COASTAL SALINITY INDEX

User Guide

v1.0 – February 2019

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Contents

Purpose and intended audience

This User Guide provides information about the following:

- Why the CSI was developed
- How the CSI is calculated
- CSI graphs and plots
- Links to CSI references and resources

This User Guide was created for the following audience:

- **Resource managers**—Those who monitor drought conditions in order to make decisions and manage resources, such as water, fisheries, wildlife, refuges, preserves, and forests
- **The drought monitoring community**—Those who monitor drought conditions, make determinations regarding drought status, and disseminate drought information, for example, drought coordinators and response committees, State climatologists, and National Weather Service offices
- **Researchers**—Those who are interested in studying drought and improving understanding of the drivers and effects of drought in coastal areas

What is the Coastal Salinity Index (CSI)?

- The CSI is a drought index tool that uses salinity data to characterize saline (drought) and freshwater (wet) conditions in coastal surface waters.
- The CSI uses an approach similar to the Standardized Precipitation Index (SPI) to show the probability of recording a given amount of salinity.
- The CSI can be computed for multiple time intervals from 1 to 24 months to characterize short- and long-term conditions.
- The CSI does **not** depict hourly to daily salinity fluctuations, but the response to monthly (and longer) precipitation and streamflow conditions.

Photograph credits: Green, Chandler and Carolina Integrated Sciences and Assessments. Flying Ahead of Troubled Waters (published August 8, 2016). https://www.youtube.com/watch?v=6DS9bWMsBNM

Why was the Coastal Salinity Index (CSI) developed?

- Droughts uniquely affect coastal ecosystems and water resources through changes in salinity conditions and the location of the freshwater-saltwater interface.
- Commonly-used drought indices use inputs such as precipitation volume, streamflow, temperature, evaporation, and soil moisture conditions, but these indices do not capture the changing salinity dynamics that affect coastal areas during drought.
- The CSI was developed as a tool to monitor changing salinities in coastal surface water bodies and associated effects on estuarine habitats and freshwater availability for ecological, municipal, and industrial needs.

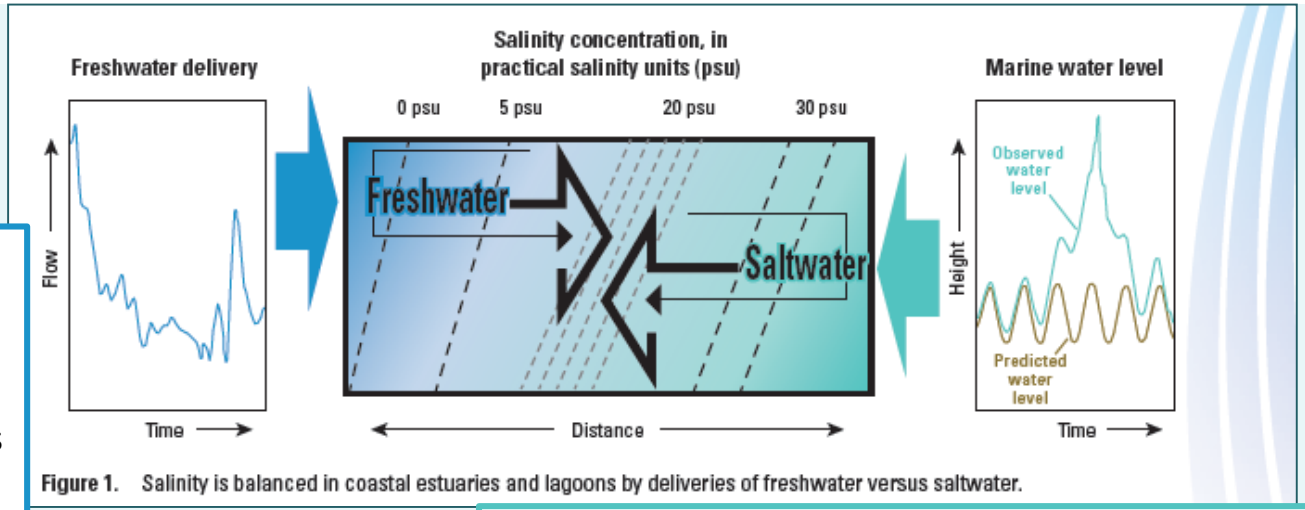


Figure 1. Salinity is balanced in coastal estuaries and lagoons by deliveries of freshwater versus saltwater.

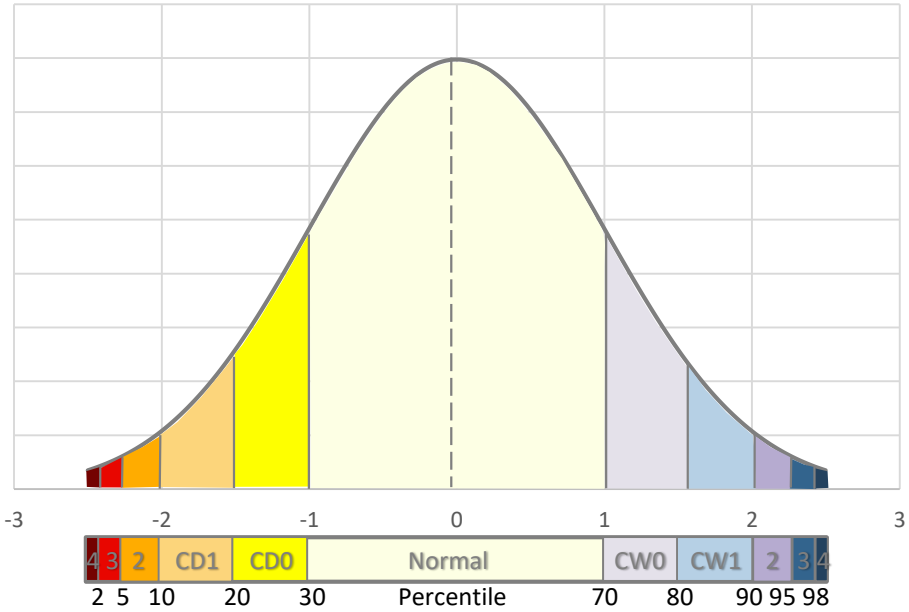
High precipitation, such as caused by storms, contributes to high flows, causing decreased salinity levels in the estuary.

Low precipitation, such as caused by drought, contributes to low river flows, causing increased salinity levels in the estuary. Wind patterns can also contribute to changes in the location of the freshwater-saltwater interface.

Conrads, P.A., Rodgers, K.D., Passeri, D.L., Prinos, S.T., Smith, C., Swarzenski, C.M., and Middleton, B.A., 2018, Coastal estuaries and lagoons—The delicate balance at the edge of the sea: U.S. Geological Survey Fact Sheet 2018–3022, 4 p., accessed July 8, 2019, at https://doi.org/10.3133/fs20183022.

How is the CSI calculated?

- Monthly mean salinity data are fit to a gamma distribution and then normalized (mean of zero and standard deviation of one).
- Index values are standard deviations from the normalized mean values.
- An index value of zero indicates historical mean salinity.
- Negative and positive values represent increasingly saline and fresh conditions, respectively.
  - CD: Coastal drought
  - CW: Coastal wet
- SPI threshold values were used to develop the coastal drought thresholds and designations.

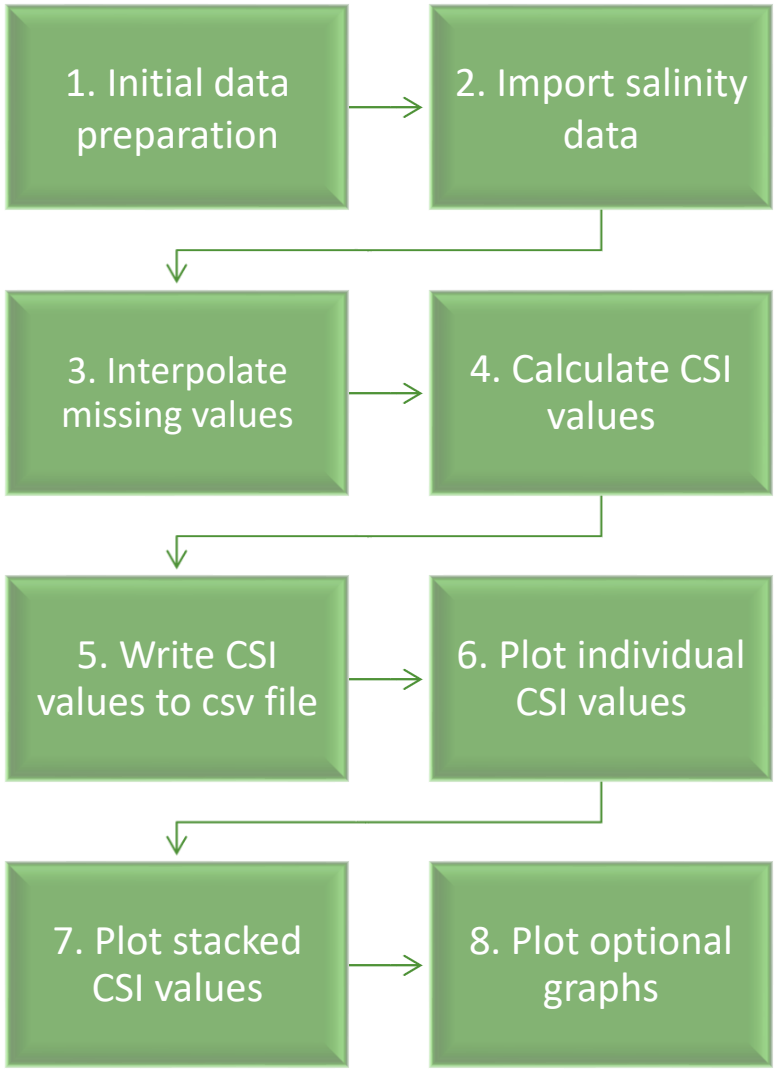


Coastal Salinity Classification	Description	Icon	Range	CSI Threshold values	Cumulative percentage
CD4	Exceptional salinity conditions		(∞, -2]	-2	2
CD3	Extreme salinity conditions		(-2.0 to -1.6]	-1.6	5
CD2	Severe salinity conditions		(-1.6 to -1.3]	-1.3	10
CD1	Moderate salinity conditions		(-1.3 to -0.8]	-0.8	20
CD0	Abnormal salinity conditions		(-0.8 to -0.5]	-0.5	30
Normal	Normal salinity conditions		(-0.5 to 0.5]	0	70
CW0	Abnormal freshwater conditions		(0.5 to 0.8]	0.5	80
CW1	Moderate freshwater conditions		(0.8 to 1.3]	0.8	90
CW2	Severe freshwater conditions		(1.3 to 1.6]	1.3	95
CW3	Extreme freshwater conditions		(1.6 to 2.0]	1.6	98
CW4	Exceptional freshwater conditions		(2, ∞)	2	100

