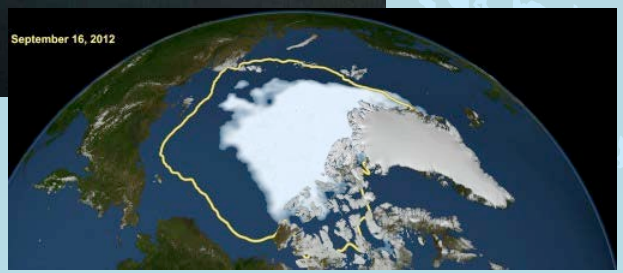
MFE 659 Lecture 3b Global Warming

"2010 tied for the warmest year on record" NASA. 2012 on track to be the 9th warmest year on record.



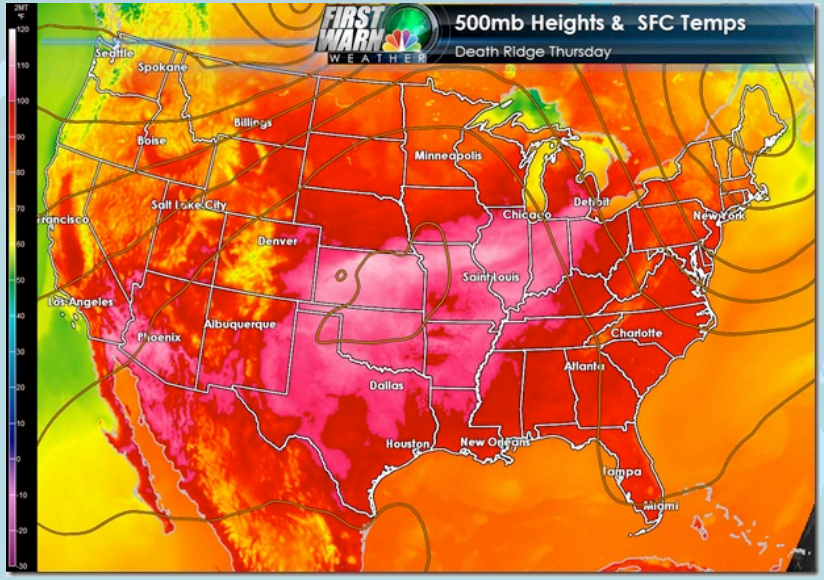
Global Warming and Hawaii

Steven Businger (businger@hawaii.edu)

Outline

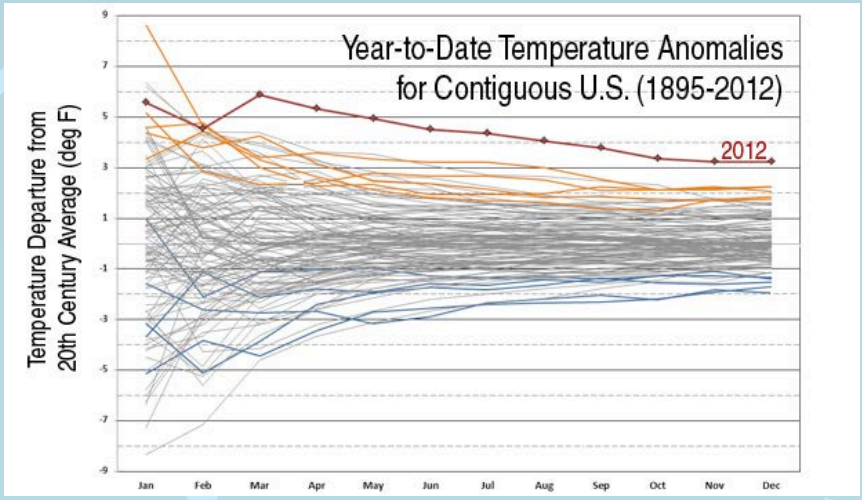
1. What is the evidence for global warming? Just the facts.
2. Global warming and Hawaii
3. Human factor: can the increases in carbon dioxide in the atmosphere be linked to burning of fossil fuels?
4. Should we take action regarding global warming? If so, what actions can we take?

Heat Wave 5 July 2012



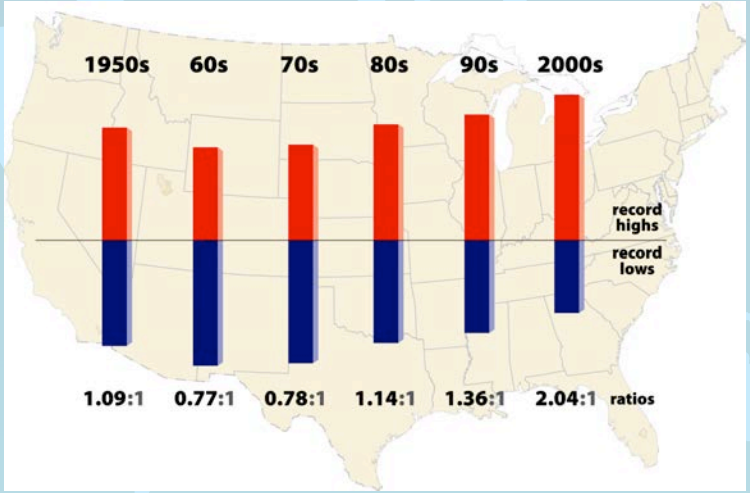
How hot was 2012? Hottest on record in US, by a long shot.

How Hot was 2012?



Source: NOAA's National Climatic Data Center. The warmest 5 years are highlighed in orange: 1998, 2006, 1934, 1999 and 1921. The coolest 5 years are in blue: 1903, 1924, 1895, 1912 and 1917.

What About the Record Cold Last Winter?



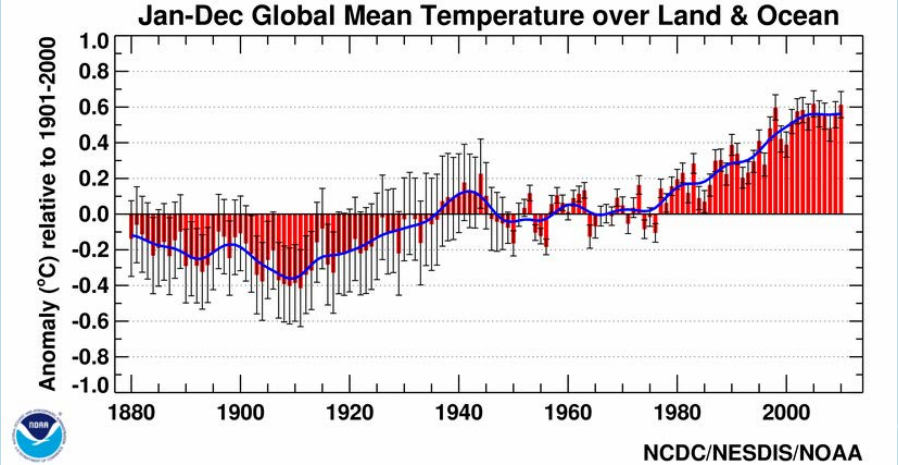
- Record High Temperatures Far Outpace Record Lows Across US in recent decades.

