-- 12th AeroCom Workshop, Sept. 23, 2013 --

The full HIPPO black carbon aerosol vertical profile dataset compared to AeroCom Phase II

HIAPER Pole-to-Pole Observations (HIPPO) of Carbon Cycle and Greenhouse Gases Study

Supported by NSF, NOAA, and NASA

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Outline

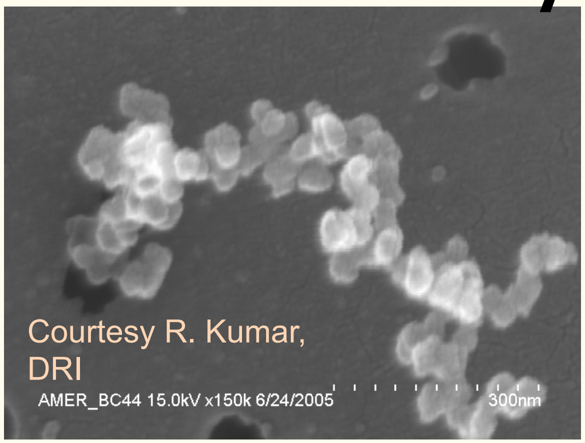
0. BC Microphysical observations/new data product

1. HIPPO/AeroCom Ensemble Comparison

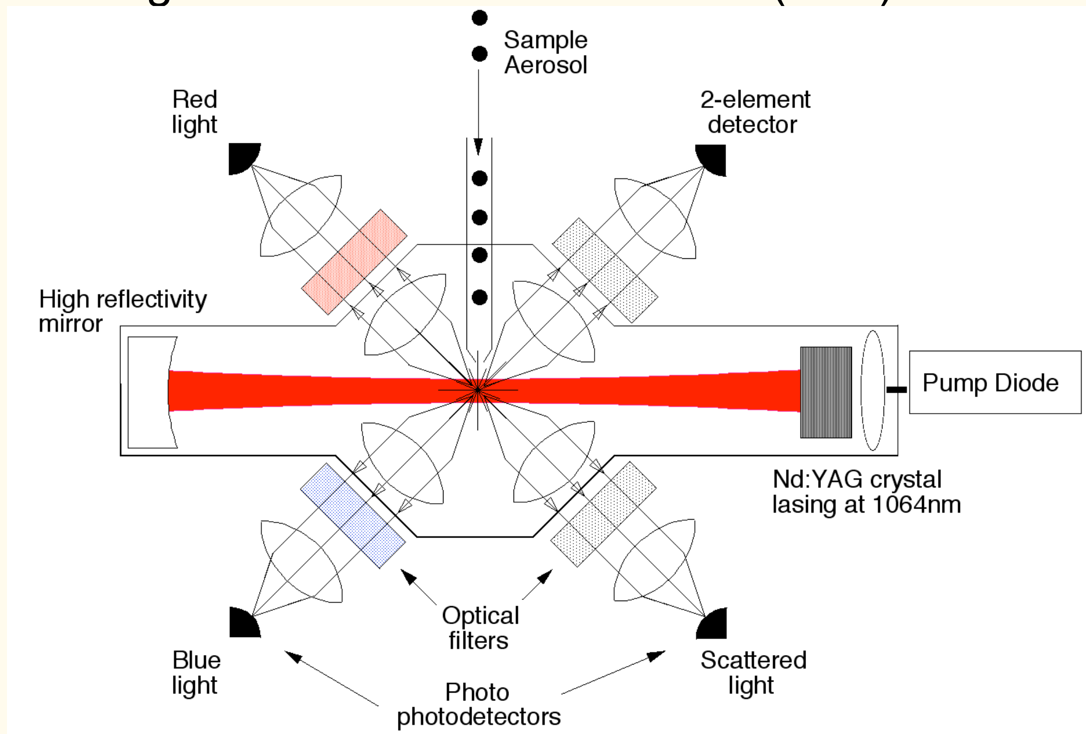
2. Individual Model results

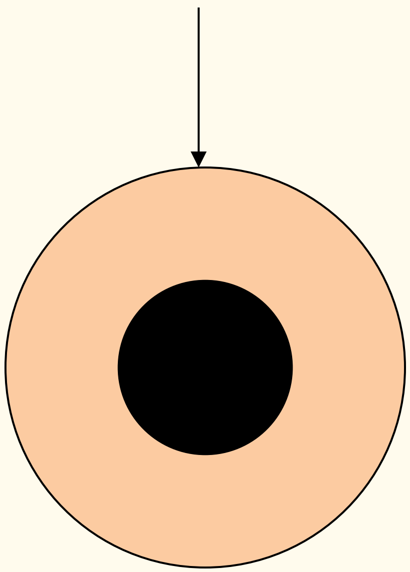
3. Proposed future analyses

Quick Refresher - Experimental Approach



Single Particle Soot Photometer (SP2)





Shell-and-core simplification

- Assume index of coating
- Pretend geometry

1)BC-containging particle enters edge of powerful laser: we optically size it.
2)Non-refractory materials are vaporized: we note evidence of such removal
3)The BC component heats to ~4000K, emits visible light proportional to its mass: we record it, and optically size the core.

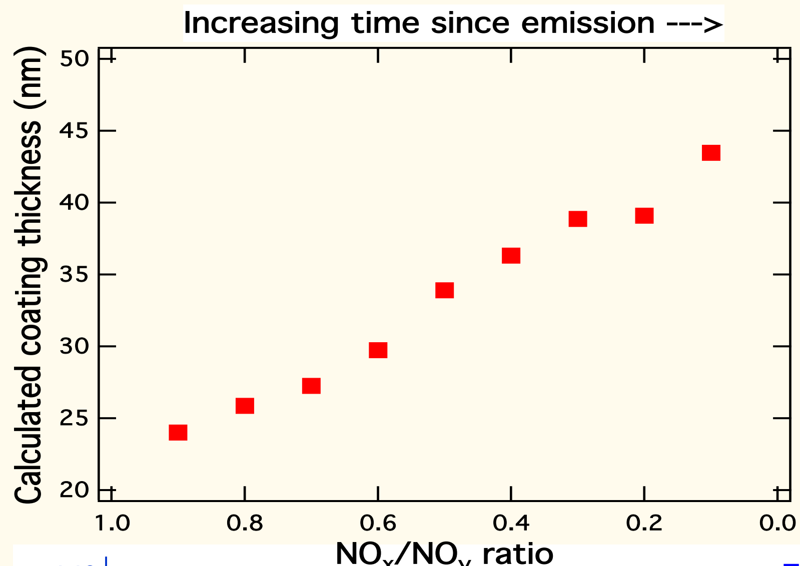
BASIC MEAUREMENTS: BC MASS
TOTAL PARTICLE OPTICAL SIZE
BC OPTICAL SIZE

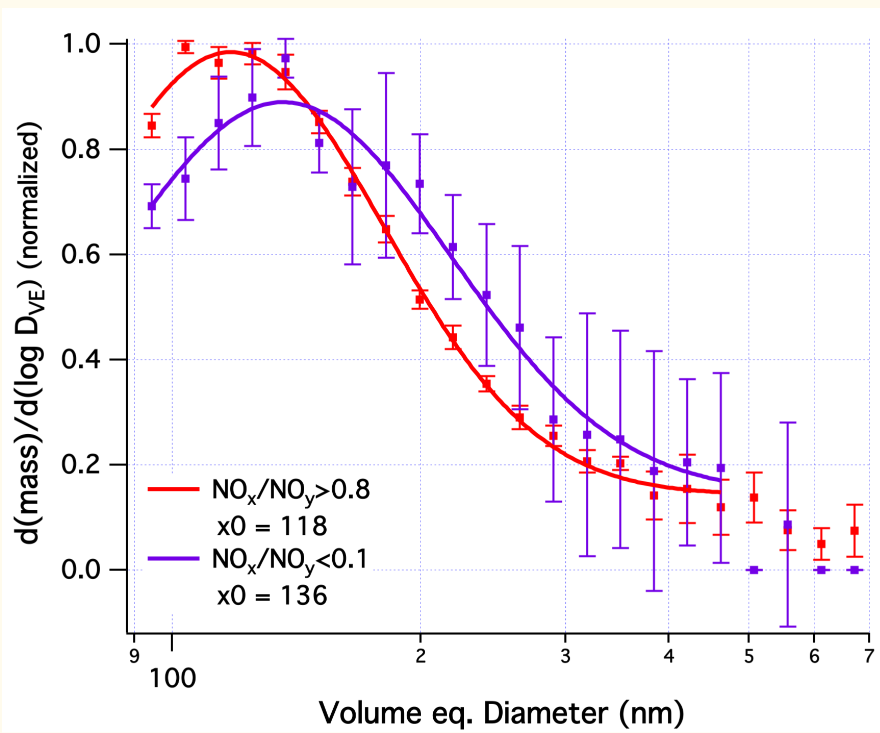
Near-source observations of BC

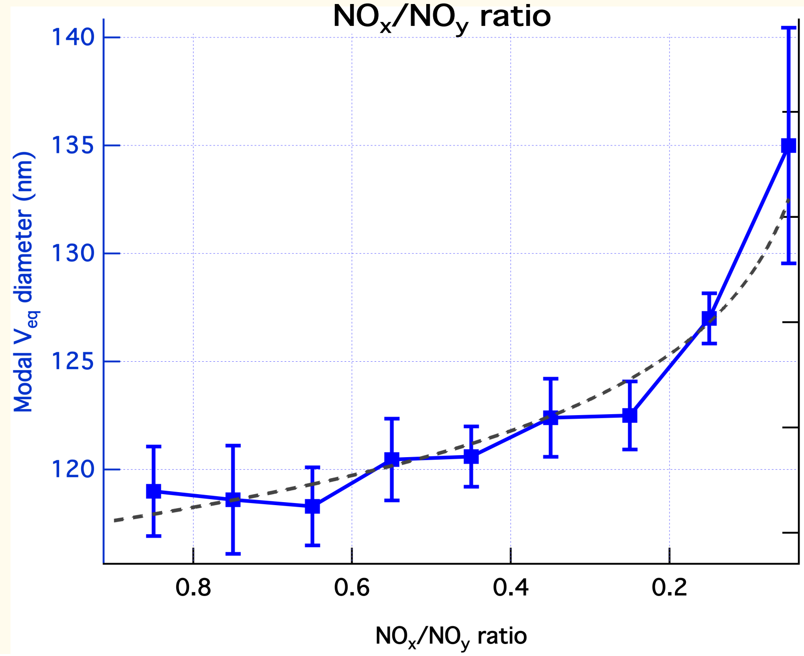
CalNex 2010: Los Angeles, CA

• BC particles in LA are small relative to previous observations and initially uncoated.

• Particle size and coating thickness increase with increasing photochemical age increasing the likelihood of removal over time.





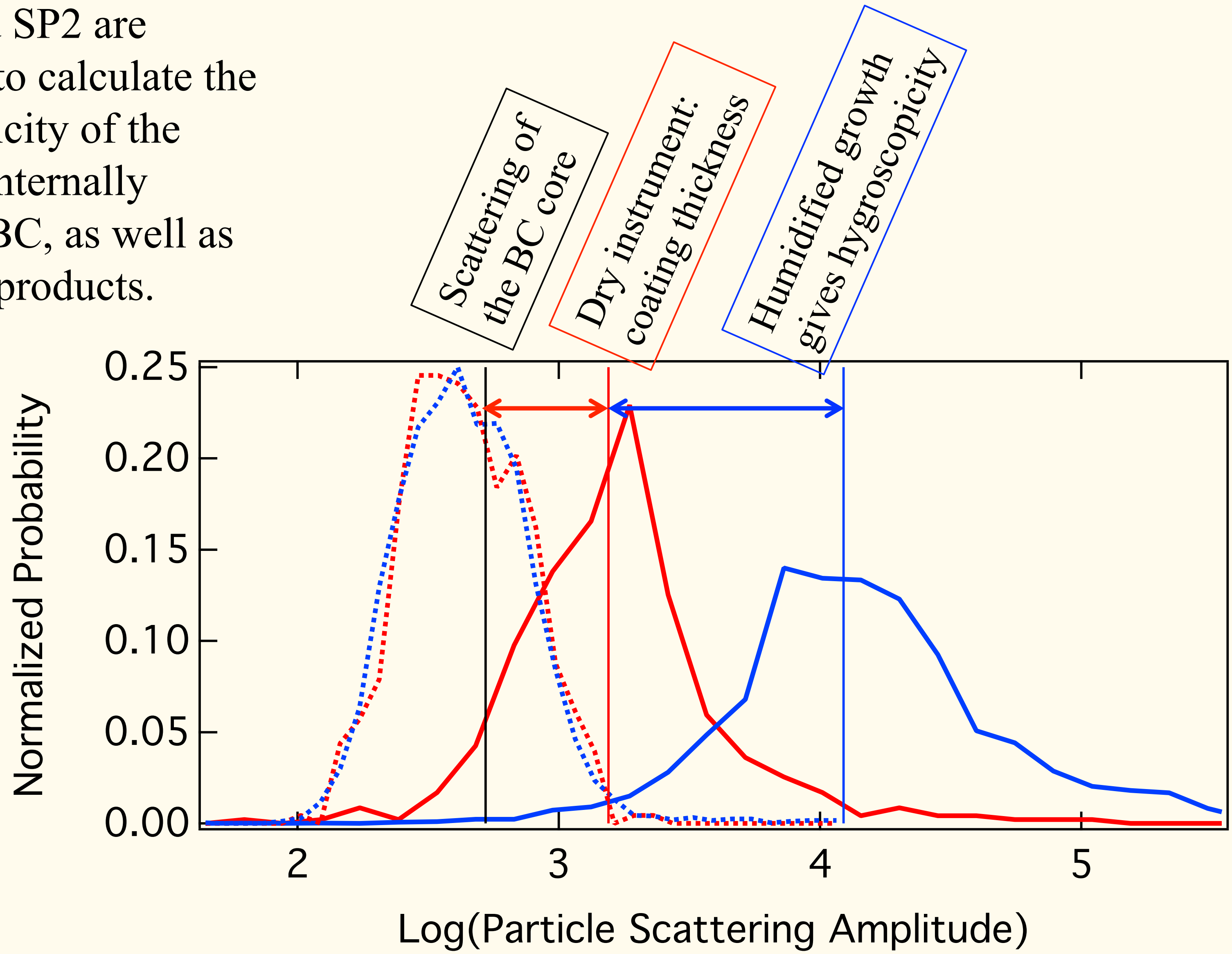


Perring et al., in prep. 2013

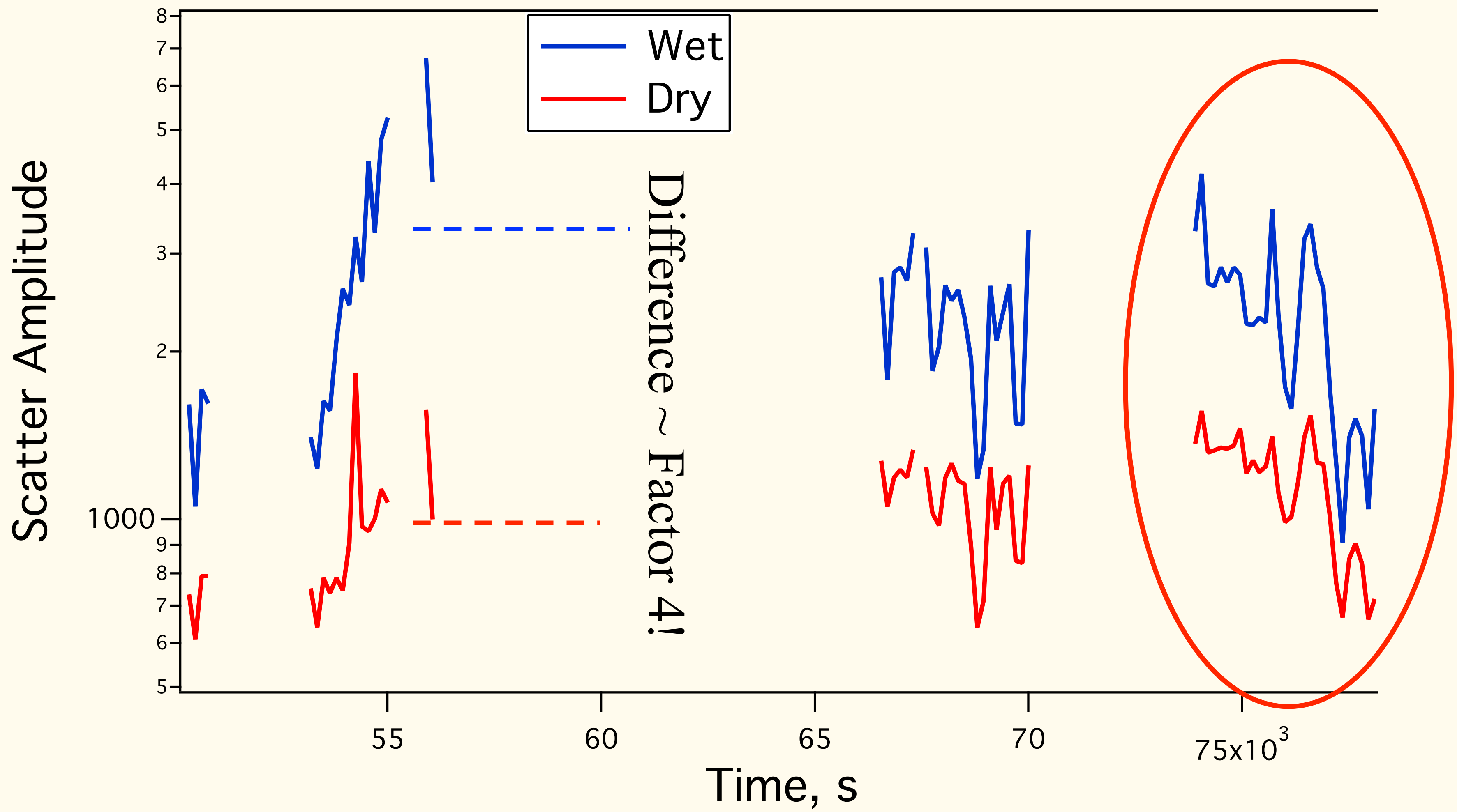
Motivation

- Black carbon *atmospheric lifetime* depends on the amount and hygroscopicity of internally mixed material associated with BC.
- Generally, the *optical properties* of BC-containing aerosol depend on ambient humdity.
- Hygroscopicity of these materials *may differ from bulk aerosol*
- *Few ambient measurements* based on morphology changes with water uptake:
  - Covert and Heintzenburg, *SotTE,* 1984 – humidified impactor
  - McMeeking et al., *ACP,* 2011 – hTDMA/Single Particle Soot Photometer

The data from a dry and a humidified SP2 are combined to calculate the hygroscopicity of the materials internally mixed on BC, as well as other data products.



