# Sustainable land imaging requirements to monitor surface soil moisture with HyspIRI-like data

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# Outline

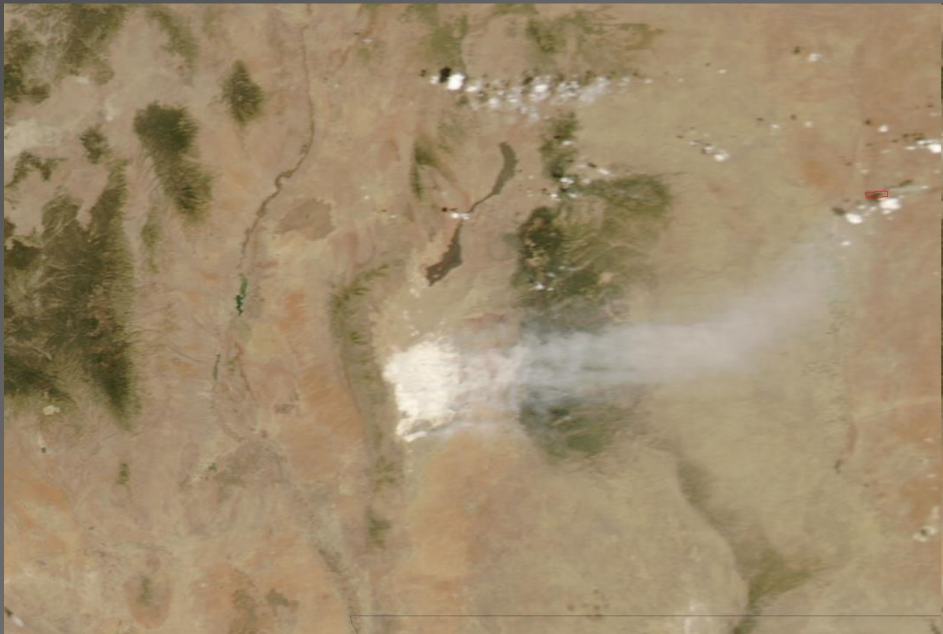
- **Background**
  - importance of soil moisture
  - relevant HyspIRI science questions
  - what is TI/ATI and how is it measured?
    - examples


*[Sosnowski, 2012]*

- **Sustainable Measurements?**
  - HyspIRI-specific possibilities
  - limitations/synergies with other sensors (e.g., SMAP, Landsat, …) and modeling approaches (e.g., ET/PET)

# Soil Moisture Content (SMC)

- **Importance in a Changing Climate**
  - soil moisture only represents ~0.05% of the global water budget
    - however, it has an disproportionate influence to its volume
    - fundamentally affects a variety of global climatic conditions
      - e.g., vegetation, ET, soil organic matter, aridity
    - in semi-arid landscapes soil moisture changes can be more impactful and can increase the mobilization and entrainment of dust, for example



White Sands, NM (MODIS: 14 March 2008)

# HyspIRI Relevant Science

- **TQ3: Water Use and Availability**
  - *TQ3c:* How can we improve early detection, mitigation, and impact assessment of droughts at local to global scales?
    - as a *T-question*, the description focuses only on ET/PET
- **CQ5: Surface Composition and Change**
  - *CQ5c:* How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers *(e.g., desertification, seasonal/yearly climate change, weathering, disturbances)*?
    - this *C-question* focuses only on the spectral mapping

# Soil Moisture Content (SMC)

- **Measurements in Semi-Arid Lands**
  - soils experience rapid drying following precipitation
    - importance of diurnal TIR measurements
  - low vegetation makes calculation of ET more reliant on soil emissivity/composition
  - field measurements over a large geographical region
    - are difficult and expensive
      - sensitive sensors to measure low water/high salinity soils
  - influence of SMC on soil mobility/erosion

U.S. Climate Reference Network (USCRN) sites

# One Approach

- **Thermophysical Properties**
  - function of temperature differences and albedo
  - able to interpret diurnal to seasonal weather-related processes:
    - soil moisture content (SMC) → *link to future SMAP data?*
    - soil erosion potential in arid/semi-arid lands
    - consolidated vs. rocky soils, soil density/cohesion
    - <u>thermal inertia:</u> resistance of a material to change in temperature, $\mathbf{I = (\kappa\rho c)^{1/2}}$
    - <u>ATI:</u> apparent thermal inertia, $\mathbf{ATI} = \boldsymbol{NC}\mathbf{(1\text{-}A)/(T_d\text{-}T_n)}$
      - a measure of the magnitude of the daily thermal curve moderated by albedo (A) and changes in solar flux with latitude and solar declination (N and C)

