Deriving soil moisture and sediment mobility using future HyspIRI-derived thermal inertia

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Scheidt, S., Ramsey, M. & Lancaster, N., Determining soil moisture and sediment availability at White Sands Dune Field, NM from apparent thermal inertia data, *JGR – Earth Surface, in press,* 2009.

HyspIRI Relevant Science

- **TQ3: Water Use and Availability**
  – Can we improve early detection, mitigation, and impact assessment of droughts at local to regional scales anywhere on the globe?
  – How does the partitioning of precipitation into ET, surface runoff and ground-water recharge change during drought?

- **CQ5: Surface Composition and Change**
  – How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers *(e.g., desertification, weathering, climate change, human disturbance)*?

What Is Missing in the CQ's?

- **Thermophysical Properties**
  - interpret diurnal, seasonal, or climatic surface and subsurface temperature variations
    - thermal inertia: controls the amplitude of the daily thermal curve, **$I = (k\rho c)^{1/2}$**
    - albedo: controls the average temperature fluctuation
    - ATI: apparent thermal inertial, **$ATI = (1-A)/(T_d-T_n)$**
  - derived products:
    - soil moisture *(linkage to future SMAP data)*
    - particle size, density
    - soil erosion potential in arid/semi-arid lands
      - *direct relationship to surface roughness/soil moisture*

Background: Soil Moisture

- **Measurements difficult in large arid lands**
  - permeable sands typically experience a quick drying
  - field measurements over a large geographical region are difficult and expensive
    - remote location and difficult working conditions
    - the need for very sensitive in-situ sensors to measure the low water / high salinity content of desert soils
  - soil mobility
    - important for desertification/agriculture conditions
    - local to regional climate impacts
    - the upper few centimeters are the most critical for understanding erosion potential

Background: Soil Moisture

- **Using Microwave Sensors**
  - regional to continental scale (e.g., PSR, AMSR-E)
  - future Soil Moisture Active Passive (SMAP)
    - spatial resolution of 1-3 km every 12 hours
    - surface roughness and vegetation
      - important for sediment transport studies
  - spatial resolution of 25 km (AMSR-E) and 1-3 km (SMAP) limits the interpretation of soil moisture for specific landforms
    - example, the White Sands eolian system is only 26 km^2
      - ~1 AMSR-E pixel, ~80 SMAP pixels
      - ~190,000 HyspIRI pixels

Background: White Sands, NM

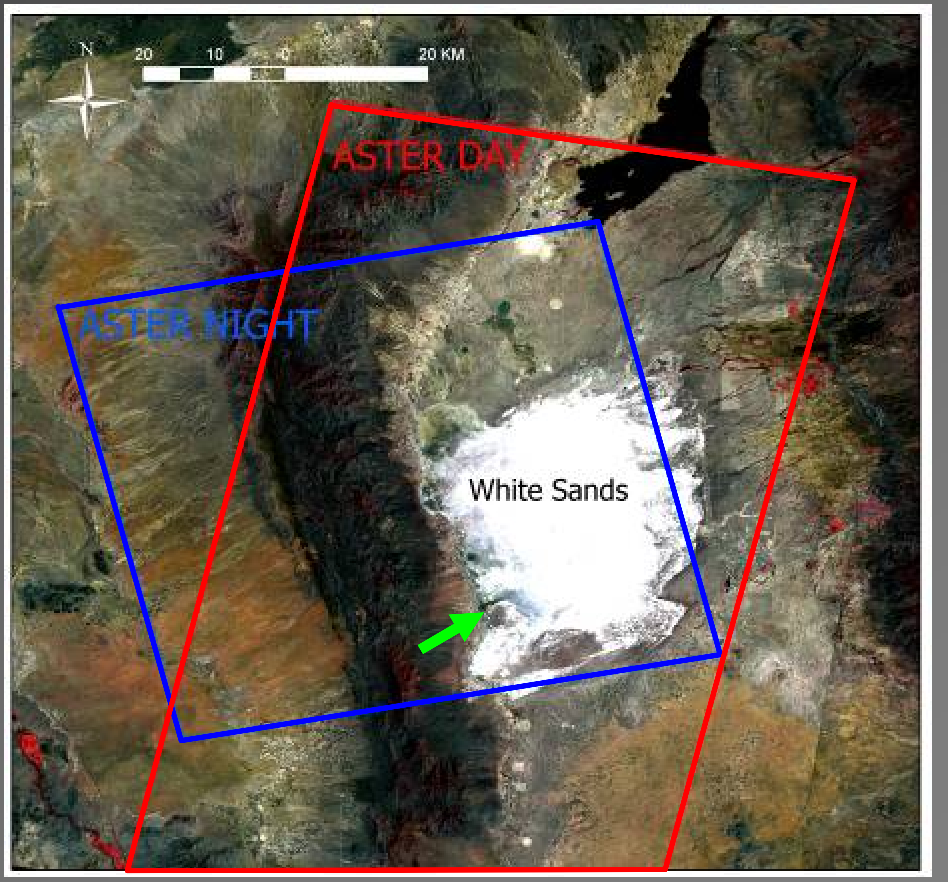
- **Understand the relationship between**
  - apparent thermal inertia (ATI) ↔ thermal inertia ↔ surface soil moisture ↔ sediment availability

- **Objectives:**
  - how are the differences in ATI over time explained for the same geographic areas?
    - can these be used to determine soil moisture/sediment mobility?
  - how do the calculations of ATI compare between ASTER and MODIS Terra?

White Sands: 14 March 2008

Background: White Sands, NM

- **Eolian System**
  - gypsum dominated
  - material is transported by W winds from ephemeral playa lakes
    - timing is determined by wet-dry cycles
    - resupply determined by the availability of the gypsum created by evaporation and mineral formation



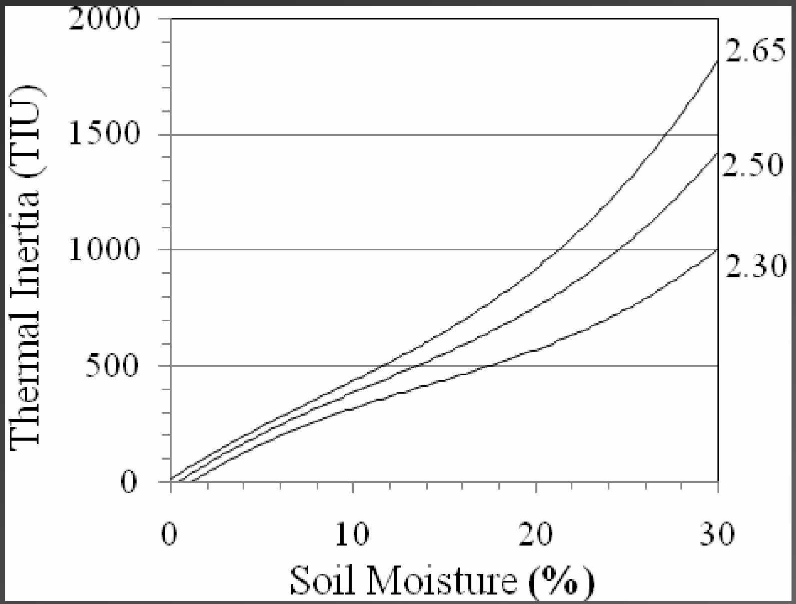
area of overlap of the ASTER day and night images (green arrow - Lake Lucero)

