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Magellan's Crossing of the Pacific:

Using Computer Simulations to Examine Oceanographic Effects on One of the World's Greatest Voyages

SCOTT M. FITZPATRICK AND RICHARD CALLAGHAN

And if our Lord and the Virgin Mother had not aided us by giving good weather to refresh ourselves with provisions and other things we had died in this very great sea. And I believe that nevermore will any man undertake to make such a voyage

Antonio Pigafetta, 1521¹

THREE QUESTIONS ARISE WHEN CONSIDERING MAGELLAN'S VOYAGE THROUGH THE straits named after him and his subsequent crossing of the Pacific. First, why did he encounter such benign weather conditions when leaving the Straits and entering the Pacific? Most who followed him either through the Straits or via Cape Horn encountered inclement weather off the southern coast of Chile.² Second, why did he travel considerably north of the equator — when his goal, the Moluccas, was known by him to lie along the equator — and cross the doldrums in a crippled ship with a starving crew? Third, why did he only see two uninhabited islands after crossing such a vast distance of ocean? We investigate these questions using computer simulations and suggest an answer that applies to all these questions.

On 28 November 1520, Fernão de Magalhães (Ferdinand Magellan) and his depleted fleet sailed around the tip of South America. After a tumultuous 38-day attempt to pass through the straits that now bear his name, Magellan gazed out into the vast sea and called it *Mare Pacifico* or 'calm sea' which was appropriate (although misleading) considering what they had just endured. The passage through the Straits was notable for a number of reasons, not the least because it was the first time Europeans had sailed to the other side of the Americas through a westerly route, ultimately leading to what would become the first successful circumnavigation of the globe.

Magellan's main objective was to find a westward route to the Moluccas or 'Spice Islands' on the equator and claim their lucrative wealth for Spain.

¹ Antonio Pigafetta, *Magellan's Voyage: a narrative account of the first circumnavigation*, trans. and ed. R. A. Skelton (New York 1994), 195.

² Felix Riesenber, *Cape Horn* (New York 1939).

Magellan had received letters from his Portuguese friend Francisco Serrão (Serrano), who had been one of the three captains sent by Afonso de Albuquerque, the viceroy of India, from Malacca to explore the Moluccas in 1511. In his correspondence to Magellan, Serrão described the riches of the Spice Islands and urged him to come: 'I have found here a new world richer and greater than that of Vasco de Gama... I beg you to join me here, that you may sample for yourself the delights that surround me.'³ Magellan replied, 'God willing, I will soon be seeing you, whether by way of Portugal or Castile, for that is the way my affairs have been leaning; you must wait for me there, because we already know it will be some time before we can expect things to get better for us.'⁴

Magellan suspected that the Moluccas were little more than three to four days sailing from the tip of South America, in part because Serrão had described them as being further east than where they lay. This may have been an effort to disguise their location and place them within Spanish territory so that it would not violate the 1494 Treaty of Tordesillas. This was an extremely contentious treaty between the Portuguese and Spanish that had been drawn up by Pope Alexander and, in effect, bestowed the eastern hemisphere of the world to Portugal and the western half to Spain. The Treaty of Tordesillas did nothing to curtail disputes, however, and instead 'touched off a furious race between the nations to claim new lands and to control the world's trade routes even as they attempted to shift the line of demarcation to favor one side or the other'.⁵

After a harrowing trip across two oceans, Magellan made landfall on the island of Guam in the Marianas Islands at 13°N on 6 March 1521. His voyage across the Pacific alone took his increasingly emaciated fleet over three months to accomplish, in which they sailed more than 8,100 nautical miles (15,000 kilometres). In the process, they lost dozens of men to dehydration, malnutrition and scurvy, and saw only two small uninhabited coral islets along the way. What led Magellan to follow the course that eventually brought them to the Marianas instead of the Moluccas or other island groups? Although the Pacific is the world's largest ocean, comprising one-third of the surface of the globe, which could easily fit all the present-day land masses inside with room to spare, it is still astonishing as to why: (1) Magellan saw virtually no other islands after moving across almost 70° of latitude with thousands of islands in-between them and their final destination; and (2) he travelled so far north of the Moluccas, which he knew to lie along the equator. The 'Genoese Pilot' sailing with Magellan notes that their reasoning behind travelling so far north was because they believed the Moluccas did not have enough food:

They ran on until they reached the line (equator), when Fernan de Magalhaes said that now they were in the neighborhood of Maluco [the Moluccas], as he had

³ Quoted in Laurence Bergreen, *Over the Edge of the World: Magellan's terrifying circumnavigation of the globe* (New York 2003), 30–1.

⁴ *Ibid.*, 31.

⁵ *Ibid.*, 8.

information that there were no provision at Maluco, he said that he would go in a northerly direction as far as ten or twelve degrees.⁶

But this seems unreasonable, considering that they had already spent months battling severe storms in their crossing of the Atlantic, suffered a failed mutiny along the coast of South America, and lost two of their five ships before even setting sail in the Pacific. In addition, they would have had to know that a stay-over in the Moluccas for weeks, or more likely months, would be required to obtain their cargo of spices.

Decisions made by Magellan and his pilots to go in a particular direction, whether guided by real beliefs of where they should go or not, certainly played a role in why they landed on Guam first. But did oceanographic conditions also play a role? Unfortunately, historical scholars have focused little attention on this segment of Magellan's trip which would help determine whether oceanographic conditions influenced the fleet's course and the degree to which it was dictated by Magellan's orders. Would the vessels have moved in a different direction if they had entered the Pacific during other times of the year, and could this have changed the ultimate outcome of their voyage?

To investigate these questions, we use historical accounts and computer simulations of voyaging to determine: (1) whether oceanographic conditions influenced the fleet's direction of travel; (2) whether they would have been successful in reaching the Marianas had they left at a different time of the year; and (3) whether a ship entering the Pacific from the Straits could have drifted west. Answering these questions can help us to assess whether Magellan's decision to move northward was deliberate or by chance. The historical records indicate that ocean conditions were unusually calm when Magellan entered the Pacific. Computer simulations suggest that he could have sailed to the Marianas even during poor weather conditions had he maintained his original course. However, if Magellan had simply drifted from the Straits after passing through them, the strong easterly currents and gale-force winds would most likely have pushed him back toward the Atlantic and wrecked his fleet on the rocky shoals. Overall, historical accounts and computer simulations together point to anomalous weather conditions that appear to have eased northward movement and influenced Magellan's decision to cross over the equator away from the Moluccas.

Magellan's Crossing of the Pacific

Magellan and his *Armada de Molucca* began their journey from Sanlucar de Barrameda in Spain on 20 September 1519 with approximately 270 men on five

⁶ 'Genoese Pilot', 'Navigation and voyage which Fernando de Magalhães made from Seville to Maluco in the year 1519', in Henry Edward John Stanley, Baron Stanley of Alderley (trans. and ed.), *The First Voyage round the World by Magellan: translated from accounts of Pigafetta and other contemporary writers* (London 2005 [facsimile of the London 1874 Hakluyt Society edn]), 9. Torodash notes that this pilot may have been 'Juan Bautista de Punzorol (or de Poncerva) or Leon Pancaldo (or Pancado)' who wrote the *Roteiro* and was later captured by the Portuguese. Martin Torodash, 'Magellan historiography', *Hispanic American Historical Review*, 51:2 (1971), 319.

ships — the *Santiago*, *Concepcion*, *San Antonio*, *Victoria* and the flagship *Trinidad*.⁷ The *Victoria* is of particular interest as it was one of the three ships that crossed the Pacific (to Cebu), but the only ship that circumnavigated the globe. The ship was a *nao* of 85 tons burthen and massively built.⁸ A replica recently built under the direction of Ignacio Fernández Vial measured 27 × 3.5 metres.⁹ Although a strong ship, its rigging allowed extremely limited sailing to windward. Given normal conditions along the south coast of Chile, Magellan could not have made any headway.

