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19th Atmospheric Transport and Dispersion Conference
George Mason University, Fairfax (VA)
June 9-10, 2015

Aerosol Detection and the Hilbert Huang Transform in 2D

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- Surface Reflectance and Aerosols Detection
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- Hilbert Huang Transform in 2D – Example
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- TOA Radiances of the 2009 Station Fire
- Decomposition of Fires, Clouds and Surface Features
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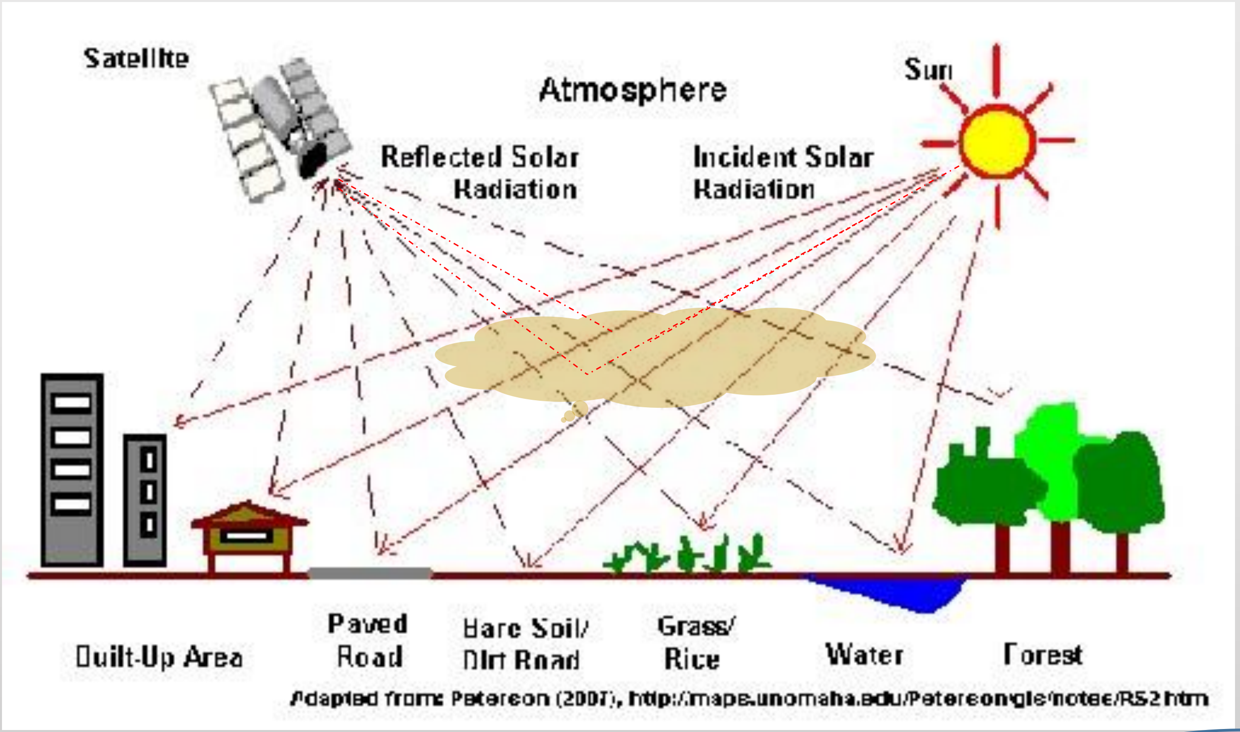
Aerosol Observations Over Land



$$Ne\Delta\tau = \pi Ne\Delta\rho \frac{4\cos(\theta_0)\cos(\theta_v)}{\omega_0 P(\Theta)}$$

$$\rho^*_\lambda(\theta_0,\theta,\phi) = \rho^a_\lambda(\theta_0,\theta,\phi) + \frac{F_\lambda(\theta_0)T_\lambda(\theta)\rho^s_\lambda(\theta_0,\theta,\phi)}{1 - s_\lambda\rho^s_\lambda(\theta_0,\theta,\phi)}$$

