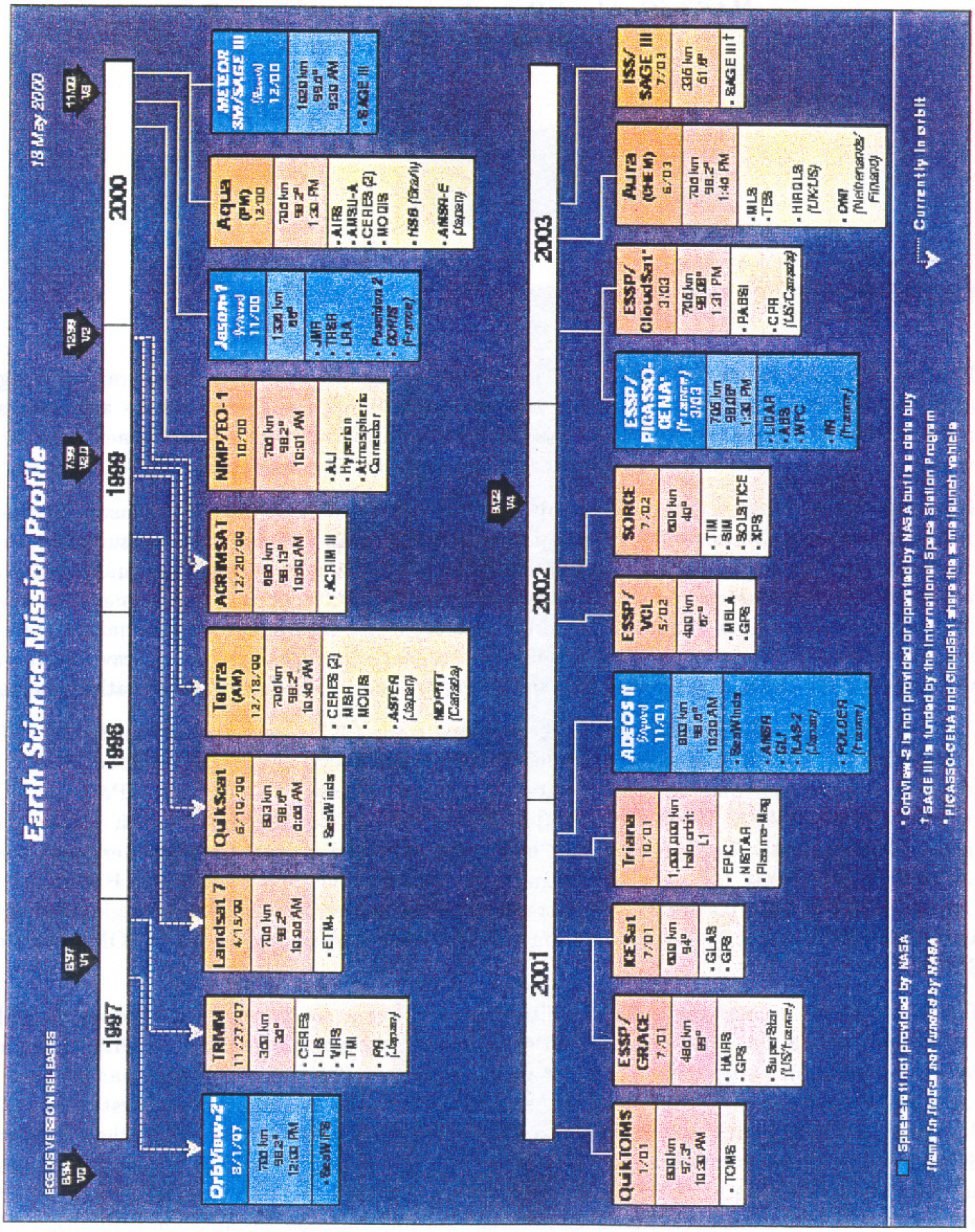

Figure 1: Timeline of NASA Earth Science Satellites and Instruments

2 EOS Terra

The EOS Terra satellite is the flagship of the EOS program. It was launched on 18 December 1999 aboard an Atlas-ILAS rocket. Flying on Terra are the Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER), Clouds and the Earth's Radiant Energy System (CERES), the Multi-angle Imaging SpectroRadiometer (MISR), the Moderate-Resolution Imaging Spectroradiometer (MODIS), and Measurements of Pollution In The Troposphere (MOPITT) instruments. Terra is in a polar, sun-synchronous orbit with a 10:30 equator crossing time, and with an inclination of 98.2°. It has a nominal six year lifetime, with direct broadcast and downlink available.

MISR consists of 9 cameras (fore- and aft- viewing) that image the same scene at different viewing angles in four different bands. This unique design enables the retrieval of aerosol, cloud, and surface properties.

MOPITT is an 8 channel correlation spectrometer using carbon monoxide (CO), and methane (CH_4) measuring reflected and thermal radiation in the infrared with a horizontal footprint of 22 × 22 km. Figure 2 shows prelimary retrievals of CO over the western U.S. in August, 2000 when there were widespread wildfires in the region. Along with smoke and particulate emissions, carbon monoxide is another byproduct of fire. Enhanced CO has also been detected over biomass burning regions in central Africa. MOPITT is provided under a memorandum of understanding with the Canadian Space Agency (CSA).

