SAFARI 2000: AirMISR Flights and Observations as Part of the Dry Season Campaign

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1. Introduction - This report summarizes the scientific work carried out by AirMISR on behalf of the SAFARI 2000 Dry Season Campaign of August-September, 2000, and in support of achieving the scientific goals of the experiment and MISR.

2. SAFARI 2000 Science Goals - The principal science goals of the SAFARI 2000 Dry Season Campaign have been summarized well in the SAFARI 2000 Science Plan as follows:
(1) characterize, quantify and understand the processes driving biogenic, pyrogenic and anthropogenic emissions in southern Africa, (2) combine atmospheric transport and chemistry models with ground-based, airborne, and satellite-based observations to validate and extend our understanding of the transport and transformations of these emissions, (3) identify where, when, and how the emissions are deposited, and determine their impacts, and (4) lay the foundation for monitoring longer term climatic, hydrological and ecosystem consequences of these biogeochemical and physical processes.

3. Characteristics of AirMISR - AirMISR (Diner, *et al*., 1998) is the name given to the aircraft simulator for MISR, the Multiangle Imaging SpectroRadiometer, AirMISR was developed to assist in validation of and calibration of MISR. The instrument was constructed from a single spare engineering model MISR camera and mounted on a pivoting gimbal. The instrument therefore has radiometric and spectral response similar to MISR cameras. The instrument is mounted in the nose of the ER-2 aircraft and operates at an altitude of 20 km above sea level. The gimbal mount is computer controlled and moves in a plane along the flight direction to view the surface at nadir and angles of 26.1, 45.6 60.0, and 70.5 deg both fore and aft about the local vertical. The camera contains four detector line arrays, each overlain by a spectral filter at 446, 558, 672, and 866 nm, which have spectral bandwidths of 42, 29, 22, and 40 nm, respectively. Unlike MISR the single AirMISR camera has a fixed focal length so that images and pixel size vary in dimension as a function of look angle. The swath width for example, varies from 11 km in the nadir to 32 km at the most oblique look angle. The pixel size varies from 7 m cross-track x 6 m along track in the nadir to 21 x 55 m at the most oblique look angle. Full multiangle viewing of the surface from operational aircraft altitude requires a flight line 145 km in length, and a flight time of about 15 minutes to traverse. An example of AirMISR imagery relative to MISR of brush fires at Timbavati Game Reserve, RSA is shown in Figure 1.

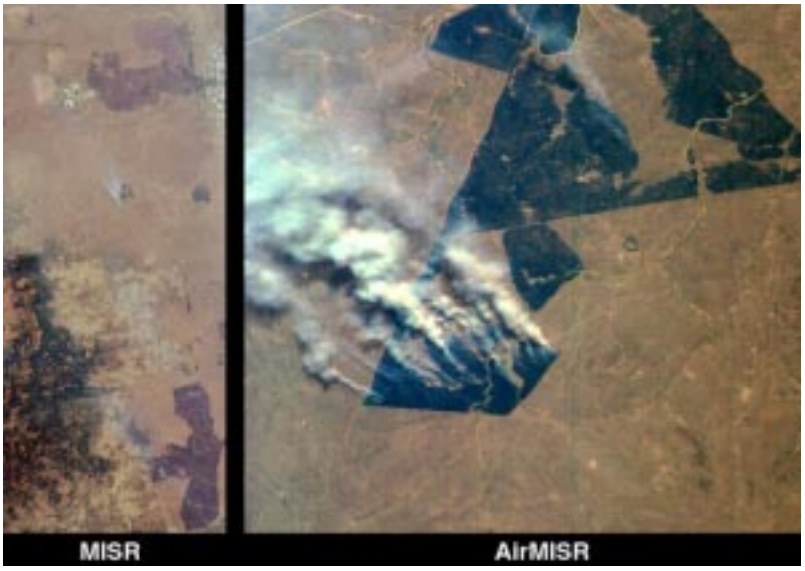

Figure 1. A comparison of the MISR and AirMISR images of the Timbavati prescribed brush fire at Timbavati Game Reserve, Kruger National Park, September 7, 2000. The right-hand AirMISR image has 35 times finer spatial resolution than MISR, illustrating clearly the simulator's utility in aiding fine structure investigations of targets with MISR. AirMISR image covers an area 9 km x 9 km.

4. Principal Uses of AirMISR at SAFARI 2000 - The presence of AirMISR as part of an ER-2 payload at SAFARI 2000 dry season campaign was requested by Michael King. to aid achieving scientific goals of the experiment. Funding for all phases of the operation was provided for the instrument and engineering crew in South Africa throughout duration of the campaign. Ghobad Saghri was the principal engineer for AirMISR at Pietersburg, RSA, during the entire campaign. He was supported at various times by Jim Knighton, Ian McCubbin, Steve Adams, Chuck Sarture.

1. Air MISR serves an extremely useful purpose, illustrated in Figure 1, of providing a scale link between the footpriint size of MISR and the detailed footprint size prevalent at field operations level of meters to kilometer. Remember, for example, that MISR retrieves aerosol optical thickness (AOT) with the heterogeneous land algorithm at a regional scale of 17,6 x 17.6 km. to insure good statistical representation of covariance matrices for construction of the Empirical Orthogonal Functions (EOF's) used in representation of the angular emergent surface radiation, while solar radiometers sample the column average atmosphere over the scattering layer, which amounts to a linear scale O(1 km) more or less.

2. AirMISR offers advantage of specific location of ground targets, such as towers, BRF sites, and/or study of inhomogeneous surfaces or canopies, if needed, down to a scale of 10s of meters, which now become manageable at plot scale in surface studies. Remember, the Cloud Absorption Radiometer (CAR) (*e.g.*, Tsay, *et al*., 1998) has a full BRF footprint ideally falling over a circular flight path ~ 3 km in diameter, with an IFOV of 1 deg, so that large homogeneous targets are preferred; location of sampled ground targets may be difficult. The actual flight path may be subject

to distortion from the ideal circle to an even larger non-circular area if the CV-580 is blown by winds. Nevertheless the macroscopic sampling characteristics and quality of BRF data retrieved by CAR (see for example, Tsay, *et al*., 1998) are of such good characteristics that comparisons with BRF data from AirMISR are sought wherever possible as part of CV-580 and ER-2 sampling.

3. AirMISR can provide flexible timing of multiangle observations to catch important special lighting conditions and cloud free, cloudy conditions of any type, or haze only, depending on ER-2 coordination possibilities and patience and resources of the investigators.

4. With respect to cloud albedo and BRF problems, coordination of flights with instruments such as the Solar Spectral Flux Radiometer (SSFR, Pilewski) unlimited of cloud, cloud plus surface fields are possible.

5. The multiangle viewing capabilities of AirMISR provides the capability of stereoscopic height retrievals of cloud formations and surface topography, limited in spatial resolution of course by the fundamental distance resolving capabilities of the instrument.

6. Coupling AirMISR observations with RC-10 conventional color or IR film photography makes possible study of surface targets by high resolution stereoscopic photography, if needed.

