Mapping Wetland Inundation Dynamics Using Multi-Source Satellite Data

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Webinar
Association of State Wetland Managers
Wetland Mapping Consortium (WMC)
July 19, 2017

UNIVERSITY OF MARYLAND

Colleagues

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- US-FWS/NWI: **Megan Lang**
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- NASA GSFC: **Mark Carroll**

- NASA Land Cover and Land Use Change Program:
  - http://lcluc.umd.edu

Outline

1. Need for information on inundation dynamics in wetlands
2. Earth Observation: opportunities and challenges for wetland inundation mapping and monitoring
3. New algorithms for detecting wetland inundation using open satellite data
4. Conclusions and future research

landsat.gsfc.nasa.gov

palmerlab.umd.edu

sofia.usgs.gov

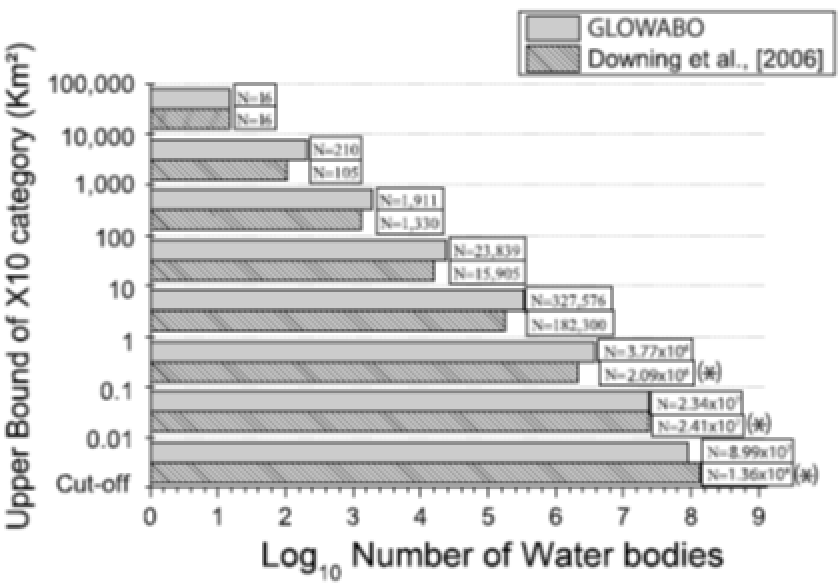
1. Inundation dynamics

a) Carbon cycling
b) Hydrologic connectivity
c) Mapping & inventorying wetlands

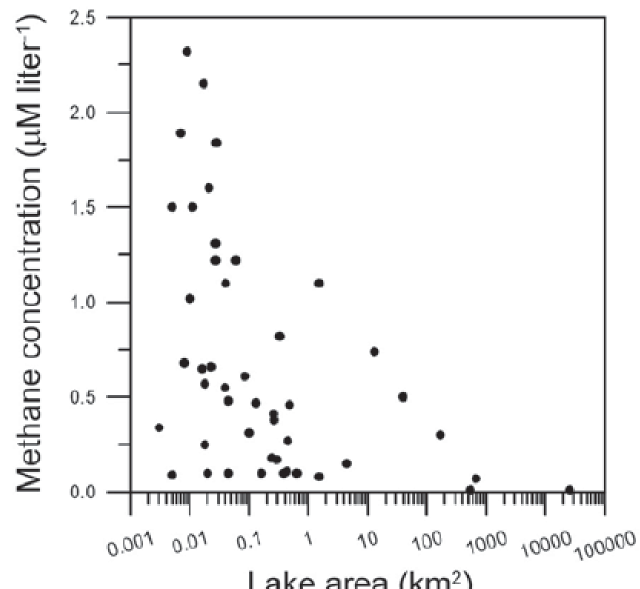
Image: https://phys.org/news/2013-11-subarctic-lakes-years.html

a) Carbon cycling

- High uncertainty in carbon balance due to wetlands (especially methane)
- Role of small water bodies disproportionately large
    - emissions, storage (burial), etc.
- Inundation dynamics are an important determinant of carbon dynamics
- Alterations to hydrologic regime linked to carbon emissions



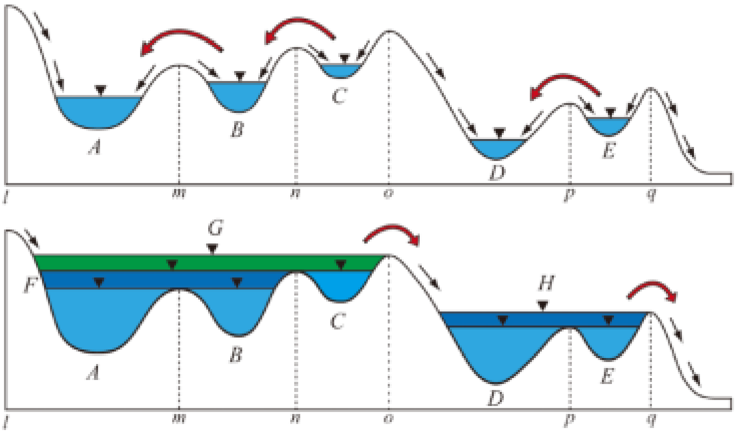
Verpoorter et al. (2012), *Geophysical Research Letters*



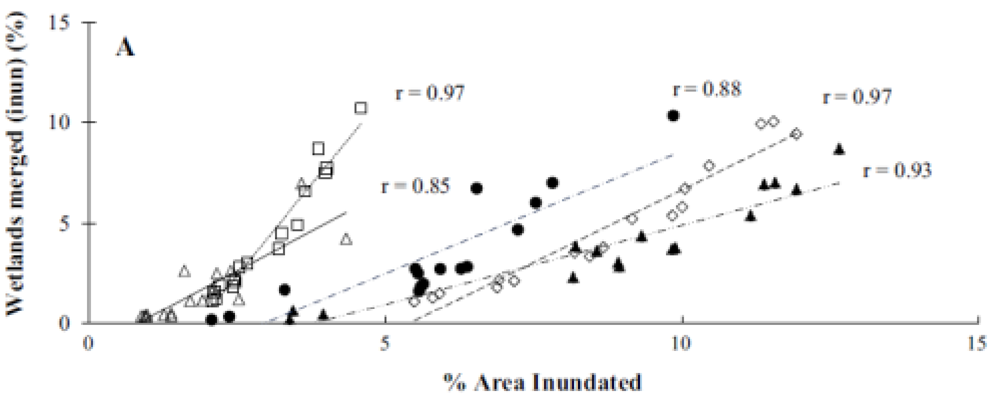
Downing (2010), *Limnetica*

b) Hydrologic Connectivity

- Governs the transport of matter, energy and organisms through watersheds (Freeman et al., 2007)
- Many wetlands exhibit *seasonal* or *intermittent* connectivity – complex dynamics



Wu and Lane (2017), *Hydrol. Earth Syst. Sci.*



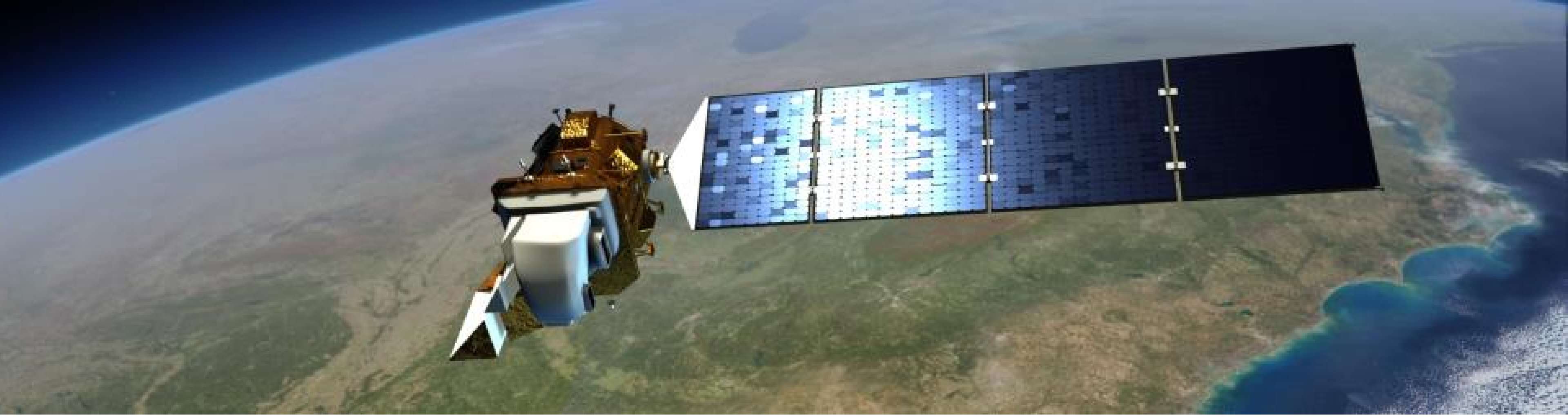
Vanderhoof, Alexander and Todd (2015) *Landsc. Ecol.*

c) Wetland inventories and observation systems

- US-FWS National Wetlands Inventory
  - https://www.fws.gov/wetlands/
- Canadian Wetlands Inventory
  - http://www.ducks.ca/initiatives/canadian-wetland-inventory/
- Global Wetland Observing System (GWOS)
  - http://geobon.org/global-wetlands-observing-system-gwos/

Challenges:

