The Black Carbon Burden in the Northern Hemisphere Pacific

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Harvard University

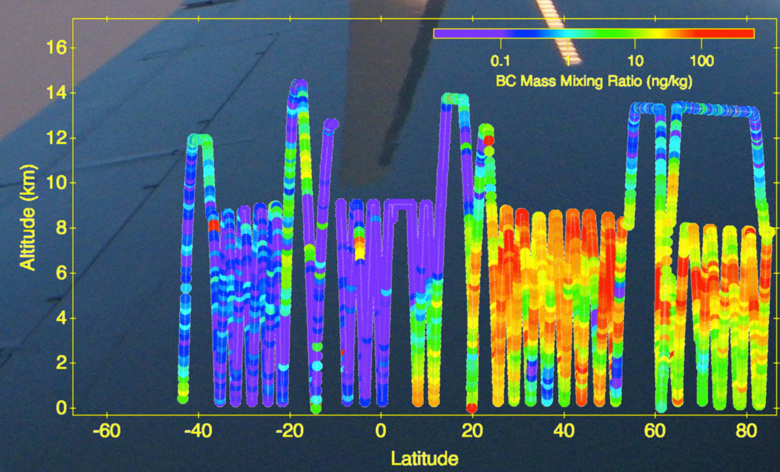


Photo Credit: E. Kort

The Black Carbon Burden in the Northern Hemisphere Pacific

Outline

- Black carbon (BC) and climate
- BC model-measurement intercomparison
- BC measurements and methodology
- BC mass loadings in the remote atmosphere from 67°S to 85°N

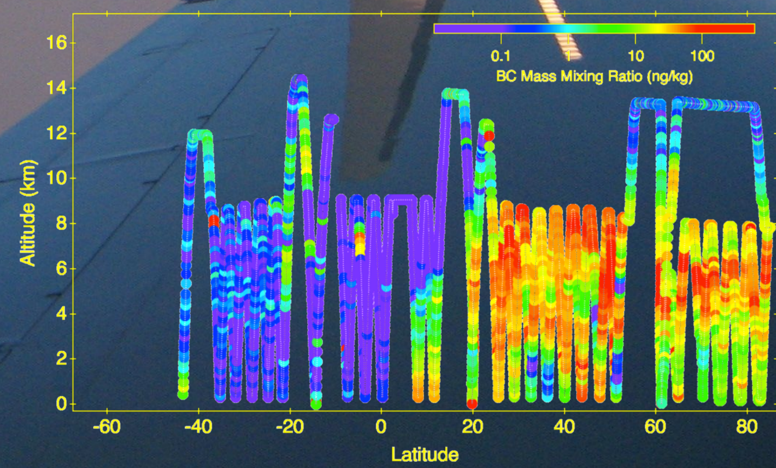


Photo Credit: E. Kort

BLACK CARBON AND CLIMATE

- Black carbon (BC) affects climate through:

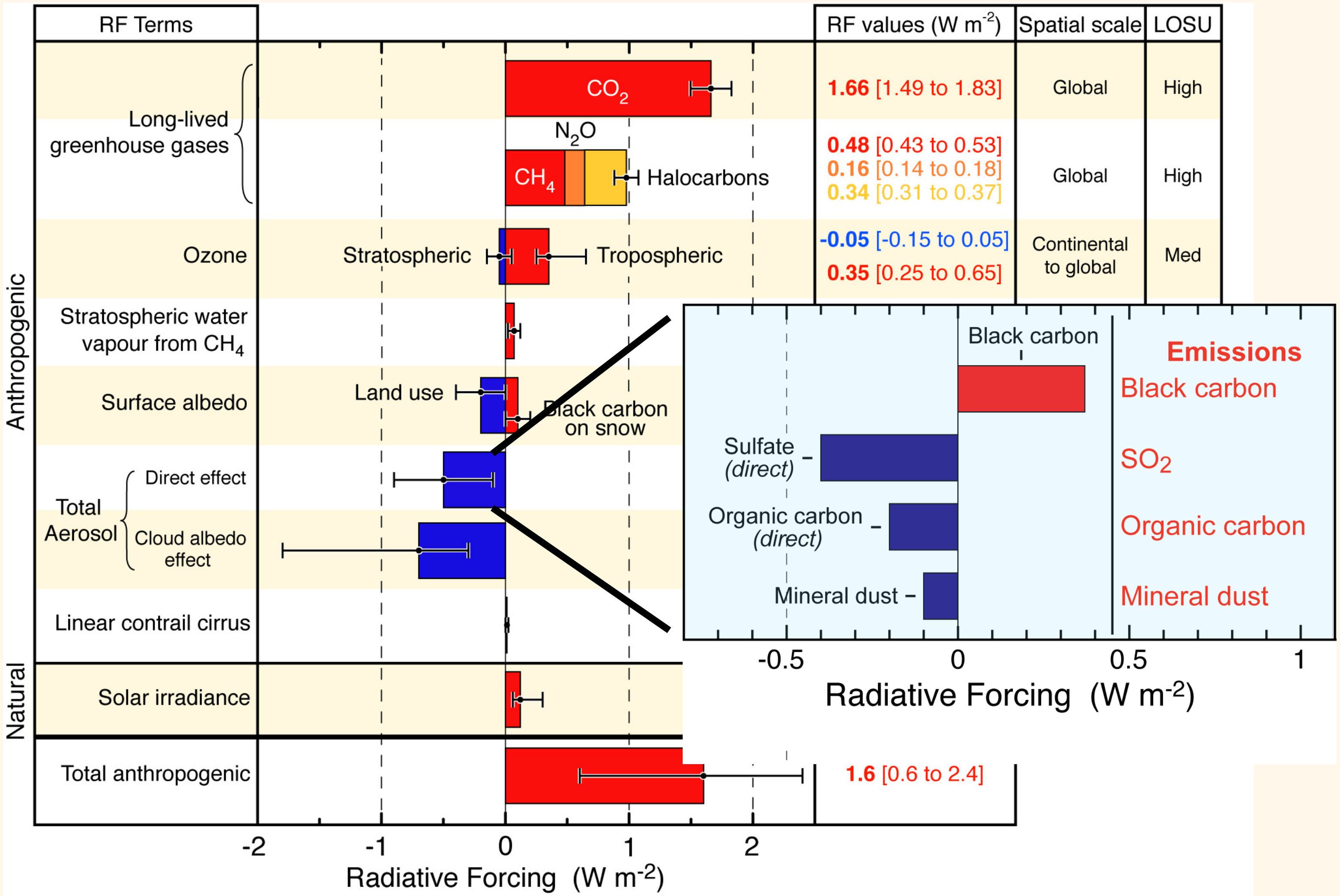
  (i) direct (absorption of solar radiation) and
  (ii) indirect (cloud effects) radiative forcing

- What are the processes controlling BC (emission, transport, removal) necessary to constrain global aerosol models?

