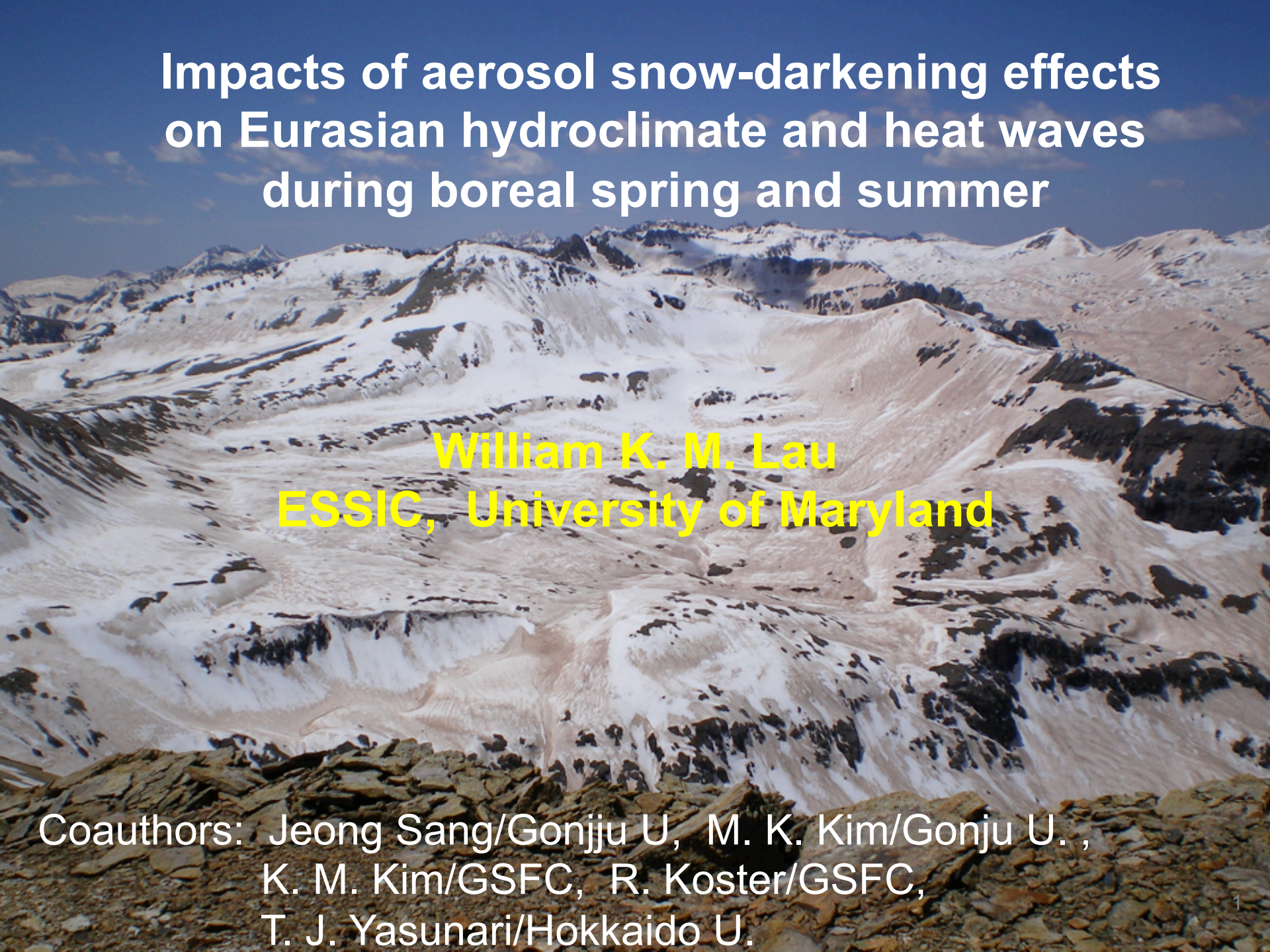
Impacts of aerosol snow-darkening effects on Eurasian hydroclimate and heat waves during boreal spring and summer



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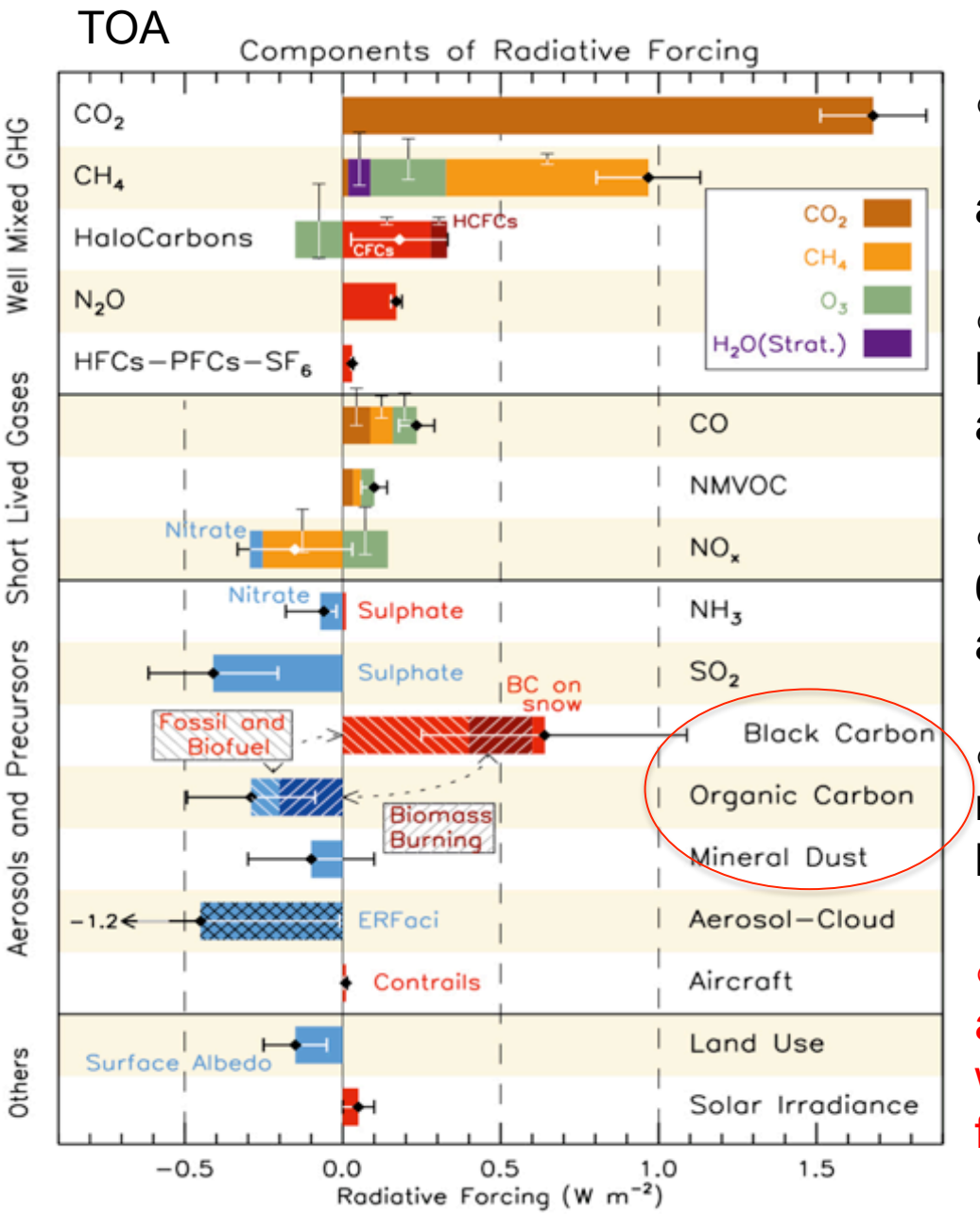
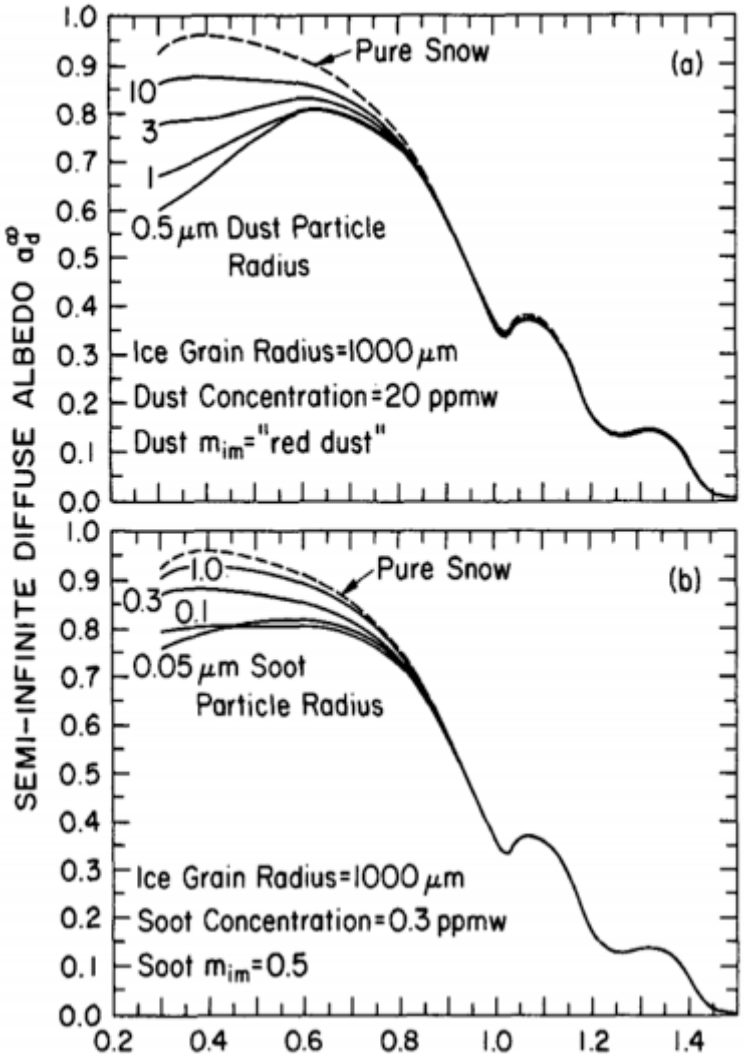
K. M. Kim/GSFC, R. Koster/GSFC,
T. J. Yasunari/Hokkaido U.



