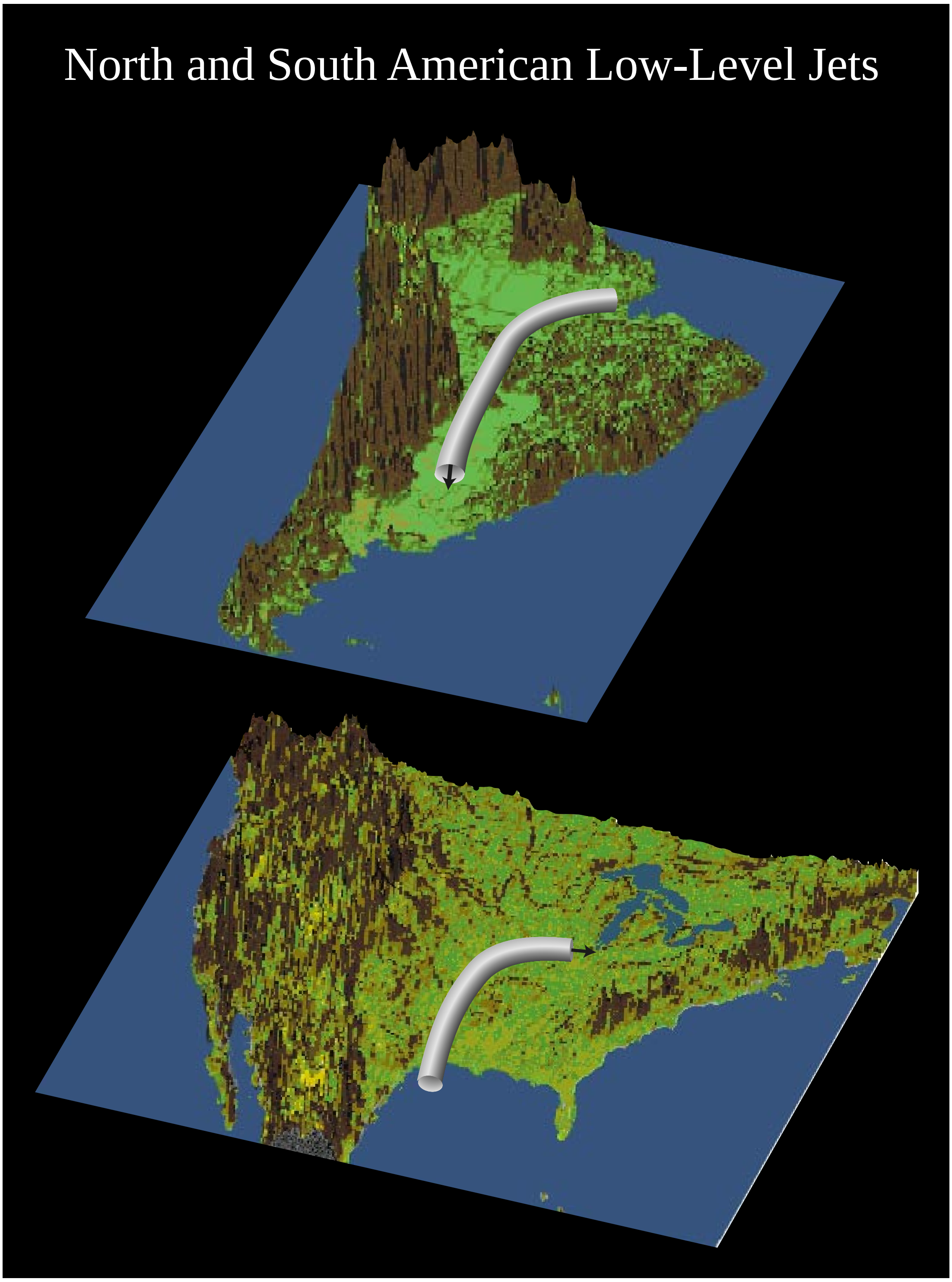
American Low Level jetS

A Scientific Prospectus and Implementation Plan



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Executive Summary

Review of observed climate variability, regional hydrology, and high impact weather over the Americas points to a prominent gap in past monitoring of low-level atmospheric jets. These circulations promote exchange of atmospheric water vapor from low to mid-latitudes and its subsequent condensation. They modulate spring and summer rainfall events over the Mississippi and La Plata river basins and exert controlling influences for droughts, floods, and severe weather. Broad, agriculturally productive river basins of North and South America are naturally irrigated by moisture that is transported by low level jets (LLJ) and precipitated downwind of their speed maxima. Organization of American droughts, floods, and severe weather over these American bread-baskets is often modulated by these narrow LLJs characterized by cross-stream scale of several hundred km and synoptic to continental streamwise dimensions. LLJ variations occur on all time scales, with regular diurnal fluctuations featuring nocturnal maxima.

Low-frequency variability from the intra-seasonal to the interdecadal has been shown to modulate LLJs suggesting the predictive potential of these orographically bound currents. Realization of this potential requires identification of the source of this variability both with respect to remote influences and regional forcings. The ALLS program will promote improved climate prediction with emphasis on forecast model components related to surface moisture sources, atmospheric moisture transport and regional precipitation modulation.

Operational observing systems do not resolve LLJs over either American continent. Modern data assimilations consequently contain monthly averaged moisture flux uncertainties on the order of 50% over large river basins of the Americas, and related diurnal precipitation cycles are seriously distorted in global data assimilations. The uncertainties are due directly to inadequate resolution of LLJs by operational observing systems.

Portions of the broad LLJ spectrum are potentially predictable manifestations of interaction of ambient circulations with orography, soil moisture, and sea surface temperature. The diurnal cycle should be particularly predictable because it is so regular. Atmospheric scientists do not understand why GCM simulations of related phenomena such as nocturnal precipitation and wind maxima are so poor, and will not remedy this deficiency until sufficient observations are available to calibrate model simulations of the full diurnal cycle.

During the past half decade, special asynchronous observations have started to fill observation voids over North America, and field experiments over South America have started to fill gaps of LLJ observations there. The intent of the ALLS program is to promote and extend these efforts so that accurate, averaged moisture fluxes can be obtained over the larger river basins of North and South America allowing evaluation of gridded data sets used in empirical studies and calibration of climate and regional models at both short and long time scales.

This document summarizes current understanding on ALLS and their variability in sections 2 and 3 and identifies gaps in present knowledge. These include deficiencies on accurate depiction of i) variability of American Low-Level-Jets ii) related atmospheric hydrological budgets and iii) orographic modulation of the phenomena. Improvements in model and assimilated data required to advance the ALLS program are also discussed in these sections. Although serious observing gaps characterize much of the Americas, the most pressing deficiencies arise over South America. An important first step is to continue and enhance monitoring of South American LLJs designed to improve understanding and predictability of moisture transport between the Amazon and La Plata river basins, and its response to natural and anthropogenic influences. This is therefore the emphasis of the Implementation Plan in section 4 which focusses solely on South America. Linkages to other programs and project infra-structure are presented in section 5.

1. What is the ALLS program?

The ALLS program is an internationally coordinated effort to monitor, quantify, and analyze low-level circulations that modulate regional rainfall. These circulations commonly assume a jet-like structure in the lower troposphere, referred to as the Low-Level Jet (LLJ). American Low-Level Jets (ALLS) are characterized by mesoscale cross-stream structure, and synoptic to continental scale along-stream dimension.

Fig. 1 shows a 40 year average of 925 mb winds obtained from the NCEP/NCAR reanalysis and the monthly deviation of the meridional component of the wind from the January and July means (contoured every .3 m/s). The two panels show the jet-like structure east of the Rocky and Andes mountains during summer. A jet structure is still present over South America in winter. In contrast, over North America westerlies prevail east of the Rockies during winter. Such seasonal differences may be rooted in the geographical setting of North and South America with pronounced land masses over middle and tropical latitudes respectively. Summer low-level circulations over both continents present two distinct poleward flows; the strongest meridional flow is located close to the high mountains of the West. There is also a secondary current over the east coast of the continents associated with the Atlantic subtropical highs. The south-Atlantic high is weaker in summer than in winter unlike other subtropical highs which maximize during summer. The low level circulation in both continents is therefore strongly modulated by the subtropical highs in July. Distinctive features of the summer monsoonal circulation over South-America are the strong north-easterly trades (see http://www.met.utah.edu/jnpaegle/research/miami_report.html) which enter the continent between 5^{o}S and 10^{o}N.

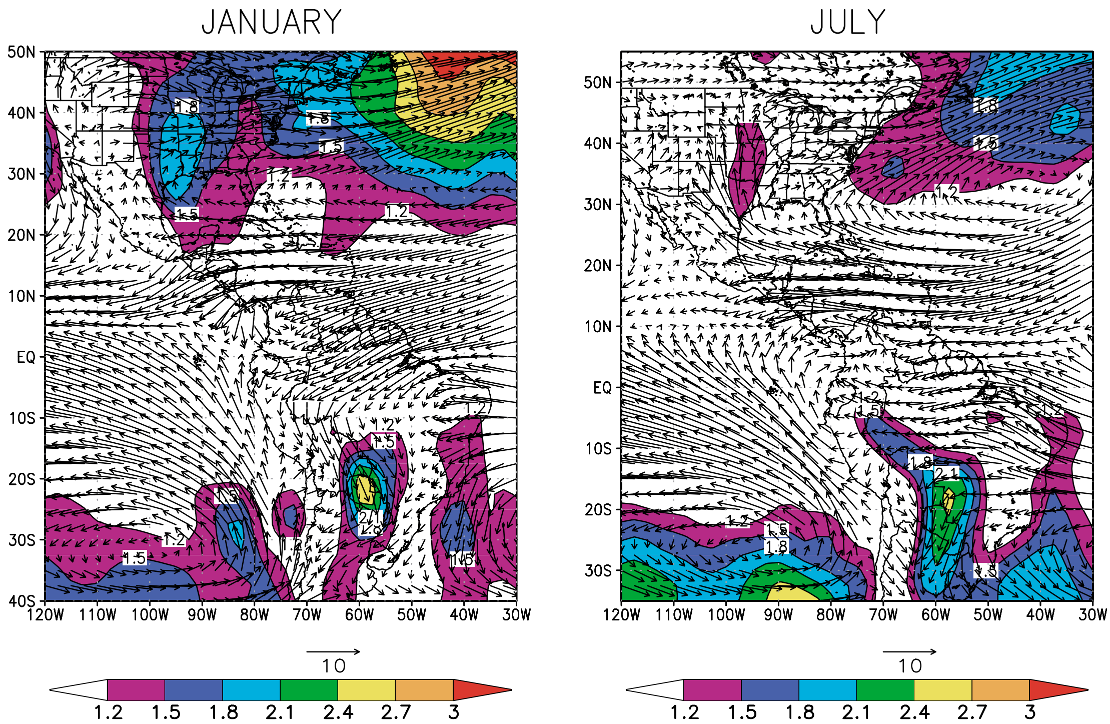


Fig. 1: 925 mb winds from NCEP/NCAR reanalysis and standard deviation of monthly meridional wind values.

The meridional wind east of the Andes exhibits variability in time scales longer than a month approximately co-located with the meridional wind maxima. Peak values of approximately 3m/s represent about 50% of the meridional wind maximum. This is not the case over North-America where variations in monthly and longer time scales are small compared to the meridional wind.

LLJs over both continents represent corridors that transport atmospheric tracers (e.g., water vapor) from the tropics and subtropics toward higher latitudes. The transported moisture condenses in a region of ascent downwind of the jet maximum. Here, explosive convection may occur within mesoscale convective complexes that feed upon, and modulate the LLJ. The convection and LLJ both have strong diurnal cycles, typified by nocturnal maxima. The nocturnal convection maxima are not reproduced by global climate models, and nocturnal LLJ maxima are not resolved by the current operational American observing system. It is likely that these systematic deficiencies of current short and long-range climate simulation models impede predictability of related phenomena.

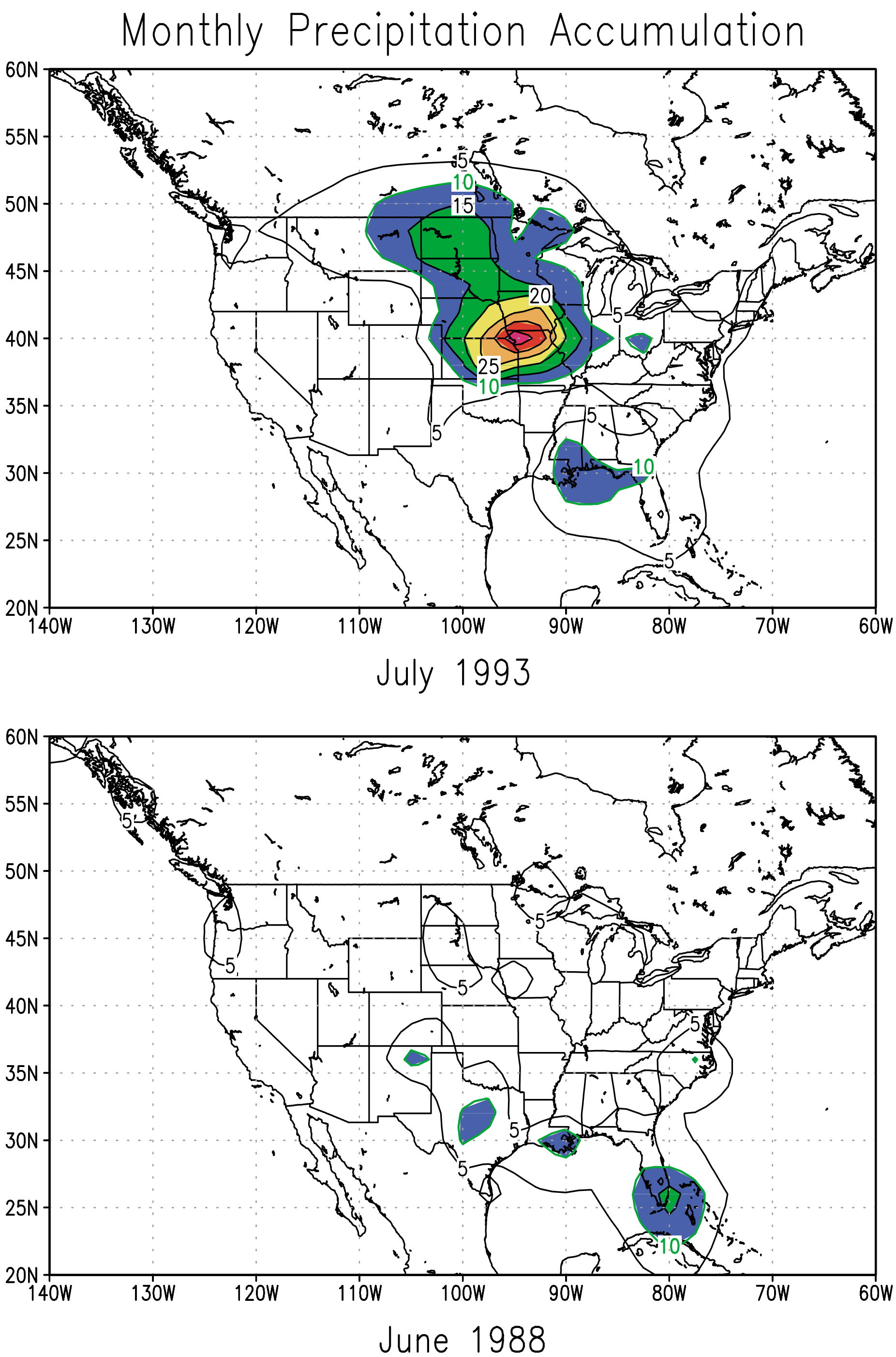


Fig. 2: Total precipitation from gridded analysis (Higgins et al., 1996a) of station data, for July 1993 (top) and June 1988(bottom). Contour interval is 0.05m.

American LLJs vary substantially on interannual, as well as intraseasonal time scales. Evidence for interannual oscillations appears in comparative studies of dry and wet summers over North America. The Great Plains jet in drought episodes similar to that of summer 1988 was only about half as strong as those observed for flood conditions similar to summer 1993 (Mo et al., 1995). These estimates are based on gridded analyses. Heavy Great Plains rainfall of summer 1993 (Fig. 2) was partly supported by LLJ connections with a remote moisture source over the Caribbean, while this distant source was virtually shut down in the Great Plains drought year (Fig. 3).

