



Coastal oceanic warming and its effects on biogeography and biodiversity

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Coastal ecosystems

Provide half of Earth's total ecosystem goods and services (Costanza *et al.* 1997)

- Disturbance regulation
- Nutrient cycling
- Habitat providing
- Revenues from tourism and from the production of food and raw materials

Most highly impacted marine systems (Halpern *et al.* 2008)
Suffer the cumulative pressure of:

1. Anthropogenic land-based processes

- Overpopulation
- Agricultural runoff and pollution

2. Ocean-based human activities

- Over-fishing
- Intense maritime traffic

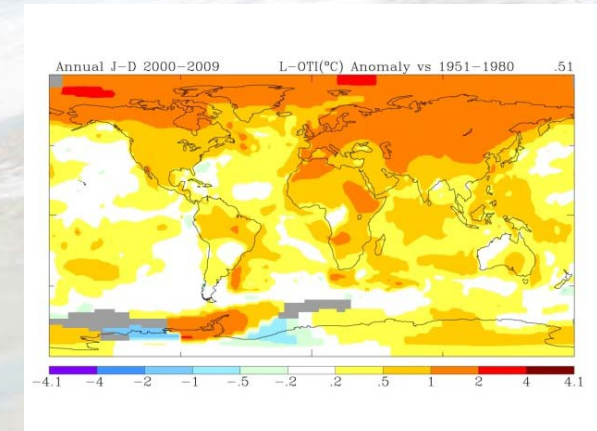
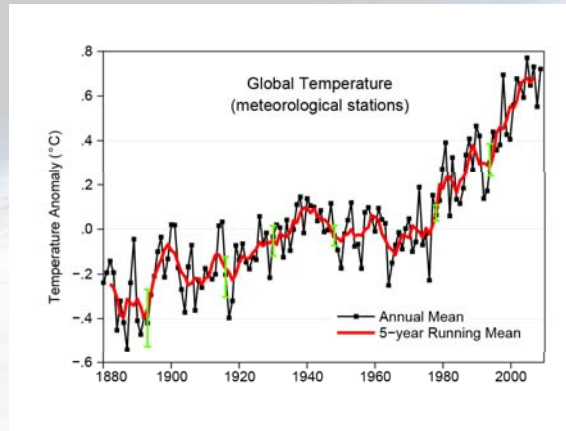
3. Climate change



Global warming

Recent warming

- 0.2°C/decade, since 1980
- 2000-2010 was the warmest decade since 1880
- Anthropogenic contribution is now undeniable



Biological consequences of global warming

- Biogeographical shifts (upward in altitude and poleward in latitude)
- Changes in species phenology (timing of events)
- Changes in species interactions



European intertidal ecosystems

Intertidal organisms

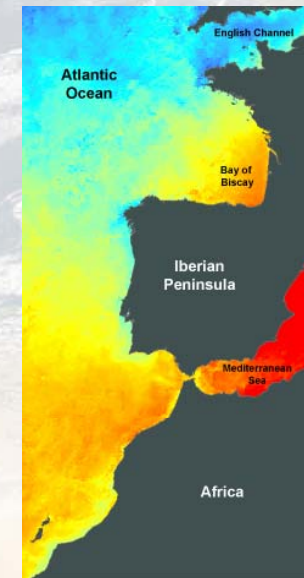
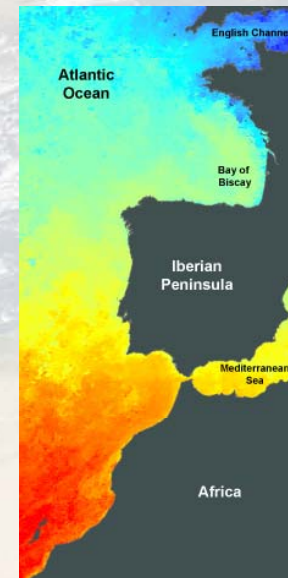
- Marine origin
- Have to withstand the cyclic effect of tide
- Low tide is highly stressful (temperature and desiccation)
- Distributional ranges well-defined



Sensitive indicators/early warning system for climate change

SW European coast

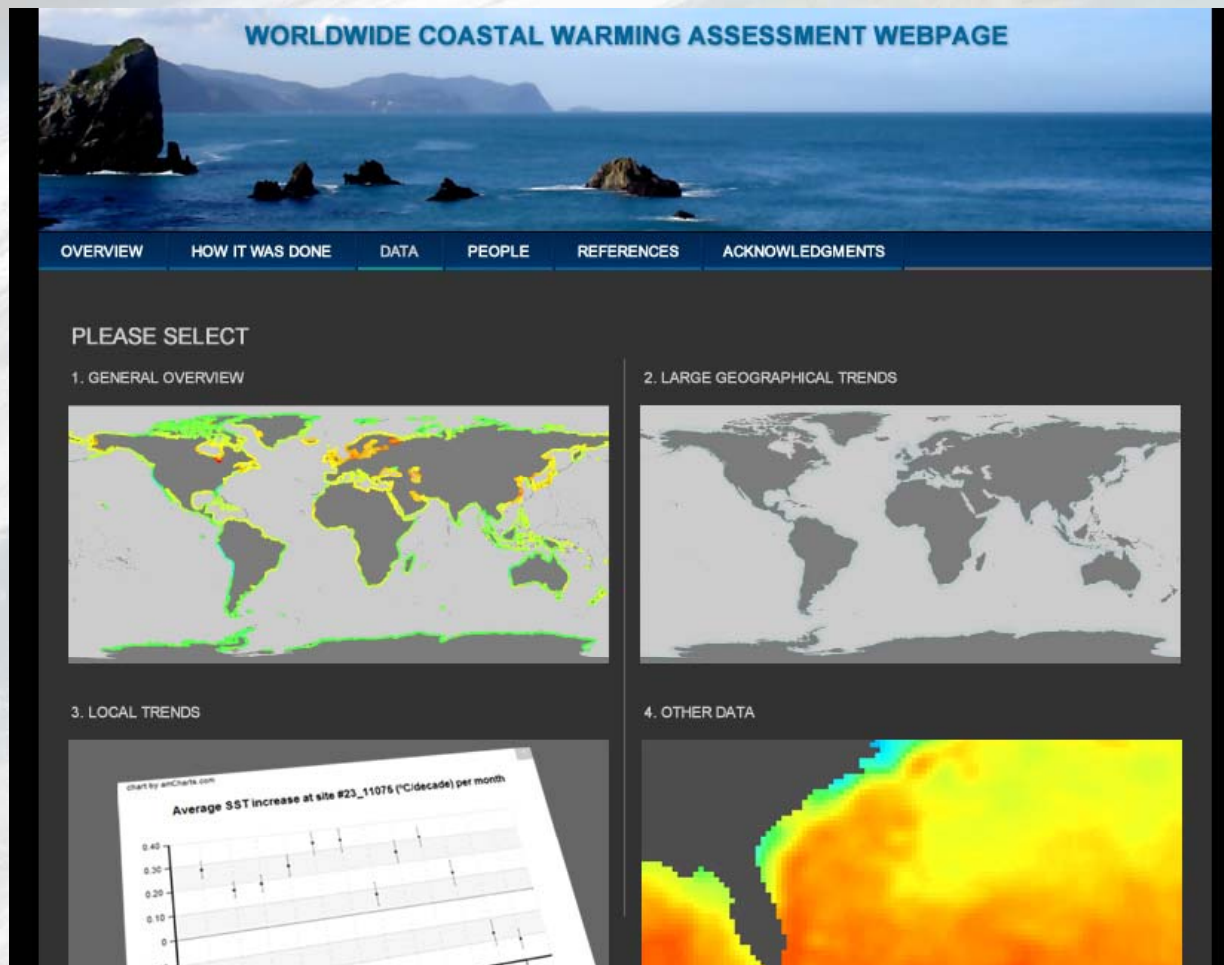
- Well suited for the study of the effects of climate warming on species distribution
- N-S temperature cline in winter
- Alternation between warm and cold areas in summer
- Numerous species with distributional limits here



