DOI: 10.21917/ijsc.2019.0262

FOUR-LAYER SPHERICAL SELF-ORGANIZED MAPS NEURAL NETWORKS TRAINED BY RECIRCULATION TO FOLLOW THE PHASE EVOLUTION OF A NEARLY FOUR-YEAR RAINFALL SIGNAL

Dario Alberto Huggenberger
Group of Mechanical Vibrations, Universidad Tecnologica Nacional Faculty Delta, Argentina

Abstract

This work is intended to organize a big set of time series of rainfall reanalysis built on the Fourier harmonic that corresponds to the 4.8-year cycle of variability. To do that a self-organized map is implemented in four spherical layers trained by recirculation. The methodology is shortly described. It is used to organize time series on grid point around the Earth to follow the phase evolution of the signal. The phase and amplitude are the main criterion for organization. It is shown how the successive layers contain more general abstractions, their representativeness around the Globe and in regional scale. The main objective is to show how to use the neural network tool to follow the phase evolution of the signal around the Globe. It is described as an anomaly with highest amplitude in the central Pacific Ocean, this evolution and return after 4.8 years.

Keywords:

Neural Network, Spherical Self-Organized Maps, Recirculation, Signal Analysis. Phase Evolution, Rainfall Reanalysis, Climate Variability

1. INTRODUCTION

An oscillation on the scale of four to five years has been detected and referred to an almost four-year oscillation (Quasi-Quadrennial Oscillation QQO). In Eastern Pacific Jiang [1] detected a cycle of 52 or 53 months as containing the most relevant signal to contribute with a 28.5% of the variability to Niño 3 signal and presented maximum amplitude in 1957/8, 1969, 1972/3, 1982/3 and 1986/7. Oscillations around four years are recorded on regions of Europe in rainfall, the pressure at sea level and the temperature on the surface of the sea [2]. In paleo climatic series variability in the order of four years on Western Europe [3] has been identified. Kimoto [4] found oscillations around four years in the tropical Pacific basin through general circulation models.

In an earlier work, the question of modeling the operation of the cerebral cortex in the perceptual process simulation has been proposed. We want to use it now with the objective to follow the phase evolution of a rainfall signal of 4.8 years around the Globe. At first we will describe shortly the methodology that can be found in detail in [5].

A four-layer self-organized spherical map trained by recirculation has been built to organize patterns of rainfall around the Globe. It allows to solve border problems on the surface of the Earth and the four layers facilitate the organization of patterns at different levels of abstraction. Recirculation tries to simulate aspects of perception and abstraction.

1.1 SHORT METHODOLOGY REVIEW

This brief digression is intended to observe that the so-called "self-organized Kohonen maps" can implement features of sensation, perception and abstraction, at the same time consistent with the concepts of assimilation, accommodation, internal organization, and with an approach to the notion of operational reversible groups, classification and abstraction of typical patterns in the context of the constructivist concepts of genetic epistemology concerning the development of human intelligence.

In the context of the work that is developed herein, "stimulus" means a signal expressed as a time series or sequence of numeric values. "Sensation" will be the pattern of activity resulting from external stimuli on a set of neurons in the first layer of the network expressed as signal integration in a single numeric value. The "perception" will consist of the pattern of response of the neurons in the first layer to sensation in terms of a new time series. The training of the network will allow to maximize the similarity of this sequence (perception) with the pattern of entry (stimulus). "Abstraction", on the other hand, is related to the pattern of activity remnant and resident in the synaptic connections of internal neurons in the absence of sensation and perception, but that allows us to reconstruct an image internal to the network, stable and representative of stimuli, that is expressed numerically in the pattern of synaptic weights which produce the response of the network.

The organization of patterns is essential to the mode of operation of self-organized maps. In this respect, neighborliness between patterns characterized by the network is projected onto database as links between the groups established. In general, this organization expressed in the database meets intuitive criteria or theoretical models of the process in question, but sometimes allow to set an order or sequence processes expressed in the signal under study. For example, if the patterns are fields, the organization expresses a time evolution. This approach was used in Alessandro [6] to organize the time evolution of blocking anticyclones in southern South America and the oceans. If patterns are time-series taken in different locations, the organization allows to establish a spatial development process characterized by the series as in [5].

In the present work the border effect is intended to be solved through a two-dimensional network of neurons equidistant in angular terms on the surface of a sphere. The locations are defined by vectors of unit module that identify the location of the neurons in the network and its position is identified by the azimuth and zenith angles in the net.

Another unique aspect of the proposed method is to apply recirculation to the training of the network [7]. This procedure consists of interconnecting visible neurons by synaptic weights addressed to and from neurons visible or sensitive to the hidden or internal. Each of the hidden neurons synthesized the information received or stimulus from neurons visible by way of sensation integrated in a single parameter. A pattern of inverse synaptic weights, i.e. from hidden neurons to the visible neurons, returns a set of images by way of perceptions or primary responses to the original sensation generated from the parameter scale "sensation" and neurons synaptic weights. Among all the answers or primary perceptions, that maximum similarity to the original pattern of stimuli is set. The same direct synaptic weights projected a new internal synthesis on inner neuron that generated it as a secondary reflection from selected primary perception. The recirculation procedure is to modify the direct and inverse weights so that the parameters that define the internal image of direct sensation and the reflected perception converge to the same value, as well as the primary perception is gradually approaching the pattern presented by external stimuli. As the iteration process evolves, primary perception stabilizes becoming definitive perception, or merely perception, and the pattern of synaptic weights sets up a stable abstraction that can be used in two ways: as reference pattern for future perceptions and as stimulus to train more internal network layers without evoking the original pattern that configured the stimulus.

At the end of the training, stimuli are again presented to the network. Applying the same definition of distance between the individual patterns of information or stimuli and elaborated perceptions from abstractions, the most similar is identified between perceptual responses to each stimulus. Thus the stimulus is linked to the neuron that represents it and gets a classification of input signals through the resulting perceptions of the network in terms of the abstractions in the synaptic weights of inner layer. These patterns of synaptic inverse weights are residents by way of abstractions and organized by vicinity.

Another feature of the proposed network is to be formed by four spherical layers. The outer layer of sensitive neurons transfers stimuli (original scaled time series) by way of sensation to the first layer of internal neurons. In the application to signals of global rainfall, this external layer is set up on the basis of N_0=18142 grid points over the surface of the Earth and stimuli are expressed as time series for each of these grid points. The first inner layer is formed on N_1=256 neurons arranged on a spherical network.

The second layer of the network contains N_2=64 neurons and connects with 256 neurons in the first layer. Perceptions generated by the inverse weights associated with neurons in the first layer allow to reconstruct the signals by way of an elementary abstraction. These abstractions of the first inner layer are presented as examples to the second layer of 64 neurons being configured using the same procedure applied to the time series of entrance to the first layer, a network map that contains abstractions more general and deeper. The training of the second layer is developed showing random patterns of abstractions stored in the first layer and reconstructed from the inverse weights. These patterns operate as signals that relate 256 neurons in the first layer as projections over 64 neurons of the second layer, which thus are specialized to recognize certain patterns of the first. In the same way a third layer of 16 neurons is configured and trained, receiving examples generated in the second layer of 64 neurons. The training of the third layer is carried out following the same procedure, showing the 64 reconstructions from abstractions that relate the second layer with the first 16 neurons of the third layer. Finally, a fourth layer of N_4=4 neurons receives stimuli as examples configured on 16 neurons of the third layer so that the fourth layer contains more general abstractions. The training of the fourth layer is made showing the 16 patterns that relate the third with the second layer to the four neurons of the fourth layer. The inner layers training procedures operate by way of organization of the abstractions in the outer layers of the network.

The determination of the set of input patterns better represented by each neuron is done through a measure of Euclidean distance between input to the layer pattern and the pattern reconstructed for each neuron layer by selecting as the most representative neuron whose reconstructed pattern is closer to the pattern of origin, i.e., the neuron that offers the best perception of the input stimulus.

The positions of neurons have been defined by vectors V_{ijk}^{m}, where *m* identifies the neuron in the azimuth and zenith angle *ij* and *k* runs 636 synaptic weights that link each neuron with the input pattern.

