National Polar-orbiting Operational Environmental Satellite System (NPOESS)

Advanced Sounder Perspectives for NPOESS 2nd Generation [NexGen]

4th Advanced High Resolution Infrared Observations Workshop 2008 Hosted by EUMETSAT

EUMETSAT, Darmstadt, Germany
September 15-17, 2008

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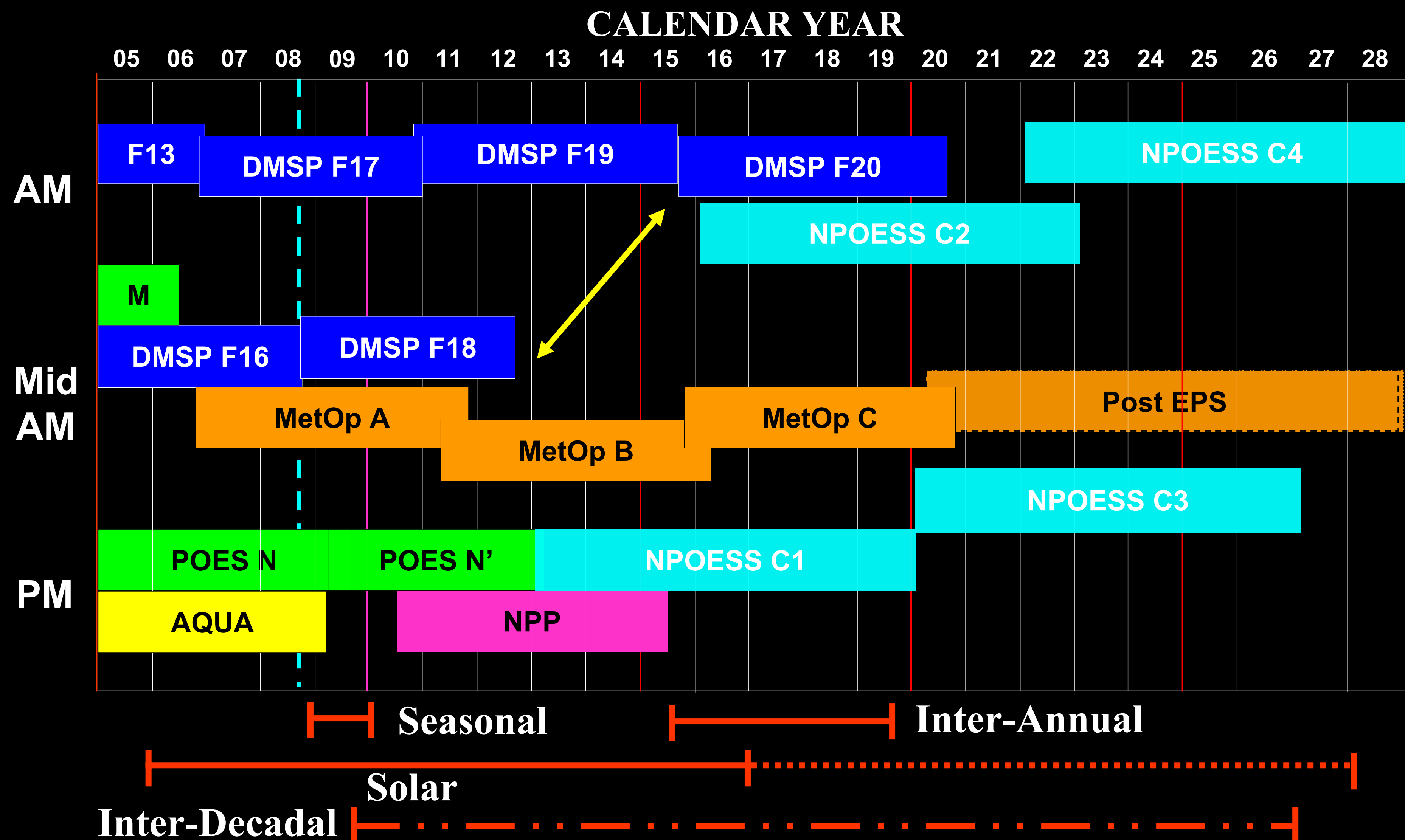
Polar Satellite Constellations

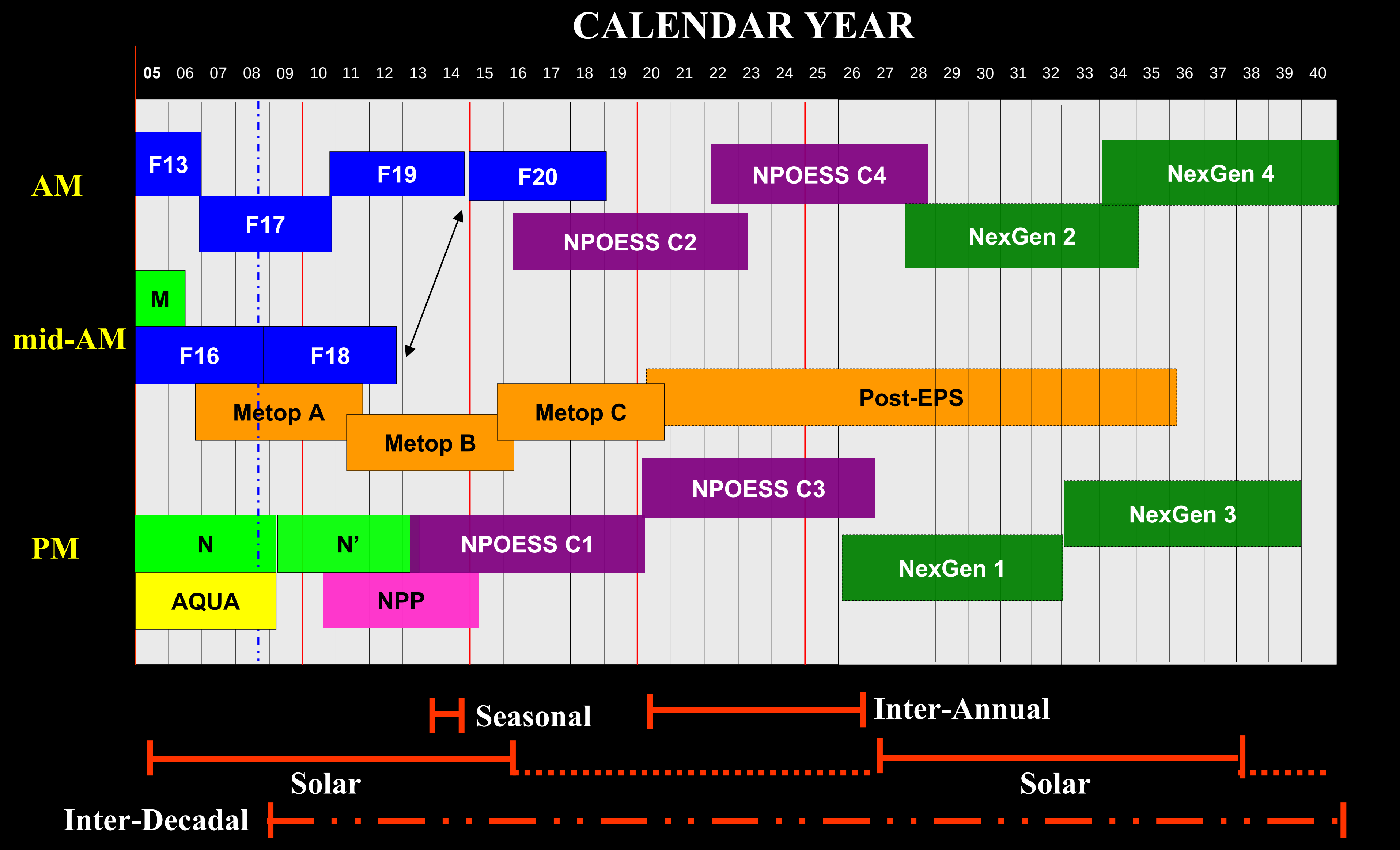
MetOp, NPP, NPOESS "First Generation" ~ 2010-2026 +

Several Climate & Weather [NWP] Time Scales Covered

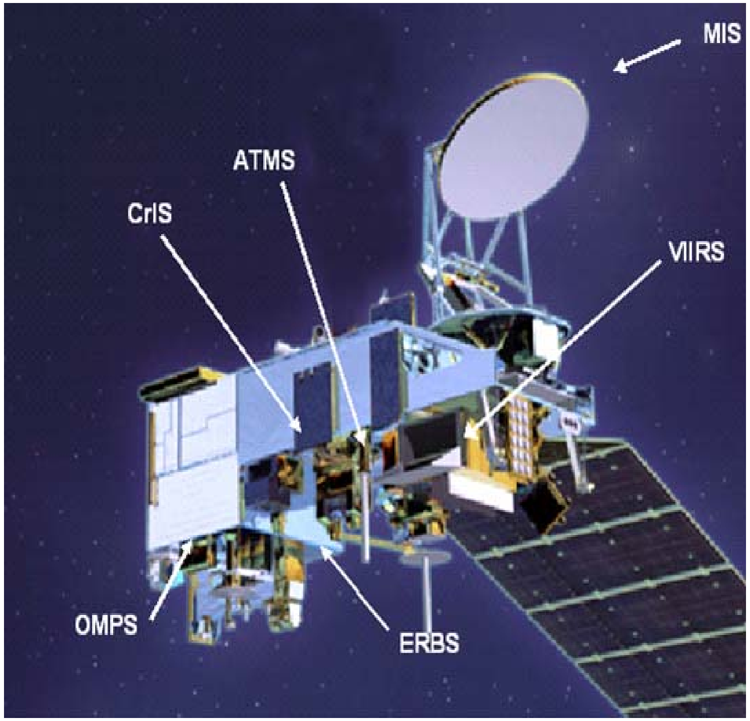


Polar Satellite Constellations

Notional NPOESS "2nd Generation" & European Post-EPS – Post 2026+



NPOESS 1st Generation Satellites & Sensors



Sensor	1330 LAN Afternoon Orbit	1730 LAN Morning Orbit	1330 LAN NPP Mission
Visible/Infrared Imager/Radiometer Suite **VIIRS**	X	X	X
Microwave Imager/Sounder **MIS**	C-3	C2,C4	
Cross-track Infrared Sounder **CrIS**	X		X
Advanced Technology Microwave Sound **ATMS**	X		X
Ozone Mapping and Profile Suite **OMPS**	N		X
Space Environment Monitor **SEM**	X		
Advanced Data Collection System **ADCS**	X	X	
Search & Rescue Satellite Aided Tracking **SARSAT**	X	X	
Cloud's and Earth's Radiant Energy System **CERES**	C-1		X
Total Solar Irradiance Sensor **TSIS**	C-1		

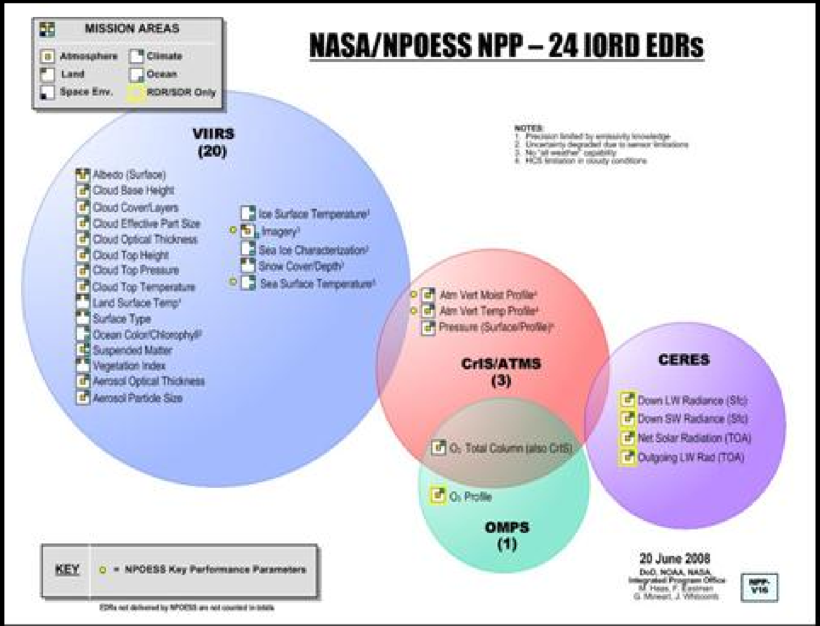
Entries in Blue – Manifested or Remanifested since 2006 NPOESS restructuring

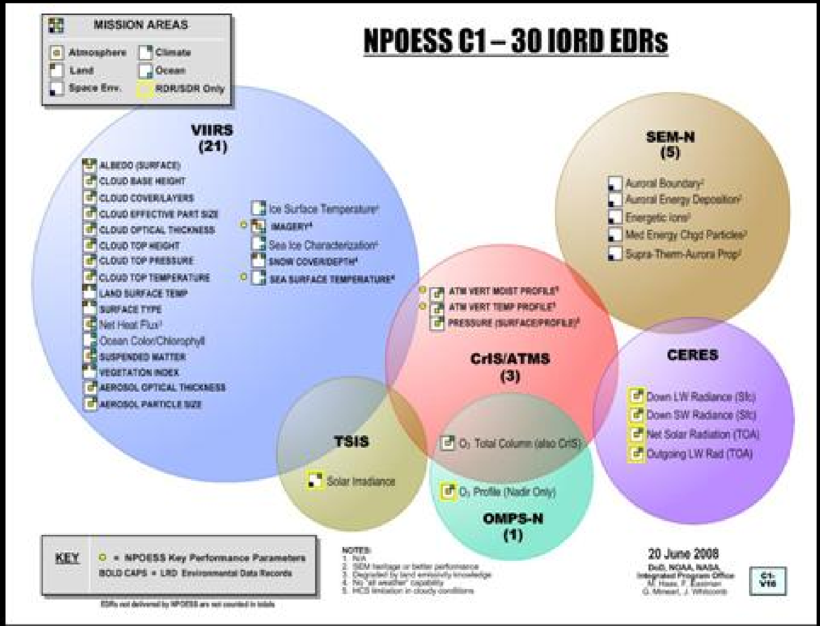
N = Nadir sensors only [total column & nadir profiler]

