Conducting short duration field programs to evaluate sounding site representativeness and potential climate monitoring biases. Examining the low-level jet over the Venezuelan llanos during the 2005 dry season.

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ABSTRACT

It is often difficult to obtain good agreement between upper air observations in the tropics, made by radiosonde or pilot balloons, and output from a data assimilation system, such as the NCEP reanalysis. Sometimes the only available observations are affected by local topographic conditions which large-scale analyses do not resolve. Another factor that limits comparisons is the difficulty in determining a "true" 24-h mean wind at a location for comparison of the mean values produced by a data assimilation system. Such a comparison requires observations throughout the diurnal cycle – which are very rarely carried out – even for short periods. In Latin American most radiosonde sites make only one observation daily. As part of the PACS-SONET effort to monitor winds over Latin America with inexpensive once-daily pilot balloon observations, we have been evaluating the uncertainty in assessing daily mean winds from these once-daily observations. Observations from some sites have shown interesting features, such as localized low-level jets, but such features cannot be easily compared with monthly mean analyses produced by global data assimilation systems.

One way to estimate the bias of a particular sounding time in generating a mean daily wind is by simply making more observations per day. While this is not feasible for long periods, pilot balloon observations, because of their low individual cost, can be made frequently for short periods. With these high frequency measurements the bias in inferring mean winds from one observation per day can be estimated. To identify the diurnal variability of a low-level jet observed in morning sounding data from a Venezuelan site, twice-daily observations were requested to be made during one month (February 2005). This was followed by a short program of much more frequent soundings in March 2005 to better resolve the diurnal cycle of the winds. The details of this activity, carried out in February and March 2003, are described in this paper.

In addition to resolving better the diurnal wind variability as a function of height, the Venezuelan activity involved special observations being made at seven sites, allowing us to estimate the horizontal scale of the jet. The steadiness of the dry season jet allows us to extend our conclusions to much of the dry season; the validity of our conclusions would have to be verified at other times of the year, especially the wet season.

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Because the results presented here are very preliminary, a focus is on the details involved in actually carrying out such a validation effort. These details will show that such an activity is feasible in almost any part of the tropics, even with very limited resources.

1. General concept of validating reanalysis products

The use of global or regional reanalysis products has become nearly universal since the availability of the first widely available reanalyses in the mid 1990's. Reanalyses provide a standardized product for climate research activities, since the available historical observations area assimilated as part of a numerical model data assimilation procedure. Because climate researchers want the longest period of data to be assimilated, and since computational resources are finite and expensive, the assimilating models have somewhat lesser resolution (2.5 degree lat/long) than state of the art operational models used for short-range weather forecasts. Thus, there has been concern that the global reanalyses products might have significant limitations for regional climate studies.

Recently, a higher resolution regional reanalysis product has become available, the North American Regional Reanalysis (NARR), which extending back to 1979. This only covers North America, though it extends to northern South America. These analyses area available at 3-hourly resolution, and are available on a 32km grid, having been a product of a 32km ETA model assimilation system. Thus, the spatial resolution is approximately 8 times that of the original global NCEP reanalysis.

As the trend will be to continue to generate successive reanalyses, each using a better assimilating model (higher horizontal and vertical resolution, more complete physics etc), some effort at independent evaluation seems warranted. Though this may increasingly take place in the centers responsible for the reanalysis generation, independent evaluation has been shown to be useful. With increasing spatial resolution of the available analyses the point is being reached where even over land areas there is insufficient validation of important features appearing in the analyses. And since the geographical coverage of in-situ observations varies widely over the globe, the level of confidence we can have in the reanalysis products is naturally of some concern.

To validate any reanalysis product would seem to be difficult, since the historical data set cannot be changed. However, certain features of the mean fields produced by the reanalysis data assimilation system can be validated, using special observations. For example, suppose that a feature of every monthly mean 850mb wind analysis over the Caribbean Sea for the period 1979-2003 shows that the maximum wind speeds occur in a particular geographical region. If the feature is very regular, and appears at the same location every year (during the same month) we might suspect it is a feature commonly seen on most days. Thus, one could organize an observational effort that, by measuring routinely around the region of interest for a month, the feature's validity could be conclusively determined. By removing the special observations from the data assimilation data base (or assuring that they did not enter the assimilation data base) one could compare the analysis produced without the special observations with an analysis produced with the special observations. Such a study would both improve the confidence in the assimilation products for climate diagnostic studies and help design observing systems that might make observations in the locations crucial for the most useful analyses.

Sometimes it in not feasible to make measurements for a long enough time to reliably identify systematic problems with a feature shown for example, in monthly mean values. In this event, it is possible to measure for a shorter period, perhaps one week. If the mean conditions during this week are similar to the monthly mean conditions it may be possible to infer that the measurement campaign has measured conditions similar to the climatology of the region. This would not necessarily be true if the mean is dominated by the average of large eddies that approximately cancel (extratropics) but might be approximately valid in the tropics where daily conditions are often similar to the climatology. Other sources of information, such as satellite imagery, can also be used to assess whether the measurement campaign has sampled a period similar to the climatological conditions.

This paper discusses one procedure for validating important features that might appear in the reanalysis products now existing or in the future. This is simply to make more observations in a selective manner; observations that are focused on measuring parameters that can be easily verified. We have applied this procedure in more than one locality in recent years, but this paper focuses on the most recent, and perhaps most substantial such effort. This was carried out during part of March and April 2005, with a focus on a persistent feature over the llanos of Venezuela. This paper details the procedures, and some results of the study.

2. Antecedents

In 2001 a pilot balloon observation site was established at San Fernando de Apure in the heart of the Venezuelan llanos (Fig. 1a), the very flat region along the drainage of the Orinoco River, south of the Cordillera de la Costa. The purpose of establishing this site, part of the PACS-SONET[2] project, was to make daily wind soundings to monitor the trade wind flow and its variability over the interior of northern South America (Fig. 1b). No other wind soundings were being made at the time in this region on a routine basis. After the San Fernando installation was completed, other sites at Cd. Bolivar and Maracay were also established (see Fig. 2 for sites mentioned in text).

