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REMOTE SENSING AND HOLOCENE VEGETATION: HISTORY OF GLOBAL CHANGE

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INTRODUCTION

Predictions of the future evolution of the earth's atmospheric chemistry and its impact on global circulation patterns are based on global climate models (GCMs) that integrate the complex interactions of the biosphere, atmosphere and the oceans. Most of the available records of climate and environment are short-term records (from decades to a few hundred years) with convolved information of real trends and short-term fluctuations. GCMs must be tested beyond the short-term record of climate and environment to insure that predictions are based on trends and therefore are appropriate to support long term policy making. An appropriate timeframe should extend over the Holocene period (the last 10,000 years) when most contemporary climate and environmental processes began.

Since its inception in 1916, pollen analysis has successfully reconstructed the paleoecology of the last 10,000 years for many sites around the world, thus providing a powerful time-link between short- and long-term processes in the biosphere. However, pollen analytic results cannot be used in physiological models driven by remotely sensed data. Further, modern ecology and climate data are necessary to calibrate pollen analytical models. These are available for extensive regions in the northern hemisphere, particularly for eastern United States and Canada, and western Europe. In other parts of the world, weather stations are scattered, records extend over a period of only few years, and there are no systematic climate records for large portions of the globe. This is the case of Patagonia in Argentina where a few weather stations are located close to the Atlantic seaports, fewer stations are in towns located near the eastern Andean foothill, and fewer still are scattered on the extensive Patagonian plateau.

This problem became evident after completion of the Argentine-German Program of Palynology (PROPAL), a cooperative effort of National University of Mar del Plata (Argentina) and University Bamberg (Germany) to produce a modern pollen database for the Pampa and Patagonia regions. PROPAL pollen data were used by undergraduate and graduate students for their theses and

dissertations. Five of them analyzed Quaternary pollen profiles but none was able to perform calibration due to the lack of modern climate data.

To solve this problem, a new approach to calibration was attempted by D'Antoni and Spanner (1993). By calibrating modern pollen data of southern Patagonia (Figure 1) with satellite remote sensing data they produced predictive models of reflectance in the red (RED) and near infrared (NIR) regions of the electromagnetic spectrum.

As sensed by the Advanced Very High Resolution Radiometer (AVHRR) mounted on the NOAA-9 satellite, RED (580-680 nm) includes the wavelengths absorbed by chlorophyll pigments

Figure 1 The study area - Transect (T) 1, sites L45-L19; T 2, sites C28-C1; T 3, sites S1-S29, T 4, sites 30-35; and, T 5, sites T30-T0, Location of the study area en South America (box)

(Hoffer, 1978), while NIR (725-1100 nm) is characterized by scattering and increased reflectance of infrared wavelengths by the cellular structure of leaves (Gausman and Allen, 1973). Typically, dense vegetation absorbs more RED and reflects more NIR. Deserts and other environments with highly reflective soil surfaces also have high reflectance in the NIR band.

