The HISTORY & SCIENCE of CO_2 & Greenhouse Gas Monitoring

INFORMING THE FUTURE

History of CO_2 Measurements

Early Science, Carbon Cycle, Network Evolution

Greenhouse Gas (GHG) Measurements

Modern Network, Measurement Accuracy

CO_2 & GHG Information

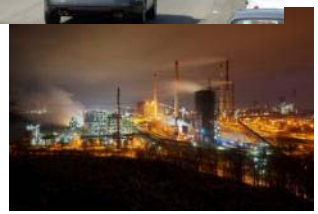
CO_2 Measurements in Action, North American Programs

The Future is Now

Future Measurements, Collaborations

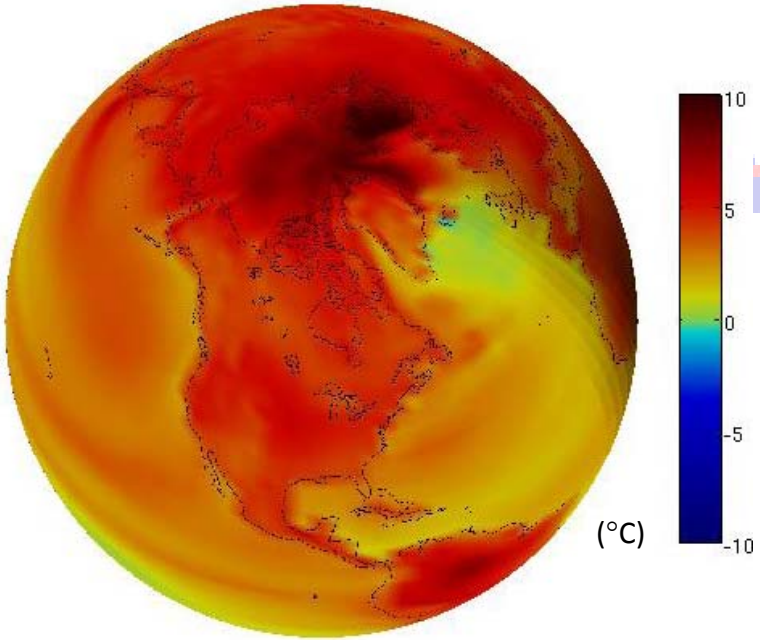
Dr. Alexander MacDonald
Director, NOAA Earth System Research Laboratory

Understanding CO_2 *Matters*

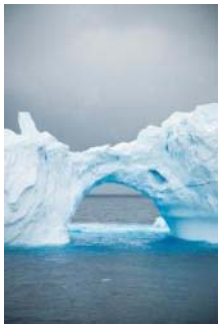


- *How will human & natural processes affect the carbon cycle on land, in the atmosphere, & in the oceans?*

- *How will decisions impact atmospheric carbon. What are likely environmental impacts of different emission strategies?*



- *How will ecosystems & natural resources be affectea by increasing greenhouse gas concentrations & by carbon management decisions?*



- *How will feedbacks affect the carbon cycle?*

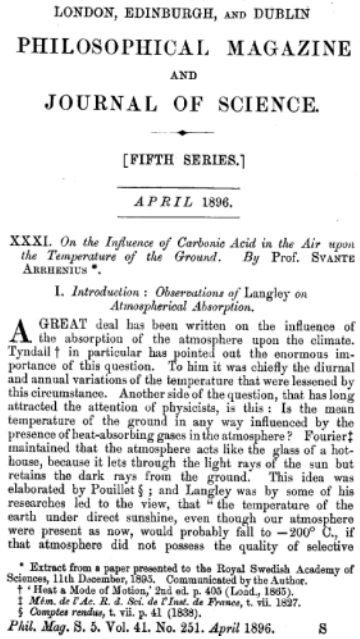
Understanding the Carbon Cycle requires observation & global collaboration – the CO_2 story is a key part of the Climate story

History of CO_2 Measurements – *Early science*

Scientists have known since 1896 that CO_2 affects surface temperatures

Arrhenius first proposed that changes in atmospheric CO_2 levels could alter surface temperatures through the greenhouse effect.

Svante Arrhenius
1859-1927



THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 403 (Lond., 1865).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).
Phil. Mag. S. 5. Vol. 41. No. 251. *April* 1896. S

But, they didn't know by how much

Would CO_2 released from burning fossil fuels accumulate in the atmosphere or be absorbed by the oceans or land?

And, they didn't have accurate enough measurements

Early techniques for measuring CO_2 were rudimentary.

The beginning of the CO_2 story started over 100 years ago

History of CO_2 Measurements – *First measurements*

In 1956, Charles 'David' Keeling developed a way to measure CO_2 accurately

Keeling developed the observing technique that provided the first high-precision measurements.

Keeling confirmed the rise of atmospheric CO_2

Keeling's data showed that CO_2 levels were rising steadily.

Accurate measurements are the cornerstone of the CO_2 story

History of CO_2 Measurements – *Early measurements*

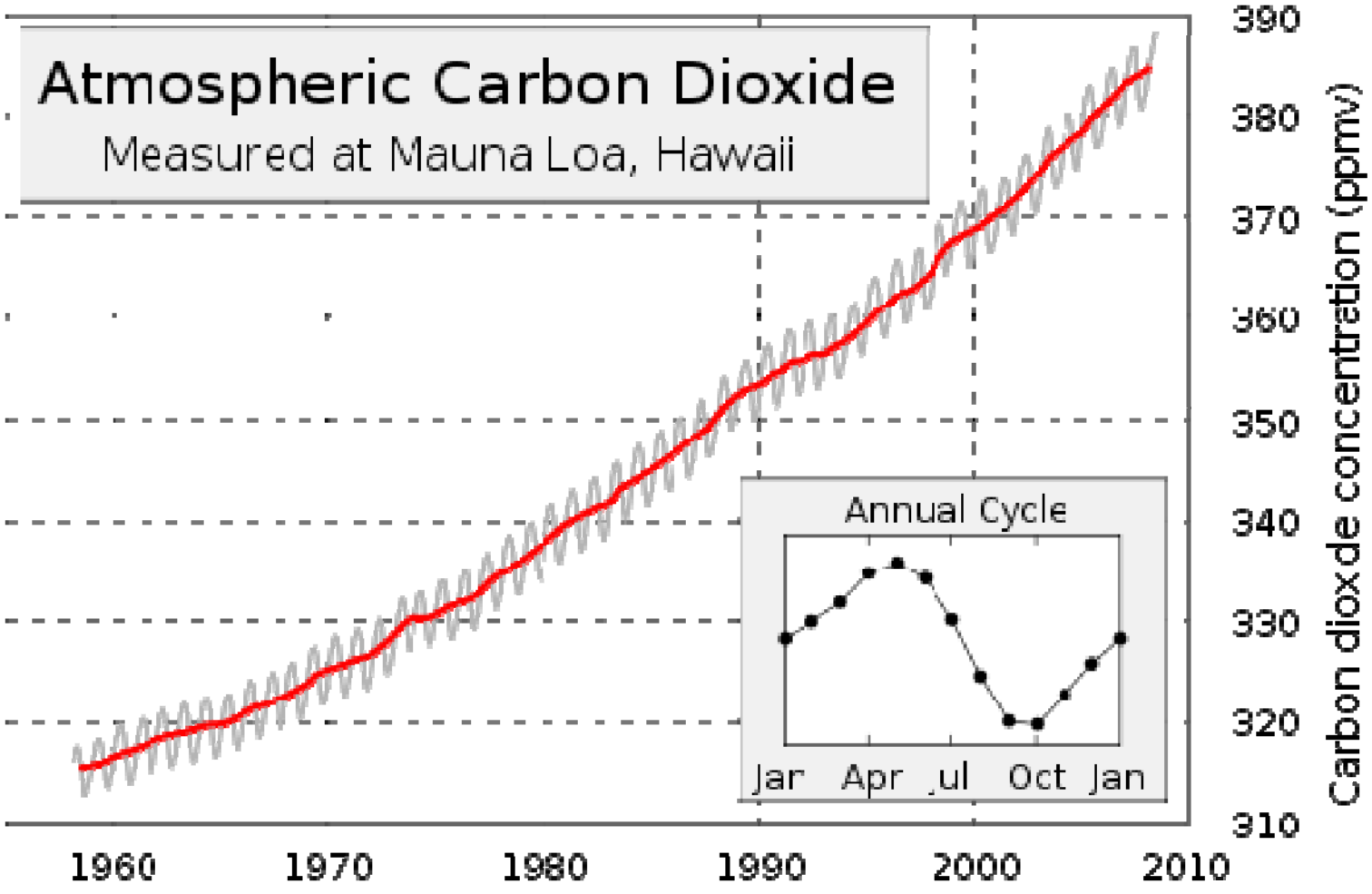
Keeling's early CO_2 measurements were obtained at South Pole & Hawaii in '57

