1. Andes du nord

The relationships between Vegetation and Climate in the Andean mountains, approached by a Mathematical model

T.A. WIJMSTRA [1]

The Ecoandes project has gathered many data on various disciplines. Amongst others we may mention : actuo and palaeoecology, micro and macro climate, pedology, geo-morphology. The principal feature of the data is that they are all situated along a gradient from the tropical lowland into the paramo. During the Ecoandes project several transects have been sampled in this way. The project aims to deepen insight into the various vegetational systems along these transects and their relation with accompanying physical parameters.

A. THE PLANET EARTH GETS ITS ENERGY FROM THE SUN

The amount of energy received from the sun, may be taken as 2 cal/cm^2/min.

The variability of the sun's energy output can be observed at various timescales. Present knowledge of the solar variation may be put briefly as follows. On one hand, no significant variation of the total energy output has been demonstrated however by radiation measurements ; indirect evidence is becoming impressive. The variations of the suns output at the extreme short wave end and in the long wave part of the spectrum correlate roughly with the increases and decreases of the sunspot number. Much greater variation of the earth annual radiation budget is caused by the very long term periodic changes in the earth's orbit, the tilt of its rotation axis and seasonal variation of the earth's distance from the sun. The combined effect of the long term periodic changes can be separated in characteristic epochs defined by the orbital situation. Such epochs commonly change their character only slowly, over some thousands of years.

The seasonal differences of radiation budget that occur every year within each epoch, including the present, due to changing length of day and altitude of the midday sun and partly to changing distance of the earth from the sun are enormously greater than any secular variation of solar constant known. When one considers the climatic difference between times stretching over many thousands of years the astronomical constants of the earth orbit must be treated as variables.

There are three distinct variations going on simultaneously all the time.

a) *The ellipticity* and *eccentricity* of the earth's orbit varies between extremes of about zero (circular) and 0.06 in the course of an oscillation of variable amplitude and period, the latter averages 96 000 years. When the orbit is most elliptical the intensity of the solar beam reaching the earth must undergo a seasonal range of about 30 % between aphelion and perihelion ; at present it is only 7 % ; when the orbit is most circular it becomes 0.

b) *The tilt of the earth's axis of rotation* relative to the plane of its orbit (the obliquity of the ecliptica) is believed to vary a least between 21° 8' and 24° 4' over a regular period of about 40 000 years.

How greater the tilt the stronger the radiation difference between winter and summer. At present it is almost 23° 7' and decreasing by about half a second of arc a year ; the last maximum was about 10 000 years ago.

c) *A third cyclic variation* with a period about 21 000 thousand years is superimposed on these other two because of the rotation of the earth's elliptical orbit and the slow precession of the equinoxes around the orbit. This means that the season at which the earth is nearest the sun (perihelion) gradually changes, getting about one day later every 70 years.

(1) *Vakgroep Bijzondere Plantkunde, Universiteit van Amsterdam, Hugo de Vries Laboratorium, Kruislaan 318, 1098 SM Amsterdam, the Netherlands.*

B. THE NEXT PROBLEM, RELATION OF VEGETATION DATA AND THEIR GEOGRAFIC PATTERNS TO THE ATMOSPHERIC CIRCULATION PATTERN

Several solutions for this problem are proposed, some using transfer functions, other response surfaces.

Ecological response surfaces are non-linearfunctions describing the way how abundances of taxa X, on a continental scale depend on the joint effect of two or more environmental variables.

The relative abundances of plant taxa are dominated by the effects of macroclimate on the competitive balance among taxa. Pollenanalysis record such regional variations for major vegetation components. These response surfaces can be estimated by *multiple regression.*

The abundance of a species may be represented as the height Z of a surface at coordinate X, Y of two predictor variables e.g. % of picea pollen (Z) as a function of the mean july temperature (X) and mean annual precipitation. Response surfaces are non linear functions and typically have at least one optimum or saddle point. A general, third degree polynomial response surface model is used as a model of estimation. In this way recently some insight is obtained into the relation between climate and vegetational distribution by means of response surfaces.

C. BIOLOGISTS HAVE LONG RECOGNIZED THE FACT THAT THE GENERAL STRUCTURE OF THE ATMOSPHERE IS THE DOMINANT FACTOR CONTROLLING THE DISTRIBUTION OF BIOMES ON THIS PLANET

However the evidence of causal links between the large scale structure of the atmosphere and regional structure of vegetation has been elusive.

Global climate regimes have now spatially defined within a complex deterministically structured atmosphere and correlated with the general outline of major floristic regions. Investigations into the temporal association of such diverse events as north pacific SST anomalies, the sahelian droughts and many other climate have led to the consensus that they are related to specific pertubations in the coupled ocean-atmosphere flow structure.

These so called teleconnections are brought about by the behaviour of the long-wave patterns of the jet streams.

A second approach is the use of principal component techniques. In this approach the recent vegetational data and their accompanying climate variables are use to establish the relation between these two data sets by regression. The fact that we are dealing with a generally not statistically independant number of species "n" brings forward that we must first process the vegetational data in some way to extract non redundant information, expressed as "m" statistically independant end members. This is done by a mathematical procedure called *Q-mode factor analysis.*

A Q-mode analysis of the data would reveal this covariation pattern by expressing the observed vegetation at every locality as proportions of several assemblages (also called factors or end members) within which the proportions remain constant. The factor analysis would not only eliminate ecological redundancy and simplify problems of data display but offer insight into the underlying structure and complexity of the ecosystem.

