Global-Scale Black Carbon Profiles Observed in the Remote Atmosphere and Compared to Models

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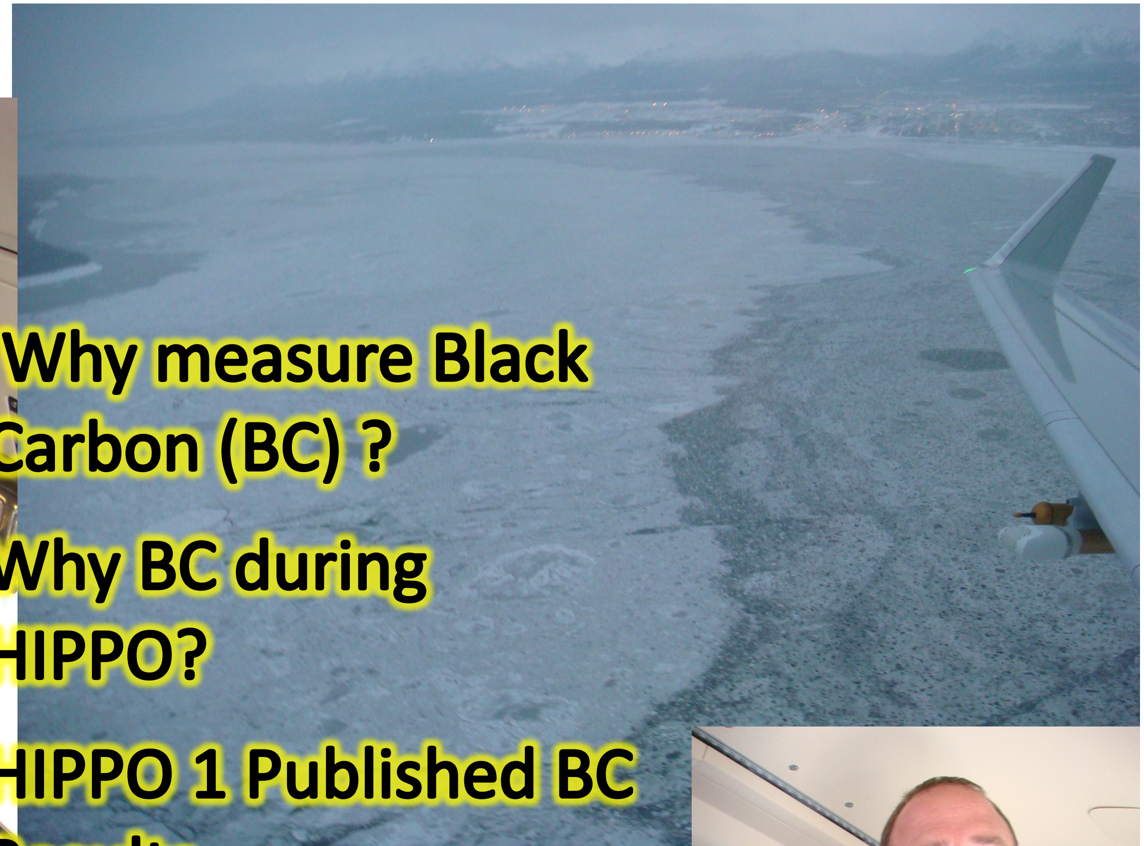
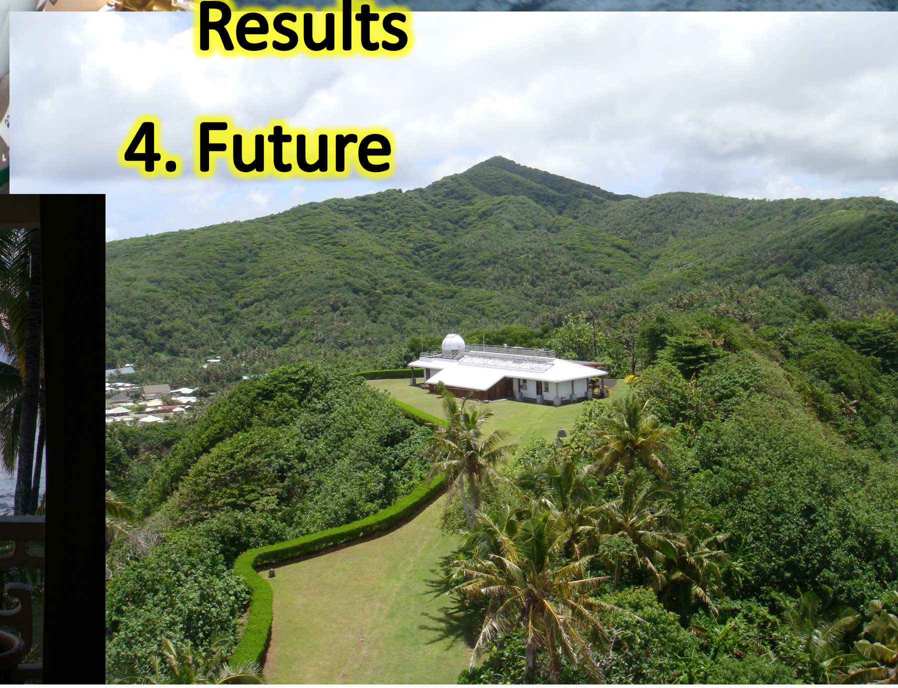
Thanks to the pilots and crew of the NSF/NCAR HIAPER, S. Freitag, S. Howell and T. Clarke, U-Hawaii. Mission supported by NSF, NOAA, NASA

HIPPO Science, 03/11

Organization

1. Why measure Black Carbon (BC) ?
2. Why BC during HIPPO?
3. HIPPO 1 Published BC Results
4. Future

Why measure BC?

Black Carbon (BC) is a product of incomplete combustion:

- Significant quantities emitted/year
- Efficient absorber of radiation
- Large anthropogenic component
- Lifetime limited by physical removal

Most aerosol absorption of shortwave solar radiation is attributed to BC

Global climate forcing

Direct effect: absorption of radiation
Indirect effect: CCN activity
} Contributes to solar dimming

Semi - direct effect - warming/drying of clouds

Snow albedo - direct

Heterogeneous chemistry

~"Perhaps the second most important anthropogenic forcer of climate after CO_2" -
Michal Jacobson *Serena Chung*
William Chameides *Philip Stier*
Tami Bond *John Seinfeld*

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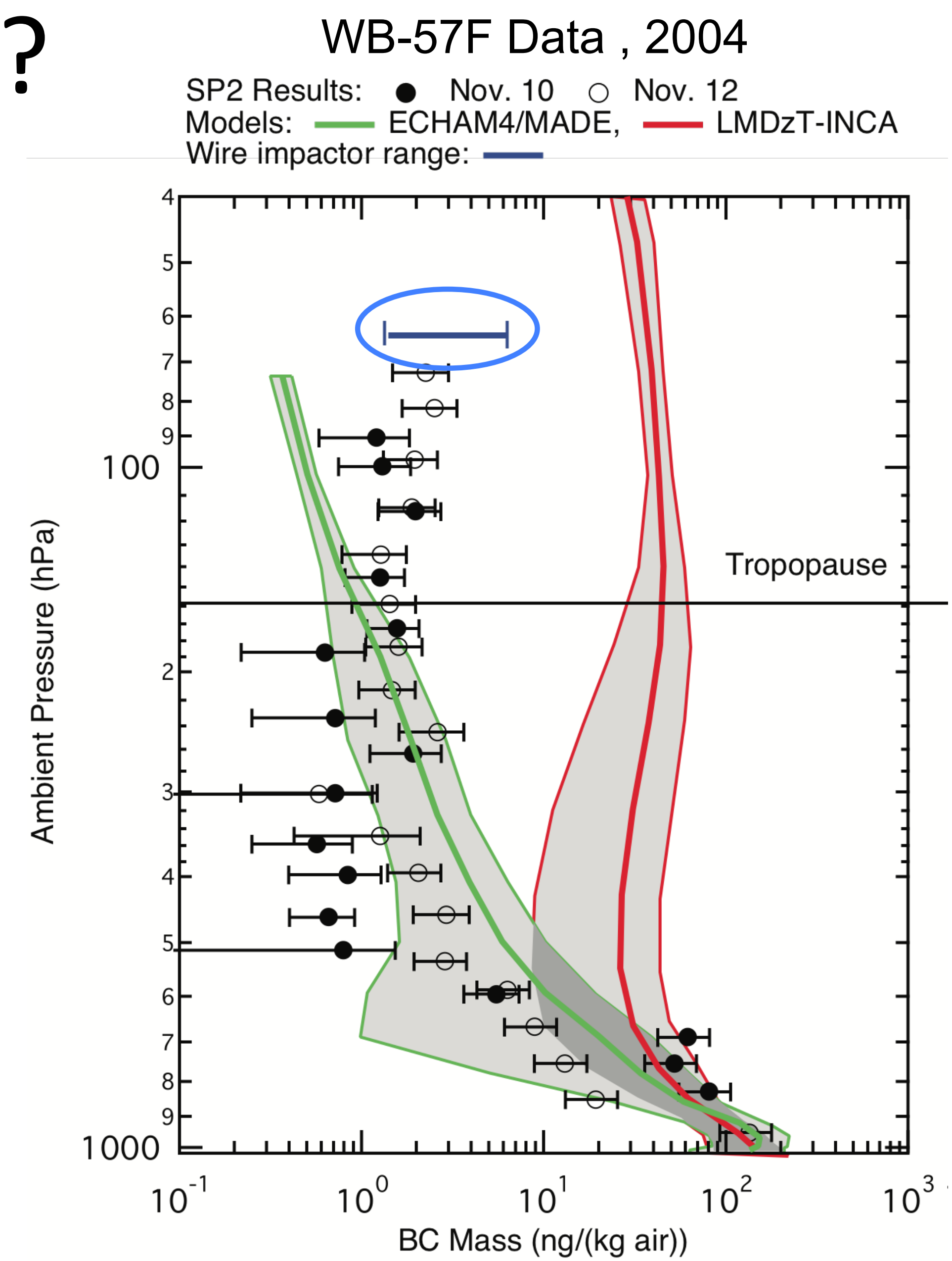
… and BC atmospheric distribution/quantity is only poorly known

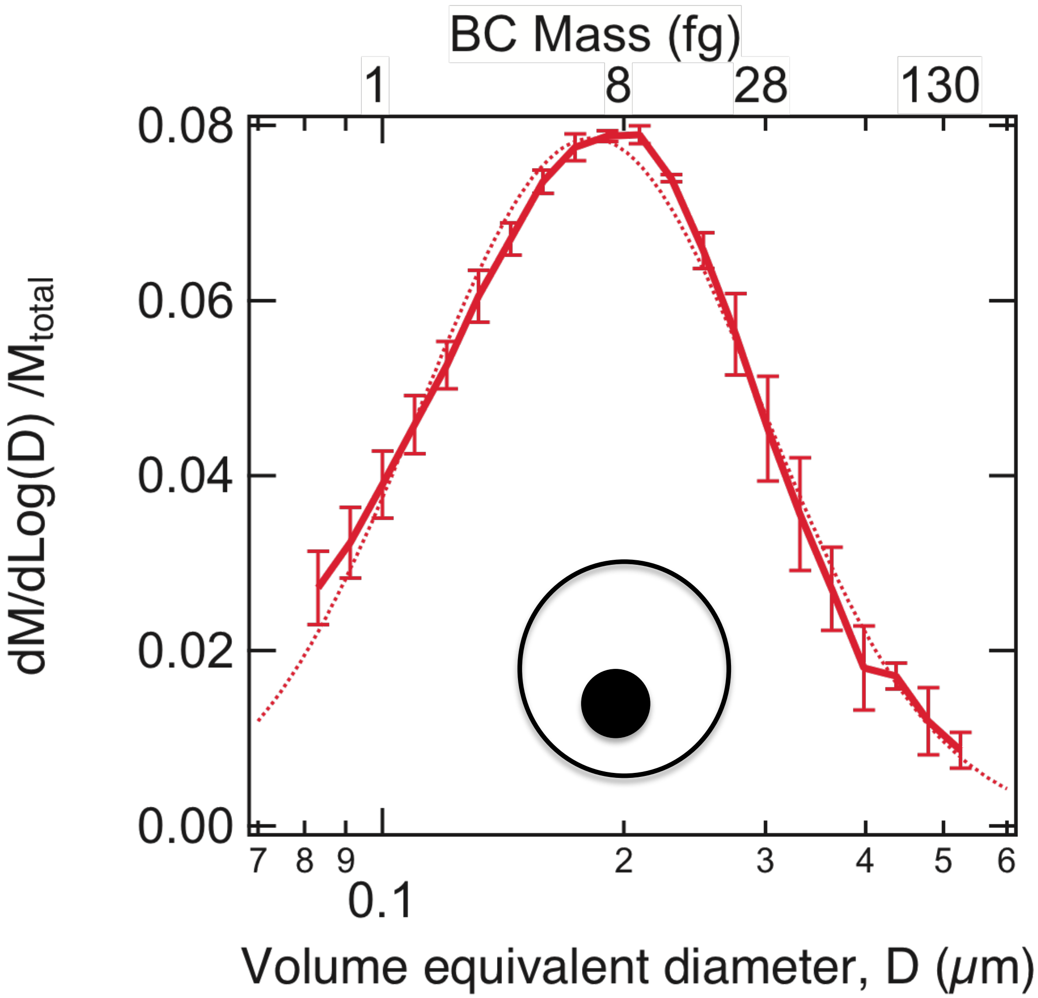
Why BC in HIPPO?

