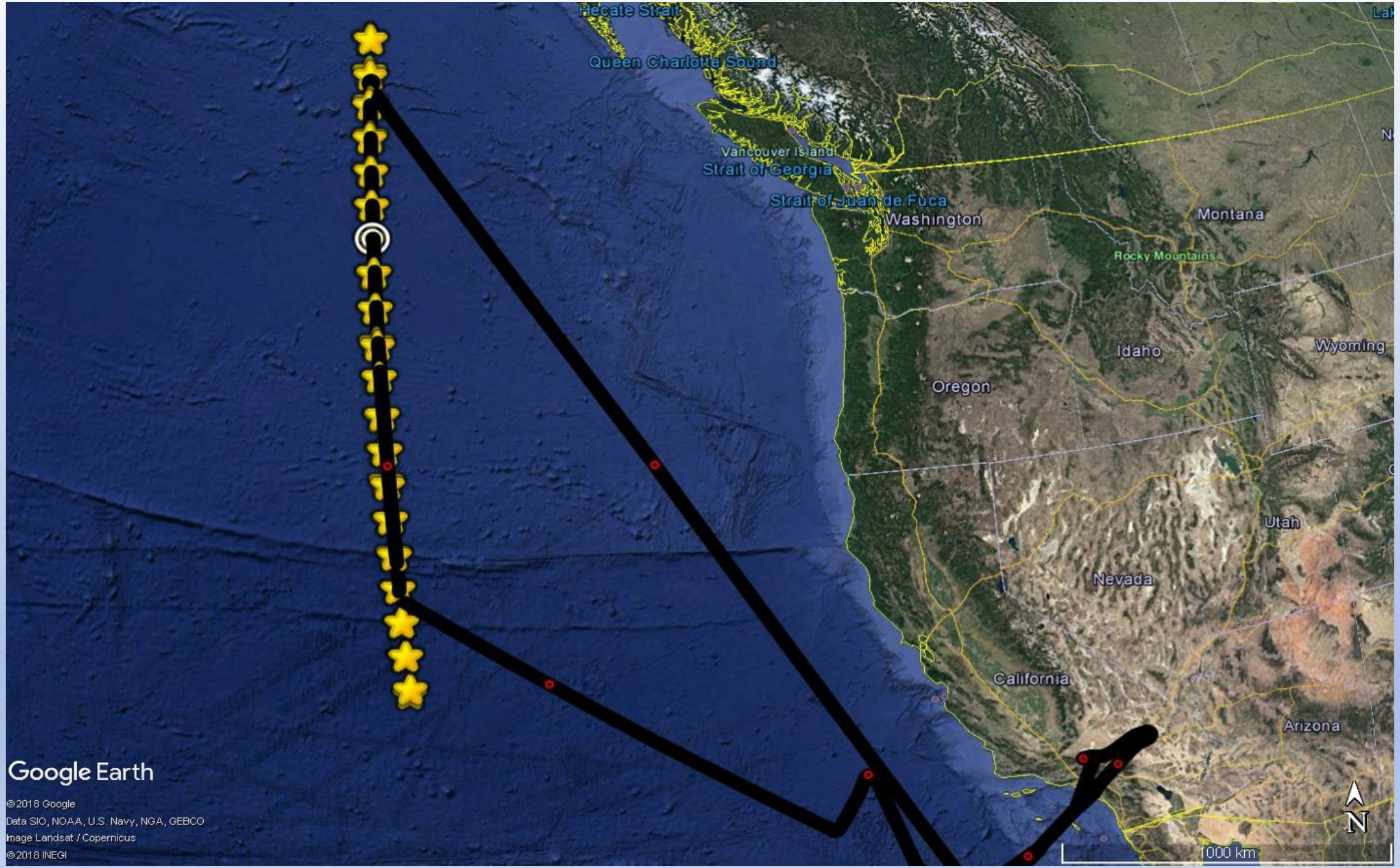

0423 Underflight DAWN-Aeolus Profile Comparison (Aeolus #350)
DAWN
Aeolus Rayleigh Clear
X – Mie Cloudy
X
Altitude (m)
HLOS Wind Speed (m/s)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-20
-15
-10
-5
0
5
10
15
20