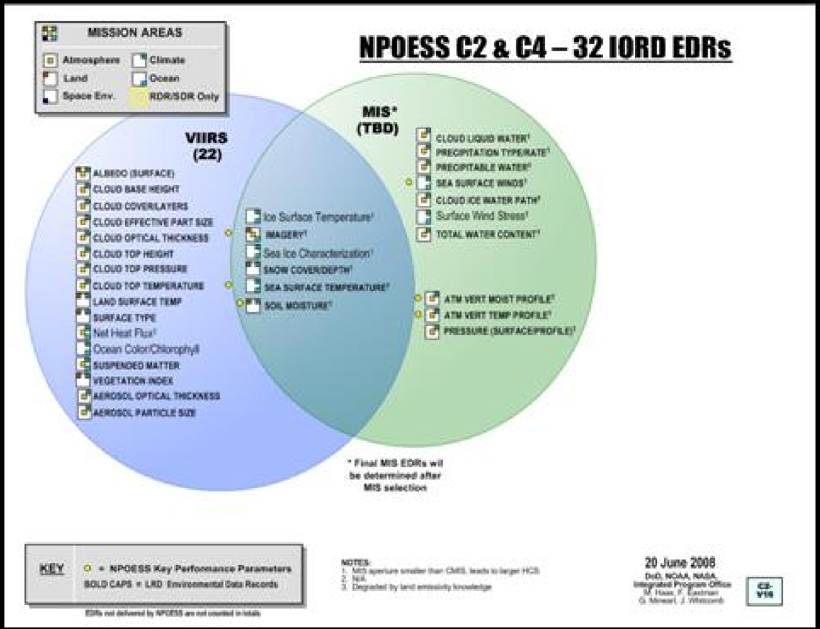
(Rep) = Replaces a demanifested sensor

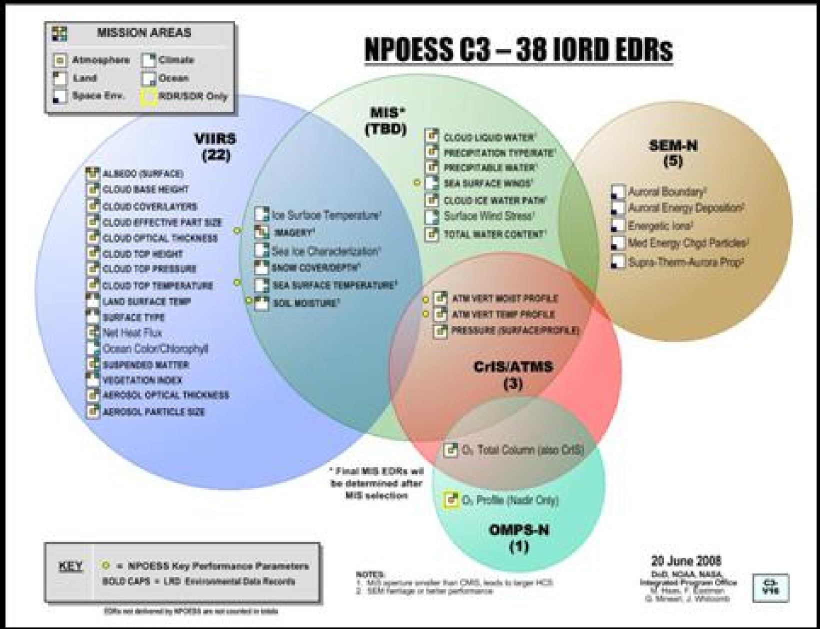
Adapted from ""NPOESS Program Status" – Mike Haas, IGARSS 2008, Boston, MA

NPP & NPOESS 1st Generation EDR [Level 2] Products









Polar Satellite Sensor Products [POES, MetOp, NPOESS]

		Instrument	POES	MetOp	NPOESS
Science Observations	Imagery Sea Surface Temp. Vegetation Snow/Ice Cover Aerosols Radiation Budget	Vis/IR Imager	AVHRR (4 km resolution)	AVHRR (1 km resolution)	VIIRS (0.75 km resolution)
	Radiances	IR and Microwave sounders	HIRS	IASI / HIRS	CrIS
	Atmospheric Temps		AMSU-A	AMSU-A	ATMS
	Atmospheric Moisture Hydrology Products		MHS	MHS	ATMS
	Total Ozone and Profiles	UV Backscatter Sensor Scanning Spectrometer	SBUV	GOME-2	OMPS
	Space Weather	Space Environment Monitor	SEM	SEM	SEM
	Ocean Surface Winds	Scatterometer		ASCAT	MIS

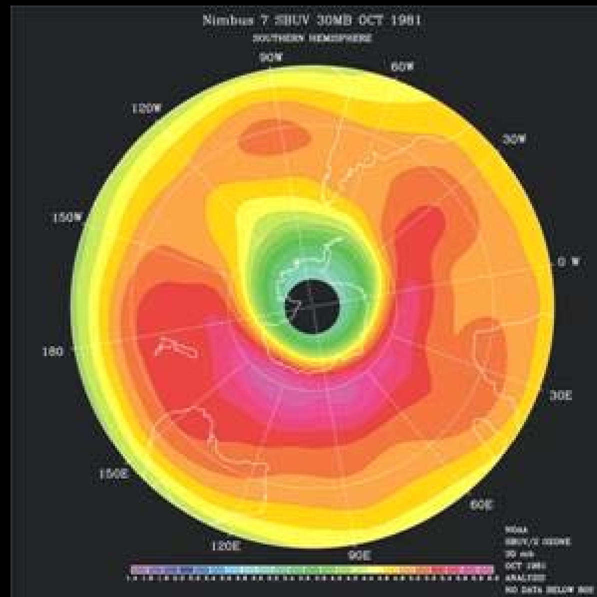
Over 145 Polar Products Available From MetOp data; will be similar for NPOESS 1st Generation

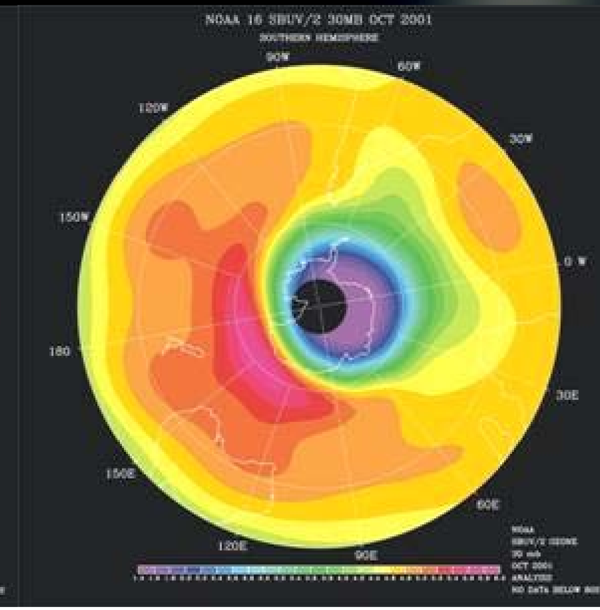
Adapted from NOAA/NESDIS - Tom Schott

Expected Applications of OMPS & CrIS EDRs, SDRs, Intermediate and other Products

Operational

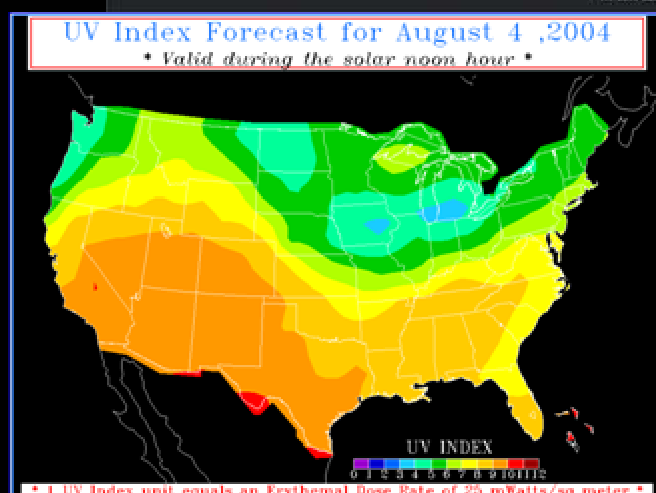
- Assimilation into NWP
- Ozone Hole Monitoring
- UV Index Forecast
- Air Quality Forecasts
- Hazards (Volcanic Ash)
- Space Environment (MgII)

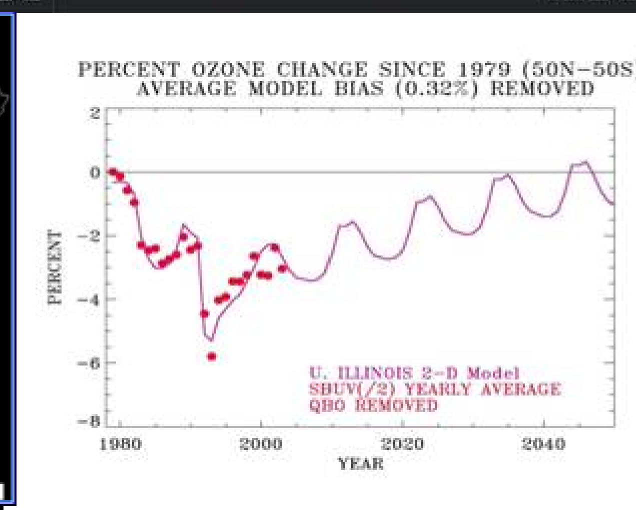




Climate

- Ozone Trends
- Cloud Reflectivity
- Surface UV Trends
- Aerosol Trends
- Atmospheric Chem. Process Studies





Adapted from Lawrence E. Flynn – NOAA / NESDIS

OMPS & CrIS Ozone [O_3] Observations Potential role in NWP / Air Quality / Climate

[e.g. of Improved Products]

Ozone measurements can make at least two types of major contributions to NWP / Air Quality-Human Health / Climate

1. **Improved Assimilations**:

   Features in the ozone total column and in isentropic sections of the ozone profile indicate the locations of fronts and of high and low pressure systems

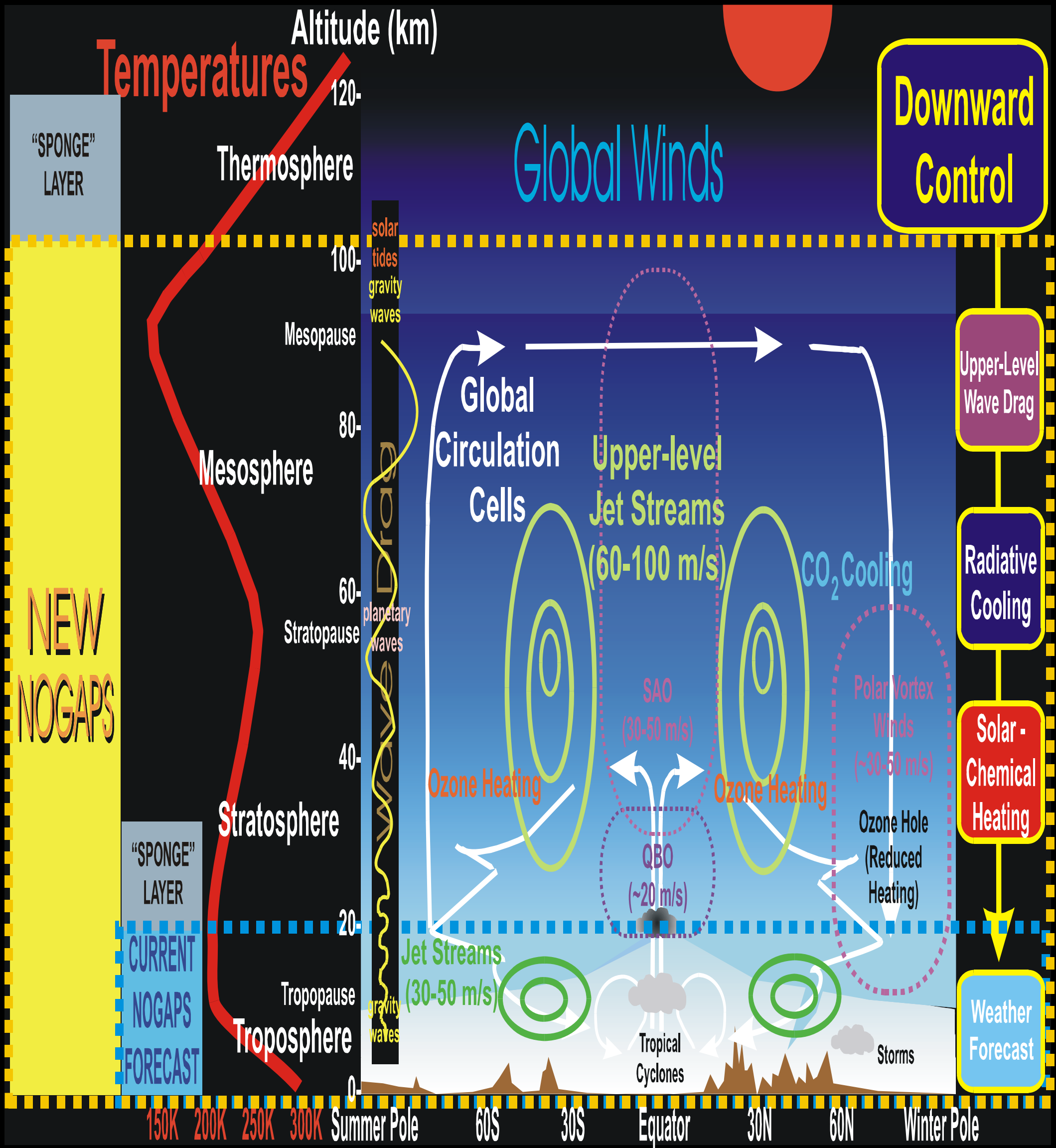
   — Improved input for forecasts of tropospheric and stratospheric weather
   [better "initial values" & "boundary values"]

   — Better maps of UV-A and UV-B at the surface
   [better "boundary values"]

   Isentropic surface = surface of constant potential temperature
   Potential temperature = The temperature an air parcel would have if it were moved adiabatically to 1000 mb [~surface]

2. **Improved Long-Term Forecasts**

Weather / Climate Forecasting - Influence of Ozone [O_3]



NOGAPS = Navy Operational Global Atmospheric Prediction System

Ozone distribution in low and mid-stratosphere

⇓

Temperature distribution in lower stratosphere

⇓

Circulation in lower stratosphere

⇓

Jets and other winds at tropopause

⇓

Formation & steering of surface weather systems

Stratospheric ozone influences tropospheric weather !

2. Improved Long-Term Forecasts

Stratospheric Ozone – Impact on Tropospheric Forecasts

Daily data on stratospheric ozone should improve long-term (6 to 10 day) tropospheric forecasts (available in NPP and NPOESS eras)

-- The stratosphere is a global temperature inversion created when solar UV photochemically produces ozone and then heats that ozone

-- Solar heating and IR cooling of ozone strongly influence (dominate) the temperature distribution in the stratosphere, and hence the winds; in particular, the global jet streams

-- Jet streams steer and influence the lifetime of low pressure systems and affect the upward propagation of gravity and planetary waves, hence, they affect hurricanes, thunderstorms, etc. in the troposphere [i.e. "tropospheric weather"]

-- Short term forecasts depend primarily on daily analyses of the wind field, which already implicitly include the effect of ozone

-- Long term forecasts depend heavily on forecasts of the wind field, which will be correct only if the ozone field is correct

Observations of the Atmosphere

Some Considerations for NPOESS 2st Generation (~2026-2042)

- In addition to the 1st generation NPOESS Capabilities & Products [EDRs & FCDRs]
- For the 2nd Generation NPOESS, NexGen, newer products, [EDRs and FCDRs]/sensors are being studied for potential newer *baselines*, such as:

1. Aerosol Polarimetry Sensor [APS or APS-like]
   [for aerosol EDRs & FCDRs, cloud property EDRs & FCDRs]
2. Improved Cross-track Infrared & Microwave Sensor Suites
   [improved temperature, moisture and pressure profiles and trace/greenhouse/photosynthetically active gases for atmospheric constituents, such as, CO, CH_4, CO_2, N_2O, O_3 EDRs & FCDRs]
3. A Doppler Wind Lidar for vertical wind profile EDRs & FCDRs
4. An advanced CO_2 observation system

National Academy of Sciences Committee on Earth Science Applications from Space [ESAS]

Decadal Survey

May 16, 2005

"Earth Observations from Space: A Community Assessment and Strategy for the Future"

Recommendations for NOAA & NASA R&D Missions; NPOESS a Research-to-Operations Potential Transition Partner

NAS ESAS Decadal Survey Mission Recommendations for NOAA 3 Missions

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 - 2013—Missions listed by cost				
CLARREO (Instrument Re-flight Components)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometers	$65 M
GPSRO	High accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate and space weather	LEO	GPS receiver	$150 M
Timeframe 2013 – 2016				
XOVWM	Sea surface wind vectors for weather and ocean ecosystems	LEO, SSO	Backscatter radar	$350 M

TABLE ES.1 Launch, orbit, and instrument specifications for the recommended NOAA missions. Shade colors denote mission cost categories as estimated by the NRC ESAS committee. Green and blue shadings represent medium ($300 million to $600 million) and small (<$300 million) missions, respectively. Detailed descriptions of the missions are given in Part II, and Part III provides the foundation for selection.

