Initial examination of radar imagery of optical radiometric calibration sites

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ABSTRACT

In-flight absolute radiometric calibration is critical for multi-temporal and multi-sensor data comparisons. In the case of vicarious calibration of optical sensors based on ground-level measurements, the test site must be well characterized in spatial, radiometric, spectral, and temporal domains. Remotely sensed data acquired at other wavelengths can contribute to a baseline understanding of ground targets and provide insight into the usefulness of such targets for in-flight calibration of optical sensors. With these considerations in mind, multi-temporal ERS-1 SAR data have been obtained for White Sands, New Mexico, and Lunar Lake and Railroad Valley playas in Nevada. This paper reports on an initial examination of these SAR image data sets and the significant pattern changes observed in the scenes. It is concluded that surface roughness, soil moisture and run-off are major factors giving rise to the observed scene characteristics.

1. INTRODUCTION

In order to accurately evaluate surface conditions with respect to long-term monitoring for global change studies, long time series of satellite and airborne sensor data from diverse sensors and platforms need to be quantitatively compared. Because the radiometric performance characteristics of different sensors vary, and the radiometric responsivities and spectral characteristics of any given sensor are known to change with time[9], absolute radiometric calibration is a necessity in both prelaunch and postlaunch time frames. One of the possible methods for in-flight absolute calibration[6,8] of optical sensors involves the selection of reliable and accessible calibration sites and field measurements of the surface reflectance behaviour and atmospheric properties such as aerosol optical depth at the time of satellite overpass. The ground test site must be well characterized in spatial, radiometric, spectral, and temporal domains. However, the procedures for acquiring the necessary field data are usually constrained and sub-optimum because of the difficulty in rapidly characterizing large surface areas and the costs involved in a systematic program of field deployments.

Because of the importance of calibration test sites, any additional information on their characteristics is worth consideration, including remotely sensed data acquired at other wavelengths such as in the thermal infrared or in the microwave portions of the electromagnetic spectrum. With this idea in mind, multi-temporal ERS-1 Synthetic Aperture Radar (SAR) data have been obtained for three optical calibration sites: White Sands, New Mexico, and Lunar Lake and Railroad Valley playas in Nevada. These and other sites are currently being considered as potential calibration sites for sensors to fly on the Earth Observing System (EOS) spacecraft in the coming years.

Multi-temporal SAR data have the potential to contribute to a baseline understanding of ground targets and provide insight into the usefulness of such targets for in-flight calibration of optical sensors. This paper presents the concept of possible synergies from the use of such cross-over data sets and reports on an initial examination of multi-temporal SAR image data sets acquired for three optical calibration sites. Significant pattern changes observed in the scenes are noted and briefly discussed.

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2. OPTICAL CALIBRATION TEST SITES

2.1. White Sands

The alkali flats at the White Sands, New Mexico (east of the San Andreas Mountains) cover an area of roughly 20 km square and are situated at 32.23°N and 106.28°W at 1200 m Above Sea Level (ASL). The highly reflective alkali (gypsum sand) flats area of White Sands (just north of Chuck Site) has been used for surface reflectance measurements[6,10] for in-flight radiometric calibration of optical satellite sensors such as the Landsat Thematic Mapper (TM) and the SPOT Haute résolution visible (HRV). Extensive data sets exist for airborne sensor calibration campaigns in addition to the satellite data. The nearest weather station is situated about 60 km south of Chuck Site at the White Sands Missile Range military base. A very crude soil map[7] is available at a scale of 1:100,000.

White Sands is similar to Lunar Lake and Railroad Valley in many aspects, but it is covered by level gypsum sands rather than by clay and silt. The thickness of the gypsum ranges from 30 cm along the outer margins of the old lake bed to more than 1.5 m near the centre. Vegetation occurs where the gypsum sand is less than 1 m deep over lacustrine sediments. The water table is near the surface (within a depth of 2 m) and runoff is slow. Like Lunar Lake and Railroad Valley, topography is virtually flat at the calibration site. Mountains on the west and sand dunes on the northeast are the only topographical features, and these remain relatively constant in radar backscatter throughout time.

2.2. Lunar Lake playa

The Lunar Lake playa is located at 38° 23' 50" N and 115° 59' 40" W at an elevation of 1750 m ASL. It is on the eastern edge of the Pancake Mountain Range in the Lunar Crater Volcanic Field about 250 km north of Las Vegas, Nevada. The playa is on U.S. Bureau of Land Management land and may be accessed from Tonopah, Nevada by driving 130 km east on Highway 6 and then 12 km south on a dirt road. The Lunar Lake playa is roughly oval in shape and about 2 km by 4.5 km in size.

The high reflectance of the Lunar Lake playa in optical bands as well as its smooth surface make the area a suitable radiometric calibration target for high spatial resolution optical sensors. A number of optical and radar data sets have been acquired at Lunar Lake over the years. The Advanced Solid-State Array Spectroradiometer (ASAS) on board the NASA C-130 collected images over Lunar Lake on July 17, 1989 as part of the Geologic Remote Sensing Field Experiment (GRSFE)[1]. In addition, the ground-based Portable Apparatus for Rapid Acquisition of Bi-directional Observations of Land and Atmosphere (PARABOLA) was used to acquire visible and near-infrared surface reflectance data on July 18, 1989.