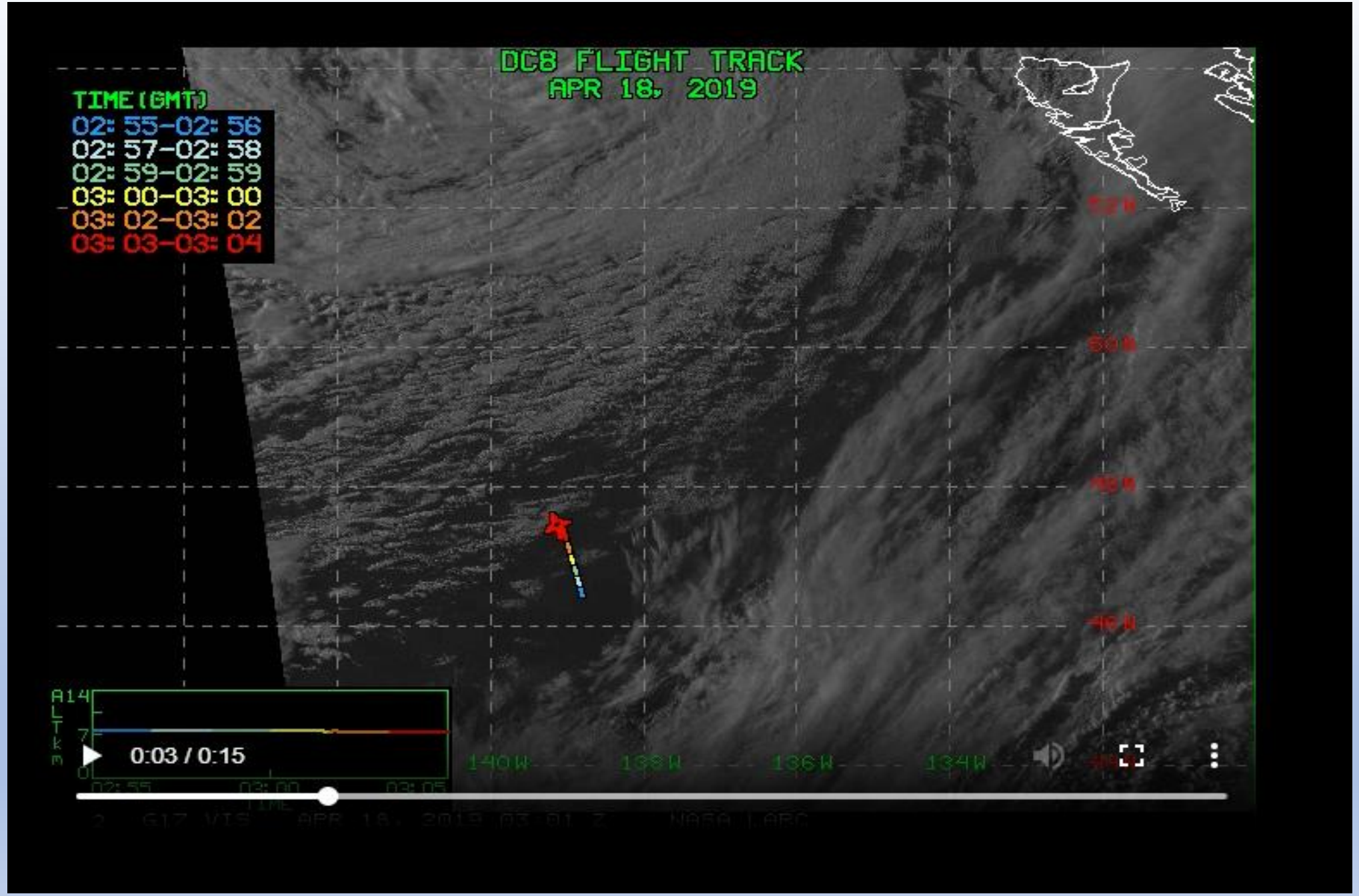
AEOLUS DIRECTLY OVERHEAD

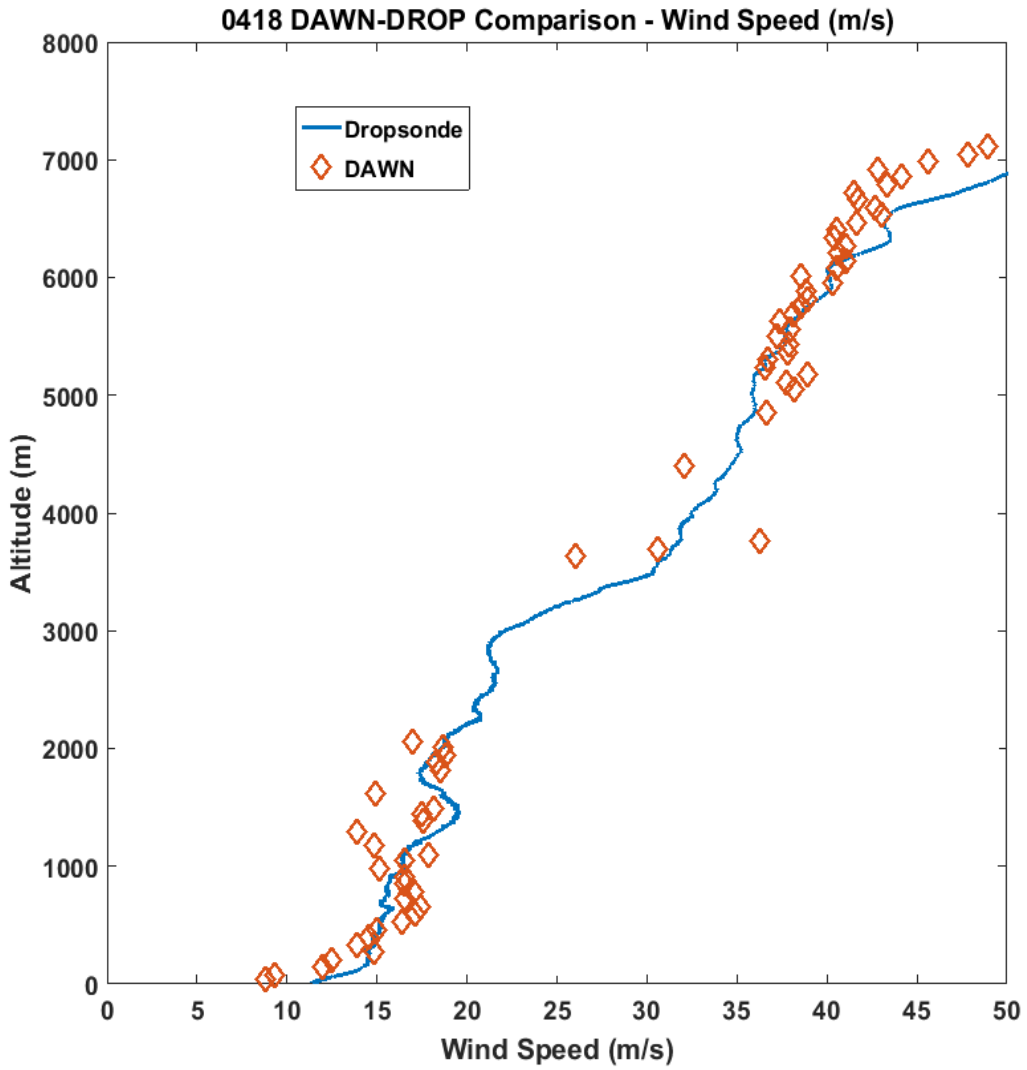


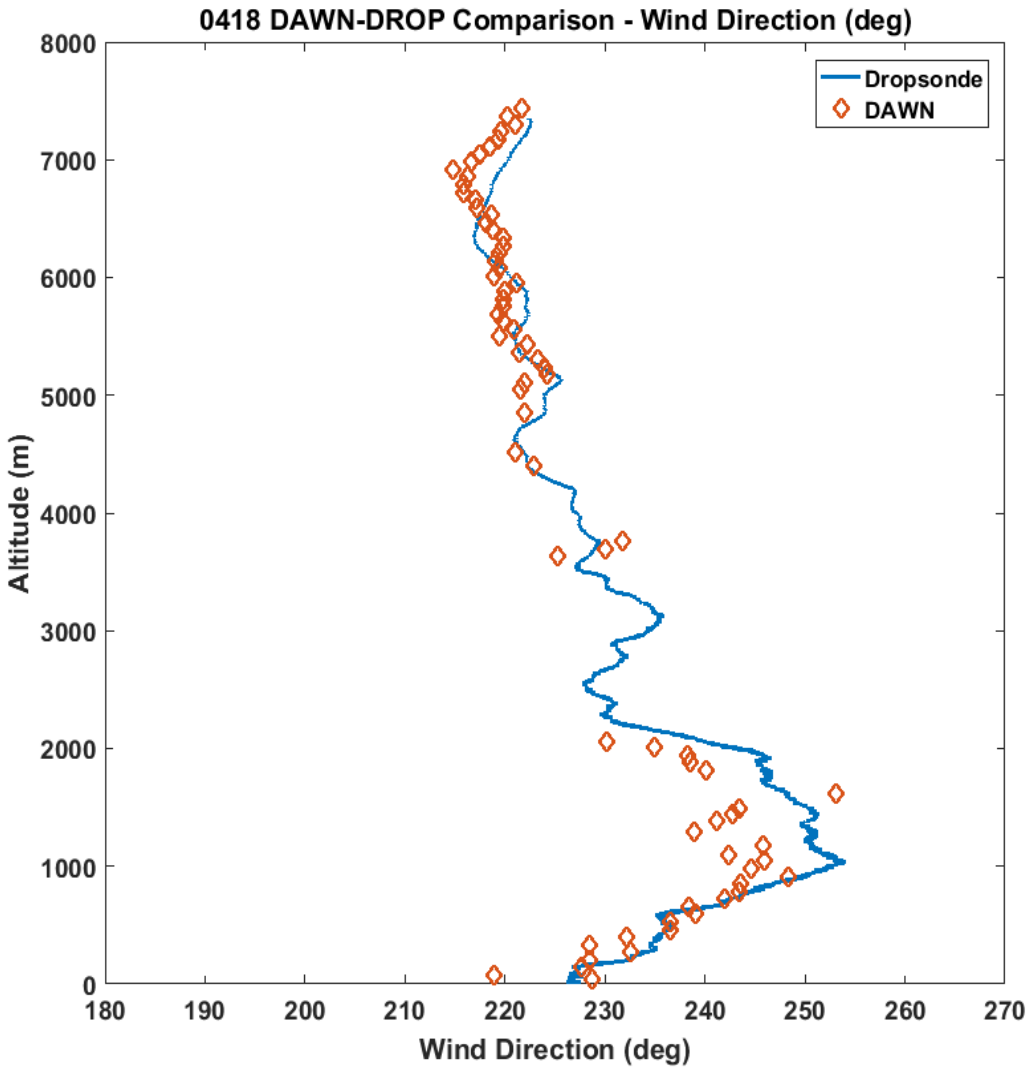
0418 DAWN-AEOLUS HLOS COMPARSIONS

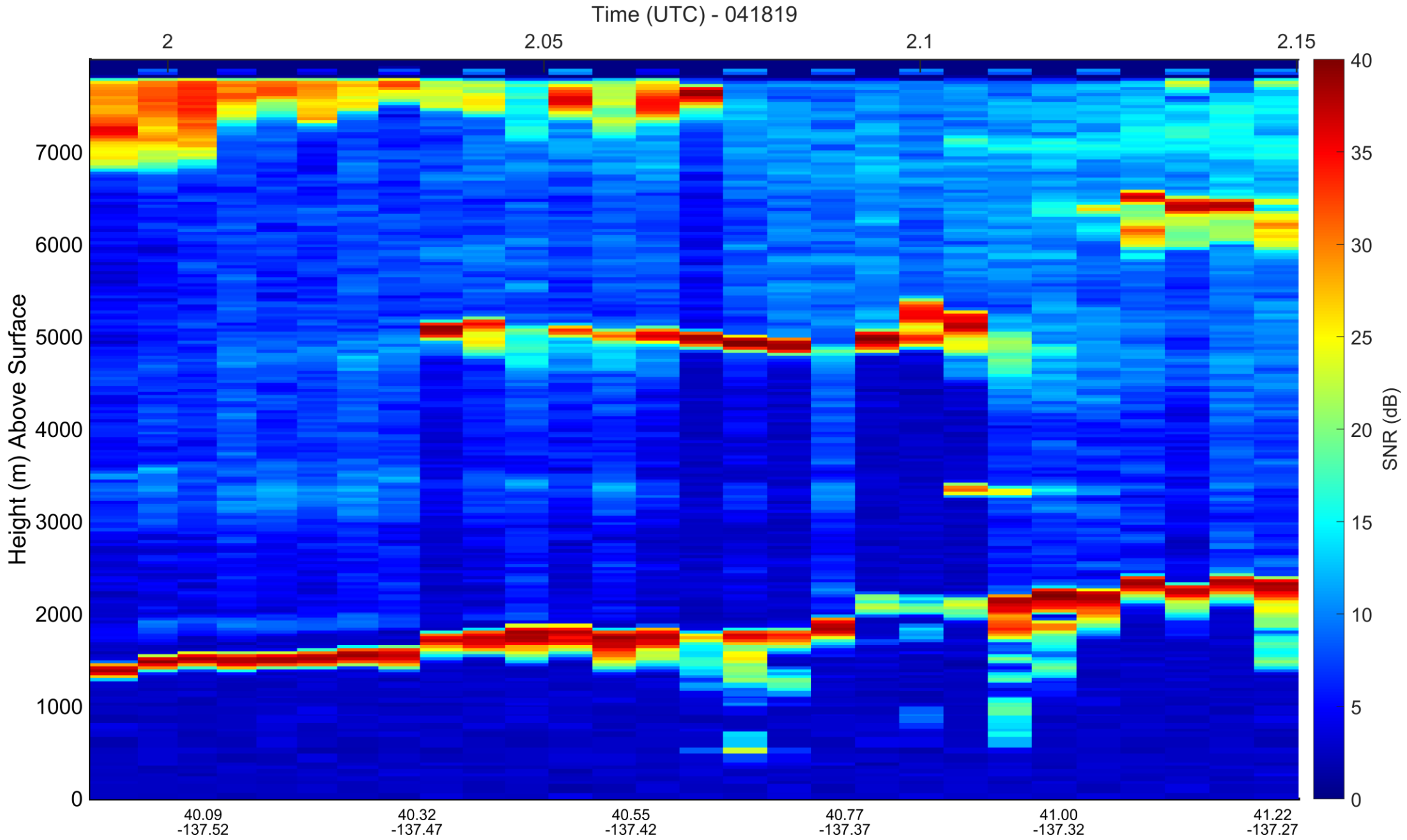
1) AEOLUS S-N 02:56 - 03:00Z
2) DAWN N-S 01:51 – 03:32Z
3) 7 AEOLUS profiles along DAWN under-flight track
    - Rayleigh Clear (21-24 winds)
    - Mie Cloudy (1-4 winds)
4) DAWN mostly operated in STARE (1 Look) mode, only small portion of underflight where full profiles measured
5) DAWN SNR and Aeolus projection HLOS shown for 30 DAWN profiles along DAWN under-flight (but other short segments of 2-4 scans/profiles)
6) Individual comparisons between AEOLUS profile and closest individual DAWN profile