NAS ESAS Decadal Survey Recommendations for NASA 15 Missions

(Pink = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Decadal Survey Mission	Mission Description	Orbit	Instruments	$ Estimate
Timeframe # 1: 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar and Earth radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: # 2: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
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	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M

NAS Decadal Survey Recommendations - 17 Missions

(Pink = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Timeframe # 3: 2016 -2020, Missions listed by cost

LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

***Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high-accuracy SST measurement**

Aerosol radiative forcing remains the largest uncertainty in climate change studies

FY04 US President's budget called for accelerated "development and launch of an <u>advanced polarimeter</u> to increase our understanding of black carbon soot and other aerosols as causes of climate change" .

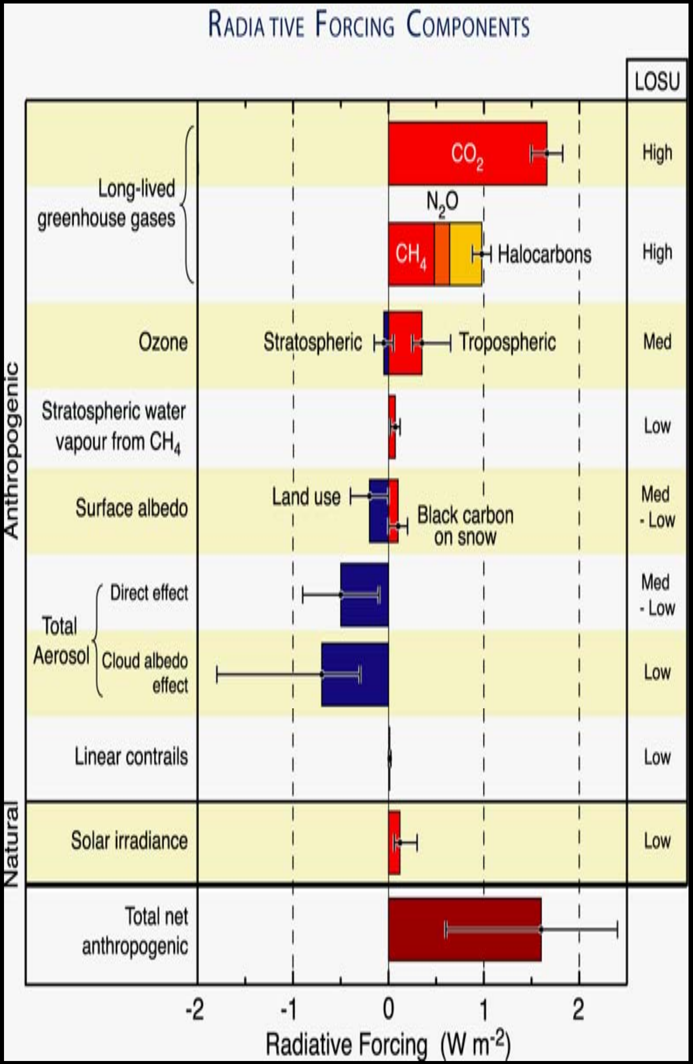
Science objectives of the Glory mission:

- Determine the global distribution of natural and anthropogenic aerosols and clouds with accuracy and coverage sufficient for a reliable quantification of the aerosol direct and indirect effects on climate.
- Start long-term, global, continuous aerosol record as soon as possible.

Aerosols represent the largest uncertainty in climate research

The **direct radiative forcing** due to black carbon aerosols, via absorption of the solar energy followed by re-radiation of the absorbed energy at infrared wavelengths, is positive, i.e., contributes to global warming. *S*ulfates and other nonabsorbing aerosols reflect the Sun's radiation back to space and typically cause cooling.

Aerosols also cause an **indirect cooling effect** by modifying cloud radiative properties and modulating precipitation.

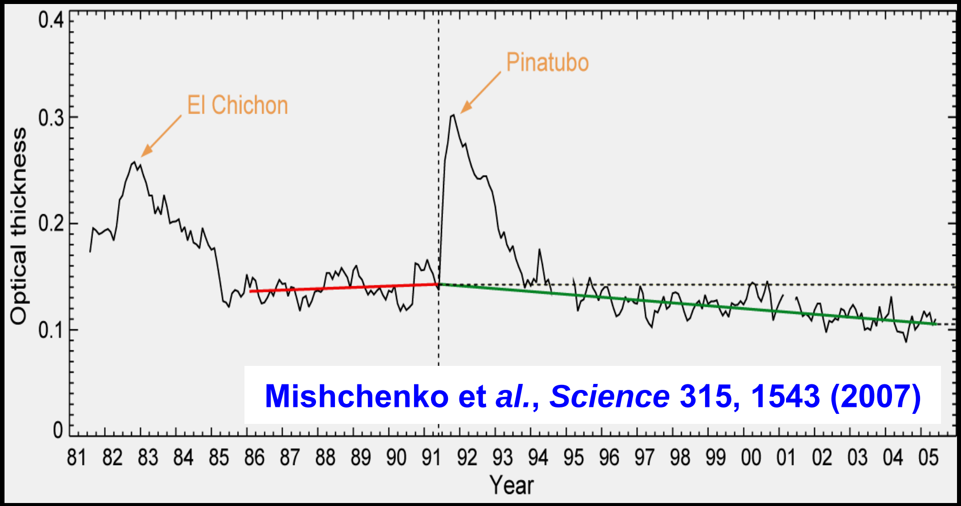


IPCC Summary for Policymakers, 2007

- Estimates of the net aerosol forcing over the 20th century based on the observed warming **range between : –2.6 and –0.3 W m^{-2}**.
- The large uncertainty in total aerosol forcing makes it difficult to accurately infer the climate sensitivity from observations.
- It also introduces large uncertainties in results that attribute cause to observed climate change, and is in part responsible for differences in projections of future climate change.
- The estimated 0.6°C to 1.3°C greenhouse warming has been partly offset by aerosol cooling estimated at 0.1°C to 0.7°C. *IPCC, 2007*

Declining aerosols cannot counterbalance greenhouse gases

AVHRR long-term record



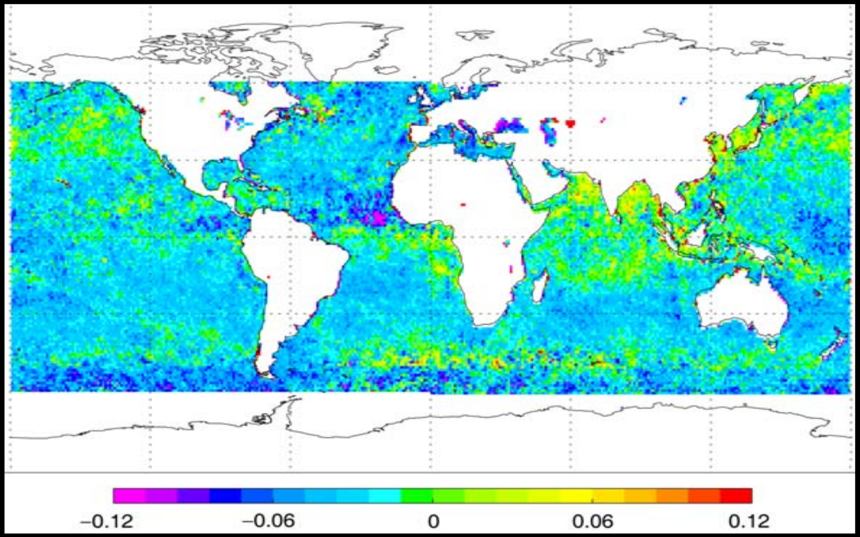
The famous switch from global solar dimming to solar brightening at around 1990 made the Earth less reflective and accelerated global warming. The contemporaneous decrease in the amount of aerosols (plot on the left) may have been partly responsible for this phenomenon.

We do not know definitively whether the decreasing aerosol trend was real and, if yes, whether it was a natural or an anthropogenic event.

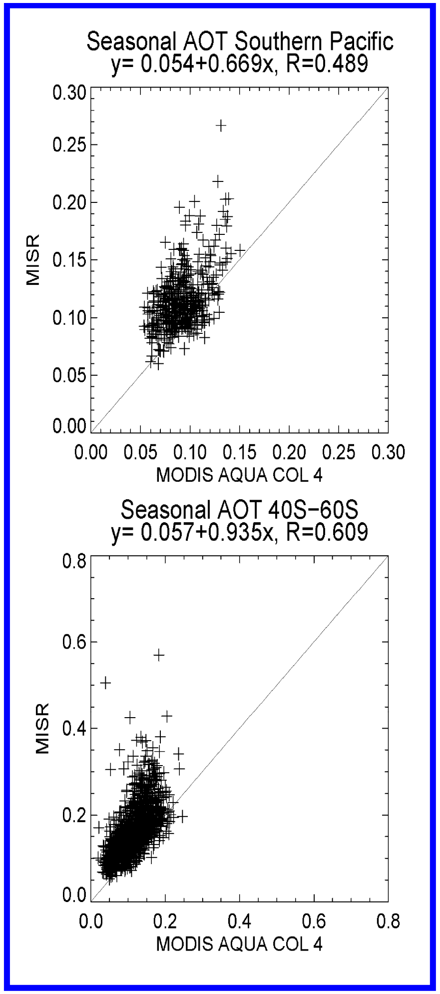
Multi-decadal satellite data appear to reveal strong regional aerosol trends and demonstrate increasing pollution in Asia and reduced aerosol concentrations in much of Europe (plot on the right).

However, definitive attribution and quantification of this variability are impossible with existing or planned instruments.

Aerosol optical thickness difference between the early 2000s and late 1980s



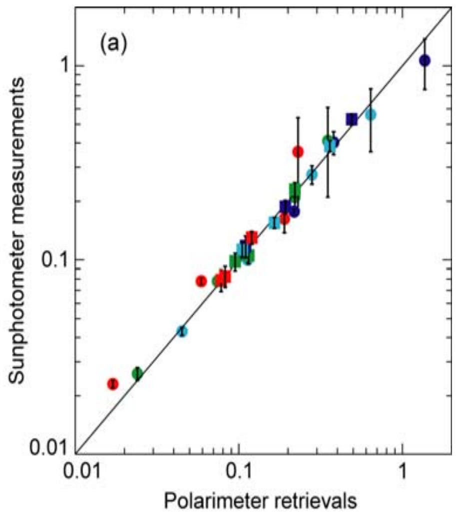
Current/planned aerosol capability is inadequate



The plot on the left contrasts MODIS and MISR AOT retrievals averaged over 3 months and over 1,000 x 1,000 km boxes. Despite averaging over ~10,000 pixel-level AOT values to compute each data point, the MODIS–MISR differences far exceed the individual uncertainty claims.

Neither instrument retrieves aerosol refractive index/chemical composition or detailed size distribution information.

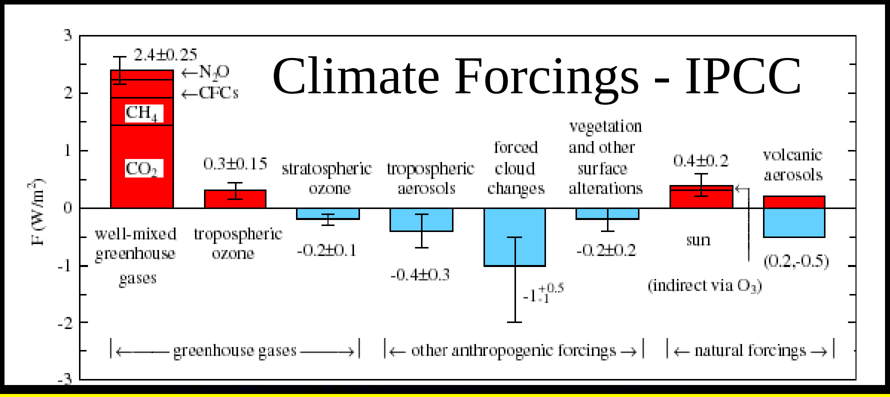
RSP Retrievals from A/C Prototype of APS



- **Spectral AOT values retrieved from precise polarimetric measurements agree exceedingly well with those measured by ground-based sunphotometers over an AOT range from 0.05 to more than 1.**
- **The absence of spectrally-dependent biases demonstrates the reliability of the size distribution estimate for both small and large modes of a bimodal aerosol distribution.**
- **In situ and retrieved size distributions also agree extremely well (difference in aerosol effective radius of less than 0.04 μm).**

Mishchenko *et al.*, *Bull. Am. Meteorol. Soc.* 88, 677 (2007)

APS [Aerosol Polarization Sensor]
First Flight – NASA Glory Mission - 2009
Aerosol & Cloud Product Science Requirements



Aerosols cause a direct climate forcing
by reflecting sunlight to space and
Aerosols cause an indirect climate forcing
by altering cloud properties.
Aerosol radiative forcing remains the largest
uncertainty in climate change studies.

Aerosol Products

- Aerosol optical thickness - Fine, coarse, total
- Aerosol particle size distribution
  - Fine mode radius and effective variance
  - Coarse mode radius and effective variance
- Aerosol refractive index, single-scattering albedo (ssa) and shape
  - Fine mode real refractive index and ssa
  - Coarse mode real refractive index and ssa
  - Non-spherical shape ID & retrieval based on set of prescribed non-spherical models.

