

**Studying Earth's Environment
From Space**

<http://see.gsfc.nasa.gov/edu/SEES>

**Module 3:
Computer Lab
Exercises**

**EXPLORING
OCEANOGRAPHY
USING NASA
SATELLITE DATA**

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**NASA Goddard Space Flight Center,
Earth Sciences Directorate**

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Exploring Oceanography Using Satellite Data — Sea Surface Temperature

Overview

The set of exercises that follow were designed to explore characteristics of ocean circulation using satellite data. These exercises introduce students to basic image processing skills for displaying and analyzing images. Each exercise has scientific discussions explaining what the student is observing. Students will use NASA Image2000, to display and analyze the data sets.

The exercises are inquiry based and designed for advanced high school or introductory level undergraduate Earth science classes and associated computer labs. They were designed to be used in concert with an electronic lecture that contains scientific background information on ocean circulation and satellite observations of the sea surface and includes graphics that can be made into viewgraphs or slides to facilitate development and delivery of lectures. This “eLecture” is the Class Resources component of this SEES module.

Why Study Sea Surface Temperature

Earth’s climate has remained essentially unchanged for centuries. This is because the amounts of heat and water from all sources that enter (input) the atmosphere must equal the amounts removed (output) from the atmosphere for the climate to remain basically unchanged. Today, emissions of gasses such as carbon dioxide into the atmosphere (by humans) may be upsetting the temperature of the atmosphere necessary to maintain the balance between heat gained and heat lost. That is one problem that has scientists worried. Another is that recently scientists have been observing some global climate fluctuations that are taking place on the time scale of our human lives and seem to be linked to an oceanographic event called El Niño . Remember the severe weather associated with the powerful 1997-1998 El Niño :

- severe coastal storms, heavy rainfall, flooding and mud slides in California
- droughts in Mexico and Central America, which led to forest fires that burned for long periods of time sending heavy smoke north to the United States
- droughts in Australia that caused a shortage of water
- unusually mild winters on the east coast of the United States
- droughts in the Midwest of the United states
- economic disaster to the Peruvian fisheries

- ice storms in eastern Canada and New England that caused some areas to be without power for over a month as rain froze on contact with telephone poles, power pylons, wires and trees-- the weight of the ice caused pylons and poles to crumple and wires to break.

But, what do the oceans have to do with climate, you ask? The answer, a lot! The oceans and the atmosphere form a closely linked “dynamic duo.” Energy from the Sun, plant distributions, and greenhouse gases in the atmosphere can affect temperature and circulation patterns of this ocean-atmosphere duo.

The Sun is the Earth’s main source of energy. Solar (Sun) energy is absorbed (taken in) by both oceans and continents (land). BUT, because the oceans cover over 70% of Earth’s surface and are darker than the continents, they absorb more of the Sun’s energy. Here’s another big idea-- oceans not only absorb lots of energy from the Sun, they can also store lots of solar energy in the form of heat, AND they can do this with very little change in temperature. Scientists believe the way the oceans store and transport (move) heat is related to climate. One way scientists study the way the oceans store and transport heat is to look at the temperature of the oceans, specifically the sea surface temperature.

The seasons are an example of the annual variation of the Earth-Sun system. On the other hand, the dramatic warming of the eastern tropical Pacific Ocean during an El Niño event is an example of an interannual variation in the oceans. One reason scientists study the annual and interannual variability of the oceans and atmosphere is to identify and examine unusual or anomalous events that are caused by some natural or human induced forcing that may in turn cause severe weather patterns worldwide.

Sea surface temperature (SST) variability is an important parameter for monitoring climate change and periodic phenomena like El Niño. A global increase of SST, for instance, may be an indicator of global warming, and the change in its geographical distribution (which is what happens during an El Niño) can be a sensitive indicator of climate change.

In these exercises you will use research-quality SST data to investigate

- Geographical distribution of SST planetwide and associated features of ocean circulation
- Seasons, or the seasonal cycle (also called the annual variation) as expressed in SST
- Year-to-year variability, also known as the interannual variation, of SST

- How SST during an El Niño event varies from SST during “normal” conditions.

Global Monthly SST Data Set For 1982–1998

The data set you will use for these exercises is composed of gridded, monthly averaged SST measurements from both spaceborne instruments and ocean buoys and ships. The satellite SST measurements are derived from the Advanced Very High Resolution Radiometer (AVHRR) aboard the NOAA polar orbiting satellites. During the period 1982–1989, the in situ data, which consist of logbook and radio reports, were obtained from the Comprehensive Ocean Atmosphere Data Set. For the more recent periods, 1990–present, the in situ data were obtained from radio messages carried on the Global Telecommunications System. These data are produced as a real-time global SST analysis by Dr. Richard Reynolds of the Climate Modeling Branch of the National Centers for Environmental Prediction of the National Oceanic and Atmospheric Administration (NOAA). The data consist of 202 monthly files covering the period 1982–1998 and containing monthly averages of SST.

Before working with any data it is important to understand their characteristics. A knowledge of the data type, data source, geophysical units, file naming convention, and temporal and spatial resolution are critical to ensure correct scientific interpretation. Equally important is the software tool available for displaying and analyzing these data. You will be using *NASA Image2000*, a cross-platform modification of NIH Image that was developed especially for the Studying Earth’s Environment From Space educational modules.

Before You Begin

These exercises assume that the *NASA Image2000* software and the Exercise Data are correctly installed on your system. Refer to the *Image2000 Users Guide: Basic Operations* for assistance in installing the software.

Characteristics Of The Global Monthly Sea Surface Temperature Data Set For 1982–1998

Geophysical Measurement:	Sea Surface Temperature
Units of Measurement:	Degrees Celsius
Data Source:	Satellites (NOAA AVHRR) and in situ buoys
Temporal Resolution:	Monthly averages
Spatial Resolution:	1° latitude x 1° longitude
Software application:	<i>NASA Image2000</i>

NASA-Image2000

NASA-Image2000 is an image processing software package available on multiple platforms, designed to bring high-end scientific image processing capabilities to the standard desktop computer. Developed to meet the needs of educators, *NASA Image2000* supports the display, analysis and processing of satellite imagery.

In the past, users have been forced to choose between software designed for expensive high-end computer systems, and software that lacked many of the tools necessary for performing analysis of satellite images. *NASA Image2000* is designed to provide those tools in a system that is suitable for simple applications, such as would be used in a classroom, but is powerful enough to support research.

The functionality built into *NASA Image2000* was designed to provide the capability for the display and analysis of geo-coded satellite imagery. The breadth of functionality, however, goes well beyond this scope, and most types of images can be used. Users can perform standard image processing tasks, similar to those available in general graphics packages. In addition, the system provides other less common functions, which are specifically intended for use with scientific images. These exercises provide an introduction both to image processing in general, and to the specific use of *NASA Image2000*.

Loading the Data

All the images and software required for using these lessons are included in the *NASA Image2000 CD* (v.1.1 or higher). Simply install the software as indicated in the Read Me file on the DC or in the *NASA-Image2000 Basic Users Guide (Section 2)*, located in the doc folder.

EXAMPLE

...Title of procedure...

1. Insert ...
2. Select ...
3. Go to:

`<i2kinstalled>/data/SEES/Ocean/ocex1/
GA801001.N7T`

- 4—Click on ...
-

Important Notes On Presentation

Because there are multiple data source possibilities, navigational paths for moving through the hierarchical directory structure of your computer and *NASA Image2000* materials are referenced from the location of your *NASA Image2000* installation. The path is shown as follows:

`<i2kinstalled>/data/SEES/Ocean/<exercise >/<file name>`

In addition, notes, specific tasks and exercises are presented in the left column (see example at left).

For Further Research:

How to use the SEES electronic text to support inquiry based exercises

In several of the computer lab exercises, questions will be asked of the user that can not be directly answered through the image analysis software and activities. These questions can be directed to the SEES electronic textbook. This electronic textbook is organized like a printed textbook. It also contains digital files for the graphics that you may either view directly on screen or obtain high-resolution versions for sending to a printer to make color view graphs for overhead projectors. A glossary for each module is also provided. The electronic textbook for each module can also be used to support lecture materials, independent student investigations, or other applications that may require more detailed scientific background.

Accessing the SEES electronic textbook

The SEES electronic textbook is available in two locations:

- 1) On the web at <http://see.gsfc.nasa.gov/edu/SEES>. From the home page, find the link “Class Resources” under the module you are interested in. This will pull up the textbook homepage for that module. Links to each chapter are listed here, leading you to the detailed etext, digital files, and graphics you are searching for.
- 2) On the CD “Studying Earth’s Environment from Space, educational materials for students and teachers grades 11-16,” available from the NASA CORE (Central Operation of Resources for Education), at <http://core.nasa.gov> or toll free 866-776-CORE. Once the CD is loaded on your computer, you can access the home page for the etext by going to sees_v1/htmlpages/index.html for ozone and global land vegetation modules and sees_v2/htmlpages/index.html for polar sea ice and oceanography modules.

If you have comments, problems, or suggestions, please e-mail helpdesk@see.gsfc.nasa.gov.

Exercise 1: Investigating The Characteristics Of The Global Monthly Sea Surface Temperature Data Set For 1982–1998

Overview

In this activity you will learn how the global sea surface temperature (SST) data files were named, how to open and display the data files as images using *NASA Image 2000*, and how to apply a color table to the images. You will also learn how to convert an image's pixel values to actual temperatures in degrees Celsius.

