Mapping Forested Wetland Inundation in the Chesapeake Bay Watershed with Landsat Time-Series Data

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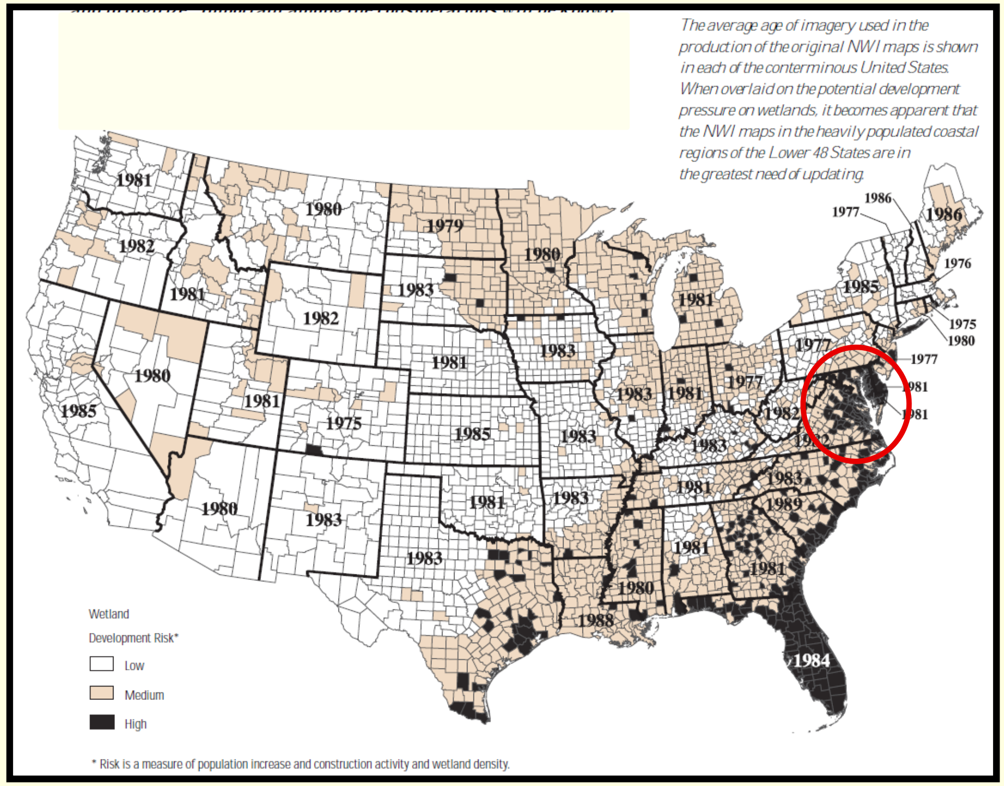
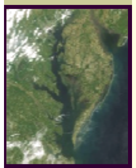
Chesapeake Bay Watershed

- CBW has lost >60% of historic wetlands
- Existing wetlands are at high risk for future loss.
- To best manage remaining wetlands we must know where they are located.



Risk Based on Historic Population/Construction Data and 1980s NWI Wetland Density

Credit: US FWS. 2002. NWI: A Strategy for the 21st Century



Wetland Mapping

- Forested wetlands are difficult to map using aerial photography, even harder with moderate resolution multispectral satellite data (e.g., Landsat)
  - Majority of wetlands in US and CBW are forested
- Rapid changes in land cover further confound wetland mapping in developing areas, like the CBW.
- Need to improve ability to map wetlands using moderate resolution data because doing so will allow the rapid update of wetland maps and the monitoring of dynamic wetland functioning

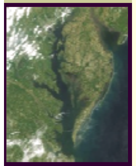
Wetland Functional Driver

- **Hydroperiod** - Duration and frequency of inundation and soil saturation at a specified depth
  - **Key to mapping wetland extent and function**
  - Changes in response to weather and human impacts.

- Single most important abiotic factor controlling wetland extent and function.
  - Controls biogeochemical cycling, habitat, and more.

