Volcanoes, geophysics, climate and art

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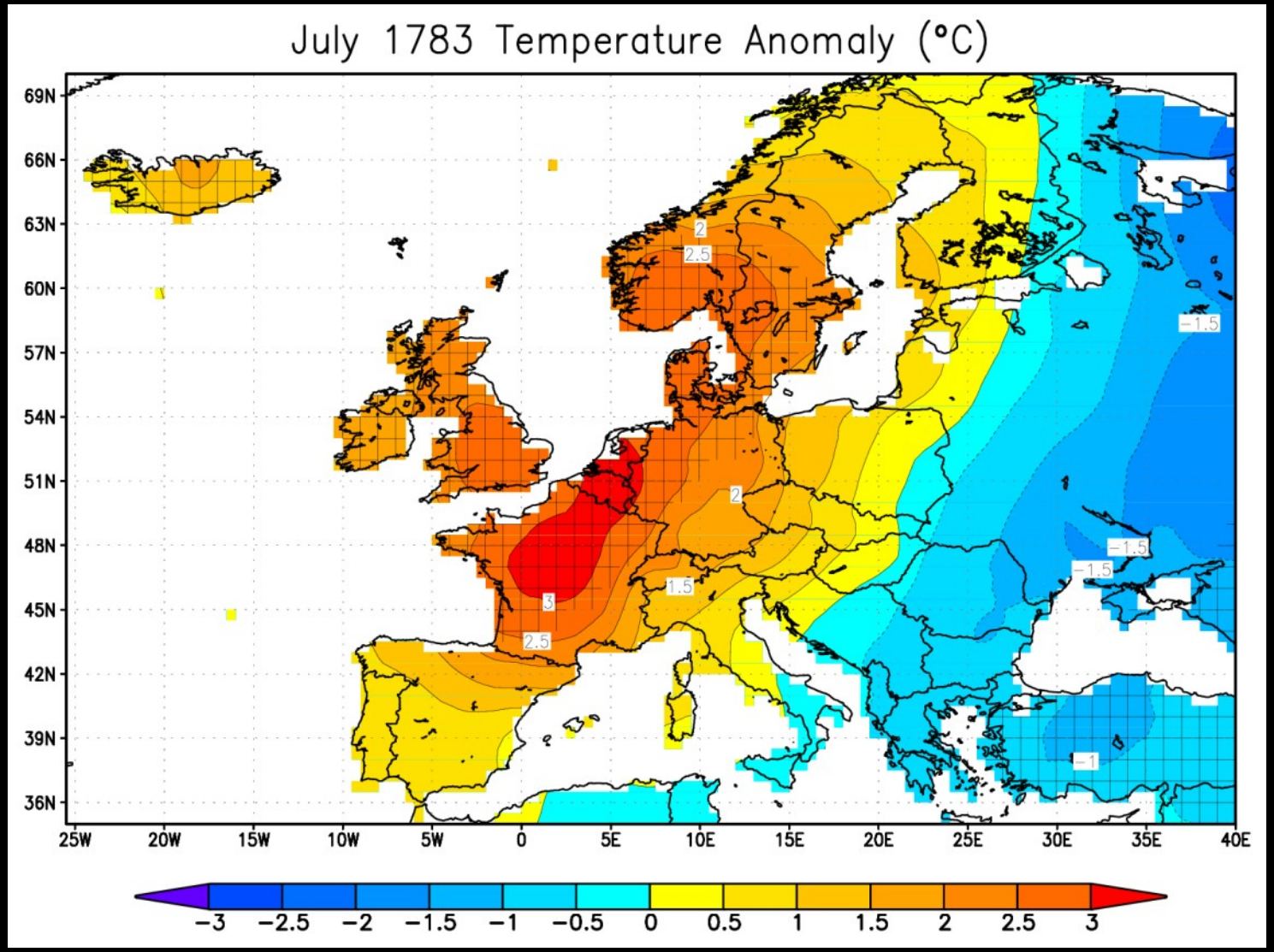
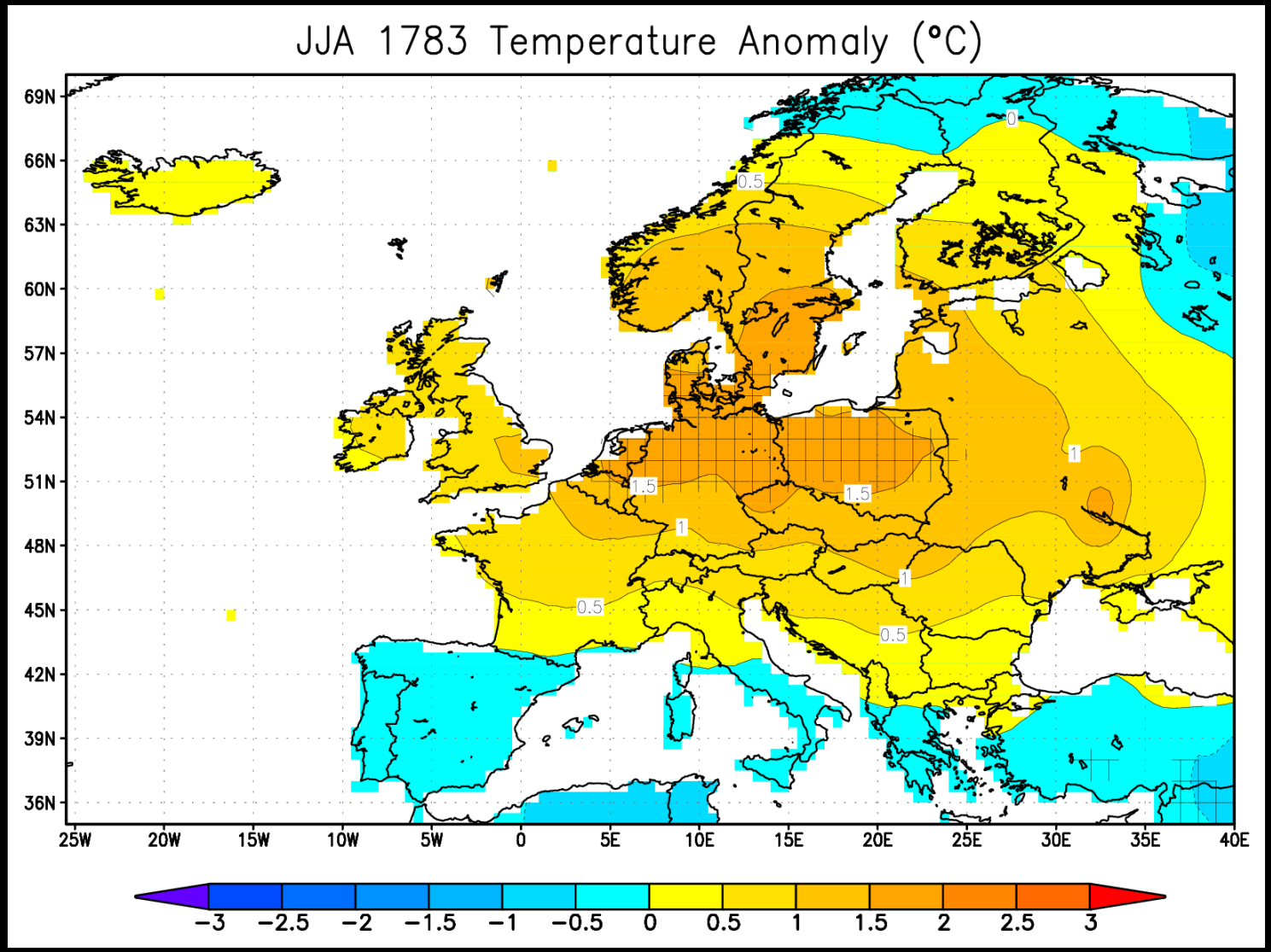
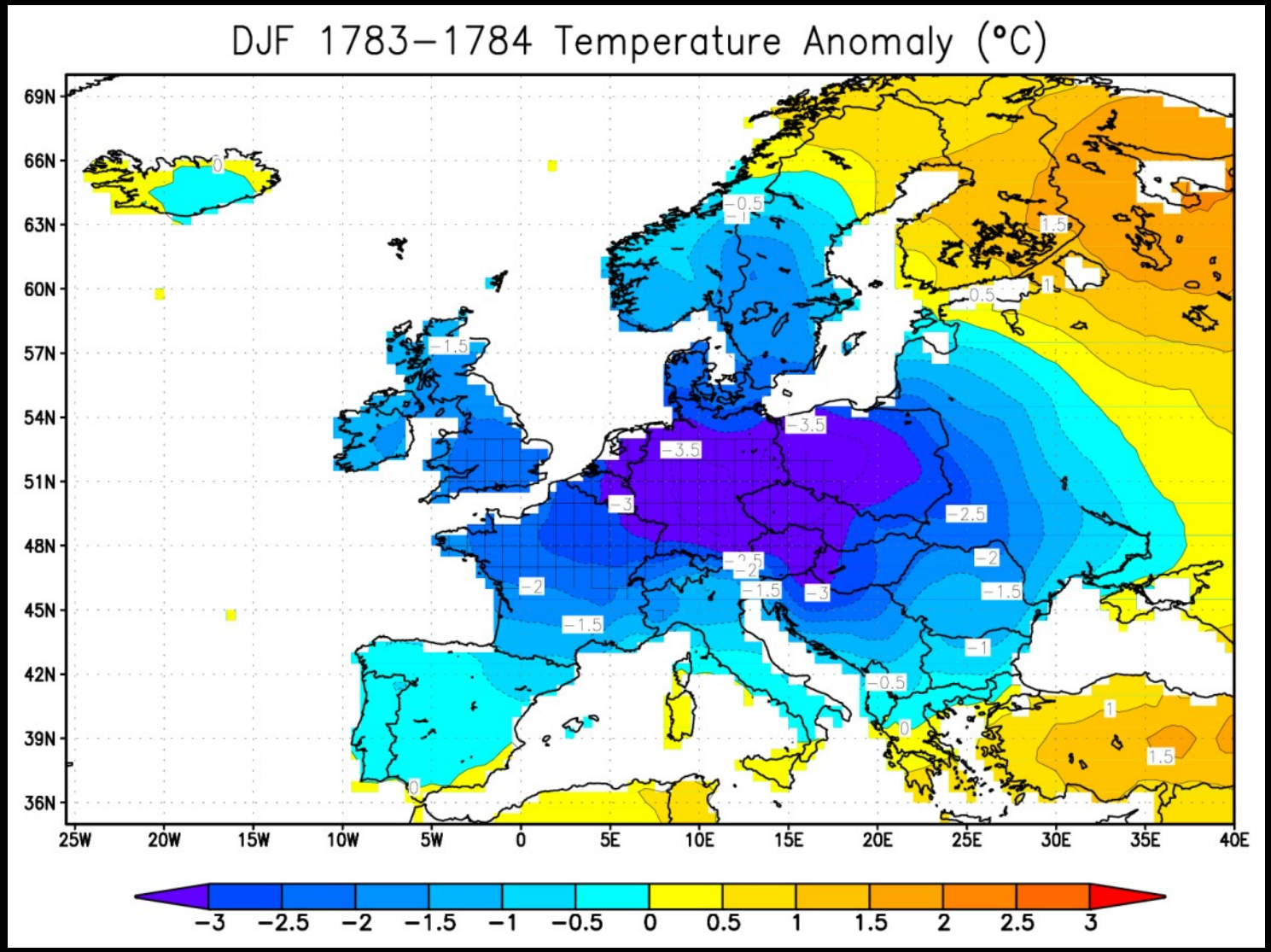
Etna Erupting

The active volcano Laki in Iceland


July 1783 Temperature Anomaly (°C)
69N
66N
63N
60N
57N
54N
51N
48N
45N
42N
39N
36N
25W
20W
15W
10W
5W
0
5E
10E
15E
20E
25E
30E
35E
40E
2
2.5
−1.5
2
−1.5
−1.5
1.5
3
2.5
−1
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5
3


JJA 1783 Temperature Anomaly (°C)
69N
66N
63N
60N
57N
54N
51N
48N
45N
42N
39N
36N
25W
20W
15W
10W
5W
0
5E
10E
15E
20E
25E
30E
35E
40E
0
0.5
1
1.5
1.5
1
1
0.5
0.5
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5
3