5. Science goals of the campaign involving AirMISR-

1. The principal goals of the flight plans for AirMISR as part of SAFARI 2000 were designed to afford comparisons between AirMISR BRF and aerosol retrievals, MISR aerosol and BRF retrievals, and ground based measurements.: We have emphasized validation goals here, leaving connections between, for example, BRF and LAI, FAPAR to other investigators specializing in such matters.

2. Achieve as many data acquisitions with ground-based atmospheric and surface BRF observations as permitted. When sampling for BRF recoveries fly a rosette flight line pattern (three lines, one in plane of MISR ground track, one in principal plane of Sun, a third bisecting directions of first two) to provide multiple view angle and illumination angles as possible over the complete range of azimuth angles for comparison with surface data such as PARABOLA and scattering models of the aerosols present.

3. Achieve as many co-flights with CAR in BRF mode as possible, using the rosette pattern, consistent with flight time available

4. Achieve as many co-flights with CV-580 and aerosol direct sampling program and AirMISR based aerosol model retrievals (see future work section)

5.Where possible, seek stacks of observations involving surface, CV-580, ER-2 and MISR measurements.

6. AirMISR Runs at SAFARI 2000 - The following Table shows the dates, runs, targets and scientific objectives of the AirMISR runs accomplished as part of SAFARI 2000.

Date	AirMISR LIne No.	Targets	Science Measurements	Aircraft Instruments	AirMISR data status
06Sep00	1	Mongu (SAVE), Botswana	Daily aerosol, LAI, fAPAR, canopy refl., albedo, met sta. CIMEL solar rad. streaker, pyranometer, PAR, MFRSR, MPL, ozonesondes	CV-580 aerosol and BRDF, AERONET, AirMISR	Radiometrically calibrated, geometrically corrected, co-registered (*e.g.*, L1B2). At DAAC, soon available
07Sep00	1-3, 5-8	Kruger (Timbavati fires), RSA, Phalaborwa industrial site, RSA	Biomass burning, fresh and ageing smoke, industrial pollution	AirMISR + other(2)	L1B2
	9	Oliphant River Valley, RSA	Environmentally sensitive area, pollution monitoring	AirMISR + other (2)	L1B2

(1)Source of much of this is Mission Descriptions of ER-2 sorties
(2)Other operational instruments aboard ER-2 include CPL, MAS, MOPITT-A, S-HIS, SSFR
(3) Other operational instruments aboard ER-2 include CPL, MAS, MOPITT-A, S-HIS, SSFR,RC-10,
(4) Other operational instruments aboard ER-2 include CPL,LAS, MAS, MOPITT-A, S-HIS, SSFR, RC-10, UK C-130.

Date	AirMISR LIne No.	Targets	Science Measurements	Aircraft Instruments	AirMISR data status
13Sep00	1	Tshaney (SAVE), Botswana	Rangeland Project	AirMISR + other (3)	L1B2
	2-4	Off West Coast, Namibia	Clear sky and cloud validation, cloud BRDF	AirMISR + other(3), CAR	L1B2
	5	Transit to Etosha from coast	Terra ground validation interest	AirMISR + other (3)	L1B2
	6-8	Etosha Pan, Namibia	Terra overpass, aeolian dust source. No surface insts.	AirMISR + other (3)	L1B2
	9	Okwa River, Namabia	Terra ground validation interest	AirMISR + other (3)	L1B2

(1)Source of much of this is Mission Descriptions of ER-2 sorties
(2)Other operational instruments aboard ER-2 include CPL, MAS, MOPITT-A, S-HIS, SSFR
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Date	AirMISR LIne No.	Targets	Science Measurements	Aircraft Instruments	AirMISR data status
14 Sep00	1-6	Namibia land traverse, east to west	Engineering checks of UPS, interactions with LAS	AirMISR + other (4)	L1B2
	7-10	Marine stratocumulus off Namibian and Angolan coasts	Cloud validation	AirMISR + other (4)	L1B2
	11, 12	Brandberg volcanic complex, other geology	Geologic	AirMISR + other (4)	L1B2
	13	Okaukuejo Camp, Etosha National Park	Dust source	AirMISR + other (4)	L1B2
	14	Namibia terrain	Engineering checks of instrument?	AirMISR + other (4)	L1B2
	15	?	Partial line only	AirMISR + other (4)	L1B2

(1)Source of much of this is Mission Descriptions of ER-2 sorties
(2)Other operational instruments aboard ER-2 include CPL, MAS, MOPITT-A, S-HIS, SSFR
(3) Other operational instruments aboard ER-2 include CPL, MAS, MOPITT-A, S-HIS, SSFR,RC-10,
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AirMISR	Airborne MISR Simulator
CPL	Cloud Physics Lidar
LAS	Leonardo Airborne Simulator
MAS	MODIS Airborne Simulator
MOPITT-A	MOPITT Airborne Simulator
S-HIS	Scanning High-resolution Interferometer Sounder
SSFR	Solar Spectral Flux Radiometer
RC-10	Aerial Camera, 9”×9" format
CAR	Cloud Absorption Radiometer, CV-580

Figures 2 , 5,7, 10, are compilations of the AirMISR flight lines for each day a flight took place.

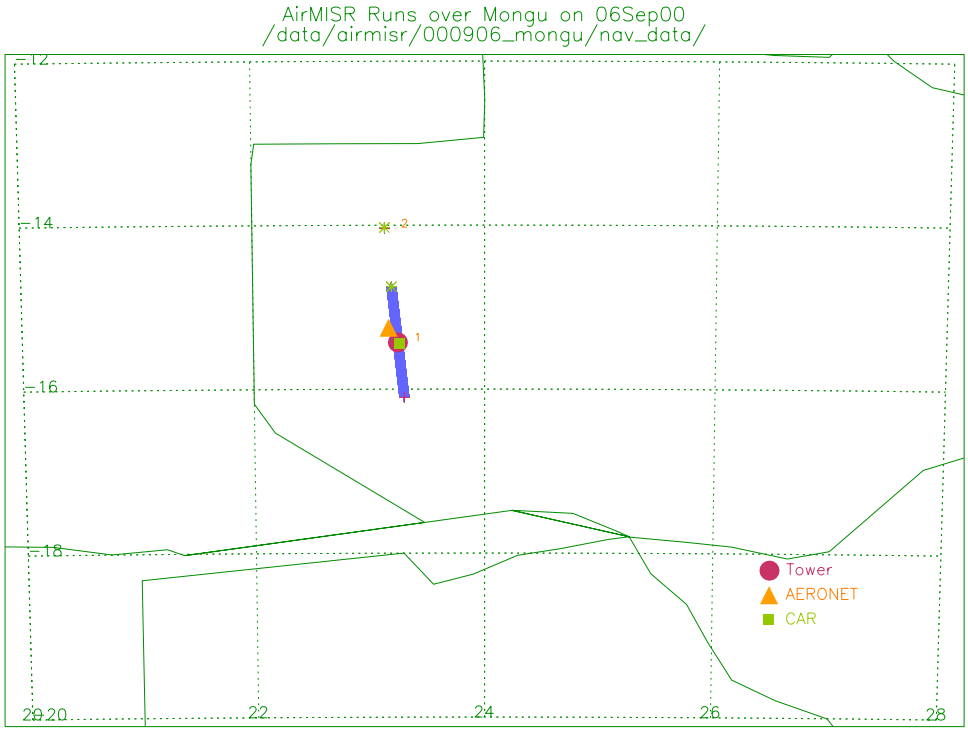

Figure 2. AirMISR flight line for Mongu Tower, Zambia, 06Sep00, showing positions relative to the Tower, the AERONET station and CAR BRDF site for that day.