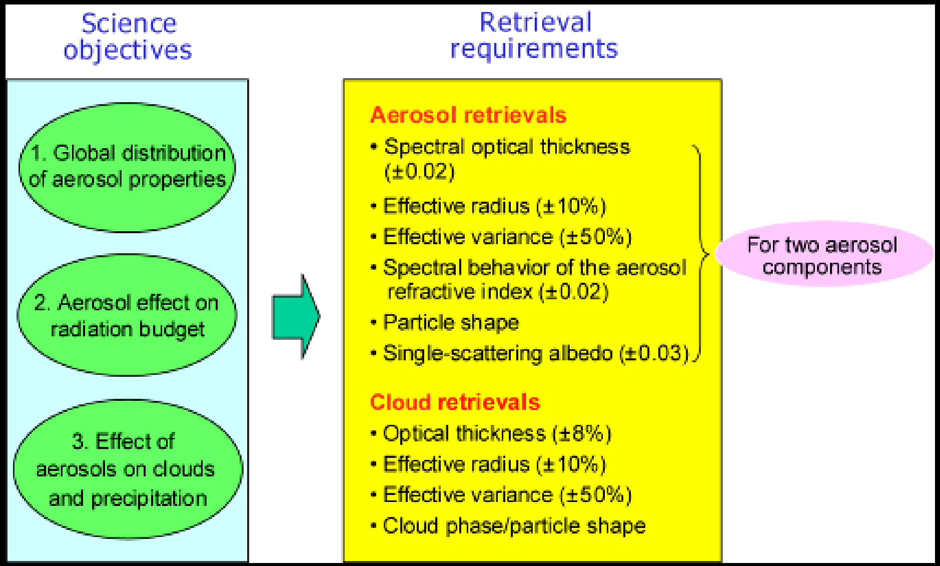
Additional products
- Column Water Vapor
- Stratospheric aerosol optical depth and size dist.
  - Effective variance and effective radius

Cloud Products

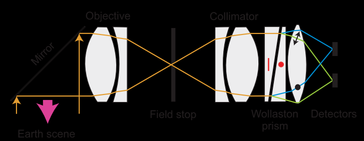
- Liquid cloud optical thickness
- Liquid cloud particle size distribution
  - Effective radius and effective variance

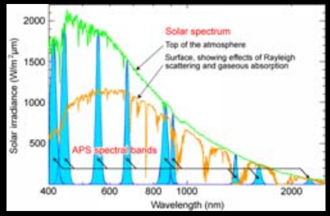
Additional products
- Cloud top height
  Rayleigh barometer used to determine cloud height from 410 nm band.
- Ice cloud optical thickness
- Ice cloud particle size distribution
  - Effective radius, effective variance
- Ice cloud shape ID
  - ID based on differentiation between set of prescribed mixtures

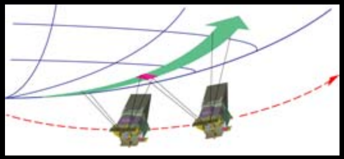
Requisite aerosol and cloud characteristics (NPOESS and Glory APS EDRs)

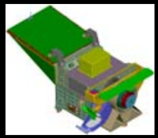


Aerosol Polarimetry Sensor (APS)



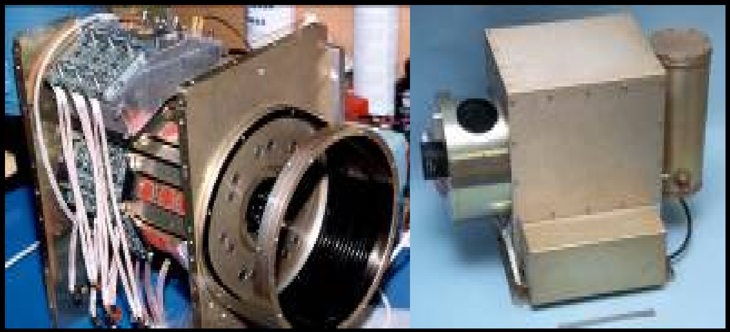






1. Perfect simultaneity of polarization measurements
2. No detector cross-talk
3. Viewing exactly the same piece of real estate
4. Exquisite calibration

Research Scanning Polarimeter (RSP)



"Must haves" of an Aerosol/Cloud Polarimeter

Precise polarimetry (~0.002): particle size distribution, refractive index, & shape

Wide scattering angle range (i + p): particle size distribution, refractive index, & shape

Multiple (∀15) angles (i + p):
(i) cloud particle size via rainbow angle
(ii) particle size, refractive index, and shape
(iii) ocean surface roughness
(iv) aerosol retrievals in cloud-contaminated pixels

Wide spectral range (i + p):
(i) separation of submicron and supermicron particles
(ii) spectral refractive index ⇒ chemical composition

1370 nm (i + p): characterization of thin cirrus clouds

2200 nm (p):
(i) characterization of the land surface contribution at visible wavelengths
(ii) cloud particle sizing

APS Measurement Approach

- The measurement approach developed for the Glory mission is to use multi-angle, multi-spectral polarimetric measurements because:
  - Polarization is a relative measurement that can be made extremely accurately and that is highly sensitive to the amount of aerosol that is present.
  - The variation of polarization with scattering angle and wavelength allows aerosol particle size, refractive index and shape to be determined.
  - Polarimetric measurements can be accurately and stably calibrated on orbit.
  - Appropriate measurement approach provides inherent redundancy.

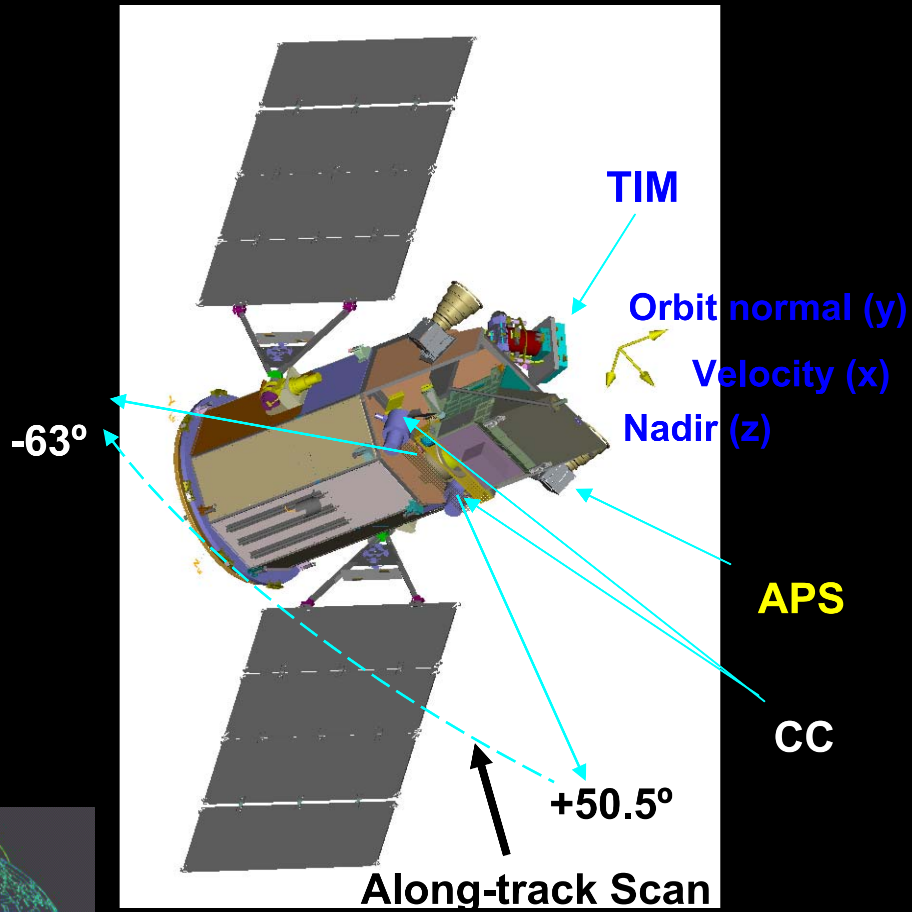
APS Measurement Approach

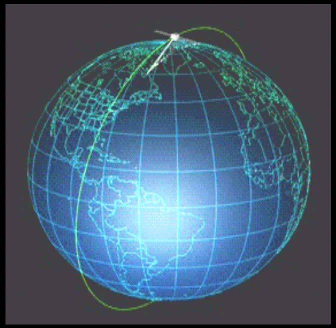
- Polarization observations are less affected by the surface and are more sensitive to aerosols than intensity measurements.

- False color images using measurements at 410, 865 and 2250 nm - left panel is reflectance, right panel is polarized reflectance.
- Intensity shows strong spectral contrast and weak variation of reflectance with scattering geometry.
- Polarization shows weak spectral contrast and large variation with scattering geometry of polarized reflectance
    - This is because the principal sources of polarization are single scattering and front facet (Fresnel) reflection.
- Easier to separate surface contribution from atmospheric contribution using polarized reflectance.

Glory Overview & APS Context

- Glory Mission to provide climate data to complement the US Global Change Research Program (GCRP)
- Spacecraft: Orbital Sciences
- Solar Total Irradiance Monitor (TIM): University of Colorado Laboratory for Atmospheric & Space Physics (LASP)
- Aerosol Polarimetry Sensor (APS): Raytheon SBRS/El Secundo
- Cloud Cameras (CC): GSFC
- Launch: 2009
- Orbit: 705 km 1330 ascending polar sun-synchronous





Possible Roadmap to NexGen CrIS

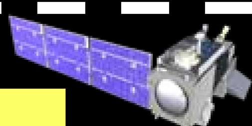
Advancements in atmospheric sounding for the purpose of improved weather, climate, and air quality observation and forecasting

Improved spatial, spectral, & radiometric performance →

POES
HIRS
(1978)

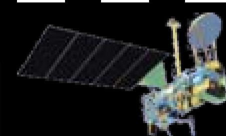
EOS
AIRS
(2002)

MetOp
IASI
(2006)

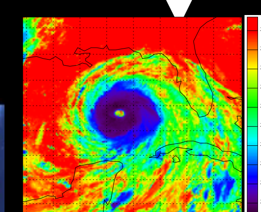


NPP
CrIS
(2010)

NPOESS
CrIS
(2013)



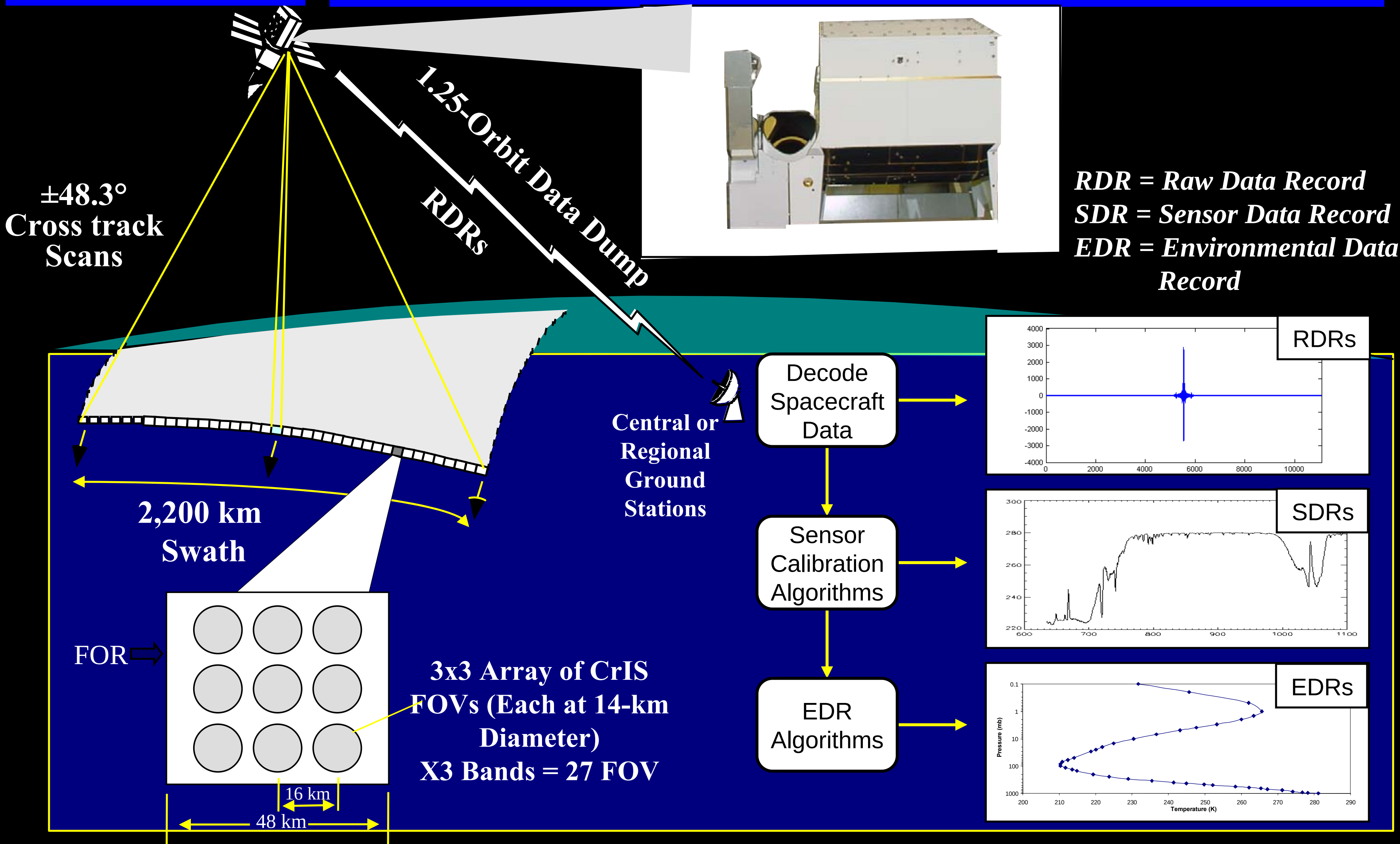
NPOESS
NexGen CrIS
(2026)



POES: Polar-orbiting Operational Environmental Satellites
HIRS: High Resolution Infrared Radiation Sounder
EOS AIRS: Earth Observing System Atmospheric Infrared Sounder
MetOp: Meteorological Operational satellite program
IASI: Infrared Atmospheric Sounding Interferometer
NPP CrIS: NPOESS Preparatory Project Cross-track Infrared Sounder
NPOESS: National Polar-orbiting Operational Environmental Satellite System
NexGen: NPOESS 2nd Generation

CrIS Mission Overview

Basic Mission: Produce Atmospheric Vertical Profiles of Temperature, Moisture, & Pressure (EDRs)

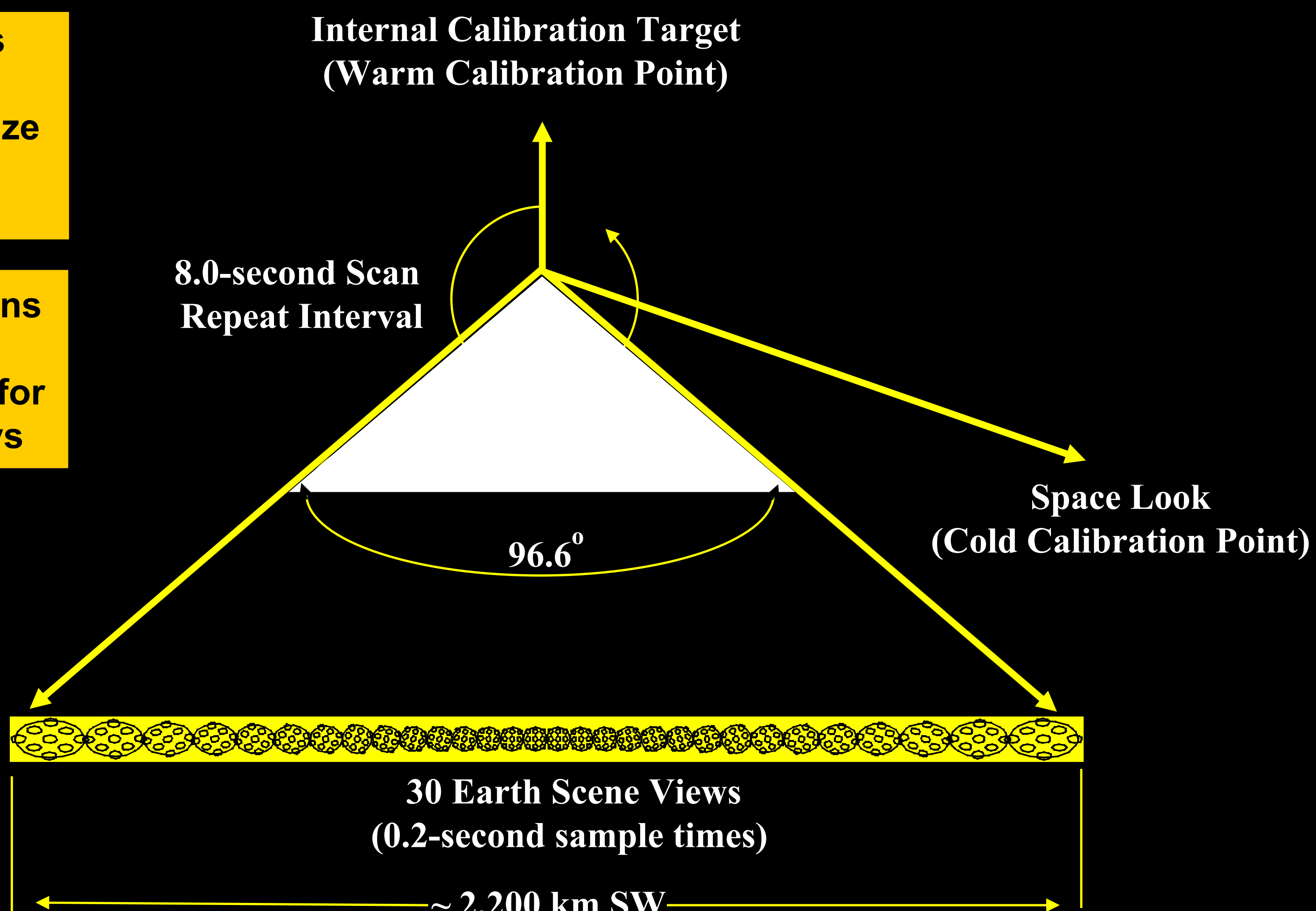


Mission Overview

NPOESS CrIS Operations

Continuous Calibration Looks Minimize Calibration Errors

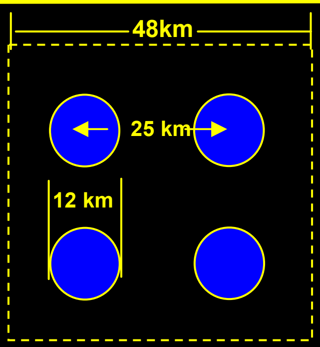
CrIS Operations Are Fully Autonomous for Up to 60 Days

