



北海道大学

The third ACAM Workshop in
Guangzhou, China (June 5-9, 2017)

Theme 2.1 Aerosols and Clouds

The role of snow-darkening effect in the Asian monsoon region

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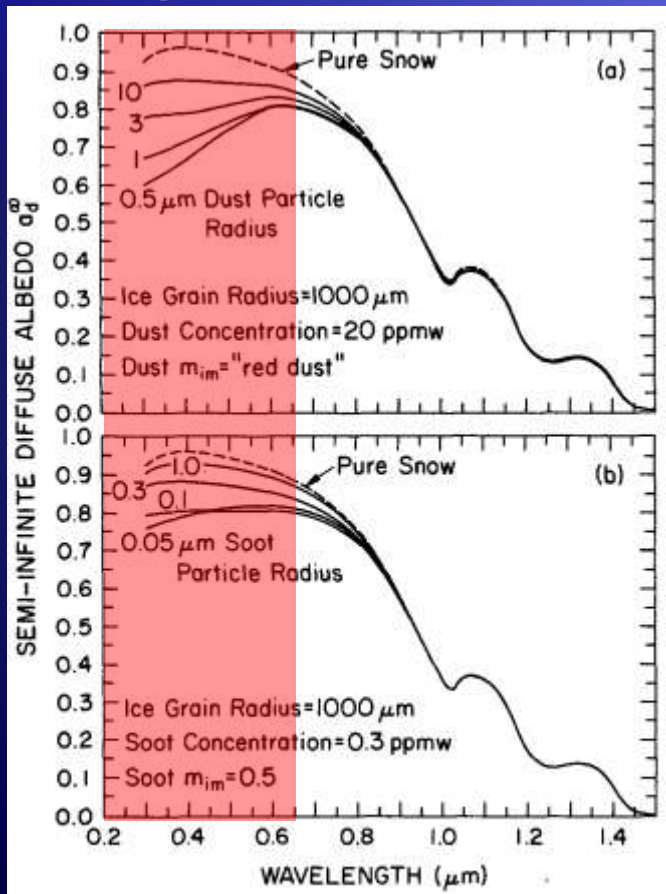
Background



What's
snow-darkening effect?

What is snow darkening effect (SDE)?

Dust, Black carbon, and organic carbon transports



Light Absorbing Aerosols (LAA) absorb solar radiation especially in visible wavelengths and can accelerate snow melting.

Snow darkening effect and its feedbacks can not be ignored on the climate discussion in the cryosphere.



Suggested snow albedo feedbacks by the snow darkening effect
(Translated and adapted from Figure 2 in Japanese of Aoki and Tanaka, 2008, *Tenki*)

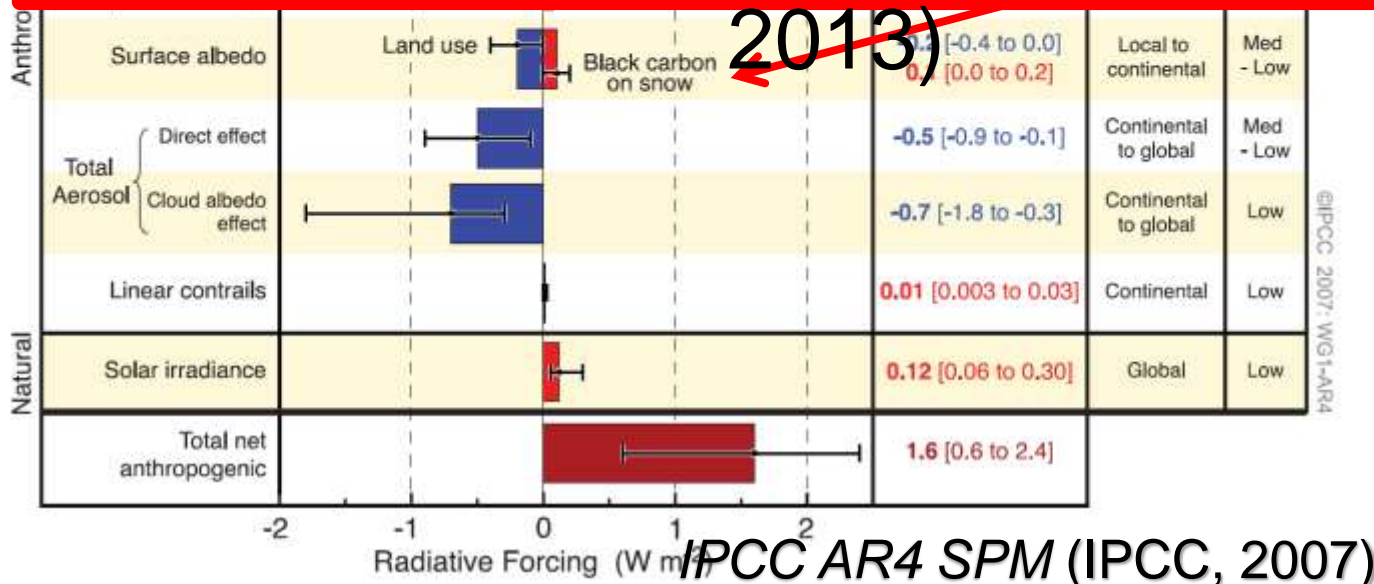
Recent updates on the BC RF on snow:

ve

+0.046 (+0.015 to + 0.094) $W m^{-2}$
 summarized by Bond et al. (2013, *JGR*);

+0.04 (+0.02 to +0.09) $W m^{-2}$
 adapted by *IPCC AR5* (Boucher et al.,

was
 based
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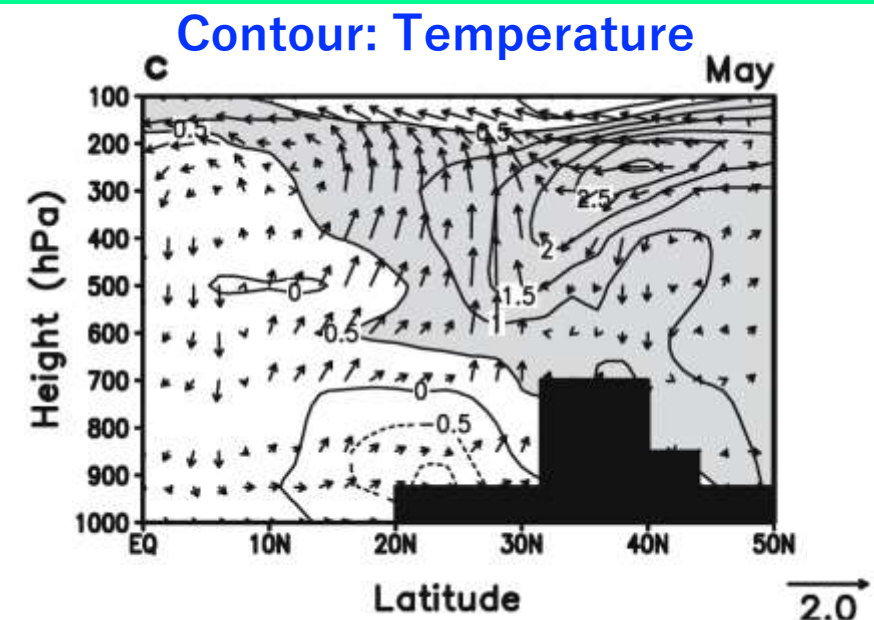
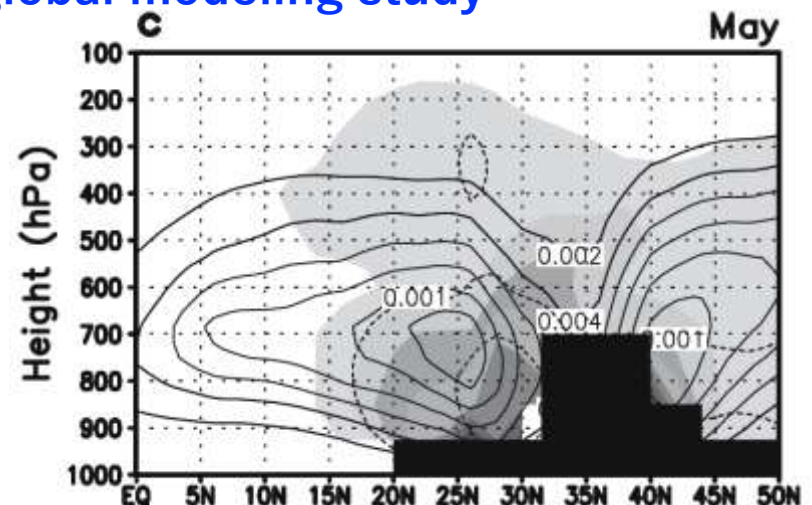


Nazarenko
 (2004,
PNAS) and
 Hansen et al.
 (2005, *JGR*)

What has
the NASA team
done so far?

Build-up aerosols over the Indo-Gangetic Plain (IGP) in pre-monsoon (spring) season would change atmospheric temperature distributions and circulation patterns (e.g., Lau et al., 2006).

