Using the jet stream for sustainable airship and balloon cargo and hydrogen transportation

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Abstract

The maritime shipping sector is responsible for around 3% of the total CO_2 emissions and are expected to increase from between 50% to 250% from 2012 to 2050 depending on economic growth and development[1]. There are several alternatives for reducing the emissions from shipping, such as lower ship speeds, using of sails[2], improving overall logistics or switching the fuel to hydrogen produced through renewable energy[3]. This research proposes the utilization of the jet stream to transport airships or balloons at altitudes of 10 to 20 km for a combination of cargo and hydrogen transportation in a future sustainable world. The jet streams flow in mid-latitudes predominantly in the west-east direction, reaching an average wind speed of 165 km/h[4]. Using this combination of high wind speeds and reliable direction, hydrogen filled up airships or balloons could be used to carry hydrogen with small fuel requirements and short travel times compared to conventional shipping. Jet streams at different altitudes in the atmosphere were used to identify the most appropriate circular routes for a global airship travel. Round the world trips would take 16 days in the northern hemisphere and 14 in the southern. This alternative mode for hydrogen transport could compete liquefied

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hydrogen tankers in the development of a sustainable future hydrogen economy, especially due to its lower energy consumption and shorter delivery time for cargo transportation.

Key words: jet stream, emissions, transport, hydrogen, shipping

Introduction

Airships, an alternative that has received increased attention in recent years from researchers and investors, were introduced in the first half of the 20th century[5], preceding the use of conventional aircraft for the long-range transport of cargo and passengers. However, it discontinued due to several reasons, such as, the risks involving a hydrogen explosion[6], lower speed when compared with airplanes, weather unreliability, lack of reliable weather forecasts at the time and finally the increased availability of cheap petroleum fuels, which reduced the costs of conventional air transport that is a more convenient, faster and safer alternative for long-range transportation.

The airship has been receiving increasing attention due to the current need for reducing CO_2 emissions and energy consumption to achieve the 1.5^{o}C maximum world average temperature increase established in the Paris Agreement, the foreseen growth in the maritime shipping, the availability of new materials and significant improvements in weather forecasts. Airships have been used or proposed for military uses[7], broadband services[8], as an alternative for exploration of other planetary bodies[9]**,** high altitude platform systems for surveillance and photography[10], stratospheric tourism[11], racing competitions, advertisement, and reduce incoming solar radiation with the release particles in the stratosphere[12]. Another major area of research and investment is the airship for cargo transportation[13], such as food delivery[14], and humanitarian aid[15] are also being considered.

Airships flying in the jet stream can reduce CO_2 emissions and fuel consumption for hydrogen and cargo transportation. The jet stream would contribute to the majority of the energy required to move the airship between destinations. The energy requirement relates to the needs to vary the pressure inside the airship to change its altitude. An example of using the jet stream for high speed transportation happens in balloon races (Fig. 1 b)[16].

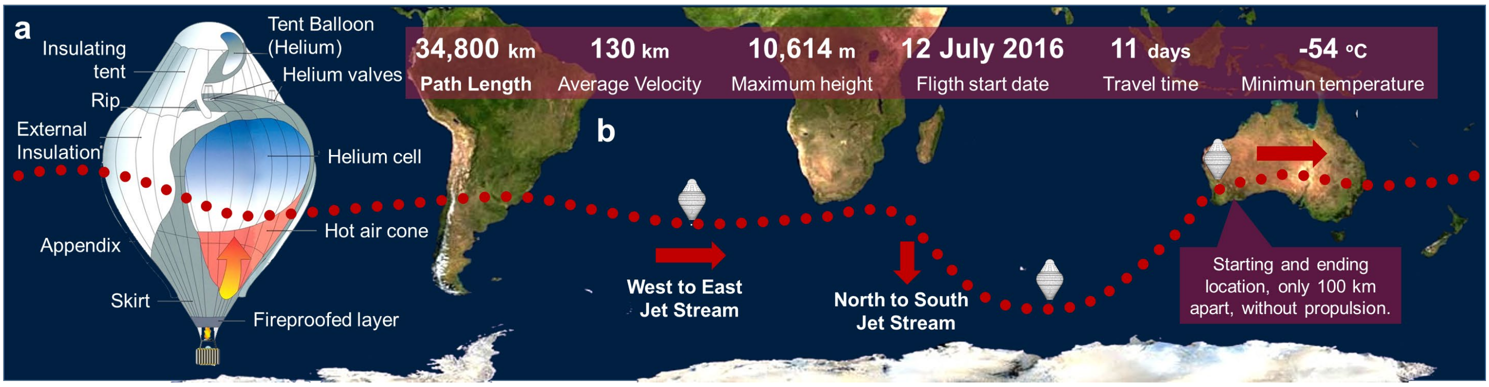


Fig. 1 | Latest ballooning around the world record [16]**. a,** Roziere balloon components used on the trip, it combines the buoyancy created from helium gas and increases in temperature by burning propane. Propane is used to vary the altitude of the balloon to catch appropriate wind speed and direction to reach the final destination in the shortest time. **b,** Global circumnavigation in 11 days set in 2016 by the Russian Fedor Konyukhov in the Southern hemisphere, including the route and other details. The balloon latitude varied from -27 to -60 degrees of latitude.