More recently, several calibration campaigns for the Airborne Visible/Infra-Red Imaging Spectrometer (AVIRIS) took place at the Lunar Lake playa, the latest being October 27, 1994. JERS-1 optical data were acquired on the same day. Landsat-5 TM data were acquired the day before (October 26). An earlier AVIRIS calibration campaign occurred on April 4, 1994.

Many ERS-1 SAR images of the Lunar Lake area have been acquired. Unfortunately, none of them were closely coincident in time with the aforementioned optical data acquisition campaigns. Polarimetric JPL AIRSAR data were acquired at C, L, and P bands on September 13, 1989[3].

2.2.1. Physical description

The main features of the Lunar Lake playa and surrounds are displayed in Fig. 1. Compacted clay-rich lacustrine deposits in Lunar Lake form a mud-cracked playa surface. The mineralogy consists of over 90% clay particles (smectites, kaolinite, and vermiculite) with less than 10% carbonate, quartz, feldspar and mica grains as well as lithic fragments. The tiles vary in size from 20 to 30 cm in diameter in the southern part to 10 to 20 cm in diameter in the northern part. The smooth playa in the central region of Lunar Lake is very homogeneous except for some mud cracks and small scattered basalt clasts. In general, the playa has a root mean square (rms) height of ~1 cm and rms slopes of zero degrees at metre scales to less than 5 degrees at the centimetre scale based on field observations and microtopographic profiles with a helicopter stereo-photography system[4,5].

At the extreme southern end of the playa there is an area which sometimes collects standing water. Also, there is a concentration of basalt clasts up to 20 cm in size which covers between 20% and 85% of the immediate surroundings. Basalt fragments extend from this area to the western edge of the lake and up two thirds toward the north end of the playa. A well-compacted alluvium surrounds the playa. Steep slopes abut on the east and west sides of the playa with those on the west side being steeper. Remnants of volcanic cones occur along the western slopes. To the northwest, an alluvial fan protrudes into the playa. This fan is part of an active drainage system and is constantly reworked. The windblown sandy area is sparsely covered with sagebrush, atriplex and patches of grass. Vegetation in most parts of the playa occupies less than 1% of the area. The playa is thought to dry towards the fan, which probably results in mineral variations.

2.2.2. Ancillary data sets (soil, topography and meteorology)

There are topographic maps of the playa but limited soil maps. Two weather stations are situated in the vicinity of the playa. One is located near Twin Springs Ranch about 25 km southwest of Lunar Lake and the other at the Tonopah airport some 130 km west. The precipitation data recorded at both stations reveal a substantial variation in amounts of rainfall. The most reliable information for the area would be in-situ field observations.

2.2.3. Field observations

In late October 1994, the playa was visited as part of a geological radar study. Observations supported by photographs were made in order to interpret the hydrogeology. One significant observation is that the clay and silt material of the playa surface is sufficiently indurated and compact that wind action does little to alter the surface. Only when the surface is inundated will the texture and surface roughness change from the wave action and redeposition of silt and clay. Older mud cracks were observed to be infilled by these flooding and redeposition events. Some ice casts were observed indicating a freezing event of standing water in the previous weeks.

The topographic changes are measured in cm per 100 m such that drainage is poor and soil moisture patterns as observed in ERS-1 SAR imagery would be spatially broad. Small pools of standing water were observed at both the extreme north and south ends next to the feeders marked by narrow sandy channels. Two major feeders are situated at the north end dominated by a sloping vegetated sandy area (Fig. 1). One of the water holes used by cattle at the north end is consistently observed as a bright target on the SAR images. Some of the inflow is through ground water infiltration from the surrounding detrital slopes. The basalt outcrop in the south end is a permanent bright feature in the SAR images. There are cobble fields scattered across the south end of the playa. The cobble stones consist of vesicular basalt fragments up to 10 cm in diameter which are semi-buoyant. There appears to be a sorting of cobbles indicative of wave action when the playa is inundated. It would take many flooding episodes (over several years) to alter the radar backscatter behavior of these cobble fields with respect to their distribution. Based on these observations, the primary backscatter features observed in the ERS-1 SAR data time series at Lunar Lake would be due to soil moisture and precipitation-related events rather than to changes in vegetation or playa surface roughness.

2.3. Railroad Valley playa

The Railroad Valley playa has received attention recently as a test site for airborne sensor calibration and as a possible site for EOS sensor calibration in the future because it is larger than the other two sites. It is situated about 20 km east of the Lunar Lake playa at 38° 28' N and 115° 40' W at an elevation of 1430 m ASL.

The visual extent of the Railroad Valley playa is some 12 km by 12 km square. A 3 km by 3 km area in the west central region of the playa that provides the same spatial coverage as the playa in the Lunar Lake time series was selected for visual comparison of the radar backscatter at the same spatial scale. The general description of the playa surface sediment (without the basalt clasts) is assumed to be similar to that of the Lunar Lake playa. Currently, no soils or geology maps have been obtained for the area. Meteorological data are available from the same weather stations used for Lunar Lake.

3. ERS-1 DATA SETS

In order to help characterize the spatial and temporal stability of the selected optical calibration test sites, ERS-1 SAR C_{VV} (5.3 GHz or 5.6 cm) data were acquired frequently (35-day repeat orbit) in either the daytime descending orbit or nighttime ascending orbit with an incidence angle of 21 degrees. To date, there have been 22 images acquired for White Sands spanning the period from January 16, 1992 to May 18, 1995 (6 ascending and 16 descending orbits). From April 24, 1992 to May 17, 1995, 30 images (9 ascending and 21 descending orbits) were acquired for the Lunar Lake playa and 25 images (8 ascending orbits and 17 descending orbits) were acquired the for the Railroad Valley playa.

