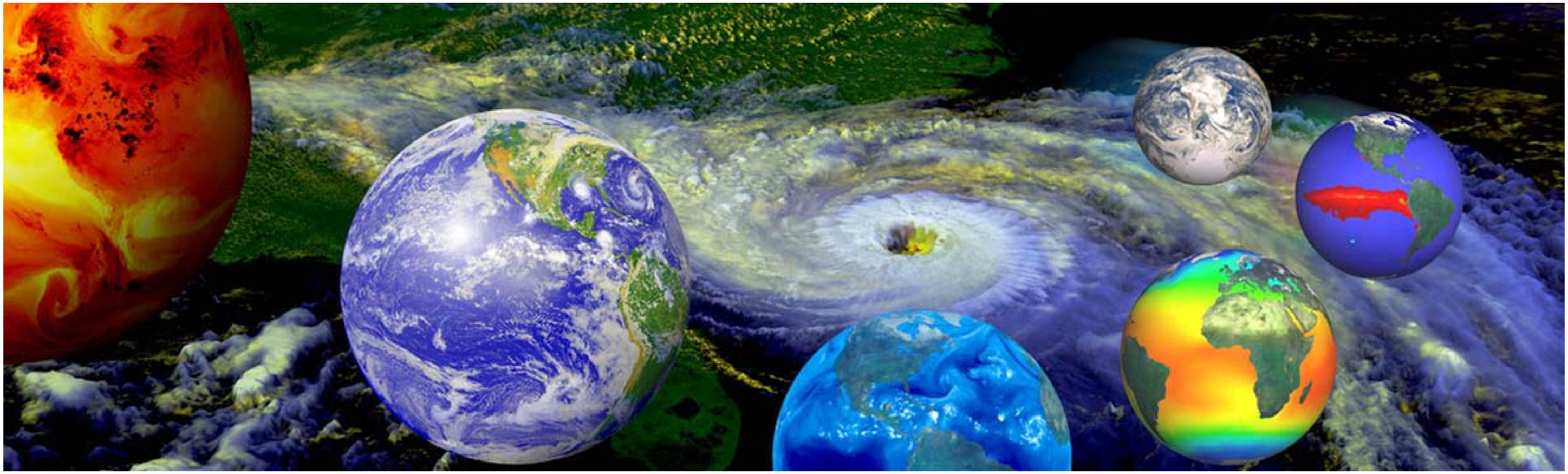


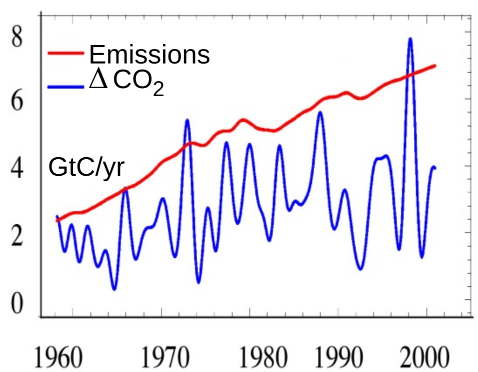
Airships and Earth Science Opportunities

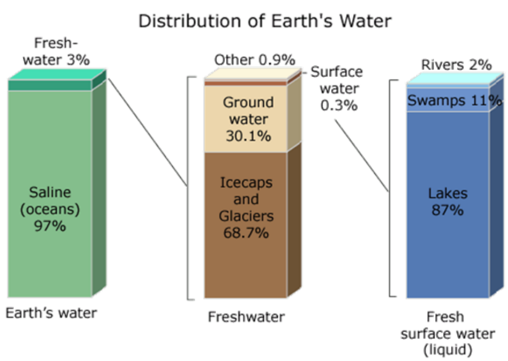
Randy Friedl, Jet Propulsion Lab

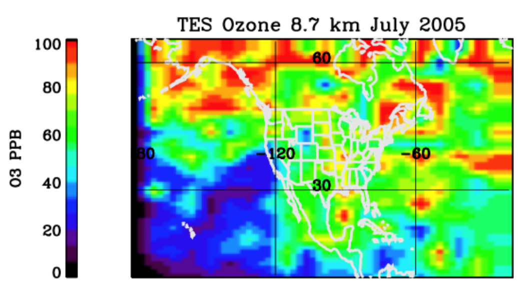
KISS Workshop on Airships: A New Horizon for Science

April 30, 2013

Current Societal Challenges







Energy

- In 2002, two-thirds of the world's energy consumption came from fossil fuels (43% from oil). Global energy consumption has risen by 56% since 1973.
- Burning of fossil fuels accounts for approximately 80% of human-induced greenhouse gas emissions. Between 1973 and 2002, these emissions increased by more than 50%.
- 10 million hectares of ancient forests are being cleared every year, thus reducing the available carbon sink.

Water

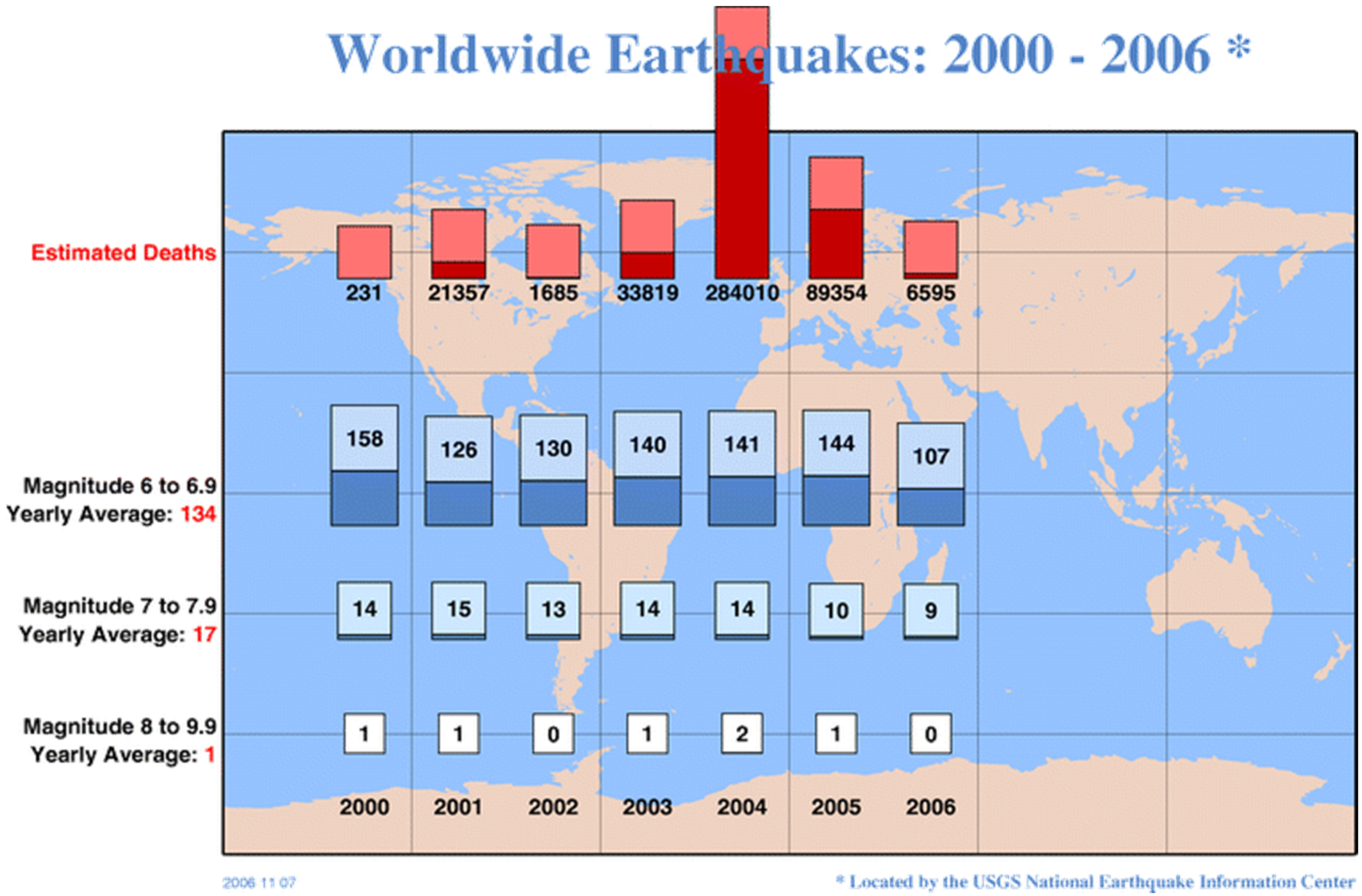
- Unclean water, along with poor sanitation, kills over 12 million people each year.
- Humans will be using 70% of accessible freshwater sources by 2025 (compared with 54% today).
- 2 million tons of waste per day is disposed of in freshwaters, including agricultural, industrial and human waste.

Urbanization

- In 2002, 48% of the population lived in urban environments compared with 39% in 1980.
- By 2030, 60% of the population will live in cities. There will be at least 23 cities with more than 10 million inhabitants.
- Every year between 0.5 and 1 million people die prematurely due to diseases associated with urban air pollution.

