A Space-Based View of a Changing Climate and its Implications

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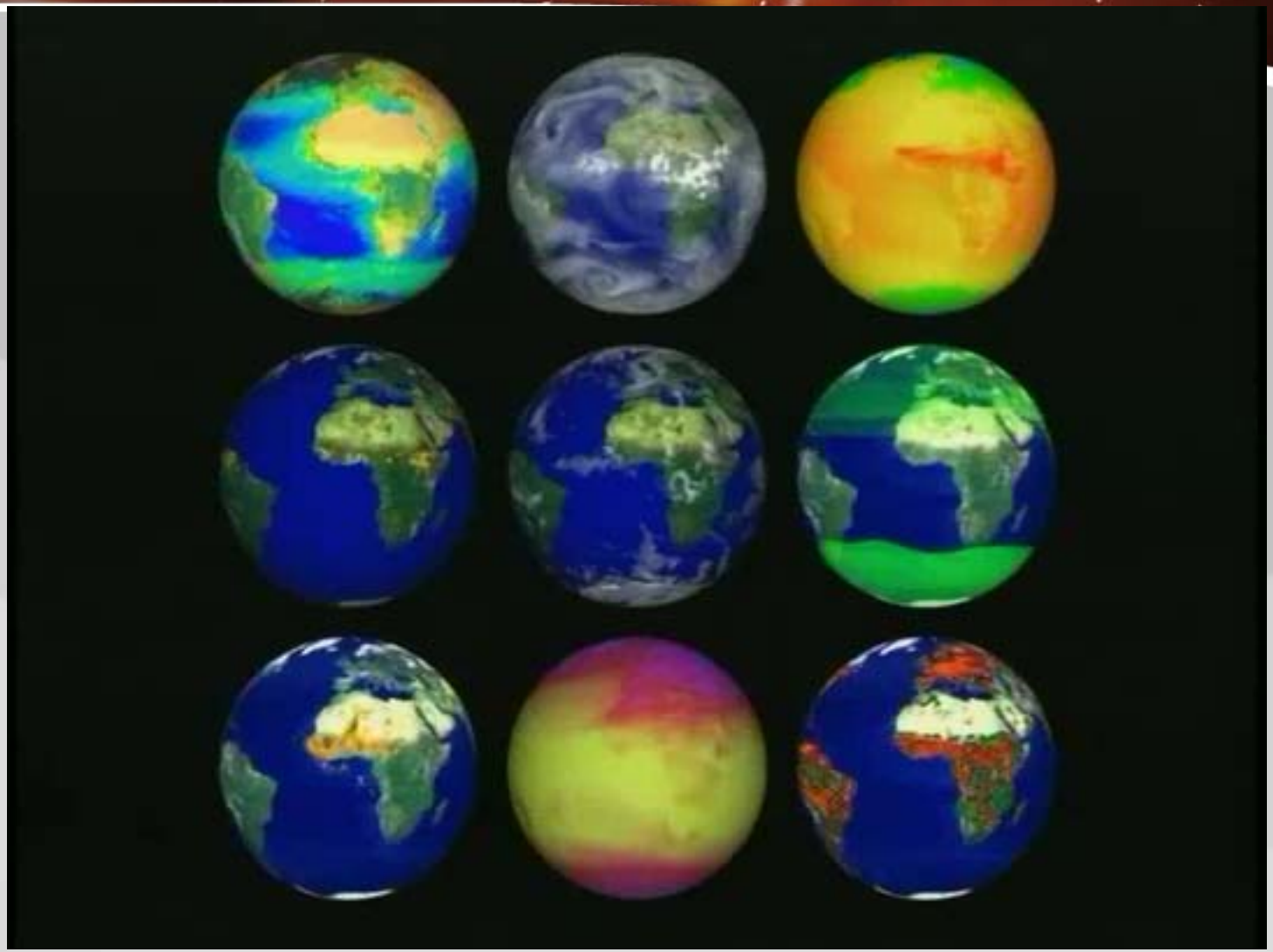
Associate Director for Research
Earth Science Division
Science Mission Directorate

NASA Headquarters

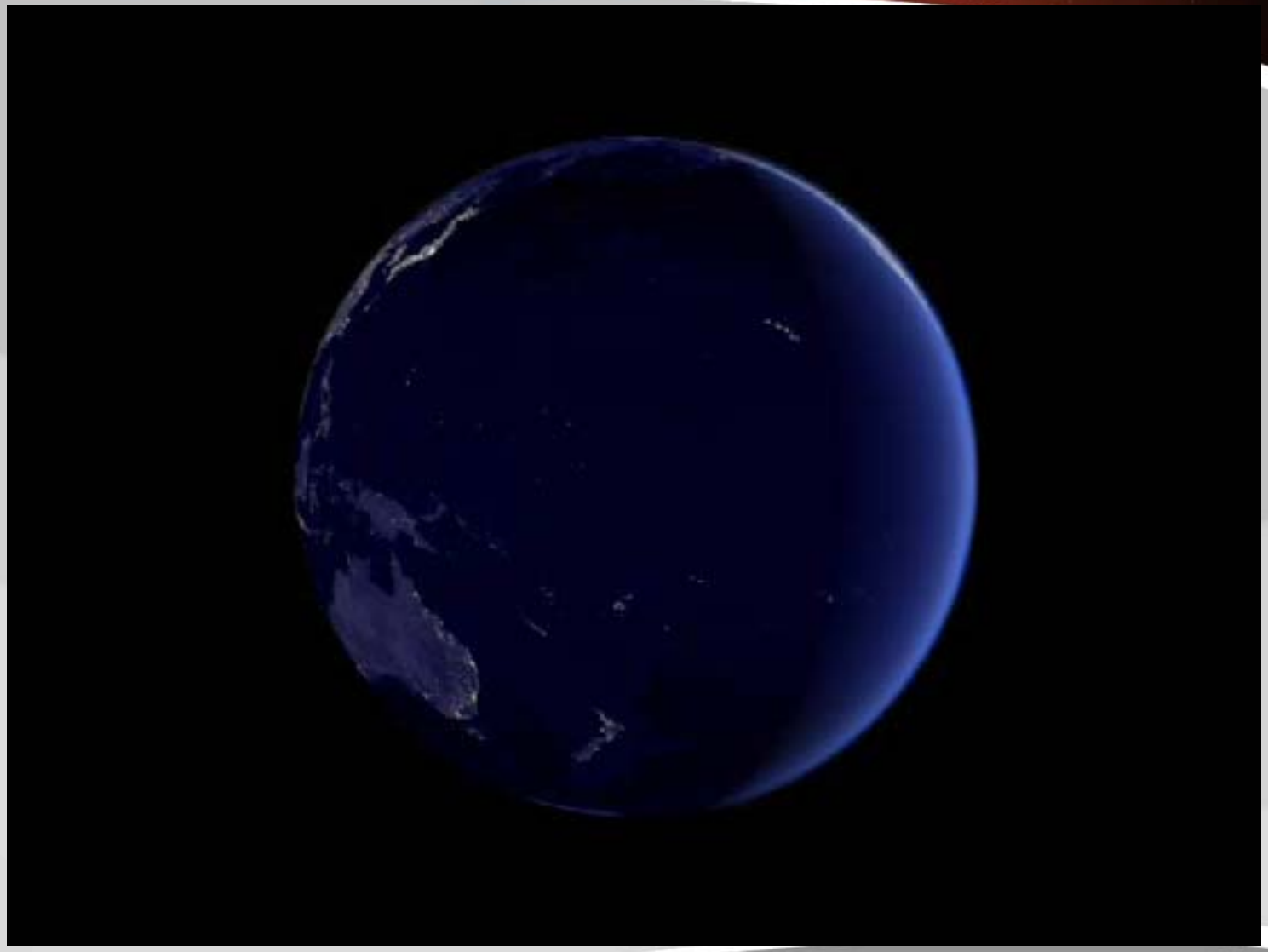
September 30, 2009

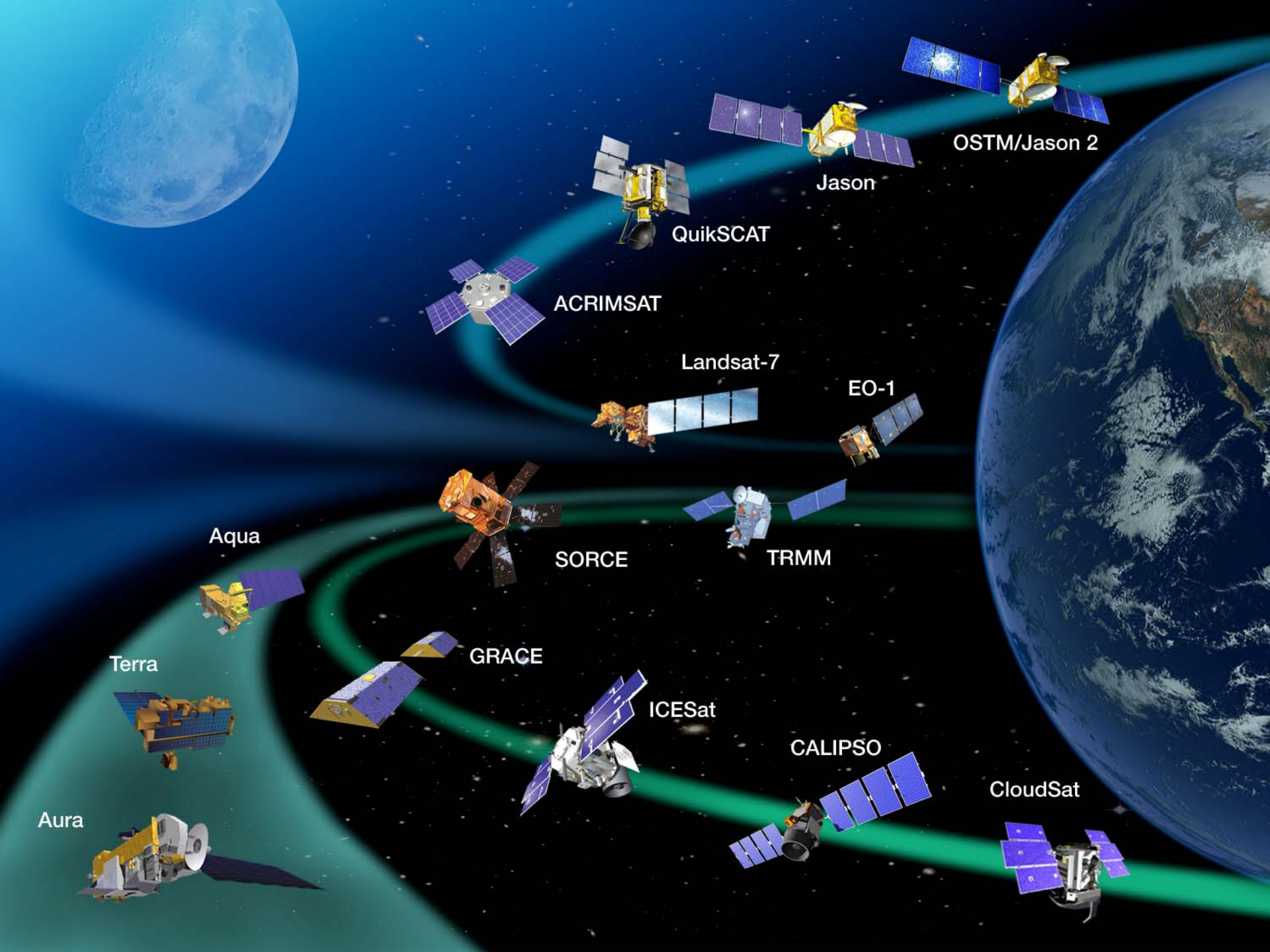
The Earth is a ☐Dynamic System...



