Earth Science Enterprise Technology Planning Workshop

Integrated Optics and Spectral Technologies

Diane Wickland (Co-Chair) - NASA HQ

Jim Gleason (Co-Chair) - GSFC

David Crisp (Facilitator) JPL

23-24 January 2001

Earth Science Enterprise Technology Planning Workshop

Integrated Optics and Spectral Technologies

Agenda

Tuesday, Jan 24, 2001

Introduction	Diane Wickland/Jim Gleason
Overview of NMP Hyperspectral Imaging and Atmospheric Spectroscopy Workshops	Dave Crisp (NMP/JPL)
Overview of Interagency Workshop on Hyperspectral Imaging	Jeff Simmonds (JPL)
Far Infrared Atmospheric Spectroscopy	Marty Mlynczak (LaRC)
Hyperspectral Remote Sensing Land and Ocean	Laurie Richardson
Wide Field Imaging Spectrometer	Randy Pollock (OSC)
High Resolution Linear Variable Etalons (HRLVE)	Aidan Roche (LM)
Fourier Transform Spectrometer for Solar Occultation	David Johnson (LaRC)
Digital Array-Scanned Interferometer	William H. Smith (Washington U.)
Advanced Thermal IR Sounders	Thomas Pagano (JPL)
Discussion: Science Need/Technology Readiness Summary Results and Issues	Diane Wickland/Jim Gleason

Agenda

Wednesday, Jan 24, 2001

Identify convergence of Science needs and candidate Technology approaches

- new capabilities enabled
- reductions in implementation and life-cycle costs

Define specific capability/technology needs for each measurement class
Describe and illustrate the current state of the art for the technology

Itemize the major technology components and current technology readiness level

Identify ongoing investments

Identify technology development gaps

Formulate draft technology development roadmaps

- Show key development and flight validation objectives and milestones
  - Ground development and validation needed
  - include technology flight validation where necessary

Summary Plenary Session

- 10-minute presentations by Chairs of each Breakout Session

Adjourn

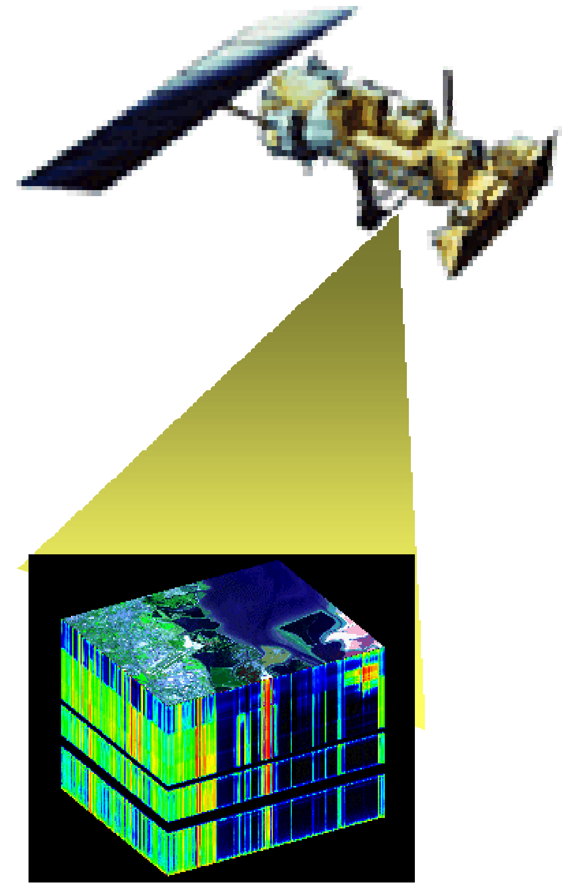
Participants

• Jim Gleason	GSFC
• John Brasunas	GSFC
• Peter Silverglate	JHU APL
• W. H. Smith	Washington U.
• D. Johnson	LaRC
• Carl Holden	LaRC
• Hongwoo Park	GSFC
• William B. Cook	LaRC
• Mark J. Chopping	USDA/ARS
• Diane E. Wickland	NASA HQ
• Phil DeCola	NASA HQ
• Gary Wilson	BATC

• Clayton Turner	NASA/LaRC
• Marty Mlynczak	NASA/LaRC
• Jeff Simmonds	JPL
• Faiz Rahman	Rutgers Univ
• Felicia Jones-Selden	GSFC
• Ron Kraus	Northrop
• Randy Pollock	Orbital Sci.
• Petya Entcheva Campbell	GSFC
• Mark Abrams	ITT/A/CD
• Aidan Roche	Lockheed
• David Crisp	JPL
• Nicholas Eftimiades	Nat'l Security Space Archt.

Land / Ocean Hyperspectral Imaging

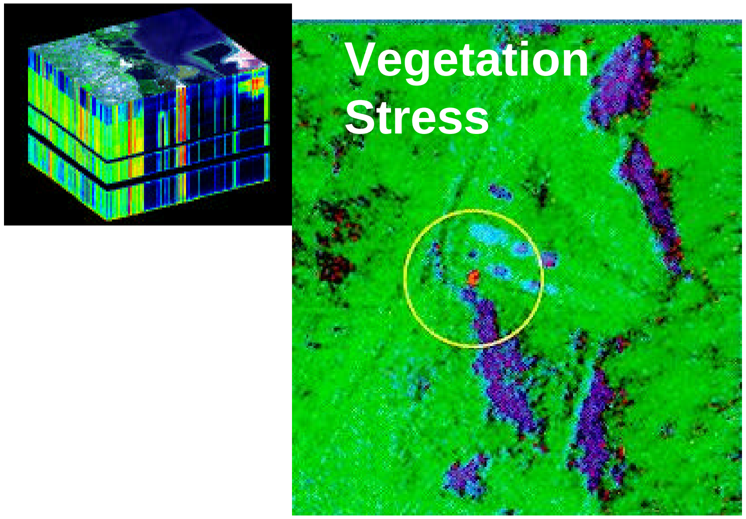
- Science Capability Needs
  - Global productivity
  - Coastal processes
  - Vegetation recovery
  - Land cover inventory
- Technologies Needed
  - 0.4 - 2.5 µm ocean/land --> 8 - 12 µm
  - 10 nm resolution / spectral precision / pathway
  - 20 - 30 m IFOV --> Higher resolution desirable
  - S/N > 1000 in VNIR 0.4 - 1.0 µm; 250 - 500 in SWIR
  - Area coverage (swath) ~ 200 km