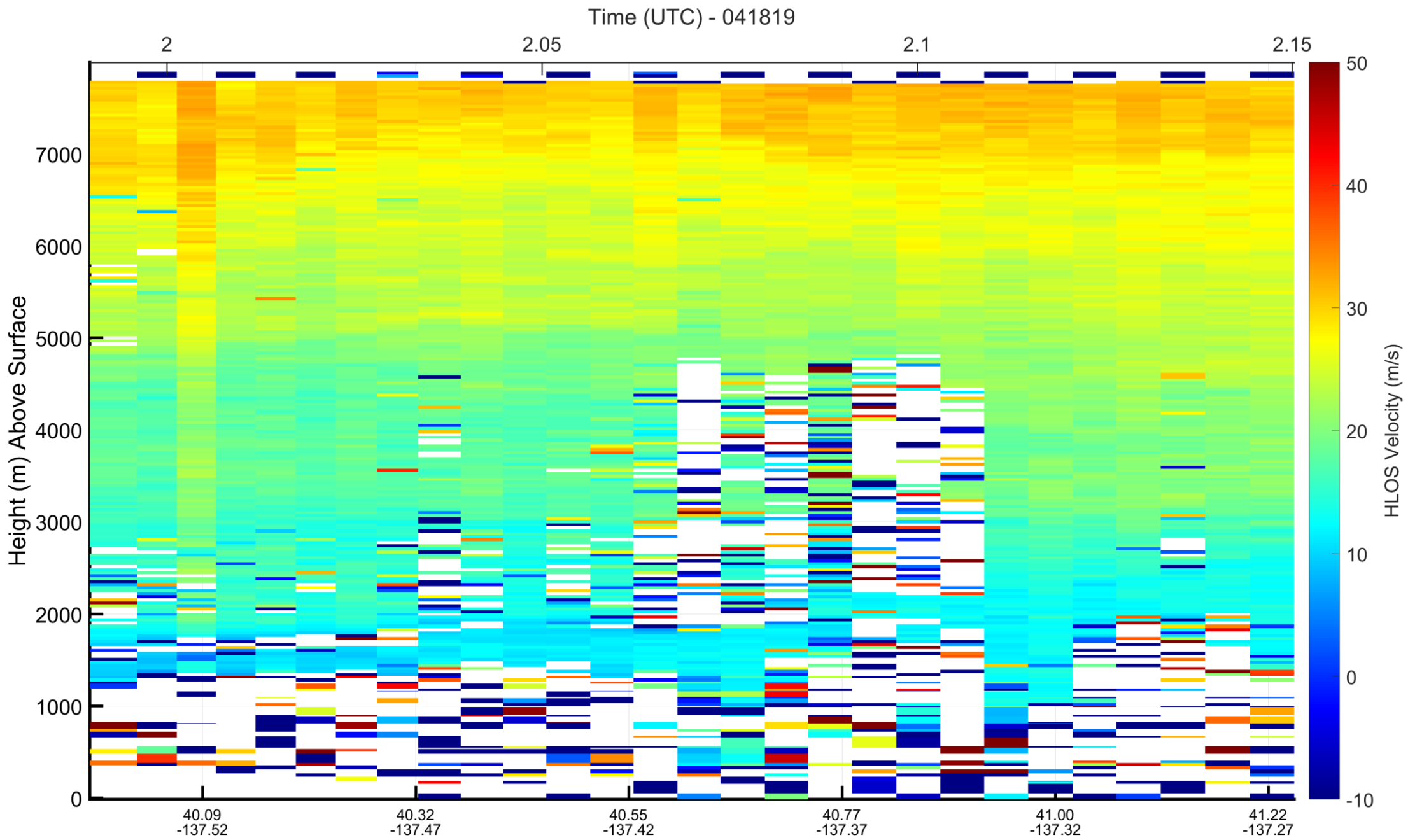

Hecate Strait
Queen Charlotte Sound
Vancouver Island
Strait of Georgia
Strait of Juan de Fuca
Washington
Montana
Rocky Mountains
Idaho
Wyoming
Oregon
Utah
Nevada
California
Arizona
Google Earth
©2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
©2018 INEGI
N
1000 km

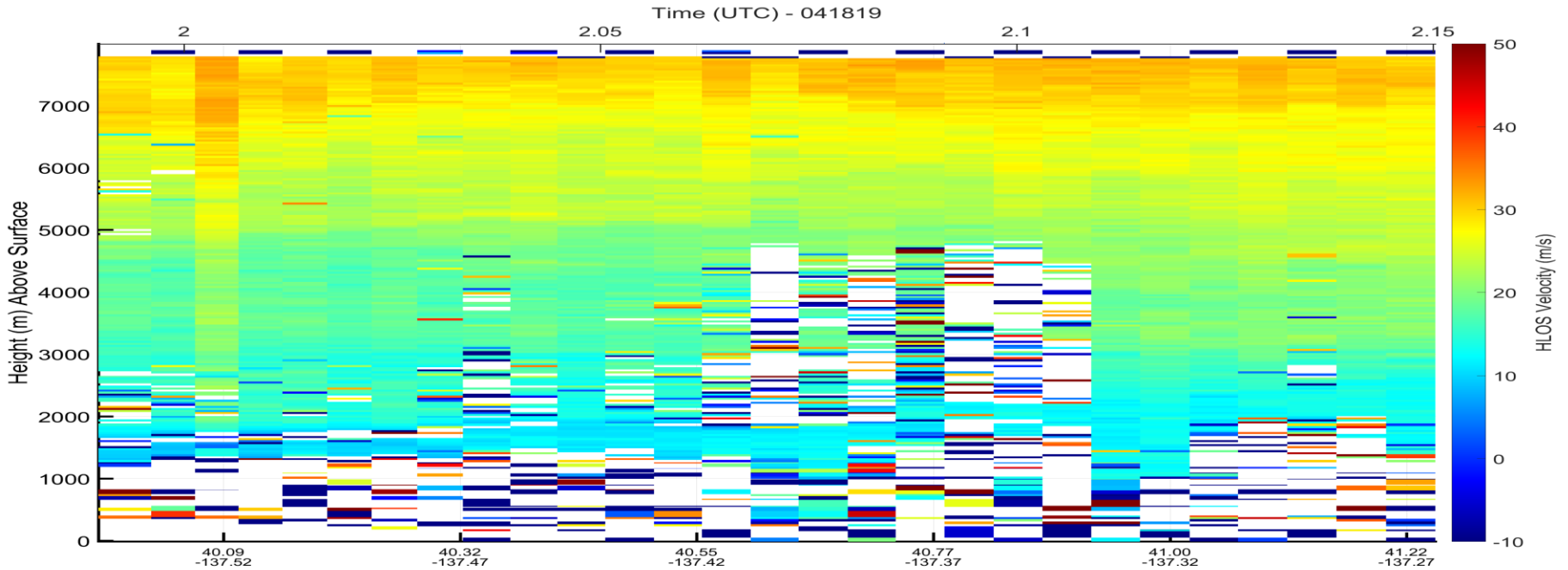

DC8 FLIGHT TRACK
APR 18, 2019
TIME(GMT)
02:55-02:56
02:57-02:58
02:59-02:59
03:00-03:00
03:02-03:02
03:03-03:04
140W
138W
136W
134W
A14
ALTkm
0:03 / 0:15

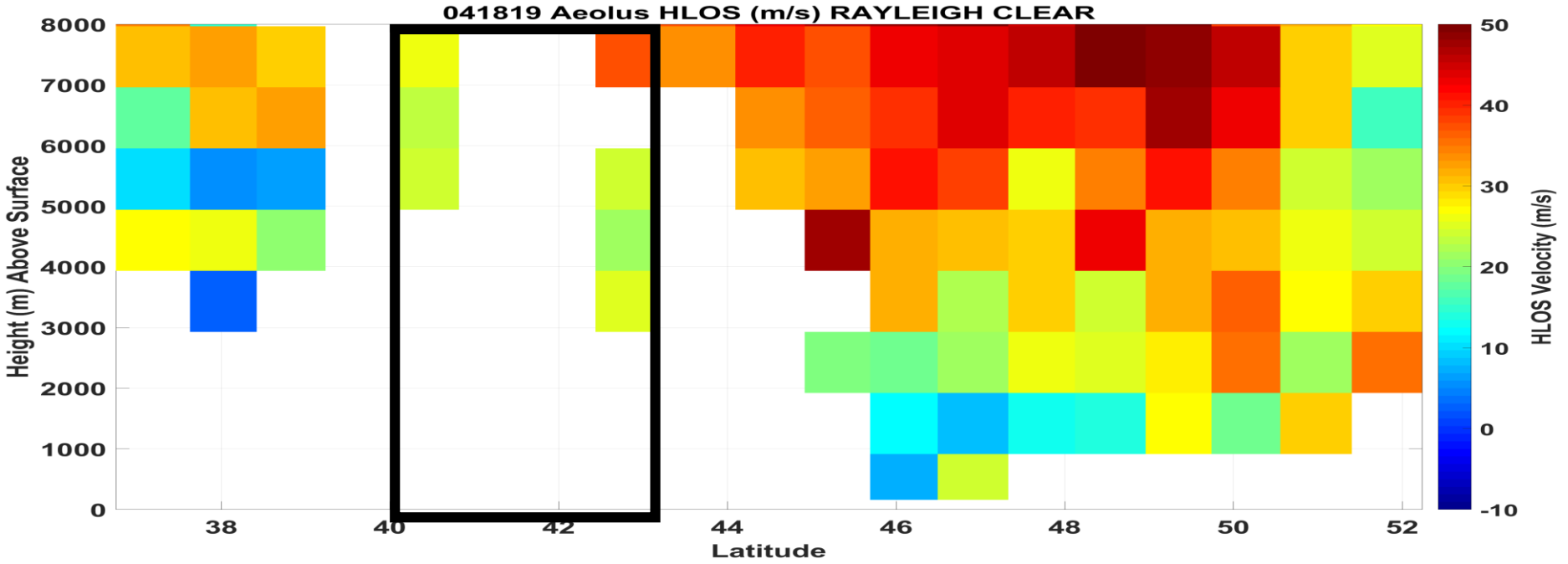

0418 DAWN-DROP Comparison - Wind Speed (m/s)
Dropsonde
DAWN
Altitude (m)
Wind Speed (m/s)
0
1000
2000
3000
4000
5000
6000
7000
8000
0
5
10
15
20
25
30
35
40
45
50

