REMOTE SENSING OF PHREATOPHYTIC SHRUBLAND: BACKGROUND, PROCESSING, AND APPLICATION

Justin Huntington, PhD

Phreatophyte Shrubland, Spring Valley

Outline

- Introduction
  - Motivation and background on satellite remote sensing of vegetation
  - Landsat satellites
  - Common Vegetation Indices
- Approach for monitoring shrubland habitat with Landsat
- Previous work
- Methods used for processing Landsat data
  - Atmospheric corrections
  - Cross-sensor corrections
  - Cloud filtering
  - Processing and data extraction
- Dataset used for estimating precipitation
- Spatial averaging Landsat and precipitation data to phreatophyte shrub areas
- Summary

Introduction

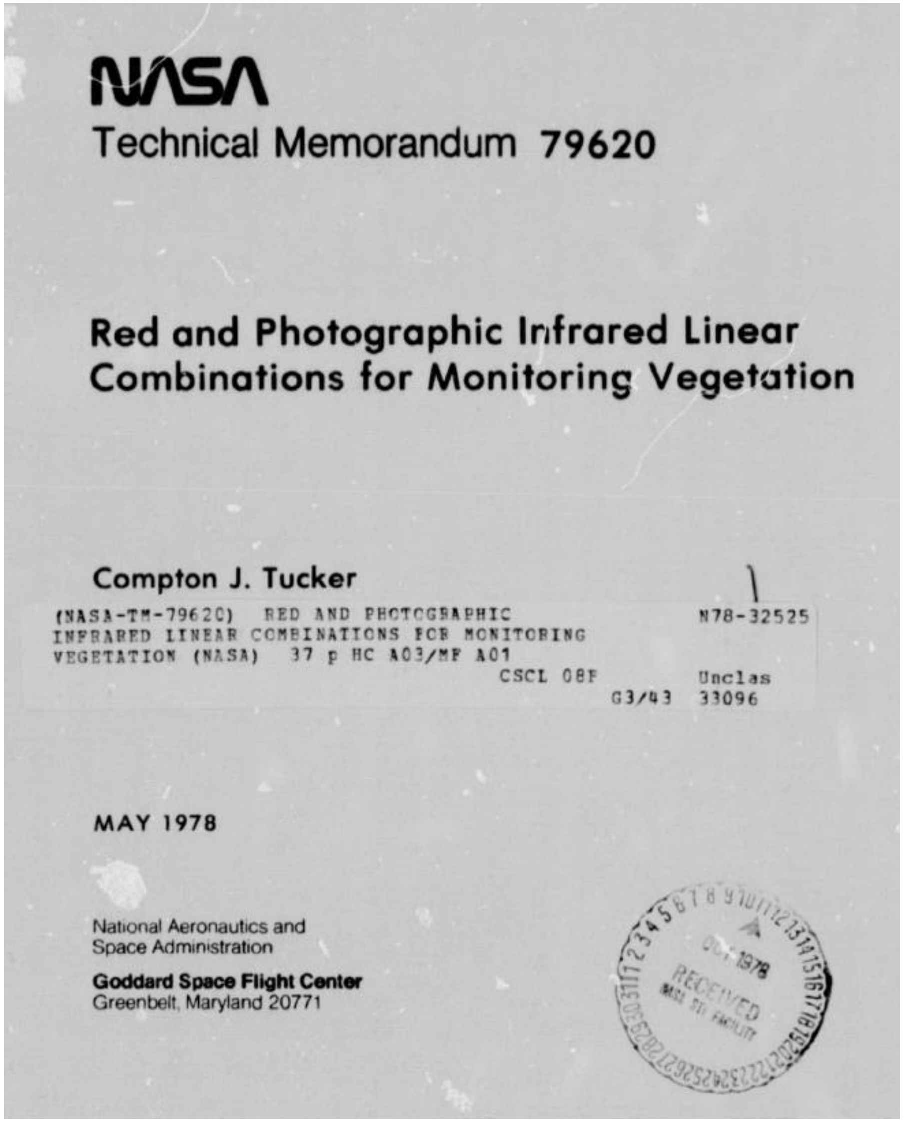
Phreatophytic Shrubland, Spring Valley

- Assessing long-term (i.e. ~30 years) variability is needed for establishing baseline conditions, and for assessing changes with respect to climate, hydrology, and resource management

- However, long-term monitoring of vegetation (i.e. greenness and cover) in time and space is generally lacking, especially phreatophytic shrublands of the Great Basin

Introduction: Remote Sensing of Vegetation

- Remote sensing of vegetation has been a common science application for monitoring vegetation since the late-1970s
- Based on detecting the amount of reflected light from vegetation within different “bands” of the electromagnetic spectrum
  - Started with red and Near-Infrared “bands”



NASA

Technical Memorandum 79620

Red and Photographic Infrared Linear Combinations for Monitoring Vegetation

Compton J. Tucker

(NASA-TM-79620) RED AND PHOTOGRAPHIC INFRARED LINEAR COMBINATIONS FOR MONITORING VEGETATION (NASA) 37 p HC A03/MF A01 CSCL 08F — N78-32525 — Unclas G3/43 33096

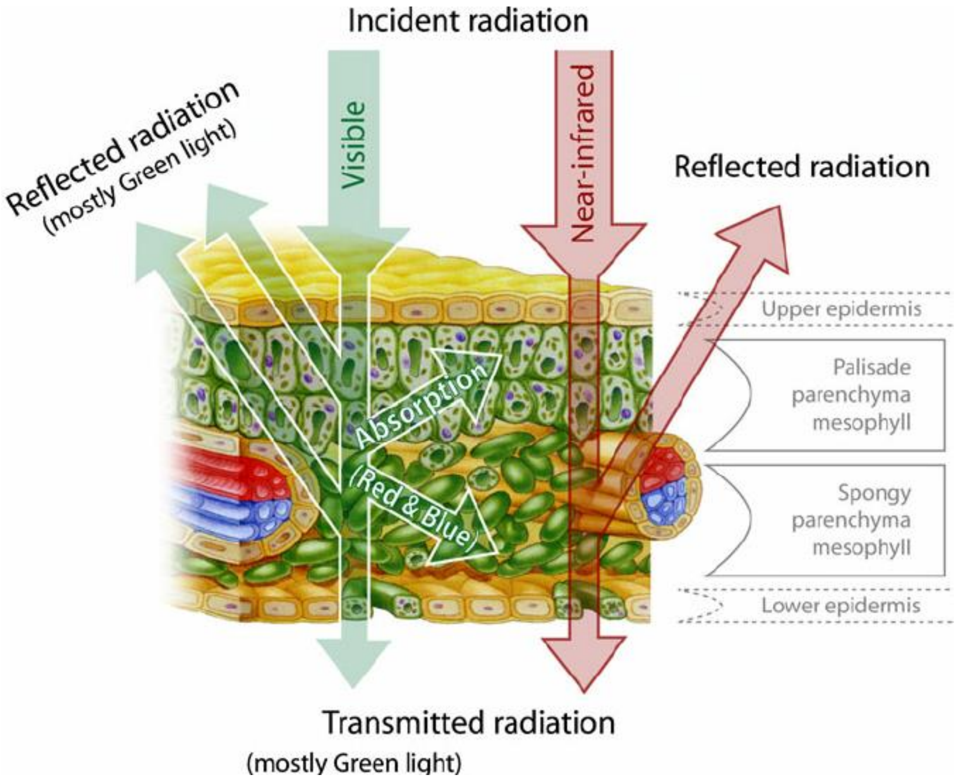
MAY 1978

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

Introduction: Remote Sensing of Vegetation

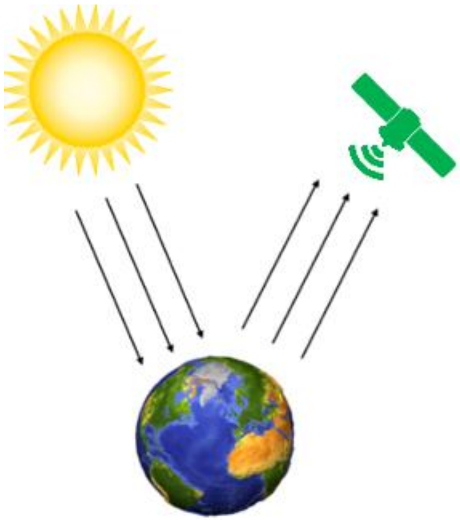
- Chlorophyll is a pigment found in plants, and allows plants to absorb energy from light
- Chlorophyll is primarily responsible for absorption of the light in visible region of the electromagnetic spectrum (e.g. blue and red)
- Mesophyll tissues reflects near-infrared (NIR)

