Constraining global models of black carbon aerosol with Pole-to-Pole observations

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

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CIRES

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Motivation: Climate

IPCC AR5 BC DRF - ~0.4 W/m^2 ± 0.4

(Bond et al., 2013: ~0.7 W/m^2 ± 0.6
BC DRF + non direct: 1.1 ± 0.9)

Measure –

Model –

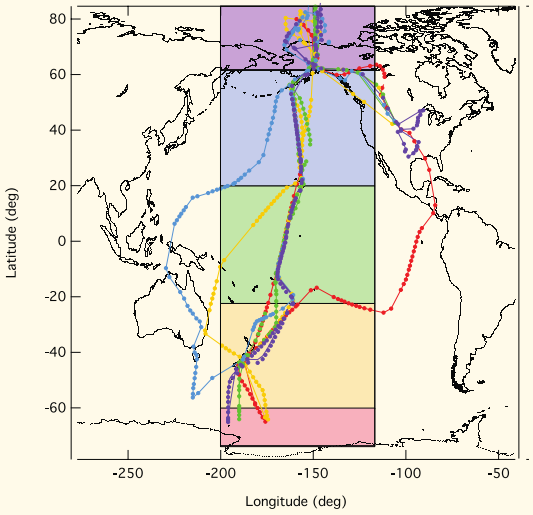
Compare –

Improve –

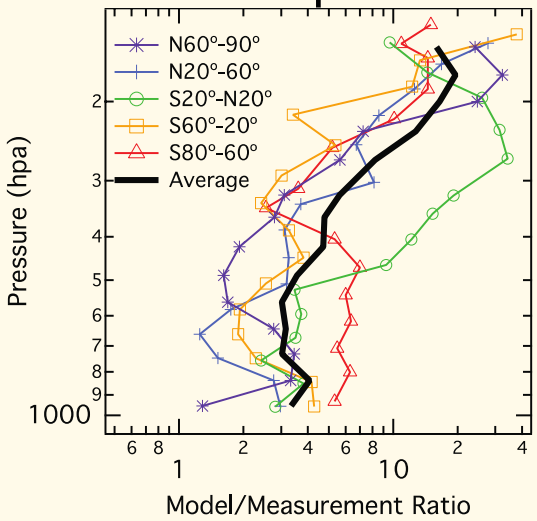
See where we are.