Reference: Conrads and Darby, 2017

Computing the CSI using the CSI R package—general steps

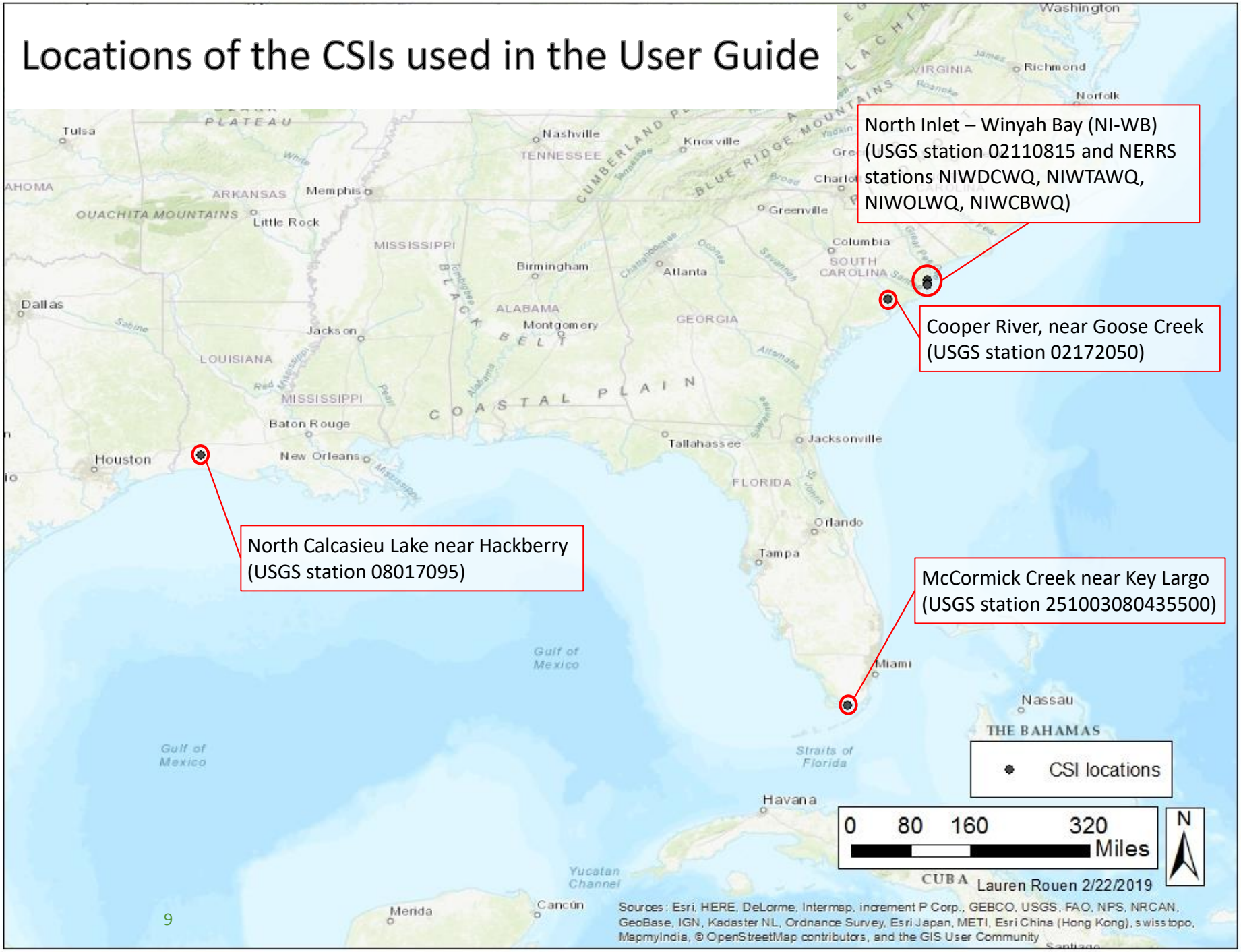
1. Initial data preparation
2. Import salinity data. Any source can be used (some data cleanup may be required—see package documentation for details on input formats). The U.S. Geological Survey (USGS) and National Estuarine Research Reserve System (NERRS) are two good sources of consistent data that have been used to calculate CSIs. Station data may be collected at any frequency from, for example, 6 to 30 minutes to hourly, daily, and so on. Specific conductance data can be converted to salinity within the R package.
3. Estimating missing values by interpolation, if desired
4. Calculate CSI values. Values are calculated for individual stations and are relative to each site.
5. Write CSI values to csv file
6. Plot CSI values on individual plot
7. Plot CSI values on stacked plot
8. Plot optional graphs



Example CSI R package workflow

```
> install.packages("devtools")
> devtools::install_github("USGS-EDEN/CSI")
> library(CSI)
> sc <- CSIimport_daily("~/Desktop/specific_conductance.csv")
        # Input daily specific conductance values with gaps

> sal_na <- CSIspec_con(sc)
        # Convert specific conductance values to salinity values

> sal <- CSIinterp(sal_na)
        # Linear interpolation to remove internal NA [null] values

> csi <- CSIcalc(sal)
        # Calculate CSI values on all gages in salinity object (scale 1-24)

> CSIwrite(csi, "~/Desktop/csi_values/")
        # Write CSI values to CSV files

> CSIplot(csi, "~/Desktop/csi_plots/")
        # Produce individual interval plots for all gages

> CSIstack(csi, "~/Desktop/csi_stacked_plots/")
        # Produced stacked CSI plots for all gages
```

Locations of the CSIs used in the User Guide



R package output—CSI values (comma-separated values [CSV])

Date (Year-month)

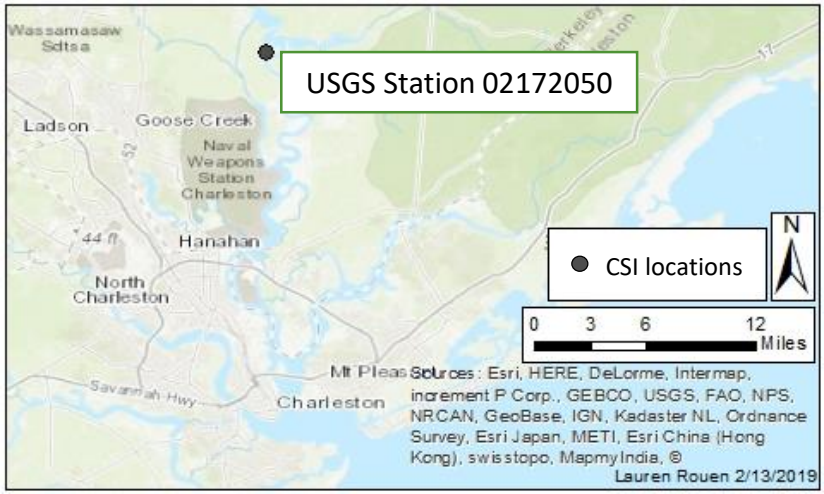
5-month CSIs (file includes values for 1 to 24 months)

Example CSV file

	1	2	3	4	5	6
1983-12	1.80075	NA	NA	NA	NA	NA
1984-1	0.035479	1.005482	NA	NA	NA	NA
1984-2	NA	0.052744	1.000505	NA	NA	NA
1984-3	NA	NA	0.04199	1.023545	NA	NA
1984-4	NA	NA	NA	0.060207	1.097926	NA
1984-5	2.979148	3.009404	2.943909	2.89788	1.442673	1.744983
1984-6	2.011916	2.661414	2.780837	2.831286	2.843461	1.912772
1984-7	1.876407	2.043076	2.458695	2.579658	2.666351	2.726766
1984-8	2.207211	2.176365	2.217223	2.529385	2.617929	2.693924
1984-9	2.049747	2.5549	2.419469	2.416288	2.625615	2.660091
1984-10	1.655514	2.1065	2.574553	2.473004	2.486758	2.646984
1984-11	1.38371	1.676721	2.062412	2.46208		
1984-12	1.755525	1.74066	1.910194	2.20801		

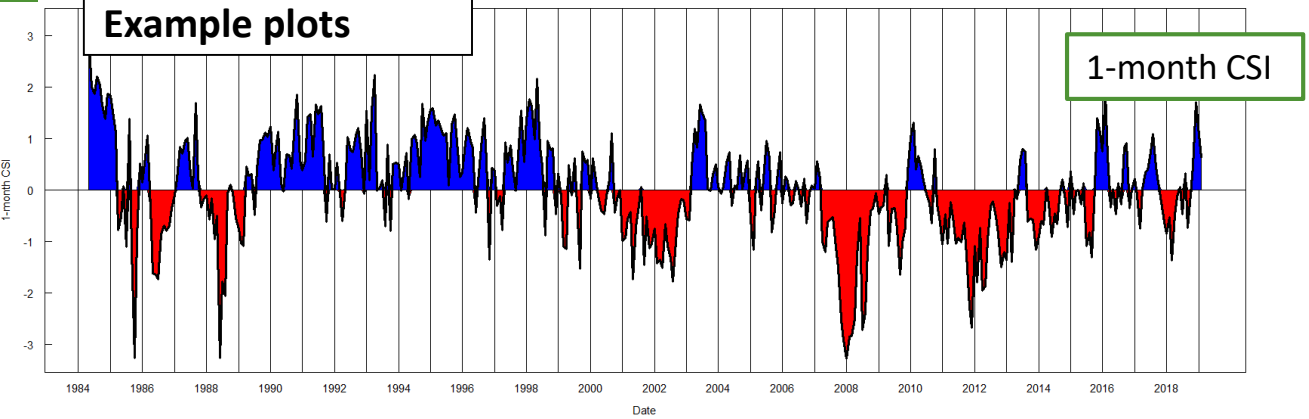
6-month CSIs cannot be calculated until there is 6 months of data

