1 Place-based science from Okinawa: 18th-century climate and geology
2 recorded in Ryukyuan classical music

3 Justin T. Higa[1,2], June Y. Uyeunten[2], Kenton A. Odo[2]

4 [1]Department of Earth Sciences, University of Hawaiʻi at Mānoa, Honolulu, Hawaiʻi, USA
5 [2]Ryukyu Koten Afuso Ryu Ongaku Kenkyu Choichi Kai USA, Hawaiʻi Chapter, Honolulu, Hawaiʻi, USA

6 *Correspondence to*: Justin T. Higa (higa.justint@gmail.com)

7 **Abstract.** Indigenous knowledge can record scientific observations of specific "places" that may be difficult to preserve in
8 the geologic record. Such place in "place-based" science highlights issues local to a learner for engaging audiences with the
9 scientific problems relevant to their communities. Here, we focus on a popular seafaring repertoire of ~~indigenous~~Indigenous
10 Ryukyuan classical music, called Nubui Kuduchi and Kudai Kuduchi, to examine place-based observations of 18th-century
11 climate and geology in the Ryukyu Islands (21st-century Okinawa Prefecture, Japan). By c~~C~~omparing the environmental
12 conditions recorded in these songs with those of 20th–21st-century studies, we find that surface winds, ocean currents,
13 typhoons, and volcanism from lyrics parallel their respective observations in the scientific record. This novel perspective of
14 art and science highlights the relevance ~~relevancy~~ of Ryukyuan classical music in teaching contemporary issues such as
15 climate change and natural hazards. Thus, Ryukyuan ~~indigenous~~Indigenous knowledge can play an innovative role in
16 science engagement for 21st-century Okinawans in Okinawa Prefecture and their diasporic kinsfolk worldwide.

17 1 Introduction

18   Indigenous knowledge can preserve geologic histories that are difficult to infer from the geologic record~~s~~, thus
19 guiding modern scientific inquiry. However, it was not until the ~~1990s~~late 20th century that researchers began incorporating
20 such untapped data in ~~natural~~ environmental science literature (e.g., climate science; Petzold et al., 2020). Indigenous
21 knowledge of~~–~~ plant, ~~and~~ animal, and weather cycles ~~from traditional agriculture or elder knowledge~~ have since been
22 examined for signals of ~~signals of~~climate change and fortifications against climate hazards (e.g., Harmon et al., 2021;
23 Hinzman et al., 2005; Hiwasaki et al., 2015; Turner and Reid, 2022). Workers also utilized Indigenous oral histories (e.g.,
24 Cascadia earthquakes in Ludwin et al., 2005), written records (e.g., Hawaiian hurricanes in Businger et al., 2018), and other
25 sources of ~~Indigenous~~ gray knowledge (e.g., various hazards of Aotearoa New Zealand in Bailey-Winiata et al., 2024)
26 to~~geologic~~ improve modern-day disaster preparedness~~(e.g., Bailey-Winiata et al., 2024)~~. Notably~~Of note~~, ~~collaborations~~
27 ~~between~~ scientists and cultural practitioners have ~~have~~ focused on Indigenous visual and performing arts ~~and visual arts~~ to
28 examine historical ~~historical records of~~volcanic activity (Swanson, 2008), earthquakes (Hough, 2007; Ludwin et al., 2005),
29 and ecological resources (Gibson and Puniwai, 2006; Turner and Reid, 2022). Expanding the scientific analyses of artistic

30 traditions ~~to~~ to more ~~underrepresented~~ Indigenous cultures can increase research ~~scientific~~objectivity and creativity by

31 introducing new questions ~~may~~from these ~~marginalized~~ marginalized viewpoints (Bang et al., 2018; Intemann, 2009). Thus,

32 ~~c~~As ~~such~~continued efforts in geoscience to incorporate Indigenous knowledge from art have great potential to 1) document

33 more historical records of climate and geological phenomena, 2) jumpstart new collaborations between cultural practitioners

34 and geoscientists, and 3) diversify scientific ways of knowing through the integration of Indigenous traditions.

35 ~~These works have linked indigenous knowledge from oral histories, elder knowledge, and gray literature with~~

36 ~~observable processes such as permafrost loss (e.g., Hinzman et al., 2005), seasonal plant cycles (e.g., Turner and Reid,~~

37 ~~2022), sea level rise (e.g., Harmon et al., 2021; Hiwasaki et al., 2015), and a suite of natural hazards (e.g., Bailey Winiata et~~

38 ~~al., 2024; Businger et al., 2018; King and Goff, 2010; Ludwin et al., 2005; Swanson, 2008).~~ In addition to research,

39 ~~h~~Highlighting ~~I~~indigenous knowledge within a "place-based" framework allows educators and students to better engage with

40 the ~~environmental~~ geosciences by tapping personal ~~and familiar~~ experiences of specific "places" ~~in~~ from their local, natural

41 world (Semken et al., 2017). For example, ~~previous~~ workers in Hawai'i ~~have~~highlight how ~~incorporating~~tested ~~indigenous~~

42 ~~stewardship~~ how ~~in~~ ~~geo~~Earth science ~~courses~~ classes can increase engagement with students by incorporating local ~~by~~

43 ~~emphasizing the local, land human interactions to which a learner has an ancestral connection, Hawaiian,~~and indigenous

44 stewardship, elder knowledge, Hawaiian place name meanings, and Hawaiian language newspaper records~~–~~ into their

45 curriculum (e.g., Chinn et al., 2014; Gibson and Puniwai, 2006). Efforts in the Acoma Pueblo community of New Mexico,

46 USA, have similarly integrated place-based concepts into education to ~~ed~~Indigenous teach about local stratigraphy,

47 hydrology, and natural resources (e.g., Reano and Hasara, 2024; Reano and Ridgway, 2015). Furthermore~~In fact~~, Palmer et

48 al. (2009) focused on Indigenous art from the Southern Great Plains of North America to teach undergraduate ~~natural and~~

49 ~~environmental~~ science modules across mineralogy, groundwater ~~hydrology~~, and ~~local~~ climate hazards. These ~~e~~Educators

50 have demonstrated how rigorous programs that incorporate multiple ways of knowing can~~ve~~ increased~~d~~ the interest,

51 participation, and retention of students from marginalized communities (Alexiades et al., 2021). ~~(Intemann, 2009)~~These

52 ~~narratives complement efforts to more effectively teach peer-reviewed environmental science to all levels of learners (Lanza~~

53 ~~and Negrete, 2007). Thus~~Therefore, expanding ~~examining~~place-based, artistic, and ~~indigenous~~Indigenous knowledge in

54 geoscience engagement ~~has proved~~is likely key to addressing the needs of more Indigenous Peoples~~in valuable for the Earth~~

55 ~~sciences as well as for place-based environmental education and engagement in the contemporary world~~.

56 A promising candidate for science engagement with place-based Indigenous knowledge ~~recorded in art~~involves the

57 Ryukyuan Peoples from the Ryukyu Islands, comprising 21st-century Okinawa Prefecture, Japan. Previous works have

58 connected Ryukyuan Indigenous knowledge with broad geoscience topics such as groundwater resources (Takahashi, 2022),

59 regional fisheries (Toguchi et al., 2016), and coral reef geobiology (Toguchi and Nishime, 2013). However, to the best of our

60 knowledge, no works in English or Japanese have examined the connections between geoscience and one of the most

61 influential ~~indigenous~~Indigenous art forms across Okinawa and the Okinawan diaspora, Ryukyuan classical music, also

62 known as *Ryūkyū koten ongaku* (琉球古典音楽; hereafter RKO). We compare this tradition with contemporary science

63 across the atmo-, hydro-, and geosphere to address the question: Does RKO record place-based environmental phenomena

64   useful for geoscience engagement? Here, we focus on a popular RKO repertoire, Nubui Kuduchi (上り口説) and Kudai

65   Kuduchi (下り口説), to trace the 18th-century experiences of Ryukyuan seafaring envoys between Okinawa and Kyushu

66   islands (Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984). A review of contemporary geoscience

67   literature finds parallels between these songs and science in Ryukyuan surface winds, oceanic circulation, typhoon activity,

68   and volcanism. Such similarities highlight how Nubui Kuduchi and Kudai Kuduchi may record benchmarks of historical

69   environmental conditions and, how Ryukyuan Indigenous knowledge can connect a prominent art form with complex

70   environmental research. Educators and cultural practitioners may use these insights in place-based geoscience engagement,

71   where demand for this work is likely high due to an active Ryukyuan arts scene across the world. Accordingly, we showcase

72   how popular Indigenous music can document scientific observations of climate and geology to engage Indigenous Peoples

73   with their contemporary environmental heritage.

75 1.1 Ryukyu Kingdom, Okinawa Prefecture, and the Okinawan diaspora

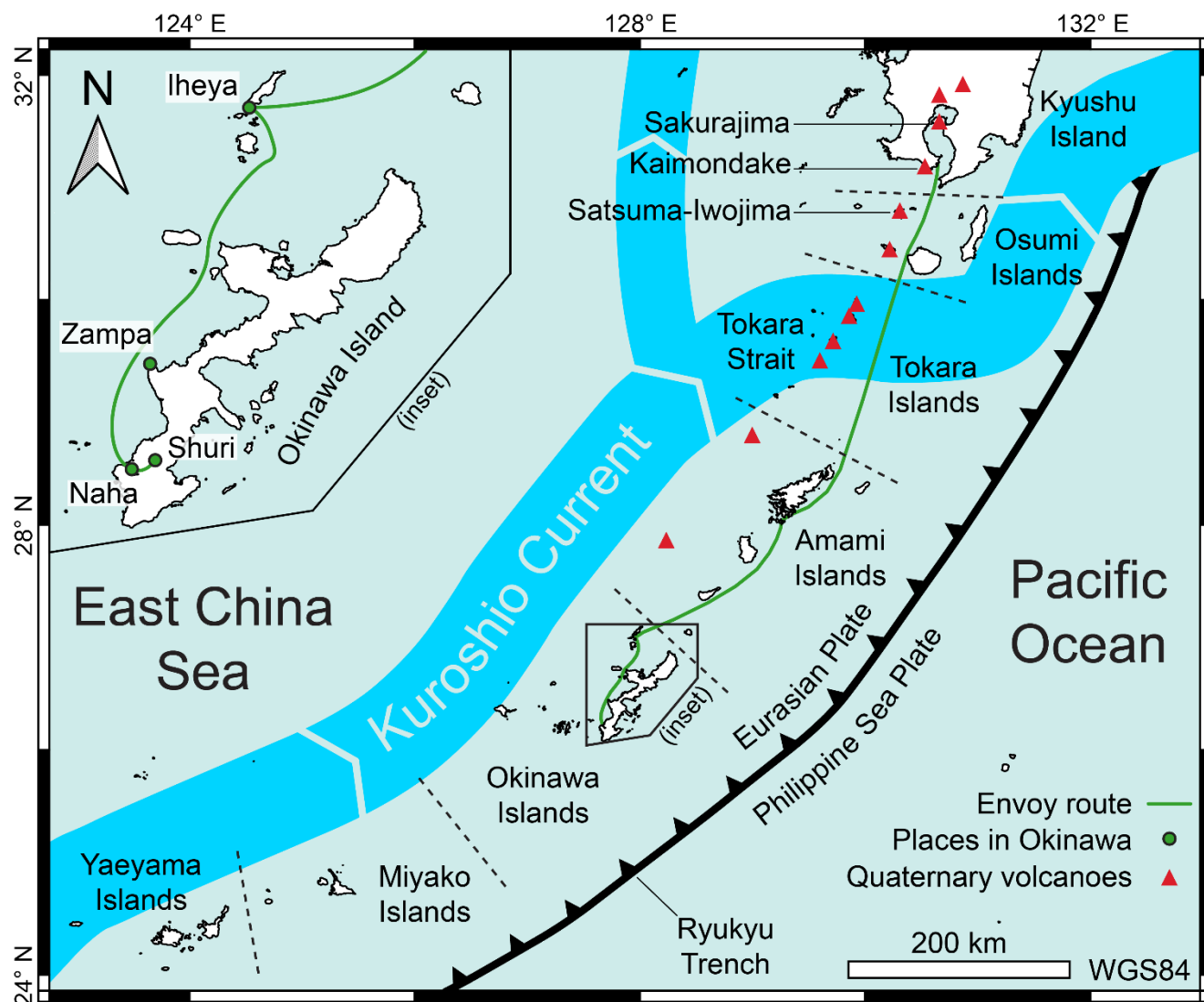



Figure 1: The Ryukyu Islands and southern Kyushu. Map shows the Kuroshio Current (Gallagher et al., 2015), Ryukyu Trench (Kamata and Kodama, 1994), approximate route of Ryukyuan envoys (Okinawa Prefectural Cultural Promotion Association, 2001), and subaerial Quaternary volcanoes (Global Volcanism Program, 2024). (inset) Detailed map of Okinawa Island. Geography from U.S. Department of State, Office of the Geographer (2013).