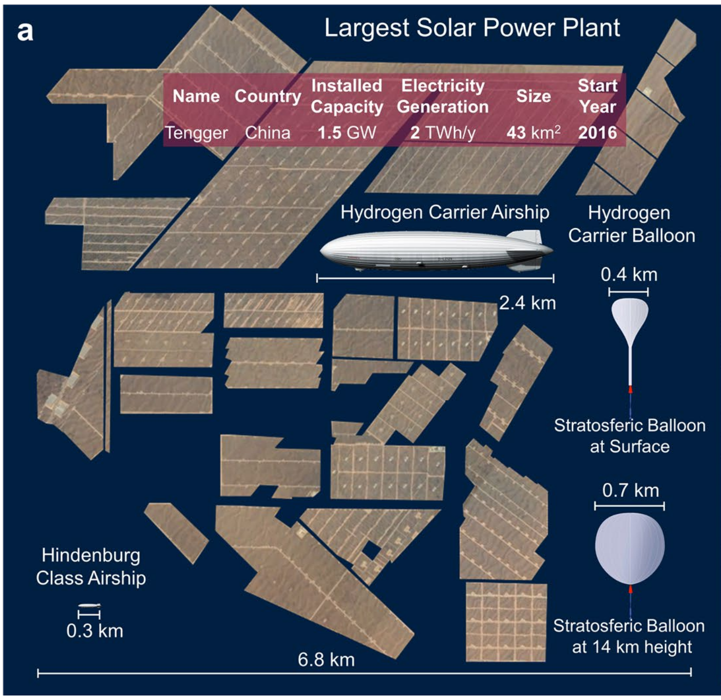
At present airships can be filled with helium to create enough buoyancy for the airship to stabilize at heights between 10 to 20 km (avoiding airplanes during most of its journey), although high costs reduce the commercial viability, especially if there were large demands from the sector. In comparison, hydrogen is cheap and abundant[17–19], however, poses a larger risk[20], due to the possibility of explosion, such as the Hindenburg disaster, which is the main reason why airships were discontinued[21]. Around 90% of the reported accidents with hydrogen airships involved fire and the majority involved fatalities[22]. If airship transportation, unloading and loading were to be performed autonomously, airship ports located in isolated areas and they were not allowed to pass above large cities at low altitudes, the risk of fatalities with hydrogen airships would reduce considerably.

Hydrogen is a good energy carrier and a valuable energy storage alternative, with a gravimetric energy density (120 MJ/kg) three time higher than that of gasoline[22]. Given that renewable electricity, for example excess wind power, can be transformed into hydrogen through the electrolysis of water, many are optimistic that the hydrogen economy will form a fundamental part of a clean and sustainable future[23]. The most promising progress to date has been in the vehicle transport sector of Japan[24], with more than 100 hydrogen filling stations as of 2018. Challenges of implementing a hydrogen based economy involve cooling to -253°C and liquefaction of the hydrogen, which consumes approximately 30% of the embodied energy[25], with further energy required for transport of around 3%, assuming hydrogen has a higher energy density than LNG[26]. The energy consumed and costs involved with hydrogen liquefaction significantly hinders the viability of a hydrogen based economy.

However, hydrogen could be transported in large airships or balloons filled with hydrogen. Instead of using energy in liquefaction, hydrogen can be transported in gaseous form inside the airship or balloon and transported by the jet stream with lower fuel requirements. Once the airship or balloon reaches its destination the cargo is unloaded and around 60% or 80% of the hydrogen used for lift removed, respectively. 40% or 20% of the hydrogen has to stay in the airship or balloon so that there is enough hydrogen for the return trip without the cargo. This assumes that the weight of the airship without cargo and hydrogen is around 40% or 20% of the weight of the airship or balloon with cargo and without hydrogen. In the Hindenburg, around 30% of the weight was for cargo and 70% for the airship itself. This reduction in airship and balloon weight is due to advances in materials engineering and gains with scale, especially with the reduced envelope requirements.

The energy consumption for transporting hydrogen with airships or balloons is mostly related to the energy required to pressurize the hydrogen to change its height or to return to the surface. This consists of around 12% of the energy it carries. Assuming that the hydrogen is stored in tanks with a total pressure of 25 bar, the average compression energy is 1.7 kWhe/kg of H2[27], the energy used to pressurize the hydrogen comes from fuel cells 70% efficient, that 30% of the energy from decompression is stored and reused, 90% of the hydrogen in the airship or balloon has to be pressurized twice (once full and once empty) to reach the surface and a similar amount of energy is required to gain or lose altitude to fly at the most appropriate wind speeds. Note that part of this energy requirement could be generated with solar arrays on the top of the airship or balloon. Compared to liquefied hydrogen tankers, the energy consumption is around three times smaller. Another advantage of airships over liquefied hydrogen tankers is that they also carry cargo and has a shorter delivery time.

To date, the largest airships ever constructed were the Hindenburg class airships developed in the 1930s[28,29], which allowed a crew of 40 people, 72 passengers, had a length of 245 m, diameter of 41 m, volume of 200,000 m^3 and a useful lift of 10 tons. The envelope area and hydrogen or helium gas volume ratio reduce considerably with the increase in airship dimensions. For example, a tenfold increase of the diameter and length of the airship will increase by 1,000 times the hydrogen volume stored and its useful lift, but only increase the envelope material (surface area) by a factor of 100. This means that the cost of the envelope of the airship reduces tenfold (Fig. 2).