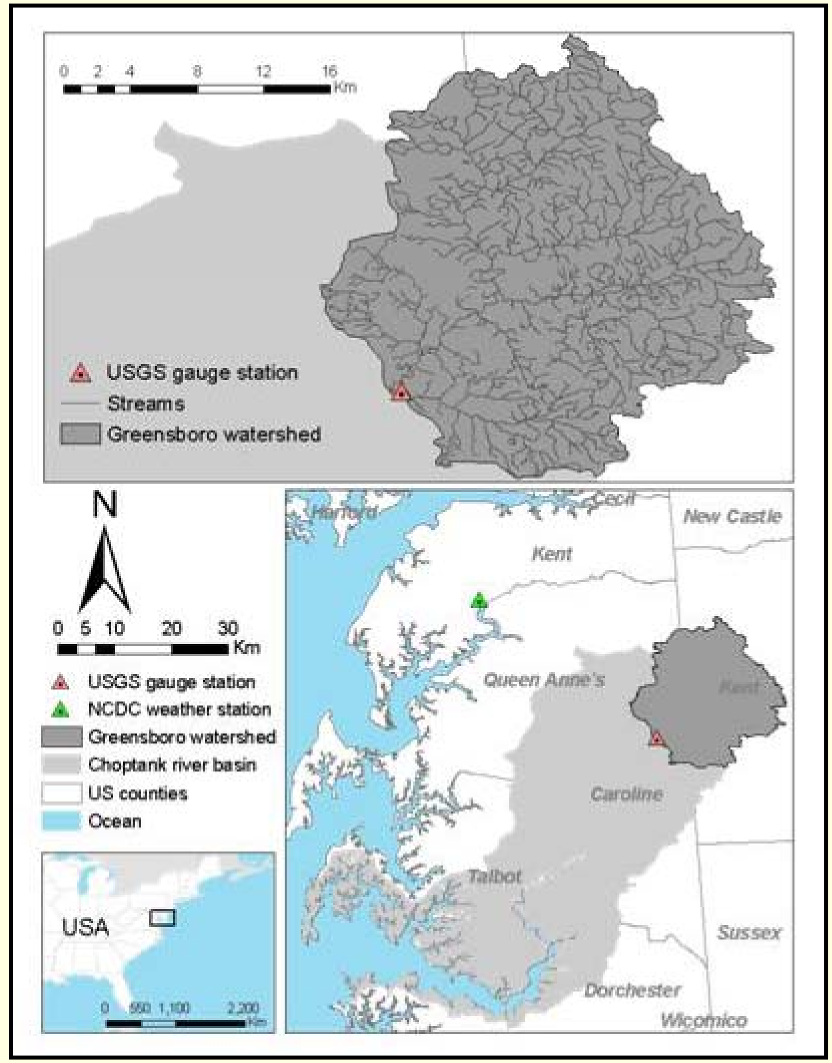
Study Objective

- To develop a new approach for mapping inundation dynamics in forested areas using commonly available datasets



Study Area

- Headwater forested wetlands in the Choptank River Watershed
  - Coastal Plain of the Chesapeake Bay Watershed
  - Primarily agricultural area with low water quality
  - Wetlands are mostly depressional, with smaller areas of flats and riparian wetlands.



Landsat Time Series

- Only long-term civilian archive of satellite imagery at the scale of human influence
- Series of seven Landsat systems collecting images since 1972
- Landsat record should continue into the future.
  - Landsat Data Continuity Mission (Landsat 8) successfully launched in 2013

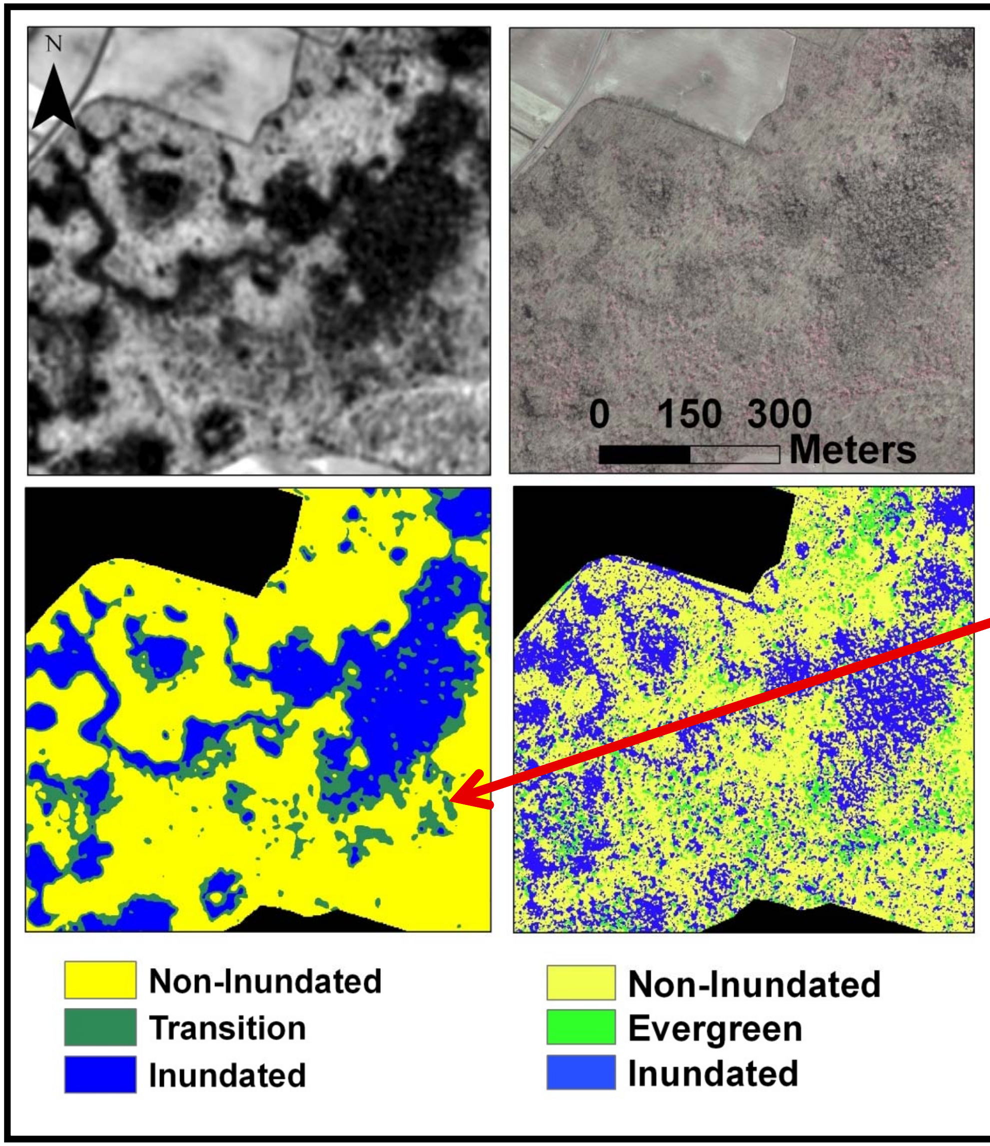
Landsat Preprocessing

- Spring leaf-off Landsat images without clouds
  - 2007/09: average and dry years
    - Correspond with LiDAR cal/val data
  - 2005/10: average and wet years
- Level 1T Landsat images converted to top of atmosphere reflectance (TOA) and atmospherically corrected using LEDAPS
- Dark object subtraction used to normalize all years to 2007