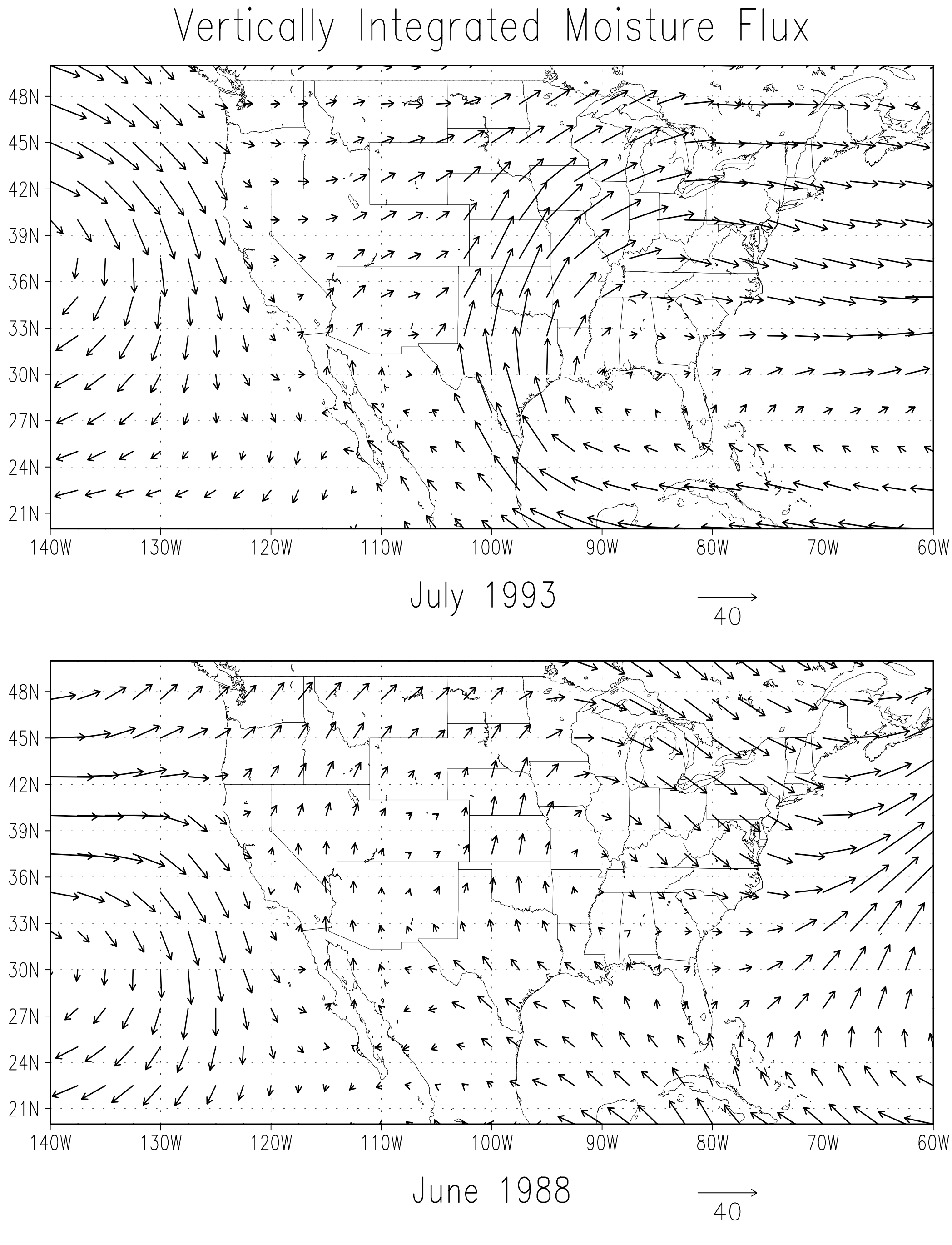


Fig. 3: Vertically integrated water vapor transport from the NCEP/NCAR reanalysis, for July 1993 (top) and June 1988(bottom). Maximum vector is 50 kg (m/s)

Recent studies demonstrate pronounced, episodic fluctuations of the east-Andean LLJ and related rainfall over the La Plata river basin. Some of these oscillations have characteristics associated with ENSO time scales, and others have periods on the order of weeks. The North American Great Plains jet episodically connects moisture of tropical seas to agriculturally productive regions of mid-latitudes. The Andean jet of South America supplies the fertile plains of southeastern South America with the moisture source of the Amazonian rainforest at semi-regular intervals (Paegle, 1987). Estimates of moisture recycling over the Amazon Basin depend strongly upon estimated east Andean jet strength.

2. Why the American Jets?

American Low Level Jets modulate much of the moisture supply to the fertile plains located east of the North American Rockies, and situated over the La Plata river basin (Fig. 4)

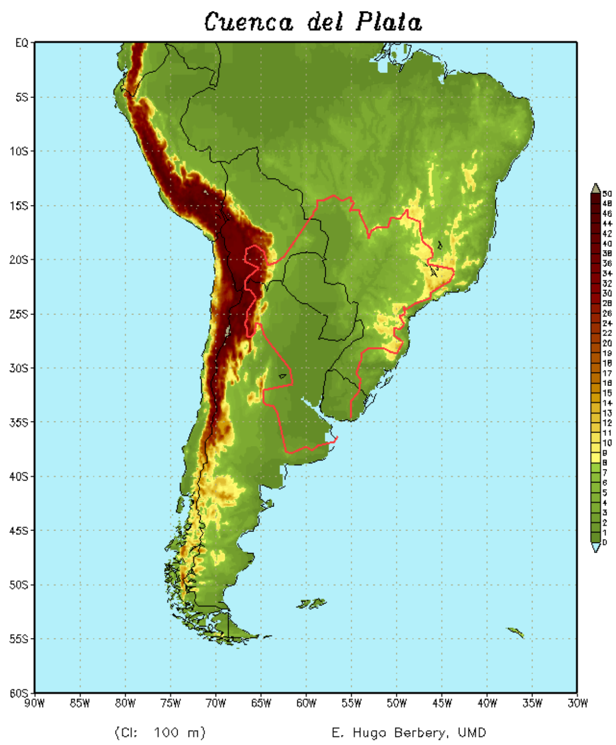


Fig. 4: (left) La Plata river basin

The La Plata basin drains a region similar in size to the Mississippi river basin, and water cycles have comparable magnitude. Main tributaries to the La Plata basin are the Parana, Paraguay and Uruguay rivers. The basin covers parts of five countries: approximately 30% is in Argentina, 7% in Bolivia, 46% in Brazil, 13% in Paraguay and 4% in Uruguay. The La Plata basin is of great importance for the regional economies; about 70% of the total GNP of the five countries combined is produced within the basin, which is also inhabited by about 50% of their combined population. Agriculture and livestock are among the region's most important resources. Several hydroelectric plants provide energy to the region; with 92% of the energy produced by Brazil obtained from hydroelectric resources. La Plata basin rivers provide water to one of the most densely populated regions of South America, including its two largest cities (Buenos Aires and São Paulo). Both basins, together with fertile regions of Canada and Mexico produce large agricultural exports. This production, and its regional and global human and economic dimensions are sensitive to natural climate variability associated, for example with ENSO, and possibly with anthropogenically induced changes associated, for example with global warming and tropical rainforest destruction. Modulations of the South Atlantic Convergence Zone (SACZ) have a marked effect on rainfall distribution over South America (Kousky and Kayano, 1994). The SACZ undergoes fluctuations on intraseasonal time scales; i.e. when the SACZ is enhanced the northerly flow east of the Andes is weakened (Nogues-Paegle and Mo, 1997; Li and Le Treut, 1999). Intraseasonal rainfall modulations are of practical interest to timing of seeding, harvesting, and irrigation over the agricultural regions of central and northern Argentina, south-east Brazil and Paraguay.

Floods and droughts of large portions of these American agricultural "breadbaskets" correlate with intensity and positioning of regional LLJs, whose mesoscale cross-stream dimensions modulate the mesoscale structure of summer and spring rains. The prediction of these mesoscale events has great practical significance, but is in principle limited by the chaotic nature of the atmosphere, and by the resulting sensitivity to uncertainty of the initial state. For unforced phenomena, the limit of accurate prediction is typically not much longer than the period of the predicted phenomena. In the case of transient mesoscale phenomena (such as the mesoscale convective systems over northern Argentina), characterized by periods on the order of a day or less, the period of accurate prediction is approximately one day, and often much shorter.

Predictability is higher for phenomena forced by interaction of well-specified ambient flow with foreknown surface conditions such as topography, soil moisture and sea surface temperature. American LLJs are such phenomena, and this fact can be used to enhance their deterministic predictability and that of associated rainfall. Climatological studies show distinct nocturnal maxima of both American LLJs and related downwind precipitation maxima. A summer thunderstorm is approximately three times more likely at mid-night than mid-day over a North American location such as Kansas City and a central Argentine site such as Cordoba. This relates to stronger nocturnal moisture influx and convergence associated with night-time LLJ maxima. The correlation can be used to enhance accuracy of local precipitation timing at very short time scales. For reasons that are not yet well-understood, GCMs are unable to simulate nocturnal precipitation maxima of climatology (Ghan et al., 1996). Understanding and correction of this deficiency requires simulation of an accurate nocturnal LLJ, hypothesized to be the controlling agent for nocturnal precipitation maxima. It is difficult to correct or calibrate an unobserved or poorly observed field. The premise of the proposed work is that adequately observed diurnal LLJ oscillations are required to improve predictability of related diurnal precipitation oscillations.

A related goal of the project is to determine if predictability enhancement is possible at longer time scales and to develop tools to exploit this possibility. It is postulated that American Low-Level Jets are orographically bound phenomena possessing mesoscale cross-stream dimensions. Their variability, as well as that of attendant precipitation fields, is influenced by local and remote phenomena. The former include surface conditions. The latter include global-scale climate phenomena, whose intraseasonal and interannual variability has potentially predictable aspects. The hypothesis cannot be presently validated, and may not be exploited without adequate observations and correct simulations of the LLJs that provide the dynamical foundation of the scale and frequency linkages to regional precipitation.

This premise may be equally valid over other regions. The American focus reflects the large amount of preliminary work that has already been done over the Americas, the evident social and economic impacts here, and the special need and recently renewed monitoring activities in these regions. Both North and South America are situated in longitude bands where neither conventional observing time of 00 nor 12 UTC occurs close to the time of the nocturnal jet maximum. The best-defined climatologies of the Great Plains jet use observations that are 40 years old, when some rawinsondes were launched at 6 hour intervals over the Central United States.

Emergence of the demonstration wind profiler network during the past half decade partly fills temporal observing gaps over North America and national efforts in South America partly compensate observation gaps there. The proposed work will build upon these efforts and promote further monitoring, analyses and prediction as outlined in remaining sections.

3. Science Objectives

Science objectives of ALLS are to understand the role of American low-level jets in moisture and energy exchange between the tropics and extratropics and related aspects of regional hydrology, climate, and climate variability. Specific hypotheses to be tested within this program are:

Water vapor transports by ALLS are key components of the water cycles over the continents.

- ALLS have substantial variability on daily, intraseasonal and interannual time scales. This variability is influenced by ENSO as well as by climate anomalies in the Atlantic and Interamerican Seas.
- Improved observational datasets on ALLS will contribute to more successful weather and climate forecasts.
- Comparative analyses of LLJs over North and South America will contribute to improve our understanding of the phenomenon in view of interhemispheric similarities and differences.

The ultimate goal is to improve short and long term prediction through the following strategy:

- obtain an improved description of the temporal and spatial structure of the LLJs based on expanded monitoring activities and special field experiments,
- evaluate the veracity of numerical representation (forecasts and analyses) of LLJs against special observations and,
- determine improvements of initial state representation and model parameterizations required to improve prediction.

3.1 Identify LLJ events and variability

3.1.1 North America

Reviews of American LLJs demonstrate connections between the LLJ and convective weather. Stensrud's (1996) comprehensive overview references approximately 90 prior studies. That study and many others refer to a jet definition originally formulated by Bonner (1968), who examined rawinsonde observations for 1959 and 1960. Observations were then routinely taken at 6 hour intervals at several stations, and depicted the nocturnal speed maximum. Those observations afforded sufficient resolution to determine a relationship between nocturnal convection and nocturnal LLJ maxima (Bonner et al., 1968).

For three decades, ending in 1994, there were no regular upper air wind observations over North America during the nocturnal phase of the jet. Since 1994, the demonstration wind profiler network started to fill the gap in a region centered over Oklahoma. These data suggest that the wind maximum is approximately 4 times more likely to occur within 2 h of local mid-night than within 2 h of the standard observing times of 00 and 12 UTC, (Stensrud, 1996). Consequently, quantitative estimates of the diurnal LLJ cycle over all of North America from approximately 1963 to 1994 can only be done through assimilated, gridded data sets. Unfortunately, intercomparisons of gridded analyses show substantial nocturnal discrepancies between separate, but equally credible assimilation systems (Wang and Paegle, 1996). Wind analysis discrepancies contribute to large moisture flux uncertainties over both short and long time periods.

The demonstration wind profiler network has started to fill the temporal observing gap over the Central United States, and increased use of ACARS observations on aircraft ascent and descent may fill temporal gaps elsewhere. ACARS on freight cargo aircraft are particularly useful because those operate more commonly during the night. These data could substantially improve monitoring of the diurnal cycle of the LLJ over North America. New problems include contamination of profiler signals by migratory birds, and one objective of proposed research is to demonstrate how well profiler and ACARS data are assimilated in gridded analyses.

American LLJs, their diurnal oscillations and related weather display episodic fluctuations. McCorcle (1986) used 4/day observations in May 1958 and May 1962 at Fort Worth and Kansas City to compare jet strength with surface observations of severe weather. The jets, their diurnal oscillations, and severe weather were much more prominent in May 1962 than May 1958 (Figs 5 and 6). Stronger Great Plains LLJs occurred in the summer 1993 floods, when a stationary trough was found over North-America, than during the droughts of summer 1988, (Fig. 2) characterized by upper level anticyclonic anomalies. The low-level flow is strongly influenced by the proximity of the Bermuda anticyclone, with enhanced southerlies with a strong high close to the continent.

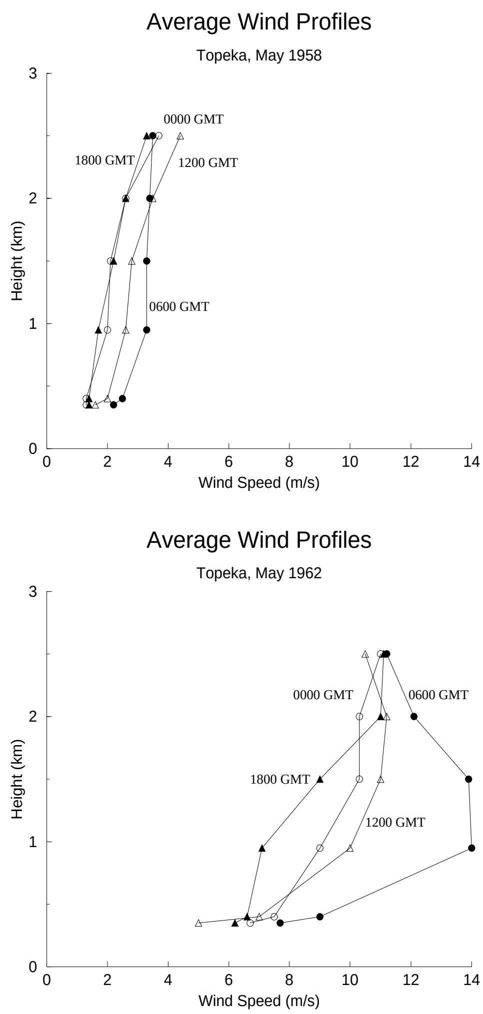


__Fig. 5__: Vertical wind profiles from McCorcle (1986). Maximum and minimum values are obtained at 06 and 18 GMT, which are not included in the current operational rawindsonde network

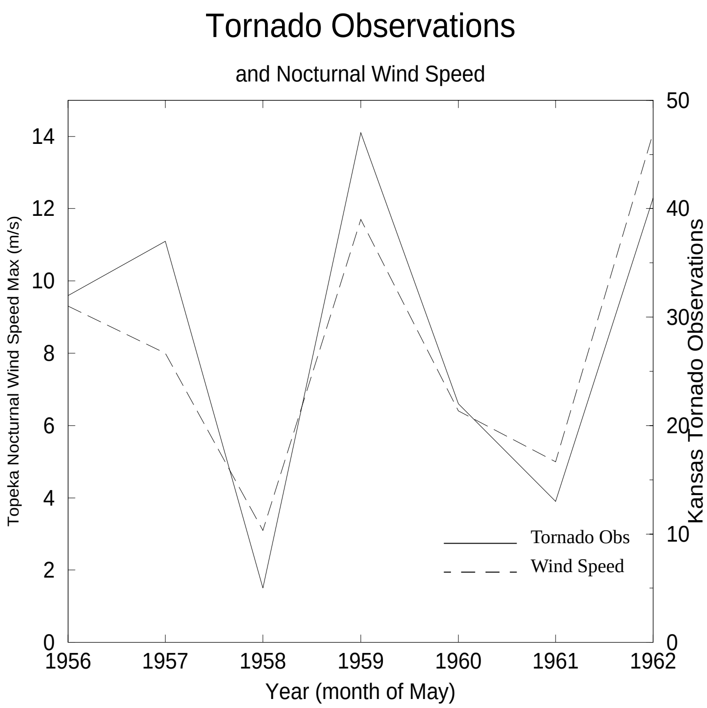


Fig. 6: *Time series of severe weather and nocturnal boundary layer wind maxima. From McCorcle (1986)*

Enhanced summer monsoon rains over central and northern Mexico and Arizona and New Mexico are associated with a LLJ in the vicinity of the Gulf of California (Dunn and Horel, 1994). The Great Plains LLJ and related convective activity are suppressed in these circumstances. Such dipole patterns have also been found by Higgins et al. (1998). Both land and ocean surface conditions have been invoked to provide long term memory for monsoonal variability in interannual and longer time scales. Higgins et al. (1999) summarize studies linking sea surface temperature anomalies to the strength of the summer monsoon, and suggest that the interannual variability of summer monsoons over Arizona and New Mexico is modulated by decade-scale fluctuations of the North Pacific SSTs. Gutzler and Preston (1997) show connection of the summer monsoon to antecedent spring and winter snows over the Rocky mountains.

There is also evidence for low level jets in the Caribbean during summer (Magaña, 1999). This feature is modulated by the strength of the Pacific ITCZ and the ENSO cycle.

The foremost deficiency of available studies of variability of North American LLJs is that their diurnal cycles are of unknown quality, except in early years of the record. It is probable that the diurnal cycle of North American LLJs is poorly resolved in all assimilated analyses and this deficiency is due to inadequate sampling of the nocturnal phase and assimilation of asynchronous data. In addition to these time-resolution deficiencies, there are regions, especially around the Southwest Monsoon that have inadequately observed spatial coverage.