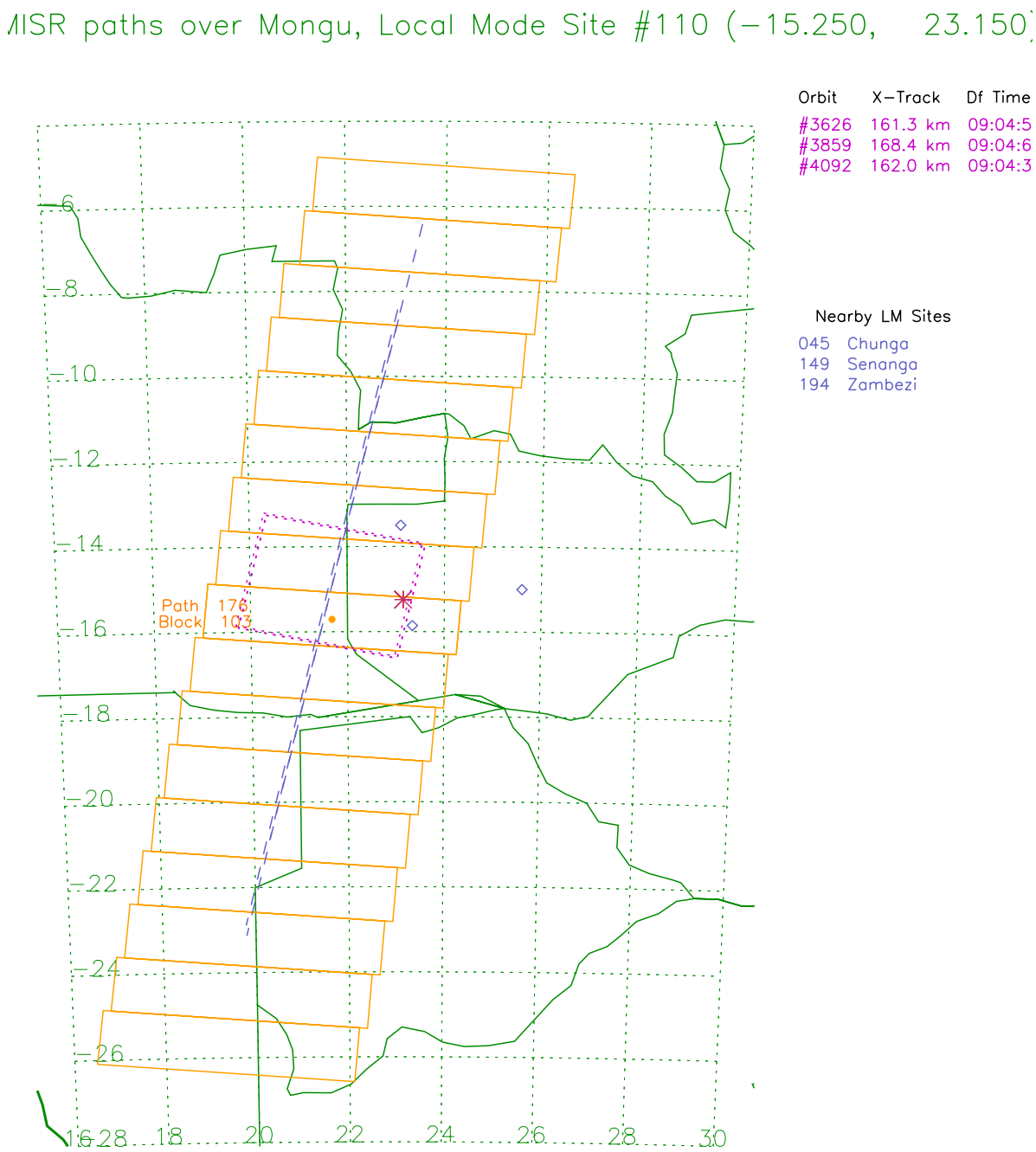
MISR paths over Mongu, Local Mode Site #110 (−15.250, 23.150)
Orbit X−Track Df Time
#3626 161.3 km 09:04:5
#3859 168.4 km 09:04:6
#4092 162.0 km 09:04:3
Nearby LM Sites
045 Chunga
149 Senanga
194 Zambezi
Path 176
Block 103
−6
−8
−10
−12
−14
−16
−18
−20
−22
−24
−26
16 28 18 20 22 24 26 28 30

Figure 3. MISR overpass of Mongu Tower (red star) for 06Sep00, representing the nearest overpass in time to the acquisition of AirMISR and CAR data for the site on 06 Sep00. Golden rectangles represent blocks (400 km $\times$ 150 km). Red dash rectangles represent area of local mode acquisition, where taken. Small blue diamonds are nearby MISR local mode sites

