Robert Mossman, *Endurance* and the Weddell Sea Ice

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Abstract

Before Shackleton arrived at South Georgia aboard *Endurance* on 5 November 1914 he was aware that *Endurance* might meet bad pack-ice in the Weddell Sea. This had been forecast on the basis of climate analysis by Robert Mossman, the meteorologist on the Scottish National Antarctic Expedition (1902-04), who was currently working at the Argentine Meteorological Office. Mossman was interested in teleconnections linking meteorological and oceanic conditions in widely separated places and had studied the links between the Weddell Sea and South America. Mossman's Antarctic data were mainly records from the Orcadas station in the South Orkneys which had operated continuously from 1903. He found a correlation between extensive pack-ice in the Weddell Sea and plentiful rain in a belt across South America that included Buenos Aires. The experiences of *Endurance* supported this. Modern studies of the El Niño-Southern Oscillation (ENSO) broadly confirm Mossman's conclusions.

Introduction

In his book *South*, the account of the ill-fated Imperial Trans-Antarctic Expedition (ITAE), Ernest Shackleton wrote *'I knew that the ice had come far north that season, and, after listening to the suggestions of the whaling captains [at South Georgia], had decided to steer to the South Sandwich Group. ... The whalers emphasized the difficulty of getting through the ice in the neighbourhood of the South Sandwich Group '* (Shackleton 1919). Successive biographies of Shackleton and accounts of the *Endurance* expedition have interpreted this statement as the whalers at South Georgia telling Shackleton that ice conditions in the Weddell Sea were particularly bad that year (1914), for example: '*The whalers reported very bad ice conditions in the Weddell Sea, ...*' (Mill 1923) and *'The pack was further north than any of the whalers could recall'* (Huntford 1985). This is not so; the whalers merely said that the South Sandwich Islands region was a bad place for ice.

It was already known in 1914 that the Weddell Sea was a dangerous place in terms of pack-ice. Mossman had drawn attention to this in an article in the *Manchester Guardian* (1914), a week after Shackleton's intention to cross the continent of Antarctica from the Weddell Sea to the Ross Sea had been announced in *The Times* for 30 December 1913. He wrote: '…the vital point bearing on the success of Shackleton's expedition is not what he will do when he reaches his base at lat. 78°S; the main difficulty lies in his getting there through perhaps 1100 miles of pack ice.' Mossman recommended sailing down the eastern side of the Weddell Sea where a channel of open water allowed the expeditions of Bruce (1902-04) and Filchner (1911-12) to navigate to high latitudes. Wadhams (2014) examines the fate of *Endurance* in the light of modern knowledge of the drift and extent of the Weddell Sea ice.

In fact, the whalers at South Georgia had never been farther south than the South Sandwich Islands and had visited these islands only on three occasions since Antarctic whaling started 10 years earlier (Headland 2009). Frank Hurley's diary entry for 7 November gives the only eye-witness account of the conversation with the whalers: '*Mr Jacobsen & his captains cautioned our immediate prospects re reports rec'd in B.A. Conditions are severe, the ice extending as far this way as the S. Sandwich Islands. ... Our host & others intoning Endurance will not escape the ice, the recent disaster to Antarctic fresh in their minds, thereat advising a month's delay.*' (Murphy 2000). (*Antarctic* was the expedition ship of the Swedish Antarctic Expedition led by Otto Nordenskjöld. Captained by CA Larsen who later built Grytviken whaling station, she had been crushed by pack-ice off Paulet Island, Antarctic Peninsula, in 1903.) Hurley's account gives no indication that the whalers regarded the current year as unusual. The idea that 1914 was an unusually bad year for sea-ice has come from dramatisation of the *Endurance* story by later writers. The intriguing question is how Shackleton '*knew that the ice had come far north that season*' (Shackleton 1919) before he had even got to South Georgia.

It should be mentioned that descriptions of the Weddell Sea ice are confusing in contemporary accounts. Ice is described as 'heavy', 'dense' or 'bad'. This can be interpreted either that the area of pack ice is very extensive or that the floes are thick and packed so that headway by a ship is difficult. Even in a year of minimal ice, a ship can report bad ice because it has been trapped when wind has forced the ice floes together, particularly against a lee shore. *'Not having broken out early'* does not necessarily mean that the pack ice cover is very extensive. *'Ice had come north*' can mean either that a larger than normal area of sea froze during the winter or that the ice has broken out and drifted north. Shackleton was unclear about the differences. Although he wrote in *South* that the ice had come far north (page 1), he contradicted himself in a letter to Reginald Perris (Shackleton 1914) by writing: *'…the ice is further South than it has been for years… and that means that the pack has not broken up*'.

