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

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Abstract. Indigenous knowledge can record scientific observations of specific "places" that may be difficult to preserve in the geologic record. Such place in place-based science highlights issues local to a learner for engaging audiences with the scientific problems relevant to their communities. Here, we focus on a repertoire of indigenous Ryukyuan classical music to

10 examine place-based observations of 18th-century climate and geology in the Ryukyu Islands (21st-century Okinawa Prefecture, Japan). Comparing environmental conditions recorded in songs with 20th–21st-century studies, we find that surface winds, ocean currents, typhoons, and volcanism from lyrics parallel their respective observations in the scientific record. This novel perspective of art and science highlights the relevancy of Ryukyuan classical music in teaching contemporary issues such as climate change and natural hazards. Thus, Ryukyuan indigenous knowledge can play an

15 innovative role in science engagement for 21st-century Okinawans in Okinawa Prefecture and their diasporic kinsfolk worldwide.

1 Introduction

Indigenous knowledge can preserve geologic histories difficult to infer from geologic records, thus guiding modern scientific inquiry. However, it was not until the 1990s that researchers began incorporating such untapped data in natural science

20 literature (Petzold et al., 2020). These works have linked indigenous knowledge from oral histories, elder knowledge, and gray literature with observable processes such as permafrost loss (e.g., Hinzman et al., 2005), seasonal plant cycles (e.g., Turner and Reid, 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 al., 2024; Businger et al., 2018; Hough, 2007; King and Goff, 2010; Ludwin et al., 2005; Nunn and Pastorizo, 2007; Swanson, 2008). Highlighting indigenous knowledge within a "place-based" learning framework allows

25 students to better engage with the environmental sciences by tapping their personal and local experiences of the natural world (Semken et al., 2017). For example, previous works highlight how incorporating indigenous stewardship in Earth science courses can increase engagement by emphasizing the local, land-human interactions to which a learner has an ancestral connection (e.g., Alexiades et al., 2021; Chinn et al., 2014; Gibson and Puniwai, 2006; Reano and Ridgway, 2015). These narratives complement efforts to more effectively teach peer-reviewed environmental science to all levels of learners

30   (Lanza and Negrete, 2007). Thus, examining indigenous knowledge has proved valuable for the Earth sciences as well as for place-based environmental education and engagement in the contemporary world.
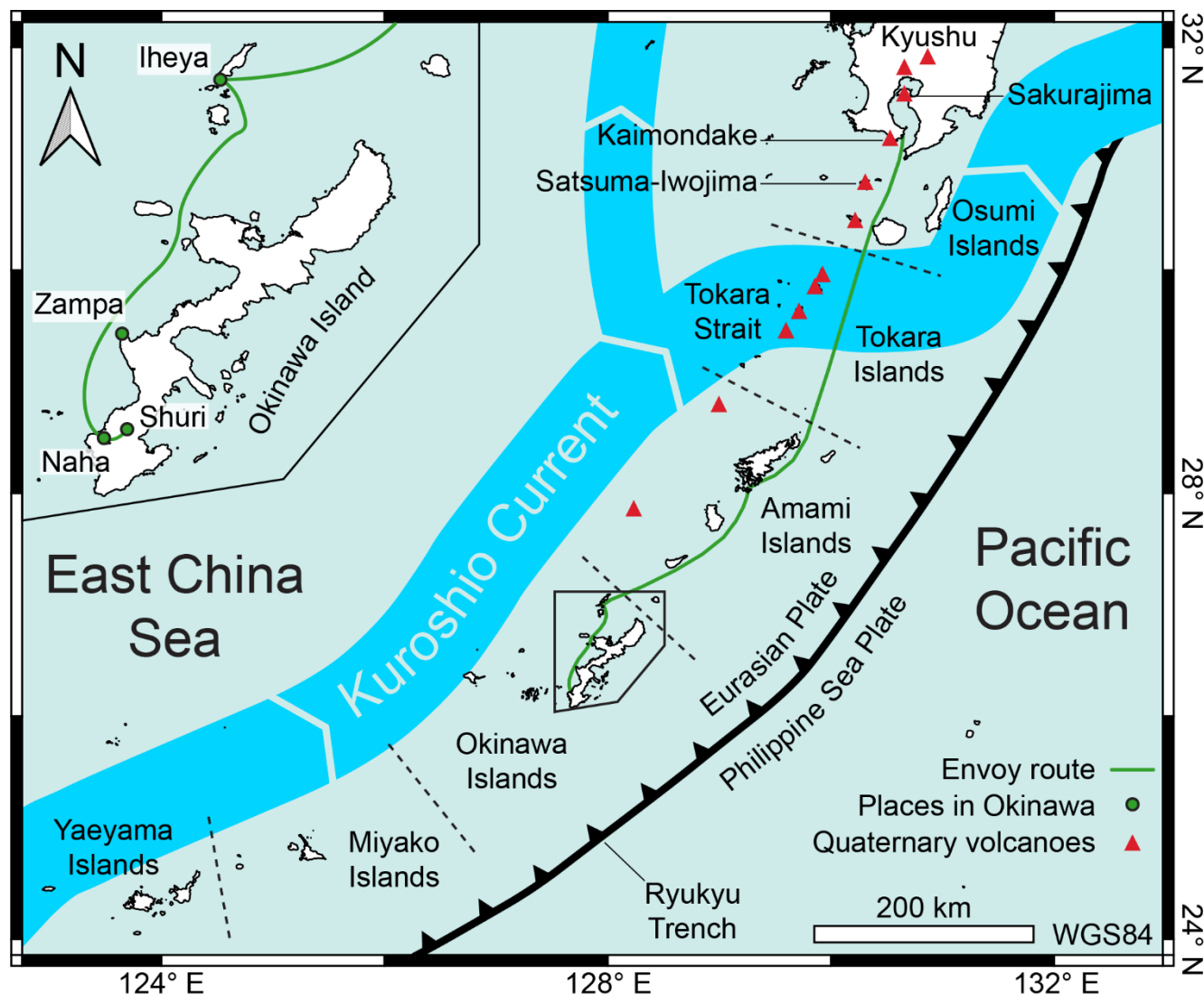
Figure 1: Map of the Ryukyu Islands showing the Kuroshio Current (Gallagher et al., 2015), Ryukyu Trench (Kamata and Kodama, 1994), envoy route (Okinawa Prefectural Cultural Promotion Association, 2001), and subaerial Quaternary volcanoes
35   **(Global Volcanism Program, 2024). (inset) Detailed map of Okinawa Island. Geography from U.S. Department of State, Office of the Geographer (2013).**

