S. A. Andrée's understanding of Arctic ice drift during his 1897 balloon expedition

Citation for the original published paper (version of record):

Lantz, B. (2023). S. A. Andrée's understanding of Arctic ice drift during his 1897 balloon expedition. Polar Record, 59(7501). http://dx.doi.org/10.1017/S0032247423000219

Polar Record

www.cambridge.org/pol

S. A. Andrée's understanding of Arctic ice drift during his 1897 balloon expedition

Björn Lantz

Technology Management and Economics, Chalmers University of Technology, Gothenburg, Sweden

Research Article

Cite this article: Lantz B. S. A. Andrée's understanding of Arctic ice drift during his 1897 balloon expedition. *Polar Record* **59**(e26): 1–17. https://doi.org/10.1017/S0032247423000219

Received: 17 April 2023
Revised: 2 August 2023
Accepted: 7 August 2023

Keywords:
Andrée expedition; Cape Flora; Arctic ice drift; Coriolis effect

Corresponding author: Björn Lantz;
Email: bjorn.lantz@chalmers.se

Abstract

The tragic Andrée balloon expedition of 1897 serves as a haunting reminder of the dangers posed by ice drift during polar exploration. This paper examines Andrée's initial decision after his balloon flight to march towards Cape Flora in Franz Josef Land, despite its much greater distance compared to the Sjuøyane archipelago. The rationale behind this choice remains unclear, but potential factors include stored supplies, the demonstrated winter survival in Franz Josef Land and the scientific interest in unexplored regions. By analysing historical accounts and employing scenario analyses, this study contributes to a better understanding of Andrée's perception of ice drift and its impact on their ill-fated journey. The paper explores major forces affecting ice drift, reviews the historical development of understanding ice drift in the area, and presents an analysis of Andrée's understanding and decision-making. The overall conclusion is that Andrée probably was unaware of the substantial deflection to the right of the direction of the wind that ice drift in the Arctic on average is characterised of due to the Earth's rotation (the Coriolis effect). Without this deflection, the decision to march towards Cape Flora would have made sense under the assumption of continued northerly winds.

Introduction

During the late 19th and early 20th centuries, embarking on journeys towards the high latitudes of the Arctic posed immense challenges and risks. Among the numerous perils faced by brave adventurers, ice drift emerged as a particularly problematic and sometimes fatal issue. Expeditions such as Robert Peary's 1905–1906 North Pole attempt, which experienced an approximately 130 km eastward drift on an ice floe slightly north of 85°N during six days of westerly gales that impeded progress (Henderson, 2005), exemplify the treacherous nature of Arctic exploration as they encountered formidable difficulties caused by ice drift. Similarly, during other notable Arctic expeditions of the time, such as the Italian Arctic expedition of 1899–1900 led by Luigi Amedeo di Savoia (Duke of the Abruzzi), the ice drift directly resulted in the loss of expedition members (Lantz, 2021). These expeditions serve as haunting reminders of the tragic consequences that explorers could face when confronted with the merciless grip of ice drift. They not only underscore the inherent dangers and complexities of Arctic exploration but also emphasise the critical importance of comprehending and analysing ice drift as a pivotal aspect of these historic endeavors.

One contemporary expedition where the ice drift was the indirect cause of death of its members was the Andrée balloon expedition. In 1897, Salomon August Andrée, along with his companions Nils Strindberg and Knut Frænkel, departed from Danskøya (Danes Island) in northwestern Svalbard in the hydrogen balloon *Örnen* with the aim of reaching the North Pole (Andrée, Strindberg, & Frænkel, 1931, p.54). After going missing for 33 years, their remains and sledging equipment were discovered by chance on Kvitøya (White Island), the desolate island that constitutes the easternmost part of Svalbard, in 1930 by a combined sealing and research expedition that had visited Kvitøya to hunt walrus and to do some exploring (Andrée et al., 1931, p.252). Their diary notes documenting their balloon journey from Danskøya to 82°56'N 29°52'E and the subsequent attempted retreat over the ice back to civilisation were also recovered. The diaries revealed that their initial plan after the balloon journey was to reach Cape Flora in the Franz Josef Land archipelago (Andrée et al., 1931, p.125), but they abandoned that attempt after a few weeks and instead turned southwest towards the Sjuøyane (Seven Islands) archipelago north of the Svalbard mainland (Andrée et al., 1931, p.147). After another two months on the ice without being able to reach land, the men went ashore on Kvitøya where they seemingly all perished in a brief period of time.

After the diaries had been analysed more thoroughly, it became evident that the ice drift was the main obstacle that prevented Andrée from reaching Cape Flora or northern Svalbard after the balloon journey (Lantz, 2019b). Research has suggested that Andrée and his men could have survived if they had chosen to march directly towards Svalbard – in the same direction as the expected ice drift – instead of first attempting a march towards Franz Josef Land (Lantz, 2018). On the face of it, it seems puzzling that they attempted a march in another direction than the

CAMBRIDGE UNIVERSITY PRESS

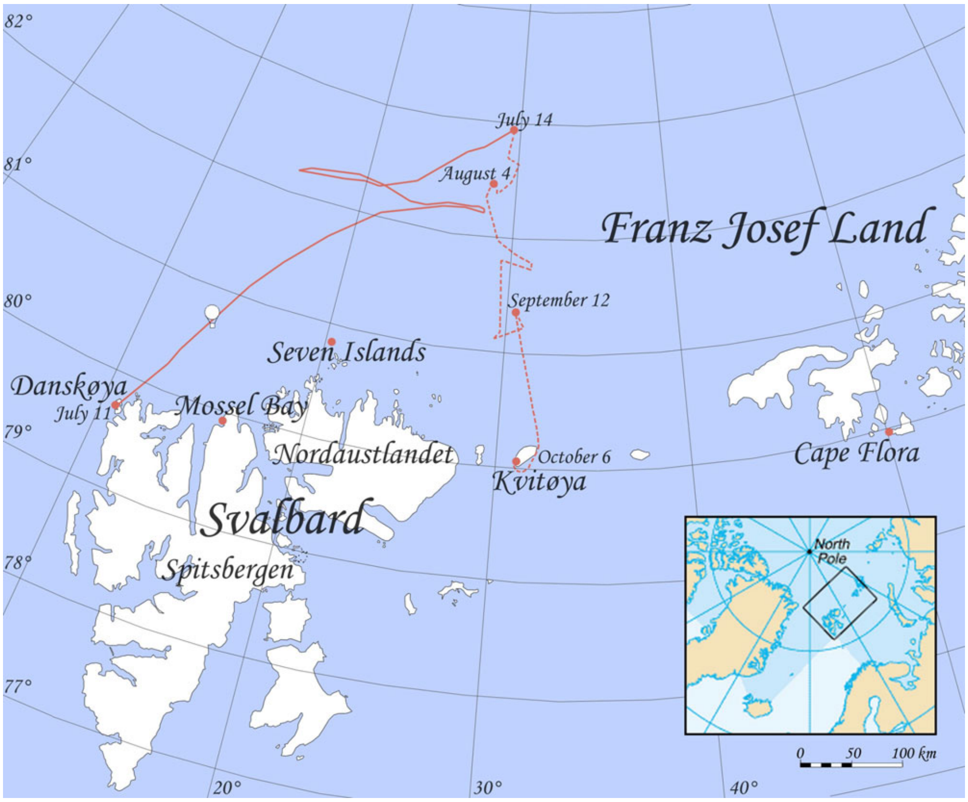

Figure 1. Map depicting the route of the Andrée expedition. The map was created by Johan Eliasson and is published under the terms of the GNU Free Documentation License.

general direction of the ice drift, even considering that Frederick Jackson's camp at Cape Flora was the location in the area that offered the best chances to survive the upcoming polar winter. It does not matter how good a destination might be, if it is impossible to reach it.

Figure 1 displays the flight path from 11 July to 14 July (solid line), the subsequent attempted retreat route (dashed line) and the key locations mentioned above. It also highlights the crucial decision points during the attempted retreat. On 4 August, Andrée and his team chose to abandon their initial attempt to reach Cape Flora and instead march towards Svalbard. On 12 September, they made the decision to completely halt the march and construct a hut on the ice floe they were residing on, with the intention to passively drift further south with it. In early October, finally, the ice floe disintegrated, forcing the men to relocate all their supplies and equipment to Kvitøya – the location where they all perished.

Andrée's tentative plan before the expedition, if he had to land the balloon somewhere on the Arctic pack ice, would be to march towards the nearest land (Svedenborg, 1922, p.59). In his diary, Andrée wrote on 15 July, the day after the landing on 82°56'N 29° 52'E, that a decision had been made to begin a march, although he did not state the conceived destination for that march (Andrée, Strindberg, & Frænkel, 1930, p.397). Given the fact that Andrée and his men had decided that a march (i.e. towards land) would be a better option than to remain on the ice floe where they had landed and drift passively with it, there were only two realistic directions in which they could march: towards Rossøya (Ross Island) in the Sjuøyane archipelago in the southwest or towards Cape Flora in the Franz Josef Land archipelago in the southeast.

