Wet removal of black carbon in Asian outflow: Aerosol Radiative Forcing in East Asia (A-FORCE) aircraft campaign

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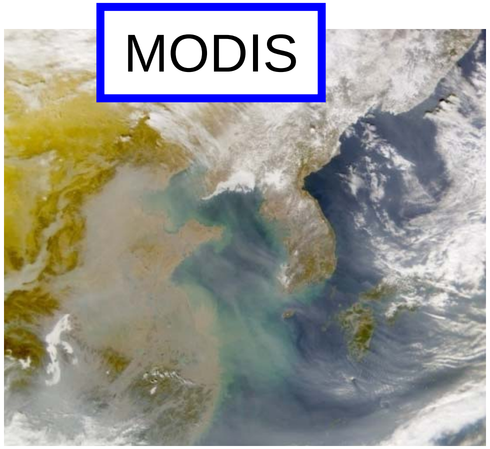
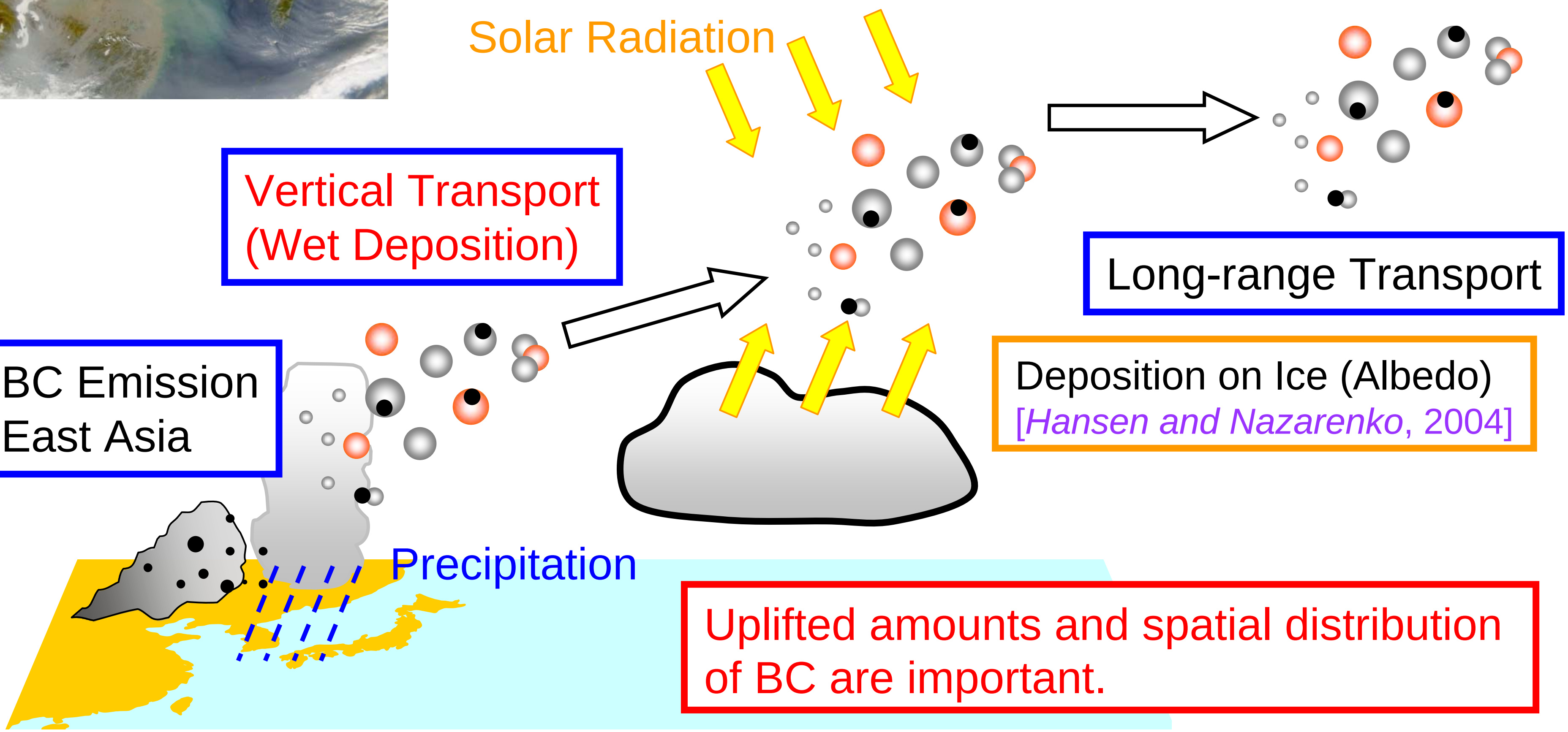
10th AeroCom Workshop, October 5, 2011, Fukuoka, Japan

Vertical Transport of Black Carbon (BC)



BC forcing strongly depends on its altitude [*Hansen et al*., 2005]
BC above clouds enhances its forcing [*Haywood and Shine*, 1997]



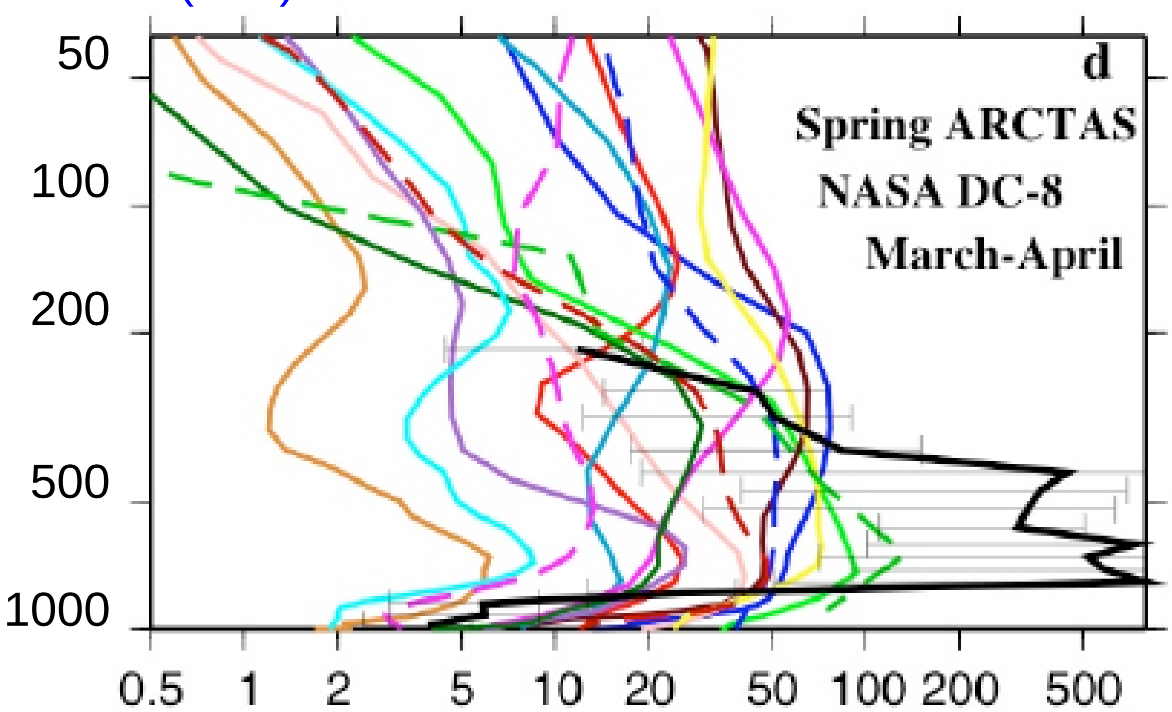
Uplifted amounts and spatial distribution of BC are important.

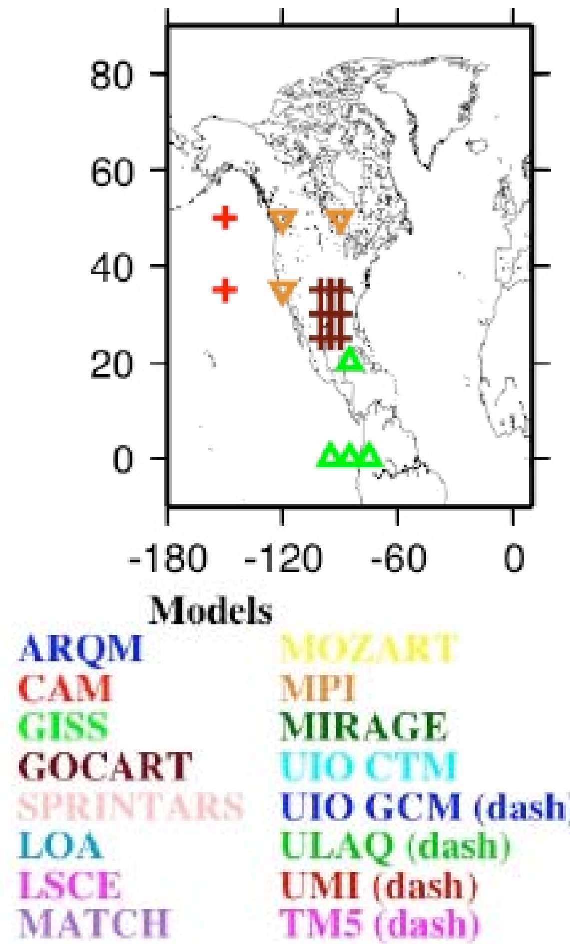
Previous Studies

Wet removal of BC are not well understood.

- Large uncertainties in wet deposition processes of aerosols in 3-D models.
  [*Textor et al*., 2006, *Vignati et al*., 2010]
- Not good predictions of vertical distribution of BC by 3-D models.
  [*Schwarz et al*., 2006, *Koch et al*., 2009]

Pressure (hPa)





Vertical profile of BC (ng/kg) [*Koch et al*., 2009]

Objectives

Wet removal of BC are not well understood.

• Large uncertainties in wet deposition processes of aerosols in 3-D models.
[*Textor et al*., 2006, *Vignati et al*., 2010]

• Not good predictions of vertical distribution of BC by 3-D models.
[*Schwarz et al*., 2006, *Koch et al*., 2009]

• Not enough BC observation data in the FT, especially over East Asia.

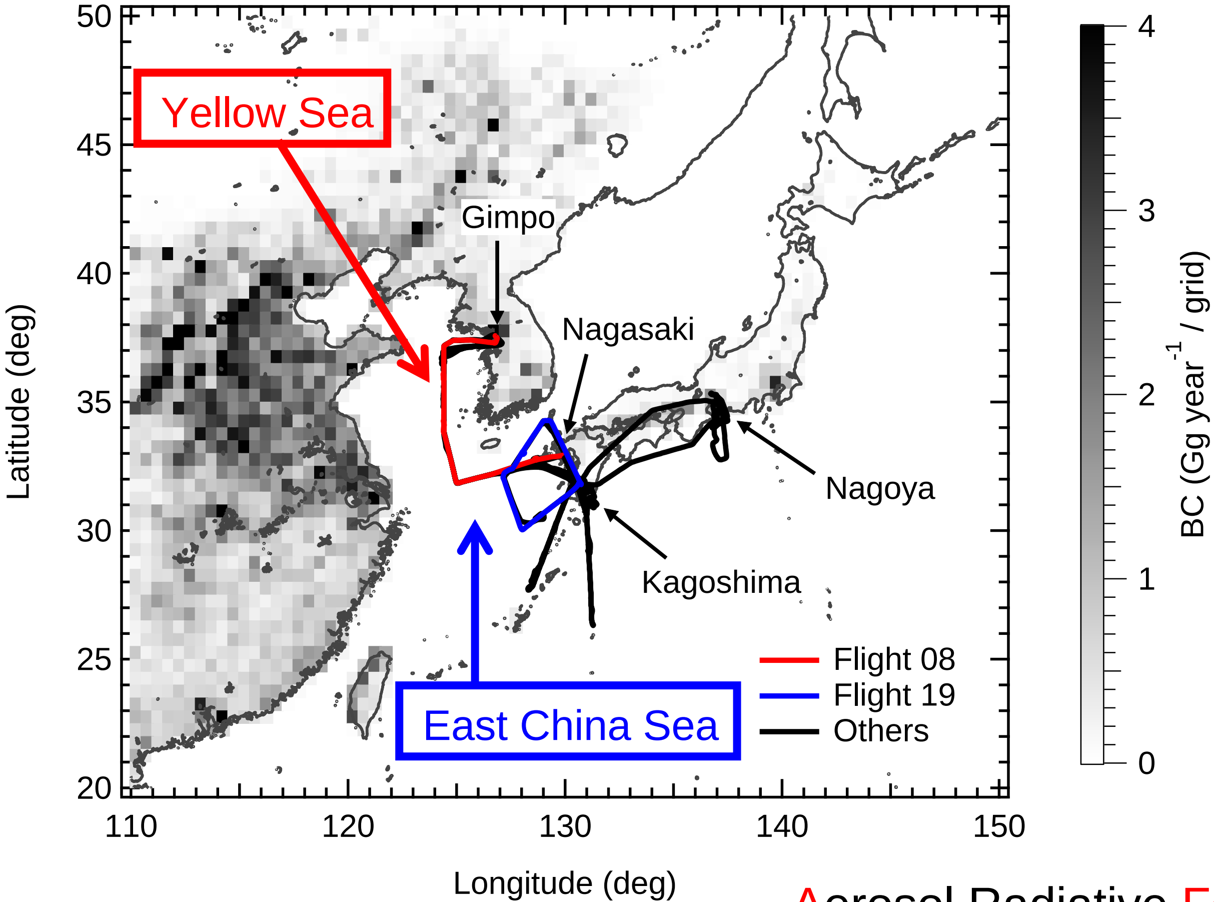
Objectives

• Obtain BC observation data in the FT over East Asia.