Outline

HIPPO Campaign



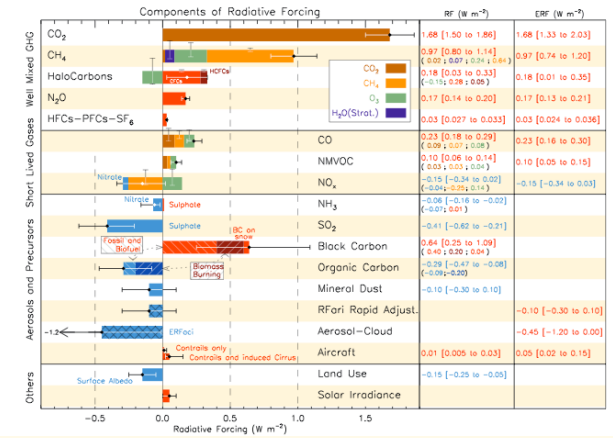
AeroCom Model BC Comparison



12 Global models

CAM3	SPRINTARS
CAM4	OsloCTM2
CAM5	MPI-HAM
GISS	INCA
GMI	IMPACT
GOCART	HADGEM2

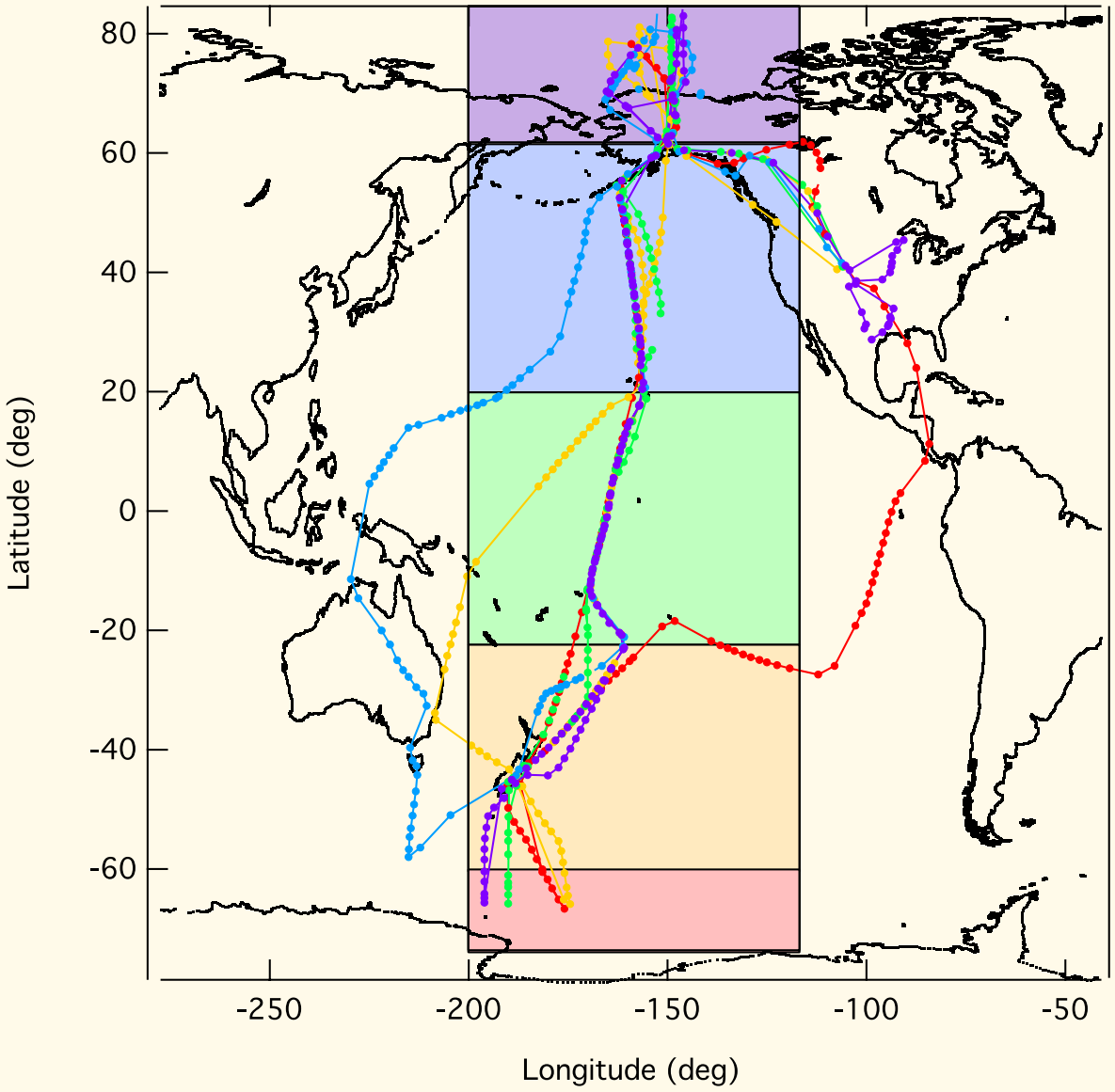
BC DRF Implications



IPCC AR5, 2013

1/3 of the BC DRF is in play

HIPPO Overview

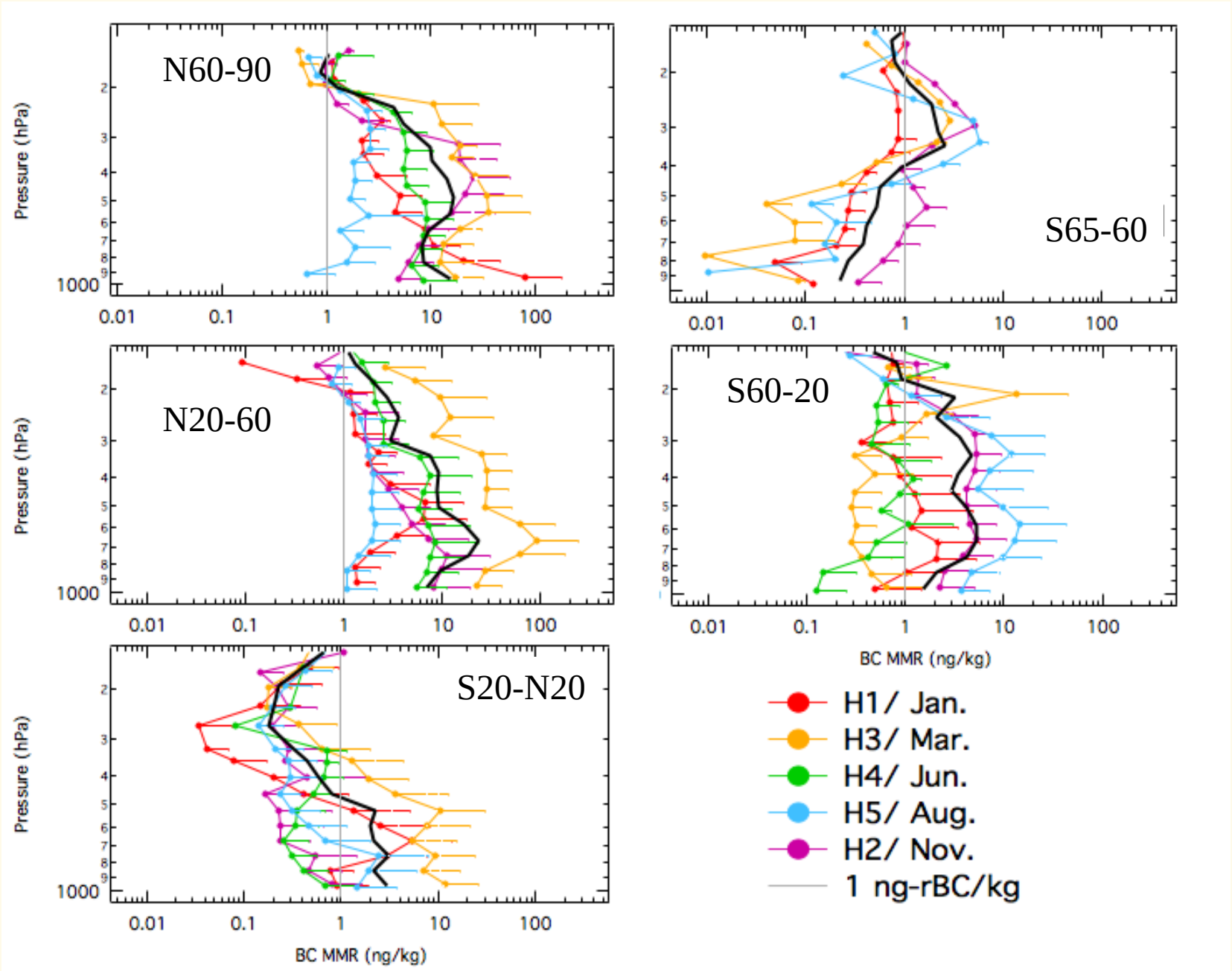


- Unbiased sampling strategy
- Seasonal coverage
- Global scale
- Remote airmasses
- Five flight series:

Jan. ‘09
Nov. ‘09
M/Apr. 10
June ‘11
Aug. ‘11

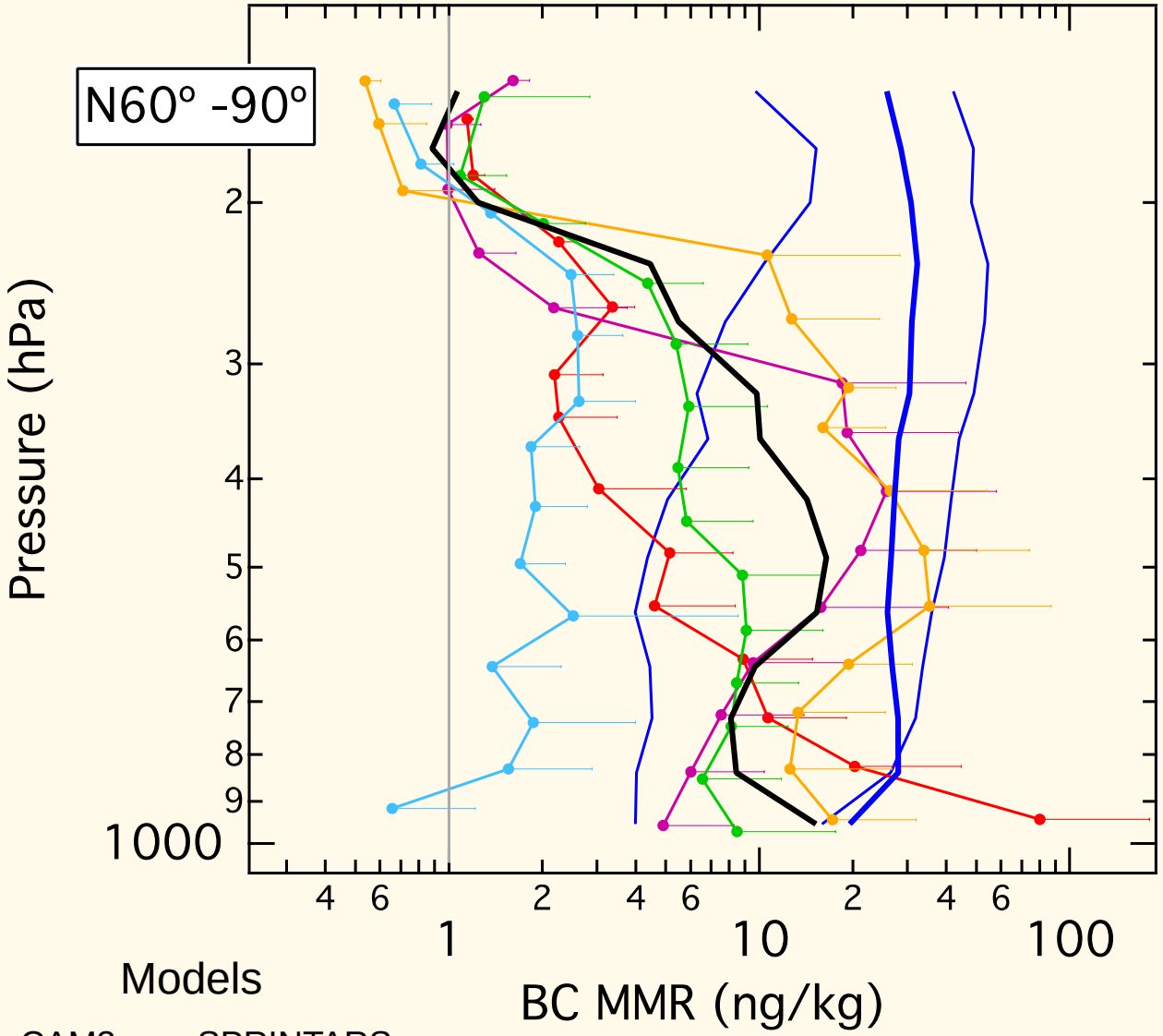
- Vertical coverage

BC Results: Climatology over the remote Pacific



Northern Polar

- High seasonal variability in measurements up to the tropopause
- Dramatic collapse of variability into the LS
- Similar behavior in the SH
- Boundary condition -powerful model constraint