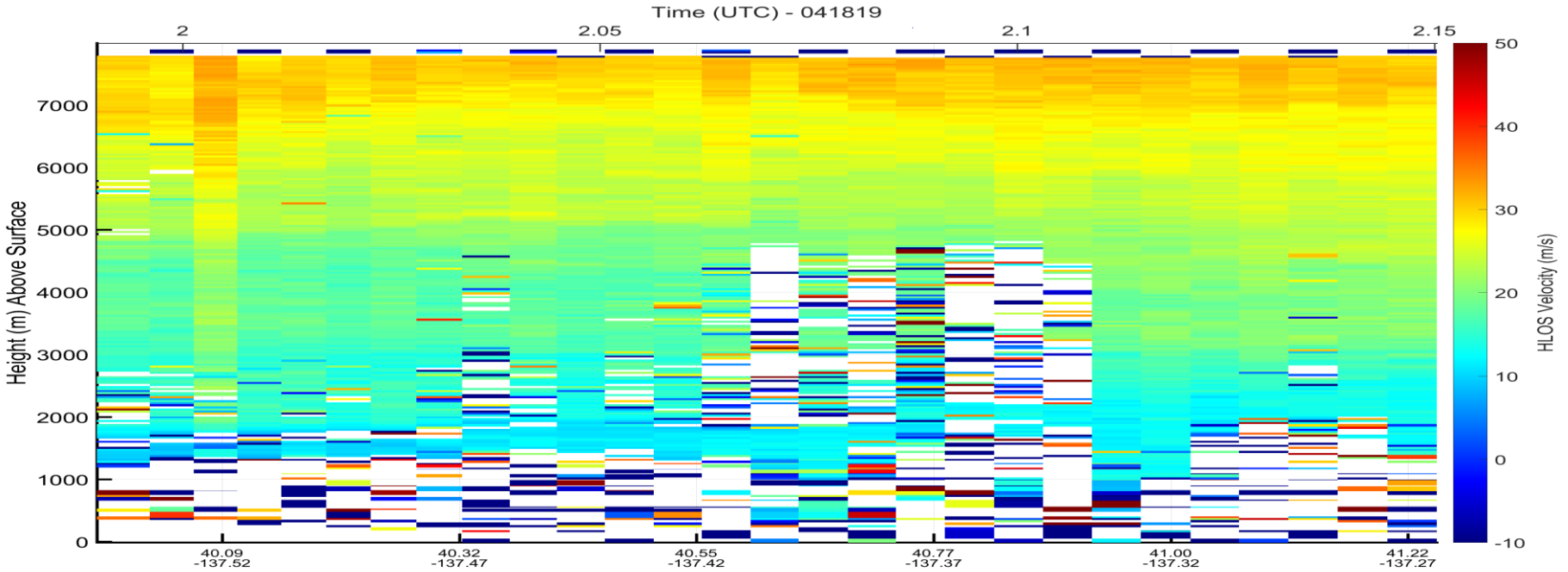

0418 DAWN-DROP Comparison - Wind Direction (deg)
Dropsonde
DAWN
Altitude (m)
Wind Direction (deg)
0
1000
2000
3000
4000
5000
6000
7000
8000
180
190
200
210
220
230
240
250
260
270

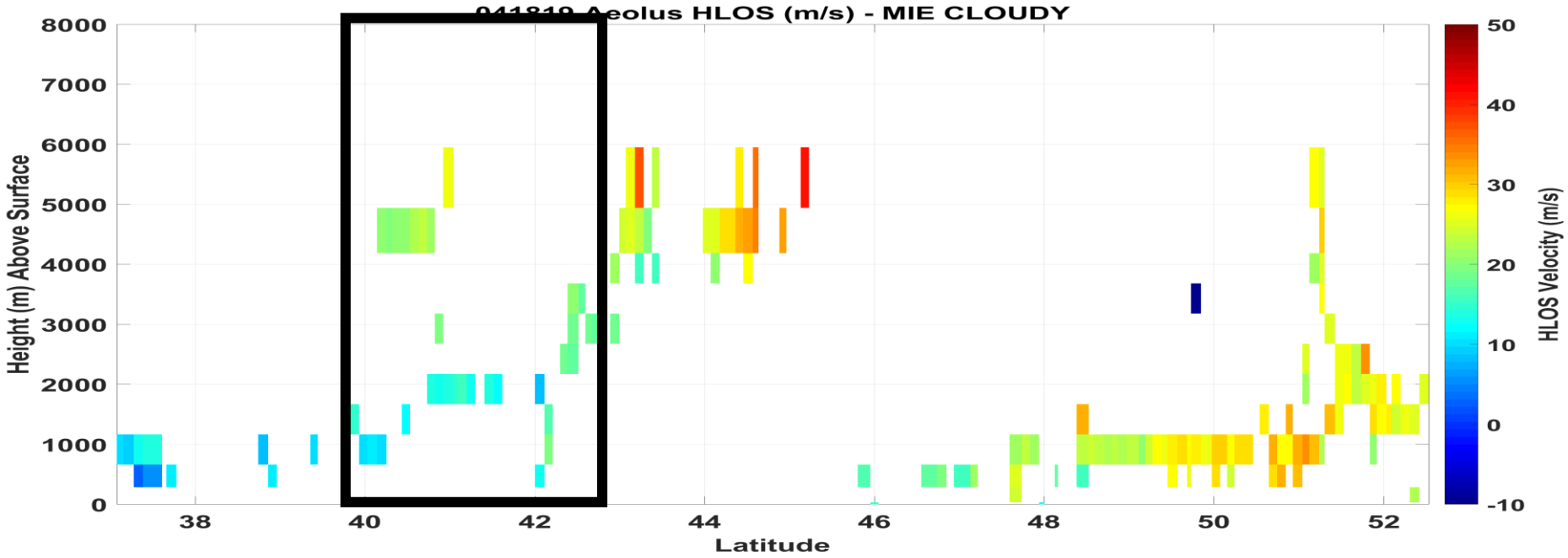

Time (UTC) - 041819
2
2.05
2.1
2.15
Height (m) Above Surface
0
1000
2000
3000
4000
5000
6000
7000
40.09
-137.52
40.32
-137.47
40.55
-137.42
40.77
-137.37
41.00
-137.32
41.22
-137.27
SNR (dB)
0
5
10
15
20
25
30
35
40


Time (UTC) - 041819
2
2.05
2.1
2.15
Height (m) Above Surface
0
1000
2000
3000
4000
5000
6000
7000
40.09
-137.52
40.32
-137.47
40.55
-137.42
40.77
-137.37
41.00
-137.32
41.22
-137.27
HLOS Velocity (m/s)
50
40
30
20
10
0
-10


Time (UTC) - 041819
2
2.05
2.1
2.15
Height (m) Above Surface
0
1000
2000
3000
4000
5000
6000
7000
40.09
-137.52
40.32
-137.47
40.55
-137.42
40.77
-137.37
41.00
-137.32
41.22
-137.27
HLOS Velocity (m/s)
50
40
30
20
10
0
-10

