NSF PROPOSAL--DRAFT

Summary

This proposal suggests integrating two independent methods of studying South America's climate history, namely, numerical models and the fossil record. We propose running an atmospheric general circulation model (AGCM) with various scenarios of paleo-topography and sea surface temperatures (SSTs) to mimic the general climate history of South America from the Miocene to the present. These global model integrations will provide distributions of precipitation, temperature, and other biotically significant climate variables for South America. Using these global GCM boundary conditions, we will embed more detailed regional or mesoscale topographic histories for four areas; the northern Andes of Colombia & Ecuador, the Bolivian altiplano, western and northwestern Argentina, and Patagonia. The climatologies of these four embedding experiments will summarize patterns of regional climate change resulting from Neogene tectonism and uplift at a scale more comensurate with the geographic and temporal resolution of the fossil record. Then, arguing from the correlation between climate, primary productivity and species richness patterns in living mammals, we will compare the biotic implications of the embedded regional climate scenarios with the best available sequences of the Neogene fossil mammal record in South America. We will integrate the GCM output with data on primary productivity, plant and mammal species richness using Geographic Information System (GIS) cartographic control which will serve as the basis for 1) matching geographic and temporal resolution between the GCM, primary productivity, and species richness datasets, 2) statistical tests of geographic goodness of fit, and 3) as the mapped basis for regional mesoscale predictions about species richness patterns in the fossil record. The study will confirm and broaden our understanding of Andean uplift as a mechanism of climate change, and provide a test of ideas about the chronology of Andean uplift as estimated by independent methods.

INTRODUCTION

For the South American Neogene, the mammalian fossil record is one of the most complete archives of the continental biota and offers a potential source of biotic proxies for understanding natural variability in the earth system.

We propose to explore the potential of the mammalian fossil record in South America to validate models of Neogene climate change produced by different aspects of Andean uplift (in particular, distinct regional tectonic histories, developing N-S continuity, increasing latitudinal extent, increasing width at certain latitudes, and oroclinal bending). The GCM we will use (identify) has proven successful for mimicking large scale change in summertime precipitation fields in mountain/no-mountain simulations in which Andean topography is represented by a broad rounded dome roughly corresponding to the altiplano-puna plateau of the central Andes. While other modeling experiments have used slightly different Andean topographies, all are inadequate to enable a reasonable validation from the fossil mammal record. The reason for this is that the fossil record is largely restricted to intermontane basins within the Andean orogen and the back-arc area proximal to and just east of the Cordillera and mammalian species richness (the proxy) is very sensitive to rainfall and orographic rainshadow effects at small geographic scales.

We propose to apply a nested GCM-LAM model to effectively extend the narrow Andean orography southward to Patagonia and northward to the equator where we have potentially useful climate proxies in the fossil mammal record. In addition, given a more detailed history of changing mountain orography for the Central Andes, and would like to model a topographic representation that more faithfully matches the geographic resolution of the fossil record there. Finally, another reason for attempting GCM-LAM embedding relates to the higher density of meteorological data within the Andes, data that might enable us to model developing rainshadow effects more closely. GCM's have proven in

The purpose of this research is to validate regional scenarios of developing Neogene climate in South America using boundary conditions generated by a global general atmospheric circulation model (AGCM). The South American mammalian fossil record will prove useful as a means of validating climate models at the megannum temporal scale and the regional geographic scale comensurate with the function and geographic configuration of the principal forcing mechanisms of regional climate change, Andean uplift. Moreover, the nested modeling approach allows us to control for temporally calibrated global and continental-scale change in the global system, such as the steepening latitudinal gradient of sea-surface temperatures and sea-land configurations.

Given the equatorial to polar latitudinal extent of South America, validation of our understanding of the climatology is particularly important and is of global significance. Given the severe geographic and temporal limitations of the paleobotanical or macrofloral record in South America, we here propose to use the mammalian fossil record. Given recent work in the South American mammalian fossil record in the Miocene and later (Kay et al.,; Fleagle, et al., ; Madden et al.,), there is at present, no better biologic proxy for validating model simulations of late Cenozoic climate change. While we recognize that the South American mammalian fossil record is not ideal, we propose judicious applications to validate shifting geographic patterns of precipitation and temperature at specific time intervals or temporal “snap-shots” through the Neogene (see below).

The approach explores quantitative continental patterns of mammalian species richness within guilds as biotic proxy constraints for modeled climatologies via the correlation between species richness, mammalian guild structure and primary productivity. Mammalian species richness data can be related to summertime precipitation rates, evapotranspiration potential, and minimum monthly temperatures (among other climate variables) through GCM models with , links to species richness within guilds (dietary, substrate, body size) 2) are known to be limiting for vegetation types (Prentice et al.) and 3) to underlie primary productivity (Kay et al., 1998). Canonical community ordination demonstrates the IMPROVE THIS MANIFESTO!

THIS SOUNDS LIKE WE ARE SAYING THAT THE UPLIFT RECORD FOR THE ANDES IS NOT KNOWN. BUT AREN'T WE PLANNING ON TAKING SOME "KNOWN" CHRONOLOGY OF UPLIFT? CAN YOU POINT ME TO A PAPER OR TWO ON UPLIFT CHRONOLOGY?

Mountains produce abrupt changes in temperature and moisture over short geographic distances. The low spatial resolution of GCM's results in topographic smoothing, where Andean orography is reduced to a broad rounded dome, limiting the question that climate modeling can address to the consequences of broad plataeu uplift. This limitation is compounded if the spatial resolution of the baseline climate and/or modern climate-bioproxy datasets have a topographic texture of higher resolution than the GCM. The greater the resolution mis-match, the more the analysis is forced toward validating large regions of uniform climate far-removed from the high topography (Ruddiman et al., 1997). We propose to get around resolution mis-match by seeking comparable resolution between the AGCM, a regional climate model, modern climate, and bioproxy databases. We propose to deal with meridional and latitudinal variation in the Andean orogen, and regionally variable uplift chronologies by translating large scale climate anomalies into mesoscale variations by embedding four higher-resolution mesoscale models using boundary conditions set by the global GCM. The GCM must produce accurate climate statistics for special grid area (which is problematical for Patagonia and the equatorial Andes, but less so for Bolivia and NW Argentina). How will we know that the GCM is producing accurate enough climate variables that it makes sense to impose an estimate of locally increasing topographic complexity? If the GCM has no topography in either Colombia and Patagonia, then climate variables at the grid boxes in these regions should be accurate. Using these as boundary conditions, we will insert modern local topography! and Neogene topography sequences!

