Remote sensing for mapping near-surface playa moisture

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Introduction

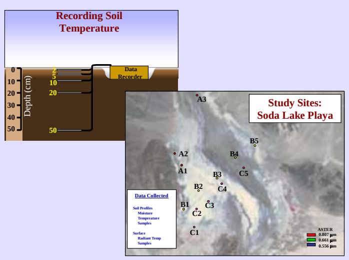
Sub-surface soil moisture is important for a wide variety of applications including agriculture, biologic studies, planetary (analogs for evaporite deposition such as Mars), studies on playa landform development, and surface trafficability. Even sub-surface moisture affects the surface temperatures: moist soils are slower to warm and are cooler than similar dry soils. This is because solar heat from the surface diffuses into the soil, raising temperatures according to the heat capacity of the soil. The heat capacity of moist soil is a factor of as much as 5 greater than that of dry soil, so more heat is required to raise the temperature of moist soil. Therefore, diurnal thermal measurements of the surface can be used to detect subsurface moisture. In order to test this potential, we used a thermal (FLIR) camera to image Soda Lake playa, which has various levels of subsurface moisture.

The purpose of this study is to:

1) Establish the detectability limits of soil moisture in playas.
2) Relate daily changes in radiant surface temperatures measured by remote sensing to soil moisture.
3) Estimate soil wetness at the surface and at depth.
4) Connect these results to a larger model of desert surface development.

Methods

Soil measurements (composition, water content, and temperature) were measured along transects crossing Soda Lake playa. The measurements were made at depths of >1, 2, 5, 10, 20, and 50 cm. Soil water content and composition were measured in the lab from samples collected during the experiment while temperatures were measured with thermocouples buried at the sites and recorded on a data recorder.

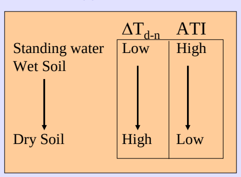


Thermal images (FLIR) were taken every hour for approximately 24 hours. Patterns of soil moisture appear as patterns of thermal inertia differences.

Thermal inertia: resistance of a surface to changing its temperature.

Thermal inertia is not directly measurable, so apparent thermal inertia is used instead:

$$ATI = (1\text{-}Albedo)/(T_{day}\text{-}T_{night})$$

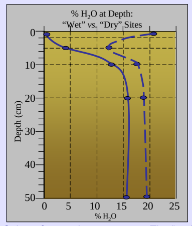


- The ATI was calculated and compared to the soil temperature and water content measurements
- The field FLIR images were taken in coordination with a day/night ASTER overpass to compare ATI as measured in the field to that measured by ASTER.

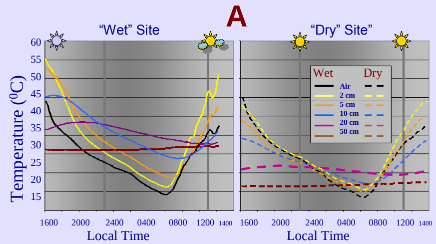
Results / Discussion

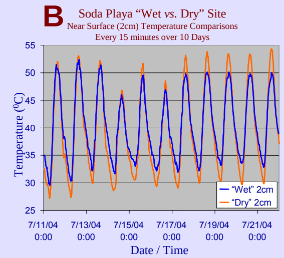
Field Soil / Thermocouple Measurements

The temperatures measured in a relatively "dry" site *vs.* those measured in a wetter site are shown below (A). The "wet" site remains warmer throughout the diurnal cycle. At night the difference between the two sites is within 3 ºC at the surface. This difference increases by 10 to 12 ºC at the warmest time of the day, but decreases with depth. The wetter sites have a higher thermal inertia and, therefore, decreased day/night temperatures extremes (B).



Sub-surface moisture content. The "wet" site is 3-4% wetter at depth, but significantly wetter in the top 5 cm due to the proximity to surface springs.