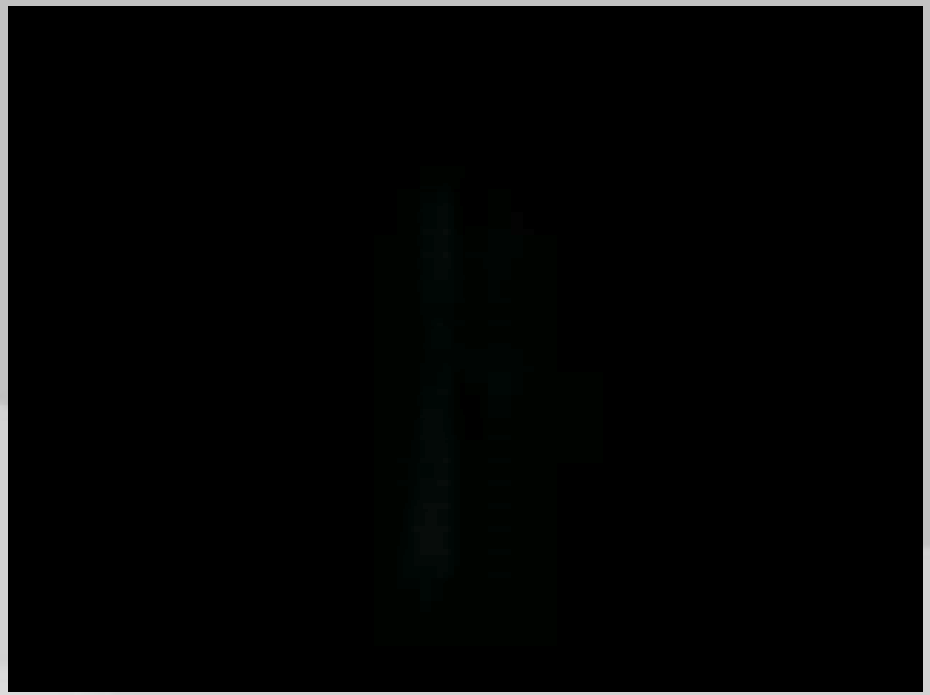
…That Changes on all Time Scales

Land Cover & Biosphere

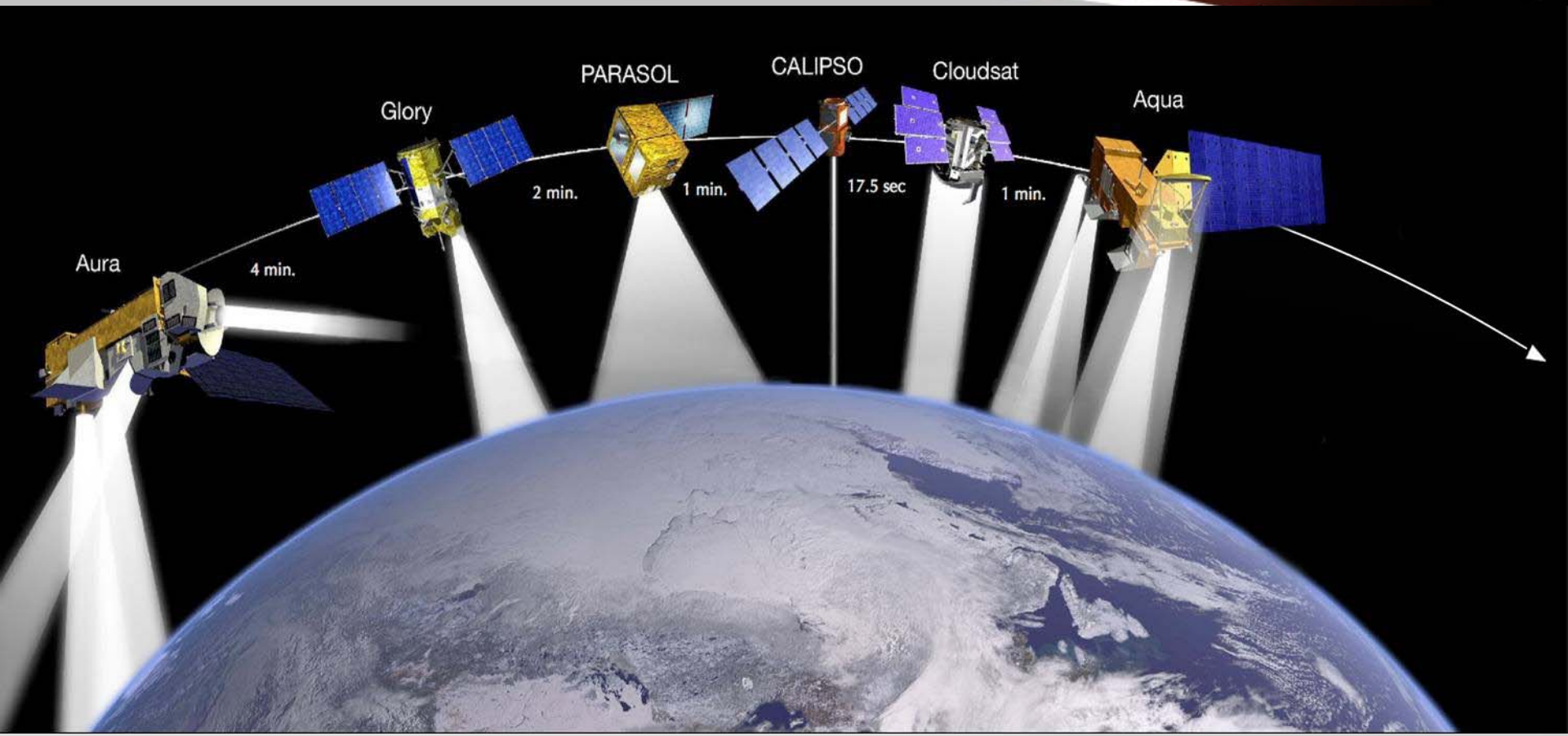



OSTM/Jason 2
Jason
QuikSCAT
ACRIMSAT
Landsat-7
EO-1
SORCE
TRMM
Aqua
GRACE
Terra
ICESat
CALIPSO
CloudSat
Aura

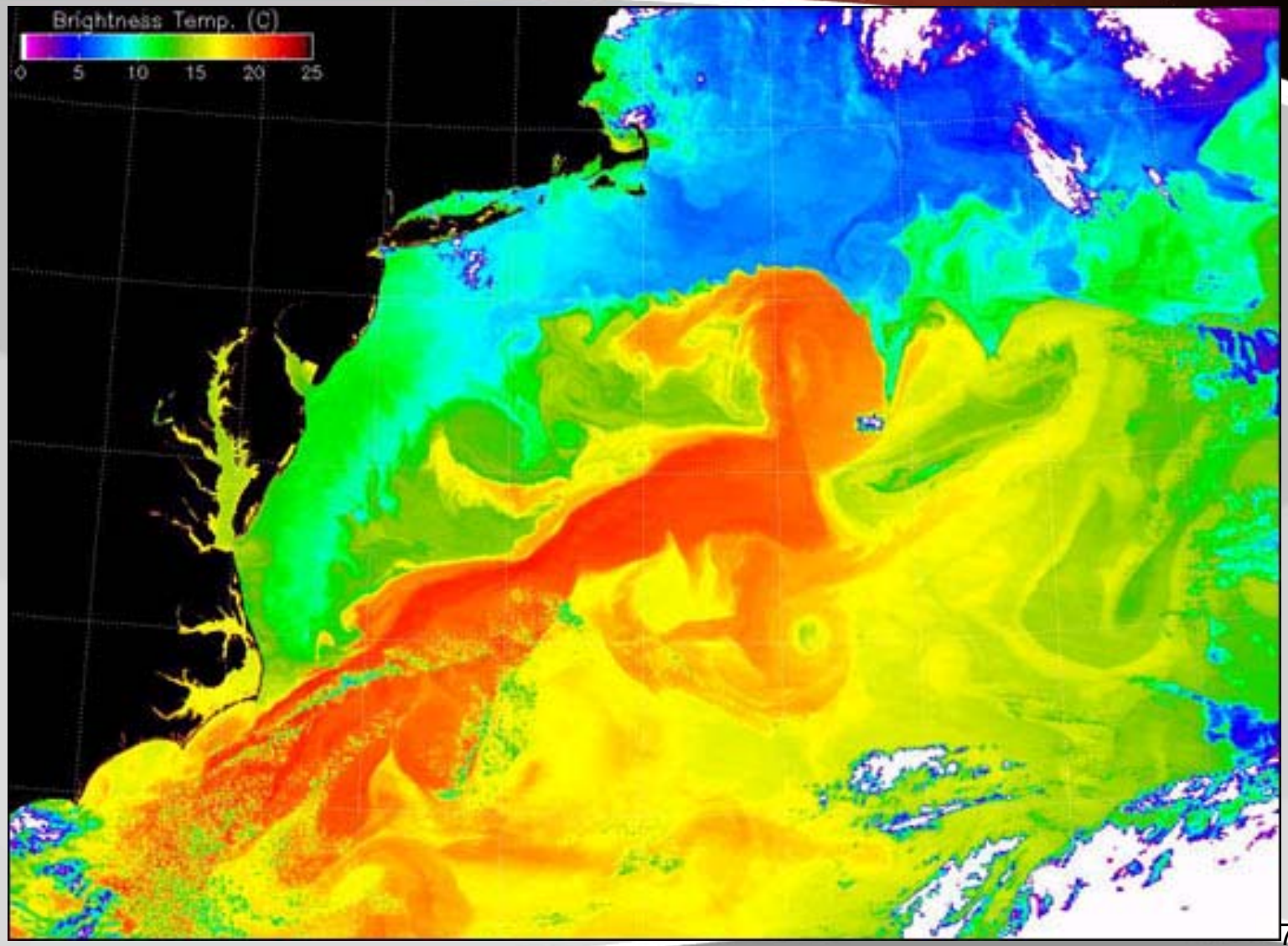
OSTM (Jason-2) Launch



The “A-Train”

