Soot Emission Uncertainties at the Cretaceous-Paleogene Boundary (KPB)

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Background

- Cretaceous-Paleogene mass extinction coincided with the Chicxulub asteroid impact
- Sedimentological records show soot deposition contemporaneous with iridium deposition
- Model simulations suggest soot emissions led to reduction in light, temperature, and precipitation
- Controversy over the source of the soot
    - Asteroid impact, fires, or both

Potential Soot Sources

- Soot from fires associated with reentry of impact material
  - Emitted at the tropopause over vegetated regions
  - Both coarse and fine soot
- Soot from material ejected at the impact site
  - Emitted globally at 50 km
  - Only fine soot

Goal

- Explore uncertainties of soot emission;
- How? Compare model simulations with sedimentological records of soot deposition
  - Sensitivity of soot deposition to various factors including emission timing, duration, fraction at tropopause, coarse soot mean radius, etc.
- Explore the climate response to different possible soot emission scenarios at the KPB.

Methodology

- CESM 2.1.3 code base
- WACCM4 (high top atm) + CARMA (aerosols)
- Cretaceous-Paleogene Boundary conditions
  - Topography, GHGs, vegetation, solar constant
- Soot and water vapor emissions from asteroid impact
- Soot abundance and fine fraction records at 12 sites across the KPB (Wolbach et al., 1990 ; Wolbach et al., 2003)

You probably do not need this slide.

The post-processed data is probably sufficient.

TABLE 2. CARBON AND IRIDIUM AT THE K/T BOUNDARY

Site		Carbon Abund.* (mg/cm_2)		Soot (%)	$\delta^{13}C_{PDB}$ (‰)	Iridium Abund. (ng/cm^2)	Ref.† C	Ref.† Ir
Woodside Creek	NZ	4.8	±0.5	69	-25.23	91	1	1
Chancet Rocks	NZ	35[a]	+5/-20	68	-25.42	32[a]	1	1
Stevns Klint	KD	11[be]	+11/-1	21	-25.81	250[e]	2	5
Caravaca	E	10[bceh]	+10/-1	14	-25.00	38[e]	2	6
Gubbio	I	13[bceh]	+13/-1	17	-25.48	15[e]	2	7
Agost	E	3.6[g]	+3.8/-0	~2	-26.04	≤24.5	2	8
Raton	USA	4.0[ag]	+6.5	~1	-26.70	7.2	2	9
El Kef	TN	15[begh]	+15	19	-26.57[i]	49[e]	2	10
Flaxbourne River	NZ	≤1.3[d]	+0/-0.6	55	(-26.08)[d]	134	3	11
Elendgraben	A	>0.8[f]	+8/-0	12	(-23.37)	125	2	12
Sumbar	SU	13[g]	±3	15	-25.96	580	4	13

The wrong column is outlined?

Uncertainties for carbon deposition only, no uncertainties provided for fine soot fraction

Wolbach et al., 1990

TABLE 1 PROCESSED AND RAW DATA OF CARBON RECORDS AT THE KPB

Site	Total Carbon Deposition(mg/cm^2)		Fine Soot Ratio(%)
Raw Data			
Woodside Creek, NZ	4.8	+5/-5	69
Chancet Rocks, NZ	35	+5/-20	68
Stevns Klint	11	+11/-1	21
Caravaca	10	+10/-1	14
Gubbio	13	+13/-1	17
Agost[1]	3.6	+3.8/-0	2
Raton[1]	4.0	+6.5	1
El Kef	15	+15	19
Flaxbourne River, NZ	1.3	+0/-0.6	55
Elendgraben[2]	0.8	+8/-0	12
Sumbar	13	+3/-3	15
DSDP 465[3]	3.6	+0.4/-0.4	0.5
Processed Data			
NZ avg	11.1		64
Stevns Klint	16		21
Caravaca	14.5		14
Gubbio	19		17
El Kef	22.5		19
Sumbar	13		15
DSDP 465	3.6		0.5

Post-processing

site	Total carbon	Error bar for total carbon	Total carbon corrected	Fine soot ratio
Woodside Creek	4.8	+0.5/-0.5	4.8	69
Chancet Rocks	35	+5/-20	27.5	68
Flaxbourne River	1.3	+0/-0.6	1.0	55
Stevns Klint	11	+11/-1	16	21
Caravaca	10	+10/-1	14.5	14
Gubbio	13	+13/-1	19	17
El Kef	15	+15	22.5	19
Sumbar	13	+3/-3	13	15
DSDP 465	3.6	+0.4/-0.4	3.6	0.5