DJF 1783–1784 Temperature Anomaly (°C)
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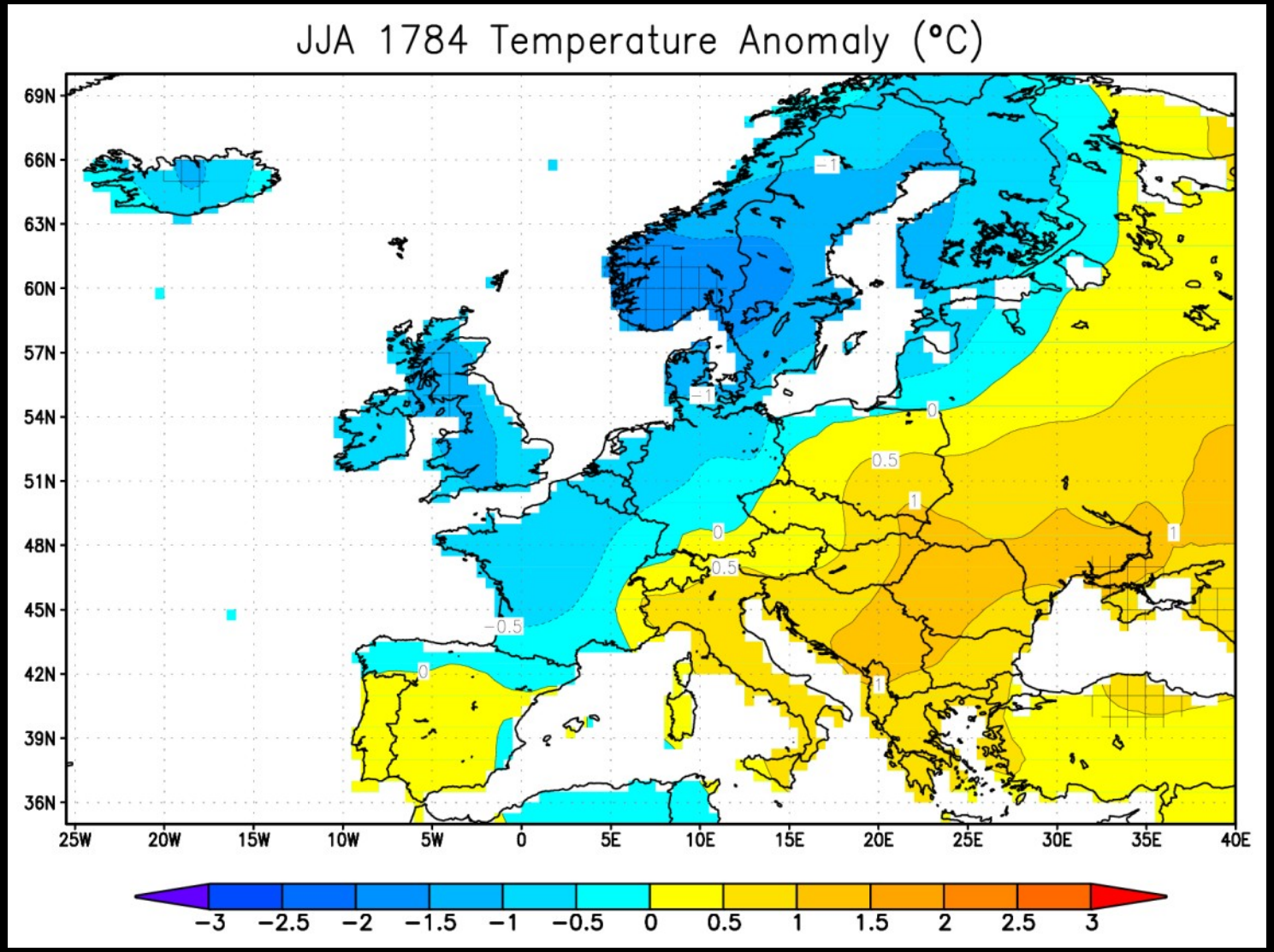
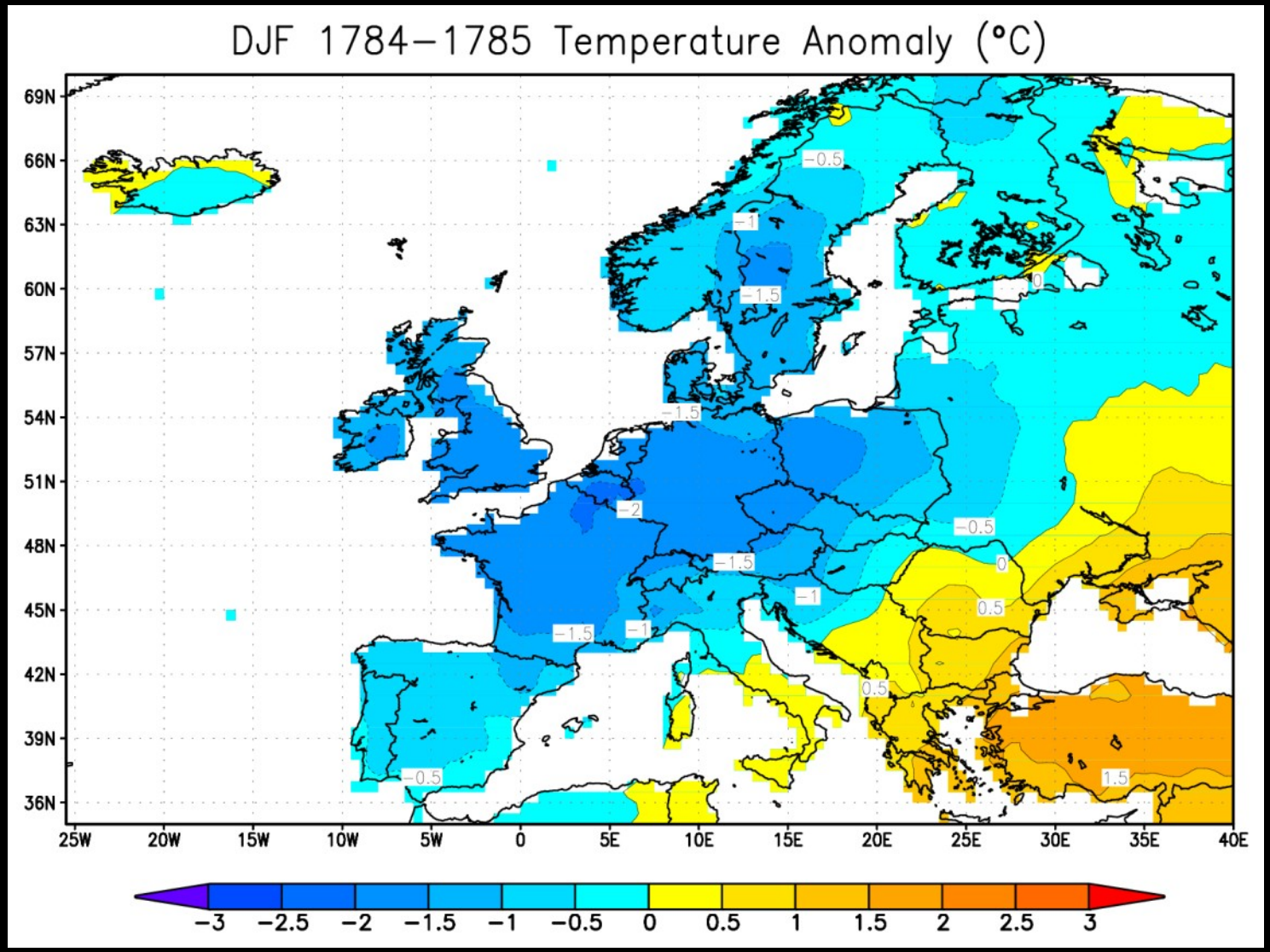
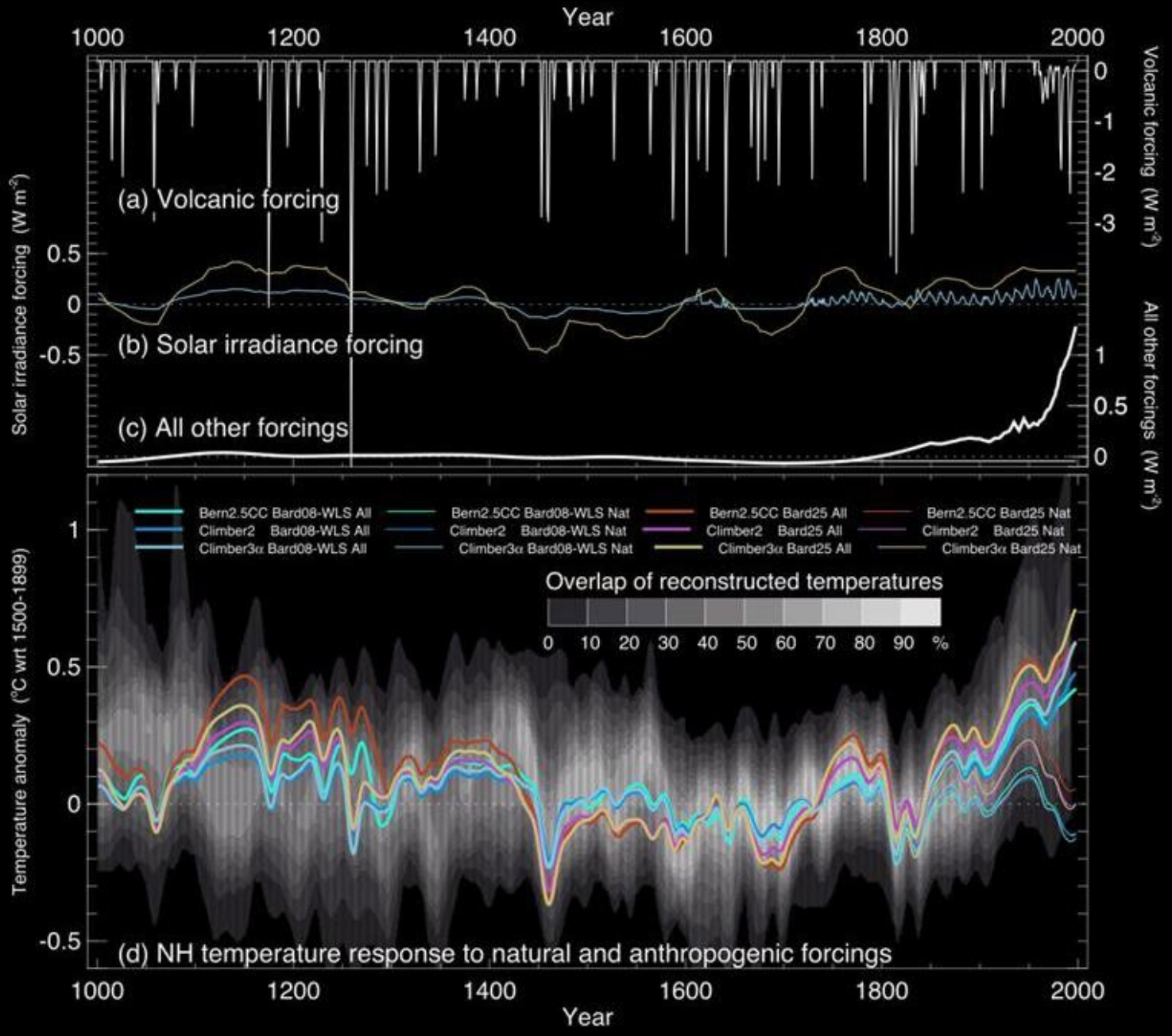
66N
63N
60N
57N
54N
51N
48N
45N
42N
39N
36N
25W
20W
15W
10W
5W
0
5E
10E
15E
20E
25E
30E
35E
40E
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5
3


JJA 1784 Temperature Anomaly (°C)
69N
66N
63N
60N
57N
54N
51N
48N
45N
42N
39N
36N
25W
20W
15W
10W
5W
0
5E
10E
15E
20E
25E
30E
35E
40E
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5
3


DJF 1784–1785 Temperature Anomaly (°C)
69N
66N
63N
60N
57N
54N
51N
48N
45N
42N
39N
36N
25W
20W
15W
10W
5W
0
5E
10E
15E
20E
25E
30E
35E
40E
−0.5
−1
−1.5
−2
0
0.5
1.5
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5
3

Volcanic aerosols improve our knowledge of the climate of the past

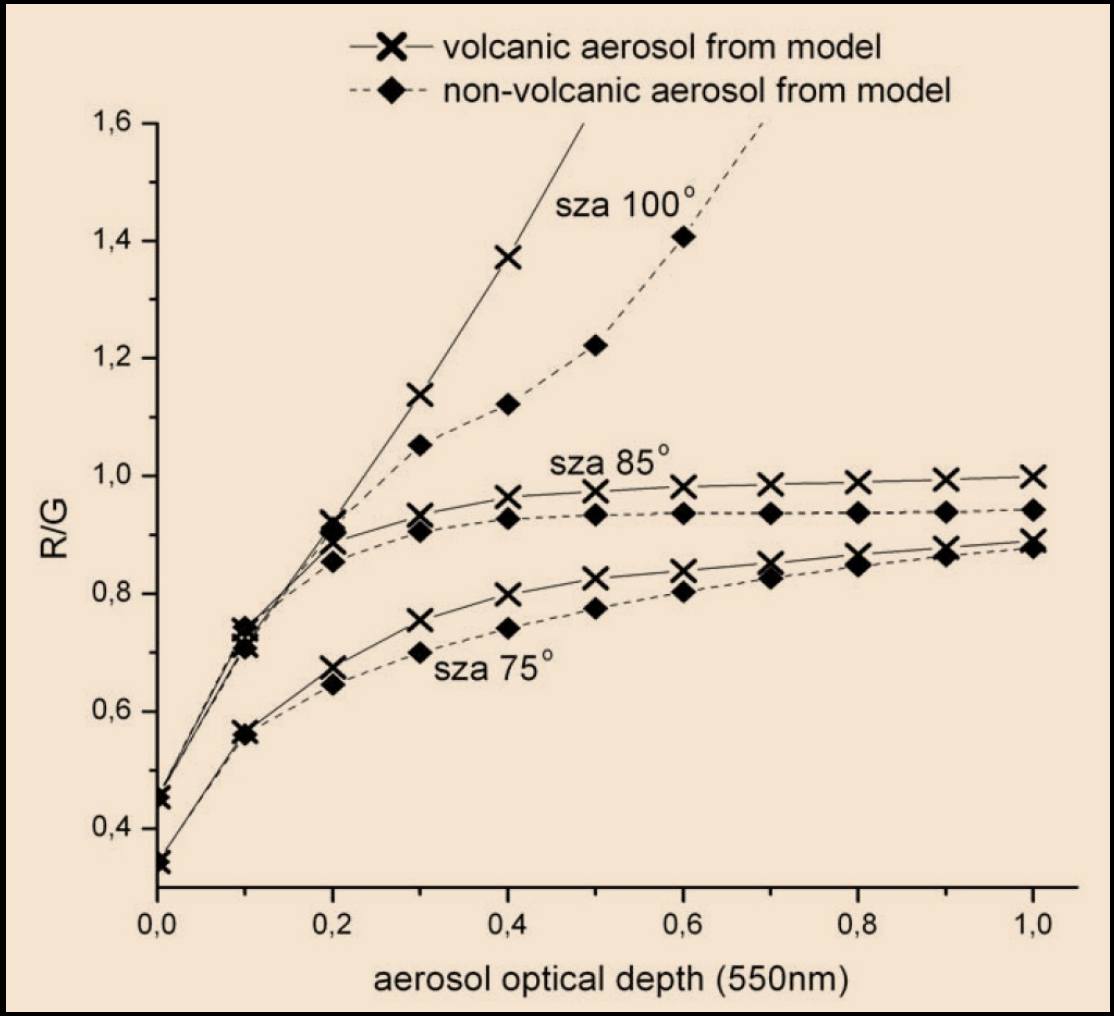


The volcano Tambora, in 1815, created the «Year Without Summer» (1816)

"Darkness" by Lord Byron (1788-1824)

I had a dream, which was not all a dream.
The bright sun was extinguish'd, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air;
Morn came and went—and came, and brought no day,
And men forgot their passions in the dread
Of this their desolation; and all hearts
Were chill'd into a selfish prayer for light:
And they did live by watchfires—and the thrones,
The palaces of crowned kings—the huts,
The habitations of all things which dwell,
Were burnt for beacons; cities were consumed,
And men were gather'd round their blazing homes
To look once more into each other's face; . . .