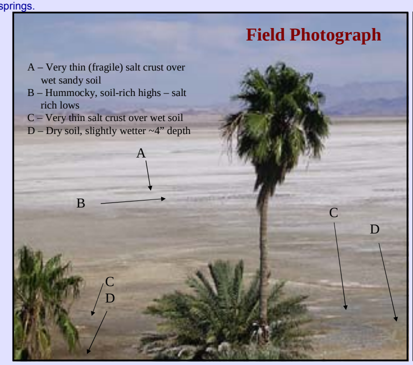


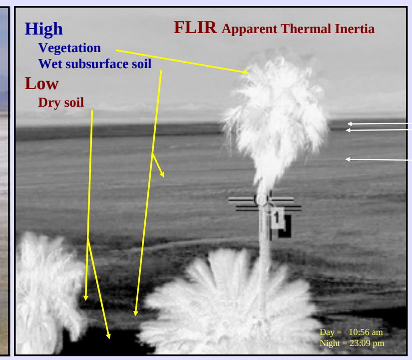


Playa crusts near Zzyzx, on the western edge of Soda lake.

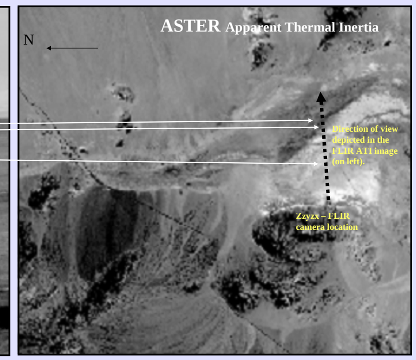
Image Analyses

To the right is a series of images taken from Zzyzx of the Soda Lake Playa. The first image is a field photograph of the area imaged with the FLIR camera. Identified wet and dry areas are labeled A thru D. The surface is dominated by silt and sand closer to the playa edge, and by evaporites in the distance. The middle image is the ATI image calculated from FLIR images taken at 10:56am and23:09pm. Dryer soils are darker (lower ATI) while wetter areas are brighter (higher ATI). In the far distance is a zone that is dark indicating dryer soils. This same pattern is evident in the ATI image made from day / night ASTER images. The white arrows connect the same zones as seen in the FLIR and ASTER ATI results.

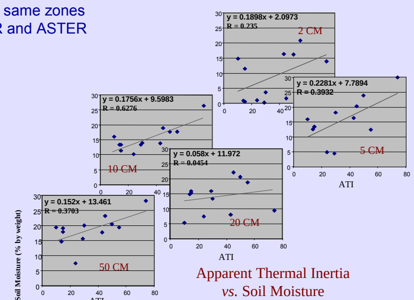




FLIR ATI image of Soda Lake playa, CA. Drier soils appear darker and wetter soils are lighter. The palm trees have a high ATI because of their high water content.

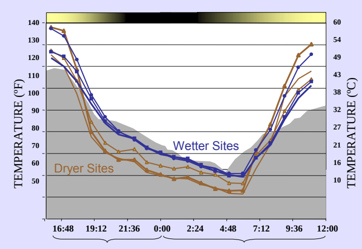


ATI image produced from day (5/5/04) / night (4/5/04) ASTER images taken of Soda Lake Playa, CA.



Apparent Thermal Inertia *vs.* Soil Moisture

Apparent thermal inertia vs. soil moisture at measured depths for all instrumented sites. ATI appears most correlated to soil moisture at ~10 cm depth. This is possibly because: 1) above 10 cm, temperature is influenced by local compositional/density changes, and 2) below 10 cm, the heat wave from day/night temperature fluctuations is largely attenuated.



Temperature changes in wet *vs.* dry zones as measured by the FLIR camera. Temperature changes in wetter areas are less extreme and rates are slower rate than in dry areas.

The warmest time of the day during this experiment was ~15:00 while the coolest was ~06:15 (just before sunrise).

Conclusions

1) Diurnal fluctuations of soil temperature are minimal at depths of 20 cm or more.
2) Daytime radiant temperatures were 10-22 ˚C higher than near-surface thermocouple measurements. The difference was only 4 ˚C for nighttime measurements
3) Near-surface soil moisture can be detected and mapped using day/night thermal images. Increased near-surface soil moisture increases the thermal inertia, thereby buffering the rate of temperature increase (daytime) and decrease (night) compared to drier soils. These differences are clearly measurable even when the playa is covered with a thin (1 – 1.5 cm) crust of dry soil.
4) Apparent Thermal Inertia is most strongly correlated to soil moisture measured at 10 cm. Moisture at shallower depths has a variable affect on ATI.

Sponsors

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