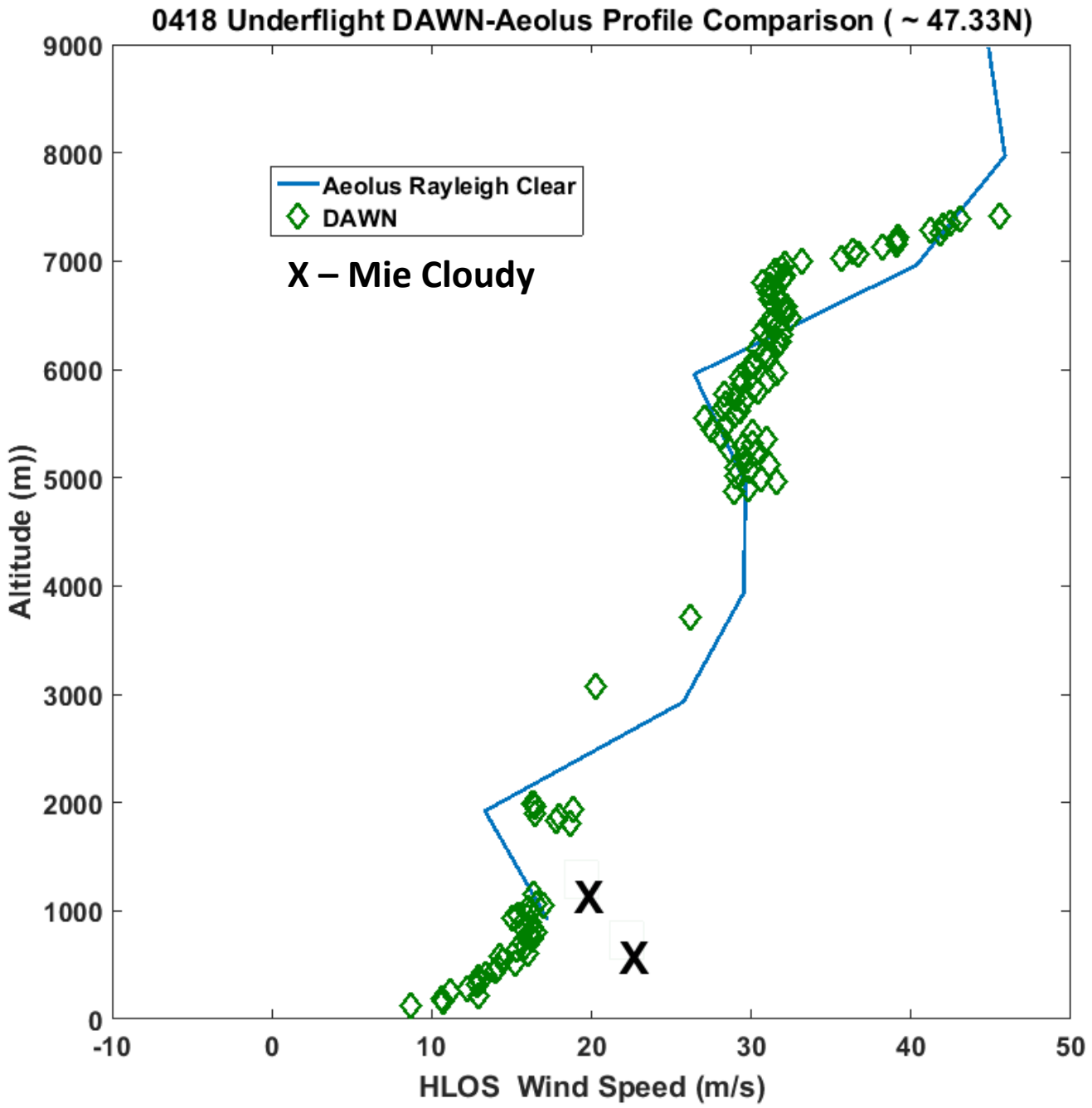

041819 Aeolus HLOS (m/s) RAYLEIGH CLEAR
Height (m) Above Surface
0
1000
2000
3000
4000
5000
6000
7000
8000
38
40
42
44
46
48
50
52
Latitude
HLOS Velocity (m/s)
50
40
30
20
10
0
-10

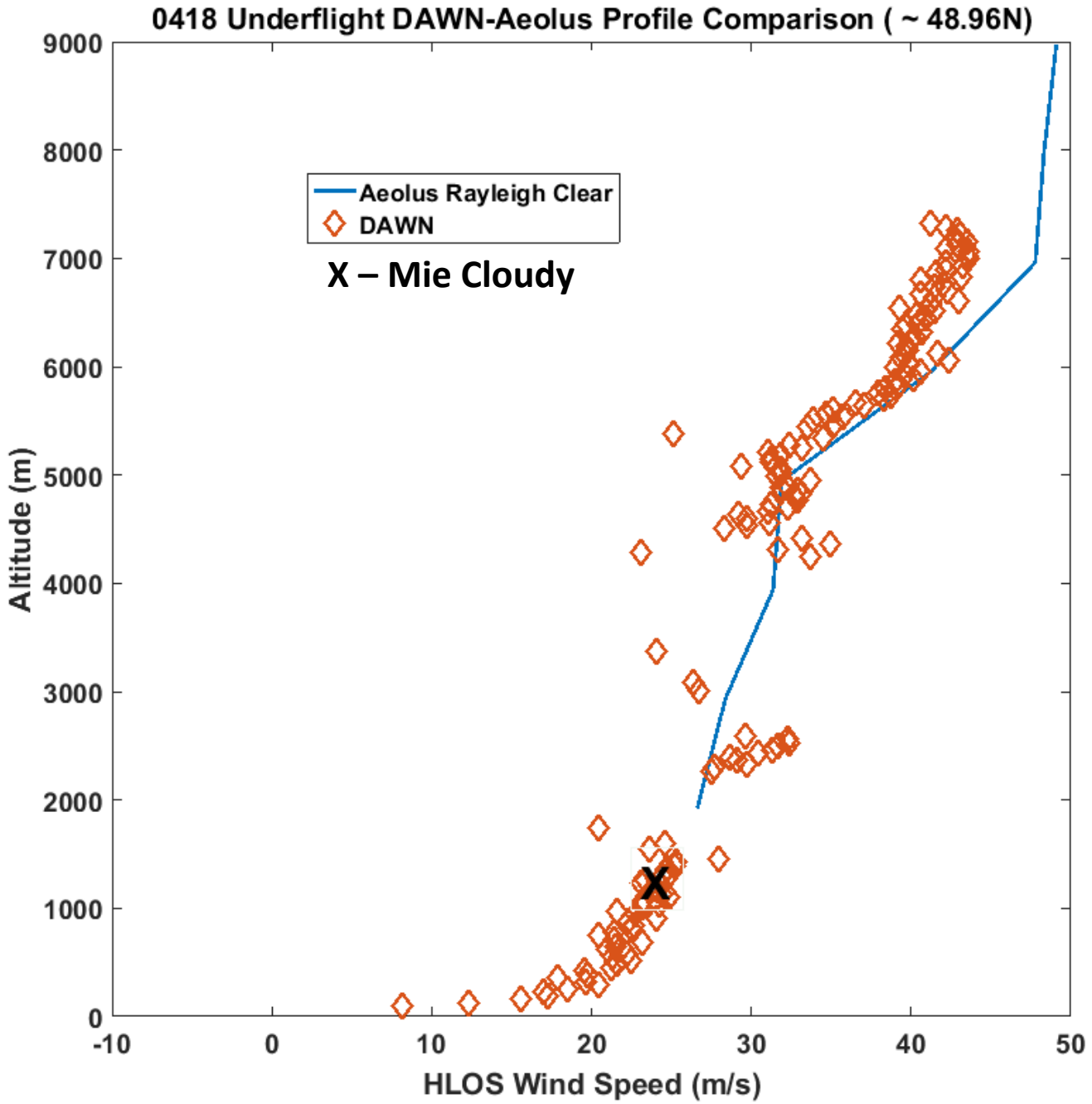

Time (UTC) - 041819
2
2.05
2.1
2.15
Height (m) Above Surface
0
1000
2000
3000
4000
5000
6000
7000
40.09
-137.52
40.32
-137.47
40.55
-137.42
40.77
-137.37
41.00
-137.32
41.22
-137.27
HLOS Velocity (m/s)
50
40
30
20
10
0
-10


