Aircraft Measurements in Polluted Winter Boundary Layers
Opportunities and Challenges for Western Mountain Basins

Steven S. Brown
Chemical Sciences Division, NOAA Earth System Research Laboratory, Boulder, CO
The Challenge and Opportunity

- Winter boundary layers are shallow: of order 100 – 800 m generally
- Characterizing composition as a function of height above ground in this range is crucial to winter air quality science
- How best to solve this challenge? Are research aircraft the best / most effective way to do this? If so, what is the optimum size (aircraft) and scale (spatial domain)?

Image of inversion depth during late January – early February 2017 PCAP in Salt Lake City

Sebastian Hoch, U. Utah
Recent U.S. Winter Aircraft Studies

DISCOVER-AQ 2013
- Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality
- NASA P-3

WINTER 2015
- Winter Investigation of Transport Emissions and Reactivity
- NSF C 130

UWFPS 2017
- Utah Winter Fine Particulate Study
- NOAA Twin Otter
DISCOVER-AQ San Joaquin Valley

- January – February 2013
- ~ 85 Flight hours / 12 research flights / 10 flights in the SJV
- Repeated flight pattern (3x each day) across multiple days
- 9 AM takeoff time each day (no night flights)

P-3B Instruments

| + Anderson, Bruce   | LARGE (aerosols) | NASA LaRC |
| + Barrick, John    | PDS (met,nav)    | LaRC-SSAI  |
| + Cohen, Ron       | TD LIF (NO2, HNO3, PNs, ANs) | U of CA, Berkeley |
| + Diskin, Glenn    | DLH (H2O), DACOM (CO, CH4) | NASA LaRC |
| + Fried, Alan      | IR Absorption Spectrometer (CH2O) | U of CO, Boulder |
| + Weinheimer, Andy | Chemiluminescence (O3, NO2, NO, NOy) | NCAR |
| + Wisthaler, Armin | PTRMS (non-methane hydrocarbons) | University of Innsbruck |
| + Yang, Melissa    | AVOCE (CO2)      | NASA LaRC  |
Example DISCOVER-AQ Flight – January 18, 2013

- Missed approaches / Vertical profiles to characterize boundary layer structure, depth & composition
- Level legs at 300 m ASL (≈ AGL here) are well within the polluted part of the BL
DISCOVER Vertical Distributions

Concentrated part of the mixed layer to 400 m ASL

Max BL depth 1000 m

NASA P3 sampled routinely at 300 m ASL, with vertical profiles from the surface to 3000 m
Wintertime INvestigation of Transport, Emissions and Reactivity (WINTER)

NSF / NCAR C-130 Aircraft February 1 – March 15, 2015, United States East Coast

- 13 Research Flights / ~ 100 hours
- Approximately 50% of flight hours at night
- 70% within 1 km of the surface
- No two flights the same – individual goals for each research flight

Research Goals
- Distribution and lifetime of primary pollutants
- Heterogeneous / multiphase processes
- Secondary aerosol formation mechanisms
- Wintertime oxidants

Comprehensive gas and aerosol payload

NASA Langley
**WINTER – Example Winter BL Flight**

- Daytime flight to Ohio River Valley, February 6 2019
- Aircraft sampled at ~ 400 – 700 m ASL / 300 – 500 m AGL
- Missed approaches to regional airfields
- Night flights sampled in a similar altitude range – but condition dependent
Utah Winter Fine Particulate Study (UWFPS)

January 15 – February 14, 2017

A Twin Otter aircraft and ground based investigation of high PM$_{2.5}$ events in basins of northern Utah

23 research flights / ~80 hours
Intensive, repeated sampling of 3 major basins + Great Salt Lake
Nighttime and daytime flights
Twin Otter minimum cruise altitude of 500’ (150 m) over rural areas, 500 – 1000’ (150 - 300 m) over urban areas.
Opportunity for Future Western U.S. Winter Aircraft Study

Proven capability to fly in shallow winter boundary layers, but limited payload / scientific goals and range

Extensive payload / detailed instrumentation and ability to sample the entire western U.S. but potentially less appropriate for shallow BL

NOAA aircraft request timeline:
• Nov – Jan window for following year
• Discussion ongoing at NOAA CSD currently re: a winter 2022 or 2023 project
NOAA/ESRL/CSD TOPAZ Ozone and Aerosol Lidar
(TOPAZ = Tunable Optical Profiler for Aerosols and oZone)

- Ground-based scanning system permits pointing at shallow elevation angles
- Time resolution: 5 min per multi-angle scan
- Altitude coverage: 15 m – 3 km AGL
- Ozone and Aerosol Backscatter profiles

NOAA / CSD Airborne Doppler Lidar

- Downward looking scanning Doppler Lidar
- Vertical and Horizontal wind and aerosol backscatter intensity
- Resolution: 60m along beam, 10Hz beam rate
- Altitude coverage: through the boundary layer

Clean Mountain air
- Downward looking scanning Doppler Lidar
- Vertical and Horizontal wind and aerosol backscatter intensity
- Resolution: 60m along beam, 10Hz beam rate
- Altitude coverage: through the boundary layer

Frontal passage over Boulder CO
- Arrows show direction / color is wind speed.
- Curtain is aerosol measurement – green is higher concentration vs blue
NOAA/ESRL/CSD TOPAZ Ozone and Aerosol Lidar

(TOPAZ = Tunable Optical Profiler for Aerosols and Ozone)

- Ground-based scanning system permits pointing at shallow elevation angles
- Time resolution: 5 min per multi-angle scan
- Altitude coverage: 15 m – 3 km AGL
- Ozone and Aerosol Backscatter profiles

NOAA / CSD Doppler Lidar

- Ground based, scanning Doppler Lidar
- Turbulence and Horizontal wind and aerosol backscatter intensity
- Boundary layer heights

Wind Speed and Direction

Aerosol Backscatter Intensity

Vertical Velocity Variance