How much has the coastal ocean been warming?

www.coastalwarming.org

- Daily temperature records from satellite imagery from 1982 until 2009
- 17793 coastal locations analyzed

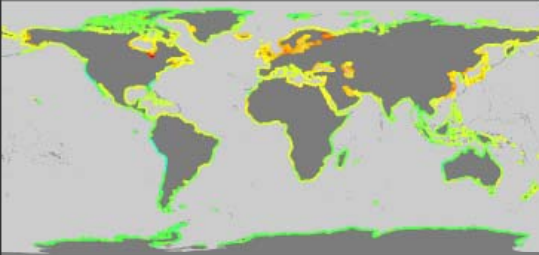


WORLDWIDE COASTAL WARMING ASSESSMENT WEBPAGE


OVERVIEW HOW IT WAS DONE DATA PEOPLE REFERENCES ACKNOWLEDGMENTS

PLEASE SELECT

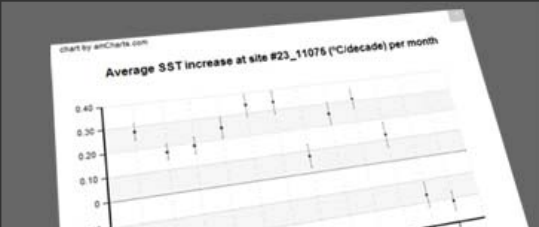
1. GENERAL OVERVIEW



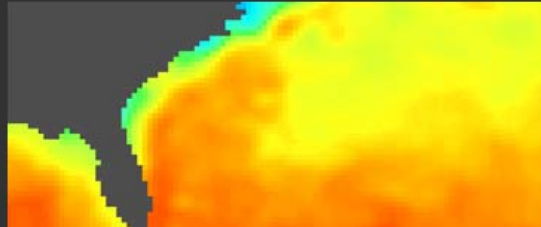
2. LARGE GEOGRAPHICAL TRENDS



3. LOCAL TRENDS