Evidence for Global Warming

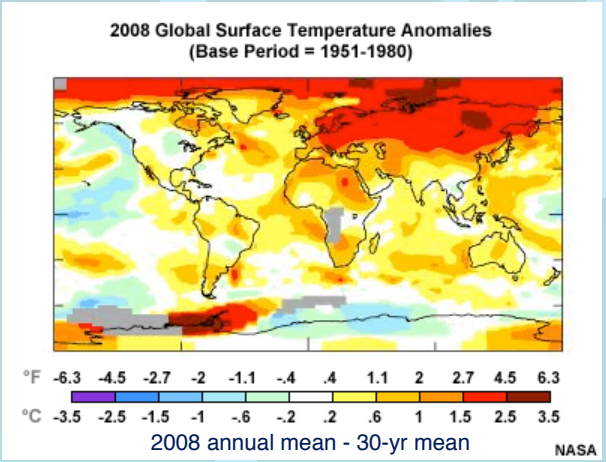
- Higher temperatures - especially on land and at higher latitudes (Changes at regional level)
- Reduction in Arctic sea ice and mountain glaciers
- Hydrological cycle more intense (droughts and storms intensify)
- Increased size and number of wild fires
- Sea level rise
- Coral Bleaching


Mordor: Tar Sands

Global Mean Temperature

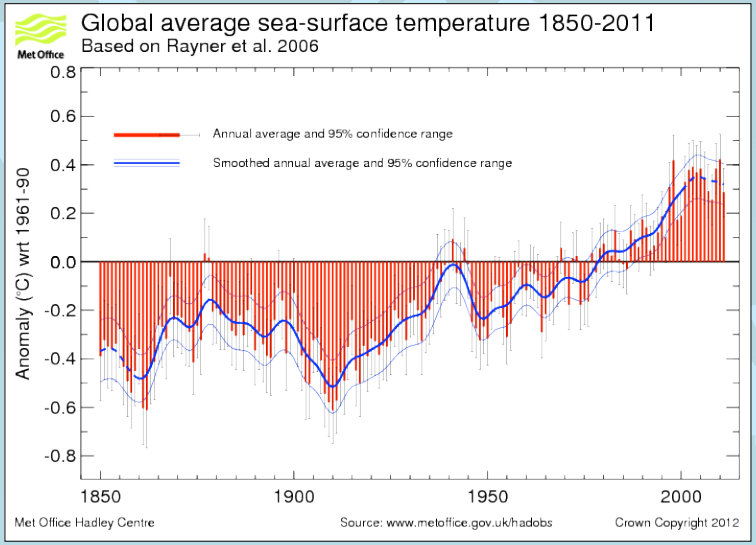


Global Warming is Non-Uniform

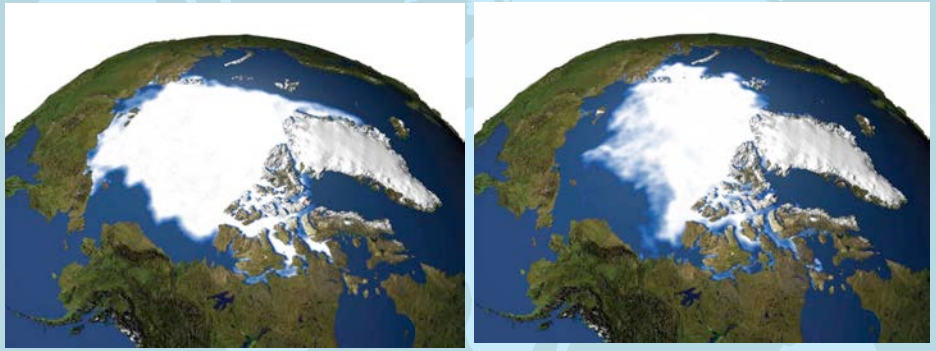


Polar regions have warmed significantly more that equatorial regions of the Earth.

Sea-Surface Temperature Trend

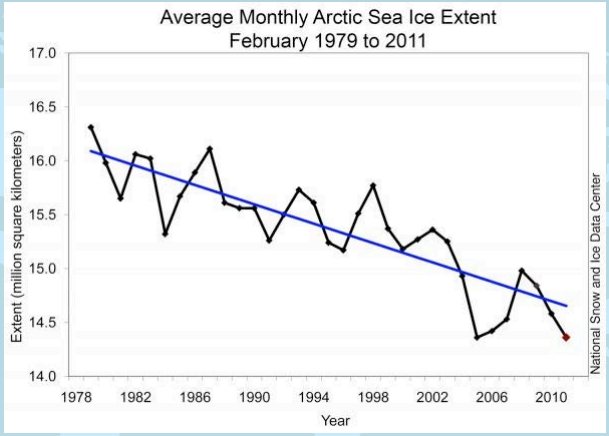


Arctic Sea Ice Changes



Change in the Arctic sea ice over the past 30 years.

Arctic Sea Ice Change



This figure illustrates September ice extent (millions of square kilometers) for the period covered by the satellite data record. A line fit to the data points shows that over the years 1979 to 2012, there has been a trend toward lower summer minimums. As this figure illustrates, there is considerable variability in minimum extent from year to year.

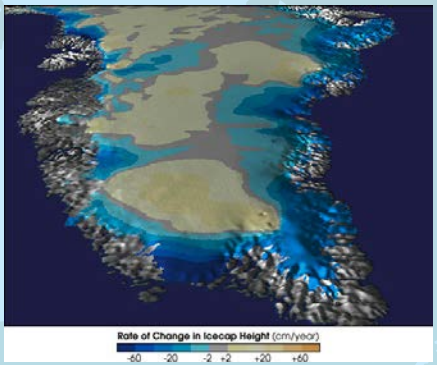
Ice-Water Feed-Back Mechanism

Warmer surface temperatures cause ice to melt, making more solar radiation available to warm the planet, because less is reflected back to space.

