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1 **The Sky in Edvard Munch's "The Scream"**

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ABSTRACT

11 “The Scream” is a well-known painting by Edvard Munch (1863–1944).
12 The Norwegian word used by Munch is “Skrik,” which can be translated as
13 “shriek” or “scream”. “The Scream” may be of interest to meteorologists be-
14 cause of the quite striking representation of the sky. It has been suggested
15 that the dramatic red-colored sky was inspired by a volcanic sunset seen by
16 Munch, after the Krakatau eruption in 1883, that it was inspired by a sighting
17 of stratospheric nacreous clouds and also that it is part of the artist’s expres-
18 sion of a scream from nature. The evidence for the volcanic sunset theory
19 and Munch’s psyche are briefly reviewed. We provide support that Munch’s
20 inspiration may have been from a sighting of nacreous clouds, observable
21 from southern Norway during the winter months. We show that the colors
22 and patterns of the sky in Munch’s painting match the sunset colors better if
23 nacreous clouds are present. Their sudden appearance around and after sunset
24 creates an impressive and dramatic effect. By comparing the color content of
25 photographs and paintings of regular sunsets, volcanic sunsets, and nacreous
26 clouds after sunset, with the color content of the sky in “The Scream”, the
27 match is better with nacreous clouds present. If this conjecture is correct then
28 Munch’s sky in “The Scream” represents one of the earliest visual documen-
29 tations of a nacreous cloud display.

30 **Capsule Summary**

31 The sky in Edvard Munch's "The Scream" is compared with photographs of a display of nacre-
32 ous clouds, and through the use of a color analysis a striking similarity is found.

33 **1. Introduction**

34 The representation of clouds and other meteorological phenomena in art has been recognised
35 for some time as a source of potential data to describe aspects of the atmosphere long before the
36 widespread use of quantitative measuring devices, e.g., Neuberger (1970), Brimblecombe and Og-
37 den (1977), Thornes (1999), Zerefos et al. (2007), Zerefos et al. (2014). A notable example of
38 this was the use of William Ascroft's pastel sketches (Ascroft 1888) showing dramatic sunsets that
39 appear on the frontispiece of the Royal Society's publication "The Eruption of Krakatoa and Sub-
40 sequent Phenomena" (Symons 1888). These sketches depict observations from Chelsea, London,
41 on 26 November 1883 and show the effects that aerosols high in the atmosphere have on the color
42 of the sky. We cannot be sure that the chromo-lithograph reproductions of the sketches accurately
43 represent the spectral content of the sky, as we also cannot be sure that Ascroft himself accurately
44 depicted the colors using the palette of crayons to him, but modern photographs of volcanic sunsets
45 resemble these sketches well.

46 Hamblyn (2001) describes the origin of the systematic categorisation of clouds by Luke Howard.
47 Clouds had hitherto been assumed to be ephemeral shapes in the sky. This "invention" had an
48 immediate impact on the scientific community and was recognised at the time as an important
49 paradigm. Howard's descriptions included sketches of various cloud types, but interestingly not

50 all. Fikke et al. (2017) have hypothesised that the sky in “The Scream” has a striking similarity to
51 mother-of-pearl or nacreous clouds. They discuss anecdotal evidence concerning the possibility
52 that Munch observed these clouds whilst out walking with friends one evening, or perhaps on
53 another occasion or occasions. They suggest that although Munch himself seems not to have
54 regarded his observation as one of clouds (he refers to the sky), since this type of cloud was rare
55 he may not have recognised that the atmospheric display was connected to the presence of high
56 clouds. Here we discuss previous ideas concerning the inspiration behind Munch’s depiction of the
57 sky. These include the volcanic sunset hypothesis, the idea that Munch used colors for symbolic
58 meaning, for example red to represent passion and blood, and the nacreous cloud hypothesis of
59 Fikke et al. (2017). The paper briefly discusses the first two ideas and then concentrates on the
60 nacreous cloud hypothesis. Because the exact dates of the paintings and Munch’s motives are
61 uncertain, this and previous discussion have been limited to conjecture. We also include some
62 background on Munch, his art and his mental state. The main focus of this paper, however, is
63 an objective color analysis of his paintings of “The Scream”, of photographs of volcanic sunsets
64 and nacreous clouds. By analysing the color content and patterns of the depiction of the clouds
65 and sky in “The Scream”, this study supports Fikke et al. (2017)’s suggestion that nacreous clouds
66 provided the inspiration for his depiction of the sky in “The Scream”.

67 **2. The art of Edvard Munch**

68 Edvard Munch (1863-1944) was a Norwegian artist noted for his sombre motifs and expression-
69 ist style. Munch was the second child born to Christian Munch who was a very religious, stern
70 and conservative man and had a strong influence on Edvard. His mother died in December 1868

71 of tuberculosis, a fate also suffered by his grandfather, Edvard Storm Munch, and who was insane
72 at the time of his death. The hardships, grief, gloominess and Edvard's conviction that he would
73 eventually succumb to insanity are believed to have influenced his artistic style and subject matter.
74 Indeed the themes of blood and melancholy are present in many of his paintings.

75 Of relevance to this study, Munch is known to have been indifferent to dating his artwork
76 (Prideaux 2012). This may have been due to his desire to keep his paintings with him and up-
77 date them from time to time by adding brushstrokes, but also may have been due to his view that
78 the chronology of his work only mattered when he considered the work finished (Prideaux 2012).
79 He is also known to have dated his works going back many years before they were first exhibited,
80 as well as producing many versions of the same painting. The relevance, as we shall see, is that it
81 is difficult to say precisely when he first painted "The Scream" and indeed when he first conceived
82 the idea.

83 The materials and paints used by Munch are also somewhat uncertain. He seems to have
84 favoured using unprimed canvas or cardboard (see Figure 1, later). He did not use varnishes
85 and was somewhat haphazard in the use of oils, pastels, crayons or pencils and would often mix
86 these on the same canvas leading to a distinctive textural style. It must be stressed here that in
87 attempting to apply a scientific analysis to an artwork of Munch we are greatly hindered by a lack
88 of certainty over the chronology of his work, the materials used and not least, by his motivations.

89 *a. The Scream*

90 The most famous, certainly the most iconic, of Munch's works is "The Scream". The image
91 is familiar to modern culture and has been reproduced many times and copied by other artists

92 such as Andy Warhol and the cartoonist Gary Larson. There are four known color versions of
93 “The Scream” (Figure 1), all believed to have been produced between 1893 and 1910, and one
94 lithograph produced in 1895. Two of the color versions are the signed and dated 1893 version
95 held by the National Museum of Art, Architecture and Design in Oslo, and a version with no date
96 but thought to have been produced in 1910 and now held in the Munch Museum in Oslo. “The
97 Scream” comes with a narrative that Munch himself penned in a diary dated 22 January 1892.
98 There are actually several versions of this narrative written in Norwegian and in French, and the
99 one given below is from the English translation of his selected prose (Guleng 2011, see: MM T
100 2760-56r):

