Eyes in the Sky: Detecting Tornadoes from Outer Space

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Presentation Outline
- A. WOMBLE:
  - Background: Need for Detecting “Missing” Tornadoes
  - Case Study – 2011 National Building Code of Canada
- D. KINGFIELD:
  - Fundamentals of Satellite Remote Sensing
  - The Disturbance Index
- L. SCHULTZ:
  - Use of NASA Satellite Data and Products
  - Case Studies

Background and Case Study

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What is Structural Engineering?

“STRUCTURAL ENGINEERING is the art of molding materials we do not wholly understand into shapes we cannot precisely analyze, so as to withstand forces we cannot properly assess, in such a way that the community at large has no reason to suspect the extent of our ignorance.”

What is Structural Engineering?

(Or A. R. Dykes, 1976)

The Need to Detect “Missing” Tornadoes

- Many tornadoes go undetected or unrated
  - Especially rural and forested areas
- Historical records incomplete (Doswell and Burgess 1988)
- Missing tornadoes affect tornado climatology
- Errors for tornado risk modeling
  - Structures may be under-designed
  - Ability to accurately discern any long-term trends may be jeopardized (Hayes 2012; Brooks et al. 2013)
  - (Are we really having more tornadoes, or do we just know about more of them?)
“Population Bias” in Tornado Data

- Historical records appear to show more tornadoes in more populous areas, but inconsistent with regional climatology
- Low population density credited with much of inability to observe tornadoes (Cheng et al. 2013; Anderson et al. 2007; Schaefer and Galway 1982; Strohl 1977)
- Limited statistical corrections possible, but not in sparsely populated regions (Canada, Central U.S.) with lake effects (Ikner et al. 2013; Anderson et al. 2007; King, 1997)

Limited view from the ground

- Tornadoes in remote areas
  - May not be detected (if they do not impact “civilization”)
  - Access for ground survey not always possible
- How many tornadoes in an outbreak?
- Tornado extents may be hard to determine from ground alone

The Canadian Story

- Integration of lighting flash density (common tornado predictor) with population density
  - Study suggested >50% of tornadoes are not reported in sparsely populated areas

SW Ontario appears to have large population bias (Sills 2012b)
(Low pop. density) + (High likelihood of tornado)

Potential Solutions

- Cheng et al. (2015) suggested statistical modeling framework for tornadoes throughout North America
  - Based on atmospheric conditions and population density
  - Suggested approach needs verification

Sills et al. (2012)
Probability of Tornado Strike (based on historical records)
Fundamentals of Satellite Remote Sensing

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We All Have Something In Common...

- Everything on the Earth reflects, absorbs, transmits, and emits electromagnetic energy
- Each object has a different “signature” depending on its composition and structure
  - Soils, plants, humans, and buildings are all different
  - Represented by energy different wavelengths on the electromagnetic spectrum

"The Visible Spectrum"
What humans can see...
Why look outside the visible spectrum?
• Just because we don’t see it, doesn’t make it insignificant
  — Machine health, species classification, damage identification

How do we explore these regions?
• Passive Remote Sensing
  — Definition: Acquire information about an object or target using an instrument a known distance away
• Multispectral Imagery
  — Captures information at different wavelength ranges across the electromagnetic spectrum

Benefits of Satellite Remote Sensing
Large Areal Coverage
Rapid Data Acquisition
Controlled Revisit Interval

How Does Multispectral Remote Sensing Work?
1) Satellite scans Earth
2) Sensor captures returned energy at various wavelengths (bands)
3) Images at each band are built

Applications: Color Combinations
True Color
False Color
- Create an image similar to what we see with our eyes
- Vegetation reflects green light the most than others so plants appear green
- Create a “new” image substituting non-visible bands
- Vegetation reflects NIR light the most so plants now appear red

Application: Vegetation Indexes
A tool to combine multiple images into a single output

Normalized Difference Vegetation Index (NDVI)

\[
NDVI = \frac{NIR - R}{NIR + R}
\]
- Healthy Vegetation
  — Reflects more near-infrared light and less red light
- Unhealthy Vegetation
  — Reflects less near-infrared light and more red light
- Output range: -1 -> +1
  — Closer to +1 = Healthier vegetation