South Pole, Antarctica

Mauna Loa, Hawaii

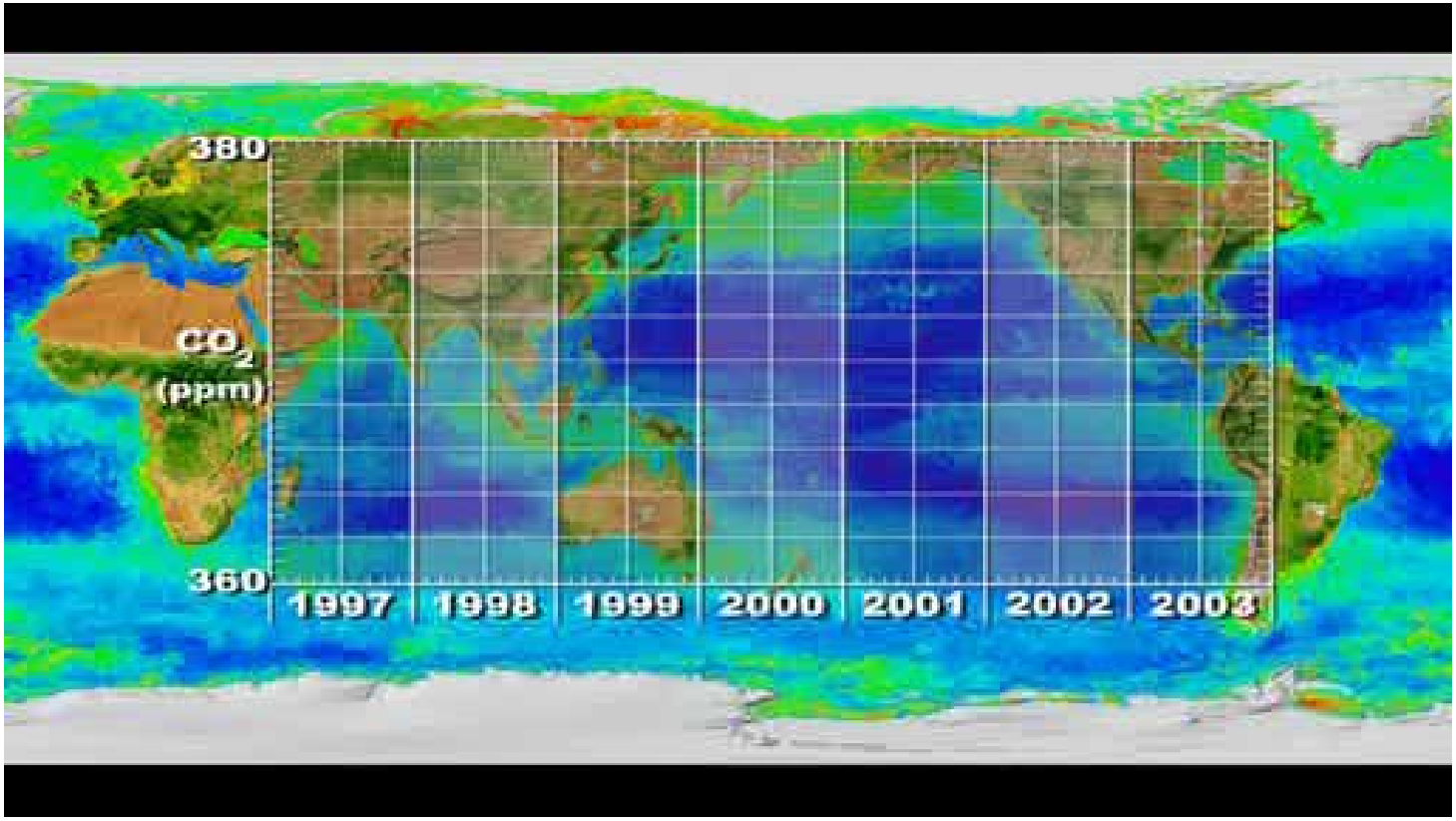
The longest *continuous* record of atmospheric CO_2 in the world is from Mauna Loa – *52 years & counting*

History of CO_2 Measurements – *Keeling Curve*



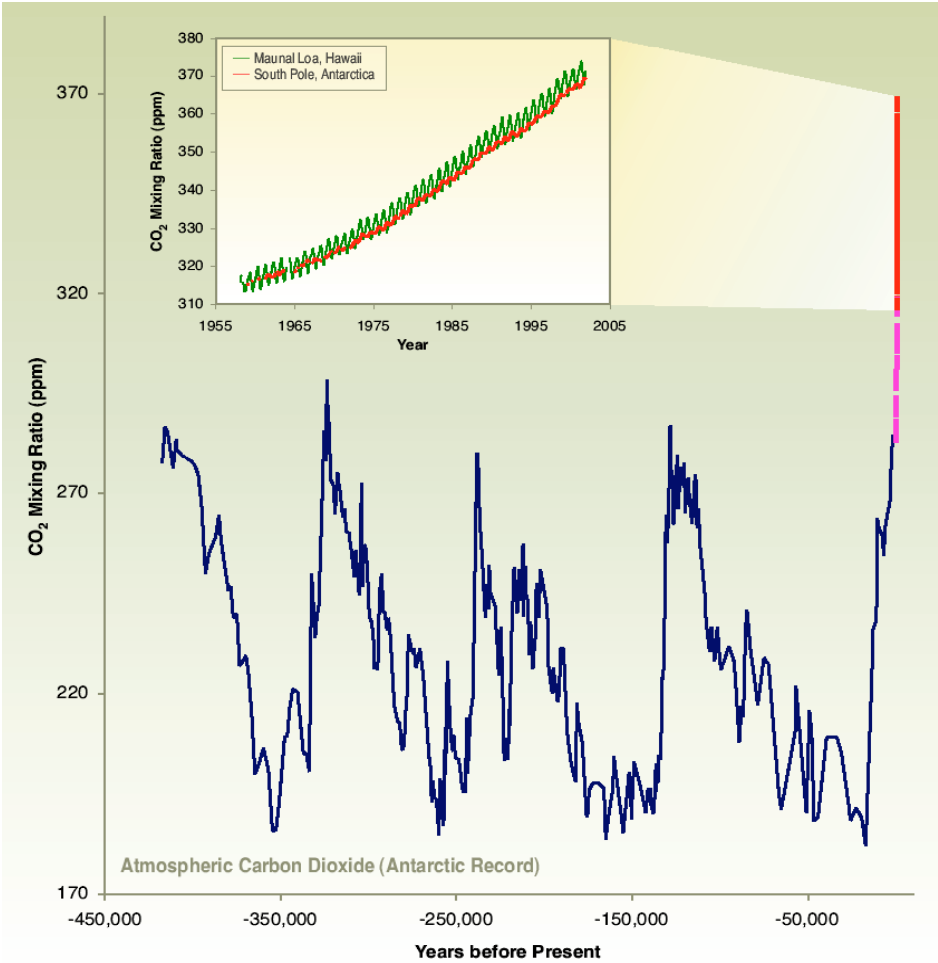
The *Mauna Loa* record has proven to be the most important data set for the study of global climate change

History of CO_2 Measurements – *Carbon cycle*



Keeling established CO_2's strong seasonal pattern: peaks in the Northern Hemisphere winter followed by dips during spring & early summer as plant growth increases in the land-rich Northern Hemisphere.

History of CO_2 Measurements – *Putting CO_2 into context*



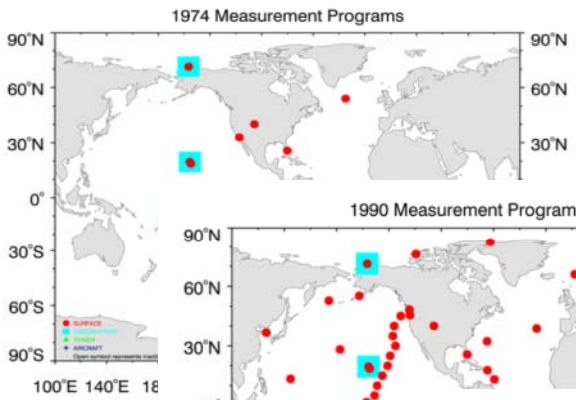
Over the past several decades, the Keeling Curve has been put into geologic context using reconstructions of historical climate.

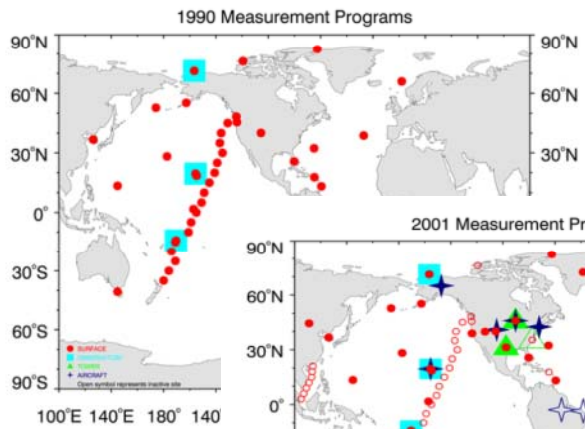
Analysis of Antarctic ice cores show that today's CO_2 levels are higher than at any point in at least the past 800,000 years.

