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Topographic Correction of Landsat Time Series

Assessing the spatial, spectral, and temporal consistency of correction methods in mountainous forests of Nepal

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Content

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- Introduction
  - Background on topographic correction
  - Types of topographic correction methods
- Study area and design
  - Overview of study area
  - Image pre-processing
  - Multi-criteria evaluation of topographic correction methods
- Results
- Conclusions

Background on topographic correction

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Effects of topography on the reflectance:

> Illumination condition changes with slope and aspect
> Terrain orientation results in differences in the reflectance
> Reflectance of a land cover type can vary across space / time

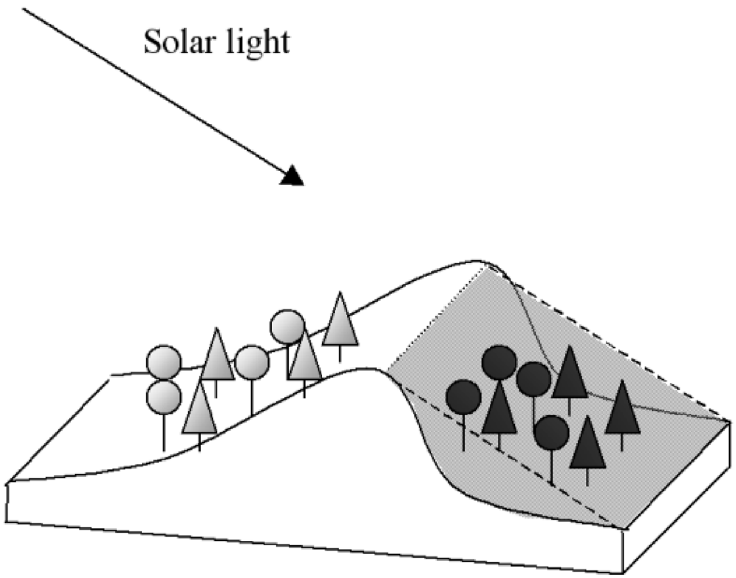

Image source: Riaño et al., 2003

Background on topographic correction

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Effects of topography on the reflectance:

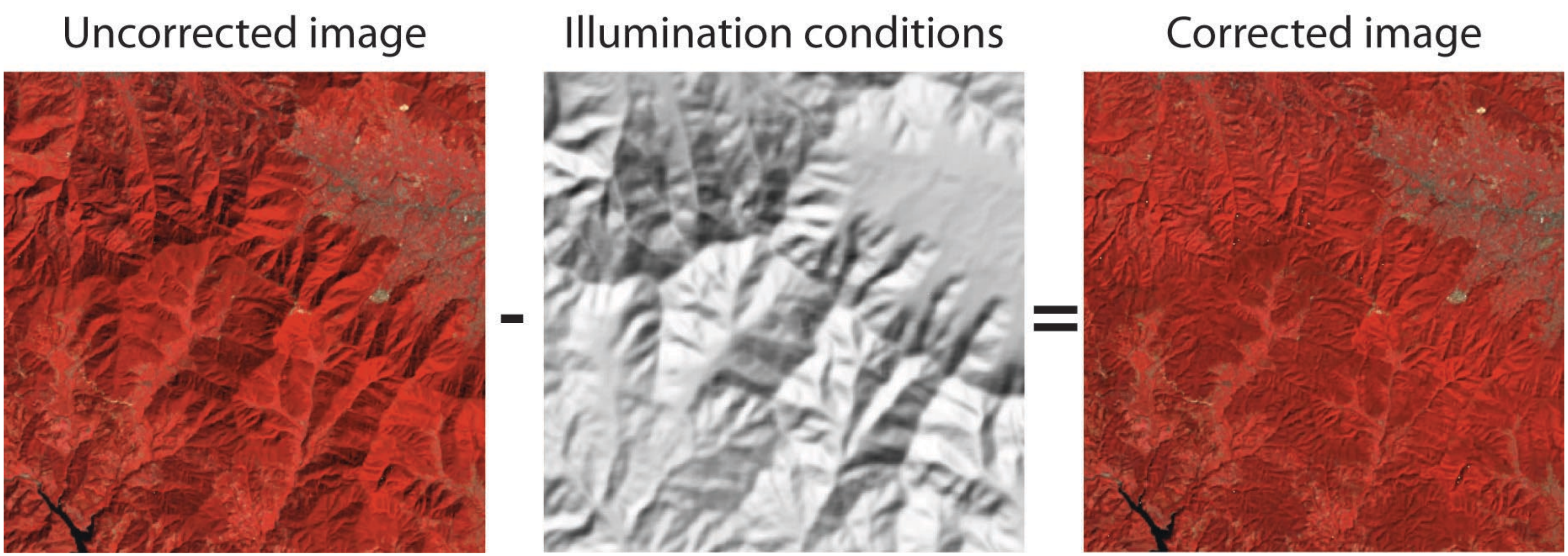
> Illumination condition changes with slope and aspect
> Terrain orientation results in differences in the reflectance
> Reflectance of a land cover type can vary across space / time