Before working with any data it is important to understand their characteristics. A knowledge of the data type, data source, geophysical units, file naming convention, and temporal and spatial resolution are critical to ensure correct scientific interpretation. Equally important is the software tool available for displaying and analyzing these data. You will be using *NASA Image2000*, a cross-platform modification of NIH Image that was developed especially for the Studying Earth's Environment From Space educational modules.

Characteristics Of The Global Monthly Sea Surface Temperature Data Set For 1982–1998

Geophysical Measurement:	Sea Surface Temperature
Units of Measurement:	Degrees Celsius
Data Source:	Satellites (NOAA AVHRR) and in situ buoys
Temporal Resolution:	Monthly averages
Spatial Resolution:	1° latitude x 1° longitude
Software application:	<i>NASA Image2000</i>

Exploring Global, Monthly Sea Surface Temperature

There are three types of SST data files provided.

- Global, monthly-average SST files for 1982–1998 (202)
- Global, monthly, climatological SST files (12)
- Regional, high resolution, monthly-average SST data sets for four regions for 1988–1993

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

The first two data sets contain monthly-average values of SST in units of degrees Celsius over the entire planet, excluding land. The spatial resolution of these images is approximately 1° latitude by 1° longitude per pixel. This means that each pixel in the image has the equivalent geographic scale of about 1° latitude by 1° longitude. The monthly climatological SST data set is provided for use in Exercise 4 and was obtained by averaging the monthly, global SST data for the period 1982–1998. The regional, high resolution SST data sets are also monthly averaged, however the spatial resolution is about 9 km by 9 km per pixel. High resolution regional data exist for the following areas.

- Northeast Pacific Ocean
- Northwest Atlantic Ocean (including the Gulf Stream)
- Gulf of Mexico
- Indian Ocean (including the Arabian Sea)

For the three SST data types described above, the file names are constructed as follows:

Global, monthly-average SST files for 1982–1998

gmYYMMt.tif

where YY = last two digits of the year (from 82–98)

MM = two digits representing the month (from 01–12) where 01=January, 02=February, etc.

Global, monthly climatological SST files

glocIMMt.tif

where MM = two digits representing the month (from 01–12) over which the climatological average was computed

Regional, high resolution, monthly-average SST data sets for four regions for 1988–1993

RRRYMMt.tif

where RRR= nep for Northeast Pacific
nwa for Northwest Atlantic
gom for Gulf of Mexico
ind for Indian Ocean

YY = last two digits of the year (from 88–93)

MM = two digits representing the month (from 01–12) where 01=January, 02=February, etc.

Opening And Displaying A Global SST Data Image

Before Beginning

- Make sure you have read through the Introduction to Module 3: Exploring Oceanography Using Satellite Data-Computer Lab Exercises document.
- Start *NASA Image2000*, or if it is already running close any open images

Exercise 1.A

Open a data file in *NASA Image2000*

1. Pull down the **File** menu and choose **Open** OR
Click on the **Open** icon on the toolbar.
The **Open** window is displayed.
2. Locate the folder called “Monthly” and select any monthly averaged image for any year.
<I2KInstalled> | data | SEES | Ocean | sst_entire | monthly | <year> | <file>
3. Click on the **Open** button to open the image.

Overview

We will begin by using *NASA Image2000* to open and display a Global SST data image.

Do Exercise 1.A now.

You should see an image on your screen that looks like a rectangular map of Earth in shades of gray.

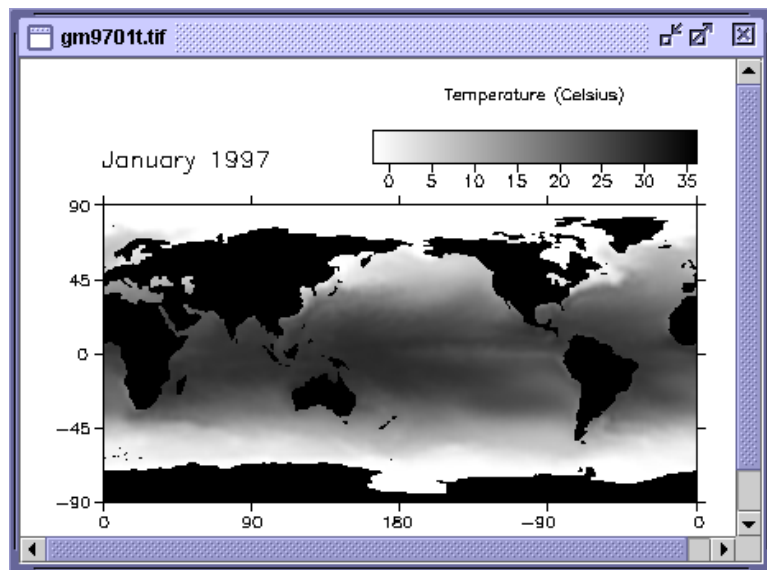


Figure 1.1 This image is a monthly average SST image for January 1997.

Answer These Questions:

1. Write down the name of the file you imported.

2. Interpret the file name and record the year and month of the SST image you displayed.

Month _____

Year _____

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

**Exercise 1.B**

Color the image using a Look Up Table (LUT):

1. Pull down the **View** menu and select **Lookup Table (LUT)**

The LUT window is displayed.

2. Click on the **Load** button.

The Open File window is displayed.

3. Select the LUT you wish to apply, called “SST.lut”

4. Click on the **Open** button.

The new LUT is displayed in the LUT window, showing you the new RGB display values for each raw pixel value. The image is also updated to display the new values.

5. Click in the **Use as default** checkbox.

As long as the LUT window is open, this LUT will be applied to future images.

Adding Color To The Image

To better distinguish differences in SST of the oceans we can apply color to the image using a color table, also called a color look-up table (LUT), that assigns SST values to each color.

**Do Exercise 1.B now.**

The image should now be displayed in color and the LUT window will display the color range used. Notice that the LUT window corresponds to the color legend on the image. This legend associates the color of the pixels in the image to their corresponding SST.

Understanding Display Windows And Images

If you do not have a global SST image open on your screen, open one now. You do not need to apply color to this image. This is called the Display Window. Notice the elements that make it up. Across the top of the Display Window the file name is displayed. In the top, right corner there is a color legend, labeled with the units of the data. To the left of the color legend, the month and year of the data are displayed. The image itself has a thin black border around it and tick marks indicating latitude and longitude. In these exercises, “the image” refers to only the information within the latitude-longitude annotations. “Display Window” refers to the entire figure including the color legend and annotations. In most of these exercises, you will be working with only the image itself, not the entire Display Window.

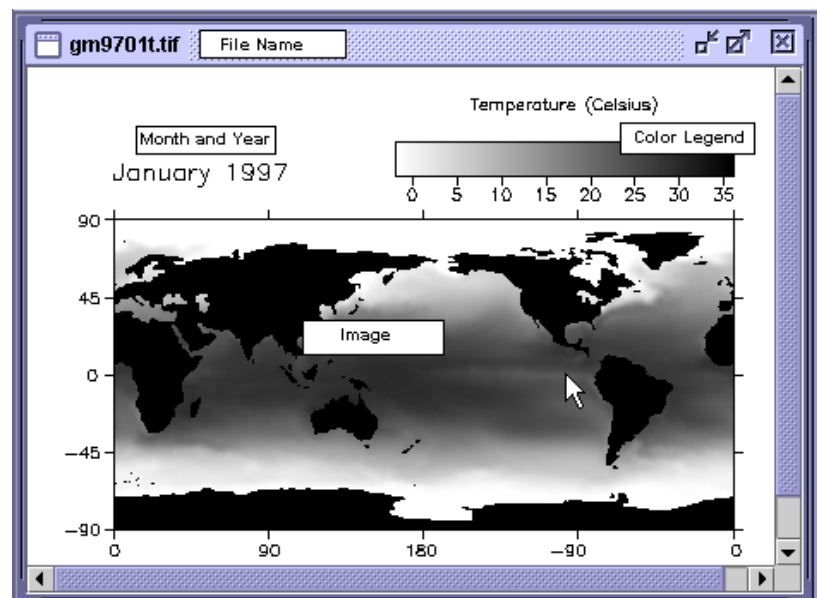


Figure 1.2 Sample image display window.

Studying How The Images Are Organized Geographically

Now study the latitude and longitude annotations on the image. North latitudes are always positive and south latitudes are always negative. These images are centered on the Equator (0° latitude) and the International Date Line (180° longitude). Longitudes are referenced to the Greenwich Meridian (0° longitude) with longitudes to the east of 0° being positive and longitudes to the west being negative. Answer some general questions to get familiar with the geographic layout of the image.




Exercise 1.C

Pick your spot

1. Pull down the **View** menu and choose **Image Info**.

The **Image Info** window is displayed.

2. Select the Rectangular Selection Tool from the Tools Window so your cursor will look like a crosshair. Place your cursor on the approximate geographic center of the image . 

3. Move your cursor up to the Color Legend and slide it along the color bar until you observe the same value in the Info Window as you recorded in Question #3.



Do Exercise 1.C, steps 1 and 2 now.

3. Record the Pixel Value from the Info Window at this location.

Value: _____



Do Exercise 1.C, step 3 now.

- 4a. Read the SST in degrees Celsius from the color legend and record it below.

SST in degrees C: _____


- 4b. Similarly, locate and record below the SST approximately at the intersection of the Greenwich Meridian and the Equator.

SST in degrees C: _____



Exercise 1.D

Add Labels

1. Select the Text Tool  and label north and south latitudes and east and west longitudes directly on the image by typing the words “north,” “south,” “east,” and “west” in the appropriate locations. Click once on the Text Tool and you can begin typing right on the image.

