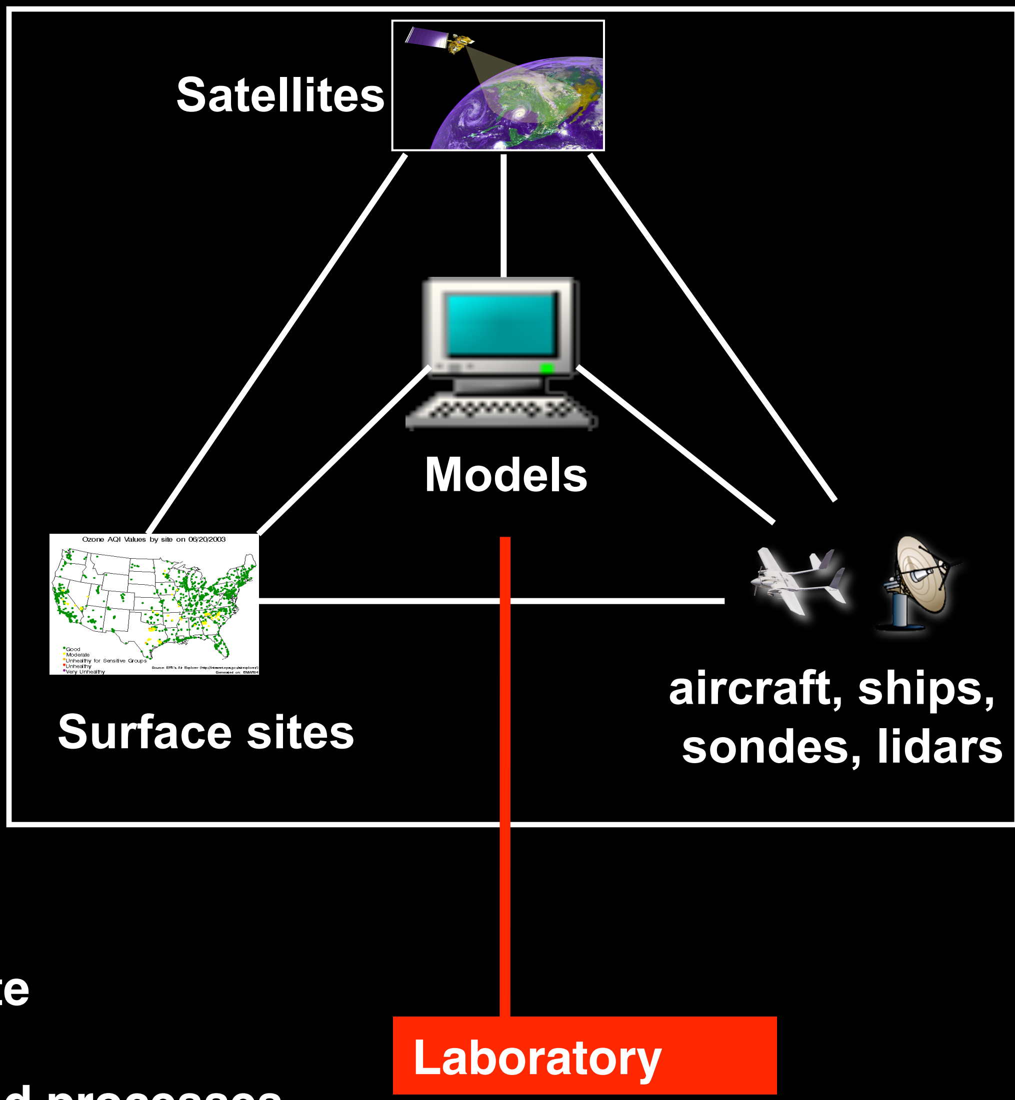
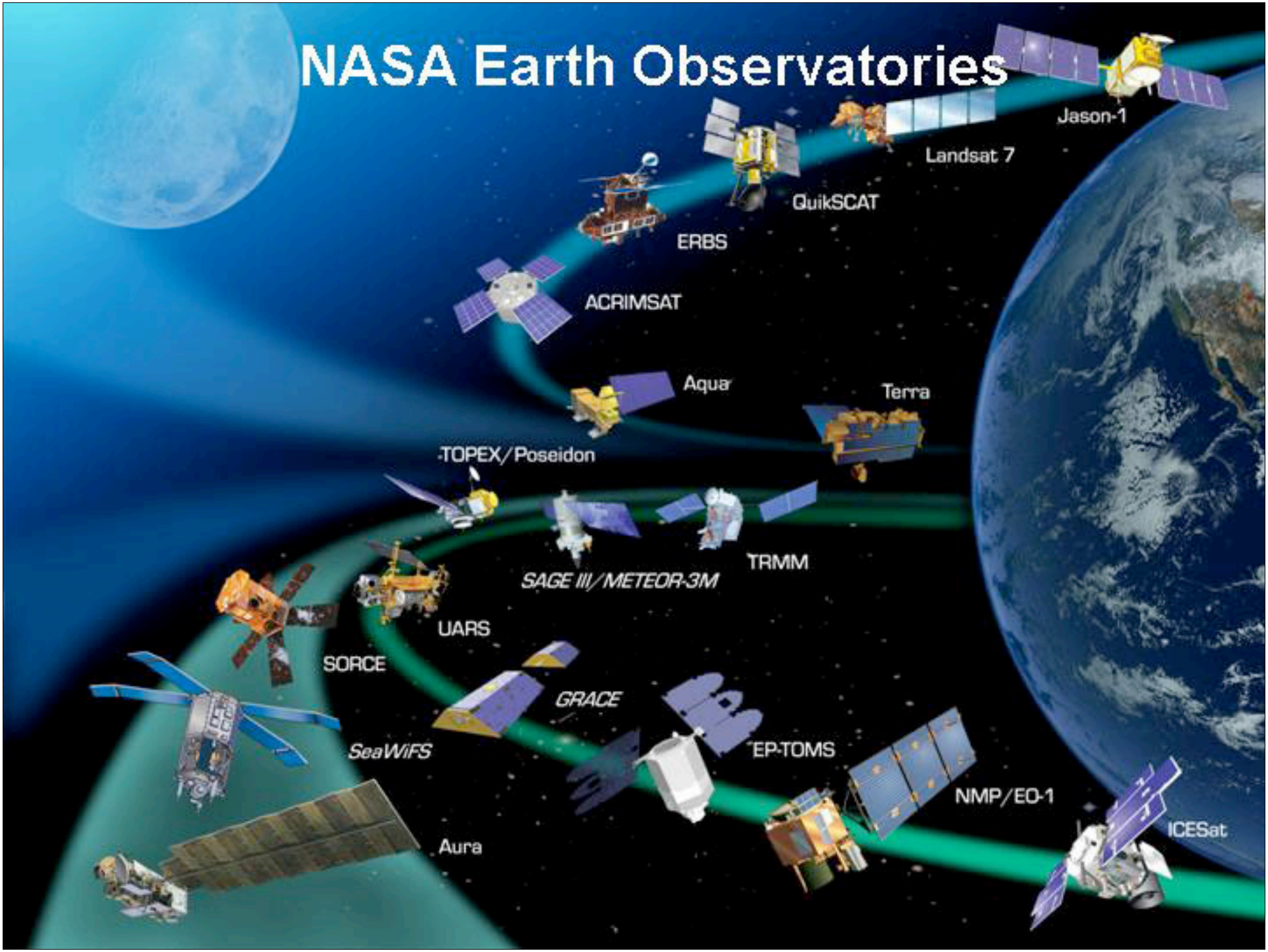
EARTH OBSERVATION STRATEGIES
and examples

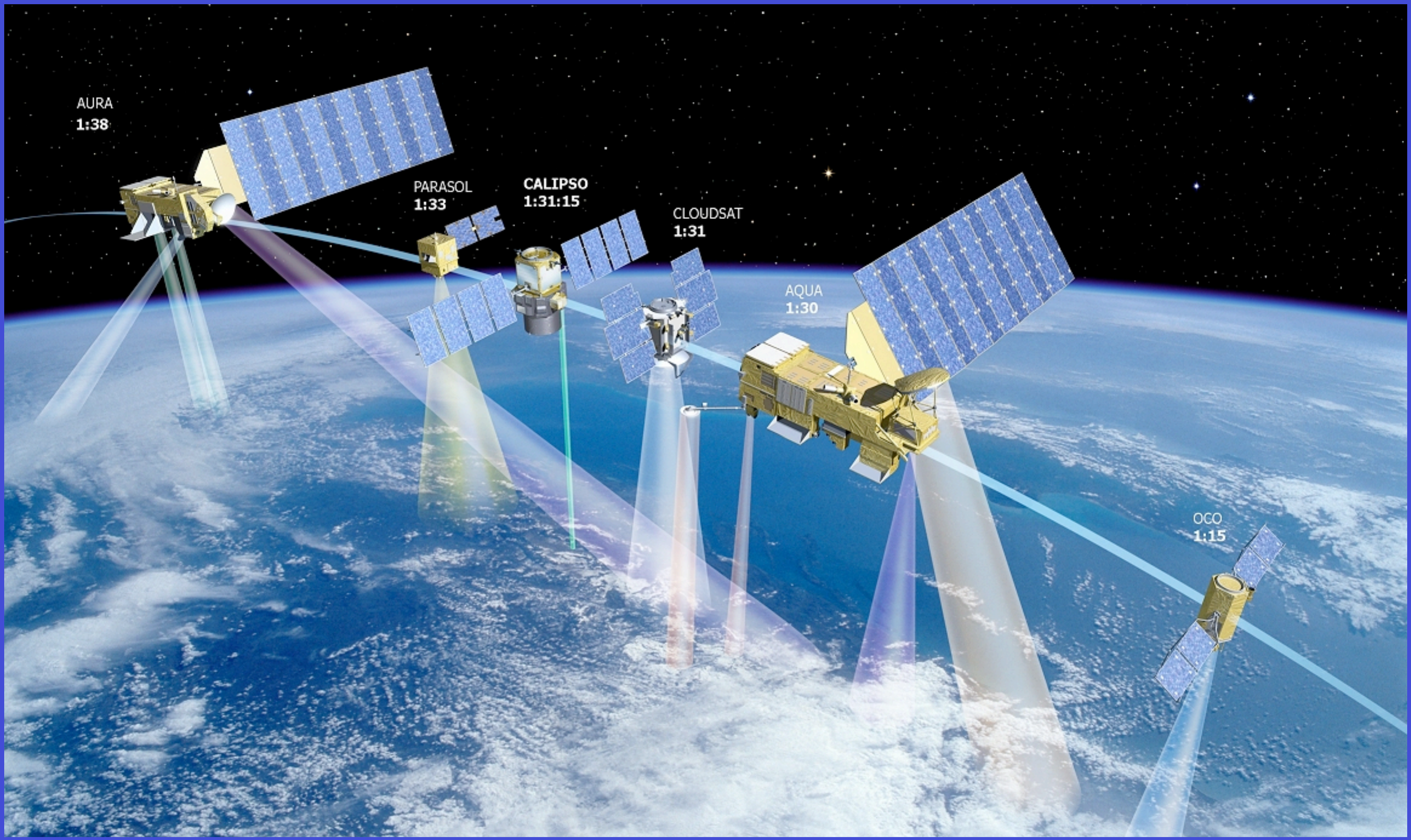


Why observe the Earth?

1. To characterize the current state
2. To monitor trends
3. To understand relationships and processes


NASA Earth Observatories
Jason-1
Landsat 7
QuikSCAT
ERBS
ACRIMSAT
Aqua
Terra
TOPEX/Poseidon
TRMM
SAGE III/METEOR-3M
UARS
SORCE
GRACE
EP-TOMS
SeaWiFS
NMP/EO-1
ICESat
Aura

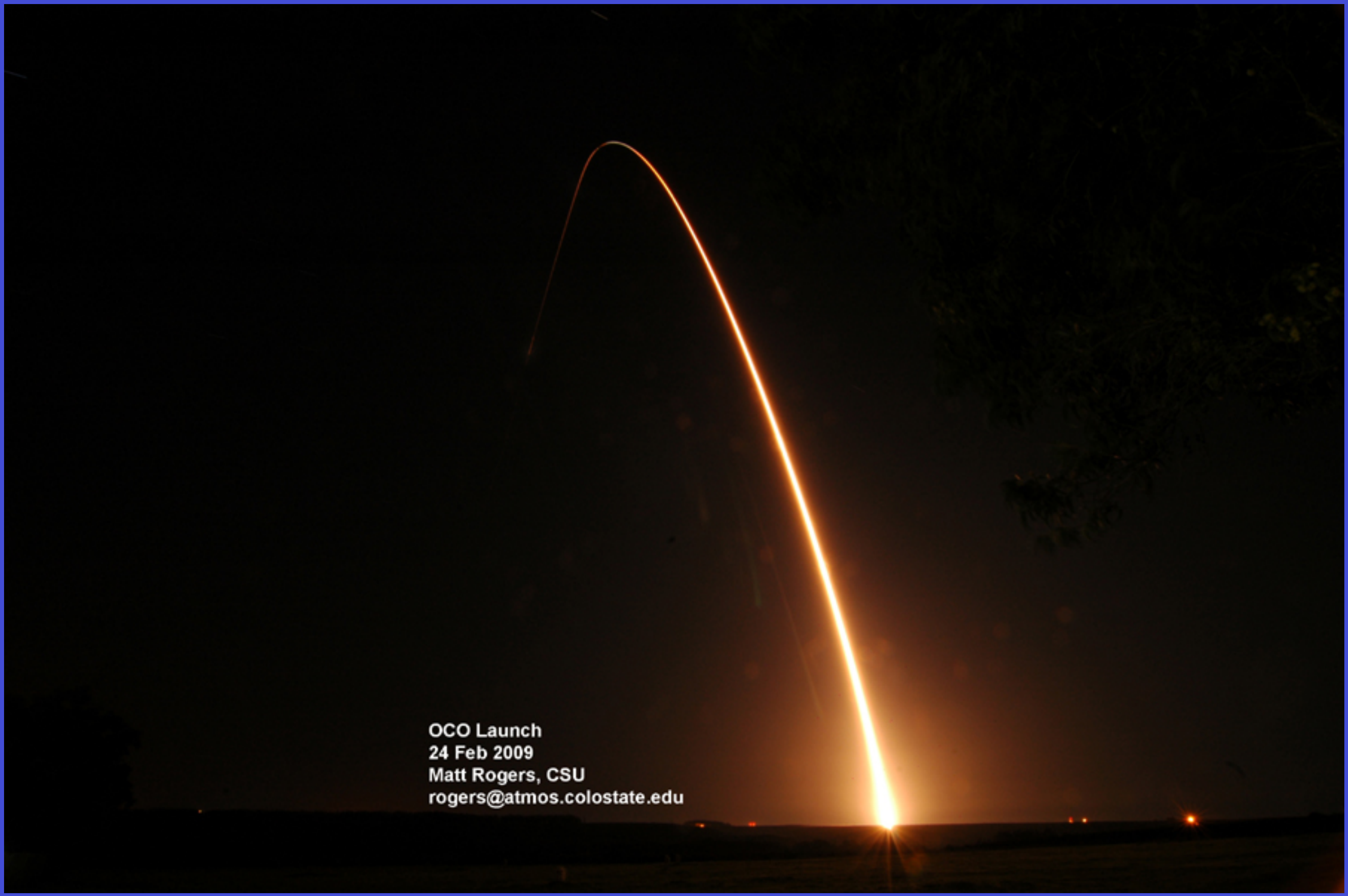
THE NASA 'A-TRAIN'