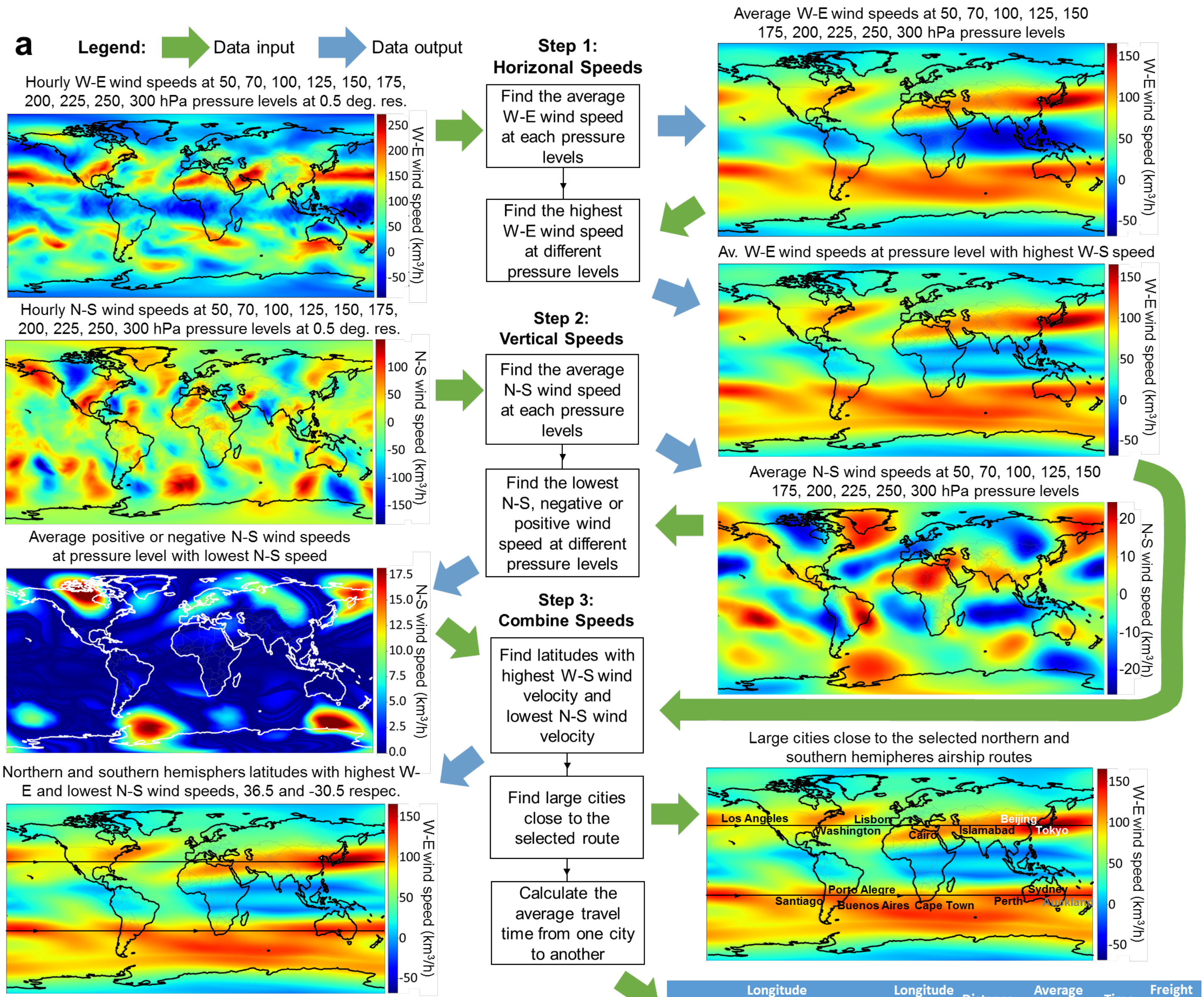
b Airships and Balloons Hydrogen Carries

Description	Hindenburg class	Airship hydrogen carrier	Balloon hydrogen carrier* Stratosphere	Balloon hydrogen carrier* Sea level
Type	Rigid		Non-rigid	
Dimensions				
Dimensional increase	x 1	x 10	x 2.97	x 1.58
Length (m)	245	2453	727	386
Diameter (m)	41.2	412	727	386
Volume				
Volume ratio	x 1	x 1,000	x 1,000	x 1,000
Hydrogen Volume (km^3)	0.0002	0.2	0.2	0.03
Surface Area				
Envelope ratio	x 1	x 100	x 75.2	
Envelope (km^2)	0.022	2.207	1.660	
Weight				
Cargo useful lift (tons)	10	21,000	28,000	
Empty weight (tons)	25	14,000	7,000	
Total weight (tons)	35	35,000	35,000	
Cargo weight share (%)	28	60	80	
Hydrogen weight (tons)	3.3	3,280	3,280	
Hydrogen delivery (tons)	0.9	1,968	2,624	
Services				
Energy storage (GWh)	0.1	100	100	
Energy delivery (GWh)	0.03	60	80	
Deliveries per year	20-25	20-25	20-25	
Delivery & return (days)	15-20	15-20	15-20	
Other				
Maximum altitude (km)	15	15	15	

Fig. 2 │. Hydrogen airship and balloons characterizes. a, Size comparison of the largest solar power plant, the Hindenburg class airship, the hydrogen carrier airship balloon. The Tengger Desert Solar Park in China has a 1,547 MW generation capacity and generates electricity. One airship or balloon hydrogen carrier, with an energy storage of 0.1 TWh, can deliver all the energy produced by the solar power plant, assuming 25 deliveries per year, and that 80% of the hydrogen is delivered. **b,** changes in dimensions, volume, envelope area and useful lift of airships and balloons. An airship with a length 10 times larger than the Hindenburg class airship or a balloon on the surface with a length 1.6 times larger than the Hindenburg class airship would be able to transport 0.2 km^3 of hydrogen, which is equivalent to 3,280 tons of hydrogen assuming a minimum pressure in the airship or balloon of 150 hPa, at 15 km height, and a temperature of -50^{o}C (average temperature at the stratosphere) and a density of 0.0164 kg/m^3. The largest LNG tanker (Mozah) has 128,900 deadweight tonnage. Assuming, 25 deliveries around the world per year, 1,125 of these airships would be able to transport the energy equivalent to 10% of current world electricity consumption.