Here, "NA" indicates missing salinity data



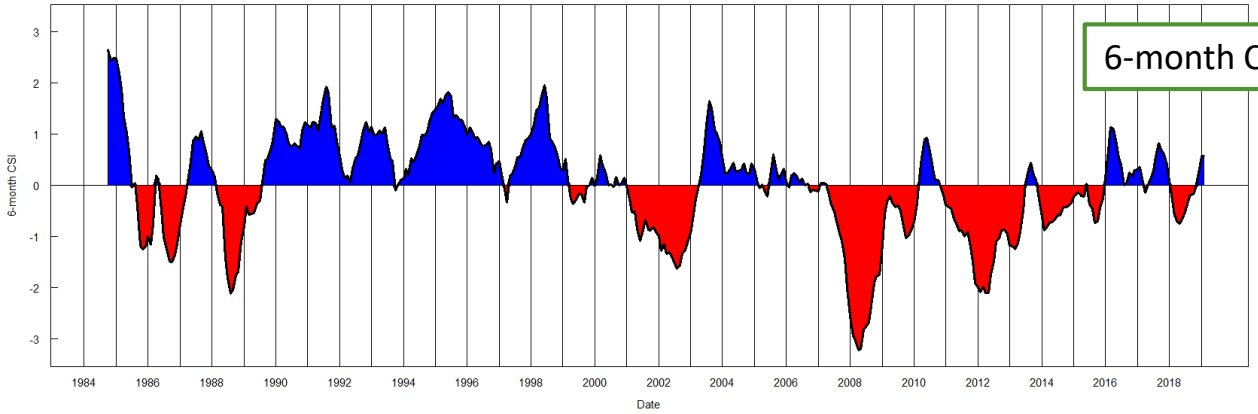
R package output—departure from mean plots

Example plots

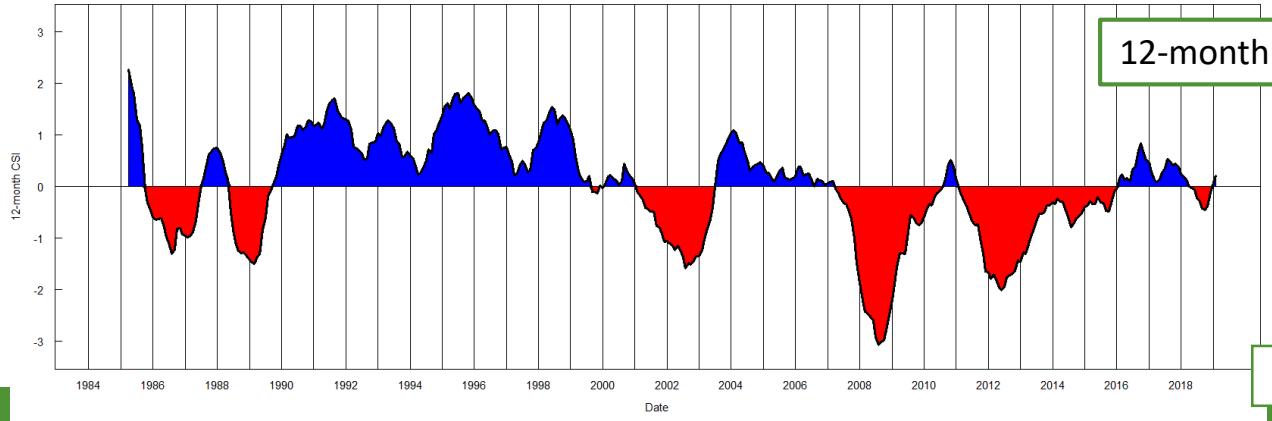


1-month CSI

Departure from mean plots show wetter-than-average conditions (positive CSI values) in blue, and drier-than-average conditions (negative CSI values) in red.



6-month CSI

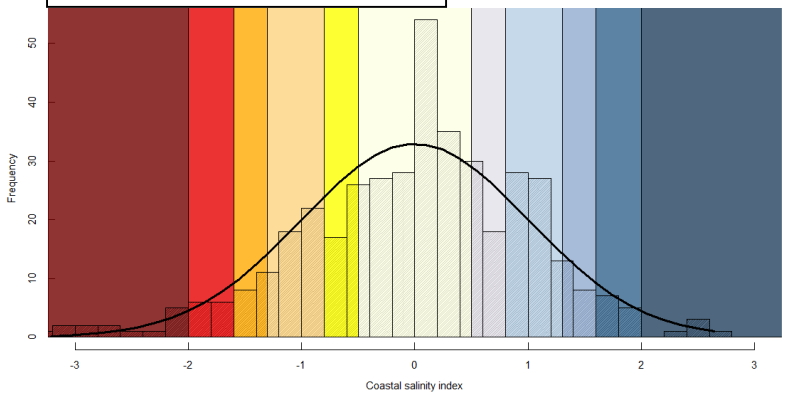


12-month CSI

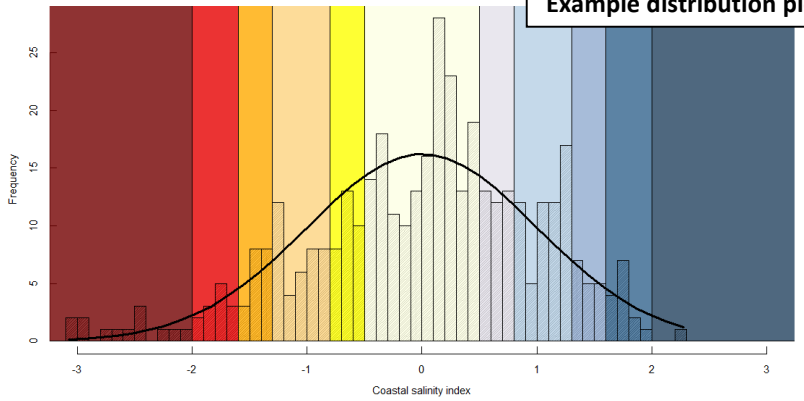
USGS Station 02172050

R package output—distribution and cumulative percentage plots

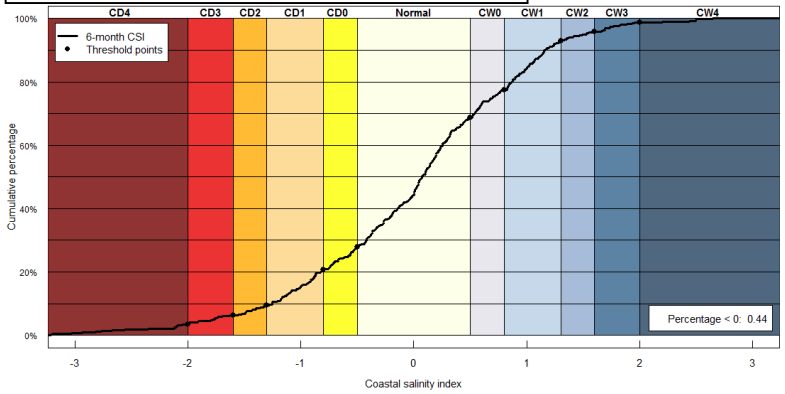
Example distribution plot (CSI-6)



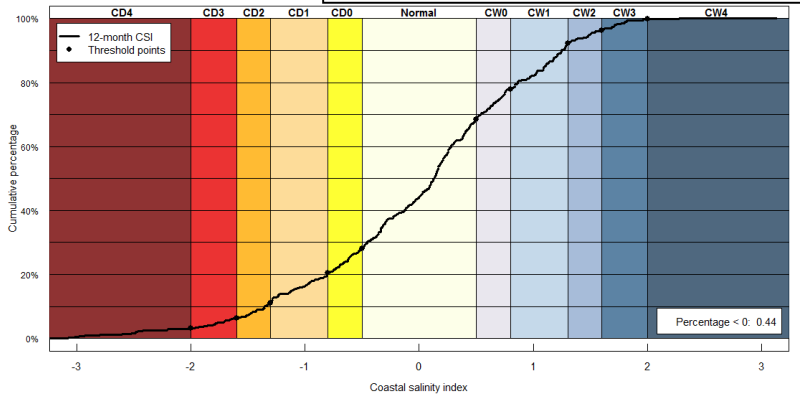
Example distribution plot (CSI-12)



Example cumulative percentage plot (CSI-6)



Example cumulative percentage plot (CSI-12)