To succeed in finding a westward route, Magellan was prepared to sail southward as far as 75° to find the passage, but did so instead at 52°. Francisco Albo, a Greek officer who served as master's mate on the *Trinidad* and was later promoted to acting pilot for the *Victoria*,¹⁰ describes navigating through the Straits of Magellan:

after we had come out of the two straits or narrows, we found a very large bay, and we found some islands, and we anchored at one of them; and took the sun, and found ourselves at 52 1/3°, and thence we came in a S.S.E. direction, and found a spit on the left hand, and from thence to the first mouth there will be a matter of 30 leagues;¹¹ after that we went to S.W. a matter of 20 leagues, and there we took the sun, and we were in 53 2/3°, and from there we returned to N.W., a matter of 15 leagues, and there we anchored in 53° latitude.¹²

After over five weeks of sailing 130 leagues, his three remaining ships, the *Concepcion*, the *Victoria* and the *Trinidad*, finally reached the Pacific.

One of the most important accounts of Magellan's voyage into the Pacific comes from the journal entries written by Antonio Pigafetta, an Italian nobleman and diplomat and one of only 18 surviving members of the original crew who attempted the trip.¹³ Pigafetta's descriptions provide good, but often fairly

⁷ For other descriptions of Magellan's voyage apart from those cited in this paper, see José Toribio Medina (ed.), *Collección de Documentos ineditos para la Historia de Chile*, vols I–II: *Navigacion y viaje que hizo Fernando de Magallanes desde Sevilla para el Maluco en el ano 1519* (Santiaio de Chile 1888); Tim Joyner, *Magellan* (Camden ME 1994); X. de Castro and L.P. Thomaz, *Le Voyage de Magellan (1519–1522): la relation d'Antonio Pigafetta and autres témoins*, 2 vols (Chandeigne 2007); C.E. Nowell, *Magellan's Voyage round the World* (Evanston 1962). For further details on these and other writings regarding Magellan, see Torodash, 'Magellan historiography'.

⁸ Riesenber, *Cape Horn*, 15–16. A *nao* was a kind of boat also known as a 'carrack', the precursor to the galleon.

⁹ 'Vuelta la mundo de la Nao Victoria', <http://www.elmundoviajes.com/elmundoviajes/especiales/2004/12/naovictoria/expedicion.html> (accessed 24 June 2008).

¹⁰ Joyner, *Magellan*, 346.

¹¹ One Spanish *legua* (league) (pre-1568) = 0.752 nautical leagues, 0.865 US statute league, 4.18 km, 2.26 international nautical miles, or 2.6 miles. However, Magellan used (as shown in his 1519 Memorandum to the King and other instances) the module of 17.5 leagues per degree of great circle (i.e. latitude) — thus a league of 3.428 nautical miles.

¹² Francisco Albo, 'Extracts from a derrotero or log-book of the voyage of Fernando de Magallanes in search of the strait, from the cape of St Augustine', in Stanley, *The First Voyage round the World by Magellan*, 219. It should be noted that Lord Stanley's transcription of Albo's *derrotero* is not completely reliable, as he missed some important observations at the beginning of the Pacific log and made one or two transcription errors in the headings (Andre Rossfelder, pers. comm.).

¹³ The translations of Pigafetta's journal relied upon for this article are Pigafetta, *Magellan's Voyage*; Antonio Pigafetta, *The Voyage of Magellan: the journal of Antonio Pigafetta*, trans. Paula Spurlin Paige (Upper Saddle River 1969).

general accounts about their travels. Entries from the log of Francisco Albo and the 'Genoese Pilot' describe in greater detail their headings, latitude positions, currents, winds and general climatic conditions as they made their Pacific crossing.¹⁴

Moving northward after passing through the Straits, Albo describes the Chilean mountains and the course they set out into the Pacific after first running along the coast:

In this strait there are a great many elbows, and the chains of mountains are very high and covered with snow, with much forest. After that we went N.W. and a quarter W., and in this course there are many islets; and issuing from this strait the coast turns to the north, and on the left hand we saw a cape with an island, and we gave them the name of Cape Fermoso and Cape Deseado, and it is in the same latitude as the Cape of the Virgins, which is at the beginning of the straits, and from the said Cape Fermoso we afterwards went to N.W. and to N., and to N.N.E., and we went in this course two days and three nights, and in the morning we saw land of pointed hills, and it runs North and South (thus runs the coast of the South sea) and from this land to Cape Fermoso there is a matter of 20 leagues, and we saw this land the 1st December.¹⁵

Pigafetta also notes how they needed to adjust their compass settings by two points (22½ degrees) as they travelled northward.

Our lodestone always moved a little toward its Arctic Pole, but it had not so much force as from its side and its ring. Wherefore, when we were in that gulf, the captain-general asked all the pilots, always keeping our course, what sailing track we should prick [mark] on the charts. They all replied, by his course exactly as laid down. And he replied that they pricked it wrongly (and it was so) and that the needle of navigation should be adjusted, because it was not receiving so much force as from its side. Being in the midst of that gulf, we saw a cross of five very bright stars right in the west [i.e., the 'Southern Cross'], which were exactly placed with one another.¹⁶

According to Albo, the fleet proceeded to run parallel to the Chilean coast, where they eventually picked up the Peruvian Drift from astern and the westerlies from abeam.¹⁷ It should be noted that Antonio de Herrera, the official chronicler of the Spanish court who had access to the Spanish and Portuguese archives before most were lost or destroyed, indicates that the flotilla went through a severe storm from 2 to 18 December after leaving the Strait, battling heavy seas rather than high winds.¹⁸ Another estimation indicates that there may have indeed been stormy activity, but that it probably ceased around 12 December,¹⁹ although this is not mentioned by Pigafetta in his ship logs. If this were the case, it would still mean that Magellan was able to sail northward a distance of 6°, or around 360 nautical miles (47¼° to 41¼°) over a period of 10 days or so from 2 to 12 December, 6½° (40° to 33½°) from 13 to 18 December,

¹⁴ Albo, 'Extracts from a derrotero', 211–36; 'Genoese Pilot', 'Navigation and voyage', 1–32.

¹⁵ Albo, 'Extracts from a derrotero', 219–20.

¹⁶ Pigafetta, *Magellan's Voyage*, 58.

¹⁷ Albo, 'Extracts from a derrotero', 220.

¹⁸ Joyner, *Magellan*, 351.