Signal data were received by the Gatineau Satellite Station (GSS) in Canada and processed to image amplitude data. The 30-m pixels were resampled to a (4-look) Multi-Look Data (MLD) product format with a pixel spacing of 12.5 m. Each image consists of 8000 pixels by 8000 lines which covers an area of 100 km by 100 km. The geometry of the satellite orbit is quite stable such that a simple lateral shift will compensate for the westerly drift of 3 pixels per day for images acquired in the same orbital direction. Time series collages were generated from the ERS-1 SAR scenes. The selected subscene areas are 25.6 km square for White Sands (Fig. 2), 6.4 km square for the Lunar Lake playa (Fig. 3) and 25.6 km square (Fig. 4) plus 6.4 km square (Fig. 5) for the Railroad Valley playa.

For most of the images, the ERS-1 SAR amplitude data were converted into approximate backscatter coefficients. The processing sequence includes compensation for the antenna pattern and for range attenuation, as well as the application of a calibration constant. The ascending images were rotated. A window was selected from the full scene for image to image registration. A second-order polynomial was applied with nearest neighbour resampling. The SAR data were linearly scaled to 8-bits. A non-linear contrast stretch was applied to enhance the radar backscatter or amplitude image. A Frost adaptive filter (3 by 3) was applied to remove most of the speckle from the radar images for visual enhancement.

Unfortunately, the SAR processor used was not designed to generate absolutely calibrated data and does not have a fixed processor gain. Thus, despite the application of a calibration constant, the backscatter data cannot be trusted for quantitative multi-temporal comparisons of surface moisture or surface roughness effects. Thus, only visual or relative changes attributable to possible standing water, topographic effects, surface roughness and soil moisture effects in the multi-image collages were addressed in the study. The visual interpretation was supplemented by daily meteorology reports in the vicinity and crude soil and topographic maps.

4. SAR IMAGE INTERPRETATION

Radar backscatter intensity as measured by calibrated SAR systems is primarily controlled by three factors: local incidence angle, surface roughness, and dielectric permittivity of surface materials. The dielectric constant fluctuates as a function of soil moisture content, which may be mapped quantitatively from calibrated SAR data[2]. Because of the absence of directional row structures on the playa and the gypsum flats, it was felt that data from ascending and descending orbits could be considered together for the purposes of qualitative interpretation.

The dry flat regions appear dark in the ERS-1 SAR images. Because the surface at White Sands consists of gypsum sand rather than silt and clay, the effects of changing dielectric constant are not well understood, whereas the effects of surface roughness (small-scale) should be more evident. The sand is porous and the water table is near the surface, so that increased soil moisture will be readily evident as a brightening of the area. Also, sand is easily moved by winds, creating roughness patterns which could appear as brighter backscatter. One feature which is constant throughout the images is a dark cross near the centre of the flats. These two crossing runways at Northrup Strip appear dark by reason of their smoothness.

Most of the Lunar Lake playa appears dark in the C-band images during dry spells because it is flat and rather smooth. The most noticeable of the radar-detected surface effects is the presence of concentrated basalt fragments in the south end. The basalt fragments produce a surface which is rough at C-band wavelengths, such that the area appears bright on the images. The surrounding areas to the south and west have a more mottled appearance, indicating the presence of more basalt cobbles, but with less concentration. These features are fairly constant on all scenes. The sparse vegetation contributes little to the radar signal. The manner of drying of the playa could account for the differing size of mud tiles which affects surface roughness. If one area dries less quickly than another, the soils could have differing proportions of silt and clay, which in turn would control the size and character of the mud cracks formed. Changes in the dielectric constant of the playa surface sediment are readily observed in the backscatter images. When the playa surface gets wet, the dielectric constant increases and the surface appears brighter. As the surface has low porosity, any significant amount of rain will cause flooding. Standing water on the playa will appear black in C-band if the water is calm and bright if wavy. There is little redistribution of the lacustrine sediment by wind because of the consolidated nature of the playa surface.

4.1. Preliminary interpretation of time series

4.1.1. White Sands (Fig. 2)

There is a particularly large dark portion in the southern part of the flats in the January 16, 1992 image which may indicate a relatively dry smooth flat surface. Extensive flooding is evident in the February 9, 1992 image. A bright drainage channel is observed extending to the south from the bright triangular area. These regions and the bright pools across the flats indicate standing water with surface waves or very moist gypsum sands. Much of the backscatter patterns in the May 5, 1992 image may be an expression of surface roughness, texture and soil moisture from recent rain in the absence of standing water.

The August 22, 1993 scene is similar to the first one except for brighter patches in certain areas, indicating more soil moisture. The October 31, 1993 scene exhibits less contrast than the previous image with little or no rainfall in the interim. In the December 27, 1993 scene, the image tone in the south part of the flats appears more uniform, probably because of recent rain. The minimal contrast in the May 18, 1994 image indicates a relatively quiescent period with no significant surface moisture effects.

The subdued radar backscatter in conjunction with rainfall data indicates limited soil moisture in the August 20, 1994 image. In the November 2, 1994 image, the enhanced radar backscatter indicates increased soil moisture. The February 4, March 28, and May 18, 1995 images were acquired during a dry period. Brighter speckle in the gypsum flats may indicate surface roughness or texture differences.

