Remote Measurement of Pollution—A 40-Year Retrospective: Part II—Aerosols and Clouds

An historical assessment of the RMOP Report, NASA SP-285, at (http://ntrs.nasa.gov)

AMS 10th History Symposium, Paper 1.1

by
Ellis Remsberg, Gary Gibson, and Malcolm Ko

Science Directorate
NASA Langley Research Center
Hampton, Virginia

Direction and Context

The **RMOP Workshop was convened in 1971**, following the SCEP Report of MIT in 1970 and as NASA began to emphasize its Space Applications Programs.

Environmental concerns at the time included regional-scale transport of pollution, acid rain, degradation of coastal estuaries, and effects of emissions from SST aircraft.

Morris Tepper, Director of Meteorology, and **Jules Lehmann**, Manager of Advanced Applications Flight Experiments (AAFE), directed Langley to conduct the Workshop.

There were 3 key RMOP Panels: Gaseous Species (**Will Kellogg**), Particulates (**Verner Suomi**), and Water Pollution (**Gifford Ewing**).

The RMOP Report represents a blueprint for NASA's Space Applications programs for the following two decades.

Sensor Capabilities and their Historical Development

- The focus of this talk is on **remote sensing research at Langley Research Center (LaRC)**, as placed **within the larger historical context** of other concurrent developments by the other NASA, NOAA, academic, and international communities.

- Last year at the 9th Symposium I presented a retrospective on the temperature and gaseous species (RMOP—Part I). My findings were also published in April 2011 as a 73-pg *NASA Technical Memorandum (NASA/TM-2011-217087)* that includes ***citations to many key papers***.

- The current review (RMOP—Part II) addresses the development and deployment of passive and active techniques from the 1960s to today for the measurement of **aerosols and clouds from satellite platforms**.

Suomi and Kellogg—Visionaries of the 1950s-1970s

This retrospective focuses on **clouds and aerosol profiles and distributions** as measured from a satellite platform for studies **at regional to global scales**. Ultimately, experiment selection for a spaceflight opportunity is based on **scientific goals and sensor performances.**

Suomi and Thomas Haig of Wisconsin demonstrated the **Spin-Scan Camera** from NASA's Advanced Technology Satellites (ATS) and for NOAA's GOES. They and former students, Fred House, William Smith Sr., and Thomas VonderHaar, designed instruments for measuring Earth's radiation budget.

Peter Kuhn, Steven Cox, Don Johnson, and Reid Bryson of U. of Wisconsin obtained profiles of the net radiative fluxes from water vapor, clouds, and tropospheric aerosols using Suomi's **balloon-borne radiometersondes**.

Kellogg and Richard Cadle directed a group of researchers at NCAR in the further characterization of stratospheric aerosols or "the Junge layer".

1940's → 1971 → Present

Aeronautics Focus

- Model atmospheres, ground to thermosphere, for development of the X-15.
- Passive sensing studies of Earth's horizon for spacecraft attitude/reentry.
- Laser sensing of fluid flow in wind tunnels and turbulence in the lower atmosphere.

RMOP Workshop

Remote Sensing Applications

- Laser radar or lidar from Space.
- Measurements by solar occultation (SO) techniques.
- Limb emission and scattering.
- Nadir-viewing photometry and radiometry for aerosols and clouds, particularly cirrus.
- Aerosol polarimetry.

Techniques for the Current Decade

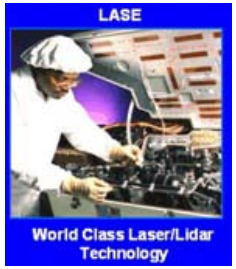
- Limb scattering from stratospheric aerosols for the OMPS on NPOESS Preparatory Project (NPP).
- SO via SAGE III from International Space Station.
- High-spectral resolution lidar for the troposphere.
- Continuation of radiation budget record w/CERES.
- Further measurements of aerosols and clouds w/CALIPSO lidar.