The CERES instrument has a heritage from the Earth Radiation Budget Experiment (ERBE) instruments. It is designed to improve the accuracy of estimates of radiative fluxes throughout the atmosphere and at the Earth's surface. Figures 3-4 show retrieved reflected shortwave and longwave fluxes, respectively, from February 26, 2000. A massive storm system is visible that produced rain and snow over the northwest U.S. pacific coast. Highly reflective thunderstorm clouds (bright in the shortwave but dark in the thermal longwave) stand out in the Intertropical Convergence Zone (ITCZ).

ASTER was provided by the Japanese Ministry of International Trade and Industry. It produces high-spatial-resolution (15-90 m) multispectral images in the visible through thermal infrared of the Earth's surface and clouds.

MODIS is a 36 band cross-track visible and infrared (0.4-14.5 μm) imager with spatial resolutions of 250, 500, and 1000 m at nadir. Many products are being derived from these radiance measurements. They include surface skin temperature, ocean color properties, vegetation properties such as leaf area index and vegetation indices, snow cover, land cover type and change detection, cloud mask, fire occurrence and burn scars, aerosol properties, and cloud properties. An example of retrieved cloud properties is given in figure 5. Many other examples from MODIS and the other Terra instruments can be found on `http://terra.nasa.gov`.

3 EOS Aqua

Like the Terra platform, the Aura satellite will carry CERES and MODIS instruments. In addition, the satellite carries a sounder suite consisting of the Atmospheric InfraRed Sounder (AIRS), the Advanced Microwave Sounding Unit-A (AMSU-A), and the Humidity Sounder for Brazil (HSB) as well as the Advanced Microwave Scanning Radiometer-EOS version (AMSR-E). Aqua is also in a polar, sunsynchronous orbit with a 1:30 equator crossing time. It is scheduled for launch in 2001 on a delta-class rocket.