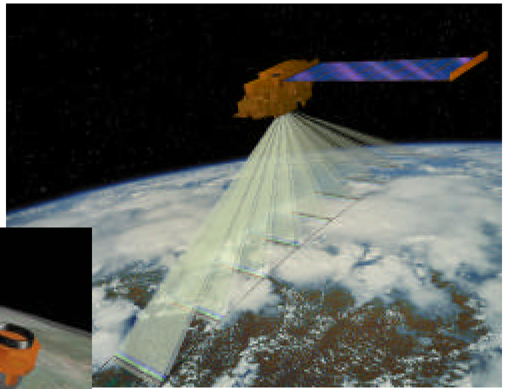
Hyperspectral Imaging

HYPERSPECTRAL IMAGING

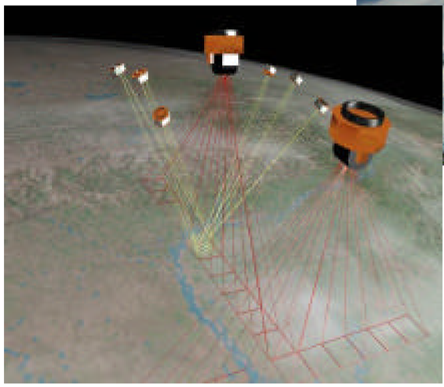
- Land & Ocean Productivity
- Land Cover Inventory
- Landscape Response
- Surface Aeology



- Example science & measurement requirements
  - Hyperspectral w/high S/N (1000) demonstration from space
  - On-board calibration
  - Targeting
    - nodding, staring,
    - multi-angle



Multi-Angle Observations

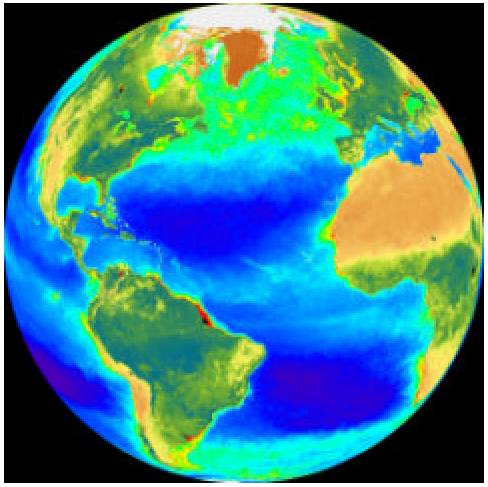


Coordinated, Multi-Spacecraft Observations

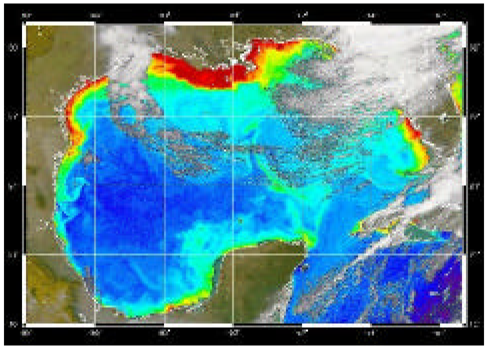
Global Productivity

Global Productivity

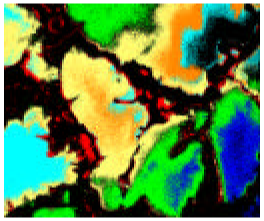
- Land
  - improving 1^{o} productivity estimate by including physiological/stress spectra
- Coastal Processes
  - 15% of area, but 70% of 1^{o} prod
    - this is a missing data set because we can't do measurements/estimations with existing sensors
  - Very complex spectrally
    - hyperspectral data essential
  - Can enhance NASA goals by
    - identifying phytoplankton type (pigments)
    - support algorithm development
    - (new for chlorophyll in Case II, input from SeaWiFS, MODIS)



Land and ocean chlorophyll



Phytoplankton concentration in the Gulf of Mexico from SeaWiFS, February 23, 1998



AVIRIS Observations of phytoplankton off the Florida coast

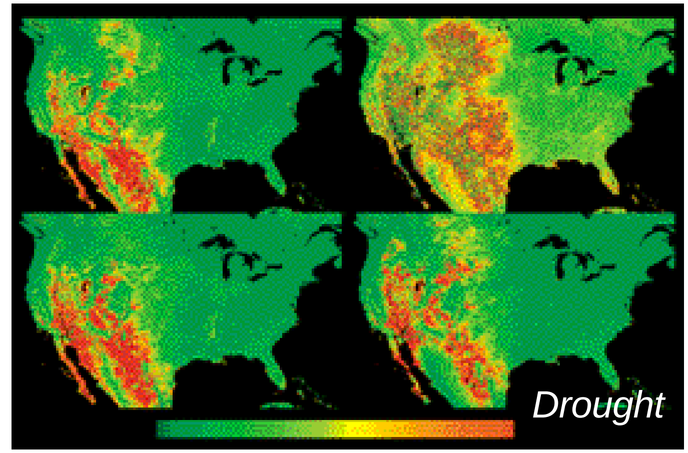
Land Remote Sensing

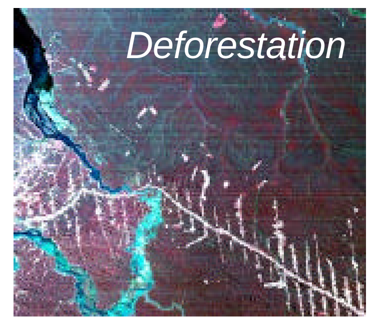
Vegetation Recovery from Stress

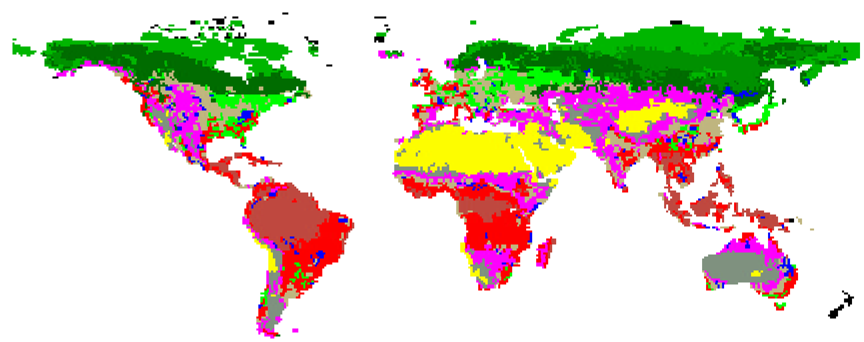
- improve estimates carbon sequestration by vegetation (spectral signature association)
- pigments/biologically active carbon (BAC) estimates can support algorithm development
  - not possible with current sensors