- HIPPO flights designed to provide excellent vertical coverage on a global scale.
- Vertical profiles of BC MMR provide much stronger constraints on models than do more limited measurements



From Schwarz et al., *JGR,* 2006

Single Particle Soot Photometer (SP2)

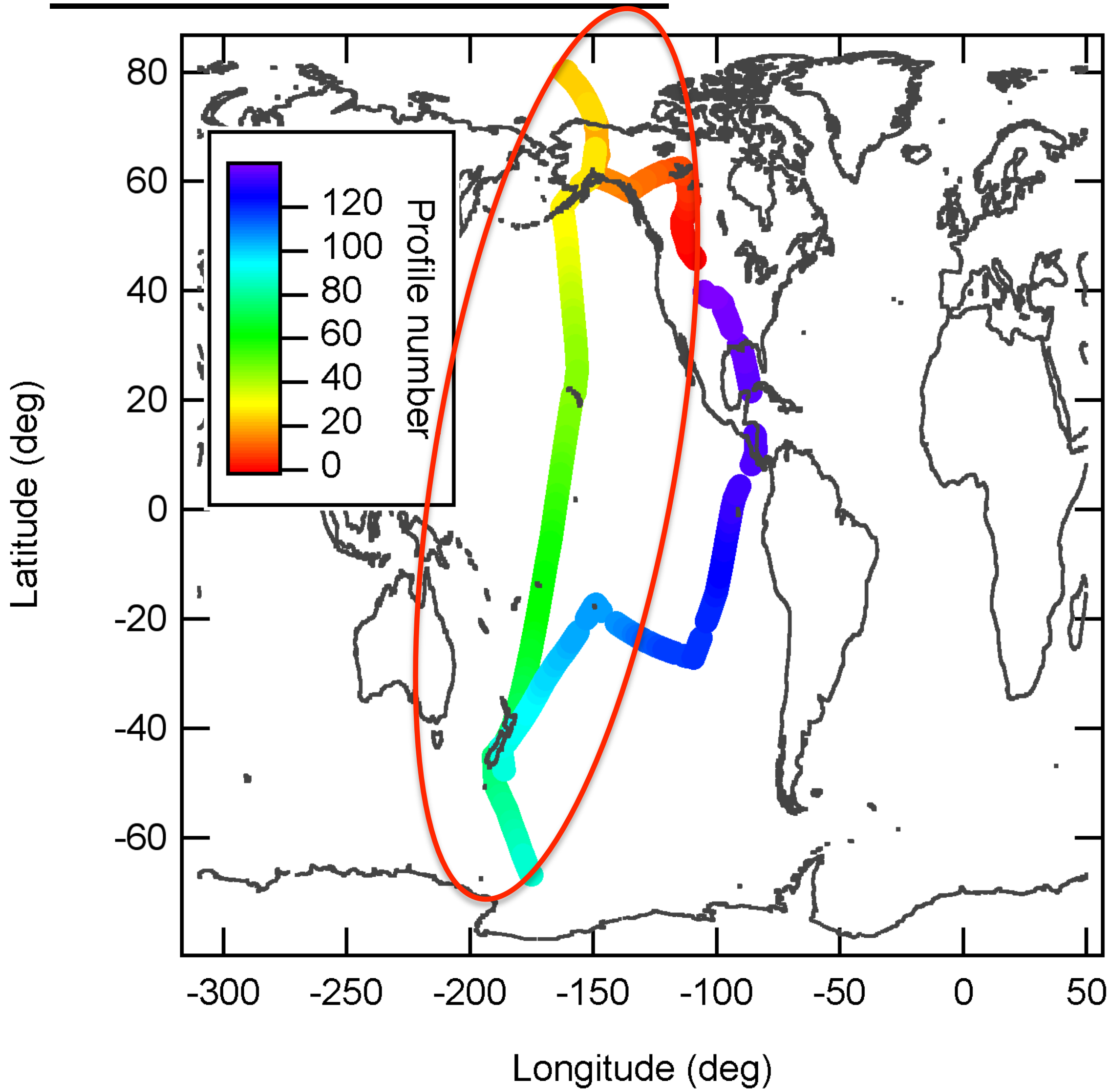


•SP2 detects individual particles containing BC in a mass range equivalent to 80-550 nm volume equivalent diameter – "Fantastic sensitivity"

•Volume equivalent diameter assuming rBC density = 2 g/cc

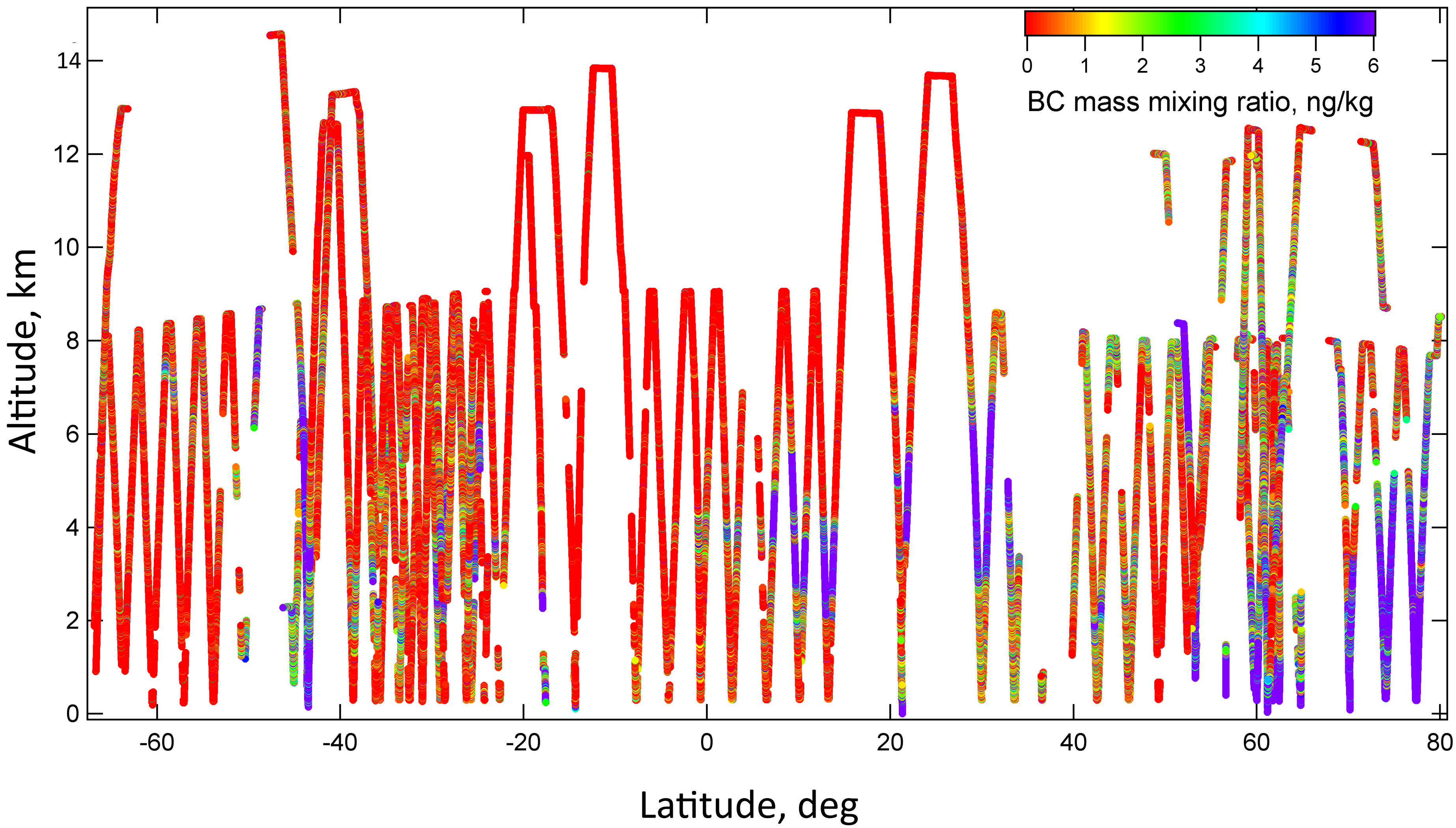
•~90% of accumulation mode BC mass detected

HIPPO1: BC RESULTS:



1. Montana
2. Alaska
3. Northern Survey
4. Hawaii
5. American Samoa
6. New Zealand
7. Southern Survey
8. Tahiti
9. Easter Island
10. Costa Rica
11. Colorado