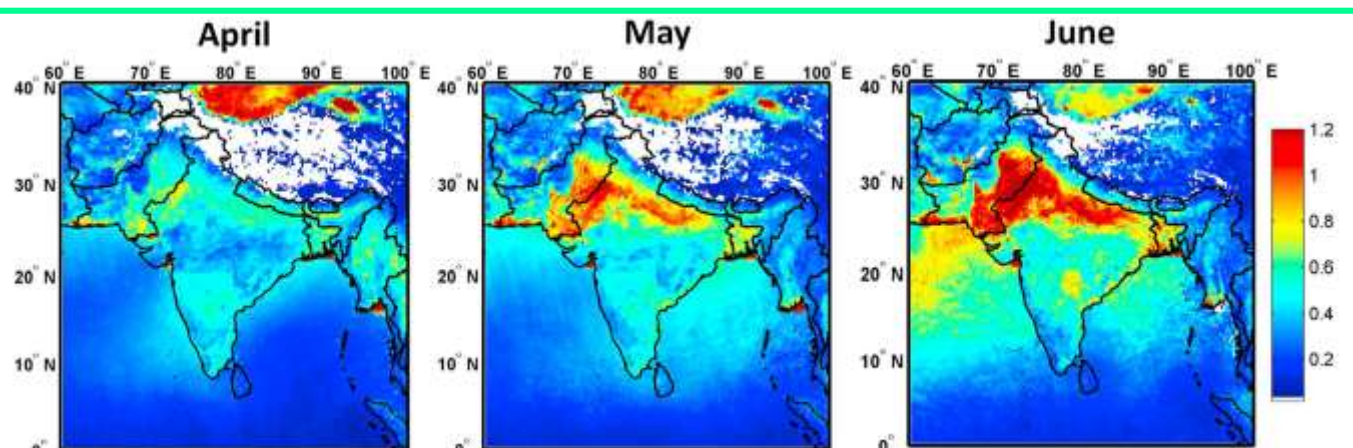
A global modeling study



Solid & dashed lines:
Dust & BC AOT

Adapted from Lau et al. (2006, Clim. Dyn.)

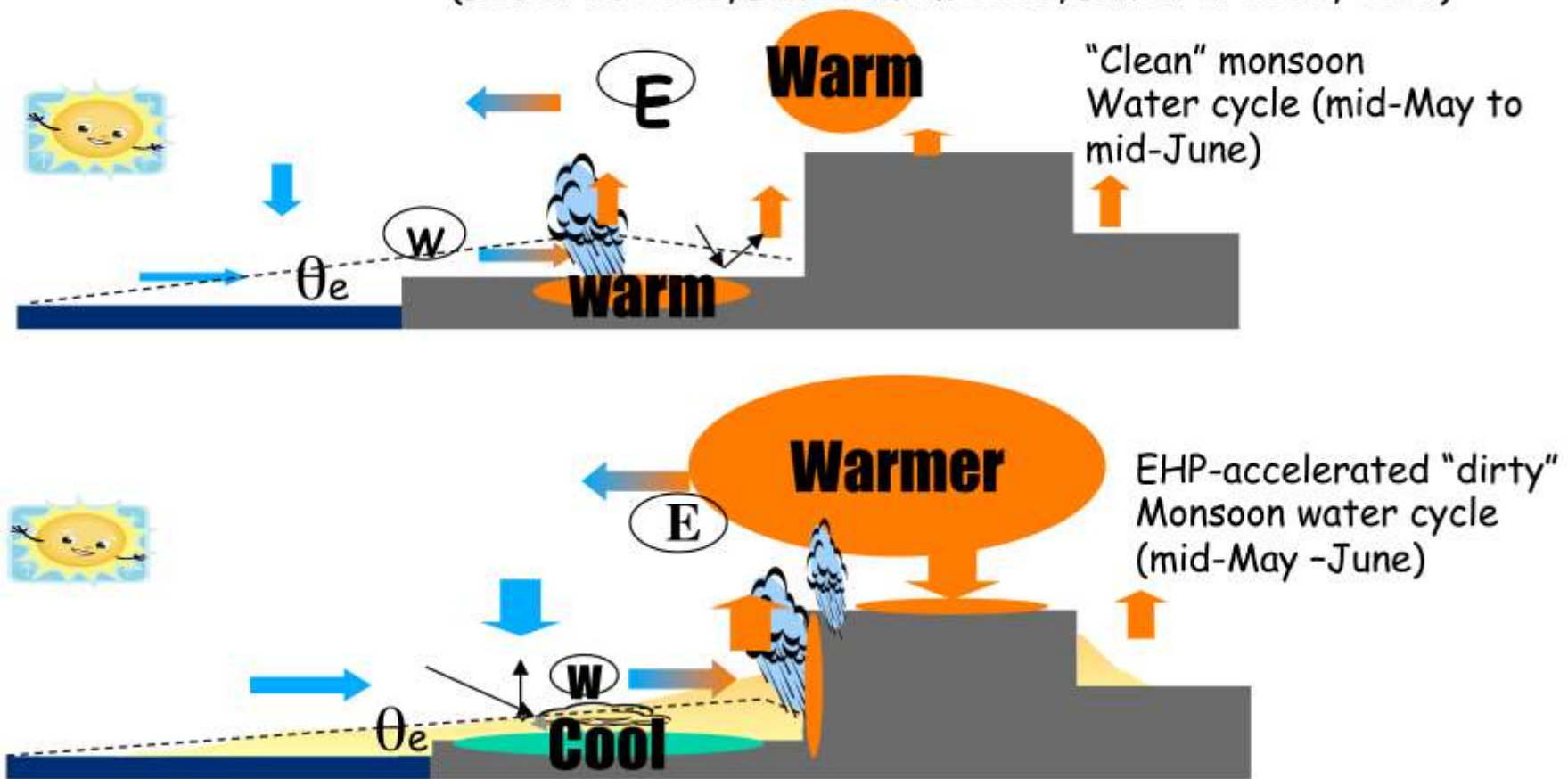
Satellite data analysis:
AOD climatology based on the daily Aqua MODIS aerosol product (Level 2)



Gautam et al. (2010, J. Geophys. Res.)

The Elevated Heat Pump (EHP) hypothesis

(Lau et al. 2006, Lau and Kim 2006, Lau et al 2008, 2010)

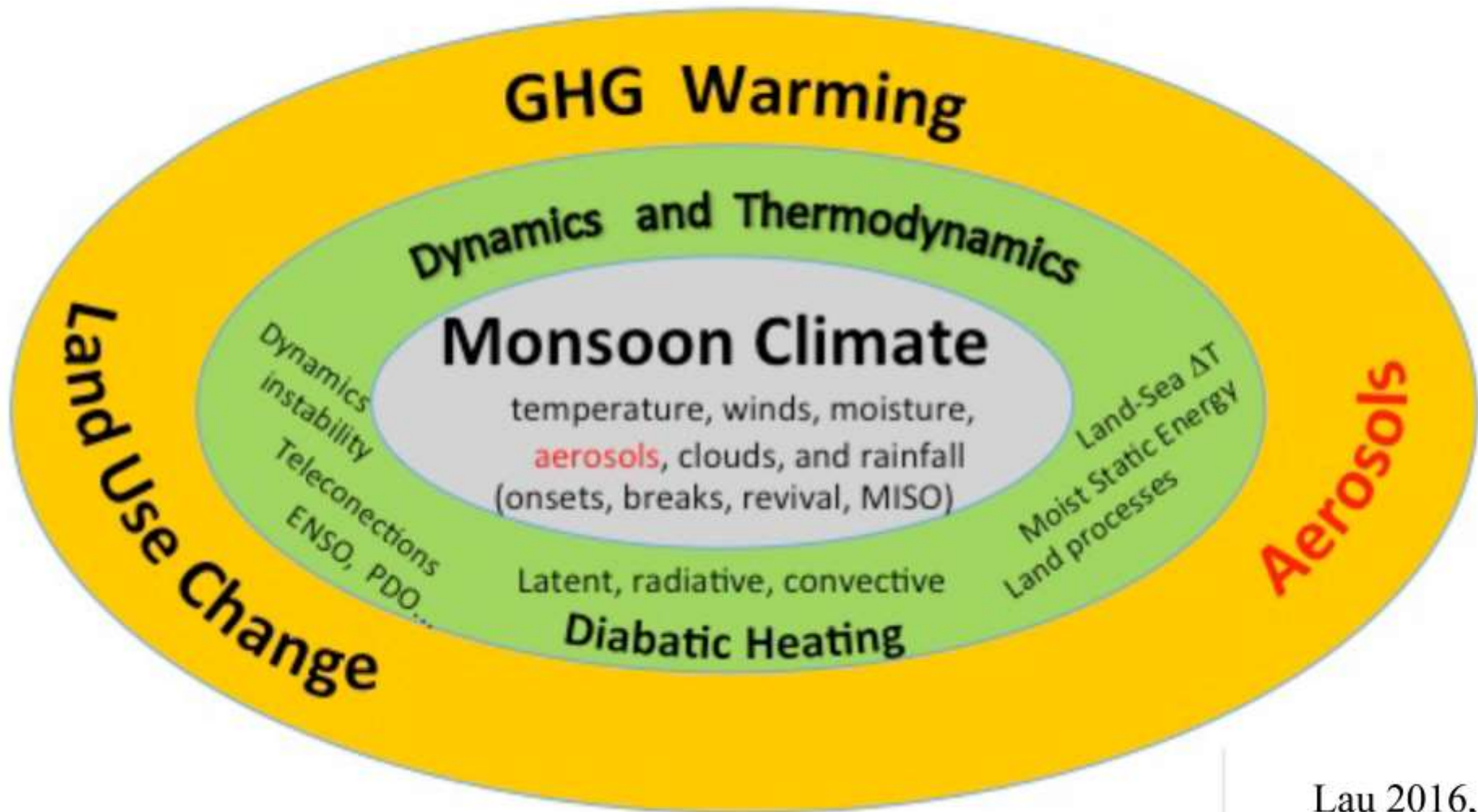


EHP postulates:

- Warming and moistening of the upper troposphere over the Tibetan Plateau
- An advance of the rainy season in northern India/Nepal, Himalayas foothills in May-June
- The increased convection spreads from the foothills of the Himalayas to central India, resulting in an intensification of the Indian monsoon in June-July
- Subsequent reduction of monsoon rain in central India in July-August
- Enhanced snowmelt and rapid retreat of Himalayan glacier

Lau (2016) mentioned that aerosols now have an important role in assessing the monsoon climate system.

