Evaluation of Remote Sensing Methods as Proxy for Salinity Measurements in the Lower Mekong Delta

Thailynn Munroe
Graduate Research Assistant
University of Alabama in Huntsville
NASA SERVIR-Mekong

Saltwater Intrusion:

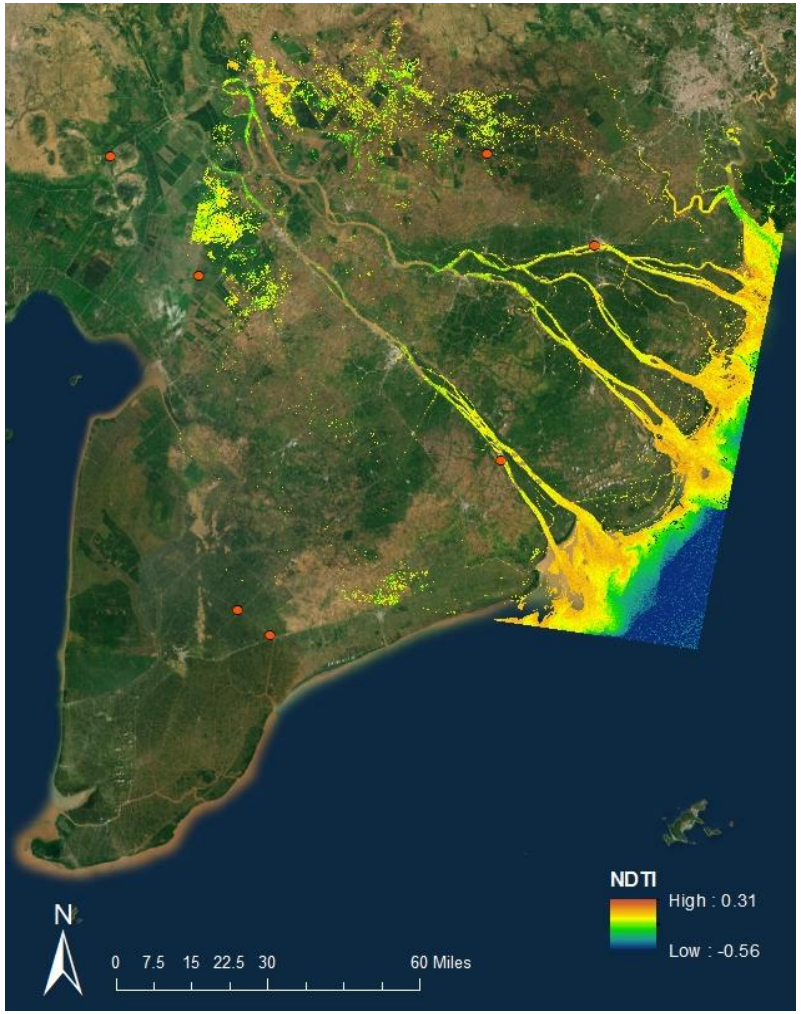
- Vietnam Delta major agricultural region
- 2015-2016 dry season was a record breaking drought year in Vietnam
- Salinity intrusion started 2 months earlier and extended further upstream than before, up to 50 km in some places
- Some mitigation practices include sluices and dykes, planting more salinity and drought resistant crops, combination pond/fields
- Need for better early warning system and water management

Background & relevant studies:

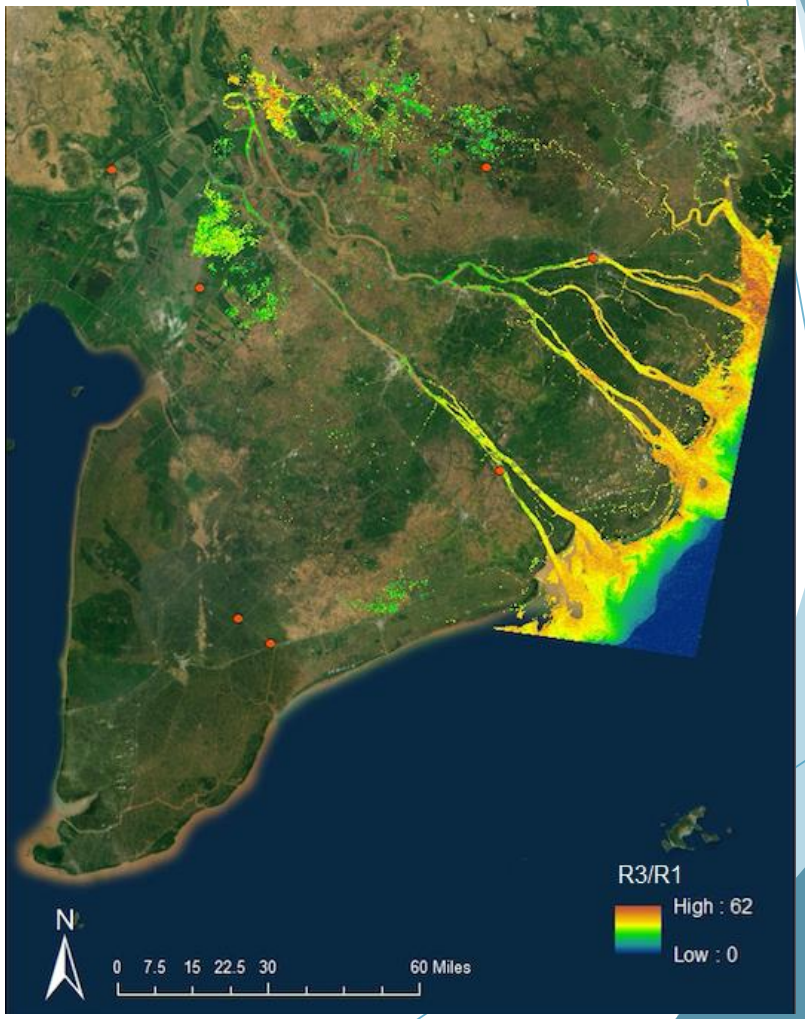
- Major motivation from Mekong needs assessment
- SMOS and SMAP measure ocean salinity
- In general, inverse relationship between CDOM and salinity in bays, estuaries, and lakes
- Keith et al. (2016) used MODIS and HICO to create CDOM and salinity algorithms for New England, Gulf of Mexico, and Mid-Atlantic
- Fang et al. (2007) performed similar study in Pearl River Estuary, China