[2] Additional information on this project can be found at the web site: http://www.nssl.noaa.gov/projects/pacs and the LLANOJET activity is at the link: http://www.nssl.noaa.gov/projects/pacs/web/VENEZUELA2005/

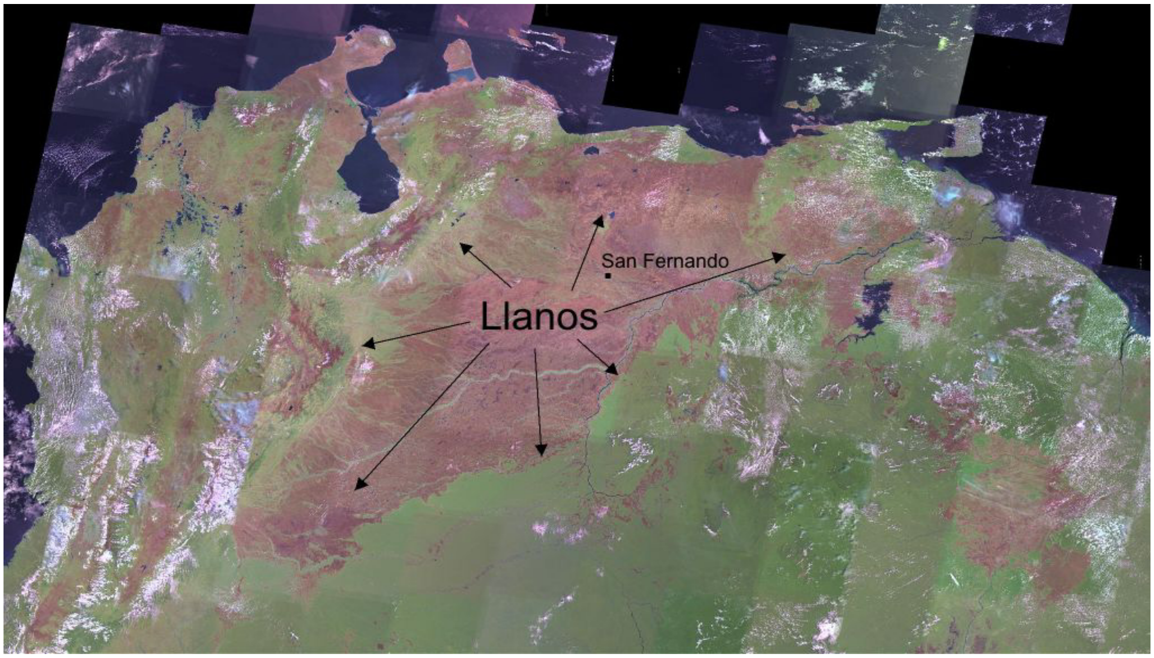


Fig. 1a The geographical region in northern South America know as the llanos encompasses the flat region of Venezuela and Colombia that lies along the tributaries of the Orinoco River and is a savanna-type vegetation (brownish in this dry-season LANDSAT composite image), except along rivers where forest is found.

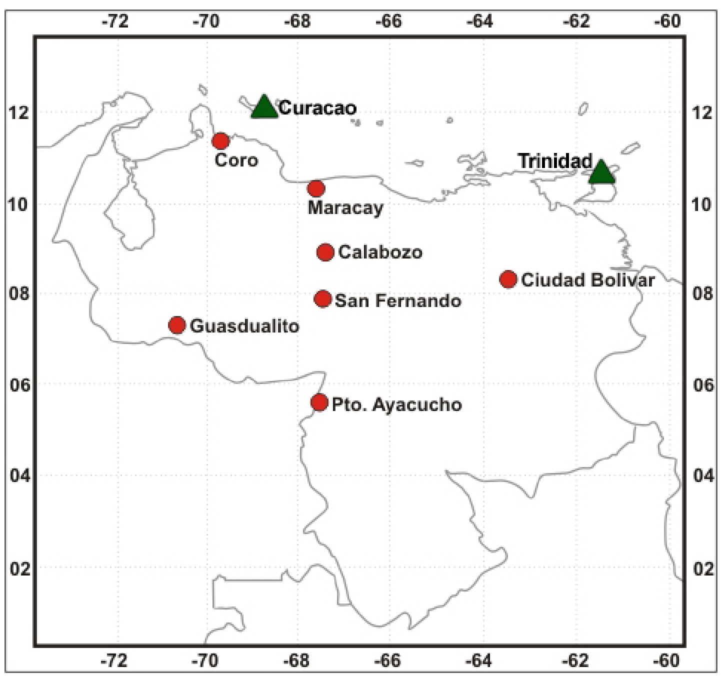


Fig. 2. Sites mentioned in text. Red dots are pilot balloons sites for LLANOJET , green triangles are radiosonde sites operating at this time (once daily). Ciudad Bolivar, Maracay and San Fernando were operating several years before LLANOJET, the others were established especially for LLANOJET. For geographical scale the area of Venezuela is very close to the area of Texas and Oklahoma combined.

The most striking aspect of the pilot balloon wind observations made at San Fernando during the past four years (data set is not continuous during this period due to gas supply problems at times) has been the nearly constant presence of a low-level jet in the morning soundings during the dry season (November – April) (Fig. 3). Since the observations were made at San Fernando only during the morning, it was suspected that afternoon observations might reveal different profiles, as with low level jets observed elsewhere. Thus, during February 2005 afternoon observations were requested and started at San Fernando, to identify the extent of the diurnal variation. Comparison of the morning and afternoon observations made during this time showed significant diurnal changes (Fig. 4). This was the initial motivation for a more extensive set of measurements planned for the following month.