LaRC's Current Engineering Expertise Supports Earth Science

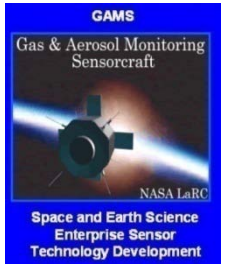
Capabilities

Advanced Concepts Development	Advanced Technology Development	Technology Demonstration	Flight Systems Development

Areas of Expertise



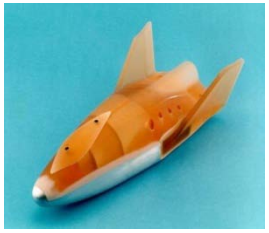
Lidar/Laser Systems



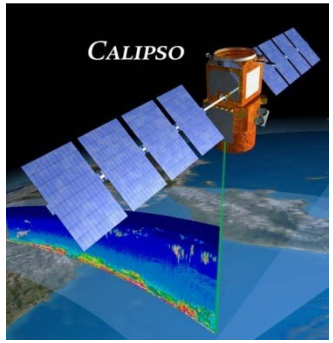
Sensor/Sensing Systems

Engineering Environments

Fabrication and Manufacturing



Flight Systems



Current Satellite Instruments from Langley

- **CALIPSO Mission**: A global 3D view of aerosols and clouds—a joint U.S./French (CNES) lidar experiment launched in **April 2006** into orbit and operating as part of the EOS Aqua "A-train" (Winker et al., *BAMS*, doi:10.1175/2010BAMS3009.1, 2010).

- **Stratospheric Aerosol and Gas Experiment (SAGE-III)** is slated for deployment on the International Space Station (ISS) in **2014** (Thomason and Taha, *Geophys. Res. Lett.,* 30, doi:10.1029/2003GL017317, 2003).

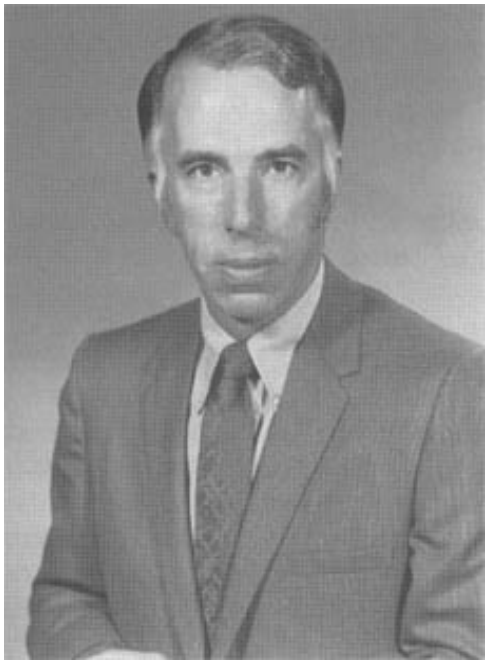
- **Clouds and the Earth's Radiant Energy System (CERES)—**launched 6th flight instrument on NPOESS Preparatory Project (NPP) satellite **November 2011** (Smith et al., *Adv. Space Res.,* doi:10.1016/j.asr.2011.03.009, 2011)

- Participating in **2011-12** in the demonstration of **NPP-OMPS limb profiler** measurement for lower stratospheric aerosols and ozone (Rault and Loughman, *Proc. of SPIE*, 6745, 674509, doi:10.1117/12.737325, 2007).

Early Key Players for Langley

- **Edgar Cortright**, LaRC Director (1968-75), created its atmospheric science organization.
- **J. Don Lawrence, Jr.,** served as AESD/ASD Division Head 18 yrs.
- **Charles Mathews** from LaRC led the NASA Headquarters Office of Applications beginning in 1972.

- Langley was already focused on stratospheric ozone and its related species because of the associated implications to the SST and national policy. ***Don Lawrence quickly recognized that the relevant atmospheric measurements would need to be of excellent quality, requiring careful calibration and independent validation.***



Dr. Edgar Cortright
[Photo credit: NASA]

Information content of retrievals of radiances and transmittances

Morris Tepper (top) and Don Lawrence (bottom) co-sponsored a **Workshop on Inversion Methods in Atmospheric Remote Sounding** in December 1976. [photo credit: NASA]

Trade-offs between measurement **accuracy** and the desired **spectral and spatial resolutions** were defined.

Sensitive detectors, accurate instrument pointing, calibrated measurements, and a proper discrimination between Rayleigh and aerosol extinction were important requirements**.**

RMOP Particle Air Pollution Panel Members

(*Persons in red became directly associated with successful satellite instruments.*)

Verner Suomi, Univ. of Wisconsin, **Panel Chair**

Henry Blau, Jr., Arthur D. Little, Inc.

Charles Byvik, NASA Langley

Robert Fraser, NASA Goddard

Gerald Grams, NCAR

Thomas Haig, Univ. of Wisconsin

Franklin Harris, Jr., Old Dominion Univ.