3.1.2 South America

The Andes and the Rockies (Fig. 7) are major mountain ranges that deflect the prevailing atmospheric flow producing low level jets. Both mountain ranges extend from the tropics to high latitudes, and effectively block the low-level circulation, particularly in summer. There are however, important differences in topography. The Andean peaks are nearly twice as high as the Rocky mountains, and they rise abruptly from low elevations, without substantial intervening zones of gently sloping terrain. Although the Andes extend from high latitudes to equatorial latitudes, they exhibit mesoscale dimensions of the order of 500 km or less in the east-west direction. Possibly because of this, the seasonal cycle of the east Andean LLJ may not be as pronounced as that of its North American counterpart (Nogués-Paegle et al., 1998). Elevated orography is also found around southeast Brazil, near the Atlantic coast. Although these mountains are much lower than the Andes, they are more extensive than the Appalachian mountains of eastern North America, and play a prominant role in low-level circulations of South America.

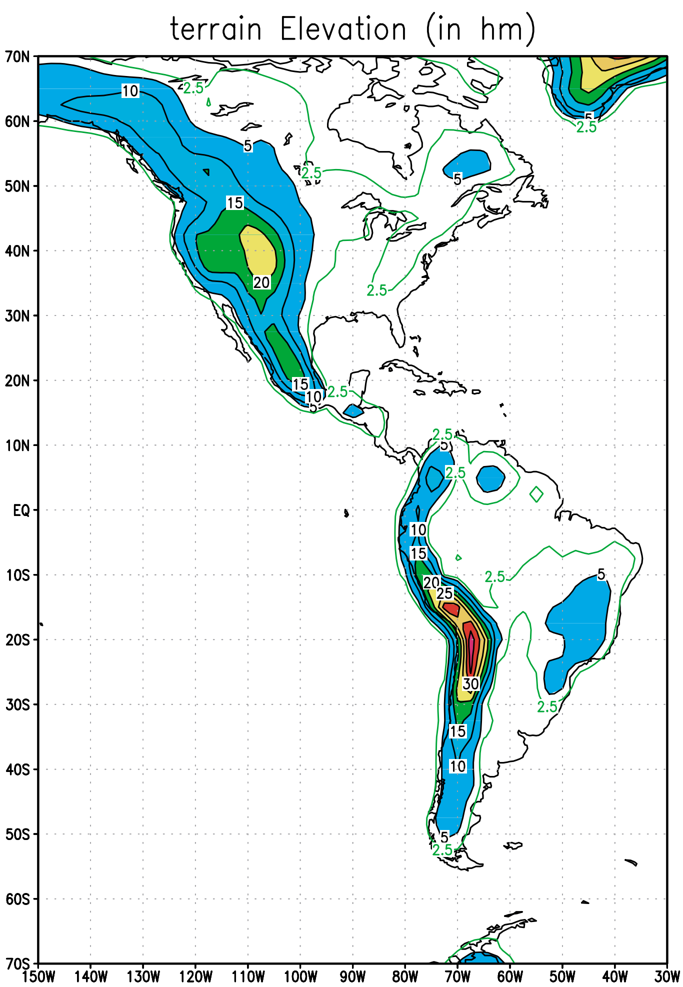


Fig. 7: Terrain elevation in hectameters, contoured every 500 m, for a 2.5 by 2.5 degree resolution. Values higher than 500 m are shaded and the 250 m contour is added.

Unfortunately, observational evidence for LLJs east of the Andes is sparce. Fernandez and Necco (1982, 1984) describe the vertical structure of the wind obtained from Argentine radiosondes at 12 GMT. Their results for Resistencia (59°W 27°S) and Cordoba (64°W 31°S) indicate northerly flow below 800 mb during January. There are few upper air observations, expected once a day, but commonly missing. Figure 8 shows that the number of upper air stations over South America is only about 20% of the number over North America, and that the average number of reports per station is less than one per day for most years. Spatial coverage is compromised by local support logistics, impeded communications, and poor timing of reports.

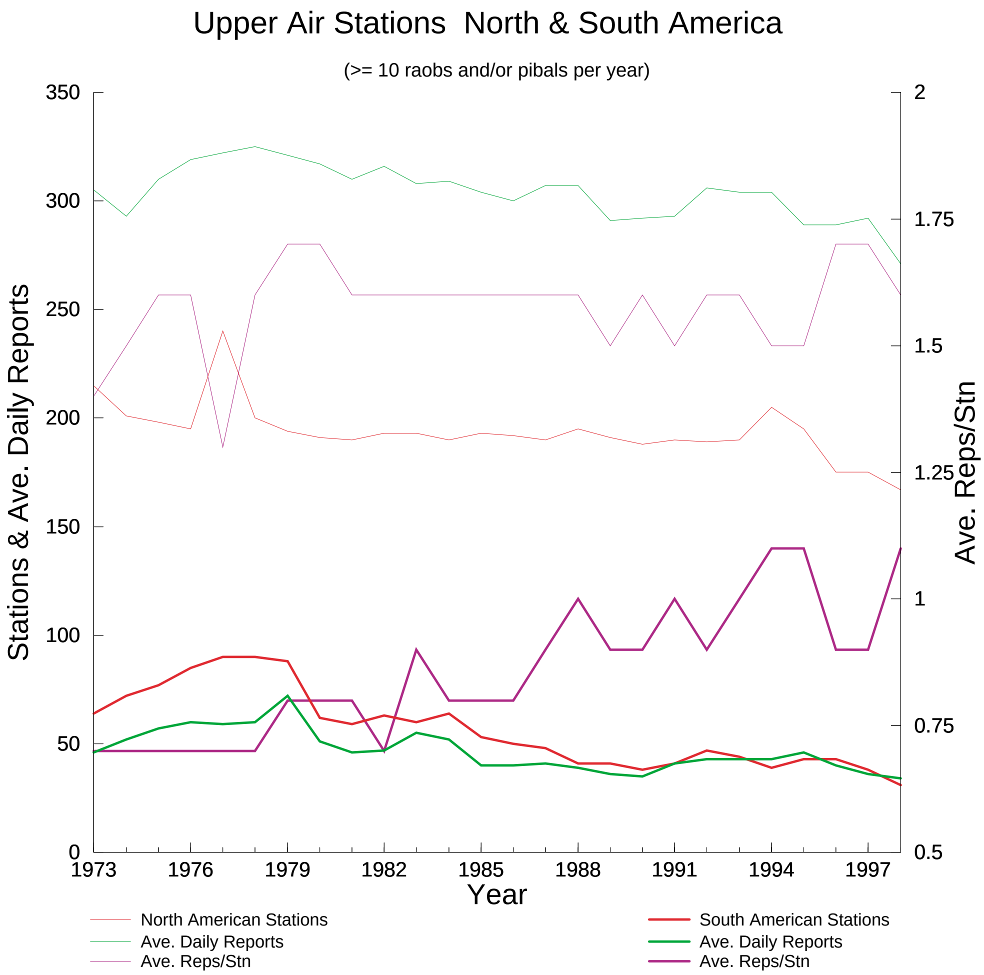


Fig. 8: *Upper-air observation counts prepared by Gregg Walters at NCAR/SCD in April 1999. North America-top three curves, South-America - bottom three curves.*

Because of poor observational coverage, many current descriptions of South American LLJs are based upon idealized model integrations or analyses of sparse observations through techniques of four dimensional data assimilation. Such investigations include studies with long-term reanalyses by Douglas et al. (1998, 1999), Wang and Paegle's (1996) intercomparison of different operational analyses over South America, and Nogués-Paegle and Mo's (1997) description of South American LLJ oscillations revealed by NCEP reanalyses. Eltahir and Bras' (1994) Fig. 7 displays strong moisture flux east of the Andes, emerging from the Amazon basin in operational ECMWF analyses. This moisture outflux has large impact on moisture recycling estimates for the Amazon.

Several observational studies provide insight at selected sites. Berri and Inzunza (1993) compare modeled and observed estimates of moisture flux over northern Argentina, and Inzunza and Berri (1991) analyze twice daily rawinsonde and pibal observations at selected sites over Northern Argentina. Because of low frequency of observations for 00 UTC in other years, those studies focus on 1973 and 1974. Douglas et al. (1998, 1999) describe pibal observations taken at a specific site near the Andean foothills.

Several regional observational studies have also been reported. Lichtenstein (1980) describes the thermal low of Northern Argentina; Virji (1981) notes a South American LLJ in wind vectors derived from satellite cloud imagery; and Nogués-Paegle (1981) analyzes diurnal cycles of thunderstorms and showers for five years of hourly Argentine surface reports. The latter study displays nocturnally enhanced convection over central Argentina similar to diurnal thunderstorm cycles observed over central portions of North America. Velasco and Fritsch (1987) show extensive intercomparisons of mesoscale convective complexes over most of the Americas. Their analyses of satellite inferred cloud-top temperatures show that mesoscale complexes east of the Andes are stronger than those east of the Rockies, and they also support the nocturnal convection maxima described in other studies.

Some aspects of South American observations, including Argentine nocturnal convection are consistent with North American counterparts. More recent analyses of wind soundings by Berri and Inzunza (1993) and Inzunza and Berri (1991) and by Douglas et al. (1998, 1999) show intriguing differences with North American LLJs. These include a deep and late afternoon rather than shallow and early morning wind maximum at Santa Cruz, Bolivia and much more cloudiness and rain at this site in the morning than in the late afternoon. Since Santa Cruz is only 25 km east of the steep Andean topography, it is situated similarly to Denver, Colorado and the Rockies, a location that clearly favors afternoon and evening convection (Wallace, 1975).

Those investigations suggest a variety of structures and unexpected features in the South American LLJs. Possibly associated phenomena, such as nocturnal convection peaks over the plains are similar to observations in North America. Other aspects, such as the depth and timing of maximum low-level winds are not adequately resolved, but the evidence suggests striking local differences with other LLJs. These imply different driving mechanisms than for North American LLJs and further measurements and analyses are essential.

3.2 Quantify LLJ contributions to the hydrological cycle

3.2.1 North America

Early water budget studies are founded upon subsets of the approximately 800 stations within the MIT General Circulation Data Library under the direction of V. P. Starr. The data consist of radiosonde soundings analyzed at 50 mb intervals over the northern hemisphere and tropical portions of the southern hemisphere from May 1958 to April 1963. Atmospheric portions of the water budget within these analyses in regions such as North America may be better specified than those obtained for later years from assimilated data sets. Rasmusson (1968) used observed data over North America to determine hydrology of the Mississippi river basin. The Great Plains LLJ plays a major role in atmospheric moisture transport, and diurnal variations of moisture flux divergence are on the same order as computed mean values. The uncertainty appears to be a relatively small fraction of individual terms of the budget, of the order of 1/2 cm/month liquid equivalent.

Equally good results have not been obtained in recent analyses using gridded, assimilated data sets. This may be due to lack of nocturnal observations in later years, and may also reflect analysis sensitivity to the model used to provide the first guess as discussed in Section 3.5. Intercomparisons of different gridded assimilated data sets by Wang and Paegle (1996) show substantial monthly averaged discrepancies between equally credible analyses of the moisture flux over eastern North America. The discrepancies are several cm liquid equivalent/month and are a significant fraction of the total estimated moisture flux. Nocturnal phases of low-level jets are substantially different in the different data archives, and signal/noise ratios of moisture budgets may be improved most rapidly by better wind observations and analyses.

In principle, the atmospheric portion of the moisture budget is the simplest to estimate, since it requires only measurement of wind and humidity, that can be done with sufficient accuracy by rawinsondes. This requirement is less demanding than estimates of ground water, subsurface flow, surface evaporation and precipitation, which generally require much higher resolution observations or instruments with less coverage and more limited development than the radiosonde. In practice, most regions lack the necessary radiosonde coverage in space and time to adequately describe the atmospheric component of the moisture budget. Wang and Paegle (1996) document UKMO-NCEP 850 mb monthly averaged wind analysis differences up to 4 m/s at the time of the nocturnal LLJ maximum. Monthly averaged moisture flux uncertainties into South Texas are consequently approximately 40% of the monthly average.

Higgins et al. (1996b) compare moisture fluxes analyzed by the NASA DAO and by the NCEP Reanalyses. The former systematically underestimate LLJ contributions, while the latter overestimate this contribution with respect to available rawinsondes. The transports across the Texas coast are approximately 50% larger in the NCEP Reanalysis. Neither analysis captures observed nocturnal precipitation maxima, which provide positive feedback upon LLJs (Nicolini et al., 1993). The feedback is distorted in models that do not generate nocturnal rain maxima. Analyses and forecasts from regional models show more promise. The operational Eta model of NCEP reproduces broad aspects of the diurnal precipitation cycle (Berbery and Rasmusson, 1999), and would properly handle the feedback. The latter study also emphasizes importance of high temporal resolution for moisture budgets.

Mo et al. (1997) study pentad composited spring and summer rainfall centered on the Central Mississippi River Basin. They find that when it rains heavily in the Mississippi River Basin, increased horizontal convergence of atmospheric water vapor is the main moisture source. This is consistent with Roads et al.'s (1994) conclusion for short time scales. Mo et al. (1997) also determine that wet composites have strong moisture flux across the Gulf coast, into the Mississippi Basin, while dry composites exhibit small moisture flux across this coastline. These results suggest that the main source of moisture for summer rain events on the scale of this river basin is atmospheric convergence of moisture transported from the Gulf of Mexico, and implicate relatively short term (order of weeks) fluctuations of the LLJ. The LLJ exerts an important control on longer time scales as well. The Great Plains LLJ is approximately twice as strong in summer months of the flood year of 1993 than it is in the drought year of 1988 (Fig. 2).

There is evidence of a fine-scale LLJ that moves periodically poleward along the Gulf of California, and augments moisture surges toward the southwest monsoon. This LLJ was observed in the field experiment SWAMP (e.g. Dunn and Horel, 1994), but is not accurately depicted in globally gridded analyses because of its relatively small horizontal dimension.

The above studies are largely founded upon assimilated, gridded data sets, or older data archives that included 4/day rawinsonde data. The reliability of estimates obtained from assimilated data needs to be improved, particularly at night.

3.2.2 South America

Many past studies of South American hydrology focus on estimates of water recycling by the rainforest of the Amazon. There is no doubt that the rainforest is a moisture source, for the atmospheric water vapor content is higher here than over the surrounding tropical oceans (e.g. Berbery and Collini, 1999). The rainforest is disappearing due to economic and development pressures. Response of local climate to these changes is unknown, and sensitivity of local ecosystems to tropical rainforest destruction has been studied in a number of GCM simulations.

These simulations suffer from two evident problems. First, control experiments of unperturbed conditions cannot be calibrated without better observation of the actual water cycle that characterizes the continent. Second, global GCMs have relatively coarse resolution, and are blunt tools for studies of regional hydrology. There is also a possibility that while land-use changes are most evident in tropical sectors of the continent, their greatest indirect impacts might occur at extratropical margins, for example the fertile La Plata river basin.

Many earlier studies of the geophysiology of Amazonia are collected in a text edited by Dickinson (1987). A chapter of this text (Salati, 1987) summarizes analyses leading to the conclusion that the water recycling of the Amazon region might explain up to 50% of the water vapor contributing to rainfall of the region. More recent estimates use assimilated gridded fields and reanalysis data sets to address these issues. Matsuyama (1992) used gridded ECMWF analyses to compare atmospheric flux convergence of water vapor to river discharge in the Amazon basin. Atmospheric inflow needs to be multiplied by 1.37 to match river outflow. That study also concludes that the ratio of evapotranspiration to precipitation is about 50% over the Amazon basin, in agreement with a number of prior estimates.

Eltahir and Bras (1994) emphasize that the ratio of evapotranspiration to precipitation does not necessarily reflect the precipitation recycling of a given area and conclude that only about 25% of all the rain that falls in the Amazon Basin is contributed by evaporation within the basin. This is a substantially lower estimate than obtained in other studies, and the authors explain the difference by noting that prior studies have treated the Amazon basin as a closed domain, and underestimated the importance of atmospheric outflux of water vapor to other regions.

One such region includes the subtropical and mid-latitude portions of South America, connected hydrologically to the Amazon rainforest via the LLJ. It is not surprising that fundamental estimates of continental hydrology differ so greatly, given the substantial differences in moisture budgets by different equally credible analyses. Wang and Paegle (1996) demonstrate that over a 2000 km by 2000 km domain centered south of the Amazon basin a monthly averaged atmospheric moisture flux is convergent in operational UKMO analyses and divergent in operational NCEP analyses. Monthly averaged analyses at 00 UTC are strongly divergent in both analyses, and monthly averaged analyses at 12 UTC are strongly convergent in both analyses. Diurnal cycles of moisture flux dominate monthly averages, but important aspects of this fluctuation are not sufficiently well-determined to obtain a well-specified monthly average.

A number of mechanisms influence diurnal cycles of South American moisture budgets. These include diurnal oscillations of the LLJ, convective instability, and land and sea-breezes (Berbery and Collini, 1999), as well as solenoidal circulations generated by elevated plateau effects discussed in Section 3.3 below.

In addition to strong diurnal oscillations, there are prominent longer-term oscillations. Nogués-Paegle et al. (1997) find two conspicuous LLJ's in the vicinity of South America. One of these is the east Andean LLJ schematized in Fig. 1; the other is a poleward jet situated east of the South Atlantic Convergence Zone (SACZ) near the Atlantic coast. The SACZ occurs semi-regularly with period on the order of weeks. Prominent SACZ circulations contain strong LLJ's to their east, and correlate with weak east Andean LLJs and relatively light rainfall over the plains of south-central South America. The opposite phase is characterized by substantial rainfall in this area, and pronounced east-Andean LLJs. Semi-regular reversals of this pattern may enhance regional predictability. Unfortunately, all quantifications of these circulations are based upon assimilated data sets, and founded upon sparsely distributed observations (e.g. Fig. 2). It is not possible to calibrate either models or objectively assimilated data sets with the current operational observing system of South America.