Open Access image from Wikimedia Commons:
https://commons.wikimedia.org/w/index.php?search=rice+drought&title=Special:Search&go=Go&uselang=en&searchToken=6etruhbg7kvf0cic8hl3hl226

Viewing NDTI:



and band ratio:



Optical Satellite Imagery:

- Landsat 5 TM
- Using Google Earth Engine (GEE)
  - Around 70 points corresponded with satellite pass-overs
  - Using GEE simple cloud score band, only 4 points contained pixels less than 50% likely to be a cloud
  - GEE = somewhat of a black box…
- Using USGS Earth Explorer
  - USGS Surface Reflectance product → already atmospherically corrected
  - Much larger dataset
  - Plus/minus 1 day from observations

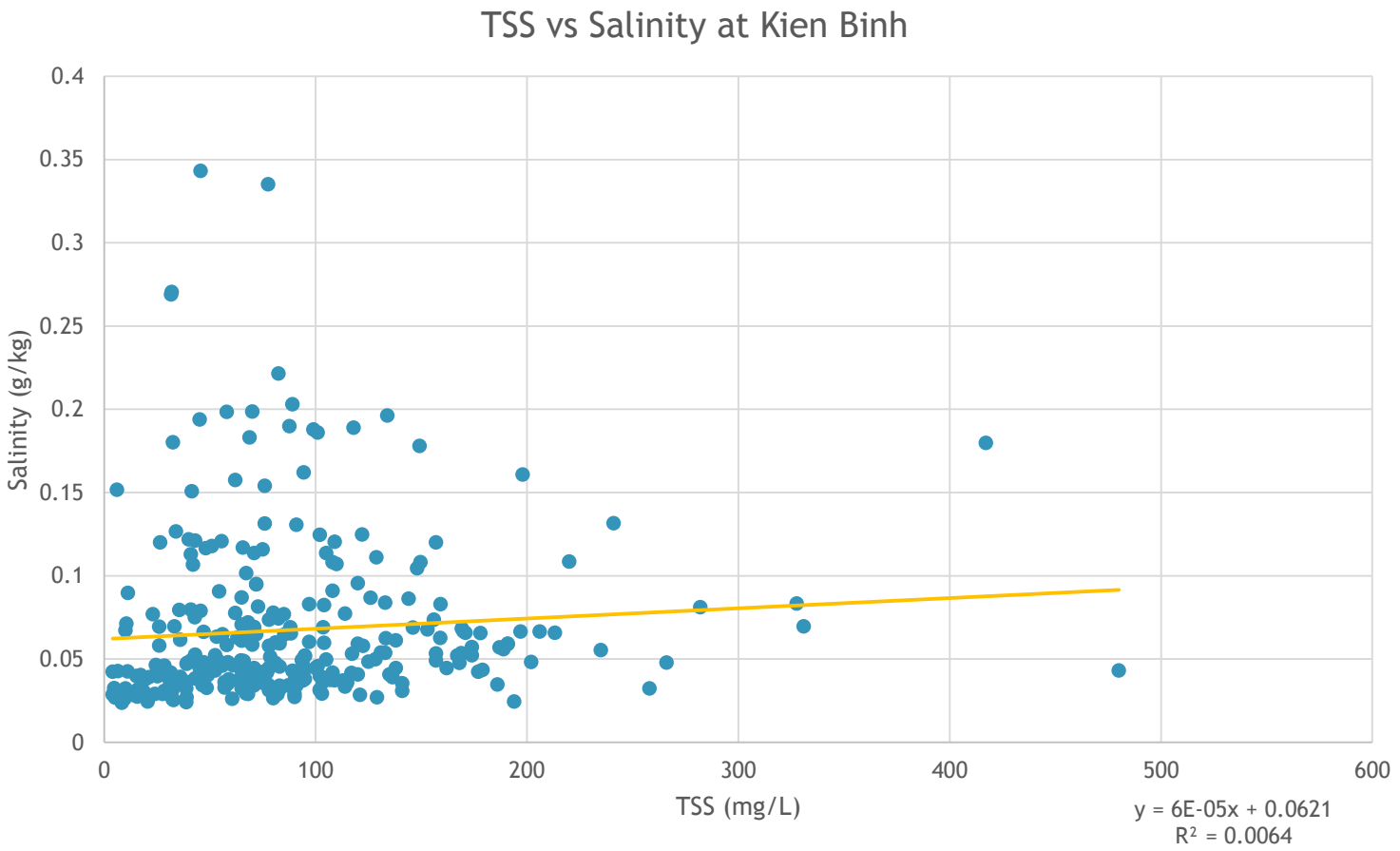
Image processing:

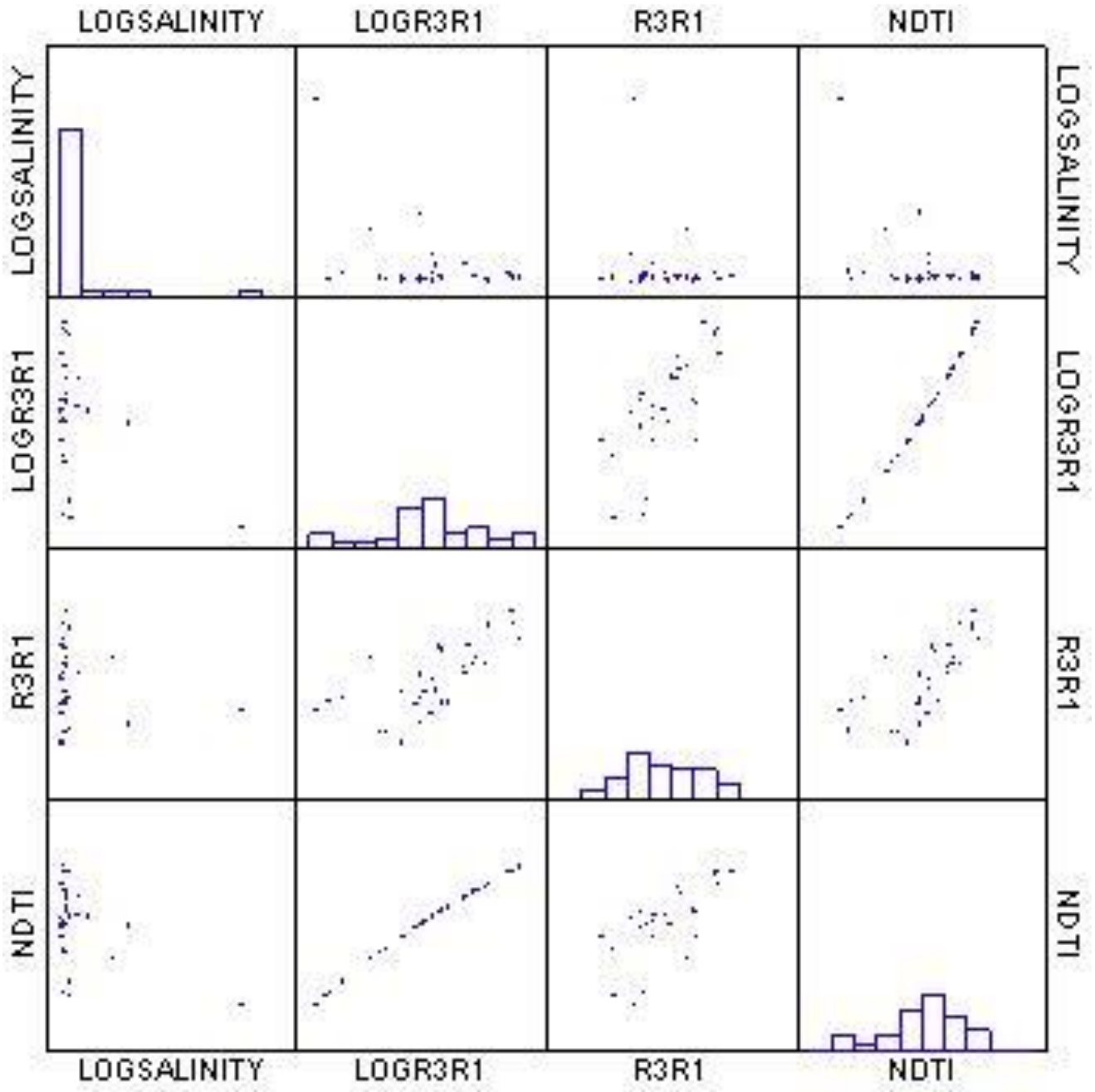
- Used cloud mask to remove clouds, cloud shadows, and land
- Calculated Normalized Difference Turbidity Index from Lacaux et al. (2007):
  - NDTI = $\frac{(Red - Green)}{(Red + Green)}$
- Calculated band ratio between red and blue bands