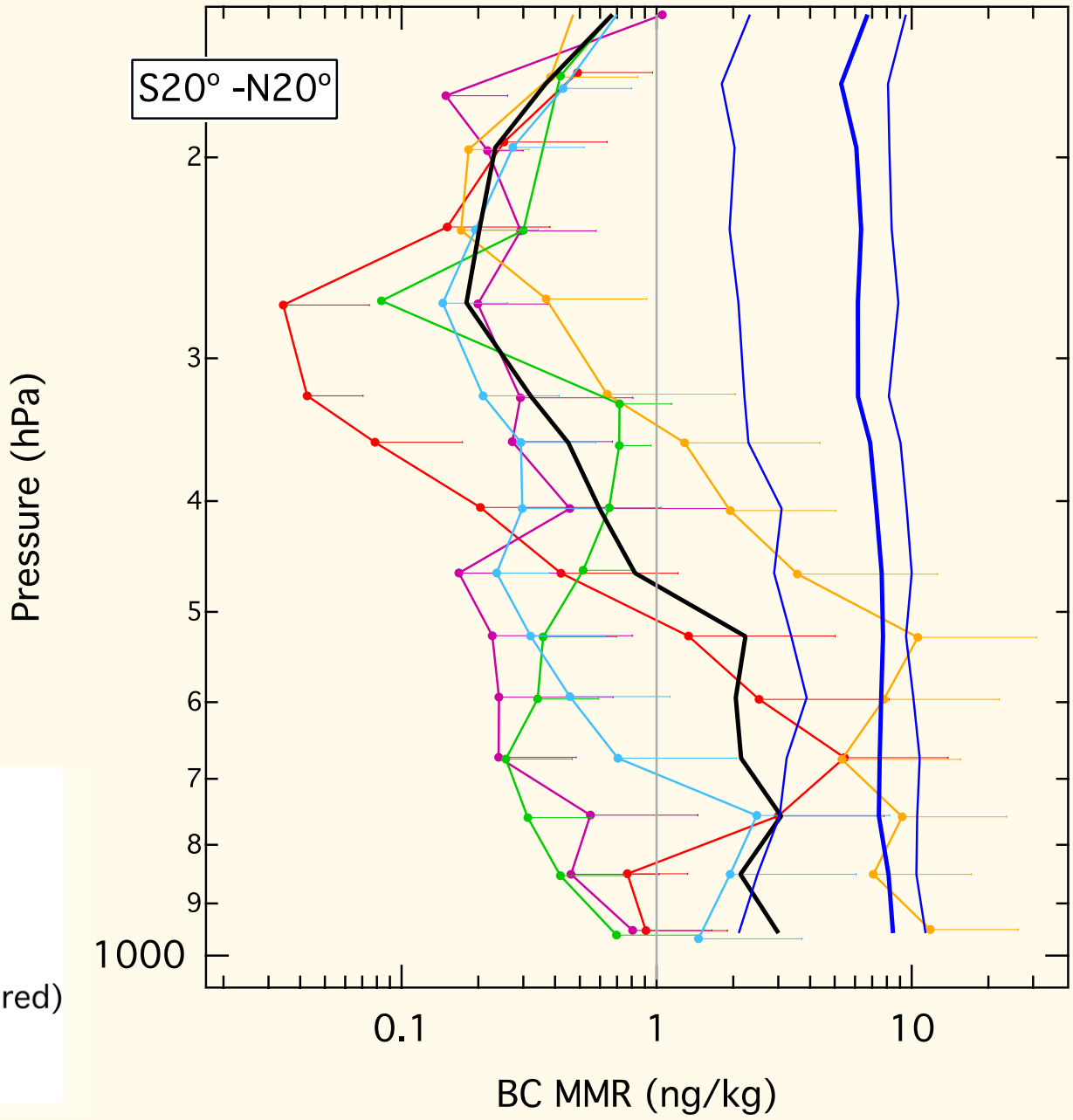
H1/ Jan.
H3/ Mar.
H4/ Jun.
H5/ Aug.
H2/ Nov.
Average (measured)
AeroCom
1 ng-rBC/kg

Models

CAM3	SPRINTARS
CAM4	OsloCTM2
CAM5	MPI-HAM
GISS	INCA
GMI	IMPACT
GOCART	HADGEM2

Equatorial

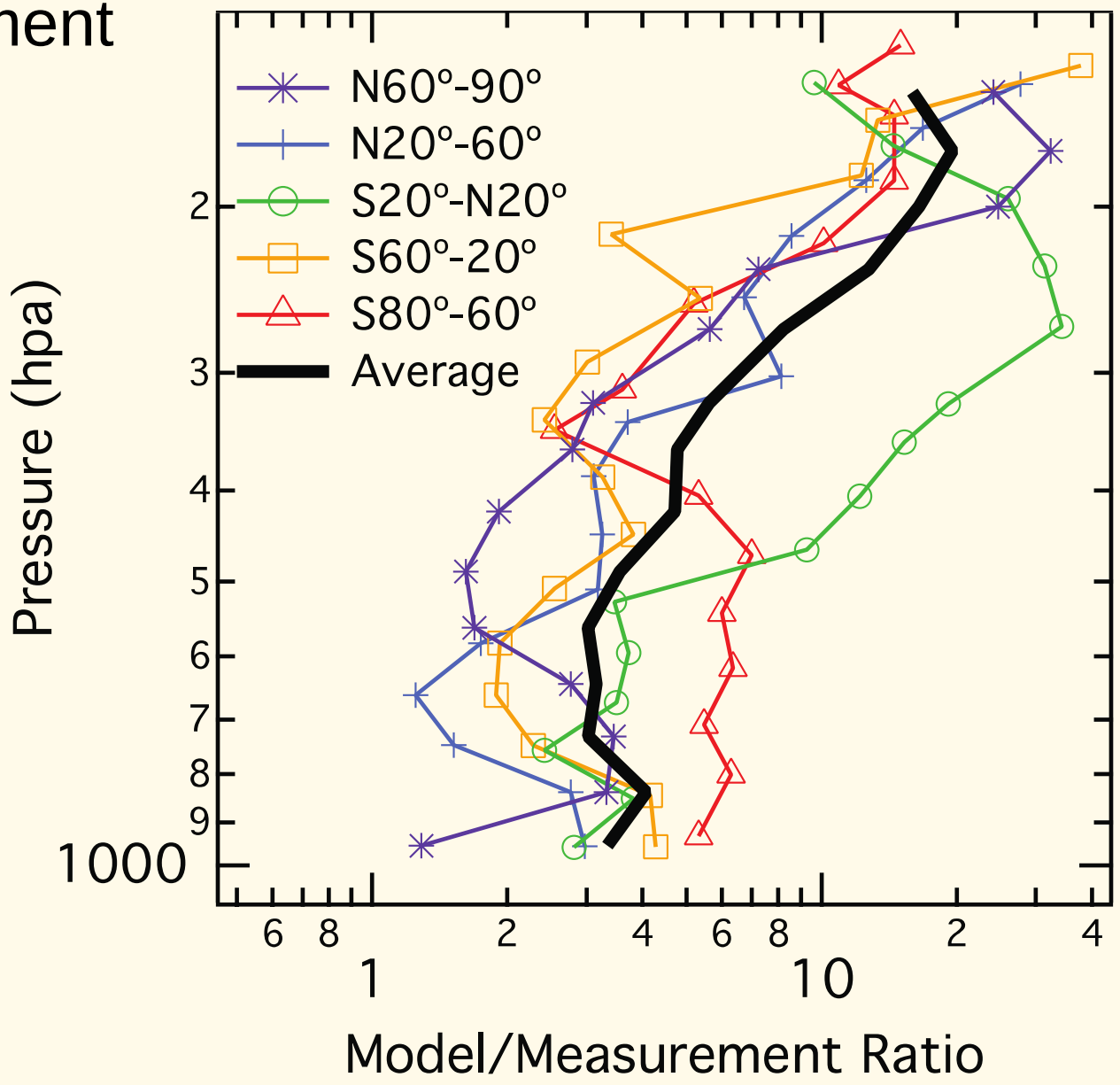
- Annual minimum in rBC MMR consistent with convective outflow region
- Very low variability in rBC MMR above minimum
- Model ensemble mean doesn't reflect this feature