Mossman's prediction

Robert Mossman was the meteorologist on William Speirs Bruce's Scottish National Antarctic Expedition (1902-04). After wintering on Laurie Island, South Orkneys, Bruce handed over the base, which became known as 'Orcadas', to the Oficina Meteorológica Argentina and Mossman remained for a second winter to train new staff. He then took up a permanent post with the Oficina in Buenos Aires. He was interested in teleconnections – correlations of meteorological and oceanic conditions in different localities - and he was particular interested in links between weather and ice in the Antarctic and weather in South America. The ability to predict rainfall in the South American grain belt between latitudes 30° and 40° South was of obvious economic value. Mossman referred to this link when writing to Bruce about the latter's planned trans-Antarctic expedition (abandoned through lack of funds and the outline plan was taken up by Shackleton with Bruce's blessing): *'I hope your expedition will come off. Conditions in the Weddell Sea area are again favourable as the winter rains have failed on the coast of Chile south of lat 33° so that the ice must be far south.'* (Mossman 1910c)

Mossman's assessment of the expedition plans for ITAE in the *Manchester Guardian* (5 January 1914) included a means of predicting the state of the Weddell Sea ice: *(Ian: the point about 1100 miles of ice was made on lines 41-42)* '*As regards the actual ice conditions in the Weddell Sea, information may be gained beforehand by cabled reports of the quantity* *of rain that has fallen on the Chilean coast between the latitudes of 30° and 38° S. In close seasons in the Weddell Sea the winter rains on the Chilean littoral have been found to be very heavy, owing to the northern track taken by cyclonic systems coming from the west; if the Chilean rains are light the Weddell Sea is open or at least comparatively ice free. In other words, when the ice is far south the cyclones are far south, but when the ice is lying north, then the cyclonic systems in the South Pacific are also far north.'* The correlation extended to the same latitudes on eastern side of South America between latitudes 40° and 35° S (Mossman 1914), a zone that includes Buenos Aires. In the *Liverpool Journal of Commerce* for 21 September 1914 (just before he left England to join *Endurance* at Buenos Aires) Shackleton was quoted as saying '*A heavy ice season means a heavy rainfall in Chile and parts of the Argentine, and a light ice season in the Weddell Sea means a light rainfall in those places.'* He had evidently read the article about the prospects for his expedition by Robert Mossman in the *Manchester Guardian* (5 January 1914).

Endurance was to witness unusually wet weather in October 1914. (run on)James Wordie, the expedition geologist, wrote in his diary for 20 October 1914:*'...it looks as if the pack would be very heavy this season; this is following Mossman's theory of heavy rains in the Argentine in Spring (just what we are having) being due to the ice in the Weddell Sea not having broken out early.'* On 24 October he added '*As far I can remember, every other day seems to have been wet in Buenos Aires. The people here say it is most unusual weather. Mossman's explanation, of course, is that it is due to the ice not having broken out of the Weddell Sea this season, and if his theory is correct, it may quite easily prevent our getting down to Coat's Land this season'* (Wordie Diary).

Frank Hurley's diary records 11 days with rain out of the 15 days of October that he spent in Buenos Aires (Murphy 2000) – a definite spell of wet weather. Long-term records indicate that the spring of 2014 was exceptionally wet. The annual rainfall total for Buenos Aires for 1914 was the second highest between 1861 and 1924, with only 1900 being wetter (P. Jones, personal communication, 16 March 2015). When *Endurance* reached the Weddell Sea, the crew found that the pack was indeed very heavy. Mossman's prediction had proved correct.