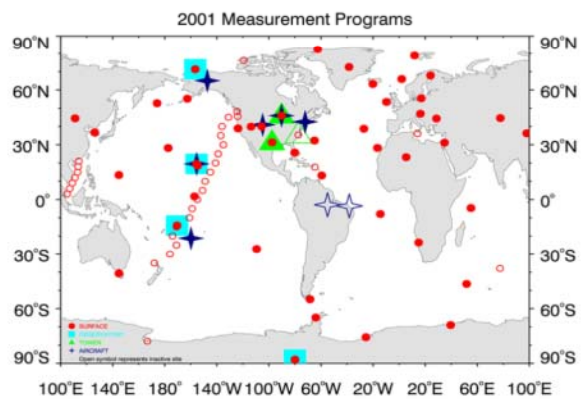
At no point in the past 800,000 years have CO_2 levels approached 2009's concentrations of 387 PPM

Nature **453**, 379-382 (15 May 2008)

History of CO_2 Measurements – *Evolution of U.S. measurements*





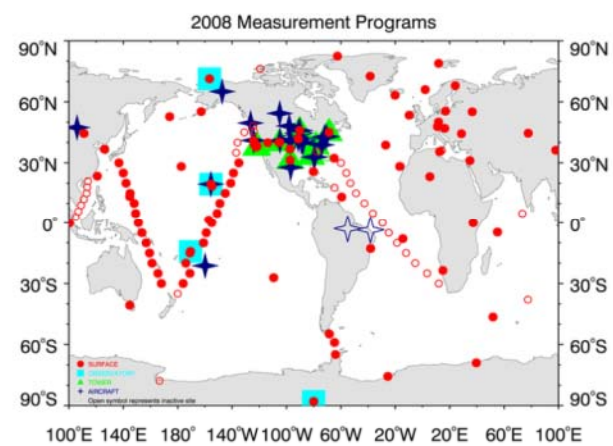


1970s: *Determine global* distributions & trends

1980s: *Understand global* distributions & trends

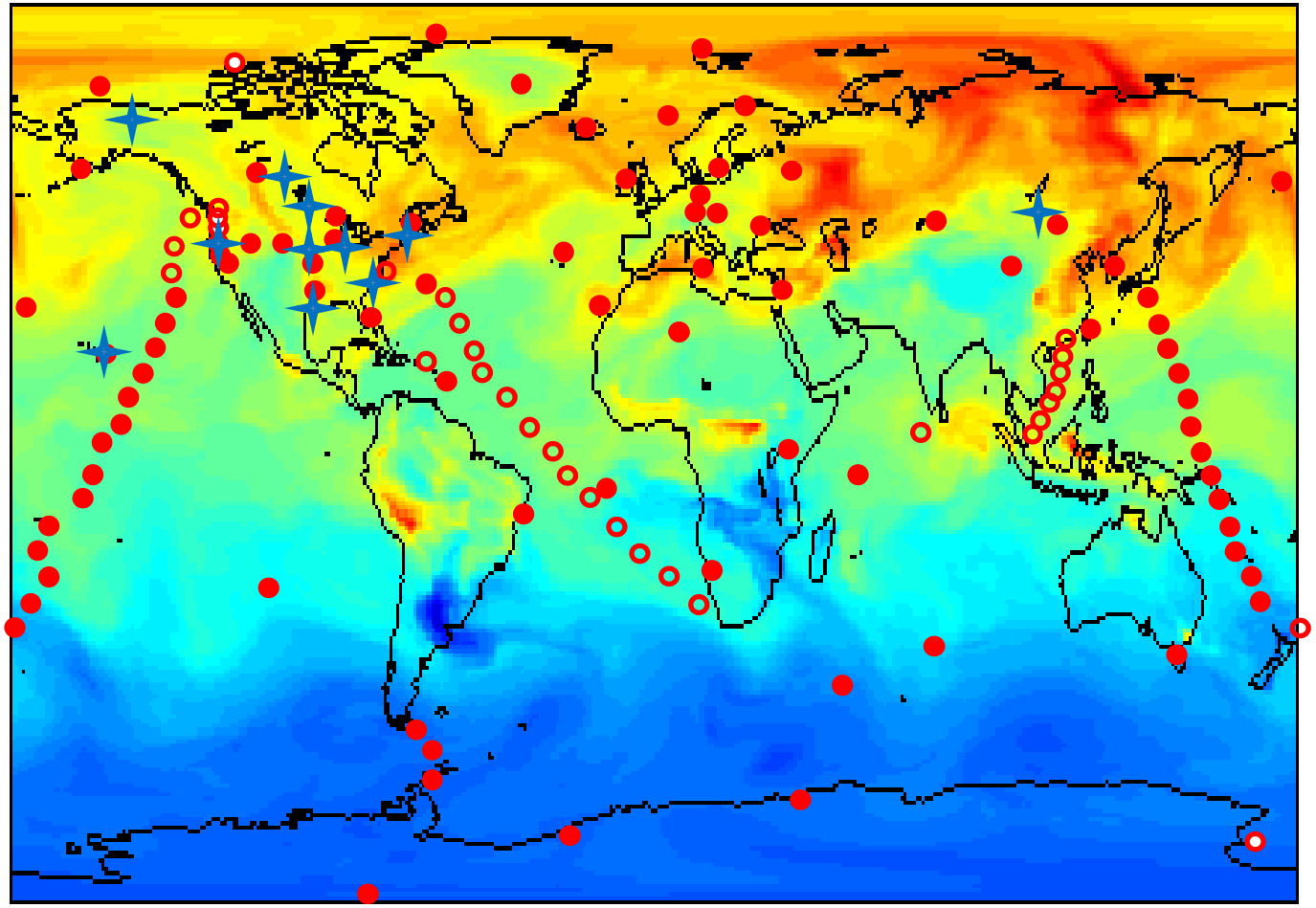
1990s: *Understand regional* sources & sinks

2000s: *Estimate and track regional* sources & sinks



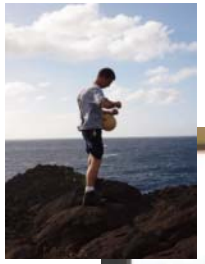
Over the past 40 years, the CO_2 measurement network has expanded with our understanding of the CO_2 system

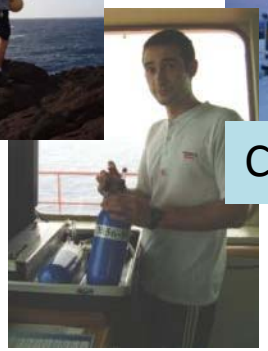
Current Greenhouse Gas Measurement Program *– 2009*



CO_2 is sampled cooperatively in 45 countries, with over 20,000 flask samples in 2009 from observatories, ships, planes, & towers

Current GHG Measurement Program – Components & programs



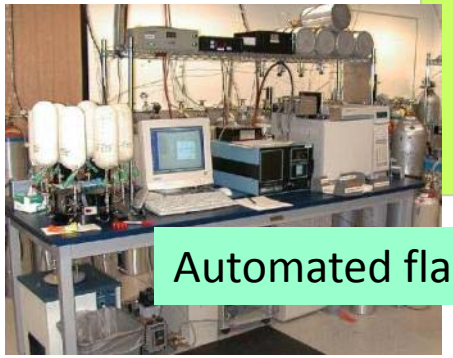


Cooperative sampling

In-situ sampling

Tall towers

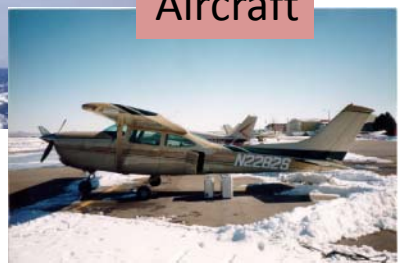
Modern flask sampling, analysis, & calibration programs provide the foundation of our global CO_2 measurements



Automated flask analysis

Central Calibration Laboratory

Portable flask packages



Aircraft

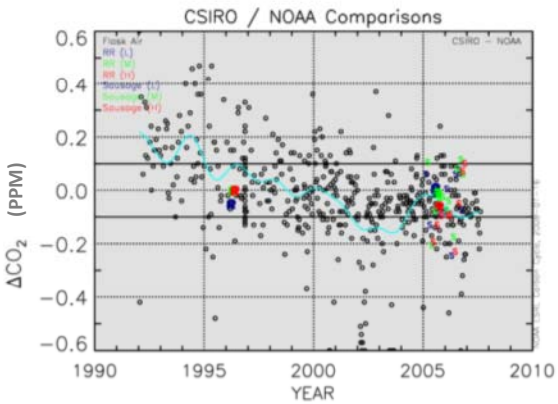
CO_2 measurements taken around the world are accurate

U.S. maintains the Central CO_2 Calibration Laboratory & Standards

A common calibration scale is required for accurate carbon measurements. WMO designated NOAA as the world's Central CO_2 Calibration Laboratory.