An Aerosol-Monsoon Climate System - A New Paradigm



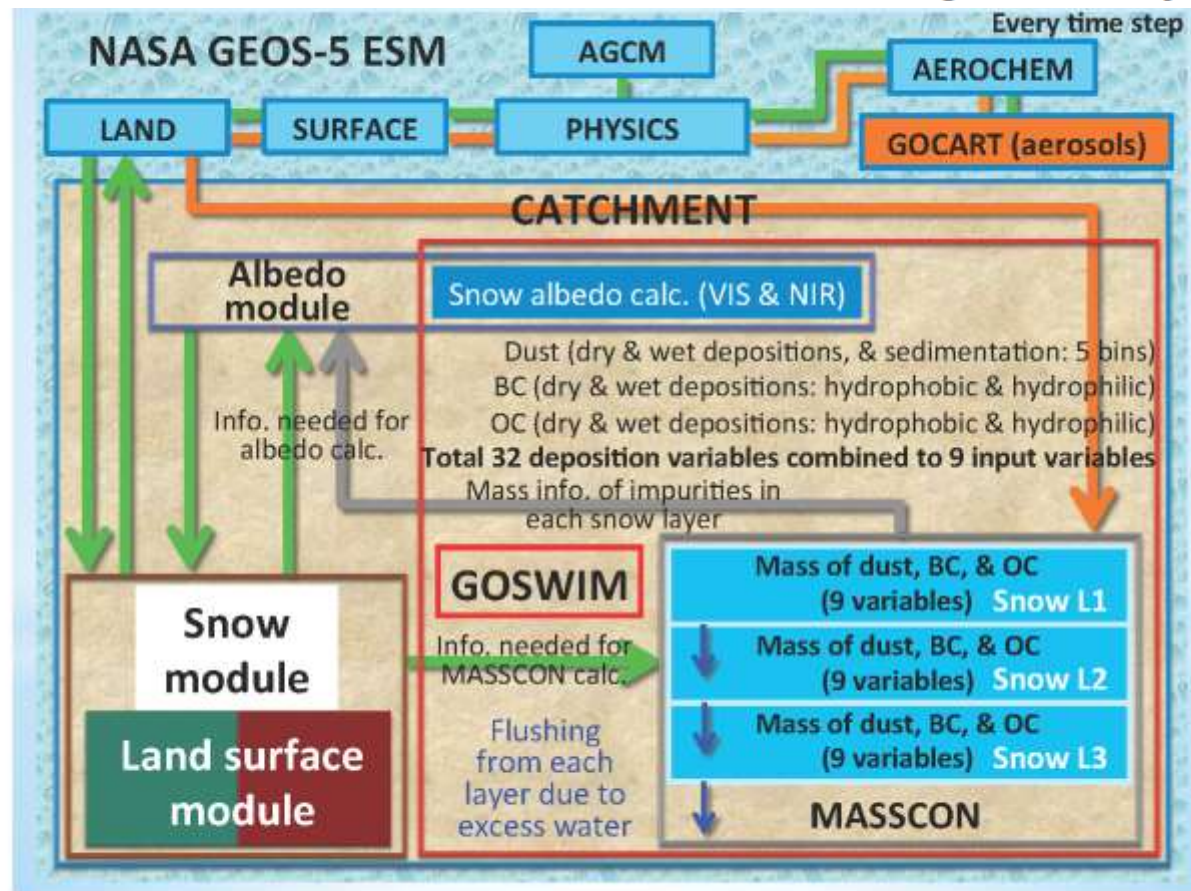
Lau 2016, JMR

The GOSWIM

for the NASA GEOS-5 Earth System Model:

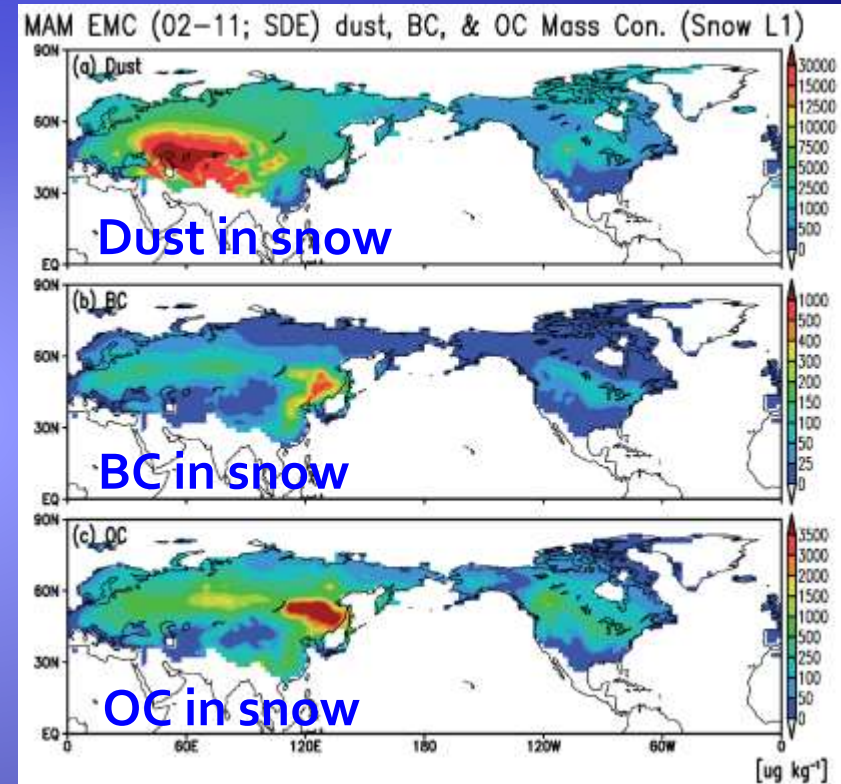
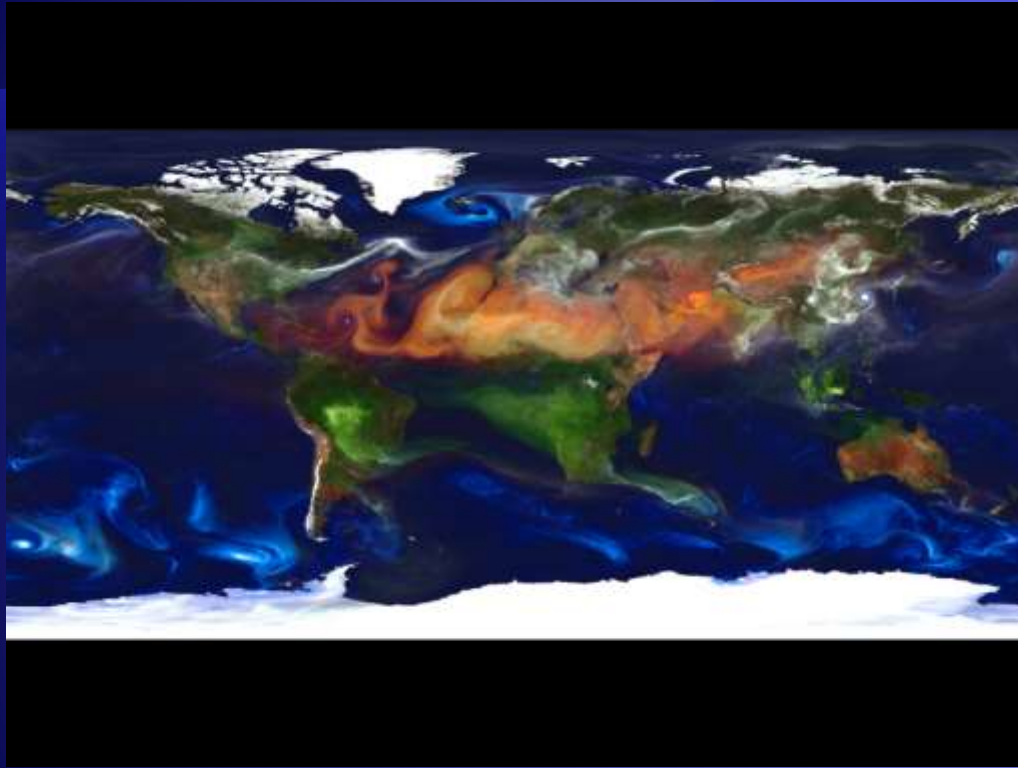
Preliminary Comparisons with Observations in Sapporo, Japan

Teppei J. Yasunari^{1,2}, K.-M. Lau², Sarith P. P. Mahanama^{3,2}, Peter R. Colarco², Arlindo M. da Silva², Teruo Aoki⁴, Kazuma Aoki⁵, Naoto Murao⁶, Sadamu Yamagata⁶, and Yuji Kodama⁷



Snow darkening simulations of seasonal snowpack by NASA GEOS-5 over the land region

Yasunari et al., 2015, *J. Geophys. Res. Atmos.*



High-resolution global atmospheric modeling on aerosols by NASA GEOS-5: http://www.nasa.gov/multimedia/imagegallery/image_feature_2393.html

Simulated dust, BC, and OC mass concentrations in spring (MAM) in the top of snow layer by NASA GEOS-5 model (10-year ensemble mean climatology)

With and without the snow darkening effect (SDE) in the GEOS-5 experiments

Start dates
with initial conditions

Yasunari et al., 2015, *J. Geophys. Res. Atmos.*

Exp. name	Start date	Restart file date
Exp 1	06/09/2001	06/09/2000
Exp 2	06/29/2001	06/29/2001
Exp 3	06/14/2001	06/14/2002
Exp 4	06/18/2001	06/18/2004
Exp 5	06/03/2001	06/03/2005
Exp 6	06/23/2001	06/23/2006
Exp 7	06/08/2001	06/08/2007
Exp 8	06/27/2001	06/27/2008
Exp 9	06/12/2001	06/12/2009
Exp 10	06/17/2001	06/17/2011