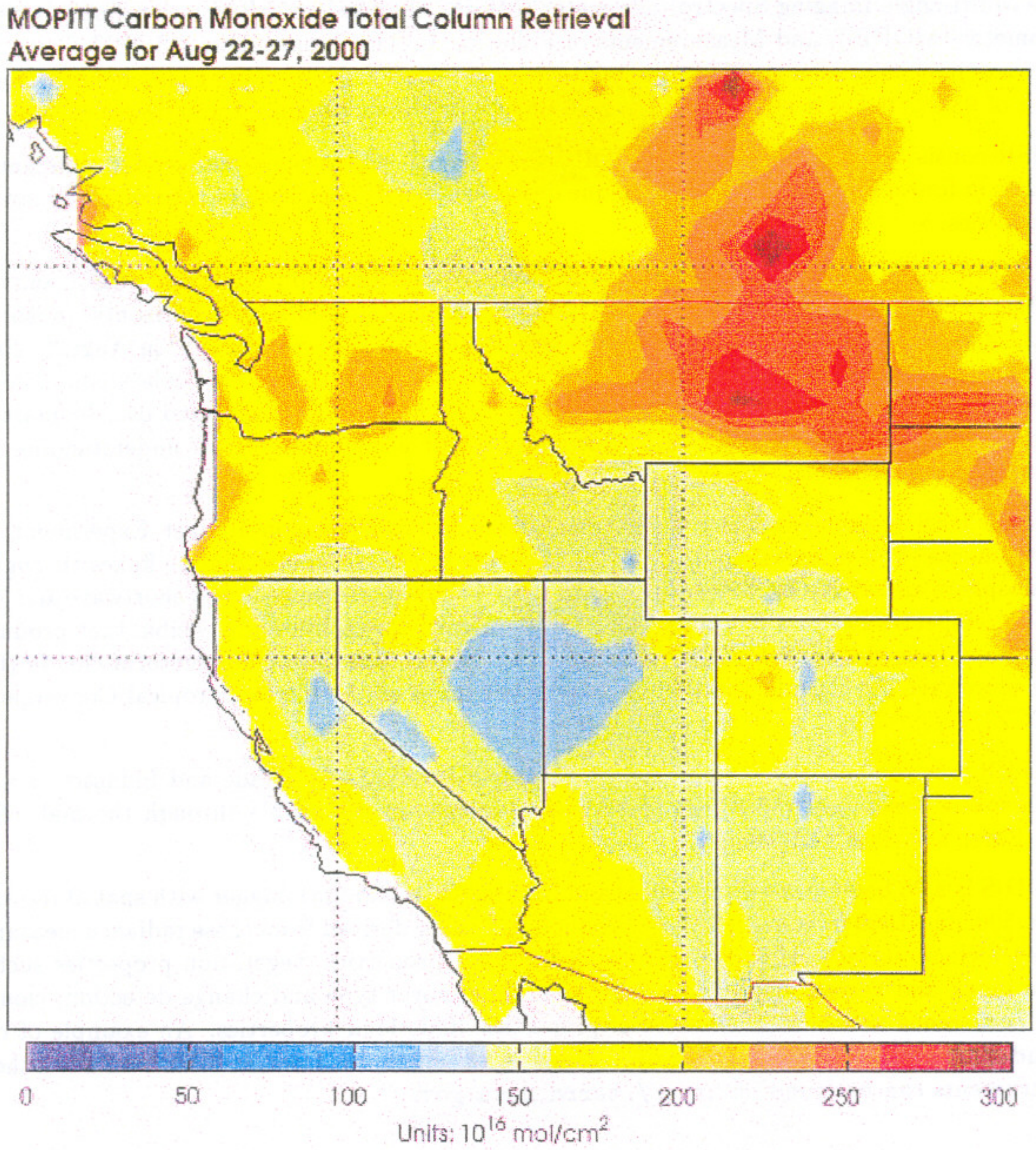

Figure 2: CO concentration from MOPITT averaged for the period Aug. 22 - 27, 2000. Red pixels show relatively high levels of carbon monoxide, yellows are intermediate values, and blues are relatively low values. Courtesy MOPITT science team and the National Center for Atmospheric Research.

