Pulsed Lidar measurements of XCO_2 in the 2017 ASCENDS airborne campaign, *& beyond …*

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IWGGMS-14
Paper 6.12

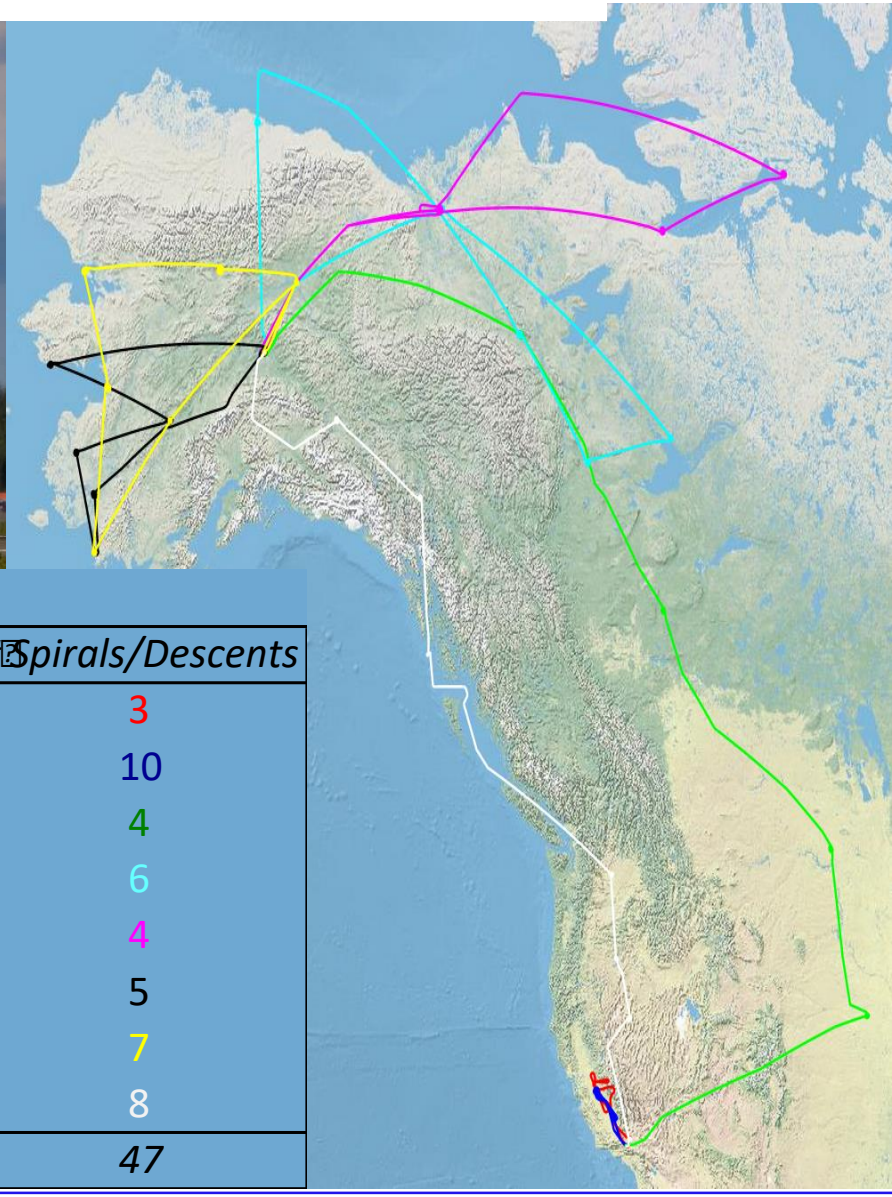
Support from NASA's:
ASCENDS Pre-formulation Activity, ABoVE Science Investigation, Airborne Science Program

May 10, 2018

Overview & Summary

- A very successful airborne campaign - all instruments & aircraft worked well
  - Made IPDA lidar measurements in Arctic for the 1st time
  - 1st airborne campaigns with long (34–70 deg lat.) north/south flight lines
  - 40+ spirals allow comparisons of lidar vs. in-situ XCO2 for a wide variety of locations & atmospheric conditions
- Will show samples of new results:
  - In situ measurements: CO2 was lower & quite variable in Arctic
  - Arctic backscatter profile measurements: show considerable variability in haze, vertical & horizontal cloud structure
  - CO2 Sounder lidar worked well – produced a large & rich data set !
- Path to space – made additional & significant progress

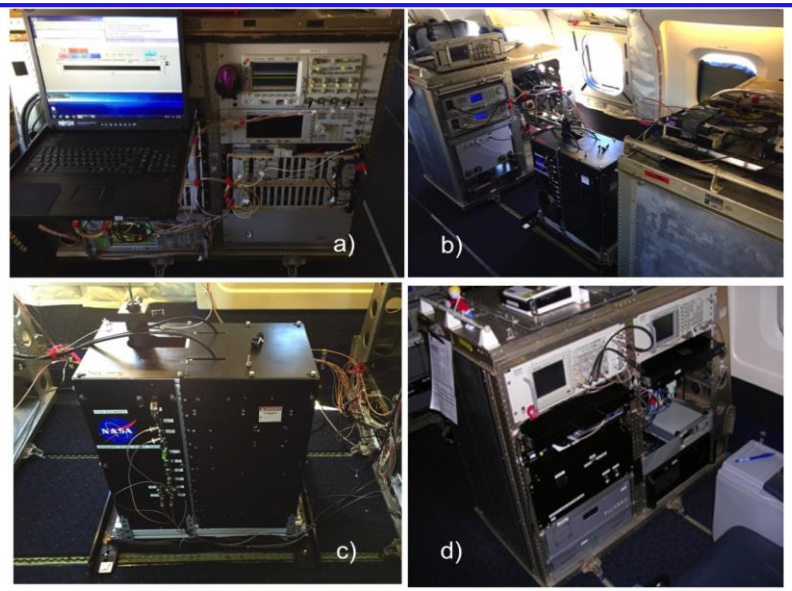
Overview - 2017 ASCENDS Airborne Campaign
Jul 20- Aug 8, 2017

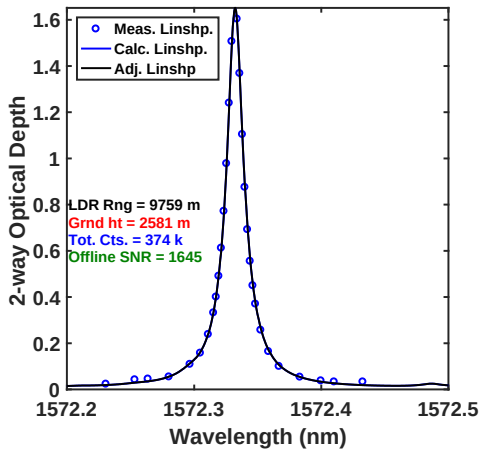


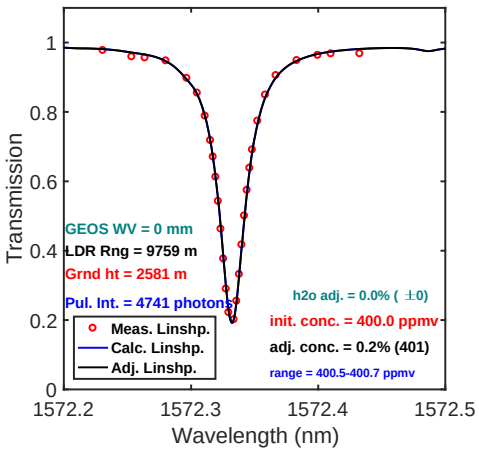
Flights & Legend:

Dates	Name	Duration (hrs)	# Spirals/Descents
20-Jul	Engineering	4.4	3
21-Jul	Calibration	5.6	10
27-Jul	Northbound science/transit	9.4	4
31-Jul	Western NWT	8	6
2-Aug	Northern NWT	6.6	4
5-Aug	South-Central Alaska	6.2	5
6-Aug	Central Alaska	7	7
8-Aug	Southbound science/transit	8.1	8
8	*Totals:*	*55.3*	*47*

CO_2 Sounder Lidar & other campaign instruments







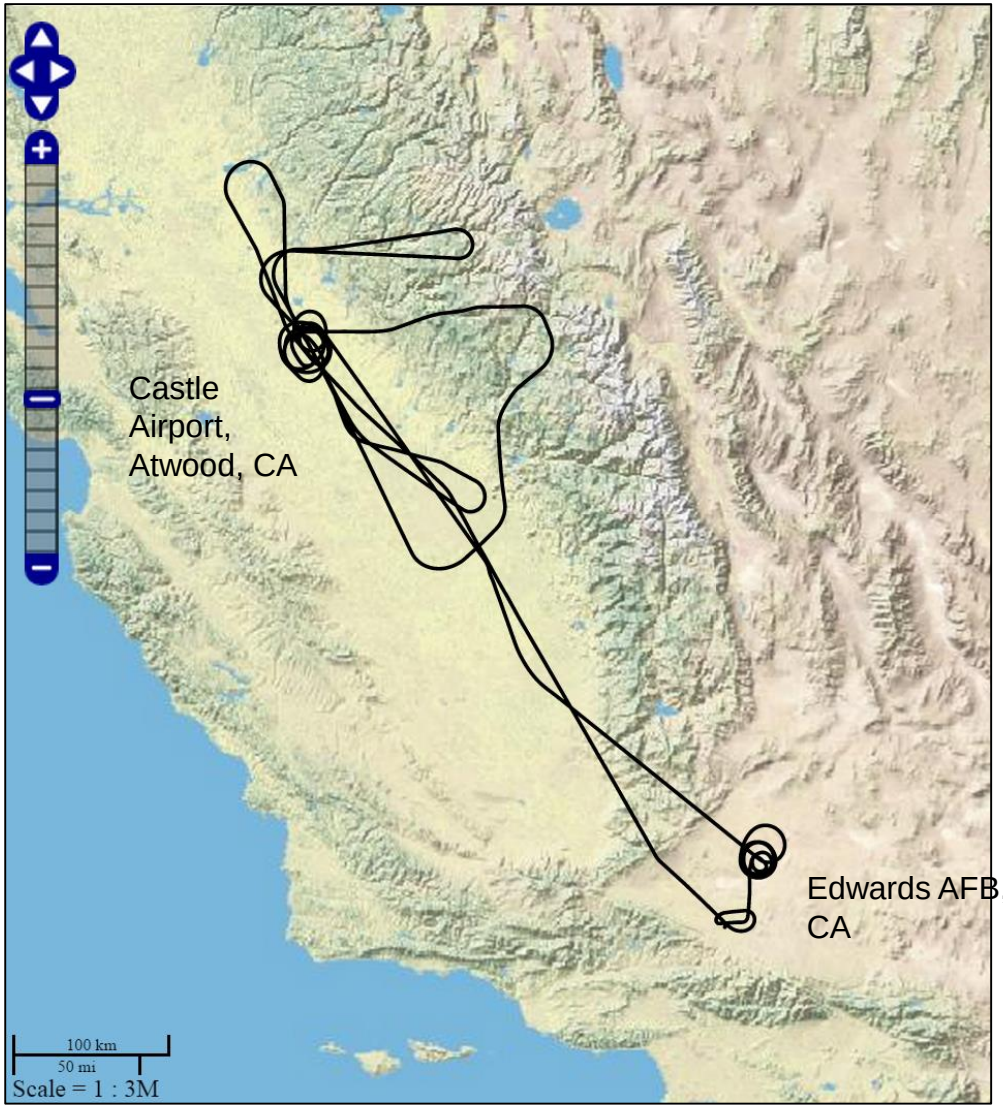
Other science instruments on ASCENDS 2017 campaign