IPCC 2013

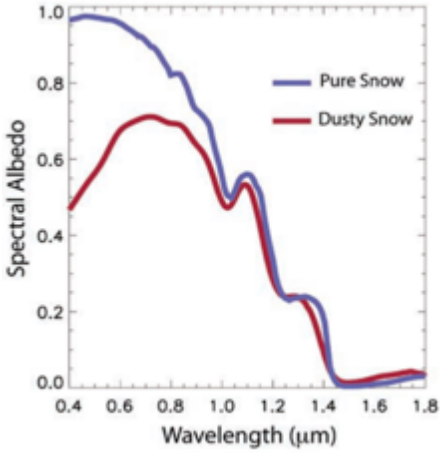
- Aerosol-Cloud-Climate (ACC) feedback is important for global and regional climate change
- ACC feedback processes involve both anthropogenic and natural aerosols
- Globally, natural aerosols are 6- 10 times more abundant than anthropogenic aerosols
- Absorbing aerosols (BC, OC and mineral dusts) amplify atmospheric heating
- Snow-darkening by absorbing accelerate snowmelt, amplify global warming by snow-surface albedo feedback

Snow Darkening Effect (SDE)

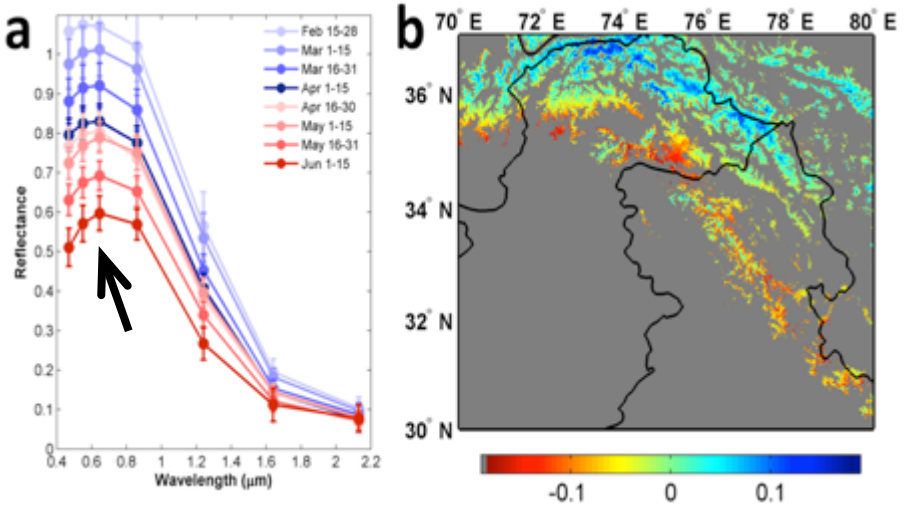


Warren and Wiscombe, 1980

Dust and black carbon reduce snow albedo in the visble wavelenghts



Painter et al., 2009



Gautam et al., 2012

GEOS5 model with a new snow-darkening GOddard SnoW IMpurity (GOSWIM) module

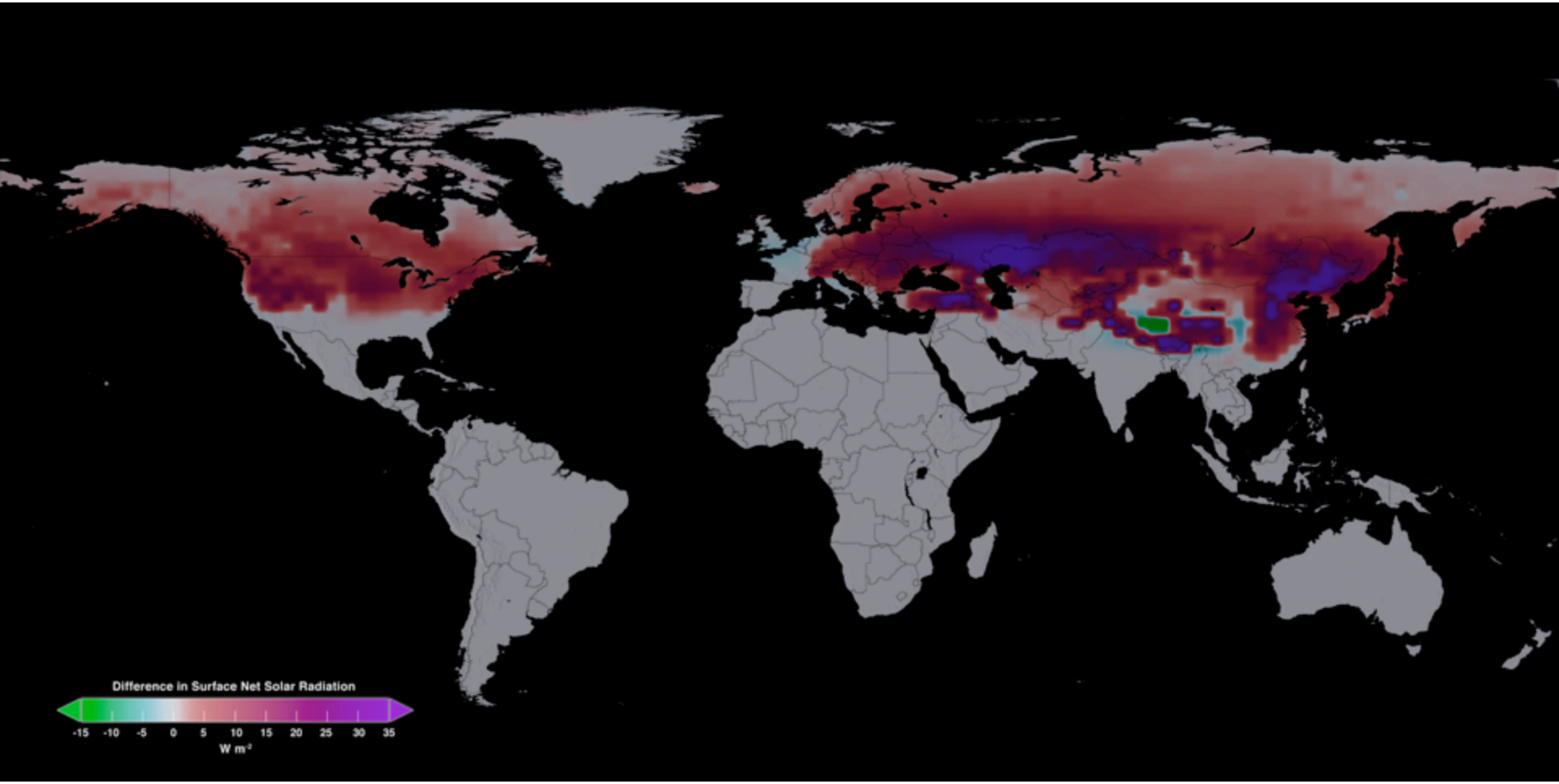
Model	Period	ENS	Experiment	
NASA-GEOS_5	2002.01.01 ~2011.12.31 (10 years)	ENS_MEAN (10 members)	SDE	with snow darkening effect
			NSDE	without snow darkening effect

Snow impurities include dust, BC, and OC (natural + anthropogenic)

Snowdarkening effects by absorbing aerosols on:

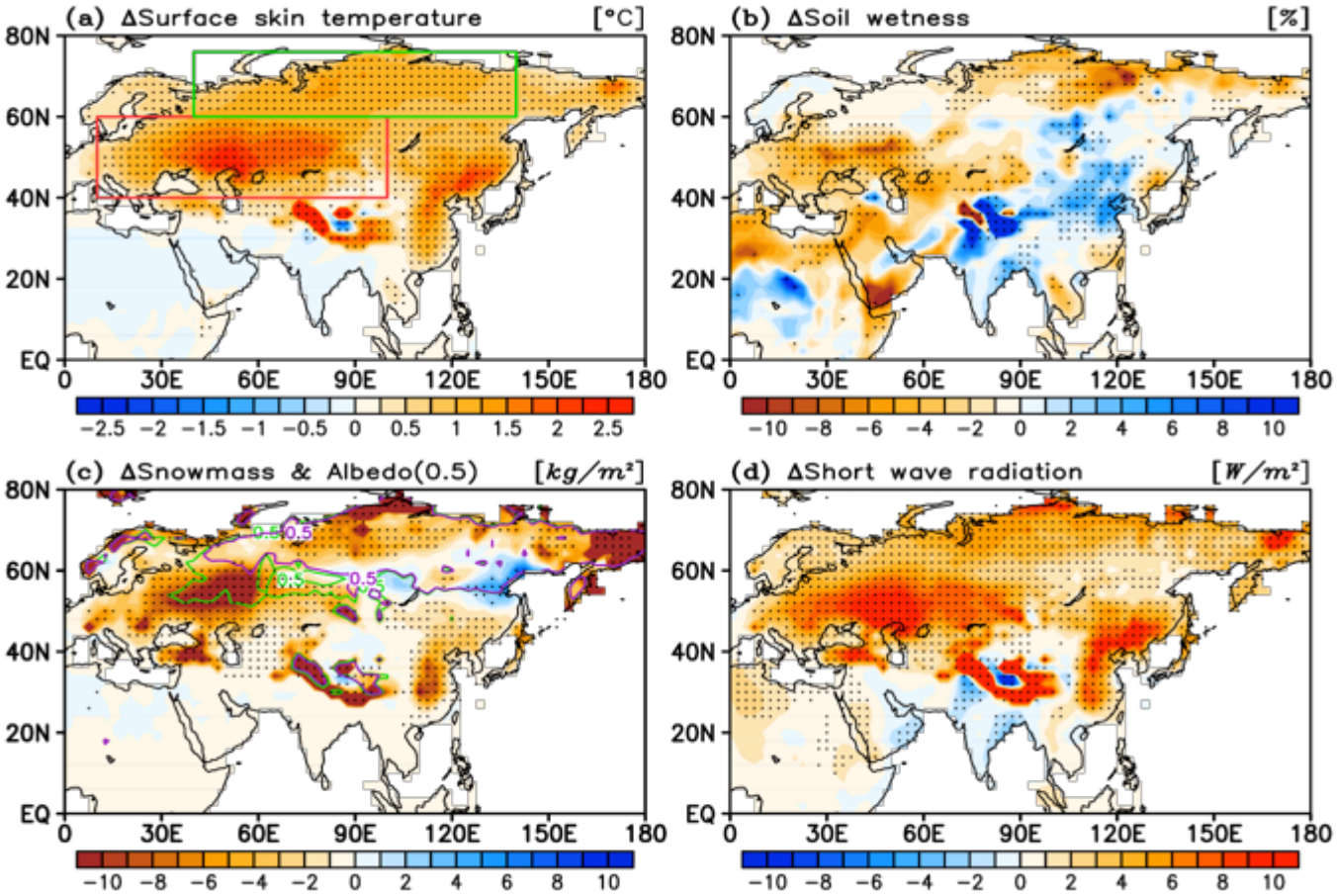
1. Global climate, regional land surface energy and water balances (Eurasia/Central Asia, East Asia, North America and Tibetan Plateau (Yasunari et al. 2015, JGR)
2. Hydroclimate feedback and heatwaves over Eurasia (Lau et al., 2018, JGR, in press)
3. Effects on Asian monsoon precipitation : A revisit of the Blandford hypothesis (Lau and Kim, 2018, in preparation)

Snow-Darkening Effect (SDE): reduced snow albedo by deposition of absorbing aerosols (dust, BC, OC) leads to increased in net surface solar radiation, during the boreal summer melting season (MAM)