The process of identification of patterns to reconstruct the series of successive layers starting from the activation of neurons that are trained in the deeper layers, which is obtained by multiplying a pattern of inverse synaptic weights by the corresponding coefficient of sensation. Then it compares internal reconstructed patterns with the more external from the fourth layer to the first until the original source of data or sensitive external layer is reached (in what follows, the reference to the layer numbers will be in the form of text (one, two, three...), while the reference to the neurons will be in numeric format (1, 2, 3...)). Thus, four large regions identified in the fourth layer of neurons as more general patterns or deeper abstractions are defined over the Globe. In turn the third, second and first layers define more delimited areas which describe in more detail the behavior of time series of data.

All the computer code was built by the author in Visual Basic 6.0. It should be noted that the application of the methodology in other computer and other network resulted in topologically different results in the internal structure of the network, but with projections on the sensitive layer, i.e. on the terrestrial globe, comparable with those presented.

2. DATA AND SPECIFIC APPLICATION

In this work a set of neurons will be specialized in the recognition, organization and evolution of patterns of anomalies in global precipitation reanalysis, and characterizing the geographical distribution and spatial spread of the fields annual cycles. Background information consists of 53-year reanalysis (636 monthly values between 1948 and 2000 obtained from the variable "prate" from the Internet addresshttp://cola8.iges.org:9090/dods/rean_2d.info, June 2006, NOAA 2012). A set of 18142 patterns of inputs is used.

This variable represents the speed of precipitation in cubic meters per second. In the file, data are in units SI, that is, in kg/m²s. To use more environmentally friendly units to regular use, these values were multiplied by 3600 as a scaled equivalent time to preserve the stability of the neural network process and 86400*30.45 for the purposes of having monthly totals in units comparable to mm of precipitation for analysis and presentation, so that the unit SI is adjusted on a usual scale to represent the rain accumulated monthly at each grid point. These data are considered as unprocessed by not having applied any pre-filtering technique. It is known that the precipitation is among the least trusted variables or type C in the reanalysis [8], almost exclusively calculated in accordance with the model physics. Anyway this reconstruction contains considerable information about the pattern of rainfall regularly covering the Globe, especially the monthly totals by integrating short-term variability in regional scale.

Series of rainfall anomalies have been rebuilt using one selected harmonic Fourier for such period of 4.8 years. It explores, in this way, another very particular potential application of the spherical network in the study of the phase of periodic processes. In order to follow the evolution of the phase of the signal of 4.8 years it was appealed to the organization of a pattern of signals which uses network map so that each signal consists of a single sinusoidal harmonic generated from the series of absolute anomalies in the monthly total rainfall obtained from reanalysis on grid points. This harmonic differs only in phase and amplitude at each grid point that in the spherical network is expressed by means of closed loops on the surface of the network. These loop closed paths in the inner layers are projected on the sensitive or external layer to obtain the geographical evolution of the phase of the signal on the Globe.

In synthesis, the field of absolute anomalies with respect to the monthly average of global rainfall is reconstructed by harmonic eleven on a period of 53 years (1948-2000), so that it corresponds to an oscillation of about 4.8 years (58 months). Even though it's a rigid harmonic signal, their ordering is simple and the topography of the network is only associated to the phase and the amplitude.

3. RESULTS

The fourth layer of the network features four patterns of anomalies. The neuron 3 responds to an oscillation with amplitude of about 5mm and a phase with peak in early 1973. The year 1973 will be taken as a reference to the relative location of the phases.

The Fig.1 and Fig.2 show the reconstruction of the series through neurons 3 and 4 with their associated anomaly fields. It can be seen that the behavior of the wave of 4.8 years in the neuron 3 presents a very singular pattern in the Pacific equatorial band with extensions towards the southern cone of South America and USA. It is observed scattered in the Indian Ocean, Central Asia and along oceanic band to southern Africa and Australia to reappear in the southern Pacific. Neuron 4 describes a wave pattern almost in phase opposition with respect to the characterized by the neuron 3. The spatial expansion associated with neuron 4 presents rainfall anomalies over the Amazon, the equatorial Atlantic and equatorial West Africa, Indonesia, tropical North Central Pacific and coastal areas of the Pacific off China to Alaska, and against the East coast of Australia with a deep incursion into the south Pacific. The field of anomalies extends to the coast of Chile and on the tropical North Central Atlantic reappearing on the North Sea, northern Europe and Scandinavia, central Europe and some regions of Siberia. The neighbor region of the coast of southern Mexico and Central America on the Pacific responds to anomalies characterized by neuron 4. It may be noted also that in the South Pacific in high latitudes a pattern of anomalies complementary to the equatorial is observed: while dominates the pattern of waves on the central and oriental Pacific in equator, at high latitudes is manifested in the south of Australia, the Indian Ocean and the Ross Sea; so when the wave is expressed in the western Pacific, in the south Pacific is expressed on the south-eastern edge to the south of Chile and the Antarctic Peninsula.

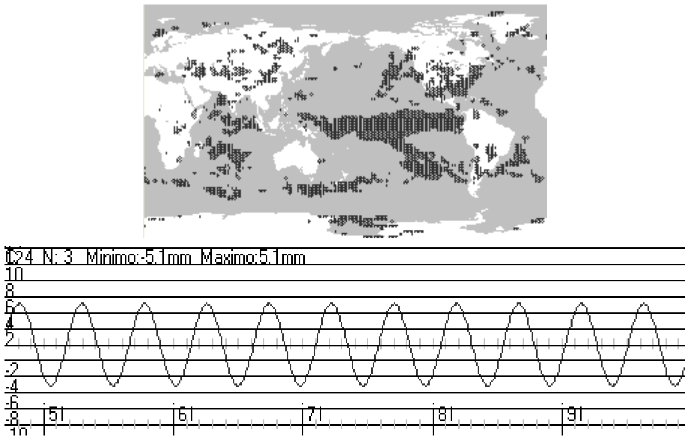


Fig.1. Spatial representativeness (left) and time series (right) in the neuron 3 of layer four on absolute anomalies reconstructed by Fourier harmonic eleven

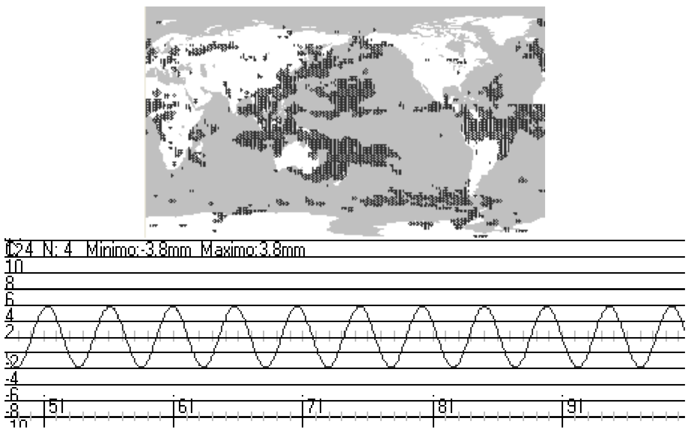


Fig.2. Spatial representativeness (left) and time series (right) in the neuron 4 of layer four on absolute anomalies reconstructed by Fourier Harmonic Eleven

Neurons 1 and 2 (Fig.3 and Fig.4) characterized the behavior of the anomalies on extra tropical and polar region. The neuron 1 pattern is dominant in the Arctic and neuron 2 in the Antarctic. The neuron 1 prevails, on the other hand, in Africa, the Atlantic and some regions of the Pacific in mid-latitudes, while the neuron 2 is expressed on the Indian Ocean, Australia, America in mid-latitudes and coastal areas of the Atlantic near western Africa and Europe. The amplitudes are significantly lower and almost in phase opposition between them. If we take the neuron 3 as the start of the process, the neuron 2 follows with a year in delay. Yet a year later neuron 4 series manifests and last seen in phase sequence neuron 1 with more than three years late with respect to the neuron 3.

In synthesis, we observe the evolution of this wave in four stages. The neuron 3 predominates over equatorial eastern and central Pacific areas with a secondary maximum over the Indian Ocean. The neuron 2, one year later in the sequence, presents a maximum expression on mid- and high latitudes but especially in the southern hemisphere. The neuron 4, in phase opposition with the 3, prevails in equatorial and tropical regions of the western Pacific, the Amazon and Atlantic. Secondary maximum of representativeness in neurons 3 and 4 in mid-latitudes are zonally in a complementary manner with those observed at low latitudes. The neuron 1, also with a predominance of representativeness in middle latitudes, now has greater expression over high latitudes of the northern hemisphere, especially in the Arctic, and in southern hemisphere mid-latitudes.