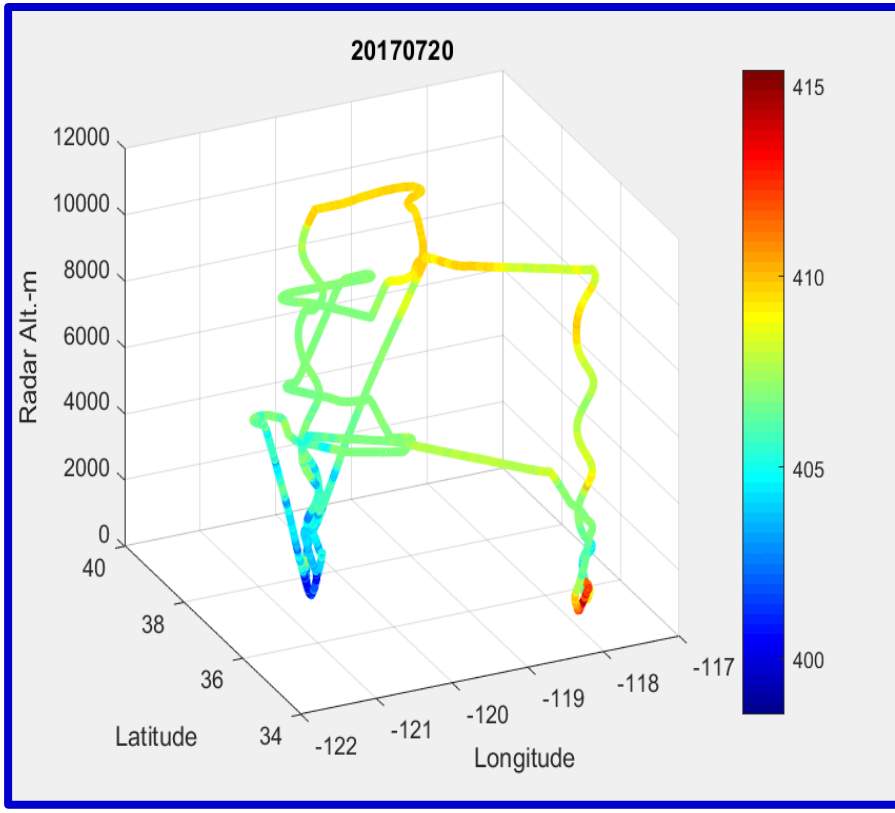
- **Picarro** (Randy Kawa) – in situ CO2 and WV
- **AVOCET** (Josh DiGangi/LaRC) – in situ CO2, CH4, CO
- **DLH** (Glenn Diskin/LaRC) – in situ WV
- **ACES** (Mike Obland/LaRC) – IPDA lidar to measure XCO2 using a line near 1571 nm

  - Uses modulated CW lasers at 3 wavelengths

- Direct Detection IPDA lidar - emits 10 kHz train of laser pulses
- Measures column CO_2 absorption using 1572.33 nm line.
- Laser pulses - stepped in 30 wavelengths across line.
- Wavelengths are locked relative to CO2 absorption line center
- Time resolved receiver uses HgCdTe APD detector
- Measures backscatter profile, range & samples of CO_2 line shape
- XCO2 Retrievals:
  - Line shape samples, range to scattering surface
  - Atmospheric state (measurements or model)

Engineering Flight July 20, 2017

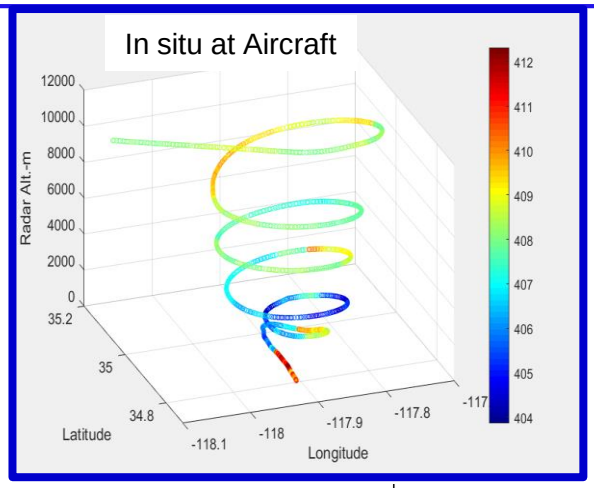




CO2 concentrations at the aircraft:

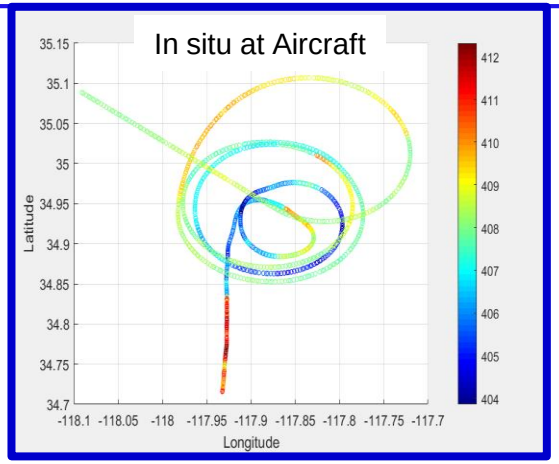
Color coded Picarro in-situ CO2 measurements made from the DC-8 aircraft during the flight

Engineering Flight July 20, 2017
Spiral over Edwards CA: CO2 & XCO2 Retrievals

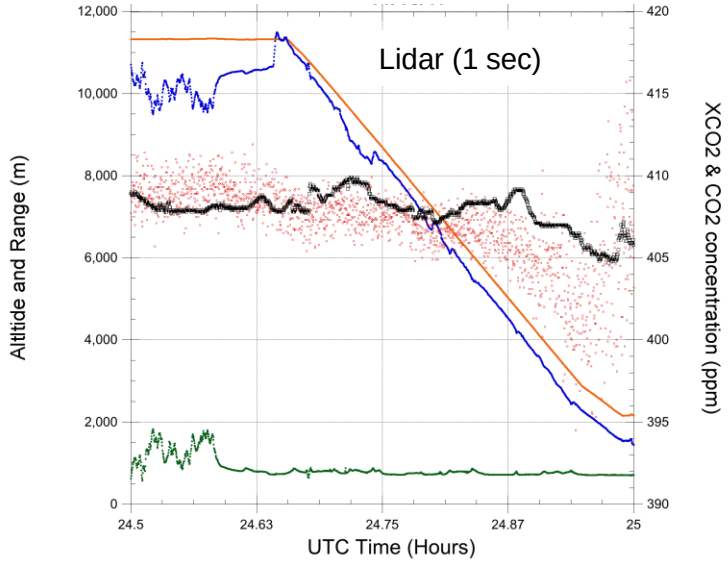


Picarro (in situ) CO2 measurements at aircraft made during spiral

<- Side view ***Top view->***

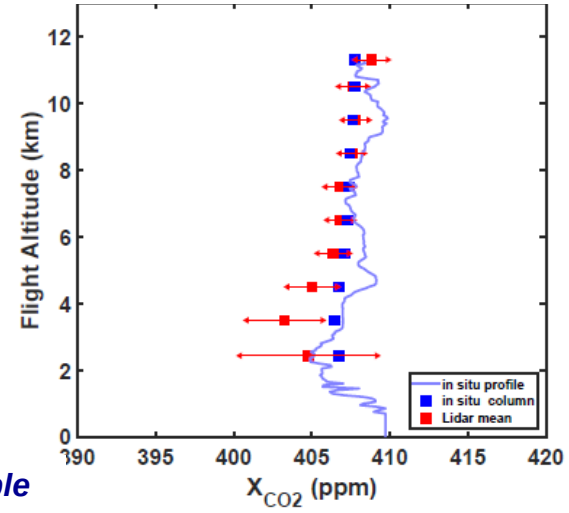


Red dots: XCO2 from CO2 Sounder Lidar
Black dots: CO2 (at altitude) from in situ
All XCO2 Retrievals use 1 second averaging time



Reference atmosphere (LUT) for XCO2 retrievals based on:
DC-8 T & P
PICARRO H2O

Comparison of XCO2 measurements:
- ***Red – lidar***
- ***Blue dots - In situ, ave'd to surface***



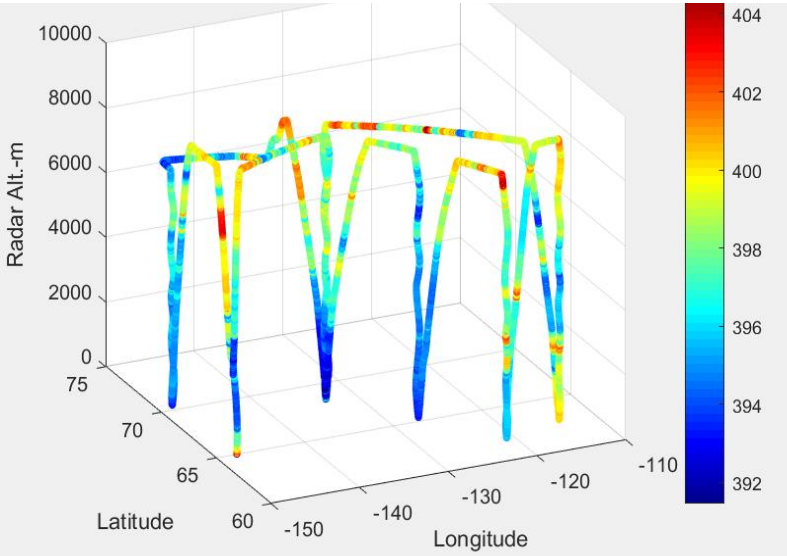
Same format used for other sample results

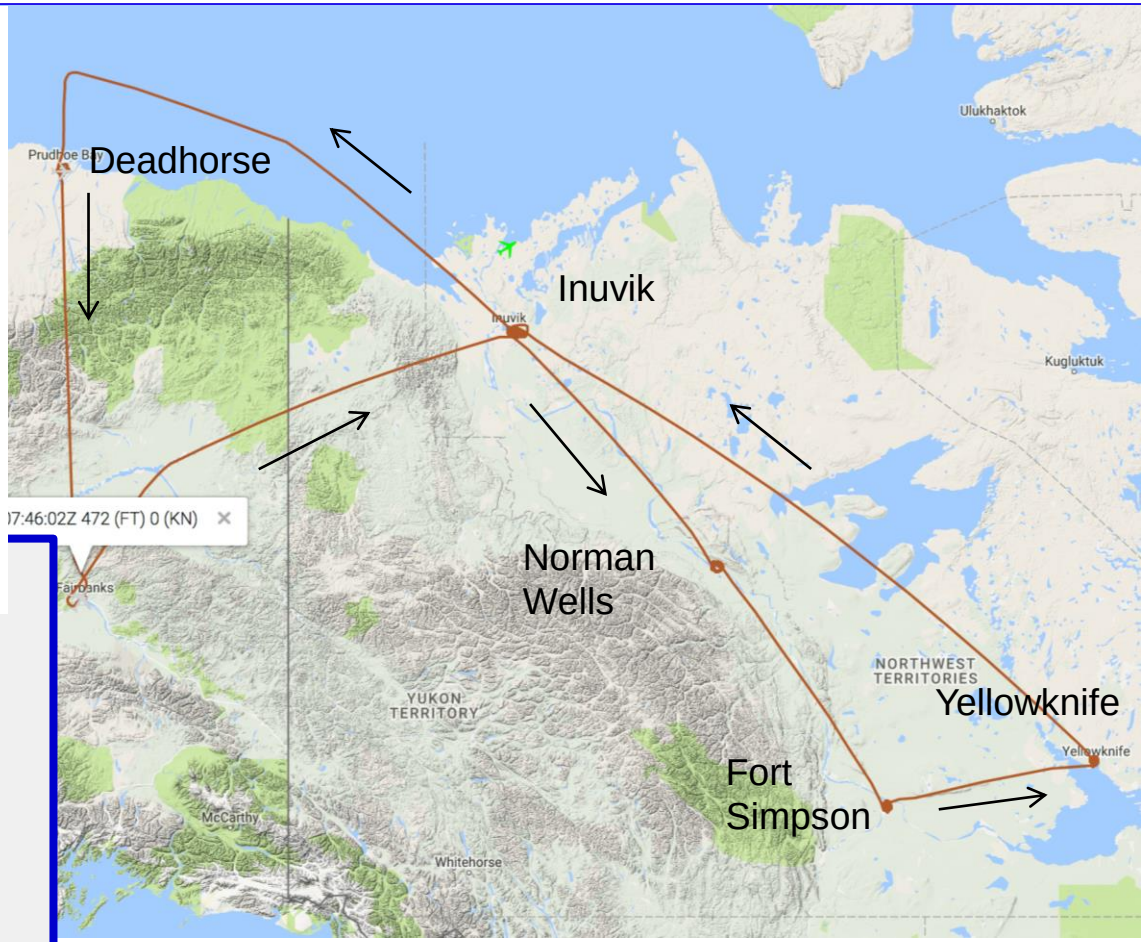
ASCENDS 2017 Flight
NWT Canada 1 - Monday July 31, 2017

The route went east from Fairbanks to Inuvik, then primarily south, east, then back north along the Mackenzie River, then out of the Arctic Ocean, over Deadhorse AK, then back to Fairbanks.

