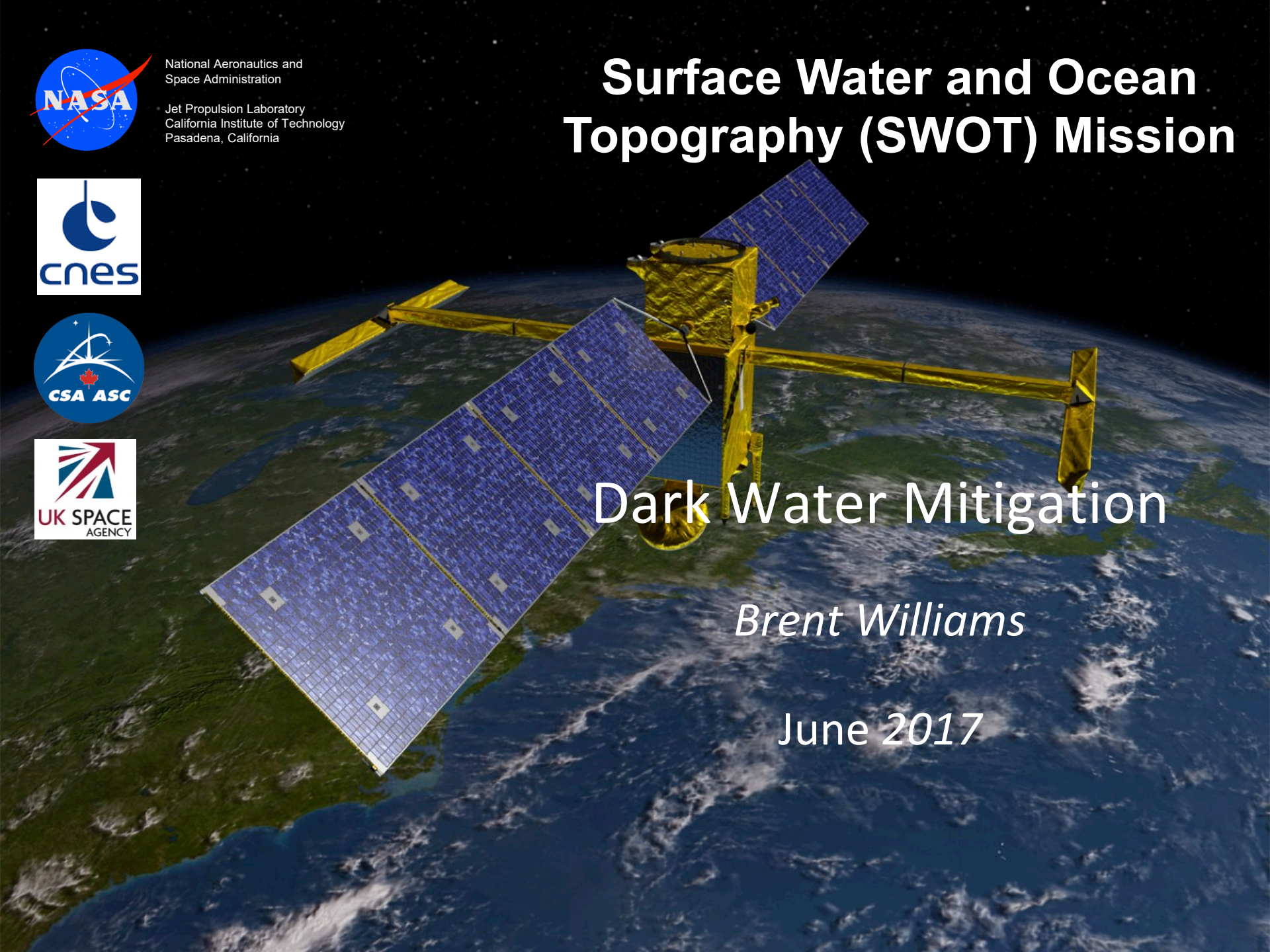
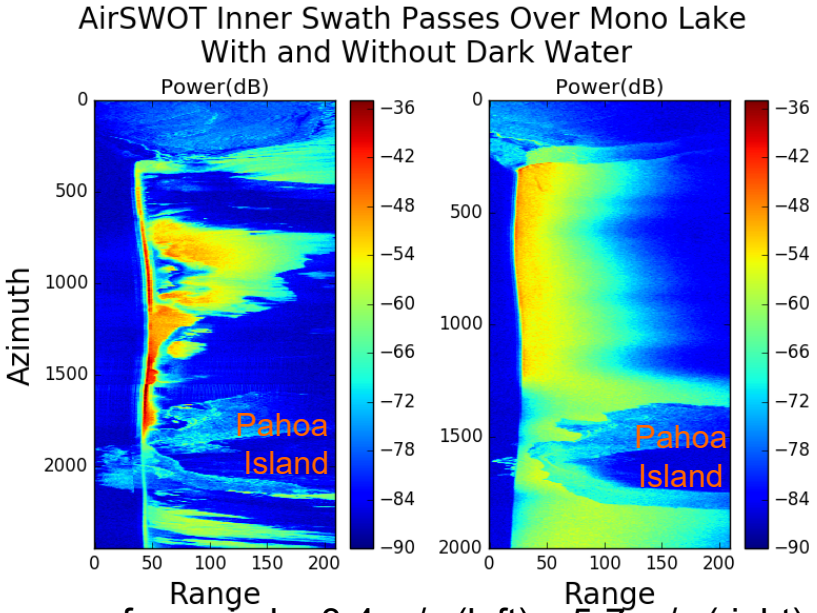
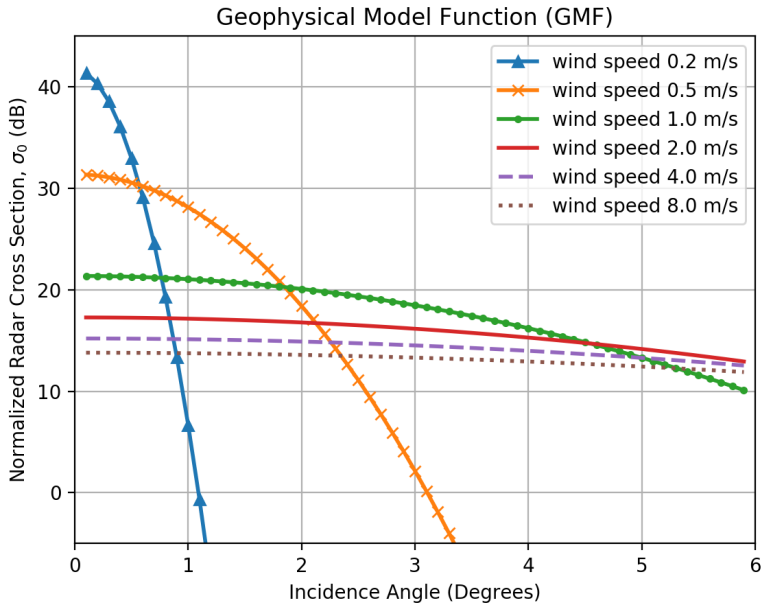