Benjamin Herman, Univ. of Arizona

Alfred Holland, NASA Wallops Station

J. Don Lawrence, NASA Langley

William Matthews, MIT

S. Harvey Melfi, NASA Langley

G. D. Robinson, Univ. of Connecticut

Zdenek Sekera, UCLA

Development and demonstration of lidar at Langley

- Ground-based, mobile **48-inch pulsed ruby backscatter lidar** system from the late 1960s through 1980s—**Lawrence, Melfi, and M. Patrick McCormick**.

- **Raman lidar** measurements of emissions from power plant plumes in the late 1960s and the 1970s—**Melfi and Sherman Poultney (ODU)**.

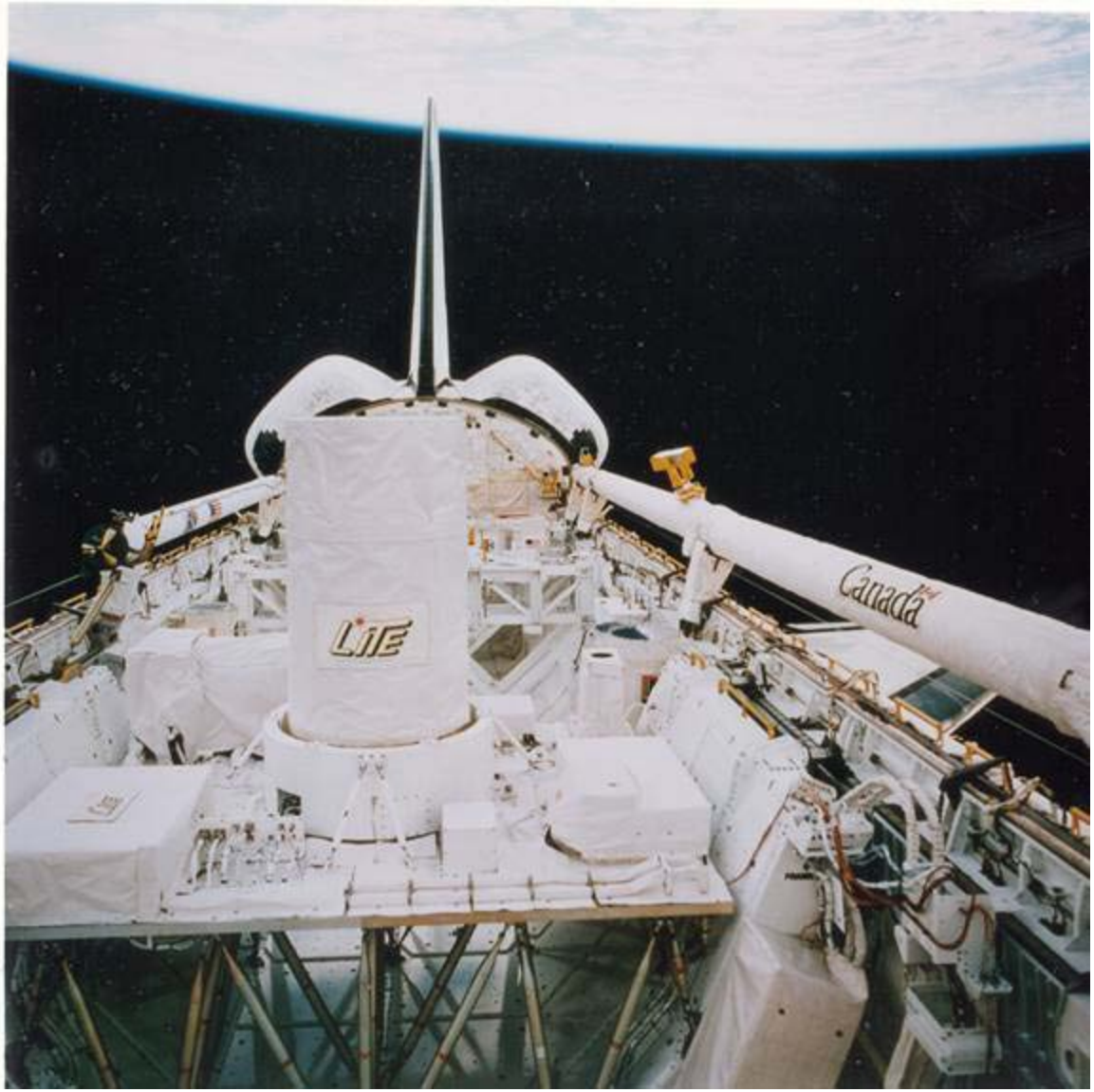
- Ground-based and airborne **differential absorption lidar (or DIAL)** from the mid 1970s and onward—**Edward Browell, Syed Ismail, and William Grant**.