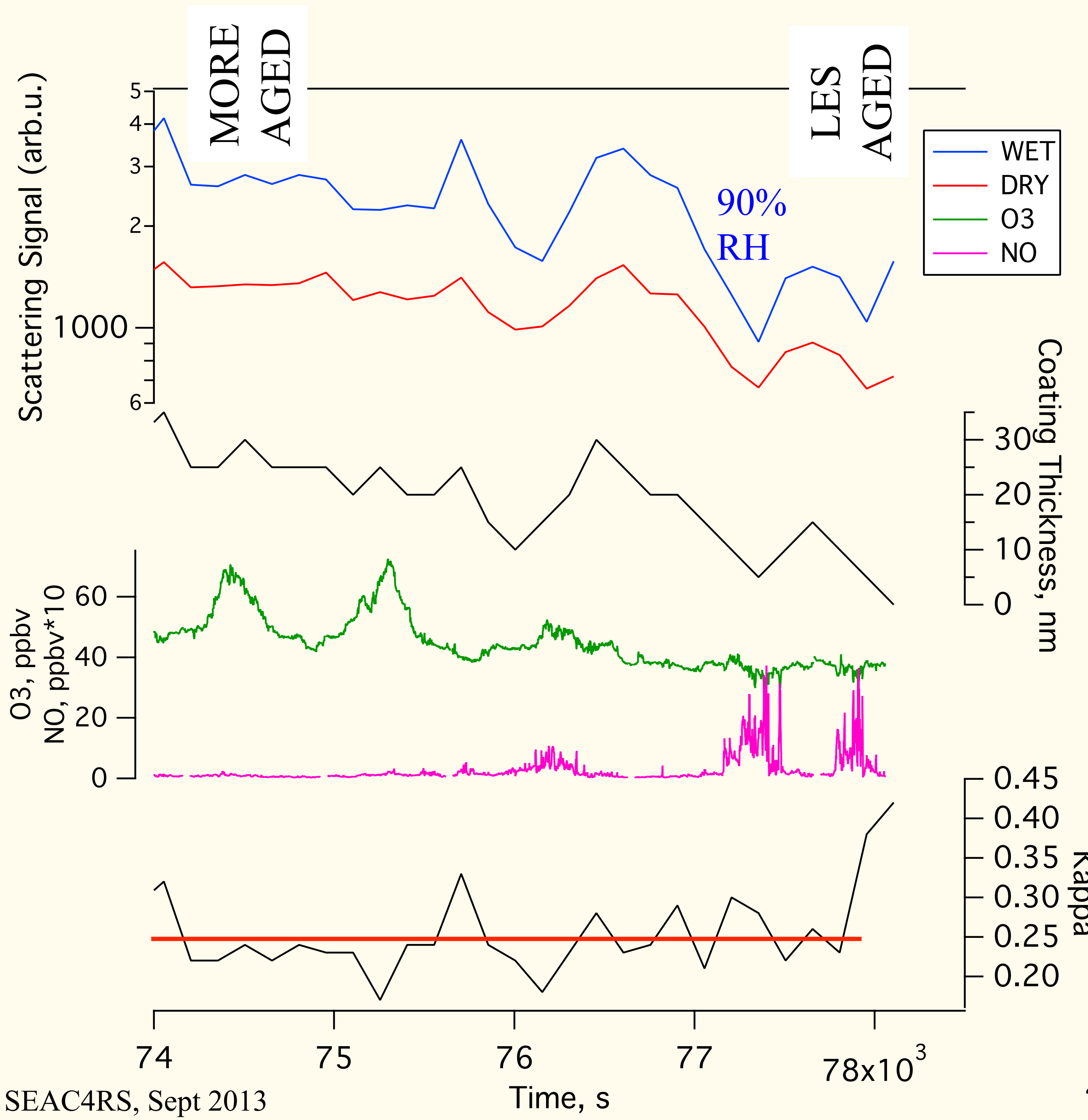
Total-particle Sizing in flight:
Tracking differences in dry coating thickness/
in impact of water uptake on scattering



Schwarz et al., preliminary data, SEAC4RS, Sept 2013

Preliminary interpretation:

- Urban plume
- Increasing coatings with age (hours)
- Increased scattering with humidification
- Little shift in Kappa!

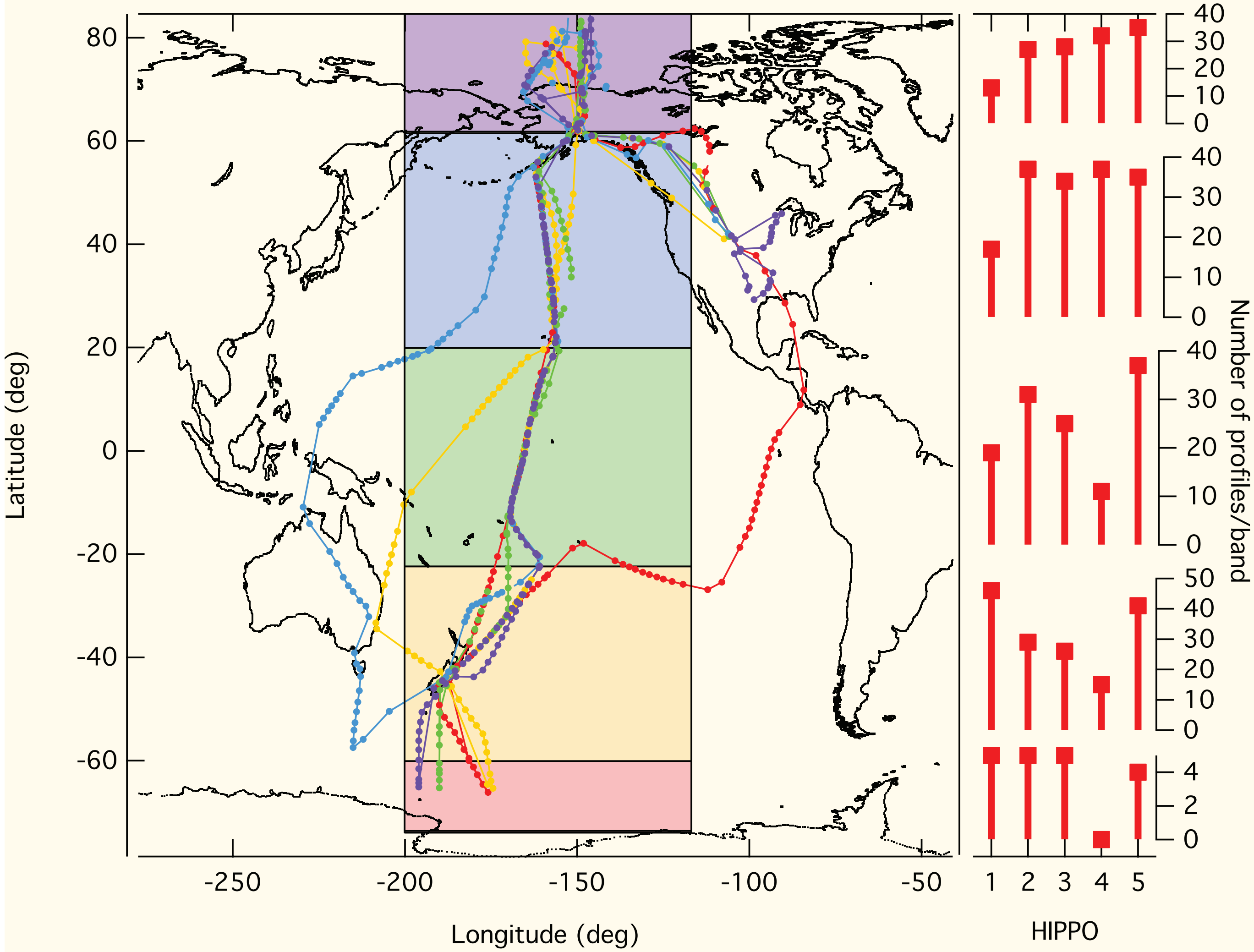


Schwarz et al., preliminary data, SEAC4RS, Sept 2013

Summary (only this section)$_1$

- Are you interested/do you want BC size information, even if variations are small?
- Are you interested/do you want "coating thickness" values, even if they are based on mie shell/core interpretation for only a narrow slice of the BC mass distribution?
- Are you interested/do you want kappa value for material internally mixed on BC (with similar caveats as for "coating thickness"?

Overview



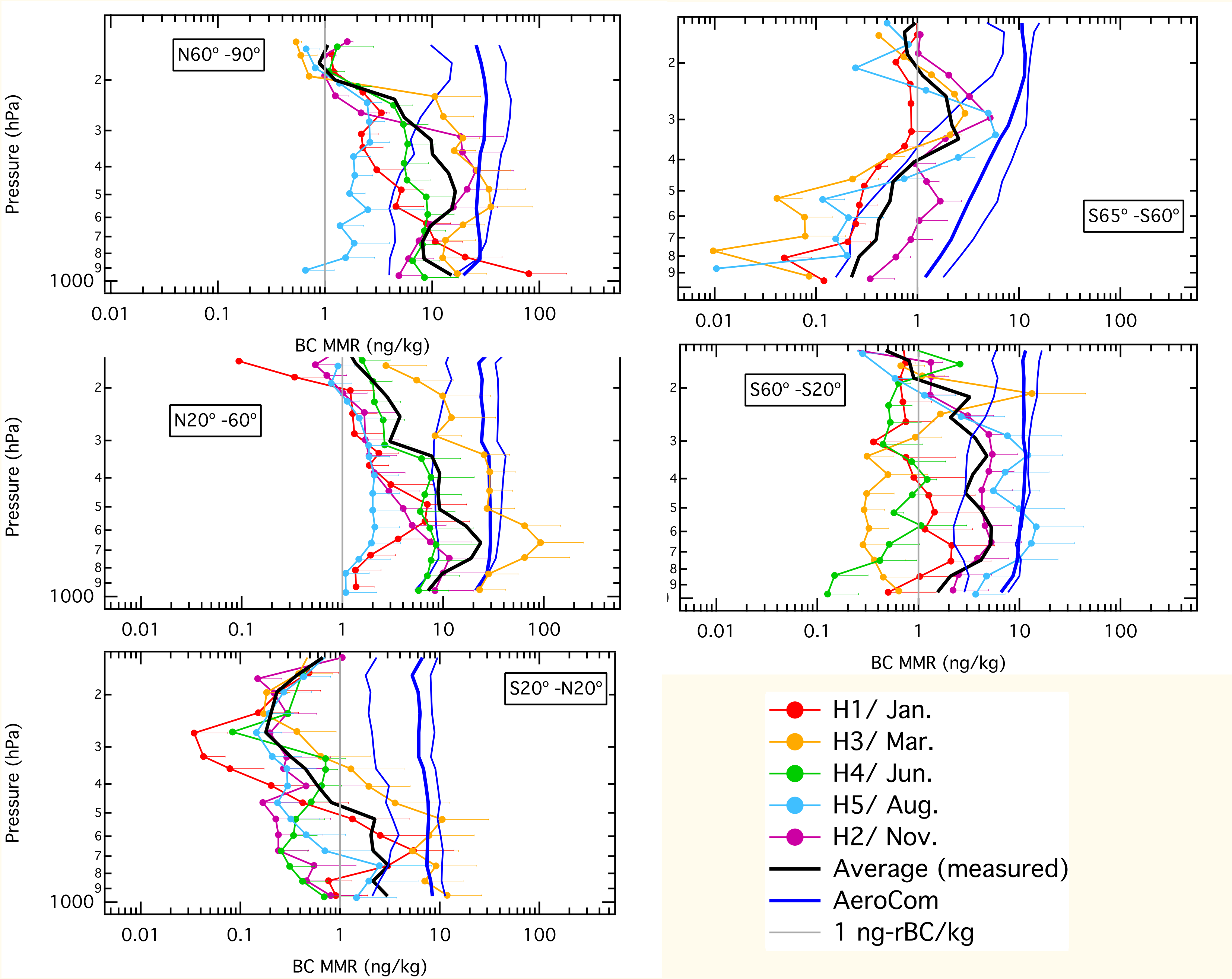
->HIPPO BC CLIMATOLOGY

- 5 flight series, 2009 – 2011
- 85N – 67 S
- Roughly evenly spaced throughout a calendar year
- ~700 vertical profiles
- Over 3 years

- Phase 2:

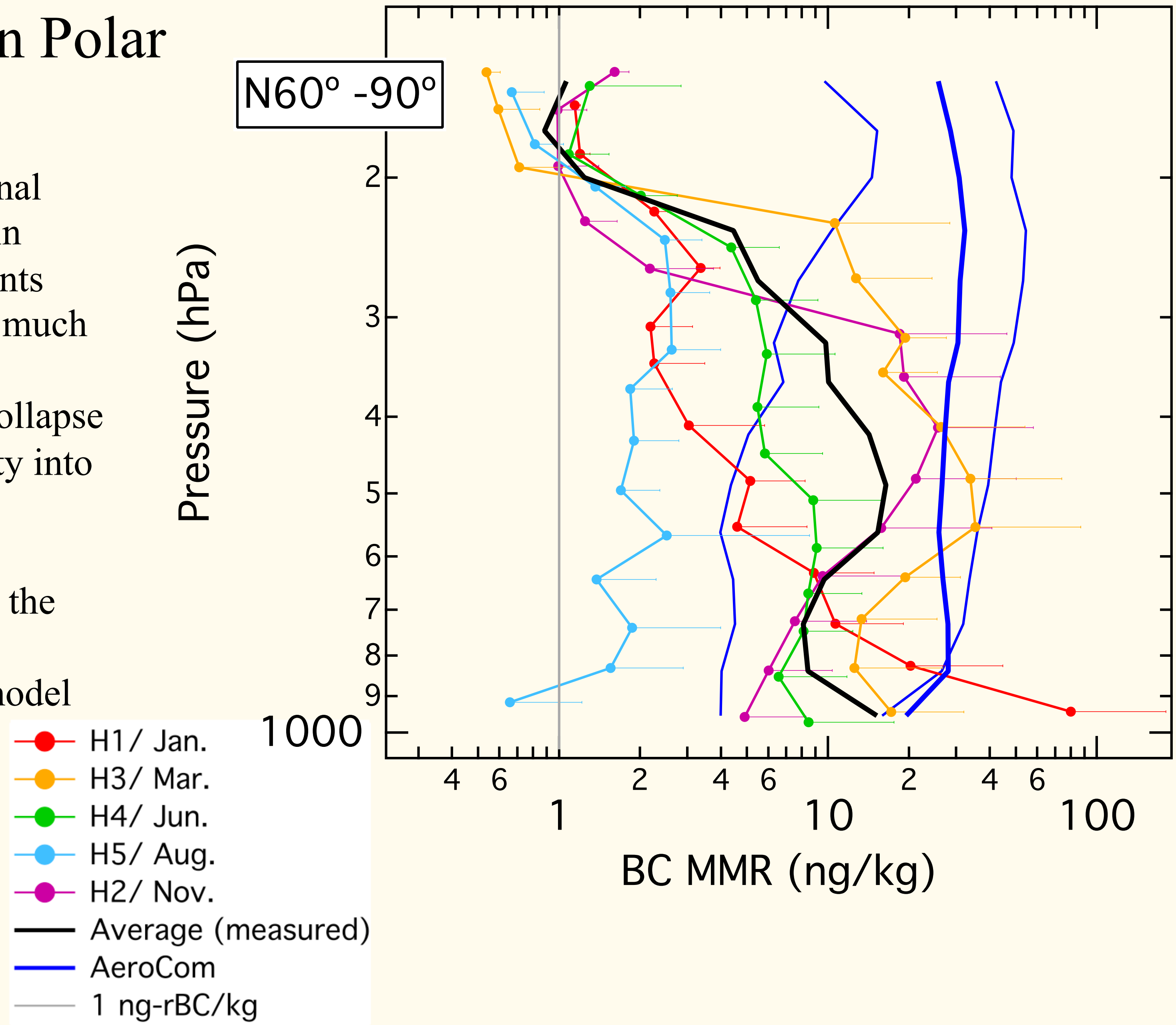
CAM1, CAM2, CAM3, GISS, GMI, GOCART, HADGEM2, IMPACT, INCA, MPIHAP, OsloCTM2, SPRINTARS