# TI Modeling Approach

$$P = \frac{(1-a)S_0C_t}{\Delta T\sqrt{\omega}}\left\{\frac{A_1\left[\cos(\omega t_2-\delta_1)-\cos(\omega t_1-\delta_1)\right]}{\sqrt{1+\frac{1}{b}+\frac{1}{2b^2}}}+\frac{A_2\left[\cos(\omega t_2-\delta_2)-\cos(\omega t_1-\delta_2)\right]}{\sqrt{2+\frac{\sqrt{2}}{b}+\frac{1}{2b^2}}}\right\}$$

*[Xue and Cracknell, 1995]*

- **Data Inputs**

  ***a*** *= albedo*

  ***ΔT*** *= temperature difference*

  $t_n$ *= day (n=1) and night (n=2) time*

  $S_0$ *= solar constant*

  ***ω*** *= angular velocity of Earth*

  $C_t$ *= atmospheric transmissivity*

  $\delta_n$ *= phase difference**

  $A_n$ *= coefficient of Fourier series**

  ** values are dependent on solar declination, latitude, and maximum daytime temperature*

- **Data Output**

  ***P****: thermal inertia (J $m^{-2}$ $K^{-1}$ $s^{-1/2}$ or TIU)*

  ***ATI:*** *(1-a)/ΔT*

- **Sources of Error**

  ***albedo:*** *dependent on instrument and calculation*

  ***ΔT:*** *satellite overpasses are not at maximum and minimum diurnal temperatures*

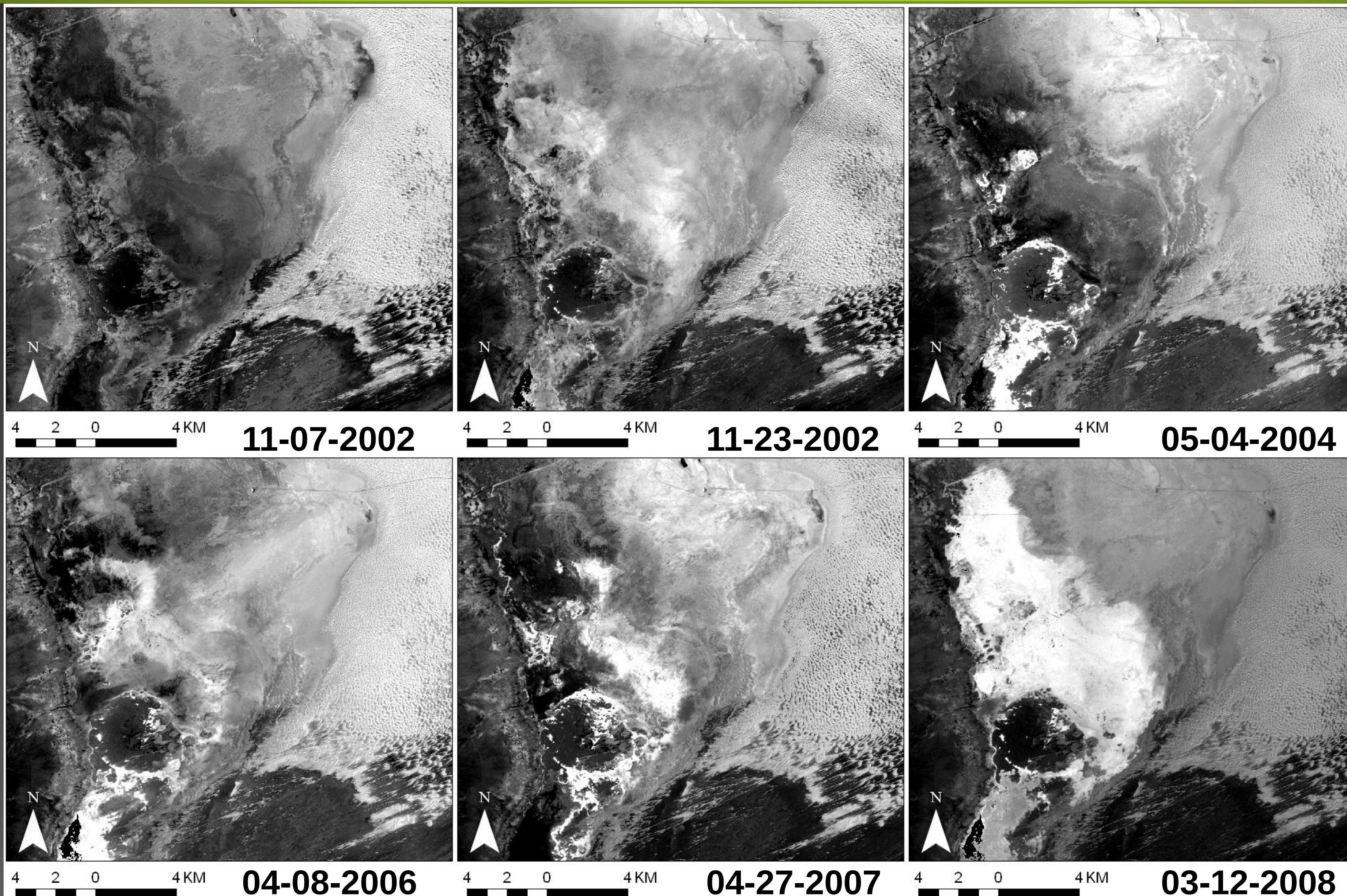
  $C_t$***:*** *assumed to be constant or corrected*