Model/Measurement

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

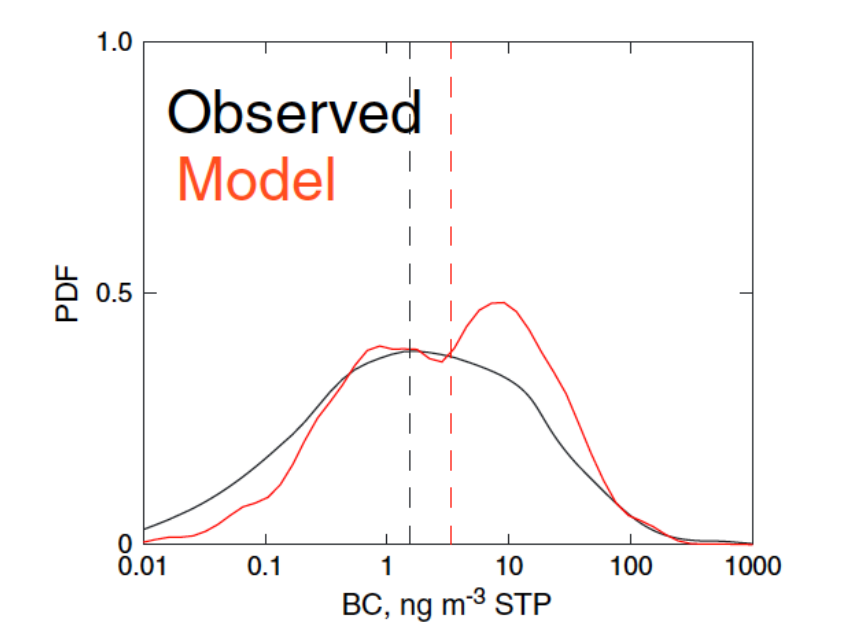
  -Very exciting region to focus on! Drives lower stratospheric biases…?



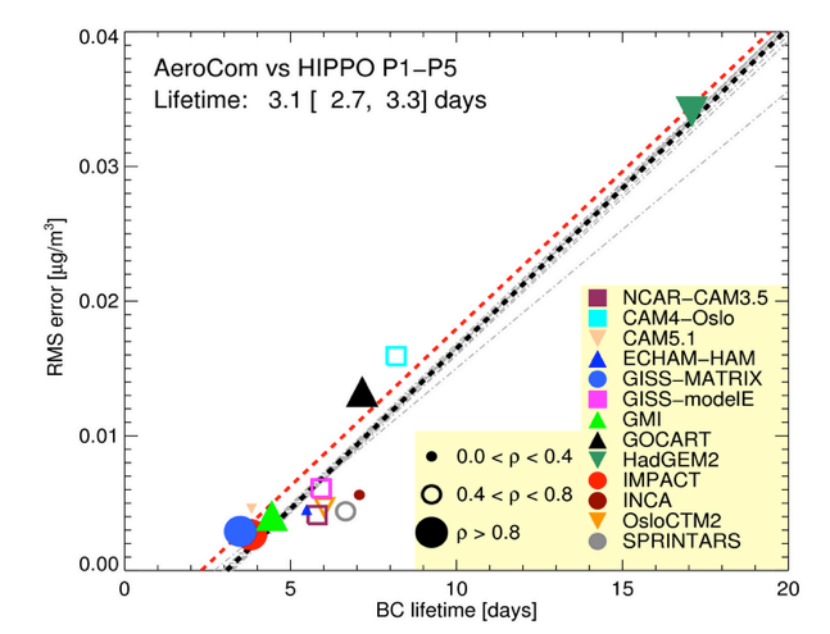
Schwarz et al., GRL 2013

Improving/Assessing Models

- GEOS-CHEM with strengthened BC removal in convection and cold clouds - improved model skill for HIPPO data set.
  - shortened BC lifetime,
  - lowered BC DRF



Wang et al., JGR 2014

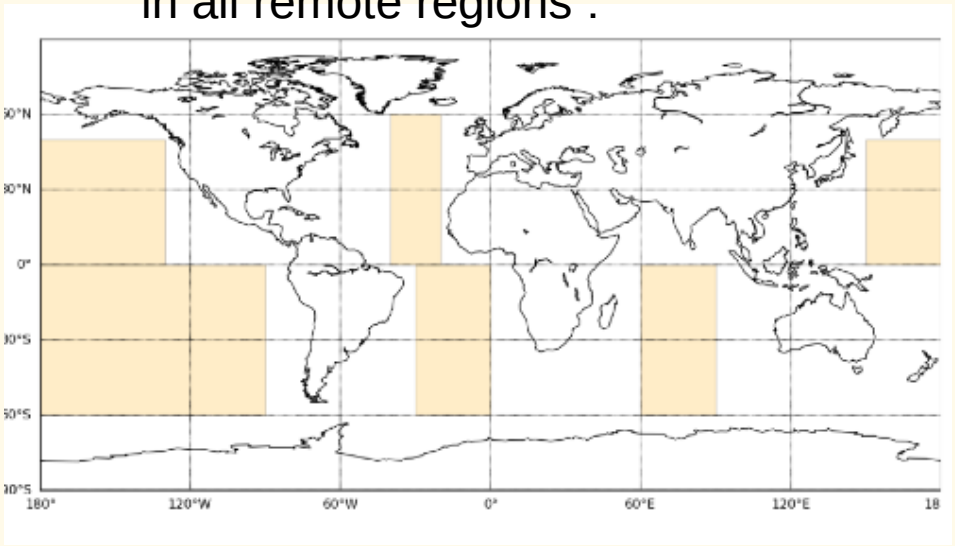


Samset et al., in prep 2014

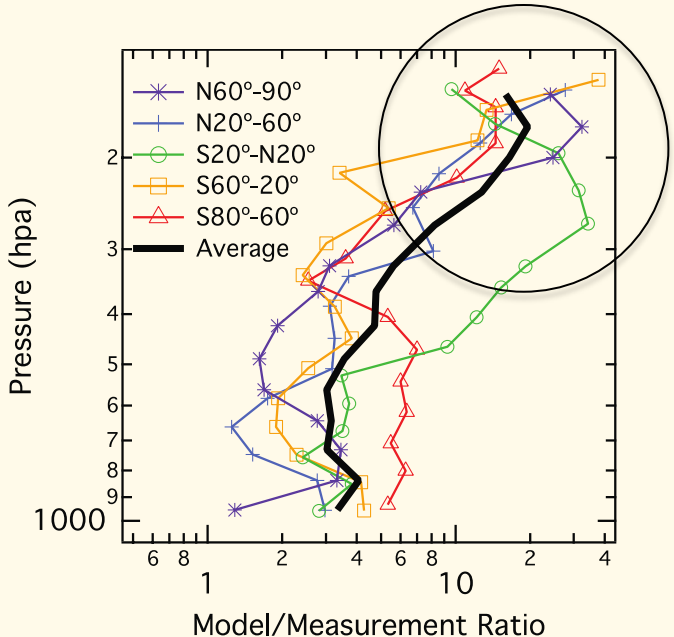
AeroCom models tested against HIPPO show skill inversely proportional to BC lifetime

AeroCom: Potential impacts on estimates of BC DRF

Theorize similar model bias
in all remote regions :



Remote:
29% of the globe…
16% of the forcing…
Constrained to HIPPO
-> 12% reduction in DRF



Theorize that upper trop/lower strat model bias is global in extent:

24% of BC RF occurs from mass above 200 hPa …

Scaling remote and high altitude lead to 33% reduction in AeroCom BC DRF estimate

Conclusions

1) HIPPO observations provide unique insight into remote BC distributions
2) Systematic AeroCom model bias in the HIPPO regions quantified and found to be strongly altitude dependent
3) Remote/high altitude contributions to BC `radiative forcing essential to it's global impact.