National Aeronautics and
Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
Surface Water and Ocean
Topography (SWOT) Mission
Dark Water Mitigation
Brent Williams
June 2017

Dark Water: Phenomenology

- Various causes of “Dark Water”
  - Calm water can be dark at SWOT incidence angles (~1-5 deg.)
  - Rain causes signal attenuation/dropout
  - Vegetation (persistent, though possibly seasonal, more difficult to mitigate)
  - Low SNR part of swath can cause missed detected water
- Impacts area, height/slope, and location estimates
  - Not detectable as water from power measurements only
  - Low SNR => height/slope/location estimates very noisy
- Detecting dark water pixels can ameliorate
  - Area estimates—by extending undetected water to that expected by a prior mask
  - Heights and slopes—more noisy but heights generally unbiased (if correctly unwrapped)



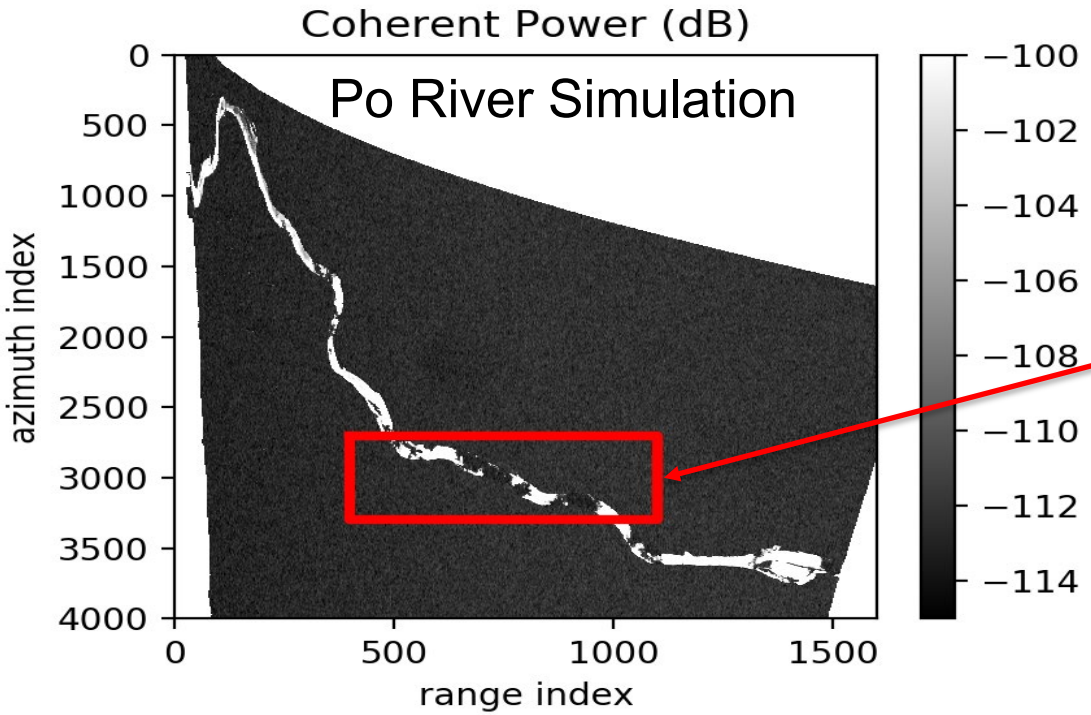
surface wind: ~3-4 m/s (left), ~5-7 m/s (right)



Simulation of Dark Water

- Generate a wind field
  - Random wind field with K^-2 spectrum
  - Scaled to mean wind speed of NCEP 6hr-ly mean speed for lat location and time (arbitrarily using year 2005)

- Project through Geophysical Model Function (GMF)
  - Sigma0 vs wind speed and incidence angle