Mossman's basis for forecasting Weddell Sea ice

How did Mossman establish this link between rain in the middle latitudes of South America and the ice in the Weddell Sea? In a series of papers published between 1910 and 1921 (*see* References), he described links between rainfall in South America and atmospheric temperature and pressure, and pack-ice in the Weddell Sea. These were based on records from the few expeditions that had penetrated deep into the Weddell Sea (Weddell 1823, Ross 1843, Larsen 1893, Nordenskjöld 1902-3, Bruce 1903 and 1904, Filchner 1911-12) and on meteorological and sea-ice observations at the meteorological station Orcadas. At the time that Mossman wrote these papers the Orcadas records were a short data-set on which to base predictions of climate; 30 years of observations are usually regarded as a minimum for meaningful analysis. However, Mossman noted some robust patterns in the data.

As early as 1910, Mossman wrote in the proceedings of the International American Scientific Congress in Buenos Aires (Mossman 1910a): '*Generally speaking, when there is little ice in the south, the winter rainfall over the greater part of the Argentine Republic is below the average; when there is much ice it is above the average. The cause of this is that the track of cyclonic storms, in their movements from west to east, varies with the position of the ice-belt. When the ice is far north, the track of the storms is also far north, and when the ice is south* *then the storm track is also south.* (This echoes Mossman's article in the *Manchester Guardian*, see above.)

'In cold winters at the South Orkneys, which are always associated with a northern extension of the pack, the weather map of the Oficina Meteorologica Argentina shows that the storm centres, instead of following the usual route to the south of Cape Horn, are deflected northward, reaching the coast of Chile between the parallels of 38 and 45 S. These storms produce heavy rains on the Chilean littoral, and to a lesser degree on the adjoining Argentine provinces on the eastern slope of the Andes, extending even as far as to the Atlantic coast.

'In the open season, as in 1903, 1908 and 1909, when there was little ice in the south, the tracks of the storms were also far to the south, and a drought prevailed very generally on the coast of Chile, between 35 and 40 S, and also over the Argentine Republic.'

In this paper Mossman noted that the height of the Rio Negro varied inversely with the air temperature at the South Orkney Islands, with a probability of 86 per cent. In a later paper, he used the depth of the River Paraná that drains southern Brazil and adjacent areas as an indicator of regional rainfall. In the month of December, when the river was high, atmospheric pressure had been high at Orcadas (Mossman 1913). He argued that it is '*not unreasonable to suppose*' that when pressure in the Antarctic anticyclone to the south and south-east of Cape Horn rises in early summer, pressure over the interior of Brazil decreases, and *vice versa*.

Figure 1 here

Having linked high pressure over the Weddell Sea with extensive sea-ice, assessment of ice cover would allow forecasting of rainfall in South America. To assess the annual extent of pack-ice in the Weddell Sea, Mossman again used observations at Orcadas. Although the

South Orkneys are on the northern boundary of the Weddell Sea, Mossman considered that Orcadas was strategically placed to get an impression of the region's pack-ice because currents sweep the ice up the east coast of the Antarctic Peninsula and across to the South Orkneys. *'As it is only ocean swell that causes the disruption of the ice on the south coast of Laurie Island, the break up of the ice is an index that the seas are clear to the west.'* (Mossman 1916).

Mossman proposed two atmospheric mechanisms to explain the connection between South American rain and Weddell Sea ice. In an undated (but written after 1916) typescript in the Scott Polar Research Institute, Mossman (undated) suggests that Antarctic conditions are consequent on South American meteorology: *'...the height of the River Parana in the month of January rises or falls in sympathy with the barometric pressure at the Orkneys during the month previous. The probable explanation is that at the beginning of summer there is a flow of air from the heated American continent to that portion of the Antarctic regions lying immediately to the south of Cape Horn, so that an anti cyclone is formed there while at the same time a low pressure area is formed over the interior of Brazil, the intensity of the rain there depending on the difference of the pressure between the tropics and the Antarctic. ... If the barometric pressure in the Antarctic in December remains low, then the physical conditions in Brazil are against heavy rain and the Parana in January consequently remains low.'*

A second explanation was hinted as early as 1909 when Mossman wrote to HR Mill *'... enough has been done to show the connection between the Lows in the Weddell and Bellingshausen Seas and the South Pacific High, and how rainfall, temperature, and other elements vary with the changes in the southern "Centres of Action"'* (Mossman 1909). He had identified two linked areas of low pressure on either side of Graham's Land (now the Antarctic Peninsula), one in the Bellingshausen Sea centred about 64°S, 90°W, the other in the Weddell Sea centred 66°S, 30-35°W (Mossman 1910b). The Bellingshausen Sea Low was, in turn, linked in a 'see-saw' effect to an anti-cyclone in the South Pacific in the region of Juan Fernandez Island (the 'High' in the South Pacific shown in Figure 2). Another link was then made between the South Pacific High and climatic conditions in Chile and Argentina to complete his teleconnection between the Weddell Sea and South America (Mossman 1911).