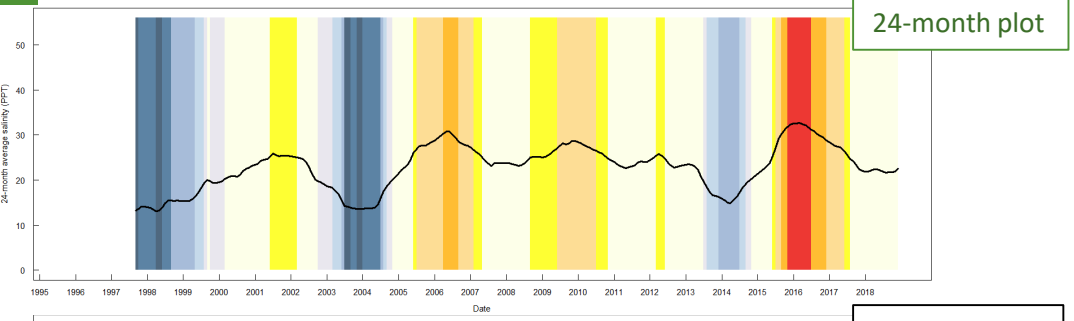


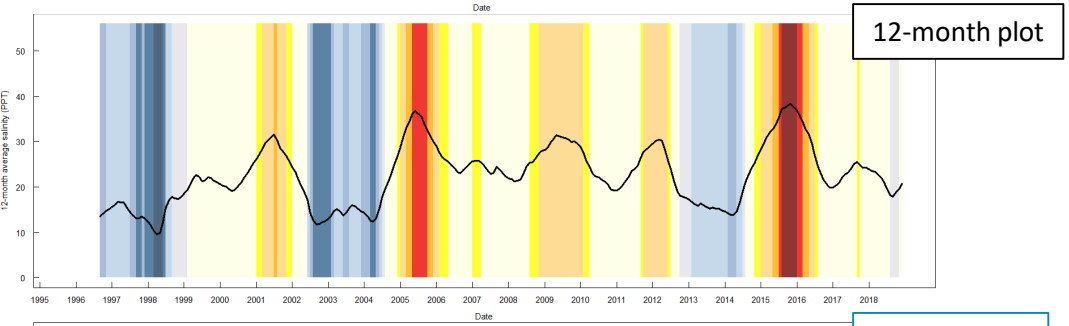
Example distribution plots and cumulative percentage plots for both 6-month and 12-month intervals.
The background color ramp represents the coastal salinity classifications.

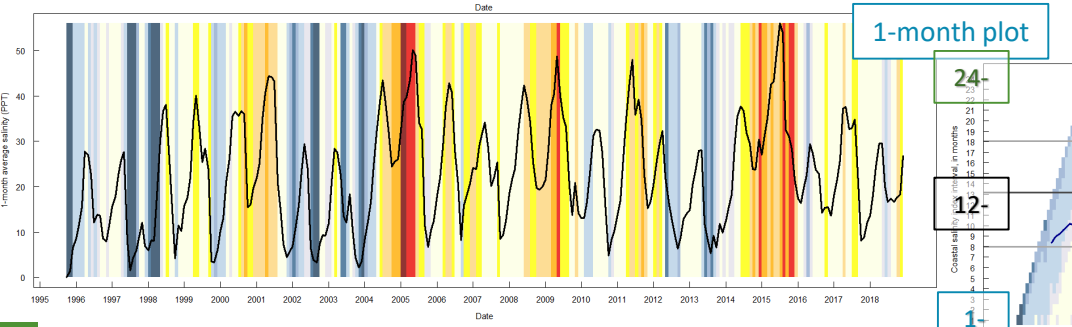
USGS Station 02172050

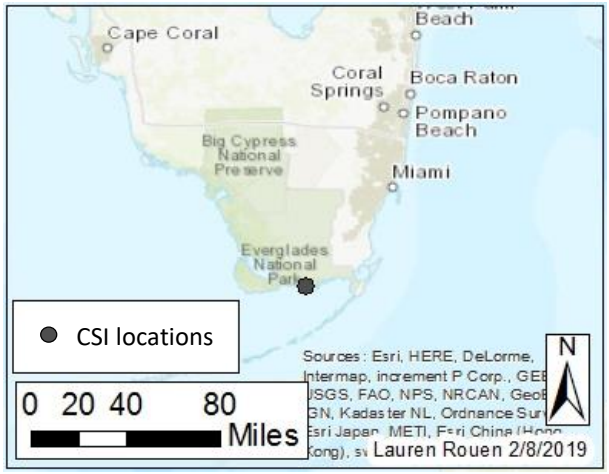
Creating a stacked CSI plot—step by step

- The stacked plot combines all interval plots (from 1 to 24 months) on one plot.
- The left Y-axis shows the computational intervals.

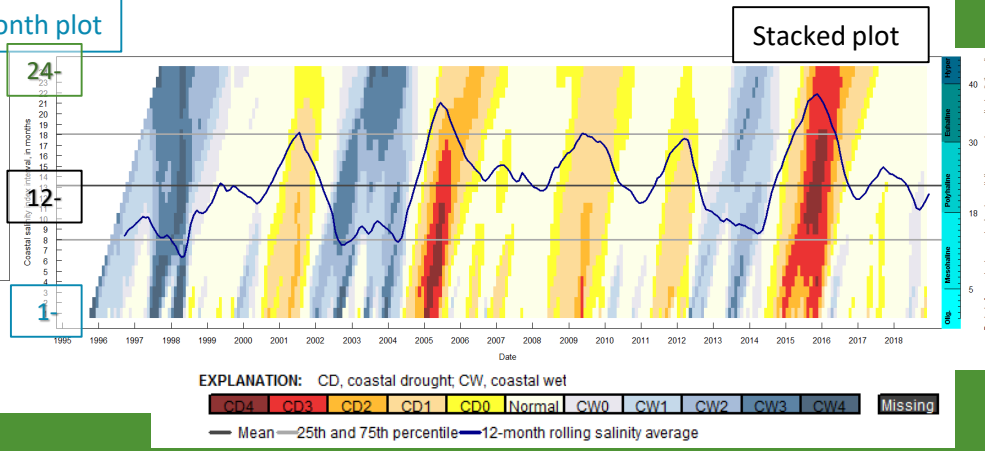






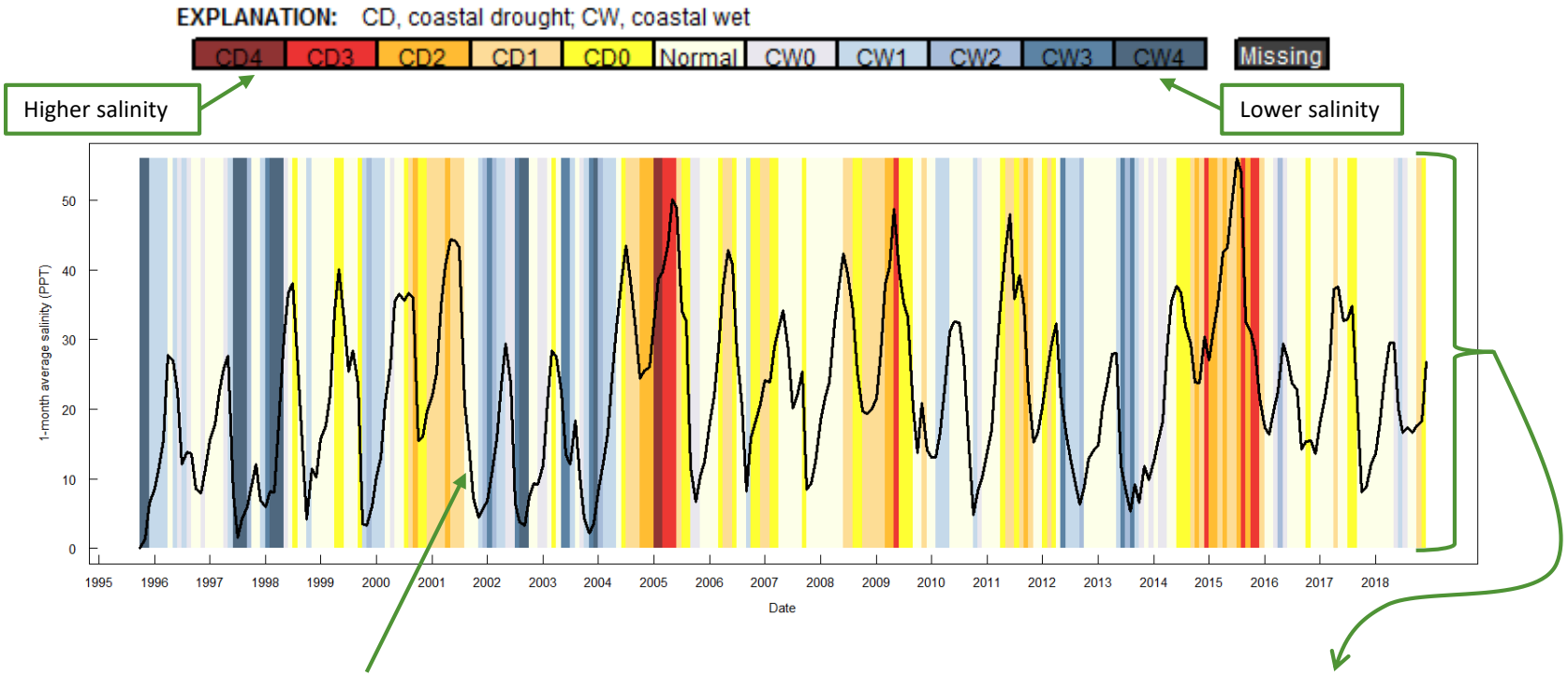


The CSI plots shown here and for the following "Creating a stacked CSI plot" examples are from McCormick Creek, USGS station 251003080435500, near Key Largo.



Creating a stacked CSI plot—step by step (continued)

The CSI can be used for short-, medium-, and long-term coastal evaluation depending on the computational interval selected. The computed 1-month CSI (CSI-1) for a location on McCormick Creek (near Key Largo, Fla.) characterizes the short-term salinity conditions.