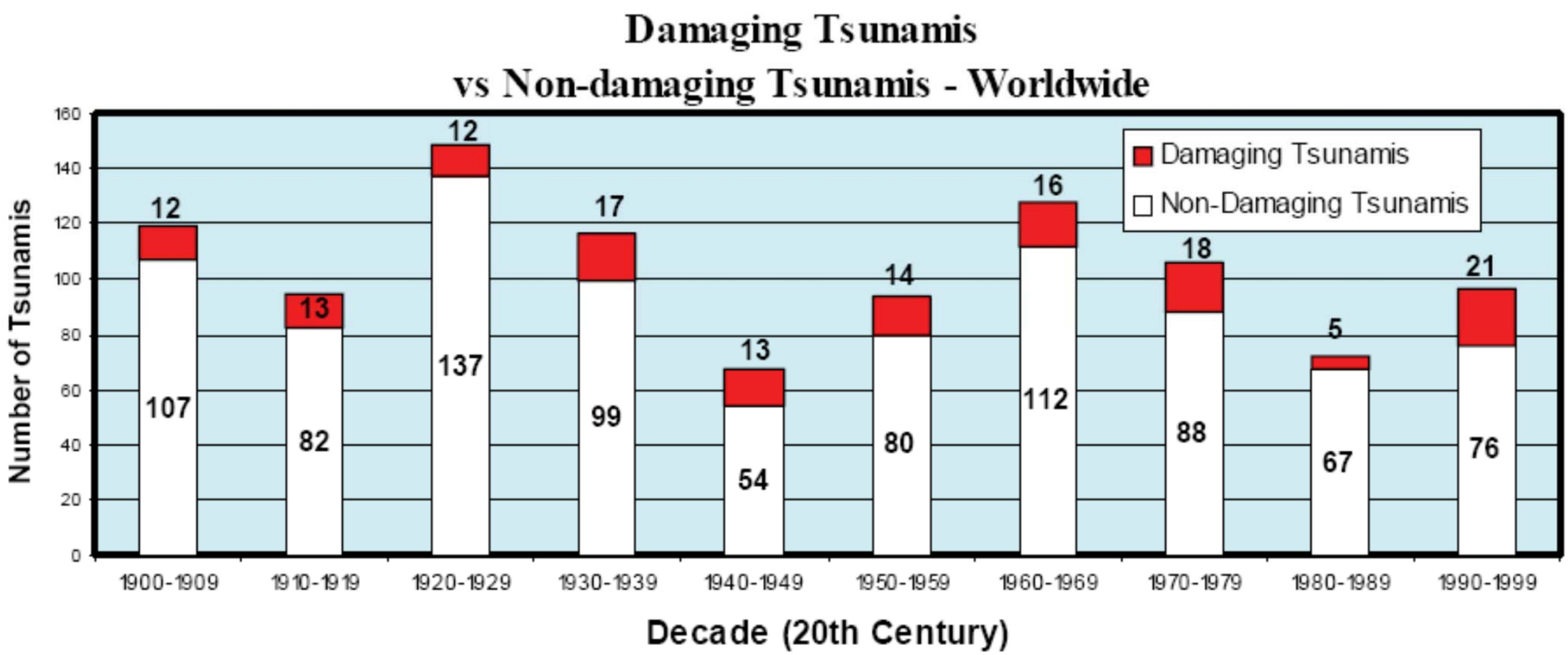
Future Natural Hazards

Nearly 180 major earthquakes will occur over the next decade



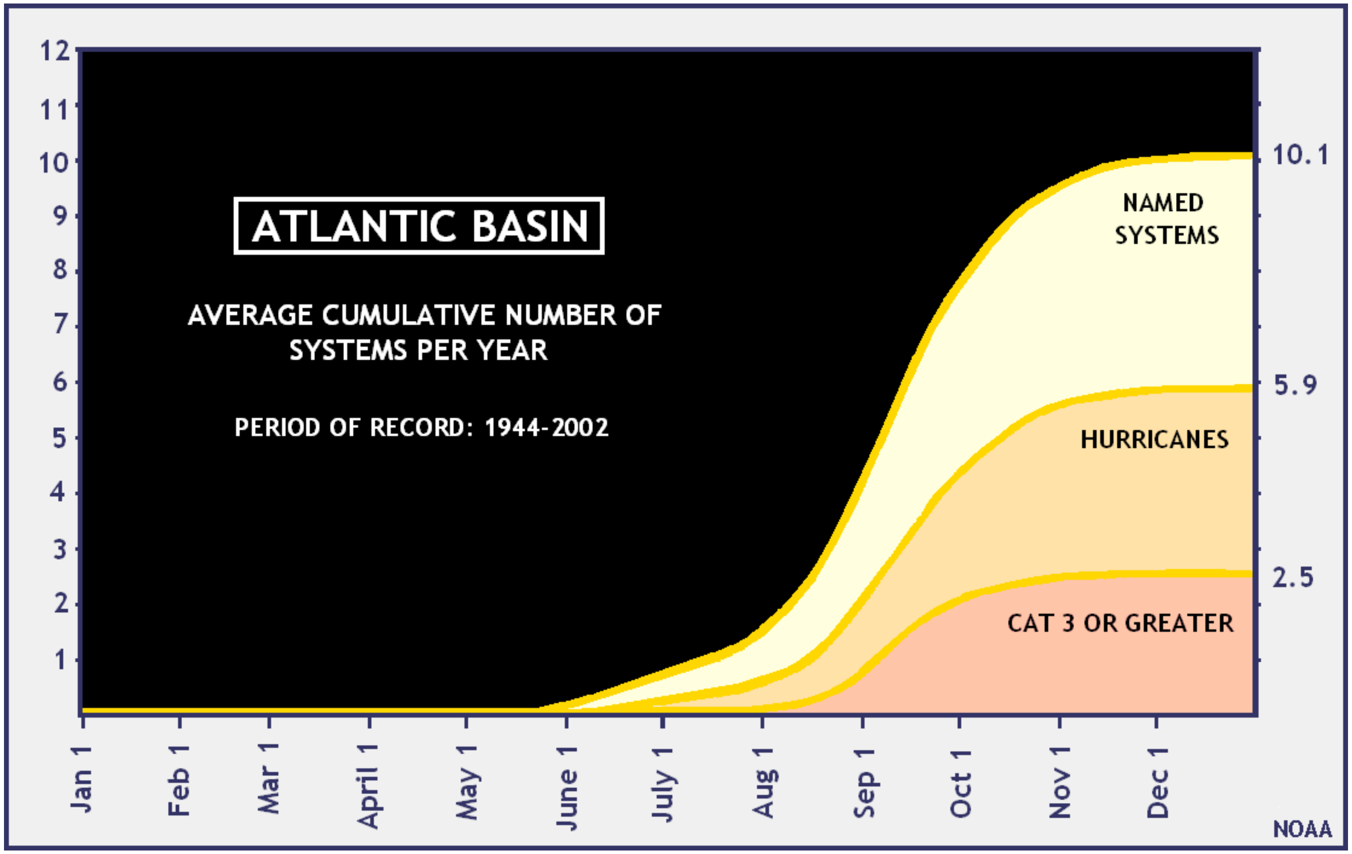
Future Natural Hazards

The major earthquakes will spawn ~10 damaging tsunamis in the next decade



Future Natural Hazards

Over 100 extreme weather events will menace the Atlantic in the next decade



NRC Decadal Survey Key Questions

- Will there be catastrophic collapse of the major ice sheets, including Greenland and West Antarctic and, if so, how rapidly will this occur? What will be the time patterns of sea level rise as a result?

- Will droughts become more widespread in the western U.S., Australia, and Sub Saharan Africa? How will this affect the patterns of wildfires? How will reduced amounts of snowfall change the needs for water storage?

- How will continuing economic development affect the production of air pollutants, and how will these pollutants be transported across oceans and continents? How are these pollutants transformed during the transport process?

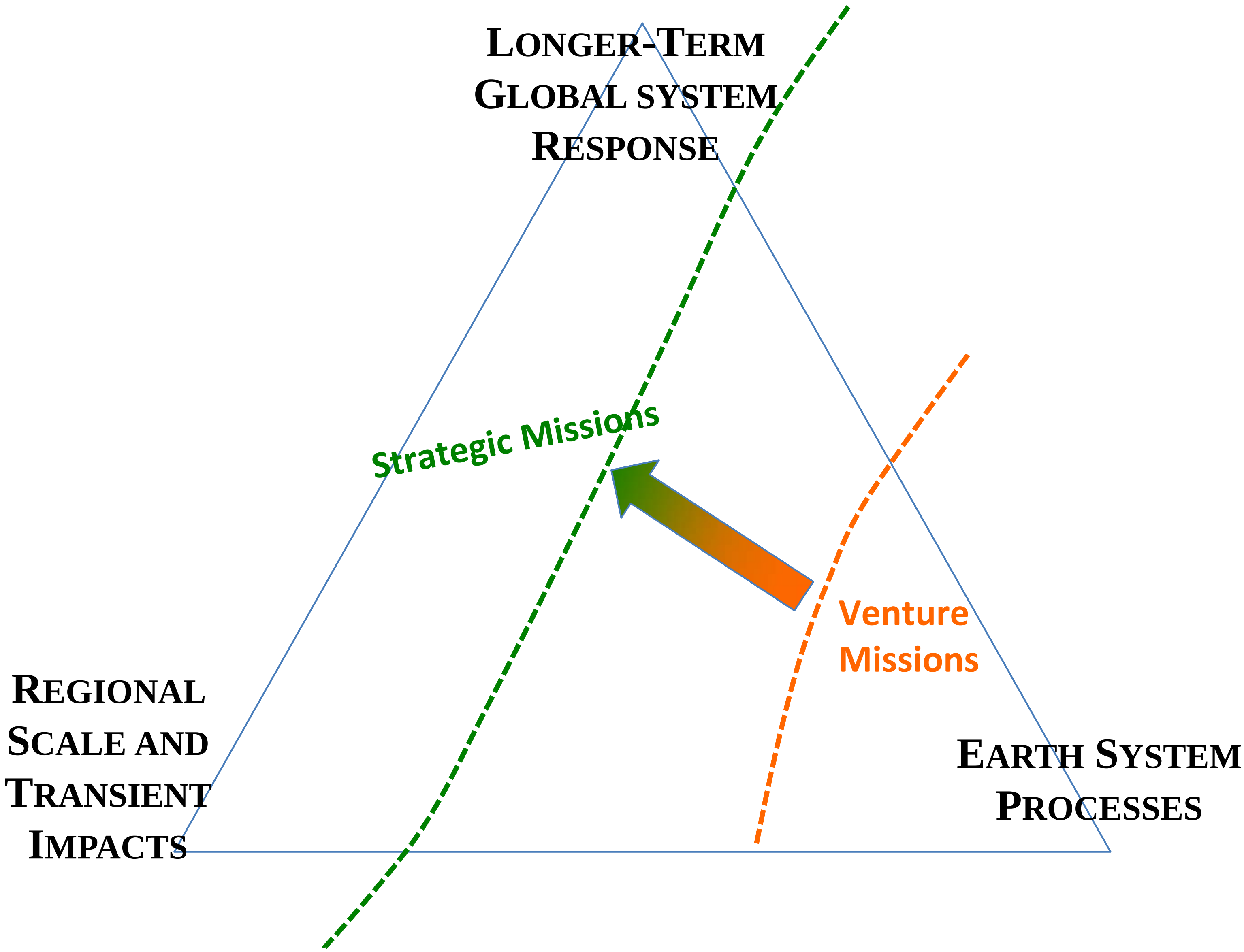
NRC Decadal Survey Key Questions (cont.)

- How will coastal and ocean ecosystems respond to changes in physical forcing, particularly those subject to intense human harvesting? How will the boreal forest shift as temperature and precipitation change at high latitudes? What will be the impacts on animal migration patterns and invasive species?

- Will previously-rare diseases become common? How will mosquito-borne viruses spread with changes in rainfall and drought? Can we better predict the outbreak of avian flu? What are the health impacts of an expanded "Ozone Hole" that could result from a cooling of the stratosphere, which would be associated with climate change?

- Will tropical cyclones and heat waves become more frequent and more intense? Are major fault systems nearing release of stress via strong earthquakes?

Earth Science Measurement Paradigm



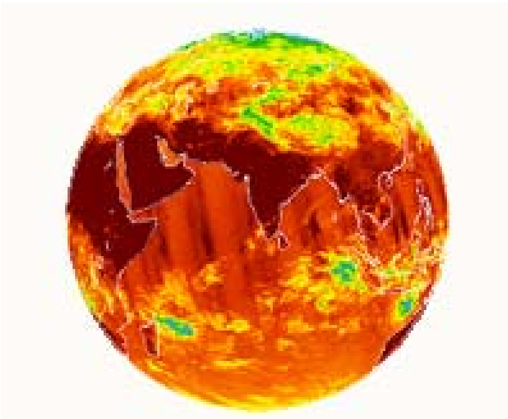
Measurement Needs

Science Target	Measurement/Observation
Processes effecting Human Health and Security:	Spectrally resolved radiometry of ozone processes; microwave, radar, hyperspectral obs. of heat stress and drought; multispectral imager of toxic and air pollution releases and waterborne infectious disease; hyperspectral obs. of vector-borne disease factors
Processes effecting Land-Use Change, Ecosystem Dynamics, and Biodiversity	Hyperspectral obs. of ecosystem function, coastal dynamics and global ocean productivity; lidar and radar obs. of ecosystem function and carbon budget
Processes effecting Solid Earth Hazards, Natural Resources and Dynamics	InSAR for surface deformation; Hyperspectral Vis/IR/TIR obs. for surface composition and resource mapping; Imaging lidar for high resolution topography; optical ranging for water storage, altimetry for seafloor topography
Processes effecting Climate Variability and Change	Hyperspectral and polarimetric obs. of clouds and aerosols; short and longwave spectrometry of surface heat flow; InSAR for ice sheet movement; Radar altimeter and scatterometer for ocean circulation and heat storage; IR and MW sounders for greenhouse gases
Processes effecting Weather	Lidar and scatterometer obs. of winds; MW spectrometer, radar and GPS for temperature, humidity and precipitation; Hyperspectral and polarimetric obs. of clouds and aerosols
Processes effecting Water Resources and the Global Hydrologic Cycle	Radar and radiometer obs. for soil moisture; altimetry for surface water levels; SAR and MW altimetry for snow-water; microwave obs. for water vapor; lidar, InSAR and laser ranging for sea ice and ground water storage

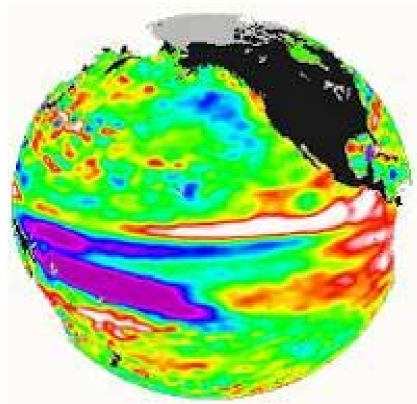
The U.S. has a highly capable Earth observing system

- NASA and NOAA have more than 20 spacecraft and over 100 instruments currently observing the Earth system (mostly in LEO)
- NRC notes that this capability will decrease dramatically over next ten years, even if U.S. implements NRC Decadal Survey recommendations

