Landsat 5 reflectance and NDVI
27-year time series inconsistencies due to satellite orbit change

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Lots of Remote Sensing Systems launched since 1972

Landsat-1

Landsat-5

Belward and Skøien, 2014
- 9:45 a.m Mean Local Time of Descending Node (MLTDN)
  - *initially* orbit maintained by periodic station keeping maneuvers to maintain ground track and orbit phase with Landsat 4
  - *initially* MLTDN required to not vary by more than ±15 minutes of 9:45 a.m
Landsat 5 local overpass time example

(path 27 row 42 somewhere in Texas)

- **9:45 a.m** Mean Local Time of Descending Node (MLTDN)
  - *initially* orbit maintained by periodic station keeping maneuvers to maintain ground track and orbit phase with Landsat 4
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Nadir view Reflectance varies with solar zenith

$SZ=65°$, more shadow, lower $\rho_{\text{red}}$  

$SZ=40°$, less shadow, higher $\rho_{\text{red}}$

NDVI vs Solar Zenith (Pinter 1993, RSE)

- **New Regrowth Alfalfa**
  - $(82 \pm 10 \text{ g m}^{-2})$

- **Lush Growth Alfalfa**
  - $(185 \pm 16 \text{ g m}^{-2})$

- **Mature Alfalfa**
  - $(280 \pm 31 \text{ g m}^{-2})$

- **Bare Soil & Litter**
  - $(0 \text{ g m}^{-2})$
Can we see Landsat 5 orbit drift effects in TM images?

Consider:
- 3 sites (Vogelmann et al. 2016 RSE), Crater Lake National Park, Oregon

At each site:
- 9 adjacent 30m pixels
- 12 L1T Landsat 5 cloud-free images spanning 1991-2010
- Atmospherically corrected
- Summer anniversary date images (no more than ±5 days of Sep. 1)
3 SITE TIME SERIES

Blue: sparsely vegetated pumice desert

Green: coniferous forest with gradual NDVI increase

Orange: coniferous forest with gradual NDVI decrease

Open circles - 9 individual pixel values

Solid colored lines - median of 9 pixel values
Landsat 5 TM local overpass times
for 2 sites same path but different rows
2011 reference overpass time (red dots)
2011 reference overpass time and solar zenith
based on 12 months of non-Antarctic Landsat metadata values

\[ t_{\text{local}} = 1.36292 \times 10^{-9} \alpha^5 - 3.15403 \times 10^{-8} \alpha^4 - 3.15819614 \times 10^{-6} \alpha^3 + 0.0000652685643 \alpha^2 + 0.0120604786763 \alpha + 10.06 \]

where \( \alpha \) is latitude

\[ 22.14^\circ \leq \theta_s \leq 89.71^\circ \quad \theta_s \text{ mean} = 43.23^\circ \]

\[ \text{2011 reference} = f(t_{\text{local}}, \text{date}, \text{latitude}) \]

Minnesota $\theta_{\text{observed}} - \theta_{2011 \text{ reference}}$

Max = 5.9°

Green: summer difference values

Texas $\theta_{\text{observed}} - \theta_{2011 \text{ reference}}$

Max = 11.2°
Modeling the reflectance impacts of overpass time and solar zenith change over 27 years

\[ NBAR_{obs,\lambda} = f(\theta_{s=obs}, \theta_{v=0}, \text{MODIS BRDF parameters for } \lambda) \]

\[ NBAR_{reference,\lambda} = f(\theta_{s=2011\text{reference}}, \theta_{v=0}, \text{MODIS BRDF parameters for } \lambda) \]
consider different mean CONUS land cover MODIS BRDF parameters

Minneapolis path/row

modeled NBAR difference

NBAR_{obs} \quad NBAR_{2011 \ reference}

closed shrubland class
Texas path/row

modeled NBAR difference

\[ \text{NBAR}_{\text{obs}} \quad \text{NBAR}_{\text{2011 reference}} \]

closed shrubland class

Green: modeled NBAR difference
summer images only
Minnesota path/row

modeled NBAR difference

$NBAR_{obs}, \quad NBAR_{2011\, reference},$

closed shrubland class
Texas path/row

modeled NBAR difference

\( \text{NBAR}_{\text{obs}}, \quad \text{NBAR}_{\text{2011 reference}} \)

closed shrubland class

Green: modeled NBAR difference
summer images only
Texas path/row

modeled NBAR difference

$NBAR_{obs}$, $NBAR_{2011}$ reference,
closed shrubland class

[Graph showing local time vs. year with data points and trend lines for NBAR and NDVI differences over the years 1985 to 2010.]
Conclusions

• Landsat 5 orbit changed considerably over 27 year life
  – Overpass time changed by up to ~1 hour (>> ±15 mins of 09:45 AM MLTDN)
  – Solar zenith changed by >10°

• Can see orbit shift in actual Landsat 5 time series

• BRDF modeling findings
  – 27-year NDVI change trend 0.0006 NDVI/year, small but not insignificant
  – Comparing certain years, i.e., 1995 and 2007 may not be a good idea
    • NDVI$_{1995}$  0.11 > NDVI 2007 for anisotropic land cover types
    • NDVI 1995 0.05 > NDVI 2007 for average CONUS land cover types

• Further research to develop a Landsat BRDF normalization approach for Landsat 5 orbit drift changes is recommended

• Zhang, H.K and Roy, D.P., Landsat 5 Thematic Mapper reflectance and NDVI 27-year time series inconsistencies due to satellite orbit change, RSE, In review
Global WELD NEX Version 3.0 September 2009 30m product from 15,058 L1T scenes (7,328 Landsat 5 & 7,730 Landsat 7)

Sinusoidal Equal Area Projection
WELD Landsat 5 & 7 modeled Solar Zenith used to derive WELD NBAR

Global WELD NEX Version 3.0 September 2009 30m product from 15,058 L1T scenes (7,328 Landsat 5 & 7,730 Landsat 7)

Sinusoidal Equal Area Projection
Minnesota (path/row 27/26) modeled NBAR reflectance and NDVI using the fixed 12 month mean CONUS (blue) and closed shrubland class (red) spectral BRDF model parameters and setting the solar zenith to $\theta_{\text{observed}}$. 
Same as above but for Texas (path/row 27/42)
Satellite orbit can change significantly over its life time.
Black dots: $\theta_{reference}$ plotted every 16 days for the 2011 Landsat acquisition dates.
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