Rossøya is an almost circular and small (just over 300 m in diameter) island located on 80°49.5'N 20°20'E and is the northernmost island in the Sjuøyane archipelago (Barr, 2020). It was the nearest known land from where Andrée and his men had landed with the balloon, and it was also the tentative location for a small emergency depot of supplies that was scheduled to be laid out as far to the north as possible in the Sjuøyane shortly after Andrée's departure (Andrée, 1906). Furthermore, slightly further away in the same general direction was Adolf Erik Nordenskiöld's hut from his 1872 to 1873 expedition, located on northeastern Spitsbergen just off Mosselbukta (Mossel Bay). It would have been possible for Andrée and his men to spend the winter there (Meisenbach, 1898).

Cape Flora is often seen as the southwestern tip of Northbrook Island in Franz Josef Land, although it is in fact located on 79°57'N 50°05'E on a much smaller island off the western end of Northbrook Island and separated from it by a narrow strait (Barr, 2015). It was the base location for Frederick Jackson's contemporary Arctic expedition (Jackson, 1899). Andrée had sent supplies to Cape Flora with Jackson's ship *Windward* intended for a depot there (To Bring Jackson Back, 1897), so we know that it was a location that Andrée assumed could be of interest for him. In addition, Jackson and his men were still at Cape Flora at the time Andrée departed in his balloon – a fact that Andrée was well aware of. Beside the depot, Cape Flora also featured several huts and other types of infrastructure related to Jackson's expedition that could help Andrée and his men to survive the winter (Jackson, 1899).

The distances from 82°56'N 29°52'E to the respective potential destination would have been relatively easy for mathematically proficient persons such as Andrée, Strindberg and Frænkel (all of them held university degrees in physics or engineering) to calculate based on spherical trigonometry (see Todhunter, 1886). With such methods, one can show that the exact distance from the point where they had landed with the balloon to Rossøya was 277 km, and that the exact distance to Cape Flora was 466 km. In other words, to reach the depot at Cape Flora, they would have to travel more than 2/3 longer. Even crude approximations of the distances based on the most up-to-date map of the area that Andrée had brought (Bartholomew, 1897) would suffice to show that Cape Flora was much further away.

Despite the much longer distance to Cape Flora, Andrée and his men still seem to have considered it the logical destination for the march, at least initially. We do not know whether Andrée and his men discussed their options, and if they did, how they perceived the advantages and disadvantages of each option, before they decided that the march would be towards Cape Flora, because there is literally no information at all in the diary material on the rationale behind that decision. Of course, this entire lack of written arguments might be seen as an indication that Andrée and his men simply thought that Cape Flora was such an obvious option that it simply went without saying that they should march in that direction, despite the circumstances. This view is indirectly supported by Andrée himself, who, after an astronomical observation of their position on 31 July, claimed that "... we have driven westwards quicker than we have walked eastwards. This is not encouraging but we shall continue our course to the east some time more, as long as there is a bit of sense in doing so." (Andrée et al., 1931, p.363).

A number of hypothetical rationalisations regarding the decision to march towards Cape Flora can be found in the literature. For example, Hans W:son Ahlman, who wrote the initial narrative based on the discoveries on Kvitøya (Andrée et al., 1930), speculated that a march towards Cape Flora was the best alternative for three reasons: the large quantities of supplies that had been stored there for them, the fact that Nansen had shown that Franz Josef Land was an area where it was possible to survive a polar winter, and that Franz Josef Land still was largely unexplored and therefore would be of scientific interest (Andrée et al., 1931, p.125f). Another example is Lantz (2019a), who argued that Andrée probably thought that the Sjuøyane depot never would be laid down (although it was; see Meisenbach, 1898) because of the difficult ice conditions in the area and that he therefore perceived that he only had one viable option – Cape Flora. However, Sundman (1968, p.228) underlines that we cannot be sure about Andrée's rationales for choosing Cape Flora as the initial target, because neither diary revealed anything about that. As mentioned above, there is literally no information at all in the material that was found on Kvitøya on why they initially considered Cape Flora the natural destination for a march.

A crucial aspect of Andrée's planned march towards Cape Flora is that Cape Flora is located in an almost due southeasterly direction from where Andrée and his men had landed with the balloon, yet they marched over the ice in a due easterly direction for almost the entire duration they tried to reach that destination (Sverdrup, 1931). The only reasonable explanation for this is that Andrée assumed that the ice would drift in a general southerly direction and that the marching and the drifting distances per day were similar, since that would make the resultant movement over ground approximately southeasterly. This raises the question how much Andrée actually knew and understood about the ice drift that eventually would be the indirect reason why he and his men lost their lives.

In this paper, a scientifically based proposition is put forward regarding why Andrée and his men initially were convinced that Cape Flora was the natural destination for a march over the ice. In short, the available evidence suggests that, although Andrée evidently was aware of the long-term ice drift pattern in the area where he had landed, as well as of the fact that it was the wind that primarily propelled the ice drift in the short term, he was probably unaware of the substantial deflection to the right of the direction of the wind that ice drift in the Arctic on average is characterised of due to the Earth's rotation (the Coriolis effect). Without this deflection angle, which had been observed and documented earlier, a continuation of the approximately north-northwesterly winds of moderate strength that he had experienced during the first week after the balloon flight, the ice pack would have been pushed approximately towards the south-southeast, and daily marches of a realistic average length in a due easterly direction over the ice would then generate a resultant movement for the expedition towards Cape Flora at a higher speed than the men could march. But when one takes the deflection angle into account, it becomes clear that the ice drift most likely would be their expected foe rather than their expected friend during a march towards Cape Flora. Thus, inference to the best explanation suggests that Andrée and his men were unaware of the deflection angle.

The remainder of the paper is structured as follows. First, we will cover the major forces that provide theoretical explanations for ice drift. Then, we will review the historical development of the understanding of Arctic ice drift in practice in the relevant area up until the Andrée expedition. Next, a scenario analysis of the resultant movement during Andrée's initial march over the ice in a due easterly direction under different assumed alternative wind speeds, wind directions, deflection angles and marching speeds will be presented. Finally, we will provide an analysis of Andrée's probable understanding of the Arctic ice drift and a conclusion of the paper.

Ice drift in theory

Sea ice is influenced by four major forces that provide theoretical explanations for its movement: air stress, water stress, internal friction and the Coriolis effect (Leppäranta, 2011). Each force plays a significant role in determining the direction and speed of ice drift. When combined, these forces create the complex and dynamic patterns observed in sea ice movement.

Air stress is the force exerted by the wind on the surface of the ice. Wind interacts with the ice, generating pressure that causes it to move with the prevailing wind. The magnitude of the wind stress depends on factors such as wind speed, duration, ice roughness and flexibility. Generally, stronger winds result in higher stress levels, leading to faster ice drift. However, the relationship between wind speed and ice drift speed can also be influenced by other factors like ice concentration and thickness (Kohout, Williams, Dean, & Meylan, 2014; Leppäranta, 2011).

Water stress, on the other hand, refers to the force exerted by ocean currents on the underside of the ice. These currents apply pressure to the ice, influencing its movement by pushing it in specific directions. Similar to air stress, the magnitude of water stress depends on the speed and characteristics of the ocean currents. Strong currents can cause the ice to move more rapidly, while weaker currents have a lesser effect. The interplay between wind stress and water stress is essential in determining the overall direction of ice drift (Leppäranta, 2011).

Internal friction arises from the resistance and deformation within the ice itself. It is a result of various factors, including ice thickness, composition and internal stresses. Internal friction can counteract or modify the effects of external forces such as wind and water stress. Irregularities in the ice, such as cracks and ridges, can contribute to increased internal friction, which can cause deviations from the expected drift trajectory and impact the movement and speed of the ice (Leppäranta, 2011).

The Coriolis effect is a direct consequence of the Earth's rotation. As the ice moves, the Coriolis effect deflects its path to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, and the effect becomes stronger for higher latitudes. This deflection occurs due to the rotation of the Earth, which imparts a deflecting force on moving objects. The Coriolis effect interacts with the other forces to determine the actual path taken by the ice. It plays a crucial role in shaping the overall direction of ice drift, particularly on larger scales (Leppäranta, 2011).

In combination, these four forces work together to create the intricate and dynamic movement of sea ice. Air stress and water stress provide the primary external forces that propel the ice, while internal friction within the ice can modify and even counteract these forces. The Coriolis effect further influences the ice's direction, combining with other forces to determine its ultimate path. Thus, the interplay of air stress, water stress, internal friction and the Coriolis effect shapes the movement of sea ice in polar regions. Understanding these forces is crucial for accurately modelling and predicting sea ice drift (Leppäranta, 2011).