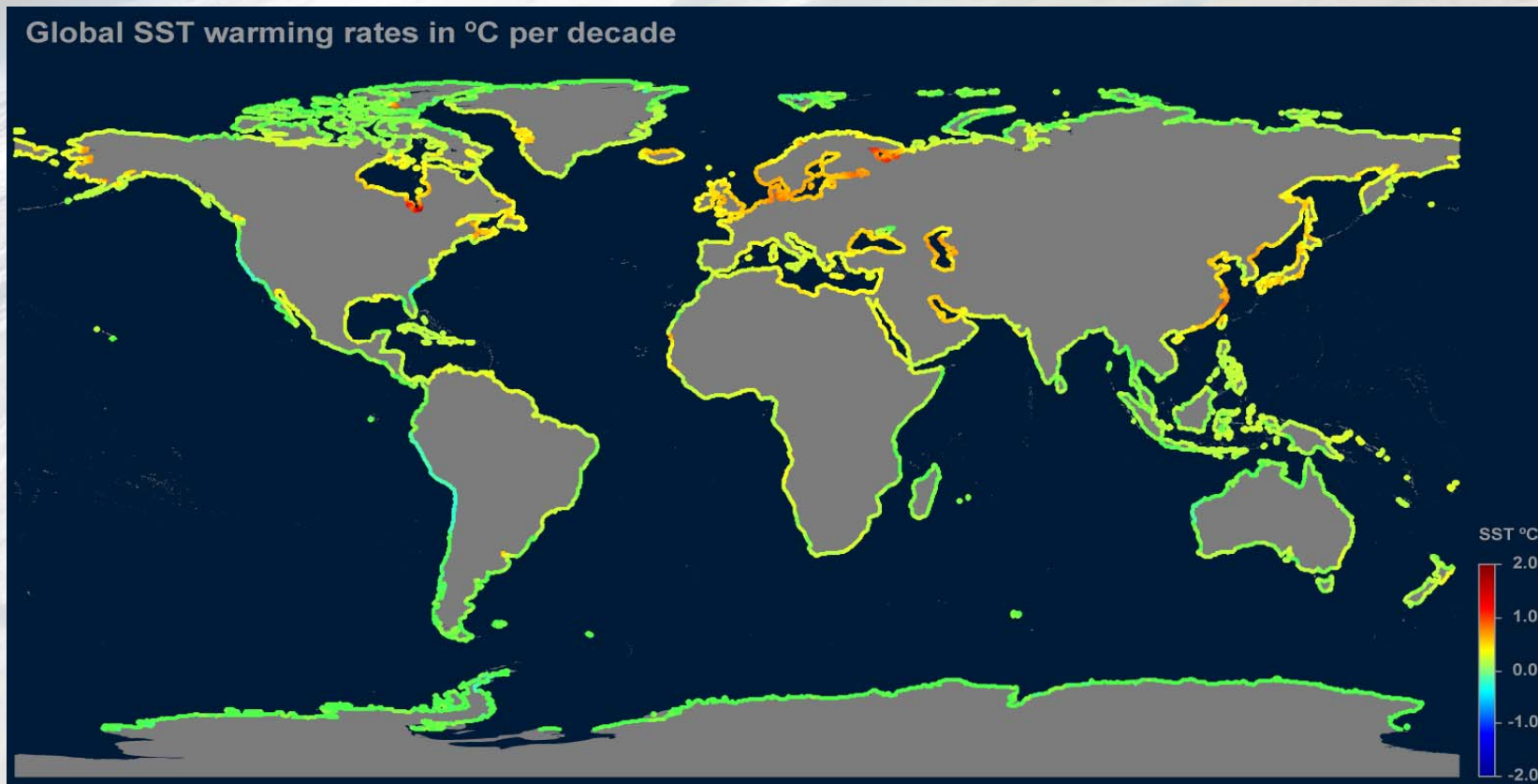
4. OTHER DATA



How much has the coastal ocean been warming?

Linear sea temperature trends since 1982

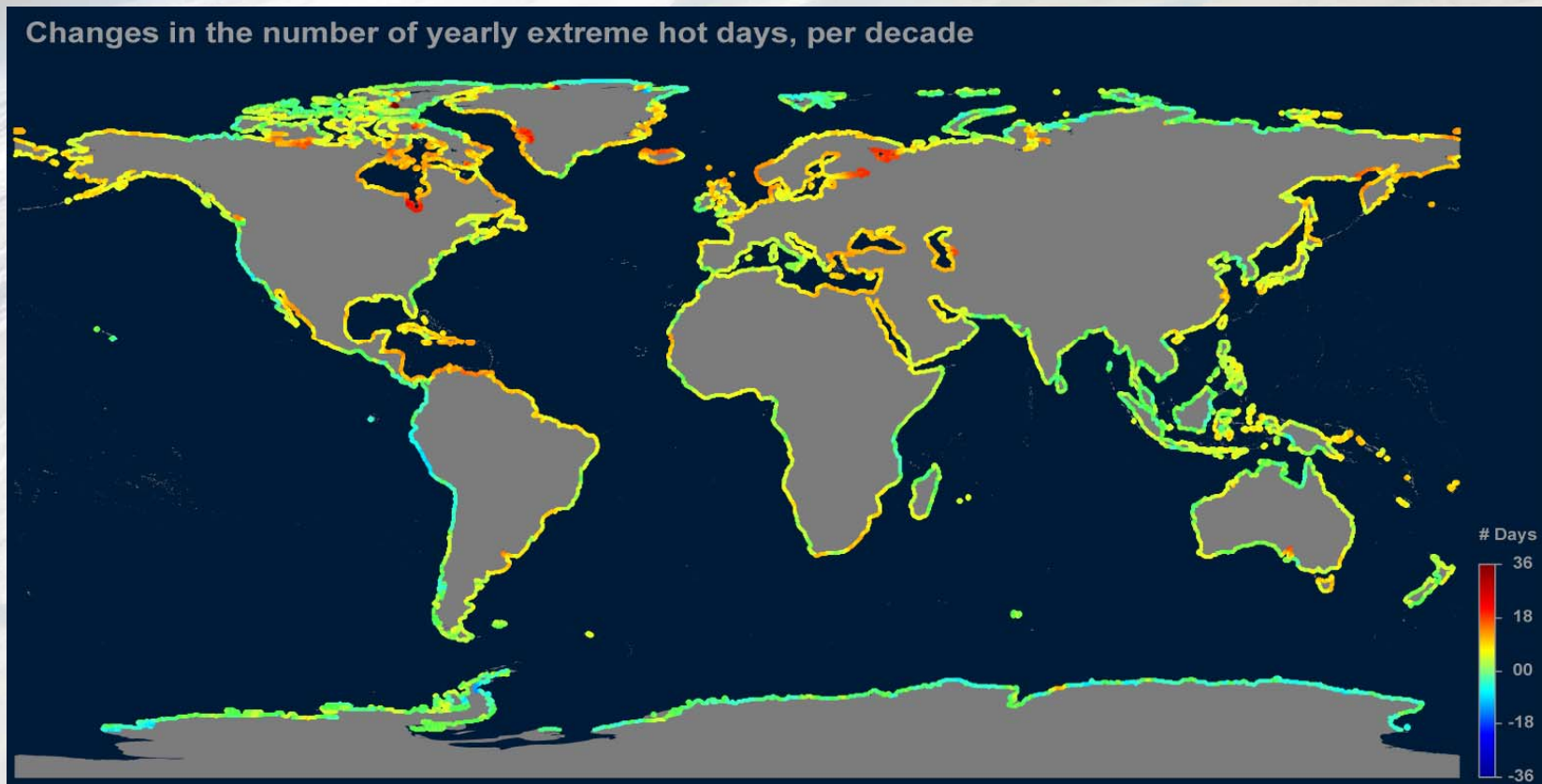
- 75.3% with significant positive changes in temperature (mean rate of 0.27 ± 0.21 °C/decade)
- One fifth (20.7%) has cooled significantly (-0.06 ± 0.07 °C/decade in average).
- Higher coastal warming rates in Eurasian and North-American seas, bays and gulfs.



How much has the coastal ocean been warming?