The RED and NIR bands have been used for calculating a simple ratio index (SR=NIR/RED) and a normalized difference vegetation index (NDVI=[NIR-RED]/[NIR+RED]). NDVI has been used for mapping vegetation. Linking remote sensing data with ecosystem process models is more complex and requires additional research work (Running, 1990). Sellers (1985, 1987) found important relationships among leaf area index (LAI), absorbed photosynthetically active radiation (APAR), and NDVI. Thus, under specified canopy properties, the APAR is linearly related to NDVI and curvilinearly related to LAI. Further, the net primary productivity NPP was shown to be a function of the APAR and the energy-conversion efficiency (ϵ), as NPP=f (Σ APAR) ϵ, integrated over the growing season (Running, 1990): It is not our intention to further discuss these relationships but to initiate a change toward a substantially richer palynological paleoecology than the one available at present. This work refines the method,
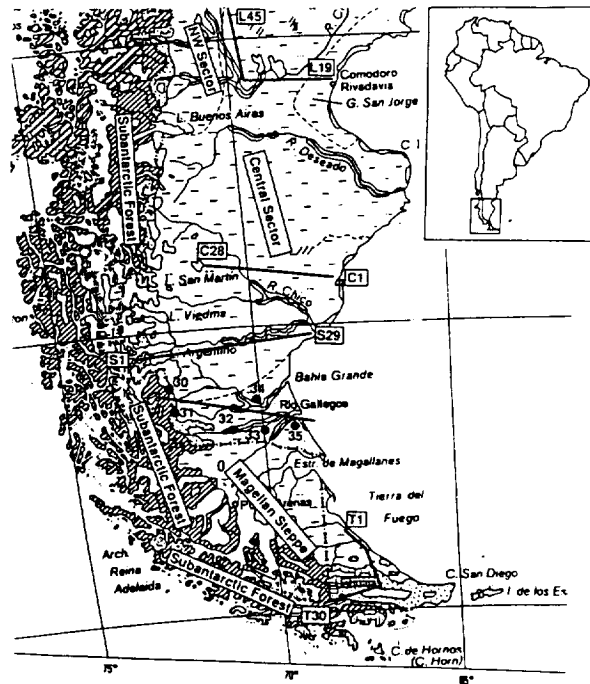
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discusses results of a remote sensing "snapshot" study of vegetation of southern Patagonia and Tierra del Fuego, and compares these results with predictions by calibrated equations. These equations are then used to predict reflectances in the RED and NIR in the past, which are then used to hindcast past vegetation indices from a fossil pollen profile sampled from a sedge bog at Meseta Latorre, (51°31'S, 72°03'W, 1,000 m above sea level) with a basal ^{14}C date of 9,055±140 years B.P. (Schäbitz, 1991).

MATERIALS AND METHODS

Remote Sensing

Remote sensing data of vegetation in southern Patagonia and Tierra del Fuego (latitude range = 45°-55° South), from the Andes to the Atlantic coast were obtained for the RED and NIR channels of the AVHRR. These data were acquired from the afternoon overpass on February 18, 1987. The study sites are distributed no further away than 15° from the center of the scene, thus minimizing illumination variations due to scan angle. The spatial resolution of AVHRR data is 1 km. The mean of a 2x2 km area was calculated for each sample and converted to albedo for the RED and NIR using the calibration coefficients proposed by Price (1987). Albedo represents the spectral reflectance that AVHRR would measure from a Lambertian surface, with the sun directly overhead at the mean Earth-Sun distance, and with no intervening atmosphere (NOAA, 1986). These constraints are not met but conversion to albedo provides a basis for normalization and comparison to other data (Spanner, et al., 1990). From the data converted into albedo values, NDVIs were calculated for each of 74 study sites.

Pollen Analysis

Surface soil samples were taken at the study sites in the summer of 1987 and early fall of 1989. Samples consisted of ca. 100 ml of soil collected with a spatula sweeping the surface to a depth of ca. 1 cm. Samples were placed in labelled plastic bags. Pollen extraction included subsampling, addition of foreign markers to allow pollen concentration estimates and then: (1) a pre-treatment aimed at neutralizing 'humic acids' in acid soils and calcium carbonate in arid soils; (2) sieving through a 200 μm mesh under a water jet; (3) floatation in a water solution of zinc chloride calibrated at 2.1 g ml^{-1} specific gravity (separation was enhanced by a 5 minutes ultrasonic treatment); (4) acetolysis treatment (up to 10 minutes) to break cellulose molecules into soluble sugar fractions then removed by water rinses; and (5) embedding residues in glycerol. Slides were made and analyzed under a light microscope. Modern pollen data were produced by L. Burry (in prep.), D'Antoni & Spanner (1993), M. Lombardo (in prep.) and M. Mancini (1989). Fossil samples were obtained by H. Stingl and K. Garleff with a Dachnowski corer. Subsamples were taken at 100 mm intervals and then several intermediate subsamples were taken at critical portions of the stratigraphy. Pollen was extracted and analyzed by F. Schäbitz (1991). Pollen sums were

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established by multinomial confidence intervals for 95% probability (Mosimann, 1965) using an unpublished program for personal computers. Pollen counts ranged between 300 and 627 grains per sample.