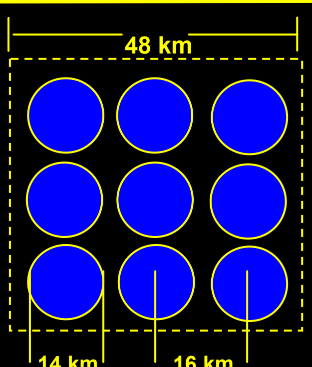


"IASI/CrIS Features - Enabling a Meaningful Global Atmospheric Sounding System"

		IASI	CrIS
# of Channels		8461	1305
Sprectral Range (cm^{-1})		650 to 770 770 to 980 1000 to 1070 1080 to 1150 1210 to 1650 2100 to 2150 2150 to 2250 2350 to 2420 2420 to 2700	650 - 1095 1210 - 1750 2155 - 2550
Sprectral Resolution (cm^{-1})		645 0.35 1210 0.35 2000 0.39 2450 0.45 2760 0.5	650-1095 <0.625 1210-1750 <1.25 2155-2550 <2.50
Sensor Parameters	Scan type	Step and dwell	Step and dwell
	Scan rate	8 sec. (30 steps earth & 3 calibration)	8 sec. (30 earth & 2 calibration)
	IFOV	3°.33 x 3°.33	3°.3 x 3°.3
	IFOC size at Nadir	12 km	14 km
	Sampling at Nadir	25 km	16 km
	Swath	± 48.3°	± 48 1/3° each side of Nadir
	Swath	± 1026 km	± 1100 km each side of Nadir
	Field of Regard (FOR)	48 km	48 km
	# IFOV's Per FOR	4 (2-by-2)	9 (3-by-3)
	Pixel/scan (FOVs x steps)	120 (4 X 30)	270 (9 X 30)

Field of Regard / Field of View





NexGen [Next Generation] CrIS Study

Purpose

Consider improvements to NexGen CrIS to advance Atmospheric Sounding capability beyond that possible with the current CrIS, first with simple improvements possible today and then beyond the nominal evolutionary improvements expected during the NPOESS program. Such improvements to Atmospheric Sounding should enable improved weather, climate, and air quality observation and forecasting.

Objectives

- To resolve profiles of important atmospheric trace gases
- To enhance accuracy/resolution of retrieved atmospheric thermodynamic profiles
- To improve sounding sensitivity in the boundary layer and upper troposphere regions
- To improve spatial and temporal resolutions of EDR products
- To enable stereo imaging & scene tasking for increased coverage of special weather events

NexGen CrIS Considerations

Improvements needed to satisfy users' needs:

- To improve evolution/trajectory forecasts of tropical cyclones
- To improve localized mesoscale weather prediction
- To improve vertically-resolved observation/prediction of global winds
- To resolve & predict chemical weather processes and air quality
- To improve SI-traceability of measurements to ensure EDRs satisfy CDR requirements
- To broaden data user community and corresponding societal benefit (e.g., aviation weather)

NPOESS NexGen Considerations

NexGen Atmospheric Sounder could significantly improve monitoring & forecasting capabilities

- **Ultra-spectral Resolution Sounding**
  - Weather and Climate
  - Chemistry and Air Quality
- **Wind Profiling**
  - Weather and Climate
  - Gas Flux and Air Quality
- **Soundings + Winds**
  - Convective Instability Tendency/Severe Storms
  - Aviation Weather
- **Multi-spectral Imagery (+ Soundings + Winds)**
  - High Spatial Resolution State and Dynamics (atmosphere, surface & clouds)
  - Nowcasting

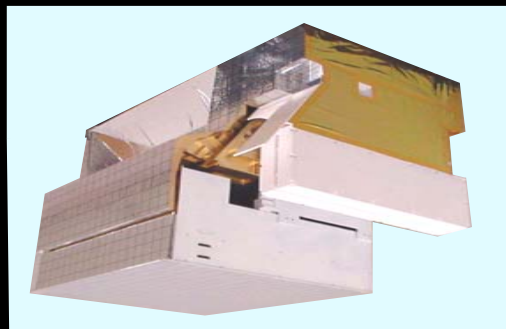
NexGen CrIS Considerations

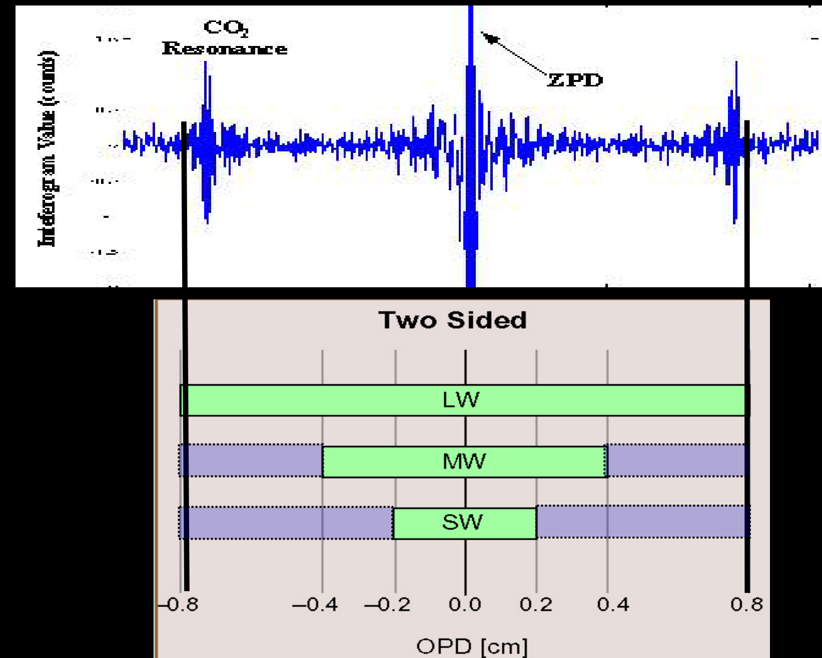
Example improvements to be addressed:

- **Higher Spectral Resolution (< 0.625 cm^{-1})**
  - Improved sensitivity of Upper Troposphere water vapor profile
  - Enhanced temperature and water vapor profile vertical resolution
  - Increased trace gas sensitivity, e.g. O_3, CH_4, N_2O, SO_2, CO_2, and CO
- **Full Spectral Coverage (e.g., 650 - 2750 cm^{-1})**
  - Consistency with MetOp IASI measurement capability
  - Improved trace gas measurement capability
  - Boundary Layer temperature and water vapor profiling
- **Higher Spatial Resolution (< 14 km)**
  - Satisfy EDR requirements for mesoscale (storm, frontal boundary, etc.) thermodynamic conditions
  - Convective scale forecasting
- **Forward, Nadir, and Aft Scan Capability (e.g., 3 Frames)**
  - Thermodynamic stability tendency measurement capability
  - Wind profiling capability
  - Stereo-enhanced vertical resolution

CrIS Changes for Improved Trace Gases (CO, CH_4, N_2O, CO_2 …)

Downlink Full Bandwidth of All Three Bands [LW, MW and SW]

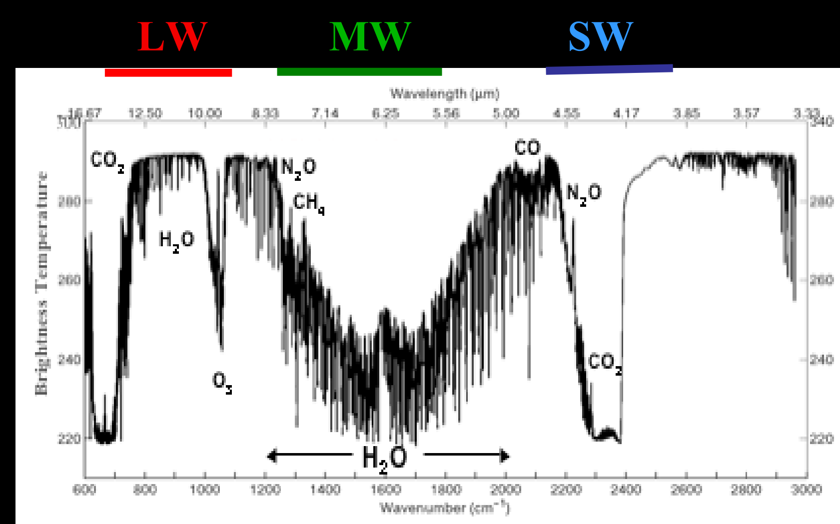




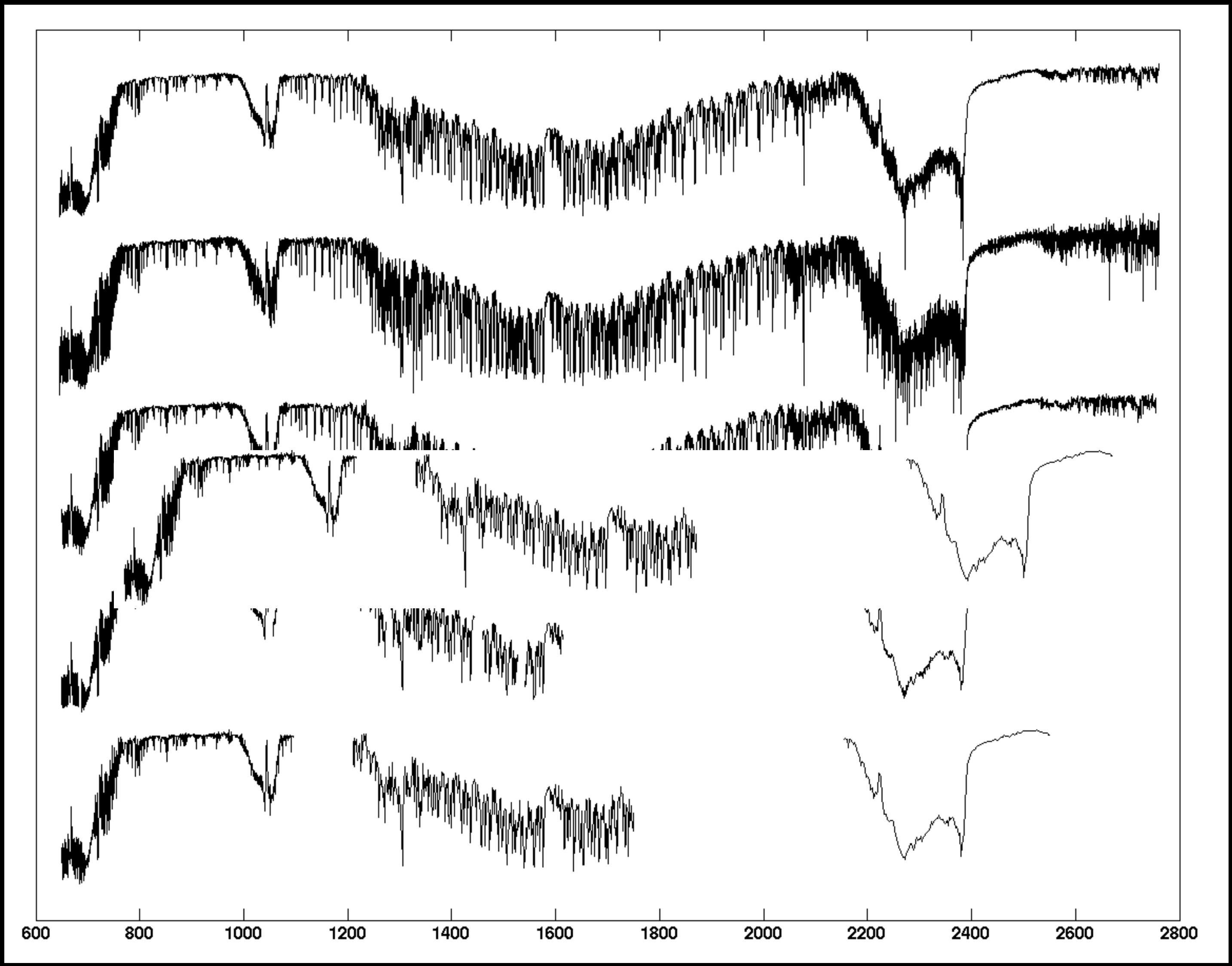
CrIS Michelson Interferometer (FTS)

- Three Spectral Bands
  - LWIR: 650-1095 cm^{-1} (713 Chan)
  - MWIR: 1210-1750 cm^{-1} (433 Chan)
  - SWIR: 2155-2550 cm^{-1} (159 Chan)
- 1305 Total Spectral Channels
- 3x3 FOVs at 14 km Diameter for each Band
- Spectral Resolution of each Band

Band	Actual Spectral Res (cm^{-1})	Full Spectral Res (cm^{-1})
LWIR	0.625	0.625
MWIR	1.25	0.625
SWIR	2.50	0.625



NAST-I, S-HIS, CrIS, & AIRS Spectra Simulated from IASI



IASI L1C
(Gaussian apodization)

NAST-I
(deapodized

S-HIS
(truncated to 1cm MOPD)

CrIS
(truncated to 0.625, 0.3125, and 0.15625 cm MOPD)

AIRS
(convolve with AIRS SRFs)

Trace/Greenhouse Gases (CO, CH_4, CO_2)

NPOESS Users' P^3I^* IORD EDR Requirements

CH_4 Column

CH_4 (Methane)	Objectives
Vert Coverage	Total Column
Horizontal Resolution	100 km
Mapping Uncertainty	25 km
Meas Range	40-80 µmoles/cm²
Meas Precision	1%
Meas Accuracy	5%
Latency	15 min
Refresh	24 hrs

CO Column

CO (Carbon Monoxide)	Objectives
Vert Coverage	Total Column
Horizontal Resolution	100 km
Mapping Uncertainty	25 km
Meas Range	0-7 µmoles/cm²
Meas Precision	3%
Meas Accuracy	+/-5%
Latency	15 min
Refresh	24 hrs

CO_2 Column

CO_2 (Carbon Dioxide)	Objectives
Vert Coverage	Total Column
Horizontal Resolution	100 km
Mapping Uncertainty	25 km
Meas Range	11,000-15,000 µmoles/cm²
Meas Precision	15-20 µmoles/cm²
Meas Accuracy	TBD
Latency	15 min
Refresh	24 hrs