4.1.2. Lunar Lake playa (Fig. 3)

The Lunar Lake time series can be broken into a number of time periods based on major radar backscatter patterns. Most of the SAR features observed result from soil moisture effects because of the flat smooth terrain, but on occasion wet snow cover and surface flooding are observed. During a dry 1992, bright areas are observed in the April 24 image in the south end and west edge of Lunar Lake because of surface roughness from the basalt clasts. Some variation in brightness is observed in the northern third of the playa on September 11, 1992 because of soil moisture from surface infiltration or inflow from the feeder channels off the alluvium slopes to the north and east.

There is a loss of tonal variability (even the bright signature of the basalt outcrop in the south end of the playa is obscured) in the January 29, 1993 image likely because of a blanket of snow over the whole image as supported by the meteorological data. The northern half of the playa may be inundated in the April 9, 1993 image. A sharp east-west line may mark the boundary between bright rough water to the north, which covers almost half of the playa, and dark calm water to the south, or that there is no standing water to the south.

The August 2, 1993 image contains an unexplained triangular region in the central east part of the playa which appears brighter than the regions to the north and south. The rainfall data do not support enhanced backscatter from surface moisture as a possible interpretation.

No strongly contrasting backscatter patterns are observed in the Lunar Lake scene of November 5, 1993. The playa which normally appears darker than the surrounding region due to its flat smooth surface was observed to backscatter in the same manner as the surrounding area (near surface soil moisture effects overshadowing the surface roughness effects on the SAR backscatter). The May 31, 1994 image seems to indicate the possibility of flooding. An irregular bright wavy pattern along the northern edge may indicate gusting winds.

In the September 2, 1994 image, the patterns at the north end of the playa are likely due to soil moisture. The November 15, 1994 image contains a very unique, irregularly-shaped backscatter feature in the north end of the playa. Subsurface water inflow from the feeder channels may be responsible. In the nighttime image of February 6, 1995, the flooded playa is frozen resulting in a dark return. Various states of surface wetness are observed in the April 2, 1995 image. The most recent image of May 17, 1995 indicates flooding in the northern third of the playa as it exhibits low-speckle radar return.

In general, the surface roughness, texture and composition determine the basic backscatter behavior for Lunar Lake where the steep rocky hills are bright, the sandy slopes surrounding the playa are moderate in tone and the clay-silt rich playa is typically dark when dry. On top of this base pattern, the backscatter is affected by surface runoff and soil moisture effects over time. Most of the unusual or transitional patterns occur in April and May or late fall, marking events which are difficult to properly interpret without field observations. Given that surface roughness and subsurface moisture effects are not always obvious in visible and near-infrared optical data, this time series provides a significant insight into the spatial uniformity and temporal stability of the surface reflectance.

4.1.3. Railroad Valley playa (Fig. 4 and Fig. 5)

Several distinct phases of backscatter behaviour are observed for the Railroad Valley time series. In a first phase, the April 24 and September 11, 1992 and January 29, 1993 images reveal a bright region within the darker backscatter of the playa. This bright region may indicate coarser surface material or increased surface roughness in an otherwise dry playa. Major flooding is in evidence along the playa boundary in the April 9, 1993 image. Although the radar backscatter tonal patterns have changed somewhat in the August 2, 1993 image, the net soil moisture effect is minimal given the extremely dry conditions of the previous months. The November 5, 1993 and May 31, September 2 and November 15, 1994 images indicate more subtle changes in backscatter patterns (not tone). This is more readily seen in Fig. 5 and may be attributed to surface texture changes arising from redistribution of material by wind or surface runoff. This phase is noted for it's more consistent rainfall. The likely cause of the overall increase in brightness in the November 15, 1994 image is not known. The last phase from February 17 to May 17, 1995 is noted for abundant rainfall or snow melt which has flooded the channels along the boundary of the playa. Once again, the surface texture may be changing with the possible introduction of new fine-textured material and the redistribution of existing material because of run-off. The texture changes are partially masked by the high soil moisture at the time. The flood channels are clearly observed in the April 2nd image. The speckled backscatter in the flood channels in the April 2, 1995 image is either because of surface winds creating a wave action or the deposition of fine material not yet blown away by wind.

In general, visual inspection of the Railroad Valley time series indicates that the position of flooding along the playa boundary changed between April 9, 1993 and April 2, 1995 after major flooding had occurred, and that the backscatter patterns in the central region change from time to time in a manner unrelated to the soil moisture regime. For this flat playa, terrain relief is considered to be a second-order effect on radar backscatter after the effects of the texture and composition of surface materials and the moisture regime.

5. CONCLUDING REMARKS

There are significant changes in radar backscatter observed in the western regions of the White Sands gypsum sand flats, but the area adjacent to Chuck Site where most of the ground reflectance measurements have been made for satellite sensor calibration is more stable. Under dry conditions, the surface texture at Lunar Lake does not change significantly and most of the variability in the backscatter may be attributed to soil moisture or standing water effects. Under dry conditions at the Railroad Valley playa, there appears to be more temporal variability in backscatter which may be due to the redistribution of surface materials by wind. This change in surface texture in the Railroad Valley playa may necessitate more frequent field measurements to characterize the surface reflectance behaviour for optical satellite sensor calibration. Nevertheless, the spatial variability in backscatter appears to be less in Railroad Valley than at Lunar Lake, supporting the concept that this site may be more suitable for radiometric calibration of optical satellite sensors.