We used 6 spiral-down maneuvers to allow comparing the lidar measurements of XCO2 against the in-situ measured CO2

In-situ CO2 at the DC-8 (Picarro):

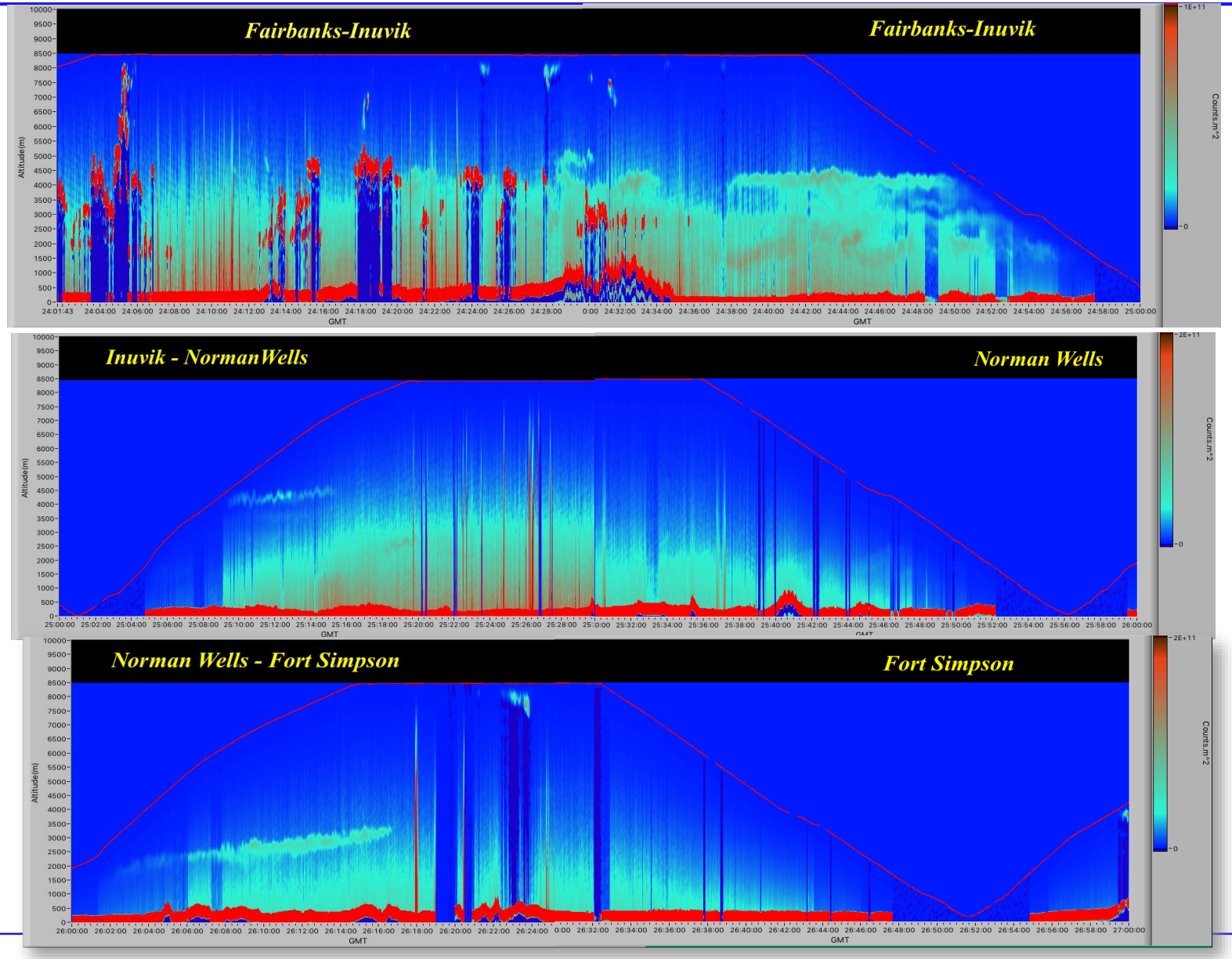




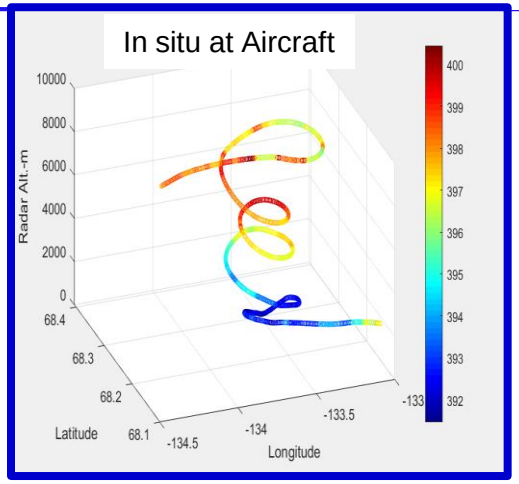
Flight on Monday July 31, based out of Fairbanks AK.

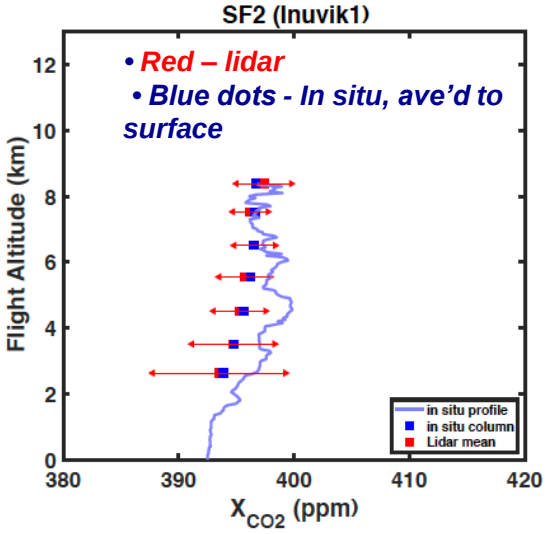
Takeoff time: 3:45pm local
Flight duration: 8 hours.

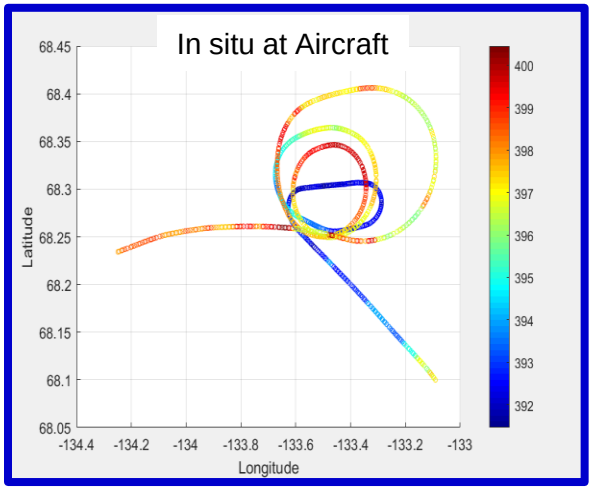
Lidar Measured Backscatter History - NWT Flight 1

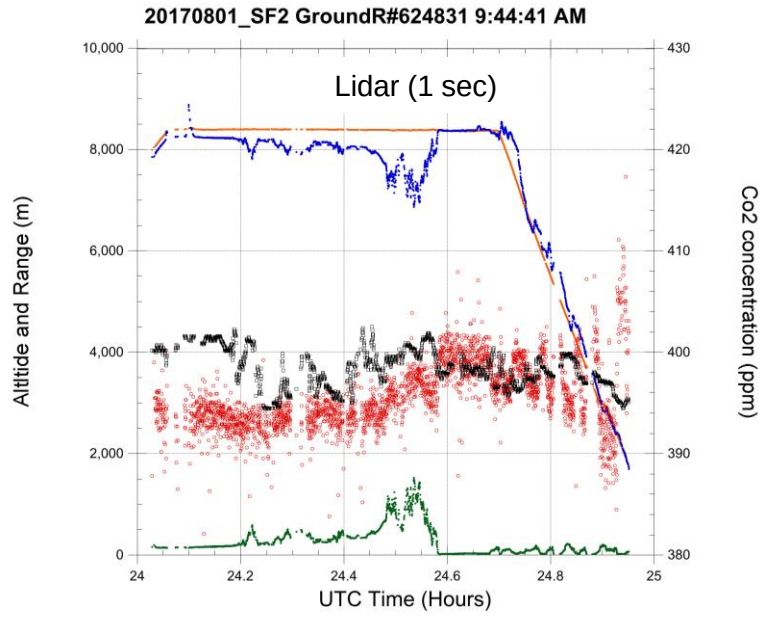


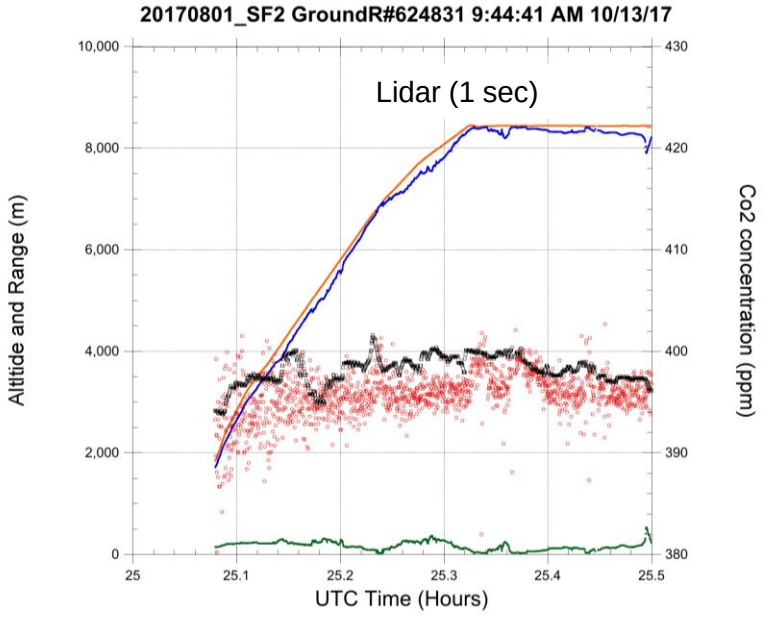
NWT Flight 1 - July 31, 2017
1st Spiral over Inuvik NWT