  ***time:*** *overpass time: 36 hours for ASTER (potential error and in-scene variability, i.e., cloud, rain, etc.)*

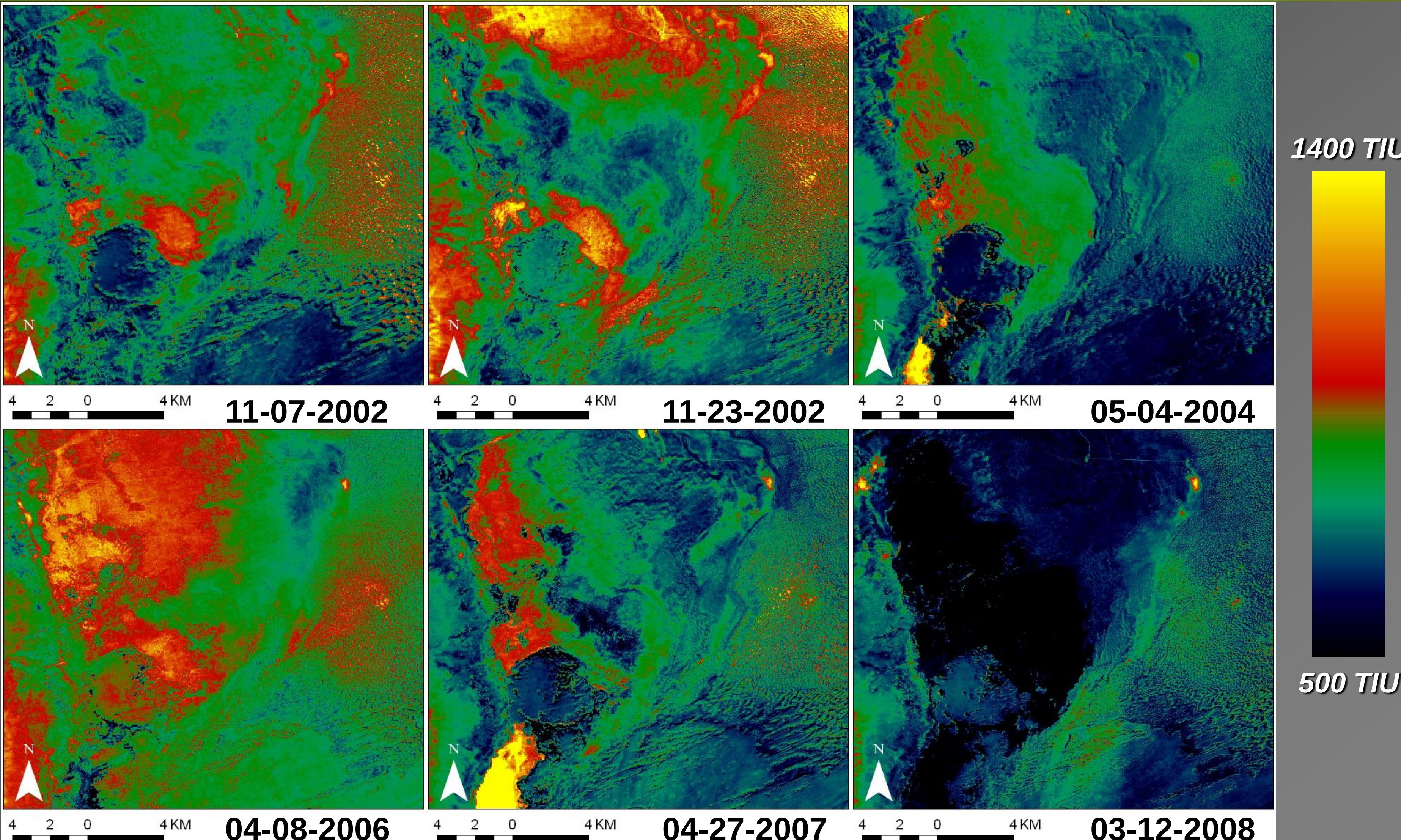
# Case Study Example

- **Examined ASTER apparent thermal inertia (ATI) at White Sands, NM**
  - calculated over 8 years
  - understand the relationship between
    - ATI ↔ TI ↔ SMC ↔ sediment availability
    - how are the differences in ATI over time explained for the same geographic area?
    - what are the errors in a vegetation-limited system?
    - can this approach determine SMC & sediment mobility?