Docking airships are challenging due to their large side, limited control and high wind drag. Another particular issue is to maintain the airship attached to the ground during windy days. The airship hydrogen carrier (Fig. 2) has the diameter similar to the height of the Empire State Building in the USA. It would be very challenging to keep such large airship from collapsing with strong superficial winds. On the other hand, balloons hydrogen carriers are not rigid and vary in size. Its volume in the surface is around 7 times smaller than in the stratosphere (assuming that its maximum operation height is 14 km). This is convenient because the size of the balloon hydrogen carrier at the surface is only 58% larger than the Hindenburg class airship and balloon can be deflated in the case of strong wind days, thus, balloons should be the most viable and practical solution for transporting large amounts of hydrogen. Another benefit of being non-rigid is that it is lighter, which allows it to deliver more hydrogen per trip.

To estimate the time for the airship to travel between different cities, we assume the velocity of the airship is 90% of the velocity of the jet stream[30] and that the average jet stream wind speeds are constant. It is important to note that the distance traveled by the airship is not the shortest distance from one city to the other. The distance assumes the same latitude throughout the route. This is because the predominant wind patterns are W-E. The round trip travel is around 16 days in the Northern hemisphere and around 14 days in the Southern Hemisphere (Fig. 3).



Initial city	Longitude of initial city	Final city	Longitude of final city	Distance (km)	Average wind speed (km/h)	Time (days)	Freight shipping (days) [63]
Northern Hemisphere							
Los Angeles	-118	Washington	-77	3,673	89	1.9	8-10
Washington	-77	Lisbon	-9	6,092	69	4.1	11-13
Lisbon	-9	Istanbul	30	3,494	73	2.2	6-8
Cairo	30	Islamabad	73	3,852	106	1.7	10-12
Islamabad	73	Beijing	116	3,852	121	1.5	9-17
Beijing	116	Tokyo	140	2,150	154	0.6	4-5
Tokyo	140	Los Angeles	-118	9,138	113	4.0	18-22
			Total	32,251	101	15.9	66-87
Southern Hemisphere							
Santiago	-71	Buenos Aires	-58	1,248	124	0.5	38-50
Buenos Aires	-58	Cape Town	18	7,296	106	3.2	14-17
Cape Town	18	Perth	116	9,408	114	3.8	18-22
Perth	116	Sydney	151	3,360	134	1.2	39-47
Sydney	151	Auckland	175	2,304	127	0.8	7-9
Auckland	175	Santiago	-71	10,943	116	4.4	20-27
			Total	34,559	116	13.9	136-172

b

Pressure levels (hPa)	Altitude (km)	Maximum W-E wind speed (km/h)	Average W-E wind speed (km/h)	Minimum W-E wind speed (km/h)	Average W-E wind speed (km/h)	Maximum N-S wind speed (km/h)	Average N-S wind speed (km/h)	Minimum N-S wind speed (km/h)	Average N-S wind speed (km/h)
50	20.481	351.66	121.76	-221.08	-25.64	268.15	39.21	-260.65	-25.55
70	18.442	334.87	116.94	-178.96	-31.47	232.07	33.34	-227.80	-23.98
100	16.180	305.38	115.26	-211.57	-54.59	207.52	27.04	-207.92	-22.73
125	14.765	323.97	133.16	-229.77	-67.47	201.23	23.47	-223.27	-22.22
150	13.609	361.60	153.05	-208.33	-63.51	244.33	23.40	-297.14	-24.88
175	12.631	428.68	161.10	-227.55	-43.26	378.87	24.89	-360.91	-29.17
200	11.784	407.08	164.90	-217.43	-48.48	331.88	22.09	-369.89	-26.95
225	11.037	401.43	162.81	-188.60	-54.94	307.05	24.60	-350.40	-26.51
250	10.363	433.81	154.26	-242.20	-38.21	371.74	27.86	-356.38	-30.44
300	9.164	421.24	137.50	-243.88	-31.39	345.87	32.39	-320.87	-30.24
All	-	433.81	164.90	-243.88	-67.50	378.87	39.21	-369.89	-30.44

Fig. 3 | Jet stream wind speeds. a, Jet Stream Airship World Potential Model Framework Step 1 inputs hourly West-East (W-E) wind speed data at all pressure levels, the average wind speeds for all the different pressure levels is found, then the pressure levels with the highest wind speeds are selected. Step 2 is similar to Step 1, however, it looks for the pressure level with the lowest N-S wind speed to maintain the same latitude. Step 3 consists of finding the ideal latitude for the airship in the northern and southern hemispheres and travel times between cities. **b,** jet stream speeds model results at different pressure levels and altitudes.

Using the jet stream for airship and balloon transportation has peculiarities. A major consideration is that the airship has to travel in one direction, from west to east, around the world. For example, an airship would fly from New York to London, however the return trip would be very difficult. Given that most energy requirements in airships and balloons are the lift to the stratosphere and that the jet stream pushes it to the final destination, they should prioritize long distance routes.

This paper proposes that airships and balloons should carry either cargo, hydrogen or both. This market flexibility would increase the viability of the technology. For example, if an airship lands full of cargo, there is no cargo available for the return trip and the cost of energy in the location is high, the hydrogen from the airship can be sold to the energy market and the airship return with less hydrogen and no cargo. Comparing the costs of transporting 21,000 tons of cargo from Denver (USA) to Islamabad (Pakistan) of 10,500,000 USD (assuming a cost of 500 USD/ton) with the costs of selling the 60 GWh energy in hydrogen of 2,400,000 USD (assuming a cost of 40 USD/MWh), shows that airships and balloons could be a viable alternative for cargo and hydrogen transportation, giving preference to cargo transportation between cities far from the coast. Cargo that required to be kept frozen or at low temperatures will be benefited, given that stratospheric temperatures average -50°C.