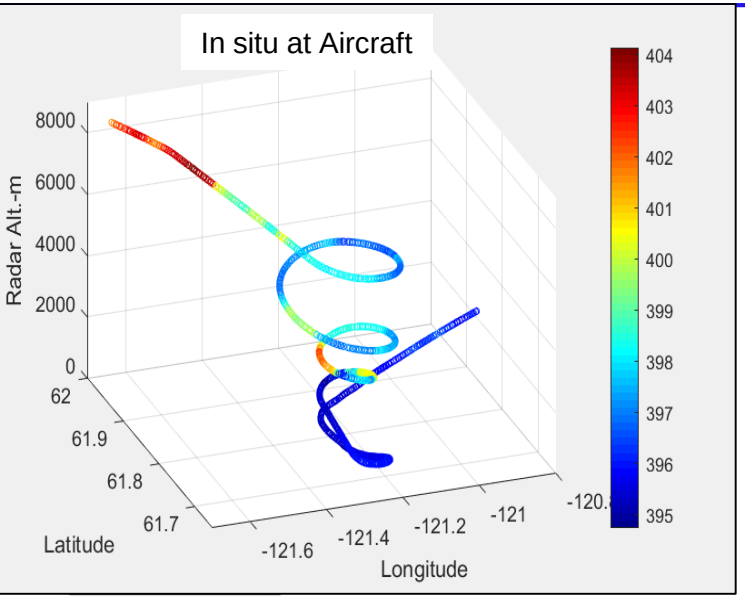


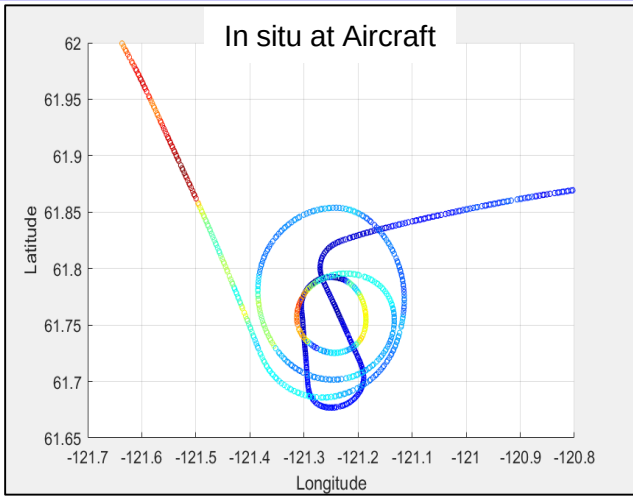


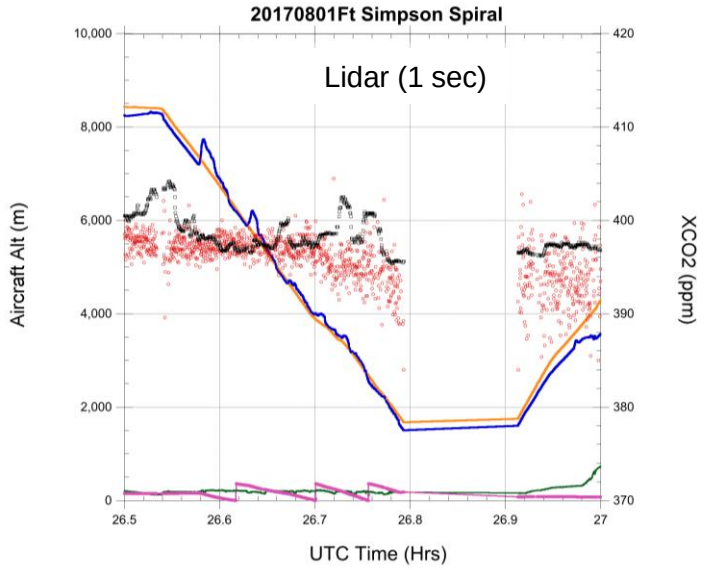


In situ & XCO2 retrievals show variability with time & altitude

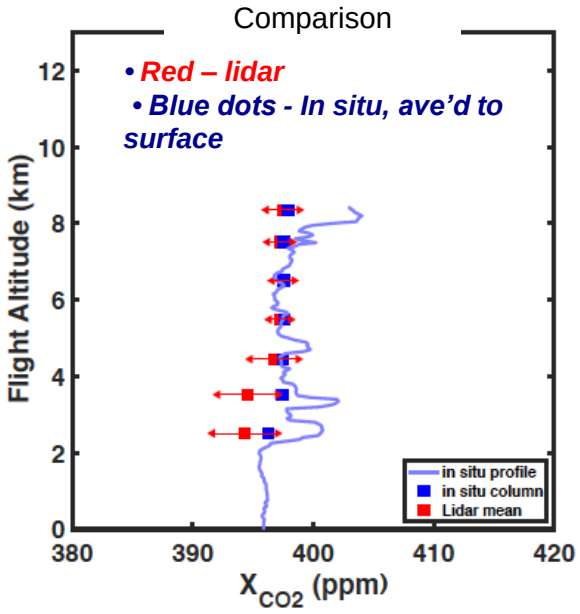
NWT1 Flight – 2nd Spiral: Fort Simpson NWT







Lidar XCO2 & Picarro
8/1 02:30-03:00 UTC
Retrievals Based on REVEA
& PICARRO data



Alaska to California Transit Flight - Aug 8, 2017

Takeoff time: 8:15 am local

Duration: 8.1 hours

Flight Events:

- Spiral - Northway Airport AK
- Spiral - Whitehorse Airport YU
- Flew due south over part of inner passage of British Columbia
- 2 in-line descent-ascents over cloud-free areas of ocean (in inner passage)
- Spiral - Moses Lake, WA
- Spiral - Wildhorse Airport, OR
- Spiral - Winnemucca, NV
- Increased altitude to 38Kft
- Spiral at Edwards AFB, CA

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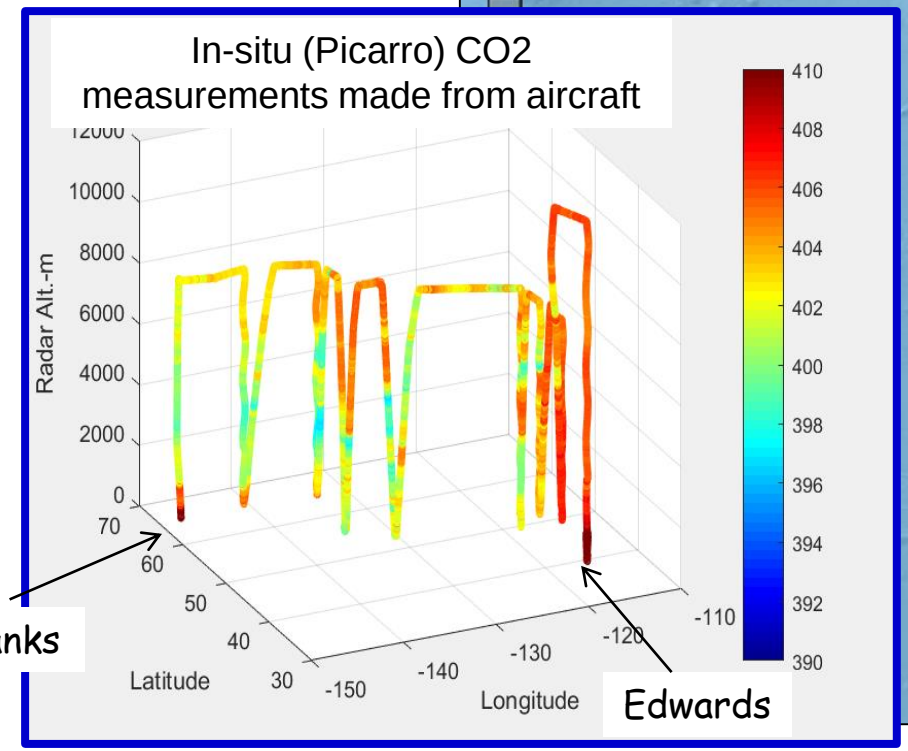
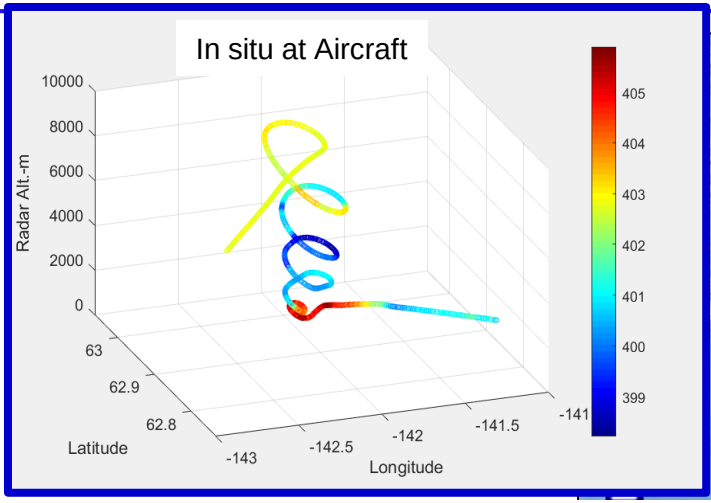
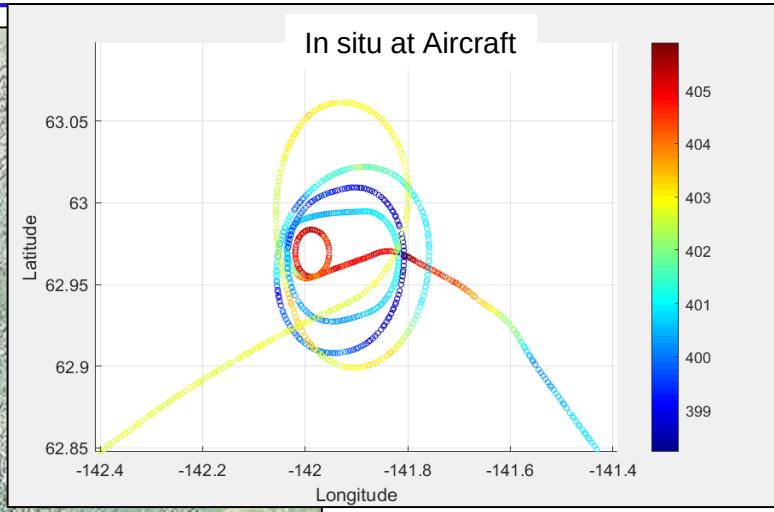
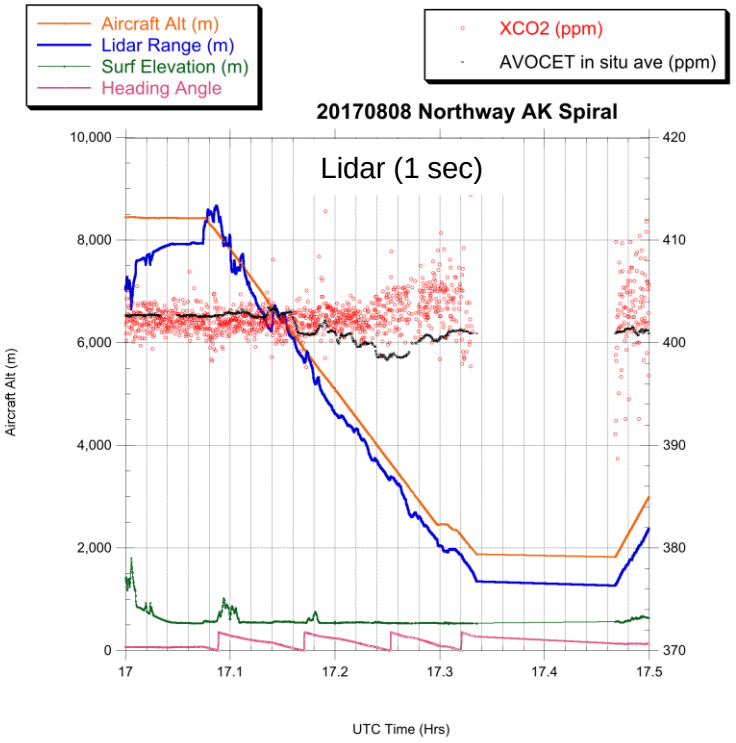
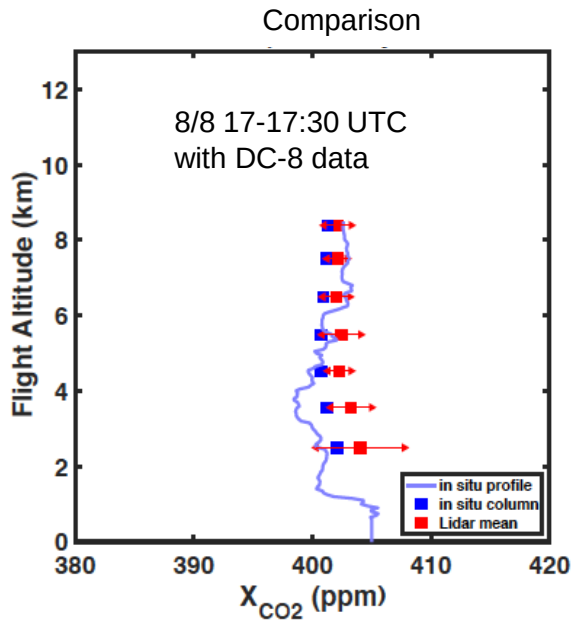