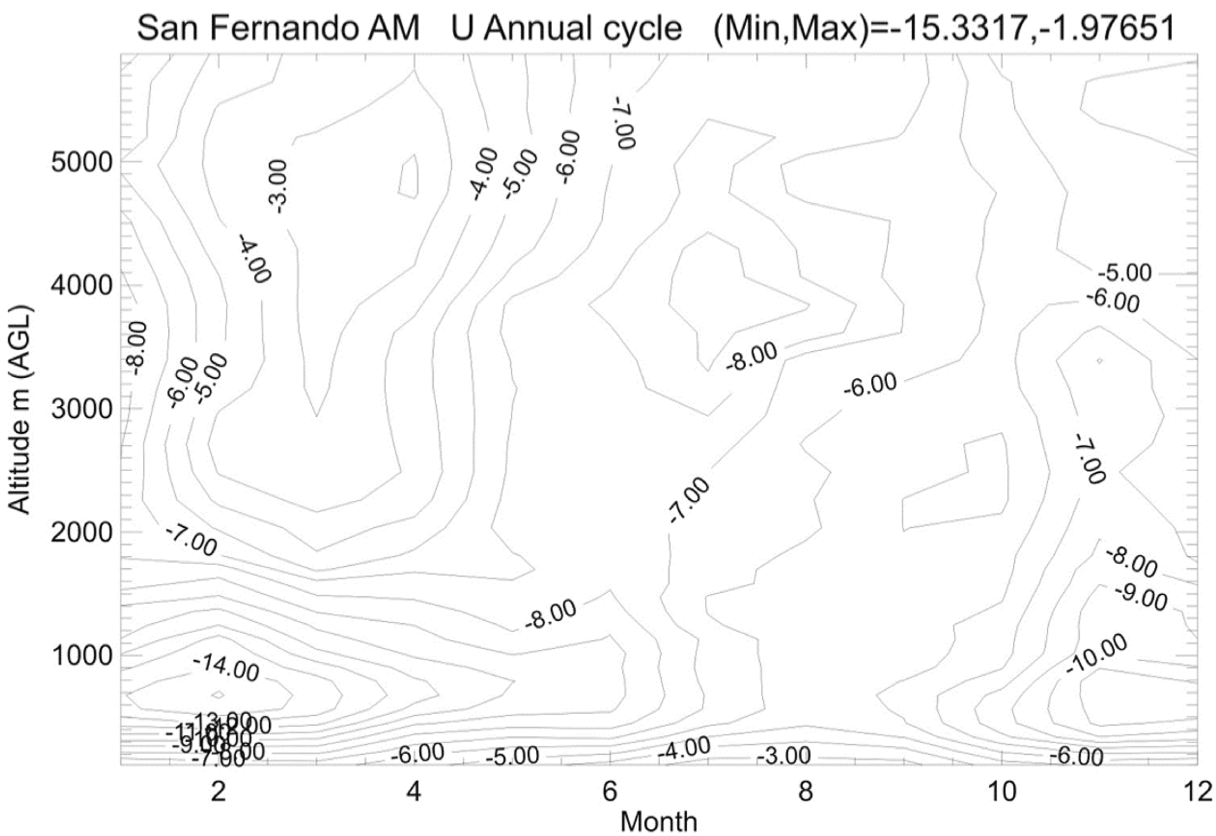


Fig. 3. The 3-year "climatology" of the zonal wind at San Fernando de Apure, based on pilot balloon observations made near 1200 UTC, or about 0800 LT. Since the number of observations decreases with height the means are less reliable at higher levels, but in the first 3 km the monthly means appear stable. The zonal wind (and total wind) is strongest in February (dry season), with values just above 15 m/s at about 750m ASL, and weakens to a minimum in August (wet season).

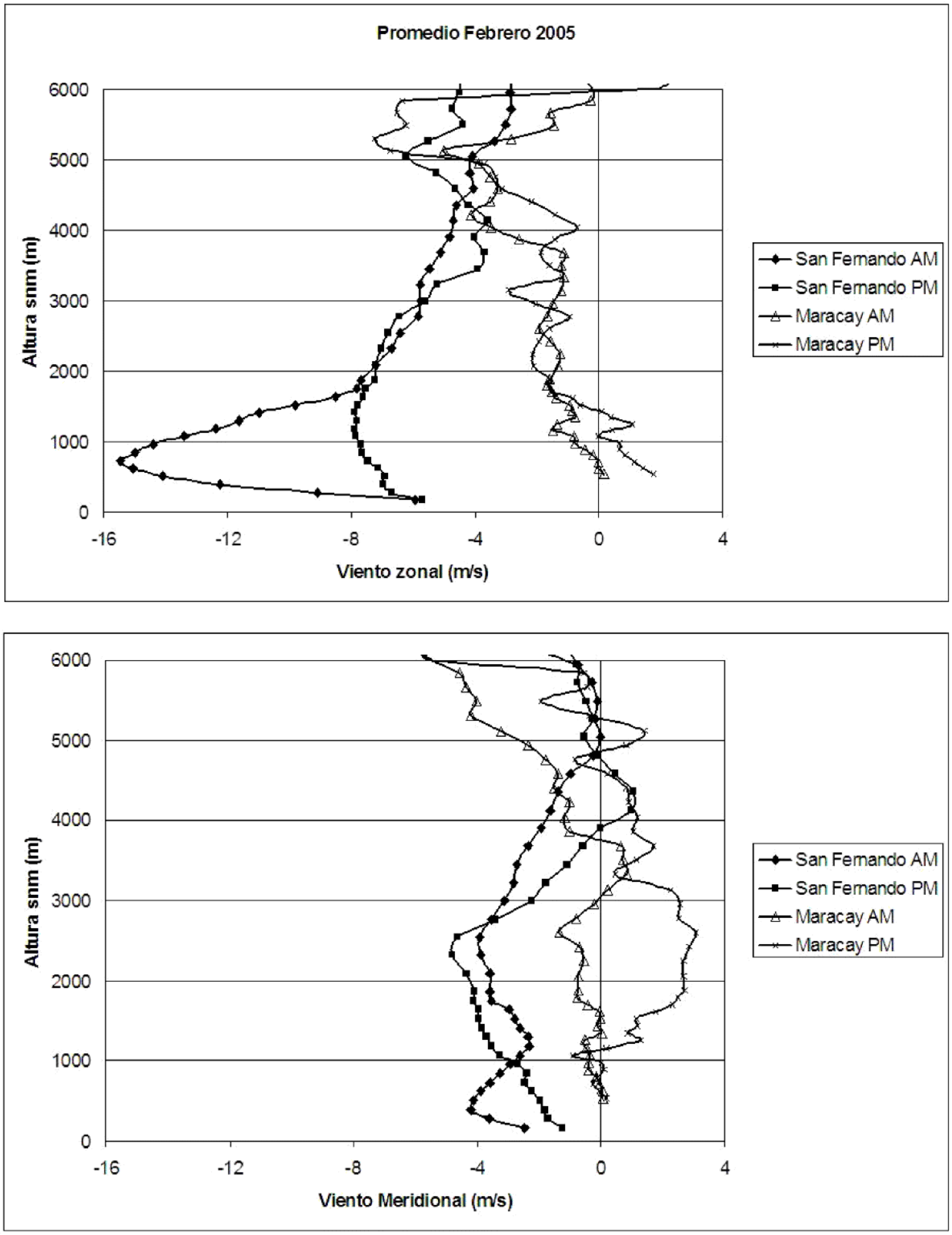


Fig. 4 Morning (~ 0800 Local Time) zonal (top) and meridional (bottom) wind profiles at San Fernando de Apure and at a site (Maracay) close to the coastal mountain range. Vertical scale is meters above sea level. Note the large diurnal variation at San Fernando and the much weaker winds and small diurnal variation at Maracay. Sample size is about 20 pilot balloon observations for each site.

After initial planning was started for the simple validation effort at San Fernando, we became aware that the NARR extended as far south and east as the Llanos. These data were used to produce maps of the mean winds over the llanos at 3-hourly time resolution (Fig 5a). Although this region is near the edge of the model domain, the NARR show a strong low-level jet with a very strong diurnal variation (Fig. 5b). This was a feature of each dry season month of 2003, we suspected that it was ubiquitous. The vertical structure of the jet was also apparent from NARR-based horizontal wind speed maps at 1200 UTC (Fig. 5c) which show the rapid weakening with height, with near calm conditions at 700 mb.