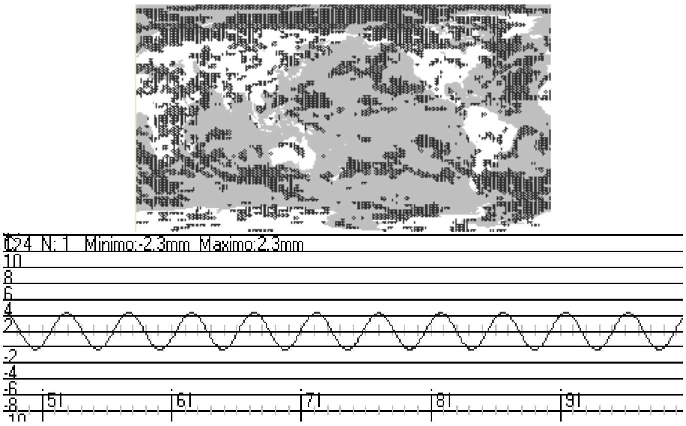


Fig.3. Spatial representativeness (left) and time series (right) in the neuron 1 of layer four on absolute anomalies reconstructed by Fourier harmonic eleven

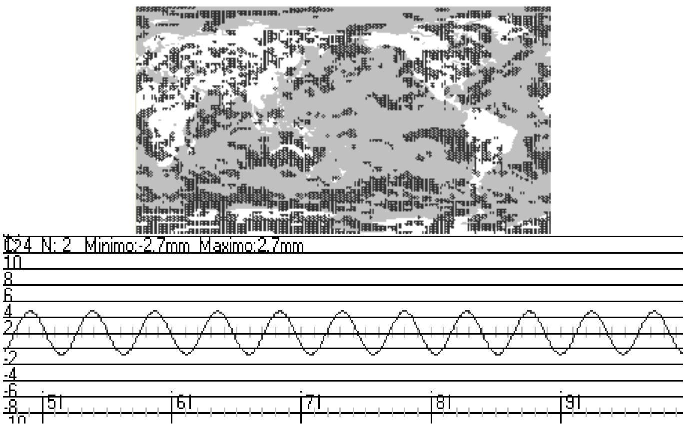


Fig.4. Spatial representativeness (left) and time series (right) in the neuron 2 of layer four on absolute anomalies reconstructed by Fourier harmonic eleven

In order to achieve a better resolution of this process, its evolution is discussed in the third layer of the network. The Fig.5 presents the third layer and the phase sequence from neuron 6 in thin line. It may be noted that it closes a cycle along a sinuous line, but if it highlights neurons representing the equatorial maximum of amplitude (6-13-1-14-15-10-6 highlighted by a thick line), the sequence of representative neurons in the network is singularly ordered and framed by side sequences. The sequence 3-2-9-4-16-3 manifests in neurons 2 and 9 at 16 and 36 months, maximum of representativeness on polar latitudes south and north respectively.

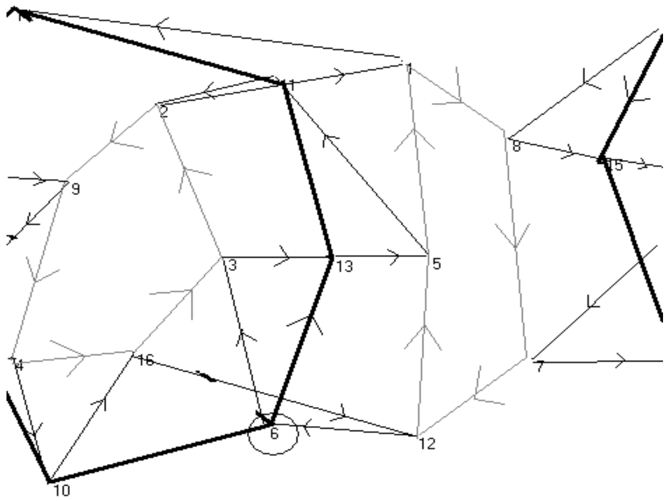


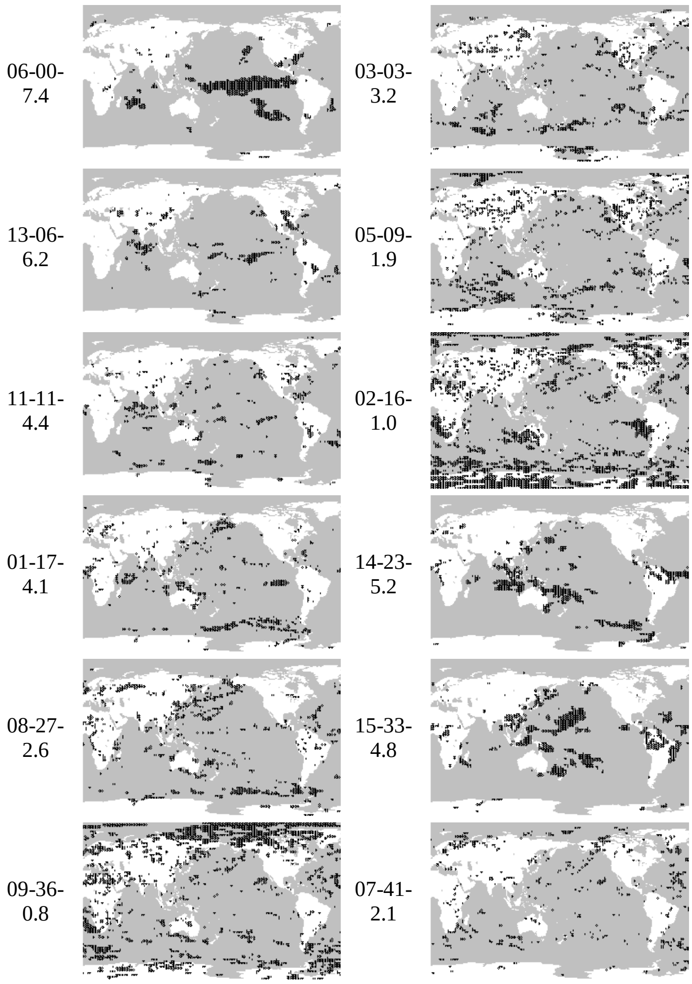
Fig.5. Third layer of the neural network shows the number of neuron, the sequence of phase with arrows, stands out in thick line representative of the equatorial band sequence and neuron 6 as the start of the process of 4.8 years (see text for details)

The Table.1 presents the number of neuron on the left column, the phase expressed in months of delay with respect to the assumed zero phase neuron 6, and the amplitude of the signal in the corresponding neuron. This Table.1 shows that sequence that would begin in the neuron 6 continues on the neuron 3, representative of middle latitudes, predominantly in the southern hemisphere, but with representation in longitude sparser than neuron 6 but always concentrated on the Pacific and the Indian Ocean. Followed by neuron 13, representative on tropical and equatorial areas, and then the neurons 5, 11, 2 and 1 distributed over middle and high latitudes. In neurons 14 and 15, not definitely in 8, shows a concentration of the signal over the western Pacific and northern South America. In the rest of the neurons referred to in the Table.1 it can be seen again a greater dispersion in the spatial representativeness and extension to middle latitudes before closing the series on neuron 6.

The Fig.6 shows the field of representation, longitudinal and latitudinal patterns of geographical distribution and reportedly on the left the order number in the Table.1, the number of neuron and the time in month characterized early stage as 00. The cycle of four years and a half to five years, which we characterized as 4.8 years, i.e. the order of 57 or 58 months, is done to start arbitrarily in the central Pacific as the region which expresses the maximum amplitude. The third layer of the network encompasses the equatorial band of the Pacific between South America and New Guinea, with extensions to tropical areas and mid-latitudes in the eastern Pacific, in North America in Mexico and the East Coast of USA, near Brazil in South Atlantic and in the Argentina Pampa areas, expressing themselves also in the Indian Ocean in front of Madagascar.