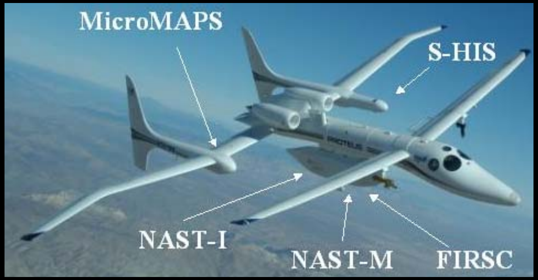
•P^3I = Pre-Planned Product Improvement Requirements in NPOESS Users' Integrated Operational Requirements Document [IORD II]

All three trace gas EDRs require :

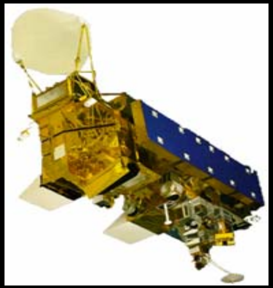
- Total column measurement
- 100 km horizontal resolution
- No Thresholds, only Objectives in IORD

Possible Future CrIS Capability e.g.
Carbon Monoxide [CO] Trace Gas Profiling & Column Density

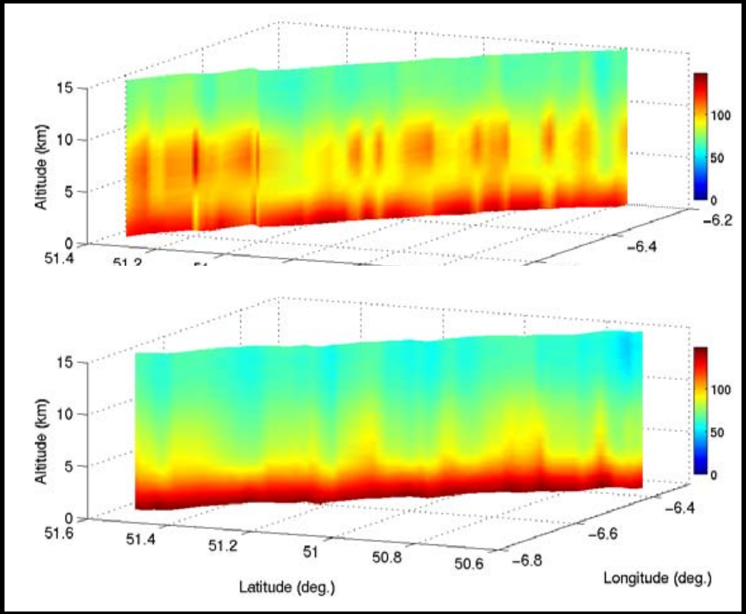
Airborne NAST- I
EAQUATE AIRS Validation Campaign
14 and 18 September 2004

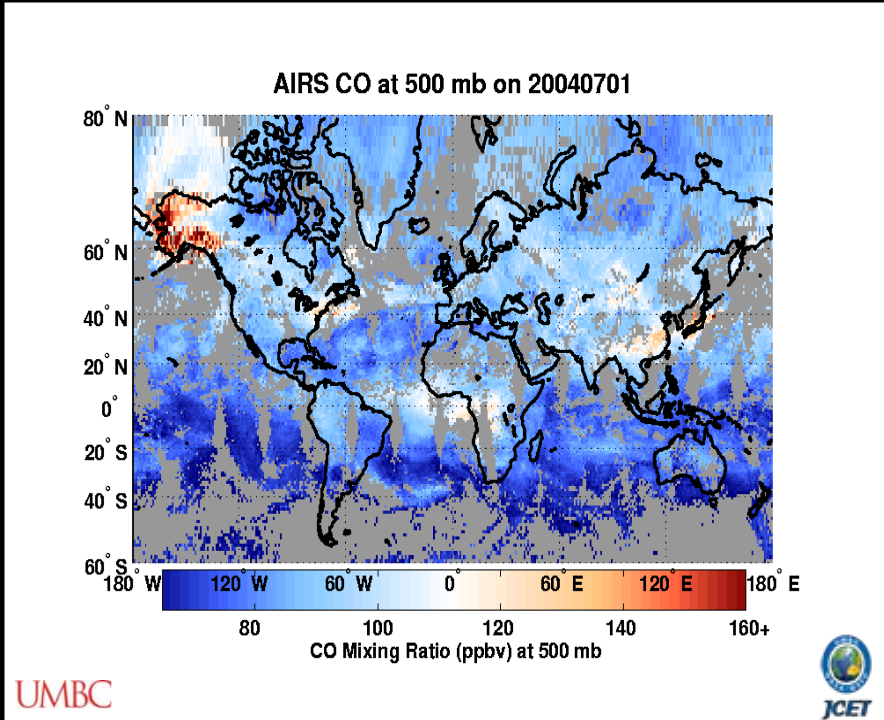


Spaceborne AQUA AIRS
CO Daily Averages - Month of July 2004
At Single Height Level - 500 mb



NAST- I CO Vertical Cross Sections
CO [carbon monoxide] in ppbv





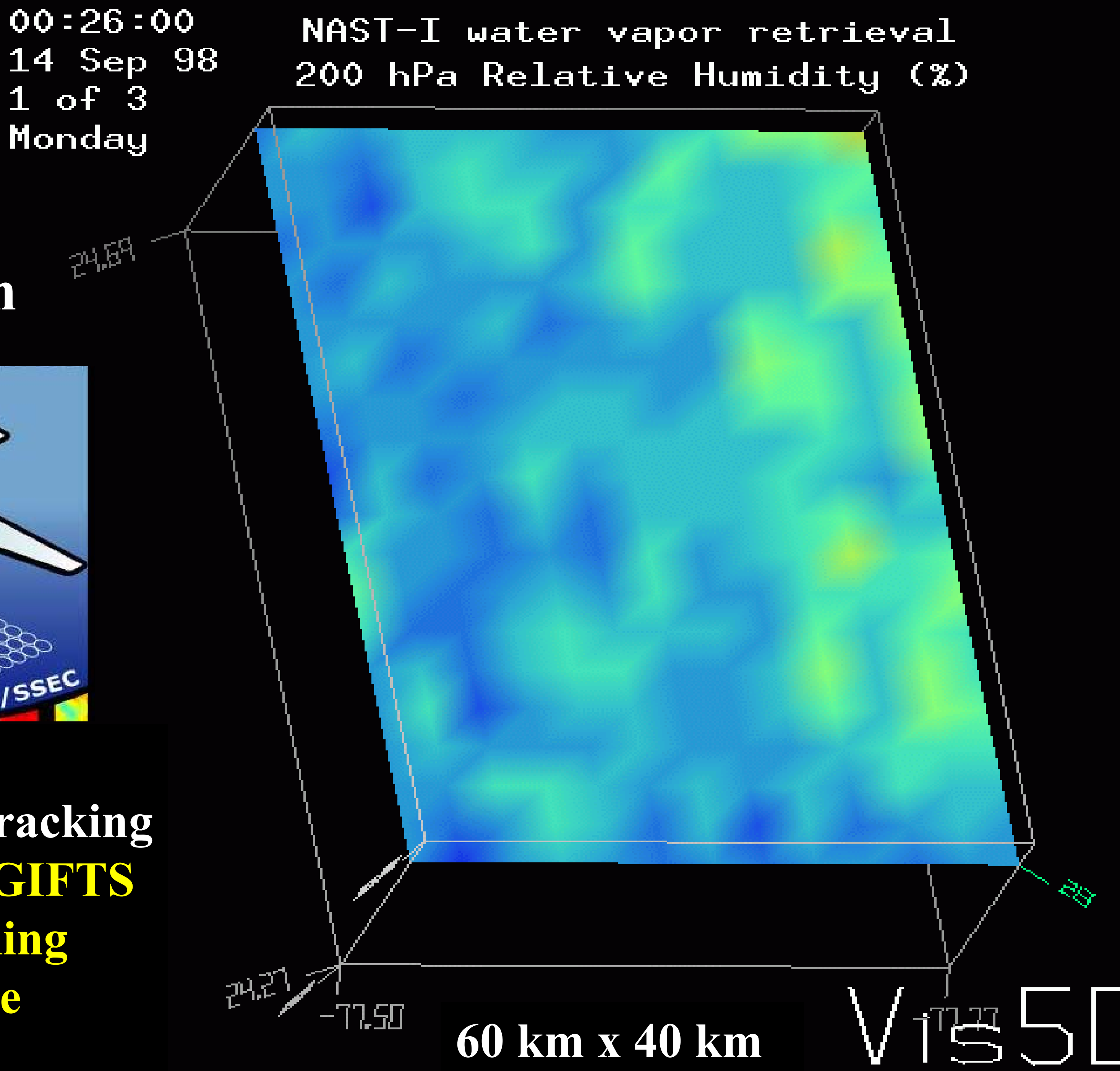
UMBC

JCET

Wind Measurement

δt~35 min

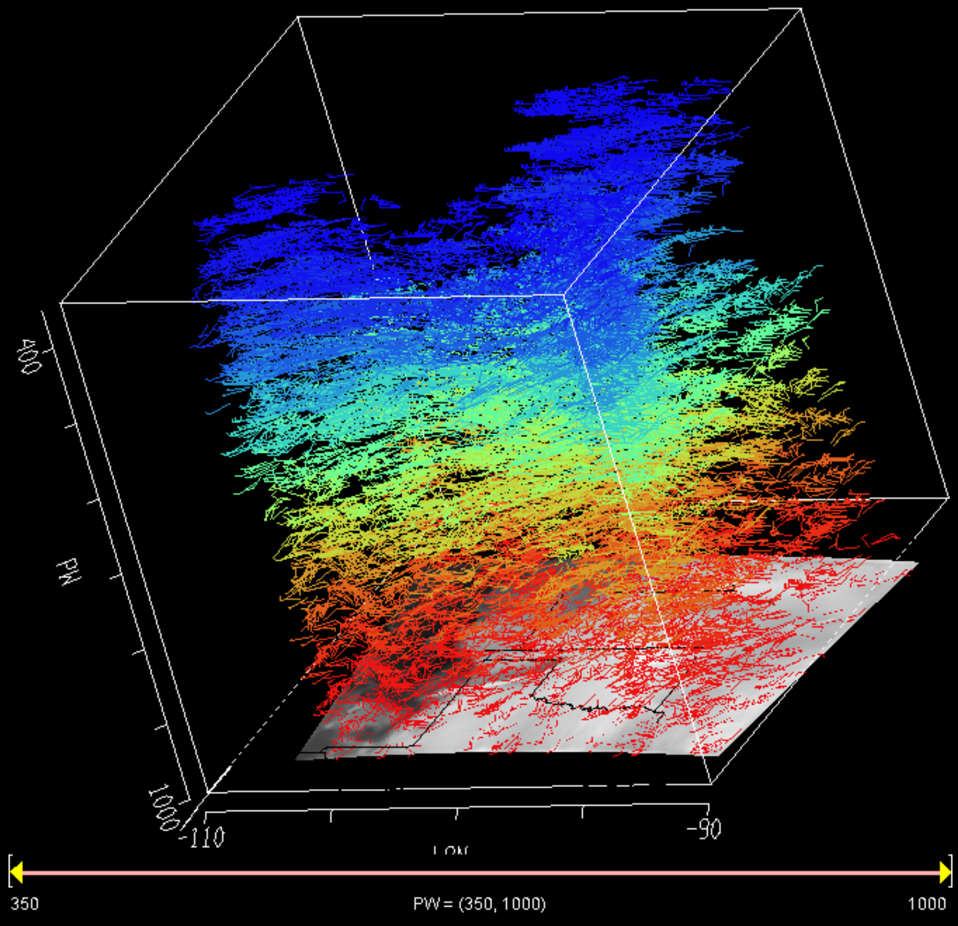
NAST-I
Water Vapor Tracking
Demonstrates GIFTS Wind Profiling Technique



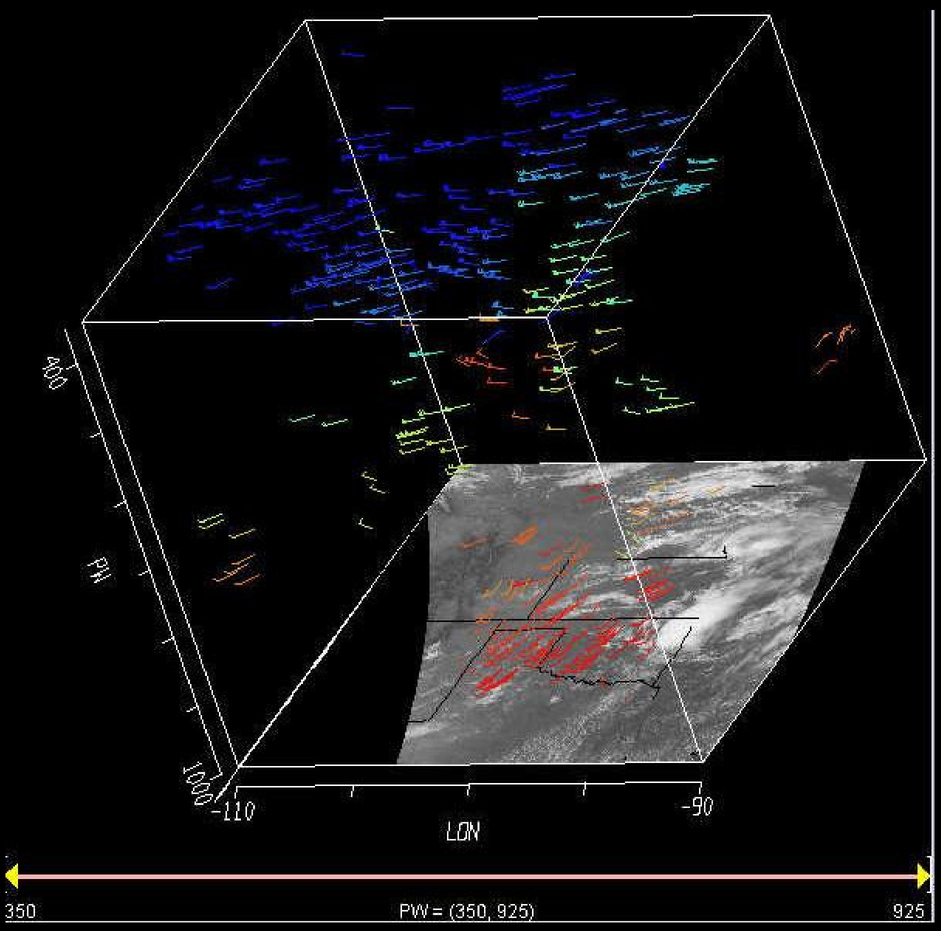
60 km x 40 km

Wind Measurements at Discrete Height Levels

GIFTS - Simulation



GOES - Observation



CIMSS

NexGen CrIS Study

Select enabling technologies to be considered:

Compact Multi-path Interferometer (FTS, TRL-3)

- Increased spectral resolution
- Dual imagery/sounding data stream
- Breadboard design and validation conducted at NASA LaRC

Large Focal Plane Detector Array (LFPDA, TRL-6)

- Large area coverage, rapid refresh sounding imagery
- Validated within GIFTS-EDU at Utah State University SDL

High Data Rate Readout Electronics (ROIC, TRL-6)