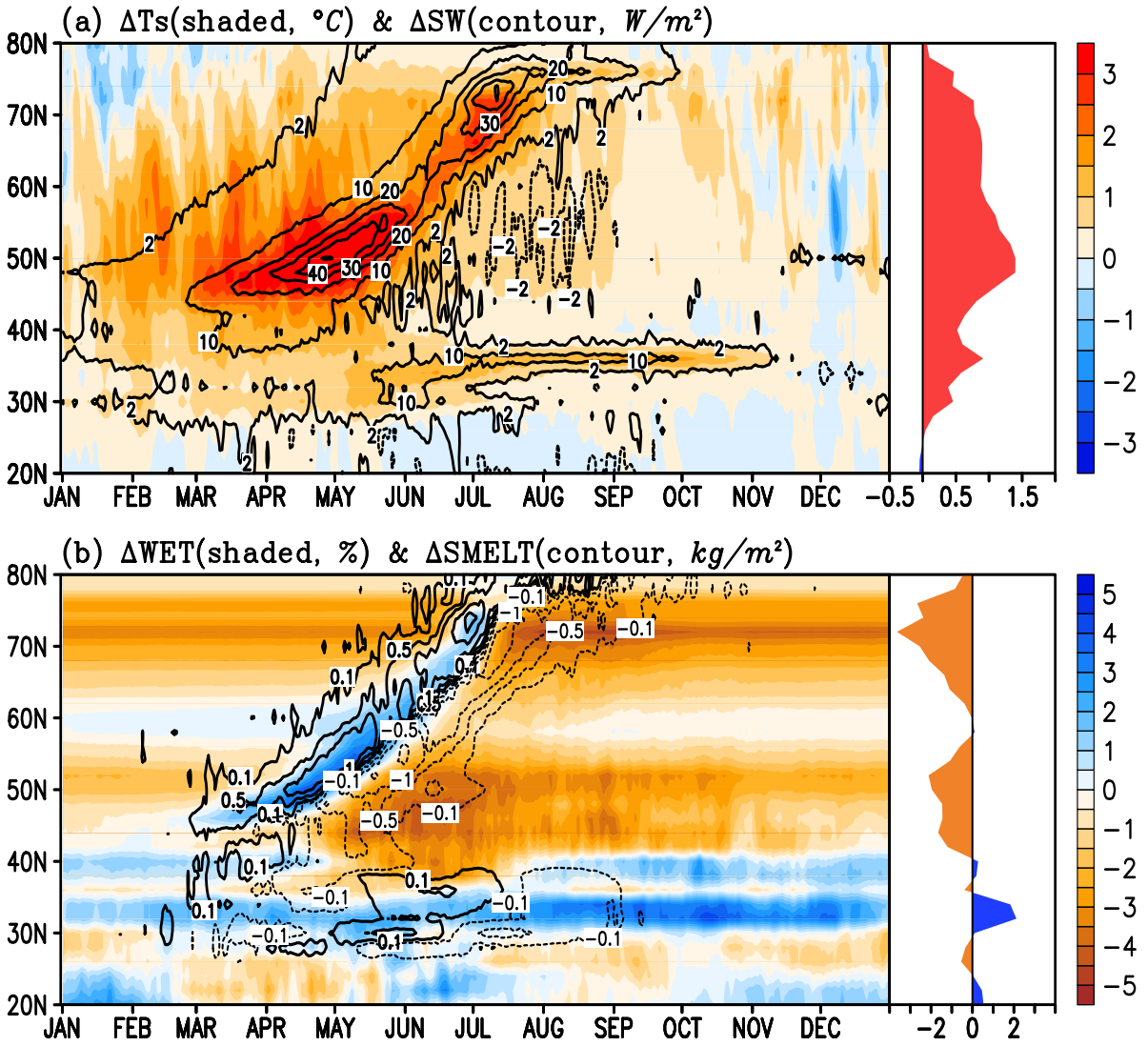
Yasunari et al (2015)

SDE induced annual mean climate change



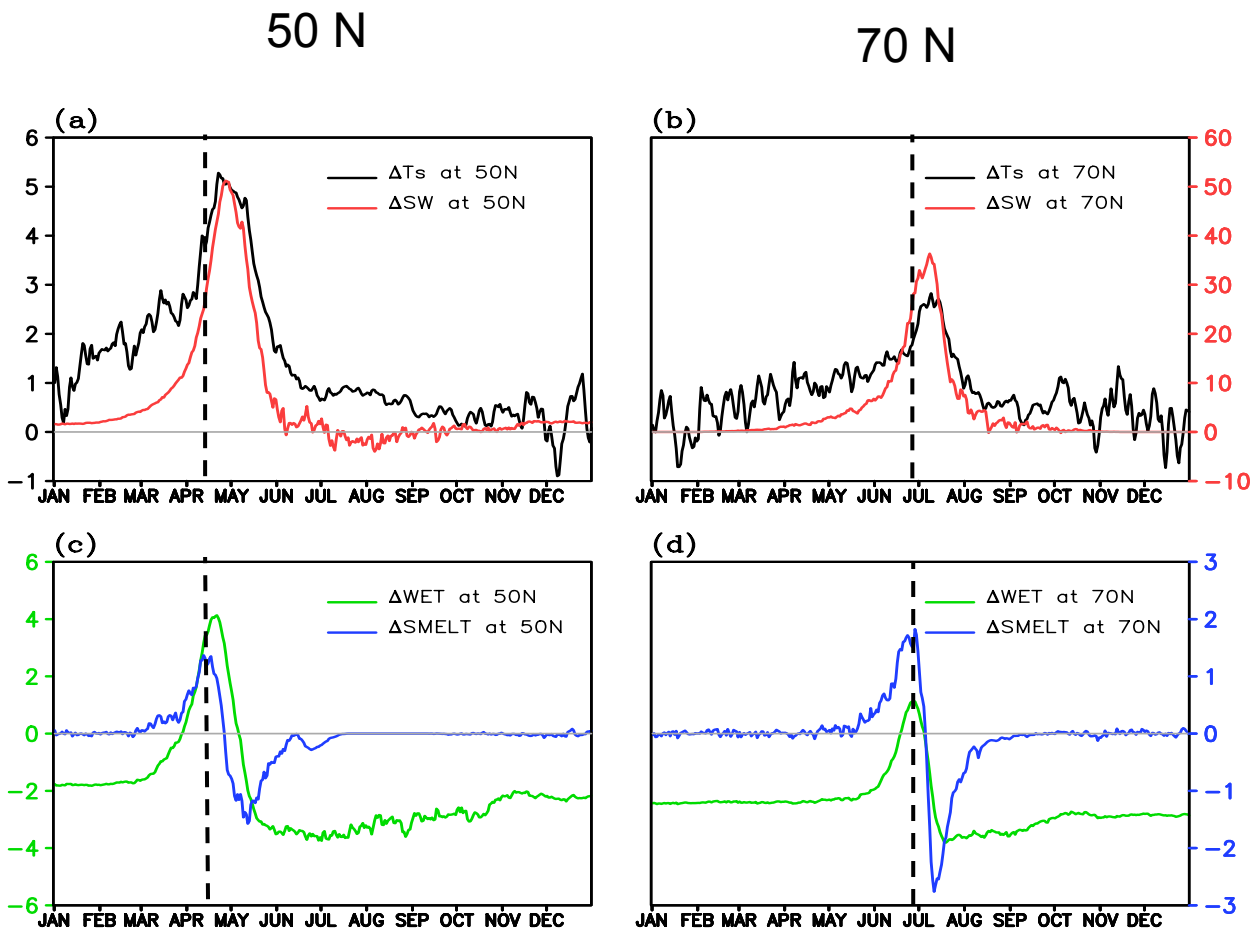
- warmer land > 40 N, entire Eurasia, TP, and and East Asian regions
  SDE increases surface absorption of SW radiation, by albedo reduction of snowcover regions, leading increased snowmelt, but
- changes in soil wetness and relationship with temperature is not obvious

Accelerated snowmelt, warming, soil wetting and drying following the seasonal migration of the snowline over Eurasian land (0-140 E).



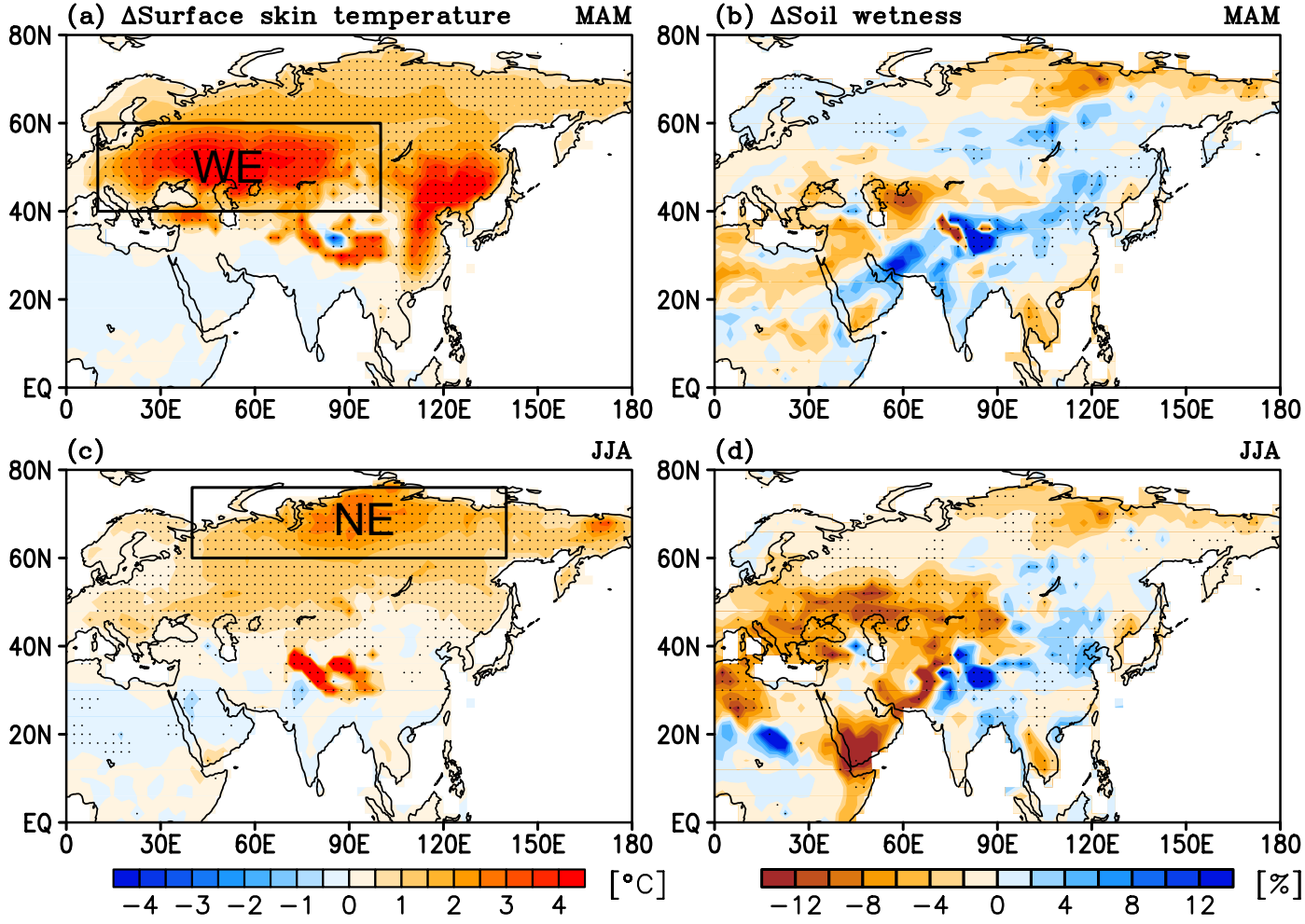
Wet-First
Dry-Later
(WFDL)

