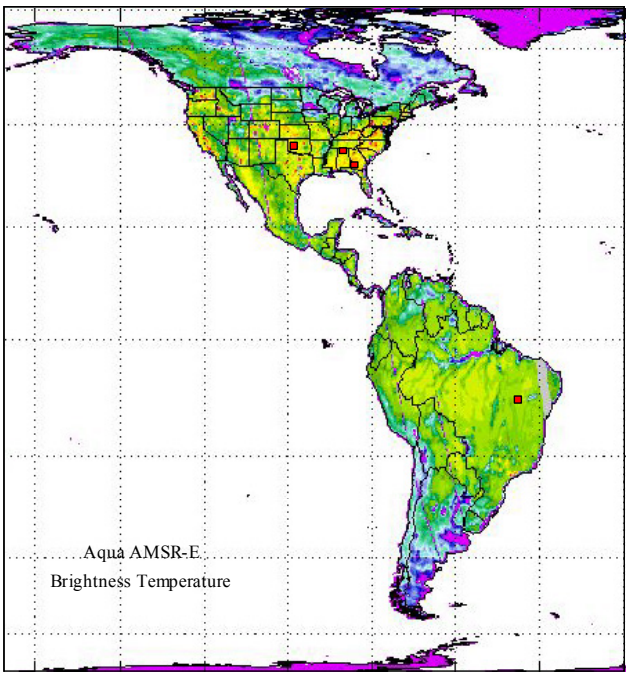
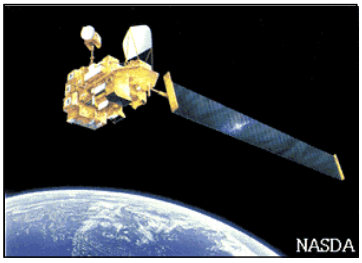
SOIL MOISTURE EXPERIMENTS IN 2003 (SMEX03)

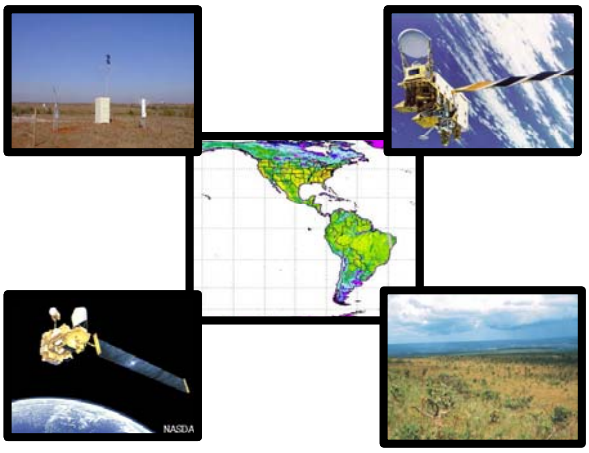
Experimento de Umidade de Solo de 2003





Brazil Experiment Plan
October 2003

SMEX03
Experimento de Umidade de Solo de 2003



Investigação conjunta entre Embrapa, NASA e USDA para compreender as interações entre umidade de solo, tempo e clima

A Embrapa, a NASA e o USDA/ARS estão desenvolvendo estudos para compreender melhor a interação entre a superfície da Terra e a atmosfera. Esses estudos fornecerão importantes subsídios para a previsão de clima e tempo.

No segundo semestre de 2003, experimentos de umidade de solo serão conduzidos no Brasil e nos Estados Unidos com o objetivo de entender a influência da umidade de solo e das culturas nas interações entre superfície da Terra e atmosfera (SMEX03).

Este é um projeto multidisciplar de grande escala que envolve a participação de aproximadamente 100 cientistas e estudantes. As atividades no Brasil ocorrerão no início de dezembro de 2003, num período de duas semanas.

Uma aeronave da NASA transportará instrumentos existentes nos atuais e nos futuros satélites e coletará dados em diferentes altitudes e com alta resolução espacial.

Amostras de campo de umidade de solo e de vegetação serão obtidas concomitantemente com o sobrevôo da aeronave. A área de estudo corresponde à região próxima à sede do município de Barreiras, Bahia.

Essas medidas de campo e de aeronave serão utilizadas para validar os dados do novo satélite da NASA denominado de Aqua, o qual foi construído para compreender o ciclo da água na Terra.

Maiores informações podem ser obtidas no website hydrolab.arsusda.gov/SMEX03/ ou através do

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1 OVERVIEW AND SCIENTIFIC OBJECTIVES

The significance of a hydrologic state variable is expressed well in the recent description of NASA's Global Water and Energy Cycle research program. *Water is at the heart of both the causes and the effects of climate change. Ascertaining the rate of cycling of water in the Earth system, and detecting possible changes, is a first-order problem with regard to the renewal of water resources and hydrologic hazards. A more complete understanding of water fluxes, storage, and transformations in the land, atmosphere, and oceans will be the central challenge to the hydrological sciences in the 21st century. Improved knowledge and prediction of the water cycle can yield large benefits for resource management and regional economies if variability and uncertainties can be understood, quantified and communicated effectively to decision-makers and to the public. The overarching objective is to improve the understanding of the global water cycle to the point where useful predictions of regional hydrologic regimes can be made. This predictive capability is essential for practical applications to water resource management and for validating scientific advances through the test of real-life prediction.*

Soil moisture is the key state variable in hydrology: it is the switch that controls the proportion of rainfall that percolates, runs off, or evaporates from the land. It is the life-giving substance for vegetation. Soil moisture integrates precipitation and evaporation over periods of days to weeks and introduces a significant element of memory in the atmosphere/land system. There is strong climatological and modeling evidence that the fast recycling of water through evapotranspiration and precipitation is the primary factor in the persistence of dry or wet anomalies over large continental regions during summer. As a result, soil moisture is the most significant boundary condition that controls summer precipitation over the central U.S. and other large mid-latitude continental regions, and essential initial information for seasonal predictions.

A common goal of a wide range of agencies and scientists is the development of a global soil moisture observing system (Leese et al. 2001). Providing a global soil moisture product for research and application remains a significant challenge. Precise *insitu* measurements of soil moisture are sparse and each value is only representative of a small area. Remote sensing, if achievable with sufficient accuracy and reliability, would provide truly meaningful wide-area soil wetness or soil moisture data for hydrological studies over large continental regions.

Development and implementation of the remote sensing component of a global soil moisture observing system will require advancements in science and technology. Many aspects of the research require validation and demonstration, which can only be accomplished through controlled large-scale field experimentation. Large-scale field experimentation requires significant resources to be successful that are usually contributed from several programs.

Through a series of workshops and research announcements science and technology priorities for soil moisture remote sensing have been identified. Elements requiring field experimentation were identified and, to the extent possible, combined into Soil Moisture Experiments for 2002 (SMEX02) and 2003 (SMEX03). SMEX02 focused on microwave remote sensing of soil moisture in an agricultural setting. SMEX03 addresses validation and a range of natural vegetation types.

At the present time there are three programs that significantly influence the direction of research and the requirements of a soil moisture field experiment. These are the Soil Moisture Mission (HYDROS), Global Water & Energy Cycle (GWEC) Research and Analysis, the Advanced Microwave Scanning Radiometers (AMSR) on Aqua and ADEOS-II. The relevant science needs of each program are described in the following sections. These were merged into the SMEX03 experiment plan.

Field experiments, in particular the series that has been conducted at the Southern Great Plains (SGP) site, have been very successful at addressing a broad range of science and instrument questions. The data have been used in studies that went well beyond the algorithm research, primarily due to an emphasis on developing map-based products.

For 2003, a field experiment was proposed that would support the science needs of Soil Moisture Missions (HYDROS and future), Global Water and Energy Cycle, and the Advanced Microwave Scanning Radiometer. Main elements of the experiment are to understand land-atmosphere interactions, validation of AMSR brightness temperature and soil moisture retrievals, extension of instrument observations and algorithms to more challenging vegetation conditions. We have chosen to address the combined objectives with ground/aircraft/spacecraft observations over sites in Oklahoma, Georgia, and Alabama during the summer of 2003 followed by a study in Brazil.

