of the relative flow volumes through the two inlets and one outlet could move the major salt deposition to the central part of the basin.

A much more successful model incorporated radial influx around the entire periphery of the basin in addition to the two inlet and one outlet flow. This is analogous to a "leaky" peripheral reef bank through which there are several water passages. The structure is similar to that of many atolls. The resulting salt concentration pattern (Fig. 4a) and salt thickness distribution (Fig. 4b) more realistically simulate the Salina salt deposition.

In addition, the rates of concentration and precipitation of salt compare favorably with those adduced for natural deposits (*4*). The first precipitation occurs in the simulation model about 1000 years after evaporation becomes dominant. A steady state in the brine concentration pattern and rate of salt precipitation occurs at about 2000 years. Approximately 12,000 years are needed to build up the 750 m of salt in the center of the basin. The critical factor that determines rate of concentration and precipitation is the net rate of evaporation, which for our experiments was chosen at 50 cm per year. In comparison with evaporite basins today, the rate is conservative.

We do not infer that the 750 m of salt in the Salina Formation was deposited in 12,000 years; only that it could have been deposited in a very short period of time if the optimum conditions for salt precipitation persisted. The Salina rocks are not only salt, but a complex sequence of evaporite and normal marine sediments which involved a longer and more complex history.

The simplified deterministic model of evaporite rock deposition, based on steady, horizontal, irrotational flow of idealized seawater into the evaporite basin, can be made to approximate the observations of the salt distribution pattern of a real geological situation. The rapidity of deposition inferred from the model is substantiated by chemical and geological data.

One lesson that might be drawn from this model and the associated experiments is that very simple geological processes combined in the proper manner can closely simulate nature. When sufficient knowledge exists concerning the processes and the geology, there is no need to invoke random, probabilistic processes.

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5. Research supported by NSF grant GP-3833.

8 November 1966

Trial Balloons in the Southern Hemisphere

Abstract. *Superpressure GHOST balloons are being launched from Christchurch, New Zealand, to determine their life, stability, and clustering characteristics at several altitudes. Three separate balloons have flown for more than 6 months at 200 millibars, proving capability of the long life that had been hoped for at such middle altitudes and providing preliminary trajectory data for the Southern Hemisphere. Icing problems at lower altitudes have not yet been solved. We expect future flight durations of several years at higher altitudes. If successful, the new balloons will be useful platforms for experimenters concerned with study of large-scale and long-term effects in the stratosphere.*

An extensible helium- or hydrogen-filled balloon of rubber or neoprene, which ascends, expands, and bursts, is the vehicle normally used by meteorologists to obtain atmospheric data. The highest known altitude reached by a neoprene balloon is 47.5 km.

The unextensible balloon, usually of rubberized fabric for manned ascents and polyethylene film for carrying instruments, is partially inflated on the ground. As it ascends, its gas content expands to fill the envelope, which must have a vent to release excess gas and so prevent rupture. Typical sporting balloons to carry people are 10 to 20 m in diameter. Balloons for transporting instruments to high altitudes range from 20 to 150 m in diameter. The highest known altitude reached by an unextensible balloon is 47 km; the heaviest gross load carried to date is 7000 kg (*Stratoscope II*). Ballast must be released from an unextensible balloon whenever the gas cools, if the balloon is to stay aloft; at least 5 percent of the weight of the system must be jettisoned to maintain altitude through sunset. Flights have lasted as long as 2 weeks, requiring hundreds of kilograms of ballast.

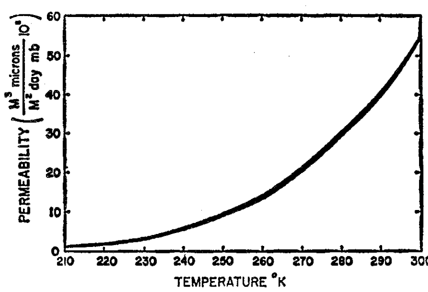

Fig. 1. Permeability of polyester film to helium.