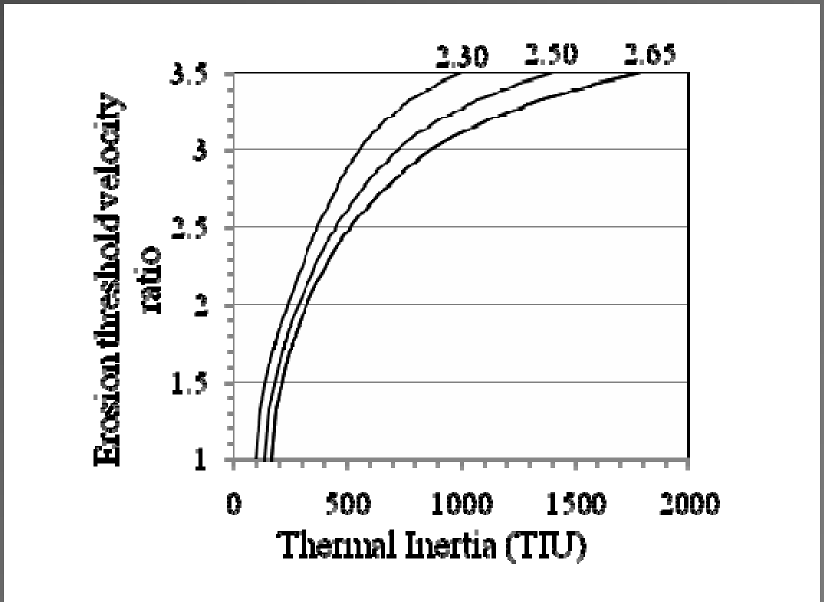
Background: Thermal Inertia

- **Previous studies**
  - have used thermal inertia to estimate soil moisture
    - Price (1985), Xue (1986), Zhang et al. (2002), Zhenhua & Yingshi (2006), Cai et al. (2007)

- **New work** [Scheidt et al., 2009]
  - reproduced a thermal inertia model for ASTER data Xue and Cracknell (1995)
    - programmed in IDL/ENVI
    - White Sands data are now presented in actual thermal inertia units (TI) units rather than ATI
    - TI is related to soil moisture and sediment availability

Models





Soil moisture vs. thermal inertia as a function of soil density reproduced from lookup (Mae and Xue, 1990)

Fécan et al. (1999) show the erosion threshold velocity ratio as a function of soil moisture

the Mae and Xue (1990) look up tables have been combined with the Fécan et al. (1999) relationship

Models

$$P = \frac{(1-a)S_0 C_t}{\Delta T\sqrt{\omega}}\left\{\frac{A_1\left[\cos(\omega t_2-\delta_1)-\cos(\omega t_1-\delta_1)\right]}{\sqrt{1+\frac{1}{b}+\frac{1}{2b^2}}}+\frac{A_2\left[\cos(\omega t_2-\delta_2)-\cos(\omega t_1-\delta_2)\right]}{\sqrt{2+\frac{\sqrt{2}}{b}+\frac{1}{2b^2}}}\right\}$$

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*

  δ_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: *overpasses are 36 hours apart (potential error and in-scene variability, i.e., cloud, rain, etc.)*

Approach

- **Examined ASTER and MODIS apparent thermal inertia (ATI)**
  - calculated over 8 years at White Sands, NM
  - 54 (day) and 70 (night) cloud-free ASTER images
    - seven day-night image pairs were selected
    - closest day/night pairs (36 hour difference)

ASTER Data

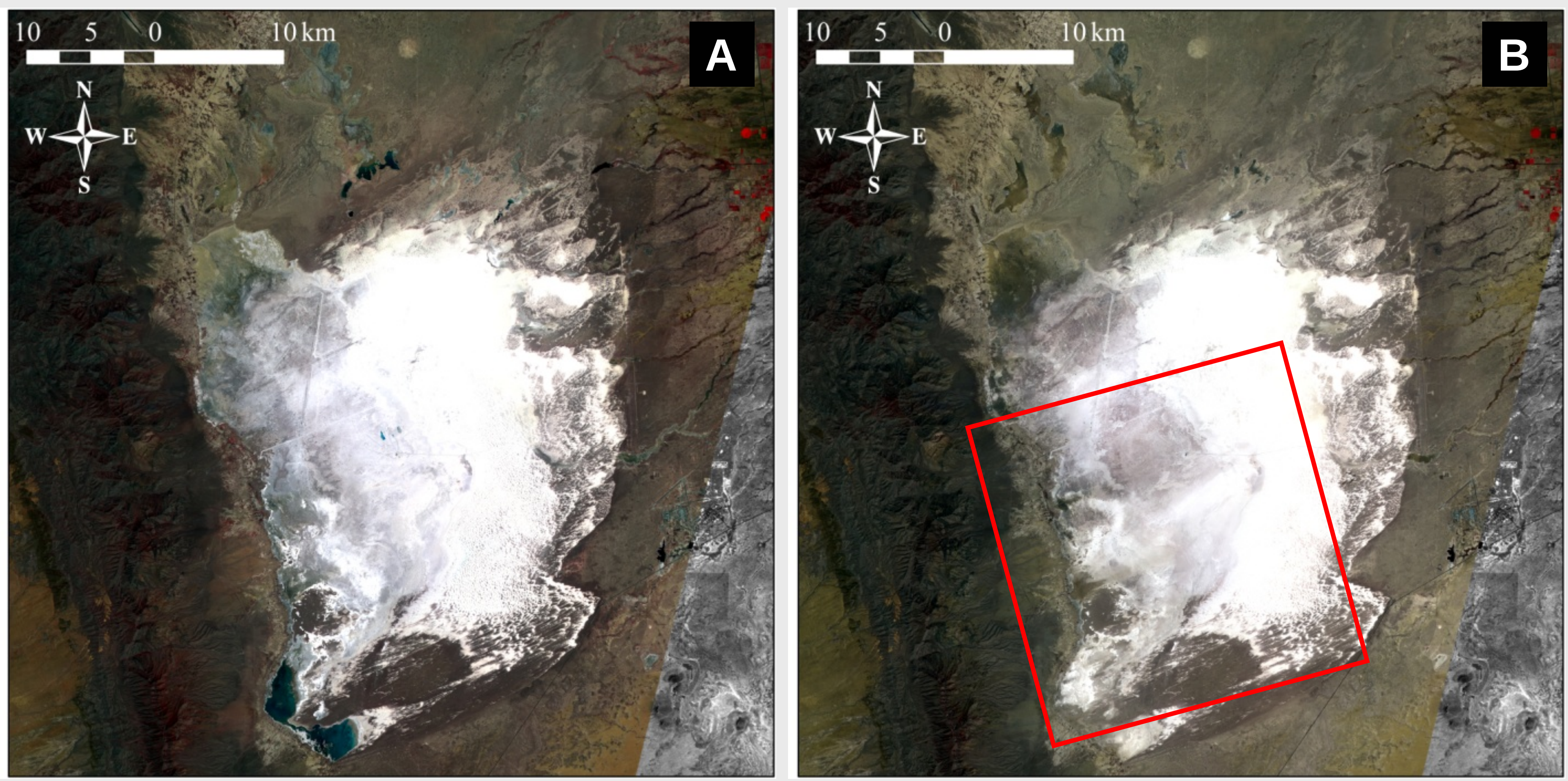
- **ASTER *(2000-2008)***
  – all data were processed to Level 2 (surface reflectance and kinetic temperature)
  – focus on two time pairs
    - April 2006 (dry period) and April 2007 (wet period)