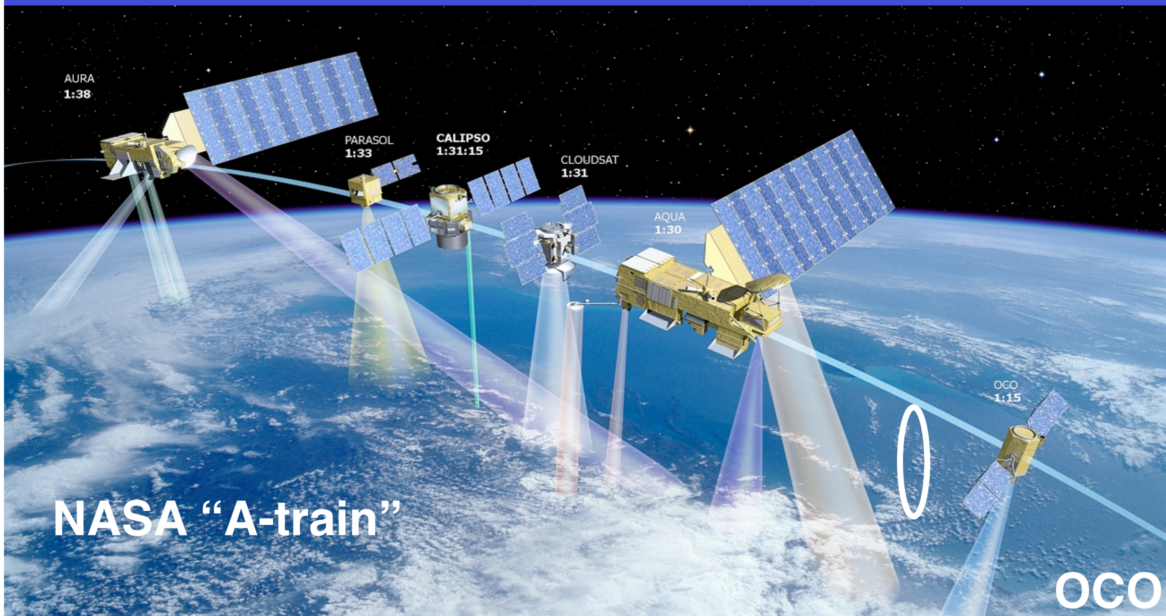
- **Constellation of polar-orbiting, sun-synchronous satellites flying in formation**
- **The satellites all observe nearly the same air-mass (and/or ground pixels) within 8 minutes of each other**

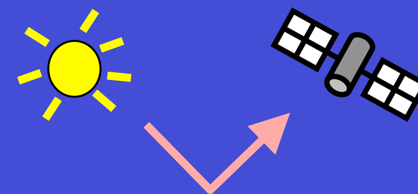
FAILED LAUNCH OF OCO - Tues Feb 24 at 4:55 EST

The Orbiting Carbon Observatory (OCO) was to provide global mapping of atmospheric CO_2 concentrations to constrain sources/sinks of carbon



OCO OBSERVATION STRATEGY

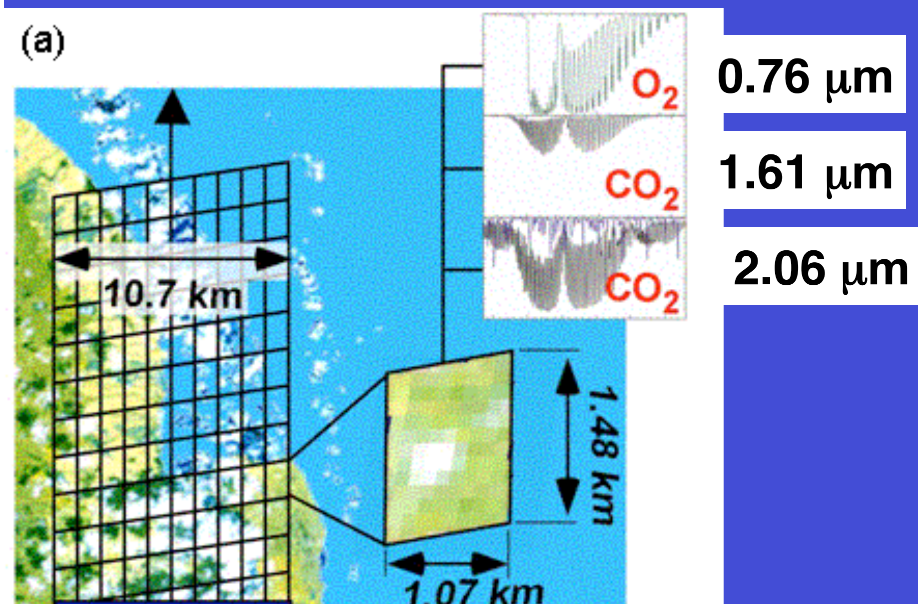




0.76 μm

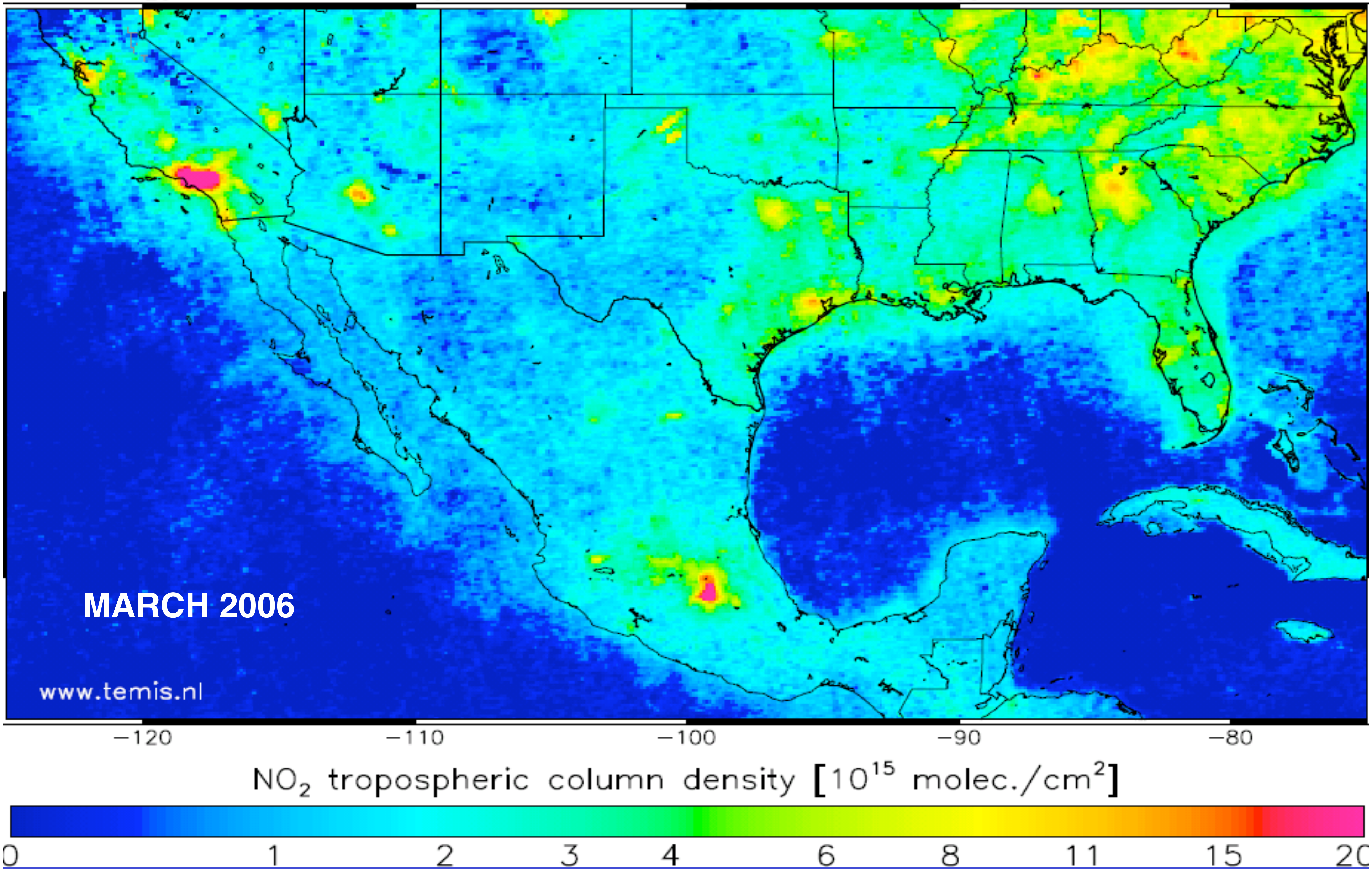
1.61 μm

2.06 μm



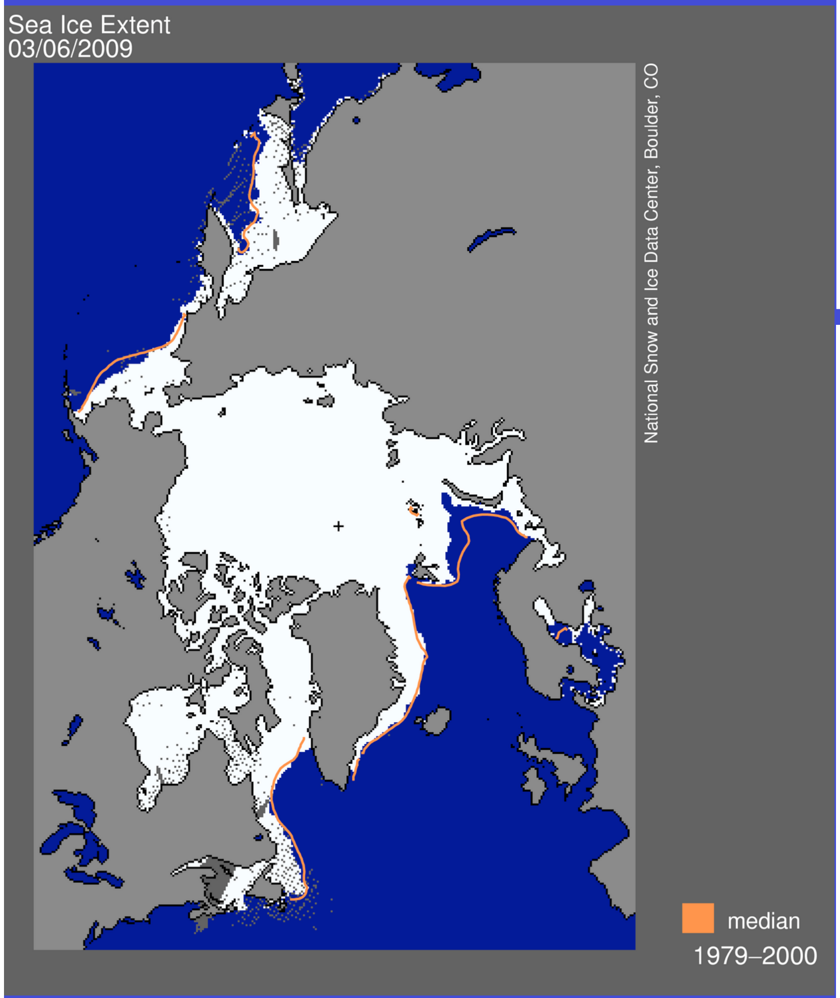
OCO would have produced global mapping of CO_2 column mixing ratios with <1 ppm (<0.3%) resolution by measurement of solar back-scatter at 0.76, 1.61, and 2.06 μm