• Understand the spatial distributions of BC over East Asia.

• Understand the wet removal of BC in Asian outflow.

A-FORCE Aircraft Measurements



18 Mar-25 Apr 2009
Total 21 flights
120 vertical profiles
at 0-9 km in altitude

Aerosol Radiative Forcing in East Asia (A-FORCE)

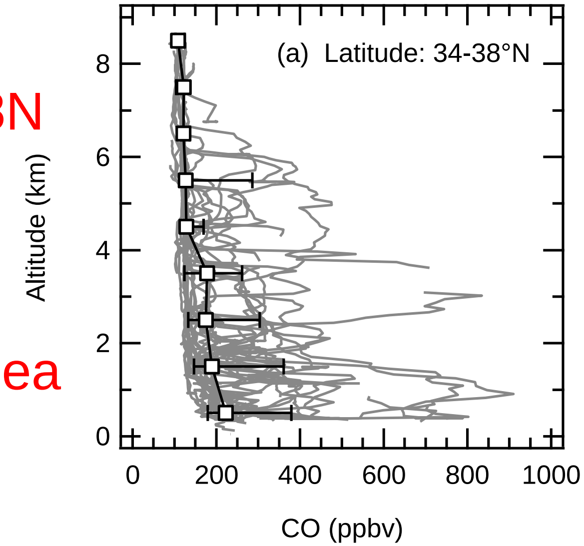
Measurements: CO, BC particles (SP2), light scattering particles (SP2),
total particle number conc. (CPC), sulfate and nitrate (PILS),
liquid water content, cloud and drizzle drop size distribution (CAPS)

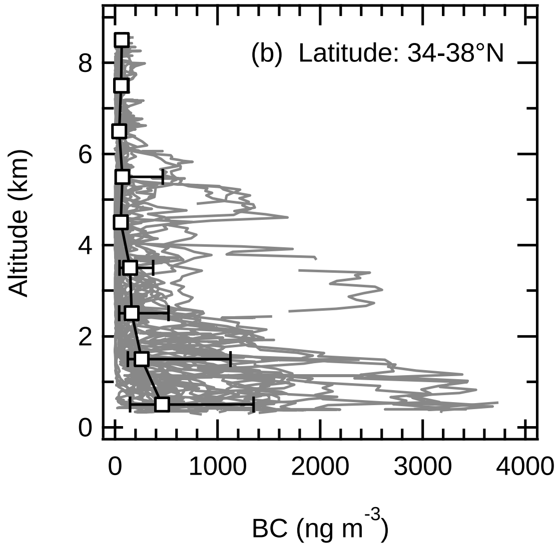
(1-min averaged data outside of clouds were used for this analysis.)

Vertical Profiles of CO and BC

CO
34-38N

Yellow Sea





BC
34-38N

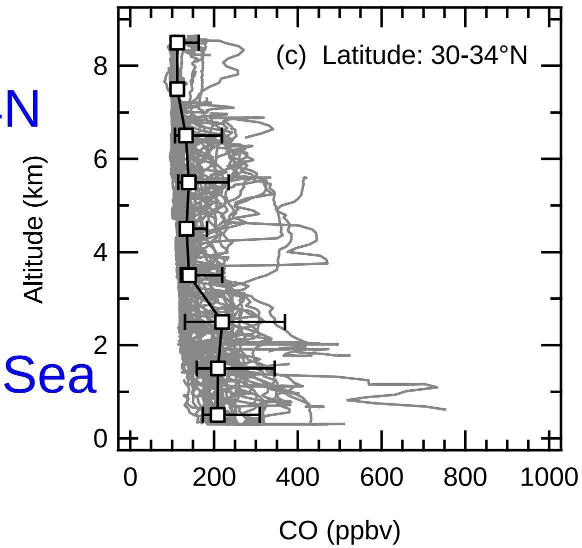
(10-sec data)

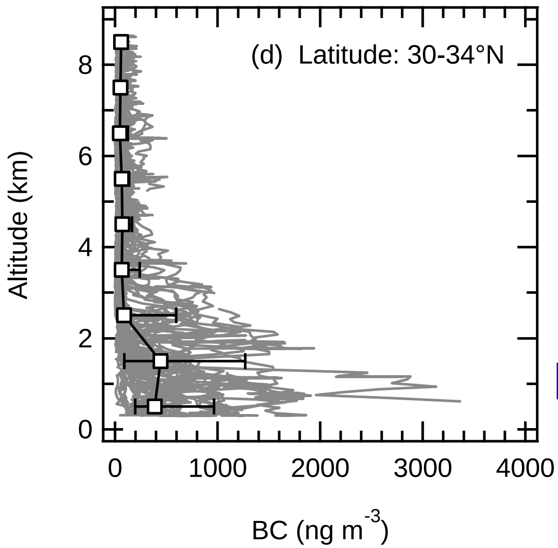
Yellow Sea

Median values and the central 67% ranges are also shown.

CO
30-34N

East China Sea



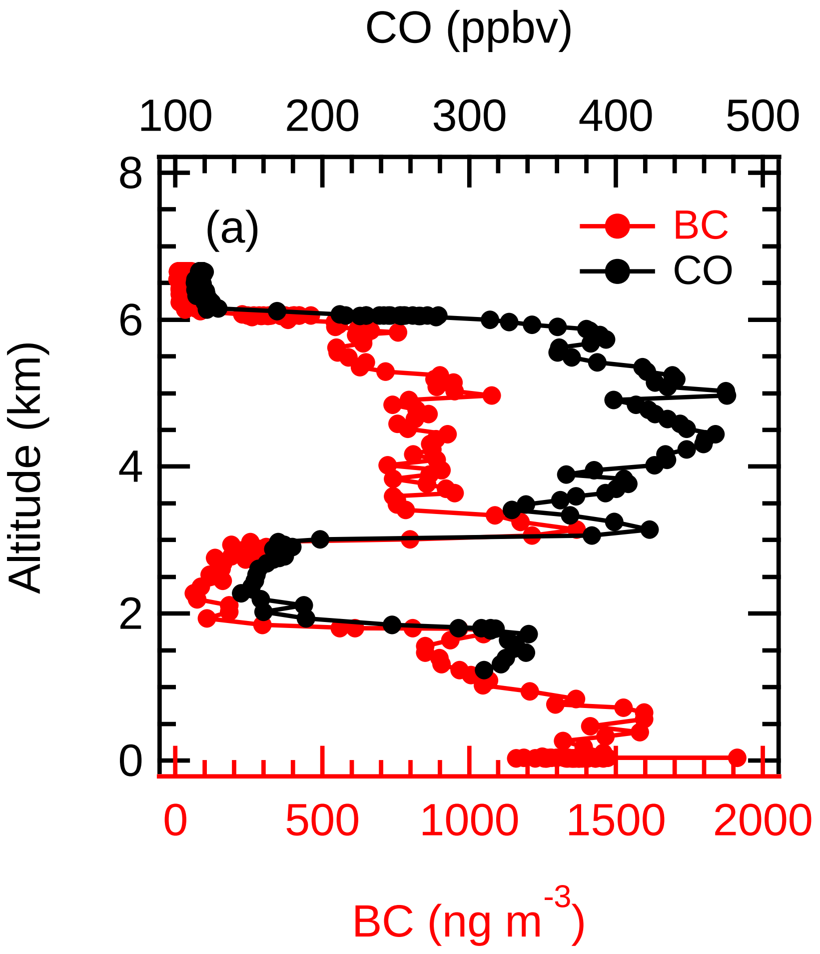


BC
30-34N

East China Sea

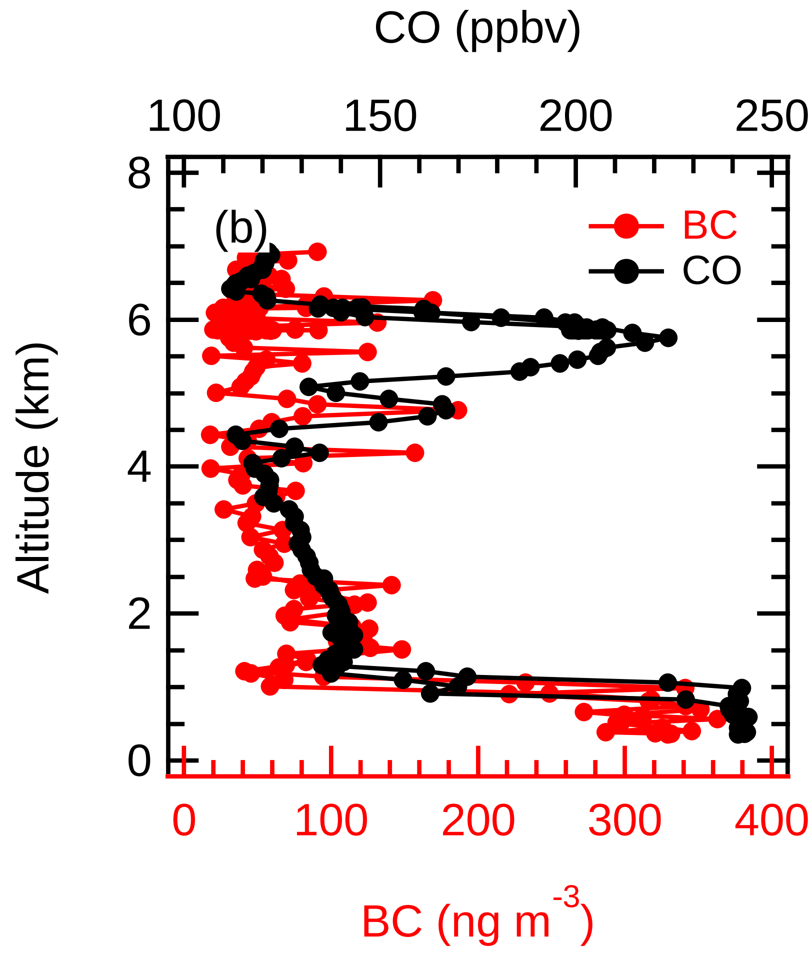
Two Case Studies (Vertical Profiles)

Yellow Sea (Flight 8, 30MAR)



Enhancements of CO and BC

East China Sea (Flight 19, 23APR)