041819 Aeolus HLOS (m/s) - MIE CLOUDY
Height (m) Above Surface
0
1000
2000
3000
4000
5000
6000
7000
8000
38
40
42
44
46
48
50
52
Latitude
HLOS Velocity (m/s)
50
40
30
20
10
0
-10

INDIVIDUAL PROFILE COMPARISONS

AEOLUS DIRECTLY OVERHEAD




0418 Underflight DAWN-Aeolus Profile Comparison (~ 48.96N)
Aeolus Rayleigh Clear
DAWN
X – Mie Cloudy
Altitude (m)
HLOS Wind Speed (m/s)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-10
0
10
20
30
40
50

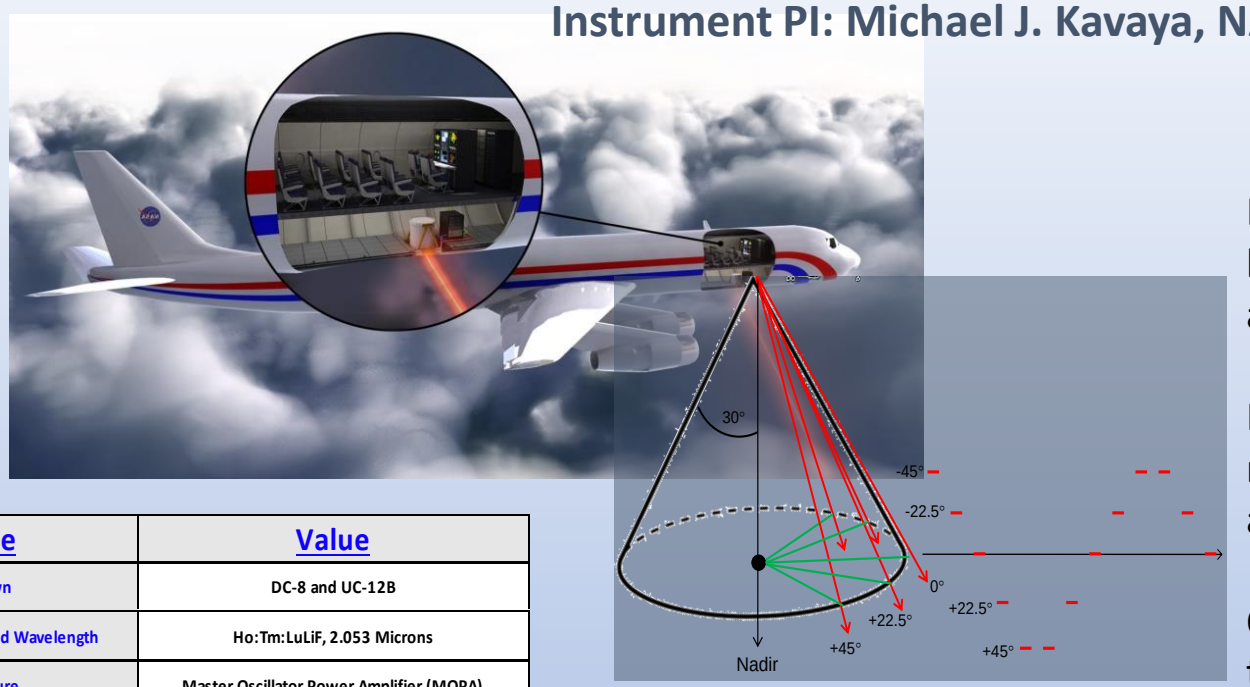
Summary

- Preliminary comparisons
  - Neither data set final
  - More experience needed working with Aeolus products
- DAWN performed well in relatively clean/low aerosol and low to partly cloud conditions
  - Comparison with Dropsondes
  - Often complete profiles
- Even with weakened laser in April 2019, very encouraging comparisons between DAWN and Aeolus
  - RAYLEIGH Clear
- More work to follow

ADDITIONAL SLIDES

Doppler Aerosol Wind (DAWN) Lidar System

Instrument PI: Michael J. Kavaya, NASA LaRC



Attribute	Value
Airplanes Flown	DC-8 and UC-12B
Solid-State Laser Crystal and Wavelength	Ho:Tm:LuLiF, 2.053 Microns
Laser Architecture	Master Oscillator Power Amplifier (MOPA)
Pumping Source, Wavelength, Duration	Laser Diode Arrays (LDA), 792 nm, 1 ms
Laser Pulse Energy E, Rate f, FWHM Duration t	100 mJ, 10 Hz, 180 ns
Telescope Diameter D, Magnification M	15 cm, 20
Light Detection Material, Technique	InGaAs, Coherent, Dual-Balanced
Scanner Diameter, Type, Deflection	15 cm, Step-Stare Rotating Wedge, 30° About Nadir
Eye Safety	Safe at any Range When DAWN Closed Up for Flight
Pointing Knowledge Technique	Dedicated INS/GPS on Lidar; dry land returns
LOS Wind Measurement Precision	< 1 m/s
Maximum LOS, Horizontal Wind	±80 m/s, ±160 m/s
Captured Data Length in Range, Altitude	0 – 16.4 km, 0 – 14.2 km
Vertical Resolution	133 m for 512-Sample Range Gate

DAWN Capabilities

High coherent Doppler lidar sensitivity to aerosol backscatter, enabling excellent vertical resolution, accuracy, and atmospheric coverage

Provides vertical profiles of horizontal wind vectors, LOS range wind and wind turbulence profiles, and relative aerosol backscatter profiles

Optional number of azimuth angles (up to 12) permits trade of wind variability determination vs. horizontal resolution