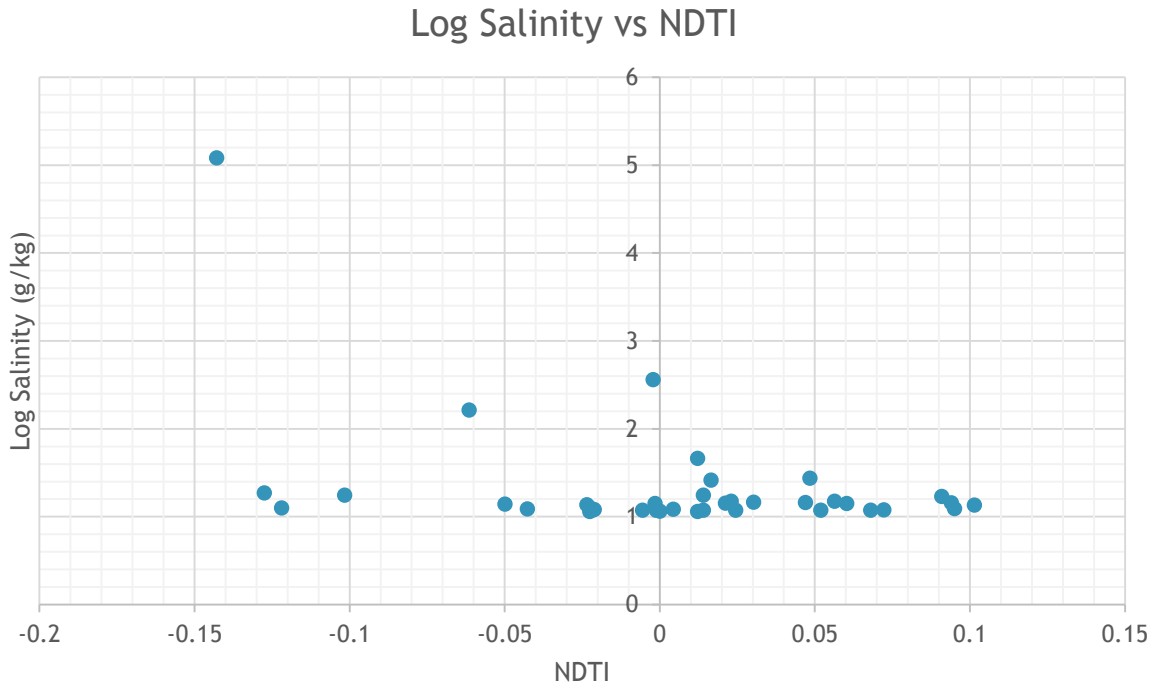
In-situ Data:

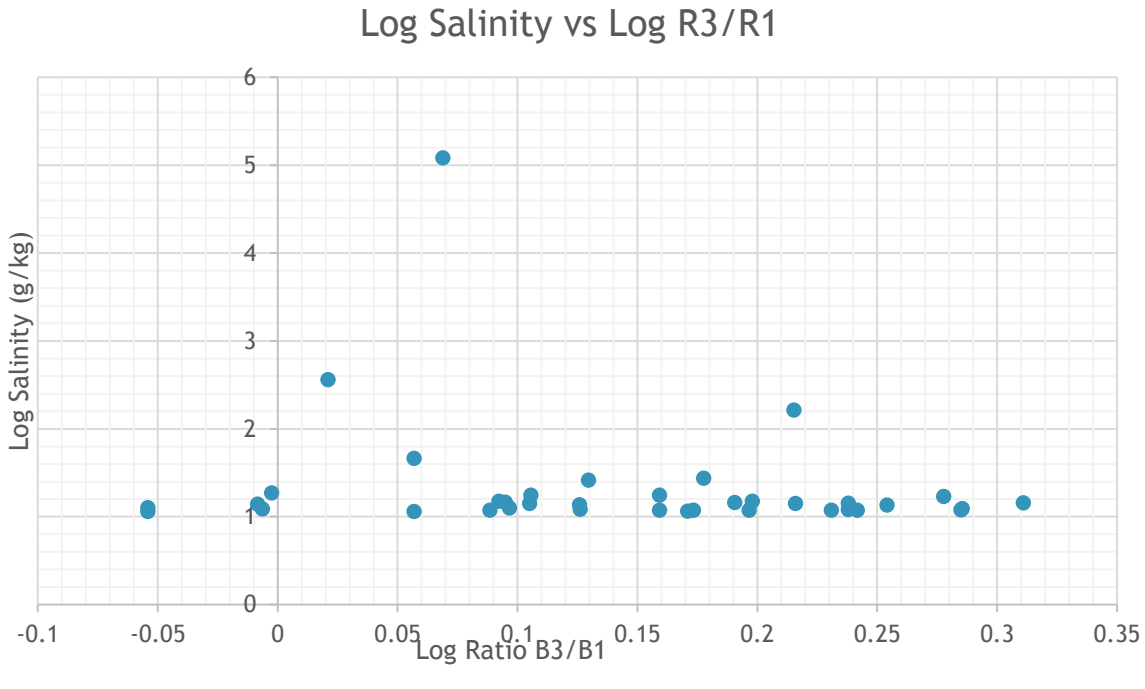
- Mekong River Commission: 48 permanent water quality monitoring stations
  - Focused on 7 stations Mekong Delta due to data sensitivity to location
  - Measurements taken “of surface water are taken from the river mid-stream every two months” or less
  - Evaluated in a lab
- Most have observations over 3 decades; many parameters
  - Used practical salinity units to combine parameters
  - Convert from milli-equivalents/liter to g/kg