Related Image and Weather Station Statistics

Image Pair Date	ΔT air (K)	Image ΔT (K)	Prior 30-day Precip (mm)	%Area Playa Inundation
Feb 7-8, '02	ND	16.8	ND	15
Nov 6-7, '02	27	22.1	26	0
Nov 22-23,'02	27	17.3	21	0
May 3-4,'04	25	33.5	21	0
April 7-8,'06	23.8	27	0	0
April 26-27,'07	22.2	32	15	50
March 11-12,'08	ND	26.5	ND	0

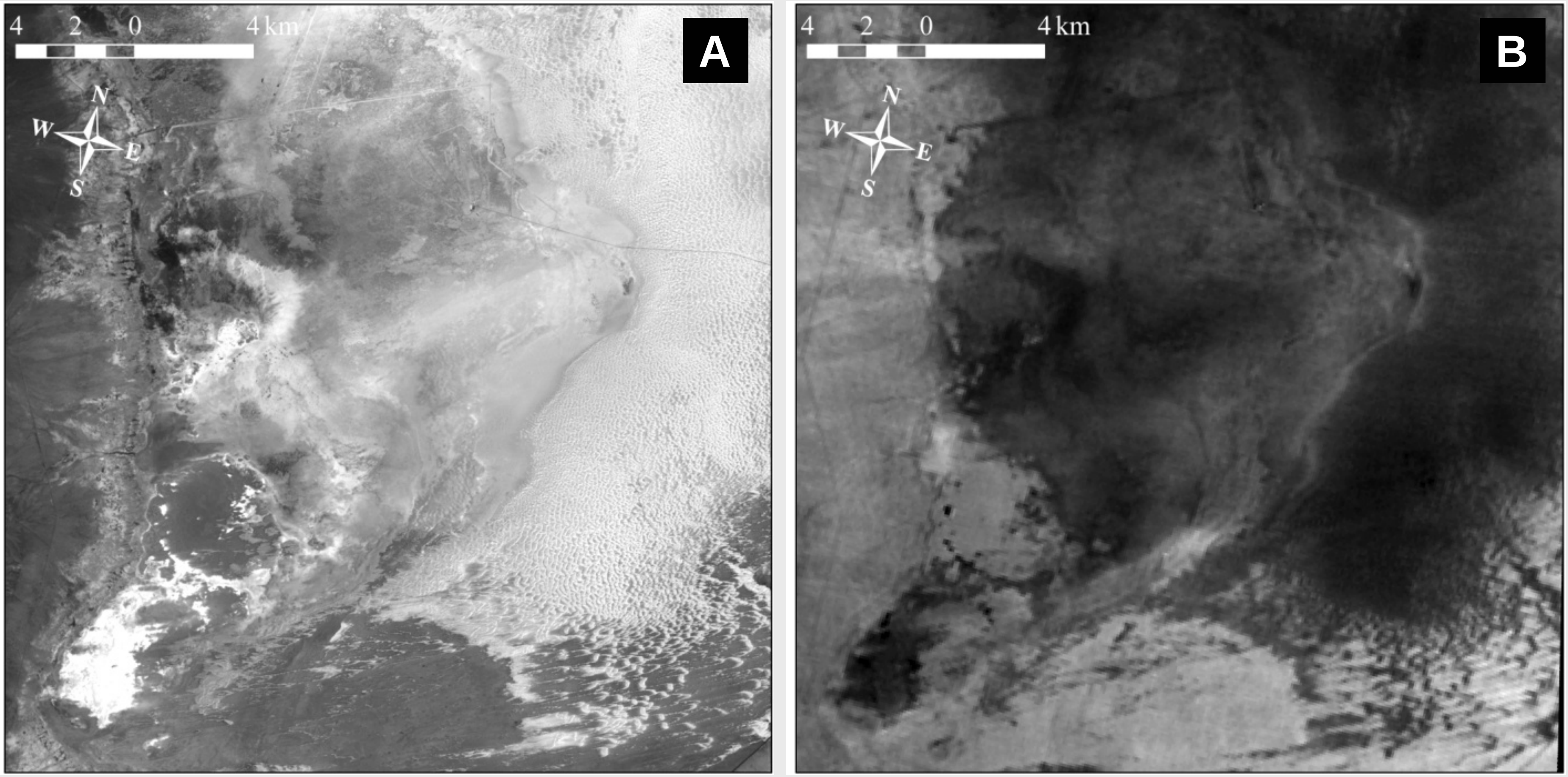
ASTER VNIR Data

27 April 2007 *(wet period)* 8 April 2006 *(dry period)*

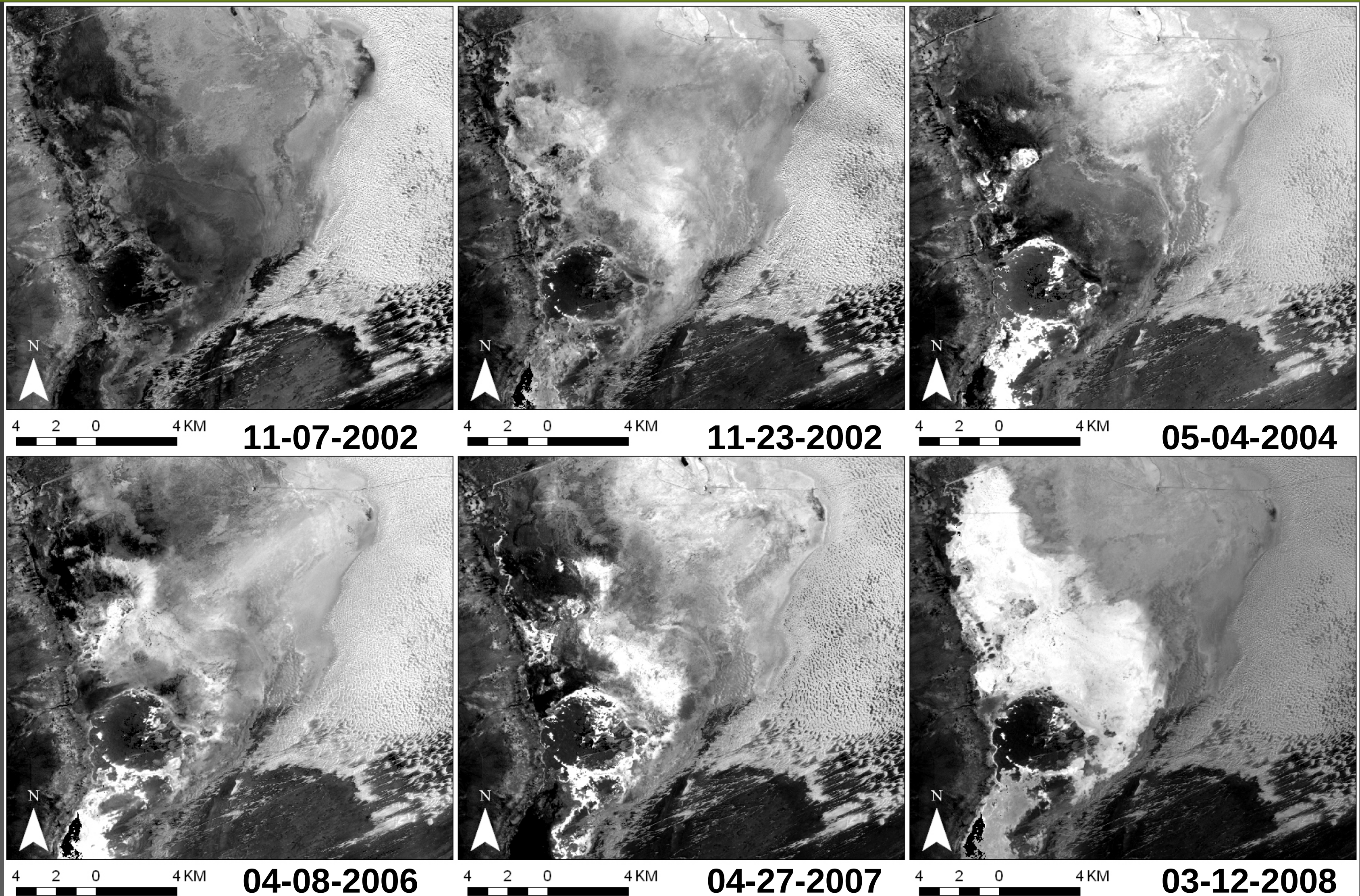


ASTER: 8 April 2006

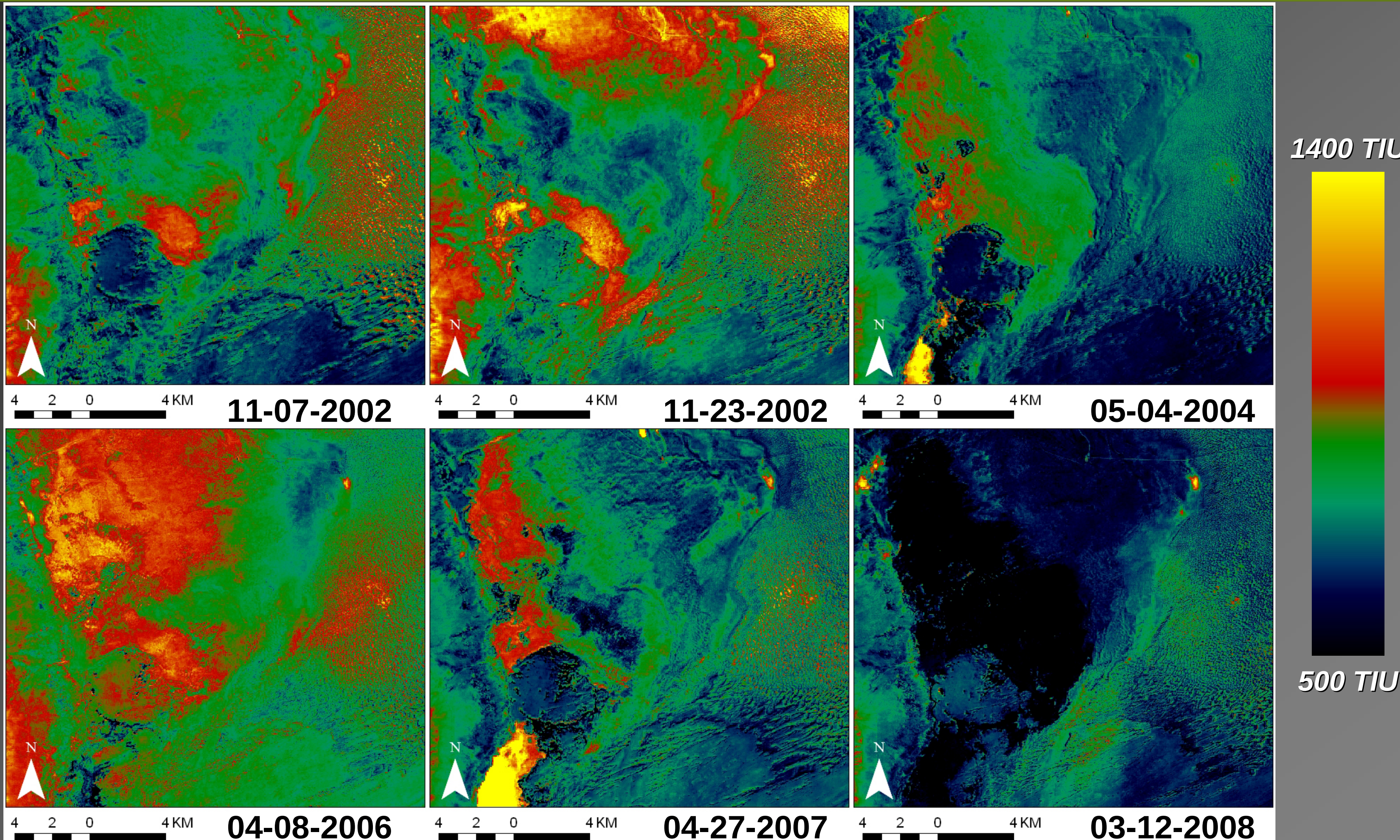