¹⁹ Andre Rossfelder, pers. comm.

and another 7°, or 420 nautical miles (32¾° to 25½°), from 19 to 31 December. This suggests that, despite encountering an apparent storm, Magellan was still able to make good headway north, and it matches well with the general progress made after mid-December. As Samuel Eliot Morison remarked, 'He could hardly have shaped a better course if he had had modern sailing directions, not only avoiding dangerous, island-studded waters, but making the best use of prevailing winds and currents.'²⁰

It is also worth noting that Nunn argued that Magellan had actually sailed further north to about 10°S and then northwest to Cipangu, as shown on Waldseemüller's map (1507), suggesting that Albo falsified his results to make the Spice Islands appear to be in Spanish territory.²¹ However, this seems unlikely, given that it would have required a conspiracy between Albo, Pigafetta and the 'Genoese Pilot', who later provided their accounts to the Crown after the voyage. According to Albo:

On the 2nd of December, we did not take the sun, but we went to the N.N.E. and were in 47¼°, and this day we found ourselves that much ahead, as all this country is in the same latitude.²²

By mid-December, Magellan altered course to the west-northwest in hopes of sighting Asia. However, this proved an unfortunate decision, and they ended up sailing for weeks without sighting land. Table 1 provides the headings and latitude that Albo recorded during the voyage.²³ With their limited stocks of food quickly dwindling and rotting, men began to perish from scurvy, malnourishment, and dehydration, or were too weak to perform their duties. Finally, on 24 January 1521, they sighted a small island that was wooded, uninhabited, inaccessible and without anchorage, which they named San Pablo, 'having discovered it on the day of his conversion'.²⁴ This was probably one of the outlying islands in the Tuamotus, possibly Pukapuka, Fangahina or Angatau.²⁵

After leaving the island on 28 January, Magellan set a course of W/NW that eventually led them to another uninhabited island at around 10° which they called La Isla de los Tiburones, because they were able to catch so many sharks there.²⁶ Pigafetta describes this portion of the trip.

During this time of two months and twelve days, we sailed between west and northwest, and northwest by west, and northwest, until we came to the equinoctial line [the celestial equator] at one hundred and twenty-two degrees from the line

²⁰ Samuel Eliot Morison, *The European Discovery of America: the southern voyages* (New York and Oxford 1974), 407.

²¹ George E. Nunn, 'Magellan's route in the Pacific', *Geographical Review*, 24 (1934), 625–33.

²² This quote follows Stanley's translation (Albo 'Extracts from a derrotero', 220) except for substituting 'the same latitude' for Stanley's 'the same altitude'. The Spanish text from Navarrete gives 'la misma altura' which means 'the same latitude', not 'the same altitude' as found in Stanley. Martin Fernandez de Navarrete, *Colección de los viajes y descubrimientos que hicieron por mar los Españoles desde fines del siglo XV*, vol. IV, no. 22: *Diario o Derrotero... por Francisco Albo* (Madrid 1837), 209–247.

²³ Albo, 'Extracts from a derrotero', 220–3.

²⁴ *Ibid.*, 222.

²⁵ See also Bergreen, *Over the Edge of the World*, 215.

²⁶ Albo, 'Extracts from a derrotero', 222.

TABLE 1. From the log of pilot Francisco Albo, showing travel days, headings and latitude. (Francisco Albo, 'Extracts from a derrotero', in Henry Edward John Stanley, *The First Voyage round the World by Magellan* (London 2005 [1874]), 219–223.)

Day	Heading	Latitude	Notes
December 1520			
4	NW	45 1/2	
5	N 1/4, NW	44 1/4	
6	NE 1/4 E	44	
7	NE 1/4 E	43 2/3	
8	NE 1/4 N	43 1/4	
9	NNE	42 2/3	
10	NE 1/4 E	42 12'	
11	NE 1/4 E	41 2/3	
12	NE 1/4 E	41 1/4	
13	NE 1/4 N	40	
14	N	38 3/4	
15	N 1/4 NE	38	
16	N 1/4 NW	36 1/2	
17	NW 1/4 N	34 1/2	
18	N 1/4 NW	33 1/2	
19	NW	32 3/4	
20	NW	31 3/4	
21	NW	30 2/3	
22	W 1/4 SW	30 2/3	
23	WNW	30	
24	WNW	29 3/4	
25	WNW	29 1/2	
26	NW 1/4 W	28 3/4	
27	NW 1/4 W	27 2/3	
28	NW 1/4 W	26 2/3	
29	WNW	26 1/3	
30	W	26	12 leagues
31	NW	25 1/2	
January 1521			
1	W 1/4 NW	25	
2	WNW	24	
3	NW 1/4 W	23 1/2	
4	WNW	22	
5	W 1/4 SW	23	
6	W 1/4 NW	22	
7	W	22	25 leagues
8	W	22	23 leagues
9	W 1/4 NW	22 1/2	
10	W 1/4 NW	22	
11	W 1/4 NW	21 3/4	
12	W 1/4 NW	21 1/3	
13	W 1/4 NW	21	
14	NW 1/4 W	20 1/2	
15	WNW	19 1/2	
16	WNW	19	
17	WNW	18 1/4	
18	WNW	17 1/2	
19	NW 1/4 W	16 1/4	
20	NW 1/4 W	15	

(continued)

TABLE 1. Continued

Day	Heading	Latitude	Notes
21	SW	15 2/3	
22	SW	16 3/4	
23	W 1/4 NW	16 1/2	
24	W 1/4 NW	16 1/4	Sight uninhabited islands
25	NW 1/4 W	15 3/4	
26	NW 1/4 W	15 1/3	
27	NW 1/4 W	15	
28	WNW	14 1/2	
29	WNW	13 3/4	
30	W 1/4 NW	13 1/2	
31	W 1/4 NW	13 1/3	
February 1521			
1	NW	13	
2	NW	12 1/2	
3	NW	11 3/4	
4	NW	11 3/4	Sight uninhabited island
5	NW	10	
6	NW	9 1/4	
7	NW	8 2/3	
8	NW	7 2/3	
9	NW 1/4 W	6 1/2	
10	NW	5	
11	NW	2 1/2	
12	NW	1	
13	NW	0	30' N of the line
14	NW	1	N latitude
15	NW	1 3/4	
16	WNW	2 1/2	
17	WNW	3 1/2	
18	WNW	5	
19	WNW	5 3/4	
20	WNW	6 1/2	
21	WNW	8	
22	WNW	9 1/2	
23	WNW	11 1/2	
24	W 1/4 NW	12	
25	W 1/4 NW	12 1/3	
26	W	12	
27	W	12	
28	W 1/4 NW	13	
March 1521			
1	W	13	
2	W	13	
3	W	13	
4	W	13	
5	W	13	
6	W	13	Sight the Marianas

of demarcation. Which line of demarcation is thirty degrees from the meridian, and the meridian is three degrees east of Cape Verde.

During these three months and twenty days, we sailed in a gulf where we made a good four thousand leagues across the Pacific Sea, which was so rightly named. For during this time we had no storm, and we saw no land except two small uninhabited islands, where we found only birds and trees. Wherefore we called them the Isles of Misfortune. And they are two hundred leagues distant from one another. And there is no place for anchoring because no bottom can be found.