Implications for image analysis:

> Increases the noise in the image
> Spatial: Higher variability of land cover reflectance reduces classification accuracies
> Temporal: variations of the sun angle affect temporal consistency of image time-series (e.g. issues with change / trend detection)

Background on topographic correction

Conceptual approach to topographic correction



Types of topographic correction methods

Three categories of topographic correction methods

Method	Input	Advantage	Problems
Empirical	• Image	• No additional data needed (band ratios)	• Loss in spectral resolution • Do not account for variations in diffuse irradiance
Physical	• DEM • (Image)	• Path of radiance through atmosphere fully modelled	• Do not account for variations in diffuse irradiance
Semi-empirical	• DEM • Image	• Account for diffuse irradiance	• Derive correction parameters from image and DEM • Computationally intensive

Physical and semi-empirical methods simulate the Illumination conditions (IL) at the time of image acquisition using a Digital Elevation Model (DEM)

Semi-empirical methods used in this study

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Method	Source	Equation
C-correction (C-C)	(Teillet et al., 1982)	$L_{H,\lambda} = L_{T,\lambda} \cdot \left(\frac{cos(Z) + c_{\lambda}}{IL + c_{\lambda}} \right)$
Sun-Canopy-Sensor and C-correction (SCS+C)	(Soenen et al., 2005)	$L_{H,\lambda} = L_{T,\lambda} \cdot \left(\frac{cos(s) \cdot cos(Z) + c_{\lambda}}{IL + c_{\lambda}} \right)$
Bin Tan	(Tan et al., 2013/9)	$L_{H,\lambda} = L_{T,\lambda} - m_{\lambda} \cdot (IL - cos(Z))$
Statistical-Empirical (S-E)	(Teillet et al., 1982)	$L_{H,\lambda} = L_{T,\lambda} - (b_{\lambda} + m_{\lambda} \cdot IL) + \overline{L_{T,\lambda}}$
Variable Empirical Coefficient Algorithm (VECA)	(Gao and Zhang, 2009)	$L_{H,\lambda} = L_{T,\lambda} \cdot \frac{\overline{L_{T,\lambda}}}{(m_{\lambda} \cdot IL + b_{\lambda})}$
Minnaert with slope (M-S)	(Colby, 1991)	$L_{H,\lambda} = L_{T,\lambda} \cdot cos(s) \cdot \left(\frac{cos(Z)}{IL \cdot cos(s)} \right)^{k_{\lambda}}$

L_H= reflectance of a horizontal surface; L_T= reflectance of an inclined surface; Z = solar zenith angle; s = terrain slope; m = slope and b = intercept of the linear regression between L_T and IL; $c = \frac{b}{m}$; $\overline{L_T}$ = average reflectance of the image or the land cover stratum considered for correction; k = Minnaert constant; λ = band/wavelength.