101 *I was walking along the road with two friends*

102 *– the sun was setting*

103 *– I felt a wave of sadness –*

104 *the Sky suddenly turned blood-red*

105 *I stopped, leaned against the fence*

106 *tired to death – looked out over*

107 *the flaming clouds like blood and swords*

108 *– the blue-black fjord and city –*

109 *– My friends walked on – I stood*

110 *there quaking with angst – and I*

111 *felt as though a vast, endless*

112 *scream passed through nature.*

113 In the French version Munch writes: “... *pendant des nuages rouges comme du sang et comme*
114 *des langues de feu.*” This translates as blood-red clouds and tongues of fire. Much has been
115 made of this narrative and art historians recognise the motifs of red and blood associated with
116 anxiety and often used by artists to describe pain, morbid feelings and angst. This “interruption”
117 between the normal being and a highly charged emotional state with a feeling of detachment is
118 a constant theme in the interpretation of the art of Munch. It is unclear whether this description
119 can be treated as an actual observation (a real event) – Munch often added prose statements¹ to
120 accompany his art and they exist in many different versions. Hilde Dybvik suggests that Munch
121 followed the Kristiania Bohemians’ tenet to “write one’s own life” (Guleng 2011). Although there
122 is no definitive evidence that this event actually happened, there are circumstantial clues that point
123 to a physical location for the walk that fit well with the scene depicted in “The Scream” as well as
124 with the prose commentary. There is a road near the city of Oslo in a commune called Ekeberg,
125 close to Utsikten, that overlooks Oslo fjord and has a view towards the south west in the direction
126 of the setting Sun during the winter months. The location is now marked by commemorative
127 plaque to honour Munch. At the time that Munch may have made this walk, the road was a
128 path and, interestingly, a slaughterhouse and a mental asylum were located nearby. It has been
129 suggested that the idea of “The Scream” may have been influenced by the sound of animals being
130 slaughtered nearby. A possible reason for Munch walking in this area, suggested by Sue Prideaux
131 in her book “Behind The Scream” (Prideaux 2012), is that he was visiting his younger sister who
132 had recently been admitted into the asylum. There are also speculations that Munch had seen an
133 exhibit of a Peruvian mummy in Paris and this has influenced the the way the main figure in “The

¹Referred to as ‘prose poetry’, see Guleng (2011), p.137.

134 Scream” is depicted, with a hairless, contorted face. The world of art history makes little comment
135 on such influences and there is virtually no analysis of the sky in “The Scream”, the main topic
136 of discussion in this work. If the narrative is to be treated literally then there are some important
137 remarks that provide clues to the cause of the dramatic sky. He mentions the Sun was setting and
138 that the sky “suddenly” turned blood-red. He mentions “flaming clouds” and “swords”. The word
139 “wave” appears in the written statement and the sky is depicted as “wavy”. This suggests that
140 if the observation is to be treated as real, then it is likely that the colors were influenced by an
141 appearance of clouds. Nacreous clouds fit this description well, as we shall see later.

142 Although many people look at the painting and think that the character is screaming, due to the
143 open mouth, it is clear from Munch’s narrative that it is the sky that is screaming, and the figure
144 is covering his or her ears, in a futile attempt to smother the sound. Munch used the same setting
145 to produce other paintings with the same red and yellow sky, mountains, and Oslo fjord in the
146 background, such as “Despair” in 1892, another “Despair” in 1894, and “Anxiety”, also in 1894.
147 In these paintings, the sky has a much less wavy character, and the sky just curves to exactly match
148 the mountains beneath. This argues against the interpretation that he is depicting nacreous clouds,
149 at least in these later images.

150 *b. Chronology*

151 The generally accepted date of the first pastel version (tempera and crayon on cardboard) of
152 “The Scream” is 1893. Later versions are dated to 1895 and also as late as 1910. The date for
153 the version held at the Munch Museum in Oslo is disputed, although most experts agree on a
154 date of 1910, while some argue for an earlier date in the 1890s. It is quite possible that Munch

155 started work on this subject earlier, but “The Scream” was not seen in public until the exhibition
156 at Unter den Linden in Berlin in the winter of 1893. The work would later become part of the
157 “Frieze of Life” which also included “Angst” (1894) and “Despair” (1894), which both have a
158 strong resemblance to “The Scream”. The problem with making a chronology of Munch’s work
159 comes from his habit of not always dating and signing his work until he felt it to be complete. It is
160 also known that he had wrongly dated some of his work (Ydstie 2008). The four color versions of
161 “The Scream” are shown in Figure 1.

162 *c. Interpretations*

163 Robock (2000) first suggested that the red sky in “The Scream” was reminiscent of a volcanic
164 sunset. Accepting the date of the work as 1893, Robock looked for a large eruption occurring
165 in the year before that might have caused reddened skies in Europe. The Awu (Sangihe Islands,
166 Indonesia) eruption of June 7–12 1892 seemed to fit this scenario and so he suggested this volcano
167 as the culprit. This speculation was corrected later by Robock (2007) based on the work of Olson
168 et al. (2004) who suggested it was the eruption of Krakatau in August 1883 that was the true
169 cause for the remarkable blood-red clouds that Munch had described. Olson et al. (2004) seem to
170 have come to this conclusion by accepting the date of the painting as 1893 but noting that there
171 was little else that could have caused such a dramatic sky in that year. The argument then becomes
172 somewhat interpretive in the sense that it must be accepted that Munch had seen a Krakatau sunset,
173 most likely in the winter of 1883, remembered it and then painted it some 10 years later. There
174 are numerous problems with this interpretation, not least that such a dramatic event in his life was
175 not expressed in his art until so much later. So is it possible that Munch painted “The Scream” in

176 1883 or 1884? At that time, Munch was living the life of a Bohemian in Kristiania (now Oslo).
177 He was 19 years old and had not yet decided to devote his life to art. Further, his expressionist
178 style, of which “The Scream” is an example, had not yet developed – and would not be fully
179 developed until after he had seen the works of Van Gogh, Gauguin and Monet on visits abroad.
180 Another factor that points to a later date for the painting is that there are reasons why Munch may
181 have been experiencing acute depression and anxiety. Munch’s father died in 1889 and this had a
182 profound effect on Munch’s mental state. His younger sister Laura was also experiencing mental
183 health problems and had been admitted into the asylum near Ekeberg. Munch lived in constant fear
184 of having a mental breakdown himself. This combination of events could provide the backdrop
185 and motivation for expressing his morbid feelings in his art. Olson et al. (2004) argue that a later
186 date (much later than his actual observation) fits with other paintings he made that feature events
187 from a much earlier experience in his life. The important point here is that he could only have seen
188 a Krakatau sunset after late November 1883 and before March 1886, when the volcanic sunsets
189 had disappeared over northern Europe. If we consider his whereabouts during this period and
190 that it must have been a wintertime observation then it really narrows down the observation to the
191 winter months of 1883. If we accept that the observation was real, then the possible candidates
192 are an abnormal or particularly striking sunset, a volcanic sunset or some other meteorological
193 phenomenon, not yet disclosed.

194 Fikke et al. (2017) report observations and photographs of a display of nacreous clouds in De-
195 cember 2014 from Oslo, Norway. They noted the similarity of the color and pattern of the nacreous
196 cloud display to the sky in Munch’s “The Scream”. As also found here, Fikke et al. (2017) and

197 Olson et al. (2004) are unable to provide a likely date when Munch observed the “blood red” sky,
198 but like Fikke et al. (2017) we favour an explanation based on an observation of nacreous clouds
199 rather than a volcanic sunset. We believe the meteorological nacreous cloud explanation fits with
200 the chronology, the geography and more importantly with the way the sky is depicted in “The
201 Scream”. Our evidence is presented in the following sections, and we approach this in a scientific
202 manner rather than as an artistic interpretation. We also admit that it is impossible to know what
203 was in the mind of Munch when he painted “The Scream” and hence we are making the same
204 implicit assumption as Fikke et al. (2017), Robock (2000, 2007) and Olson et al. (2004) that the
205 event (Munch’s observation on the walk as described in his prose) actually occurred and that this
206 was the subject matter for the painting. None of the interpretations depend on Munch painting
207 “The Scream” while he watched the sun set so it is a matter of weight of evidence to decide which
208 interpretation is more plausible. Art historians might argue that the actual observation is not im-
209 portant – the visual effect is the same whether he imagined it or whether it was based on a real
210 experience. An imagined experience remains a completely plausible explanation.