Table.1. Sequence of neurons in Fig.5. On the left column reporting the number of neuron; in the central, phase of delay expressed in months and on the right the amplitude in mm

Neuron	Phase	Amplitude (mm)
6	0	7.4
3	3.1	3.2
13	6.4	6.2
5	9.1	1.8
11	11.6	4.4
2	16.9	1
1	17.3	4
14	24	5.2
8	27.9	2.6
15	34	4.8
9	36.9	0.8
7	41.9	2.1
4	43.6	3.9
10	50.1	4.4
16	54.3	1.9
12	56	4.1
6	58	7.4



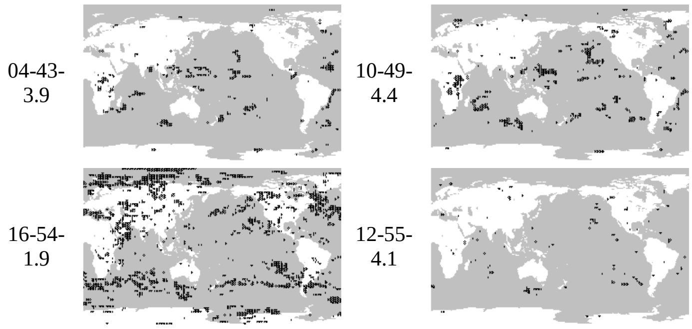


Fig.6. Spatial evolution of the signal of 4.8 years on the third layer of the network. Spatial representativeness in neurons in Table.1 of the layer three on absolute anomalies reconstructed by harmonic eleven of Fourier. Left informs the number of neuron, phase in months and the amplitude of the signal in mm

It can be seen that regions of maximum expression are located in the central Pacific and in the Indian Ocean at the same time as in equatorial areas with a more pronounced extension towards the southern hemisphere. This oscillation has a maximum of 7.4mm which coincides, in one of its phases, with the first months of 1973 and the second half of 1982. Three months later, this signal was extended to middle latitudes, predominantly in the southern hemisphere, with little manifestation in the equatorial area and a maximum width of 3.2mm. It is expressed dispersed in Asia and North America while it appears in all the mid-latitudes band of the southern hemisphere and even in the Antarctic boundary between the Ross Sea and the South Pacific. Six months later and with an amplitude of 6.1mm, it is observed even in the central Pacific but in marginal areas to the equatorial band and in tropical regions, whereas on the Indian register positive anomalies in the south of India. It manifests itself also in some parts of Asia, but predominantly in eastern U.S. and in the south of Brazil, which would correspond in phase at the beginning of 1983. Nine months after the maximum expression in the equatorial Pacific, with amplitude of 1.8mm, it reappears in mid- and high latitudes especially on the South Indian Ocean, the South Pacific and Atlantic tropical and middle latitude. It may be noted that, in longitudinal terms, it is expressed on the Indian Ocean, Central Asia and the Arctic north of Siberia, and on the American continent. Almost a year later, with amplitude of 4.4mm, it manifested so dispersed over the Globe although mostly on the Indian Ocean and the western Pacific. Sixteen months later it shows singularly on Antarctica and Antarctic Circumpolar Ocean edge at the same time in desert areas of the southern hemisphere. Dispersed mode is observed in mid- and high latitudes of the northern hemisphere. Almost together in time and with an amplitude of 4mm, it manifests itself in the band in high latitudes of the South Pacific, in the region of Bering and tropical parts of the Indian Ocean, Indonesia, and equatorial Africa. The Pacific is expressed in a tropical band, especially near Peru. Almost two years later, with an amplitude of 5.2mm, it is expressed mainly on the western Pacific, Indonesia and northern Australia, but also in the equatorial and tropical north Atlantic, and north of South America, including the north of the Amazon, while the on the South Pacific as a band of anomalies of rainfall to the south of Chile and the Drake Passage. It could consider a mechanism of purely oceanic origin in the Pacific if it weren't manifested so clear in the Atlantic at the same time as in the western Pacific.

With a range of 2.6mm and a 27-month delay with respect to the maximum in the central Pacific, the field of anomalies is expressed predominantly in middle and high latitudes. A band of peaks is observed in the South Pacific in high latitudes at the same time as in the North Pacific, although further west off the Asian coast and Australia in mid-latitudes. It is also observed in the North Atlantic and the Baltic. Almost three years later it appears with amplitude of 4.8mm, in the western Pacific, tropical Atlantic and in the north of South America, covering much of the Amazon. This period is observed with a delay of three years and amplitude of less than 1mm predominantly over the Arctic north of the Pacific and even Greenland. It is also expressed in the southern hemisphere predominantly on the Atlantic Ocean in middle and high latitudes between South America and Africa. With a delay of nearly three years and a half and an amplitude of 2.1mm, in middle and high latitudes, predominantly on the Atlantic, Alaska, some parts of the Indian Ocean and the Baltic. With a 43-month delay and an amplitude of 3.9mm in subtropical latitudes, and then in mid-latitudes with an amplitude of 4.4mm but with a delay of 49 months, predominance of maximum is observed on some areas of the Pacific hinting a shift towards the east with an interval of six months, at the same time as observed in equatorial Africa and some regions of the Atlantic and the Indian Ocean. Four years later and almost completing the cycle, with an amplitude of 1.9mm, expressed in middle latitudes on the southern hemisphere, on the North Atlantic, the Mediterranean and Middle East, but also in the eastern North Pacific and especially on regions of the Arctic in the north of Europe and western Asia. Almost closing the process, with amplitude of 4.1mm, it is expressed on some scattered regions of the western Pacific.

The extension to mid-latitudes appears to be resulting nuclei of anomalies in equatorial areas. On the Indian Ocean, Indonesia and the Pacific it seems to express a process that moves eastward. The sequence is complex if it joins middle latitudes. A more organized pattern shows if a sequence following the maxima of amplitude, i.e., rainfall anomalies on the equatorial belt, as shown in the following Table.2.

Table.2. Sequence of neurons corresponding to the main loop in Fig.5. In the left column reporting the number of neuron, in the central phase delay expressed in months and on the right the amplitude in mm

Neuron	**Phase**	**Amplitude (mm)**
6	0	7.4
13	6.4	6.2
11	11.6	4.4
14	24	5.2
15	34	4.8
10	50.1	4.4
6	58	7.4

The Fig.7 presents a selection of the Fig.6 which shows the sequence of the signal in the loop (thick line) shown on Fig.5. The starting point in the sequence corresponds to neuron 6 with 7.4mm of rainfall decreasing in amplitude for six months to respond to the pattern of neuron 13. The second maximum occurs in neuron 14 after 24 months of started the process on neuron 6 and extends up to 34 months of the cycle in neuron 15.

Maximum coincides with the concentration of anomalies over the equatorial region, as it can be seen in neurons 6, 14 and 15. It is remarkable to note that corresponding to this distribution of anomalies pattern a structure set up with bipolar character on the equatorial belt: the maximum over the central and eastern equatorial Pacific at the beginning of the cycle is in opposition in the sequence to the maximum of the western Pacific, Indonesia, Brazil and the Atlantic in the middle of the process.

The cycle made up of neurons 3, 2, 9, 4 and 16 of the network, with phases 3, 17, 37, 44 and 54 months, expresses a process in mid- and high latitudes reaching the polar regions almost a year and a half after the start of the process in the center of the Pacific in the southern hemisphere and three years later in the northern hemisphere. The loop formed by neurons 1, 5, 7, 8 and 12 of the network shows the process in middle latitudes.

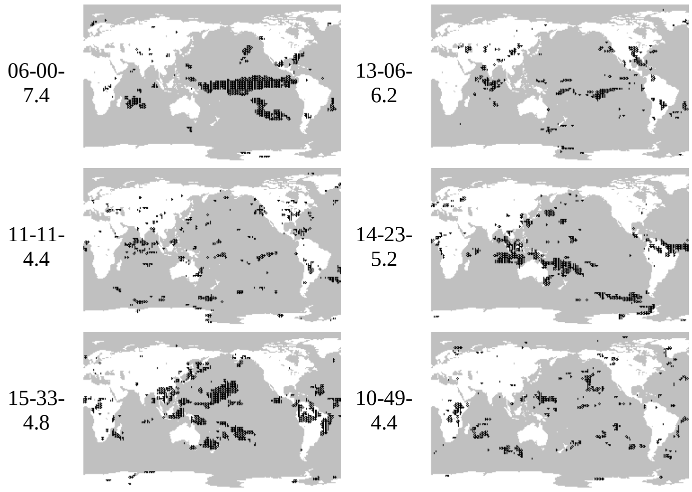


Fig.7. Spatial evolution of the signal of 4.8 years in the central loop of the third layer of the network

Spatial representativeness in neurons referred to in Table.2 of layer three. Left informs the number of neuron, phase in months and the amplitude of the signal in mm.