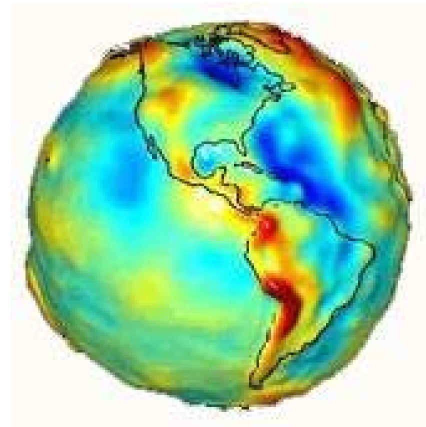
Satellites Provide New Earth Views



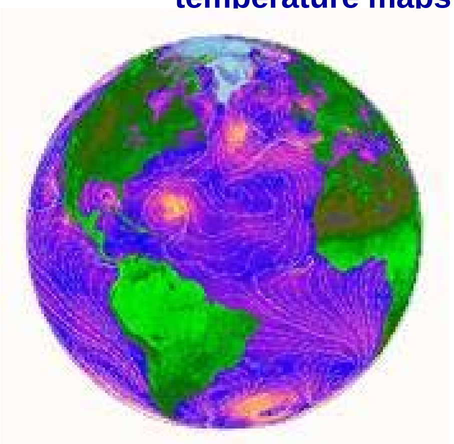
Atmospheric Infrared Sounder (AIRS) provides monthly global temperature maps



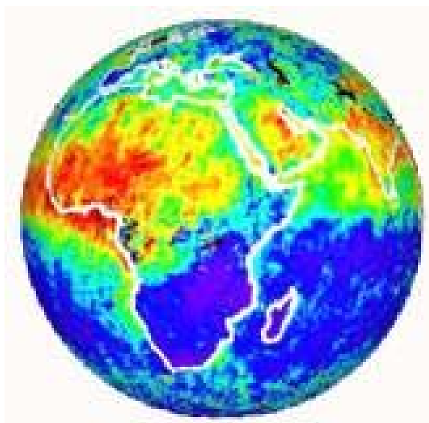
Jason provides global sea surface height maps every 10 days



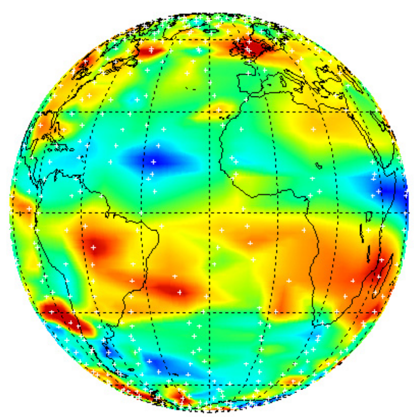
Gravity Recovery and Climate Experiment (GRACE) provides monthly maps of Earth's gravity



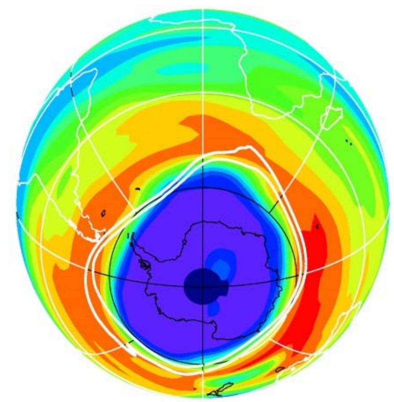
QuikSCAT provides near global (90%) ocean surface wind maps every 24 hours



Multi-angle Imaging Spectro Radiometer (MISR) provides monthly global aerosol maps



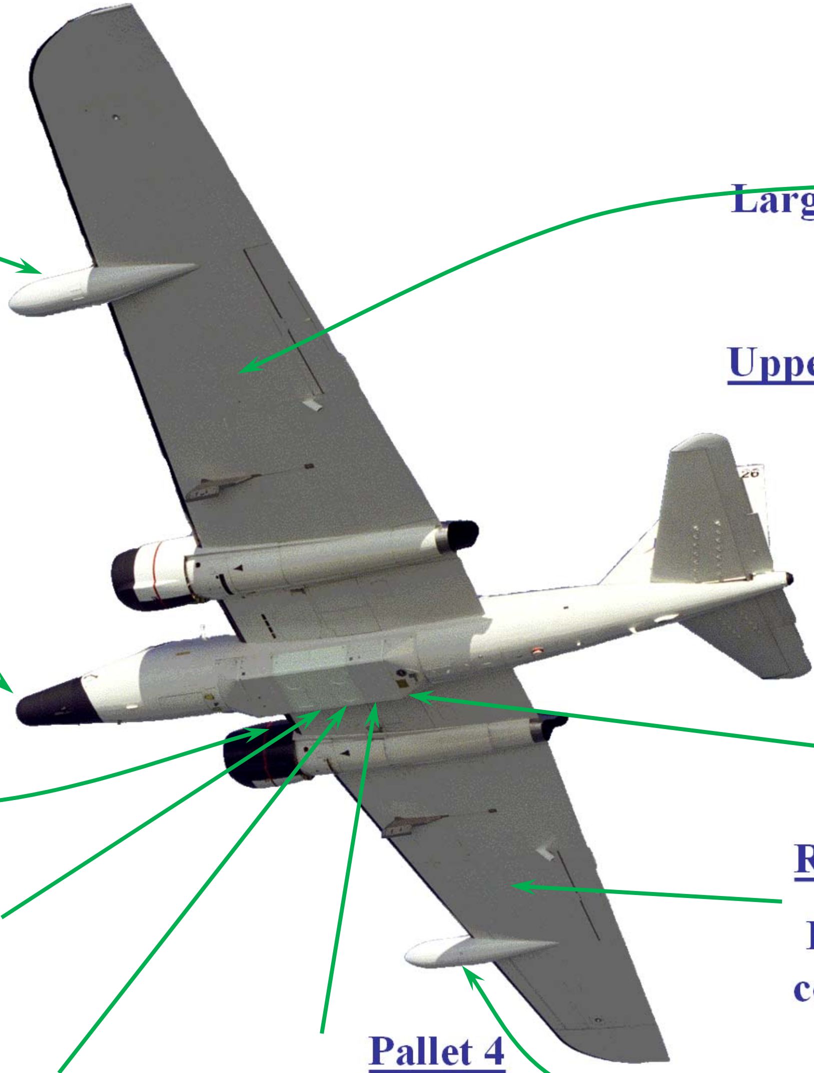
Tropospheric Emission Spectrometer (TES) provides monthly global maps of Ozone



Microwave Limb Sounder (MLS) provides daily maps of stratospheric chemistry

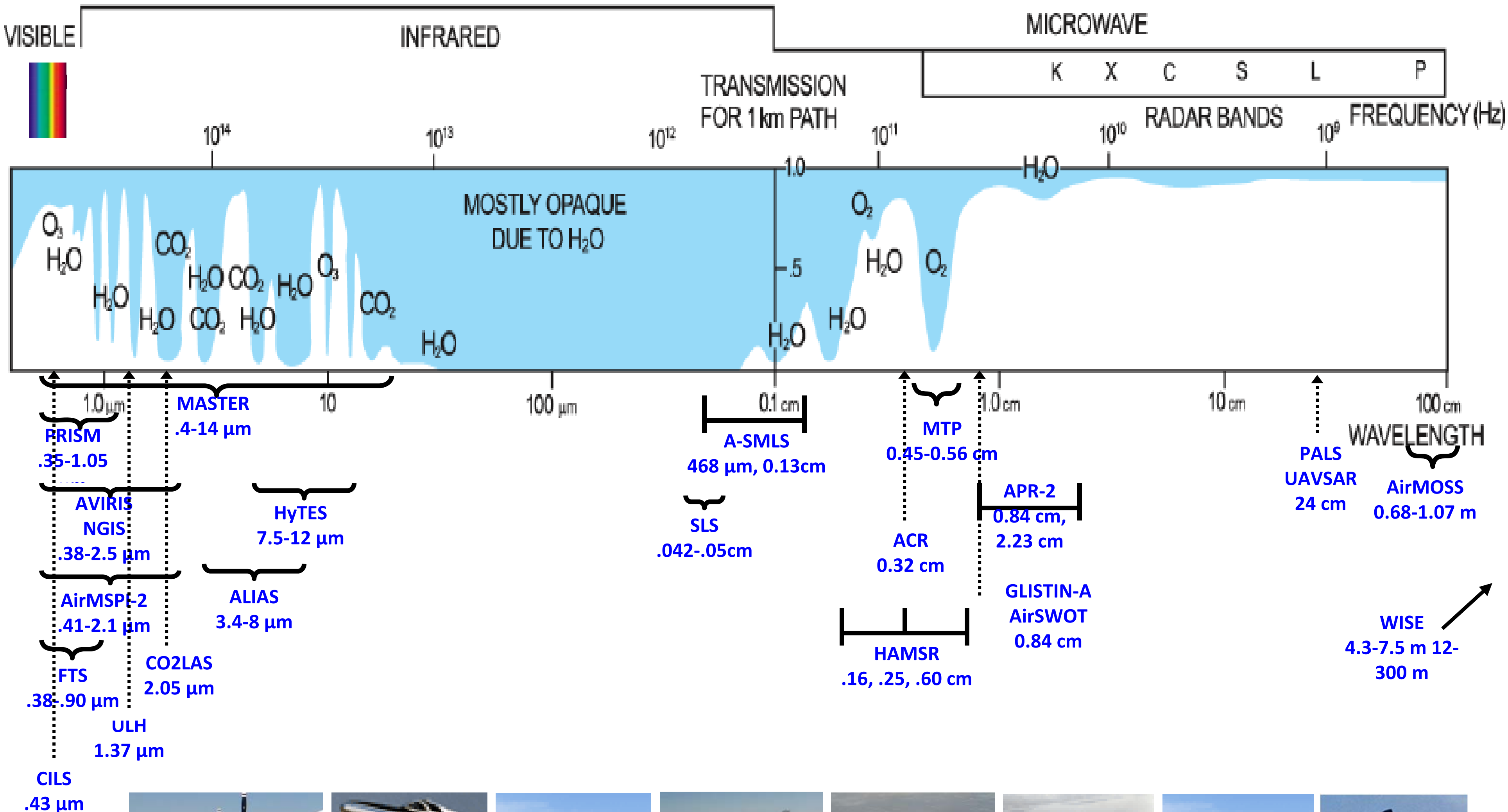
Aircraft Provide Critical Complement to Satellites

Aircraft Payload Example: CRYSTAL-FACE WB-57



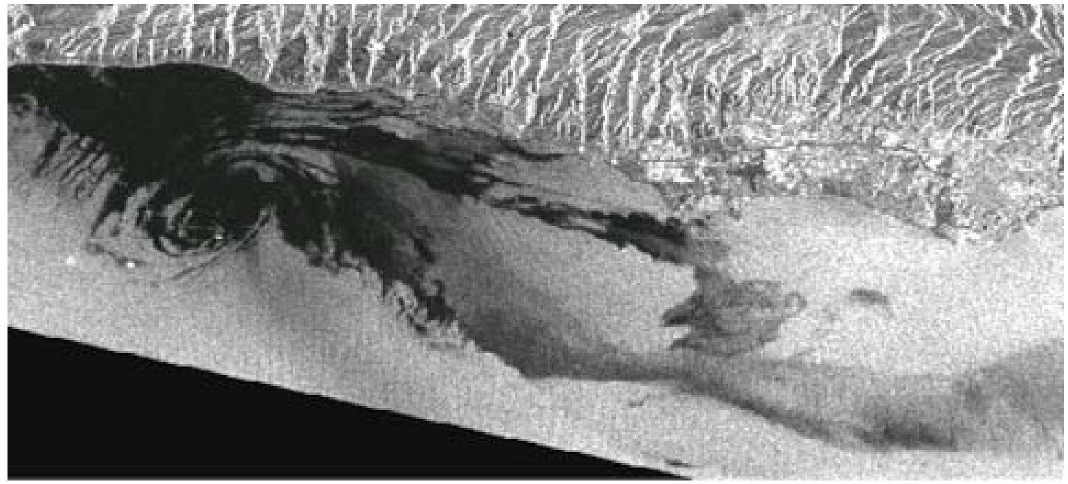
Intensive Effort Required for Aircraft Science Investigations