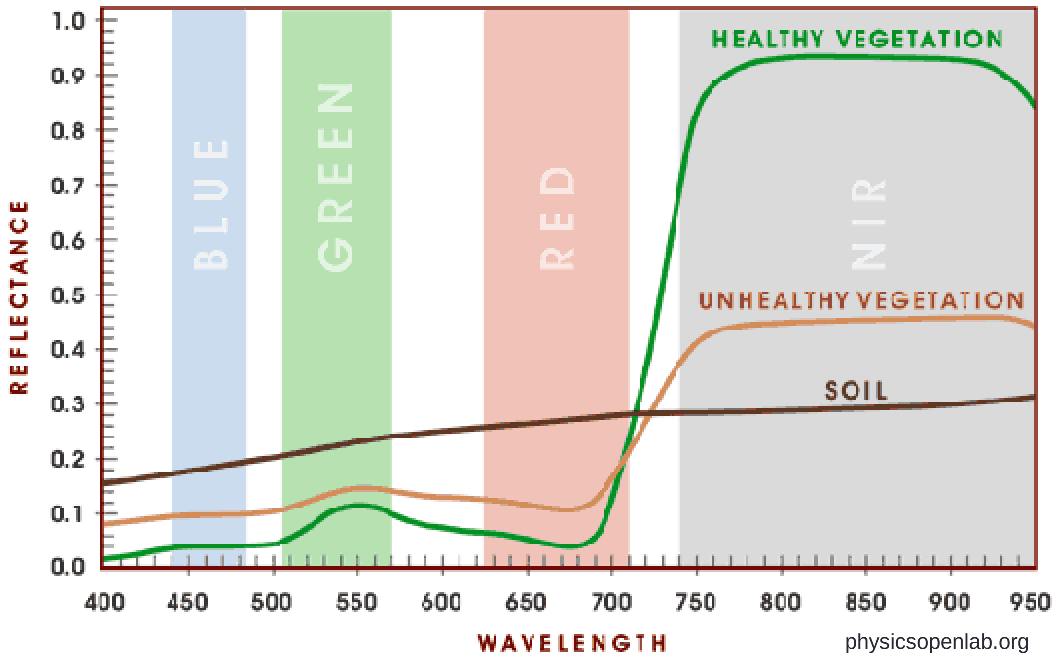


Introduction: Remote Sensing of Vegetation

- Remote sensing vegetation indices have been formulated to exploit these physical properties of vegetation
- The use of Red and NIR bands are common across most vegetation indices
- The Normalized Difference Vegetation Index

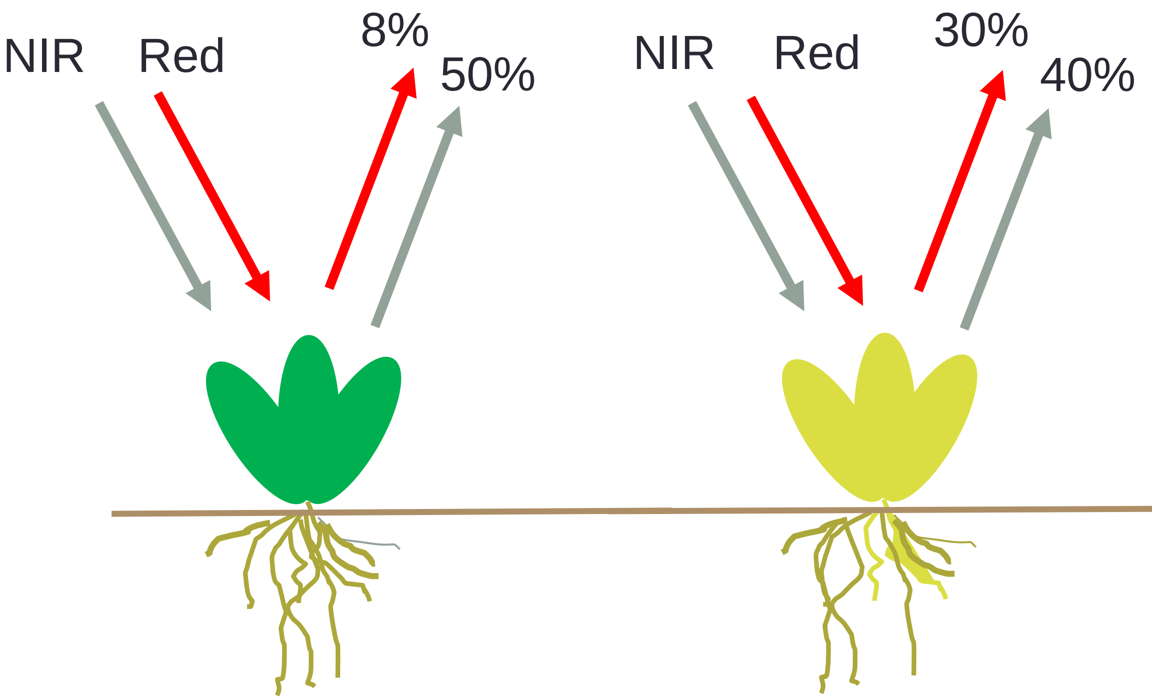
NDVI = (NIR – Red) / (NIR + Red)





Introduction: Remote Sensing of Vegetation

- A simple example of how NDVI responds to differences in vegetation vigor
- Because it is physically based and simple, NDVI is the most widely used vegetation index



NDVI = (NIR – Red) / (NIR + Red)