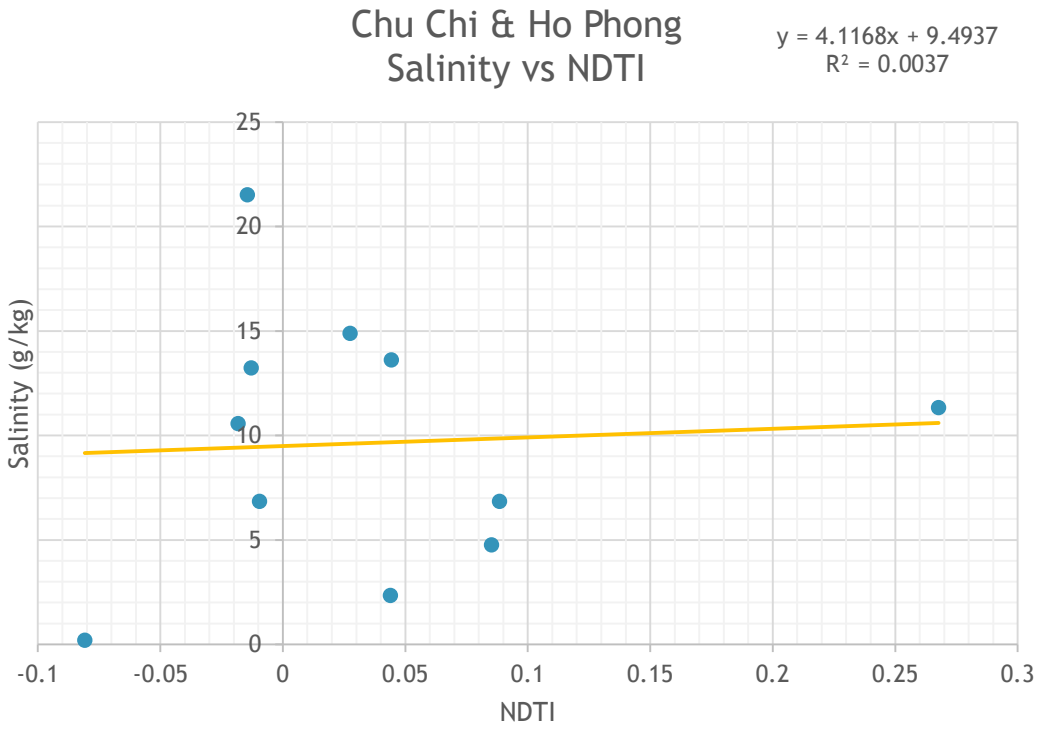
In-situ TSS vs Salinity:

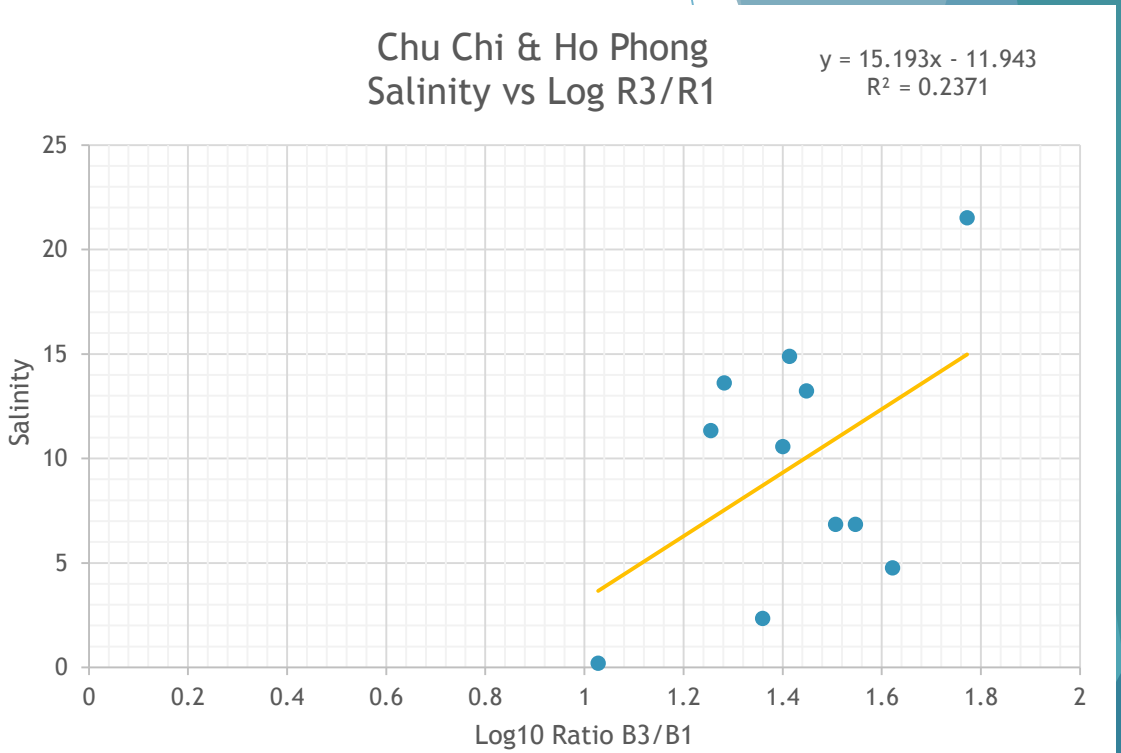



LOGSALINITY
LOGR3R1
R3R1
NDTI
LOGSALINITY
LOGR3R1
R3R1
NDTI
LOGSALINITY
LOGR3R1
R3R1
NDTI
LOGSALINITY
LOGR3R1
R3R1
NDTI


Log Salinity vs NDTI
Log Salinity (g/kg)
NDTI
6
5
4
3
2
1
0
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15


Log Salinity vs Log R3/R1
Log Salinity (g/kg)
Log Ratio B3/B1
6
5
4
3
2
1
0
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35


Chu Chi & Ho Phong
Salinity vs NDTI
y = 4.1168x + 9.4937
R² = 0.0037
Salinity (g/kg)
NDTI
25
20
15
10
5
0
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3


Chu Chi & Ho Phong
Salinity vs Log R3/R1
y = 15.193x - 11.943
R² = 0.2371
Salinity
Log10 Ratio B3/B1
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

R3/R1 OLS for lower salinity stations:

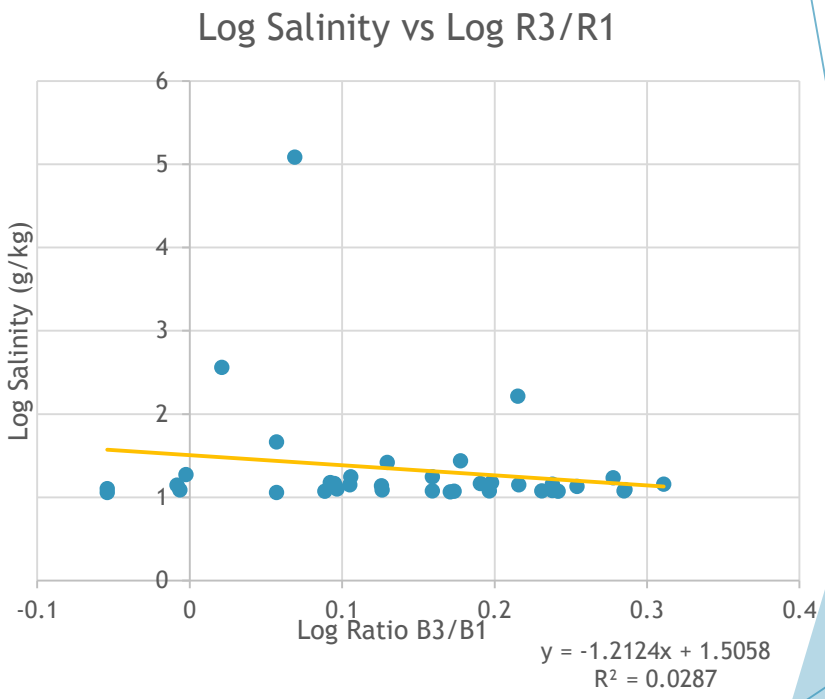
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.169439716
R Square	0.028709817
Adjusted R Square	0.000958669
Standard Error	0.704894074
Observations	37

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.51404033	0.51404033	1.034545211	0.316073326
Residual	35	17.39064793	0.496875655		
Total	36	17.90468826			

