Dixon Butler added that NASA Earth Science initially wanted to work with whomever wanted to participate—but the agency wanted worldwide cooperation, and DoD did not want to do that for military security concerns. So, DoD's role was diminished so that NASA could collaborate globally, although there was—and still is—large DoD investment.

The full discussion can be viewed online (**Track B, Day 1**, *00:44:20*).

Session 2B. Monitoring the Earth Environment

Jennifer Levasseur [NASM] was the moderator for this session.

Christopher Neigh [GSFC—*Landsat 9 Project Scientist*] spoke about "The History of Landsat and the Earth Environment" (**Track B, Day 1**, *01:48:12*). He showed the famous "Earthrise" image taken as the Apollo 8 astronauts were returning from orbiting the Moon in 1968 and noted that this image captured the public's imagination. This photo alone is considered a significant impetus for the modern environmental movement, showing, as it does, a colorful, dynamic Earth floating in the utter blackness of space. The first Earth Day came soon after, in 1970.

"The vast loneliness is awe-inspiring, and it makes you realize just what you have back there on Earth."
*—**Jim Lovell**, Command Module Pilot for NASA's Apollo 8 mission*

The Landsat program is a 50-year partnership between USGS and NASA, in which NASA builds and launches the missions, and USGS manages and distributes the data. Neigh discussed some of the early history that led to the creation of the first Landsat mission—originally called Earth Resources Technology Satellite (ERTS). He mentioned the role that **William Pecora** [USGS—*Director* (1965–1971)] and **Stuart Udall** [U.S. Secretary of Interior (1961–1969)] played in moving the first mission from concept to reality, as well as the pioneering role of **Virginia Norwood** [Hughes Aircraft Company], who designed the Multispectral Scanner (MSS) that flew on Landsat 1-4, and is known as the "Mother of Landsat."[8]

Overall, Neigh summarized the importance of the Landsat program, explaining that the observations from Landsat missions have allowed for major advances in understanding the global land surface beyond what was available from 50 years of prior air photo surveys.

Neigh referenced the book, ***Landsat's Enduring Legacy***, as an excellent summary of Landsat history. He noted that an open access version of this book (available at the link above) has recently been released. While there are many stories in the book that could be highlighted, Neigh chose to focus on a few. He discussed how Landsat transitioned from the analog era to the digital era, developing the ability to process large amounts of Multispectral Scanner (MSS) data—including the important contribution of **Valerie Thomas**, a FORTRAN programmer at the USGS's Earth Resources Observation and Science (EROS) Center, who used MSS datasets to "train" a vegetation model to detect crop types.

Figure 2. Logo for the Large Area Crop Inventory Experiment (LACIE), which ran from 1974–1979, was the first large-scale experiment that used Landsat data, and a precursor for other Landsat investigations.

Neigh also told the story that led to the start of the **Large Area Crop Inventory Experiment** (LACIE), which was initiated in 1974, and was the first Landsat experiment to test large area crop mapping to monitor global agriculture commodities and ultimately to produce production forecasts. This is an interesting case where Cold War politics and the resulting impact on the U.S. economy converged to provide impetus for the development of a new satellite technology. (See **Gemma Cirac Claveras**' presentation in Section 5B for more on the impact of history and politics on satellite technology development.)

Furthermore, Landsat provided the optimal ground resolution and spectral bands of publicly available data to efficiently track land use and document land

[8] Another key name from the history of Landsat is **Darrel Williams**, former Landsat Project Scientist, who in 2008, shared his perspective on the early days of EOS, including his role in both EOS leadership and the development of Landsat. See **Reflections on the Early Days of EOS: "Putting Socks on an Octopus"**, in *The Earth Observer: Perspectives on EOS Special Edition*, pp. 7–9.

change due to climate change, urbanization, drought, and wildfire. In addition, the continuous archive [1972–Present] provides essential land change data and trending information not otherwise available. Landsat represents the world's longest continuously acquired collection of space-based, moderate-resolution land remote-sensing data. Landsat data have led to the most science publications of any Earth observing instrument—the Moderate Resolution Imaging Spectroradiometer (MODIS) in orbit on Terra and Aqua, two EOS-era platforms, runs a distant second—and have been used for myriad societal applications.

Landsat provided the optimal ground resolution and spectral bands of publicly available data to efficiently track land use and document land change due to climate change, urbanization, drought, and wildfire.

Neigh concluded that, with free and open access to data combined with recent advances in cloud computing and the implementation of open science at NASA, William Pecora's original vision for the Landsat program from 50 years ago has been fulfilled.

Laurence Rothman [Center for Astrophysics | Harvard & Smithsonian (CfA),[9] *recorded*] discussed "The **High-Resolution Transmission Molecular Absorption Database** (HITRAN) Project: Molecular Spectroscopic Database Archive for Environmental Monitoring" (**Track B, Day 1**, *02:00:31*). He summarized the history and development of the HITRAN project, which began in the 1960s in response to an Air Force desire to develop a means to detect enemy aircraft by their radiance, while filtering out atmospheric contributions to retrievals. Advances in infrared detectors, computing capabilities, and high-resolution spectrometers converged to allow development of the original proto-HITRAN spectroscopic database, which was publicly released in 1973. Rothman mentioned that the Kitt Peak National Observatory (in Tucson, AZ) was—and continues to be—an important source of HITRAN data.

Rothman described the rapid growth of HITRAN capabilities and use in the last quarter of the twentieth century. He gave three main reasons for growth during this period: continued technological developments that enabled greater scope (e.g., increased spectral range, improved representation of transition states, and more species addressed), the inception of programs that made use of the database (e.g., EOS and later the NASA Planetary Atmospheres program), and the establishment of various collaborative initiatives (e.g., international data assimilation activities, biennial conferences, and journal special issues). More recently, the twenty-first century has seen continued growth in the capabilities of HITRAN and an increase in published results—with increased precision and accuracy—using the database. He said that requirements were driven by the environmental satellite missions of NASA as well as by its Planetary Atmospheres program. It was at this time that the management of HITRAN moved to the CfA. Rothman mentioned, among the more recent advances, the development of a new relational database, expanded validation, *YouTube* tutorials, and an improved website providing easier access to data.

To close, Rothman briefly showed the HITRAN website (see link above) and demonstrated access to one of the most commonly accessed areas: the line-by-line transition parameters of the program. He said that the CfA releases a new HITRAN version every four years; however, interim updates are posted on the website. He ended with a demonstration of HITEMP—the high-temperature analog for HITRAN—in which he showed simulated comparisons to a low-resolution spectra of carbon dioxide in an exoplanet atmosphere obtained by the James Webb Space Telescope.

Robert E. "Bob" Murphy [NASA HQ and GSFC, *emeritus*] described "Land Biosphere Interactions with the Climate System—The Addition of Biology to NASA's Earth Science Program 1983–1996" (**Track B, Day 1**, *02:11:02*). In his presentation, he told the story of how the "rocket science" world of 1970's NASA came to engage

[9] CfA is not an independent legal organization, rather it exists via a memorandum of understanding between Harvard University and the Smithsonian Institution to jointly manage and coordinate the related research activities of the Harvard College Observatory and the Smithsonian Astrophysical Observatory.