PNNL

Analysis of TBS INP measurements during the AGINSGP experiment

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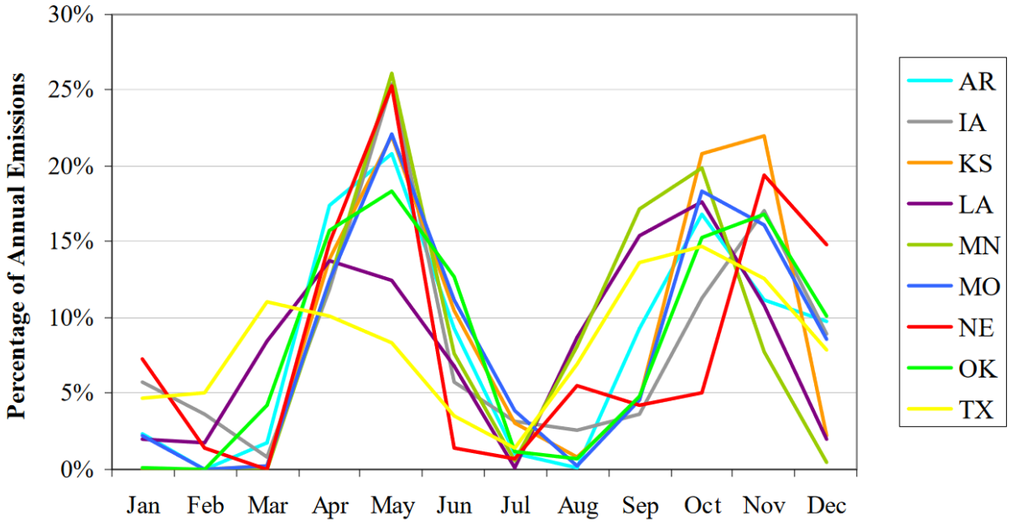
Motivations

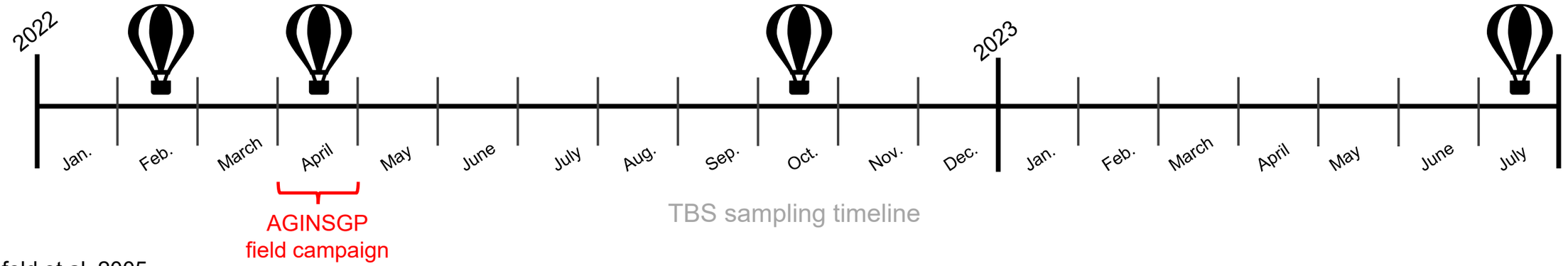
- Ice nucleation activity is a strong function of size, and thus INP concentrations tend to be dominated by large particles
- Vertical transport of ice nucleating particles (INPs) is required for them to be able to impact clouds
- The efficiency of the vertical transport of large particles and INPs is not well constrained
- There are limited observations of vertical profiles of INPs
- The TBS is well-suited to measure the vertical profiles of aerosol particles

Project overview

- Collaboration with EMSL and ARM to use the TBS to measure vertical profiles of aerosol and INPs at the SGP site
  - Agricultural soils are hypothesized to be a prominent source of INPs at SGP
  - Four sampling campaigns conducted at SGP during different times of the year in order to capture different time points within the agricultural emission cycle (right)
  - One of these campaigns overlapped with the AGINSGP campaign
  - See poster sessions for more details on field campaign



Seasonal cycle of agricultural soil emissions in the Great Plains.



TBS sampling timeline

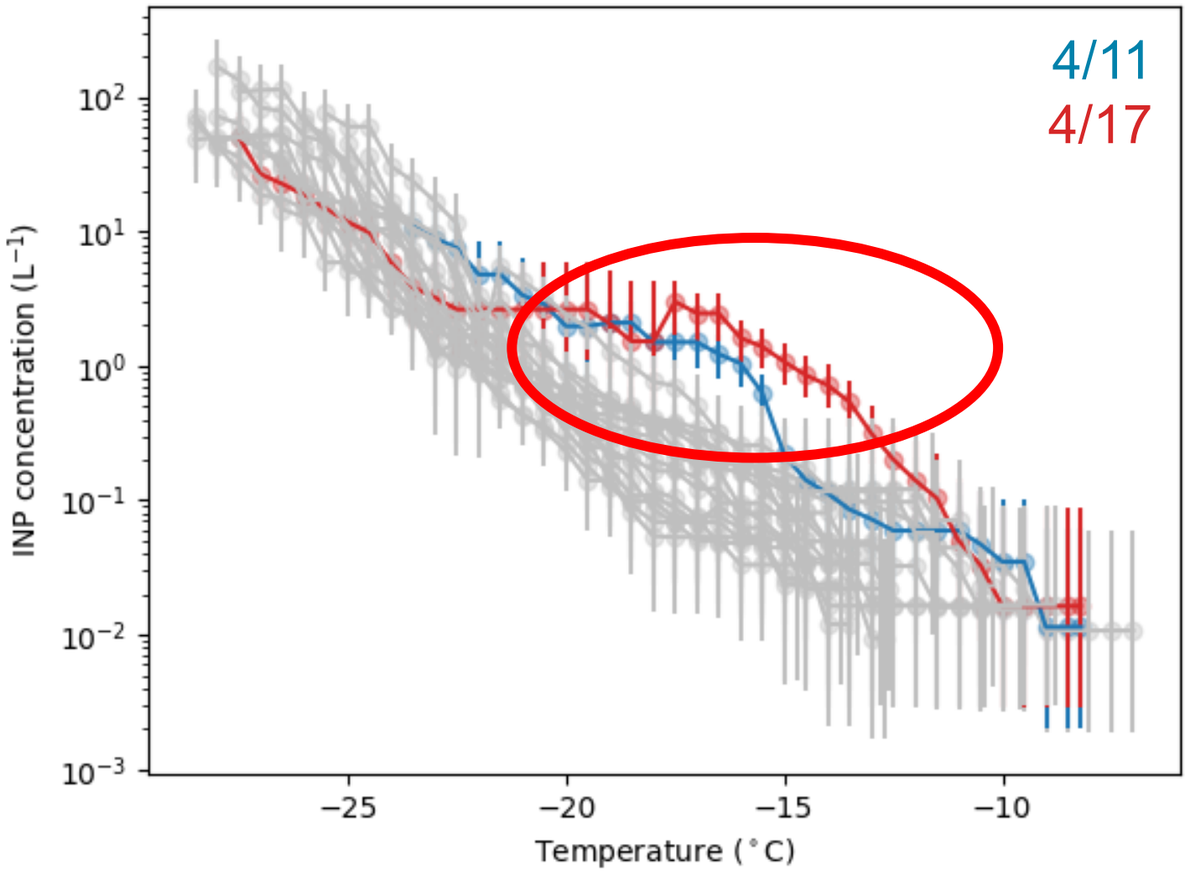
Penfold et al. 2005.

Overview of TBS flights during the AGINSGP campaign

Photo of the TBS in action on April 11. Photo courtesy of Dari Dexheimer.

- Payload included CPC, POPS, meteorology sensor, STAC (substrate sampling), and IcePuck
  - IcePuck samples were frozen after collection and shipped to CSU for analysis
  - Immersion freezing INPs were quantified using the ice spectrometer
- Total of 18 flights where INP samples were collected
- Ground-based measurements provide complementary information
  - INP concentrations (CFDC and PINE), particle size (APS), composition (miniSPLAT and substrates)
  - ARM measurements

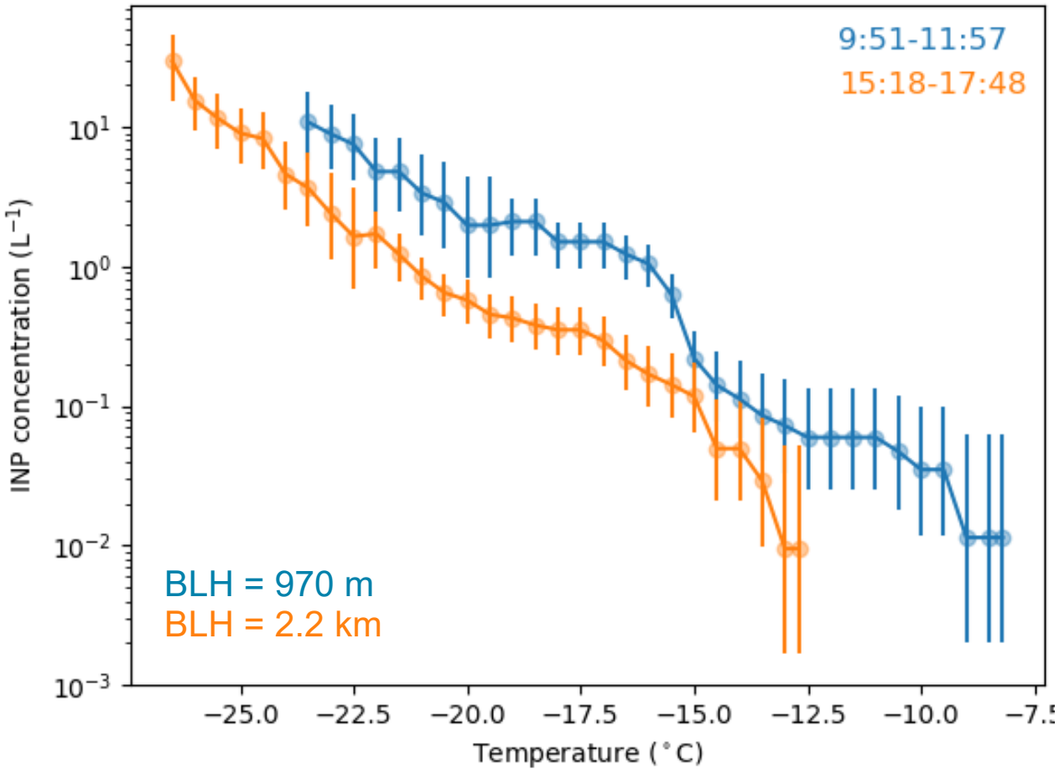
Two of the flights had high INP concentrations at warmer temperatures



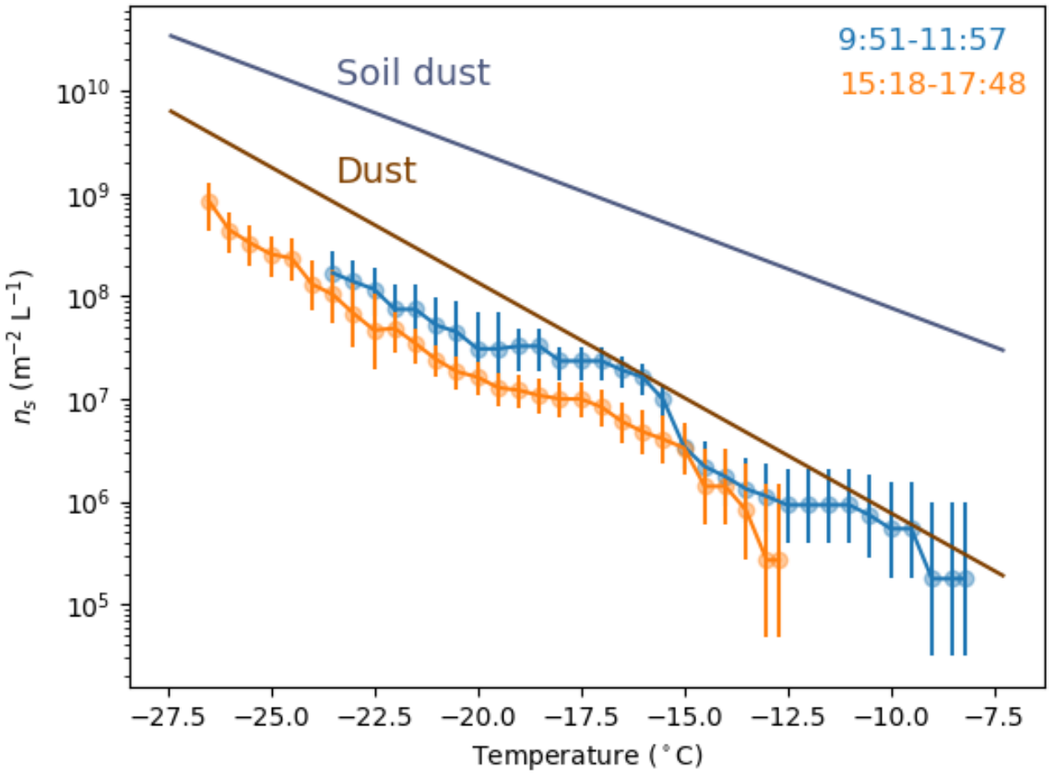
INP concentrations from samples collected aboard the TBS during the AGINSGP campaign.