- Airborne measurements of BC are limited and some model-measurement comparisons show large discrepancies (Koch et al., *Atmos. Chem. Phys.*, 2009)

- Global measurements of BC support process studies that provide physical bounds on global aerosol models

IPCC 2007: COMPONENTS OF RADIATIVE FORCING FOR EMISSIONS OF AEROSOLS



- Black carbon aerosol is an important component of anthropogenic climate forcing

IPCC, AR4, 2007 www.ipcc.ch

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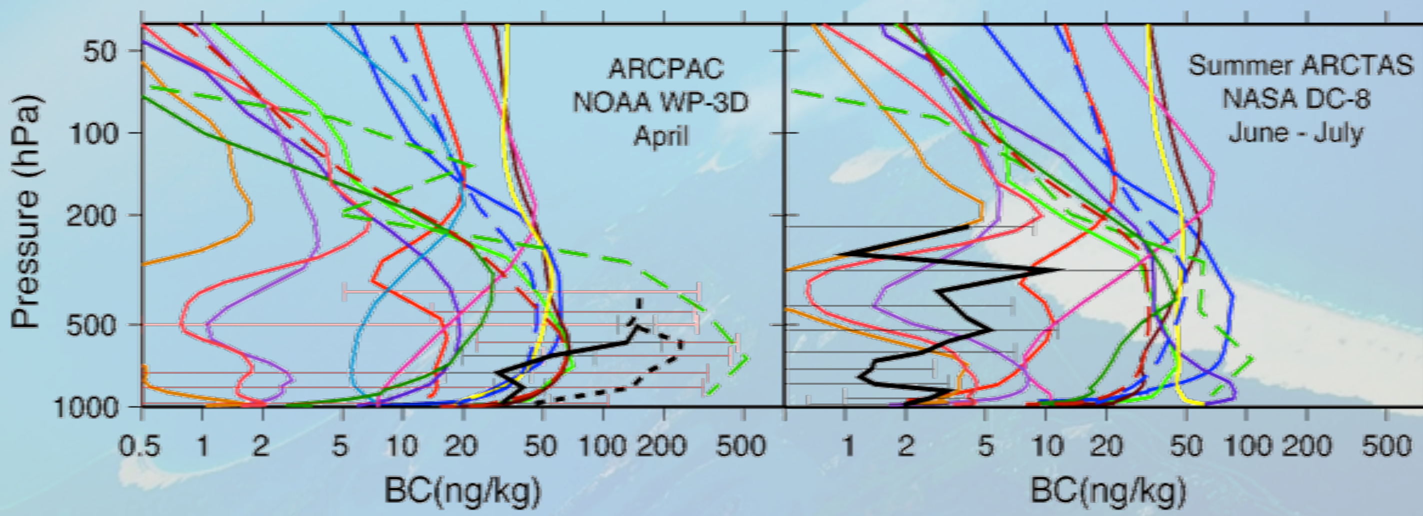
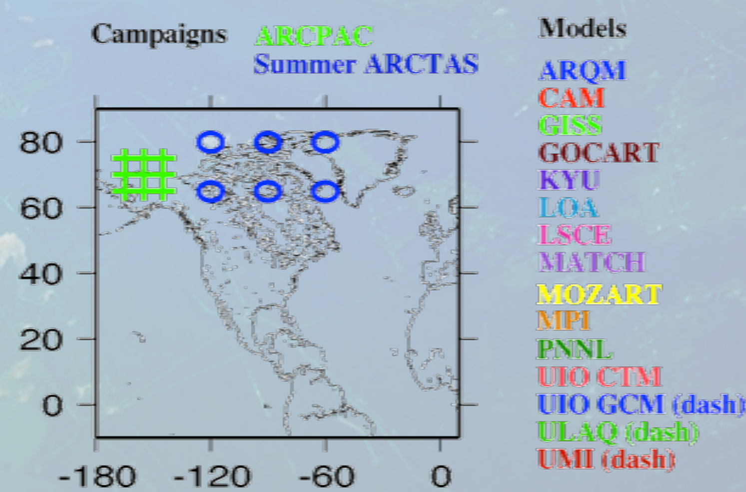
Black Carbon Measurements and Models



- Spring: model results do not reproduce the observations in the Arctic
- Summer: model results do not change much between spring and summer like measurements
- Transport has bigger impact on BC than model microphysics?



Koch *et al.*, *Atmos. Chem. Phys.*, 2009

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

- HIPPO science objectives:

  Surface emissions
  Transport timescales
  Sinks for gases and aerosols

- Global-scale measurements:

  67°S to 85°N
  ~140+ vertical profiles

- HIPPO outreach website:

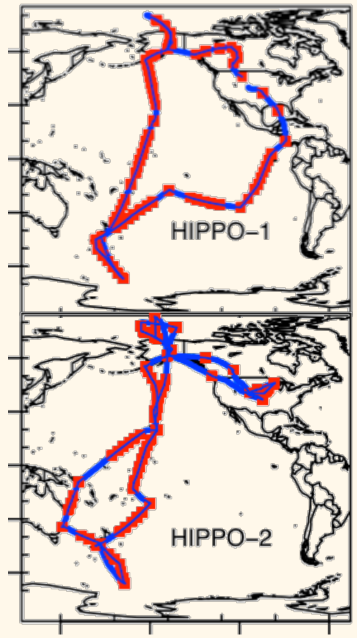
  http://hippo.ucar.edu

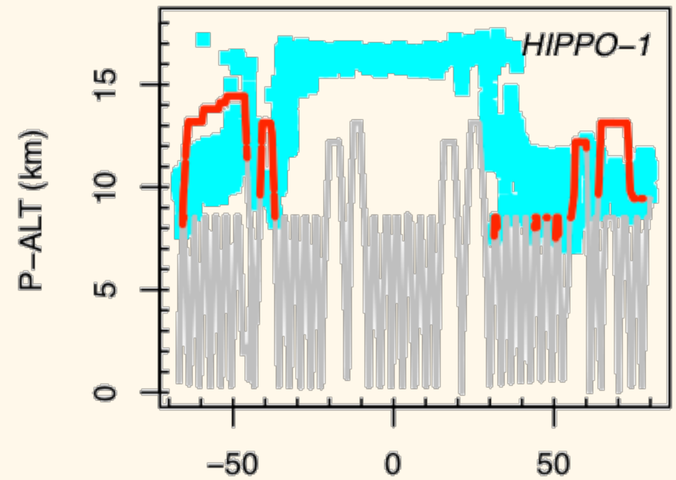
- Global-scale measurements:

  HIPPO-1: January 2009
  -2: November 2009
  -3: April 2010
  -4: June 2011
  -5: September 2011

- Fine-grained meridional cross sections:

  2.2° latitude resolution in middle of profile
  4.4° latitude resolution near surface



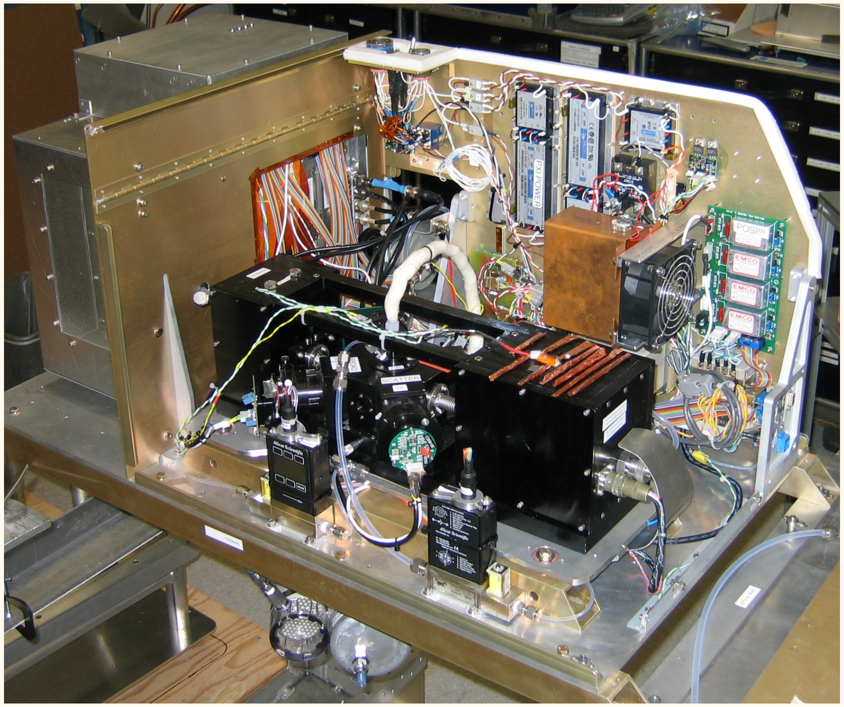


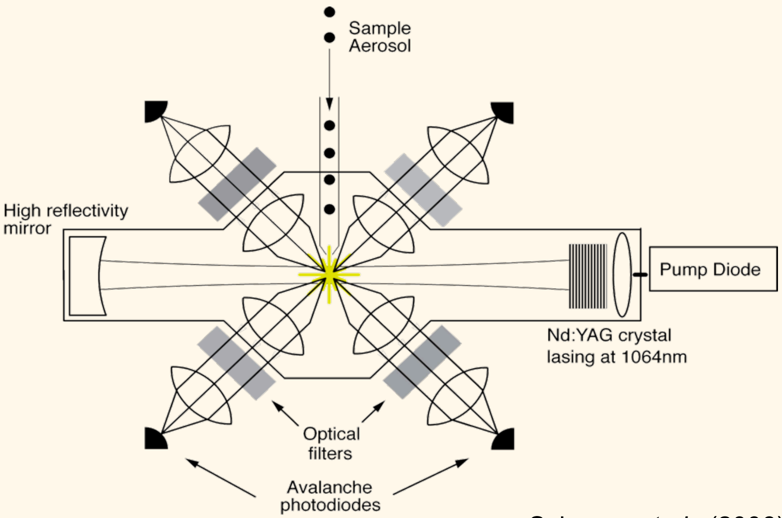
Wofsy *et al.*, *Proc. R. Soc. A*, in press