Linear trends in the number of extreme hot days since 1982

- 65.7% with a significant increase in the number of extreme hot days (avg. additional 7.98 ± 4.46 warm days/decade)
- 19.5% with a significant decrease in extreme hot events (less 4.93 ± 2.91 hot days/decade)

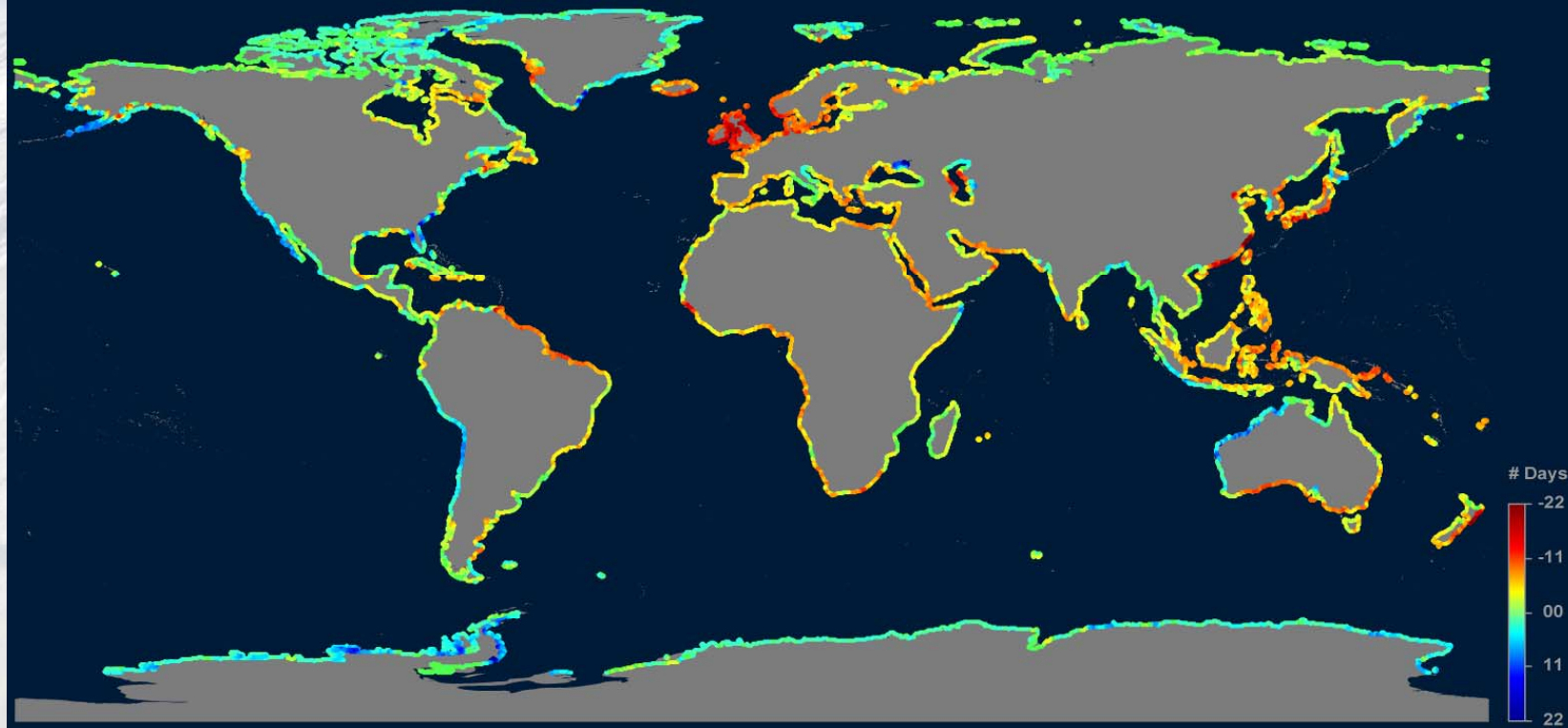


How much has the coastal ocean been warming?

Linear trends in the number of extreme cold days since 1982

- 59.8% with a significant decrease in the number of extreme cold days (avg. less 6.47 ± 4.21 cold days/decade)
- 10.5% of the locations showed both an increase in the yearly hot and cold extremes. 5.7% experienced the opposite trend.