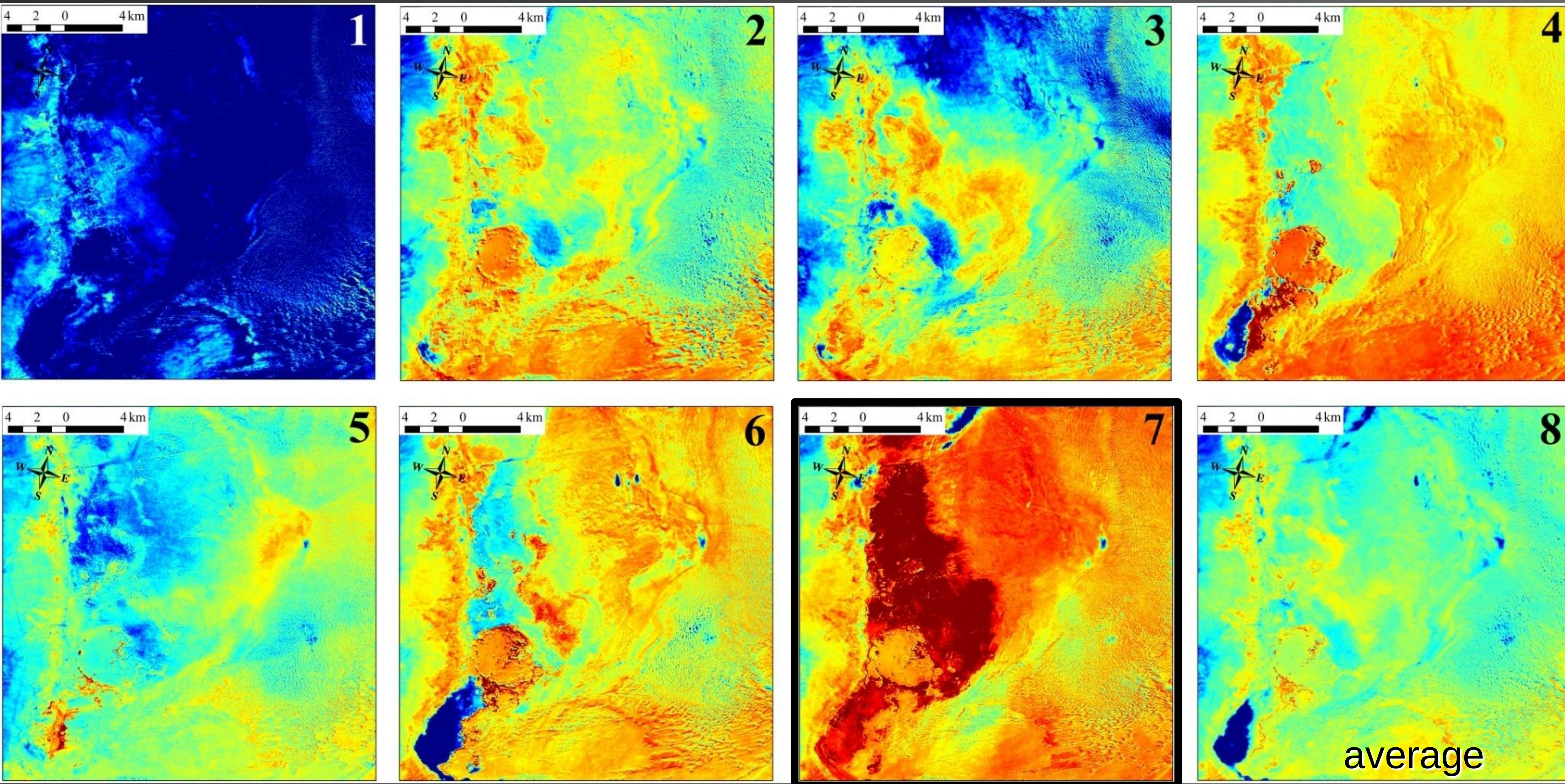
# ASTER Relative Albedo Changes



# Derived