Cal/Val Data Development

- Field data are costly and often difficult to collect, but are vital to the development of accurate maps.
- Highly accurate, field validated LiDAR intensity based maps of inundation were used to provide cal/val data over a much larger area than would have been possible with field data alone.

LiDAR Intensity Maps of Inundation

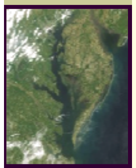


LiDAR Intensity
97% Accurate

Aerial Photography
70% Accurate

These maps were spatially aggregated to calculate percent inundation within the corresponding 30 m Landsat pixel

Lang and McCarty. 2009. LiDAR intensity for improved detection of inundation below the forest canopy. Wetlands. 29:1166-1178.



Examination of Bands & Indices

- Examined the correlation of Landsat bands, tasseled cap bands, and wetland related indices individually with SIP
  - Normalized Difference Vegetation Index
    - NDVI; (B4 – B3) / (B4 + B3)
  - Normalized Difference Wetness Index 1
    - NDWI-1; (B4 – B5) / (B4 + B5)
  - Normalized Difference Wetness Index 2
    - NDWI-2; (B3 – B5) / (B3 + B5)
  - Tasseled Cap Wetness – Greenness Difference
    - TCWGD; TCW - TCG
  - Tasseled Cap Angle
    - TCA; Arctan (TCG / TCB)
  - Infrared-Visible Ratio
    - IVR; B5 / B2
  - Infrared Ratio
    - IR; (B5 – B7) / (B5 + B7)

Examination of Bands & Indices

Coefficient of determination (R^2) of the linear relationship between sub-pixel inundation percentage (SIP) and Landsat bands and derived indices.

B1	B2	B3	B4	B5	B7	NDVI	NDWI-1
0.16	0.18	0.17	0.25	0.32	0.22	0.00	0.00
NDWI-2	TCB	TCG	TCW	TCWGD	TCA	IVR	IR
0.01	0.29	0.07	0.22	0.41	0.00	0.02	0.00

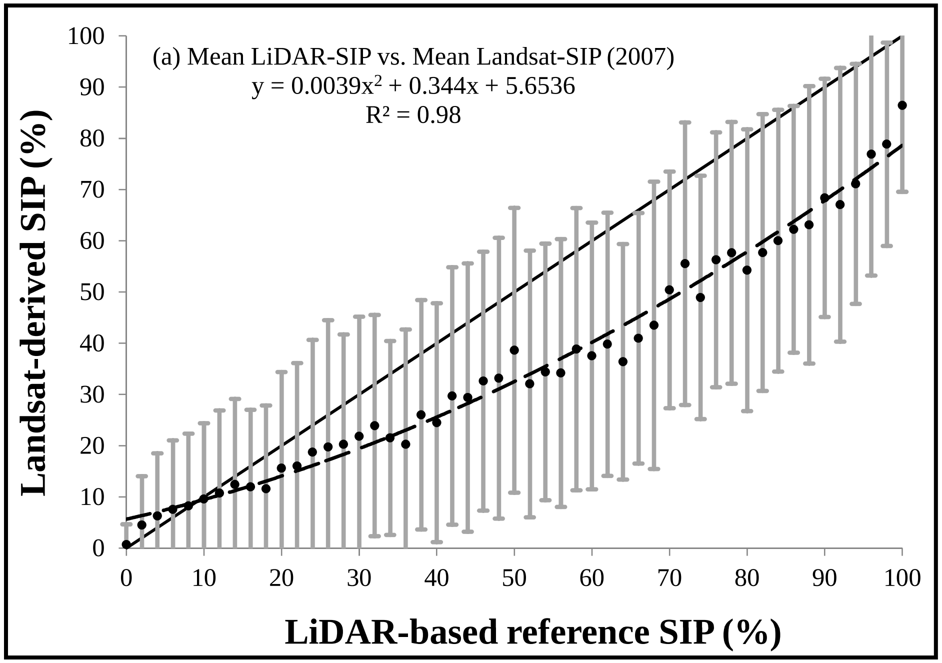
- The greatest correlations with SIP were found with TCWGD, band 5, and tasseled cap brightness, in that order.
  - TCWGD was developed as part of this study to help reduce the influence of greenness on tasseled cap wetness.

Model Development

- Stepwise linear regression was used to determine which bands, transformations, and indices in combination were most predictive of inundation (R^2 = .51; [TCWGD R^2 = .41]).
- A regression tree (Cubist) was used to create a model of SIP for 2007 based on the most predictive inputs (R^2 = .72; linear).
  - 30% of the 30 m aggregated LiDAR based inundation for 2007 were used to calibrate the RT model and 70% were used to validate.