The Ryukyu Islands, situated in the western Pacific Ocean (Fig. 1), are the ancestral home of the indigenous Ryukyuan People and the former Ryukyu Kingdom (Sakiyama and Oshiro, 1995; Toby, 1984). This community has experienced Earth processes that span geology (e.g., Kamata and Kodama, 1994), oceanography (e.g., Gallagher et al.,

40   2015), and climatology (e.g., Ikema et al., 2010). Records of such phenomena may be preserved in an intricate performing

arts tradition that developed from the kingdom's establishment in the 15th century (Sakiyama and Oshiro, 1995). 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., Kaneshiro, 2002; Miyashiro, 2018; Olsen, 1980, 1982; Sutton, 1983; Teruya, 2014; Ueunten, 1989). As such, scientific research on indigenous Ryukyuan culture may illuminate

45   historical environmental processes and create new opportunities for place-based science engagement across the western Pacific.

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

50   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

55   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

The Ryukyu Islands span a north-south transect between Kyushu and Taiwan and include the Osumi, Tokara, Amami,

60   Okinawa, Miyako, and Yaeyama islands (Fig. 1). 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). Here, the East Asian monsoon system drives a seasonal transition of winds in the Ryukyu Islands,

65   from northeasterlies during the Boreal winter to southwesterlies during the Boreal summer (Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et al., 1995). Previous research highlights how the Kuroshio Current and East Asian monsoon, 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, monsoonal winds (Kitoh, 2017) and Hadley cell circulation (Lu et al., 2007) may weaken over the western Pacific.
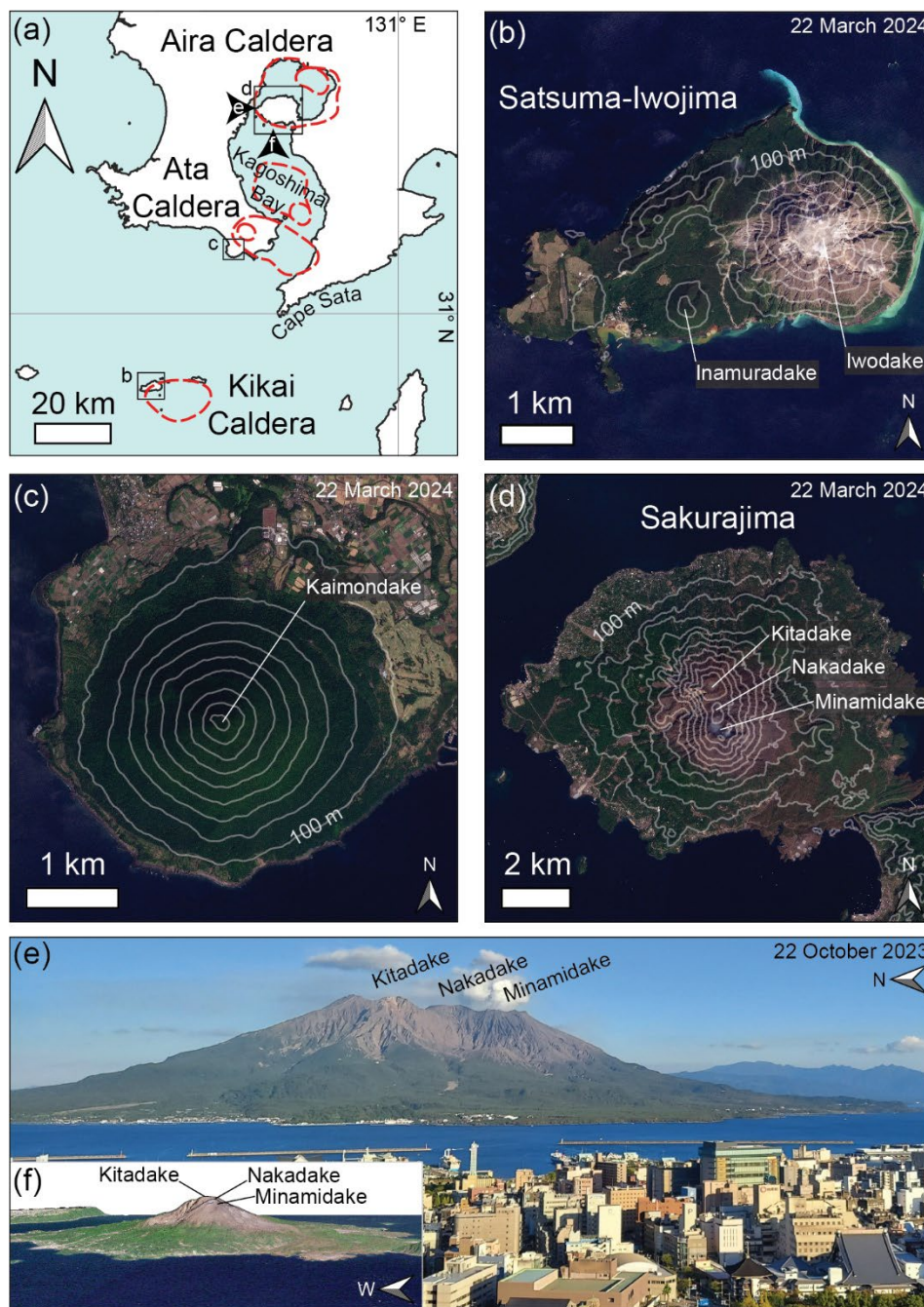