Source	Total soot Emission	fine soot / total element soot ratio	fine soot emission fraction at tropopause	coarse soot emission fraction at tropopause	duration (day)	Emission Timing	Coarse soot mean raduis
fire	72400 Tg	**0.266**	1	1	1	May	10um
fire	72400 Tg	0.11	1	1	1	May	10um
fire	72400 Tg	0.11	1	1	**14**	May	10um
fire	72400 Tg	0.11	1	**0**	1	May	10um
fire	72400 Tg	0.11	**0.5**	1	1	May	10um
fire	**2500 Tg**	1	1	1	1	May	10um
fire	**148332 Tg**	0.11	1	1	1	May	10um
fire	72400 Tg	0.11	1	1	1	**March**	10um
fire	72400 Tg	0.11	1	1	1	**July**	10um
fire_impact	72400 Tg	0.266	1	1	1	May	10um
fire	72400 Tg	0.266	1	1	1	May	**7.5um**
fire	72400 Tg	0.266	1	1	1	May	**5.0um**

Fine Soot Ratio

26.6% mean of all sites
11.0% minimum fine soot fraction among all sites.

Total Soot Deposition (mg/cm^2)

WACCM/CARMA)

Wolbach

Fine Soot Fraction

Fine Soot Ratio

26.6% mean of all sites
11.0% minimum fine soot fraction among all sites.

WACCM/CARMA)

Wolbach

Emission Amount

148,339 Tg assume all the vegetation in our simulation (based on CLM4) are burned.

Total Soot Deposition (mg/cm^2)

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Fine Soot Fraction

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Total Soot Deposition (mg/cm^2)

Emission Duration

Extended emission from May 1st to 14th

WACCM/CARMA)

Wolbach

Fine Soot Fraction

Emission Duration

Extended emission from
May 1st to 14th

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Seasonal Timing

Emit soot in March, May, or July

Total Soot Deposition (mg/cm^2)

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Wolbach

Fire vs Fire_Impact

Fire_Impact case:

Replaced the 2500 Tg of fire-generated fine soot with the impact soot

Total Soot Deposition (mg/cm^2)

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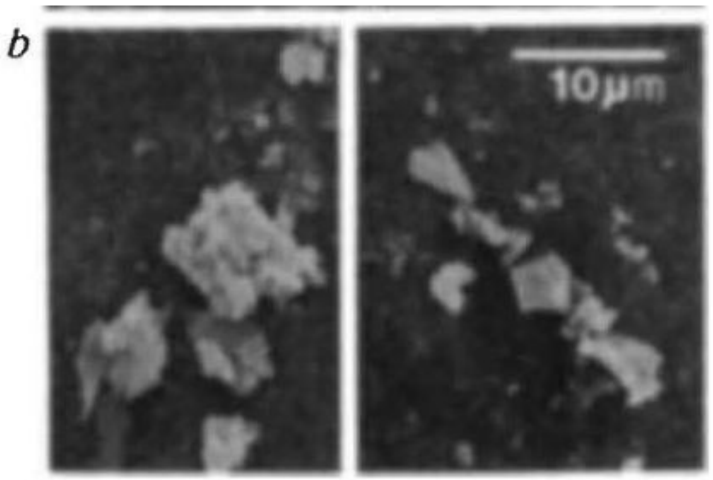
WACCM/CARMA)

Wolbach

Total Soot Deposition (mg/cm^2)

Coarse Soot Particle Size

7.5 um Reid et al., (2005)
5.0 um Reid et al., (2005)
10 um Wolbach et al., (1998)