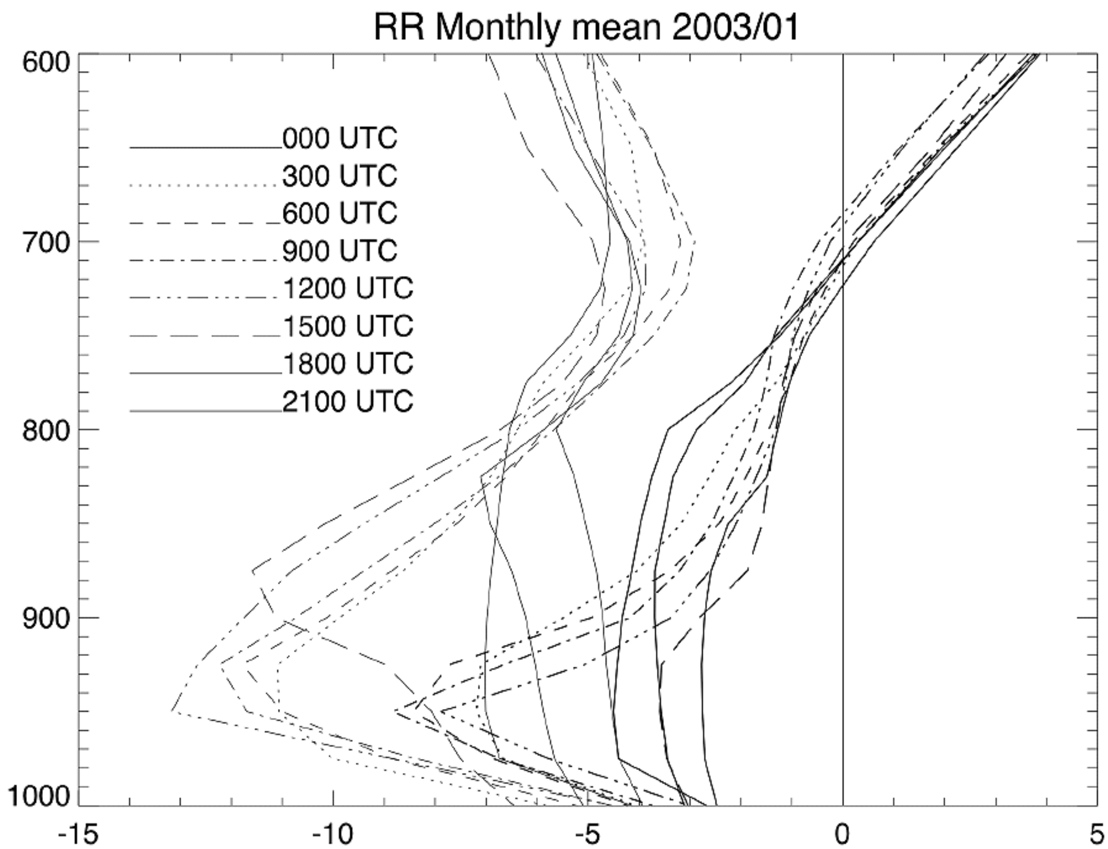
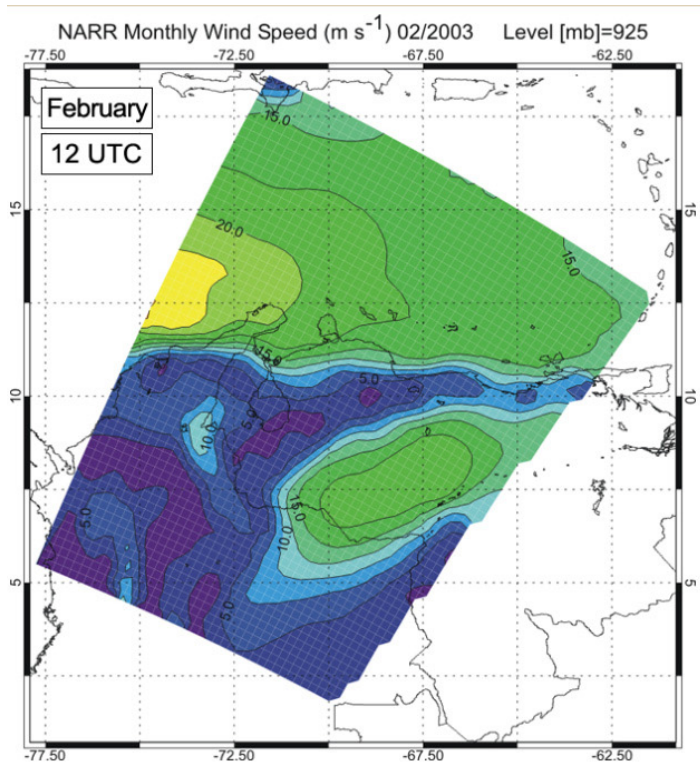


Fig. 5a Profiles of the zonal wind every 3 hours from the NARR, showing the significant diurnal variation of the low-level jet at a point near San Fernando de Apure.



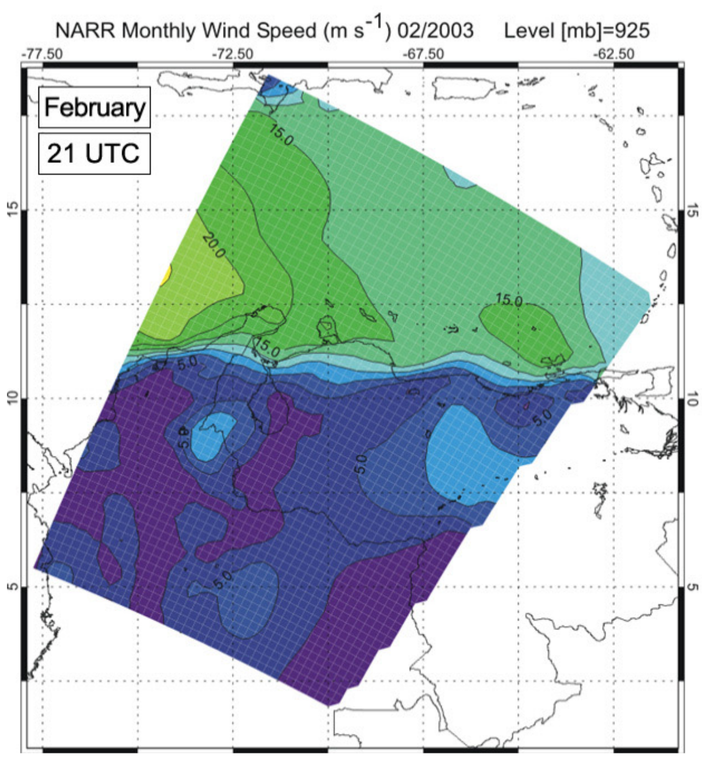


Fig. 5b. February 2003 mean wind speed (m/s) at 925mb from NARR, showing strong llanos jet at 1200 UTC but very weak flow at 2100UTC. Note only small changes over the Caribbean. SE limit of NARR data cuts across eastern Venezuela, but covers most of the llanos.

