Threshold considerations for future volcanic hotspot and ash detection using HyspIRI

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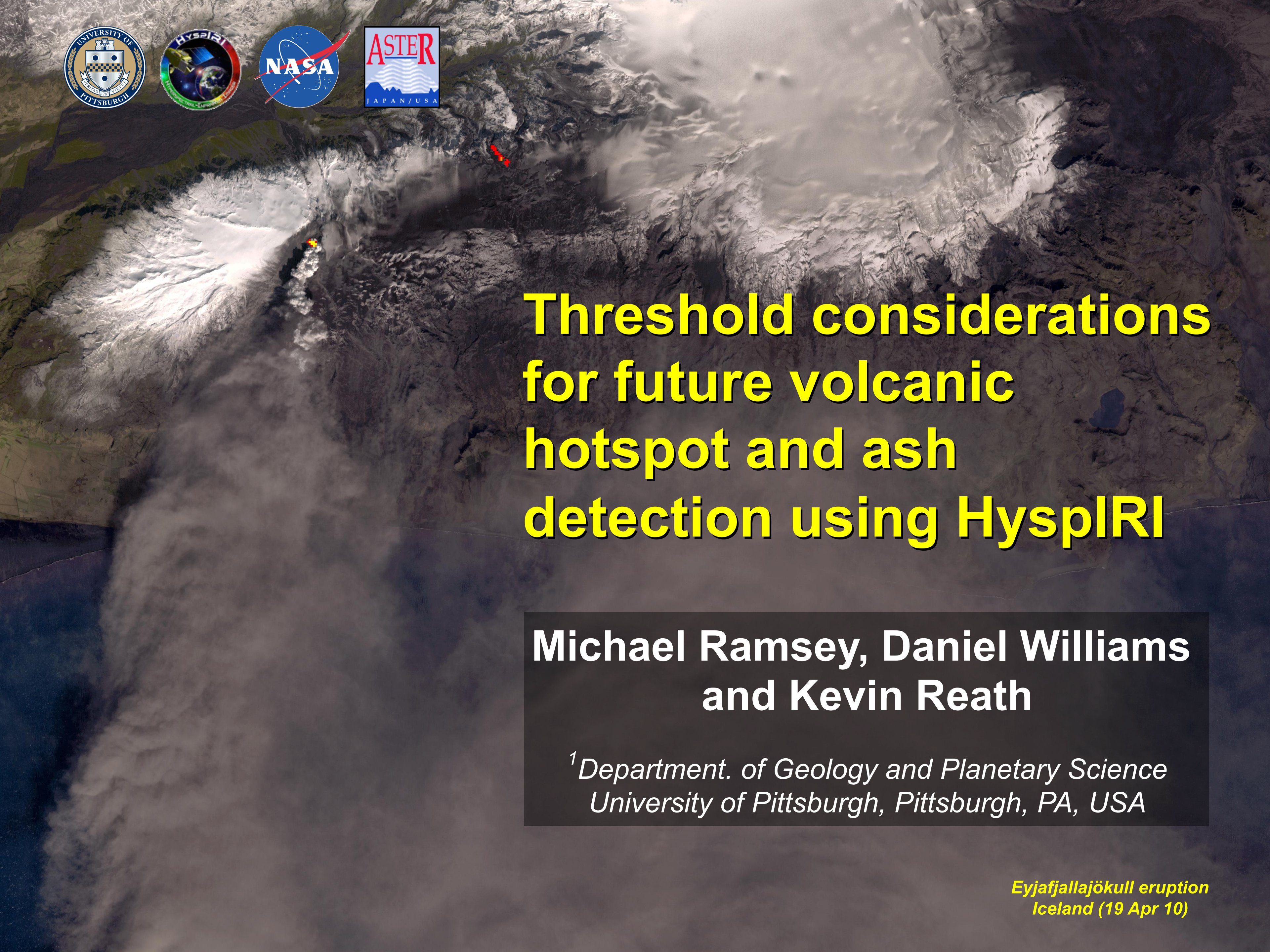


Eyjafjallajökull eruption
Iceland (19 Apr 10)

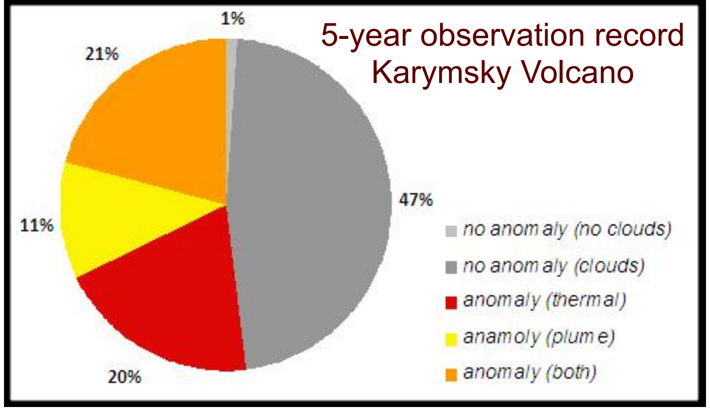
Overview

- **Presented Previous Work Using ASTER TIR Data**
  - specifically with the Urgent Request Protocol (URP) system
  - help predict expected HyspIRI TIR results
    - dynamic volcanic processes
    - expected cloud cover

- **This Work** [Reath et al., 2013; Williams et al., 2013]
  - thermal and compositional thresholds
    - use of temperature changes as volcanic eruption precursors
    - ash-rich plumes/clouds
      - spectral variability with particle size and composition for mapping of the proximal plume
      - statistical/trajectory modeling of distal plumes to identify source locations

ASTER URP Program

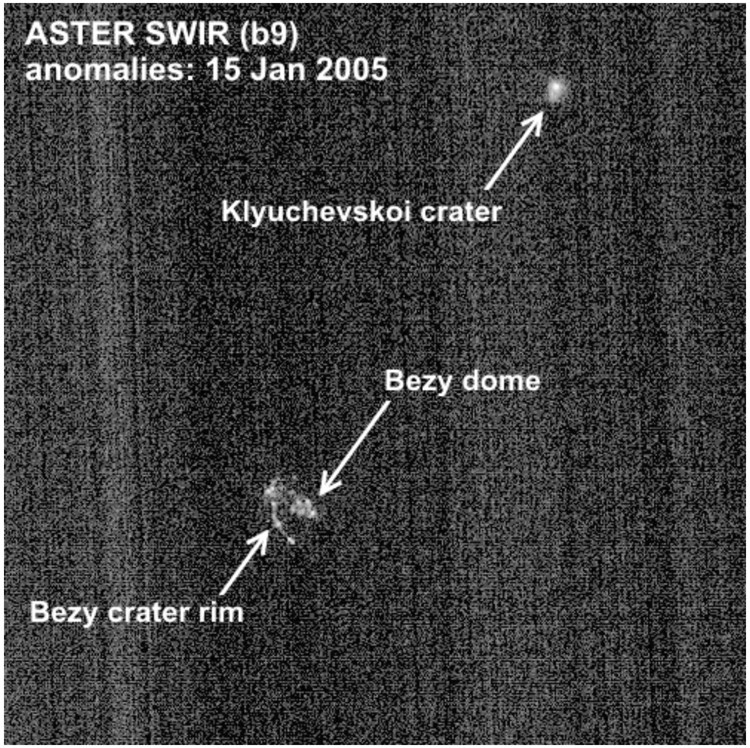
- **Has Improved the Temporal Frequency of ASTER**
  - based on thermal alert triggers from AVHRR and MODIS
    - AVHRR: all volcanoes in Northern Pacific region *(> 100)*
    - MODIS: 20 volcanoes globally *(most active)*