A superpressure balloon is an unextensible balloon that is not vented. When the balloon's volume is filled and it continues to ascend, the free lift is converted to overpressure; if the balloon's skin is strong enough, it will not burst. If the modulus of elasticity of the balloon's skin is high enough, its volume will increase only slightly and it will float at an altitude of constant atmospheric density. Films of polyethylene terephthalate (polyester) or cellophane are materials strong enough and having a high-enough modulus to permit stable flight; by happy coincidence, both have excellent low-diffusion characteristics for helium.

The percentage of gas lost per day through the skin of a spherical balloon may be expressed:

$$\text{Gas loss } (\%) = (300 \cdot \delta \cdot p)/(r \cdot t)$$

where r is the radius of the balloon in meters, δ is the diffusion constant in (M^3 microns)/(M^2 day mb), t is film thickness in microns, and p is pressure in millibars. The diffusion constant for helium as a function of temperature, for polyester film, is shown in Fig. 1; Table 1, based on such considerations, lists data on the theoretical life of balloons now being flown from Christchurch, New Zealand.

All plastics have defects. A balloon having several square meters of surface area of plastic film will inevitably have some small holes. However, if a laminated film is made from two sheets of good plastics, we can virtually eliminate single-sheet defects since holes in each sheet have little chance of being superimposed. If a balloon can be fabricated from such laminate without introduction of additional pinholes, if the seals and fittings can be made free from leaks, and if the balloon suffers no new defects during packing, handling, or inflation, this balloon should fly for its theoretical life, unless forced down by icing or by deterioration, by radiation, of the seals or film. Experience indicates that laminates of 65 μ or thicker are seldom damaged during fabrication, packing, or inflation; laminates between 35 and 65 μ in thickness are often damaged; and those thinner than 35 μ are usually damaged.

As the overpressure in a superpressure balloon increases, the skin stress increases and the film expands. Polyester film has a modulus of elasticity of 5.7×10^{3} dyne/cm^{2}. A 1-percent increase in the supertemperature (lifting-gas temperature minus air temperature) of the balloon gas causes 0.15-percent increase in balloon volume for a typical balloon design—corresponding to a change in altitude of about 10 m at the equilibrium-density level. The gas temperature of the balloon cools between 3 and 4 percent at sunset, the change effecting an altitude variation of 30 to 40 m between night and day. In addition to this predictable day-night change, supertemperature changes are caused during the day by variation in environmental radiation; they produce an unpredictable variation in altitude of $\pm$ 20 m.

Table 1. Theoretical lives of balloons (in perfect condition) being flown in the Southern Hemisphere in the GHOST program.

Balloon						
		Film				
Altitude (mb)	Diameter (m)	Thickness (μ)	Temp., av., assumed (°K)	Initial overpressure at night, min. (%)	Life (days)
30	6.7	25	223	10	30,000
200	2.0	38	230	6–10	1000–1600
200	2.26	50	230	14	2500
300	2.26	75	248	10	850
500	1.52	63	260	4–18	80–360

Less than 20 percent of the Northern Hemisphere is adequately observed meteorologically; only 10 percent of the Southern Hemisphere has even marginal meteorological coverage. Numerical models of atmospheric circulation have been developed that promise useful long-range forecasts of the general circulation of the atmosphere over periods as long as 2 weeks, provided that observations of wind, temperature, and pressure at several levels are adequate. Picture-taking satellites cannot provide the quantitative data required for insertion into the computer model. Expansion of existing radiosonde networks becomes prohibitively expensive when the areas to be covered are the oceans and remote land areas.

The superpressure balloon provides the only known possibility of obtaining global data on the atmospheric circulation at reasonable cost. Since the balloon moves as part of the air parcel, constant knowledge of its position provides the essential data on atmospheric circulation.

