A new dry deposition scheme for aerosols in CAM5 and impacts on aerosols and climate

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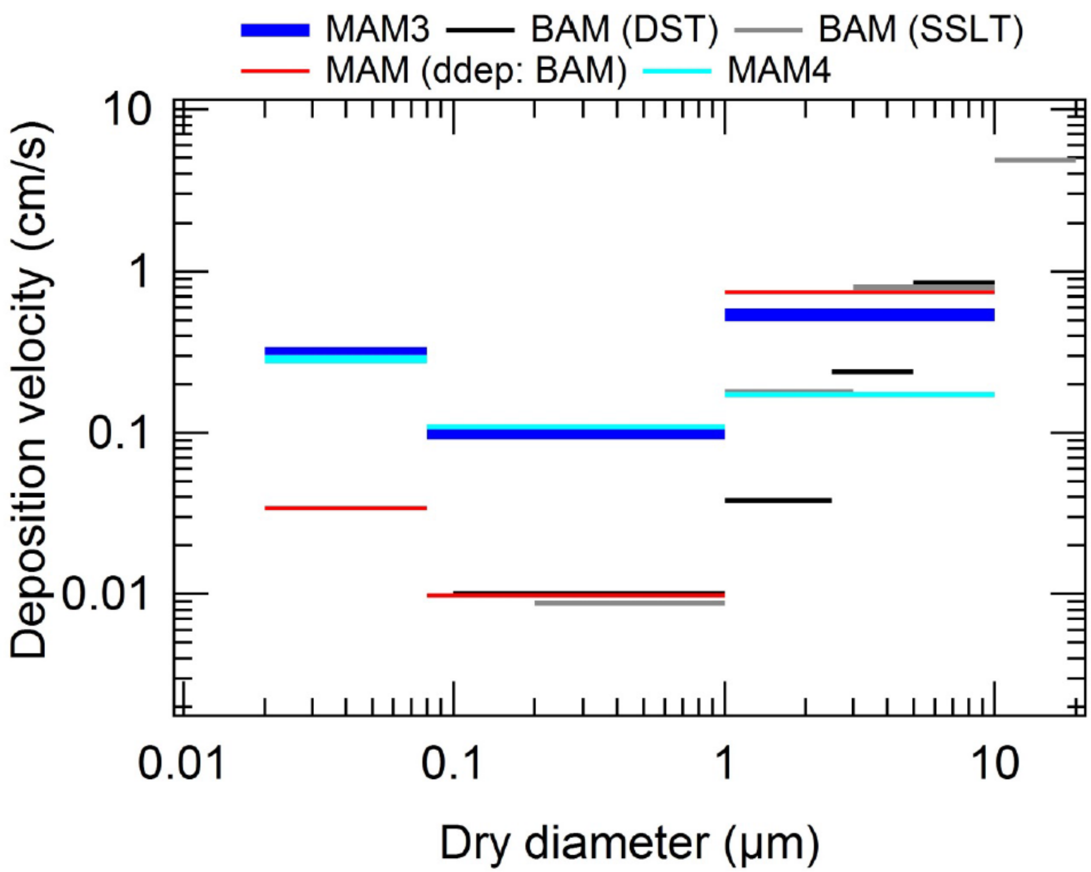
1. Introduction

Aerosol dry/wet removal at low latitudes can strongly influence the distribution of aerosols at high latitudes (e.g., Kinne et al., 2006; Textor et al., 2007; Shindell et al., 2008)