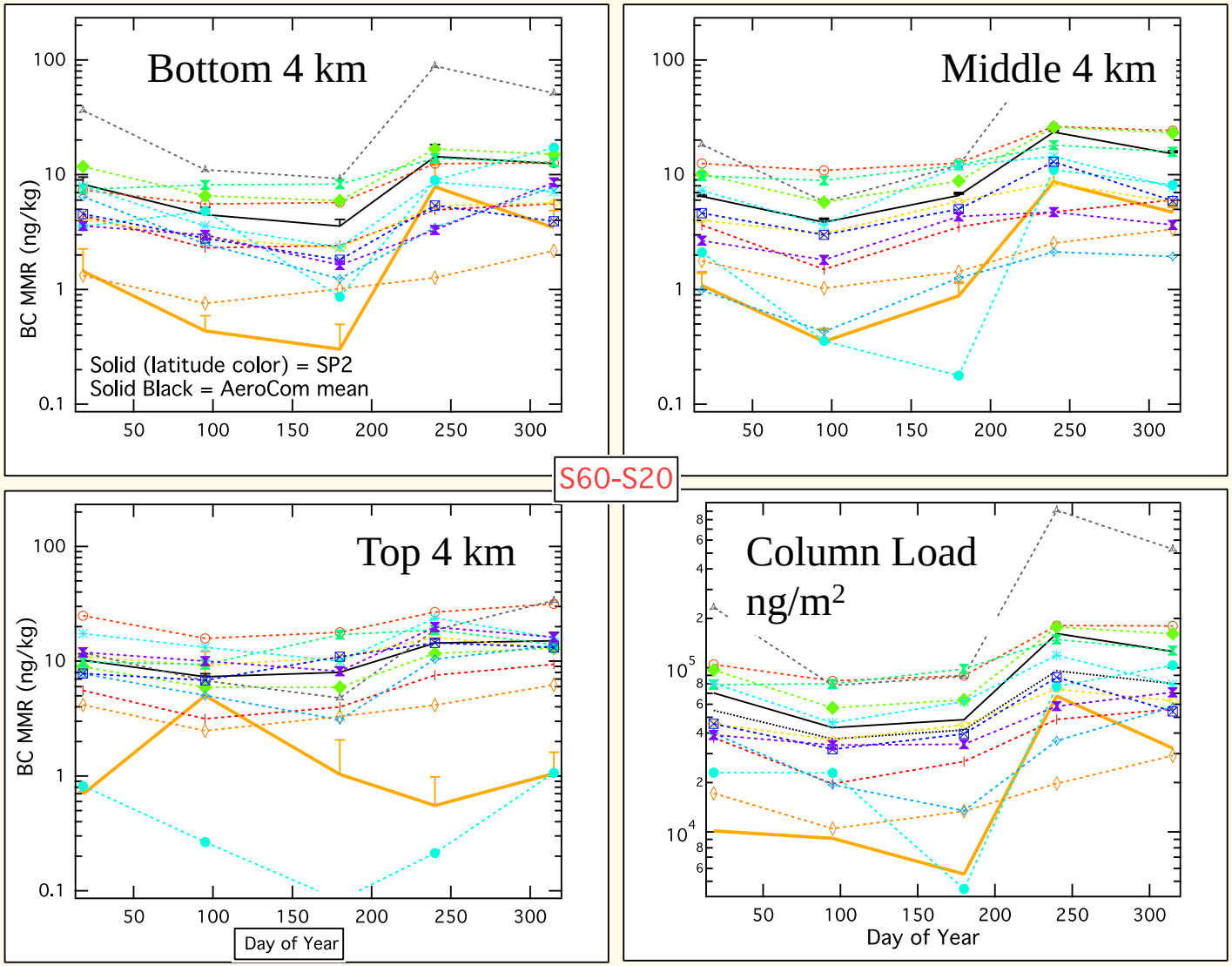
– Thanks to the pilots and crew of the NSF/NCAR GV

Comments/questions?

Thank You!

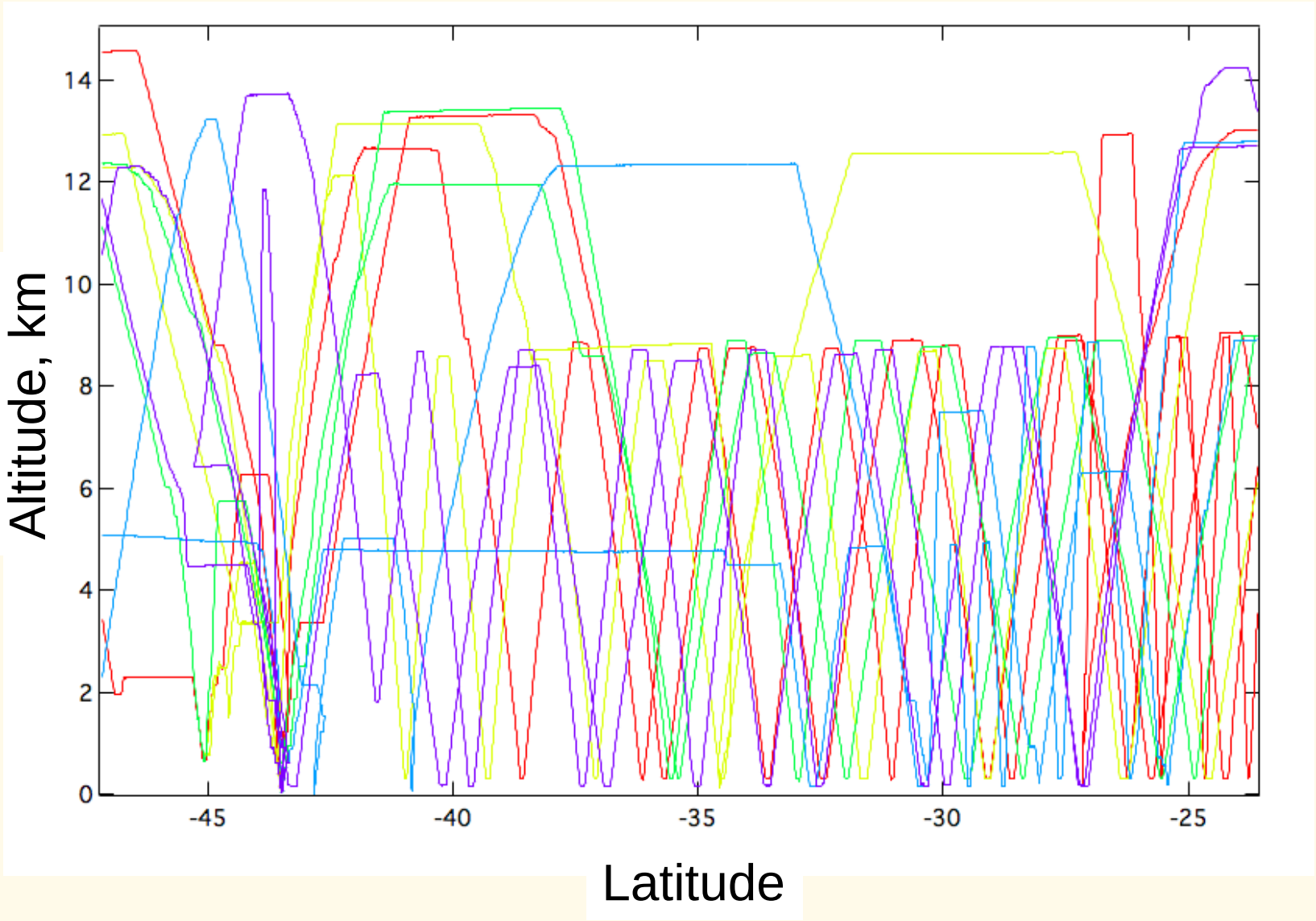
SEASONALITY CAUGHT BY MODELS – Southern Midlatitudes