The first island is in fifteen degrees of latitude going by the south wind, and the other island is in nine degrees. By this wind we made each day fifty or sixty leagues or more, sometimes at the stern, at others at the windward side, or otherwise.²⁷

Torodash remarks that:

It does seem that if Magellan had pursued the more southerly course below the equator, he most certainly would have made some landfalls between the Strait and Guam besides the two uninhabited islands. Otherwise, one must reach the conclusion that Fate frowned upon him in a uniquely perverse fashion as even a casual glance at a map will confirm.²⁸

By the time Magellan's armada had reached the equator on 13 February 1521, they had been sailing for 72 days. By 4 March, the *Trinidad's* food provisions were emptied, 19 more men had died, and less than a dozen were able to work at all. It is curious, then, why Magellan decided to sail so far north of the equator. He had already had to suppress one mutiny, lost a ship to wreckage and another to desertion, and dozens of men had died or were unable to work due to starvation, overexertion and various ailments. Despite their increasingly dire situation, the proposed track effectively moved them further away from the Moluccas northward and, unknowingly, a greater distance from numerous inhabited islands throughout eastern Polynesia and Micronesia. It has been suggested by Guillemard that he was, instead, heading to China or the Ryukyu archipelago (south of Japan), which was known by the Portuguese as 'Lequios'.²⁹ As mentioned previously, the 'Genoese Pilot' noted that Magellan had information that there was no food available in the Moluccas. This course of action seems unlikely, however, especially as they would have had to lay-over in the Moluccas for weeks, if not months, to establish formal relations with the Islanders, oversee the harvest and storage of the spices, weigh and load the cargo onto the ships, collect provisions, and conduct any necessary repairs.

Pigafetta further describes the voyage as they crossed the equator and eventually sighted the Marianas:

After we passed the equinoctial line, we sailed between west and northwest, and west by north, and then we made two hundred leagues toward the west, and changed course to west by south as far as thirteen degrees toward the Arctic Pole... After sailing sixty leagues on the aforesaid course, and being in twelve degrees of latitude

²⁷ Pigafetta, *Magellan's Voyage*, 15.

²⁸ Torodash, 'Magellan historiography', 318.

²⁹ Francis Henry Hill Guillemard, *The Life of Ferdinand Magellan and the First Circumnavigation of the Globe, 1480-1521* (London 1890), 222.

and one hundred and forty-six of longitude, on Wednesday the sixth of March we discovered a small island to the northwest, and two others toward the southwest.³⁰

Pigafetta then briefly notes, with little fanfare, their first sighting of a major and populated land mass since sailing into the Pacific several months earlier:

One of these islands was larger and higher than the other two. And the captain-general wished to approach the largest of these three islands to replenish his provisions. But it was not possible, for the people of those islands entered the ships and robbed us so that we could not protect ourselves from them.³¹

Magellan had reached the Marianas, initially named *Isla de las Velas Latinas* or 'Islands of the Lateen Sails' and then *Los Ladrones*, or 'Islands of Thieves', on 6 March 1521.³² The first island sighted was probably Rota, although Guam is where they eventually anchored and made contact with native Chamorros. Maximilian of Transylvania, who interviewed the survivors of the *Victoria*, records the native names *Inuagana* and *Açaça*, equated by Guillemard with *Hagåtña* in Guam and *Sosan* in Rota.³³

Their contact with the Chamorros was brief and violent. They were first met by dozens of canoes, but the natives stole several items, including Magellan's personal skiff. The captain retaliated by sending his men to the village, who burned several huts, killed a number of men, and retrieved the boat. They decided then to travel west-southwest and, a month later, on 7 April 1521, Magellan landed on the island of Cebu in the Philippines. Ironically, Magellan never did see the Moluccas which he had tried so hard to find, as he was later killed in a skirmish with competing groups on Mactan after befriending a local chief and becoming embroiled in local disputes. His effort to convert the locals to Christianity and impress his new-found ally by attacking a neighbouring village on Mactan proved fatal, and he was killed on 27 April; his body was never recovered.

Although historical accounts provide a great deal of information on the route that Magellan took, it is unclear just how much of his voyage was dictated by oceanographic conditions versus conscious decision-making to proceed in a particular direction. It is also interesting that Magellan's fleet only sighted two uninhabited islands during the trip. The islands west of 160°W are small and arranged in tightly clustered parallel formations, and may have inhibited the easy sighting of islands; island size and configuration could help explain the reason why they were never seen (something noted in later voyages by Schouten and Le Maire in 1616). Nonetheless, it is still puzzling and requires further examination.

³⁰ Pigafetta, *Magellan's Voyage*, 58–60.

³¹ *Ibid.*, 60.

³² Joyner, *Magellan*, 174.

³³ Maximilian the Transylvanian, 'A letter from Maximilianus Transylvanus to the most Reverend Cardinal of Salzburg', in Stanley, *The First Voyage round the World by Magellan*, 198; Guillemard, *The Life of Ferdinand Magellan*, 223, n. 2. See also R.A. Skelton's note in Pigafetta, *Magellan's Voyage*, 158.

The Simulation Program

To examine the route that Magellan's fleet may have taken in their crossing of the Pacific, we conducted computer simulations of voyaging based on detailed oceanographic, anemological, and climatological data to postulate how their ships may have moved or reacted to ocean conditions during the times of the year when they sailed. We also tested the track that their voyage may have taken had they sailed during other times of the year, to examine whether this would have affected their trajectory.

This approach to studying seafaring has been used increasingly to investigate issues surrounding human colonisation, migration and culture contact in the Pacific Islands,³⁴ the Caribbean,³⁵ between Central and South America,³⁶ from Japan to North America,³⁷ and other regions worldwide.³⁸ The results of these simulations can then be coupled with other data to develop more robust hypotheses regarding the movement of peoples, both prehistorically and historically, across vast distances of open ocean.³⁹

The program is based on the United States Navy *Marine Climatic Atlas* and includes all the world's seas and oceans with the exception of Arctic waters.⁴⁰ The data are organised at a resolution of one degree Marsden squares (one degree of longitude by one degree of latitude). This allows the effects of smaller and more variable currents to be accurately reflected in the outcomes. The program also automatically shifts to the database for the following month after the month originally selected for has expired. This feature better reflects the reality of changing wind and current conditions over long voyages. A conversion to spherical coordinates has also been added in order to increase positional accuracy outside the tropics. Within the tropics, one degree of longitude is roughly equal to one degree of latitude, making fairly accurate calculations possible using plane geometry as if the world were flat. As one moves away from the equator a degree

³⁴ Michael Levison, R. Gerard Ward and John W. Webb, *The Settlement of Polynesia: a computer simulation* (Canberra 1973); Geoffrey Irwin, *The Prehistoric Exploration and Colonisation of the Pacific* (Cambridge 1992); Chris Avis, Álvaro Montenegro and Andrew Weaver, 'The discovery of Western Oceania: a new perspective', *Journal of Island and Coastal Archaeology*, 2 (2007), 197–209; Richard T. Callaghan and Scott M. Fitzpatrick, 'On the relative isolation of a Micronesian archipelago during the historic period: the Palau case study', *International Journal of Nautical Archaeology*, 36 (2007), 353–64; Richard T. Callaghan and Scott M. Fitzpatrick, 'Examining prehistoric migration patterns in the Palauan archipelago: a computer simulated analysis of drift voyaging', *Asian Perspectives*, 47: 1 (2008), 28–44.

³⁵ Richard T. Callaghan, 'Ceramic age seafaring and interaction potential in the Antilles: a computer simulation', *Current Anthropology*, 42 (2001), 11–22; Richard T. Callaghan, 'Comments on the mainland origins of the Pre-ceramic cultures of the Greater Antilles', *Latin American Antiquity*, 14 (2003), 323–38.

³⁶ Richard T. Callaghan, 'Prehistoric trade between Ecuador and west Mexico: a computer simulation of coastal voyages', *Antiquity*, 77 (2003), 796–804; Richard T. Callaghan and Warwick Bray, 'Simulating prehistoric sea contacts between Costa Rica and Colombia', *Journal of Island and Coastal Archaeology*, 2 (2007), 4–23.