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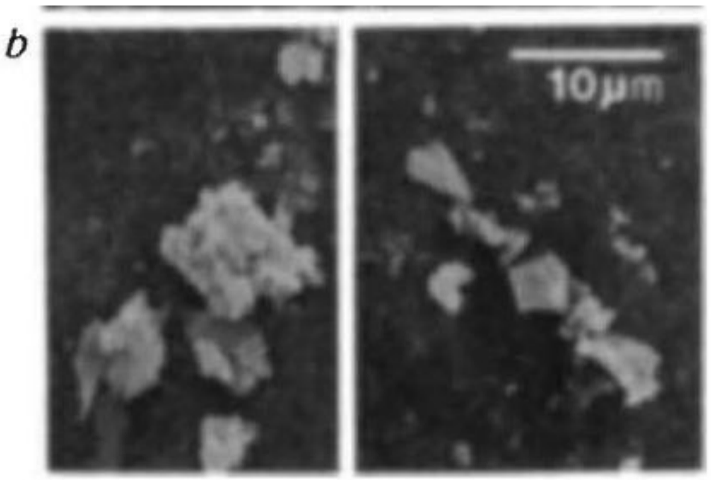
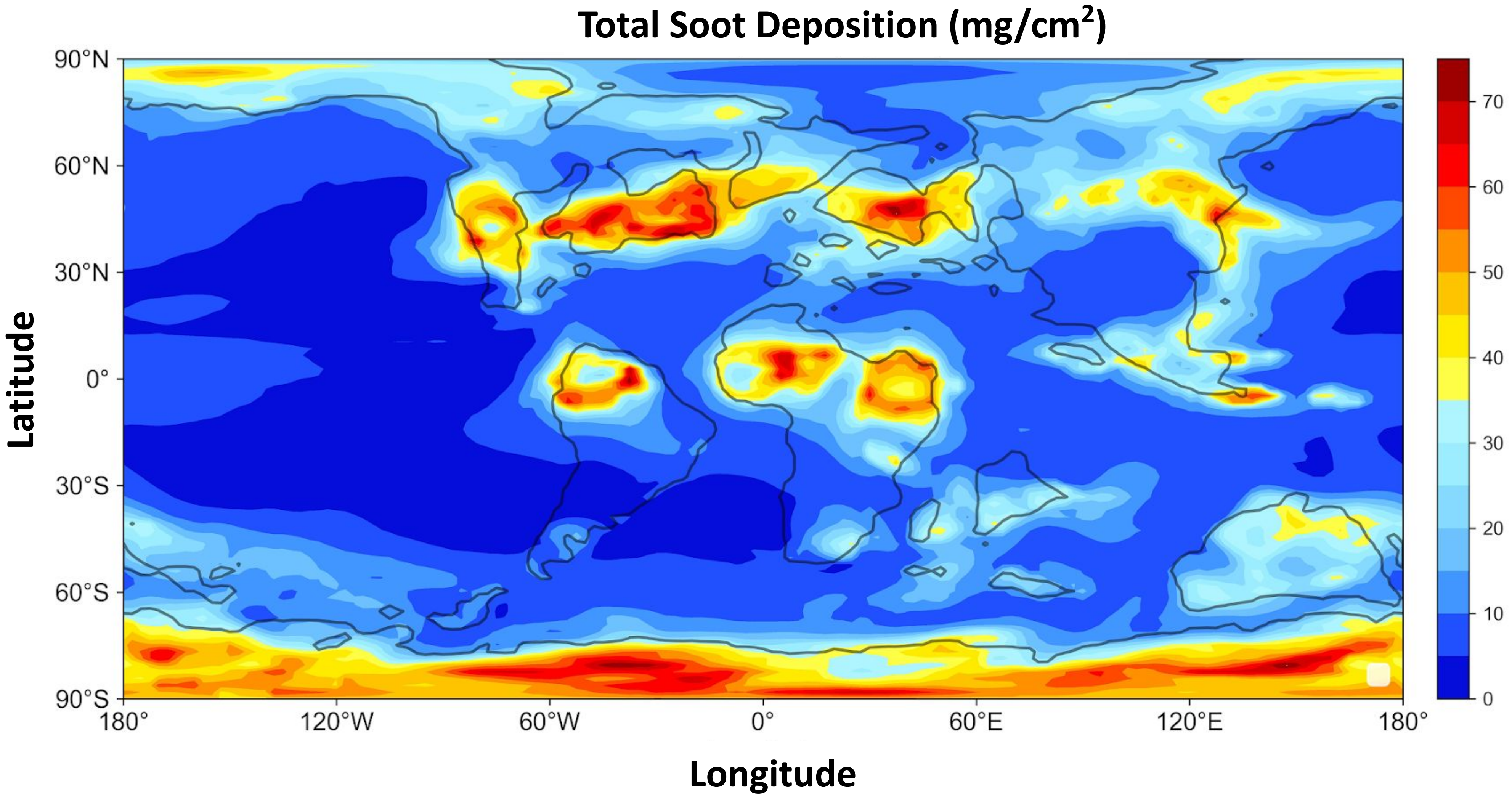


WACCM/CARMA)