Land Cover Inventory

- - provide ability to interface with JPL's vegetable & mineral spectral libraries - immediately
- enhance detail in land cover inventory
  - add new dimension to inventories - physiological & BAC properties
- Technology -
  - Need on board calibration & support for ground-truth algorithm development & validation







Global Land Cover Inventory

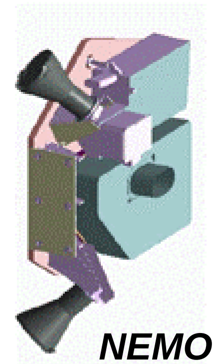
Hyperspectral Imaging

- NEMO, Warfighter, & Hyperion - S/N too low
- AVIRIS - good, but only an aircraft instrument
  - Cannot provide global coverage
  - Limited NASA science support
- Future Instruments for space
  - need fast optics
    - f/1 is a goal - to support high SNR (AVIRIS quality) data from space
    - need 1 million photons per sample
      - current detectors can't do this
  - Need on-board calibration (target of 1%)
- Algorithm development
  - AVIRIS offers opportunity for algorithm development now, but needs funding

VALIDATION PLANS

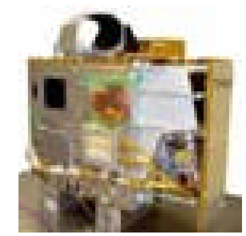
- Need to go beyond S/N
- Address stray light problem
  - spectral contrast, calibration

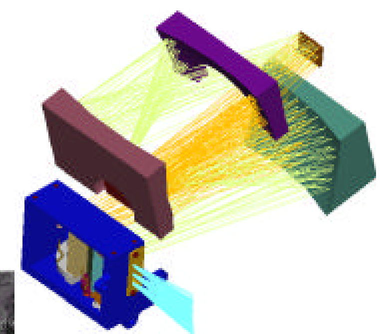
AVIRIS

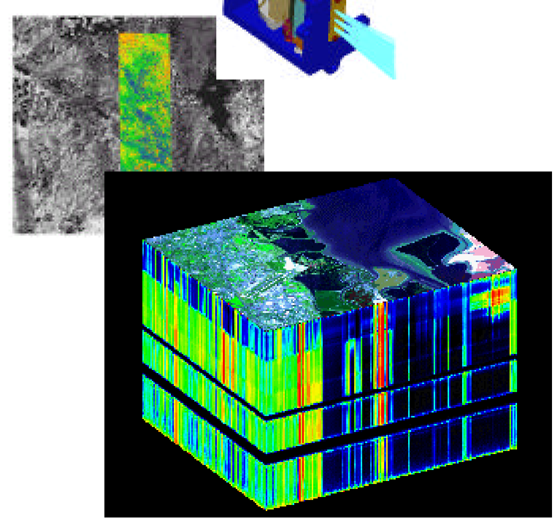


NEMO

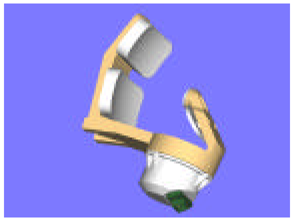
EO1 Hyperion



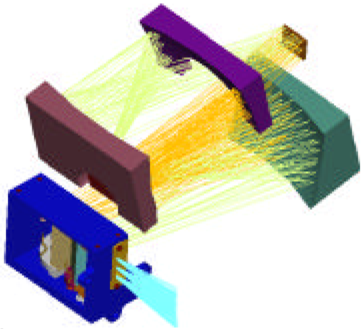


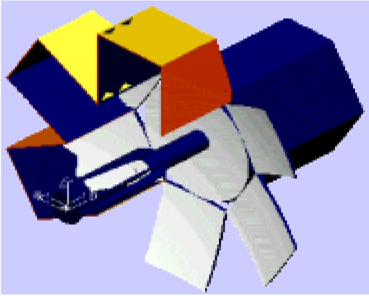


Optical Component Technology



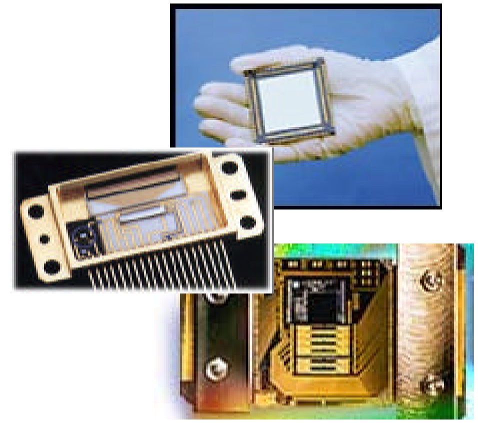
- Fast (small f/#) optics
  - large aperture - high S/N
  - small focal length - small system
  - wide field of view - precludes need for scan mechanism
- Wide angle optics
- "Large" lightweight optics
  - Large optics needed for high resolution IR Observation
    - Unlike astrophysical systems, may not have to be cryogenic
  - Composite optics
    - high cost for first unit, but low recurring cost
      - may be appropriate when multiple copies are needed(sensor web)

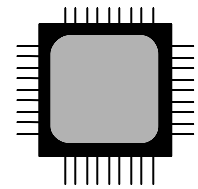


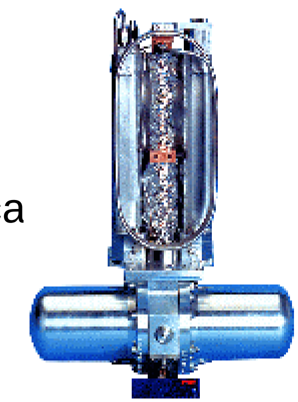


Technologies Needed for Advanced Hyperspectral Imaging

- Detectors
  - better IR performance (beyond 15 μm)
  - larger numbers of larger pixels
  - special resolution - higher S/N
  - addressable pixels, flexible readout
- Detector Electronics
  - low noise - high speed readout
  - space quality existing CoTS hardware video amps
  - fast, linear, low power, A/D converter
    - 10’s of megapixels/second (50 megapixels/second)
    - 16 bit
- Better Coolers for Detectors
- Calibration Systems - Ground - On Orbit
  - long-lived stable - full aperture systems, radiometric & spectral ca
  - flight quality calibration systems