81   The Ryukyu Islands span a north-south transect between Kyushu and Taiwan in the western Pacific Ocean,

82 encompassing the Osumi, Tokara, Amami, Okinawa, Miyako, and Yaeyama islands at its maximum geographical extent (Fig.

83 1). This island arc is the ancestral home of the Indigenous Ryukyuan People and the former Ryukyu Kingdom, established in

84 the 15th century and centered on Okinawa Island (Sakiyama and Oshiro, 1995; Toby, 1984). The kingdom colonized south to

85 the Yaeyama Islands and north to the Tokara Islands during the height of this ~~of this~~ dynastic period (Akamine, 2017).

86 Contact from foreign trade ~~then~~influenced ~~on~~ Ryukyuan culture, ~~from~~including from China, Japan, Korea, Thailand,

87 Malaysia, and Indonesia (Sakiyama and Oshiro, 1995). However, in 1609 CE, the Ryukyu Kingdom was invaded and

88 subsequently controlled by Japanese forces in the Satsuma Domain of southern Kyushu and the Tokugawa Shogunate in Edo

89 (pre-1868 CE name for Tokyo; Akamine, 2017; Toby, 1984). Consequently, most Ryukyuan territory north of Okinawa

90 Island was ceded to the Satsuma Domain (Akamine, 2017). Historical records suggest ~20 Ryukyuan envoys traveled

91 between Okinawa, Satsuma, and Edo to pay tribute to the Shogunate from 1610 CE until 1872 CE (Okinawa Prefectural

92 Cultural Promotion Association, 2001; Toby, 1984), followed by the annexation of the Ryukyu Kingdom by Japan as

93 Okinawa Prefecture in 1879 CE (Akamine, 2017). During this colonial period, the Japanese government employed

94 assimilationist education policies with the goal of eliminating Ryukyuan languages and cultures (Hammine, 2019;

95 Kaneshiro, 2002). ~~and""(e.g., Hammine, 2019; Kaneshiro, 2002; Kodama, 1981; Ueunten, 1989)~~This policy lasted until

96 1945 with the end of World War II and the start of occupation by the USA (Hammine, 2019). Since the reversion of

97 Okinawa Prefecture from the USA back to Japan in 1972, Ryukyuan culture experienced a resurgence across grassroots

98 movements (e.g., Inoue, 2004), language revitalization efforts (e.g., Heinrich, 2018; Zlazli, 2021), and statements from the

99 Okinawan prefectural government (e.g., Abe, 2023).~~(Anon, 2015)~~

100 Despite this marginalization, the Ryukyu sphere of influence expanded out of East Asia during 19th–20th-century

101 emigration from Okinawa Prefecture, namely to Hawaiʻi, Brazil, and Peru that~~(e.g., Kaneshiro, 2002; Roberson, 2010;~~

102 ~~Ueunten, 1989)~~ received roughly 20,000, 15,000, and 11,000 immigrants by 1938, respectively (Sellek, 2003). Estimates

103 place cumulative Okinawan immigration between 150,000–200,000 people before the end of World War II; immigrants

104 ~~(Roberson, 2010; Sellek, 2003)~~to the Japanese mainland were mostly comprised of factory workers, whereas those abroad

105 worked on plantations (Roberson, 2010; Sellek, 2003). In Japan, Okinawans faced a similar system of discrimination as in

106 Okinawa, compounded by social isolation, low wages, and dangerous working conditions (Roberson, 2010). Migrants

107 overseas faced discrimination from two sources: poor plantation conditions by the elite-class plantation owners and a

108 previously established, Japanese immigrant community that held similar prejudices as in Japan (Kaneshiro, 2002; Kodama,

109 1981; Ueunten, 1989). In Hawaiʻi, such racial tensions continued until roughly the end of World War II, when second-

110 generation Okinawan and Japanese Americans became dominant over the first-generation immigrants; shared experiences in

111 plantation labor unions, American military service, and communal education likely led to the gradual relinquishment of

112 former prejudices (Ueunten, 1989). Nonetheless, the initial separation of Okinawan and Japanese led to a distinct, Okinawan,

113 and diasporic identity. This identity is evident in the establishment and success of the Hawaiʻi United Okinawa Association

114 (HUOA), an amalgamation of ~50 affinity groups that support Okinawan culture and ~~diasporic~~ community in Hawaiʻi

115 (Kaneshiro, 2002; Kodama, 1981; Ueunten, 1989). ~~(e.g., Kaneshiro, 2002)(e.g., Sutton, 1983; Teruya, 2014)(Mori,~~

116 ~~2003)(e.g., Olsen, 1982)(Alonso Ishihara, 2022)(Okamura, 2022)(e.g., Olsen, 1980)~~An example of HUOA's success is the

117 annual Okinawan Festival, one of the largest cultural events in Hawaiʻi that attracts ~50,000 attendees in the 21st century

118 (Taira, 2023). Brazilian- (Mori, 2003) and Argentine-Okinawans (Alonso Ishihara, 2022), as well as Okinawan communities
119 across the USA (Okamura, 2022), founded similar associations. Moreover, HUOA and these other associations participate in
120 the Worldwide Uchinanchu Festival hosted by Okinawa Prefecture (Uchinanchu means "Okinawan People" in one
121 Ryukyuan language); overseas associations sent ~8,000 attendees in 2016 (Okamura, 2022). Such efforts are fueled by a
122 "Born Again Uchinanchu" movement that encapsulates third and later generations of the Okinawan diaspora looking to
123 reconnect with their culture and heritage (Chinen, 2025). Accordingly, Okinawan identity remains visible and active ~~in~~
124 ~~diasporas~~worldwide.

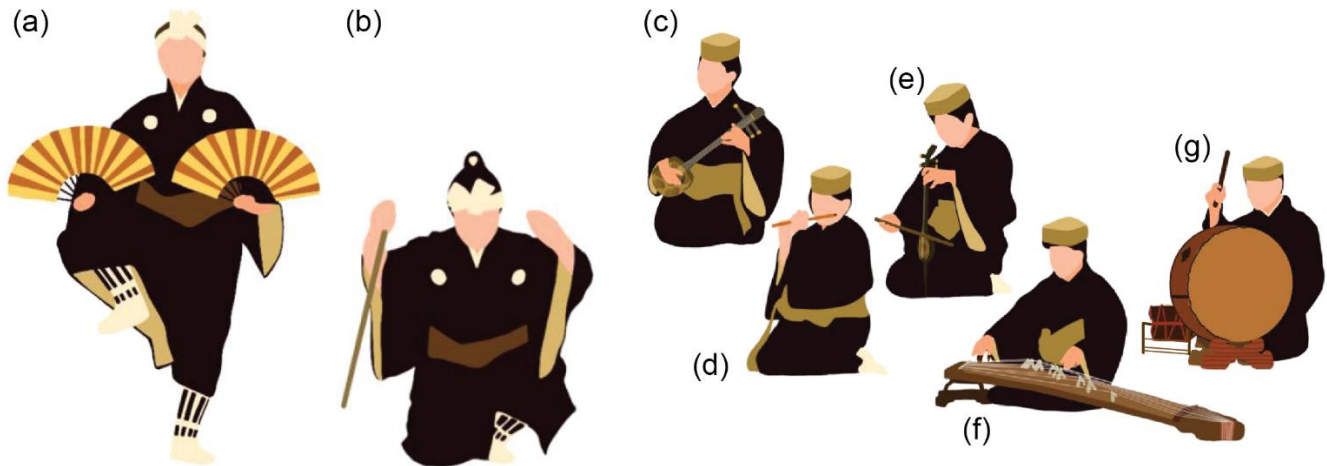



Figure 2: Illustrations of (a) Nubui Kuduchi and (b) Kudai Kuduchi dancers with (c) *uta sanshin*, (d) *fwansō*, (e) *kūchō*, (f) *kutū*, and (g) *tēku* musicians. Actual performances may have more than one dancer or musician per instrument, particularly for *uta sanshin*. Illustration by B. Kuhasubpasin.

1.2 *Ryūkyū koten ongaku* (RKO) and ~~geologie~~Indigenous knowledge

130 RKO is one of many visible cultural identifiers for Okinawans in Okinawa Prefecture and in the diaspora (Gillan,
131 2016; Kaneshiro, 2002; Teruya, 2014; Ueunten, 1989, 2020). ~~The Ryukyu Islands, situated in the western Pacific Ocean~~
132 ~~(Fig. 1), are the ancestral home of the indigenous Ryukyuan People and the former Ryukyu Kingdom (Sakiyama and Oshiro,~~
133 ~~1995; Toby, 1984). This community has experienced Earth processes that span geology (e.g., Kamata and Kodama, 1994),~~
134 ~~oceanography (e.g., Gallagher et al., 2015), and climatology (e.g., Ikema et al., 2010). Records of such phenomena may be~~
135 ~~preserved in an intricate performing arts tradition that developed from the kingdom's establishment in the 15th century~~
136 ~~(Sakiyama and Oshiro, 1995).~~ According to Sakiyama and Oshiro (1995), Ryukyuan classical music, or *Ryūkyū koten* (琉球
137 古典), was developed for entertaining foreign nobility and ambassadors during visits to the Ryukyu Kingdom, which unified
138 individual fiefdoms on Okinawa Island in 1429 CE. The kingdom expanded from Okinawa Island to surrounding island
139 groups in the following 100 years. Cross-cultural exchange from foreign trade led to the influences of China, Japan, Korea,
140 Thailand, Malaysia, and Indonesia on *Ryūkyū koten*. However, in 1609 CE, the Ryukyu Kingdom was invaded and

subsequently controlled by governing forces in the Satsuma Domain of south Kyushu and the Tokugawa Shogunate headed in Edo (pre-1868 CE name for Tokyo; Akamine, 2017; Toby, 1984). Consequently, records suggest ~20 Ryukyuan envoys traveled between Okinawa Island, Satsuma, and Edo to pay tribute to the Shogunate from 1610 CE until 1872 CE (Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984), followed by the dissolution and annexation of the Ryukyu Kingdom by Japan as Okinawa Prefecture in 1879 CE (Akamine, 2017). In the 21st century, Ryukyuan classical arts survive through practitioners in the lands that have become Okinawa Prefecture, Japan (e.g., Hanashiro, 2007), and in the Okinawan diaspora worldwide (e.g., Olsen, 1980, 1982; Sutton, 1983). (Kaneshiro, 2002; Miyashiro, 2018; Teruya, 2014; Ueunten, 1989)(e.g., Takahashi, 2022; Toguchi and Nishime, 2013)As such, scientific research on indigenous Ryukyuan culture may illuminate historical environmental processes and create new opportunities for place-based science engagement across the western Pacific.Utilizing According to Sakiyama and Oshiro (1995), RKO is an aristocratic genre that developed during the Ryukyu Kingdom's dynastic period for entertaining visiting emissaries, historically accompanied by male dancers from the noble class (Fig. 2a–b)(Sakiyama and Oshiro, 1995). RKO lyrics are originally from Ryukyuan poetry, which often focuses on metaphors of the natural world to convey human emotions and experiences. These performances are led by *uta sanshin* (唄三線), or a three-stringed lute with vocals (Fig. 2c). The *sanshin* lute itself was brought to Okinawa from China and became a symbol of Okinawan identity (Gillan, 2016). Nonetheless, the *uta* vocal component holds the melody of most RKO songs and is often said to be more central to RKO than *sanshin* (Ueunten, 2020). Other instruments that accompany *uta sanshin* include *fwansō* (笛; bamboo flute; Fig. 2d), *kūchō* (胡弓; fiddle; Fig. 2e), *kutū* (箏; zither; Fig. 2f), and *tēku* (太鼓; drums; Fig. 2g). Such RKO gained distinct Japanese influences after the Satsuma invasion and increased contact with the Satsuma Domain through Ryukyuan envoys (Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984). RKO developed into commercial and popular theater when the demand for Ryukyuan court music collapsed after Japanese annexation (Gillan, 2016), which ended historical class and gender restrictions in these aristocratic arts. As such, 21st-century RKO performing arts schools have wide participation in Okinawa Prefecture and the Okinawan diaspora; these schools remain the main mode of RKO transmission to new learners (e.g., Gillan, 2016; Hanashiro, 2007; Kaneshiro, 2002; Ueunten, 1989). RKO is also visible to non-artists as stone monuments to transformative songs, called *kahi* (歌碑). These monuments are often installed where songs have some lyrical or historical connection to a place, functioning as community centers, artistic venues, and memorials to collective Okinawan experiences (e.g., World War II) or as landmarks in popular paying *kahi* tours (Gillan, 2017). Furthermore, RKO also gained national and prefectural support through designations of National Living Treasures by the Japanese government and the establishment of institutions such as the Okinawa Prefectural University of Arts and the National Theatre Okinawa (Gillan, 2016). Thus, RKO remains a vibrant marker of Ryukyuan artculture across the Okinawan community.