Although our visual evaluation of the multi-temporal SAR data sets is based on imagery that is not fully calibrated, most of the inferred spatial and temporal trends are considered to be valid. There is a definite need for additional field observations, particularly on satellite overpass days. With the recent launch of ERS-2 and the forthcoming launch of the Canadian Radarsat in 1995, it should be possible to extend studies of this kind. The special nature of optical calibration sites might make it feasible to use them for Radarsat data validation purposes.

Statistical analysis of multi-temporal SAR sequences could help significantly to characterize the spatial and temporal homogeneity of the surface reflectance properties of sites used for in-flight absolute radiometric calibration of optical satellite sensor data. Coincident radar and optical satellite data acquisitions should continue to be sought, even though they are difficult to obtain.

Similar cross-over data studies should be undertaken involving other wavelength domains, such as an examination of thermal infrared imagery of test sites used for the calibration of visible and near-infrared data.

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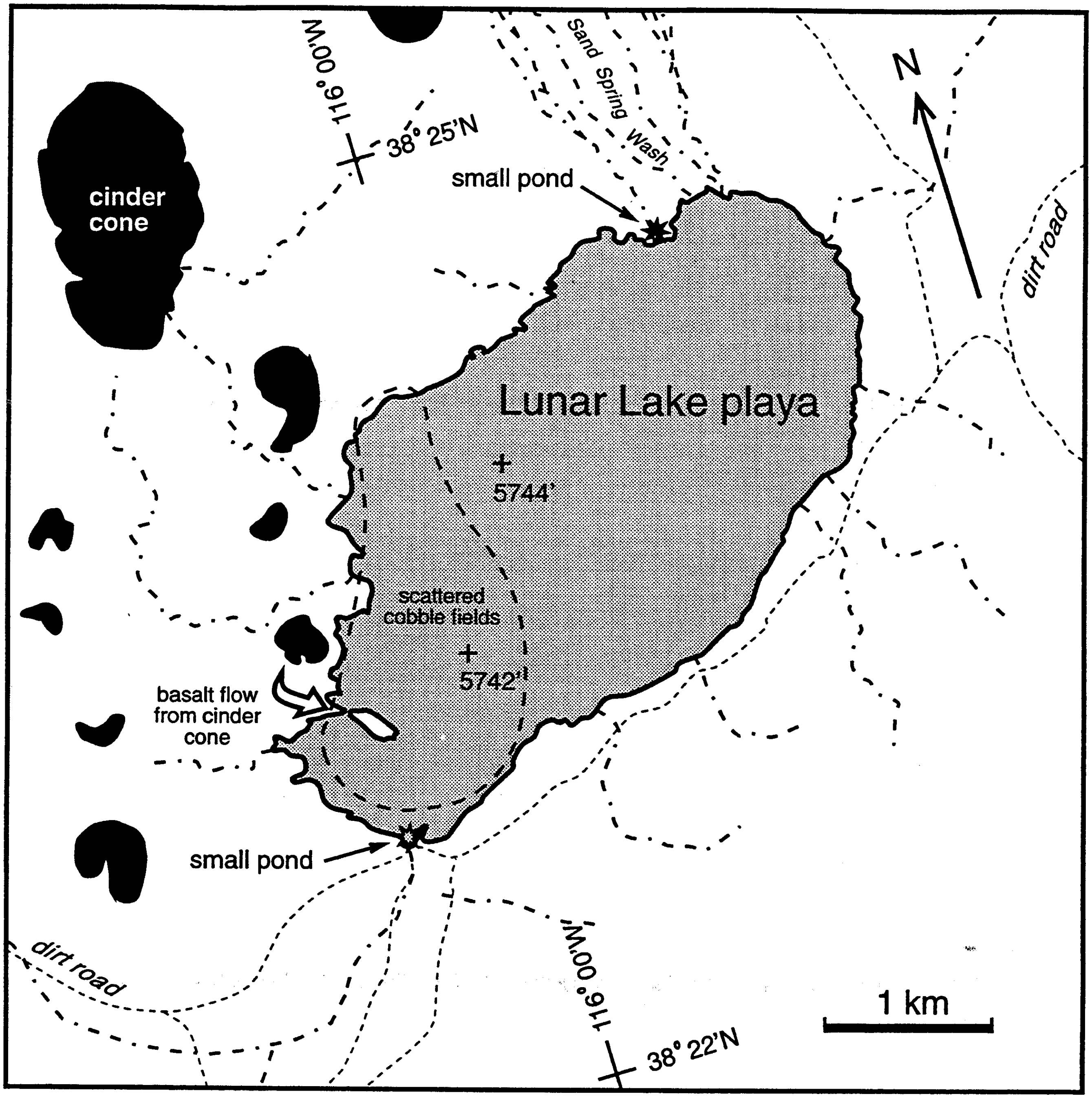

Figure 1. Schematic diagram of the Lunar Lake playa encompassing an area of 6.4 km by 6.4 km.