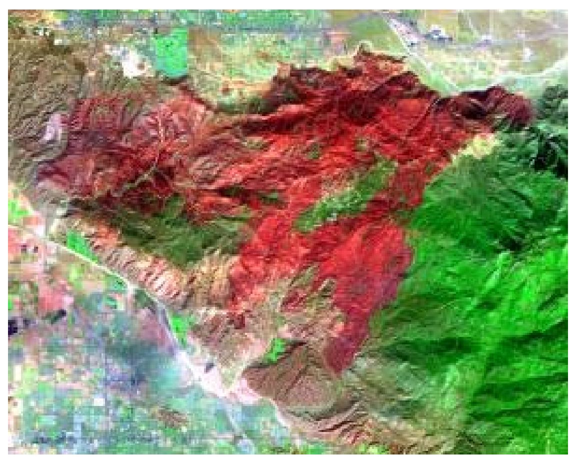
Airborne Instruments Observing Frequencies

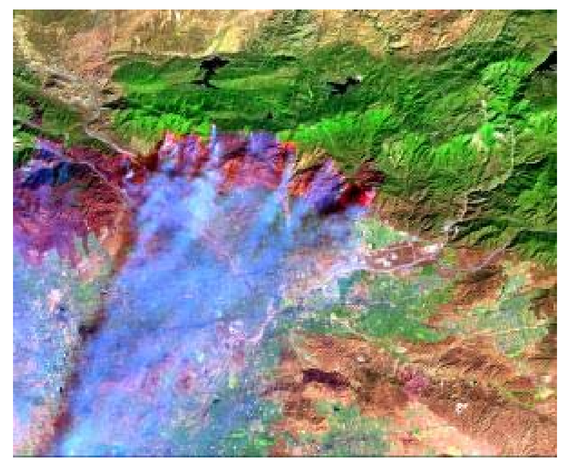


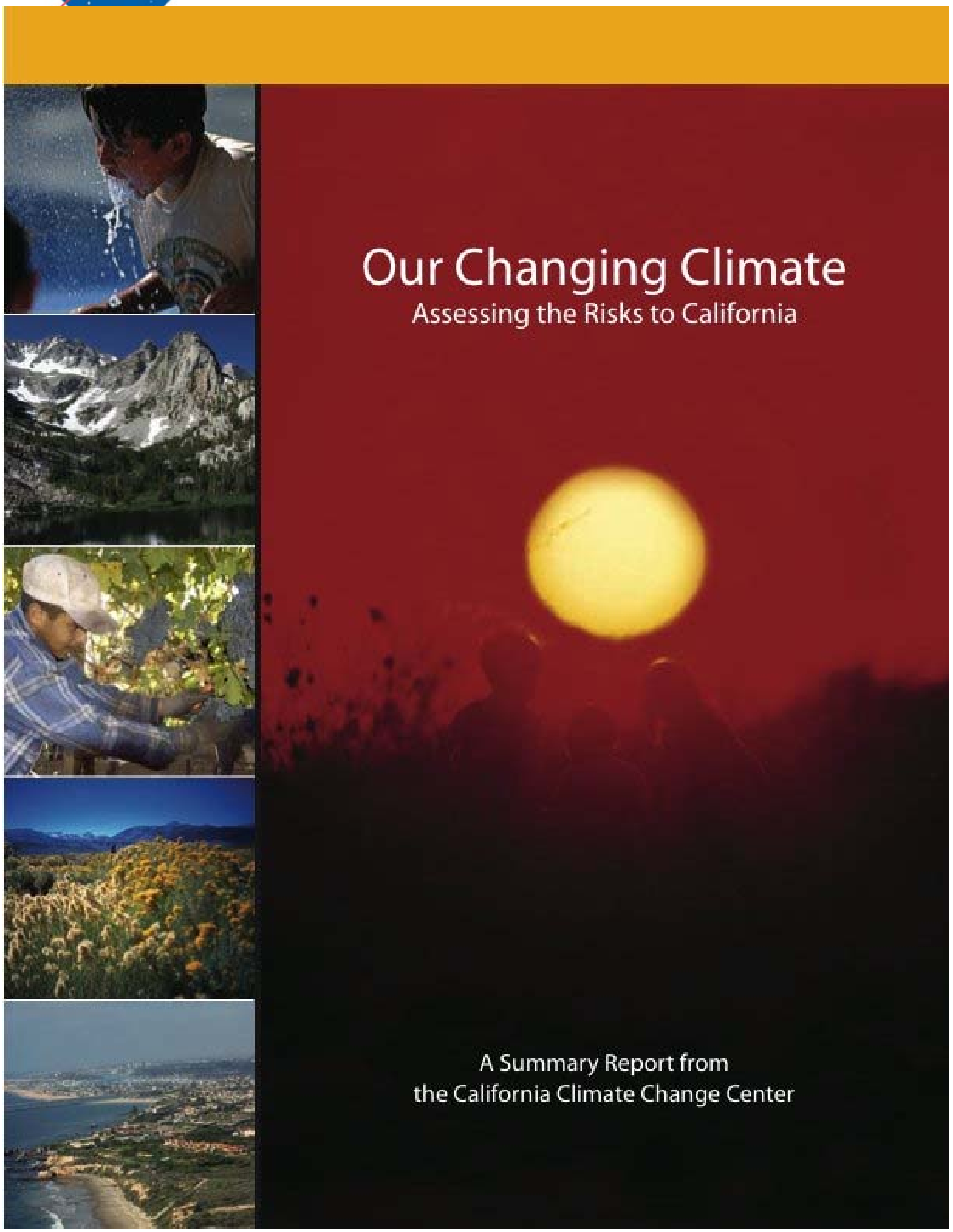
Increasing Focus on Regional Scale

Increasing number of passive and active instruments can resolve local and regional scale processes









CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

Climate Action Team Report to
Governor Schwarzenegger and the Legislature

CALIFORNIA
Climate
ACTION TEAM

March 2006

Our Changing Regional Climate
(Assessment Priorities)

Public Health
- Air Quality
- Heat

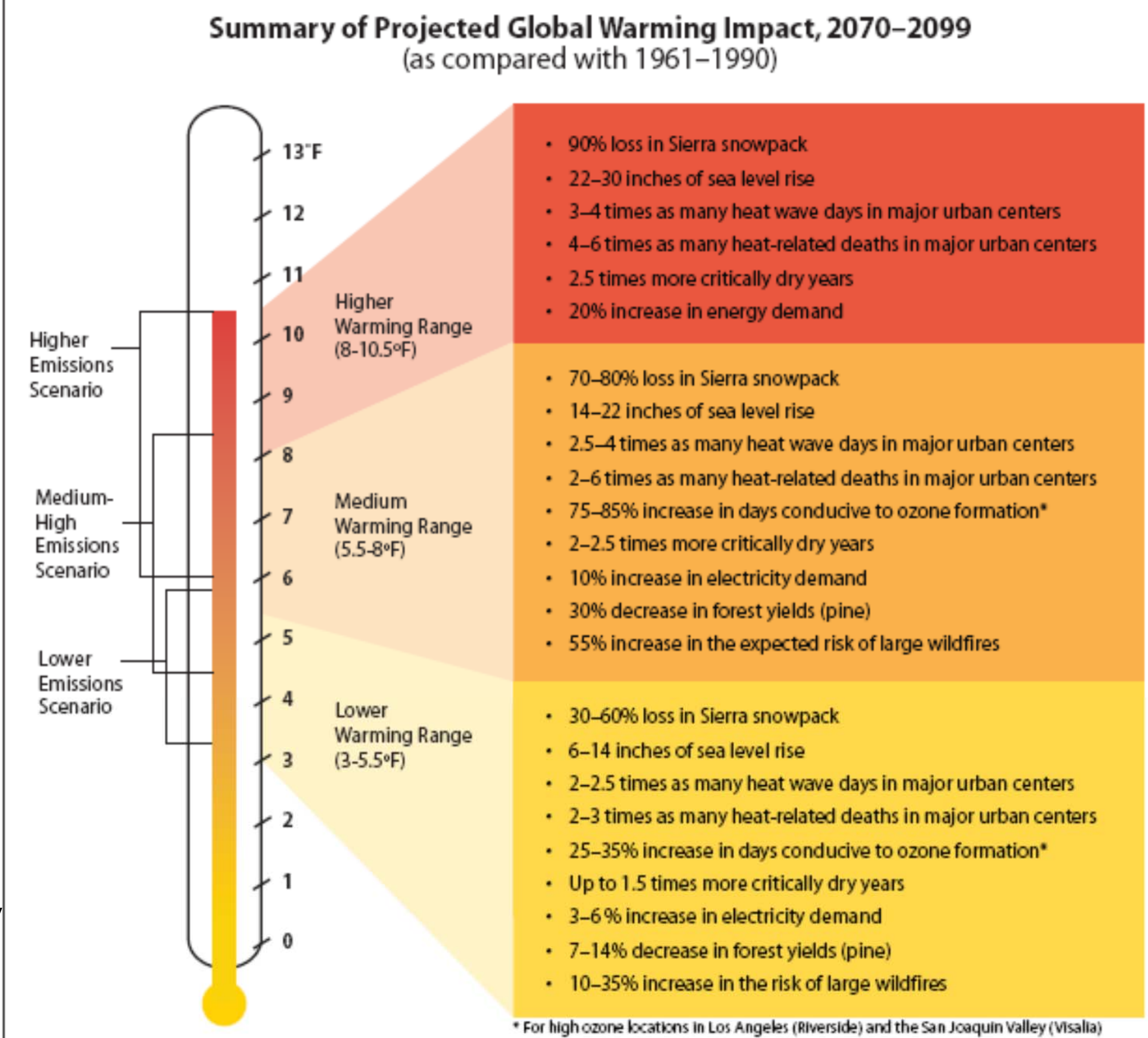
Agriculture
- Temperature increases
- Pests / pathogens
- Stresses

Rising Sea Level
- Coastal Flooding / Levees
- Shrinking beaches

Water Resources
- Sierra Snowpack
- Water supply
- Hydropower
- Winter Recreation

Forests & Landscapes
- Wildfires
- Invasive species
- Shifting vegetation
- Declining forest productivity

Carbon Sources and Sinks



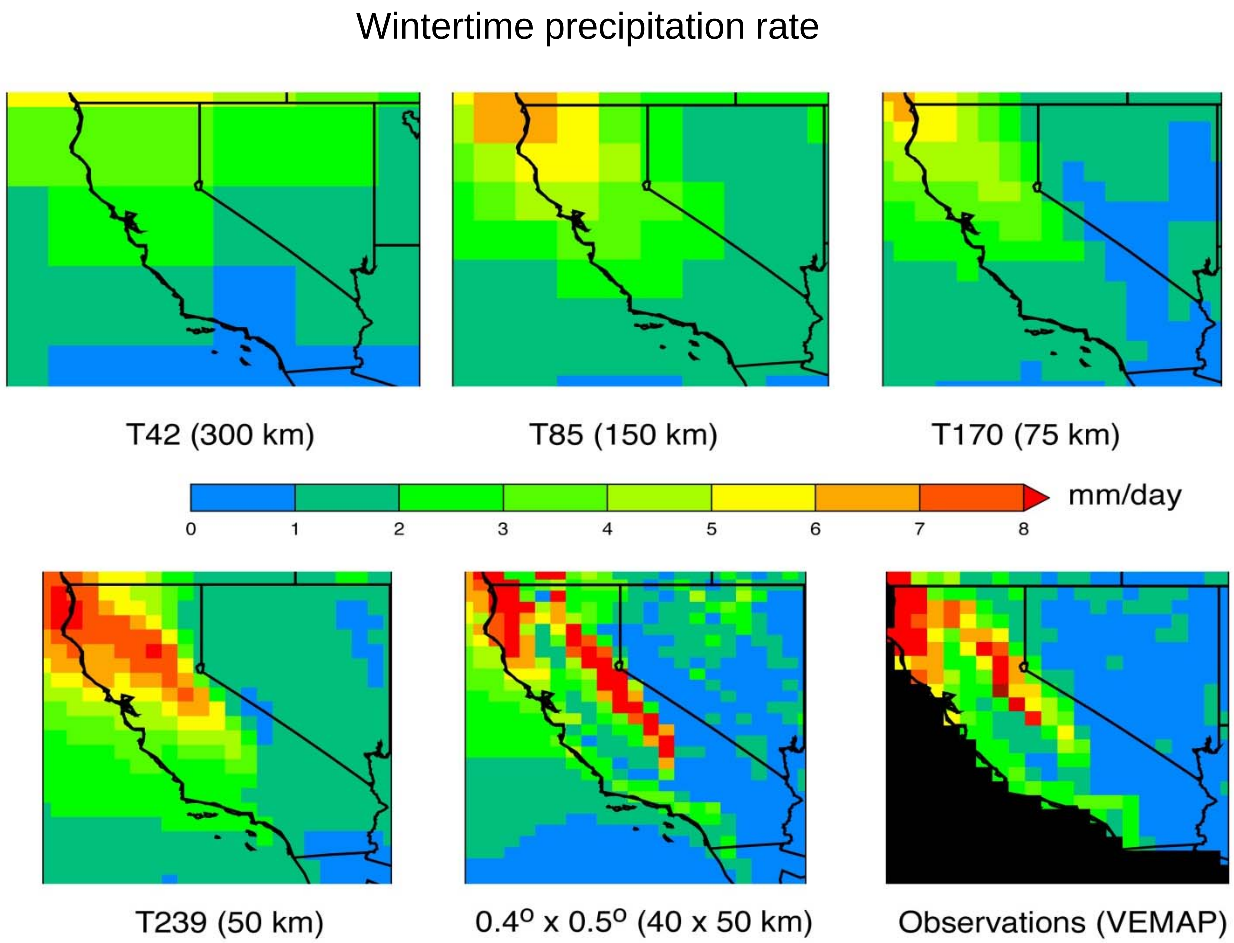
Science Challenges Require High Spatial and Temporal Measurements and Models