Study area – 4 footprints in Nepal, focus on forest areas only

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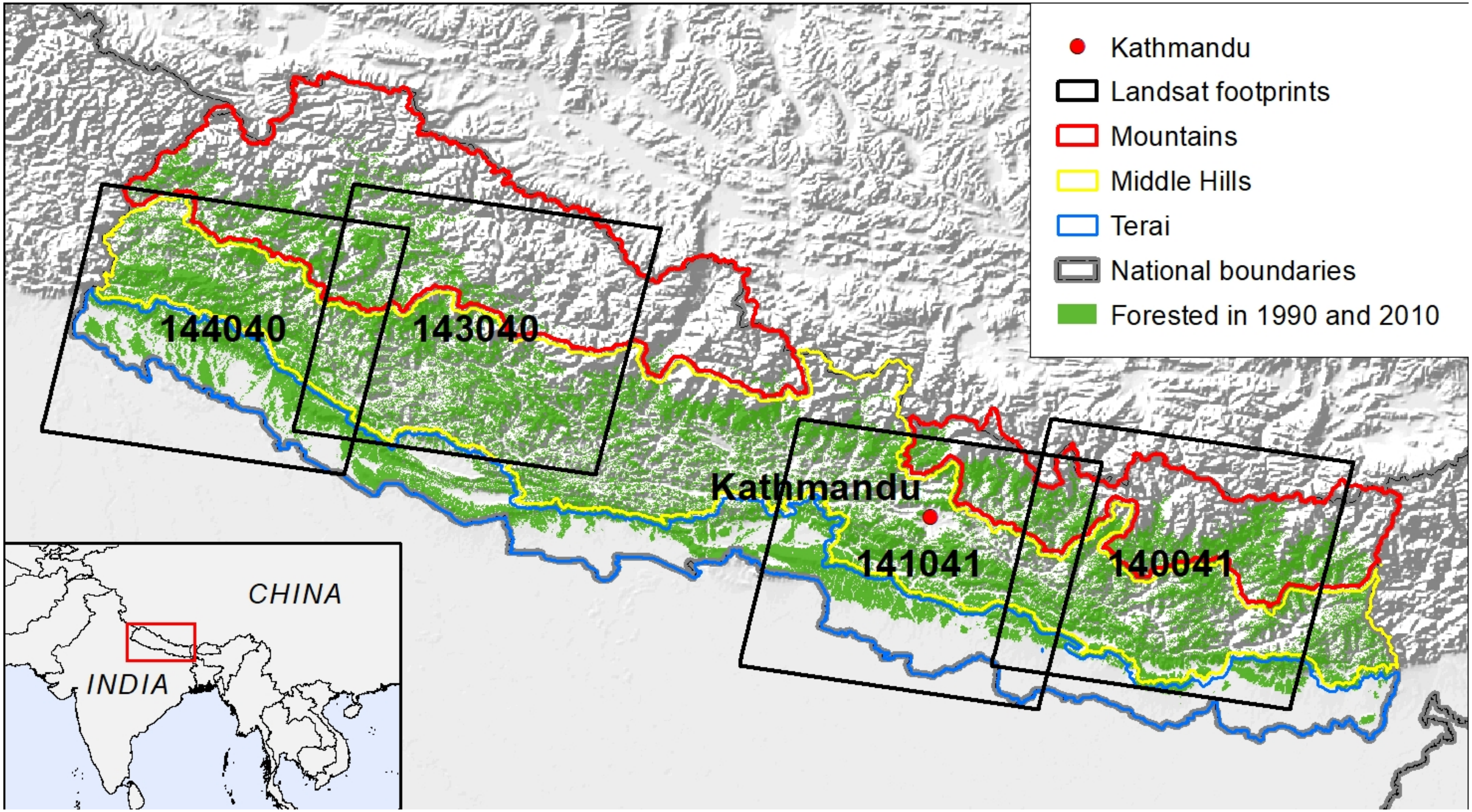

Image pre-processing

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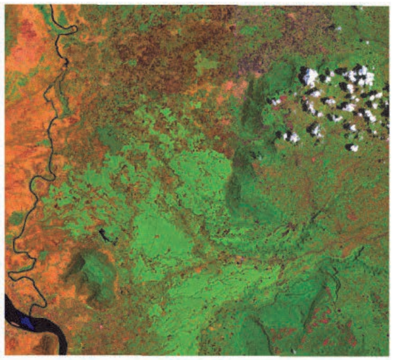
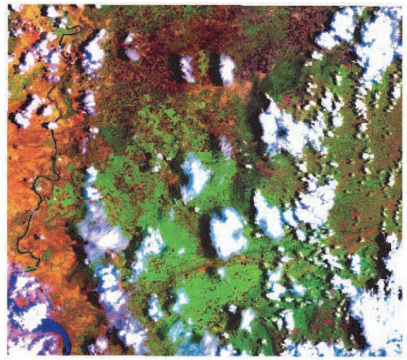
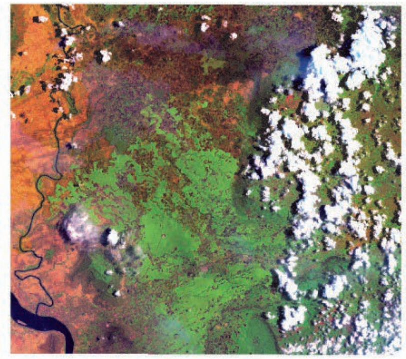
- Use of all Landsat 5, 7, and 8 surface reflectance images during the growing period (Jul-Oct) from 1988-2016
- Applying the 6 topographic correction methods to all images of the time series
  - 6 Landsat time-series with TC and 1 time-series without TC for 4 footprints in Nepal
- Creation of yearly image composites for each footprint
  - time-series of yearly image composites, 6 with TC and 1 without TC for 4 footprints in Nepal