Arctic ice drift in practice

An old practical rule of thumb (see, e.g. Thorndike & Colony, 1982) is that sea ice in the Arctic moves with a speed of about 2% of the surface wind (hereafter called *the wind factor*) in a direction of up to 45° to the right of the wind (hereafter called *the deflection angle*). However, one must keep in mind that this is merely a rule of thumb, and also a rather unreliable one. The wind factor and the deflection angle have both been shown in empirical studies to vary substantially depending on factors such as location, ice conditions and season (Leppäranta, 2011; Sinsabvarodom, Chai, Leira, Høyland, & Næss, 2022), and it is not difficult to understand why given the previously discussed theoretical aspects. For example, the Coriolis effect that creates the deviation from the direction of the wind becomes stronger with higher latitudes; hence, one generally finds larger deviation angles at locations closer to the North Pole (Leppäranta, 2011). In addition, coastlines act as physical barriers, obstructing the movement of ice and altering the wind–ice interaction. Yet another example is that wind resistance increases in dense ice, resulting in a non-linear relationship between wind speed and ice drift; higher wind speeds have diminishing returns on ice drift due to the greater resistance (Leppäranta, 2011). There is also a strong seasonal cycle in both the wind factor and the deflection angle due to natural variation in the internal friction in the ice (Sinsabvarodom et al., 2022; Sverdrup, 1928).

Naturally, we understand much more today about ice drift and the factors that determine it (for a recent brief review of this literature, see de Vos, Kountouris, Rabenstein, Shears, Suhrhoff & Katlein, 2023) than what Andrée and his contemporaries knew. For the purpose of this study, however, it is primarily the state of the knowledge at the time of the Andrée expedition that is of relevance. Hence, this section reviews the literature on this topic until 1897 from two different perspectives, namely (1) the general large-scale ice drift patterns in the vicinity of Svalbard and Franz Josef Land, and (2) the short-term relationship between the wind and the ice drift, that is, the wind factor and the deflection angle.

Large-scale ice drift patterns

The major physical obstacle for the early explorers attempting to reach a high northern latitude or to find a passage through the Arctic from Europe to the Bering Strait northwest passage or a northeast passage was the ice. Its pure existence blocked the progress of ships, and, furthermore, when ships were caught in the ice or when sledging journeys over the ice were attempted, the drifting ice often moved the expeditions in undesirable directions. As several of the early explorers before Andrée had documented, the Arctic pack ice is subject to drift. Nowadays, we know for a fact that the Arctic ice drift pattern has two primary components (Macdonald, Harner, & Fyfe, 2005). Firstly, there is a clockwise circulation (viewing from above the North Pole) called the Beaufort Gyre in the Beaufort Sea north of Alaska. Secondly, there is a direct movement – the Transpolar Drift (TPD) – from the Laptev Sea north of Siberia across the Eurasian Basin, primarily exiting into the North Atlantic between Svalbard and Greenland. The average speed of these components and their typical variation patterns over the season are also well-known factors today (Macdonald et al., 2005). For the purpose of this study, it is primarily the TPD that is of interest.

The earliest indirect evidence (findings of objects with a very distant origin compared to where they were found, implying that they must have drifted a long way to their destination with either a sea current or in the pack ice) of the TPD was probably documented by Constantine John Phipps during his 1773 Arctic expedition. While making observations in the northwestern part of the Svalbard archipelago, Phipps noted in his journal that "The driftwood in these seas has given rise to various opinions and conjectures, both as to its nature and the place of its growth. All that which we saw (except the pipe-staves taken notice of by Doctor Irving on the Low Island) was fir, and not worm-eaten. The place of its growth I had no opportunity of ascertaining." (Phipps, 1774, p.71). No trees grow on Svalbard, so Phipps' confusion regarding the driftwood is understandable.

A major contribution related to the understanding of the driftwood that could be seen on Svalbard was made by Adolf Erik Nordenskiöld, who brought back samples of it to Sweden after his 1872–1873 expedition to Svalbard. The narrative from Nordenskiöld's expedition refers to Jacob Georg Agardh, a Swedish professor of Botany, who had done a thorough analysis of the driftwood samples, with the result that its main source was northern Siberia (Leslie, 1879). Even though Agardh himself was very confident about the origin of the driftwood, he never discussed ice drift in his research; he only assumed that most of the pieces of wood that could be found along the northern shores of Svalbard were conveyed out in the Kara Sea through the Ob River and then transported to Svalbard by some sea current (Agardh, 1869, pp.113–114). But since there was no empirically known sea current at the time that could explain why so much Siberian driftwood ended up north of Svalbard, Nordenskiöld was probably confused. Now we know the process, where driftwood is carried from Siberia to the northern shores of Svalbard by way of the TPD, in or on the ice, much more in detail (Häggblom, 1982; Linderholm, Gunnarson, Fuentes, Büntgen, & Hormes, 2021).

More specific indirect evidence of the TPD was obtained in June 1884. Debris that evidently originated from *Jeannette* was found on an ice floe near Julianehåb, near the south-western corner of Greenland (Lytzen, 1885). *Jeannette* was an expedition ship under George W. De Long which had sailed through Bering Strait and continued northwards in 1879 where it was caught by the drifting pack ice. It was eventually crushed in 1881 just northwest of the New Siberian Islands between the Laptev Sea and the East Siberian Sea (De Long, 1884). The debris included signed documents and garments with name tags, so we know for a fact that the source was *Jeannette*. The only realistic explanation for the discovery was that the items had drifted on the ice across the Arctic Ocean from the east to the west. Hence, it constituted proof of the existence of a westerly ice drift across the Eurasian Basin.

Yet another piece of indirect evidence of the TPD was obtained by Fridtjof Nansen during his Greenland expedition in 1888, where he had collected samples of dust and mud from the ice between Iceland and Greenland. The samples were later examined by the Swedish geologist Alfred E. Törnebohm (Nansen, 1893, p.10), who concluded that their origin must be northern Siberia, and that the material most likely had been carried out to the sea by the great Siberian rivers before if got frozen into the ice that seemed to drift across the Eurasian Basin.

Many Arctic seafarers and explorers had experienced the drifting Arctic ice first-hand in different ways throughout the 19th century before the Andrée expedition. The first one to publish some empirical insights on the topic that related to TPD was probably the whaler and explorer William Scoresby, who, after having sailed north of Svalbard in his ship *Resolution*, wrote that "When speaking of the currents of the Spitzbergen Sea, I remarked, that the polar-ice, in this situation, has a constant tendency to drift to the south-westward" (Scoresby, 1820, pp.290–291). He also noted that " . . . in less than a fortnight, while at rest with regard to the ice, our drift, as ascertained by astronomical observations, had been 60 or 70 miles to the south, and a distance nearly as great to the west" (Scoresby, 1820, p.296).

The first reasonably realistic attempt to reach the North Pole over the ice that was not an abject failure was made in 1827 by William Edward Parry, who was a very experienced polar explorer after his three previous attempts to find a northwest passage. In his pursuit of exploration, Parry used his ship HMS *Hecla* to establish multiple depots in the Sjuøyane Archipelago (Parry, 1828). The ship was subsequently anchored in Sorgfjorden (Treurenberg Bay), located at the northern coast of Spitsbergen. Parry and his party, consisting of three officers and 24 men, then utilised two "boat-sledges," *Enterprise*, commanded by Parry himself, and *Endeavour*, commanded by James Clark Ross, to sail to the ice edge north of the Sjuøyane and continue their journey northward over the ice. The "boat-sledges" were essentially lifeboats that had been fitted with sledge-runners, enabling them to function as boats in water and sledges on ice. However, despite the clever construction, the boats' heavy weight hindered Parry's ability to carry enough food and fuel, ultimately compelling him to turn back south after reaching 82°45'N – the furthest point north that a human had ever traversed at that time.

Parry (1828) faced a significant obstacle during his pursuit of further exploration northwards over the ice – the ice drift. He frequently complained in his expedition account about the apparent southward movement of the ice, which he observed on many evenings after a gruelling day's march. Parry noted many times in his narrative that he found himself south of the expected latitude, based on dead reckoning, particularly when he approached his farthest north point on 23 July, approximately 82°45'N (Parry, 1828). Additionally, he made explicit mention of the westerly component of the ice drift, remarking that during his return southwards, several degrees of longitude west of where he had been at the same latitude during his outward journey, he observed his own old tracks (Parry, 1828, p.107). Consequently, Parry conducted the first comprehensive observations of the ice drift in the region, concluding that its general direction seemed to be about southwest or south-southwest – in line with Scoresby's observations a few years earlier.

An additional contribution to the empirical record regarding the Arctic ice drift in the vicinity of Svalbard and Franz Josef Land was made by the Austro-Hungarian Polar Expedition of 1872–1874, jointly led by Julius Payer and Karl Weyprecht. While the expedition aimed to find a northeast passage from west to east for a ship north of Siberia, this goal was not realised. Nevertheless, Payer and Weyprecht made a significant discovery by becoming the first to officially document Franz Josef Land after being caught in the ice north of Novaya Zemlya with their ship *Tegetthoff* (Payer, 1876). The meandering path of the ship's erratic drift, which spanned over a year and took it from Novaya Zemlya to Franz Josef Land, initially went towards the northeast before veering westwards and then northwards. After having explored Franz Josef Land via sledging over the sea ice all the way up to Cape Fligely on Rudolf Island, the northernmost island in the Franz Josef Land archipelago, Payer and Weyprecht abandoned the ship and returned southwards over the ice using sledges.