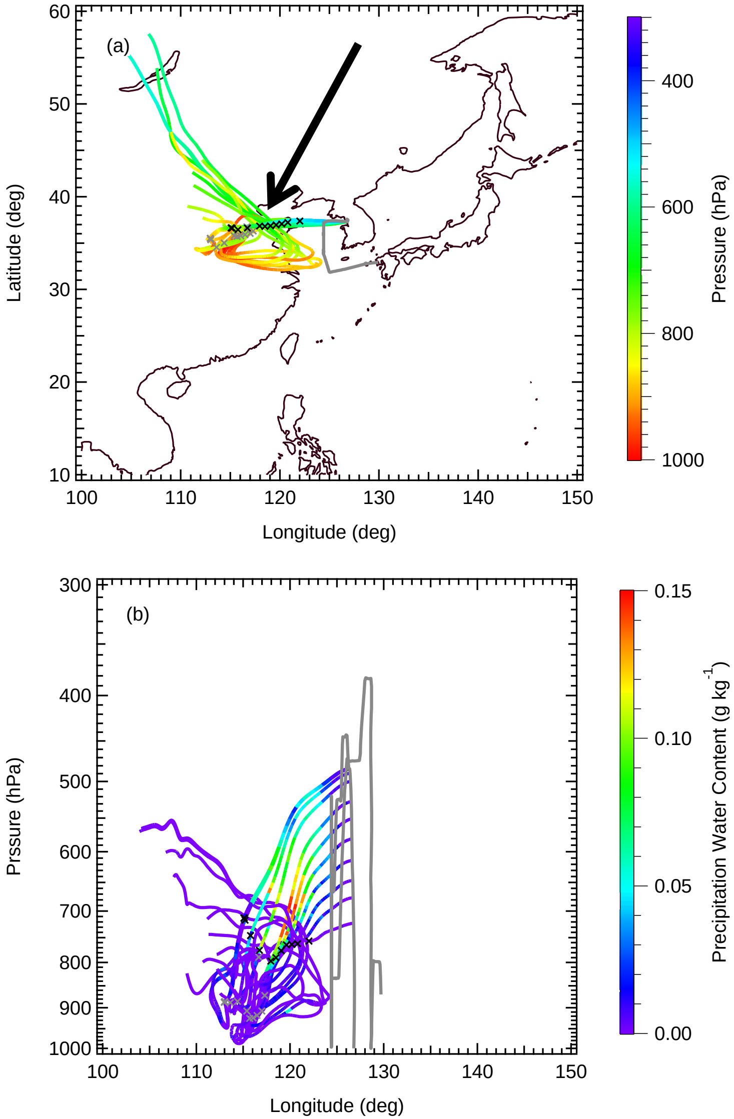


Enhancement of CO

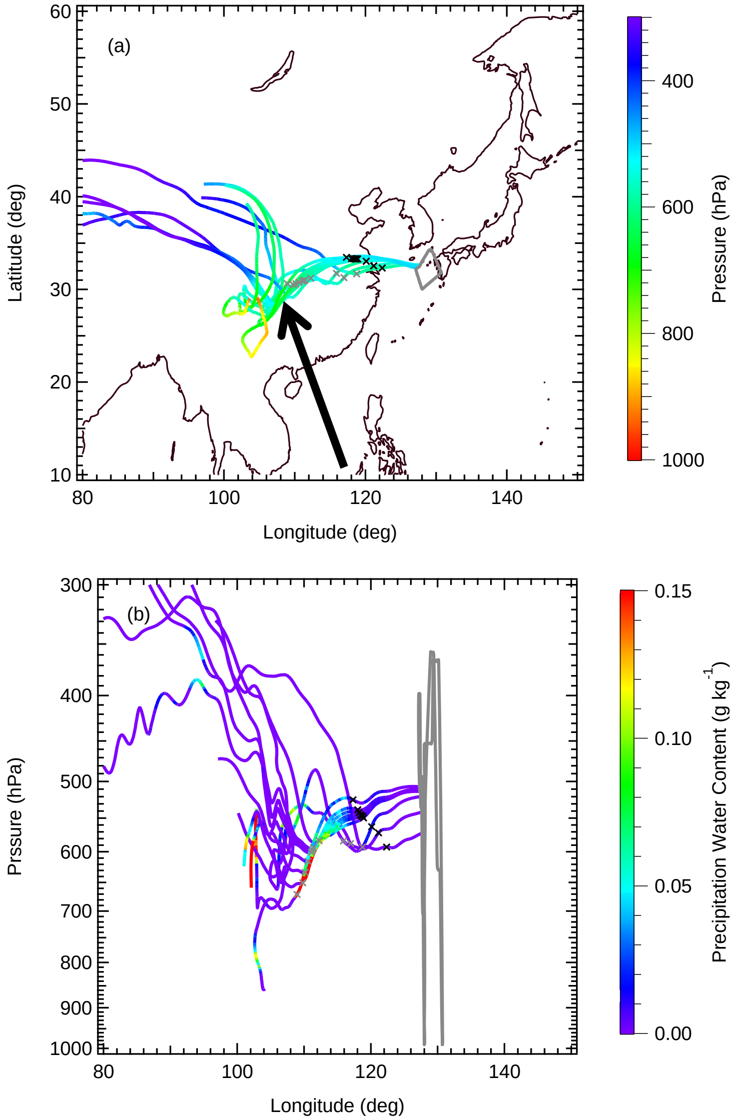
No enhancement of BC

Two Case Studies (Trajectories)

Yellow Sea (Flight 8, 30MAR)



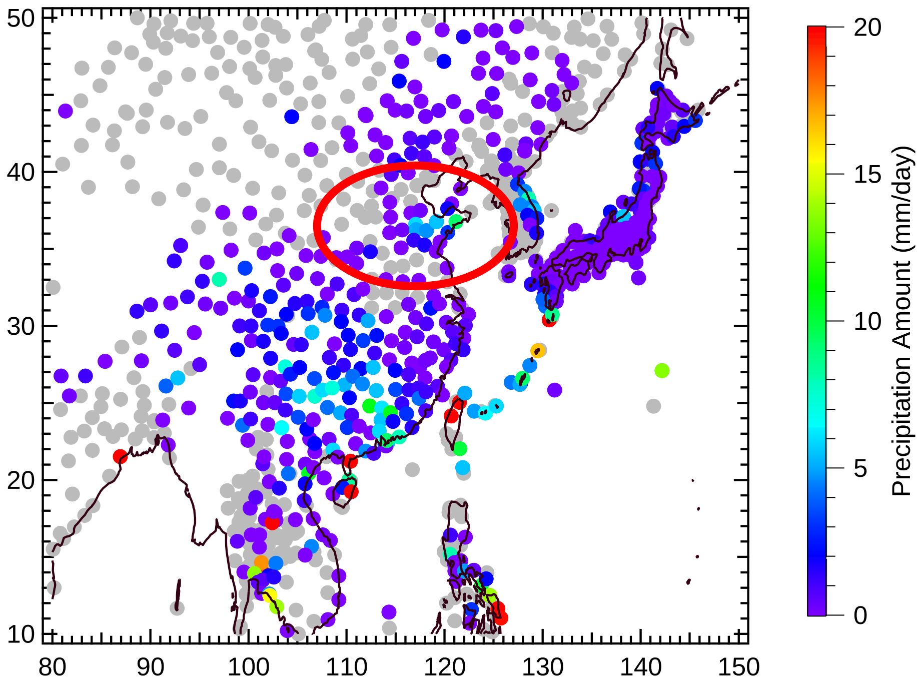
East China Sea (Flight 19, 23APR)

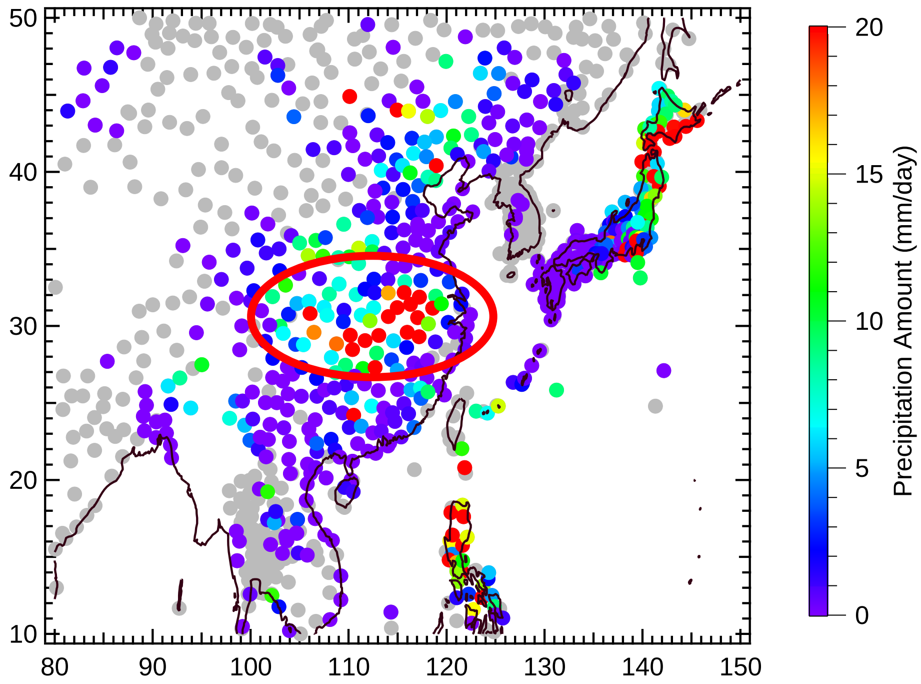


Two Case Studies (Precipitation)

Yellow Sea (Flight 8, 30MAR)

East China Sea (Flight 19, 23APR)



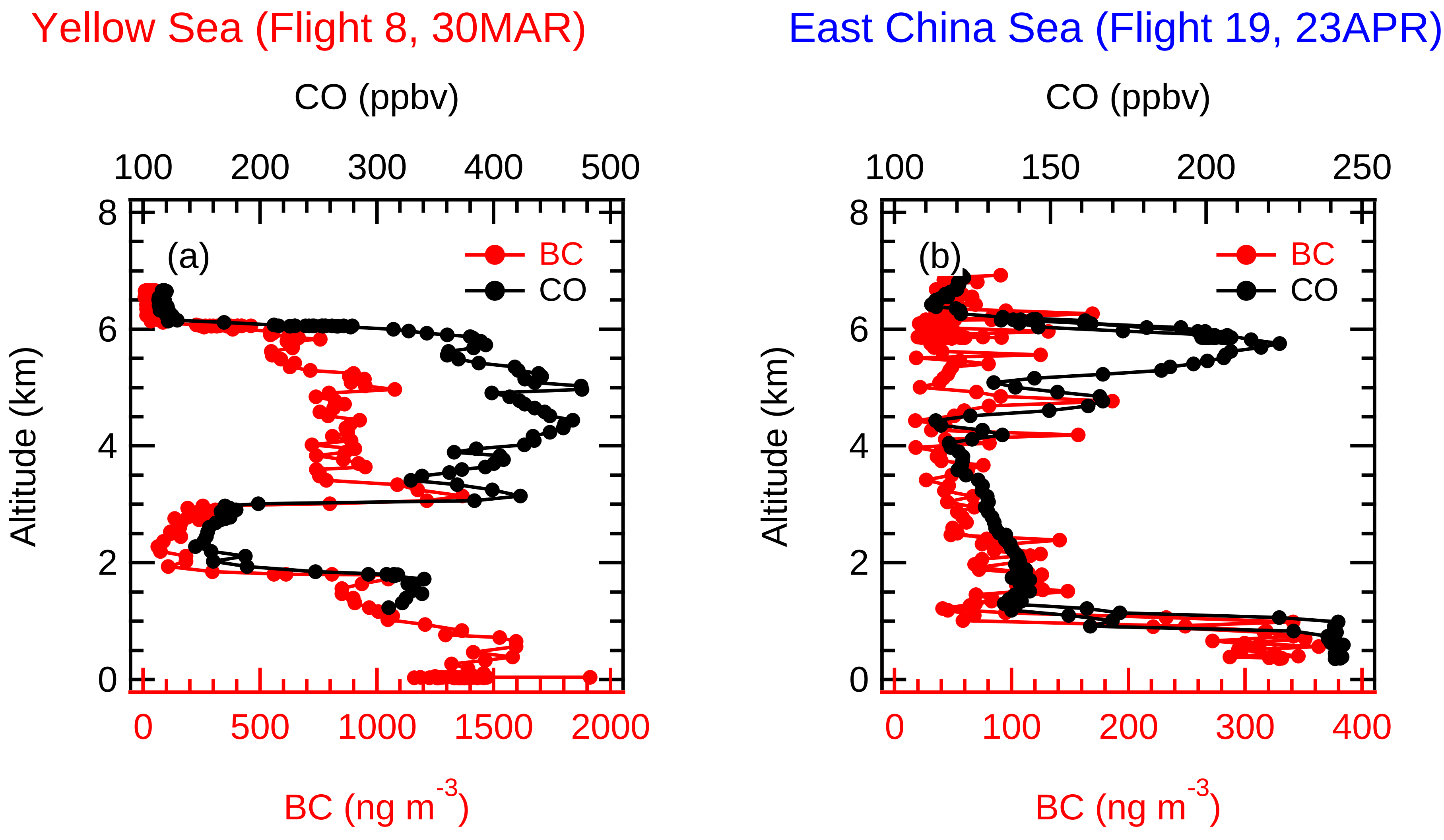


WMO precipitation data (NCDC)

Moderate precipitation (5 mm)
Uplifted over Shandong Peninsula by cyclone

Heavy precipitation (21 mm)
Uplifted over central China by cumulus convection

Two Case Studies (Vertical Profiles)

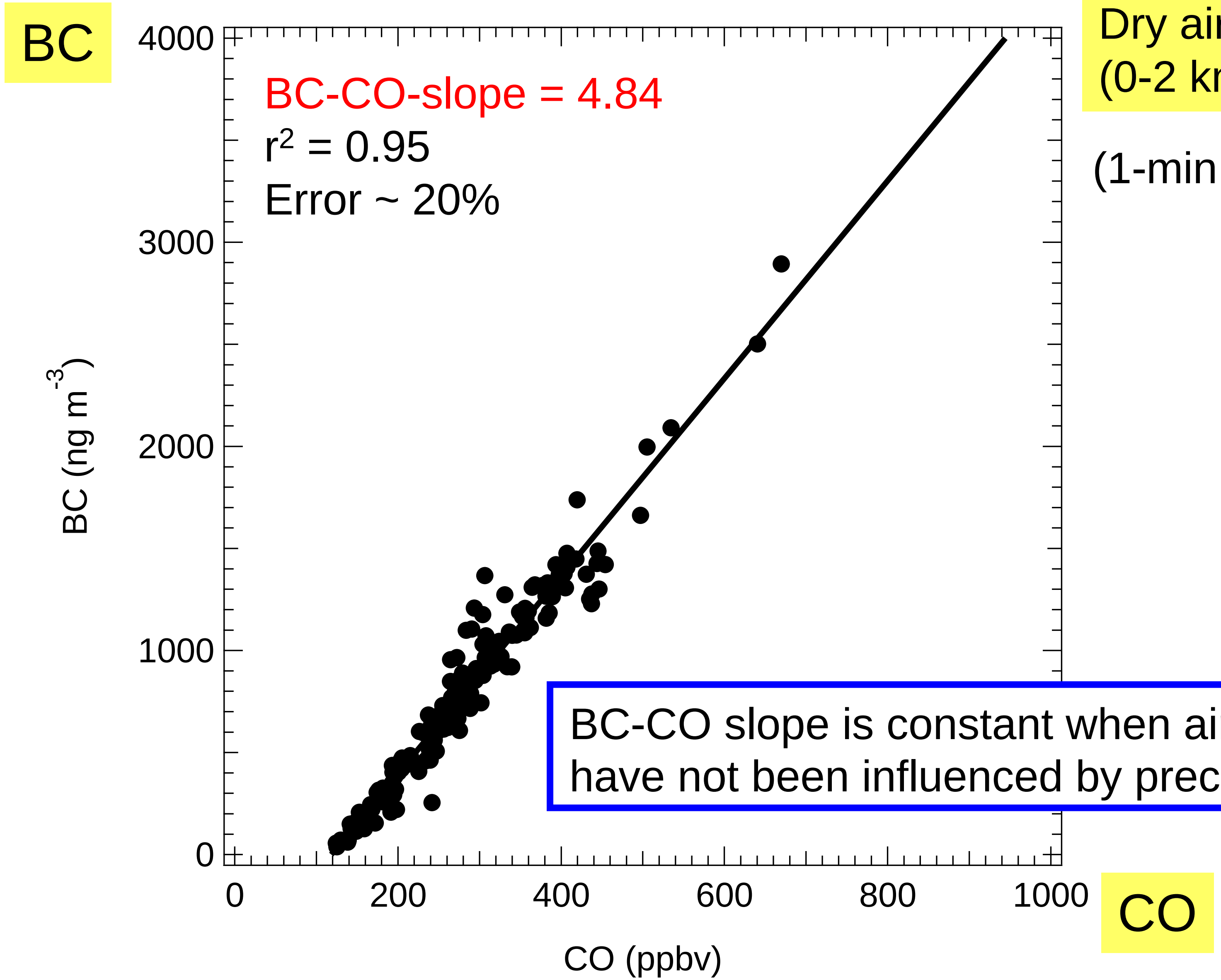


Enhancements of CO and BC

Enhancement of CO

No enhancement of BC

Transport Efficiency of BC (TE_{BC})

