Ecological Forecasting in the Coastal Zone

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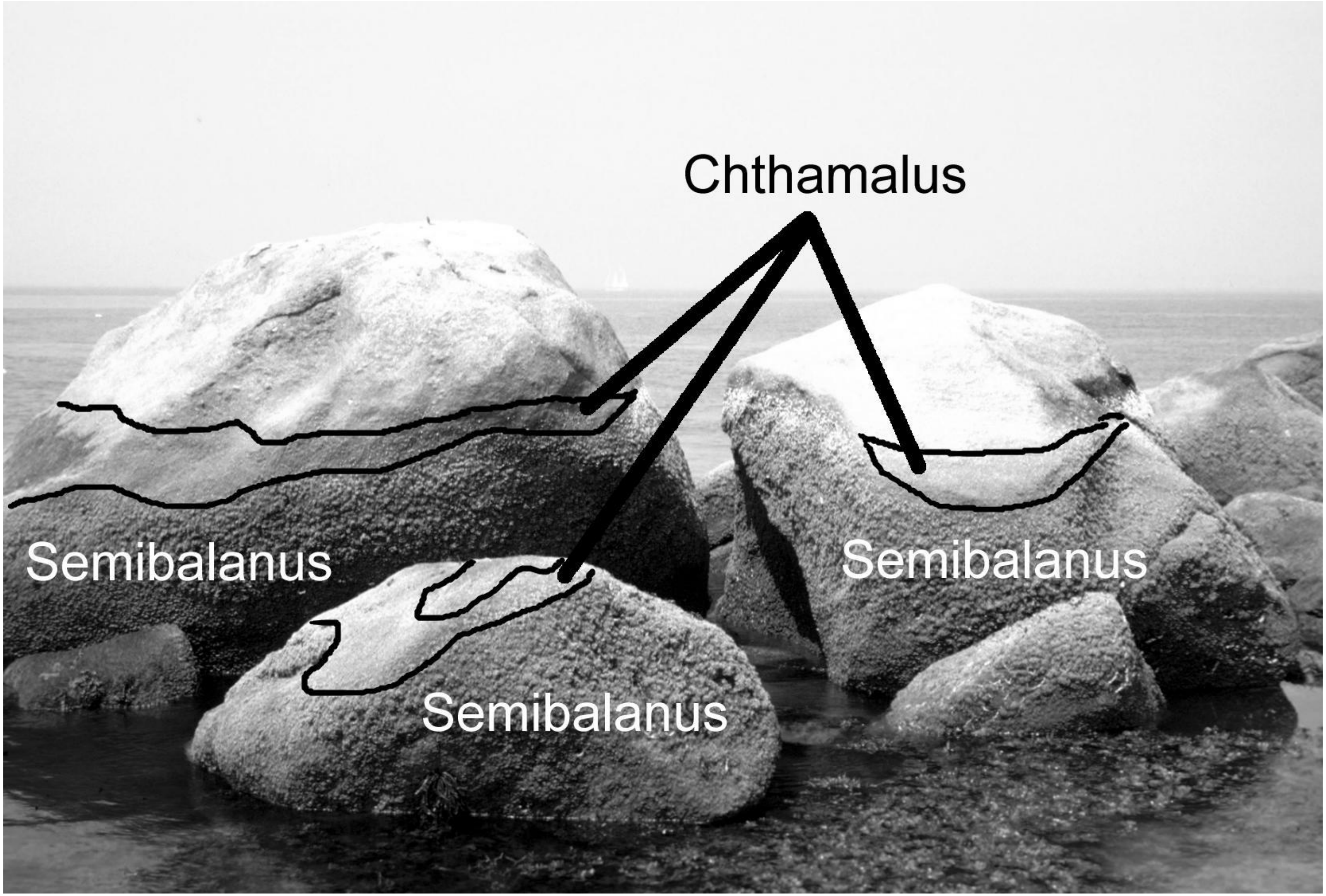
The zone between the tides as an indicator of climate change

Intertidal microclimate varies from temperate to tropical: tropical barnacles restricted to hot spots high on the shore



Linking Biogeography to Climate

- Northern and southern geographic limits of species are likely influenced by climate
- Factors that control local zonation on the shore may also control geographic distribution.

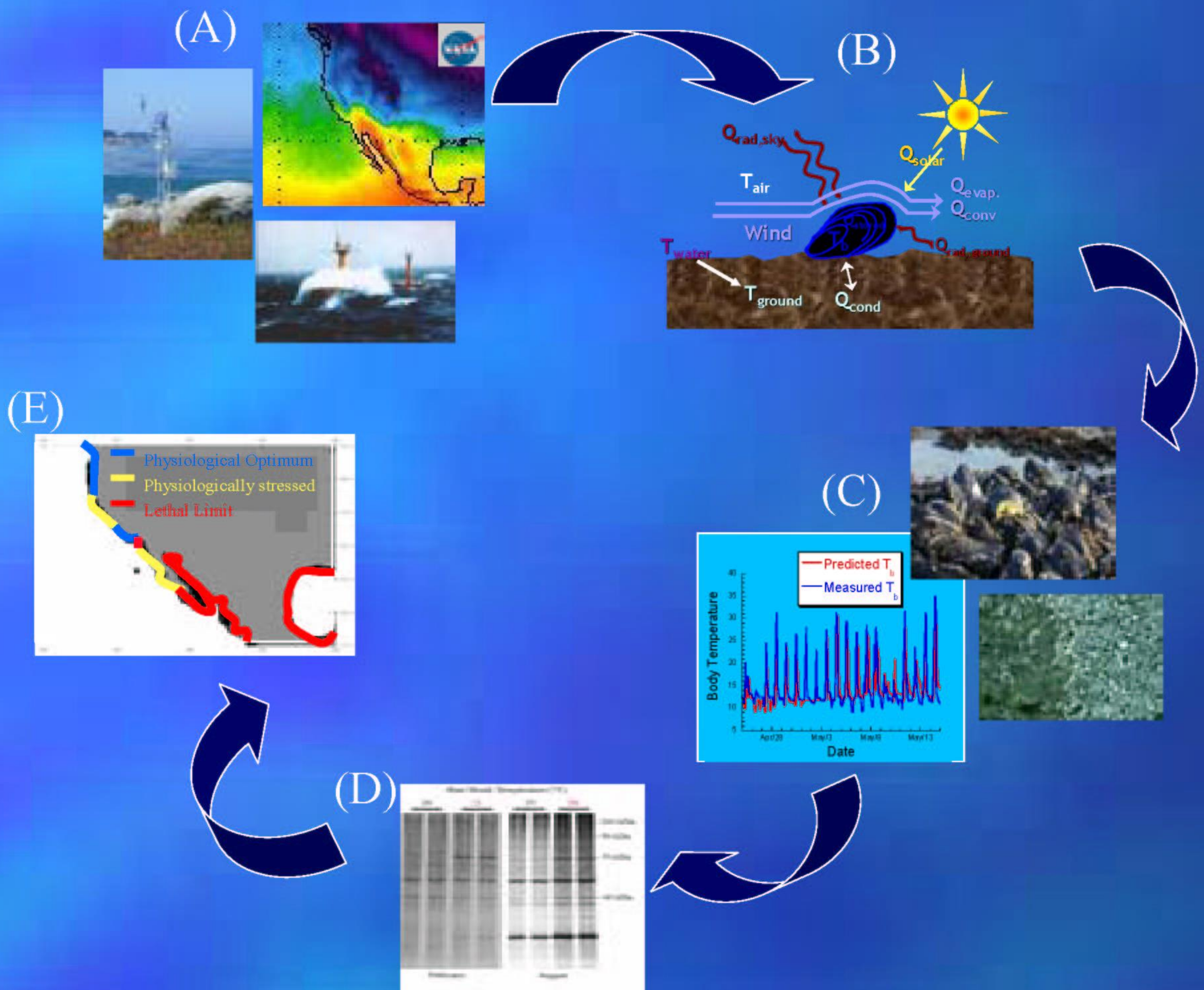
Interdisciplinary Team

- David Wethey – PI (Ecologist)
  - Field experiments, model development, rocky shores
- Brian Helmuth – Co PI (Biophysical Ecologist)
  - Biomimetic sensors, model development, rocky shores
- Jerry Hilbish – Co PI (Population Geneticist)
  - Sublethal stress measurement – heat shock, rocky shores
- Sally Woodin – Co PI (Sediment Ecologist)
  - Sublethal stress measurement – behavior, sediments
- Venkat Lakshmi – Co PI (Satellite Hydrologist)
  - Satellite image analysis
- Helen Power – Co PI (Climatologist)
  - Solar radiation modeling

General Goals

- Use NERRS observations and satellite (TOVS, AVHRR, MODIS, ASTER) to model body temperature of ecologically important intertidal species.
- Ground truth models with biomimetic sensors.
- Use validated models to produce maps of body temperature of ecologically important species on Atlantic and Pacific Coasts.
- Compare body temperature estimates to geographic limits.
- Hindcast using historical data to determine if range shifts can be explained by climate data.
- Identify intertidal “hot spots” where climate change should have large effects.
- Forecast effects of decadal and seasonal scale climate change on geographic distribution of ecosystem foundation species.
- Communicate results through NERRS Coastal Training Program.

Research Framework

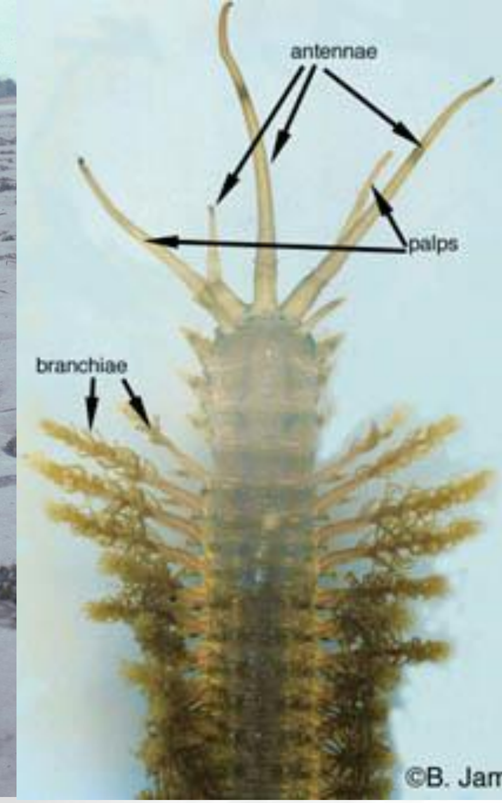


Target Organisms
Ecosystem Foundation Species

- Sedimentary Shores
  - Sediment disruptors (shrimp, worms)
  - Tube and reef builders (worms, oysters)

- Rocky Shores
  - Dominant space occupiers (barnacles, mussels)

Tube Builders



Sediment disturbers

Mussels and Barnacles – Dominant Space Occupiers

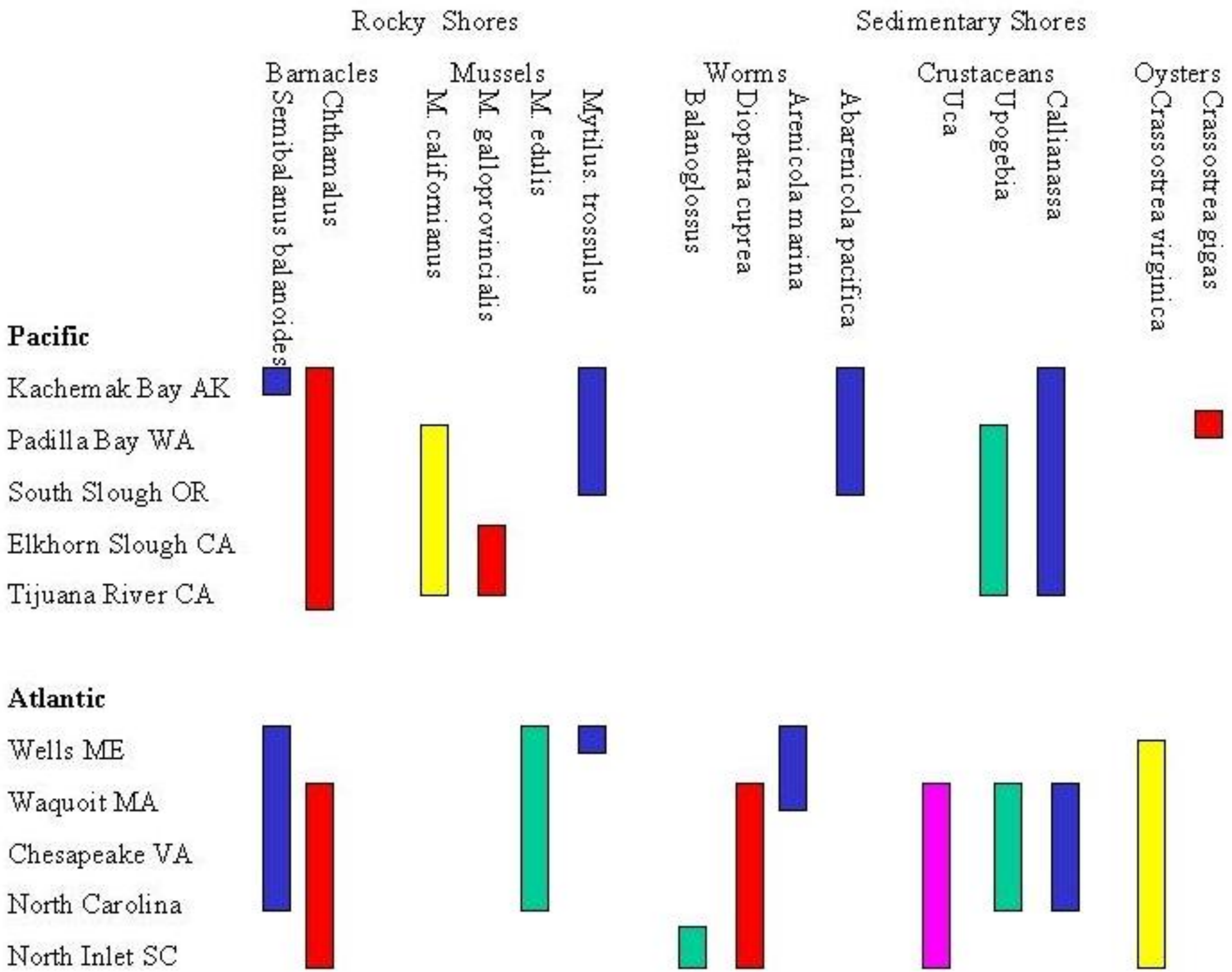

PROPERTY
THE UNIVERSITY OF MICHIGAN

Geographic Coverage

- Alaska to Mexico on Pacific Coast
- Maine to South Carolina on Atlantic Coast

- Five National Estuarine Research Reserves on each coast.
- Sites span the geographic limits of ecosystem foundation species