The Radiative Transfer Problem is Non-linear

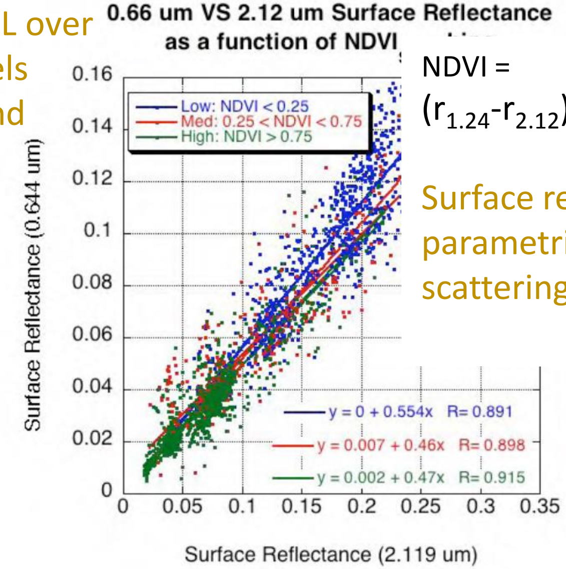
Surface Reflectance and Aerosols Detection

Detection of Aerosols Optical Depth (AOD) and Single Scattering Albedo (SSA) are highly dependent on local reflectance properties of land surfaces

Accuracy and precision of SSA of small and large particle mixtures are very sensitive to different surface types

Averaging pixels over land attenuates the effects of surface inhomogeneity

MODIS C005L over land: channels 0.47, 0.66 and 2.12 μm.



NDVI = $(r_{1.24}-r_{2.12})/(r_{1.24}-r_{2.22})$

Surface reflectance is parametrized for NDVI scattering angle

Figure 19: 0.66 μm versus 2.12 μm surface reflectance as a function of bins of $NDVI_{SWIR}$ values (low, medium and high). Both standard regression and "forced through zero" are plotted.

AOD and SSA from different instruments are hard to compare. The algorithms for AOD retrieval over land are empirically tuned for each optical instrument and ground truth measurements are geographically sparse.

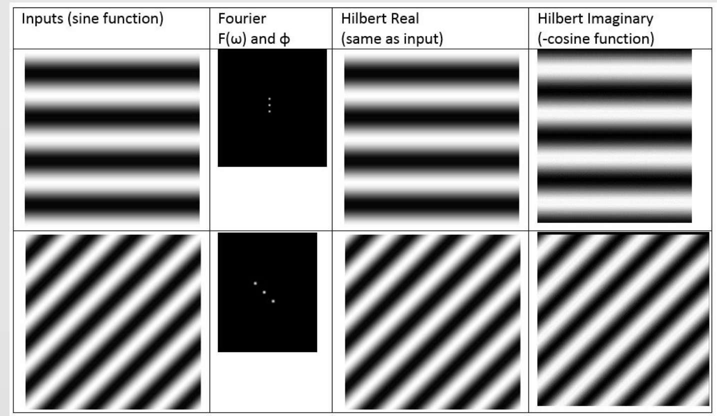
AOD and SSA Measurement Accuracy Dependent on Surface Spatial Properties

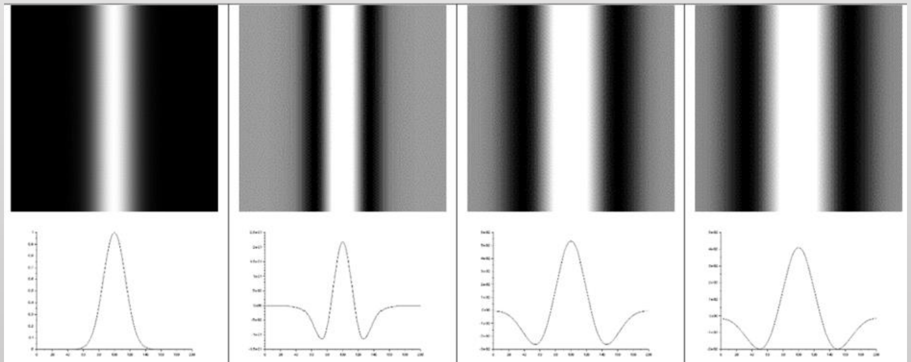
Hilbert Huang Transform in 2 D (HHT2)

The Hilbert transform:

- Is a linear operator
- Leads to harmonic analysis (HSA) and to ability to identify and select optimal filters

The Hilbert-Huang Transform applies to **non-linear and non-stationary** problems





a. Gauss function b. IMF 1 c. IMF 4 d. IMF 5

- HHT2 decomposes images according to a Bi-dimensional Empirical Mode Decomposition (BEMD)
- The application of the BEMD breaks down input image into so-called Intrinsic Mode Functions (BIMF)
- The set of BIMF's form a complete, nearly orthogonal basis for the original signal.