- Airborne UV-DIAL lidar studies of urban to regional ozone and tropospheric haze layers and in the early 1980s—**Browell and Scott Shipley.**

- Airborne, 14-inch lidar on aircraft underflights of satellite occultation measurement locations for aerosols and clouds, plus their polarizing character from the late 1970s to 2000—**McCormick and Lamont Poole**.

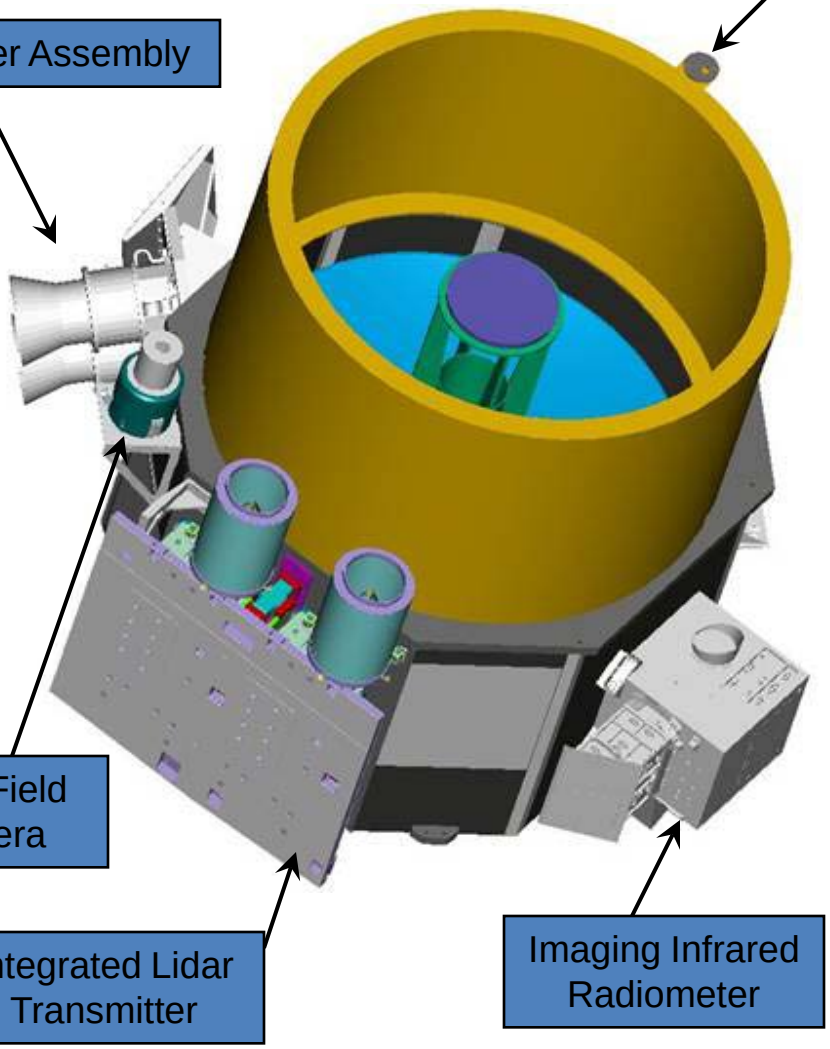
- **Lidar In-space Technology Experiment (LITE)** on Space Shuttle in 1994—**McCormick, Browell, Melfi, David Winker, Geoff Kent (STC), and William Hunt (Wyle Laboratories).**

LITE



CALIPSO Payload

- **Telescope**
  - **Third build of design type**
- **Laser**
  - **Fully Redundant Lasers**
  - **Risk Reduction Laser has accumulated over 3 Billion shots (5+ years operations)**
  - **Conservative, de-rated design**
  - **Incorporated Lessons Learned form other programs**
- **WFC: Based on COTS design (CT-633 star tracker)**
- **IIR: Sensor Module from IASI**
- **X-Band Transmitter: Cincinnati Electronics T-712**



Satellite Solar Occultation Instruments

- Apollo-Soyuz Test Project (1975)—first solar occultation transmission experiment was the **Stratospheric Aerosol Monitor (SAM)** **(T. J. Pepin, U. of Wyoming)**