Ecological Forecasting of ecosystem engineers in the coastal zone

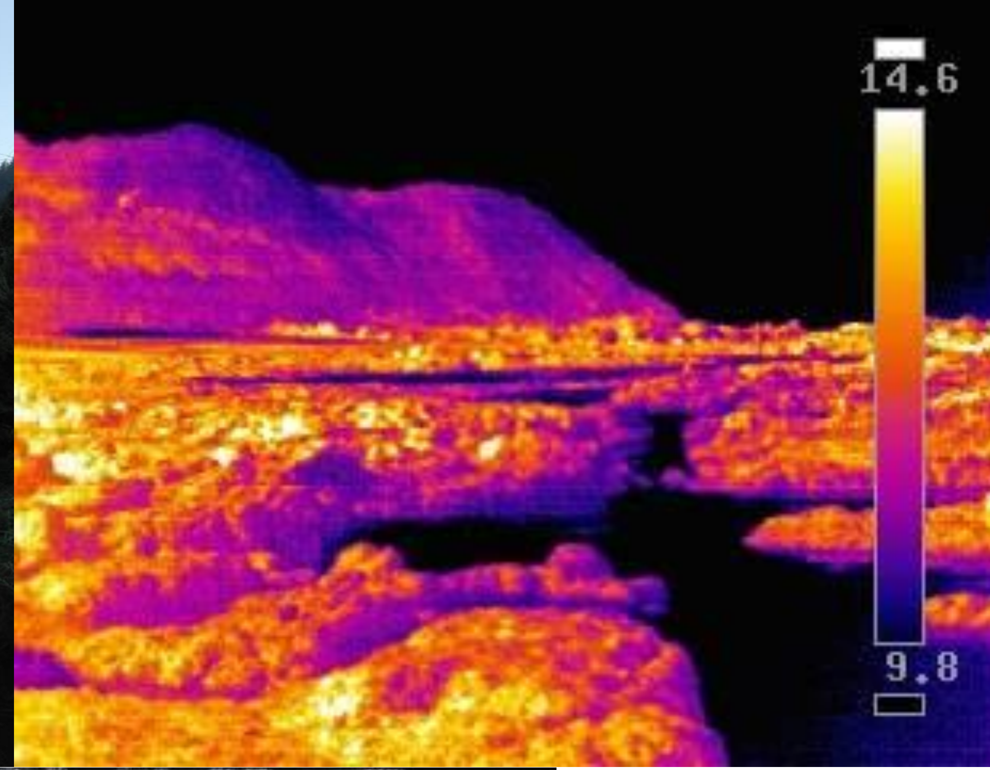


How hot is it on the shore, and how do we measure and predict temperature?

- Measurements
  - Biomimetic sensors
  - Infrared Imagery

- Forecasting, Hindcasting, Nowcasting
  - Mechanistic simulation models
  - Based on ground and satellite climate data

Biomimetic Sensors


14.6
9.8


FLIR

Satellite Data Sets

Variable	**Sensor**	**Spatial Res**	**Temporal**	**Res**
Surface Air	TOVS	1º	2/day	1980-present
Temperature	AIRS	50 km	2/day	2002-present
SST /	ASTER	90 m	Request	2000-present
Ground	MODIS	0.5-1 km	2-4/day	2002-present
Surface	AVHRR	1 – 5 km	1-2/day	1980-present
Temperature	AMSR-E	10 km	1-2/day	2002-present
	TOVS	1º	2/day	1980-present
	AIRS	50 km	2/day	2002-present
Solar Rad	GOES	0.5 º	hourly	1996-present
Clouds				

Ground Based Datasets

- NCDC Integrated Surface Hourly (TD 3505)
  - Air T, Wind, Clouds, Precip, Dewpoint
  - Global coverage (online 1990s – present)
  - we would like to visit Asheville to do downloads of older data
- NERR System Wide Monitoring Program
  - Water quality, Meteorological, Solar Rad
- NDBC offshore buoy/CMAN
  - Air T, Wind, Wave height
- NOAA CO-OPS
  - Tide observations, some met, some SST

NERR Climate Data

- System Wide Monitoring Program
  - Meteorological stations
  - Water quality monitoring

- We are providing pyranometers to NERR sites to collect solar radiation data

Microclimate Model

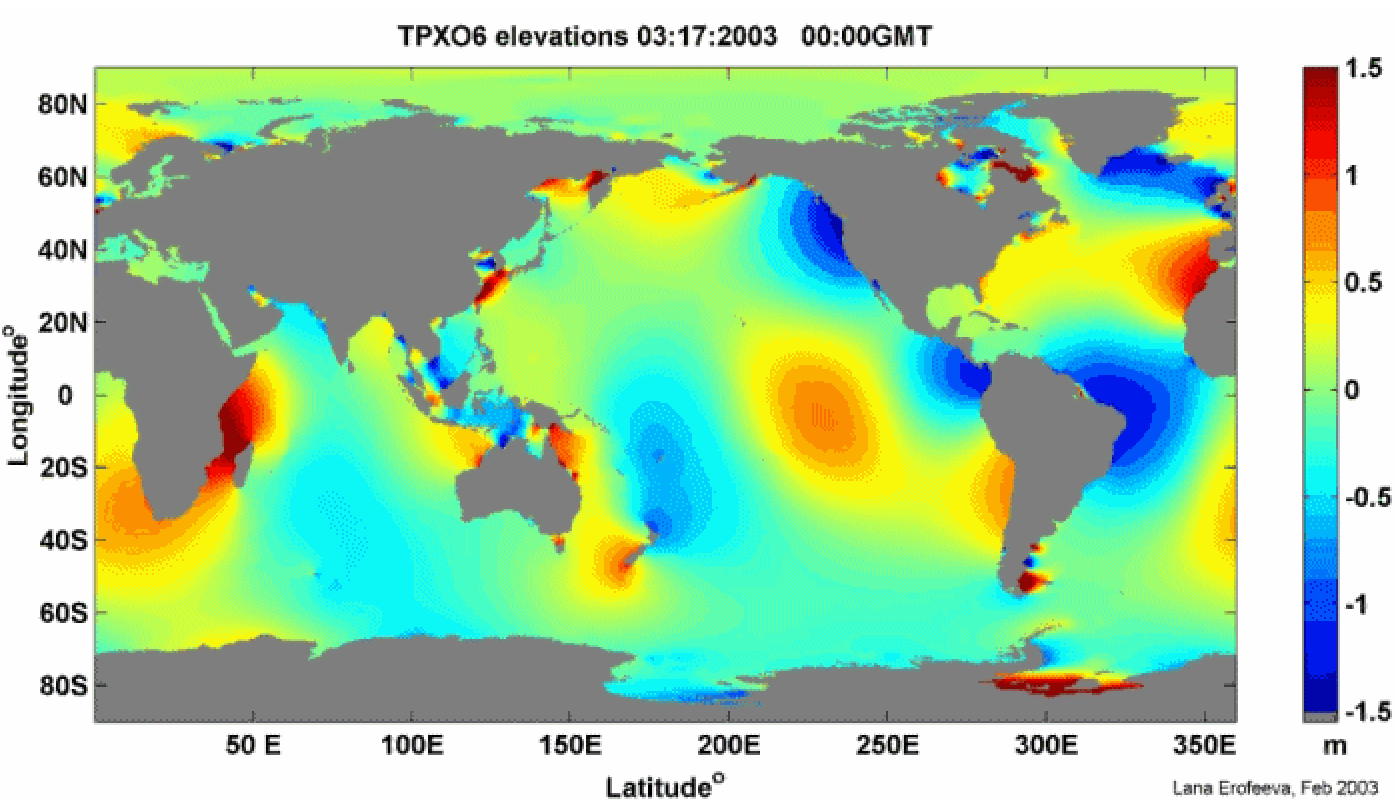
Predict rock temperature from

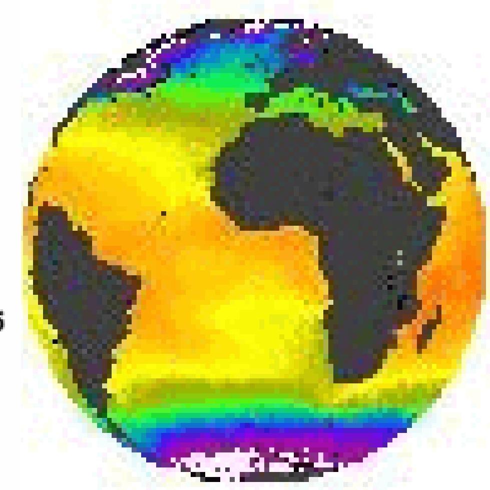
- air temperature, humidity, wind, cloud cover
    - NOAA ground & buoy observations
    - NERR SWMP
    - Satellite observations
- water temperature
    - NOAA tide station, CMAN & buoy observations
    - NERR SWMP
    - Satellite observations
- Tides
    - NOAA model /observations or WxTide
    - Wave height adjustment (NOAA buoy observations)
    - NERR SWMP
    - http://tbone.geol.sc.edu/tide
- Solar radiation:
    - angle of incidence of direct sunlight - Jet Propulsion Lab ephemeris of the sun
    - NOAA GEWEX-GCIP Solar Radiation from GOES imagery
    - NERR SWMP Ground-based pyranometers

Tides Generate Geographic Complexity

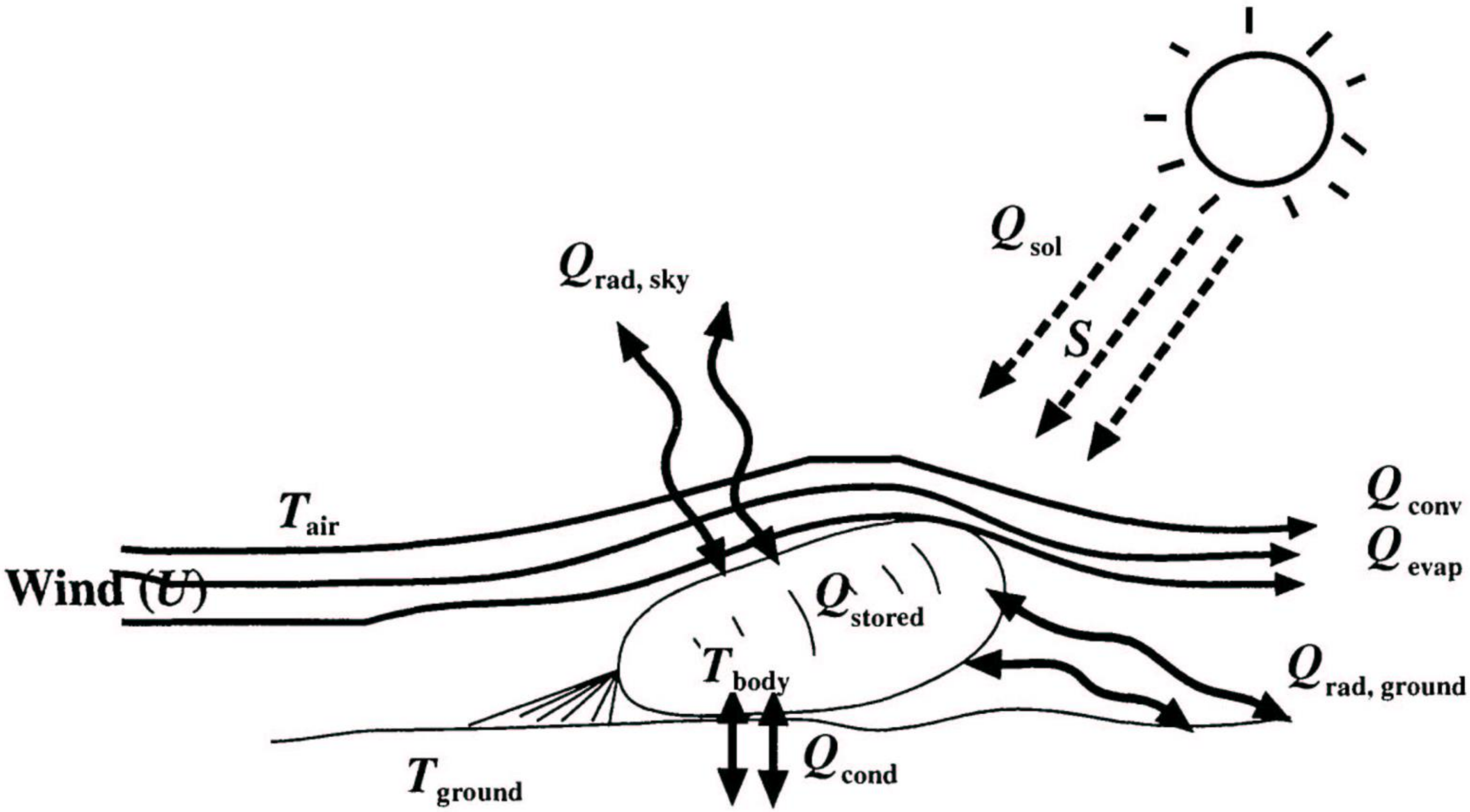
Tides

SST





Model Cartoon



Model Components

- Low Tide:
- Solve energy balance at rock/animal surface:
  - convection + radiation + solar = conduction
- Model heat conduction into rock/animal
- repeat
- High Tide:
- Model heat conduction to/from rock

Heat balance equations used to calculate body temperature of an intertidal animal, using climate data.