Dust+BC+OC SDE

- For each Exp, experiments with and without SDE were carried out.
- Ensemble mean climatology: Averaging the 10-set of exps. by 10 years (i.e., 100 samples)
- Welch's t-test assuming unequal variances

GEOS-5 settings on the experiments

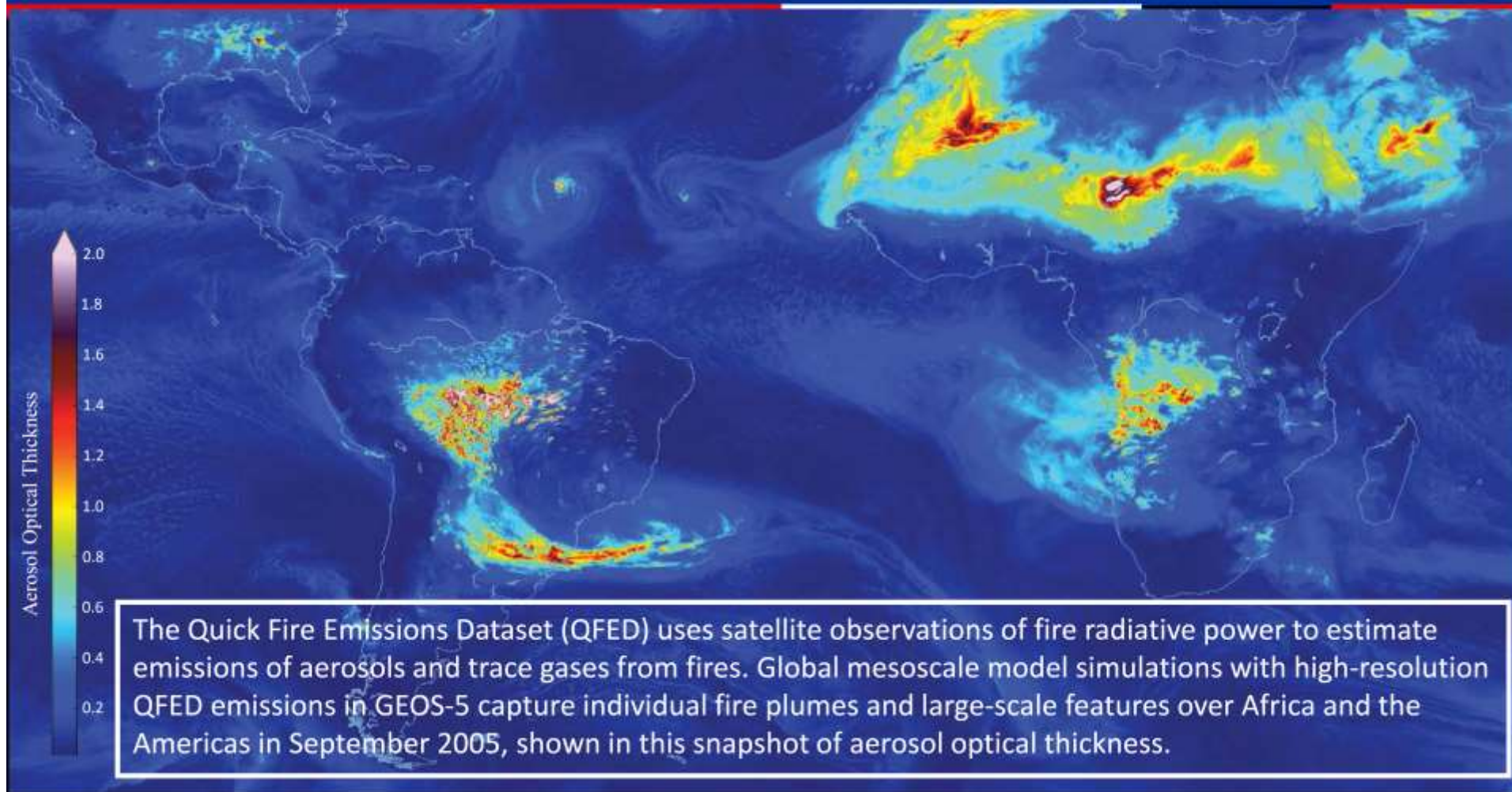
- Horizontally $2^\circ \times 2.5^\circ$; vertically 72 layers
- Dust, BC, and OC depositions from GOCART (e.g., Ginoux et al., 2000, *JGR*; Chin et al., 2000, *JGR*; 2002, *JAS*; Colarco et al., 2010, *JGR*, 2014, *JGR*)
- GOSWIM ([Yasunari et al., SOLA, 2014](#)) is coupled in the Catchment land surface model, excluding the land ice (i.e., glaciers and the ice sheets) and sea ice parts
- Prescribed observed SST (Reynolds et al., 2002, *J. Clim.*)
- Biofuel and fossil fuel emissions until 2006 based on the emission dataset (A2-MAP-v1; Diehl et al., 2012, *ACPD*; data in 2006 used after 2006). [Biomass burning emissions based on the Quick Fire Emission Data set \(QFED; Petrenko et al., 2012, *JGR*, and Darmenov and da Silva, 2015, *NASA Tech. Rep. Ser. GMDA*\)](#)
- Monthly mean outputs are used for analyses

Yasunari et al., 2015, *J. Geophys. Res. Atmos.*

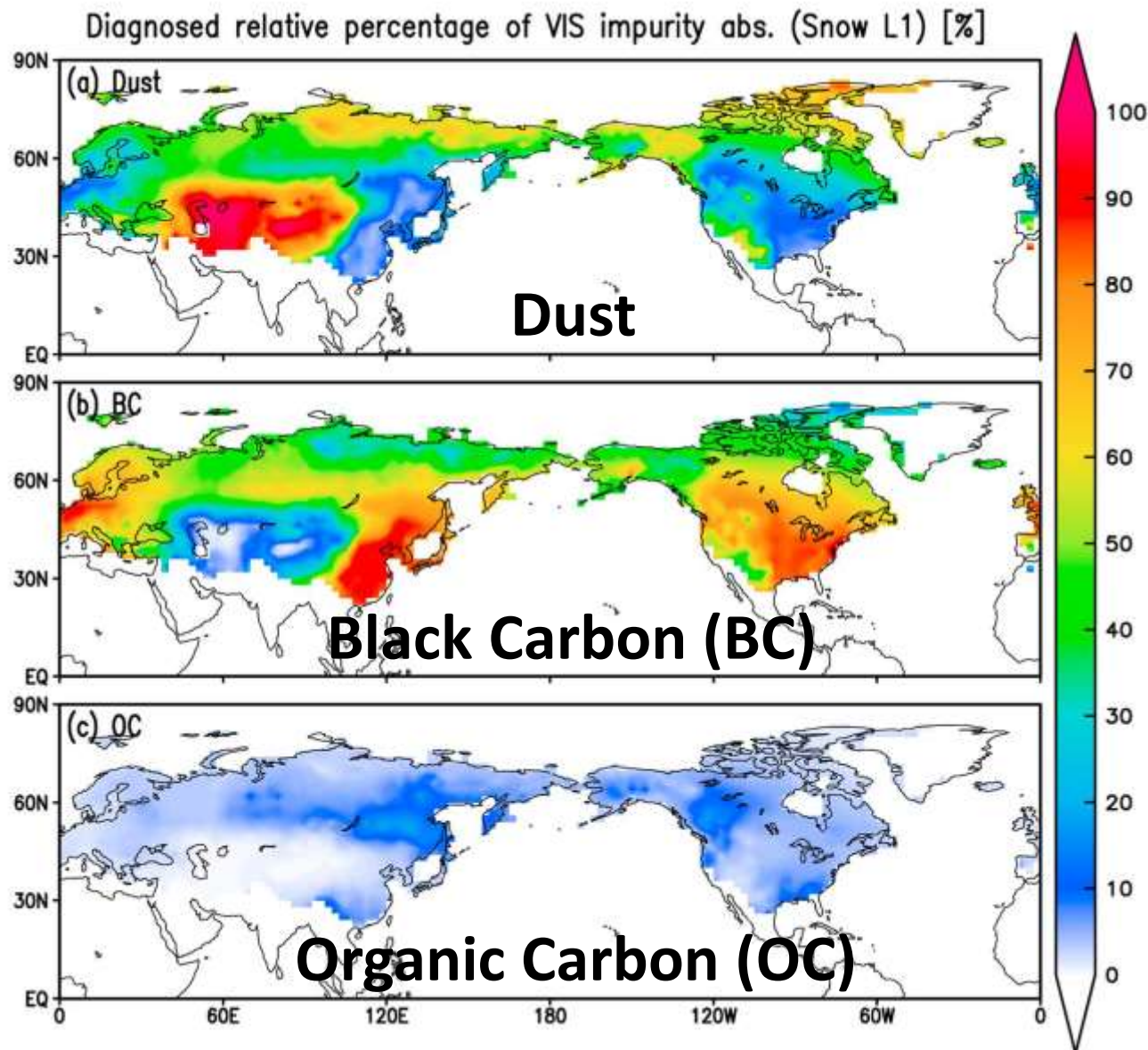


QFED - High Resolution Global Fire Emissions

Global Modeling and Assimilation Office

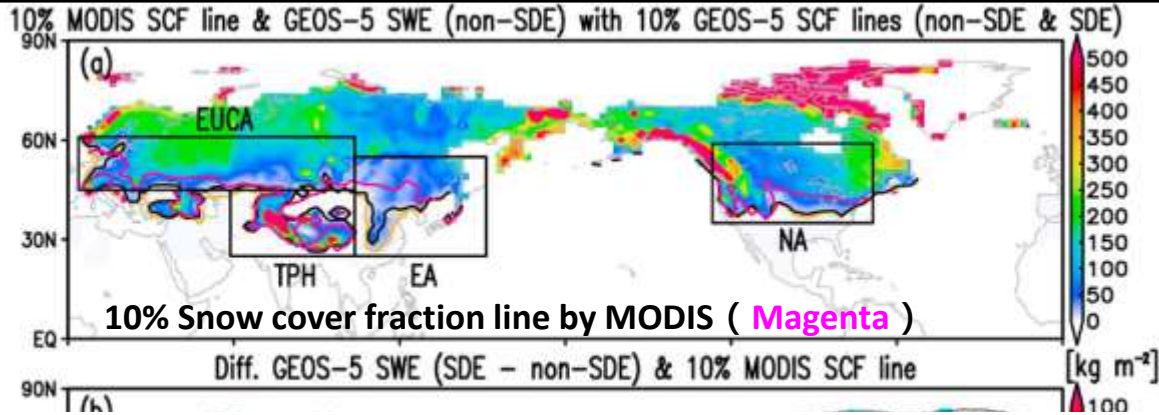


Anton Darmenov, Arlindo da Silva, and Ravi Govindaraju, QFED - High Resolution Global Fire Emissions: http://gmao.gsfc.nasa.gov/research/science_snapshots/global_fire_emissions.php