Why are INP concentrations elevated during these two flights?

INP concentrations on 4/11 are similar when normalized by particle surface area



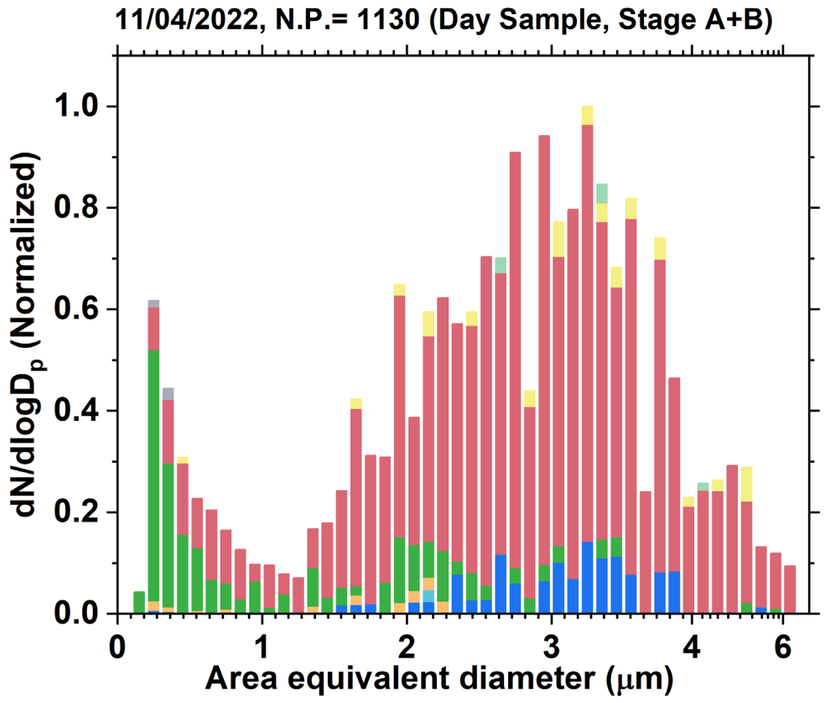
INP concentrations from TBS flights on 4/11.



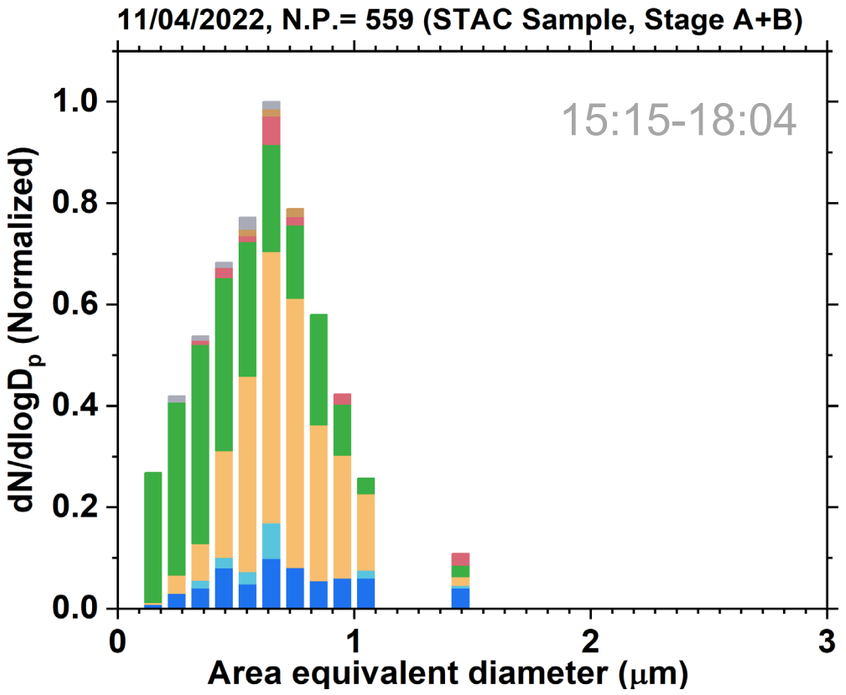
n_s spectra from the TBS flights on April 11. Particle surface areas were calculated from the POPS.

Particle composition between ground and airborne varies substantially

4/11/2022 ground all day



4/11/2022 Flight 2



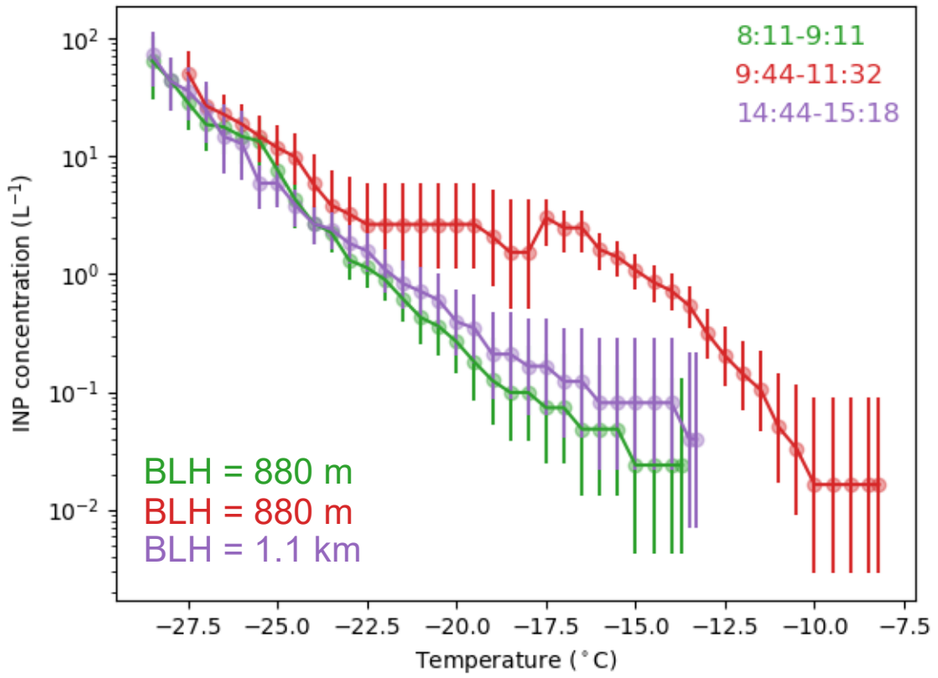
Ground sample is clearly dusty, while second flight has little to no dust

Still more work needs to be done on disentangling the effect of composition on INP activity

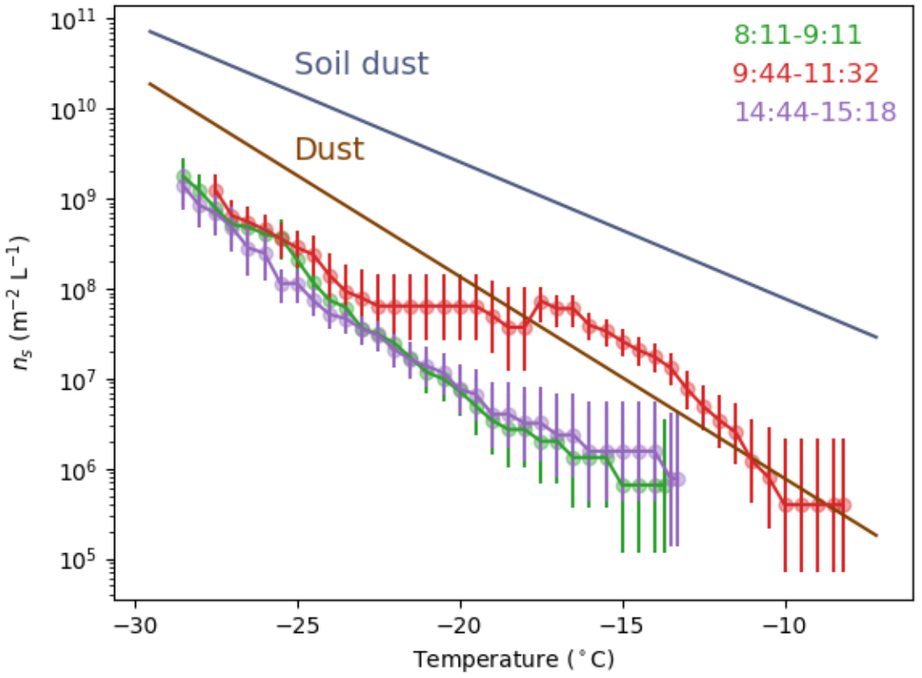
Na-rich | Na-rich Sulfate | Sulfate | Carbonaceous | Dust
Biological | Si-rich Sulfate | K-rich Sulfate | Other

Figures courtesy of Nurun Nahar Lata.

One flight on April 17 had elevated INPs and n_s



INP concentrations from TBS flights on April 17.

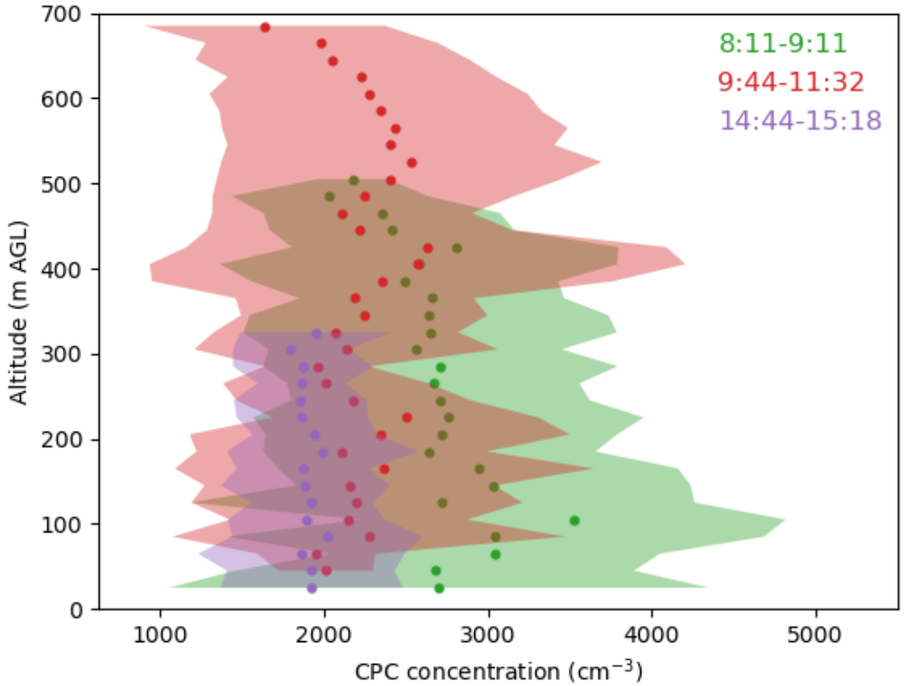


n_s spectra from the TBS flights on April 17. Particle surface areas were calculated from the POPS.