- **Statistics**
  - as of mid-2013
    - total 1580 UPR requests
    - average: 1 scene / 2 days for the past 8.5 years
      - Russia (54%), United States (32%), Africa (4.8%), S. America (2.9%), C. America (2.9%), Europe (1.8%), and Pacifica (1.5%)

Background: *Thermal Thresholds*

- **Thermal Precursory Activity**
  - most volcanoes produce some level of precursory activity prior to an eruption
    - if detected, can be analyzed over time
    - determine the time and magnitude of the impending eruption *(forecasting)*
    - example:
      - Bezymianny volcano, Russia commonly produces a clear increase in activity months ahead of a larger eruption
      - Tolbachik volcano produced no thermal precursors prior to the large effusive eruption in 2012
      - examined three large eruptions (e.g., 2005, 2007, 2009) from Kliuchevskoi volcano

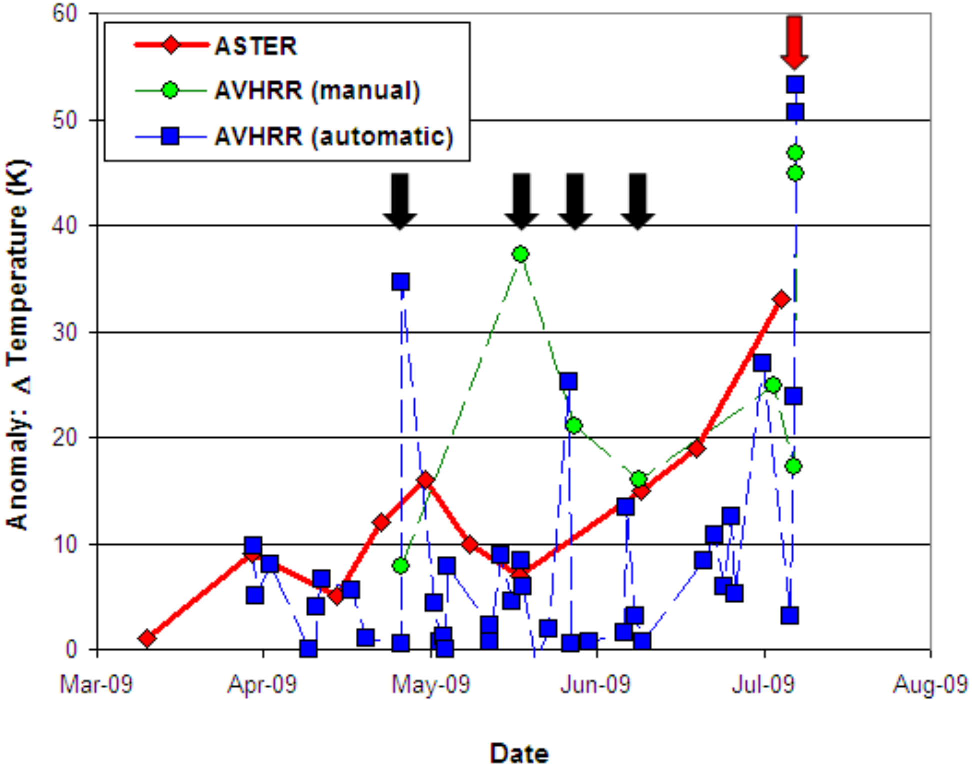


Methods: *Thermal Thresholds*

- **Thermal Precursory Activity**
  - high temporal but low spatial resolution *(i.e., hours; 1 km)* AVHRR data
    - ideal for detecting high energy events occurring over short time periods, such as small strombolian eruptions
  - high spatial but low temporal resolution *(i.e., days to weeks; 90 m)* ASTER data
    - enables the detection of much lower levels of activity
    - these anomalies are more commonly associated with the longer time scale pre-eruptive phase
  - ASTER, AVHRR & MODIS TIR data time series examined for three large eruptions of Kliuchevskoi (2005, 2007, 2009)

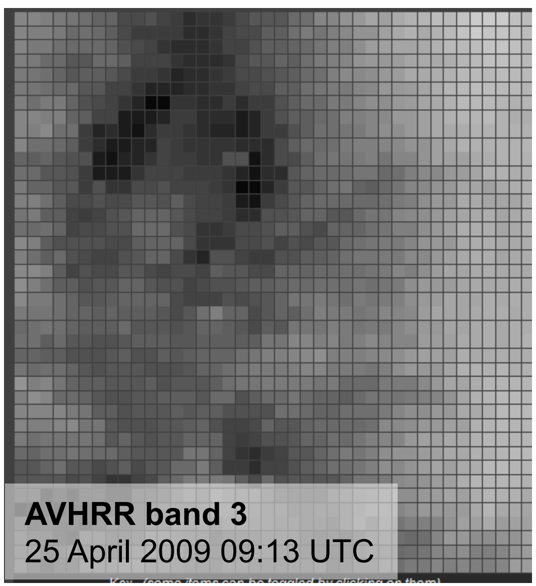
Results: *Thermal Thresholds*

- **TIR Sensitivity**
  - example: the 2009 Kliuchevskoi eruption
    - clear fluctuations occur in summit temperatures 6 to 8 months before the eruption
    - significant increase in the precursory intensity occurs 2 months before the larger eruption
      - not easily detected with AVHRR or MODIS due to the lower temperatures and spatial extent