- Nimbus 7 (1978-1993)—**Stratospheric Aerosol Measurement II (SAM II)** **(McCormick, Gerald Grams, and Benjamin Herman)**

- Atmospheric Explorer (AEM-B in 1979)—**Stratospheric Aerosol and Gas Experiment (SAGE)** **(McCormick, Grams, Herman, and William Chu)**

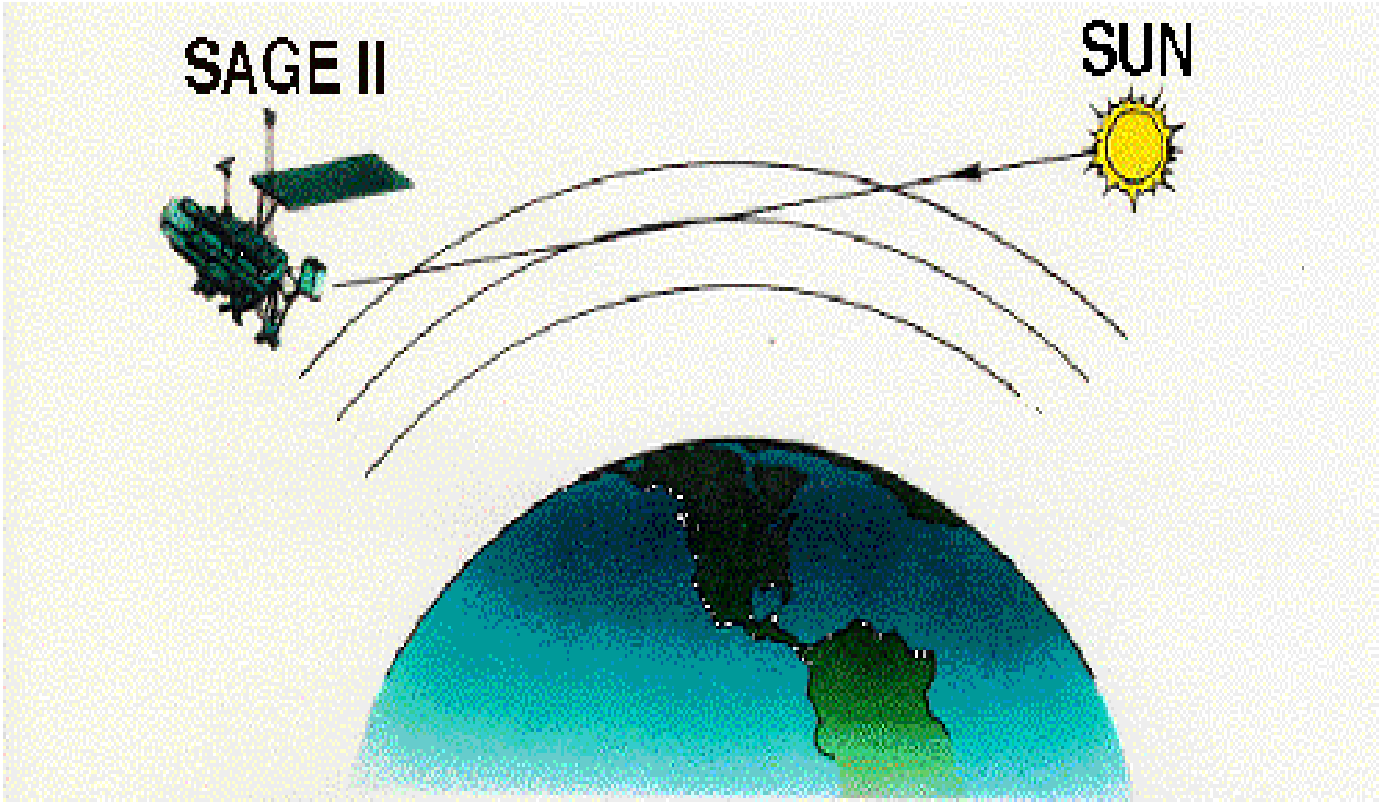
- ERBS (1984-2005)—**SAGE II** **(McCormick, J. Zawodny, L. Thomason, and G. Yue)**—***volcanic to background stratospheric aerosol trends over a 21-yr period.***

- UARS (1991-2005)—**Halogen Occultation Experiment (HALOE)** (**J. M. Russell, III and Mark Hervig (GATS, Inc.)**)—aerosol extinction at infrared wavelengths.