³⁷ Richard T. Callaghan, 'The use of simulation models to estimate frequency and location of Japanese Edo period wrecks along the Canadian Pacific Coast', *Canadian Journal of Archaeology*, 27 (2003), 62–82.

³⁸ Chris Avis *et al.*, 'The discovery of Western Oceania', 197–209.

³⁹ Richard T. Callaghan, 'Computer simulations of ancient voyaging', *The Northern Mariner*, 9 (1999), 11–22.

⁴⁰ United States Navy, *Marine Climatic Atlas of the World* (Asheville 1995).

of longitude progressively becomes shorter, making spherical geometry a necessity, particularly over long distances. Finally, the program allows the operator to change the heading of a vessel during a voyage to reflect decisions made by the crew. This last feature is important when assessing the level of skill required to reach a selected target.

In its basic operation, the program makes a random selection of direction and speed for winds and currents from the *Marine Climatic Atlas* database.⁴¹ These data are compiled from ship reports and other sources since the early 19th century. Lieutenant Matthew Fontaine Maury of the US Navy began the compilation and published his *Wind and Current Charts of the North Atlantic* in 1847.⁴² This was quickly followed by several other similar charts of the other oceans of the world. The data came from ships belonging to numerous nations, and Maury convinced mariners to make regular reports on the conditions they encountered. This was at the height of global trade by sail and understanding wind and current patterns could greatly shorten voyages and increase profits. These charts are the origin of current pilot charts.

In the simulation, a course is chosen for the vessel unless undirected drift voyages are being investigated. Performance data, calculated using either naval architecture programs or field tests, are then used to calculate the ratio of vessel velocity to true wind velocity. Wind and current forces are allowed to affect the vessel for a 24-hour period, and a new position for the vessel is then calculated. A new heading is chosen every 24 hours to move the vessel in the desired direction. Essentially, this is the same process a navigator would use in plotting a course on a chart.

In this case, the first simulation was an attempt to follow the reconstructed course that Magellan took across the Pacific Ocean beginning on 28 November 1520 (Figure 1). The goal of this simulation was to identify any marine conditions that would have forced Magellan to follow the route that he did. Three other voyages were simulated, beginning on the 28 February, 28 May and 28 August. These were conducted in order to determine whether the outcome of the voyage would have been different if it had taken place at a different time of year. In these simulations, the route of Magellan was again followed. In effect, the simulations followed Magellan's decisions as to course.

Finally, three alternative strategies were simulated in order to determine whether Magellan had other options in his choice of routes. In the first strategy (Figure 2), a heading of due west was chosen as soon as conditions allowed. In the second strategy (Figure 3), rather than sailing north and northwest after reaching approximately 15°S and 140°W, a heading of due west was chosen. In the third strategy (Figure 4), a route was chosen northward parallel to South America until reaching approximately 15°S, when the heading became due west. All three of these alternative strategies would have avoided crossing the doldrums.

⁴¹ Ibid.

⁴² Matthew Fontaine Maury, *Wind and Current Chart of the North Atlantic* (Washington 1847).

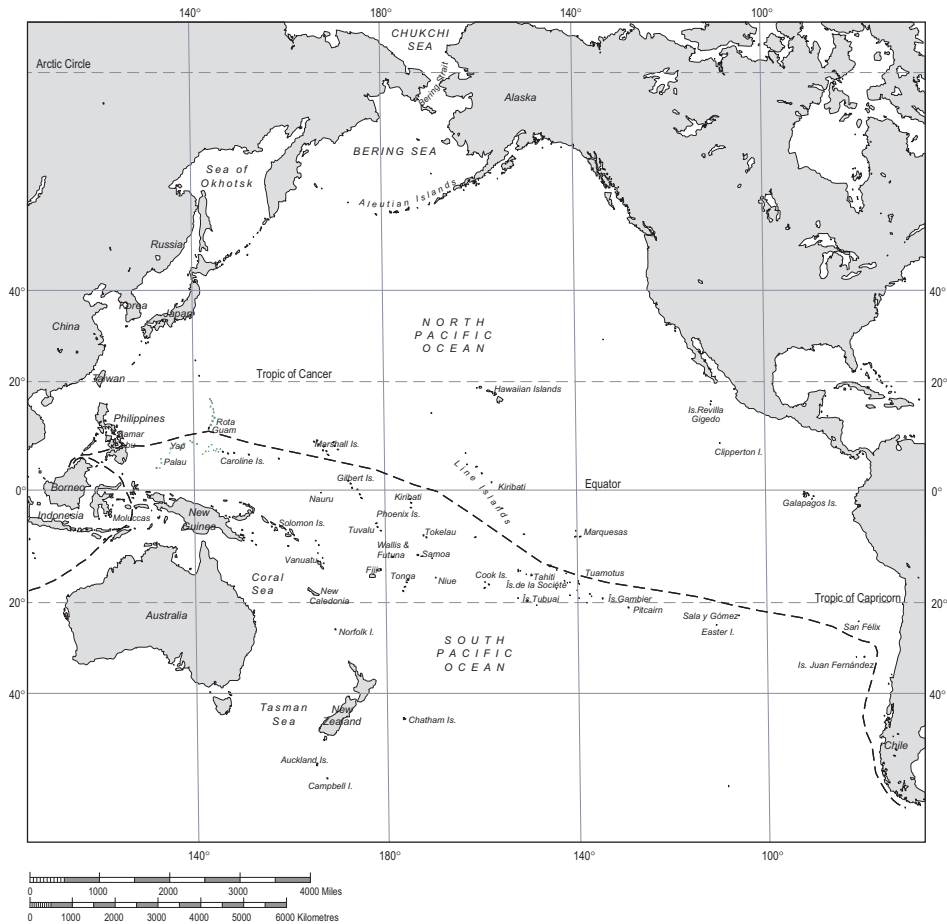


FIGURE 1: Map of the Pacific showing Magellan's probable route based on historical records, adapted from Antonio Pigafetta, *The Voyage of Magellan*, trans. Paula Spurlin Paige (Upper Saddle River 1969).

Results of Simulations

Upon leaving the Cape of Desire on Wednesday, 28 November 1520, Magellan's course was northward, parallel to the coast of South America until reaching a position north of Chiloe Island. Prior to running the simulation, an examination of the pilot charts of the South Pacific indicated that this course would have been difficult to maintain under normal conditions.⁴³ Recorded wind directions in the area for November between 55°S and 50°S are from the NW 30% of the time and W 31% of the time. Winds are from the SW about 15% of the time. Although some of this may favour sailing northward, they are strong at force 6 on the Beaufort scale. Coupled with currents from the west causing drift of 5–15 nautical

⁴³ National Imagery and Mapping Agency (hereafter NIMA), *Atlas of Pilot Charts, North Pacific Ocean*, NVPUB 108 (Reston VA 1994); NIMA, *Atlas of Pilot Charts, South Pacific Ocean*, NVPUB 107 (Reston VA 1998).

