Satellite-derived Lake Surface Temperature: Review of Current State and Future Needs

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Motivation for Study

•Lake surface temperature critical for ecology, climate change, and numerical weather prediction

•The quality and availability of satellite-derived lake SST for cloudy seasons and smaller lakes in many regions is poor

•No consensus on appropriate algorithms

•Cloud contamination and sampling errors not well-documented

•What is the path forward for obtaining improved lake SST?

Key Sources of Error

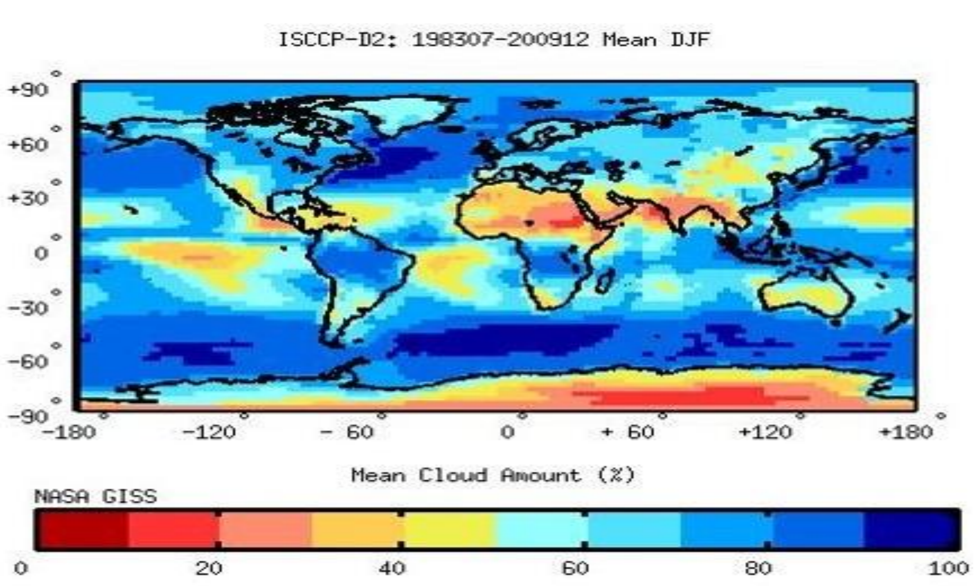
•Cloud contamination (insufficent cloud mask)

•Sampling and representativeness, processing, limited QC flags

•Geolocation and land contamination

•Retrieval algorithm

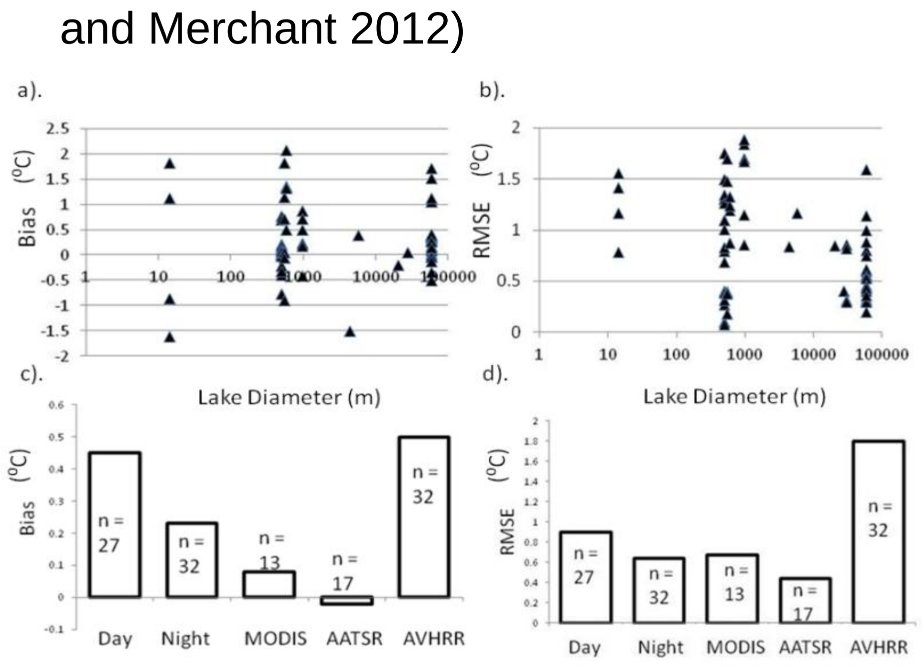
•Air-water interactions and diurnal effects