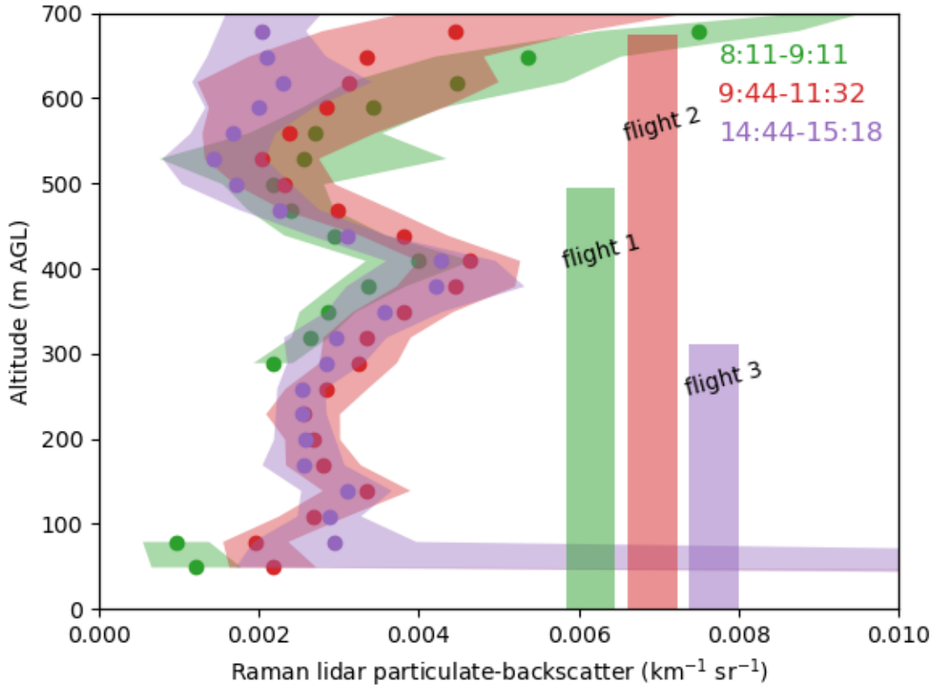
Particle composition appears to be a strong factor controlling IN activity for flight 2

Need to confirm this hypothesis with the composition analysis

Both lidar and TBS data shows elevated particle concentrations aloft



CPC concentration profiles from TBS flights on April 11.



Raman lidar backscatter vertical profiles corresponding to the time periods from the TBS flights on April 17.

Flight 2 samples higher than either of the other two flights, which may help explain the difference in IN-activity for those particles

Conclusions and future directions

Conclusions

- Two flights on separate days have higher INP concentrations
- For the first day, INP concentrations appear to be at least partly a function of total particle surface area
- For the second day, elevated INP concentrations were associated with sampling at higher altitudes
  - May be indicative of a difference in particle composition

Future directions

- Analysis of particle composition
- Investigate ground-based particle composition for periods of interest
  - WIBS, miniSPLAT are of particular interest
- Use ground-based, real-time INP measurements to better understand the relationship between INPs aloft and at the surface

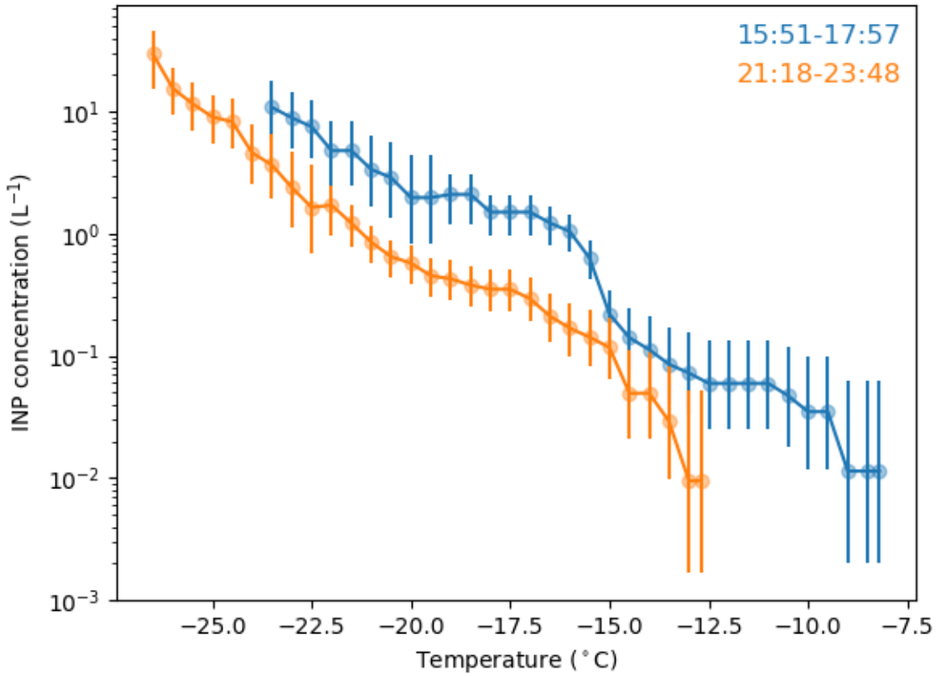
Acknowledgements

- Field campaign
  - Isabelle Steinke, Susannah Burrows
- ARM
  - Dari Dexheimer and the TBS team
  - Jessie Creamean, Tom Hill, Carson Hume
  - Mike Ritsche and the SGP site staff
- EMSL
  - Swarup China, Nurun Nahar Lata

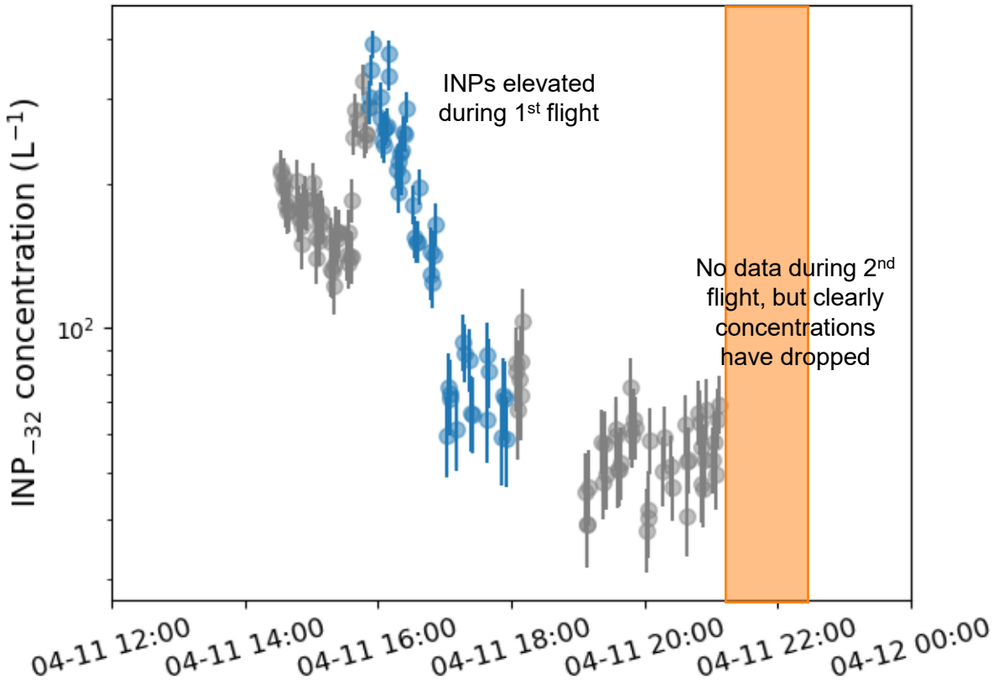
Backup slides

Comparison of aloft and ground-based INP concentrations

INP concentrations aloft and at the ground have a roughly similar temporal profile

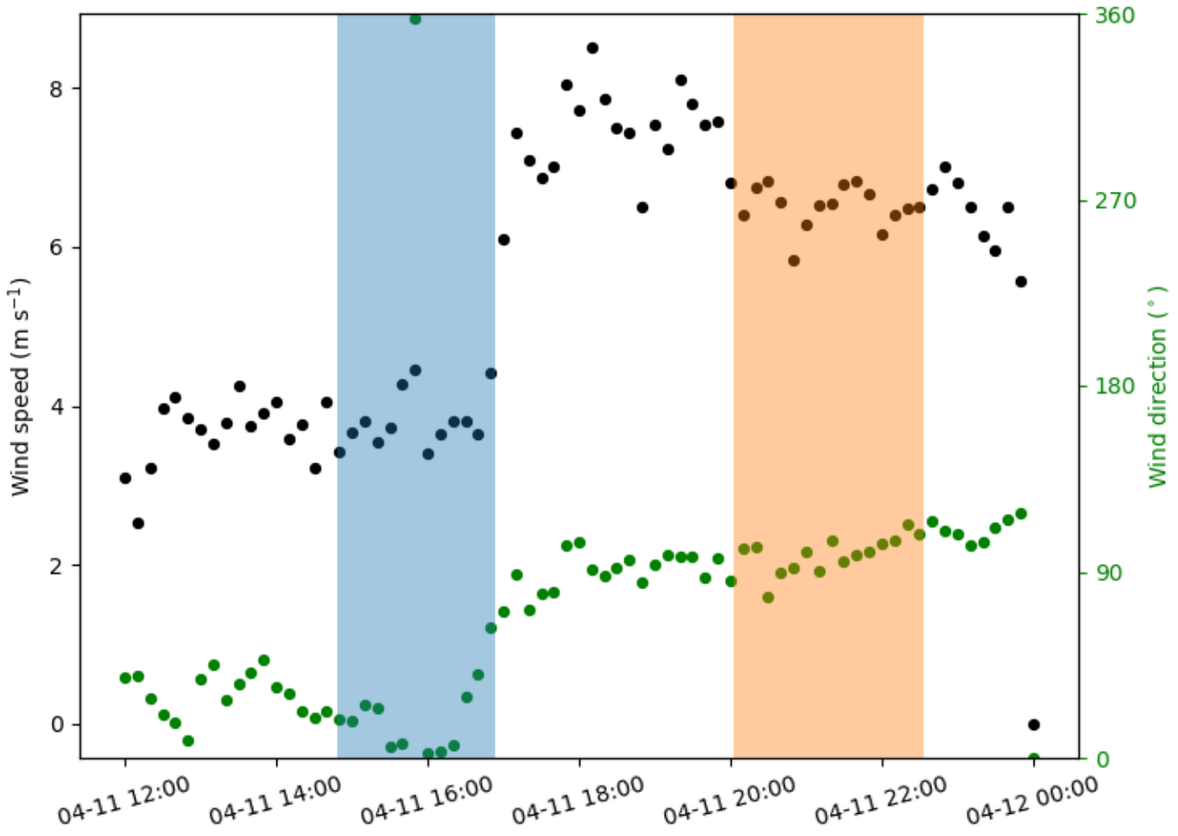


INP concentrations from TBS flights on 4/11.



INP$_{-32}$ concentrations measured by the CSU CFDC on 4/11.

Measured INP concentrations shift with change in airmass



Wind speed and direction for April 11.

Time period with elevated INP concentrations has northerly winds

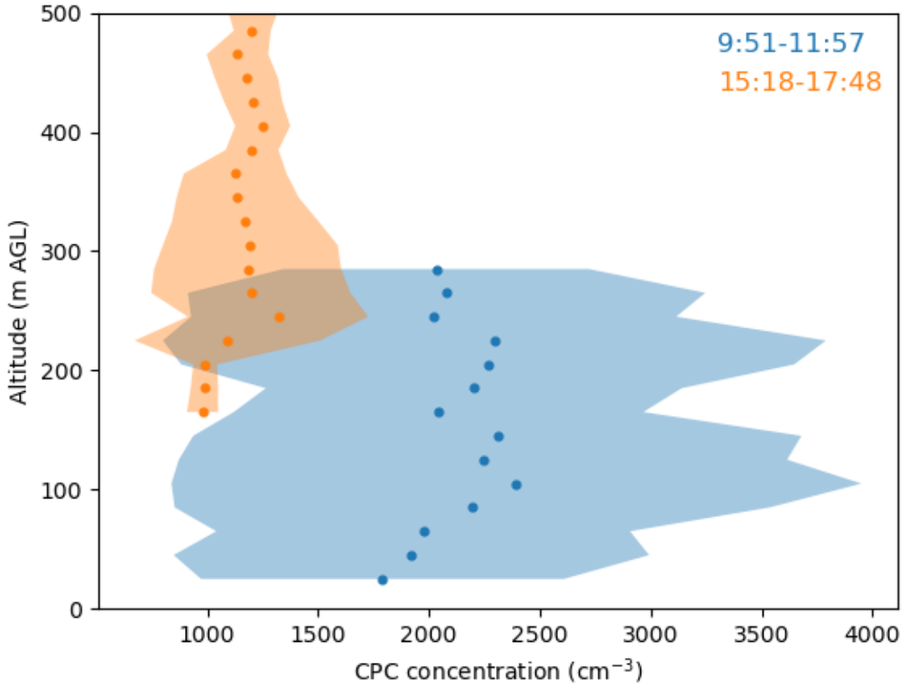
Clear change in wind speed and direction after first sampling period, then leads to period with lower INP concentrations

Winds are stronger in the afternoon

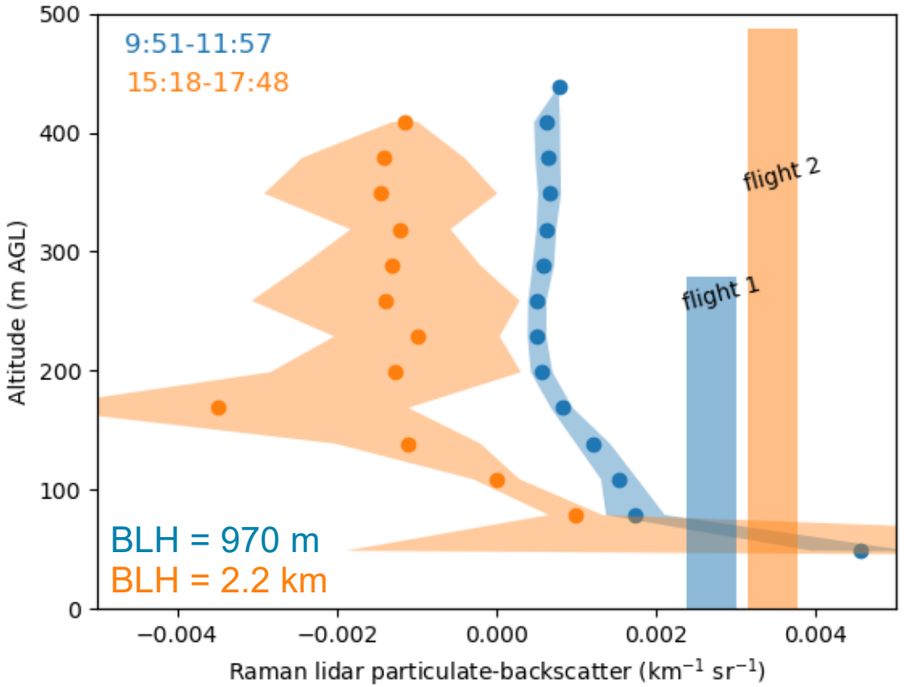
Looks like a frontal passage, but it's not! Front passes early in the morning

Change in winds *associated* with the development of the boundary layer

Particle concentrations are higher during first flight due to a lower boundary layer



CPC concentration profiles from TBS flights on 4/11.