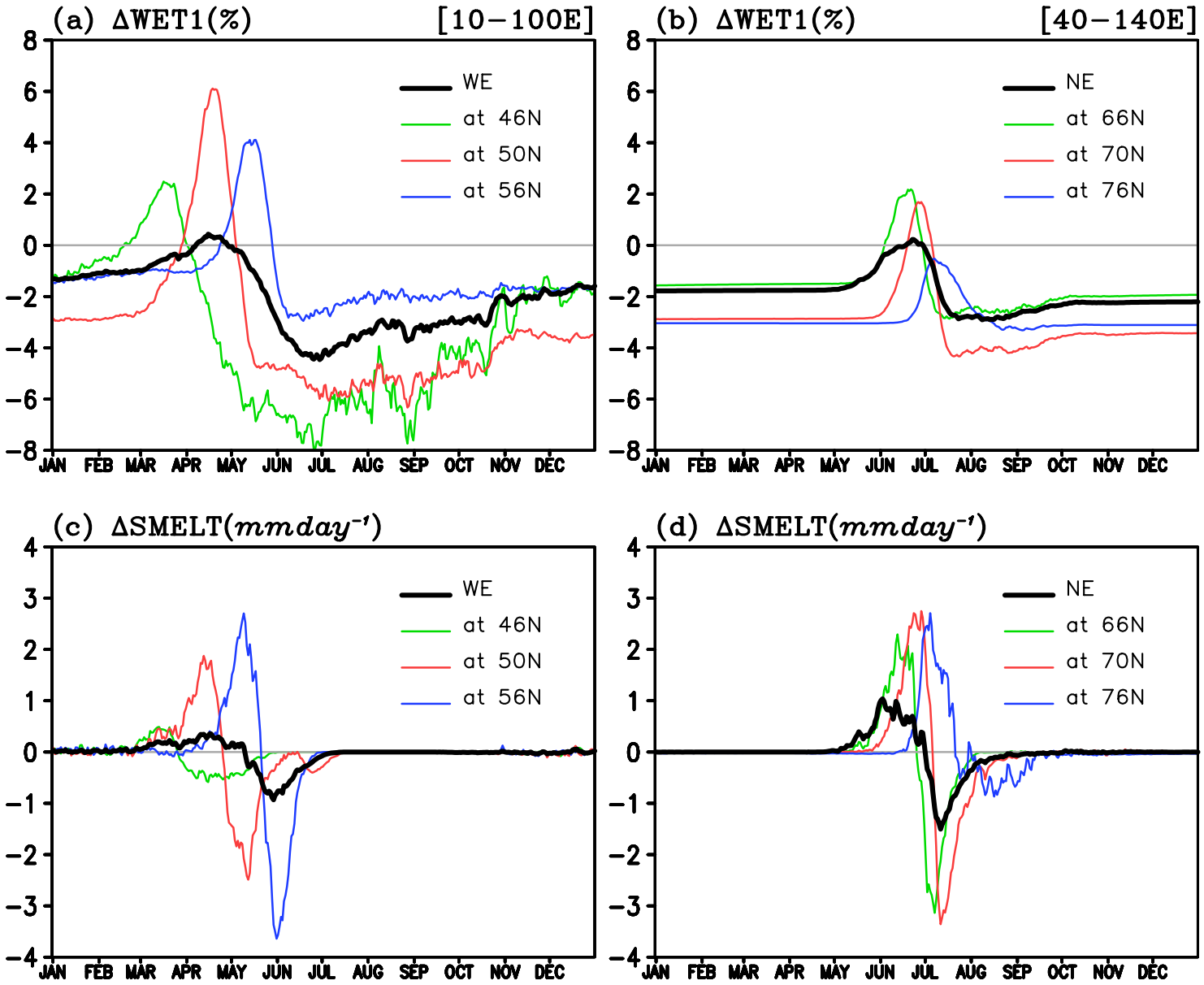
Lau et al., 2018, (JGR,)



The Wet-First- Dry-Later (WFDL) effect:

Fast and brief soil wetting followed by fast and prolonged drying at progressively later time from following the movement of the snowline from high to low latitudes


(a) ΔSurface skin temperature
MAM
WE
(b) ΔSoil wetness
MAM
(c)
JJA
NE
(d)
JJA
80N
60N
40N
20N
EQ
0
30E
60E
90E
120E
150E
180
−4 −3 −2 −1 0 1 2 3 4
[°C]
−12 −8 −4 0 4 8 12
[%]


(a) ΔWET1(%)
[10−100E]
WE
at 46N
at 50N
at 56N
(b) ΔWET1(%)
[40−140E]
NE
at 66N
at 70N
at 76N
(c) ΔSMELT(mmday⁻¹)
WE
at 46N
at 50N
at 56N
(d) ΔSMELT(mmday⁻¹)
NE
at 66N
at 70N
at 76N
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

SDE induced hydroclimate anomalies

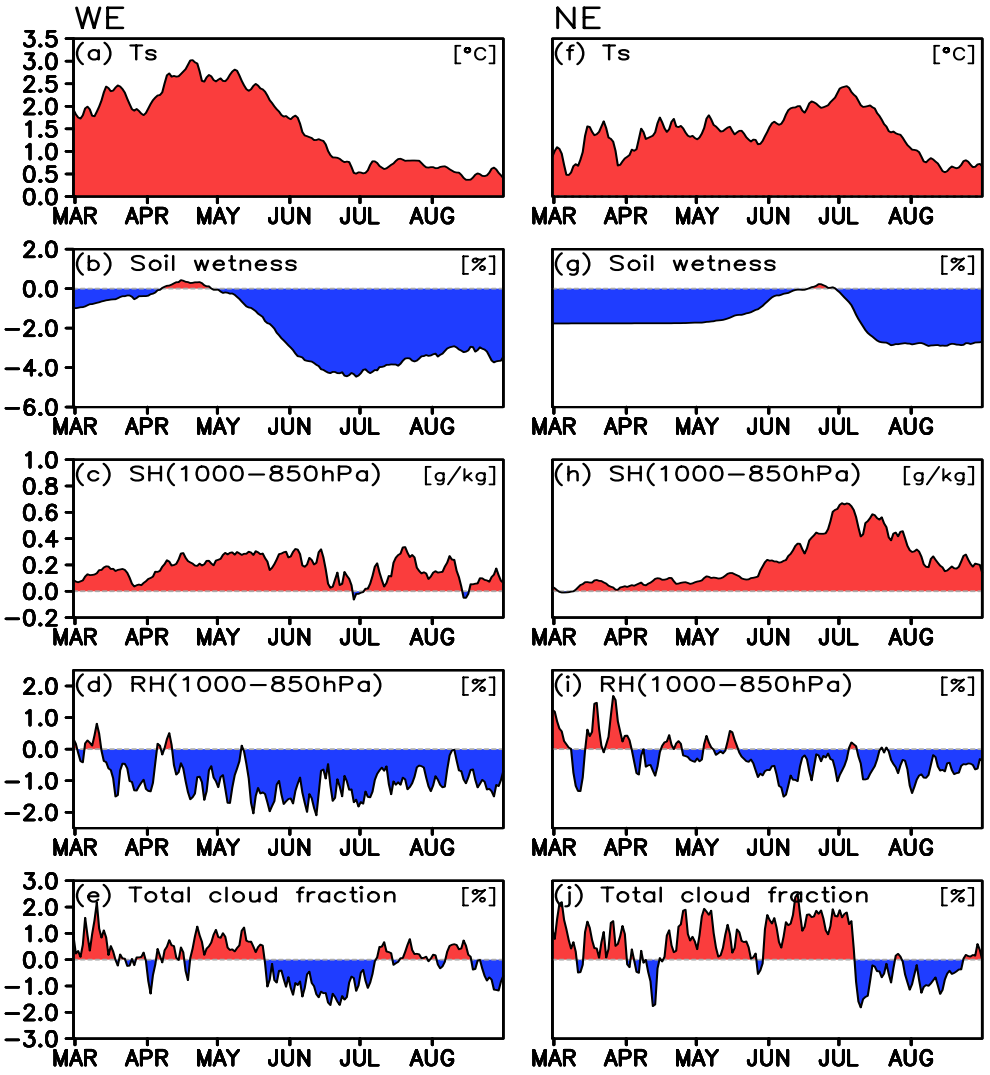
Ts

Soil Wetness

Sp H

RH

Clouds



Warmer land

Drier soil

Increased MSE (=CpT+Lq)