Crew of NSF G-V in American Samoa, April 2010

Single-Particle Soot Photometer (SP2)

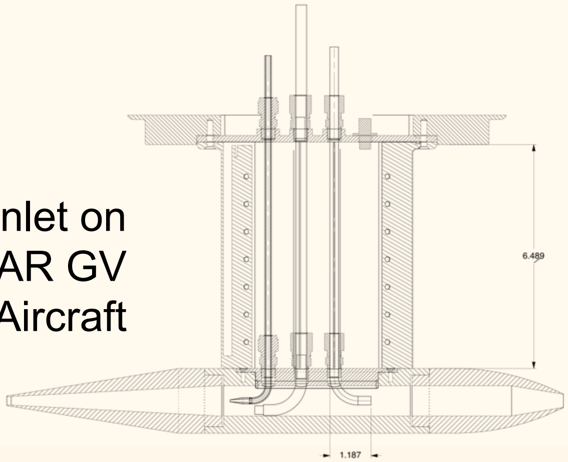
- Single particle soot photometer (SP2) detects refractory BC mass
- Laser-induced incandescence is linearly proportional to mass and independent of the mixing state of a BC particle
- SP2 samples ~90% of BC mass and ~50% of BC number
- Uncertainties: 25% mostly due to BC mass calibration





Schwarz *et al.*, (2006)

Sample inlet on NSF/NCAR GV Aircraft



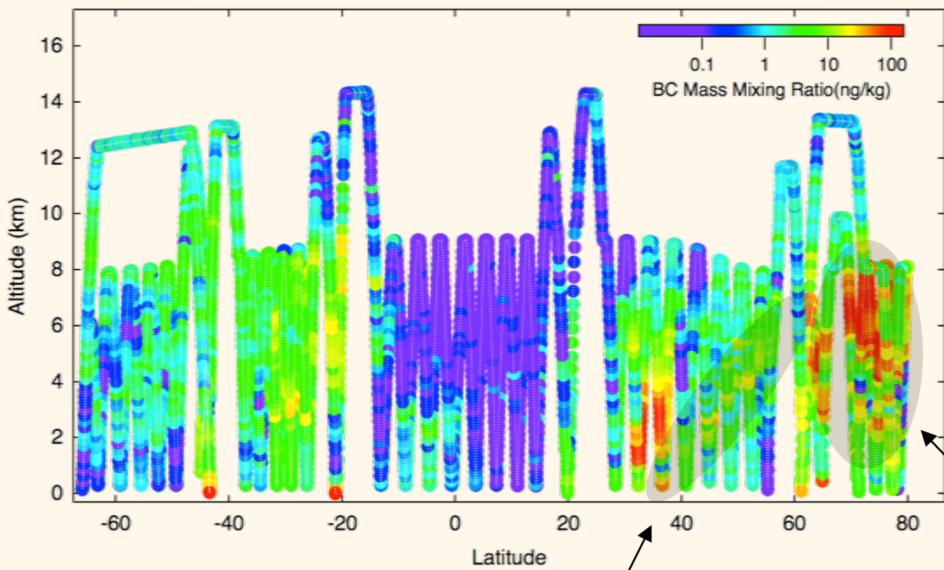
METHODOLOGY

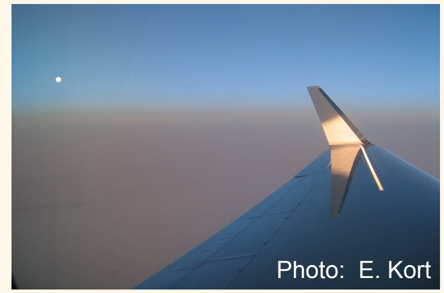
To identify air masses for process studies and evaluate the representativeness of the BC pole-to-pole observations, we are using these tools and data:

- Chemical tracer analyses (CO, CO_2, O_3, H_2O, CH_4, fine-mode aerosol)
- Global-regional model simulations (e.g., GMAO-GEOS, RAQMS)
- Satellite data: MODIS fire and aerosol optical depth, AIRS CO, MOPPIT CO
- Back trajectory analyses and convective influence diabatic trajectories
- Ground station data: Baseline NOAA Global Monitoring Division stations (Barrow, Mauna Loa, American Samoa) and AERONET sites

HIPPO-2
NOVEMBER 2009

2-11 November 2009, Southbound



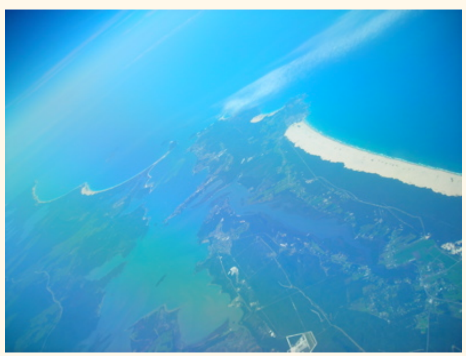


Asian and North American pollution

- High loadings of BC observed in the Arctic; well stratified plumes from Asia, Europe, and North America
- BC as a tracer of isentropic transport

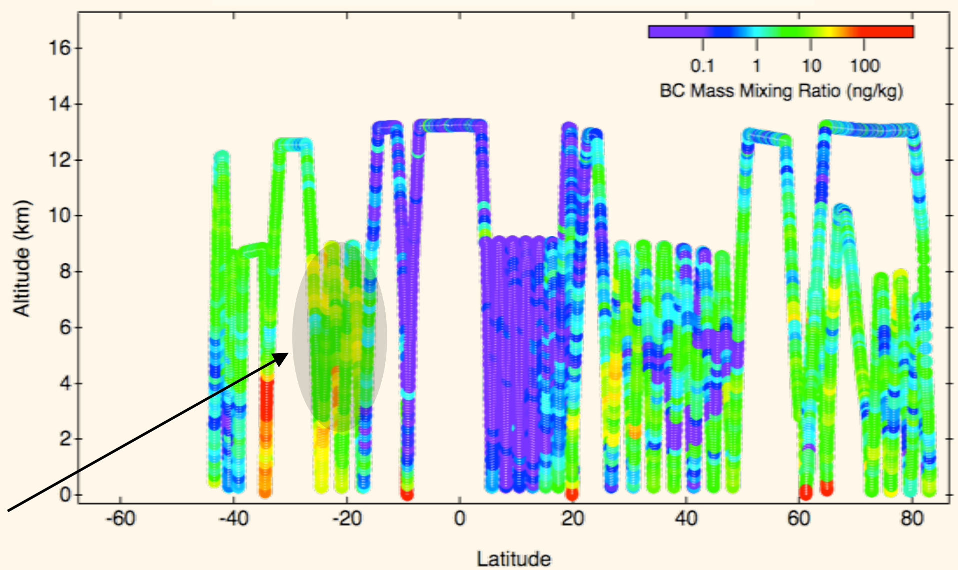
Warm Conveyor Belt

- Long-range biomass burning plumes observed in southern hemisphere from Africa and South America
- Very low BC loadings in the deep tropics