Yet another major contribution to the body of direct empirical evidence related to the TPD was generated by the aforementioned 1879 *Jeannette* expedition under George W. De Long. Instead of being able to voyage unobstructed towards the North Pole via the Bering Strait, *Jeannette* was caught firmly in the ice northeast of Wrangel Island (De Long, 1884, pp.116–119). She was never released but drifted helplessly and erratically with the ice for almost two years before she finally was crushed and sank on 12 June 1881 after having been transported about 1,000 km in an approximate northwesterly direction along a route which is very reasonable given what we know today about TPD (De Long, 1884, p.578). The entire crew of 33 men were able to take refuge on the ice after having saved several boats, sledges and a supply of freshwater and provisions; however, only 13 of the men were able to return alive to the United States. The remainder, including De Long himself, perished of starvation and other hardships during the sledge and boat journey back to civilisation. In addition, as mentioned above, various forms of debris from *Jeannette* were found on Greenland a few years after *Jeannette* was crushed and sank, providing indirect evidence of an ice drift across the Arctic Ocean from the east to the west.

The last and the most significant contributor to the understanding of the TPD before the 1897 Andrée expedition was Fridtjof Nansen on his *Fram* expedition 1893–1896. Nansen was a seasoned polar explorer who led an expedition in 1888 that achieved the first crossing of the Greenland interior (Nansen, 1890). The farthest north record before the *Fram* expedition was set by Lieutenant James B. Lockwood in 1882 at 83°24'N during the Lady Franklin Bay expedition of 1881–1884, commanded by Adolphus W. Greely (Greely, 1886). However, this record was not based on a journey across the Arctic pack ice, but along the northwest Greenland coastline. Nansen, who wanted to reach the North Pole rather than improve the record by a small margin, realised that he needed an innovative approach to expedition logistics, and he certainly had one. Through a comprehensive analysis of empirical evidence (Nansen, 1893), in particular regarding the debris originating from the *Jeannette* expedition and *Jeannette's* drift before it was crushed, Nansen arrived at the conclusion that there must exist an uninterrupted flow of Arctic ice from the Siberian Arctic Sea to the eastern coast of Greenland, travelling between the North Pole and Franz Josef Land. This conviction led him to commission the construction of a ship – *Fram* – that was specifically designed to endure the pressures exerted by the ice, with the intention of deliberately freezing the vessel into the pack ice of the Siberian Arctic Sea, and allowing it to drift across the polar basin over or in proximity of the North Pole, eventually breaking free of the ice some years later at a point north or west of Svalbard (Nansen, 1898).

In 1893, Nansen and his crew departed aboard *Fram*, sailed it to the Laptev Sea, and let the ship become stuck in the ice as planned. However, after 18 months of drifting passively in the ice, he grew restless, recognising that the drift would not transport the ship sufficiently close to the North Pole. Consequently, Nansen and his comrade, Hjalmar Johansen, left the ship, with the intention of skiing and dog-sledging across the ice to reach the pole. After attaining the northernmost record of 86°14'N, they had to abandon their efforts, owing to horrible ice conditions, and return southwards. As they knew they would be unable to locate *Fram*, they opted to proceed towards the nearest known land, Cape Fligely, the northernmost point of Franz Josef Land discovered by Payer two decades earlier (Nansen, 1898, p.170). After having reached Franz Josef Land, they were compelled to spend the winter in an improvised hut at Cape Norway on Jackson Island before resuming their journey southwards (Nansen, 1898, p.488). Meanwhile, *Fram* continued to drift as per plan (i.e. along the TPD) and was eventually released from the ice on 13 August, just north of Svalbard (Nansen, 1898, p.700).

It could be noted that many, if not most, people in the highly diverse polar community at this time did not believe in the idea of a long-term westerly drift pattern in line with the TPD, at least not until Nansen returned from his *Fram* expedition. For example, Albert Hastings Markham, rear admiral, and an accomplished polar explorer himself, stated during his lecture at the Sixth International Geographical Congress held in London in late July 1895, that "My own view regarding the direction of the currents in Arctic seas is that they have an unmistakable southern tendency, and that this southern drift is caused by the outflow from the polar basin due to the periodical thawing during the summer months of the enormous quantities of snow and ice that accumulate during the long winters in the neighbourhood of the North Pole, and which must necessarily seek an outlet to the south." (Keltie & Mill, 1896, p.189). Markham (like many others) also believed, at that time, that the Arctic ice drift primarily was a result of currents rather than being propelled by the wind. For example, regarding the drift of *Tegetthoff*, Markham stated during his lecture at the Sixth International Geographical Congress that "... some of this drift may be attributable to the wind, but the real movement was assuredly due to the influence of current alone" (Keltie & Mill, 1896, p.181). However, Nansen's return in 1896 probably sparked a change in the general understanding of the Arctic ice drift among these people.

Short-term ice drift

The first documented observation regarding the short-term relationship between the wind and the ice drift was probably made by Payer and Weyprecht during the Austro-Hungarian Polar Expedition of 1872–1874. Payer noted in his main expedition narrative (e.g. Payer, 1876, pp.236, 267) that the wind appeared to be the main cause of the ice drift. Weyprecht (1875) also concluded correctly that the main determinant of the ice drift seemed to be the wind, although he also noted the fact that the ice consistently drifted in a direction up to 45° to the right of the direction of the wind. Weyprecht was unable to provide a scientific explanation of this phenomenon:

> "I must here draw attention to a curious fact. I have above referred to the influence of the wind upon the ice. We have observed the strange fact that ice never drifts exactly in the direction of the wind, but always to windward. Thus, a north-east wind drifted us towards the north [sic] instead of to the south-west; a south-west wind to the east, instead of north-east; and a north-west wind to the south, instead of south-west. This took place without a single exception whenever there was wind. I am not able to explain this phenomenon from ocean-currents, or from deflection produced by the neighbourhood of the coast, as the operation of these would cause contrary winds to produce a contrary deflection." (Weyprecht, 1875, p.29)

The wind and drift data from the Austro-Hungarian Polar Expedition were further analysed by Wüllerstorf-Urbair (1878), who discussed the discrepancy in direction between the wind and the ice drift. However, he was unable to provide an explanation to this phenomenon beyond vicinity to coasts and sea currents. Of course, we know now that the deflection was primarily a result of the Coriolis effect.

The insights regarding the relationship between the wind and the ice drift was deepened by Fridtjof Nansen, who observed during his *Fram* expedition that the wind was the main factor that explained the short-term speed and direction of the Arctic ice drift. More specifically, he concluded, based on the empirical data from his expedition, that the Arctic sea ice on average drifts with a speed of about 2% of the surface wind, but with a deviation of between 20° and 40° to the right of the direction of the wind (Nansen, 1902).

Although the details had not yet been published at the time of the Andrée expedition, it is documented that Nansen already knew that the relationship between the wind and the ice drift in the Arctic was much more fundamental than what had been previously assumed in the polar community in general, and that some other factor in addition to the wind determined the direction in which the ice drifted. In Nansen (1897), that was published in the May issue of *The Geographical Journal* and thus was written at some time during the winter 1896–1897 (i.e. before the meeting between Nansen and Andrée in Stockholm during the spring in 1897), Nansen reveals, among other things, that "But what causes the drift of this ice over this sea? It is first of all the winds." (Nansen, 1897, p.492) and that "Nor do I think that the drift of the ice quite coincides with the direction of the prevailing winds" (Nansen, 1897, p.494). At this point, Nansen do not seem to have compared his results with the deflection observed by Weyprecht two decades earlier, but only a few years later, a theoretical explanation of Weyprecht's and Nansen's observed deflection angle was published by Ekman (1902).

Scenario analysis

Based on positions, marching and wind data from the Andrée expedition, Sverdrup (1931) estimated the actual average deflection angle during the attempted return march to 59° to the right; hence, other factors in addition to the Coriolis effect, such as water stress and internal friction, had some impact on the ice drift during this period. For the purpose of this paper, however, it is more interesting to examine what Andrée reasonably could have expected *ex ante*, given his decisions, than what the deflection angle actually was *ex post*. Therefore, this section presents a scenario analysis of what would have happened in terms of movement over ground (direction and speed) during Andrée's initial march over the ice in a due easterly direction under different assumptions regarding wind speed, wind direction, deflection angle and marching speed.