Figure 2: (a) Calderas and topographic depressions of southern Kyushu and northern Ryukyu Islands (Maeno and Taniguchi, 2007; Nagaoka, 1988) with location of subplots as boxes or arrows indicating view direction. Geography from U.S. Department of State, Office of the Geographer (2013). PlanetScope 3 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.

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). Previous research suggests that 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 recurving 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. As such, typhoons are expected to become larger (Sun et al., 2015, 2017), rainier (Ikema et al., 2010; Kitoh, 2017), and more north-recurving (e.g., Yang et al., 2020) due to anthropogenic climate change.

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., 2014; 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 decimeter-thick rhyolitic flows (Kawanabe and Saito, 2002). Residents also reported active fumaroles (volcanic gas vents) and small eruptions but with no recorded timings or further details (Kamada, 1964; Shinohara et al., 2002). Nonetheless, Iwodake gas discharge events were recorded in the 20th and 21st centuries, producing transient, fine, ash fall deposits that were observable only on smooth surfaces up to ten kilometers away (Kazahaya et al., 2014; Shinohara et al., 2002). Research has attributed this activity to Kikai Caldera magma and degassing, highlighting an interconnected magma conduit at depth (Saito et al., 2001) and activity for over 1000 years (Kawanabe and Saito, 2002; Shinohara et al., 2002).
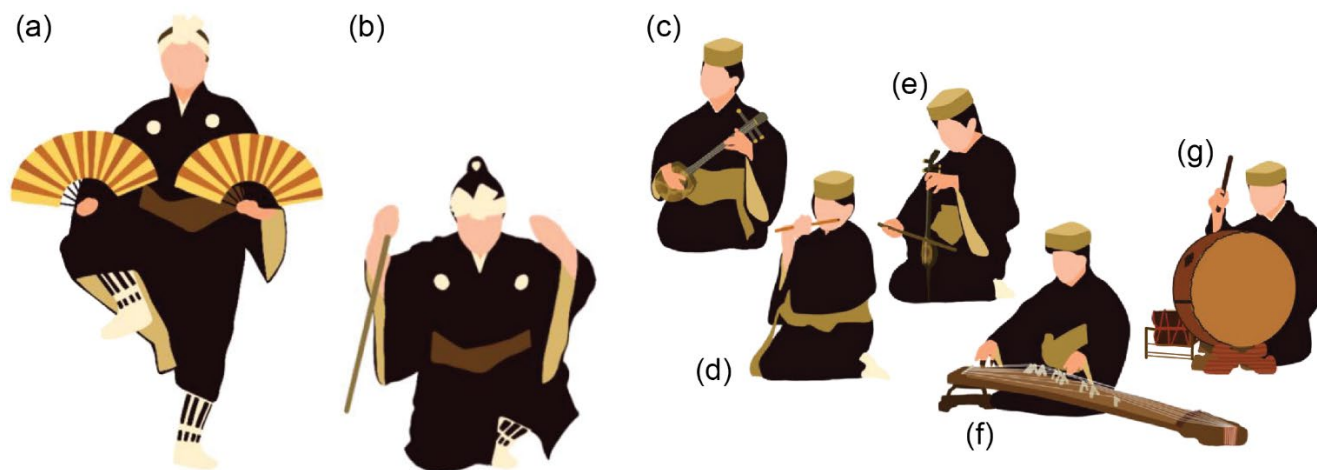
Figure 3: Illustrations of (a) Nubui Kuduchi and (b) Kudai Kuduchi dancers with (c) *uta sanshin*, (d) *fwansō*, (e) *kūchō*, (f) *kutū*, and (g) *tēku* musicians. Actual performances may have more than one dancer or musician per instrument, particularly for *uta sanshin*. Illustration by B. Kuhasubpasin.