CAN WE INCORPORATE MORE DETAILED REGIONAL CLIMATE DATASETS (WHERE AVAILABLE) INTO THE EMBEDDING EXPERIMENTS?

Emphasis will be placed on the timing of regional Andean uplift, not the continental nor global geographic extent of the influence of mountain uplift. Also, as we are interested in climate change induced by uplift, we propose to model uplift as a regional process, and will restrict validation tests to stratigraphic sequences spanning the temporal range of late Cenozoic uplift from geographically restricted portions of the orogen, rather than attempt to validate the full geographic extent of uplift-induced change. This last is both a limitation imposed by the geographic bias of the fossil mammal record, and its principal strength. While the geographic coverage is limited, the fossil record provides a sequence of Neogene paleofaunas at pre-, mid-, and post-uplift times suitable for mesoscale embedding experiments in four areas 1) Colombia-Ecuador (), 2) western Bolivia (altiplano and Eastern Cordillera, 3) NW Argentina (Mendoza, San Juan & Catamarca) and 4) Patagonia.

Control Experiments = modern control-base simulation

mountain/no mountain experiment or simulation

modern SSTs, late Oligocene SSTs and chronology of change in the latitudinal SST gradient

embedding experiments using ”snap-shots” at time slices determined by geological constraints and the available fossil record

The distribution of summertime precipitation over South America generated by GCM's is in reasonable agreement with observed present patterns (REFS HERE - K WILL PROVIDE). Lenters and Cook (1995) quantified the role of topography and SST distributions in establishing this distribution in GCM integrations with various boundary conditions, including runs with and without the Andes. Such GCM-generated scenarios of summertime precipitation fields for the pre-uplift configuration of South America provide historical conjectures that are amenable to validation through the mammalian fossil record. Not only are pre-uplift scenarios testable, but regional climate change during the process of uplift can be modeled by examining more detailed topographic patterns at various time-slices (time cross-sections) during uplift.

For example, analyses of species richness within guilds based on the adaptations of 53 fossil mammal species from the middle Miocene (between 12.85 and 13.0 Ma) Honda Group in the upper Magdalena River valley of Colombia (at 4 degrees N latitude) have yielded estimates of mean annual precipitation (MAP) between 1500 and 2000mm (Kay and Madden, ref) and altitude less than 1500m (ref.). These reconstructed environmental conditions for the middle Miocene differ markedly from present conditions in both the Magdalena valley (500mm MAP at 400m elevation) and in areas of Colombia with more analogous geography on the eastern piedmont of the Andes (>4000mm MAP at 1000m elevation). The valley of the Magdalena River between the Central and Eastern Cordilleras of the Colombian Andes, is very dry today because of mountain-induced rain-shadow. In the middle Miocene, the geography was more directly comparable to that of the eastern piedmont of Colombia because there was no significant elevation to the Eastern Cordillera (Hoorn et al., 1995; Guerrero, 1996; Lundberg et al., 1986). Stratigraphic, sedimentologic and pollen evidence suggests that the differences between middle Miocene and modern climate should be attributed to uplift-induced climate change subsequent to deposition of the fossiliferous Honda Group (Guerrero, ref; Hoorn et al., ref.; pollen ref.). The best estimate of the date of the initial uplift of the Eastern Cordillera is post-middle Miocene (Campbell and Bürgl, 1965; Guerrero, 1996; Hoorn et al., 1995) and only following important episodes of uplift during the Pliocene, did the Colombian Eastern Cordillera attain its present elevation (Hooghiemstra and Ran, 1994; Hammen and Cleff, 1986; Wiel, 1981).

However, preliminary results from the mammalian fossil record suggest that some uplift had occurred in the area of the Colombian Central Cordillera by the middle Miocene (although altitudes were less than 1500m). We propose to test this scenario by modeling the influence of uplifted topography on the distribution of precipitation and temperature in Colombia and Ecuador by embedding this regional orographic history using GCM-generated climatology as boundary conditions. We propose to mimic a scenario of middle Miocene topography for the Central and Eastern Cordilleras of the northern or equatorial Andes, including no topography (pre-uplift) and C. Andes topography of 1500m. And we propose similar tests of uplift-induced climate change elsewhere in the Andes. We propose applying this method across the broad latitudinal range of the Andes using the fossil mammal faunas of 1) the Deseadan of Patagonia and the north Bolivian altiplano, 2) the Santacrucian-Colloncuran in Patagonia, 3) contemporaneous middle-Miocene faunas of southern Bolivia (Qda Honda), Colombia (La Venta) and Ecuador , 4) the Pliocene faunas of the Montehermosan, Chapadmalalan, and north Bolivian altiplano; and 5) the Quaternary faunas of Tarija (Bolivia) and Lagoa Santa
(Brazil).

BACKGROUND

1. Climate Modeling

The GCM that will be used to generate the paleo-climate scenarios is a version of the model developed by the Climate Dynamics Group at NOAA's Geophysical Fluid Dynamics Laboratory (ref). As is the case for all GCM's, the model is based on the primitive equations of large-scale atmospheric motion, and simulates four-dimensional (latitude, longitude, height, and time) fields of atmospheric temperature, horizontal wind (2 components), vertical velocity, pressure and density. A seventh governing equation, based on conservation of water mass, provides for the simulation of the atmospheric moisture content. Other imporatnt processes for determining climate, such as long and short wave radiative fluxes and precipitation, are treated with physical parameterizations.