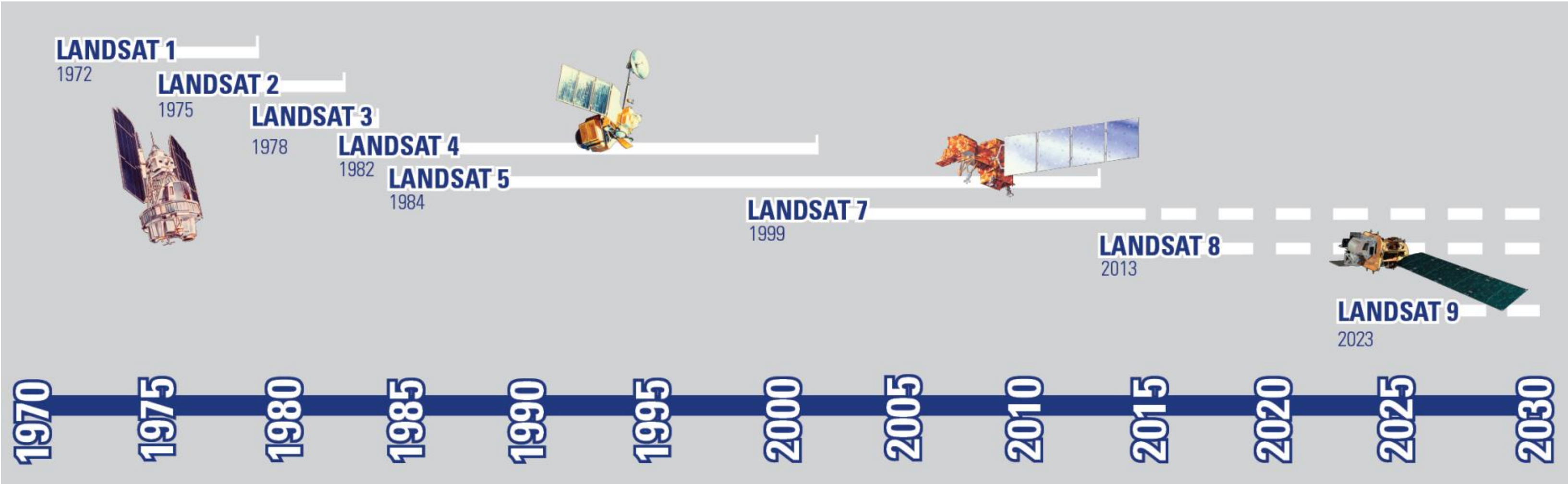
(0.50 – 0.08) / (0.50 + 0.08) = 0.72

(0.40 – 0.30) / (0.40 + 0.30) = 0.14

Landsat

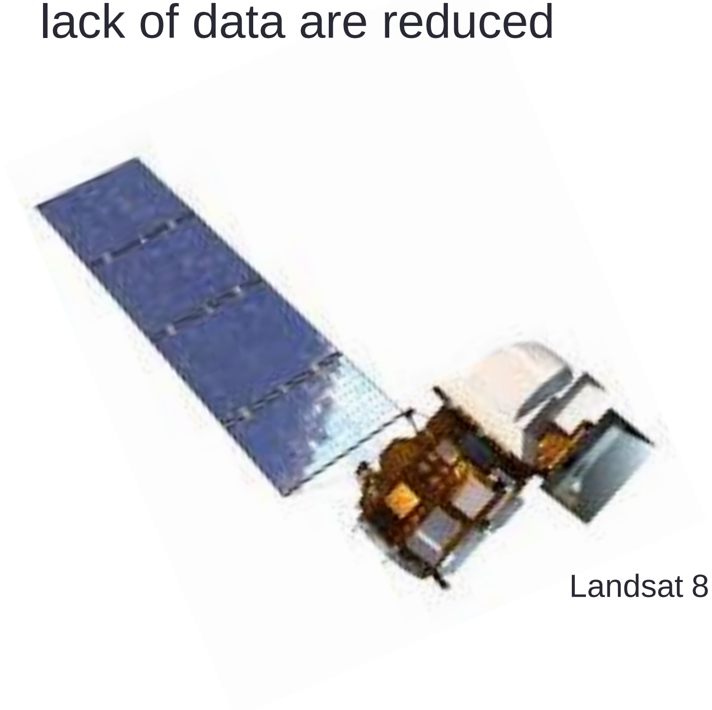
Landsat 8

- This joint NASA/USGS Landsat program provides the longest continuous space-based record of Earth's land in existence
- Every day, Landsat satellites provide essential information to help land managers and policy makers make wise decisions about our resources and our environment
- Due to differences in image quality and sensor compatibility, most studies of vegetation and vegetation change focus on the use of the Landsat 5, 7, and 8 archives (1984 to pres.)
- Planned launch for Landsat 9 is 2020 (moved up from 2023)
- Planning for Landsat 10 design for continued Earth observations is ongoing
- European Space Agency recently launched 2 Landsat-like satellites (Sentinel 2a,b) that can also be used for vegetation monitoring



Why Remote Sensing with Landsat?

- Can provide vegetation cover information over the last 30+ years at relatively high resolution (i.e. 30m pixels)
- Optimal spatial resolution for mapping vegetation over space and time and resource management scales (i.e. field scale)
- Can complement field measurements of vegetation cover
- Can provide estimates where field measurement do not exist
- Also, with free availability of Landsat data for everyone, disputes over data or lack of data are reduced



Landsat and Ecology

Articles

Landsat's Role in Ecological Applications of Remote Sensing

WARREN B. COHEN AND SAMUEL N. GOWARD

“Given the more than 30-year record of Landsat data, mapping land and vegetation cover change is becoming common place.” -- 2004

Remote sensing, geographic information systems, and modeli
and applications that are explicitly spatial and temporal. Of a
otal role in spatial and temporal scaling. Modern terrestrial e
ing land cover, vegetation biophysical attributes, forest structu
of Landsat data, mapping land and vegetation cover change a
article, we summarize this large body of work, highlighting the unique role of Landsat.

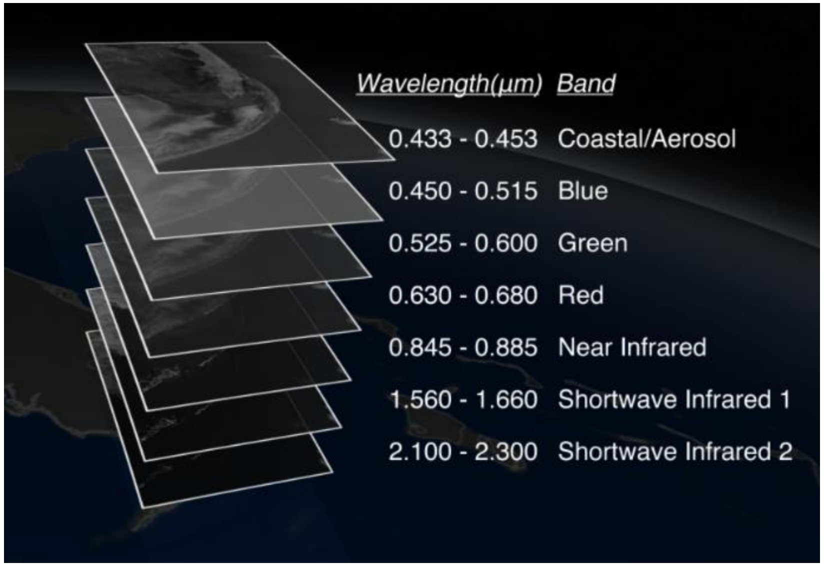
Keywords: remote sensing, Landsat, spectral vegetation indices, vegetation mapping, change detection

The discipline of ecology has undergone tremendous growth and diversification over the past century. These advances were driven by a variety of sociological, political, environmental, and technological developments that fostered new theory as well as new applications. Public concern over the state of the environment, which had been increasing over the decades leading up to the 1960s, led to landmark sociopolitical action. The Clean Air Act of 1963, later amended in 1970 and 1990, was perhaps the most important initial

of Earth from space, and a discipline known as remote sensing was born. With the launch of the first Landsat satellite in 1972, scientists could suddenly view tangible human impacts on the whole Earth system on a regular basis. By necessity, field measurements and experiments focused (and have continued to focus) mainly on plots with sizes up to several square meters (m^2). Remote sensing enabled scientists to spatially reference their plots to images showing the land-cover and landform context of their data. Because Landsat data were

Landsat Specifications

- Landsat measures reflectance from Earth's surface in 7 to 11 different bands of the electromagnetic spectrum