211 **3. Volcanic sunsets**

212 The idea that the sky in “The Scream” was inspired by a volcanic sunset is pervasive; a web
213 search for “The Scream” will most often include a reference to a volcanic connection. Indeed
214 volcanic aerosols high in the atmosphere (typically 20 km or higher) produce some of the most
215 spectacular red sunsets. The processes leading to highly reddened skies after the Sun has set are
216 well-known and involve selective scattering of light. SO₂ emitted during volcanic eruptions is
217 converted to sulfate aerosols (H₂SO₄ in aqueous solution – typically 75% acid to 25% water) that

218 form stable layers in the lower stratosphere. These high-altitude layers contain millions of small-
219 sized aerosols (diameters $< 1 \mu\text{m}$) that can scatter light, but because their size is comparable or
220 larger than the wavelength of visible light, that scattering occurs in the Mie region. The sunsets due
221 to these aerosols have a different appearance to ordinary sunsets where Rayleigh scattering (strong
222 wavelength and particle size dependence) is responsible for the reddening. The scattering from
223 volcanic aerosols becomes noticeable when the light path from the Sun grazes the atmosphere,
224 while still intersecting the aerosol layer. This leads to two noticeable effects: reddening due to
225 the selective scattering of light as it takes a long path through the atmosphere, and an afterglow
226 usually strongest 20–30 minutes after sunset due to scattering of the reddened light off the aerosol
227 layer. Almost no blue light is intensified by this scattering process but there is a small enhancement
228 of green light. Since the stratosphere is stable (the temperature increases with increasing height)
229 there is a tendency for the aerosols to form in layers. The well-known Junge layers are the stable
230 background layers formed by repeated injection and depletion of these aerosols in the stratosphere
231 over time (Junge 1955). Volcanic sunsets get progressively stronger as the Sun sinks lower below
232 the horizon and then they diminish as the sunlight is eclipsed by the Earth and the light rays no
233 longer reach the layer. The dramatic effect can last for 20 minutes or longer and the speed of
234 onset depends on the latitude of the observer: the Sun sets faster at the equator than at 60°N . The
235 spectral content of the light from a non-volcanic sunset is depleted in blue light, has more longer
236 wavelength light closer to the horizon and culminates in the strongest enhancement at the red end
237 of the spectrum after which the sensitivity of our eye to longer wavelengths ends. A typical eye has
238 a maximum sensitivity at $\sim 550 \text{ nm}$, dropping to 20% at 489 nm and 637 nm (Goss and West 2002).

239 Under twilight conditions there is a shift in sensitivity towards shorter wavelengths. Non-volcanic
240 sunsets can become more dramatic and noticeable if there are high-level clouds that can also
241 scatter light back towards the observer. Figure 2 shows a photograph of a volcanic sunset captured
242 from an aircraft flying at 38,000 ft (11,582 m) over the South Pacific in July 2011, following the
243 eruption of Puyehue-Córdon Caulle in southern Chile. This photograph has been selected (among
244 the many fine examples available) because it illustrates all the main features of a volcanic sunset
245 that show the strong reddening of the sky near the horizon (in shadow), changing through orange
246 to yellow and finally to the deep blue of the outer atmosphere. There are noticeable stratifications,
247 due to aerosol layers. The question of whether Munch could have seen a sunset due to the eruption
248 of Krakatau was raised by Olson et al. (2004), and also later in Olson (2014), who simply assumed
249 he would have had the opportunity. Fikke et al. (2017) also address this matter, suggesting that the
250 stratospheric haze due to Krakatau was rather diffuse as observed from latitudes around 60°N. The
251 sunsets were most vivid in the winter of 1883 over Europe. The Symons (1888) report provides the
252 best consolidated set of observations of optical phenomena due to Krakatau aerosols and includes
253 a map of the approximate northern limit of the main sky phenomena by the end of November
254 1883. This is based on the relatively sparse set of observations available, but it clearly shows that
255 Krakatau optical phenomena could have been seen from southern Norway at the start of the winter
256 of 1883. There are observations of “glows” on 29 and 30 November 1883 from Kristiania and
257 these continued until February 1884, although there are no specific dates given. The glows are
258 reported to have diminished by March 1884 in Europe. It is highly unlikely that Krakatau optical
259 phenomena would have been visible as late as the 1890s over southern Norway. This gives a range

260 of dates from late November 1883 until February 1884 for Munch to have seen a glow. But what
261 of an abnormally bright sunset of non-volcanic origin? There are many examples of these, e.g.,
262 Minnaert (1974). They are particularly striking when the atmosphere is clear (large dust and other
263 particles in the troposphere tend to reduce the color of the sky) or when there are clouds that can
264 reflect and enhance the scattering of the Sun's reddened light. The sequence of colors from such a
265 sunset usually starts at the horizon with red, orange-red, yellow, and then deep blue, but there can
266 be subtle differences depending on the angle of the Sun below the horizon (Minnaert 1974, page
267 295, Fig.169). One way to decide whether Munch tried to reproduce what he had seen is to look
268 at the sequence of colors. We examine this in a later section.

269 **4. Nacreous clouds**

270 In the insightful investigation made by Olson et al. (2004) of the circumstances contributing
271 to the depiction of the sky in "The Scream", they note that after searching for possible causes
272 of the blood-red sky over Oslo fjord, none were apparent in 1893. However, as shown by Fikke
273 et al. (2017) the appearance of nacreous clouds, a very dramatic phenomenon and hardly known
274 at the time, could have caused such a sky. Minnaert (1974) describes the phenomenon this way:
275 *"Sometimes, these clouds are striped, undulating, cirrus like; at other times, the entire cloud*
276 *bank is almost one color, with spectral colors along the edges in oblong horizontal rows..."* and
277 *"The whole scene is indescribably lovely and majestic."* Minnaert is describing nacreous clouds,
278 known by atmospheric physicists as one type of polar stratospheric clouds (PSCs) and by the more
279 descriptive moniker of mother-of-pearl clouds (MPCs). He goes on to write that they are visible
280 from southern Norway in winter. Nacreous clouds generate very dramatic skies and are most

281 noticeable as the Sun sets, when the color of the clouds reddens and could certainly be described
282 as “blood red” as the photographs shown later demonstrate. Munch had ample opportunity to
283 see such a display. When not travelling abroad, he lived in southern Norway and the direction
284 and location of the scene depicted in “The Scream” also fits with the direction and location for
285 nacreous cloud observations. Furthermore, as shown next, nacreous clouds observations from
286 southern Norway were documented on at least five occasions in 1892. Nacreous clouds should not
287 be confused with the much higher altitude noctilucent clouds (Gadsden and Schröder 1989), that
288 seem to have been documented and photographed in the mid-1880’s (Dalin et al. 2012).

289 *a. Occurrence*

290 Mohn (1893) describes observations of nacreous clouds made in 1892 from England and Nor-
291 way, while Størmer (1929) discusses these clouds in a systematic manner from a series of pho-
292 tographs made from sites in Oslo, southern Norway in 1926. Størmer (1929) notes that between
293 1872 and 1892 nacreous clouds were observed from Norway, but that after 1893 he did not ob-
294 serve them again until 1926, despite careful observations. Stanford and Davis (1974) provide a
295 list of dates when these clouds were observed from Europe; in 1892 there are five confirmed ob-
296 servations from Norway and there are observations in every year before that until 1881, except
297 1883 and 1888. While it is generally considered that these clouds are rare, apparently from the
298 right location (southern Norway) and at the right time of year (winter) there is a good chance of
299 observing them². Fikke et al. (2017) also show some spectacular photographs of nacreous clouds
300 taken in late December 2014. Munch therefore likely had the opportunity to witness a nacreous

²FP has observed them from southern Norway on four separate occasions during 2008–2014.

301 cloud display from exactly the location that he made his walk with his two friends, looking in the
302 right direction towards the southwest during many days in most of the winters between 1872 until
303 1892. In the 1880s and 1890s these clouds had not been classified and their height and occurrence
304 were unknown.