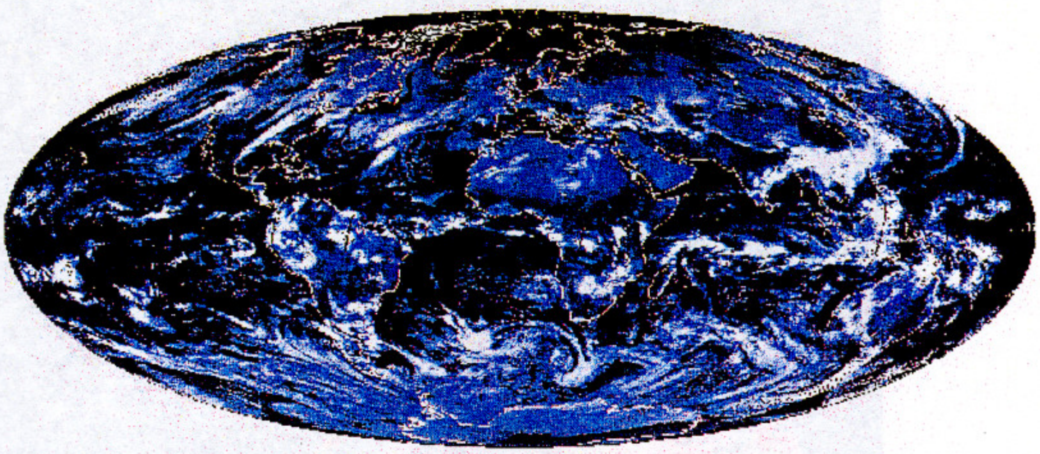

Figure 3: CERES reflected shortwave flux from February 26, 2000. Courtesy CERES instrument team, NASA Langley Research Center.

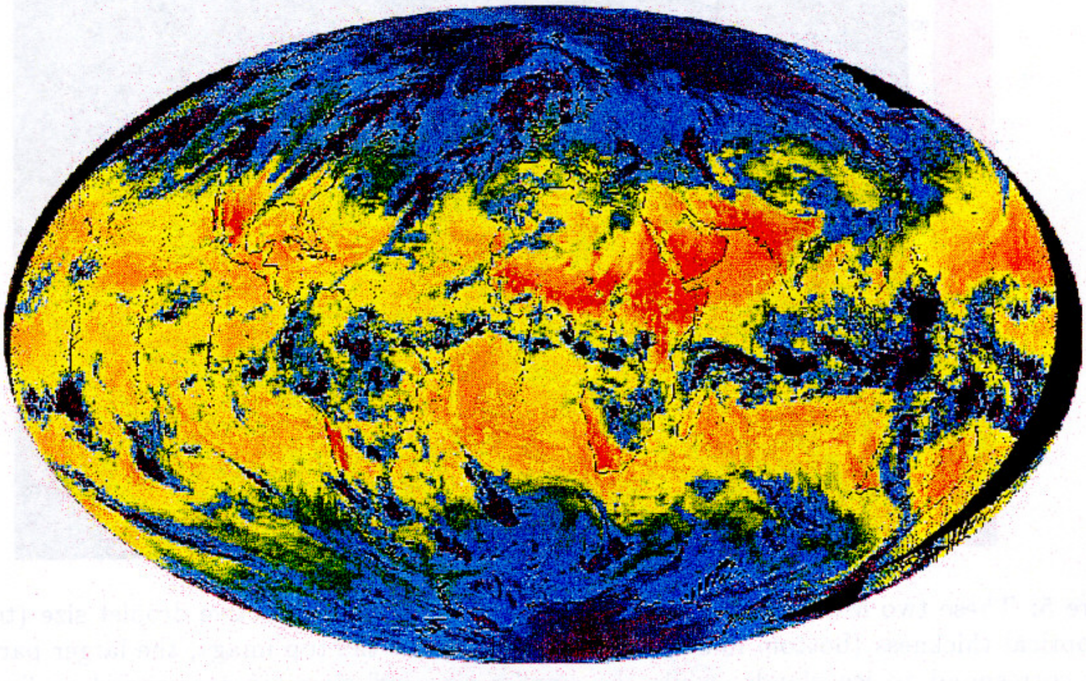

Figure 4: CERES emitted longwave flux from February 26, 2000. In this image, blue values come from cold scenes with low thermal emission, while red values come from hot ones with high emission. Courtesy CERES instrument team, NASA Langley Research Center.