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

2.3 Ryukyu Kingdom and culture

According to Sakiyama and Oshiro (1995), Ryukyuan classical music, or *Ryūkyū koten* (琉球古典), was developed for entertaining foreign nobility and ambassadors during visits to the Ryukyu Kingdom, which unified individual fiefdoms on Okinawa Island in 1429 CE. The kingdom expanded from Okinawa Island to surrounding island groups in the following 100 years. Cross-cultural exchange from foreign trade led to the influences of China, Japan, Korea, 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).

2.4 Nubui Kuduchi and Kudai Kuduchi

Nubui Kuduchi and Kudai Kuduchi are a pair of *Ryūkyū koten* songs composed during the Satsuma Domain's rule over the Ryukyu Kingdom. These songs are usually attributed to the *Ryūkyū koten* master Yakabi Chōki (屋嘉比朝寄; 1716–1775 CE; surname first following Japanese naming convention; Gillan, 2012; Kinjo, 1992). *Kuduchi* (口説) refers to a subgenre of

135 *Ryūkyū koten* with a distinctly Japanese, rather than Ryukyuan, seven-five beat structure (Kinjo, 1992). *Kuduchi* lyrics often tell a chronological story or describe a scene (Seki, 2024), where *nubui* (上り) refers to "climbing up" to Satsuma and *kudai* (下り) to "climbing down" to Okinawa Island (Kinjo, 1992; Seki, 2024). As such, these songs detail an envoy's 18th-century journey between the Ryukyu Kingdom and Satsuma Domain (Fig. 1).

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

140 were historically reserved for entertaining Satsuma Domain officials in the Ryukyu Kingdom. Dancers perform with a folding fan in each hand or a traveler's cane for Nubui Kuduchi or Kudai Kuduchi, respectively (Fig. 3a–b). This repertoire may be accompanied by *uta sanshin* (唄三線; vocals and a three-stringed lute; Fig. 3c), which leads *fwansō* (笛; bamboo 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 represent different aspects of the journey and have a relatively masculine connotation related to its brisk tempo, karate

145 influence, and the harrowing journey itself. In the 21st century, schools working to preserve the Ryukyuan arts often perform Nubui Kuduchi, Kudai Kuduchi, and other *Ryūkyū koten* songs at cultural events across Okinawa Prefecture (e.g., Hanashiro, 2007) and for the Okinawan diaspora worldwide (e.g., Miyashiro, 2018; Olsen, 1980, 1982; Sutton, 1983; Teruya, 2014; Ueunten, 1989).

3 Methods

150 First, we create English synopses of Nubui Kuduchi and Kudai Kuduchi. We utilize a version of both songs from the Afuso Ryū (安冨祖流) school of *Ryūkyū koten*, alongside interpretations from Kinjo (1992), Sakiyama and Oshiro (1995), and Seki (2024). Following best practices in Younging (2018), the authors here include *Ryūkyū koten* Master Instructors June Y. Uyeunten and Kenton A. Odo (hereafter J.Y. Uyeunten and K.A. Odo, respectively) with the Ryukyu Koten Afuso Ryu Ongaku Kenkyu Choichi Kai USA (hereafter Choichi Kai USA), serving the Okinawan diaspora in Hawai'i, USA. Both

155 authors provide access to oral and written information on Nubui Kuduchi and Kudai Kuduchi, including personal communications and interpretations from Clarence T. Nakasone (hereafter C.T. Nakasone; 1998) of the Hooge Ryu Hana Nuuzi no Kai Nakasone Dance Academy, also based in Hawai'i. In addition, the first author is an *uta sanshin* practitioner with the Choichi Kai USA at the time of publication. We provide supplementary videos with song lyrics, translations, and interpretations from the above sources with permission and production from J.Y. Uyeunten, K.A. Odo, and the

160 aforementioned dance academy (Higa et al., 2024a, b). We caution that these supplements are solely to provide references for lyrical synopses; we do not claim intellectual property for the lyrics themselves. These precautions are to ensure that

indigenous knowledge is properly attributed and utilized. 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). Lastly, we use the discussion to propose that these links are benchmarks for climate and geologic conditions across century

165 timescales. By connecting observations through time, we aim to showcase the utility of Ryukyuan indigenous knowledge for Earth science engagement, linking an ancestral art form with environmental issues facing Okinawans in the 21ˢᵗ century.