The second layer of the network in Fig.8 presents the same structure as in the third, but in greater detail in the spatial and temporal resolution of the process. The red lines link moments of equal phase, the thick at yearly intervals and the thin in six-month intervals. The cylindrical representation of a spherical network shows that, on the field, the black lines represent a closed circle displaced with respect to a central or equatorial line which divides the network into two halves. The process begins in the neuron 15, corresponding to the central equatorial Pacific with maximum amplitude and the sequence continues in phase with a thick black line. The thin black lines represent the process in middle and high latitudes expressing polar region through neurons 5 and 11. Closed loop that represents the process in areas of maximum rainfall divided the surface network in two non-connected areas of which the smaller represents part of the process in middle latitudes.

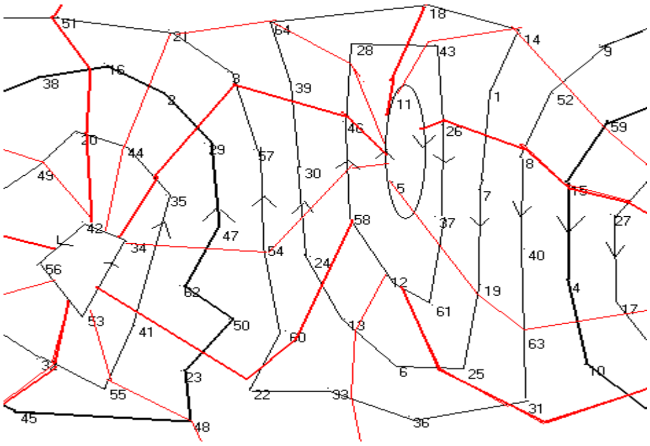
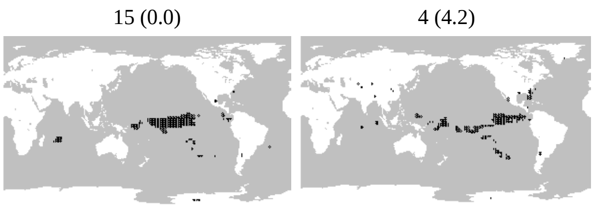


Fig.8. Second layer of the neural network

It shows the number of neuron, the sequence of phase with arrows, stands out in thick line representative of the equatorial band sequence and neuron 15 as the start of the process of 4.8 years. The red lines indicate the advance of the signal with the same phase at intervals of one year (thick line) and six months (thin line) (see text for details). It can be seen here that the organization by neighborhood of the neural network has enabled ordering process in terms of the temporal sequence in the phase and the spatial structure conditioned by the amplitudes. Through fifteen maps in Fig.9 the beginning of the process can be seen in the central Pacific (neuron 15, time 0). The second image (neuron 4, 4.2 months) displays a complete shift of the anomaly to the American continent but also toward Indonesia and preferably towards the South Pacific. The third image (neuron 9.1, 10 months) presents this signal extended to America on the one hand and to the Indian Ocean on the other. The fourth image (neuron 45, 13.3 months) shows the signal spread around the equatorial circle. The fifth and sixth images (48 and 23 in 22.4 and 17.8 month neurons) show a gradual concentration of the signal on Indonesia and the eastern Pacific. The seventh image (neuron 50, 26.4 months), almost in the middle of the process, presents a simultaneous expression of the signal over the Atlantic off the coast of Brazil and Indonesia. Perhaps the low resolution network generates an inflection in the representation of the process which manifests itself in a dispersion of the signal in the eighth picture (62, 27.6 neuron months), but retains the distribution over the eastern Pacific and the equatorial Atlantic. The ninth image (47, 31.3 neuron months) presents the maximum on the eastern Pacific and the center of the Amazon, as if the signal returned toward the center of the Pacific at the same time that crosses the American continent to move again towards the center of the equatorial Pacific. Pictures 10-15 (neurons, 29, 2, 16, 38 and 59 with phases 35.1, 38.6, 45.1, 49.7, and 54.9 months respectively) are the end of the process on the center of the equatorial Pacific previous extension to mid-latitudes. The last image shows newly neuron 15 closing evolution 57/58 months.



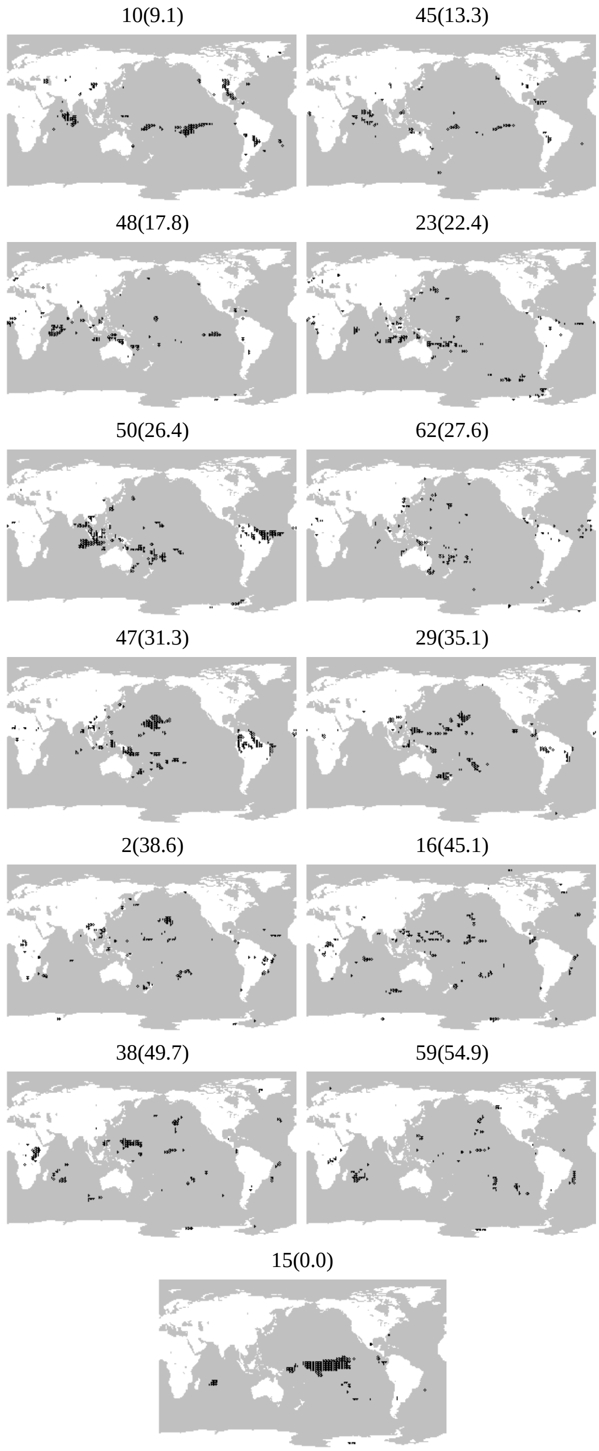


Fig.9. Evolution of the process of 4.8 years in the main loop (see Fig.8) of the second layer of the network. Fields representative of neurons are listed at the top of each figure. Delay reported in parentheses in months compared with neuron 15, taken as the origin of the process

The Fig.10 presents the evolution of the process in the first layer of the network. The most prominent black line represents the sequence on the equatorial belt while the thin black lines accompany this evolution in mid- and high latitudes. The red lines are the phases. The thicker red line indicates the start. The red lines intermediate states for 12, 24, 36 and 48 months while the thinnest at 6, 18, 30, 42 and 54 months. The Fig.11 presents the lines of equal amplitude on the first layer of the network for 15mm, 10mm, 5mm and 1mm of rainfall. Maximum anomaly is recorded in the neuron 170 (bottom right) with 17.3mm and represents the anomaly of rainfall reconstructed in the scale of 4.8 years in the central equatorial Pacific. A second maximum is located in the upper left part of the order of 11mm and represents anomalies on Indonesia and the western Pacific. Between these two peaks, the process evolves on the equatorial belt.