Long-range biomass burning plumes

14-21 November 2009, Northbound



Spackman *et al.*, in preparation

HIPPO-2
November 2009

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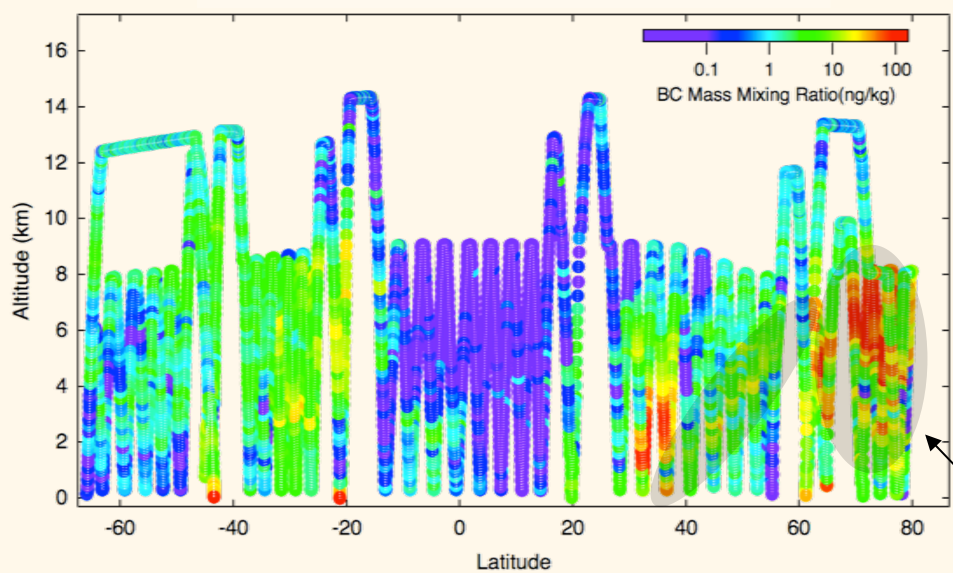

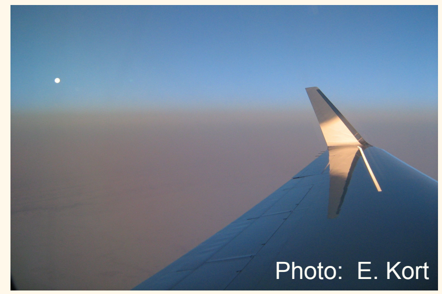

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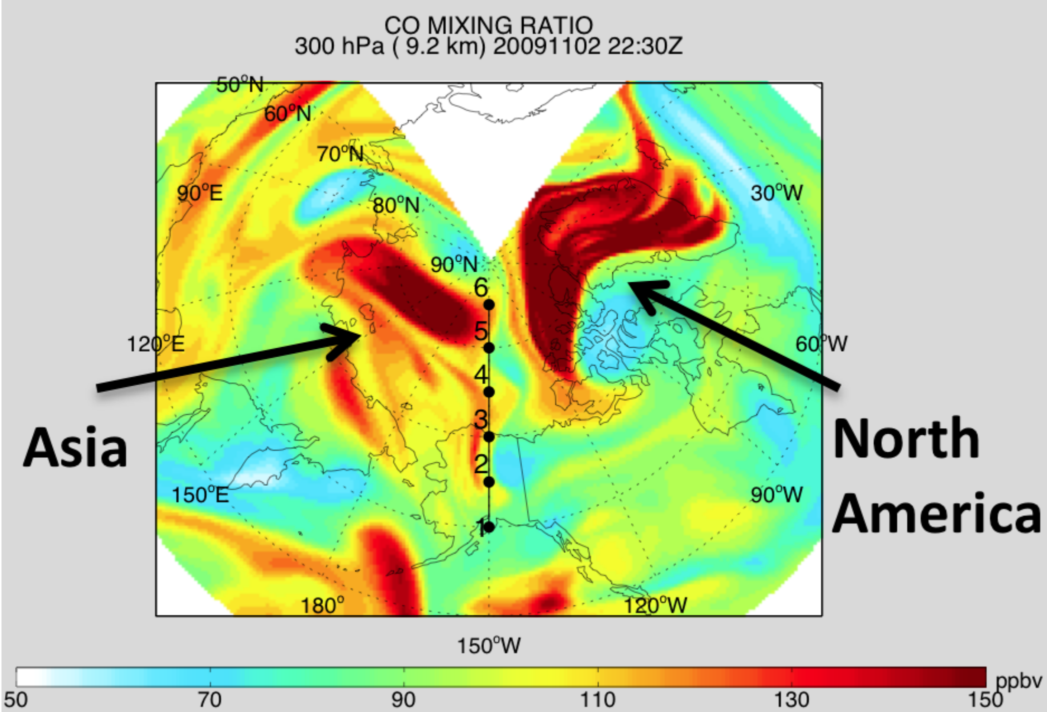

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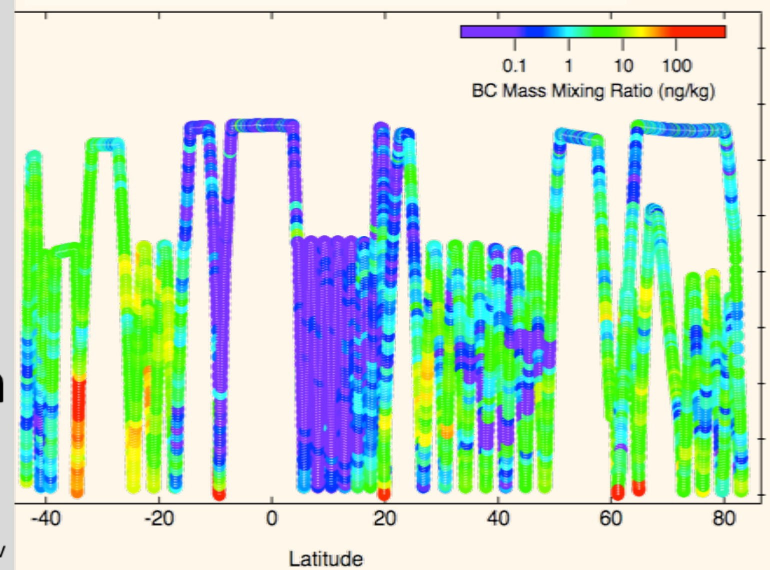


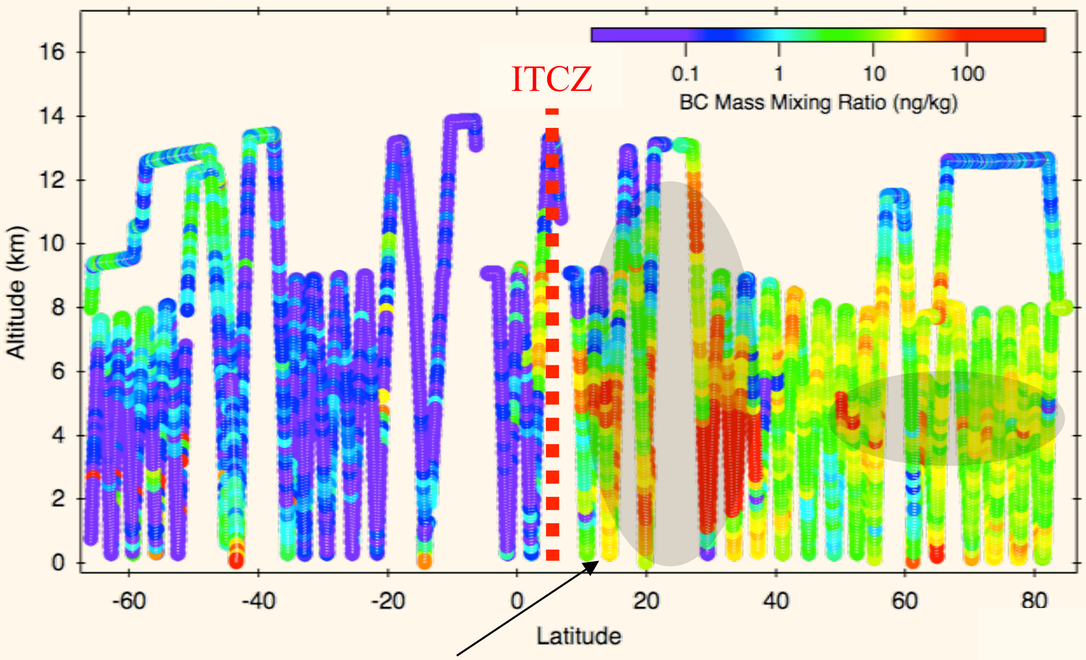
Spackman *et al.*, in preparation

HIPPO-3

April 2010

- Asian pollution well stratified in Arctic
- Biomass burning plumes from SE Asia contributed to large BC loadings between ITCZ and ~40°N