On longer time scales, independent calculations of streamflow (Mechoso and Perez Iribarren, 1992; Garcia and Vargas, 1998) and rainfall (Aceituno, 1988; Ropelewski and Halpert, 1987) provide evidence of ENSO oscillations over the La Plata Basin. These data show that the warm ENSO phase correlates with enhanced summer rainfall but decreased winter to spring rainfall. This empirical evidence can be used to make statistical forecasts associated with current or future ENSO events. Unfortunately, atmospheric observations are inadequate to evaluate deterministic numerical simulations of related regional circulations.

The most pressing objectives relating to South American hydrology are contained in objectives outlined below in regards to studies of assimilation of observed data and the proposed monitoring and field program. Lower tropospheric wind and moisture fields and a regularly monitored network of surface raingauges have special relevance.

3.3 Determine plateau effect

3.3.1 North America

The Rocky Mountains are an elevated heat source that generates solenoidal upslope circulations in summer. These circulations are most active in the afternoon, when they promote convection over the mountain peaks and slopes. Reviews by Smith et al. (1996) and by Stensrud (1996) summarize evidence that overturning summer circulations induce a stably stratified lid over the surrounding plains. Suppressed daytime summer convective activity over the extensive plains east of the mountains implies that the domain of influence of the subsiding branch of this circulation extends eastward at least 1000 km through Iowa and Missouri.

Nocturnal convection over the plains is explained by i) nocturnal change of the up-slope circulation, ii) eastward propagation of orographically generated afternoon convection toward the plains at night, and iii) strong convergence at the leading edge of the nocturnal jet that punctures inversions preferentially at night. The plausibility of several dynamical mechanisms underlines the complexity of the phenomena.

Longer-term fluctuations of mountain-plain wind reversals have also been noted. Active southwest monsoon circulations over the southern and central Rockies are characterized by relatively dry conditions over the central Mississippi river basin. Break periods of the southwest monsoon are associated with stronger lee side LLJs and heavier rains. Central Mississippi basin floods of summer of 1993 featured pronounced westerly flow across the central and southern Rockies that may have inhibited development of solenoidal mountain plain circulations, and thereby promoted release of strong convection to the lee. The dynamical effect of cross-mountain flow may also promote a southerly lee-side LLJ.

There is evidence of a relationship between spring snow cover over the Rocky mountains and summer rainfall in the southwestern United States (Gutzler and Preston, 1997). Snow cover enhances surface albedo, and above average late spring melting increases soil moisture. This weakens mountain-plain solenoidal circulations of summer seasons following above-normal spring snows, decreases summer rains over the southwest monsoon, and enhances precipitation over the plains. Interactions of these processes with the LLJ need clarification.

3.3.2 South America

The South American Altiplano is centered on Bolivia, northern Chile, and Peru. It is commonly surmounted by an anticyclonic circulation referred to as the "Bolivian high" during the southern summer. Dynamic and thermodynamic foundations of the Bolivian high are subjects of active research, (e.g. Lenters and Cook, 1997), and moisture sources of episodic convection are investigated by Fuenzalida and Rutllant (1987), Aceituno and Montecinos (1997), and Garreaud (1999).

Heavy summertime rains occur over the Altiplano, on its eastern slopes and over the extensive flatter region to the east. Unlike its North American counterpart, it is not possible to simply characterize the diurnal precipitation regime in terms of a late afternoon mountain maximum and late night plains maximum. Satellite imagery (Velasco and Fritsch, 1987 and Garraud and Wallace, 1997) display afternoon maxima over most of the Andes, although regions of nocturnally enhanced rain occur on eastern slopes. The Amazon Basin mostly experiences afternoon cloud and rain maxima, (Fig. 9) but extensive areas of the central Argentine plains exhibit nocturnal enhancement (Nogués-Paegle, 1981; Velasco and Fritsch, 1987). Satellite imagery reveals that the late spring month of November has the highest frequency of strong subtropical mesoscale convective complexes immediately to the east of the mountains (Velasco and Fritsch, 1987), although the bulk of rainfall over the Amazon Basin occurs later in the summer.

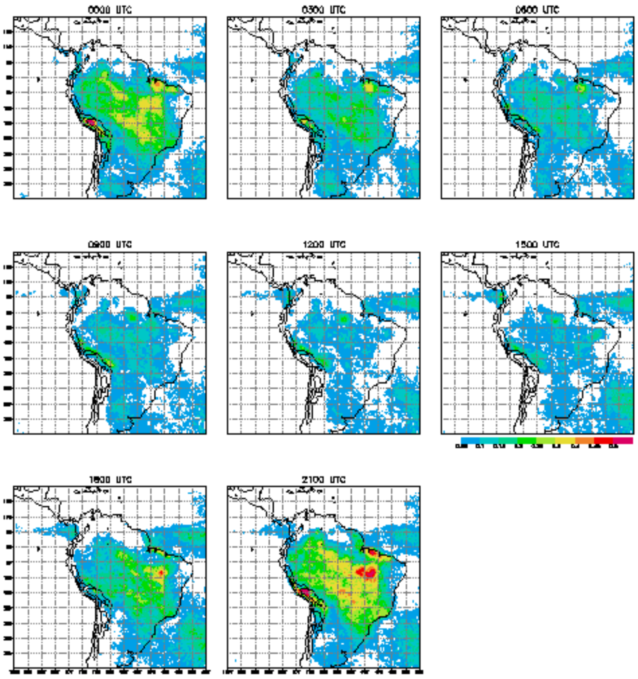


Fig. 9: *Climatological diurnal cycle of the convective cloudiness over South America during the austral summer (DJF). The time-frequency of clouds with top temperature less than 235K is shown every 3 hours.Based on GOES B3 data for the period 1983-1992. See details in Garreaud and Wallace (1997)*

Cold fronts moving across the Andes experience pronounced equatorward, leeside deflections, (Fig. 10). Kousky (1979) and Kousky and Ferreira (1981) first documented the deep tropical penetration of cold fronts into the Amazon basin, and their important role in modulating rainfall there. The poleward east Andean LLJ is replaced by strong low-level equatorward winds behind the front. The meridional flow reversals are much more frequent in subtropical latitudes east of the Andes than they are just west of the Andes, and manifest frequency and scale modulation by this mountain range.

There is evidence of enhanced late afternoon subsidence above stratus clouds of the eastern south Pacific. Rozendaal et al. (1995) find that diurnal variations in stratucumulus clouds fluctuate in ways that cannot be explained solely by radiative heating variations of the diurnal solar cycle. They suggest that the subsiding branch of continental convection that occurs selectively in the late afternoon and evening spreads westward and maximizes stratocumulus suppression after the time of strongest solar heating. This speculation is consistent with observation of late afternoon summer convection maxima over the Altiplano, and implies a relatively large domain of influence for orographically organized latent heat release. Rozendaal et al. (1995) speculate that the large domain of influence and rapid response are consequences of rapid gravity wave propagation associated with deep internal gravity modes (e.g. Silva-Dias et al., 1987). The resulting diurnal phasings of stratus clouds, surface solar and long-wave radiative fluxes, and sea surface heating are important climate elements in the surface heat balance.

Although the Altiplano is clearly relevant to South American weather, there are relatively few atmospheric measurements directly above it. Recent efforts to measure Altiplano circulations should continue in a more regular monitoring mode. It would be useful to enhance the network of raingauges around a site such as La Paz, Bolivia to determine cycles of convective weather in greater detail.

Fig. 10: From Garreaud (personal communication, 1999)

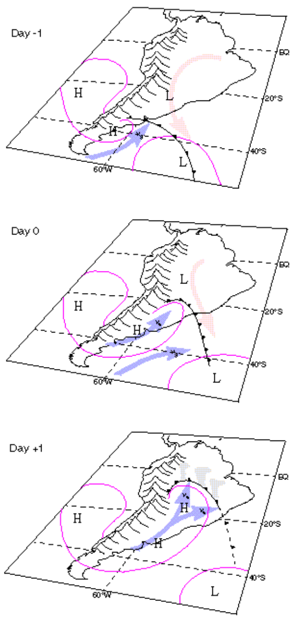


Figure A1 Conceptual model of a cold air incursion over South America. Dark (light) grey thick arrows indicate low-level winds advecting cold (warm) air. Thin magenta contours represent surface isobars, and L and H indicate surface low and high surface pressure centers, respectively. Cold front at surface is shown conventionally

3.4 Develop and validate theories on LLJ generation and variability

Diurnal cycles of convection are influenced by a number of effects including the obvious low level stabilization and destabilization that occur with surface radiational cooling at night and heating during the day. This explanation of the diurnal convection cycle does not apply to regions where convection most commonly occurs at night, such as the central plains of the United States. A number of investigators have suggested that here, the diurnal oscillations of LLJs and boundary layer convergence, induced by the sloping terrain, are responsible for modulating the low level moisture supply on diurnal cycles.

Critical latitudes, at or near the latitude where the forcing frequency equals the Coriolis parameter, produce an amplified response. In addition, theory also suggests a phase shift of approximately 10 hours from 40 to 20 degrees latitude for diurnally forced oscillations (Paegle and McLawhorn, 1983). Smith and Mahrt (1981) indicate that the critical latitude boundary layer response is somewhat variable around 30 degrees (the critical latitude for diurnally forced motion) because various effects shift the latitude of maximum response from 30 degrees. However the large phase change in the vicinity of 30 degrees should be observable. This is difficult to resolve with data sets over the United States, because data are available mainly poleward of 30 degrees and the distribution of mountains, plains and seas change abruptly at this latitude. On the other hand, South America has extensive mountain ranges and broad valleys from about 50 degrees South to the equator.

3.4.1 North America

Local dynamical foundations of North American LLJs are well understood. Theories emphasize day to night reduction of turbulent mixing (Blackadar, 1957), diurnally oscillating buoyancy forces above sloping terrain (Holton, 1967), or combinations of the two effects (Bonner and Paegle, 1970). The blocking influence of topography has also been discussed by Wexler (1961). The theories apply rather well in explanations of the diurnal cycle of summertime North American jets, which are commonly centered west of the Mississippi river, over a 1000 km region where the terrain slopes gently upwards from low elevations to approximately 1500 m at the foot of the Rockies.

Great Plains southerly LLJs are more prominent in summer than winter (Bonner, 1968), possibly due to stronger diurnal buoyancy and turbulence fluctuations in the summer season. Large-scale remote influences may also be relevant. Nogués-Paegle et al. (1998) demonstrate that the dynamical influence of the Rocky mountains induces orographically-bound cyclones above the plateau in spring and summer and topographically generated anticyclones during the winter. These seasonal reversals are produced in simple barotropic models in which subcritical to super-critical phase shifts arise in association with the seasonal cycle of ambient flow crossing the mountains (e.g. Charney and DeVore, 1979; Nogués-Paegle, 1979). Surface heating, soil moisture, and latent heat release all influence the quantitative response in more complete models (Paegle and McLawhorn, 1983; McCorcle, 1988; and Nicolini et al., 1993).

Although diurnal and seasonal oscillations of the Great Plains LLJ are contained in atmospheric models, related aspects are poorly simulated, and therefore marginally understood. Global models do not reproduce observed spring and summer nocturnal precipitation maxima (e.g. Ghan et al., 1996). This deficiency also characterizes reanalysis precipitation, in assimilated archives. Regional high resolution models and variable resolution global models may overcome the problems (e.g. Berbery and Collini, 1999 and Wang et al., 1999) and the utility of these approaches in climate simulations is being tested.

Time series analyses of atmospheric phenomena in the vicinity of the Rocky mountains show a cross-mountain frequency shift. Nogués-Paegle and Paegle (1976) find that the variance contained in long-period oscillations is about twice as great upwind of the mountains as it is downwind, whereas shorter period fluctuations exhibit the opposite distribution. They speculate that the mountains produce energy transformations from long to short periods, and suggest a simple deterministic explanation of this process. Since longer period fluctuations are characterized by relatively longer predictability (Lorenz, 1969), it follows that flows upwind of the Rockies may be relatively predictable. Higher frequency lee side fluctuations, such as the Great Plains LLJ, produced by the orographic frequency shift should then also be relatively predictable. This predictability enhancement remains to be studied.

Important elements of LLJ interaction with topography and precipitation still are marginally understood. The foremost issues are explanation of observed lee-side nocturnal precipitation maxima and potential predictability of semi-regular ambient circulations. South American diurnal rainfall cycles and related LLJ phenomena show intriguing contrasts to their North American counterparts. Comparative studies of LLJs, precipitation, and longer term variability with observations over South America may enhance understanding of North American LLJs.

3.4.2 South America

Several aspects of South American observations are consistent with idealized models. For example, Nicolini et al. (1987) and Nicolini and Paegle (1989) simulate convection and boundary layer convergence that display qualitative consistency with observations. More recent analyses of wind soundings by Berri and Inzunza (1993) and Inzunza and Berri (1991) and by Douglas et al. (1998, 1999) also reveal intriguing aspects that are not easily reconciled by theoretical analyses that have been successfully applied to North American cases. The principal discrepancies are a deep late afternoon, rather than a shallow early morning wind maximum at Santa Cruz, Bolivia (Douglas et al., 1998, 1999), and substantially enhanced nocturnal cloudiness and rainfall at this foothill site.

It is possible that those observations do not reflect climatology since they consist of only 90 observations taken over 70 days. However, a year-long data set for Salta, Argentina (Inzunza and Berri, 1991) displays qualitatively similar afternoon and morning wind variations. Preliminary analyses by Paegle (1998) propose that nocturnal latent heating above the east Andean slopes, associated with observed nocturnal precipitation maxima in this region explain the unusual afternoon wind maximum, but there is no obvious explanation of the nocturnally enhanced precipitation on this slope.

On longer time scales, semi-regular fluctuations of the east Andean jet correlate with semi-regular oscillations of the SACZ. These fluctuations have periods of a few weeks, and may also reflect semi-regular intraseasonal oscillations such as the Madden-Julian mode. Equatorward penetration of cold fronts over South America during summer (Fig. 10) is also strongly modulated by intraseasonal wave activity. Semi-regular fluctuations are not only evident in rainfall but also in upper-level circulation changes. Periods of enhanced SACZ are associated with a weak Bolivian high located west of its climatological position (Fig. 11).

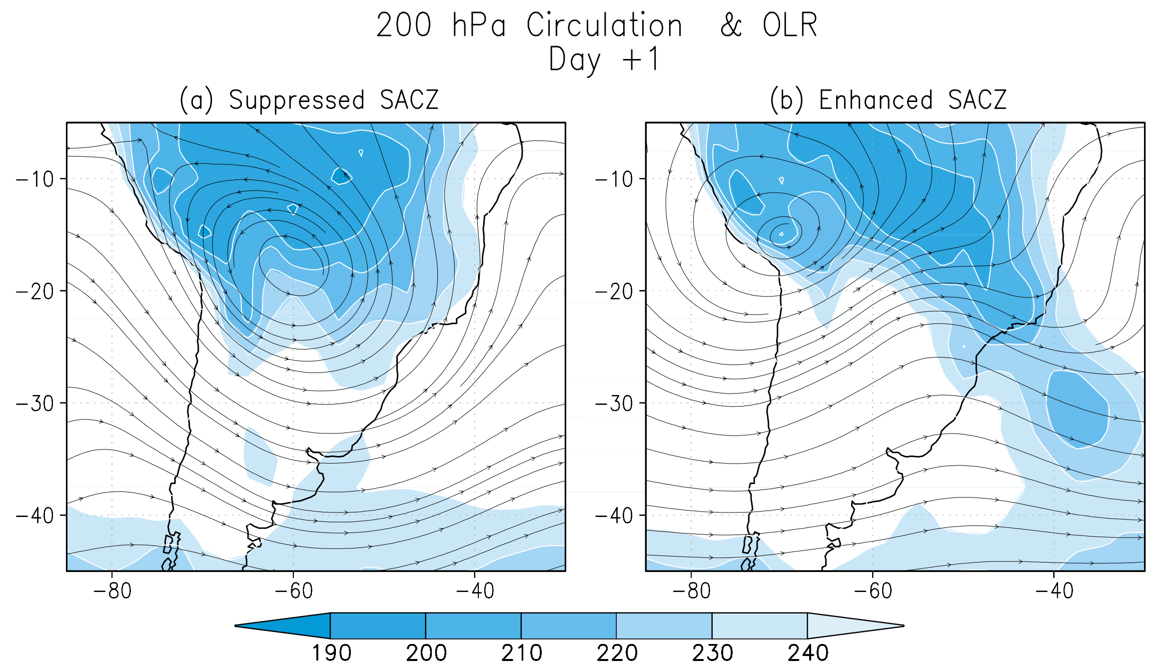


Fig. 11: *Phases of the Bolivian high during suppressed and active SACZ. From Vera (personal communication, 1999)*

Successive frontal systems penetrate into tropical latitudes and remain quasi-stationary over southeast Brazil, and tap moisture from the Amazon basin to the SACZ region (Vera, 1999). In the opposite phase, enhanced precipitation over the Altiplano and subtropical Argentina are associated with a strengthened Bolivian high located further east (Fig. 11). Unlike purely transient phenomena of shorter period, these longer term, semi-repeating oscillations ought to exhibit some predictability. Inability of operational models to predict and adequately sustain associated LLJ anomalies for more than a few days (Nogués-Paegle et al., 1998) is an outstanding deficiency of current forecast models.