Aug 8 Flight – 1st Spiral – Northway Junction AK

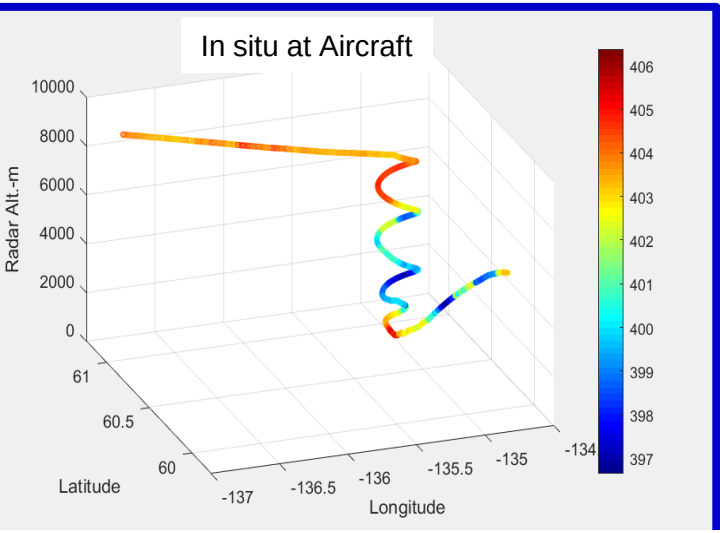


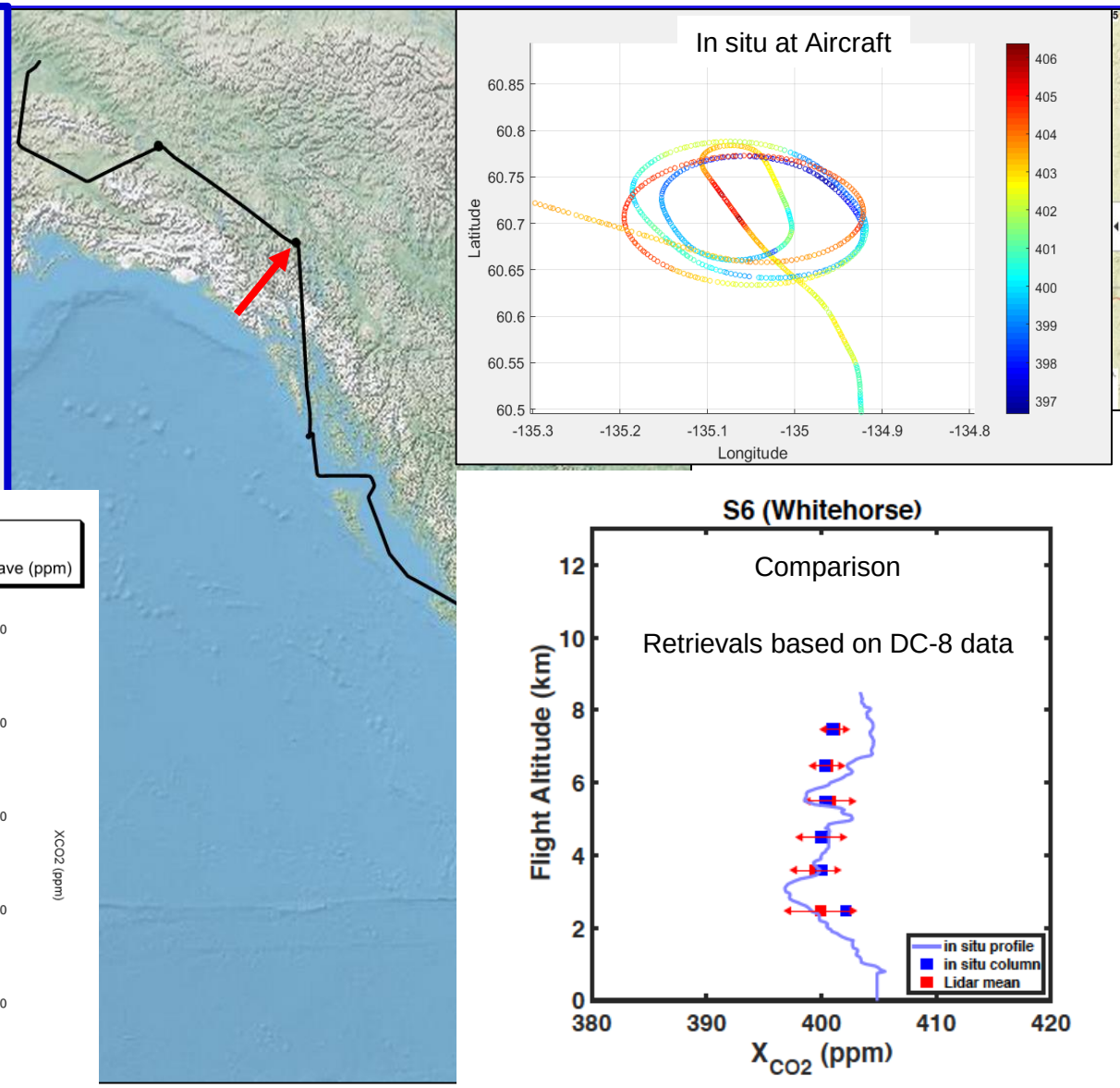


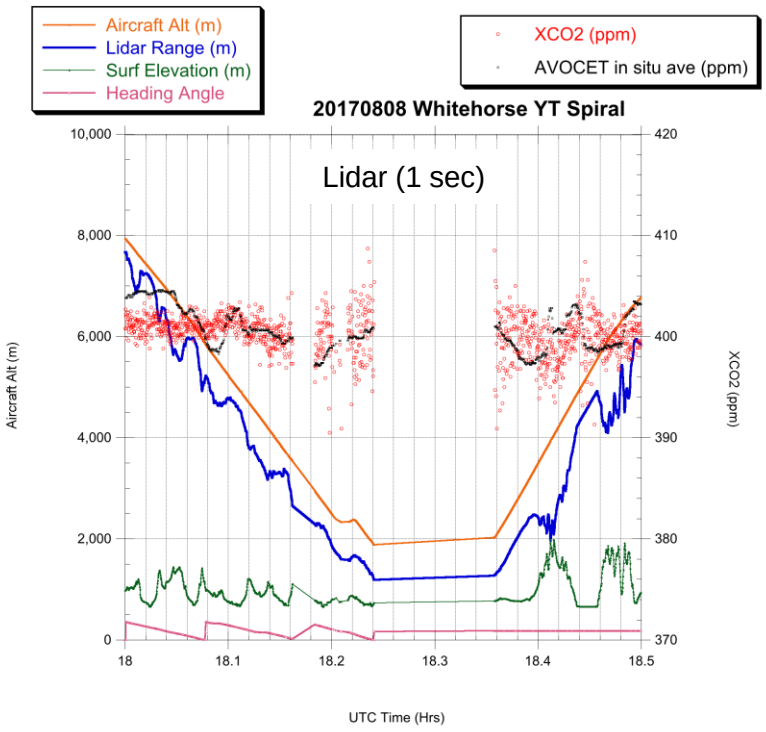




Aug 8 return Flight – 2nd Spiral – Whitehorse YT

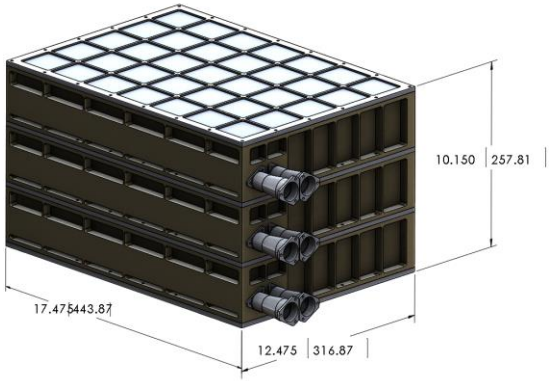




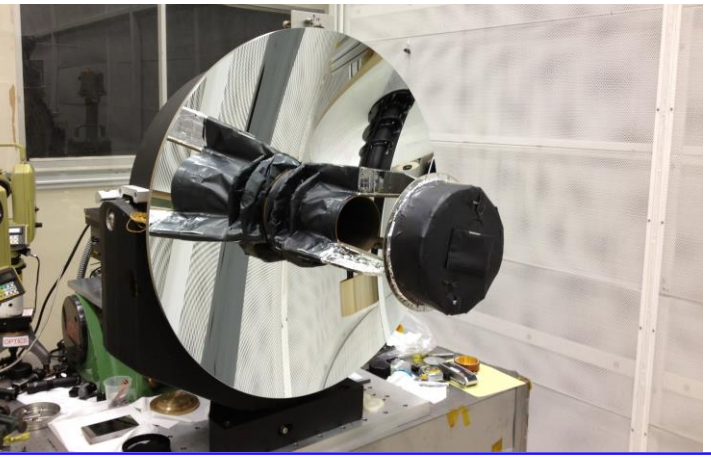


Key progress toward moving the CO_2 Sounder Lidar to Space

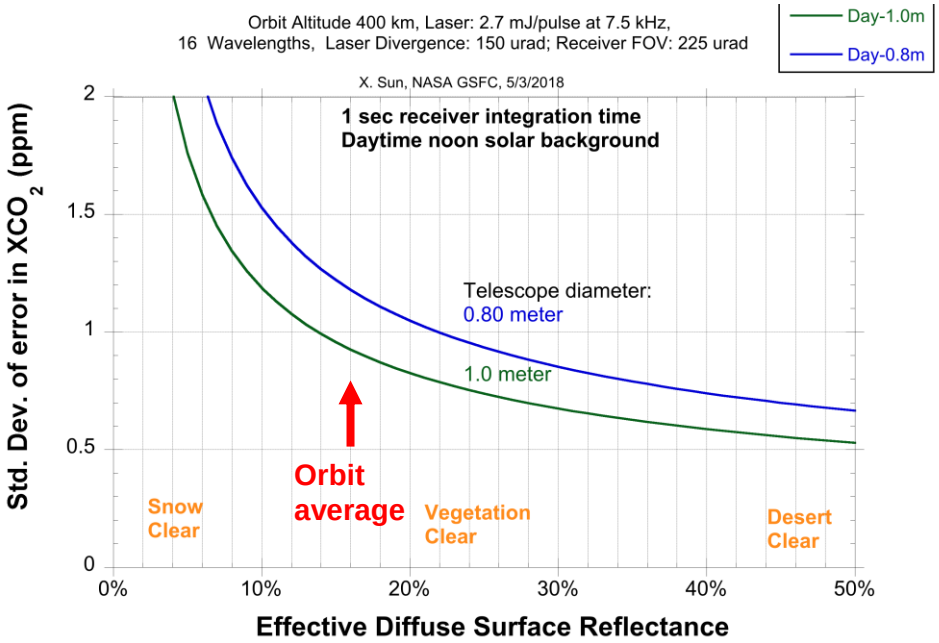
1. **Laser** with space needed performance in testing: TRL-6 by October 2018



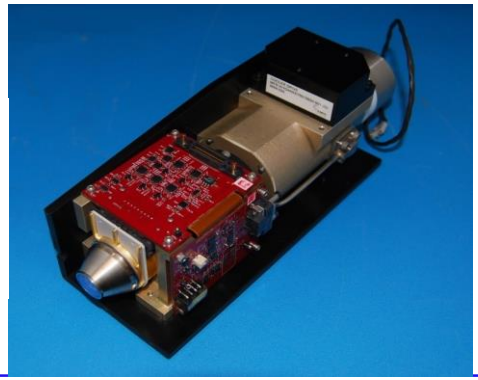
2. **Receiver telescope**:
80 & 100 cm diameter telescopes: affordable & flight proven



3. Measurement model
For space shows < 1 ppm random error



4. **Detector:**
Highly sensitive HgCdTe APD detector in cryocooler - passed space radiation & environ. tests



Why a space lidar for XCO_2 ?

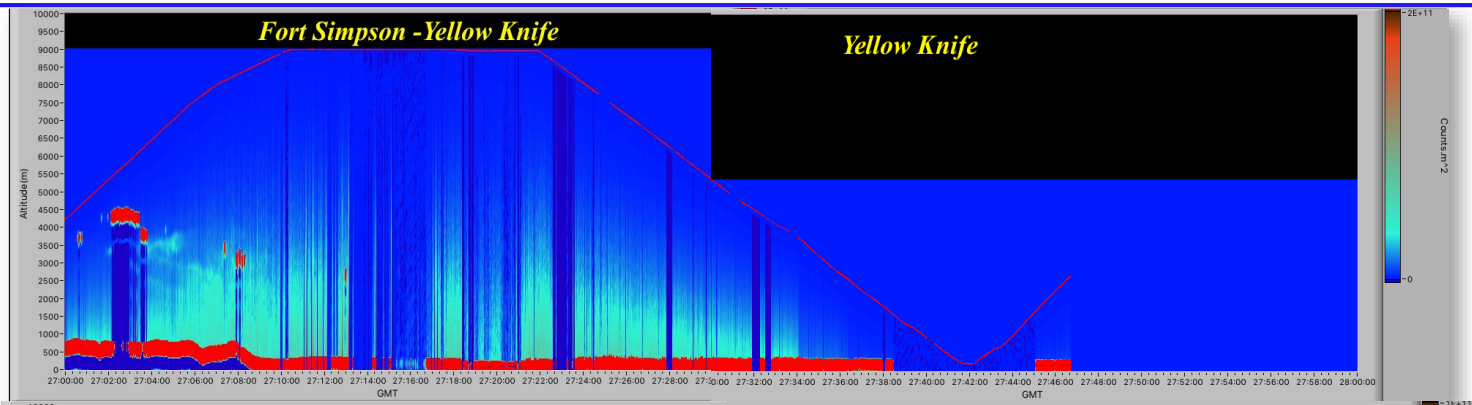
Calipso Mission Image
courtesy of D. Winker/ NASA LaRC

