APPLICATION OF SINGLE POLARIMETRIC RADARSAT-2 IMAGES IN ESTIMATING WATER STAGE IN THE EVERGLADES

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Introduction

Understanding the dynamics of hydrological regimes and their effects on Everglades ecosystems requires high resolution, spatially explicit time series data of water stages across the system. Currently, daily water stages are measured using a network of gages. While these gages provide valuable hydrologic data, their density is not sufficient to model local responses within the system.

High resolution, spatially continuous datasets can be derived from remotely sensed data. While multi-spectral data can detect open water with high accuracy, it cannot detect standing water underneath the vegetation canopy. Synthetic Aperture Radar (SAR) systems like RADARSAT-2 (RSAT2), are unaffected by cloud cover, and can detect hydrological conditions under vegetation canopies (Lu and Kwoun, 2010).

Previous application of SAR in wetland settings:

- The application of SAR data to monitor wetland hydrologic function and vegetation conditions at St. Marks National Wildlife Refuge, Florida (Tanis et al., 1994).
- SAR data obtained in wet and dry seasons were compared with ground data to determine its ability to estimate ground condition for herbaceous and woody vegetation in the Everglades (Kasischke and Bourgeau-Chavez, 1997; Kasischke et al., 2003; Bourgeau-Chavez et al., 2005).
- Interferometric SAR was used in the Everglades to estimate flow diffusivity (Wdowinski et al., 2004) and surface water level changes (Wdowinski et al., 2008).

The **purpose of this study** was to investigate the relationship between radar backscatter from RSAT2, NDVI calculated from WorldView 2 (WV2) multi-spectral data, and water stages for different vegetation types using EDEN water level gages. Vegetation classes were derived from aerial photography and WV2 data.

Theory

SAR systems emit microwave energy which illuminates earth's surface, and measure the portion of backscattered energy. The backscattered signal from the illuminated surface depends not only on the size, density, shape, and dielectric constant of the objects that interact with the radar wave, but also on SAR system characteristics, such as incidence angle, polarization, and wavelength. The resulting images are a compilation of the spatial variation in backscattering coefficient measured in Decibels for each ground unit (pixel).

For wetlands with herbaceous vegetation, the incoming radar wave interacts with various elements of the vegetation and the ground surface, which may be dry, wet or covered with standing water. In such cases, there are four types of backscattering mechanisms:

- Surface backscattering (Fig. 1a)
- Volume backscattering (Fig. 1b)
- Double-bounce backscattering (Fig. 1c)
- Specular scattering (Fig. 1d)

Microwave scattering on the ground can be quantified by the surface roughness and reflection coefficient of the ground which is dependent on the dielectric constant.