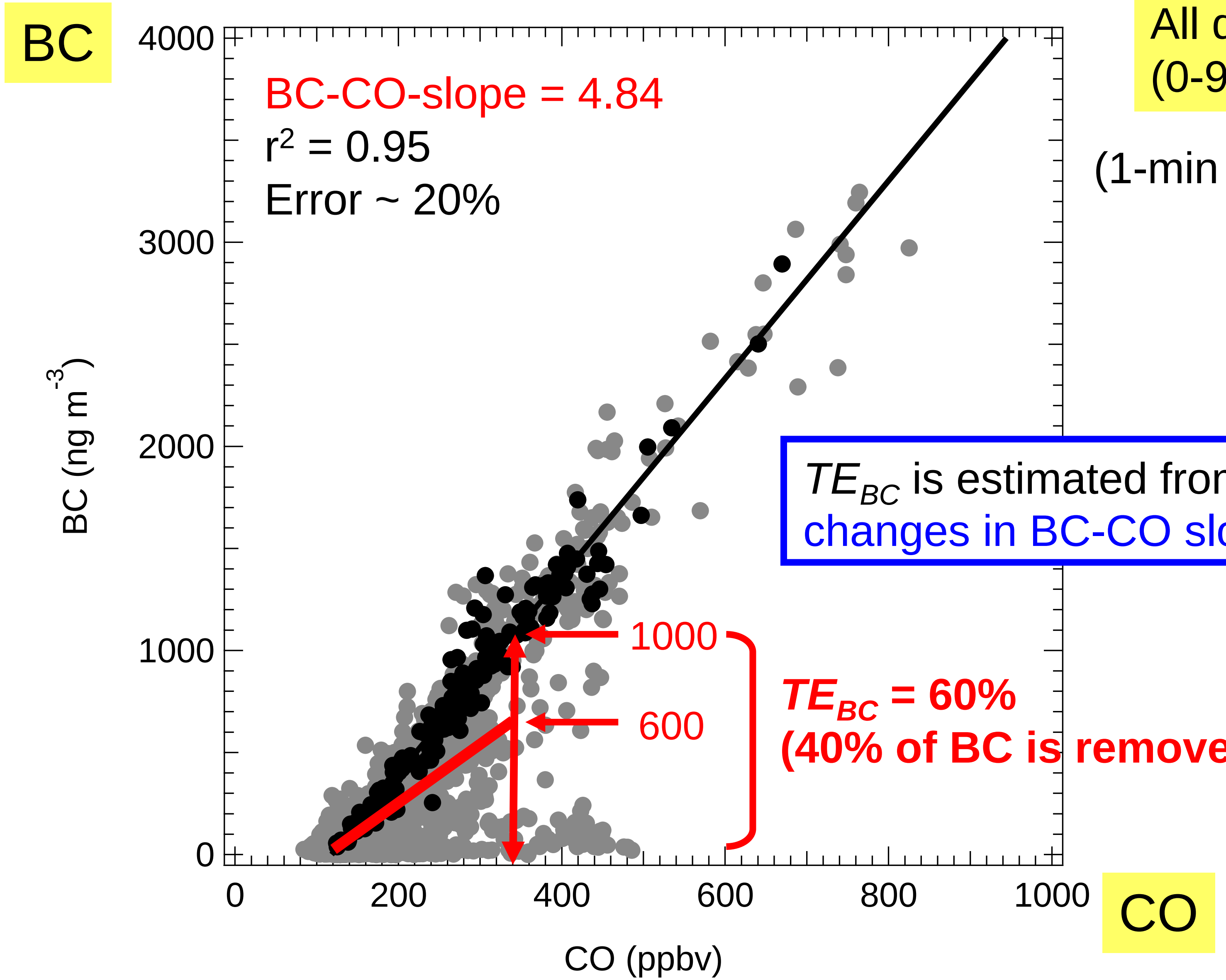


Dry air parcels
(0-2 km)

(1-min data)

BC-CO slope is constant when air parcels have not been influenced by precipitation.

Transport Efficiency of BC (TE_{BC})

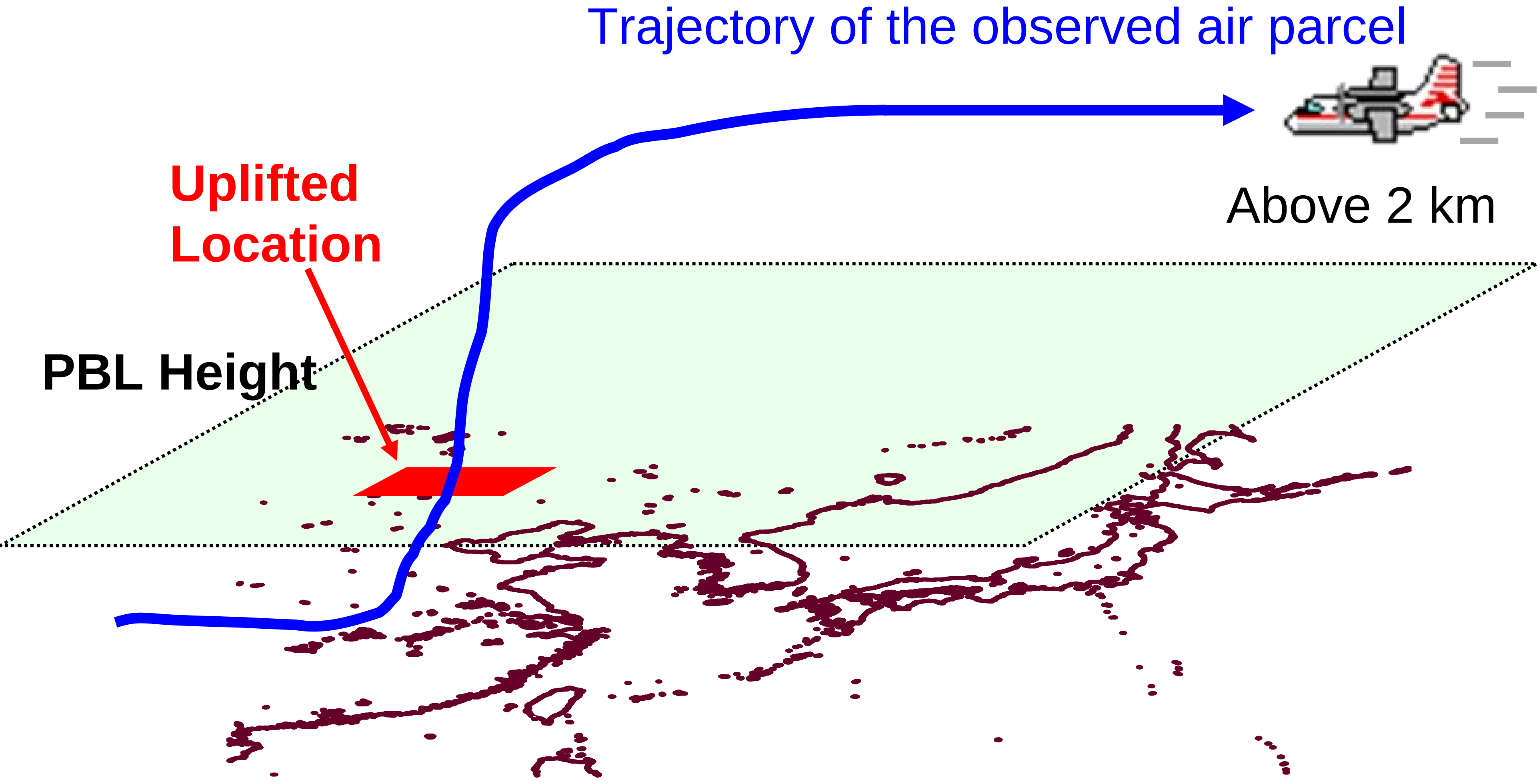


All data
(0-9 km)

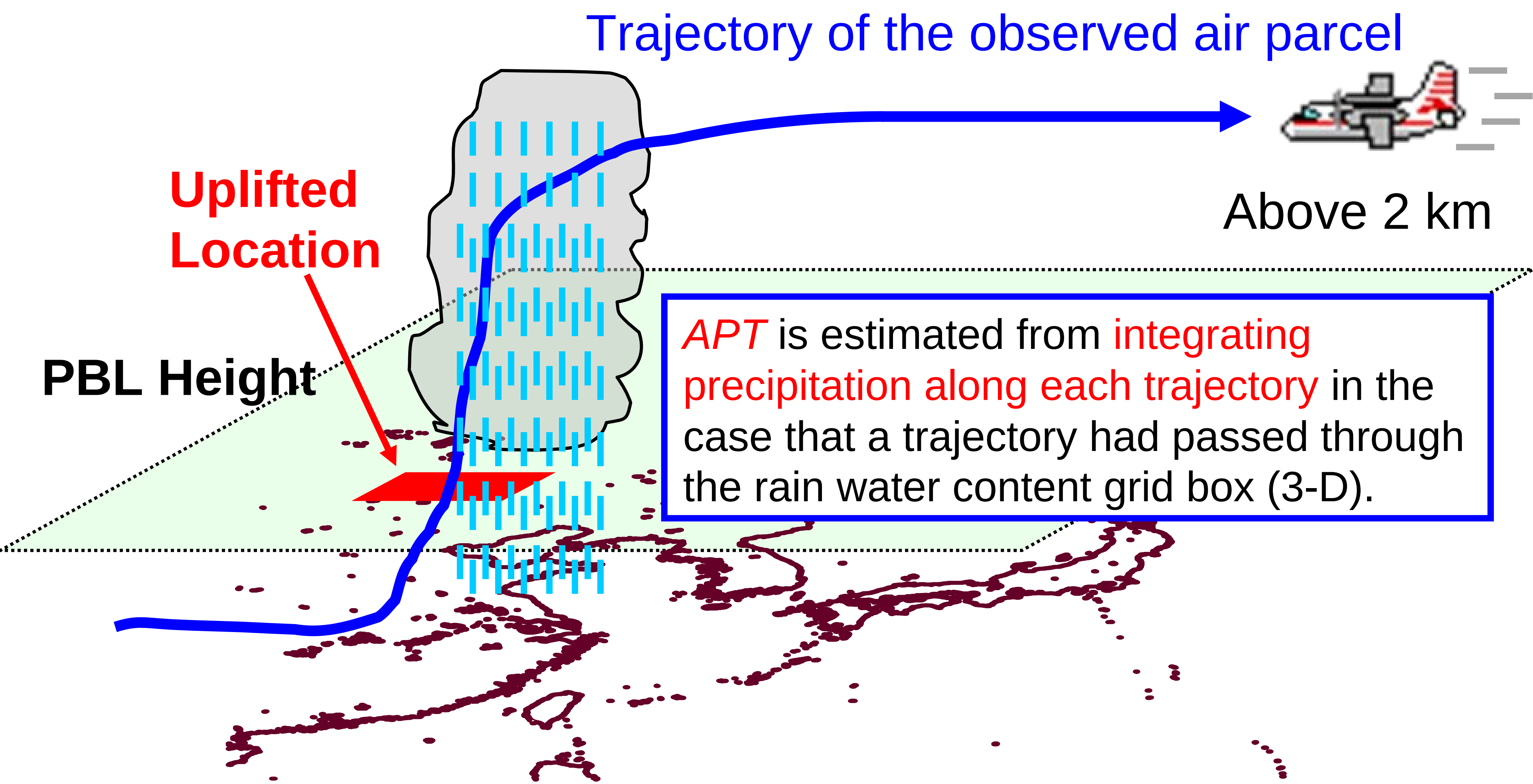
(1-min data)

TE_{BC} is estimated from changes in BC-CO slopes.