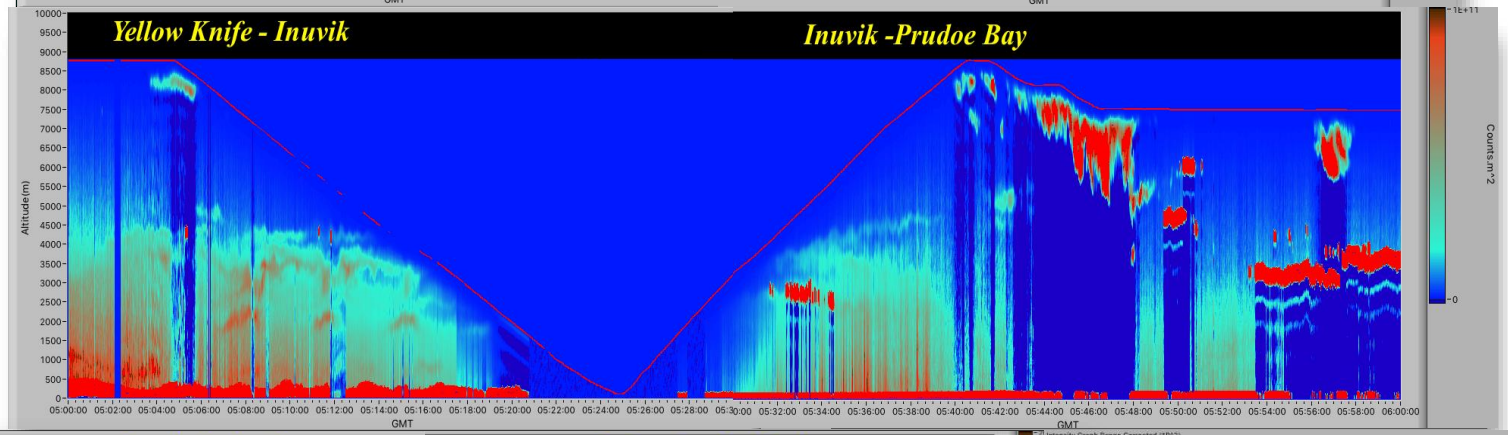
It uniquely provides:

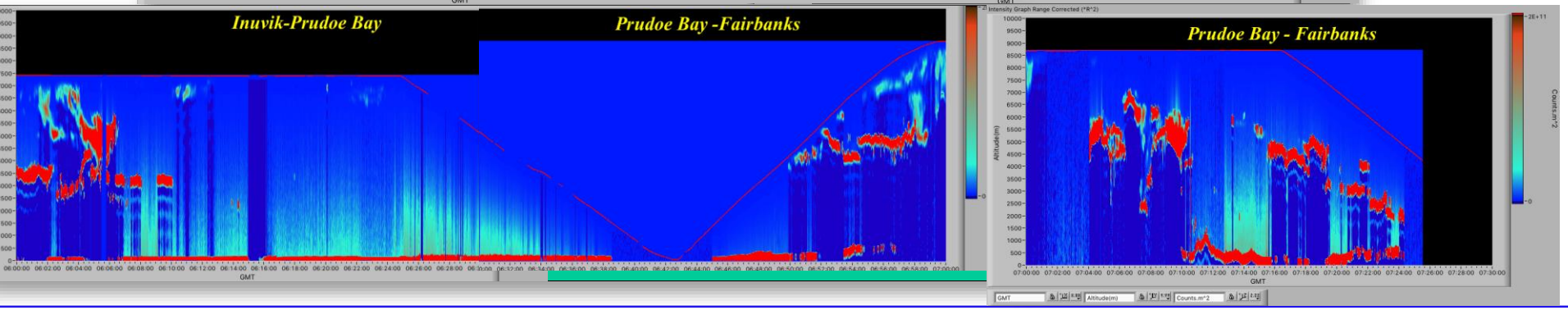
- Measurements at night & high latitudes
- High spatial resolution (small footprint)
- Using consistent vertical path
- Accurate knowledge of path length
  - Enables measurements to cloud tops
- Uses 1 line – much simpler spectroscopy
- *Multiple wavelengths on gas line shape:*
  - *Allows solving for potential biases*

Backup

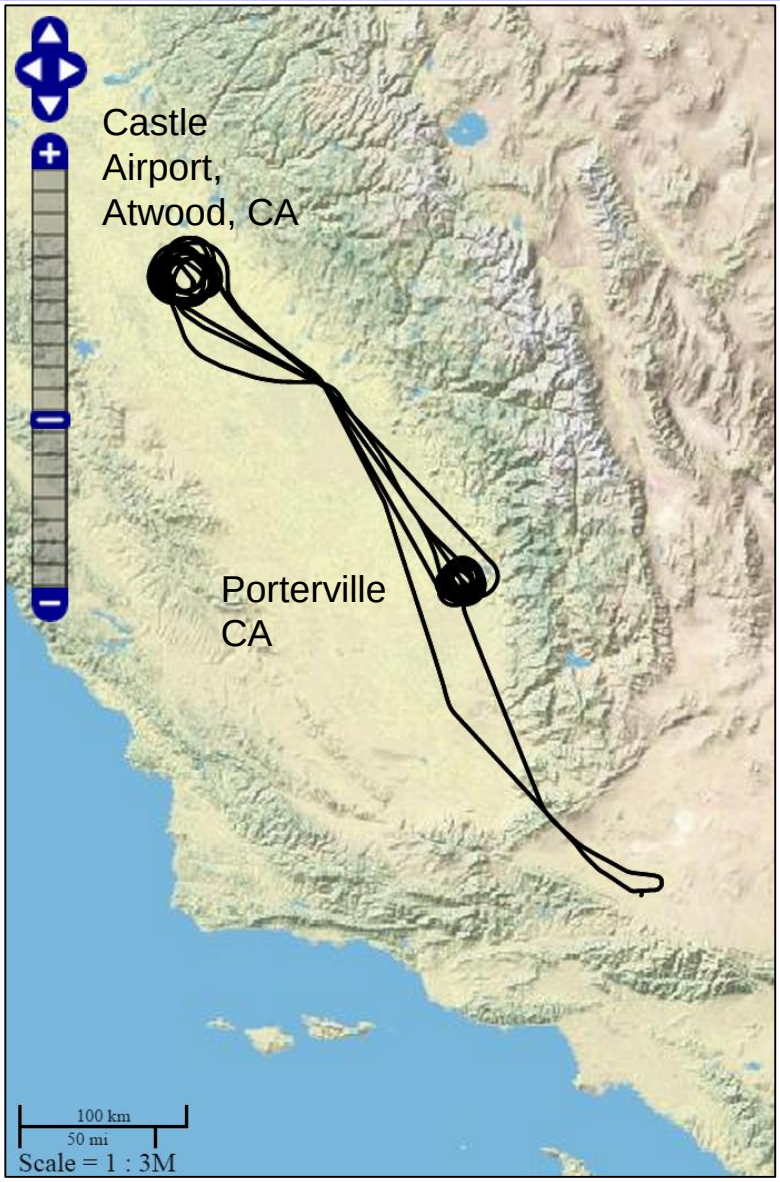
Lidar Measured Backscatter History - NWT Flight 1

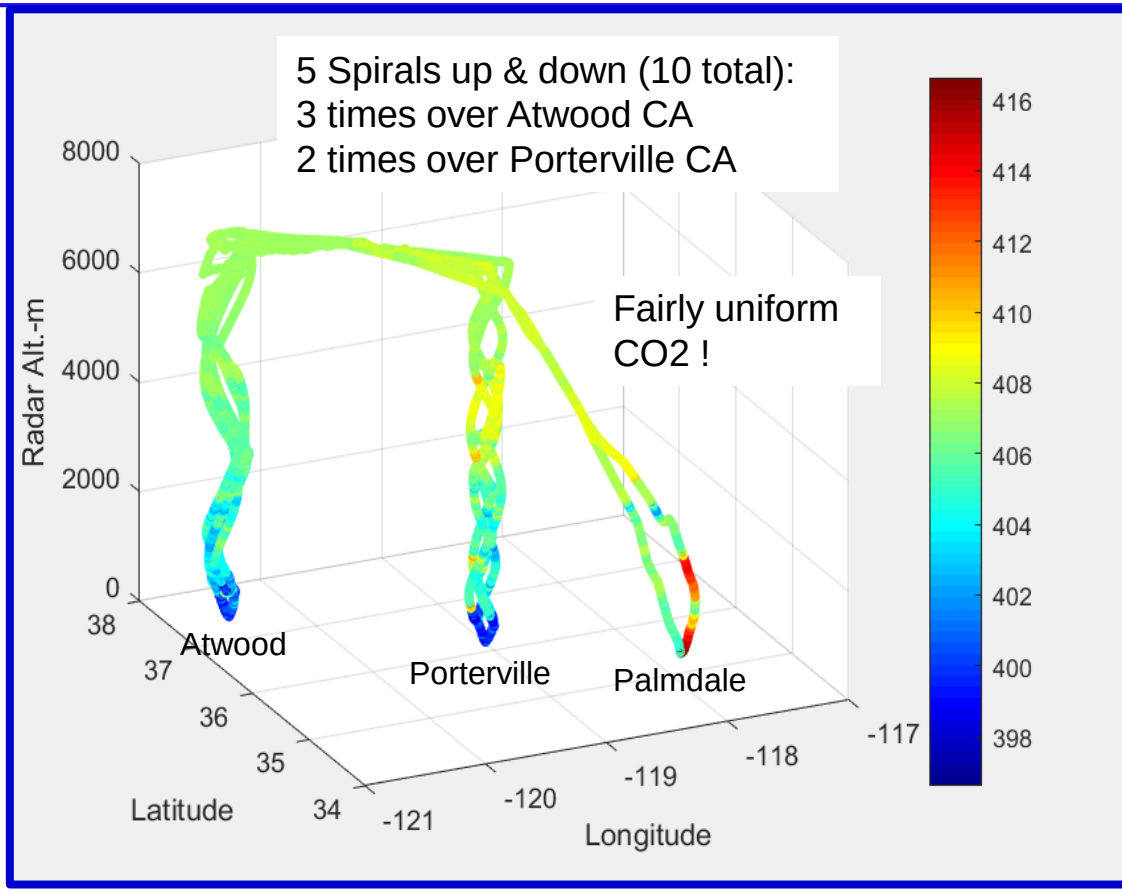






Calibration Flight: Central Valley CA, July 21, 2017





CO2 concentrations at the aircraft:

Color coded Picarro in-situ CO2 measurements made from DC-8 aircraft during the flight