albedo | ΔT



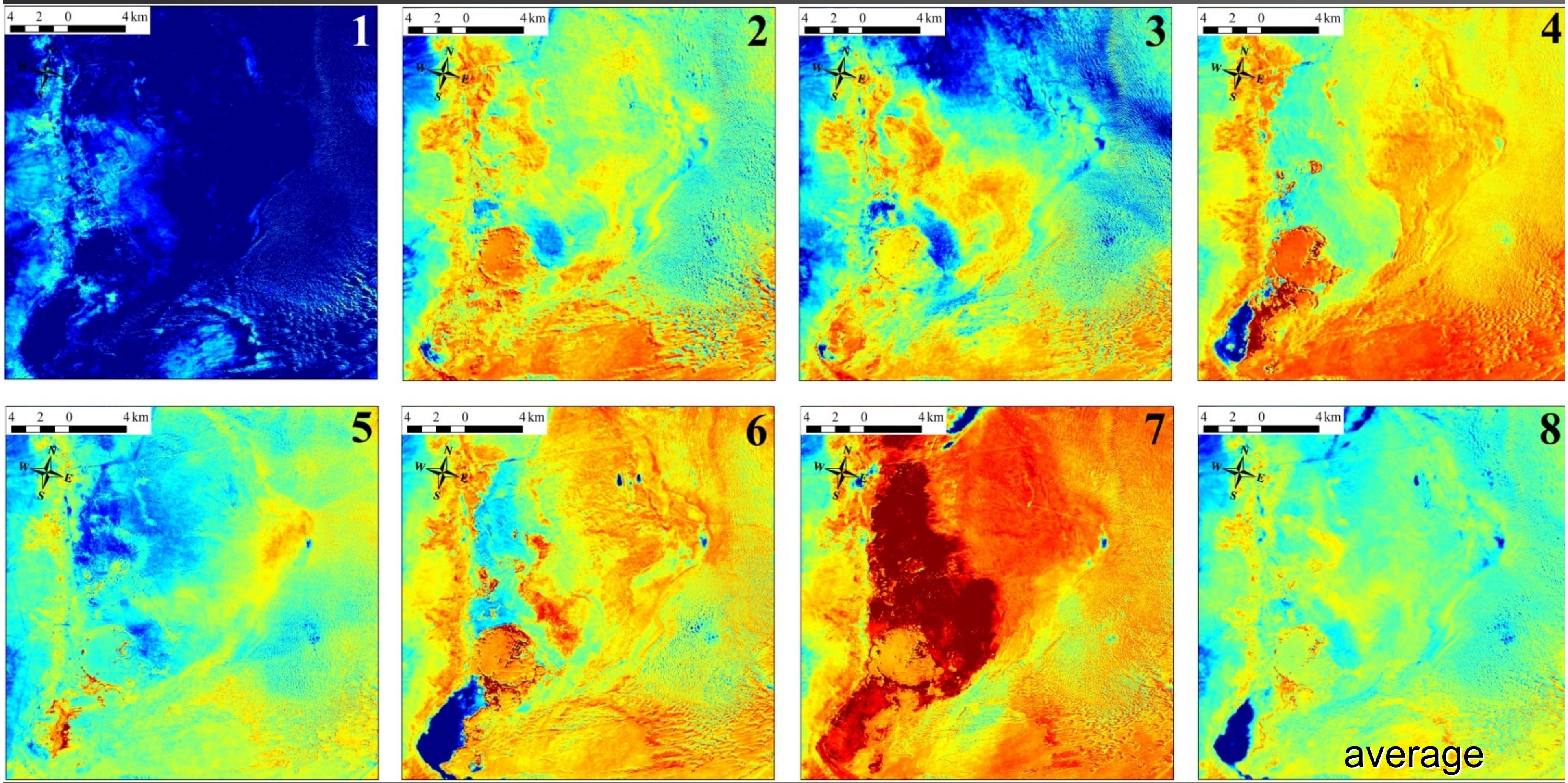
ASTER Relative Albedo Changes



ASTER Derived Thermal Inertia

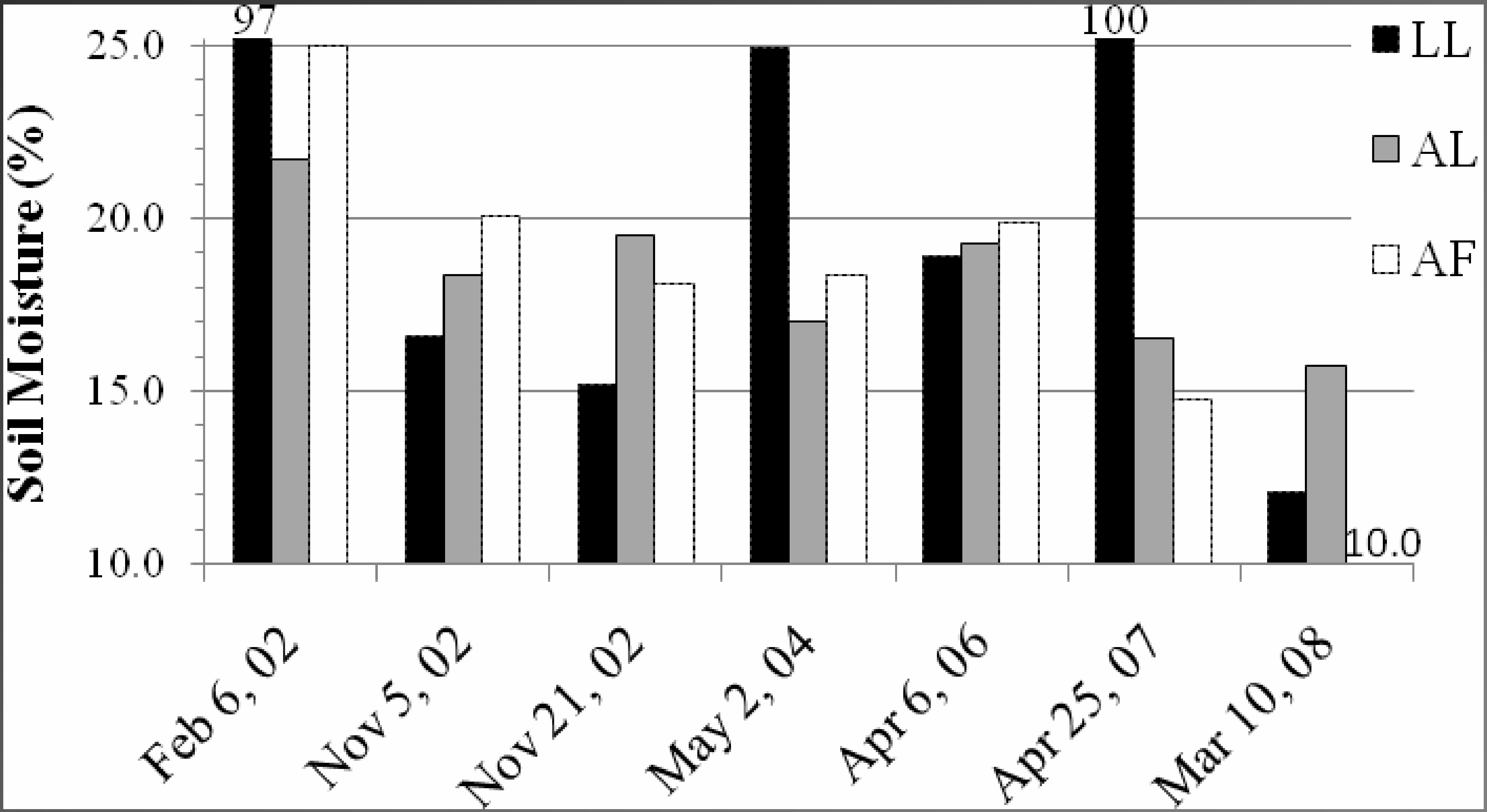


ASTER Derived Soil Moisture

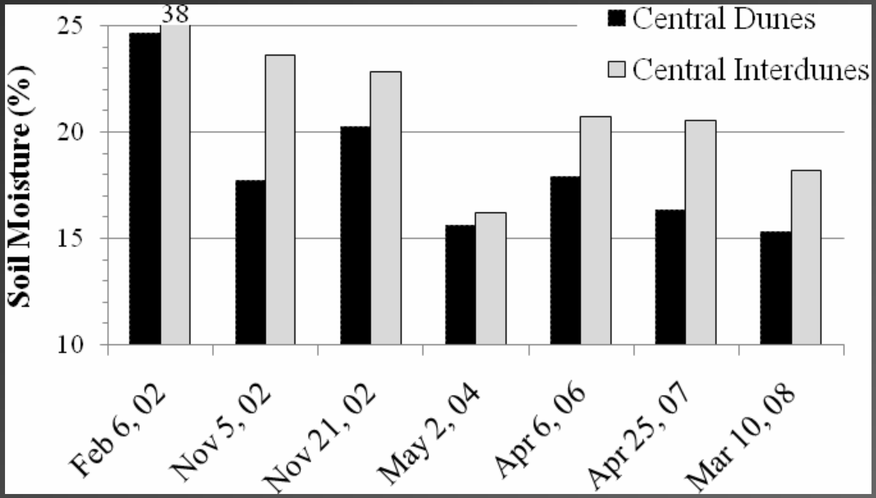


range of soil moisture values (9% - 25%)