Thermal Inertia

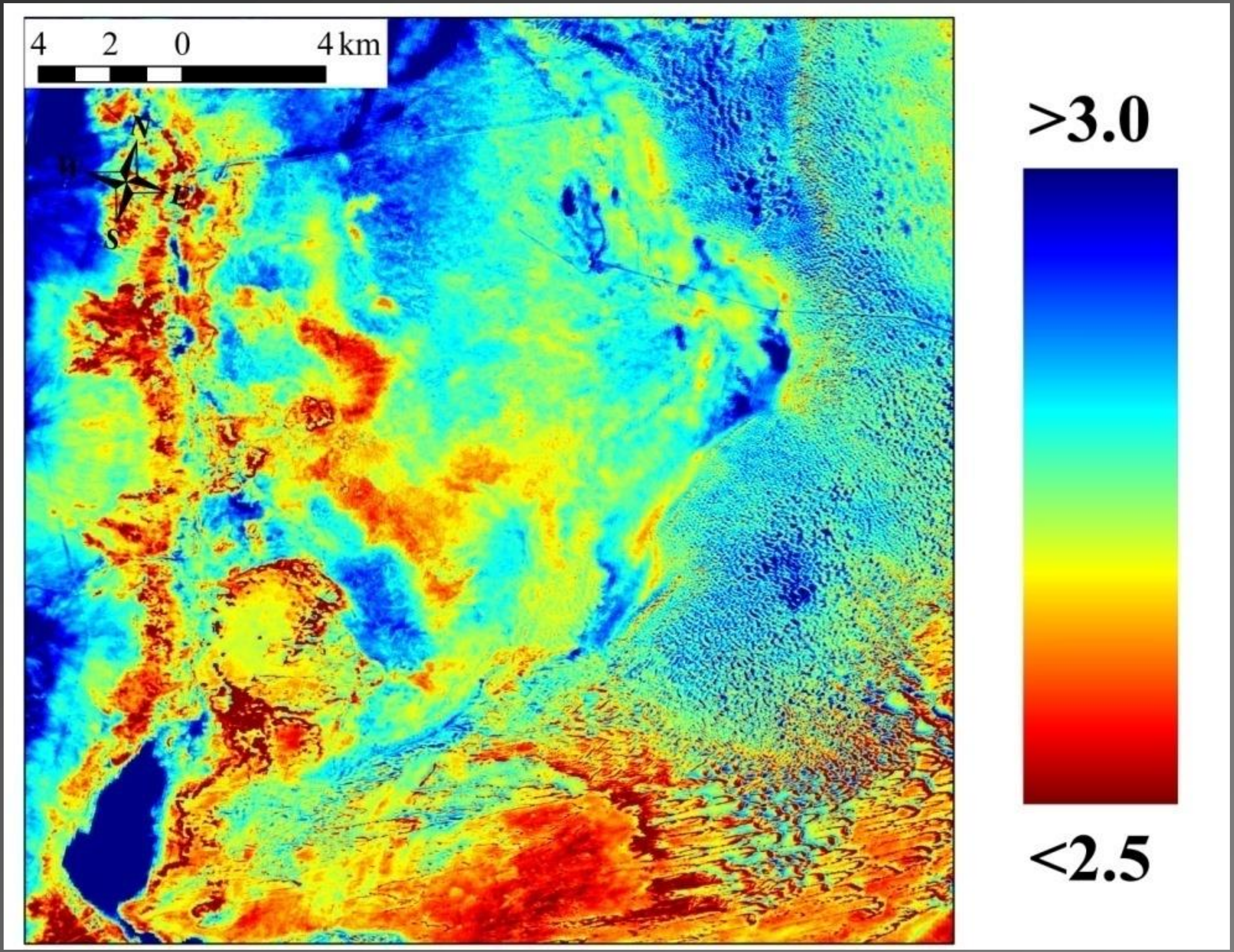


# Derived SMC