This report describes the elements of SMEX03 Brazil, however, additional information can be found in the full experiment plan http://hydrolab.arsusda.gov/smex03/. Coverage includes the aircraft and satellite soil moisture sensors, aircraft missions, ground data collection, and test sites.

2 SATELLITE OBSERVING SYSTEMS

2.1 Advanced Microwave Scanning Radiometers (AMSR and AMSR-E)

Two versions of the AMSR instrument were launched in 2002, AMSR-E on Aqua (http://wwwghcc.msfc.nasa.gov/AMSR/) in May and AMSR on ADEOS-II (http://adeos2.hq.nasda.go.jp/default_e.htm) in December. It is expected that data from both platforms will be available for SMEX03. AMSR algorithm development and validations (Njoku et al. 2003) are very important components of SMEX03.

As shown in Table 1, the lowest frequency of AMSR is 6.9 GHz (C band). However, preliminary studies indicate that there is widespread radio frequency interference (RFI) in the C band channels. Therefore, it is likely that the most useful channels for soil moisture will be those operating at the slightly higher X band. The viewing angle of AMSR is a constant 55°. Details on AMSR-E can be found at http://wwwghcc.msfc.nasa.gov/AMSR/ and AMSR at http://adeos2.hq.nasda.go.jp/shosai_amsr_e.htm. There are some small differences in the spatial resolution of AMSR and AMSR-E. The most important difference between the two satellites is the time of day of the overpasses. Aqua is 1:30 am and pm local time and ADEOS-II is 10:30 am and 10:30 pm. AMSR has a slightly larger antenna and higher altitude than AMSR-E resulting in slightly better spatial resolution and a swath of 1600 km.

Based on the results of SMMR and supporting theory (Wang, 1985, Ahmed, 1995, and Njoku and Li, 1999), we anticipate that this instrument will be able to provide soil moisture information in regions of low vegetation cover, less than 1 kg/m^2 vegetation water content. There are very few data sets that have been obtained that include the low frequencies of the AMSR instruments, especially dual polarization at off nadir viewing angles. Early research efforts did examine these frequencies in limited ground and aircraft experiments (Wang et al. 1983 and Jackson et al. 1984). Several of these data sets can be found at the following web site http://hydrolab.arsusda.gov/. Recent experiments have incorporated X and C band observations (Jackson and Hsu 2001, Jackson et al. 2002).

Table 1. AMSR-E Characteristics

Frequency (GHz)	Polarization	Horizontal Resolution (km)	Swath (km)
6.925	V, H	75	1445
10.65	V, H	48	1445
18.7	V, H	27	1445
23.8	V, H	31	1445
36.5	V, H	14	1445
89.0	V, H	6	1445

Both Aqua and ADEOS-II have additional sensors that can be of value in AMSR analyses. These include the MODIS instrument on Aqua, which is the same as that on Terra and described in later sections.

2.2 Tropical Rainfall Mapping Mission (TRMM) Microwave Imager (TMI)

The SMEX03 Brazil study area falls within the coverage domain of the Tropical Rainfall Mapping Mission (TRMM) Microwave Imager (TMI). It is a five-channel, dual-polarized, passive microwave radiometer with a viewing angle of 52.75^{o} (see Table 2). Coverage is available between + and - 38 degrees latitude. The specific dates and times during SMEX03 are listed in Table 3. The lowest frequency of the TMI is about half that of the SSM/I. Other interesting features of the TMI are its significantly higher spatial resolution (at 19 GHz the TMI is 18 km as opposed to the SSM/I 60 km). Details on this satellite can be found by starting at the following web site http://trmm.gsfc.nasa.gov/data/. There are several sources for these data and products. TMI data have been used in previous soil moisture mapping applications (Jackson and Hsu 2001, Bindlish et al. 2003).

Table 2. TMI Characteristics

Frequency (GHz)	Polarization	Horizontal Resolution (km)	Swath (km)
10.7	V, H	38	790
19.4	V, H	18	790
21.3	H	16	790
37.0	V, H	10	790
85.5	V, H	4	790

Table 3. TMI Coverage of Brazil Site During SMEX03

Date	Local Time	Distance Track to Site	Overpass
2003-09-14	03:26	60 km	Descending
2003-09-14	13:19	320 km	Ascending
2003-09-15	12:22	80 km	Ascending
2003-09-17	02:18	260 km	Descending
2003-09-18	01:22	140 km	Descending
2003-09-18	11:14	240 km	Ascending
2003-09-19	10:18	160 km	Ascending
2003-09-21	00:13	180 km	Descending
2003-09-22	23:17	220 km	Descending
2003-09-22	09:09	160 km	Ascending
2003-09-23	08:13	240 km	Ascending
2003-09-25	22:08	100 km	Descending
2003-09-26	21:12	320 km	Descending
2003-09-26	07:05	80 km	Ascending
2003-09-27	06:09	320 km	Ascending
2003-09-28	21:00	400 km	Descending
2003-09-28	20:04	20 km	Descending

2.3 Special Sensor Microwave Imager (SSM/I)

SSM/I satellites have been collecting global observations since 1987. The SSM/I satellite data can only provide soil moisture under very restricted conditions because the frequencies (see Table 4) were not selected for land applications (Jackson 1997, Teng et al. 1993). The viewing angle of the SSM/I is 53.1^{o}.

There may be as many as three satellites with the SSM/I on board in operation during SMEX03. The ascending equatorial crossing times (UTC) of the three currently available satellites are F13 (17:54), F14 (20:46), and F15 (21:20). SSM/I data are useful in some aspects of algorithm development and provide a cross reference to equivalent channels on the TMI and AMSR instruments. SSM/I data are freely available to users through http://www.saa.noaa.gov/. As in past experiments, the data will be subset and repackaged for this experiment.

Table 4. SSM/I Characteristics

Frequency (GHz)	Polarization	Spatial Resolution (km)	Swath (km)
19.4	H and V	69 x 43	1200
22.2	V	60 x 40	1200
37.0	H and V	37 x 28	1200
85.5	H and V	15 x 13	1200

2.4 Coriolis WindSat

WindSat is a multi-frequency polarimetric microwave radiometer developed by the U.S. Navy and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) (http://www.pxi.com/windsat). It is one of the two primary instruments on the DoD Space Test Program's Coriolis Mission. The Coriolis satellite was successfully launched on January 6, 2003, with an expected life cycle of three years. The WindSat data is expected to be available for SMEX03 on all sites spanning from June 24, 2003 to September 26, 3003.

The WindSat radiometer operates at nominal frequencies of 6.8, 10.7, 18.7, 23.8, and 37 GHz. Using a conically-scanned 1.83 m offset parabolic reflector with multiple feeds, the WindSat covers a 1025 km active swath (based on an altitude of 830 km) and provides two looks at both fore (1025 km) and aft (350 km) views of the swath. The nominal earth incidence angle (EIA) is in the range of 50 – 55 degrees. The inclination of the WindSat orbit is 98.7 degrees. It has a sun synchronous polar orbit with an ascending node at 6:00 PM and a descending node at 6:00 AM local time. The WindSat has similar frequencies to the Advanced Microwave Scanning Radiometers on the Earth Observing System (AMSR-E), with the addition of full polarization for 10.7, 18.7 and 37.0 GHz and the lack of 89.0 GHz. The characteristics of the WindSat radiometer are listed in Table 5. The methods developed for algorithm development and validations for AMSR-E during SMEX03 may be applied to WindSat with minimal modifications.