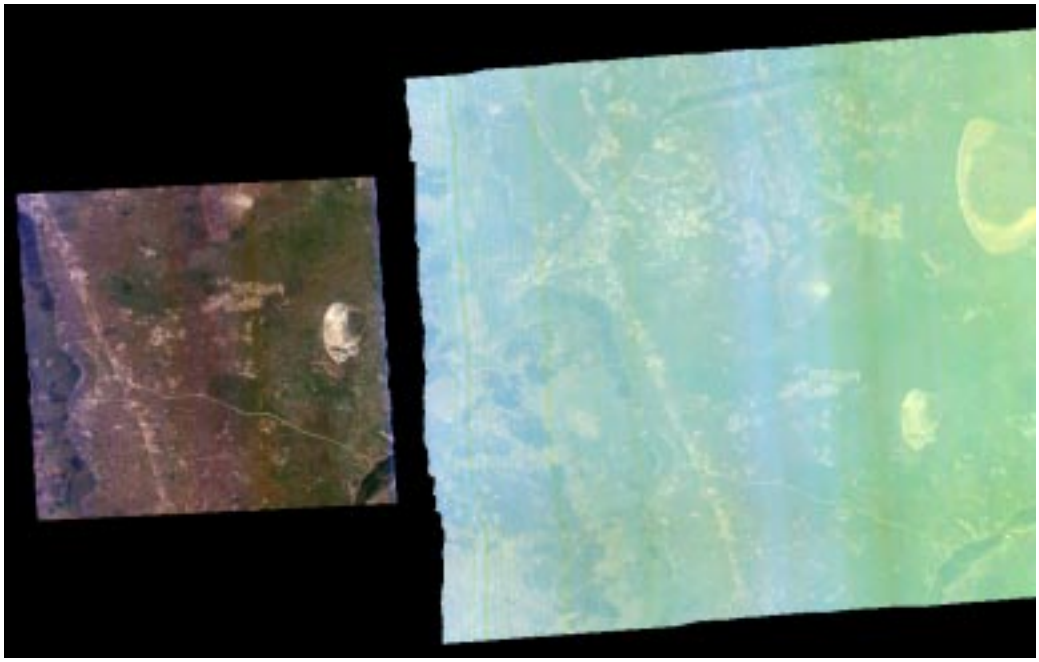

Figure 4. Identical color composite An and Ca views of Level 1B2 AirMISR data at Mongu Tower. Both images stretched identically. Hazy conditions at the site on day of overflight 00 Sep 06, are evident from foggy appearance of the image and obscuration of surface detail. Different sizes of the images arise from differences in angle of view for the fixed focal length AirMISR camera. The An view is 9 km across.

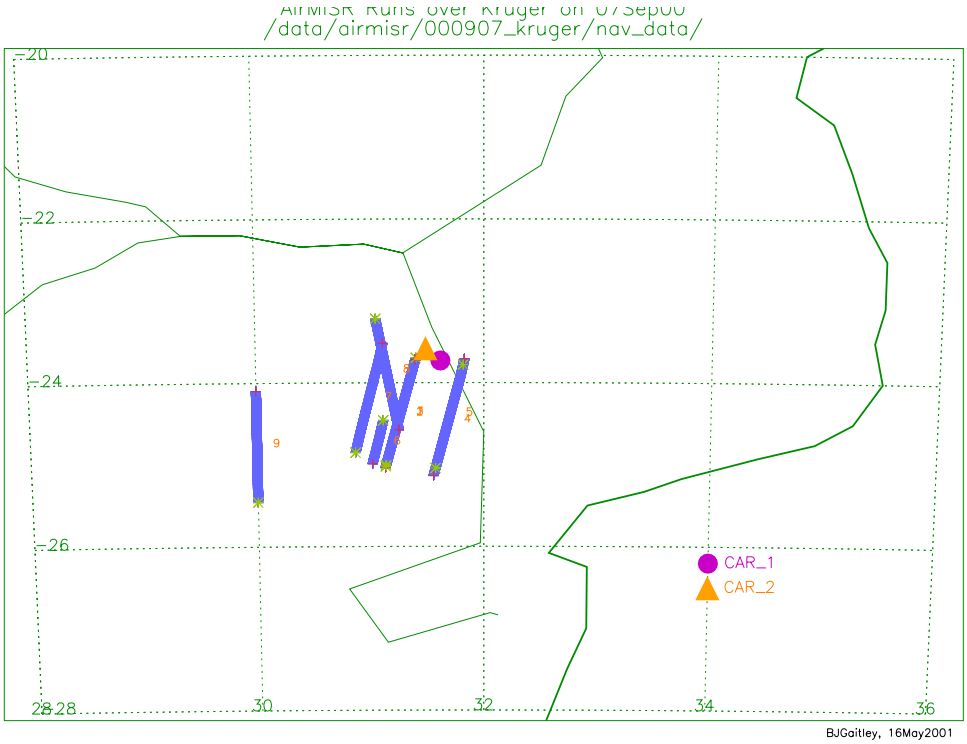

Figure 5. AirMISR flight lines at Timbavati Game Reserve (Kruger National Park), RSA, 07Sep00, showing positions relative to CAR_1 and CAR_2 , BRDF localities flown the same day. AirMISR lines 1,2, and 3 cover brush fires. The nadir view of line 2 appears as Figure 1 of the present document.

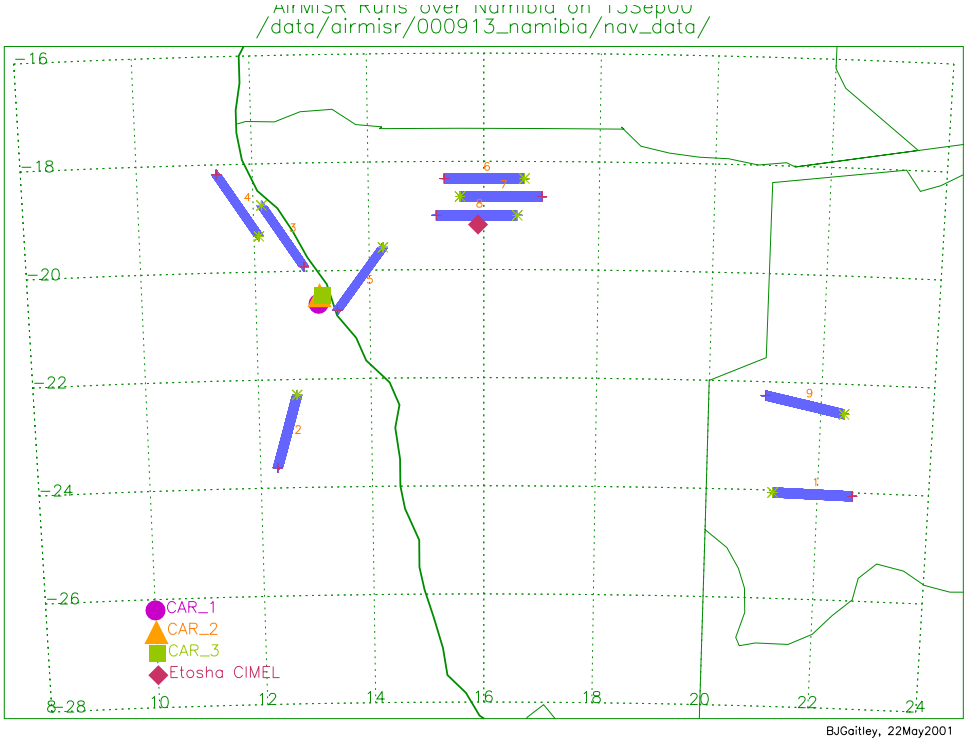

Figure 6 . All AirMISRpasses flown for 13 Sept 00 over clouds above waters off the Namibian coastline, Etosha Pan, Namibia and two flightlines in Botswana. Locations are shown of identified CAR BRF circles over cloud formations off the Namibian coast. A single CIMEL instrument, part of the AERONET, is marked at Etosha Pan by a red diamond. The next figure is a nadir view of clouds and water from line 2 of the above sequence.