http://isccp.giss.nasa.gov/climanal3.html

Lake SST Algorithms

- Generally use a single satellite platform
- Historically used split-window algorithms
  --Tuned to buoy if data available
- Recent more sophisticated algorithms using radiative transfer models using ECMWF or NCEP reanalyses to estimate atmospheric profiles over various lakes to estimate the atmospheric variability observed in different lake locations (Hulley et al. 2011; McCallum and Merchant 2012)



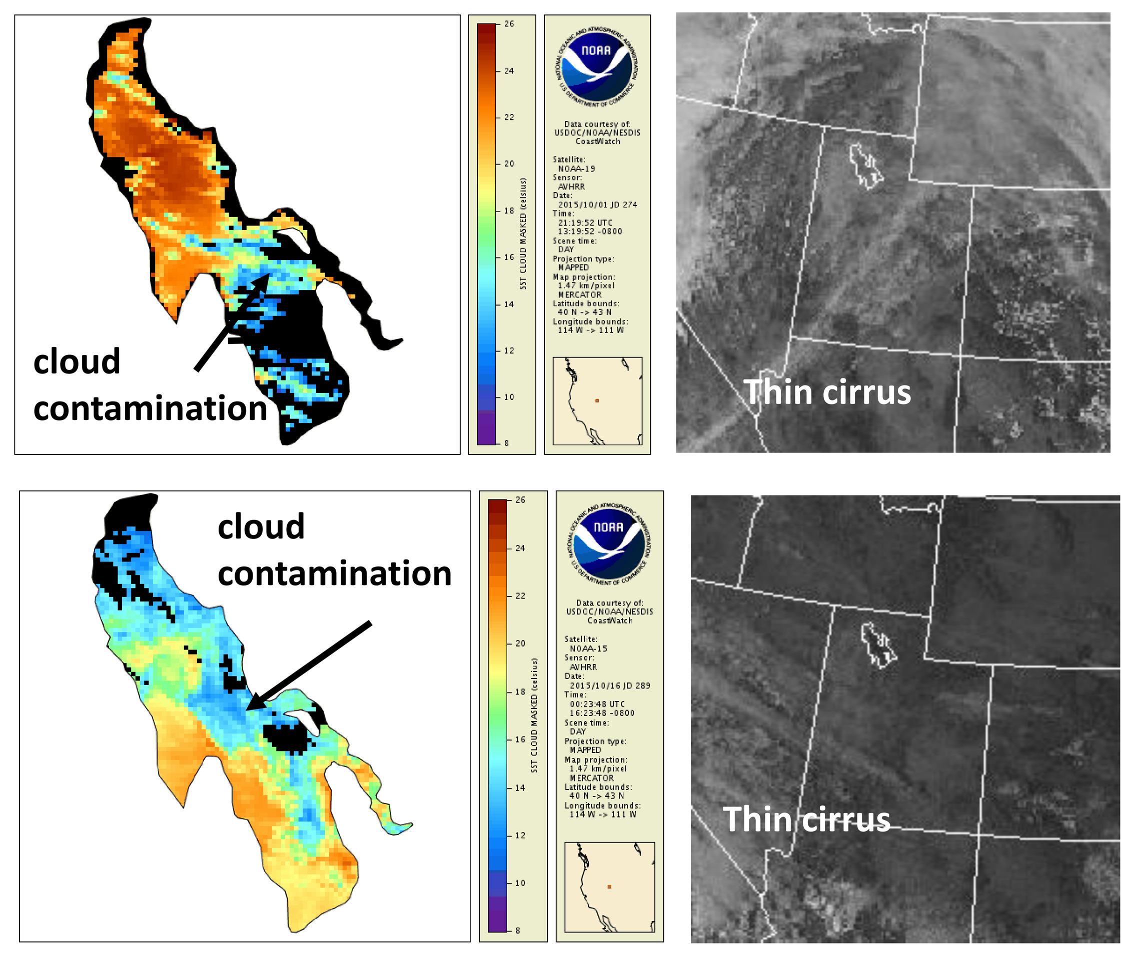
Observed biases (a, c) and RMSE (b, d) reported in lake SST studies between 1980-2013 as a function of lake area (a-b) and satellite platform (c-d)