U.S. provides standard reference gases for common analyses

NOAA maintains the international standards for CO_2, methane (CH_4), carbon monoxide (CO), & Nitrous Oxide (N_2O). Compressed gas cylinders are filled & calibrated for use as standard reference gases for measurements & intercomparisons.

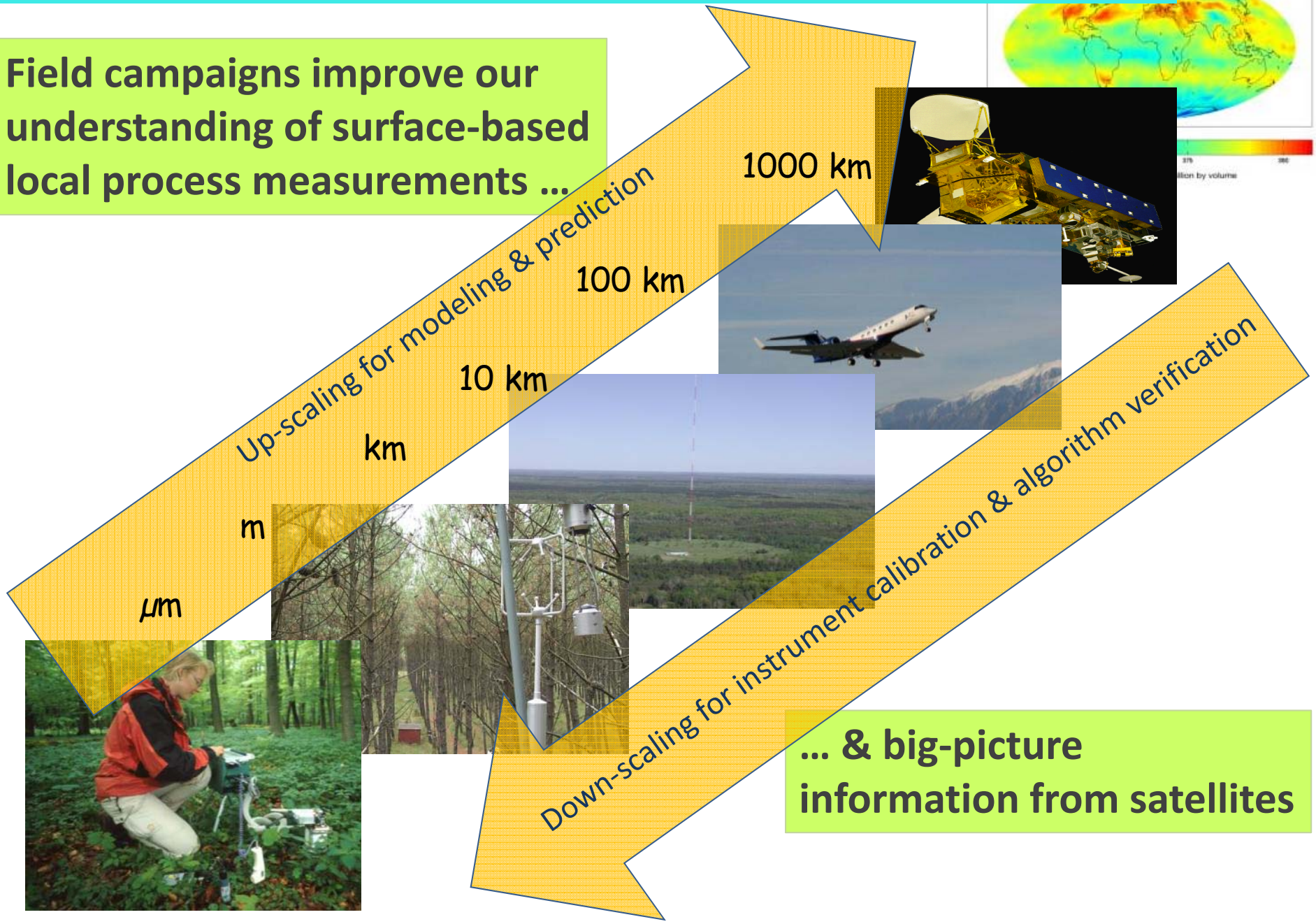


U.S. leads robust measurement intercomparison programs

Comparisons of independently obtained measurements are critical. NOAA conducts comparisons with 13 international laboratories & has been been carrying out comparisons since 1972.

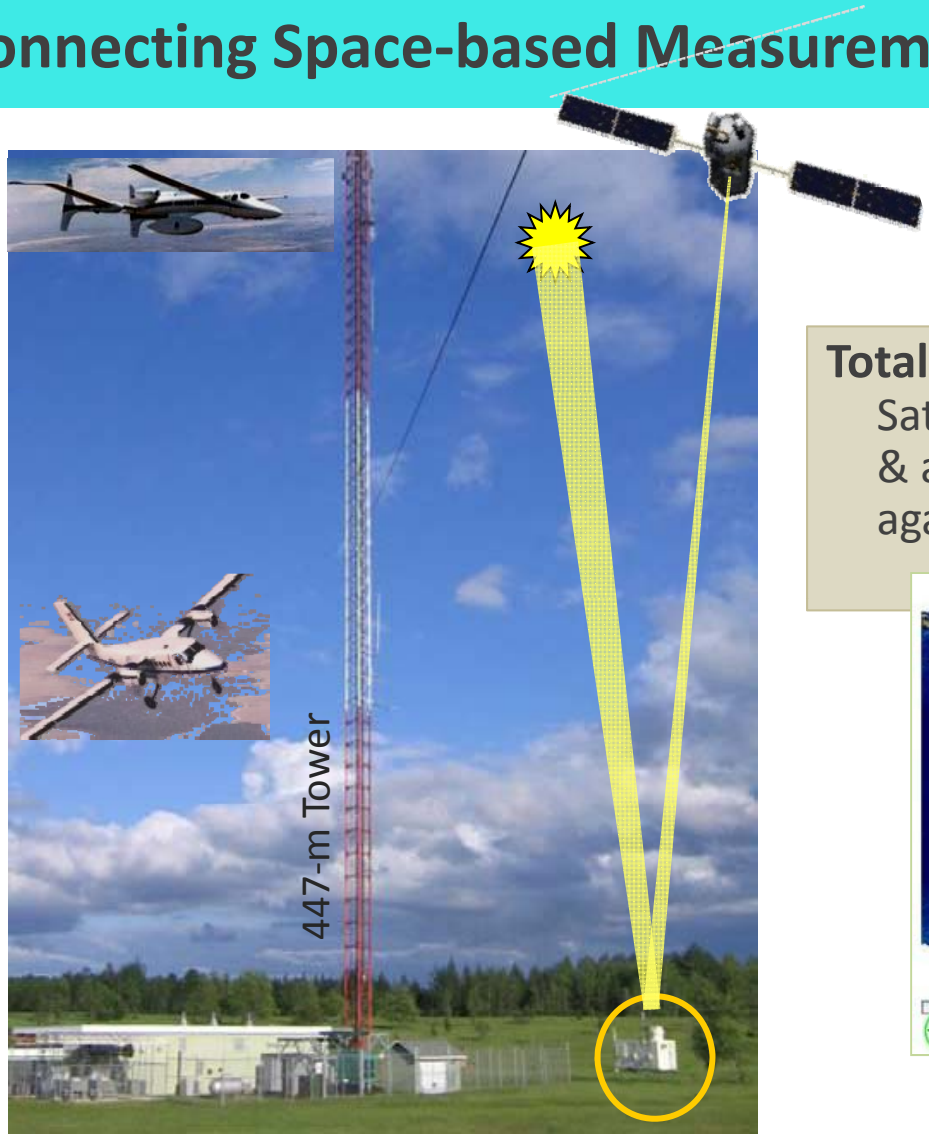
Connecting Ground-based CO_2 Measurements to Satellite

Field campaigns improve our understanding of surface-based local process measurements …