3.4.3 Local and remote influences on ALLS in relation to droughts and floods

Land and ocean surface conditions have been linked with long lasting wet and dry episodes over the American continent. Changes of surface evaporation due to prior and concurrent soil moisture content have been implicated in 1988 North American droughts by Kunkel (1989), Atlas et al. (1993), and Fennessey et al. (1994). Bell and Janowiak (1995) and Trenberth and Guillemot (1996) emphasize high soil moisture and surface evaporation for the 1993 floods, while Paegle et al. (1996) suggest that dry soils and reduced evaporation observed upstream of the floods enhanced the buoyancy forcing of the upstream LLJ and increased resulting moisture transport towards the floods.

Remote Pacific influences have been implicated in LLJ connections to Central U.S. floods. Mo et al. (1995), Bell and Janowiak (1995), and Trenberth and Guillemot (1996) show that moisture flux from the Gulf of Mexico was injected by a strong southerly LLJ in summer 1993. These studies also mention westerly flow modifications over the North Pacific and the Rockies. Paegle et al. (1987) find that stronger heating in the eastern tropical Pacific promotes cyclonic circulations over the southern Rockies in spring through enhanced local meridional circulations.

Remote Atlantic influences may also have an impact on American droughts. Buchmann et al. (1990) point out that conditions favoring drought in portions of North America seem also to be associated with drought over central portions of South America. Both continents experience accentuated subsidence and drying with strong tropical Atlantic heating (Buchmann et al., 1995a, 1995b). The westward propagating influences are consistent with the study by Rodwell and Hoskins (1996) implicating Asian monsoonal heating to North African and Southwest Asian desert climates. Such explanations of dry conditions invoke westward propagating effects from remote latent heating. Dry and probably subsiding regions are also found west of positive tropical rainfall anomalies in observations (Ropelewski and Halpert, 1987).

Validation of these and other drought and flood theories is complicated by the difficulty in measuring the water cycle. Direct observations of evapotranspiration are not made, and accurate estimates of this quantity require high-frequency surface observations of turbulent moisture and vertical velocity. These measurements and soil moisture measurements are only available over restricted portions of the American continents. Vertical motion is in principle directly observable, but has such small magnitude on synoptic and climate time scales that it eludes direct detection by the current observing system. Surface evapotranspiration and vertical motion needed in development and evaluation of conceptual theories of drought and flood can be obtained over the entire regions of interest in gridded, assimilated data archives, as discussed in section 4.2 below. Such data is used in many diagnostic investigations.

Moisture transports from Amazonia and the Atlantic are channeled by the Andes and the Bolivian plateau to the west and the Brazilian Planalto to the east. This moisture transport also depends on large-scale circulation patterns, and it is modulated by the position and strength of the south Atlantic subtropical high. The Atlantic high is farthest from the continent and weakest in summer, partly due to the development of the SACZ which intrudes and frequently splits the high (Satyamurty et al., 1999). Li and LeTreut (1999) derive a moisture transport index for this region and show that intense episodes of southward moisture transport are tightly related not only to the summer precipitation see-saws described by Nogues-Paegle and Mo (1997), but are also weakly apparent in winter. This precipitation pattern involves out-of phase variations of the SACZ and precipitation to the south-west over northern Argentina, southern Brazil and Uruguay. Kiladis and Weickmann (1992), Berbery et al. (1992), Grimm and Silva-

Dias (1995) and others link convection variability in the South Pacific Convergence Zone (SPCZ) with the SACZ through southeastward propagating waves that curve toward the northeast over South America.

Pacific and Atlantic sea-surface temperatures modulate the LLJ on interannual time scales. Fig. 12 is a schematic of prevailing low-level currents over South America and locations that exhibit interannual variations. Ropelewski and Halpert (1988) show tendencies for above-normal precipitation over northeast South America and below-normal precipitation over southeast South America for high Southern Oscillation (SO) index years, consistent with the results of Aceituno (1988). The SO index years are defined as high (low) index when the Tahiti-Darwin index remains in the upper (lower) 25% of the distribution for more than five months. Zhou and Lau (1999) also find that rainfall tends to be above normal over southeast South America and the west coast of Ecuador and lower over northeast Brazil during ENSO years. Such relationships are illustrated in the schematic by the cross-hatched ellipses with the blue indicating wet and the brown indicating dry conditions. The SACZ (indicated by green), which is not modulated by ENSO variations, appears to be linked to Atlantic SST anomalies (Robertson et al., 2000) and also undergoes interannual and interdecadal variations (Robertson and Mechoso, 2000).

Barros et al. (1999) also find relationships between summer rainfall and nearby Atlantic SST, such that with warm SST anomalies close to the South American coast, there is a southward shift of the SACZ and enhanced precipitation over southeast South America. This dependence is also illustrated in the schematic of Fig. 12 with warm Atlantic SST anomalies indicated by the red hatched ellipse. It appears that there are two distinct meridional scales for interannual variations over South America, Atlantic SSTs involve SACZ modulations with a 20 degree latitude difference between the wet and dry centers, while the ENSO response spans about a 30 degree latitude difference over the South American coast. Both patterns overlap over southeastern South America and are characterized by enhanced low level northerlies with enhanced precipitation there.

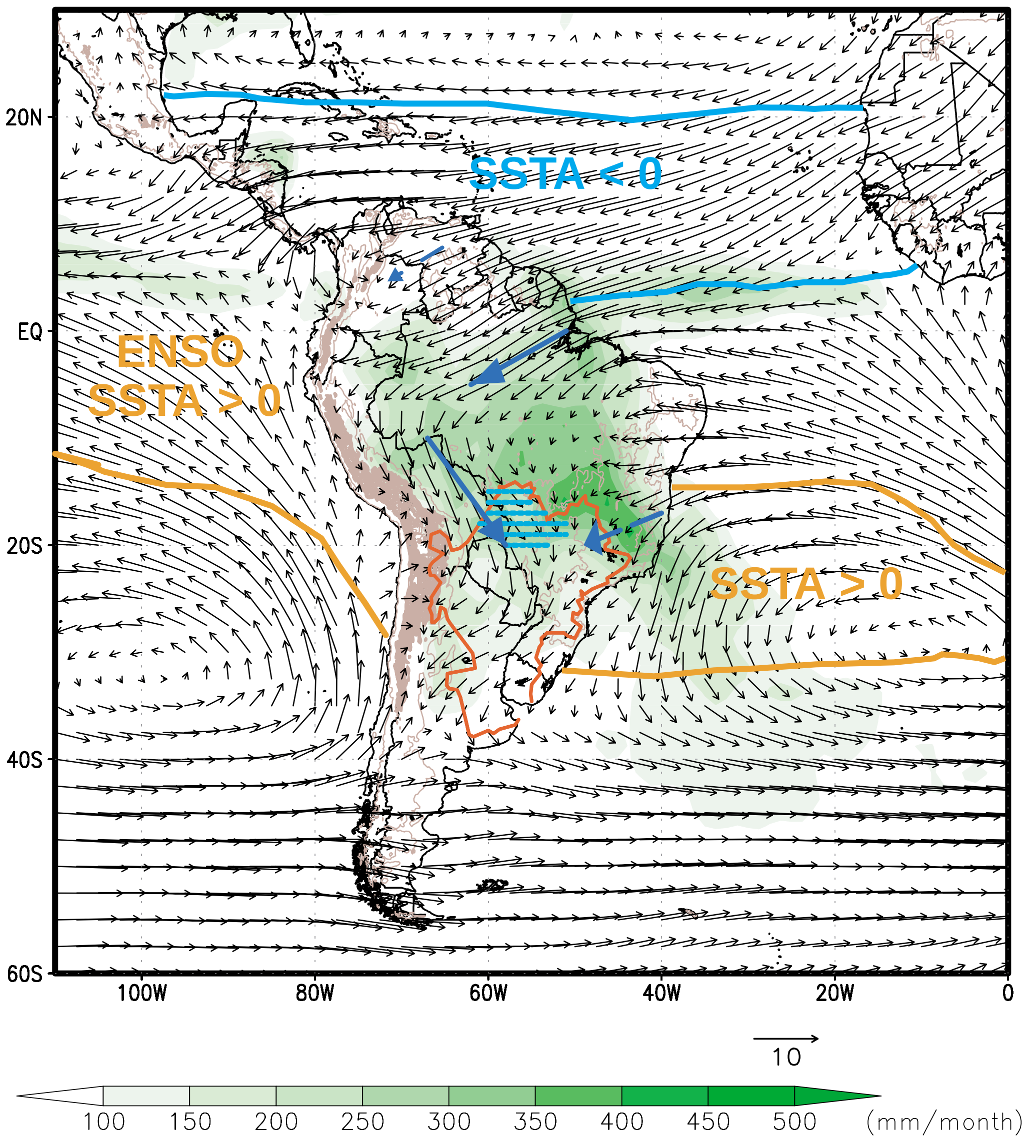


Fig. 12*: Schematic of ENSO rainfall signal and Atlantic SST IA modulation (warm SST's with enhanced rainfall over south-east South America.)*

4. Implementation Plan

This section summarizes what needs to be done to observe and understand low level atmospheric currents east of the Andes, their variability and their impact on regional summer precipitation patterns and surface hydrology. The implementation plan considers complementary activities on numerical modelling, diagnostic studies, monitoring activities and special field experiments. These are described below.

4.1 Numerical modelling

The influence of latent heat of condensation upon LLJ patterns (Nicolini et al., 1993 and Paegle, 1998) and present inability of global models for diurnal precipitation cycles is a central deficiency of global models. Higher resolution regional models produce better diurnal precipitation cycles over the La Plata river basin (Berbery and Collini, 2000), and show skill here that is similar to that obtained in operational prediction over North America. The Eta model used in that study is particularly well suited to regions of complex orography. Silva-Dias (2000) applies the RAMS model in a downscaling regional analysis mode for January 1998 to discuss the role of latent heating in the organization and intensity of low level currents bounded by the Andes. He finds that mesoscale convective activity along the slopes of the Andes has a significant effect in the timing of the maximum northerlies over Bolivia.

Nevertheless, recent results (Anderson and Arrit, 2001) suggest that simply increasing the spatial resolution of GCMs may not improve the prediction of wind in the lee of the Rocky mountains. Their evaluation of the NCEP/NCAR reanalysis with the NOAA wind profiler network reveals the inability of GCMs to realistically sustain the ageostrophic wind speed. Additionally, cumulus parameterizations in GCMs are unable to represent organized mesoscale precipitation systems.

Nested high resolution models provide an attractive alternative to global models that resolve the entire globe with high resolution. Long term simulations with high resolution global models are not now executed on a regular basis, and may be cumbersome even on powerful computers.For an example see Seth's simulations posted at http://iri.ldeo.columbia.edu/~seth/llj.html. In addition to nested limited area models, it is also possible to use variable grid models that allow adequate resolution of local precipitation events and retain globally interacting influences. Wang et al. (1999) demonstrate that the latter approach mimics the Great Plains nocturnal precipitation maximum. They also demonstrate the importance of two-way interaction between the highly resolved regional domain and the remainder of the global atmosphere to obtain reasonable precipitation simulations. Figure 13 displays sample results from a long-term simulation using a locally nested limited area model employing the eta coordinate. Figure 14 illustrates one possible grid-generation mechanism in a global, variable resolution approach and Fig. 15 displays resulting vertical wind structure. A stretched coordinate model developed at GSFC/NASA has also been applied over South America (see Ferreira et al., 2000, http://janus.gsfc.nasa.gov/~ferreira/ferreira_lba_web.html). The relative utility of locally nested and variable resolution global approaches to predictability and climate simulations remains to be determined.

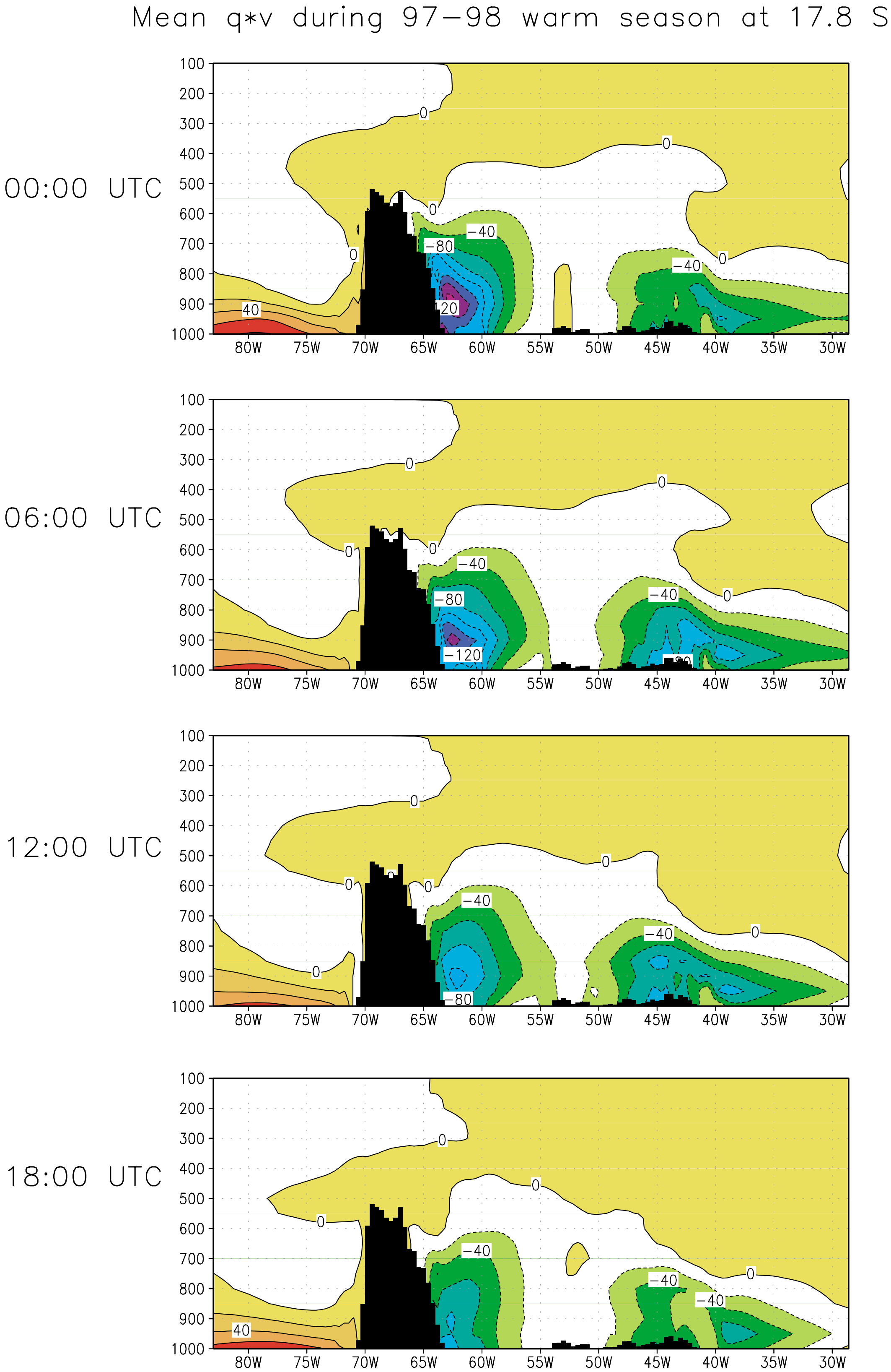


Fig. 13: *From Saulo (personal communication, 1999) Vertically integrated meridional moisture transport from 40 km eta model runs over South-America done at CPTEC, averaged for the warm season from September 1997 to February 1998. Units are (g*m)/(kg*s). This figure shows two northerly currents, one located just east of the Andes mountains and the other in the vicinity of the Brasilian Planalto.*

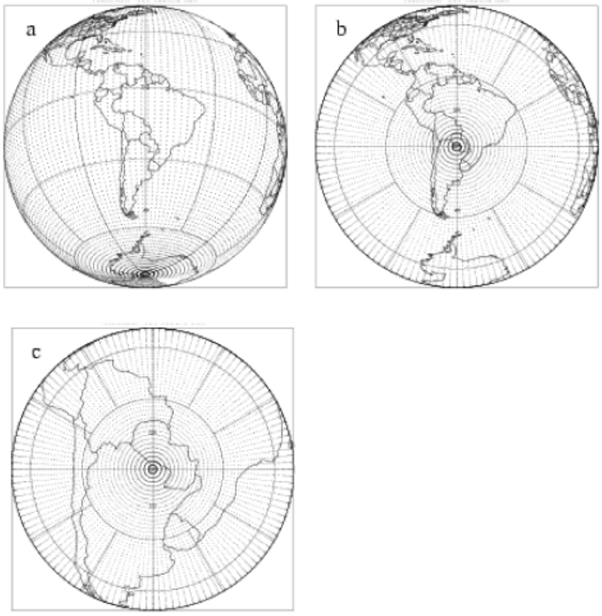


Fig. 14: *a) Uniform model grid based upon the usual spherical coordinate. b) as in (a), but the mathematical pole is rotated to a point near the Argentine-Paraguay border. c) as in b, but the resolution in latitude is enhanced to 1/2 deg from the visible pole to the perimeter of the viewing area, and left unchanged over the remainder of the globe. See Paegle (1989) for model details.*