- EOS (2001)—**SAGE III** **(McCormick, Poole, Thomason, and Mike Pitts)** on the Russian Meteor 3 for measurements of PSCs and aerosols at high latitudes.

Measurement geometry for SAGE II

(Industry partner Ball Aerospace)



Nadir-viewing photometry and radiometry

- **Landsat-1 Multi-Spectral Scanner (MSS)** radiometer (July 1972)—**Robert Fraser** (NASA Goddard) analyzed MSS images for occurrences of the outflow of Saharan dust westward across the Atlantic—precursor to Moderate Resolution Imaging Spectroradiometer (MODIS). **Bruce Wielicki** of LaRC examined MSS imagery for cloud fractions and cloud reflectances.

- **Earth Radiation Budget (ERB)** on Nimbus 6 and 7 polar orbiters (1975 and 1978)—William Smith, Herbert Jacobowitz, **G. Lou Smith,** Fred House, Thomas Vonder Haar, **Antony Jalink.**

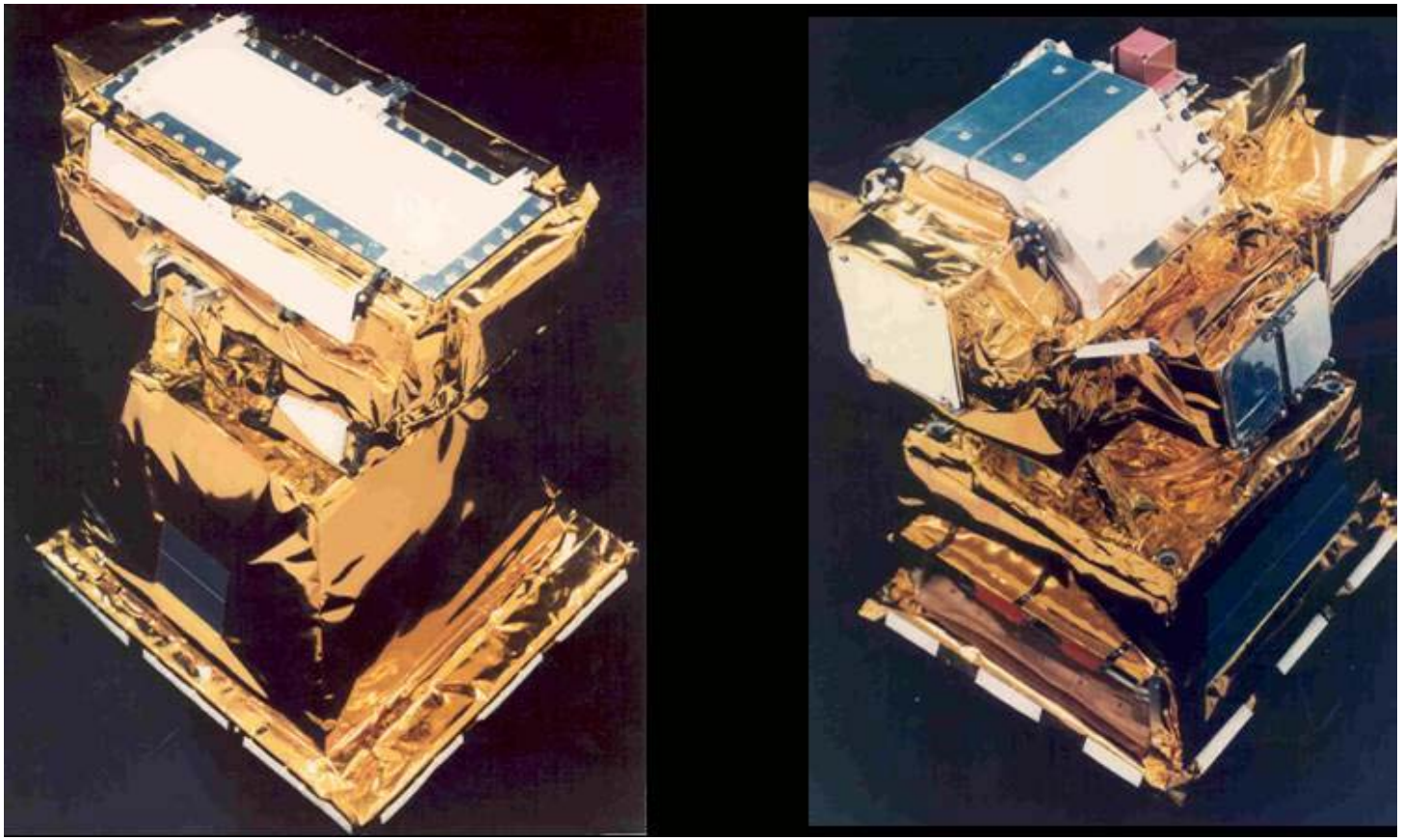
- The **Earth Radiation Budget Experiment (ERBE)** of Langley was launched from the Space Shuttle in 1984 in a non Sun-synchronous orbit to address the issue of the diurnal variability of the radiances, due mainly to clouds—**Bruce Barkstrom, Patrick Minnis, Edwin Harrison**.