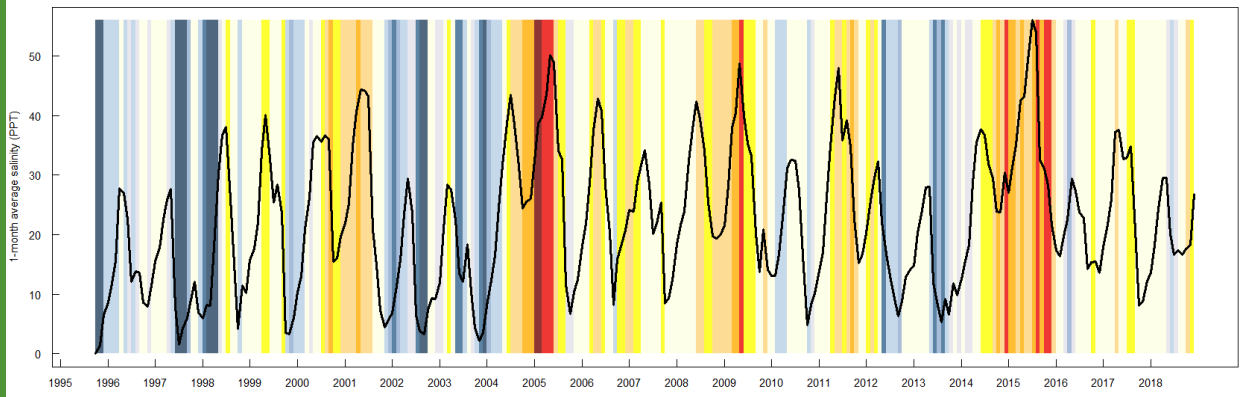


The black line depicts the average monthly salinity.

Background colors depict the coastal drought classes (CD0 to CD4; yellow-red color ramp) and coastal freshwater classes (CW0 to CW4; blue color ramp), as shown on the legend above. Extended drought periods, such as seen in 2005, and freshwater periods, as seen in 1997–1998, can be quickly identified.

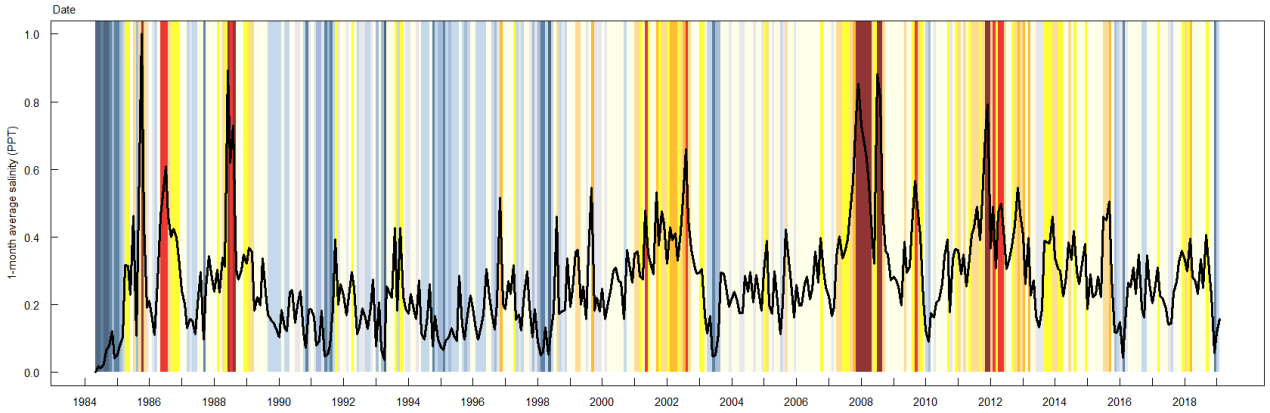
Creating a stacked CSI plot—step by step (continued)

- The CSI characterizes changes in monthly salinity conditions with respect to average conditions at a station.
- Color ramps indicate deviation of salinity conditions from the normal at a station, not a specific salinity value.
  - The blue color ramp indicates periods of lower-than-normal salinity conditions, while the red color ramp shows higher-than-normal salinity conditions.
- For example, the range of monthly salinity conditions at McCormick Creek range from 0 to nearly 60 parts per thousand (ppt). Other stations, particularly those that are further inland, may experience a much narrower range of conditions. The Cooper River station shown below is one such example, where salinity over the period of record ranges from just 0 to 1 ppt.



1-month CSI
USGS station 251003080435500
(McCormick Creek near Key Largo, Fla.)

1-month CSI
USGS station 02172050
(Cooper River near Goose Creek, S.C.)



EXPLANATION: CD, coastal drought; CW, coastal wet

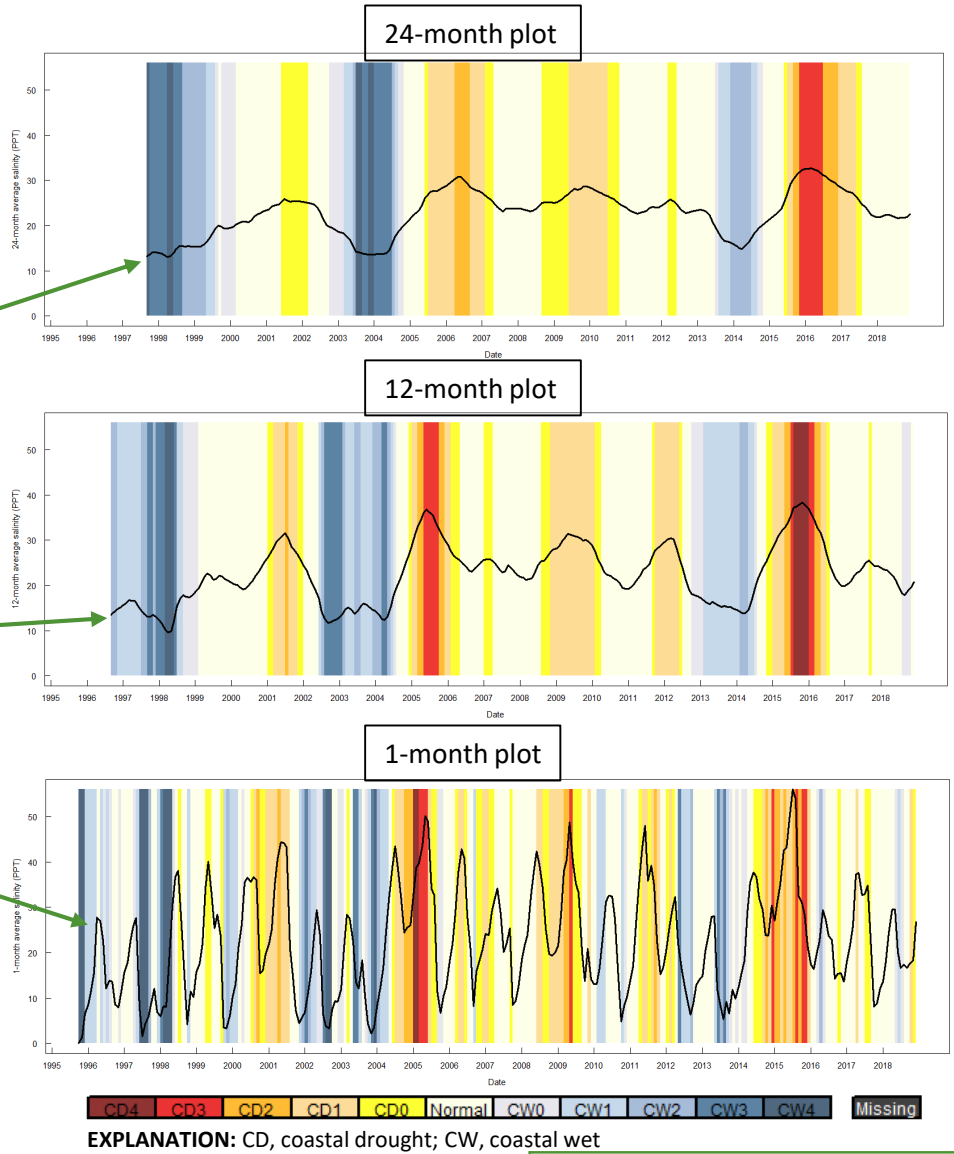
Creating a stacked CSI plot to show short- to long-term conditions

To evaluate medium- and long-term coastal salinity conditions, the CSI can also be computed for 12-month (CSI-12) and 24-month (CSI-24) intervals, respectively.

The black line for the CSI-24 shows the 24-month average salinity

For the CSI-12, the 12-month average salinity is shown

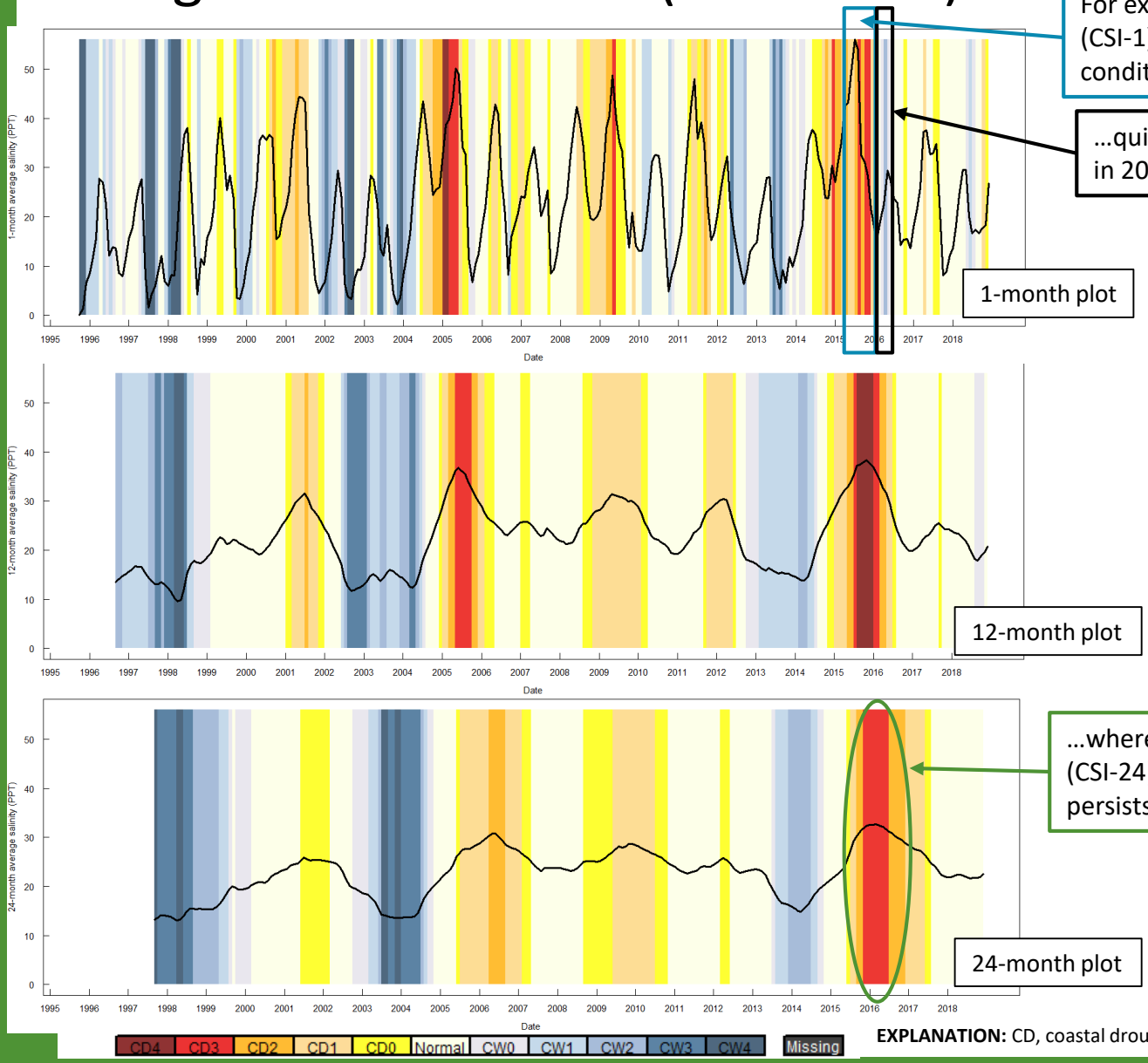
And for the CSI-1, the 1-month average salinity is shown