… & big-picture information from satellites

Connecting Space-based Measurements to Surface Standards

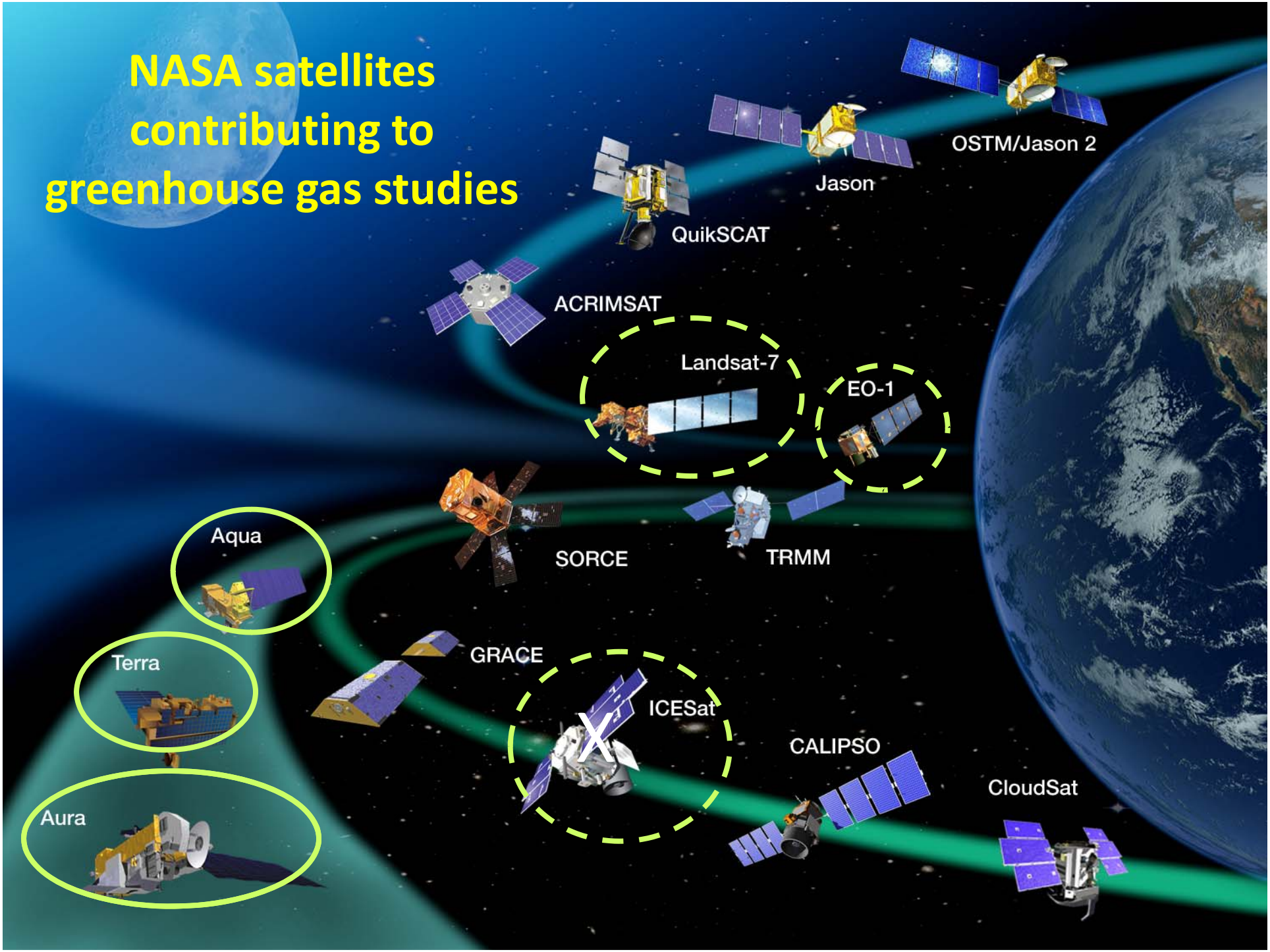


Total Carbon Column Observing Network

Satellite results are validated by ground-based & aircraft instruments that are calibrated against the WMO CO_2 standard.

Satellite data are compared to aircraft & ground-based measurements to ensure accuracy

NASA satellites contributing to greenhouse gas studies

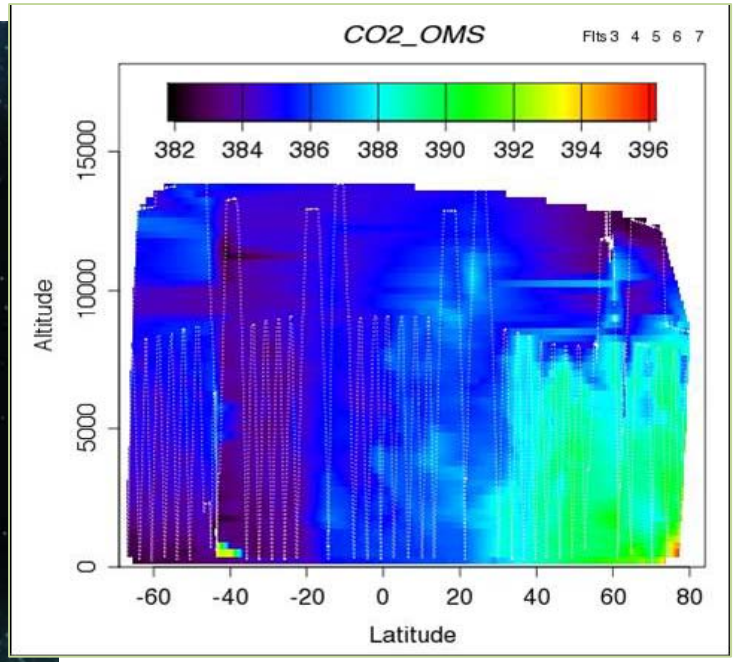


Connecting CO_2 Measurements Pole-to-Pole

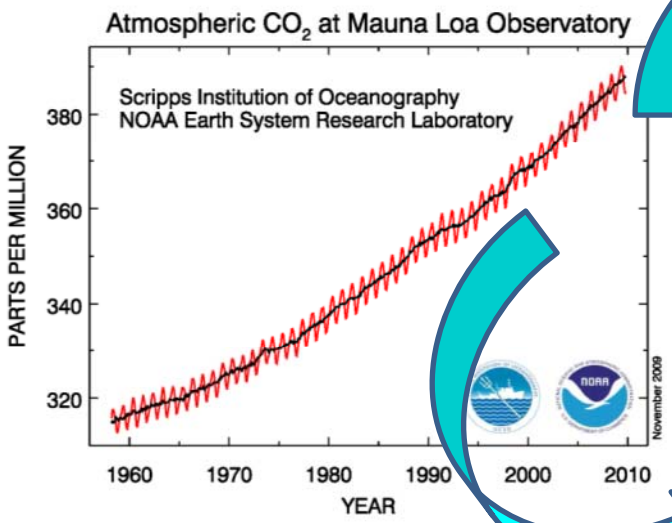
HIAPER Pole-to-Pole Observations

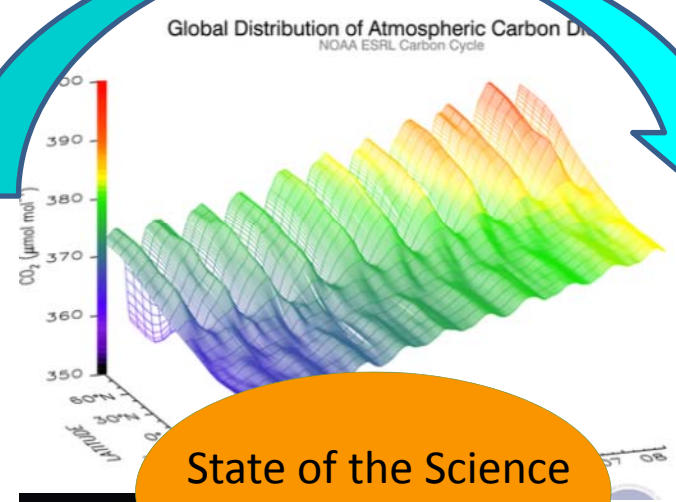
HIPPO surveys GHGs 'pole-to-pole', from the Earth's surface to the top of the atmosphere, during different seasons, over a 3-year period.

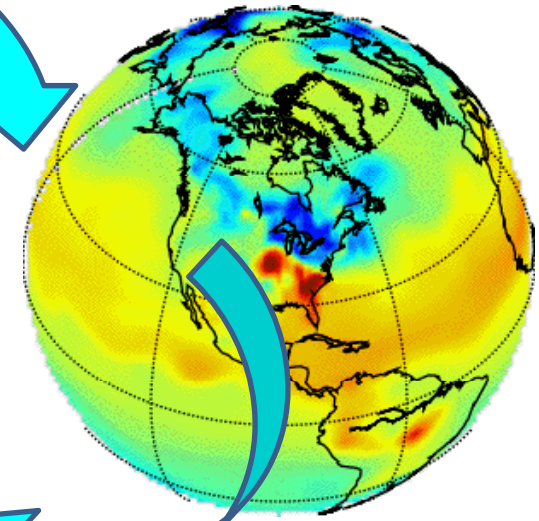
24 instruments – many fixed to the under-side of each wing, along with cameras, sample the surrounding atmosphere.