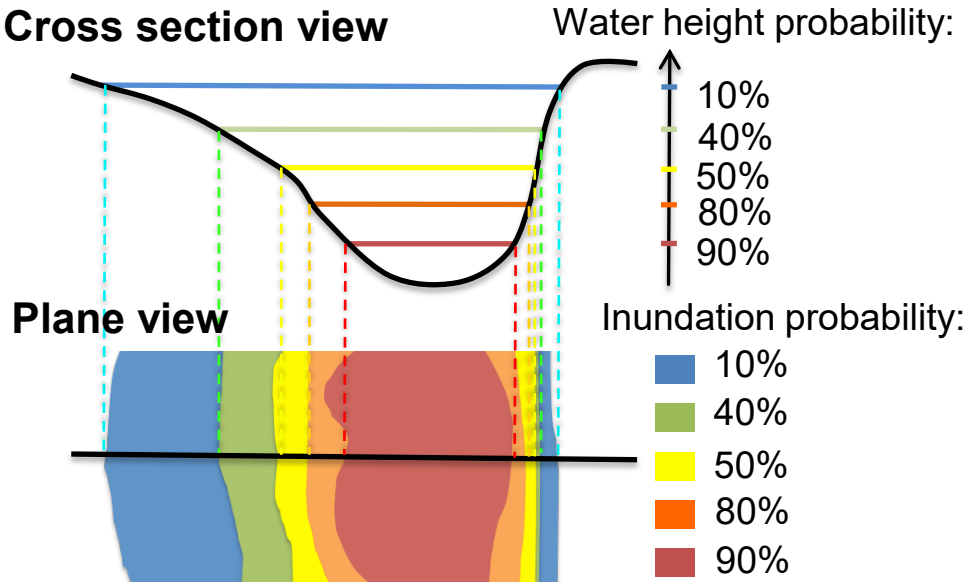


Wind/σ_0 variability causes dark patches in received power image

Wind speed Scaled to exaggerate dark water

Flagging Dark Water

- Pekel mask useful for flagging dark water
  - Global water probability map based on 30 years of Landsat data by J.-F. Pekel et. al. *
  - Water probability (occurrence) can be thresholded to give a proxy water mask at various water heights
  - Can accurately represent complex shapes of water bodies (e.g., braided rivers)



Graphic Courtesy of Claire Michailovsky

- Works as a rain and low specular water flag
- Darkening due to vegetation may be difficult to mitigate

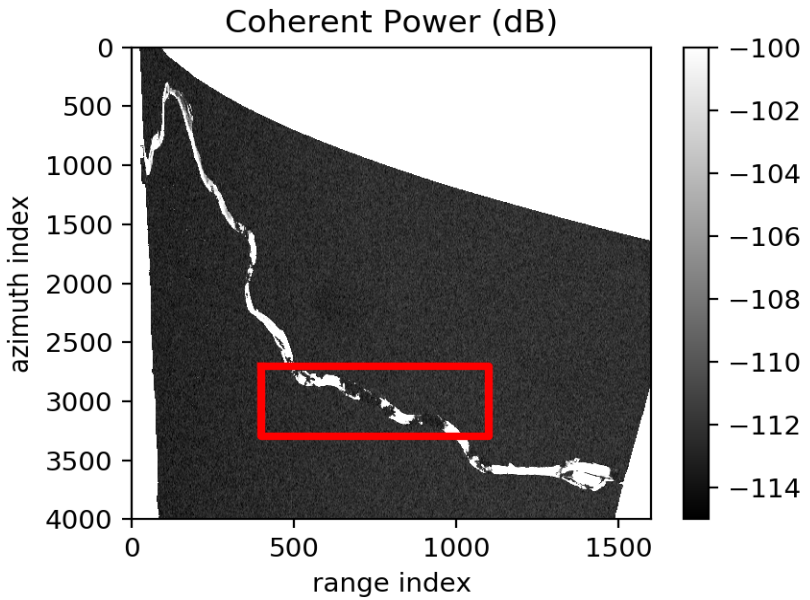
* 30 Years' Global Scale Mapping of surface Water Dynamics at 30 m resolution, J.-F. Pekel et. al. http://due.esrin.esa.int/mwbs2015/files/1_Pekel_200dpi.pdf