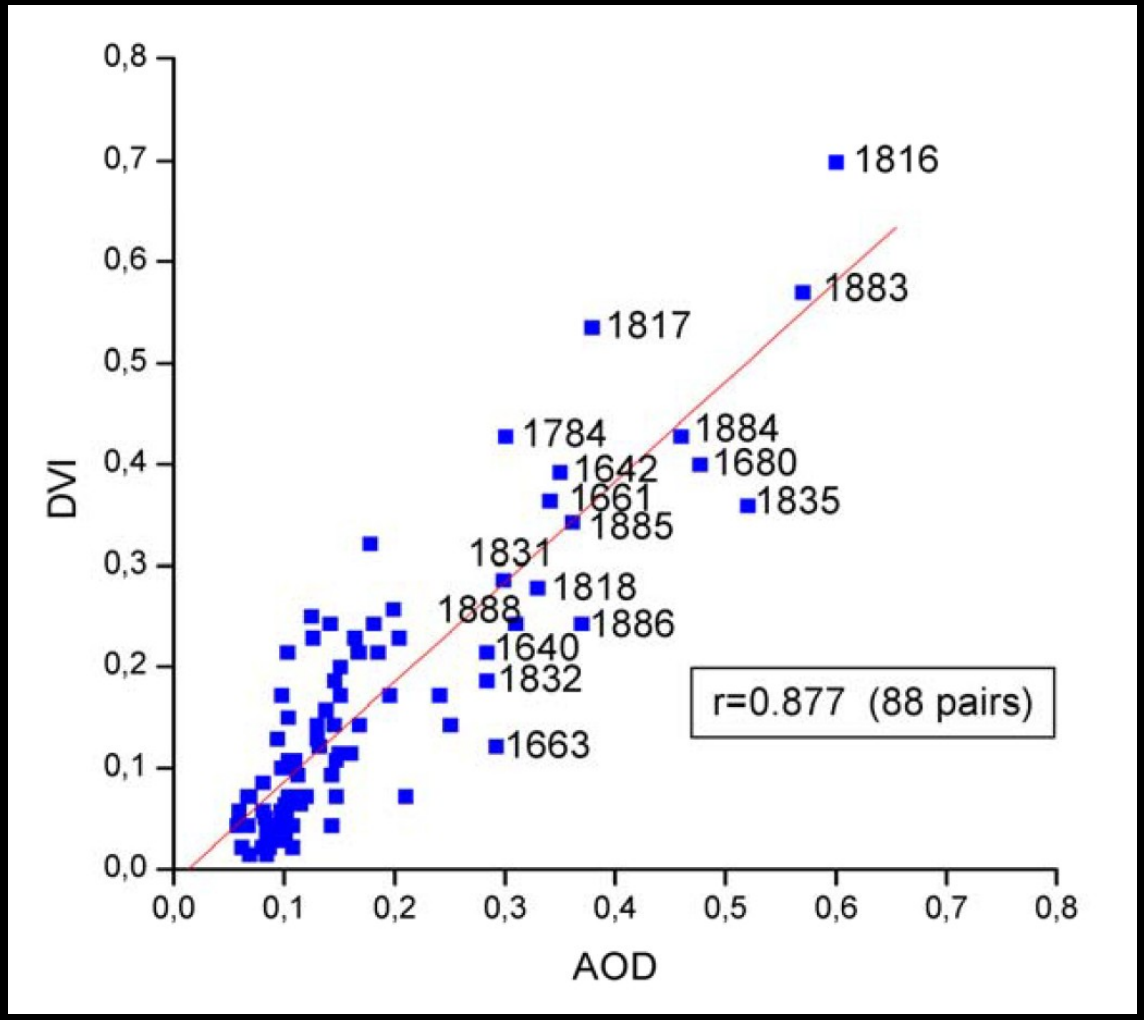
Nomogramm of R/G and aerosol optical depth as resulted from the model for three solar zenith angles calculated for non-volcanic and volcanic aerosols used to calibrate the measurements on paintings



Estimated aerosol optical depth at 550 nm corresponding to middle latitudes for each major volcanic eruption from this paper in comparison with other studies

	Volcano Name	Year of the eruption	AOD this study	Nearest estimate from other studies
1	Awu	1641	0.35	0.33 (Zielinski, 2000)
2	Katla	1660	0.29–0.34	N/A
3	Tongkoko & Krakatau	1680	0.47	N/A
4	Laki	1783	0.30	0.21–0.28 (Robertson et al.,2001) 0.19 (Robock and Free, 1996) 0.12 (Zielinski, 2000)
5	Tambora	1815	0.33–0.60	0.5 (Robertson et al., 2001) 0.5 (Robock and Free, 1996) 0.2–0.9 (Stothers, 1996)
6	Babuyan	1831	0.28–0.29	0.24 (Zielinski, 2000)
7	Coseguina	1835	0.52	0.11–0.21 (Robertson et al., 2000)
8	Krakatau	1883	0.37-0.57	0.6 (Deirmendijian, 1973)

Linear correlation between annual mean aerosol optical depth at 550 nm, estimated from sunset paintings following volcanic eruptions, and mean annual values of DVI. The errors in the AOD are less than 0.05 for values around 0.1 and can be up to 0.18 for AOD values greater than 0.5.



Error in AOD estimates derived from the average R/G variability within a painting (±0.014)

Solar Zenith angle	AOD	Error
75	0.1	< 0.05
	0.5	0.06 to 0.12
85	0.1	< 0.05
	0.5	0.1 to 0.18

Error in AOD estimates derived from a typical error in estimating the SZA in a painting within ±2°

Solar Zenith angle	AOD	Error
75	0.1	< 0.05
	0.5	0.07
85	0.1	< 0.05
	0.5	< 0.05

R/G ratios in the painting "Sunset"

R/G ratio and respective AOD (Unknown volcano ~1809)

Plate 19 John Constable, *Dedham Vale*, 1810. Private collection

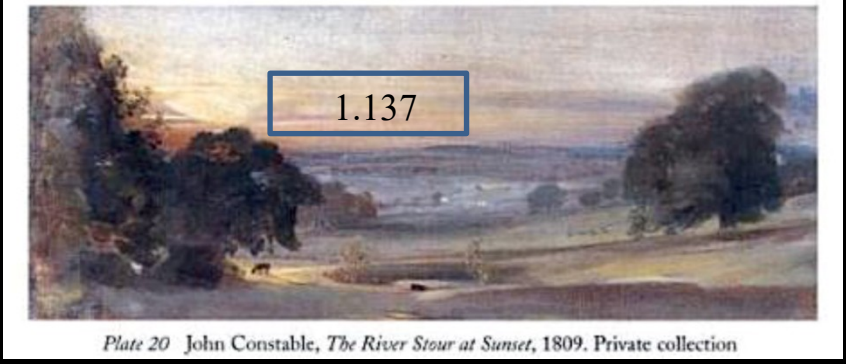


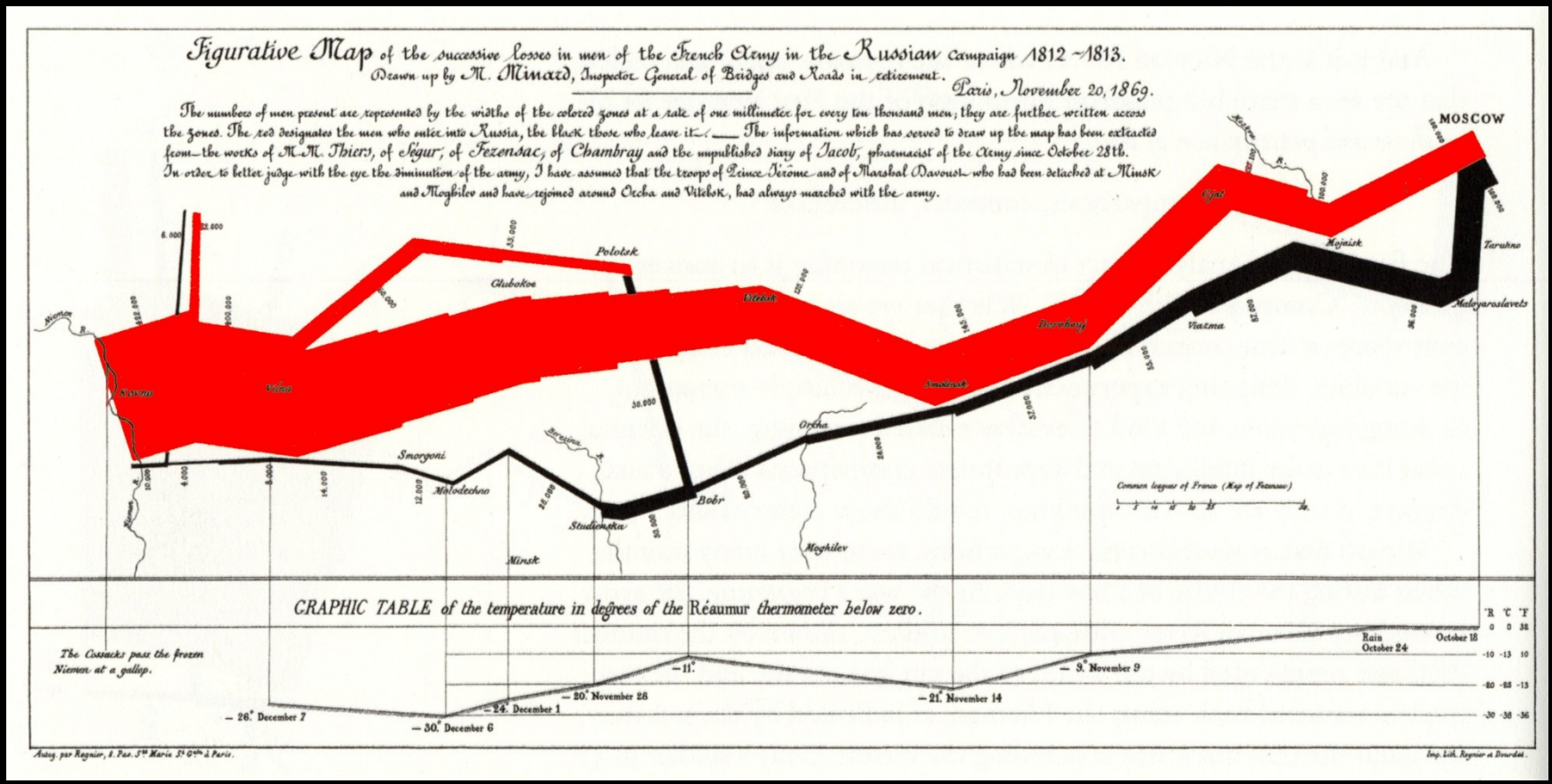
Plate 20 John Constable, *The River Stour at Sunset*, 1809. Private collection

1810
R/G ratio = 1.021
AOD ≈ 0.22

1809
R/G ratio = 1.137
AOD ≈ 0.30

Thornes, J.E., "John Constable's Skies: A Fusion of Art and Science", University Press, 1999

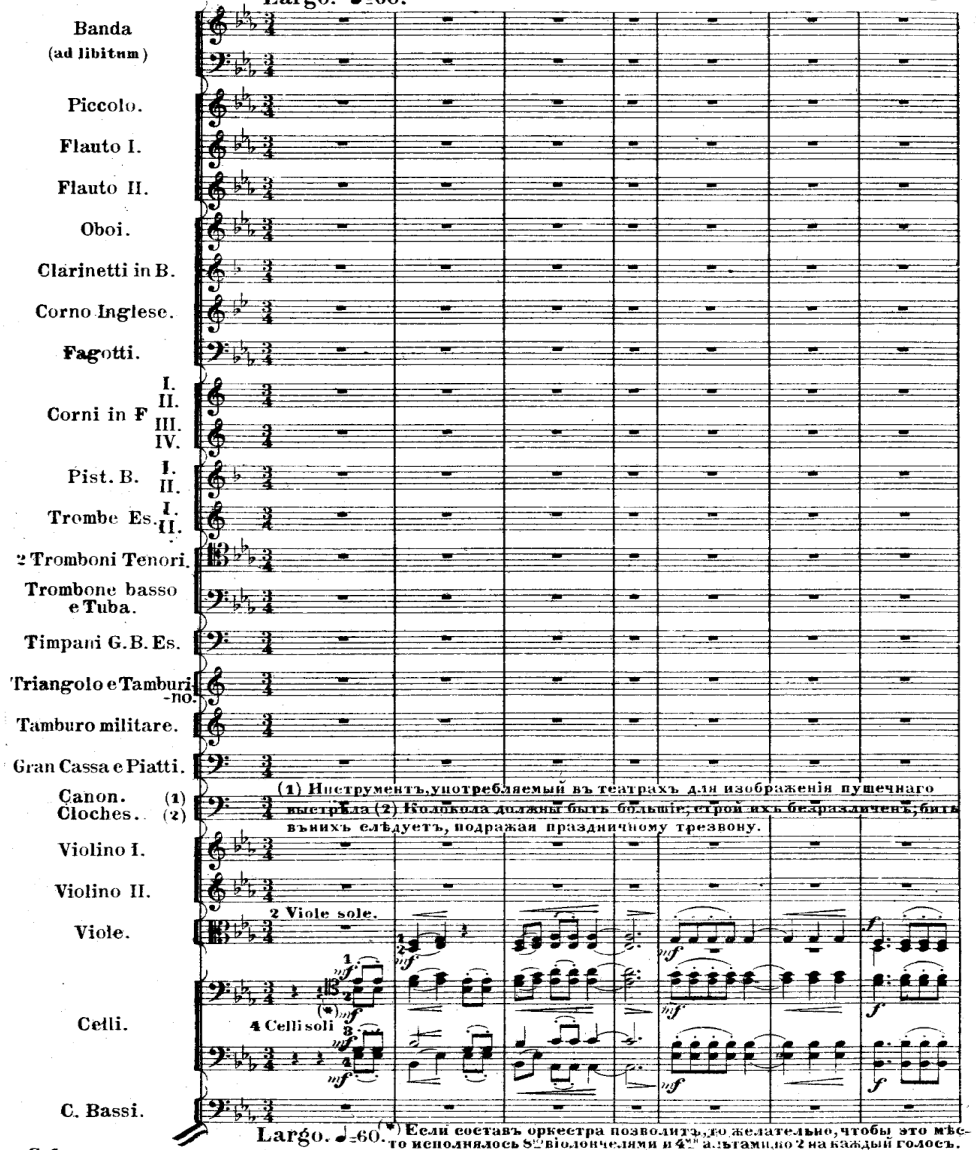
The famous Minard figurative Map showing winter temperatures and number of troops 1812-1813



1812

ТОРЖЕСТВЕННАЯ УВЕРТЮРА

П. Чайковскаго. Op. 49.



(*) Если составъ оркестра позволитъ, то желательно, чтобы это мѣсто исполнялось 8-ю віолончелями и 4-мя альтами по 2 на каждый голосъ.