In addition to providing a clean and sustainable alternative to long distance hydrogen and cargo transportation, this paper also presented the possibility of transporting hydrogen in airships or balloons with lower fuel requirements when compared with liquid hydrogen tankers. The possibility of cheap and clean transportation of hydrogen would be convenient for the implementation of a global hydrogen economy. This would ultimately support the widespread adoption of intermittent renewable energy technologies, such as solar and wind and promote sustainable development on a global scale.

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Methods

The main parameters analyzed in this paper are the wind speeds at jet stream altitudes and how it can be used to transport hydrogen and cargo from one place to another. The wind speeds data analyzed in this paper is the Pressure Levels Reanalysis ERA5 data from ECMWF[1]. The wind speed is divided into two components, the W-E wind speeds (Fig. 4a) and the N-S wind speeds (Fig. 4b). The west to east (W-E) wind speeds are represented with a positive value, for example from Buenos Aires to Cape Town. The east to west wind speeds are represented by a negative sign, for examples from London to New York. The south to north, N-S speeds are represented by a positive sign, for example from Hong-Kong to Shanghai, and north to south, N-S speeds are represented by a negative sign, for example from Germany to Italy.

As shown, the W-E wind speeds at latitudes between the tropics and the polar circles are strong and predominantly positive, i.e. from west to east. The wind at the equator and within the polar circles are weak and predominantly negative, i.e. from east to west. This pattern continues during most of the year.

The jet stream is caused by the difference in temperature between the poles and mid-latitudes, which results in warmer air flowing into the poles in high altitudes. This happens due to the Polar cycle atmospheric circulation, where air descends in the poles (because it is colder in the poles) and ascend in mid-latitudes (because it is warmer). This is combined with the rotation of the Earth, i.e. the Coriolis effect, which diverts the wind to the left in the Northern hemisphere and to the right in the Southern Hemisphere (that is in a west-east direction).

A good approach to the analysis of the behavior of the jet stream at different pressure levels is to look at the Windy website[2], select wind speed, pressure level of 150 hPa, then zoom out to see the whole world. The data from Windy are taken from European Centre for Medium-Range Weather Forecasts (ECMWF) or Global Forecast System (GFS).

Fig. 3 presents the Jet Stream World Potential Model Framework. It is divided into three steps. Step 1 consists of input hourly West-East (W-E) wind speed data at 50 to 300 hPa pressure levels (or height above the ground) at a 0.5 degree resolution. The average wind speeds for all the different pressure levels are then plotted. Given that the airship can change altitude and pressure levels to travel in faster wind speeds, the pressure levels with the highest wind speeds are selected. This results in the highest average W-E wind speed map. Step 2 consists of inputting hourly North-South (N-S) wind speed data at 50 to 300 hPa pressure levels at a 0.5° resolution. Then, the average N-S wind speeds for all the different pressure levels are plotted. Similar to Step 1, the airship can move to the pressure level with the lowest N-S wind speed to maintain its route. Combining the average N-S wind velocities with the minimum N-S speeds, the lowest average positive or negative wind speed map is created. Step 3 consists of finding the ideal latitude for the airship in the northern and southern hemispheres with Equation 1. The largest cities, close to these ideal latitudes, which might benefit from an airship route, are then selected. Thereafter the highest average W-E wind speeds map is used to estimate the travel time from one city to another using only the jet stream, and assuming that the N-S winds will not affect the route of the airship.

To find the average wind speeds and average travel times from one location to the other, the average wind speeds from 2016 and 2017 at pressure levels of 50, 70, 100, 150, 175, 200, 225, 250, 300 hPa were considered. The inclusion of several pressure levels in the analysis allows the airship operator can gain or lose altitude to find the pressure level with the most appropriate wind speeds to reach the final destination with the lowest energy consumption and time (Fig. 3b and Fig. 5).

Fig. 6 presents the minimum average latitudinal wind speeds considering all pressure levels. The negative wind speeds (North to South) were turned into positive (South to North) with the intent of finding the route with the least disruption to the airship`s latitude. The optimized travel of the airship is to use the predominant positive longitudinal wind speeds (West to East), and latitudinal wind speeds should be avoided as much as possible in order to prevent the airship being blown out of its set route. Maximum N-S wind speeds between 2016 and 2017 varied between from 380 to -370 km/h. Fig. 6 shows locations where the minimum average N-S wind speeds are equal to zero (dark blue lines) and locations with predominantly positive or negative average wind speeds, which should be avoided by airships.

Fig. 7 presents the shortest route from Buenos Aires to Cape Town. This is usually the flight route used by airplanes. However, if this route is used by airships, it would increase the chances that the N-S wind speeds will push the airship away from its final destination. This aligns with the goal of using the predominant west to east winds in mid-latitudes and to remain the airship at a constant latitude. The N-S wind direction follows a random pattern and should be avoided as much as possible. This paper, thus, proposes that the airship routes should follow a constant latitude to avoid being blown off the route by N-S winds.

Equation 1 was used to determine the airship jet stream latitude potential, which indicates how appropriate a latitude is to be used for airship jet stream transportation. The higher the average W-E velocity and the smaller the N-S velocity, the higher is the airship jet stream latitude potential.

Eq. 1 $$LP_{lat} = \sum_{lon=-180}^{180} HV_{lat,lon} - \sum_{lon=-180}^{180} VV_{lat,lon}$$

Where:

LP is the airship jet stream latitude potential at latitude *lat*.

lat is the latitude under analysis.

lon is the longitude under analysis.