~100 Vertical Profiles, 8-14 km



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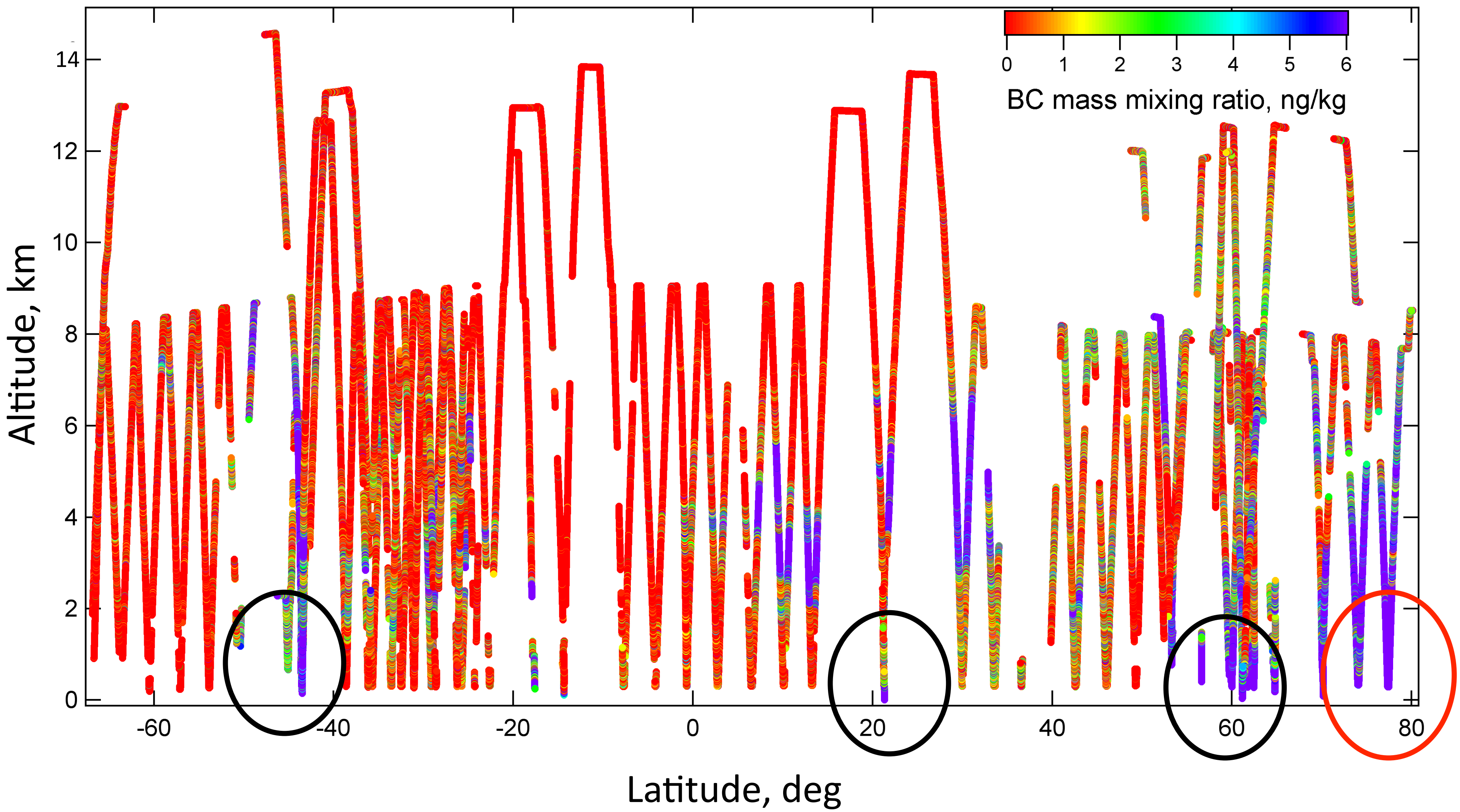
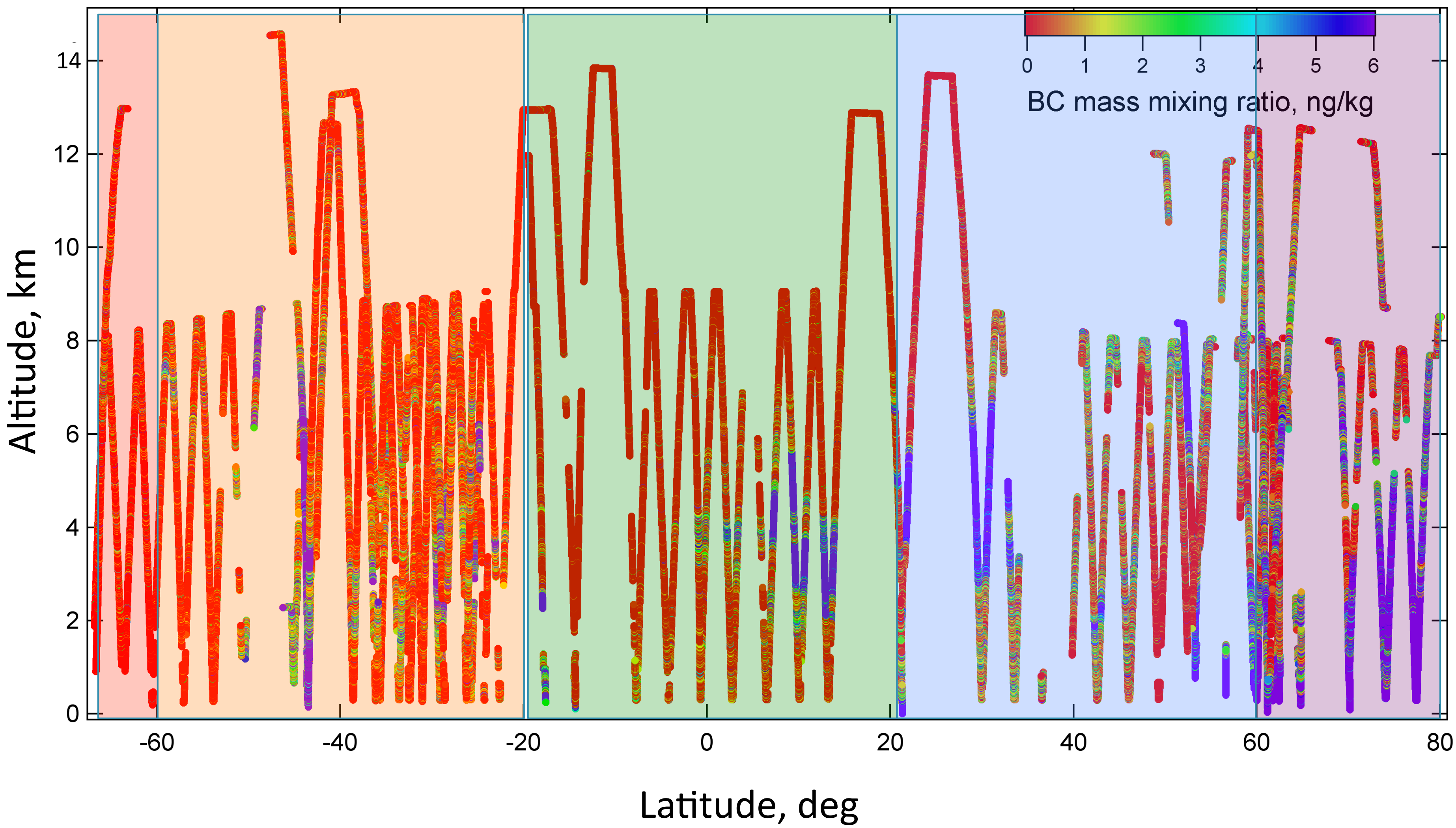


Local pollution < 2 km, strongly correlated to CO removed

Note Arctic pollution

~100 Vertical Profiles, 8-14 km

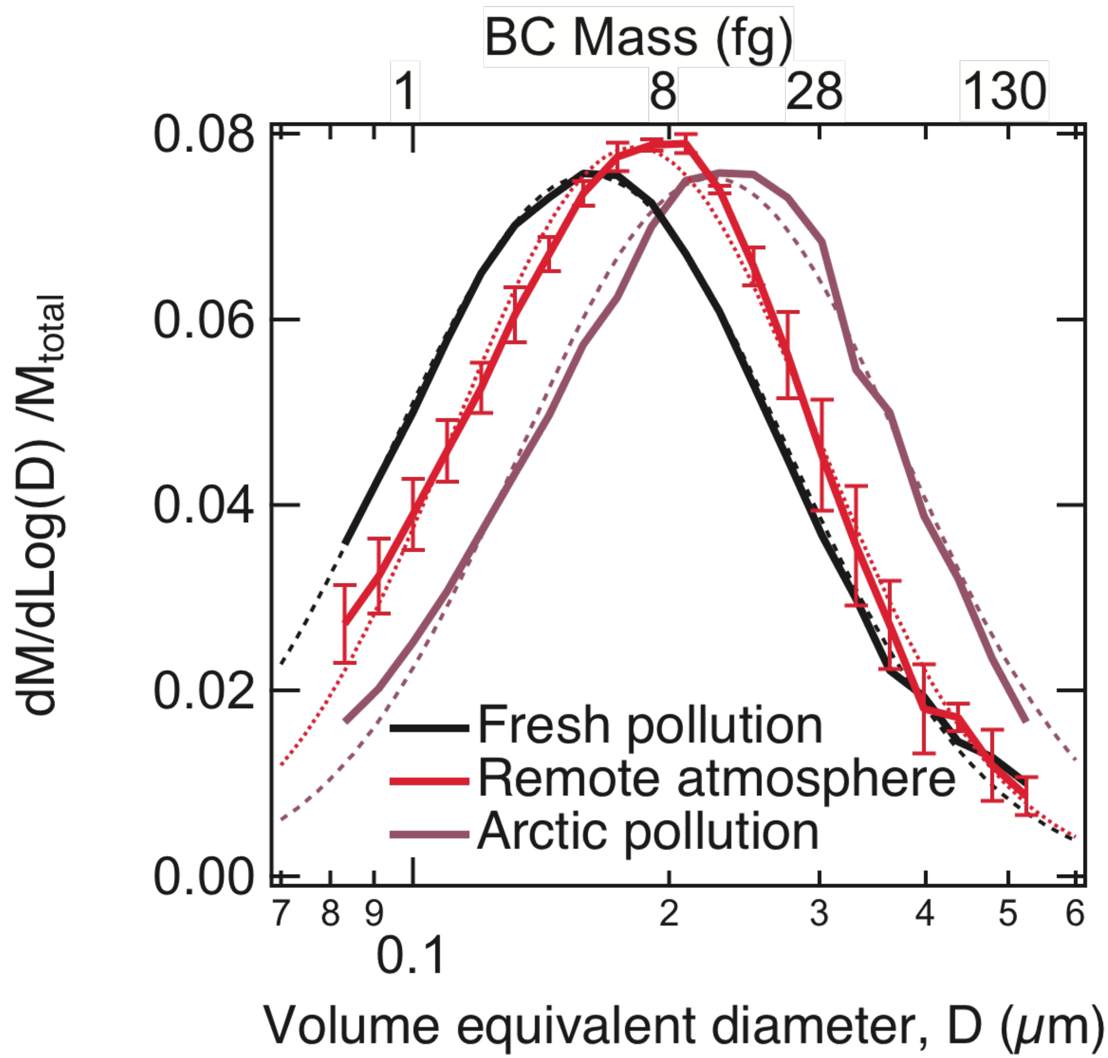


Black Carbon size distributions

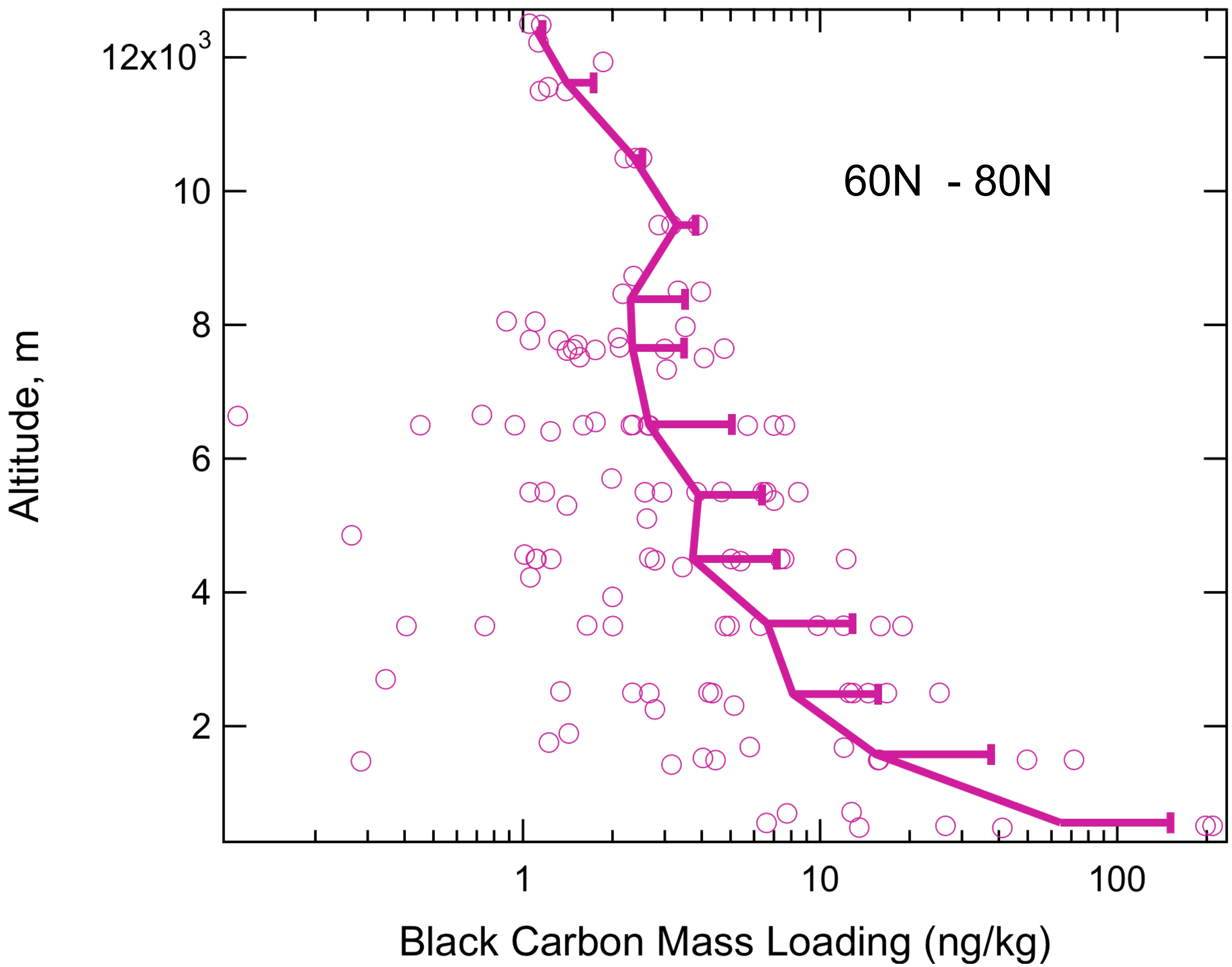
Range of BC sizes from sources illustrated by fresh anthropogenic emissions (small), and by the Arctic pollution (large).