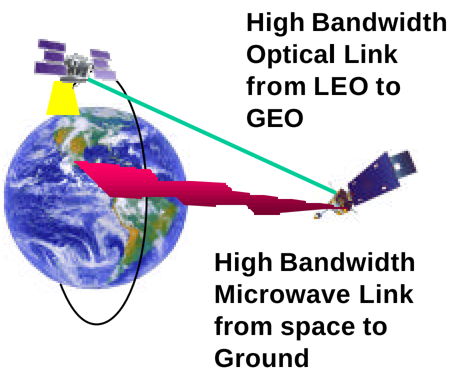




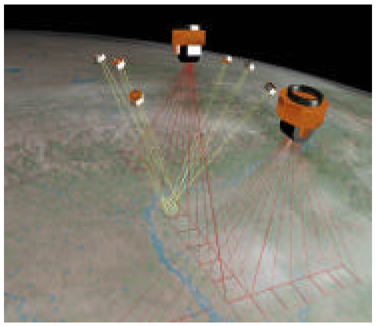
IIP development - excellent progress in many of these areas

Other Technologies Needed to Support Hyperspectral Imaging

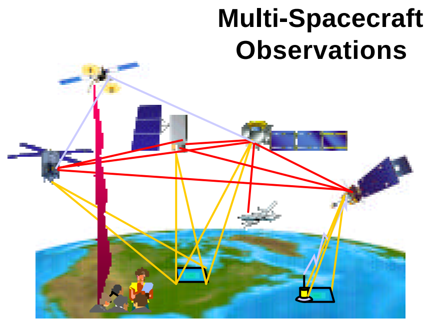
- High Data Rate Communication
  - High spectra/spatial resolution data requires high data rates



- On Board Processing
  - Data editing
    - Scientist reluctant to throw away data, but this is often essential to reduce downlink volume
    - data reduction for operational needs
      - works best when products are clearly defined
  - Coordination and scheduling of observations
    - multi-spacecraft observations of a target
    - multi-angle targeting



- Precision Navigation
  - Pointing control & knowledge for image registration
    - - l0 m pixels from LEO



Requirements for Hyperspectral Imaging

Science / Measurement Requirements

- Land and ocean productivity
- Land cover inventory
- Landscape response to anthropogenic and natural forcing
  - carbon uptake by secondary regrowth of vegetation
  - impacts of disturbances on biodiversity
- Surface Geology

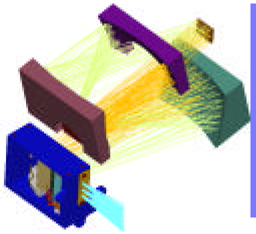
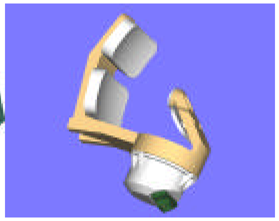
Description of Technologies

- High S/N Hyperspectral Imaging
  - reflected sunlight 0.4 to 2.5 µm
  - 10 nm spectral resolution
  - 30 m footprint
  - 200 km cross-track swath
  - S/N > 1000:1 VNIR, 500:1 NIR

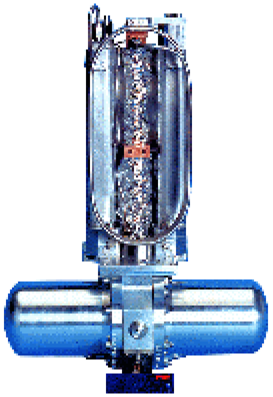
Relevance to Future ESE Missions

- Global Productivity Mission
- Coastal Processes Mission
- Vegetation Recovery Mission
- Land Cover Inventory

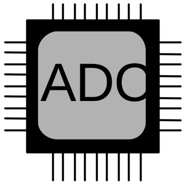
• Illustration of Technology

Fast, Wide Angle Optics



Coolers



Focal Plane Arrays

State of the Art for Hyperspectral Imaging

State of the Art for the Technology

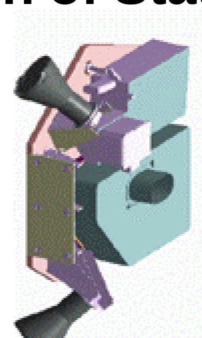
- Space Based Pushbroom systems
  - 30/60 m IFOV, 30 - 100 km wide swath
  - 400-2500 nm @ 10nm resolution
  - S/N >200:1
  - Examples
    - **EO1 Hyperion**
    - **Warfighter**
    - **Naval EarthMap Observer (NEMO)**
- Aircraft
  - AVIRIS
    - **wisk-broom scanner**
    - **1 mrad IFOV over 0.52 radian FOV**
    - **380-2500nm @10nm resolution**
    - **SNR >1000:1**

Major Technology Elements and TRL

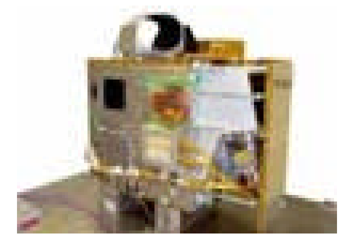
- Fast (f/2 to f/4) wide-angle optics
  - High fidelity, uniformity, and stability
- Modular Dispersive subsystem
  - Spectral: Vis, VIR, SWIR
  - Cross-track
- On-board calibration