Accumulated Precip. Along Trj. (*APT*)



Accumulated Precip. Along Trj. (*APT*)

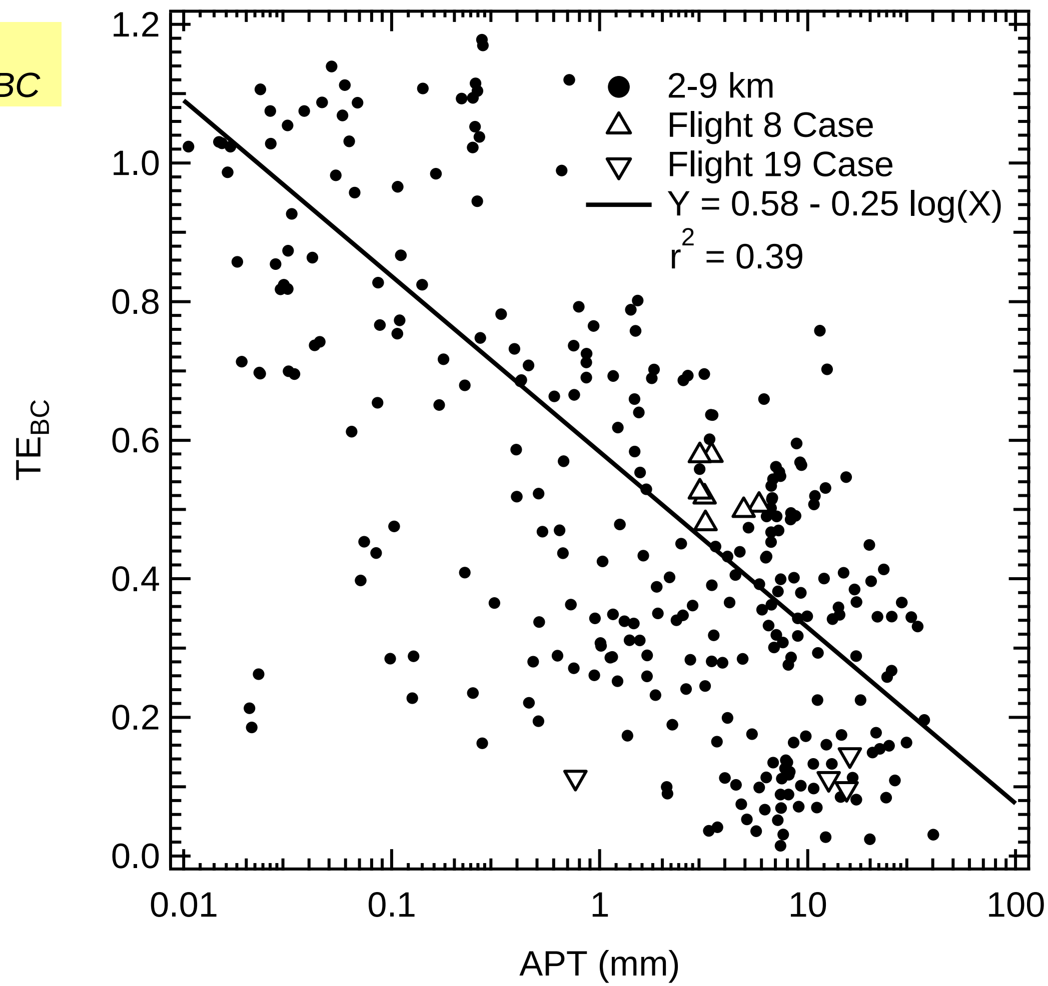


APT is estimated from integrating precipitation along each trajectory in the case that a trajectory had passed through the rain water content grid box (3-D).

Precipitation and rain water content were calculated by WRF.

Relationship between TE_{BC} and *APT*

TE_{BC}

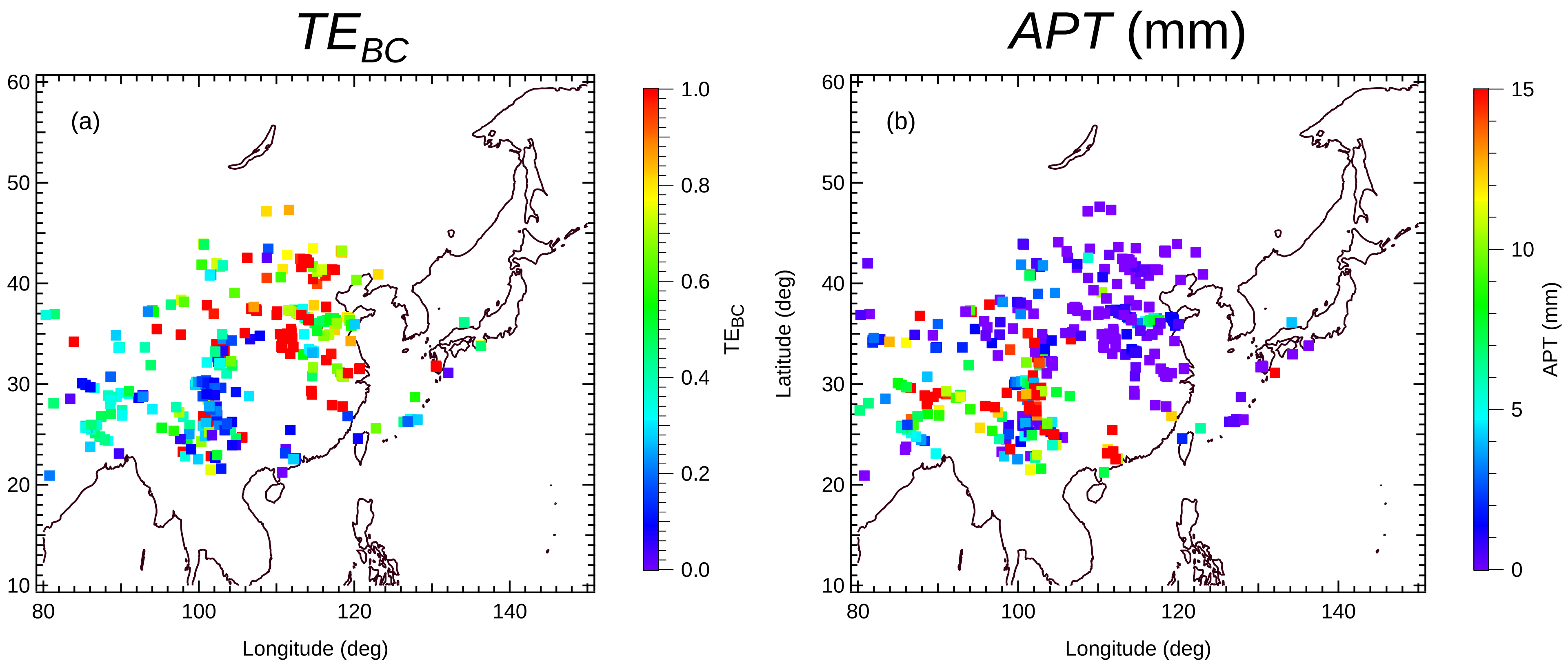


(1-min data)
Sampled at 2-9 km

APT (mm)

TE_{BC} tends to decrease with the increases in *APT*.
Wet removal of BC depended on the precipitation amount that the air parcels experienced during vertical transport from the PBL to the FT.

Spatial Characteristics of TE_{BC} and APT



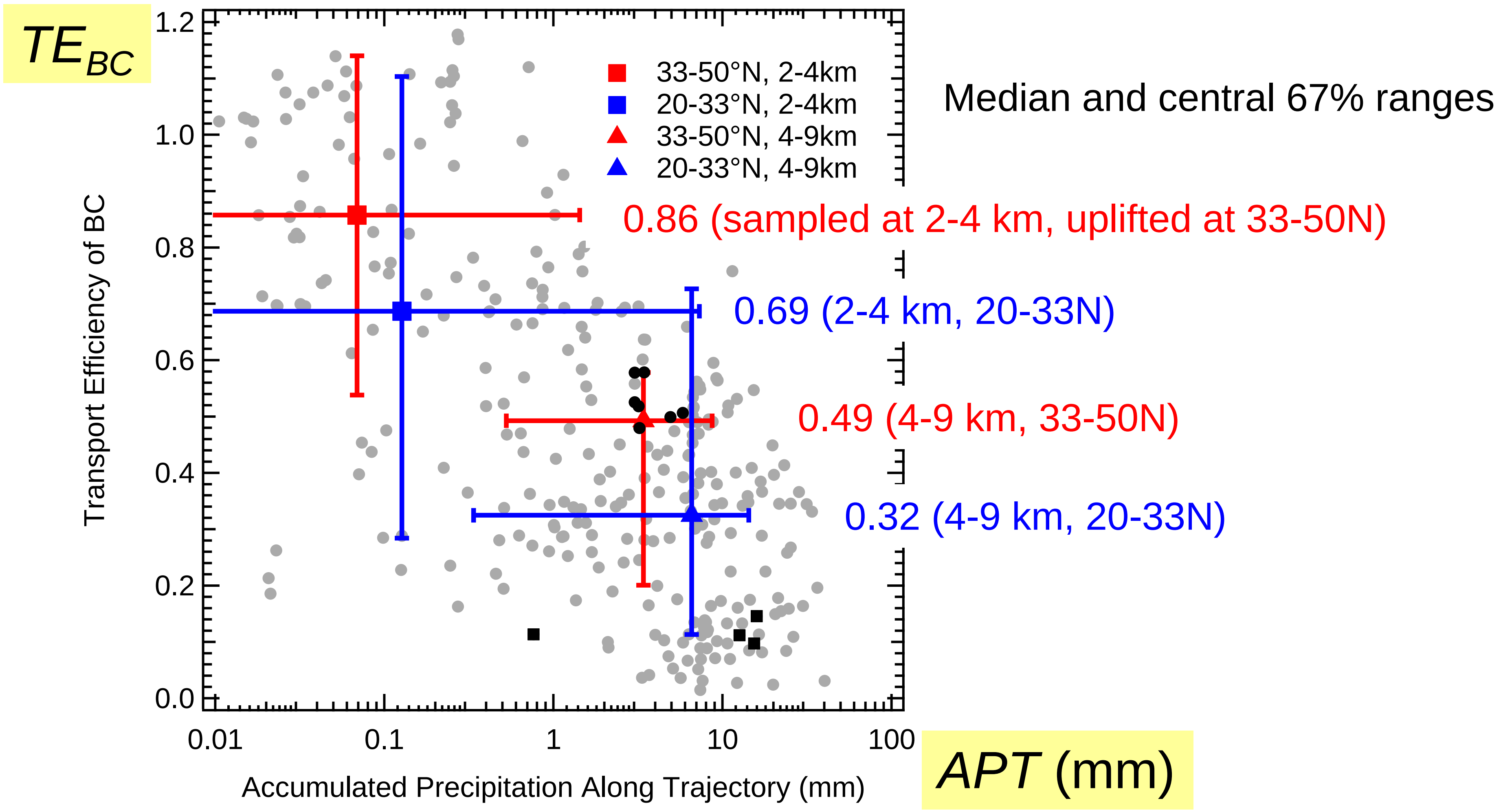
Air parcels uplifted over northern (southern) China

→ Associated with smaller (greater) precipitation amount (*APT*)

→ Greater (smaller) transport efficiency of BC (TE_{BC})

Greater (smaller) precipitation over southern (northern) China in spring.