Measurement/AeroCom Ensemble Results:



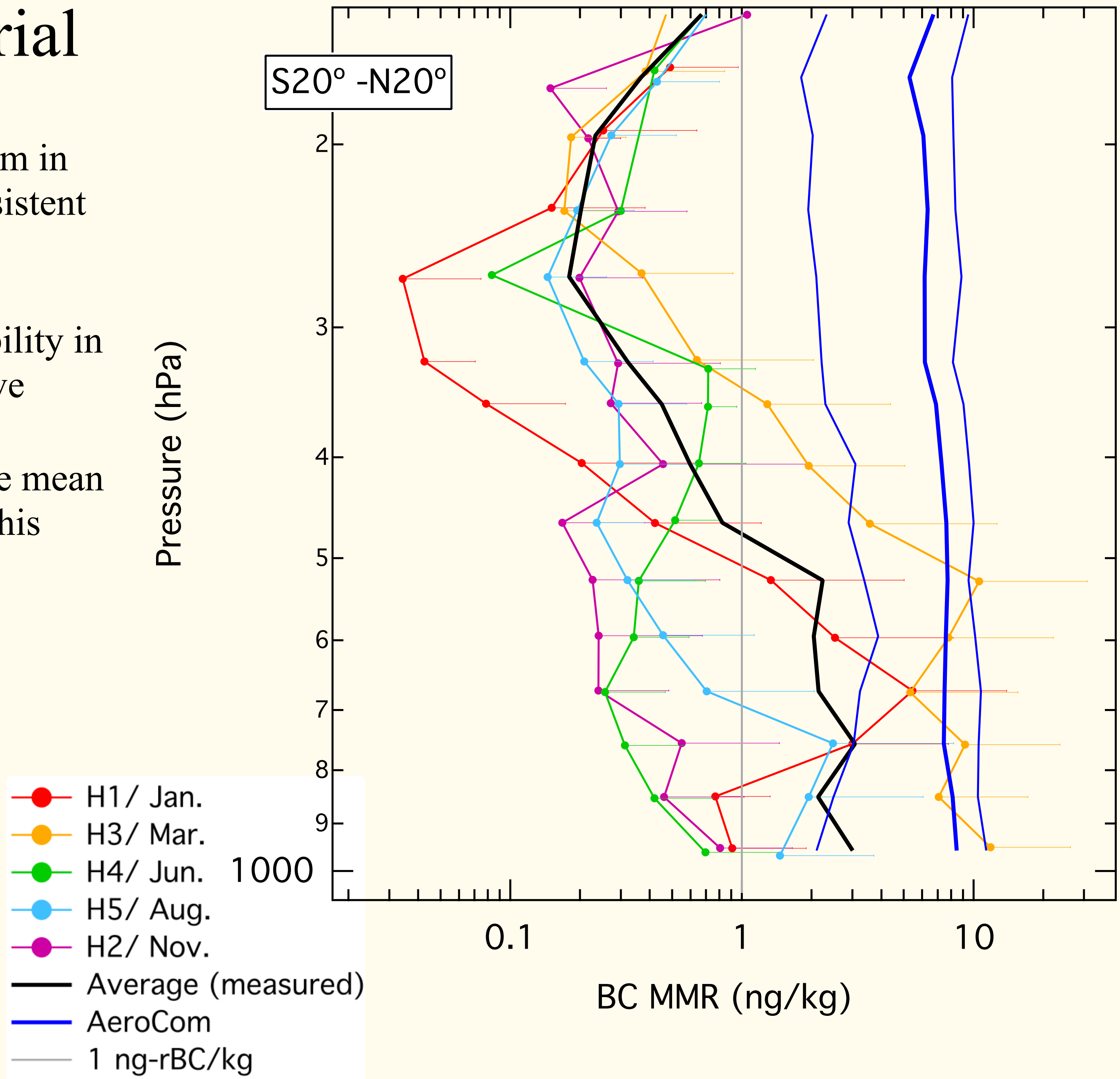
Northern Polar

- High seasonal variability in measurements throughout much of the TS
- Dramatic collapse of variability into the LS
- Similar
- behavior in the SH
- Powerful model constraint?



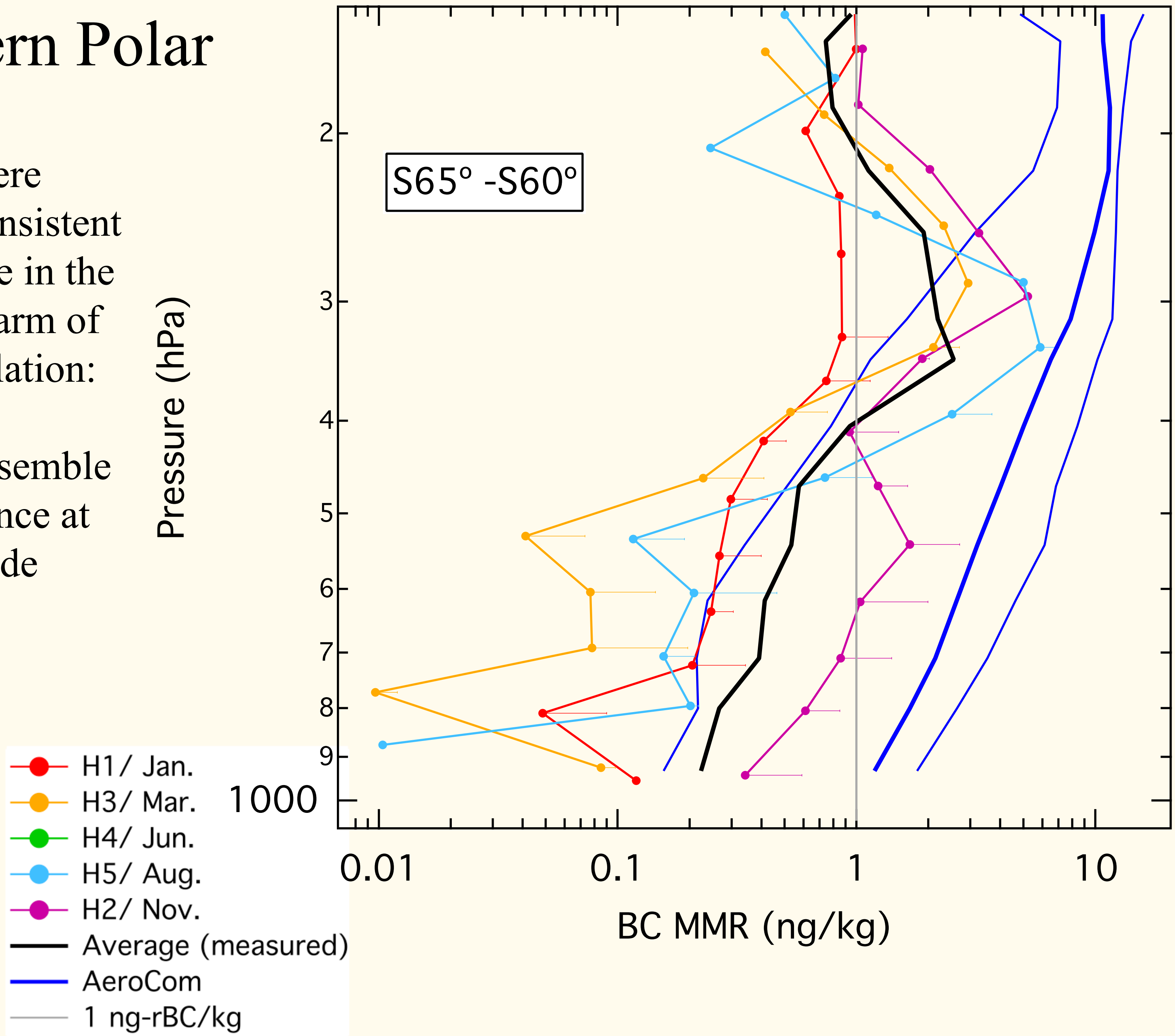
Equatorial

- Annual minimum in rBC MMR consistent with convective outflow region
- Very low variability in rBC MMR above minimum
- Model ensemble mean doesn't reflect this feature



Southern Polar

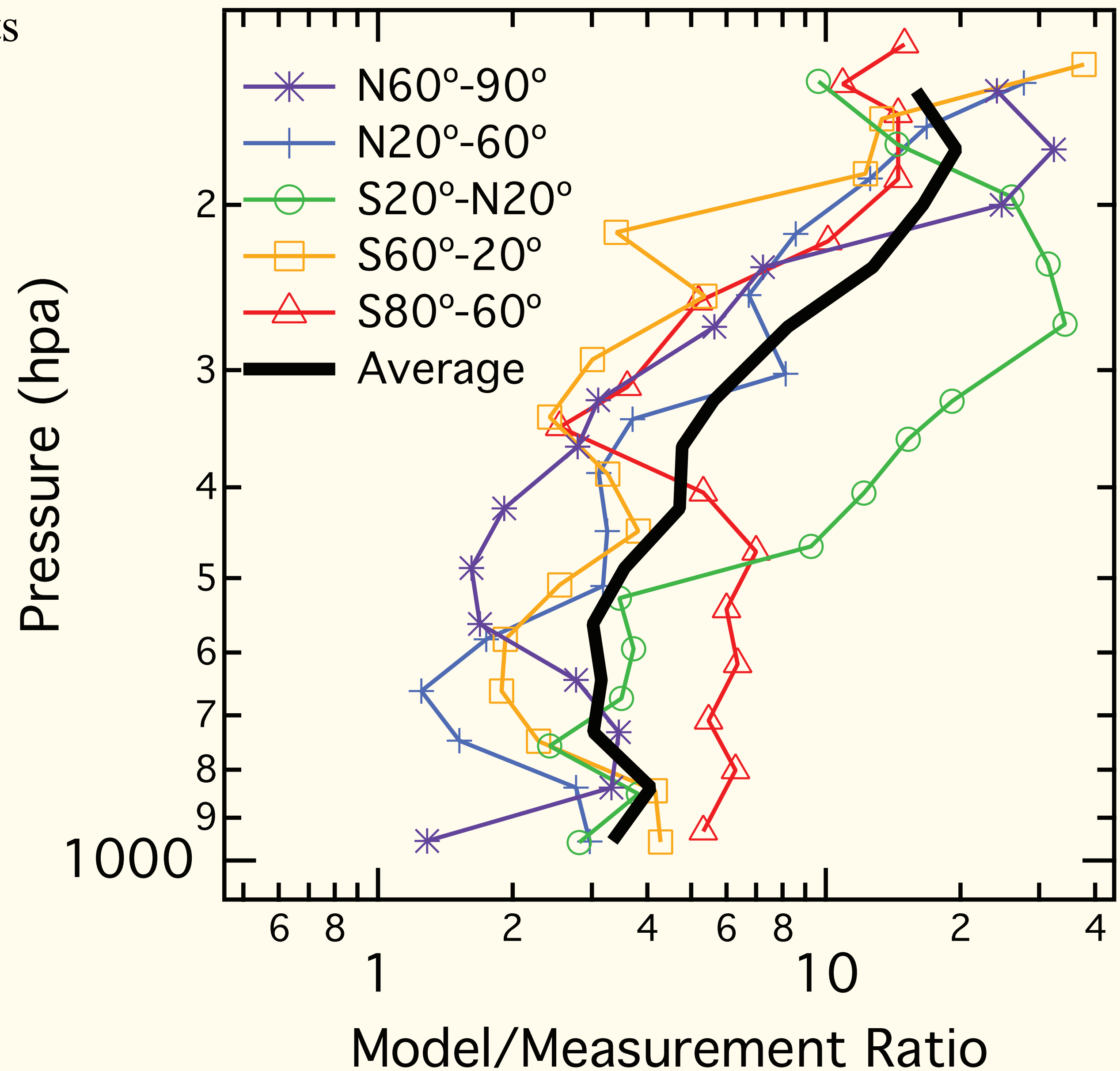
- SH lower stratosphere values consistent with those in the northern arm of BD circulation: 1ng/kg
- Worse ensemble performance at low altitude



Average Profile Results

- Approximate annual averages
- Best performance in lower trop in NH
- Consistent ensemble bias at the the highest altitudes
- Poorest performance at mid/upper TS in equatorial region

  -Very exciting region to focus on! Drives lower stratospheric biases…?



Summary (this section only)$_2$

- AeroCom biases in remote region identified by comparison to HIPPO-1 have been more clearly identified with this comparison to Phase II.
- AeroCom bias at high altitude likely more widespread than merely over the remote Pacific
- Bjørn Samset talk next: RF and more!

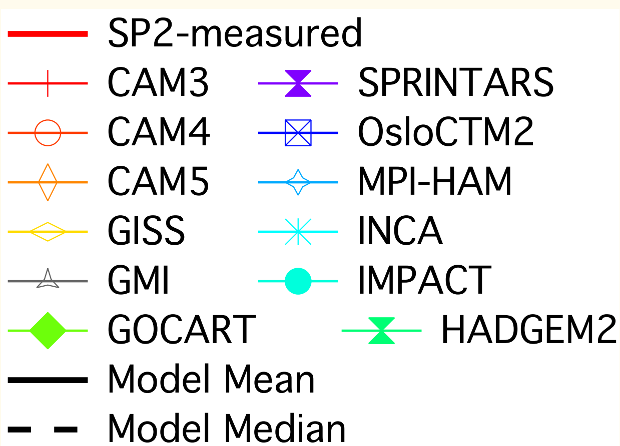
(Next: Individual models)

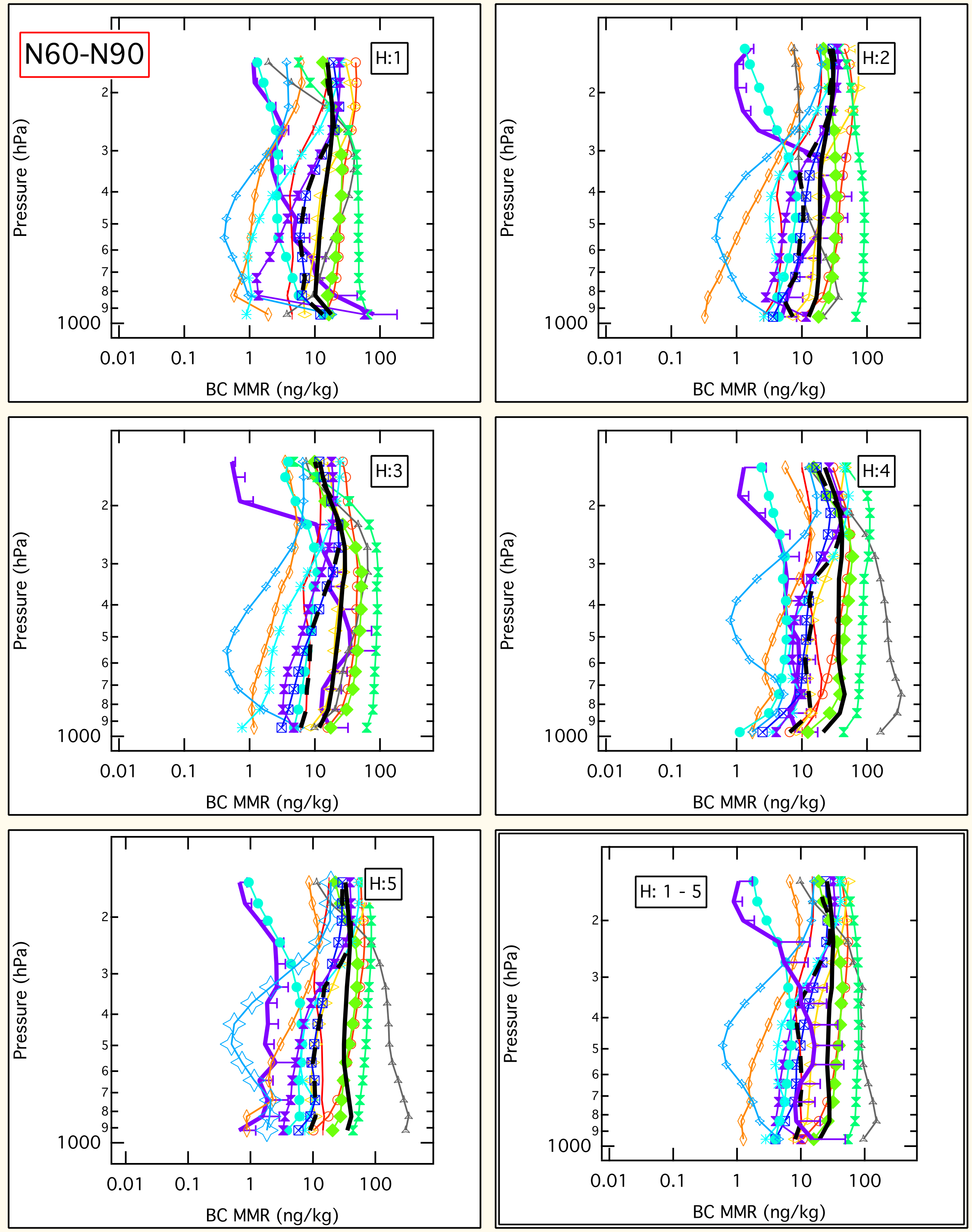
Individual models

Northern Polar:

Transition across tropopause missed in ensemble, but caught (?) by some models

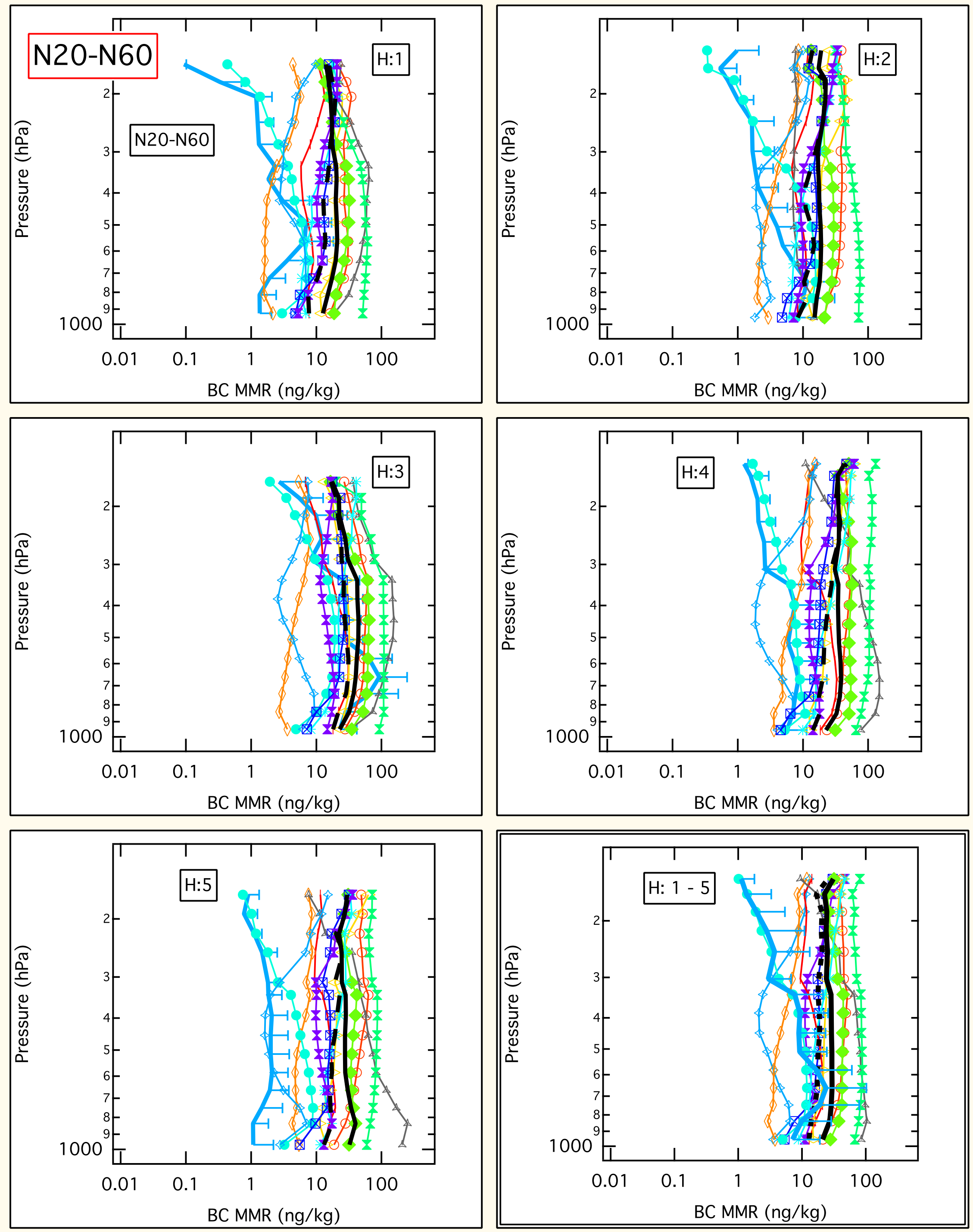
Some seasonal variability – in both models and measurements

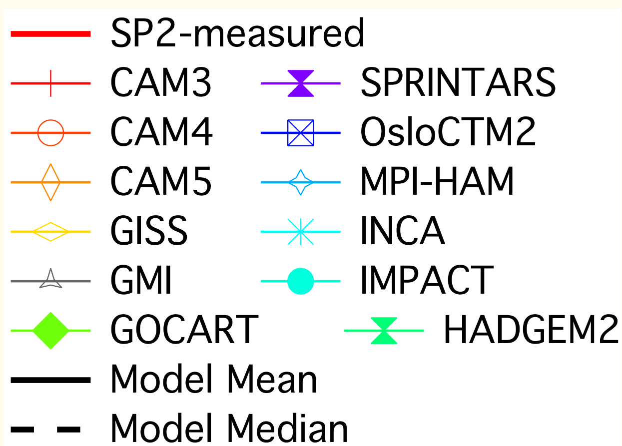




Northern Mid-latitudes

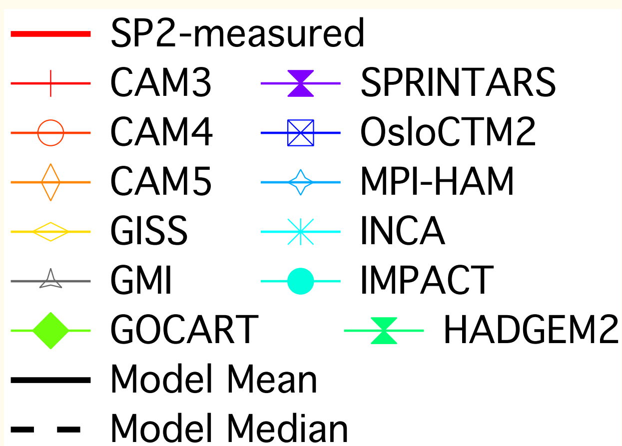
- High loadings associated with spring-time export from Asia (H3), peaking ~800-400hPa
- All seasons – BC trends toward 1ng/kg MMR at the highest altitudes

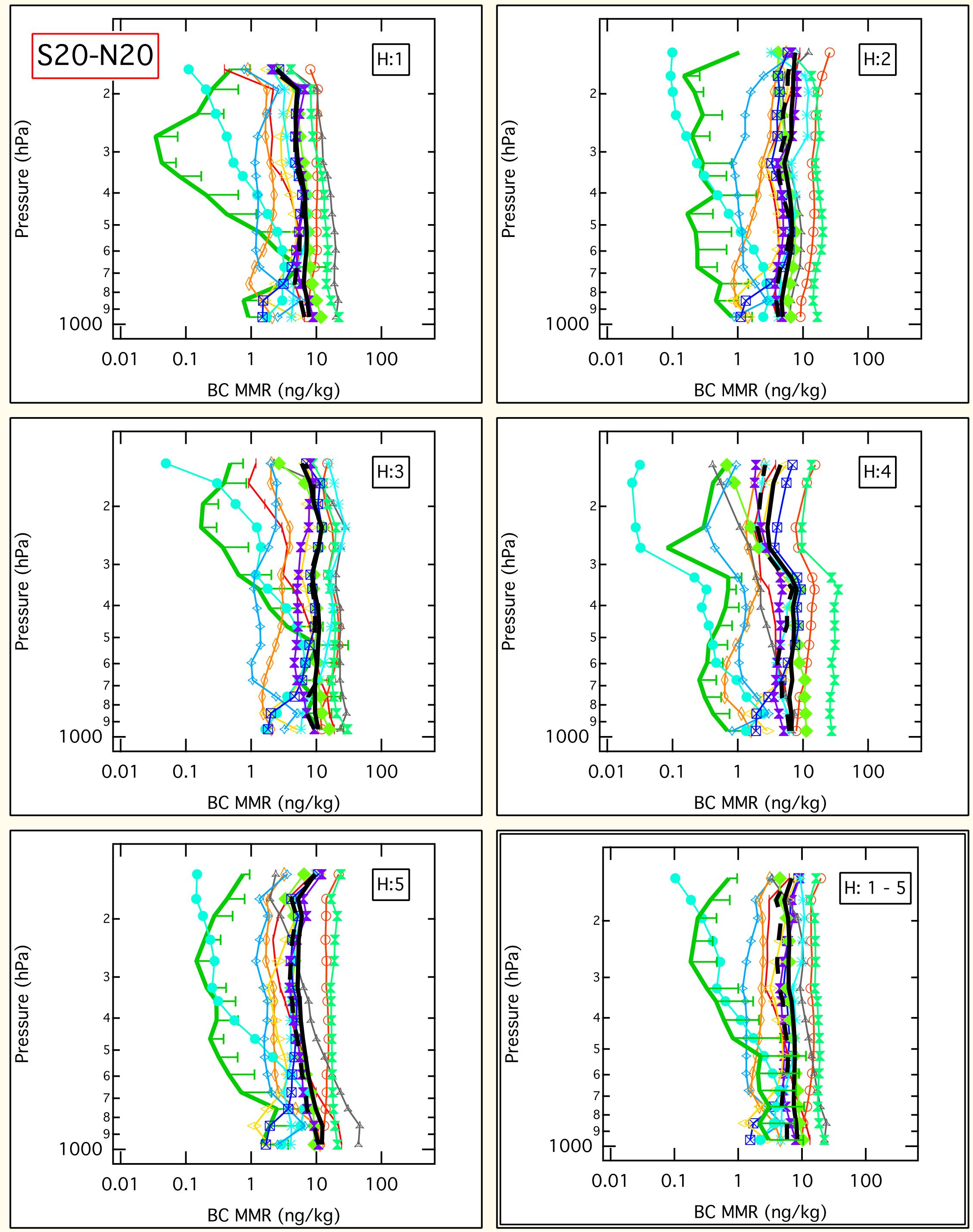




Equatorial Range –

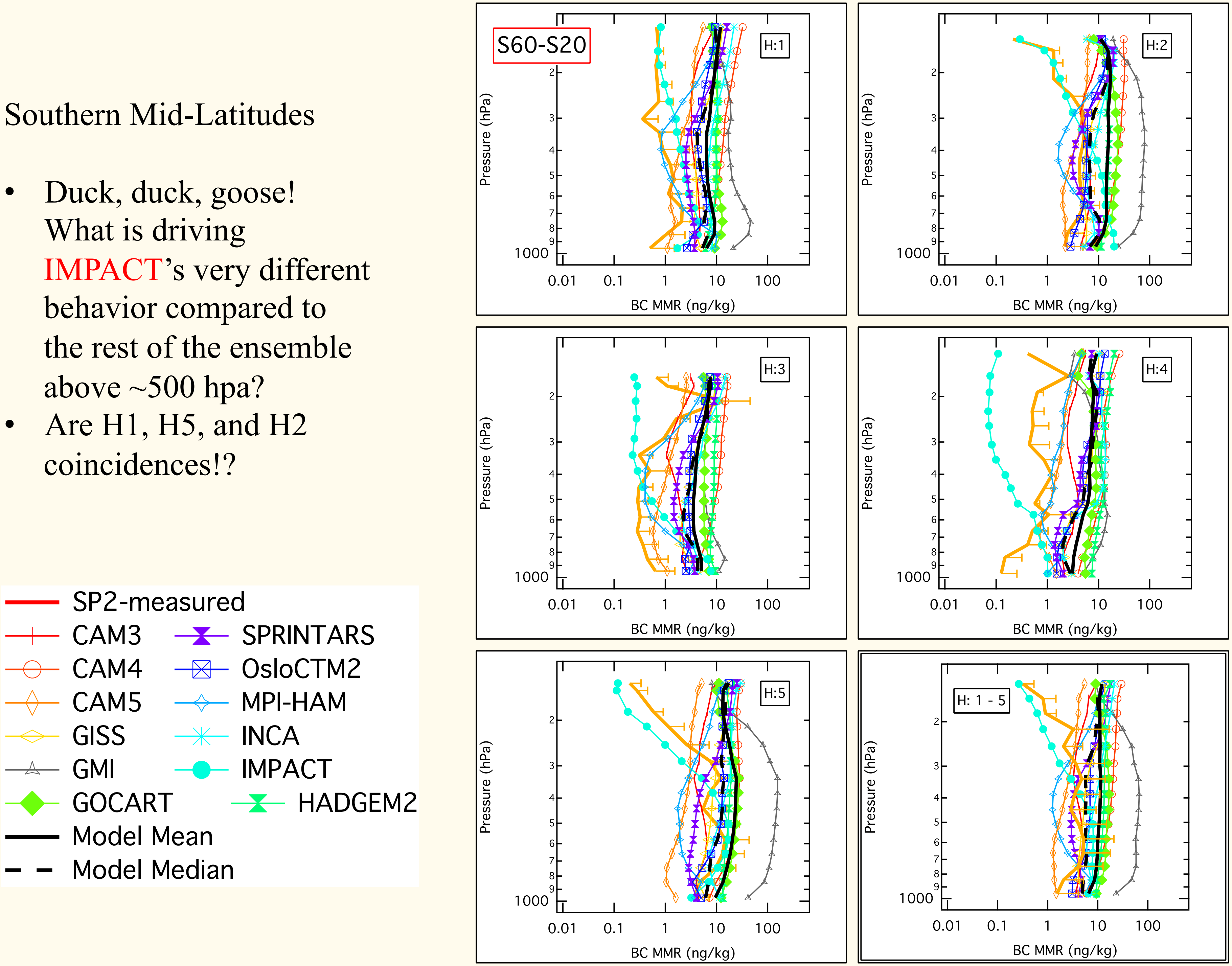
- Fairly obvious minima in vertical profile associate with region of convective outflow – suggests that the AeroCom ensemble underestimates convective removal, rather than undo uplift is source of model bias.
- Note that again, in all seasons, trends to 1 ng/kg





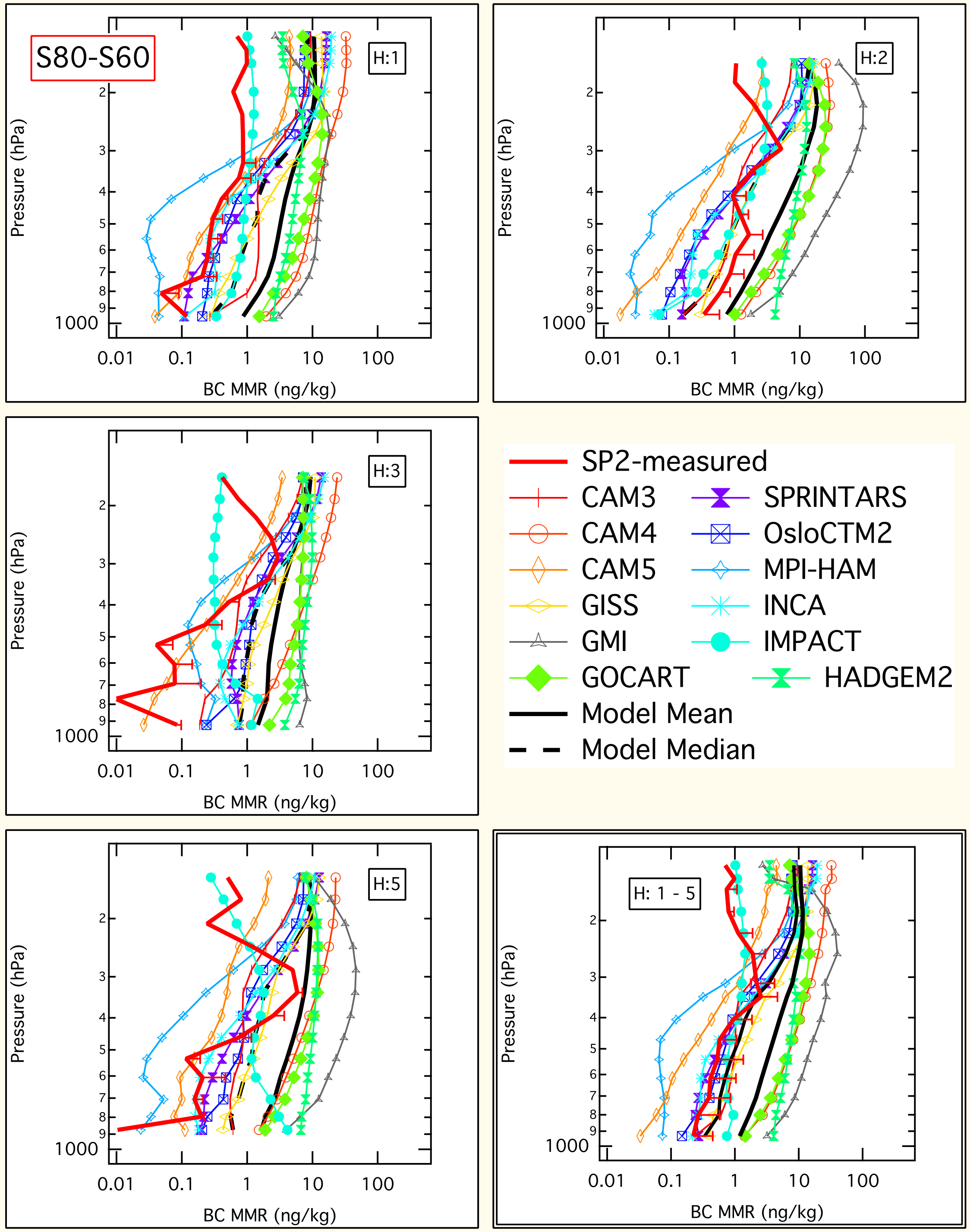
Southern Mid-Latitudes

- Duck, duck, goose! What is driving IMPACT's very different behavior compared to the rest of the ensemble above ~500 hpa?
- Are H1, H5, and H2 coincidences!?