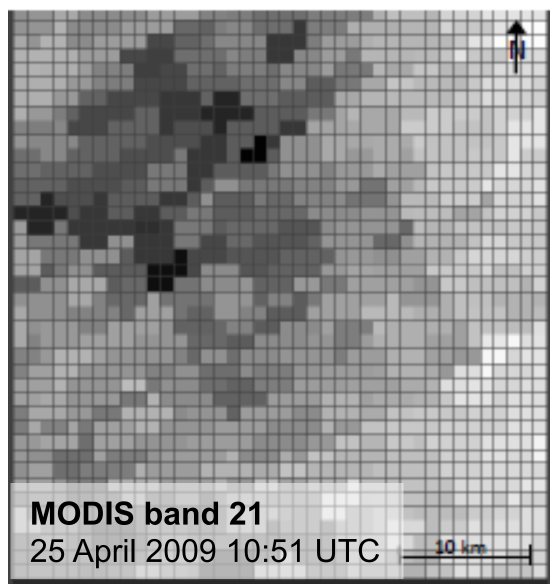


Results: *Thermal Thresholds*

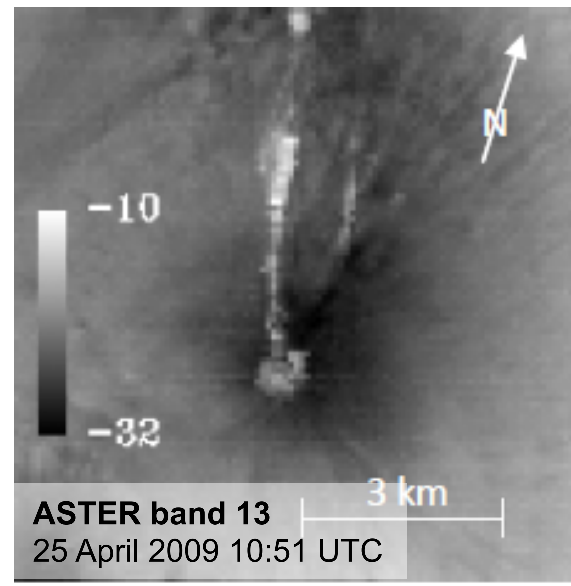
- **TIR Sensitivity: Spatial & Radiometric**
  - critical to have both high enough to detect this low-level, precursory activity
    - ASTER: 1.71 x 10^3 to 5.93 x 10^3 W/m^2 sr µm
    - AVHRR: 2.70 x 10^5 to 6.29 x 10^5 W/m^2 sr µm
    - MODIS: 2.23 x 10^5 to 9.47 x 10^5 W/m^2 sr µm