$HV_{lat,lon}$ is the average, W-E, wind speeds in pressure level with the highest speed, at latitude *lat* and longitude *log*.

$VV_{lat,lon}$ is positive, average, W-E, wind speeds in pressure level with the lowest speed, at latitude *lat* and longitude *log*.

Equations 2 and 3 are then used to find the optimal latitude for the northern and southern hemisphere airship routes, respectively. The maximum airship jet stream potential latitude in the northern and southern hemispheres were found to be 36.5 and -30.5, respectively.

Eq. 2 $$SL_N = \max(LP_{lat}) \quad if\ lat > 0$$

Eq. 3 $$SL_S = \max(LP_{lat}) \quad if\ lat < 0$$

Where:

SL_N is the maximum airship jet stream potential latitude in the northern hemisphere

SL_N is the maximum airship jet stream potential latitude in the southern hemisphere

The airship design should have a variable drag, which should be as high as possible. However, the drag should be reduced as much as possible if the jet stream is pushing the airship away from the final destination. The drag could be varied by the use of adjustable sails. It should be noted that a structure say larger than 1 km is extremely delicate. If there is a considerable difference in the wind velocities between the front and the back of the airship it could be torn in a half. Thus, it should be built strong enough to withstand the shear caused by the winds from different directions.

The airships proposed in this paper could have solar arrays installed. Batteries would allow the airship to generate and store energy for when the airship needs to fly in a direction different from the jet stream's direction, the stored energy could be used to operate motors to maintain the airship on its original route. Alternatively some of the hydrogen stored in the airship could be used for propulsion.

Info Boxes

1) **Cooling services:** Once the airship arrives at its final destination, the hydrogen used for buoyancy will be pressurized and at temperature around -50°C, which is the average temperature of the stratosphere. Assuming that the airship is carrying 3,280 tons of hydrogen, a specific heat of 14.4 KJ/kg.C, a temperature difference of 70 degrees, no losses occur and that the heat is extracted in one day. The hydrogen could be used as a cooling sink with a cooling power of 30 MW (equivalent to cool a large airport or resort in a

tropical location). This could be used to run district cooling services or industrial processes, such as natural gas liquefaction or liquid air production.

2) **Artificial precipitation**: In tropical regions, airships or balloons could carry water to stratospheric heights with negative temperatures. The water is then released at a height where the water is cooled and freezes before entering the troposphere, and then melts in the troposphere. Cooling down the temperature of the troposphere will increase the relative humidity of the atmosphere until it saturates and starts to precipitation. The commencement of the precipitation will initiate a convection rain pattern, feeding more humidity and rain into the system.

3) **Space Launch:** Airships could be used to carry space supplies to the stratosphere, from where they can be expelled into space with a pressure gun. This technology could be used to supply the international space station or to reduce the costs for the manned missions to Mars from various space agencies[3,4].