Southern Polar

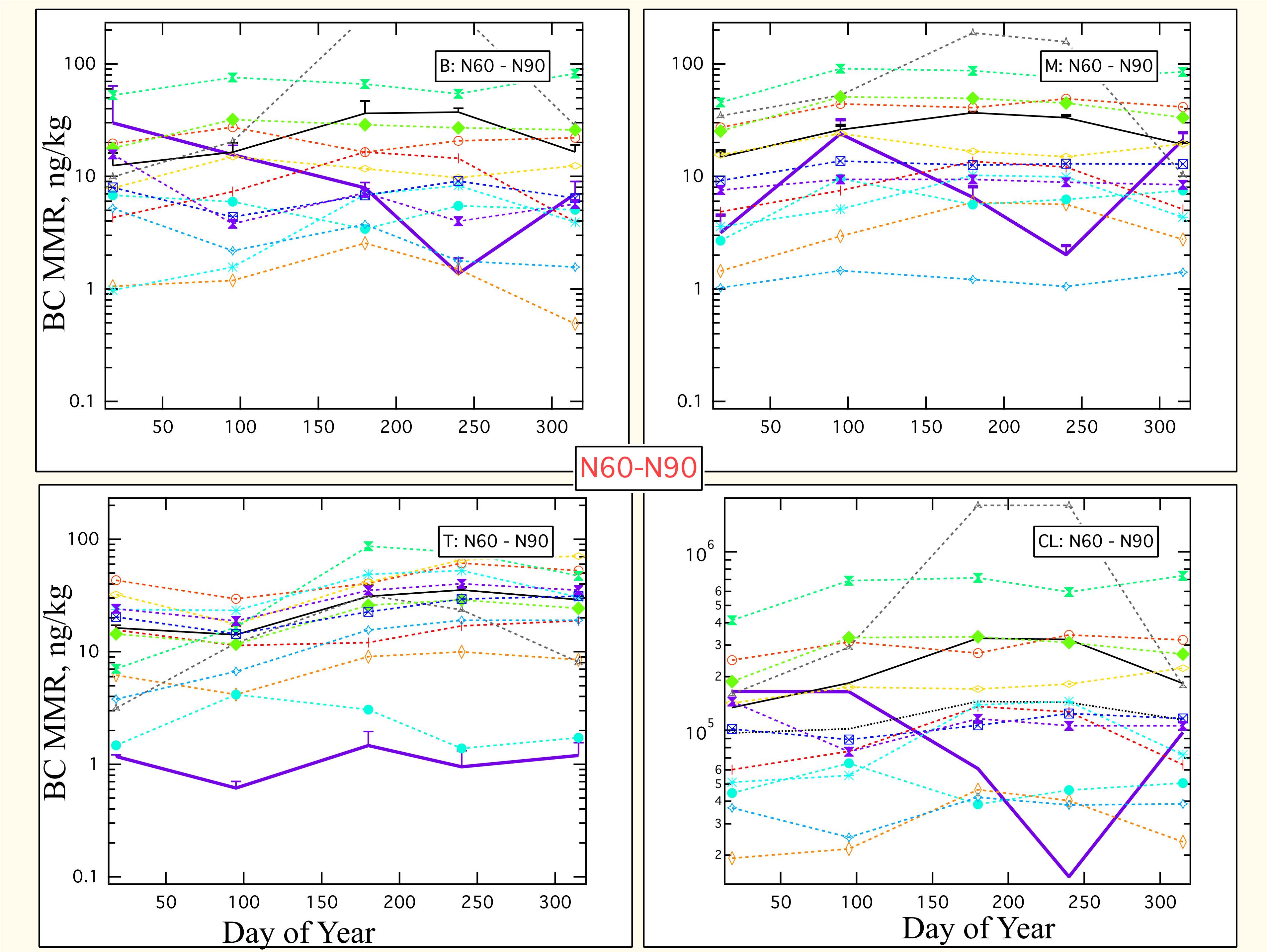
- This region - poorest statistics, especially at higher altitudes.
- Correlation of BC MMR with altitude captured by AeroCom up to ~400 hPa, then divergence.
- IMPACT behaves differently than other models aloft in this latitude band.

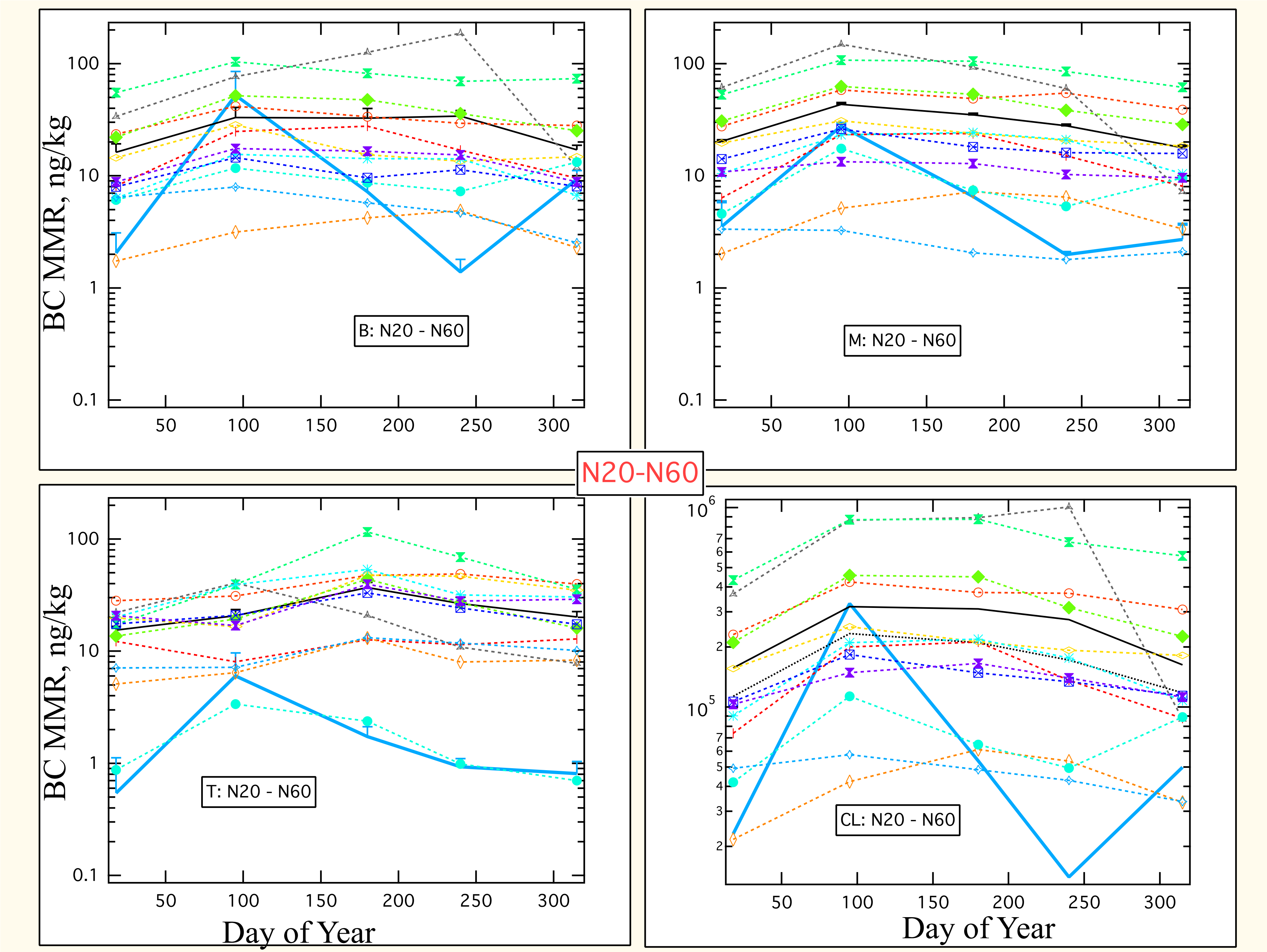


Summary (this section only)$_3$

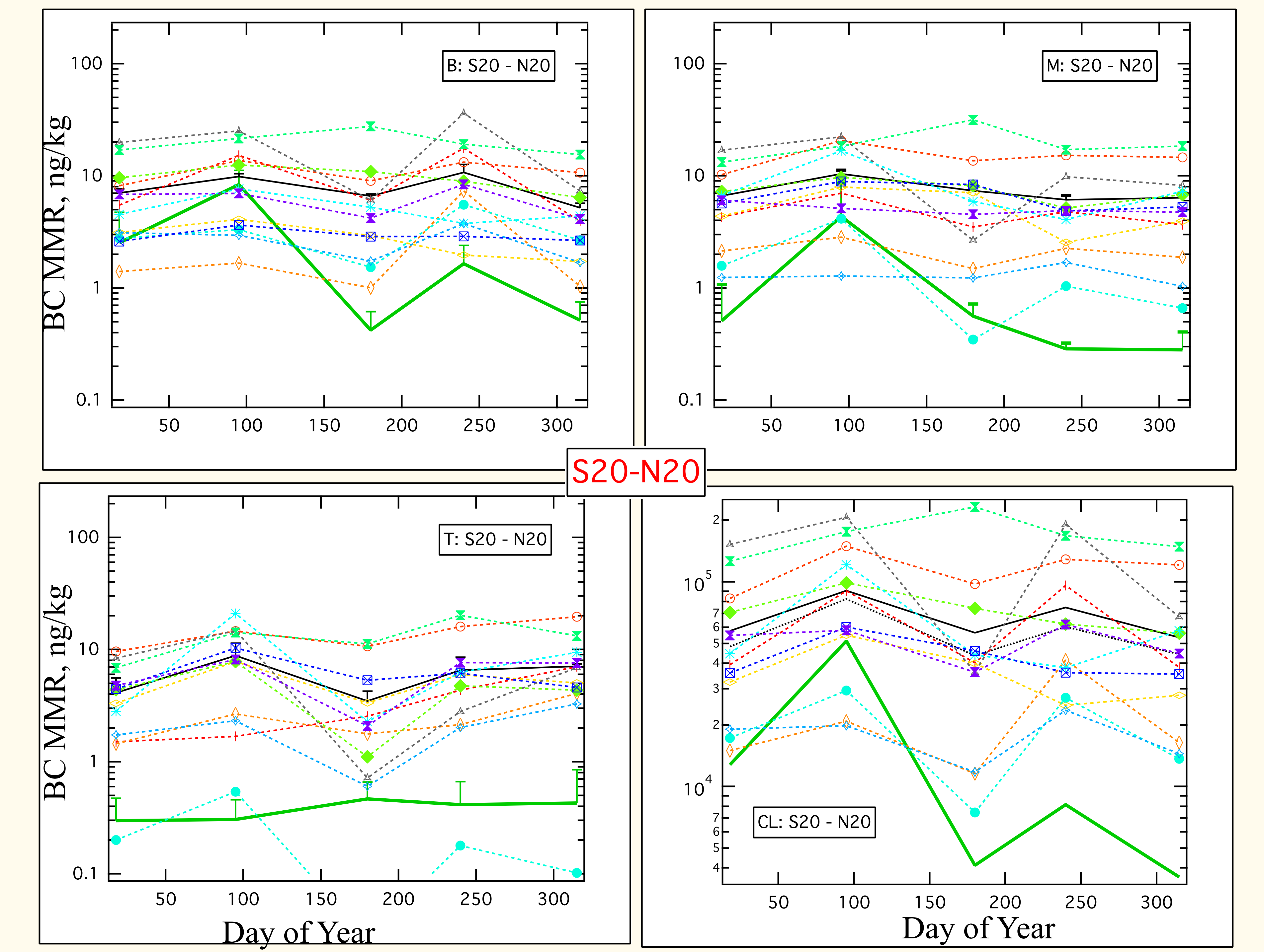
- Very different model behavior.
- IMPACT stands out above ~300 hPa
- Interest in exploring these sensitivities with a reasonably robust BC climatology as a metric?

Next: Seaonality

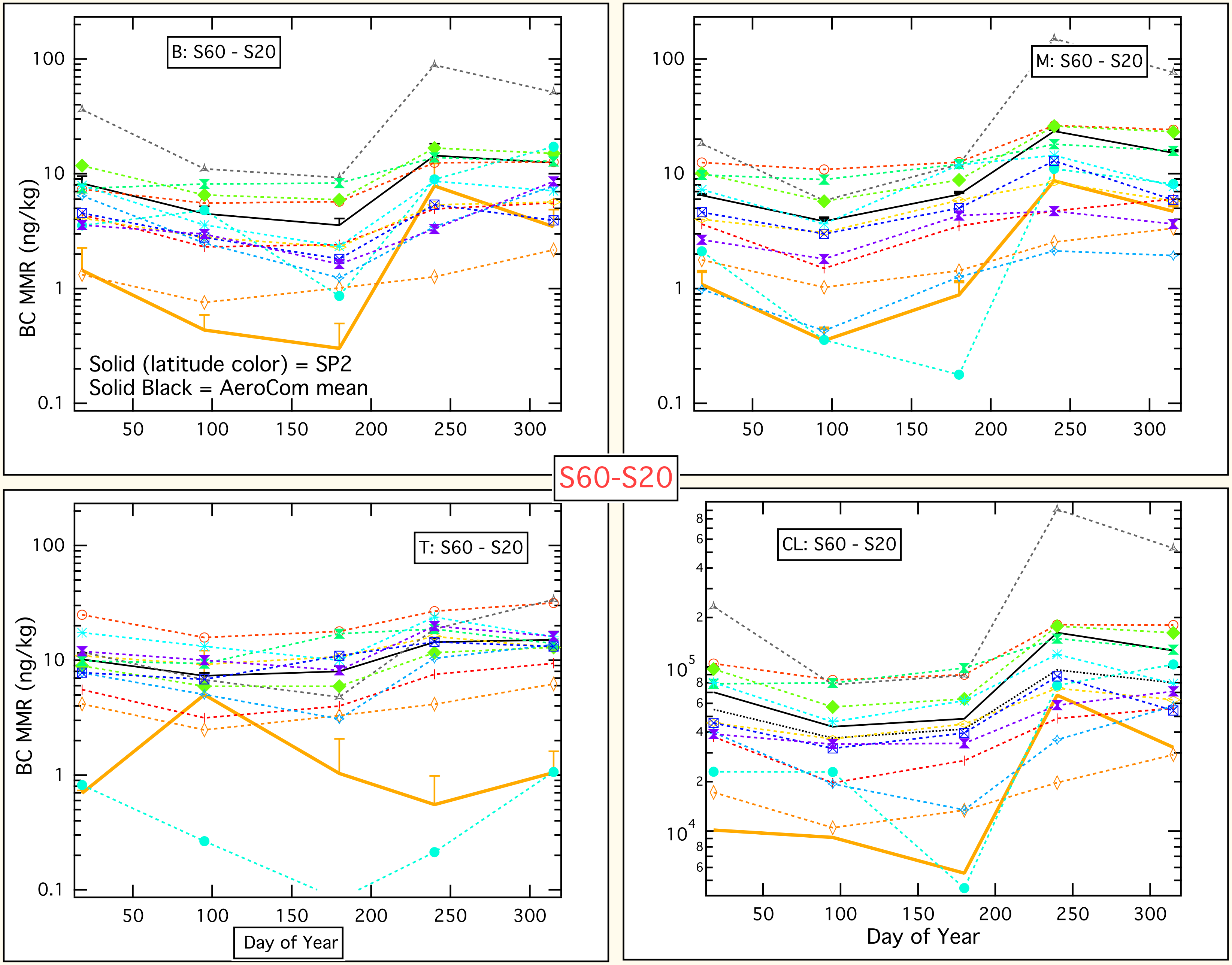

B: N60 - N90
M: N60 - N90
T: N60 - N90
CL: N60 - N90
N60-N90
BC MMR, ng/kg
Day of Year



N20-N60
B: N20 - N60
M: N20 - N60
T: N20 - N60
CL: N20 - N60
BC MMR, ng/kg
Day of Year


B: S20 - N20
M: S20 - N20
S20-N20
T: S20 - N20
CL: S20 - N20
BC MMR, ng/kg
BC MMR, ng/kg
Day of Year
Day of Year

IN THIS LATITUDE BAND YOU SEE SOME CLEAR SEASONALITY CAUGHT BY MODELS



Summary (this section only)$_4$

- AeroCom suite and models generate observed seasonal trends at different altitudes and in different latitudes sometimes.
- This suggests that these seasonal trends are real.
- Biases seem mostly independent of season.

Summary (all)$_6$

-Future analyses:

- Interpretations/publication of individual model results?
- Individual model sensitivity runs against BC?