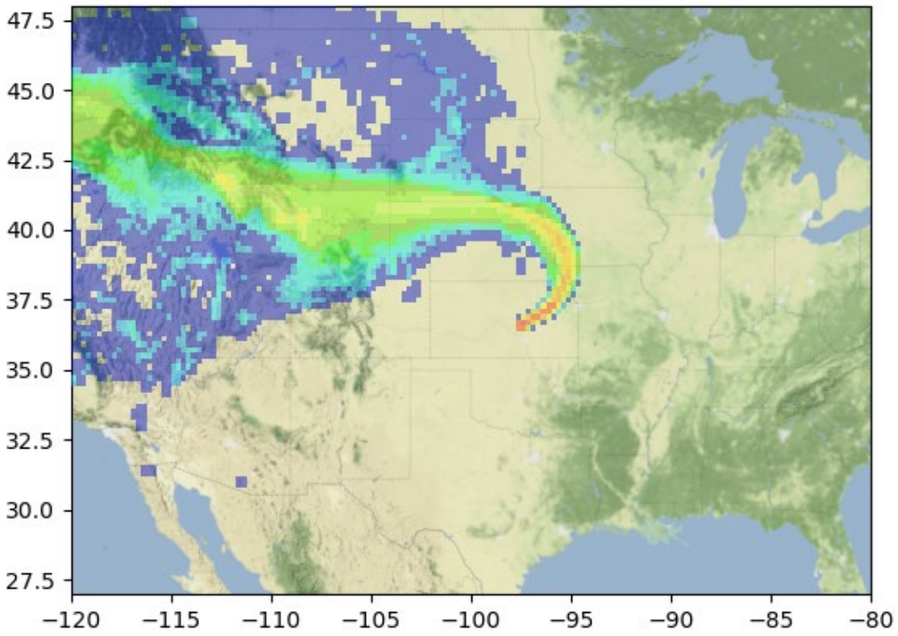


Raman lidar backscatter vertical profiles corresponding to the time periods from the TBS flights on 4/11.

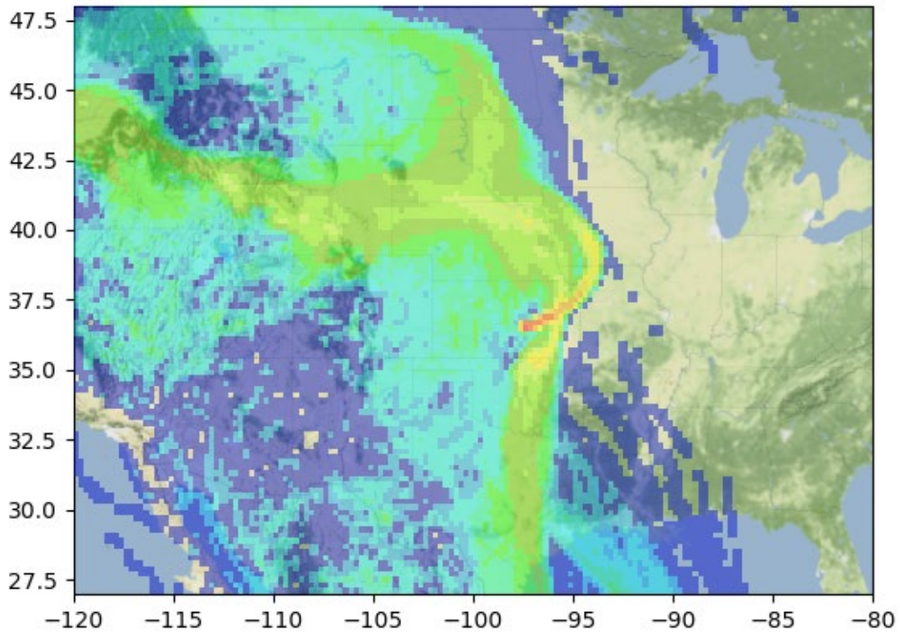
Boundary layer is well-mixed for both flights, but is substantially higher during second flight which has lower particle concentrations