Note: To change the color of the text, click once on the “top” square in the left-hand color box that appears at the bottom of the tool window when the Text Tool is selected. Then, move the cursor into the color picker on the right, and click once on the color you wish to use.



Do Exercise 1.D now.

Later on, in the section on the relationship between pixel value and SST, we will examine the relationship between the Value (also called a “pixel value”) and the SST in degrees Celsius. For now, just familiarize yourself with the various *NASA Image2000* windows and with reading the SST from the color legend.

Studying Data Spatial Resolution



Exercise 1.E

Identify X and Y values to determine the size and resolution of the image

1. Position cursor at the left-hand edge of the image (not the display window) and note the X value from the Image Info window.
Then, position the cursor at the right-hand edge of the image, and note the X value from the Image Info window. The difference between the two values is the number of pixels wide.
2. Repeat Step 1 from the top of the image to the bottom, recording the Y values from the Image Info window. Again, the difference between the two values is the number of pixels high.

Overview



Do Exercise 1.E now.

Answer These Questions:

- 1a. How many pixels wide is the image? _____
- 1b. How many pixels high is the image? _____

These images have

- 2a. _____ pixels per degree of latitude and
- 2b. _____ pixels per degree of longitude.
- 3a. Therefore, the smallest SST feature that can be resolved in these images (the spatial resolution) is _____
- 3b. The images in this data set have a spatial resolution of _____ latitude by _____ longitude.

Some characteristics of Earth observing satellites make it difficult to interpret the data without some considerable manipulation. One such characteristic of thermal-infrared sensors such as AVHRR is the inability to “see” the ocean’s surface in the presence of clouds. For this reason, and to reduce the overall data volume, we will use monthly averaged images in these exercises. It is useful, however to consider a satellite image of the ocean’s surface temperature for a single day.

Open the file

`<I2KInstalled> | data | SEES | Oceans | sstex1 | gd94182t.tif`

and apply the SST LUT, if necessary. This image depicts the SST distribution for a single day, July 1, 1994. What colors represent land and missing data (clouds) in this image?

- 4a. Land _____
- 4b. Clouds _____
- 5a. Estimate what percentage of Earth is covered by ocean: _____


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- 5b. Estimate the percentage of ocean area covered by clouds:_____
- 6a. Discuss the benefits and drawbacks of monitoring the ocean temperature using daily images such as this one.
- 6b. Discuss the benefits and drawbacks of monitoring the ocean temperature using monthly images.

Close all images before proceeding to the next section.

The Relationship Between Pixel Value And SST In Degrees Celsius

Overview

 Repeat Exercises 1.A and (if needed) 1.B to open and color a data file from either year.

Record the month and year of the image you opened.

Month: _____ Year: _____

Move the cursor around in the image you opened. Look at the number associated with Value in the Info Window. These are the pixel values associated with each color. The images are stored as byte data with pixel values between 0 and 255 ($2^8 = 256 = 1$ byte). This is a way to compactly store data in a digital format. As you move your cursor around in the image using the mouse, the Info Window shows you the X and Y coordinates of the current position of the cursor, relative to the lower left corner of the Display Window, and the pixel Value associated with that position in the image. Become familiar with this notation before moving on.

The relationship between pixel values, which range from 0 to 255, and the actual SST values, which range between 0.0° C and 35.0° C, is an important one to understand. Pixel values of 0 and 255 are the only two that do not correspond to an SST value in degrees Celsius. They are always reserved to delineate certain features of an image.

Answer These Questions:

- 1a. What pixel value is associated with black? _____
- 1b. What is represented by these pixel values?
- 1c. What pixel value is associated with white? _____
- 1d. What is represented by these pixel values?

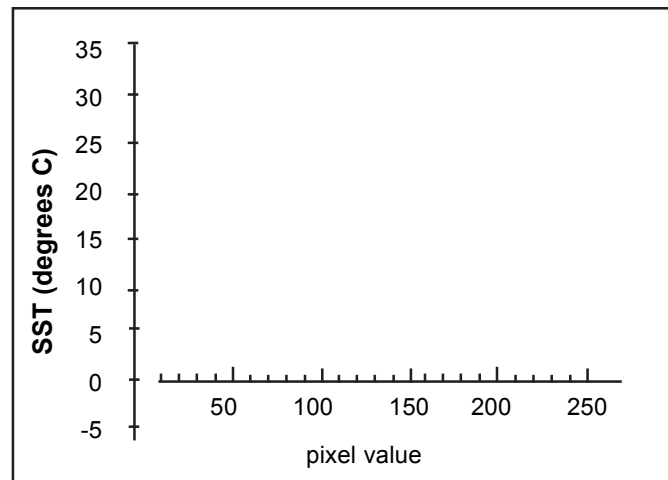
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The following table contains the pixel values from one of the global, monthly-average SST images (we'll call this variable A). Move the cursor along the color legend on the Display Window so that the Pixel Value in the Image Info window corresponds to each of the pixel values in column A. Read the corresponding SST value from the color legend (get as close as you can within the 5° increments), and write the degree amounts in the B column of the table.

2.

	A B Pixel Value	SST (°C)
1	2	
2	34	
3	74	
4	101	
5	152	
6	185	
7	208	

3. Graph the above pairs of numbers on the axes below.



4. Study the graph of points you just plotted. Describe the relationship between the pixel values and corresponding SST values (in °C). How are they related?

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

It appears that the points lie along a straight line; i.e., there is a linear relationship between pixel values and SSTs.

- 5a. Draw a “best fit” line that comes closest to connecting the points on the graph.
- 5b. Is the slope of this line positive or negative? _____
- 5c. Is the Y-intercept of the line positive or negative? _____

A line, like the one you drew to connect the points you plotted can be described by the following equation.

$$y = mX + b$$

where m is the slope of the line

b is the Y-intercept (the value of Y when $X=0$)

The slope of a line is described by the following equation.

$$m = (Y_2 - Y_1) / (X_2 - X_1)$$

- 6a. Find the slope (m) of the line you graphed by substituting values of X_1 , X_2 , and Y_1 , Y_2 from the table on page 11 into the above equation. Do this for more than two X , Y pairs to convince yourself of the result.

$$m = \underline{\hspace{2cm}}$$

- 6b. Now find the Y-intercept (b) by reading the value of Y when $X = 0$ from your graph.

$$b = \underline{\hspace{2cm}}$$

- 6c. Substitute m and b into the equation of a line as it is written below.

$$\text{SST} = m(\text{pixel value}) + b$$

Congratulations! You just derived the relationship between pixel values in an image and SST in °C.

Now compare your Question 3 plot with others in your class.

7. How alike are they and why?

The range of pixel values in these images is from 1 to 254 (remember that 0 and 255 correspond to land and ice, respectively).

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

8. Using the equation you just derived, what is the corresponding range of SSTs?

Remember, you may always simply read the SST value from the color bar legend provided in the Display Window.

Move your cursor over regions of land and ice in the image and study the values in the Info Window. Move your cursor all around the image now and answer the following questions.

9. What is the approximate range of temperature values displayed in this image and where in the oceans are the coolest and warmest SSTs? Fill in the values.

COOLEST REGION

WARMEST REGION

Pixel Value= _____

Pixel Value= _____

SST= _____°C

SST= _____°C

Color= _____

Color= _____

Location is _____

Location is _____

Before proceeding to the next section:

- Reset the Measurement Table
Pull down the **Image** menu and select **Analysis>Measurement Table**. Then click on the **Reset** button.
 - Close all image windows.
-

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

Exercise 1.F continued...

7. As you did for Question 3, slide your cursor along the image's color bar, use the Image Info Window to match the values, and read the sea surface temperature in degrees from the color bar on the image itself to get the SST associated with each pixel value in the Mean column. Write the corresponding degree numbers in the SST (°C) column next to each pixel value in the table on the previous page.
8. Pull down the **Image** menu and select **Properties>Density Calibration**. In the dialog box select the Straight Line radio button and type in "deg C" for the Unit of Measure.
9. Type in the "Known" SST values, from the table on page 1-12, in the second column of the table in the dialog box.
10. Click the **Save** button and name the file "SST_Standards."

Note: Be sure you save this file in a place on your hard drive where you'll be able to find it later. This will save these calibration points in a file so that next time you need to calibrate an image you simply open this standards file.

Click **Export**. You'll again see the Calibration dialog box.

11. Click **Fit Points** and a plot window will appear that shows you the points you selected from the image, the line of best fit through those points, and the coefficients of the line of best fit. (See Figure 1.5, on the following page.) You may close this plot without saving it.
12. Click **OK** to apply the Density Calibration to the image.

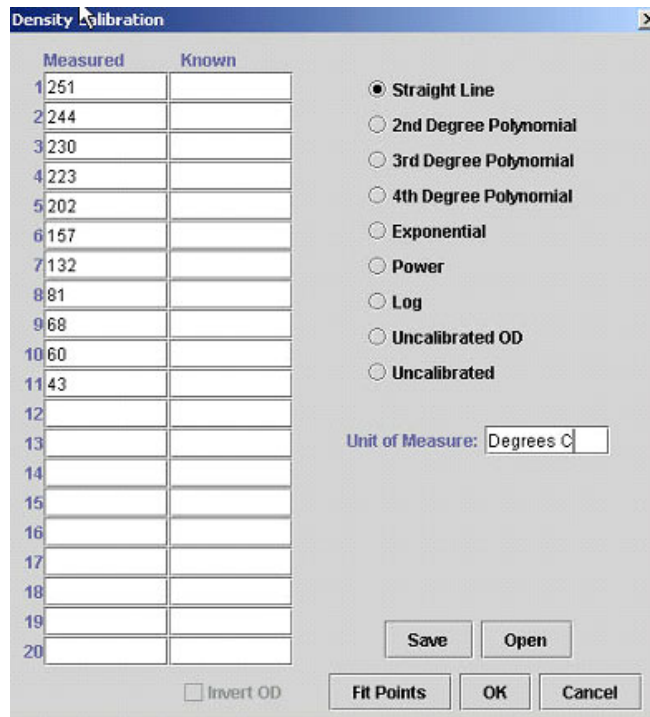


Figure 1.5: Density Calibration window

Now move your cursor around in the image and watch the Info Window. You will see the actual SST displayed for each pixel, with the corresponding pixel value in parentheses.