The next step is how to extract ecological information from the biological data matrix reduced in complexity by the factor analysis. The physical observations can be assembled in a column vector Y. Our objective now is to relate Y to the biological parameters in the factored biological matrix. This is done by *regression techniques.*

The next step is to describe the results from a palaeoecological investigation in terms of the end member assemblages. Once we have done this it is possible by mean of the equations derived from the recent situation to make an estimate from the environment in the past, provided that all possible vegetational compositions in the past are represented nowadays. This might be the case in the situation of the Ecoandes project.

We in Amsterdam have been working up to now on two topics.

1. *Construction of models* for accumulation rate of organic material in peat sections. The reconstruction of timebases for ecological and palaeoclimatological events is a must if one wishes to evaluate long-and short term fluctuations.

In our laboratory a method is developed on the assumption of a constant influx of pollen grains over time.

With this method, it is possible to get an idea of the time present between samples in a sedimentary colum.

2. *Time series analysis* of palaeoecological events in order to evaluate short and long periodicities. Short term fluctuations found in peat sections in the Netherlands demonstrated the presence of cycles of 70-90, 170, 400, 700 and 1 400 years.

Determination of longterm fluctuations in the sections from Greece and Bogota.

In these long section the wellknown cycles of Milankovitch could be demonstrated 23 000, 41 000, 100 000 and 250 000 years.

For the construction of our model representing the relation between climate and vegetation patterns we will use the following data sets from the Ecoandes project vegetation releves along the various transects along the Andean Cordillera's, pollen analytical data from lake peat and soil sections related to the transects and outside the transects, relevant data concerning the relation between present vegetation and pollenproduction, the data concerning temperature and rainfall distribution as gathered along the transects. Other data of meteorological importance from the various stations in Colombia concerning climate and weather. The first step in the construction of the model will be to establish the relation between the actual change in vegetation along the transect and the variation observed in the physical parameters.

In a first approach we will take temperature magnitude of rainfall and distribution of rainfall over time as the independant variables and a compilation of the vegetational data as dependant variables. The compilation of the vegetation data will be done by programs for arranging multivariate data in ordered two way table by classification of the individuals and attributes.

The established relation between climate and vegetation dataset can be used to reconstruct maps of the temperature and rainfall in the past. From the arising patterns the relation to the general circulation patterns can be constructed in the same way by analysing the response sufaces with contour algorithmes.

The Pliocene and Quaternary history of the northern Andes

T. VAN DER HAMMEN [1]

The final upheaval of the northern Andes takes place in the Early to Middle Pliocene. It is then that the higher mountain environments are created. During the Tertiary, however, hills and low mountains were formed during pre-Andean and proto-Andean orogenetic phases, possibly not higher than 1 000 m. In these hills and low mountains the evolution of the Andean montane flora started already, but during and after the Pliocene upheaval to the present elevations (locally up to approx. 5 800 m), the present montane and páramo flora and vegetation came into being by evolution-adaptation and immigration. As at the same time the isthmus of Panama came into being, immigration could take place not only from the southern temperate area, but especially also from North America. The first immigrants from the north are elements from the subtropical to warm temperate Tertiary Laurasian flora ; later follow more temperate elements. In the páramo flora about 50 % of the genera is of temperate origin, but going downward via the upper and lower montane forests, this cipher decreases fastly, and below 1 000 m almost all the genera are of neotropical origin.

Palynological study of Pliocene sediments in the area of the high plain of Bogotá revealed the gradual uplift of the area to the present elevation of 2 580 m, showing the change of tropical to montane and páramo vegetation.

A large lake is formed in the area of this high plain, towards the end of the Pliocene ; it continues to exist (with temporal fluctuations of the lake level) until some 30 000 years ago. However, the lake of Fúquene, at the same elevation as the high plain of Bogotá, continues to exist till the present day. The total sequence of lake sediments is at least 400 m. Pollenanalysis of these sediments has revealed a long sequence of glacial and interglacial periods. The forest limit is depressed 1 000-1 200 m or more during the cold periods. The temperature may then have been 6°-8° C lower than today. The montane forest belts were also depressed. In the Occidental Cordillera the oak forest, today between approx. 2 000-3 000 m altitude, was present at 1 500 m during the Last Glacial, but the temperatures at sea-level were probably only some 2° lower than today. This means that the temperature gradient must have been much steeper, in the order of 0.8-0.9 °C.

During the strong tectonic movements of the Pliocene large mud streams, often with large blocks of rock, were formed, often closely associated with faults. During the early Pleistocene, much angular brexious material was still being deposited in the marginal area of the high plain, probably by solifluction. At the same time, gravels of probably fluvioglacial origin were deposited, and palynological data indicate a very cold climate. Volcanic ash layers from immediately below were dated around 3 million years, and the complex might represent the first larger Glacial.

The Last Glacial is known with much more detail. There is a cool and very wet period during the Middle Pleniglacial, when lake levels were high and a broad zone of Polylepis was present in the hills around the

(1) *Hugo de Vries, Laboratorium, University of Amsterdam, Kruislaan 318, 1098 SM Amsterdam, the Netherlands.*