The basic plan for adequate global meteorological coverage is known as GHOST (Global HOrizontal Sounding Technique). The plan calls for balloons to fly stably at several levels of constant density, each remaining aloft for several months. They are expected to spread in distributed patterns rather than to cluster in preferred areas. By satellite we propose to track the balloons accurately and constantly; thousands will be kept flying simultaneously. They will constitute a negligible hazard to aircraft. If all expectations are met, we shall be able to furnish a suitably programmed computer with a complete and continual description of the physical state of the atmosphere on a global basis. With such data we hope to be able to provide useful predictions of atmospheric circulation.

A test program (*1*) in New Zealand is now exploring essential questions about balloon life, stability, and clustering: 100 balloon flights are being made at 500, 200, or 30 mb (5500, 12,000, or 24,000 m, respectively).

For locating the balloons and telemetering data on their performance, we developed a simple, lightweight, long-lived electronic system (Figs. 2 and 3; *2*). On most flights, we depended on a single transducer to determine Sun's angle of elevation; the amount of light received by a photoresistor, when Sun shines through a series of filters and an infrared diffuser, is a function

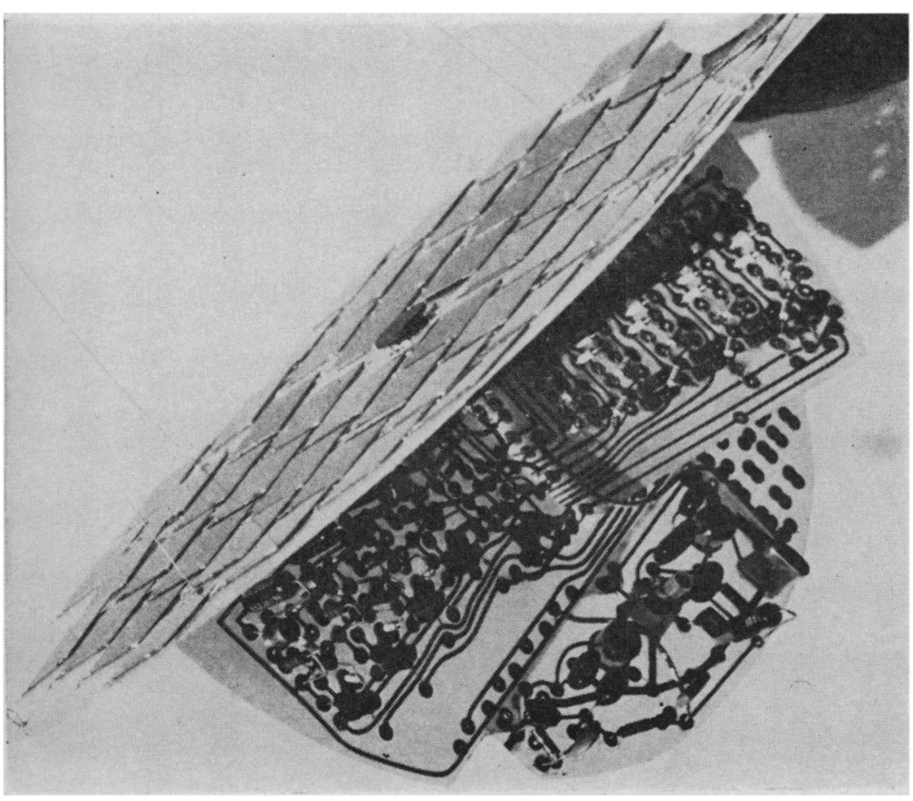

Fig. 2. Electronic package attached to GHOST balloons. A man's thumb appears at top right.