- The radiative effects of multilevel clouds were studied by **Wielicki, Minnis, and Bryan Baum** with the aid of imagery from Advanced Very High Resolution Radiometer (**AVHRR**), MODIS, and now from VIIRS on NPP. Operations of AVHRR by NOAA began with TIROS-N in 1978.

- LaRC launched its 1st **Clouds and the Earth's Radiant Energy System (CERES)** instrument in 1997. CERES obtains both solar-reflected and Earth-emitted radiances at top-of-atmosphere.

ERBE Non-Scanner and Scanner

Earth Radiation Budget Experiment



Flown on NOAA S/C in 1984 and 1986

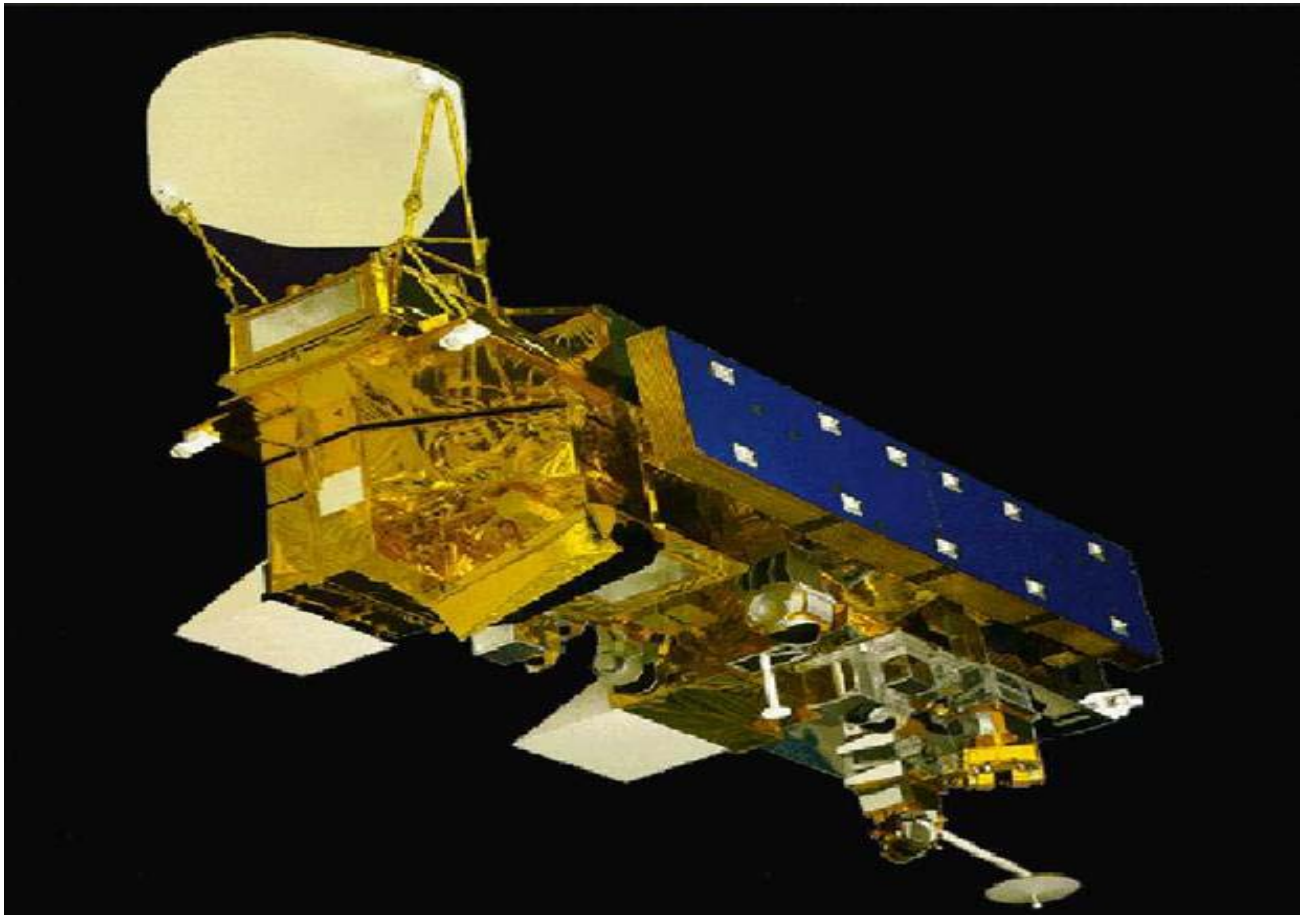
CERES

- CERES is a follow-on to the ERBE Scanner instruments. Developed essentially by the same engineering team at TRW (now Northrup Grumman), these instruments are currently flying on four separate spacecraft, having two instruments each on the EOS Terra and Aqua spacecraft. LaRC continues with having its personnel perform the instrument integration at the spacecraft level.

- Langley personnel have accumulated critical capabilities and experience with these radiation budget instruments, and they are recognized for their key roles in the integration and testing. In particular, they were able to field a refurbished proto-flight model (PFM) in time for its launch on the TRMM spacecraft in 1997.

CERES

Flown on TRMM, 1997; Terra, 1999; Aqua, 2002; and NPP 2011.



Limb emission and scattering and degree of polarization

- In the 1960s **Thomas McKee** of LaRC evaluated rocket measurements of Earth's horizon in the uv and visible for the design of sensors for **improved spacecraft attitude and control**.

- Jointly with **Steven Cox** at CSU, he calculated the **scattering of visible radiation by finite clouds** and determined their effects on **Earth's albedo**—a topic of interest to Verner Suomi.

- **Infrared emission from PSCs** was detected in the Arctic by the Nimbus-7 Limb Infrared Monitor of the Stratosphere (LIMS) experiment of 1978-79 by **Ellis Remsberg**. The LIMS experiment was led by RMOP Gas Species Panel Members, **John Gille and James Russell III**.