305 Hesstvedt (1958) studied 168 cases of observations of MPCs and found a mean height of 24
306 km, a predominance of wintertime observations (December–February), a preferred location to
307 the eastern side of the Norwegian mountains and a correlation with the synoptic weather pattern.
308 Stanford (1973) provides a physical basis for their formation and occurrence and they are discussed
309 further by Fikke et al. (2017).

310 *b. Known photographs*

311 The earliest photographs of nacreous clouds are given by Størmer (1926) and there are numerous
312 examples of photographs of these clouds now available on the web. The website: [http://www.
313 atoptics.co.uk/](http://www.atoptics.co.uk/) has some striking examples of nacreous clouds and the recent article by
314 Fikke et al. (2017) also includes some fine examples. In January 2008 there was a particularly
315 vivid display of these clouds and one of us (FP) was lucky enough to be in southern Norway
316 (Leirsund $\sim 60^\circ\text{N}$, $\sim 11^\circ\text{E}$) and make a series of photographs looking towards the southwest as the
317 Sun set. The change in the appearance of the clouds as the Sun disappeared below the horizon
318 was remarkable: the sky reddened and the full spatial extent of the clouds became more evident.
319 Part of the series of photographs is shown in chronological order in Figure 3. Before sunset, the
320 clouds appeared cirrus-like (as Minnaert noted), white with only a hint of the spectacular colors
321 to come. A short time later, as the light diminished, hues of blue, green, pink and red began to

322 emerge. The wavy nature of the clouds became clearer and the progression of colors followed
323 an intermittent pattern with blues and reds mixed in a wavelike structure. Finally, as the Sun set
324 the clouds became reddened, appearing very bright and vivid but with the wavelike nature still
325 noticeable. A comparison between a section of the sky in “The Scream” (two versions), a section
326 from a photograph of nacreous clouds and a section from the Puyehue-Córdon Caulle photograph
327 are provided in Figure 4. While all four panels show reddened skies, there is a striking resemblance
328 between the skies of “The Scream” and those of the nacreous clouds, in pattern and color structure.
329 The waviness in the sky in “The Scream” is absent in the volcanic sunset. The alternating patterns
330 of colors in “The Scream” is evident in the nacreous cloud photograph and there is no uniform
331 progression of color from red to deep blue in “The Scream” that is so clear in the Puyehue-Córdon
332 Caulle sunset. The ‘eye-like’ structure in the middle of Figure 4(a) is often noticeable in nacreous
333 cloud photographs. What more appropriate sight in the sky could there have been to ignite Munch’s
334 morbid thoughts than a turbulent cloud structure full of reds and oranges? There is a certain
335 iridescence in nacreous clouds that is not reproduced in “The Scream”. This could be because
336 of the limited materials available to Munch (see Singer et al. (2010) for a detailed analysis), or
337 because after sunset the iridescence is less pronounced (see Fig. 3, bottom two photographs).
338 “The Scream” has never been restored (Ydstie 2008) and it must have been much brighter when
339 first produced. Singer et al. (2010) analysed the pigments used in several of Munch’s paintings
340 including both versions of “The Scream”. They found that Munch’s palette was not extensive
341 and also that some of his paintings were left outside, suggesting that they were deliberately left to
342 ‘weather’. The original paintings may have been more vibrant than what we see now. Nevertheless

343 the main features that separate nacreous clouds from all other types, the progression of colors, the
344 waviness, and their appearance after sunset suggesting great height, are all captured in the sky over
345 Oslo fjord as depicted in “The Scream”.

346 **5. Color analysis**

347 In an attempt to be as objective as possible with our interpretation of Munch’s sky we analysed
348 the relationship between the colors in photographs of sunsets and nacreous clouds as well as in
349 various paintings that depict red skies. Of course interpretation of color itself is subjective and
350 there is no generally accepted relationship between perceived color and spectral wavelength. A
351 quantitative approach would seem to require that the color representation in both paintings and
352 the photographs bore a known relationship to the spectral content of the scene being depicted (or
353 photographed). In this approach the relationship between the instrument being used to measure
354 the color content (the eye in the case of the artist and a charged coupled device in the case of a
355 modern photographer) and the spectral content of the scene must be known. Finally, in the case of
356 the artist, the palette of available colors may not be sufficient to reproduce the color content of the
357 scene. This leaves aside the possibility that the artist may not wish to duplicate exactly the color
358 content of the scene. Nevertheless there are tools that can allow us to interpret the relationship
359 between different colors as they are portrayed in a photograph or painting.

360 *a. The HSL color wheel*

361 The Hue-Saturation-Lightness (HSL) wheel (e.g., Munsell et al. 1950; Feisner and Reed 2013;
362 Kasson et al. 1995; Weeks et al. 1995) is a method to transform the colors in an image to re-

363 veal spectral color content. The HSL conversion has been used to study images in art previously
364 (Ivanova and Stanchev 2009). The usual interpretations of these color qualities are: hue is what is
365 normally thought of as ‘color’, e.g., red, green, blue, and so; saturation, sometimes referred to as
366 chroma, may be thought of as dullness or vividness, and lightness represents the intensity, e.g., a
367 light or dark color.

368 The analysis of the images and mapping on to the HSL color wheel proceeds by computing the
369 RGB components of the image, in Joint Photographic Experts Group (JPEG) format. A Python
370 programming language algorithm was written to extract the color table from the images. The RGB
371 color table was then converted to the HSL color wheel and plotted. The hue (H) progresses around
372 the circumference of the wheel (measured in degrees), while the saturation (S) lies in the radial
373 direction. In this two-dimensional plot, the lightness L variation is not shown as it varies in a
374 direction orthogonal to the H and S axes, that is, out of the page. It is possible to construct the plot
375 as a cylinder but here we simply report the mean lightness value.

376 The HSL color wheel analysis was used on sections of three photographic images and a section
377 from the 1910 version of “The Scream”. The image sections and their corresponding HSL color
378 wheels are shown in Figure 5. The top panels show an example from a portion of an image
379 containing a rainbow. A perfectly vivid rainbow would have colors evenly spread around the
380 circumference of the wheel at large radial values (close to 1 for a highly vivid rainbow). Compare
381 this wheel with that from a volcanic sunset (right-hand, top panel) and it can be seen that certain
382 colors (greens, yellows) are poorly represented, but that the blue hues are more abundant and more
383 vivid. The rainbow image is about 10% lighter than the volcanic sunset, as may be expected since

384 the illumination is likely lower for the sunset. The color wheel for “The Scream” (bottom, left
385 panel) is more similar to that for the nacreous cloud (bottom, right panel) than either the rainbow
386 or sunset wheels. In particular the ‘flaring’ of the hues within the pink-red section of the wheel
387 is striking and characteristic of nacreous clouds. The saturation of the colors in “The Scream” is
388 greater than that in the photograph of the nacreous clouds. This could be due to the limited palette
389 of colors available to Munch but also due to the degradation of the painting over time.

390 *b. Pattern analysis*

391 A distinctive feature of “The Scream” is the pattern of waviness of the clouds in the sky, or in
392 the sky itself if it is interpreted as cloudless. This is generally not seen in red sunsets and volcanic
393 sunsets, where the cloudless sky tends to be variegated and the sky with clouds tends to have vari-
394 ations but little or no waviness. It is possible to investigate the amount of waviness objectively by
395 taking vertical sections through the sky part of “The Scream” and comparing this with vertical sec-
396 tions through photographs of sunsets. This is done by analysing the RGB components separately.
397 Figure 6 shows vertical sections through a photograph of a volcanic sunset, through a photograph
398 of nacreous clouds and finally through a section of the sky in “The Scream”. The waviness is
399 apparent in both the nacreous cloud photograph and “The Scream” but much less so in the sunset.
400 The relationship of the RGB components is also different in the volcanic sunset, where the order
401 of the size of the components with line number (which may be interpreted as elevation) changes
402 from R, G, B to B, G, R. No such change occurs in the nacreous cloud photograph or the section
403 of “The Scream”, where the order is predominantly R, G, B, except in a few places where G and B

404 are swapped and at the lowest part of “The Scream” where the color is dark grey (R, G, B equal).
405 This order of the color components does not resemble the order expected in a volcanic sunset.