ASTER Derived Soil Moisture

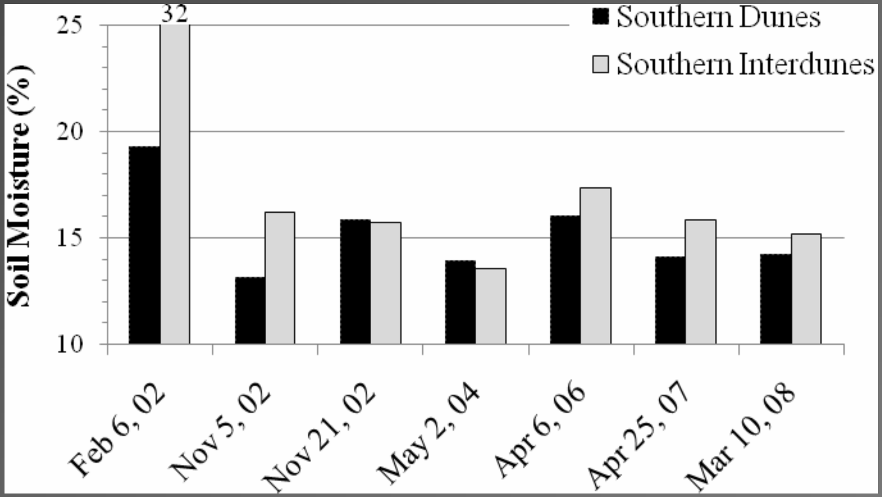


ASTER Derived Soil Moisture



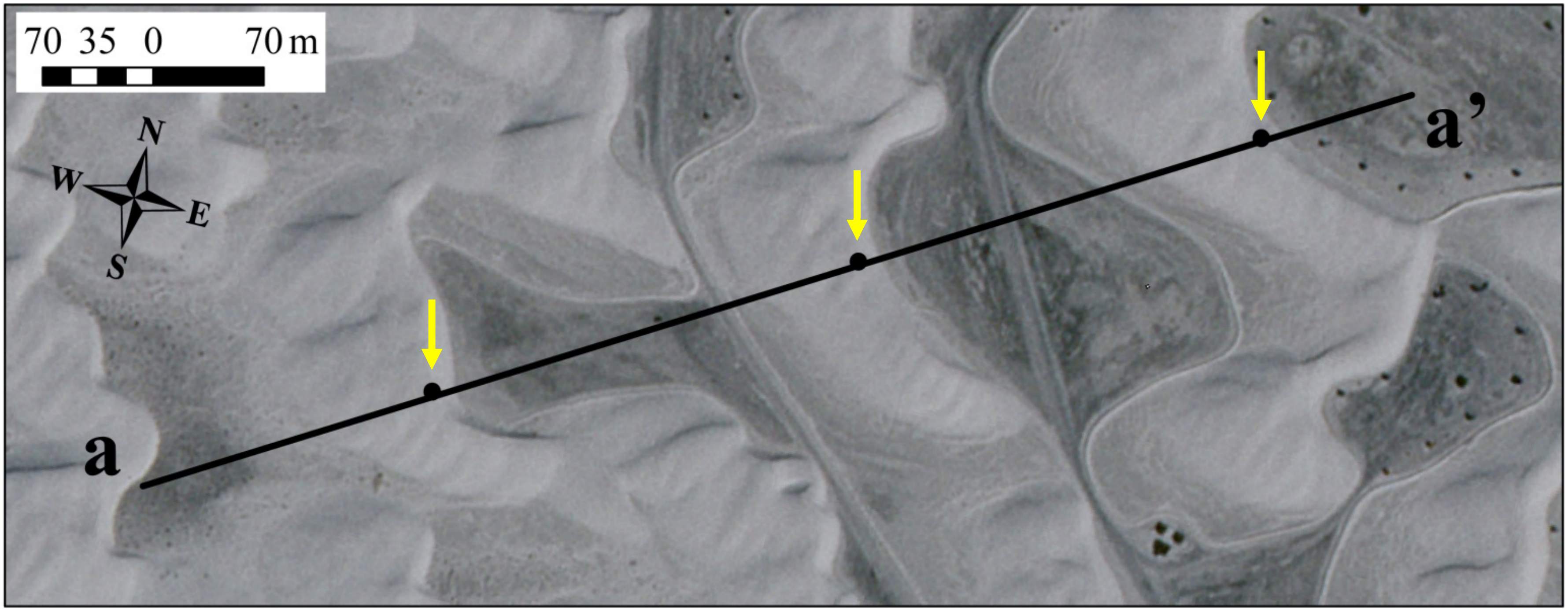
crescentic dunes

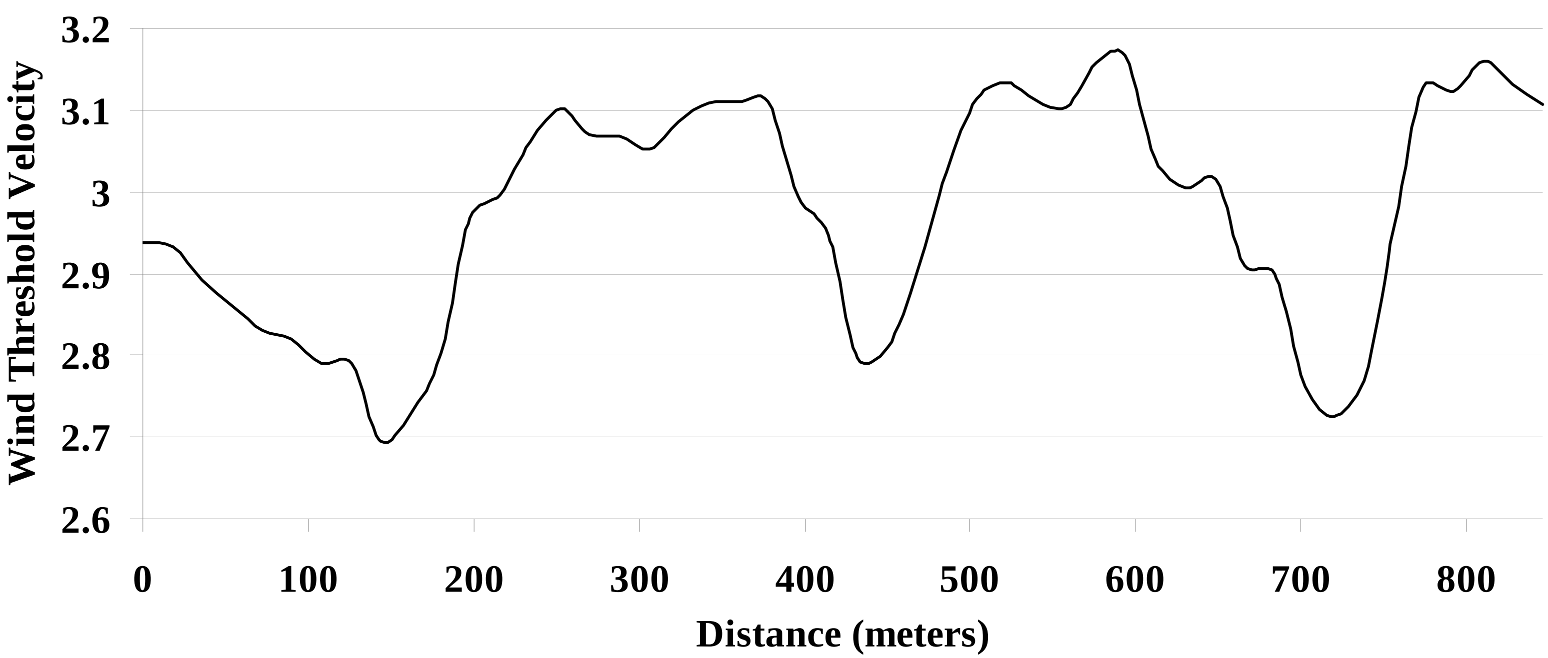
wind