We would use the model with the so-called R30 resolution, which is equivalent to a horizonal resolution of about 2.25 degrees of latitude and 3.75 degress of longitude. There will be 14, or possible 22, vertical layers in the atmosphere. These settings for the model resolution have proved adequate for simulating the large-scale structure of the South American precipitation climatology in summer, while still being computationally efficient for additional integrations to explore the dependence on various boundary conditions (Lenters and Cook, 1995, 1997).

The model is initialized as a dry, isothermal atmosphere at rest. About 200 days of integration insures that the model has "spun up" from these initial conditions and established a climate that is consistent with the prescribed boundary conditions (such as topography) within the constraints of the governing equations and physical parameterizations. The model is then integrated for several years or more of model time, and the time-dependent fields (which have variability similar to that observed) averaged to form a climatology. Although GCM's are essentially the same models used by the National Weather Service to predict the weather, they solve a different problem. Weather prediction consists of using a model to evolve a realistic initial state through a few days, while climate modeling involves finding an atmospheric state that is consistent with a given set of boundary conditions, independent of the initial state.

INSERT SHORT PARA. ON VALIDATION OF CLIMATE MODELS FOR PALEOCLIMATE MODELING, INCLUDING MENTION OF THE TIBETAN UPLIFT CASE

validation of this model in particular for South American climate. How good is the precip etc simulation in Lenters and Cook. Discuss the importance of the filtering of topography for the South American problem ..., Andean topography was filtered, resulting in a smoothed representation of the Andes which is broader and has a maximum height of only 2km, Also, the Pacific Ocean continental boundary was extended (Lenters & Cook, ref).

Pre- and Post-Uplift Patterns. discuss role of topography and SSTs for today's precipitation distribution - make the case that topog is probably more important to get right than SSTs

2. Neogene Climate Evolution in South America

THE FOLLOWING SUMMARIZES THE MOST SIGNIFICANT FEATURES OF THE GLOBAL NEOGENE CLIMATE RECORD (Frakes, Francis and Syktus, 1992. Climate Modes of the Phanerozoic: The History of the Earth’s Climate over the Past 600 Million Years. Cambridge Univ. Press.)

Following the tectonic process opening the Drake Passage between South America and Antarctica that extended from the middle Oligocene to the Oligocene-Miocene boundary, the circum-Antarctic current began to isolate Antarctica in a polar cold zone during the early Miocene. Thereafter, a general process of global cooling was established, interrupted by a middle Miocene (between 17.5 and 13.3 Ma) period of high biological productivity in the oceans and strong coastal upwelling resulting from strong zonal winds. A sharp decline in global temperatures and the build-up of the permanent East Antarctic ice cap between 12-14 Ma (Savin 1977) produced an increase in the pole-to equator surface temperature gradient during the middle Miocene from 6 to 12 degrees C through cooling of high-latitude surface water and slight warming of low-latitude water temperature (Miller, Fairbanks & Mountain, 1987). Thereafter, the East Antarctic ice cap expanded between 6.2 and 5.7 Ma (Shackleton & Kennett, 1975; Miller & Hsu, 1987) with pulses of glacial expansion at 5.2 Ma, 4.8 Ma, that reached a peak at 3.59Ma with Patagonian glaciation (Mercer, 1983). Following a brief early Pliocene (3.5-2.4 Ma) warming of 2-3 degrees in mid-latitude of the Southern oceans, climate deterioration resumed in the late Pliocene with northward migration of polar front and the further intensification of glaciation.

At the close of the Paleogene, South American floras had become diverse and vegetation zones multiplied to include, 1) tropical rainforest, 2) paratropical (MAT 20-25 degrees C) rainforest south of the equatorial tropics, and a south temperate vegetation complex comprising 3) mixed coniferous forest extending meridionally northward from Patagonia, bounded to the East by 4) broad-leaved evergreen forest (south of XX degrees S latitude) and to the West by 5) notophyllous woodland and xerophyllous scrub (Wolfe, 1985). Wolfe () and Solbrig () attribute the origin and spread of low-biomass vegetation to the intensification of the subtropical high-pressure system and the development of conditions of summer drought along the western Pacific margin of the continent. Macroflora records are unable to further resolve the history of South American vegetation in the Neogene. SEE ROMERO E.J. 1986. Paleogene phytogeography and climatology of South America. Annales of the Missouri Botanical Garden 73:449-461. but nothing here on the Neogene.

Regional Chronologies (Tempo and Rates) of Neogene Uplift

Colombia. Tuné Formation redbeds, the oldest fossil mammal-bearing sediments in the Magdalena valley, bear a mammalian fauna of Deseadan aspect probably not older than late Oligocene or early Miocene (). There follows a temporal hiatus in sediment accumulation until deposition of the Honda Group. During the time of deposition of the Honda Group between 13.4 and 11.8Ma, the Colombian Central Cordillera (the source area of these volcaniclastic sediments) was of unknown elevation and there was no significant elevation to the Colombian Eastern Cordillera (Hoorn et al., 1995; Guerrero, 1996; Lundberg et al., 1986). The best estimate of the date of the initial uplift of the Eastern Cordillera is post-middle Miocene (Guerrero, 1996; Hoorn et al., 1995). Only following important episodes of uplift during the Pliocene, did the Colombian Eastern Cordillera attain its present elevation (Hooghiemstra and Ran, 1994; Hammen and Cleff, 1986; Wiel, 1981). Paleoelevations for the Eastern Cordillera have been estimated through the Neogene from pollen assemblages (Wijninga, 1996).