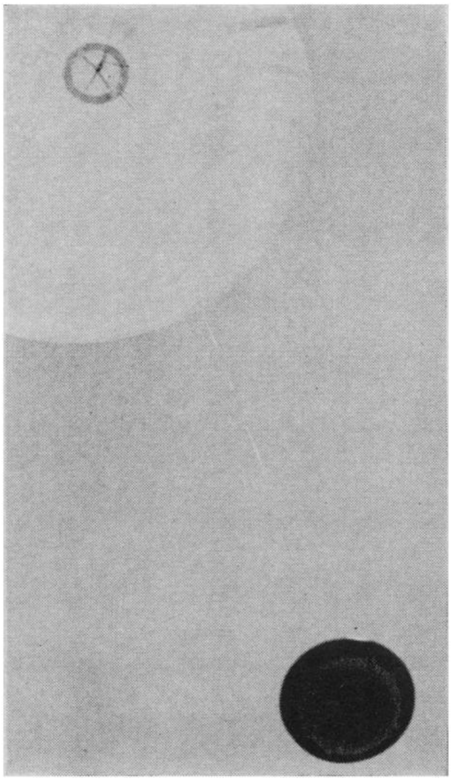

Fig. 3. Package attached to a balloon.

of the angle. The varying resistance changes the frequency of a unijunction oscillator, which changes the code-transmission rate for a simple Morse-code encoder. The transmitted Morse signal at 15.025 Mhz is a single identification letter repeated continually during daylight hours. Any person equipped with a radio receiver, a stopwatch, and a calibration chart for the flight can take data and determine the angle of Sun's elevation by timing the period of successive code groups; an intersect is thus provided. Continuous readings over several hours permit determination of the balloon's location and velocity—and so of the wind velocity.

The entire package, including solar-cell power supply, weighs but 100 g. Reception has been reliable at 8000 km and marginal at 10,000 km with modest antennas. Tracking stations are operated by the cooperating nations in New Zealand, French Polynesia, Peru, Brazil, Argentina, Zambia, Angola, South Africa, Mauritius, and Australia.

Between 4 March and 4 December 1966 we launched 54 balloons from Christchurch and four from McMurdo Station, Antarctica: 16 flights were at 50 mb; 41 at 200 mb; and 1 at 30 mb. The flight program is only now beginning at 30 mb. The large size of the balloons makes field testing for pinholes difficult. Since the theoretical life of these balloons is 90 years, we are limiting our tests to ten balloons initially lest we create a serious problem: removal of balloons to make way for more sophisticated balloon-satellite systems of the future.

At levels at or below 500 mb we have encountered a serious and still-unsolved problem with icing in supercooled clouds of water vapor. Surface treatments have improved the balloon's ability to shed water, but we still lack a satisfactory surface treatment against ice. Larger and thicker-walled balloons, with the higher overpressure needed to carry heavier loads of ice, will be tested. If all else fails, we plan to fly balloons above the icing level and measure wind data (including shears) below by means of long, trailing lines having a breaking strength of 2 kg and constituting no danger to aircraft. The longest flight yet achieved at 500 mb was 21 days; average duration has been 10 days. The balloons at higher altitude have flown stably; our pressure elements are still too insensitive to detect variations in altitude.

Of the 41 flights completed at 200 mb, 11 were rejected because of damage at launch (three), icing during ascent (two), or defective transmitters (three), or because the balloons had not been tested for holes (three). Of the remaining 30 balloons, 12 are still flying; three have flown longer than 6 months, and the average life of successfully launched balloons that have descended is 70 days. Balloons that appeared marginally acceptable in ground tests came down within 20 to 40 days, indicating that undetected defects tended to become more serious with time (probably because ablation of the plastic film, by helium escaping through a very small hole, enlarged the hole).

With improved techniques for detecting leaks and with improved quality control in fabrication, average life longer than 1 year should be realizable at all altitudes above 300 mb. Such theoretical life expectancies will depend largely on the extent of ultraviolet deterioration of films. To study such deterioration we are now flying, in competition at 200 mb, clear balloons and balloons