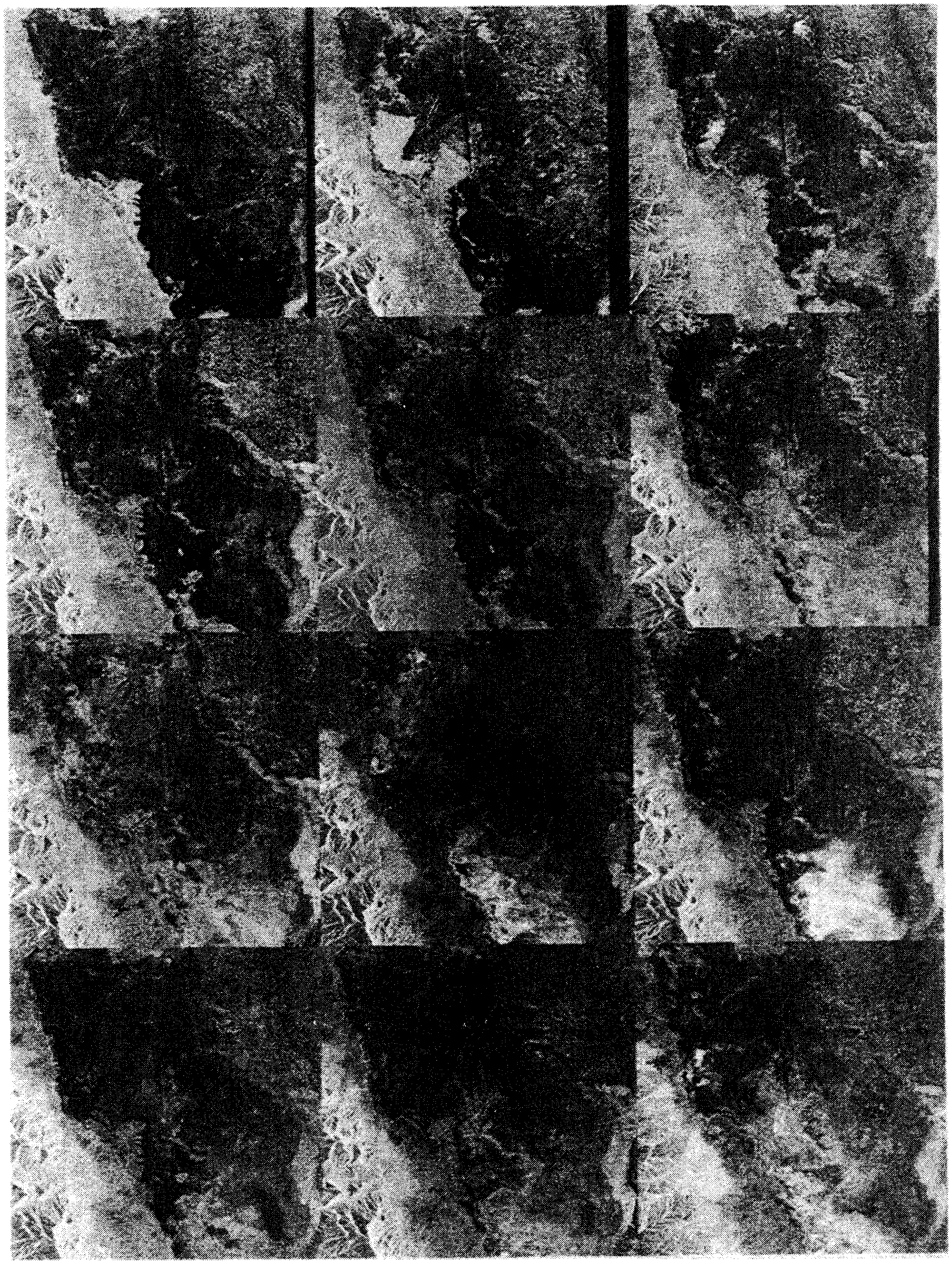

Figure 2. ERS-1 SAR data time series for a 25.6 km by 25.6 km subscene at White Sands, New Mexico.
Dates (from left to right) in row 1: January 16, February 9 and May 5 in 1992;
row 2: August 22, October 31 and December 27 in 1993;
row 3: May 18, August 20 and November 2 in 1994;
row 4: February 4, March 28 and May 18 in 1995.