Drier PBL

Less cloud during warming period

$\delta RH = \delta q / q_s - \alpha R_h \delta T$ *CC relationship,*

$\alpha = L(R_v T^2)^{-1} \sim 6\% K^{-1}$

Land surface energy balance

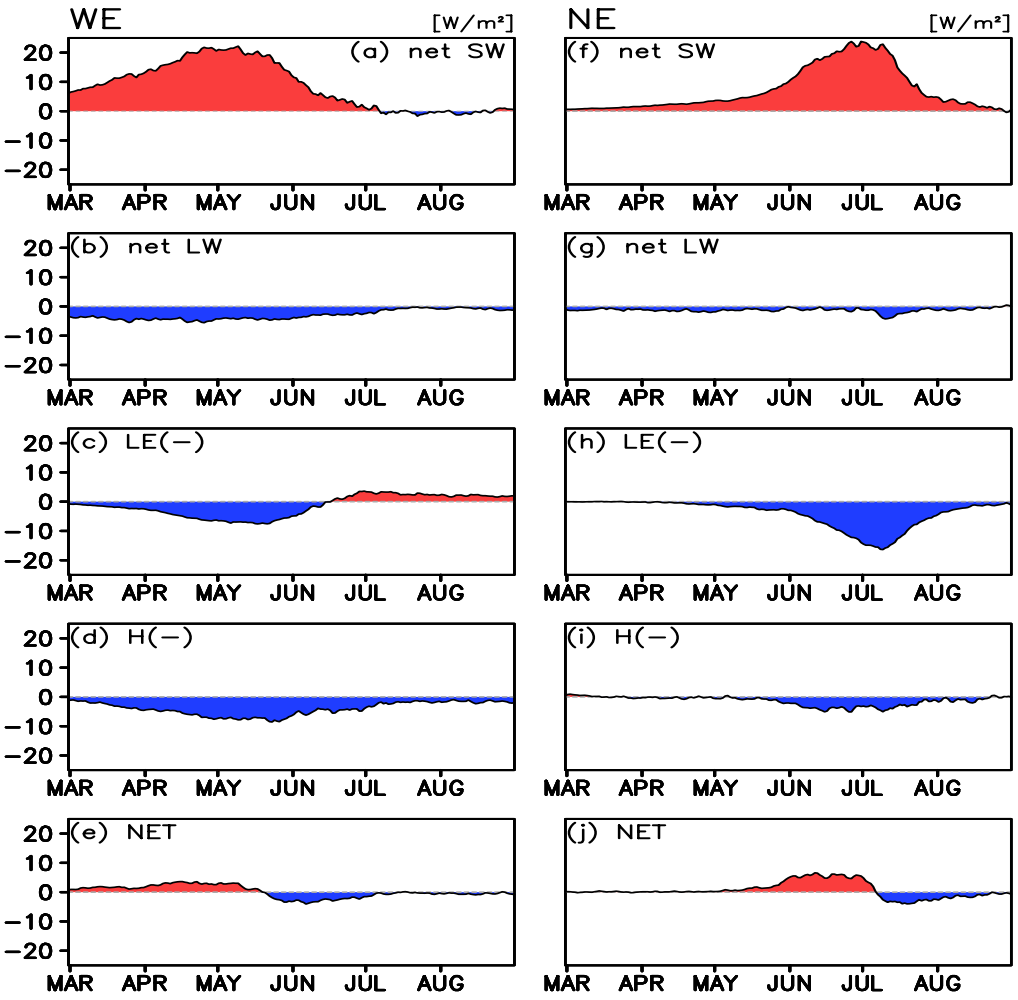
SW

LW

LE

H

Net



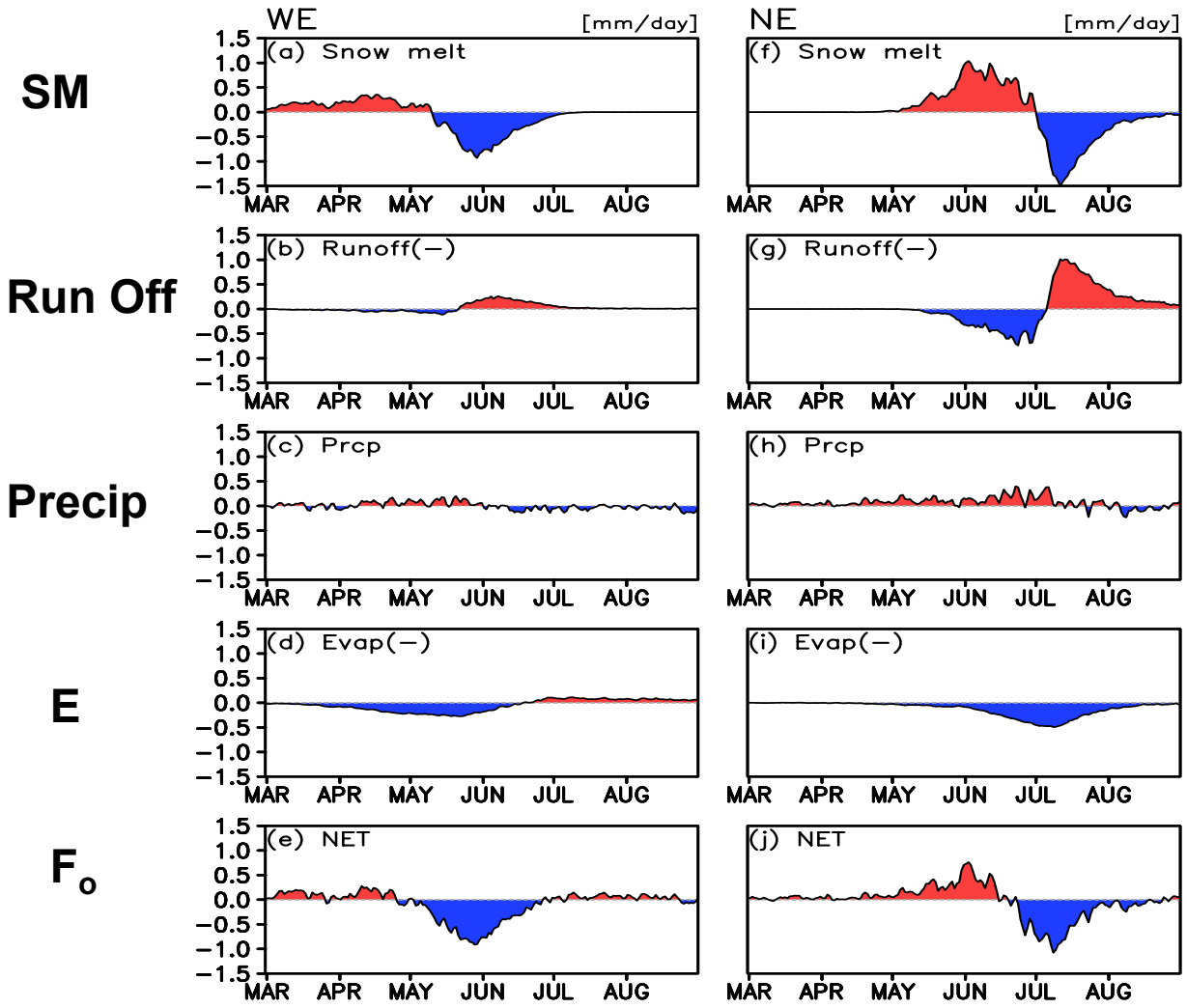
Land gain

Land lost

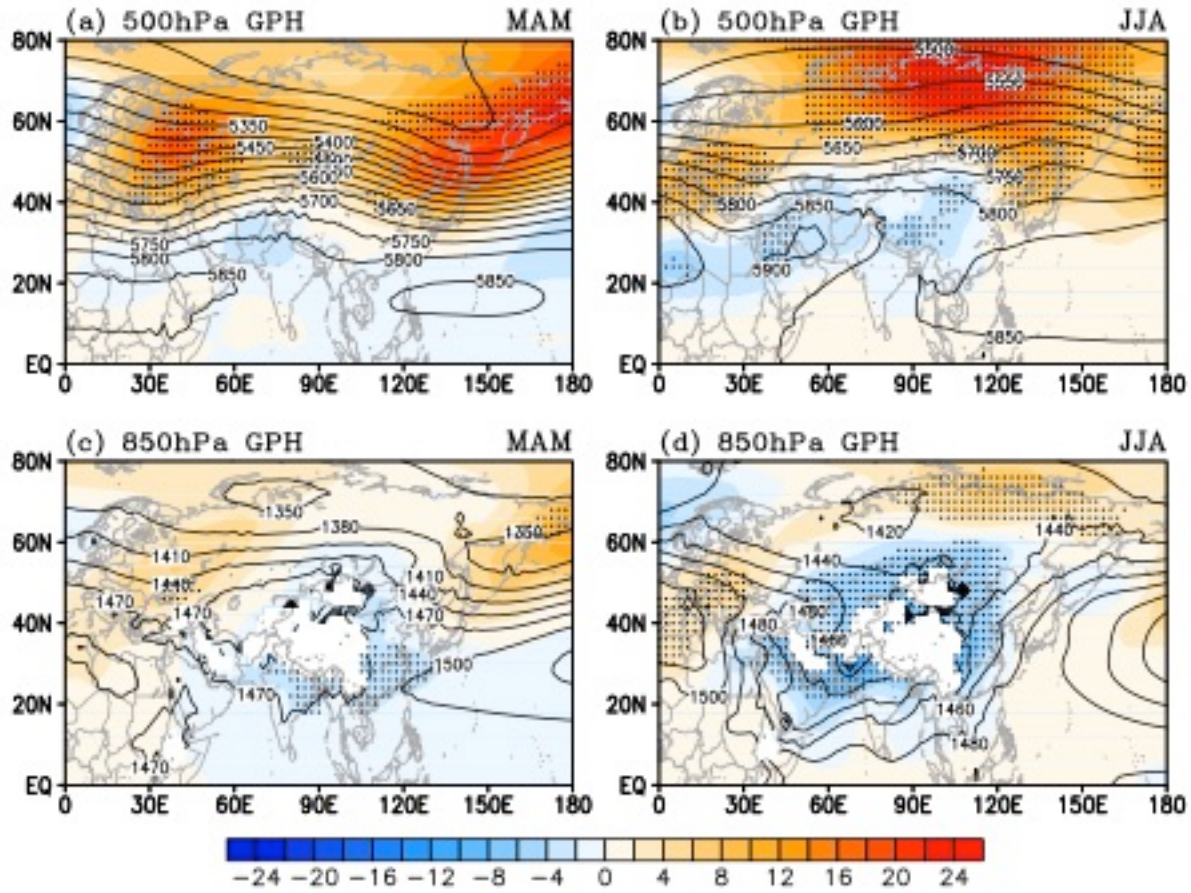
Land Surface Water Balance:

$F_o = SM - R + P - E$

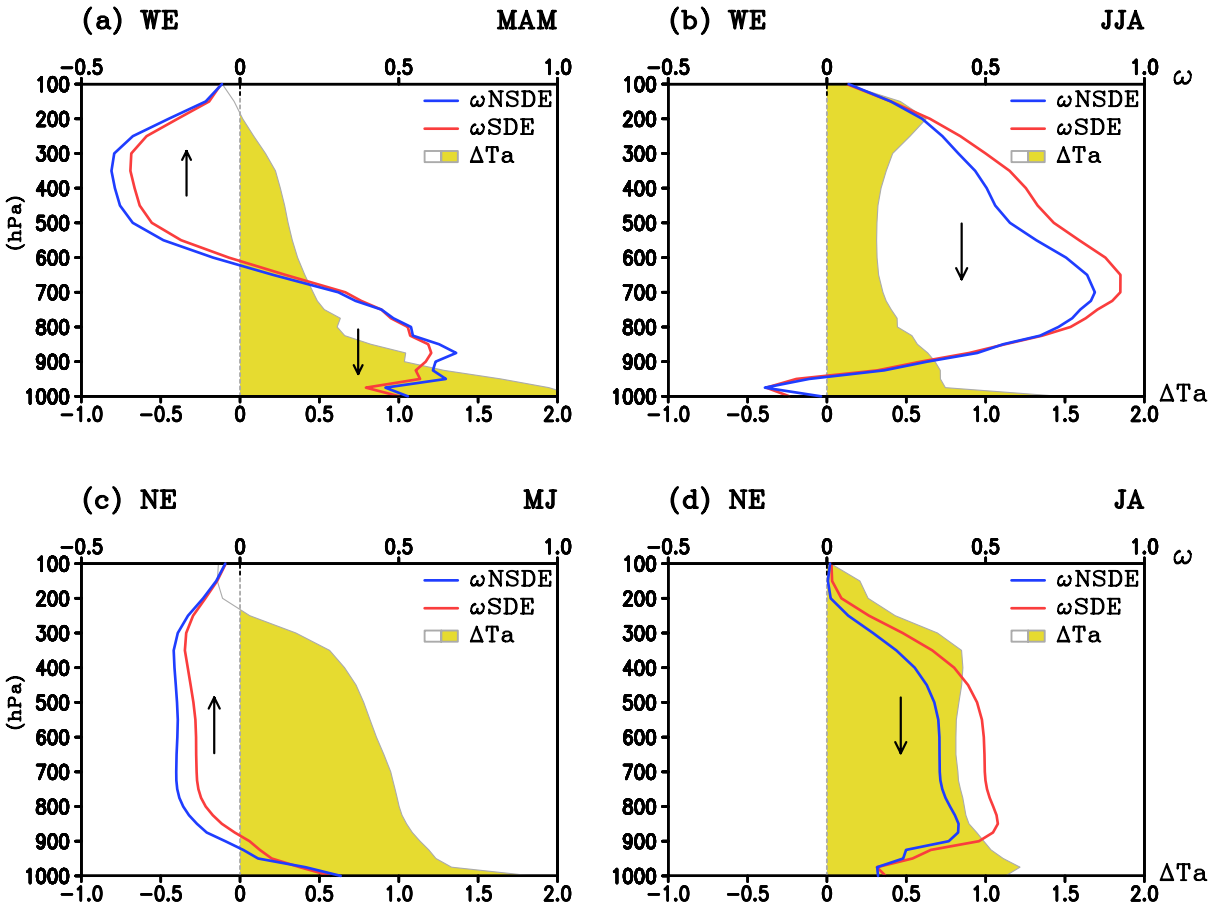
Land Gain
Land Lost



Favorable conditions for heatwaves:
High seasonal mean GPH over WE and NE,



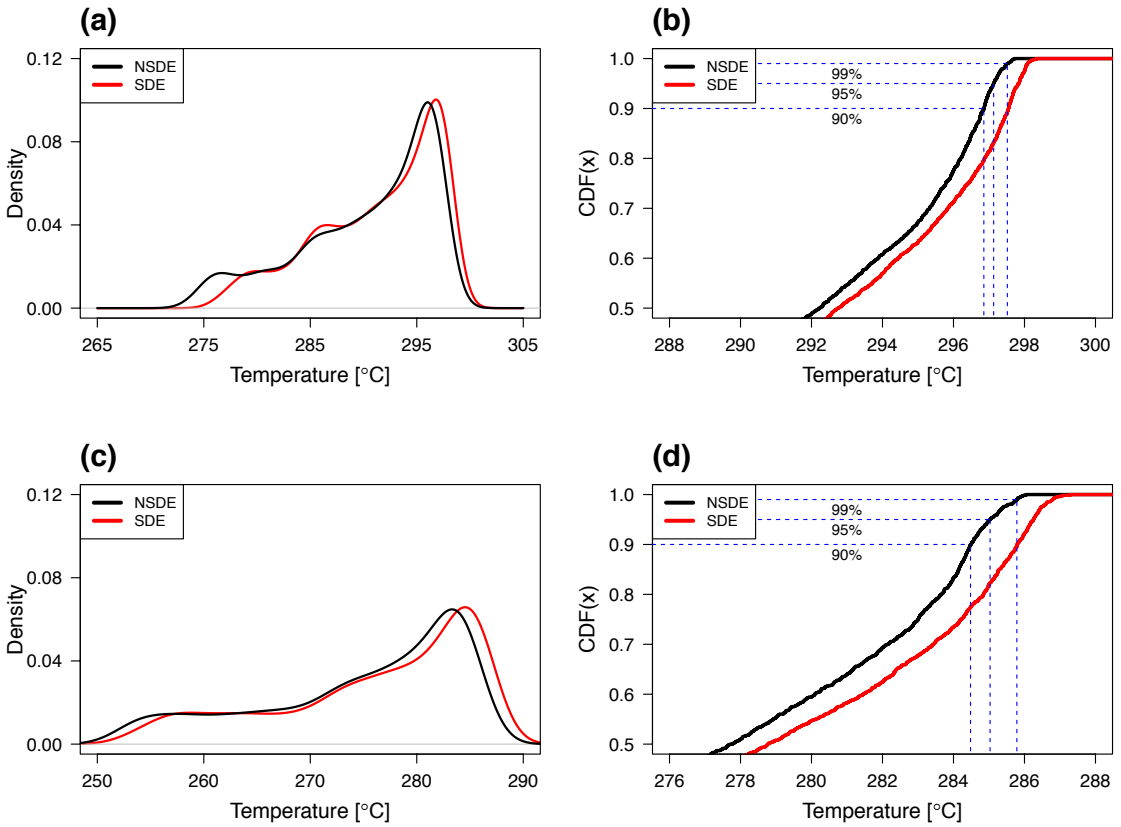
SDE induces warmer surface and troposphere, and stronger subsidence



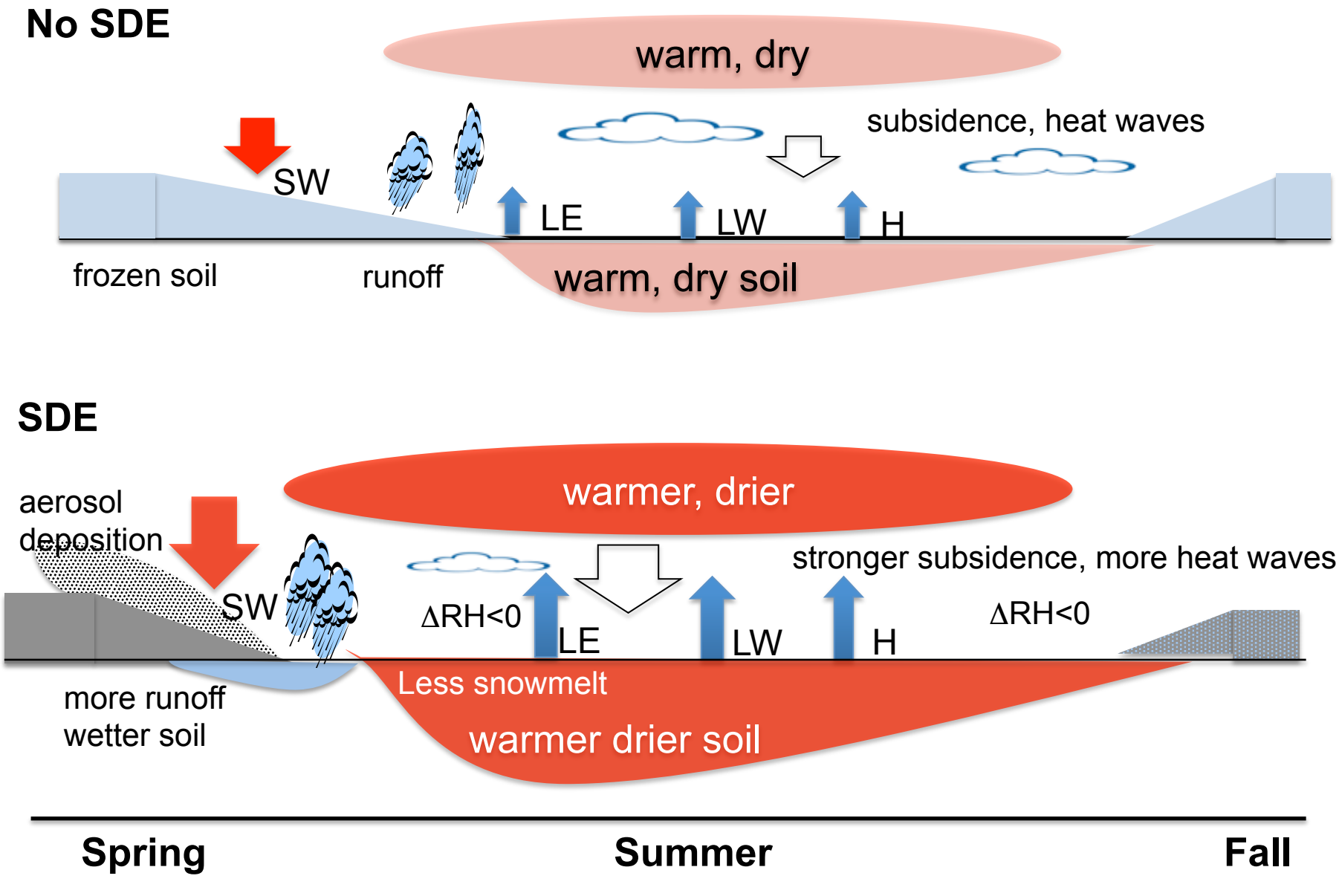
SDE increases frequency of 1% (~10%) extreme heating days (NSDE) by 10 (~20) fold)

WE

NE



NSDE		10%	5%	1%
SDE	WE	20	17	11
	NE	23	18	10


No SDE
warm, dry
subsidence, heat waves
SW
LE
LW
H
frozen soil
runoff
warm, dry soil
SDE
warmer, drier
aerosol deposition
stronger subsidence, more heat waves
SW
ΔRH<0
LE
LW
H
ΔRH<0
Less snowmelt
more runoff
wetter soil
warmer drier soil
Spring
Summer
Fall