Source-receptor footprints for April 11

Flight 1

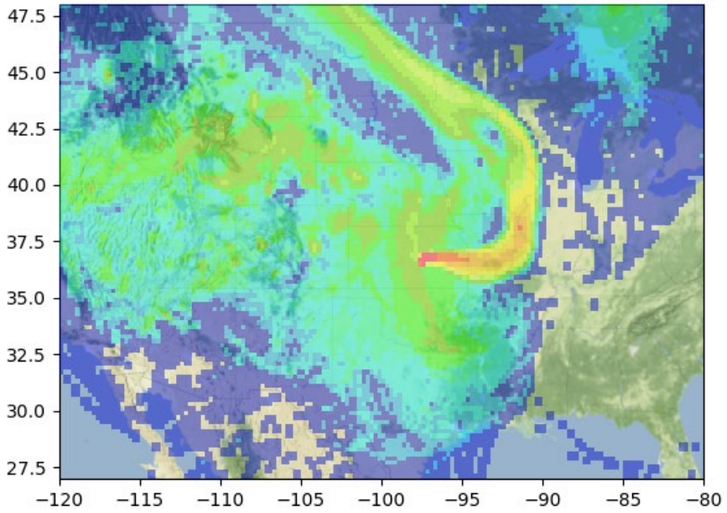


Flight 2

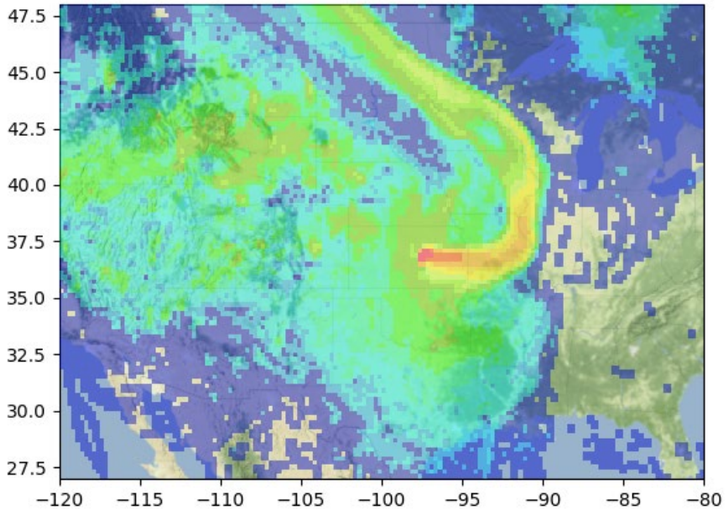


Source-receptor footprints for April 17

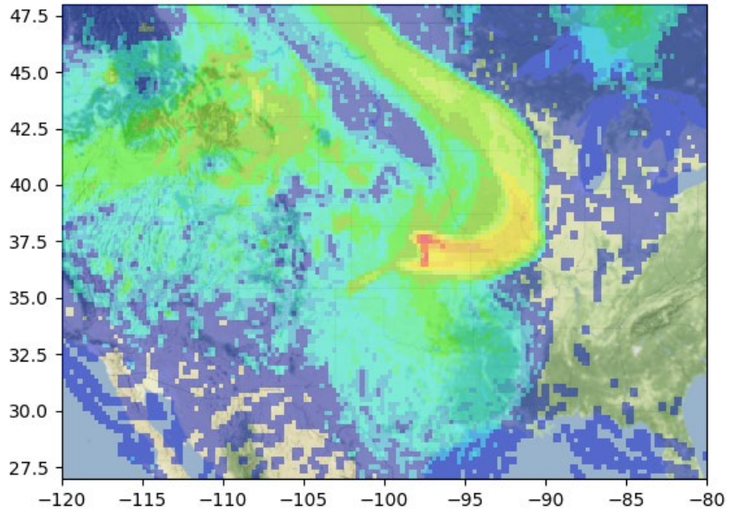
Flight 1



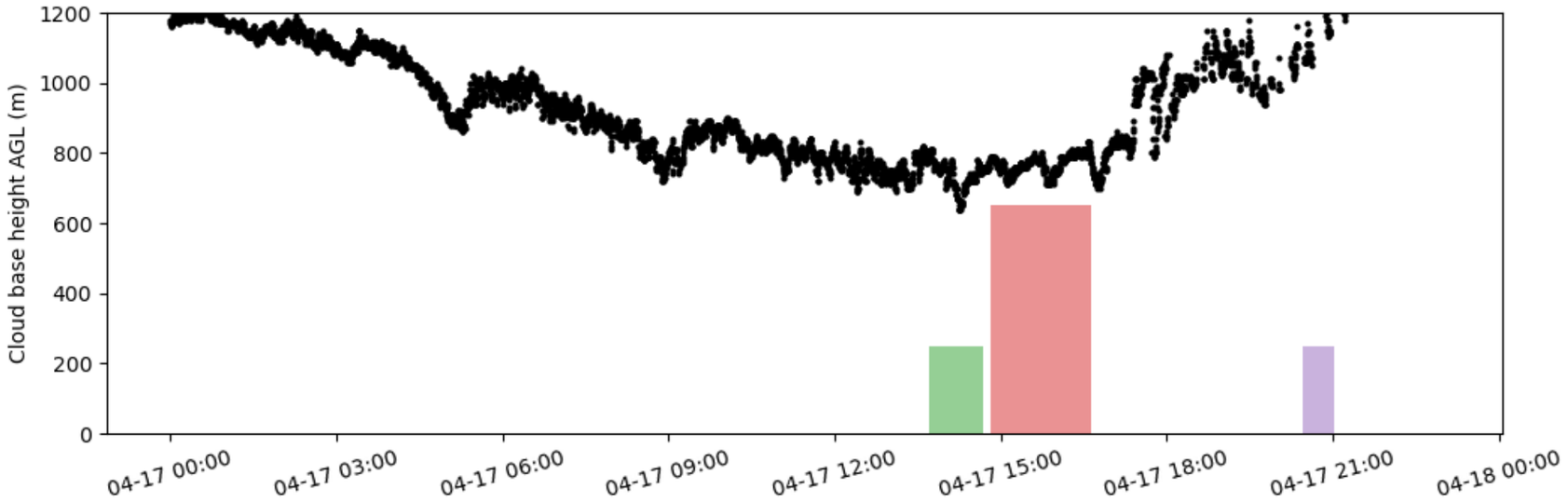
Flight 2



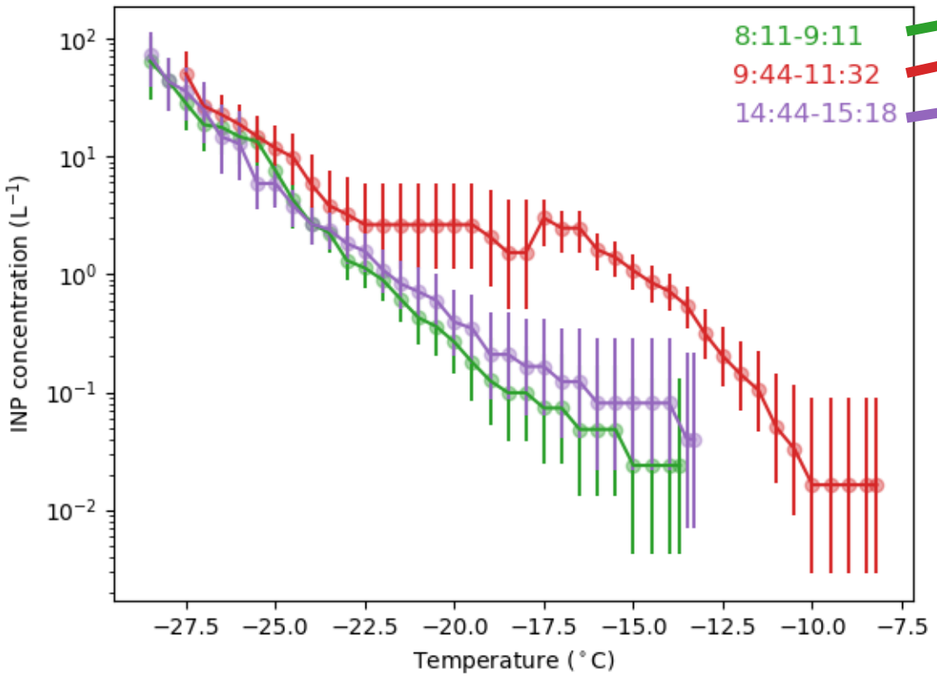
Flight 3



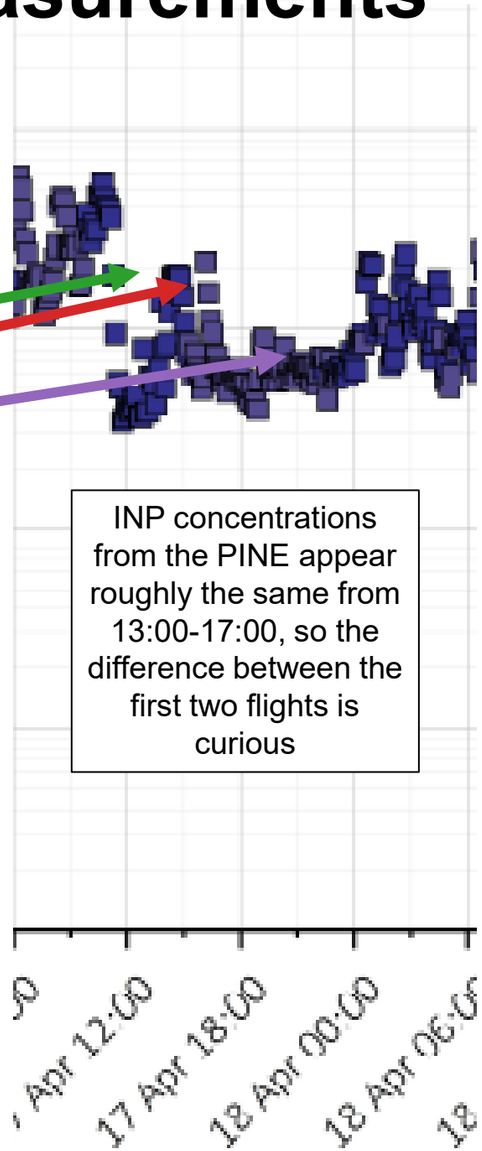
Flight 2 sampled just below cloud base



Comparison of TBS INP concentrations on April 17 with ground-based measurements

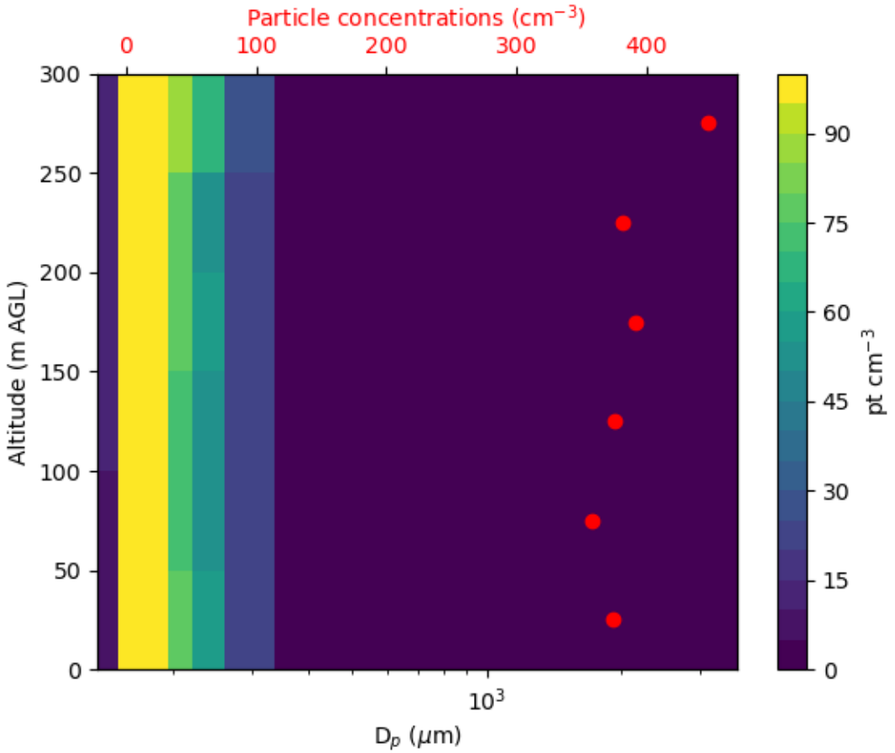


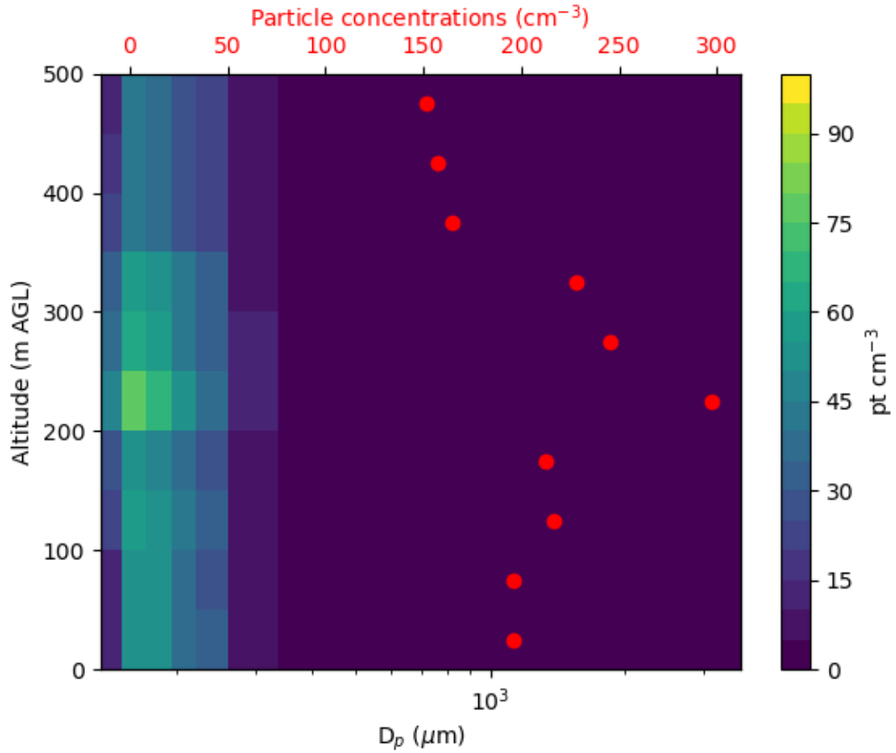
INP concentrations from TBS flights on April 17.



INP concentrations from the PINE appear roughly the same from 13:00-17:00, so the difference between the first two flights is curious

POPS size distributions by altitude for April 11





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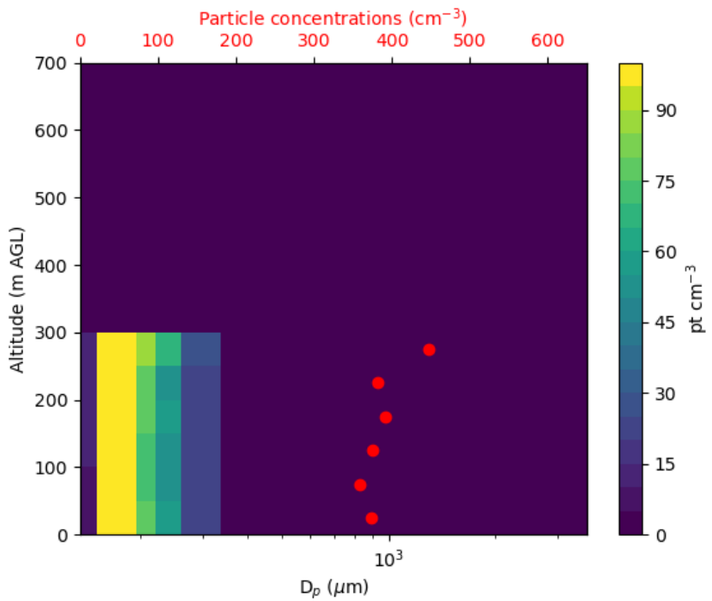
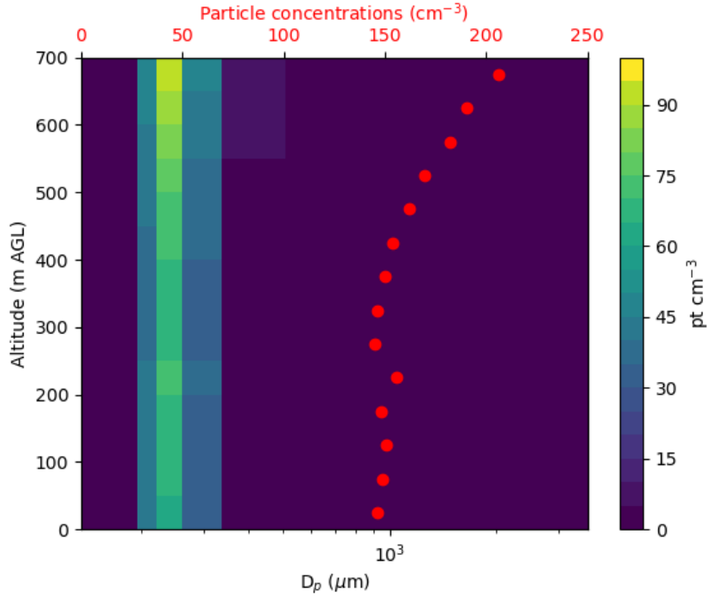
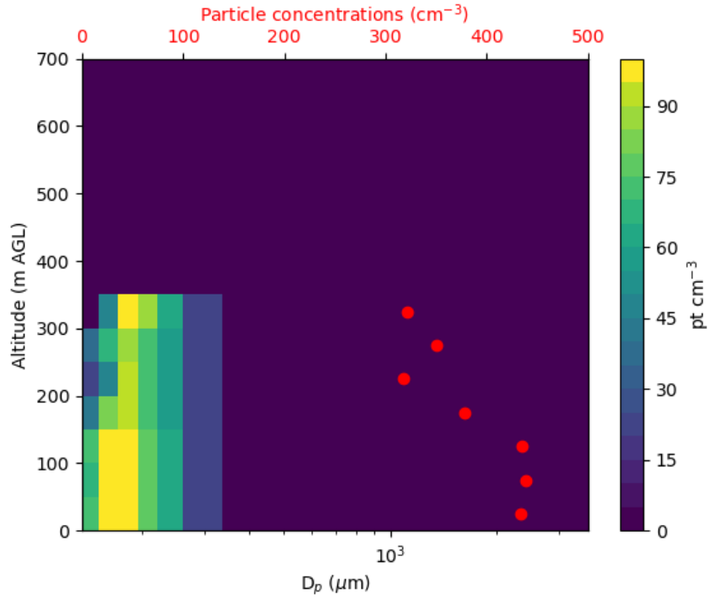
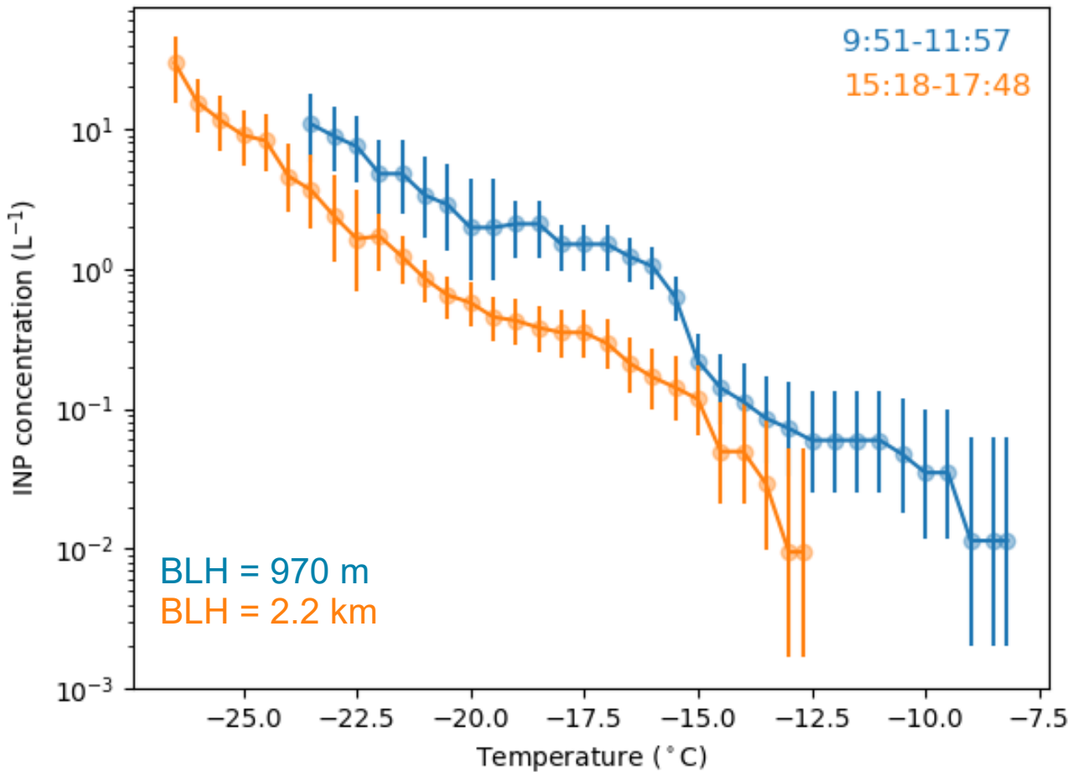