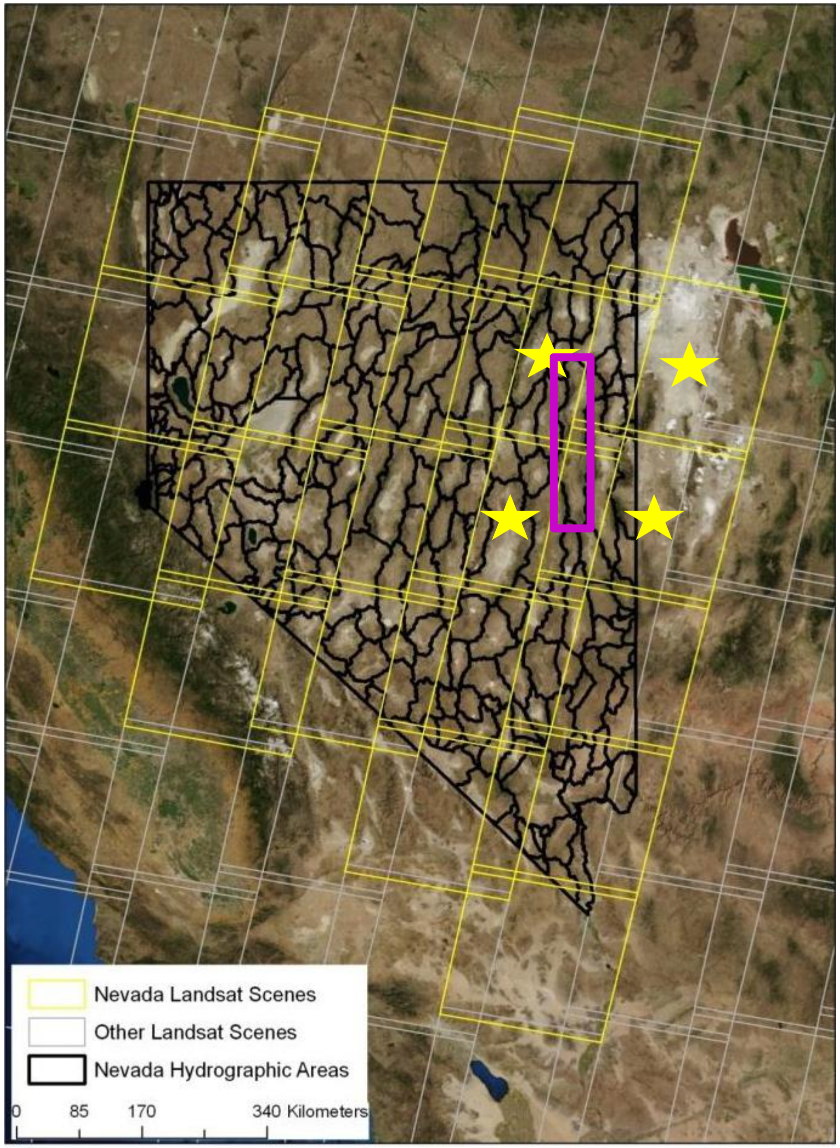
- Landsat 5 Thematic Mapper (TM) images are available every 16 days from 1984-2012

- This interval is reduced to 8 days when combined with the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) (1999 – present), and when Landsat 7 is combined with Landsat 8 Optical Land Imager (OLI) (2013 – present).

- Landsat image are available every 7 days when the area of interest lies within an overlap of two Landsat paths, which is the case for the majority of Spring Valley shrubland areas analyzed.

Landsat Path and Rows

- Landsat data are broken out by path and row, or “scenes”
- Spring Valley contains 4 different paths and rows (39:32, 39:33, 40:32, 40:33)
- ~1000+ Landsat images per path/row since 1985
- Equates to ~4,000 possible images to process for Spring Valley
- Equal to ~$ 2.5 million in imagery prior to 2009 ($600/image)
- Now it is all freely available via USGS, and in Google and Amazon clouds



Landsat

- The open Landsat archive is rapidly advancing how we monitor vegetation, and is an ideal satellite platform for monitoring vegetation over long time histories

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Opening the archive: How free data has enabled the science and monitoring promise of Landsat

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A B S T R A C T

Landsat occupies a unique position in the constellation of civilian earth observation satellites, with a long and rich scientific and applications heritage. With nearly 40 years of continuous observation – since launch of the first satellite in 1972 – the Landsat program has benefited from insightful technical specification, robust engineering, and the necessary infrastructure for data archive and dissemination. Chiefly, the spatial and spectral resolutions have proven of broad utility and have remained largely stable over the life of the program. The foresighted acquisition and maintenance of a global image archive has proven to be of unmatched value, providing a window into the past and fueling the monitoring and modeling of global land cover and ecological change. In this paper we discuss the evolution of the Landsat program as a global monitoring mission, highlighting in particular the recent change to an open (free) data policy. The new data policy is revolutionizing the use of Landsat data, spurring the creation of robust standard products and new science and applications approaches. Open data access also promotes increased international collaboration to meet the Earth observing needs of the 21st century.

Common Vegetation Indices Applied to Landsat Data

- Common vegetation indices computed with Landsat data include:
  - Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI)
- NDVI has been extensively used in Nevada to quantify vegetation vigor, plant cover, evapotranspiration (Nichols, 2000; Devitt et al., 2011; Beamer et al., 2013; Garcia et al., 2015), and groundwater dependent ecosystem conditions over time (Huntington et al., 2016; Carroll et al., 2017)
- NDVI was selected for this work over other vegetation indices for numerous reasons:
  - Shown to better quantify sparse-to-moderate vegetation cover in arid environments (McGwire et al., 1999; Wu 2014)
  - Does not require parameter calibration
  - Has better statistical correlation with evapotranspiration from phreatophytic shrubs than other common indices in Spring Valley (Devitt et al., 2011)
  - Differences in NDVI across different Landsat satellites (i.e. Landsat 5, 7, and 8) have been assessed and calibration factors developed and applied in the Great Basin (Huntington et al., 2016)
  - Has the breadth and history of usage not matched by other indices, is simple, and widely accepted across research and practitioner communities
- The use of Landsat derived NDVI is commonly used as a proxy for vegetation cover, and is an appropriate method for monitoring shrubland habitat in the Great Basin

Approach

General Approach:

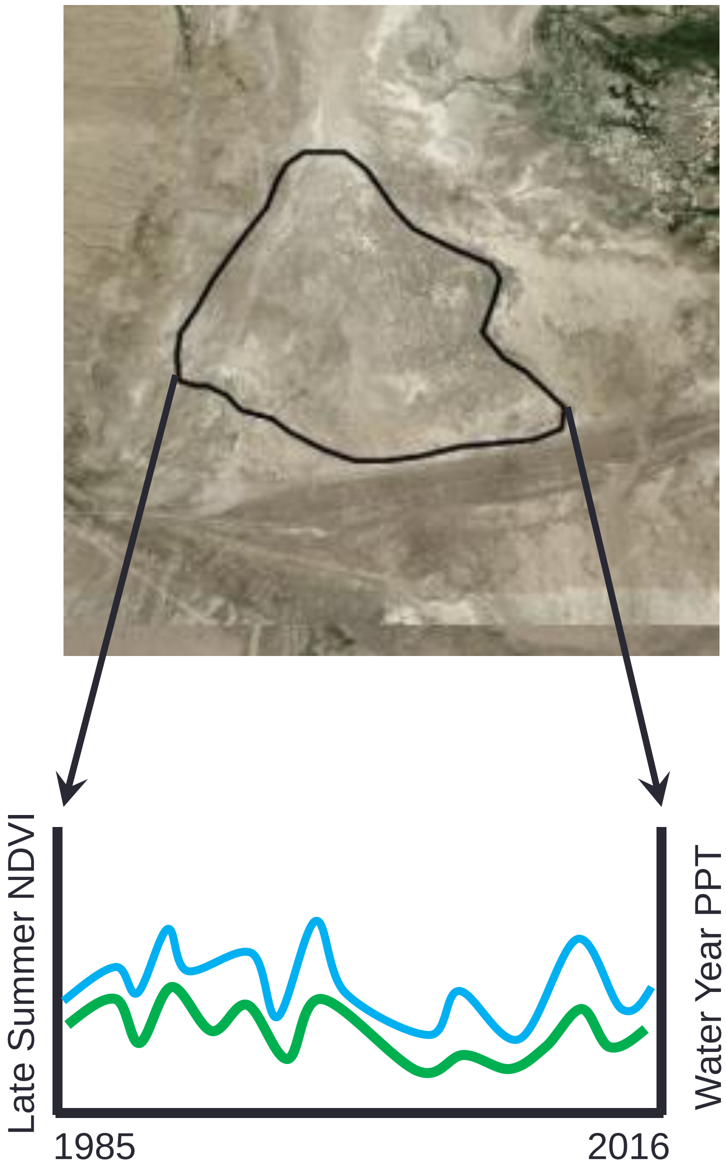
1) Define analysis areas

2) Derive time series of Landsat NDVI from 1985-2015

   - Focus on mid to late-summer period to minimize the signal from vegetation that can be highly variable due to seasonal precipitation, and maximize the relevant signal for tracking annual changes in vegetation in relation to groundwater availability