Illustration of State of the Art

AVIRIS

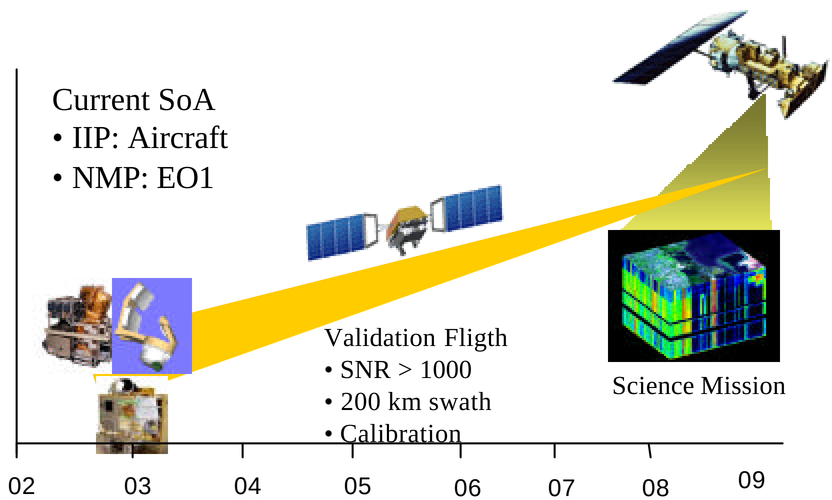


NEMO



EO1 Hyperion

Technology Development Roadmap



Validation Plans for Hyperspectral Imaging

Description/Justification of Proposed Space Validation

- Subsystem validation of advanced hyperspectral imager in LEO to demonstrate:
  - S/N > 1000:1
  - Modular system with fast (f/2 to f/4, wide-field (>200km cross-track) optics
  - Accurate, on-board calibration
  - Partially-populated focal plane

Expected Benefits

- Demonstrate a breakthrough in S/N and that will enable a host of new, quantitative, hyperspectral science from space
  - should encourage commercial applications as well as NASA and DoD
- Demonstrate a wide FOV (200 km) at high spatial resolution (30 m)
- Demonstrate high stability and calibration

Accommodation Requirements

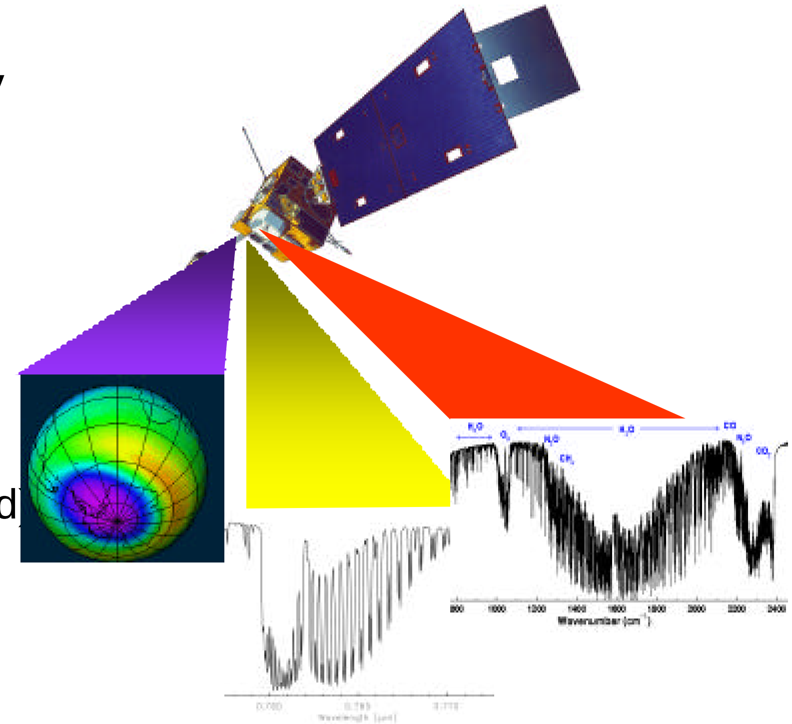
- Mass: 20 to 50 kg
- Volume: 0.5 m^3
- Power: 30 Watts (avg)
- Pointing accuracy: 0.012 to 0.04 mrad
- Pointing Stability: < 0.01 mrad/sec
- Mass Storage system (>32 GB)
- Lifetime:
  - 1 week to test optical system
  - mininum of 1 year to demonstrate calibration stability

Top-Level Development and Flight Schedule

- Validation flight formulation could start as early as FY02.
- Validation flight in ‘05
- First science mission launch in ‘08

Atmospheric Spectroscopy

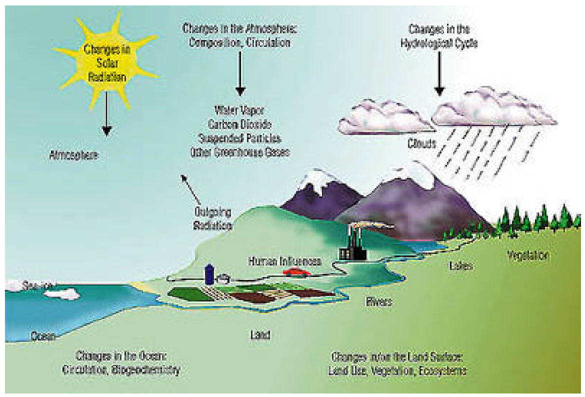
- Science Capability Needs
  - Tropospheric and stratospheric chemistry
  - Greenhouse gas monitoring
  - Clouds and aerosols
  - Temperature and water vapor sounding
- Technology Needs
  - Temperature and humidity sounding
    - 6 --> 60 µm (FIR not adequately measured)
  - Atmospheric composition and chemistry
    - High resolution; UV/NIR/MIR/TIR spectra
    - Very high spectral resolution (< 0.1 cm^{-1})
    - Low spatial resolution
    - Advanced detectors
      - larger arrays, larger pixels
  - Aerosol and clouds
    - Wide fields of view / High spectral resolution
    - Low scattered light