- expensive to produce/maintain inventories
- often static and/or outdated

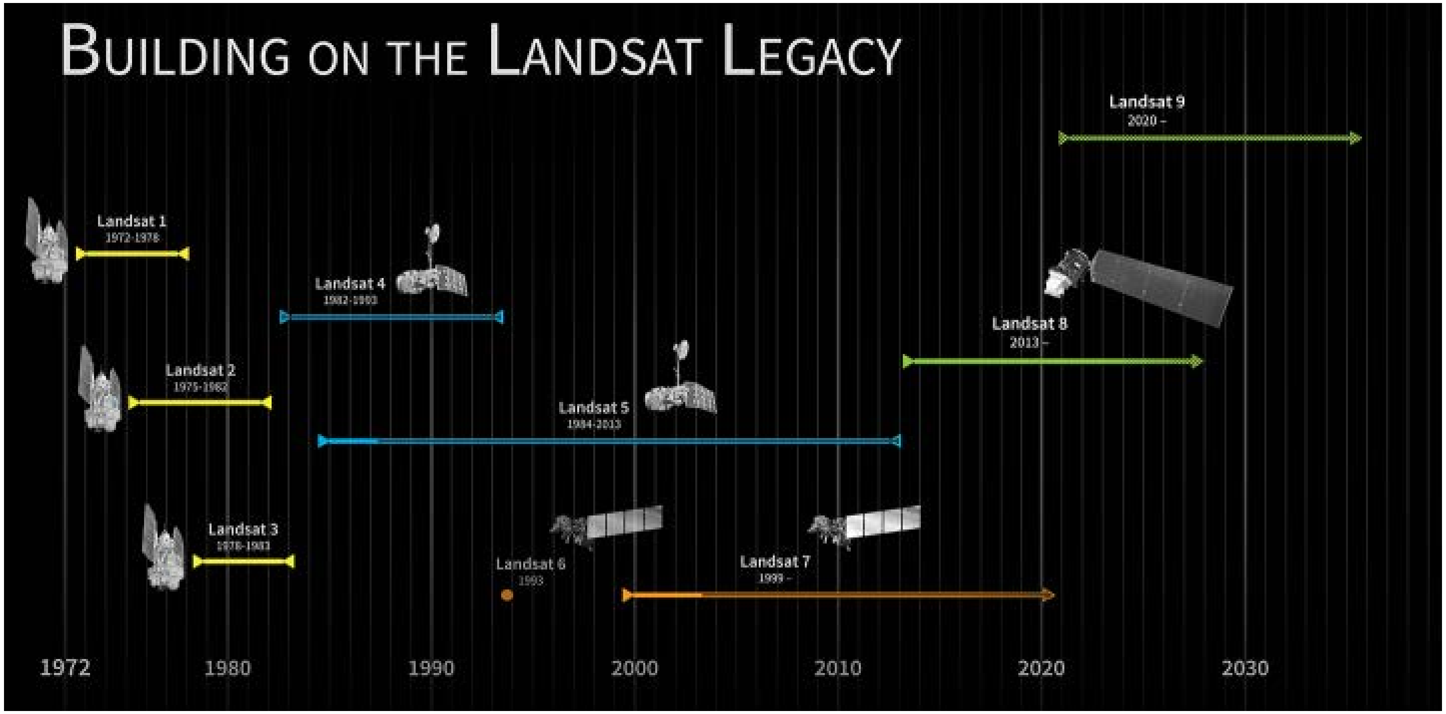


2. Earth Observation

Opportunities for mapping wetlands and tracking inundation

Image: https://www.nasa.gov/content/goddard/nasa-usgs-landsat-8-satellite-celebrates-first-year-of-success/

Landsat



- Medium resolution optical data (30m)
- Landsat 1-8 represent the longest continuous Earth Observation record
- Opening of archive in 2008 → massive innovation → product development
- Landsat-7 (with SLC-off gaps), Landsat-8 currently in operation
- Landsat-9 planned for launch in 2020
- Landsat-10 aimed for launch in 2027

Wulder et al. (2012), *Remote Sens. Environ.*

Sentinel-2

- Launch of ESA/Copernicus Sentinel-2A and -2B in 2015, 2017 respectively
- 5-day joint revisit time at full operation
- (Approximately) same non-thermal bands as Landsat; no thermal bands; additional red-edge bands
- Multi-resolution (10m, 20m, 60m)

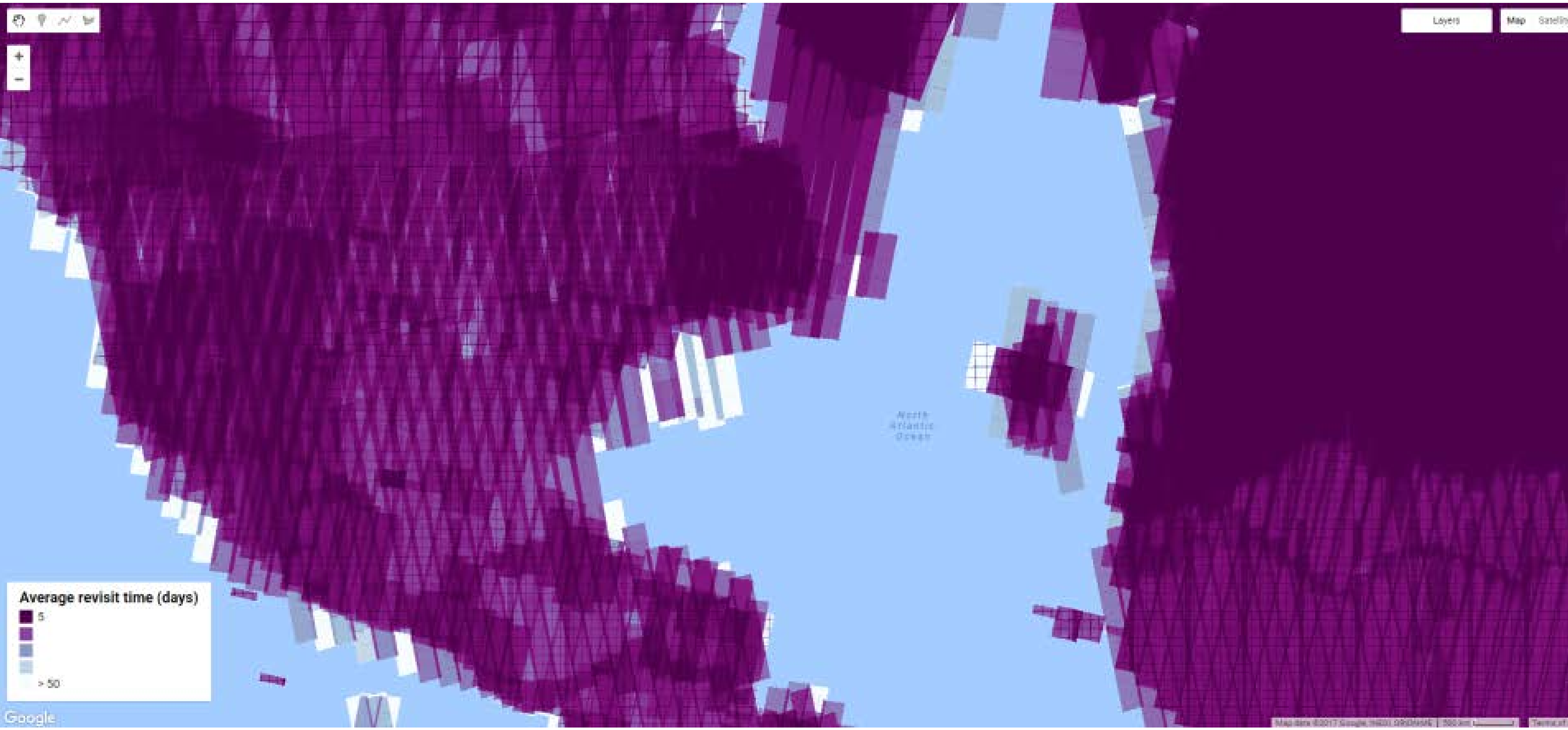
esa

Copernicus
The European Earth Observation Programme

Sentinel-1

- Launch of ESA/Copernicus Sentinel-1A and -1B in 2014 and 2016, respectively
- C-band Synthetic Aperture Radar (SAR) sensor
- Dual polarization (mainly VV/VH)
- At operational Interferometric Wide Swath mode, resolution approximately 20-30m
- Joint revisit time of 6 days over Europe, 12 days over North America

‘LSS’ Virtual Constellation:
Landsat / Sentinel-2 / Sentinel-1

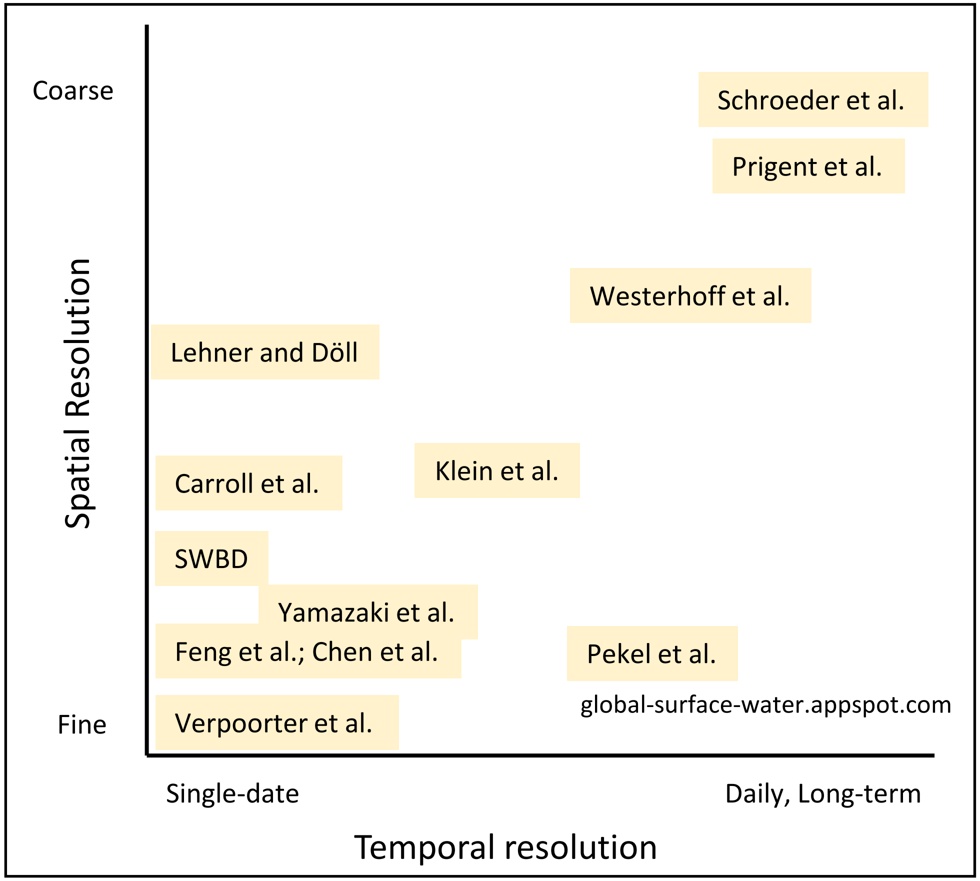


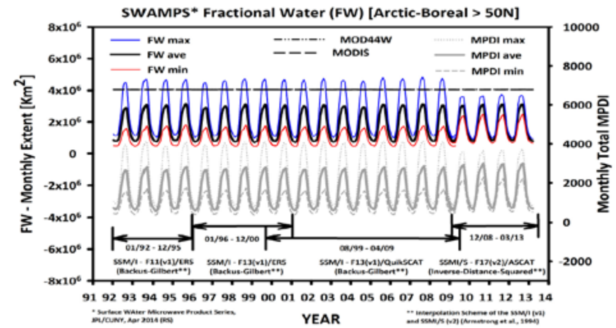
LSS Combined temporal resolution:

- Full capabilities not yet realized
- Approaching “near daily” frequency

Google Earth Engine

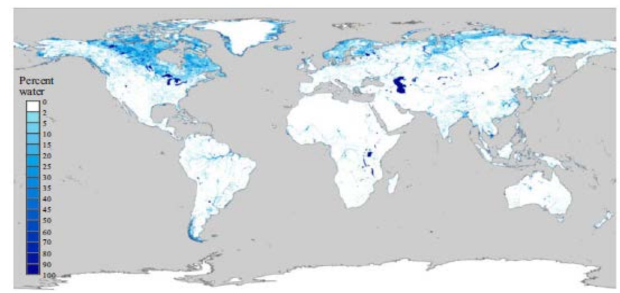
Global surface water datasets





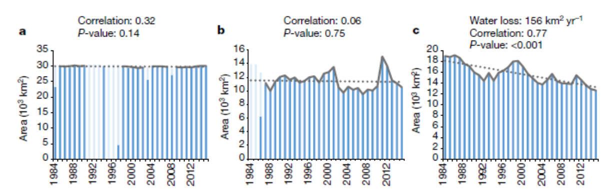
(Schroeder et al. 2015)

- Daily
- 25 km



(Feng et al. 2015)

- 2000
- 30 m



(Pekel et al. 2015)

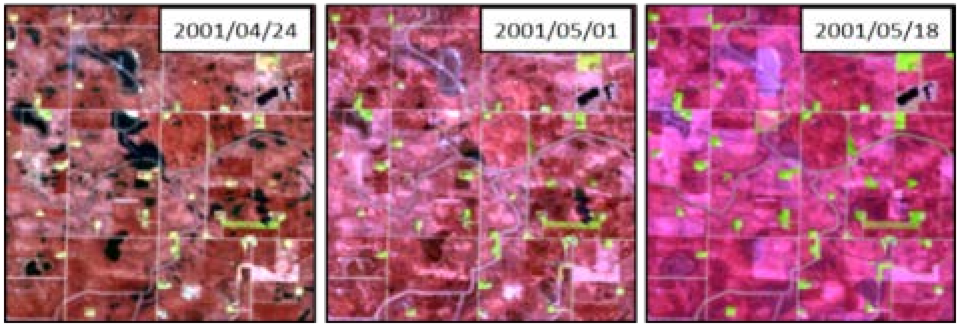
- Monthly to annual
- 30 m

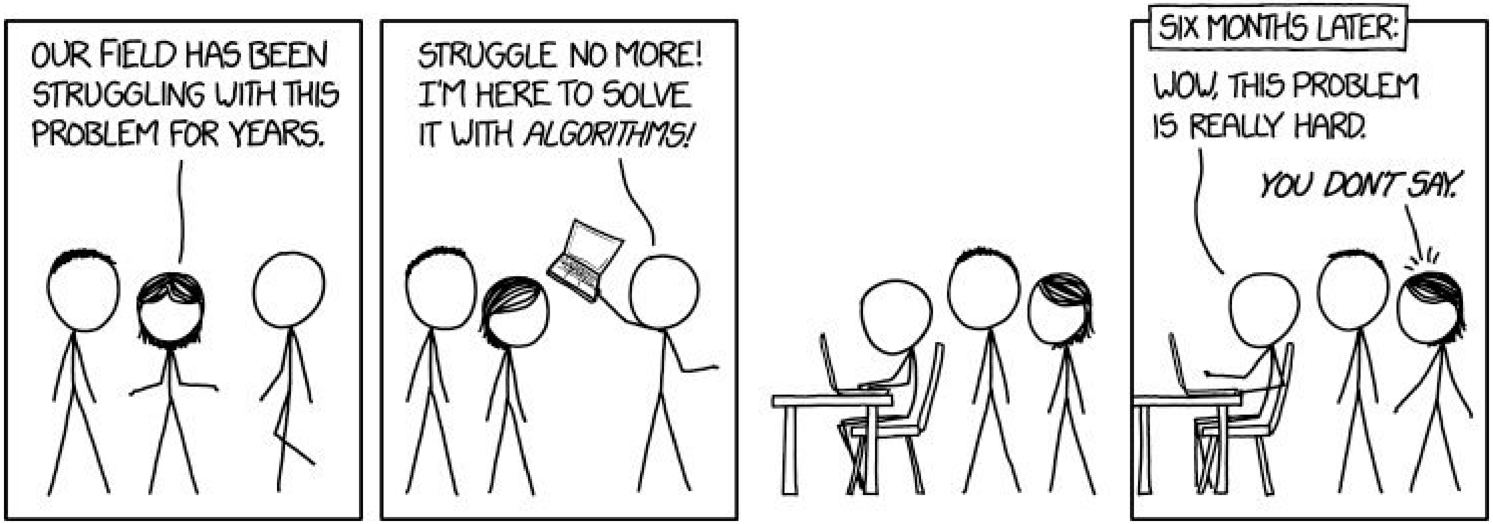
Trade-offs between spatial and temporal resolution

- High spatial resolution → "snapshot"
- High temporal resolution → coarse spatial resolution

Objectives

- There is a need for consistent inundation records to support observation-driven analyses and inventories
- Earth Observation capacities translate to opportunities for improving wetland inundation records in space and time
- Develop fully automated and scalable algorithms using to track wetland inundation using **optical** and **synthetic aperture radar** (SAR) remote sensing data
- Validate algorithms using fine resolution datasets and *in situ* measurements
- Integrate optical and SAR inundation datasets to produce inundation datasets at high temporal resolution over large areas





xkcd.com

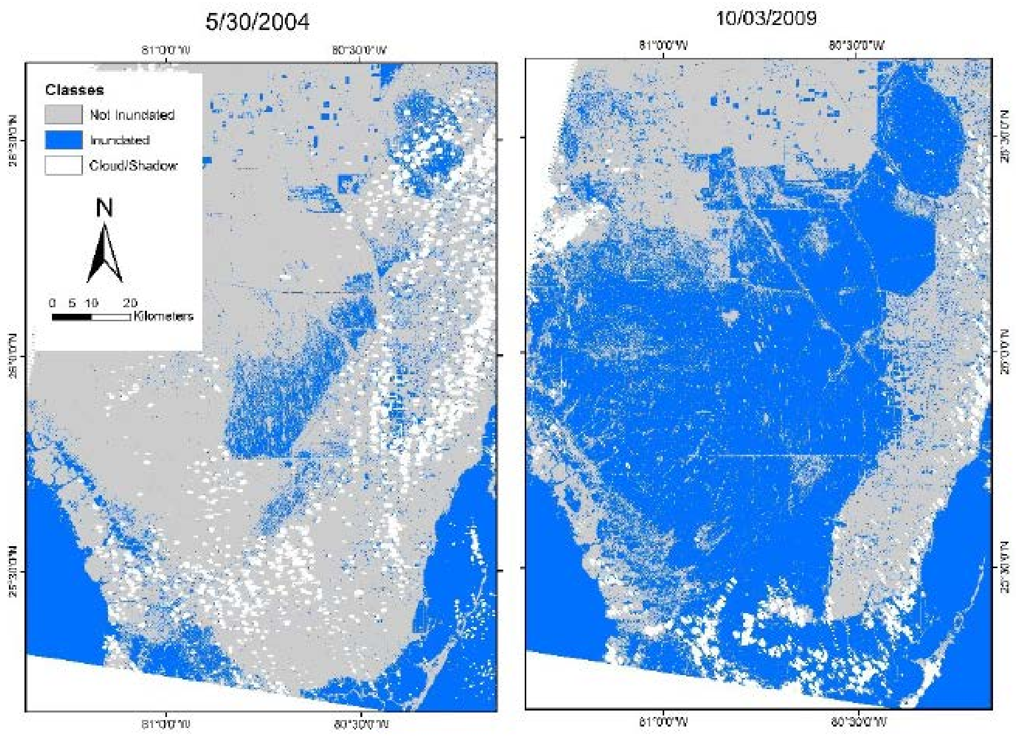
3. Inundation algorithms

Optical and SAR based inundation tracking methods & results

Optical and SAR remote sensing:
- strengths and weaknesses

- Optical:
  - Water bodies absorb strongly in the infra-red region (dark pixels)
  - Methods exist to ‘unmix’ pixels with water and emergents or water body edges
  - Challenge: frequent cloud reduces observation frequency
- Synthetic Aperture Radar (SAR):
  - Very low backscatter over calm, open water
  - Can penetrate clouds – all-season imagery
  - Can sense below canopies of some forested wetlands under certain conditions
  - Challenge: complex backscatter signatures over some wetland types

Dynamic Surface Water Extent

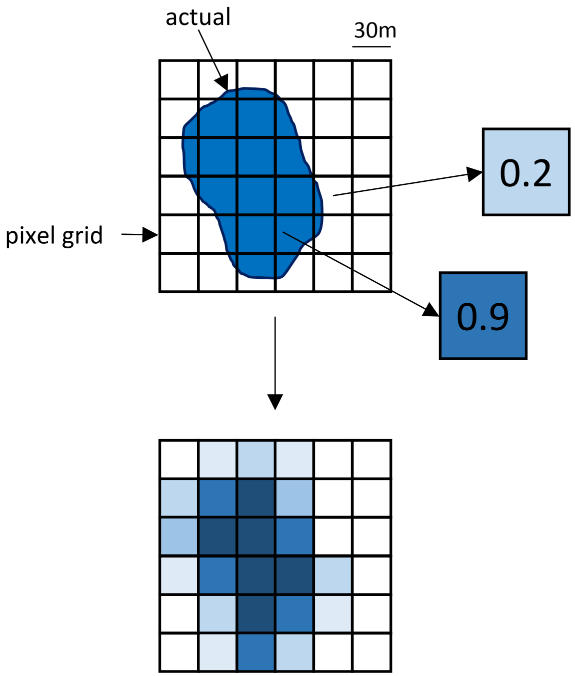


Jones (2015), *Remote Sensing*

https://remotesensing.usgs.gov/ecv/SWE_overview.php

- USGS Essential Climate Variable (ECV)
- Unsupervised algorithm based on series of decision rules
- Leverages several published water/moisture indices
- Basic classes:
  - Land
  - Water (high confidence)
  - Water (moderate confidence)
  - Partial water