For the previous and following descriptions, we 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 when kana and kanji are not provided.

170 **4 Results**

4.1 Lyrical synopses

Based on Kinjo (1992), Sakiyama and Oshiro (1995), and Seki (2024), discussions with J.Y. Uyeunten and K.A. Odo of Choichi Kai USA, and personal communications with C.T. Nakasone, Nubui Kuduchi details the perilous journey from Okinawa Island to Kyushu. K.A. Odo describes how the word *nubui* also references the difficulty and anxiety of leaving

175 home as an upwards climb. The first four verses describe the envoy's foot journey from Shuri, the Ryukyu capital at the time these songs were composed, to the main port on Okinawa Island in Naha (Fig. 1). Along the way, voyagers pray at and pass by various Ryukyuan shrines and Buddhist temples for safe travels (Fig. 4a–b), noting people coming and going. In particular, families of the envoy shed tears due to the dangers at sea facing their loved ones. The fifth and sixth verses detail the start of the voyage when sails pick up winds from the south-southwest and the envoy travels out of Naha port, vowing to

180 someday return to the Miegusuku Fortress (Fig. 4c) and Cape Zampa on the west coast of Okinawa Island (Fig. 4d). Here, south-southwest is referred to as the direction of the Horse and Sheep, collectively assigned this cardinal direction from the Chinese Zodiac (Seki, 2024). In the seventh verse, the envoy encounters rough seas near Iheya Island, ~100 km from the port but only ~40 km from the north point of Okinawa Island. Looking out over a "route of many islands" (i.e., Amami Islands; Okinawa Prefectural Cultural Promotion Association, 2001), the envoy surveys the upcoming seven islands (i.e., Tokara

185 Islands in the Tokara Strait) that are often rough sailing and expresses hope for a peaceful transit. The last verse describes the final approach to Satsuma, wherein the envoy observes smoke from Satsuma-Iwojima (Fig. 2b). Of note, the version of this song from C.T. Nakasone describes the smoke as rising (*tachuru*; 立ちゆる), while the Choichi Kai USA version notes the smoke is burning or glowing (*moyuru*; 燃ゆる). Finally, the envoy sails past Cape Sata on southern Kyushu (Fig. 2a), where Kaimondake (Fig. 2c) and Sakurajima (Fig. 2d) come into view. The song ends with Sakurajima being hailed as mistakeable

190 for the iconic Mount Fuji.

Figure 4: Historical sites in Nubui Kuduchi and Kudai Kuduchi on Okinawa Island photographed from 2023–2024 CE. (a) Shuri Kannondo Buddhist temple in Shuri from first verse of Nubui Kuduchi and (b) Sogenji Buddhist temple ruins in Naha from second verse of Nubui Kuduchi where voyagers prayed for ocean safety. (c) View from Miegusuku Fortress in Naha from both
195 **songs, looking west out of Naha port where voyagers departed from and returned to Okinawa Island and (inset) atop fortress ruins. (d) Cape Zampa from both songs, looking west near where voyagers noted wind and ocean conditions. See locations in Fig. 1.**

Based on Sakiyama and Oshiro (1995) and Seki (2024), discussions with J.Y. Uyeunten and K.A. Odo, and personal communications with C.T. Nakasone, Kudai Kuduchi begins when envoy members are called to return to Okinawa Island from Satsuma around the ninth to tenth month of the lunar calendar (approximately September to October). Such

200 travels occur after the envoy transits from Satsuma to Edo and back, which is not recorded in this repertoire. As *kudai* refers to the act of climbing down, K.A. Odo notes the subtext of an easier, downhill, and more hopeful return home. Consequently, joyous celebrations, more prayers for safety, and Satsuma bureaucratic processes are described in the first to fifth verses. In the sixth to eighth verses, sails pick up north-northeasterly winds after passing Cape Sata, the rough seas of the Tokara Islands, the Amami Islands, and Iheya. North-northeast is referred to as the direction of the Rat and Ox zodiacs (Seki, 2024).

205 Here, the envoy is accompanied by friendly vessels when Cape Zampa comes back into view (Fig. 4d). The final verse describes arriving at the same port from which the envoy left, with crowds of people welcoming the voyagers back home.

4.2 Links to climate

We link the south-southwesterly winds described in Nubui Kuduchi with 20th–21st-century observations of climatological winds. Historical records and genealogies show the ~20 departures from Naha port occurred between the fifth and eighth

210 months of the lunar calendar (approximately May to August; Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984). 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 the envoys returning to Okinawa Island on early autumn north-northeasterly winds. Historical records show that envoys returned to Naha port between the eleventh and fourth month of the lunar calendar (approximately

215 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). Thus, the specific directions and seasonality of winds in Nubui Kuduchi and Kudai Kuduchi can be leveraged in a place-based framework to link the East Asian monsoon system with Ryukyuan history and culture.