406 The volcanic sunset photograph was taken in a cloudless sky and one might expect more vari-
407 ation in the order of the color components when clouds are present. To investigate this we have
408 analysed 8 photographs of red sunsets with clouds present and analysed 16 sections of the colored
409 skies from 12 separate photographs of Ascroft’s sketches of the Krakatau sunsets observed near
410 London. The Ascroft photographs were taken at Blythe House, where they are archived by the Sci-
411 ence Museum, London, using a 24 megapixel Nikon camera under artificial (fluorescent) lighting,
412 without a flash. All camera processing features were turned off and a color temperature of 5000
413 K was used, which is typical for accurate representation of colors in art galleries. The sections
414 are shown in Figure 7. As before, vertical transects were taken through the sections; in this case
415 an average of 10 pixels was taken along the central line of each section. The means and standard
416 deviations for the RGB color components were derived and are shown in Figure 7. There is a
417 separation of the R, G and B components in an order similar to that found for the nacreous cloud
418 and “The Scream” sections. The waviness is less pronounced and there is a slight tendency for
419 the G and B color components to increase towards the higher elevation, but less pronounced than
420 in the volcanic sunset section. There is little doubt that Ascroft was sketching the sky and cloud
421 colors associated with volcanic aerosols, and the similarity of the order of the RGB components
422 (but not the waviness) with “The Scream” is apparent. Many of Ascroft’s sketches include what
423 are obviously colored clouds and these clouds tend to redden an otherwise blue or dark blue sky,
424 resulting in more R color component in the sketches at higher elevation.

425 Further photographs of volcanic clouds, many containing clouds were obtained from vari-
426 ous sources and subjected to the color pattern analysis. Nine sections from nine different pho-
427 tographs are shown in Figure 8. Many more photographs of volcanic sunsets can be found here:
428 <http://www.spc.noaa.gov/publications/corfid/sunset/>. The volcanic sky
429 sections were analysed in exactly the same manner as the Ascroft sky sections. The results are
430 shown in Figure 8. The pattern of the variation of the RGB components with elevation is different
431 to that of the Ascroft sections. Here there is a decrease in the R color component with elevation
432 and an increase of the B component and very little change in the G component. The variation of
433 each color component with elevation is very smooth, probably reflecting the fact that in these nine
434 sections clouds were less dominant. It can be surmised that the variation with elevation of each in-
435 dividual component is due to clouds, while the change in count value (increasing color brightness)
436 with elevation, and its relative change between the RGB components, is due to the phenomenon
437 producing the sky colors. The analysis here seems to support the notion that the sky in “The
438 Scream” contains clouds and that the change in color component brightness with elevation as well
439 as the relative change, are more similar to that found in nacreous cloud photographs. We also ex-
440 amine the pattern of colors in a spectacular sunset, but one that is not affected by unusual aerosols.
441 The example used is a section from a photograph of a sunset over Port Philip Bay, Melbourne, Aus-
442 tralia taken in March 2017 from an elevation of 150 m (a.s.l.) when the view of the sky contained
443 some clouds but otherwise was free of volcanic aerosols. The sunset was particularly red, with
444 just a few clouds to add structure to the pattern of colors. Figure 9(a) shows the mean and standard
445 deviation of a 20 pixel wide vertical transect of the RGB color components. The transect is shown

446 (rotated 90 degrees clockwise) inset and aligned with the line number and Fig. 9(b) shows the
447 larger section taken from the photograph with the location of the vertical transect indicated. The
448 sequence of colors is, as before, R largest count, followed by G and B. In this case the brightness
449 changes little with elevation (line number) except where there are cloud layers. At those locations
450 the variation of the count value in all three components increases. This is but one example; it
451 would appear that with the right distribution of cloud layers in the sky, variations in brightness or
452 waviness could be reproduced to appear similar to the waviness seen in “The Scream”. Another
453 photograph analysed contains both a red non-volcanic sunset and a nacreous cloud display. Per-
454 forming the same analysis on a section of this photograph (Figure 9(c),(d)) shows the waviness
455 structure in the RGB color components and the smoother variation of the sunset at lower eleva-
456 tion. These analyses provide an objective means to distinguish between the sequence of colors
457 generated by volcanic sunsets (with and without clouds), spectacular (non-volcanic) sunsets (with
458 and without clouds), nacreous cloud displays and, in one case, a combination of a non-volcanic
459 sunset and a nacreous cloud display in the same photograph, and so having the same atmospheric
460 conditions.

461 **6. Conclusions**

462 The sky depicted in Munch’s “The Scream” has a remarkable similarity to the patterns and
463 colors seen in a display of nacreous clouds (Fikke et al. 2017). Such clouds are observed on rare
464 occasions during cold winter months in the southern part of Norway, where the meteorological
465 conditions are conducive to their formation. Edvard Munch was prone to spend time outdoors
466 and many of his artworks include depictions of skies and country scenes. Previous researchers

467 have suggested that Munch may have seen a volcanic sunset due to Krakatau and painted the sky
468 in “The Scream” based on a memory of that event. But the recent article by Fikke et al. (2017)
469 suggests the painting may have been inspired by a sighting of nacreous clouds. There appears
470 to be little definite evidence of exactly what the event was, if any, that inspired Munch to paint
471 the sky in that way. Although he wrote a commentary stating it was an actual observation that
472 inspired him, it is known that Munch was prone to include prose with his art, sometimes after he
473 had painted the work. Munch is also known to have been a poor chronicler of his work and there
474 are even suggestions that he dated work much later than he actually painted it. This lack of factual
475 evidence makes conclusions concerning his motivation rather difficult. Thus an interpretation
476 that the painting was inspired by a volcanic sunset or motivated by his mental state cannot be
477 ruled out. Instead here we provide support to an alternative hypothesis for Munch’s sky based
478 on the similarity of the painted image with photographs of nacreous cloud displays. Munch had
479 ample opportunity to observe nacreous clouds and they were noted (but not depicted) in records
480 during the period 1883–1910, during which it is believed Munch painted several versions of “The
481 Scream”.

482 The color analysis presented attempts to add some quantitative assessment of the color pat-
483 terns and spectral content of “The Scream” compared with photographs of volcanic sunsets, non-
484 volcanic sunsets, and nacreous clouds. While we readily admit that the interpretation of color in
485 art and in photographs is problematic, there are at least indications that the color variations and
486 order of the RGB color components in “The Scream” better match those of a nacreous cloud dis-
487 play than a cloudless volcanic sunset. Similar suggestions regarding the wave-like features were

488 made by Fikke et al. (2017). Finally, if Munch did indeed observe and then paint the sky in “The
489 Scream” based on a nacreous cloud display, then this in all likelihood would represent the first
490 graphical depiction of a type of cloud largely unknown to meteorology at the time. In this con-
491 text, this hypothesis will be relevant to those interested in clouds and in historical aspects of the
492 development of cloud science in meteorology.

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497 alogues. Captain Klaus Sievers (Lufthansa) is thanked for providing his photographs of volcanic
498 sunsets.

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552 tent in red-to-green ratios as depicted in paintings by great masters. *Atmospheric Chemistry and*
553 *Physics*, **14 (6)**, 2987–3015.