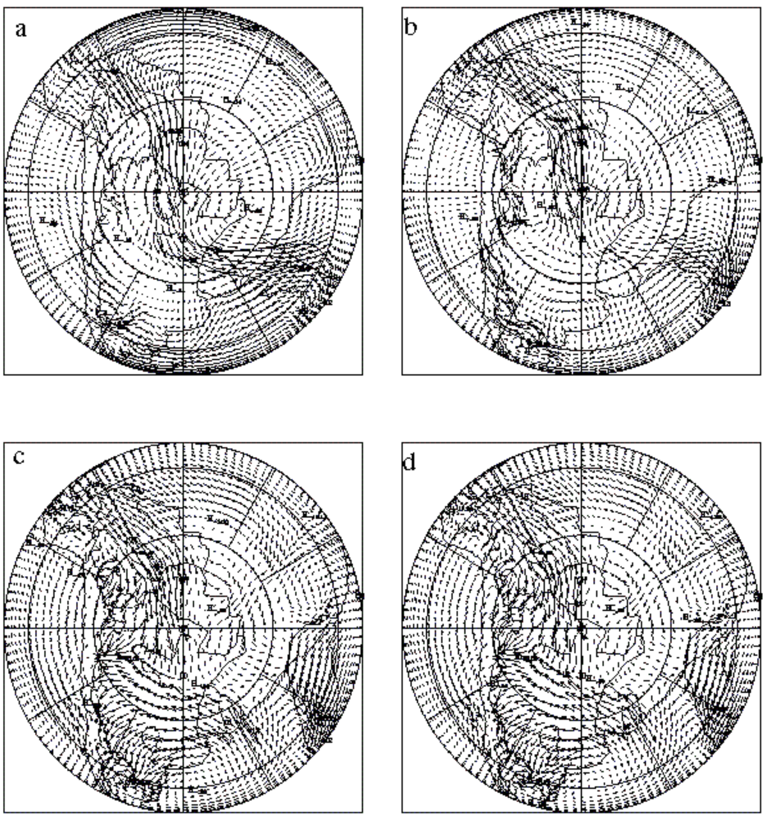


Fig. 15: *Horizontal wind vectors at day 6 in a simulation started from average November conditions at a) 2500 m, b) 1500 m, c) 400 m, d) 160 m. Peak vectors are 30 m/s. Deep maximum occurs near Santa Cruz, Bolivia, and strong vertical shears at other sites.*

4.2 Diagnostic Studies

Observing systems that may enhance LLJ understanding include asynchronous components such as ACARS and wind profilers. Such systems do not record at standard observing times and locations. The ACARS wind data are observations of opportunity tied to operational aircraft schedules and routes. Wind profilers can report at standard observing times, but may be contaminated by targets such as migratory birds. All data require extensive quality control through comparisons with nearby observations and earlier or first guess estimates. Asynchronous observations are interpolated in space and time to a regular grid at standard observing times through the process of data assimilations. When many observations are available, the fields represent high quality interpolations. When few observations are available the results represent extrapolations in time from prior analyses. These extrapolations are provided from the first guess and are heavily influenced by the forecast model used for the assimilation process.

The quality of analysis consequently depends upon the quality of the model used in the assimilation cycle. One method to evaluate their utility is to intercompare separate analyses of the same phenomenon. When two independent analyses produced by separate equally credible assimilation systems produce similar results, the analyses might be reliable. Analyses are not trustworthy when equally credible assimilation systems produce different results.

Independent modern analyses of North American Great Plains LLJs provide monthly averaged depictions that differ by approximately 1 m/s at the standard observing time of 00UTC, (Wang and Paegle, 1996). Monthly averaged analyses differ by up to 4 m/s at 06 UTC in this region, at a time of few regular observations. These LLJ discrepancies produce monthly averaged nocturnal moisture flux uncertainties on the order of 40% over the Great Plains. The situation is even worse over South America, where diurnal cycles may dominate monthly moisture budgets over large river basins, and few observations are available at any time of day.

Discrepant analyses are mainly produced by differences of model predictions of the first guess. The LLJ evolution can be portrayed as the superposition of a free oscillation of inertial period, and forced oscillations, dominated by diurnal and longer periods. The free oscillation is predictable from good observation of the ageostrophic wind at earlier times. Simulations of forced components are limited by errors of model buoyancy and stratification. Accurate simulation of these processes depends upon parameterization of turbulent, radiative, and latent heating in the atmosphere and at the surface. The parameterizations are highly model dependent, and LLJ discrepancies between different modern analyses imply fundamental model problems. No operational global models has documented skill for the nocturnal convection maximum observed downwind of the LLJ maximum, and all such models therefore lack correct diurnal phasing of latent and cloud radiative heating.

Modern assimilated data consequently have marginal utility for proposed ALLS goals. A two tiered approach is required to overcome analysis shortcomings. First, the impacts of emerging observing systems such as wind profilers and ACARS and special monitoring efforts of PACS-SONET need to be determined. One method for doing this is continued intercomparison of separate equally credible analyses of the LLJ. The analyses should converge if observations are adequately assimilated. Intercomparison efforts should be explicitly endorsed because they appear routine and sometimes suffer in peer review from apparent lack of science content. The second fundamental deficiency is a lack of field programs to resolve the horizontal variability of the east Andean jet. Field programs have examined the horizontal structure of the Great Plains jet, and provide an impression of observational sampling requirements. The horizontal variability of east Andean jets has not been measured.

As new observations enter assimilated analyses, a number of ALLS objectives can be studied. Many of these objectives have been motivated in prior sections. The particular proposed steps are outlined below.

i) Study LLJ links with surface conditions, including orography, vegetation cover, and soil moisture. The motivation is to explore extended predictability of LLJ and related processes through the enhanced memory of surface processes. The links have been found in model simulations, but lack unequivocal demonstration in observed or analyzed data.

ii) Determine the evolution of the LLJ during wet and dry episodes around selected river basins (Mississippi, La Plata) and examine local and remote atmospheric and oceanic influences associated with this evolution. Local and remote drivings of anomalous LLJ and rainfall patterns have been proposed for 1988 and 1993 events over North America and on intra-seasonal periods over South America. The important nocturnal phase of the LLJ is not well-resolved for North America, and is inadequate in earlier analyses over South America.

iii) Explore the role of the LLJ as driver and modulator of deep convection and for the onset of the rainy season in the vicinity of the basins. The LLJ has been viewed as the driving mechanism of rains in the vicinity of the Mississippi and La Plata basins. Recent evidence suggests that latent heat modulates LLJ response in important ways, but validation of this effect requires adequate LLJ depictions. Global models do not simulate observed nocturnal correlation of LLJ and convective peaks, while locally higher resolution models are more successful in this regard. The reasons for these differences require clarification.

iv) Validate accuracy of reanalyses for LLJ events and explore the possibility to incorporate new understanding in analysis of prior data sets. New observing systems allow calibration of modern reanalyses, and should be more extensively used in validation studies. The South American field campaign proposed below will provide especially useful data in the extensive data void regions of South America. These observing systems and special data allow study of deficient aspects of past assimilation systems. The gained understanding can be incorporated in analyses of prior data sets and official reanalyses could be regionally "post-processed" for periods of special interest such as 1993 and 1988 using advanced regional models driven in the free troposphere with official reanalyses and incorporating improved parameterizations for improved LLJ depiction. If successful, the resulting, post-processed reanalyses could be used to address objectives (i)-(iii) in earlier years.

4.3 Field Component of ALLS

Extensive voids within the operational observing system have prompted a number of field programs around South America. Chemical and water cycles were studied over Amazonia in field campaigns such as LBA (Nobre, 1999) and predecessor projects (Marengo et al., 1998), including ABLE. Aceituno and Montecinos (1997) describe a field experiment over the Chilean Altiplano designed to study moisture cycles in this location. Collaborations between Bolivian, Argentine, and U.S. scientists (Douglas et al., 1998, 1999) have demonstrated a pronounced LLJ around the Bolivian foothills of the Andes.

None of these projects define horizontal structure of the east Andean jet, although indirect estimates of its structure are provided by satellite sensing techniques. Satellite information includes cloud-track estimates of wind and diurnal cycles of cloud cover, and radiances assimilated by operational analysis systems. Those analyses have deficiencies outlined above, and require calibration, as discussed previously.

Better documentation of horizontal LLJ structure is critical. The Rockies and Andes are superficially similar. Both mountain ranges extend from the tropics to high latitudes, and both are significantly higher than the LLJ depth. The Great Plains jet has been shown by special field projects to extend over the gently sloping terrain that rises gradually from the Mississippi to 1500 m at the base of the Rockies. The Andes, by contrast, rise abruptly from foothills that start only slightly above sea-level to elevations exceeding 5000 m. There is no evidence of a deep, strong afternoon jet in the immediate foothills of the Rockies; and here climatology shows an afternoon precipitation maximum. Deep LLJs and nocturnal precipitation maxima have recently been documented around the Bolivian foothills, but their relevance to conditions further east is unknown. These deficiencies of current and past field programs of the South American LLJ motivate the field experiment outlined below. This field experiment consists of a Phase I buildup program and a phase II special observing period, as described below.

Phase I. Build-Up phase

- Compile and analyze special South American soundings of 1998, 1999 and compare with operational analyses and model simulations. Bolivian and U. S. scientists have collaborated on pibal soundings at Santa Cruz, Bolivia. A portion of this research is documented by Douglas et al. (1998, 1999), but the soundings have continued beyond the point summarized in that research, and a more extensive series of observations is contained in the vertical profiles shown in Fig. 16. These soundings constitute valuable data to evaluate the accuracy of detailed circulations obtained in downscaling experiments with high-resolution numerical models.

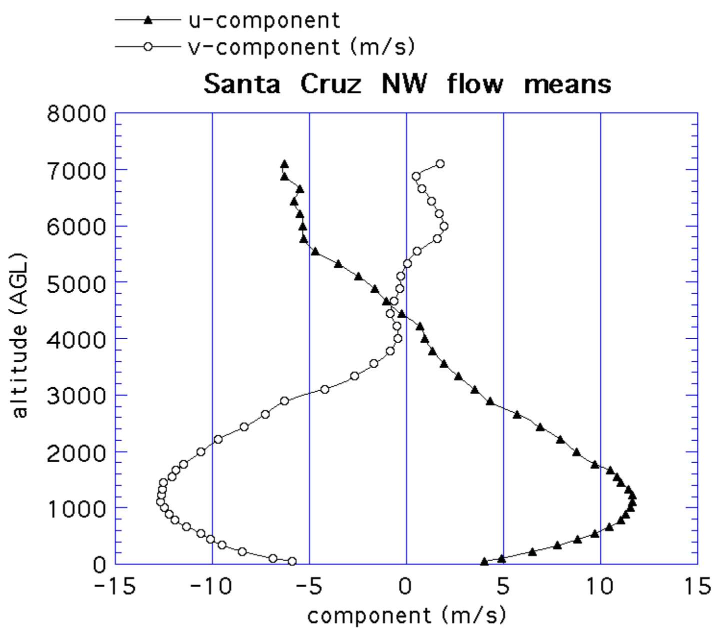


Fig. 16: *Composite observations for northwesterly flow cases from theodolite observations at Santa Cruz, Bolivia. (M. Douglas, 1999, personal communication)*

- Much data have been collected in the recent LBA field campaign, and their analysis could reveal useful aspects of flow fields upwind of the east Andean jet. Prior data sets (Marengo et al., 1998) can also be used for this purpose.

- Establish long-term monitoring (sounding) network in the region and continue through all field phases discussed below. This has already commenced with the PACS-SONET network, and received continued financial endorsement from NOAA's Office of Global Programs. The monitoring program is essential to quantify intra-seasonal, seasonal, and inter-annual variability of South American LLJs, and to thereby validate, calibrate, and tune assimilation systems.

- Assist in the strengthening of meteorological infrastructure in participating countries. Major benefits of improved observations should occur in the vicinity of the enhanced observing system. The successful maintenance of these systems requires trained personnel and specific data acquisition and communication systems incorporated within local weather monitoring activities.

- Improve rainfall measurements in the region. The most impactive manifestation of the LLJ is its apparent modulation of precipitation. The only evidence of a similar connection in South America is through indirect satellite rainfall estimates. A network of recording raingauges should be established in the Bolivian altiplano, the Chaco region and downwind of the east Andean LLJ maximum, centered over northern Argentina.

Phase II: Field Experiment Special Observing Periods

The interannual variability of the low-level jet might require two field campaigns depending on the ENSO phase for the currently plan campaign of 2002-2003. We focus here on one such campaign, with the understanding that if needed, the field experiment may be repeated within two years of the first experiment. Two Special Observing Periods (SOPs) are currently planned to operate for a month each within a period of 3-4 summer months 2002-2003 (and if needed 2003-2204 or 2004-2005).

The SOP timing is influenced by schedules of Chilean scientists to study Pacific stratus and Brazilian scientists to study Amazonian circulation, and may coordinate with GEWEX plans for the CEOP project.

4.3.1. Region of focus for the ALLS South American Field Program

The study region should be sufficiently large to encompass the major portion of the low-level jet east of the Andes Mountains, as depicted on monthly mean analyses at 850mb (the level near which the wind speeds associated with the jet reach their maximum values.) On a daily basis the jet axis may vary considerably in strength and position, and may not be present at all during post cold frontal conditions over eastern Bolivia and Paraguay. However, limited observations made during special field campaigns during 1998 and 1999 indicate that the position of the strongest winds associated with the jet lie close to the positions indicated from monthly mean maps generated from large scale analyses. Thus, as a first approximation, monthly mean wind analyses from the NCEP reanalyses can be used to help define the domain of the field observing program.

As a reference for the remainder of the text, Figure 17 shows most of the countries and stations mentioned in the text.

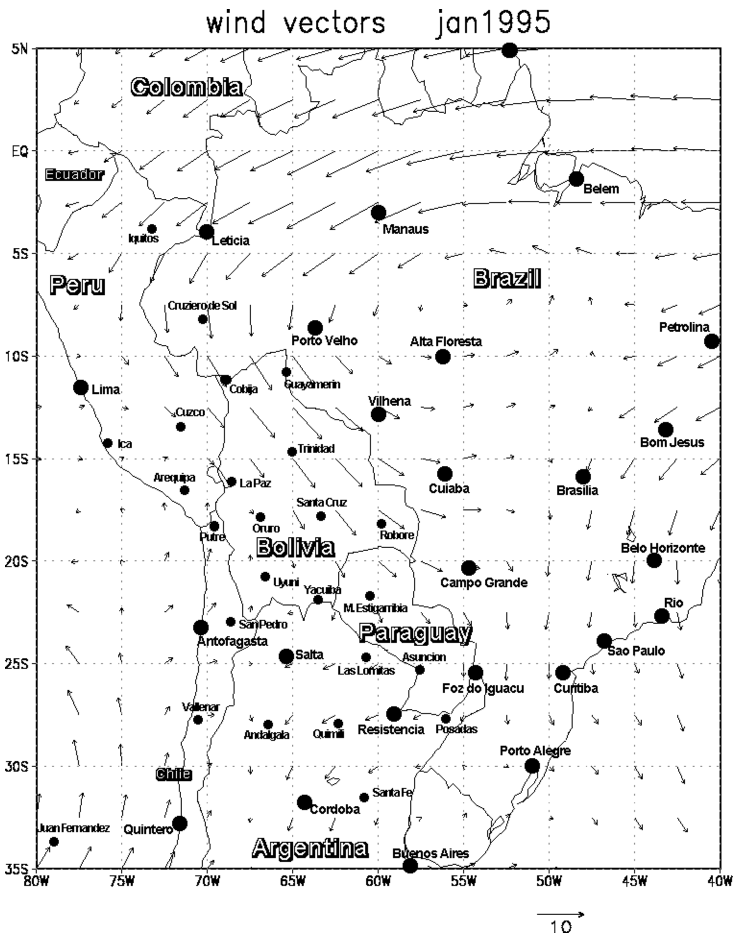


Fig. 17: Countries and stations mentioned in the text. Large dots are current radiosonde sites, smaller dots are proposed/possible sites for ALLS.

Monthly mean NCEP 850 mb wind analyses show that the region of strongest winds lies over eastern Bolivia during the months of December to March. Synoptic variability of the flow could result in the jet core of northwesterly winds being found over a broader region, from far western Brazil to Paraguay or even far northern Argentina or Southeastern Brazil. Since in general terms the jet core is found in the region of maximum pressure gradient, and since the pressure gradient is determined by the distribution of pressure patterns over a larger region, it is necessary to measure the atmospheric characteristics over a substantially larger region than that covered by the jet core alone. Although in principal it would be desirable to describe the atmospheric conditions over all of South America, this is not practical, and the ALLS network configuration discussed in this document is a compromise between the need to describe the LLJ and its variations and the limited observational resources expected to be available for the ALLS field campaign.

The overall philosophy of the field program to augment the pre-existing routine observing systems over the region of interest with special observations that will acceptably describe the features of interest. For example, the current radiosonde stations over the region only make one sounding per day.

In the following sections each of the proposed observing systems are discussed.

4.3.2. Radiosonde network

Radiosonde observations are necessary for describing the vertical structure of the humidity, temperature and wind fields in the atmosphere. Although other systems can provide wind profiles, and temperature fields can be deduced indirectly via various means, radiosondes provide the most accurate estimates of the vertical structure of the humidity field.

The proposed radiosonde network for ALLS involves several different aspects. The most straightforward operation is the supplementing of selected current radiosonde station launch schedules to twice-daily. This will involve some labor charges and arrangements for the second radiosonde launch daily. The existing stations at Manaus, Leticia, Porto Velho, Vilhena, Cuiaba, Campo Grande, Foz de Iguazu, Resistencia, Salta and Cordoba would be operated twice-daily for the duration of the SOP. The cost of this supplement would be about $200/observation, or about $60K per month for the ten stations.