Real and Imaginary Part HHT2 Retain Original Pixel Coordinates

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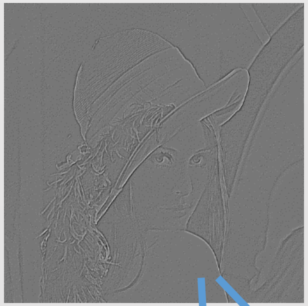
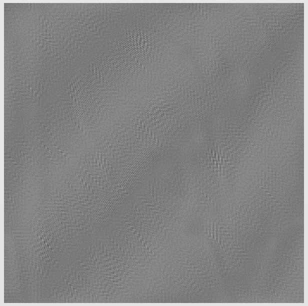
Hilbert Huang Transform in 2D - Example

Picture

Picture + sine

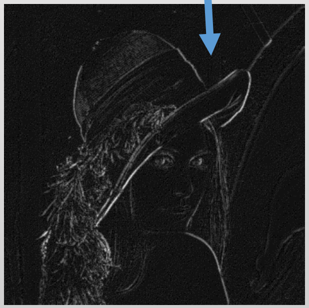


$BIMF_1$

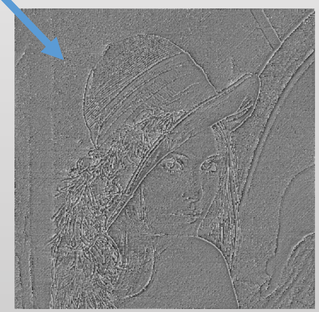


$BIMF_{100}$

- The first BIMF isolates the sharpest edges in the image
- The higher the order of BIMF, the greater the contributions from the lowest frequencies
- Amplitude and Phase of a BIMF form the HSA of the BIMF ($A_* e^{i\phi}$)



$BIMF_1$ - Amplitude



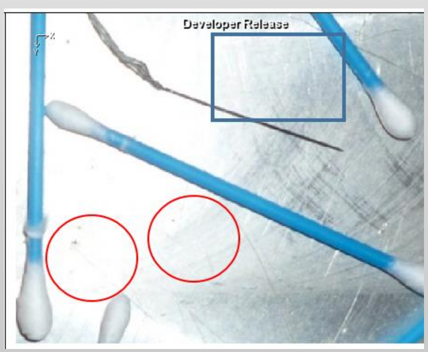
$BIMF_1$ - Phase

HSA Can Be Used on All the BEMDs Components of an Image

Examples of Hilbert Huang Transform in 2D

Input image

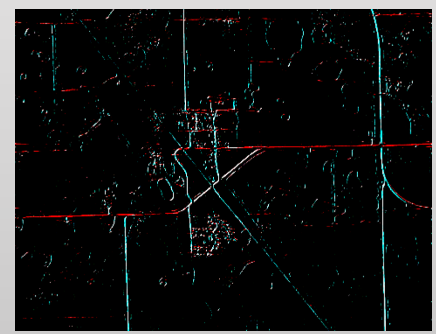
Filtered image output



Input image

Filtered image output

Input image



Phase (color coded) $BIMF_1$

Non-linear Features Can Be Separated with BIMF Selections

Filtering TOA Radiances with HHT2

HHT2 provides a new method for analyzing non-stationary and nonlinear radiative processes in satellite images

1. The HHT2 process decomposes TOA radiances into their spatially nearly orthogonal BIMF components
   - The BIMF's form a complete and nearly orthogonal basis of the observed radiances
   - The BEMD process decomposes satellite images according to spatial domain textures or frequencies
2. The HHT2 preserves local spatial features because there is a one-on-one correspondence between pixels in the BIMFs and the original
3. The BIMF of the radiances observed at different wavelength bands separate aerosols, smoke, dust, and surface features according to spatial frequency distributions

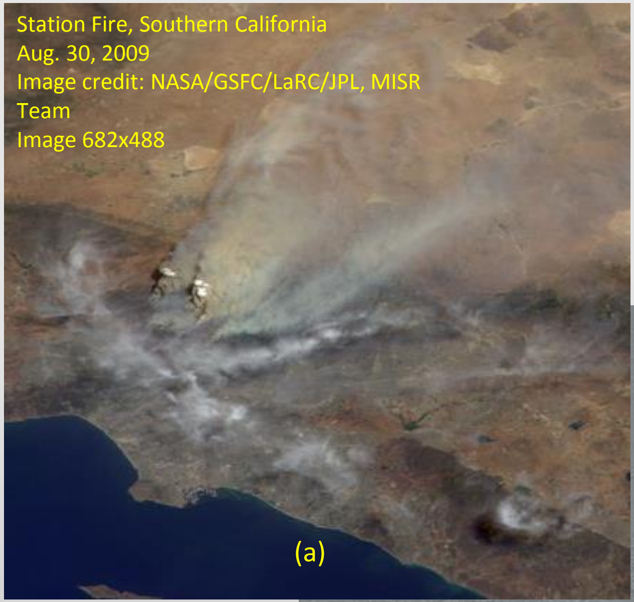
$F_{12} = \sum_{n=1}^{m}(a_n V^n{}_1 + b_n V^n{}_2)$; $m = number\ of\ BIMF$; $n = BIMF\ index$