	Coefficients	Standard Error	t Stat	P-value
Intercept	1.505800313	0.205322186	7.333841231	1.42405E-08
X Variable 1	-1.212406412	1.191992402	-1.017125956	0.316073326



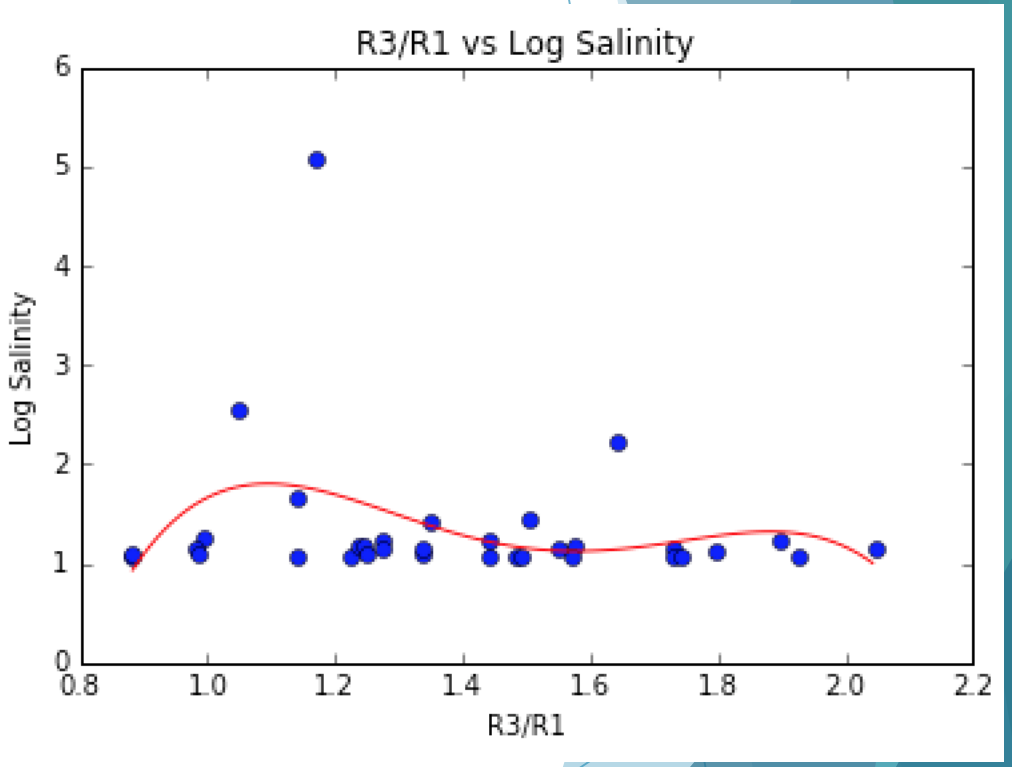
R3/R1 Polynomial regression: Y = -22.83x^4 + 136.77x^3 – 299.85x^2 - 284.02x - 96.21

Validation:

- Mean relative error: -36.43 %
- Root mean square error: 0.462 ppt
- Bias: -0.407

Cross validation (k-fold, k=n):

- LOO cross validation mean relative error: -270.87 %
- LOO cross validation root mean square error: 0.804 ppt



NDTI OLS for lower salinity stations:

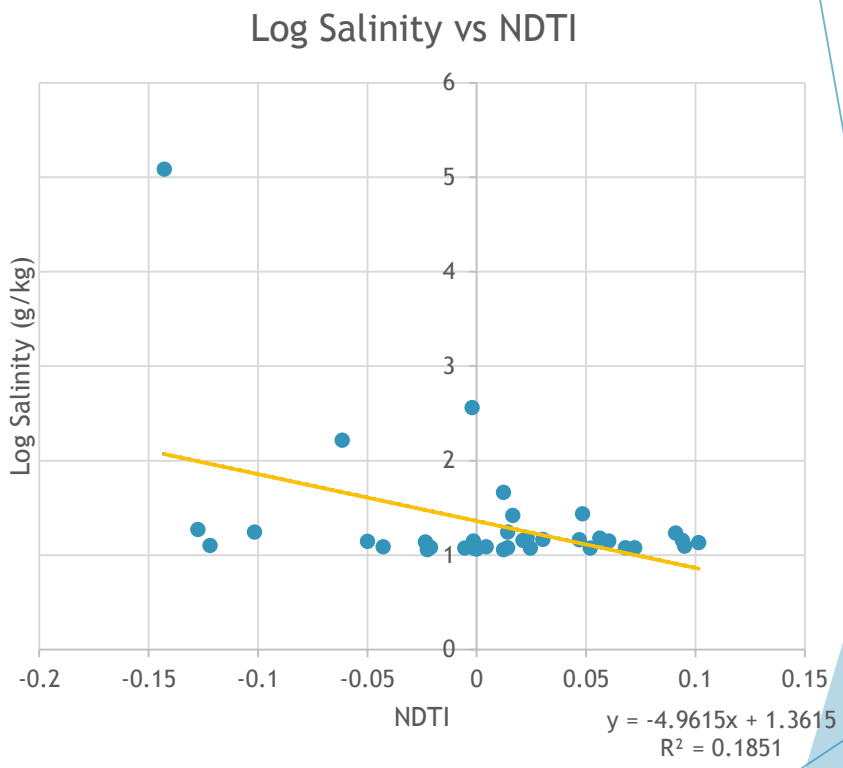
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.430236184
R Square	0.185103174
Adjusted R Square	0.161820408
Standard Error	0.645655229
Observations	37