Indigenous knowledge of climate and geology may be preserved in RKO, similar to that preserved in traditional ecological practices across the Ryukyu Islands (i.e., Takahashi, 2022; Toguchi et al., 2016; Toguchi and Nishime, 2013). Such artistic knowledge may be adapted into place-based science engagement that addresses issues specific to 1) 1)

174 Okinawans in Okinawa Prefecture and 2)2) diasporas across the world. Ryūkyū koten in science has the potential to address

175 environmental and societal issues in 21st-century Okinawa Prefecture. First, subtropical Okinawa Prefecture The Ryukyu

176 Islands will likely face challenges due to 21st-century anthropogenic climate change, including coastal flooding, typhoon

177 intensification, and coral bleaching (IPCC, 2023). Likewise, Okinawathe pPrefecture faces a stagnant college matriculation

178 rate and low standardized test scores relative to the whole of Japan (Kakazu, 2012), which follows historical marginalization

179 (e.g., Abe, 2023; Hammine, 2019; Inoue, 2004) (Kakazu, 2012). These statistics must be contextualized within the history of

180 discriminatory and assimilationist education policies implemented by the Japanese government after annexation with the

181 goal of eliminating Ryukyuan languages and cultures (Hammine, 2019). Research in science education finds that such

182 marginalization can preclude the next generation of marginalized people from entering environmental science studies and

183 careers (Martin and Fisher-Ari, 2021; Padgett, 2001). Due to RKO's visibility in Okinawan culture, More positive

184 representations of indigenous knowledgethis art form are likelymay be key to geoscience engagement and on and retention

185 efforts in Okinawa Prefecture (Semken et al., 2017). Consequently, increased visibility of Ryūkyū koten may stimulate novel

186 research on the prefecture's climate future, expose students to the utilities of indigenous knowledge, and refocus ancestral

187 arts and culture towards the issues that impact 21st-century Okinawans (e.g., Alexiades et al., 2021; Chinn et al., 2014;

188 Gibson and Puniwai, 2006; Reano and Ridgway, 2015).Second, RKO and other folk music genres serve as pillars of

189 Okinawan identity for the Okinawan diaspora, separated from Okinawa by three or more generations in the 21st century and

190 interested in ways to express their identity (Kaneshiro, 2002; Ueunten, 1989). These later generations may not understand

191 Ryukyuan languages and RKO lyrics(Ueunten, 1989), which poses a barrier to accessing Ryukyuan Indigenous knowledge

192 (Chinen, 2025). However, most RKO instructors in the diaspora have trained in or are from Okinawa Prefecture, increasing

193 direct access to such knowledge directly from the homeland (Chinen, 2025; Kaneshiro, 2002; Miyashiro, 2018; Teruya,

194 2014; Ueunten, 1989). The activity in Okinawan associations, like HUOA, exemplifies a demand for more access to RKO-

195 and place-based Indigenous knowledge. (Taira, 2023)(Okamura, 2022)As such, our investigation of RKO can fulfill

196 geoscience engagement goals in Okinawa Prefecture and the global diaspora by elevating place-based, Ryukyuan,

197 Indigenous knowledge as a reputable way of knowing.

198 Such place-based goals follow contemporary endeavors to recognize Ryukyuan indigeneity, particularly against the

199 backdrop of marginalization (e.g., Abe, 2023; Hammine, 2019; Nishiyama, 2023). Works in the similarly subtropical

200 Hawaiian Islands provide ample precedent for utilizing marginalized, indigenous, and Native Hawaiian knowledge in

201 teaching about place-based environmental science (e.g., Chinn et al., 2014; Gibson and Puniwai, 2006; Lemus et al., 2014;

202 Seraphin, 2014; Wiener and Matsumoto, 2014). In fact, the Native Hawaiian Renaissance movement of the late 1900s,

203 during which Hawaiian culture experienced a resurgence amid historical marginalization, provided a direct influence on

204 parallel efforts in 21st-century Okinawa Prefecture (e.g., Heinrich, 2018; Kina, 2020). Collaborations therein between the

205 Okinawan diaspora in Hawai'i, Okinawans in Okinawa Prefecture, and the Native Hawaiian community facilitate cross-

206 cultural exchange towards these cultural revitalization endeavors (Ohara and Slevin, 2019). Furthermore, the Hawai'i

207 Okinawa diaspora and those across the Americas (e.g., conterminous USA, Brazil, Peru) also work towards propagating

Ryūkyū koten and other Ryukyuan arts (e.g., Izumi, 2020; Kaneshiro, 2002; Miyashiro, 2018; Olsen, 1980, 1982; Sutton, 1983; Teruya, 2014; Ueunten, 1989). These practitioners are often separated from Okinawa by three or more generations in the 20th–21st centuries and may not understand Ryukyuan languages, and therefore *Ryūkyū koten* lyrics (e.g., Ueunten, 1989). This population, looking to connect with their distant homeland, may be an additional audience for Ryukyuan science engagement through a place based lens by ancestry rather than locality (Semken et al., 2017). Thus, advancements in *Ryūkyū koten* and place based pedagogy may help develop the global Ryukyuan indigenous movement.

We take a step toward connecting 18th century atmo , hydro , and geosphere observations with 20th 21st century scientific studies by investigating a repertoire of classical songs from the Ryukyu Kingdom. Nubui Kuduchi (上り口説) and Kudai Kuduchi (下り口説) trace historical envoys between Okinawa and Kyushu islands (Fig. 1), during which voyagers experienced diverse climate and geological phenomena. Here, we perform a lyrical analysis to extract observations of such phenomena for comparison with contemporary scientific literature. Surface winds, oceanic circulation, typhoon activity, and volcanism in lyrics parallel their descriptions in research ~300 years later. These similarities highlight how traditional songs may be historical benchmarks of past environmental conditions. Such benchmarks are likely useful for place based science engagement among Okinawan communities, linking ancestral arts with climate and geology that can be experienced in the 21st century. Therefore, we present a foundation for integrating Ryukyuan indigenous knowledge and contemporary scientific perspectives to enhance our understanding and pedagogy of Earth surface processes.

2 Background

2.1 Climate

2.2 Volcanism

Philippine Sea Plate subduction under the Eurasian Plate occurs east of the Ryukyu Islands at the Ryukyu Trench (Fig. 1; e.g., Kamata and Kodama, 1994). Quaternary island arc volcanism, characteristic of such ocean continent subduction, is focused north of Okinawa Island (Global Volcanism Program, 2024). In particular, the northern Ryukyu region includes Kikai Caldera, which produced at least three ignimbrite eruptions, including one in the mid Holocene with a volcanic explosivity index of seven out of eight (Fig. 2a; Machida and Arai, 2003; Maeno and Taniguchi, 2007; Ono et al., 1982). Satsuma Iwojima ("iwo" referring to *iō*, 硫黄, or sulfur in Japanese) is an island on the perimeter of this submarine caldera and is composed of two volcanoes with different lava types: the basaltic Inamuradake cone and the rhyolitic Iwodake dome (Fig. 2b). The oldest recorded observation of Iwodake activity is from Japanese written tradition, the Heike Monogatari (平家物語), which details late 12th century volcanism, sulfur mining (Kamada, 1964; Kazahaya et al., 2002; Shinohara et al., 2002), and political banishments to the island (Antoni, 1991). However, subsequent records of volcanic activity from this period are sparse despite a likely Iwodake eruption between ~1300 1450 CE, determined from calibrated ^{14}C ages in

239 decimeter thick rhyolitic flows (Kawanabe and Saito, 2002). Residents also reported active fumaroles (volcanic gas vents)
240 and small eruptions but with no recorded timings or further details (Kamada, 1964; Shinohara et al., 2002). Nonetheless,
241 Iwodake gas discharge events were recorded in the 20th and 21st centuries, producing transient, fine, ash fall deposits that
242 were observable only on smooth surfaces up to ten kilometers away (Kazahaya et al., 2002; Shinohara et al., 2002). Research
243 has attributed this activity to Kikai Caldera magma and degassing, highlighting an interconnected magma conduit at depth
244 (Saito et al., 2001) and activity for over 1000 years (Kawanabe and Saito, 2002; Shinohara et al., 2002).

245 Extensive caldera complexes are also located in southern Kyushu (Nagaoka, 1988). The Ata and Aira Calderas host
246 the Quaternary active stratovolcanoes Kaimondake and Sakurajima, respectively (Fig. 2a). Kaimondake is a relatively
247 uneroded cone at the entrance to Kagoshima Bay that last erupted in 885 CE (Fig. 2c; Fujino and Kobayashi, 1997). Roughly
248 50 km north, Sakurajima is a volcano in Kagoshima Bay and hosts three peaks: Kitadake, Nakadake, and Minamidake
249 (translated as north, central, and south peaks; Fig. 2d–e). In particular, Minamidake and surrounding fissures and craters had
250 four recorded major eruptions between the 8th–20th centuries, impacting communities including the city of Kagoshima less
251 than ten kilometers away (Fig. 2a; Kobayashi and Tameike, 2002). Sakurajima remains active in the 21st century, with nearly
252 3000 Vulcanian style eruptions between 2008–2011 CE (e.g., Iguchi et al., 2013).

253 ## 2.3 Ryukyu Kingdom and culture

254 According to Sakiyama and Oshiro (1995), Ryukyuan classical music, or *Ryūkyū koten* (琉球古典), was developed
255 for entertaining foreign nobility and ambassadors during visits to the Ryukyu Kingdom, which unified individual fiefdoms
256 on Okinawa Island in 1429 CE. The kingdom expanded from Okinawa Island to surrounding island groups in the following
257 100 years. Cross-cultural exchange from foreign trade led to the influences of China, Japan, Korea, Thailand, Malaysia, and
258 Indonesia on *Ryūkyū koten*. However, in 1609 CE, the Ryukyu Kingdom was invaded and subsequently controlled by
259 governing forces in the Satsuma Domain of south Kyushu and the Tokugawa Shogunate headed in Edo (pre-1868 CE name
260 for Tokyo; Akamine, 2017; Toby, 1984). Consequently, records suggest ~20 Ryukyuan envoys traveled between Okinawa
261 Island, Satsuma, and Edo to pay tribute to the Shogunate from 1610 CE until 1872 CE (Okinawa Prefectural Cultural
262 Promotion Association, 2001; Toby, 1984), followed by the dissolution and annexation of the Ryukyu Kingdom by Japan as
263 Okinawa Prefecture in 1879 CE (Akamine, 2017).

264 ## 2.4 Nubui Kuduchi and Kudai Kuduchi

265 Nubui Kuduchi and Kudai Kuduchi are a pair of *Ryūkyū koten* songs composed during the Satsuma Domain's rule over the
266 Ryukyu Kingdom. These songs are usually attributed to the *Ryūkyū koten* master Yakabi Chōki (屋嘉比朝寄; 1716–1775
267 CE; surname first following Japanese naming convention; Gillan, 2012; Kinjo, 1992). *Kuduchi* (口説) refers to a subgenre of
268 *Ryūkyū koten* with a distinctly Japanese, rather than Ryukyuan, seven-five beat structure (Kinjo, 1992). *Kuduchi* lyrics often
269 tell a chronological story or describe a scene (Seki, 2024), where *nubui* (上り) refers to "climbing up" to Satsuma and *kudai*

270 ~~(下り) to "climbing down" to Okinawa Island (Kinjo, 1992; Seki, 2024). As such, these songs detail an envoy's 18th-century~~

271 ~~journey between the Ryukyu Kingdom and Satsuma Domain (Fig. 1).~~

272 ~~According to Kinjo (1992) and Sakiyama and Oshiro (1995), Nubui Kuduchi and Kudai Kuduchi performances~~

273 ~~were historically reserved for entertaining Satsuma Domain officials in the Ryukyu Kingdom. Dancers perform with a~~

274 ~~folding fan in each hand or a traveler's cane for Nubui Kuduchi or Kudai Kuduchi, respectively (Fig. 3a–b). This repertoire~~

275 ~~may be accompanied by *uta sanshin* (唄三線; vocals and a three-stringed lute; Fig. 3c), which leads *fwansō* (笛; bamboo~~

276 ~~flute; Fig. 3d), *kūchō* (胡弓; fiddle; Fig. 3e), *kutū* (箏; zither; Fig. 3f), and *tēku* (太鼓; drums; Fig. 3g). The song and dance~~

277 ~~represent different aspects of the journey and have a relatively masculine connotation related to its brisk tempo, karate~~

278 ~~influence, and the harrowing journey itself. In the 21st-century, schools working to preserve the Ryukyuan arts often perform~~

279 ~~Nubui Kuduchi, Kudai Kuduchi, and other *Ryūkyū koten* songs at cultural events across Okinawa Prefecture (e.g., Hanashiro,~~

280 ~~2007) and for the Okinawan diaspora worldwide (e.g., Miyashiro, 2018; Olsen, 1980, 1982; Sutton, 1983; Teruya, 2014;~~

281 ~~Ueunten, 1989).~~

282 ## **2** ~~3~~ **Methods**

283 ### **2.1 Song background and lyrical interpretation**

284 We focus on Nubui Kuduchi and Kudai Kuduchi, which ~~are a pair of *Ryūkyū koten* songs~~ were composed during the

285 Satsuma Domain's rule over the Ryukyu Kingdom. These songs are usually attributed to the ~~Ryūkyū koten~~RKO master

286 Yakabi Chōki (屋嘉比朝寄; 1716–1775 CE; surname first following Japanese naming convention; Gillan, 2012; Kinjo,

287 1992). *Kuduchi* (口説) refers to a subgenre of RKO ~~*Ryūkyū koten*~~ with a distinctly Japanese, rather than Ryukyuan, seven-

288 five beat structure (Kinjo, 1992) and often ~~. *Kuduchi* lyrics often~~ tells a chronological story ~~or describe a scene~~ (Seki, 2024).