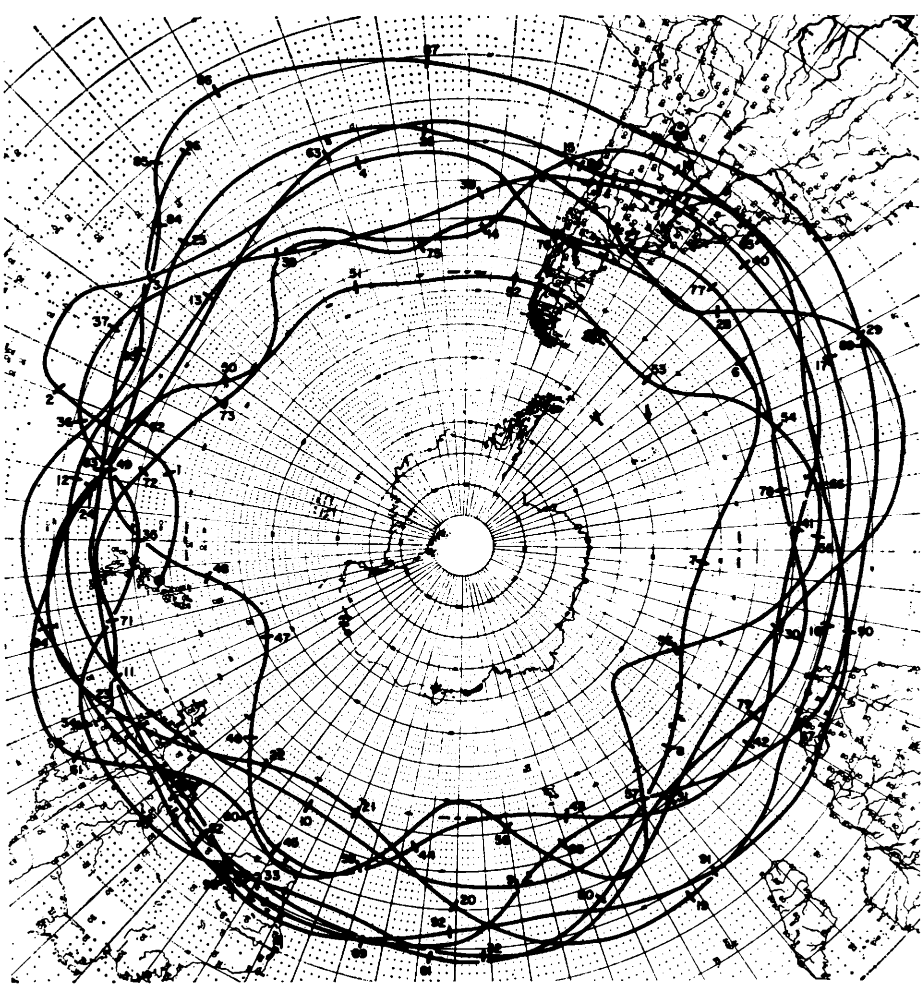

Fig. 4. Course during the first 96 days of flight of GHOST balloon X.

carrying an ultraviolet-resistant coating; results will be definitive by 1968.

Figure 4 is a plot of successive positions during the first 96 days of a balloon launched from Christchurch on 28 April 1966; after 192 days it descended into the South Atlantic during the night of 4 November while on its 17th circuit of the globe. Detailed data on trajectories and winds for this and all other flights (including Antarctic launches) should be available to all by about March 1967—and at regular intervals thereafter.

Several development programs envisage a balloon-satellite system. France has a program (Project EOLE) whose initial aim is the flight in 1969 of 500 balloons at 300 mb in the Southern Hemisphere, with accurate tracking by satellite. (Initial EOLE flight tests in July and August 1966 showed evidence of an icing problem even at 300 mb.) The National Aeronautics and Space Administration is developing a system for interrogating and locating balloons and other moving platforms from a low-orbiting satellite named IRLS (Interrogation, Recording, and Location System); it will be tested during the Nimbus-B and Nimbus-D flights. Now being studied by NASA is the possible use of a low-frequency location system, in conjunction with a synchronous satellite, to provide accurate data on position.