If you will be working with many images during a given session (which is the case for many of these exercises), calibrate the first one you open at the beginning of the session. All subsequent images will then be calibrated. Likewise, if you will be working with a series of images in a stack, first create the stack, then calibrate the first image in the stack and the rest will automatically be calibrated.

TIP

To use a previously saved standards file, follow these steps.

1. Pull down the **Image** menu and select **Properties>Density Calibration**.
2. Select the **Straight Line** radio button
3. Type "deg C" in the box titled **Units of Measure**
4. Click on the **Open** button. The Load Calibration window opens. Find your standards file in the location you saved it. Click **Open**.
5. From the Density Calibration window, click **OK**.

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

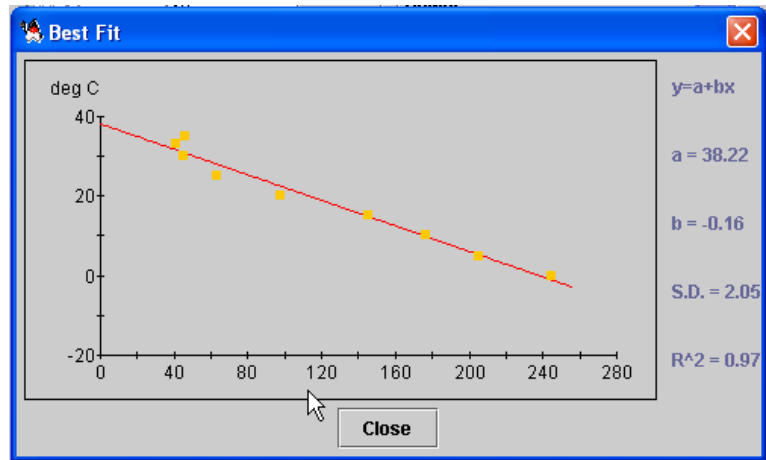


Figure 1.5: Example “Best Fit” plot.

Before proceeding to the next Exercise:

- Reset the Measurement Table
Pull down the **Image** menu and select **Analysis>Measurement Table**. Then click on the **Reset** button.
 - Close all image windows.
-

Qualitatively Observing The Geographic Distribution Of SST



Exercise 2.A

Open a data file in *NASA Image2000*

1. Pull down the **File** menu and choose **Open** OR click on the **Open** icon on the toolbar.
2. Locate and select this file:
<I2KInstalled> | data | SEES | Oceans | sstex2 | gm9503t.tif
3. Click on the **Open** button to open the image.

Overview

Continue exploring the geographic variations of SST by studying one monthly SST image from the global monthly sea surface temperature data set for 1982–1998 using the Density Slice Tool in *NASA Image2000*.



Do Exercises 2.A, 2.B and 2.C now.



Exercise 2.B

Color the image using a Look Up Table (LUT):

1. Pull down the **View** menu and select **Lookup Table (LUT)**
The LUT window is displayed.
2. Click on the **Load** button.
The Open File window opens.
3. Select the LUT you wish to apply, called “SST.lut”
4. Click on the **Open** button.
The new LUT is displayed in the LUT window, and the image is also updated to display the new values.
5. Click in the **Use as default** checkbox to use this LUT with future files. (Do not close the LUT window.)



Exercise 2.C

Calibrate the image with an existing calibration file.

1. Pull down the **Image** menu and select **Properties>Density Calibration**.
2. Select the **Straight Line** radio button, and type “deg C” in the box titled **Units of Measure**
4. Click on the **Open** button, opening the Load Calibration Data window, and find and locate the calibration file you saved and named SST_Standards.csv, and click **Open**.
5. From the Density Calibration window, click **OK**.

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

Exercise 2.F, con't...

4. Click and hold in the middle of the Density Slice color block and drag it first to the top of the LUT window and then slowly drag it toward the bottom. As you drag the color block down the LUT Window you will highlight in gray those regions with the same SST values, and the range of values highlighted will display in the Info Window and on the Color Legend in the Display Window. Do this several times to familiarize yourself with this procedure.
 5. Close the Density Slice Editor window when you are satisfied with the changes.
-

4. Study the geography of the Southern Hemisphere and describe a unique feature of the southern high latitudes that may affect SST. How do high latitude regions in the Northern Hemisphere differ in this respect from high latitude regions in the Southern Hemisphere?

Deactivate the Density Slice tool by clicking on the **Slice** button, and then clicking on the **Delete** button on the Density Slice Editor. This will return the LUT to the SST Color Table. Now, close the Density Slice editor.

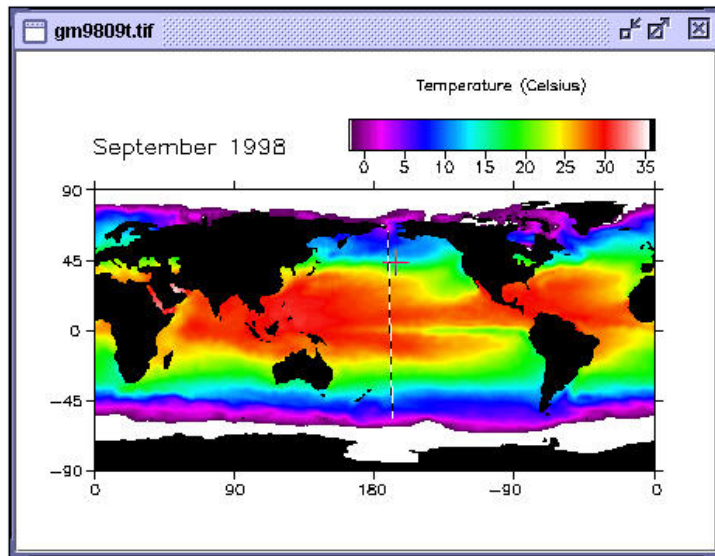


Figure 2.5: Vertical segment selection

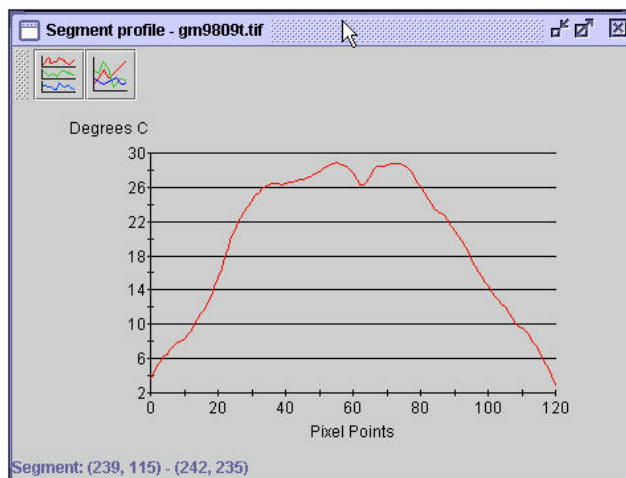


Figure 2.6: Vertical segment plot

Answer These Questions:

- 1 a. Study the two segment plots you just created. Are there spikes in the horizontal segment plot (across 45 degrees S) which are quite a bit out of range of the rest of the temperatures along that line? What are these spikes?

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

- 6a. Region 1:
- 6b. Region 2:
7. If, in an average year, the tropics receive more heat from the Sun than they lose, and the poles lose more heat than they receive from the Sun, what is preventing these regions from just continuing to heat up and cool off, respectively, until they are uninhabitable? Study the map of ocean currents and the image of SST you've been working with to describe a mechanism to answer this question.

Close all images.

Exercise 3: Observing The Seasonal Variation Of Sea Surface Temperature (SST)

Before Beginning

- Make sure you have read through the Introduction to Module3: Exploring Oceanography Using Satellite Data-Computer Lab Exercises document.
 - Start *NASA Image2000*, or if it is already running, close any open images
 - To complete this exercise, you will need the calibration file created in Exercise 1.F, named SST_Standards.
-



Exercise 3.A

Make a stack of images

1. Pull down the **File** menu and choose **Open** OR Click on the **Open** icon on the toolbar.
2. Locate and select the directory you wish to open:

```
<i2kinstalled> | data |SEES |
Oceans | sstex3 | 1995
```

Note: Do not open the directory. Simply select the folder.

3. Click on the **Open** button to open the images.
The Open Directory dialog opens.
 4. Select the **Stack** radio button.
 5. Click on the **OK** button to continue.
The images are opened in a stack.
-



Exercise 3.B

Color the stack using a LUT:

Color the image using a Look Up Table (LUT):

1. Pull down the **View** menu and select **Lookup Table (LUT)**
The LUT window is displayed.
2. Click on the **Load** button.
The Open File window opens.

continued...

Overview

This exercise has five sections. In the first three you'll use some of the tools from *NASA Image2000* to explore the seasonal variation of SST in a qualitative, or descriptive manner, where you'll

- Use a familiar *NASA Image2000* tool, the Density Slice, to observe the temporal variability from month to month
- Learn to create a movie of the monthly images, called an Animation
- Create a Montage of the twelve monthly images to observe SST changes throughout the seasons.