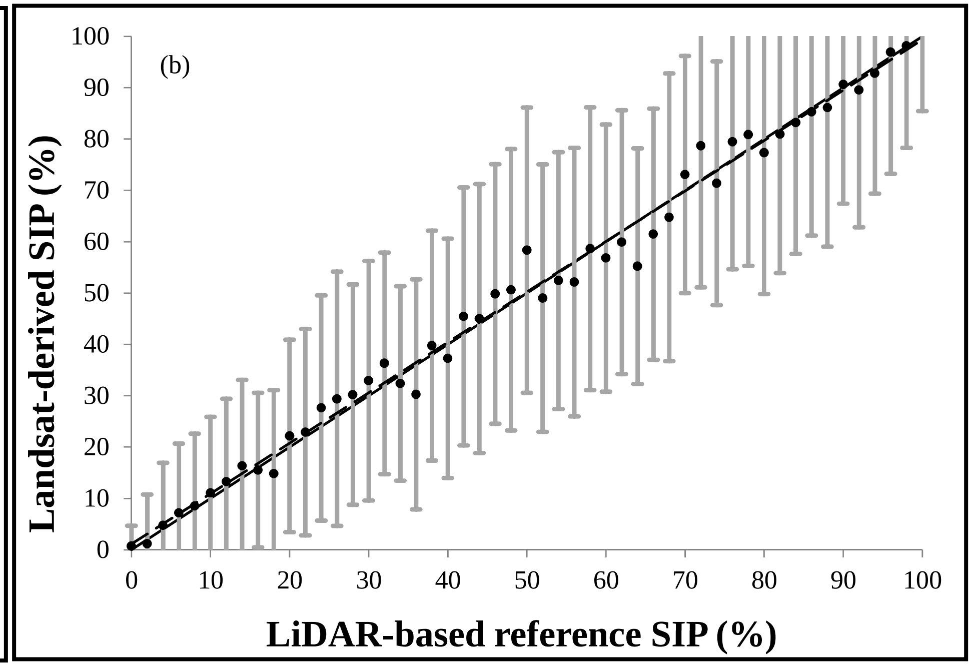
Model Normalization

Relationship between Landsat and Validation Data Before Correction



Mean SIP values of the initial 2007 RT prediction were lower than the mean reference SIP within 2% bins

Relationship between Landsat and Validation Data After Correction



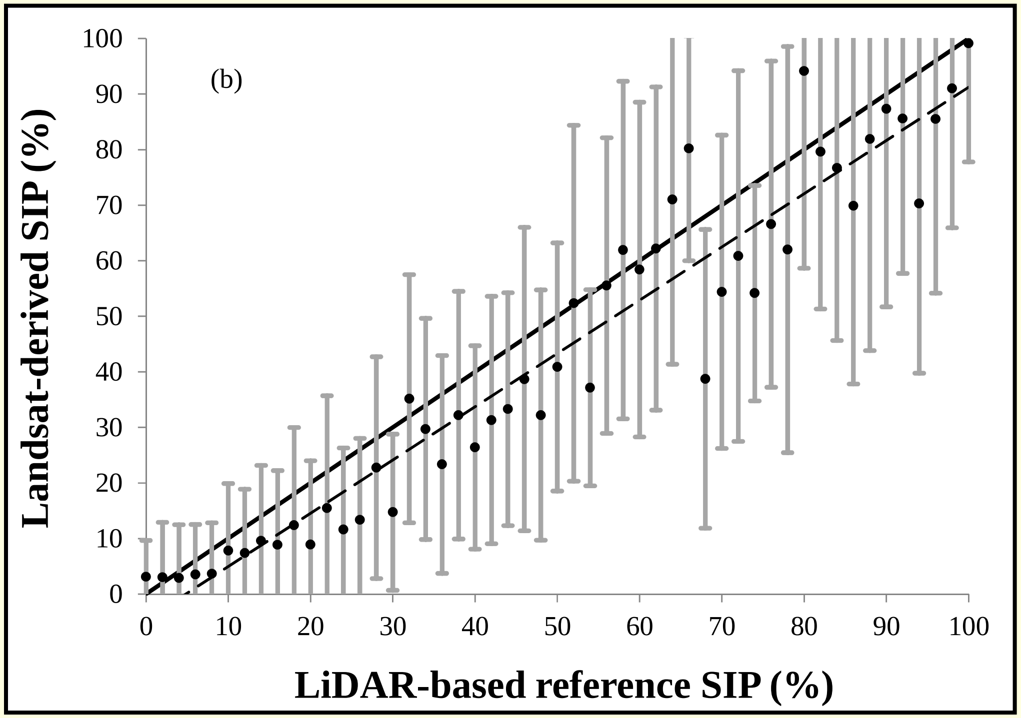
Biases were corrected by fitting a 2nd order polynomial function between mean reference values and mean predictions.

Mean prediction and its standard deviation within 2% bins are shown in a black dot and a gray bar, respectively. The solid and dashed lines represent the 1:1 and fitted lines, respectively.