Supplementary Information

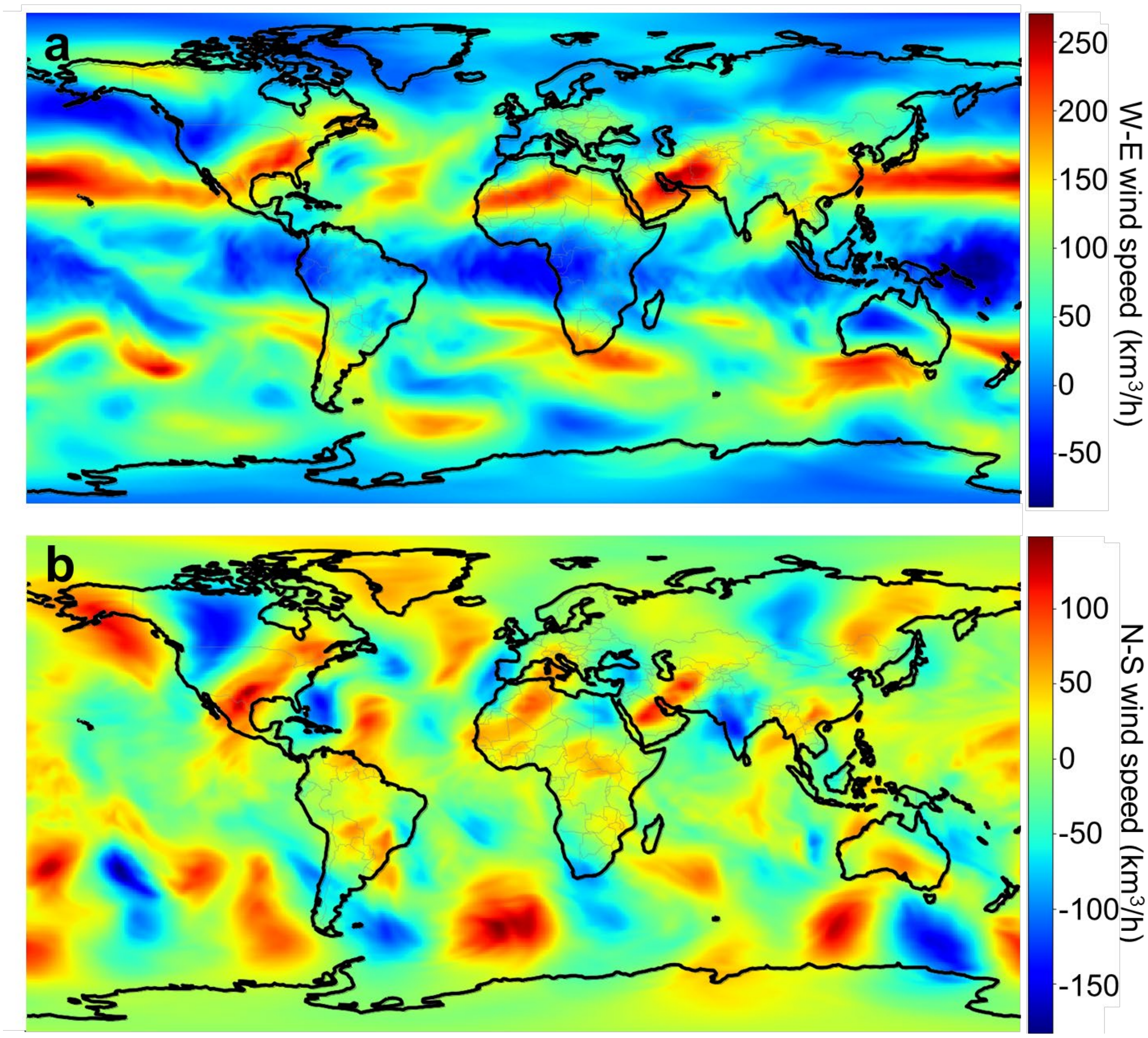

Fig. 4 | Jet stream (a) W-E and (b) N-S wind speeds at 225 hPa pressure level on the 1st of April 2016 00:00 pm[1].

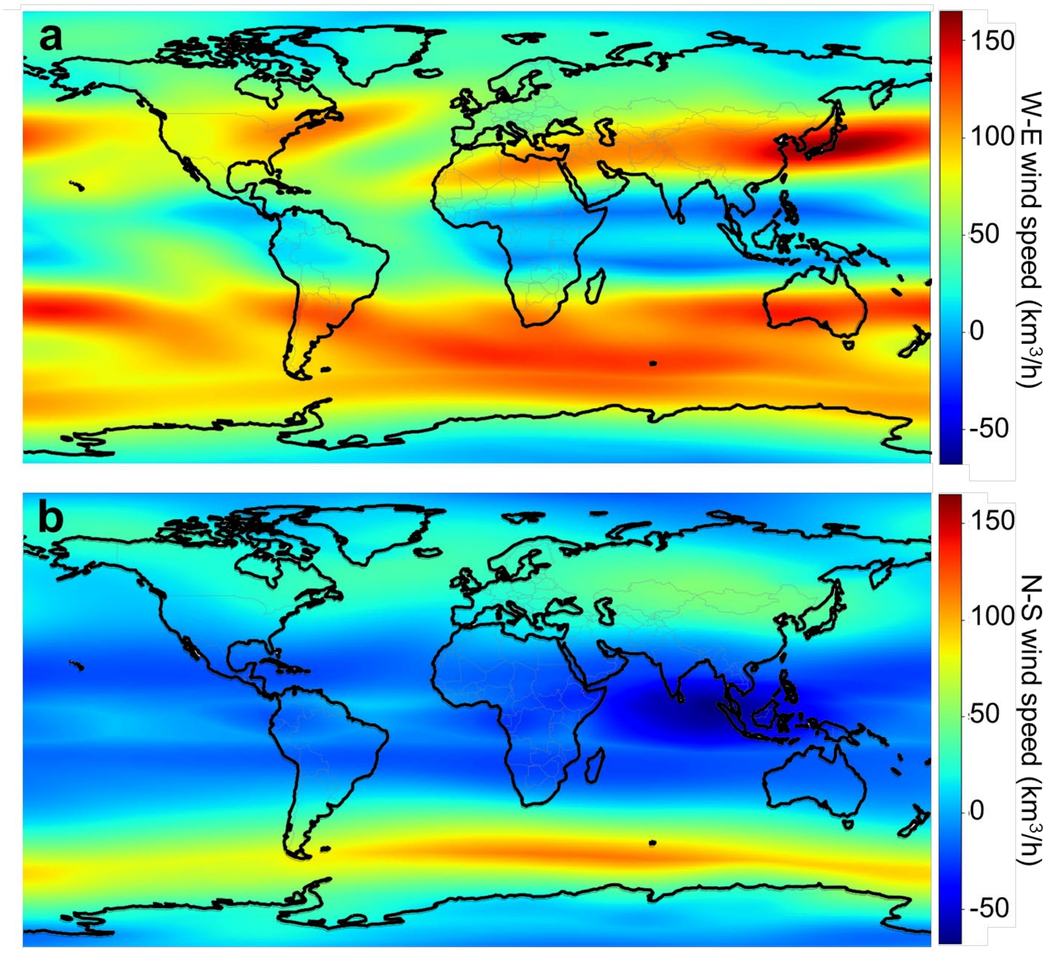

Fig. 5 | Average W-E wind speeds considering the (a) maximum and (b) minimum W-E speed at all pressure levels from 2016 to 2017[1].