Table 5. Characteristics of WindSat.				
Frequency (GHz)	Polarization	Incidence Angle (Deg.)	Footprint (Km)	Fore/Aft Swath (Km)
6.8	V, H	53.5	40 x 60	1025/350
10.7	V, H, U 4	49.9	25 x 38	1025/350
18.7	V, H, U, 4	55.3	16 x 27	1025/350
23.8	V ,H	53.0	12 x 20	1025/350
37.0	V, H, U 4	53.0	8 x 13	1025/350

2.5 Terra Sensors

The NASA Terra spacecraft (http://terra.nasa.gov/About/) includes several instruments of value to the soil moisture investigations proposed here. Of particular interest are the Moderate-resolution Imaging Spectroradiometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

MODIS can view the entire surface of the Earth every 1-2 days. MODIS is a whisk broom scanning imaging radiometer consisting of across-track scan mirror, collecting optics, and a set of linear arrays with spectral interference filters located in four focal planes. MODIS has a viewing swath width of 2330 km (the field of view sweeps ± 55° cross-track) and will provide high-radiometric resolution images of daylight-reflected solar radiation and day/night thermal emissions over all regions of the globe. Its spatial resolution ranges from 250 m to 1 km at nadir, and the broad spectral coverage of the instrument (0.4 - 14.4 µm) is divided into 36 bands of various bandwidths (Table 6) optimized for imaging specific surface and atmospheric features. Coverage time is about 16:15 UTC. MODIS data are publicly available through NASA DAAC facilities.

ASTER provides high-resolution multispectral data (Table 7) on request. Coverage will be requested for a portion of the SMEX03 Brazil study region on September 21, 2003.

2.6 Landsat Thematic Mapper

The Landsat Thematic Mapper (TM) satellites collect data in the visible and infrared regions of the electromagnetic spectrum. Data are high resolution (30 m) and are very valuable in land cover and vegetation parameter mapping. Additional details on the Landsat program and data can be found at http://geo.arc.nasa.gov/sge/landsat/landsat.html. The Landsat paths and row reference numbers for the SMEX03 Brazil study regions are 220/68 (primary) and 220/69. At the present time only Landsat 5 is providing data pending the resolution of a problem with Landsat 7. The availability of Landsat data is unknown.

Table 6. MODIS Band Characteristics		
Band	Bandwidth (μm)	Spatial Resolution (m)
1	620 - 670	250
2	841 - 876	250
3	459 - 479	500
4	545 - 565	500
5	1230 - 1250	500
6	1628 - 1652	500
7	2105 - 2155	500
8	405 - 420	1000
9	438 - 448	1000
10	483 - 493	1000
11	526 - 536	1000
12	546 - 556	1000
13	662 - 672	1000
14	673 - 683	1000
15	743 - 753	1000
16	862 - 877	1000
17	890 - 920	1000
18	931 - 941	1000
19	915 - 965	1000
20	3.660 - 3.840	1000
21	3.929 - 3.989	1000
22	3.929 - 3.989	1000
23	4.020 - 4.080	1000
24	4.433 - 4.498	1000
25	4.482 - 4.549	1000
26	1.360 - 1.390	1000
27	6.535 - 6.895	1000
28	7.175 - 7.475	1000
29	8.400 - 8.700	1000
30	9.580 - 9.880	1000
31	10.780 - 11.280	1000
32	11.770 - 12.270	1000
33	13.185 - 13.485	1000
34	13.485 - 13.785	1000
35	13.785 - 14.085	1000
36	14.085 - 14.385	1000

Table 7. Characteristics of the ASTER Sensor Systems			
System	Channel	Spectral Range (µm)	Spatial Resolution (m)
VIR	1	0.52-0.60	15
	2	0.63-0.69	
	3N	0.78-0.86	
	3B	0.78-0.86	
SWIR	4	1.60-1.70	30
	5	2.145-2.185	
	6	2.185-2.225	
	7	2.235-2.285	
	8	2.295-2.365	
	9	2.360-2.430	
TIR	10	8.125-8.475	90
	11	8.475-8.825	
	12	8.925-9.275	
	13	10.25-10.95	
	14	10.95-11.65	

2.7 Advanced Very High Resolution Radiometer (AVHRR)

AVHRR is an instrument on the TIROS-N series satellite designed to operate in a near-polar, sun-synchronous orbit. During SMEX03 it is anticipated that 2 satellites may be providing AVHRR data Currently these NOAA 15 (morning coverage) and NOAA 16 (afternoon coverage). The AVHRR sensor collects data in the visible and infrared regions of the electromagnetic spectrum and has a spatial resolution of approximately 1 km. Additional information on these data can be found at http://www.saa.noaa.gov/.

Data can be acquired in three formats from the satellite. High Resolution Picture Transmission (HRPT) data are full resolution image data transmitted to a ground station, as they are collected. The average instantaneous field-of-view of 1.4 milliradians yields a HRPT ground resolution of approximately 1.1 km at the satellite nadir from the nominal orbit altitude of 833 km (517 mi). Local Area Coverage (LAC) is full resolution data that are recorded on an onboard tape recorder for subsequent transmission during a station overpass. Resolution is the same as HRPT. Global Area Coverage (GAC) data are derived from a sample averaging of the full resolution AVHRR data. Four out of every five samples along the scan line are used to compute one average value and the data from only every third scan line are processed, which results in a 1.1 km by 4 km resolution.

2.8 Geostationary Operational Environmental Satellites (GOES)

GOES satellites provide continuous monitoring in selected visible and infrared electromagnetic channels. Coverage of Iowa is currently provided by GOES-8. Of particular interest to this project is the imager. This is a multichannel instrument (0.65, 3.9, 6.7, 11, and 12 micrometers) that senses radiant energy and reflected solar energy from the Earth's surface and atmosphere. The resolution is 1 km for the visible and 4 km for the infrared channels. Additional information can be found at http://www.saa.noaa.gov/.

3 AIRCRAFT REMOTE SENSING INSTRUMENTS

3.1 Polarimetric Scanning Radiometer (PSR)

The PSR is an airborne microwave imaging radiometer operated by the NOAA Environmental Technology Laboratory (Piepmeier and Gasiewski 2001) for the purpose of obtaining polarimetric microwave emission. It has been successfully used in several major experiments including SGP99 and SMEX02 (Jackson et al. 2002).

A typical PSR aircraft installation is comprised of four primary components: 1) scanhead, 2) positioner, 3) data acquisition system, and 4) software for instrument control and operation. The scanhead houses the PSR radiometers, antennas, video and IR sensors, A/D sampling system, and associated supporting electronics. The scanhead can be rotated in azimuth and elevation to any arbitrary angle. It can be programmed to scan in one of several modes, including conical, cross-track, along-track, and spotlight. The positioner supports the scanhead and provides mechanical actuation, including views of ambient and hot calibration targets. The PSR data acquisition system consists of a network of four computers that record several asynchronously sampled data streams, including navigation data, aircraft attitude, scanhead position, radiometric voltage, and calibration target temperatures. These streams are available in-flight for quick-look processing.

During SMEX03, the PSR/CX scanhead will be integrated onto the NASA WFF P-3B aircraft in the aft portion of the bomb bay. The PSR/CX scanhead is an upgraded version of the previously successful PSR/C scanhead used during SGP99 and was used in SMEX02 (Figure 1 and Table 7). The installation will utilize the NOAA P-3 bomb bay fairing, and will locate the PSR immediately aft of the NASA GSFC ESTAR L-band radiometer.

The PSR/CX scanhead will have the polarimetric channels listed in Table 8 for SMEX03. The system will operate using conical scanning. Mapping characteristics are described in Table 9. Figure 2 shows the results of one day of mapping brightness temperature using the PSR in SGP99.

At the end of a each set of flight lines a steep (~60 degree) port roll will be requested for the purpose of calibrating the PSR radiometers using cold sky looks. Additional details on the PSR not presented here can be found at http://www1.etl.noaa.gov/radiom/psr/.

Figure 1. PSR/C scanhead installed on the NASA P3-B aircraft during the SGP99 experiment.