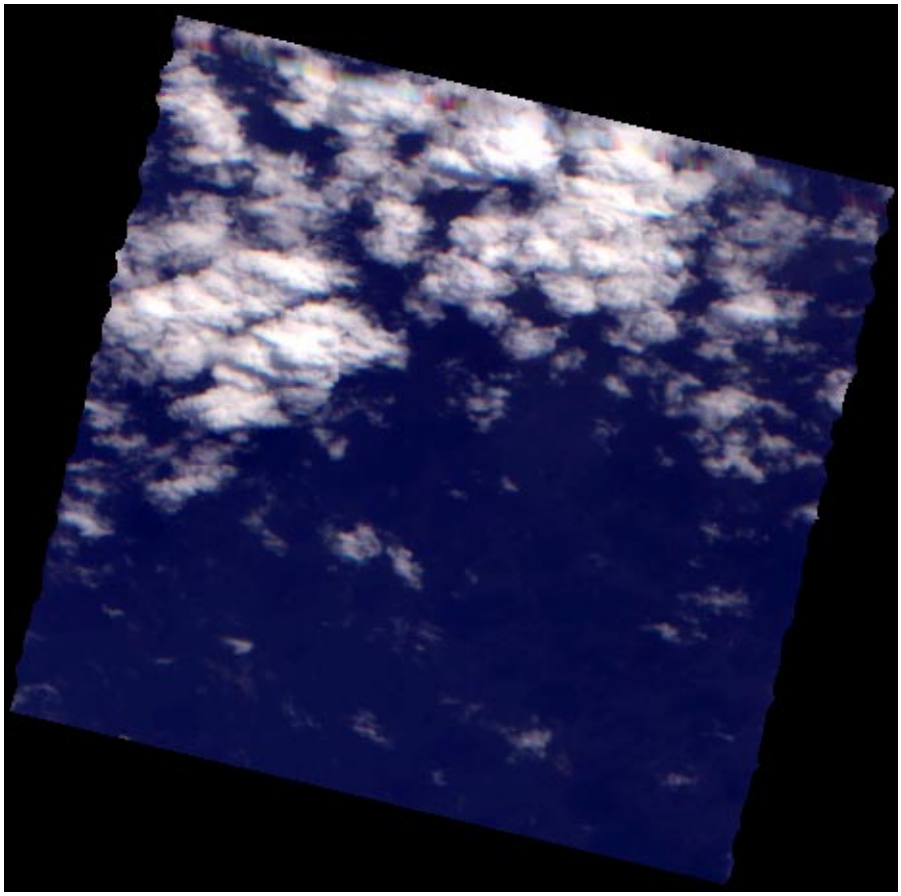

Figure 7 . AirMISR nadir view from line 2 off Namibian coast showing broken marine stratus clouds and patches of open water.

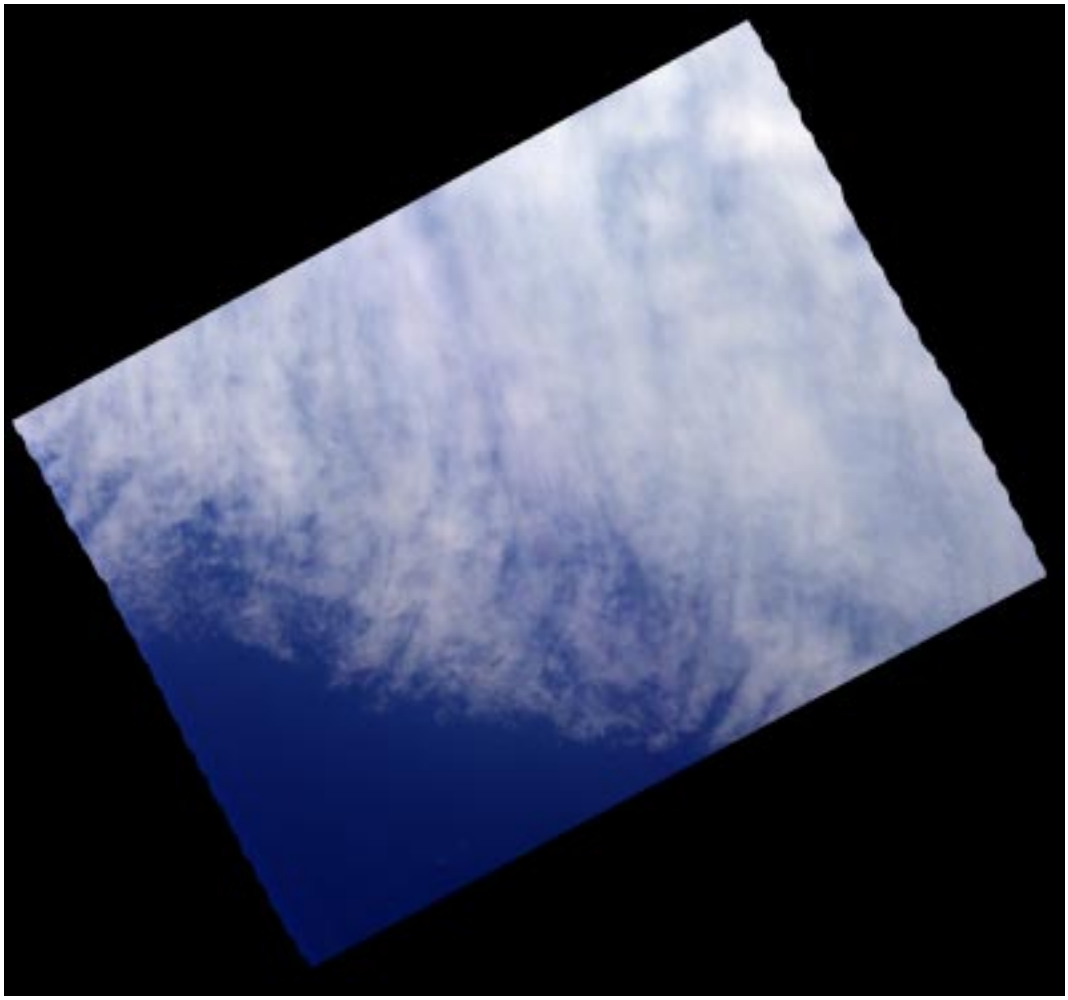

Figure 8. Cloud formations and open water in Cf image of Line 4, 00 Sep 13 off Namibian coast.