GCM grid ~ 150-300 km

RCM grid ~ 10-100 km

Aircraft & Satellite resolution

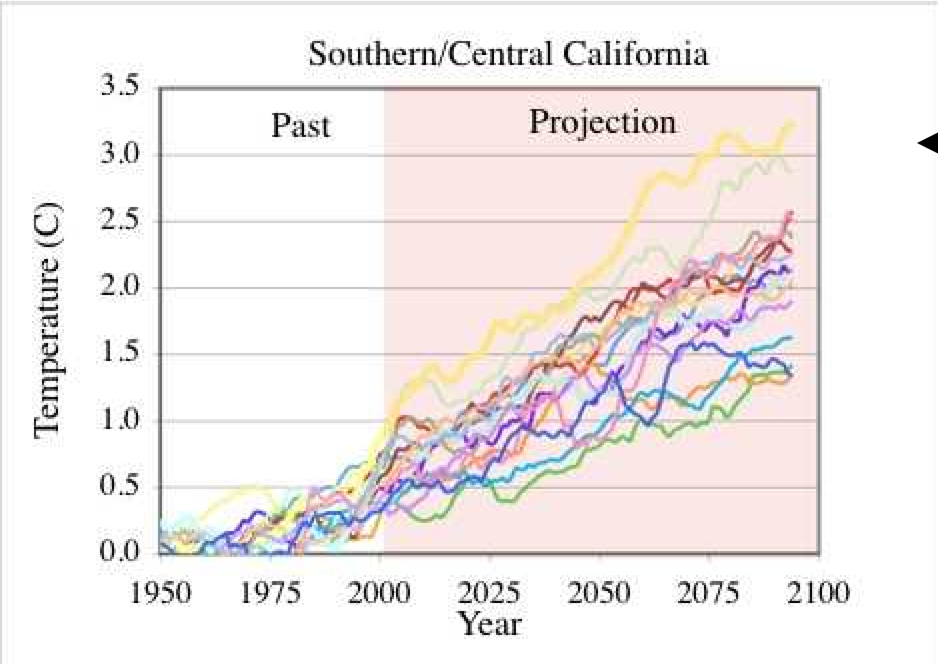
~ 0.1 – 100 km



Source, Duffy, LLNL

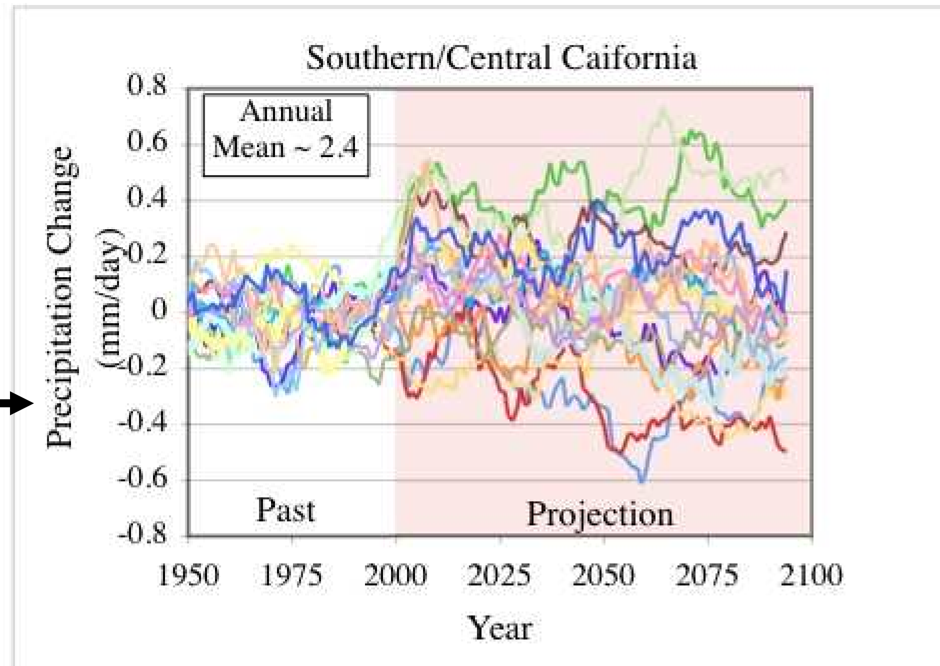
Regional Predictions Highly Uncertain

IPCC, 4th (newest) Assessment Report



Systematic Warming
1.5 - 3.0 C
2.7 - 5.4 F
Relatively Agreeable

+/- 20%
Much Less Certain

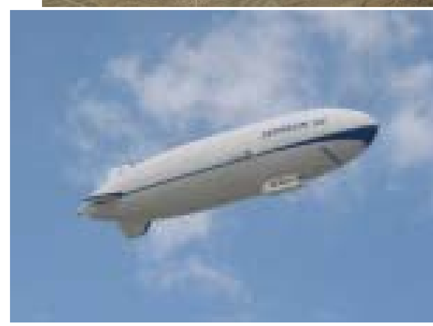


Courtesy of Duane Waliser

Comprehensive Observation Strategy Needed for Regional

Airborne

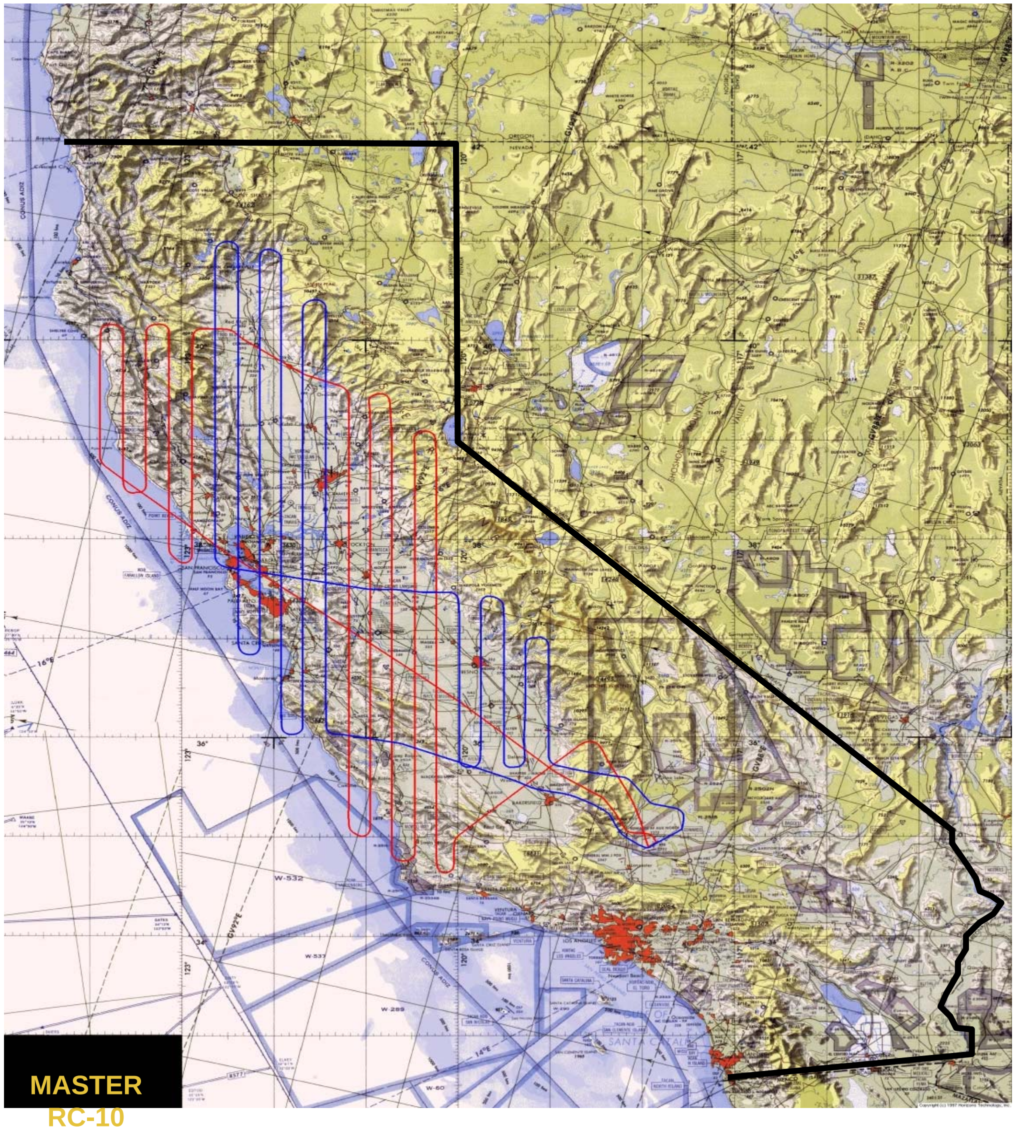
Conventional Aircraft
Unmanned Aerial Systems (UAS)
Airships
Balloons



Space based

- Low Earth Orbit (LEO)
  - * Single spacecraft
  - * LEO Constellation
- Medium Earth Orbit (MEO)
- Geostationary Orbit (GEO)
- Langrange Point (L1)

Aircraft Enable Flexible Observation Strategy



- Significant trade-offs between spatial and temporal coverage for given number of flight hours

Red: Flight 03-951
8 August 2003

Blue: Flight 03-952
11 August 2003

(7 Flight hours each)