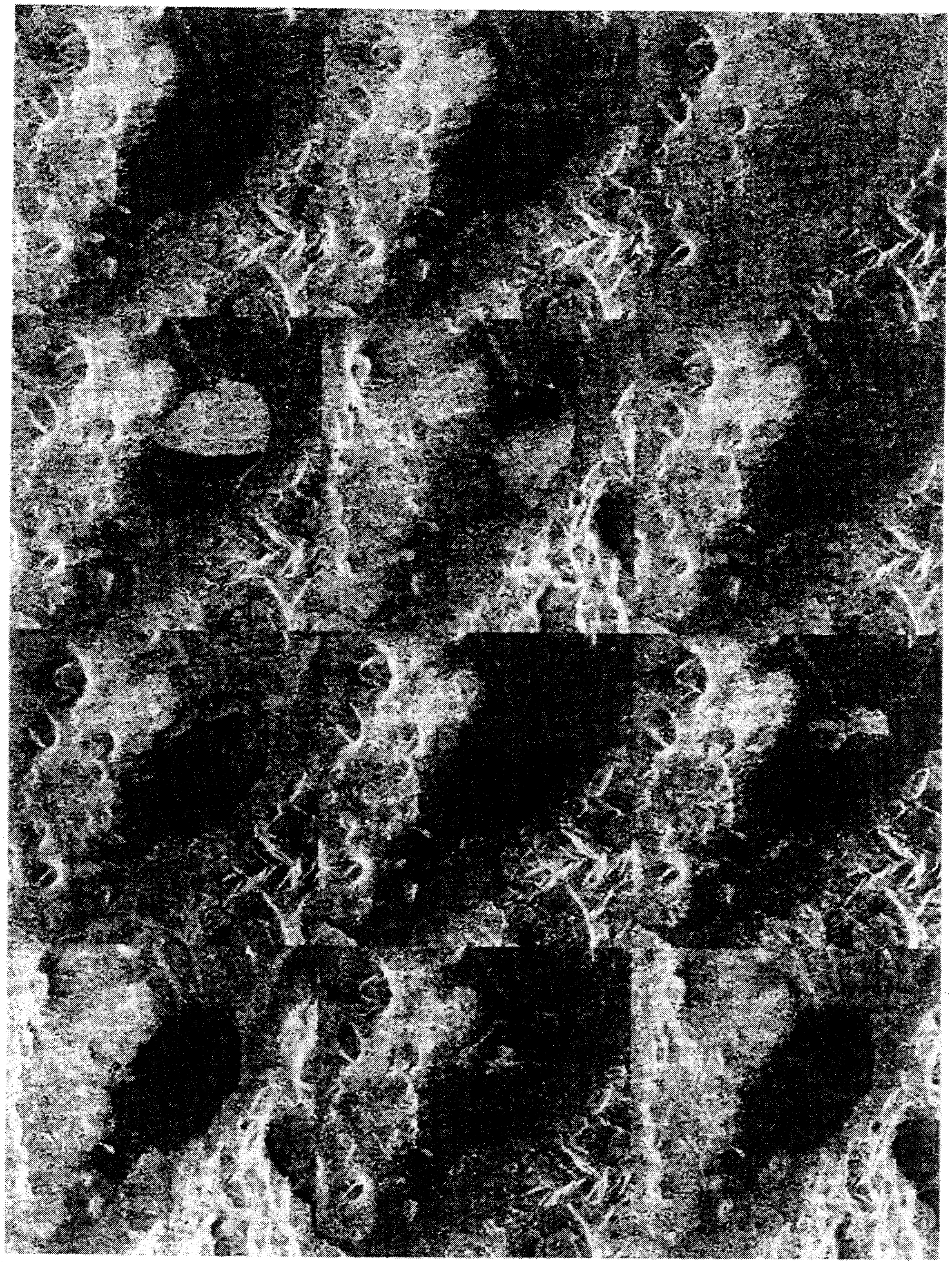

Figure 3. ERS-1 SAR data time series for a 6.4 km by 6.4 km subscene of the Lunar Lake playa.
Dates (from left to right) in row 1: April 24 and September 11 in 1992, January 29 in 1993;
row 2: April 9, August 2 and November 5 in 1993;
row 3: May 31, September 2 and November 15 in 1994;
row 4: February 6, April 2 and May 17 in 1995.