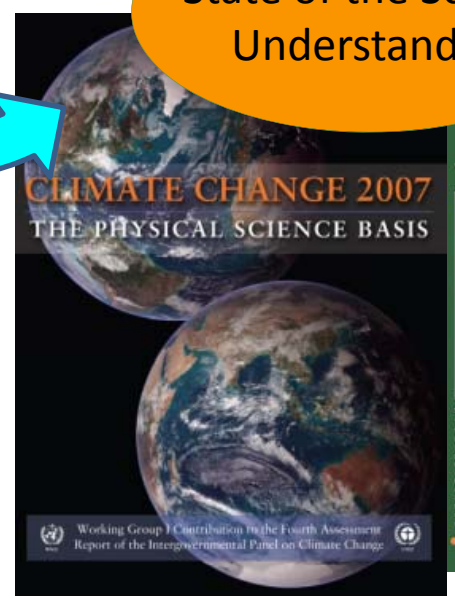
What We've Learned from all these Measurements

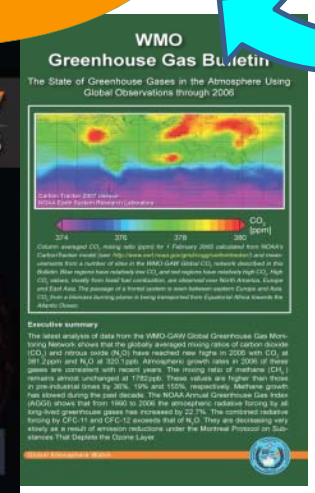






State of the Science Understanding



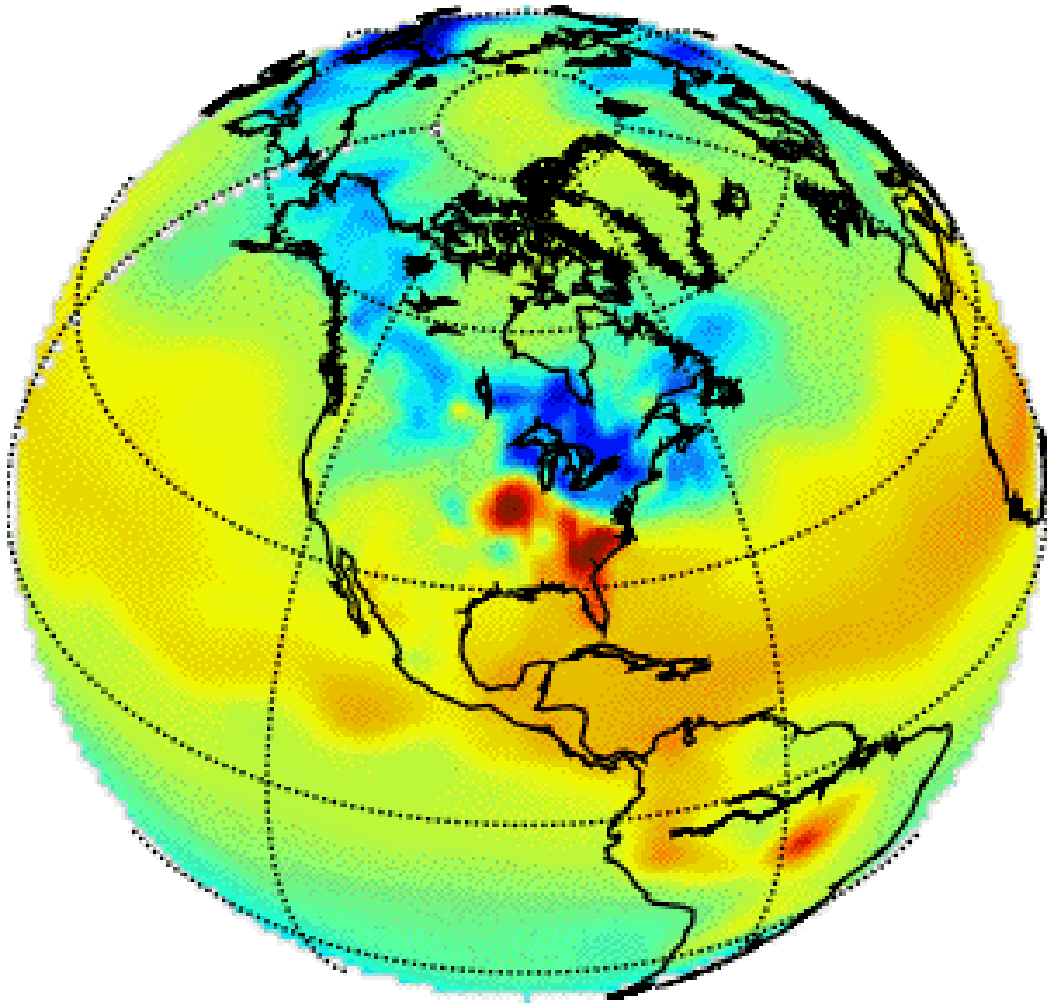


The primary source of the increased atmospheric CO_2 concentration since the pre-industrial period results from fossil fuel use

The concentration of atmospheric CO_2 has increased from a pre-industrial value of about 280 ppm to 387 ppm in 2009

Increasing atmospheric CO_2 concentrations lead to increasing acidification of the oceans

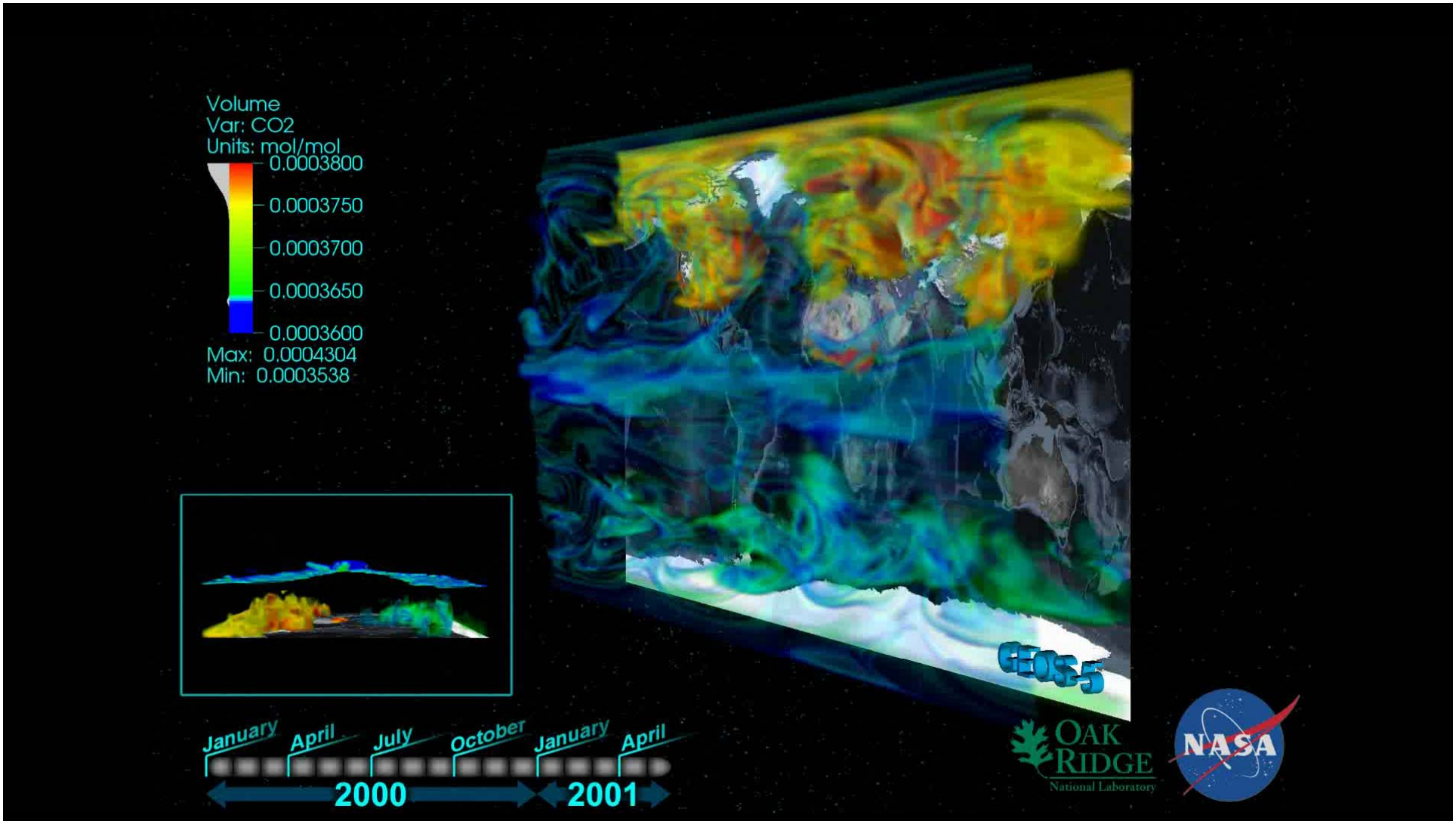
Global CO_2 Measurements in Action



CarbonTracker

CO_2 uptake & release at Earth's surface during August 2006

Global CO_2 Measurements in Action



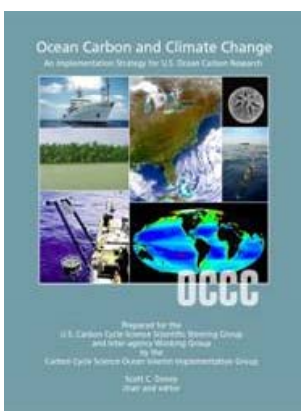
Model simulation of CO_2 – a demonstration of what can be done using visualizations