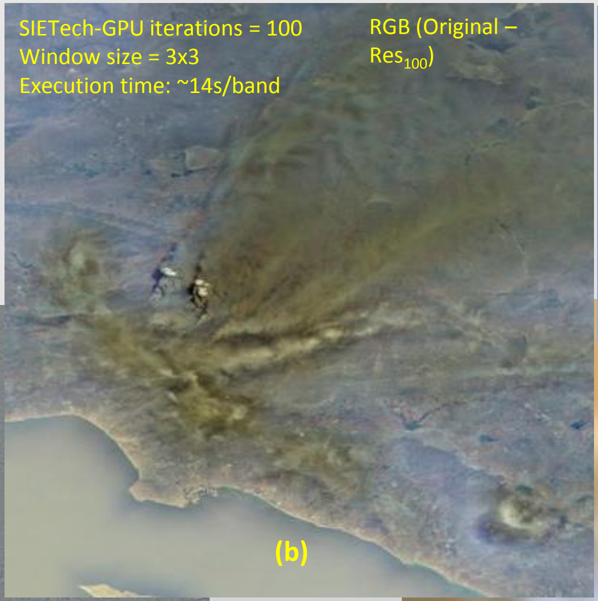
$V^n{}_1, V^n{}_2 = BIMFs\ at\ \lambda_1\ and\ \lambda_2$

$a_n, b_n = Weights$

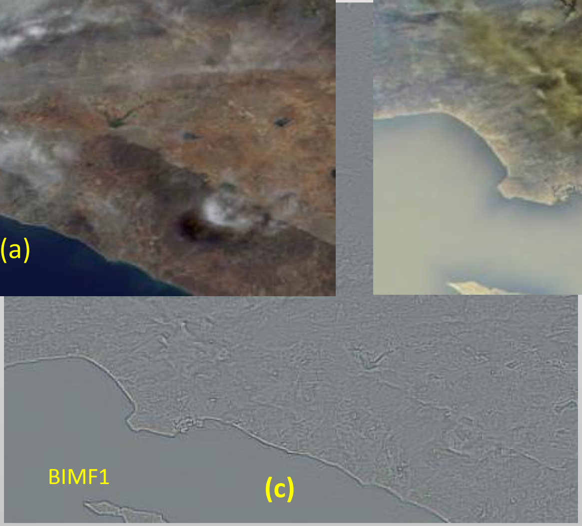
Aerosols and Surface BIMFs are likely to improve AOD and SSA retrievals

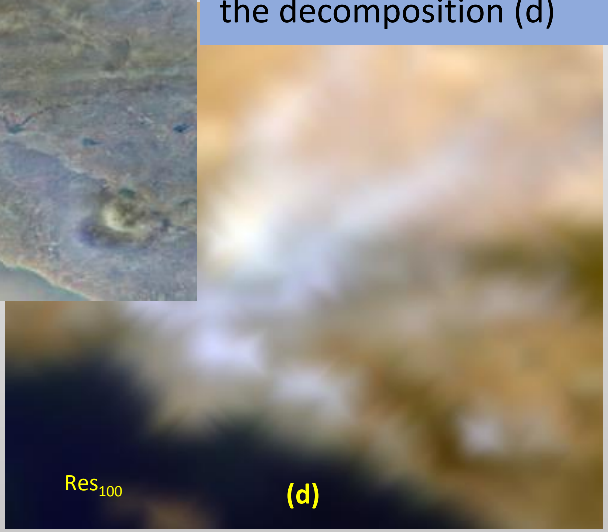
TOA Radiances of the 2009 Station Fire





The details in the image of the Station Fire in 2009 (a) are emphasized in the image (b) obtained subtracting the low resolution background residual at the end of the the decomposition (d)