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.31421463	3.31421463	7.950222518	0.007862975
Residual	35	14.59047363	0.416870675		
Total	36	17.90468826			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.361549633	0.106613406	12.77090459	9.82655E-15
X Variable 1	-4.96150314	1.7596392	-2.819613895	0.007862975



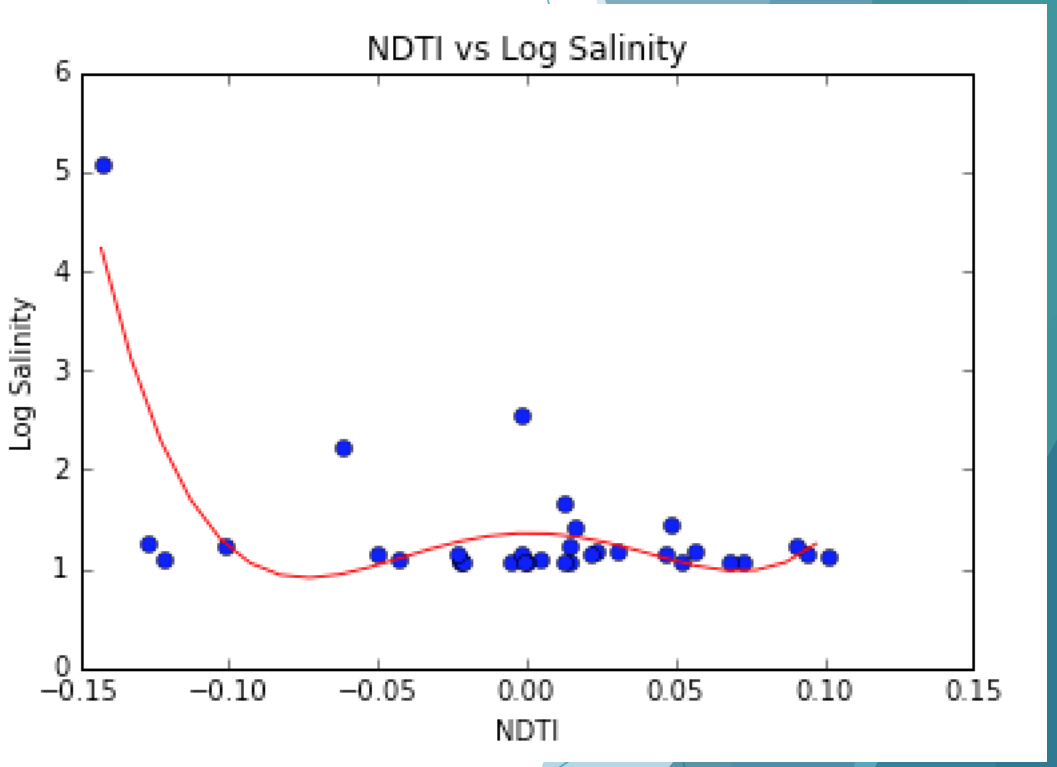
NDTI Polynomial regression: Y = 1811x^4 - 395.3x^3 + 183.4x^2 - 1.521x – 1.415

Validation:

- Mean relative error: -25.32 %
- Root mean square error: 0.451 ppt
- Bias: -0.28

Cross validation (k-fold, k=n):

- LOO cross validation mean relative error: -146.06 %
- LOO cross validation root mean square error: 0.786 ppt



Caveats and discussion:

- Many hydrologic parameters that could affect salinity, especially where salinity is low:
  - streamflow, precipitation
  - storm surge, surface runoff
  - sedimentation, nutrient loading, irrigation practices
  - evaporation, surface temperature
  - channel type (natural vs canal)
- Each station could have its own algorithm
- Would like to have had data from last winter

Conclusions:

- No significant correlation between R3/R1 ratio and salinity, or NDTI and salinity
- Many factors could be contributing to the local salinity levels
- Moving forward: will include Landsat 7 images, will look at relationship between other band combinations

References:

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- Kutser, T., Pierson, D., Tranvik, L., Reinart, A., Sobek, S., & Kallio, K. (2005). Using satellite remote sensing to estimate the colored dissolved organic matter absorption coefficient in lakes. *Remote Sens. Environ.*, *8*(6), 709–720.
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