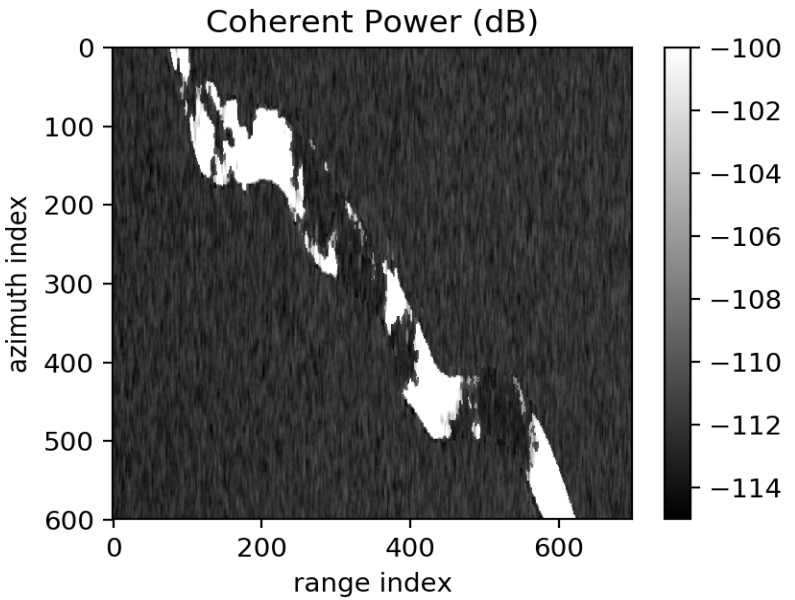
Flagging Dark Water

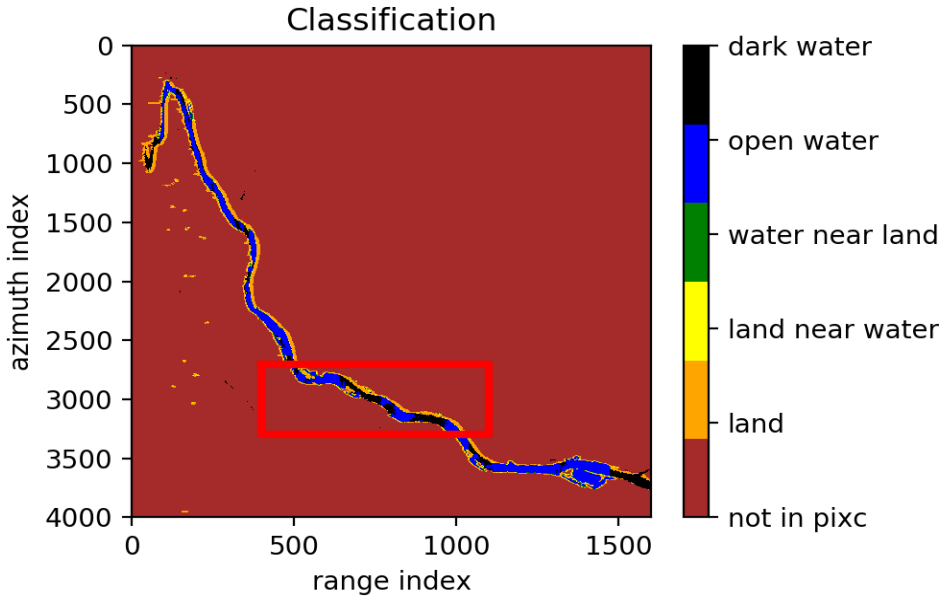
- First cut algorithm is implemented and has been distributed
  - Based on Pekel mask thresholding in slant range
  - Project Pekel mask into slant plane with reference DEM
  - Finds best cross-track shift (to handle height errors in DEM) and probability threshold (Pekel Occurrence) to fit data best
  - Flag as dark water anything not detected as water where best mask says should be water
  - Implemented but not tested extensively

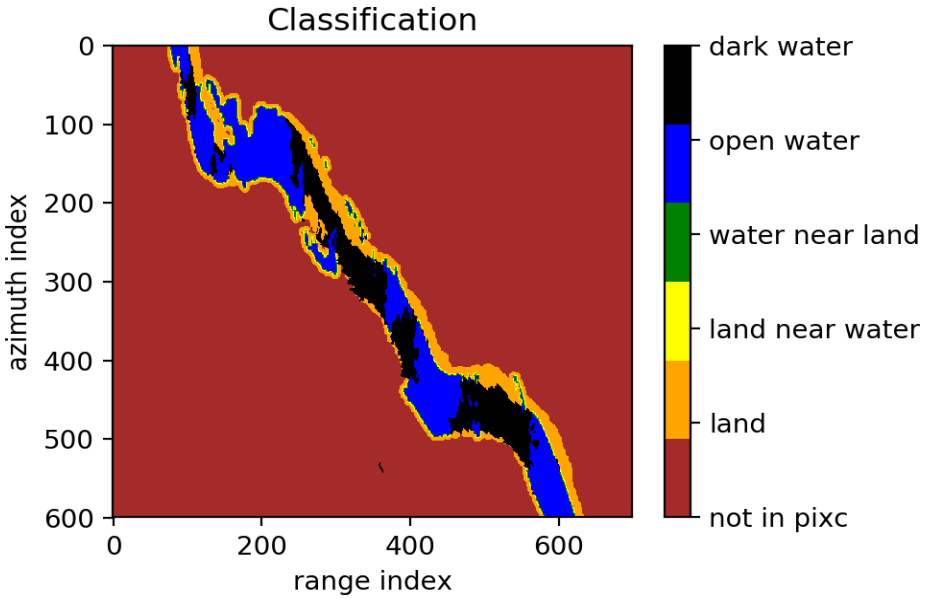
- Upgrades/refinements planned after geolocation
  - Can also flag dark water after geolocation
    - Ameliorates issues with using reference DEM to project into geometry
  - Have to impose height smoothness constraint for dark pixels that can be geolocated well (both land and water)
    - Interpolate/extrapolate from good water geolocations (which have been smoothed)
    - Assumption is good for dark water but not land, but gives same topology as slant plane and is useful for comparing to Pekel
  - Can alternatively update the DEM with estimated water heights and loop over flagging

Example (Radar Geometry)