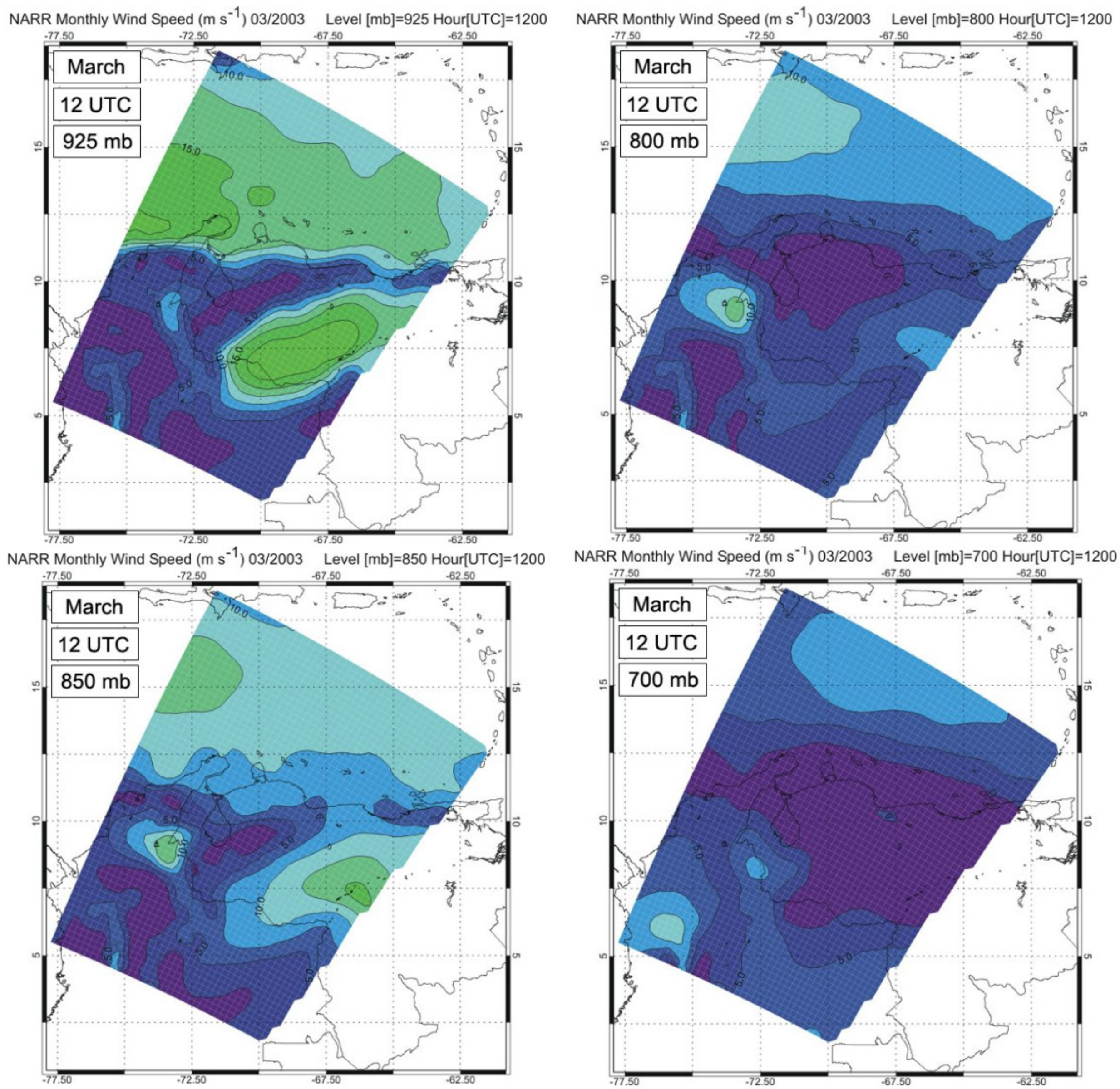


Fig 5c. Mean vertical structure of the low-level jet (mean wind speed in m/s) during March 2003 from the NARR.

3. Preparations for the special observations

Since daily pilot balloon observations were also already being made at Maracay and Cd. Bolivar, the possibility existed of mapping the horizontal structure of the windfield better than previously possible with a modest extension of the activities. It would then be possible to evaluate the horizontal structure of the low-level flow over the llanos as well as its diurnal variation near San Fernando. Thus, several additional sites were proposed for establishment. To describe the along-jet variability a site was proposed for Guasdualito, downwind from San Fernando. To improve the cross-jet resolution of the flow and its suspected diurnal variation the sites at Calabozo and Puerto Ayacucho were planned. Finally, to make comparative measurements in the trade wind flow north of the Venezuelan coast observations were planned for Isla Orchila. This site would likely show weak diurnal variations, in line with the NARR, which sowed only weak diurnal variations over the Caribbean Sea.

The feasibility of the proposed sounding network was only possible because these sites were already surface synoptic observation sites operated by the Venezuelan Air Force. At these sites there were communication facilities, sleeping and cooking facilities, and other conditions that permitted round-the-clock observations. In years past these sites had made pilot balloon observations, though few of the current observers could remember this.

Since it would be necessary to send additional observers to each of the planned sites, there was justification for more frequent observations to be made at each site. This was only possible because, as noted in Sec 1, that the cost of the individual soundings was relatively small compared with other components in the activity. In summary, extensive measurements were planned for mid-late March 2005, to take place prior to the onset of the rainy season. The climatology of the LLJ at San Fernando, based on the 3+ years of PACS-SONET pilot balloon soundings (Fig 3) showed the jet to be the strongest in February, but still quite evident in March. Thus the stage was set for a relatively short verification effort to evaluate the accuracy of regional reanalysis products, and to estimate independently the diurnal cycle of the low-level jet over the llanos. Hereafter, we refer to the entire field activity as the LLANOJET.

4. Logistics of the LLANOJET

Although the logistics of a field program are not commonly the focus of a scientific paper we discuss these because they illustrate the potential to carry out such activities at short notice and at relatively low cost. This is in contrast to many field research activities that may take years to plan and involve substantial budgets.

We contacted the FAV (Venezuelan Air Force) in February 2005 regarding the possibility of making additional measurements at several stations around the llanos to better describe the LLJ. We prepared a brief web document showing an idealized set of stations and the motivation for the activity. The FAV agreed to the activity and by early March other individuals were being contacting other individuals (Rigoberto Andressen, Jorge Lopez, and Rafael Garcia) at universities in Venezuela, some of whom had participated in a PACS-SONET-organized course in Panama in 2001.

Four theodolites were shipped to Venezuela via Miami, where they were picked up by the Venezuelan Air Force, as part of regular flights to Miami. Additional balloons and other accessories were also sent. A radiosonde system from NSSL (old Vaisala PP-11 system) and RS-80 radiosondes (RS-80 15N Omegasondes) were taken to Venezuela with us on March 16th. This equipment was established at San Fernando, while the other pilot balloon theodolites were sent to different sites. The actual network as proposed by the FAV included the three operating sites of San Fernando, Cd. Bolivar, and Maracay, and also temporary sites at Guasdualito, Calabozo, Puerto Ayacucho, and Isla Orchila (about 100km offshore in the Caribbean). These were sites where there were already FAV meteorological observers and where some communications infrastructure already existed. All sites could also be accessed by air transport. The Isla Orchila site had to be changed to the near-coastal site of Coro at the last minute due to difficulties in obtaining permission from the Venezuelan Navy to use the Orchila island facilities.

The purpose of the sites were as follows:

San Fernando: describe diurnal variation of the winds and boundary layer near the suspected core of the jet.
Calabozo: help describe the wind gradient between the weak winds at Maracay and the LLJ core near San Fernando.
Guasdualito and Cd. Bolivar: describe downstream and upstream winds from the suspect region of maximum winds near San Fernando
Coro: describe trade wind regime and its variations along the north coast of Venezuela to see if diurnal cycle and synoptic variations were in phase with those over the llanos.