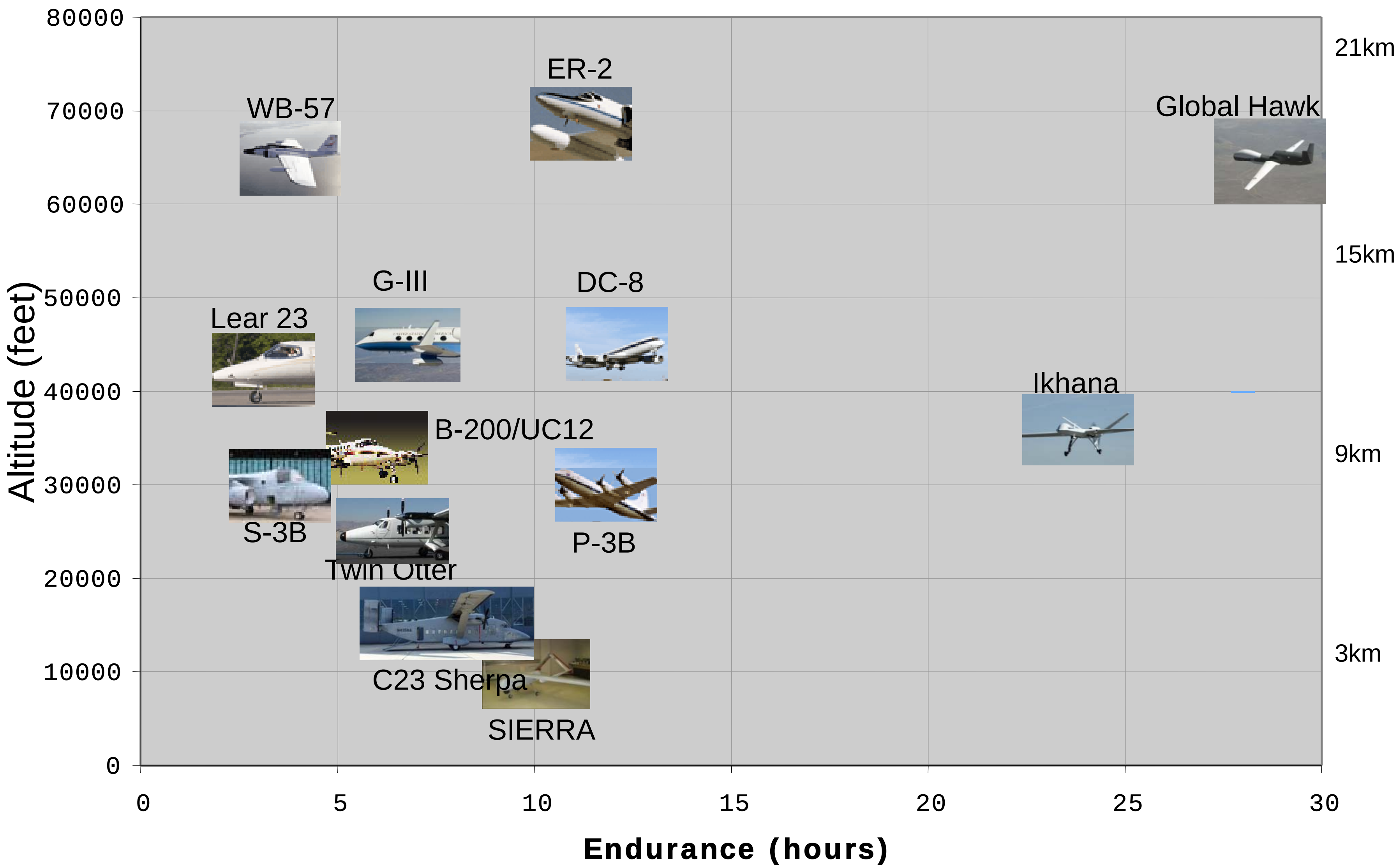
Flight Line Spacing:

12nm / 23km

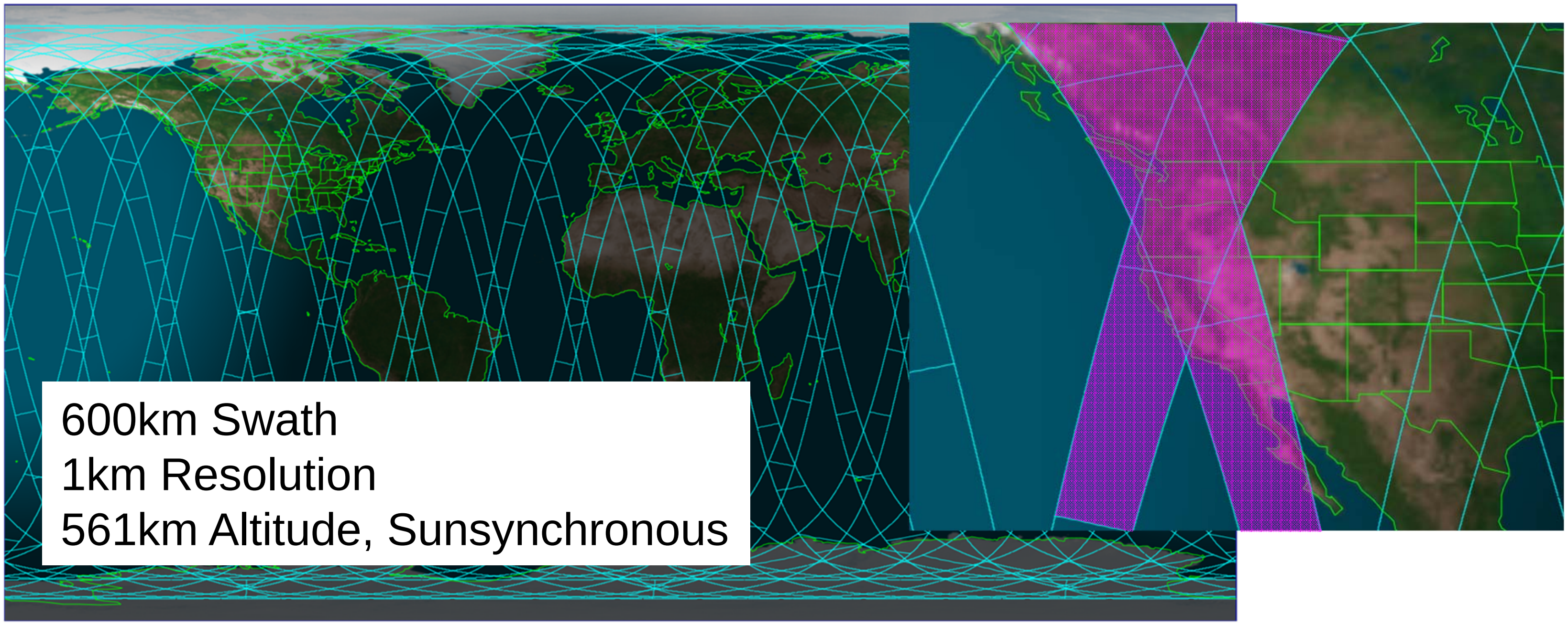
5 flights needed to fully cover state

Total Flight Time: 35 hours

NASA ASP Platform Capabilities



Low Earth Orbit (LEO) Trades Temporal for Spatial Coverage



At least once-daily coverage of all of California (twice daily for some parts of northern California)
Daily coverage of US pacific cost, and California Baja
Daily coverage of nearly the entire US east cost
Sparse global coverage including:

- UK, France, Spain, Japan, China, Russia

Complete Daily coverage of polar regions between 70° and 84° Latitude
Non-sun synchronous orbits open up more coverage possibilities

The NASA LEO Orbiting Carbon Observatory (OCO-2) Mission will travel over California 6 times every 16 days

The green lines represent OCO flight paths over California and neighboring land and ocean regions

These flight paths are repeated every 16 days

- ~2 weeks between exact revisits
- 5 days between nearest neighbor paths

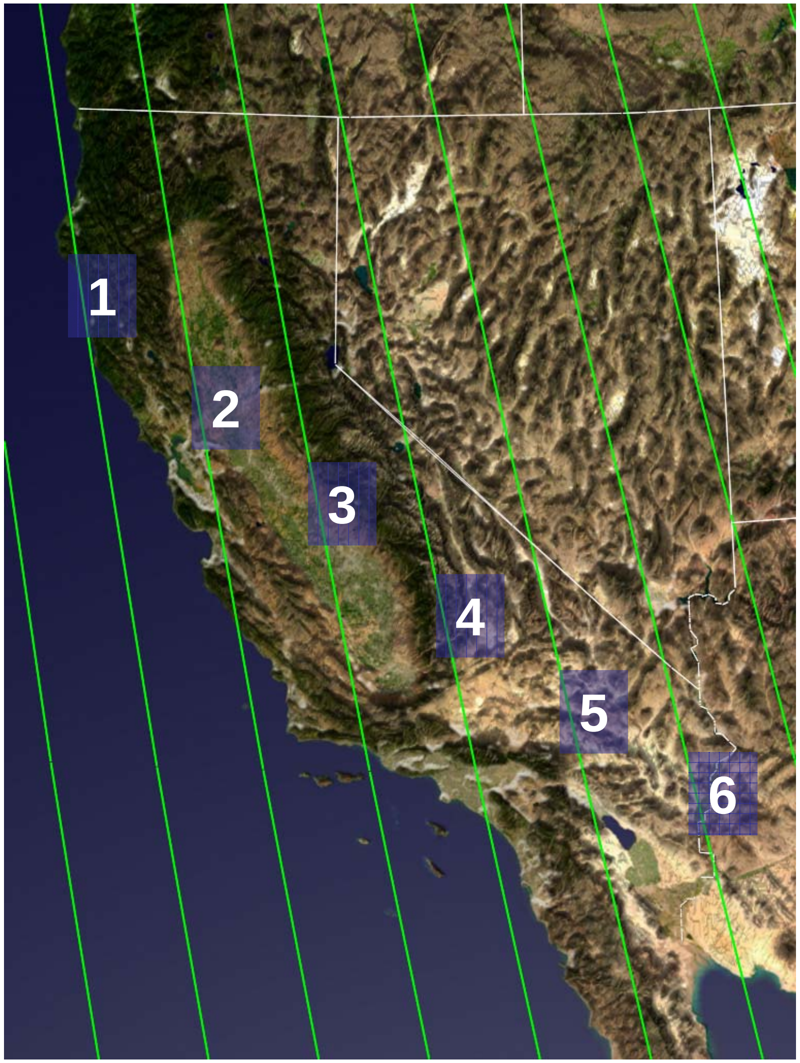
OCO makes more than 20,000 measurements over California every month

- Clouds and aerosols will prevent many measurements from sampling all the way to the surface

Measurements from flight paths over the land and ocean regions surrounding California can establish the net flow of CO_2 emissions in and out of the state

In its standard survey mode, OCO will be able to detect X_{CO2} variations as small a 1 ppm out of 380 ppm (0.3%) in a single sounding over bright surfaces

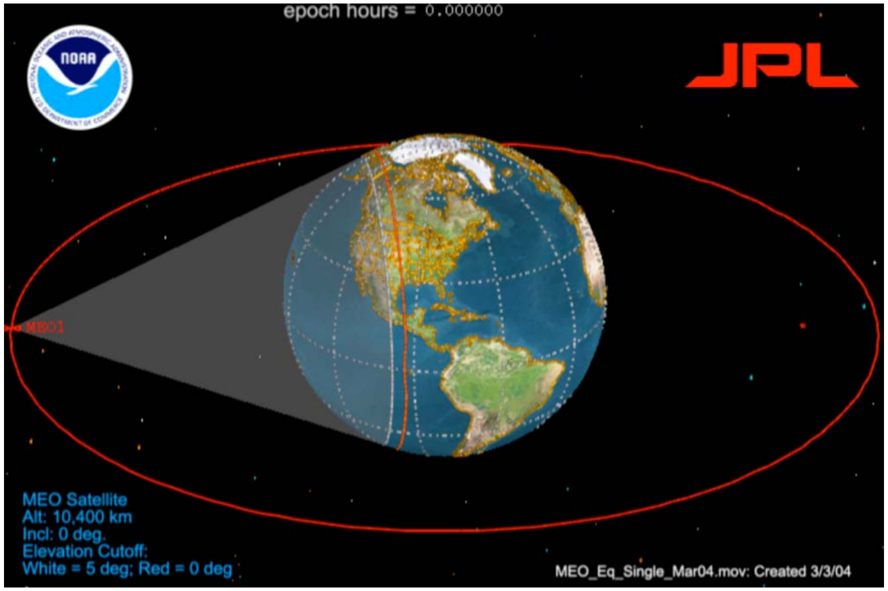
- This corresponds to CO2 sources produced by burning as little as 7500 gallons of gasoline or diesel (<2 tanker trucks)
- OCO should easily detect heavy traffic patterns over major urban areas