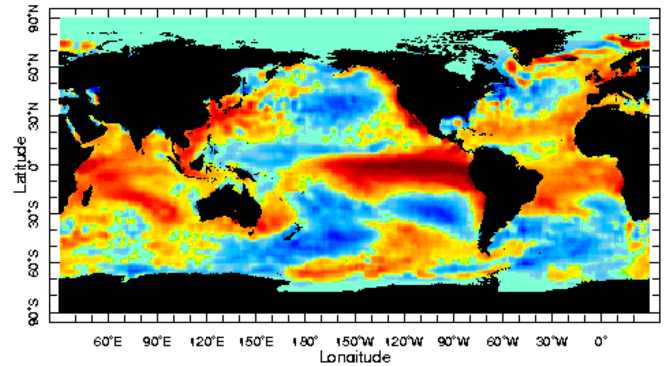
Climate and Ozone Monitoring

ATMOSPHERIC SPECTROSCOPY

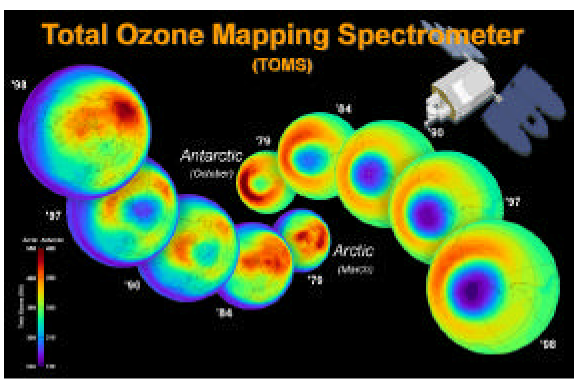
- Science Needs/Areas
  - Global Energy Cycle
    - Spectral ERB
    - Aerosols
    - Clouds



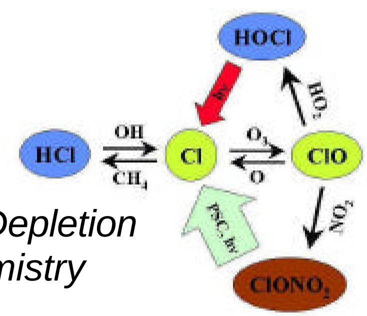
- Climate variability + trends
  - Aerosol radiative forcing
  - Cloud radiation feedback
  - Volcanic gas/ash emission



- Stratospheric and Tropospheric Chemistry, Exchange, + Trends



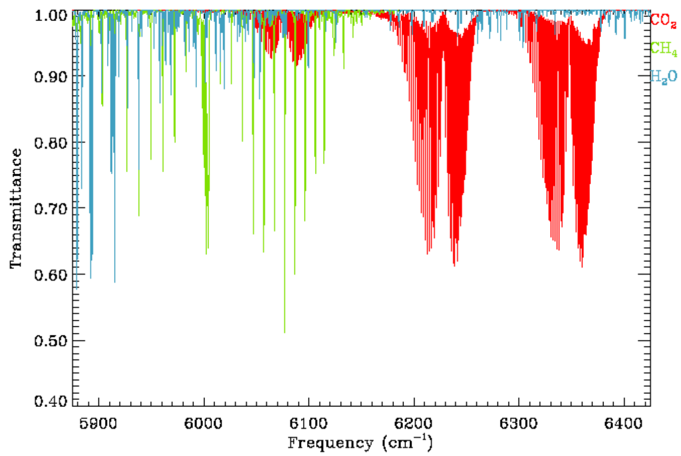
- Stratospheric Composition
- Stratospheric ozone response to climate variations



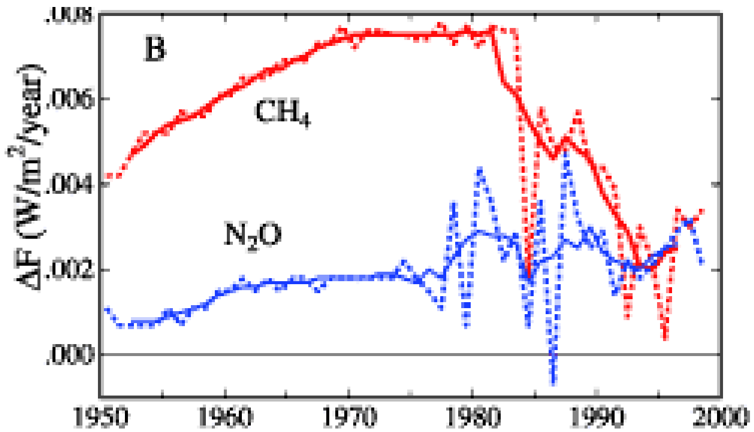
Ozone Depletion Chemistry

Atmospheric Sounding

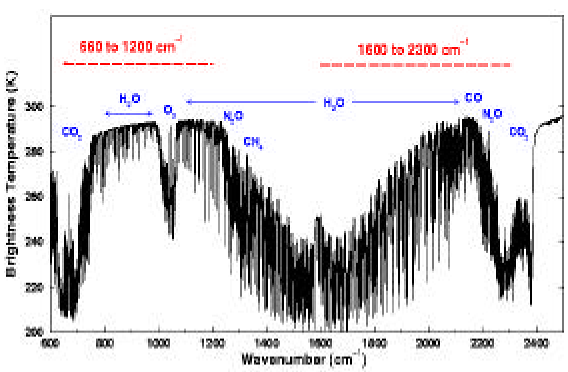
- Regional Chemistry and Climate
  - pollution
  - Greenhouse gas buildups