If it is following the developments in greater detail in the first layer of the network, it will see that the neuron whose time series presents a maximum of amplitude corresponds to a region located in the central equatorial Pacific with peaks at the end of 1972 (neuron 170). Assuming this disturbance as the beginning of a process sequence, we can develop it in terms of phases through a delay with regard to this initial phase.

The sequence can be seen on the net and corresponds to the neurons 170, 140, 188, 89, 168, 163, 122, 123, 256, 1, 179, 87, 95, 79, 144, 152, 56, 147, 49, 10, and 55 (the underlined represent annual displacement). After the start (neuron 170) it manifests itself three months later a sliding zone of maximum anomaly both eastward and westward over the equatorial Pacific at the same time the amplitude of the oscillation decreases (neuron 140). Almost five months later, the oscillation has scattered on the equatorial belt of the Pacific with greater impact on the west and advanced edge on the Caribbean (neuron 188). Seven months later, in an arc extending especially the equatorial Pacific but predominantly in the south of the region from the beginning of the process, the oscillation reaches slightly south of USA but also some regions to the north of the India and Iran (neuron 89). Almost ten months later, even decreasing the amplitude, it persists over the central Pacific but is better defined on Central Asia, the Americas and begins to be seen in the Indian Ocean (neuron 168). At the end of the first year the presence of the oscillation over the Pacific is diluted, the amplitude has been reduced to about 8mm, but defined on the Indian Ocean to the south of India and the Americas (neuron 163). At the same time, it reaches its maximum extension in anticyclone areas off Angola, off northern Chile and in Antarctica (neuron 111). A year and three months later, it is expressed more clearly on the Indian Ocean and America (neuron 122). Almost a year and a half after the start, a minimum of intensity is reached in the equatorial band and increases the definition of Indonesia (neuron 123), but the disturbance has reached around the Globe. At a year and eight months the oscillation manifests itself only on Indonesia and the Indian Ocean (neuron 256). Almost two years later, the amplitude is increased again, persists on Indonesia and the Indian Ocean, but also begins to manifest itself over the equatorial Atlantic (neuron 1).

The Fig.10 Shows the number of neuron, the sequence of phase with arrows, stands out in thick line representative of the equatorial band sequence and neuron 170 as the beginning of the process of 4.8 years at the intersection of black thick curve stroke with the red curve also thick stroke. The red lines indicate the advance of the signal with the same phase at intervals of one year (thick line) and six months (thin line) green arrows indicate the direction of evolution of the phase of the signal. (See text for details).

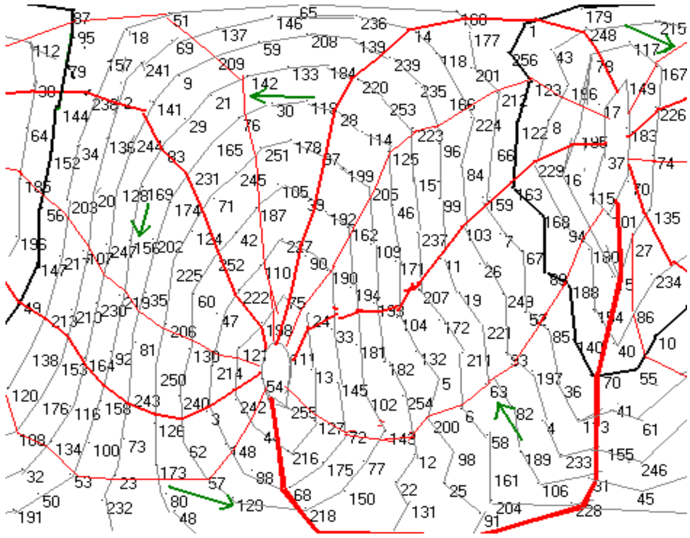


Fig.10. First layer of the neural network

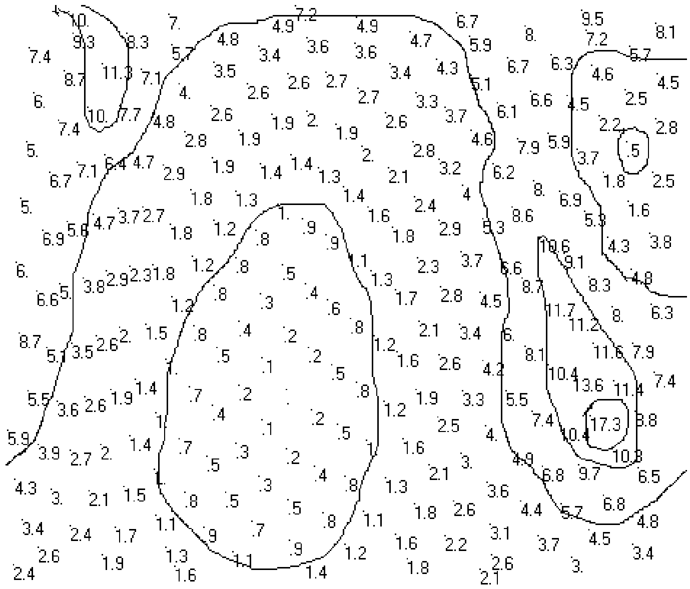
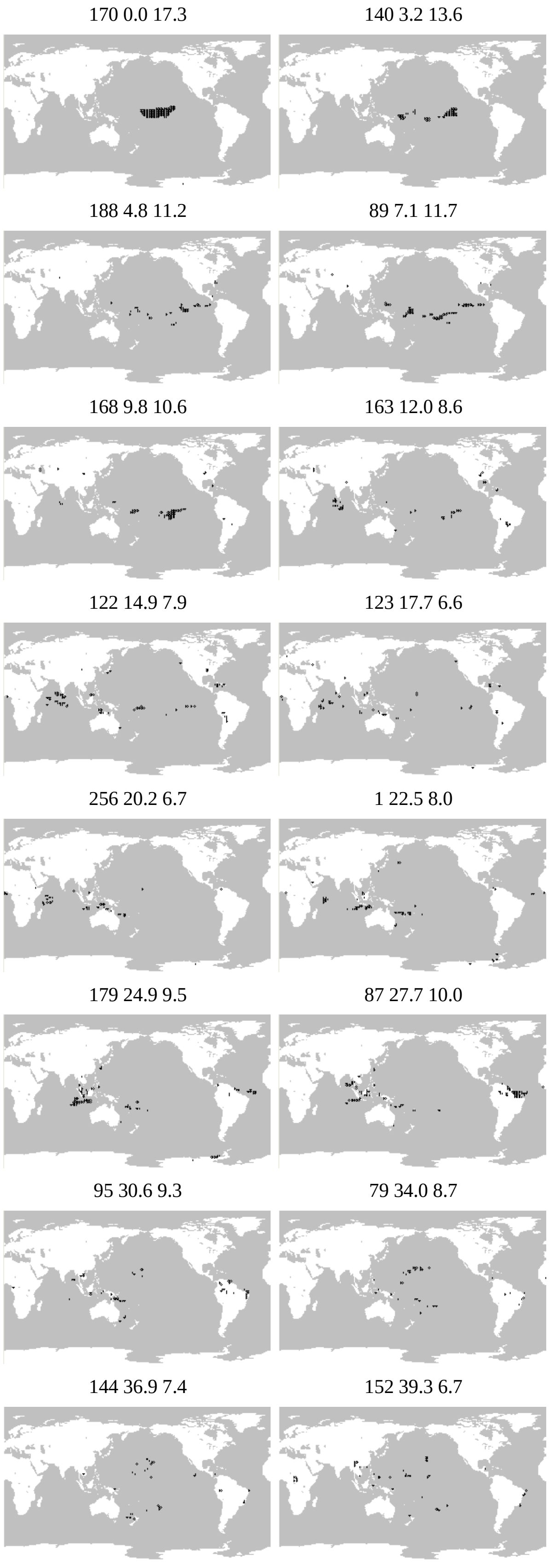


Fig.11. Lines of amplitude in the first layer of the neural network. It indicates the amplitude of the harmonic 11 of anomalies in the position corresponding to each neuron. The lines delimit contours of 5mm, 10mm and 15mm

Over the two years, it persists on Indonesia with amplitude increase but more clearly defined over the equatorial Atlantic from Brazil (neuron 179). Two years and four months after the start, the amplitude continues increasing expressing themselves on the northeast of Brazil, part of the Amazon and Indonesia (neuron 87). After two and a half years, is established on the Amazon and Indonesia but moving toward the Pacific and the western part of the Amazon (neuron 95). Two years and nine months later, it prevails over the Amazon and northern South America, east of Indonesia and moves to the central Pacific, but north of the equator (neuron 157). Three years later, the oscillation moves to the Pacific once again blurring on South America (neuron 238) reaching the amplitude now 10mm. After three years and three months expressed in diffuse way over the western Pacific but also on central equatorial Africa and around the coasts of Brazil with amplitude decrease (neuron 152).