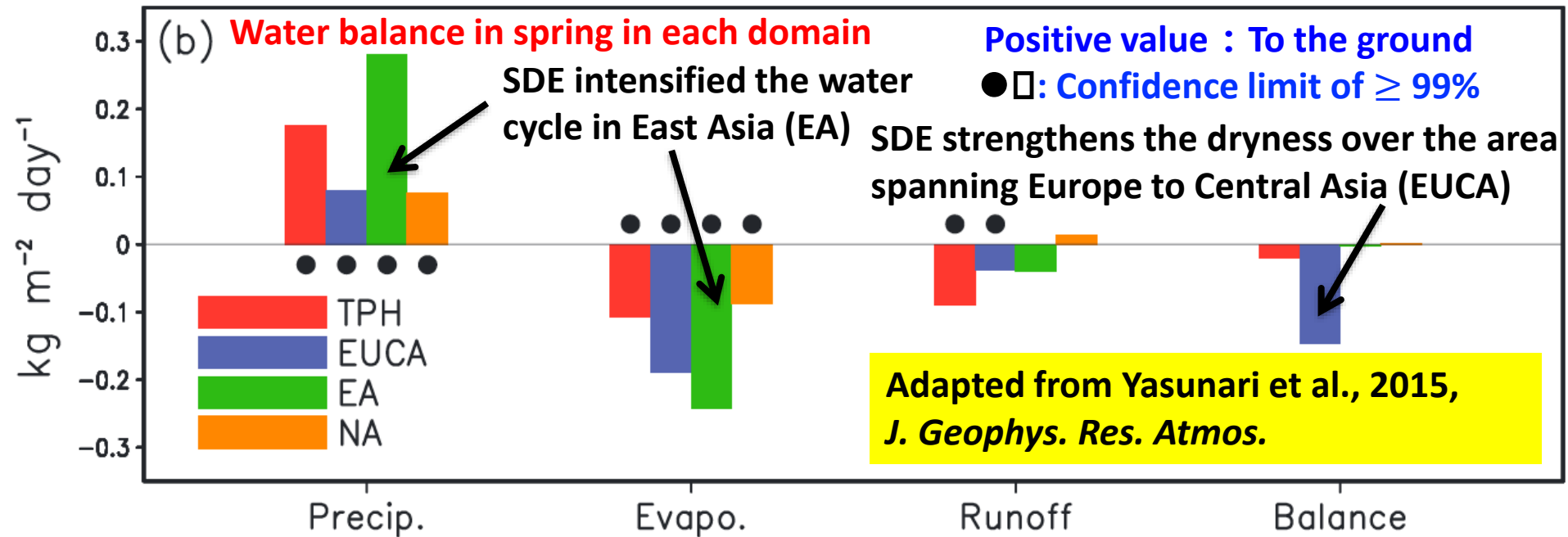


Diagnosed relative percentage of dust, BC, or OC (mass of OM was used) visible absorption coefficients in the total absorption of them in the top snow layer
(The SDE case; the calculations were based on the calculated visible absorption coefficients for these snow impurities from the spring ensemble mean climatologies)

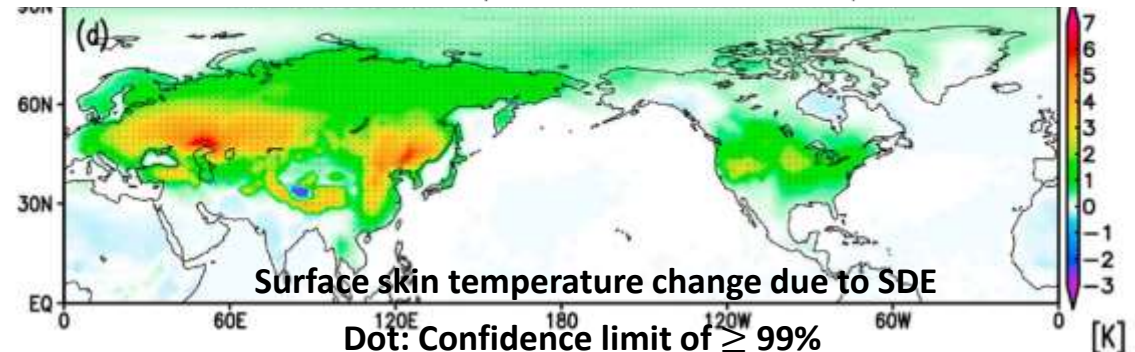
Adapted from Yasunari et al., 2015, *J. Geophys. Res. Atmos.*



**GOSWIM-module coupled
NASA GEOS-5 simulations
for the northern hemisphere spring
Snow-Darkening Effect (SDE)**



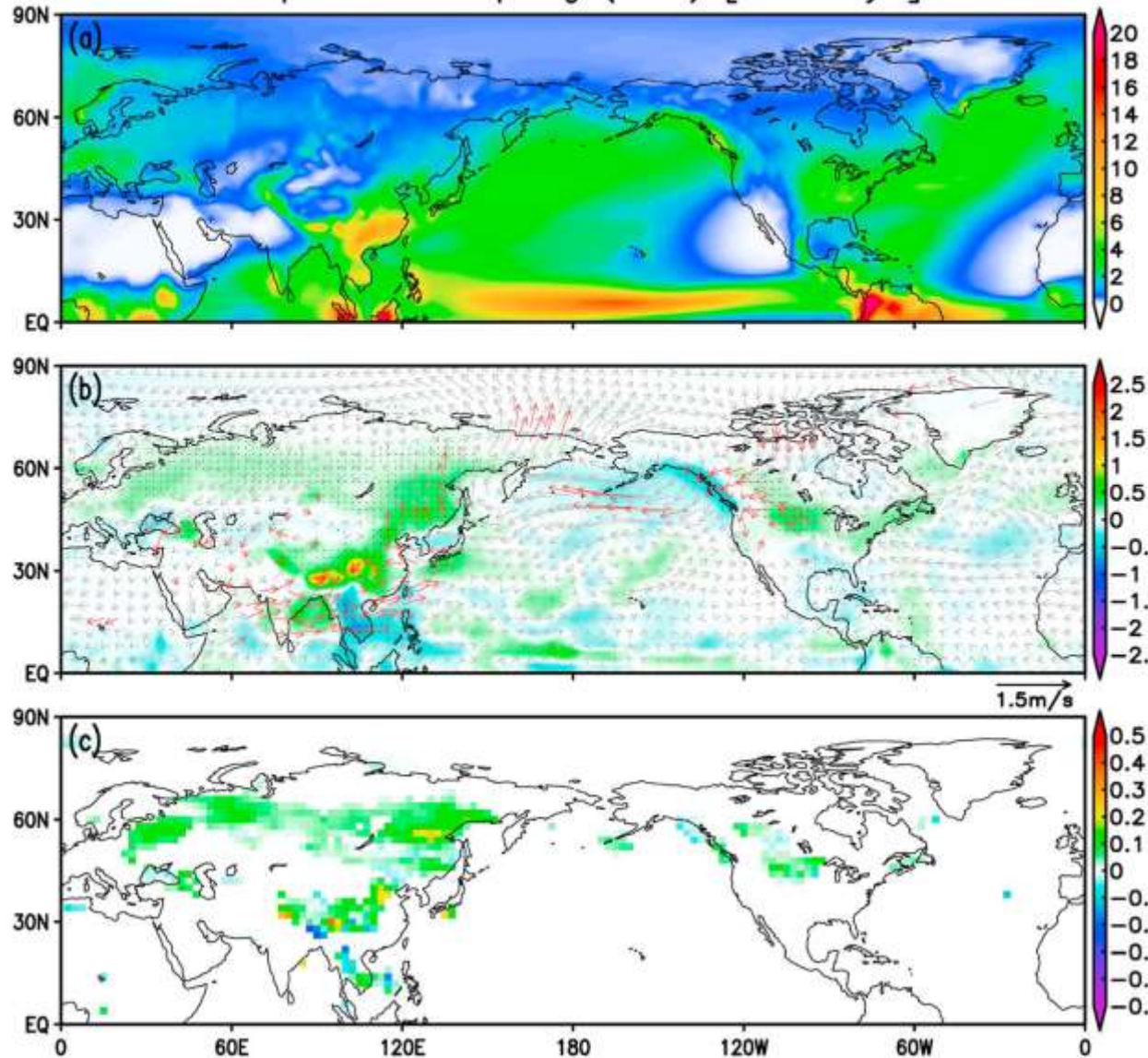
**Adapted from Yasunari et al., 2015,
*J. Geophys. Res. Atmos.***



**Adapted from Yasunari et al., 2015,
*J. Geophys. Res. Atmos.***

The existence of snow-darkening effect (SDE) significantly increased advection from the ocean (i.e., implying atmospheric water vapor increase), and precipitation over the area spanning from the Himalayas to East Asia.