EXPLANATION: CD, coastal drought; CW, coastal wet

USGS Station 251003080435500

Creating a stacked CSI plot to show short- to long-term conditions (continued)



For example, short-term (CSI-1) coastal drought conditions in 2015…

…quickly recover in 2016…

1-month plot

In 2016, the 1-month interval indicates some degree of coastal wetness, whereas the longer 24-month interval indicates the persistence of coastal drought conditions that began in 2014.

12-month plot

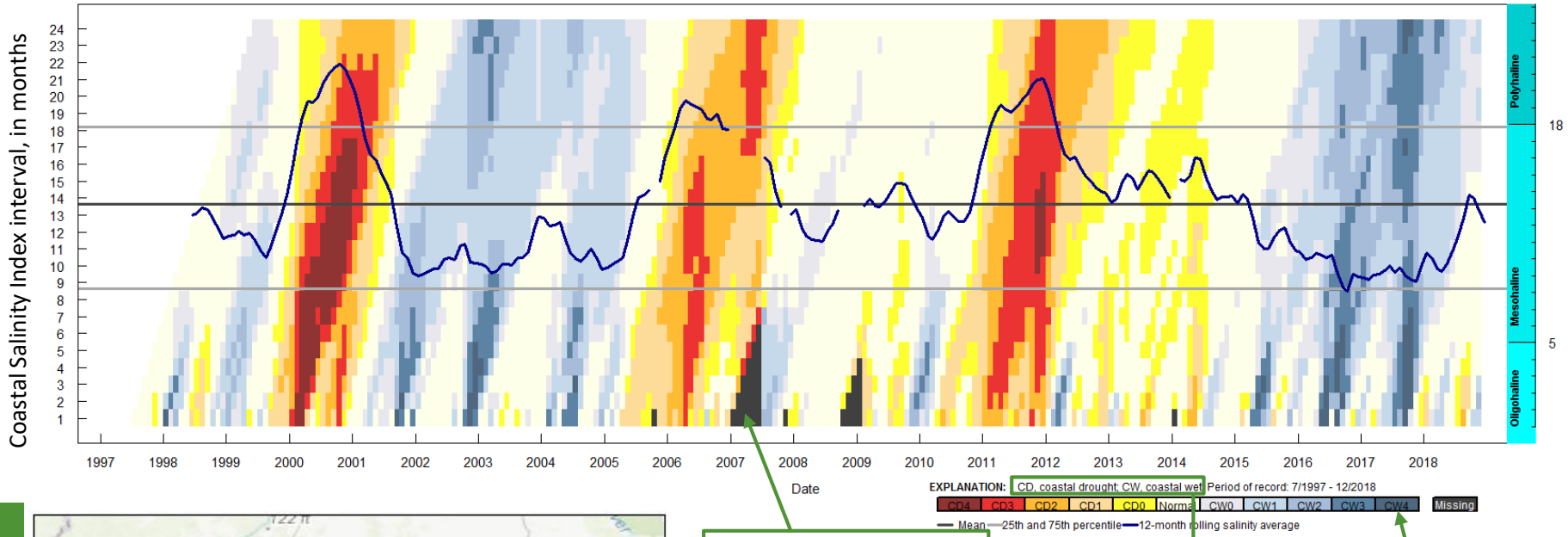
…whereas long-term (CSI-24) drought persists through 2016.

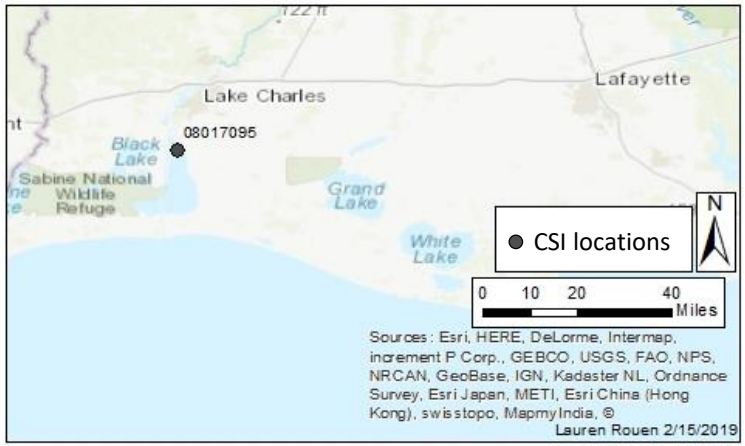
24-month plot

EXPLANATION: CD, coastal drought; CW, coastal wet

Elements of the CSI stacked plot—legend

The CSI plot shown below, and on the following "Elements of the CSI stacked plot" examples, is for North Calcasieu Lake (08017095), near Hackberry, Louisiana.





Months with missing data are indicated in gray

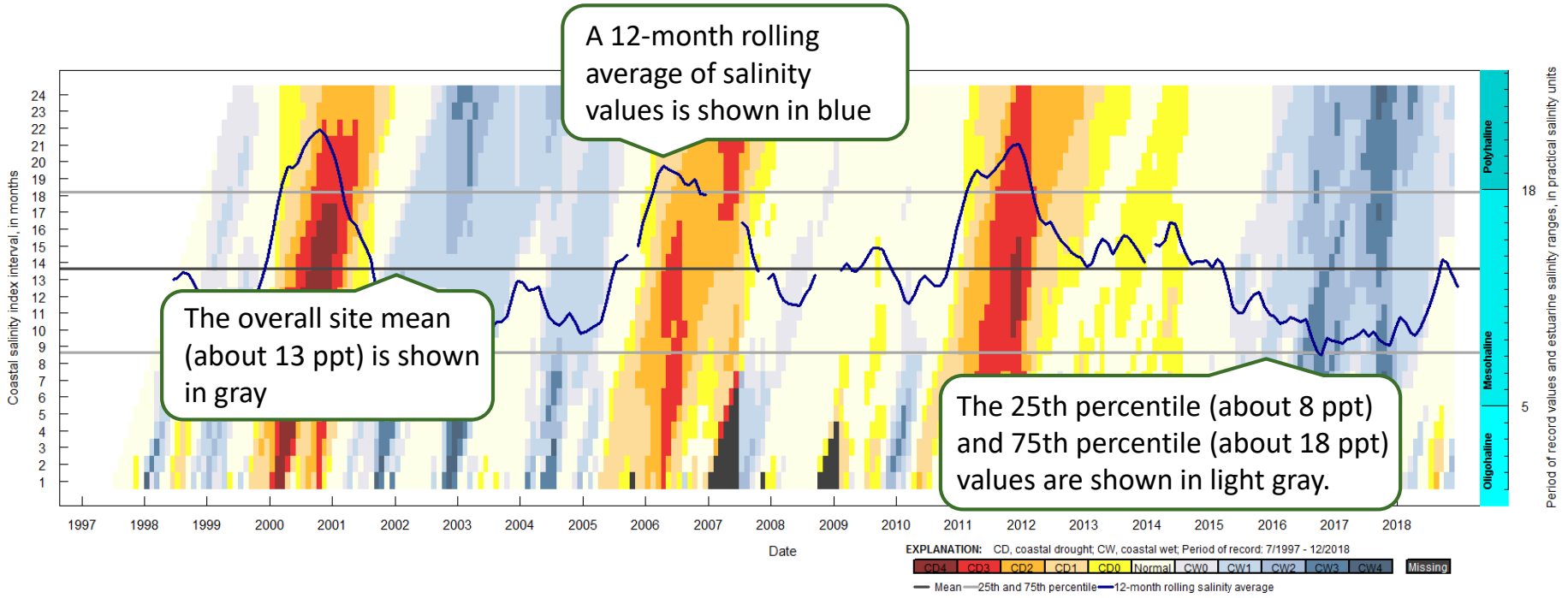
CD: Coastal drought
CW: Coastal wet

The color ramp indicates the Coastal Salinity Index value. A value of "normal" indicates historical mean salinity amount, and positive and negative values represent increasingly fresh and saline conditions, respectively. The color ramp is relative to the period of record and salinity range for each station, so a value of CW4 for this station may not be equivalent to a value of CW4 at a different station.