On Thursday, March 17th, a summary talk was presented to a combined group of experiment participants, which included approximately 14 FAV personnel and about 10 students from two universities. The groups were established for each site, with both students and FAV personnel being deployed to each site.

The actual deployment to the sites was organized by the FAV, and involved having all personnel fly to the sites onboard FAV aircrafts. Personnel for Cd Bolivar flew on one aircraft, while all others were transported to the sites using one C-130 that was scheduled to visit all of the other sites on Friday, March 18th. Given the relatively large distances involved, and the poor state of some of the road segments, this was viewed as the most efficient manner to deploy personnel to the various widely separated sites. (Note: gasoline (and presumably AV gas for the aircraft) is extremely inexpensive in Venezuela, about 20 US cents per gallon, thus gas costs are a relatively small cost, even with aircraft usage). The first site the aircraft reached (approximately on time) was Coro. The aircraft then proceeded to Maracaibo, where it was to pick up equipment to take elsewhere. There were delays on the ground at Maracaibo, and one engine did not start. After a starter motor was changed it eventually was started but during the flight to the next location, Guasdualito, the engine quit. Thus, the pilot decided to return to Maracay directly. Thus on March 18th, only the personnel for Guasdualito and Coro were deployed via the C-130 aircraft. The Cd. Bolivar site personnel were also deployed by aircraft; the aircraft made an emergency landing prior to reaching Cd Bolivar and the personnel made the rest of the journey by bus that day.

The next day, the remaining personnel for Puerto Ayacucho, San Fernando and Calabozo returned to the airport near Maracay to prepare for another flight. Before take off it was decided that the Calabozo team and part of the larger San Fernando team would travel by car to their sites. This they did, arriving in late afternoon in San Fernando. The aircraft teams were successfully deployed to Puerto Ayacucho and also San Fernando – the aircraft arrived a half hour sooner than the vehicle sent via road, despite the plane having stopped at three other sites prior to San Fernando. Thus, all sites were operating by late afternoon of Saturday, March 19th.

Fig. 6. Pictures taken during the Llanojet Experiment. The top right figure shows a group getting ready for an afternoon observation at San Fernando. The hazy atmosphere due to smoke stands out. The top right figure shows the C130 aircraft that transported equipment and personnel to Coro and Guasdualito. The bottom left figure shows a group getting ready for a radiosonde launch at San Fernando. The bottom right figure shows the San Fernando de Apure meteorological station.

5. The sounding strategy

The need for hydrogen gas had been previously estimated and delivered to each site before the additional observers for each site arrived. The need for additional observers was because round the clock observations were anticipated, including nighttime pilot balloon soundings. Three gas cylinders had been deployed to each site (sufficient for about 60 soundings that were anticipated at each site) except for San Fernando where there were additional cylinders for the planned radiosonde launches. The sounding schedule as it finally evolved included pilot balloon soundings at all sites at 0000, 0430, 0700, 1000, 1300, 1600, and 1830 local time. The 0000, 0430 and 1830 observations were made using pilot balloon lights, attached to the balloons by line approximately 3 m long.

At San Fernando more observations were made than at the other sites, and included radiosonde observations, using 100gm balloons, at 0000, 0700, 1300, and 1800 LT. During the last two days radiosonde observations were also made at 1000 LT. Pilot balloon observations at San Fernando were made at 0430, 1000, 1600, and 2030 initially, with additional observations at 0200, 0830, 1130, and 2200 during the last two days. Thus, between 8 and 12 observations were made per day at San Fernando.

The observations began as soon as each site was established, with Coro, Guasdualito and Cd. Bolivar beginning on Friday, March 18th, while the other special sites began on March 19th. San Fernando had run out of balloons on March 18th, and began soundings again on the afternoon of March 19th.

Longer period observations after the intensive observing period (IOP)

Because the IOP was relatively short, and because there was an excess of gas available after the end of the IOP, it was decided to continue additional observations at some sites for several additional weeks. These sites include Calabozo, San Fernando, and Cd Bolivar, where twice-daily observations were made for a period of approximately 4 weeks after the IOP ended. This will improve estimates of the difference between AM and PM winds, and identify any systematic differences between the winds at the three sites.

6. Preliminary scientific results

To recap, the main objectives of the special measurements were to:

1) evaluate the accuracy of the NCEP regional reanalyses over the Venezuelan llanos, which are at the extreme end of NARR domain. The spatial extent of the llanos jet and the strong diurnal cycle shown in the NARR were of particular interest

2) describe the diurnal cycle of the Low Level Jet at San Fernando with better temporal resolution than available from once-daily soundings

3) describe the spatial extent of the LLJ from a network of stations and map the geographical variation of the low level jet over the area of study

and

4) evaluate the relative importance of different stations for future monitoring activities.

From an examination of Fig. 5 several features of the LLJ are evident from the NARR analyses. The strongest winds and the largest diurnal cycle are near 925mb, or about 750m ASL. The highest winds from the NARR were near 1200 UTC, or 07LT. The RR spatial resolution was sufficient (32km grid) to show considerable spatial variability of the LLJ, with the mountains along the northern coast of Venezuela asserting a major impact on the flow. The NARR show a distinct separation between the trade wind flow over the Caribbean, showing weak diurnal variation, and the flow over the llanos, which shows a strong diurnal variation. The NARR also show much weaker flow overall in the lee of the elevated terrain over southern Venezuela.

The spatial extent of the llanos low level jet

Observations made during the 5-day period confirmed that the LLJ extends the extent of the llanos, but that the strongest winds are near San Fernando. Fig 7 shows the mean winds at 750m

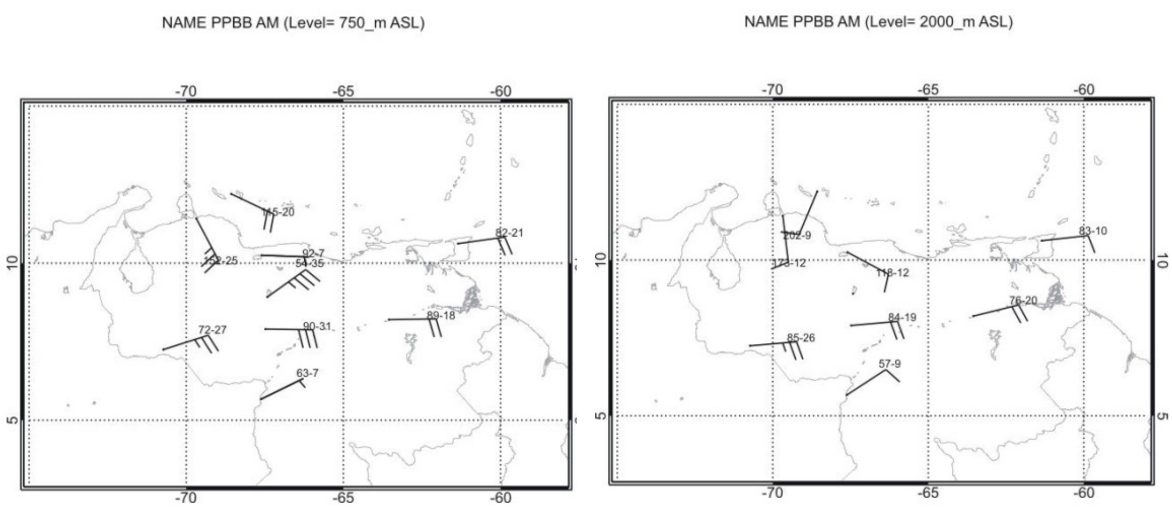


Fig. 7. Mean winds at 1200 UTC over the 5-day LLANOJET at 750m and 2000 m ASL. Note the radiosonde station data at Trinidad and Curacao is included.