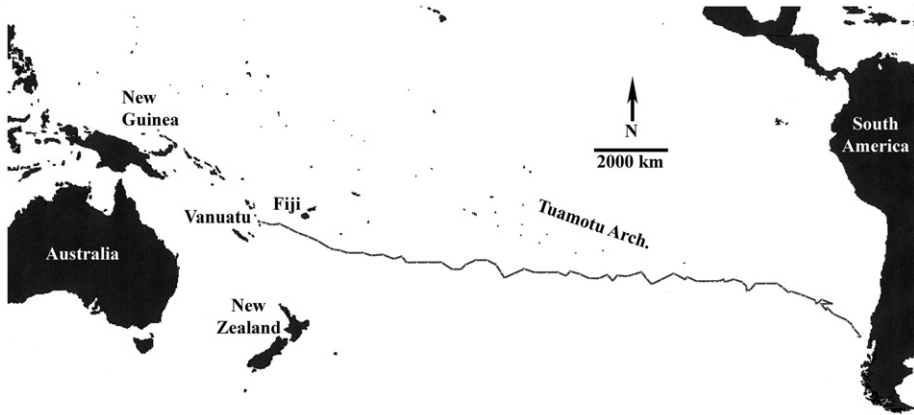


FIGURE 2: Simulation of a heading due west when conditions allowed.

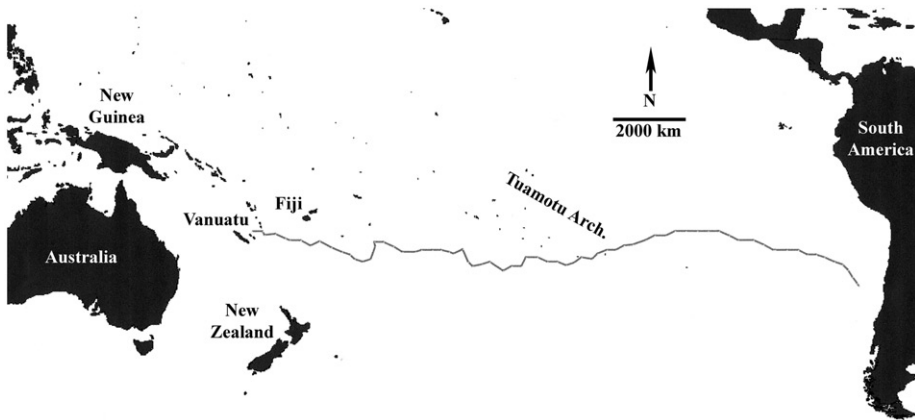


FIGURE 3: Simulation of a due west heading, rather than sailing north and northwest after reaching approximately 15°S and 140°W.

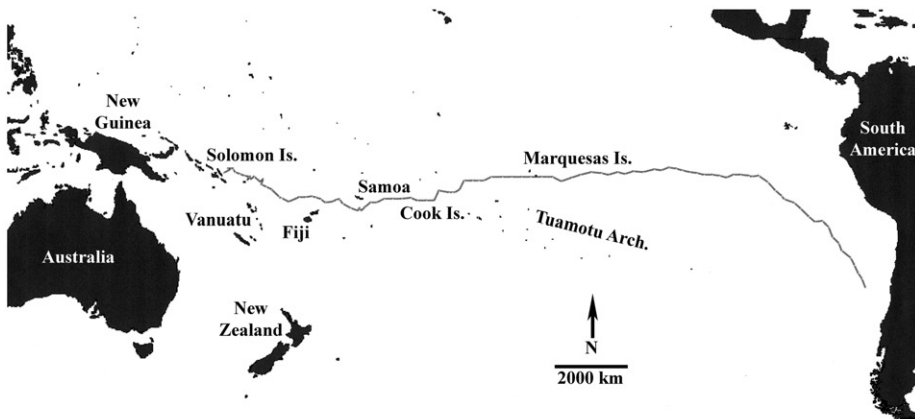


FIGURE 4: Simulation of a route chosen northward parallel to South America until reaching approximately 15°S when the heading became due west.

miles per day towards South America, and then moving around Cape Horn into the Atlantic, it would have been difficult to stay offshore. Further, Pigafetta states that they encountered no storms during the entire voyage across the Pacific.⁴⁴ The pilot charts give the average percentage of ships reporting gales of force 8 or greater in the region as 28% in November.⁴⁵

Continuing northward and moving ahead to December, between 50°S and 45°S, the most likely wind conditions to encounter are 31% from the NW, 20% from the W, and 15% from the SW. The speeds of these winds average 5, 5 and 4 on the Beaufort scale, respectively. Under normal conditions, Magellan would have begun to pick up winds blowing from the south at about 45°S. Currents shift northward with an expected daily drift of 5–20 nautical miles. For ships passing through the region, reported gale activity for the month is 5%. Further north, and approaching the point where Magellan is thought to have begun to sail more westward, winds are still primarily expected to be from the NW, W and SW. However, these winds are lighter on average, and winds from the south increase to about 15% at force 4. The currents continue to set to the north with drift of 10–20 nautical miles per day. Gale activity drops to 3% of reports.

All of this suggests that marine conditions at the time of Magellan's entrance into the Pacific Ocean were unusual. These conditions probably continued until about 40°S. After this, expected conditions become very favourable for Magellan's crossing of the Pacific with good winds and currents and little likelihood of gales. Without the unusual weather, the fleet would have had to take Magellan's alternative route as far as 75°S,⁴⁶ thus leading them deep into Antarctica. Pigafetta also surmised that, if they sailed due west, they would eventually return to the eastern entrance of the Straits without hitting land.⁴⁷ This is most likely true, although they may have encountered the Kerguelen Islands in the Indian Ocean.

The first simulation run was set to begin on 28 November at Cape Desire. It proved to be virtually impossible to make any headway to the north. The vessel was constantly pushed to the southeast, although, as would be expected, some occasional progress was made. This was then lost in subsequent movement. Even intervening in the simulation and giving the nearly impossible headway of four knots, regardless of wind direction and speed, the vessel tended to move south and then east around the Horn into the Atlantic. It was then decided to begin the simulation starting at about 47° 50' S on 15 December. December 16 was the day Magellan shifted his course from north to northwest.⁴⁸ Initially, the vessel moved south, but then proceeded north, and from there it was quite easy roughly to follow Magellan's route to the Marianas

⁴⁴ Pigafetta, *The Voyage of Magellan*, 57.

⁴⁵ NIMA, *Atlas of Pilot Charts, North Pacific Ocean*; NIMA, *Atlas of Pilot Charts, South Pacific Ocean*.

⁴⁶ Pigafetta, *The Voyage of Magellan*, 53.

⁴⁷ *Ibid.*, 58.

⁴⁸ *Ibid.*, 157.

by simply keeping headings to the N, NW and W, much as Pigafetta and Albo describe (Table 1).⁴⁹

The simulated vessel reached the Tuamotus at the end of January, a few days later than Magellan, who sighted the first of the 'Isles of Misfortune' on 24 January. This difference is most likely due to the initial movement south in the simulation. Interestingly, the Marianas were reached on 6 March, the same day as Magellan, although there was no attempt deliberately to achieve this result. The simulated voyage took 81 days, while Magellan's took 98 days. However, as the simulation started about six degrees north of Magellan's entrance into the Pacific Ocean, and 18 days later, it does suggest that, for 18–20 days out of the Straits, the weather was very unusual with a large deviation for what would be expected from the pilot charts.⁵⁰ Subsequent weather conditions throughout the rest of Magellan's voyage across the Pacific were in accordance with the pilot charts, favourable winds and currents, with little chance of a gale. It appears that missing all the islands in the South Pacific was a factor of decisions that Magellan made and did not have anything to do with oceanographic conditions, other than them allowing him apparently to move north fairly easily.