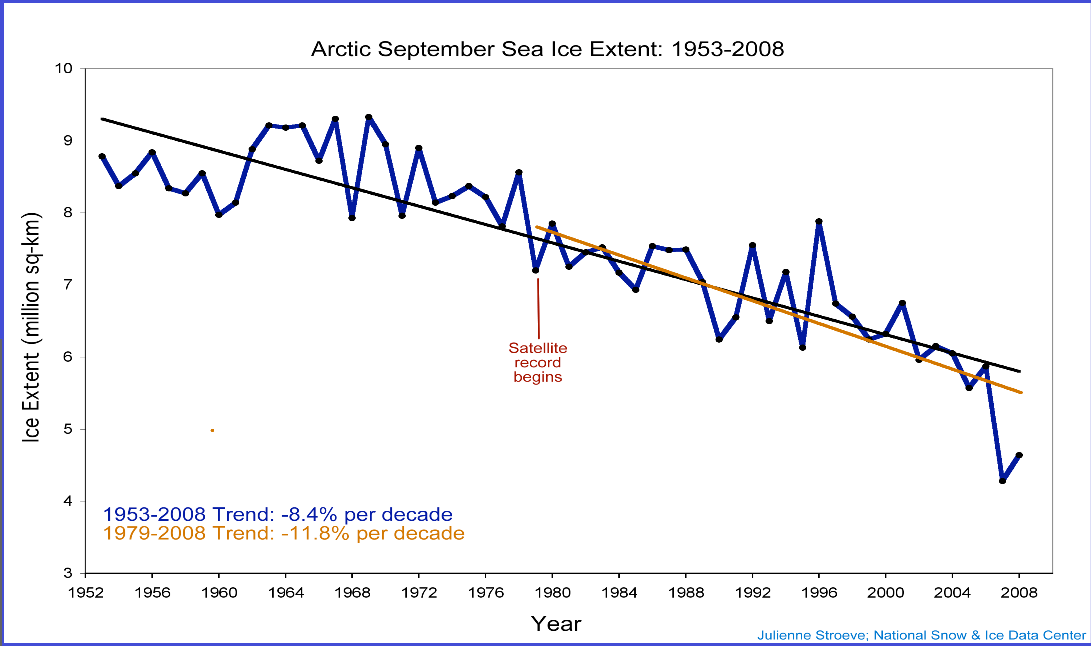
TROPOSPHERIC NO_2 FROM OMI:
Daily mapping of nitrogen oxide emissions with 13x24 km^2 resolution

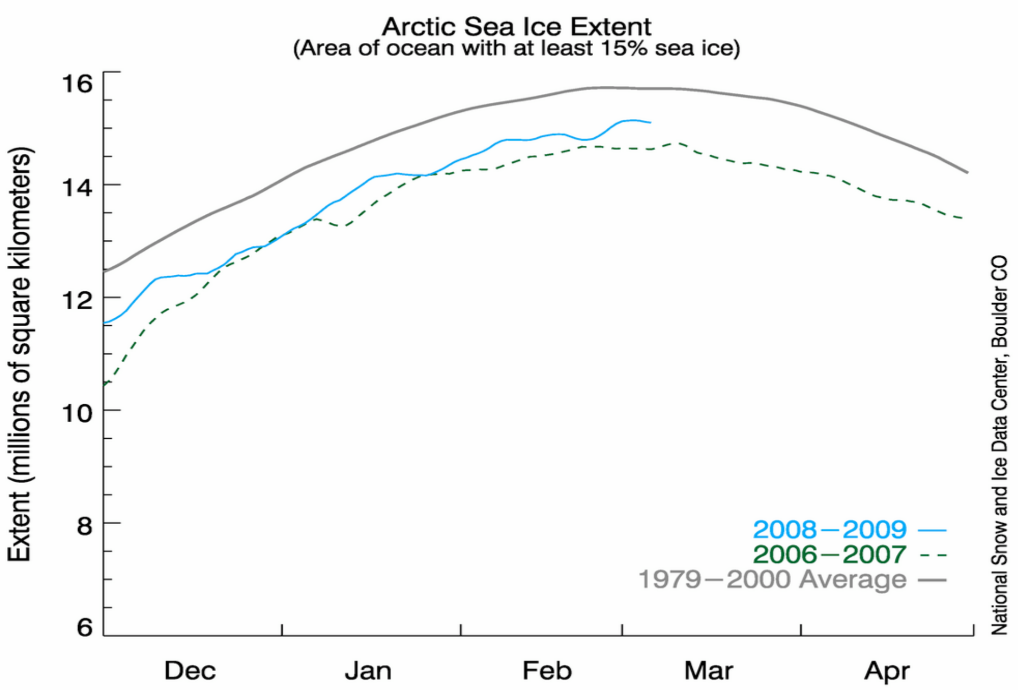


K. Folkert Boersma (Harvard)

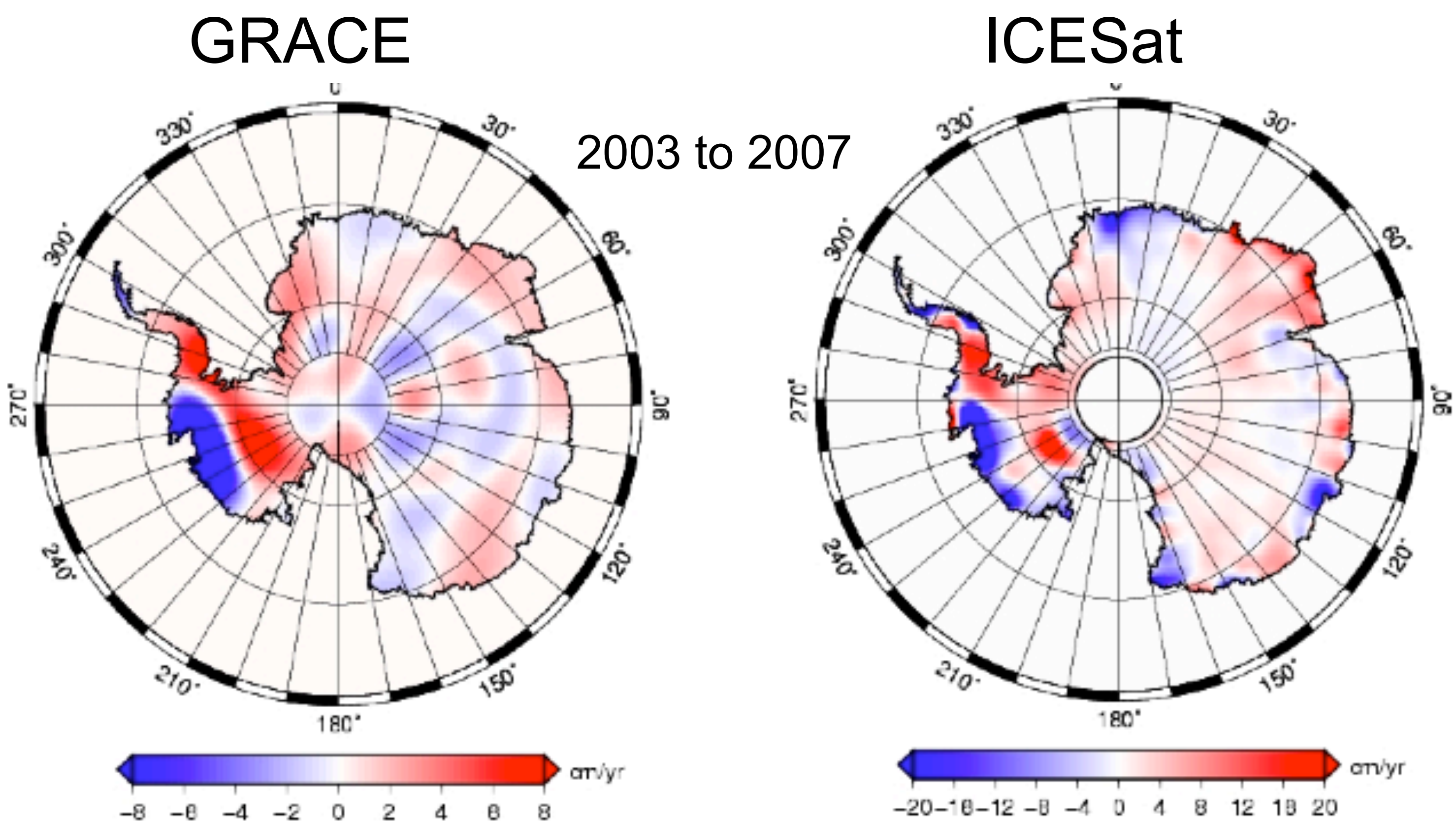
TRENDS IN ARCTIC SEA ICE







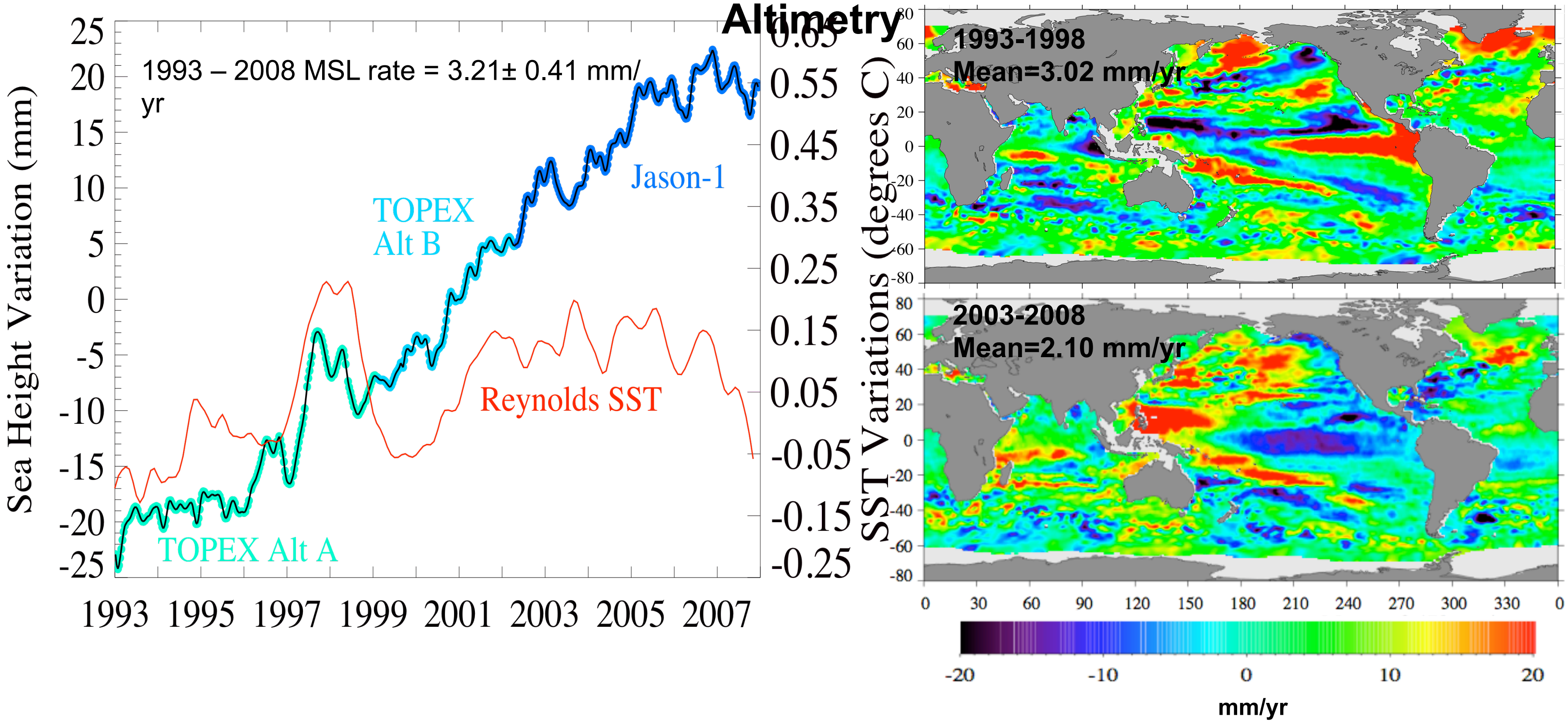
CHANGES IN ANTARCTIC ICE THICKNESS



Both GRACE and and ICESat missions observe spatially similar changes in Antarctica. GRACE = cm/y of equivalent water height, ICESat = cm/y of elevation change

[Gunter et al., J. of Geod, in review]

Global and Regional Mean Sea Level Trends from TOPEX/Poseidon and Jason-1 Altimetry

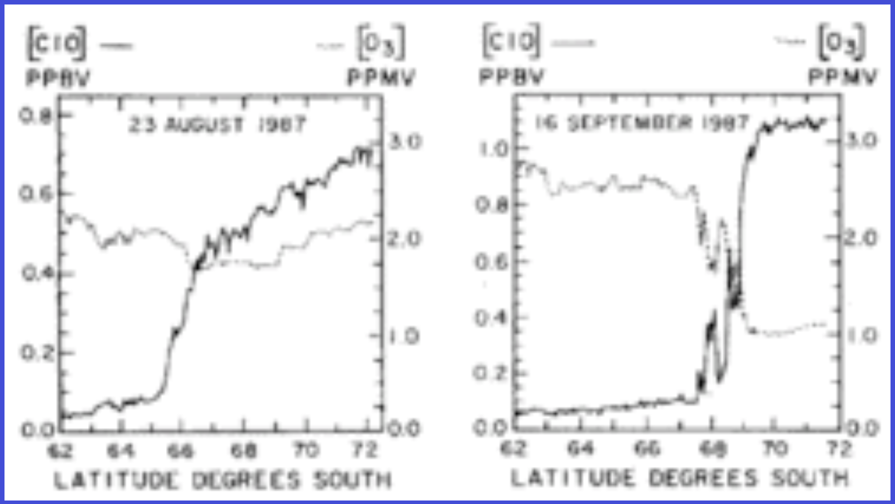


Global mean sea level (MSL) variations are estimated from the combined 16 year record of T/P and Jason-1 altimetry based on revised orbits adhering to a consistent terrestrial reference frame (**ITRF2005**)and unified geophysical modeling. The thin red curve is the global Reynolds' sea surface temperature variations for comparison. **The MSL linear rate of 3.21 mm/yr (no GIA adjustment) is derived after removal of annual and semi-annual signals. The global MSL rate is modulated by inter-decadal type signals (such as El Nino and La Nina**). The top right figure shows regional MSL rates during the development of the 1997 El Niño while the lower figure shows impact of current La Niña conditions. The launch of OSTM (Jason-2) will further extend the TOPEX & Jason-1 altimeter data time series and will improve detection of subtle longer-period signals and allow a better understanding of their impact on future MSL trends.