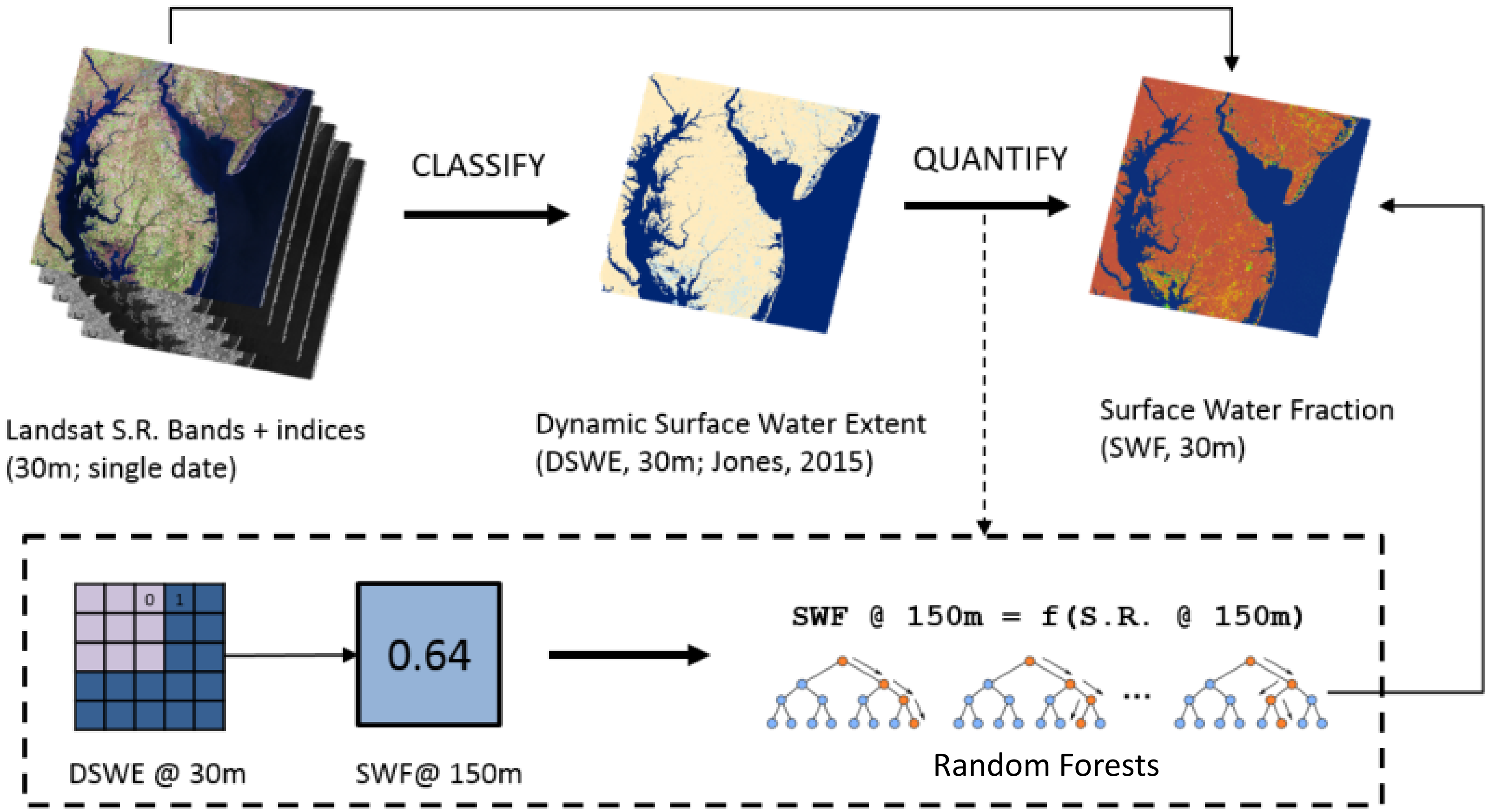
Sub-pixel water fraction (SWF)



Why sub-pixel water fraction (SWF)?

- Better representation of water body edges
- Resolve inundated features below pixel size
- Detect inundation in presence of other reflectance targets (flooded vegetation, soils, etc.)

“Self-trained” SWF regression



DeVries et al., 2017, *Remote Sensing*. In revision.
Rover et al. (2010), *IJRS*

Algorithm Assessment

Saskatchewan Prairie Pothole Region
- Small depressional wetlands
- GPS-based surveys (2005)

Delmarva Peninsula
- Forested depressional wetlands
- Gridded LiDAR Intensity (2007/9)

Everglades
- Wetlands with emergents, forested
- Water depth gages (1980's – present)

landsat.gsfc.nasa.gov

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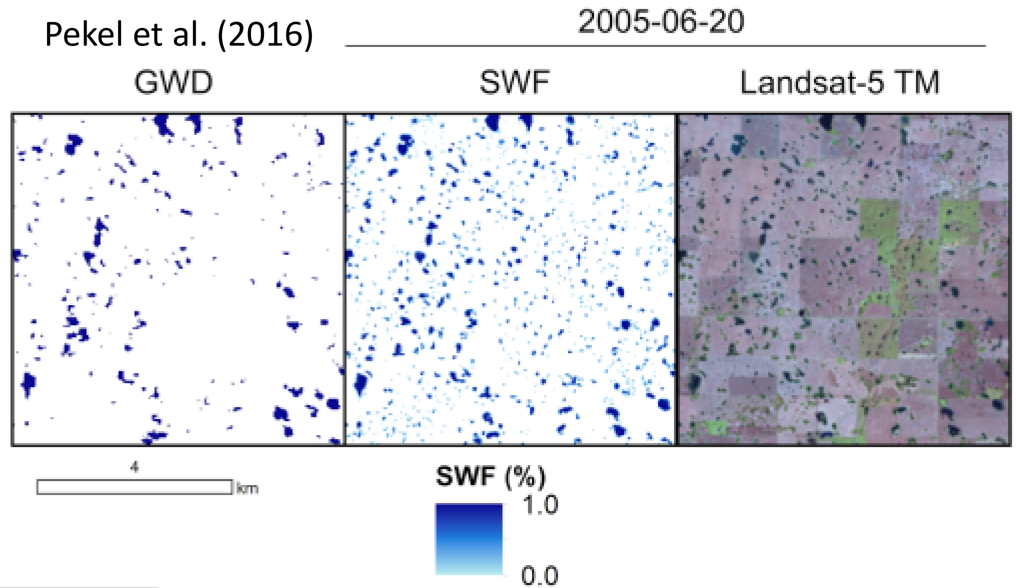
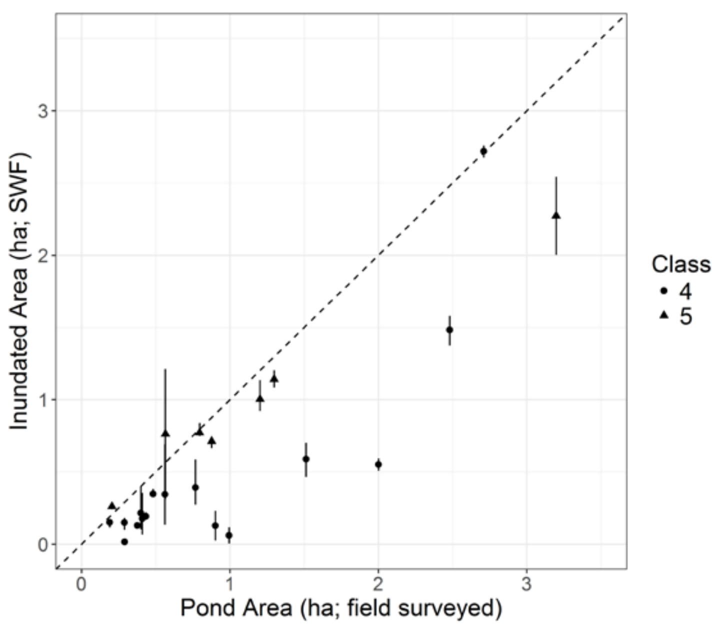
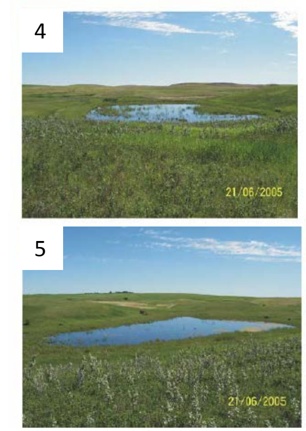
sofia.usgs.gov