Table 8. PSR/CX Channels for SMEX03		
Frequency (GHz)	Polarizations	Beamwidth
5.82-6.15	V,h	10o
6.32-6.65	V,h	10o
6.75-7.10 *	v,h,U,V	10o
7.15-7.50	V,h	10o
10.6-10.8 *	v,h,U,V	7o
10.68-10.70 *	V,h	7o
9.6-11.5 um IR	V+h	7o

* Indicates close to an AMSR-E channel.

Table 9. PSR Flightline and Mapping Specifications for SMEX03	
Altitude (AGL) in m	7300
Number of parallel flight lines	4
Flight line length (km)	150
Flight line spacing (km)	19
Scan period (seconds)	8
Incidence angle (deg)	55
3-dB footprint resolution	3.0 km at 6 GHz 2.0 km at 10 GHz
Sampling	Oversampling above Nyquist

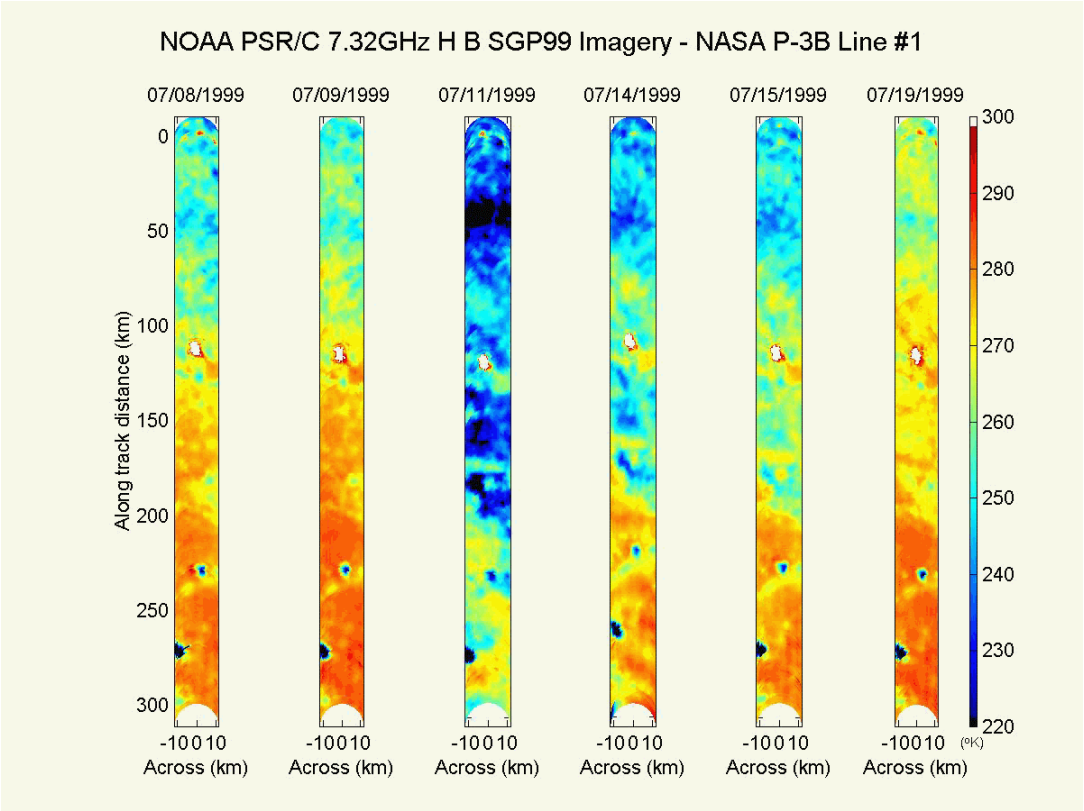


Figure 2. SGP99 PSR/C conically-scanned brightness temperature imagery 7.325 GHz channel, H-polarization, North looking.

3.2 Electronically Scanned Thinned Aperture Radiometer (ESTAR)

ESTAR is a synthetic aperture, passive microwave radiometer operating at a center frequency of 1.413 GHz and a bandwidth of 20 MHz. As installed in the SMEX03 mission it is horizontally polarized.

Aperture synthesis is an interferometric technique in which the product (complex correlation) of the output voltage from pairs of antennas is measured at many different baselines. Each baseline produces a sample point in the Fourier transform of the scene, and a map of the scene is obtained after all measurements have been made by inverting the transform. ESTAR is a hybrid real and synthetic aperture radiometer that uses real antennas (stick antennas) to obtain resolution along-track and aperture synthesis (between pairs of sticks) to obtain resolution across-track (Le Vine et al., 1994). This hybrid configuration could be implemented on a spaceborne platform.

The effective swath created in the ESTAR image reconstruction (essentially an inverse Fourier transformation) is about 45° wide at the half power points. The field of view is restricted to 45° to avoid distortion of the beam but could be extended to wider angles if necessary. The image reconstruction algorithm in effect scans this beam across the field of view in 2° steps. The beam width of each step varies depending on look angle from 8 to 10°, therefore, the individual original data are not independent, since each data point overlaps its neighbors. Contiguous beam

positions can be achieved by averaging the response of several of these data points. This results in approximately nine independent beam positions. For this experiment the swath will be restricted to approximately 35°. Another approach to using the data, especially in a mapping mode, is to interpret each of the original nonindependent observations as a sample point and then use a grid overlay to average the data. The final product of the ESTAR is a time referenced series of data consisting of the set of beam position brightness temperatures at 0.25 second intervals.

Calibration of the ESTAR is achieved by viewing two scenes of known brightness temperature. By plotting the measured response against the theoretical response, a linear regression is developed that corrects for gain and bias. Scenes used for calibration include black body, sky, and water. During aircraft missions, a black body is measured before and after the flight and a water target during the flight. Water temperature is determined using a thermal infrared sensor. The match in level and pattern is quite good and in general the ESTAR calibration should be considered accurate and reliable. For interpretation purposes it should be noted that the sensitivity of soil moisture to brightness temperature is 1% for 3°K.

ESTAR has demonstrated the potential of L band radiometry and STAR technology (Levine et al. 1994 and 2001, Jackson et al., 1995 and 1999). Figure 3 is an example of the type of product produced after processing the ESTAR data. Details on ESTAR and soil moisture products can be found at the following web site http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/SGP97/estar.html.

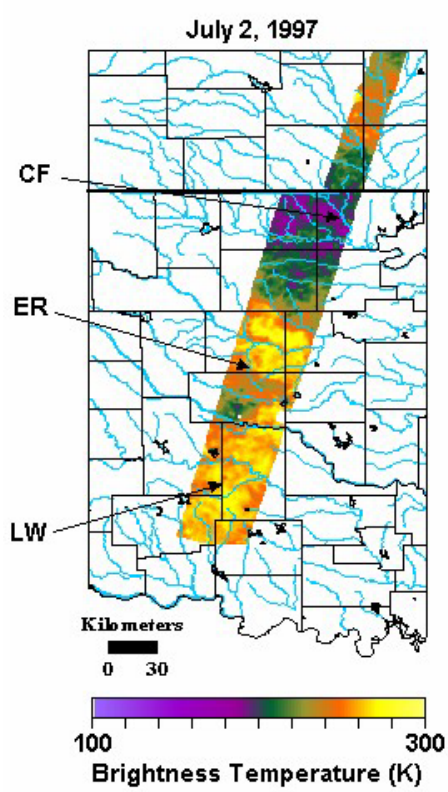


Figure 3. ESTAR brightness temperature image from the SGP97 experiment (Jackson et al. 1999).

4 BRAZIL (BZ) STUDY AREA

4.1 Regional Description

The quality of the soil moisture product derived from AMSR-E will in part depend upon the specific regional validation efforts. There are obvious gaps in the geographic and climatic conditions that are currently planned for study. The inclusion of sites in Brazil will greatly improve the robustness of the validation effort.

The Brazilian ecological region known as the Cerrado (Figure 4) was selected as the focus of the SMEX03 experiment. This region consists of over 200 million hectares dominated by grasslands. Typical vegetation conditions within the study region are illustrated in Figure 5. Figure 6 shows general vegetation conditions as reflected in a Landsat image obtained in February 2000. A validation site in this domain would be compatible with AMSR capabilities and would also be representative of a large geographic region. For SMEX03 a site that includes the Cerrado and the bordering semi-arid region called the Cattinga was selected for mapping.