Major components ***Q*** of the heat budget at low tide are:

$$Q_{stored}=Q_{direct\ solar}+Q_{diffuse\ solar}+QIR_{sky}+QIR_{ground}+Q_{conduction}+Q_{convection}+Q_{evaporation}$$

At low tide when animals are exposed to air, this is expanded as:

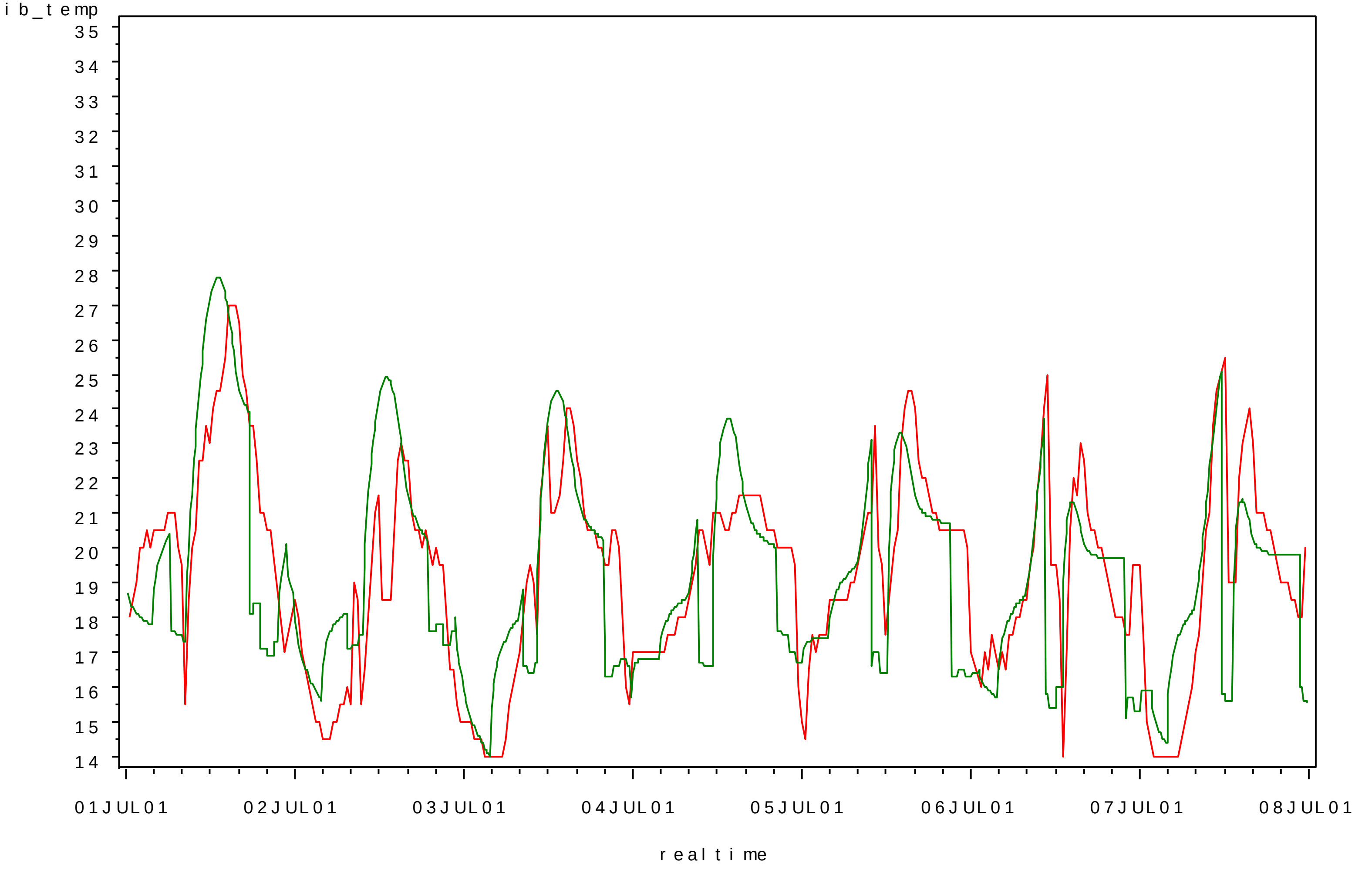
$$\Delta T_{body}\, m_{body}\, cp = \alpha\, A_{solar}\, S + A_{diffuse}\, S_{diffuse} + \sigma\varepsilon\, A_{radiation}(T_{sky}{}^{4}-T_{body}{}^{4}) + \sigma\varepsilon A_{ground}(T_{ground}{}^{4}-T_{body}{}^{4}) + 0.5KL^{-1}A_{conduction}(T_{ground}-T_{body}) + C\, A_{convection}(T_{air}-T_{body}) - \lambda m^{*}$$

At high tide when animals are immersed in the ocean, this is expanded as:

$$\Delta T_{body}\, m_{body}\, cp = 0.5KL^{-1}A_{conduction}(T_{ground}-T_{body}) + C\, A_{convection}(T_{water}-T_{body})$$

Ground Truth - Cape Cod Canal

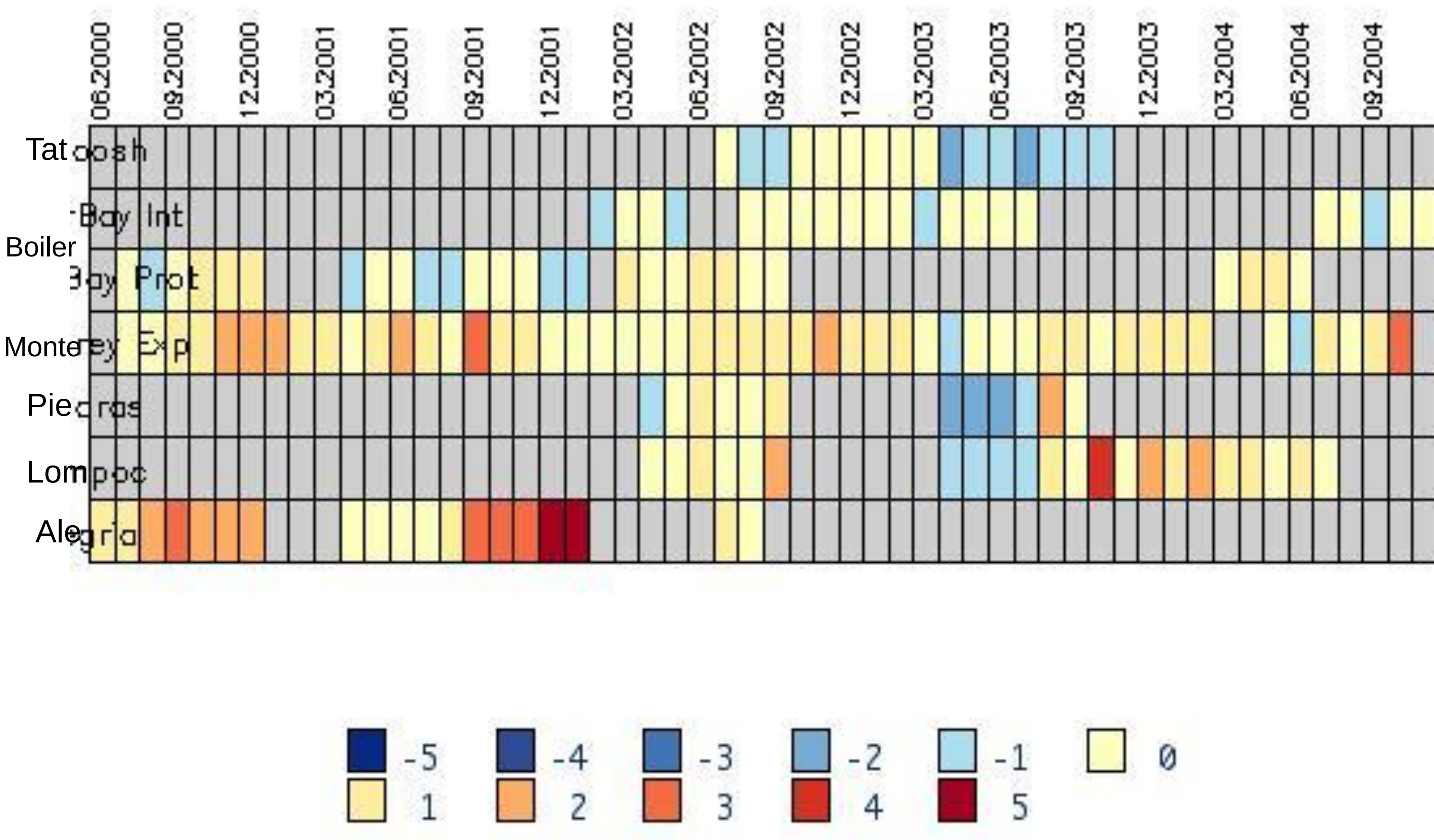
Green = Model, Red = datalogger



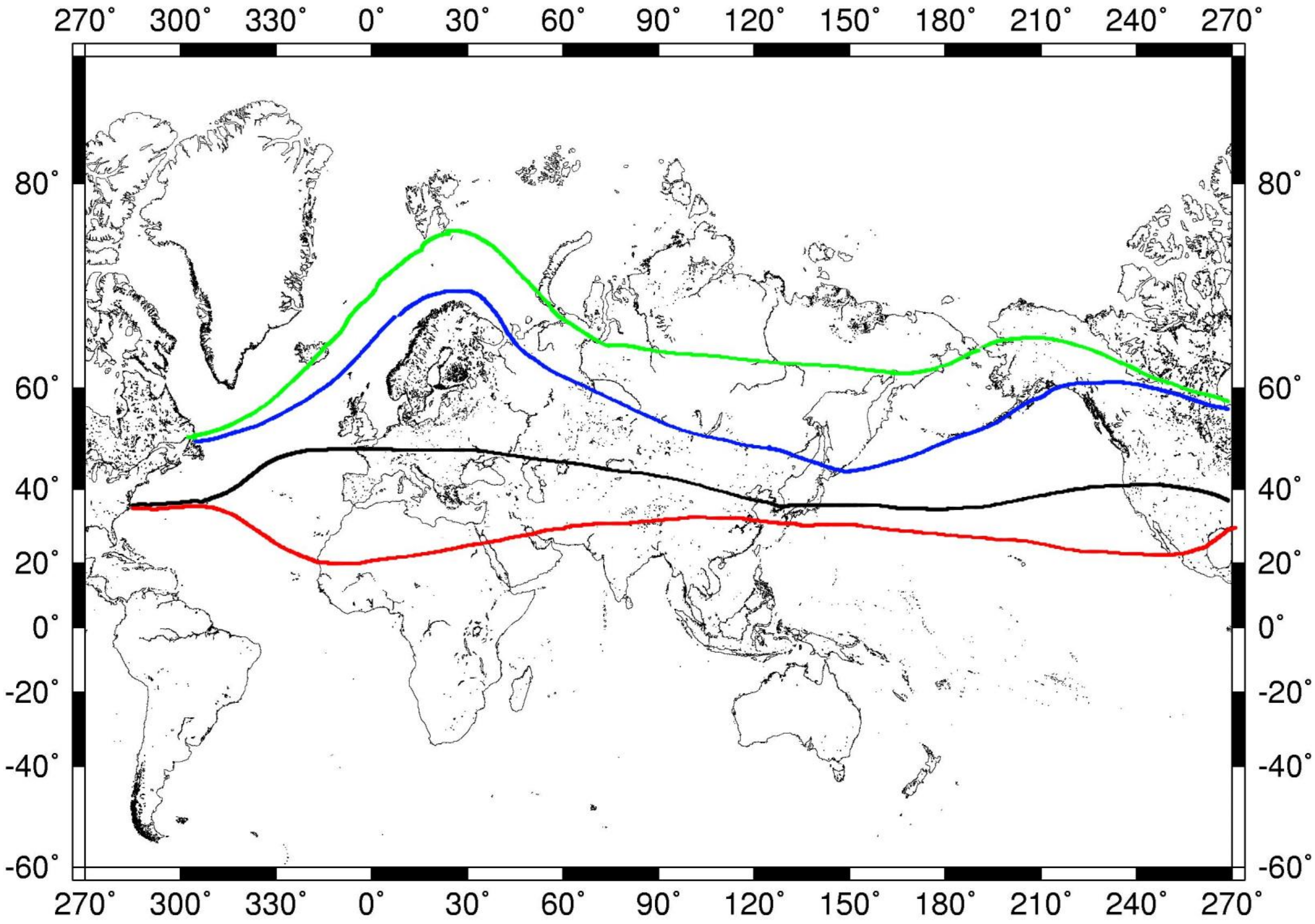
Ground Truth

- Biomimetic loggers
  - Measure average daily maximum and average daily minimum temperature monthly per logger
  - Determine Mean and Std Deviation of these values at sites from California to Washington
- Model
  - Logger predictions are mostly within 2 SD of logger mean.
  - Indicates model predicts average daily maxima as well as loggers measure it.