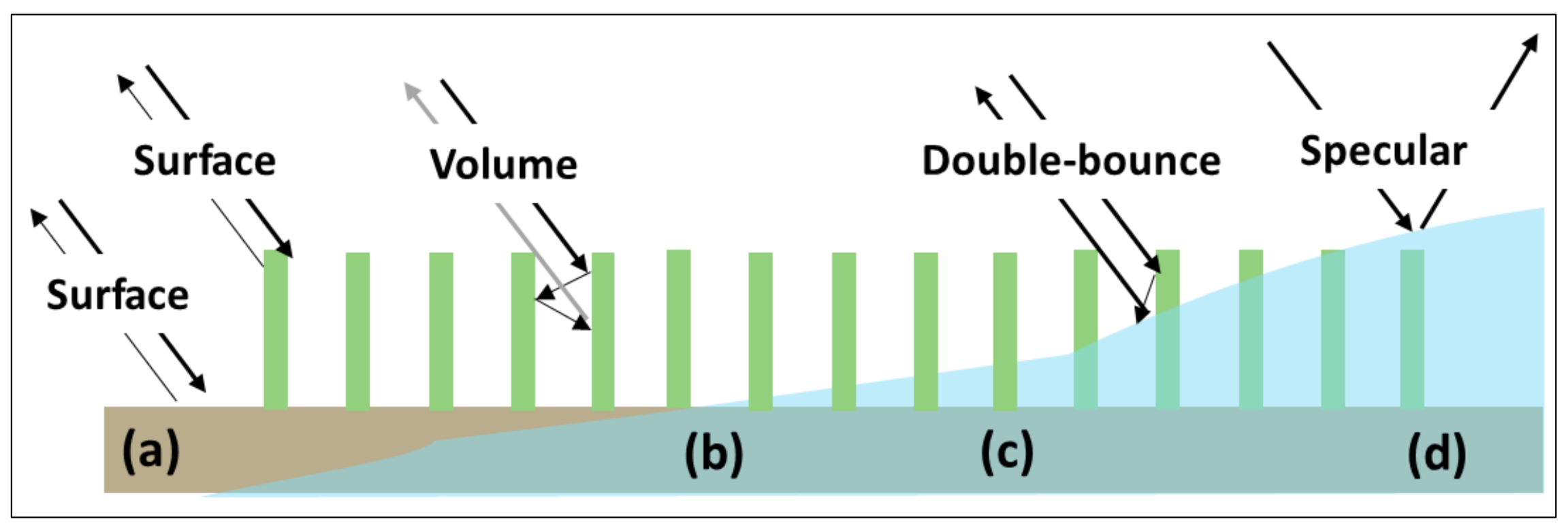


Figure 1. Radar backscatter mechanisms for herbaceous vegetation in wetlands.

- A **dry ground layer** has a low dielectric constant and a low reflection coefficient; hence, radar energy backscattered is attenuated due to multiple scattering between vegetation and the ground surface.
- As the **soil moisture increases**, the dielectric constant of the surface increases, which reduces transmission of the radar energy resulting in increased backscatter.
- When there is **standing water on the ground**, the backscatter contribution of the soil is eliminated and the incident wave is forward scattered by the water surface. In such cases, backscatter is highly dependent on the height of the vegetation.
  - If the **vegetation is fully submerged**, the incident energy is specular scattered away from the receiver resulting in very low backscatter.
  - If the **above-water stems** are large enough and oriented in the right direction, the backscattered energy is increased due to double-bounced scattering.

Methodology

This study used water stage data from EDEN stations to quantify hydrological ground conditions and NDVI measurements from WV2 images to characterize the biomass. Linear regression models for backscatter with ground condition were developed for five different vegetation classes; *Cladium jamaicense*, dense *Cladium*, sparse *Cladium*, graminoid prairie, and wet prairie.

- **Hydrology data** on May 4th and May 7th, 2013 was obtained from 52 EDEN stations (Fig. 2). This data consisted of **water levels and ground elevation** at the stations. Gage readings in NGVD29 were converted to NAVD88 using the local conversions provided with the data, and subtracted from ground elevations to calculate the water stage.
- **RSAT2 images** acquired on May4th (Fig. 2) and May7th, 2013 were geo-referenced in ArcGIS using landmarks on the ground. A 3x3 mean filter to reduce speckle, and a cosine law to normalize the pixel values based on the incident angles were applied across both images. The **radar backscatter (dB)** corresponding to the EDEN stations were extracted.
- **WV2 images** were geo-rectified and atmospherically corrected. The **Normalized Difference Vegetative Index (NDVI)** values were calculated from near-infrared (nIR) and red (R) reflectance ((nIR – R) / (nIR + R)) and extracted for the station locations.
- **Vegetation classes** were determined by visual interpretation of aerial photography and spectral analysis of the WV2 data. 19 stations that experienced a major vegetation change (fire, regrowth, etc.) between WV2 and RSAT-2 acquisition dates were dropped.