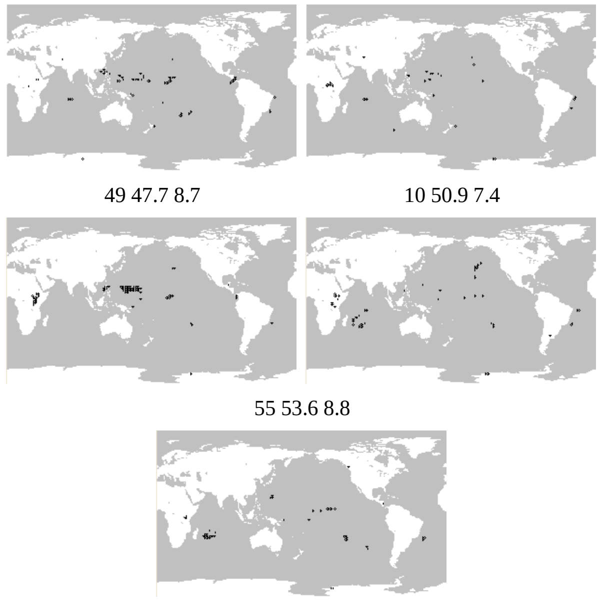
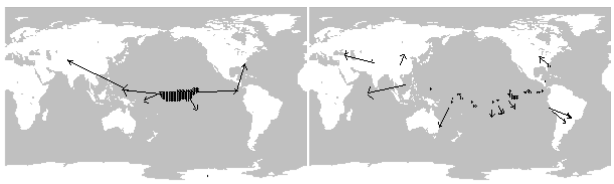


Fig.12. Evolution of the process of 4.8 years into the loop formed by neurons 170, 140, 188, 89, 168, 163, 122, 123, 256, 1, 179, 87, 95, 79, 144, 152, 56, 147, 49, 10 and 55 of the first layer of the network

At the top of each field the number of neuron is reported, the phase of the signal in months from the reference in the neuron 170 and the amplitude of the signal in mm/month. From Indonesia the signal begins to move towards the east, and from the Amazon westward over northern South America. More than three years and a half after the start is expressed so little defined over the western tropical Pacific and some regions of South America and Africa (neuron 56). Almost four years after it persists in the western Pacific, eastern equatorial Africa and locally in South America with amplitude again rising (neuron 49). Four years and three months after the start, undefined mode in the central tropical Pacific, Indian, eastern equatorial Africa and around South America (neuron 10) is observed. After four and a half years, focusing again on the central equatorial Pacific and with amplitude rising is also seen on the Indian Ocean near Madagascar and even over eastern equatorial Africa and near Brazil (neuron 55). It should also be noted that the path followed by the oscillation in network map runs a line from the edge right up to then descend on the left edge (remember that it is a cylindrical projection of a spherical network) to close the process.

The process in the equatorial region is which seems to lead the cycle, so we synthesize its evolution in five stages over the equatorial circle. A first phase of expansion from the central Pacific lasts 13 months (neurons 170, 140, 188, 89, 168 and 163, Fig.13).



3 months 13 months

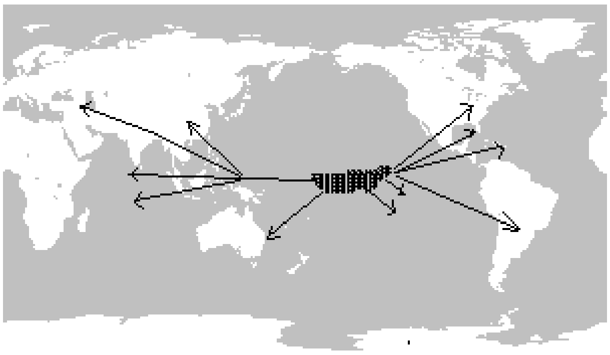


Fig.13. Schematic summary of the evolution of the process of 4.8 years during the first year (see details in the text)

It can be subdivided into two stages, the first rapid expansion (140, 170 and 188 neurons) and the second of moderate or slow expansion (89, 168 and 163 neurons). In the first stage the signal spreads in three months over the entire equatorial Pacific band and in latitude less than five degrees to the south while in six months it exceeds Indonesia, then it was observed to the north of India and reaches Florida on the coast of USA, reaching a southern expansion of about ten degrees to the south. In the second stage it reaches the Caucasus, north of China, the Indian Ocean to the south of India, northeast of Australia, eastern United States, southern Brazil and northeastern Argentina. It should be noted that the southern movement are conditioned by the amplitude of the signal represented by neuron. In the lines of phase on the network map, it can be seen that there is a complex progression in longitude in high latitudes that accompanies the signal in the equatorial band. During a second stage (122, 123 and 256, neurons Fig.14), in which the signal reaches a minimum amplitude (6mm in the neuron 123), between 13 and 21 months, while persists an expansion into the northern hemisphere up to Japan at 16 months and up to the northwest coast of USA at 19 months, the expansion eastward will stop returning from the Caribbean to the north of South America and from the south of Brazil to Bolivia and Peru. On the other hand, the expansion towards the west continues over northern Australia, Indonesia, the Indian Ocean north of Madagascar and weak signals are observed over northern Europe. It is possible that it propagates over equatorial Africa with lower amplitude and, therefore, not identified by the network, but reappears in the equatorial Atlantic south of Nigeria. This westward expansion continues up to twenty-one months. A shift towards the west of the signal is observed over the Antarctic region.

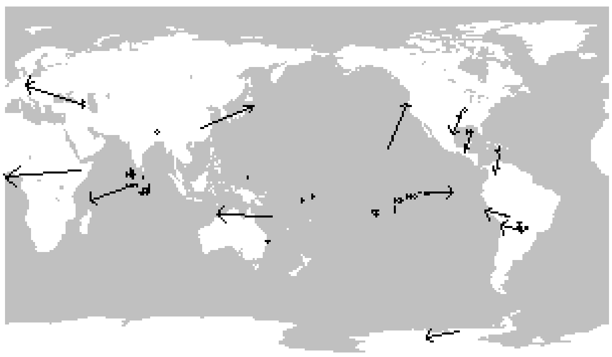


Fig.14. Schematic summary of the evolution of the process of 4.8 years during the second year (see details in the text)

The third phase, which involves neurons 1, 179 and 87 (Fig.15), extends between 23 and 29 months completing half of the period of 4.8 years. The signal on the Indian Ocean, Africa, Europe and West Asia fades while a slight expansion is seen over the North Pacific to the south of Kamchatka. On the other hand, there is a shift of the signal toward the northeast on Indonesia and the western Pacific and begins to suggest a return to the central Pacific.

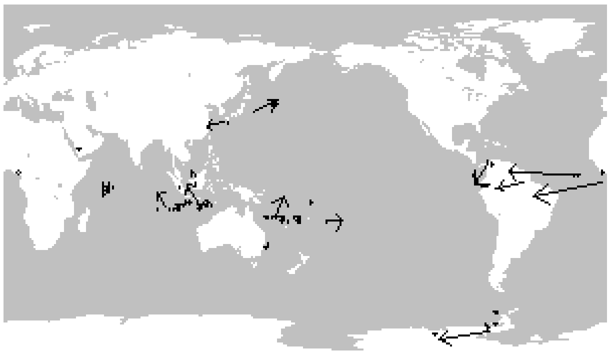


Fig.15. Schematic summary of the evolution of the process of 4.8 years during the first half of the third year (see details in the text)

From the Antarctic Peninsula the signal moves westward over the Antarctic continent. Over the Atlantic the signal moves appreciably from Africa to South America and on the Amazon westward reaching the Andes. The fourth phase involves neurons 95, 79, 144 and 152 (Fig.16) between 29 and 41 months. While on Africa there is a slow shift of the signal to the east, on Indonesia and the western Pacific manifests a noticeable shift in the same direction addressing the signal to the central Pacific. Instead, on South America it presents a shift from the northeast of Brazil, near the mouth of the Amazon, to Central America, the west and the south covering all of northern South America, but predominantly oriented to the west without incidence over the Atlantic.