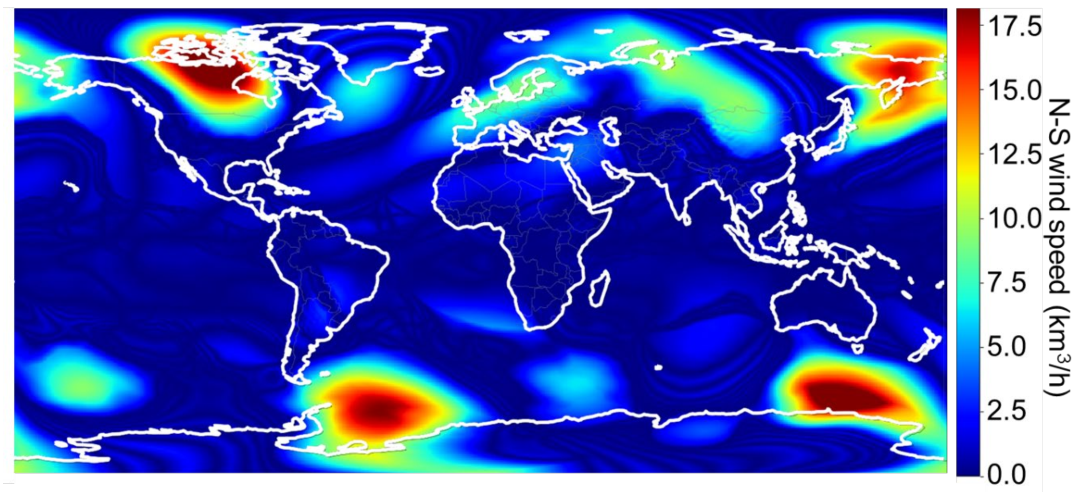

Fig. 6 | Average, positive, N-S wind speeds considering the minimum N-S speed at all pressure levels from 2016 to 2017[1].

Although seasonal variations were not included in this paper's analysis, they have considerable impact on the transport time when compared with the yearly average. To highlight the impacts of seasonal variations on the W-E wind speeds, Fig. 8 presents the average W-E wind speeds of the highest and lowest speed pressure levels in the winter and summer in the northern hemisphere. This shows that the W-E wind speeds in the northern hemisphere are stronger during the summer in the northern hemisphere and the W-E wind speeds in the southern hemisphere are stronger during the summer in the southern hemisphere. It can also be seen that the lowest W-E average wind speeds in the southern hemisphere are higher than the northern hemisphere, particularly during the summer in the southern hemisphere. This reduces the chances of the airship moving at low speeds.

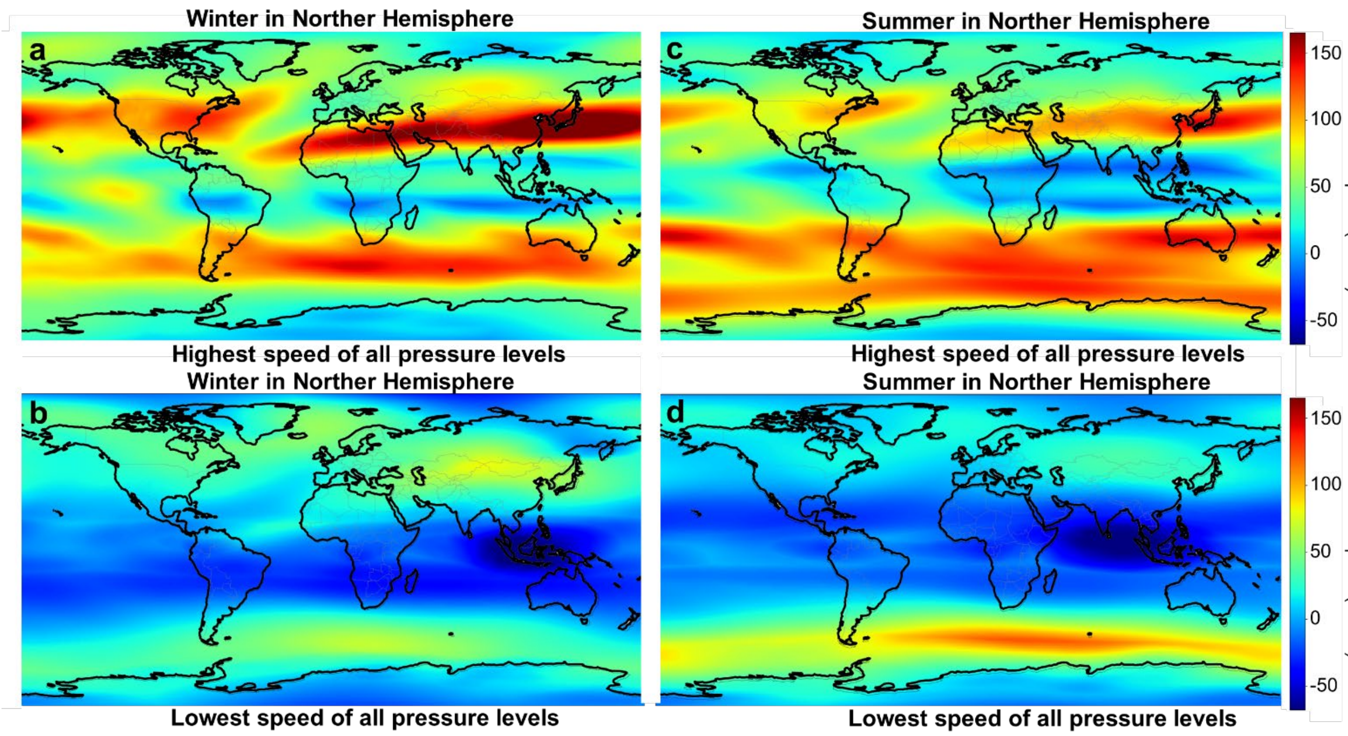

Fig. 7 | Average W-E wind speeds at pressure levels with highest and lowest speeds in the winter and summer in the northern hemisphere.

Several research projects on airship use are currently underway, such as the development of new designs[5,6], analysis of the dynamics of airship operation[7–12], ascension to the stratosphere using wind energy[13], the impact of thermal variations on ascent and descent trajectories[14,15], analyses of new materials, such as aerogel[16], for the construction of airships[17–

[19], proposal of alternative propulsion systems[20], which have been published and which are still underway. Unmanned airships have been considered to reduce the risk of accidents, especially if the airship uses hydrogen for buoyancy[21].

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