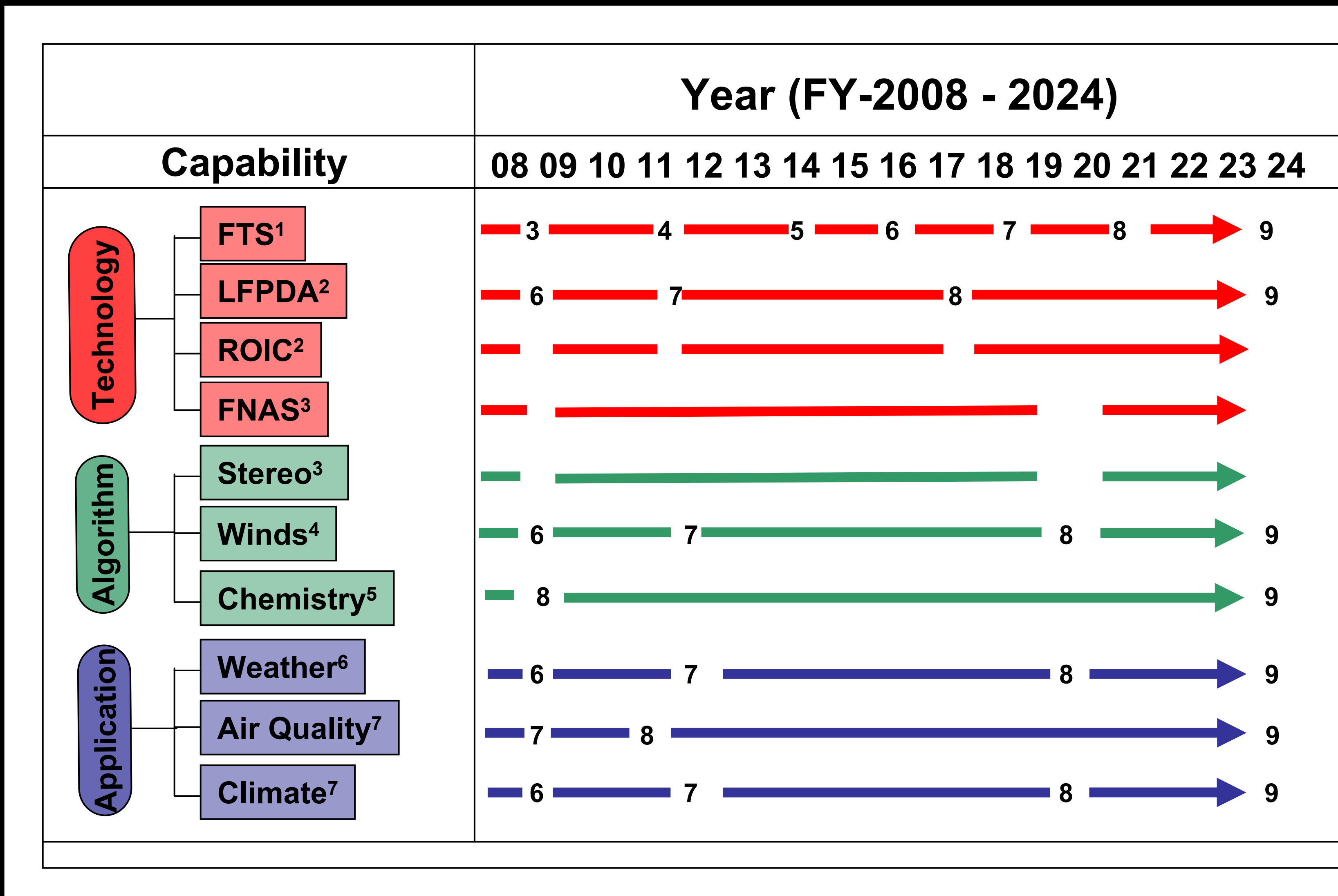
- Large area format focal plane detector readout
- Validated within GIFTS-EDU at Utah State University SDL

Forward, Nadir, and Aft Scan Capability (FNAS, TRL-7)

- Stereo imaging and 3 frame rapid refresh for feature tracking
- Space demonstrated with the Terra MISR instrument

NexGen CrIS Considerations

New System Capability TRL Roadmap



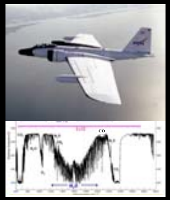
NexGen CrIS Notional Technology Risk Mitigation

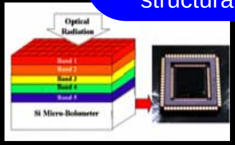
Improvements in atmospheric sounding would be enabled by: higher spectral, spatial, and radiometric resolutions; enhanced flight operations capabilities; and algorithm improvements

Technology advancements
- Components: detectors, electronics, optics, materials
- Sub-systems: Michelson interferometer (ultra-high, variable resolution)
- Processes: systems engineering; design & analysis (optical, radiometric, thermal, structural, mechanical)

Technology & lessons-learned
- EOS Aqua AIRS, MetOp IASI, NPP CrIS, NPOESS CrIS
- NRC Decadal Survey missions
- Other international missions (United States, Europe, Canada, Japan, China, India, Brazil)

Risk-mitigating testbed
- Satellite system performance verification (cal/val)
- SI-traceability (calibration)
- Measurement/instrument concept & data product demonstrations
- TRL advancement
- RTO evolution



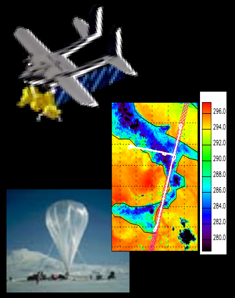


CrIS (2008)

Technology infusion

- Hardware
- Space-based advanced sensors
- Airborne Prototype (NAST / NAST-NG)
- Field Experiment Campaigns
- Analysis & Algorithms
- Flight Operations

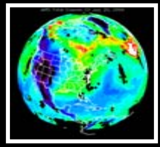
NexGen CrIS (~2026)



Performance verification
- Satellite system cal/val
  - Sensor
  - Measured radiances
  - Derived data products
  - L1 & L2 algorithms
- Inter-satellite cross-validation
- Proxy data generation

Capabilities assessment & realization
- NWP assimilation & advancements
- OSSEs
- Data fusion (other sensors)
- Super fast RT models
- Cloud RT modeling
- Hybrid retrieval schemes
  Cloud & sfc. properties
  Soundings (T, q, & trace species)

Implementation advancements
- Forward, nadir, and aft scan capability
- Rapid refresh rate
- Near-real-time scene queueing
- On-board processing



The Needed Measures of the Atmosphere

- **Mass Field** --- T (z), P (z), g (z), mu (z)
  NPOESS *Atmospheric Sounders – CrIS, ATMS, OMPS, MIS*
- **Moisture Field** --- q (z)
  NPOESS *Atmospheric Sounders – CrIS, ATMS, OMPS, MIS*
- **Motion Field** --- v (u,v,z) " 3D Winds"
  Doppler Wind Lidar [DWL]

Vertical Wind Profiles
NPOESS # 1 Unaccommodated EDR

NexGen Hybrid Doppler Wind Lidar - NWOS

Possible NPOESS Wind Observing System For Vertical Wind Profiles

2007 NAS Decadal Survey

Recommendations for Tropospheric Winds

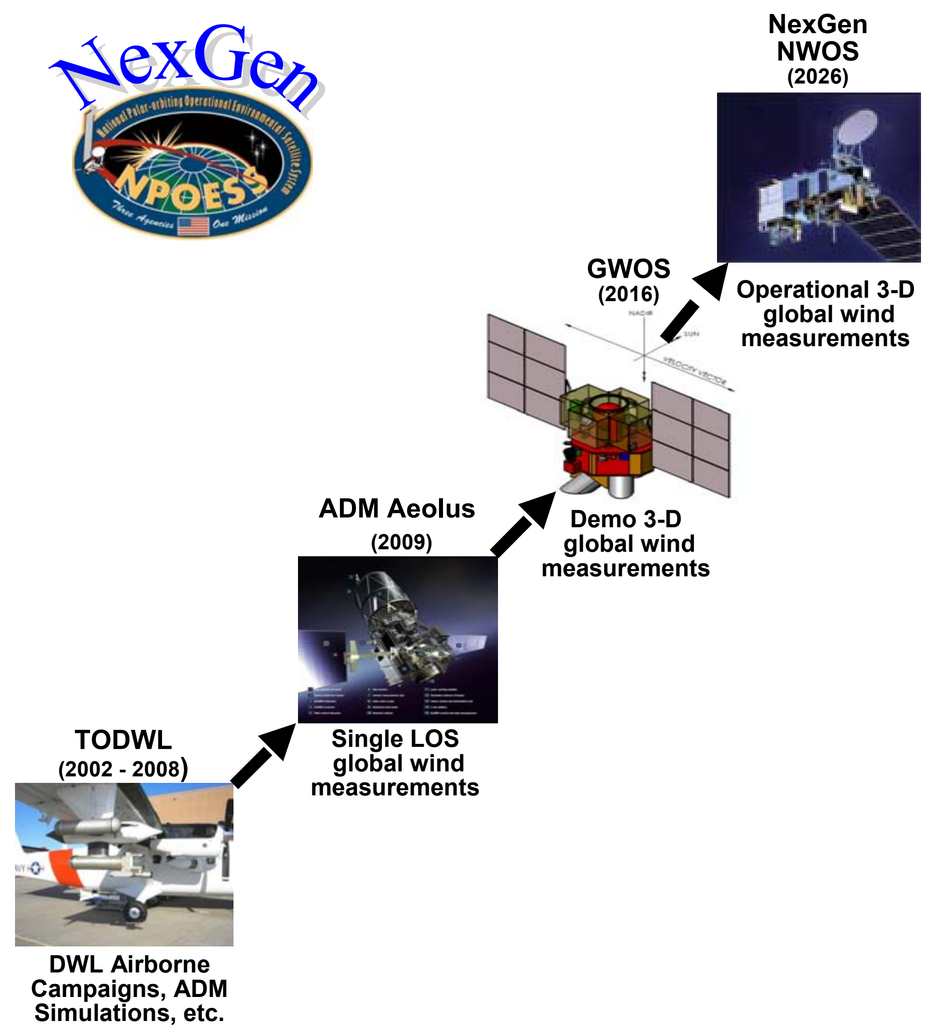
- **3D Tropospheric Winds mission called "transformational" and ranked #1 by Weather panel.**
  3D Winds also prioritized by Water Cycle panel.

"The Panel strongly recommends an aggressive program early on to address the high-risk components of the instrument package, and then design, build, aircraft-test, and ultimately conduct space-based flights of a prototype Hybrid Doppler Wind Lidar (HDWL)."

"The Panel recommends a phased development of the HDWL mission with the following approach*:*

GWOS *Stage 1:* Design, develop and demonstrate a prototype HDWL system capable of global wind measurements to meet demonstration requirements that are somewhat reduced from operational threshold requirements. All of the critical laser, receiver, detector, and control technologies will be tested in the demonstration HDWL mission. *Space demonstration of a prototype HDWL in LEO to take place as early as 2016.*

NWOS *Stage II:* Launch of a HDWL system that would meet fully-operational threshold tropospheric wind measurement requirements. It is expected that a **fully operational HDWL system could be launched as early as 2022."**



TODWL: Twin Otter Doppler Wind Lidar [CIRPAS NPS/NPOESS IPO]
ESA ADM: European Space Agency-Advanced Dynamics Mission (Aeolus) [ESA]
GWOS: Global Winds Observing System [NASA/NOAA/DoD]
NexGen: NPOESS [2nd] Generation System [PEO/NPOESS]

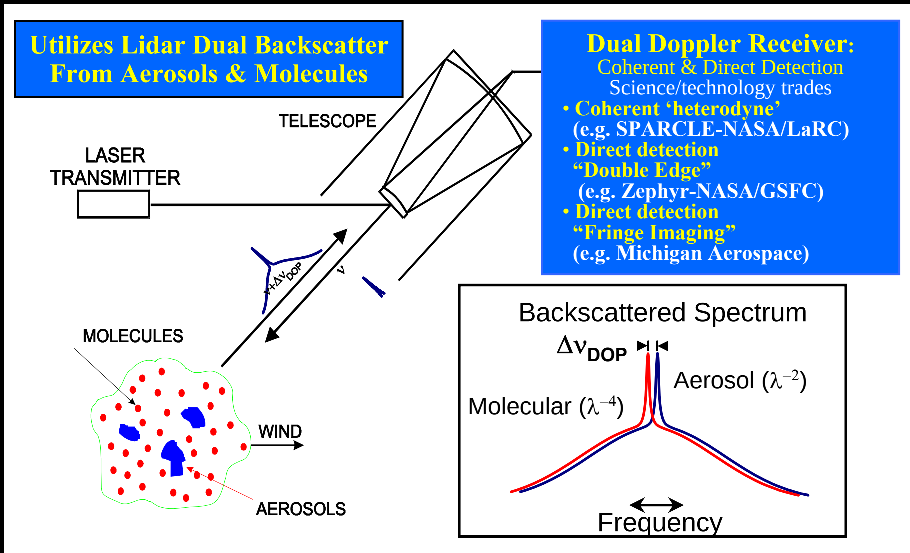
GWOS/NWOS Comparisons with ADM

Attribute	ADM	GWOS	NWOS
Orbit Altitude	400	400	825
Orbit Inclination	98	98	98
Day/Night	Night only	Day/Night	Day/Night
Duty Cycle	25%	100%	100%
Components per profile	Single –Model estimated second component	Two components - full horizontal vector	Two components - full horizontal vector
Horizontal Resolution	200 km between single LOS's	300 km with full profile both sides of ground track	300 km with full profile both sides of ground track
Vertical Resolution	PBL 1 km Troposphere 2 km	PBL 0.25 - 0.5km Tropo 2 – 3 km	PBL 0.25 - 0.5 Tropo 2 – 3 km
Collector Diam.	1.5 m (1x)	0.5 m (4x)	0.7 m (4x)

NexGen Hybrid Doppler Wind Lidar [HDWL] - NWOS

Possible NPOESS Wind Observing System For Vertical Wind Profiles

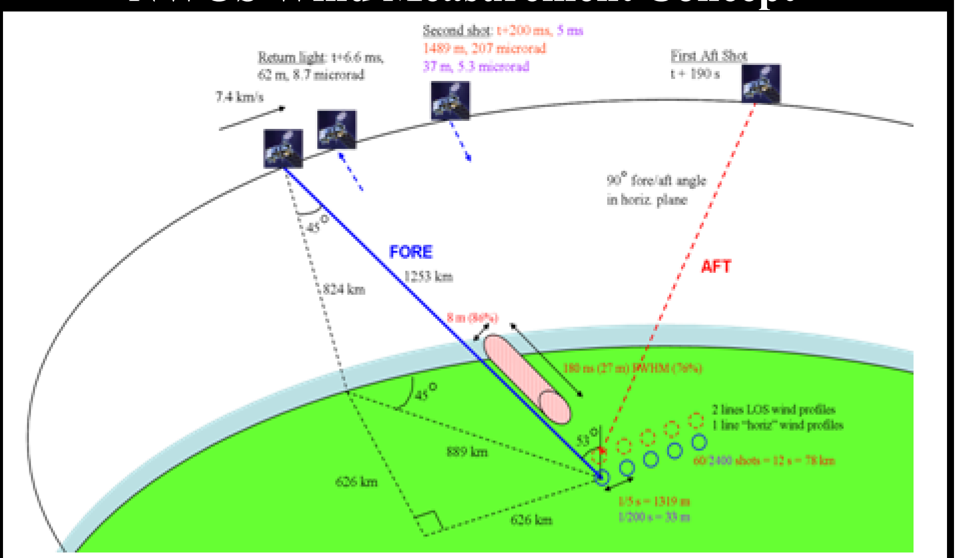
HDWL [Hybrid Doppler Wind Lidar] Concept



Hybrid DWL Technology Solution

- The **coherent** subsystem provides very accurate (<1.5m/s) observations when sufficient **aerosols** (and clouds) exist.
- The **direct detection (molecular)** subsystem provides observations meeting the threshold requirements above 2 km, clouds permitting.
- When **both** sample the same volume, the most accurate observation may be chosen for assimilation into the NWP or Climate Model.
- The **combination** of **direct and coherent detection** yields higher data utility than either system alone.