Hindcasting

Predictive equations were calibrated for the RED and NIR with modern pollen data, using the approach discussed by D'Antoni and Spanner (1993), and further discussed by D'Antoni (1993). Thus, all the pollen sums were recalculated based on 30 pollen types that satisfied the constraints established by Webb (1985). The values of each pollen type were plotted against those of AVHRR's RED and NIR reflectances to visualize their relationships. Pollen variables not linearly related to RED or NIR were transformed (linearized) by rising their values to either the .5 or the .25 power. These simple procedures allowed the use popular multiple linear regression algorithms for the models.

RESULTS

This 'snapshot' study of vegetation is based on one AVHRR scene acquired on February 18, 1987. Therefore, large differences in signature can be expected when a more thorough study is performed. For this work, NDVIs were calculated for all 74 calibration sites. In general terms, NDVIs for the northwestern sector of Patagonia vary between .159 and .001. NDVIs of the arid central sector (Patagonian plateau) vary around .050. Humid sectors with open vegetation have NDVIs above .150 and forest locations have NDVIs between .250 and .320.

A linear regression model for all possible subsets (BMDP 9R) was used to generate the models. Mallows' CP statistic was used to control bias. Square multiple correlation adjusted to the number of predictors, and other statistics were used to further control the models. Cross validation was performed as described by D'Antoni (1993). In Figure 2, predicted NDVIs are plotted against NDVIs calculated from AVHRR reflectances, thus NDVIs were calculated from red and near infrared bands of the AVHRR sensor mounted on NOAA-9 satellite. Odd-numbered samples were used to calibrate the model and predict the NDVIs of pair-numbered samples and *vice versa*.

These equations were used to generate the Paleo-NDVIs for the fossil profile. The models used follow. The abbreviations are, CA: Caryophyllaceae; CH: Cenopodiaceae; CO: Compositae Tubuliflorae; CR: Cruciferae; CY: Cyperaceae; EP *Ephedra*; GR: Gramineae; GU *Gunnera*; NA: *Nassauvia*; PA: Papilionaceae; PO: *Polygala*; and SO: Solanaceae.

$$RED = 6.7 + .17\sqrt{(CA)} + .73(CH)^{25} + .24\sqrt{(CO)} + .17\sqrt{(CR)} + .37\sqrt{(NA)}$$

Statistics for the model: number of predictors (p): 5; Mallows' CP for p=5, 3.02; adjusted squared multiple correlation, for p=5: .79. Standard error for intercept =.60; for coefficients, CA=.09; CH=.15; CO=.07; CR=.07; NA =.05. Standard error of estimations =.73. RED values range [12.13;5.94].

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$$\sqrt{NIR} = 3.86 -.02\sqrt{(CO)} -.009(CY) -.005(EP) -.04\sqrt{(GR)} -.04(GU) -.08\sqrt{(MI)} -.003(NA) - .016(PA) -.037(PO) -.083(SO)$$

Statistics for the model: number of predictors (p): 10; Mallows' CP for p=10: 8.9; Adjusted squared multiple correlation, for p=10: .52. Standard error for intercept = .099; for coefficients, CO=.01; CY=.005; EP=.003; GR=.01;
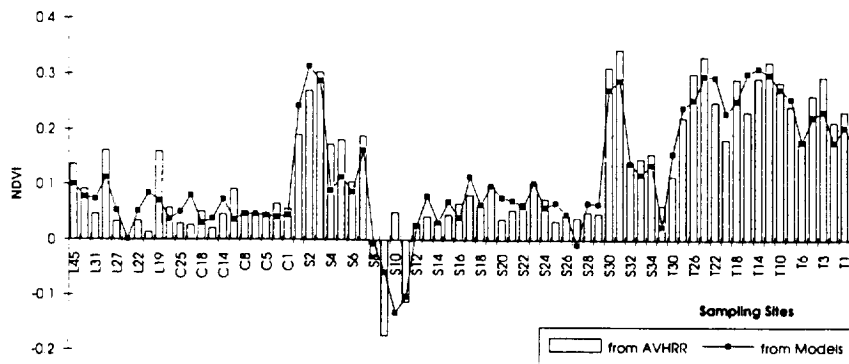

Figure 2 Model cross validation

GU=.017; MI=.029; NA=.002; PA=.009; PO=.011; SO=.038. Standard error of estimations =.12; $\sqrt{(NIR)}$ values range [3.85;2.40].