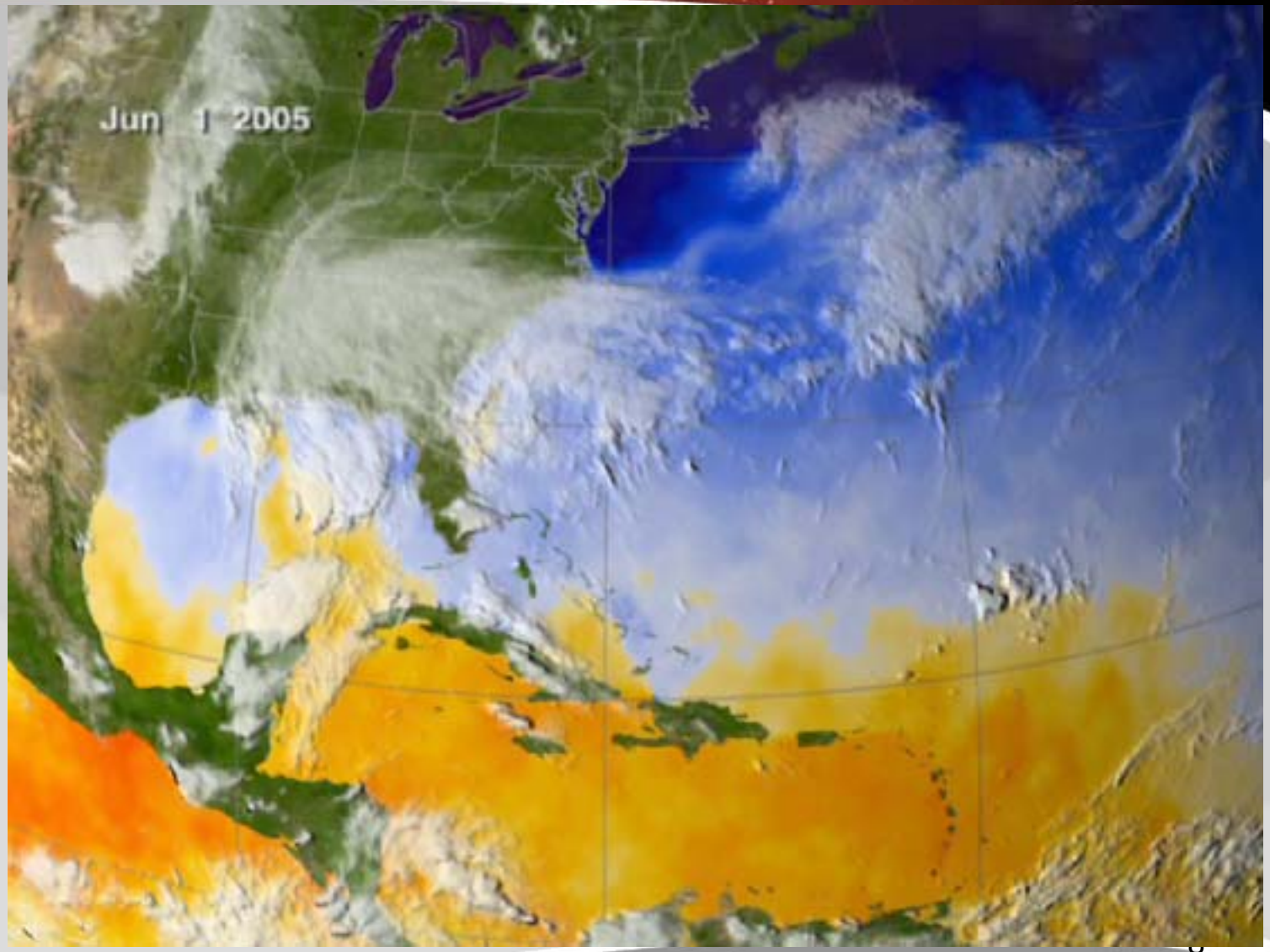

Aura
4 min.
Glory
2 min.
PARASOL
1 min.
CALIPSO
17.5 sec
Cloudsat
1 min.
Aqua

Sea Surface Temperature: MODIS



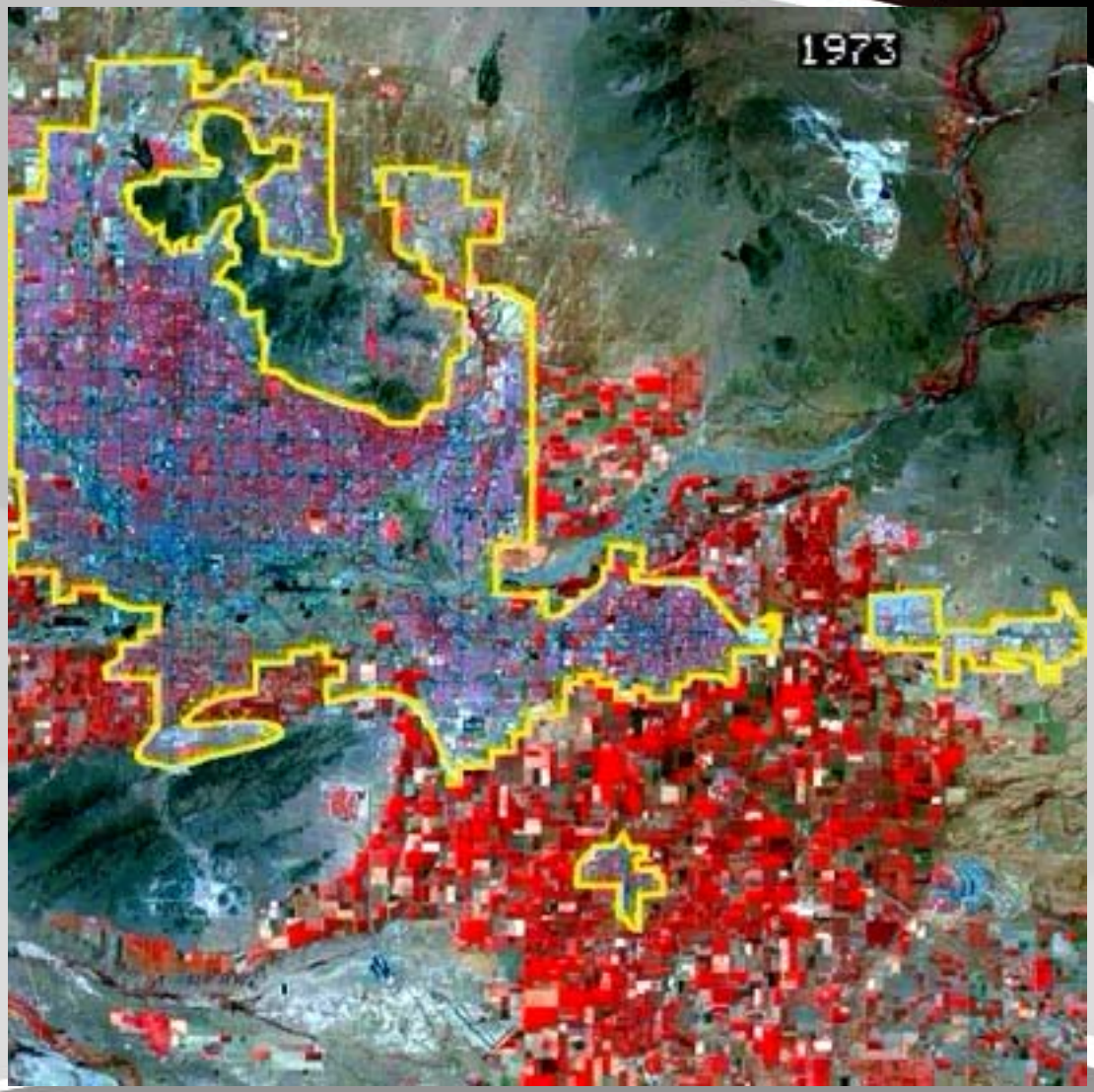
Terra/MODIS, May 2001

2005 Hurricane Season



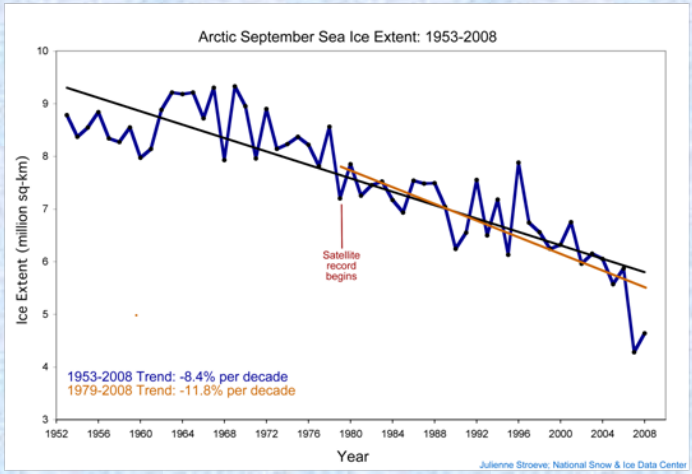
Observing how urban areas are changing over time due to human activities

Phoenix, AZ
Landsat Composite
1973-1992

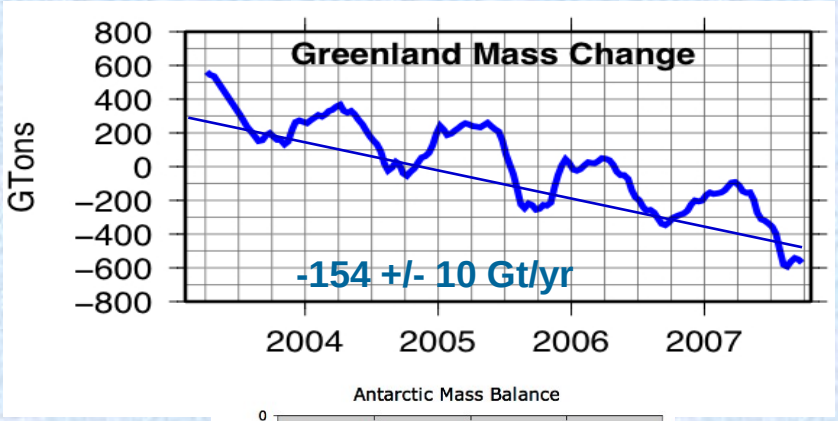


NASA-Observed Changes Occurring in the Polar Regions

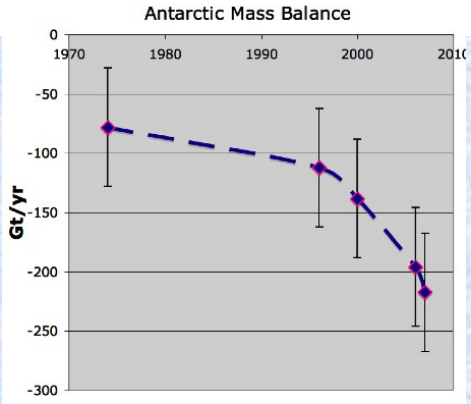
- **Reduction in Arctic Sea Ice Extent**
  - Dramatic reduction in 2007 followed by little recovery in 2008 measured by Japanese AMSR-E instrument on board the NASA Aqua Satellite and the US Air Force SSM/I on board the DMSP satellite



- **Reduction in Ice Mass in Greenland**
  - Seasonal changes and overall trend in ice mass associated with winter precipitation and summer melting measured from the US-German GRACE satellite pair. The mass loss corresponds to about 50 mm/century of sea level rise



- **Ice Mass Loss in Antarctica**
  - Accelerating ice mass loss data observed in West Antarctica between 1974 and 2007, using LANDSAT, RADARSAT, ERS-1 and -2, and PALSAR data



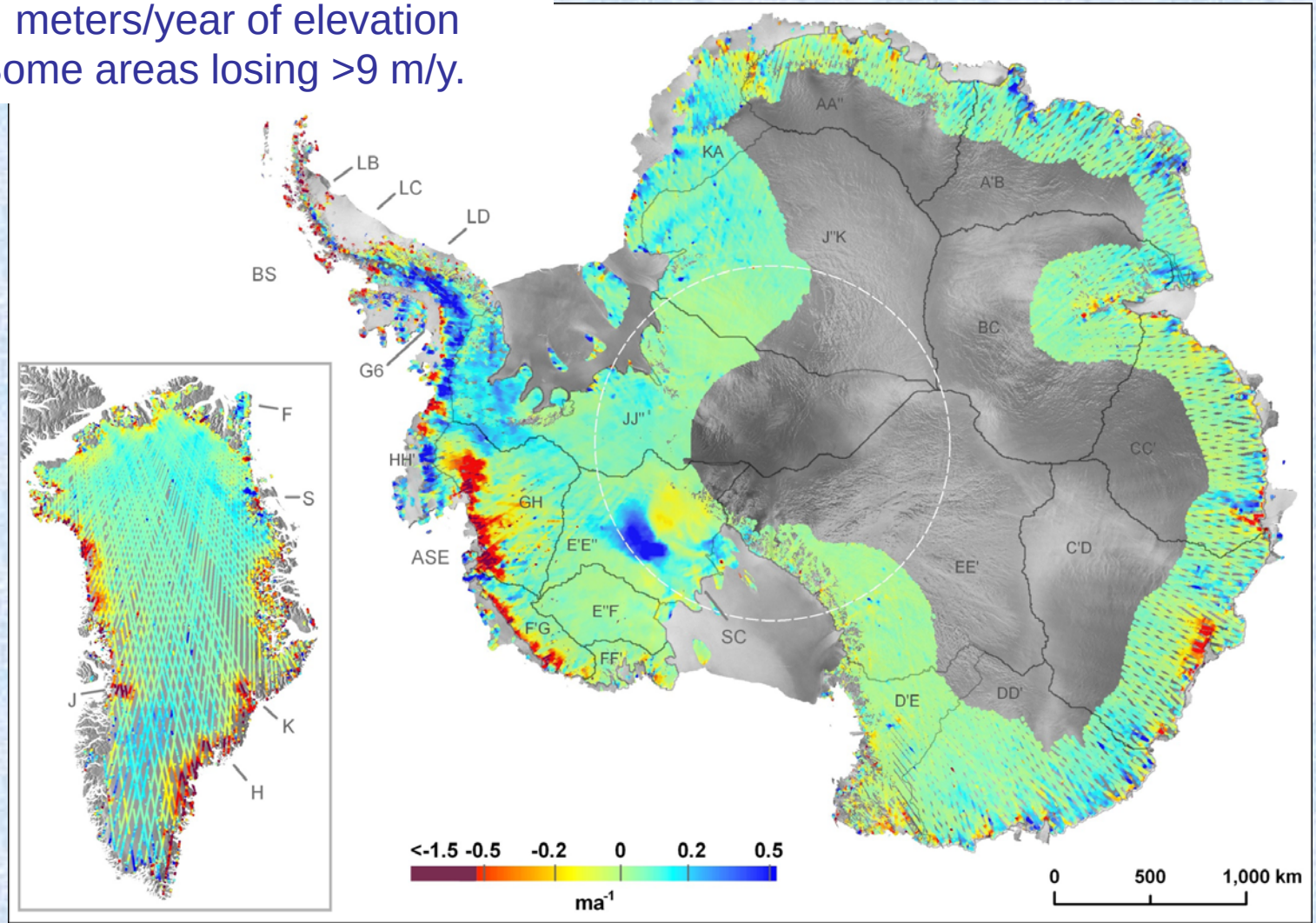
Figures from J. Stroeve, S. Luthcke, E. RIgnot

New results from ICESat

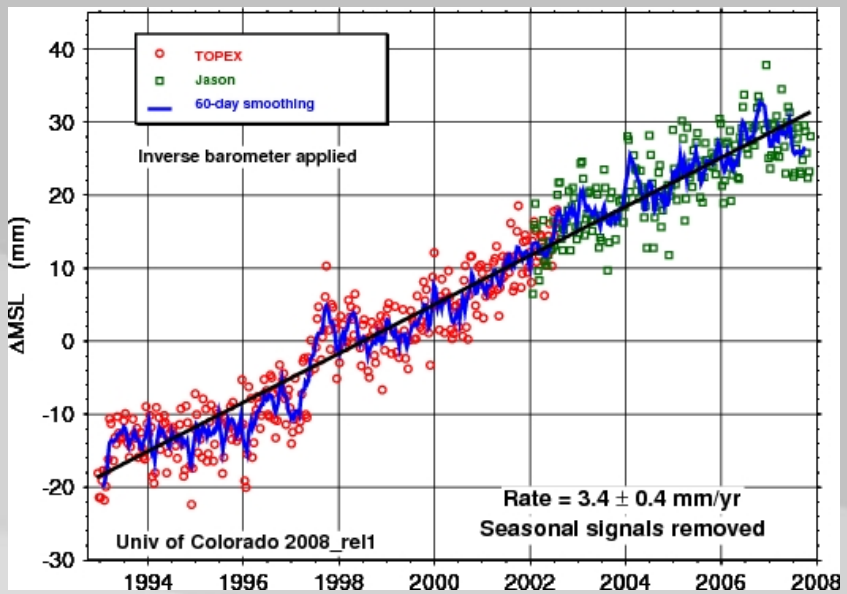
Nature, 23-Sept-2009
(doi:10.1038/nature08471)