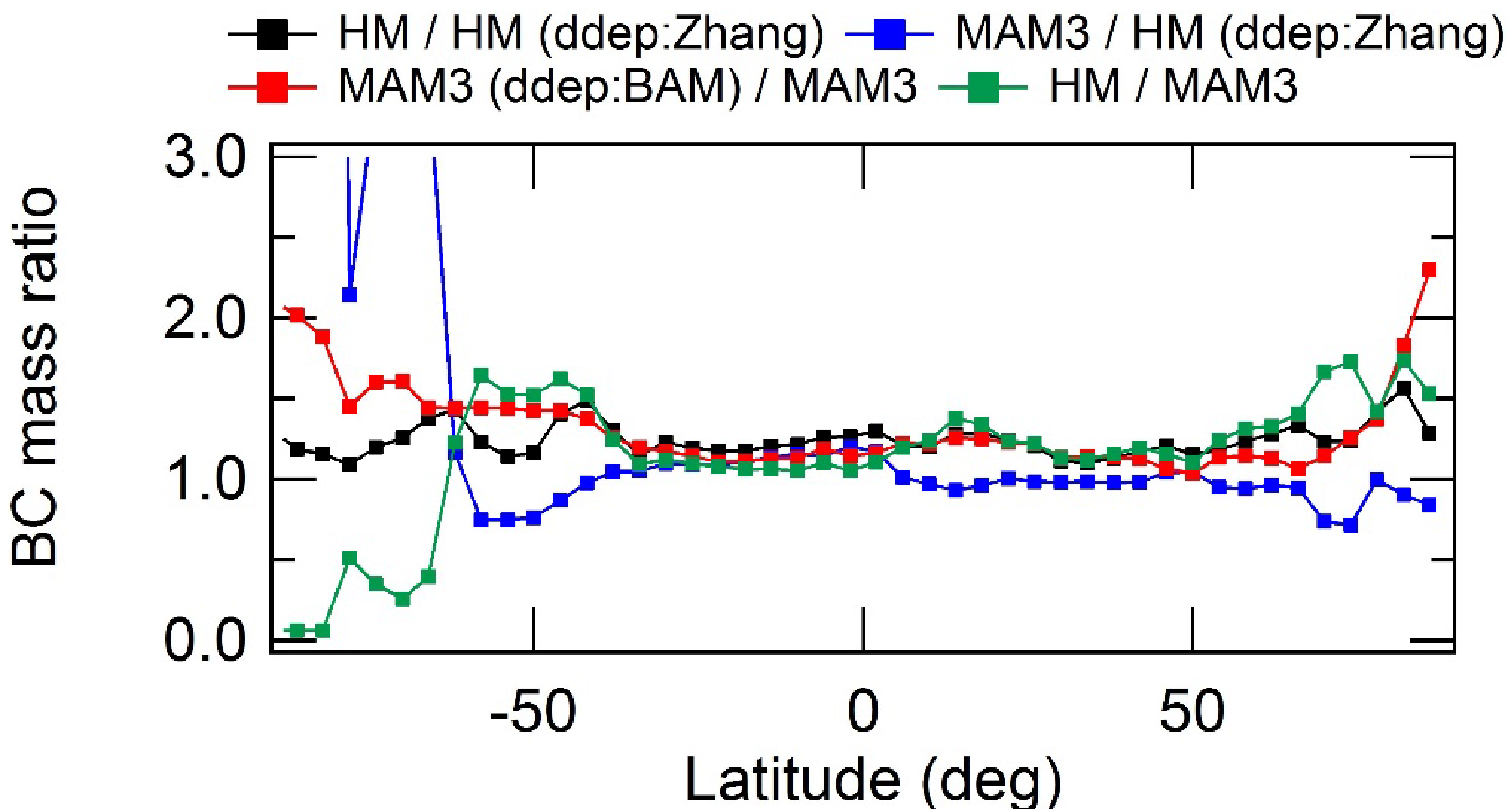
Dry deposition scheme by **Zhang et al. (2001)** tends to overestimate in a significant way the particle deposition in the fine mode, as measured by various investigators (**Petroff and Zhang, 2010**).



from Natalie Mahowald, 2016 CESM Workshops

1. Introduction

BC concentration in high-latitudes remote regions is strongly influenced by dry deposition.



from Natalie Mahowald, 2016 CESM Workshops

HM: 2D bin module for aerosol microphysics by Matsui, ACP, 2014

2. Method – Dry Deposition Scheme

similar "resistance" structure

$$V_d = V_{drift} + \frac{1}{R_a + R_s}$$

Zhang et al., 2001 (Z01)

$V_{drift} = W_S$ gravitational settling velocity

$$R_s = 1/\varepsilon_0 u_* \left(E_B + E_{IM} + E_{IN}\right) R_1$$

$E_B = Sc^{-\gamma}$ collection efficiency from **Brownian diffusion**

$$E_{IM} = \left(\frac{St}{\alpha + St}\right)^2$$ collection efficiency from **impaction**

$$E_{IN} = \left(d_p / A\right)^2 / 2$$ collection efficiency from **interception**