Beckley, B., F. Lemoine, S. Luthcke, R. Ray, and N. Zelensky, NASA Goddard Space Flight Center, May 2008

Polar stratospheric clouds:

What do we know of their role in the polar ozone loss process…from observations? *A case study*.



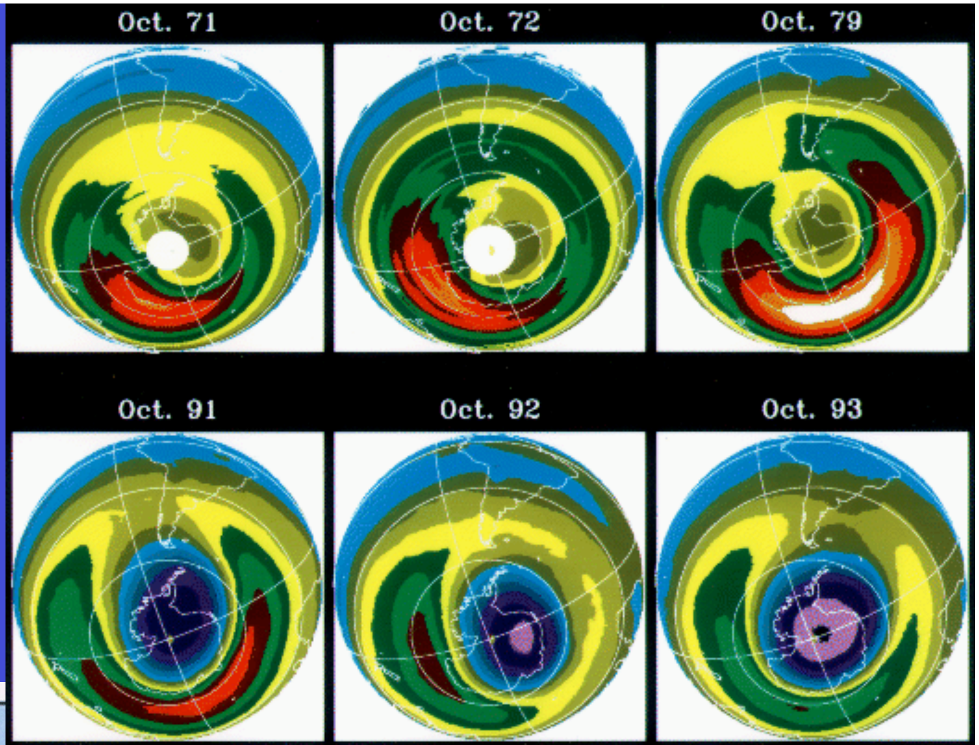
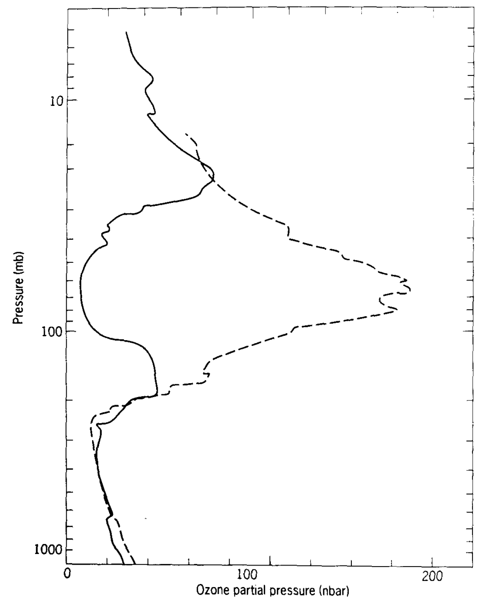
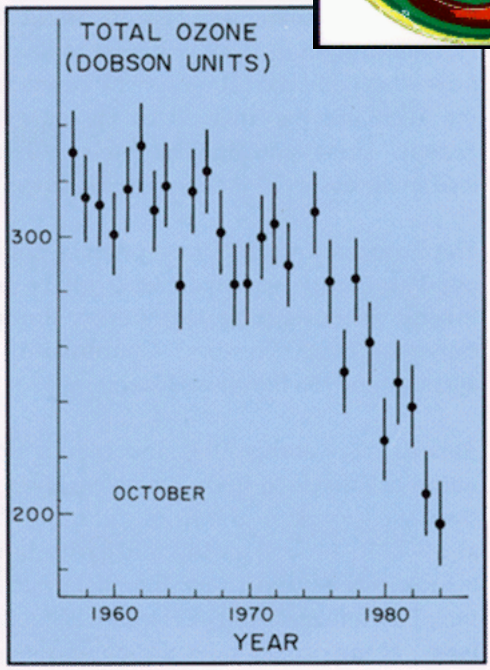


Figure 7: *Vertical distribution of ozone partial pressure (nbar) observed at Halley Bay Station on 15 August 1987 (high values), and 15 October 1987 (low values), respectively.*



Source : J. C. Farman (in WMO 1990a).



The first sign of the Ozone Hole: October ozone amounts at Halley Bay, Antarctica.

Discovering the "ozone hole" : *remote sensing and in situ measurements*

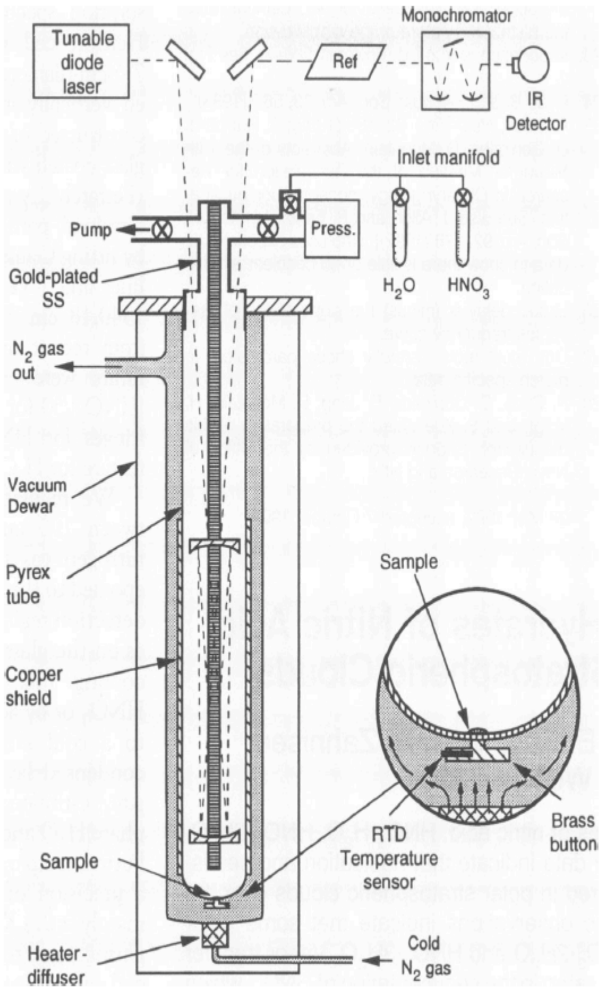
The ER-2 Aircraft

Vapor Pressures of Solid Hydrates of Nitric Acid: Implications for Polar Stratospheric Clouds

Douglas R. Worsnop,* Lewis E. Fox, Mark S. Zahniser, Steven C. Wofsy

SCIENCE • VOL. 259 • 1 JANUARY 1993

Fig. 1. Experimental apparatus; SS, stainless steel. Gas-phase HNO_3 and H_2O mixtures are condensed on the coldest point at the bottom of the Pyrex chamber. A thermal gradient, between the cold spot above the brass button and the warmer side walls heated by the copper shield, confines the size of the condensed sample to ≤1 cm diameter (inset). Gas-phase equilibrium vapor pressures are measured by infrared (IR) laser absorption using multiple pass mirrors.



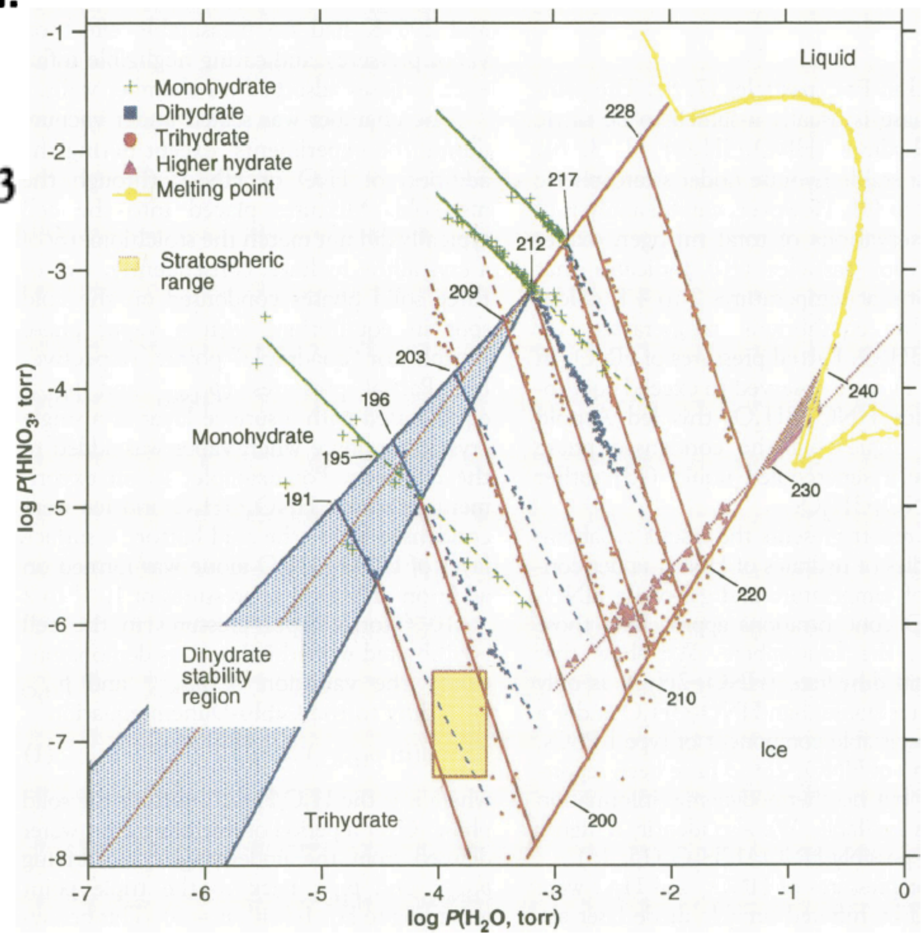


Fig. 2. Nitric acid–water phase diagram [log p_{HNO_3}(torr) versus log p_{H_2O} (torr)], with data for each phase-coded by color and symbol as shown in the key. Color-coded lines with slopes −1, −2, and −3 represent the Gibbs-Duhem relation (Eq. 1) at the specified temperature for the corresponding value of n. Solid and dashed lines denote stable and metastable phases, respectively. Lines with positive slopes delineate phase boundaries between ice, $HNO_3 \cdot 3H_2O$, $HNO_3 \cdot 2H_2O$, and $HNO_3 \cdot H_2O$ for stable (solid lines) and metastable (dotted lines) phases calculated from the equilibrium constants determined in Fig. 3. A higher hydrate was observed in coexistence with ice as shown (magenta). The shaded areas show regions of stability for $HNO_3 \cdot 2H_2O$ and the higher hydrate (blue and magenta, respectively). The melting point curve is interpolated based on the use of two sets of data from Pickering (*15, 16*).

Polar stratospheric clouds: Laboratory measurements

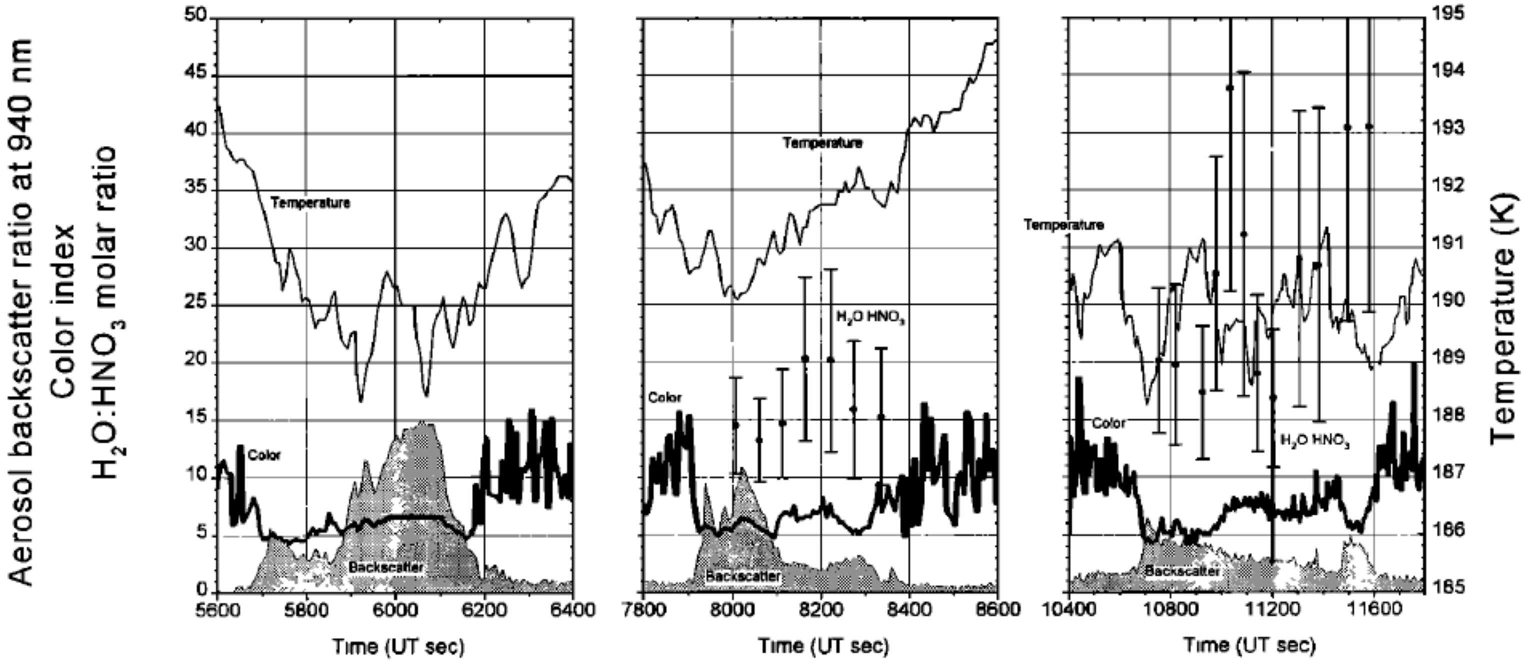


Figure 1. Composite plot of chemical and optical measurements as a function of time (UT seconds) during the balloon-borne flight from Kiruna on January 25, 1998. The upper panel shows the aerosol backscatter ratio (β_{940}, shaded area), air temperature (thin solid), geopotential altitude (thick solid), and air pressure (dotted) throughout the whole flight. PSC layers were encountered around 6000, 8000, and 11,000 s as seen from the elevated values of the backscatter ratios. The lower panels show in more detail, during these PSC encounters, the aerosol backscatter ratio, color index (β_{940}/β_{480}, thick solid curve), temperature, and the H_2O:HNO_3 molar ratios (symbols with error bars), measured during the last two PSC encounters. Temperatures are read off the right-hand axes, the other quantities off the left-hand axes.