Figure 9. CA view of Line 8 of 00 Sep 13 (Etosha Pan)**.**

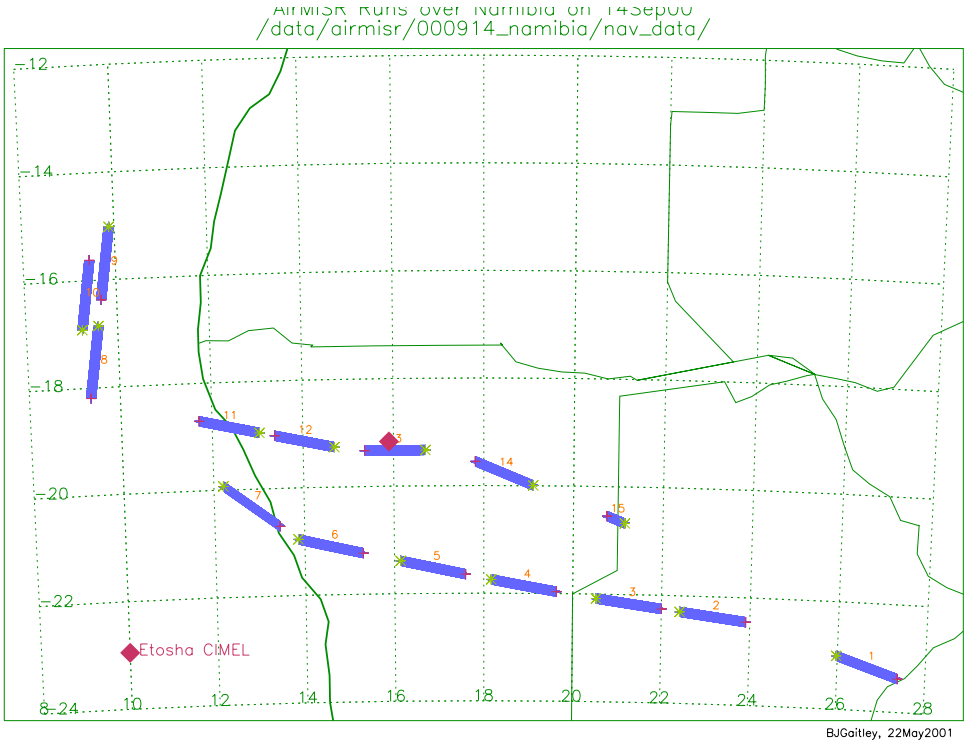

Figure 10. All AirMISR flightlines acquired over Botswana, Namibia and of cloud formations off the coasts of Angola and Namibia on Sept 14, 2000. Location of a single CIMEL instrument located at Etosha Pan, is shown by a red diamond. The next figure is line 12 of this set (nadir view).

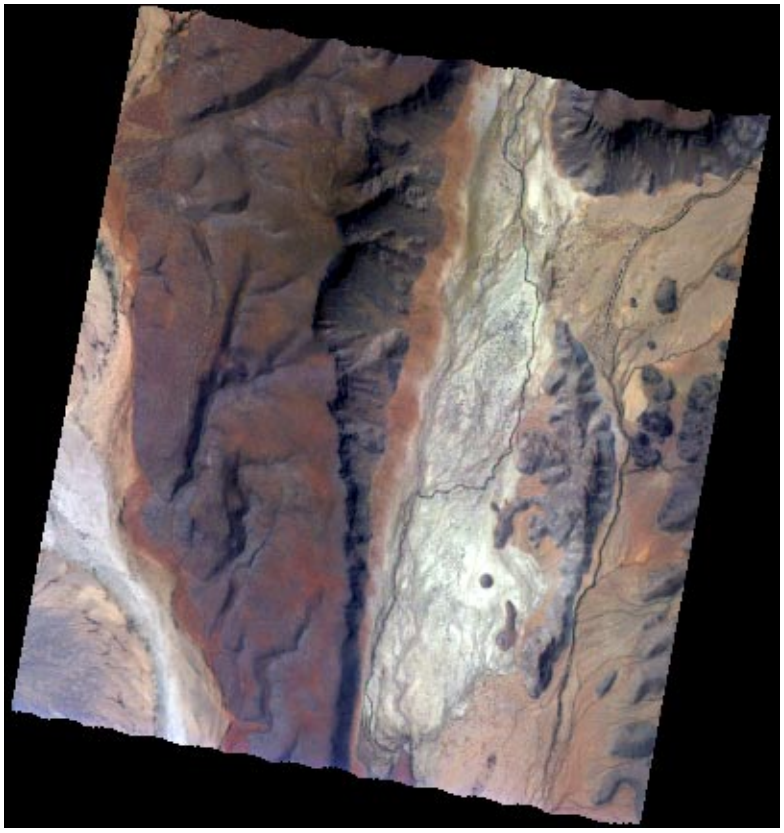

Figure 11. Nadir view from AirMISR of Line 12 of the 00 Sep 14 data ser, Brandberg volcanic complex.

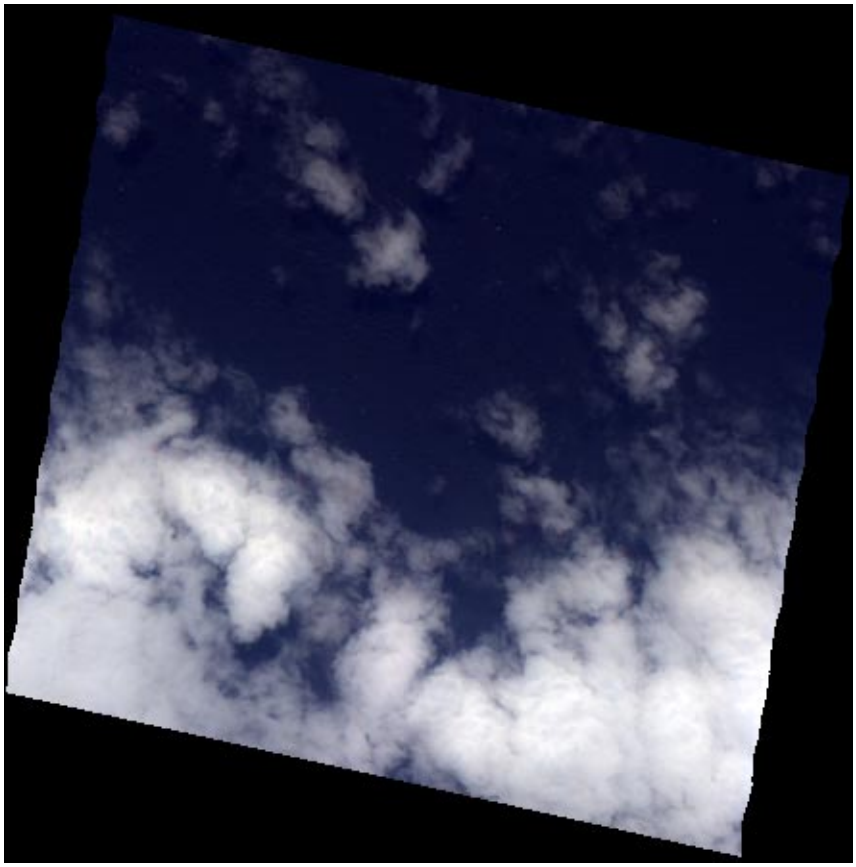

Figure 12. Nadir view of AirMISR Line 8 off Namibian coast for 00 Sep 14, clouds and clear water.