Prairie Pothole Region

Image: landsat.gsfc.nasa.gov





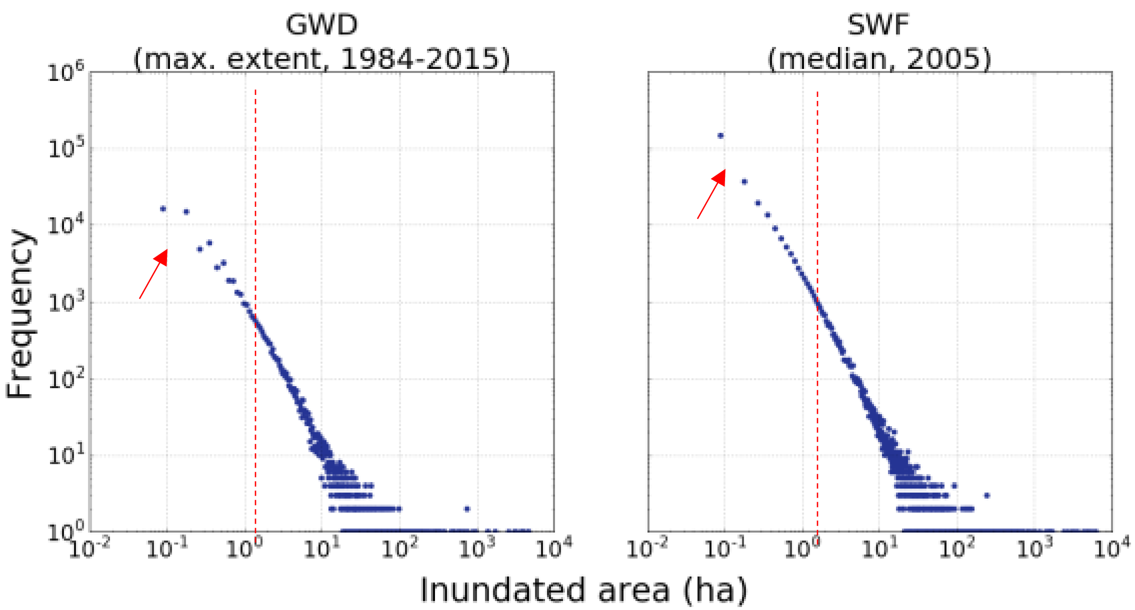


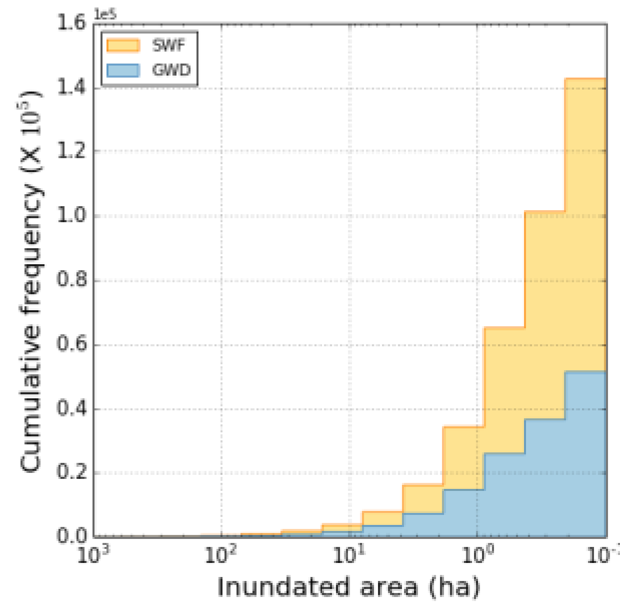
Photos:
Stephen Carlyle (2006)

DeVries et al., 2017, *Remote Sensing*. In revision.

Prairie Pothole Region

Sub-pixel inundation mapping captures 4.5 times more sub-hectare inundated wetlands than the GWD product

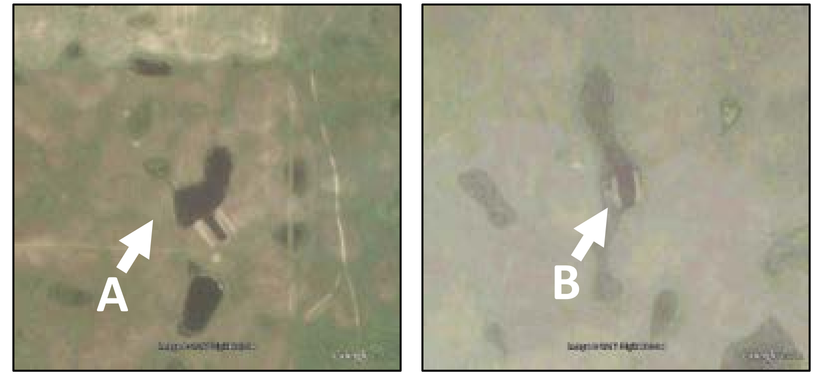


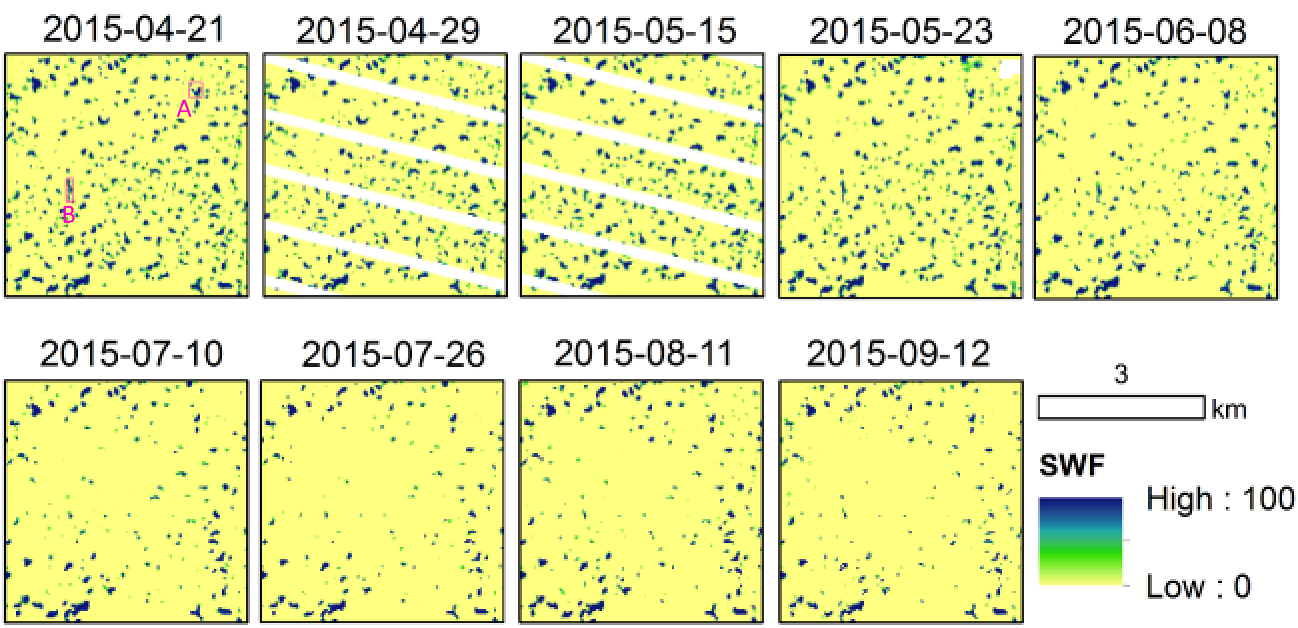


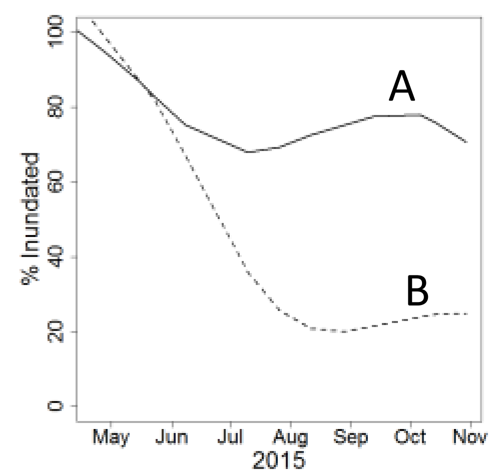
DeVries et al., 2017, *Remote Sensing*. In revision.