The last two sections of this exercise will hone your quantitative skills in analyzing the data, where you'll

- Create and plot a time-series of SST using *NASA Image2000* to collect the time-series data
- Use Image Math in *NASA Image2000* to compute the difference between two images.



Do Exercises 3.A, 3.B, and 3.C now.

Exploring Oceanography Using Satellite Data—Computer Lab Exercises

Exercise 3.B, con't...

3. Select the LUT you wish to apply, called "SST.lut"
4. Click on the **Open** button.

The new LUT is displayed in the LUT window, and the image is also updated to display the new values.
5. Click in the **Use as default** checkbox to use this LUT with future files. (Do not close the LUT window.)

Calibrating the top image in the stack will cause all images in the stack to be calibrated with the same calibration standards. To verify that the image has been calibrated, open the Image Info window (by pulling down the **View** menu and selecting **Image Info**) and move your cursor around the image.

**Exercise 3.C**

Calibrate the top image of the stack with a saved calibration file

1. Pull down the **Image** menu and select **Properties>Density Calibration**.
2. Select the **Straight Line** radio button
3. Type "deg C" in the box titled **Units of Measure**
4. Click on the **Open** button, and find and locate the calibration file you saved and named SST_Standards., and click **Open**.
5. From the Density Calibration window, click **Fit Points**. Close the Best Fit window if you are satisfied you chose the correct standards file. Click **OK** in the Density Calibration window to apply the calibration.

NOTE: If you don't have the file because you skipped Exercise 1.F, go back and do it now.

Use The Density Slice Tool To Observe Monthly Changes In SST

Overview

To begin your observations of how SST changes with time throughout a year, use the Density Slice Tool as you were instructed in Exercise 2, Step E. This tool allows you to identify a range of temperatures with a contrasting color and step through the images in the stack superimposing this temperature range on each image.

Position the stack with the January image on top by using the arrows or slider at the bottom of the image window.



Exercise 3.D

Density slice your stack

1. While viewing the LUT, click on the Slice button.
The Density Slice Editor window is displayed.
2. Click on the **Color Chooser** button. The Color Chooser window is displayed. Click on the Recent Colors block (which should display grey) and click OK. The Density Slice color block in the LUT window should be gray.
3. Click, hold, and drag the Density Slice color block to the warmest temperatures on the image's color bar (between 28°C and 32°C).

- Note: You can also accomplish this by entering 32 as the "Start deg C" and 28 as the "End deg C" in the Density Slice Editor window.
4. Using the "slider" at the bottom of the stack window, move slowly through the images in the stack, a month at a time, and watch what happens to the range of SSTs you've highlighted with the Density Slice Tool.



Do Exercise 3.D now.

Answer These Questions:

1. Describe what happens to the warm SSTs as you advance through the monthly images.

Position the stack with the January image on top once again but this time move the Density Slice Tool until it corresponds to the coldest temperatures on the image's color bar (between about 2°C–7°C) and move slowly through the stack again, using the slider or arrows..

2. Describe what happens to the cool SSTs in each hemisphere.

Study the cool SSTs in the southern oceans.

- 3a. Is there much north-south variation in SST from month to month in this region?
- 3b. Comment on the variation you observe in the southern high latitudes as compared with the same SST range in the northern high latitudes.
4. What's the explanation for what you observe?

Deactivate the Density Slice tool by clicking on the **Slice** button, and then clicking on the **Delete** button on the Density Slice Editor. This will return the LUT to the SST Color Table.

Close the Density Slice Editor now. Do not close the stack.

Investigating Seasonal Variations In SST From An Animation

Overview

A technique commonly used by scientists to visualize data collected over time is called animation. Each image in a stack is displayed automatically, and in sequence, to give the impression of a movie.



Exercise 3.E

Animate your stack

1. Pull down the **Stack** menu and select **Animate...**

The Animate Stack window is displayed.

2. For “quick” animation, accept the default radio button selection of Frames/Second (1-30), and edit the text field to define the speed of the animation (in frames per second).
 3. Click on the **Start** button to start the animation.
-



Do Exercise 3.E now.

Answer These Questions:

1. Describe what you see. Does this technique of animating the monthly SST images bring anything new to light in your observation of the seasonal variation of SST?
2. Paying close attention to western boundaries, especially in the North Atlantic and the North Pacific, describe the SST variability in these regions.

Return the January image to the top of the stack before proceeding, and close the Animation window..

Investigating SST Seasonal Variation From A Montage



Exercise 3.F

Make a montage of your stack

1. Pull down the **Stack** menu and select **Montage...**
The Create Montage window is displayed.
2. Enter “3” for rows, “4” for columns, and leave the rest at the default. Click **OK**.
A new untitled montage image window opens.
3. Now experiment with the montage features. Close the previous montage window and start over creating montages with the suggestions below.

Try entering 3 columns, 2 rows, and select **Advanced Layout**. Change the increment to 2. This will display a montage of every other month, and each cameo will be larger. You can montage the first 6 months by entering the same columns and rows and “1” for the increment, as another example.



Exercise 3.G

Study the northern hemisphere in the montage

1. Select the Rectangle Tool from the Tools Window and select the entire Southern Hemisphere from the top row of images.
2. Pull down the **Edit** menu and select **Cut**.
3. Repeat steps 1 and 2 for each row of images in the Montage.
4. Answer questions 1 and 2, then close the montage without saving.



Exercise 3.H

Study the southern hemisphere by montage

1. Select ‘Stacks/Make Montage.’ Enter “4 (or 3)” for columns, “3 (or 2)” for rows, and leave the rest at the default.
2. Use the Rectangle Tool again, this time selecting the Northern Hemisphere and using ‘Edit/Cut’ to remove the selection from each row.

Overview



Do Exercises 3.F and 3.G now.

Answer These Questions:

- 1a. In what months are SSTs warmest in the Northern Hemisphere?
- 1b. Where do they occur and what are the approximate values?
- 2a. In what months are SSTs coldest in the Northern Hemisphere?
- 2b. Where do they occur and what are the approximate values?



Do Exercise 3.H now.

- 3a. In what months are SSTs warmest in the Southern Hemisphere?
- 3b. Where do they occur and what are the approximate values?
- 4a. In what months are SSTs coldest in the Southern Hemisphere?
- 4b. Where do they occur and what are the approximate values?

Comparing the two montages you just made,

- 5a. Do the Northern and Southern Hemispheres have the same approximate range of SSTs? Yes ___ No ___
- 5b. Is this what you would expect? Yes ___ No ___
- 5c. Why?

Close the montages but leave the stack open to use in the next section.

Creating An SST Time-Series To Observe Seasonal Variations

Overview

Now we'll perform some analysis on the monthly SST data identical to that performed by scientists in their research for studying the temporal variation of a geophysical parameter. You'll use *NASA Image2000* to compute the average SST in a Northern Hemisphere ocean basin for each month and create a plot of the SST as a function of month. You'll do the same thing for a Southern Hemisphere ocean basin. Comparing the two plots will clearly show how the seasons affect SST.



Exercise 3.1

Calculate the Standard Deviation of the Stack.

1. Pull down the **Stack** menu and select **Statistics>Standard Deviation**.

The Result Options window is displayed. Select "Float" as the Output.

- Note:** The resulting image is automatically calibrated such that the values shown in the Info Window, when you move the cursor around the image, represent the standard deviation in °C of each pixel.
2. Select the SST.lut to apply color to this image.




Do Exercise 3.1 now.


Answer These Questions:

- 1a. What is the significance of this image of the standard deviation of SST computed over 12 monthly images?
- 1b. What is it used to illustrate?
- 2a. What do areas of white correspond to?
- 2b. What do areas of red, yellow and green correspond to?
- 3a. In the Pacific and Atlantic Oceans, what range of latitudes has the highest standard deviations?
- 3b. What range of latitudes has the lowest standard deviation?

 **Exercise 3.J**

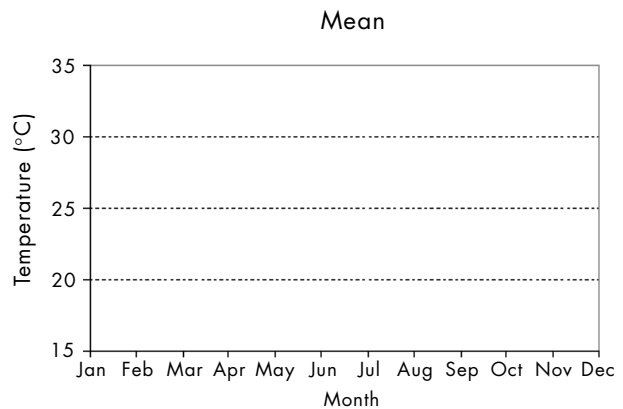
Plotting deviations

1. Select the Rectangle Tool from the Tools Window. Using the standard deviation image as a reference, select a region of high standard deviation in the North Pacific Ocean and draw a small rectangle over this region on the top (January) image in your stack.
2. Pull down the **Image** menu and select **Analysis>Measurement Table**. Be sure that the Table is empty; if it is not, click on the **Reset** button.
3. Click on the **Options** button and choose “**Mean**”, “**Std Dev.**”, and “**Image Name.**” Then click **OK**.
4. Click on the Stack to make it active.
5. Click on the Measure icon button on the tool bar, or pull down the **Image** menu and select **Analysis>Measure**. 
6. Use the “slider” tool to move to the next window (February) in the stack and notice that the rectangular selection you did in Step 1 automatically appears on this image. Click on the Measure icon again. There are now two measurements in the Measurement Table Window; January’s and February’s. Repeat this step a month at a time until you’ve completed all 12.
7. Click on the Image Measurements window and save the Results Window by selecting ‘File/Export’ and naming the file with something you’ll recognize later.
7. Use the slider tool to position the January image back on top of the stack.
8. Now place the cursor arrow over the middle of your selected region (see the color picture, at right). Click and hold the mouse and drag the rectangle to an area of high standard deviation in the South Pacific Ocean. Repeat Steps 2–6 for the South Pacific.
9. Open the two results files you saved and type in the name of the month in place of the number in the first column for each row of measurements.