VEGETATION HISTORY

Profile Meseta Latorre I (51°31'S, 72°03'W) was sampled in a sedge bog at 1,000 meter elevation, near the upper timberline of a forest of *Nothofagus spp.* Classification of samples by stratigraphically constrained cluster analysis (CONISS) produced a finer zonation than that proposed by Schäbitz (1991) but fully compatible with it (Figure 3).

Zone 1 (Z1) reflects an early postglacial environment, with dominance of bog elements, low proportions of grasses and bushes, and a still distant forest. The site was then located considerably above the upper timberline. It includes Schäbitz's zones ML1, ML2, and ML3.

Subzone 1 (S1) Paleo-NDVIs vary between .098 and .178. This range is similar to those found in modern Andean locations and this zone developed between years 9,000 and 8,000 B.P. (Schäbitz's ML1).

Subzone 2 (S2) Paleo-NDVIs vary between .191 and .218 but includes sample 27 with Paleo NDVI =.154. Schäbitz (1991) placed this sample in zone ML3. It is a rather peculiar sample. Higher soil coverage, lower proportion of sedge, higher proportion of grasses. The upper timberline of *Nothofagus spp.* forest is near by. Tundra conditions are still prevalent. It can be placed between 8,000 and 6,800 years B.P.

Subzone 3 (S3) Paleo-NDVIs vary between .192 and .214. Tundra conditions are still prevalent. A richer flora is developing and lower proportions of sedge are observed. This zone developed between 6,800 and 5,000 years

Figure 3 Pollen diagram of Profile Meseta Latorre I

B.P., and is approximately equivalent to Schäbitz zone ML3.

Zone 2 (Z2) is characterized by the processes leading to today's vegetation.

Subzone 1 (S1) Paleo-NDVIs vary between .201 and .249. This is a transition period with reduction of sedges, advance of grasses and the arrival of the *Nothofagus spp.* forest. It has vegetation similar to that of the upper timberline. This subzone developed between 5,000 and 3,720 ± 60 years B.P. and is similar to Schäbitz's ML 4a.

Subzone 2 (S2) Paleo-NDVIs vary between .247 and .281. Proportions are minimum for sedge, medium for grasses, and high for forest. In the upper timberline environment, *Nothofagus spp.* dominate the pollen spectra. This subzone developed between 3,720 and 2,500 years B.P., and corresponds to the lower third of Schäbitz's ML 4b.

Subzone 3 (S3) Paleo-NDVIs vary between .228 and .252. It includes an advance of sedges, stable values of grasses and some reduction of forest elements. This subzone developed between 2,500 and 2,000 years B.P. It corresponds to the central section of Schäbitz's ML 4b.

Subzone 4 (S4) Paleo-NDVIs vary between .252 and .285 (profile's highest). Subzone developed between 2,000 and 1,000 years B.P. including a ^{14}C of 1,315 ± 65 years B.P. The highest values of the *Nothofagus spp.* forest, and lower values for grasses and sedges. Conditions prevalent today below the upper timberline. It corresponds to the upper section of Schäbitz's subzone ML 4b.
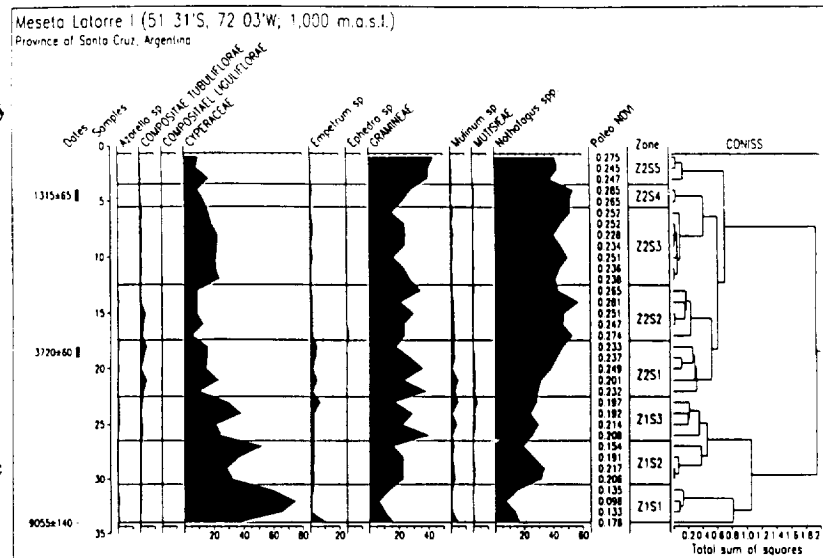
Subzone 5 (S5) Paleo-NDVI vary between .245 and .274. Modern conditions (the last 1,000 years): an open forest not far from the upper timberline, high proportion of grasses and a reduced sedge bog. It corresponds to ML 4c.