Northbound Transit & Science Flight
July 27, 2017 - Palmdale to Fairbanks Alaska

The campaign's long south-to-north science flight occurred on July 27

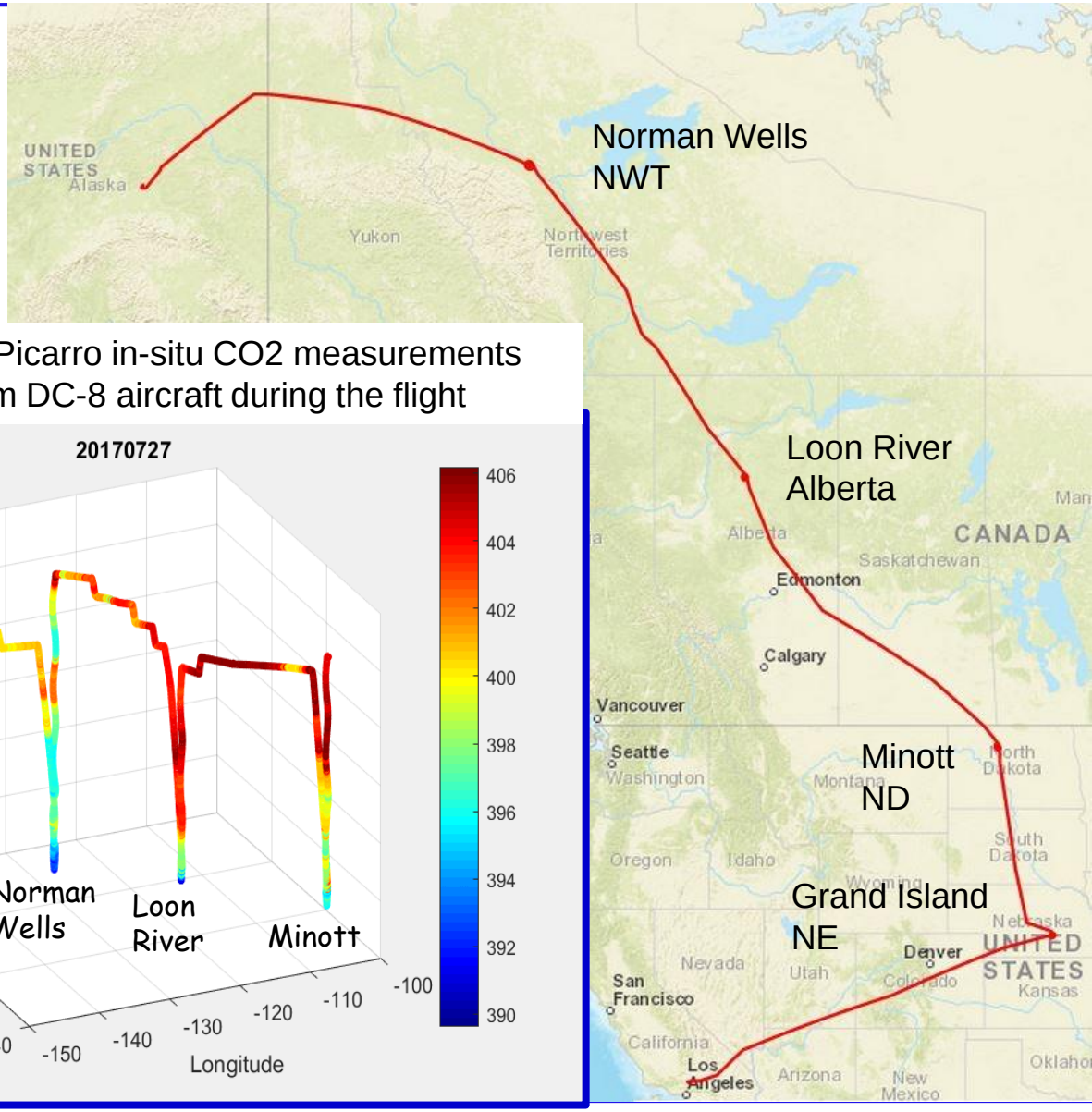
Takeoff time: 9 am local

Flight duration: 9.4 hrs.

Eastward path to avoid mountains and clouds

Spiral down maneuvers at:

- Grand Island, NE
- Minott, ND
- Loon River, Alberta
- Norman Wells, NWT



Color coded Picarro in-situ CO2 measurements made from DC-8 aircraft during the flight

ASCENDS Flight - Saturday Aug 5, 2017
1st Alaska Flight - South-Central Alaska

The takeoff time: 9 am local

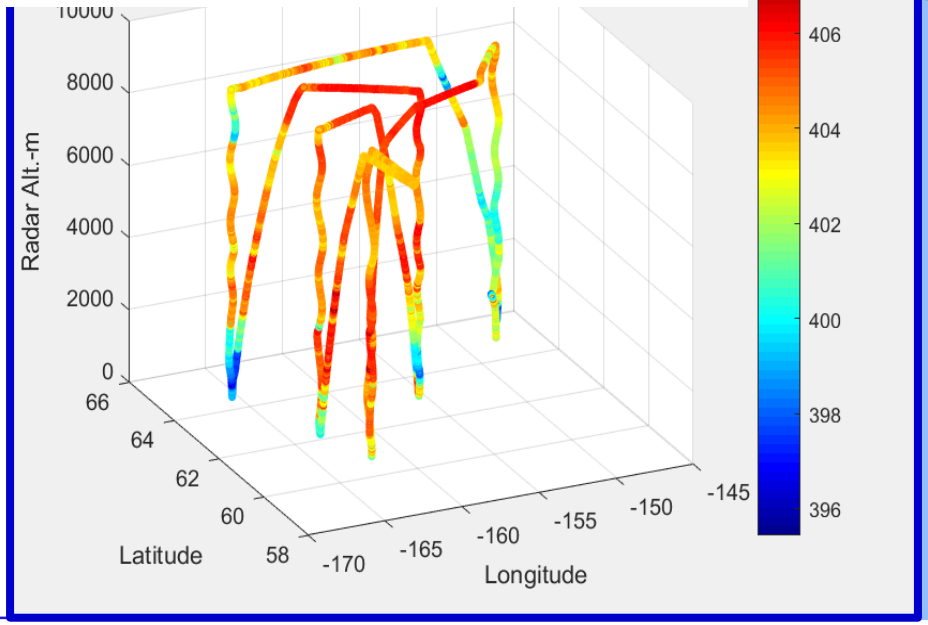
Flight duration was 6.2 hours.

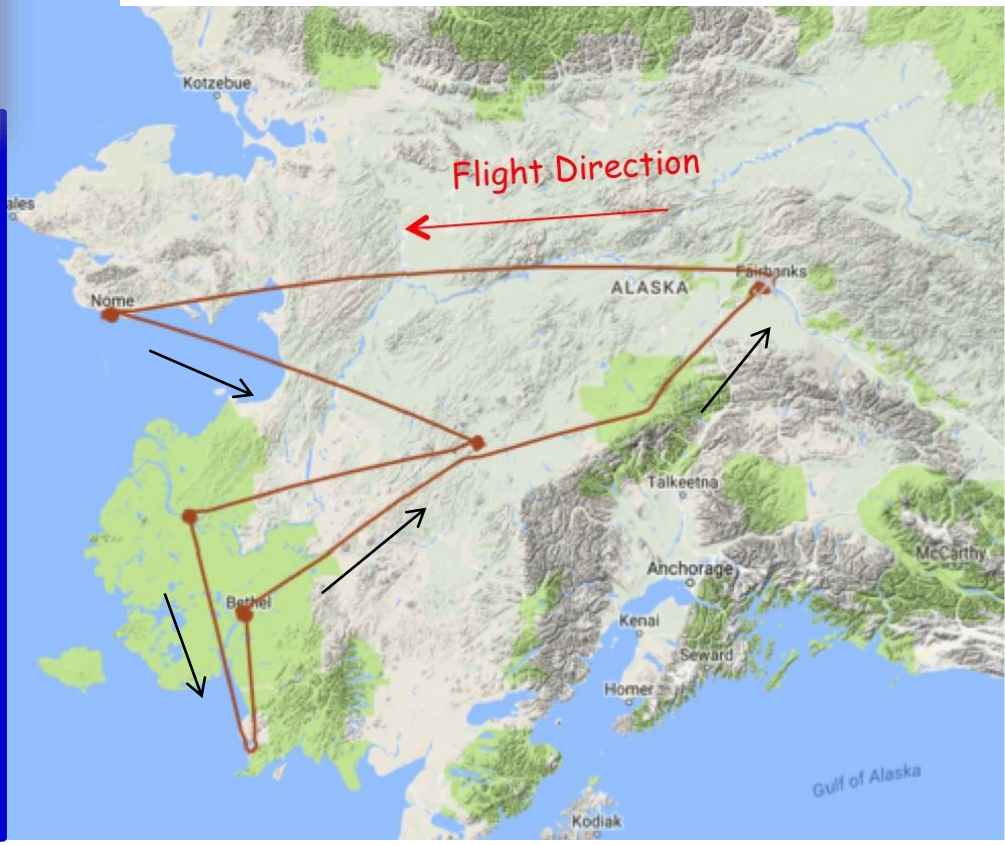
Spiral-downs at:

Nome, McGrath, Saint Mary's, Bethel, Fairbanks.

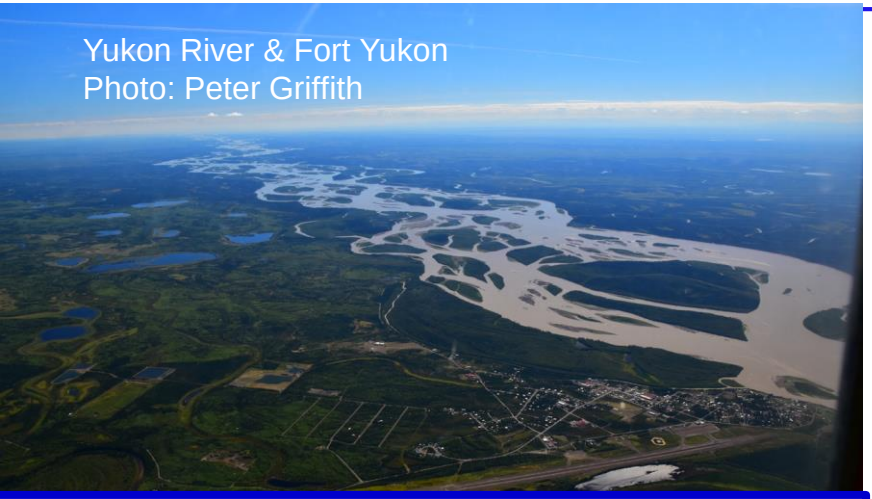
A planned spiral at southernmost point of route (Platinum) not possible - cloud cover.

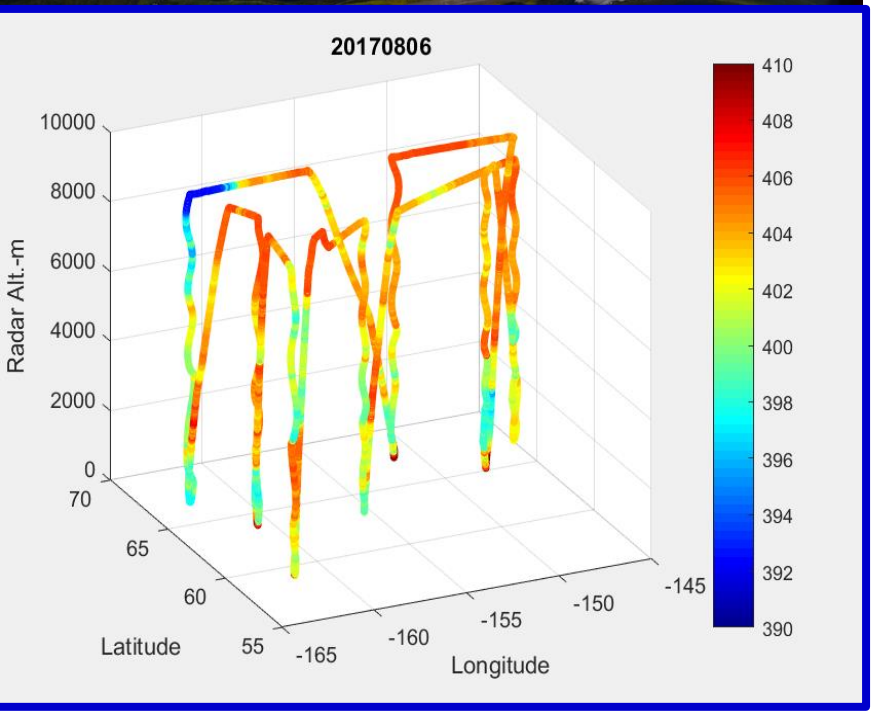
In-situ (Picarro) CO2 measurements made from aircraft