St Stokes number

BAM

$V_{drift} = W_S$ $\quad R_s = 1/u_* \left(E_B + E_{IM}\right)$

$$E_B = \begin{cases} Sc^{-1/2} & \text{wet} \\ Sc^{-2/3} & \text{non-wet} \end{cases} \qquad E_{IM} = 10^{-3/St}$$

Petroff and Zhang, 2010 (PZ10)

phoretic effects on water/ice/snow $\quad V_{drift} = W_S + V_{phor}$

Rs derived by a 1D aerosol transport model

Rs more sensitive to LUCs $\quad R_s = 1/V_{ds}$

non-vegetated surface

$$V_{ds} = u_* \left(E_{gb} + E_{IT}\right) \qquad E_{gb} \propto Sc^{-\gamma} \quad \left(1/2 \le \gamma \le 2/3\right)$$

Egb Brownian diffusion efficiency on the ground below veg

Sc Schmidt number viscosity/mass diffusivity

E_{IT} collection efficiency due to turbulent impaction

vegetated surface

$$V_{ds} = u_* \left(E_{gb} + E_{gt}\right) \frac{1 + \left[Q/Q_g - \alpha/2\right] \cdot \tanh(\eta)/\eta}{1 + \left[Q_g + \alpha/2\right] \cdot \tanh(\eta)/\eta}$$

Q time scale ratio turbulent transport/vegetation collection

$$\eta = \sqrt{\alpha^2/4 + Q}$$

2. Method – Model Configuration and Experiments

CAM5 setup

Configuration: CAM5.4, MG microphysics, MAM4, CLM4.0, data ocean,
Runtime period: 2002 to 2012, last 10 years for analysis
Resolution: $1.9^{o} \times 2.5^{o}$
Meteorology: U, V nudged to ERA-interim Reanalysis

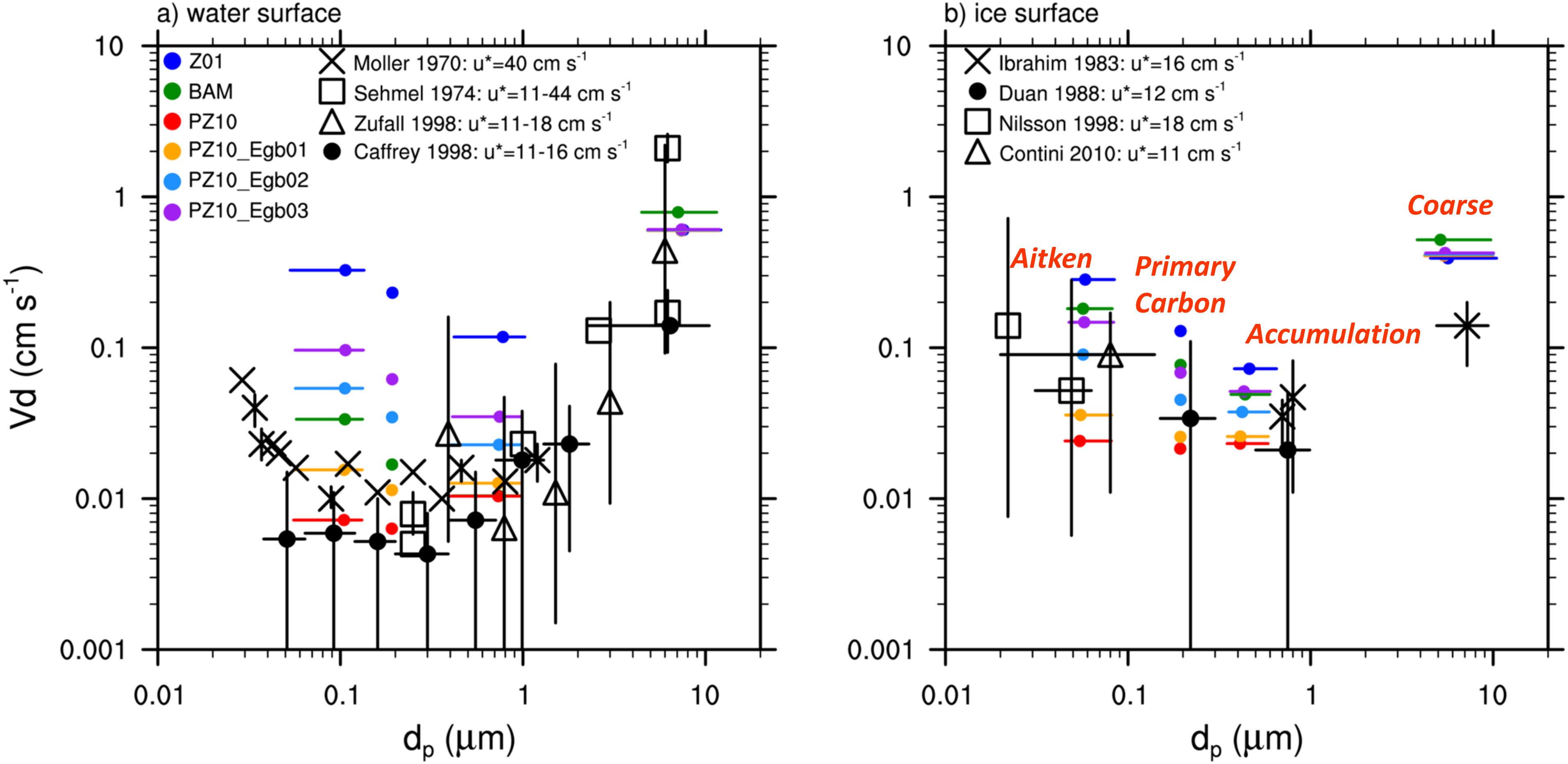
Each experiment run for PD and PI aerosol emissions
Radiative forcing calculation follows Ghan, ACP, 2013