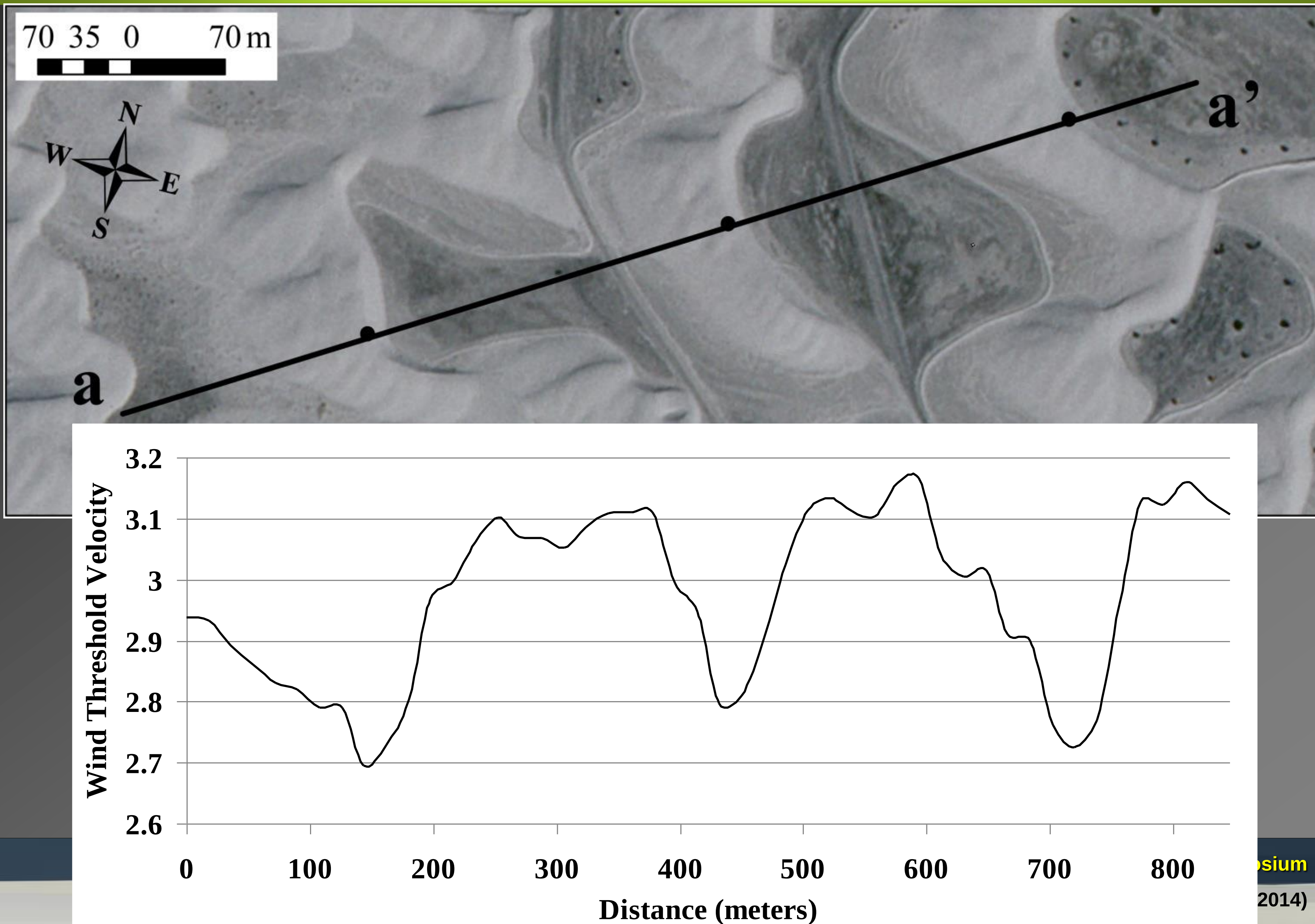

range of soil moisture content (9% - 25%)