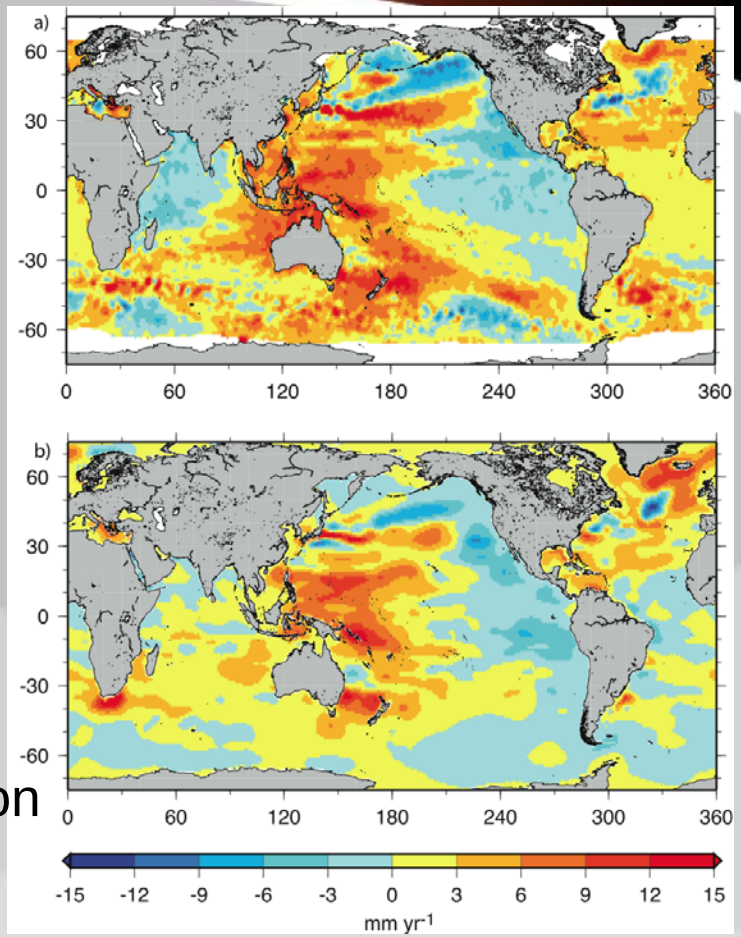
- **Thinning occurring at outlet glaciers all around Greenland—even the northernmost glaciers—and tapping the deep interior in places.**
- **Antarctic glaciers thinning rapidly in coastal areas. Some losing 9 meters of elevation per year.**
- **Areas of Antarctica long considered stable in East Antarctica are losing major amounts of ice.**

Changes in elevation from 2003-2007 with ICESat ground tracks. Red areas losing ice. Units: meters/year of elevation change. Some areas losing >9 m/y.



Sea Level Rise from Satellite Altimetry



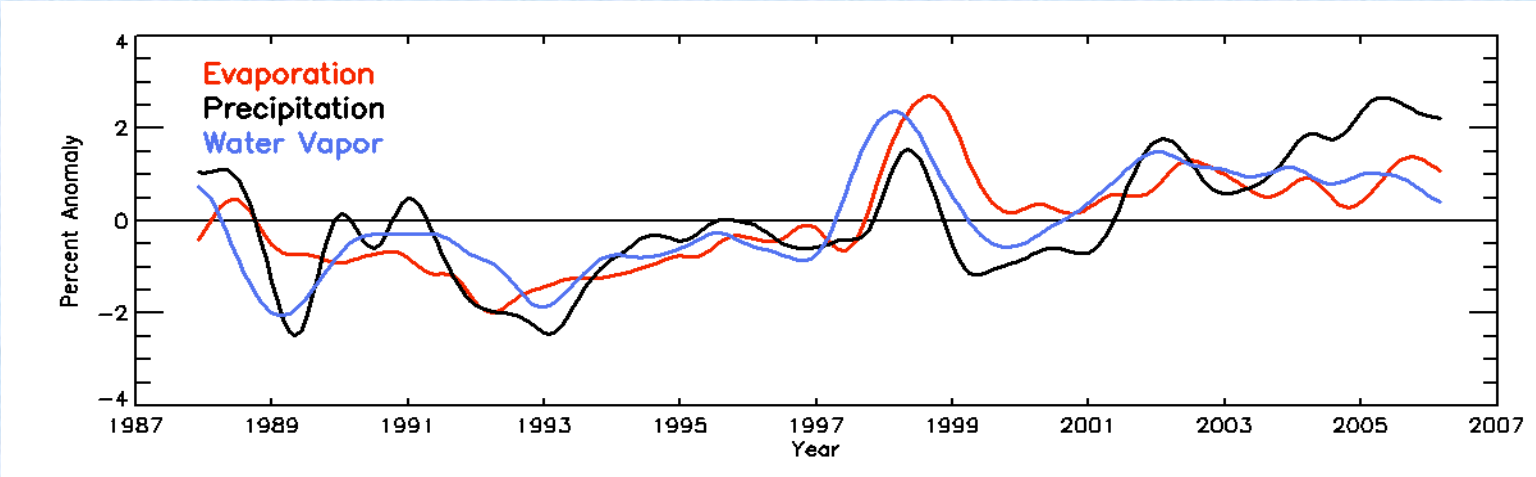


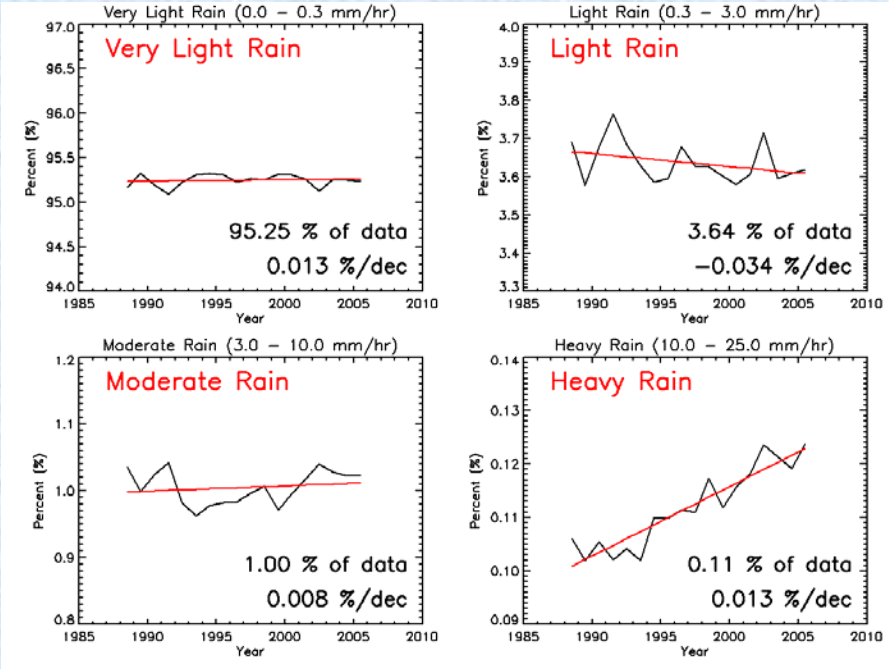
Total

Steric Contribution

IPCC WG1 FAR (2007)

Precipitation Is Increasing On a Global Scale





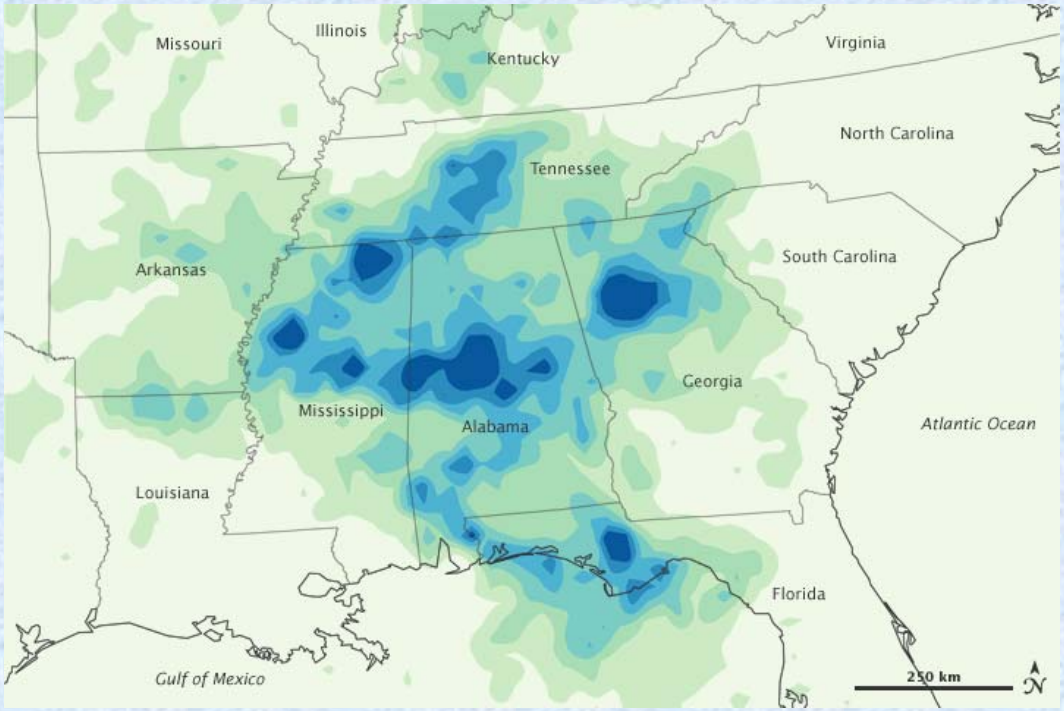
Satellite data show that precipitation is increasing as the climate warms and water vapor increases.

The increasing precipitation comes from increasing heavy rain, which is consistent with increasing water vapor.

Remote Sensing Systems
www.remss.com

SOUTHEAST SOAKED BY HEAVY RAINS

Severe flooding in the southeastern United States brought about by several days worth of heavy showers and thundershowers. Atlanta, Georgia was especially hard hit with reports of over 15 inches of rain in the metro region. The TRMM-based, near-real time Multi-satellite Precipitation Analysis (TMPA) at the NASA Goddard Space Flight Center is used to monitor rainfall over the global Tropics. TMPA rainfall totals are shown here for the period 14 - 21 September 2009 for the southeastern US and the surrounding region. Nearly the entire southeastern US from the Gulf Coast to the Ohio Valley and from the southern Mississippi Valley to the southern Appalachians received at least 2 inches of rain with a good portion receiving at least 6 inches.



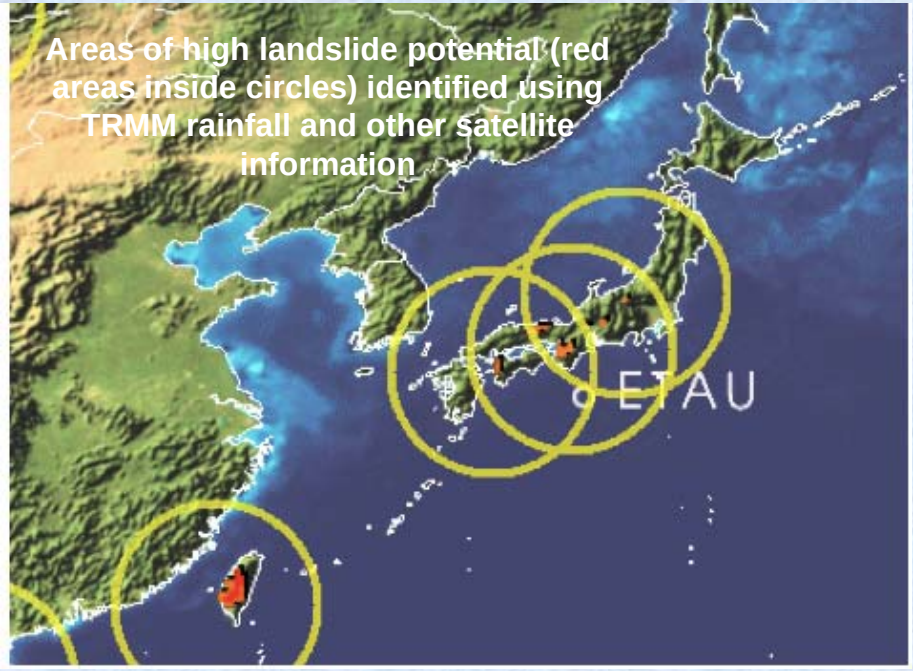
In order to support users who wanted more timely TRMM data to determine its usefulness in areas such as modeling, weather monitoring, disaster monitoring, etc., the TRMM science team authorized the establishment of a real-time processing and distribution of TRMM data. The goal is to have data available for retrieval within 3 hours of collection.