Pekel et al., (2016) *Nature*

Inundation dynamics in PPR

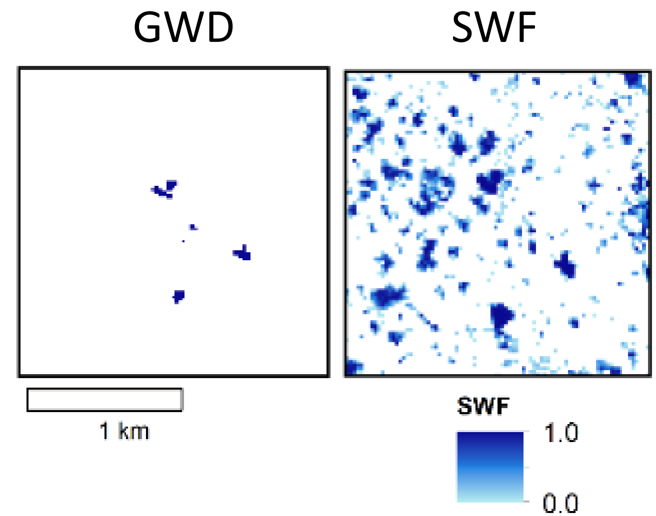


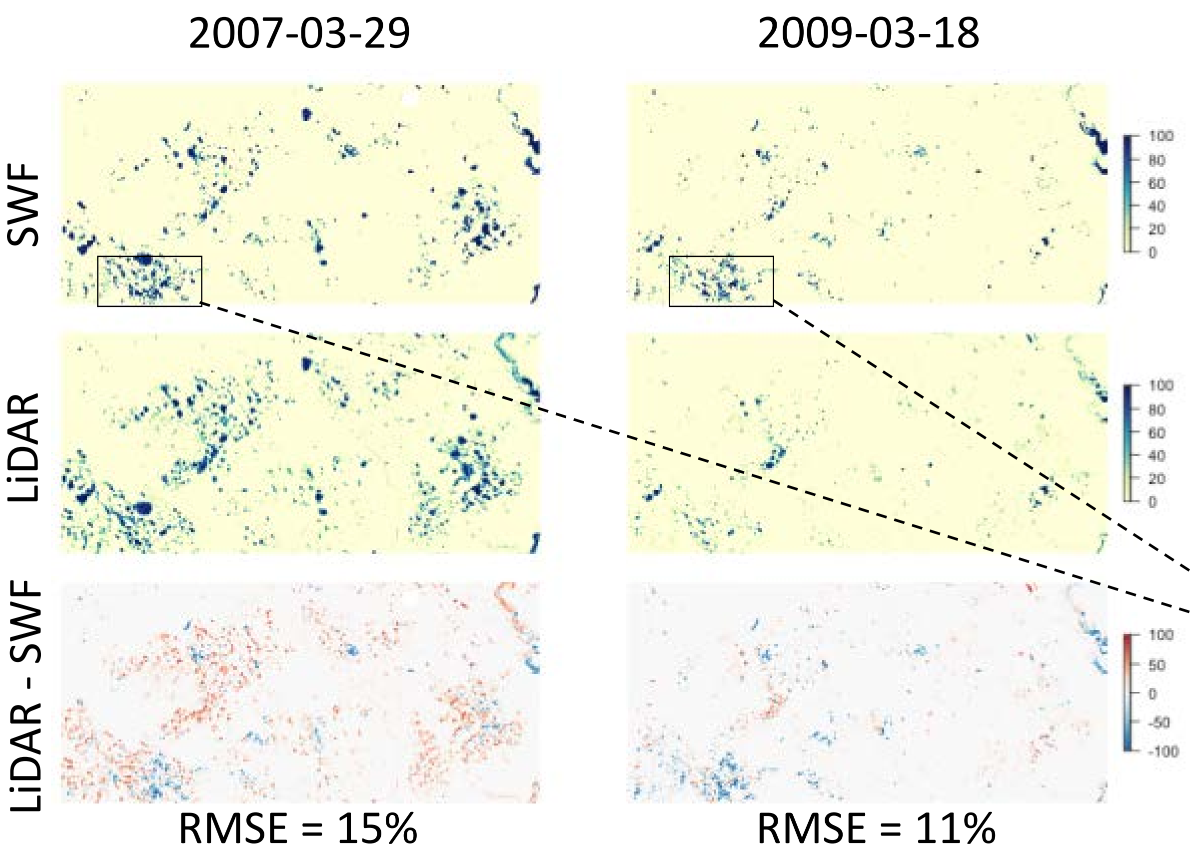




Delmarva Peninsula

Pekel et al., (2016) *Nature*



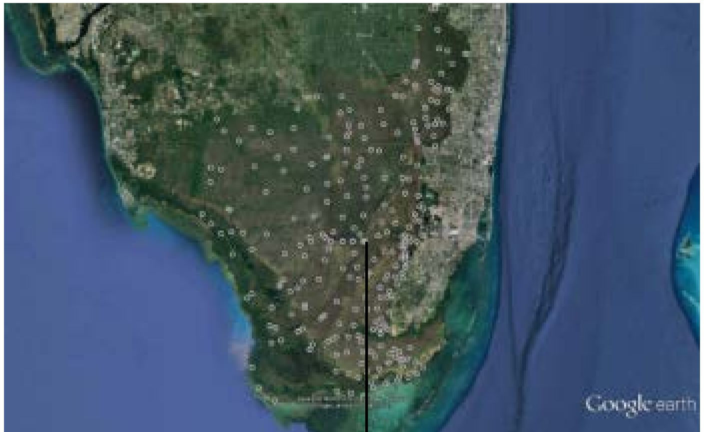


04/2008

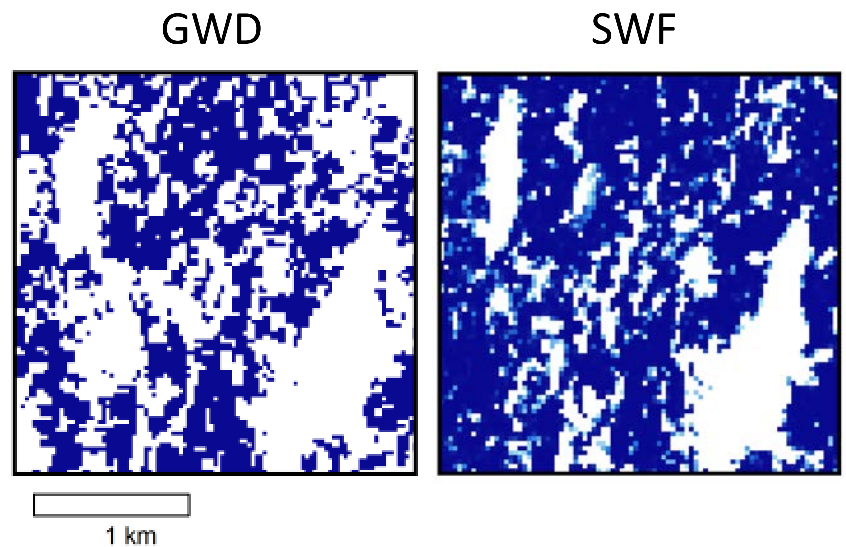
DeVries et al., 2017, *Remote Sensing*. In revision.