554 **LIST OF FIGURES**

555 **Fig. 1.** Four versions of “The Scream”. Starting from the left: 1893 tempera on cardboard
556 (Nasjonalmuseet for kunst arkitektur og design, Oslo); 1895 pastel on cardboard (sold at
557 Sotheby’s for US\$119,922,600 to Leon Black on 2 May 2012); 1910(?) tempera on hard
558 cardboard (Munch-museet, Oslo); 1893 crayon on cardboard (Munch-museet, Oslo). The
559 1910(?) version (panel 3 from left), on display at the Munch museum (Ydstie 2008). The
560 ”?” following the date is to indicate that the actual date is contested, some believing it is
561 contemporary with the 1893 version. The work is unsigned and undated. 31

562 **Fig. 2.** Volcanic sunset of the South Pacific due to aerosols from the Puyehue-Córdon Caulle erup-
563 tion, southern Chile on 5 June 2011. Photograph taken by F. Prata on 11 July 2011. 32

564 **Fig. 3.** Series of photographs of nacreous clouds taken on the evening of 20 January 2008 from
565 Leirsund, southern Norway. Top-left: 15:08:56; top-right: 15:32:47; middle-left: 15:33:17;
566 middle-right: 15:34:20; bottom-left: 15:46:35; bottom-right: 15:48:11. Time of sunset was
567 15:00. All times are UTC on 20 January 2008. Location: 59° 59’ 38.84 N, 11° 06’ 21.20 E,
568 181 m a.s.l. (Photographs taken by F. Prata) 33

569 **Fig. 4.** Intercomparison of part of the sky in “The Scream” with nacreous clouds and a volcanic
570 sunset. (a) Top-left: Section from the 1910 version. (b) Top-right: Section from the 1893
571 version. (c) Bottom-left: Section from a photograph of Nacreous clouds. (d) Bottom-right:
572 Section from photograph of a Puyehue-Córdon Caulle sunset. 34

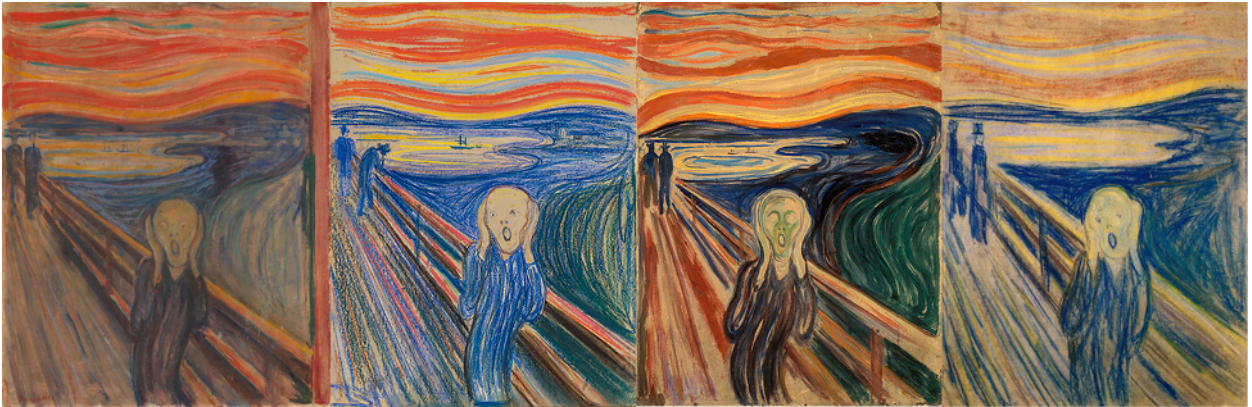
573 **Fig. 5.** (a) A rainbow spectrum and the corresponding HSL color wheel. (b) PCC sunset and the
574 corresponding HSL color wheel. (c) Section of a photograph of nacreous clouds and the
575 corresponding HSL color wheel. (d) A section of the “The Scream” and the corresponding
576 HSL color wheel. 35

577 **Fig. 6.** (a) Mean and standard deviation of a vertical section of the PCC sunset photograph shown
578 in (b)–indicated by semi-transparent rectangle. (c) As for (a) but through a vertical section
579 of the nacreous cloud photograph shown in (d). (e) As for (a) but through a vertical section
580 of “The Scream” pastel painting shown in (f). Each vertical section is 30 pixels wide. 36

581 **Fig. 7.** (a) *Left-hand panels:* Sixteen sections of the sky extracted from photographs of 12 of As-
582 croft’s sketches of sunsets over London. Photographs taken by FP of the original sketches
583 held in the Blythe House archive of the Science Museum, London, UK. (b) *Right-hand side:*
584 Mean and standard deviation of the RGB color components for a 10 pixel-wide vertical tran-
585 sect through the central part of the sections shown in Fig. 7(a). Line number refers to the
586 image line in the vertical direction on each of the sections shown in the left-hand panels.
587 Higher line number corresponds to higher elevation. 37

588 **Fig. 8.** (a–i) *Left-hand panels:* Sections from the sky regions of nine different photographs of vol-
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590 tralia). b. Helio Vital (Calbuco, 26 May 2014, Santiago, Chile). c. A. Robock (El Chichón,
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596 transect through the central part of the sections shown in the left-hand panels. 38