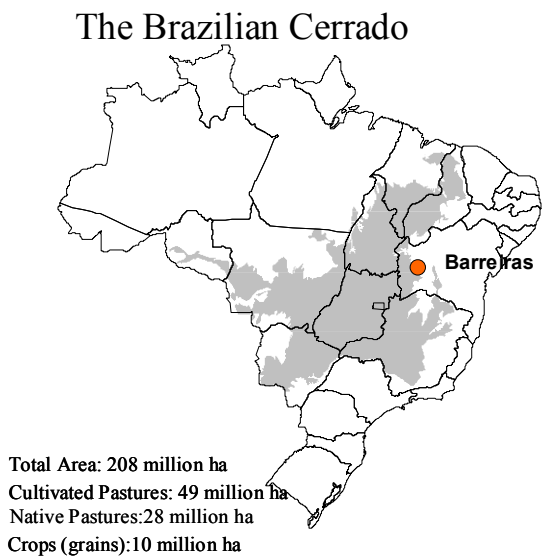


Figure 4. The Cerrado Region of Brazil.

An additional objective of SMEX03 in Brazil is to increase our understanding of the passive microwave response of the diverse vegetation types found in this region of the world. We are particularly interested in the rainforest. There is evidence that there is no below canopy contribution to the passive microwave emission at the AMSR frequencies and that the brightness temperature is nearly constant over extended periods. This allows the rainforest to be used as a calibration (hot) target for the satellite sensors. Considering the current uncertainties that exist with AMSR calibration this may be a significant contribution of SMEX03. To address this objective we will study a transect from Brasilia to Santareum on the last day of the mission.

Vegetation Near Barreiras
S 12.100º W 44.977º

MN-1 Abandoned Pasture
S 12.000º W 44.941º

MN-4 Cultivated Pasture
S 11.750º W 44.748º

LE-2 Rice
S 11.917º W 45.289º

Figure 5. Potential sampling sites illustrating vegetation cover conditions in the BZ Region. Photos were obtained in March 2003.

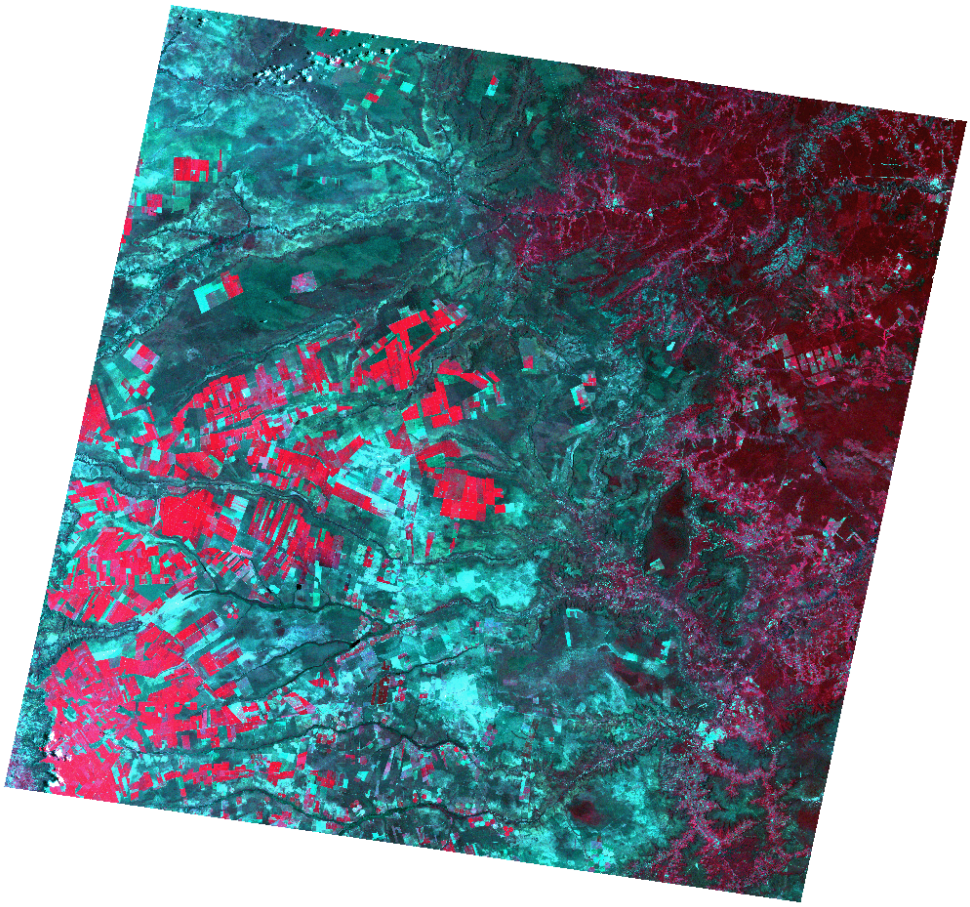


Figure 6. Landsat 7 TM image obtained February 22, 2000 (220/68) of the Cerrado Region near Barreiras, Brazil.

4.2 Soil Moisture, Temperature, and Vegetation Ground Sampling Protocols

Ground based soil moisture measurements are critical to SMEX03. The general model we have established for sampling is shown in Figure 7. The two primary objectives are:

- Provide footprint scale (~ 50 km) average surface volumetric soil moisture for the development and validation of satellite microwave remote sensing soil moisture retrieval algorithms at a range of frequencies. This is called Regional sampling.
- Provide calibrated continuous soil moisture for water balance investigations as well as temporal adjustments of the Regional sampling results. This is called Tower sampling.

The goal of Regional soil moisture sampling is to provide a reliable estimate of the VSM mean and variance within a single satellite passive microwave footprint (~50 km) and multiple EASE-grid 25 km cells at the nominal time of the Aqua or ADEOS-II AMSR overpass (1330 or 1030 local standard time). The exact center location and orientation of the satellite footprint will vary with each overpass. A grid of sites will be sampled each day that covers a domain of approximately 50 km by 100. Efforts should be made to have a nominal 8-10 km between sites, however, logistics may alter

this. A single location within each of these sites will be sampled. As noted, these measurements are used primarily to support the AMSR based microwave investigations; therefore, the Regional sampling will be conducted within a two to three hour time window of the satellite overpass.

The primary measurement made will be gravimetric soil moisture of the 0-6 cm soil layer. In addition, measurements will be made with a Theta Probe (TP). Dielectric constant provided by the TP is converted to volumetric soil moisture using a calibration equation. There are built in calibration equations, however, we will develop field and site specific relationships using supplemental either volumetric soil moisture or gravimetric soil moisture and bulk density sampling. Figure 7 illustrates how regional sampling was performed in SMEX02, which will have to be adapted for Brazil.