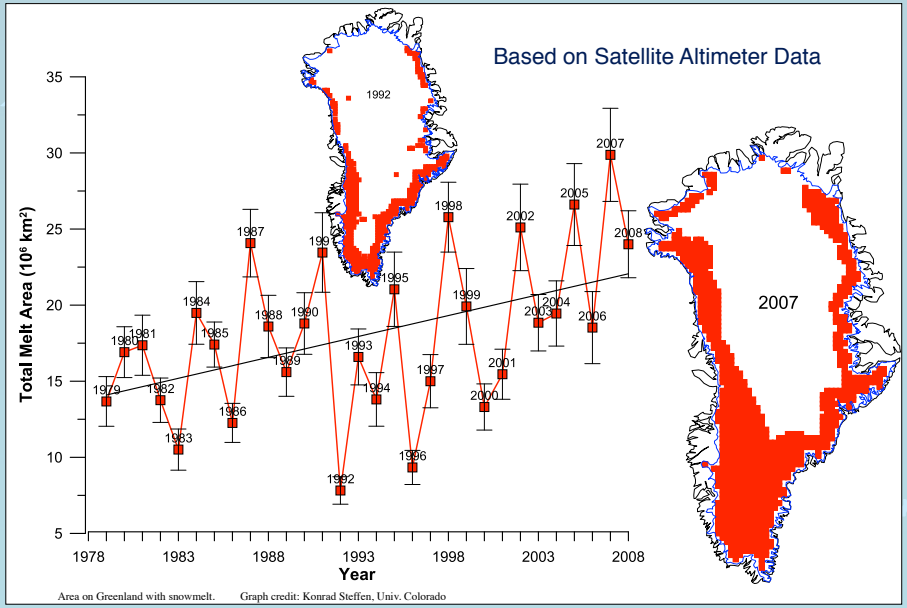
Greenland Melting

Greenland melt descending into a moulin, a vertical shaft carrying water to ice sheet base.

Changing Greenland Ice Cap



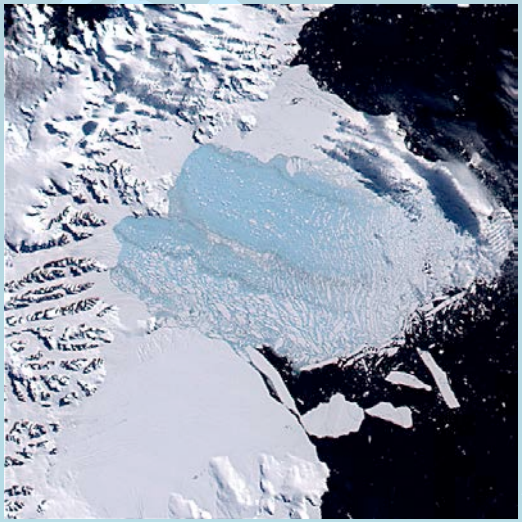
Greenland Total Melt Area



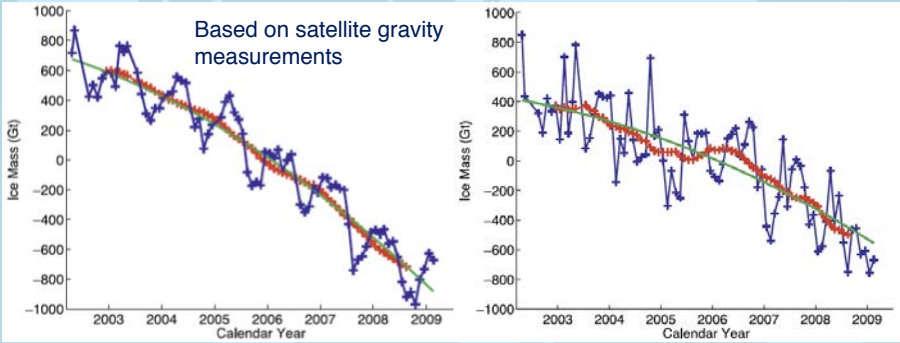
Breakup of Larsen Ice Shelf

Breakup of Larsen ice shelf in the Antarctic.

Average winter temperatures on the Antarctic Peninsula have risen nearly 9°F (5°C) since 1950.

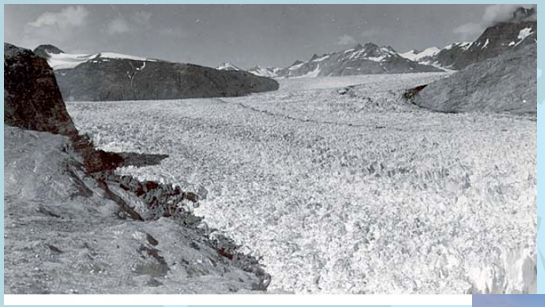


Gravity Satellite Ice Sheet Mass Measurements



Greenland Ice Sheet **Antarctic Ice Sheet**

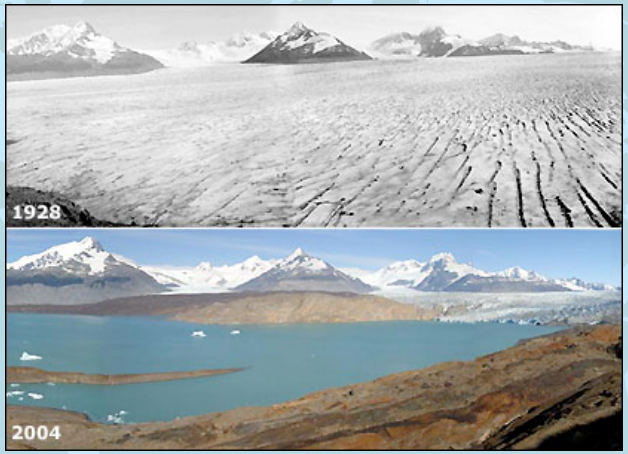
Source: Velicogna, I. *Geophys. Res. Lett.*, **36**, L19503, doi:10.1029/2009GL040222, 2009.



Retreating Glacier

Miur Glacier, AK
1941 vs 2004

Alpine Glaciers are in Retreat

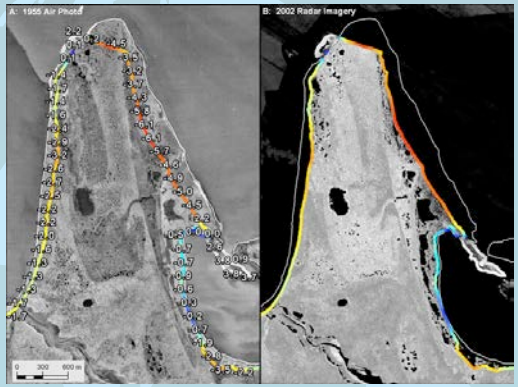


Upsala Glacier in Patagonia, Argentina 1928 vs 2004

Kilimanjaro Snow Melt

Permafrost is Melting

Permafrost is Melting



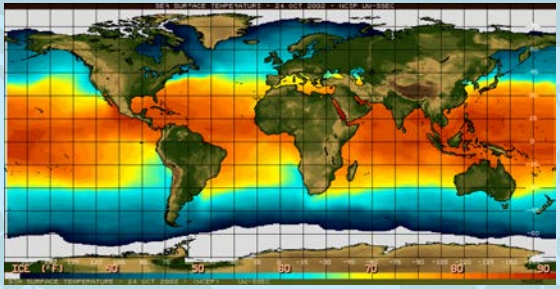
Coastal Erosion has accelerated and AK villages need to be moved as a result of the melting of permafrost and coastal erosion by storm waves, in areas protected by sea ice in the past.