AVHRR band 3
25 April 2009 09:13 UTC



MODIS band 21
25 April 2009 10:51 UTC



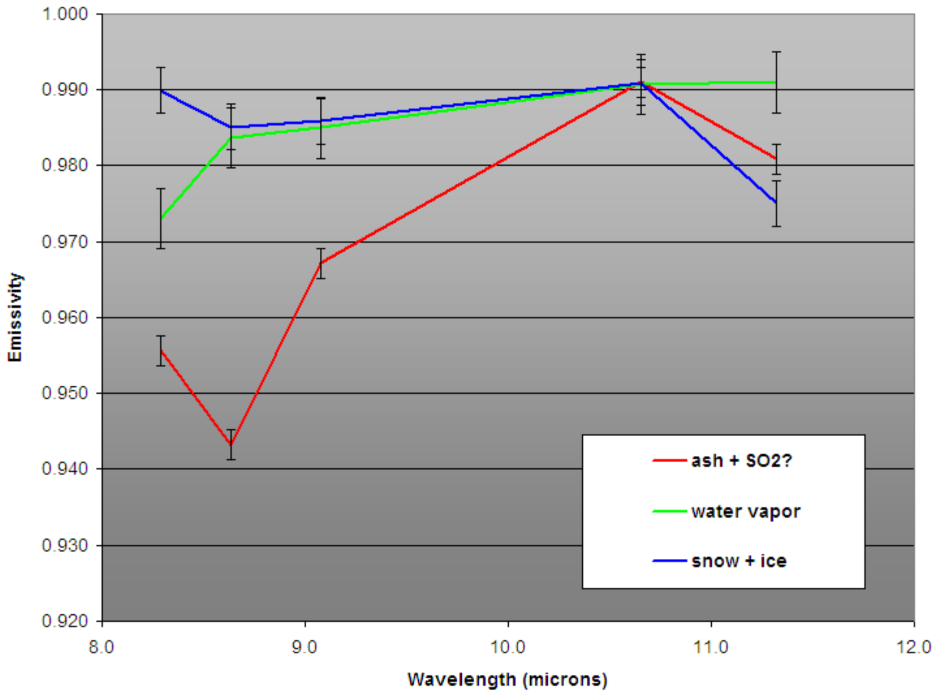
ASTER band 13
25 April 2009 10:51 UTC

Methods: *Ash Thresholds*

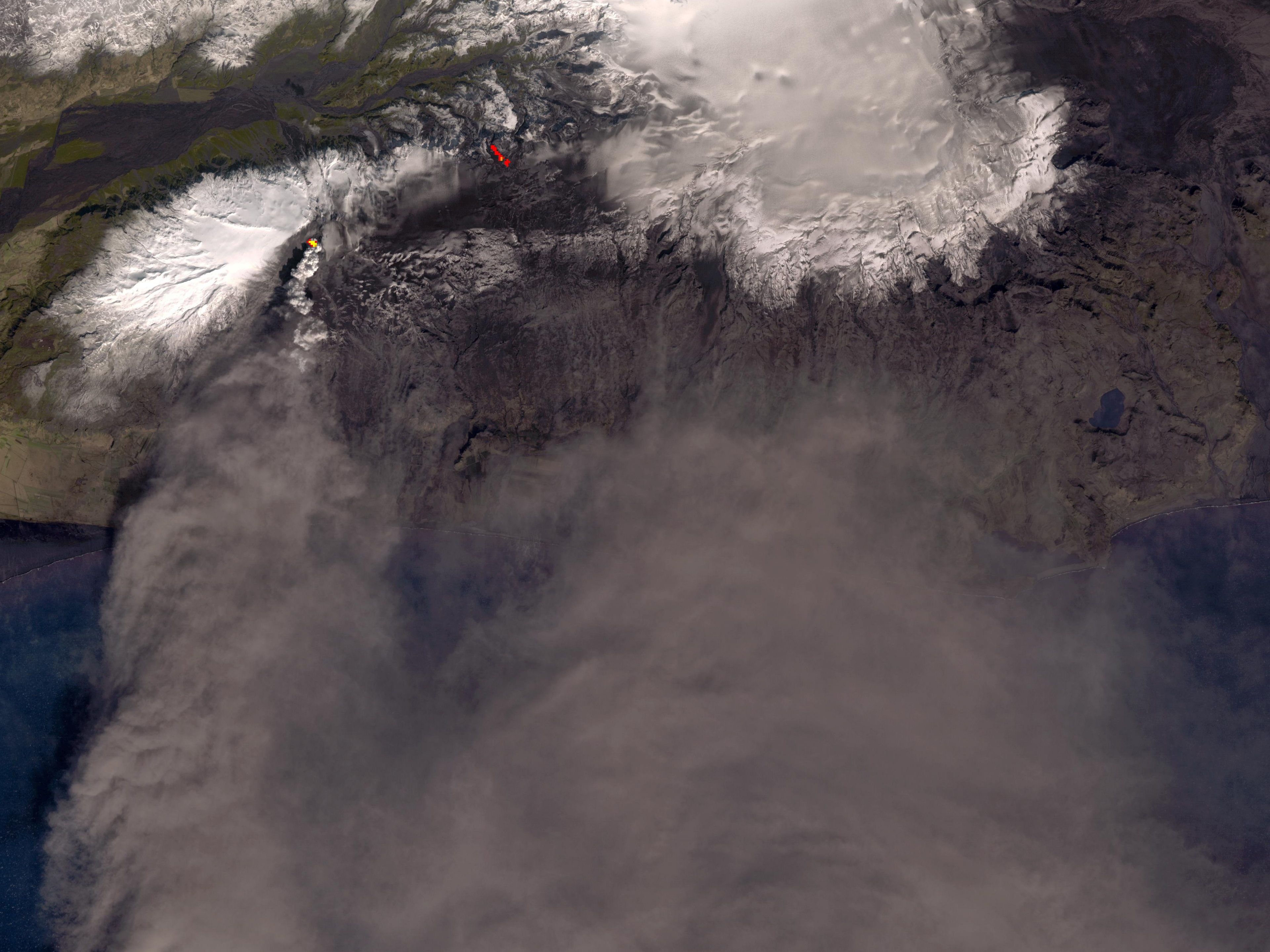
- **TIR Emissivity of Silicate Ash**
  - prior work on volcanic ash has focused primarily on detection and future movements
    - relies on the transmission spectrum of silicate ash
      - upwelling radiance interacts with the ash plume
        - lower transmission at 10μm than at 12μm
        - basis for the brightness temperature difference (BTD) method of detection
  - very limited work on the emission spectra of volcanic ash
    - variation with mineralogy/particle size
  - *hypothesis:* proximal plume is a complex mixture of particle sizes and composition
    - optically thick and emits similar to a solid

Methods: *Ash Thresholds*

- **TIR Emissivity of Silicate Ash**
  - proximal plume of the Eyjafjallajökull 19 April 2010 eruption was examined
  - emissivity end-members extracted from the ASTER TIR image data



  - dominant silicate (± SO_2?) spectral feature detected
  - applied a linear deconvolution approach
    - able to map the small-scale spatial variations of the ash end-member

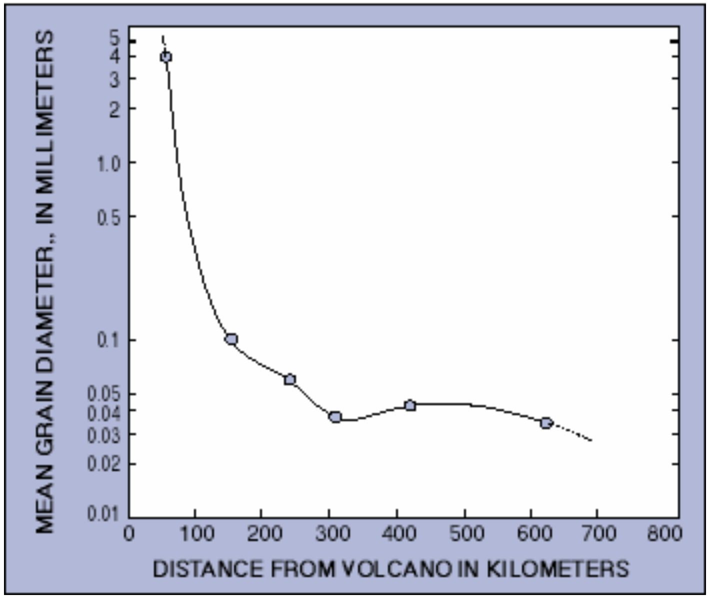


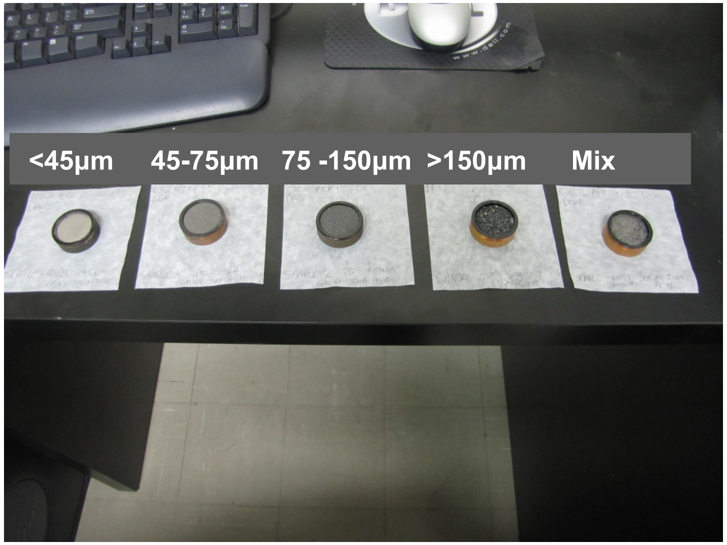

ash end-member

Methods: *Ash Thresholds*

- **Spectral Libraries**
  - artificial, high-SiO_2 (obsidian)
    - crushed and dry-sieved to >150, 75-150,45-75 and <45µm
    - <45µm was separated into 10µm fractions using a Stokes settling
  - natural, low-SiO_2 (Sakurajima v.)
    - dry-sieved for coarse fractions
    - Stokes settling for fine fractions
  - preliminary emissivity spectra acquired
    - examined at full and HyspIRI spectral resolutions

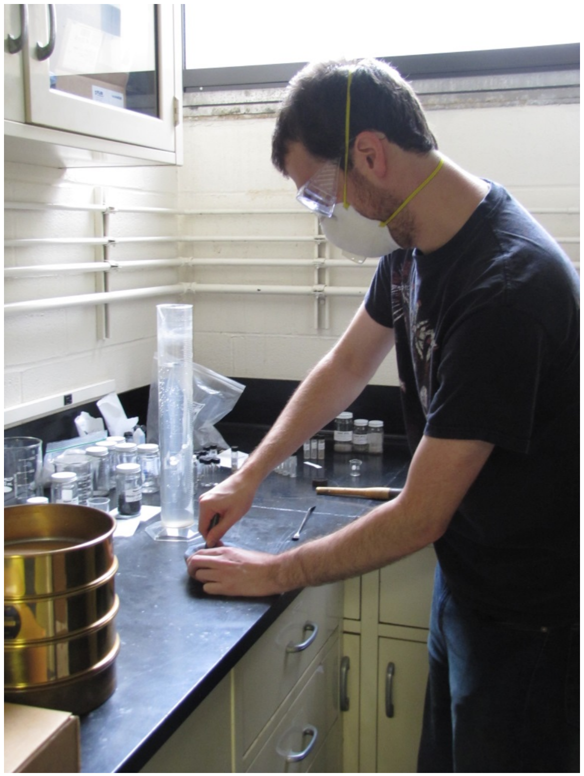
[Sarna-Wojcicki et al., 1981]