289 Then, ~~, where~~ *nubui* (上り) refers to "climbing up" to Satsuma and *kudai* (下り) to "climbing down" to Okinawa Island

290 (Kinjo, 1992; Seki, 2024). Thus~~As such~~, these songs detail a Ryukyua~~n~~ envoy's 18th-century journey between the Ryukyu

291 Kingdom and Satsuma Domain during the Japanese colonial period (Fig. 1).

292 ~~According to Kinjo (1992) and Sakiyama and Oshiro (1995),~~ Such~~Nubui Kuduchi and Kudai Kuduchi~~

293 performances were historically reserved for entertaining Satsuma Domain officials in the Ryukyu Kingdom, where ~~. Dancers~~

294 performers ~~with~~dance with a folding fan in each hand or a traveler's cane for Nubui Kuduchi or Kudai Kuduchi, respectively

295 ~~(Fig. 2a–b)~~(Fig. 2a–b; Sakiyama and Oshiro, 1995). ~~This repertoire may be accompanied by *uta sanshin* (唄三線; vocals and~~

296 ~~a three-stringed lute; Fig. 3c), which leads *fwansō* (笛; bamboo flute; Fig. 3d), *kūchō* (胡弓; fiddle; Fig. 3e), *kutū* (箏; zither;~~

297 ~~Fig. 3f), and *tēku* (太鼓; drums; Fig. 3g).~~ The ~~song and~~ dance represents different aspects of the ~~journey~~envoy and ~~have~~has a

298 relatively masculine connotation related to its brisk tempo, karate influence, and the harrowing journey itself (Kinjo, 1992).

299 B~~oth~~ songs remain popular in 21st-century RKO performances for entertainment and cultural preservation (Hanashiro,

300 2007).~~In the 21st-century, schools working to preserve the Ryukyuan arts often perform Nubui Kuduchi, Kudai Kuduchi, and~~

301 other *Ryūkyū koten* songs at cultural events across Okinawa Prefecture (e.g., Hanashiro, 2007) and for the Okinawan

302 diaspora worldwide (e.g., Miyashiro, 2018; Olsen, 1980, 1982; Sutton, 1983; Teruya, 2014; Ueunten, 1989).

303

304   FirstHere, we create English synopses of Nubui Kuduchi and Kudai Kuduchi to scientifically interpret both songs.

305 We utilize a version of both these songs from the Afuso Ryū (安冨祖流) school of RKO (one of two major schools; Garfias,

306 1993; Gillan, 2012)*Ryūkyū koten*, alongside interpretations from Kinjo (1992), Sakiyama and Oshiro (1995), and Seki (2024).

307 Following best practices in Younging (2018), the authors here include RKO *Ryūkyū koten* Master Instructors June Y.

308 Uyeunten and Kenton A. Odo (hereafter J.Y. Uyeunten and K.A. Odo, respectively) with of the Ryukyu Koten Afuso Ryu

309 Ongaku Kenkyu Choichi Kai USA (hereafter Choichi Kai USA), serving the Okinawan diaspora in Hawai'i, USA. Both

310 authors provide access to oral and written information on Nubui Kuduchi and Kudai Kuduchi, including personal

311 communications and interpretations from Clarence T. Nakasone (hereafter C.T. Nakasone; 1998) of the Hooge Ryu Hana

312 Nuuzi no Kai Nakasone Dance Academy, also based in Hawai'i. In addition, the first author is an *uta sanshin* practitioner

313 with the Choichi Kai USA at the time of publication. We provide supplementary videos with song lyrics, translations, and

314 interpretations from the above sources, with permission and production from J.Y. Uyeunten, K.A. Odo, and the

315 aforementioned dance academy (Higa et al., 2024a, b). We caution that these supplements are solely to provide references

316 for lyrical synopses; we do not claim intellectual property for the songs and lyrics themselvesand do not assert that these

317 songs should enter the public domain or become *gnaritas nullius* ("no one's knowledge" in Latin; i.e., Younging, 2018).

318 These precautions are to ensure that indigenousIndigenous knowledge is properly attributed credited and utilized. In addition,

319 we acknowledge that the other major RKO school, Nomura Ryū (野村流), may hold different versions of Nubui Kuduchi

320 and Kudai Kuduchi. However, as all authors are members of an Afuso Ryū branch, we opt to use our school's version as a

321 base, which is supplemented by insights from other textual and academic sources (i.e., Kinjo, 1992; Sakiyama and Oshiro,

322 1995; Seki, 2024). We note that in Afuso Ryū and Nomura Ryū diverged from two students of the same Master Instructor in

323 the 19th century and that most differences between the schools occur in singing or playing style; Afuso Ryū techniques are

324 said to be closer to the original lineage, whereas those of Nomura Ryū were simplified and standardized to make the art more

325 accessible (Garfias, 1993; Gillan, 2012). As the lyrics are mostly consistent across schools (except where we indicate notable

326 variations), differences in interpretation due to version control are likely minimal.variations.

327 **2.2 Climate and volcanology literature review**

328   We link observations of climate, geology, and the environment within Nubui Kuduchi and Kudai Kuduchi synopses

329 to 20th- and 21st-century scientific studies by noting similarities and differences therein, similar to Swanson (2008). Swanson

330 (2008) utilizes a Hawaiian oral history of the volcano deity Pele and her sister Hi'iaka in combination with 1812 CE written

331 records from European Christian missionaries to improve scientific interpretations of caldera formation at Kīlauea Volcano,

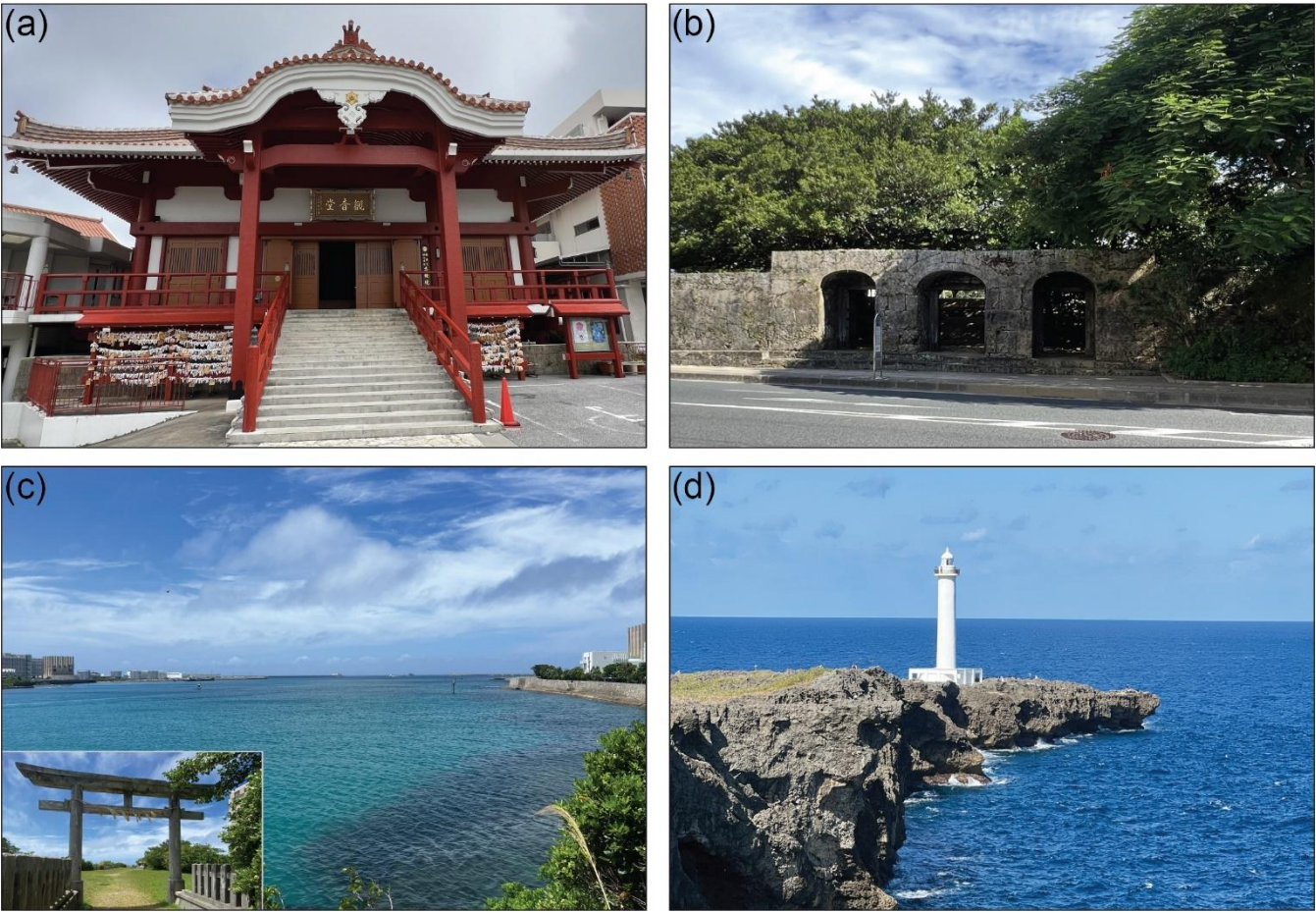
332 Hawai'i. The version of the oral history examined in Swanson (2008) is believed to be the most unaffected by Western

influences, but other versions are likely to be fundamentally similar, much like~~just as~~ Nubui Kuduchi and Kudai Kuduchi ~~are likely similar~~ are similar across RKO schools. Swanson (2008) presents a literature review on Kīlauea geochronology and stratigraphy to compare with the oral and written histor~~iesy~~. It was found that radiometric dating, Hawaiian oral tradition, and written records agree that the extant Kīlauea Caldera likely formed between 1470–1500 CE; the caldera was previously thought to have formed in 1790 CE during an explosive eruption. A~~Consequently~~ major discussion point of Swanson (2008) is that such a conclusion may have been accepted by the scientific community earlier if Indigenous knowledge had been seriously considered.

Here, w~~We~~ follow the methods of Swanson (2008) because we have a parallel aim to examine the correspondence between an Indigenous record and scientific literature. ~~Second, we link observations of climate, geology, and environment within these songs to 20th and 21st-century studies by noting similarities and differences therein, similar to Swanson (2008). (Ludwin et al., 2005)(Businger et al., 2018)W firstreview~~For our literature review, we cover 20th – 21st-century research across Ryukyuan climate and volcanology, two topics that we identify as likely recorded in Nubui Kuduchi and Kudai Kuduchi~~d~~. We focus our review on the natural conditions of climate and volcanic systems that Ryukyuan envoys may have experienced during 18th-century travels. We also review potential impacts on 21st-century Okinawans by anthropogenic climate change or volcanic hazards. ~~iswho~~Next, we systematically extract lyrical observations from our synopses as either climate- or volcanology-related. We then subgroup these observations into specific phenomena or locations from the corresponding scientific ~~from the scientific~~ literature to ~~Thusse~~showcase similarities or differences between sources. Finally, we discuss novel scientific and cultural implications from such climate and volcanic links, which ~~can be tailored to address~~geoscience engagement in Okinawa Prefecture and abroad. We acknowledge that, unlike Swanson (2008), Nubui Kuduchi and Kudai Kuduchi do not point to a single geologic event, but rather to general climate or geologic conditions. Nonetheless, these generalized links can be used in lessons to relate RKO with environmental research~~place based~~. ~~Lastly, we use the discussion to propose that these links are benchmarks for climate and geologic conditions across century timescales. W~~By connecting observations through time, we therefore ~~aim to showcase~~demonstrate the utility of ~~Ryukyuan indigenous~~Indigenous knowledge from RKO ~~for~~to increas~~eing Earth~~ geoscience engagement in Okinawan communities~~, linking an ancestral art form with environmental issues facing Okinawans in the 21st-century~~.