3) Derive time series of gridded weather data: water year precipitation (PPT) from 1985-2015

4) Develop useful graphical and statistical characterizations of baseline conditions for understanding temporal and spatial relationships between vegetation cover and climate, hydrology, and management



Approach – Follows Recent Work in NV

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Assessing the role of climate and resource management on groundwater dependent ecosystem changes in arid environments with the Landsat archive

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Phreatophytes
Complementary relationship
Evaporative demand

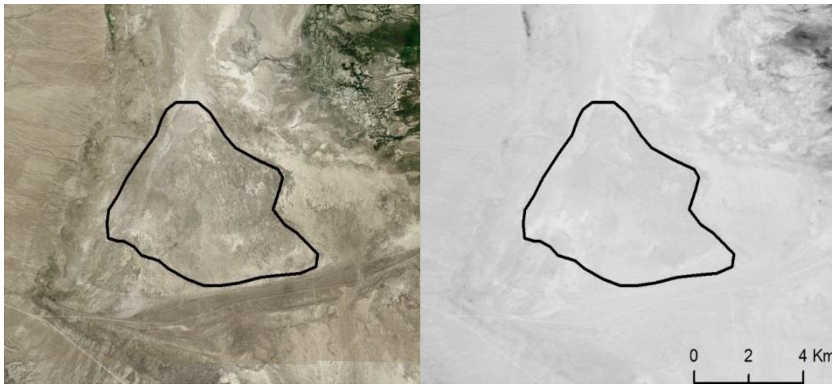
A B S T R A C T

Groundwater dependent ecosystems (GDEs) rely on near-surface groundwater. These systems are receiving more attention with rising air temperature, prolonged drought, and where groundwater pumping captures natural groundwater discharge for anthropogenic use. Phreatophyte shrublands, meadows, and riparian areas are GDEs that provide critical habitat for many sensitive species, especially in arid and semi-arid environments. While GDEs are vital for ecosystem services and function, their long-term (i.e. ~30 years) spatial and temporal variability is poorly understood with respect to local and regional scale climate, groundwater, and rangeland management. In this work, we compute time series of NDVI derived from sensors of the Landsat TM, ETM+, and OLI lineage for assessing GDEs in a variety of land and water management contexts. Changes in vegetation vigor based on climate, groundwater availability, and land management in arid landscapes are detectable with Landsat. However, the effective quantification of these ecosystem changes can be undermined if changes in spectral bandwidths between different Landsat sensors introduce biases in derived vegetation indices, and if climate, and land and water management histories are not well understood. The objective of this work is to 1) use the Landsat 8 under-fly dataset to quantify differences in spectral reflectance and NDVI between Landsat 7 ETM+ and Landsat 8 OLI for a range of vegetation communities in arid and semiarid regions of the southwestern United States, and 2) demonstrate the value of 30-year historical vegetation index and climate datasets for assessing

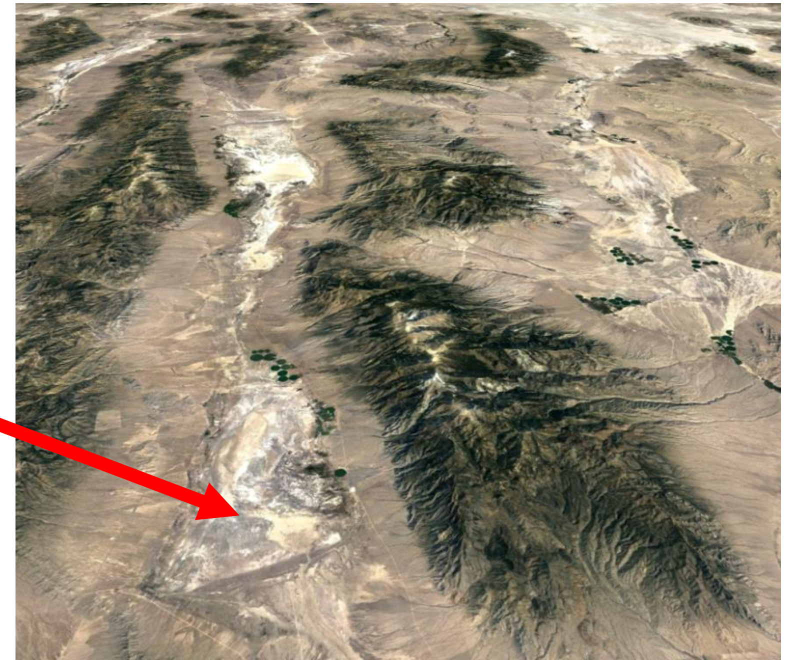
Approach – Follows Recent Work in NV

- Natural Background Variability
  - Spring Valley phreatophyic shrub area
- Groundwater level changes
  - Fish Lake Valley
- Riparian Restoration
  - Maggie Creek and Susie Creek – Middle Humboldt River

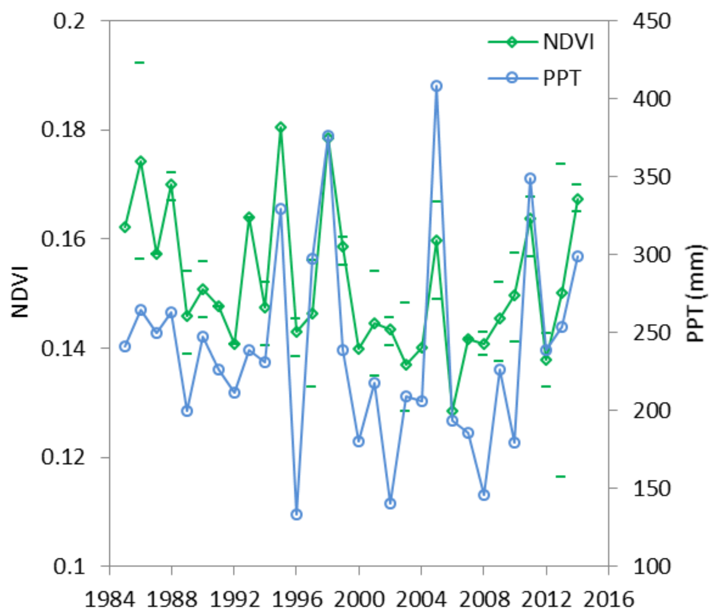
Spring Valley, NV



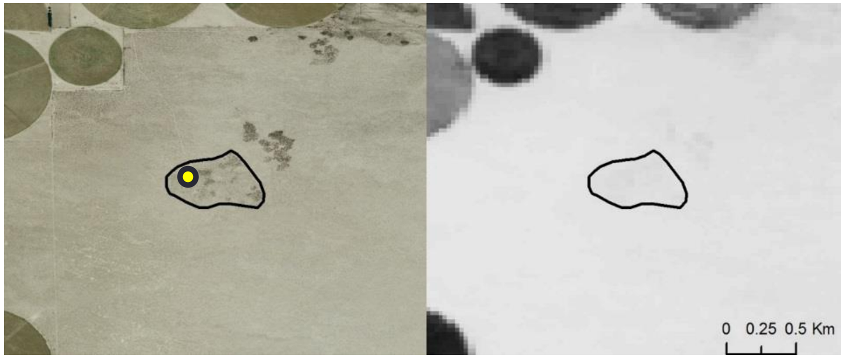
NDVI; Black = High, White = Low



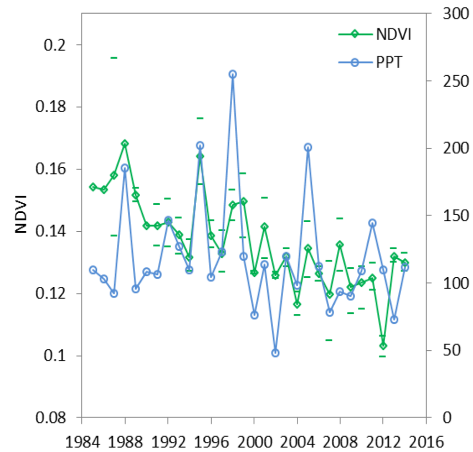
- Water year precipitation (derived from gridMET data) and Landsat NDVI generally track well over time
- Primary factors limiting the correspondence between water year precipitation ("PPT") and summer average NDVI are likely antecedent soil moisture conditions, and shallow groundwater stabilizing minimum vegetation vigor and NDVI
- The use of Landsat NDVI along with PPT estimates allows for baseline variability of vegetation and climate to be established at local to regional scales