Figure 2 here.

In 1916 Mossman proposed another link between the Antarctic and South America. Mr Hessling, a colleague at the Argentine Meteorological Office, had shown that, from 1903 to 1916, there was a correlation between the winter temperature at Orcadas and the amount of rain that fell in parts of Argentina 3½ years later (Mossman, 1918) *see* figure 3. A hard winter was followed by a drought and a very mild winter by wet weather. Mossman believed that the fluctuating quantity of pack-ice caused temperature changes in the South Atlantic that induced changes in the volume, direction, and temperature of the ocean currents. This, in turn, would affect pressure in the overlying atmosphere and lead to changes in the tracks of the cyclonic and anticyclonic systems in Southern America (Mossman, undated). This relationship is referred to by Shackleton's meteorologist Leonard Hussey in *South* (Shackleton, 1919. Appendix I. Meteorology, 347-351).

Figure 3 here

Was Mossman correct?

Mossman had access to relatively comprehensive records from meteorological stations in South America but only very limited observations from the Weddell Sea. Apart from the few ships that had sailed in Antarctic waters and even fewer temporary research stations, his data came almost exclusively from the Orcadas station. Given this very limited data-set, he could establish his teleconnections only in the most general terms. An interesting question is whether they are substantiated by modern research which has access to long runs of meteorological data at land stations and satellite observations of sea surface temperature and sea ice extent.

Since Mossman's time, the idea that climate phenomena in different parts of the world can be linked through atmospheric and oceanic teleconnections has become accepted by climatologists and the physical basis underlying these teleconnections is now understood, in principle if not in detail.

Mossman's explanation of the relationship between sea-ice recorded at Orcadas and the large scale pattern of ice in the Weddell Sea has received some confirmation (Murphy and others 1995). Since satellite data became available from 1973, there appears to be a good correlation in general terms between observations of fast-ice in the South Orkneys and the pack-ice in the western Weddell Sea, in that disappearance of the fast-ice probably means the seas are '*clear to the west*' as Mossman described it. However, this may not reflect the situation in the eastern Weddell Sea.

Data collected by weather satellites since the late 1970s have helped to fill the Antarctic 'data void' and have allowed detailed investigation of atmospheric events over the Antarctic and neighbouring oceans. These data have shown that there are teleconnections between Weddell Sea weather and ice extent and the tropical Pacific phenomenon of El Niño-Southern Oscillation (ENSO). An El Niño event is a band of warm sea surface temperature that develops at irregular intervals of two to seven years off the western coast of South America.

The Southern Oscillation is the atmospheric component of ENSO. (*See* Glantz 2001 for further information on ENSO).

The warm water of El Niño is associated with very wet weather in April–October along the coasts of South America and spreading into southern Brazil and northern Argentina to produce significantly wetter than normal conditions mainly during the spring and early summer (Andreoli and Kayano 2005). Between El Niño events, there is the opposite event of La Niña in which a cold pool of water forms in the eastern Pacific and there is reduced rainfall in South America.

ENSO also influences conditions around Antarctica through atmospheric teleconnections. El Niño results in the Weddell Sea tending to become colder with more sea ice. The exact opposite warming occurs during La Niña. This 'see-saw' pattern is known as the Antarctic Dipole (Yuan and Martinson 2001; Yuan 2004). The link is atmospheric convection associated with the changing patterns of tropical sea surface temperature that create large-scale waves in the atmosphere known as Rossby waves. These waves move southwards and disturb the atmospheric circulation around the Antarctic. During El Niño events, pressure to the west of the Antarctic Peninsula is high and generates an anticyclone that promotes ice formation in the western Weddell Sea. (With a La Niña event, the pattern is reversed.)