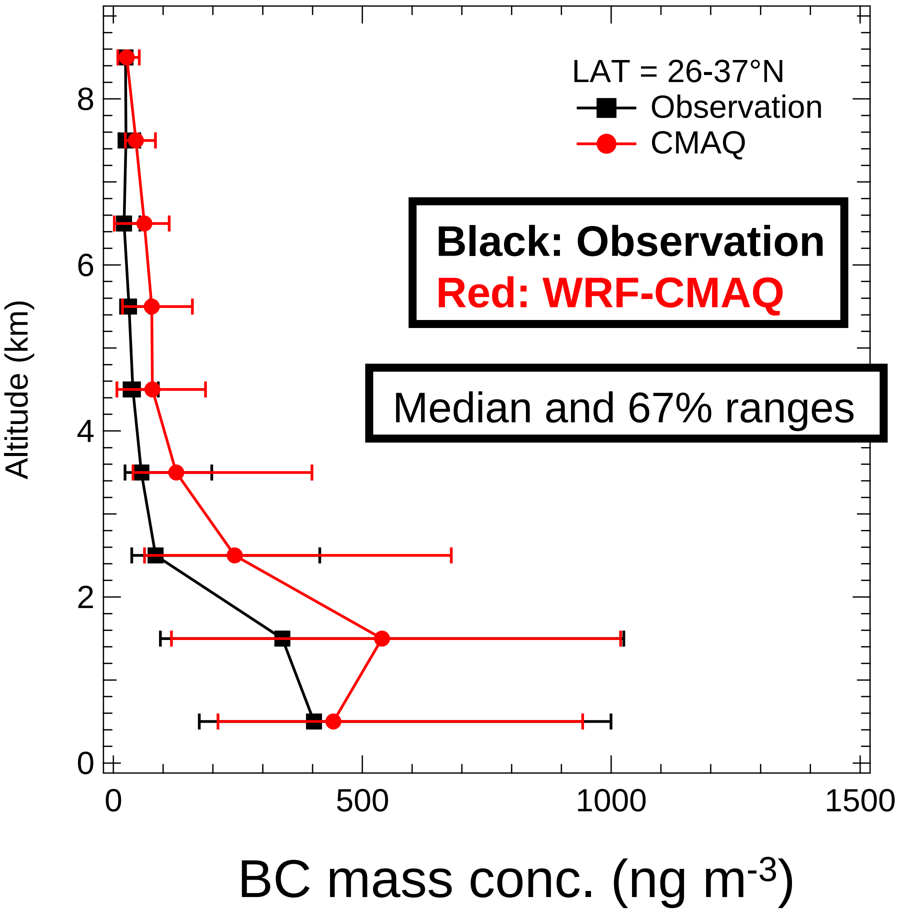
Relationship between TE_{BC} and *APT*

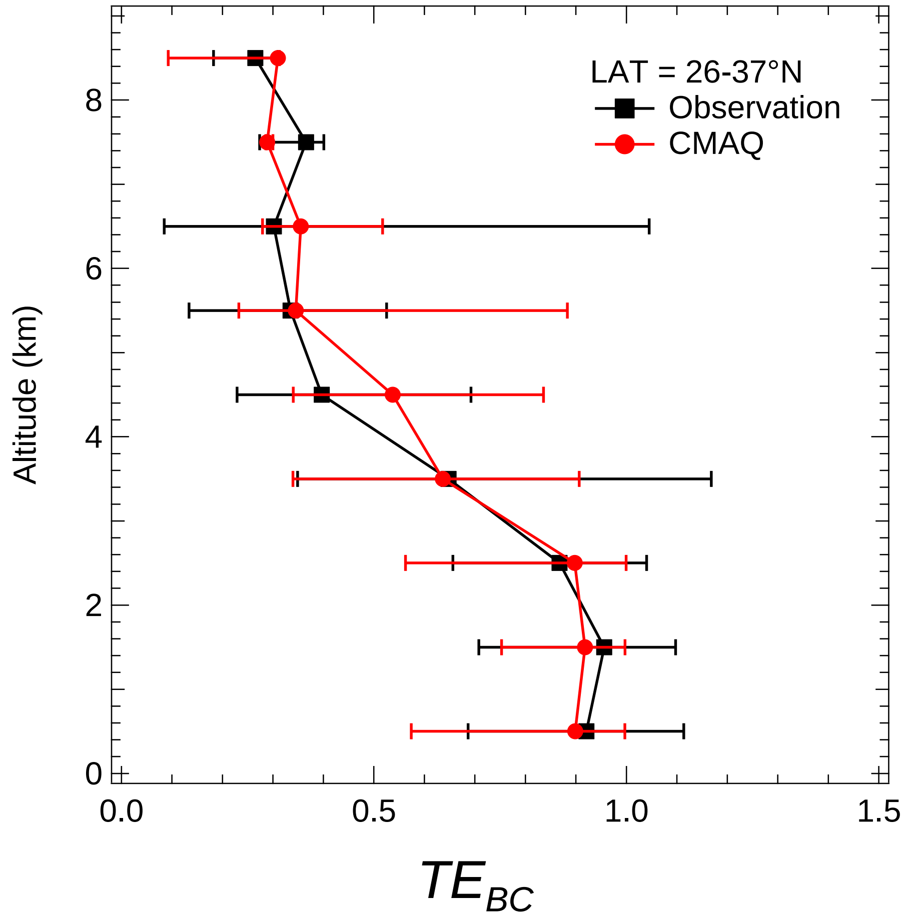


TE_{BC} depended on *APT*.

APT depended on the altitude and origin (latitude) of the sampled air parcels.

Comparison (Model and Observation)





A-FORCE data set is useful for model validations.

Two CMAQ Simulations
1. With wet dep.
2. W/O wet dep.

CMAQ: TE_{BC} = BC (with wet dep.) / BC (W/O wet dep.)

Summary

Observation of BC in the FT over East Asia

- A-FORCE aircraft campaign was conducted over East Asia in spring 2009.
- A total of 120 vertical profiles of BC and CO were obtained at 0-9 km.
- Large enhancements of BC and CO were observed over the Yellow Sea.
- No substantial enhancements of BC were observed over the East China Sea.

Wet removal of BC in Asian outflow during A-FORCE

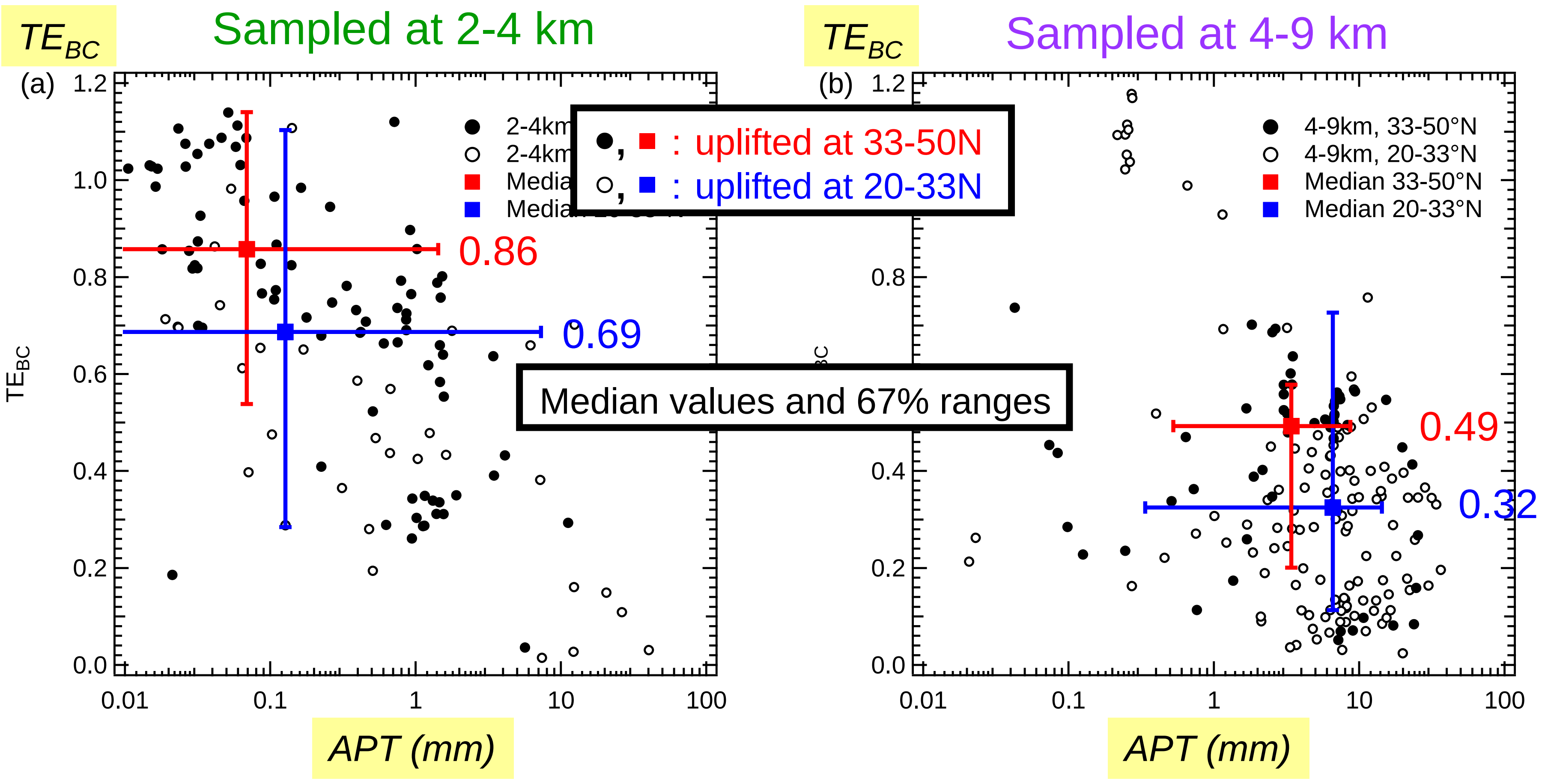
- Transport efficiency of BC (TE_{BC}) depended on precipitation amount (*APT*) that air parcels experienced during vertical transport.
  (TE_{BC} decreased statistically with the increase in *APT*.)
- *APT* depended on the altitude and origins (latitude) of sampled air parcels.
- The median values of TE_{BC} for the sampled air parcels were
  0.86 (2-4km, northern China), 0.69 (2-4km, southern China)
  0.49 (4-9km, northern China), 0.32 (4-9km, southern China)

A-FORCE data set for modeling studies

- A-FORCE data set is useful for model validations.
- The data set can contribute to reduce uncertainties in 3-D models.

[*Oshima et al., JGR, submitted*]