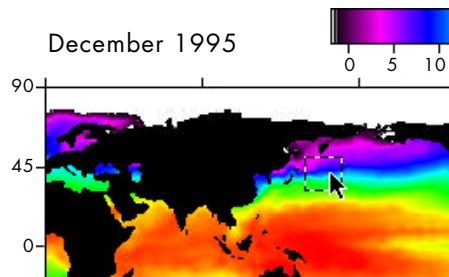
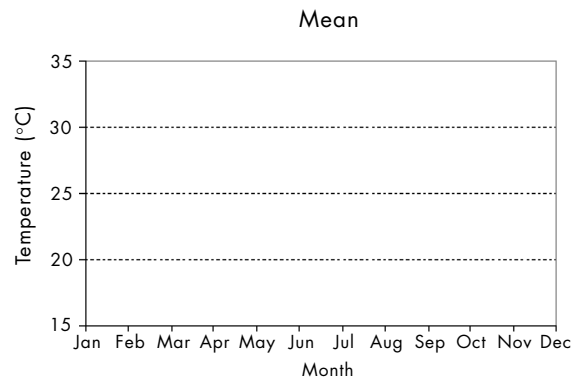
 **Do Exercise 3.J now.**

Now create two plots of these data, either by hand or using a plotting package you may have. Plot the months on the x-axis and the mean SST on the y-axis for both

4a. the North Pacific Ocean and

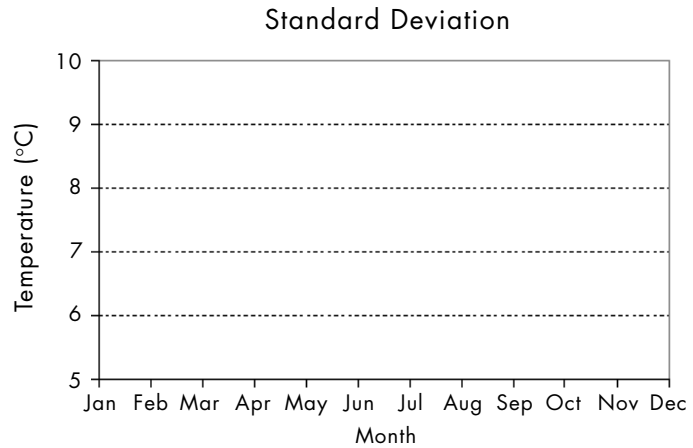


4b. the South Pacific Ocean.



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- 4c. Now create a plot with the month plotted on the x-axis and the standard deviation for the measurement table for the North Pacific and the South Pacific on the y-axis.



- 4d. Write a discussion interpreting the plots, comparing the North and South Pacific, and including reasons for the trends and magnitudes of the curves. use additional paper as needed.

Close this stack in preparation for the next section.

Using Image Math To Observe The Seasonal Variation In SST



Exercise 3.K

Make a “difference image”

1. Open one image for March (gm9503t.tif) and make sure the SST color table has been selected.
2. Calibrate the image (see Exercise 3.C).
3. Open the September image for the same year (gm9509t.tif). Make sure the image is calibrated. If it isn't, select the image window and repeat Step 2, above.
4. Pull down the **Image** menu and select **Math>Calculator**. Choose the files such that the March image is subtracted from the September image. Select (* 1.) for Scale and (+0.) for Offset. Since the images are calibrated, select “real result.”



Exercise 3.L

Using the LUT and the Density Slice tool to enhance the colors for easier interpretation.

1. Pull down the **View** menu and select **Lookup Table (LUT)**.
2. Click on the **Load** button. The Open File window opens.
3. Select the “Rainbow1.lut”
4. While viewing the **LUT** window, click on the **Slice** button.
5. Click on the **Color Chooser** button, then click on the Recent Colors block which is grey. The resulting Density Slice color block in the **LUT** window and in the image will be grey.

Overview

Another type of analysis used to see how data change with time is to simply subtract one image from another.

If you still have a stack open, close it now, along with any other open windows.



Do Exercise 3.K now.

The resulting image represents the arithmetic difference between the 2 months. Notice that this “difference image” is very uniform in color, mostly shades of green. We can highlight the temperature differences between March and September with a more appropriate range of colors by manipulating the color LUT.



Do Exercise 3.L now.

Answer These Questions:

- 1a. What colors represent positive values?
- 1b. What colors represent negative values?
- 2a. What does it mean when the differences are positive?
- 2b. What does it mean when the differences are negative?
- 3a. Where in the oceans are the differences between March SST and September SST positive?
- 3b. Why?
- 4a. Where in the oceans are the differences between March SST and September SST negative?
- 4b. Why?
- 5a. Where are the largest differences?
- 5b. Where are the smallest differences?

Exercise 4: Observing The Year-to-year, Or Interannual, Variation Of Sea Surface Temperature (SST)

Before Beginning

- Make sure you have read through the Introduction to Module3: Exploring Oceanography Using Satellite Data-Computer Lab Exercises document.
- Start *NASA Image2000*, or if it is already running, close any open images
- To complete this exercise, you will need the calibration file created in Exercise 1.F, named SST_Standards.



Exercise 4.A

Build a stack

1. Pull down the **File** menu and choose **Open** OR Click on the Open icon on the toolbar.
The Open window opens.
 2. Locate and select the directory you wish to open:
`<i2kinstalled>/images/ Oceans/ sstex4/Decembers`
- Note:** Do not open the directory. Simply select the folder.
3. Click on the **Open** button.
The Open Directory dialog opens.
 4. Select the **Stack** radio button.
 5. Click on the **OK** button to continue.
The images are opened in a stack.



Exercise 4.B

Calibrate the top image of the stack with a saved calibration file

1. Pull down the **Image** menu and select **Properties>Density Calibration**.
2. Select the **Straight Line** radio button
3. Type “deg C” in the box titled **Units of Measure**
4. Click on the **Open** button, and find and locate the calibration file you saved and named SST_Standards., and click **Open**.

continued...

Overview

This exercise is an open-ended exploration of the El Niño phenomena in the eastern Equatorial Pacific Ocean. To embark on this exploration, you must be able to do the following Exercise 3 procedures in *NASA Image2000*.

- Open a series of images and create a stack (Step A)
- Apply the SST LUT to the stack (Step B)
- Calibrate the stack (Step C)
- Use the Density Slice Tool (Step D)
- Animate a stack (Step E)
- Make a montage from a stack (Step F)
- Use the ‘Analyze/Measure’ command to find the mean and standard deviation of a rectangular selection in each image of a stack and create a time-series from these data (Step J).

Qualitative Observation Of Long-term Interannual Variability



Do Exercises 4.A, 4.B and 4.C now.

Exercise 4.B, con't...

5. From the Density Calibration window, click **OK**.

NOTE: If you don't have the file because you skipped Exercise 1.F, go back and do it now.

6. Pull down the View menu and select Image Info to view the Image Info window and check that your image is calibrated.
-

**Exercise 4.C**

Color the stack using a LUT:

- Pull down the **View** menu and select **Lookup Table (LUT)**
The LUT window is displayed.
 - Click on the **Load** button, and select the LUT you wish to apply, called "SST.lut"
 - Click on the **Open** button.
The new color LUT will be applied to all images in the stack.
-

**Exercise 4.D**

Make a montage

- Pull down the **Stack** menu and select **Montage...**
The Create Montage window is displayed.
 - Fill out the **Basic Layout** tab as follows:
 - Scale:** 100;
 - Rows** 4 (2 if you want to look at 8 years at a time);
 - Columns:** 4;
 - Click on the **Advanced Layout** tab and complete it as follows:
 - Increment:** 1
 - First Image:** 1;
 - Last Image:** 16 (8 if you want to look at the first 8 years initially);
 - Click **OK**.
A new untitled montage image window opens.
-

Using the tools in *NASA Image2000* that you are familiar with from the first three exercises, explore the long-term variation of the global SST and record your observations. Here are some suggestions for your exploration.

- Start by simply moving through the stack one image at a time using the "slider" tool until you are familiar with the data and can record some general comments about SST throughout the 17 year period.
- Use the Density Slice Tool (Exercise 3, Step D) to highlight the warmest $\sim 27^{\circ}\text{C}$ – 31°C) SSTs and observe how they vary throughout the years.

Answer These Questions:

- In which 2 years does this range of SSTs cover the largest area?
_____ and _____
 - In which 2 years does this range of SSTs cover the smallest area?
_____ and _____
- How does the geographic distribution of SST differ between the years when the area covered is high as compared with years when the area covered is low?

Create a montage from the images in the stack and use the selection and drawing tools to isolate regions (the Equatorial Pacific is a good region to look at) in order to make it easier to compare them visually. Remember, a selection made on the top image in a stack automatically appears on every image in the stack when it's displayed.