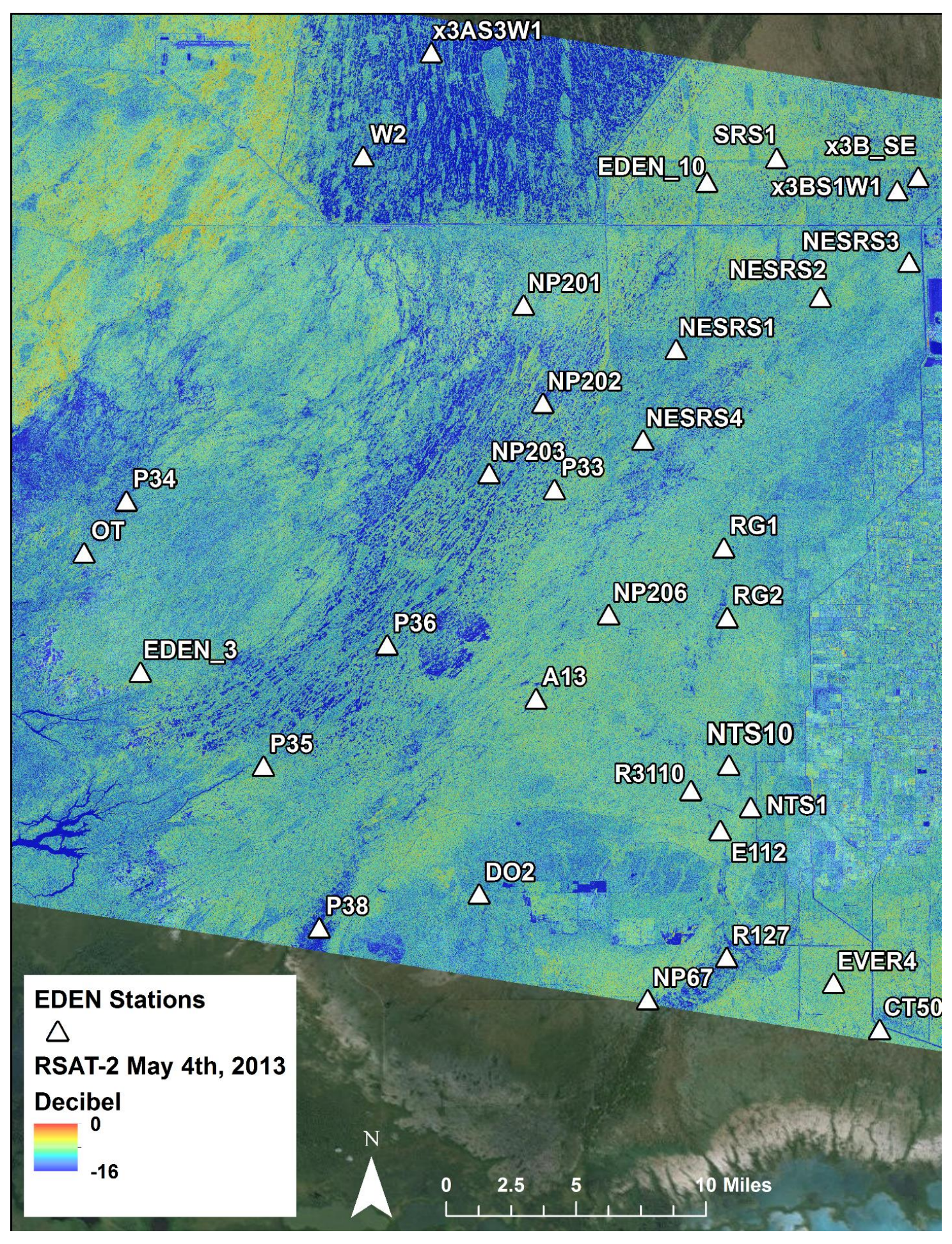
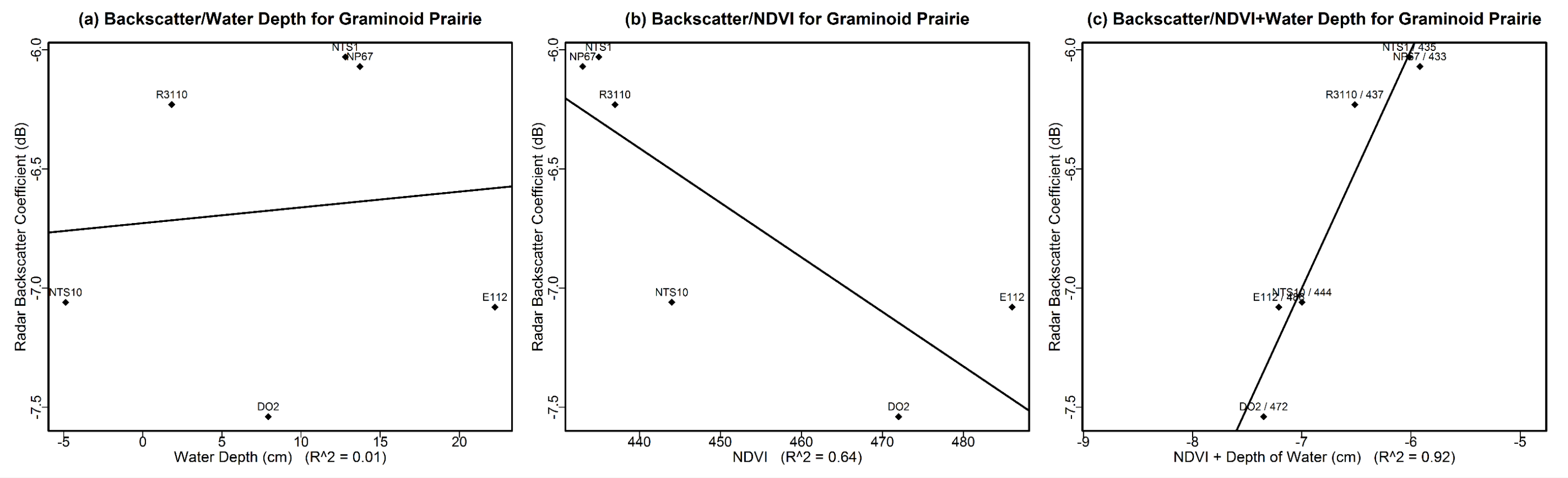