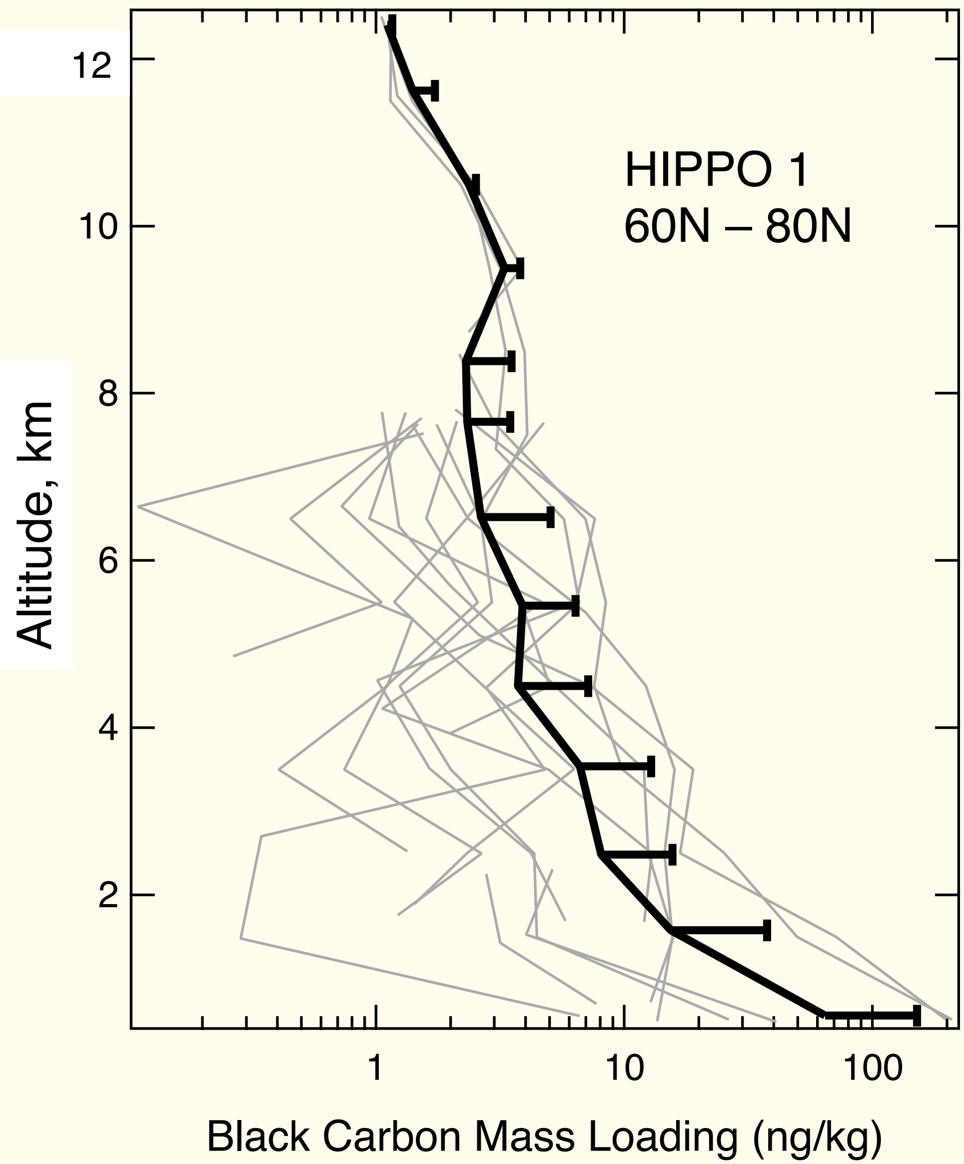
- Future Missions:
  Planning/aiming for more HIPPO-like aircraft campaigns.

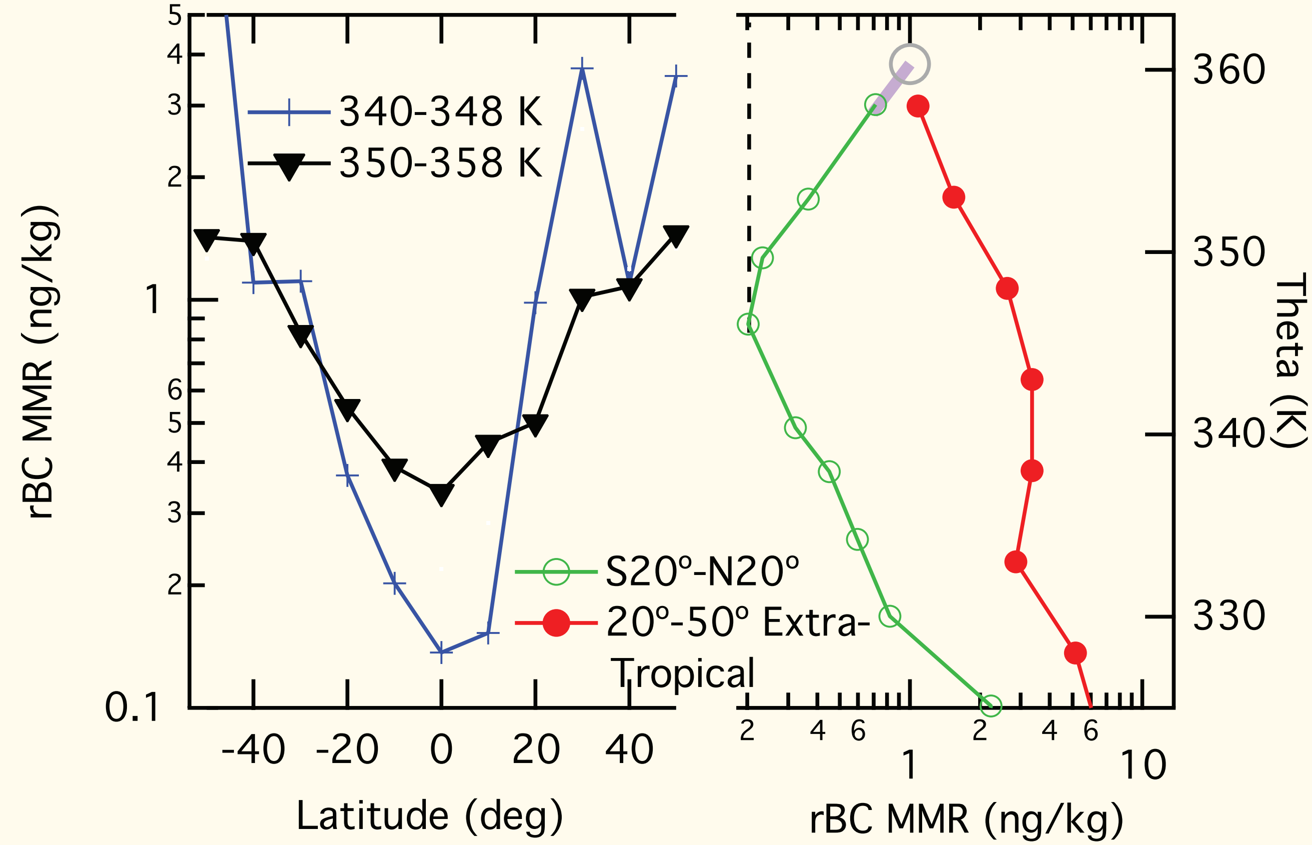
Many thanks for your kind attention!

Comments/questions?

Analysis approach

- 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



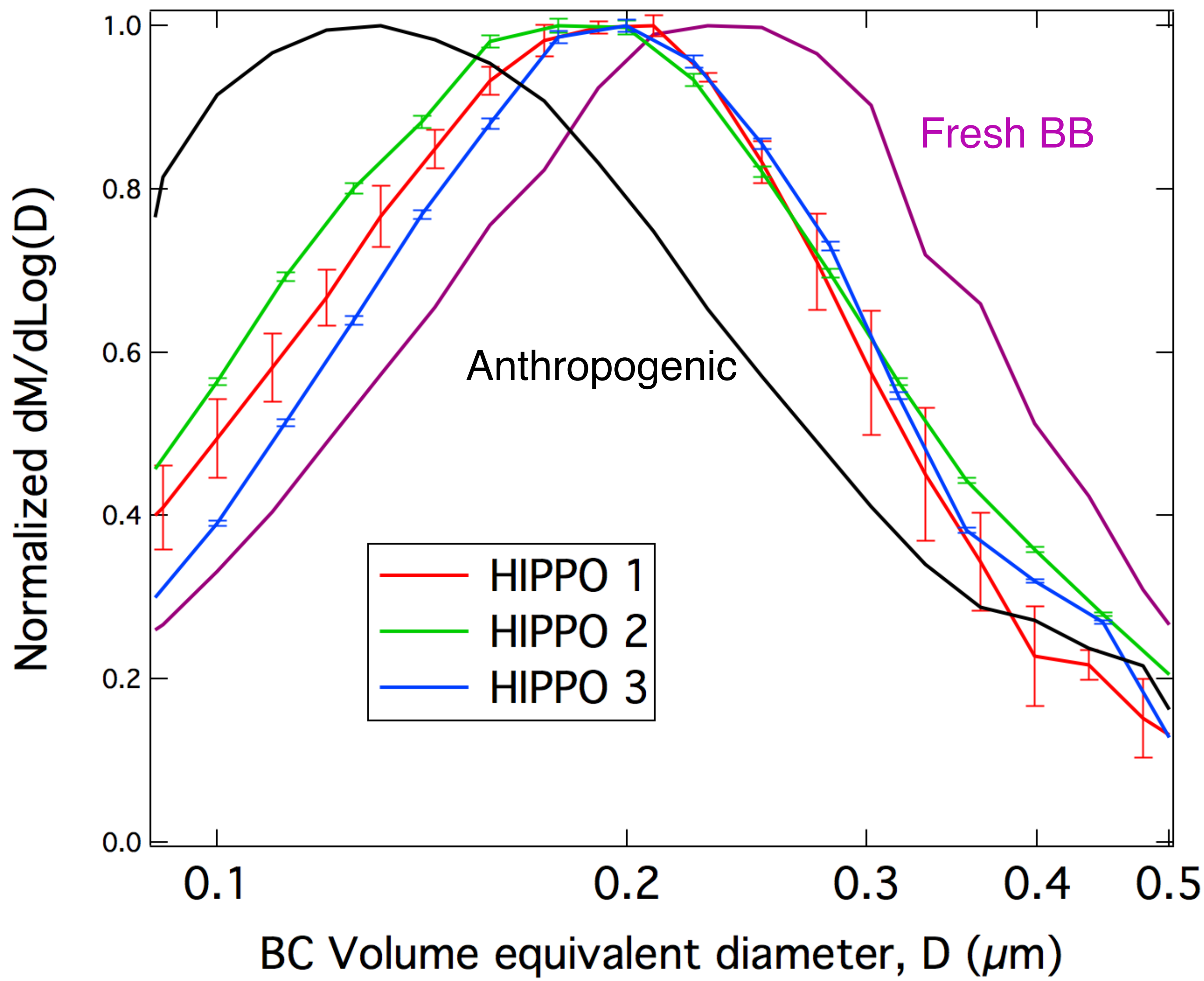


340-348 K
350-358 K
S20°-N20°
20°-50° Extra-Tropical
rBC MMR (ng/kg)
Latitude (deg)
Theta (K)

BC Mass Size Distributions

•Greatly reduced variability in remote air masses – simplifies treatment, provides model constraint

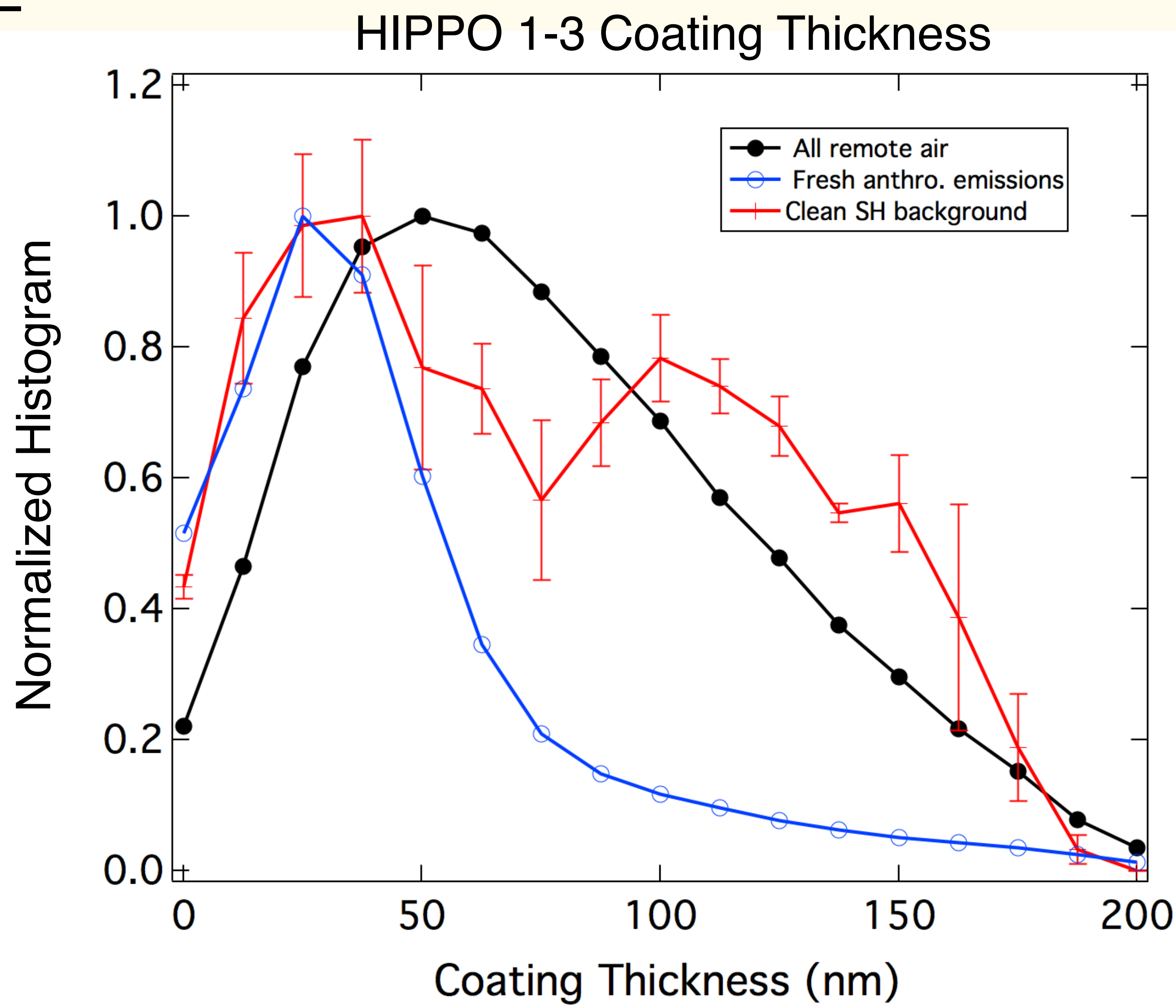
• A good estimate of a "general remote" BC size distribution is: 182 nm mass median diameter, σ = 1.64