26 March – 5 April 2010, Southbound

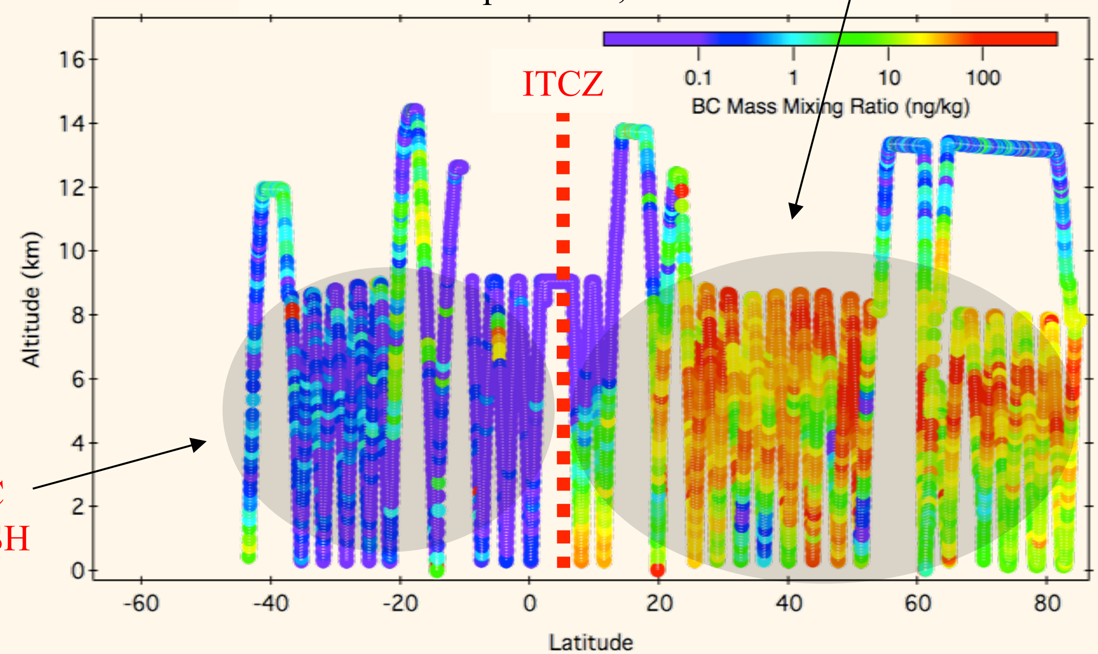


Stratified Asian pollution plumes

Biomass-burning from SE Asia

High BC mass in NH

8–15 April 2010, Northbound



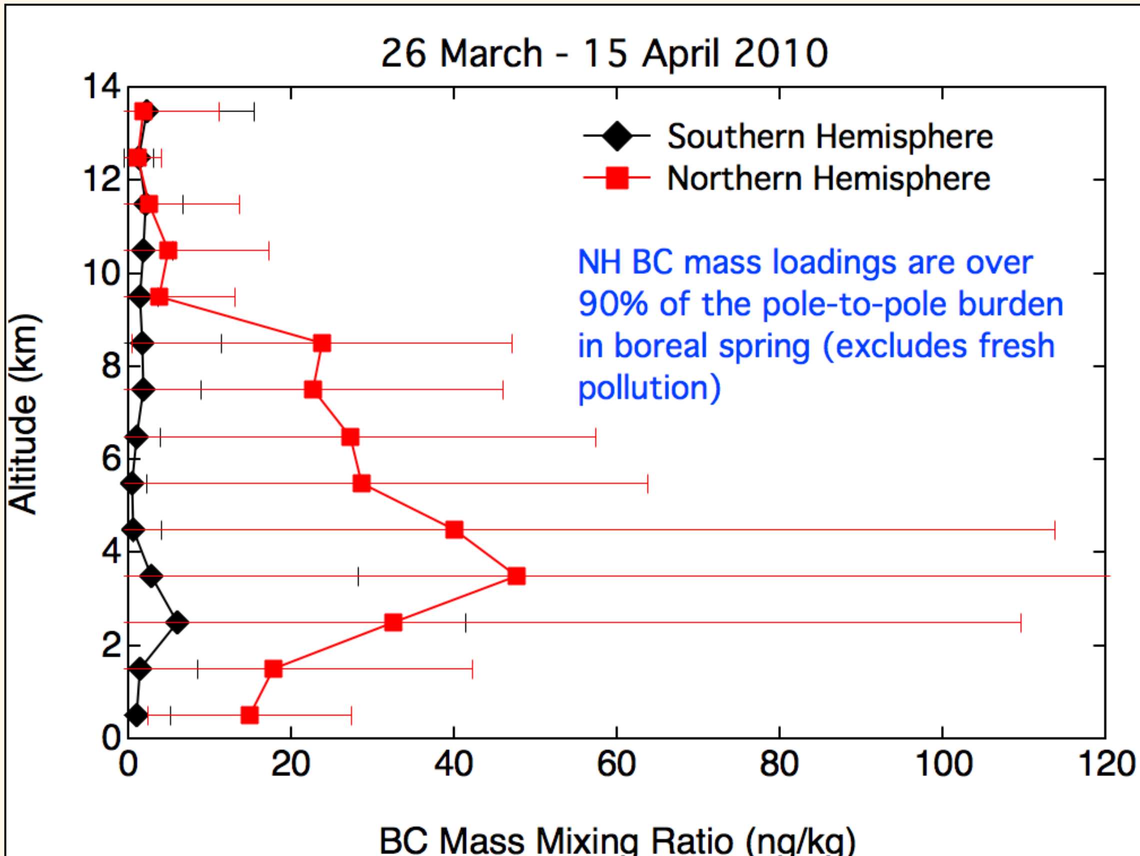
- Very low BC loadings in the southern hemisphere (SH)
- Large BC loadings in the northern hemisphere (NH) with loadings comparable to those in urban areas
- Strong interhemispheric gradient at the ITCZ