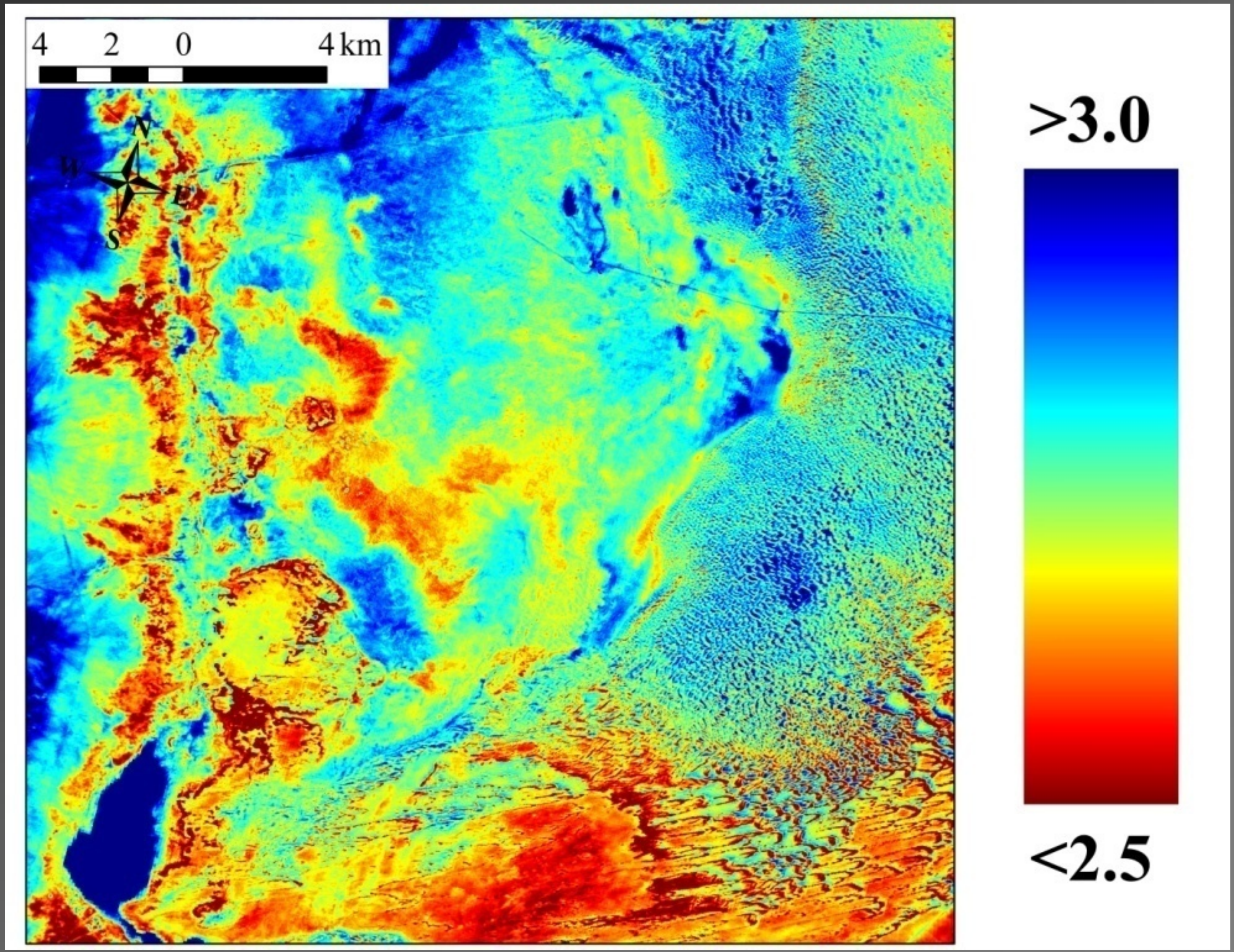
parabolic dunes

wind


70 35 0 70 m
N
W
E
S
a
a’

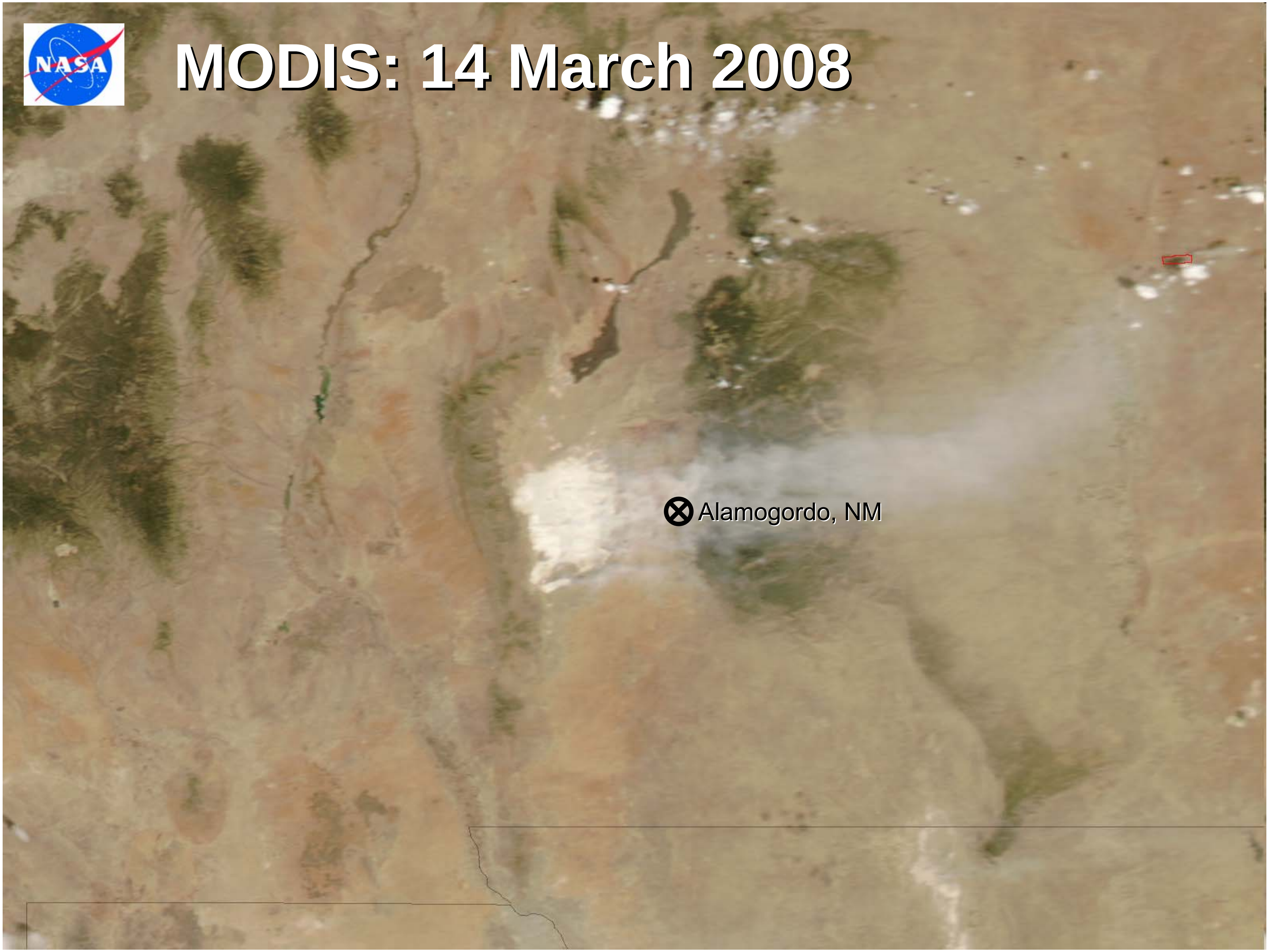

Wind Threshold Velocity
3.2
3.1
3
2.9
2.8
2.7
2.6
0
100
200
300
400
500
600
700
800
Distance (meters)