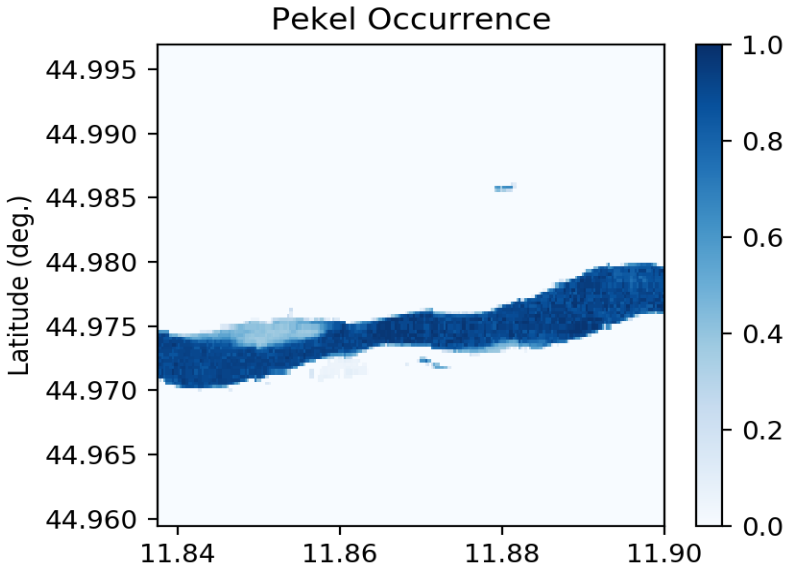


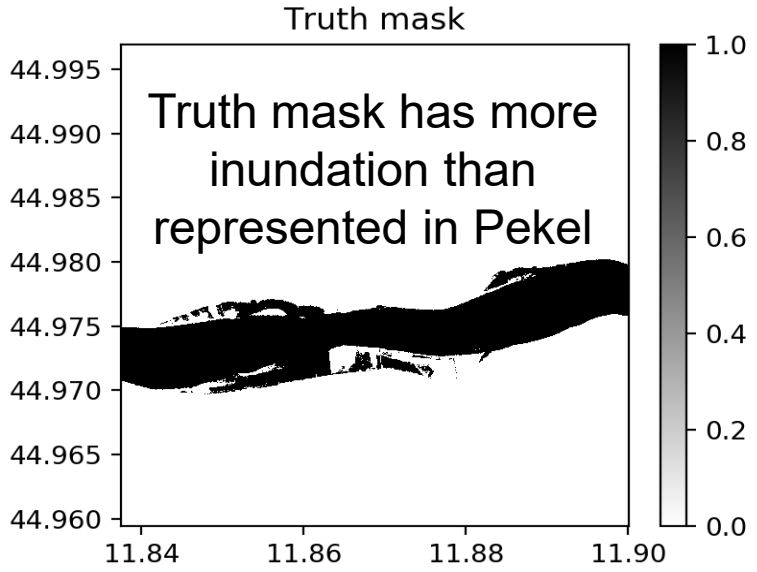


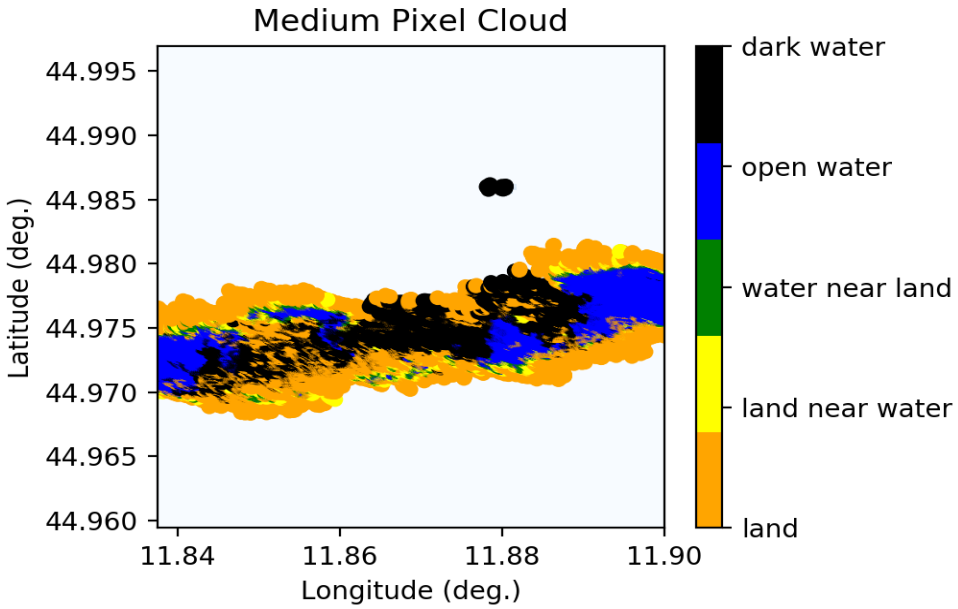


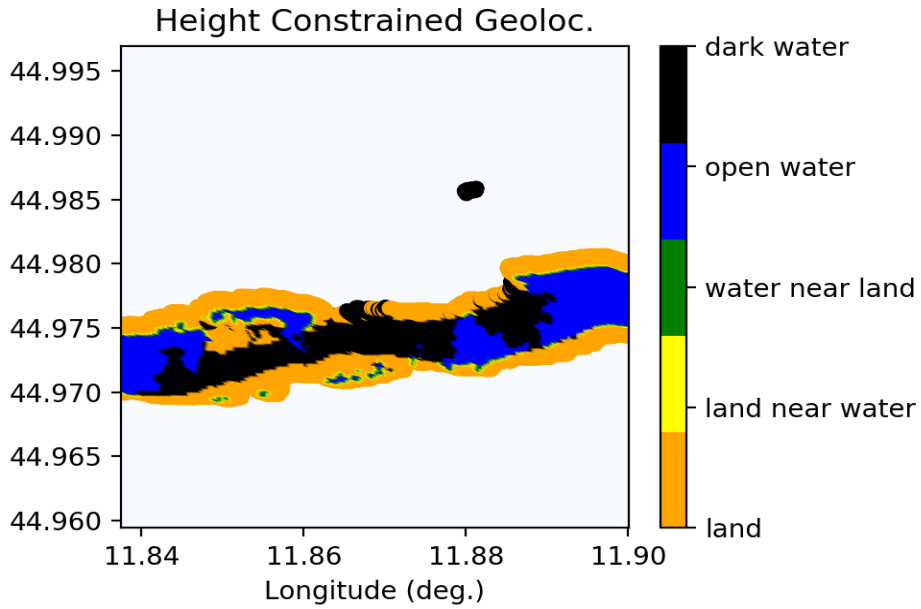


Example (Ground Geometry)