Elements of the CSI Plot—salinity

Information on the measured salinity at the site is also shown on the stacked CSI plot. The CSI characterizes deviations from average conditions for the computed interval but does not provide information on actual salinity values at the site.

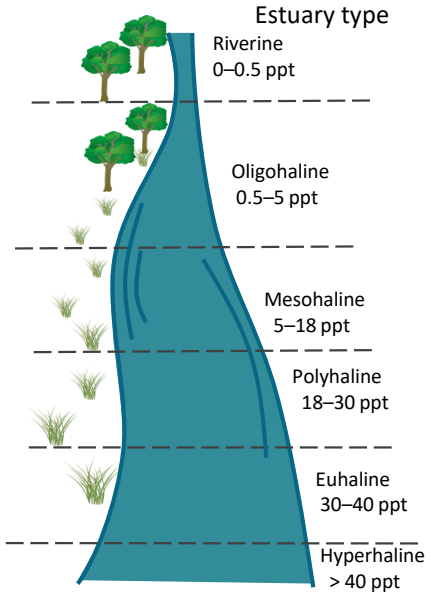
The stacked plot combines CSI values as well as measured salinity at the site. The right Y-axis shows the mean, 25th and 75th percentile salinity values.

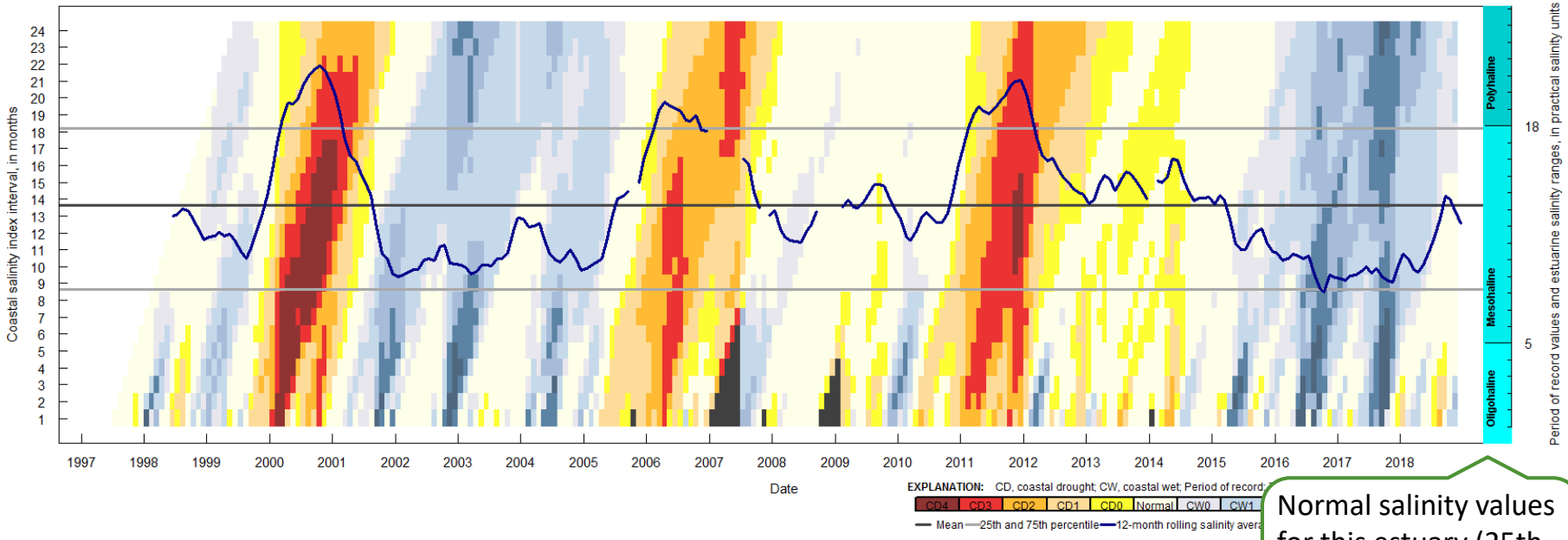


Elements of the CSI plot—right y-axis

The right y-axis of the stacked CSI plot shows typical salinity classifications for tidal waters from oligohaline (between 0.5 and 5 parts per thousand [ppt]) to euhaline (greater than 30 ppt).

For North Calcasieu Lake, the mean salinity conditions are in the mesohaline range.



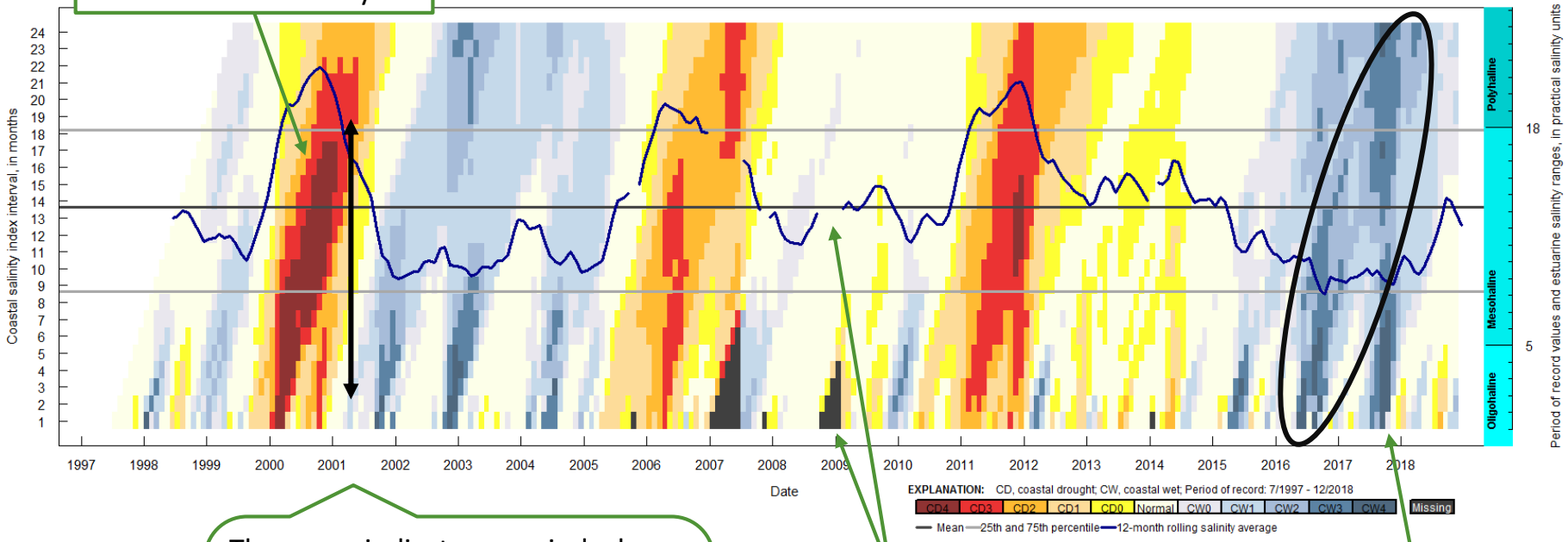


Normal salinity values for this estuary (25th to 75th percentiles) are mesohaline.

Reading the CSI stacked plot

These were some of the driest conditions (CD4) experienced by this station over its history.

The wet period that began in 2015 led to long-term wet conditions.



The arrow indicates a period when short-term conditions were fresh, but long-term CSI values indicate drought conditions. The short-term conditions indicate a recovery from longer-term drought conditions.

Gray indicates missing salinity data in the original record. CSI values cannot be calculated. Average salinity values also cannot be calculated, indicated by breaks in this line.

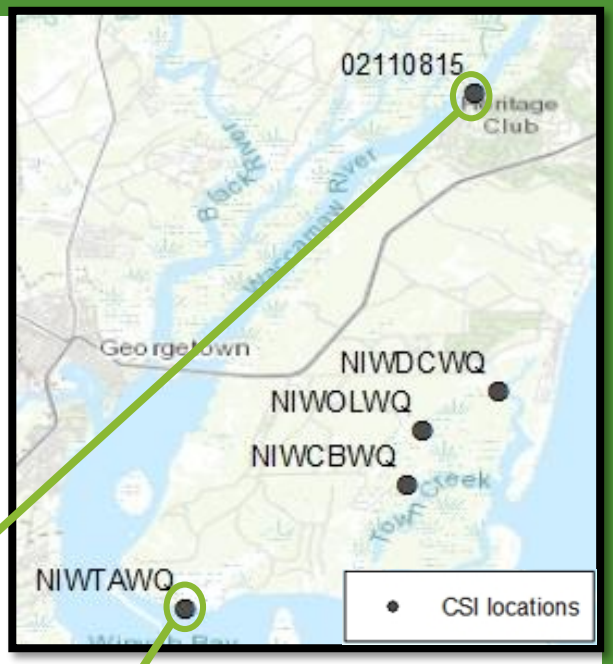
The CSI values shown here (CW4) indicate that these were some of the wettest conditions experienced by this station over its history.