- The information content from **scattered radiances** about particle shapes and size distributions—their angular scattering—was determined by RMOP Panel members, **Herman, Franklin Harris, and Alfred Holland**, and measured in the atmosphere by **Jerold Twitty and Adarsh Deepak** in the 1970s. **Polarization effects** were calculated by RMOP Panel Member**, Z. Sekera,** and have been demonstrated by Brian Cairns (NASA GISS) with his airborne Research Scanning Polarimeter (RSP) since then.

Limb scattering on NPP-OMPS

- Initial assessments were presented on the **information content from uv and visible limb scattering measurements** at the 1976 Workshop, sponsored by **Tepper and Lawrence**.

- Developed by Ball Aerospace, **SAGE III** was a follow-on to the SAGE II, SAGE, and SAM II Earth science occultation instruments. Flown in 2001 on the Russian spacecraft, Meteor, this effort provided a unique experience in the integration and operation with a foreign system.

- **David Flittner and Didier Rault** of LaRC analyzed uv and visible measurements from SAGE III and also evaluated algorithms for retrieving higher vertical resolution, ozone profiles using the limb scattering technique.

- Flittner and Rault are applying their algorithms for the retrieval of **ozone profiles in the lower stratosphere** from the radiances observed by the Ozone Monitoring and Profiling Suite (OMPS) on the NPP spacecraft that was just launched in November 2011.

SAGE III

Stratospheric Aerosol and Gas Experiment

Russian Meteor S/C Instrument

Summary

Better accuracies, spatial and spectral resolutions, and long-term measurement stability are still technology goals, ***as identified at the RMOP Workshop.***

- The RMOP report of 1971 was the **precursor to** the Earth Observing System (EOS) program of the 1990s and then to the **current Decadal Plan** for NASA's Earth Sciences as outlined in the National Research Council (NRC) Report of 2007.

- The original RMOP blueprint for sensor development within **the AAFE Program** has been continued since the mid-1990s via NASA's New Millenium Program (NMP), Instrument Incubator Program (IIP), and Earth System Science Pathfinder (ESSP).

- Langley's Science and Engineering Directorates are continuing to develop remote sensor concepts for the measurement of aerosols, clouds, and Earth's radiation budget from environmental and meteorological satellites.

- **The atmospheric measurements envisioned by Suomi, Kellogg, and Lawrence are providing critical information for the evaluation of climate science.**