Experiments

Z01: Zhang et al. (2001).
BAM: BAM (Slinn and Slinn, 1980)
PZ10: Petroff and Zhang (2010)
PZ10_Egb01: same as PZ10, $Sc^{-2/3}$ to $Sc^{-1/2}$ in Egb.
PZ10_Egb02: same as PZ10_Egb01, Egb*5
PZ10_Egb03: same as PZ10_Egb01, Egb*10

3. Results - Dry Deposition Velocity

Validation of dry deposition velocities over water and ice surface



PZ10 predicts much smaller deposition velocity for fine particles in accumulation, Aitken, and primary carbon mode, which is closer to observations.

As Egb becomes larger (PZ10-PZ10_Egb03), dry deposition velocity increases.

3. Results - Aerosol Distribution and Budgets

BC Budgets

BC	Dry Deposition ($Tg\ yr^{-1}$)	Wet Deposition ($Tg\ yr^{-1}$)	Lifetime (day)	Burden (Tg)
Z01	1.6622	6.0870	5.4434	0.1156
BAM	0.8386	6.9095	6.2392	0.1324
PZ10	0.4262	7.3219	6.7318	0.1429
PZ10_Egb01	0.4490	7.2990	6.7073	0.1424
PZ10_Egb02	0.5486	7.1996	6.6014	0.1401
PZ10_Egb03	0.6612	7.0870	6.4824	0.1376