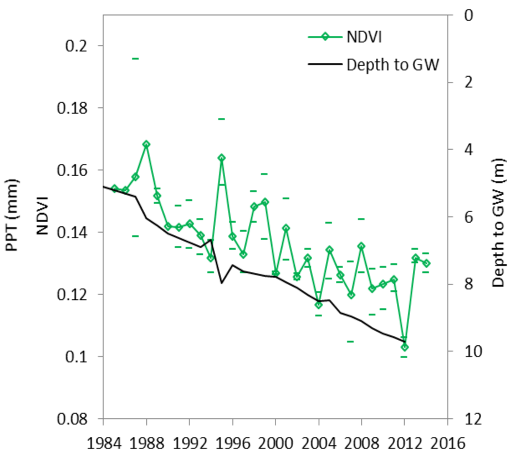


Fish Lake Valley, NV – Shallow Groundwater Level Changes



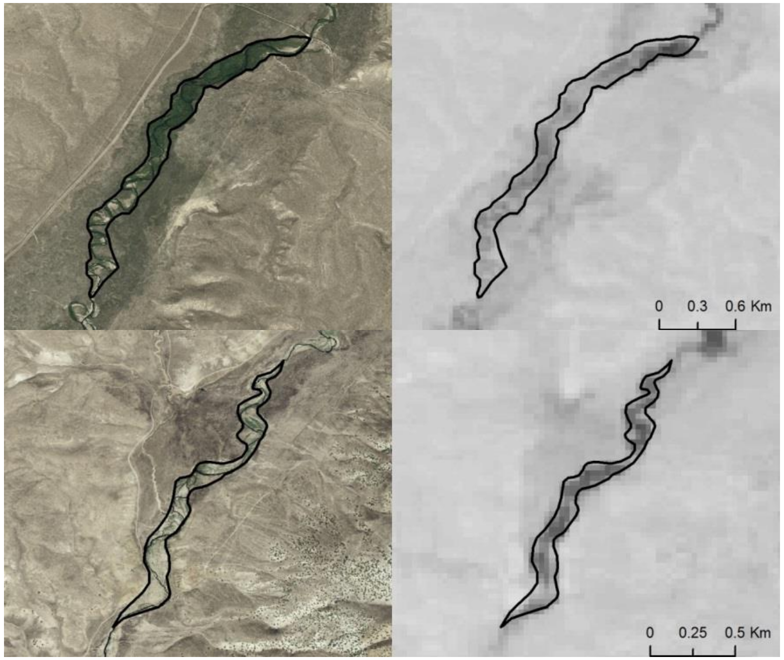
NDVI; Black = High, White = Low





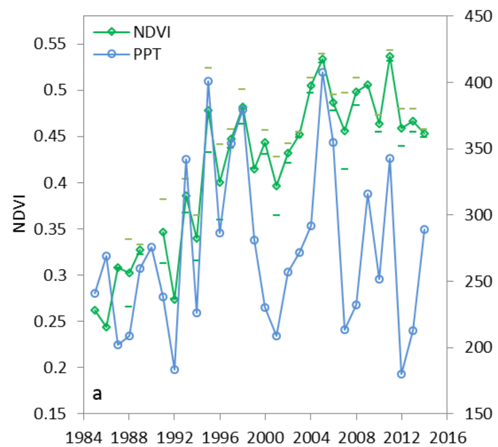
- Inter-annual variability of Landsat NDVI generally corresponds with water year PPT variability
- Groundwater levels at the Arlemont Ranch well have steadily decreased since at least 1979 due to groundwater pumping for irrigation
  - Depth to groundwater was shallow prior to pumping
  - Approximately 5 m in 1985 and was 10m in 2014
- NDVI has also declined during the period of groundwater level decline, with intermittent NDVI increases that correspond to anomalously high annual PPT
- NDVI following groundwater decline never reaches early year values, even in wet years
- The trends of summer average, maximum, and minimum Landsat NDVI from 1985-2014 are statistically significant at the 95% confidence level
- Inter-annual Landsat NDVI time series can effectively be used to assess vegetation impacts due to lowering of shallow groundwater levels

Maggie Creek and Susie Creek – Humboldt River Basin, NV

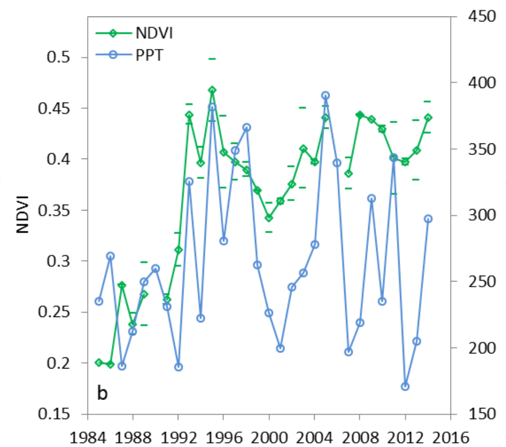


NDVI; Black = High, White = Low

Maggie Creek



Susie Creek



- Watershed restoration occurred in the early 90s, and included fencing, culvert replacement, prescriptive livestock grazing, and development of livestock water sources away from stream areas
- Since restoration occurred Landsat July-August average NDVI time series shows that during lengthy droughts of the late 1990s and early 2000s, NDVI never fell below pre-restoration values
- Since restoration, Maggie and Susie Creek NDVI has increased by 54% and 67%, respectively
- Important attributes of successful restoration are improved drought resistance and recovery
- The use of inter-annual Landsat NDVI time series is an ideal approach for monitoring change and restoration

Methods

- SNWA requested data derived from Landsat satellite imagery to quantify changes in shrubland habitat vegetation for the purpose of establishing baseline conditions and conducting long-term monitoring its Spring Valley monitoring, management, and mitigation (3M) program

- Landsat composite images, cloud masks and cloud score datasets, cross-sensor calibrated at-surface reflectance NDVI datasets, and gridMET PPT datasets from 1985-2015 were provided to SNWA for the Spring Valley Hydrographic Area

- Process
  - Accessed the Landsat Archive in the Google cloud
  - Applied atmospheric corrections
  - Applied Landsat cross-sensor corrections
  - Extracted cloud masks
  - Performed calculations in the Google cloud and downloaded image products
  - Provided image products to SNWA

Methods – Atmospheric Correction

- Atmospheric correction of Landsat top-of-atmosphere reflectance imagery was completed to account for attenuation and scattering of light by the atmosphere between the satellite sensor and the land surface, and is required to compute at-surface reflectance
- The Tasumi et al. (2008) approach is an operational approach that provides a consistent method for atmospheric correction
- Relied on hourly vapor pressure from the North American Land Data Assimilation System (NLDAS - NASA) to calculate perceptible water in the atmosphere according to Tasumi et al. (2008)
- The Tasumi et al. (2008) approach has been shown to have more consistency than standard Landsat atmospheric correction products in Nevada (Huntington et al, 2016)

At-Surface Reflectance and Albedo from Satellite for Operational Calculation of Land Surface Energy Balance

Masahiro Tasumi[1]; Richard G. Allen[2]; and Ricardo Trezza[3]