Ecuador. Biblián Formation redbeds, the oldest fossil mammal-bearing sediments in southern Ecuador, are 22Ma (Lavenu et al., ref). There followed a temporal hiatus in sediment accumulation until deposition of the intermontane basin sediment sequences from about 12.5 to 9.0 Ma (Madden et al., in press) when lacustrine sedimentation associated with basin formation and drainage reorganization was initiated. Paleontological evidence indicates that initial sediment accumulation occurred near sea-level (Feldmann et al.,) and the highly endemic invertebrate faunas reflect the topographic isolation of these intermontane basins from western Amazonia (Nuttall, 1990). Prior to basin formation, fossil mammals have their closest phylogenetic affinities with mammals from Colombia. Subsequent to the formation of intermontane lake basins, the fossil mammals of southern Ecuador share closest phylogenetic affinities with fossil mammals from Bolivia and Argentina, suggesting that faunal continuity southward along the Andean orogen may have become established at that time.

Bolivia. The oldest fossil mammals of the Neogene sedimentary sequence in Bolivia are from the Salla redbeds. The base of the Salla beds at 29Ma is taken to represent the age of initiation of uplift. The main fossil-bearing portion of the section yielding a Deseadan fauna has been dated to between 25 and 26Ma (Kay et al., 1998). There follows a significant temporal hiatus in the fossil mammal record of the Bolivian altiplano until the middle Miocene. The Puna surface of southern Peru, Bolivia and northwestern Argentina is a regionally extensive low-relief erosion surface (presently between 1500 and 4600m elevation) originally formed by either peneplanation (at sea level) or by pedimentation (coalesced pediments) already at significant elevation. These alternative modes of formation imply two distinct models for the timing of the formation and uplift of the Puna. A late uplift model posits that most uplift was a Plio-Pleistocene event (post 2.5 Ma) and supporting evidence for this model includes an uplift rate curve derived from a fission-track annealing study (Benjamin et al.,) and the presence of Mio-Pliocene fossil floras of tropical affinities in the Bolivian altiplano (although the tropical signature of these floras was argued through floristic affinities not leaf physiognomy). The contrasting early uplift (or two stage) model posits significant uplift prior to 10Ma. Supporting evidence for the early uplift model include 1) geomorphic surfaces that indicate sea-level landscape at 18Ma () and 2) geochemical data indicating hyperaridity and rainshadow at 15Ma (vander , ref), environmental conditions that require between 2-3km of pre-existing uplift. It is conjectured that the tempo of Central Andean uplift was episodic (Sebrier et al., 1988) and paleoelevations have been estimated for temporal cross-sections during the late Cenozoic (MacFadden et al., 1994). Fission-track anealing evidence indicates the rate of uplift of plutonic rocks in the Cordillera Real accelerated through the late Cenozoic (Benjamin et al., 1987).

North Argentina. The oldest fossil mammals of Neogene age in Mendoza occur at Malargüe, a Deseadan fauna (). There occurs a significant temporal hiatus in the fossil mammal record of this part of Argentina until the middle Miocene Chinches Formation (Carlini et al., 1996). Uplift of the Principal Cordillera is thought to have initiated at about 21Ma (Jordan et al., 1997). In the late Miocene, an important faunal change is conventionally attributed to the geographic reorganization of sediment deposition and aridification associated with Andean uplift (Ortiz & Pascual, 1990) occurs at the base of the faunal sequence in the valley of Santa Maria (Catamarca) in the Chasicoan and more extensively in structural valleys east of the Andes during the Huayquerian (Ortiz & Pascual, 1990). Continuous uplift occurred during the interval from 15 to 9 Ma and the eastern Frontal Cordillera began to uplift about 9Ma (Jordan et al., 1997).

Patagonia. An important faunal transformation has long been associated with the Santacrucian-Colloncuran (”Friasian”) boundary (Ortiz & Pascual, 1990) between 16.0 and 15.8Ma (Fleagle et al., 199x; Franchi et al., in press) and the initiation of Patagonian Andean uplift can be no older than this. Thick sequences of coarse-grained sediments in the east Andean piedmont are nearly four million years younger, and the age of significant faunal turnover, and presumably climate change associated with tectonism in the Patagonian Andes, is constrained to between 13.2 and 11.7 Ma (Franchi et al., in press).

Longitudinal Synchrony of Neogene Uplift

For the purpose of developing a model topography for simulating the uplift history of the Andean orogen, we distinguish three aspects of local Andean uplift: 1) The initiation of sediment accumulation in the foreland region (that is, the age of sediments derived from source areas involved in the physical process of Neogene uplift) establishes the initial age of uplift. 2) The age of significant topography refers to evidence for significant change in stream-flow direction or drainage in local successions. 3) The age of most significant mammalian faunal change based on increases in the proportion of first appearances in local stratigraphic successions not biased by temporal gaps in the record.

Region/Cordillera

LatitudeInitial
Age of

Uplift
(approx.)
Age of Significant TopographyAge of Most Significant Local Faunal Change

ReferencesColombia
Eastern Cordillera4o N---12.8-12.6---Guerrero, 1997; Madden et al., 1997
Ecuador
southern basins4o S2212.511.2-11.5Lavenu et al., 1992; Madden et al., in press
Bolivia
Altiplano16-23o S2925-26---Kay et al., 1998; Jordan et al., 1997
North Argentina
Salta-Jujuy23-28o S16-1715---Vandervoort, 1993; Jordan et al., 1997
West Argentina
Mendoza31-34o S25-2619est. 12Pérez & Ramos, 1996; Jordan et al., 1977; Ortiz & Pascual, 1990
Patagonia45o S16.013.2-11.811.8Fleagle et al., 199x; Franchi et al., in press

Transverse Asymmetry in the Geometry of Andean Uplift.