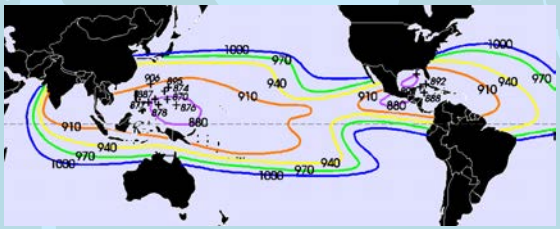
Warmer Oceans

- result in sea level rise, coral bleaching and the death of coral reefs
- support higher humidities, heavier rains and more powerful hurricanes

Hurricane Sandy

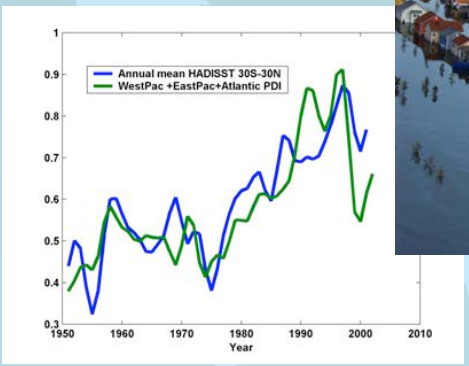
Hurricane Energy Source – SST





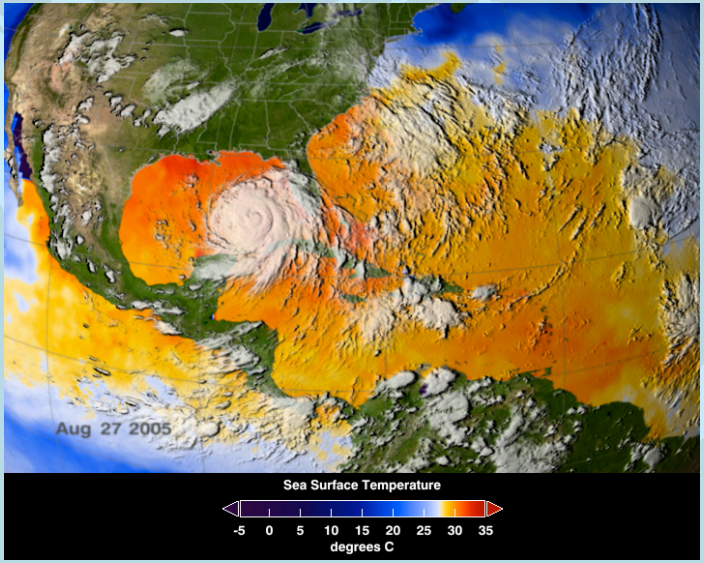
Observed sea surface temperature and SST-linked and observed minimum central pressure (in mb) at sea level in tropical cyclones.

Warmer Oceans: Stronger Tropical Storms

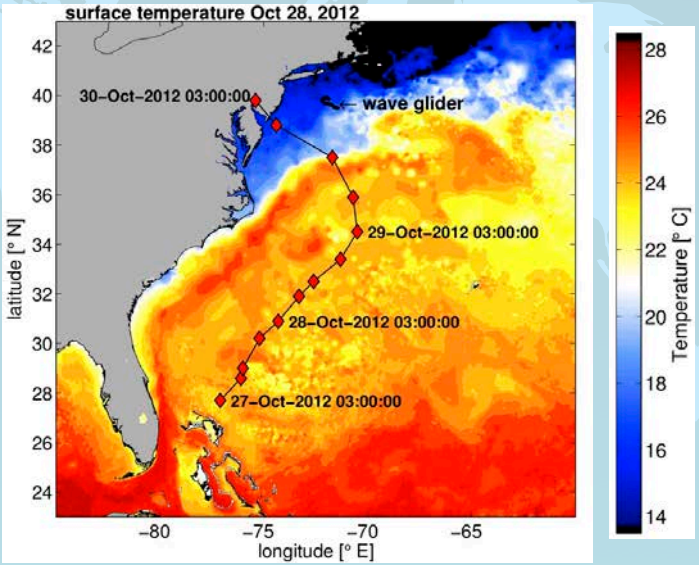


Annual mean sea-surface temperature and hurricane intensity index (strength times duration).

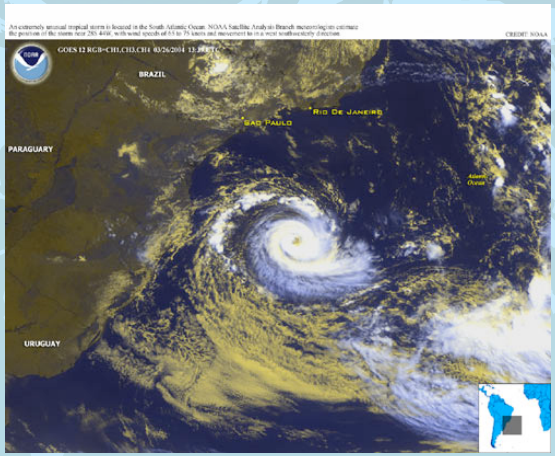
Hurricane Katrina and SST



Hurricane Sandy Track and SST



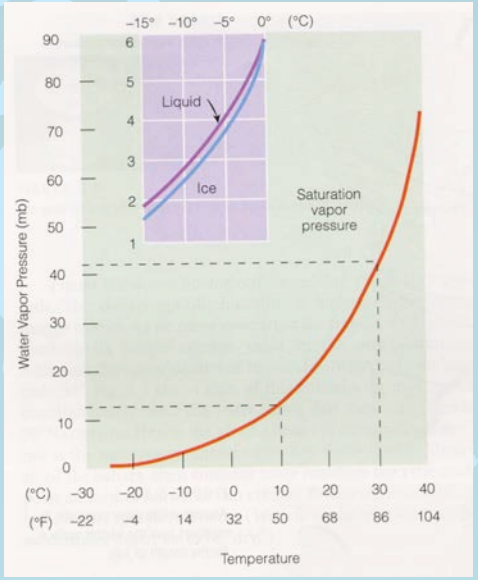
Warmer Oceans and Tropical Storms



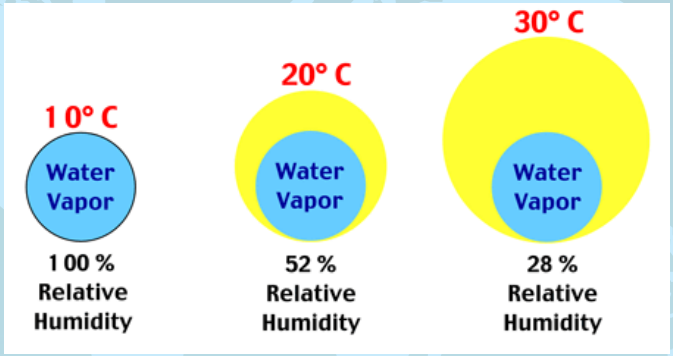
Warmer oceans support more powerful hurricanes. Photo above is of the first hurricane ever to strike Brazil.