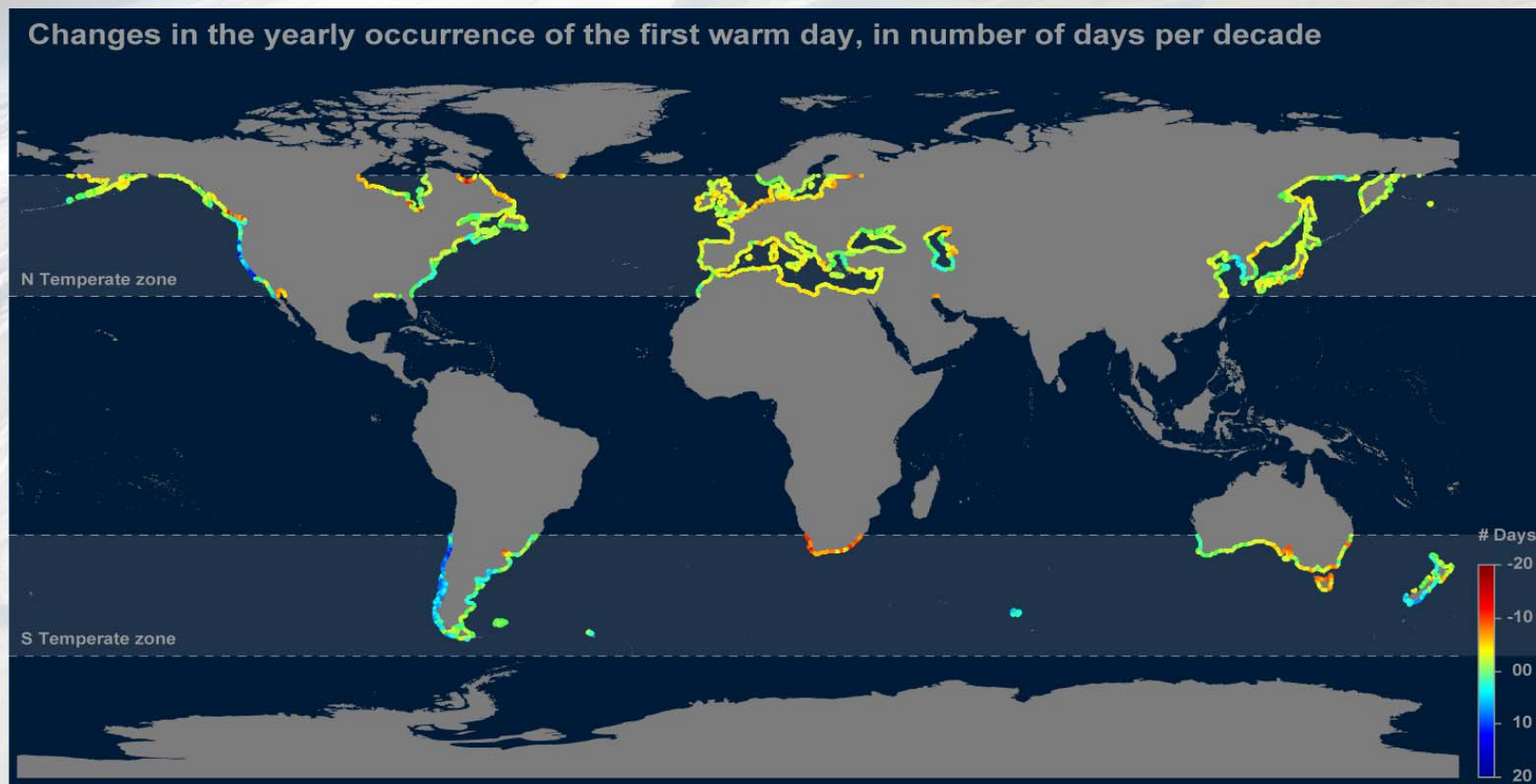
Changes in the number of yearly extreme cold days, per decade



How much has the coastal ocean been warming?

Linear trends in the “start of spring” since 1982

- In 79.7% of the locations, seasonal warming has been occurring earlier (less 4.78 ± 2.53 days/decade)
- A delay in the start of the warm season, (4.59 ± 2.96 days/decade later) was only detected in 7.4% of the locations.



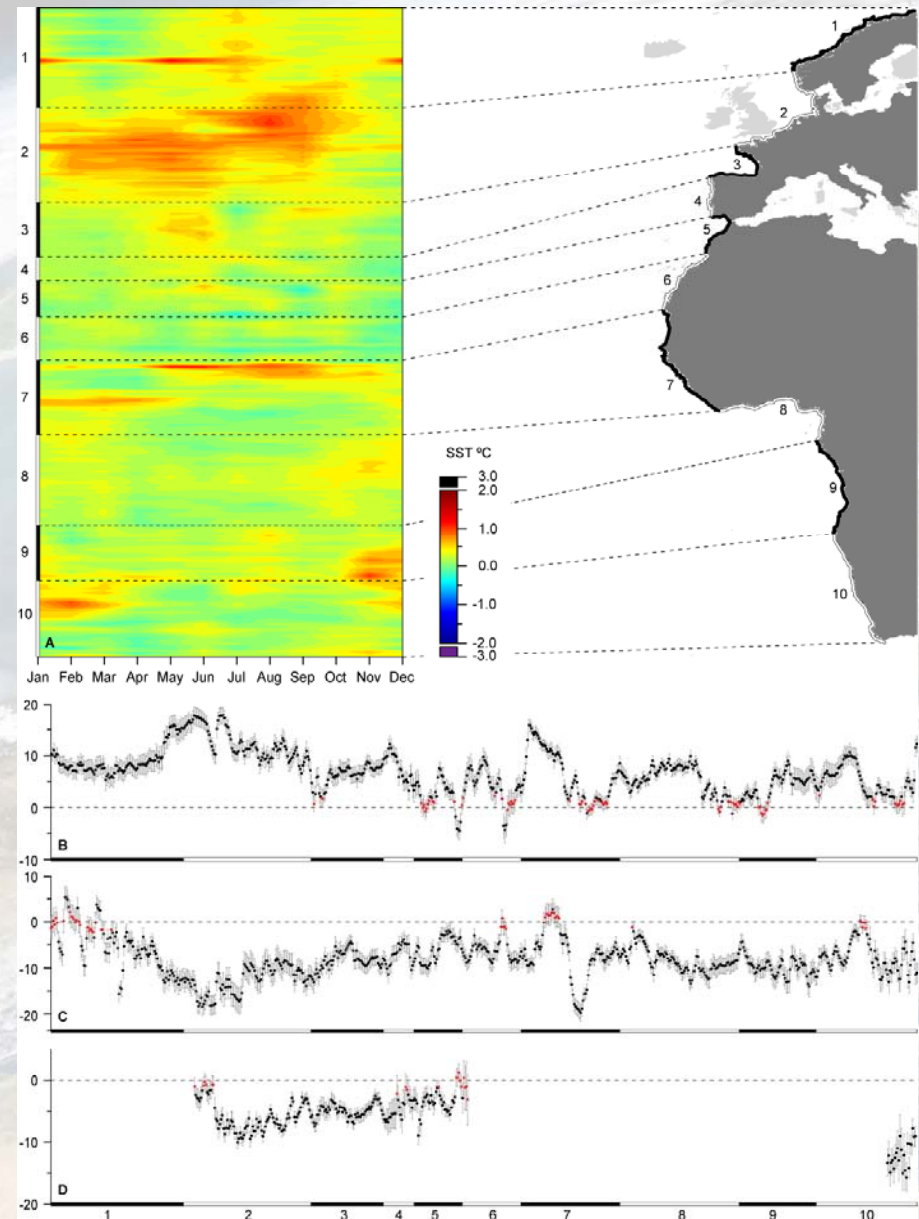
How much has the coastal ocean been warming?