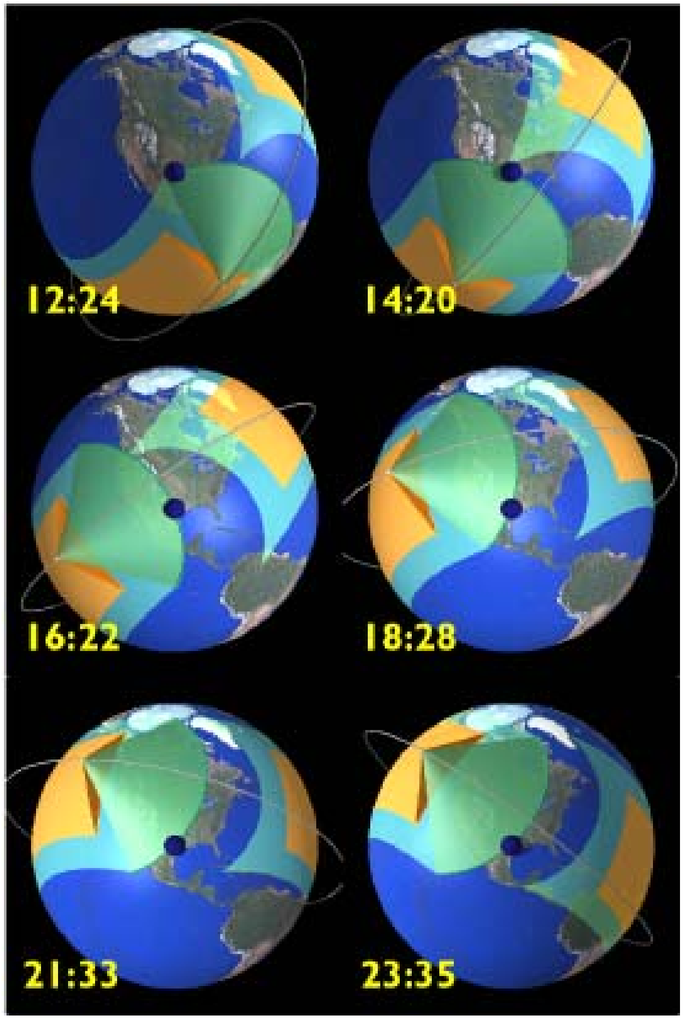


Medium Earth Orbit (MEO) provides Spatial – Temporal Compromise

- MEO altitudes are between ~1500 – 35000 km

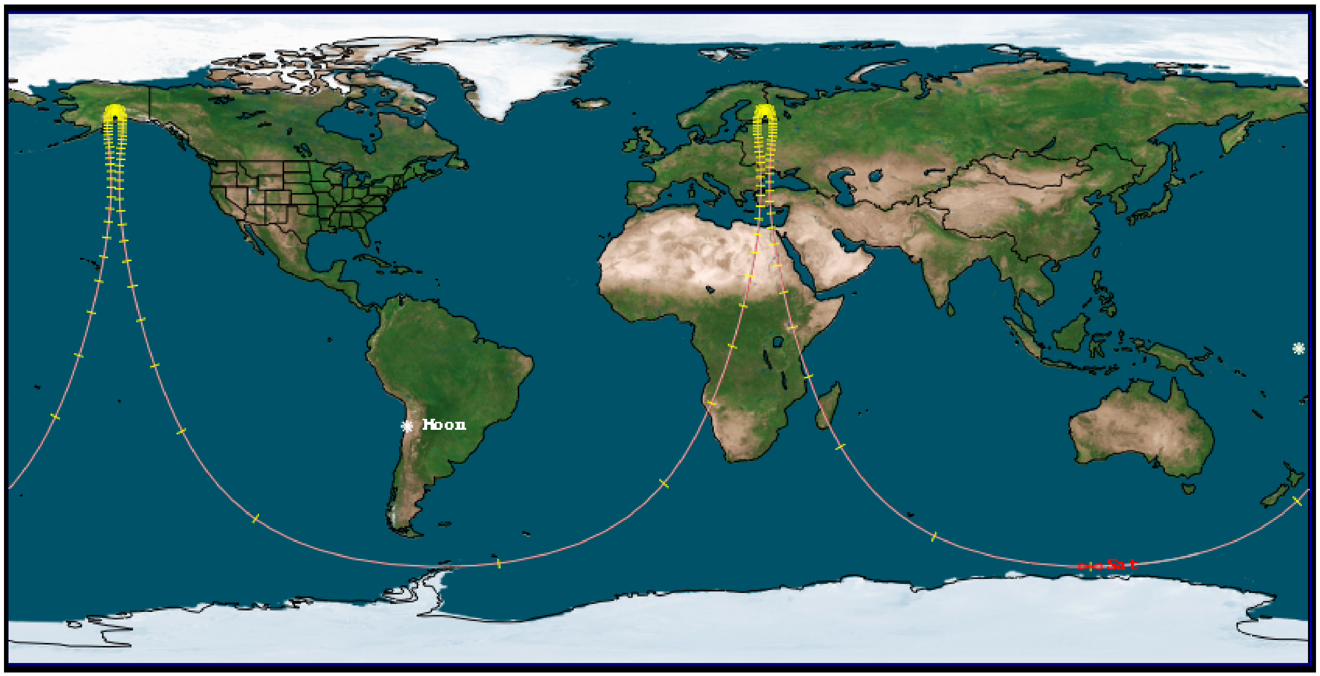
•Combining MEO orbit with wide swath (~1000 km) instrument can provide up to 6 passes over California per day





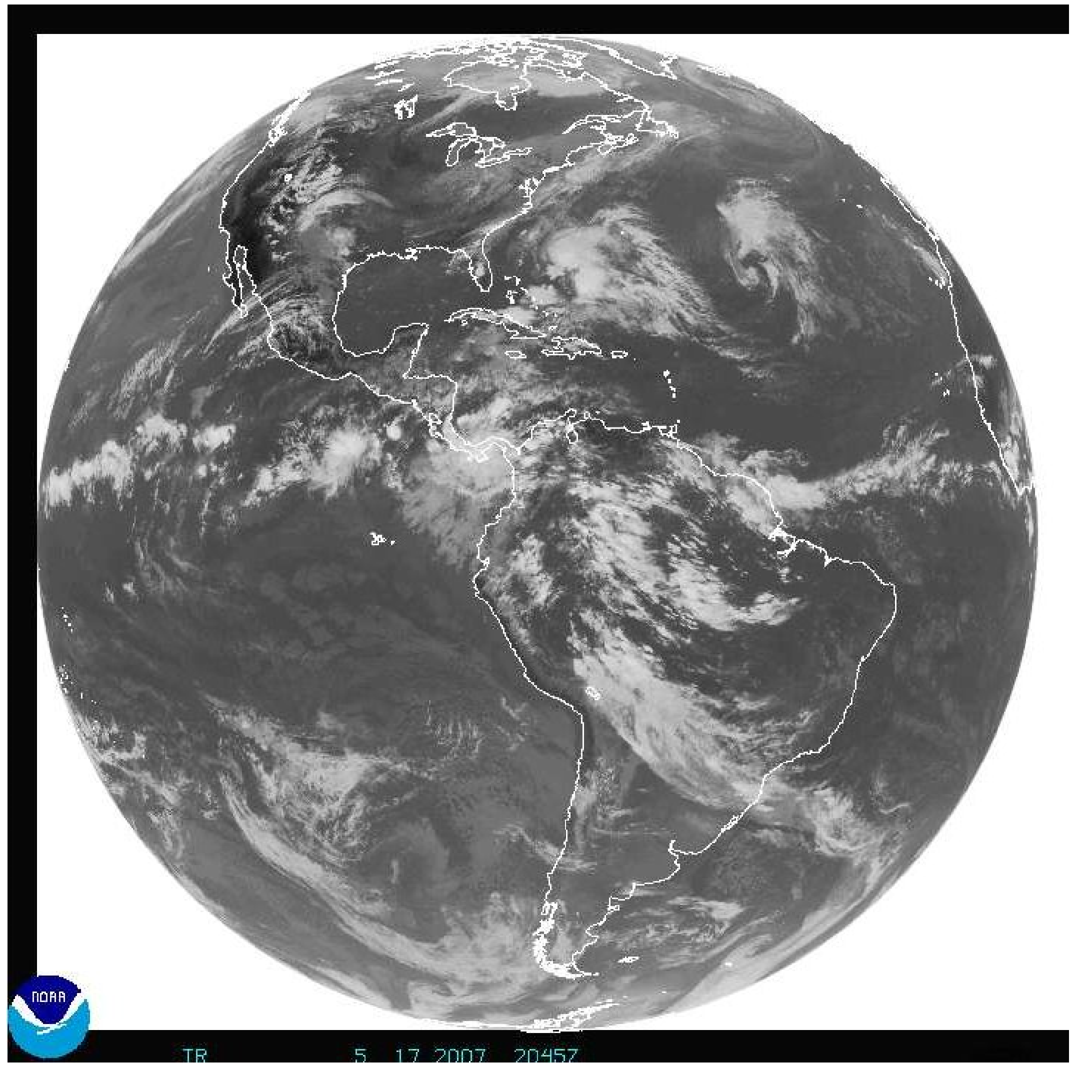
Molniya Orbit Provides Longer Regional View

A highly elliptic orbit with 63.4° inclination and ~12 hour orbital period. Satellite spends ~ half day over a designated area of the earth. Orbital altitude is near 40,000 km.



Geosynchronous Orbit (GEO) Provides Constant View of Full Disk

- GEO altitude is ~35,000 km
- Full Disk GOES Image (+/- 65°)
- Provides ability to stare at given region; provides high temporal resolution
- Ideal for tracking fast moving events such as forest fires

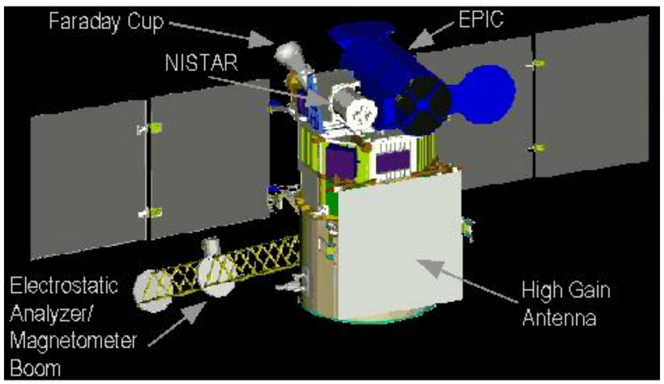


Langrange point (L1) provides full, daytime view of Earth

• L1 Orbit is ~1.5 million km from Earth; undergoes 4-15 degree Lissajous orbit

- DSCOVR was planned to provide first Earth observations from L1 (e.g. O3, aerosols, water)

- Federal/Industrial partnership being studied for DSCOVR



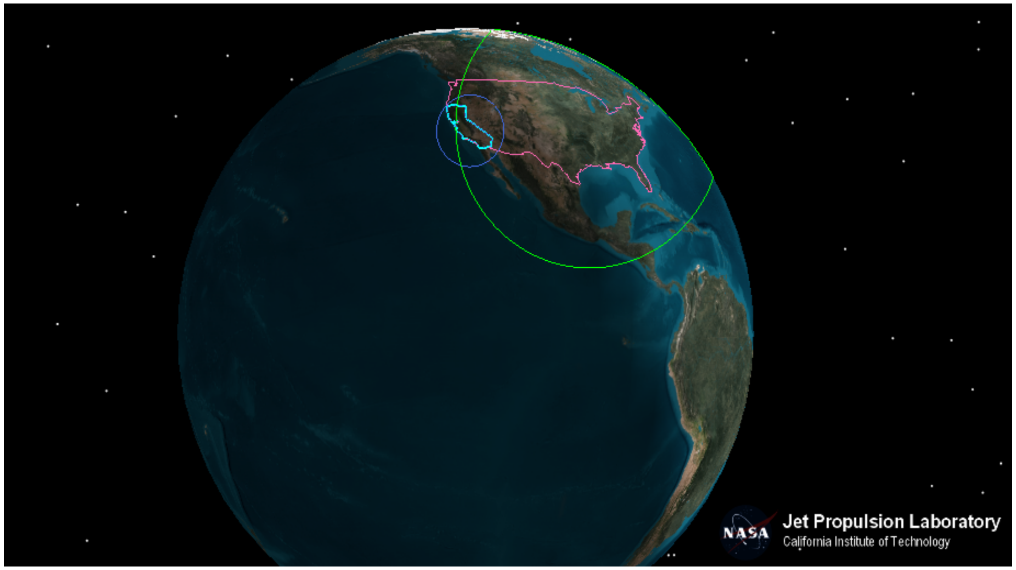
DSCOVR's View

Simulated nearly instantaneous DSCOVR view

Francisco P. J. Valero

Comparison of Earth Views from GEO and L1

•Optics at GEO. The blue circle represents a 1 degree half angle that covers California and the green circle represents a 4 degree half angle to cover the continental US.



• Optics at L1. The red circle represents a 0.1 degree half angle to cover California.