Both songs also mention prayers for safe travels, showing that the envoy acknowledged the dangers of the

220 upcoming voyages. We link lyrical observations of potentially dangerous ocean conditions between Iheya and the Tokara Islands with three scientific points. First, 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). In fact, the timings of some journeys put envoys in the timeframe of the highest typhoon activity (July to September; Wu and Wang, 2004). Second, the region between Kyushu and

225 Taiwan has relatively high average and maximum wave heights compared to surrounding seas, in part because of the presence of typhoons (Wu et al., 2014; Young et al., 2011). Third, the Tokara Strait is where the Kuroshio Current crosses the Ryukyu Islands and reenters the Pacific Ocean (Fig. 1). Here, the envoy intersects the apex of the current (Gallagher et al., 2015), which is associated with comparatively high wave heights than farther away (Hwang, 2005). Interactions between the current and high-relief bathymetry, such as seamounts, are also thought to induce turbulence in the near-surface Tokara

230 Strait (Nagai et al., 2021; Tsutsumi et al., 2017). Therefore, Nubui Kuduchi and Kudai Kuduchi can be utilized to examine the impacts of typhoons, atmosphere-ocean coupling, and currents on Ryukyuan oceanic conditions.

4.3 Links to volcanism

Upon arrival in Satsuma, Nubui Kuduchi mentions Kaimondake and Sakurajima but likely only holds geologically interpretable observations of Satsuma-Iwojima (see Sect. 5.1 for Kaimondake and Sakurajima). Here, the envoy describes

235 Satsuma-Iwojima activity as a gas or ash plume from the summit of Iwodake. We link these lyrical observations to historical and scientific observations of active fumaroles. In fact, lyrics of burning or glowing smoke are similar to the discharge of hot and illuminated gases described in Shinohara et al. (2002). Therefore, 18th-century Nubui Kuduchi adds an intermediary observation of Iwodake activity between the 12th-century Heike Monogatari and 20th–21st-century scientific studies. Despite

sparse records from what are effectively three observations of volcanism through time, such activity has extensive impacts
240   on water quality by hydrothermal leaching (e.g., Kiyokawa et al., 2012) and air quality by sulfate aerosols (e.g., Itahashi et
al., 2019) locally and throughout the western Pacific. Combining lyrical observations with volcanology exemplifies how
indigenous knowledge from Nubui Kuduchi can highlight local eruptive histories and regional volcanic impacts across and
beyond the Ryukyu Islands.

5 Discussion

245   ### 5.1 Lyrics infer historical climate and volcanism

The seasonality of historical wind directions in Nubui Kuduchi and Kudai Kuduchi are similar to scientific observations up
to the 21st century, as seen by comparing the lyrics themselves, historical documents (Okinawa Prefectural Cultural
Promotion Association, 2001; Toby, 1984), and the modern monsoon (Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et
al., 1995). Therefore, this repertoire implies a reliance on predictable monsoonal winds, which facilitated ~20 envoys
250   (Okinawa Prefectural Cultural Promotion Association, 2001; Toby, 1984) that could be explored as historical climate
benchmarks. For example, genealogies suggest a 1791 CE envoy was required to wait in Satsuma between the fourth to tenth
lunar months of 1791 CE due to unfavorable winds earlier in the year (Okinawa Prefectural Cultural Promotion Association,
2001). These records could signify a failure of the East Asian Boreal summer monsoon that coincided with El Niños between
1788–1796 CE, known collectively as the Great El Niño (Cook et al., 2010; Grove, 2006; Quinn et al., 1987). Records show
255   that envoys did not resume until 1796–1797 CE near the end of this climate anomaly (Okinawa Prefectural Cultural
Promotion Association, 2001; Toby, 1984), but more historical analyses are required to assert that this envoy gap reflects a
monsoon failure. Nubui Kuduchi and Kudai Kuduchi then detail prayers and tears shed for the dangerous journey ahead (e.g.,
at locations in Fig. 4a–b). These actions may foreshadow typhoons, waves, and ocean currents in the 21st century.
Speculatively, Ryukyuan voyagers could have been indirectly praying for La Niña conditions associated with a lower
260   probability that typhoons will track towards the Ryukyu Islands (Ito et al., 2020; Sun et al., 2015, 2017; Wang and Chan,
2002; Wu and Wang, 2004; Yang et al., 2020). Likewise, the envoy may have recorded the impacts of typhoons (Wu et al.,
2014; Young et al., 2011) and the Kuroshio Current (Hwang, 2005; Nagai et al., 2021; Tsutsumi et al., 2017) on ocean
conditions in and around the Tokara Strait. As such, these songs provide a proof-of-concept for extracting historical climate
from *Ryūkyū koten* lyrics, which can be used to connect the cultural arts to science and education in the western Pacific.
265   Voyages north of Okinawa Island, where active volcanoes are located (Fig. 1), then offer a rare opportunity to
record volcanism in Ryukyuan songs. If Nubui Kuduchi describes average degassing across the composer's lifetime (1716–
1775 CE; Gillan, 2012; Kinjo, 1992) or the envoy's activity (1610–1872 CE; Okinawa Prefectural Cultural Promotion
Association, 2001; Toby, 1984), perhaps this song represents volcanic processes over ~60 or ~250 years, respectively.
Regardless, this volcanic benchmark from 18th-century Nubui Kuduchi bridges an ~800-year gap between the 12th-century
270   Heike Monogatari and 20th–21st-century studies at Satsuma-Iwojima and Kikai Caldera (e.g., Kawanabe and Saito, 2002;