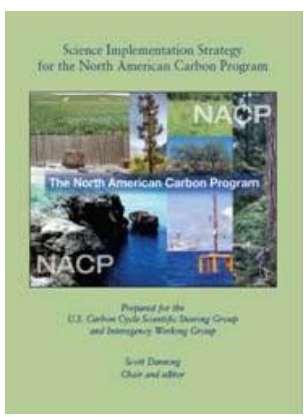
U.S. Agencies Working Together

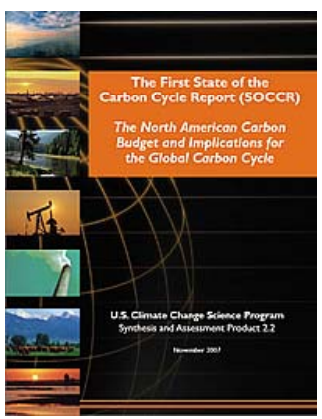
U.S. Carbon Cycle Science Program

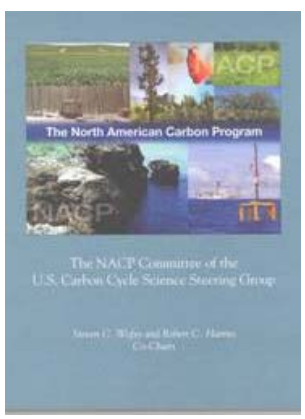
This program is clarifying the changes in Earth's carbon cycle, from sources, sinks & fluxes between the land, ocean & atmosphere, to the underlying mechanisms including fossil fuel emissions, land use, & climate.

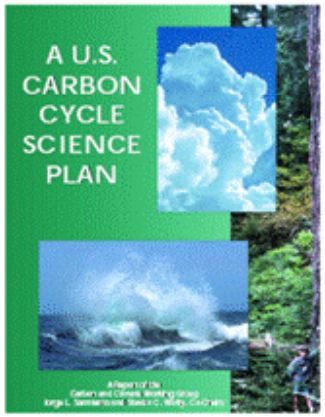
10 U.S. agencies coordinate & support the **Carbon Cycle Science Program**



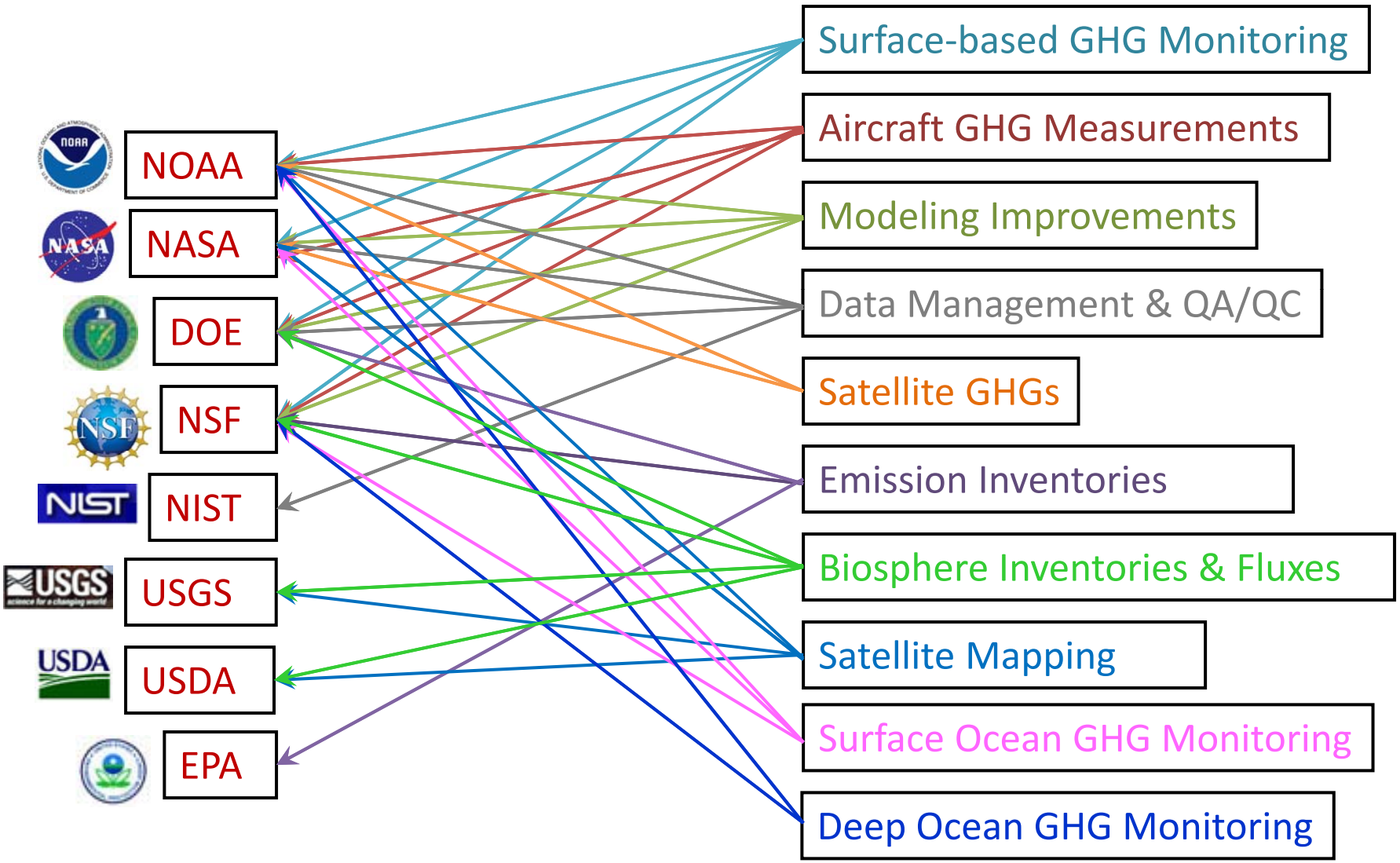




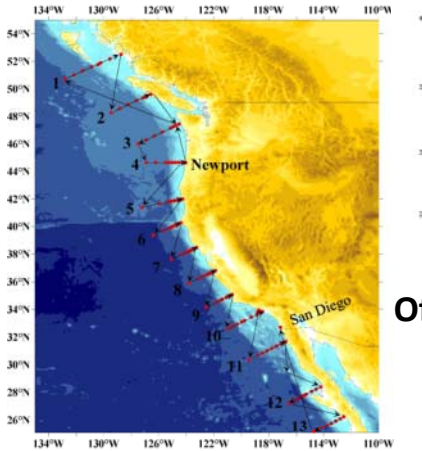


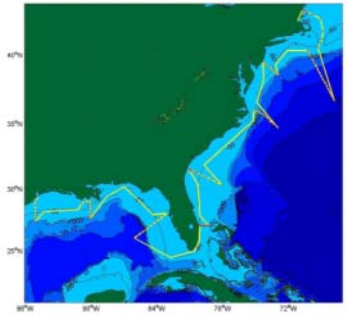


Building Cooperative U.S. Efforts

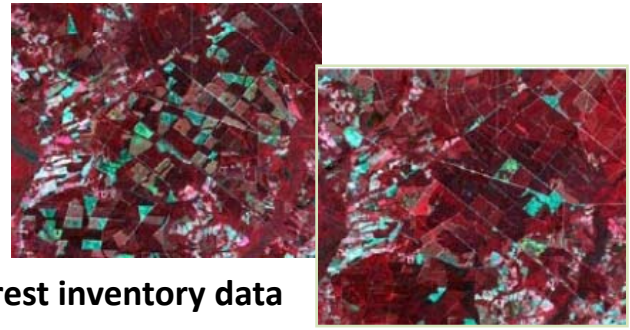


The North American Carbon Program



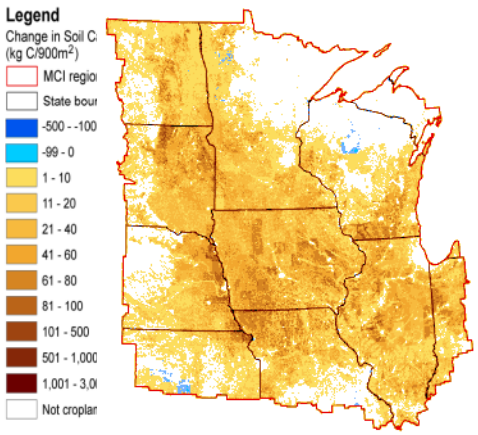


Offshore data transects

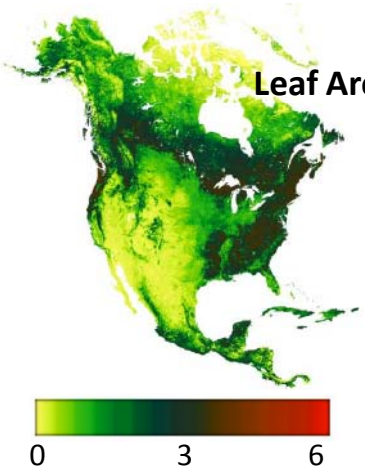


Forest inventory data

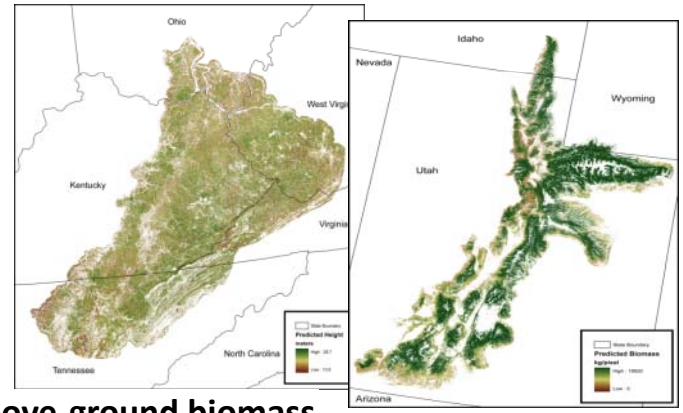
The central objective of the U.S. North American Carbon Program is to measure & understand the sources & sinks of CO_2, CH_4, & CO in North America & adjacent ocean regions