2007 Model Application

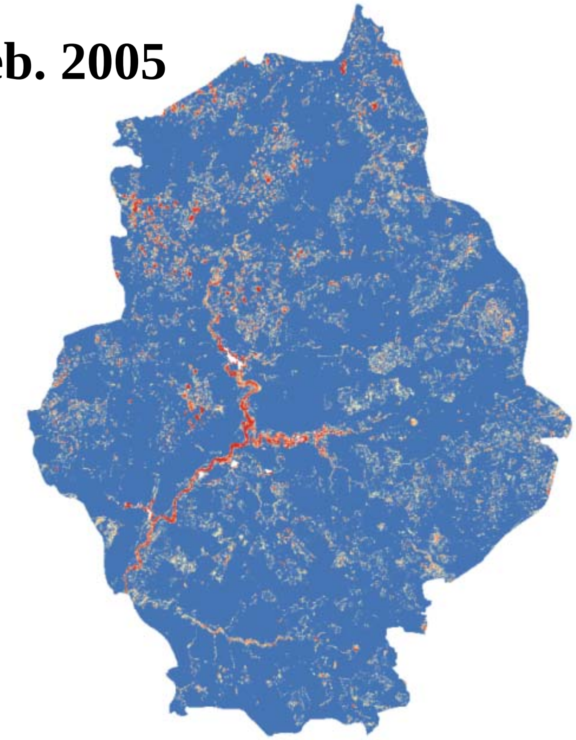
- The normalized model developed for 2007 was applied to the other dates

There was a robust correlation between Landsat and LiDAR SIP for 2009, but the Landsat map underestimated SIP by ~5%

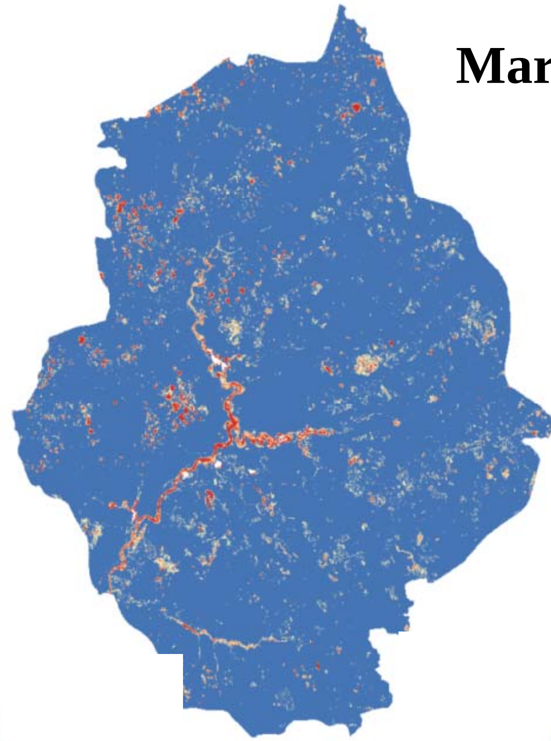


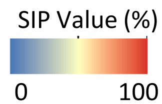
Mean prediction and its standard deviation within 2% bins are shown in a black dot and a gray bar, respectively. The solid and dashed lines represent the 1:1 and fitted lines, respectively.