Long-term Lake SST Data Sets and Trends

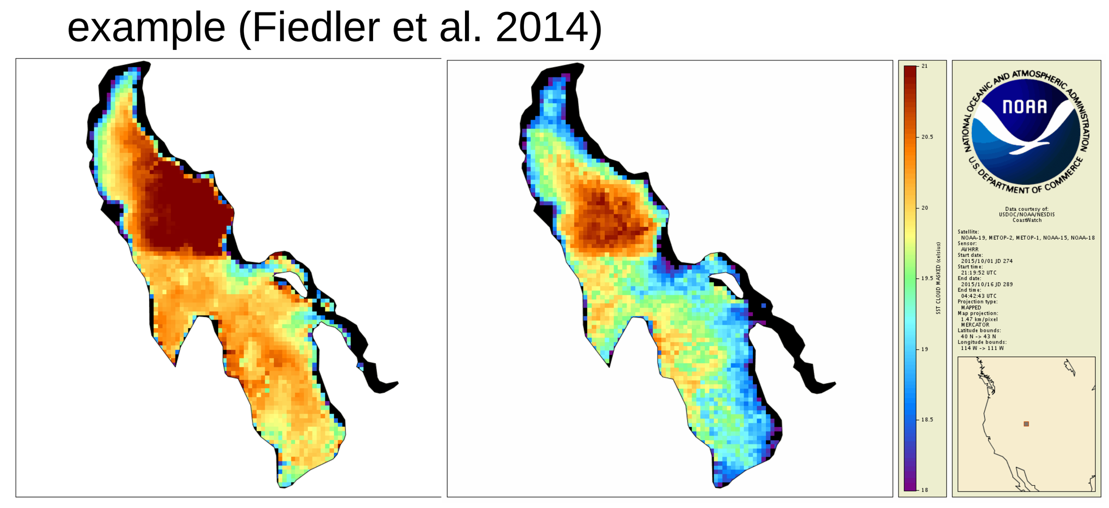
- Groundbreaking lake climate research is ongoing (e.g., O'Reilly et al. 2015; Riffler et al. 2015; Layden et al. 2015)
- Lakes worldwide are warming at dramatically different rates (up to 2.0 °C/ decade)
- Different studies give different answers, and every lake is different
- Many studies limited to summer seasons due to cloud and sampling issues
- Errors discussed above could be complicating analyses (Riffler et al. 2015)
- How to synthesize multiple data sets (e.g. AATSR, MODIS, AVHRR)?

Cloud Contamination and Temporal Averaging Errors

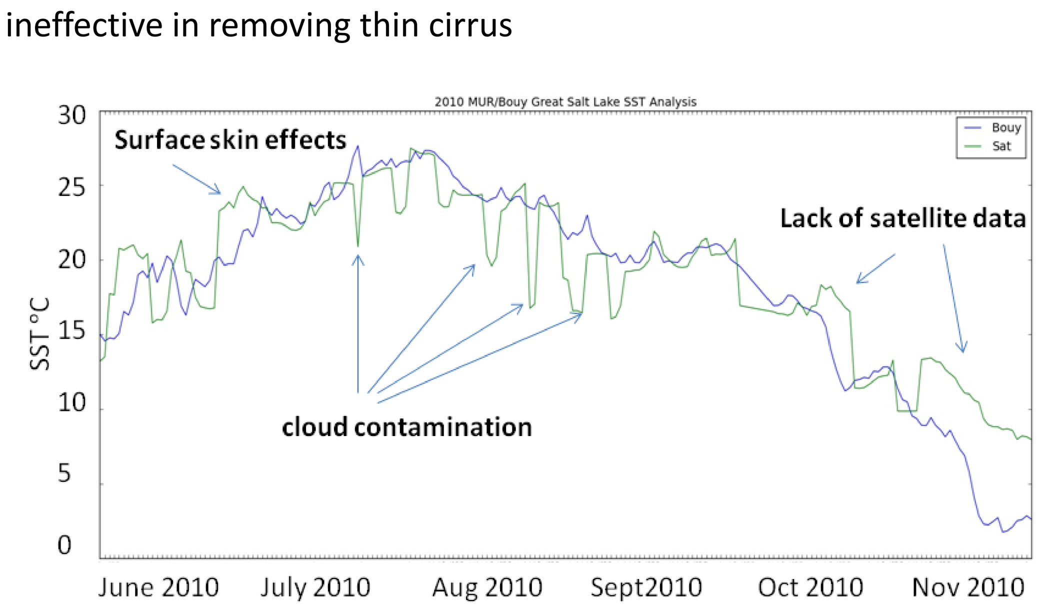
- Crosman and Horel (2009) required visual inspection of all images to create MODIS lake temperature climatology
- Grim et al. (2013) found that statistical methods and other QC checks can help remove clouds