Note that the wind speeds and directions are assumed to be defined based on vector computation (Bailey, 2000) and not on simple arithmetic averages that disregard the varying direction of the wind. Because the average wind speed calculated through vector computation at a variable wind direction always is lower than the simple arithmetic average wind speed, the wind speeds included in this analysis are lower than what the average wind speed would be when the wind direction is disregarded. More specifically, we use the wind speeds 1, 2 and 3 m/s, which, at a 2% wind factor, correspond with approximate ice drift speeds of 1.7, 3.5 and 5.2 km/day. Furthermore, average wind directions including a southerly component were excluded from the analysis, because such winds are relatively rare in the area; hence, the average wind directions that were included in the analysis were W, NW, N, NE and E. Moreover, the deflection angles that were considered were (in degrees to the right of the wind) 0, 15, 30, 45 and 60. Finally, the marching speeds included in the analysis were based on the typically poor, average and good daily marching distances over the ice that Andrée and his men actually were able to achieve: 2, 4 and 6 km per day.

Thus, the analysis is based on $3 \times 5 \times 5 \times 3 = 225$ different scenarios (see Tables 1–5 in the appendix). For example, we can see in Table 1 that a marching speed of 4 km per day, combined with a westerly wind with a 45° deflection angle at a speed of 1 m/s that would result in an ice drift in a 135° direction (i.e. towards the southeast) at an average speed of 1.7 km/day, would have been beneficial for Andrée due to the resultant average movement for the expedition at a speed of 5.3 km/day in a 103.0° direction (i.e. approximately east by south). We can also see in Table 3 that a marching speed of only 2 km per day combined with a northerly wind with a zero deflection angle at a speed of 3 m/s that would result in an ice drift in a 180° direction (i.e. towards the south) at an average speed of 5.2 km/day also would have been beneficial for Andrée due to the resultant average movement for the expedition at a speed of 5.6 km/day in a 159.0° direction (i.e. approximately south-southeast).

A necessary condition for Andrée to succeed with his attempt to reach Franz Josef Land would be to first reach the northwestern coast of Alexandra Land – the large westernmost island in the Franz Josef Land archipelago and the first land on the straight line from the position where Andrée landed with the balloon to Cape Flora. From there, large-scale ice drift would no longer hinder an attempted march to Cape Flora. The northwestern coast of Alexandra Land was about 350 km away towards the southeast (i.e. in an approximate 135° direction) from where Andrée landed with the balloon, but Andrée could not know that with certainty, because the coastlines of Alexandra Land was still largely unexplored at the time of the Andrée expedition (Bartholomew, 1897).

The polar night at the latitude of Cape Flora would begin in late October (Burn, 1996); hence, Andrée knew that to not be forced to travel in darkness, he had approximately 100 days to reach it when he began his march on 22 July. In other words, he needed to approach Cape Flora with an average speed of almost 5 km per day. Given these facts, the overall view from the scenario analysis is that westerly winds (Table 1) would have been highly valuable to Andrée in the attempted march to Cape Flora, almost no matter what deflection angle he could have expected. Northwesterly winds (Table 2) would also have been useful for him as long as the deflection angle was not too large.

Northerly winds (Table 3), however, would basically only have been beneficial to him if he assumed a zero deflection angle. For example, we can see in Table 3 that daily marches of an average length of 4 km in an easterly direction and an average ice drift in a due southerly direction of 3.5 km per day would create a net movement of 5.3 km per day in a 131.2° direction, which would suffice to reach Cape Flora before the polar night set in. But as soon as the deflection angle is introduced in the analysis, northerly winds effectively make it almost impossible for Andrée to reach Cape Flora since it would slow his easterly advance too much or even create a resultant movement away from Cape Flora.

Finally, winds from the northeast (Table 4) or east (Table 5) would apparently always hinder him from reaching Franz Josef Land – the movement over ground would not be in a direction remotely towards Cape Flora, despite marching towards the east, or the ice drift in a wrong direction would be strong enough to prevent Andrée to reach land before the polar winter set in.

Based on these data, it is clear that Andrée, as a mathematically highly proficient person, can hardly have expected even a slight westerly long-term element in the ice drift when he chose Cape Flora as the initial destination for the march. Thus, if he expected the generally northerly winds from the first week on the ice to continue, he cannot have assumed a deflection angle in the ice drift. Furthermore, the scenario analysis clearly demonstrates how the drift speed moderates the influence of the deflection angle on Andrée's likelihood of survival. It is plausible that Andrée underestimated the ice drift speed, even under moderately windy conditions, potentially rendering him even more reliant on favourable winds.

Andrée's understanding of Arctic ice drift

This section will discuss Andrée's demonstrated or implied understanding of the Arctic ice drift in three different aspects: the long-term drift patterns in the vicinity of Svalbard and Franz Josef Land, the wind factor and the deflection angle. As we will see, Andrée seems to have had a good understanding of the long-term drift pattern as well as of the wind factor, but ignorance regarding the deflection angle – a fact that contributed substantially to the fact that he and his two men perished during their attempted return after the balloon flight.

The long-term drift pattern

Although Andrée's general understanding of Arctic ice drift seems to mostly have been a result of his meetings with Nansen in 1896–1897 and other information from the *Fram* expedition, we know that Andrée and his men, like most other 19th-century polar explorers, reviewed and took part of the experiences of their predecessors as part of their own preparations. For example, in his "manifesto" (Andrée, 1895), Andrée referred explicitly to several earlier Arctic explorers regarding general observations on wind and ice (albeit not the relation between them), but he specifically mentioned Nansen's ongoing attempt to drift across the Arctic Ocean with *Fram*, so he knew well what Nansen was doing at the time and, thus, what his underlying assumptions were regarding the long-term ice drift in the area. Another example is that Knut Frænkel had written a summary of Parry's 1827 expedition in one of his notebooks (see Pallin, 1934) – which of course is particularly interesting given that Parry was the only one besides Nansen who had been far out in the pack ice in the vicinity of the position where Andrée and his men landed with the balloon and experienced the ice drift there first-hand. As mentioned above, Parry explicitly noted a southerly as well as a westerly element in the ice drift in his narrative from the expedition (Parry, 1828).

A recent piece of information regarding the ice drift had been delivered personally to Andree by Otto Sverdrup and the crew of Nansen's *Fram*, on Danskøya 14 August 1896, the year before Andrée departed in the balloon (Andersson, 1906). *Fram* had been released from the ice the day before just northwest of Spitsbergen, after almost three years of drift, close to Nansen's original prediction (Nansen, 1897), and passed Danskøya on its way back home. Andrée and a few other men went on board *Fram* and was told the story of *Fram's* adventure (Lachambre & Machuron, 1898, p.160). At the same occasion, Sverdrup also showed them the chart of the *Fram's* voyage according to all observations of latitude and longitude that had been made during the drift in the ice along the TPD (Lachambre & Machuron, 1898, p.165). This constituted first-hand proof of Nansen's assumed continuous drift of ice across the Eurasian Basin, so even though Andrée might have been concerned that the North Pole had already been reached (as mentioned before, Nansen himself was not on board *Fram* at this time because he had left in early 1895 together with Hjalmar Johansen in an attempt to reach the North Pole with dog sledges over the ice), it should have been clear to him what *Fram's* long drift implicated regarding the general ice drift in the area north of Svalbard and Franz Josef Land. In addition, the Swedish geographical journal *Ymer* featured a review by Alfred Nathorst (1896) on the scientific aspects of the *Fram* expedition, which coincided with the publication of Andrée's (1896) scientific findings from his 1896 trip to Svalbard. Nathorst (1896, p.202) succinctly concluded his assessment of the *Fram* expedition with the statement (translated from Swedish by the author) that "Nansen's view of the ice drift in that section of the Polar Sea seems to have been confirmed by the expedition in large part, and the conditions for it have thus been found to be correct."

On his way back to Sweden, after having aborted the 1896 attempt to carry out the balloon flight, Andrée encountered Nansen himself in Tromsø in late August when Nansen had just reappeared from the ice after his failed attempt to reach the North Pole over the ice from *Fram*. Andrée probably received even further information regarding the arctic ice conditions at this occasion (Häggblom, 1998, p.18). Additionally, Nansen engaged in a meeting with Andrée in Stockholm during the spring of 1897, wherein discussions probably revolved around Nansen's insights from the recently completed *Fram* expedition and Andrée's imminent balloon venture (Andrée et al., 1931).

In addition, Andrée refers several times to the "great stream that Nansen has shown to exist" in his diary from the attempted retreat over the ice after the balloon flight. For example, on 3 August 1897, just before Andrée turned towards Svalbard, he explicitly contemplated the relationship between the movement of the ice where he was and the "great polar stream" in his diary (Andrée et al., 1931, p.367). Hence, the overall interpretation is that Andrée probably had a reasonable understanding of the large-scale ice drift pattern in the general area of the Arctic Ocean, although it should be acknowledged that neither Parry nor Nansen had been at the exact location where Andrée landed with the balloon.