Thus, there is a direct link during an El Niño event between increased rainfall in northern Argentina and more sea ice in the Weddell Sea, as Mossman predicted in his 1909 and 1911 papers. There is less support for Mossman's later link of sea-ice with rainfall in South America 3 ½ years later. Our modern understanding of teleconnections as patterns associated with the propagation of Rossby waves would suggest that there should be little delay between

ENSO variations in the tropical Pacific and an Antarctic response. Hessling's identification of a delayed response may be an artefact of his having only a short (13 year) record. The longer Orcadas record now available contains significant interdecadal variability, which could result in spurious lagged correlations if only a short portion of the record were analysed.

It is remarkable that Mossman was able to identify the existence of South American - Antarctic teleconnections from such limited data some 80 years before they were fully documented and explained. The ENSO phenomenon and its associated teleconnections were not described until Sir Gilbert Walker published his extensive investigations into global teleconnections over ten years later (Walker 1927). (Sir Gilbert Walker was Director of the India Meteorological Department, 1904-24, where one of his assistants was G.C. Simpson, later to become meteorologist on Scott's last expedition.) Walker quotes Mossman's work extensively and it is clear that that Mossman's ideas strongly influenced the thinking of the man who is generally credited with being the founder of the science of teleconnections.

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References

Andreoli, R. V. and M. T. Kayano. 2005. ENSO-related rainfall anomalies in South America and associated circulation features during warm and cold Pacific decadal oscillation regimes. *International Journal of Climatology* 25(15): 2017-2030.

Glantz, M.H. 2001. *Currents of Change* (second edition). Cambridge: Cambridge University Press.

Headland, Robert Keith. (2009) *A Chronology of Antarctic Exploration*. London: Bernard Quaritch Ltd.

Huntford, Roland. 1985. *Shackleton*. London: Hodder and Staughton.

Mill, Hugh Robert. 1923. *The Life of Sir Ernest Shackleton*. London: William Heinemann Ltd.

Mossman, R.C. 1909. Letter to Hugh Robert Mill 7 October 1909. Cambridge: Scott Polar Research Institute MS 100/81/1-12;D.

------------------ 1910a. Meteorology at the International American Scientific Congress, Buenos Aires, July 1910. *Symon's Meteorological Magazine*. 45 (538): 177-182.

------------------ 1910b. Meteorology in the Weddell quadrant during 1909. *Scottish Geographical Magazine* 126: 407-419.

------------------ 1910c. Letter to William Speirs Bruce 5 December 1910. Cambridge: Scott Polar Research Institute MS 101/63/1-20; D.

------------------ 1911. Climate of Chile. *Journal of the Scottish Meteorological Society* XV: 317-18.

------------------ 1913. Southern hemisphere seasonal correlations. *Symon's Meteorological Magazine* 48: 1-34.

----------------- 1914. Prospects of Sir E. Shackleton's Expedition. *Manchester Guardian* 5 January 1914.

----------------- 1916. The physical conditions of the Weddell Sea. *Geographical Journal*. 48: 479-500.

---------------- 1918. The climate and meteorology of Antarctic and sub-Antarctic regions. *Journal of the Scottish Meteorological Society* XXXV: 18-29.

---------------- undated. *Utility of the South Orkney observatory*. Typescript. Cambridge: Scott Polar Research Institute MS 356/74/5.

Murphy, Eugene J., Andrew Clarke, Caroline Symon and Julian Priddle. 1995. Temporal variation in Antarctic sea ice: Analysis of a long-term fast-ice record from the South Orkney Islands. *Antarctic Science* 42 (7): 1045-1062.

Murphy, Shane. 2000. *Shackleton's Photographer. Frank Hurley's annotated diaries.* CD-ROM.

Shackleton, E. 1914. Letter to Reginald Perris. 30 November 1914. Cambridge: Scott Polar Research Institute MS 1537/2/32/3.

Shackleton, Sir Ernest. 1919. *South*. London: William Heinemann.

Wadhams, Peter. 2014. Sea Ice and Shackleton's Expeditions. *Nimrod* 8: 60-66.

Walker, G.T. 1927. *Correlation in seasonal variations of weather, IX . A further study of world weather.* Memoirs of the Indian Meteorological Department vol. XXIV, 275-332 (available for download from http://www.rmets.org/sites/default/files/classicindia2.pdf)

Wordie, James. Diary. 1914-1916. Typescript. Wordie family papers.