average z-score for daily 97%ile



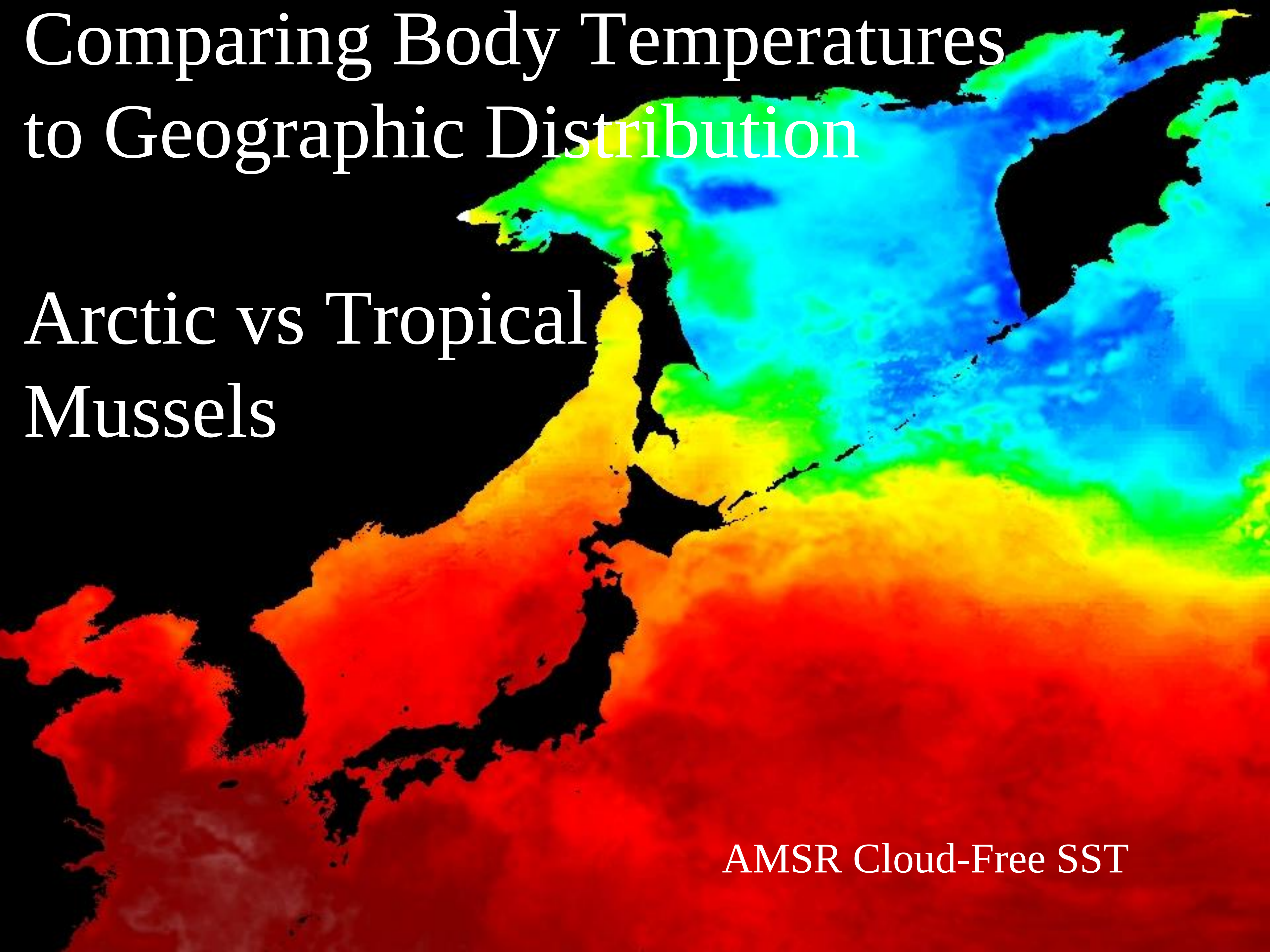
Biogeography and climate - the Mediterranean mussel

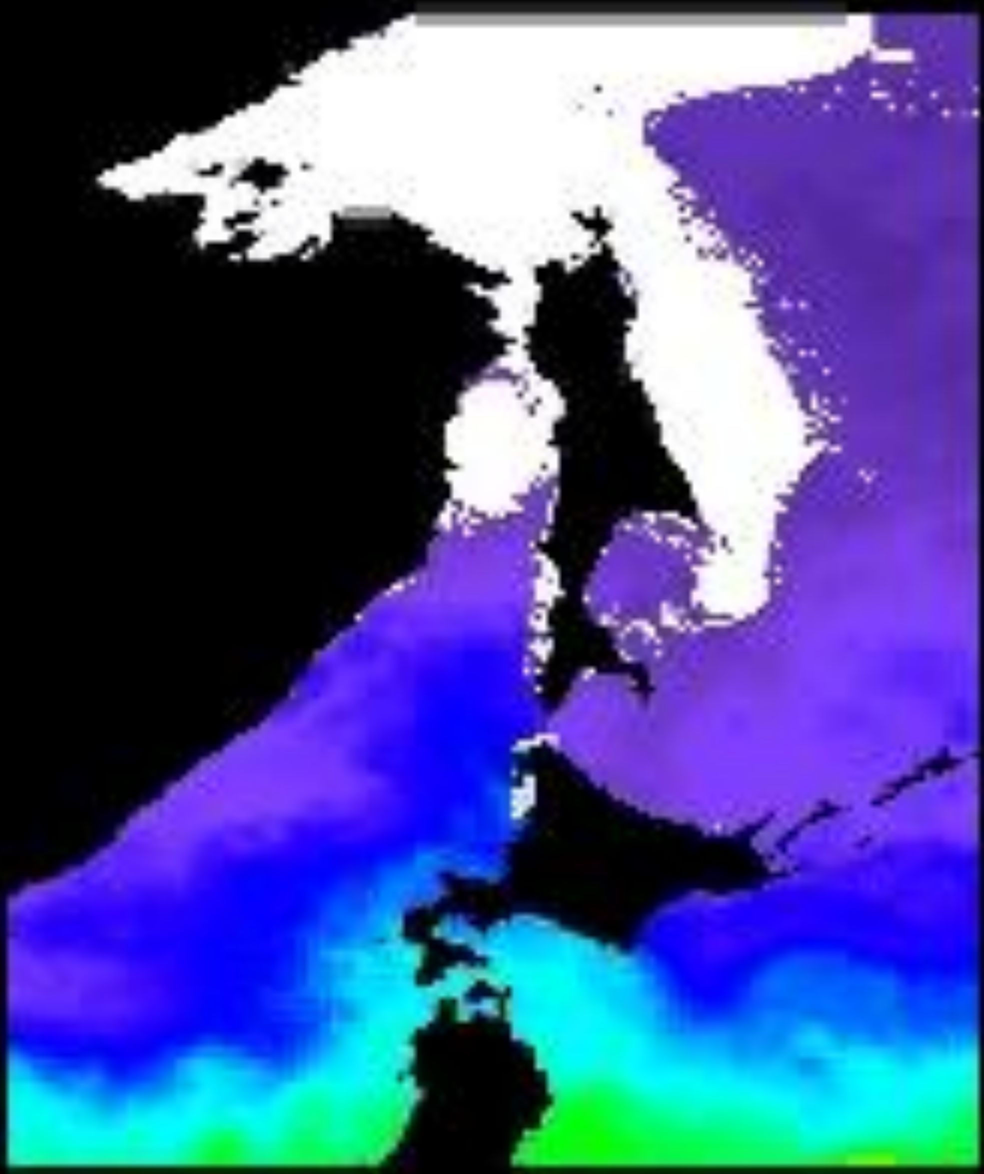


Black = winter SST 8°C Red = summer SST 30 ° C

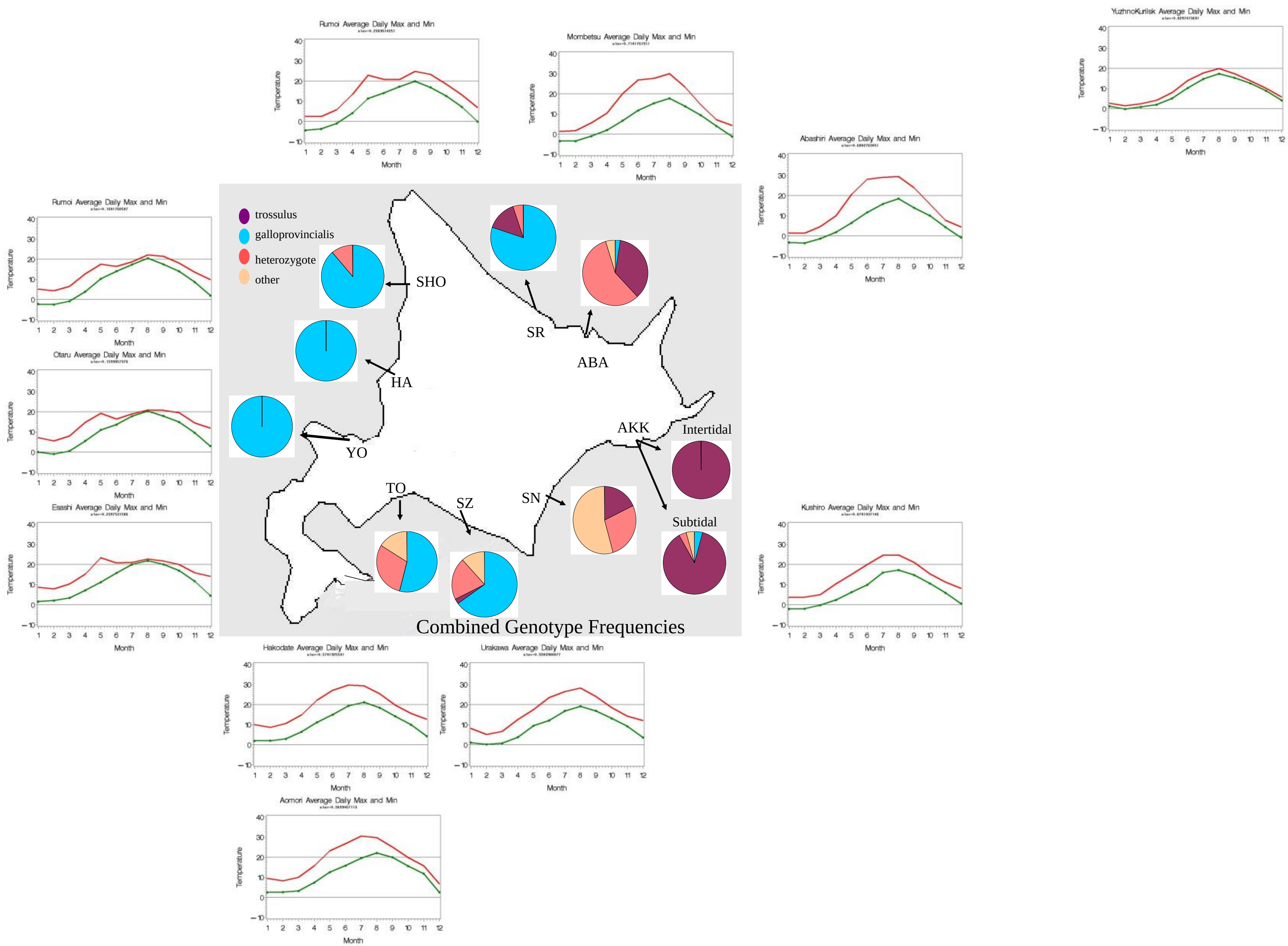
Comparing Body Temperatures to Geographic Distribution