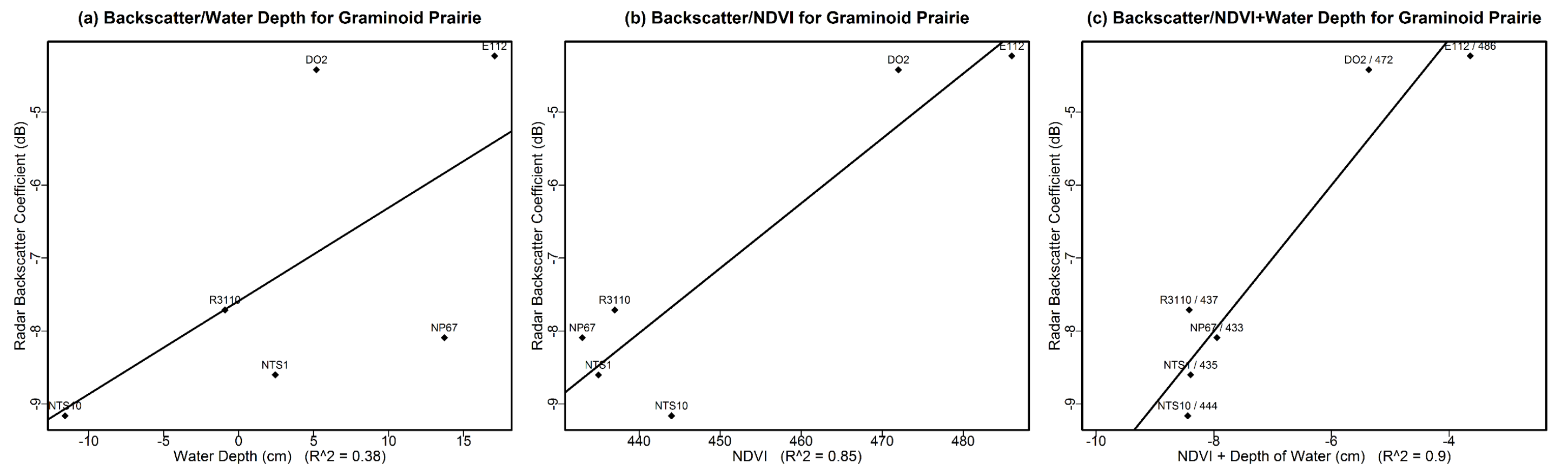