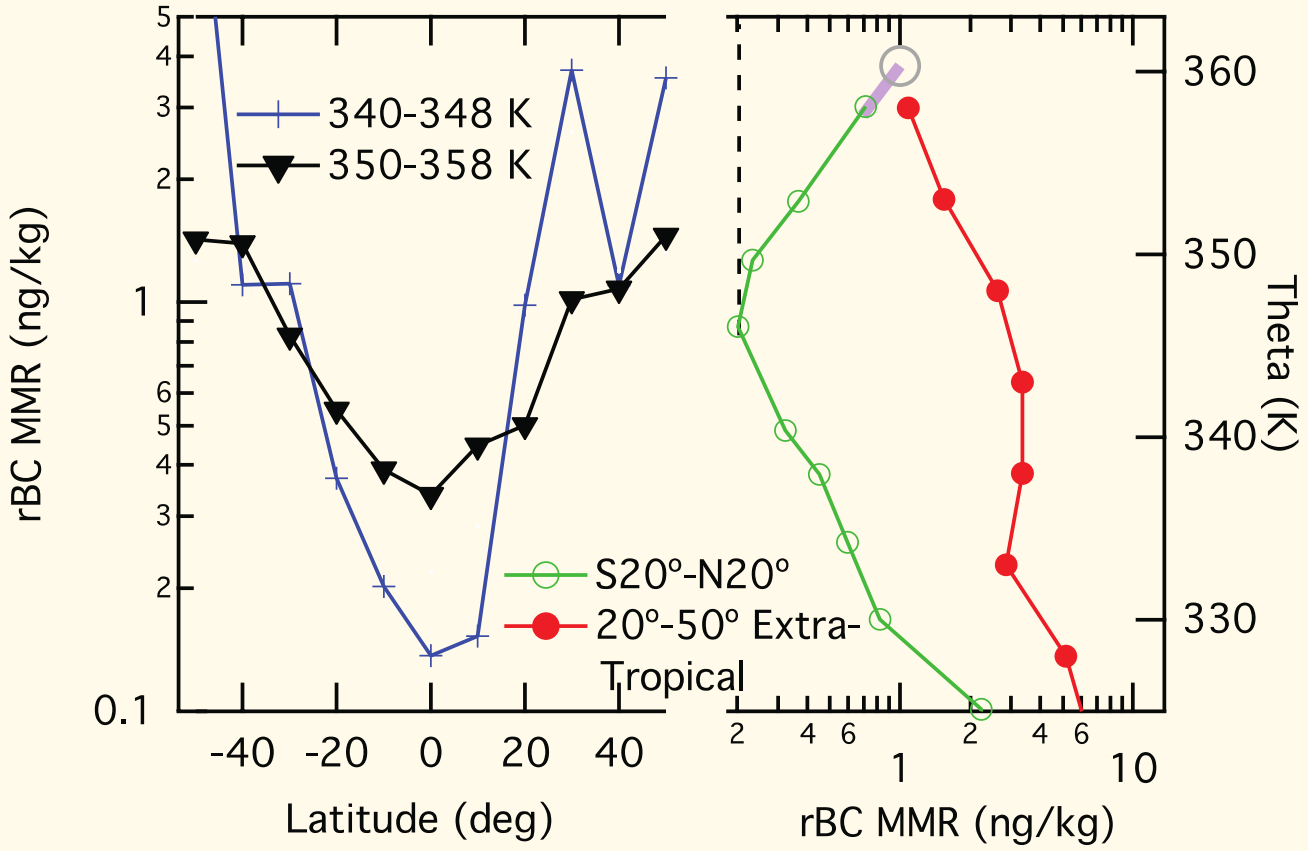
The climatological models succeed in capturing some of the seasonality in BC loadings, likely due to seasonal emissions inventories and large scale transport



Measurement: Heavy orange line
AeroCom Mean: heavy black
AeroCom models – Light dashed lines

HIPPO Overview: Vertical Coverage




rBC MMR (ng/kg)
5
4
3
2
1
6
5
4
3
2
0.1
340-348 K
350-358 K
S20°-N20°
20°-50° Extra-Tropical
-40
-20
0
20
40
Latitude (deg)
360
350
340
330
Theta (K)
2
4
6
1
2
4
6
10
rBC MMR (ng/kg)

HIAPER Pole-to-Pole Observations

- PIs: Harvard, NCAR, Scripps, NOAA
- Global and seasonal survey of CO_2, O_2, CH_4, CO, N_2O, H_2, SF_6, COS, CFCs, HCFCs, O_3, H_2O, CO_2 isotopes, Ar, black carbon, halocarbons and hydrocarbons (over 90 species).
- NSF / NCAR Gulfstream V
- Five 3-week campaigns over 3 years, across Pacific between 87 N and 67 S
- Continuous profiling between surface and 8-14 km
- 64 flights, 434 flight hours, 787 profiles
- hippo.ucar.edu, www.eol.ucar.edu/hippo, hippo.ornl.gov