For the previous and following descriptions, we italicize Ryukyuan and Japanese common nouns and utilize diacritical marks for Ryukyuan and Japanese words where kana and kanji scripts are provided. Some kana may not reflect 21st-century Japanese pronunciation but represent common transliterations of the Ryukyuan languages. We use anglicized names and roman type for proper nouns or when kana and kanji are not provided.

362 ## 4 3 Results

363 ### 4 3.1 Lyrical synopses

364

365 **Figure 3: Historical sites in Nubui Kuduchi and Kudai Kuduchi on Okinawa Island photographed from 2023–2024. (a) Shuri**
366 **Kannondo Buddhist temple in Shuri from first verse of Nubui Kuduchi and (b) Sogenji Buddhist temple ruins in Naha from**
367 **second verse of Nubui Kuduchi, where voyagers prayed for ocean safety. (c) View from Miegusuku Fortress in Naha from both**
368 **songs, looking west out of Naha port where voyagers departed from and returned to Okinawa Island and (inset) atop fortress**
369 **ruins. (d) Cape Zampa from both songs, looking west near where voyagers noted wind and ocean conditions. See locations in Fig. 1.**

370

371 Based on Kinjo (1992), Sakiyama and Oshiro (1995), and Seki (2024), discussions with J.Y. Uyeunten and K.A.
372 Odo of Choichi Kai USA, and personal communications with C.T. Nakasone, Nubui Kuduchi details the perilous journey
373 from Okinawa Island to Kyushu. K.A. Odo describes how the word *nubui* also references the difficulty and anxiety of
374 leaving home as an upward climb. The first four verses describe the envoy's foot journey from Shuri, the Ryukyu capital at
375 the time these songs were composed, to the main port on Okinawa Island in Naha (Fig. 1). Along the way, voyagers pray at
376 and pass by various Ryukyuan shrines and Buddhist temples for safe travels, including Shuri Kannondo and Sogenji for safe

377 ~~travels~~ (Fig. 3a–b)~~, noting people coming and going. F~~In particular, families of the envoy shed tears due to the dangers at sea

378 facing their loved ones. The fifth and sixth verses detail the start of the voyage when sails pick up winds from the south-

379 southwest and the envoy travels out of Naha port, vowing to someday return to the Miegusuku Fortress (Fig. 3c) and Cape

380 Zampa on the west coast of Okinawa Island (Fig. 3d). Here, south-southwest is referred to as the direction of the Horse and

381 Sheep, collectively assigned this cardinal direction from the Chinese Zodiac (Seki, 2024). In the seventh verse, the envoy

382 encounters rough seas near Iheya Island, ~100 km from the port but only ~40 km from the north point of Okinawa Island.

383 Looking out over a "route of many islands" (i.e., Amami Islands; Okinawa Prefectural Cultural Promotion Association,

384 2001), the envoy surveys the upcoming seven islands (i.e., Tokara Islands in the Tokara Strait) that are often rough sailing

385 and expresses hope for a peaceful transit. The last verse describes the final approach to the Satsuma Domain of southern

386 Kyushu (~~Fig. 2~~Fig. 4a), wherein the envoy observes smoke from Iwodake volcano on the island of Satsuma-Iwojima (~~Fig.~~

387 ~~2~~Fig. 4b). Of note, the version of this song from C.T. Nakasone describes the smoke as rising (*tachuru*; 立ちゆる), while the

388 Afuso Ryū version notes the smoke is burning or glowing (*moyuru*; 燃ゆる). Finally, the envoy sails past Cape Sata on

389 Kyushu, where Kaimondake (~~Fig. 2~~Fig. 4c) and Sakurajima (~~Fig. 2~~Fig. 4d) volcanoes come into view. The song ends with

390 Sakurajima being hailed as mistakeable for the iconic Mount Fuji.

391 Based on Sakiyama and Oshiro (1995) and Seki (2024), discussions with J.Y. Uyeunten and K.A. Odo, and

392 personal communications with C.T. Nakasone, verse one of Kudai Kuduchi begins when envoy members are called to return

393 to Okinawa Island from the Satsuma Domain around the ninth to the tenth month of the lunar calendar (approximately

394 September to October). Such travels occur after the envoy transits from Satsuma to Edo and back, which is not recorded in

395 this repertoire. As *kudai* refers to the act of climbing down, K.A. Odo notes the subtext of an easier, downhill, and more

396 hopeful return home. Consequently, joyous celebrations, more prayers for safety, and Satsuma bureaucratic processes are

397 described in the first to fifth verses. In the sixth to eighth verses, the sails pick up north-northeasterly winds after passing

398 Cape Sata, the rough seas of the Tokara Islands, the Amami Islands, and Iheya Island. North-northeast is referred to as the

399 direction of the Rat and Ox zodiacs (Seki, 2024). Here, the envoy is accompanied by friendly vessels when the voyagers

400 return to ~~when~~ Cape Zampa, as promised ~~comes back into view~~ (Fig. 3d). The final verse describes arriving ~~at the same port~~

401 ~~from which the envoy left~~home, with crowds of people welcoming the voyagers ~~back home~~ at Miegusuku Fortress (Fig. 3c).

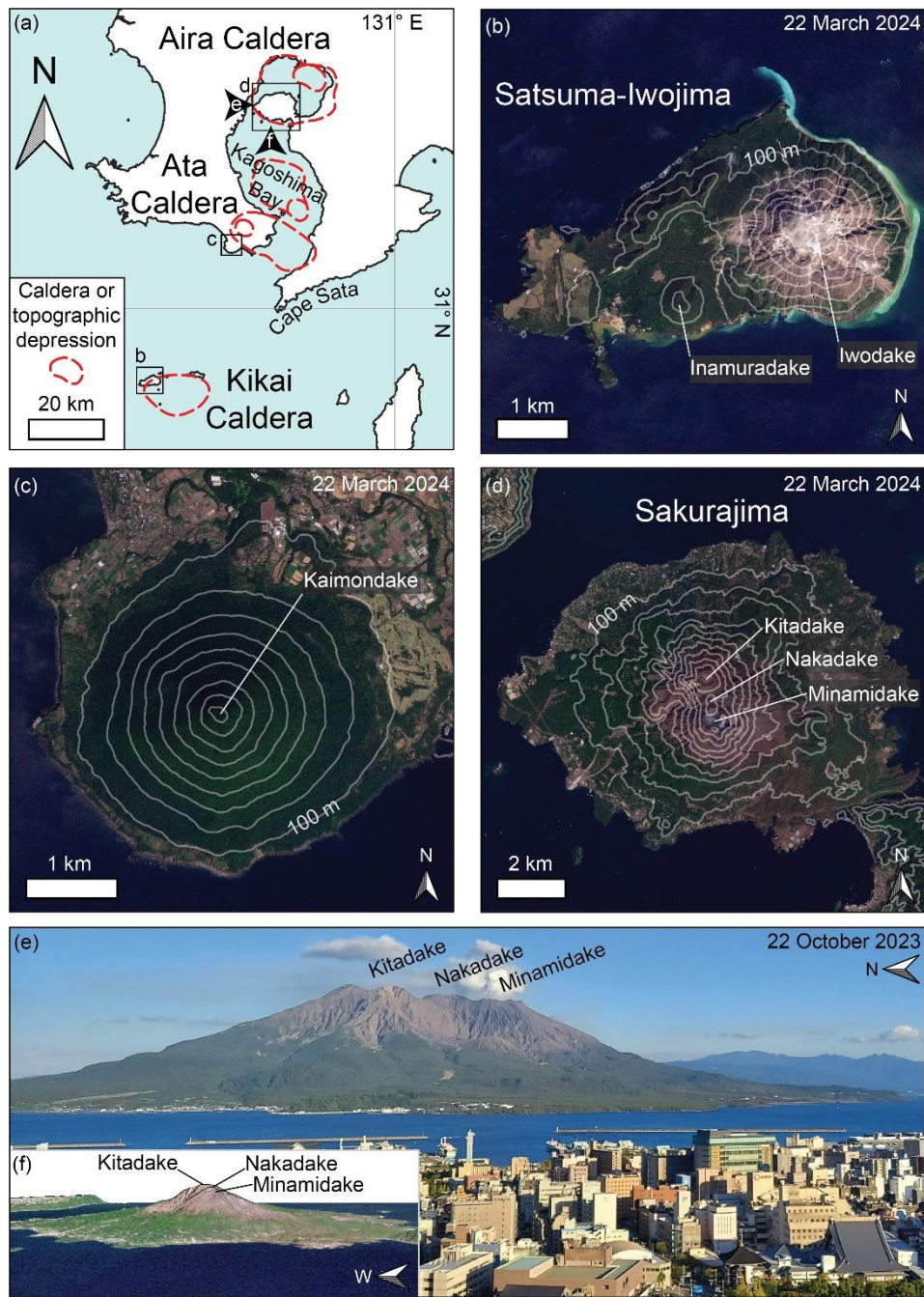



Figure 4: (a) Calderas and topographic depressions of southern Kyushu and the northern Ryukyu island arc (Maeno and Taniguchi, 2007; Nagaoka, 1988) with location of subplots as boxes or arrows indicating view direction. Geography from U.S. Department of State, Office of the Geographer (2013). PlanetScope 3 m resolution images of (b) Satsuma-Iwojima, (c) Kaimondake, and (d) Sakurajima (Image © 2025 Planet Labs; Planet Team, 2025) with 100 m elevation contours from 1 arc-second Shuttle Radar Topography Mission. (e) Sakurajima with Kagoshima City in foreground looking east versus (f) looking north with PlanetScope image draped over elevation.

43.2 ~~Cl~~Links to ~~cl~~imate

3.2.1 Ryukyu climate review

~~Here, the Kuroshio Current dominates oceanic circulation, bringing equatorial waters north into the East China Sea; this warm current then reenters the Pacific Ocean through the Tokara Strait and into the northern Pacific gyre (Fig. 1; Gallagher et al., 2015). By bringing warm water in contact with cool air, the Kuroshio Current is also important for atmospheric conditions across the Ryukyu Islands, particularly during the winter and spring (Liu et al., 2013).~~ The East Asian monsoon system drives atmospheric circulation and a seasonal transition of winds in the Ryukyu Islands, from northeasterlies during the Boreal winter to southwesterlies during the Boreal summer (Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et al., 1995). Then, the Kuroshio Current dominates oceanic circulation, bringing equatorial waters north into the East China Sea following the Ryukyu island arc; this warm current reenters the Pacific Ocean through the Tokara Strait and into the northern Pacific gyre (Fig. 1; Gallagher et al., 2015). Measurements of the Kuroshio Current along the Ryukyu Islands and through the Tokara Strait show high wave heights and ocean turbulence due to ocean-atmosphere coupling (Hwang, 2005) and interactions with bathymetric features such as volcanic seamounts along the Tokara Islands (Nagai et al., 2021; Tsutsumi et al., 2017). Previous ~~research~~works highlight~~s~~ how the ~~Kuroshio Current and~~ East Asian monsoon and Kuroshio Current, thus the climate of the Ryukyu Islands, may be altered by anthropogenic climate change. ~~For example, the Kuroshio Current is vulnerable to shifts in location and strength (e.g., Sakamoto et al., 2005; Wu et al., 2012; Zhang et al., 2020). Likewise~~For example, monsoonal winds (Kitoh, 2017) and Hadley cell circulation (Lu et al., 2007) may weaken over the western Pacific. Likewise, the Kuroshio Current is vulnerable to shifts in location and strength (e.g., Sakamoto et al., 2005; Wu et al., 2012; Zhang et al., 2020).

