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# THE IMPACT OF HIGH-RESOLUTION SALLJEX DATA ON NCEP GLOBAL ANALYSES

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## 1. INTRODUCTION

In recent years several studies demonstrated the important role that the South American Low-Level Jet (SALLJ) plays in transporting moisture from the Amazon Basin to higher latitudes over the continent. Many of these studies have utilized the National Centers for Environmental Prediction (NCEP) reanalysis data (e.g., Nogués-Paegle and Mo 1997, Berbery and Collini 2001, Marengo et al. 2004) and the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis data (Salio et al. 2002, Wang and Fu 2004), as the basis for studying climate and climate variability. For data rich areas, the Climate Data Assimilation System (CDAS-1, Kalnay et al. 1996 and CDAS-2, Kanamitsu et al. 2002) data provide a fairly homogeneous set of analyses spanning more than 50 years, which are ideal for climate studies. However, for data sparse regions, including many areas in the Southern Hemisphere, certain doubts arise concerning the validity of those analyses. The characteristics (parameterization, resolution, topography, etc) of the general circulation model (GCM), which serves as a nucleus of the data assimilation system, became increasingly important in determining circulation features as the spatial and temporal resolution of the observations decreases. Anderson and Arritt (2001), using the NCEP reanalysis data to investigate the LLJ in the Great Plains, pointed out the risk of using data analyzed at times when the analyses are heavily influenced by the GCM (times when observations are relatively sparse).

The South American Low-level Jet Experiment (SALLJEX) field campaign was carried out in western-central South America during the period 15 November 2002 -15 February 2003 (Vera et al. 2006). The SALLJ program, a component of CLIVAR/VAMOS, is an internationally coordinated effort to contribute to a better understanding of the role of the SALLJ in the moisture and energy exchanges between the tropics and extratropics, and to related aspects of the regional hydrology, climate and climate variability for the region of the South American Monsoon.

During SALLJEX, a dense observation network was deployed with sixteen new pilot balloon stations and six new rawinsonde stations in Bolivia, Paraguay, central and northern Argentina, western Brazil and Peru (Fig. 1). Most rawinsonde sites operated twice daily (at 06Z and 18Z), except during the Intensive Observing Period (IOP) when some sites operated four times daily. These datasets were not included in the Global Telecommunication System (GTS) and, therefore, they can be used as an independent verification of the sensitivity of assimilation systems (NCEP, ECMWF and DAO/NASA).

The emphasis of this paper is on the impacts of high-resolution field-experiment data on the strength, position and structure of the Low-level Jet east of the Andes, using the NCEP operational data assimilation systems. Specifically, comparisons are made between analyses produced with and without the SALLJEX data using the Climate Data Assimilation System (CDAS-1), that was used in the NCEP/NCAR Reanalysis Project (Kalnay et al. 1996), CDAS-2 that was used in the Reanalysis-2 Project (Kanamitsu et al. 2002) and a reduced resolution version of the operational NCEP Global Data Assimilation System (GDAS). The present results will serve as a benchmark for similar data impact studies using higher resolution regional data assimilation systems

## 2. DATA SETS AND METHODS

### a. SALLJEX Observations

The SALLJEX field campaign took place during 15 November 2002 -15 February 2003 over west-central South America east of the Andes

Mountains. Enhanced (temporal and spatial) atmospheric soundings were made over Argentina, Bolivia, Brazil, Paraguay and Peru. These included twenty-two new upper air observation stations, with sixteen pilot balloon (PIBAL) and six rawinsonde (RAOB) stations (Fig. 1). Most RAOB stations operated twice daily (06Z and 18Z) while PIBAL stations operated four times daily during the Special Observation Period (SOP) during 6 January -15 February 2003. During the Intensive Observation Period (IOP) most RAOB sites operated 3-4 times daily and up to 8 PIBAL ascents per day were made at selected sites. These observations were not available to the Global Telecommunications System (GTS) and were not assimilated into any operational systems in real time. They are used here as an independent verification of the NCEP assimilation systems (CDAS and GDAS). Table 1 shows the soundings that were used by CDAS and GDAS systems during the period 15 December 2002 -15 February 2003.

**b) Global Data Assimilation System**

The basic idea of reanalysis is to use a frozen state-of-the-art analysis/forecast system to perform data assimilation using past data. In this study we compare the analyses, derived from three different data assimilation systems (CDAS1, CDAS2 and GDAS), for the period 15 December 2002-15 February 2003.