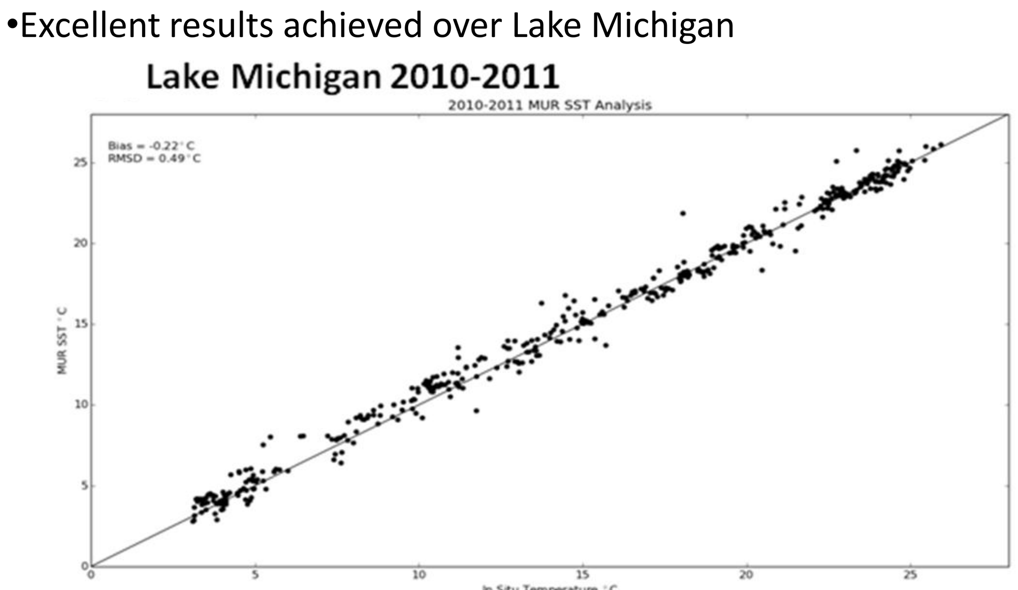
- Grim et al. (2013) found that statistical methods and other QC checks can help remove clouds
- O'Reilly et al. (2015) found cloud cover is decreasing at the most rapidly warming lakes
- Riffler et al. (2015) found possible systematic differences between MODIS versus AVHRR cloud masks
- Most long-term climate studies limited to summer seasons due to contamination and sampling frequency issues with clouds in other seasons
- Operational NWP need real-time, timely lake SST estimates year-round. Recent OSTIA lakes effort an example (Fiedler et al. 2014)



Left: Lake surface temperature for 15 day period using NOAA AVHRR overpasses after visual removal of cloud contaminated and geolocation errors
Right: The same period with no manual removal of suspect data Rigorous CLAVRR cloud masking algorithm applied but remain ineffective in removing thin cirrus