Wolbach

Best-Estimate Case Soot Deposition



Best-Estimate Case Fine Soot Fraction

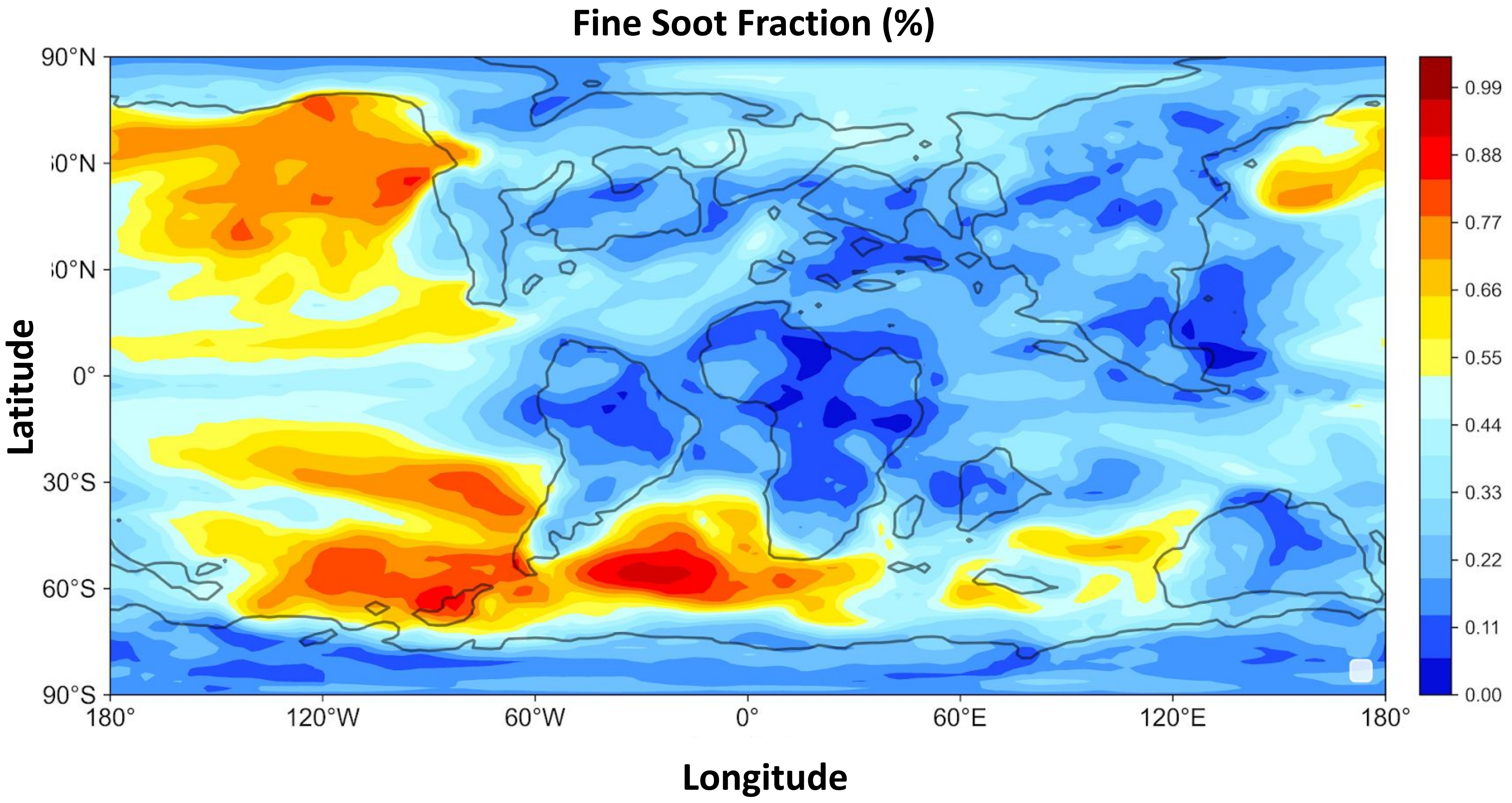


TABLE 1 PROCESSED AND RAW DATA OF CARBON RECORDS AT THE KPB

Site	Total Carbon Deposition(mg/cm^2)		Fine Soot Ratio(%)
Raw Data			
Woodside Creek, NZ	4.8	+5/-5	69
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Gubbio	13	+13/-1	17
Agost[1]	3.6	+3.8/-0	2
Raton[1]	4.0	+6.5	1
El Kef	15	+15	19
Flaxbourne River, NZ	1.3	+0/-0.6	55
Elendgraben[2]	0.8	+8/-0	12
Sumbar	13	+3/-3	15
DSDP 465[3]	3.6	+0.4/-0.4	0.5
Processed Data			
NZ avg	11.1		64
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Caravaca	14.5		14
Gubbio	19		17
El Kef	22.5		19
Sumbar	13		15
DSDP 465	3.6		0.5

Note: NZ avg refers to the average between Woodside Creek, Chancet Rocks, and Flaxbourne River, NZ. The total carbon deposition data in the processed data session are corrected by taking the mid of the provided error bar in the raw data session; Raw data is from Wolbach et al., (1990). The fine soot ratio does not have error bar. Agost, Raton, and Elendgraben are removed.
1.Etched for 600h, to remove resistant kerogen
2.Used the H_2O_2 procedure
3.From Wolbach et al., (2003)

What is the point of this slide? It is not a good slide for a presentation.