If properly timed, the SOP's will benefit from observational enhancements planned for LBA follow-up (Brazil) and stratus (Chile) campaigns. The stations involved are:

Brazil: Rio Branco, Vilhena, Cuiaba, P. Suarez, Campo Grande, São Paulo, Porto Velho. There are plans to enhance rawinsonde observations to 4 daily at these sites for the summer field-LBA follow-up phase during 2003.

Chile: enhanced observations on two islands (San Felix, about 25°S, 85°W; Juan Fernandes, about 500 km west of Santiago). San Felix would be instrumented specially for a field program emphasizing stratus studies. Juan Fernandes will soon become operational after 30 years of in-activity (2 rawinsondes daily) under partial support from Japan for expendables. Additionally a coastal site (perhaps Antogagasta or nearby) and a Chilean altiplano site are being discussed for enhancement in the summer stratus study.

In addition to supplementing soundings at current stations, it will be necessary to establish temporary radiosonde stations in Bolivia and Paraguay, where no such stations currently exist. Figure 18 shows the proposed network; the new sites include Cobija, Trinidad, Santa Cruz, Uyuni and Mariscal Estigarribia. Four of these stations lie along the jet axis, one is on the alti-plano, and it may be desirable to operate another at La Paz, Bolivia. Most of the radiosonde stations will utilize GPS navigation to obtain winds, as these are more practical for temporary sites. Pilot balloon observations have already been made at each of these sites during the past several years. The figure also includes two stations over Uruguay.

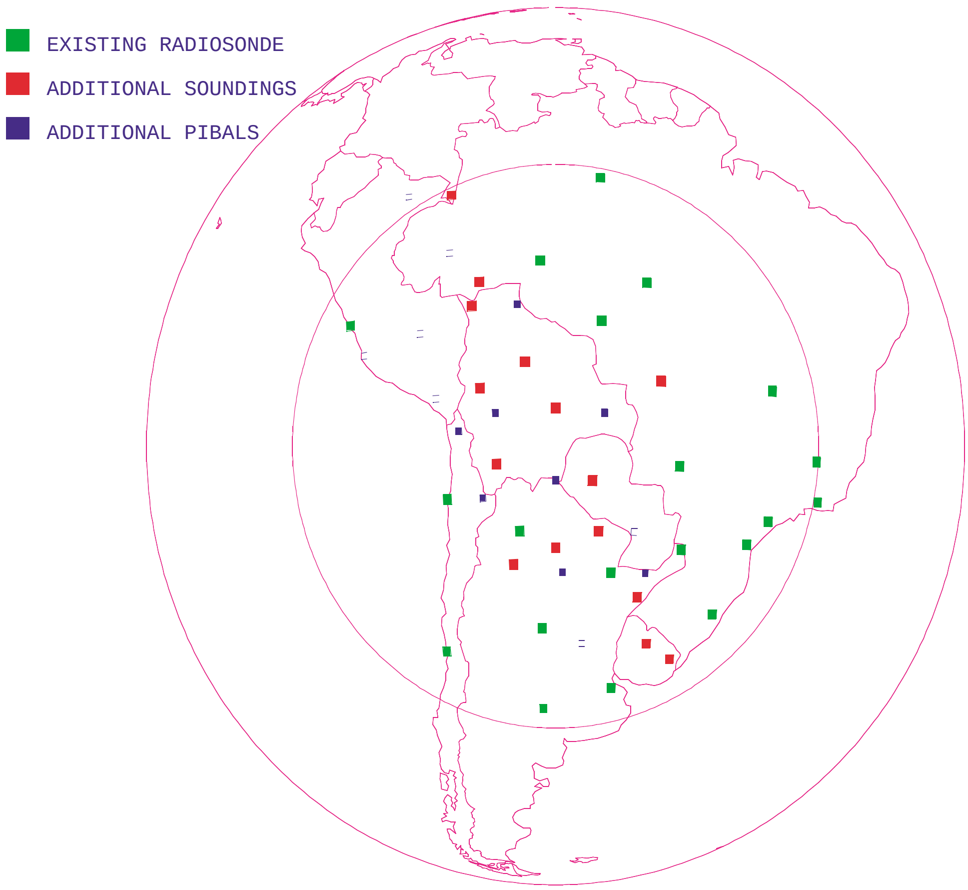


Fig. 18: *Locations of the current and enhanced radiosonde and pibal balloon observations in the ALLS domain (circumscribed by a circle) of South America.*

4.3.3. Pilot balloon observations

Although radiosonde observations will form the backbone of the ALLS sounding network, there are needs for more spatially dense observations and at times, very frequent wind profiles that can more economically (~10% cost of radiosondes) be provided by pilot balloon observations. At a number of sites around the LLJ core and over and west of the Andes, where skies are more cloud-free, pilot balloon sites will be established. Although these will provide twice-daily soundings during the entire SOP, during the IOPs much more frequent (8-12 times daily) soundings should be possible. These observations can be useful for better estimates of diurnal variations, or describing rapidly changing features (such as rapidly propagating cold fronts) or for averaging to provide better estimates of the daily mean flow. Pilot balloon theodolites may be co-located with radiosonde ground stations at some priority sites, so that a mix of radiosonde and pilot balloon observations can be routinely made.

4.3.4. Wind profiler observations

One of the objectives of ALLS is to describe the diurnal variation of the LLJ. This can be accomplished with the greatest temporal resolution if wind profilers are used. Precipitation, low clouds, and nighttime conditions prevent or complicate pilot balloon observations, and hourly radiosonde observations are prohibitively expensive to obtain for the extended periods needed to calculate stable mean wind profiles. For logistical and cost considerations at least two 915 MHz profilers will be requested for at least a two month period. With the prevailing deep, moist, and turbulent boundary layer conditions over eastern Bolivia during NW flow events, 915 MHz profilers should be capable of obtaining wind data to 3-4 km altitude on a routine basis, and possibly higher.

The main limitations on widespread use of 915 MHz profilers is their availability and monthly cost. It would be highly desirable to operate an array of profilers over the flat terrain of eastern Bolivia or western Paraguay. Two possible modes of deployment are shown in Fig. 19. One strategy would be to place three profiler in a SW-NE oriented line extending NE from Santa Cruz to west of Cuiaba. Such observations would provide a cross section normal to the jet axis, and be useful for describing across-jet evolution of the jet.

A second placement strategy for profilers would be to extend them along the core of maximum winds - probably close to a line formed by the stations Cobija, Trinidad, Santa Cruz, and Mariscal Estigarribia. Such an orientation would be useful for identifying the propagation of along-jet transients, or of cold frontal surges. The diurnal variation along the jet axis would also be detailed by such an orientation.

If three profilers were available, an alternative profiler arrangement to the two above would be a triangular array, perhaps formed by Santa Cruz, Mariscal Estigarribia, and a site SW of Cuiaba. This would provide direct measurements of the diurnal cycle of divergence, vertical motion (kinematically calculated), and vorticity over the triangle.

As a final note, the configuration of the profiler, pilot balloon and special radiosonde sites should be arranged to optimize the overall network effectiveness. It should be recognized that current radiosonde sites are the least flexible in terms of positioning, followed by wind profilers (once they are established) and finally special radiosonde and pilot balloon sites.

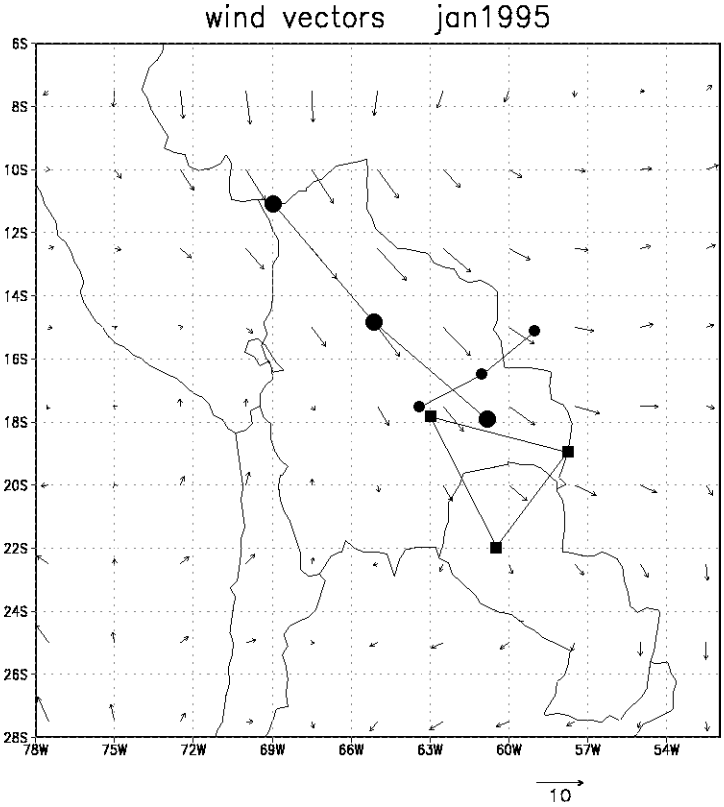


Fig. 19: Possible deployment strategies of 3 wind profilers. The large dots show an along-jet orientation, while the small dots are designed to describe cross-jet variations. The squares indicate a triangular array that would describe temporal variations in divergence and vorticity.

4.3.5. NOAA P-3 missions:

Scientific Objectives

- Measure horizontal gradients associated with LLJ near the Andes (from a few km from foothills to about 400 km) with better resolution than can be provided by radiosonde network. This is needed for comparison with model simulations of the flow.
- Measure vertical structure of the flow between a few hundred m and 4000 m altitude while simultaneously measuring the horizontal structure.
- Measure the along-jet flow in the vicinity of eastern Bolivia, and specifically between Cobija and central Paraguay, to describe the effect of the topography on the flow variations.

Flight strategy

The P-3 is the only observing platform that will be able to provide high spatial resolution views of the LLJ over large regions. However, the basic aircraft characteristics:

- flight duration ~ 8 - 9 hours
- flight speed ~ 240-280 knots (~ 4 - 4.5\232 latitude/hr)
- maximum altitude ~ 500 mb initially, 350 mb later in flight
- place certain restrictions on the types of missions possible. The scientific objectives place additional restrictions; the object of advanced planning is to optimize flight strategies to maximize useful data collection. This section summarizes some of the possible flight missions and their scientific objectives.

A decision on principal base of operations for the aircraft has not been made, and will require an examination of facilities available for the aircraft operations, as well as ground support, including access to meteorological forecasts. Santa Cruz appears to be a leading contender, as it is located at the core of the jet. In addition, for some flight missions, it may be desirable to have a recover airport different from the main base of operations. Crossing political boundaries has the potential of complicating flight planning, and considerable effort will have to be put into arranging, well in advance, this aspect of aircraft operations.

One aspect of the majority of the flight patterns is that they should be fixed relative to the topography and geographical boundaries. This is because the LLJ, although variable in intensity, is generally fixed with respect to the position of the Andes. Thus, flight patterns can be constructed that can be pre-planned in considerable detail, and the same patterns can be used for successive flights to make detection of small differences between one LLJ event and another easier.

The tentative start date for the aircraft operations is January 10th, 2003 (after the new years holidays that extend until January 6th in much of the region). The flight operations should continue until February 15th, or until the allotted aircraft hours are used.

Possible missions:

(i) Horizontal and vertical structure of the LLJ

This is probably the main justification for the P-3 activities. The aircraft would be flown transverse to the LLJ, either in constant-level flight near the level of maximum winds, or more likely, in a series of ascents and descents (Fig. 20b) to determine 1) the level of maximum winds and how it varies across the jet 2) the across-jet variations in wind speed and stability from the mountain slopes to ~500 km from the mountains. The flights could be either along the same track, so that a more reliable mean section could be generated, or along several different tracks normal to the flow (Fig. 20a).

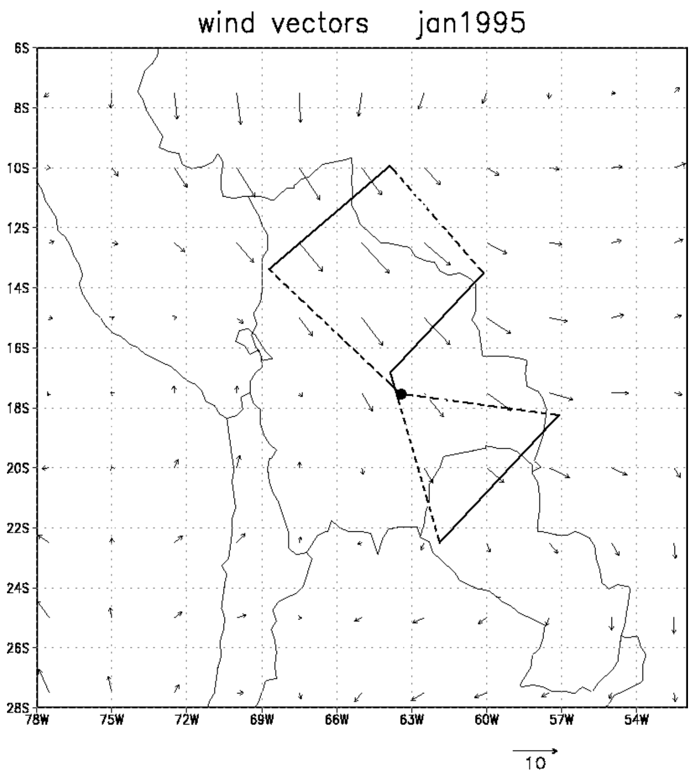


Fig. 20a: Flight track to sample cross-jet structure along 3 sections (solid segments). Ferry legs are shown as dashed. Santa Cruz is solid dot.

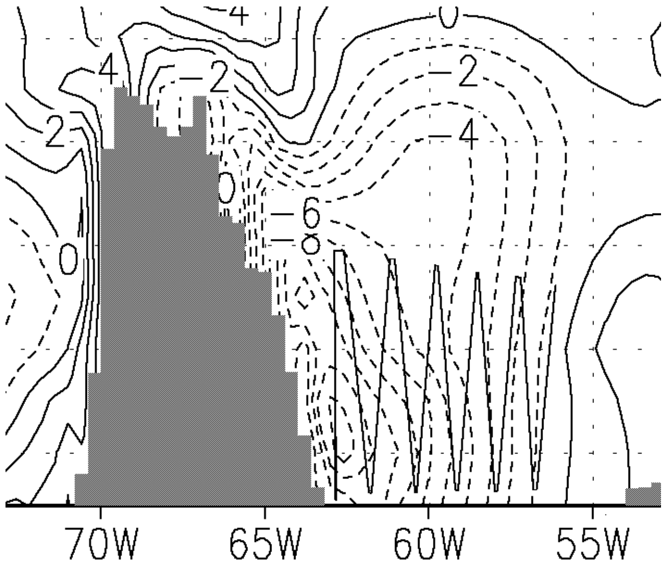
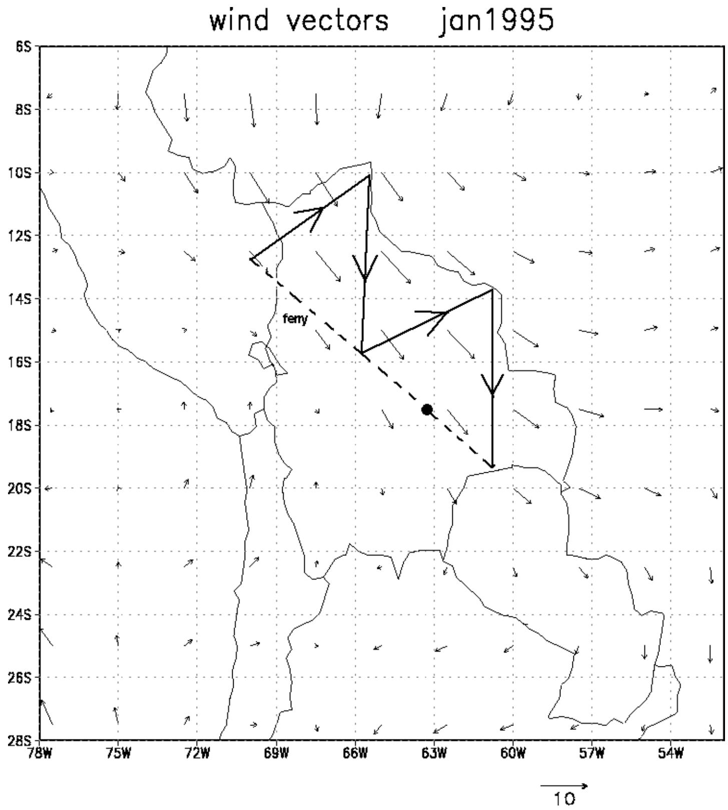


__Fig. 20b:__ Schematic showing how P-3 might profile vertically (diagonal solid lines east of Andes) while crossing jet axis over Bolivian lowlands (solid legs in Fig. 6a). Dashed lines are isotachs of mesoscale simulation.

(ii) Along-jet core variations of LLJ



This flight pattern (Fig. 21) would measure along-jet variations in windfield structure and stability. The actual length of the pattern would be limited by the aircraft's endurance. The flight should probably be flown in the sense indicated in Fig. 7 so as to cover slightly more area, as the flight is with the wind (larger groundspeed). Ferry flights to the beginning and end of the pattern should be at normal ferry flight levels (better airspeed and less headwinds).

__Fig. 21:__ Flight track to describe both along-jet and cross-jet variations. Dashed lines are ferry flights to start of pattern and to return to base at end of flight. P-3 would vertically profile (as in Fig. 20b) along the solid track segments.

(iii) Heat low structure over western Paraguay, Southern Bolivia and northern Argentina.