ASTER Erosion Ratio

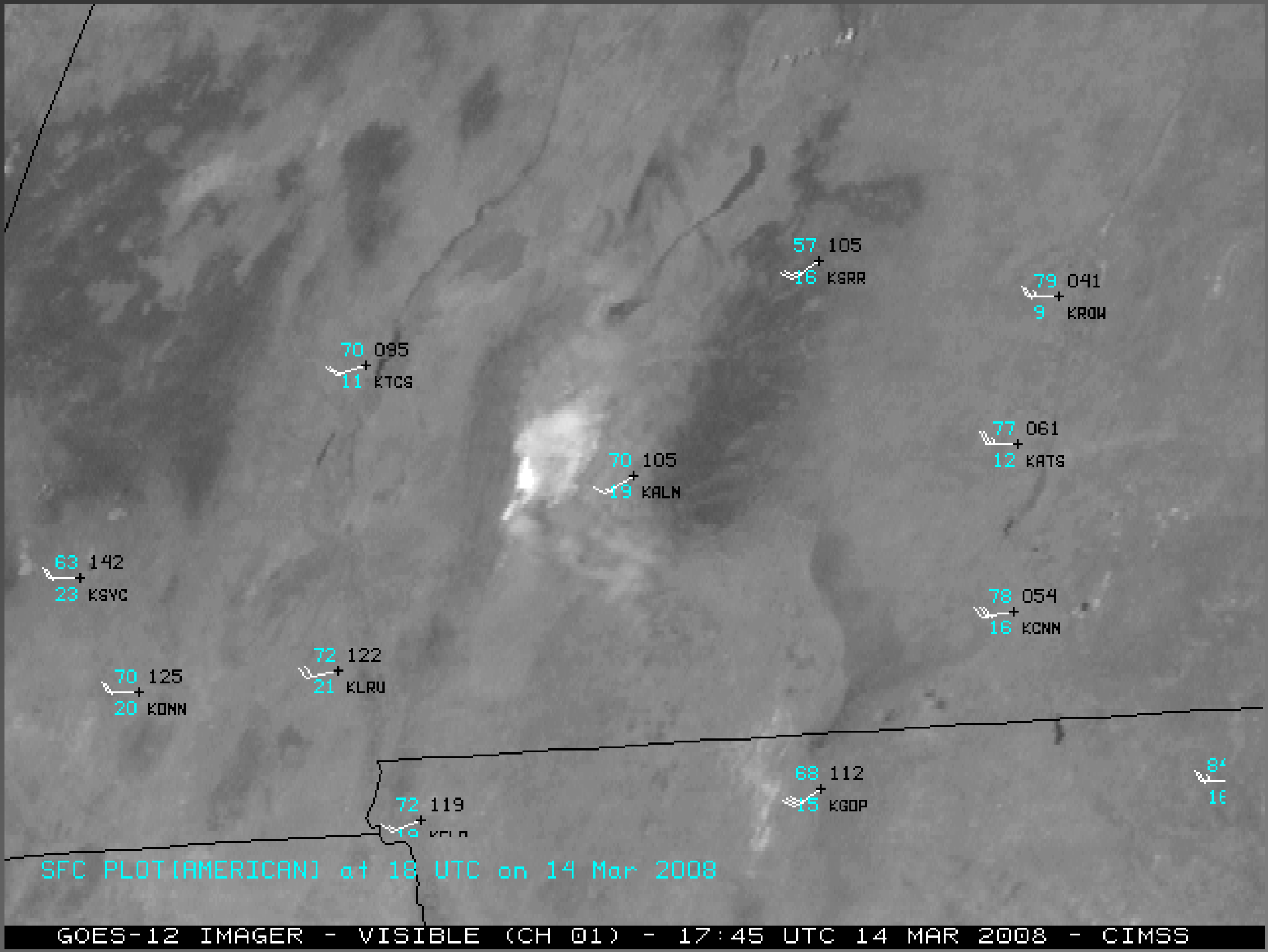


time-averaged image of the unit less erosion threshold wind velocity ratio (u^*_θ/u^*_d)

MODIS: 14 March 2008



GOES: 14 March 2008



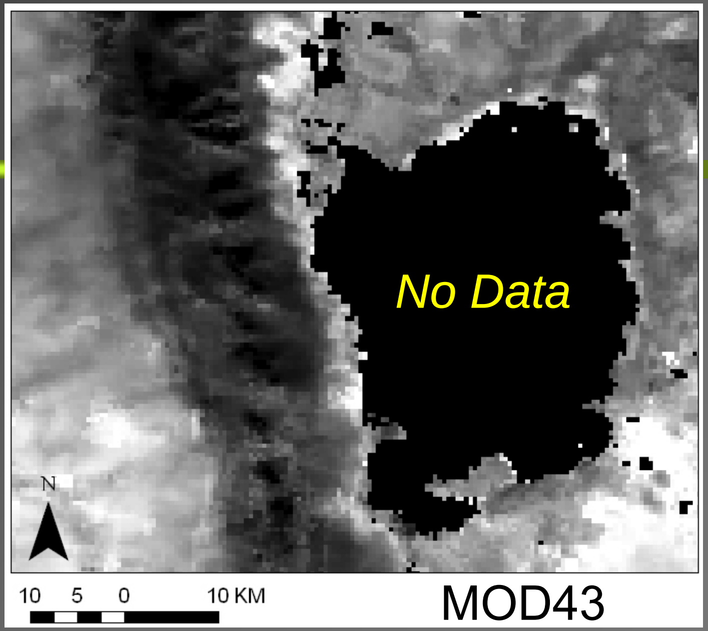
Conclusions

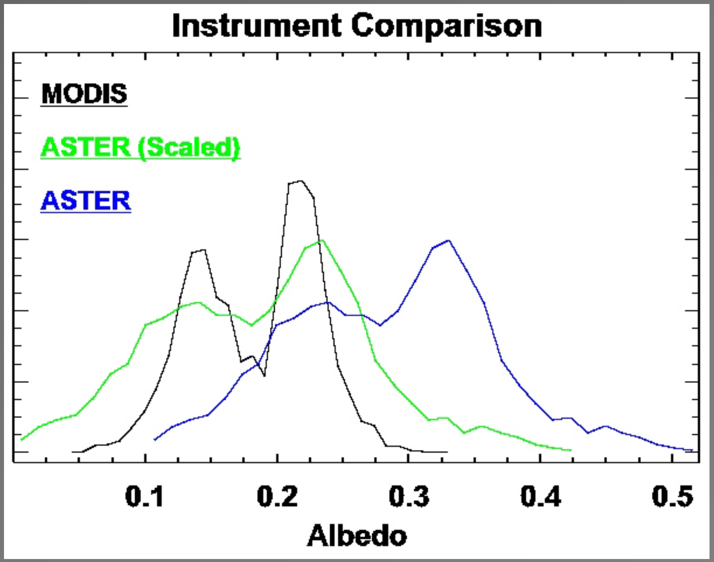
- **Retrieved TI, Soil Moisture, and Wind Threshold Velocity**
  - at a high spatial resolution using ASTER
  - for eolian systems
    - soil moisture is the most important parameter where estimating sediment availability
    - values are slightly higher than would be expected for the dunes
      - model 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?)*

extra slides

MODIS Albedo

- **MODIS products**
  - MOD43:16-day averaged albedo product
    - not retrieved for White Sands
    - false snow or cloud detection?
  - MOD09: reflectance product
    - can be used if assumed to be lambertian surface
  - solution: scale the ASTER albedo to MODIS albedo using scene statistics of the same pixels





Albedo Calculation

- **Compared ASTER and MODIS**
  - albedo derived from standard reflectance products
  - broadband albedo calculations from Liang (2000)
    - published for both MODIS and ASTER
  - ASTER albedo model:
    - $a = 0.484*b_1 + 0.335*b_3 - 0.324*b_5 + 0.551*b_6 + 0.305*b_8 - 0.367*b_9 - 0.0015$
  - *MODIS albedo model:*
    - $a = 0.160*b_1 + 0.291*b_2 - 0.243*b_3 + 0.116*b_4 + 0.112*b_5 - 0.081*b_7 - 0.0015$