CDAS1 is the frozen analysis/forecast system that was used to perform the NCEP/NCAR reanalysis (R-1, Kalnay et al. 1996) for the period 1948 to present. CDAS2 is an updated NCEP/NCAR reanalysis (R-2, Kanamitsu et al. 2002), covering 1979 to present, with an improved forecast model and data assimilation system. GDAS is a reduced resolution version of the operational NCEP global model data assimilation system (2005).

The resolutions of the systems are T62L28 for CDAS, approximately 250 km horizontal resolution with 28 levels in the vertical, and T170L42 for GDAS, approximately 100 km horizontal resolution with 42 levels in the vertical.

**c) Experiments**

In order to assess the impact that the introduction of the SALLJEX dataset has on the analyses, the following experiments were performed, using CDAS1, CDAS2 and GDAS:

1) control runs without the SALLJEX data;
2) runs only including rawinsonde data (CDAS1r, CDAS2r and GDASr);
3) runs including all SALLJEX upper-air data, rawinsonde and pilot balloon (CDAS1rp, CDAS2rp and GDASrp).

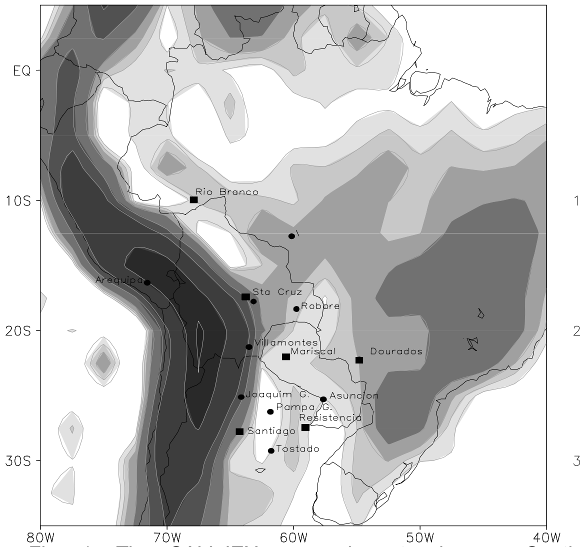


Fig. 1. The SALLJEX upper-air network over South America. Topography in shaded (intervals 100, 200, 300, 500, 1000, 1500, 3000 and 4000 m).

**3. REGIONAL IMPACT OF SALLJEX**

The use of global reanalysis, which combines general circulation model (GCM) predictions with observations, is a powerful tool for understanding many climate and weather questions that would otherwise remain elusive because of the limited availability of the data over some regions. However, due to differences in data assimilation systems (models and assimilation techniques) there is a degree of uncertainty in the reanalyzed fields. An example of this uncertainty is pointed out in Fig. 2 which shows the low-level (850-hPa) vector wind over South America during the period 15 January-15 February 2003. The strength of the low-level flow east of the Andes mountains varies by up to 40% in the analyses, with CDAS2 (Fig. 2b) having the strongest jet and GDAS, the operational data assimilation system, having the weakest jet (Fig. 2c). Figures 2d, 2e and 2f show the impact of including SALLJEX data in the CDAS1, CDAS2 and GDAS systems, respectively. The influence of SALLJEX data is concentrated over the region where the rawinsonde and pilot balloon observations were made (Fig. 1) and the global influence is close to zero outside of the region (not shown). The strength and location of the core of the low-level jet analyzed in the three systems, CDAS1rp, CDAS2rp and GDASrp (Figs. 2d, 2e and 2f), are in better agreement than in the control runs, CDAS1,CDAS2 and GDAS (Figs. 2a, 2b and 2c).