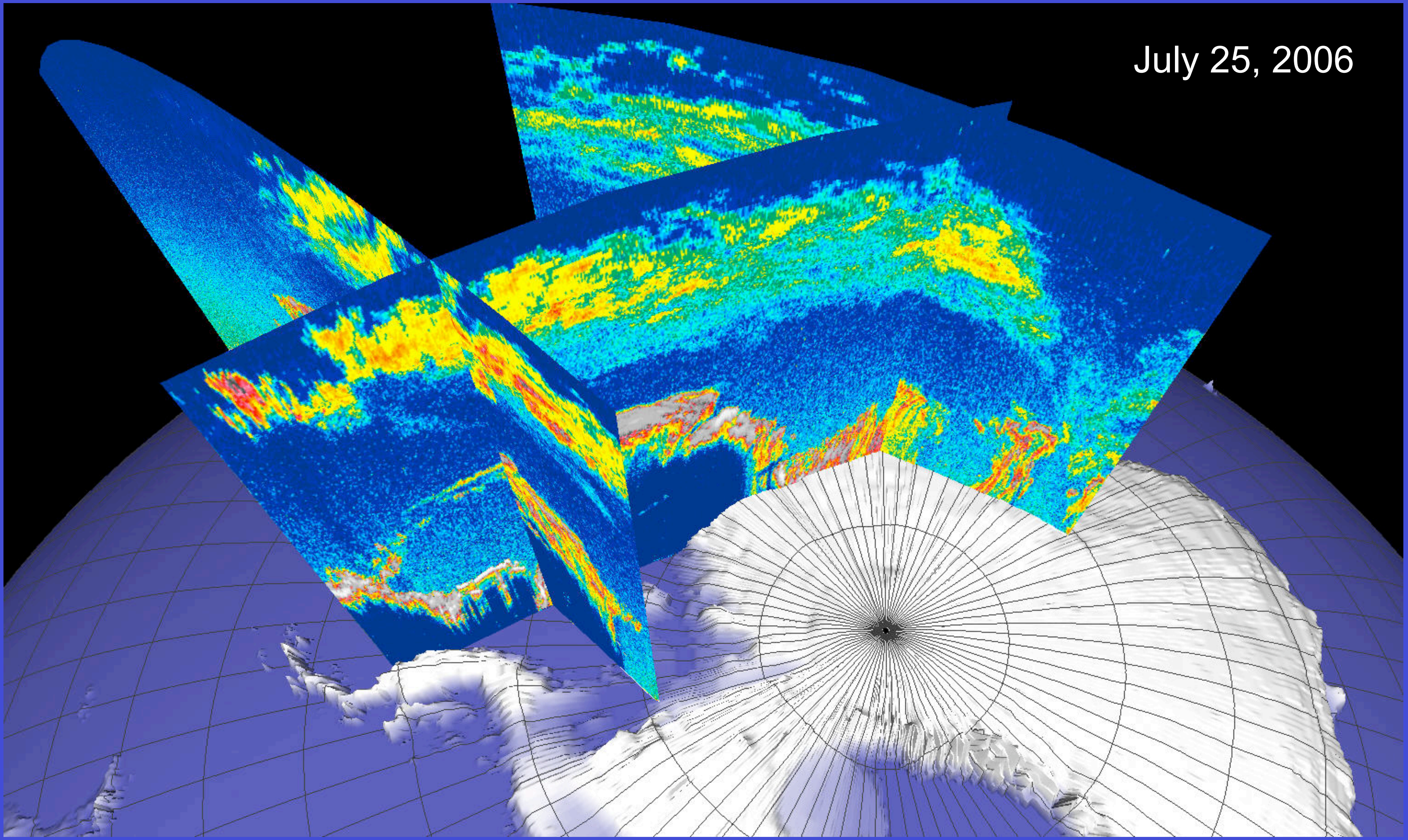
LARSEN ET AL.: CHEMICAL AND OPTICAL PSC MEASUREMENTS

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 105, NO. D1, PAGES 1491–1502, JANUARY 20, 2000

In situ; balloon, aircraft

CALIPSO Observations of Polar Stratospheric Clouds (PSCs)

Critical agents for formation of the Antarctic ozone hole



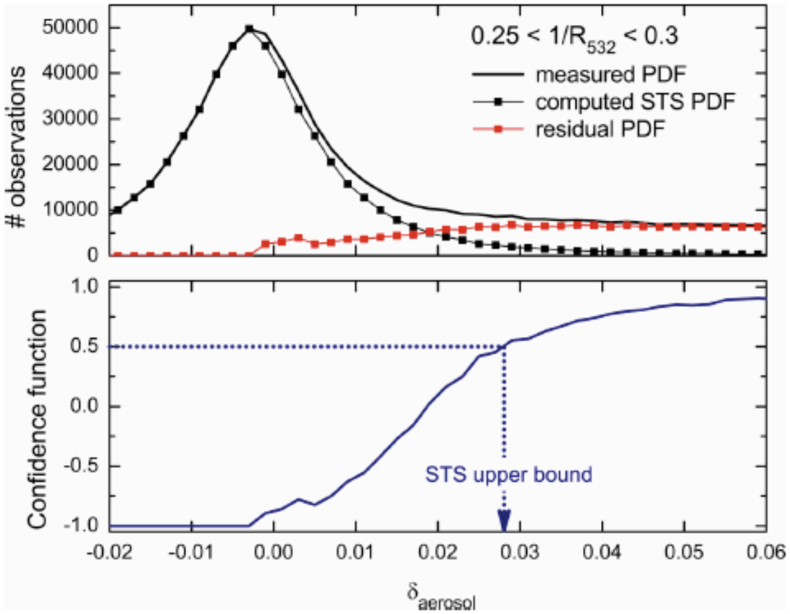


Fig. 9. Illustration of procedure used to define the upper bound in $\delta_{\mathrm{aerosol}}$ for the STS PSC composition class.

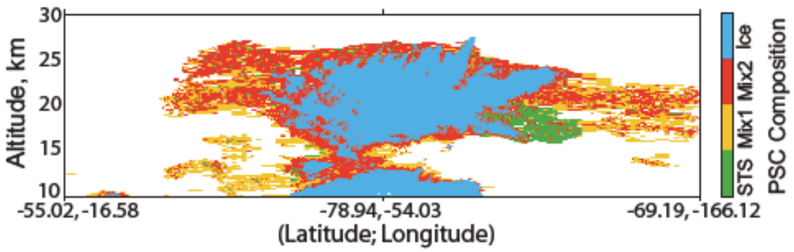


Fig. 10. PSC composition discrimination for the cloud scene from 24 July 2006 (same scene as shown in Fig. 2).

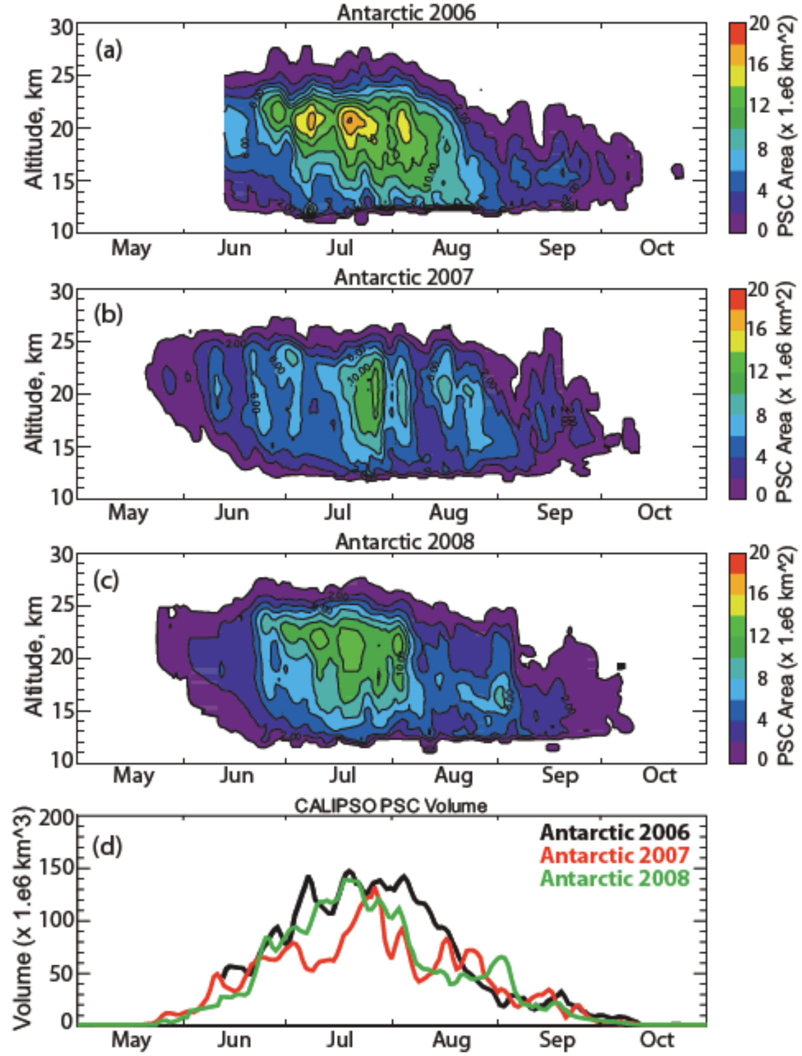
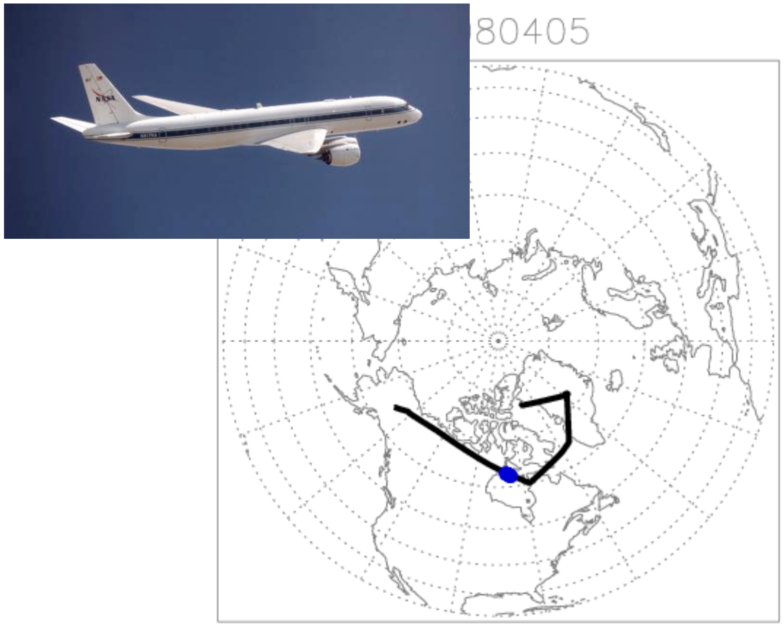


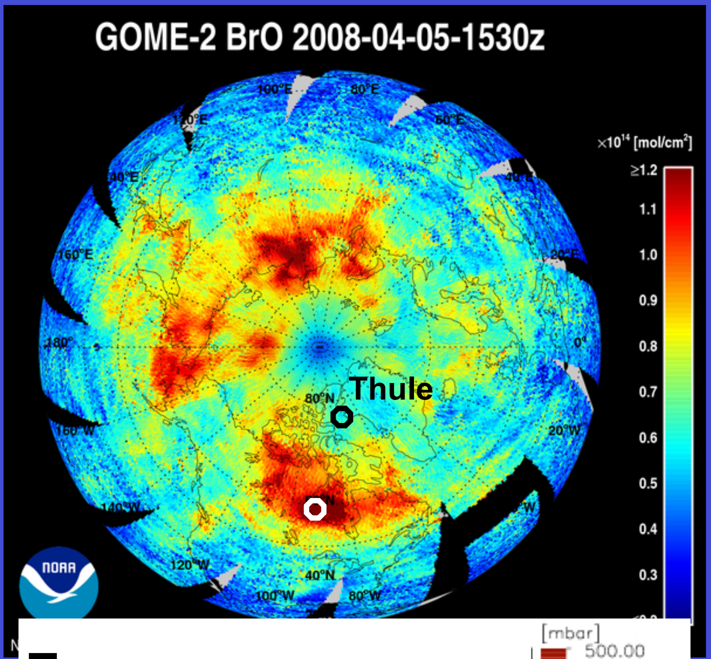
Fig. 11. Daily time series of CALIPSO PSC area as a function of altitude for the **(a)** 2006, **(b)** 2007, and **(c)** 2008 Antarctic seasons. The total volume PSC coverage for all three seasons is shown in panel **(d)**.