While work continues on the sophisticated balloon-satellite systems of the future, it appears that we can take advantage of the extraordinary performance of our interim GHOST electronics package to provide useful operational weather data for the nations of the Southern Hemisphere. With rapid communication to a computer in Boulder, Colorado, Washington, D.C., or Melbourne, Australia, from only three stations—in New Zealand, South America, and Africa—we can provide trajectories and winds for as many as 50 balloons, and these data can be fed back to the Southern Hemisphere with only a few hours' delay. This service will double the volume of data on the upper air in the Southern Hemisphere, and at modest cost. With the cooperation of the nations concerned, this program can be in operation within 1 year.

On the planned flights at 30 mb, 2 kg of the capacity is unused. Our telemetry system can handle from one to four channels of data. Since we expect many of these balloons to remain at altitude for several years, we should like to encourage other scientists to consider piggyback experiments by which, from a platform at 24,000 m, they could do such things as measure long-term effects such as variation in intensity of incoming radiation, measure ozone, count rare events, or determine degradation of materials; the cost should be less than \$1 kg^{-1} day^{-1}.

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12 December 1966

Structure of Silica Glass

Abstract. *From configurational entropy considerations, it is estimated that the grains in silica glass are far more likely to have a cristobalite structure than a pentagonal dodecahedral one.*

The idea that liquids preserve some of the structure of their corresponding solids is not new. Krishnamurti (*1*) concluded this from his studies of organic compounds, and Randall *et al.* (*2*) thought of glasses as having the structure of the corresponding crystals in domains of 10 to 100 Å. Zachariasen (*3*) stated: "The glasses are built up of extensive three dimensional networks without symmetry or periodicity, these networks being in other respects essentially the same as the ones we find in corresponding crystals."

Warren (*4*) established that the tetrahedral coordination of oxygen around silicon, which characterizes the crystalline silicates, persists in glass. He concluded from his investigations that a random network represents the structure of glass better than an agglomerate of cristobalite crystallites and that if the cristobalite structure did exist in glass it was restricted to domains smaller than about 8 Å. The ideas of Zachariasen and of Warren are generally accepted.

A grain structure such that silicon is linked to oxygen to silicon in some less than random manner for a few atomic distances is indicated by considerable physical and chemical evidence from a number of sources (*5*). Such a grain structure does not necessarily conflict with the Zachariasen-Warren theory but merely restricts the randomness to regions outside of these grains, that is, outside of a few SiO_4 tetrahedral distances instead of only one. The work of Warshaw (*6*) and of Zarcycki and Mezard (*7*) are particularly convincing of grain structure in the 25- to 150-Å range, and Oberlies and Dietzel (*8*) showed that the atomic arrangement in silica glass is probably not far removed from that in cristobalite.

The structure of these grains has been the subject of some debate. Do they contain cristobalite polyhedra or are they, as suggested by Bernal's (*9*) study of packing in liquids, composed of statistical molecular configurations with varieties of coordination patterns geometrically different in kind from any occurring in a regular solid? From experiments compressing plasticene spheres, Bernal concluded that arrangements in pentagonal faces are necessary to dense packing. Because a coordination number of 5 does not permit long-range order, any such arrangement of molecules must be fluid. Tilton (*10*) had previously postulated his Vitron theory of glass structure based on pentagonal dodecahedral assemblages.

Recently, Robinson (*11*) has computed the geometry of distorted pentagonal dodecahedra in some detail and he concluded that grains built upon this structure would give an x-ray diffraction pattern in agreement with experiment. However, x-ray techniques applied to glass yield accurate values of interatomic distances for only a few near neighbors, and, as Robinson points out, plane pentagonal rings and puckered hexagonal rings cannot be distinguished. Thus in order to choose, data from other sources are needed.

One serious difficulty with the pentagonal dodecahedral model is that it yields a density 10 percent less than that of the glass, and it is very difficult indeed to imagine a reasonable random packing arrangement of these structures which could increase the density by this much. On the other hand, the density of cristobalite appears to be about 0.5 percent greater than that of silica glass at high temperatures. A cristobalite-structured grain is also suggested by the ease with which silica glass devitrifies. This indicates rather