Typhoons are also common occurrences across the Ryukyu Islands (e.g., Ikema et al., 2010), constituting a critical feature of local climate and weather. Oceanic moisture (Ikema et al., 2010; Kitoh, 2017) and atmospheric forcing (Sun et al., 2015, 2017) help form then steer these storm systems from the tropical western Pacific toward subtropical East Asia (e.g., Wu and Wang, 2004; Yang et al., 2020). In turn, typhoons impact ocean conditions through increased wind speed and wave heights in the western Pacific region (Wu et al., 2014; Young et al., 2011). ~~Previous research suggests that~~Moreover, the El Niño-Southern Oscillation (ENSO) can ~~also~~ affect typhoon tracks. El Niño (i.e., periods of warming sea surface temperatures) is correlated with more typhoons recurring north, often toward the Ryukyu Islands; conversely, La Niña (i.e., periods of cooling sea surface temperatures) is characterized by more storms tracking west toward continental Asia (Ito et al., 2020; Sun et al., 2015, 2017; Wang and Chan, 2002; Wu and Wang, 2004; Yang et al., 2020). Variability in the western North Pacific Subtropical High is important for such ~~typhoon~~ tracking, as an eastward retraction of this persistent zone of high pressure allows typhoons to recurve north (Sun et al., 2015, 2017). These typhoons heading to higher latitudes help facilitate poleward energy transport (Wang and Chan, 2002). Therefore, while typhoons are weather phenomena, they both impact and are impacted by ~~(e.g., ENSO)~~ climate (e.g., ENSO). ~~T;~~typhoons are expected to become larger (Sun et al., 2015,

441 2017), rainier (Ikema et al., 2010; Kitoh, 2017), and more north-recurving (e.g., Yang et al., 2020) due to anthropogenic
442 climate change.
443

(a) Climate

Lyrical observations

Voyages from Okinawa to Kyushu during summer south- southwesterlies
• Nubui Kuduchi verse 5

Voyages from Kyushu to Okinawa in the ninth or tenth lunar month
• Kudai Kuduchi verse 1

Winter north-northeasterlies
• Kudai Kuduchi verse 6

Prayers for safe travels (Fig. 3a–b), vows to return to specific landmarks (Fig. 3c–d)
• Nubui Kuduchi verses 1, 2, 4, 6
• Kudai Kuduchi verses 2, 8, 9

Rough seas between Iheya and the Amami Islands
• Nubui Kuduchi verse 7
• Kudai Kuduchi verse 8

Famously dangerous Tokara Strait
• Nubui Kuduchi verse 7
• Kudai Kuduchi verse 6

East Asian Monsoon

Scientific literature

Voyages from Okinawa to Kyushu occurred around summer (Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984) when the Boreal monsoon is characterized by south-southwesterlies (Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et al., 1995).

Voyages from Kyushu to Okinawa occurred between autumn to spring when the Boreal monsoon is characterized by north-northeasterlies (Dobby, 1945; Fu et al., 1983).

Ocean conditions

Western Pacific Ocean is a typhoon hotspot during summer to autumn months when envoys were active (e.g., Ito et al., 2020).

Envoy path has statistically high wave heights, partially due to typhoon activity (Wu et al., 2014; Young et al., 2011).

Kuroshio current interactions with atmosphere and bathymetry in the Tokara Strait may induce ocean turbulence (Fig. 1; Hwang, 2005; Nagai et al., 2021; Tsutsumi et al., 2017).

Shuri Kannondo (Fig. 3a)

Sogenji (Fig. 3b)

Miegusuku (Fig. 3c)

Cape Zampa (Fig. 3d)

(b) Volcanism

Smoke is burning/rising from Satsuma Iwojima
• Nubui Kuduchi verse 8

Kaimondake comes into view and Sakurajima's majesty could be mistaken for Mount Fuji
• Nubui Kuduchi verse 8

Satsuma-Iwojima

Young ages of Iwodake lava (Kawanabe and Saito, 2002) and observed 20th–21st century fumaroles and ash eruptions (Kamada, 1964; Kazahaya et al., 2002; Shinohara et al., 2002; Fig. 4b).

Sakurajima and Kaimondake

The unincised Kaimondake edifice (Fujino and Kobayashi, 1997) is more geomorphically similar to Mount Fuji than Sakurajima (Fig. 4c–e).

Lack of historical recorded eruptions during the time of the envoy precludes that this mismatch is due to a catastrophic Sakurajima eruption (Fig. 4d–e; Kobayashi and Tameike, 2002).

Sakurajima (Fig. 4e)

444

Figure 5: L~~Summarized~~ inking lyrical observations with scientific literature on climate and volcanic systems that Ryukyuan envoys may have experienced. First, we extract (a) climate and (b) volcanic observations from ~~18th-century verses of Nubui Kuduchi (left) and Kudai Kuduchi (right)~~Nubui Kuduchi and Kudai Kuduchi (top). ~~linked with 20th-21st-century scientific observations and literature of climate and volcanism (center). Climate and volcanism are divided into specific phenomena or locations that are likely sung about in both songs.~~ Then, we subgroup lyrics that correspond with scientific literature on the East Asian Monsoon, ocean conditions, Satsuma-Iwojima, or Sakurajima and Kaimondake, related to ~~Some verses or observations may discuss~~ oceanic ~~conditions~~ currents (Fig. 1), landmarks (Fig. 3), and ~~volcanic landforms~~volcanoes (Fig. 4) ~~that are~~ observable or visitable in the 21st century (bottom).

3.2.2 Lyrical links to climate

We link the south-southwesterly winds described in Nubui Kuduchi with 20th–21st-century observations of the south to southwesterly winds that prevail during the Boreal summer monsoon from May to September (Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et al., 1995). As Nubui Kuduchi does not explicitly mention the timing of Satsuma-bound envoys, ~~climatological winds.~~ we utilize h~~H~~istorical records and genealogies that ~~show~~ show the ~20 departures from Naha port occurred between the fifth and eighth months of the lunar calendar (approximately May to August; Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984), agreeing with lyrics and the scientific literature (Fig. 5a)~~. Here.~~, ~~south to southwesterly winds prevail during the Boreal summer monsoon from May to September (Sect. 2.1; Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et al., 1995).~~ After arriving in Satsuma and traveling to and from Edo, Kudai Kuduchi ~~shows~~ describes the envoys returning to Okinawa Island on early autumn north-northeasterly winds. H~~H~~istorical records show that envoys returned to Naha port between the eleventh and fourth month of the lunar calendar (approximately November to April; Okinawa Prefectural Cultural Promotion Association, 2001). ~~. These lyrics and records are~~ consistent with the northeasterly Boreal winter monsoon from September to May (Dobby, 1945; Fu et al., 1983). Accordingly, ~~the~~ we can link the specific directions and seasonality of winds in Nubui Kuduchi, ~~and~~ Kudai Kuduchi, and historical records ~~can be leveraged in a place-based framework to link~~ with the East Asian monsoon system in scientific literature ~~with Ryukyuan history and culture~~.

Both songs ~~also~~ then mention prayers for safe travels, ~~showing~~ implying ~~that~~ the envoy acknowledged ~~the~~a dangerous ~~dangers of the upcoming~~ voyages ~~(Fig. 5)~~. We link this and other lyrical ~~observations of~~concerns for ~~potentially dangerous~~ ocean conditions ~~between Iheya and the Tokara Islands~~ with three scientific points (Fig. 5a). First, the envoy intersects the apex of the Kuroshio current at the famously dangerous seas of the Tokara Strait (Fig. 1). This region is associated with high wave heights from ocean-atmosphere coupling (Hwang, 2005) and interactions with seamount bathymetry that induce turbulence in the near-surface ocean (Nagai et al., 2021; Tsutsumi et al., 2017). ~~First~~Second, Holocene geologic evidence, modern climatological data, and numerical models highlight the commonality of typhoons that ~~may~~ cross the envoy's approximate path ~~(Fig. 1; Ito et al., 2020; Sun et al., 2017; Wang and Chan, 2002; Wu and Wang, 2004; Yang et al., 2020)~~, particularly during El Niño periods of ENSO (Ito et al., 2020; Sun et al., 2017; Wang and Chan, 2002; Wu and Wang, 2004; Yang et al., 2020). In fact, the timings of some journeys put certain envoys in the timeframe of the highest typhoon activity from July to September (Wu and Wang, 2004). ~~Second~~Third, the region between Kyushu and Taiwan has relatively high average and maximum wave heights compared to surrounding seas, in part ~~because of~~due to the

481 presence of these typhoons (Wu et al., 2014; Young et al., 2011). ~~Third, the Tokara Strait is where the Kuroshio Current~~
482 ~~crosses the Ryukyu Islands and reenters the Pacific Ocean (Fig. 1). Here, the envoy intersects the apex of the current~~
483 ~~(Gallagher et al., 2015), which is associated with comparatively high wave heights than farther away (Hwang, 2005).~~
484 ~~Interactions between the current and high relief bathymetry, such as seamounts, are also thought to induce turbulence in the~~
485 ~~near surface Tokara Strait (Nagai et al., 2021; Tsutsumi et al., 2017).~~ Therefore, Nubui Kuduchi and Kudai Kuduchi can be
486 ~~utilized to examine~~linked with the impacts of ocean currents, typhoons, and ~~atmosphere-ocean~~ocean-atmosphere coupling ~~,~~
487 ~~and currents~~ on dangerous ocean conditions in the western Pacific Ocean~~Ryukyuan oceanic conditions~~.

489 ## ~~4~~3.3 ~~V~~Links to volcanism

490 ### 3.3.1 Ryukyu volcanism review

491 Philippine Sea Plate subduction under the Eurasian Plate occurs east of the Ryukyu Islands at the Ryukyu Trench
492 (Fig. 1; e.g., Kamata and Kodama, 1994). Quaternary island arc volcanism, characteristic of such ocean-continent subduction,
493 is focused north of Okinawa Island (Global Volcanism Program, 2024). In particular, the northern Ryukyu region includes
494 Kikai Caldera, which produced at least three ignimbrite eruptions including one in the mid-Holocene with a volcanic
495 explosivity index of seven out of eight (Fig. 4a; Machida and Arai, 2003; Maeno and Taniguchi, 2007; Ono et al., 1982).
496 Satsuma-Iwojima ("iwo" referring to *iō*, 硫黄, or sulfur in Japanese) is an island on the perimeter of this submarine caldera
497 composed of two volcanoes with different lava types: the basaltic Inamuradake cone and the larger, rhyolitic Iwodake dome
498 (Fig. 4b). The oldest recorded observation of Iwodake activity is from Japanese written tradition, the Heike Monogatari
499 (平家物語), which details late-12th-century volcanism, sulfur mining (Kamada, 1964; Kazahaya et al., 2002; Shinohara et
500 al., 2002), and political banishments to the island (Antoni, 1991). However, subsequent records of volcanic activity from this
501 period are sparse despite a likely Iwodake eruption between ~1300–1450 CE, determined from calibrated ^{14}C radiometric
502 ages in decimeter-thick rhyolite flows (Kawanabe and Saito, 2002). Residents also reported active fumaroles (volcanic gas
503 vents) and small eruptions but with no recorded timings or further details (Kamada, 1964; Shinohara et al., 2002).
504 Nonetheless, Iwodake gas discharge events were recorded in the 20th and 21st centuries, producing transient, fine, ash fall
505 deposits that were observable only on smooth surfaces up to ten kilometers away (Kazahaya et al., 2002; Shinohara et al.,
506 2002). Research has attributed this activity to Kikai Caldera magma and degassing, highlighting an interconnected magma
507 conduit at depth (Saito et al., 2001) and activity for over 1000 years (Kawanabe and Saito, 2002; Shinohara et al., 2002).
508 ~~Despite sparse records from what are effectively three observations of volcanism through time~~In the 21st century, such
509 activity has extensive impacts on water quality by hydrothermal leaching (e.g., Kiyokawa et al., 2012) and air quality by
510 sulfate aerosols (e.g., Itahashi et al., 2019) locally and throughout the western Pacific region.
511 Extensive caldera complexes are also located in southern Kyushu (Nagaoka, 1988). The Ata and Aira Calderas host
512 the Quaternary-active stratovolcanoes Kaimondake and Sakurajima, respectively (Fig. 4a). Kaimondake is a relatively

513 uneroded cone at the entrance to Kagoshima Bay that last erupted in 885 CE (Fig. 4c; Fujino and Kobayashi, 1997). Roughly

514 50 km north, Sakurajima is a volcano in Kagoshima Bay and hosts three peaks: Kitadake, Nakadake, and Minamidake

515 (translated as north, central, and south peaks, respectively; Fig. 4d–e). In particular, Minamidake and surrounding fissures

516 have four recorded major eruptions between the 8th–20th centuries, impacting communities including the city of Kagoshima

517 less than ten kilometers away (Fig. 4a; Kobayashi and Tameike, 2002). Sakurajima remains active in the 21st century, with

518 nearly 3000 Vulcanian-style eruptions between 2008–2011 (e.g., Iguchi et al., 2013).