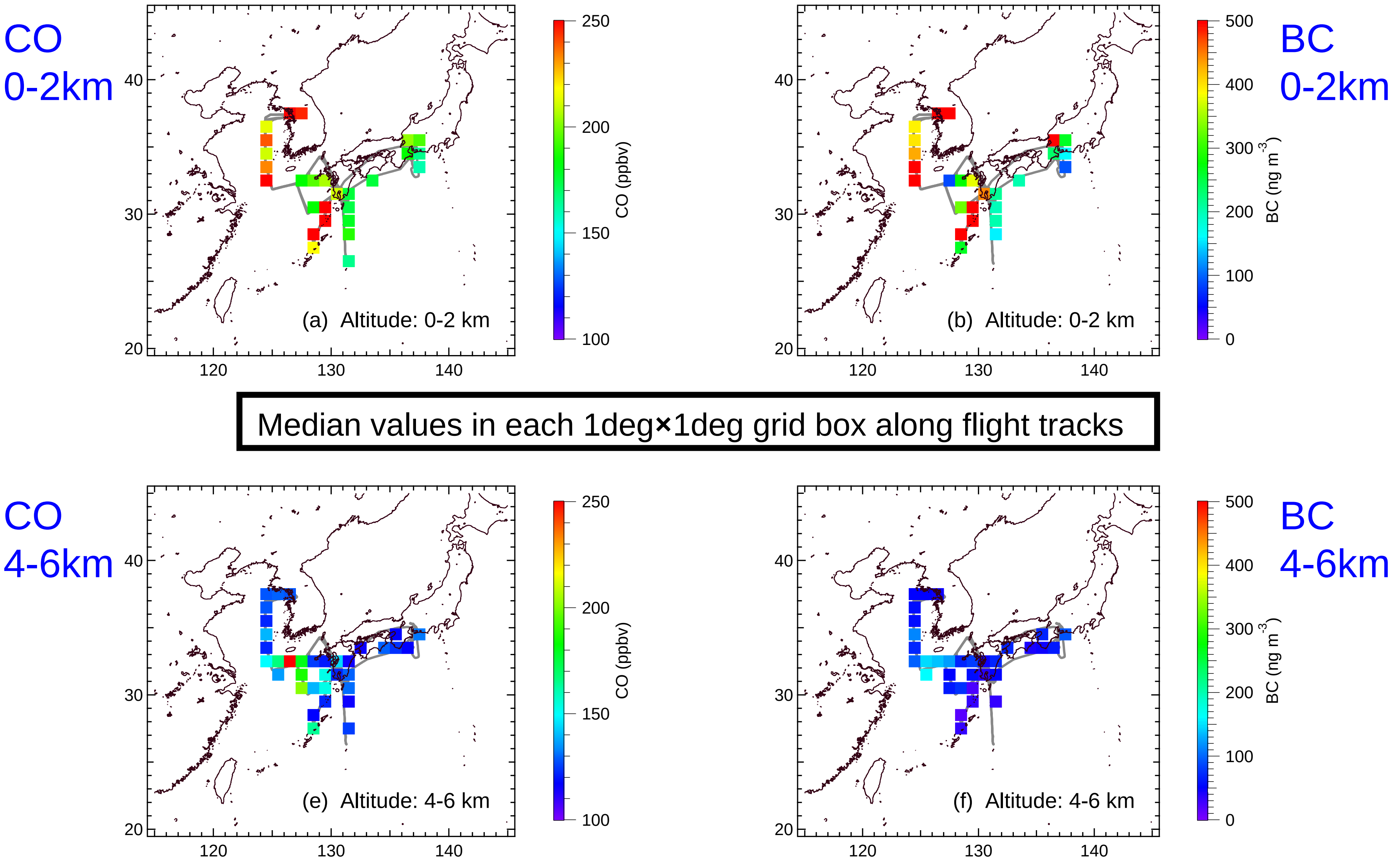
Relationship between TE_{BC} and *APT*



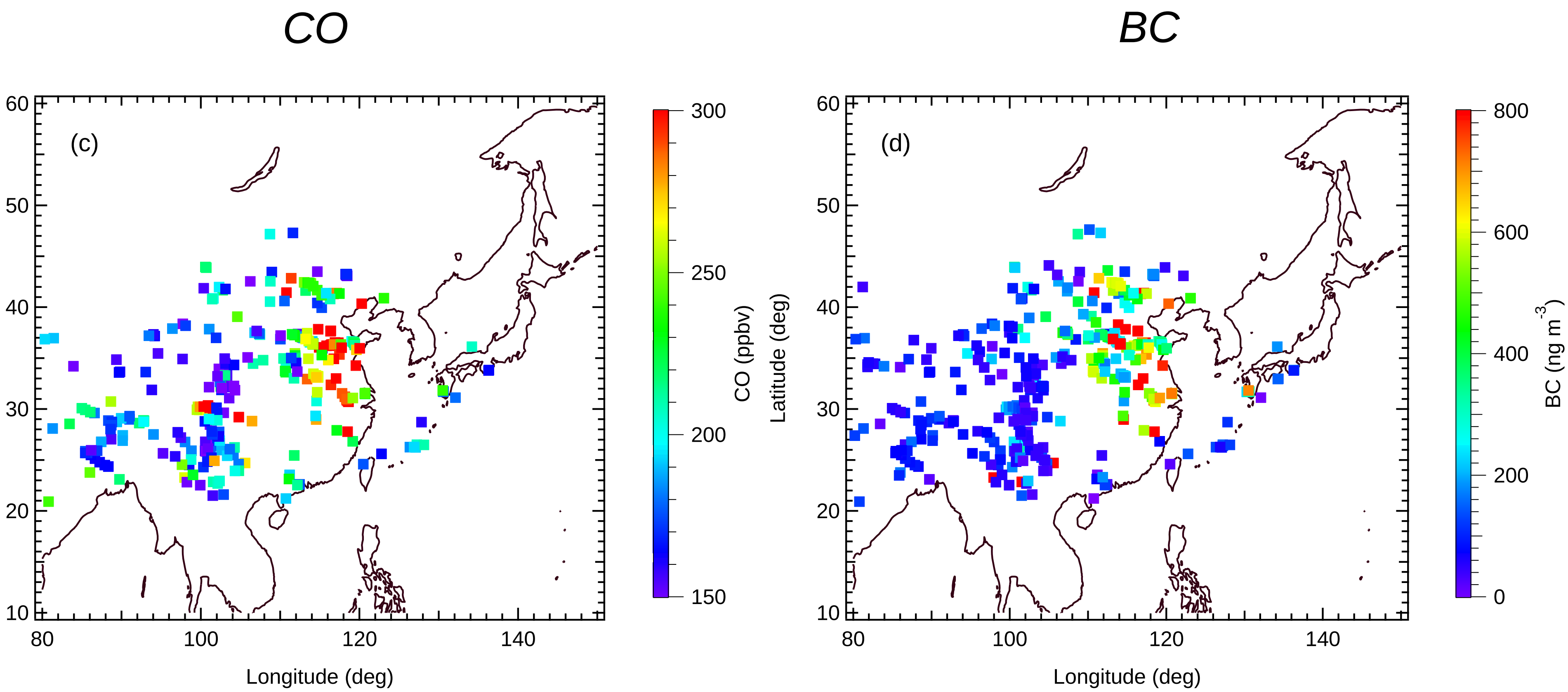
TE_{BC} for the air parcels sampled at 4-9 km were smaller than those at 2-4 km.

TE_{BC} depended on *APT*.
APT depended on the altitudes and origins of the sampled air parcels.

Horizontal Distributions of CO and BC

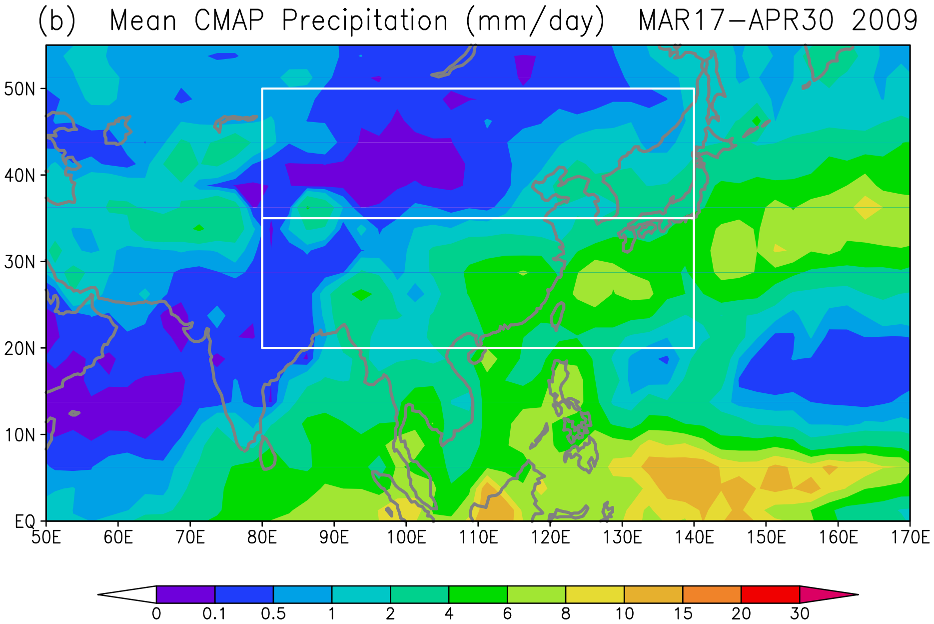


CO and BC Conc. in Sampled Air Parcels

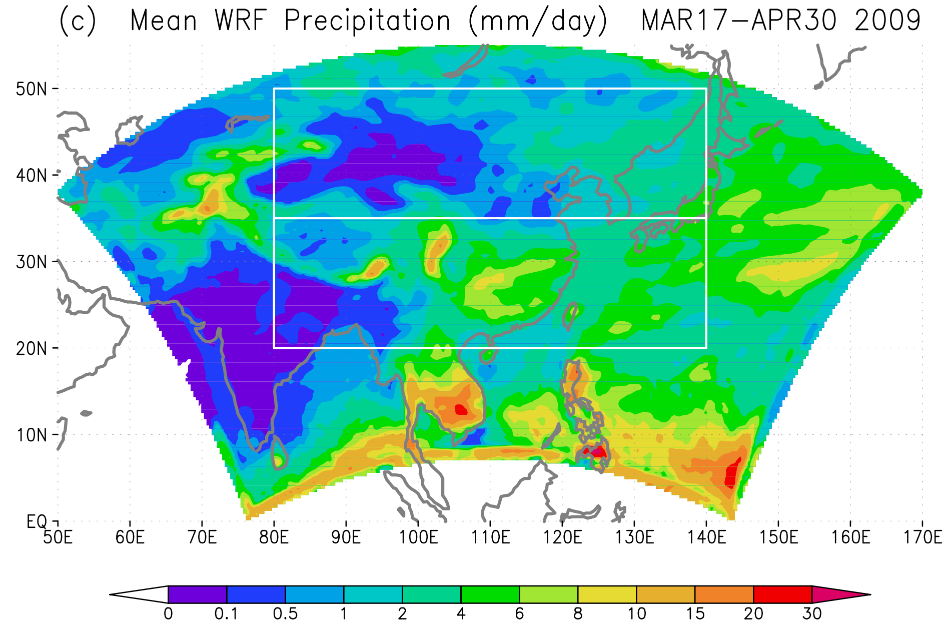


Comparison of Precipitation

CMAP Precipitation (mm/day)



WRF Precipitation (mm/day)

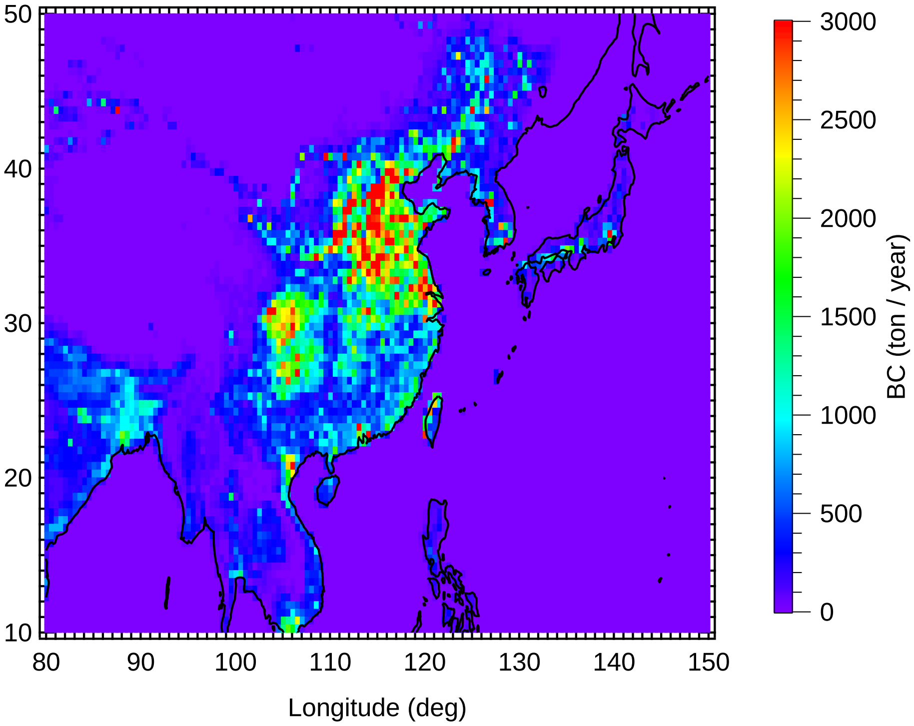


WRF simulation overestimated precipitation by 20% (20-50N, 80-140E)

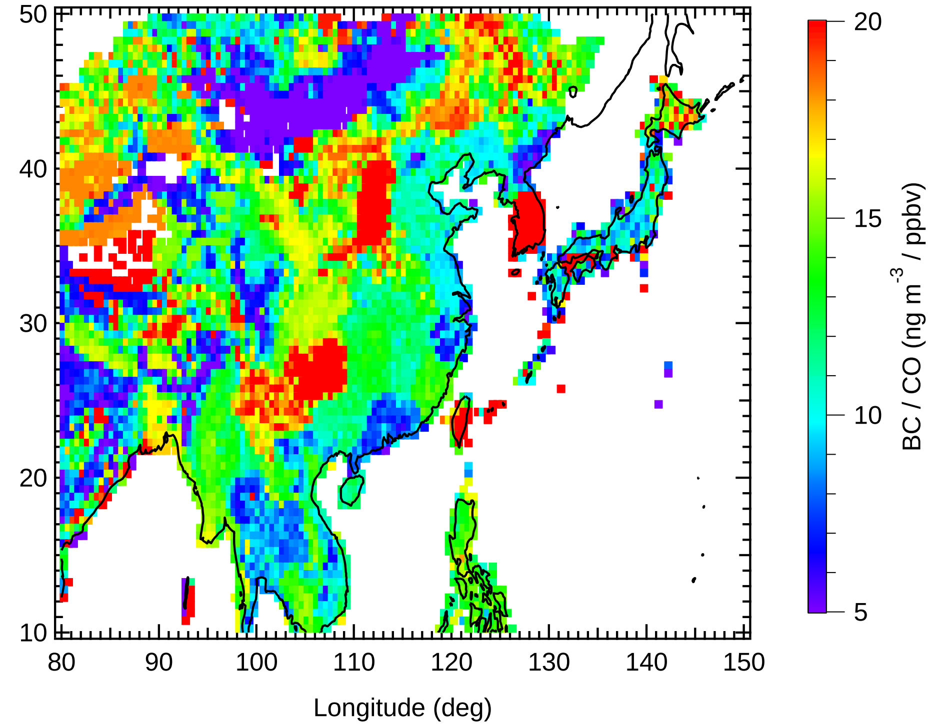
Mean 17MAR-30APR 2009

Emission Inventory [*Zhang et al.*, 2009]

BC Emission



BC/CO Ratio



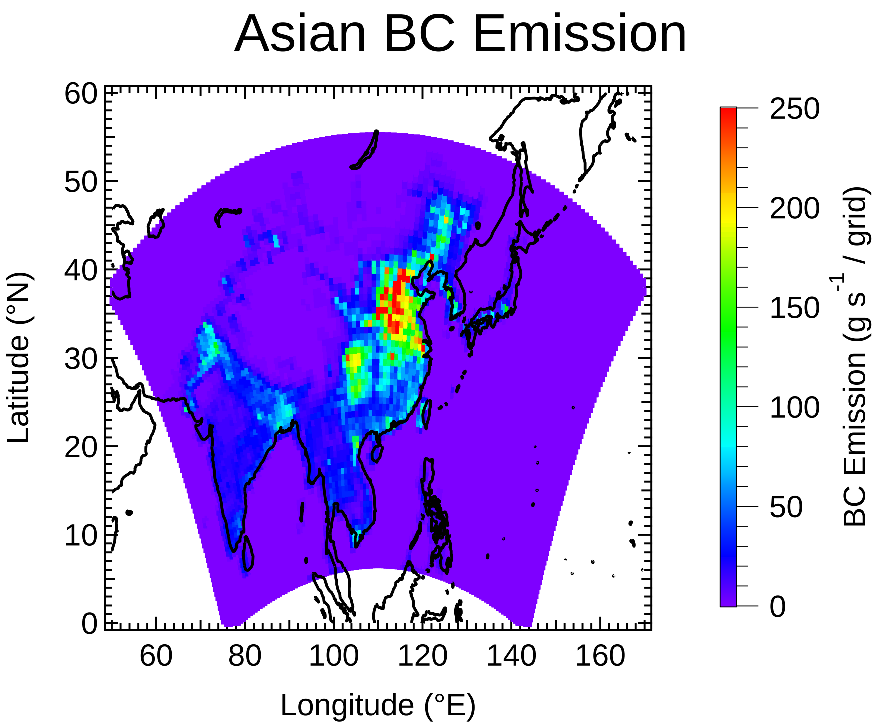
Observation
東京: 5.7
北京: 4.8
広州: 5.4
辺戸: 6.7

3-D Chemical Transport Model Simulations

WRF(v2.2) - CMAQ(v4.6)
Period: 01MAR – 30APR in 2009
Horizontal: 81km×81km (117 × 69) over East Asia
Vertical: 21 layers (Top = 100hPa, 10 layers in the PBL)
Emission: 0.5deg×0.5deg [*Zhang et al*., 2009]