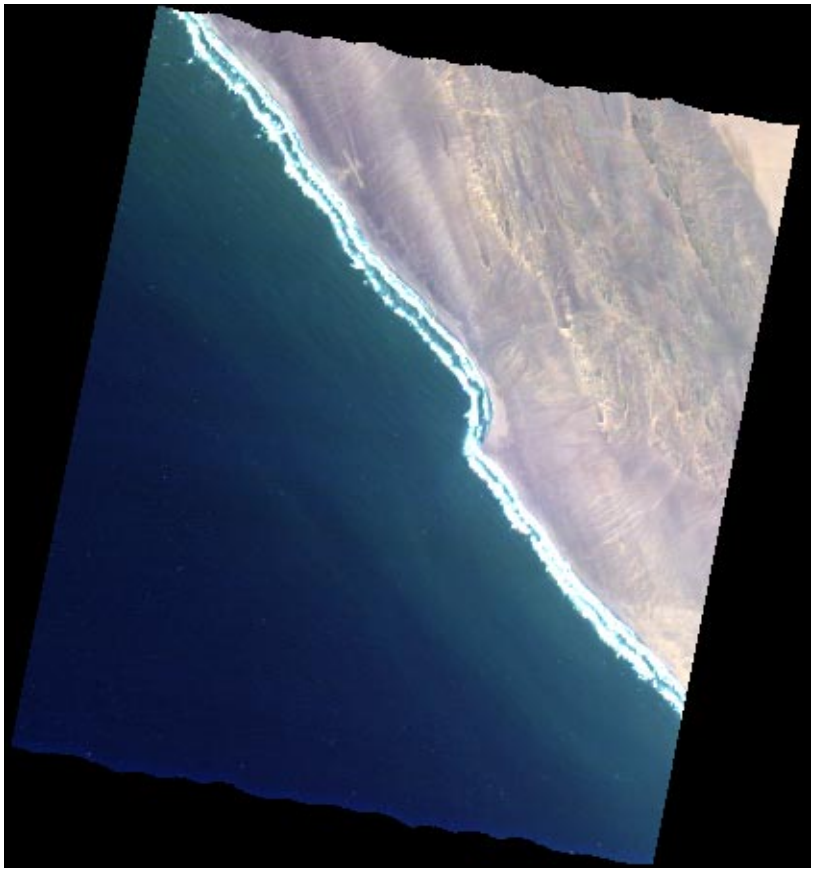

Figure 13. Nadir clear sky view of Namibian shoreline in Line 11 of AirMISR run of 00Sep 14.

7. Related ground locations at Skukuza. Another area of intensive ground investigation was at Skukuza. These are shown in Figure . Skukuza Tower was the location of a BRF measurement by CAR on August 29, 2000. The PARABOLA instrument was mounted on Skukuza Tower beginning observations September 23, and extending intermittently through Oct 1. A brush fire passed through the Tower site on the afternoon of Sept 25, burning the grassy understory. The Skukuza Tower site was not visited by AirMISR during the campaign. The JPL atmospheric instruments were located at Skukuza Airport. These included CIMEL, MFRSR, Reagan radiometers, and a meteorological station.

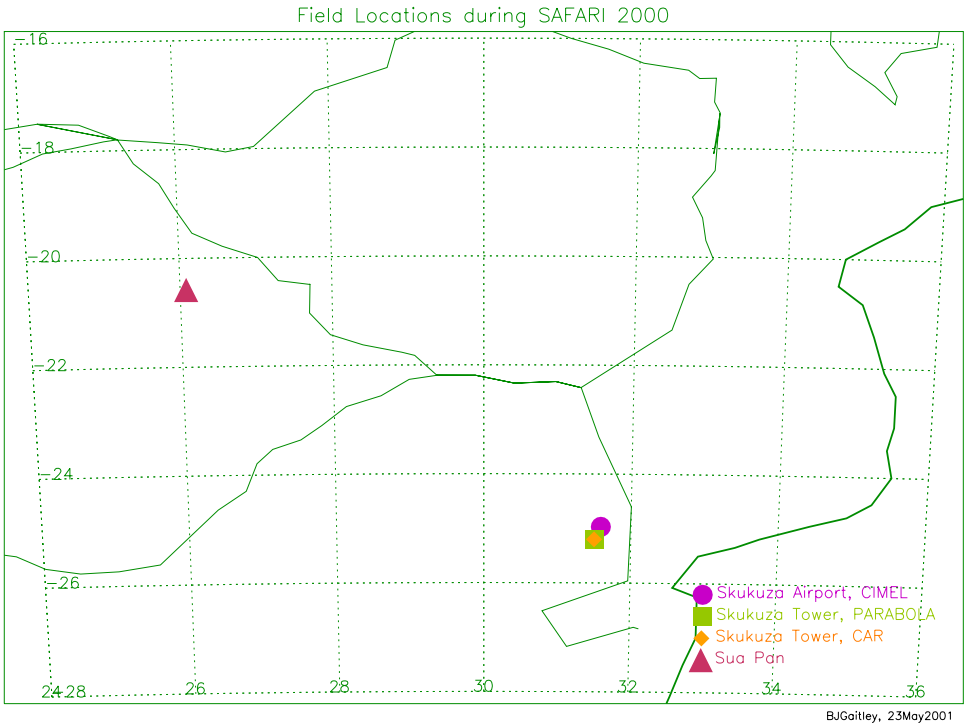

Figure . Locations of the Skukuza Airport, Tower and Sua Pan.

8. Future Studies - It is expected that Table 1will be further completed as a result of workshop consultations. Speaking principally but not exclusively to the AirMISR and MISR data, some of the more urgent tasks to be completed include;

(1)Develop Level 2 algorithms for processing of L1B2 AirMISR data.

(2) Identify spatial and temporal coincidences of simple cloud free MISR and AirMISR and CAR data sets suitable for aerosol and BRF comparisons.

(3) Identify MISR, AirMISR and CAR data sets to define spatial and temporal coincidences that exist of the aerosol retrievals and direct measurements. From these establish realities of the MISR aerosol climatologies used in the heterogeneous land retrieval algorithms.

(4) Identify other ground and aircraft aerosol sampling data sets that may coincide spatially and temporally with MISR/AirMISR.

(5) Analysis of MISR, AirMISR and CAR data sets to define spatial and temporal coincidences that exist of BRF retrievals

(6) Identify in MISR and AirMISR imagery and CAR of coincident dark water scenes (Namibian waters) where aerosol retrievals can be carried out using MISR (dark water) algorithms

9. Application of MISR AOT retrieval to Angolan and Namibian aerosol - The following section is based on *Diner et al.* (2001). The first-generation MISR aerosol retrieval algorithm over land is aimed primarily at retrieval of AOT. Subsequent refinements to improve aerosol type discrimination based on particle microphysical properties are the subject of continuing work. The mean column optical depth at 558 nm averaged over all successful models within a 17.6×17.6 km region is called the "regional mean optical depth" in the MISR aerosol product. It is used here to represent the MISR-derived optical depth over land. Figure 7 shows an example of the MISR multiangle viewing strategy helps the process of aerosol retrieval over land. These images of eastern Angola and northeastern Namibia are from 30 August 2000.