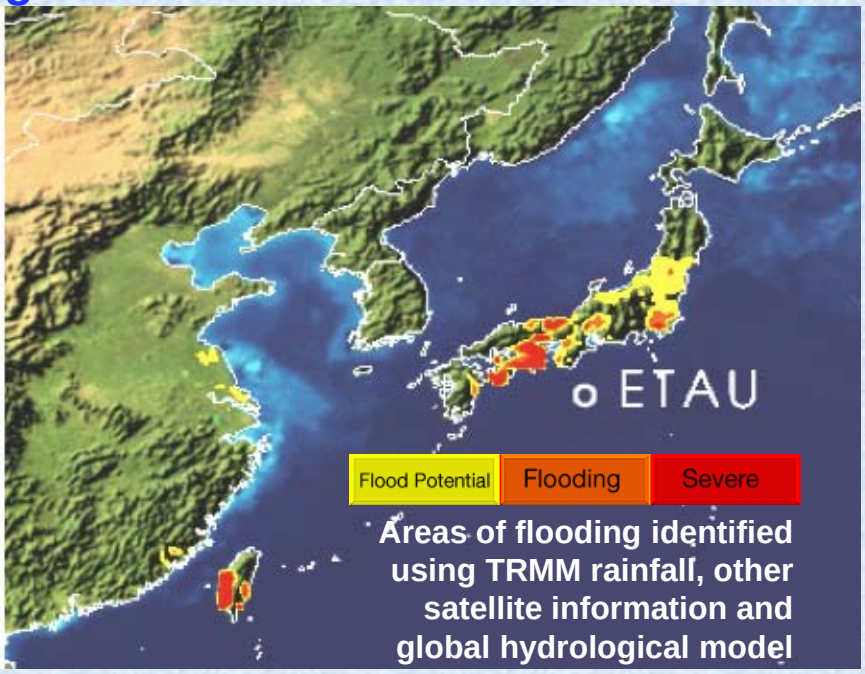
Landslides and Flooding in Taiwan and Japan

Real-time Global Monitoring Using Satellite Data (including TRMM Rainfall Estimations) and Hydrological Models and Landslide Algorithms

http://trmm.gsfc.nasa.gov Click on Global Floods and Landslides

1200 GMT 10 August 2009





400 unaccounted for in Taiwan mudslide

PETER ENAV
The Associated Press
Monday, August 10, 2009; 3:32 PM

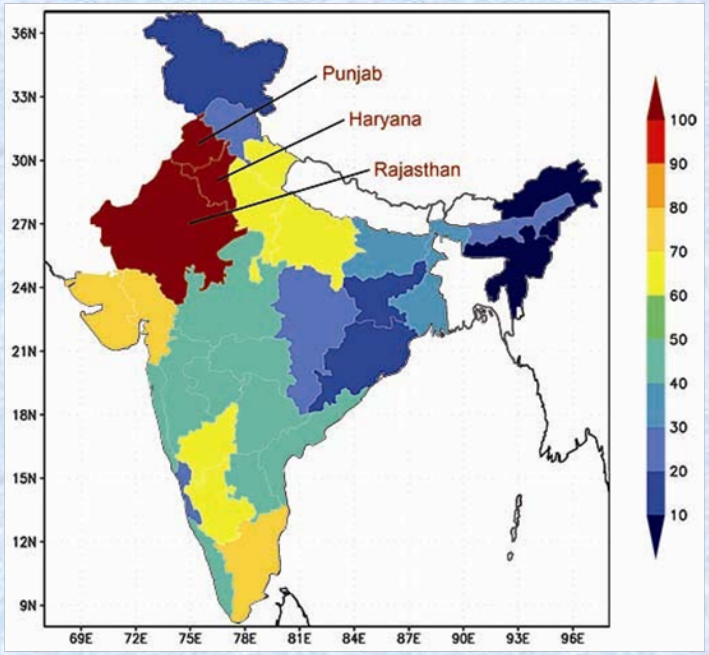
TAIPEI, Taiwan -- A mudslide touched off by a deadly typhoon buried a remote mountain village, leaving at least 400 people unaccounted for Monday, and military rescue helicopters unable to land because of the slippery ground dropped food to desperate survivors.

Research supported by NASA's Applied Science and Precipitation Measurement Missions (PMM) Programs

R. Adler--U. of Maryland--College Park and NASA GSFC

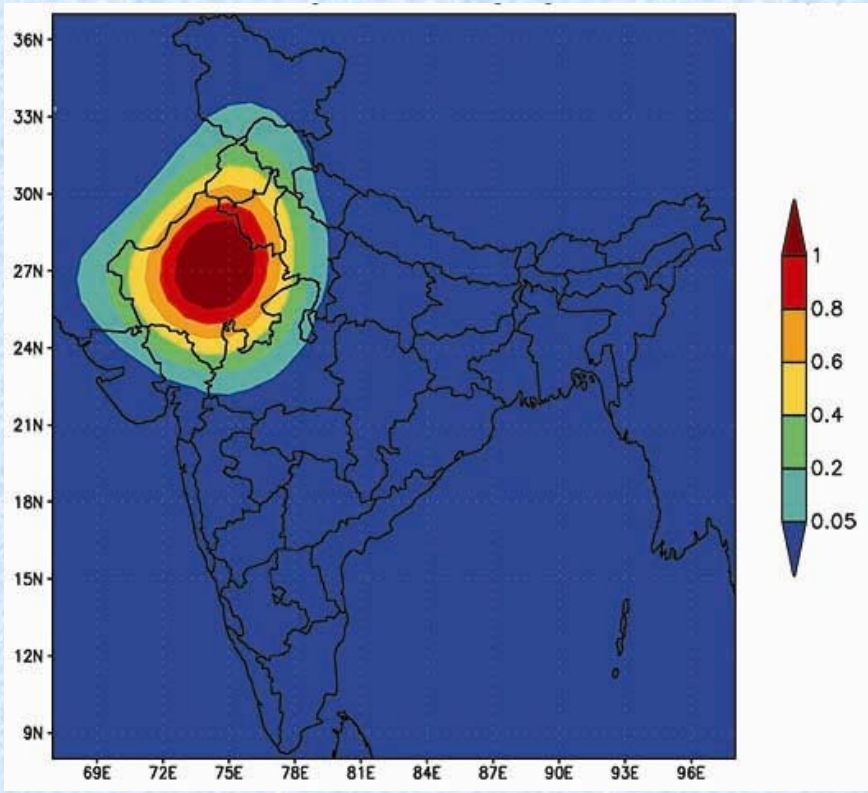
Pierce, Policelli, Hong, Yilmaz, Kirschbaum, Huffman

GRACE Studying Ground Water Depletion in NW India



- Groundwater levels declining by 1 meter every 3 years.
- More than 109 cubic km of groundwater disappeared between 2002 and 2008

Rodell et al
Appeared in *Nature* Aug 20, 2009

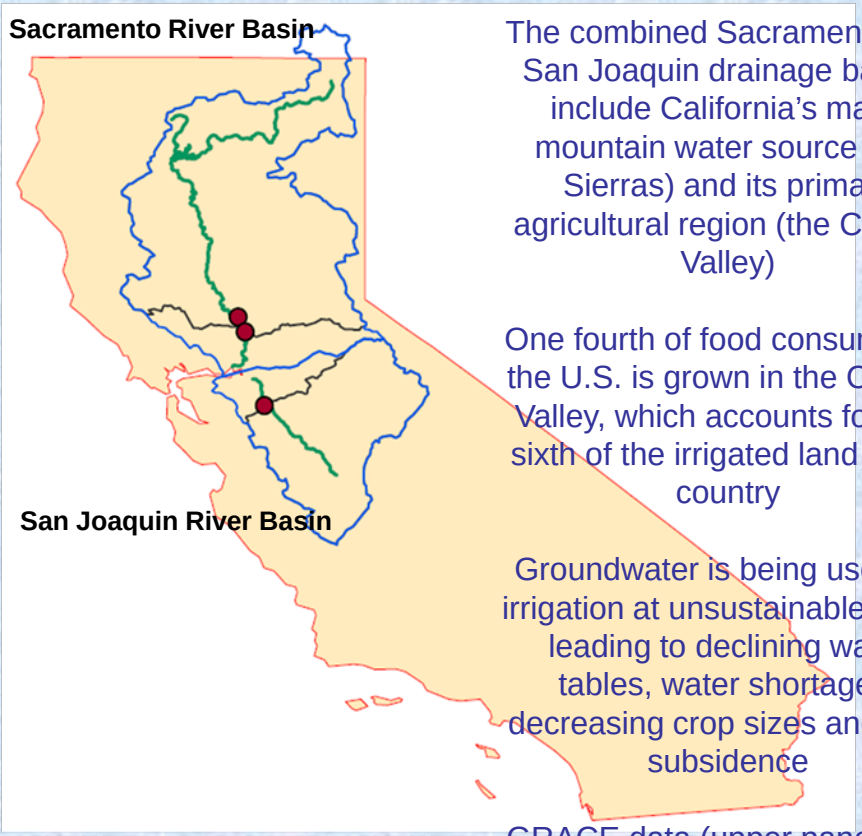


GRACE Story as Described in The Nation (Pakistan)

"THE warning by NASA that Pakistan and India could go to war over the sharing of Indus waters should be taken seriously. At fault is New Delhi which the NASA believes is responsible for the whole situation. It has warned that Pakistan will run out of water because of India's diversion of Indus waters, the building of dams and pumping of underground water have pushed the water table to a very low level and at a speed where it cannot be replenished by the natural process. The NASA is right in its assessment that this could spell disaster for Pakistan's agriculture. Because of the global warming which is depleting the fresh water resources by making the ice on the glaciers melt at a fast speed, the prediction that water will be the oil of the 21th century and that wars would be fought over it, could become an ugly reality. Though Pakistan in the recent past has done its best to assert its claim over its share of the Canal waters, it is obligatory upon the World Bank to wake up to its duty and compel India to respect the Indus Waters Treaty and not create a situation that could lead to war between the two nuclear armed neighbours."

http://www.nation.com.pk/pakistan-news-newspaper-daily-english-online/Opinions/Editorials/19-Aug-2009/Impending-water-wars; thanks to Dwayne Brown (NASA PAO) for calling this to our attention!

GRACE Observations of Groundwater Depletion in California's Central Valley



The combined Sacramento and San Joaquin drainage basins include California's major mountain water source (the Sierras) and its primary agricultural region (the Central Valley)

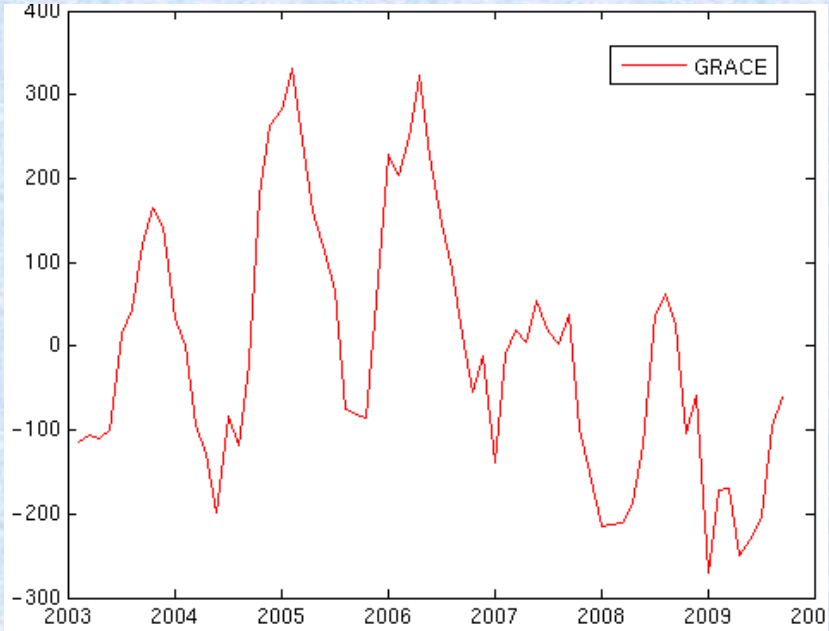
One fourth of food consumed in the U.S. is grown in the Central Valley, which accounts for one sixth of the irrigated land in the country

Groundwater is being used for irrigation at unsustainable rates, leading to declining water tables, water shortages, decreasing crop sizes and land subsidence