SATELLITE OBSERVATIONS OF BROMINE MONOXIDE (BrO)

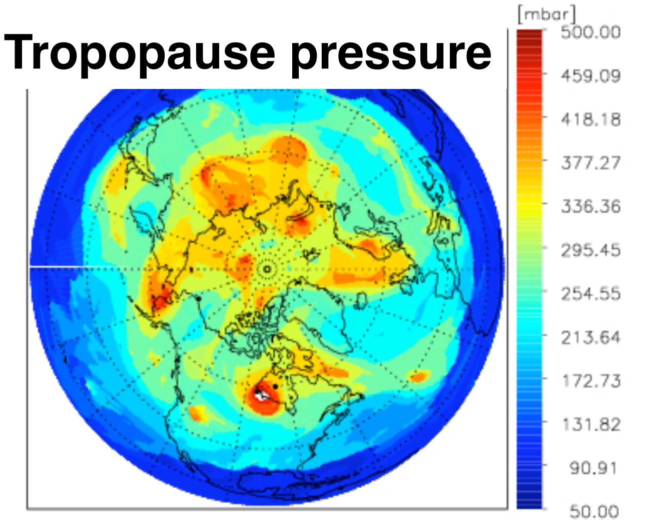
…and aircraft validation during the ARCTAS mission (spring 2008)



NASA DC-8 flight on April 5, 2008



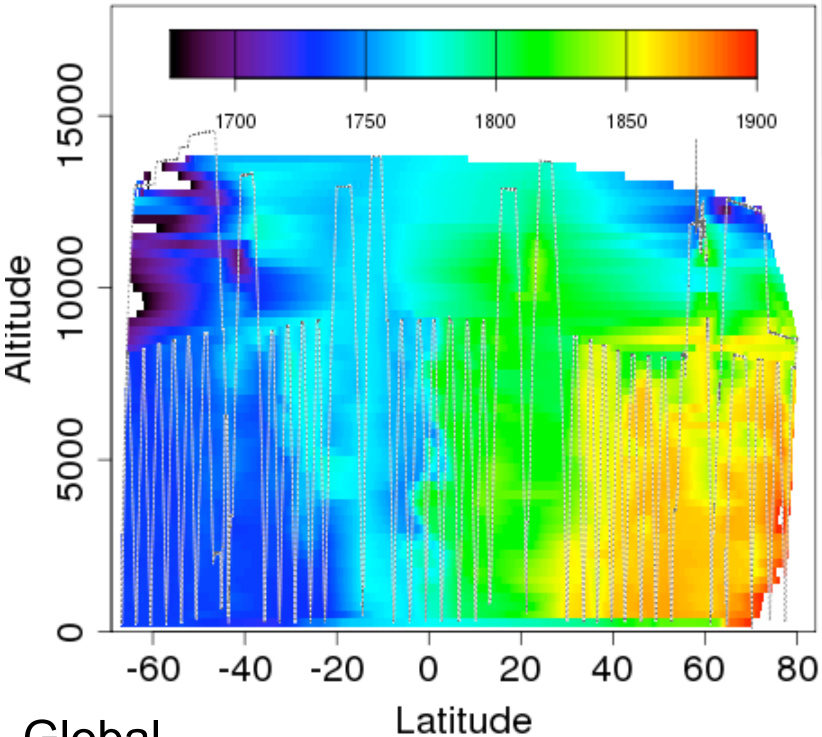
Tropopause pressure



Aircraft in-situ data show that elevated BrO seen from space is in stratosphere, not troposphere

HIAPER Pole-to-Pole Observations 2009 (“HIPPO”)

Steven C. Wofsy



Global CH_4

Overview of mission framework and observations

Brooks Range, AK

HIPPO (HIAPER Pole-to-Pole Experiment)

- **Science Objectives:**

Utilize observed distributions of major greenhouse gases to help determine the continental-scale sources and sinks of major greenhouse gases.

- **Motivation:**

Models obtained the global distributions of surface fluxes for GHGs by optimizing *a priori* emission rates to match time series observations at surface stations.

- **Result:**

Models fit the data! But they give very different results for the optimal fluxes ☹ … *even using the same data and flux regions [TRANSCOM 3]*.

- One factor: different vertical mixing [*Stephens et al. 2007*].
- Another: spatial/temporal distributions of surface flux.

***Transport rates** (emergent property) and **spatial distributions of surface flux** are not readily optimized in inverse analyses.*

Surface networks: (almost) global; sustained over time.
No vertical structure, limited resolution of horizontal gradients, key regions not sampled (e.g. Southern Ocean).

Satellite Data: (almost) global; moderately sustained.
Poor resolution of *vertical distributions in the troposphere*; cannot view *cloudy* (e.g. ITCZ) or *polar* regions.

Aircraft Data: fine grained, (may) cover the vertical profile.
Infrequent, "one shot", short-term, limited areas.

HIPPO, *is a new type of data set:*
global *and* ***extremely fine grained.*** *Detailed vertical and horizontal gradients.* ***Repeated*** *5 times for all seasons; very wide range of constituents.*

GEOSECS is a role model for **HIPPO. Cross Sectional Data to assess and challenge models, develop new questions, test ideas, and provide a reference data set for detection of future change. Requires absolutely calibrated data, repeated very long transects, comprehensive tracer suite for applications not yet envisioned.**

Comparing the Observed and Modeled Gradients

- 3 models that most closely reproduce the observed annual-mean vertical CO_2 gradients (4, 5, and C):

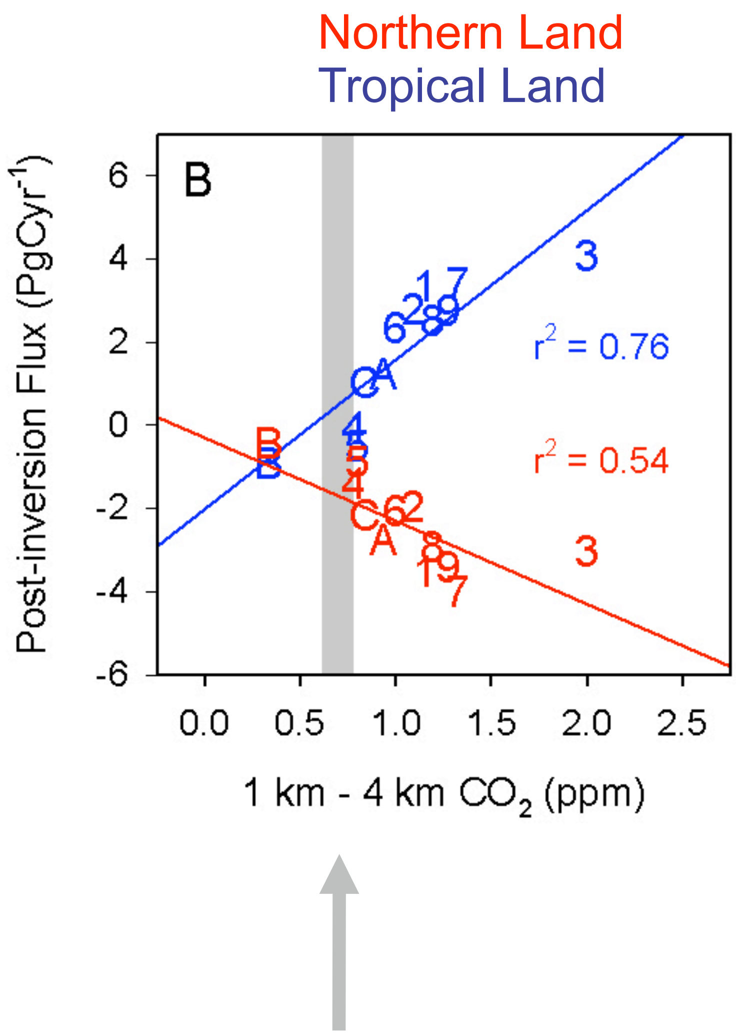
  Northern Land = -1.5 ± 0.6 $PgCyr^{-1}$

  Tropical Land = +0.1 ± 0.8 $PgCyr^{-1}$

- All model average:

  Northern Land = -2.4 ± 1.1 $PgCyr^{-1}$

  Tropical Land = +1.8 ± 1.7 $PgCyr^{-1}$

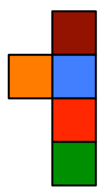


Observed value

Most of the models overestimate the annual-mean vertical CO_2 gradient

Slide courtesy Britt Stephens (NCAR)

HIPPO Aircraft Instrumentation

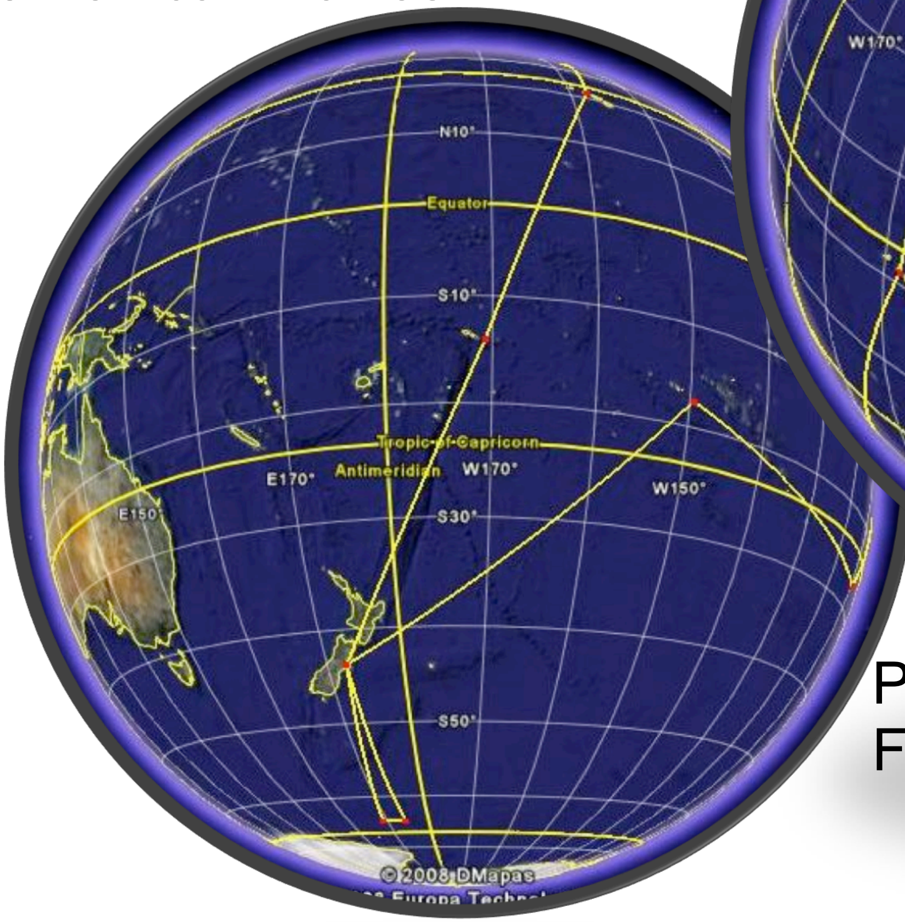
Harvard/Aerodyne—HAIS QCLS	**CO_2**, **CH_4**, **CO**, **N_2O** (*1 Hz*)
NCAR AO2	O_2:N_2 , **CO_2** (*1 Hz*)
Harvard OMS CO_2	**CO_2** (*1 Hz*)
NOAA CSD O_3	O_3 (*1 Hz*)
NOAA GMD O_3	O_3 (*1 Hz*)
NCAR RAF CO	**CO** (*1 Hz*)
NOAA- UCATS, PANTHER GCs (1 per 70 – 200 s)	CO, **CH_4**, **N_2O**, CFCs, HCFCs, **SF_6**, CH_3Br, CH_3Cl
Whole air sampling: NWAS (NOAA), AWAS (Miami), MEDUSA (NCAR/Scripps) 	O_2:N_2, **CO_2**, **CH_4**, **CO**, **N_2O** , other GHGs, **COS**, halocarbons, solvent gases, marine emission species, many more
Princeton/SWS VCSEL	H_2O (*1 Hz*)
NOAA SP2	Black Carbon (*1 Hz*)
MTP, wing stores, etc	T, P, winds, aerosols, cloud water

HIPPO_1 Global Mission:

09 – 30 January 2009

46 000 km

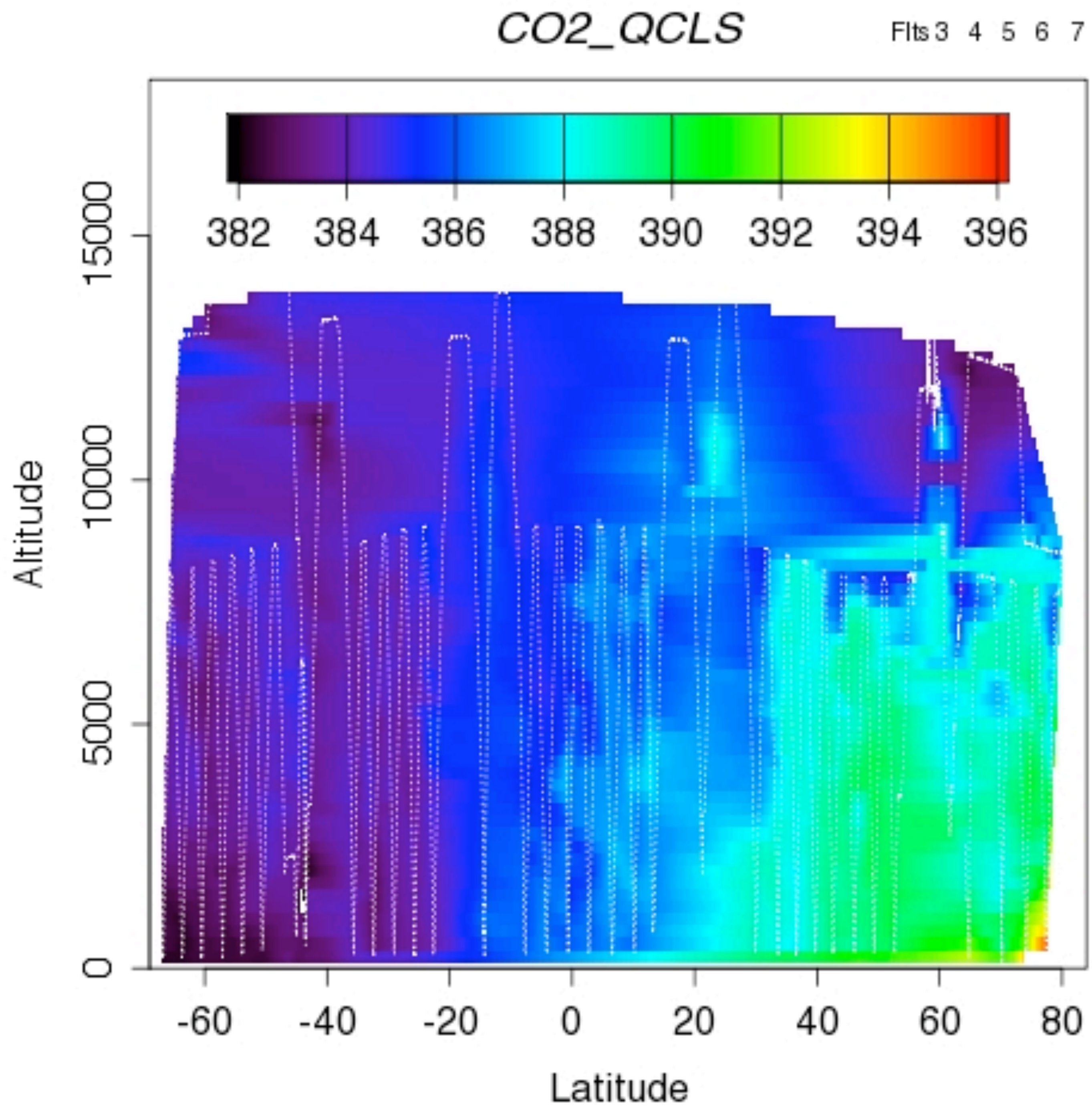
135 Vertical Profiles

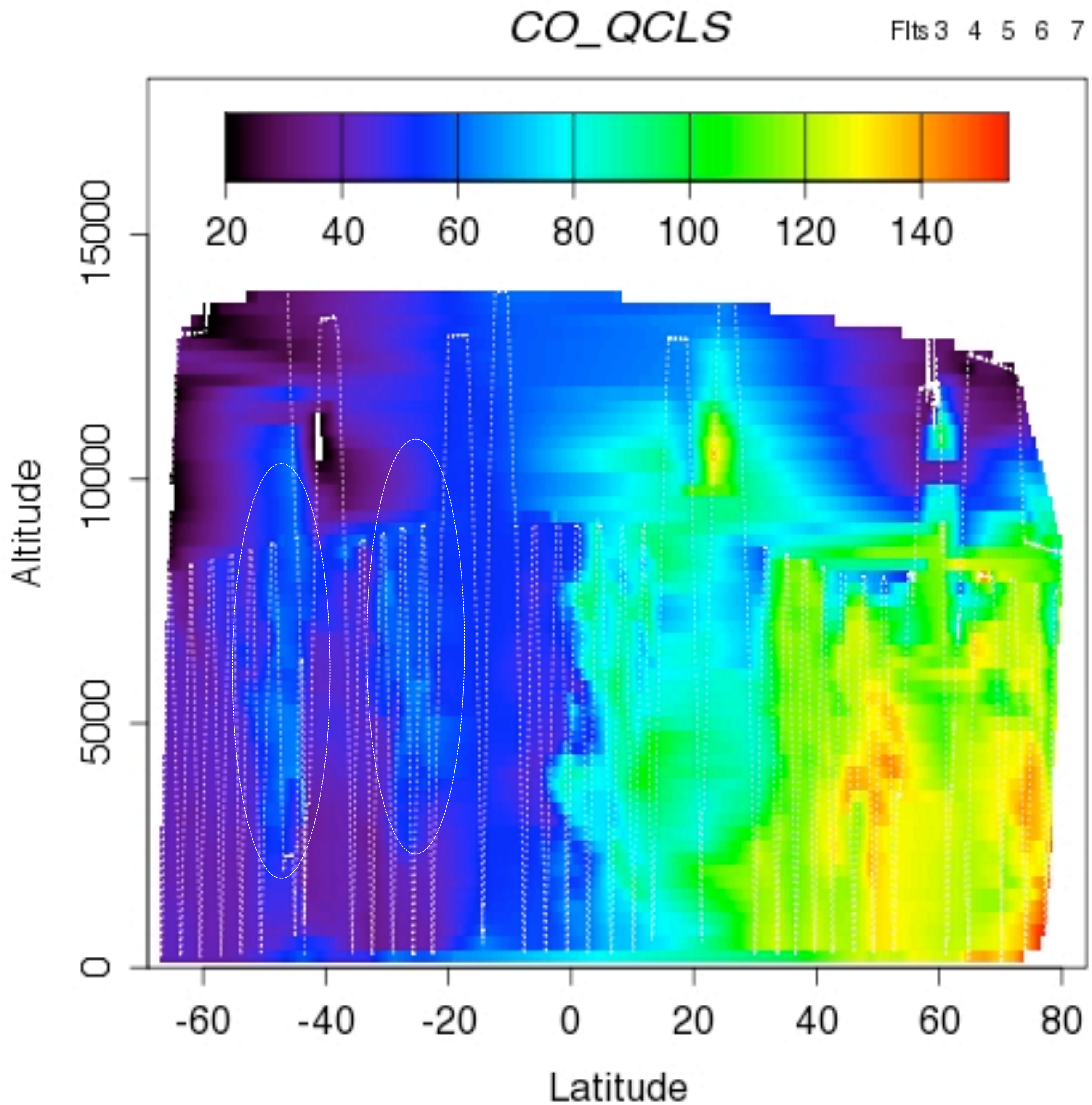


Platform: NCAR Gulfstream V
Funding: National Science Fdn
plus: NOAA, NASA, Harvard

1 Regional (N. Am, "Pre-HIPPO")
5 global missions

N677F
National Center for Atmospheric Research
NSF
National Science Foundation


CO2_QCLS
Flts 3 4 5 6 7
382 384 386 388 390 392 394 396
Altitude
0
5000
10000
15000
-60 -40 -20 0 20 40 60 80
Latitude



CO_QCLS
Flts 3 4 5 6 7
20
40
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Altitude
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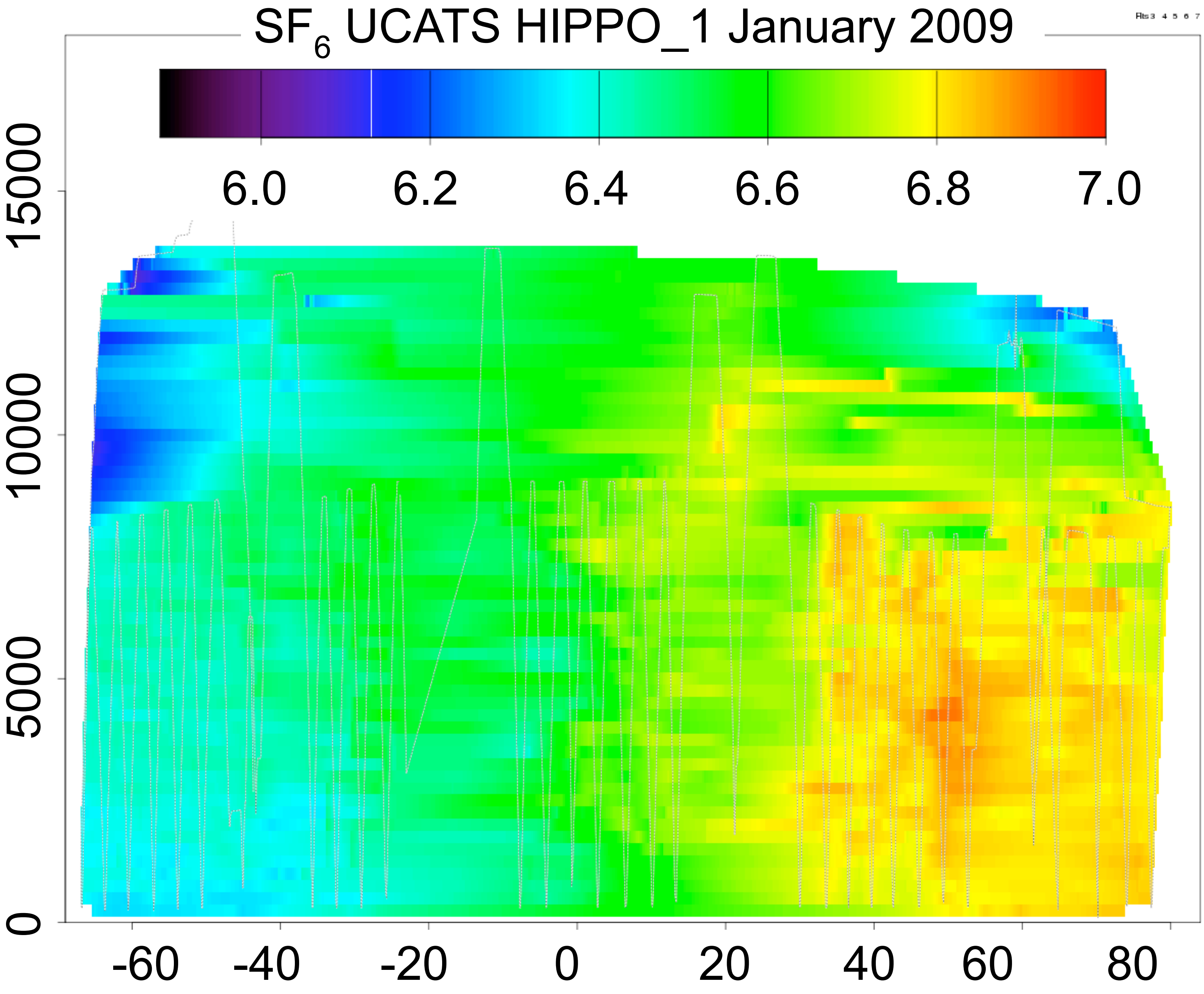
80
Latitude


SF6 UCATS HIPPO_1 January 2009
6.0
6.2
6.4
6.6
6.8
7.0
15000
10000
5000
0
-60
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-20
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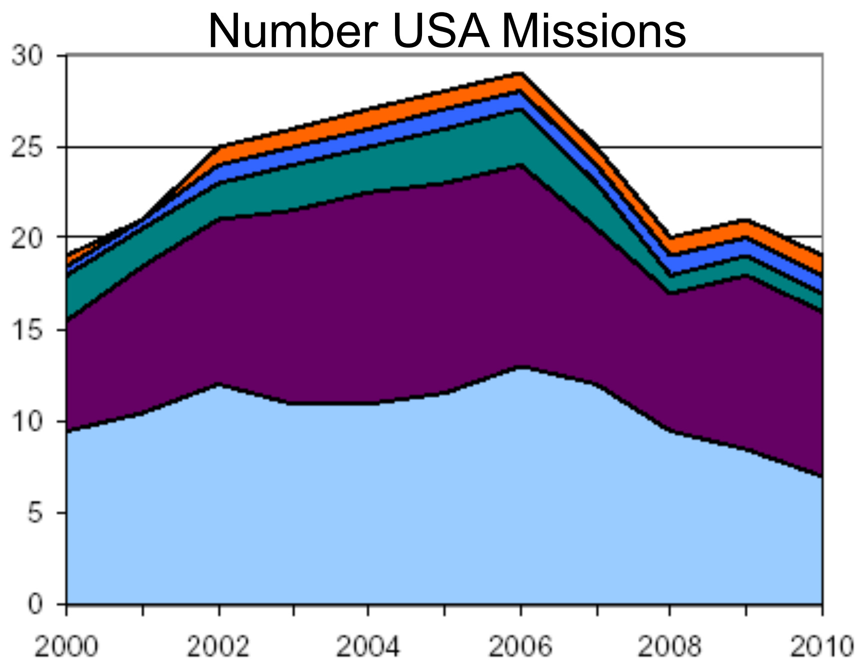
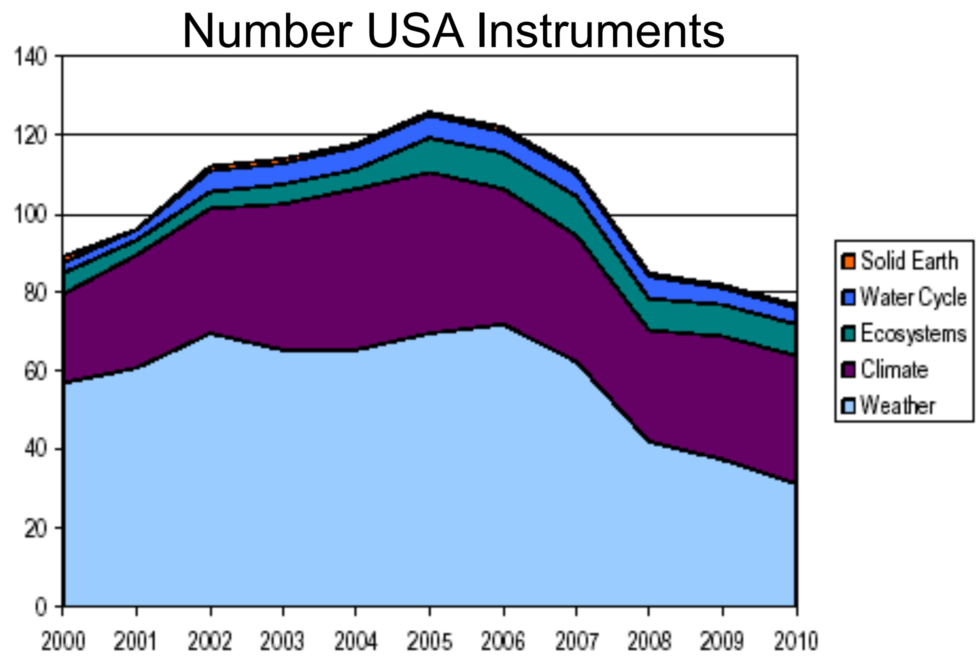
20
40
60
80