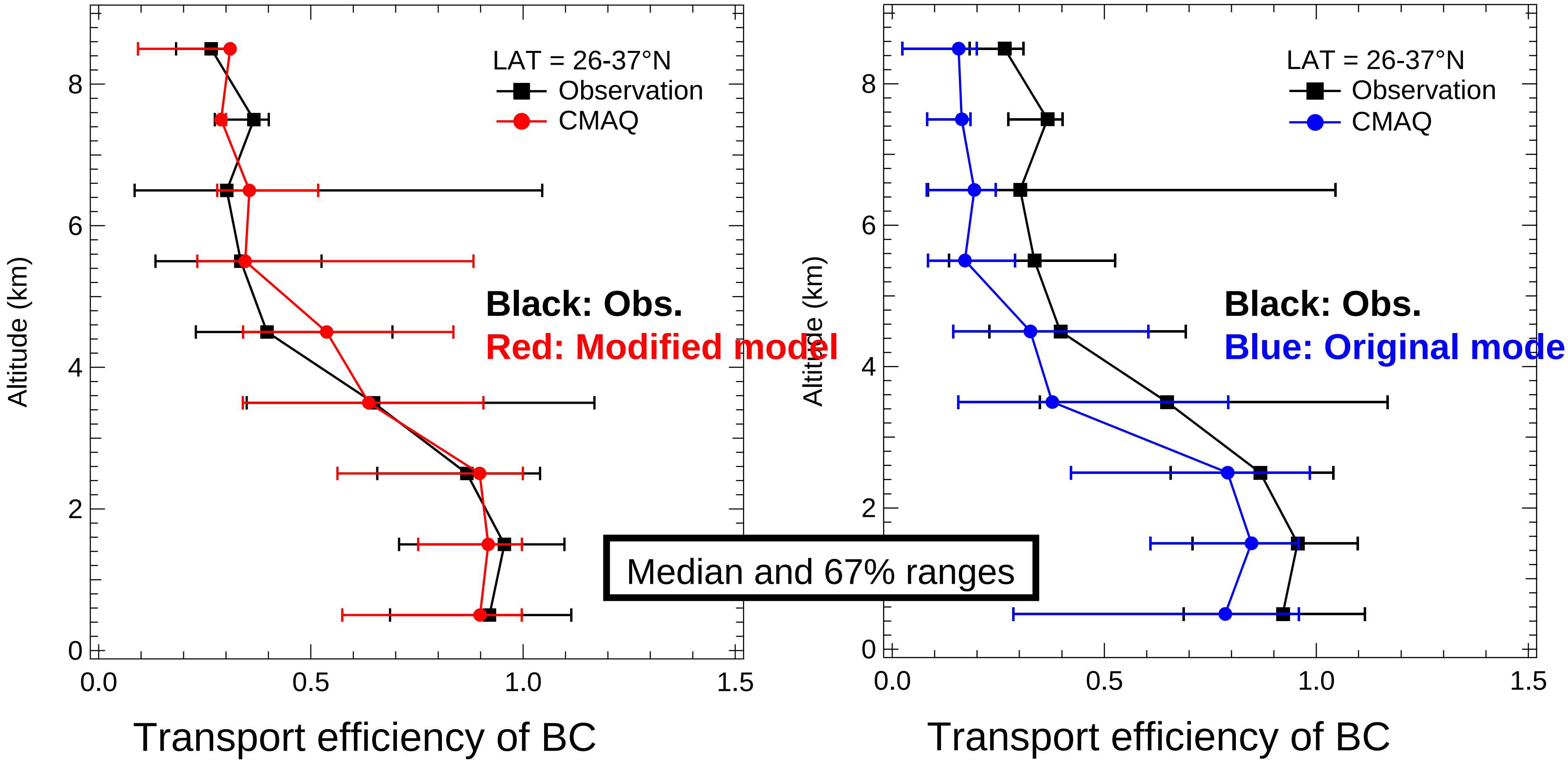
Modification of treatments of aerosol wet deposition in CMAQ
Separately treats in-cloud (rainout) and below-cloud scavenging (washout) of aerosols by precipitation.
(Turn off the washout)

Two CMAQ Simulations
1. With wet dep. (baseline)
2. W/O wet dep.

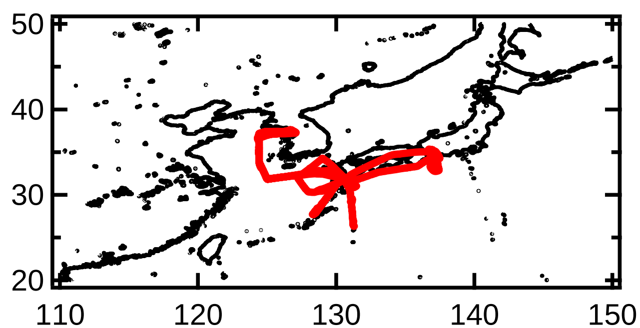


CMAQ: TE_{BC} = **BC (with wet dep.) / BC (W/O wet dep.)**

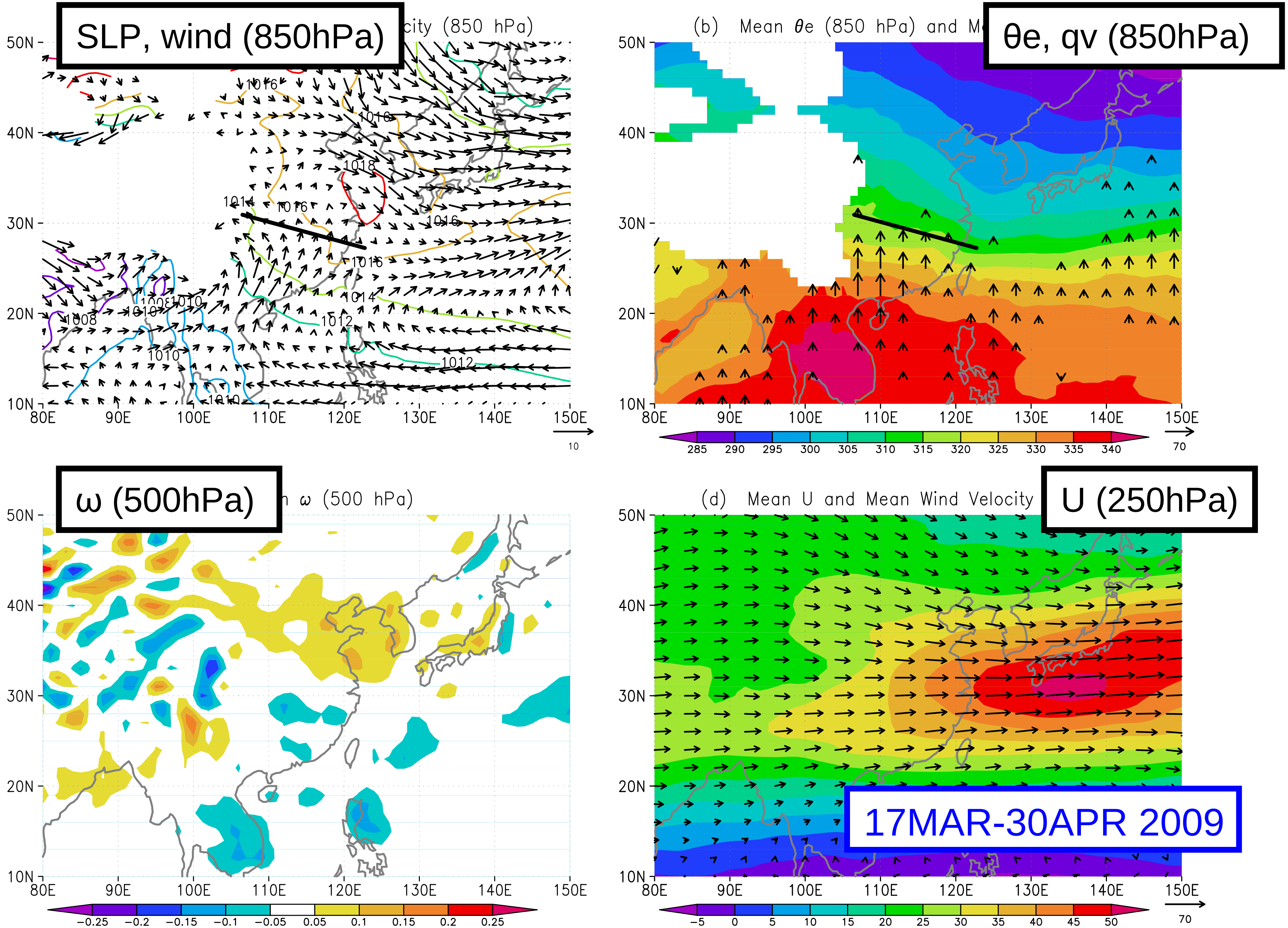
Improvement of CMAQ Wet Deposition



A-FORCE aircraft campaign
18 Mar-25 Apr 2009

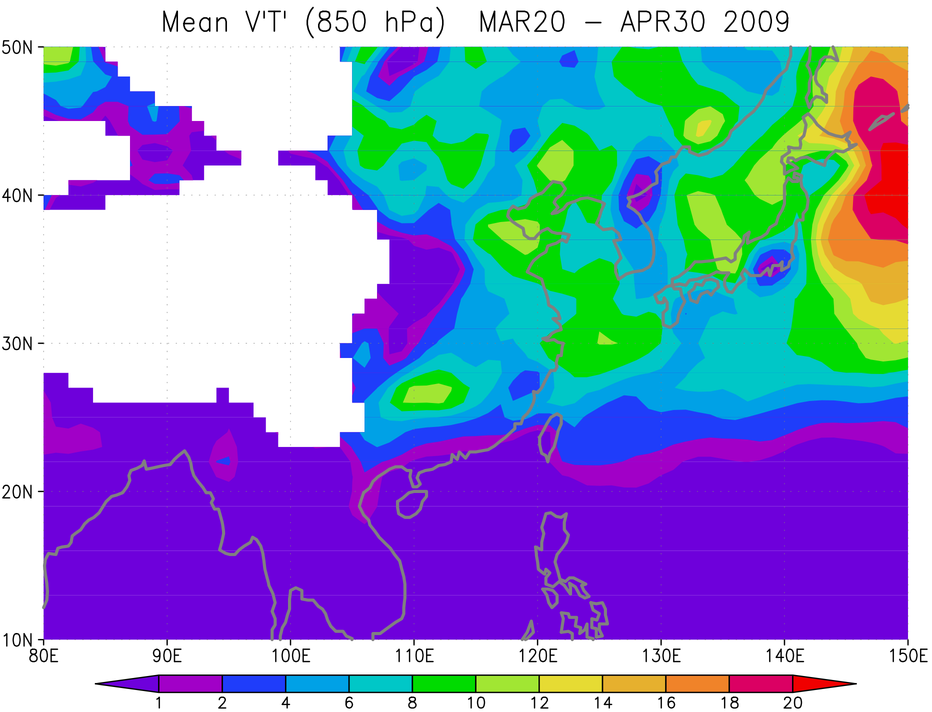


Mean Meteorological Fields

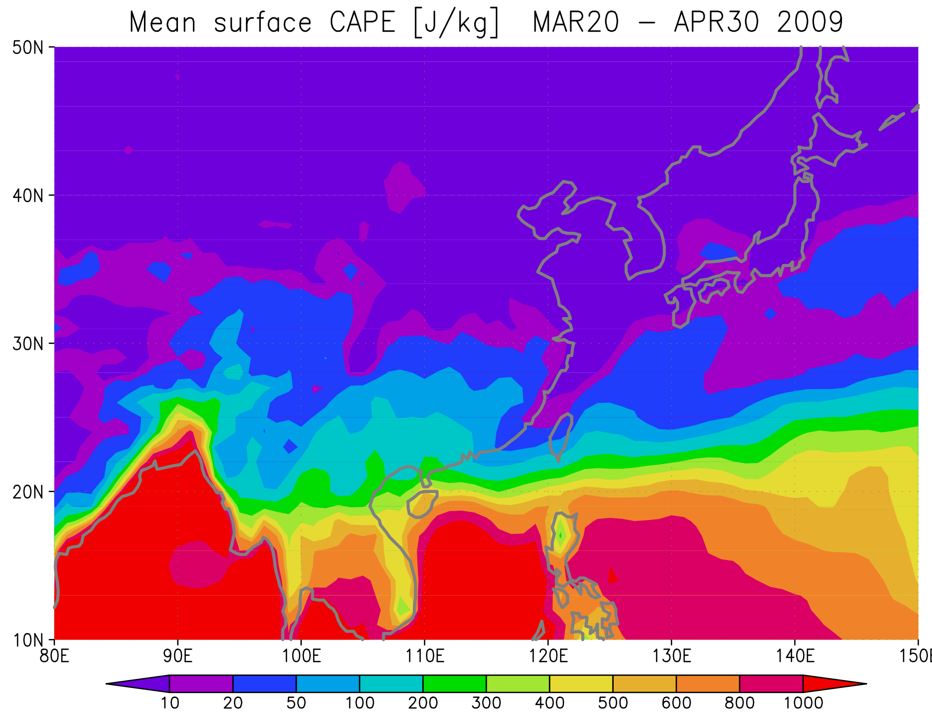


Activities of Cyclones and Convections

Poleward Eddy Heat Transport ($\overline{V'T'}$)
(Activity of Migratory Cyclones) at 850hPa



Surface CAPE
(Possibility of Convections)



$$V' = V - \overline{V}$$

$$T' = T - \overline{T}$$

Differences in Uplifting Mechanisms
Northern China: Cyclones
Southern-central China: Cyclones and Convections

NCEP data Mean 20MAR-30APR 2009