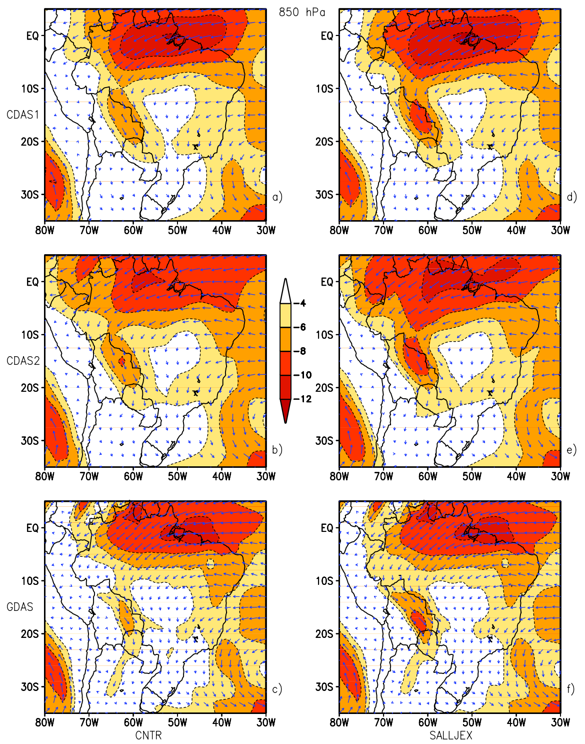


Fig. 2. Mean low-level wind (vector) and wind speed magnitude (shaded) at 850 hPa for 15 January to 15 February 2003. a) CDAS1, b) CDAS2, c) GDAS, d) CDAS1rp, e) CDAS2rp and f) GDASrp. Units are in m s$^{-1}$

Salio et al. (2002), in a study of intense moisture transport from tropical latitudes southward to the La Plata basin (northern Argentina, Paraguay and southern Brazil), pointed out that during extreme low-level jet events the 850-hPa wind speed anomalies are concentrated over the La Plata basin and that there is no discernable difference in the strength of the trade winds over northern South America. This is in agreement with the results shown in Figs. 2d, 2e and 2f. There are only small differences outside of the area where enhanced observations were made during SALLJEX. GDASrp (Fig. 2f) shows a narrow jet concentrated near the Andes with the maximum wind speed close to Santa Cruz, with values higher than 8 m s$^{-1}$.

An examination of the vertical structure of the mean meridional wind at 18ºS, 62ºW (near Santa Cruz) reveals that the maximum impact of the inclusion of SALLJEX data occurred at 0600 UTC in GDAS (Fig. 3b) at low-levels. It also shows that in most of the cases the inclusion of rawinsonde data alone has more impact than when both rawinsonde and pilot balloon data are included. The diurnal cycle in the strength of the LLJ is clearly evident, with a maximum strength at 0600 UTC near 900 hPa in GDAS and at 850 hPa in CDAS. CDAS1 also shows a second maximum at 925 hPa. The mean altitudes of the maximum low-level wind increase from 0600 UTC to 1800 UTC in GDAS, which is not evident in CDAS1 and CDAS2. The GDAS results agree with previous results of Bonner et al. (1968) for the North America low-level jet. The lowest impact in all systems is at 0000 UTC. This is related to a lack of observations at that time, which contributes to increased uncertainty in the analyses.

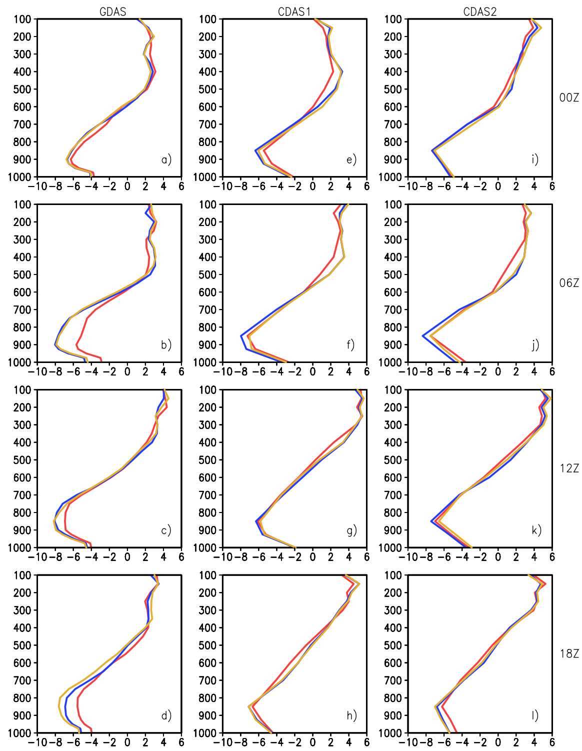


Fig. 3. Mean meridional wind profile composite for control runs (red), including only radiosonde (blue) and radiosonde and pilot balloon (yellow) at the grid point nearest Santa Cruz, Bolivia. Results from CDAS1: a), b), c) and d), for 00, 06, 12, and 18 UTC, respectively. Results from CDAS2: e), f), g) and h), for 00, 06, 12 and 18 UTC, respectively. Results from GDAS: i), j), k) and l), for 00, 06, 12 and 18 UTC, respectively. Units are in m s$^{-1}$.