# Derived Threshold Wind Velocity

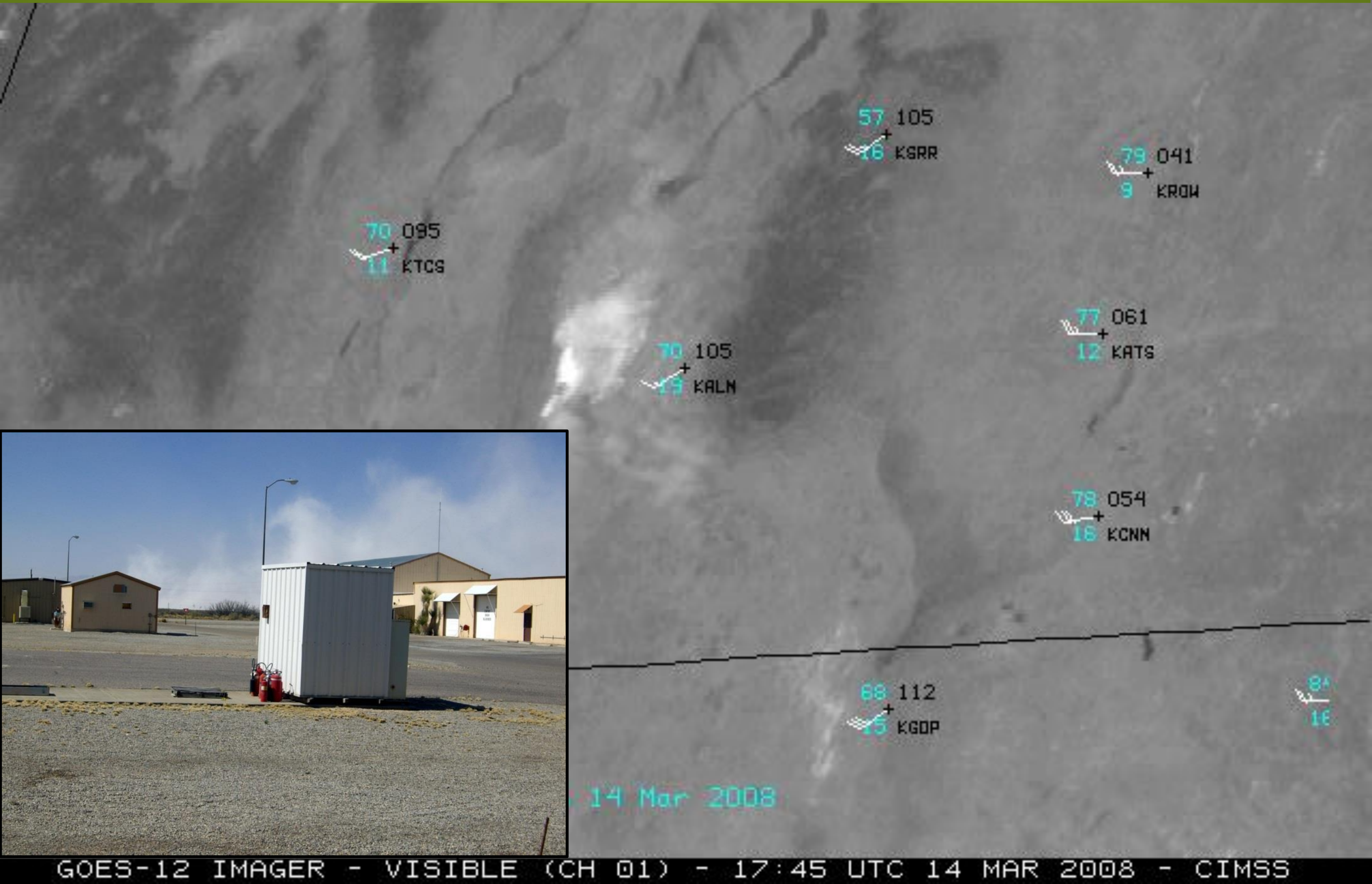



time-averaged image of the unit less erosion threshold wind velocity ratio ($u^*_\theta/u^*_d$)