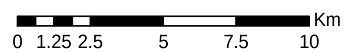
Feb. 2005



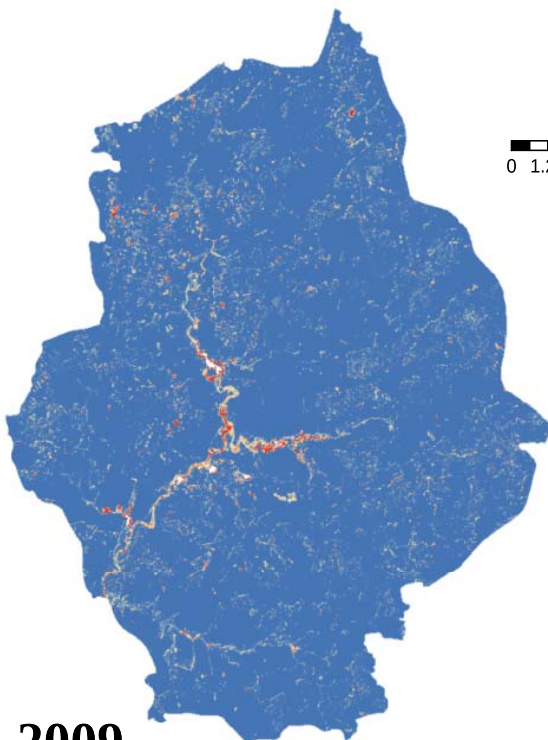
Mar. 2007



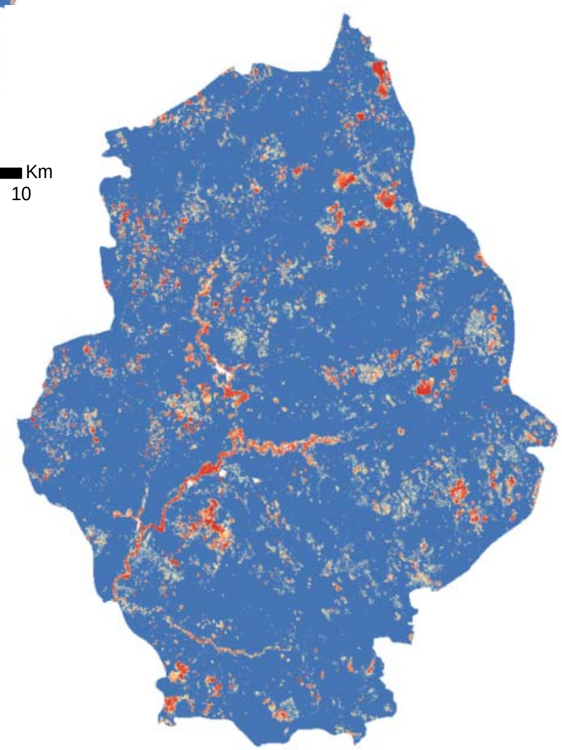




Final SIP maps derived using the inundation modeling approach

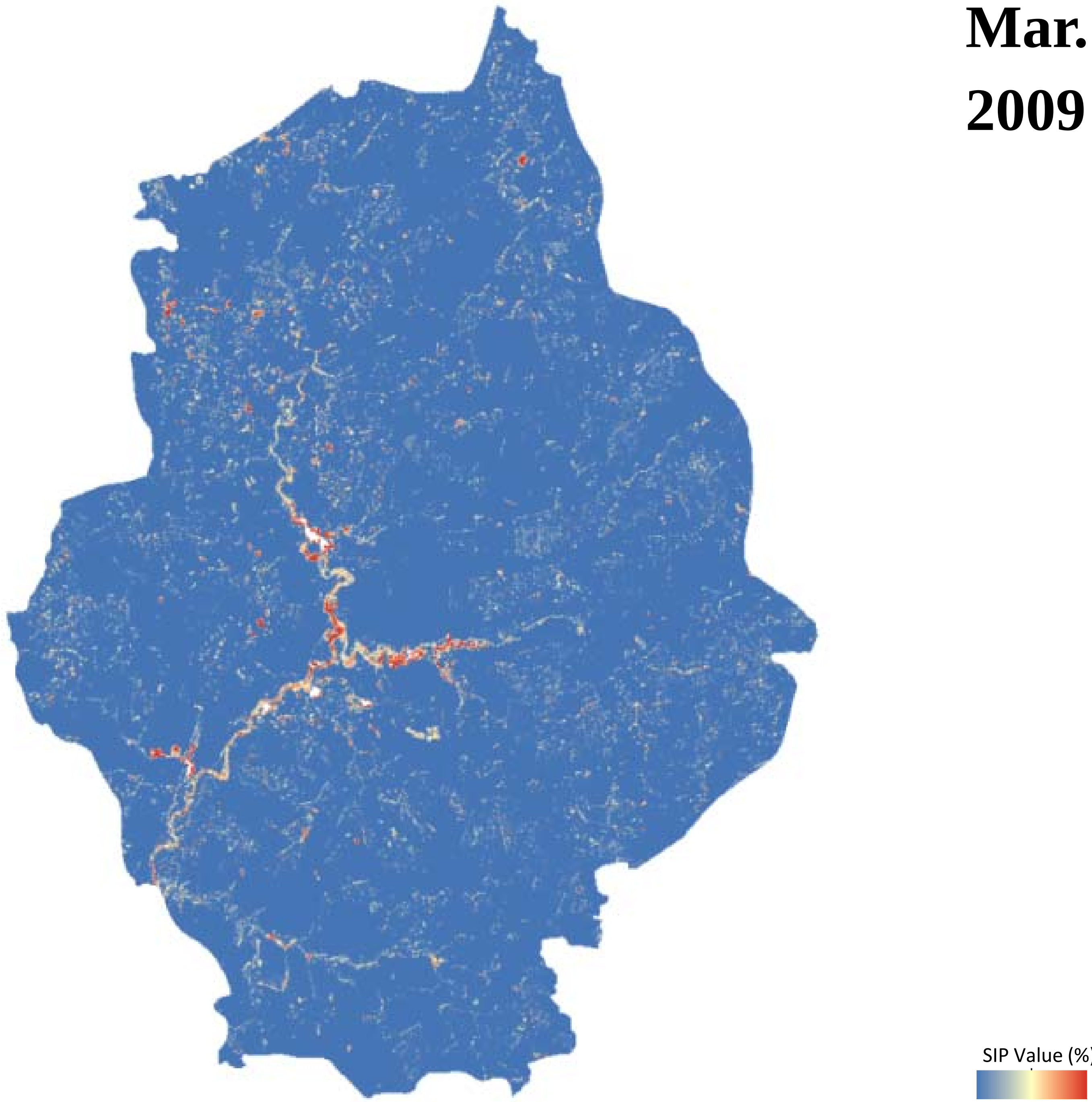


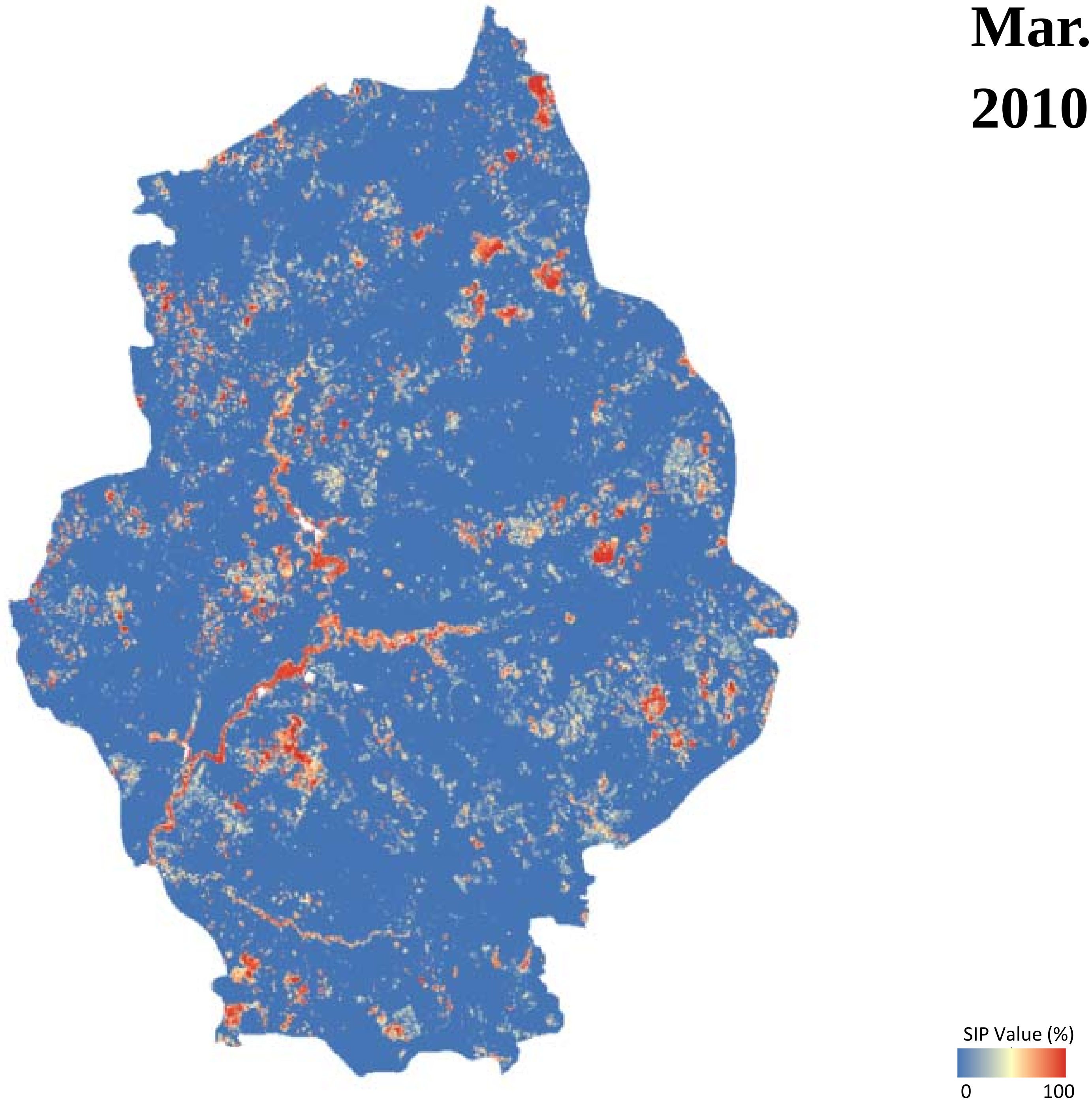
Mar. 2009



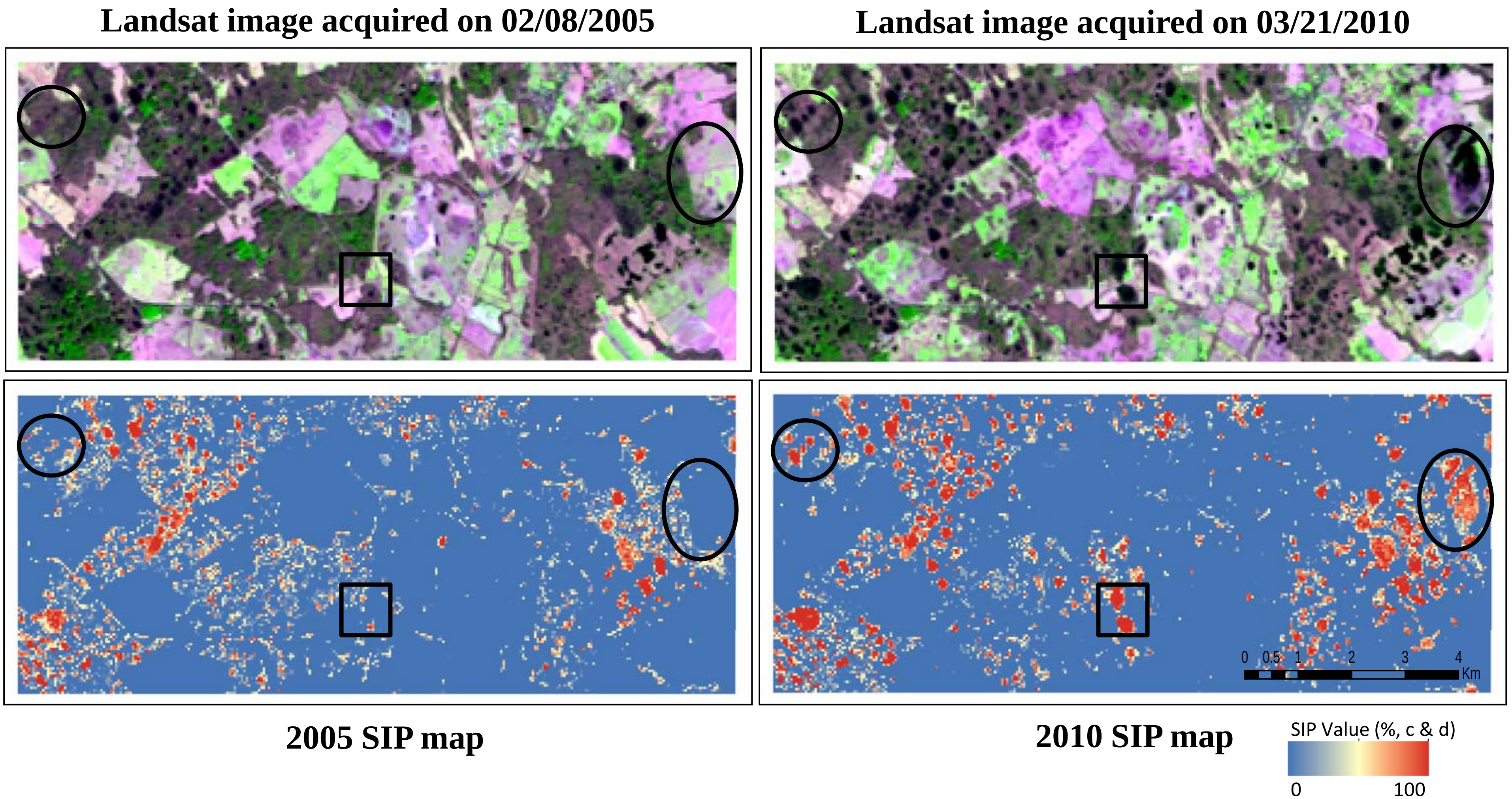
Mar. 2010

Mar. 2009




Mar.
2010
SIP Value (%)
0
100

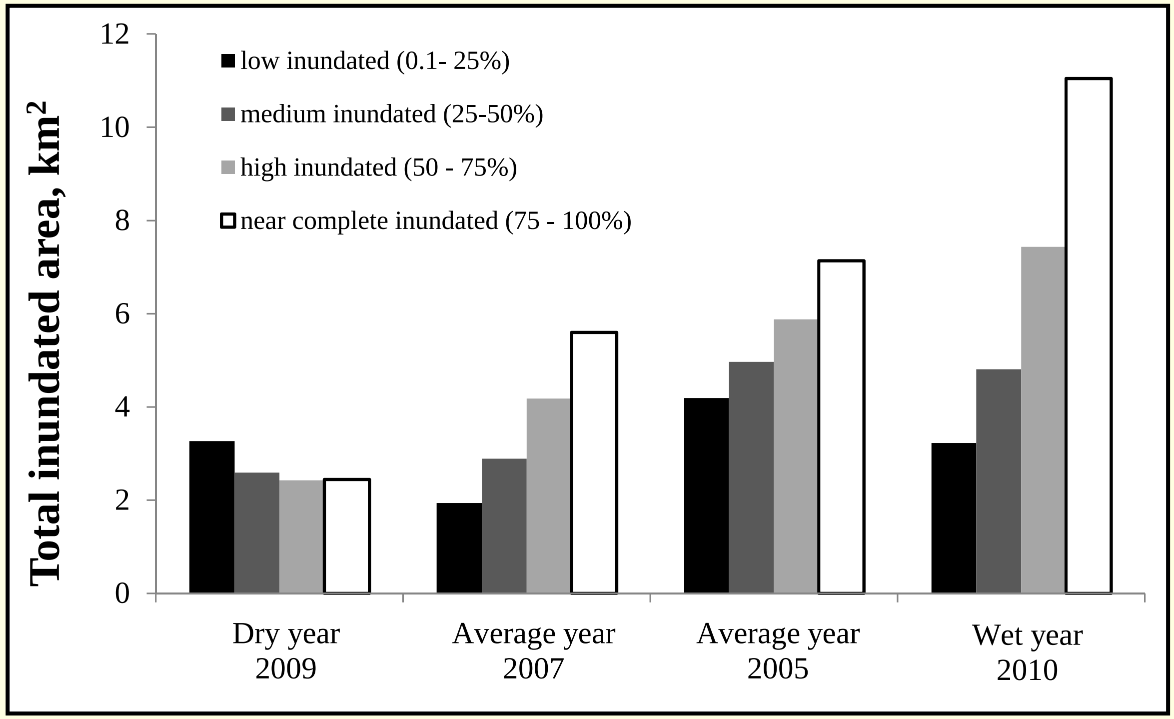
SIP Maps for 2005/10 Using 2007 Model



Inundation and Weather

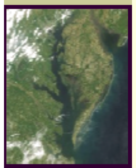
△Inudated 0-25%	Class 1: $R^2 = 0.00$
×Inundated 25 - 50%	Class2: $R^2 = 0.59$
○Inundated 50-75%	Class3: $R^2 = 0.93$
●Inundated 75-100%	Class4: $R^2 = 0.99$

Relationship between Inundation and Palmer Drought Severity



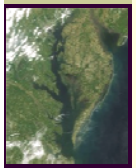
Inundated Area per Inundation Class for Years Studied

Note: Area with higher levels of inundation are very well correlated with weather while areas with smaller amounts of inundation are not well correlated with weather.



Conclusions

- The importance of this study is linked to the 40+ year continuous record of Landsat images, which can now be used to quantify long-term trends in wetland hydrology.
- The technique developed as part of this study will enhance our ability to detect influences of climate and land use change on wetland ecosystems and the services which they provide, and develop adaptation strategies.



Acknowledgement

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Thank you!

Additional details can be found in:
Huang, C., Y. Peng, M. Lang, I.-Y. Yeo, G. McCarty, 2014. Wetland inundation mapping and change monitoring using Landsat and airborne LiDAR data. *RSE,231-242.*