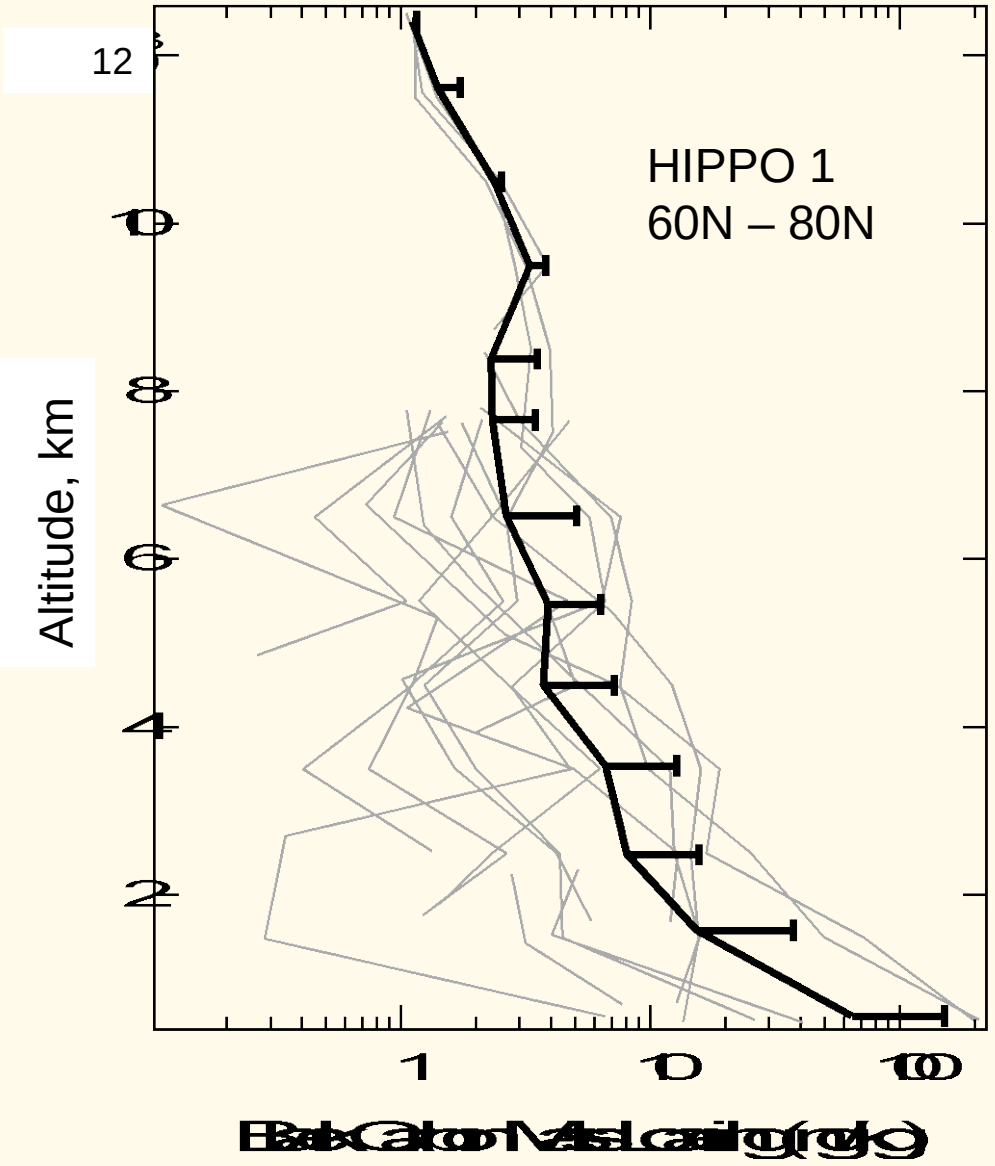
Canterbury, New Zealand

Pago Pago, American Samoa

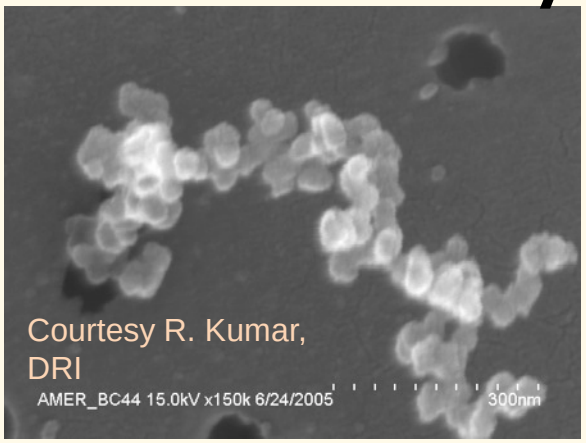
Brooks Range, Alaska

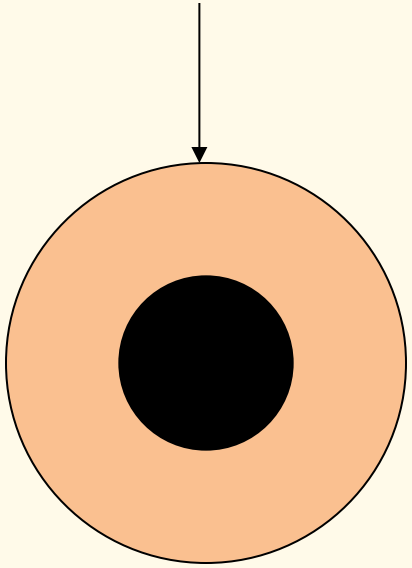
Analysis approach

- 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



Quick Refresher - Experimental Approach

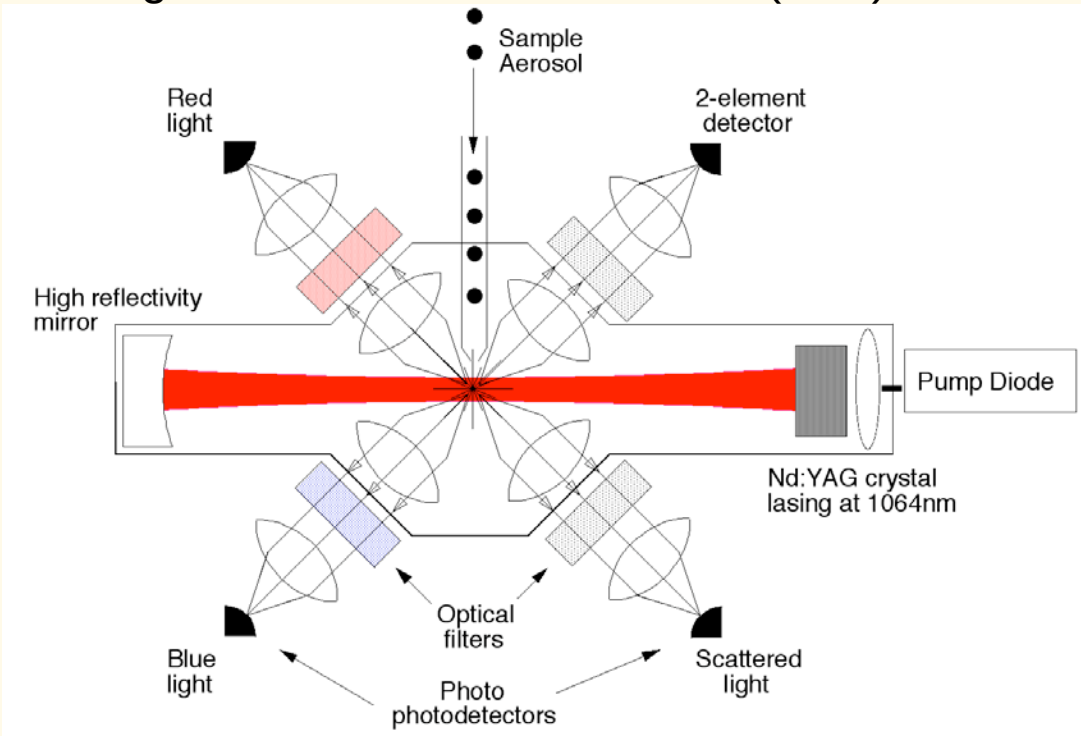




Shell-and-core simplification

- Assume index of coating
- Pretend geometry

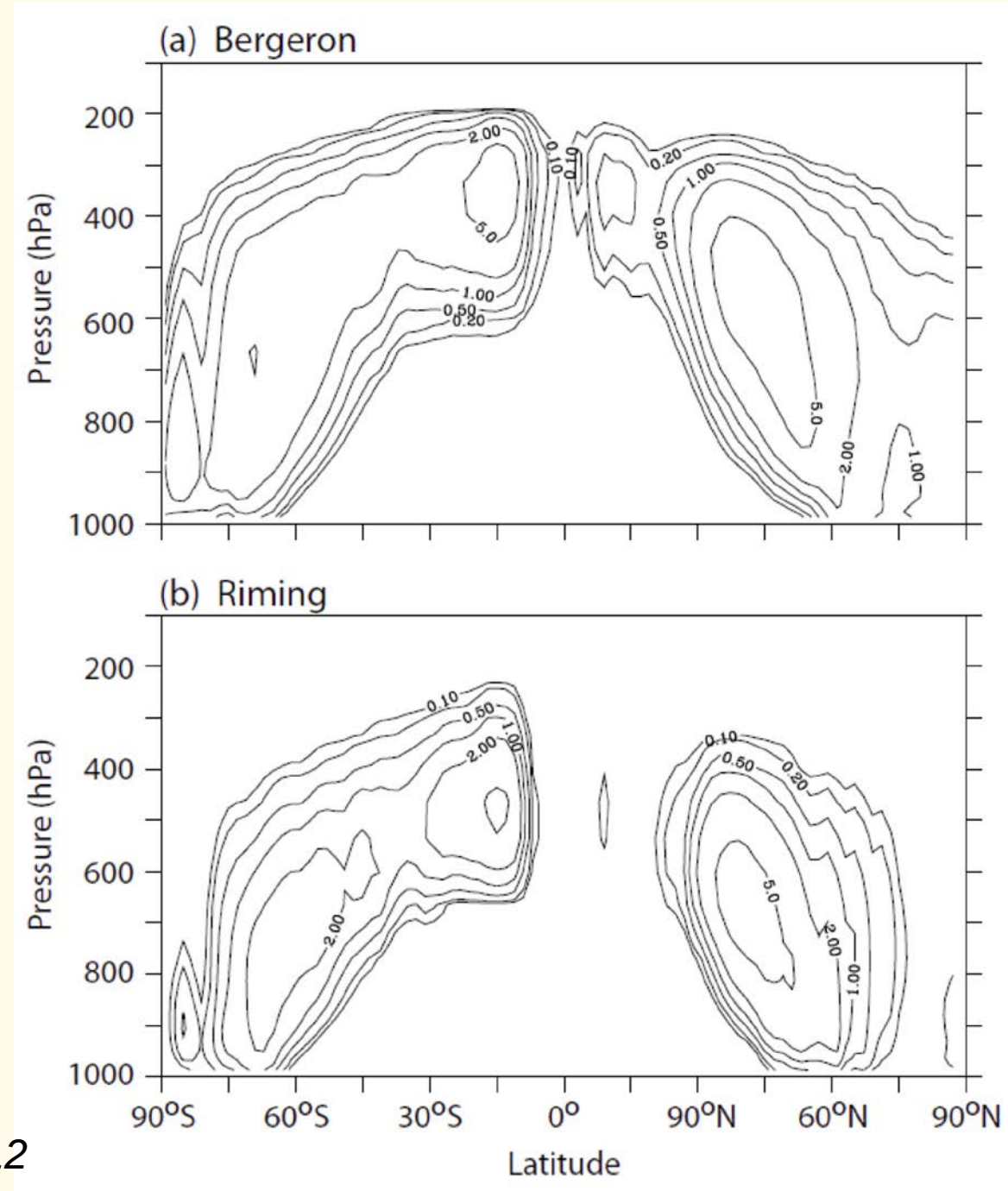
Single Particle Soot Photometer (SP2)