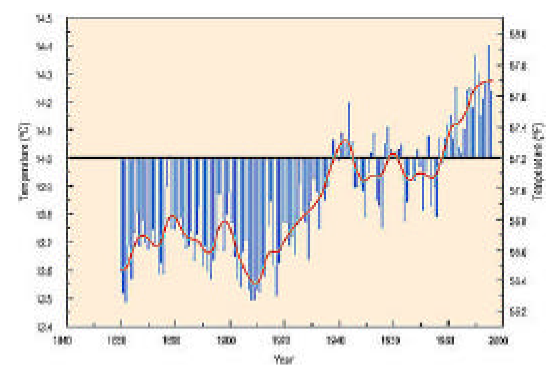
- Tropospheric Chemistry

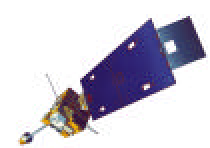


- Temperature, moisture, and trace gas soundings

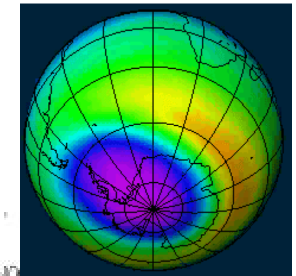


- Advanced LEO sounder
- Advanced GEO sounder



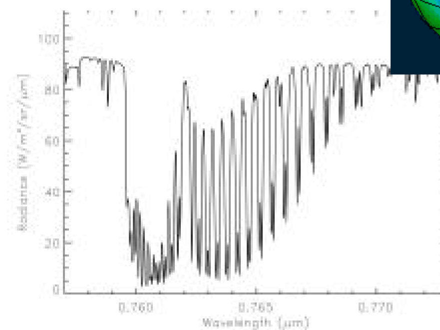


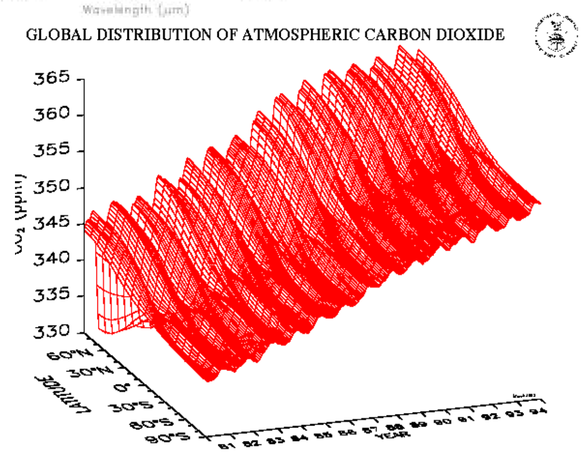
Atmospheric Spectroscopy

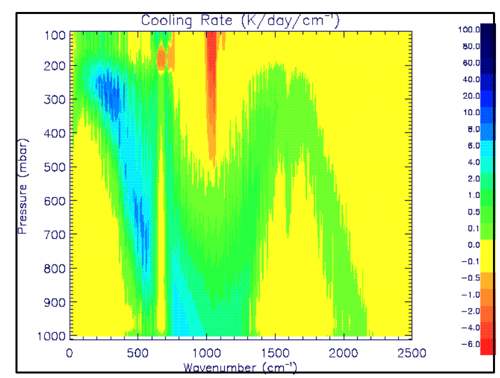


Measurement Techniques

- Solar Spectrometers
  - Ozone sounders
    - Vertical profiles (solar/stellar occultations)
    - Column ozone maps (nadir)
  - Constituent profiles (NO_2, H_2O, others)
  - High resolution systems
    - Constituent profiles (NO_y, Cl_y, CH_4, BrO, others) (IR)
    - Cloud aerosol profilers (O_2 A-band) (Vis)
    - Column O_3, H_2O, CO_2, CH_4, BrO, others (UV-Vis)
- Thermal emission spectrometers (IR-Far IR)
  - Vertical profiles of
    - Temperature, H_2O, O_3, NO_y, Cl_y, others
- Global radiation budget and climate feedbacks
- Cloud properties (radiative forcing)







Requirements for High Performance Atmospheric Spectrometers

Science/Measurement Requirements

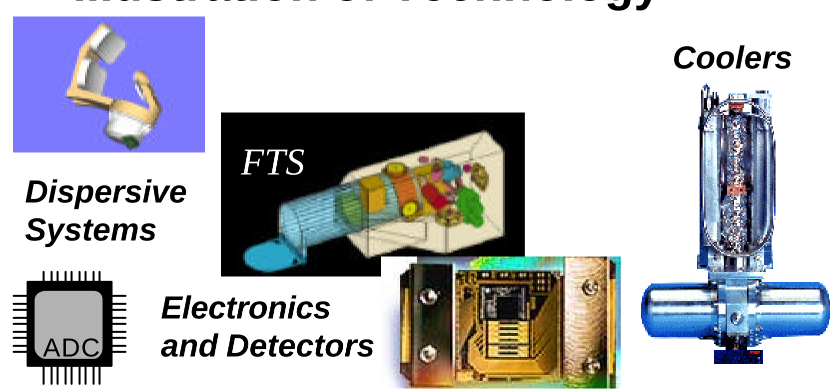
- Tropospheric/Stratospheric Chemistry
  - O_3, NO_x, OH-, OCS, SO_2
- Greenhouse Gas Monitoring (CO_2, CH_4)
- Clouds and Aerosols
- Temperature and Water Vapor Sounding
- 3-d Cloud/Water vapor tracked winds
- Spectral Earth Radiation Budget

Relevance to Future ESE Missions

- Climate Variability and Trend
- Stratospheric Composition
- Tropospheric Chemistry
- Aerosol Radiative Forcing
- Cloud Radiation Feedback
- Advanced LEO Sounder
- Advanced GEO Sounder
- Volcanic Gas/Ash Emission Mapping
- Future ESSP

Measurement Techniques

- Solar Spectrometers
  - Ozone and trace gas sounders
    - vertical profiles (solar/stellar occultation)
      - improved pointing and calibration
    - column ozone maps (nadir)
      - calibration stability
  - High resolution systems
    - cloud/aerosol profilers (O_2 A-Band)
    - column water vapor, CO_2, CH_4
- Thermal Emission Spectrometers
  - Temperature, water vapor and trace gas
    - large format focal plane arrays
    - coolers
  - Far-IR (20 -100 µm) instruments
- **Illustration of Technology**