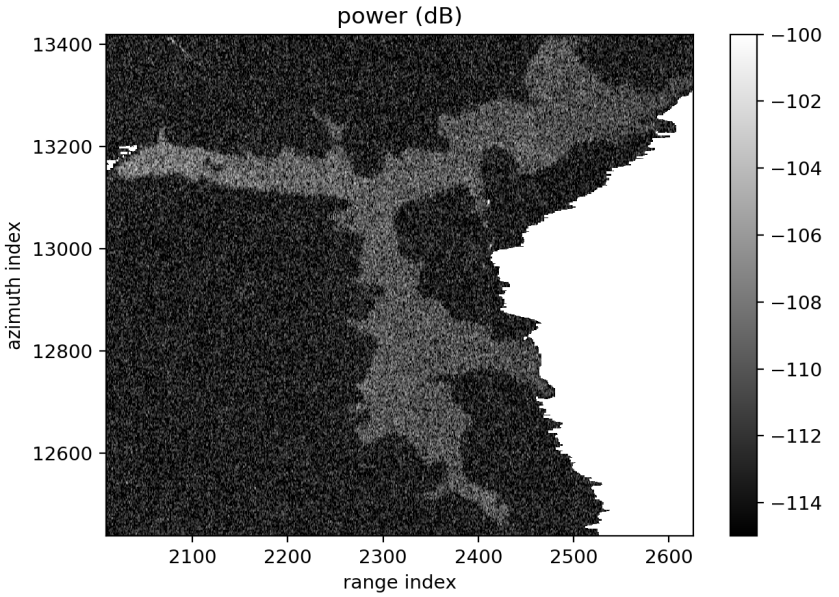


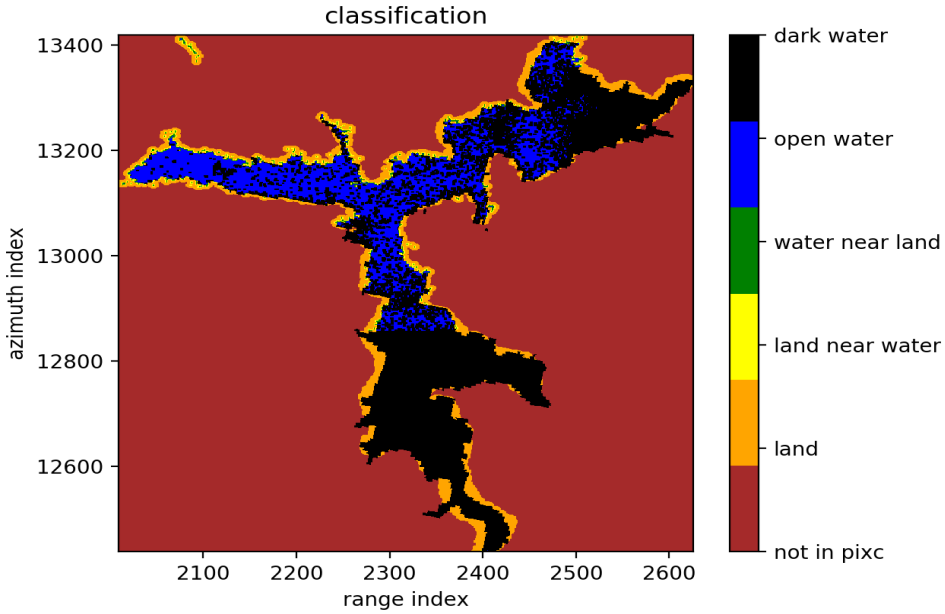


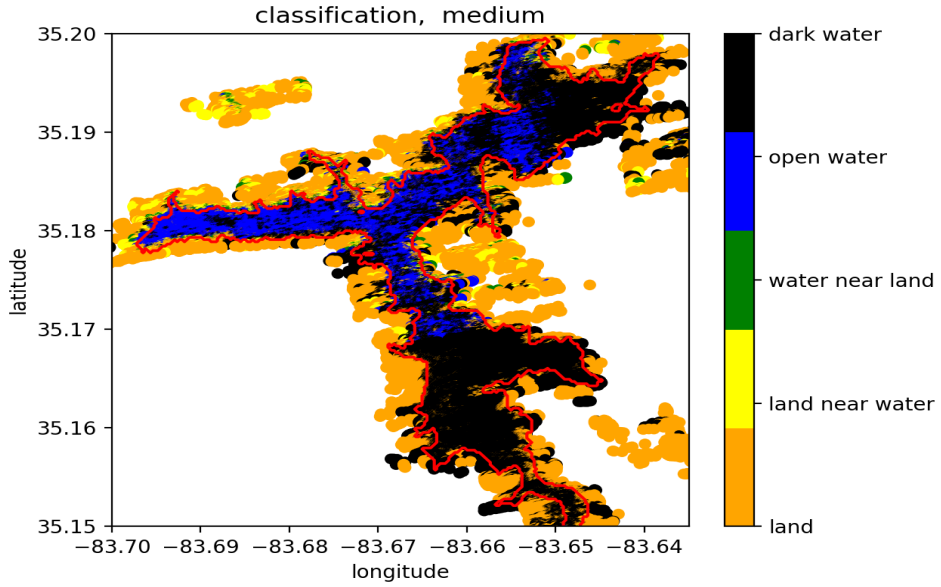


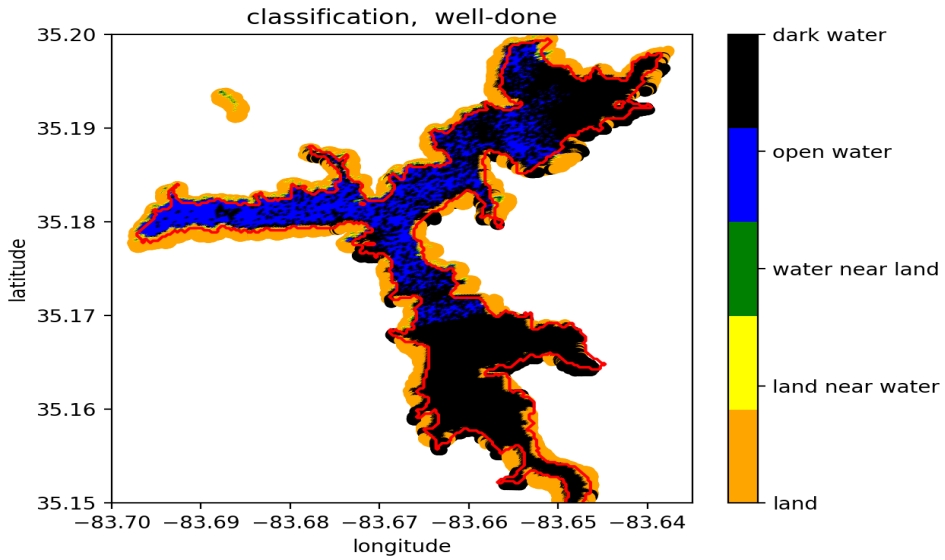


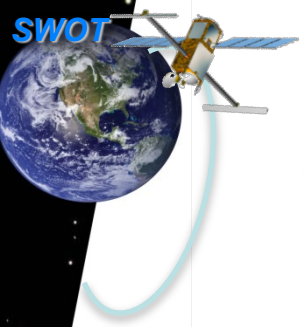
Far Swath, Low SNR Case







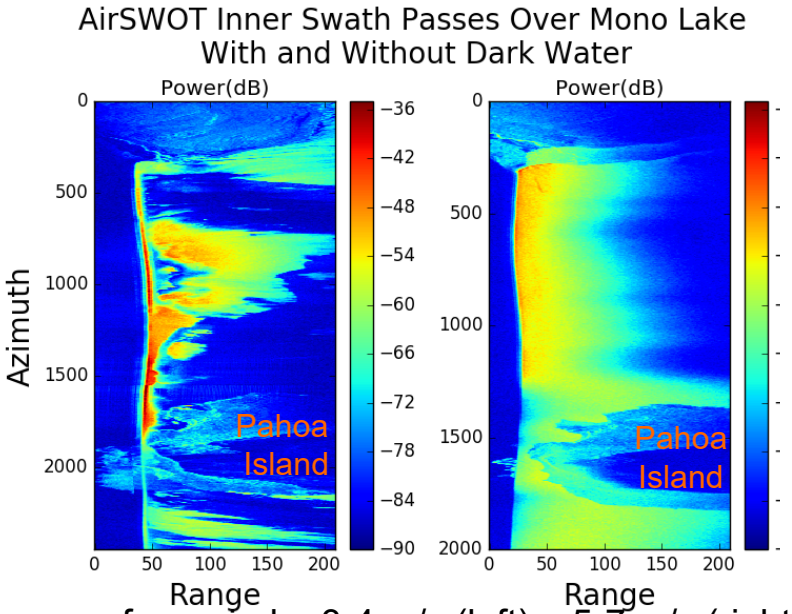




Backup

Water Detection Problems and Science Team Interaction

- Developing more complex methods to be more robust to phenomenological uncertainties and measurement artifacts
  - Dark Water: specular reflection over water due to decreased surface stress causes bright return at nadir, but dark at SWOT incidence angles
  - Vegetation: attenuates ground signal, may dampen surface stress (more specular water under vegetation)
  - Layover: modulates power, phase and coherence—limiting science utility of the data
- Many of these approaches involve prior information or the use of multi-temporal data
  - Science Team can provide important feedback on legitimacy/limitations of proposed priors and multi-temporal time scales