Kazahaya et al., 2014; Saito et al., 2001; Shinohara et al., 2002). Such a gap may be in part because Satsuma-Iwojima's population was historically ignored and othered by Japanese society (Antoni, 1991). Thus, lyrical observations from the Ryukyu Kingdom can help scientists understand the continuity of volcanic activity on this island. For example, long-term degassing, as suggested by these historical records, agrees with evidence of over 1000 years of eruptive activity from

275 radiometrically dated Iwodake rocks (Kawanabe and Saito, 2002; Shinohara et al., 2002). These observations fit into a previously proposed model of a long-term, convecting, and stratified Satsuma-Iwojima magma chamber that feeds basaltic Inamuradake and rhyolitic Iwodake. Here, workers suggest that denser basalt magma may sit lower in the chamber to 1) supply the less dense rhyolite magma above with volatile gases that 2) cause this rhyolite to ascend in the Iwodake magma column and 3) induce surface degassing by decompression to 4) cause this magma to descend once degassed of buoyant

280 volatiles (Kazahaya et al., 2014; Saito et al., 2001; Shinohara et al., 2002). Therefore, Nubui Kuduchi can connect surface phenomena with supposedly long-lived and deep magmatic processes at Satsuma-Iwojima over ~800 years.

    Nubui Kuduchi also compares Sakurajima's geomorphology to that of Mount Fuji. However, the uneroded and single-peaked Kaimondake (Fig. 2c) is more similar to the conical Mount Fuji than Sakurajima (Fig. 2d–e; Fujino and Kobayashi, 1997). Historical records (Kobayashi and Tameike, 2002) from this well-populated area precludes that this

285 discrepancy signals that an eruption dramatically altered Sakurajima's shape into its current form. The lyrics described herein are likely a poetic interpretation of the first sight of this volcano. Alternatively, the north-south alignment of summit peaks (Fig. 2d) and the south-opening Kagoshima Bay suggest that arriving voyagers would see a more conical volcanic profile than if seen from the east or west (Fig. 2e). This geography may also lead to the generous interpretation of Sakurajima as mistakable for Mount Fuji.

290 **5.2 Future work for place-based *Ryūkyū koten***

Nubui Kuduchi and Kudai Kuduchi can be utilized in place-based engagement aimed at connecting 21st-century Okinawan students with their local environment, which follows previous efforts in Hawai'i and North America (e.g., Alexiades et al., 2021; Chinn et al., 2014; Gibson and Puniwai, 2006; Reano and Ridgway, 2015). For example, students may examine the East Asian monsoon system, ENSO, and their influences on observable wind patterns in the 21st-century Ryukyu Islands

295 (Dobby, 1945; Flohn, 1957; Fu et al., 1983; Ueda et al., 1995). Likewise, although not directly cited, the impacts of typhoons and the Kuroshio Current hinted at in both songs provide ancestral connections to the history of natural disasters (e.g., Ikema et al., 2010) and oceanic voyaging in Okinawa. Visiting the sites where voyagers acted upon their knowledge of dangerous wind and ocean conditions could also highlight meaningful, place-based connections between ancestors and contemporaries (Fig. 4; Semken et al., 2017). Critical thinking modules can then allow students to hypothesize how climate change may

300 modify Ryukyuan winds (e.g., Kitoh, 2017; Lu et al., 2007), typhoons (e.g., Ikema et al., 2010; Sun et 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 future. Farther outboard, Iwodake provides opportunities to teach how scientists observe volcanic plumes and measure their impacts on water and air quality (e.g., Itahashi et al., 2019; Kiyokawa et al., 2012). Thus, educators can engage 21st-century Okinawan students with

place-based science by highlighting a diversity of environmental benchmarks and ancestral connections in this repertoire of
305 *Ryūkyū koten*.