INP concentrations for flights on April 11 are similar when normalized by particle surface area



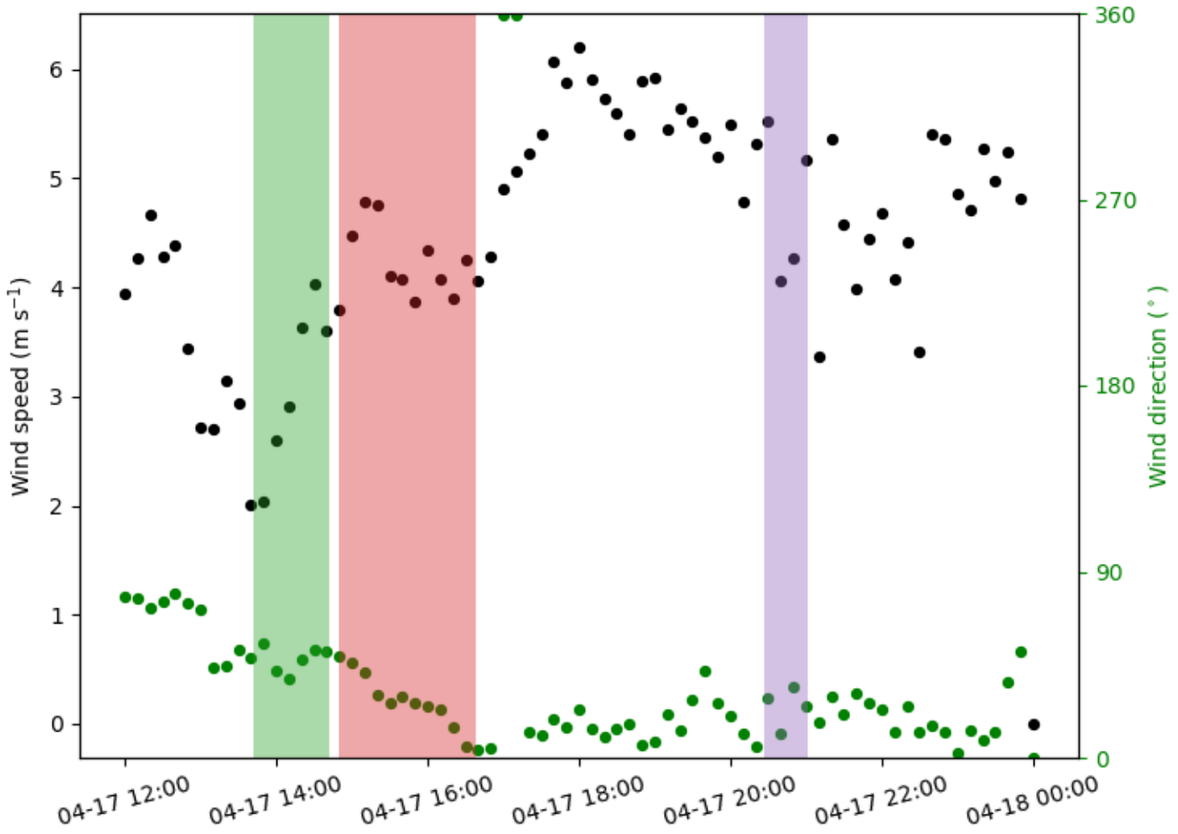
n_s spectra from the TBS flights on April 11. Particle surface areas were calculated from the POPS.

Ice nucleation active site density (n_s) normalizes INP concentrations by particle surface area, and describes the IN activity of particles

The n_s profiles for the two flights are quite similar, which implies that some of the difference in INP concentrations is particle concentrations

SEM can help clear up what role composition plays

No clear connection between surface winds and INP concentrations

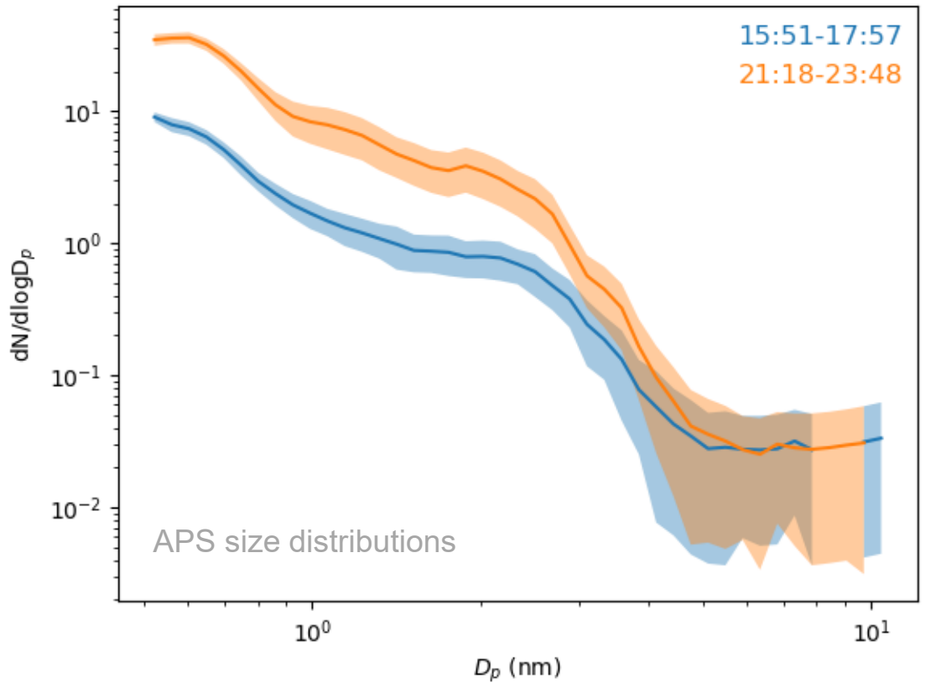


Wind speed and direction for April 17.

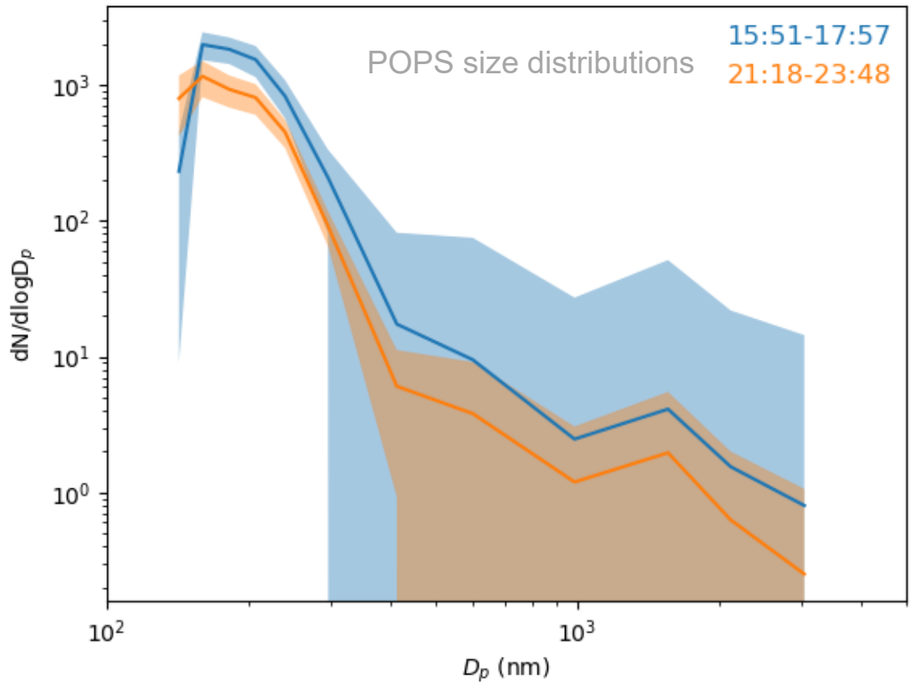
Winds start off E/NE then slowly shift toward northerly winds