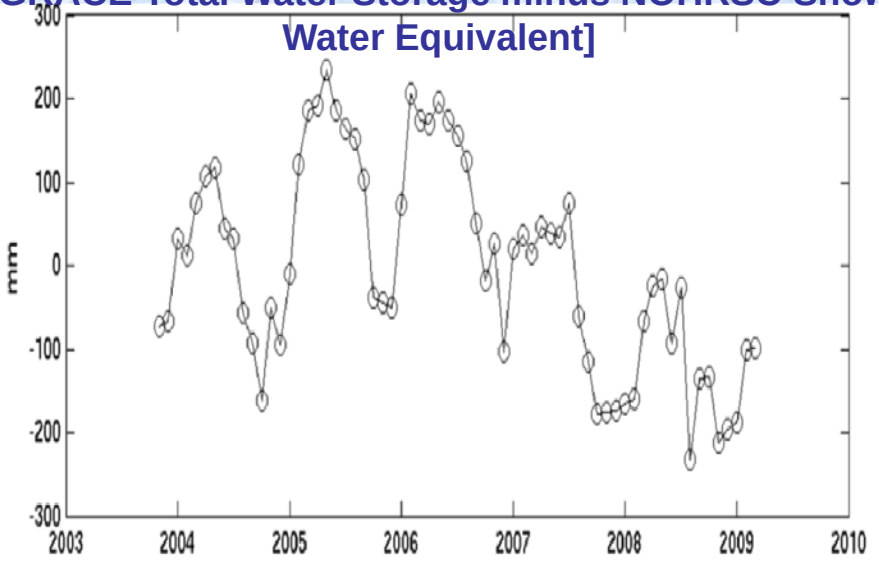
GRACE data (upper panel) can quantify rates of groundwater depletion (lower panel) for the entire Central Valley in near real time, which can be used by water managers to make informed decisions regarding water allocations

Jay Famiglietti, UC Center for Hydrologic Modeling, UC Irvine

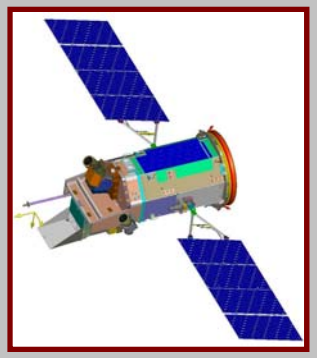
GRACE Observation of Variations of Total Water Storage (mm) in the Sacramento and San Joaquin River Basins



Central Valley Groundwater Storage Variations [GRACE Total Water Storage minus NOHRSC Snow Water Equivalent]



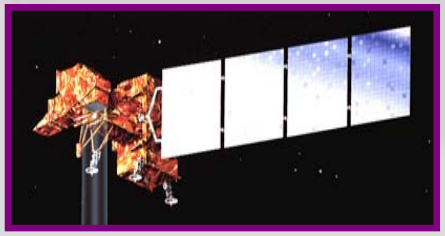
Missions in Formulation and Implementation



GLORY

AQUARIUS

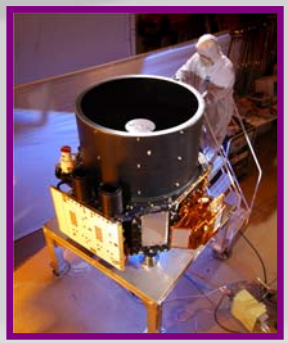
NPP



LDCM

GPM

SMAP



ICESat-II

NRC Decadal Survey Recommended Missions

- National Research Council decadal survey (released 1/07) recommended a list of 15 missions for NASA to launch in 2010-2020 time frame
- Missions were broken into 3 categories - near-term (2010-2013), mid-term (2013-2016), and long-term (2016-2020)
- Two missions were set up for initiation in FY09 budget – SMAP for soil moisture and ICESat II for ice sheet thickness (primary goal)
- Remaining "Tier 1" missions are CLARREO (climate reference) and DESDynI (earth surface motion and vegetation)
- Tier 2 and Tier 3 missions cover a broad range of subjects

Decadal Survey Mission	Mission Description	Orbit	Instruments
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar

Decadal Survey Mission	Mission Description	Orbit	Instruments
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar

Highlights of Recent USGCRP Report

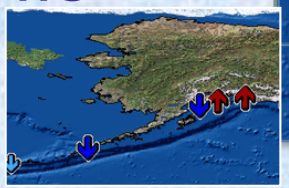
- Global warming is unequivocal and primarily human-induced
- Climate changes are underway in the United States and are projected to grow
- Widespread climate-related impacts are occurring now and are expected to increase
- Climate change will stress water resources
- Crop and livestock production will be increasingly challenged
- Coastal areas are at increasing risk from sea-level rise, storm surge, and other climate-related stresses
- Threats to human health will increase
- Climate change will interact with many social and environmental stresses
- Thresholds will be crossed, leading to large changes in climate and ecosystems
- Future climate change and its impacts depend on choices made today

Following Charts were Provided by Tom Karl (NOAA) – selected from larger set to describe report.

2. Climate changes are underway in the U.S. and are projected to grow

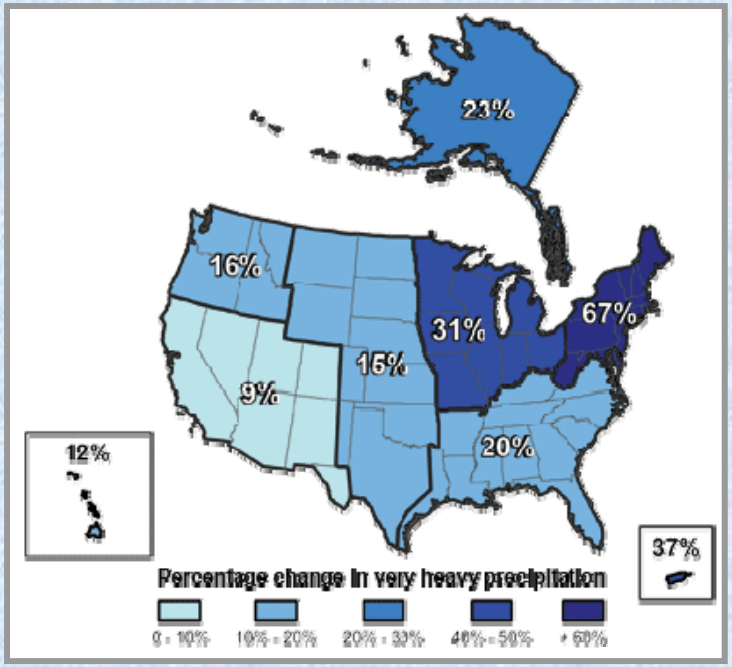
- Temperature rise
- Sea-level rise
- Increase in heavy downpours
- Rapidly retreating glaciers
- Thawing permafrost
- Longer growing season
- Longer ice-free season in the ocean and on lakes and rivers
- Earlier snowmelt
- Changes in river flows

Observed U.S. Sea-Level Changes

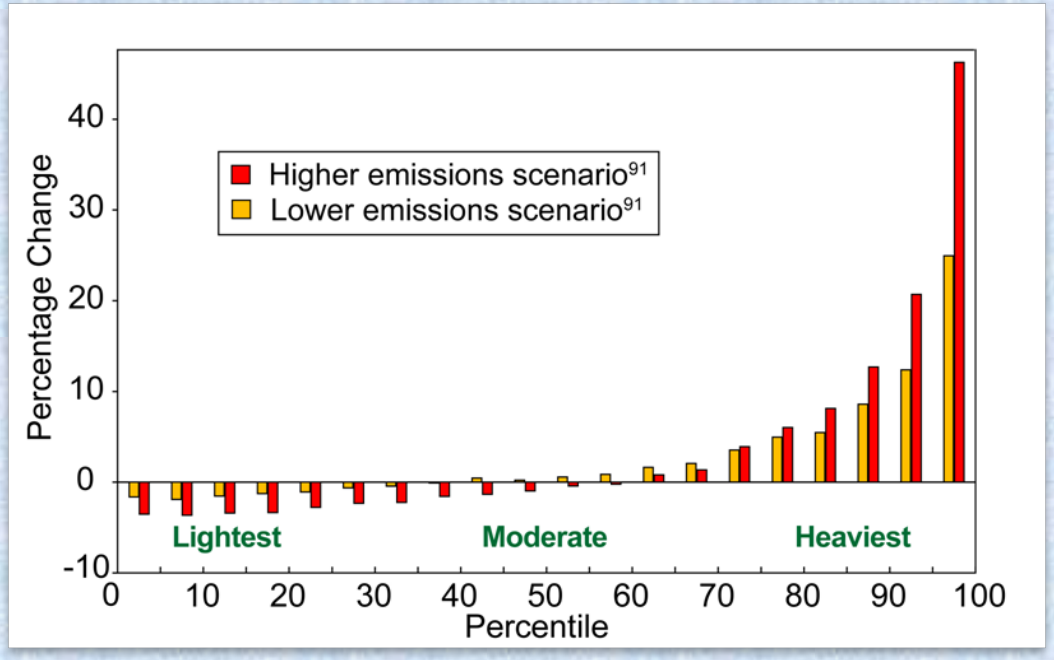


2. Climate changes are underway in the U.S. and are projected to grow

Observed Increases in Very Heavy Precipitation (1958 to 2007)



Projected Change in Precipitation Intensity (2080-2099)

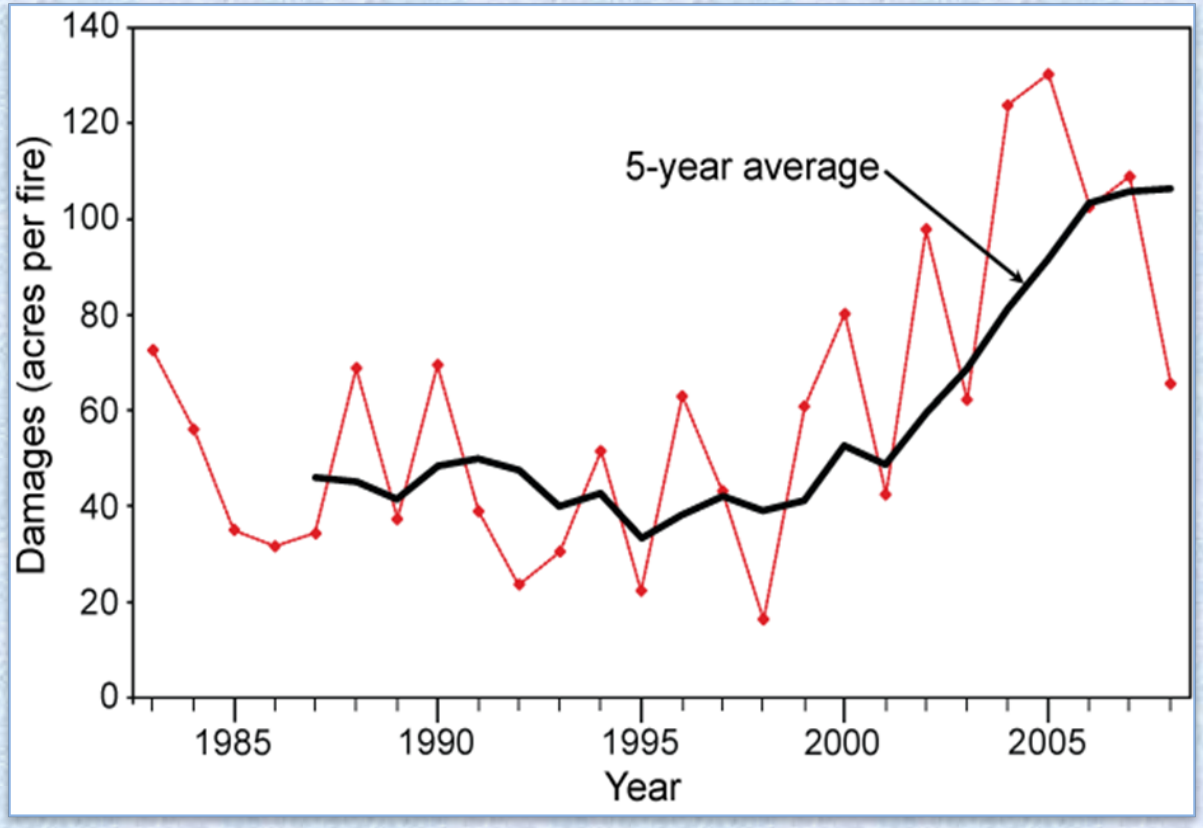


3. Widespread climate-related impacts are occurring now and are expected to increase

Forests, Safety, Quality of Life

Climate change interacts with other environmental and social factors in complex ways