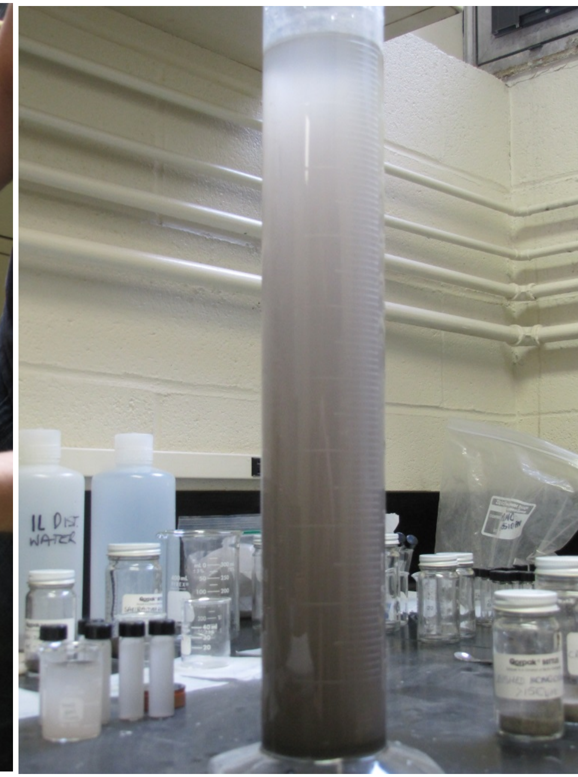
Methods: *Ash Thresholds*

- **Sample Preparation**



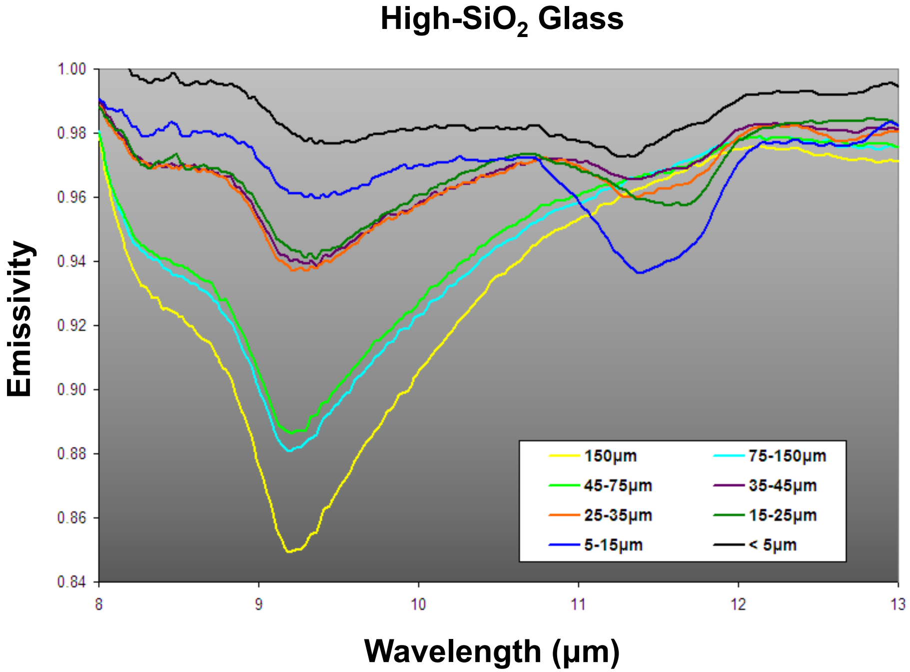
crushing

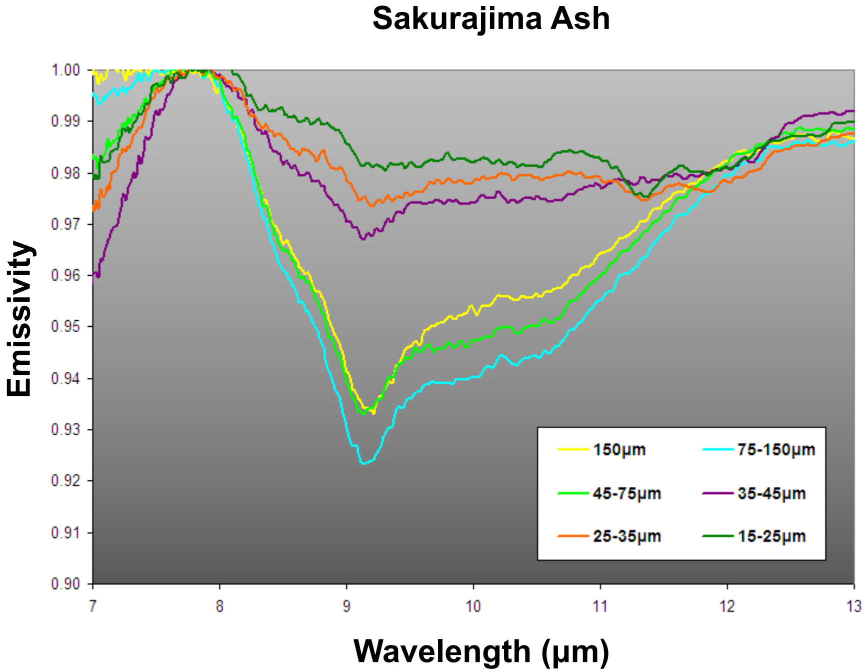
sieving



settling

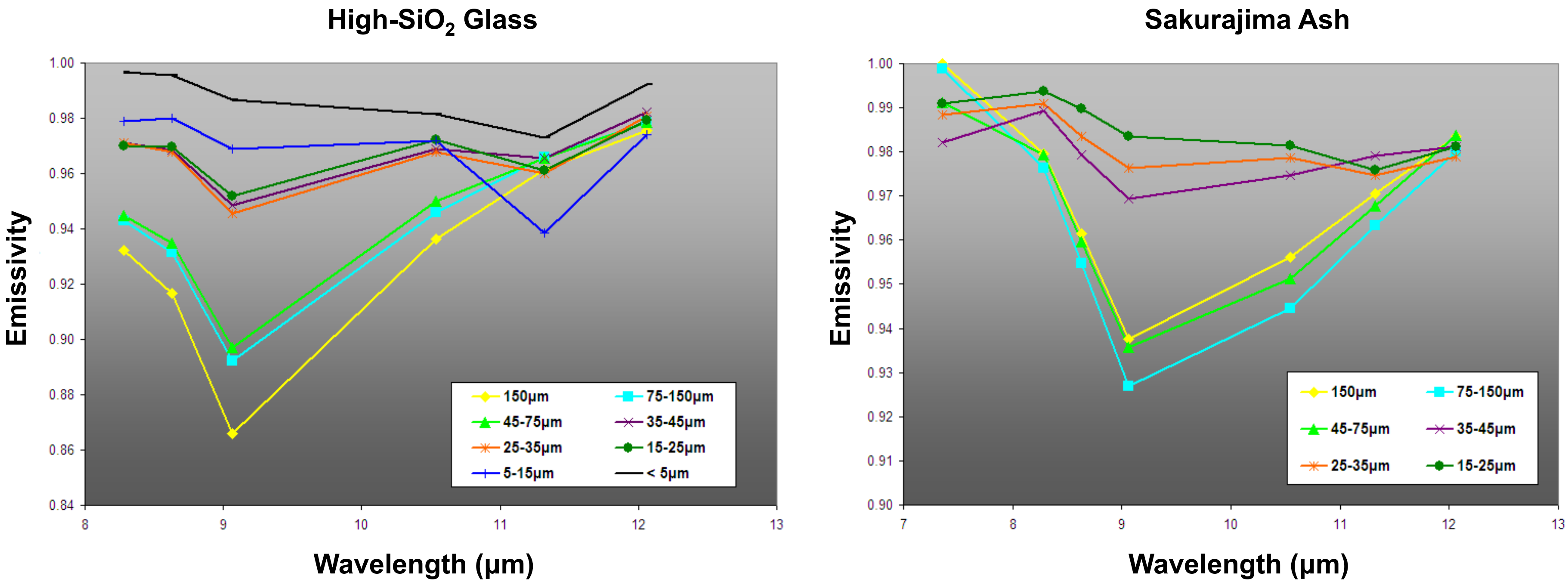
Results: *Ash Thresholds*





- **Preliminary Results**
  - spectral data acquired over the past week
  - not all size fractions complete; ash samples – lower SNR