Low BC mass in SH

Spackman *et al.*, in preparation

HIPPO-3

APRIL 2010



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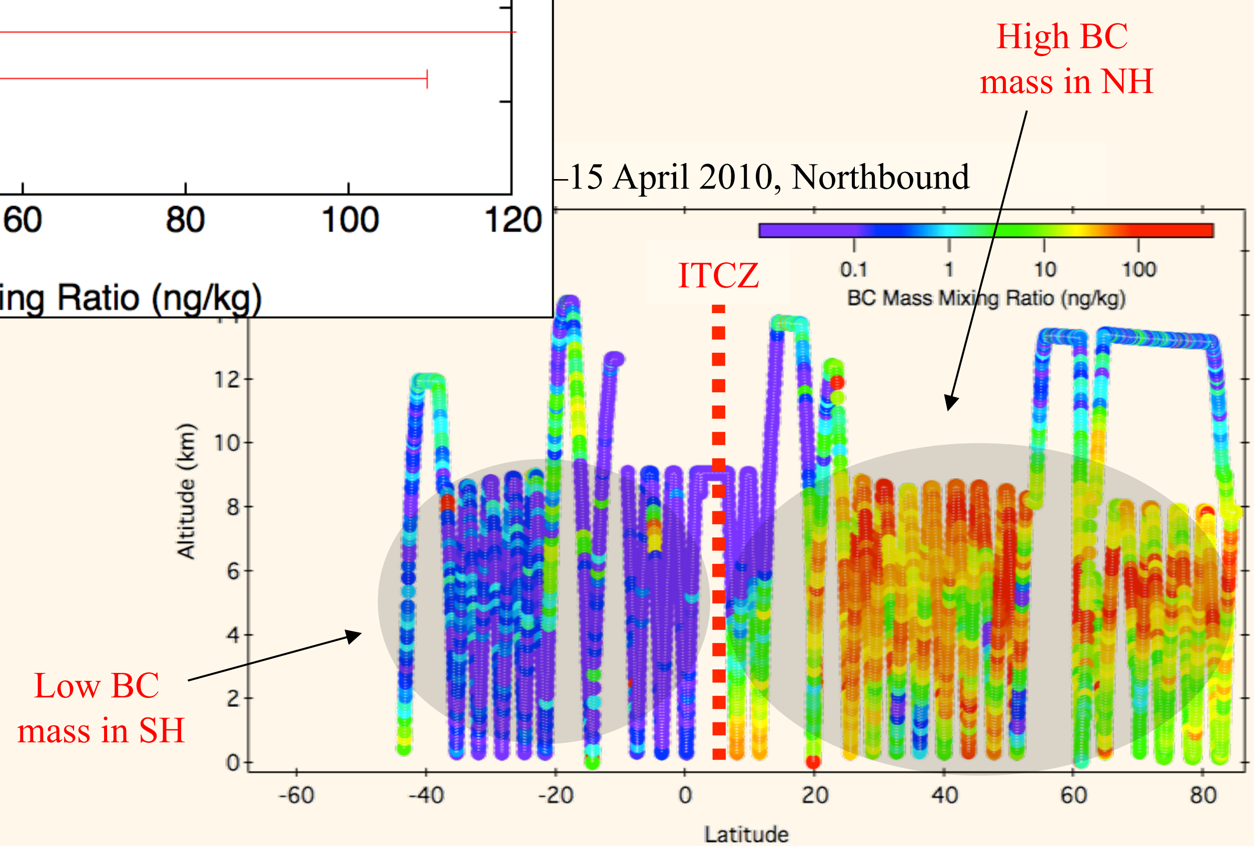

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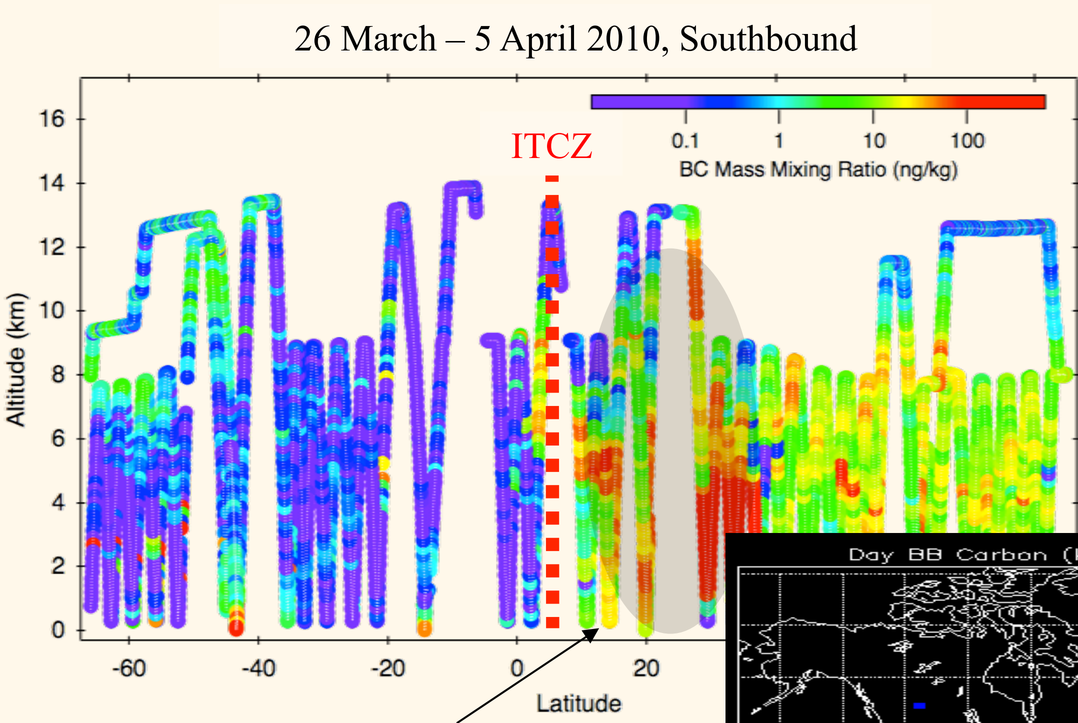

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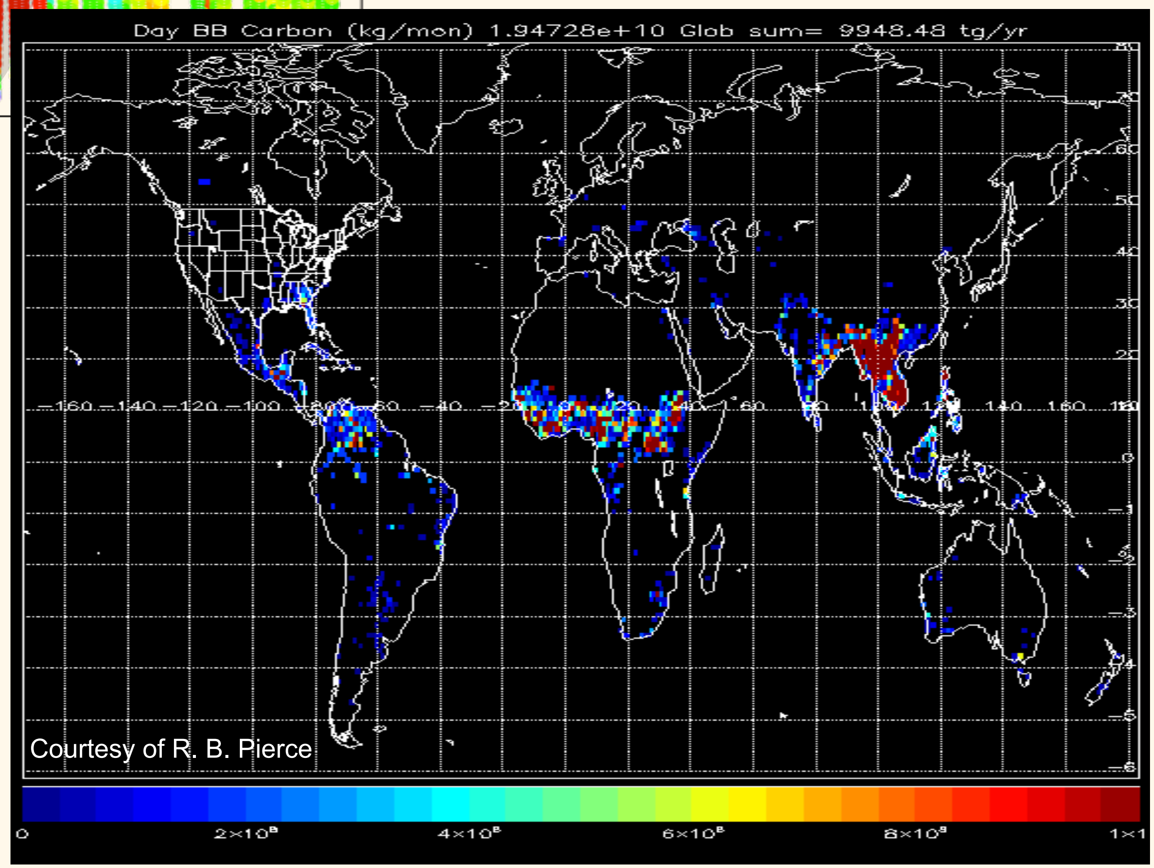