Figure 2. EDEN stations and RSAT2 image of May 4th, 2013.

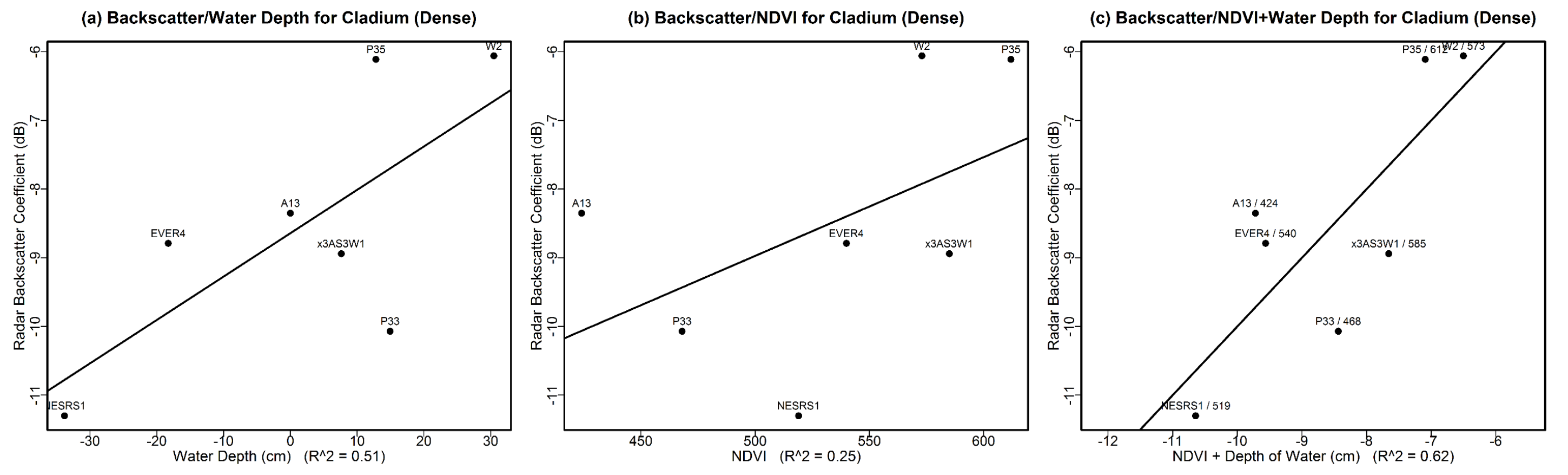
Preliminary Results & Discussion



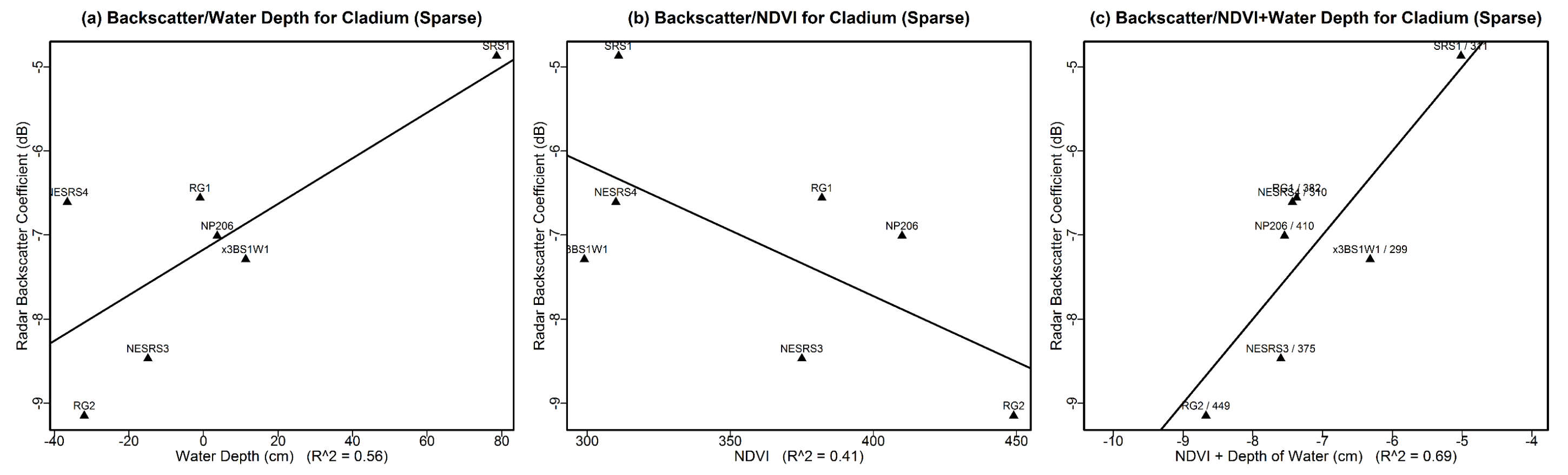
- **May 4th, 2013**
  Graminoid Prairie
  - Higher incident angle causes reduction in backscatter with NDVI through surface scattering
  - More specular scattering witnessed with higher incident angles