ASL over the 5-day LLANOJET period, this is near the level of maximum winds over the llanos. The San Fernando and Calabozo sites show similar intensity winds, with those at Guasdualito and Cd Bolivar somewhat weaker. The winds at Cd Bolivar were known, from previous PACS-SONET observations, to be weaker than San Fernando, at least at 1200UTC.

The winds at Maracay are very weak, this had been known from previous SONET observations. Maracay lies at the southern foot of the Cordillera de la Costa, with a near continuous ridge of mountains extending to about 2.5km between Maracay and the coast. This range, essentially parallel to the trade wind flow, apparently has a large impact on the winds on either side of the range.

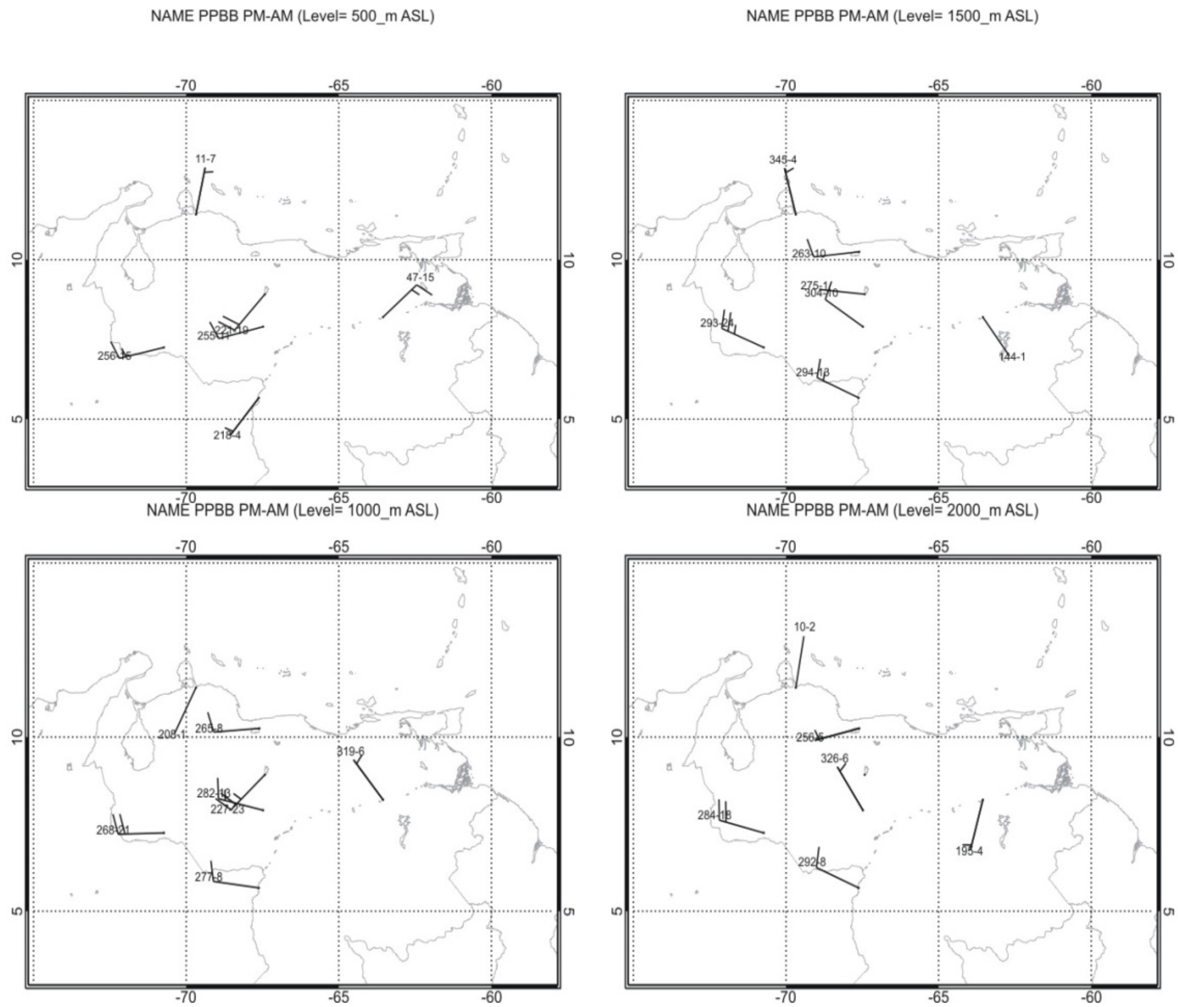


Fig. 8. Difference (in kts) between afternoon and morning winds (PM-AM) at 4 levels (500, 1000, 1500, 2000m ASL) during the 5-day LLANOJET. (Calabozo winds need adjustment, rotation 35 degrees clockwise.) Note opposite phase of Cd. Bolivar (far eastern site) at the lowest levels.

The Calabazo winds as shown in Fig. 7 are seemingly at odds with surrounding sites. This motivated an additional analysis which discovered that there was a systematic error in the azimuth of the theodolites of approximately 35 degrees. When this is applied the data conform in both direction and speed with the surrounding sites.

The diurnal variation, as estimated by subtracting the AM mean wind from the PM mean wind, shows reasonable spatial coherence (Fig. 8). These results are preliminary, and more details will be presented in the poster.

The diurnal variation of the LLJ at San Fernando, near the jet core.

These data are still being processed and quality controlled, so no results of the mean diurnal cycle at San Fernando are shown here. However the time series of the winds (Fig. 9) shows the data that is available. Only the first 3 km are shown for clarity.