4592

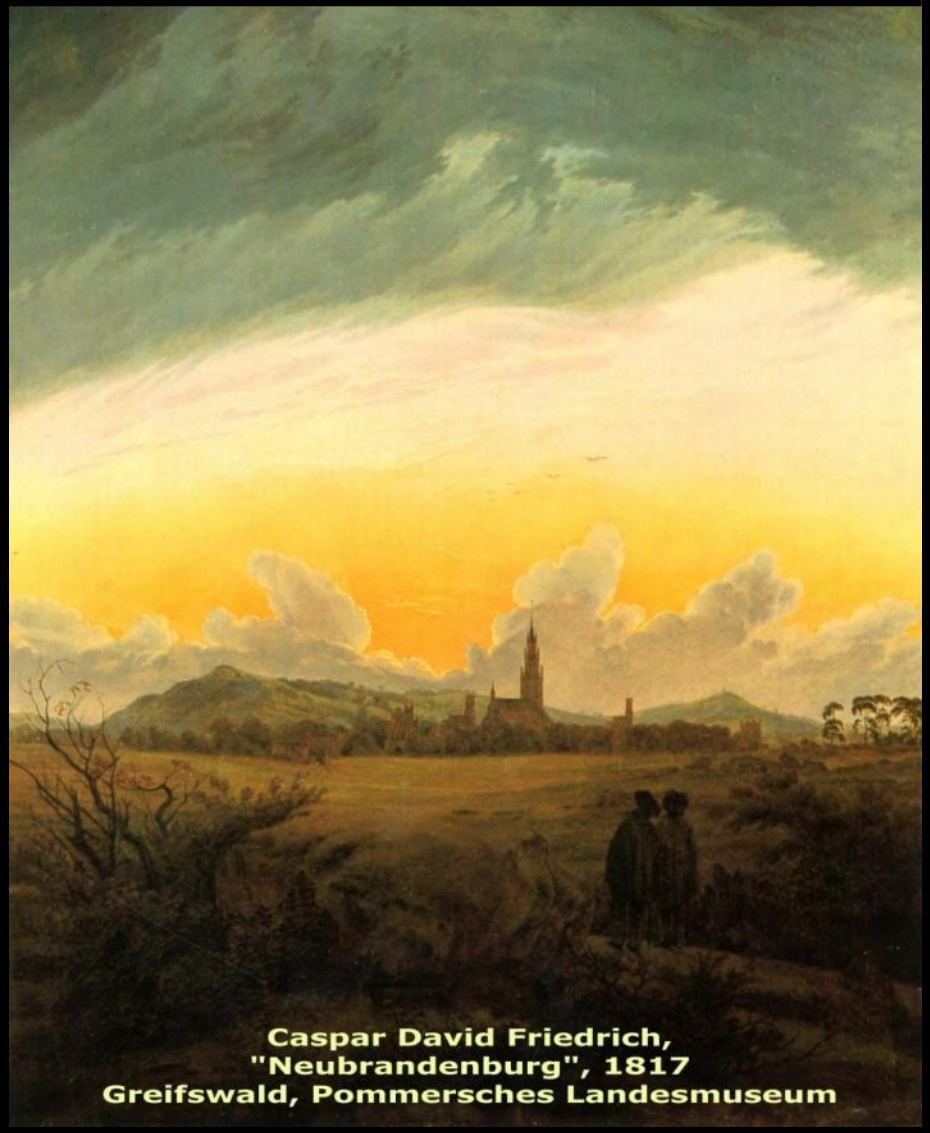
П. Юргенсона въ Москвѣ.

Frozen Thames 1814

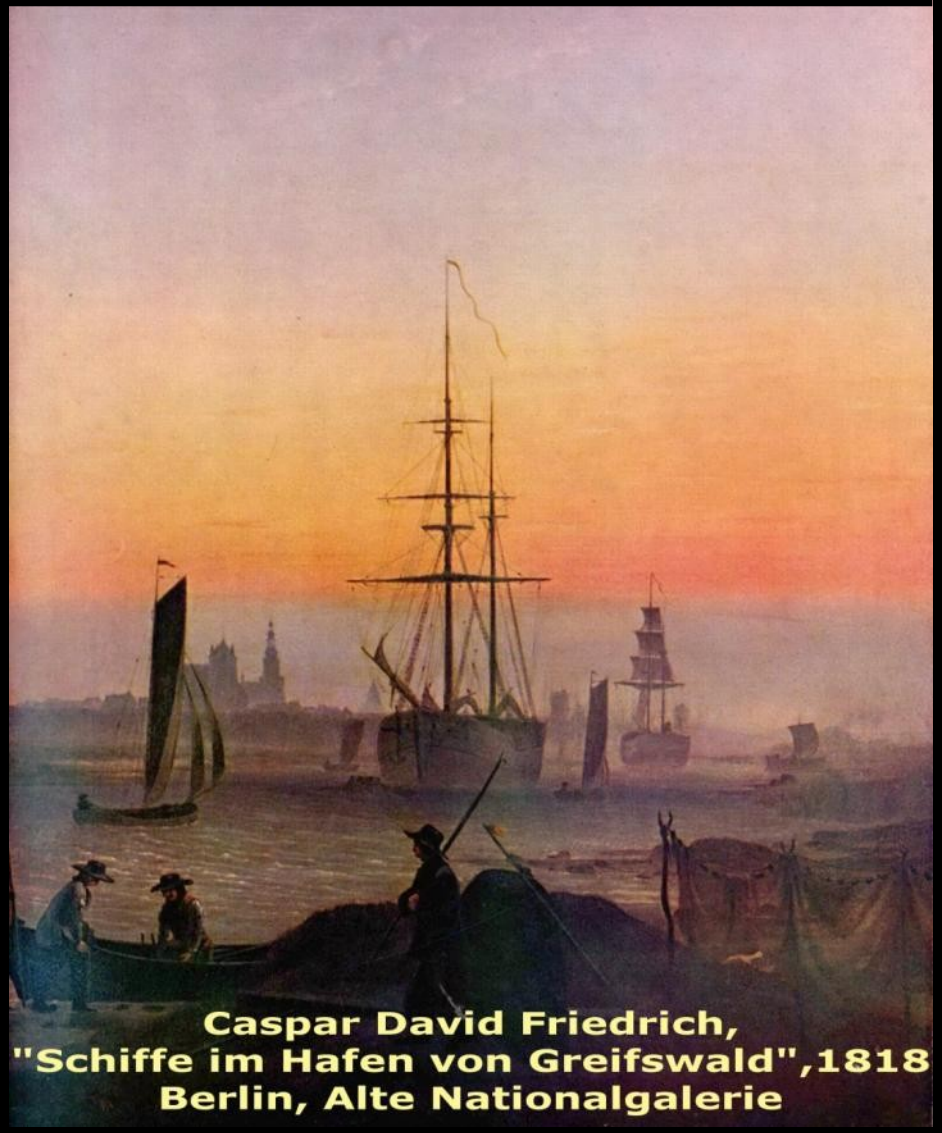
ICE IN THE THAMES AT LONDON BRIDGE.

The chromatic understanding of the artist changes after the eruption of Tambora in 1815, and returns to normal levels after a few years

1817: 2 years after Tambora



1817: 3 years after Tambora



Friedrich Caspar David (1774-1840)

Sunset after Tambora

"Woman in front of the Setting Sun", 1818, Museum Folkwang, Essen, Γερμανία

Sunset without volcano

"Evening", 1824, Kunsthalle, Manheim, Γερμανία

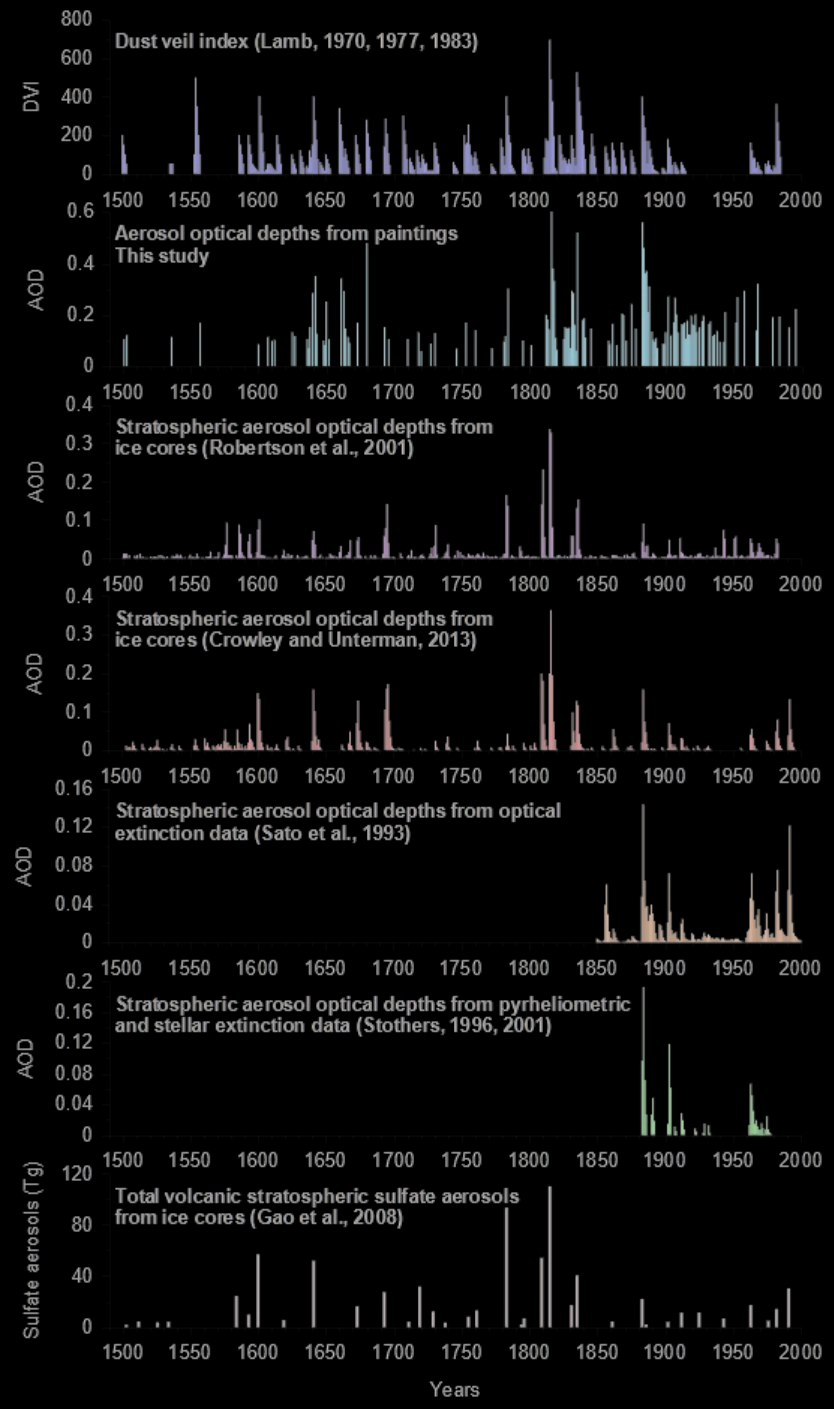
J.M.W. Turner (1775-1851)

Sunset after Babuyan

"Sunset", 1833, Tate Gallery

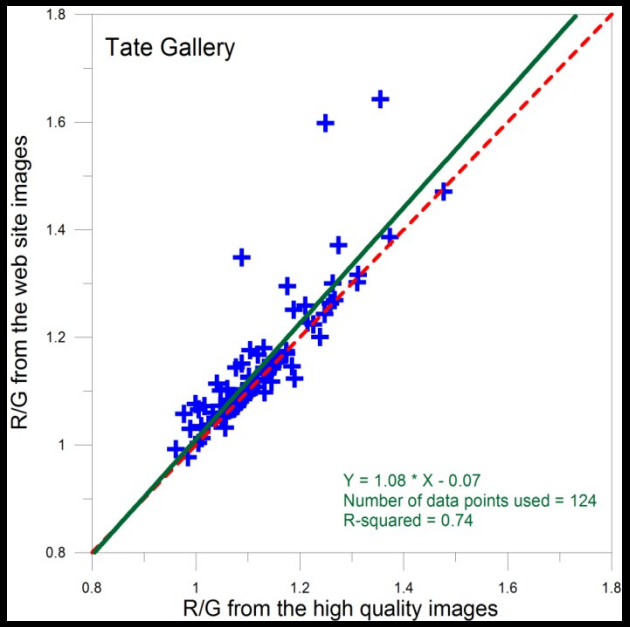
Sunset without volcano

«Chichester Canal», 1828, Tate Gallery

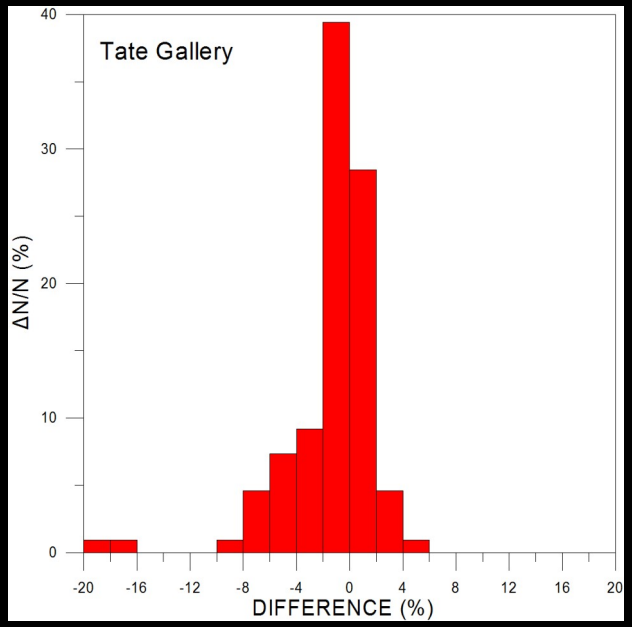


Aerosol optical depth from paintings and other proxy indices during the past 500 years from different proxies (Zerefos et. al., 2014)

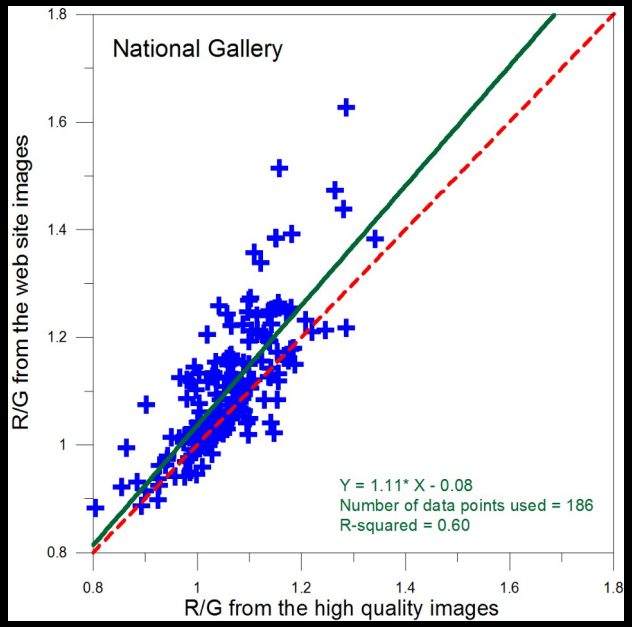
R/G ratios derived from painting digital images from website (low resolution) vs. R/G ratios for the same paintings obtained through colour profile protocol (high resolution) at the Tate Gallery.