Net change in soil carbon



Leaf Area Index



Above-ground biomass

U.S. Agency Goals & Commitment

Developing & maintaining, long-term, global networks for measuring CO_2, CH_4, & related gases

Making the highest quality measurements by maintaining calibration scales & leading intercomparisons

Making data fully accessible to inform a global understanding of the carbon cycle

Developing products that serve a broad spectrum of society from scientists & educators to policy makers

Maintaining & building international partnerships

U.S. Contributions to International Efforts

World Meteorological Organization

- U.S. is over 1/2 of Global Atmospheric Watch measurements
- World Central Calibration Laboratory is in Colorado
- Scientific Advisory & Experts Committee (GHGs)

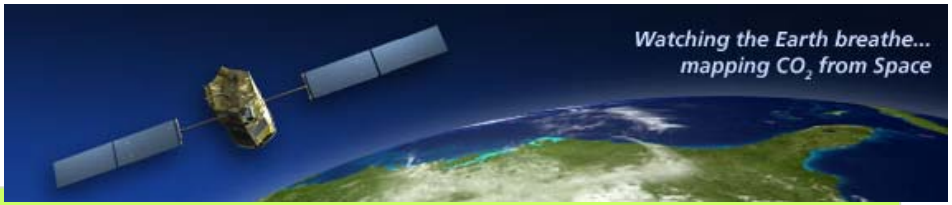
Global Earth Observation System of Systems

Linking observing systems around the world

IPCC, UNEP

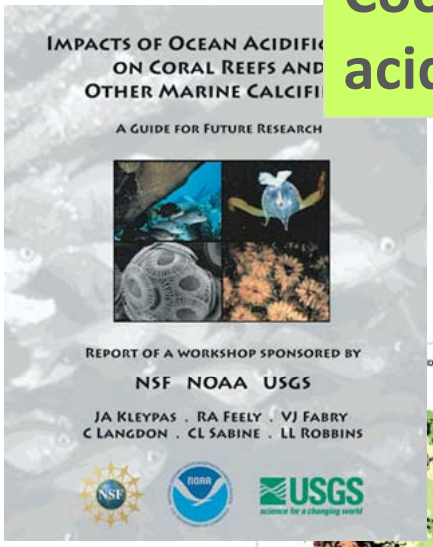
Providing information relevant to international programs

Future Global & Regional Measurement Goals

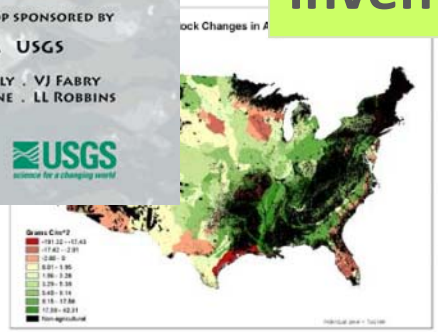


Satellite, integrated tower, & aircraft sampling of carbon & related species

Coordinated global ocean & ocean acidification observing networks



Global networks of terrestrial inventories, fluxes, including soils



Monitoring & assessment of human systems, including mitigation & adaptation strategies & associated impacts

Carbon Cycle Science Working Group Recommendations Summary
U.S. Carbon Cycle Science Plan for 2010 to 2020

Moving Forward on What We Know

If society is to manage or reduce carbon emissions, reliable & accurate information will be needed on local, regional, & global scales.

Accurate CO_2 measurements of sources & sinks are essential to support emission mitigation or verification & evaluation of new energy strategies.

The current worldwide network coordinated by NOAA forms a global foundation for monitoring & understanding these trends.

Our developing North American network will provide the kind of regional information necessary for rational management of carbon emissions.

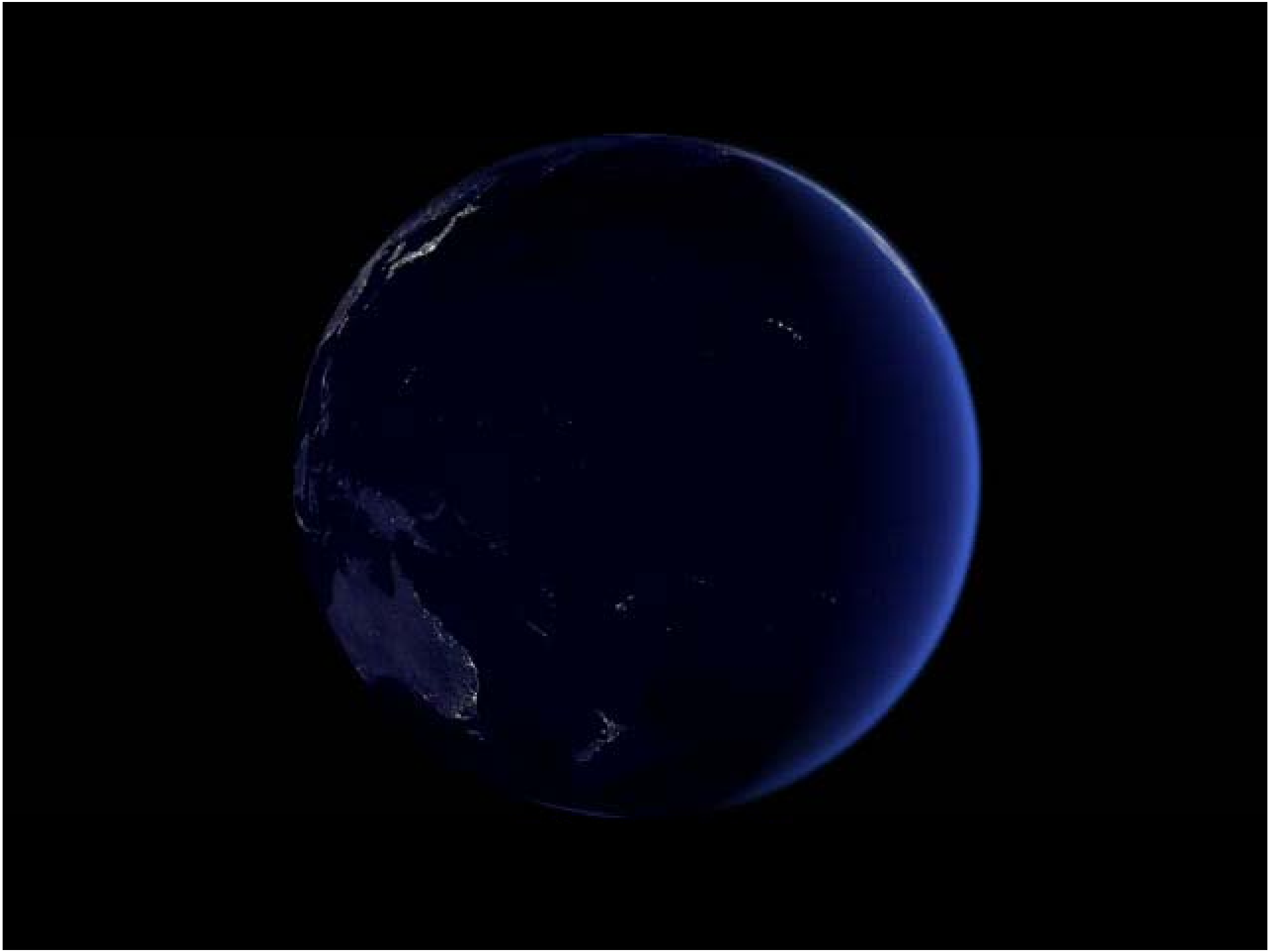
Coupling CO_2 models with other environmental models will improve predictions & long-term stewardship strategies.

For more information on U.S. CO_2 Monitoring

www.noaa.gov

www.nsf.gov

www.nasa.gov

www.carboncyclescience.gov

Thank you