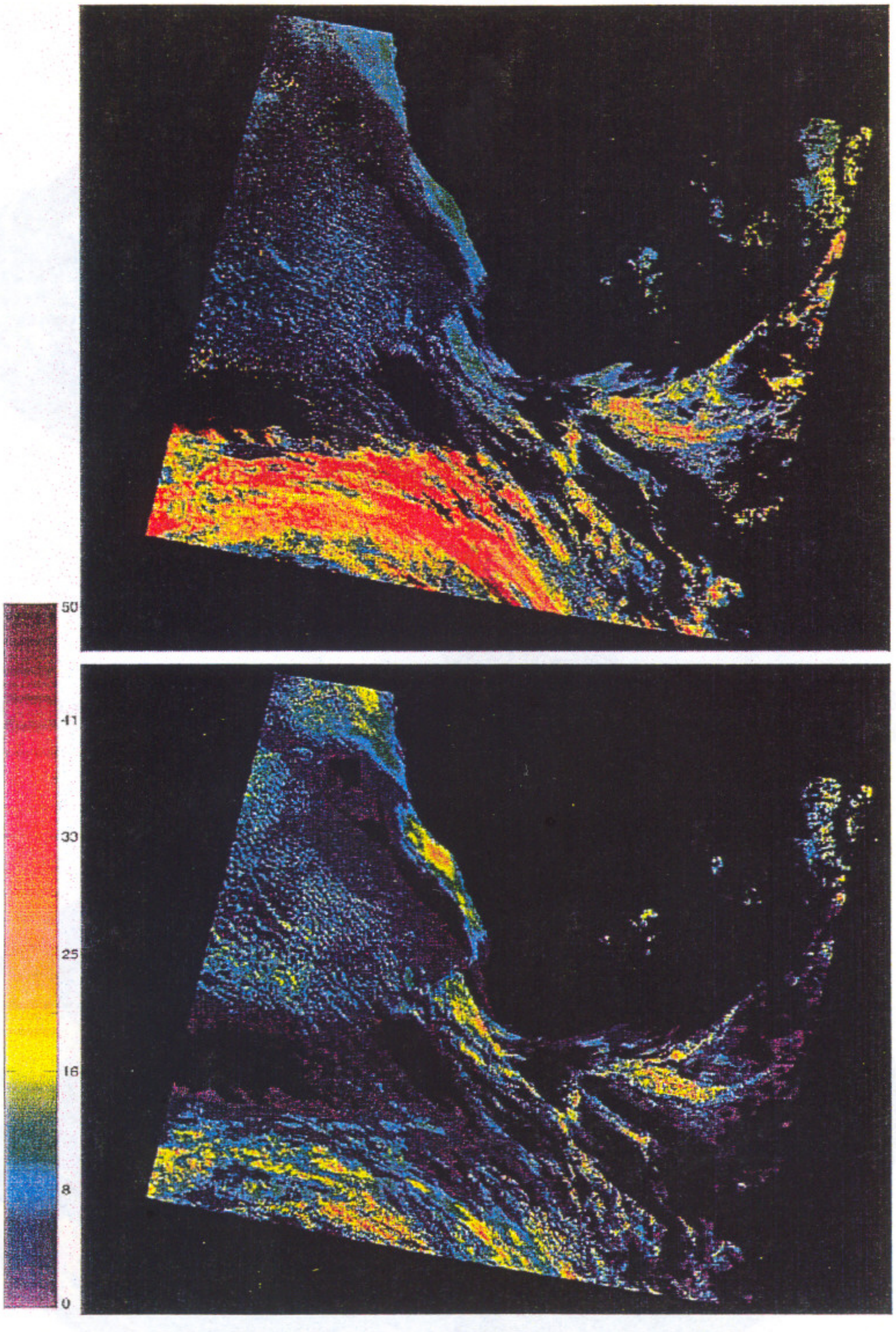

Figure 5: These two MODIS images indicate retrievals of cloud effective droplet size (top image) and optical thickness (bottom image) off South Africa. In the top image, the larger particle sizes (red) correspond to ice clouds, while the smaller sizes off Namibia correspond to liquid water stratocumulus. The color bar is scaled to micrometers for the top image and is dimensionless for the bottom image. Courtesy Mark Gray, NASA-GSFC Atmosphere Team.