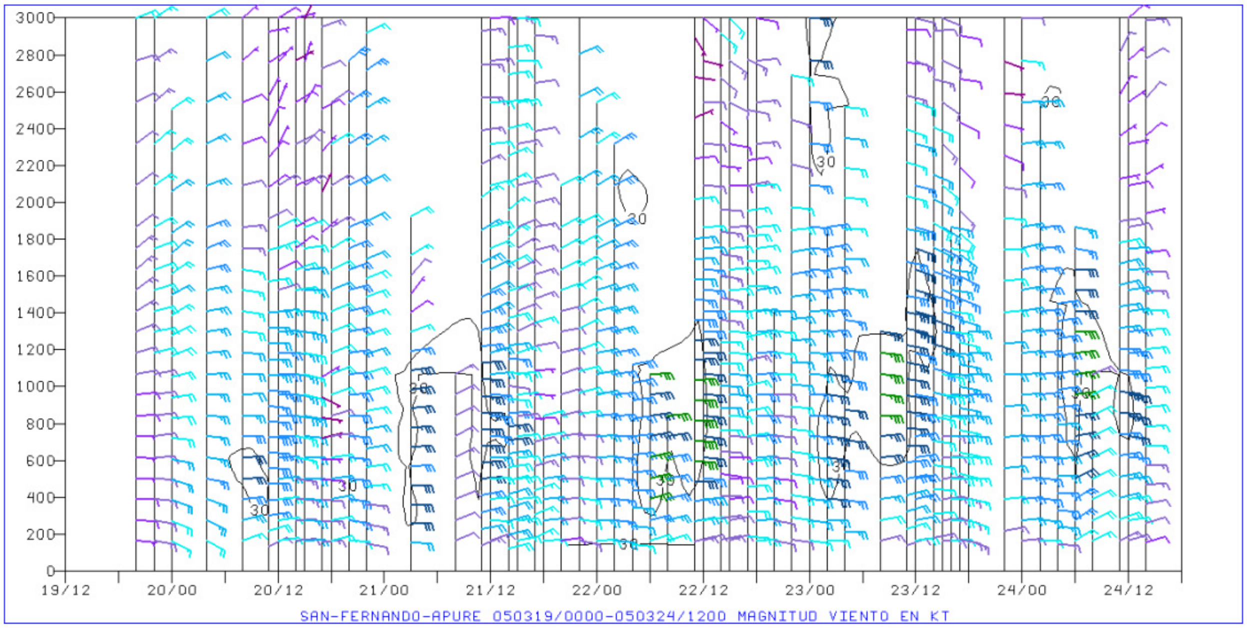
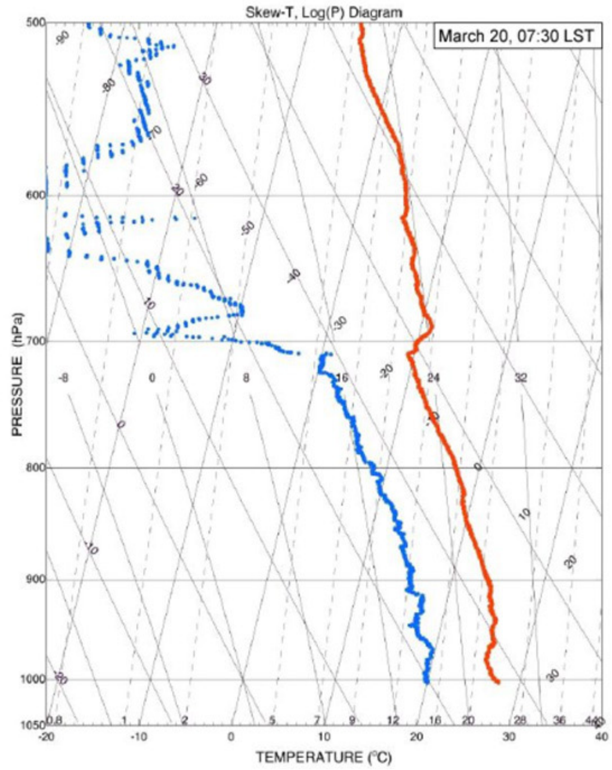


Fig. 9. Time-height section of the winds at San Fernando de Apure during LLANOJET. Purple colors are weaker winds, green is stronger winds.

The overall quality of the NARR

Our overall assessment of the NARR analyses is greatly limited by the fact that we cannot compare directly the analyses for the same period as the observation, since the NARR was unavailable for 2005. However, the overall agreement is very good in that the diurnal cycle phase and amplitude is in broad agreement with the LLANOJET observations. Also, the confinement of the strong jet to the flat llanos, with very weak flow around the Cordillera de la Costa and over the Guiana highlands south of the llanos is evident in the data.



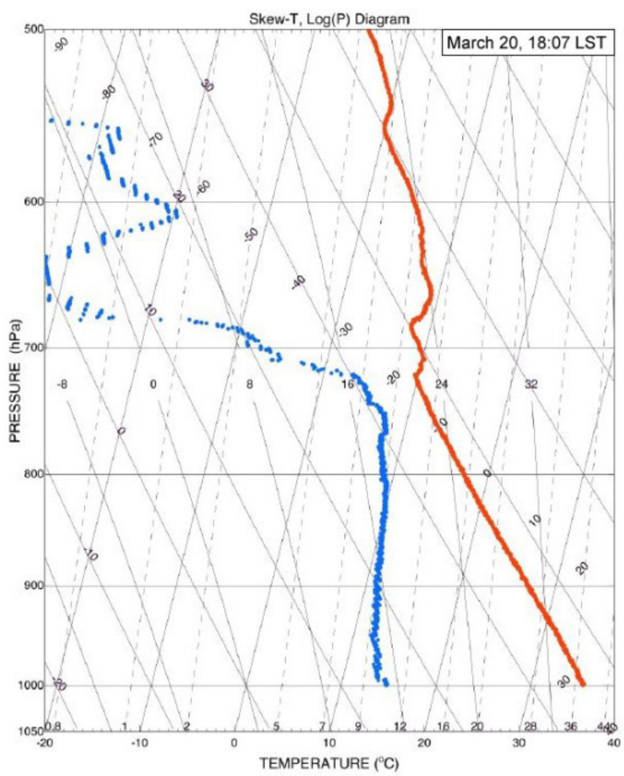


Fig. 10. Radiosonde soundings made on March 20 in San Fernando. The top panel represents the morning sounding and the bottom panel the afternoon sounding.

Final comment

To see the latest results please refer to the PACS-SONET web site or the specific LLANOJET link at: http://www.nssl.noaa.gov/projects/pacs/web/VENEZUELA2005/ . This site will continue to be supplemented with new results. In addition, the processed data is available there, as are other sources of information.

Acknowledgments

Special thanks are due to all of the members of the Venezuelan Air Force (FAV) involved in the Llanojet activity. Their ability to organize and carry out such a major activity on short notice, and with a high level of motivation was exceptional. St1 Arnaldo Lugo of the FAV in particular oversaw many of the logistical details and helped in most aspects of the experiment. In San Fernando the help of the entire station staff, overseen by St2 Arcides Lugo, was invaluable. Participants from at least three universities in Venezuela also provided many students and staff. Faculty members included Jorge Lopez and Rafael Garcia from the University Centro-Occidental Lizandro Alvarado (UCLA) and Rigoberto Andressen from the University de Los Andes in Merida. In all, more than 50 individuals participated in Llanojet and the hard work of all is greatly appreciated.

Finally, thanks are due to NOAA's Office of Global Programs for funding this activity as part of the educational and research components of the PACS-SONET project.