Abstract: This paper presents a rapid, operational method for estimating at-surface albedo applicable to Landsat and MODIS satellite sensors for typical cloud-free, low-haze conditions and sensor view angles less than 20°. At-surface albedo estimates are required input to various surface energy balance models that are applied operationally. The albedo calculation method was developed using the SMARTS2 radiative transfer model and has been applied in recent versions of the University of Idaho METRIC model as a component of the surface energy balance for determining evapotranspiration. The albedo procedure uses atmospheric correction functions developed to require only general humidity data and a digital elevation model. The atmospheric correction functions have a reduced structure to enhance their operational applicability in routine instantaneous surface energy balances and to estimate evapotranspiration. The method does not require high levels of knowledge in atmospheric physics and radiation transfer processes, common to traditional radiation transfer models, which enhances their use by a broad range of agricultural and hydrologic scientists and engineers. The atmospheric correction and surface albedo estimation procedures are developed primarily for use with Landsat imagery, which does not have an official albedo product. However, the procedure is also applicable to MODIS imagery that has an official albedo product at the 1 km scale, for situations where full broadband albedo having 500 m resolution is needed, where albedo is needed for select days having small sensor view angles for reduction of pixel blurring, or where image striping or reflectance data fallout has occurred in the standard MODIS albedo product. Method results have been compared to literature values and independent data sets. Test applications against MODIS albedo products in New Mexico, Florida, and Idaho indicate that the expected error for actual albedo from the developed method is within the interval of –0.035 to +0.033 (95% confidence level), equivalent to a standard error of 0.017, over broad ranges in land surface elevation, humidity, and sun angle.

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CE Database subject headings: Energy; Satellites; Evapotranspiration; Hydrology.

Methods – Cross Sensor Calibration

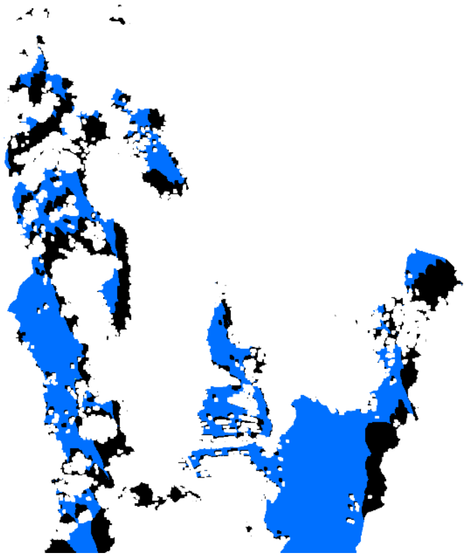
- Since Landsat “bands” are slightly different across the different Landsat sensors (mainly the NIR band) corrections should be applied for long time series analysis using multiple Landsat sensors
- The effect of changes in Landsat 8 spectral bands for NDVI (red and NIR bands) was assessed and corrected for using Mojave and Great Basin images from Landsat 8 and 7 that were acquired within 7 min of each other on March 29, 2013 during the “under-fly” testing of the Landsat 8 system

Huntington et al. (2016) Remote Sensing of Environment

Processing – Cloud Mask

- Cloud mask (FMASK) and Cloud Score images were computed and provided to SNWA for each Landsat Image from 1985-2015
- Cloud mask and cloud score images are used to identify erroneous reflectance values due to cloud cover
- Cloud mask and cloud score images were used by SNWA to identify and filter out erroneous NDVI values due to cloud cover

True Color Composite

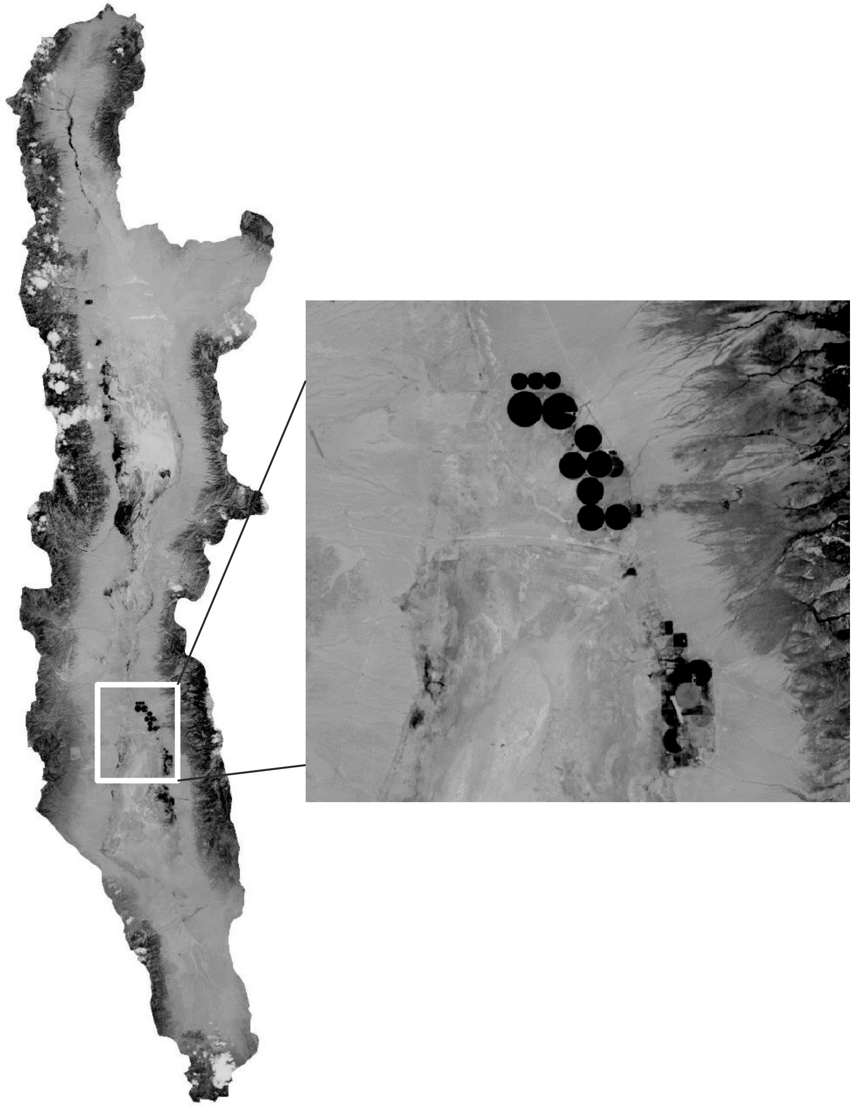


FMASK
White = Cloud
Black = Shadow
Blue = Clear

Cloud Score
White -> Black
Cloud -> Clear

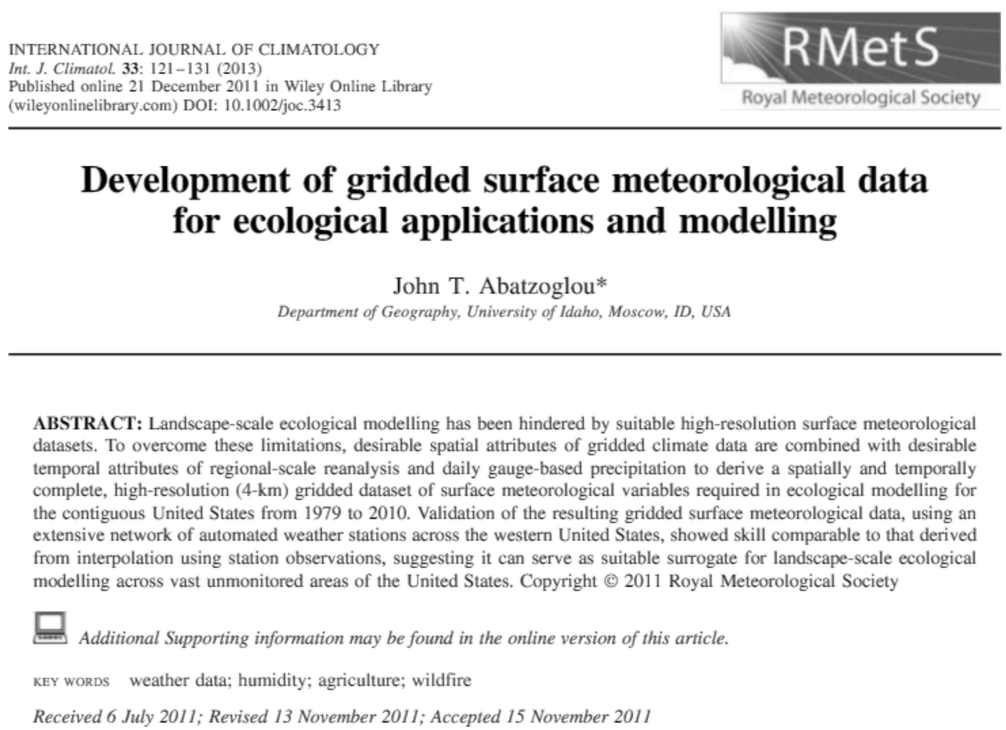
Processing – Computation and Data Extraction