More Intense Hydrological Cycle

There is an exponential increase in the amount of water vapor in the air at saturation as the temperature increases. Thus, given a source of vapor from the ocean, the amount of water available in the air to rain out increases rapidly with warmer ocean temperatures.



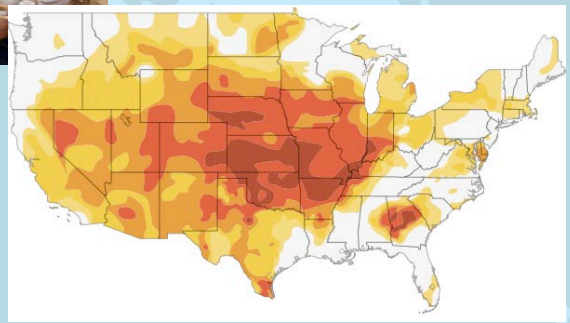
More Intense Hydrological Cycle



If the amount of water in the air is limited as it is over inland areas, but the temperature increases, then the relative humidity drops. Lower relative humidity means drier conditions are experienced, e.g., droughts.

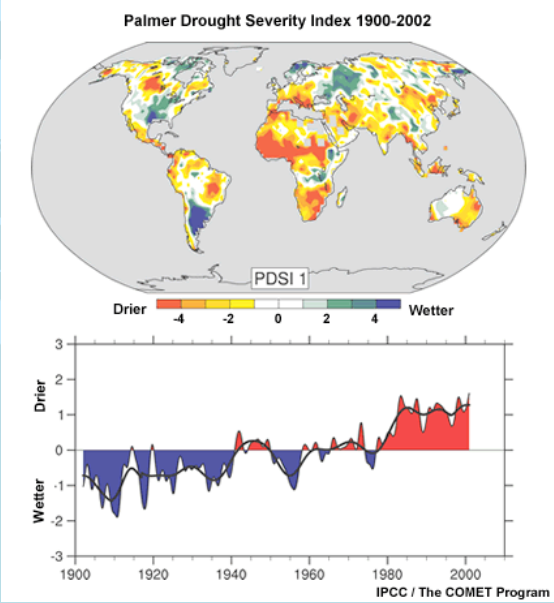
More Intense Hydrological Cycle

El Dorado, Kansas, 2012

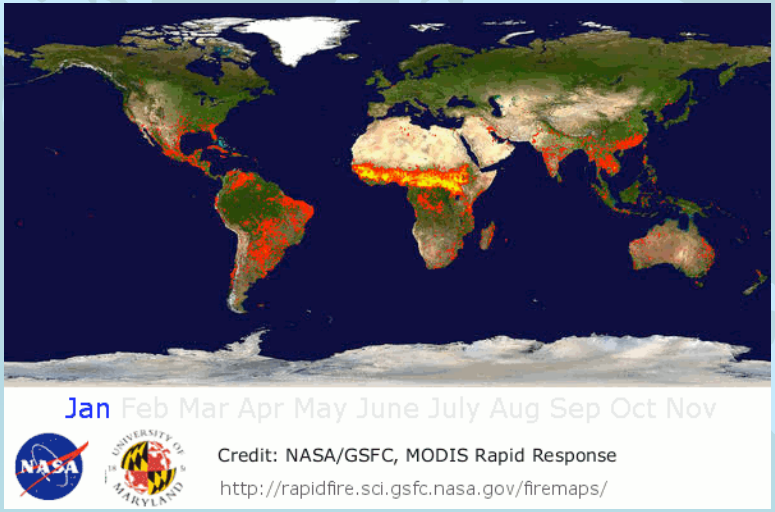


Severe drought in US in 2012 is consistent with predictions of more droughts over continents.

Increase in Droughts

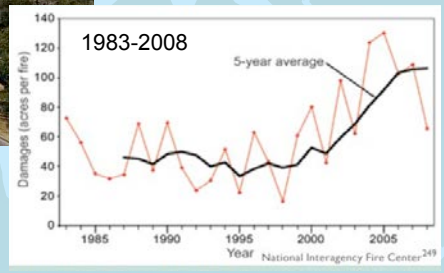


Global Wildfires



Wildfires Are Increasing World-Wide

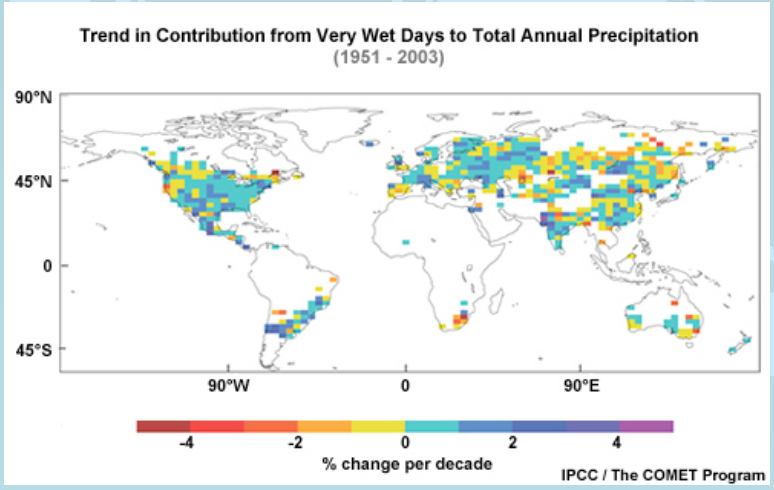
The Bastrop fire destoyed **1660** homes



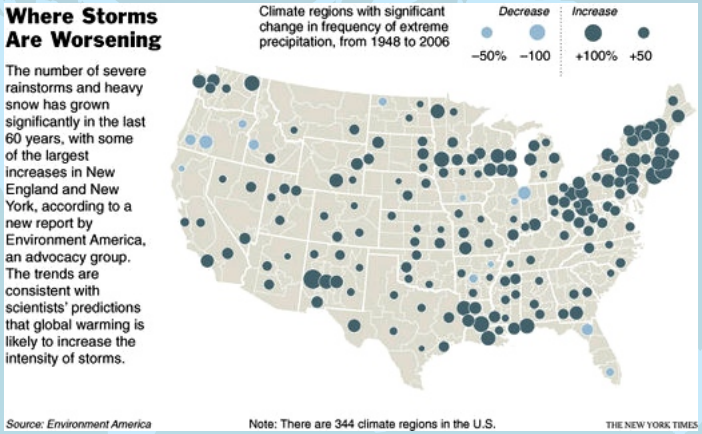
Size of wildfires in US is increasing.