Spackman *et al.*, in preparation

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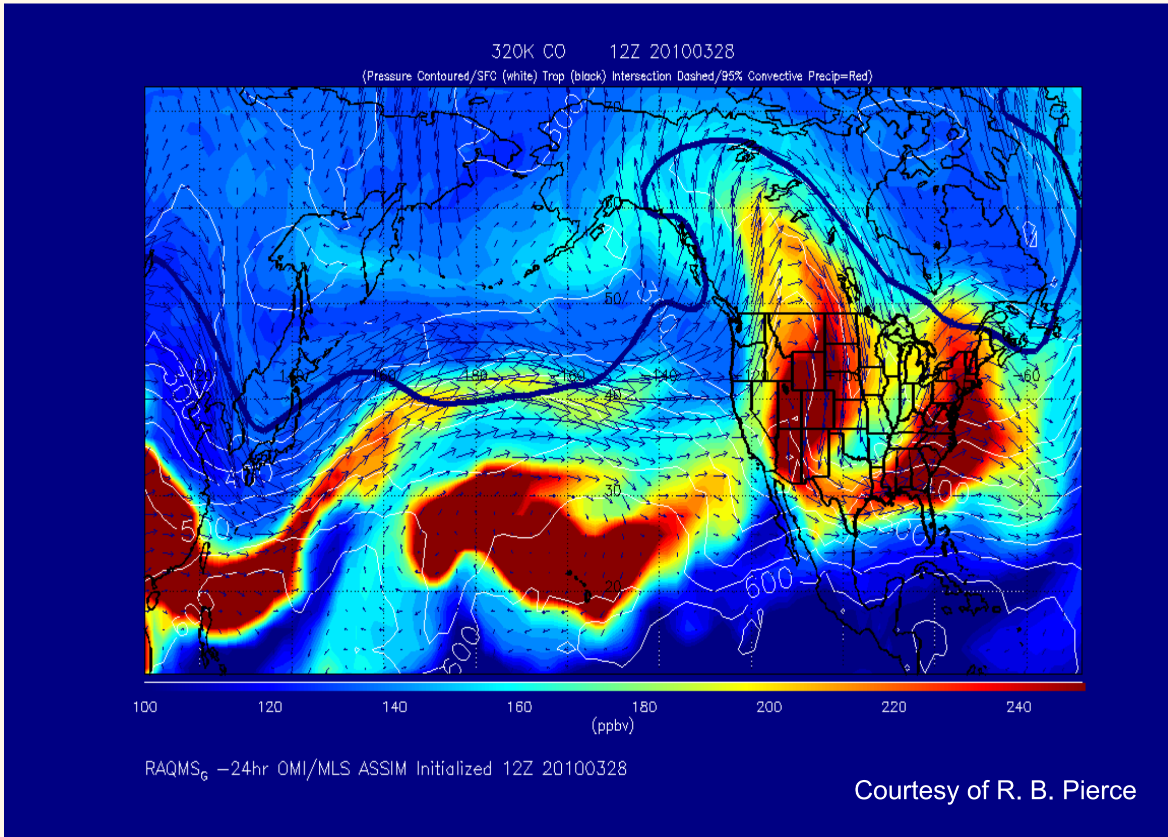
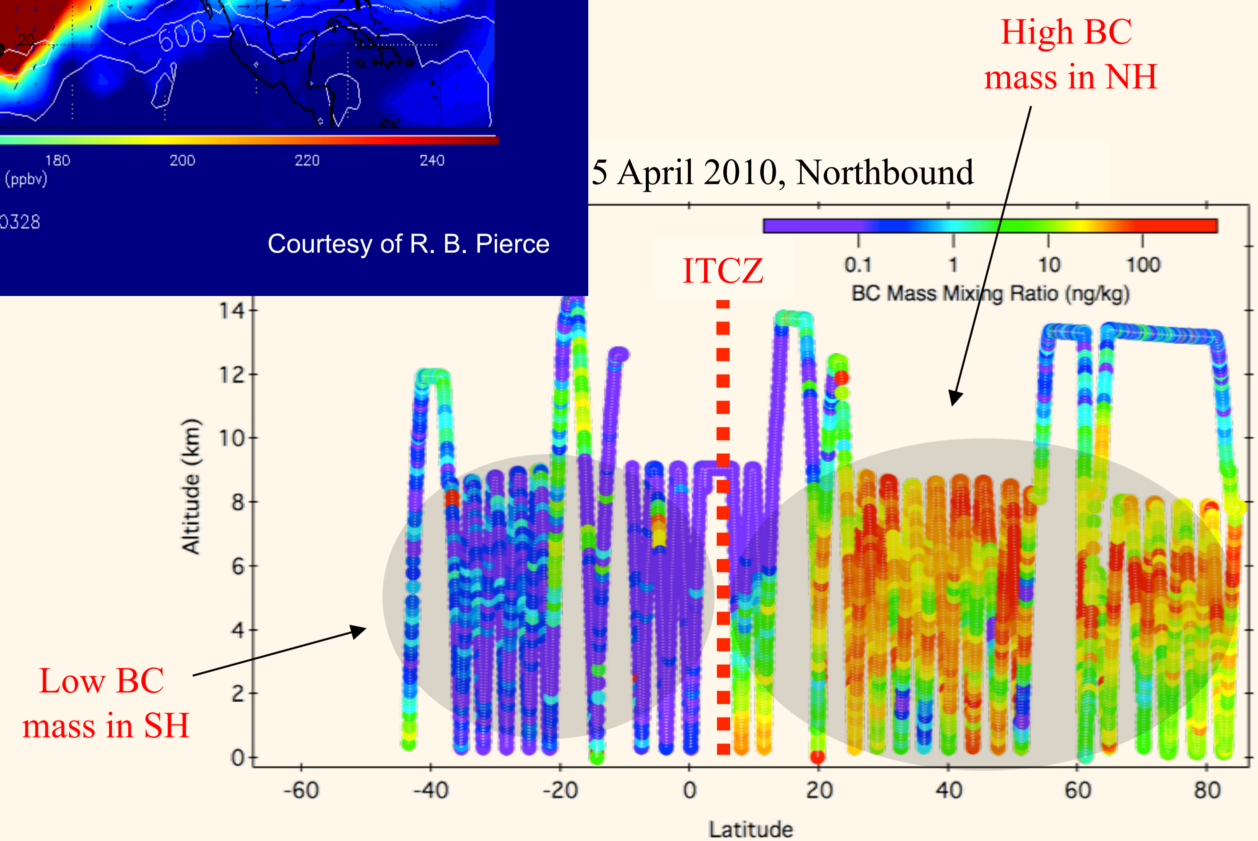


Courtesy of R. B. Pierce

5 April 2010, Northbound



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Spackman *et al.*, in preparation

CONCLUSIONS

- ➢ Unique single-particle measurements of BC mass were performed from pole-to-pole with 400+ vertical profiles over 3 seasons
- ➢ Chemical tracer analysis, satellite data, model studies, and back trajectory analyses are being used to identify air masses to conduct process studies and evaluate the representative of these data
- ➢ High BC mass loadings (10–1000 ng/kg) were observed in the springtime NH accounting for over 90% of the remote pole-to-pole burden of BC mass:
  - BC loadings from anthropogenic sources in Asia were often diffuse at midlatitudes but well-stratified in the Arctic
  - Biomass-burning plumes from southeast Asia contributed to large BC loadings between the ITCZ and 40°N
  - ITCZ marks a sharp boundary to interhemispheric transport