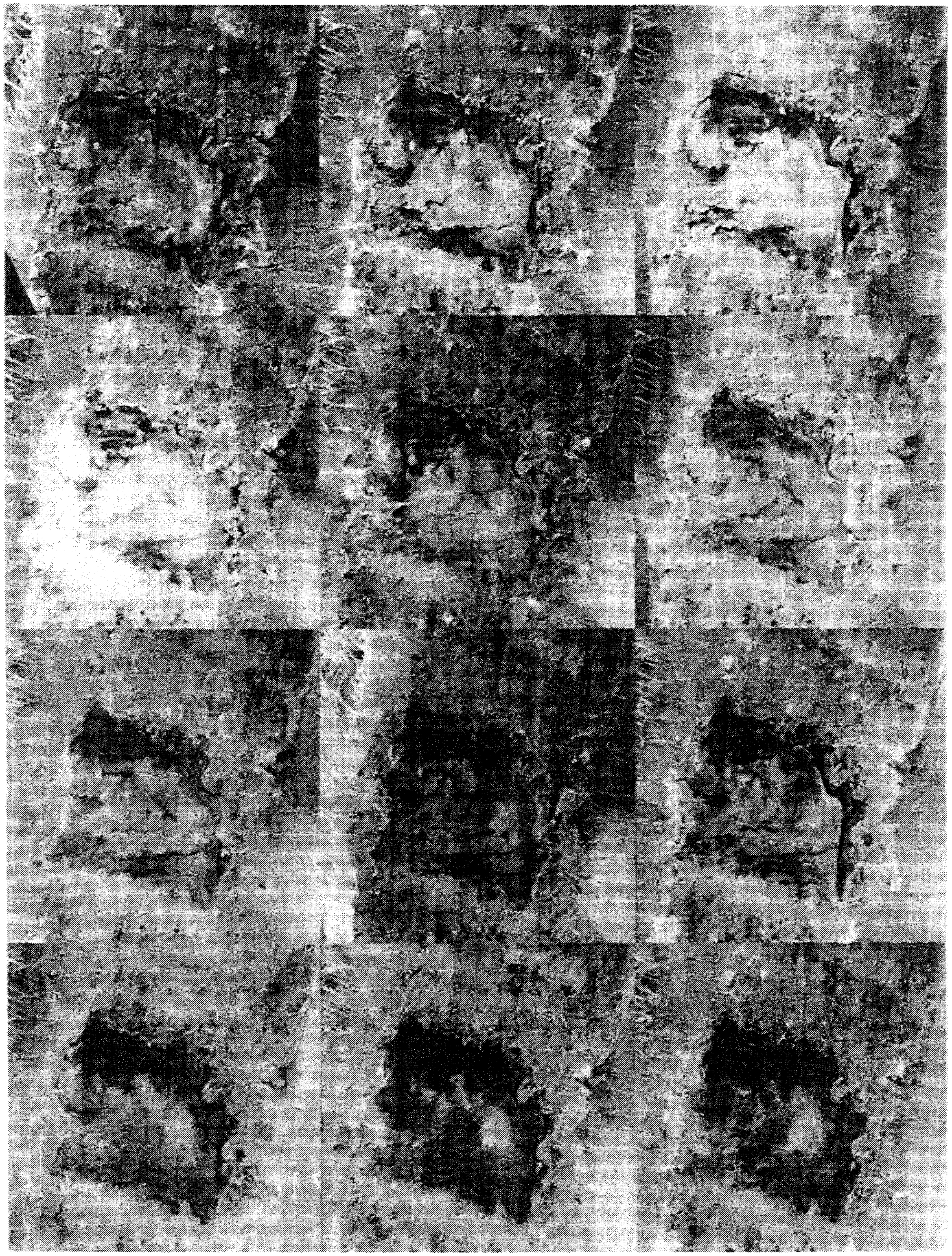

Figure 4. ERS-1 SAR data time series for a 25.6 km by 25.6 km subscene of the Railroad Valley playa.

Dates: (from left to right) in row 1: April 24 and September 11 in 1992, January 29 in 1993;
row 2: April 9, August 2 and November 5 in 1993;
row 3: May 31, September 2 and November 15 in 1994;
row 4: February 17, April 2 and May 17 in 1995.

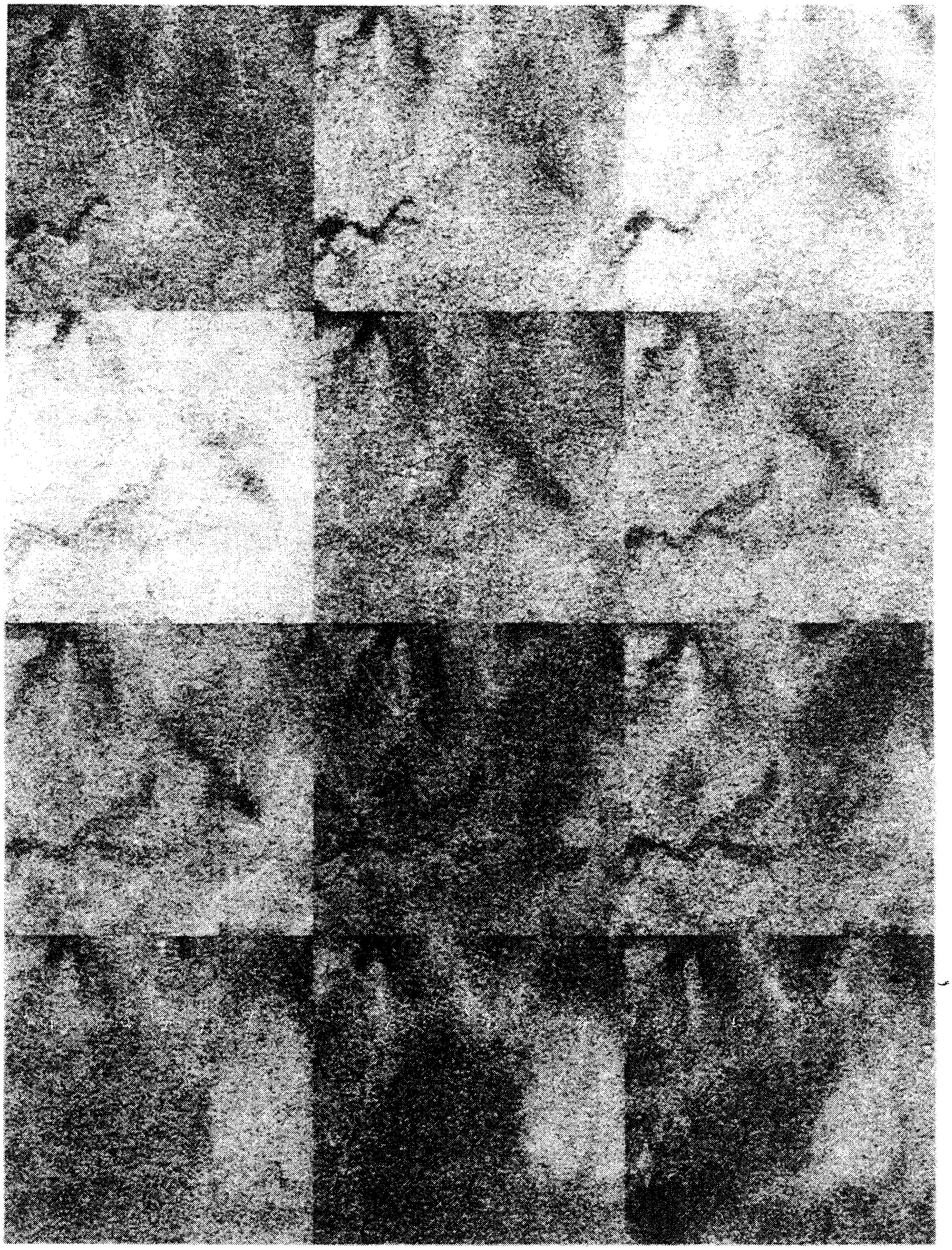

Figure 5. ERS-1 SAR data time series for a 6.4 km by 6.4 km subscene of the Railroad Valley playa.
Dates: (from left to right) in row 1: April 24 and September 11 in 1992, January 29 in 1993;
row 2: April 9, August 2 and November 5 in 1993;
row 3: May 31, September 2 and November 15 in 1994;
row 4: February 17, April 2 and May 17 in 1995.