Detailed picture of the W European coast

- Average warming of 0.34 ± 0.19 °C/decade
- 5.0 ± 3.5 additional hot days/decade
- Less 7.66 ± 3.5 cold days/decade

Along the Portuguese coast

- Warming has been from 0.2 to 0.3 °C/decade
- More 4 to 5 warm days/decade
- Less 5 to 9 cold days/decade
- Seasonal warming has been occurring from 3 to 5 days earlier/decade
- Most warming before/after summer peak



Have the intertidal organisms already been affected?

Distributional changes of several mollusks

Warm-water species

Patella rustica



Siphonaria pectinata



Onchidella celtica



Cold-water species

Patella vulgata



Nucella lapillus



Littorina saxatilis



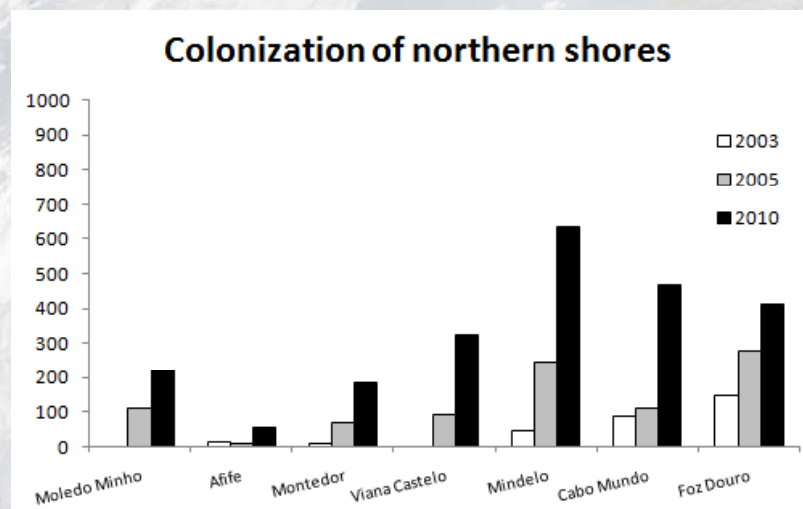
Have the intertidal organisms already been affected?

The case of *Patella rustica*

- Warm-water species, known to be absent from northern Portugal at least since the beginning of the 20th century



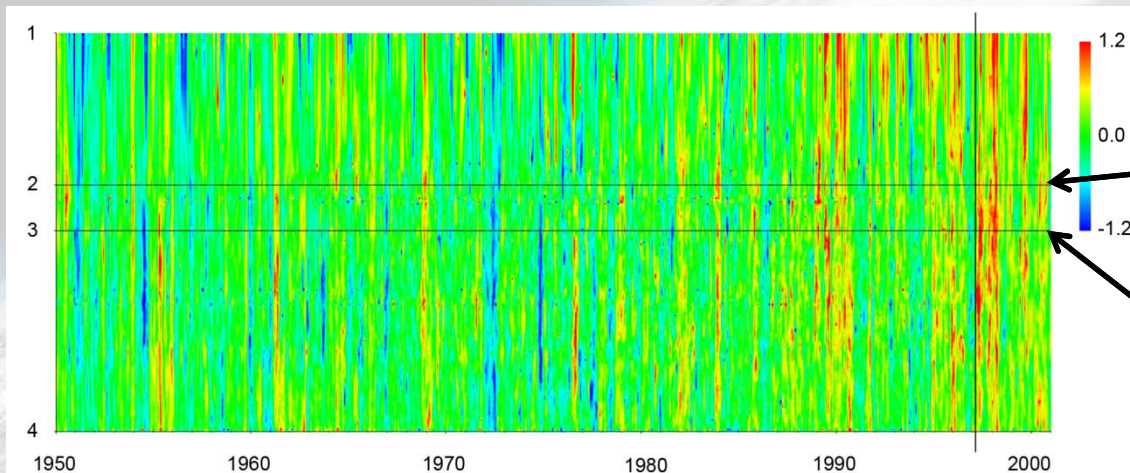
- Started to colonize the gap in the late 1990s



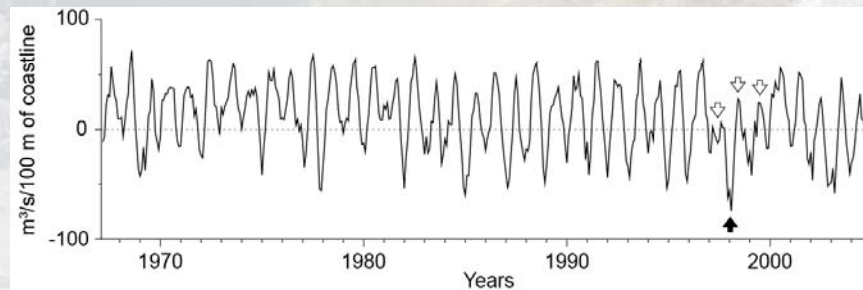
Have the intertidal organisms already been affected?

The case of *Patella rustica*

- Distribution changes seem to have started in a period of significant warm anomalies



- The expansion was also coincident with the lowest NAO record and upwelling indexes reached historical minima

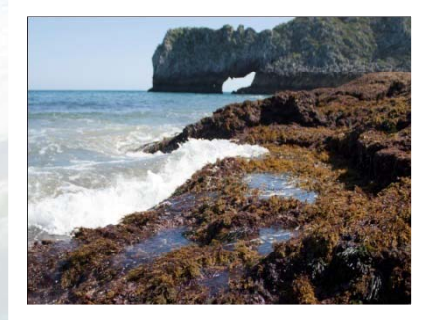


Northward currents associated with abnormally high temperatures

Have the intertidal organisms already been affected?