Four latitude ranges compared: mass mean diameter matched to 1 nm!

Surprising because BC only 1 component of total particle mass.

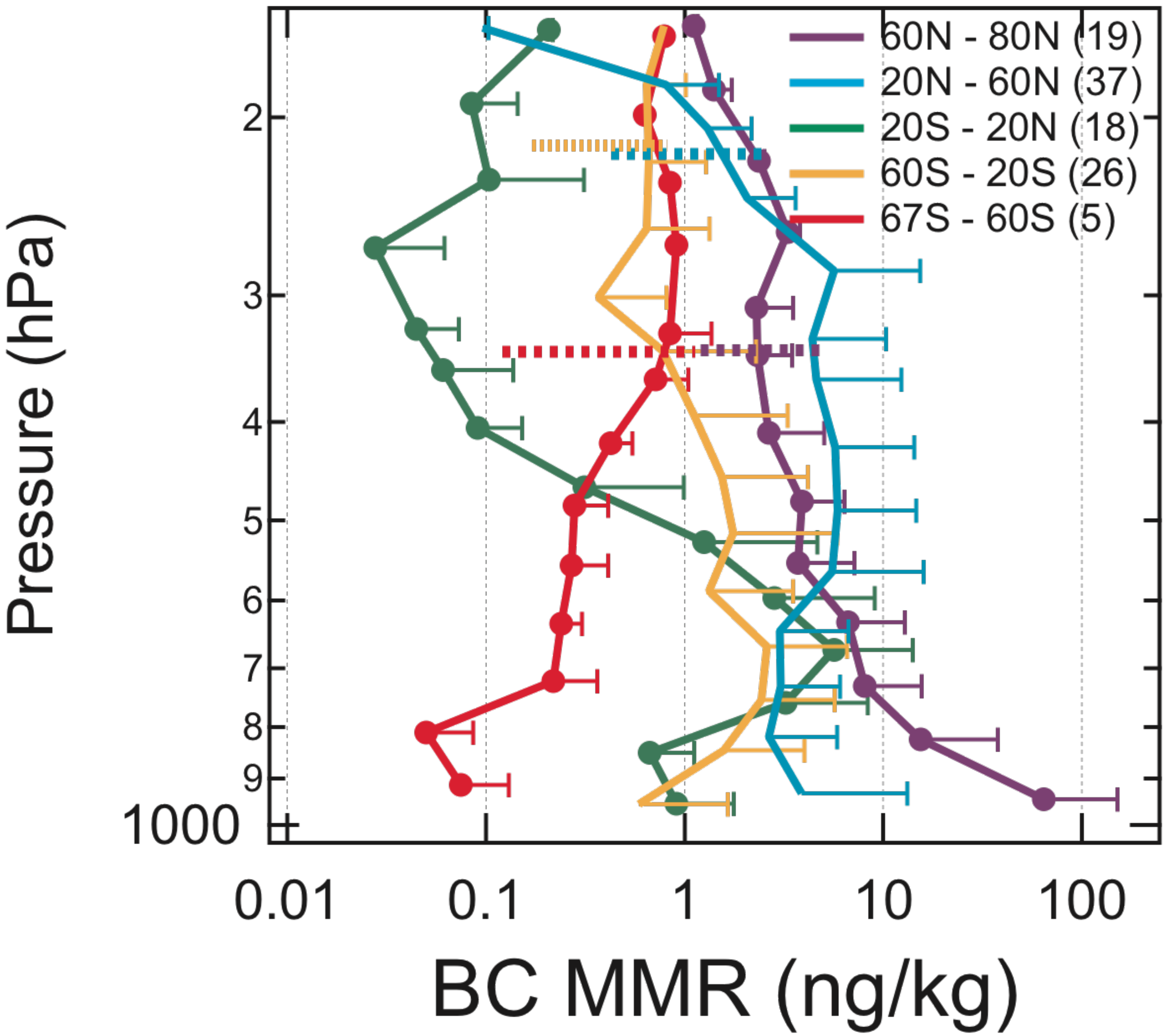


Data Reduction



- Each vertical ascent/descent treated as an independent profile measurement: statistics based on inter-profile variability.
- Whiskers represent standard deviation at each altitude/ pressure bin
- ~1km resolution

Zonal Averages



- On average 21 profiles averaged into each zonal average.
- For southernmost average, 5 profiles

AEROCOM Global Models

- 14 global models included:
- Harmonized BC emissions: 2000
- Black carbon emission based on Tami Bonds' inventory (2004): largely EC based, so we expect reasonable consistency to SP2 measured rBC load
- Models provided vertical profiles at position of each measured profile.
- Each model interpolated to measurement vertical profile resolution
- Model results are monthly mean for "January"

•LMDzT-INCA(LSCE)
•ECHAM5(MPI)
•GCM/CAM
•MIRAGE
•CTM2
•CCM-Oslo
•LMDzT (LOA)
•GOCART
•MATCH
•IMPACT/DAO
•ECHAM-MADE (DLR)
•GISS
•TM5
•MOZART-GRDL-NCAR

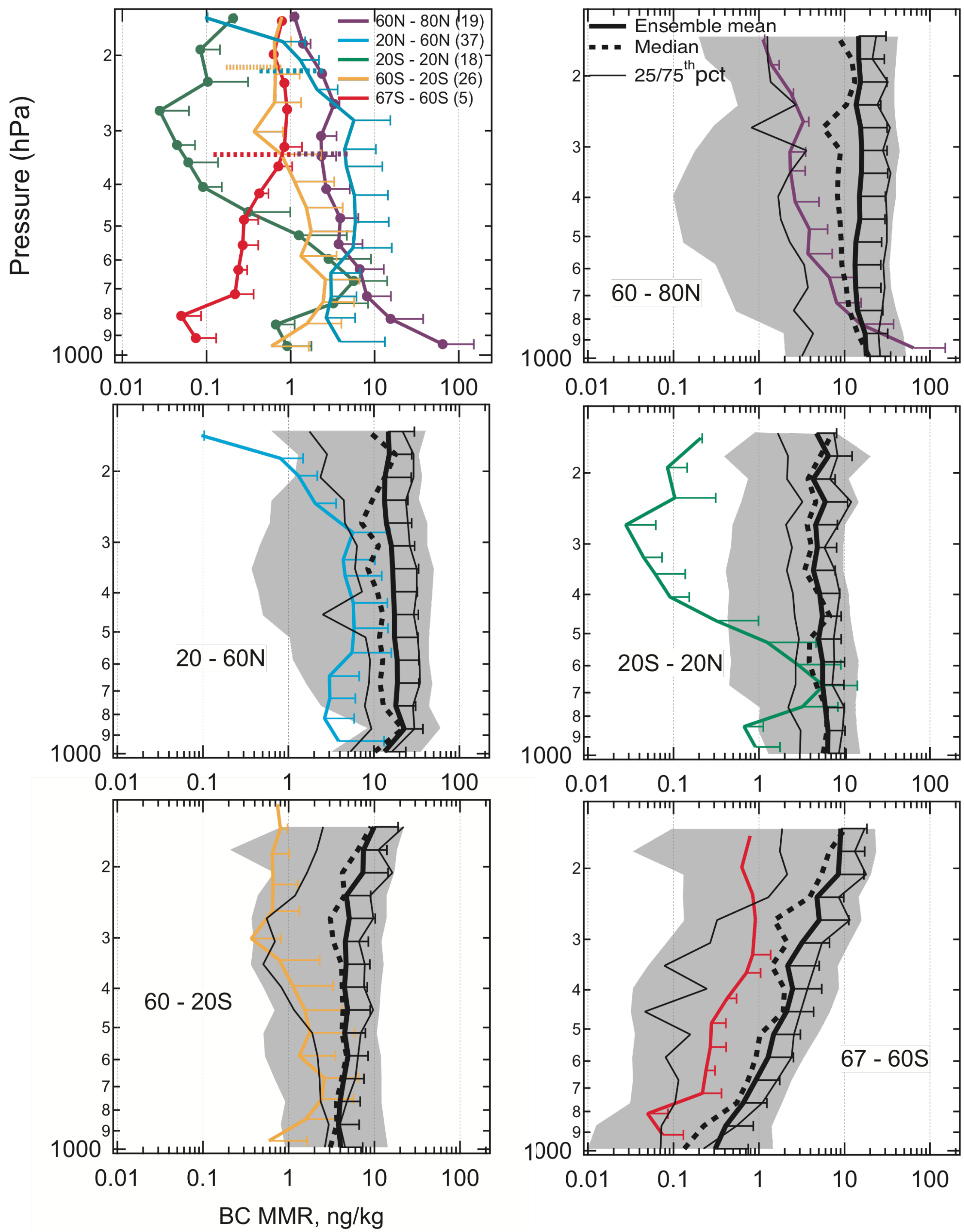
•Grey region represents model range

•Colored line is SP2 measured zonal average

•Dark line is model mean

•Dashed line is model median

•Thin lines are models 25th and 75th percentiles



Conclusions of HIPPO1 analysis:

- Global models show wide range of BC loadings in monthly zonal averages. On average, model ensemble overestimates remote BC by a factor 5.

- Likely source of model overestimate is insufficient removal

- Size distributions of BC underlying accumulation mode in remote air masses surprisingly stable – mechanism controlling it in addition to total aerosol coagulation/ condensation/removal?

Schwarz, J. P., J. R. Spackman, R. S. Gao, L. A. Watts, P. Stier, M. Schulz, S. M. Davis, S. C. Wofsy, and D. W. Fahey (2010), Global-scale black carbon profiles observed in the remote atmosphere and compared to models, *Geophys. Res. Lett.*, 37, L18812, doi:10.1029/2010GL044372.