ACKNOWLEDGMENTS

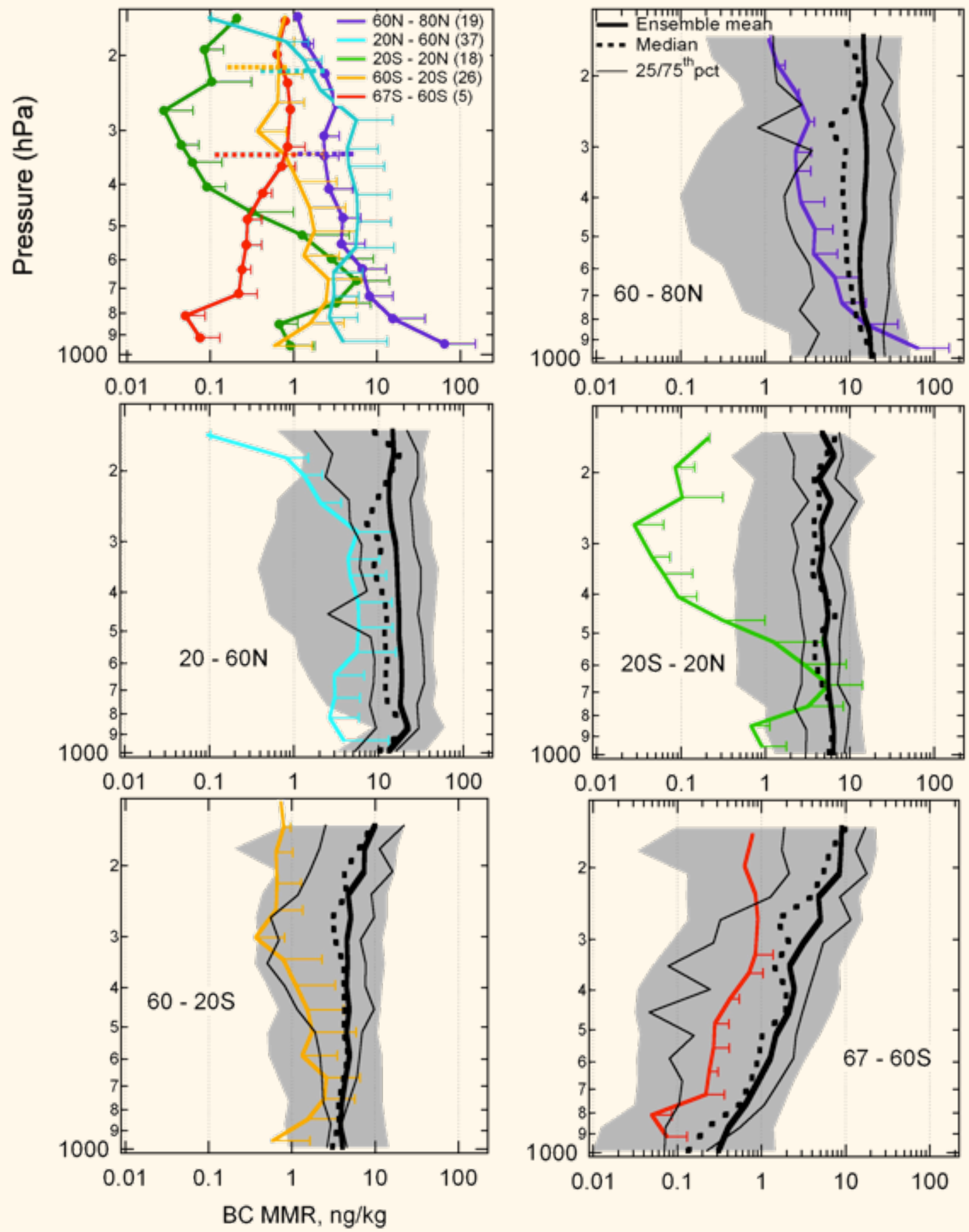
HIPPO: NCAR/NSF G-V Pilots and Crew

Research supported by NASA, NOAA, NSF

HIPPO-1 BC Measurement-Model Comparison

AEROCOM MODELS
(January average):

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



Schwarz *et al.*, 2010

HIPPO G-V AIRCRAFT INSTRUMENTATION

Harvard/Aerodyne—HAIS QCLS	**CO_2**, **CH_4**, **CO**, **N_2O** (*1 Hz*)
NCAR AO2	O_2:N_2 , **CO_2** (*1 Hz*)
Harvard OMS CO_2	**CO_2** (*1 Hz*)
NOAA CSD O_3	O_3 (*1 Hz*)
NOAA GMD O_3	O_3 (*1 Hz*)
NCAR RAF CO	**CO** (*1 Hz*)
NOAA- UCATS, PANTHER GCs (1 per 70 – 200 s)	CO, **CH_4**, **N_2O**, CFCs, HCFCs, **SF_6**, CH_3Br, CH_3Cl
Whole air sampling: NWAS (NOAA), AWAS (Miami), MEDUSA (NCAR/Scripps)	O_2:N_2, **CO_2**, **CH_4**, **CO**, **N_2O** , other GHGs, **COS**, halocarbons, solvent gases, marine emission species, many more
Princeton/SWS VCSEL	H_2O (*1 Hz*)
NOAA SP2	Black Carbon (reported @ *1 Hz*)
MTP, wing stores, etc	T, P, winds, aerosols, cloud water

HIAPER Pole-to-Pole Observations (HIPPO)

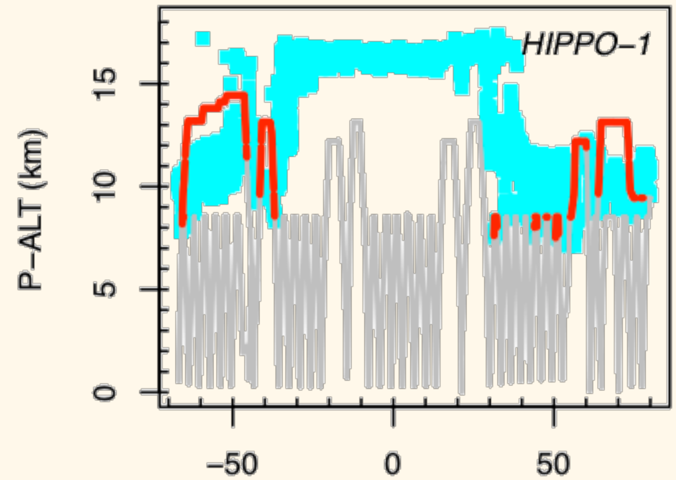
- 5 pole-to-pole missions, 4 seasons

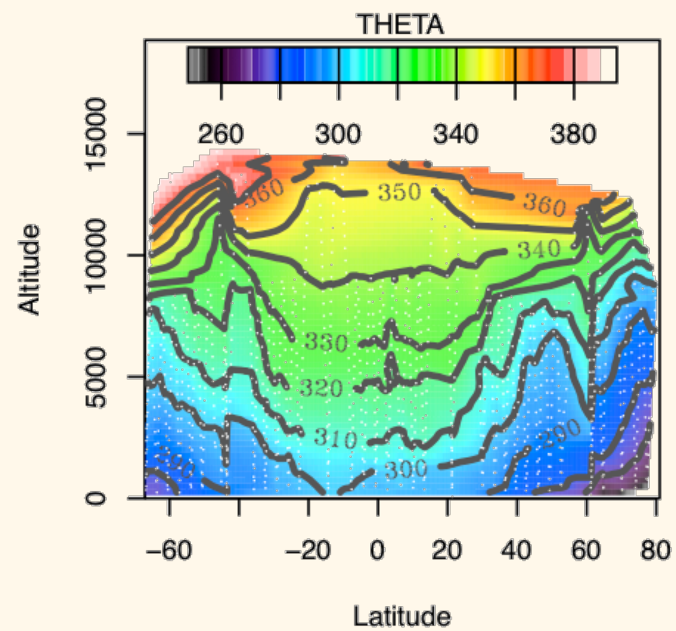
  HIPPO-1: January 2009
  -2: November 2009
  -3: April 2010
  -4: June 2011
  -5: September 2011

- Fine-grained meridional cross sections

  2.2° latitude resolution in middle of profile
  4.4° latitude resolution near surface

Anchorage, January 2009





Wofsy *et al.*, *Proc. R. Soc. A*, in press

Aircraft Measurements of Black Carbon from Pole-to-Pole

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University of Colorado, Boulder