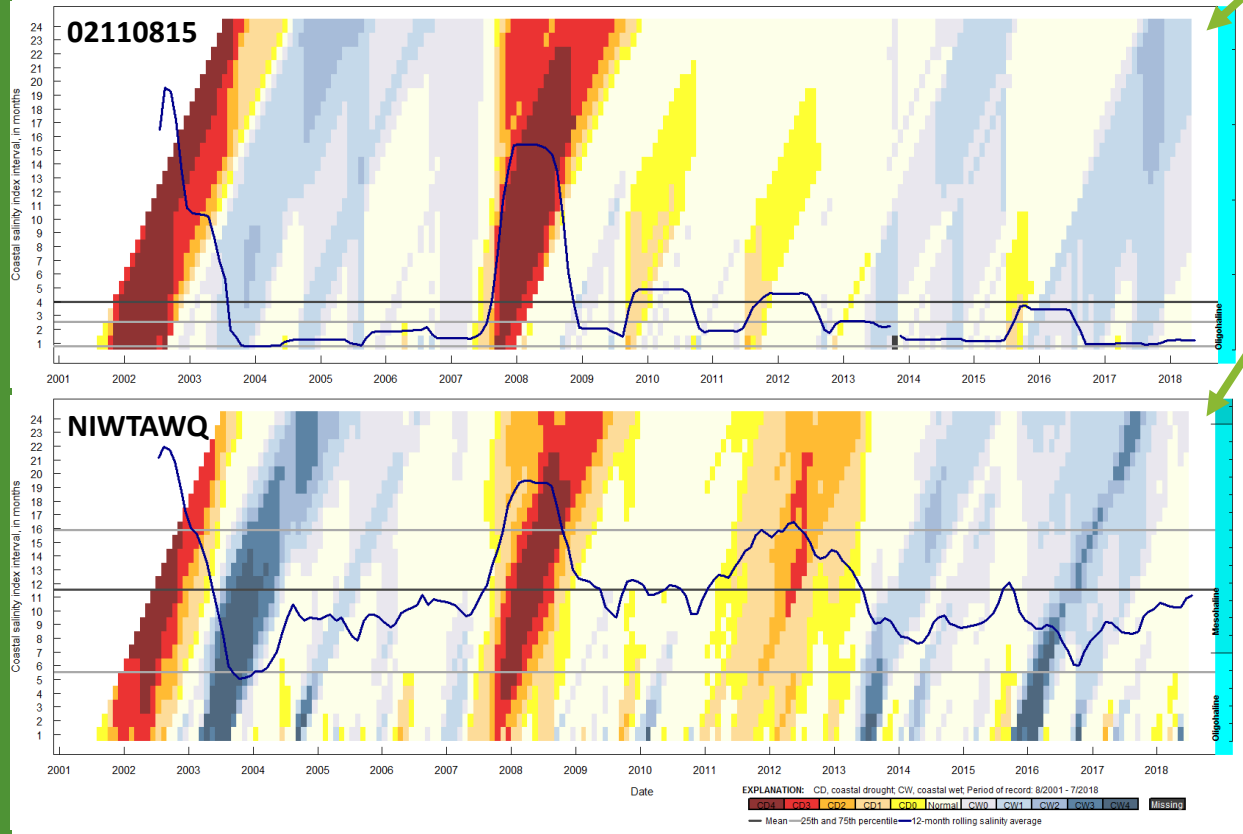
Comparing CSI results

This and the next slide show CSI values for multiple sites in the Winyah Bay watershed area of South Carolina.

02110815 is a USGS station, located on the Waccamaw River.

NIWTAWQ is a NERRS station, located in Winyah Bay. This is the third largest estuary on the east coast, based on watershed area, and is fed by five major rivers.



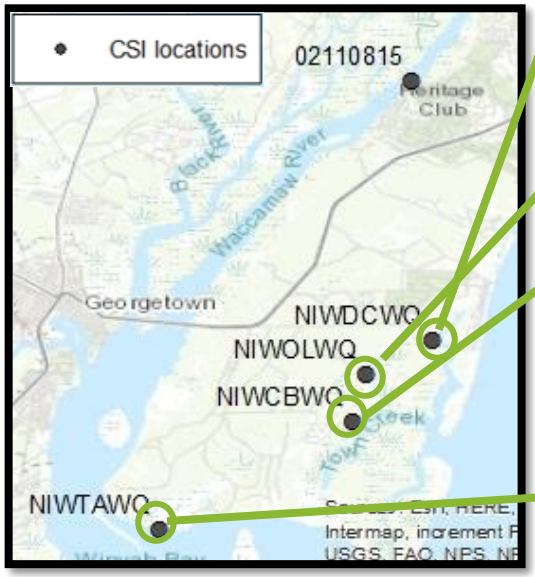


Station	Average salinity (ppt)	Classification
02110815	0.3	Oligohaline
NIWTAWQ	8.3	Mesohaline
NIWDCWQ	32.3	Euhaline
NIWOLWQ	32.7	Euhaline
NIWCBWQ	33.0	Euhaline

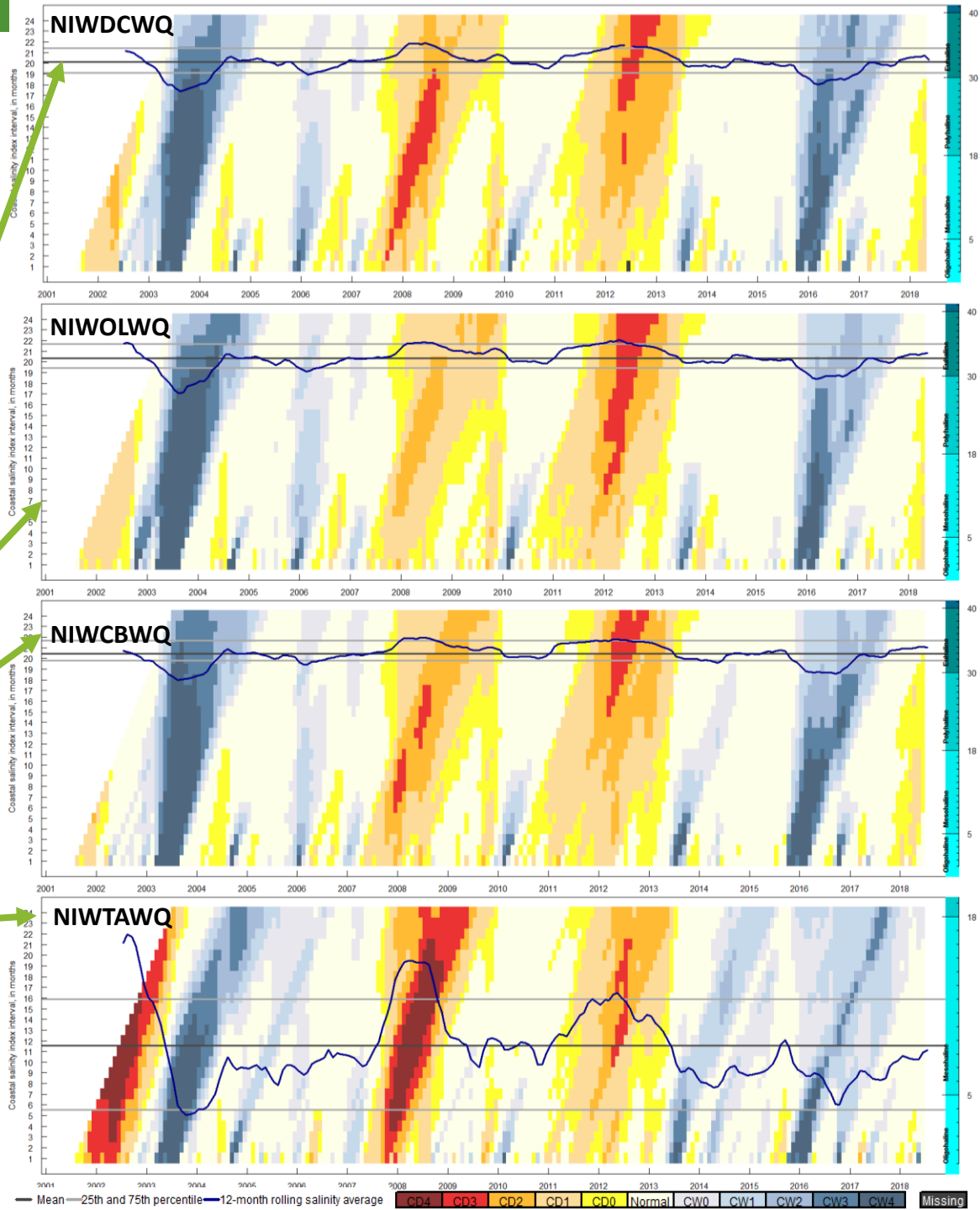
Comparing CSI results (continued)

All of the North Inlet-Winyah Bay NERRS sites are shown here, including the site shown previously (NIWTAWQ).

The NIWDCWQ, NIWOLWQ, and NIWCBWQ stations are located in the small, ocean-influenced North Inlet estuary.



Remember: the color ramp indicating wetter to drier conditions is relative for each site.



Selected references

Conrads, P.A., and Darby, L.S., 2017, Development of a Coastal Drought Index using salinity data: Bulletin of the American Meteorological Society, v. 98, no. 4, p. 753–766, accessed July 8, 2019, at https://doi.org/10.1175/BAMS-D-15-00171.1.

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Resources

- Coastal Salinity Index (CSI) GitHub, https://github.com/USGS-EDEN/CSI
  - CSI R package
- The National Integrated Drought Information System (NIDIS) Coastal Carolinas Drought Early Warning System (DEWS), https://www.drought.gov/drought/dews/coastal-carolinas
  - Information about the NIDIS program and projects in the Coastal Carolinas
- Conrads, P.A., 2016, Development of a Coastal Drought Index using salinity data: U.S. Geological Survey data release, accessed July 8, 2019, at https://doi.org/10.5066/F7TD9VDB.
  - U.S. Geological Survey data release that contains all supporting data for the Conrads and Darby (2017) article documenting the development of the CSI. It provides CSI values for the Hagley Landing and Little Back River stations.
- Petkewich , M.D., McCloskey, B.J, Rouen, L.F., and Conrads, P.A., 2019, Coastal Salinity Index for Monitoring Drought: U.S. Geological Survey data release, accessed July 8, 2019, at https://doi.org/10.5066/P9MQLNL2.
  - CSI values for 97 stations through September 30, 2018
- USGS Coastal Everglades Depth Estimation Network (EDEN), https://sofia.usgs.gov/eden/coastal.php
  - Real-time CSI values for South Florida locations within the EDEN
- USGS South Atlantic Water Science Center (SAWSC), www2.usgs.gov/water/southatlantic/projects/coastalsalinity/home.php
  - Real-time CSI values for select stations in North Carolina, South Carolina, and Georgia

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