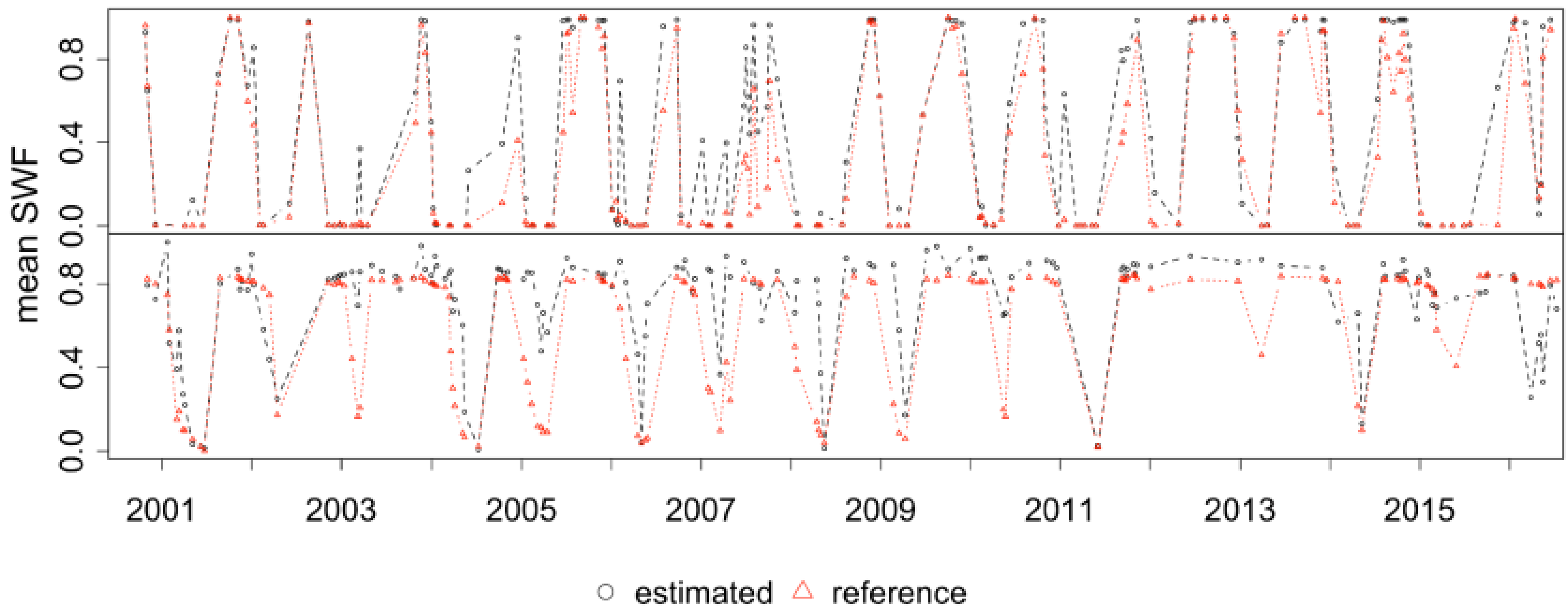
Everglades

https://sofia.usgs.gov/eden/

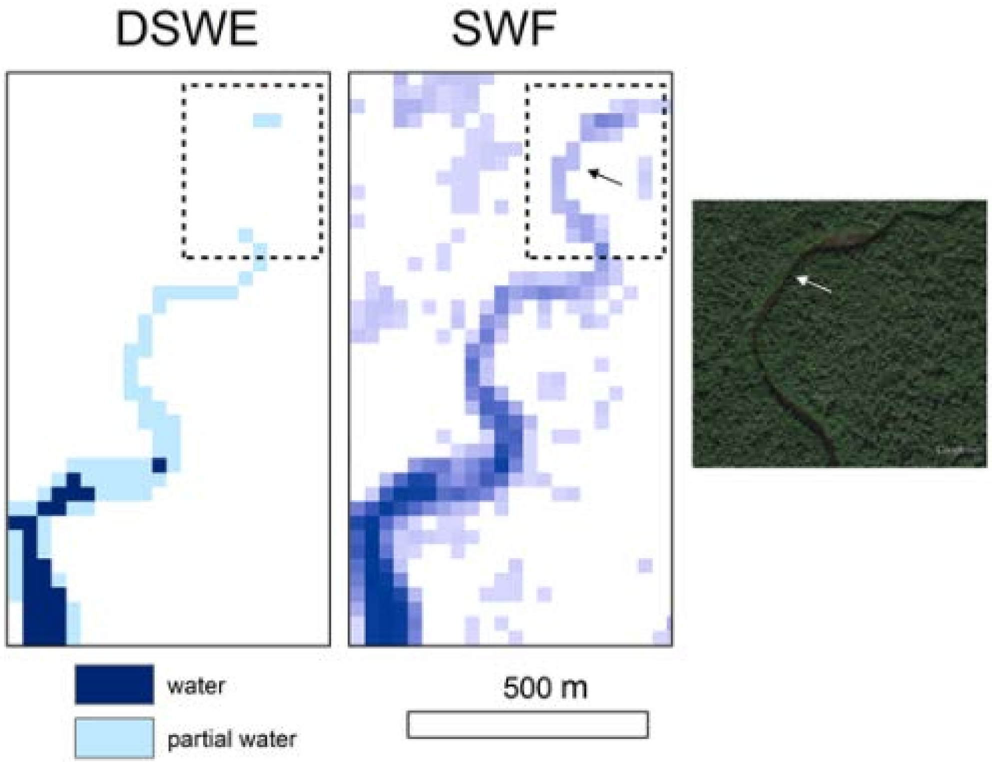


Pekel et al., (2016) *Nature*





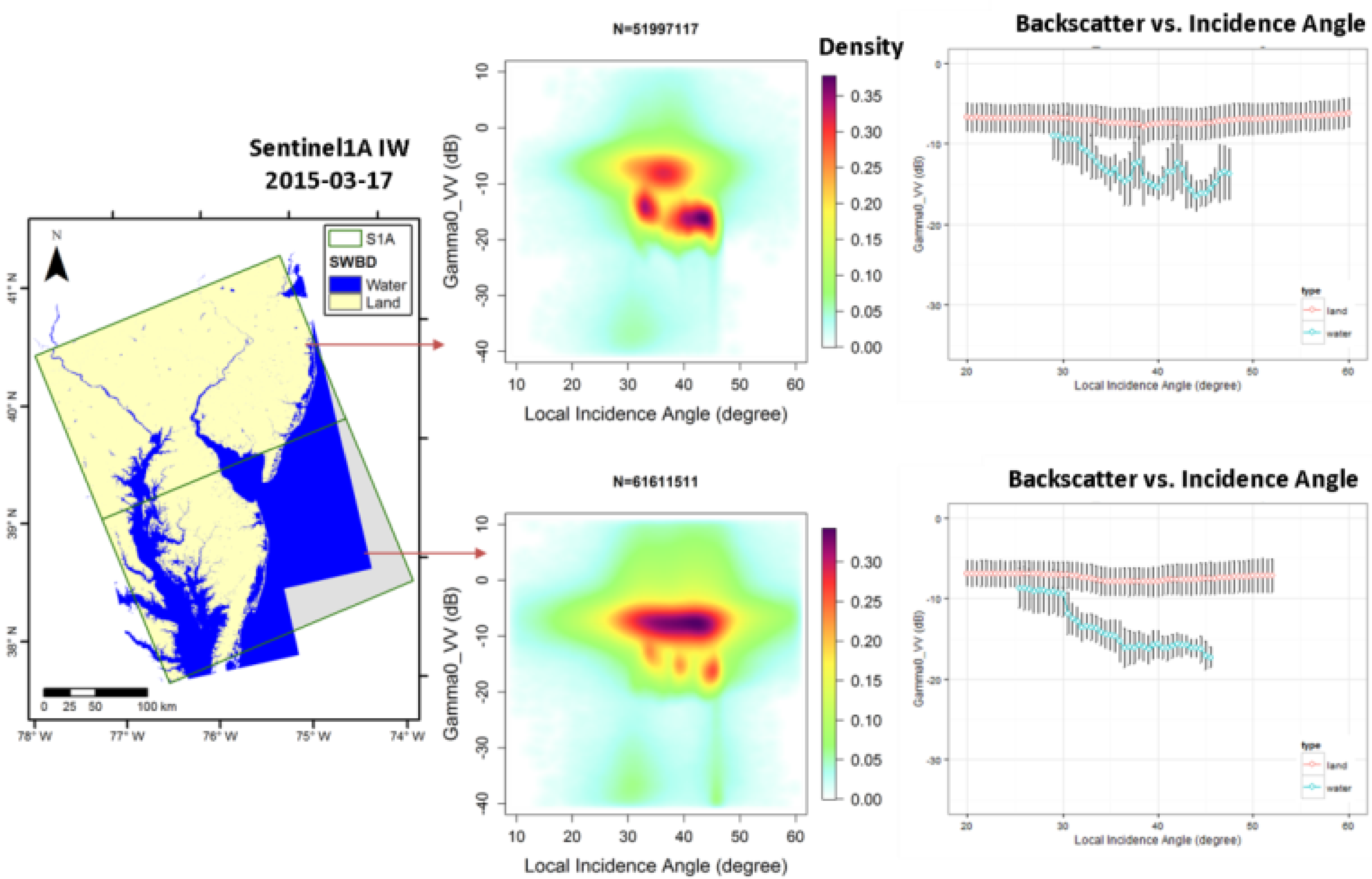
DeVries et al., 2017, *Remote Sensing*. In revision.



- Sub-pixel representation of surface inundation allows for resolution of inundated features well below the pixel size (30m)
- Implications for measuring hydrologic connectivity?

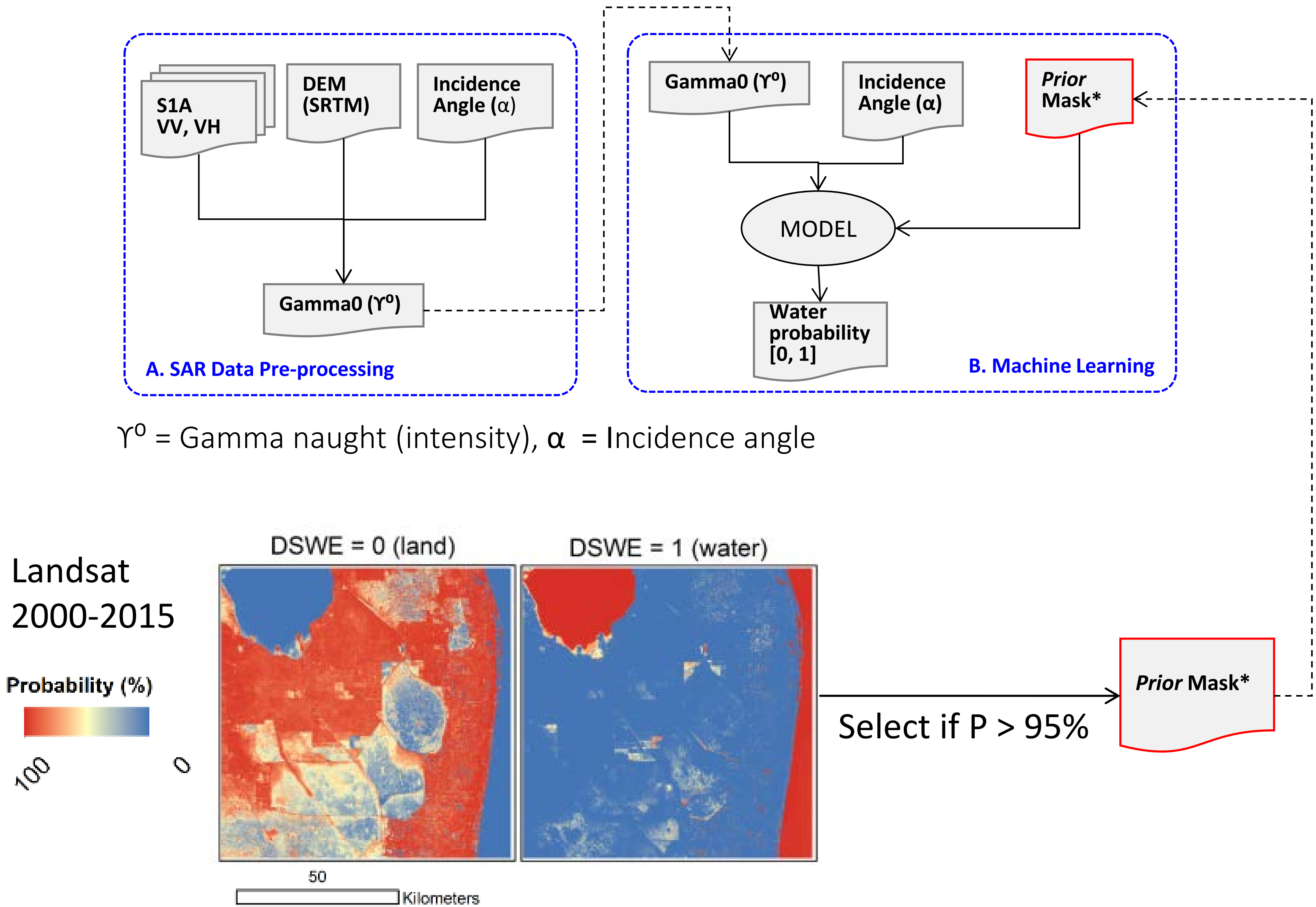
DeVries et al., 2017, *Remote Sensing*. In revision.