598 **Fig. 9.** (a) Variation of the mean and standard deviation of the RGB color components for a 20
599 pixel-wide vertical transect through the central part of a section of the photograph shown in
600 (b) for a non-volcanic sunset. (c) Variation of the mean and standard deviation of the RGB
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602 of the photograph shown in (d) for a non-volcanic sunset and a nacreous cloud display at
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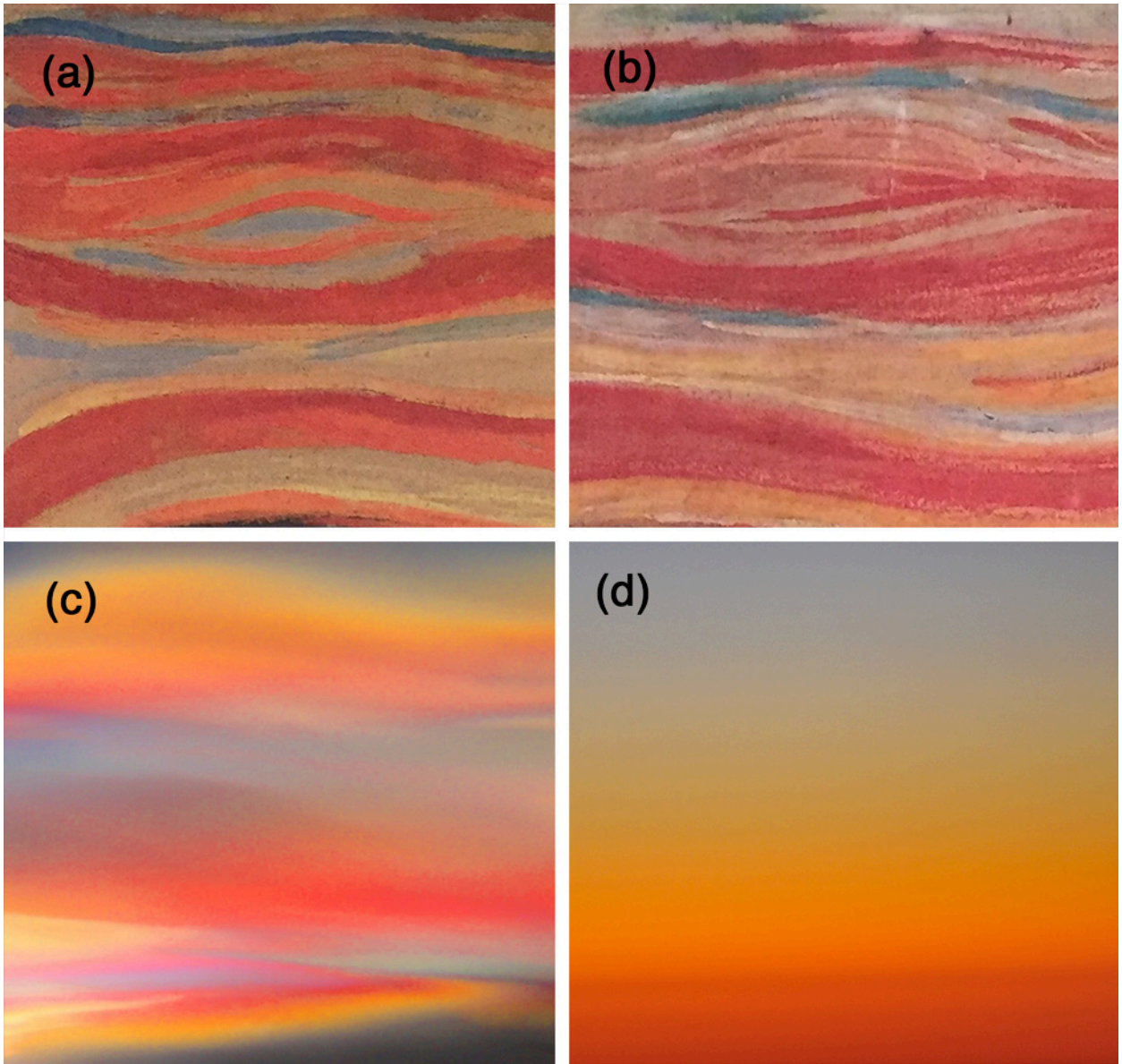