## 4. COMPARISON WITH OBSERVATIONS

Figure 4 compares the observed 850-hPa specific humidity at Santa Cruz (Fig. 1) with the analyses from GDAS, CDAS1, and CDAS2, interpolated to the grid point nearest the sounding site.

The GDASrp fits well with the rawinsonde data (red on Fig. 4a), better than the operational GDAS (green on Fig. 4a). Both operational and GDASrp capture very well the features associated with a strong southerly jet, which occurred during the dry period 23-24 January. In general the differences between GDAS and GDASrp are smaller than 2 g kg$^{-1}$.

The biggest differences occur in CDAS1 and CDAS2. CDAS1 shows a strong diurnal cycle that is not evident in the observations. It also has values higher than 20 g kg$^{-1}$, as compared to 15 g kg$^{-1}$, which is approximately the highest observed value (Fig. 4b). There is no significant impact when the SALLJEX dataset are included, showing an inability of the analysis system to assimilate these data. Similar results can be observed with CDAS2, but the diurnal cycle is not as strong as in CDAS1 and CDAS1rp. Neither system was able to capture the strong impact of the frontal system that affected the region during 23-24 January (Figs. 4b and 4c).

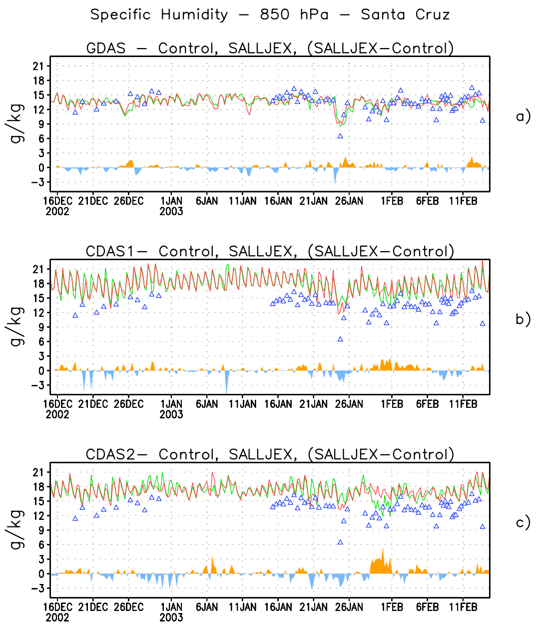


Figura 4. Time series of 850 hPa specific humidity at the grid point nearest Santa Cruz for 15 December 2002 to 15 February 2003. a) results from GDAS (green) and GDASrp (red) and the difference between both. The observational values are in blue triangle. b) same as in (a) for CDAS1 and CDAS1rp. c) same as in (a) for CDAS2 and CDAS2rp. Units are in g kg$^{-1}$.

These large differences between the GDAS and CDAS, including the limitations of CDAS, can be associated with the more realistic topography in GDAS and the ability of GDAS to more accurately simulate certain physical processes.

Figure 5 shows the 850-hPa meridional wind component and the differences between GDAS and GDASrp. The largest differences occur after the middle of January and extend until the end of the month (Fig. 5a), which are related to the availability of the rawinsonde data. GDASrp agrees very well with the rawinsonde data and captures the maximum and minimum (Fig. 5c) associated with the southerly and northerly low-level jet, respectively. In general the control run, GDAS, underestimated the meridional wind component.