Precipitation in spring (MAM) [mm day^{-1}]

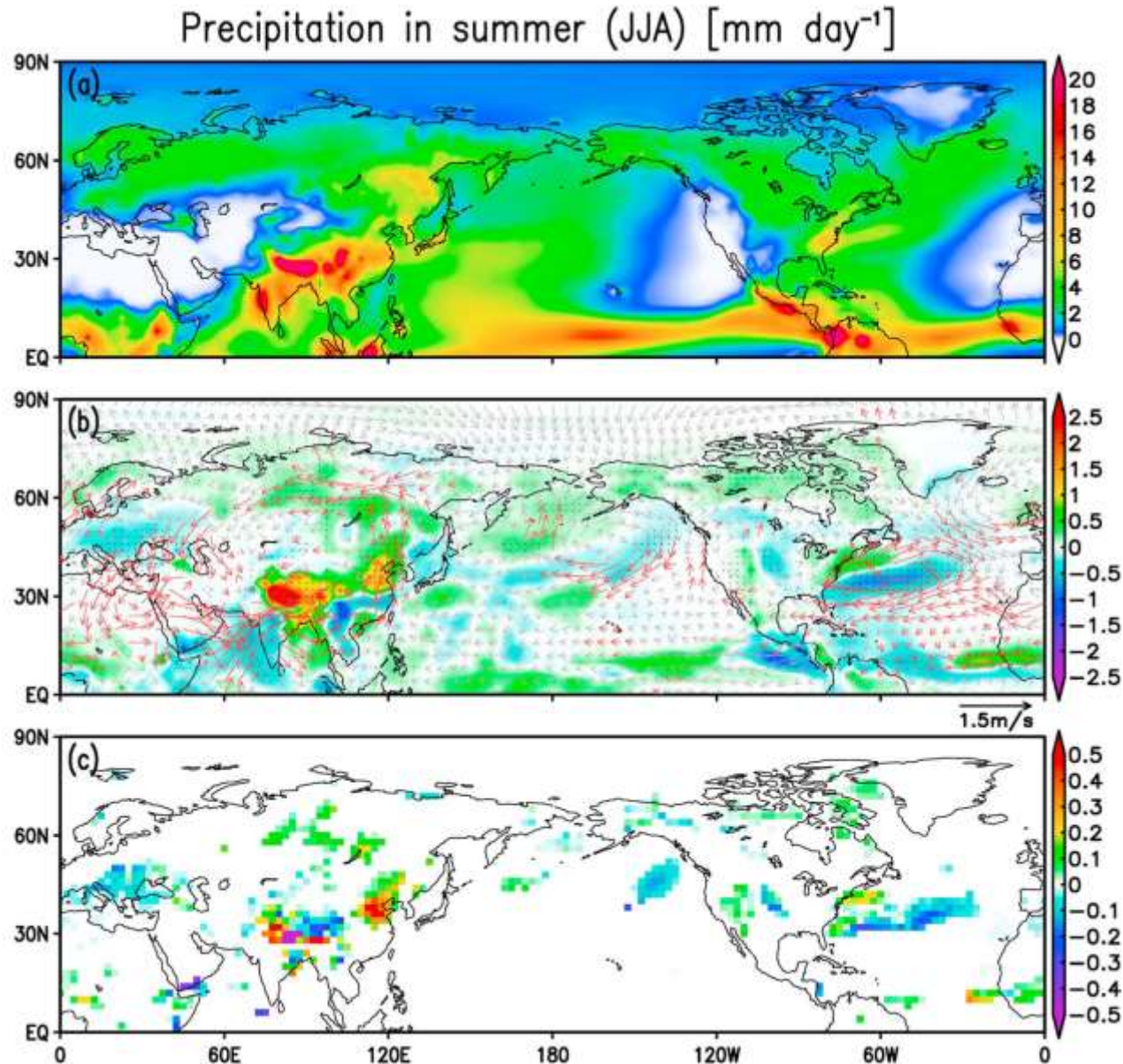


Precipitation climatology in **spring** without SDE (The control case)

Changes of precipitation and wind fields at 850 hPa with SDE (Dots & vectors in red denote confidence limits on precipitation & either horizontal or meridional wind component of $\geq 99\%$, respectively)

Difference of standard deviations on precipitation between the cases with and without SDE (Only the grid points where the confidence limits were $\geq 99\%$ in Panel (b))

The existence of SDE further increased precipitation over the areas spanning the areas from the Himalayas to East Asia, compared to that of spring.



Precipitation climatology in **summer** without SDE
(The control case)

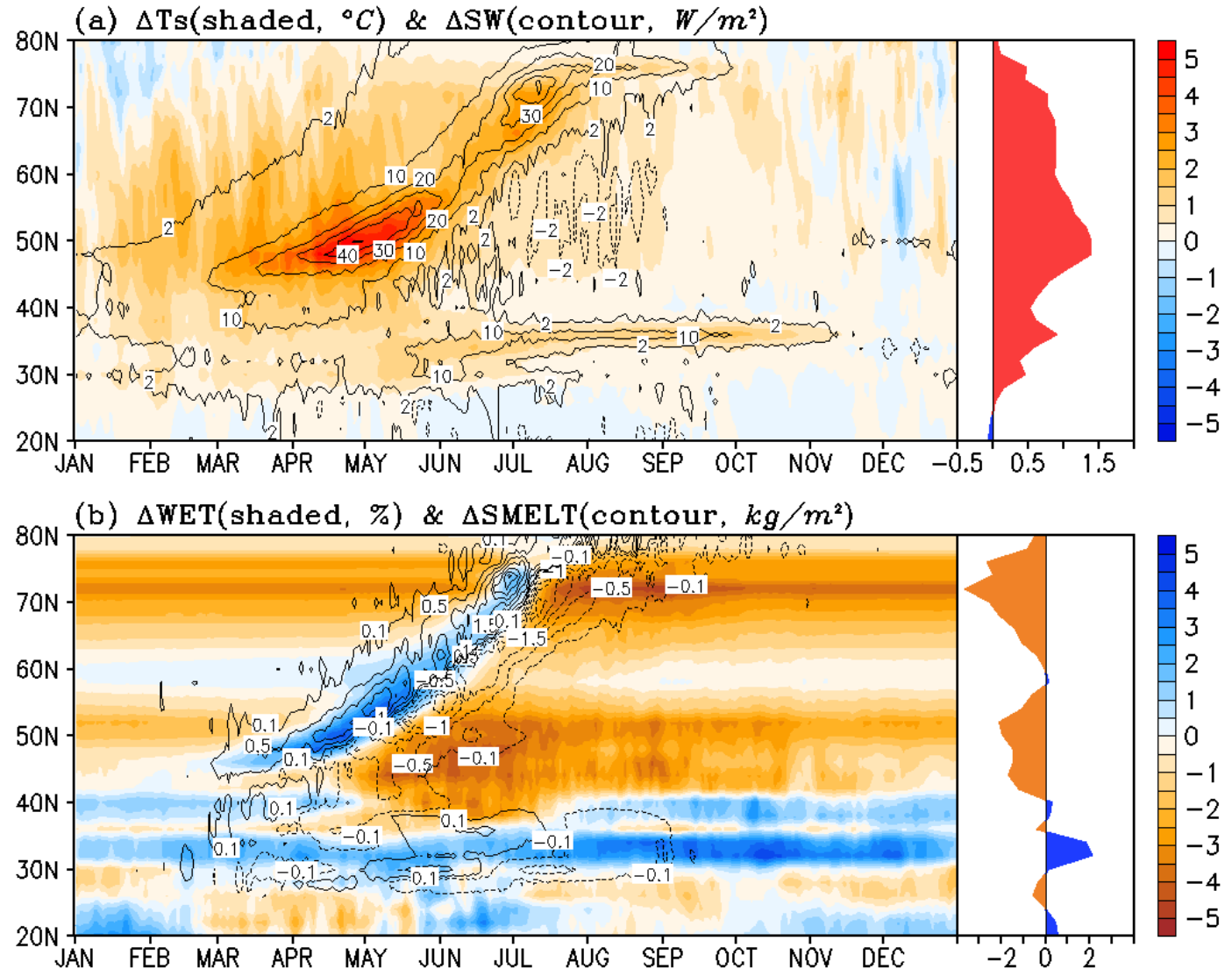
Changes of precipitation and wind fields at 850 hPa with SDE

(Dots & vectors in red denote confidence limits on precipitation & either horizontal or meridional wind component of $\geq 99\%$, respectively)

Difference of standard deviations on precipitation between the cases with and without SDE
(Only the grid points where the confidence limits were $\geq 99\%$ in Panel (b))

SDE over the Eurasia can induce the **Wet-First-Dry-Later (WFDL)** feedbacks, which is suggested by Lau et al. (in preparation).

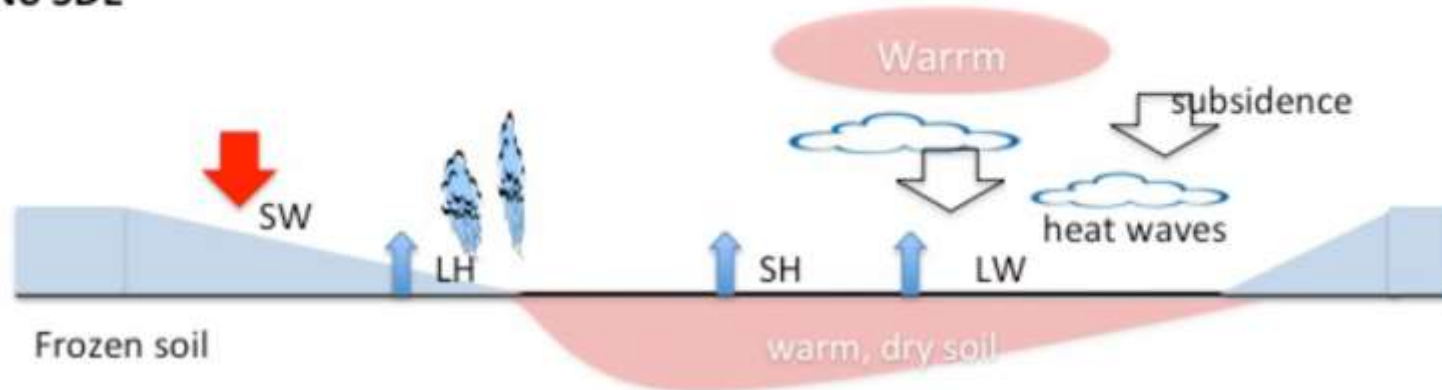
Changes of zonal mean latitude-time cross-sections of the seasonal cycle anomaly of the surface skin temperature, with net surface short wave radiation, and soil wetness with snowmelt rate the Eurasia (10-140°E, 20-80°N).