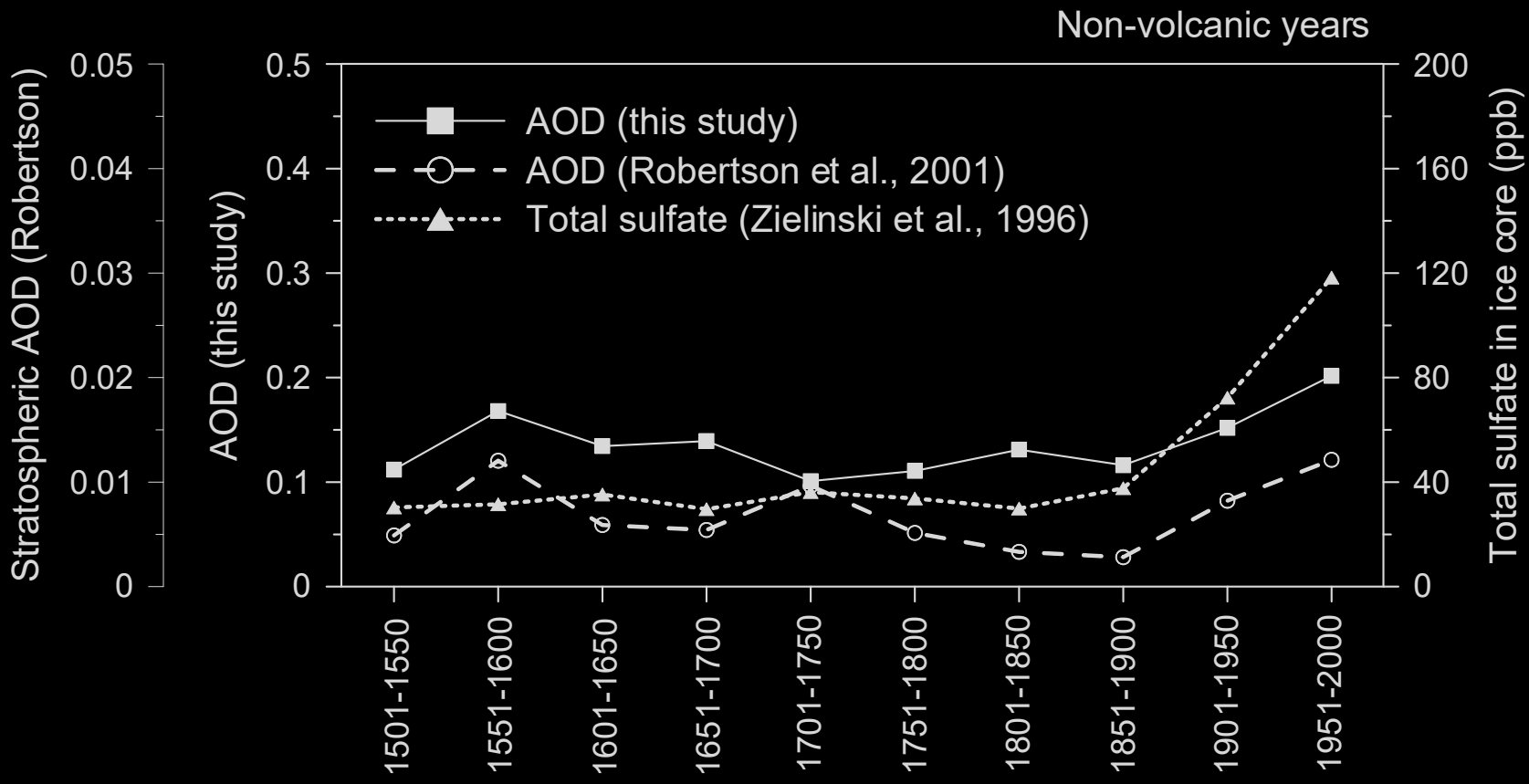
Distribution of the relative differences (in %) between the R/G ratios derived from the high- and the low-resolution images from 124 landscape sunsets at the Tate Gallery.



Results from a completely independent sample of paintings. R/G ratios derived from painting digital images from the website (low resolution) vs. the same R/G ratios from high resolution digital images at the National Gallery, London.



Atmospheric aerosols increased after the 19th century (Zerefos et. al., 2014)



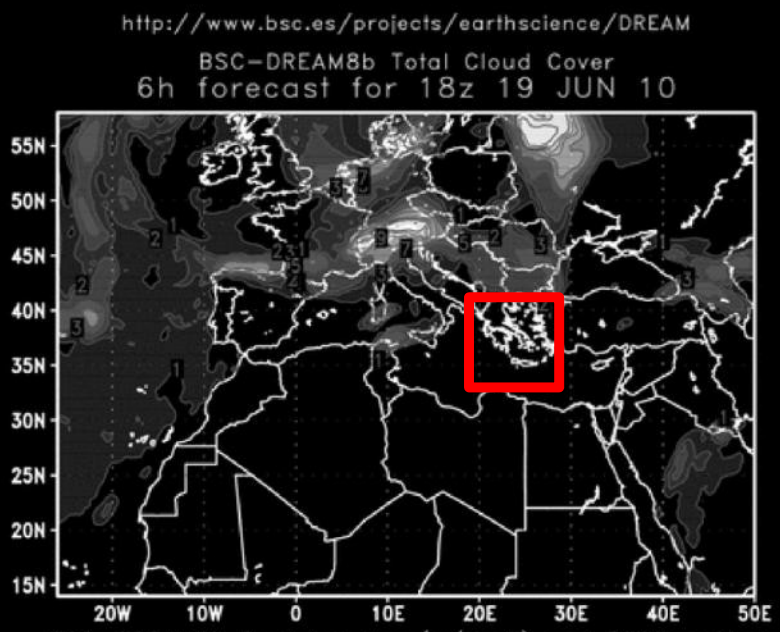
Correlation coefficients between volcanic aerosol indices and AOD proxies

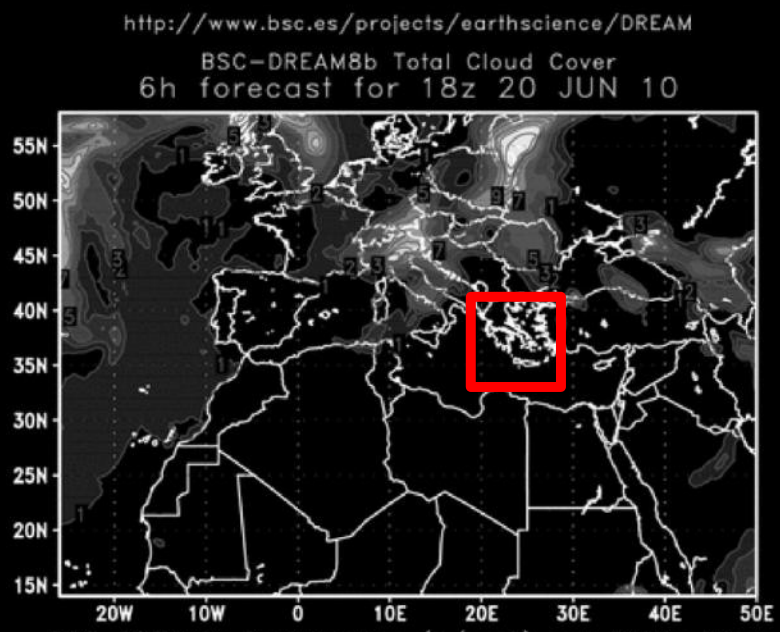
1500–2000	DVI	AOD (this study)	AOD (Robertson)	AOD (Crowley and Unterman)	AOD (Sato)	AOD (Stothers)	Sulfate (Gao)
DVI	1						
AOD (this study)	**0.85** [102]	1					
AOD (Robertson)	**0.65** [227]	**0.58** [118]	1				
AOD (Crowley and Unterman)	**0.57** [154]	**0.54** [74]	**0.80** [239]	1			
AOD (Sato)	**0.65** [66]	**0.55** [61]	**0.57** [126]	**0.91** [78]	1		
AOD (Stothers)	(*) [29]	(*) [21]	**0.83** [37]	(*) [29]	**0.92** [38]	1	
Sulfate (Gao)	(*) [23]	(*) [14]	**0.88** [33]	(*) [24]	(*) [11]	(*) [6]	1

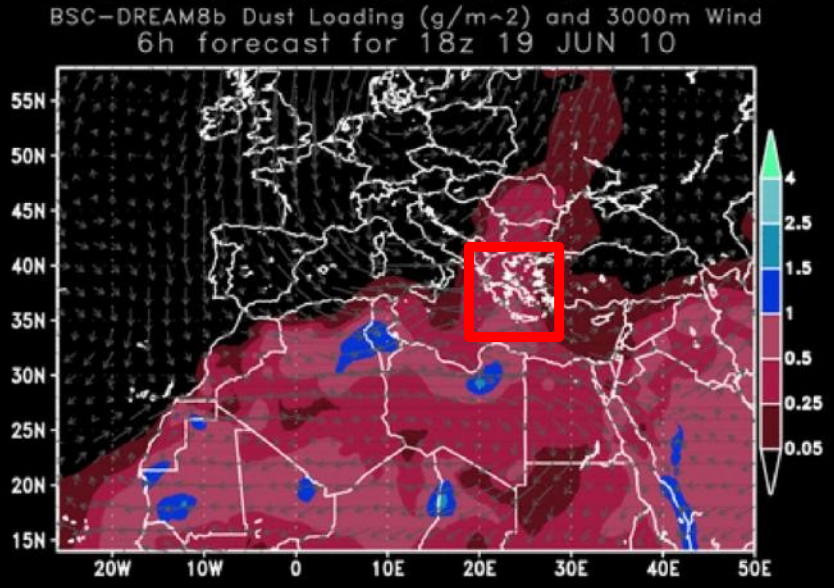
Bold: all the above correlations are significant at the 99 % confidence level (*t* test).
* missing correlations are those possessing less than 30 years of data.
In brackets: number of pairs.

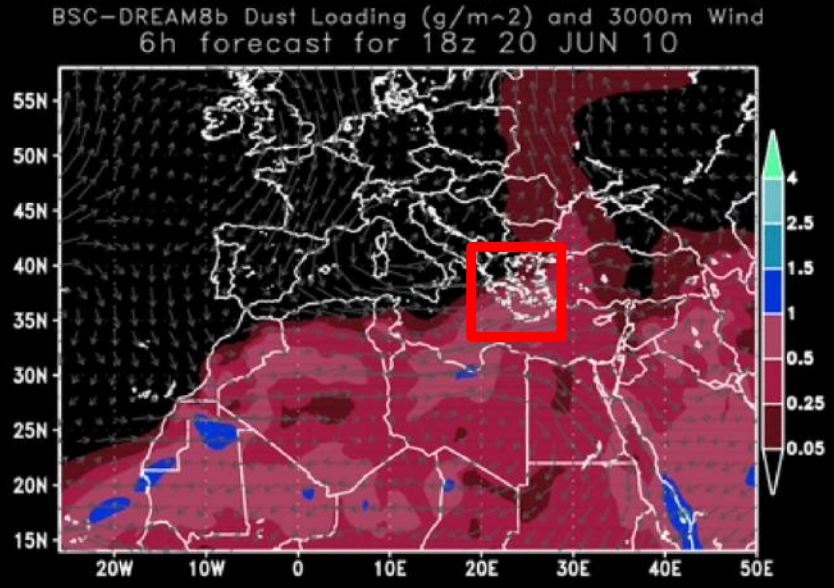
The experiment of Hydra island (19 & 20 June 2010)