REDUCED NASA BUDGETS FOR EARTH SCIENCE HAVE COMPROMISED FUTURE OF EARTH OBSERVATION FROM SPACE



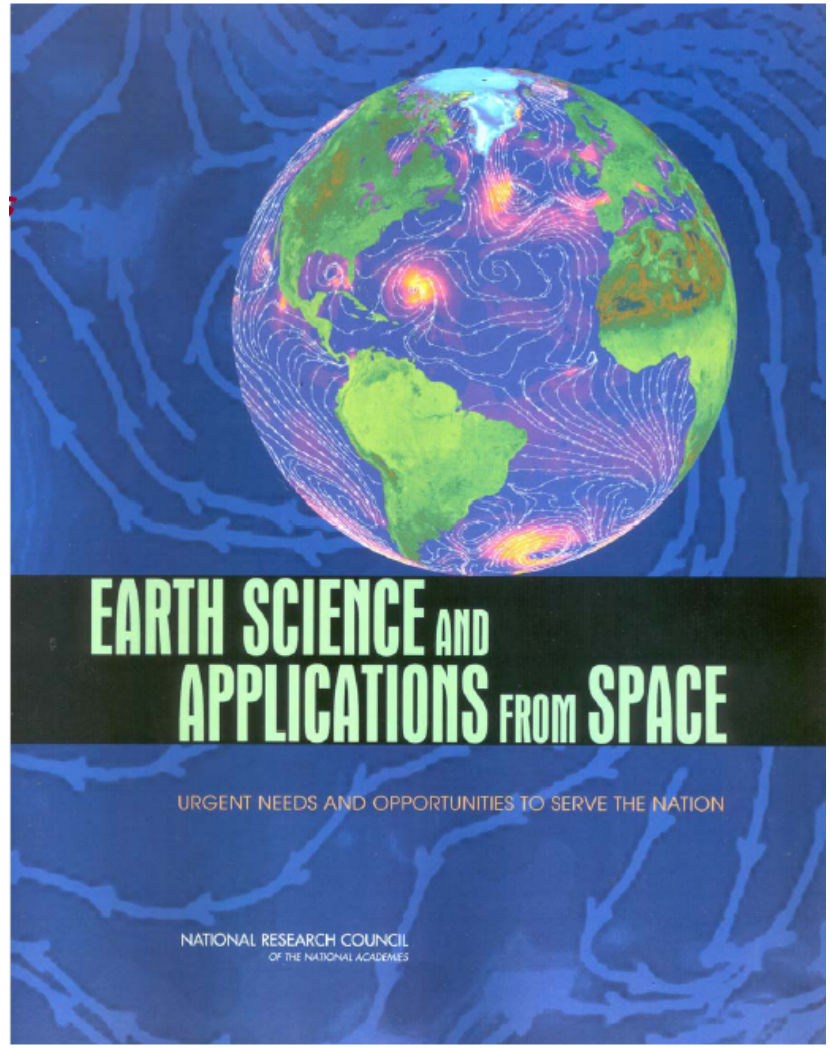


"Today, the system of environmental satellites is at risk of collapse."
Decadal Survey Interim Report, April 2005

"At a time of unprecedented need, the nation's Earth observation satellite programs, once the envy of the world, are in disarray." ***Decadal Survey Final Report, January 2007***

National Research Council Decadal Survey (Jan 07)

- Assembled by a broad committee and panels of Earth scientists with strong community input, NRC oversight
- Identifies societal priorities for Earth Science at a time of great public concern over global environmental change
- Does so in the face of decimated NASA budgets for Earth Science (down 30% since 2000)
- Presents a recommended schedule of NASA satellite missions for the next decade (2010-2019)

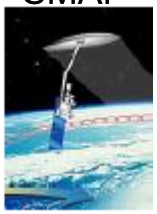


17 Recommended New Missions by the Decadal Survey: "Minimal Yet Robust Program"

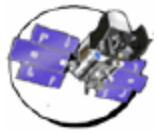
"2013-2016"

"2010-2013"

SMAP

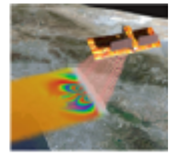


ICESat-II



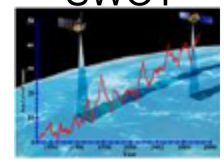
& LIST

CLARREO



DESDynI

SWOT

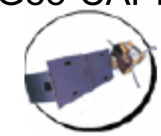


A very well thought-out and balanced program – but:

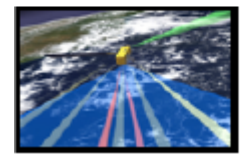
- **de facto delay of at least 3 years (1st launch planned in 2013)**
- **would require tripling of NASA Earth Science budget of 1.5B**
- **is not built on collaboration with international space partners**
- **does not take into account new developments: NPOESS debacle in transition to monitoring, failed OCO launch, stratospheric monitoring gap…**

…needs a review!

Geo-CAPE



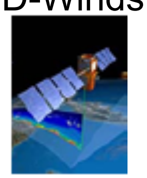
ACE



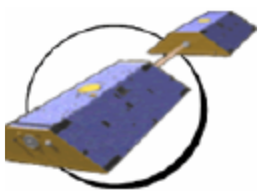
HyspIRI

ASCENDS

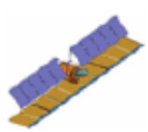
3D-Winds



GRACE-II



SCLP

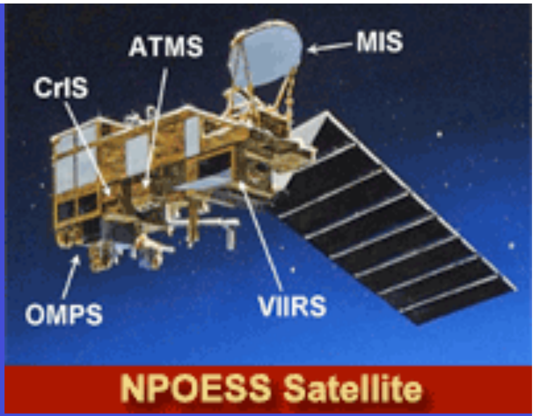


PATH

GACM

"2016-2019"

National Polar-Orbiting Environmental Satellite System (NPOESS)



- Next generation of NOAA/DoD operational satellites, starting in 2016

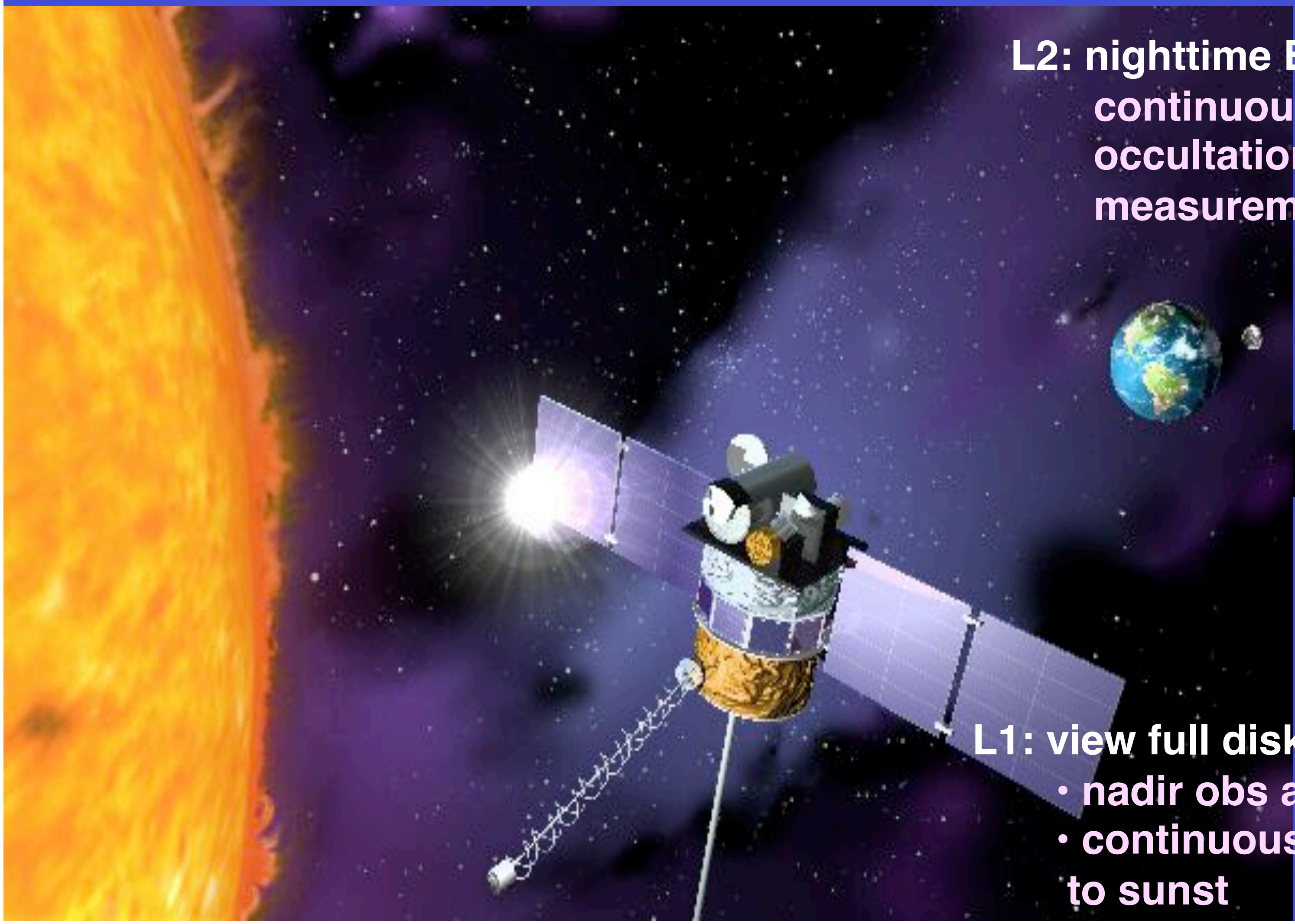
- …was intended to include long-term monitoring of critical climate variables through "transition to operations" of NASA instruments for solar irradiance, outgoing infra-red radiation, surface temperatures, stratospheric ozone profiles, aerosols

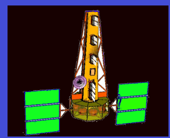
- …went into >20% cost over-runs in 2006 that required reconfiguration

- …climate sensors were the first to be descoped; timid re-scoping since then

Long-term records are critical for climate *science,* but cannot count on NPOESS

LAGRANGE POINTS MISSION CONCEPTS





L2: nighttime Earth

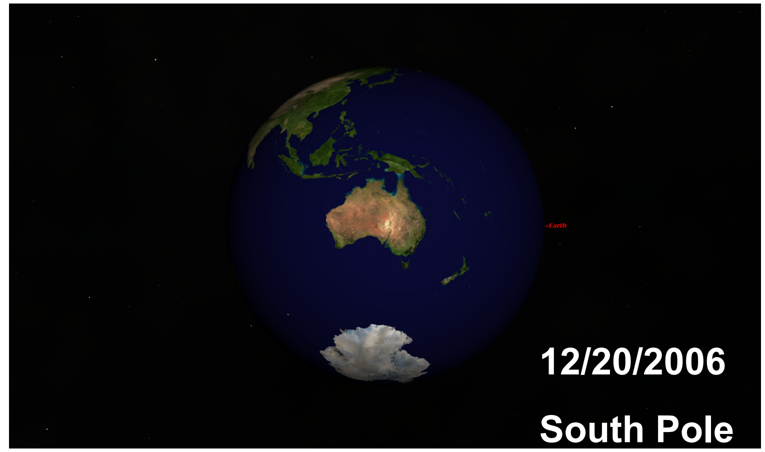
continuous solar occultation measurements

L1: view full disk of sunlit Earth

- nadir obs as in geostationary
- continuous obs from sunrise to sunst

EARTH OBSERVATION FROM THE MOON

as enabled by the NASA Lunar Exploration Program



- **Lunar platform could provide continuous full-disk view of the Earth; a platform at the Earth-Moon L1 point would be particularly attractive**
- **Support from Lunar Exploration Program could enable stable platform, maintenance support, deployment of large hardware**

CONCERNS:

- **Planned location of south polar base is inadequate for Earth viewing**
- **Instrumentation on lunar surface is subject to dust, moonquakes, day-night heating differential, harsh radiation, power storage requirements**

"Observing the Earth" (summary)

- Atmospheric science (environmental science) must rely on observations of the Earth, because classical controlled experiments on the environment are not possible.
- Laboratory experiments are critical complementary elements.
- All types of observations have important roles to play in developing scientific understanding:

- in situ
- remote sensing
- detailed, fine grained ⇔ intermediate ⇔ large scale
- short term, intensive ⇔ intermediate ⇔ long term

The US is sorely in need of an earth observing strategy with commitment and continuity.