**Do Exercise 4.D now.**

It might be easier to look at just 8 years at a time in the montage by modifying the "Rows" and "Last Slice" choices to "2" and "8" respectively. Then if you want to see just the last 8 years, use "2" and "16." Try using the Density Slice Tool on your montage to highlight the warmest SSTs.

- Record your observations.

If you drew lines on the images in the Montage or altered them by cutting out sections, now is the time to close this montage and work again with the original stack of 17 December images.



Exercise 4.E

Animate your stack

1. Pull down the **Stack** menu and select **Animate...**

The Animate Stack window is displayed.

2. For "quick" animation, accept the default radio button selection of Frames/Second (1-30), and edit the text field to define the speed of the animation (in frames per second).
 3. Click on the Start button to start the animation.
-

**Do Exercise 4.E now.**

4. Record anything new you observe.

Based on your observations using the Density Slice Tool on the Stack of images, making a montage from the stack, and animating the stack, answer the following questions.

5. Which *NASA Image2000* tools made it easiest for you to observe the interannual variation of SST?
6. Where in the oceans did you notice the largest variability from one year to the next?
 - 7a. Which years appeared anomalous; that is, which years looked very different from the other years?
 - 7b. Why are these years anomalous?
8. What other general comments can you make regarding the interannual variations of SST?

Quantitative Observations Of Long-term Interannual Variability In The Eastern Equatorial Pacific Ocean



Exercise 4.F

Scaling your stack

1. If necessary, reopen the December images and put them in a stack. Add the SST LUT and calibrate the stack if it hasn't already been done. (See Exercises 4.A, 4.B, and 4.C.)
2. Pull down the **Image** menu and select **Properties>Set Scale**.
 - Select Kilometers from the **Unit** pop-up menu.
 - Enter "111" for the **Known Distance**.
 - Enter "1" as the **Measured Distance**.
 - Make sure that the **Pixel Aspect Ratio** is set to 1 and the Scale reads .01. Click **OK**.
3. Use the Density Slice Tool (Exercise 3.D) to highlight the warmest ~27°C–31°C SSTs.
4. Select the Rectangle Tool from the Tools Window and use it to select the image only (don't select any annotations or the color legend), by clicking and dragging a rectangle around just the image.
5. Make sure your stack is positioned with December 1982 on top; use the slider tool as necessary.
6. Pull down the **Image** menu and select **Analysis>Measurement Table**. Click on the **Reset** button.
7. Click on the **Options** button and make sure **Area**, **Mean**, and **Standard Deviation** are selected.
8. Click on the Measure icon button on the tool bar, or pull down the **Image** menu and select **Analysis>Measure**, to measure the area covered by the Density Slice. Step through the stack using this command for each image. When you've measured each of the 17 Decembers, you can use the measurements in the Results Window to answer quantitatively some questions you were asked previously.

Overview

Now you'll use the *NASA Image2000* Set Scale function to scale the image such that 1 pixel is equivalent to approximately 1° of latitude or longitude — 1° of latitude is approximately equal to 111.0 kilometers. This "calibration" of the image scale will permit you to answer the questions that follow quantitatively.



Do Exercise 4.F steps 1–7 now.

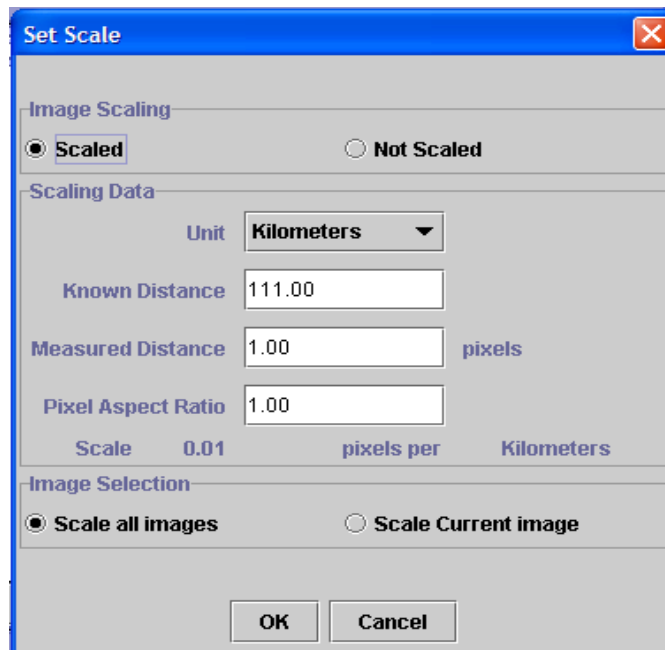


Figure 4.1: Scale Image window.

Now you're ready to measure the area of the region of warmest SSTs you highlighted with the Density Slice Tool. If the Density Slice is not active, please make it active now and highlight temperatures between about 27°C and 31°C.



Do Exercise 4.F, step 8 now.

Answer These Questions:

1a. Year: _____ Area Covered:

1b. Year: _____ Area Covered:

In which 2 years does this range of SSTs cover the smallest area, and what is the area in square Km?

2a. Year: _____ Area Covered: _____

2b. Year: _____ Area Covered: _____

3. How does the geographic distribution of SST differ between the years when the area covered is high as compared to years when the area covered is low?

Review questions 1–8 from the last section and adjust your answers now that you have collected some quantitative information about the area, mean, and standard deviation of the region of warmest SST as highlighted by the Density Slice Tool.

Row ID	Area	Mean	Std Dev
1	93,454,785....	29.23 deg C.	35.42 deg C.
2	85,384,530....	29.06 deg C.	35.46 deg C.
3	75,675,582....	28.97 deg C.	35.51 deg C.
4	80,936,649....	29.09 deg C.	35.42 deg C.
5	89,216,361....	29.08 deg C.	35.44 deg C.
6	96,239,331....	29.20 deg C.	35.41 deg C.
7	78,386,202....	29.02 deg C.	35.50 deg C.
8	85,483,098....	29.05 deg C.	35.44 deg C.
9	91,200,042....	29.11 deg C.	35.43 deg C.
10	86,222,358....	29.07 deg C.	35.43 deg C.
11	80,271,315....	29.04 deg C.	35.48 deg C.
12	89,857,053....	29.09 deg C.	35.43 deg C.
13	88,033,545....	29.16 deg C.	35.39 deg C.
14	89,364,213....	29.13 deg C.	35.43 deg C.
15	85,495,419....	29.14 deg C.	35.40 deg C.
16	108,745,14...	29.28 deg C.	35.41 deg C.
17	89,056,188....	29.19 deg C.	35.42 deg C.

Figure 4.2: Sample image measurements.

As you've probably figured out, even though the human eye is a very sensitive instrument, it's hard to observe very subtle changes in SST from year to year. That's why scientists also use quantitative techniques involving statistics and the creation of time-series to discern such changes. You'll now create some time-series of mean SST and standard deviation for a very interesting region of Earth's oceans: the eastern Equatorial Pacific.

Exercise 4.G

Make a Standard Deviation Image

1. You should still have all 17 Decembers in a stack. If not, create it now, apply the SST LUT to it, and calibrate it.
2. Pull down the **Stack** menu and select **Statistics>Standard Deviation** to generate an image of the standard deviation at each pixel over all images in your stack. You'll be asked to name the resulting standard deviation image. Be sure to save it in TIFF format.
3. Load a LUT called "System.LUT" from the LUT window (pull down the **View** menu and click **LUT**).

Do Exercise 4.G now.

4. Study this image and describe in which regions of the ocean there is the most variability over time.
5. How does this statistical result compare with your qualitative observations from the previous section?

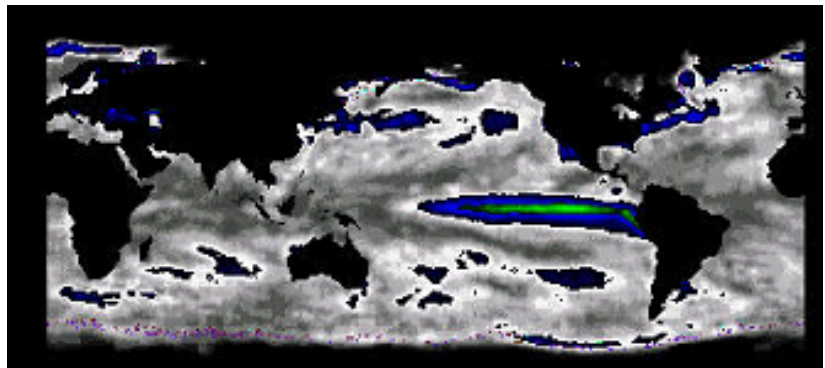




Figure 4.3: The resulting image of standard deviation is automatically calibrated such that the values shown in the Info Window, when you move the cursor around the image, represent the standard deviation in °C of each pixel in the image.