SAR-based water classification

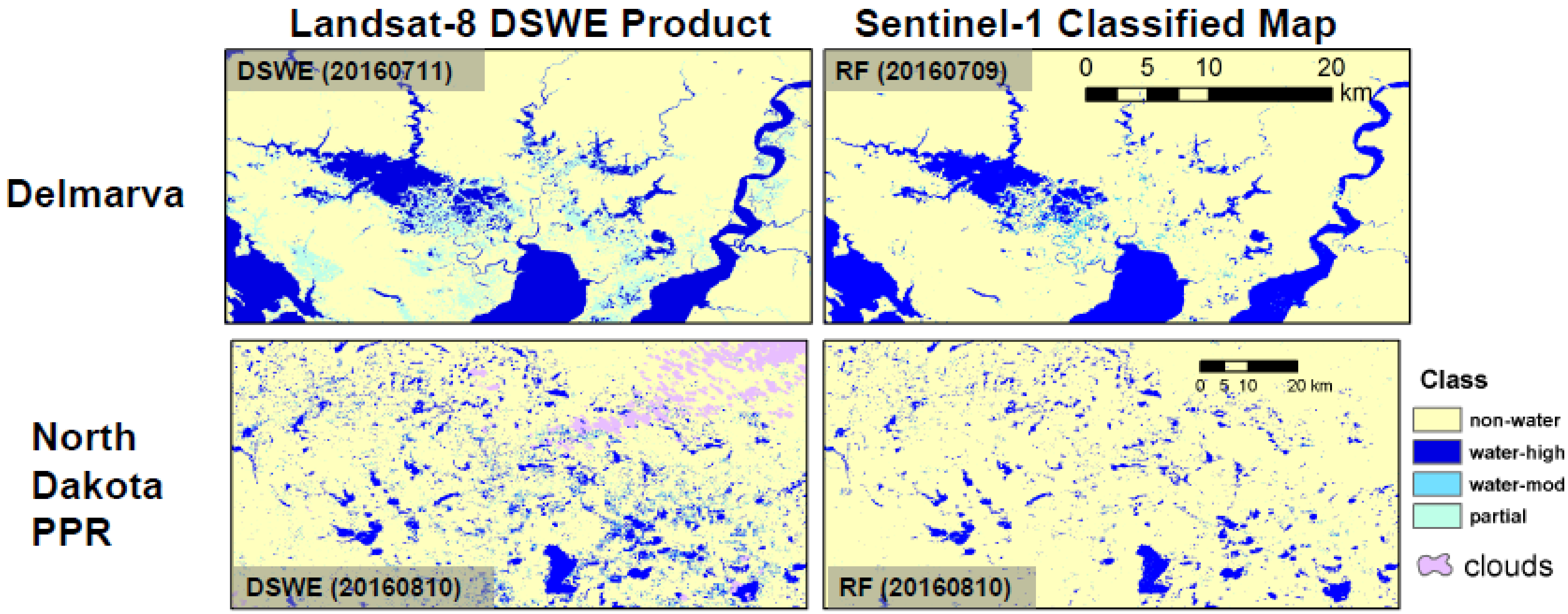


Huang et al., *in preparation*

Automated inundation mapping with Sentinel-1



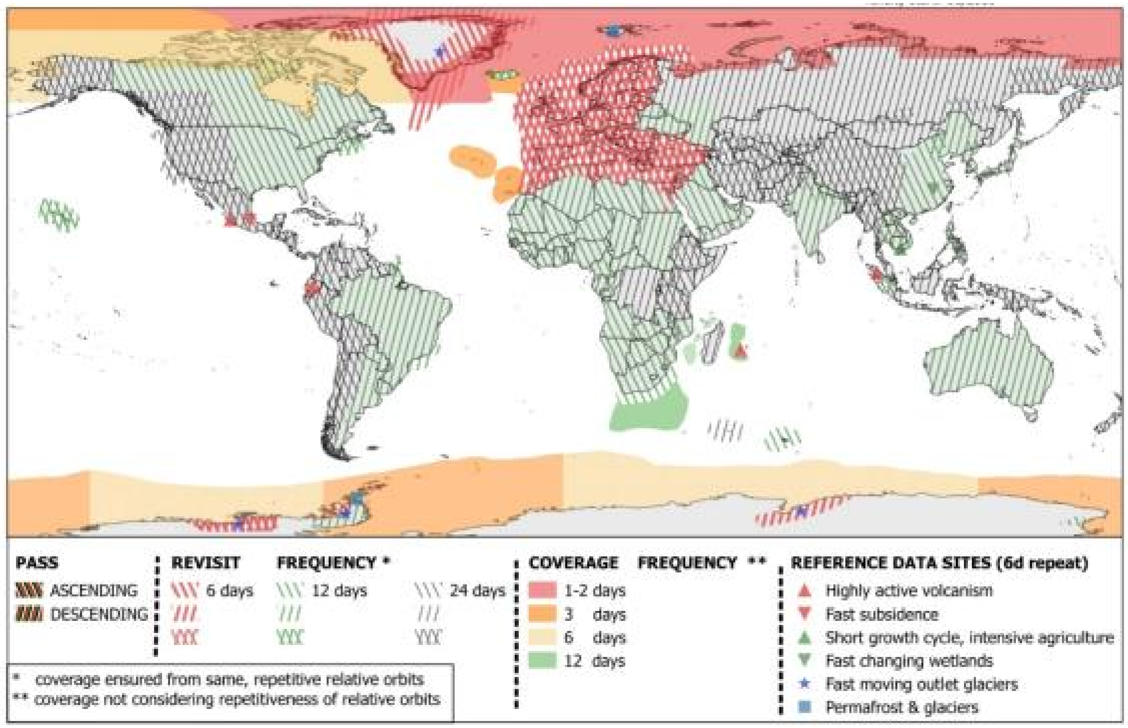
Huang et al., *in preparation*



- High accuracies (95%) over North Dakota PPR when compared with NAIP imagery
- Omission errors due to a number of factors:
  - Speckle filters → reduce effective spatial resolution
  - Complex backscatter signatures → water + emergent yields double-bounce backscatter

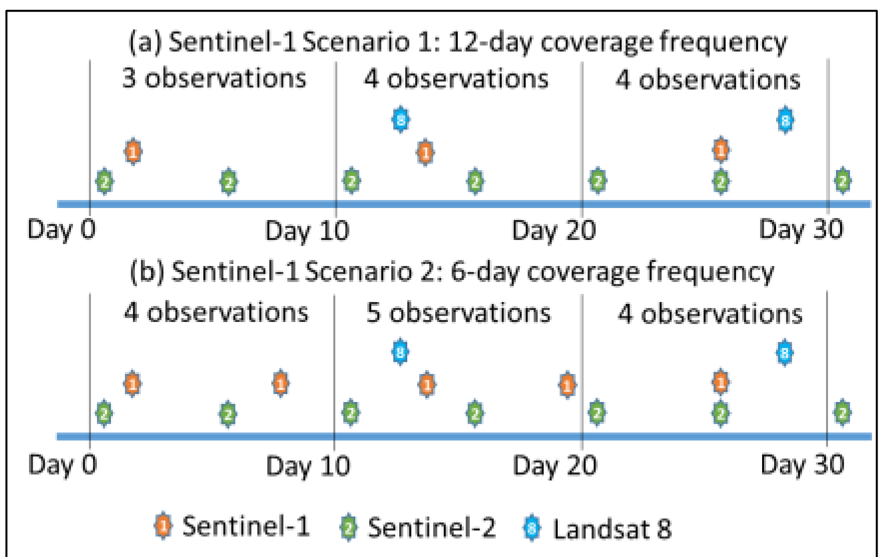
Huang et al., *in preparation*

Sentinel-1 observation scenario

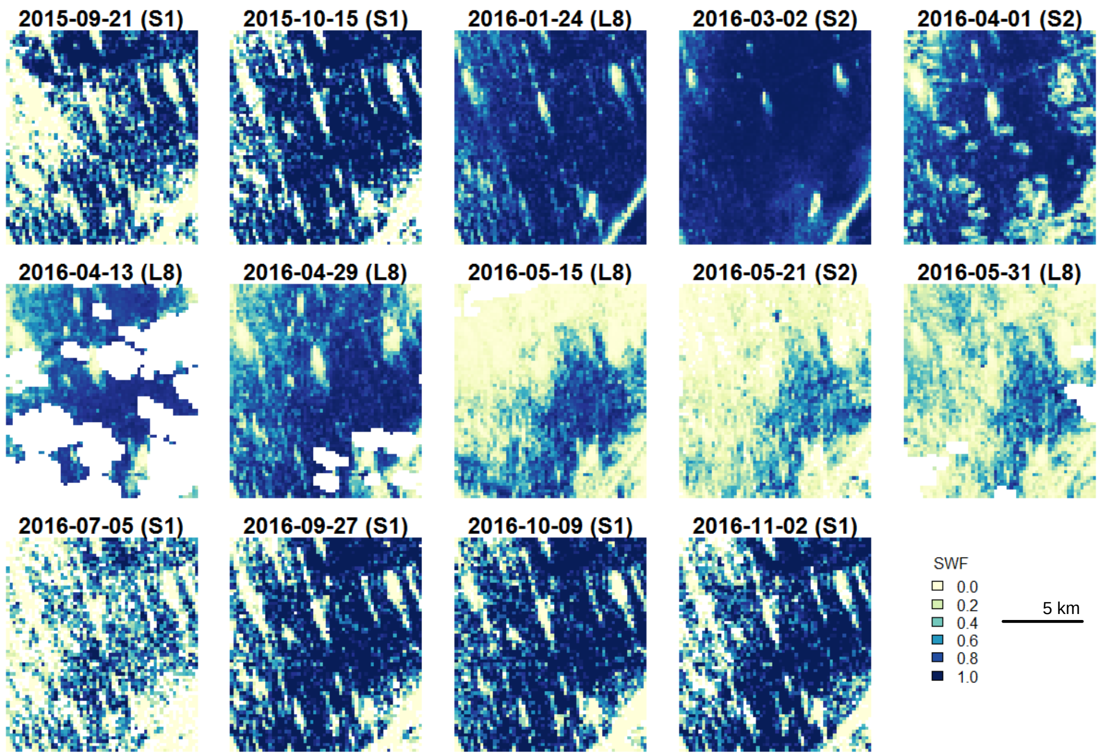


https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario

Example:
Quasi 10-day temporal composites

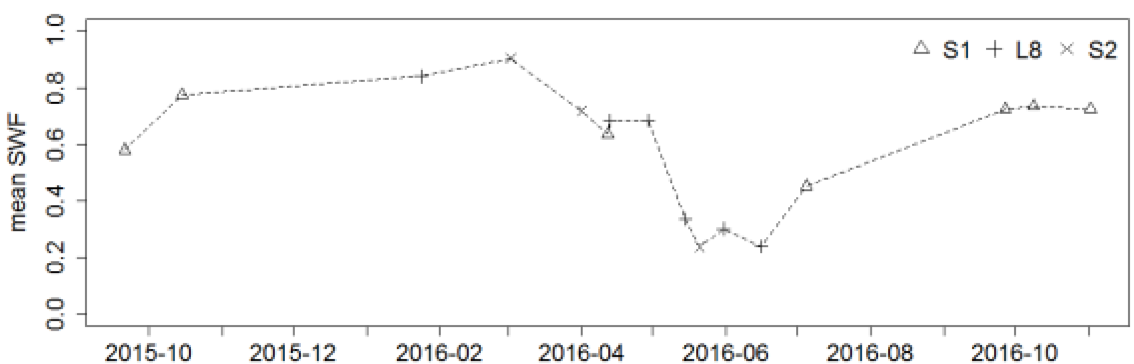


Cloud cover in optical imagery will create larger gaps – SAR needed to ensure consistency



Everglades

Inundation change within above area



Multiple sensors needed to fully capture inundation dynamics

> “A great deal of effort has been expended here, but to what end?”
>
> 36 notes

shitmyreviewerssay.tumblr.com

4. Conclusions

& Future Research

Conclusions

- Satellite data can provide a *synoptic* and *consistent* record of wetland inundation
- Open data policies → ongoing monitoring to support mapping & inventories
- Use of sub-pixel information greatly improves ability to map small wetlands
- Landsat time series useful for deriving training data for SAR algorithms
- SAR data are essential for maintaining temporally consistent records of inundation in highly dynamic ecosystems
- Complexity of SAR backscatter signal is a challenge for fusing optical and SAR data streams

Ongoing & Future Research

- Investigate new methods for consistent integration of optical and SAR inundation estimates
- Integration with other data sources
  - Topographic indices (SRTM, LiDAR, etc.) to decrease uncertainties
- Develop continental inundation products
  - Currently working on CONUS and Canada
- Application of dynamic inundation products
  - Hydrologic connectivity studies
  - Integration with hydrologic models

Thank you!

- Wenli Huang, Chengquan Huang, Megan Lang, John Jones, Irena Creed, Mark Carroll
- NASA LCLUC Program
- USGS/EROS (Landsat data)
- ESA Copernicus (Sentinel-2, Sentinel-1 data)
- USGS South Florida Information Access (SOFIA) / EDEN
- python, R & the open-source community
- Google Earth Engine

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