3.3.2 Lyrical links to volcanism

520 Upon arrival in Satsuma, Nubui Kuduchi mentions Kaimondake and Sakurajima but likely only holds geologically

521 interpretable observations of Satsuma-Iwojima (see Sect. 4.1 for Kaimondake and Sakurajima). Here, the ~~envoy~~ song

522 describes Satsuma-Iwojima activity as a gas or ash plume ~~from the summit of Iwodake. W.~~ We link these lyrical

523 observations ~~to~~ with the historical (Kamada, 1964) and scientific (Kazahaya et al., 2002; Shinohara et al., 2002) observations

524 of the active Iwodake fumaroles and ash eruptions documented in the 20th–21st centuries (Fig. 5b). In fact, lyrics of burning

525 or glowing smoke are similar to the discharge of hot and illuminated gases from a 1996 nighttime eruption described

526 in~~described in~~ Shinohara et al. (2002). Therefore, 18th-century Nubui Kuduchi adds an intermediary observation of Iwodake

527 activity between the 12th-century Heike Monogatari and 20th–21st-century scientific studies~~.~~. We ~~Despite sparse records~~

528 ~~from what are effectively three observations of volcanism through time, such activity has extensive impacts on water quality~~

529 ~~by hydrothermal leaching (e.g., Kiyokawa et al., 2012) and air quality by sulfate aerosols (e.g., Itahashi et al., 2019) locally~~

530 ~~and throughout the western Pacific. Combining lyrical observations with volcanology~~ exemplif~~ies~~y how

531 ~~indigenous~~Indigenous knowledge from Nubui Kuduchi supports relatively consistent volcanic activity from Iwodake as

532 suggested by radiometric dating and observed eruptions (Kawanabe and Saito, 2002; Shinohara et al., 2002)~~can highlight~~

533 ~~local eruptive histories and regional volcanic impacts across and beyond the Ryukyu Islands~~.

534

~~5~~ 4 Discussion

~~5~~4.1 Lyric~~als~~ implications for~~infer~~ historical climate and volcanism

537 ~~The seasonality of historical wind directions in~~The similarity of seasonal wind directions in Nubui Kuduchi and

538 Kudai Kuduchi ~~are similar to scientific observations up to the 21st century, as seen by comparing the~~ lyrics ~~themselves~~,

539 historical documents (Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984), and the modern monsoon

540 (Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et al., 1995)~~. Therefore, this repertoire~~ implies a reliance on predictable

541 monsoonal winds~~, which facilitated~~ for the ~20 Ryukyuan envoys going to and from Satsuma (Okinawa Prefectural Cultural

542 Promotion Association, 2001; Toby, 1984)~~that could be explored as historical climate benchmarks~~. Deviations from this

543 norm could be highlighted and explored as monsoonal abnormalities. For example, genealogies suggest that a 1791 CE

544 envoy was required to wait in Satsuma between the fourth to tenth lunar months of 1791 CE due to unfavorable winds earlier

545 in the year (Okinawa Prefectural Cultural Promotion Association, 2001). These records could signify a failure of the East

546 Asian Boreal summer monsoon that coincided with El Niños between 1788–1796 CE, known collectively as the Great El

547 Niño (Cook et al., 2010; Grove, 2006; Quinn et al., 1987). Records show that envoys did not resume until 1796–1797 CE

548 near the end of this climate anomaly (Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984), but more

549 historical analyses are required to assert that this envoy gap reflects a monsoon failure. Nubui Kuduchi and Kudai Kuduchi

550 then detail prayers and tears shed for the dangerous journey ahead (e.g., at locations in Fig. 3a–b), foreshadowing deadly ~~.~~

551 ~~These actions may foreshadow~~ typhoons, waves, and ocean currents ~~in the 21st century~~. Speculatively, Ryukyuan voyagers

552 could have been indirectly praying for La Niña conditions associated with a lower probability that typhoons will track

553 toward~~s~~ the Ryukyu Islands (Ito et al., 2020; Sun et al., 2015, 2017; Wang and Chan, 2002; Wu and Wang, 2004; Yang et

554 al., 2020). Likewise, the envoy may have indirectly recorded the impacts of typhoons (Wu et al., 2014; Young et al., 2011)

555 and the Kuroshio Current (Hwang, 2005; Nagai et al., 2021; Tsutsumi et al., 2017) on ocean conditions in and around the

556 Tokara Strait, which is highlighted as a treacherous location in both songs. As such, Nubui Kuduchi and Kudai Kuduchi

557 ~~these songs~~ provide a proof-of-concept for extracting historical climate from ~~Ryūkyū koten lyrics~~RKO~~, which can be used~~ to

558 connect the cultural arts ~~to~~ with geoscience ~~and education~~ in the Ryukyu Islands~~western Pacific~~.

559 Voyages north of Okinawa Island, where active volcanoes are located (Fig. 1), then offer a rare opportunity to

560 record volcanism in Ryukyuan songs. If Nubui Kuduchi describes average degassing across the attributed composer's

561 lifetime (1716–1775 CE; Gillan, 2012; Kinjo, 1992) or the envoy's activity (1610–1872 CE; Okinawa Prefectural Cultural

562 Promotion Association, 2001; Toby, 1984), perhaps this song represents volcanic processes over ~60 or ~250 years,

563 respectively. Regardless, this volcanic benchmark from 18th-century Nubui Kuduchi bridges an ~800-year gap between the

564 12th-century Heike Monogatari and 20th–21st-century studies at Satsuma-Iwojima and Kikai Caldera (e.g., Kawanabe and

565 Saito, 2002; Kazahaya et al., 2002; Saito et al., 2001; Shinohara et al., 2002). Such a gap may be in part because Satsuma-

566 Iwojima's population was historically ignored and othered by Japanese society (Antoni, 1991). Thus, lyrical observations

567 from the Ryukyu Kingdom can help scientists understand the continuity of volcanic activity on this island. For example, the

568 long-term degassing ~~, as~~ suggested by ~~these historical records,~~this song agree~~s~~ with evidence of over 1000 years of eruptive

569 activity from radiometrically dated Iwodake rocks (Kawanabe and Saito, 2002; Shinohara et al., 2002). These observations

570 fit into a previously proposed model of a long-term, convecting, and stratified Satsuma-Iwojima magma chamber that feeds

571 basaltic Inamuradake and rhyolitic Iwodake. ~~W~~Here, ~~w~~orkers suggest that denser basalt magma may sit lower in the

572 chamber to 1) supply the less dense rhyolite magma above with volatile gases that 2) cause this rhyolite to ascend in the

573 Iwodake magma column and 3) induce surface degassing by decompression to 4) cause this magma to descend once

574 degassed of buoyant volatiles (Kazahaya et al., 2002; Saito et al., 2001; Shinohara et al., 2002). Therefore, Nubui Kuduchi

575 may connect surface phenomena with supposedly long-lived and deep magmatic processes at Satsuma-Iwojima over ~800

576 years.

577   Nubui Kuduchi also compares Sakurajima's geomorphology to that of Mount Fuji. However, the uneroded and

578 single-peaked Kaimondake (Fig. 2Fig. 4c) is more similar to the conical Mount Fuji than Sakurajima (Fig. 4d; Fujino and

579 Kobayashi, 1997). Historical records (Kobayashi and Tameike, 2002) from this well-populated area precludes that this

580 discrepancy signals that an eruption that dramatically altered Sakurajima's shape into its current form (Kobayashi and

581 Tameike, 2002). The lyrics described herein are likely a poetic interpretation of the first sight of this volcano. Alternatively,

582 the north-south alignment of summit peaks (Fig. 2Fig. 4d) and the south-opening Kagoshima Bay suggest that arriving

583 voyagers would see a more conical volcanic profile than if seen from the east or west (Fig. 2Fig. 4e–f). This geomorphology

584 may also lead to the generous interpretation of Sakurajima as mistakable for Mount Fuji.

585 **5**4**.2 Future** work for**of place-based** *Ryūkyū koten ongaku*

586   The links we establish between Nubui Kuduchi, and Kudai Kuduchi, and scientific literature can be utilized in

587 place-based engagement aimed at connecting to highlight the impacts of climate and volcanism on 21st-century Okinawan

588 students with their local environment, which follows previous efforts in Hawai'i and North America (e.g., Alexiades et al.,

589 2021; Chinn et al., 2014; Gibson and Puniwai, 2006; Reano and Ridgway, 2015). For exampleOkinawans in Okinawa

590 Prefecture, students may examine the East Asian monsoon system, ENSO, and their influences on observable wind patterns

591 in the 21st-century Ryukyu Islands on which 18th-century voyagers likely relied (following Dobby, 1945; Flohn, 1957; Fu et

592 al., 1983; Ueda et al., 1995). Likewise, although not directly cited, the impacts of typhoons and the Kuroshio Current hinted

593 at in both songs provide ancestral connections to the history of natural disaster awarenesss (following Ikema et al., 2010) and

594 oceanic voyaging in Okinawa. Visiting the sites where voyagers acted upon their knowledge of dangerous wind and ocean

595 conditions, which are now famous landmarks (e.g., Fig. 3)Fig. 3, could emphasize place-based links between Indigenous

596 knowledge and scientific literature (Fig. 5; Semken et al., 2017). Visiting the sites where voyagers acted upon their

597 knowledge of dangerous wind and ocean conditions could also highlight meaningful, place-based connections between

598 ancestors and contemporaries (Semken et al., 2017). Critical thinking modules can then allow students to hypothesize how

599 climate change may modify Ryukyuan winds (e.g., Kitoh, 2017; Lu et al., 2007), typhoons (e.g., Ikema et al., 2010; Sun et

600 al., 2015, 2017; Yang et al., 2020), and currents (e.g., Sakamoto et al., 2005; Wu et al., 2012; Zhang et al., 2020) into the

601 future. Farther outboard, Iwodake provideslinkingNubui Kuduchimodern ones presents an opportunityies to teach recent

602 Ryukyuan volcanology and the complex tectonic and geologic processes of the Ryukyu Trench and Kikai Caldera,

603 respectively(following Kamada, 1964; Kazahaya et al., 2002; Shinohara et al., 2002) how scientists observe volcanic plumes

604 and measure their impacts on water and air quality (e.g., Itahashi et al., 2019; Kiyokawa et al., 2012). Critical thinking

605 modules can then allow students to hypothesize how climate change may modify Ryukyuan weather and storms (e.g., Kitoh,

606 2017; Lu et al., 2007) or examine how modern scientists quantify volcanic impacts on air and water quality (e.g., Itahashi et

607 al., 2019; Kiyokawa et al., 2012). For the Okinawan diaspora, modules on Ryukyuan climate change or volcanic hazards

608 could be showcased high at popular Okinawan events, such as HUOA's Okinawan Festival. Place-based geoscience

609 connections could also be incorporated into field trips when visiting Okinawa Prefecture for the Worldwide Uchinanchu

Festival (Okamura, 2022) or *kahi* tours (Gillan, 2017). Thus, educators can engage 21st-century ~~Okinawan~~ learners in Okinawa Prefecture and across the overseas diaspora ~~with~~ using the links to contemporary science that we have found in ~~place-based science by highlighting a diversity of environmental benchmarks and ancestral connections in this repertoire of Ryūkyū koten~~Nubui Kuduchi and Kudai Kuduchi.

~~Taken together, Nubui Kuduchi and Kudai Kuduchi tell a story that matches current knowledge and can fill gaps in understanding the climate and geology of the Ryukyu Islands. Similar~~Similar ~~Earth~~ geoscience insights could be ~~expanded examined from~~by applying this framework to ~~additional~~ additional Ryukyuan performing arts. ~~Here, island communities rely on springs for survival, transforming groundwater into a sacred resource (Takahashi, 2022). Likewise, popular songs such as~~Following the works on Indigenous knowledge of freshwater resources in Takahashi (2022), Nuchibana (貫花) and Amakā (天川) are popular songs that also speak of rivers and water around Okinawa (Seki, 2024). Then, ~~Researchers then document traditional names of fishing areas that describe reef geobiology (Toguchi and Nishime, 2013)~~descriptions of the Okinawan nearshore environment in Toguchi and Nishime (2013) and Toguchi et al. (2016), parallel ~~to~~ songs such as Tanchamē (谷茶前) and Umi nu Chinbōrā (海ぬチンボーラー) that make observations of ~~nearshore~~ shallow sardine and cone snail species, respectively (Seki, 2024). These commonly performed ~~songs~~ numbers (Hanashiro, 2007) may ~~collectively link places with~~highlight local hydrological, biological, and geological phenomena to familiarize Okinawa~~ns n populations~~ with their ~~local~~ environment. Therefore, future work in preserving and compiling ~~indigenous~~Indigenous knowledge within ~~Ryukyuan song~~the Ryukyuan arts could be key for ~~future~~ place-based ~~science~~ engagement across the Okinawan community~~in the Ryukyu Islands~~.