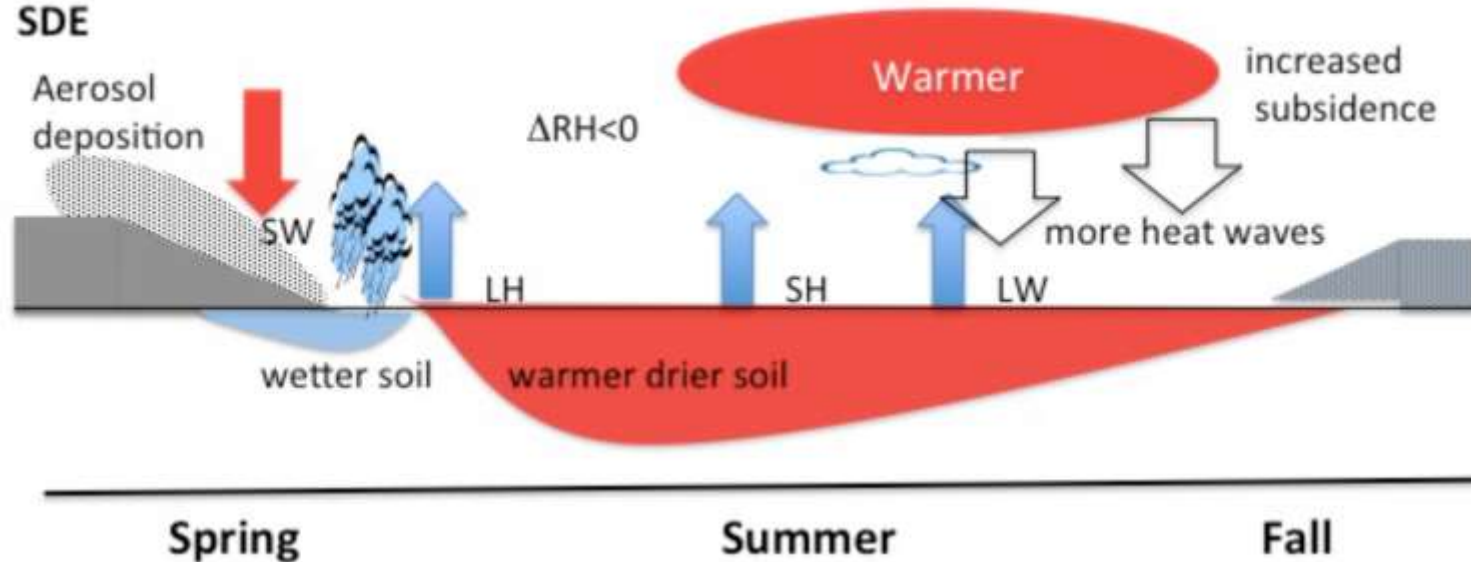
Lau, W. K. M., J. Sang, M. K. Kim, K. M. Kim, T. J. Yasunari, and R. Koster, Impacts of aerosol snow darkening effects on Eurasian hydro-climate and heat waves, in preparation.

A wet-first-dry-later (WFDL) land-atmosphere feedback induced by aerosol snow-darkening effect (SDE)

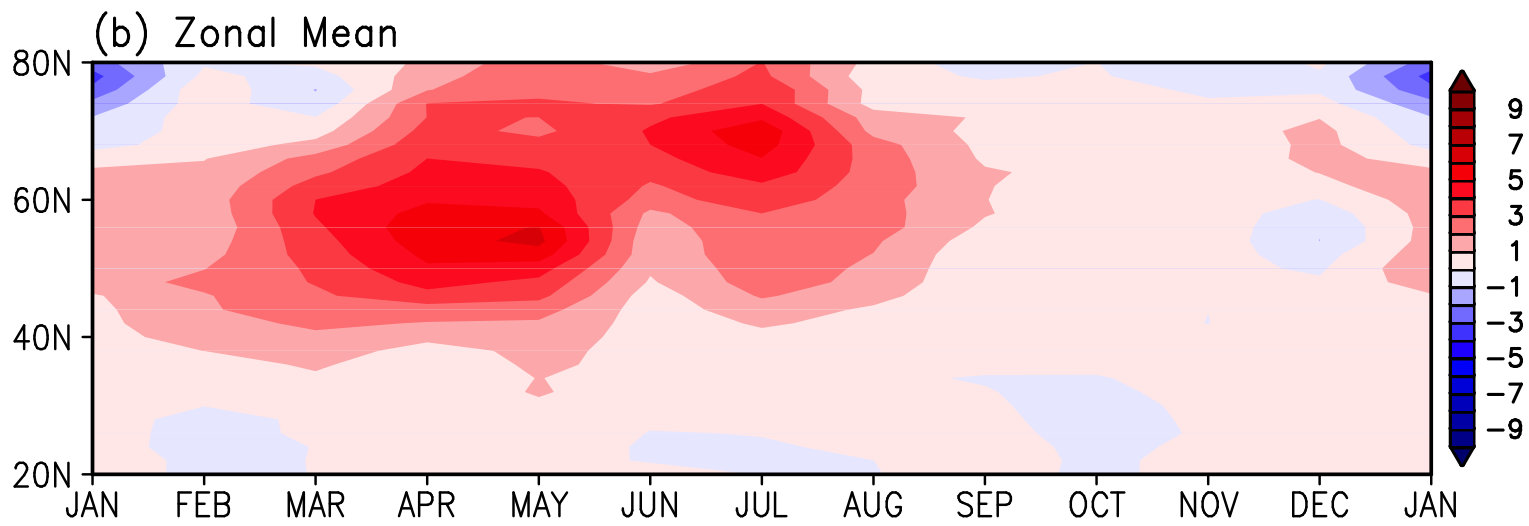
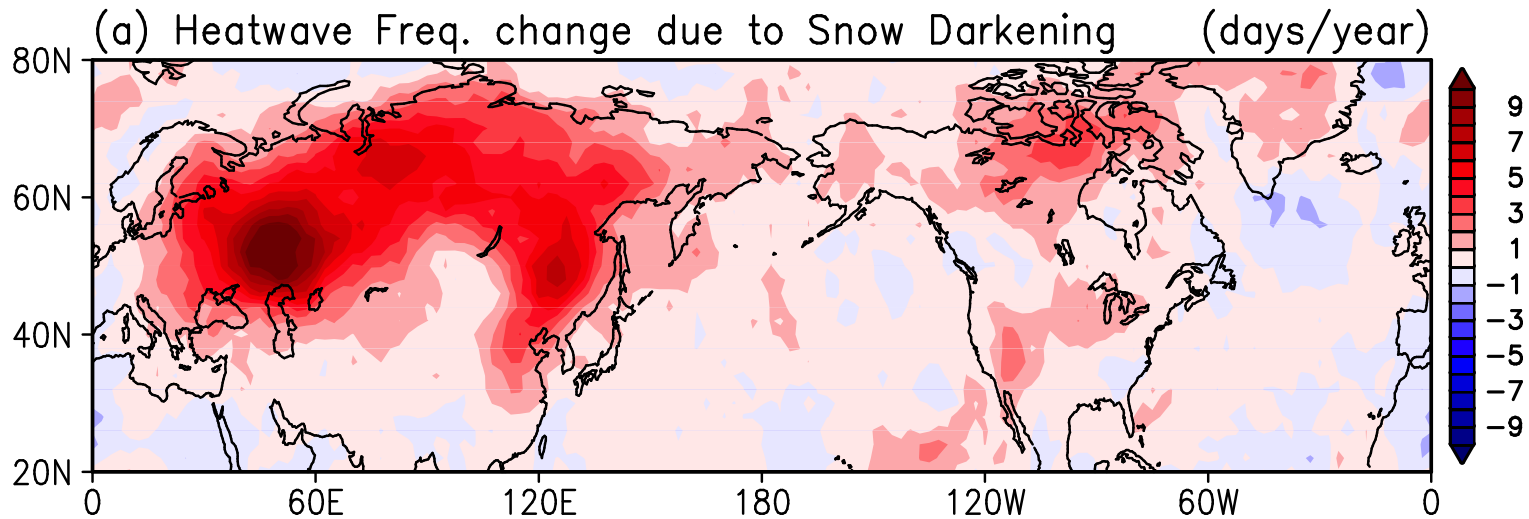
No SDE



SDE



The changes of heatwave frequency over Eurasia due to SDE showed a boomerang shape in which two stronger regions were seen in Central Asia and China. The peak seasons of higher heatwave frequency at 40-60°N and 60-80°N were in spring and early summer, respectively.



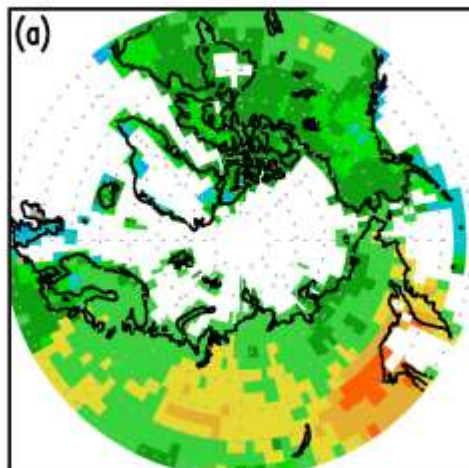
What's the current issue on
SDE modeling
for GCM?