Passage of a Saharan dust event

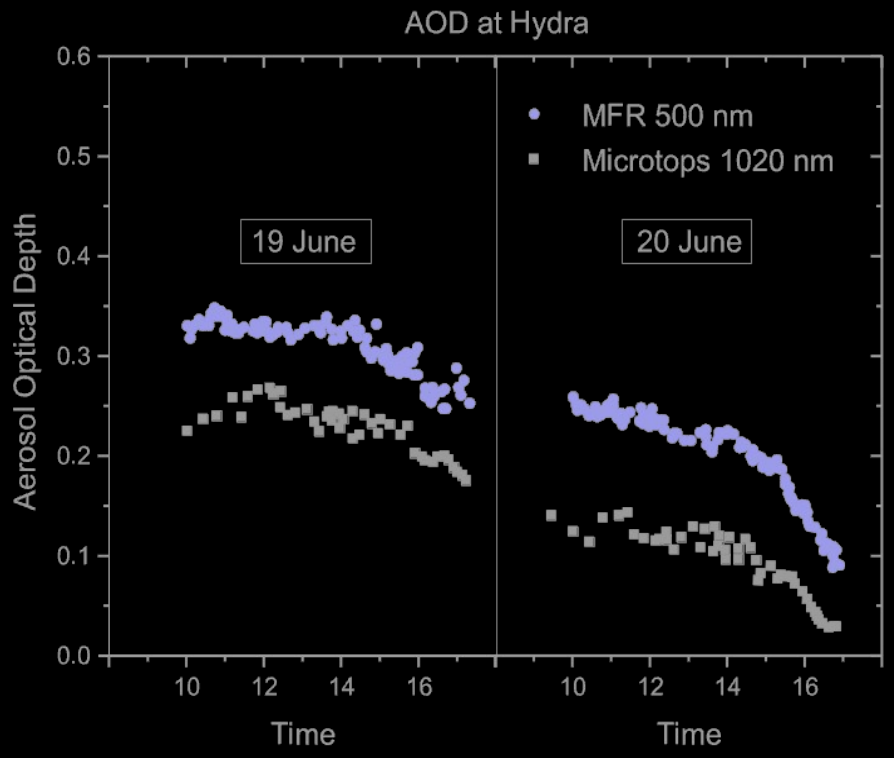




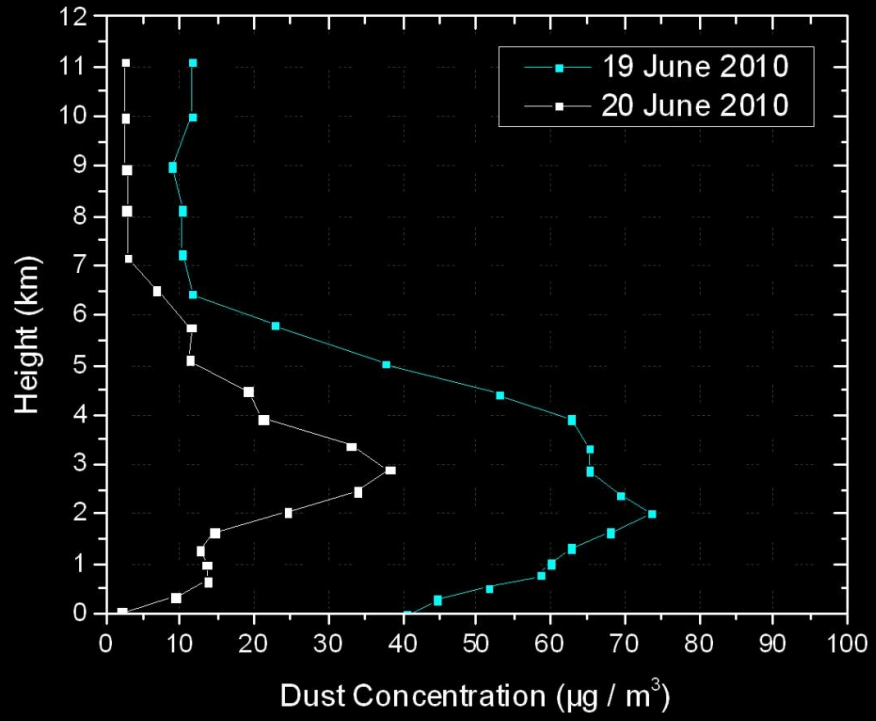




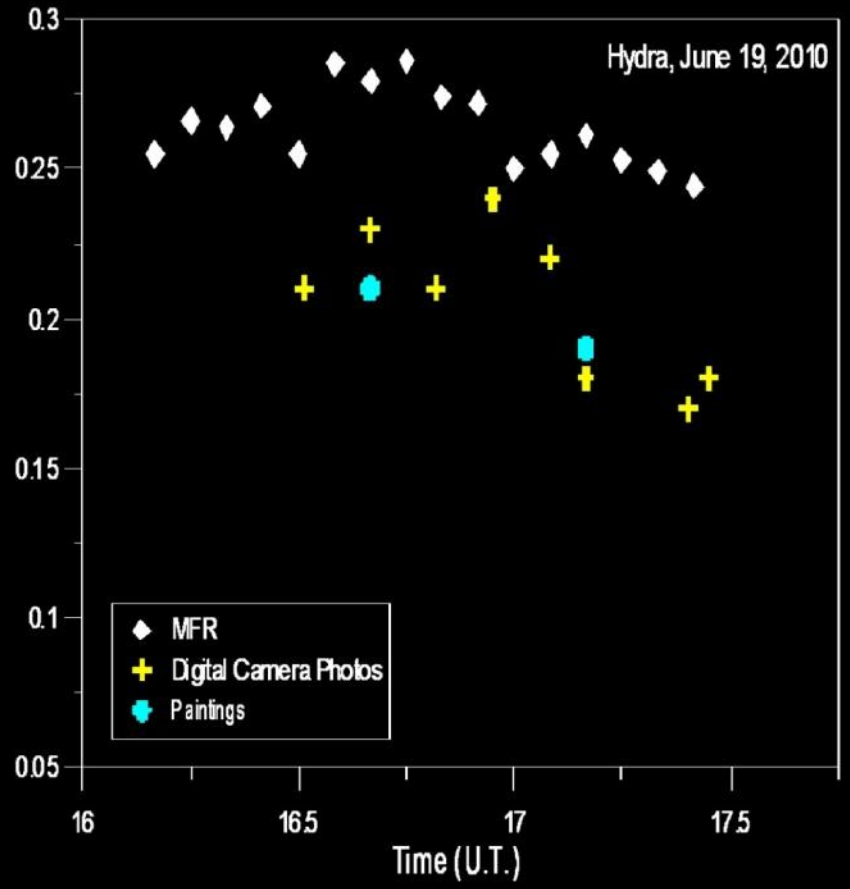
MFR-7 AOD retrievals at 500 nm on 19 and 20 June 2010 at Hydra campaign site. Microtops II AOD retrievals at 1020 nm are superimposed

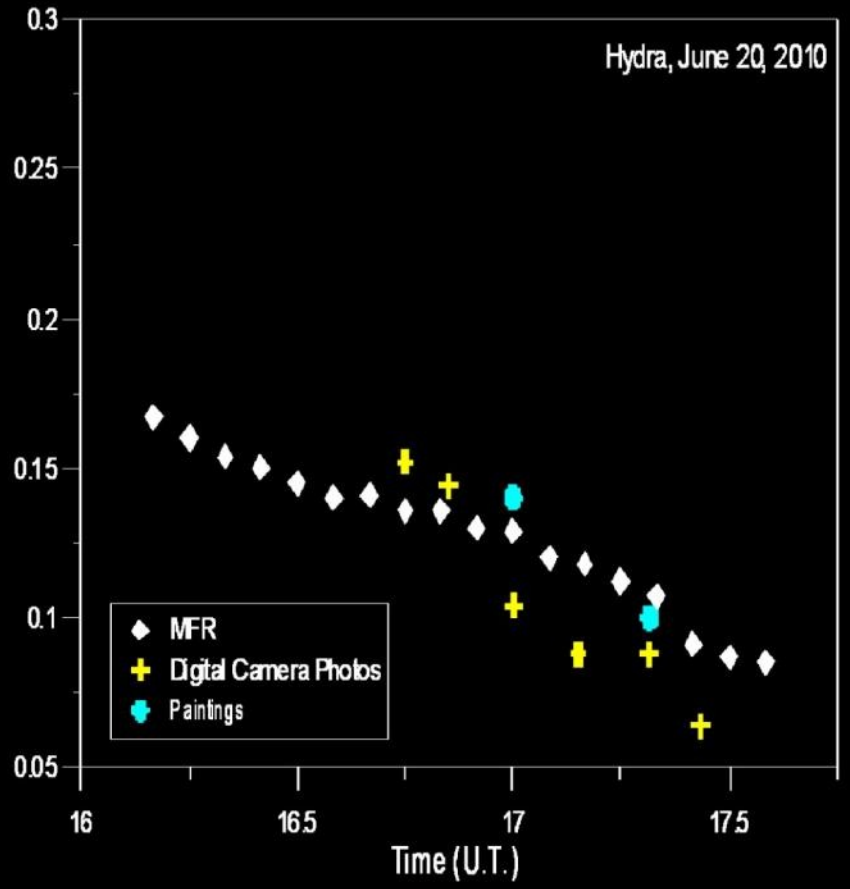


The profile of Saharan dust



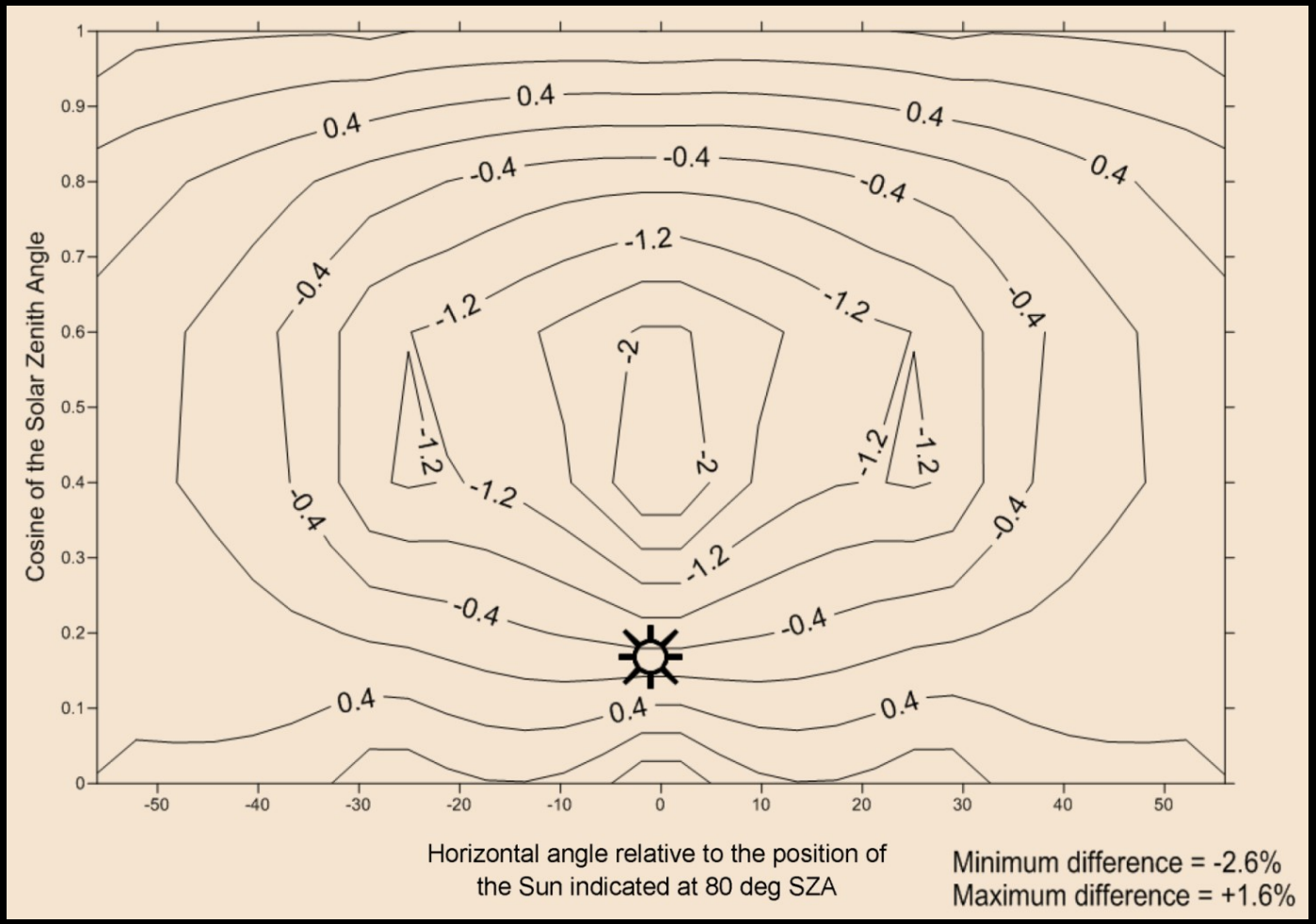
Aerosol measurements during the two days of the experiment



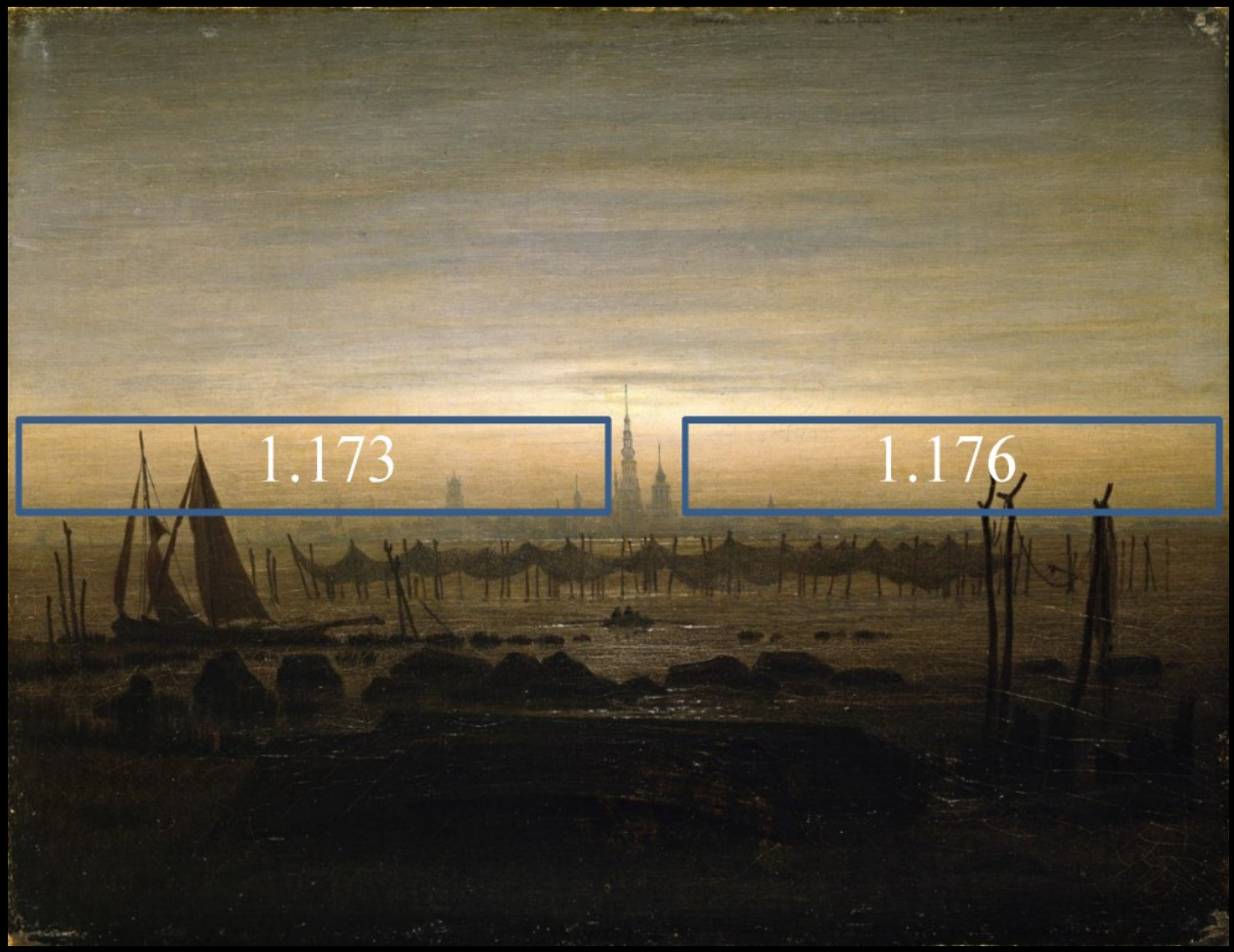


Upper: Digitally compressed paintings by P. Tetsis at the Hydra experiment under higher (left panel) and lower (right panel) AOD conditions. Bottom: Digital camera photos of the landscape.

Percent difference in R/G ratios between the measured at Hydra Sahara dust mineral aerosol profile and a typical modelled volcanic aerosol profile. In both cases AOD (500 nm) was set to 0.25.