Future analysis

1. Extending Measurement/Model Comparison

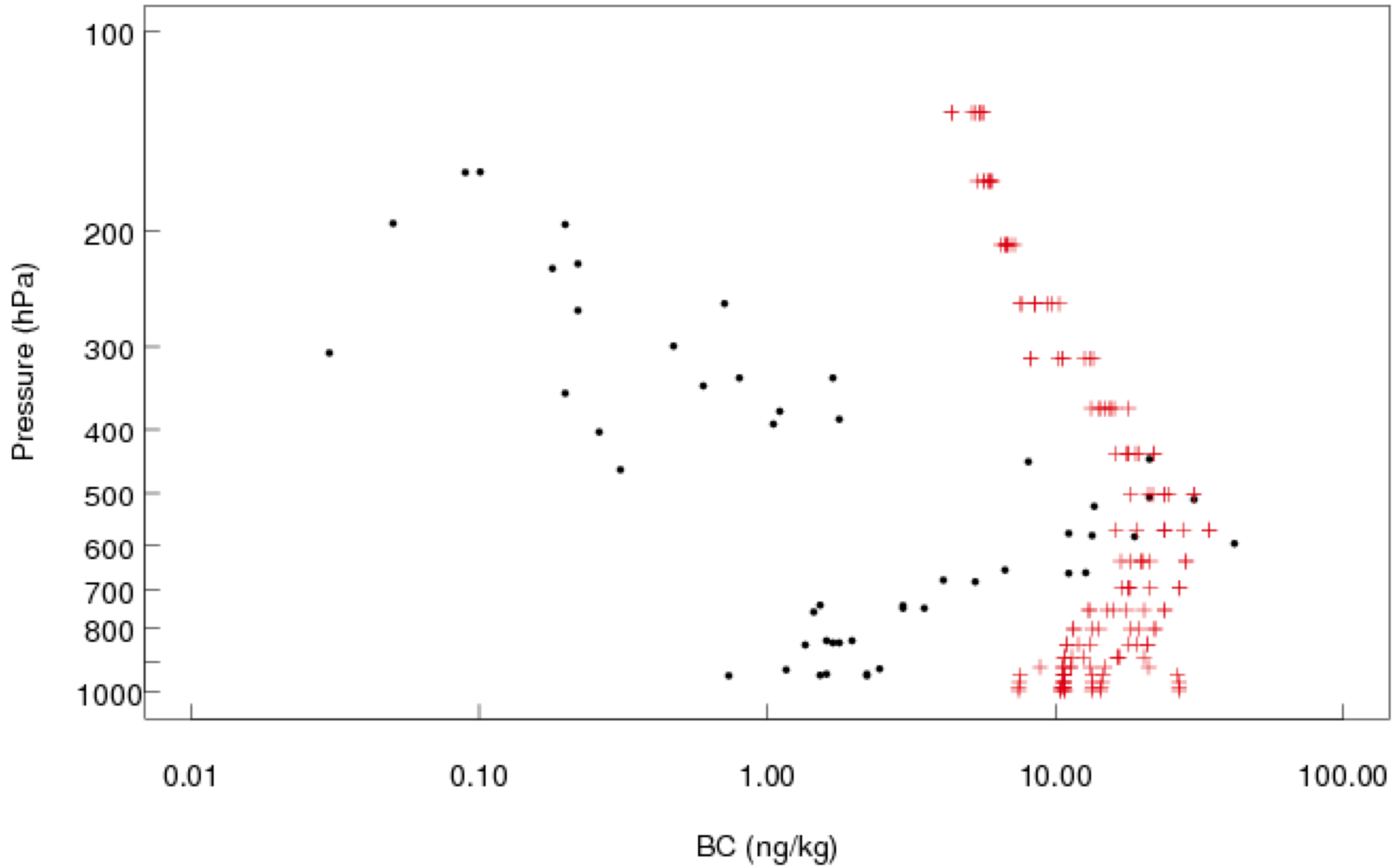
- Sharing SP2 data with modeling groups →

- Looking at full (HIPPO 1 – 5) data set to detect seasonal model/measurement trends

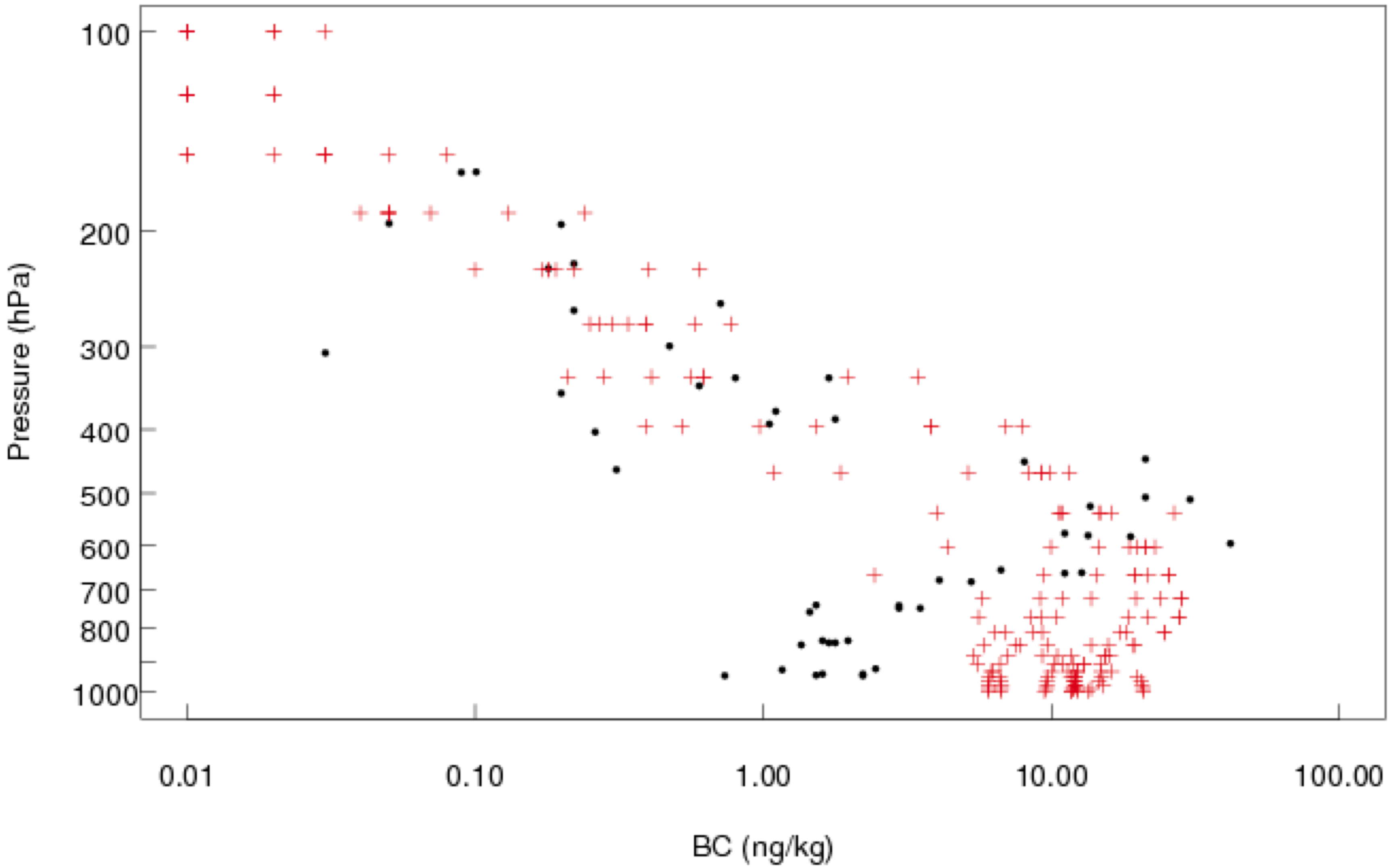
- Extending comparison to "real-time" models

Carslaw Group – Leeds
Hendricks Group – DLR
Stier Group – Oxford
Lohmann Group – U. Michigan
Koch Group – GISS
Jacob Group - Harvard
Songmiao Fan – NOAA GFDL
Jacobson – Stanford
Gahn Group – PNNL

Offline Transport Model: GFDL GCTM

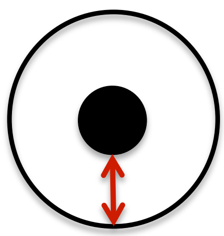


Online Transport Model: AM3



Future analysis

2. Extending analysis of SP2 data to BC mixing state, and to HIPPO 1,2, and 3:



SP2 provides an estimate of dry-coating Thickness of non-BC material associated with Individual cores in a narrow size range

(SIMPLIFIED VIEW OF A COMPLICATED REALITY)

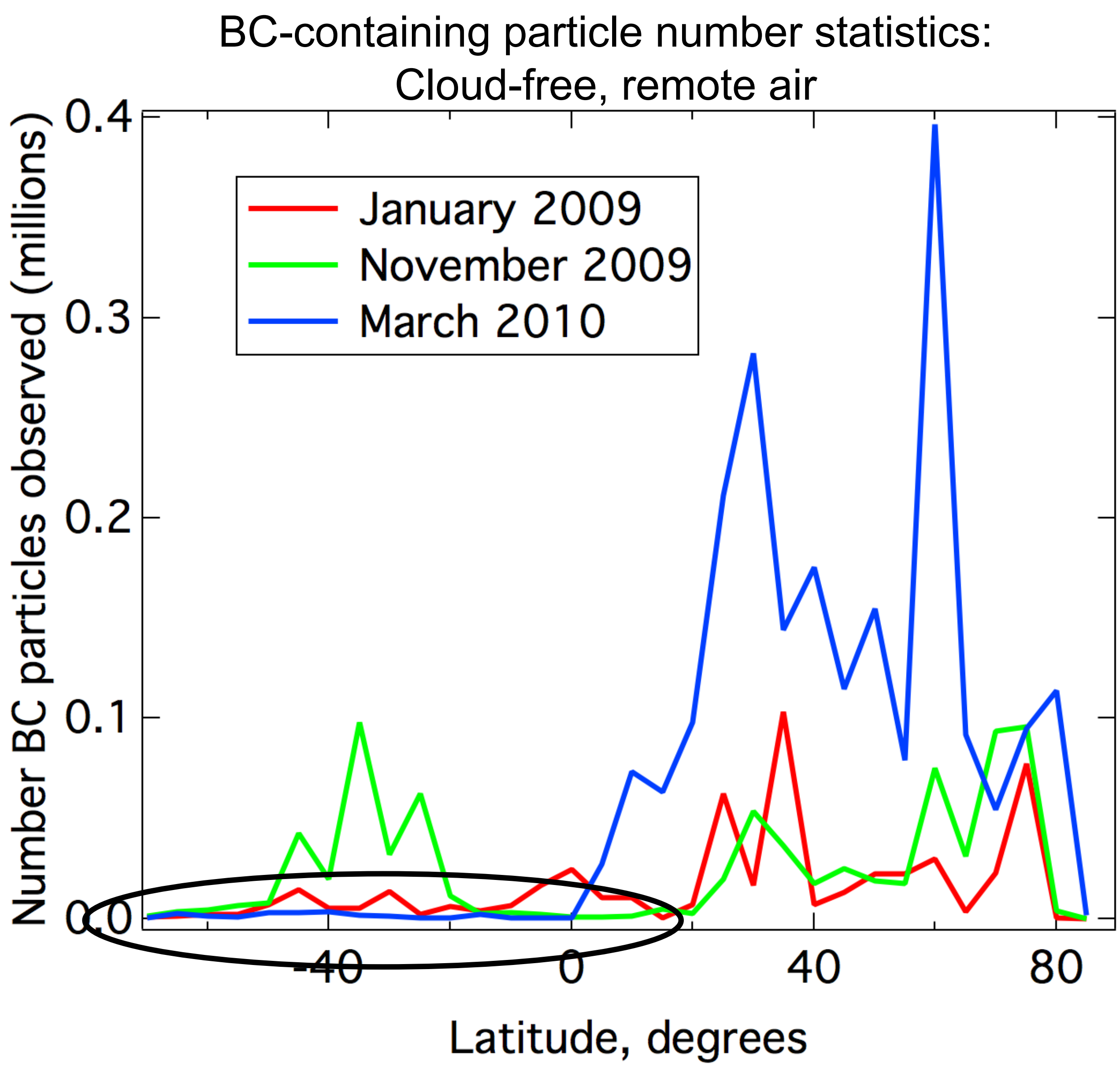
BC Mixing State: Data Overview

Focus on:

- complete remote dataset (4 million BC particles) – heavily weighted towards NH transpacific transport events

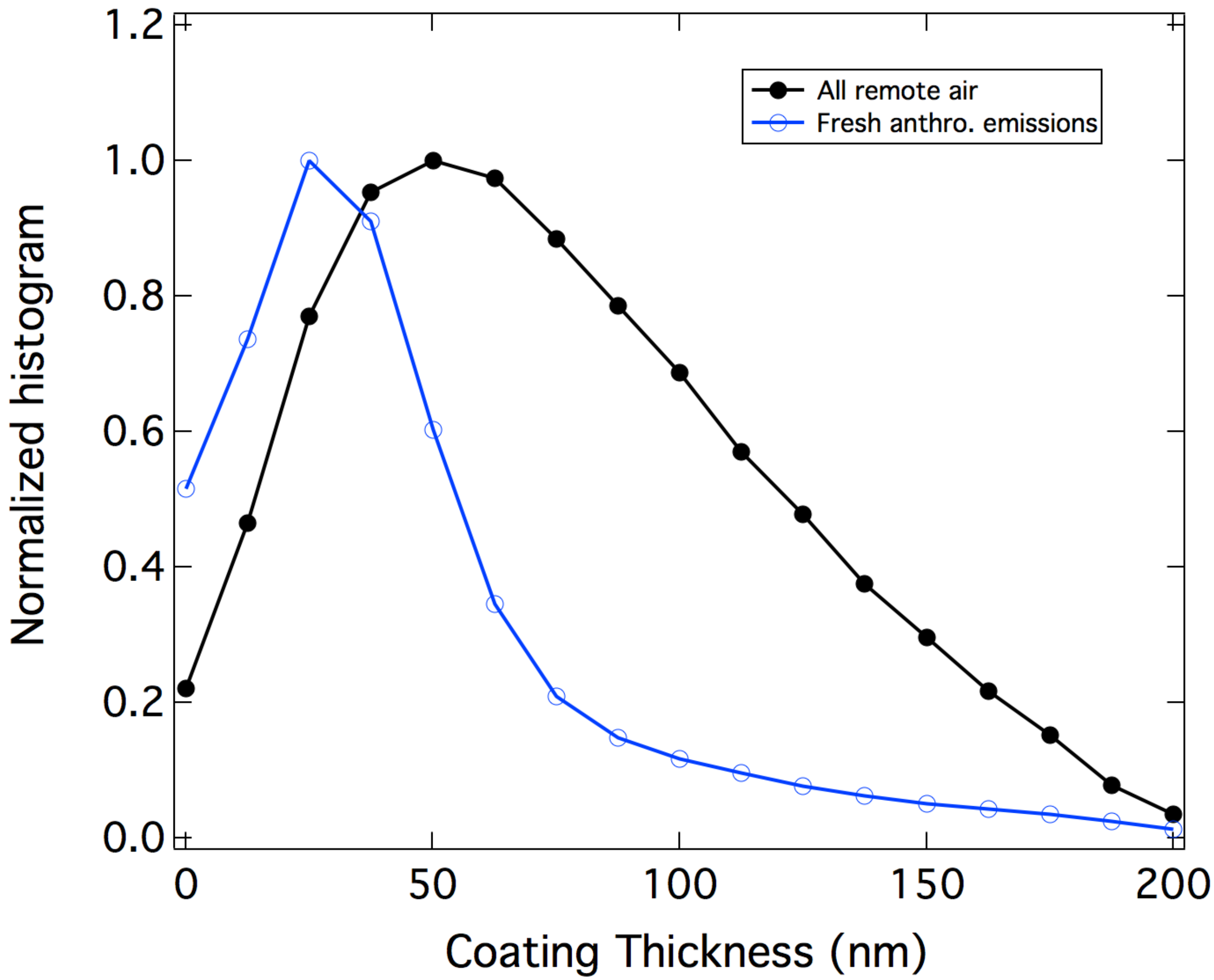
•Fresh anthropogenic emissions observed below 2 km (includes non-fossil fuel, 7 million BC (not shown))

•Background SH air (20,000 BC-containing particles)



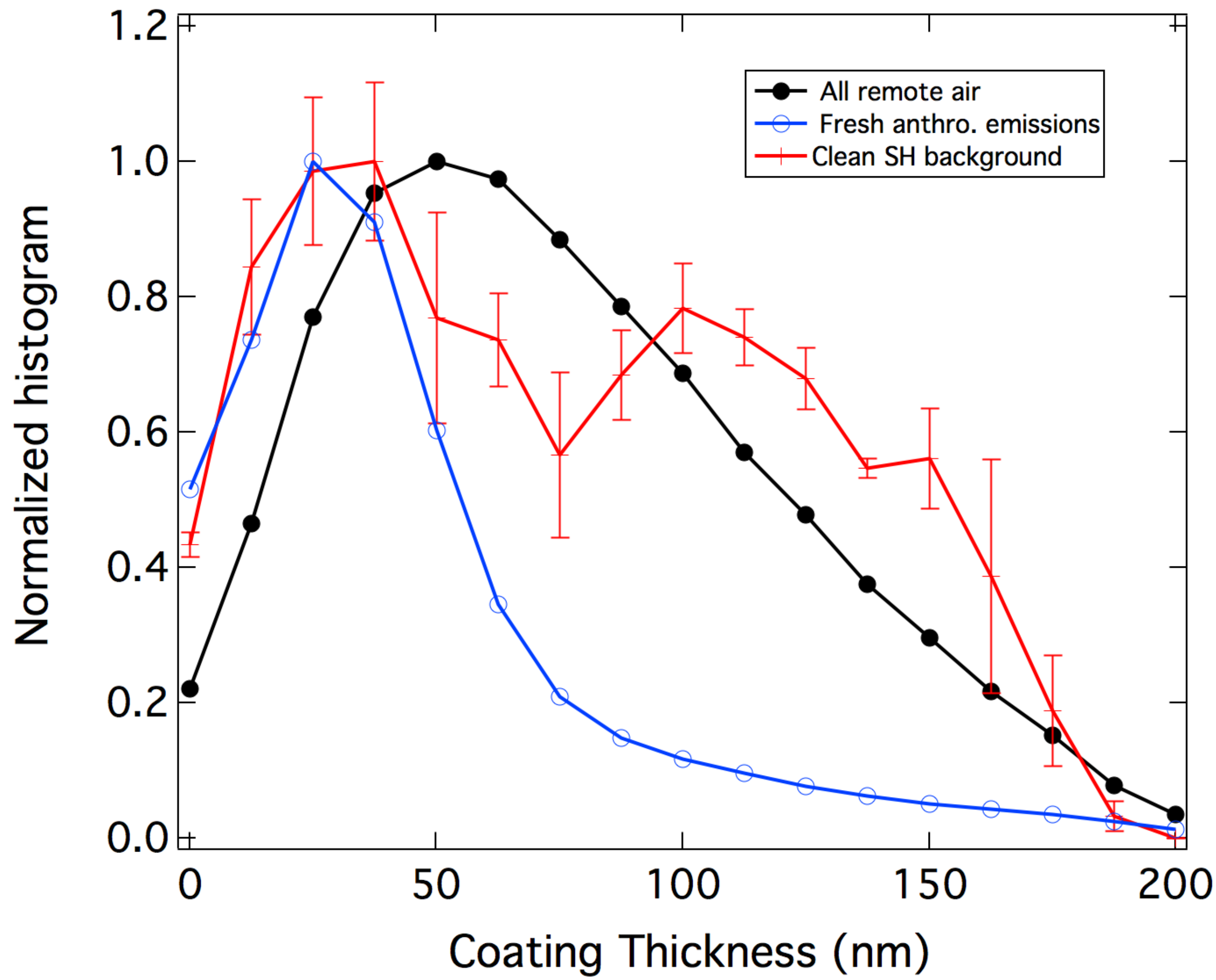
Dry Coating Thickness on BC cores of 150-180nm

- Distributions of coating thickness provide information about source (for fresh emissions), age, and removal events
- Coating thickness associated with fairly efficient combustion (e.g. cars, clean flames) tend to smaller values than inefficient combustion (biomass burning, rich, sooty flames)



Dry Coating Thickness on BC cores of 150-180nm

- Whiskers represent only statistical uncertainty
- Bimodal distribution in coating thickness associated with clean SH air suggests dual populations of BC that have not undergone cloud processing and those that have