AIRS is a cross-track high-spectral-resolution infrared (0.4-15.4 μm) sounder with over 2300 channels. The resolving power ($\lambda/\Delta\lambda$) of 1200. The spatial resolution is 13.5 km at nadir. The 15 channel AMSU-A instrument is already flying on the NOAA operational Polar Orbiting Environmental Satellites (POES) with the 20 channel High-Resolution Infrared Radiation Sounder (HIRS) and AMSU-B. Eleven of the AMSU-A channels reside in the 50-60 GHz oxygen resonance band. Positive impact in data assimilation has already been demonstrated with this instrument (see ECMWF, 1999). The 4 channel HSB is very similar to the 5 channel AMSU-B. Both instruments have 3 channels in the 183 GHz water vapor band. Together these instruments will be used in data assimilation systems to improve knowledge of the atmospheric state and to improve the accuracy of numerical weather prediction forecasts. In addition, AIRS will be used to investigate atmosphere-surface interactions, to monitor climate variations and change, and to retrieve information about greenhouse gases.

The AIRS instrument represents an increase of two orders of magnitude in the number of available spectral channels for data assimilation over the current HIRS sounder. This presents a challenge to data assimilators and data providers. The data must be distributed within hours if it is to be useful to NWP centers. Given the current available bandwidth, some form of data compression or subsetting is required (see Collard *et al.*, this proceedings). Figure 6 shows a simulated AIRS spectrum and a preliminary channel subset (approximately 230 channels) that will distributed in near real time.

The heritage of the AMSR-E is the Special Sensor Microwave/Imager (SSM/I) flown on the Defense Meteorological Satellite Program (DMSP) satellites and the Advanced Earth Observation Satellite (ADEOS II) AMSR. AMSR-E has channels at 6 microwave frequencies with dual polarization that can be used to retrieve sea surface wind speed, precipitation rate, cloud liquid water, total precipitable water, sea surface temperature, ice, and snow. In addition to channels similar to those previously used on the TRMM TMI, it contains a longer wavelength channel that can be used for soil moisture sensing.

4 EOS Aura

Aura will follow in the same orbit as Aqua with an equator crossing time 15 minutes later (1:45). Also flying in formation with Aura will be Cloudsat and Picasso, both of which will carry instruments designed to measure cloud properties. It is scheduled for launch in 2003. Aura carries the Microwave Limb Sounder (MLS), the Tropospheric Emission Spectrometer (TES), the High-Resolution Dynamics Limb Sounder (HIRDLS), and the Ozone Monitoring Instrument (OMI).

The Aura platform is focused on determining whether stratospheric ozone is recovering as predicted by atmospheric models. All of the instruments will make ozone measurements. They will use different spectral bands and viewing geometries to give a comprehensive picture of the Earth's ozone layer and the ozone-destroying radicals from nitrogen, hydrogen, and chlorine species. The instruments will be used to compute the amount of UV radiation reaching the Earth's surface. They are capable of retrieving information about constituents, including water vapor and aerosol, in the troposphere on regional and super-regional scales. This information will be important for assessing global changes in pollutants. Because they affect the Earth's radiative balance, these constituents are important for understanding global climate change.

The heritage for the Aura MLS is the Upper Atmosphere Research Satellite (UARS) MLS which provided several stratospheric (and upper tropospheric) products including temperature, humidity, ozone, and ClO. Aura MLS has advanced technology to provide new measurements. This is accomplished with several higher frequency bands including 640 GHz primarily for retrieval of N_2O,