Distributional changes of 129 algal species

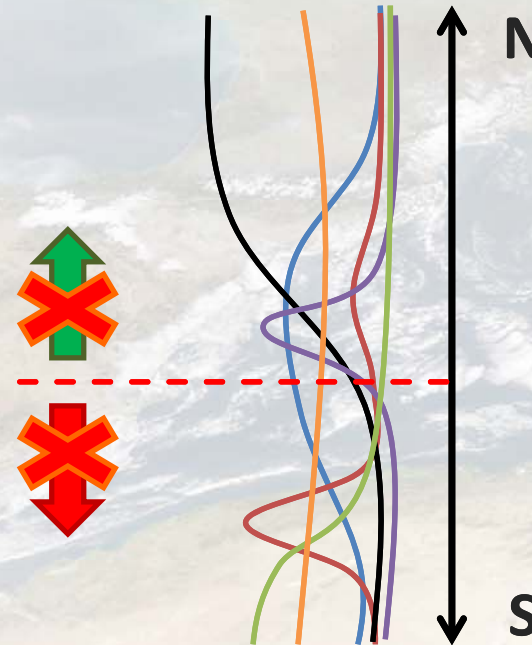
Comparing present distribution patterns with data from the 1950-1960s (Ardré, 1971)



1. Looking for a northward community shift

- Using information on the abundance of all species at once
- Identifying the “shifting point” with purpose-written software

The hypothesis of a northward community shift was rejected

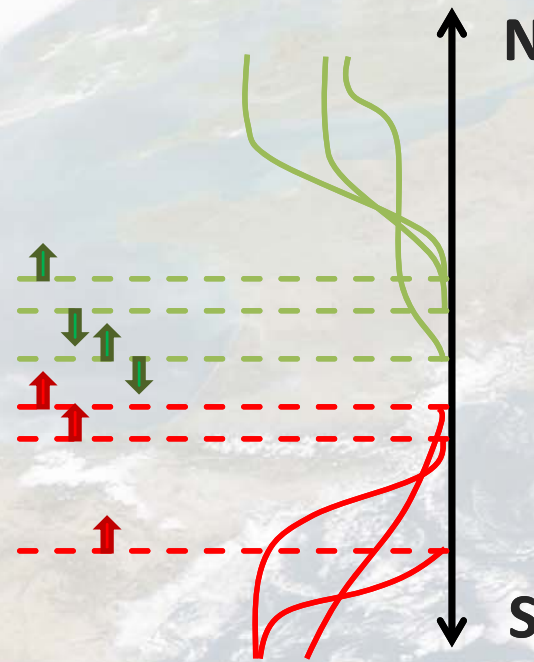


Have the intertidal organisms already been affected?

Changes on the distributional limits of 39 algal species

2. Looking for a northward shift on a *species by species* approach

| Direction of shift | Cold-water species | Warm-water species |
|-----------------------|--------------------|--------------------|
| Northwards | 7 | 8 |
| Southwards | 7 | 0 |
| Non-significant shift | 12 | 5 |
| Total | 26 | 13 |



Also here warm-water species are shifting, in contrast with cold-water species

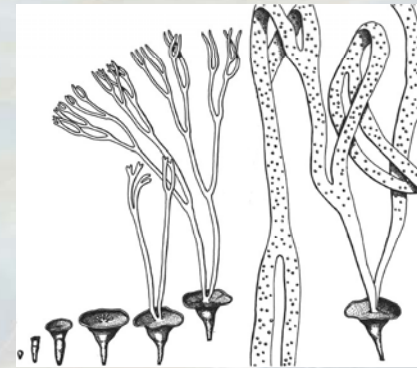
Have the intertidal organisms already been affected?

The case of *Himantalia elongata*

- Cold-water species, historically present in up to the Tagus mouth, nowadays is restricted to the north.

Hypothesis: The retreat is warming-driven

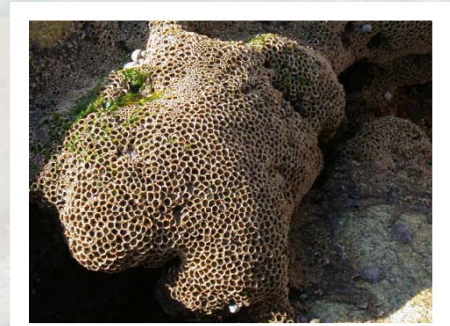
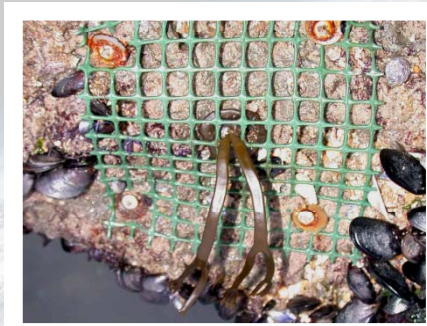
- Biannual algae. Reproductive structures develop on the 2nd year and account up to 98 % of the algal biomass
- The reproductive growing was used as a measure of fitness
- During 2001 and 2004 transplants were taken to southern locations where the species was present in the 1950s and 1960s
- Non-transplanted specimens were used as controls



Have the intertidal organisms already been affected?

The case of *Himanthalia elongata*

- Similar growth was observed between transplanted and non-transplanted specimens
- Apparently the species was not constrained by temperature beyond its current southern limit



- All transplanted individuals were grazed. Never observed within the current range
- In southern shores, many transplants were overgrown by *Sabellaria alveolata*



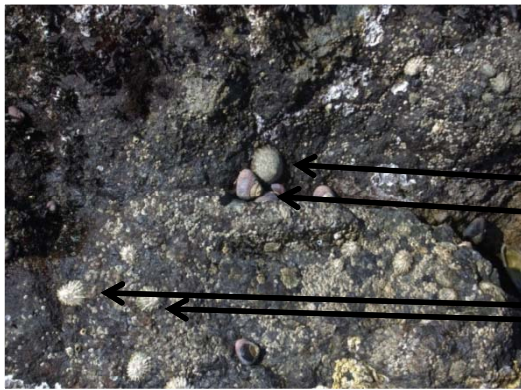
Biological factors (driven or not by climatic factors) could have played a more important role than previously thought