The wind factor

We know for a fact that Andrée knew that the wind propelled the ice drift. In the diary that Andrée wrote during his time on Danskøya 1897 before the balloon journey, he wrote explicitly about the ice drift and the fact that the wind was its primary short-term determinant, and that sea currents only were secondary (translated from Swedish by the author):

> "You can see here in detail that currents in the water, even if they are considerable, do not significantly affect the position of the ice in other cases than when there is stillness. As soon as a wind, even a weak one, rises, the air takes care of the movement of the ice and drives it where the air itself goes. The sea ice in particular and the polar ice above all should follow this law, because that ice is screwed and offers excellent points of attack for the wind." (Andrée, 1906, p.241f)

In addition, Andrée exclaimed satisfaction in his diary from the attempted return march after the balloon flight several times when he and his men experienced winds that he thought could drive the ice in a direction that supported their efforts to return (e.g. "Northerly wind, hurra," see Andrée et al., 1931, p.359).

The deflection angle

Even though Andrée knew well that the wind was the main cause of the ice drift, there are no implications anywhere in Andrée's diaries or other writings that he assumed that the wind could drive the ice another direction than due downwind. On the contrary, in the diary quote from Andrée (1906, p.241f) above, he explicitly states that he believes that the wind drives the ice towards the same direction that the wind blows.

Furthermore, the fact that Andrée exclaimed satisfaction in his diary about northerly winds during the attempted march to Cape Flora shows that he cannot have counted on a deflection angle, because, as the scenario analysis in this paper has shown, northerly winds together with a deflection angle would drive the ice in a way that would obstruct his march. In addition, it can be noted that the wind at the time for this diary note by Andrée, according to Fraenkel's observations, was towards 200°, that is, in an approximately south-southwesterly direction (Sundman, 1968, p.235), which even without a deflection angle would be more aggravating than helpful.

It should be noted that Andrée and his men was provided with an indication of the deflection angle before they began their march. From Frænkel's meteorological journal, we know that the wind during their first five days on the ice after the balloon journey seems to have been rather stable, about 4 m/s and from an approximate north-northwesterly direction (see Sundman, 1968, pp. 224–229). Based on Nansen's observations regarding wind factor and deflection angle, simple arithmetic would suggest that the ice that Andrée and his men were residing on should theoretically drift about 30 km slightly west of south during such a time under such conditions. Based on the geographical positions taken by the men on 14 July and 20 July, their actual drift was 28.2 km in an approximate 190° direction (Lantz, 2019b). In other words, they drifted almost exactly in line with Nansen's observations of the relationship between wind and ice drift from the *Fram* expedition. Even though Andrée, Strindberg and Frænkel were all highly proficient in mathematics, they did not seem to have considered or even taken notice of the fact that they had drifted in a direction to the right of the wind and even less incorporated it in their strategy before they began their march towards Cape Flora.

If the assumption of an expected ice drift in a due southerly direction as a result of due northerly winds had been valid, Andrée's strategy to march towards Cape Flora would have made sense, despite the long distance to the destination. As the scenario analysis above showed, the daily marching distances they actually managed to accomplish, together with a southerly drift of typical strength, could have enabled Andrée and his men to cover the distance to Cape Flora before the polar night. However, that assumption was not valid: a northerly wind must, given the Coriolis effect, be assumed to drive the ice in a general southwesterly rather than a southerly direction, and Andrée and his men, with their limited experience and capacity, were simply unable to offset such a westerly element in the ice drift. In fact, there were mostly northerly winds during the two weeks they had Cape Flora as their intended destination, according to the notes in Frænkel's meteorological journal, (see Sundman, 1968, pp. 230–243). Not surprisingly given the results from the scenario analysis, their resultant movement was approximately towards the southwest even though they marched over the ice towards the east.

Conclusion

The expedition of 1897 led by Andrée stands as an iconic event in the annals of polar exploration, captivating the collective imagination with its bold ambition of reaching the North Pole in a balloon. However, the trajectory of the expedition took an unforeseen turn when the balloon was compelled to make an emergency landing deep within the expanse of pack ice. Subsequently, Andrée and his companions assumed the difficult task of marching towards Cape Flora, located southeast of their landing site. This decision has aroused speculation regarding Andrée's comprehension of ice drift and the factors that influenced his choice of direction.

By delving into the available evidence, this study has demonstrated that Andrée likely lacked awareness of the deflection to the right, induced by the Coriolis effect, that on average characterises ice drift in the Arctic. If Andrée had possessed knowledge of this phenomenon, he would have realised that even if the prevailing northerly winds persisted during the initial weeks on the ice, marching towards Cape Flora would have likely proved futile. On the other hand. If he assumed that the ice would drift in the direction of the wind without deflection, and that the generally northerly winds he had experienced during the week on the ice would continue, the decision to march in a due easterly direction over the ice with the idea to reach Cape Flora was just as logical as Andrée seems to have thought during the last week of July 1897.

Scrutinising historical records, encompassing Andrée's expedition diaries and other writings, provided insights into his understanding of wind patterns and their influence on ice drift. Furthermore, an exhaustive examination of scientific literature and the prevailing knowledge during the late 19th century elucidated the comprehension of the Coriolis effect and its ramifications on Arctic ice drift. It became evident that while early studies conducted by scientists like Fridtjof Nansen contributed to the theoretical and empirical understanding of ice drift, the dissemination of such knowledge to the broader public, including explorers like Andrée, may have been limited at that time.

The findings of this research indicate that Andrée's decision to march towards Cape Flora, despite the prevailing knowledge of ice drift, aligns with the hypothesis that he likely lacked an understanding of the deflection angle, although he was well aware that wind constituted the primary determinant of ice drift in the short term. This also underscores the importance of considering the historical context and scientific awareness of the era. It would be unjust to accuse Andrée of failing to comprehend the issue with the deflection angle, as there appear to be no implications in the scientific or other literature of the time beyond Weyprecht (1875), Payer (1876), and Nansen (1897). Three years after the Andrée expedition, Umberto Cagni, just like Andrée, erroneously expected northerly winds to drive the ice pack on which he was marching on the return from his farthest north during the Italian Arctic expedition in a southerly direction (Cagni, 1903, p.520), even though the Italians had had thorough discussions with Nansen before their expedition. However, in the years following these expeditions, Nansen (1902) and Ekman (1902) provided deeper scientific knowledge concerning the deflection angle in Arctic ice drift, as well as the Coriolis effect in general.

The significance of this study lies in its contribution to the broader understanding of historical events and the intricate interplay between scientific knowledge and the decision-making processes of explorers embarking on perilous expeditions. By unraveling the motivations and circumstances surrounding Andrée's fateful decision, valuable insights have been gained into the complexities faced by early polar explorers and the potential impact of limited scientific understanding on their choices.

As we conclude this research, it is crucial to acknowledge the inherent limitations of studying historical events. The available evidence offers glimpses into Andrée's understanding, but the complete extent of his knowledge and thought processes may forever remain elusive. Nevertheless, the exploration of this research gap has enriched our comprehension of the 1897 Andrée balloon expedition and the challenges encountered by its participants.

In conclusion, this research has shed light on Andrée's decision-making process in light of Arctic ice drift patterns. By highlighting the likelihood of Andrée's unfamiliarity with the Coriolis effect and its influence on ice drift, this study injects a new dimension into the discourse surrounding the expedition. It underscores the intricate relationship between scientific knowledge, historical context, and the choices made by explorers in the face of uncertainty. As the legacy of the Andrée balloon expedition endures, this research contributes to a deeper understanding of this remarkable chapter in the history of polar exploration and the ceaseless human pursuit of knowledge and adventure.

Acknowledgements. The author would like to express his sincere appreciation to the anonymous reviewers for their many insightful comments and suggestions.

Financial support. This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Competing interests. The author declares none.

References

Agardh, I. G. (1869). Om den Spetsbergska Drifvedens ursprung. *Öfversigt af Kongl. Vetenskaps-Akademiens Förhandlingar 1869*, *2*, 97–119.

Andersson, G. (Ed.) (1906). *S. A. Andrée, hans följeslagare och hans polarfärd 1896–1897*. Stockholm: P. A. Norstedt & söners förlag.

Andrée, S. A. (1895). Förslag till polarfärd med luftballong. *Ymer*, *15*, 55–70.

Andrée, S. A. (1896). Rapport angående 1896 års svenska polarexpedition. *Ymer*, *16*, 181–192.

Andrée, S. A. (1906). Andrées egen skildring af polarfärdens förberedelse och början. In G. Andersson (Ed.), *S. A. Andrée, Hans Följeslagare och Hans*

Polarfärd 1896–1897 (pp. 107–253). Stockholm: P. A. Norstedt & söners förlag.

Andrée, S. A., Strindberg, N., & Frænkel, K. (1930). *Med Örnen Mot Polen: Andrées polarexpedition år 1897*. Stockholm: Albert Bonniers Förlag.

Andrée, S. A., Strindberg, N., & Frænkel, K. (1931). *The Andrée Diaries*. London: John Lane the Bodley Head.