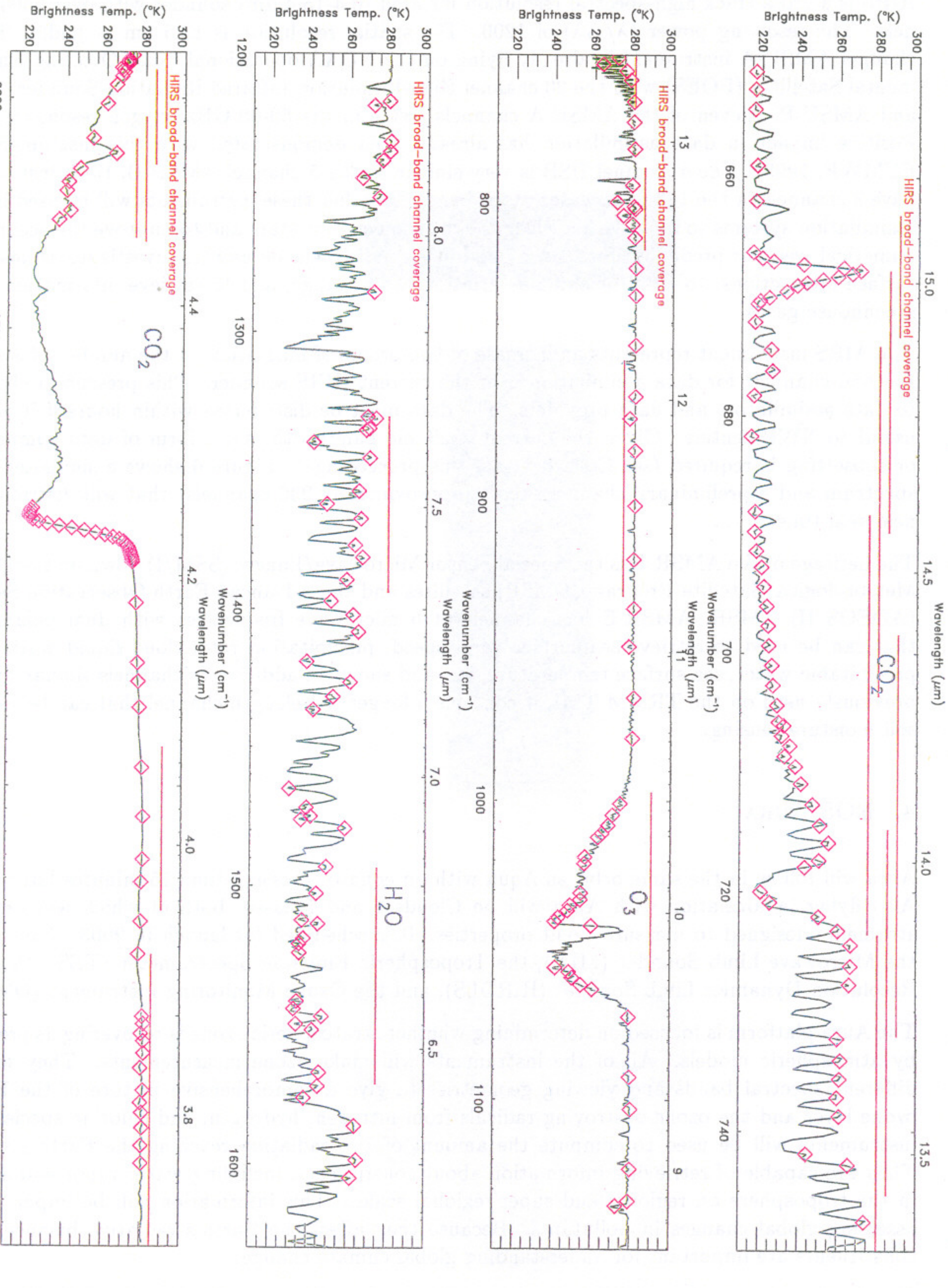

Figure 6: Simulated brightness temperature spectra at AIRS resolution with HIRS broad-band channel coverage above. Diamonds indicate prelimary channel subset for distribution and assimilation.