So, generalizations should be taken with caution. Each case is a different case

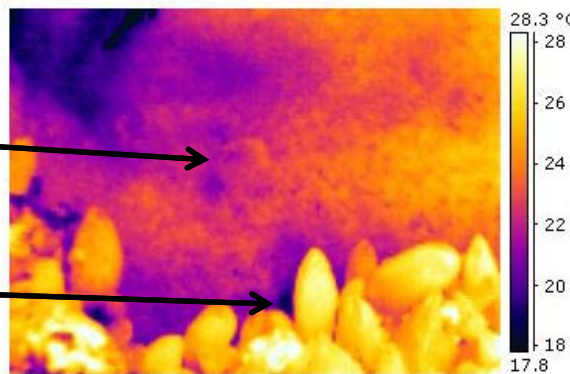
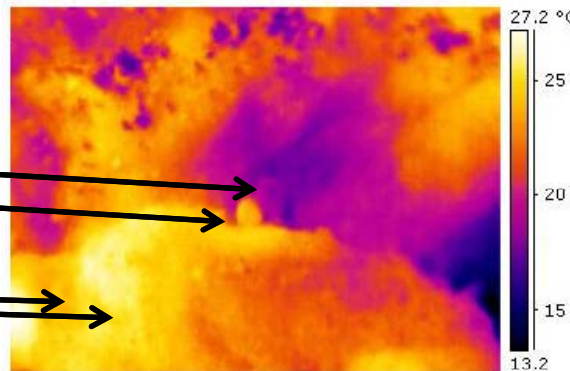
Recent evidence emphasizes the importance of small-scale temperature variability

- Different species even in the same microenvironment may show a temperature difference of approximately 10° C

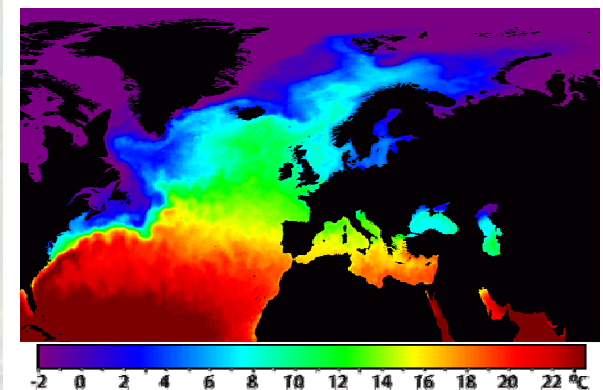
Normal photos



Thermal photos



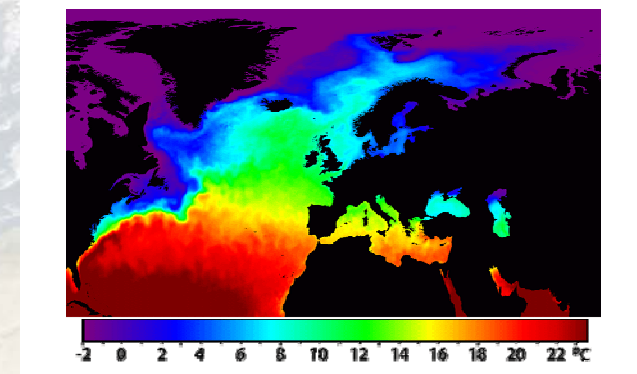
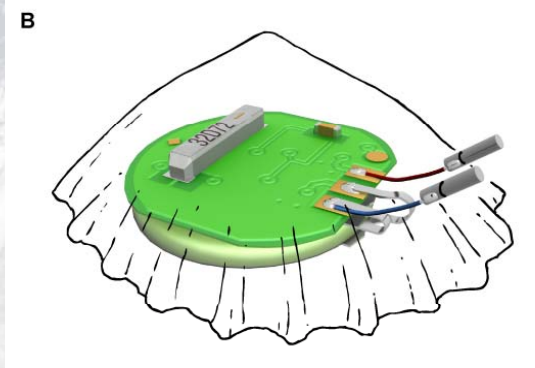
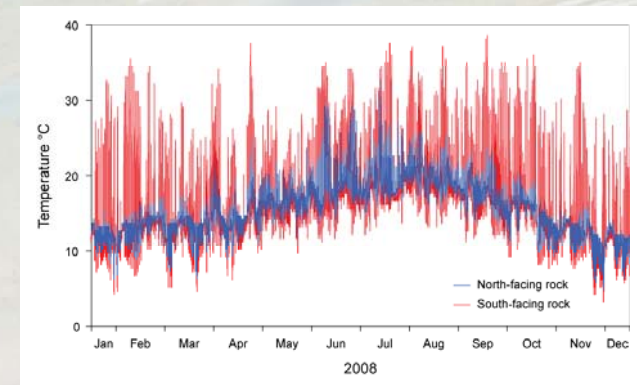
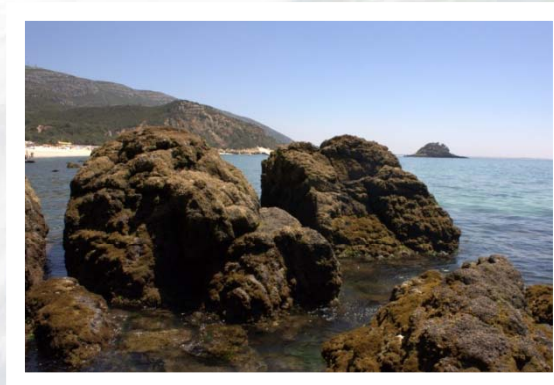
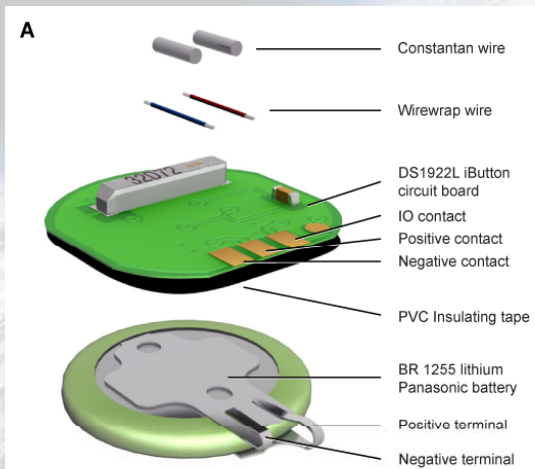
Large-scale sea temperature



Present and future work

Recent evidence emphasizes the importance of small-scale temperature variability

- Same species but some meters apart may show a temperature difference of approximately 15° C



Acknowledgements

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