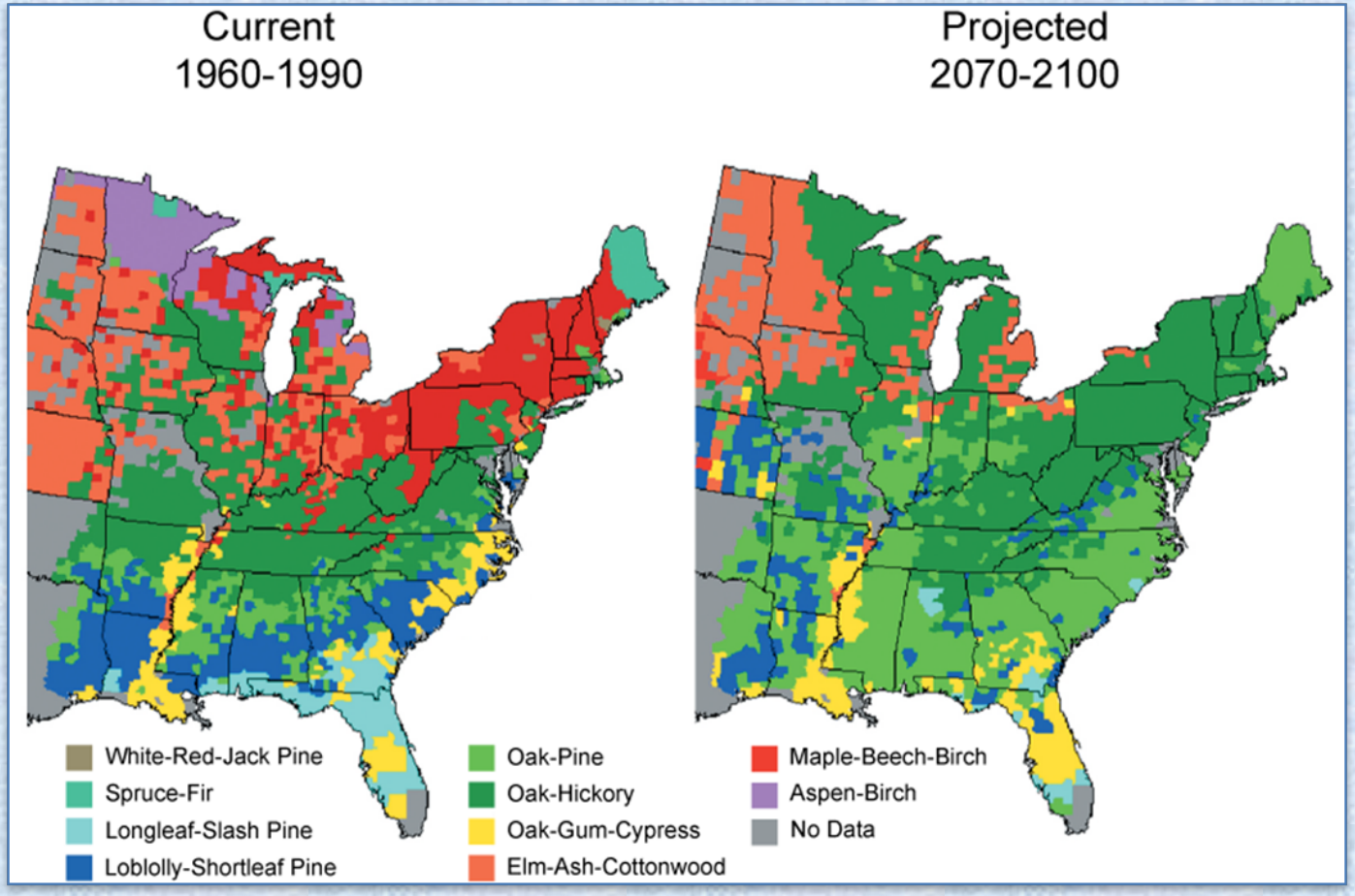
U.S. Wildfire Size



3. Widespread climate-related impacts are occurring now and are expected to increase

Ecosystems, Quality of Life

Projected Shifts in Forest Types



3. Widespread climate-related impacts are occurring now and are expected to increase

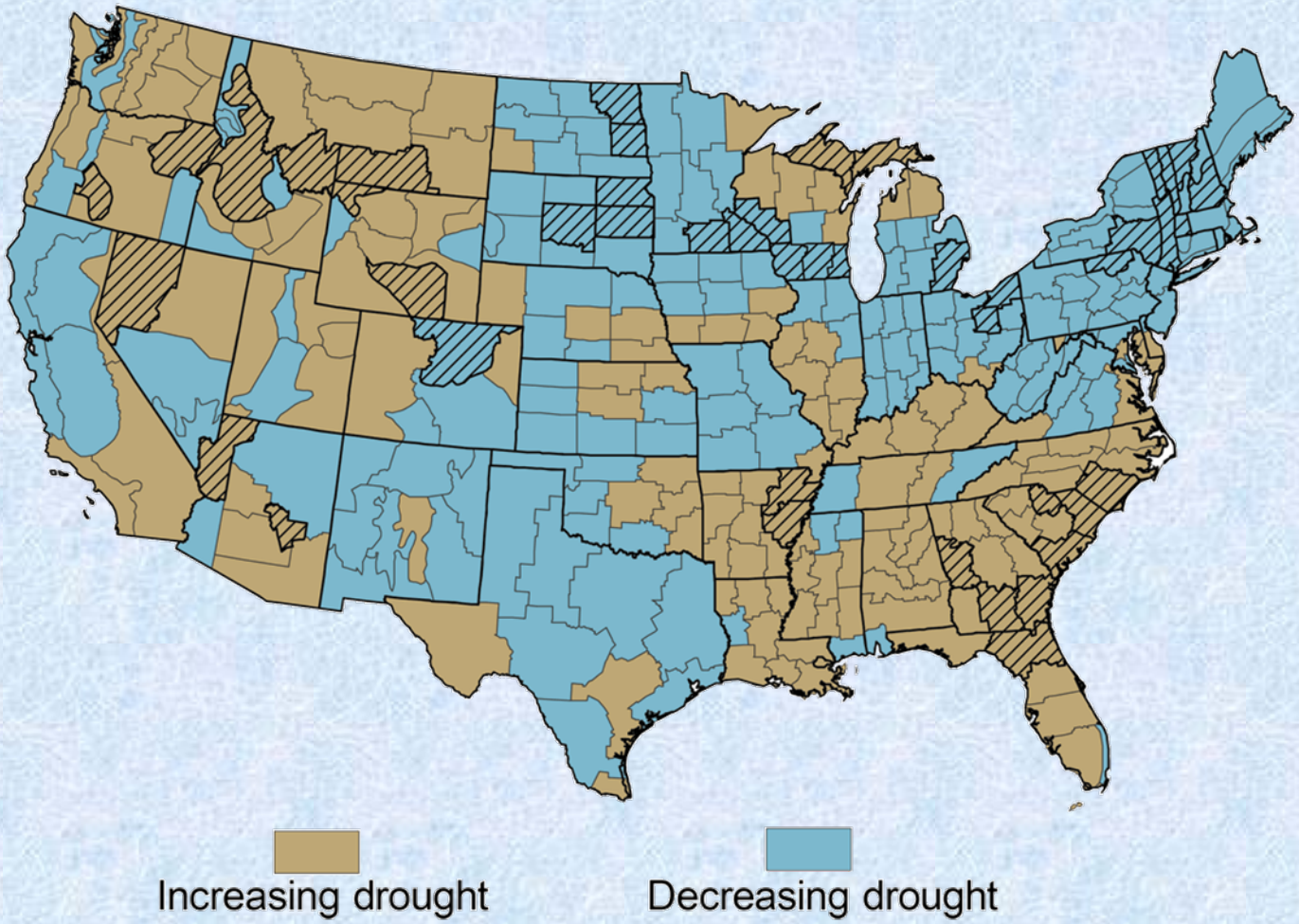
Impacts on **energy** supply and use include:

- Increases in electricity use and peak demand in most regions (mainly due to increased air conditioning)
- Rising temperature and limited water supplies reduce energy production
- Hydropower reductions in regions where precipitation or water from melting snowpack decreases
- Extreme weather events threaten energy production and delivery systems in vulnerable regions

A Key Unknown: *How will climate change affect solar and wind resources?*

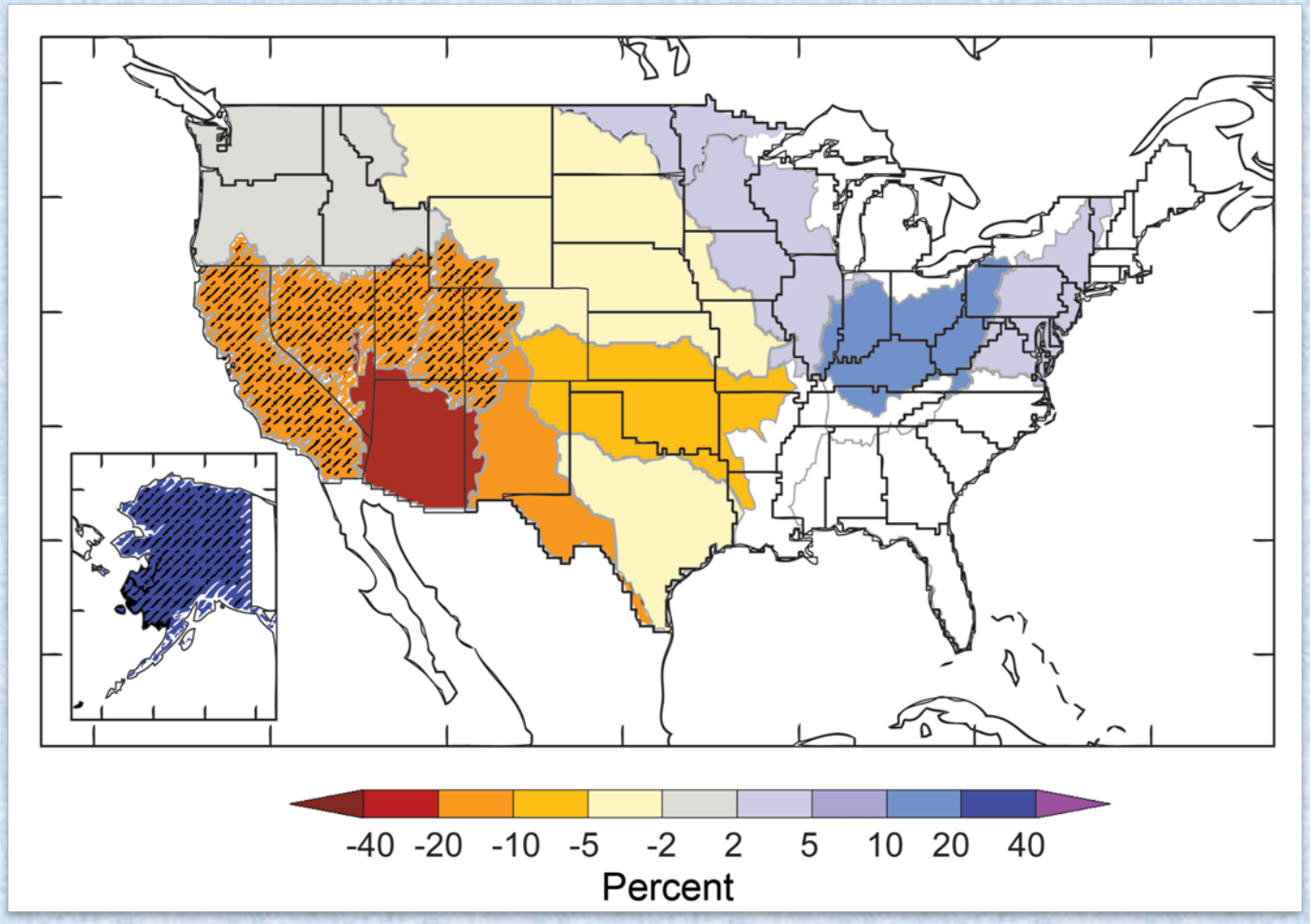
4. Climate change will stress water resources

Observed Drought Trends 1958-2007



4. Climate change will stress water resources

Projected Changes in Annual Runoff

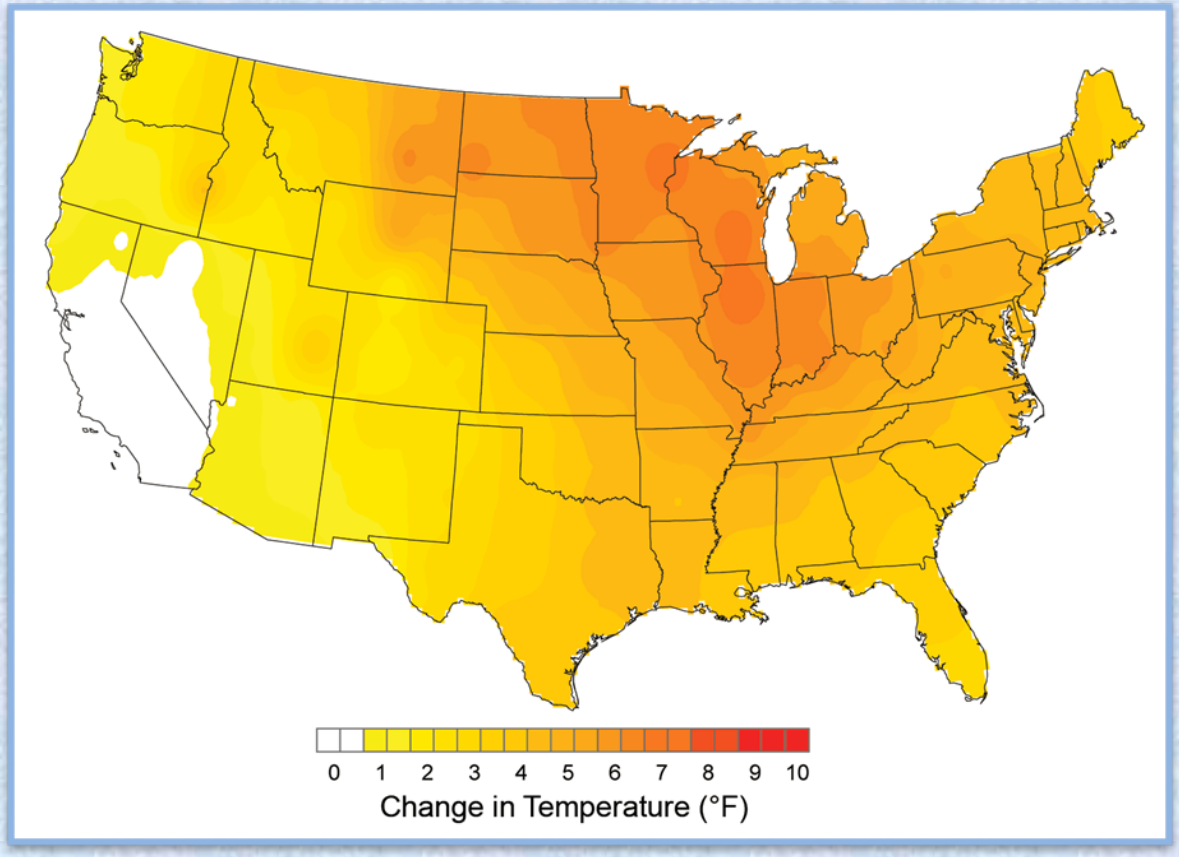


5. Crop and livestock production will be increasingly challenged

- Winter temperatures rising faster than in any other season, especially in many key agricultural regions