Yuan, Xiaojun. 2004. *ENSO-related impacts on Antarctic sea ice: a synthesis of phenomenon and mechanisms.* Antarctic Science 16 (4): 415–425.

Yuan, X. J. and D. G. Martinson. 2001. *The Antarctic Dipole and its predictability*. Geophysical Research Letters 28(18): 3609-3612.

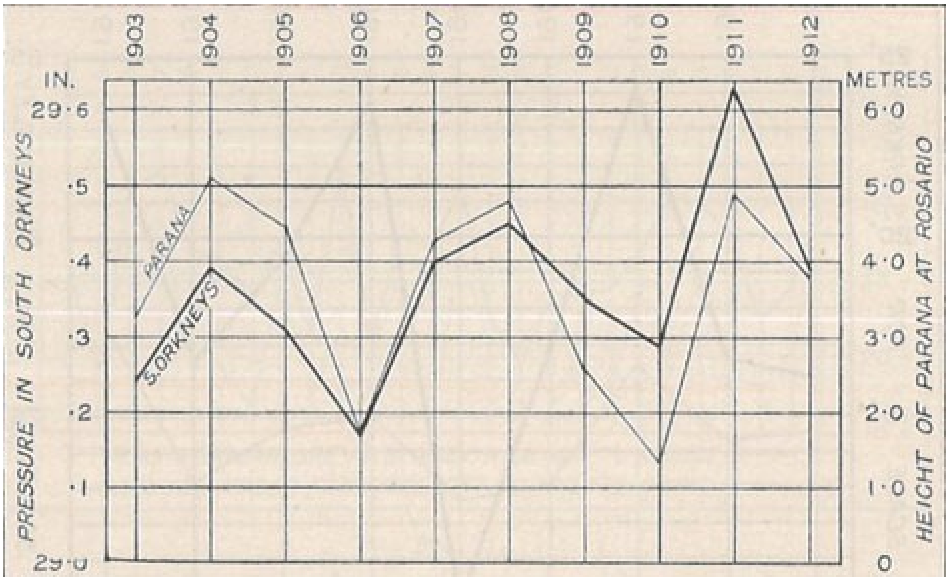

Figure 1. December values of atmospheric pressure at Orcadas, South Orkney Islands, and the height of the river Paraná at Rosario, 1903-1912, as plotted by Mossman (1913). The two time series are highly correlated (correlation coefficient =0.7).