TABLE 2 RESULTS OF NORMALIZED RMSE AND CORRELATION COEFFICIENT

Case Name	RMSE	Correlation Coefficient
Global Carbon Deposition		
A.72400_0.266_1_1_fire_1d_May_10μm	0.50	0.154
B.72400_0.11_1_1_fire_1d_May_10μm	0.58	0.148
C.148339_0.11_1_1_fire_1d_May_10μm	1.53	0.076
D.72400_0.11_1_1_fire_1d_March_10μm	0.55	0.048
E.72400_0.11_1_1_fire_1d_July_10μm	0.94	0.052
F.72400_0.11_0.5_1_fire_1d_May_10μm	0.58	0.151
G.72400_0.11_1_0_fire_1d_May_10μm	0.92	0.021
H.72400_0.11_1_1_fire_14d_May_10μm	0.61	0.048
I.72400_0.266_1_1_fire_impact_1d_May_10μm	0.54	0.142
J.72400_0.266_1_1_fire_1d_May_ 7.5μm	0.50	0.057
K.72400_0.266_1_1_fire_1d_May _5μm	0.44	0.079
Fine Soot Ratio		
A.72400_0.266_1_1_fire_1d_May_10μm	0.38	0.630
B.72400_0.11_1_1_fire_1d_May_10μm	0.73	0.715
C.148339_0.11_1_1_fire_1d_May_10μm	0.59	0.471
D.72400_0.11_1_1_fire_1d_March_10μm	0.72	0.897
E.72400_0.11_1_1_fire_1d_May_10μm	0.61	0.630
F.72400_0.11_0.5_1_fire_1d_May_10μm	0.76	0.792
G.72400_0.11_1_0_fire_1d_May_10μm	0.66	0.255
H.72400_0.11_1_1_fire_14d_May_10μm	0.74	0.614
I.72400_0.266_1_1_fire_impact_1d_May_10μm	0.42	0.540
J.72400_0.266_1_1_fire_1d_May_ 7.5μm	0.47	0.722
K.72400_0.266_1_1_fire_1d_May _5μm	0.50	0.756

Note: All modelled global carbon deposition and fine soot ratio at each site in Table 1 are averaged over surrounding eight grid cells and normalized before calculating RMSE and correlation coefficient.
Each case is labelled by alphabetical letter ahead of the name of the case;
Case name consists of total element soot amount, fine soot ratio, fine soot ratio emitted at tropopause, coarse soot ratio emitted at tropopause, source of soot, emission duration, emission timing, coarse soot mean radius respectively. And each element in the case name is separated by the dashed underline.

Label	Total soot Emission	fine soot fraction	fine soot emission fraction at tropopause	coarse soot emission fraction at tropopause	duration (day)	Emission Timing	Coarse soot mean radius
Fire72_May_1d_**0.266fine**At_trop_coarseAt_trop_10µm	72400 Tg	**0.266**	1	1	1	May	10µm
Fire72_May_1d_0.11fineAt_trop_coarseAt_trop_10µm	72400 Tg	0.11	1	1	1	May	10µm
Fire72_May_**14d**_0.11fineAt_trop_coarseAt_trop_10µm	72400 Tg	0.11	1	1	**14**	May	10µm
Fire72_May_1d_**0.11fineAt_trop_coarseAt_srf**_10µm	72400 Tg	0.11	1	**0**	1	May	10µm
Fire72_May_1d_**0.11fine50%At_trop_coarseAt_trop**_10µm	72400 Tg	0.11	**0.5**	1	1	May	10µm
Impact25_May_1d_0.11fine_10µm	**2500 Tg**	1	1	--------	1	May	10µm
Fire14_May_1d_0.11fineAt_trop_coarseAt_trop_10µm	**148332 Tg**	0.11	1	1	1	May	10µm
Fire72_**Mar**_1d_0.11fineAt_trop_coarseAt_trop_10µm	72400 Tg	0.11	1	1	1	**March**	10µm
Fire72_**July**_1d_0.11fineAt_trop_coarseAt_trop_10µm	72400 Tg	0.11	1	1	1	**July**	10µm
Fire&Impact72_May_1d_0.266fineAt_trop_coarseAt_trop_10µm	72400 Tg	0.266	1	1	1	May	10µm
Fire72_May_1d_0.266fineAt_trop_coarseAt_trop_**7.5µm**	72400 Tg	0.266	1	1	1	May	**7.5µm**
Fire72_May_1d_0.266fineAt_trop_coarseAt_trop_**5µm**	72400 Tg	0.266	1	1	1	May	**5.0µm**