CONCLUSIONS

Remote sensing data are useful in palynologic predictive models of paleoclimate and paleoecology taking advantage of world-wide coverage and appropriate spatial scale. Remote sensing data are available for any point on the earth's surface, and repeated observations permit time-series analysis.

AVHRR data of vegetation match field observations. NDVI and 'Paleo-NDVI' values can be used to estimate canopy-level photosynthesis and transpiration as well as other functional parameters required by predictive ecophysiological models of global change. NDVI is related to LAI, APAR and NPP. At this point, one can foresee that calibration of pollen data in terms of remote sensing data will lead to paleoecological reconstructions of photosynthetic capacity, leaf area, absorbed radiation and net primary productivity. Such reconstructions will in turn be used to drive ecosystem process models contributing a much larger time window than those in use today. As a consequence, the GCMs will produce more accurate predictions.

REFERENCES

D'Antoni, H.L., Paleotemperatures of La Malinche: A palynological hypothesis, *Grana* **32**, 354-358 (1993).

D'Antoni, H.L. and M.A.Spanner, Remote sensing and modern pollen dispersal in southern Patagonia and Tierra del Fuego (Argentina): Models for palaeoecology, *Grana* **32**, 29-39 (1993).

Gausman, H.W. and W.A. Allen, Optical parameters of leaves of 30 plant species, *Plant Physiology* **52**, 57-62 (1973).

Hoffer, R.M., Biological and physical considerations in applying computer-aided analysis techniques to remote sensing data, In *Remote sensing: The quantitative approach*, P. Swain and S. Davis (eds.), 227-289, McGraw-Hill, New York (1978).

Mosimann, J.E., Statistical Methods for the Pollen Analyst: Multinomial and Negative Multinomial Techniques, In Kummel and Raup (eds.), *Handbook of Paleontological Techniques*, Freeman, San Francisco (1965).

National Oceanic and Atmospheric Administration (NOAA), *NOAA Polar Orbiter Data Users Guide*, NOAA, NES-DIS & NCDC-SDSD, Washington (1986).

Price, J., Calibration of satellite radiometers and the comparison of vegetation indices, *Remote Sensing Environ*, **21**, 15-27 (1987).

Running, S.W., Estimating Terrestrial Primary Productivity by Combining Remote Sensing and Ecosystem Simulation, in Hobbs and Mooney (eds.), *Remote Sensing of Biosphere Functioning*, Ch. 4:65-86, Springer Verlag, New York (1990).

Sellers, P.J., Canopy reflectance, photosynthesis and transpiration, *Int. J. Remote Sens*, **6**:1335-1372 (1985).

Sellers, P.J., Canopy reflectance, photosynthesis and transpiration, II, The role of biophysics in the linearity of their interdependence, *Remote Sens. Envir.* **21**:143-183 (1987).

Schäbitz, F., Holocene vegetation and climate in southern Santa Cruz, Argentina, *Bamberger Geographische Schriften*, **11**, 235-244, Bamberg (1991).

Spanner, M., L. Pierce, S. Running and D. Peterson, The seasonality of AVHRR data of temperate coniferous forests: Relationships with Leaf Area Index, *Remote Sensing Environ*, **33**, 97-112 (1990).

Webb, T., III, Holocene palynology and climate, In *Paleoclimate analysis and modeling*, A. Hecht (ed.), 163-169, J. Willey & Sons Inc., New York (1985).