Period with higher INP concentrations (red) has mostly north-easterly winds

Comparison of ground-based and onboard size-distributions for April 11



Particle concentrations measured at the ground are higher for the second flight



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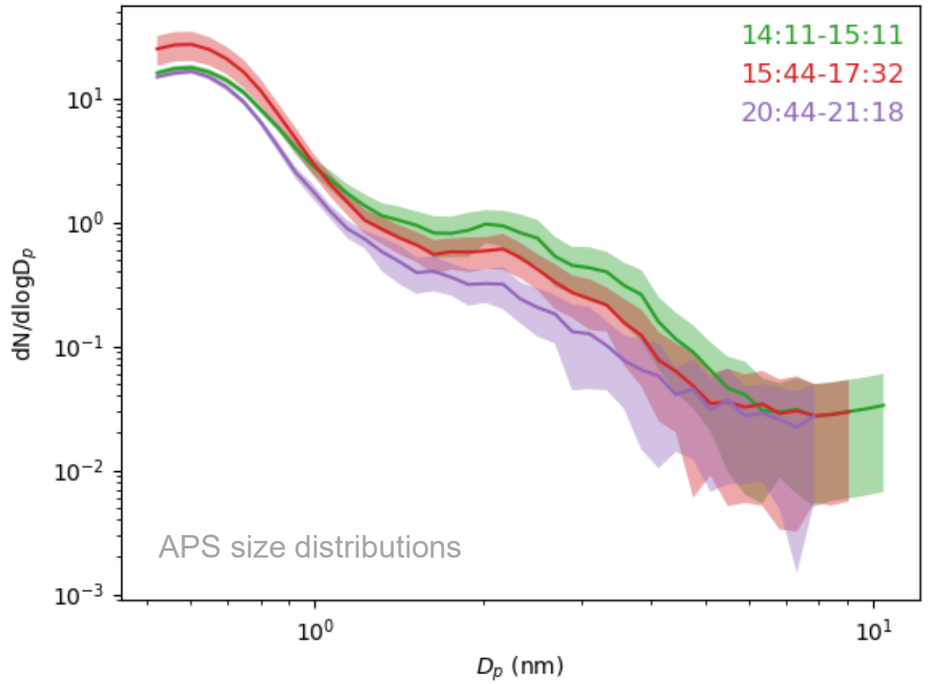
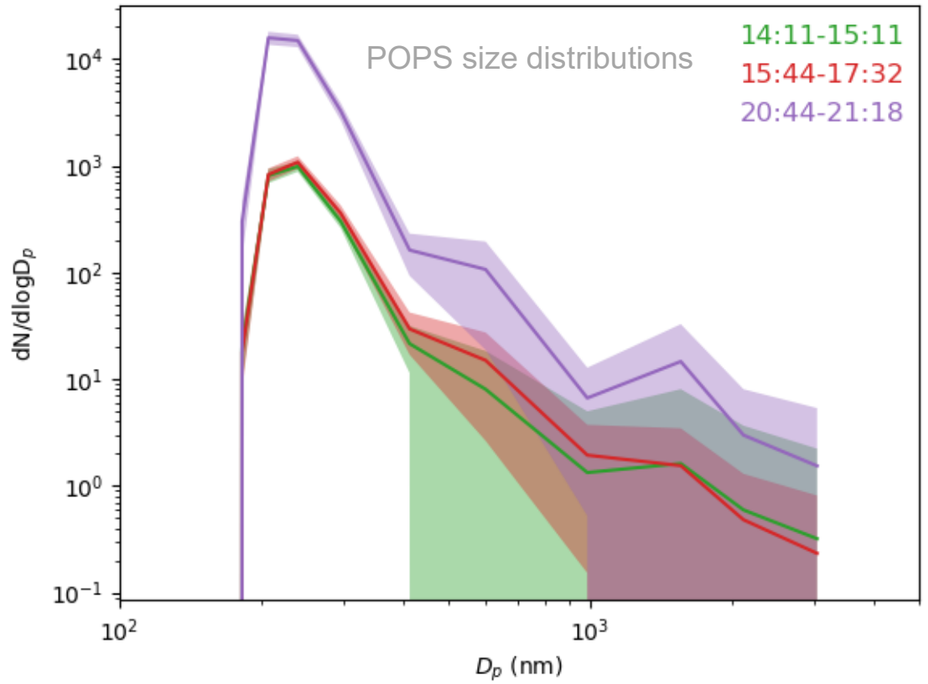
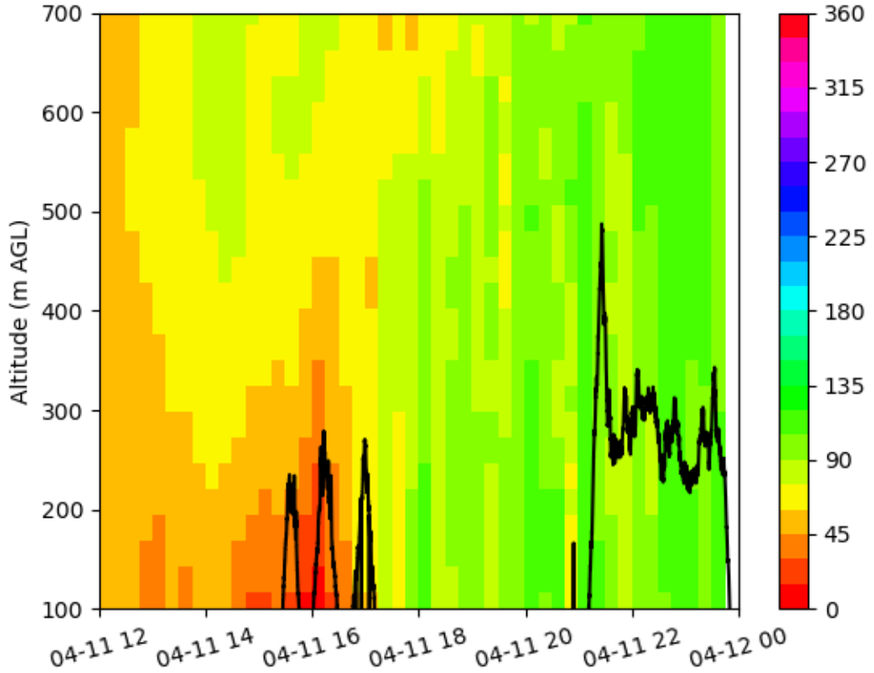


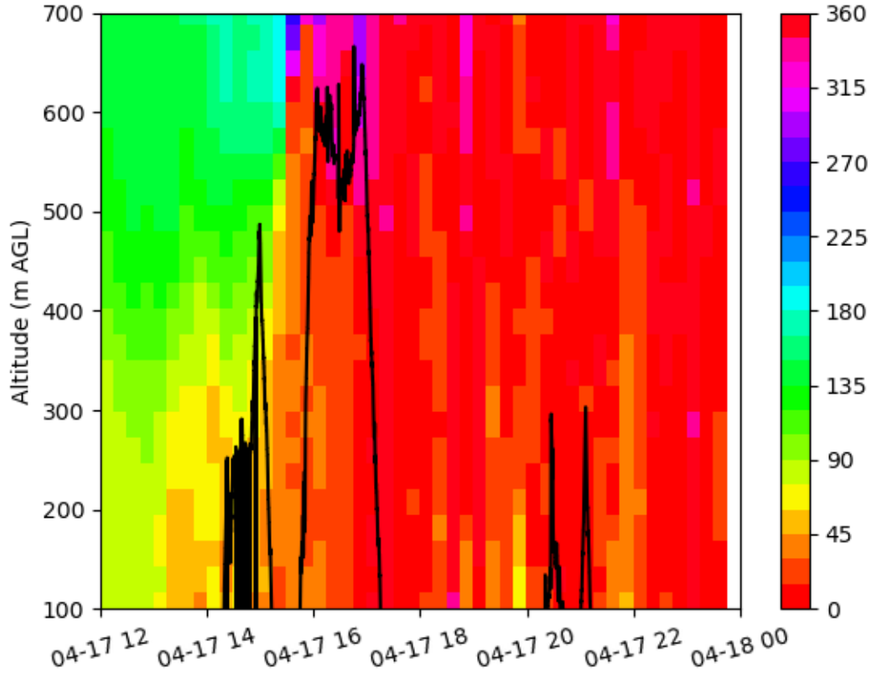
As size/number does not seem to be a major factor in INP concentrations, the composition of these particles is likely a significant factor

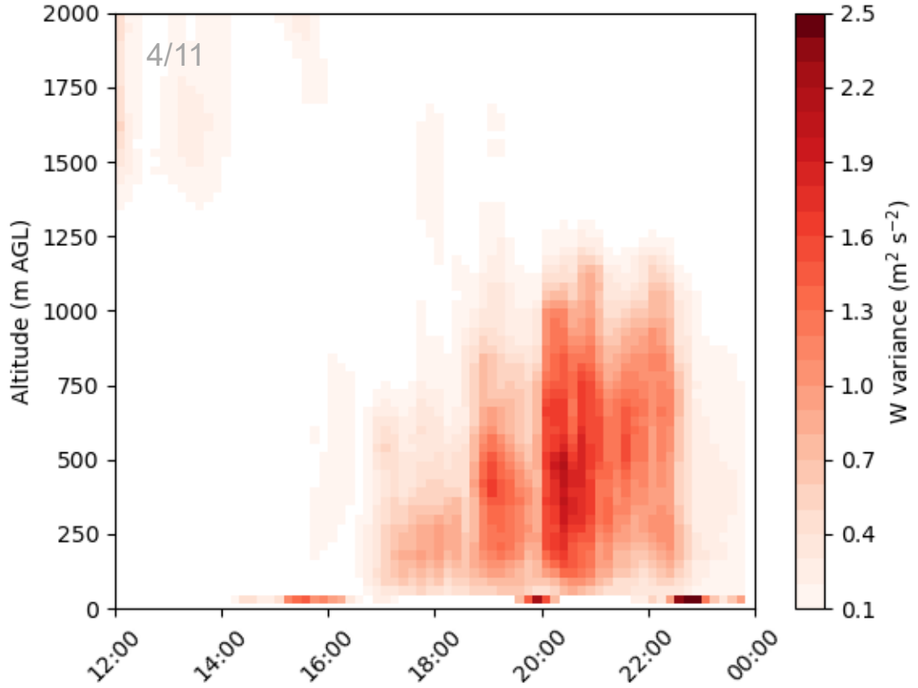


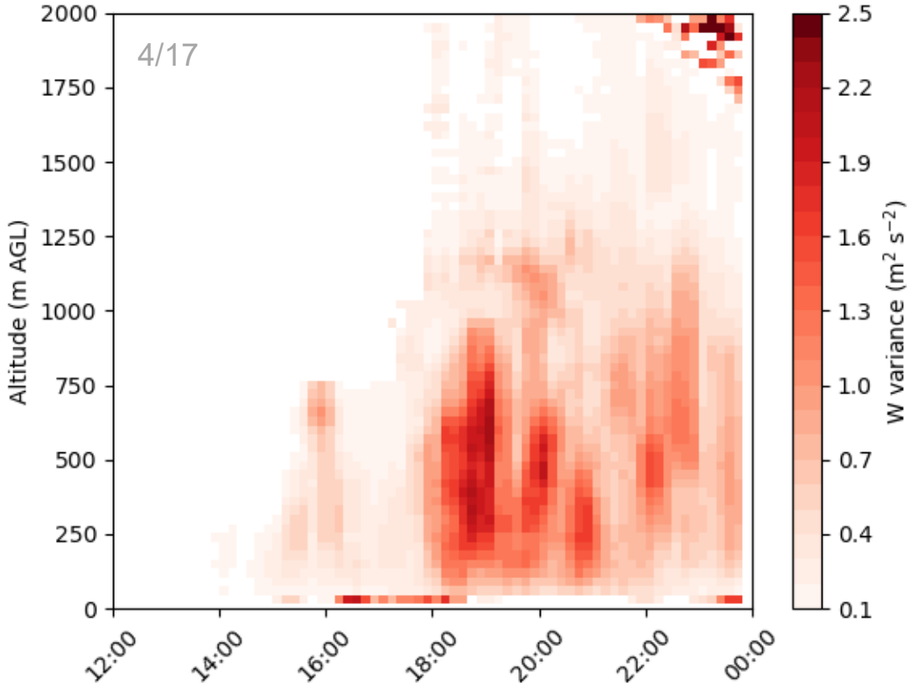
Once again, there is not great agreement between the two different particle sizers (which is not necessarily surprising)