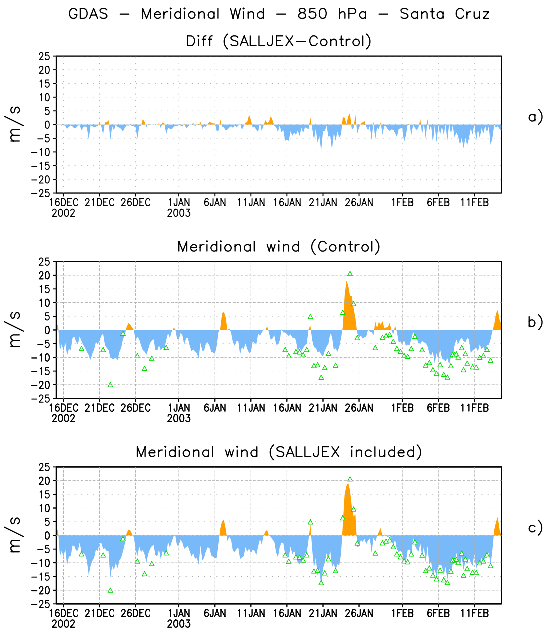


Fig. 5. Time series of 850 hPa meridional wind at the grid point nearest Santa Cruz for 15 December 2002 to 15 February 2003, for GDAS and GDASrp and the difference between both. The observational values are in green triangle. Units are in m s$^{-1}$.

Both CDAS1 and CDAS2 (not shown) were unable to capture the maximum and minimum values of the 850-hPa meridional wind at the nearest grid point to Santa Cruz. For the CDAS1rp and CDAS2rp the differences are small and the meridional winds are generally underestimated. The worst case is associated with the strong, southerly low-level flow during 23-24 January. The observed values are close to 20 m s$^{-1}$, and for CDAS1 and CDAS2 the maximum values are 5 m $s^{-1}$ and 3 m $s^{-1}$, respectively. For CDAS1rp and CDAS2rp the values are a little closer to the observed values, 9 m $s^{-1}$ and 10 m $s^{-1}$, respectively.

## 5. CONCLUSIONS

A data assimilation study was performed to assess the impact of observations from the South American Low-Level Jet Experiment (SALLJEX) on analyses in the region east of the Andes Mountains from western Brazil to central Argentina. The data assimilation systems, CDAS1, CDAS2 and GDAS, were run with and without the additional SALLJEX rawinsondes and pilot balloon observations (Fig. 1). This evaluation is crucially important to examine the impact of high-resolution field experiment data on the NCEP global analysis and the ability of state-of-the-art data assimilation systems to correctly analyze important climatic features of a major monsoon system.

Most of the impacts on the reanalyses that include additional SALLJEX data are regional and concentrated over the SALLJ region, with the largest differences at low levels. All assimilation systems showed improvements in the SALLJ when SALLJEX data were included. The differences between CDAS1rp and CDASrp are small when compared with the respective control runs. The largest impacts for all assimilation systems appear where the uncertainties are large, which usually occurs when there is a lack of upper-air observations.

The coarse resolution of CDAS (T62 ~ 250 km) does not adequately resolve the Andes Mountains, and, as a result, CDAS was unable to exploit the additional sounding data from Santa Cruz to improve the characteristics of the Low-level Jet and associated moisture transport. CDAS displayed only minor analysis improvements when the enhanced SALLJEX sounding data were included. Also, CDAS clearly overestimates the specific humidity in control runs, which was not corrected when SALLJEX data were included.

For all three assimilation systems the inclusion of pilot balloon data does not significantly improve analyses over those produced using only rawinsonde data. In part this may be due to the fact that the pilot balloon ascents use the first guess from the models to correct the vertical position of the data.

Some fields, such as winds, temperature and geopotential height, are generally well defined by observations and, given the statistical interpolation of the observations and first guess, the reanalyzed fields are the best estimate of the evolving state of the atmosphere, which is even better than would be obtained using only observations. For others, such as moisture variables, the model characteristics, which influence the model climatology, become more important (Kalnay et al. 1996).

For the global analyses, the GDAS provided the best results because of its higher resolution and state-of-the-art data assimilation system. GDASrp shows a narrow jet concentrated near the Andes with the maximum speed close to Santa Cruz. Silva Dias et al. (2001) found similar results indicating that the higher-resolution model confines the low-level jet to a narrower strip along the Andes. The diurnal cycle in the strength of the LLJ is clearly evident, with the maximum strength at 0600 UTC near 900 hPa in GDAS and 850 hPa in CDAS.

The data impact results for Mariscal in northern Paraguay show considerable improvement in the wind and humidity analyses, especially for CDAS. The better results for CDAS at Mariscal are probably due to the greater distance of that site from the Andes, which minimizes the effects of the model topography.

All of the datasets used in this study are available at JOSS/UCAR for distribution and use in additional validation/evaluation studies in the future.

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