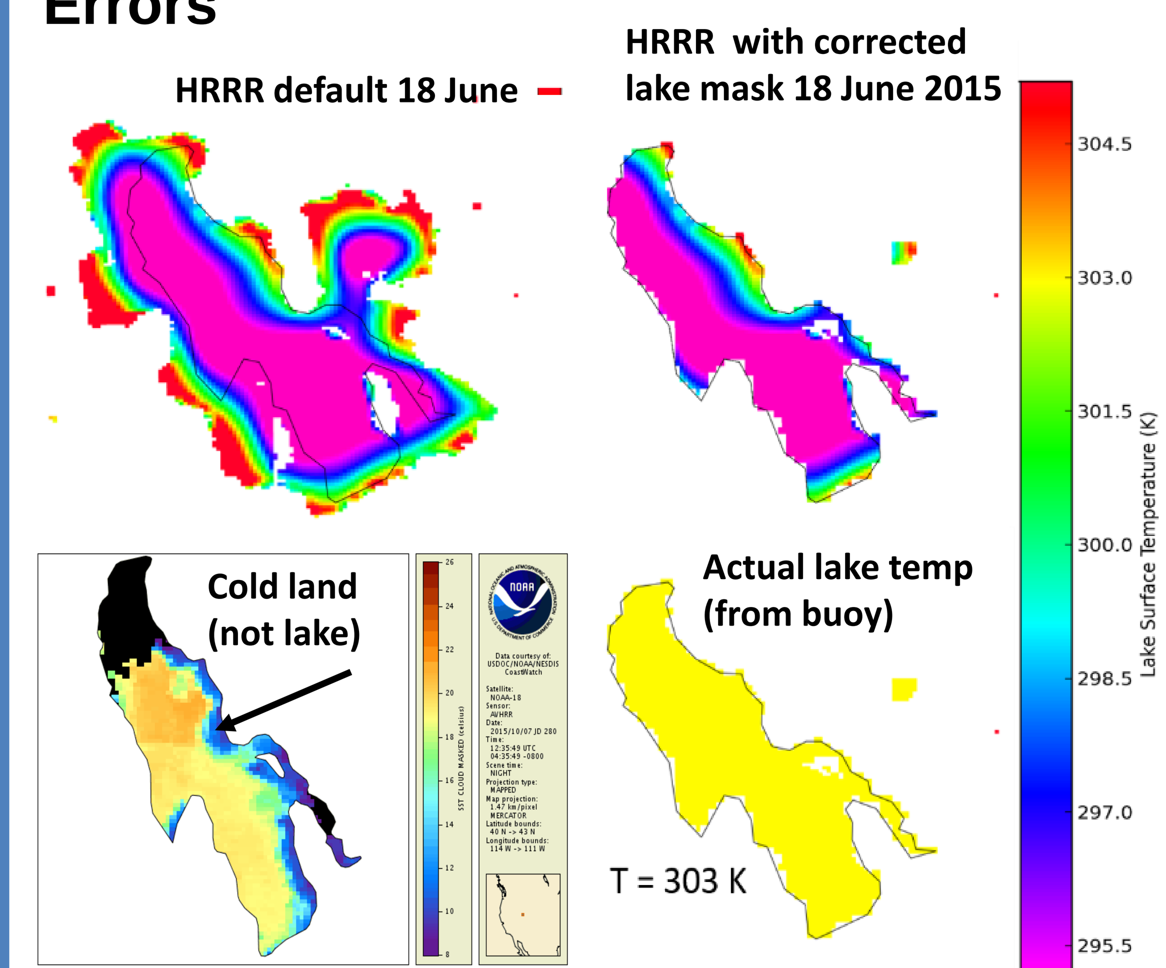


Example of Improved Lake SST: MUR SST
Multi-scale Ultra-high Resolution Sea Surface Temperature
•Multi-Resolution Variational Analysis (MRVA)
•Excellent results achieved over Lake Michigan



Validation NASA MUR over Lake Michigan NOAA Buoy 45007			
RMSE 2010	RMSE 2011	Bias °C 2010	Bias °C 2011
0.30	.0.60	-0.10	-0.30

Unrepresentativeness and Geolocation Errors



Top left: Lake surface temperature analyses for the NCEP experimental High Resolution Rapid Refresh (HRRR) operational analyses for 18 June 2015. **Top right:** The same as top left but after updated land mask applied. **Lower left**: NOAA coastwatch AVHRR image showing geolocation issues. **Lower right**: Estimated actual lake temperature based on in situ buoy data (plots courtesy of Brian Blaylock

Recommendations and Future Work

•Improved cloud masks

•Improved first-guess (needed for cloudy periods)

•Improved temporal compositing (e.g., McCallum and Merchant 2012, Grim et al. 2013)

•Multi-sensor approach to increase temporal coverage

•Improved QC flags

•Incorporating high latitude cloud mask research

•Incorporating ocean coastal research

•Improved algorithms (e.g., Hulley et al. (2011) and McCallum and Merchant (2012))

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