The Andean orogen is structurally most complex where it attains its greatest breadth in the Northern (Colombia) and Central (Bolivia, North Argentina) Andes. The Central Cordillera of Colombia, the Western Cordillera of Bolivia, and the area of the Aconcagua massif in western Argentina were probably positive topographically in the early and middle Miocene, but their paleoelevations have not been estimated. Late Cenozoic uplift increased the breadth of the orogen through uplift along the eastern margin of the northern and central Andean orogen. The Eastern Cordillera of Bolivia was probably mountainous in the middle Miocene (Jordan et al., 1997). The process generating transverse asymmetry in the Andean topography continues to the present day through various styles of eastern foreland deformation (Jordan et al., 1997).

The biological significance of increasing topographic breadth (as opposed to increasing elevation) is manifest through orographic rainfall effects. DESCRIBE

Increasing transverse complexity is also significant for the mammalian fossil record, as increasing width and complexity of the orogen serves to improve the record through the proliferation of sedimentary basins.

Oroclinal Bending and Orographic Rainfall

The angle of strike of the Andean Cordillera with respect to prevailing surface winds is an important determinant of present latitudinal variation in orographic rainfall intensity.

The intensity of the orographic rainfall effect in the Andes of the equatorial tropics varies locally with the elevation of the mountain range. A measureable rainshadow effect is produced by mountain elevations as low as 1000m. (FIGURE) With increasing elevation, the rainfall depression between windward and leeward slopes increases. Thus, the biotic consequences of uplift-induced rainfall depression in the equatorial tropics depends on both the altitude of the mountains and the amount of moisture carried by the tradewinds. The relationship predicts that for localities at or near sea-level, a rainfall depression of 50% associated with an uplift of 1500 to 2000m will result in a conspicuous change in vegetation where windward rainfall levels are less than 2000mm annually. Humid evergreen rainforest is the predominant vegetation at rainfall levels of 2000mm, whereas seasonal savanna is characteristic of areas of 1000mm annual rainfall. Uplifts of similar magnitude would not produce conspicuous change in the structure of vegetation where annual rainfall levels on the windward side are greater than 4000mm. Within the equatorial tropics where windward rainfall exceeds 4000mm, mountains must attain elevations greater than 2000m before rainfall depression results in significant structural change in the vegetation on leeward slopes and valleys.

Annual rainfall levels in the eastern Amazonian lowlands of southern Colombia, Ecuador and northern Peru at distances greater than 100 kms from the base of the Andean cordillera rarely exceed 3000mm. Available evidence from southern Colombia suggests that annual rainfall levels for the upper Amazon in the middle Miocene may not have exceeded 2000mm (Kay & Madden, 1997). At this level of rainfall, late Miocene uplifts of 1500m would have had a significant influence on the structure of vegetation on leeward slopes and within intermontane valleys. The Massenerhebung or "telescoping" effect whereby stunted forest occurs at lower elevations in small outlying mountains compared with large continuous mountain ranges, implies that elevation zones with distinctive vegetation structure might become manifest at the earliest stages of uplift.

The intensity of orographic rainfall diminishes near the southern extreme of the tropical zone. EXPLAIN

THIS WOULD PROBABLY BE MORE TRUE OF HIGHER LATITUDES THAN AT TROPICAL LATITUDES, AND MORE THE CASE IN WINTER THAN IN SUMMER. I WAS SURPRIZED TO READ BELOW THAT THERE IS A MARKED CHANGE IN PRECIP WHERE THE DEFLECTION OCCURS. I'LL LOOK INTO THIS A BIT - THERE ARE SOME SIMPLE MODELING STUDIES WITH "KNIFE EDGE" TOPOGRAPHY THAT MAY BE RELEVANT.

The Huancabamba Deflection at 4 degrees S lat. marks a significant change in the stike of the Andean Cordillera and corresponds geographically with the highest levels of orographic rainfall (Cañadas Cruz, ref) and sub-Andean sediment thickness (Marocco, ref.) IS THIS LAST STATEMENT TRUE? WHEN DID THIS OROCLINAL BEND OCCUR?

In Bolivia, the axis of the pronounced 45 degree change in strike of the Andes at 18 degrees S corresponds with the northern limit of significant winter cold or polar advection (Ronchail, 1989; 1993) and the line of frost or critical temperature which demarcates subtropical or Koppen B climates northward from temperate or Koppen C climates to the south, climate zones also distinguished by different extremes of thermal seasonality (Unzueta, 1975). Most of the bending of the Bolivian Orocline (32 degrees or about 70%) is constrained to have occurred after 12 Ma (MacFadden et al., 1990).

Latitudinal Patterns of Sea-surface Temperatures through the Neogene.
Is there a practical way to directly compare Miocene sea-surface temperatures with those of the present (as in Shea, D.J., K.E. Trenberth and R.W. Reynolds. 1990. A global monthly sea surface temperature climatology. NCAR Tech. Note, NCAR/TN-373+STR, National Center for Atmospheric Research, POB 3000, Boulder, CO 80307-3000) you used in the GCM?

We want to use Neogene SST’s in a Global Circulation Model as a geochronologically calibrated continuous record of changing SST background conditions against which to explore more episodic aspects of mountain uplift. You may know about attempts to use Neogene ocean temperature data in “historical” modeling of climate dynamics.

An increase in the pole-to equator surface temperature gradient during the middle Miocene from 6 to 12 degrees C occurred through cooling of high-latitude surface water and slight warming of low-latitude water temperature (Miller, Fairbanks & Mountain, 1987). GET CHRONOLOGY FROM FIGURE.

I'LL LOOK INTO WHAT'S AVAILABLE, AND WHAT OTHERS HAVE DONE. HOWEVER, AS I MENTIONED ABOVE, WE MAY BE ABLE TO GET AWAY WITH DOING ONLY THE TOPOGRAPHY FORCING AS A FIRST APPROXIMATION, OR AT LEAST ARGUE THAT KNOWING THE SSTS IN A LOT OF DETAIL IS NOT NECESSARY. DEPENDING ON WHAT IS AVAIABLE IN TERMS OF THE
SST RECONSTRUCTIONS, MAYBE THE BEST THING TO DO WOULD BE A FEW SENSITIVITY EXPERIMENTS WITH EXTREME ESTIMATES OF SSTS.