  - consistent spectral behavior/other studies using minerals
    - spectral separation ~ 45µm

Results: *Ash Thresholds*

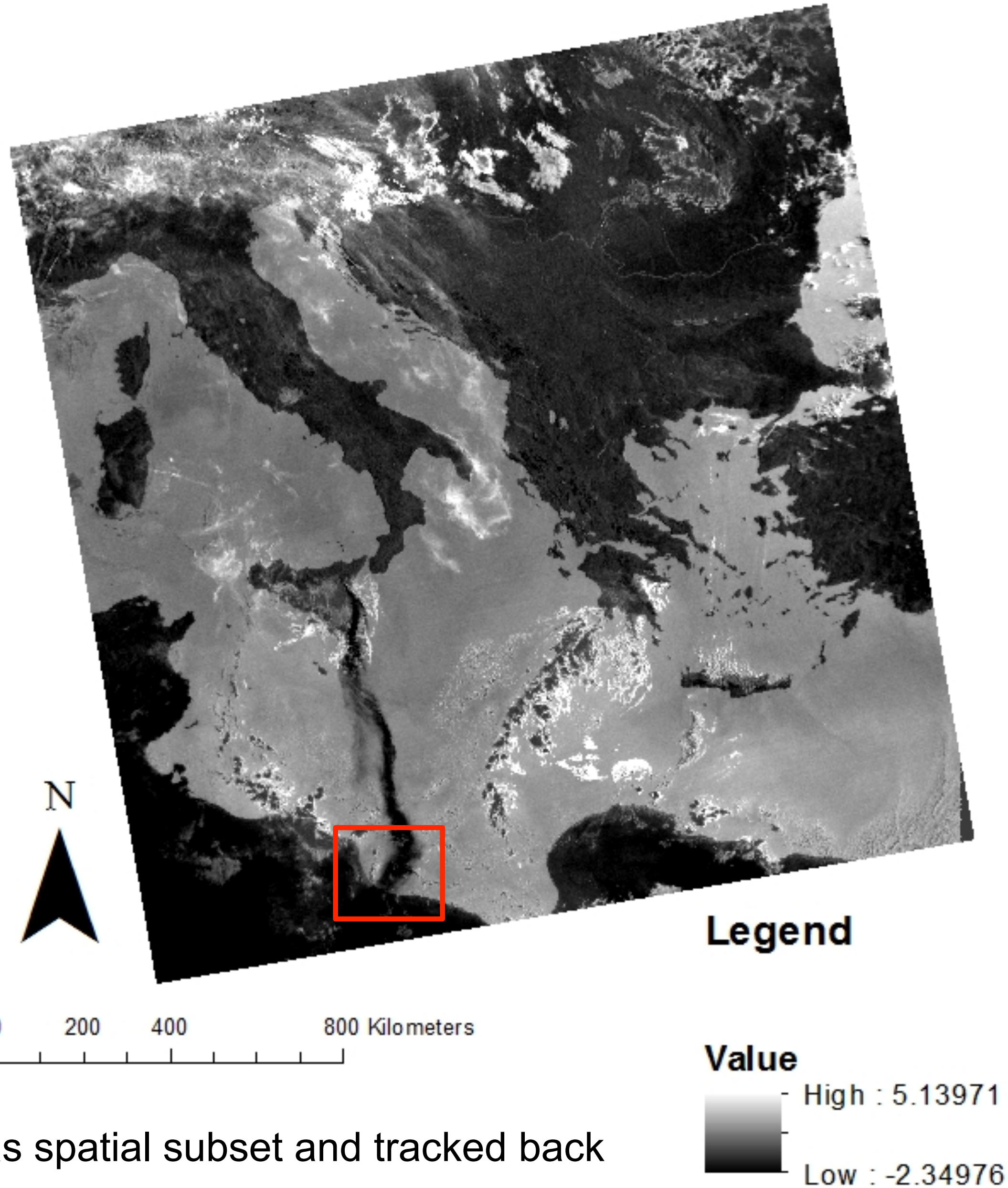


- **Preliminary Results**
  - trends are detectable at HyspIRI spectral resolution
  - should be able to distinguish composition and coarse vs. fine size fraction
    - 7.3µm / 8.2µm band ratio may be viable for stratospheric plumes