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

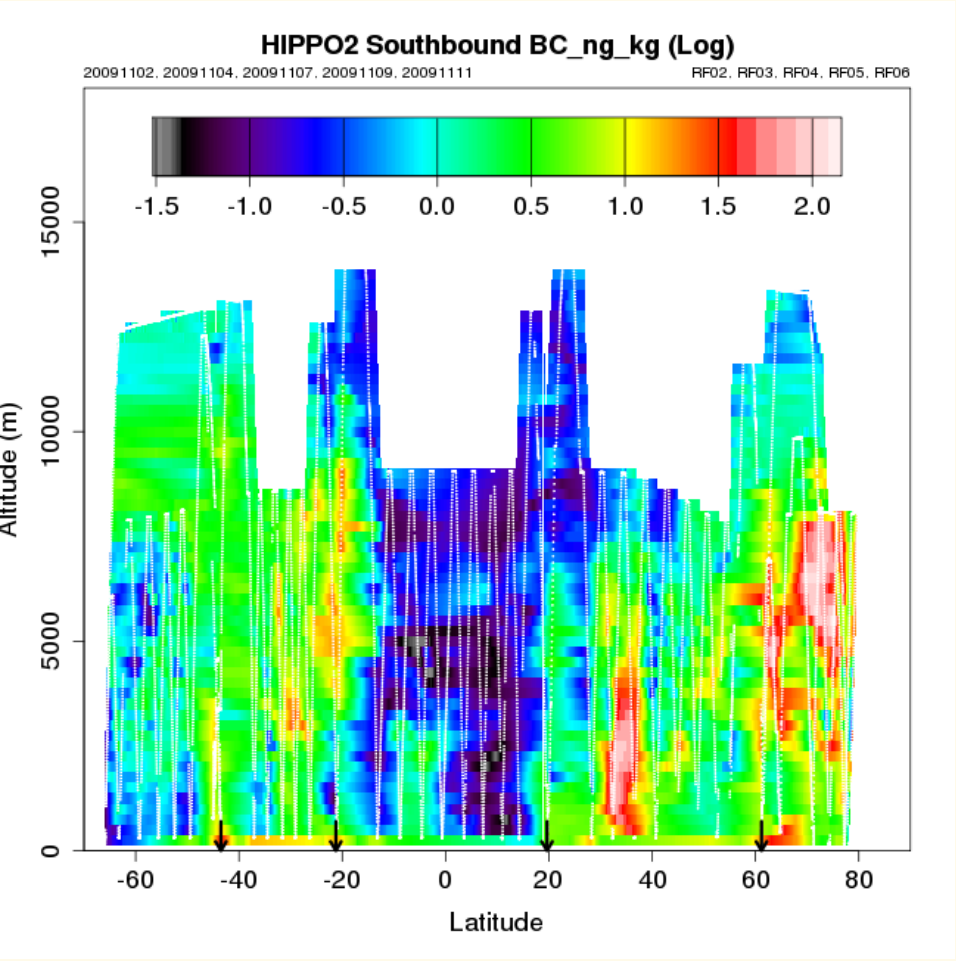
- Monthly mean ice production rates by (a) Bergeron and (b) riming processes, averaged between 160°E and 140°W in January 2009.
- Largest differences in the tropics and polar regions

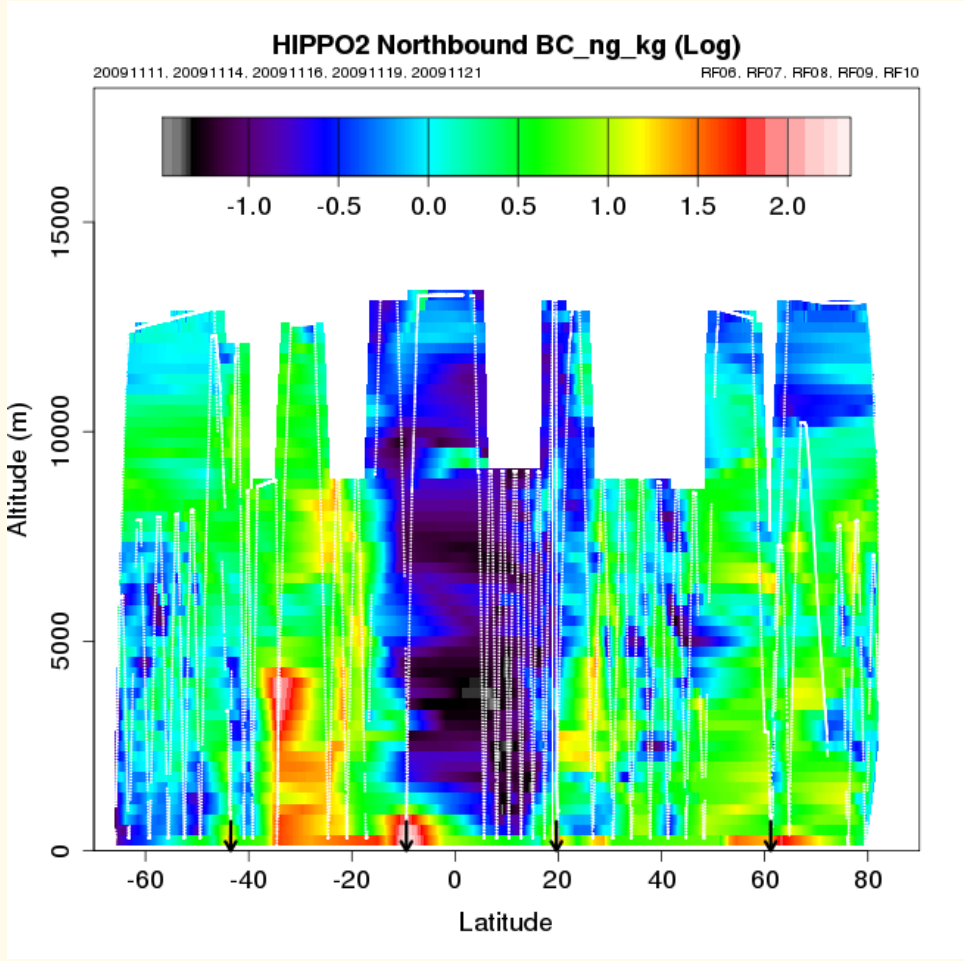


Fan et al., *submitted JGR 2012*

Curtains

Hippo 2: November 2009





Curtain plots courtesy of Britt Stephens, NCAR