SUMMARIZE SEA SURFACE TEMPERTURES AND THE GEOMETRY OF ANDEAN TOPOGRAPHY INTO A SET OF “SCENARIOS” OR TEMPORAL/CHRONOLOGIC CROSS-SECTIONS THROUGH THE PROCESS OF NEOGENE CLIMATE CHANGE IN SOUTH AMERICA (see below). HOW DOES THE TEMPORAL RESOLUTION AND GEOGRAPHY OF THE ‘BEST’ FOSSIL MAMMAL RECORD COMPARE WITH THESE CROSS-SECTIONS?

3. Mammalian Species Richness

Characteristics of mammal communities vary predictably with altitude and rainfall. Mammalian species richness and the composition or guild structure of mammalian communities vary along environmental gradients in ways that are analagous to how leaf form varies with mean annual temperature (Givnish, Wolfe et al.) and how characteristics of plants that relate to plant-animal interaction (e.g. stem to leaf ratio, fruit type and size) vary along the same environmental gradients (). In living mammals, absolute richness within guilds, the relative richness among guilds, and the number and composition of guilds vary along elevation and rainfall gradients, probably in response to variation in primary productivity, the pattern of allocation of assimilates by plants, and the architecture of the spatial distribution of food resources for mammals.

For 555 non-volant mammal species occurring in 82 faunal inventories from all latitudes in South America, observations about their diets are available for 49%, substrate preference for 44% and body mass for 68%. Where unknown, species can be assigned to broad diet and substrate preference categories by reference to general patterns within the genus. For the 82 inventories, latitude (LAT), median altitude (ALT), relief, sampling area, mean annual precipitation (MAP), temperature (MAT) and relative humidity, amplitude of mean monthly temperatures (seasonality), potential evapotranspiration (PET), and summertine (January) rainfall rate, are also known or reasonably estimated. In addition, measures of primary productivity (litterfall) and tree species richness are available over precipitation and elevation gradients for 29 sites and 78 floral inventories in South America.

Using the data from living mammals, significant correlations between mammalian species richness and single climate variables revealed by rank correlation are used in linear regression and PCA to estimate the same climate variable. Using stepwise multiple regression, subsets of richness measures that singly or together explain variation in richness along particular environmental gradients can be identified. Canonical community ordination summarizes more complex relationships among multiple variables and serves to calibrate samples (modern inventories and paleofaunal lists) for which the value of the explanatory variable is missing (e.g. fossil faunas of unknown climate).

Results show that mammalian species richness is significantly correlated with PET, MAP, LAT and ALT. PET is more strongly correlated with mammalian species richness along Andean altitudinal gradients whereas MAP is more strongly correlated with richness in the tropical lowlands. Both the absolute number of species and the proportion of total species are variably correlated with LAT, MAP, PET and/or ALT in 29 different categories of trophic level, diet, locomotor preference, and body mass. Along eastern Andean altitudinal gradients, 35 measures of absolute and relative species richness within adaptive categories are significantly correlated with ALT. In lowland Amazonia, 39 measures of richness are correlated with MAP at values between 500 and 4000mm. Using all 40 tropical inventories, 46 measures of species richness are significantly correlated with PET. Jackknife simulations using sampling with replacement permit an estimate of the robusticity of this method of estimating MAP and ALT from modern faunas.

Mammalian species richness within functional guilds has several desirable features as a tool in paleoclimatology: 1) The approach is non-taxonomic and relies as much as possible on the morphological adaptations of species, not their phylogenetic affinities. As such it is less subject to influence by taxonomic turnover events (e.g, the Great American Biotic Interchange, the immigration of Homo sapiens). 2) The assignment of fossil species to adaptive categories or guilds is based where feasible on falsifiable laws of animal design. If a structure in a living species has a clear function in all living species having the same structure, then it can be safely inferred that the presence of the structure in a fossil species implies the same function (the falsifiable comparative method). 3) The method yields a quantitative estimate of a climatic variables with well-understood relationships to primary productivity (for example, MAP, MAT, potential evapotranspiration, seasonal temperature amplitude, dry season intensity, and altitude). 4) The method is statisticaly robust and allows a confidence interval to be placed on the estimated climate parameter. 5) Finally, the method is comprehensive, it uses all significant correlations between species richness and climate simultaneously (in multivariate approaches) and/or as individual correlations which permit the identification of potential biases or for preferential weighing. Such a comprehensive multivariate approach is naturally preferred over the use of single mammalian indicator species.

4. Integration and Analysis

a) GCM Output.
WHAT DO WE NEED HERE? WE CAN DISCUSS THE VARIABLES THAT THE MODEL OUTPUTS, BUT I THINK PRECIP AND TEMPERATURE ARE THE ONLY ONES WE REALLY CARE ABOUT FOR THE COMPARISON. HOWEVER, WE WILL ALSO BE ANALYSING THE MECHANISMS THAT SUPPORT THE DIFFERENCES IN CLIMATE, SO I COULD DISCUSS THAT A LITTLE BIT. WE MIGHT ALSO PUT A DISCUSSION OF RELEVANT SPACE SCALES HERE, AND THE COMPATIBILITY BTWEEN THE SCALES OF THE MODEL AND THE FOSSIL RECORD. WHAT DO YOU THINK - NOT SURE WHAT YOU HAVE IN MIND FOR HERE ...

b) Geographic Information System (GIS). Species Richness Patterns are inherently geographic, and this data lends itself to graphical treatment through a Geographic Information System.
I AM ASSUMING THAT THIS IS YOUR BABY - I'M NOT REALLY INTERESTED IN A BIG CHANGE IN HOW I HANDLE THE GCM OUTPUT.

c) Statistical Analyses. As I preceive it, there are three or four problems (at least) that will require the consulting services of a statistician. The first has to do with the statistical demonstration of correlation between climate and mammalian species richness. I’m trying to get the newer improved data into form for Canonical Correspondence Analysis, and am still struggling.