Bailey, D. T. (2000). *Meteorological Monitoring Guidance for Regulatory Modeling Applications*. U.S. Environmental Protection Agency. EPA-454/R-99-005.

Barr, S. (2020). *Rossøya – Svalbard*: Store norske leksikon. https://snl.no/Ross%C3%B8ya_-_Svalbard.

Barr, W. (2015). A new island in Zemlya Frantsa-Iosifa [Franz Josef Land]. *Polar Record*, *52*, 372–373.

Bartholomew, J. G. (1897). *Physical Chart of North Polar Regions*. Unpaginated Map in Nansen, F. (1897). Farthest north. New York: Harper and Brothers.

Burn, C. (1996). The Polar Night. The Aurora Research Institute. Scientific Report No. 4.

Cagni, U. (1903). Report of commander Umberto Cagni on the sledge expedition towards the pole. In L. A. di Savoia, (Duke of the Abruzzi) (1903) (Ed.), *On the "Polar Star" in the Arctic Sea* (pp. 349–612). London: Hutchinson.

De Long, E. (1884). *The Voyage of the Jeannette*. Boston, MA: Houghton, Mifflin and Co.

de Vos, M., Kountouris, P., Rabenstein, L., Shears, J., Suhrhoff, M., & Katlein, C. (2023). Understanding the drift of Shackleton's Endurance during its last days before it sank in November 1915, using meteorological reanalysis data. *History of Geo- and Space Sciences*, *14*, 1–13. https://doi.org/10.5194/hgss-14-1-2023

Ekman, V. W. 1902. Om jordrotationens inverkan på vindströmmar i hafvet. *Nyt Magazin for Naturvidenskab*, *40*, 1–27.

Greely, A. W. (1886). *Three Years of Arctic Service*. New York: Charles Scribner's sons.

Häggblom, A. (1982). Driftwood in Svalbard as an indicator of Sea Ice conditions. *Geografiska Annaler. Series A, Physical Geography*, *64*, 81–94. https://doi.org/10.2307/520496

Häggblom, A. (1998). Ingenjör Andrée och den drivande veden i Arktis, *Ymer*, *117*, 11–25.

Henderson, B. (2005). *True North: Peary, Cook, and the Race to the Pole*. New York: W. W. Norton and Company.

Jackson, F. G. (1899). *A Thousand Days in the Arctic*. London: Harper & Brothers.

Keltie, J. S., & Mill, H. R. (1896). *Report of the Sixth International Geographical Congress*. London: John Murray.

Kohout, A. L., Williams, M. J. M., Dean, S. M., & Meylan, M. H. (2014). Storm-induced sea-ice breakup and the implications for ice extent. *Nature*, *509*(7501), 604–607. doi: 10.1038/nature13262.

Lachambre, H., & Machuron, A. (1898). *Andrée's Balloon Expedition*. New York: Frederick A. Stokes Company.

Lantz, B. (2018). Could the members of the 1897 Andrée balloon expedition have survived? *Polar Record*, *54*(3), 234–236. doi: 10.1017/S0032247418000402.

Lantz, B. (2019a). A note on the depots of the 1897 Andrée balloon expedition, *Polar Record*, *55*(1), 48–50. doi: 10.1017/S0032247419000159.

Lantz, B. (2019b). Ice drift during the 1897 Andrée balloon expedition, *Polar Record*, *55*(6), 385–391. doi: 10.1017/S0032247419000706.

Lantz, B. (2021). The Italian Arctic expedition 1899–1900: What happened to the first support party? *Polar Record*, *57*, e36. doi: 10.1017/S0032247421000577.

Leppäranta, M. (2011). *The Drift of Sea Ice*. Berlin: Springer.

Leslie, A. (1879). *The Arctic Voyages of Adolf Erik Nordenskiöld 1858–1879*. London: MacMillan and Co.

Linderholm, H. W., Gunnarson, B. E., Fuentes, M., Büntgen, U., & Hormes, A. (2021). The origin of driftwood on eastern and south-western Svalbard. *Polar Science*, *29*, 100658. doi: 10.1016/j.polar.2021.100658.

Lytzen, C. (1885). Levninger fra Jeanette-Expeditionen paa Grønlands Vestkyst. *Geografisk Tidsskrift*, *8*, 49–51.

Macdonald, R. W., Harner, T., & Fyfe, J. (2005). Recent climate change in the Arctic and its impact on contaminant pathways and interpretation of temporal trend data. *Science of the Total Environment*, *342*, 5–86. doi: 10.1016/j.scitotenv.2004.12.059.

Meisenbach, G. (1898). En färd till Sjuöarne sommaren 1897. *Ymer*, *18*, 127–140.

Nansen, F. (1890). *The First Crossing of Greenland*. London: Longmans, Green and Co.

Nansen, F. (1893). How can the north polar region be crossed? *The Geographical Journal*, *1*, 1–22. doi: 10.2307/1774198.

Nansen, F. (1897). Some results of the Norwegian Arctic expedition. *The Geographical Journal*, *9*, 473–505. doi: 10.2307/1774891.

Nansen, F. (1898). *Farthest North*. London: Harper & Brothers Publishers.

Nansen, F. (1902). *Oceanography of the North Polar Basin. The Norwegian North Polar Expedition 1893–1896. Scientific Results*. New York: Greenwood Press.

Nathorst, A. G. (1896). Nansens och *Frams* återkomst. *Ymer*, *16*, 193–202.

Pallin, H. N. (1934). *Andréegåtan*. Uppsala: Lindblads.

Parry, W. E. (1828). *Narrative of an Attempt to Reach the North Pole*. London: John Murray.

Payer, J. (1876). *New Lands within the Arctic Circle*. London: Macmillan and Company.

Phipps, C. J. (1774). *A Voyage Towards the North Pole*. London: J. Nourse.

Scoresby, W. (1820). *An Account of the Arctic Regions*. Edinburgh: Archibald Constable and Co.

Sinsabvarodom, C., Chai, W., Leira, B. J., Høyland, K. V., & Næss, A. (2022). Ice rose diagrams for probabilistic characterization of the ice drift behavior in the Beaufort Sea. *Ocean Engineering*, *266*, 112708. doi: 10.1016/j.oceaneng.2022.112708.

Sundman, P. O. (1968). *Ingen Fruktan, Intet Hopp*. Stockholm: Bonniers.

Svedenborg, G. V. E. (1922). Polarexpeditionen 1897 – några dagboksanteckningar. In N. Ekholm & G. V. E. Svedenborg (Eds.), *S. A. Andrées ballongfärd mot Nordpolen. Svensk Motortidning* (pp. 53–61). Kungl. Svenska Aeroklubbens skriftserie VI.

Sverdrup, H. U. (1928). The wind-drift of the ice on the North Siberian Shelf. In *The Norwegian North Polar Expedition with the "Maud" 1918–1925: Scientific Results*, (vol. 4, pp. 1–46) London: Longmans, Green, and Co.

Sverdrup, H. U. (1931). Scientific results of the Andrée-expedition. 1. Drift-ice and Ice-drift. *Geografiska Annaler*, *13*(2–3), 121–140. doi: 10.1080/20014422.1931.11880536.

Thorndike, A. S., & Colony, R (1982). Sea ice motion in response to geostrophic winds. *Journal of Geophysical Research*, *87*, 5845–5852. doi: 10.1029/JC087iC08p05845.

To Bring Jackson Back. (1897). *The New York Times*, p. 7.

Todhunter, I. (1886). *Spherical Trigonometry*. London: MacMillan & Co.

Weyprecht, C. (1875). Scientific work of the second Austro-Hungarian polar expedition, 1872–4. *The Journal of the Royal Geographical Society of London*, *45*, 19–33.

Wüllerstorf-Urbair, B. (1878). Die meteorologische Beobachtungen und die Analyse des Schiffcurses während der Polarexpedition unter Weyprecht und Payer, 1872–1874. *Denkschriften der Kaiserlichen Akademie der Wissenschaften*, *35*, 1–24.

Appendix: Tables for the scenario analysis

Table 1. Scenario analysis based on an assumed westerly wind and an easterly march.