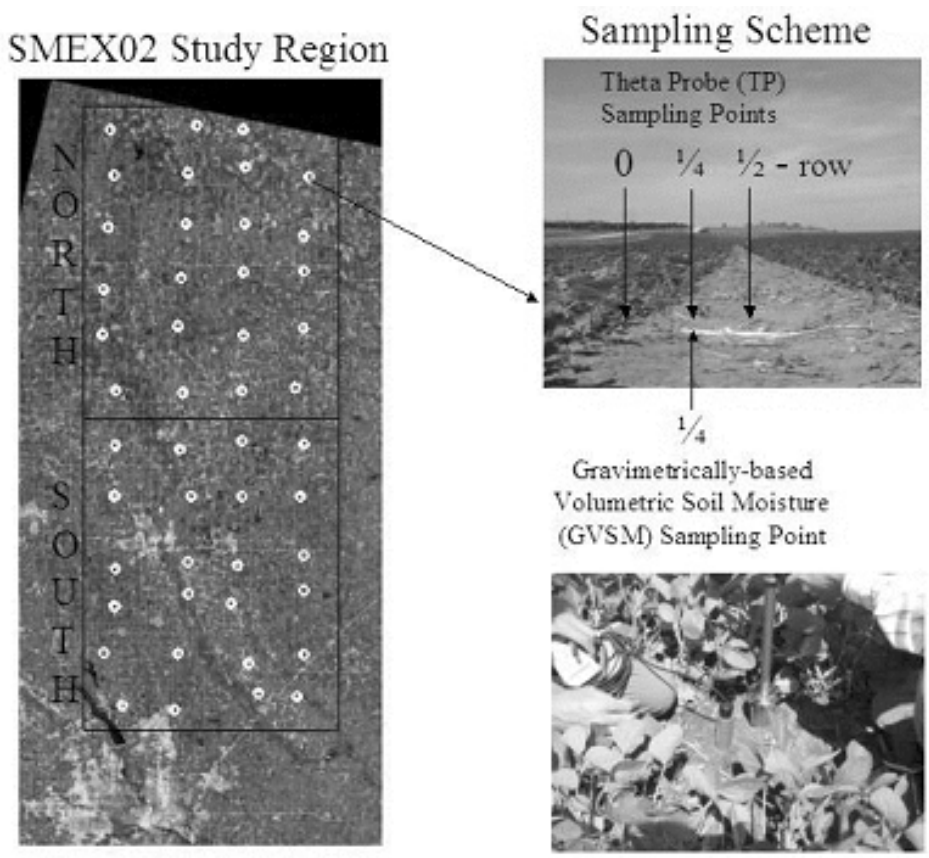


Figure 7. Regional soil moisture sampling in SMEX02.

The objectives of the soil temperature sampling are nearly identical to those of soil moisture. However, there are a few differences related to the spatial and temporal variability of temperature versus soil moisture. Typically the soil temperature exhibits lower spatial variability, especially as depth increases. The soil temperatures will be obtained using a temperature probe inserted to depths of 1 cm, 5 cm, and 10 cm depths. Regional temperature sampling will be conducted at the specific single location selected for sampling in the site.

Vegetation biomass sampling and characterization will be performed on a selected number of representative sites within each Region. The measurements that will be made are:

- Plant height
- Ground cover
- Stand density
- Phenology
- Leaf area (LAI)
- Green and dry biomass

Land cover will be mapped using satellite imagery. To support this activity a number of sites will be surveyed in each region for algorithm training.

Detailed protocols describing sampling techniques can be found in the full length SMEX03 plan located at http://hydrolab.arsusda.gov/smex03/.

Meteorological stations are sparsely distributed in the region. In addition to these, the Brazilian Embrapa team will install meteorological and insitu soil moisture stations in the study region prior to the aircraft experiment. Some of these may be left in place for continued validation of the satellite data. These stations will include the Vitel Hydra Probe at a depth of 5 cm.

4.3 Flightlines

The PSR/CX and ESTAR instruments will be installed on the NASA WFC P3-B aircraft. All data collection flights over Brazil must include a Brazilian observer. Instruments will not operate during transits without an observer on board. A copy of all data will be provided to the observer on a daily basis by the instrument PIs.

An aircraft briefing will be conducted each day. As in previous missions, the goals of the experiment design are to collect data for both algorithm development/verification and soil moisture mapping. The extent and scale of the mapping must satisfy the range of objectives of the AMSR components of SMEX03. The following section describes the general aspects of the flight missions.

The primary mission of the P3-B is to collect high altitude data over the study regions with the PSR instrument with the goal of AMSR soil moisture algorithm development and product validation. Another very important objective is to collect data with the ESTAR over the regions. Mission design and operations are dependent on the PSR and not the ESTAR.

Flights will be conducted during the day in order to match either the nominal Aqua overpass time of 1330 or ADEOS-II at 10:30 am. Each flight will be approximately 4 hours in duration. The key features are:

• Dates	December 2-December 9
• Aircraft Base	Brasilia
• Distance to Start (km)	400
• No. Lines	5

The time frame for SMEX03 Brazil is December 2-9, 2003. This could shift a few days later depending upon aircraft maintenance or weather conditions It is anticipated that the aircraft would be available for flights on five days, one of which will be a transect while returning to the U.S.. Each mapping flight might be three hours long. The aircraft base of operations will be the Brasilia Airport.

The flightlines in Brazil (BZ) (Figure 8 and 9 and Table 10) were designed to provide regional mapping several times during the deployment and coverage of an extended transect one time when returning to the U.S. Mapping lines will provide coverage of two ecological domains, Cerrados and Semi-arid.

The transect (Figure 8) line will provide coverage of a diverse set of vegetation conditions and will be supported by ground observations at important locations.

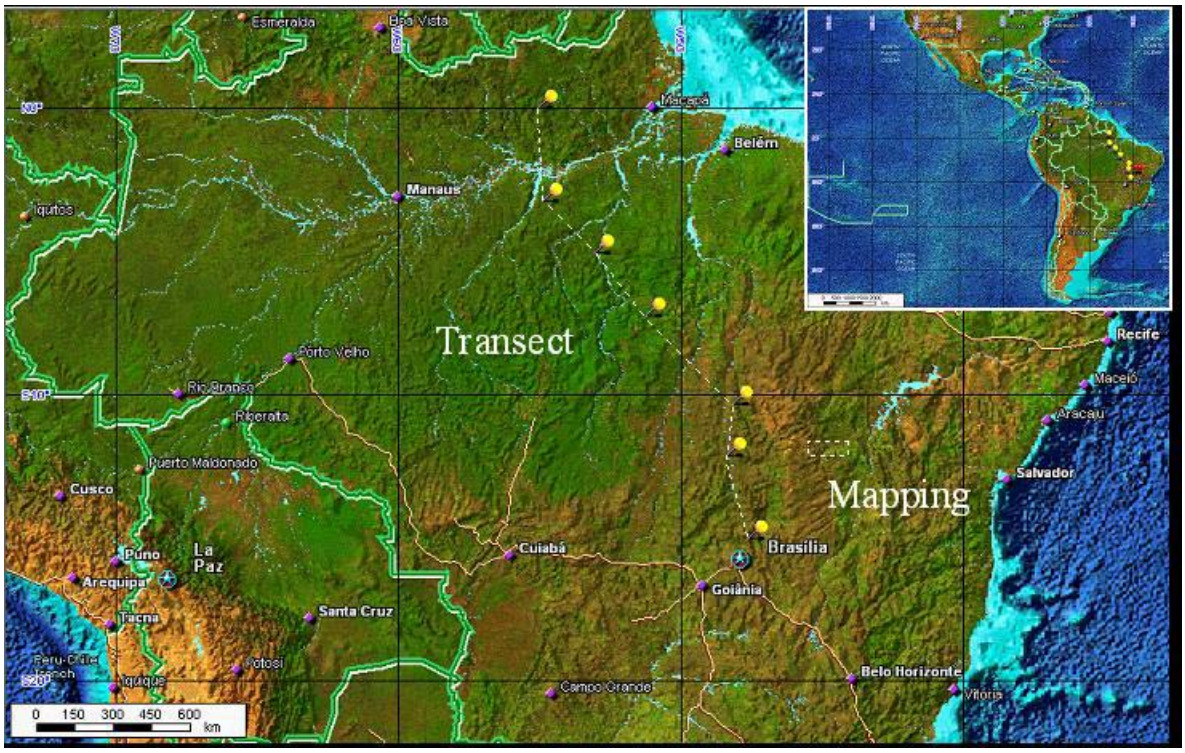


Figure 8. Location of Brazil regional study area and transect flightline.