I'M DEFINATELY NOT A WHIZ-KID WHEN IT COMES TO STATISTICS!! I'VE NEVER WORKED WITH A CONSULTANT, SO I'LL LEAVE THAT TO YOUR JUDGEMENT. HOWEVER, I DO HAVE A GOOD FRIEND WHO IS A STATISTICS PROFESSOR AT NORTH CAROLINA STATE, AND SHE MIGHT BE INTERESTED IN THIS KIND OF PROBLEM. HER NAME IS MARCIA GUMPERTZ.
(OR DO YOU HAVE SOMEONE IN MIND?)

A second problem has to do with statistics in the spatial realm. I'm not sure exactly what I mean by this, but, how does one demonstrate geographic "goodness of fit"? That is, If the General Circulation Model produces two maps of rainfall for South America (pre-Andean uplift, and post-uplift), and the post-uplift map seems to give a good approximation of the modern or present distribution of rainfall, it is concluded that the model "works". But this assertion is not buttressed by a correlation coefficient for the geographic "goodness of fit"! Can it be?
GCM MODELING IS SUCH AN ART, ISN'T IT!! A VISUAL INSPECTION OF THE SIMILARITY IN THE FIELDS USUALLY PASSES IN THE LITERATURE. PART OF THE REASON FOR THIS IS THAT THE OBSERVATIONS CAN'T BE TAKEN AS GOSPEL - THEY ALL DIFFER WITH EACH OTHER, TOO, AND WE DON'T HAVE A LONG ENOUGH PRECIPITATION RECORD TO REALLY SAY WHAT THE PRESENT DAY CLIMATOLOGY IS WITHIN 20 PER CENT OR SO OVER MOST OF
SOUTH AMERICA.

Thirdly, eventually, we want to "test" the geographic pattern of rainfall that the GCM generates for the pre-uplift scenario using measures of fossil mammal species richness at particular points in space. How can I be confident that the particular point in space actually falls within any particular geographic "region" of rainfall (rainfall is depicted on the maps in terms of contours of values of January (southern summer) rainfall rate).
ONE THING WE CAN THINK ABOUT IS THE SOURCE OF THE SPATIAL DISTRIBUTION OF RAINFALL - WHY IS CHANGES THE WAY IT DOES IN THE MODEL IN RESPONSE TO THE CHANGES IN BOUNDARY CONDTIONS. UNDERSTANDING WHAT IS GOING ON PHYSICALLY WILL HELP US HAVE CONFIDENCE IS RESULTS (OR NOT!) ANOTHER THING IS THE SIZE OF THE PRECIPITATION FEATURES, ESPECIALLY IN RELATION TO THE RESOLUTION OF THE MODEL. A THIRD FACTOR WILL COME FROM SOME SENSITIVITY SIMULATIONS - WE NEED TO BUILD THIS IDEA INTO THE PLANS T

Finally, the uplift scenarios that we run on the GCM will produce a series of maps that will have to be calibrated temporally from what evidence we have about the timing of uplift from the geologic record. We have to then "freeze" the stream of dynamically changing configurations of climate into maps depicting the geography of climate for several points in time (corresponding to the age of the fossil faunas).
How can we statistically place a confidence interval around the estimate of the "age" of the "frozen" frame map?
I DON'T KNOW.

5. Validation from the Mammalian Fossil Record

The South American Neogene fossil mammal record of the Neogene, while temporally discontinuous and geographically incomplete, is characterized by twelve (12) especially well-known faunas.

MAP

Fossil Locality
Geochronologic
Age
(Megannums) Geographic Coordinates (Decimal Degrees)

ReferencesSalla (La Paz, Bolivia)
25.8-27.017.17dS;
67.62dW
Kay et al., 1998Deseadan (Chubut, Argentina)
24.0-29.045-48d S;
66-68d WFlynn & Swisher, 1995Colhuehuapian (Chubut, Argentina)
46d S;
68.5dWKay, in pressSantacrucian (Santa Cruz, Argentina)16.5-16.050-52dS;
68-69.5dWFleagle et al., 1995; Bown & Fleagle, 1993
Colloncuran (Neuquen and Rio Negro, Argentina)
15.7-15.840-41.25dS;
70-71dWFranchi et al, in pressQuebrada Honda (Tarija, Bolivia)
12.7-13.022dS;
65dWMacFadden et al., 1990La Venta (Huila, Colombia)12.8-13.03.25dN;
75.25dW
Kay & Madden, 1996
Montehermosan (Buenos Aires, Argentina)
4.0-5.039dS;
61.5dWCione & Tonni, 1995Chapadmalalan (Buenos Aires, Argentina
3.0-4.038dS;
57.5dWCione & Tonni, 1995Ayo Ayo-Vizcachani (La Paz, Bolivia)
316.25-17.5dS;
67.75-68.5dWSaint-Andre, 1994Tarija (Tarija, Bolivia)
0.8-1.022.5dS;
64.75dW
MacFadden, refLagoa Santa (Minas Gerais, Brazil)19.6dS;
43.9dWVoss & Myers, 1991

DOES THIS SUGGEST WE INTEGRATE THE GCM FOR 5 TIME PERIODS? ARE THESE 5 TIMES DISTINCT IN TERMS OF THEIR CLIMATE AND THEIR TOPOGRAPHY? WITH SENSITIVITY INTEGRATIONS IS ESTABLISH DEPENDENCE OF "DETAILS" OF THE BOUNDARY CONDITIONS, WE ARE PROBABLY TALKING ABOUT 25 GCM INTEGRATIONS - PROBABLY THE LIMIT OF WHAT WE CAN EXPECT TO DO IN A REASONABLE TIME FRAME (LIKE 1 YEAR)

These faunas all benefit from the study of recent collections and modern taxonomic revision (completed or nearing completion). For some faunas

(Colloncuran, La Venta) it is possible to estimate the completeness of the record of species richness by examining the behavior of species discovery with sampling effort. The empirical relationship between sampling density and richness determines a point beyond which the accumulation curve for species number asymptotically approach the upper limit of discoverable species richness. FIGURE

RESEARCH PLAN

I imagine, with all our commitments, this work will take four years???