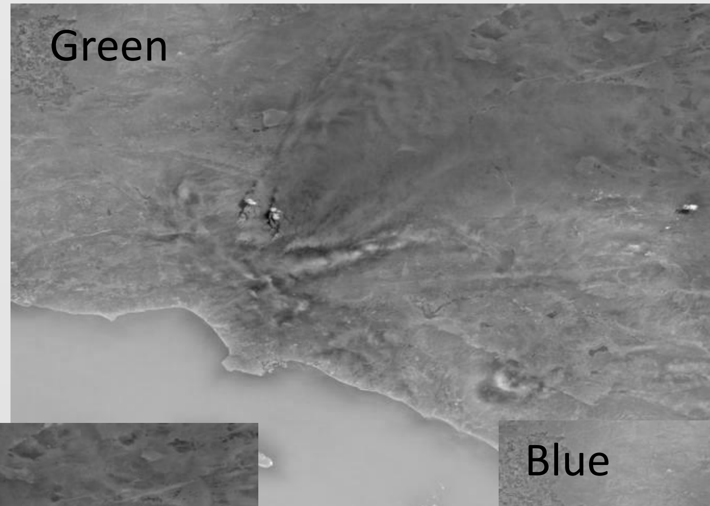




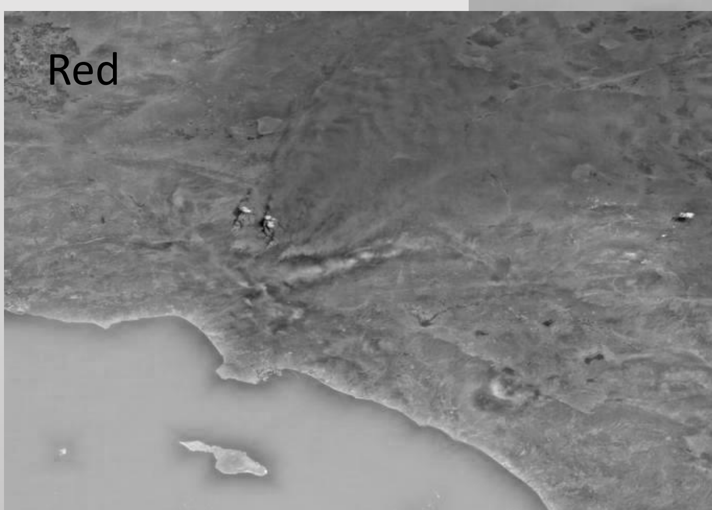
HHT2 Separates General TOA Reflectance From the Details

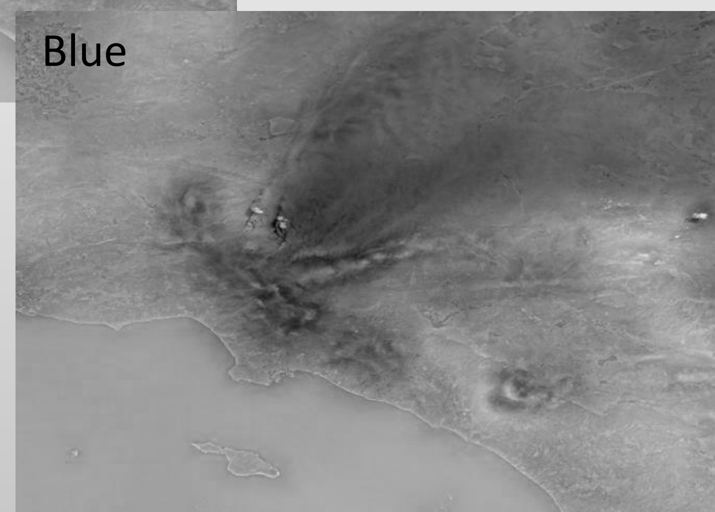
Decomposition of Fires, Clouds and Surface

Individual RGB components of the 2009 Station Fire image with the 100th order residual background removed



SIETech
Image 682x488
Time: 0.140 ms / (BIMF , band)





Band-wise HHT2 TOA Reflectance Separation for Smoke and Surface

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Conclusions

- HHT2 analysis promises to enable **accurate retrieval of AOD and SSA** over complex terrains
- Since the HHT2 is scale invariant, radiative transfer properties of terrain can be **measured and categorized according to textures** independently on linear size
- Improved **separation of aerosol according to origin** (e.g. PBL, source type, distant transport)
- TOA observations **could forecast** radiative field on the ground
- **Enhanced spatial resolution** improves forecast and modelling
- Radiative transfer retrieval have **lesser dependent** on optical resolution and instrumental properties
- Accuracy of comparisons of AOD and SSA determined with different instruments can increase

HHT2 Enables to Classify Surface Types by Their Radiative Properties