Wildfires in Western US have increased 4-fold in 30 years.

Increasing Heavy Rainfall Events

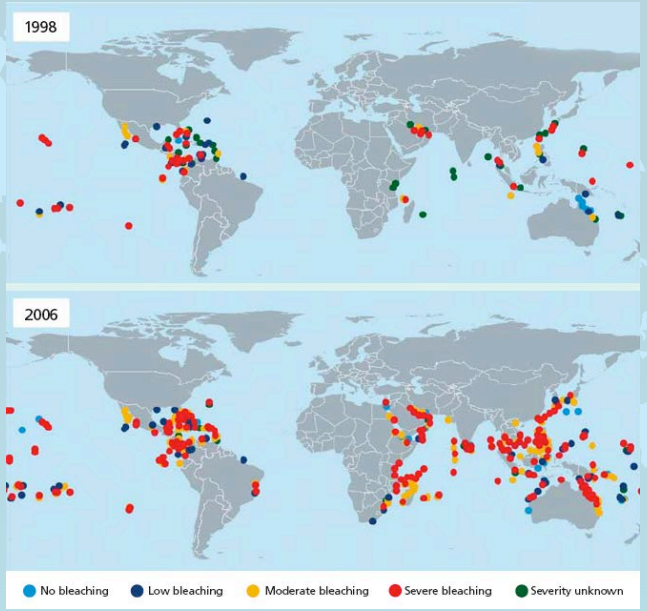


More Heavy Rainfall Events



If warm air is saturated, it contributes fuel (latent heat) to make storms more intense. Heavy rainfall events are days when it rains more than 2 inches.

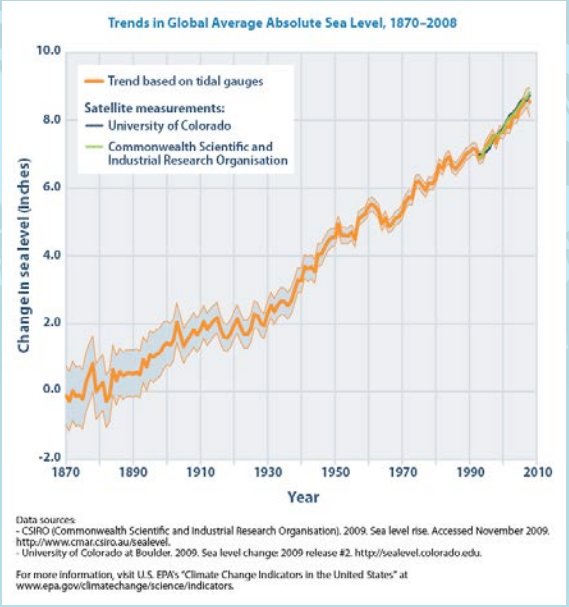
Warmer Oceans and Coral Bleaching



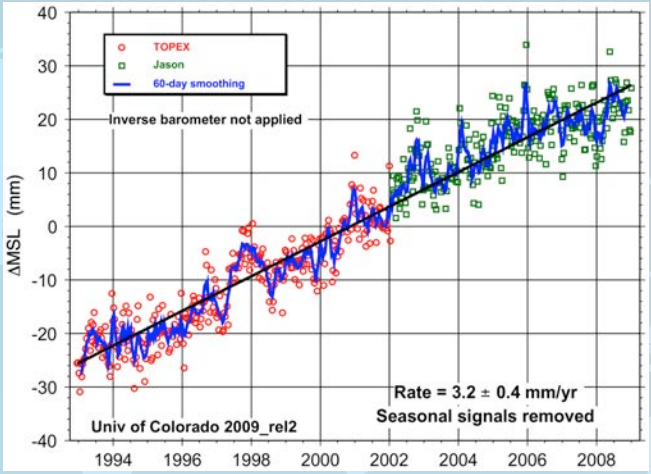
Sea-Level Rise

- Warmer temperatures cause sea level rise because of
  - Thermal expansion
  - Melting of continental and Greenland glacier ice

Sea-Level Rise



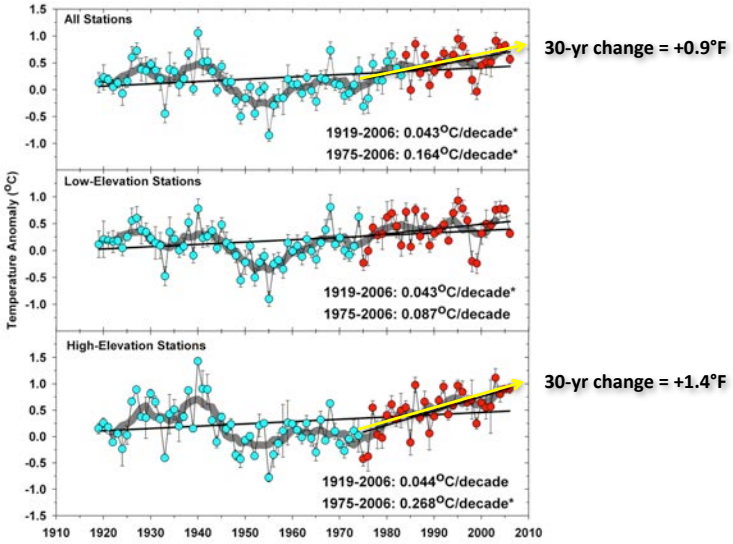
Sea-Level Rise



- Satellite altimetry record indicates 1.2” (~3 cm) rise in sea level per decade since satellite data became available.
- Experts estimate that ocean levels will be ~1 meter higher by 2100.

What About Hawaii?