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
2	90	1.7	3.7	90.0
2	90	3.5	5.5	90.0
2	90	5.2	7.2	90.0
2	105	1.7	3.7	96.9
2	105	3.5	5.5	99.6
2	105	5.2	7.2	100.8
2	120	1.7	3.6	103.8
2	120	3.5	5.3	109.2
2	120	5.2	7.0	111.8
2	135	1.7	3.4	110.6
2	135	3.5	5.1	118.9
2	135	5.2	6.8	122.9
2	150	1.7	3.2	117.3
2	150	3.5	4.8	128.9
2	150	5.2	6.4	134.4
4	90	1.7	5.7	90.0
4	90	3.5	7.5	90.0
4	90	5.2	9.2	90.0
4	105	1.7	5.7	94.5
4	105	3.5	7.4	97.0
4	105	5.2	9.1	98.5
4	120	1.7	5.5	98.8
4	120	3.5	7.2	104.0
4	120	5.2	8.9	107.0
4	135	1.7	5.3	103.0
4	135	3.5	6.9	110.9
4	135	5.2	8.5	115.6
4	150	1.7	5.1	106.9
4	150	3.5	6.5	117.8
4	150	5.2	8.0	124.3
6	90	1.7	7.7	90.0
6	90	3.5	9.5	90.0
6	90	5.2	11.2	90.0
6	105	1.7	7.7	93.3
6	105	3.5	9.4	95.5
6	105	5.2	11.1	97.0
6	120	1.7	7.5	96.5
6	120	3.5	9.2	101.0
6	120	5.2	10.8	103.9

(*Continued*)

Table 1. (*Continued*)

Marching speed (km/day)	Ice drift		Resultant movement over ground	
	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
6	135	1.7	7.3	99.5
6	135	3.5	8.8	106.3
6	135	5.2	10.4	110.8
6	150	1.7	7.0	102.1
6	150	3.5	8.3	111.4
6	150	5.2	9.7	117.6

Table 2. Scenario analysis based on an assumed northwesterly wind and an easterly march.

Marching speed (km/day)	Ice drift		Resultant movement over ground	
	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
2	135	1.7	3.4	110.6
2	135	3.5	5.1	118.9
2	135	5.2	6.8	122.9
2	150	1.7	3.2	117.3
2	150	3.5	4.8	128.9
2	150	5.2	6.4	134.4
2	165	1.7	2.9	123.9
2	165	3.5	4.5	139.3
2	165	5.2	6.0	146.3
2	180	1.7	2.6	130.4
2	180	3.5	4.0	150.3
2	180	5.2	5.6	159.0
2	195	1.7	2.3	136.5
2	195	3.5	3.6	162.1
2	195	5.2	5.1	172.6
4	135	1.7	5.3	103.0
4	135	3.5	6.9	110.9
4	135	5.2	8.5	115.6
4	150	1.7	5.1	106.9
4	150	3.5	6.5	117.8
4	150	5.2	8.0	124.3
4	165	1.7	4.7	110.3
4	165	3.5	6.0	124.6
4	165	5.2	7.3	133.2
4	180	1.7	4.3	113.0
4	180	3.5	5.3	131.2
4	180	5.2	6.6	142.4
4	195	1.7	3.9	114.8
4	195	3.5	4.6	137.5
4	195	5.2	5.7	152.1

(*Continued*)

Table 2. (*Continued*)

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
6	135	1.7	7.3	99.5
6	135	3.5	8.8	106.3
6	135	5.2	10.4	110.8
6	150	1.7	7.0	102.1
6	150	3.5	8.3	111.4
6	150	5.2	9.7	117.6
6	165	1.7	6.6	104.3
6	165	3.5	7.7	116.1
6	165	5.2	8.9	124.4
6	180	1.7	6.2	105.8
6	180	3.5	6.9	120.3
6	180	5.2	7.9	130.9
6	195	1.7	5.8	106.5
6	195	3.5	6.1	123.6
6	195	5.2	6.8	137.2

Table 3. Scenario analysis based on an assumed northerly wind and an easterly march.

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
2	180	1.7	2.6	130.4
2	180	3.5	4.0	150.3
2	180	5.2	5.6	159.0
2	195	1.7	2.3	136.5
2	195	3.5	3.6	162.1
2	195	5.2	5.1	172.6
2	210	1.7	1.9	142.0
2	210	3.5	3.0	175.3
2	210	5.2	4.5	187.6
2	225	1.7	1.4	146.4
2	225	3.5	2.5	190.9
2	225	5.2	4.0	204.5
2	240	1.7	1.0	148.2
2	240	3.5	2.0	210.5
2	240	5.2	3.6	223.9
4	180	1.7	4.3	113.0
4	180	3.5	5.3	131.2
4	180	5.2	6.6	142.4
4	195	1.7	3.9	114.8
4	195	3.5	4.6	137.5
4	195	5.2	5.7	152.1

(*Continued*)

Table 3. (*Continued*)

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
4	210	1.7	3.5	115.1
4	210	3.5	3.8	143.4
4	210	5.2	4.7	162.7
4	225	1.7	3.0	113.3
4	225	3.5	2.9	148.4
4	225	5.2	3.7	175.0
4	240	1.7	2.7	108.6
4	240	3.5	2.0	151.0
4	240	5.2	2.6	191.0
6	180	1.7	6.2	105.8
6	180	3.5	6.9	120.3
6	180	5.2	7.9	130.9
6	195	1.7	5.8	106.5
6	195	3.5	6.1	123.6
6	195	5.2	6.8	137.2
6	210	1.7	5.4	106.0
6	210	3.5	5.2	125.5
6	210	5.2	5.6	142.9
6	225	1.7	4.9	104.1
6	225	3.5	4.3	125.1
6	225	5.2	4.3	147.7
6	240	1.7	4.6	100.6
6	240	3.5	3.4	120.5
6	240	5.2	3.0	150.1

Table 4. Scenario analysis based on an assumed northeasterly wind and an easterly march.

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
2	225	1.7	1.4	146.4
2	225	3.5	2.5	190.9
2	225	5.2	4.0	204.5
2	240	1.7	1.0	148.2
2	240	3.5	2.0	210.5
2	240	5.2	3.6	223.9
2	255	1.7	0.6	140.9
2	255	3.5	1.7	236.7
2	255	5.2	3.3	246.0
2	270	1.7	0.3	90.0
2	270	3.5	1.5	270.0
2	270	5.2	3.2	270.0

(*Continued*)

Table 4. (*Continued*)

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
2	285	1.7	0.6	39.1
2	285	3.5	1.7	303.3
2	285	5.2	3.3	294.0
4	225	1.7	3.0	113.3
4	225	3.5	2.9	148.4
4	225	5.2	3.7	175.0
4	240	1.7	2.7	108.6
4	240	3.5	2.0	151.0
4	240	5.2	2.6	191.0
4	255	1.7	2.4	100.6
4	255	3.5	1.1	145.6
4	255	5.2	1.7	217.2
4	270	1.7	2.3	90.0
4	270	3.5	0.5	90.0
4	270	5.2	1.2	270.0
4	285	1.7	2.4	79.4
4	285	3.5	1.1	34.4
4	285	5.2	1.7	322.8
6	225	1.7	4.9	104.1
6	225	3.5	4.3	125.1
6	225	5.2	4.3	147.7
6	240	1.7	4.6	100.6
6	240	3.5	3.4	120.5
6	240	5.2	3.0	150.1
6	255	1.7	4.4	95.8
6	255	3.5	2.8	109.1
6	255	5.2	1.7	144.0
6	270	1.7	4.3	90.0
6	270	3.5	2.5	90.0
6	270	5.2	0.8	90.0
6	285	1.7	4.4	84.2
6	285	3.5	2.8	70.9
6	285	5.2	1.7	36.0

Table 5. Scenario analysis based on an assumed easterly wind and an easterly march.

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
2	270	1.7	0.3	90.0
2	270	3.5	1.5	270.0
2	270	5.2	3.2	270.0
2	285	1.7	0.6	39.1
2	285	3.5	1.7	303.3
2	285	5.2	3.3	294.0
2	300	1.7	1.0	31.8
2	300	3.5	2.0	329.5
2	300	5.2	3.6	316.1
2	315	1.7	1.4	33.6
2	315	3.5	2.5	349.1
2	315	5.2	4.0	335.5
2	330	1.7	1.9	38.0
2	330	3.5	3.0	4.7
2	330	5.2	4.5	352.4
4	270	1.7	2.3	90.0
4	270	3.5	0.5	90.0
4	270	5.2	1.2	270.0
4	285	1.7	2.4	79.4
4	285	3.5	1.1	34.4
4	285	5.2	1.7	322.8
4	300	1.7	2.7	71.4
4	300	3.5	2.0	29.0
4	300	5.2	2.6	349.0
4	315	1.7	3.0	66.7
4	315	3.5	2.9	31.6
4	315	5.2	3.7	5.0
4	330	1.7	3.5	64.9
4	330	3.5	3.8	36.6
4	330	5.2	4.7	17.3
6	270	1.7	4.3	90.0
6	270	3.5	2.5	90.0
6	270	5.2	0.8	90.0
6	285	1.7	4.4	84.2
6	285	3.5	2.8	70.9
6	285	5.2	1.7	36.0
6	300	1.7	4.6	79.4
6	300	3.5	3.4	59.5
6	300	5.2	3.0	29.9
6	315	1.7	4.9	75.9
6	315	3.5	4.3	54.9
6	315	5.2	4.3	32.3

(*Continued*)

Table 5. (*Continued*)

	Ice drift		Resultant movement over ground	
Marching speed (km/day)	Bearing (degrees)	Speed (km/day)	Speed (km/day)	Bearing (degrees)
6	330	1.7	5.4	74.0
6	330	3.5	5.2	54.5
6	330	5.2	5.6	37.1