YEAR 1. In the first year we could run the global GCM with the Neogene SST chronology in only two (mountain/no-mountain) scenarios using your original Andean topography. Explore integrating GCM output with my data on primary productivity, plant and mammal species richness to generate a map simulating present climate (precipitation and temperature) and mammal species richness. This will require matching GCM results at GCM resolution in terms of the data from living mammals and their correlations with rainfall rate, etc. to define the integration and resolution problems that might be solved through a GIS. During this work, the statistician could work primarily defining the problem of matching spatial resolution and “geographic goodness of fit”. During this first year, the geologists would compile an uplift chronology and draw up a series of paleogeographic (paleotopography) maps of the Andean orogen for the four regions of interest. During this first year, I would organize fossil-collecting expeditions to three areas, southern Ecuador, the Mayoan of Patagonia, and to the Neogene of western and northwestern Argentina. While collections exist, these areas could be significnatly improved with a single collecting season, and would also permit me to arrange for uniform use of a standard research protocol and for the necessary collections study during this and the following year. If any rocks can or need dating, this work could be initiated.

WE COULD JUST DO 2 GCM INTEGRATIONS THE FIRST YEAR (OR MAYBE FOUR) WITH FULL ANDES AND PRE-UPLIFT AND MAYBE A COUPLE OF SST DISTRIBUTIONS EACH. I COULD HANLDE THIS LOAD ALONG WITH A NEW STUDENT - TEACHING THE STUDENT TO RUN THE MODEL AND INTEPRET RESULTS IN THIS FIRST YEAR. I AM WORRIED ABOUT COMMITTING TO A BIG WORK LOAD BEFORE I HAVE SOME HELP, SINCE I HAVE SOME PRETTY SIGNIFICANT OBLIGATIONS!

YEAR 2. Armed with the chronologies and maps of Andean topography, the modeler could attempt the embedding, perhaps starting with two relatively easy areas, W & NW Argentina and Patagonia, say. Embedding Bolivia and Colombia/Ecuador could be given a secondary priority. Paleontologists would work up (assigning species to adaptive categories) the appropriate fossil collections.

YEAR 3. Continue and expand embedding experiments. Calibration of the patterns of fossil species richness. Validating the GCM and embedding experiments.

YEAR 4. GIS And begin to write it up!

Please, I don’t know the first thing about “running a GCM”, nor anything about “integrating” such a thing with mammal data, so don’t be bashful about setting my mind straight! WE WILL HAVE TO LEARN AS WE GO ALONG!

Where and how do we do the GCM work? I’ve been told that the Supercomputing Center at Research Triangle Park is available for Duke researchers.

IF WE SET THINGS UP SO THAT WE DO 2-4 GCM INTEGRATIONS THE FIRST YEAR (AND THE WHOLE SUITE THE FOLLOWING 6 MONTHS OR SO), IT PROBABLY MAKES SENSE TO RUN THE MODEL IN-HOUSE AT CORNELL. WE CAN'T DO HUGE NUMBERS OF VERY LONG RUNS THERE, BUT ITS CERTAINLY A WORKABLE COMPUTING ENVIRONMENT FOR THE NUMBER OF RUNS WE NEED. WE HAVE SEVERAL WORKSTATIONS SET UP FOR RUNNING THE GCM, AND WILL JUST NEED TO SUPPORT SOME DISK SPACE AND PEOPLE SUPPORT ON THE GRANT (MAYBE TO THE TUNE OF $4000 OR SO EACH year, BUT DON'T HOLD ME TO THAT!

YEARGEOLOGY
GCMSTATISTICSPALEONTOLOGY1Make Maps &
ChronologyGlobal GCM,
Regional ClimatologyStudy ProblemModern Mammals
Collect Fossils
Date Rocks?
2Resolution Matching
EmbeddingSpatial Resolution MatchingMuseum Work
Assign Categories
3ValidatingCalibration
4GIS IntegrationResults

What scenarios do we run?

SST’s
Present Pattern
Calibrated Miocene Patterns

UPLIFT
Gradual and Continuous
Episodic or Pulsed
Accelerated
WITH THE GCM, WE NEED TO RUN "SNAPSHOTS" - SOLVE THE EQUATIONS FOR A GIVEN SET OF BOUNDARY CONDITIONS. WE NEED TO ASSUME, THEN, THAT THE TIME SCALES OF UPLIFT, WHETHER EPISODIC OR SMOOTH ETC, ARE IRRELEVANT TO THE CLIAMTE CONDITIONS. THIS IS EQUIVALENT TO ASSUMING THAT THE CLIMATE ADJUSTS INSTANTANEOUSLY TO THE BOUNDARY CONDITIONS. THAT'S A GOOD ASSUMPTION, CONSIDERING WE ARE TALKING ABOUT GEOLOGICAL TIME SCALES. SO, WE DON'T REALLY
CARE (OR CAN'T ADDRESS ISSUES ASSOCIATED WITH) THE TIME-DEPENDENT NATURE OF THE UPLIFT.

INITIAL ELEVATION
Sea Level (No Topography)
1000m
2500m

CONFIGURATION
Straight
One-Bend Orocline
Two-Bend Orocline

WE NEED TO PICK OUT THE MOST IMPORTANT THINGS, SINCE WE CAN'T DO AN UNLIMITED NUMBER OF RUNS. I'LL TRY TO COME UP WITH A PROPOSED SET, WHICH WE CAN SAY IS FLEXIBLE DEPENDING ON THE RESULTS OF THE EARLY RUNS IN THE SET.

LITERATURE CITED