Vertical profiles of wind direction from the doppler lidar

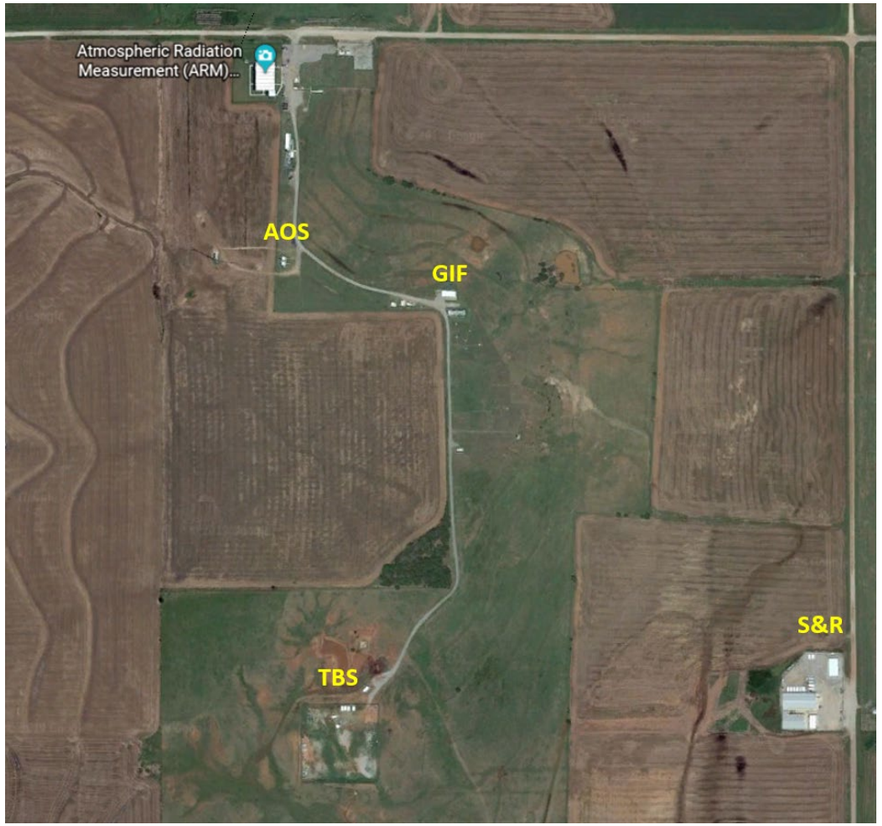


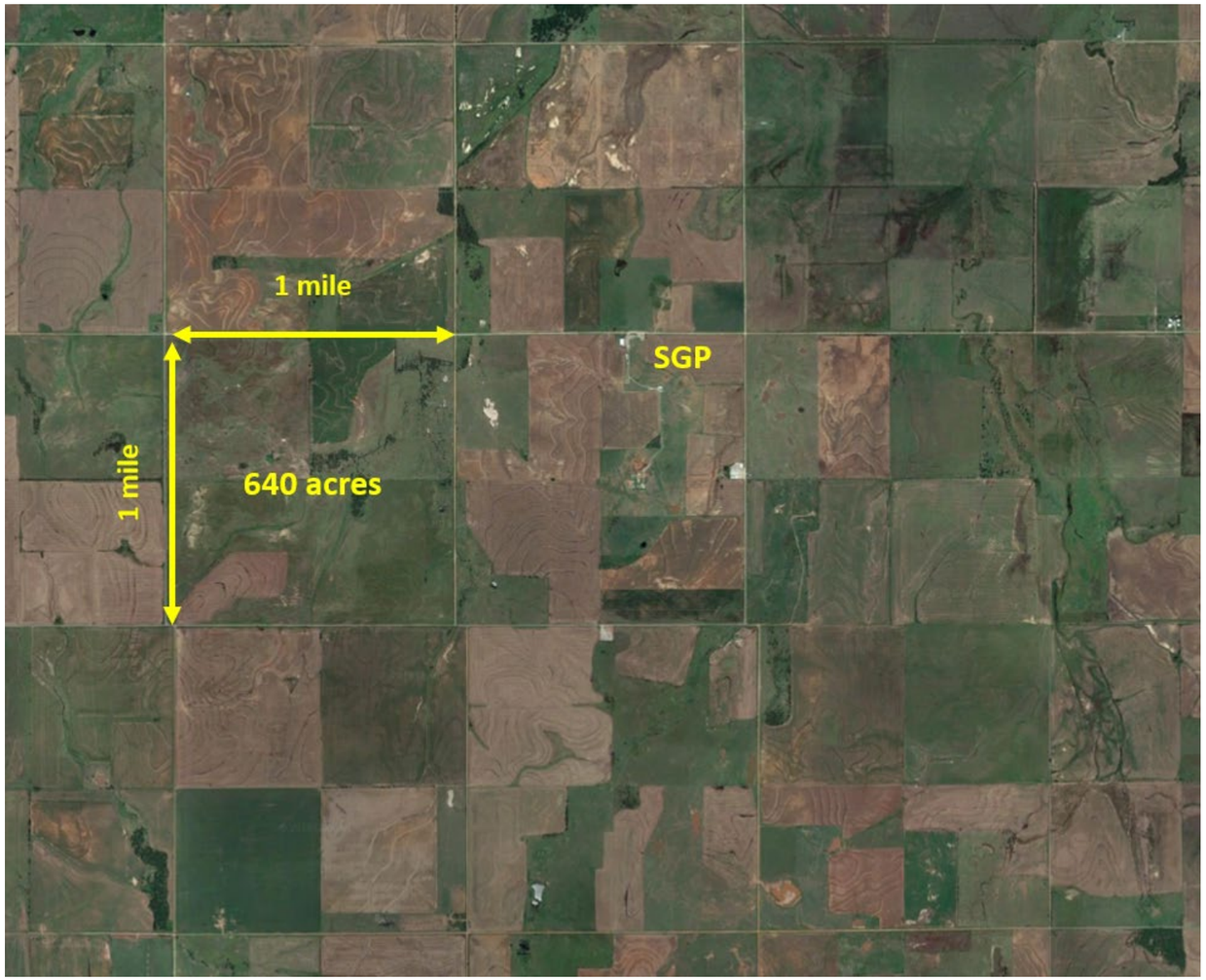


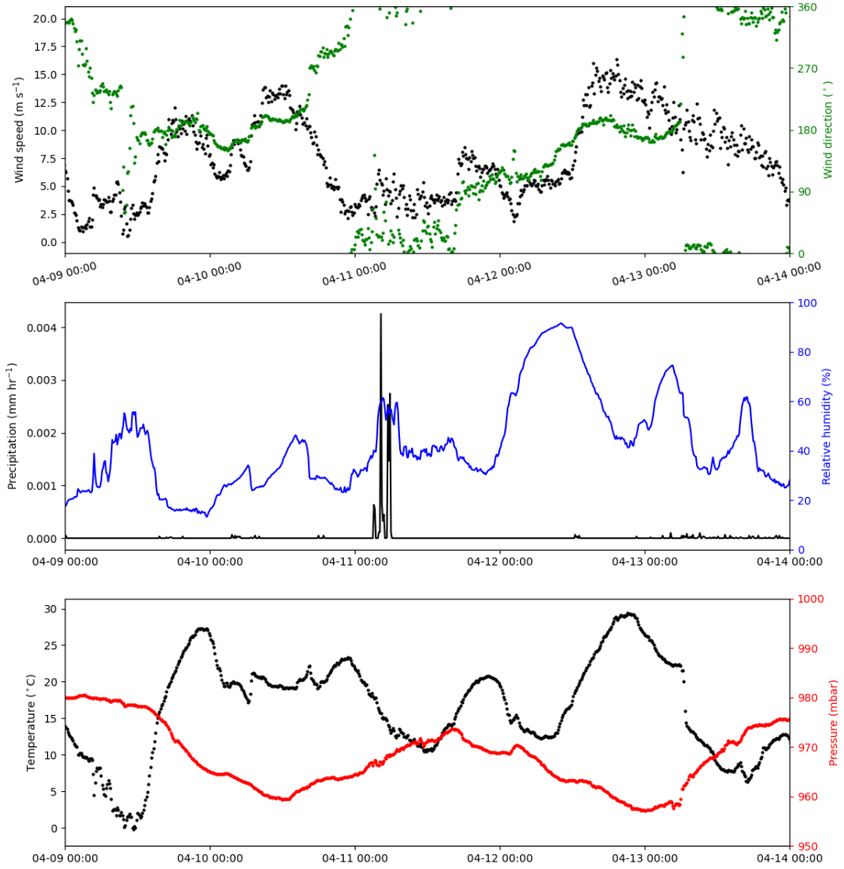

4/11
Altitude (m AGL)
2000
1750
1500
1250
1000
750
500
250
0
12:00
14:00
16:00
18:00
20:00
22:00
00:00
W variance (m² s⁻²)
2.5
2.2
1.9
1.6
1.3
1.0
0.7
0.4
0.1

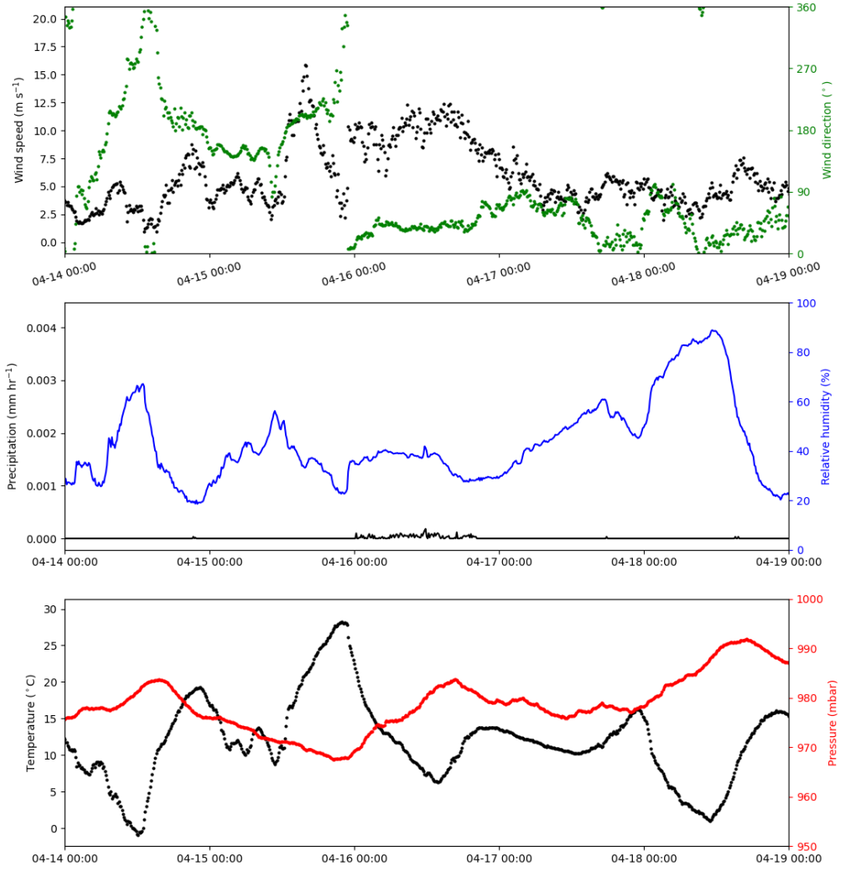

4/17
Altitude (m AGL)
2000
1750
1500
1250
1000
750
500
250
0
12:00
14:00
16:00
18:00
20:00
22:00
00:00
W variance (m² s⁻²)
2.5
2.2
1.9
1.6
1.3
1.0
0.7
0.4
0.1

PNNL


Atmospheric Radiation Measurement (ARM)...
AOS
GIF
S&R
TBS


1 mile
1 mile
640 acres
SGP


Wind speed (m s⁻¹)
Wind direction (°)
Precipitation (mm hr⁻¹)
Relative humidity (%)
Temperature (°C)
Pressure (mbar)
04-09 00:00
04-10 00:00
04-11 00:00
04-12 00:00
04-13 00:00
04-14 00:00


Wind speed (m s⁻¹)
Wind direction (°)
Precipitation (mm hr⁻¹)
Relative humidity (%)
Temperature (°C)
Pressure (mbar)
04-14 00:00
04-15 00:00
04-16 00:00
04-17 00:00
04-18 00:00
04-19 00:00

PNNL

Date	Flight #	BL height	Altitude	Start time	End time	POPS	CPC	STAC	IcePuck	R1046 (Met)	Notes
4/11/2022	1	0.97 km	0-250 m	15:34	17:57	x	x	x	x	x	A couple of descents due to instrument issues, reduced POPS concentrations
4/11/2022	2	2.2 km	250-500 m	20:54	0:04	x	x	x	x	x	A couple of descents due to instrument issues, reduced POPS concentrations
4/14/2022	1	0.49 km	250-500 m	14:15	15:35	x	x	x	x	x	Low POPS, but increases over time aloft
4/14/2022	2	0.1 km	250-500 m	15:42	17:21	x	x	x	x	x	INP event?
4/14/2022	3	0.86 km	0-250 m	18:47	20:00	x	x		x	x	Flight ended b/c of gusts
4/14/2022	4	1.8 km	0-215 m	23:42	0:00	x	x			x	Early flight
4/15/2022	1	0.49 km	0-75 m	20:20	20:35					x	Test flight with RAVEN prototype (tethersonde)
4/15/2022	2	???	0-370 m	21:00	21:51	x	x	x		x	High surface concs.
4/15/2022	3	???	0-750 m	21:58	23:01	x	x	x		x	0-250, 250-500, 500-750 STAC
4/17/2022	1	0.88 km	0-500 m	14:10	15:17	y	x	x	x	x	0-250 m, 250-500 m, and 250 loiter, I think the POPS was flown
4/17/2022	2	0.7 km	0-650 m	15:34	17:18	x	x	x	x	x	0-650 m, nimbostratus deck at 700 m
4/17/2022	3	1.1 km	0-250 m	20:07	21:15		x		x	x	TUBES instrument from Baylor
4/17/2022	4	1.3 km	0-250 m	21:24	21:42	x	x			x	CPC comparison?
4/17/2022	5	????	0-250 m	21:47	23:12	x	x	x		x	
4/18/2022	1	0.55 km	0-130 m	15:00	16:01	x	x		x	x	Ran out of IcePuck time
4/18/2022	2	1.07 km	0-110 m	17:44	19:16	x	x				MegaVOC also on instrument, loitering at 35, 75, 80, and 110 m
4/18/2022	3	1.9 km	0-250 m	20:55	22:00	x	x	x			
4/18/2022	4	2.2 km	0-550 m	22:23	23:50	x	x	x			
4/18/2022	5	???	0-250 m			x	x	x	x	x	
4/20/2022	1	0.95 km	0-45 m	21:40	22:00	x	x		x	x	high winds led to early surfacing
4/20/2022	2	1.2 km	0-250 m	23:34	1:05	x	x	x	x	x	
4/24/2022	1	0.09 km	0-450 m	21:32	0:49	x	x	x	x		NPF event
4/25/2022	1	0.8 km	0-50 m	17:25	17:33						Winds too high
4/25/2022	2	0.86 km	0-210 m	22:15	22:47						
4/25/2022	3	???	0-690 m	23:02	0:49	x	x	x	x	x	Good profiling
4/26/2022	1	0.14 km	0-350 m	14:23	15:36	x	x	x	x	x	
4/26/2022	2	0.59 km	0-750 m	15:40	17:01	x	x	x	x	x	
4/26/2022	3	0.59 km	0-1000 m	17:13	18:33	x	x		x	x	
4/26/2022	4	1.28 km	0-300 m	18:42	20:20	x	x	x	x	x	