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 Earth science insights could be expanded by applying this framework to additional Ryukyuan songs. Here, island communities rely on springs for survival, transforming groundwater into a sacred resource (Takahashi, 2022). Likewise, popular songs such as Nuchibana (貫花) and Amakā
310 (天川) speak of rivers and water around Okinawa (Seki, 2024). Researchers then document traditional names of fishing areas that describe reef geobiology (Toguchi and Nishime, 2013), 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 sardine and cone snail species, respectively (Seki, 2024). These commonly performed songs (Hanashiro, 2007) may collectively link places with hydrological, biological, and geological phenomena to familiarize Okinawan populations with their local environment. Therefore, preserving and
315 compiling indigenous knowledge within Ryukyuan songs could be key for future place-based science engagement in the Ryukyu Islands.

5.3 Empowering Okinawan communities

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,
320 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
325 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).
330 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,
335 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 Hawaiʻi, Okinawans in Okinawa Prefecture, and the Native Hawaiian community facilitate cross-cultural exchange towards these cultural revitalization endeavors (Ohara and Slevin, 2019). Furthermore, the Hawaiʻi-Okinawa diaspora and those across the Americas (e.g., conterminous USA, Brazil, Peru) also work towards propagating

340 *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*

345 *koten*- and place-based pedagogy may help develop the global Ryukyuan indigenous movement.

5.4 Lessons for science engagement

It is important for this and any future research to credit indigenous practitioners, ensure rightful recognition, and present accurate interpretations. For example, many Ryukyuan songs that describe nature are steeped in metaphor, including that of human relationships (e.g., Karaya Bushi; 瓦屋節), political rebellion (e.g., Unna Bushi; 恩納節), and homesickness (e.g.,

350 Chijuyā; 浜千鳥; Sakiyama and Oshiro, 1995; Seki, 2024). These factors often make scientific interpretations difficult (e.g., Swanson, 2008) but can be overcome by continued engagement with indigenous elders and scholars (Younging, 2018), similar to how J.Y. Uyeunten and K.A. Odo guided interpretations of Nubui Kuduchi and Kudai Kuduchi (Sect. 4.1). Although it is challenging to compare observations from songs with those from contemporary science, the ability to experience the same conditions as sung therein can enhance hands-on and place-based science engagement in the 21st

355 century. Further collaborations with *Ryūkyū koten* leaders are required to interpret additional songs for this purpose (Sect. 5.2), with great potential for partnerships between cultural practitioners and scientists in environmental research.

Nonetheless, song-to-place connections have a healthy and contemporary appreciation across Okinawa Prefecture. For example, stone monuments to transformative *Ryūkyū koten* and folk songs, called *kahi* (歌碑), are often installed where songs have some lyrical or historical connection to a place; these sites may function as community centers, artistic venues,

360 and memorials to collective Okinawan experiences, such as World War II (Gillan, 2017). Building off these preexisting ideals that value the concept of place is vital for establishing culture's role in 21st-century science engagement (Lanza and Negrete, 2007). Such efforts have stimulated and will likely continue to stimulate novel research across Earth science disciplines, including climate science (e.g., Businger et al., 2018; Hinzman et al., 2005; Turner and Reid, 2022), volcanology (e.g., Nunn and Pastorizo, 2007; Swanson, 2008), and seismology (e.g., Hough, 2007; Ludwin et al., 2005). Likewise,

365 invoking history and geoheritage can help researchers protect scientifically and historically important geosites (e.g., Motta and Motta, 2007; Reano and Ridgway, 2015) and teach natural disaster preparedness (e.g., Bailey-Winiata et al., 2024; King and Goff, 2010). These efforts to relate familiar culture with complex research provide accessible narratives for more

effective science communication (Lanza and Negrete, 2007), solidifying indigenous knowledge and place-based science as key for environmental science engagement and education.

6 Conclusions

Ryūkyū koten contains historical observations of the natural world that describe atmospheric, oceanic, and geologic processes. Here, we demonstrate how Nubui Kuduchi and Kudai Kuduchi hold 18th-century descriptions of winds, currents, typhoons, and volcanoes in the western Pacific Ryukyu Islands. Through collaborations with cultural practitioners, these observations can be explored as climate and geology benchmarks to study and teach Earth systems. Such benchmarks are likely useful for contextualizing environmental phenomena from past to present, such as the impacts of anthropogenic climate change. Researchers and educators can apply these lessons to place-based science modules centered on science engagement, cultural revitalization, and the climate and geology issues facing 21st-century Okinawa Prefecture. Thus, documentation of this performing arts tradition is scientifically and pedagogically valuable and could reveal more environmental lessons from the Ryukyu Islands.

Data availability

Data produced for this project consists of two video supplements of Nubui Kuduchi and Kudai Kuduchi (Higa et al., 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

All authors are members of the Ryukyu Koten Afuso Ryu Ongaku Kenkyu Choichi Kai USA, Hawai'i Chapter. KAO and
395   JYU are Master Instructors within this organization and permit the publication of these works with their expert discussion.
JTH has obtained verbal permission from the founder of this organization, G.S. Murata, to continue with this work and from
leaders of the Hooge Ryu Hana Nuuzi no Kai Nakasone Dance Academy, J. Okamura and L. Nakandakari, to adapt
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