Further simulations were conducted starting at different times of the year to see whether Magellan might have been forced to follow an alternative course had he not entered the Pacific at the end of November. The dates chosen were 28 February, 28 May and 28 August. For February, it proved easier to sail northward from Cape Desire than in November. However, this did require intervening in the simulation by giving the vessel an unrealistic headway. For May and August, simulations had to be started at 47°50' S. Once the vessel sailed northwest away from South America, it was easy to follow Magellan's route to the Marianas. One slight divergence from the first simulation is that in February, the voyage took 77 days, in May it took 72 days, and in August it took 70 days. Since the voyages in May and August started north of Magellan's original location, about two weeks had to be added onto the total voyage time. In the end, this suggests that Magellan may have made slightly better time crossing the Pacific if he had begun at a different time of the year. During the first weeks of the crossing, Magellan had exceptional luck in the marine conditions, but he had no luck in his decisions thereafter.

All of the alternative routes encountered the same contrary weather as would be expected under normal conditions.⁵¹ Similar to replicating Magellan's actual route, the alternative simulations had to start at about 40°S rather than at the western mouth of the Straits. In the first alternative strategy, the vessel sailed with fair weather across the South Pacific, reaching Vanuatu in about 103 days. Interestingly, no islands were encountered until Vanuatu was reached, mirroring Magellan's unfortunate northern crossing. In the second alternative strategy, Vanuatu was also where landfall was made after approximately 96 days.

⁴⁹ Antonio Pigafetta, 'Anthony Pigafetta . . . to . . . Lord Philip de Villers Lisleadon', in Stanley, *The First Voyage round the World by Magellan*, 67; see also Albo, 'Extracts from a derrotero', 219–23.

⁵⁰ NIMA, *Atlas of Pilot Charts, North Pacific Ocean*; NIMA, *Atlas of Pilot Charts, South Pacific Ocean*.

⁵¹ NIMA, *Atlas of Pilot Charts, North Pacific Ocean*; NIMA, *Atlas of Pilot Charts, South Pacific Ocean*.

However, in this case, the vessel came into close proximity to islands in the southern end of the Tuamotu Archipelago in about 56 days. The third alternative strategy, following a route westward between 15° and 10°S latitude, encountered the Marquesas after 71 days, the Cook Islands after 85 days, and Samoa after 94 days. The Solomon Islands were reached after 130 days.

HISTORICAL RECORDS INDICATE that unusually calm weather allowed Magellan's *Armada de Molucca* to move easily from the Straits into the Pacific and up the Chilean coast in November. Our computer simulations do not generally support these accounts, but this may be the result of extenuating weather conditions that fall outside the realm of statistical averages factored into the simulations. The results also demonstrate that the two uninhabited islands encountered by the crew in late January 1521 were probably part of the Tuamotu Archipelago.

The weather around the southern tip of South America is notoriously treacherous in all seasons — even much larger and better rigged ships than the *Victoria* often met with disaster. Wrecks abounded when vessels entered these waters during the California gold rush (1848–55),⁵² despite advances in naval architecture over the preceding three centuries. Many of the vessels were refitted whaling ships which were considerably larger than the *Victoria* and designed for Arctic and Antarctic waters.⁵³ The Straits of Magellan were relatively little used until 1899, but lost traffic after the opening of the Panama Canal.⁵⁴ The later vessels, however, were of a different sort entirely, being modern steel cargo steamers, some in the range of 18,000 tonnes.

After Magellan, two voyages through the Straits are of note because of weather conditions. The first was that of Sir Francis Drake in 1578. Drake made it through the Straits in about 17 days.⁵⁵ The weather was unusually favourable within the Straits, but returned to its usual contrariness soon after he entered the Pacific. Riesenbergs reconstructed Drake's course off the southwest of Chile.⁵⁶ The conditions Drake met here are very similar to those that resulted in the simulations. The interesting point, though, is the relatively calm conditions Drake encountered in the Straits and their meteorological causes. The second voyage remarkable for good conditions was that of Cook around Cape Horn in 1769. This was one of the easiest voyages in those waters ever recorded and cannot be attributed simply to improved naval architecture.⁵⁷

Had Magellan entered the Pacific at a different time of the year, but kept the same headings as described by Albo and Pigafetta, their voyage still would probably have succeeded in reaching the Marianas by passing through the northern Tuamotus, but in a shorter period (perhaps as much as 11 days in the simulated voyage). Although conditions were exceptionally calm when Magellan

⁵² Riesenbergs, *Cape Horn*, 313.

⁵³ Albert Cook Church, *Whale Ships and Whaling* (New York 1960).

⁵⁴ Riesenbergs, *Cape Horn*, 363–8.

⁵⁵ *Ibid.*, 64–5.

⁵⁶ *Ibid.*, Plate II.

⁵⁷ *Ibid.*, 210.

entered the Pacific, his decision to follow a particular course, generally N/NW, does not appear to have been influenced by any overriding oceanographic factors. The three alternative strategies for crossing the Pacific demonstrate that this was the case. Magellan could have crossed at any southern latitude and avoided the risk of being becalmed in the doldrums.

If currents and winds as historically recorded⁵⁸ did not play a major role in the route that Magellan took, why did he choose to travel so far north of the equator, especially considering that he must have been under intense pressure from the crew to find land as the voyage dragged on over a period of several months? During the trip, Pigafetta noted in his journal:

we remained three months and twenty days without taking on board provisions or any other refreshments, and we ate only old biscuit turned to powder, all full of worms and stinking of the urine which the rats had made on it, having eaten the good. And we drank water impure and yellow. We ate also ox hides which were very hard because of the sun, rain, and wind. And we left them four or five days in the sea, then laid them for a short time on embers, and so we ate them. And of the rats, which were sold for half an écu apiece, some of us could not get enough.⁵⁹

Could it be that Magellan still believed that the Moluccas were still not so far distant, hoping each day would be their last before sighting land? The crew was also in fairly good spirits after having successfully navigated through the Straits. This had the effect of temporarily revitalising their strength for the final push to the Moluccas, which they still believed were only a few days away.

Their scouting expeditions, as well as the addition of fresh vegetables to their diet, boosted their spirits and their health. Their passage through the strait, while strenuous, was far healthier than being at sea for long stretches, within the unsanitary confines of the ships, subsisting on a diet of salty, spoiled food and wine.⁶⁰

But historical accounts indicate that the crews were suffering severely from dehydration, malnutrition, scurvy and exhaustion, despite the short reprieve. Twenty-nine men and one Indian died from scurvy alone after leaving the Straits. 'Besides those who died, twenty-five or thirty fell sick of divers maladies, whether of the arms or of the legs or other parts of the body, so there remained very few healthy men.'⁶¹ The men had been so ill with scurvy after reaching the Marianas in fact, that they begged the landing party in Guam to recover the intestines of slain Chamorros so that they could eat them, believing this would cure their illness. Would Magellan have purposefully continued on this track, given the increasingly poor condition of his crew?

One possible explanation for why Magellan chose this route is that he simply desired to sail with the existing winds and currents which were moving them at a

⁵⁸ NIMA, *Atlas of Pilot Charts, North Pacific Ocean*; NIMA, *Atlas of Pilot Charts, South Pacific Ocean*; United States Navy, *Marine Climatic Atlas of the World*.

⁵⁹ Pigafetta, *Magellan's Voyage*, 57.

⁶⁰ Bergreen, *Over the Edge of the World*, 201.