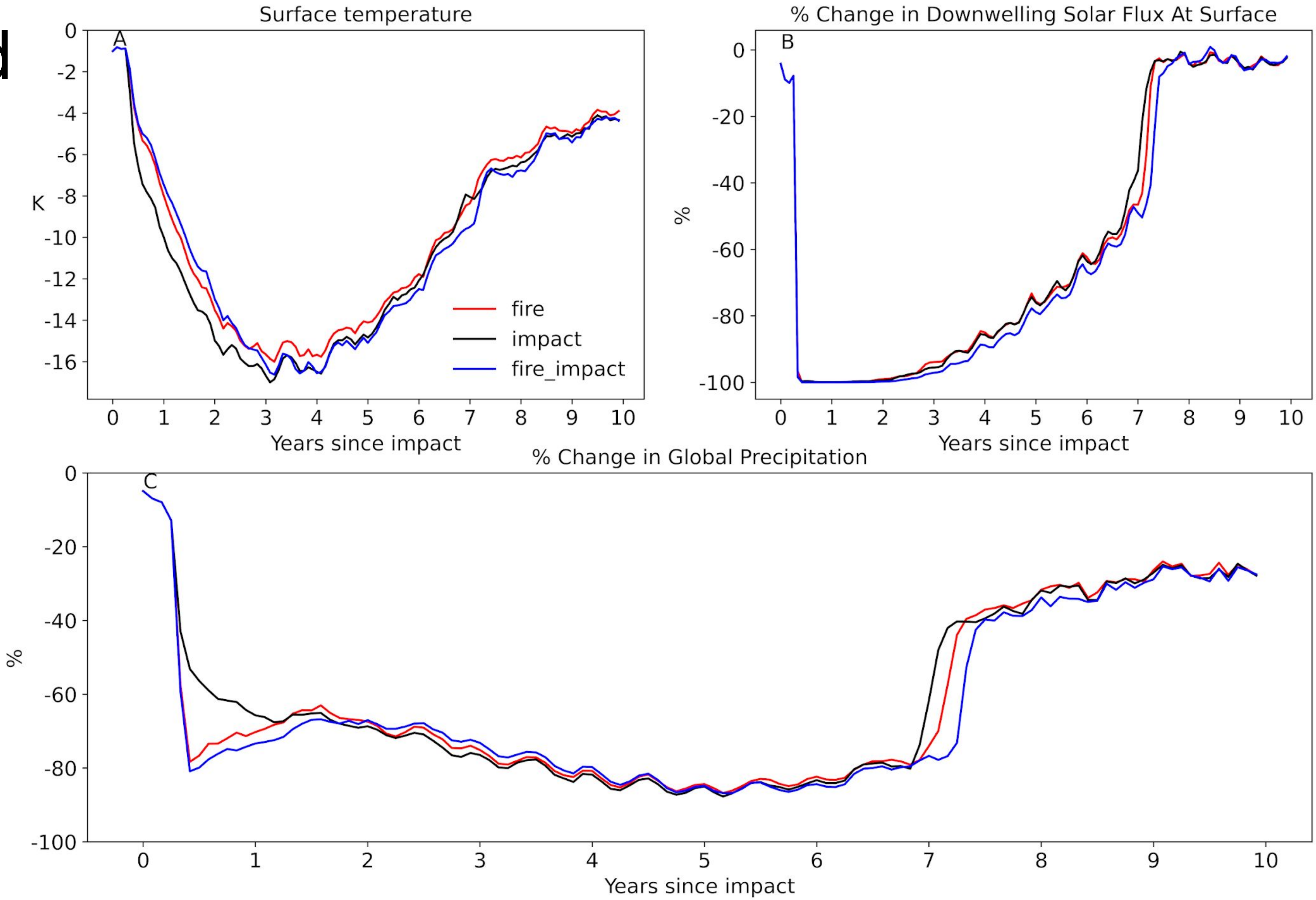
Statistics of all cases: Total Deposition-updated-corrected