The northwesterly flow undergoes a sharp change in curvature as it passes Santa Cruz, Bolivia. This change may be a result of the change in the orientation of the mountains from NW-SE to more N-S. Just south of this point appears to be the location of the cyclonic circulation that is associated with the feature known as the heat low over the Chaco. The proposed flight plan (Fig. 22) would describe, during a typical Northwesterly flow regime, the horizontal structure of the heat low, from the lowest flight level possible to about 700mb. Such flights might be extended southward depending on local synoptic conditions. Southward displacements of the LLJ into Argentina have been documented with a deepening of the thermal low centered over La Rioja and Catamarca on the north-western sector of Argentina.

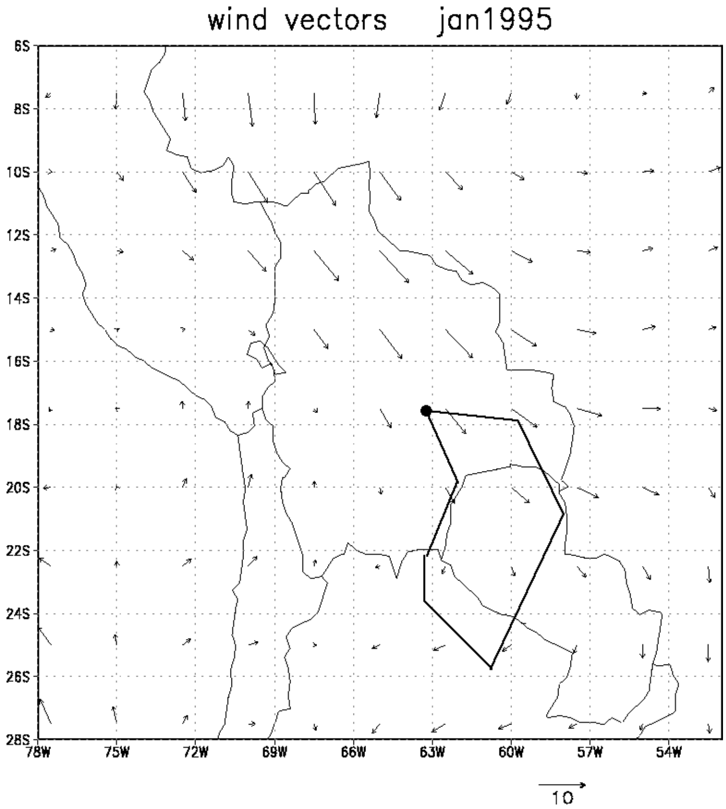


Fig. 22: Flight pattern to describe the heat low over the Chaco and its vertical structure. Entire flight track would involve vertical profiling from near surface to ~700 mb level.

(iv) Airflow and convection over the Andean altiplano

The airflow and the nature of moist convection over the high altiplano of Bolivia has not been well described from observations. The -Band and X-Band radars on the P3 could be used to document key aspects on the high-based (near 500mb) convective systems that form over the Altiplano during the summer season. While scattered surface observations and high resolution satellite imagery suggests that convective rainstorms tend to encompass the whole plateau, their spatial structure is closely related to the local complex topography (eastern and western cordilleras + isolated peaks in between). The array of thermodynamic measurements available from the P3 could document mesoscale variability of the boundary layer over the Altiplano with a basin-wide coverage. Of particular importance is the variability on low-level moisture, that appears as the key element in the occurrence of deep convection. Mesoscale variability is expected because of the marked west-east and north-south gradients in moisture. The P3 could carry out flights (e.g. Fig. 23) during both rainy and dry episodes over the altiplano. The size of the altiplano is such that the P3 could sample the whole domain in each mission.

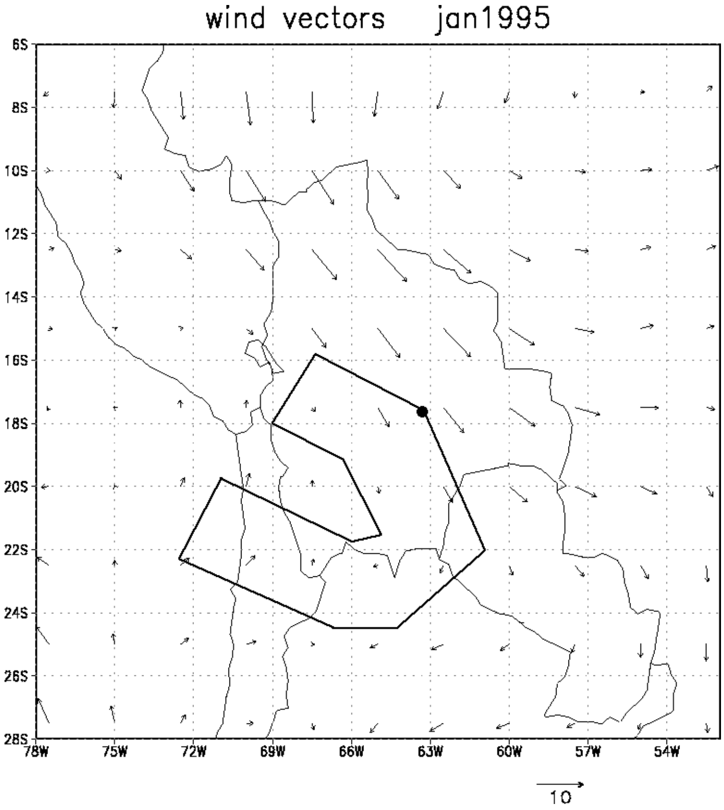


Fig. 23: *Possible flight track to describe over-altiplano conditions, as well as neighboring conditions over pacific littoral and over western Chaco and east Andean foothills. P-3 would be vertically profiling in places and using drop wind sondes in other locations.*

(v) Structure of cold frontal zones over eastern Bolivia

A flight of "opportunity" might be the investigation of the vertical and horizontal structure of a northward propagating cold front east of the Andes. Several such events are almost certain to occur during the Aircraft operation period. The objective of such a flight would be to describe the variation in frontal intensity normal to the mountain axis, with the aim of providing data suitable for comparison with high resolution mesoscale simulations of such fronts. Numerical simulations indicate that the temperature, wind and humidity gradients are concentrated in a narrow (mesoscale) band. NOAA P3 observations also will be helpful in documenting the structure of the rainstorms that typically develops ahead of the cold air.

4.3.6. Raingauge networks

One of the strengths of meteorological field programs over land areas, as contrasted with over-ocean programs, is the capability to measure rainfall directly from raingauges.

Rainfall observations over the experiment domain are necessary for:

a) determination of wet and dry periods during the experiment, so that the relationship between the LLJ and rainfall can be identified in different geographical regions.

b) providing ground truth estimates for comparison with a hierarchy of numerical simulations of rainfall over the region. Simulated rainfall is a sensitive indicator of the accuracy of the numerical forecast, and it is essential that the confidence in observational estimates of rainfall be greater than confidence in simulated values.

c) determining the accuracy of satellite rainfall estimation schemes over the region, especially when averaged over longer time scales (days to months).

The climatological rainfall network over the Chaco, east Andean foothills, and the Altiplano of Bolivia, Chile and Argentina is not particularly dense. It is proposed to augment the routine synoptic station and climatological station network in this region with additional raingauges.

Two type of raingauges may be considered. Digital recording gauges have the capability of describing the diurnal cycle of rainfall and also of unattended operation. They have the disadvantage of high cost (~$1K per site) and more complicated operation. Inexpensive (~$10) raingauges are available for widespread deployment, but these have the disadvantage of requiring daily reading by observers. Deployment of either system requires considerable time-in-field and advanced preparation, in order to be available by the start of the SOP.

Tentatively, it would be desirable to establish an expanded network of simple raingauges over parts of the relatively flat Chaco in eastern Bolivia, western Paraguay and northern Argentina. This area is undersampled by the climatological raingauge networks in each country.

Another region where additional raingauges are needed is the high altiplano of Bolivia, Chile and Argentina. Reliable rainfall estimates are desired to ensure than model simulated precipitation is validated reliably. Satellite imagery shows frequent afternoon convective cloud development over parts of the altiplano, but the rainfall from these clouds is difficult to determine independently.

Finally, the large east-west (or more precisely transverse Andes) gradients in rainfall across the Andes should be measured in high spatial resolution along several transects from the eastern lowlands across to the western slopes of the Andes, for comparison with high resolution simulations of the Andean circulations. A summary of the possible raingauge networks is shown in Fig. (24). Current plan also includes an Argentine contribution of additional raingauges over central Argentina sponsored through the GLOBE program.

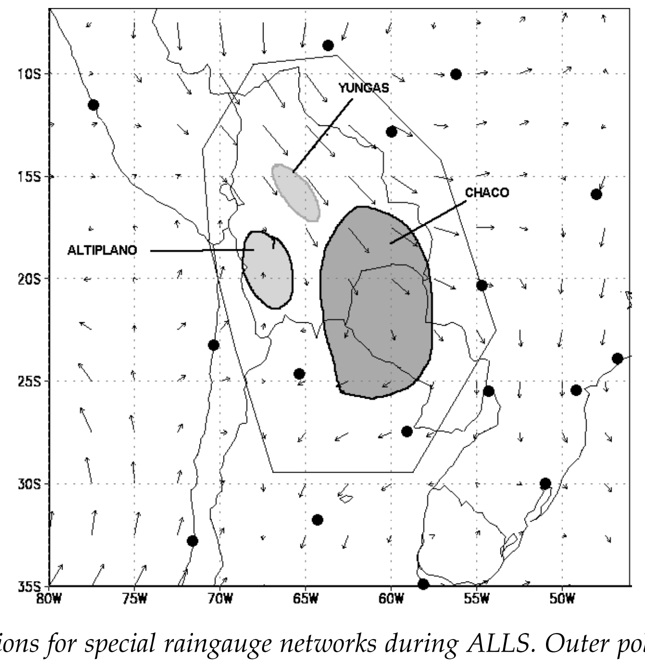


Fig. 24: *Possible locations for special raingauge networks during ALLS. Outer polygon indicates general area of greatest need for additional gauges. Yungas is region of large gradient in rainfall*

Although the cost of the raingauges is low (~$8 each); success in establishing a network depends on advanced planning and volunteer observers, usually consisting of public health clinics, rural schools, farmers, and military outposts. The deployment is usually time-consuming, and it is necessary to establish links with different organizations that can facilitate the distribution of raingauges to isolated locations. Materials for recording the data is also important. It is anticipated that the installation of raingauges would begin 3-6 months prior to the beginning of the SOP. A tentative estimate of the number of raingauges that might be installed is: Bolivia (400 gauges), Paraguay (200 gauges), Argentina (200 gauges).

Calibration of the existing surface station network

There is a reasonably widespread network of manned surface stations in the lowlands of eastern Bolivia and in Paraguay. However, there is a need to calibrate the surface pressure station data from these stations to assure that the most accurate data possible is obtained during ALLS. Validation of the pressure measurements with an accurate reference barometer is recommended. Few automatic surface stations exists in Bolivia and Paraguay. It remains to be determined if there is a need for the higher temporal resolution data that these systems can provide.

4.3.7. Timeline for the field activities

				SOP 1		**SOP 2**					
	AUG	SEPT	OCT	NOV/15	DEC/15	JAN/15	FEB/15	MAR	APRIL	MAY	JUNE
RAIN GAUGES	SETUP	SETUP	SETUP	XXXXX	XXX	XXX	XXX	XXX	XXXXX	XXX	XXXX
PIBALS		SETUP	SETUP	FULL OBS	FULL OBS	FULL OBS	FULL OBS	LIMITED OBS	LIMITED OBS		
RAOBS				FULL	FULL OBS	FULL OBS	FULL OBS	TAKEDWN			
P-3							FULL OBS				
915 PROFILER				FULL OBS	FULL OBS	FULL OBS	FULL OBS	TAKEDWN			

- July 2002: start deployment of raingauge network
- September 2002: finish deployment of raingauge network
- October 2002: begin installation of pilot balloon network
- November 2002: begin installation of radiosonde network
- November 15 /December 15: 2002 SOP 1
- January 15/February 15 2003: SOP2

International Partners.

Although P-3 operation is guided by NOAA P.I.s, collaborating scientists from Bolivia, Paraguay, Argentina, Brazil and other countries in South America would be welcome to participate in flights and to work with data collected.

General field activities, daily decisions, deployments:

The general procedures for use of the P-3 aircraft are well-documented, and these requirements will be followed during the Bolivian operation. Since radiosonde observations will be available in near real time from a number of sites in Bolivia and Paraguay, and wind profilers will additionally be situated near Santa Cruz, there should be little difficulty in determining the presence or absence of a LLJ. Forecasts of conditions out to 24 hours will be available, further aiding flight planning and selection of IOP's. It may prove valuable to consider possible joint activities with the stratus component of EPIC. A deployment to a coastal site such as Arica, Chile might be practical.

5. Programmatic context

Several national field experiments have taken place over South America in the last decade and have met with great success. Among these efforts, Brazilian scientists recently completed an LBA project (Nobre, 1999); Chilean meteorologists took special observations in a field program over the Andean Altiplano (Aceituno and Montecinos, 1997); South American scientists collaborating with U.S. investigators commenced theodolite observations near the Bolivian foothills (Douglas et al., 1998, 1999); and Argentine meteorologists enhanced their participation with international research organizations including IAI and IRI.

5.1 Linkages to existing programs

The aforementioned groups are interested in broadening the international scope of local projects in the joint venture outlined in this document. The proposed joint activities are endorsed by the CLIVAR SSG through the Variability of American Monsoon Systems (VAMOS), and in the national arena by the Office of Global Programs (OGP) of NOAA/USA. The first meeting of the VAMOS South American Monsoon Working Group held at Miami (October 22-24, 1998) was sponsored by PACS/OGP/NOAA. This working group was charged with developing cooperative, international research to investigate the South American Monsoon system. It identified enhanced monitoring and field experiments of the LLJ east of the Andes as main priorities. Such priorities were presented to the VAMOS panel meeting of March 1999, where the intersecting interests of South American and U. S. scientists, OGP, and CLIVAR were emphasized.This panel endorsed expanded international monitoring dedicated to quantification of American Low Level Jets and descriptions of their role in moisture balances and climate variability of the western hemisphere. The endorsement suggested that much can be learned in comparative studies of North and South American jets, and promoted enhanced monitoring, analyses, and simulations of related phenomena over both continents.

The proposed LLJ field experiment over South America will benefit from the following ongoing regional research programs: LBA and PROSUR (Program on Climate Variability over the Mercosur Area). PROSUR is an IAI funded 5-year program with participation from Argentina, Brazil, Uruguay, Paraguay and the USA.

ALLS science objectives are closely aligned with those of PACS (Pan American Climate Studies)/OGP/NOAA/USA through this program interest on understanding the mechanisms associated with warm seasonal rainfall and its potential predictability, and the occurrence of significant weather events over the course of a season.

Although initiated and hitherto fostered by VAMOS, ALLS will in fact provide an important linkage between CLIVAR and GEWEX. Much past research into the North American LLJ has been undertaken under the GEWEX Continental-scale International Project (GCIP) and much will now continue under the new GEWEX Americas Prediction Project (GAPP). Similarly, in the case of the South American LLJ, the proposed field studies are coincident with the GEWEX

Coordinated Enhanced Observing Period (CEOP). Further, ALLS is a component of La Plata Study, which is the first large-scale, international project to be jointly sponsored and developed by GEWEX and CLIVAR acting together.

ALLS will also contribute towards answering two of the scientific questions that motivate the US Global Water Cycle Initiative, namely (Question 1), "What are the underlying causes of variations in the water cycle on both global and regional time scales, and to what extent is this variation induced by human activity?", and (Question 2), "To what extent are variations in the global and regional water cycles predictable?" ALLS will support explicitly stated goals in US Global Water Cycle Initiative that address these questions. Specifically, in the case of the first question, the goal "to quantify the variability in the water cycle", and, in the case of the second question, the goal "to demonstrate the degree of predictability of variations in the water cycle."

5.2 Project infrastructure

The South-American LLJ field project is nationally organized by "country-coordinators". These are listed below

a) Argentina: Prof. M. Nicolini (University of Buenos Aires) and a representative from the Argentine National Meteorological Service

b) Brazil: Dr. J. Marengo (CPTEC) and Prof. Maria A. Silva Dias (University of São Paulo)

c) Chile: Prof. R. Garreaud (University of Chile)

d) USA: Dr. M. Douglas (NSSL/NOAA)

All country coordinators constitute a Science Team, which also includes the active participation of other scientists such as Prof. R. Mechoso (UCLA) as CLIVAR/VAMOS representative and Prof. J. Paegle (University of Utah) as science advisor.

The science team has formally met during VPM2 and VPM3 to discuss and coordinate plans. Informal discussions are often conducted through e-mail and individual visits.

There are some promising developments in the operational observing networks of the region. Current plans include installation of a radiosonde station in Mcal. Estigarribia (central Chaco region of Paraguay) and a weather radar may be installed in Asuncion. The Amazon Surveillance program (Brazil) has an ambitious program of aquisition and deployment of meteorological observing platforms with the goal of monitoring the Amazon region (http://www.sivam.gov.br). An Emergency Federal System (SIFEM, Sistema Federal de Emergencias) has been recently created in Argentina. The system includes plans for an ambitious deployment of weather radars in central and northern Argentina. Chile is also developing plans to improve atmospheric and oceanographic monitoring of the South Pacific off the Chilean coast. All of these developments are indicative of a growing momentum in the meteorological and oceanographic communities of South-America to improve observational networks in the region. The timing for a field experiment in the South American LLJ in the 2003-2005 time scale appears to be right for the synergism of national efforts in this subject.

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