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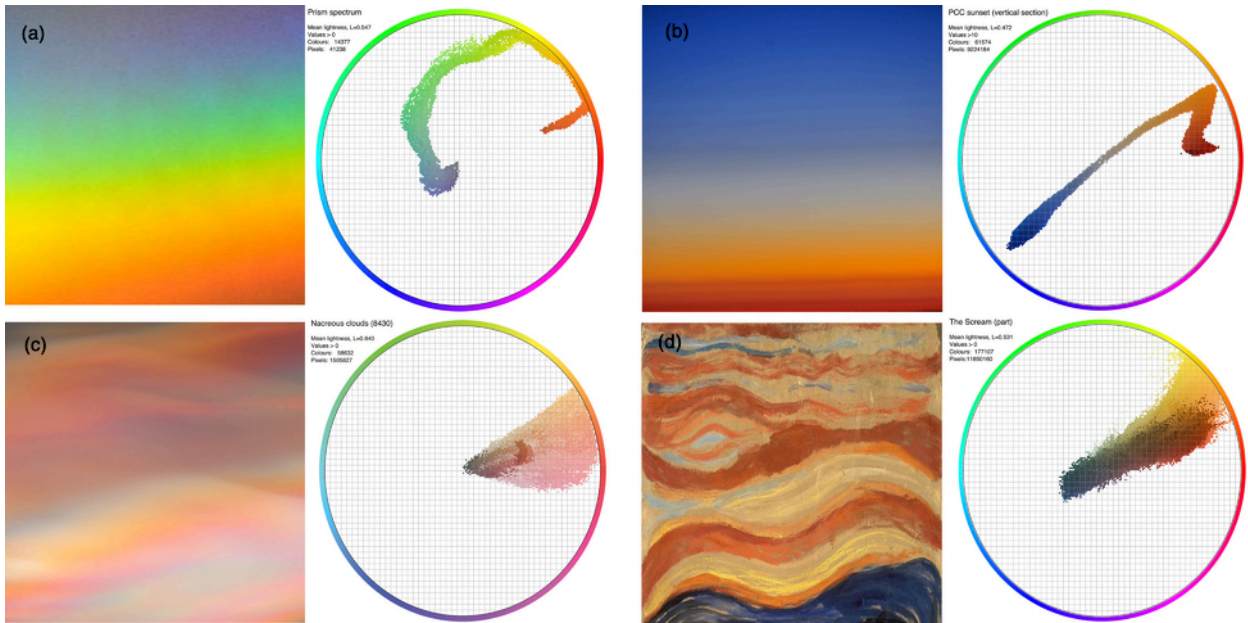
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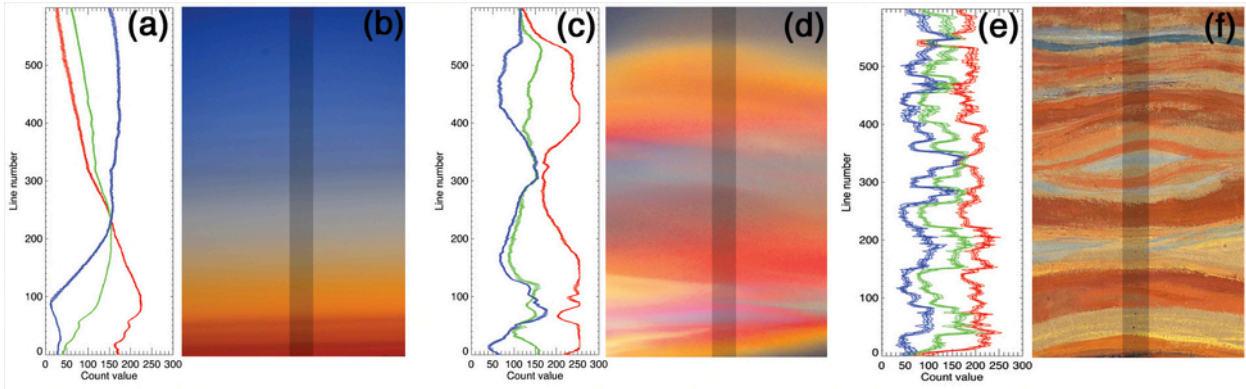
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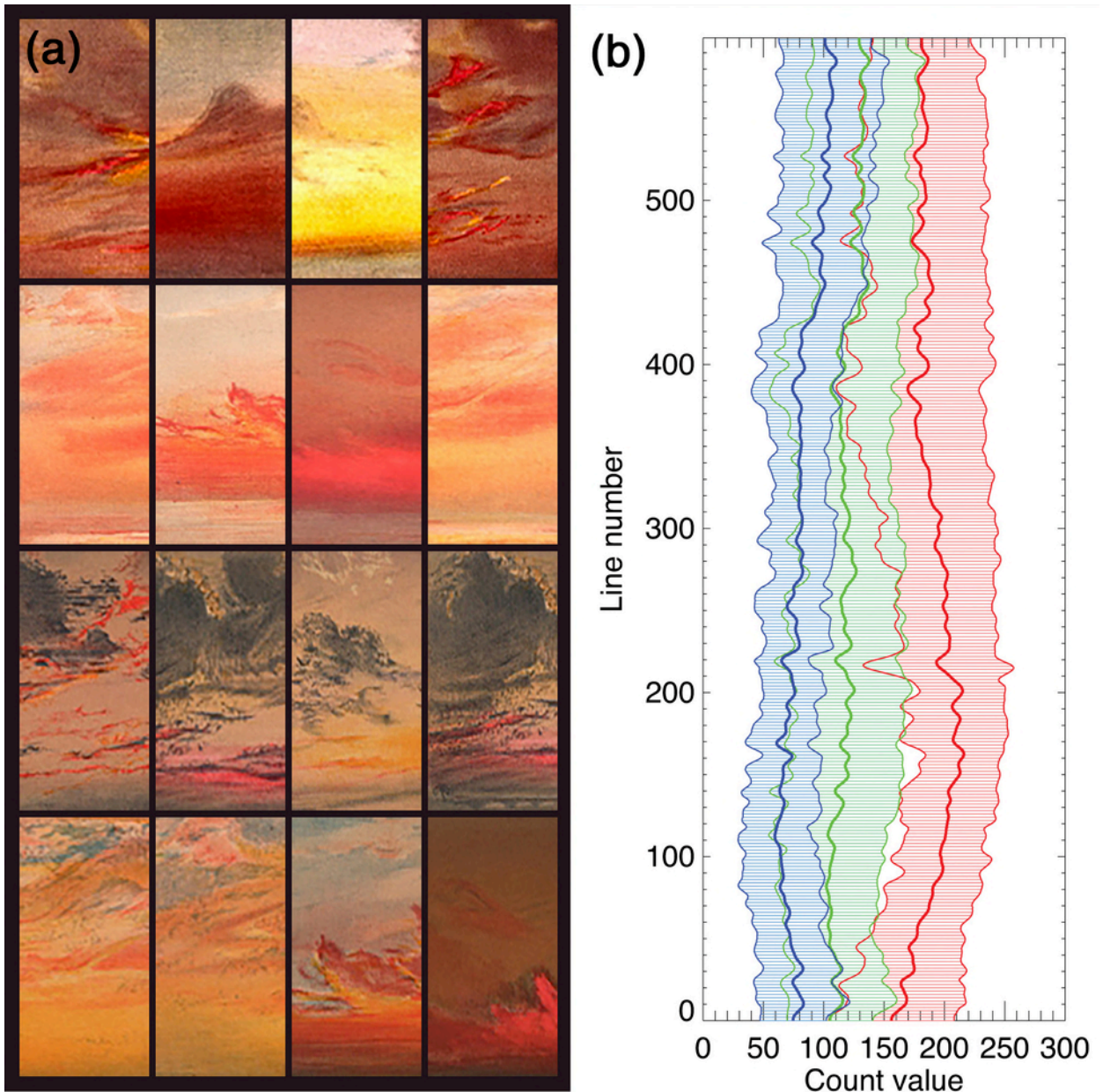
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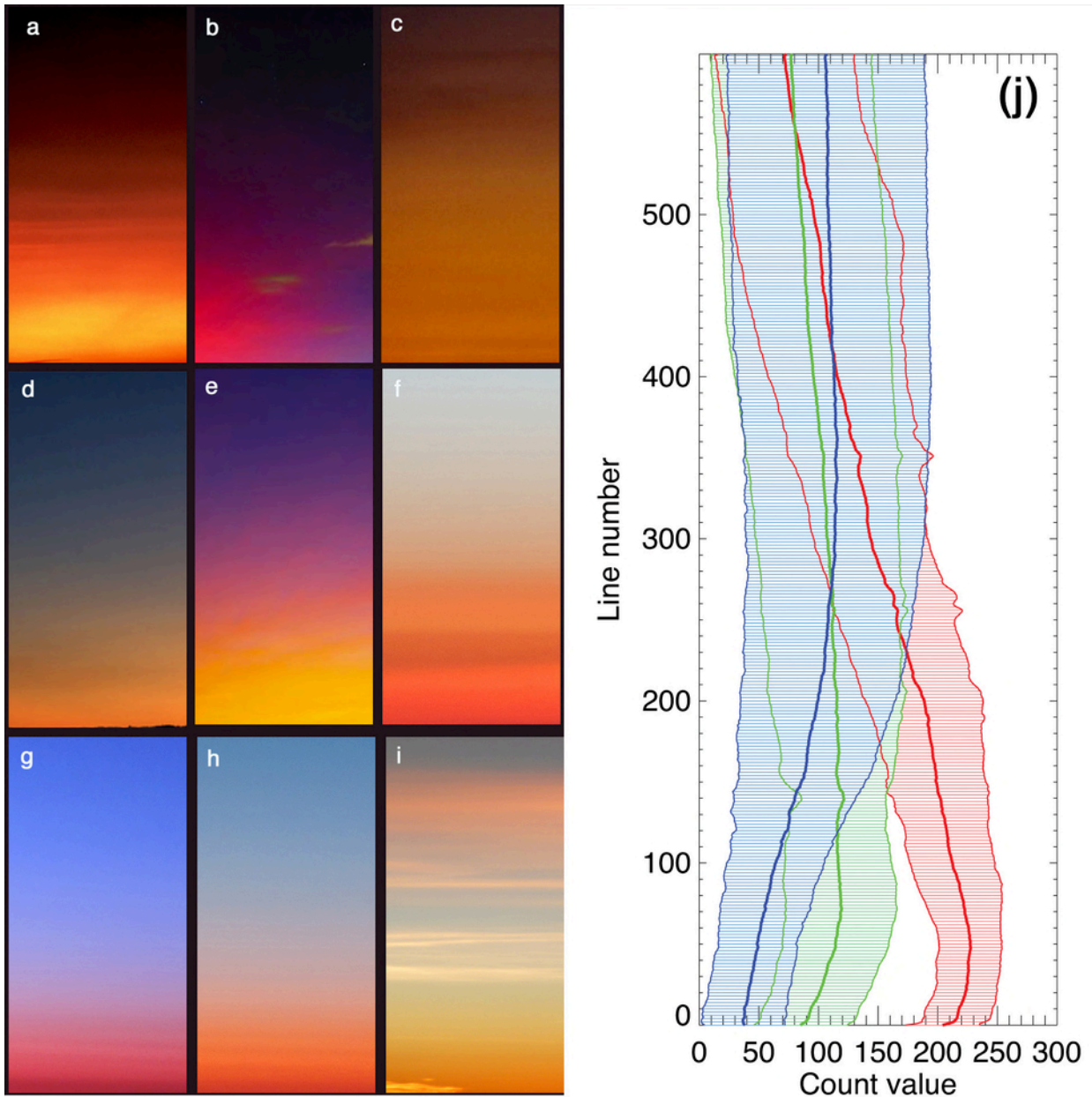
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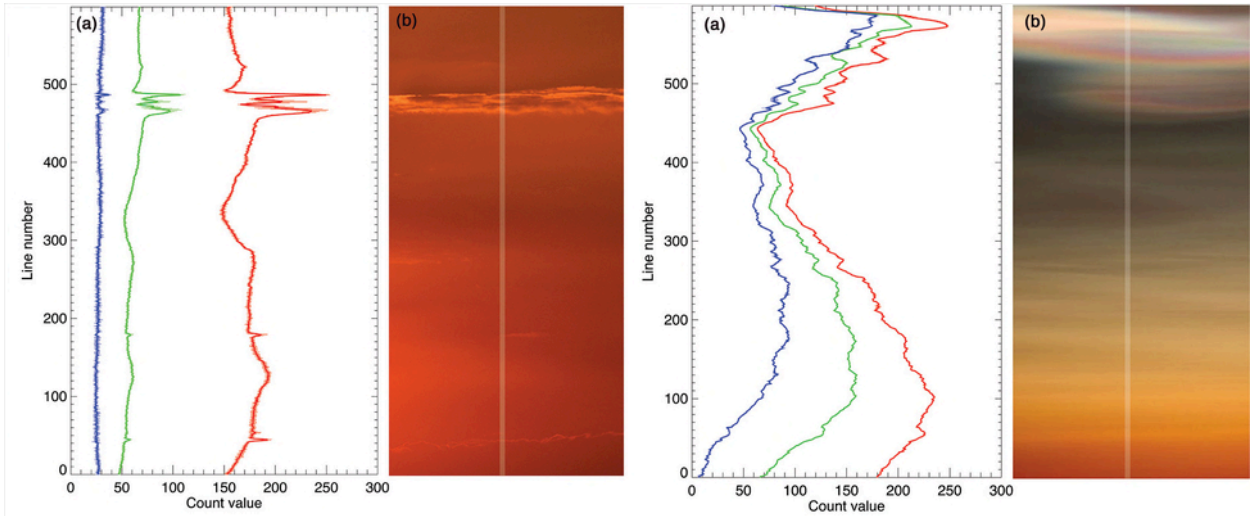
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