ASCENDS Flight - Sunday Aug 6, 2017
2nd Alaska Flight

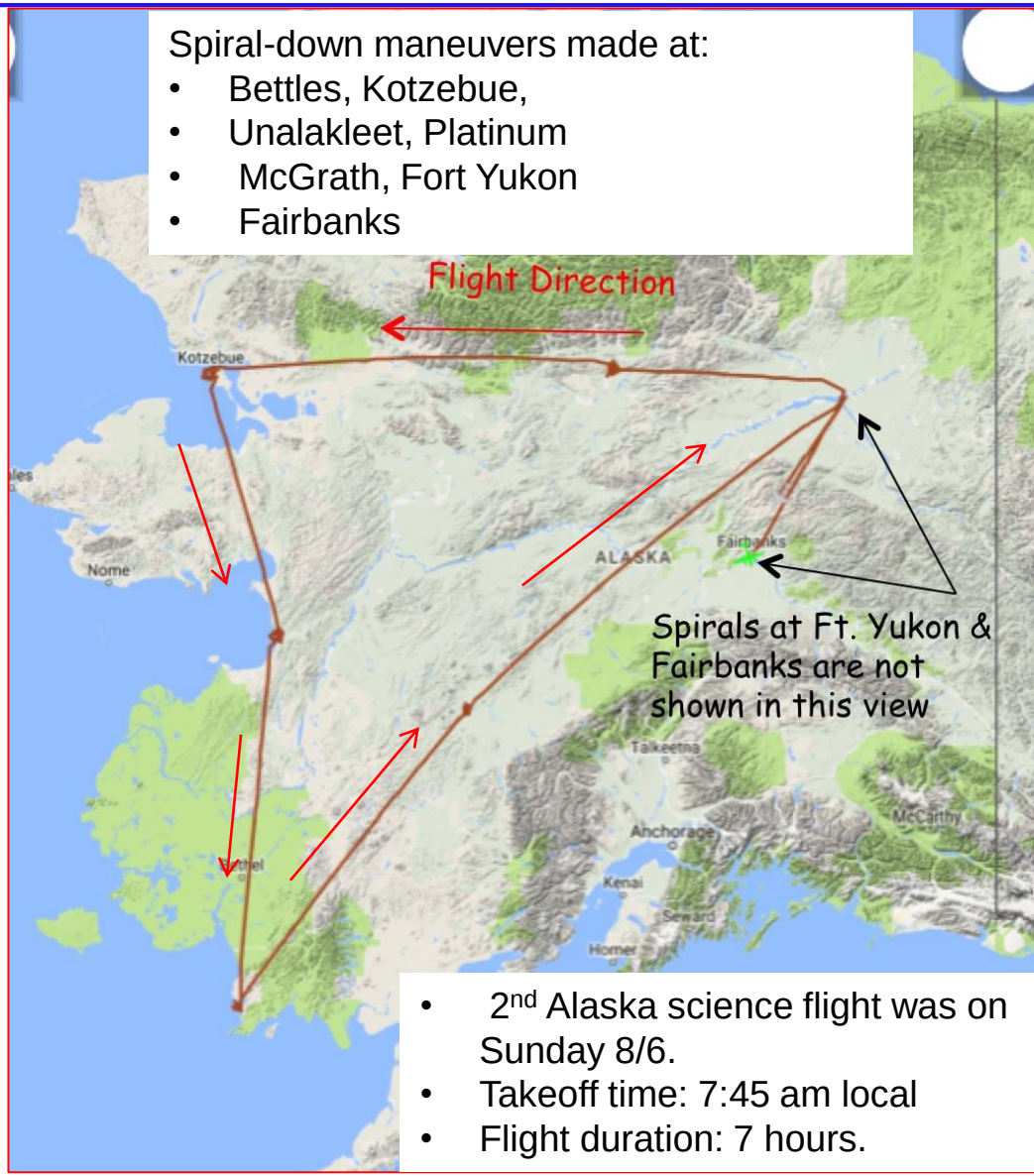




In-situ (Picarro) CO2 measurements made from aircraft

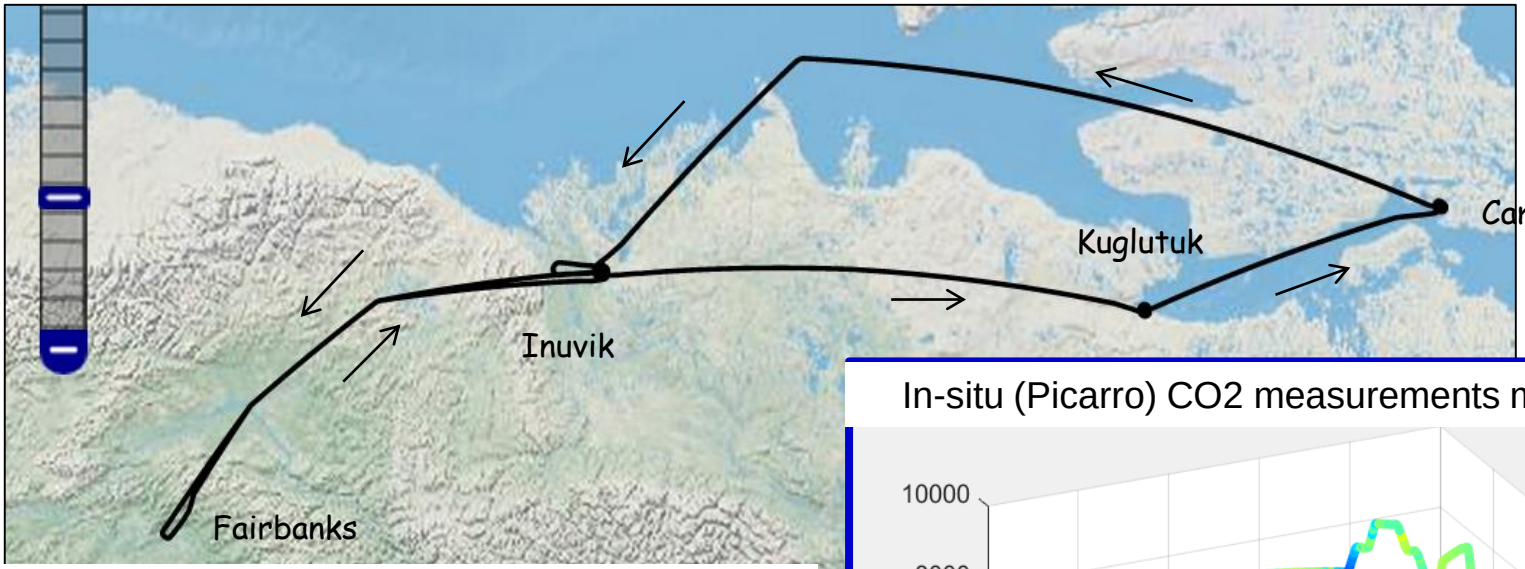
Spiral-down maneuvers made at:

- Bettles, Kotzebue,
- Unalakleet, Platinum
- McGrath, Fort Yukon
- Fairbanks



- 2nd Alaska science flight was on Sunday 8/6.
- Takeoff time: 7:45 am local
- Flight duration: 7 hours.

NWT Flight 2 - August 2, 2017



Takeoff time: 4:46 pm local

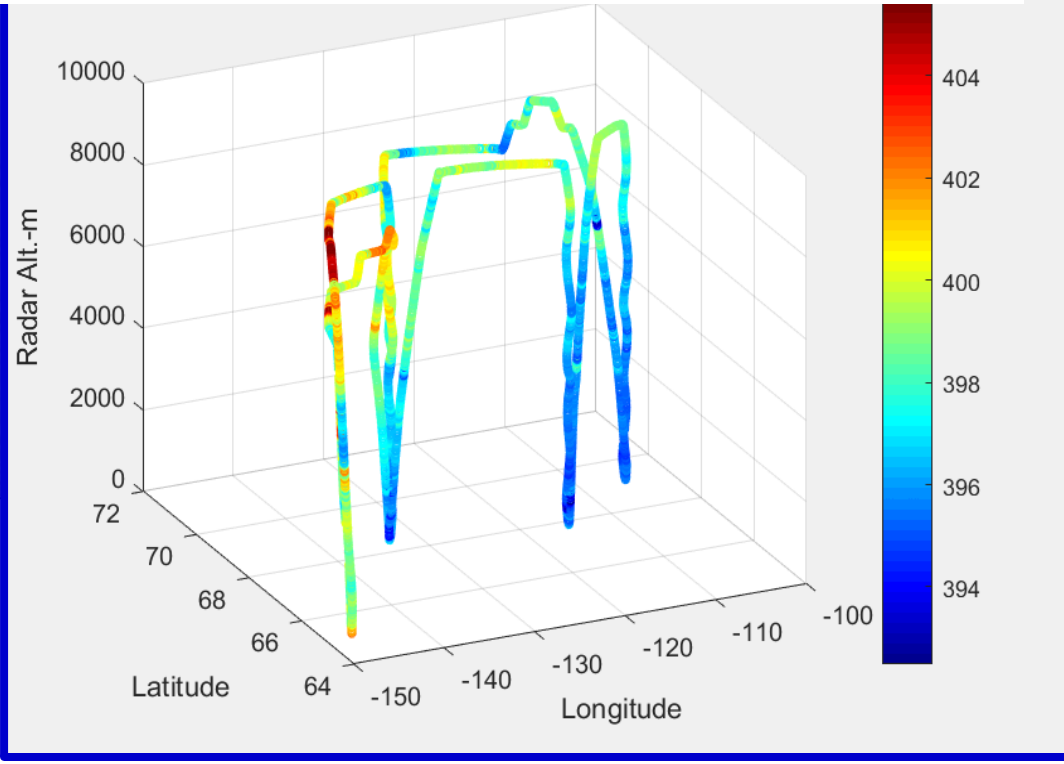
Flight duration: 6.6 hours.

Spiral down maneuvers at:

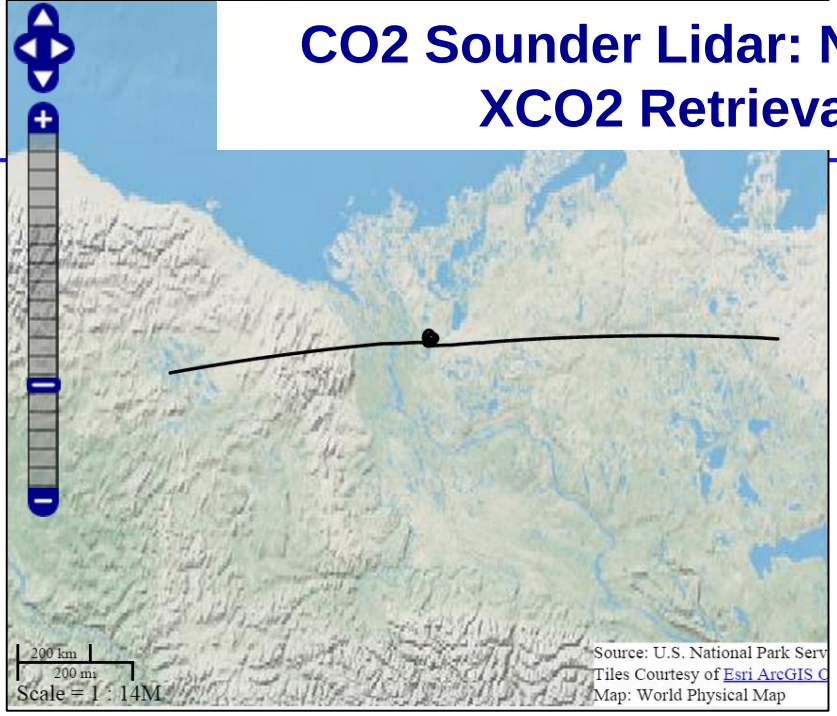
- Inuvik NWT
- Kugluktuk NWT
- Cambridge Bay NU
- Inuvik again

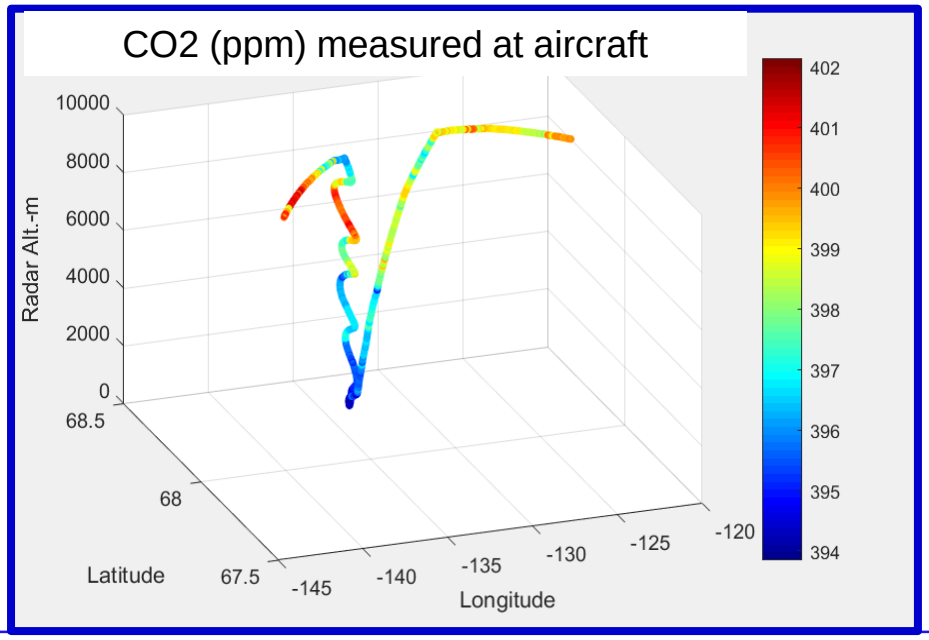
Return west and south Fairbanks.

In-situ (Picarro) CO2 measurements made from aircraft



CO2 Sounder Lidar: NWT Flight 2 - August 3, 2017
XCO2 Retrievals for 1st Inuvik Spiral





Initial L2a Retrievals for 1st Inuvik Spiral on August 3, 2017 Preliminary

Reference atmosphere (LUT) based on:
Inuvik 0Z radiosonde