Methods: *Ash Thresholds*

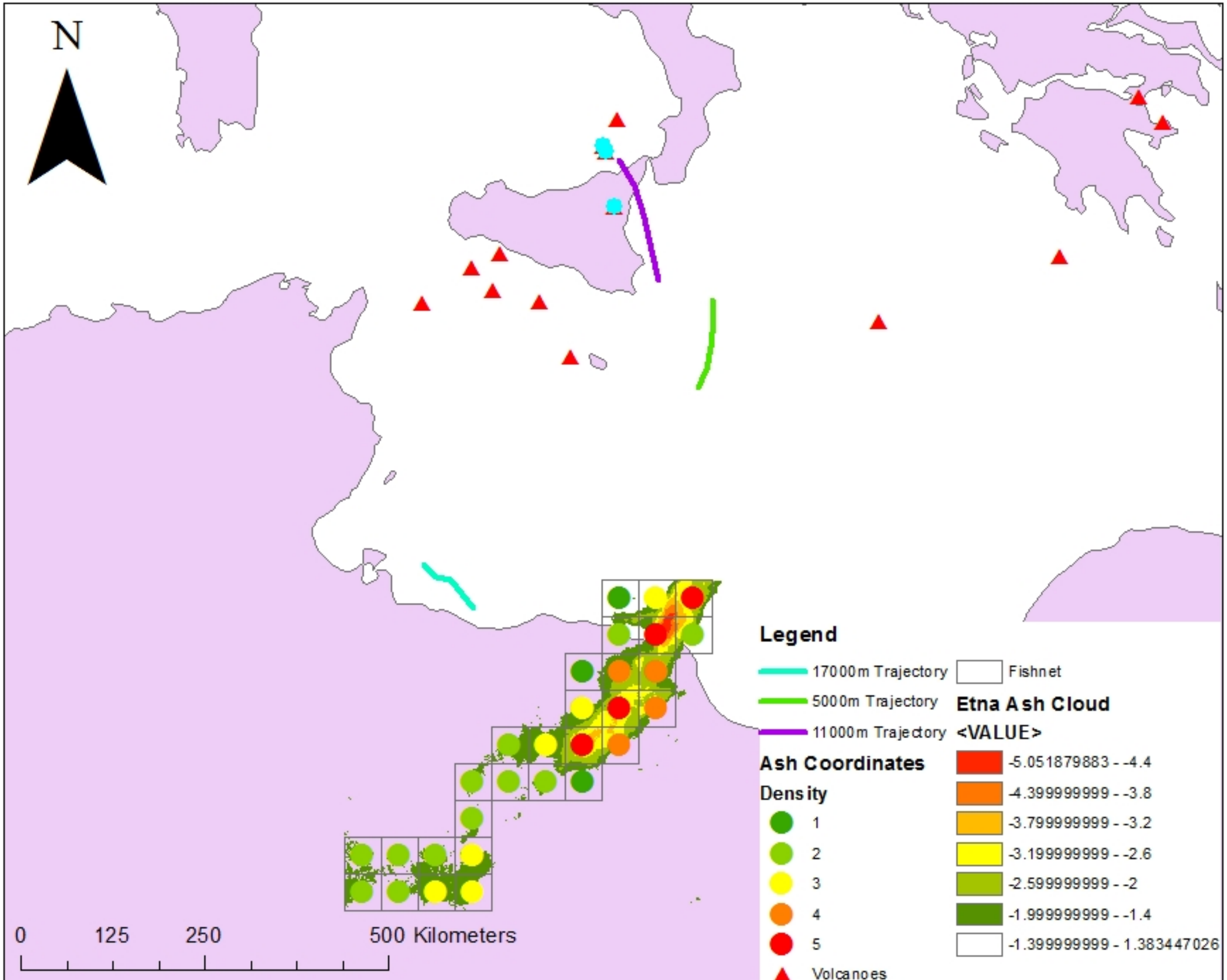
- **Plume Detection & Source Location**
  - examining approaches for predictive tracking of ash plume/ cloud back to a known source
    - triggering of other satellite observations, hazards, etc.
    - HYSPLIT, PUFF, etc. models – all that predict the *spread* of ash clouds based on wind field data
    - we have developed a method using the HYSPLIT backward trajectory function
      - MODIS brightness temperature difference (BTD) used as input *(any image-based detection approach would also work)*
      - imported into ArcMap and BTD classified/gridded on density
      - dense cloud grid cells iteratively fed into HYSPLIT at 3 different model height levels – *troposphere, tropopause, stratosphere*
        - » resulting trajectories compared to volcano proximity
        - » tropopause shows the greatest correlation [Carey et al., 2008]