⁶¹ *Ibid.*, 215.

good speed of 50–60 leagues westward per day, thereby reducing the number of men needed to attend to the ships. Most sailors were physically unable to perform their duties anyway, and simply allowing the ships to generally drift with the prevailing conditions would have eased the burden on everyone, as opposed to trying to sail with greater effort along the equator toward the Moluccas. Although Magellan was probably under intense pressure to reach their destination, it could have been an adept manoeuvre that took them along the path of least resistance, allowing continual westward movement and the conservation of much needed energy as they sailed across the vast and seemingly endless ocean. However, he could have sailed west and south of the equator as easily, again avoiding the possibility of being becalmed.

An alternative hypothesis might be that Magellan's claim of the Moluccas having no food actually had some substance. Did letters received from Serrão hint of poor conditions in Ternate? And if so, could these be related to El Niño effects which are known to have caused extensive droughts throughout Island Southeast Asia historically and in modern times?

Two further questions arise when considering Magellan's crossing of the Pacific. The first results from the simulation of his voyage. Given the near impossibility of moving a vessel of Magellan's time in the simulation from the Pacific side of the Straits northward along the southern coast of Chile, why did Magellan have such unusually fair weather both in the Straits and during the early part of his voyage into the Pacific? The second question arises out of the account of the voyage by Magellan's 'Genoese Pilot', where he attributes their sailing far to the north of the Moluccas to the fact that there was information that no food was available.⁶²

The answer to the first question lies in the conditions met by Sir Francis Drake and Captain James Cook, two later circumnavigators of the globe. When Drake entered the Straits of Magellan in 1578, he encountered extremely mild conditions where normally the weather is extremely dangerous.⁶³ He then emerged into the Pacific only to confront massive storms for months that scattered his ships and destroyed one, the *Marigold*. These conditions correspond to the tail end of the major El Niño as proposed by Quinn *et al.*⁶⁴ An El Niño event has been reconstructed from tree ring data in the years of Magellan's voyage, 1519 and 1520, and it may well have begun in 1518.⁶⁵ These events have

⁶² Pigafetta, *The Voyage of Magellan*, 158, note 5.

⁶³ Riesenber, *Cape Horn*, 59–80; Oliver Seeler, 'Drake and El Niño' (<http://www.mcn.org/2/oseeler/elnino.html>) (1997). Accessed 23 Aug. 2006.

⁶⁴ W.H. Quinn, V.T. Neal and S.E. Antenez de Mayolo, 'El Niño occurrences over the past four and a half centuries', *Journal of Geophysical Research*, 92 (1987), 449–61.

⁶⁵ Edward R. Cook, 'Niño 3 Index Reconstruction. International Tree-Ring Data Bank', IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series #2000-0052. NOAA/NGDC Paleoclimatology Program (Boulder CO 2000); Rosanne D'Arrigo, Edward R. Cook, Rob J. Wilson, Rob Allen, and Michael E. Mann, 'On the variability of ENSO over the past six centuries', *Geophysical Research Letters*, 32 (2005), L03711.

also been documented archaeologically in Peru, suggesting there was increased El Niño–Southern Oscillation (ENSO) frequency around and after the year 1500.⁶⁶ In Cook's case, there also appears to be an extended period of El Niño conditions centred on 1769.⁶⁷ If a major El Niño can account for the abnormal weather experienced by Drake and Cook, it should equally apply to Magellan's good fortune. The continued fair weather encountered crossing the Pacific early in 1521 is what would be expected under normal conditions. By 1521, the proxy data presented by the palaeoclimatologist Edward R. Cook suggests that there was a cessation of El Niño conditions as Magellan began moving westward.⁶⁸

Turning to the second question, nothing seems to have prevented Magellan taking an alternative and likely less risky route. However, if the northern route was chosen because of a lack of food in the Moluccas, Magellan would have had to hear accounts of this by 1519 in Portugal before he began working for the Spanish. Drought and accompanying famines are associated with El Niño in Island Southeast Asia and these can be exacerbated when preceded or followed by unusually wet conditions associated with La Niña, as Edward R. Cook's figures appear to suggest.⁶⁹ An example would be the 1877–78 El Niño, followed by the La Niña of 1879, with Dutch records showing substantial drops in populations in the region as a result.⁷⁰ If Serrão's letters suggested there were extended droughts or low levels of food production, this would help explain Magellan's decision to move farther north, allowing them to re-provision before landing in the Moluccas. The western reaches of the South Pacific were unknown to Magellan, but the western fringes of the North Pacific were, however poorly. Unfortunately, the original correspondence between Serrão and Magellan was destroyed in the Lisbon earthquake of 1755; all that remains are accounts written by early Portuguese historians that do not discuss these issues in detail.⁷¹

Our analysis of Magellan's voyage across the Pacific using computer simulations and historical accounts suggests that exceptional weather conditions allowed the remnants of the *Armada de Molucca* to proceed easily northward along the South American coast after passing through the southern Straits. Although it remains unclear what the underlying reasons were behind Magellan's decision to continue northward, if Serrão's letters had given some indication of drought conditions occurring in the Spice Islands, ENSO-related phenomena across the Pacific between 1518 and 1521 may have been largely responsible for structuring the route and extent of what many consider to be the world's

⁶⁶ Daniel H. Sandweiss, Kirk A. Maasch, Richard L. Burger, James B. Richardson III, Harold B. Rollins, and Amy Clement, 'Variation in Holocene El Niño frequencies: climate records and cultural consequences in ancient Peru', *Geology*, 29 (2001), 603–6; Daniel H. Sandweiss, Kirk A. Maasch, Fei Chai, C. Fred T. Andrus and Elizabeth J. Reitz, 'Geoarchaeological evidence for multidecadal natural climatic variability and ancient Peruvian fisheries', *Quaternary Research*, 61 (2004), 330–4.

⁶⁷ Cook, 'Niño 3 Index Reconstruction'; D'Arrigo *et al.*, 'On the variability of ENSO over the past six centuries'.

⁶⁸ Cook, 'Niño 3 Index Reconstruction'.

⁶⁹ *Ibid.*

⁷⁰ H.C. Brookfield, L. Potter and Y. Byron, *In Place of the Forest: environmental and socio-economic transformation in Borneo and eastern Malay Peninsula* (Tokyo 1995), 165–6.

⁷¹ Bergreen, *Over the Edge of the World*, 417.

greatest voyage. Magellan's voyage itself is probably the earliest historical record of ENSO phenomena.

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ABSTRACT

On 28 November 1520, Ferdinand Magellan and his depleted fleet of ships, with fair weather, sailed around the tip of South America in what would be the world's first successful circumnavigation of the globe. Magellan's main objective was to find a westward route to the Moluccas or 'Spice Islands' on the equator and claim their wealth for the Spanish Crown. However, instead of reaching the Moluccas first, Magellan landed on Guam in the northwest Pacific at 12°N on 6 March 1521, passing only two uninhabited islands along the way. Three questions arise: first, why did he have such fair weather on leaving the Straits in a region notorious for severe conditions? Second, why did Magellan sail so far north of the Moluccas, which he knew to lay at the equator, especially considering that the crew was suffering from severe malnutrition, dehydration and scurvy? Third, how did the fleet sail more than 15,000 kilometres without sighting any of the thousands of islands scattered throughout the Pacific? We postulate that the answers to these questions are linked. Using computer simulations, the authors examine the extent to which oceanographic conditions, a possible El Niño event and decisions made by Magellan helped structure one of the world's most famous voyages.