- At-surface reflectance and NDVI was computed for every available Landsat image from 1985-2015, clipped to the Spring Valley Hydrographic Area
- Processing, clipping to the Spring Valley HA, and data extraction was performed using Google's Earth Engine cloud computing platform
- All at-surface reflectance, NDVI, and cloud mask/score data for the Landsat archive (1985-2015) was provided to SNWA



Precipitation Data

- Monthly and annual PPT data were derived from University of Idaho's gridMET dataset
- gridMET is a hybrid 4 km spatial resolution daily PPT dataset based on the Parameter Regression on Independent Slopes Model (PRISM) (Daly et al., 1994) and NLDAS (Mitchell et al., 2004)
- gridMET has been shown to outperform or be similar to other gridded PPT products when comparing to independent valley floor PPT measurements in Spring and Snake valleys, Nevada (McEvoy et al., 2014)
- gridMET is ideal for ecohydrological applications and for pairing with Landsat data
- gridMET PPT data were processed, clipped, downloaded, and delivered to SNWA from 1985-2015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RMetS
Royal Meteorological Society

Development of gridded surface meteorological data for ecological applications and modelling

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ABSTRACT: Landscape-scale ecological modelling has been hindered by suitable high-resolution surface meteorological datasets. To overcome these limitations, desirable spatial attributes of gridded climate data are combined with desirable temporal attributes of regional-scale reanalysis and daily gauge-based precipitation to derive a spatially and temporally complete, high-resolution (4-km) gridded dataset of surface meteorological variables required in ecological modelling for the contiguous United States from 1979 to 2010. Validation of the resulting gridded surface meteorological data, using an extensive network of automated weather stations across the western United States, showed skill comparable to that derived from interpolation using station observations, suggesting it can serve as suitable surrogate for landscape-scale ecological modelling across vast unmonitored areas of the United States. Copyright © 2011 Royal Meteorological Society

Additional Supporting information may be found in the online version of this article.

KEY WORDS weather data; humidity; agriculture; wildfire

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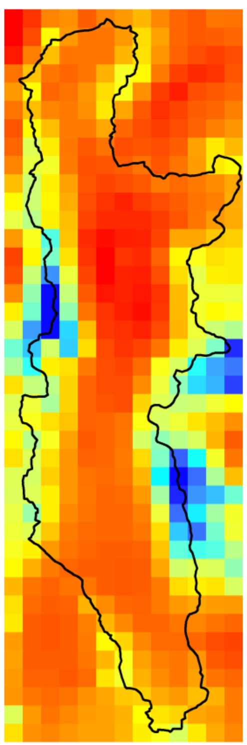
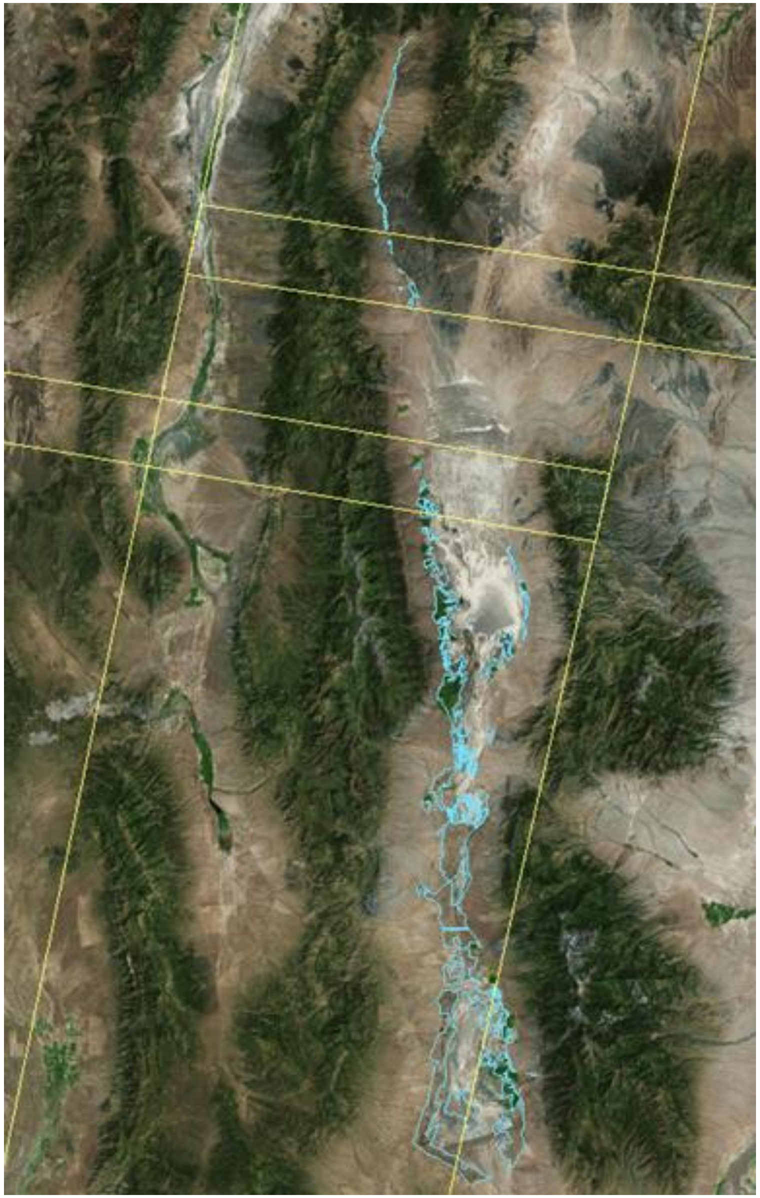


Spatial Averaging

- Python software scripts were developed and provided to SNWA for the purpose of producing NDVI and PPT zonal statistics for analysis areas
- SNWA applied the Python scripts and zonal statistic procedures correctly to produce spatially averaged NDVI and PPT datasets for analysis
- SNWA used the cloud mask and cloud score datasets appropriately to omit cloud cover data



Summary

- SNWA is utilizing data derived from satellite imagery to quantify changes in vegetation over time in order to establish baseline conditions and conduct long-term monitoring
- The Normalized Difference Vegetation Index (NDVI) is one of the most widely-used remote sensing indices for monitoring vegetation, and is commonly used as a proxy for vegetation cover
- Landsat satellite imagery was used to compute at-surface reflectance NDVI, and gridMet was used to estimate precipitation, for the Spring Valley HA from 1985-2015
- Methods used for processing
  - Atmospheric corrections
  - Cross-sensor corrections
  - Computation of at-surface reflectance and NDVI
  - Development of cloud mask and cloud score images
  - Clipping and extraction of Landsat and gridMET PPT datasets for the Spring Valley HA
- Spatial averaging scripts for post-processing Landsat and PPT data to shrubland habitat areas were provided to SNWA and used appropriately
- SNWA's final NDVI and PPT datasets used in their shrubland habitat remote sensing analysis adhere to scientifically accepted standards
- The use of NDVI and PPT data is an appropriate method for monitoring shrubland habitat cover in the Great Basin