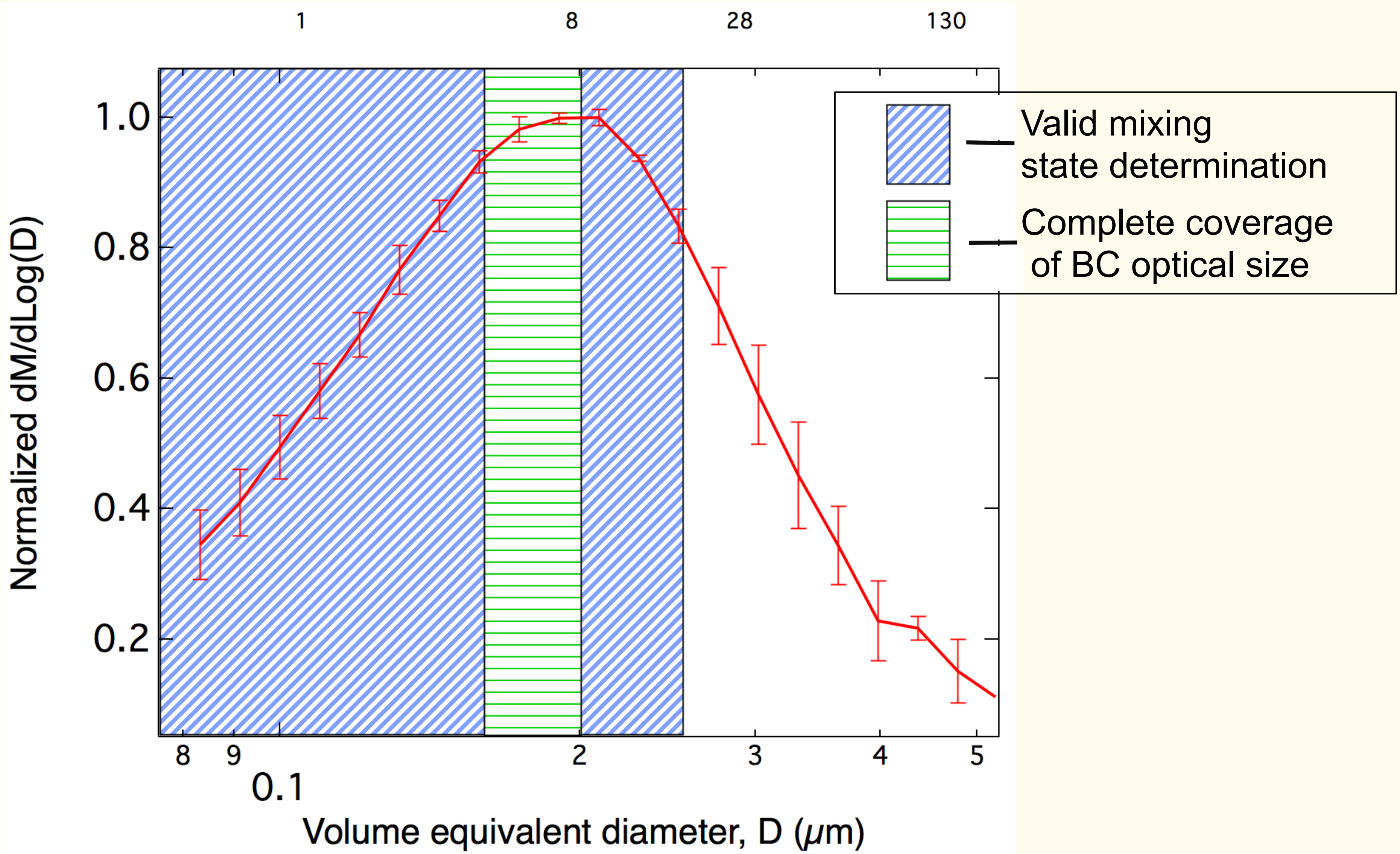
Schwarz et al., *in preparation*

Dry Coatings

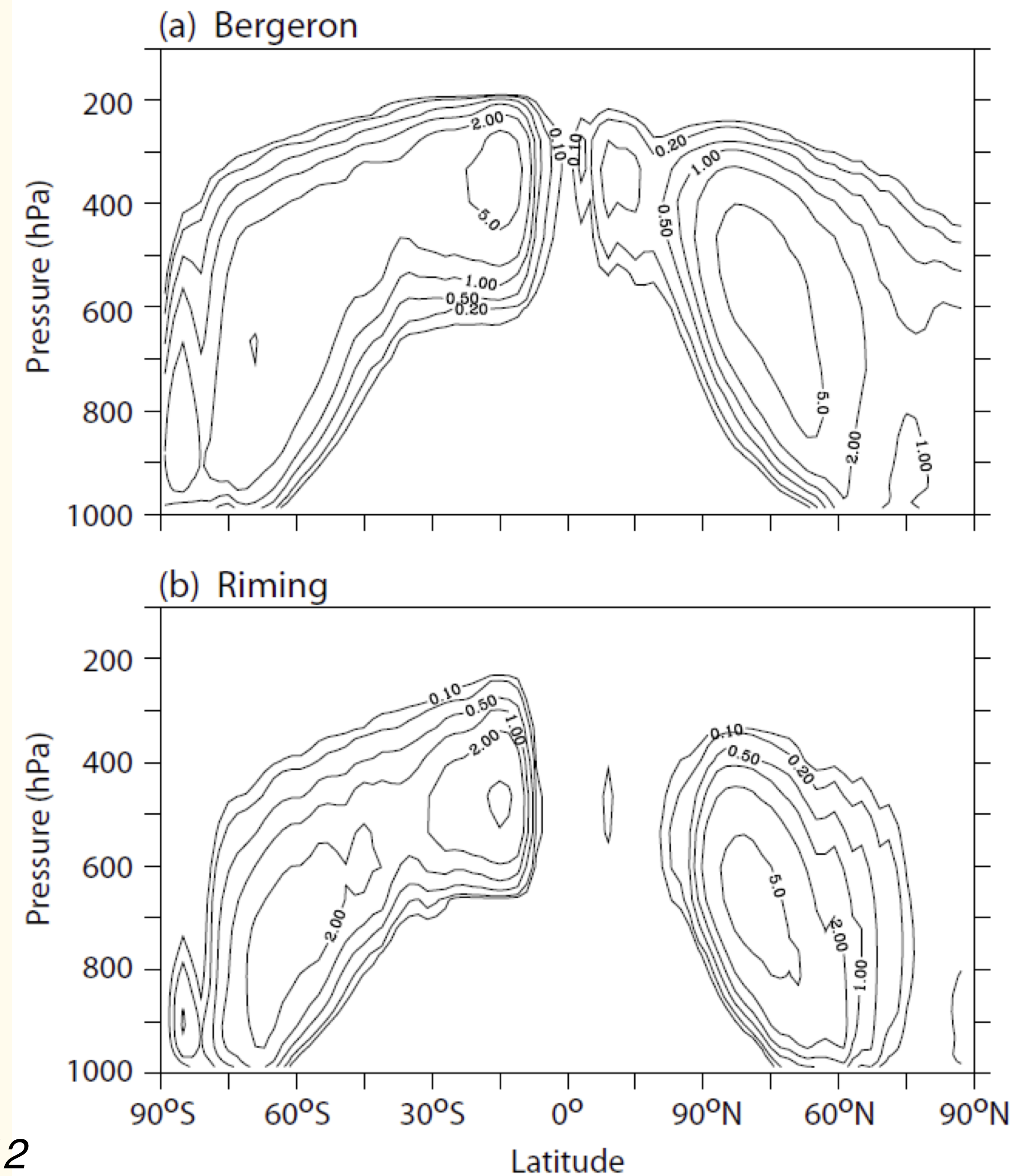
- BC cores of 150-180nm
- Optical size/BC mass interpreted with Mie theory for coating thickness
- Bimodal distribution in coating thickness associated with clean SH air
- Results generally consistent with expectations.



SP2: Coating state/optical size: Ranges of validity



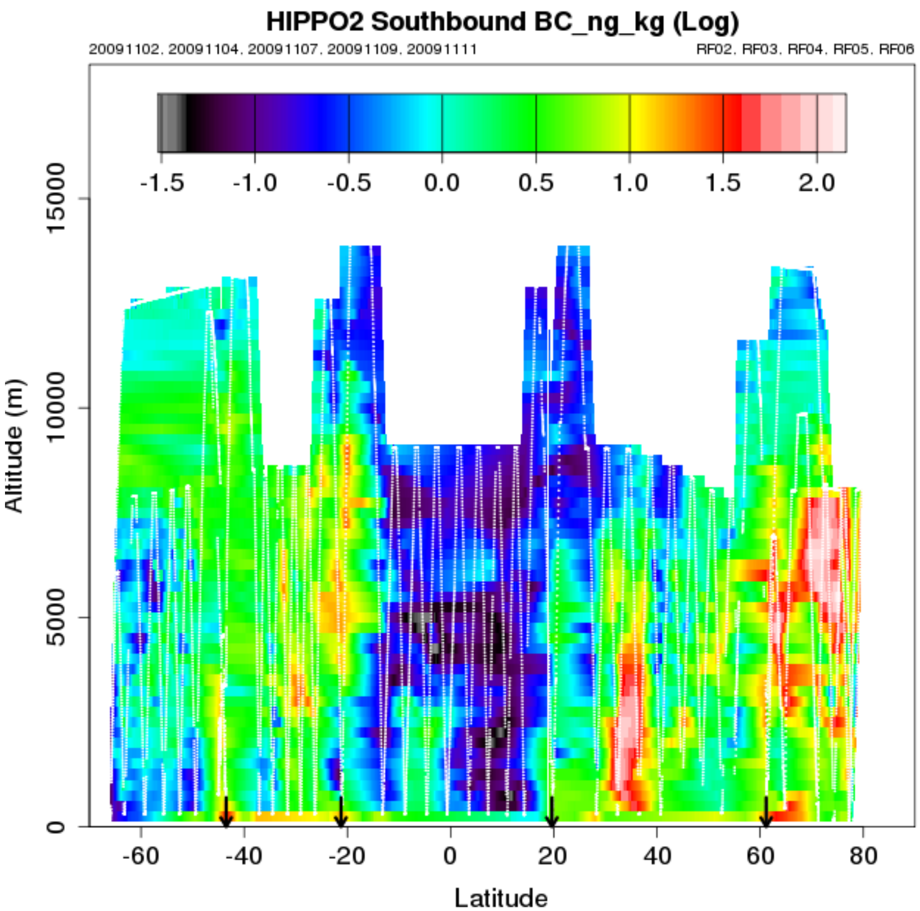
- Monthly mean ice production rates by (a) Bergeron and (b) riming processes, averaged between 160°E and 140°W in January 2009.
- Largest differences in the tropics and polar regions

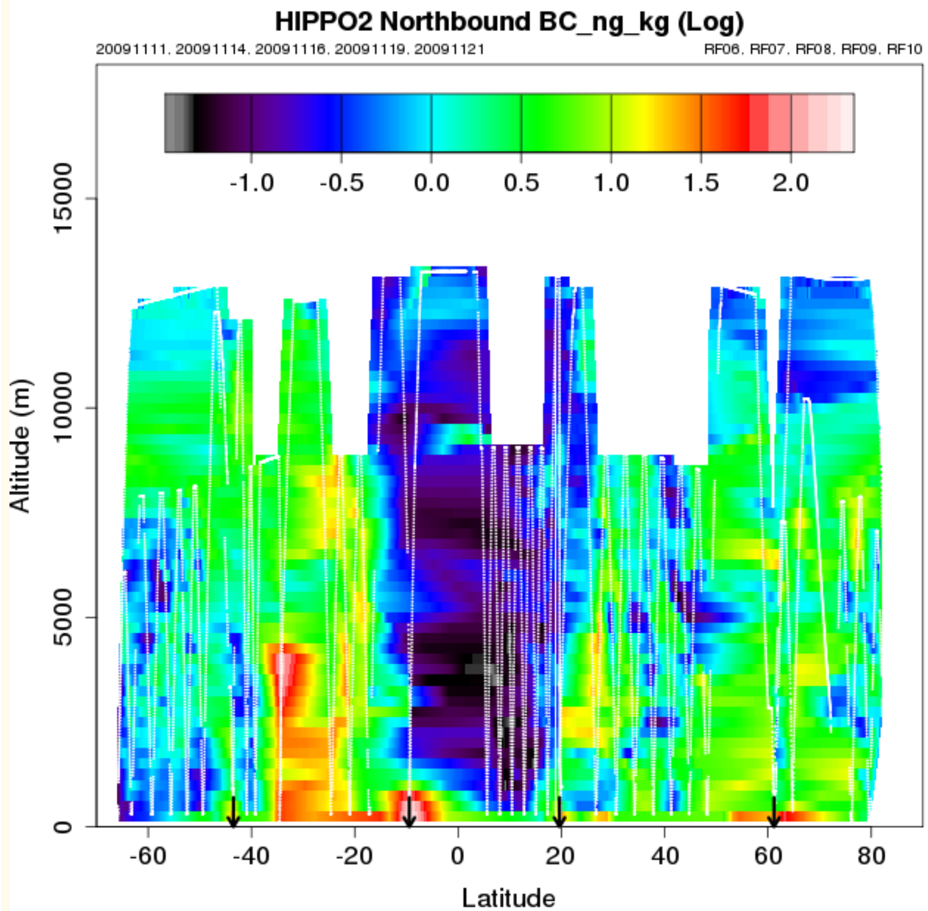


Fan et al., *submitted JGR 2012*

Curtains

Hippo 2: November 2009





Curtain plots courtesy of Britt Stephens, NCAR

BC Mixing State: Data Overview

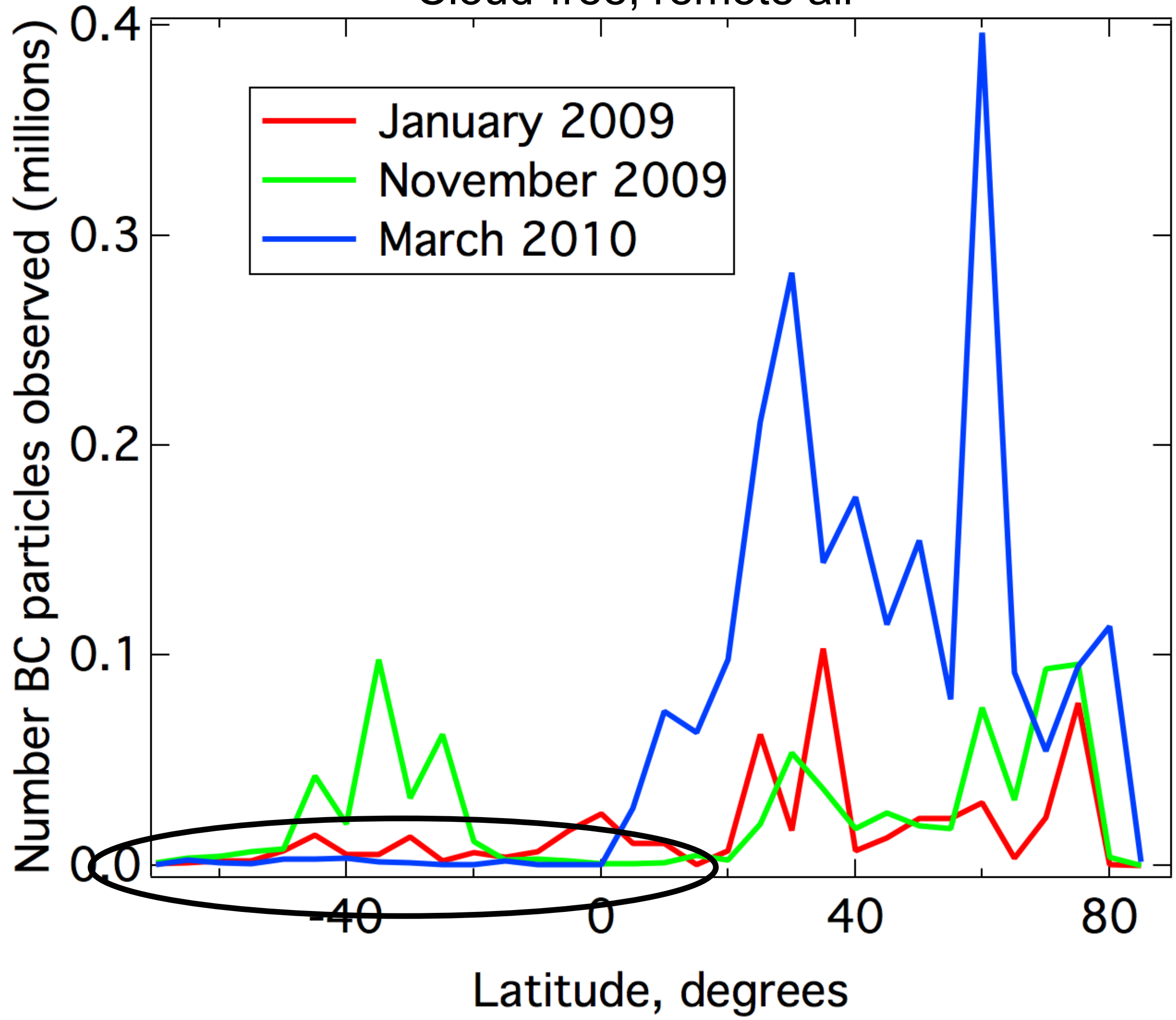
Focus on:

- 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))

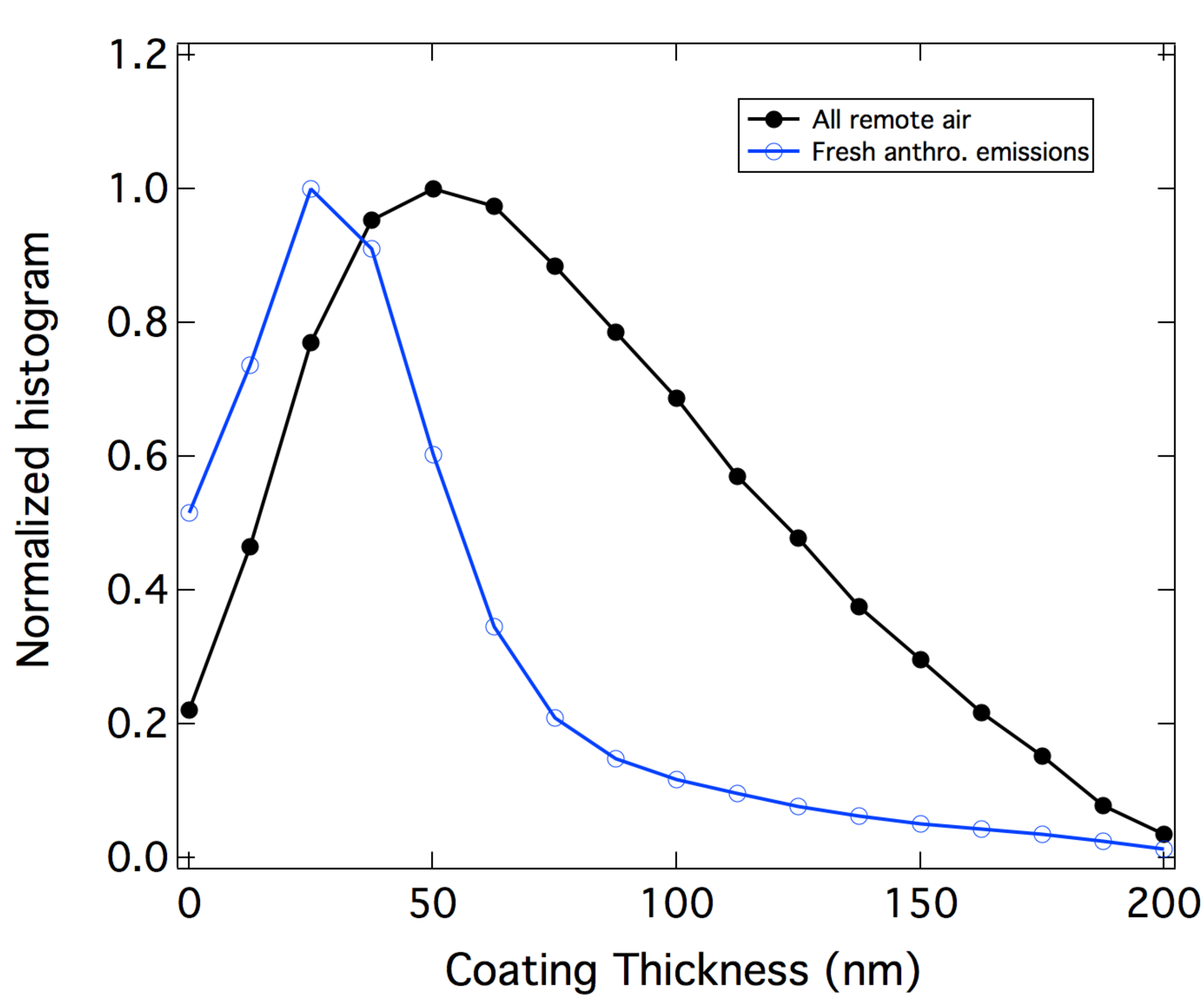
•Background SH air (20,000 BC-containing particles)