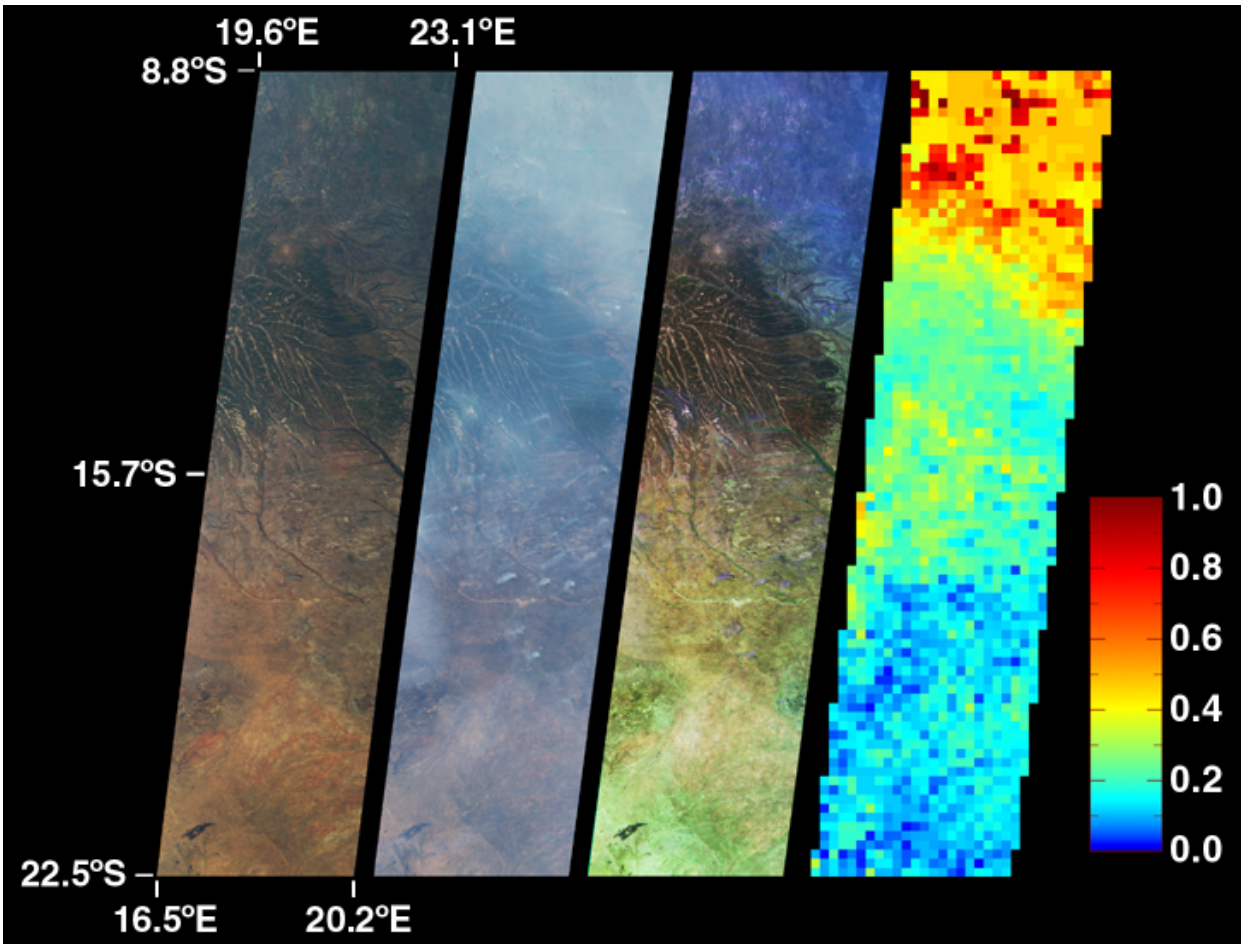

Figure 7. Eastern Angola and northeastern Namibia of 30 August 2000 (**Left**) pseudo natural color RGB composite from nadir camera. (**Second from left**) RGB composite from backward-viewing 70° camera. (**Third from left**) is multi-angle composite of (i)nadir camera red band only (ii)forward-viewing 70°camera, red band only, (iii}backward-viewing 70° camera, red band only. Areas of enhanced optical depth depicted as blue-purple. (**Fourth from left**) is MISR aerosol retrieval result. Color bar on right indicates AOT scale. Images each about 400 km in width.

10. Publications relating to SAFARI 2000 work

(1) Abdou, W.A., J.E. Conel, S.H.Pilorz, C. J.Bruegge, M.C.Helmlinger, B.J. Gaitley, and D.J. Diner, Validation of Multiangle Imaging SpectroRadiometer (MISR) aerosol optical depth retrievals using ground-based solar radiometer observations from the Aerosol Robotic Network (AERONET), Poster presented at the December15-19, 2000, meeting of the American Geophysical Union, San Francisco, CA. (http://www-misr/
(2) Helmlinger, M.C., C.J.Bruegge, W.A.Abdou, J.E.Conel, D.J.Diner, B.J.Gaitley,W.C.Ledeboer, J.V.Martonchik,S.H.Pilorz, and G.Saghri, MISR aerosol and surface data retrievals in conjunction with the SAFARI 2000 field campaign over southern Africa, Poster presented at the December 15-19, 2000, meeting of the American Geophysical Union, San Francisco, CA. (http://www-misr/)
(3) Diner, D.J., W.A. Abdou, C.J. Bruegge, J.E. Conel, K.A. Crean, B.J. Gaitley, M.C. Helmlinger, R.A. Kahn, J.V. Martonchik, and S.H. Pilorz, and Brent Holben, *Geophysical Research Letters*, accepted for publication, 18 April 2001.
(4) Conel, J. M. Helmlinger, S. Pilorz, W. Abdou, D. Diner, J. Martonchik, R. Kahn, M. Kleeman, A. Eldering, and K. Magliano, Application of multiangle imaging SpectroRadiometer (MISR) to study of regional haze problems in conjunction with California Regional Particulate Air Quality Study(CRPAQS) and SAFARI 2000 dry season campaign, (Abstract). Submitted to AGU/AWMA Regional Haze Workshop, Bend Oregon, October 2-5, 2001.

11. Other References Cited

Diner, D.J., L.M. Barge, C.J. Bruegge, T.G. Chrien, J.E.Conel, M.L.Eastwood,J.D.Garcia,M.A.Hernandez,C.G.Kurtzweil,W.C.Ledeboer,N.D.Pignatano, C.M.Sarture, and B.G.Smith, 1998, The Airborne multi-angle Imaging SpectroRadiometer, (AirMISR), *IEEE Trans. Geosci. Remote Sensing,* **GE-36(4)**, 1339-1349.

Tsay, Si-Chee, M.D.King, G.T.Arnold, J.Y. Li, 1998, Airborne Spectral measurements of surface anisotropy during SCAR-B, 1998, *J. Geophys. Res.*, **103 (D24)**, 31,943-31953.

Diner, D.J., W.A. Abdou, C.J. Bruegge, J.E. Conel, K.A. Crean, B.J. Gaitley, M.C. Helmlinger, R.A. Kahn, J.V. Martonchik, and S.H. Pilorz, and Brent Holben, Geophysical Research Letters, accepted for publication, 18 April 2001.

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