 **Do Exercise 4.H now.**

Exercise 4.H

Make time-series from your stack

1. Choose the Freehand Tool or the Polygon Tool from the Tools Window. Using the image of standard deviation as a reference, use either selection tool to select the region of high standard deviation in the eastern Equatorial Pacific Ocean on the top image of the stack, being careful to avoid land.
2. Select **Image>Analysis>Measurement Table** to open the results, and click **Reset** to clear all measurements.
3. Click the **Options** button and choose “mean density” and “standard deviation.” Click **OK** to close the options window.
4. Position the Results Window so you can see both it and the images. 
5. Click on the Measure icon button on the tool bar, or pull down the **Image** menu and select **Analysis> Measure**. You’ll see the mean and standard deviation for the region you selected on the December 1982 image appear in the Results Window.
6. Use the “slider” tool to move to the next window in the stack (December 1983) and notice that your region selection automatically appears on this image.
7. Click on the Measure icon again. There are now two measurements in the Results Window, one for each month.
8. Use the slider tool to move through the stack a month at a time, computing the mean and standard deviation for each month with ‘Image>Analysis> Measure.’
9. Once you’ve done this for all Decembers, pull down the **File** menu and select **Export** to save the Measurement Table, naming it

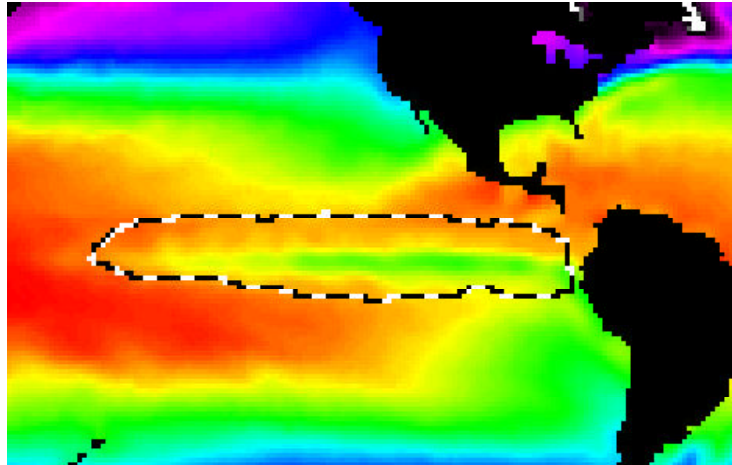


Figure 4.4: Sample image selection.

Image Measurements		
Delete Reset Options...		
Row ID	Mean	Std Dev
1	28.57 deg C.	35.10 deg C.
2	27.07 deg C.	34.59 deg C.
3	26.48 deg C.	34.63 deg C.
4	27.09 deg C.	34.48 deg C.
5	27.90 deg C.	34.79 deg C.
6	28.02 deg C.	34.89 deg C.
7	26.25 deg C.	34.36 deg C.
8	27.27 deg C.	34.64 deg C.
9	27.64 deg C.	34.53 deg C.
10	27.96 deg C.	34.74 deg C.
11	27.48 deg C.	34.61 deg C.
12	27.69 deg C.	34.78 deg C.
13	27.87 deg C.	34.73 deg C.
14	27.02 deg C.	34.58 deg C.
15	26.87 deg C.	34.48 deg C.
16	28.81 deg C.	35.14 deg C.
17	26.47 deg C.	34.60 deg C.

Figure 4.4: Sample image measurements.

- 6a. Now create plots of the means and standard deviations as a function of year either by hand (Exercise 3 has blanks you can use) or using a plotting package you have. For the first one, plot the year on the x-axis and the mean SST on the y-axis. The second plot should also have year on the x-axis, but the y-axis should be the standard deviation for the region.
- 6b. Write a discussion interpreting the plots, including reasons for the trends and magnitudes of the curves.

Using Climatological SST Data To Explore Interannual Variation And El Niño


Overview

You'll now work with an interesting data set called a "climatology." In meteorological terms, the word "climate" refers to the average pattern of weather in a region. An example may help:

If on a day in July you're asked, "What's the weather been like in New Orleans?" you might answer, "Today it's clear and cool, but yesterday was hot and muggy." On the other hand, if you're asked, "What's the climate like during the summer in New Orleans?" it would be correct to answer, "In the summer it's hot and muggy."

The climate of a region is quantified by computing very long-term averages of the weather of the region.

In the oceans, climatologies are similarly computed. In this exercise, the SST climatology you'll work with was computed as the average of a given month over many years. There are 12 monthly files in this climatology data set of SST. The spatial resolution of this data set is identical to the monthly averaged SST data set you've been working with.

 **Do Exercise 4.I now.**


The quantitative part of this exercise involves creating time-series plots to observe how SST in the eastern Equatorial Pacific varies during and between El Niño years.

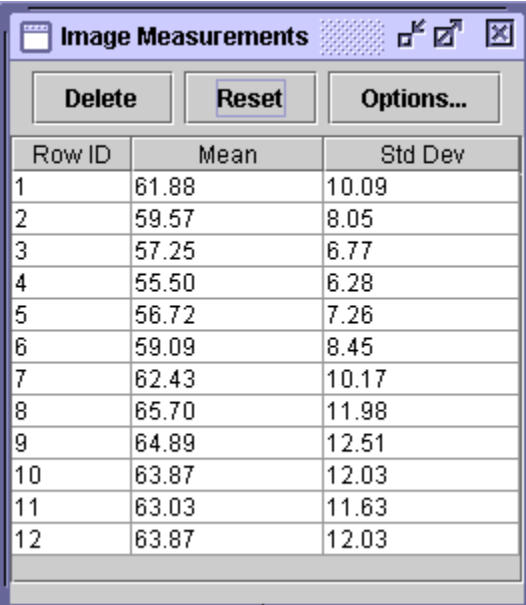
"Eq_Pac_82_98(measurements)."



Exercise 4.I

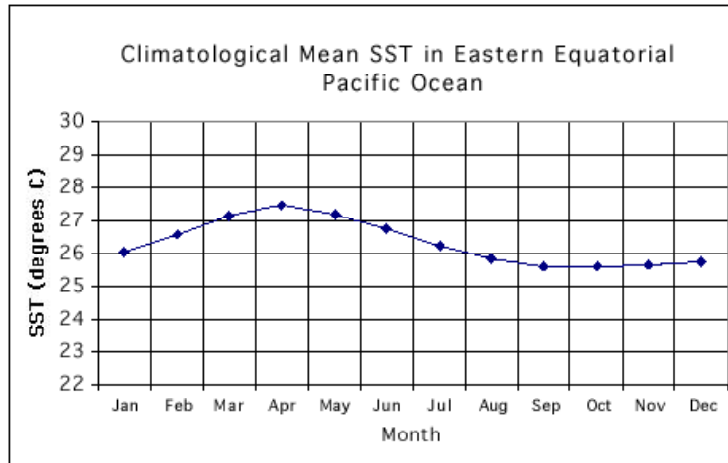
Build a stack of "climatologies"

- Select the following directory:
`<i2kinstalled>/images/ Oceans/ sstex4/climate`
 Click "Stack" to import the 12 monthly climatological SST files as a stack. Apply the SST LUT, and calibrate the top image (see Exercises 4.B and 4.C). Become familiar with this data set as you have done in other exercises.
- Pull down the **File** menu and select **Open** and open the standard deviation TIFF image you created previously from the 17 Decembers.
- Use one of the selection tools to select a region of highest standard deviation in the eastern Equatorial Pacific on the top (January) image of the stack of monthly climatological images, being careful to avoid the land mask.
- Select **Image>Analysis>Measurement Table** to open the results, and click **Reset** to clear all measurements.
- Click the **Options** button and choose "mean density" and "standard deviation." Click **OK** to close the options window.
- Position the Results Window so you can see both it and the images. 
- Click on the Measure icon button on the tool bar, or pull down the **Image** menu and select **Analysis> Measure** to record the mean and standard deviation for each of the 12 monthly climatological images in the stack. Save the Results Window for




Row ID	Mean	Std Dev
1	61.88	10.09
2	59.57	8.05
3	57.25	6.77
4	55.50	6.28
5	56.72	7.26
6	59.09	8.45
7	62.43	10.17
8	65.70	11.98
9	64.89	12.51
10	63.87	12.03
11	63.03	11.63
12	63.87	12.03


A time series plot of these results would look like this.



Close both the stack of climatological images and the standard deviation image.

The class should split into small “research teams.” Each team will gather data and plot a time-series of mean SST and the standard deviation for a different year for the eastern equatorial Pacific. Use 1982, 1983, 1986, 1987, 1991, 1992, 1992, 1993, 1996, 1997, and 1998.

 reference.

 **Do Exercise 3.J now.**

Answer These Questions:

Exercise 4.J

Make time-series plots

1. Import the 12 monthly mean SST images for the year that your “research team” has been assigned. Put them in a stack, apply the SST LUT, and calibrate the top image in the stack.
2. Load the standard deviation image you previously created from the 17 Decembers.
3. Select **Image>Analysis>Measurement Table** to open the results, and click **Reset** to clear all measurements.
4. Using the standard deviation image as a guide, use one of the selection tools to select the region of highest standard deviation in the eastern Equatorial Pacific, and, as before, generate a time-series of the SST means and standard deviation in this region for your particular year.

- 1a. As a point of comparison, all groups should create one plot of the climatological SST for all the years (1982–1998) as a function of time at the chosen area of interest within the eastern equatorial Pacific.
- 1b. Now create a similar plot for your chosen year for roughly the same area in the equatorial Pacific.

Get together and compare all years that show El Niño conditions in the eastern equatorial Pacific.

After sharing your information with the other “research teams,” discuss the following questions regarding the El Niño/Southern Oscillation.

- 2a. Which years were El Niño years?
- 2b. Which were not El Niño years?
3. Rank the El Niño years from the strongest, most severe to the weakest.

For each El Niño year,

4a. When did it begin?

4b. When did it end?

4c. When did it reach peak strength?

If there's still time in your lab, or as an independent project, try doing the same time-series exercise as above but with the western Equatorial Pacific Ocean region and compare your results to the curves for the eastern Equatorial Pacific Ocean.

Also try using "Image Math" to create anomaly fields based on the climatological SST data (as in Exercise 3). For instance, subtract the December climatology from the image for December '82, '83, '96, and '97. Compare these difference (also called anomaly) fields.