Hawai‘i Temperature Index

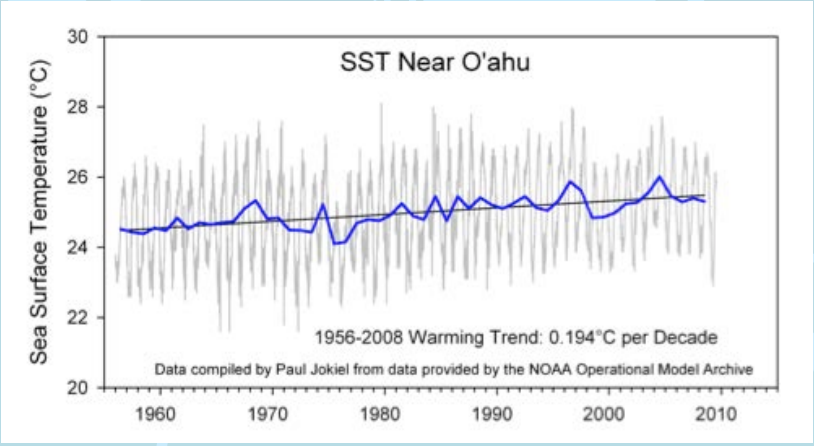


30-yr change = +0.9°F

30-yr change = +1.4°F

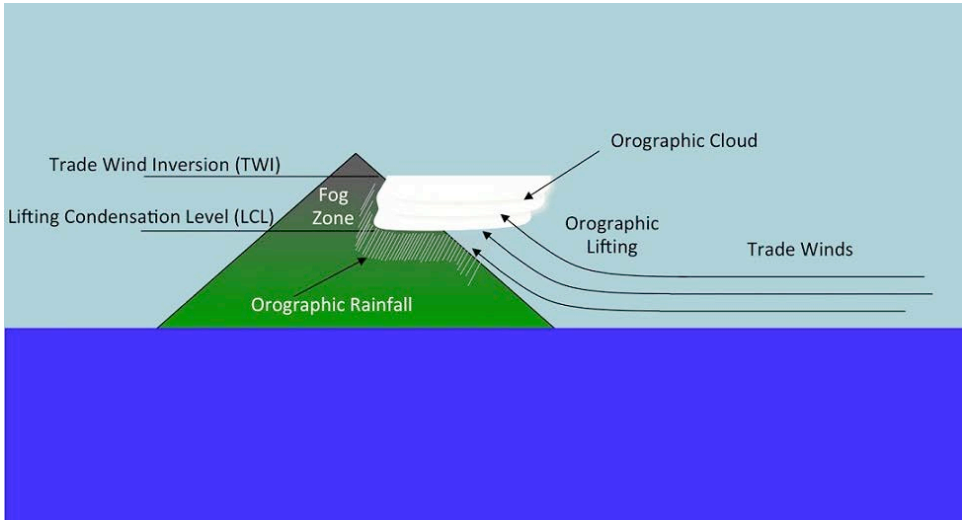
Giambelluca, T.W., Diaz, H.F., and Luke, M.S.A. 2008. Secular temperature changes in Hawai'i. *Geophysical Research Letters* 35, L12702, doi:10.1029/2008GL034377.

Sea-Surface Temperature Trend



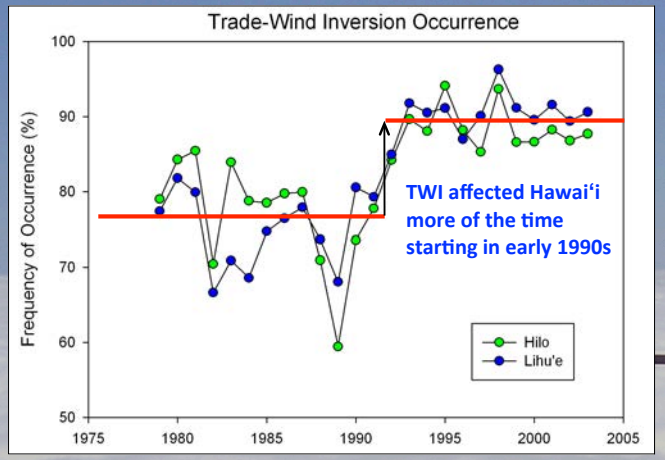
How About Precipitation Change in Hawai‘i?

The Orographic Cloud

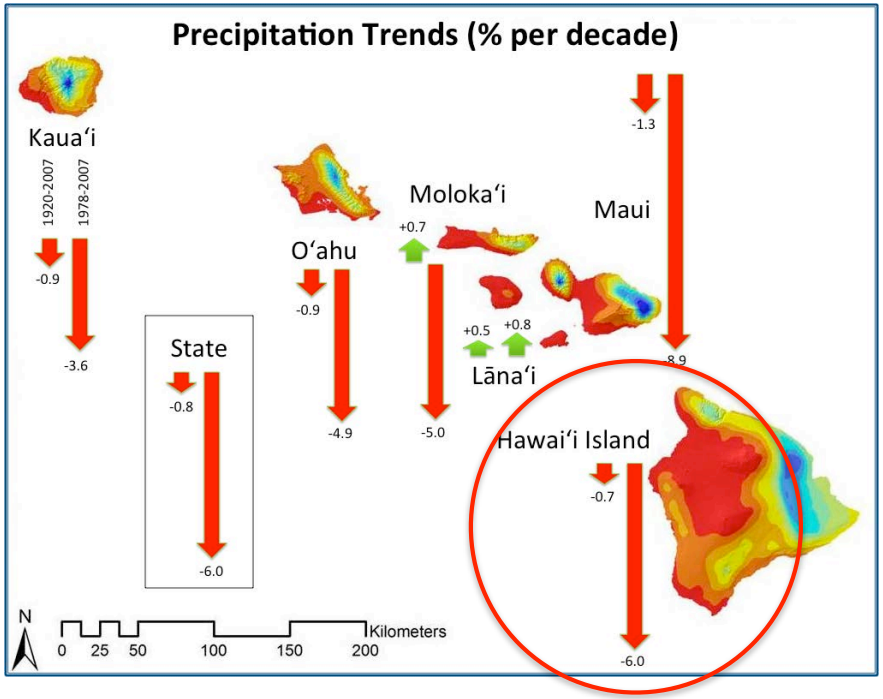


Trade Wind Inversion

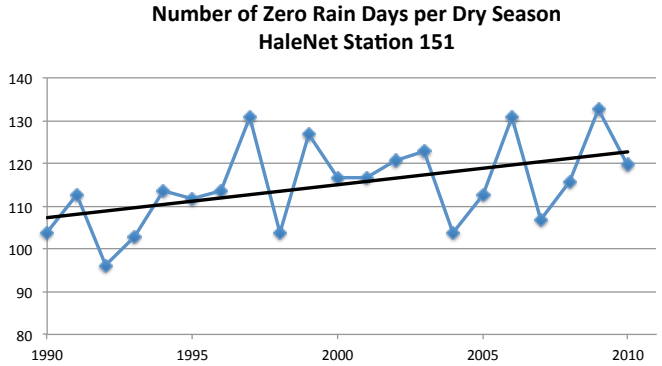
TWI Trends



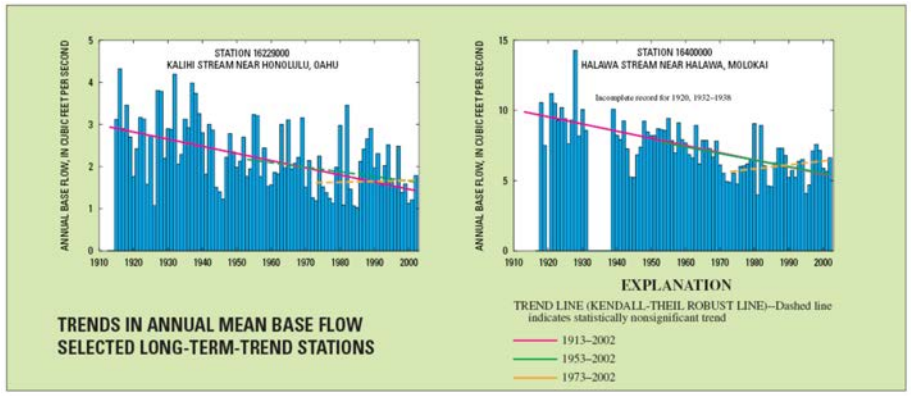
Cao et al. (2007)