Image pre-processing

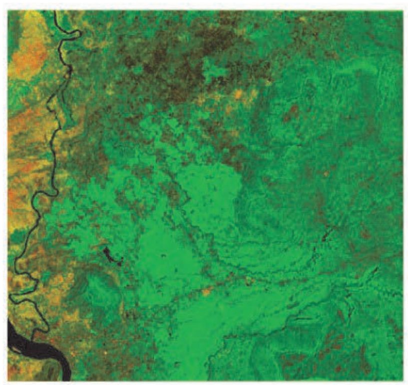






Multiple individual satellite images with varying amounts of clouds, haze, and shadows

... ...



One single image composite that minimizes clouds, haze, and shadows

Multi-criteria evaluation of TC methods

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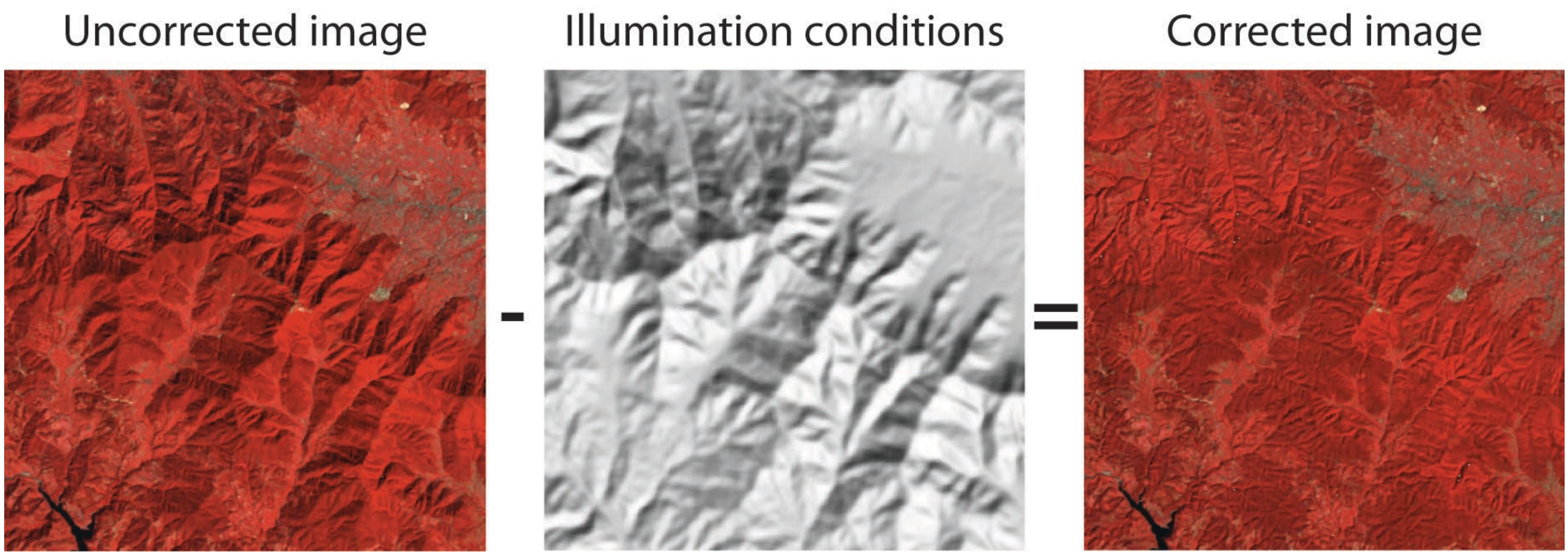
Multi-criteria evaluation because each evaluation measure only considers certain aspects of TC to the exclusion of others