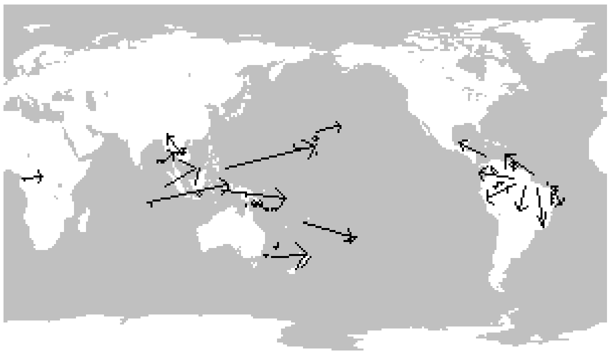


Fig.16. Schematic summary of the evolution of the process of 4.8 years during the second half of the third year and the first half of the fourth year (see details in the text)

The fifth stage, that closes the process, represented by neurons 147, 56, 10, 49 and 55 (Fig.17) between 42 and 58 months, presents a location stable of anomalies over the north of South America while on Africa there is a shift towards the east and perhaps south on the Indian Ocean. On the Pacific the anomalies move eastward in sensitive way on the west but in appearance more slowly over the center focusing on the central Pacific.

In synthesis, we see that the cycle can be subdivided into two major processes by observing displacement on Africa, the Indian Ocean, and Indonesia and the propagation of the signal amplitude maxima. First the signal moves westward since the peak amplitude in the central Pacific as time zero to stop the spread westward with a maximum on Indonesia and eastwards with a second maximum on the Amazon. While in a second phase of expansion of the signal from the Amazon, but without exceeding the scope of the South American continent, is an expansion from Indonesia and Southeast Asia to Africa, Japan, and Europe. The signal that spread over Africa reaches Brazil while on the western Pacific it starts to spread eastward. While it expands from the northeast of Brazil to the west and the south, from the western Pacific it spreads eastward. At a late stage, the signal in the central Pacific is concentrated at the end of the cycle at the same time the displacement on Africa changes direction towards the east.

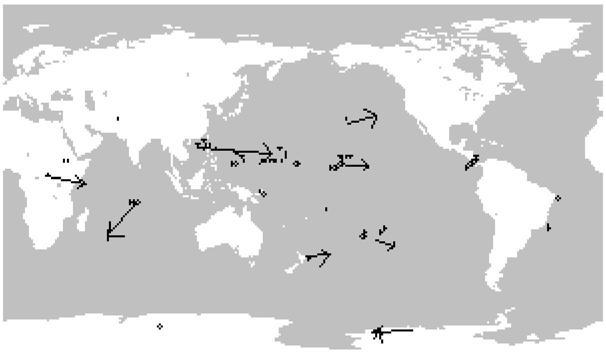


Fig.17. Schematic summary of the evolution of the process of 4.8 years during the second half of the fourth and the fifth year (see details in the text)

South America seems to arise by way of a barrier where the advance eastward of the signal originated in the central Pacific stops and forks to the south of Brazil and eastward United States. Some 20 months after, is the signal that had spread westwards reaching South America from the Atlantic. To close the first half of the cycle is this signal which seems to be renewed on the Amazon to expand westward to the new signal generated in Indonesia moves eastward, toward the Central Pacific, where it seems to stop to regenerate a new maximum in the equatorial Pacific Center.

4. CONCLUSIONS

This paper analyzes in detail the evolution of the rainfall anomaly process on the scale of 4.8 years. It is done by configuring a spherical neural network composed of a sensitive layer that receives time signals of absolute anomalies in rainfall reconstructed by harmonic Fourier which corresponds to a signal of 4.8 years. The network organizes the set of signals emphasizing the closed lines that connect neurons linked to each stage of the process in phase. These closed lines, projected on the Globe, allow to follow the geographical evolution of the signal of 4.8 years. It illustrates other use of the spherical neural network in four layers trained by recirculation to follow the phase evolution of a signal in four levels of abstraction. It should be noted that this signal is hard to follow by statistical methods as it is under the level of significance, except in few areas around the Globe. In this evolution, if taken as point or reference the maximum amplitude, registered in the central equatorial Pacific, during the first three months, a rapid expansion of the signal of 4.8 years to Indonesia and the Indian Ocean is observed, as well as to the Amazon and the Caribbean. During the remainder of the first year of the signal the expansion in longitude continues slowly and attaches an extension in latitude to the south although without exceeding the Tropic of Capricorn. In the second year the signal begins to expand northward in middle latitudes, zonally flows through Africa to the Atlantic and from the south of the Amazon and from the Caribbean it seems to move in a westerly direction as returning to the eastern Pacific. During the third year the signal that went through Africa reaches South America across the Atlantic while that on the other hand seems to return to the Pacific from Indonesia eastward. In the course of the fourth year the signal is expressed on the Amazon and seems to expand to the south and west on the north of South America while intensifies the return from Indonesia to the Central Pacific. This return configures in dispersed way towards the center of the equatorial Pacific to close the loop, predominantly from the western part of the basin. It is at least plausible to think that the distribution of landmasses and oceans determines the spatial evolution of the signal, especially the South American continent and still more the Andes in a complex pattern of reflection, refraction, diffraction and perhaps dispersion of waves. A possible expansion to middle and high latitudes can be characterized in the outermost layers of the network with a fast phase velocity of no more than twenty days from processes of intense convection in the equatorial zone. It is very important to look for signs of a propagation of a signal on the scale of almost five years in real series of rainfall or flow rates and other variables. Also, a similar methodology can be immediately applied to climate variability signals of 2.8 years, 3.6 years, 6 years, 9 years, 11 years, 13 years and 17/8 years. In this way the application of network to periodic processes was particularly useful for monitoring the spatial evolution of the phase of such processes. It is expected to have explored other use for the spherical variant of self-organized Kohonen maps oriented to the stratified organization of signals and their potential application to the analysis of the climate variability. In methodological terms there are many issues open for future research. In practical terms, it remains open to the exploration of other potentials of the methodology and the design of a utilitarian tool that does not require programming by the user.

REFERENCES

[1] N. Jiang, J. David Neelin and M. Ghil, "Quasi-Quadriennial and Quasi-Biennial Variability in the Equatorial Pacific", *Climate Dynamics*, Vol. 12, No. 2, pp. 101-112, 1995.

[2] A. Garcia, F.J. Lorente, P.M. Lorente and M.J. Ortiz Bevia, "Quasi Quadrennial Variations in European Precipitation", *International Journal of Climatology*, Vol. 32, No. 9, pp. 1295-1309, 2012

[3] Y.M. Tourre et al., "Western European Climate, and Pinot Noir Grape Harvest Dates in Burgundy, France, since the 17th Century", *Climate Research*, Vol. 46, No. 3, pp. 243-253, 2011.

[4] M. Kimoto, "Studies of Climate Variability using General Circulation Models", Available at: https://www.terrapub.co.jp/e-library/toyota/pdf/049.pdf, Accessed on 2001.

[5] D.A. Huggenberger, "Four-Layer Spherical Self-Organized Maps Neural Networks Trained by Recirculation to Simulate Perception and Abstraction Activity: Application to Patterns of Rainfall Global Reanalysis", *ICTACT Journal on Soft Computing*, Vol. 8, No. 4, pp. 1733-1749, 2018.

[6] P.A.A. Alessandro, "Identificación Caracterización de Situaciones de Bloqueo a través de un Mapa Auto Organizado de Redes Neuronales", Available at: http://www.sbmet.org.br/cbmet2010/artigos/396_64437.pdf Accessed on 2010.

[7] G.E. Hinton and J.L. Mcclelland, "Learning Representation by Recirculation", *Proceedings of IEEE Conference on Neural Information Processing Systems*, pp. 358-366, 1988.

[8] E. Kalnay et al, "The NCEP/NCAR 40-Year Reanalysis Project", *Advancing Science, Serving Society*, Vol. 77, pp. 437-470, 1996.