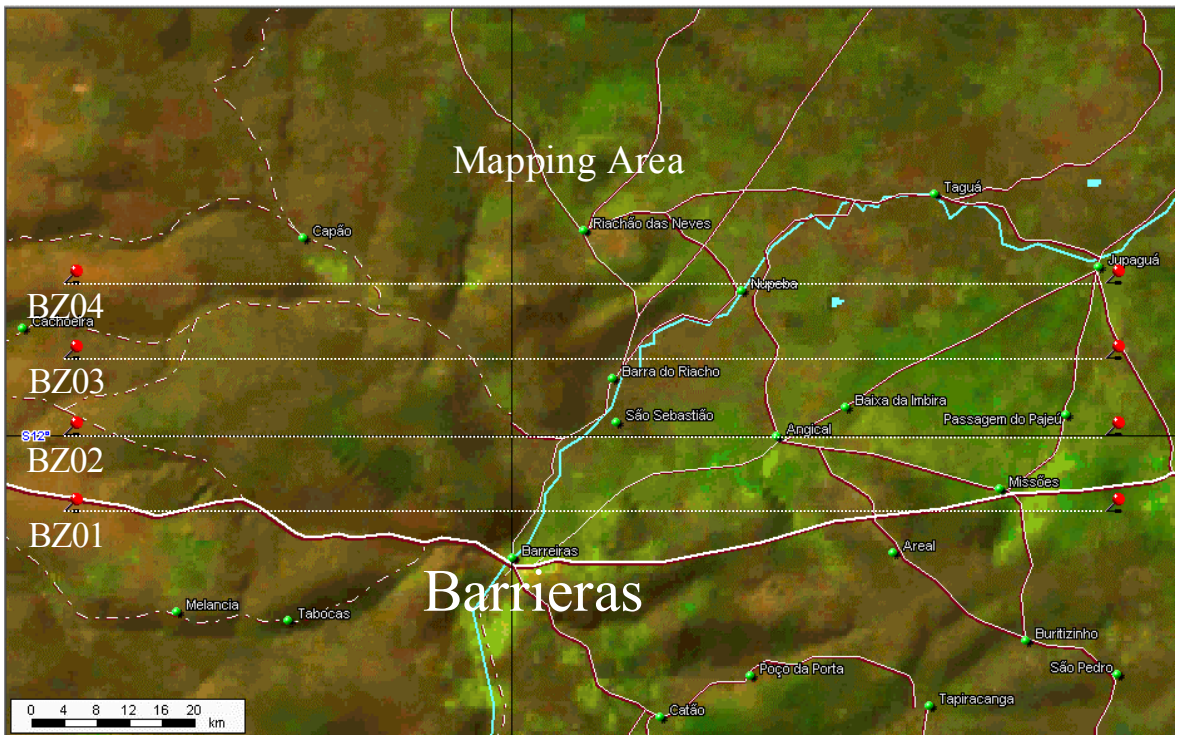


Figure 9. Brazil (BZ) regional study area and flightlines.

Table 10. SMEX03 Brazil (BZ) Flightlines

Line	Waypoint	Altitude (m above ground level)	Length (km)	Type	Latitude (Degrees)	Longitude (Degrees)
BZ01	A	7300	120	Regional Mapping	-12.083	-45.500
	B				-12.083	-44.333
BZ02	A	7300	120	Regional Mapping	-12.000	-44.333
	B				-12.000	-45.500
BZ03	A	7300	120	Regional Mapping	-11.916	-45.500
	B				-11.916	-44.333
BZ04	A	7300	120	Regional Mapping	-11.833	-44.333
	B				-11.833	-45.500
BZ05	A	7300	2130	Transect	-47.597	-15.830
	B				-48.339	-12.177
	C				-48.142	-10.351
	D				-51.223	-7.383
	E				-53.021	-5.099
	F				-54.893	-3.286
	G				-55.000	0.000

4.4 Ground Sampling Sites

The Brazilian team will have complete responsibility for the ground component of the experiment and will provide ground sampling of soil moisture, soil temperature and vegetation. To the degree possible they will follow the protocols specified.

Sampling will be primarily the Regional type. Sites will be selected to represent typical conditions and distributed over the mapping domain, subject to road access. Those listed in Table 11 and shown in Figure 10 are the current set.

Table 11. Ground sampling sites for Brazil

Site	ID	Land Cover	Reference Coordinates	
			Latitude (Deg.)	Longitude (Deg.)
BZ01	MN-1	Mansidao; abandoned pasture	-12.0000	-44.9411
BZ02	MN-2	Mansidao; regeneration	-11.9167	-44.8847
BZ03	MN-3	Mansidao; natural vegetation	-11.8333	-44.8322
BZ04	MN-4	Mansidao; cultivated pasture	-11.7500	-44.7481
BZ05	RN-3	Riachao das Neves; local farmer's backyard	-11.8333	-44.8542
BZ06	RN-4	Riachao das Neves; urban area	-11.7500	-44.9028
BZ07	SF-1	Sao Francisco farm; natural vegetation	-12.0000	-45.4411
BZ08	AE-1	Aeroporto; remaining natural vegetation	-12.0000	-45.1089
BZ09	LE-1	Luis Eduardo Magalhaes city; natural vegetation	-12.0000	-45.2767
BZ10	LE-2	Luis Eduardo Magalhaes city; rice crop	-11.9167	-45.2892
BZ11	AN-1	Angical village; urban area of Angical	-12.0000	-44.6867
BZ12	AN-2	Angical village natural vegetation	-12.0154	-44.7243
BZ13	AN-3	Angical village natural vegetation	-12.0249	-44.7458
BZ14	AN-4	Angical village natural vegetation	-12.0487	-44.8756
BZ15	MN-5	Mansidao village natural vegetation	-11.9584	-44.9115
BZ16	AE-2	Aeroporto (airport) natural vegetation	-12.0450	-45.0781
BZ17	LE-3	Luis Eduardo city natural vegetation	-12.0272	-45.2725
BZ18	LE-4	Luis Eduardo city natural vegetation	-12.0491	-45.1940
BZ19	LE-5	Luis Eduardo city cultivated	-12.0899	-45.3621
BZ20	LE-6	Luis Eduardo city natural vegetation	-12.0981	-45.3906
BZ21	LE-7	Luis Eduardo city abandoned area	-12.0713	-45.5082
BZ22	AS-1	Anel da Soja (soybean ring) harvested	-11.9178	-45.4795