# Derived Wind Threshold Velocity



# White Sands: 14 March 2008



# Conclusions: *Requirements*

- **Thermal Inertia → SMC:**
  - day/night LST *(multispectral TIR ideal)*
    - < 100m spatial, < 36 hour temporal resolution
    - better resolution of LST and surface composition
  - day albedo *(multi – hyperspectral VSWIR)*
    - < 60m spatial, ~ same time as $LST_{day}$
    - NDVI assessment for vegetation cover
  - DEM availability
    - asses and remove topographic shadowing
  - can be done with a variety of current/future sensors
  - testing needed over a variety of surface types

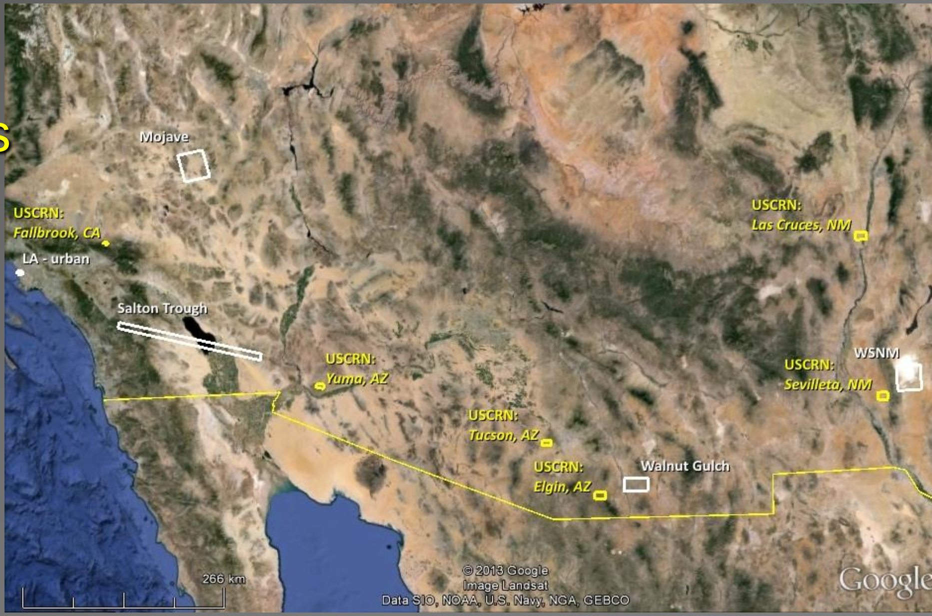
# Conclusions: *Integrative Approach*

- **Optical Sensors**
  - existing ASTER and new Landsat data
  - use of higher temporal resolution VSWIR data combined with HyspIRI TIR

- **Other Configurations**
  - ISS
    - precludes climate and solid earth science (especially at higher latitudes)
    - significant potential for soil moisture studies at mid-latitudes
      - overpass times would vary over the course of the day
      - allow temperature sampling at times excellent for ATI/TI based SMC studies

# Conclusions: *Integrative Approach*

- **Microwave Sensors**
  - upcoming Soil Moisture Active Passive (SMAP)
    - SMC maps at 9 km several times seasonally
      - for example, the White Sands eolian system is ~26 km$^2$
        - *equates to ~80 SMAP pixels / ~190,000 HyspIRI pixels*
    - limited in areas of steeper topography/higher latitudes
    - a unique synergy exists
      - TIR data captures different scales
      - proposing to carry out cal/val testing of the TIR approach at SMAP calibration targets



# Conclusions

- ***Retrieved TI, Soil Moisture, and Wind Threshold Velocity***
  - *at a high spatial resolution using ASTER*
  - *for eolian systems*
    - *soil moisture is the most important parameter where estimating sediment availability*
    - *values are slightly higher than would be expected for the dunes*
      - *model needs further refinement and testing in other regions*
      - *however, the general trends within the dunes and over time are valid*
      - *detected a dramatic decrease in soil moisture in March 2008*
        - *several days before the largest dust storm at White Sands in over a decade (used as a monitoring tool with HyspIRI?)*

# sustainable land imaging notes

– 20 year period starting in 2018