What About Other Bands?
• NDVI can be enough for a “quick look”
  — Works best in areas of vegetation
• Sharp departures can also be seen in other spectral bands
  — Mid-Infrared values increase in forested areas after a tornado
• Are there techniques that use more bands?
More Complicated Applications

- Composite Indexes
  - Combinations of all bands of information into a single image

- Example: Tasseled Cap Indices
  - Brightness: Overall reflectance
  - Greenness: Vegetation health
  - Wetness: Moisture content and vegetation density

The Disturbance Index (DI)

- If we know...
  1. What the spectral response of forests “should” look like at a satellite
  2. Where the forests are located on the ground

- We can highlight areas that shift away from what we perceive is normal

$$DI = Brightness_n - (Greenness_n + Wetness_n)$$

Calculation of DI

1) Calculate global mean/std. deviation of all pixels of the same species

2) At each forest pixel, determine how different the local B/G/W values are from these global values

$$B_n = 0.92, G_n = 0.36, W_n = -1.02$$

$$DI = B_n - (G_n + W_n) = 1.58$$

Disturbance Index Example:
27 April 2011 Tuscaloosa-Birmingham Tornado

DI Benefits:
1) Can calculate from a single image
2) Resistant to seasonal/environmental effects
3) Different equations for different land cover types

Summary

- Satellite remote sensing expands our view on the characteristics of surface features
- Provides a rapid, synoptic look at wide areas of the Earth’s surface; reaching areas where humans cannot survey easily
- Image enhancement techniques can be simple or more complicated, depending on the amount of prerequisite information provided
Project Background

- April 27, 2011: NASA SPoRT provides MODIS and ASTER imagery to National Weather Service (NWS) forecast offices in Alabama
  - Imagery was used to refine and adjust some tornado tracks, particularly those that crossed CWA boundaries or were in areas with limited road access
- Work resulted in a NASA Applied Sciences award, working with the NWS to implement satellite imagery into their Damage Assessment Toolkit

Damage Assessment Toolkit

Mobile and Web Application developed to support NWS personnel while performing surveys.
- Reduce prep time for site deployment
- Reduce perishable damage data collection time
- Improve damage survey data collection consistency
- Improve delivery of geospatially-accurate data to core partners and to the public.

Public access: https://apps.dat.noaa.gov/StormDamage/DamageViewer/

Factors Affecting Damage Detection

Resolution:
- Increases in spatial resolution improves detection capabilities
Sky Conditions:
- Clouds restrict view of the ground
- Thin clouds can allow some view, yet accuracy/confidence is diminished
Availability:
- Imaging sensors with adequate resolution are all located on polar-orbiters
  - Repeat time & swath width
- Use restrictions on high-resolution, commercial imagery
- NRT versus complex analysis products

Des Moines WFO: Track Adjustments
SPOT-6 Panchromatic from 12 May 15
Landsat data available: May 17th, June 2nd, and June 9th
• Not enough resolution to detect track

Huntsville WFO: Track Adjustment
Priceville, AL EF-2 tornado: 31 March/1 April 2016

February tornados across Southeast
Storms across the southeast on the weekend of 21-23 January 2017
Affected Jackson, Mobile, Birmingham, Tallahassee and Peachtree WFOs

WFO Jackson: Hattiesburg, MS EF-3
Synthetic Aperture Radar – Sentinel 1A; Change detection product using pre-event imagery from 29 Dec 2016 and post event imagery from 22 January 2017
WFO Jackson: Hattiesburg, MS EF-3

Special thanks to: Our NWS partners, Parks Camp, Kelsey Angle, Brian Walawender, Matt Foster, Paul Kirkwood, and Kevin Skow Brenda Jones and the Hazards Distribution team (HDDSEXplorer.usgs.gov) at the USGS/EROS

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For more information, please visit:
General: http://weather.msfc.nasa.gov/sport/disasters/
DAT Public viewer: https://apps.dat.noaa.gov/stormdamage/damageviewer/

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