Uncertainty on modeled BC mass concentration in snow is large!

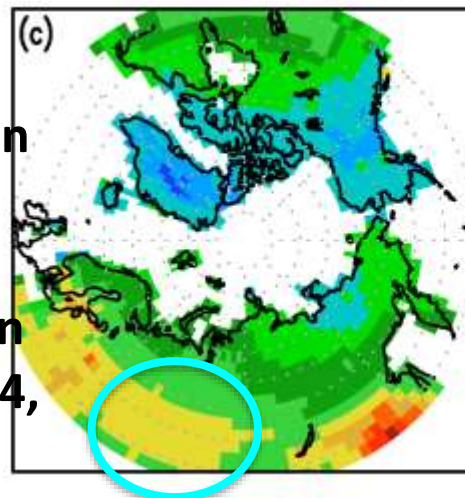
08 MAM BC Con. top (GEOS-5; replay)

08 MAM BC Con. top (CAM5; SEh)

**GEOS-5
Simulation
(using MERRA
atmospheric
fields by
Rienecker et al.,
2011, *J. Clim.*)**



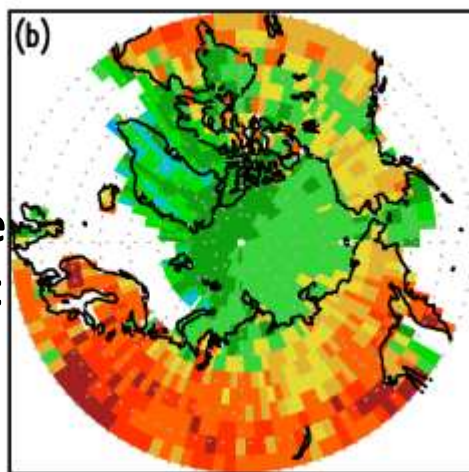
**CAM5
Simulation
(High
flushing
case; Qian
et al., 2014,
ERL)**



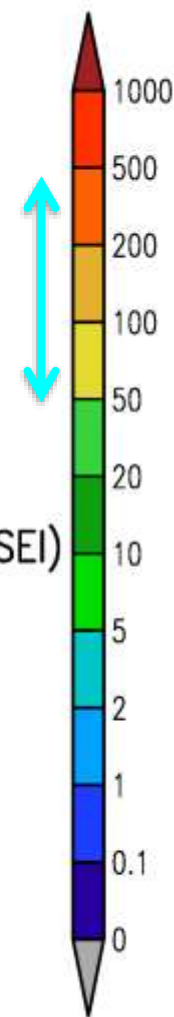
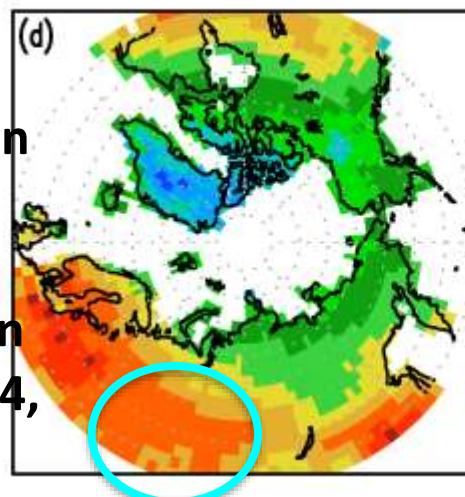
08 MAM BC Con. top (OsloCTM2)

08 MAM BC Con. top (CAM5; SEI)

**Oslo-CTM2
simulation
(data from Figure
6 of Forsström et
al., 2013, *JGR*)**



**CAM5
Simulation
(Low
flushing
case; Qian
et al., 2014,
ERL)**

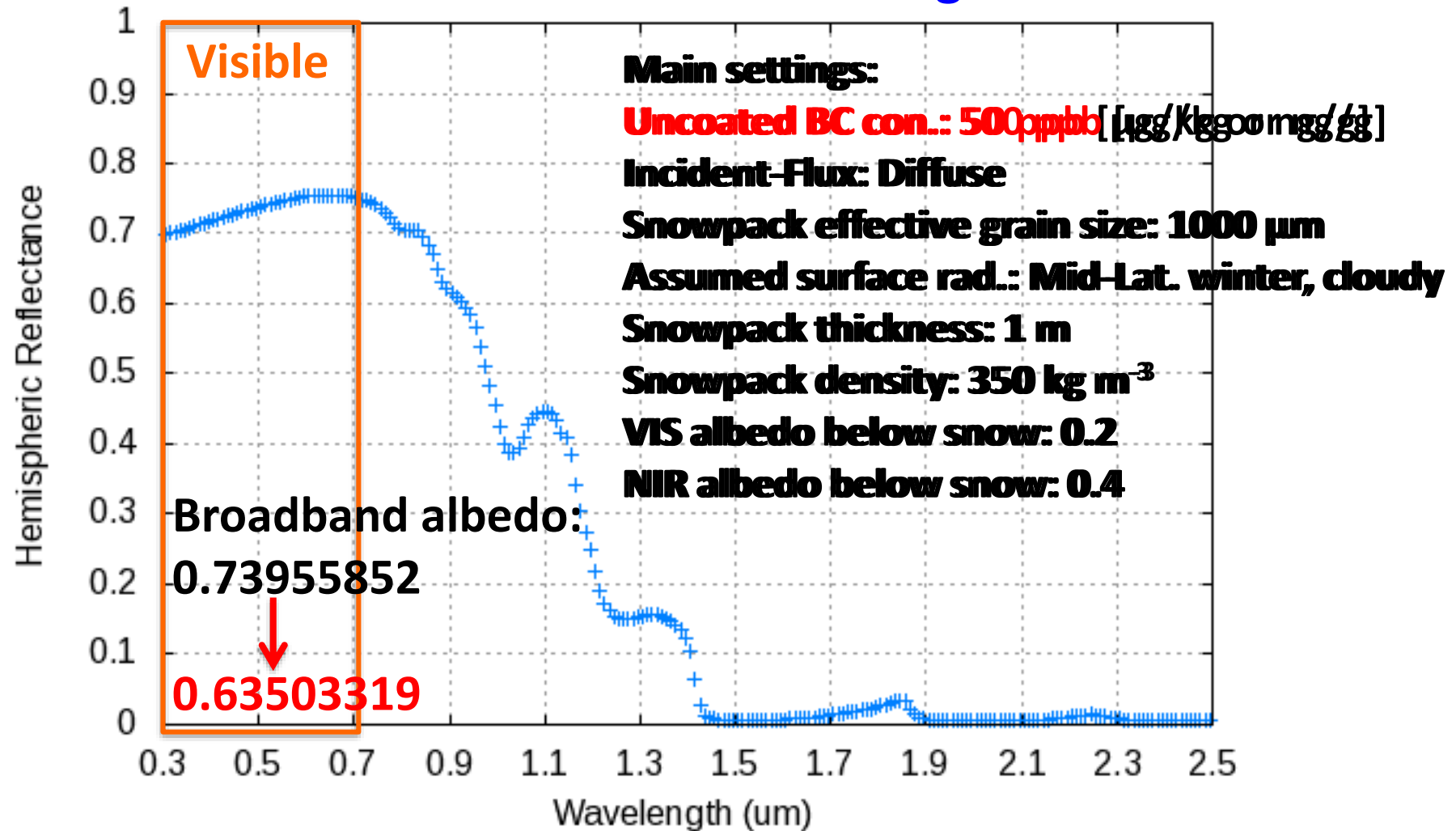


[ug/kg] or [ng/g]

Simulated BC mass concentrations in the top snow layer in MAM 2008 by three global models (GEOS-5, Oslo-CTM2, and CAM5).

Qian, Y., T. J. Yasunari, et al. (2015, *Adv. Atmos. Sci.*)

The uncertainty on the BC mass concentration difference (i.e., one order difference) has potential to change the visible broadband albedos of greater than 10%.



Cal. Snow albedo by SNICAR-Online: <http://snow.engin.umich.edu/> (Flanner et al., 2007, *J. Geophys. Res.*)
Similar and more discussions are available in Japanese (Yasunari et al., 2016, Saihyou (細永)).

Updated information on GEOS-5/GOSWIM (The snow-darkening module for GEOS-5)

- * We have been updating the GOddard SnoW Impurity Module (GOSWIM) to the latest version of GEOS-5 (from Fortuna 2.5 version to Heracles version), so that the snow-darkening calculations can be available in GEOS-5 over glaciers and the ice sheets.

Take-home message 1

- Now, our understanding on Asian monsoon study is that atmospheric LAA (e.g., Lau et al., 2006; Lau and Kim, 2006) and LAA in snow as the snow-darkening effect (Yasunari et al., 2015; Lau et al., in preparation) are both essential to further understand the Asian monsoon region on its climate system.
- Feedbacks caused by SDE in spring increased water cycle in East Asia and intensified dryness over the areas spanning Europe to Central Asia (Yasunari et al., 2015)
- SDE over the Eurasia can induce the Wet-First-Dry-Later (WFDL) feedbacks (Lau et al., in preparation).

Take-home message 2

- Simulated BC mass concentrations in snow among global models has large uncertainty (e.g., Qian et al., 2015), likely inducing one order magnitude differences which likely contribute to $\geq 10\%$ broadband albedo change (e.g., Yasunari et al., 2016)
- The NASA GEOS-5 will be able to simulate SDE over not only the seasonal snowpack but also snow over the land ice region (i.e., glaciers and the ice sheets)

Thanks for your attention,
and I will take a couple of questions!