~~5~~4.3 Empowering Okinawan communities

Incorporating Nubui Kuduchi and Kudai Kuduchi in geoscience engagement can ~~(e.g., Kaneshiro, 2002; Ueunten, 1989)~~uplift Ryukyuan culture, language, and indigeneity against the backdrop of historical marginalization. Okinawan diasporas have a unique opportunity to connect with other Indigenous Peoples who have had successful experiences with place-based geoscience education (e.g., Hawai'i; Chinn et al., 2014; Gibson and Puniwai, 2006). In fact, Native Hawaiian~~1960s and~~ revitalization and sovereignty movements have directly influenced parallel efforts to revitalize Okinawan culture and languages (e.g., Heinrich, 2018; Kina, 2020). Conversations between the highly active Hawai'i-Okinawa diaspora, Okinawans in Okinawa Prefecture, and the Native Hawaiian community have facilitated cross-cultural exchange towards Okinawan cultural resurgence (e.g., LooChoo Identity Summit, where LooChoo is an approximation for one Ryukyuan language's pronunciation of Ryukyu; Ohara and Slevin, 2019). Further collaborations in place-based pedagogy within these preexisting relationships may help legitimize Ryukyuan Indigenous knowledge and grow this Indigenous movement.

~~Utilizing *Ryūkyū koten* in science has the potential to address environmental and societal issues in 21st-century Okinawa Prefecture. The Ryukyu Islands will likely face challenges due to anthropogenic climate change, including coastal flooding,~~

typhoon intensification, and coral bleaching (IPCC, 2023). Likewise, Okinawa Prefecture faces a stagnant college matriculation rate and low standardized test scores relative to the whole of Japan (Kakazu, 2012). These statistics must be contextualized within the history of discriminatory and assimilationist education policies implemented by the Japanese government after annexation with the goal of eliminating Ryukyuan languages and cultures (Hammine, 2019). Research in science education finds that such marginalization can preclude the next generation of marginalized people from entering environmental studies and careers (e.g., Martin and Fisher Ari, 2021; Padgett, 2001). More positive representations of indigenous knowledge are likely key to science engagement and retention efforts in Okinawa (Semken et al., 2017). Consequently, increased visibility of *Ryūkyū koten* may stimulate novel research on the prefecture's climate future, expose students to the utilities of indigenous knowledge, and refocus ancestral arts and culture towards the issues that impact 21st-century Okinawans (e.g., Alexiades et al., 2021; Chinn et al., 2014; Gibson and Puniwai, 2006; Reano and Ridgway, 2015).

Such place-based goals follow contemporary endeavors to recognize Ryukyuan indigeneity, particularly against the backdrop of marginalization (e.g., Abe, 2023; Hammine, 2019; Nishiyama, 2023). Works in the similarly subtropical Hawaiian Islands provide ample precedent for utilizing marginalized, indigenous, and Native Hawaiian knowledge in teaching about place-based environmental science (e.g., Chinn et al., 2014; Gibson and Puniwai, 2006; Lemus et al., 2014; Seraphin, 2014; Wiener and Matsumoto, 2014). In fact, the Native Hawaiian Renaissance movement of the late 1900s, during which Hawaiian culture experienced a resurgence amid historical marginalization, provided a direct influence on parallel efforts in 21st-century Okinawa Prefecture (e.g., Heinrich, 2018; Kina, 2020). Collaborations therein between the Okinawan diaspora in Hawai'i, Okinawans in Okinawa Prefecture, and the Native Hawaiian community facilitate cross-cultural exchange towards these cultural revitalization endeavors (Ohara and Slevin, 2019). Furthermore, the Hawai'i-Okinawa diaspora and those across the Americas (e.g., conterminous USA, Brazil, Peru) also work towards propagating *Ryūkyū koten* and other Ryukyuan arts (e.g., Izumi, 2020; Kaneshiro, 2002; Miyashiro, 2018; Olsen, 1980, 1982; Sutton, 1983; Teruya, 2014; Ueunten, 1989). These practitioners are often separated from Okinawa by three or more generations in the 20th–21st centuries and may not understand Ryukyuan languages, and therefore *Ryūkyū koten* lyrics (e.g., Ueunten, 1989). This population, looking to connect with their distant homeland, may be an additional audience for Ryukyuan science engagement through a place-based lens by ancestry rather than locality (Semken et al., 2017). Thus, advancements in *Ryūkyū koten* and place-based pedagogy may help develop the global Ryukyuan indigenous movement.

5Likewise, Okinawa Prefecture faces a stagnant college matriculation rate and low standardized test scores relative to the whole of Japan (Kakazu, 2012). These statistics must be contextualized within the history of discriminatory and assimilationist education policies implemented by the Japanese government after annexation with the goal of eliminating Ryukyuan languages and cultures (Hammine, 2019). Research in science education finds that such marginalization can preclude the next generation of marginalized people from entering environmental studies and careers (e.g., Martin and Fisher Ari, 2021; Padgett, 2001). More positive representations of indigenous knowledge are likely key to science engagement and retention efforts in Okinawa (Semken et al., 2017). Consequently, increased visibility of *Ryūkyū koten* may stimulate novel research on the prefecture's climate future, expose students to the utilities of indigenous knowledge, and

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677 ~~et al., 2014; Gibson and Puniwai, 2006; Reano and Ridgway, 2015).~~

678 ~~Such place-based goals follow contemporary endeavors to recognize Ryukyuan indigeneity, particularly against the~~
679 ~~backdrop of marginalization (e.g., Abe, 2023; Hammine, 2019; Nishiyama, 2023). Works in the similarly subtropical~~
680 ~~Hawaiian Islands provide ample precedent for utilizing marginalized, indigenous, and Native Hawaiian knowledge in~~
681 ~~teaching about place-based environmental science (e.g., Chinn et al., 2014; Gibson and Puniwai, 2006; Lemus et al., 2014;~~
682 ~~Seraphin, 2014; Wiener and Matsumoto, 2014). In fact, the Native Hawaiian Renaissance movement of the late 1900s,~~
683 ~~during which Hawaiian culture experienced a resurgence amid historical marginalization, provided a direct influence on~~
684 ~~parallel efforts in 21st-century Okinawa Prefecture (e.g., Heinrich, 2018; Kina, 2020). Collaborations therein between the~~
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689 ~~1983; Teruya, 2014; Ueunten, 1989). These practitioners are often separated from Okinawa by three or more generations in~~
690 ~~the 20th-21st-centuries and may not understand Ryukyuan languages, and therefore *Ryūkyū koten* lyrics (e.g., Ueunten, 1989).~~
691 ~~This population, looking to connect with their distant homeland, may be an additional audience for Ryukyuan science~~
692 ~~engagement through a place-based lens by ancestry rather than locality (Semken et al., 2017). Thus, advancements in *Ryūkyū*~~
693 ~~*koten* and place-based pedagogy may help develop the global Ryukyuan indigenous movement.~~

694 **~~.~~4 Lessons for science engagement**

695 It is important for ~~this~~ this and any future ~~research~~ RKO works to ~~credit~~ empower ~~indigenous~~Indigenous practitioners, ensure
696 rightful recognition, and present accurate interpretations. For example, many Ryukyuan songs that describe nature are
697 steeped in metaphor, including ~~that of~~ human relationships (e.g., Karaya Bushi; 瓦屋節), political rebellion (e.g., Unna
698 Bushi; 恩納節), and homesickness (e.g., Chijuyā; 浜千鳥; Sakiyama and Oshiro, 1995; Seki, 2024). These factors often
699 make scientific interpretations difficult (e.g., Swanson, 2008)~~,~~. but can be overcome by continued ~~engagement~~ collaborations
700 with ~~indigenous~~Indigenous elders and scholars ~~(Younging, 2018),~~ similar to how J.Y. Uyeunten and K.A. Odo guided ~~the~~our
701 interpretations of Nubui Kuduchi and Kudai Kuduchi (Younging, 2018)~~presented here (Sect. 4)~~. Although it is challenging
702 to compare poetic observations from songs with ~~those~~ scientific observations from literature, the ability to experience the
703 same environmental conditions as sung therein can enhance hands-on and place-based science engagement in the 21st
704 century. ~~Further~~ Future collaborations with ~~Ryūkyū koten~~RKO leaders ~~–~~ are required to interpret additional songs and
705 develop engagement modules for this purpose (Sect. ~~4~~5.2)~~.~~. As such~~,~~. there is~~, with~~ great potential ~~–~~ for more partnerships
706 between the ~~cultural~~ Ryukyuan arts ~~practitioners~~ and ~~geoscience~~scientists ~~engagement in environmental research.~~

707 ~~Nonetheless, song to place connections have a healthy and contemporary appreciation across Okinawa Prefecture.~~
708 ~~For example, stone monuments to transformative *Ryūkyū koten* and folk songs, called *kahi* (歌碑), are often installed where~~
709 ~~songs have some lyrical or historical connection to a place; these sites may function as community centers, artistic venues,~~
710 ~~and memorials to collective Okinawan experiences, such as World War II (Gillan, 2017). Building off these preexisting~~
711 ~~ideals that value the concept of place is vital for establishing culture's role in 21st-century science engagement (Lanza and~~
712 ~~Negrete, 2007). Such efforts have stimulated and will likely continue to stimulate novel research across Earth science~~
713 ~~disciplines, including climate science (e.g., Businger et al., 2018; Hinzman et al., 2005; Turner and Reid, 2022), volcanology~~
714 ~~(e.g., Swanson, 2008), and seismology (e.g., Ludwin et al., 2005). Likewise, invoking history and geoheritage can help~~
715 ~~researchers protect scientifically and historically important geosites (e.g., Motta and Motta, 2007; Reano and Ridgway,~~
716 ~~2015) and teach natural disaster preparedness (e.g., Bailey Winiata et al., 2024). These efforts to relate familiar culture with~~
717 ~~complex research provide accessible narratives for more effective science communication (Lanza and Negrete, 2007),~~
718 ~~solidifying indigenous knowledge and place-based science as key for environmental science engagement and education.~~

719 **~~6~~ 5 Conclusions**

720 *~~Ryūkyū koten~~*RKO contains historical observations of the natural world that describe atmospheric, oceanic, and
721 geologic processes. Here, we demonstrate how Nubui Kuduchi and Kudai Kuduchi hold 18th-century descriptions of winds,
722 currents, typhoons, and volcanoes in the ~~western Pacific~~ Ryukyu Islands of the western Pacific. Through a novel
723 collaboration~~s~~ with cultural practitioners, ~~these observations~~we show that observations of the natural world in lyrics
724 correspond with climate and volcanological research in 20th–21st-century scientific literature. Such correspondence suggest~~s~~
725 that Indigenous knowledge in these songs can be used to ~~can be explored as climate and geology benchmarks to~~ better
726 engage Okinawans in Okinawa Prefecture and across the global Okinawan diaspora with complex geoscience topics
727 applicable to their communities. ~~Such benchmarks are likely useful for contextualizing environmental phenomena from past~~
728 ~~to present, such as the impacts of anthropogenic climate change. E~~Researchers and ~~e~~ducators can apply these lessons to
729 place-based science modules centered on ~~science engagement, cultural revitalization, and~~ the specific climate, ~~and~~ geologic~~y,~~
730 and social issues facing 21st-century Okinawa~~ns~~Prefecture. Thus, ~~documentation of this performing arts tradition~~RKO ~~is~~ is
731 pedagogically~~scientifically and pedagogically~~ vital for promoting~~valuable and could reveal~~ science engagement in and about
732 the~~more environmental lessons from the~~ Ryukyu Islands.

733 **Data availability**

734 Data produced ~~for~~ in this project consist~~s~~ of two video supplements ~~of~~ for Nubui Kuduchi and Kudai Kuduchi (Higa et al.,
735 2024a, b).

Video supplement

See video supplement for documentation of Nubui Kuduchi and Kudai Kuduchi lyrics, translations, and interpretations (Higa et al., 2024a, b).

Author contribution

Conceptualization: JTH, Data curation: JTH, Formal analysis: JTH, JYU, KAO, Funding acquisition: JTH, Investigation: JTH, JYU, KAO, Methodology: JTH, JYU, KAO, Project administration: JTH, Resources: JTH, JYU, KAO, Supervision: JTH, Validation: JTH, JYU, KAO, Visualization: JTH, Writing–original draft preparation: JTH, Writing–review & editing: JTH, JYU, KAO.

Competing interests

The authors declare that they have no conflict of interest.

Ethical statement

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