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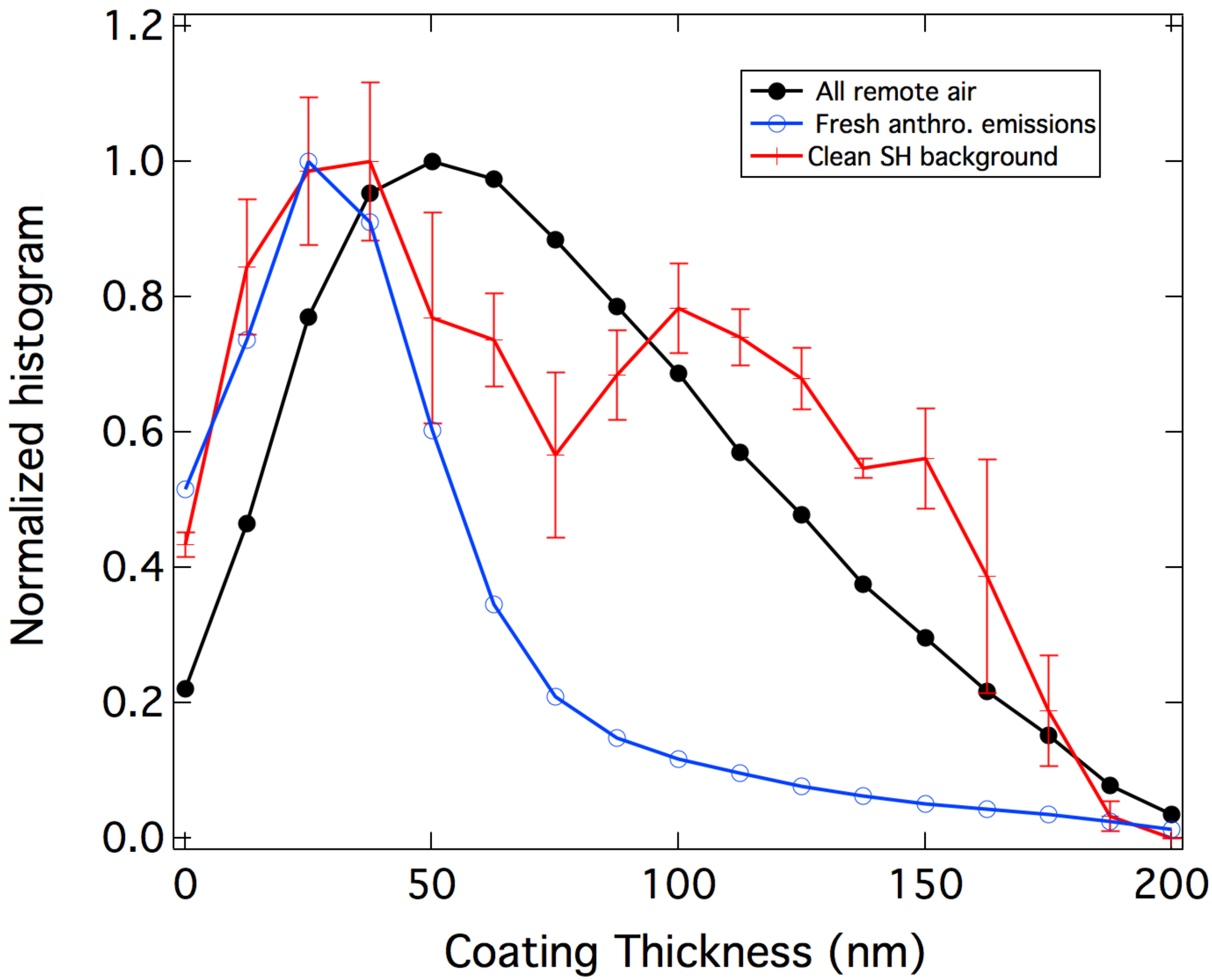
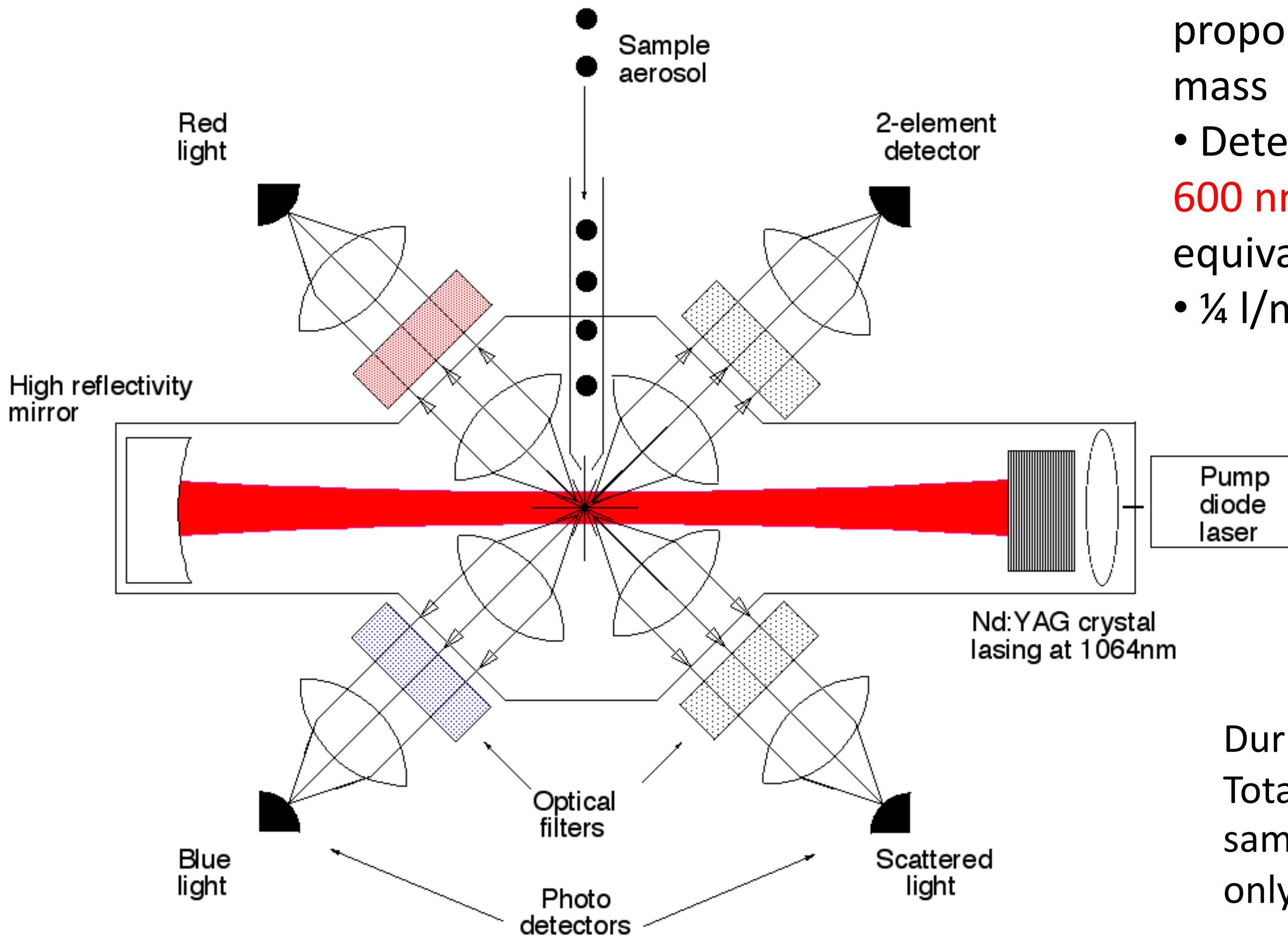



Warm appreciation for the pilots and crew of the NSF/NCAR GV, and all our
collaborators (filling the room)

Single Particle Soot Photometer (SP2)

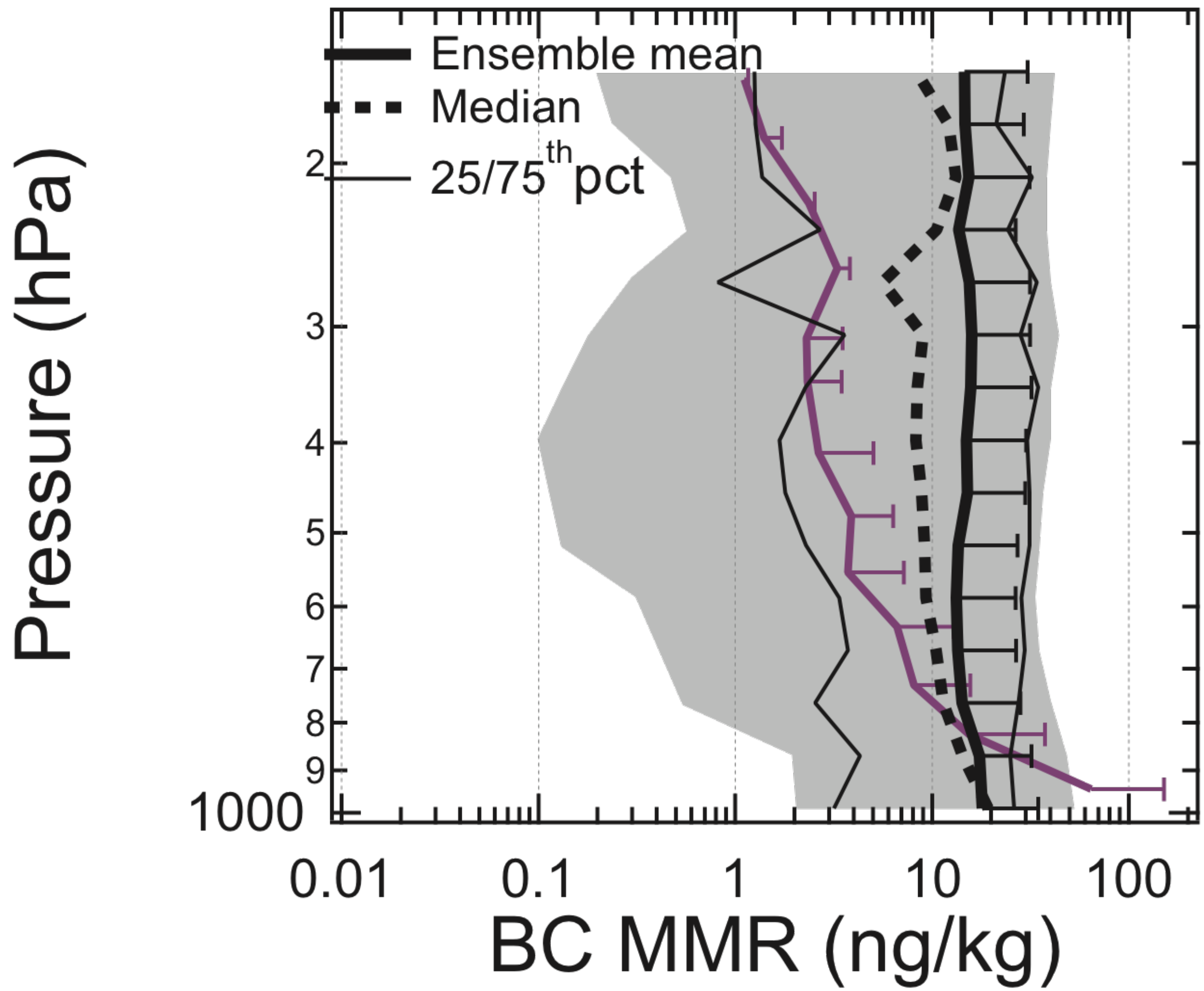


- Instrument response proportional to rBC mass
- Detection range 80 – 600 nm (volume equivalent)
- ¼ l/m sample flow

During HIPPO1:
Total rBC mass sampled by SP2 was only ~2 ng!

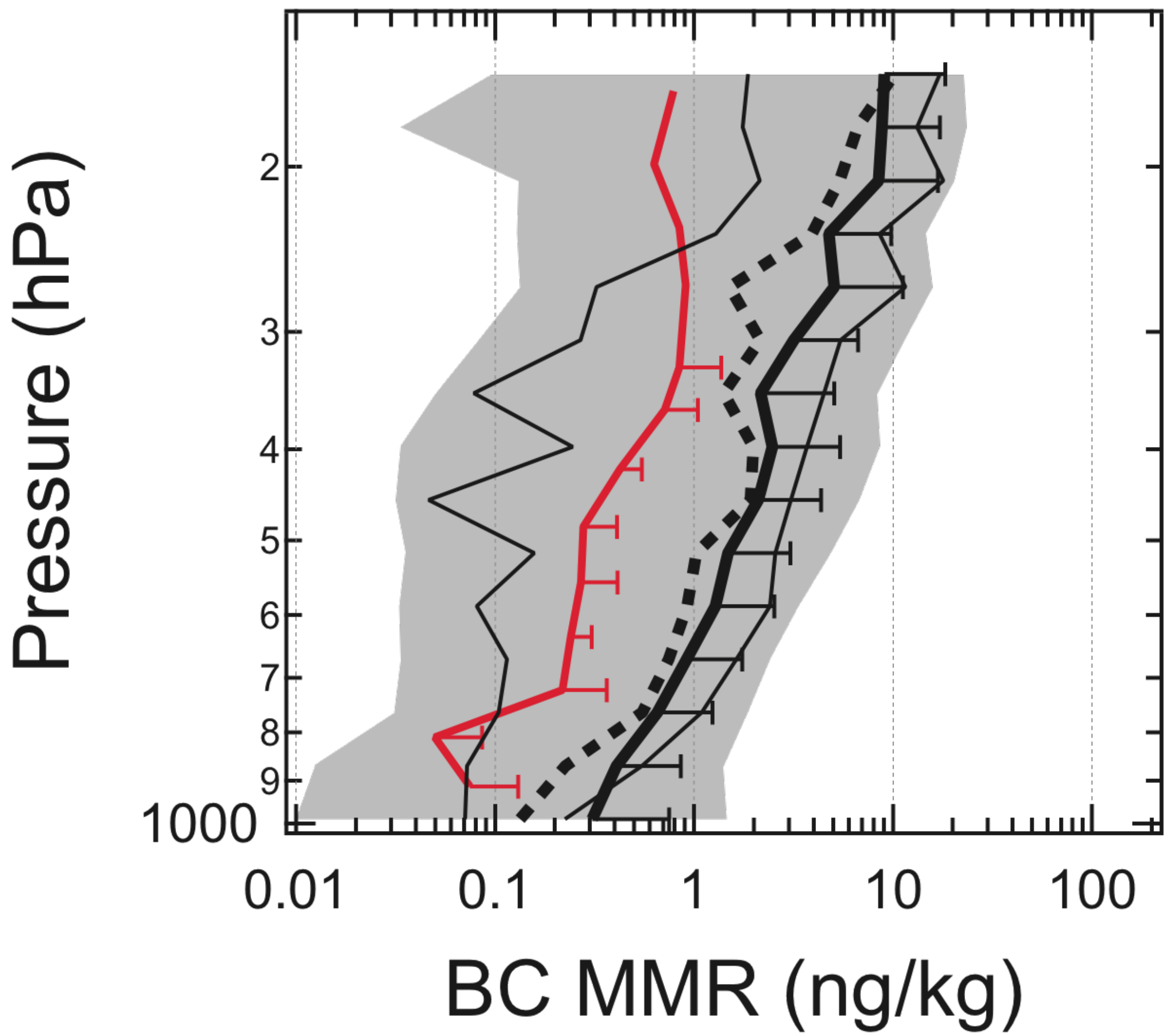
SP2: Droplet Measurement Technologies, Inc.