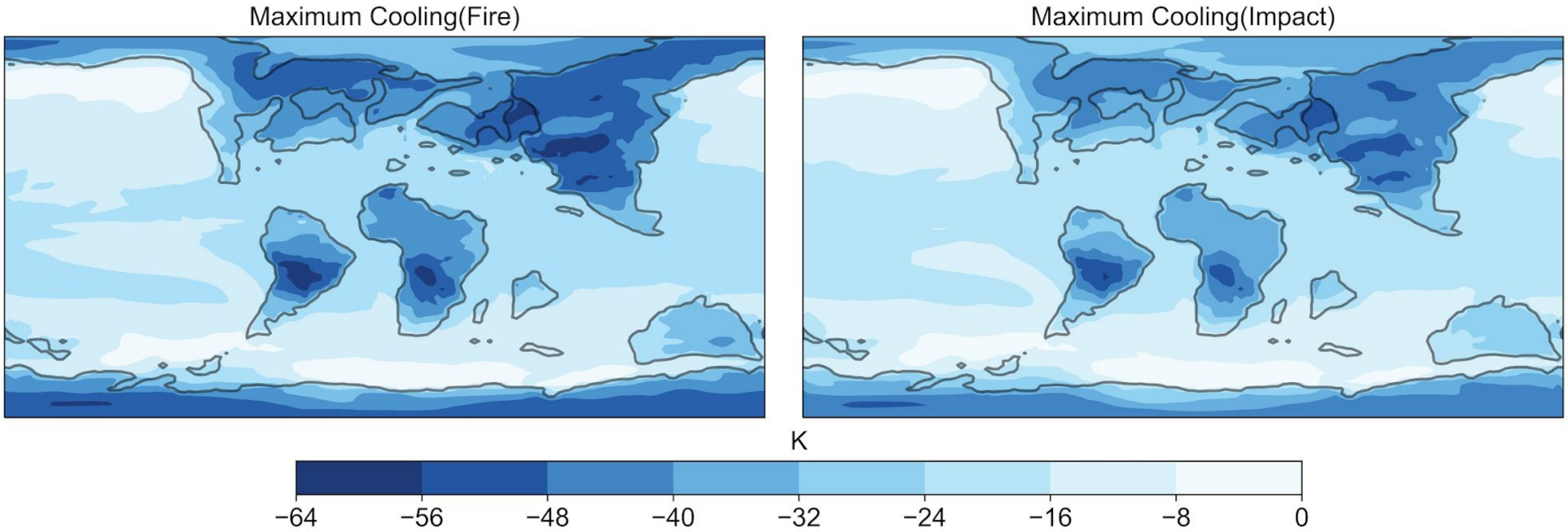
Label	RMSE	R	R-Square
Fire72_May_1d_0.266fineAt_trop_coarseAt_trop_10µm	1.102	0.3923	0.1539
Fire72_May_1d_0.11fineAt_trop_coarseAt_trop_10µm	1.109	0.384	0.147
Fire72_May_14d_0.11fineAt_trop_coarseAt_trop_10µm	1.249	0.219	0.048
Fire72_May_1d_0.11fineAt_trop_coarseAt_srf_10µm	1.307	0.1456	0.0212
Fire72_May_1d_0.11fine50%At_trop_coarseAt_trop_10µm	1.1062	0.388	0.1505
Impact25_May_1d_0.11fine_10µm	-	-	-
Fire14_May_1d_0.11fineAt_trop_coarseAt_trop_10µm	1.2036	0.2755	0.0759
Fire72_Mar_1d_0.11fineAt_trop_coarseAt_trop_10µm	1.249	0.219	0.048
Fire72_July_1d_0.11fineAt_trop_coarseAt_trop_10µm	1.243	0.227	0.051
Fire&Impact72_May_1d_0.266fineAt_trop_coarseAt_trop_10µm	1.116	0.377	0.1422
Fire72_May_1d_0.266fineAt_trop_coarseAt_trop_7.5µm	1.269	0.1939	0.0376
Fire72_May_1d_0.266fineAt_trop_coarseAt_trop_5µm	1.1987	0.28155	0.079
Fire72_May_1d_0.266fineAt_trop_coarseAt_trop_10µm	1.2338	0.238	0.057

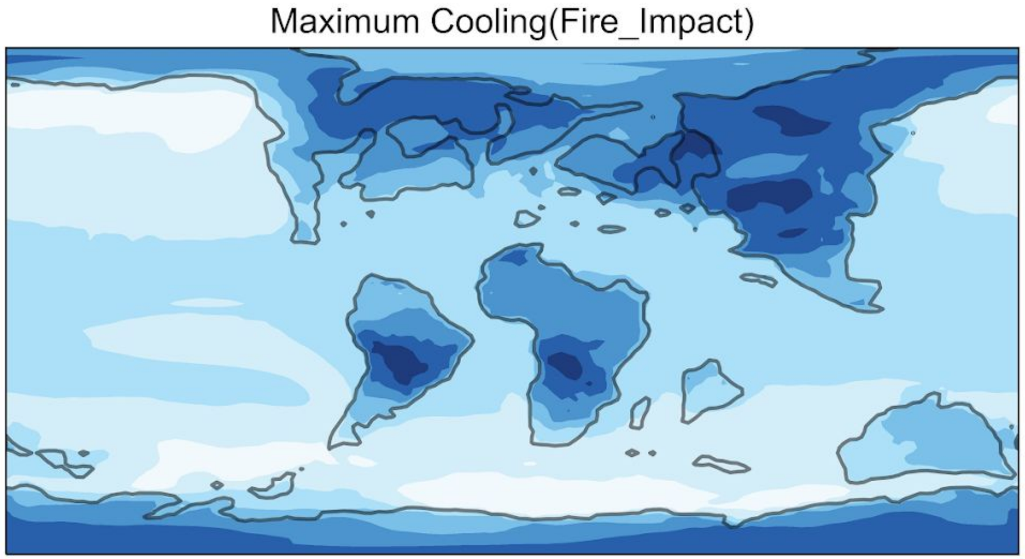
Statistics of all cases: Fine Soot Ratio