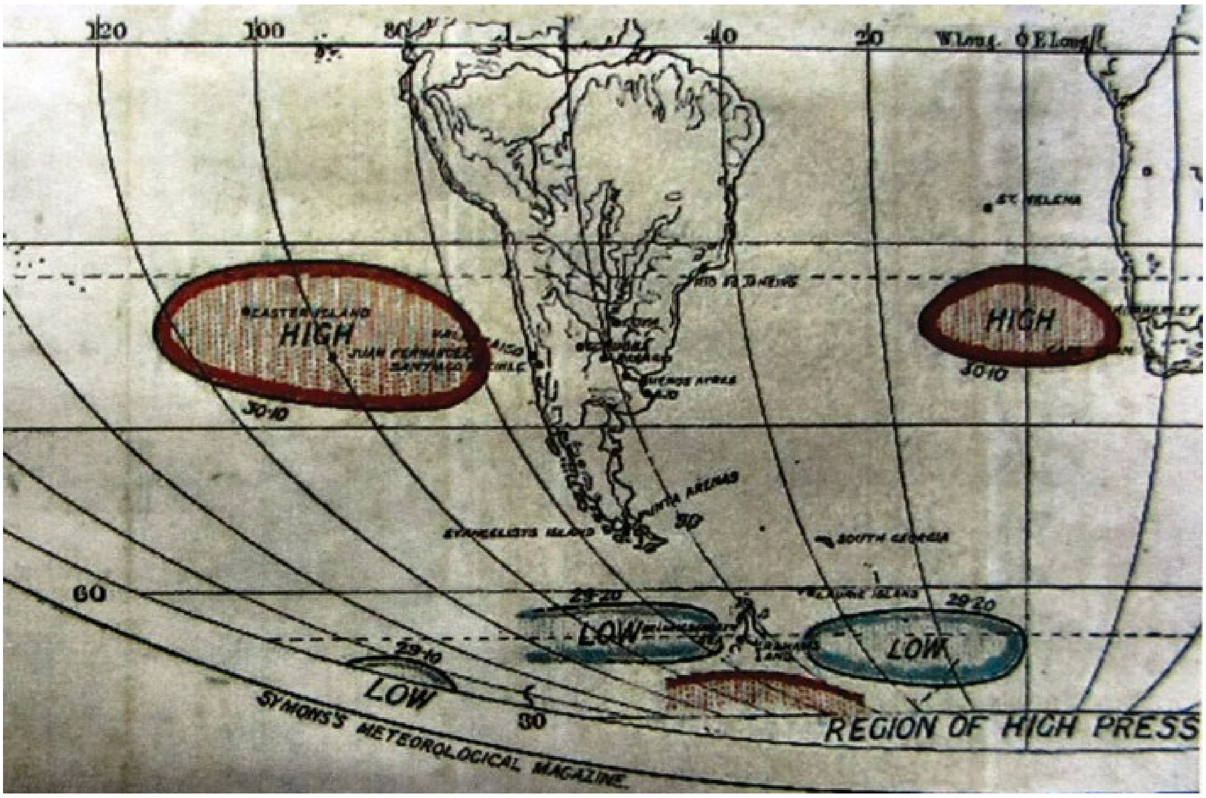

Figure 2. 'Centres of action' as described by Mossman (1913). Mossman defined these as areas of climatological high or low pressure between which interannual variations are well-correlated.

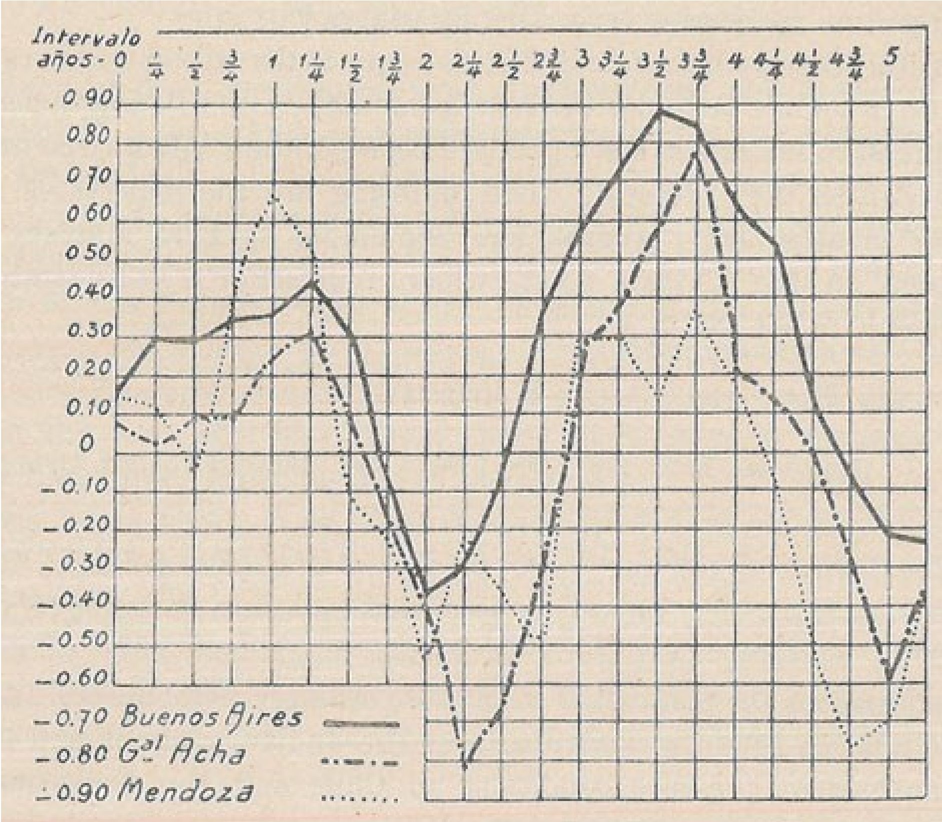

Figure 3. The relation between South Orkney winter temperature and Argentine rainfall at a later time as determined by Mossman (1918, after Hessling). The correlation coefficient (vertical axis) between South Orkney temperature and rainfall at three stations is shown as a function of the time lag imposed by the two time series (horizontal axis), from zero to five years.