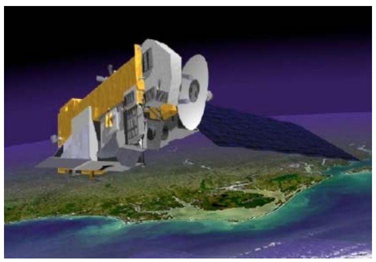
Observational Costs: Rough Order of Magnitude (ROM)*

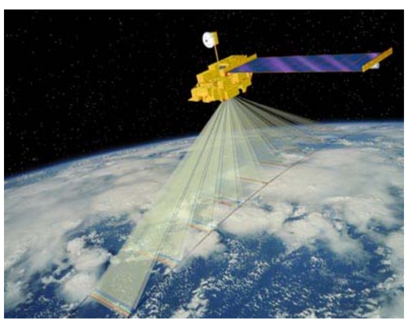
	5 Year Mission	California Coverage (~4x105Km2-hr/day)
Airborne		
Conventional Aircraft ($20M/Year)	$100M	1
Space based		
• Low Earth Orbit (LEO)		
• Single spacecraft	$150-300M	0.08
• Medium Earth Orbit (MEO)	$500M	0.08
• Geostationary Orbit (GEO) or Molniya	$800M	24
(Potential for co-launch on commercial spacecraft)	$300M	
• Langrange Point (L1)	$1000M	12
(DISCOVR refurbishment and commercial partnership)	$200M	

*Assumes creative, cost-effective implementation strategies

Maximizing Observational Assets for Regional Change Requires Clear Science and Application Goals and Detailed System Engineering

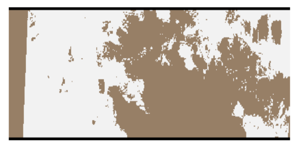
Gas and Particle Concentrations



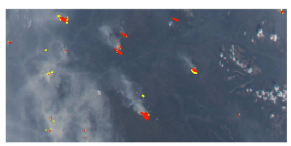


Pollutant Data

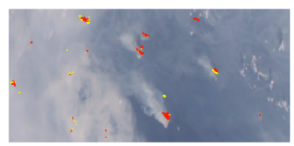
MISR's nadir (AN) camera shows three distinct smoke plumes, plus scattered smoke and clouds, over Alaska and Canada in the summer of 2004.



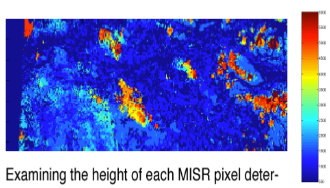
In white, smoke pixels detected by the Support Vector Machine classifier, which uses five of MISR's nine cameras to detect smoke using color, texture, and angular features.



MODIS fire detections overlaid on the MISR image in red (high confidence) and yellow (low confidence).

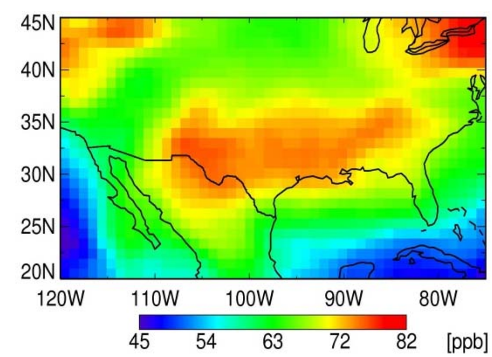


MODIS fire detections overlaid on MISR's 70.5 degree forward view. Objects above the surface shift due to parallax, but smoke is more opaque.



Examining the height of each MISR pixel determined by automatic stereo pattern matching allows us to estimate the injection height of the smoke plumes.

Air Quality Predictions



Airship opportunity: Global carbon monitoring system of fast changing emitters

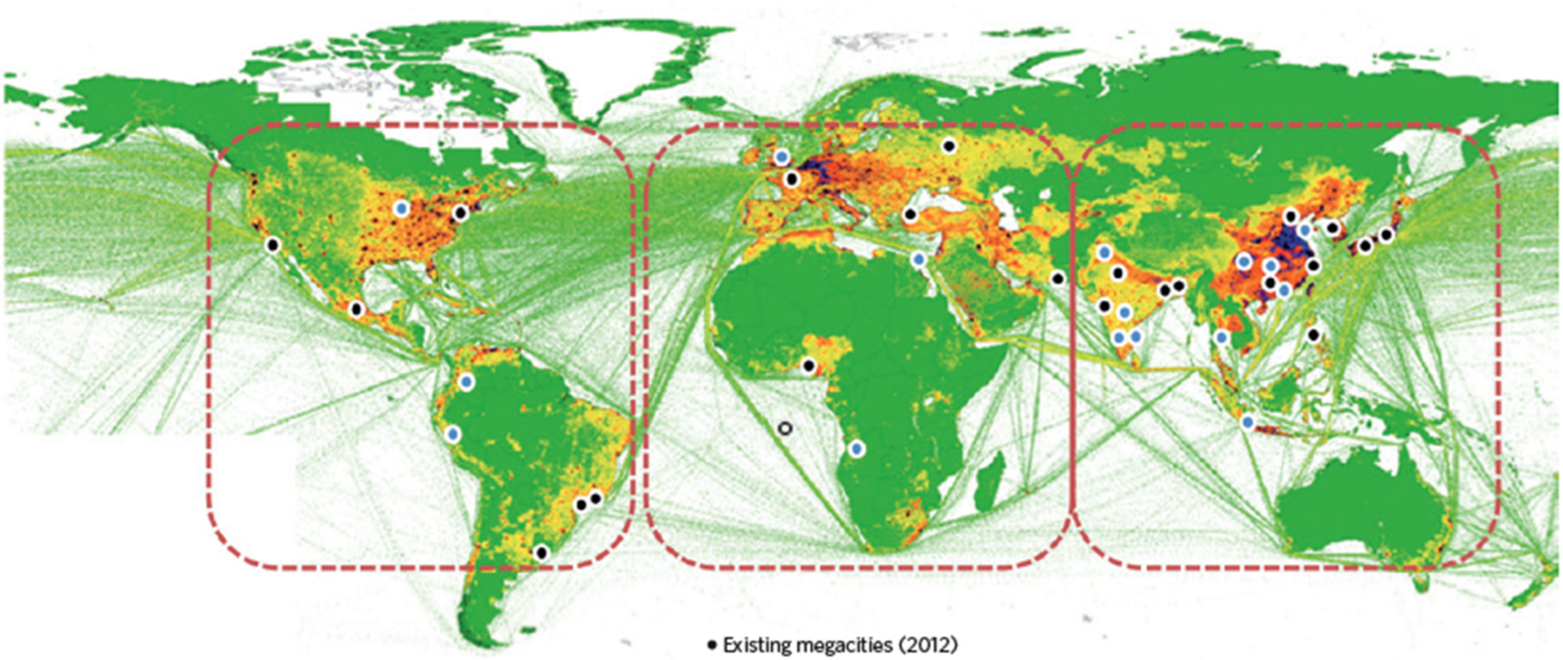
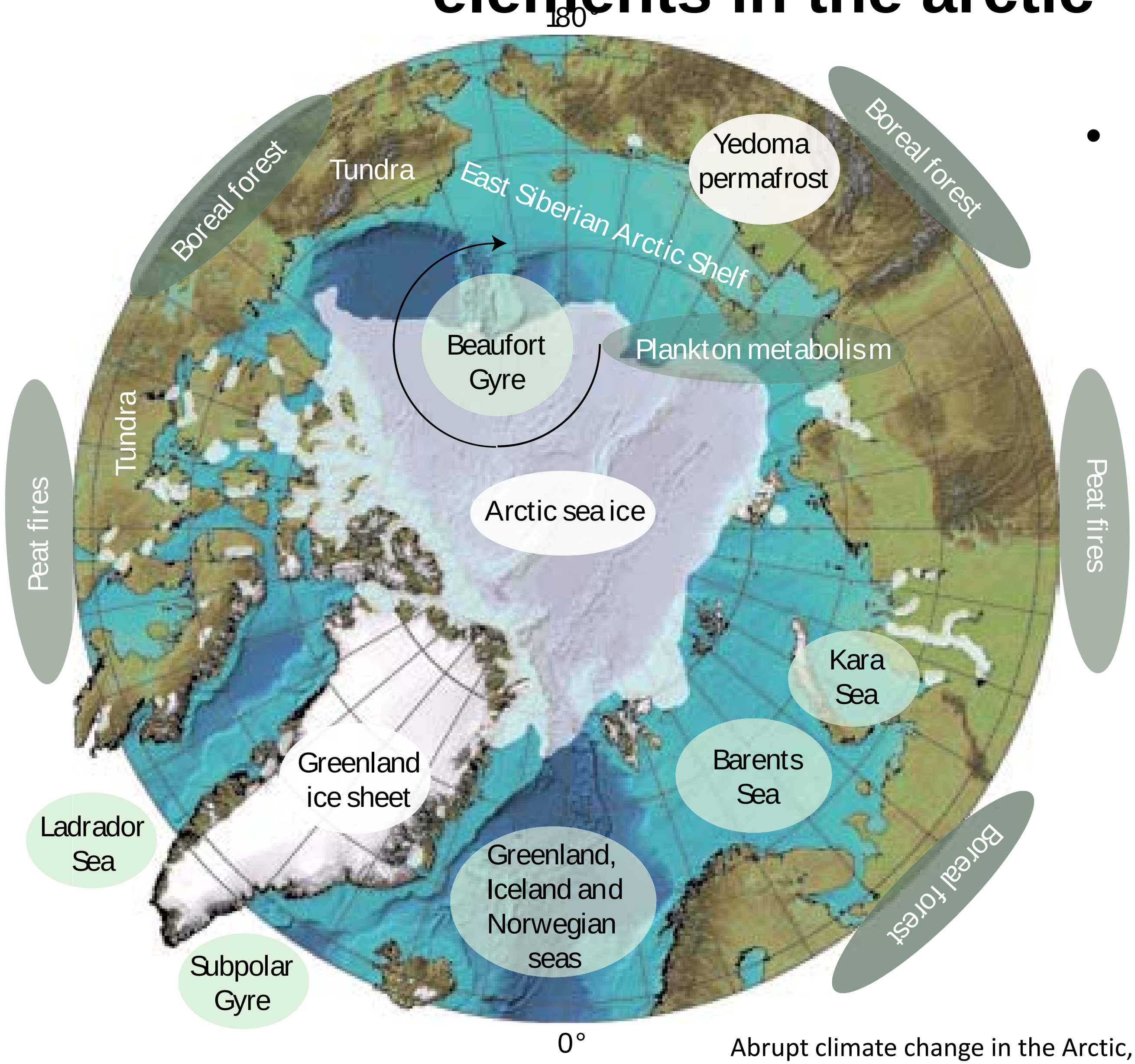


Figure 1 | A strategy for monitoring megacity carbon emissions. A 10-km-resolution gridded inventory of anthropogenic greenhouse-gas emissions in carbon dioxide equivalents indicates the distribution and intensity of emission sources, ranging from 0–55 Mg C per cell per year. Urban areas are indicated in orange, red and black. The darkest areas correspond to the emissions of urban and heavily industrialized areas. The black circles indicate proposed surface measurement networks concentrated within and around the 23 existing megacities. Blue circles indicate the 14 additional megacities projected to exist by 2025 (ref. 17). The dashed rectangles indicate the fields of regard of three remote-sensing instruments that if hosted on commercial communication satellites in geostationary orbit would offer sustained, wall-to-wall measurements of column-averaged carbon dioxide, methane and carbon monoxide mixing ratios several times per day for the vast majority of the Earth's populated areas. With such a system, a typical megacity would be sampled by over 2,500 measurements per day on average. An existing network of surface remote-sensing stations enables calibration of satellite data. Emission map taken from European Commission-Joint Research Council/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR) version 4.0 (http://edgar.jrc.ec.europa.eu) 2009.

Duren, R.M and C.E.Miller (2012), Measuring the Carbon Emissions of Megacities, *Nature Climate Change* 2, 560–562 (2012) doi:10.1038/nclimate1629.

Airship Opportunity: Climate threshold elements in the arctic

a



- (note: this figure does not directly represent the above impacts on societies and ecosystems in the arctic)

Abrupt climate change in the Arctic, Duarte et al, Nat Clim Change 2012