HCl, ClO, HOCl, BrO, HO_2, and SO_2, and 2.5 THz for OH sounding,

TES is a high-spectral-resolution infrared-imaging Fourier transform spectrometer. It has a spatial resolution of 0.53×5.3 km with a swath of 5.3×8.5 km. The spectral coverage is 3.2-15.4μm, and the spectral resolution is 0.025 cm^{-1}. It will allow for the retrieval of several constituents including CO, O_3, and H_2O as well as profiles of temperature and humidity and surface skin temperature.

HIRDLS is a joint program between the University of Colorado and Oxford University. The instrument is a 21 channel (from 6.1-17.8 μm) limb-scanning IR radiometer. It will be used to determine temperature, aerosol, and several constituents including water vapor, methane, and CFCs.

OMI, provided by the Netherlands and Finland, will provide continuity for global total ozone measurements. In addition, it will have ozone profiling capability. The spatial resolution, spectral resolution, and spectral coverage is improved over TOMS. This will enable more accurate retrievals of aerosol and trace gases such as NO_2, SO_2, BrO, and OCLO as demonstrated with the GOME instrument.

5 Triana

Triana will be the first platform to reside in an L1 orbit. The L1 orbit will keep the satellite between the sun and the Earth so that instrument can continuously make measurements on the sun-facing half of the Earth. It is scheduled for launch in 2001 and will be a 2-5 year mission. It carries three instruments.

The Earth Polychromatic Imaging Camera (EPIC) has 10 channels between 300 and 1000 nm. It will image the Earth every 15 minutes and is capable of retrieving total ozone as well as cloud, aerosol, and surface properties. The NISTAR instrument has 3 cavity radiometers: a solar (0.2-4μm), near IR (0.7-4μm), and visible-far IR (0.2-100μm). It is an absolute radiometer. Finally, Triana carries the Plasma Magnetometer Solar Weather Instrument.

6 Summary

A brief description of the instruments flying on the EOS Terra, Aqua, and Aura platforms as well as Triana has been given here. Examples have been given of how information from these satellites can be used for assimilation and evaluation of assimilation systems. As the tremendous volumes of information from these satellites, it is the challenge of data assimilators to effectively utilize the measurements given the finite amount of computational and human resources available.

Data assimilation can help product generation with EOS and other sensors by helping to detect instrument anomalies and errors in forward models that produce observed quantities such as radiance from geophysical fields. The sensors themselves provide observations for improved knowledge of the atmospheric and surface state. AIRS will provide a significant increase in information content relative to the current infrared operational sounder.

Newly-developed assimilation systems will be able to take advantage of information from the EOS suite. For example, some land-surface models are now capable of incorporating satellite-derived vegetation properties such as those provided by the MODIS instrument. Surface skin temperature is being assimilated experimentally at the DAO and will be provided by AIRS and MODIS. Aerosol information is available from MISR, MOPITT, and OMI. Ozone is measured accurately by several instruments aboard Aura. Other trace gases are measured by MOPITT, AIRS, and all of the Aura instruments. Precipitation measurements from TRMM instruments have been assimilated at the

DAO and ECMWF. Similar measurements will be available from AMSR.

References

ECMWF/EUMETSAT Workshop on use of ATOVS data for NWP assimilation - workshop proceedings, 2-5 November, 1999, European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, UK

Hou, A. Y., Ledvina, D. V., da Silva, A. M., Zhang, S. Q., Joiner, J., Atlas, R. M., Huffman, G. J., and C. D. Kummerow (1999). Assimilation of SSM/I-derived Surface Rainfall and Total Precipitable Water for Improving the GEOS Analysis for Climate Studies. *Mon. Weath. Rev.*, **128**, 509-537.

NASA (National Aeronautics and Space Administration) Earth Observing System (EOS) Science Plan, Executive Summary (1999a), Eds. R. Greenstone and M. D. King, NP-1998-12-070-GSFC, NASA/GSFC, Greenbelt, MD, USA.

NASA (National Aeronautics and Space Administration) 1999 Earth Observing System (EOS) Reference Handbook (1999b), Eds. R. Greenstone and M. D. King, NP-1999-08-134-GSFC, NASA/GSFC, Greenbelt, MD, USA.