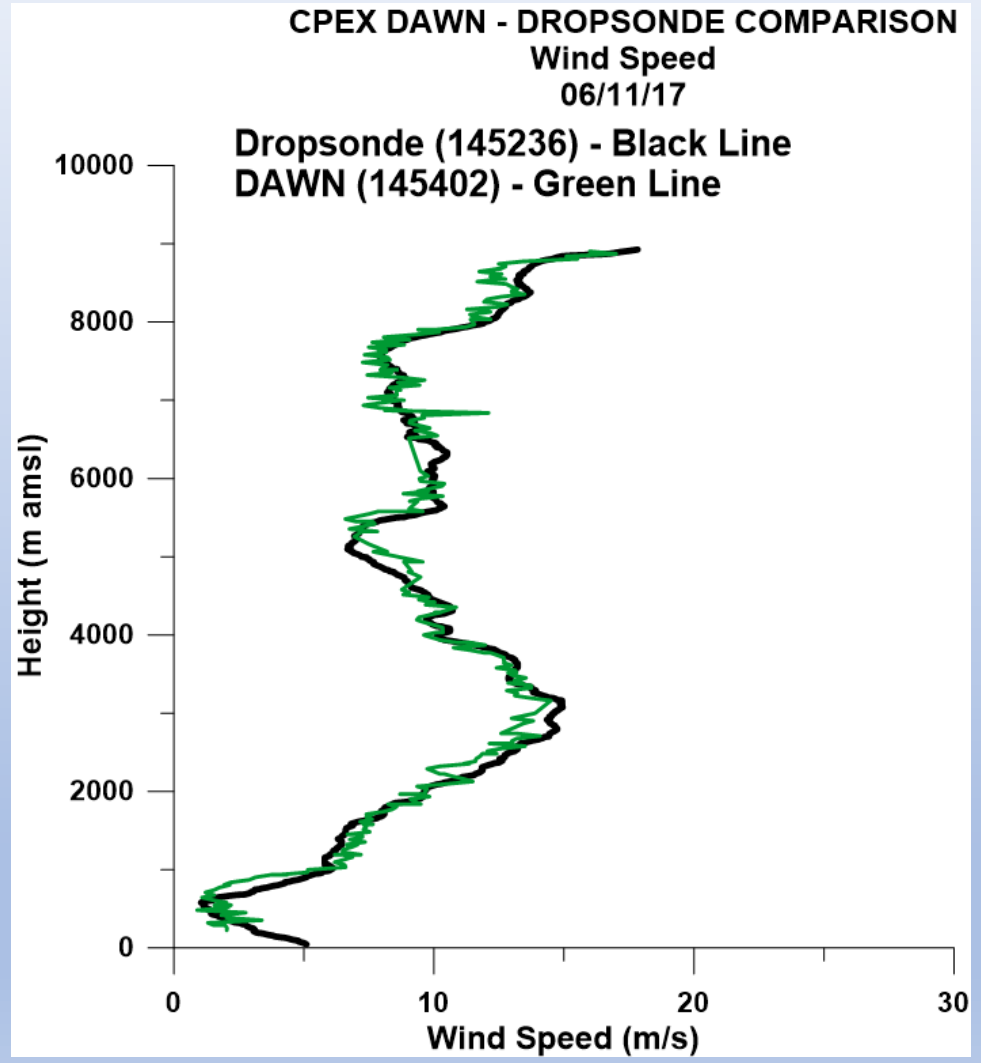
Optional number of laser shots averaged for each LOS wind profile permits trade of atmospheric coverage vs. horizontal resolution

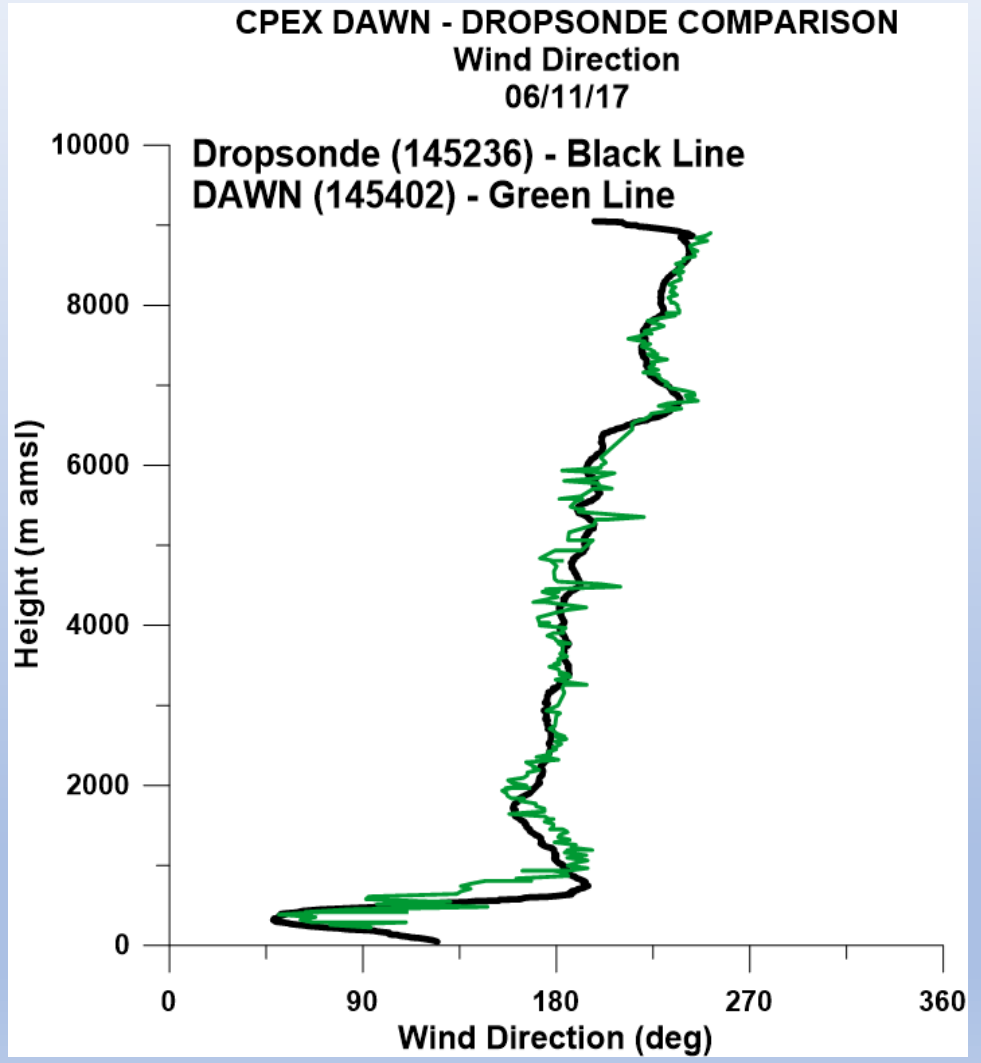
Data may be processed multiple ways to provide various combinations of vertical and horizontal resolution, atmospheric coverage, and expected accuracy statistics

Comparison setup

- Ground return calibration while over Florida peninsula
  - Straight and level between 3 and 4 km AGL
  - Perform calibration flight segment before and after an over-water mission clouds and time permitting.
  - Major changes in the DAWN system were made on June 17th.
  - Calibration products:
    - Pitch correction (~.5 degrees)
    - Yaw correction (~.5 degrees)
    - Roll correction (~ < .01 degrees)
    - Height correction (timing of outgoing pulse)
    - Unknowns folded into the pitch corrections (< .02 degrees)
  - No other corrections made to the DAWN data prior to dropsonde comparisons.
- 162 dropsondes over 14 flights were used in the comparisons (~15,000 height segments of ~ 66 meter DWL vertical resolution)
- Used only DAWN high resolution (66m processing gates and 33m display gates)

Example DAWN-Dropsonde comparison during CPEX 2017





Differences by height interval (km)

Height Interval	Number 37m seg	MEAN Z DIFF (m)	BIAS (m/s)	MEAN ABS(ΔWS)	ΔWS RMSD
0-3 km	4935	2.52	-0.02	0.95	1.26
3-6 km	2079	2.91	0.26	1.20	1.62
6-9 km	5774	3.32	0.27	1.14	1.58
9-12 km	2732	3.70	-0.20	1.38	1.84

Height Interval	Number 37m seg	MEAN Z DIFF (m)	BIAS (deg)	MEAN ABS(ΔWD)	ΔWD RMSD
0-3 km	4935	2.52	1.62	9.79	17.5
3-6 km	2079	2.91	0.78	10.10	18.4
6-9 km	5774	3.32	0.31	14.25	26.4
9-12 km	2732	3.70	-0.68	8.09	11.88