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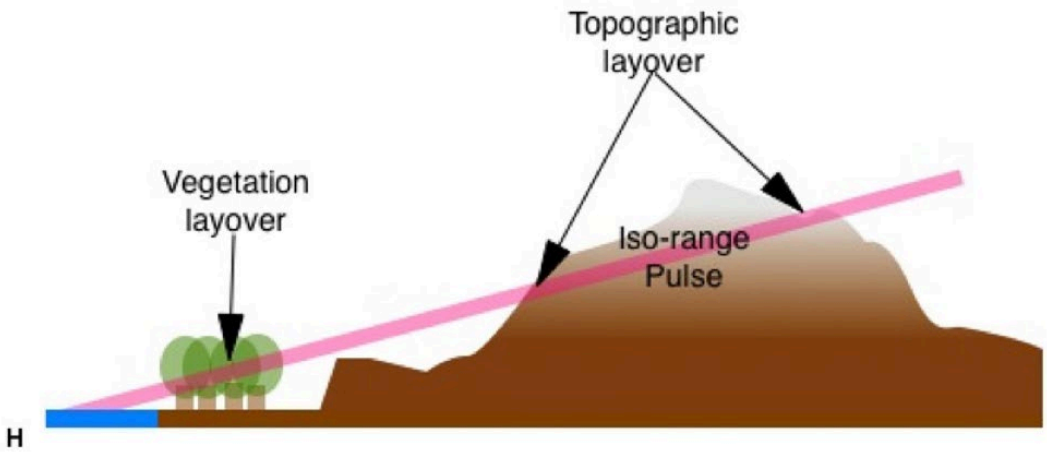


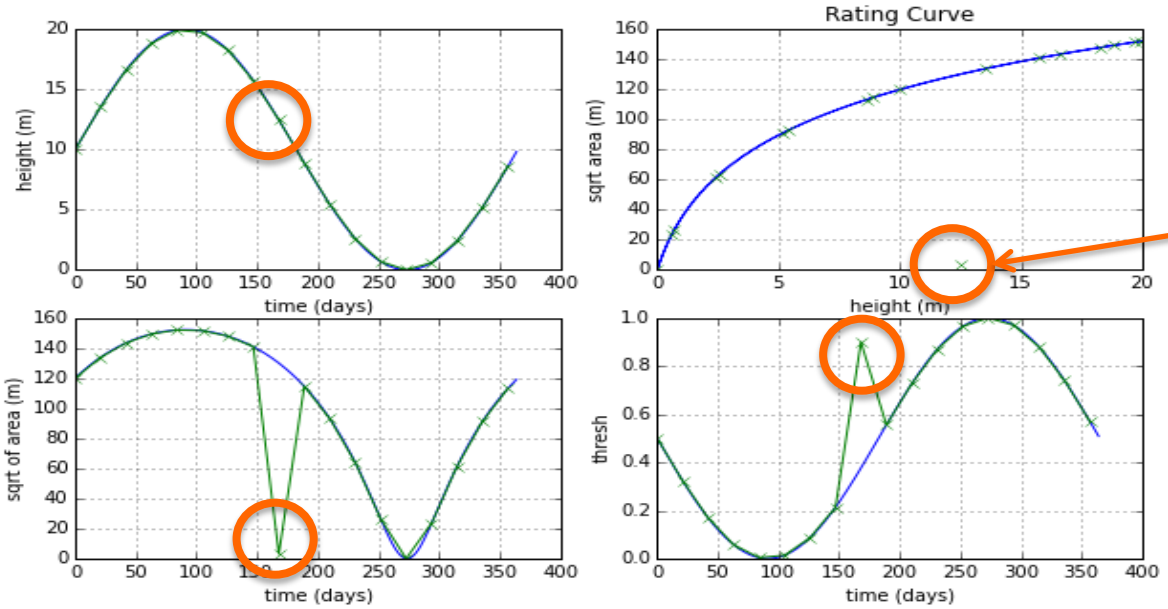
Layover figure from SWOT Mission Science Document

Dark Water

- AirSWOT has observed water with dark σ_0
- Impacts area, height/slope, and location estimates
  - Not detectable as water from power measurements only
  - Low SNR => height/slope/location estimates very noisy
- Dark water can be caused by
  - Vegetation coverage/attenuation (small canopy gap fraction)
  - Rain attenuation (signal drop-out)
  - Specular reflections (e.g., calm wind/wind shadowing, surface dampening by grasses/vegetation, surface slicks…)
- Most of these effects (except vegetation) are expected to be intermittent/non-persistent
  - Persistent dark water hard to flag/correct (problem for densely vegetated water, e.g., woody wetlands)
  - Focus on intermittent dark water flagging/mitigation
- How can we deal with this algorithmically?
  - Multi-temporal approach (using SWOT-only data)
  - Use prior information to discriminate between the dark classes (specular water, rain, land, noise floor)

Simple Multi-temporal Approach

- For given water body (pass-based vector product level)
- If the area drops anomalously low for a given pass (especially if the height is stable)
  - Flag these cases as having a large percentage of dark water
  - Possibly correct the heights and areas for flagged passes
    - ♦ E.g., Bayes estimate combining the measurement with a predicted measurement using previous passes
    - ♦ Smoothing/interpolating in time
- Difficult to handle cases where dark water occurs only over parts of water body (e.g., wind shadowing on one side of a lake)



Dark water bodies appear anomalous in area and threshold trajectories, as well as the rating curve, but not the height trajectory (unless not sufficient number of pixels to estimate height)