State of the Art for High Performance Atmospheric Spectrometers

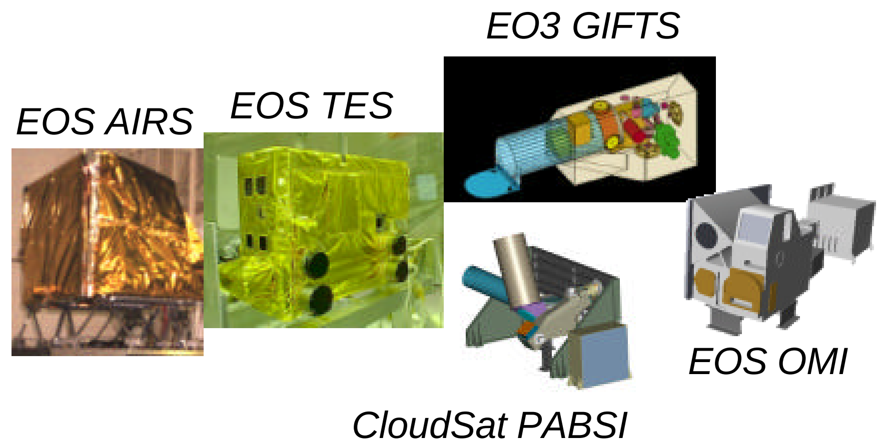
Technology State of the Art

- Thermal Infrared
  - EOS AIRS, TES
- Solar
  - GOME
  - EOS OMI
  - ATMOS

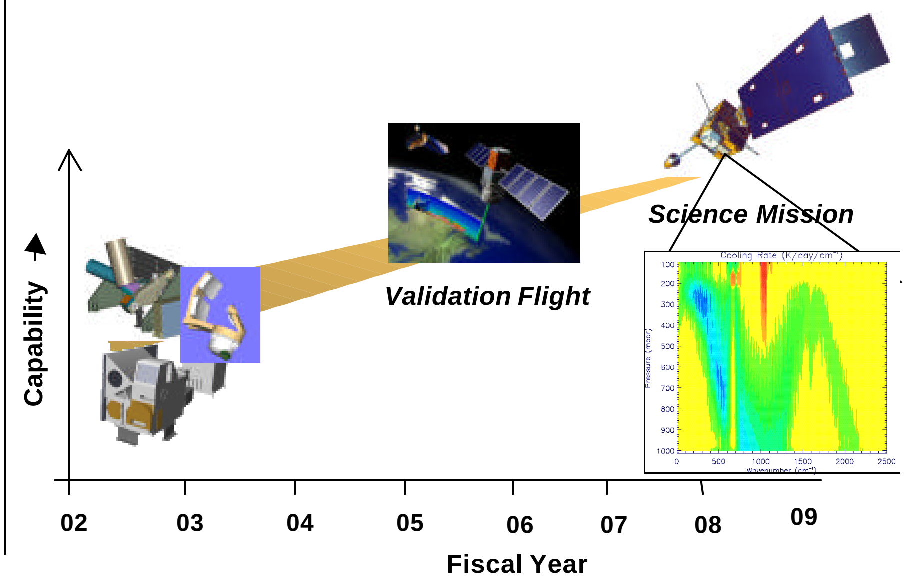
Major Technology Elements and TRL

- Fast (f/2 to f/4) wide-angle optics
  - High fidelity, uniformity, and stability
  - Wide field optics for high dispersion
- Advanced spectral dispersion systems
  - High Spectral Resolution and throughput
  - Low Scattered Light
- Large format focal plane arrays
  - Detectors for thermal IR beyond 15 microns
  - Large pixels, larger arrays for UV/VIS/NIR/TIR
- On-board calibration
  - thermal/solar reflectance
- Advanced Thermal Control
  - detector/optical system
- Advanced On-Board Data Handling

Illustration of State of the Art



Technology Roadmap



Validation Plans for High Performance Atmospheric Spectrometers for a Far IR Spectrometer

Description/Justification of Proposed Space Validation

- The following technologies have not yet been demonstrated in space
  - 20 to 100 μm Detectors
    - high-TC superconducting bolometers
  - Long-lived, closed-circuit 4K coolers
  - Diffraction limited 20-100 μm optics
    - high spatial resolution, high stability, high S/N
  - On-board calibration

Accommodation Requirements

- Mass: 25 to 50 kg
- Pointing: 1 mrad is adequate
- Partially populated focal plane
- LEO orbit
- Mission duration: weeks to months
- Cryogens could be used for flight demo if a 4K cooler is not available

Expected Benefits

- Opens a new spectral band
  - Earth's atmosphere cools to space primarily at wavelengths between 20 and 100 μm
    - currently no space-validated instruments for this spectral range
  - Could yield a much more sensitive means of monitoring
    - upper tropospheric humidity
    - greenhouse-induced changes in the tropopause

Top-Level Development and Flight Schedule

- Validation flight formulation could start as early as FY01.
- Validation flight in '04
- First science mission launch in '08

Validation Plans for High Performance Atmospheric Spectrometers for a High-Rate Processor

Description/Justification of Proposed Space Validation

- High-rate processors are needed to enable high performance atmospheric spectroscopy
  - data compression
  - sample editing
  - FTS inversions
  - principle value decomposition
- Justification for flight
  - SEU, Latch-up
  - Software development risk

Accommodation Requirements

- Stand alone system (with stimulus)
- LEO (6 months)

Expected Benefits

- Could dramatically reduce
  - downlink data rate
  - ground storage, processing

Top-Level Development and Flight Schedule

- Validation flight formulation could start as early as FY01.
- Validation flight in ‘04
- First science mission launch in ‘08

High Performance Spectrometry

Component Technologies

Very Large Format 2D FPAS

1024 x 1024 pixels or larger
Large-pixel detectors
- **0.25-1µm CCD, APS**
- **1-5µm InSb, HCT**
- **6-65µm: HCT, QWIP, Bolo arrays, etc.**

Radiation Hardness Pixel Operability

Spectrometer Optics

0.5-5 cm^{-1} spectral resolution
0.5-20 mrad spatial resolution
Imaging Spectrometers
- **fast, wide-field optics**

Ultra-stable carbon composite structures

Spectral-Radiometric Purity for high contrast scenes

Spectral-Radiometric Accuracy

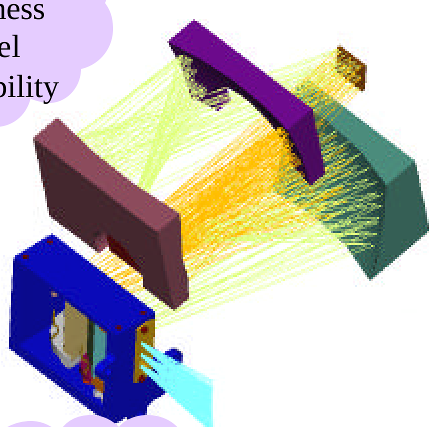
Spectral registration knowledge
Instrument line shape knowledge
Stray light / Background suppression

On-board Flight Calibration

On-Board Data Analysis

High Capacity data reduction/handling
Programmable Spectral Selection/Resolution

On-board Science Retrieval Algorithms



Measurement Approach

- Ultraviolet
- Visible
- Near IR
- Thermal IR

Science Needs

- Atmospheric Temperature, Moisture& Ozone
- Pollution Monitoring& Transport
- Volcanic Emissions
- Vegetation Type & Phenology
- Carbon Budget
- Ocean Color Monitoring