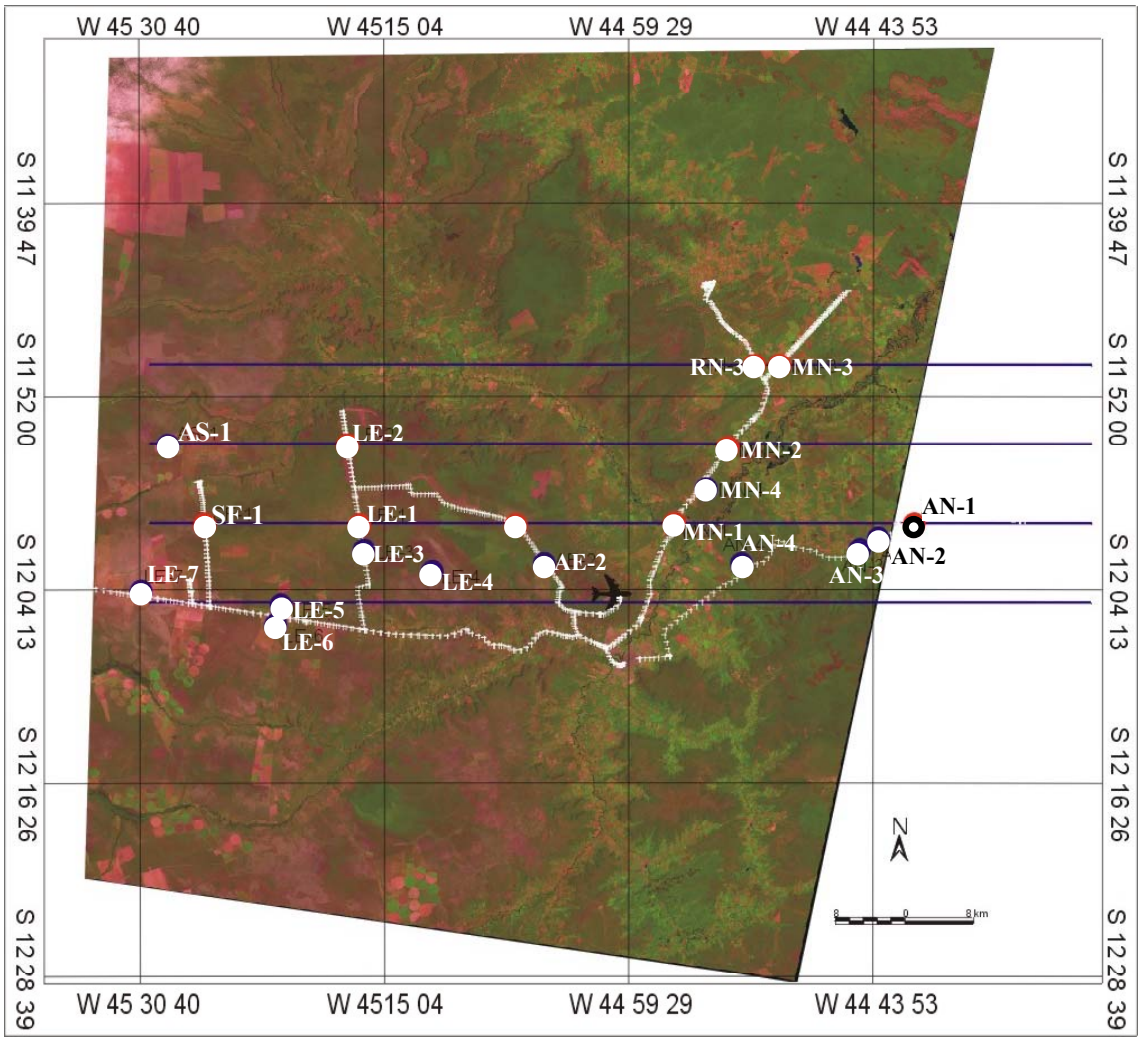


Figure 10. Soil sampling points in Barreiras, Bahia. White lines and circles correspond to the GPS track during siting. Data are superimposed on a Landsat image.

Three tower locations will operate during the field campaign that will provide measurements of precipitation and surface soil moisture (Vitel sensor) in addition to standard meteorological observations. Data will be recorded on an hourly basis. The locations of these sites are being developed. It is anticipated that these stations will operate for an extended period.

4.5 Logistics

Hotels

Brasilia

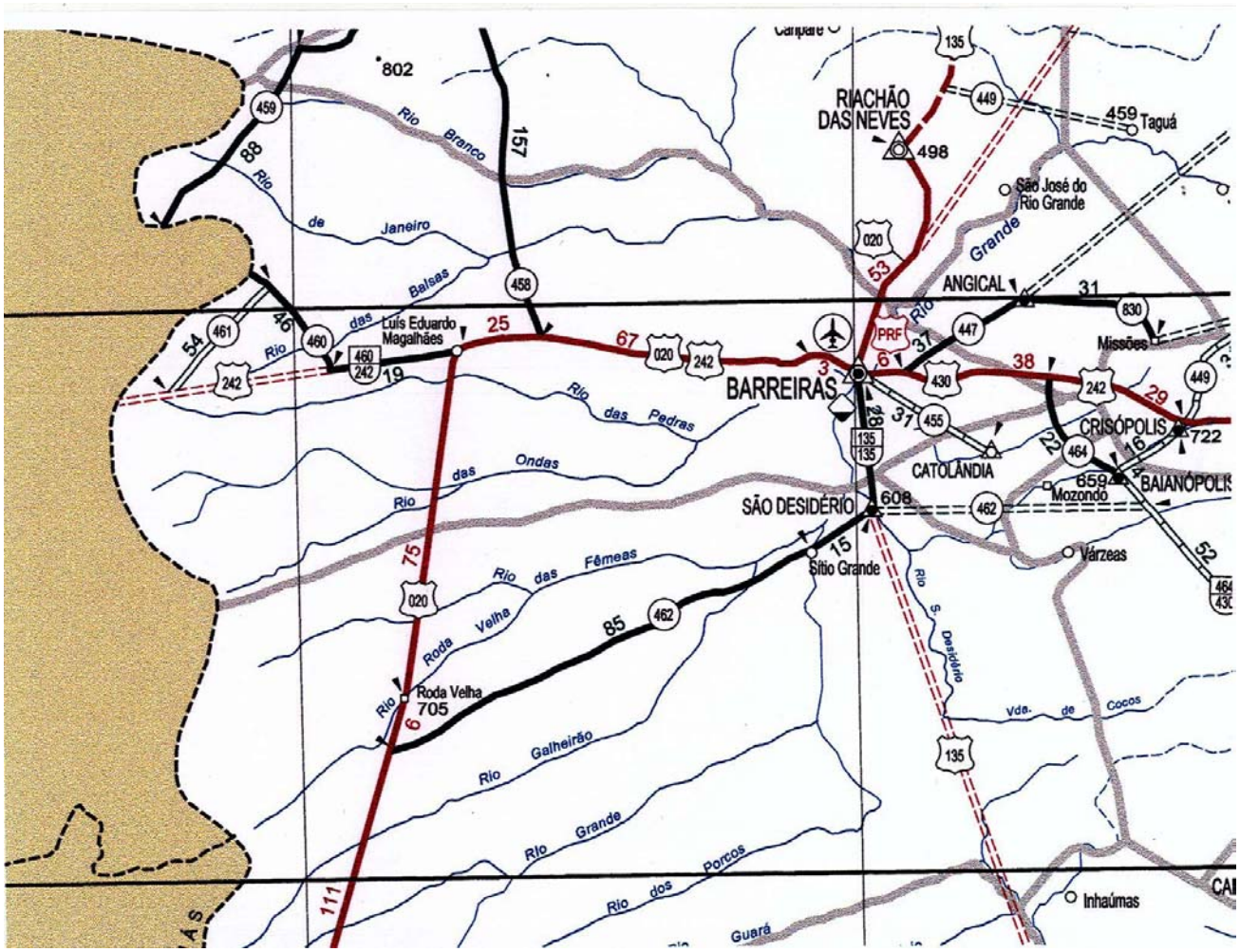
The aircraft team will use the following hotel.
Metropolitan Flat Hotel
SHN, QUADRA 2 - BLOCO H
BRASILIA, BR 70710300
Brasília - DF 70702-905
T: (5561) 424-3500
F: (5561) 327-3938
General Manager: Wlisses F. Santos
E-mail: wsantos@atlantica-hotels.com

Barreiras

The ground sampling team will use this hotel in Barreiras
Solar das Mangueiras Hotel
Coordinates: 12º 07´ 57” S and 45º 00´ 53” W
Address: Av. Ahylon Macedo, 2000
47806-180 Barreiras, BA
Phone: 55 77 612-9200
http://www.ondasnet.com.br/solar/hotel.htm

Solar das Mangueiras Hotel

Road Map



Barrieras Brazil Map

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Campus da UNICAMP
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Campinas S.P. Brazil
(19) 37895805
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5 SCHEDULES (Brazil): September 2003

30 **P-3B Arrival in Brasilia**	**1**	**2**	**3**	**4**	**5**	**6**
7	**8**	**9** **P-3B Departure from Brasilia**	**10**	**11**	**12**	**13**

7 **Satellite Coverage**	**1** **Aqua**	**2** **Aqua** **ADEOS-II** **Coriolis**	**3**	**4** **Aqua**	**5**	**6** **Aqua** **ADEOS-II** **Coriolis**
7 **Coriolis** **Envisat**	**8** **Aqua**	**9** ***Aqua** **Transect**	**10** **ADEOS-II** **ASTER**	**11** **Aqua** **Coriolis**	**12** **Coriolis**	**13** **Aqua**

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