Thank you

Conclusions

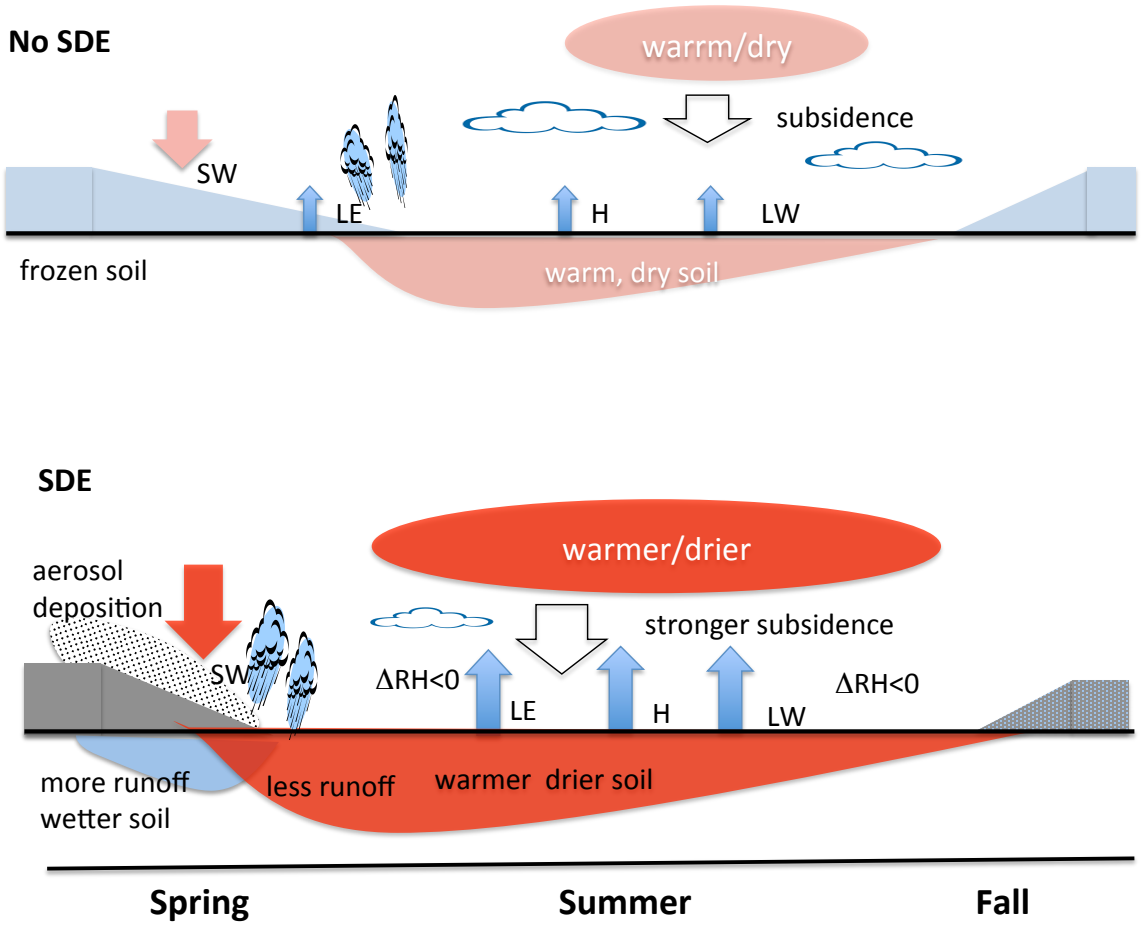
Snow-darkening effects by deposition of absorbing aerosols (dust, BC, and OC) leads to:

- a warmer and drier climate over Eurasia :an increase in annual mean surface skin temperature of up 2.5℃, with a substantial reduction (up to 10% in soil wetness over vast regions of the Europe and increased Asian summe monsoon precipitation.

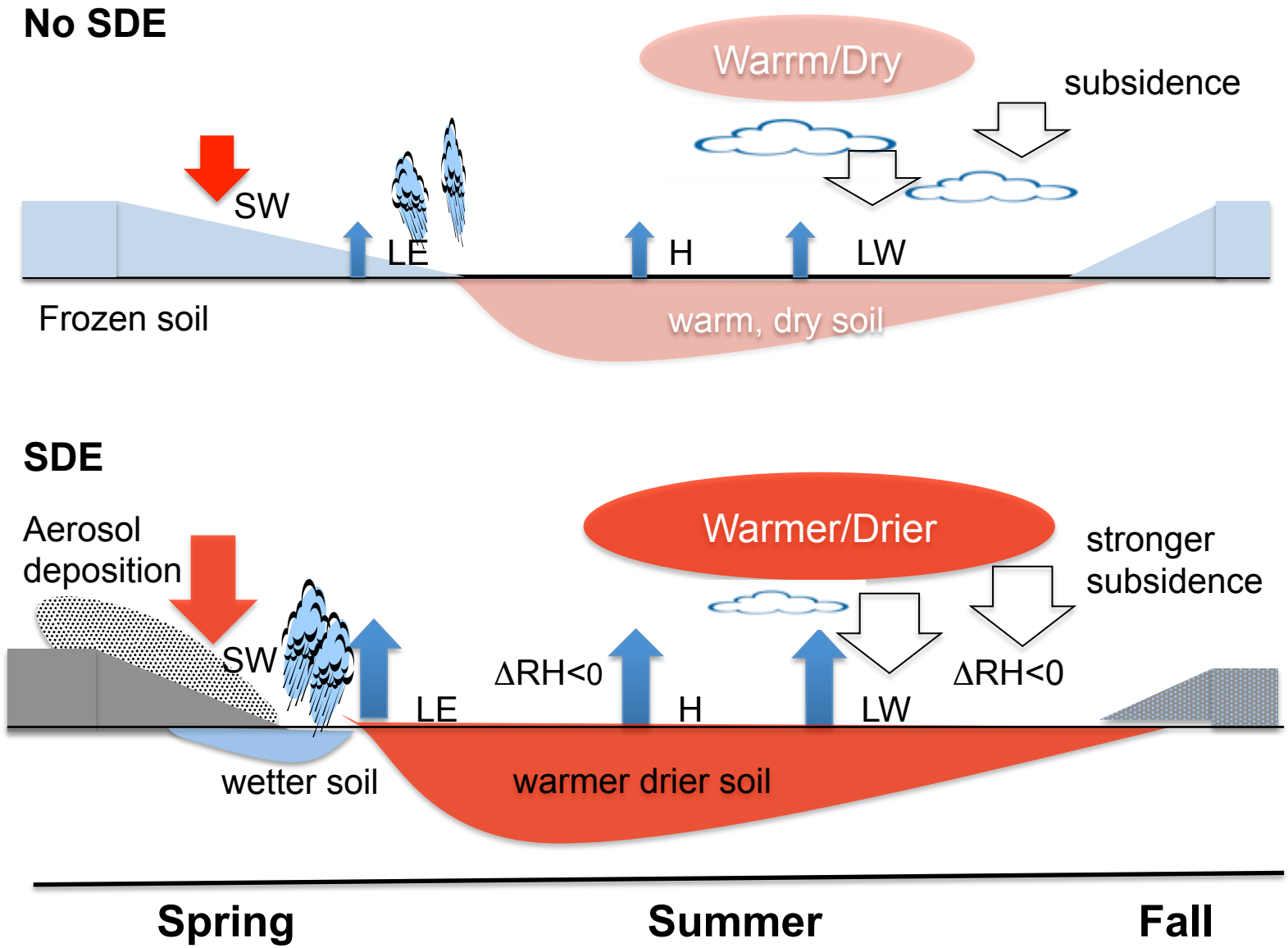
- A continental scale hydroclimate and land-atmosphere WFDL feedback, with fast and earlier snowmelt near seasonal migrating snowline, followed by prolonged and widespread over the snow-covered region of extratropical Eurasia land and high mountain regions

- Increased the top1% (10%) extreme heating days (based on NSDE) over Western Europe, and northern Eurasia by more than 10 (20) times

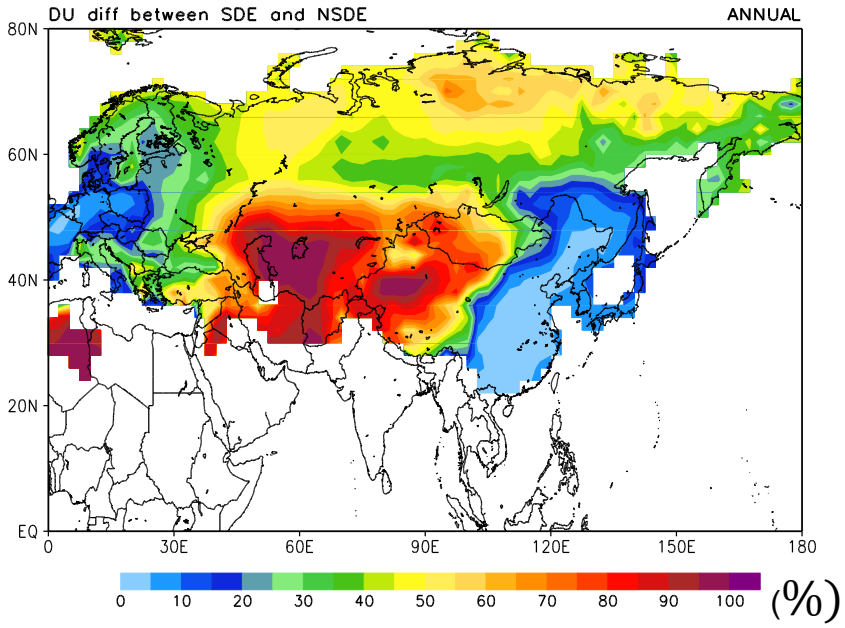
The Wet-First-Dry-Later (WFDL) hydroclimate feedback induced by snowdarkening effect (SDE)



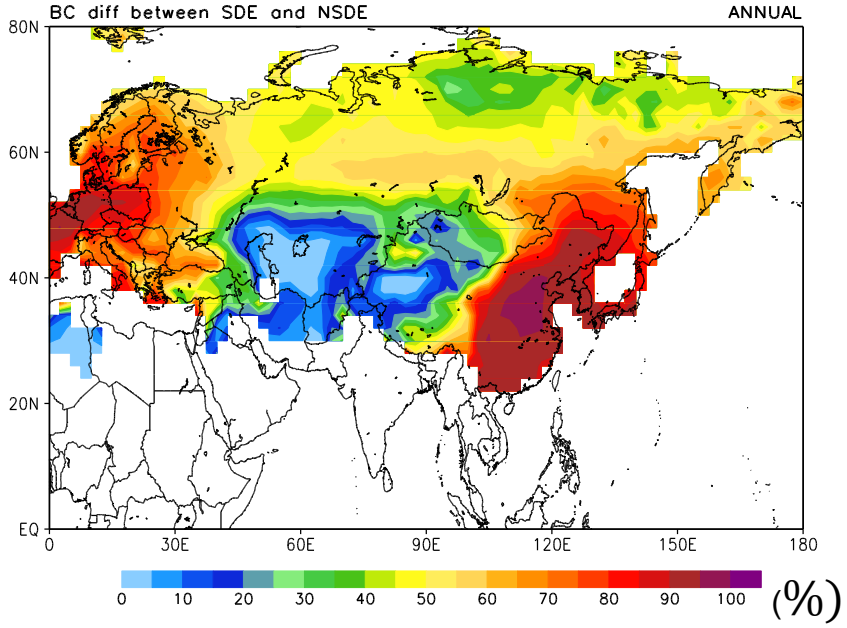
A Wet-First-Dry-Later (WFDL) hydro-climate feedback induced by aerosol snow-darkening (SDE)