Arctic vs Tropical Mussels

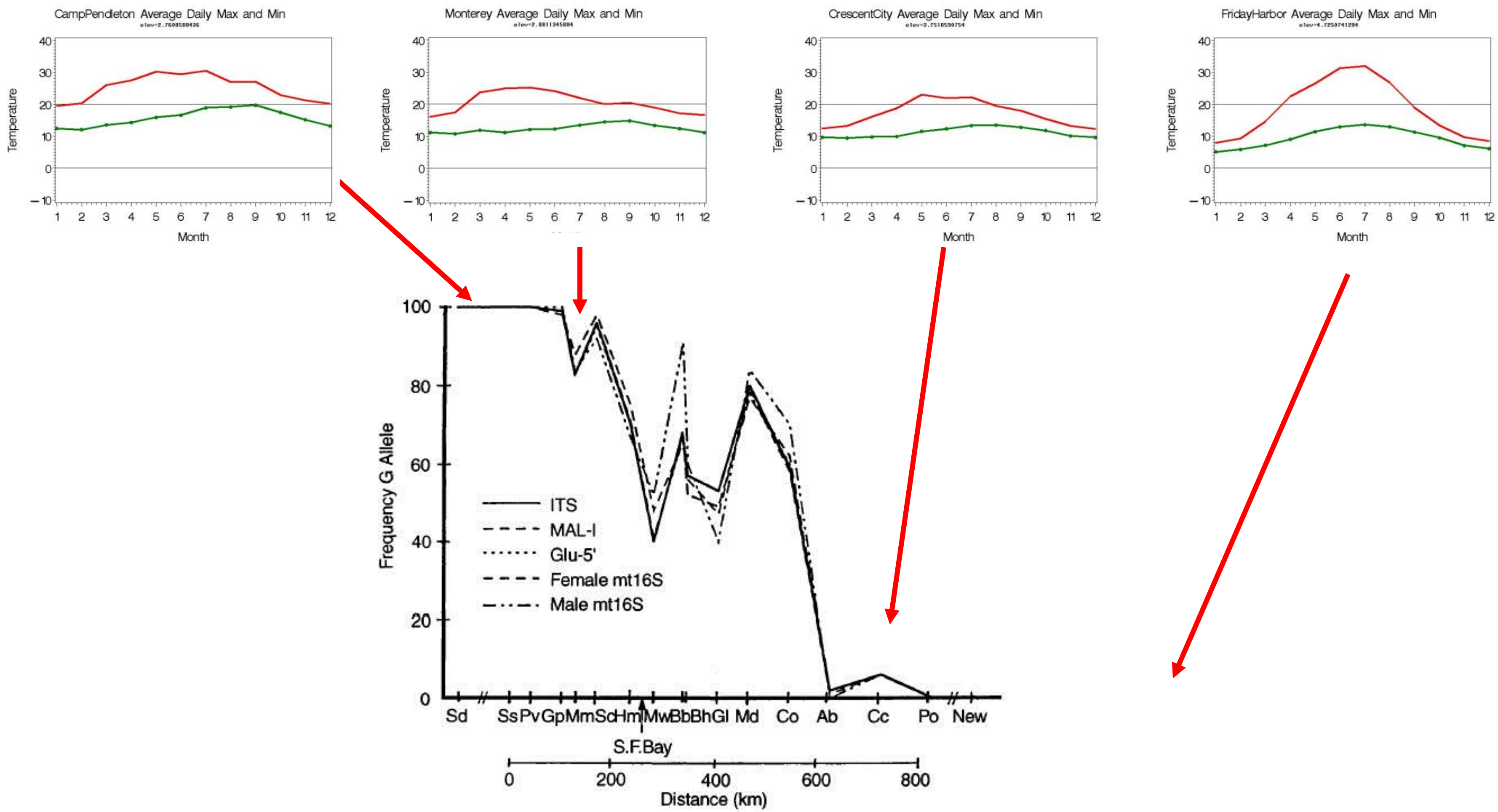




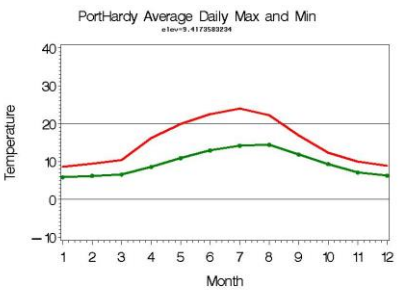
Geographic Model Predictions
Mussel species in Hokkaido

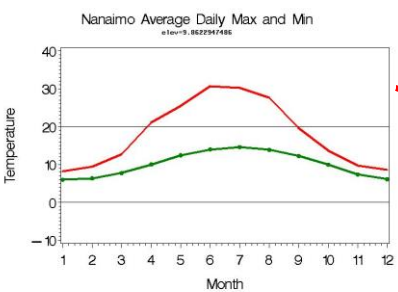


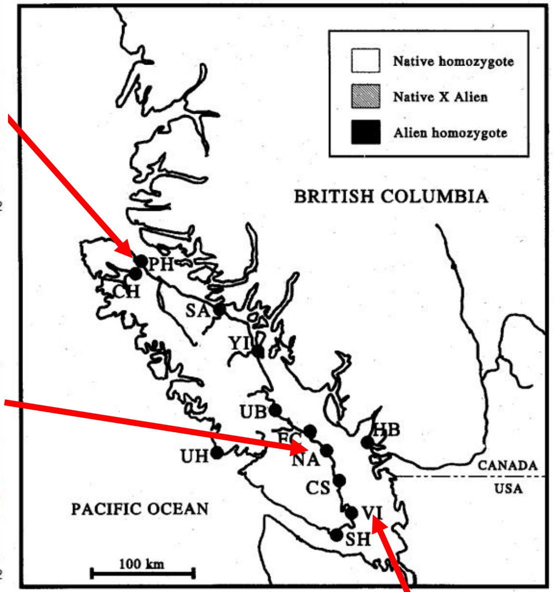
US West Coast
Mytilus galloprovincialis

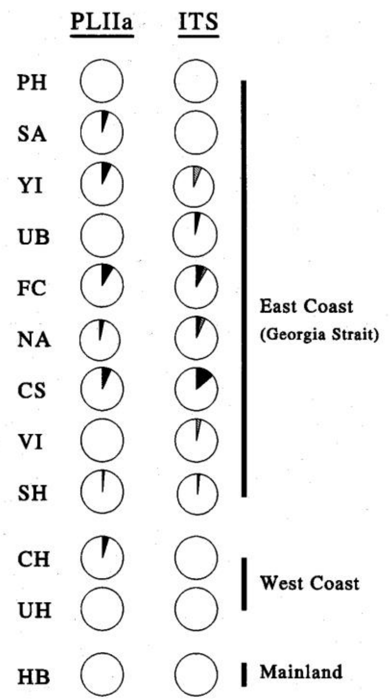


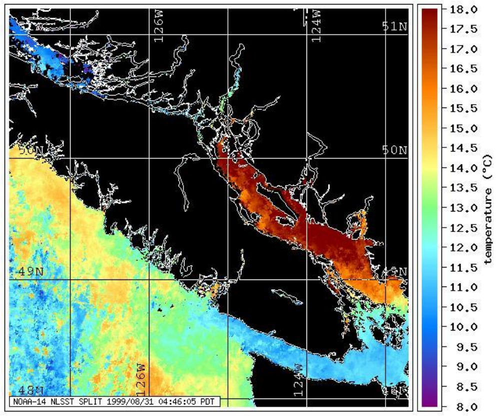
Strait of Georgia :Local *Mytilus galloprovincialis* populations

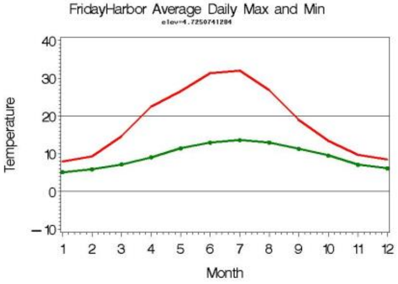












Geographic Statistics and Prediction Preliminary Tests

- GARP
  - – Genetic algorithms for statistical modeling
  - – Dependent variable – species localities
  - – Independent variables
    - Weather (Air T, SST, RH, Solar, Clouds, etc)
    - Model output (Avg Daily Max, Avg Daily Min)
- Mussel species in Hokkaido
  - – 67% of the variance in species distribution is explained by independent variables

California-Oregon
Geographic Limits of Mussels

- Field Programs Underway
  - Sampling at 50 km intervals from Pt Sur to north of San Francisco – southern limit of arctic mussel – DNA fingerprinting analysis
  - Biomimetic sensors deployed from Santa Barbara to British Columbia
- Modeling Programs Underway
  - Ground Truth of Mussel Model
  - Sensitivity Analysis

Biogeography and Climate – the arctic barnacle

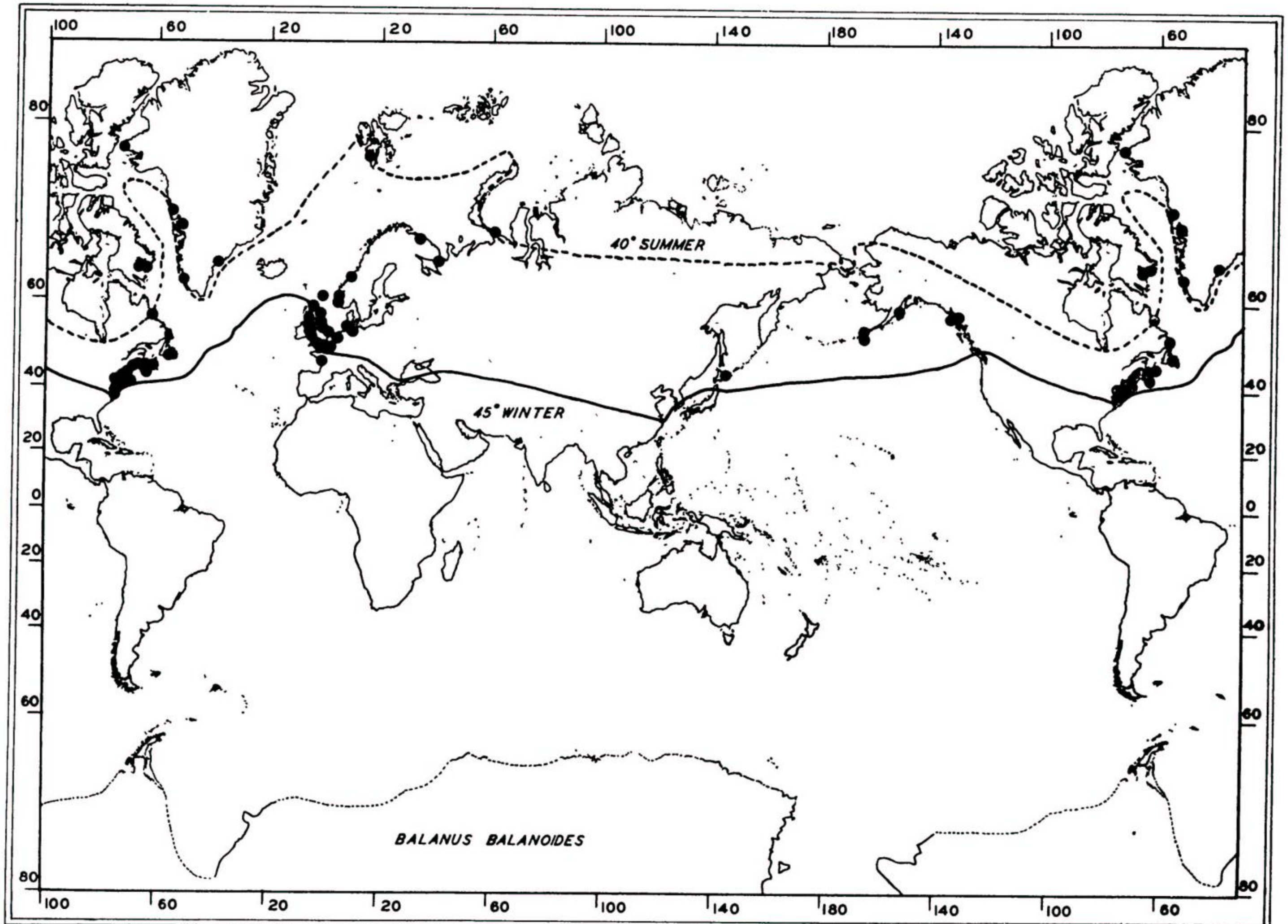
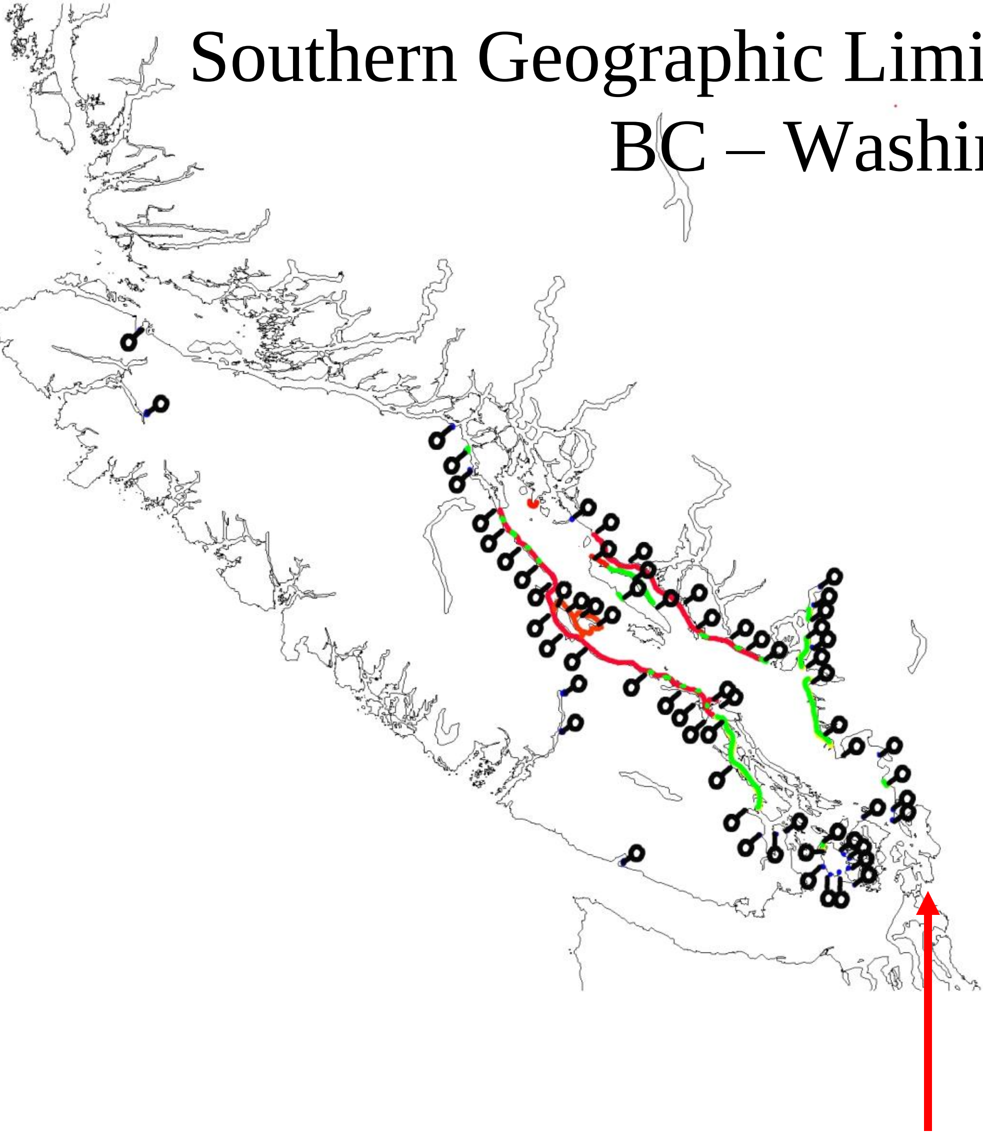
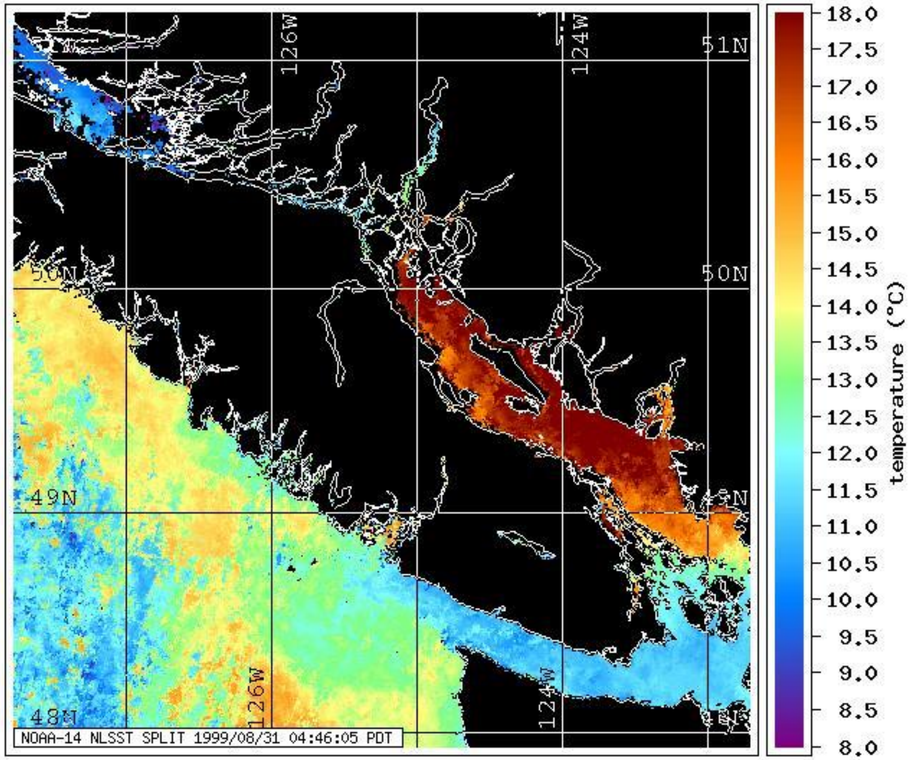