60N to 80 N



Ensemble mean
Median
25/75th pct
Pressure (hPa)
2
3
4
5
6
7
8
9
1000
0.01
0.1
1
10
100
BC MMR (ng/kg)

70S to 60 S



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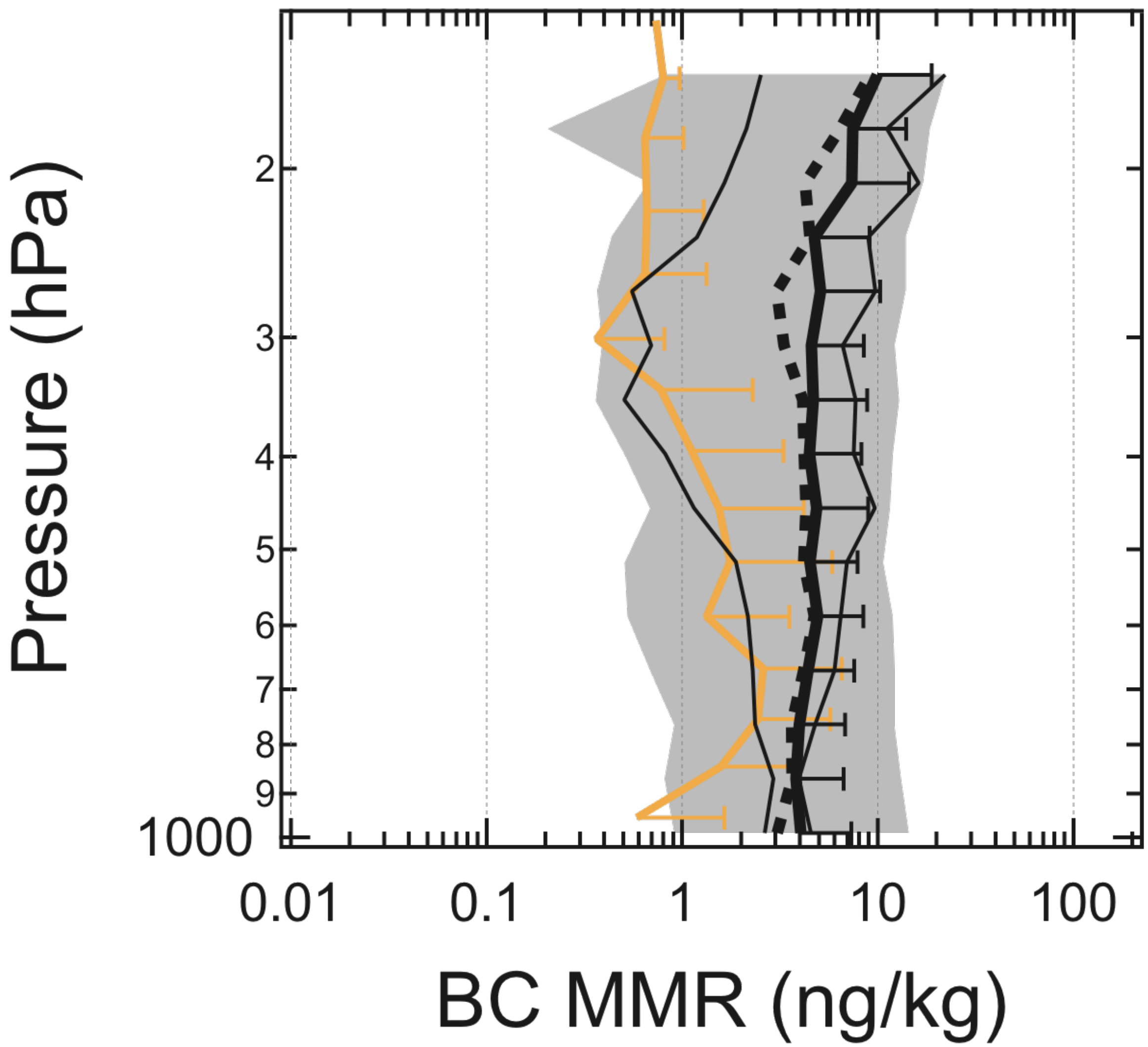
40S to 20 S



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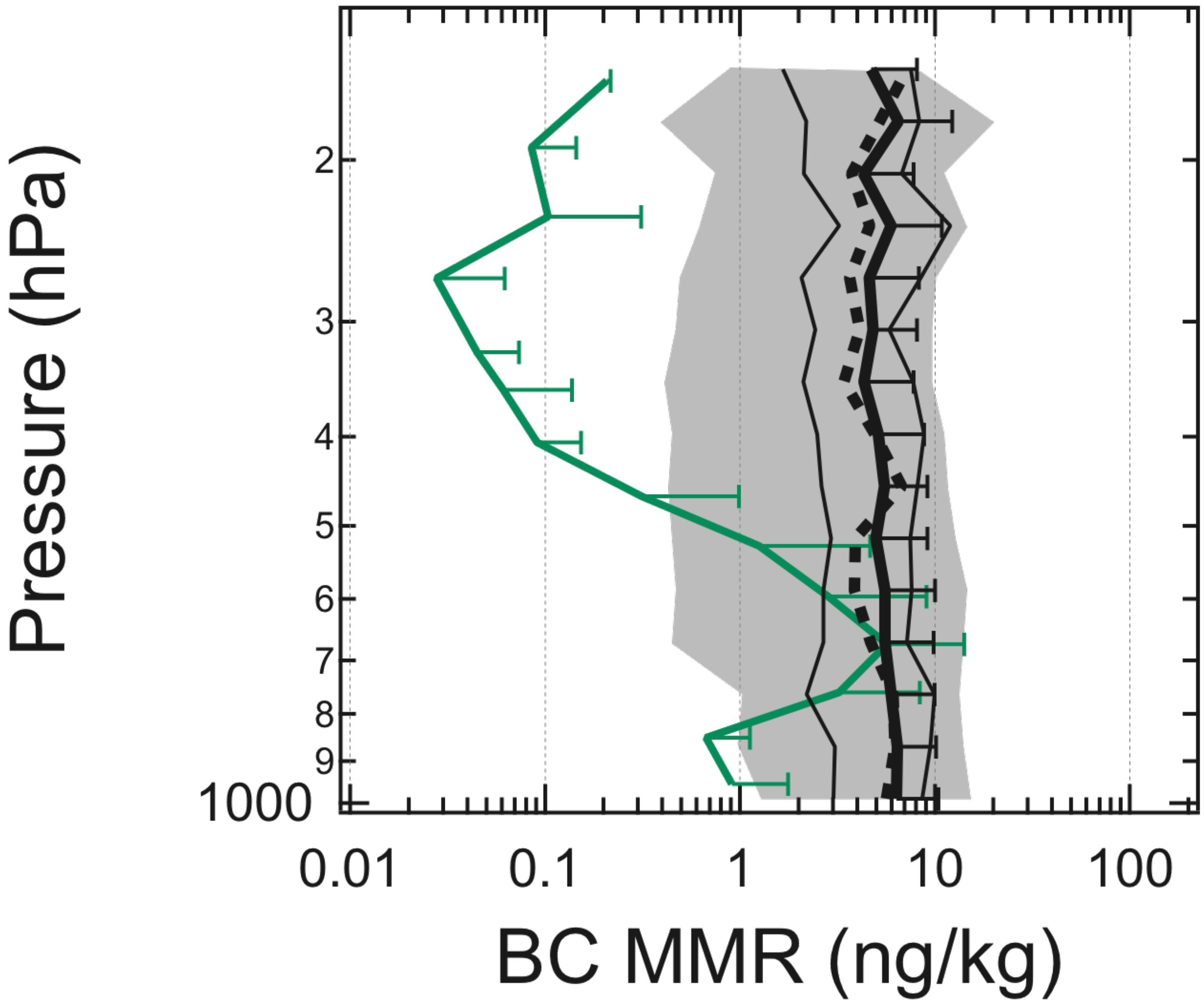
20S to 20 S



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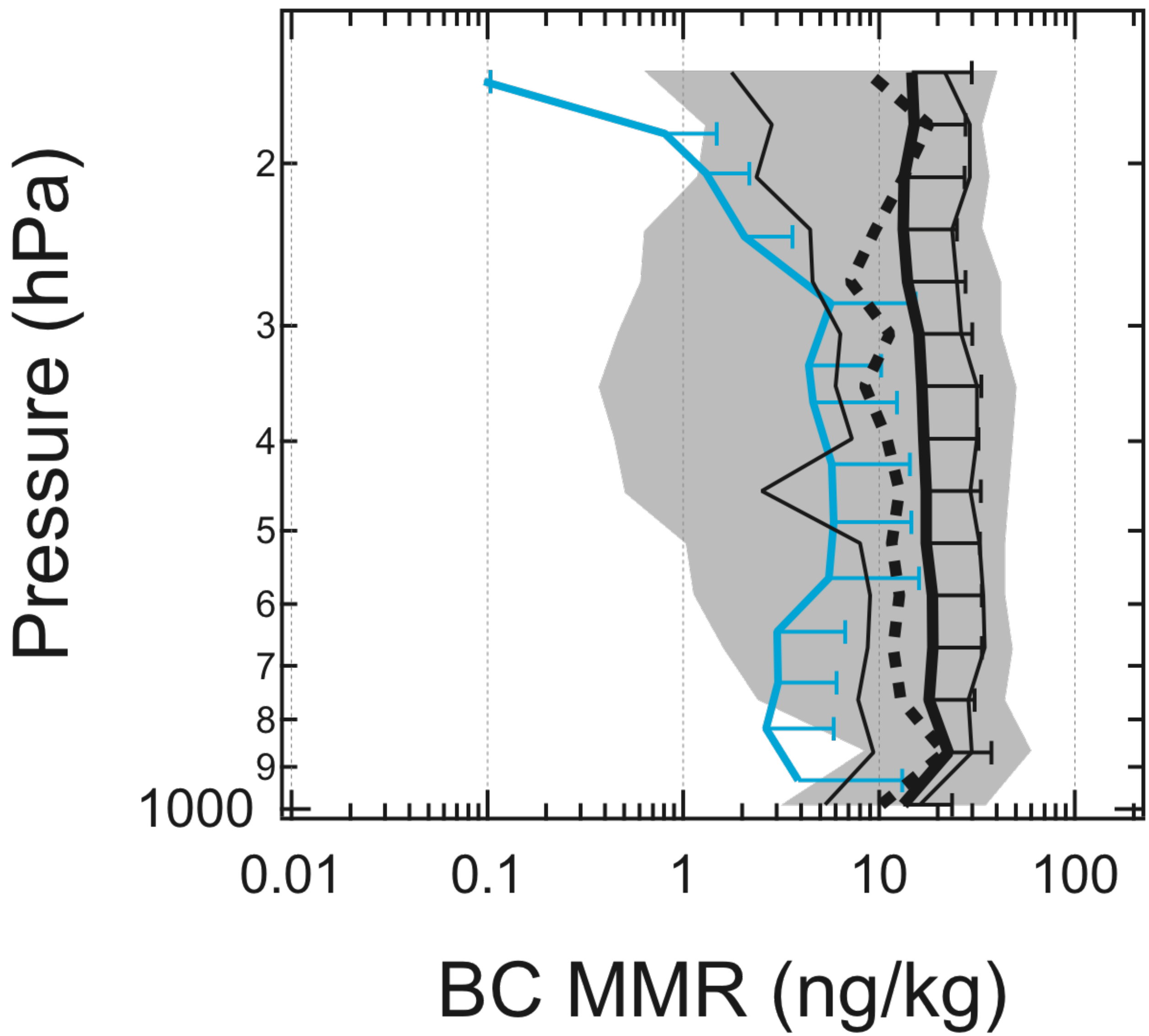
20N to 40 N



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