R/G ratios with and without structural differences after Tambora (1815)

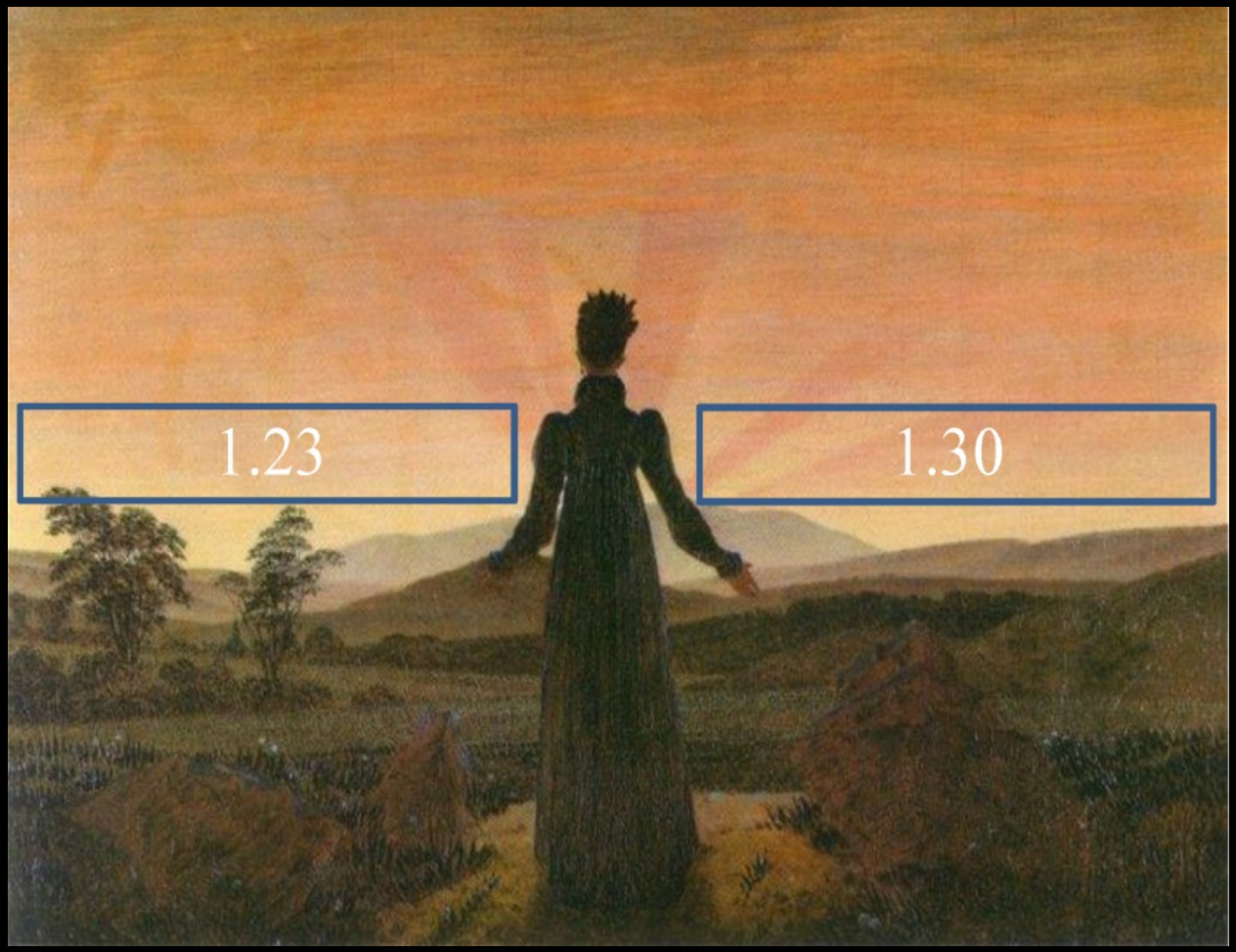


Caspar David Friedrich, Griefswald in the Moonlight, 1817.
Corresponding R/G ratios were averaged inside each box.

R/G ratios with and without structural differences after Tambora (1815)

Karl Friedrich Schinkel, The Banks of the Spree near Stralau, 1817.
Corresponding R/G ratios were averaged inside each box.

R/G ratios with and without structural differences after Tambora (1815)



Caspar David Friedrich, Woman in front of the Setting Sun, 1818.
Corresponding R/G ratios were averaged inside each box.

R/G ratios with and without structural differences after Tambora (1815)

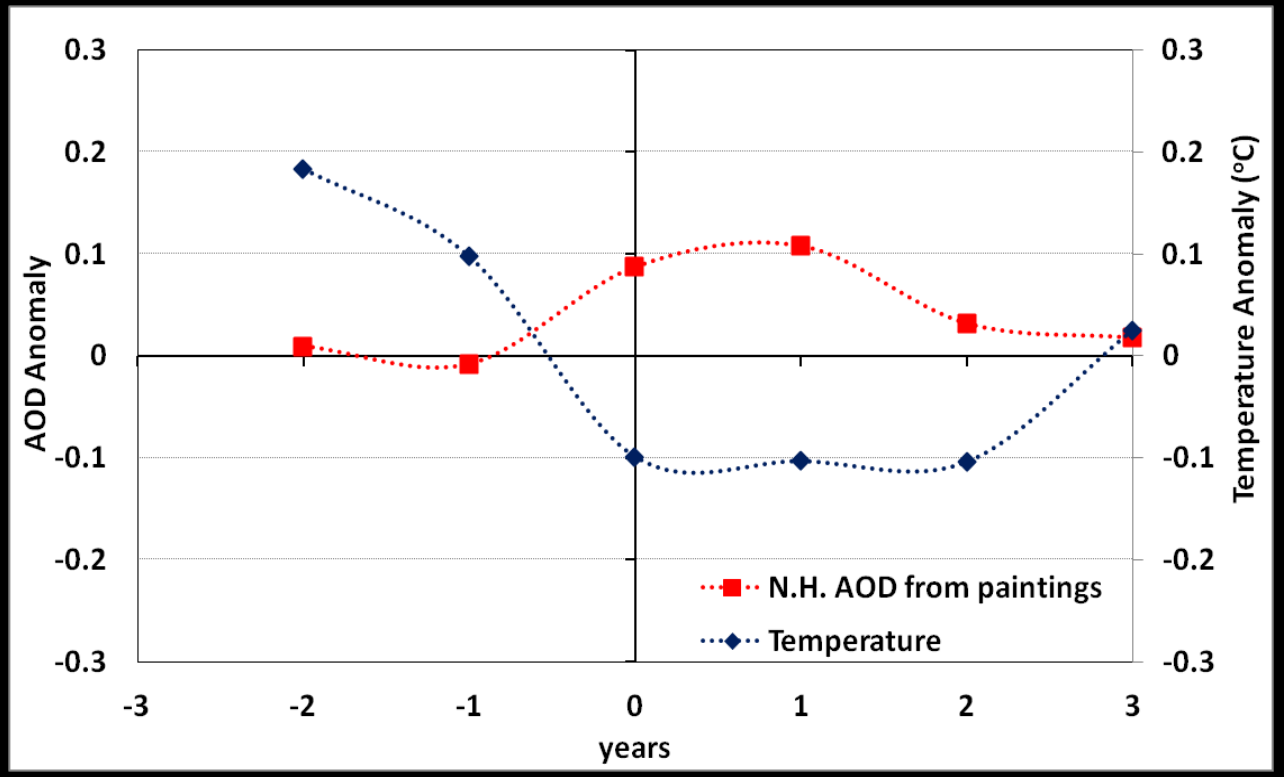
Joseph Mallord William Turner, Red sky and crescent moon, c. 1818.
Corresponding R/G ratios were averaged inside the box.

Volcanic aerosol indices and AOD proxies

Year	N.H. DVI (Lamb, 1970, 1977, 1983)	N.H. AOD from paintings (this study)	AOD (Robertson et al., 2001)	AOD Crowley and Unterman (2013)	AOD (Sato et al., 1993)	AOD (Stothers, 1996, 2001)	Sulfate aerosols (Tg) (Gao et al., 2008)
1782	45	0.115	0.0106	----	----	----	----
1783	400	----	0.1643	0.009	----	----	92.96
1784	300	0.3	0.1354	0.042	----	----	----
1785	200	----	0.0005	0.01	----	----	----
1786	160	----	0.0021	0.002	----	----	----
1787	45	----	0.0080	----	----	----	----
1788	30	----	0.0035	0.011	----	----	----
1789	15	----	0.0011	0.003	----	----	----
1790	----	----	0.0022	0.001	----	----	----
1791	----	----	----	----	----	----	----
1792	----	----	0.0013	----	----	----	----
1793	----	----	0.0292	----	----	----	----
1794	----	----	0.0177	----	----	----	1.88
1795	120	0.098	0.0043	----	----	----	----
1796	130	----	0.0017	0.018	----	----	6.7
1797	90	----	0.0041	0.006	----	----	----
1798	50	----	0.0048	0.001	----	----	----
1799	130	----	0.0060	----	----	----	----
1800	90	----	0.0010	----	----	----	----
1801	60	0.081	0.0031	0.012	----	----	----
1802	30	----	0.0036	0.004	----	----	----
1803	----	----	0.0047	0.001	----	----	----
1804	----	----	0.0019	0.018	----	----	----
1805	----	----	0.0043	0.006	----	----	----
1806	----	----	0.0011	0.001	----	----	----
1807	----	----	0.0021	----	----	----	----
1808	----	----	----	----	----	----	----
1809	----	----	0.1391	0.198	----	----	53.74
1810	----	----	0.2308	0.18	----	----	----
1811	80	----	0.0537	0.067	----	----	----
1812	180	0.199	0.0055	0.025	----	----	----
1813	170	0.181	0.0019	0.009	----	----	----
1814	170	0.142	0.0008	----	----	----	----
1815	695	----	0.3351	0.199	----	----	109.72
1816	490	0.6	0.3260	0.364	----	----	----
1817	375	0.379	0.0798	0.194	----	----	----
1818	195	0.33	0.0024	0.073	----	----	----
1819	30	0.108	0.0015	0.027	----	----	----
1820	15	0.062	0.0023	0.003	----	----	----

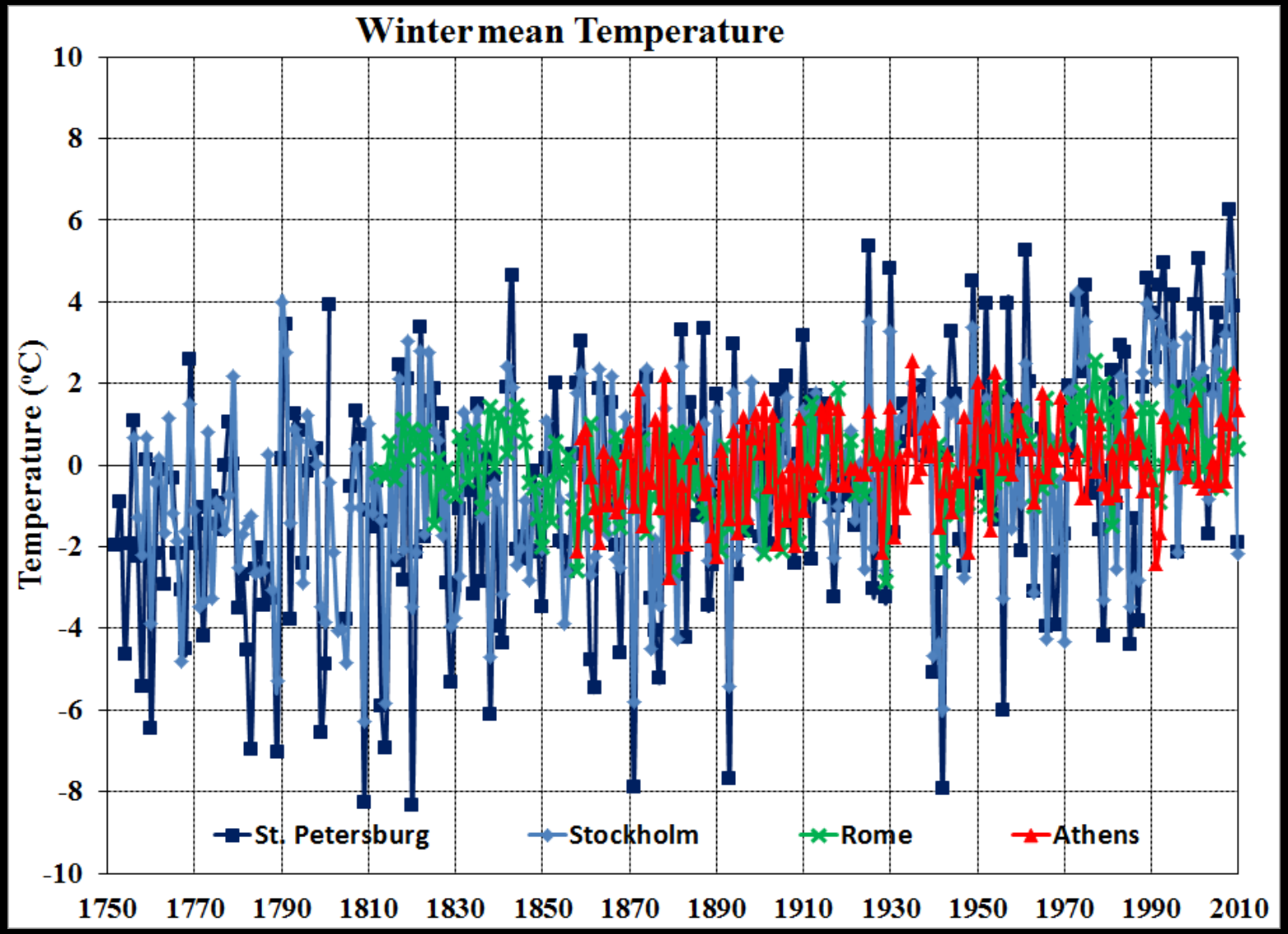
SPE Analysis with key year the volcanic eruption with VEI ≥ 5 for AOD and Temperature

No	Volcano (eraption)	Year	VEI
1	Laki	1783	6
2	Mystery 1809 Mega-eruption	1808	6
3	Mount Tambora (1815 eruption)	1815	7
4	Galunggung	1822	5
5	Cosiguina	1835	5
6	Mount St. Helens	1847	5
7	Shiveluch	1854	5
8	Askja	1875	5
9	Krakatoa	1883	6
10	Mount Tarawera	1886	5
11	Santa María	1902	6
12	Ksudach	1907	5
13	Novarupta	1912	6
14	Colima	1913	5
15	Cerro Azul	1932	5
16	Kharimkotan	1933	5
17	Bezymianny	1955	5
18	Mount Agung	1963	5
19	Mount St. Helens	1980	5
20	El Chichón	1982	5
21	Mount Pinatubo	1991	6
22	Mount Hudson	1991	5