FIG. 3. Some records of the barnacle *Balanus balanoides,* showing particularly the apparent southern limits of the species. These limits are best fitted by the isotherm of the minimum monthly mean (winter) surface water temperature of 45° F.

Southern Geographic Limit of the arctic barnacle in BC – Washington State





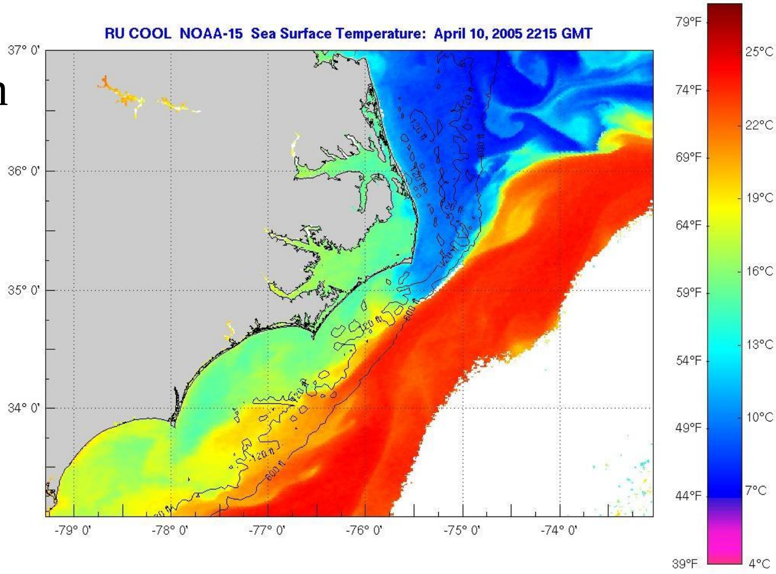
Padilla Bay NERR

BC – Washington Border: Southern Limit of Arctic Barnacle Infaunal Analysis

- Field Programs Underway
  - Biomimetic loggers in San Juan Islands
  - Biomimetic loggers in Strait of Georgia
  - Sediment thermal conductivity measurements
    - San Juan Island
  - Preliminary infaunal activity measurement
    - Padilla Bay NERR, San Juan Island

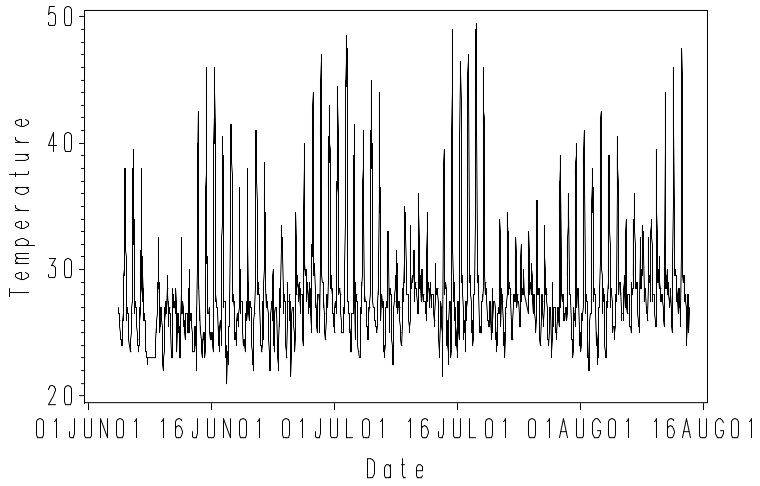
Southern Limit of
Arctic Barnacle and Arctic Mussel

- Field Experiments underway
  - Transplants beyond geographic limit
    - Growth, Mortality, Heat Shock Protein
  - Transplants within geographic range
    - Same measurements
  - Biomimetic temperature sensors deployed
- Lab Programs
  - Heat shock protein methods development
- Modeling Programs
  - Ground truth of barnacle model