- This allows many insect pests and crop diseases to expand and thrive

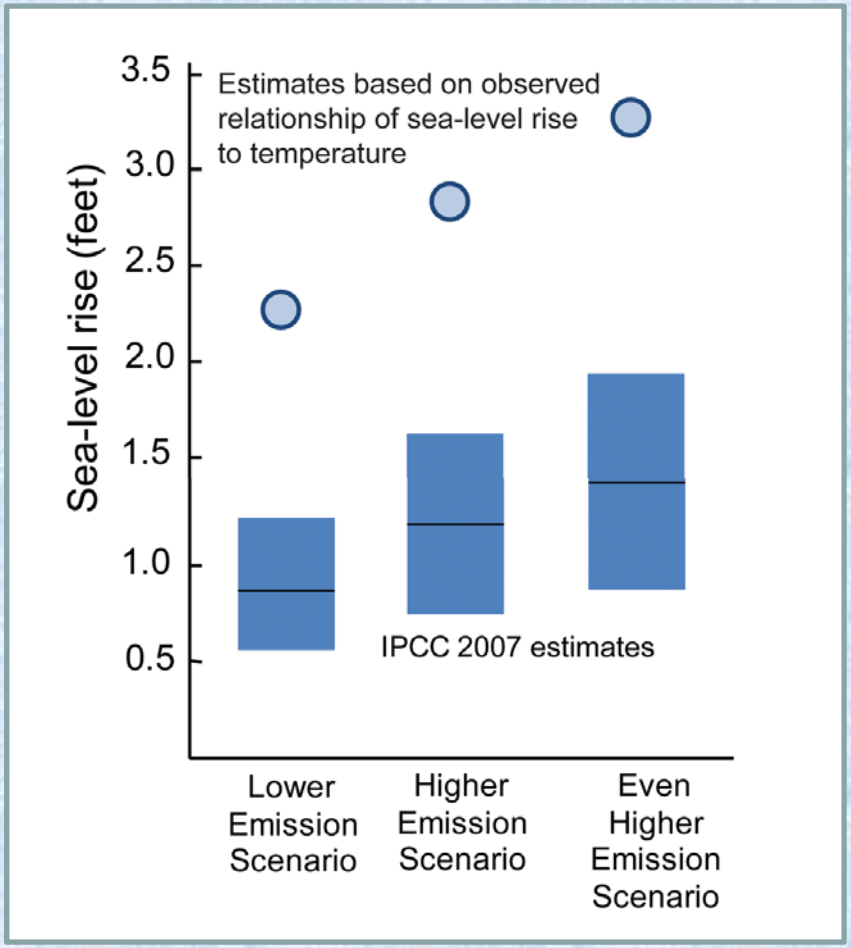
Winter Temperature Trends 1975-2007



6. Coastal areas are at increasing risk from sea-level rise and storm surge

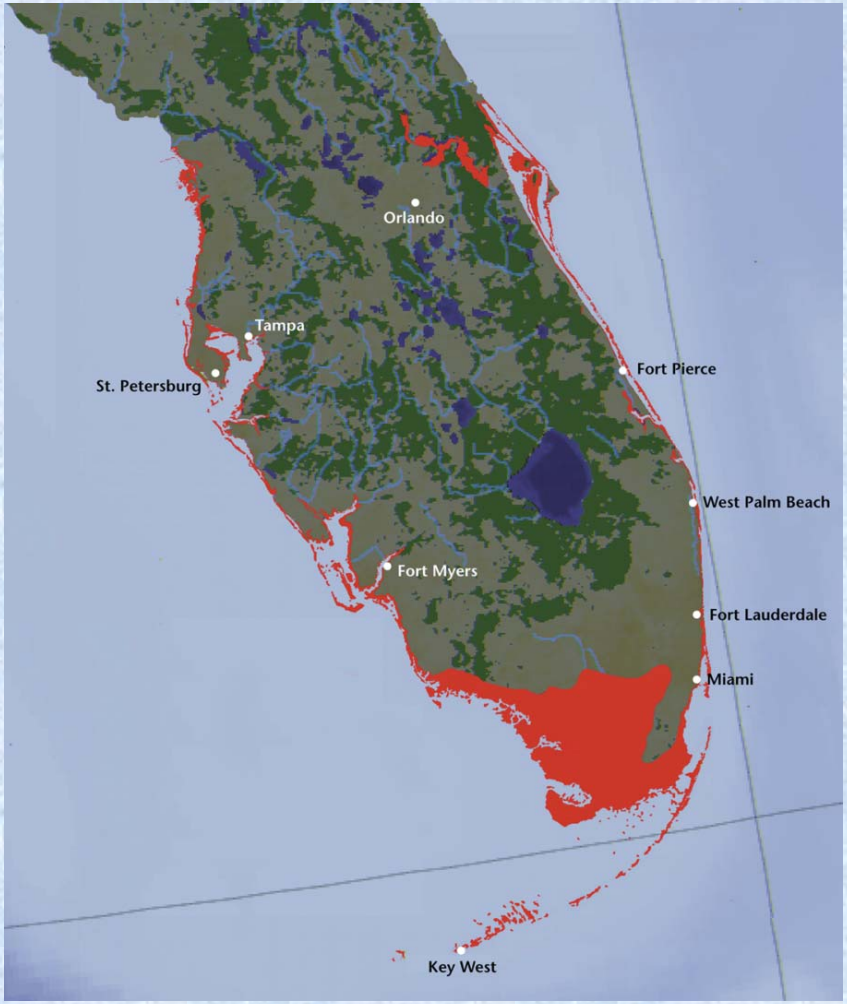
- Sea-level rise
- Storm surge
- Erosion
- Flooding

Projected Sea-Level Rise



Coastal areas are at increasing risk from sea-level rise and storm surge.

Florida with 3 feet of Sea-Level Rise

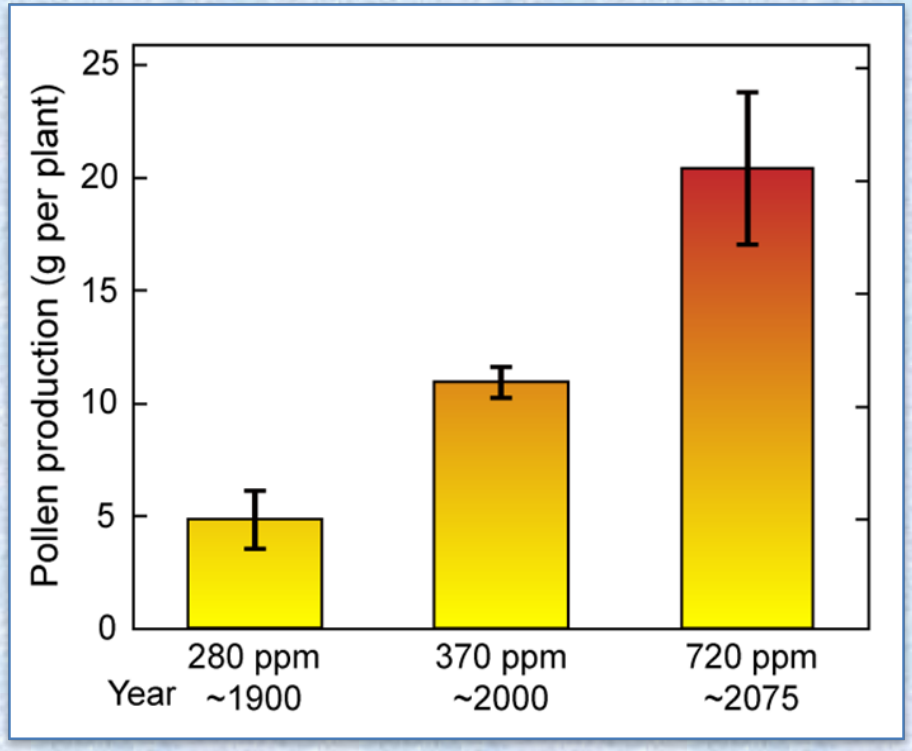


Areas in red would be under water with a 3 foot rise in sea level, projected for this century

7. Threats to human health will increase

- Heat stress
- Water-borne diseases (due to heavy downpours and higher temperatures)
- Reduced air quality
- Extreme weather events
- Diseases caused by insects and rodents
- Pollen increase

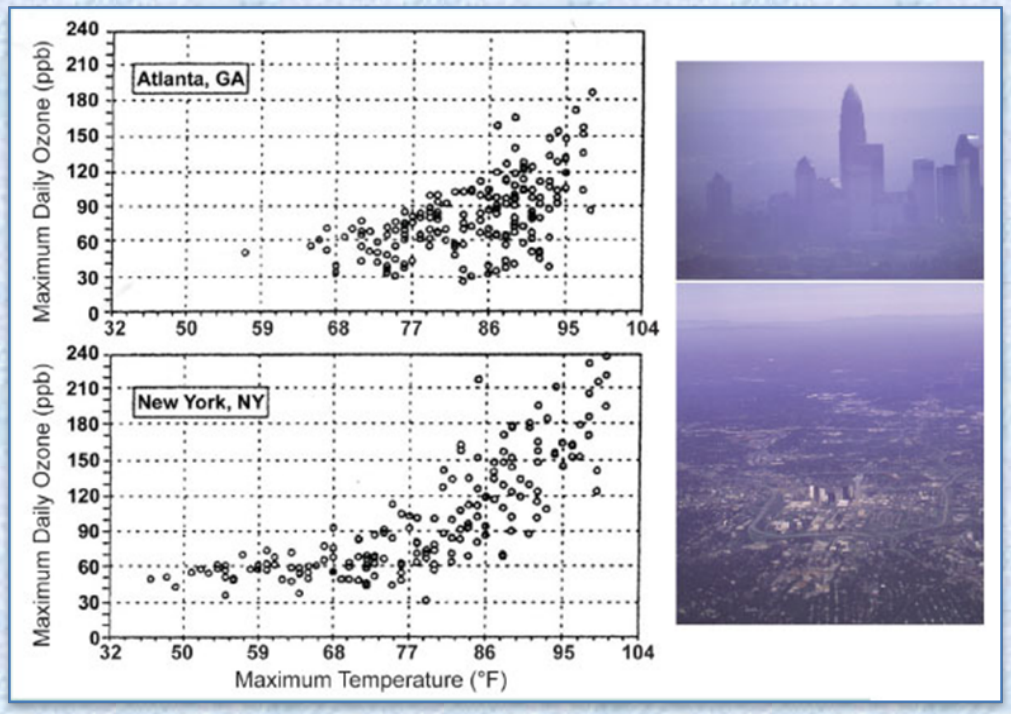
Pollen Counts Rise with Increasing Carbon Dioxide



8. Climate change will interact with many social and environmental stresses

- Pollution
- Population growth
- Urbanization
- Overuse of resources
- Other stresses

Temperature and Ground-Level Ozone



Response Strategies

“Mitigation” – reducing the amount of climate change, for example, by reducing heat-trapping emissions or increasing their removal from the atmosphere

“Adaptation” – improving our ability to cope with or avoid harmful impacts or taking advantage of newly favorable conditions

Both will be needed.

Concluding Message

- The vantage point of space provides a good approach to watch the whole planet evolve and explore the interconnections between physics, chemistry, and biology
- The current and projected suite of space-based environmental measurement capability enables scientific discovery and (for many parameters) monitoring, and can be enhanced by technology
- Current observations show significant changes in many aspects of earth system, especially in polar regions, with the potential for even more significant changes in the future
- Impacts of potential climate change for civilization are significant and require strong scientific knowledge base that supports action
- Investments in space measurements are synergistic with surface-, aircraft-, and balloon-based measurements, along with models