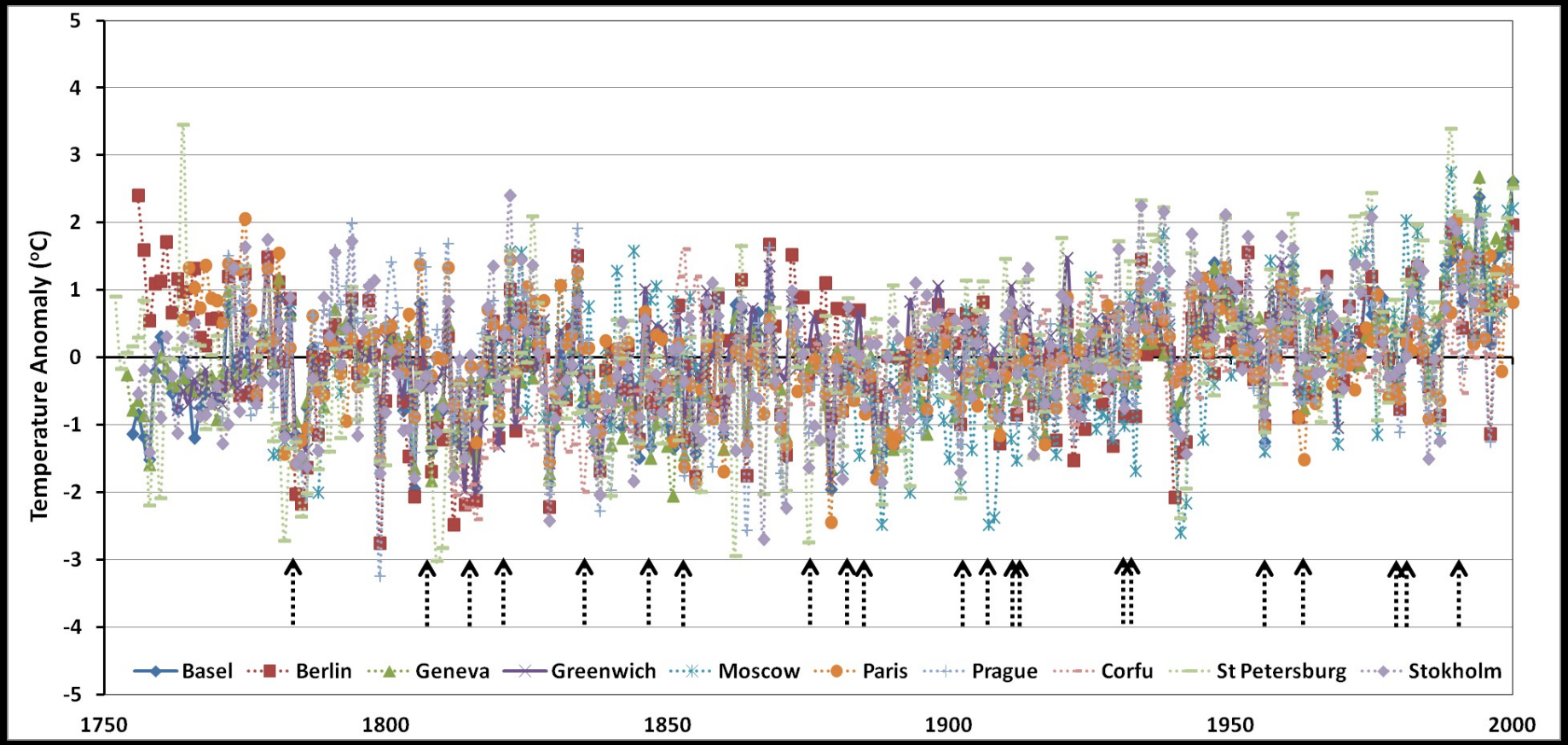


Climatic stations: Basel, Berlin, Geneva, Greenwich, Moscow, Paris, Prague, Corfu, St Petersburg, Stokholm

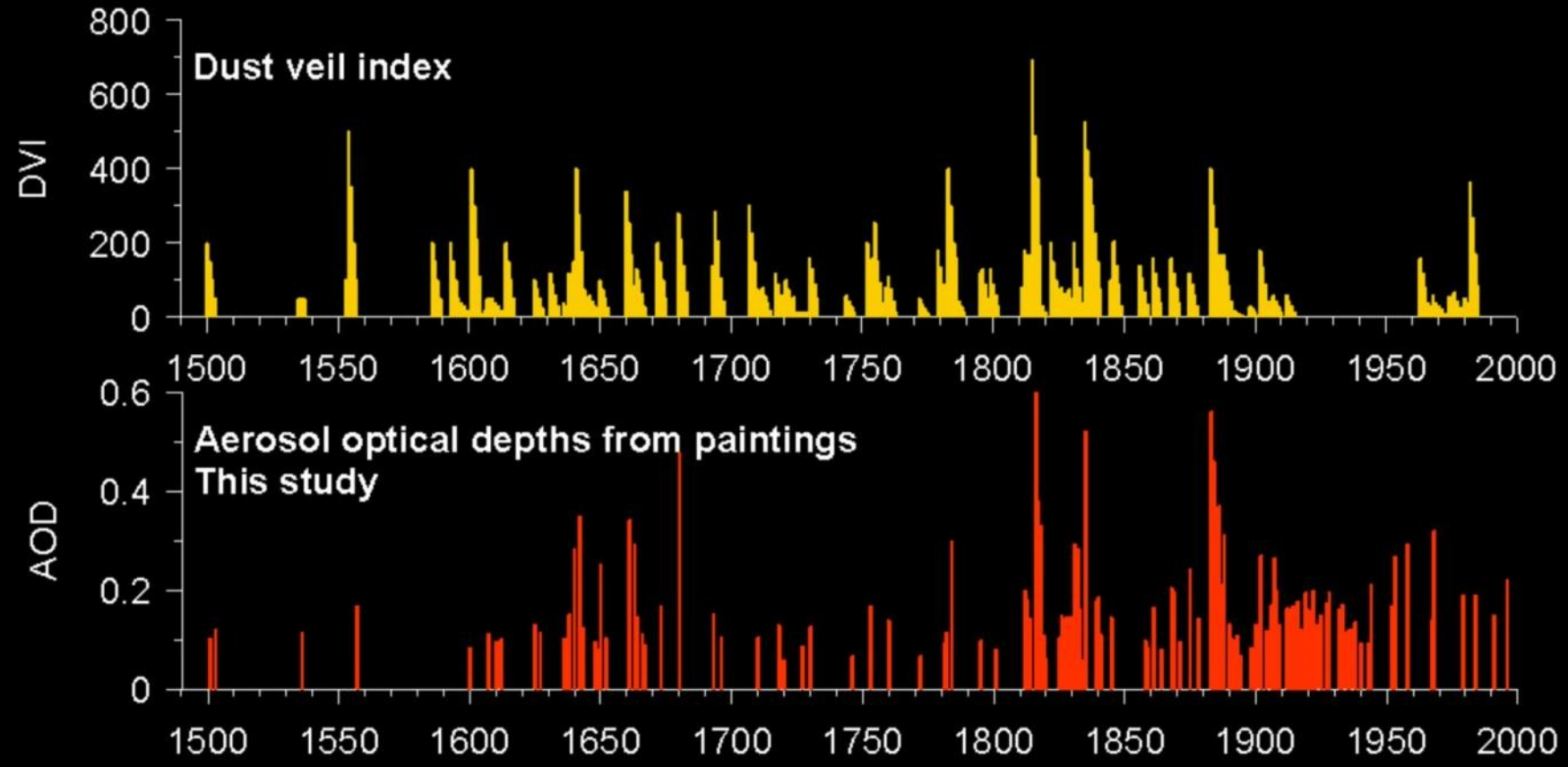
Winter mean temperatures at four sites with long term records

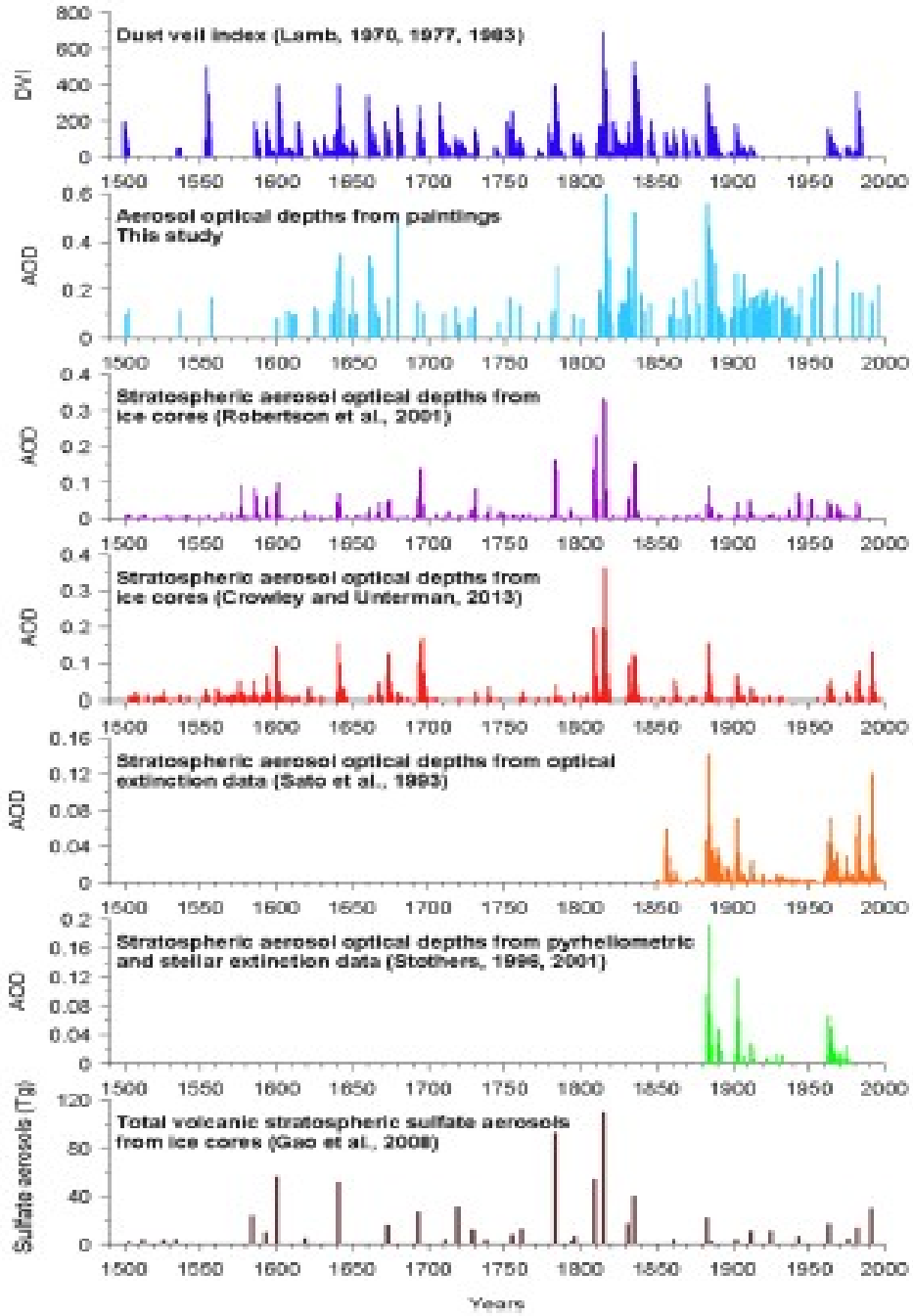


Annual mean temperatures at ten European sites with long term records



(DVI) Independent index of volcanic aerosols.
(AOD) Absorption of solar radiation in the atmosphere from measurements in paintings.




Dust veil index (Lamb, 1970, 1977, 1983)
DVI
Aerosol optical depths from paintings
This study
AOD
Stratospheric aerosol optical depths from
ice cores (Robertson et al., 2001)
AOD
Stratospheric aerosol optical depths from
ice cores (Crowley and Unterman, 2013)
AOD
Stratospheric aerosol optical depths from optical
extinction data (Sato et al., 1993)
AOD
Stratospheric aerosol optical depths from pyrheliometric
and stellar extinction data (Stothers, 1996, 2001)
AOD
Total volcanic stratospheric sulfate aerosols
from ice cores (Gao et al., 2008)
Sulfate aerosols (Tg)
1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000
Years

guardian.co.uk

How old masters are helping study of global warming

Paintings of striking sunsets show effect of huge volcanic eruptions on climate

- David Adam, environment correspondent
- The Guardian
- Monday October 1 2007

nature

RESEARCH HIGHLIGHTS

Volcanic paintings

Atmos. Chem. Phys. 7, 4027–4042 (2007)

The ash from large volcanic eruptions can cool Earth's climate and cause vividred sunsets. But the historical effects of volcanic activity on climate are difficult to quantify owing to a lack of direct atmospheric observation.

Christos Zerefos at the Academy of Athens in Greece and his colleagues have come up with a novel way to c particle content in middle latitudes isphere during the period 1500– sunsets captured in paintings by Mallord William Turner, Edgar Degas ictured is one of their subjects. *The* by Caspar David Friedrich.) lculated red/green colour ratios from dreds of paintings. They found that after major volcanic eruptions such in 1680 and 1883. The team then used to reconstruct how much light was nic ash in the air. The resulting time with and could complement existing tions of atmospheric composition.

e-tipos.com

Η ΚΑΘΗΜΕΡΙΝΗ

Μελετώντας τα ηλιοβασιλέματα

Τετάρτη, 03.10.07

ΕΛΕΥΘΕΡΟΤΥΠΙΑ

Ζωγραφίζοντας το κλίμα

Του ΦΙΛΗ ΚΑΪΤΑΖΗ, 05-10-2007

ΤΟ ΒΗΜΑ

29-11-2007

Ζωγραφική και κλιματικές αλλαγές

DER SPIEGEL 41/2007

Prisma **Wissenschaft • Technik**

Munch-Gemälde „Der Schrei"

Ausbruch des Krakatau 1883

ATMOSPHÄRE

Klima-Archiv in der Galerie

Caspar David Friedrich, Edgar Degas oder William Turner malten Sonnenuntergänge in überwältigenden Farben. Jetzt bekommen ihre Gemälde

buchen wie einen der Explosion des indonesischen Krakatau 1883, der Asche bis zu 80 Kilometer hoch in die Atmosphäre schleuderte. Die Erkenntnisse sollen nun in aktuelle Klimamodelle einfließen. „Wir können den Klimawandel nicht verstehen, wenn wir nicht die Rolle der Schwebstoffe in der At-

AP Associated Press

NATIONAL GEOGRAPHIC

The Washington Times

THE HINDU

Art as Window to Climate Change

Kate Schuman, Associated Press, Nov. 29, 2007

Discovery

msnbc.com

Süddeutsche Zeitung

Klima auf der Leinwand

Aus alten Gemälden kann man einiges lernen. Dass sie auch die Klimageschichte abbilden, ist neu: Edvar

Beispiel waren geltreue Chronisten tiefer

Von Axel Bojanowski , 12-10-2007

Schauer von Traurigkeit. Einen ähnlichen Schrei Edvard Munch einer Zustand, den er kurz darauf in

unstillbar.

Im Jahr 1883 in Oslo muss sich die Sterne abgrei einen Zaun, denn ich war traurig. Über dem blaus

REUTERS

Classic paintings had a helping hand from volcano

Thu Oct 4, 2007 12:10am EDT

By Karolos Grohmann

中外对话 chinadialogue

Old masters, new climate lessons?

David Adam

November 09, 2007

THE INDEPENDENT

Art & science: Turner's message from the skies

By Geoffrey Lean

Sunday, 7 October 2007

the eggs E.G.U. NEWSLETTER

Atmospheric effects of volcanic eruptions as seen by famous artists and depicted in their paintings

by C.S. Zerefos et al.

und seine Kollegen fest.

Contributors:

C. Zerefos, P. Tetsis, A. Kazantzidis, V. Amiridis, S. Zerefos, J. Luterbacher, K. Eleftheratos, E. Gerasopoulos, S. Kazadzis, D. Balis, V. Gerogiannis, I. Kapsomenakis