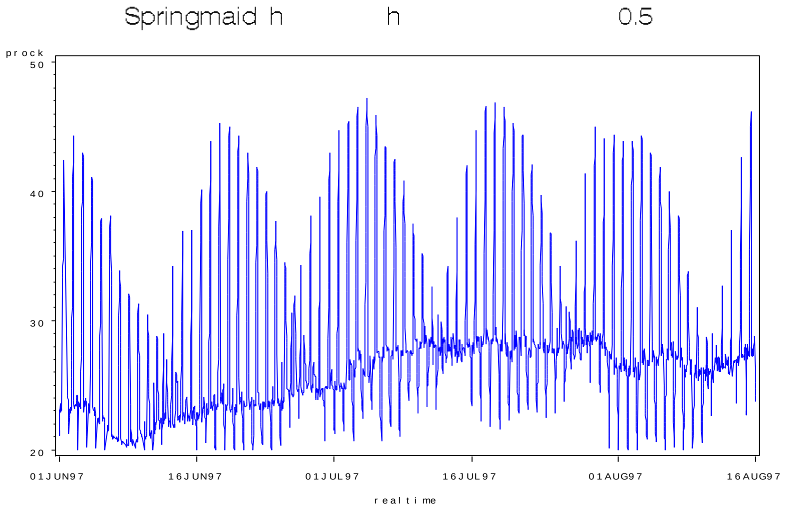


Ground Truth of Barnacle Model South Carolina Rock Temperatures

Measurement



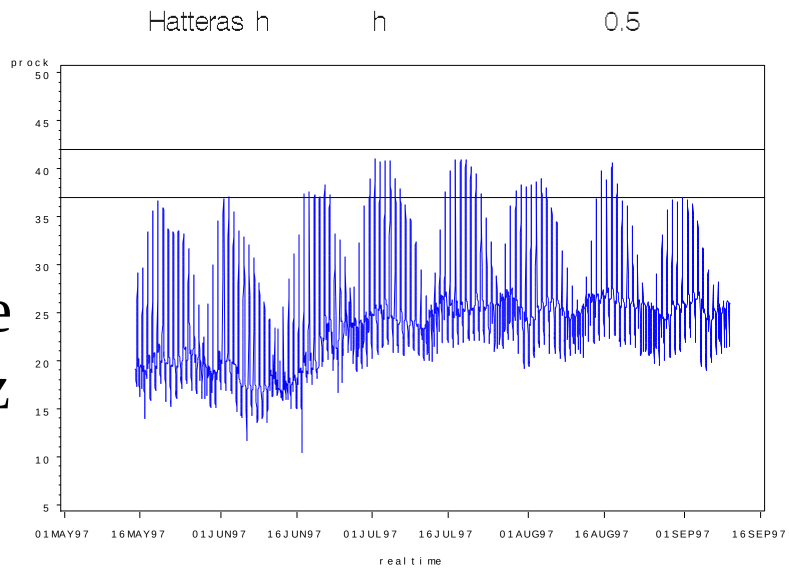
Model Prediction

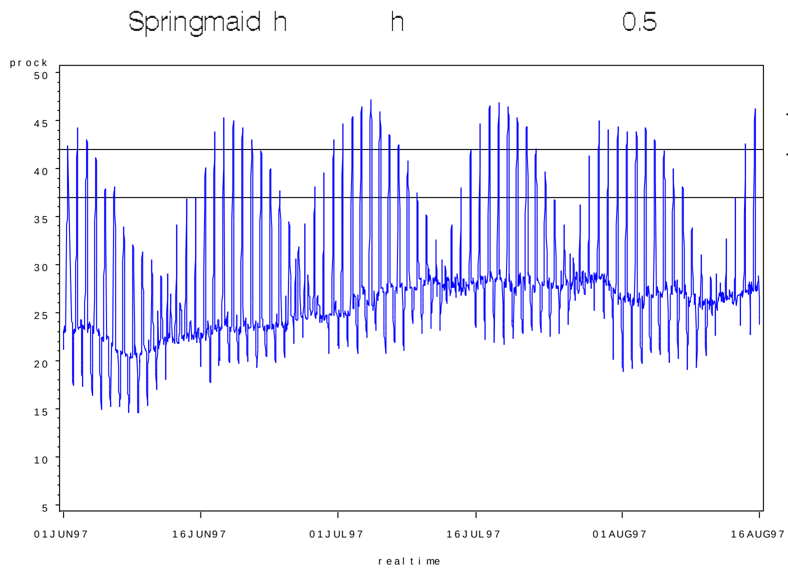


Modeled Barnacle Thermal Limits

North Carolina South Carolina

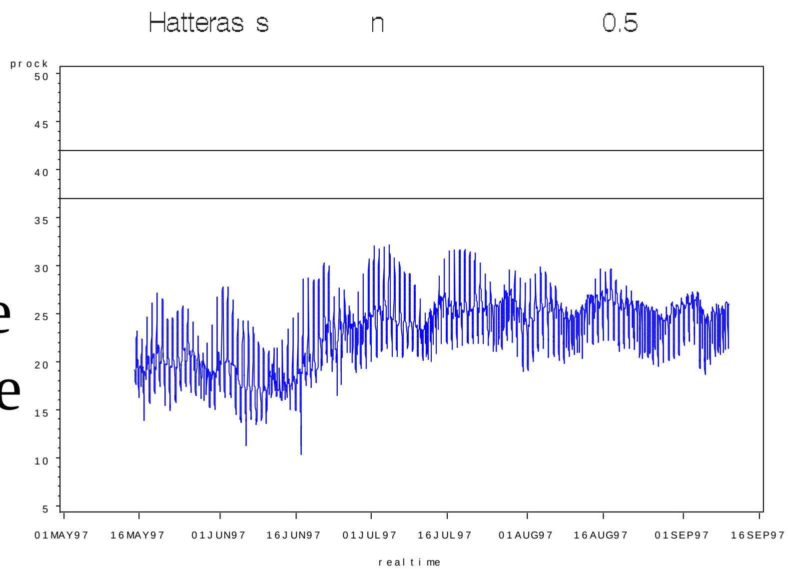
Mid Shore Horiz

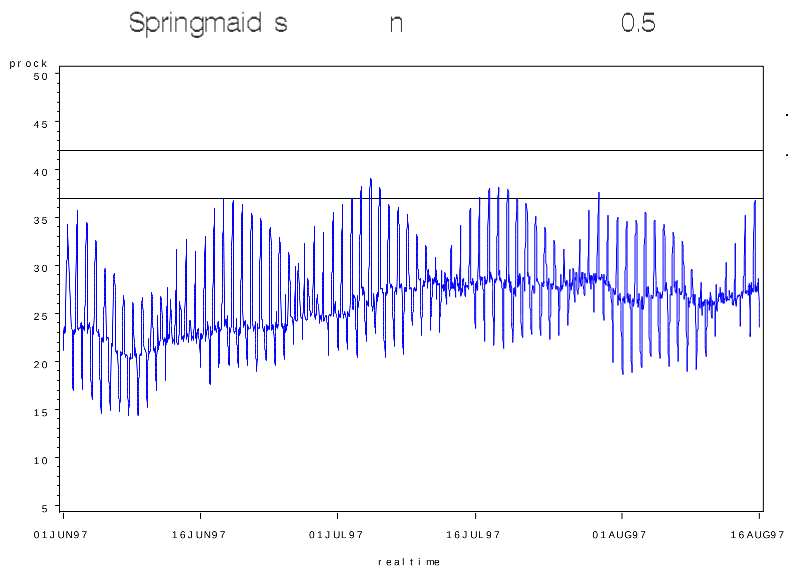




Lethal
Coma

Mid Shore N face





Lethal
Coma

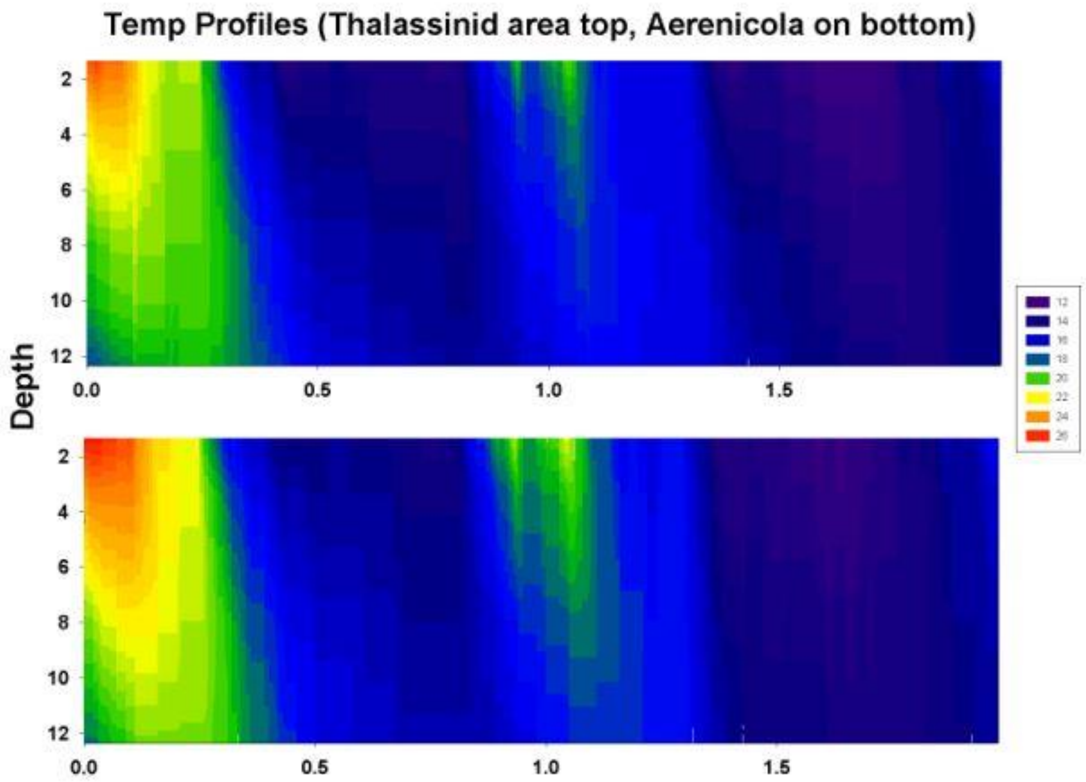
Sedimentary Habitats

- Model development
  - Thermal conductivity vs grain size

- Depth-Time profiles of sediment temperature
  - Washington – Padilla Bay NERR
  - California - Elkhorn Slough NERR
  - South Carolina – North Inlet NERR

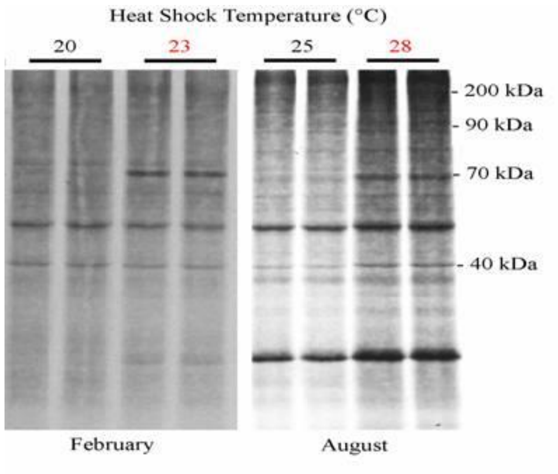
Sedimentary Habitats

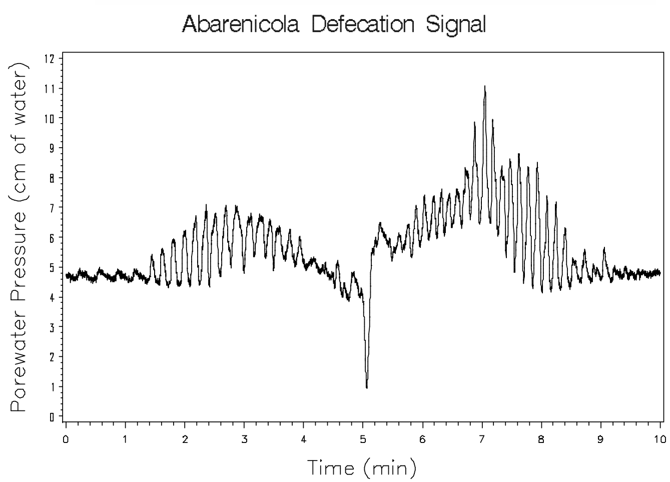
Thermal conductivity of sediments



Time (days)

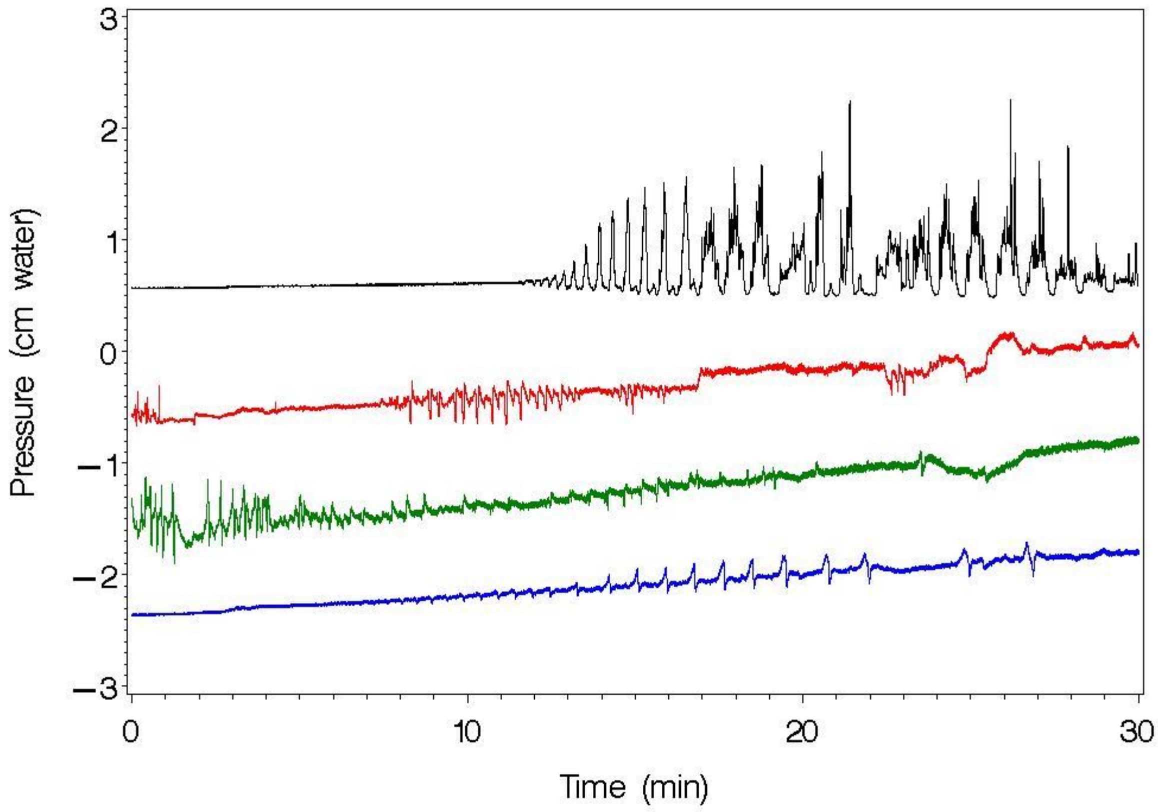
Sublethal Effects on Populations





- Heat Shock Protein Expression
- Activity
  - Non invasive recordings of infaunal activity by porewater pressure sensors
  - Behavior specific waveforms

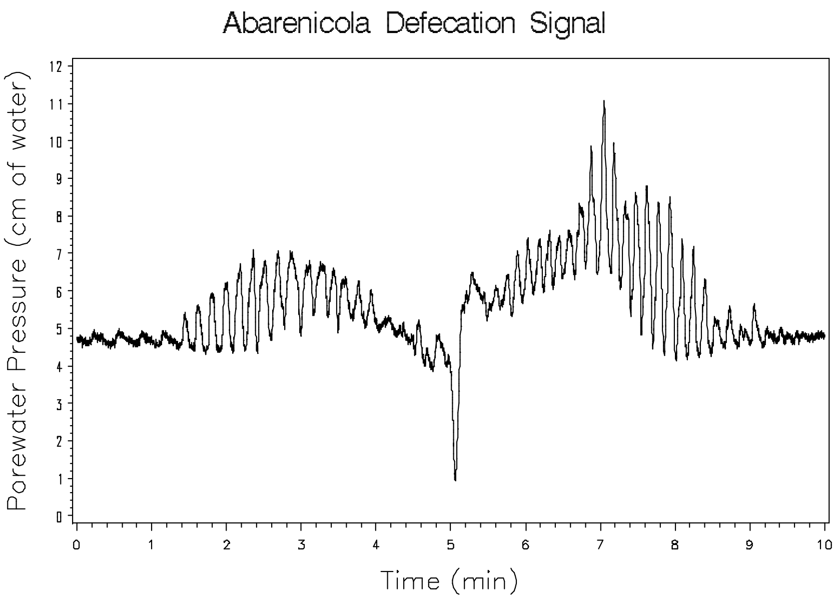
In situ behavior logging: pressure signals recorded in sediments