Results: *Etna (30 Oct 2002)*

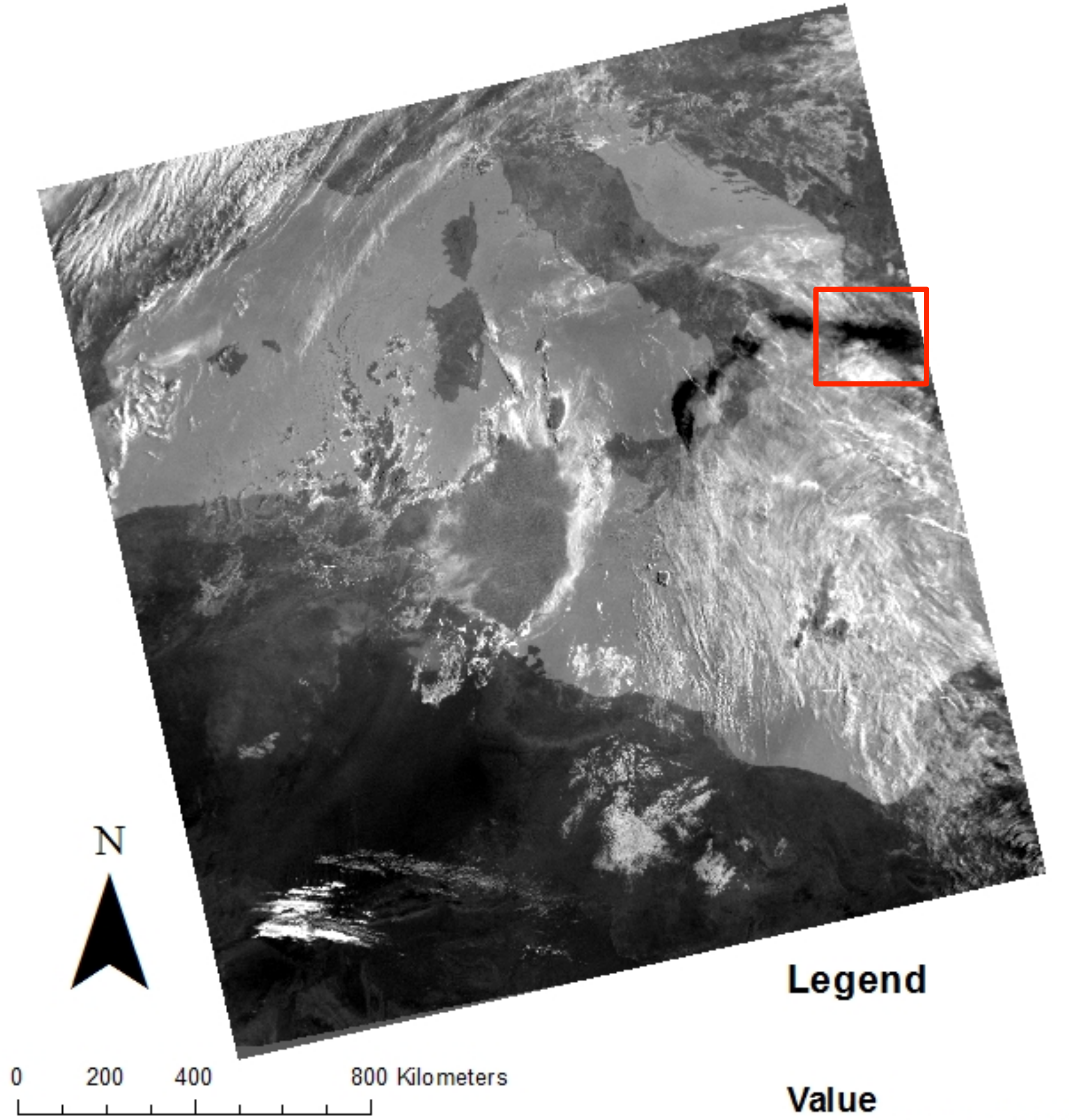


region that was spatial subset and tracked back

Etna Ash Cloud over Africa, October 30th 2002

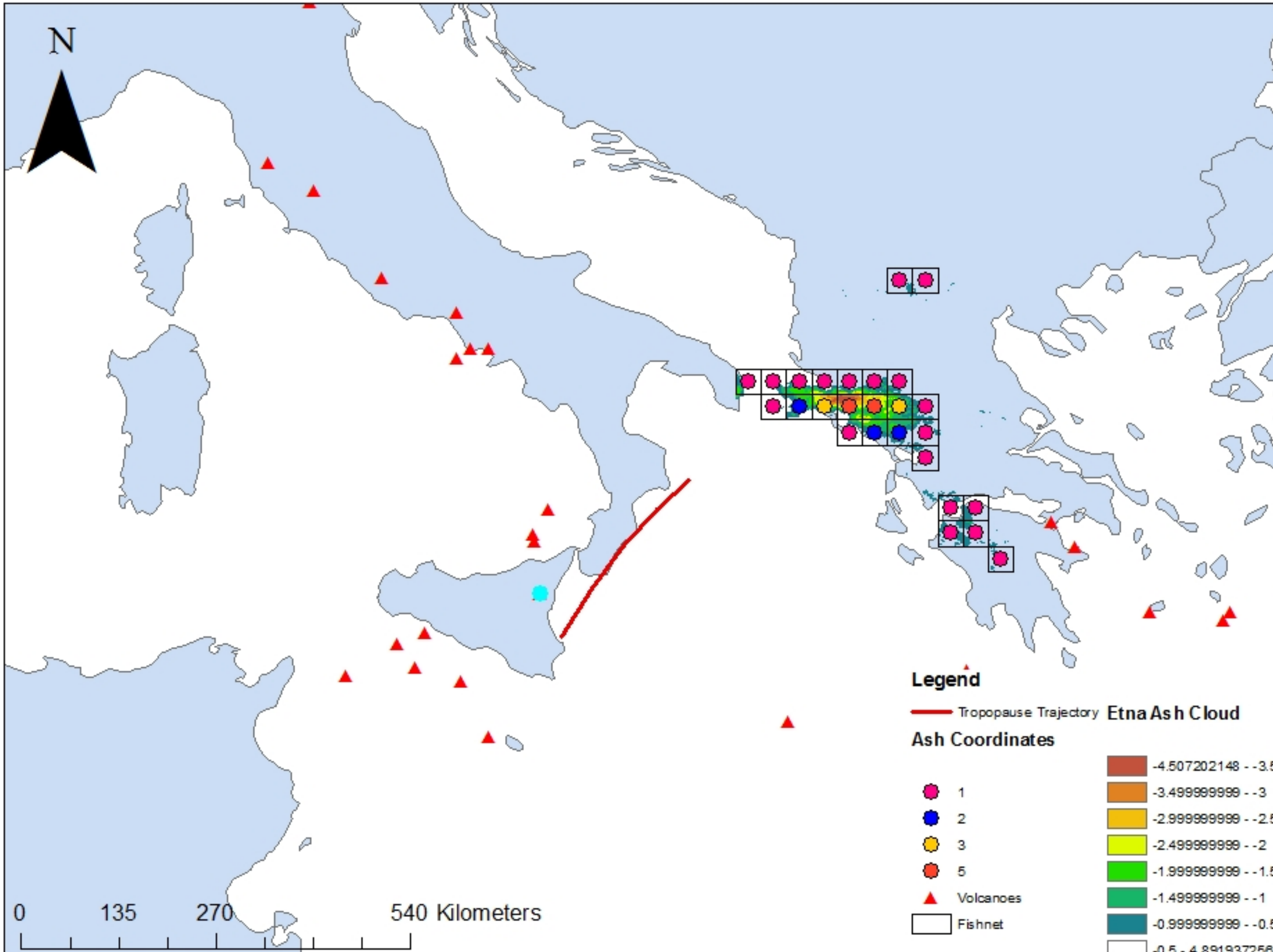


Results: *Etna (1 Nov 2002)*



region that was spatial subset and tracked back

Etna Ash Cloud over Greece, November 1st 2002



Conclusions

- **HyspIRI TIR Potential For Volcanology**
  - temporal, spatial and radiometric resolution will be a *game changer* for volcano monitoring and eruption prediction
  - combined ASTER/AVHRR/MODIS databases allow predictive volcanic capabilities for future HyspIRI
  - even with cloud cover, temperature/time record will be vital
  - composition and rough size fraction of silicate ash will be measureable using HyspIRI emissivity
  - synergistic models using remote sensing and GIS should allow for reliable predictions of source locals
  - *more work is needed to quantify these thermal and ash thresholds*


Pavlof eruption: ISS photograph (2013)


Eyjafjallajökull
19 April 2010