Label	RMSE	R	R-Square
a	0.642	0.7938	0.6301
b	0.469	0.8899	0.792
c	0.657	0.7838	0.6144
d	0.994	0.5058	0.2558
e	0.555	0.845	0.7154
f	-	-	-
g	0.792	0.6863	0.471
h	0.324	0.9473	0.89
i	0.6422	0.793	0.63
j	0.727	0.735	0.5404
k	0.946	0.552	0.3048
l	0.5108	0.869	0.756
m	0.547	0.850	0.722

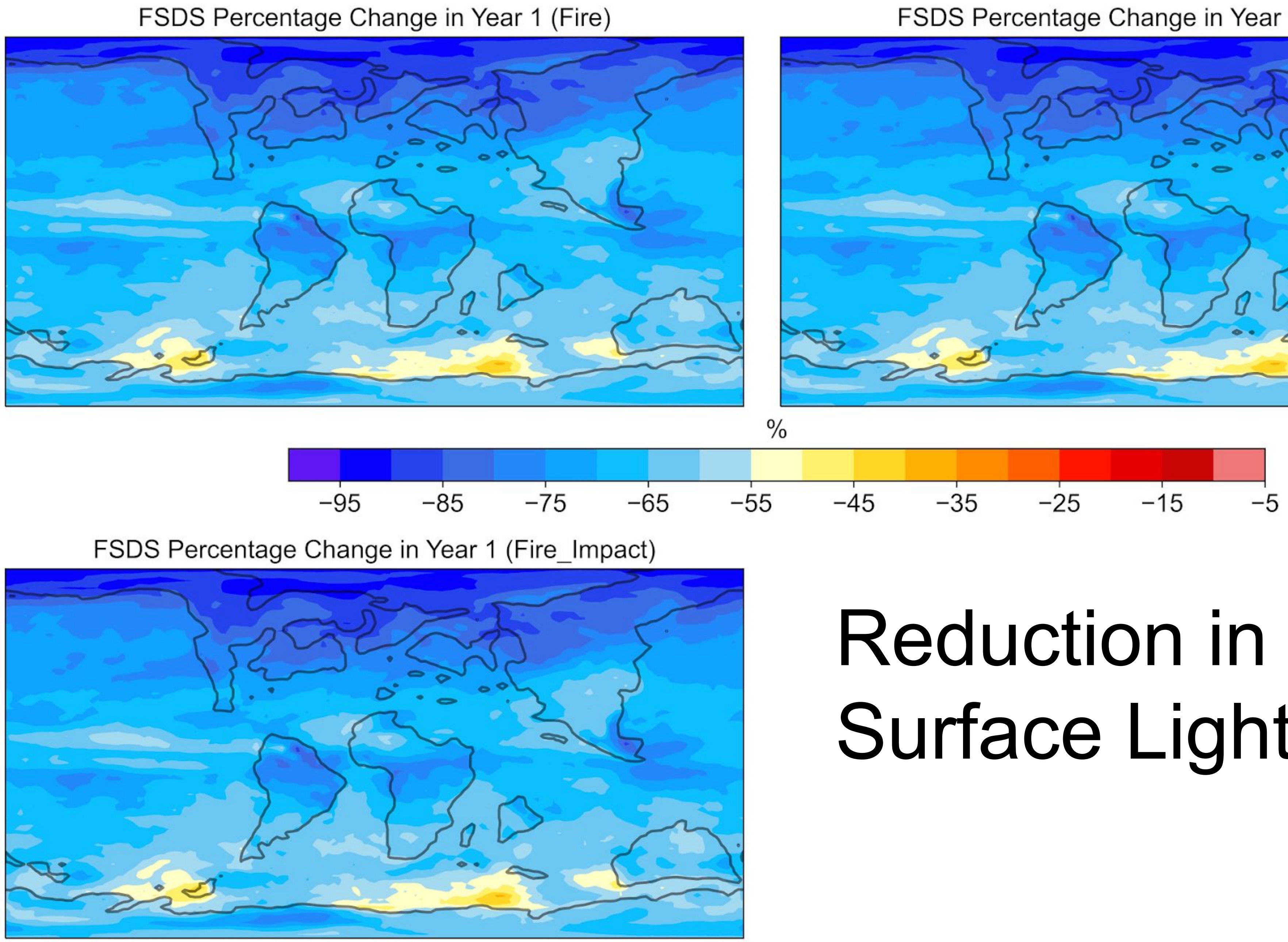
Extended Global Climate







Maximum Cooling



Reduction in Surface Light

Conclusion

- Fires are necessary to have agreement with geologic record of soot deposition after the KPB
  - Best estimate case : 72,400 Tg of soot on May 1st over 1 day, with 27% fine soot and both coarse and fine soot emitting at tropopause.
- 2,500 Tg impact soot itself could exert nearly the same climatic signal as the larger fire-driven soot emission

Questions?

Thanks for listening!