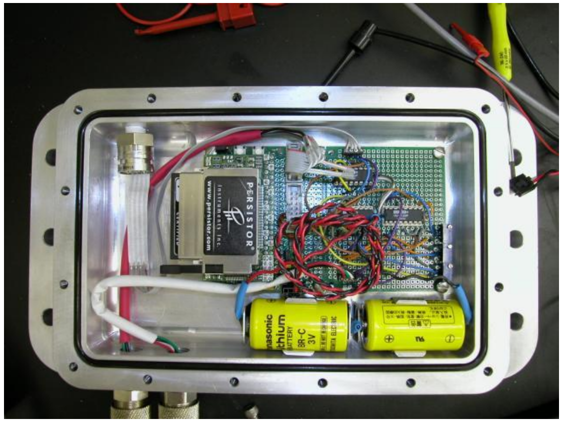


Bed of *Abarenicola*
Sediment Disruptor

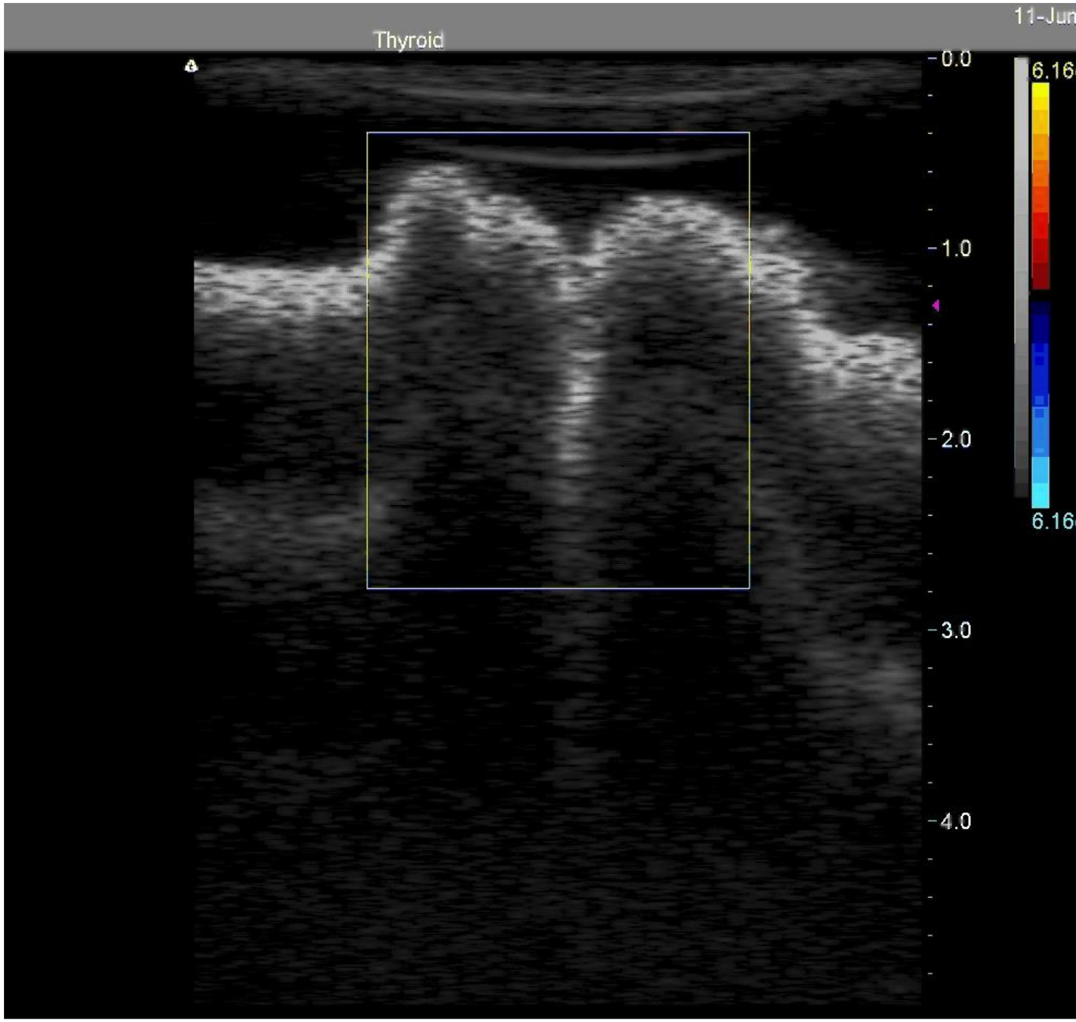
Non-Invasive Activity Measures in Sedimentary Systems

Porewater Pressure





Water Flow and Behavior



NERR Sites Visited to Date

- Padilla Bay, Washington
- Elkhorn Slough, California
- Tijuana Slough, California

- Waquoit, Massachusetts
- Outer Banks, North Carolina
- North Inlet, South Carolina

NERR System Wide Monitoring Program

- Met with the weather station technicians from all NERR sites at their annual training session in January 2005.

- Central Data Management Office is on our campus at the University of South Carolina

Data Management and Modeling Software

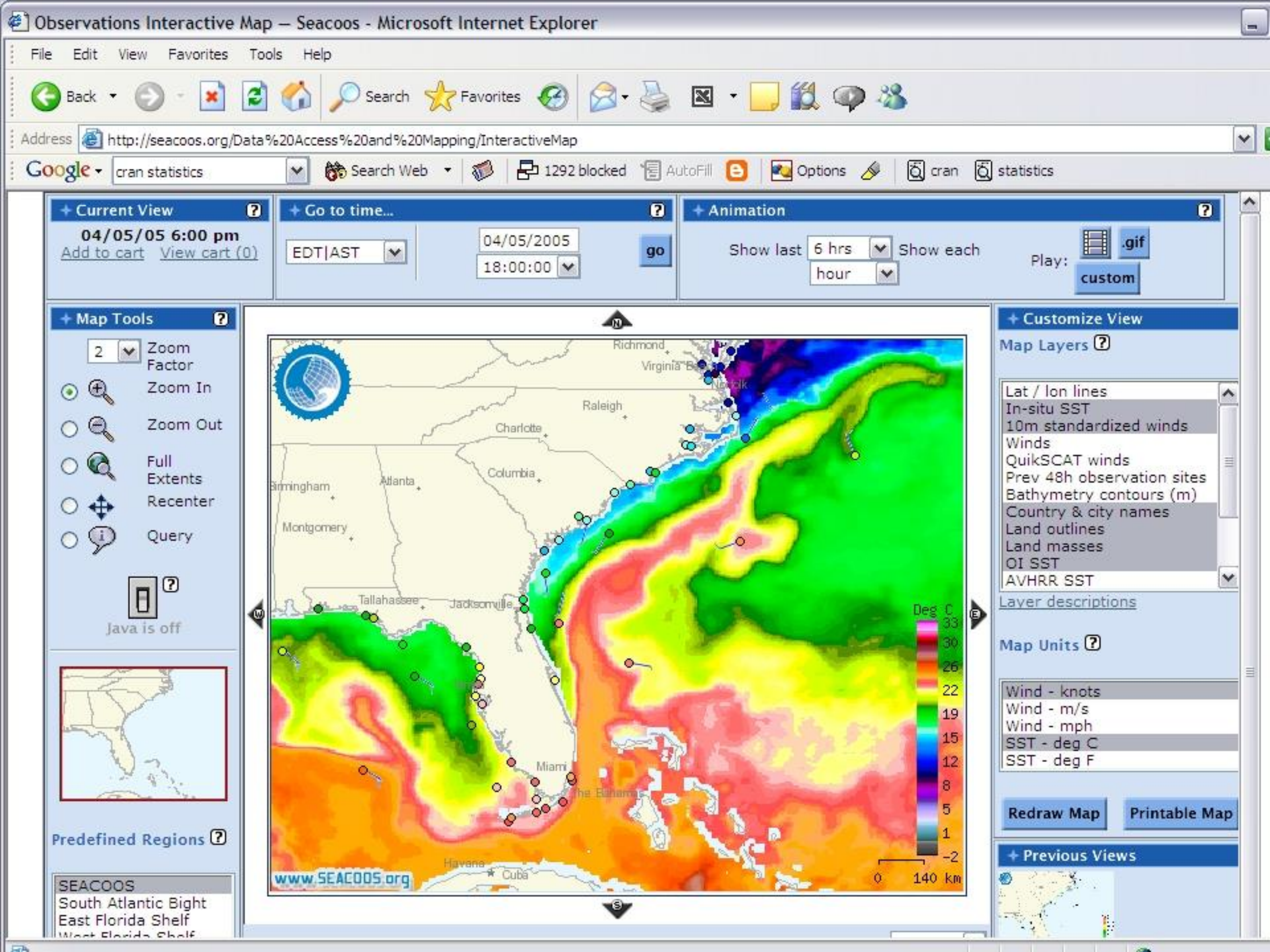
- All Open Source Software
  - PostgreSQL relational database
    - www.postgresql.org
  - PostGIS georeferencing database modules
    - www.postgis.org
  - Mapserver / Generic Mapping Tools
    - mapserver.gis.umn.edu gmt.soest.hawaii.edu
  - R statistics language
    - www.r-project.org

Model Application Example

- Resource Managers
  - Predict effects of El Nino or La Nina events when the ENSO indicators start changing.
  - Predict effects of hot or cool summers if the seasonal forecasts indicate an anomaly is coming.
  - If local die-offs or range shifts are predicted, the managers can plan a response in advance.

User Interface

- Year 3
  - Web-based front end to draw maps of
    - Forecasts
    - Hindcasts
    - Nowcasts
- We been getting advice from the programming team for CAROCOOPS, and SEACOOS who are on our campus.


Observations Interactive Map — Seacoos - Microsoft Internet Explorer
File Edit View Favorites Tools Help
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Recenter
Query
Java is off
Predefined Regions
SEACOOS
South Atlantic Bight
East Florida Shelf
Richmond
Virginia Beach
Norfolk
Raleigh
Charlotte
Columbia
Atlanta
Birmingham
Montgomery
Tallahassee
Jacksonville
Miami
The Bahamas
Havana
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www.SEACOOS.org
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Customize View
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10m standardized winds
Winds
QuikSCAT winds
Prev 48h observation sites
Bathymetry contours (m)
Country & city names
Land outlines
Land masses
OI SST
AVHRR SST
Layer descriptions
Map Units
Wind - knots
Wind - m/s
Wind - mph
SST - deg C
SST - deg F
Redraw Map
Printable Map
Previous Views

Related Value Added Projects

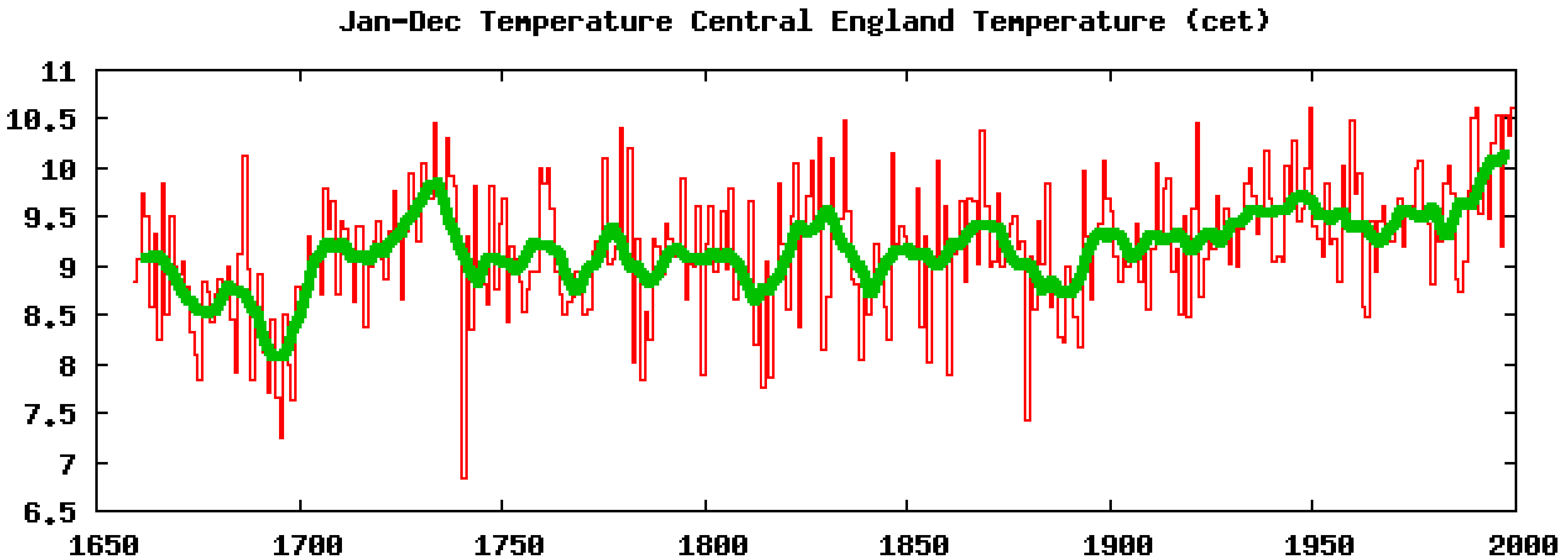
- NASA Earth Science Enterprise
  - Biogeography and climate (W Pacific, E Atlantic)
    - PI Helmuth, Co PIs Wethey, Hilbish, Lakshmi
    - Barnacles and Mussels
    - Hong Kong to Hokkaido
    - Morocco to Scotland
- ONR Science & Technology
  - Real time measurement of behavior in infauna
    - PI Woodin, CoPIs Wethey, Marinelli
    - Worms and burrowing shrimp - pressure sensor development

The tropical atlantic barnacle *Chthamalus fragilis* Darwin

- Caribbean to Cape Cod 1898

- Caribbean to Carolinas 1850

- Moving north with climatic warming?



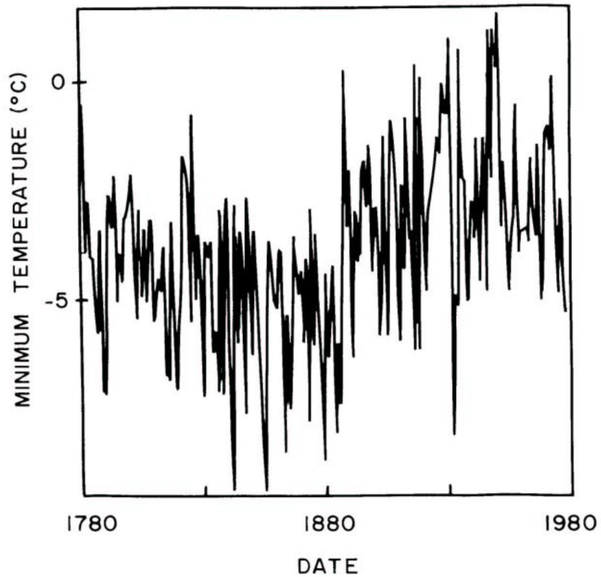


FIG. 1. Minimum monthly mean temperatures for the months December to February in each winter, 1780–1980, at Boston, Massachusetts. Data are from Paine (1834), Blodgett (1857), Pickering (1889), and United States Weather Bureau (1936, 1931–1980). Temperatures below −5°C are associated with sea ice (see Methods: Climate Reconstructions).

Chthamalus refuge vs maximum rock temperature