BC-containing particle number statistics:
Cloud-free, remote air



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)



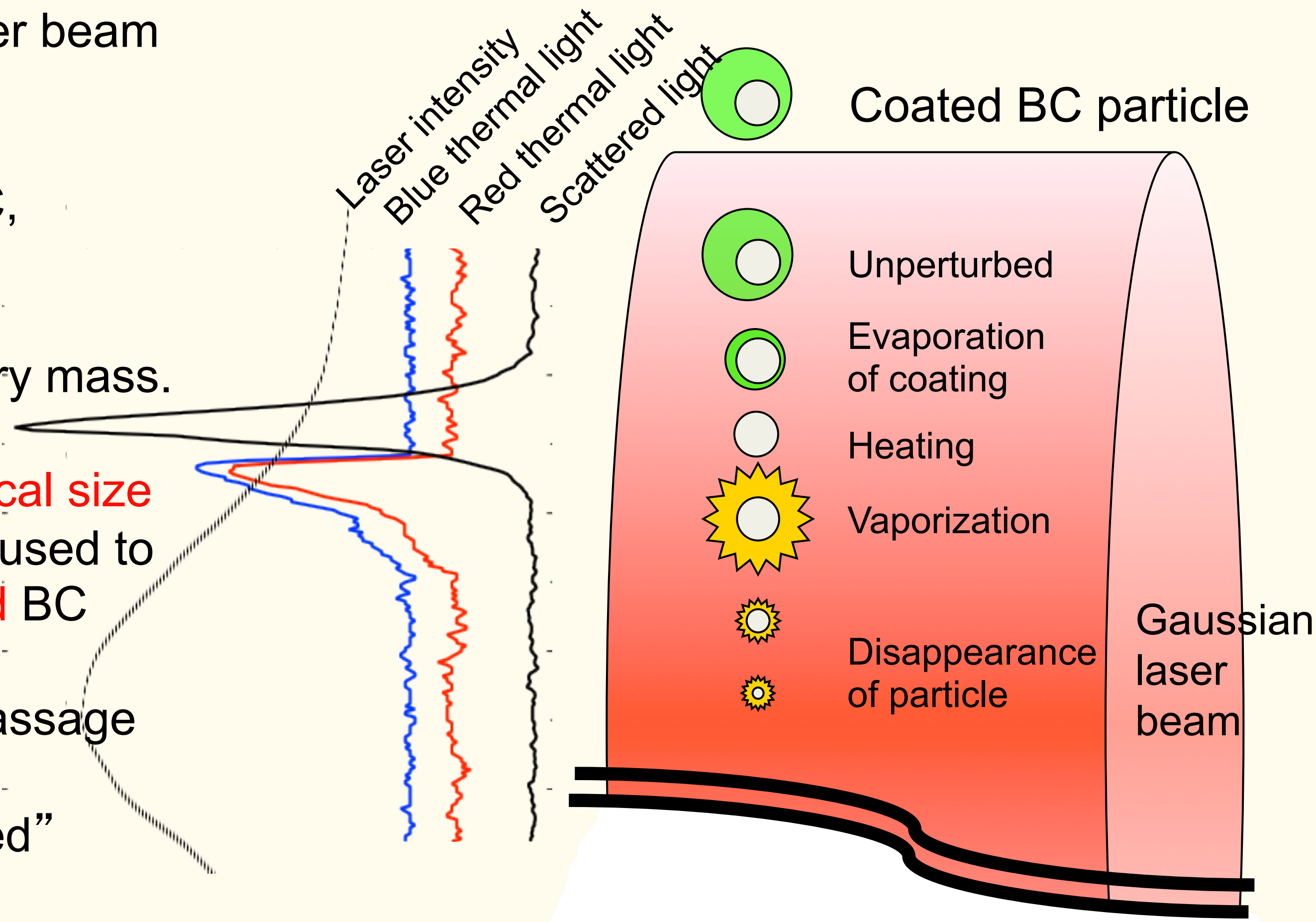
Single Particle Soot Photometer – SP2

- Individual particles enter intense intra-cavity laser beam (1064 nm).

- BC heats to ~3500 °C, emitting visible thermal radiation in amounts proportional to refractory mass.

- Clear reduction in optical size as particle is heated is used to identify internally mixed BC

- Scattered light from passage through edge of laser represents "unperturbed" aerosol optical size.



Adapted from N. Moteki, U of Tokyo

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- Laboratoire des Sciences du Climat et de l'Environnement
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- Oxford University
  - Philip Stier
- National Center for Atmospheric Research (NCAR)
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- Harvard University
  - *Steve Wofsy*
- NASA
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- University of Tokyo
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  - *Nobohiro Moteki*
- NOAA
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- Boston College/Aerodyne
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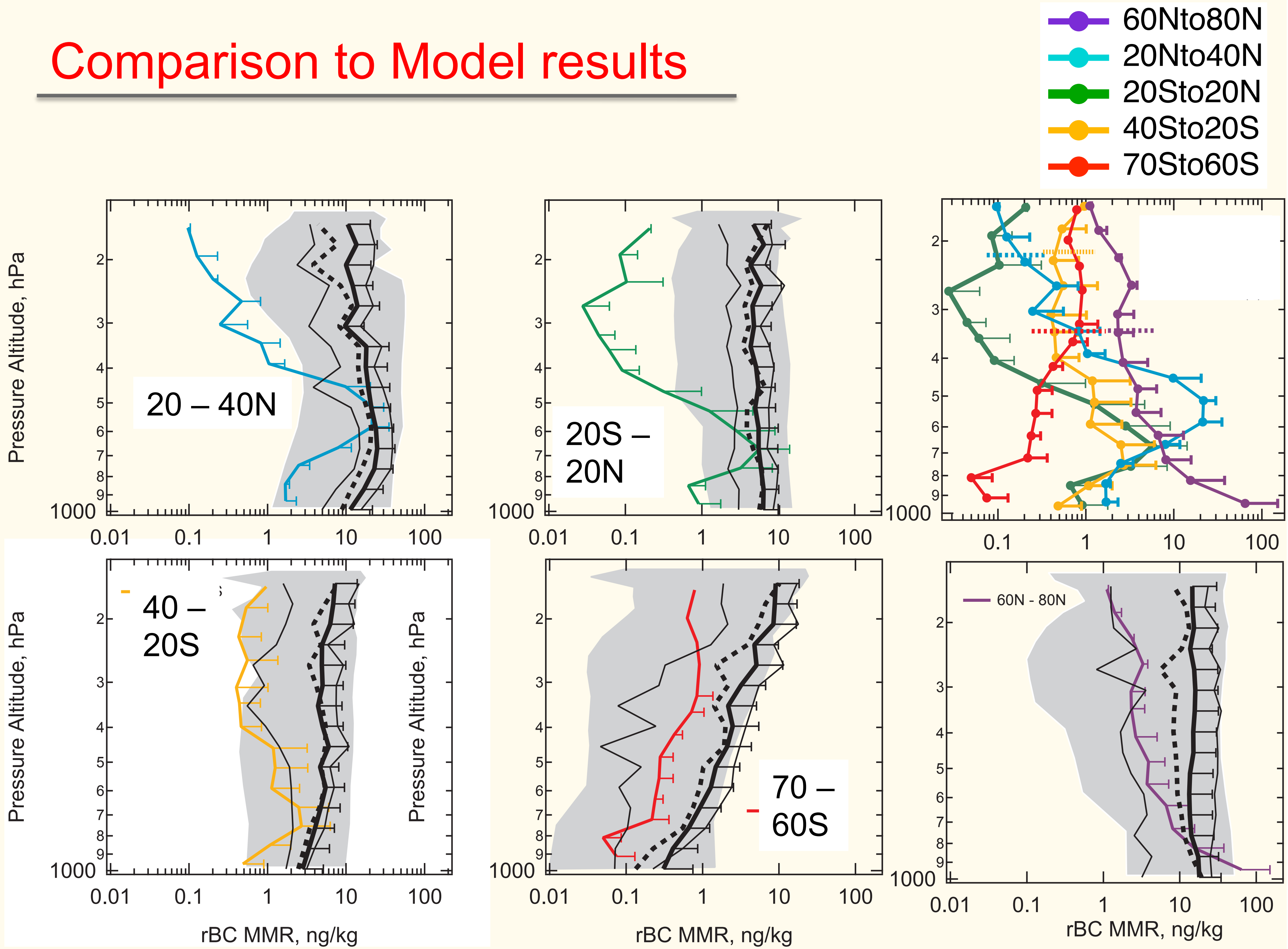
  - *Timothy O'nasch*
  - *Paul Davidovits*
  - *Doug Worsnop*
- University of Alberta
  - *Jason Olfert*
- Shezhen Graduate School of Peking University
  - *Xiaofeng Huang*

Thank You!

Comparison to Model results



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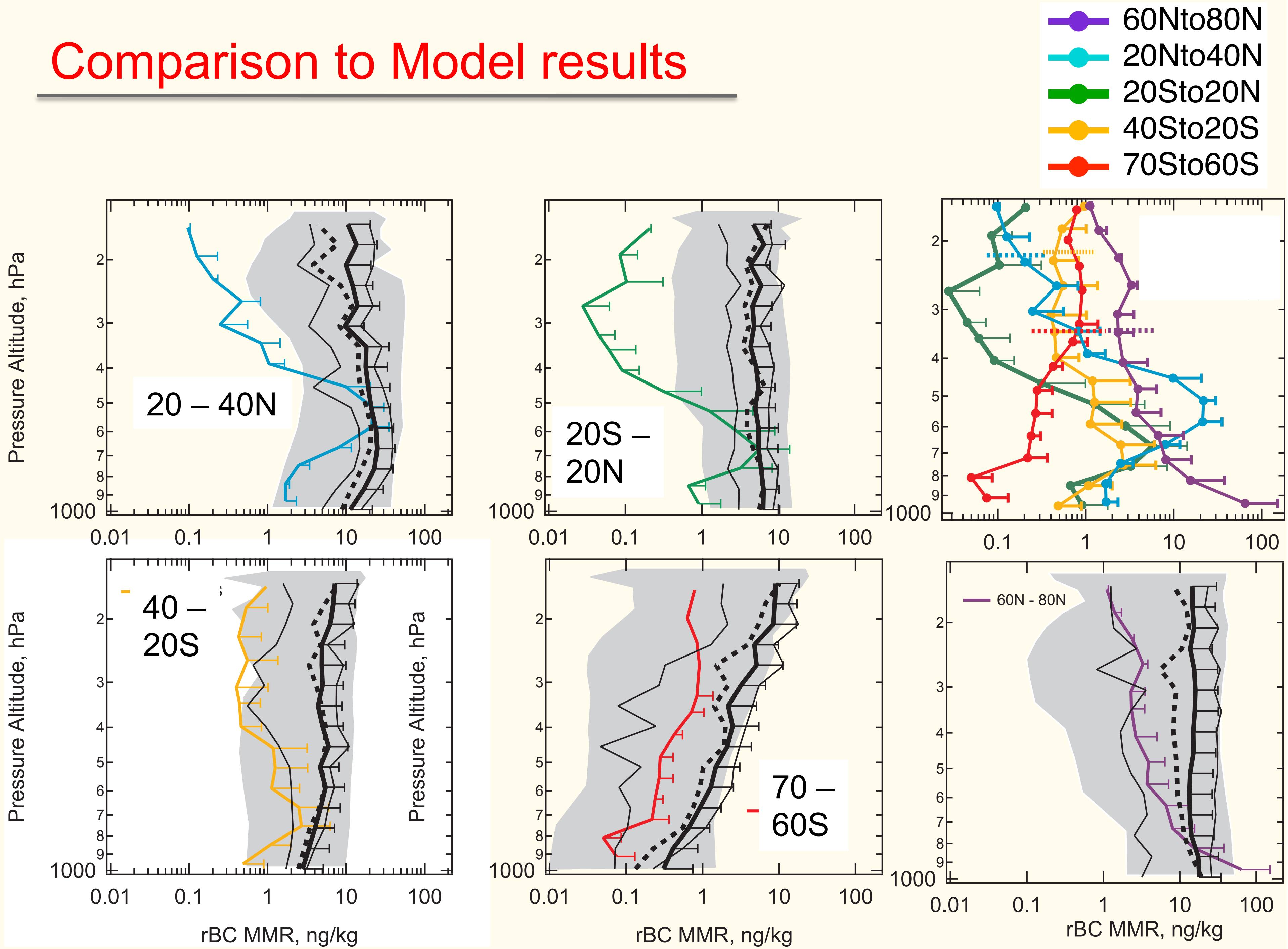

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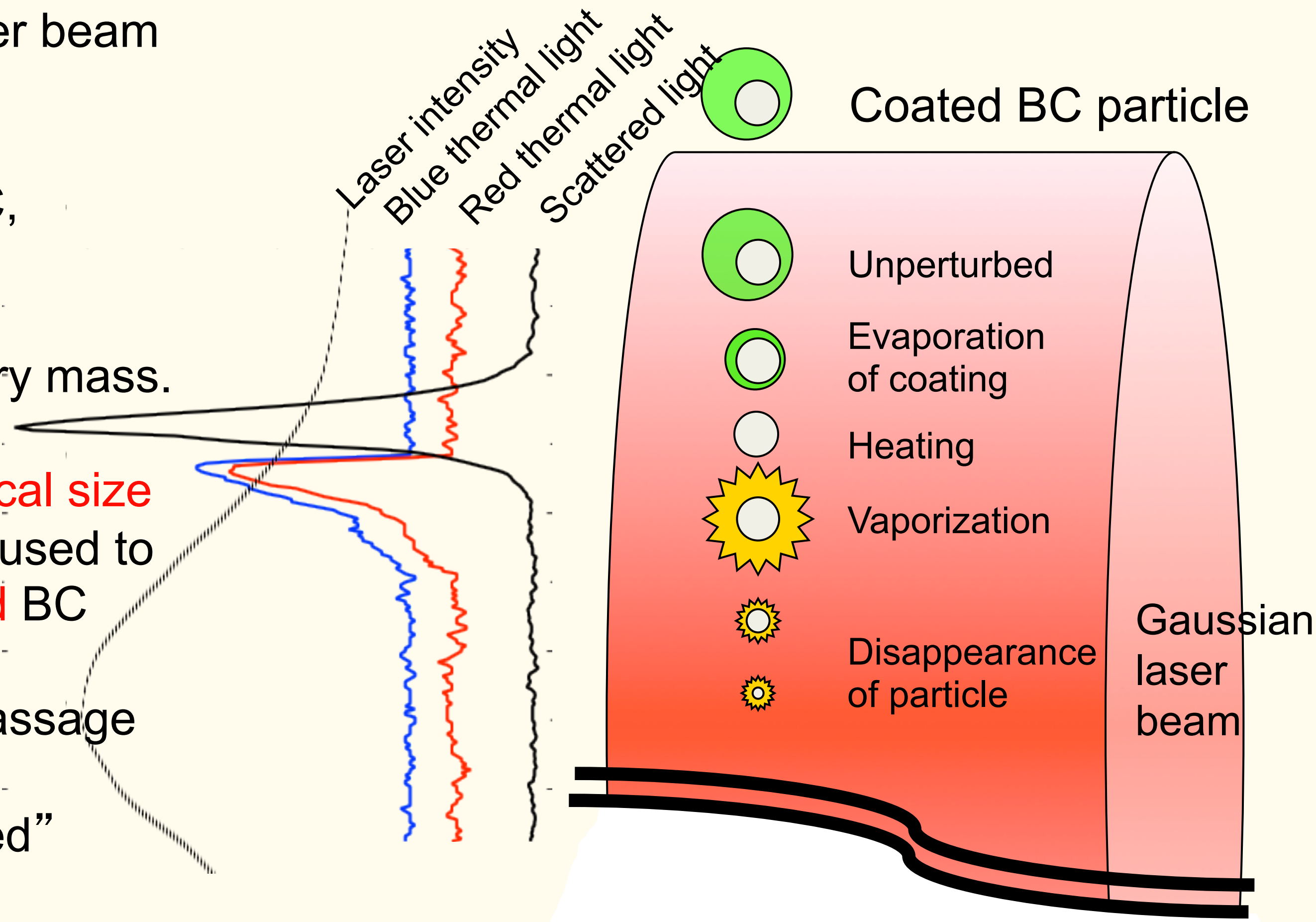

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