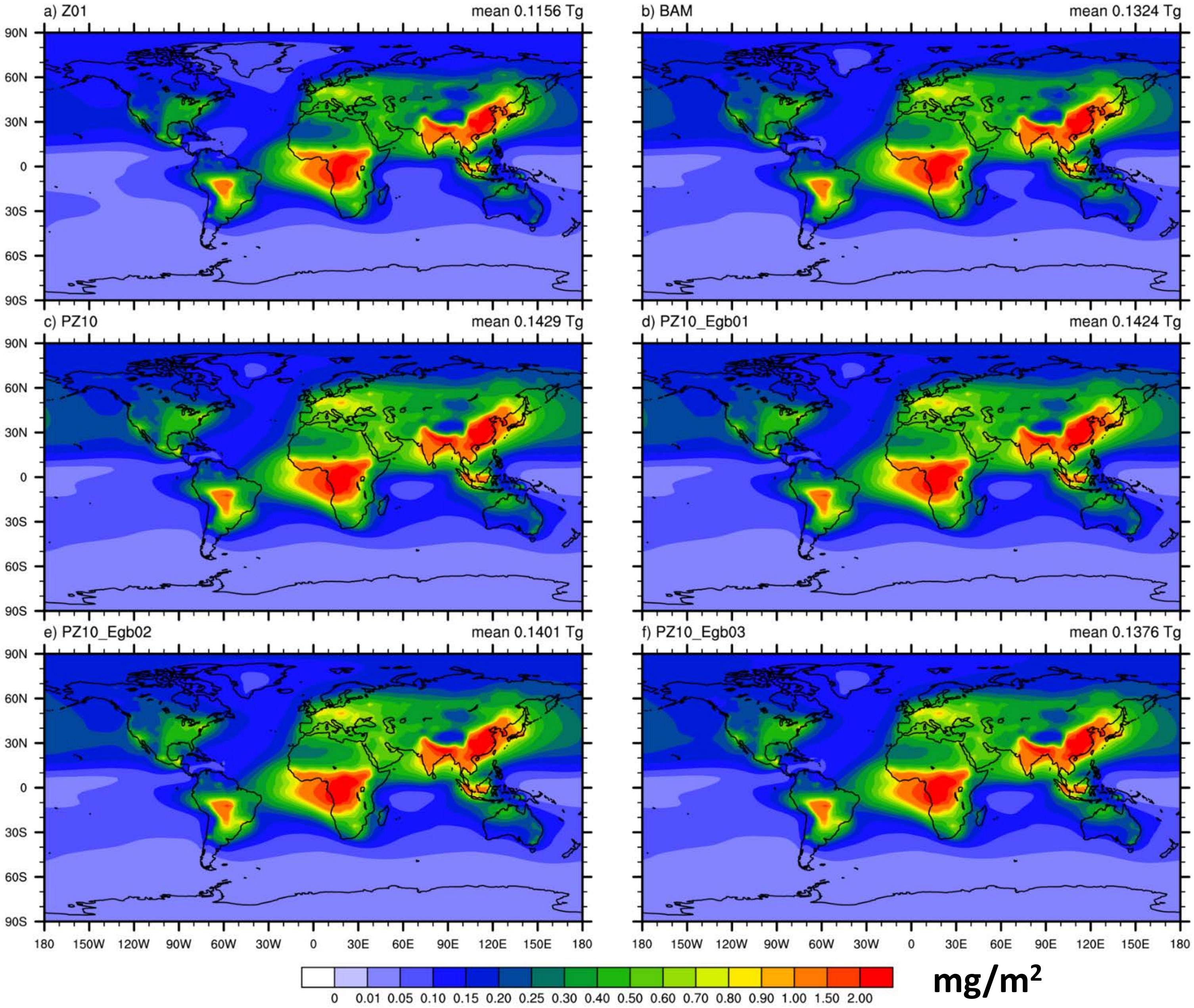
PZ10 reduces BC dry deposition by 74%, BC lifetime increases by 24%.

Similar changes for POM, sulfate, SOA.

As Egb becomes larger (PZ10-PZ10_Egb03), BC dry deposition increases, lifetime and burden decreases.