- **May 7th, 2013**
  Graminoid Prairie
  - Lower incident angles can penetrate the vegetation canopy resulting in more double-bounce and volume scattering



- **May 7th, 2013**
  ***Cladium* (Dense)**
  - Increase in backscatter with increase in water depth due to double-bounce scattering
  - Denser vegetation results in attenuation of penetrating wave



- **May 7th, 2013**
  ***Cladium* (Sparse)**
  - Increase in backscatter with increase in water depth due to double-bounce and volume scattering
  - Higher specular scattering is witnessed

- Lower incident angles penetrate the vegetation canopy resulting in interaction of the radar wave with water and vegetation (R^2 for regression models of May 7th generally higher than for May 4th).

		Water Depth		NDVI		NDVI + Water Depth	
Radar Date	Vegetation Type	R-Squared	Adjusted	R-Squared	Adjusted	R-Squared	Adjusted
4-May-13	*Cladium*	0.36	0.21	0.00	-0.25	0.41	0.01
	Cladium (Dense)	0.10	-0.08	0.22	0.07	0.41	0.12
	Cladium (Sparse)	0.23	0.07	0.03	-0.17	0.23	-0.16
	Graminoid Prairie	0.01	-0.24	0.64	0.55	0.92	0.87
	Wet Prairie	0.00	-0.25	0.22	0.03	0.33	-0.12
7-May-13	*Cladium*	0.00	-0.25	0.11	-0.11	0.13	-0.46
	Cladium (Dense)	0.51	0.41	0.25	0.10	0.62	0.44
	Cladium (Sparse)	0.56	0.48	0.41	0.30	0.69	0.54
	Graminoid Prairie	0.38	0.22	0.85	0.81	0.90	0.83
	Wet Prairie	0.21	0.01	0.00	-0.25	0.41	0.02

- For denser vegetation (dense *Cladium* and graminoid prairie), the effect of double-bounced scattering and volume scattering increases with lower incident angles resulting in an increase in backscatter with water depth.
- In the case of sparse *Cladium* with higher incident angles (May 4th), water depth is more controlling of backscatter than vegetation. While their individual models do not perform very well, the additive model results in better correlation with backscatter.
- The regression models for wet prairies perform better with lower incident angles (May 7th) and additive modeling. Modeling wet prairie backscattering is challenging due to the presence of floating periphyton, which most likely increases surface scattering.

Conclusions

- In all the cases considered, additive models explained the variation of backscatter with ground conditions better than individual models; hence, the interactive effects of the radar wave with ground (dry or wet) and vegetation controls radar backscatter. Creating better models require detailed information of both aspects.
- Models of radar backscatter with lower incident angles had higher R^2. Images with lower incident angles should provide more accurate estimates of standing water underneath vegetation canopy.
- One of the challenges of this application is the presence of floating vegetation and periphyton, which can mask the presence of standing water. In such instances, high backscatter is recorded, instead of lower backscatter associated with standing water. Inclusion of more samples in different vegetation types is required for more conclusive results.
- Preliminary results from this study indicate that combination of NDVI, detailed vegetation mapping and radar backscatter can result in the estimation of water stage, additional data points are required to validate our results. This would require the use of more RSAT2 and WV2 images with close acquisition dates.

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