NWOS Wind Measurement Concept



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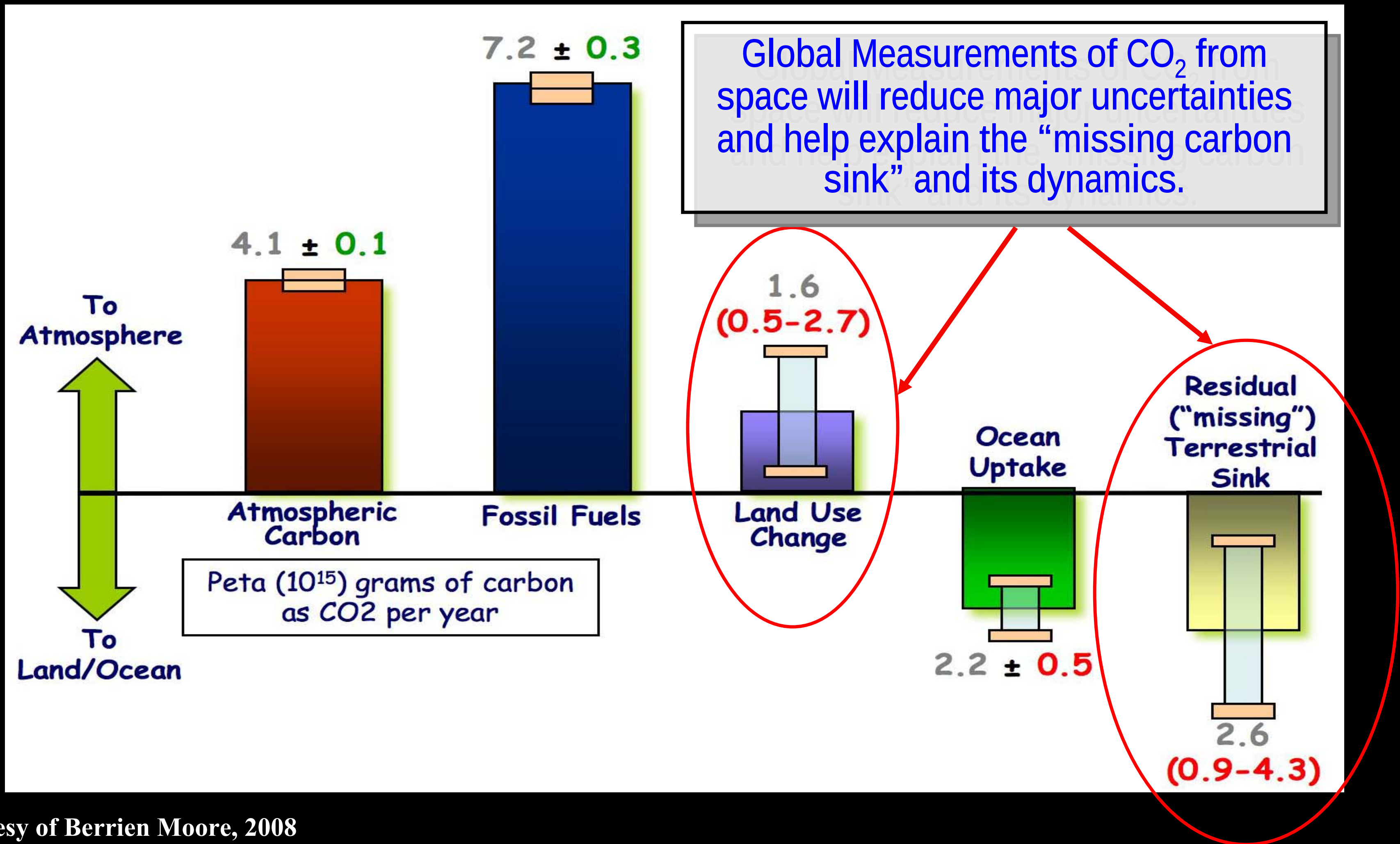
Collector Diam.	1.5 m (1x)	0.5 m (4x)	0.7 m (4x)

Adapted from & Courtesy of Bruce Gentry, Michael Kavaya, G. David Emmitt, Wayman Baker, Michael Hardesty, Stephen Mango

Importance of Global CO_2 Measurements from Space
[especially during the MetOp – NPOESS – GEOSS era(s)]

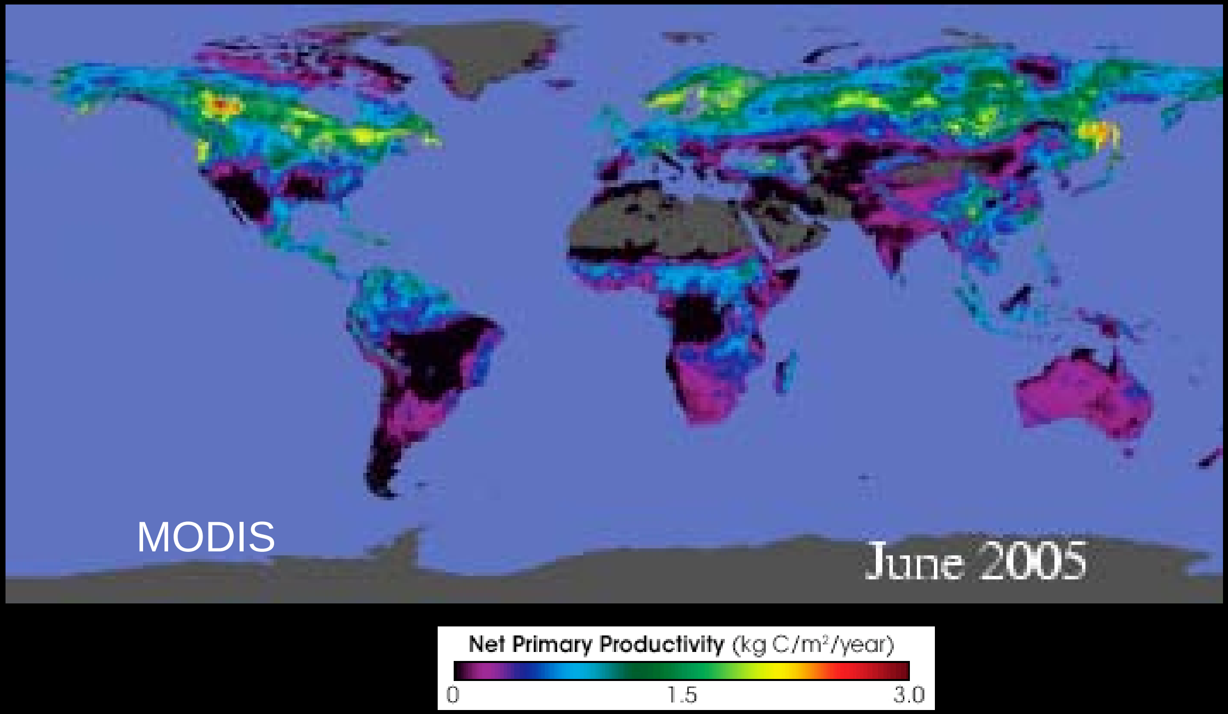
Global Carbon Budget [IPCC, 2007]



Courtesy of Berrien Moore, 2008

Challenges Posed by the Science Questions

Because of spatial and temporal variability, practical determination of the pattern of sources and sinks from surface measurements is impossible. The only viable approach is to infer aspects of the rates of exchange by inverting the causal relation between source-sinks and atmospheric concentration.



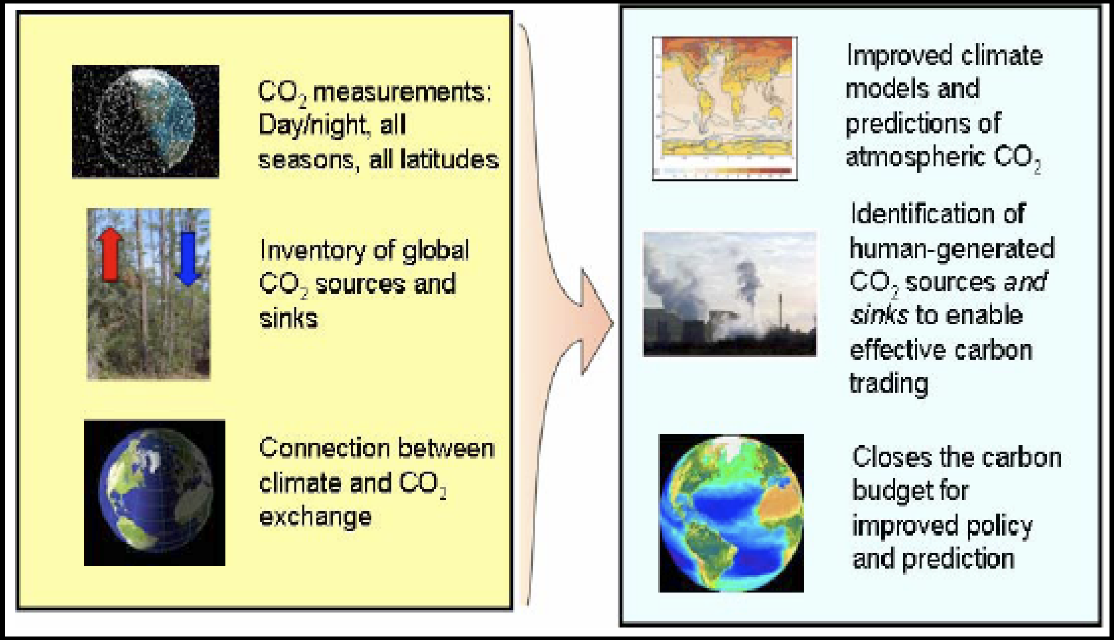
This requires measurements of total column CO_2 with high precision measurements in all seasons and all latitudes with a focus upon mid to lower troposphere, under a varying set of large-scale weather-climate modes.

Courtesy of Berrien Moore, 2008

Rationale - Mission Objectives:
ASCENDS and Subsequent NPOESS CO_2 Capability Considerations

- Goal: To significantly enhance the understanding of the role of CO_2 in the global carbon cycle and its impact on climate change by launching a "laser-based CO_2 mission" as "the logical next step after the launch of NASA's Orbiting Carbon Observatory (OCO)" ------ → ASCENDS

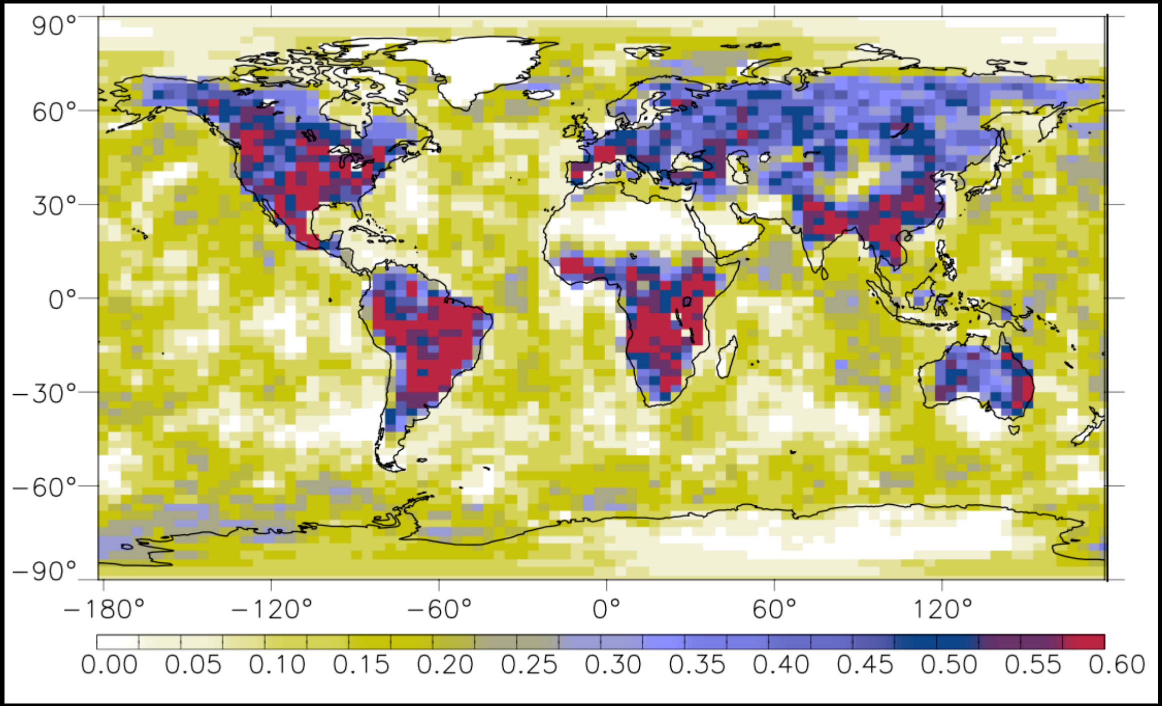
- **Objective 1.** Quantify global spatial distribution of atmospheric CO_2 on scales of weather models
- **Objective 2.** Quantify current global spatial distribution of terrestrial and oceanic sources and sinks of CO_2 on 1 degree grids at weekly resolution
- **Objective 3.** Provide a scientific basis for future projections of CO_2 sources and sinks through data-based process Earth System model enhancements



Courtesy of Berrien Moore, 2008

Rationale
Measurement Requirements

- ASCENDS CO_2 Measurement Requirements derived from Observing System Simulation Experiments (OSSEs) conducted by Peter Rayner and Frédéric Chevallier, CEA-CNRS.
- Assumed measurement precision for 100-km tropospheric CO_2 column measurement over land of 1.3 ppmv during day and 0.8 ppmv at night and over water of 4.2 ppmv during day and 2.1 during night.



Fractional Error Reduction

Average Error Reduction

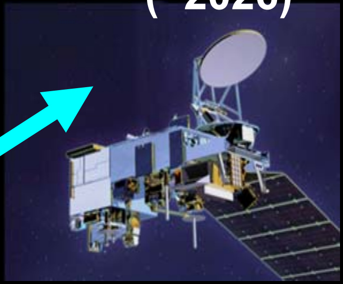
Land:	**40%**
Ocean:	**13%**
Total:	**20%**

ASCENDS and **NPOESS Follow-on** will make major contribution to knowledge of CO_2 sources & sinks.

Courtesy of Berrien Moore, 2008

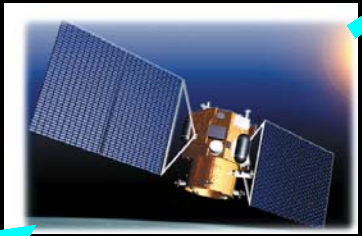
A Possible Roadmap to NPOESS NexGen Operational CO_2 Measurements

Nex-Gen NPOESS
(~2026)



Operational CO_2, O_2
Laser Absorption Spectroscopy
global measurements

ASCENDS
(2013)



Demo CO_2, O_2
Laser Absorption Spectroscopy
global measurements

OCO
(2008)

CO_2 Passive
Spectrometer
measurements

Airborne
(2009 - 2029)

CO_2, O_2 Laser Absorption
Spectroscopy Airborne Campaigns
OCO, ASCENDS, NexGen,
Simulations, etc.

Vielen Dank !