3. Results - Aerosol Distribution and Budgets

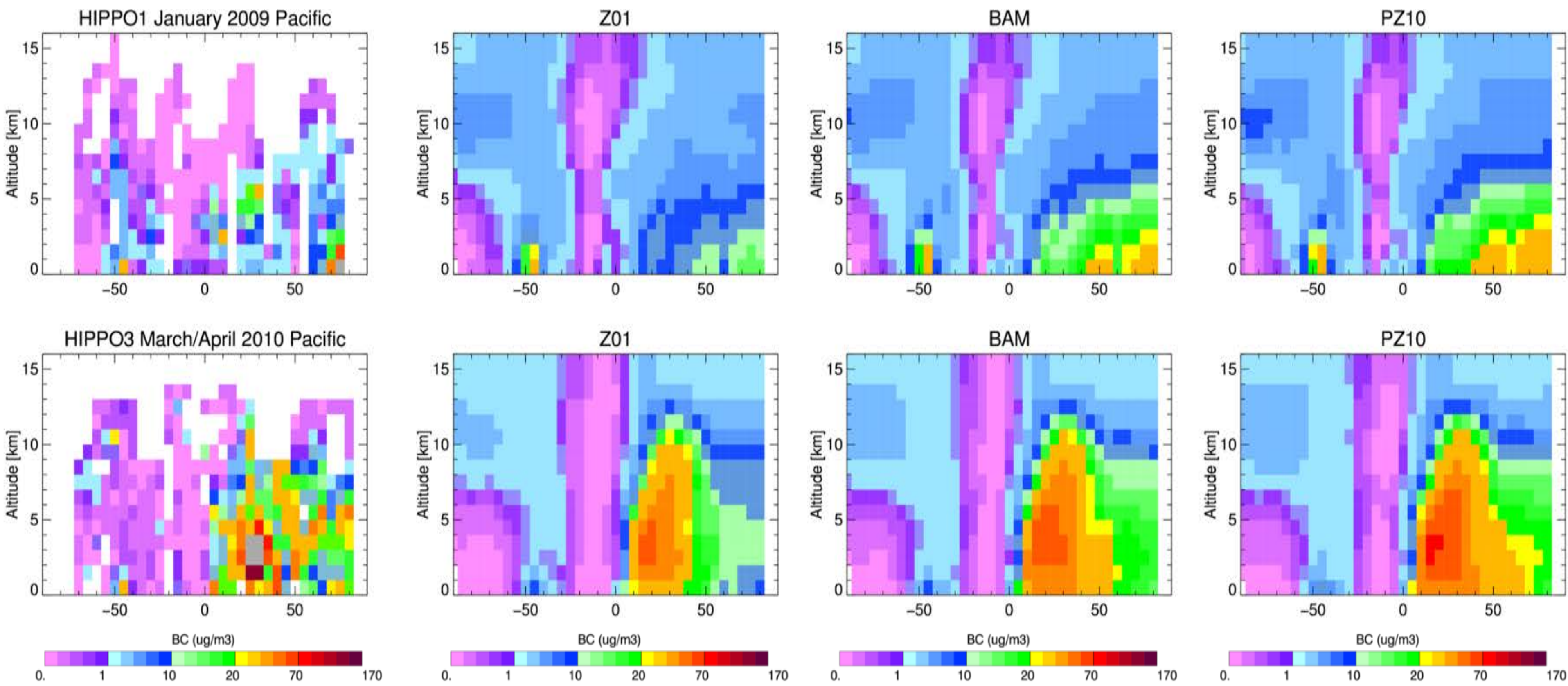
Column burden of BC



BC burden increases globally, especially over high-latitude regions

3. Results - Aerosol Distribution and Budgets

BC vertical distribution compared with HIPPO aircraft campaigns

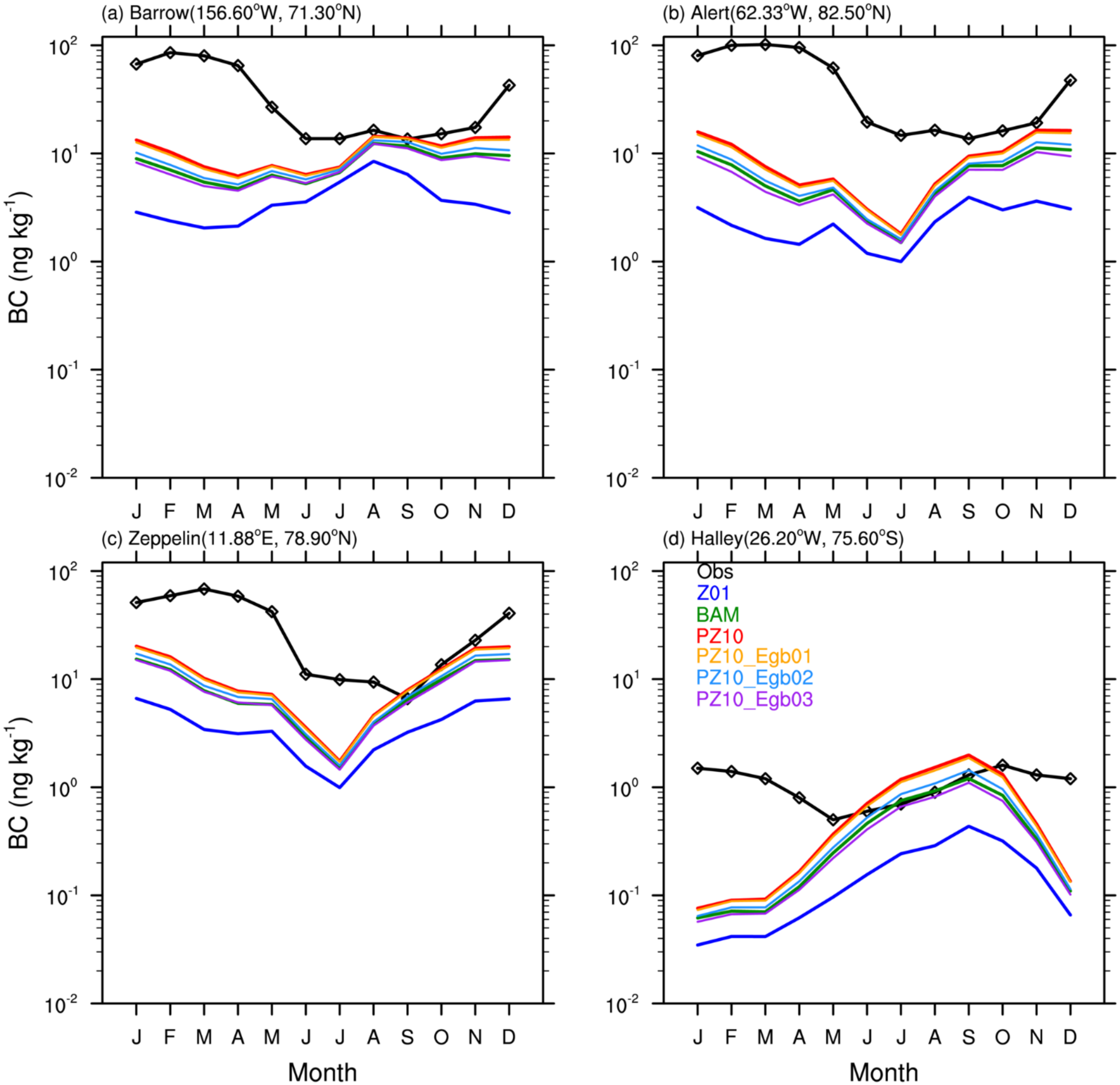


Courtesy Simone Tilmes

PZ10 and BAM increase BC concentration. In some places, the new scheme improves the BC concentration.

3. Results - Aerosol in High-latitude Remote Regions

BC surface concentration in four polar sites



Improved seasonality of BC surface concentration

Increased BC surface concentration

BC transport and total deposition increase

3. Results - Radiative Forcing

Aerosol radiative forcing (PD-PI)

Radiative forcing (W m^{-2})	Direct forcing	Indirect forcing
Z01	0.1001	-1.6696
BAM	0.1046	-1.5827
PZ10	0.1122	-1.5585
PZ10_Egb01	0.1129	-1.5575
PZ10_Egb02	0.1151	-1.5786
PZ10_Egb03	0.1169	-1.5961

Increased direct forcing, reduced indirect forcing

4. Summary

1. The new PZ10 dry deposition scheme predicts much lower **dry deposition velocity** for fine particles in accumulation, Aitken, and primary carbon mode compared with Z01.

2. The new PZ10 dry deposition scheme greatly changes the **aerosol lifecycle**. Dry deposition fluxes for BC, POM, sulfate, and SOA decreases while dry deposition fluxes for dust and sea salt increases. Column burden of BC, POM, sulfate, sea salt, and SOA all increases.

3. The new PZ10 dry deposition scheme improves the **BC representation in remote regions**. BC profiles in high-latitudes regions are improved. BC surface concentration in the Polar regions increases significantly, Seasonality of BC concentration is also improved.

4. The new PZ10 scheme results in larger aerosol direct forcing and smaller indirect forcing, and the total aerosol radiative forcing decreases.