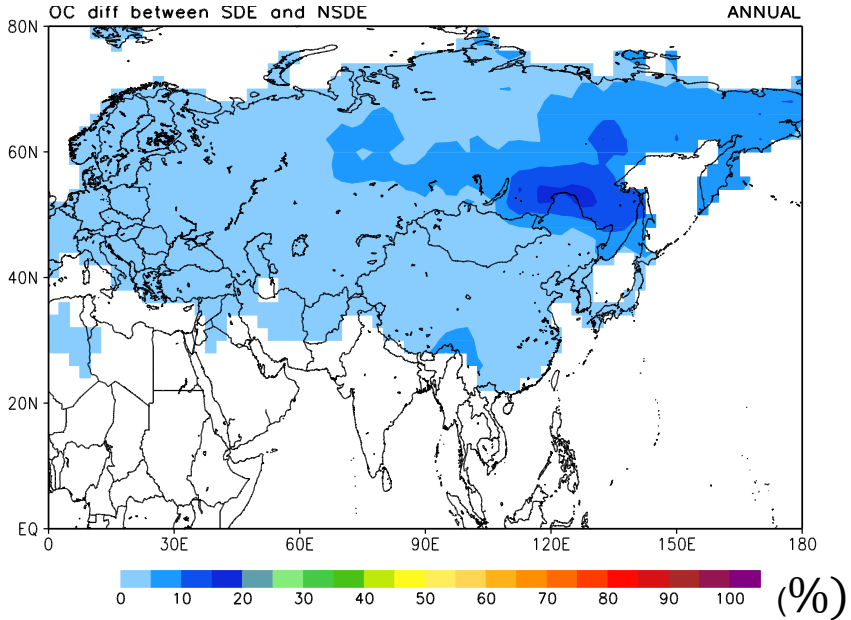
Dust



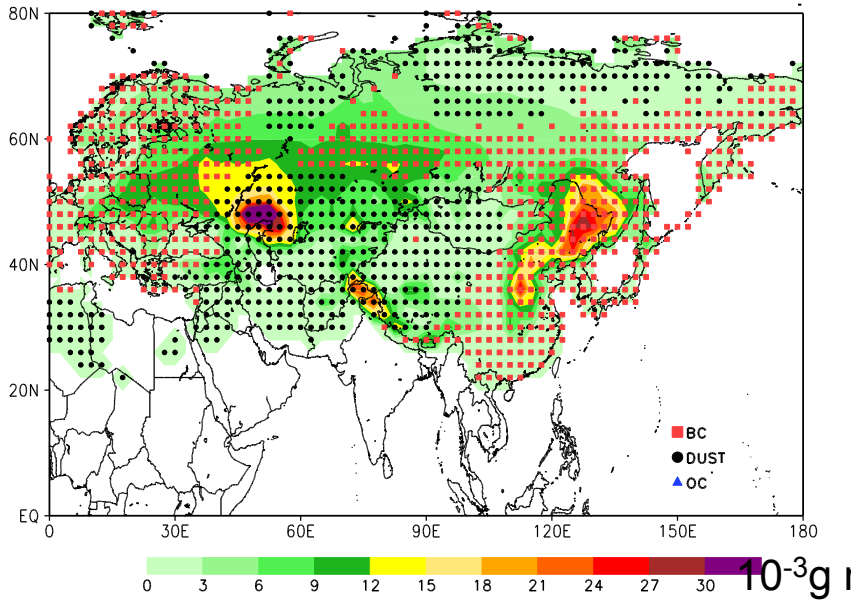
BC



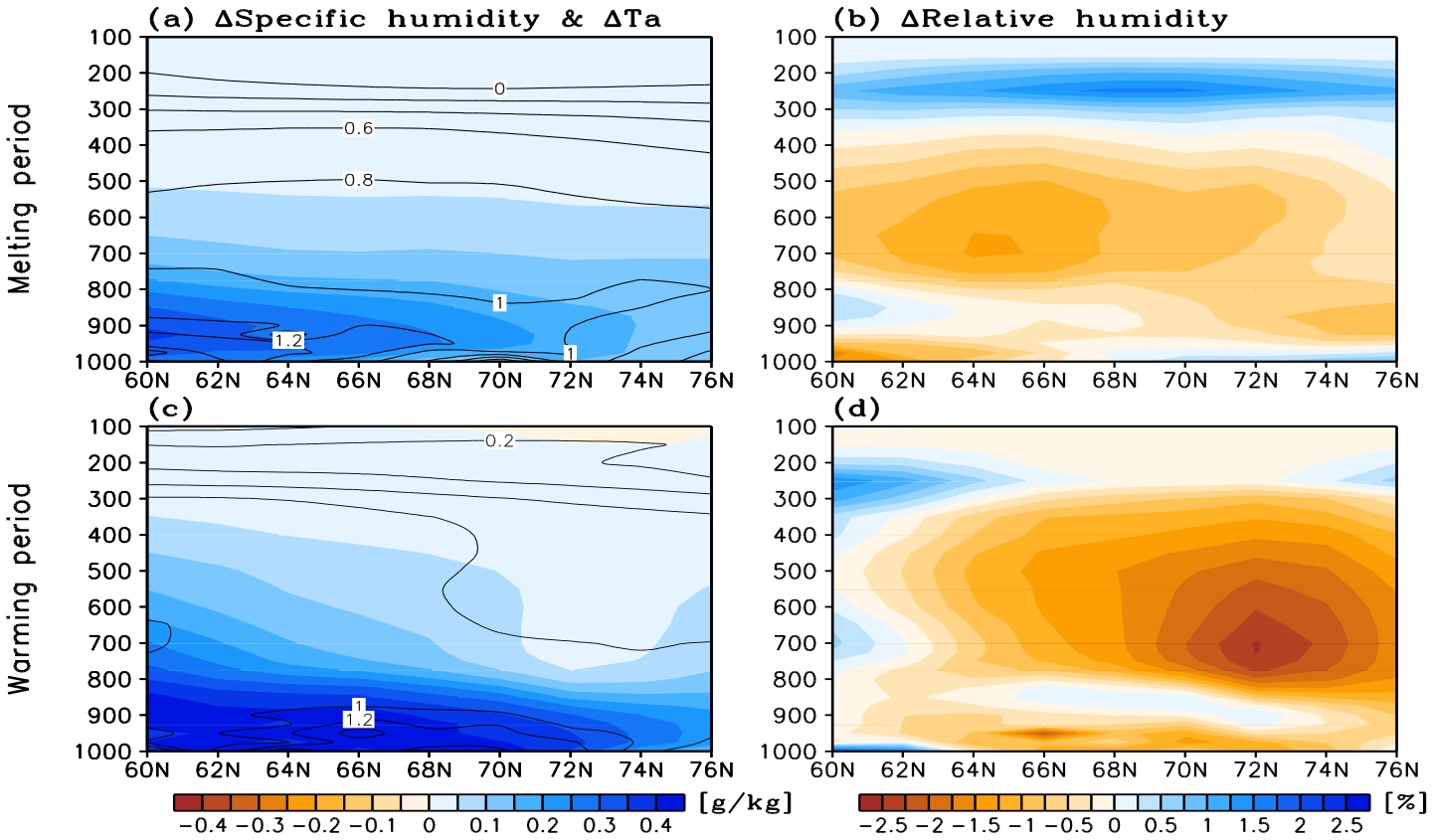
OC



Total snow impurity absorption efficiency



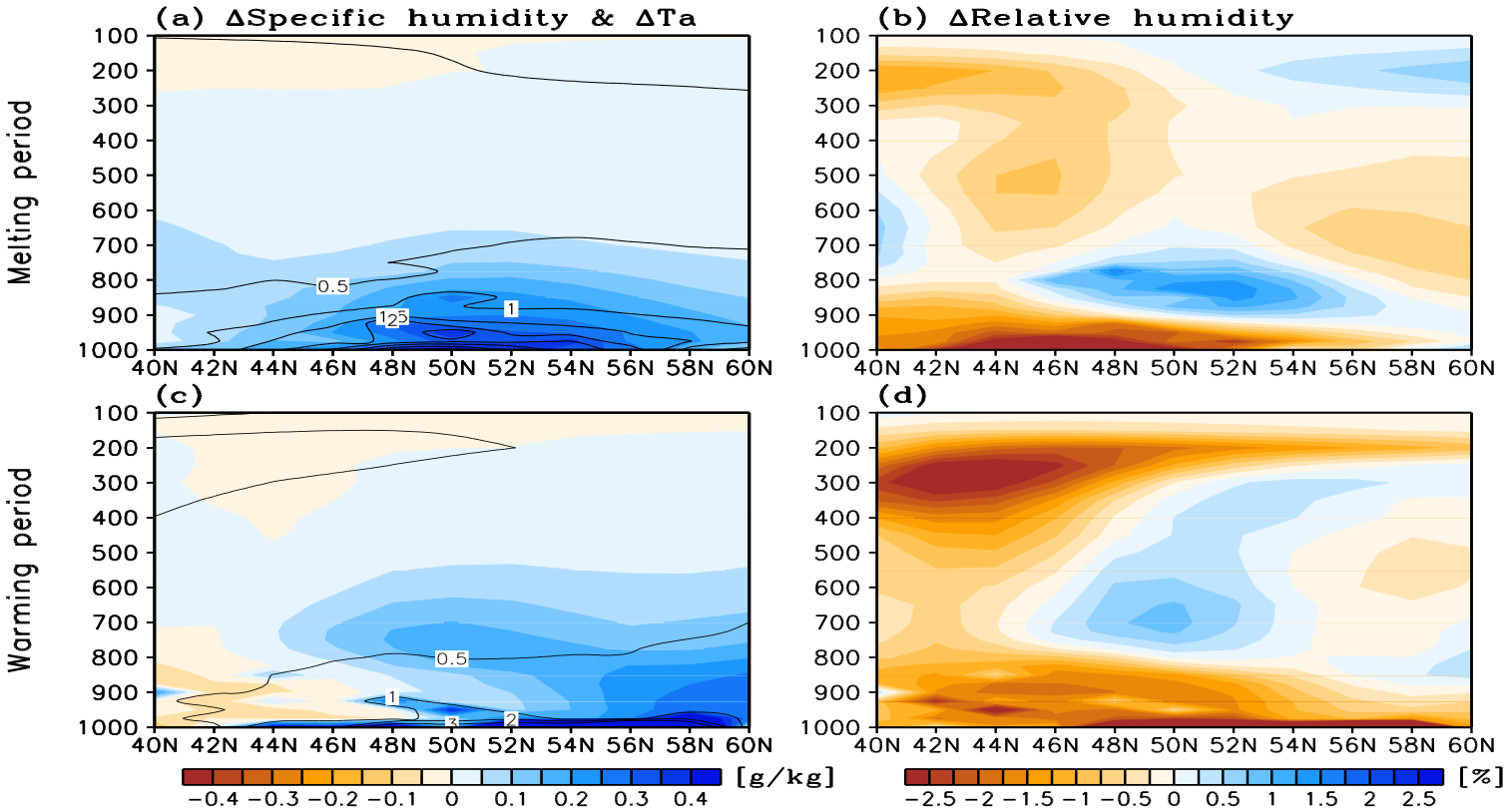
Northern Eurasia



Increase near surface and mid-troposphere MSE (Cp T + q)

Drier (ΔRH<0) surface and upper troposphere

Western Europe



Increase near surface and mid-troposphere
MSE (Cp T + q)

Drier (ΔRH<0) surface and upper troposphere