1. **Coefficient of determination** (r^2) between the IL and each spectral band
2. Comparison of the reflectance between **sunlit and shaded slopes** within the same land cover type
3. **Coefficient of Variation** (CV) of the reflectance of a land cover type
4. **Interquartile Range Reduction** (IQRR) of the reflectance of a land cover type before and after correction
5. **Relative Difference in Median Reflectance** (RDMR) of a land cover type before and after correction

Multi-criteria evaluation of TC methods

Multi-criteria evaluation because each evaluation measure only considers certain aspects of TC to the exclusion of others



Results

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Summary of multi-criteria evaluation and overall ranking

	Blue	Green	Red	NIR	SWIR1	SWIR2	All bands
Bin Tan	6 (0.58)	2 (0.33)	2 (0.30)	2 (0.20)	3 (0.23)	3 (0.23)	2 (0.31)
C-C	4 (0.55)	5 (0.58)	5 (0.53)	5 (0.59)	5 (0.58)	5 (0.50)	5 (0.56)
MS	5 (0.57)	6 (0.63)	6 (0.66)	6 (0.75)	6 (0.69)	6 (0.72)	6 (0.67)
SCS+C	3 (0.54)	4 (0.47)	4 (0.37)	4 (0.35)	2 (0.20)	2 (0.21)	4 (0.36)
S-E	2 (0.46)	1 (0.29)	1 (0.26)	1 (0.16)	1 (0.15)	1 (0.16)	1 (0.24)
VECA	1 (0.36)	3 (0.4)	3 (0.33)	3 (0.29)	4 (0.25)	4 (0.29)	3 (0.32)
Best	**VECA**	**S-E**	**S-E**	**S-E**	**S-E**	**S-E**	**S-E**

Results

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1. **S-E**: Very good performance for all evaluation criteria, never obtained the lowest rank
2. **Bin Tan**: Very good performance for all measures with exception of the RDMR (lowest rank for all bands)
3. **VECA**: Good performance, but not very efficient in reducing variations in the reflectance (CV, IQRR)
4. **SCS+C**: Good performance, but not very efficient in reducing variations in the reflectance (r^2, CV, IQRR)
5. **C-C**: Fair performance, but mostly in the low ranks, especially for the RDMR and IQRR
6. **M-S**: Poor performance for most evaluation criteria, only RDMR and IQRR show good performance for some bands

Results

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Multi-criteria evaluation of selected individual image composites

> Evaluation of composites from 1988 ,1995, 2000, 2005, 2010, and 2015 in 4 footprints
> Multi-criteria evaluation of the Near Infrared (NIR) band only

- S-E performs best (highest rank for 12 out of 24 image composites)
- Bin Tan performs well (highest rank for 9 image composites)
- SCS+C and VECA perform well, often obtaining ranks 3 or 4
- C-C and M-S show poor performance (ranks 5 or 6)

Results

Multi-criteria evaluation of selected individual image composites

> No specific pattern of the performance over time (1988-2015) can be observed
  - no effect of the amount of images used for the composite
  - no effect between Landsat 5, 7, or 8 (and combinations)
  - no effect of varying sun angles during the growing season (Jul-Oct)

> Variations of the performance across footprints seem more pronounced
  - S-E tends to perform better in areas with evergreen forests
  - S-E tends to perform better in areas with steep slopes

Conclusions

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- Statistical-Empirical (S-E), Bin Tan, as well as Sun-Canopy-Sensor + C-Correction (SCS+C) and Variable Empirical Correction Algorithm (VECA) all perform well

- S-E clearly outperforms all other methods, but depending on wavelength / band, terrain slope, and land cover type one of the above methods may show a better performance

- We recommend the use of the Statistical-Empirical (S-E) topographic correction method to pre-process Landsat images in areas with steep slopes

Conclusions

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Google Earth Engine tool for topographic correction and image composition, developed based on the experiences of this study:

http://www.cde.unibe.ch/research/projects/a_tool_for_satellite_image_preprocessing_and_composition/index_eng.html

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Thank you!