At High Elevations: Dry Days Becoming More Common



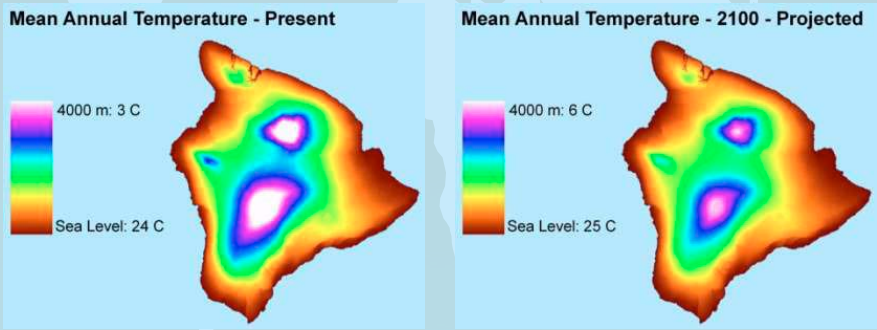
Stream Base Flow Also in Decline



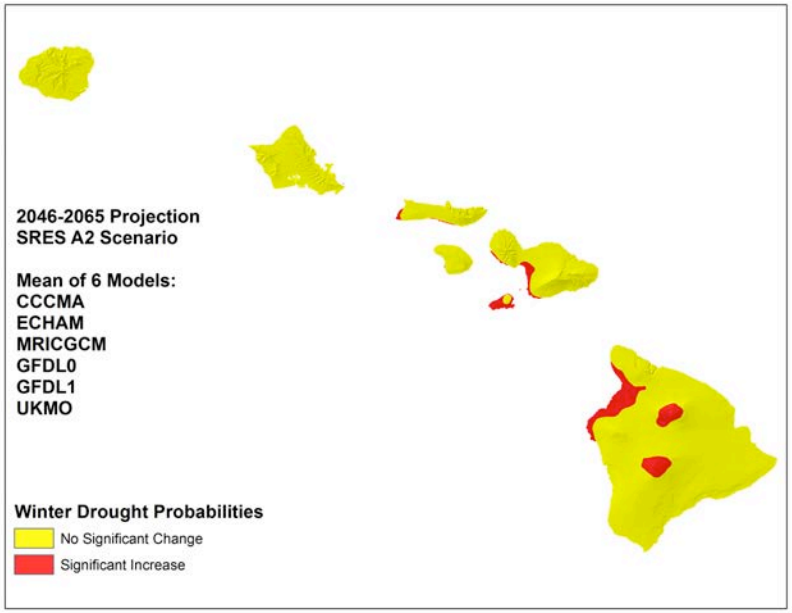
Oki, D.S., 2004, Trends in Streamflow Characteristics in Hawaii, 1913-2003: U.S. Geological Survey Fact Sheet 2004-3104, 4 p.

Anticipating Climate Change

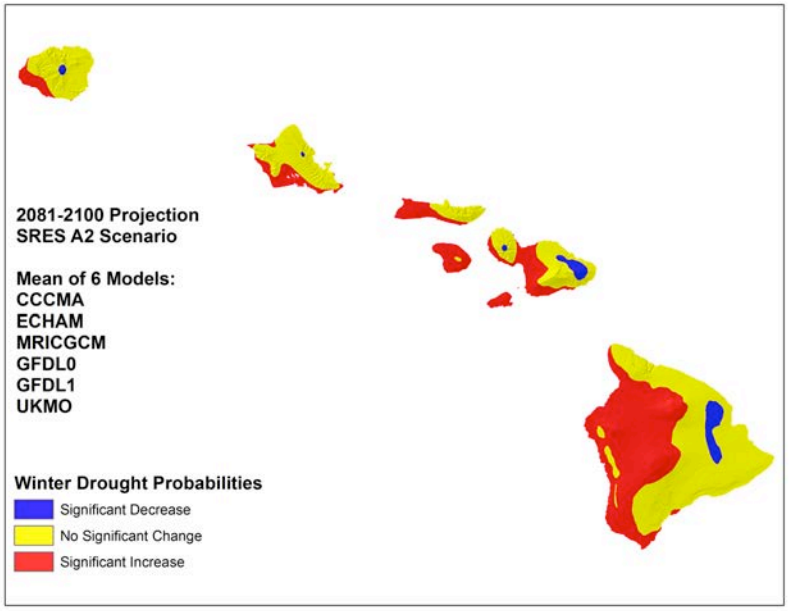
Guidance (e.g., maps below) can be developed to illustrate how the climatic zones and their attendant ecologies on Mauna Kea and Mauna Loa will be impacted by large-scale climate change.



Preliminary Projection Results

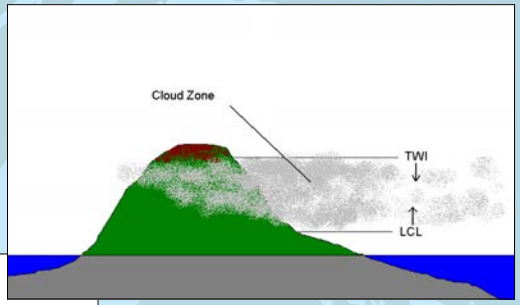


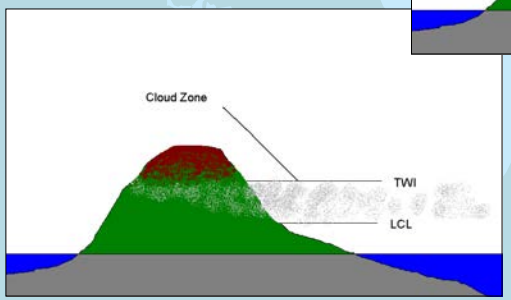
Preliminary Projection Results



Climate Change in Hawaii

Schematic illustration of the impact of changing tradewind inversion and rising lifted condensation level on the montane cloud depth, which will lead to less precipitation overall.





Future Changes in Hawai'i's Climate: Warmer and Drier

- **High Confidence:**
  - Increasing temperatures
  - Increasing sea level
- **Less Certain:**
  - Lower mean rainfall?
  - Fewer heavy rainfall events?
  - More frequent drought events?
  - Higher rates of evaporation?
  - Reduced streamflow?
  - Reduced groundwater recharge?

Questions?