# JP1.17 THE INTERNATIONAL MODIS/AIRS PROCESSING PACKAGE (IMAPP): TERRA AND AQUA DIRECT BROADCAST PROCESSING AND APPLICATIONS

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## 1. INTRODUCTION

The International Moderate Resolution Imaging Spectroradiometer / Atmospheric Infrared Sounder (MODIS/AIRS) Processing Package (IMAPP) provides users with EOS satellite Terra and Aqua direct broadcast antennae the capability to calibrate, geolocate and create environmental products from the downlinked raw data. This effort is funded by NASA and freely distributed by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison, USA with development funded by NASA (Huang et al. 2004).

This software development program builds on previous CIMSS experience in creating similar software packages for processing direct-broadcast data from the NOAA operational polar-orbiting satellites. The International TOVS (TIROS-N Operational Vertical Sounder) Processing Package (ITPP) has been distributed to members of the science community since 1985 (Huang and Smith 1986; Smith et al. 1993), and the recently released International ATOVS (Advanced TOVS) Processing Package (IAPP) implements a direct-broadcast processing capability for NOAA-15 and beyond (Li et al. 2000; Huang et al. 1997). The intention in developing IMAPP for processing direct broadcast MODIS and AIRS data is to help foster the rapid improvement of retrieval algorithms and other applications of EOS data in a variety of weather, process studies, and climate applications, just as the ITPP and IAPP have done for TOVS and ATOVS data.

MODIS and AIRS are key instruments of NASA's Earth Science Enterprise (ESE) suite of remote sensors. MODIS supplies 36 spectral channels and high spatial resolution (2 channels at 250m, 5 channels at 500m, 29 channels at 1000m) providing an unprecedented opportunity to study the effects of clouds, aerosol and water vapor on the earth's energy budget. The almost continuous spectral coverage of the AIRS (.4 to 1μm and 3.7-15.4μm) instrument will allow scientists very accurate vertical profiles of temperature and humidity for a better understanding of weather and climate.

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This paper summarizes the history, status, applications and future activities of the IMAPP program, which is funded through April 2006.

## 2. METHODOLOGY

The International MODIS/AIRS processing package consists of science software that transforms MODIS and AIRS Level 0 data into L1B (calibrated and navigated radiances), Level 2 science products, and a tutorial on creating 250 m "true color" (red (.65μm, green-.55μm, and blue-.46μm) resolution MODIS images. The software can be downloaded following the instructions on the IMAPP web page: http://cimss.ssec.wisc.edu/~gumley/IMAPP/ .

The software was designed with the end user in mind; it must be easy to use and install. These requirements were used in its development:

1) IMAPP must be portable to a wide range of UNIX/PC platforms.
2) Minimize the number of required toolkits.
3) Science data products must work using both DAAC L1B and direct broadcast IMAPP L1B as inputs.
4) All ancillary data sets must be easily accessible.
5) Downlinked spacecraft ephemeris and attitude data may be used for real-time geolocation.
6) The software must create products that are similar to those produced at the Goddard Space Flight Center (GSFC) DAAC.
7) The code must be efficient.

CIMSS is also becoming involved with teaching international IMAPP users about EOS instruments, remote sensing, and how science data products might be used to improve weather and environmental forecasting, monitoring, etc. These workshops serve as a way to stimulate interest, exchange ideas, and encourage the international community to take advantage of this freely available resource.

## 3. HISTORY and CURRENT STATUS

The first IMAPP MODIS L1B release occurred in May 2000, and consisted of MODIS geolocation and calibration modules. Since that time, a total of 14 other new releases or updates have been made, culminating in AIRS research L2 software products in August 2004. Table 2 summarizes the IMAPP activities to date.

| Release # | Date | Version | Main Features |
|---|---|---|---|
| 1 | 12 May 2000 | MODIS L1 V1.0 | L0 to L1<br>Geolocation and Calibration |
| 2 | 1 November 2000 | MODIS L1 V1.1 | Calibration and look-up-table update to Ver. 2.4.<br>Bug Fixes<br>Support definitive ephemeris and attitude data<br>Support Solarisx86 O.S. |
| 3 | 13 April 2001 | MODIS L1 V1.2 | Calibration algorithm and lookup tables update to Ver. 2.5.5 and 2.5.5.1<br>Geolocation is updated using platform ephemeris and attitude. Terrain correction for geolocation is provided. |
| 4 | 3 December 2001 | MODIS L1 V1.3 | Calibration algorithm and lookup tables update to Ver. 3.0.0 and 3.0.0.7<br>Geolocation algorithm is updated |
| 5 | 1 May 2002 | MODIS L2 V1.1 | First science product release for Terra MODIS |
| 6 | 13 September 2002 | MODIS L1 V1.4 | First version to support both Terra and Aqua MODIS<br>Aqua MODIS calibration algorithm and lookup tables use version 3.0.1, and 3.1.0.2.<br>Aqua MODIS geolocation requires ephemeris and attitude files<br>IMAPP L1 processing script handles both Terra & Aqua |
| 7 | 1 October 2002 | MODIS L2 V1.2 | Second MODIS science product release<br>Atmospheric sounding profile retrieval equivalent to DAAC MOD07 V3.1.0 |
| 8 | 19 February 2003 | MODIS L2 V1.3 | First MODIS Terra/Aqua compatible cloud mask and cloud top property release<br>Improved cloud mask<br>Band 26 radiation correction<br>Cloud mask updated to DAAC MOD35 V4.2.0<br>Cloud top property and phase updated to DAAC MOD06CT V.4.0.4<br>Test Images of Terra/Aqua provided |
| 9 | 18 September 2003 | MODIS L2 V1.4 | Update to Atmospheric sounding profile retrieval equivalent to DAAC MOD07 V4.1.0 |
| 10 | 5 November 2003 | AIRS L1 V1.0 | First AIRS/AMSU AND HSB geolocation and calibration<br>Functionally identical to GSFC DAAC version.<br>Binaries for Red Hat Intel Linux and Sun Solaris (SPARC) only. |
| 11 | 6 November 2003 | MODIS L1 V1.5 | Update to L1B software Updated geolocation software, calibration tables |

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|---|---|---|---|
| 12 | 19 November 2003 | MODIS Utility | Tutorial on producing MODIS True Color images |
| 13 | 16 January 2004 | MODIS L1 patch | Update for Terra MODIS calibration following spacecraft safe hold |
| 14 | 3 March 2004 | MODIS L2 V1.5 | First Aqua/Terra Sear Surface Temperature product release<br>Differs from DAAC version – no ancillary data sets are required |
| 15 | 6-8 June 2004 | IMAPP workshop Nanjing, China | Educate users on Aqua/Terra direct broadcast instruments, remote sensing, IMAPP products and applications |
| 16 | August 2004 | AIRS L2 V1.0 | AIRS Research CIMSS L2 products Atmospheric sounding retrievals; Temperature, moisture, ozone; Total precipitable water vapor, total ozone, surface temperature, emissivity, reflectivity and pressure |

**Table 2:** Date, version and main features of IMAPP releases and activities

MODIS IMAPP Level 1 and Level 2 software have been ported to and tested on a variety of UNIX/PC platforms, including:

SGI MIPS, IRIX 6.5
Sun Ultra, SunOS 5.7
IBM RS/6000, AIX 4.3
HP PA-RISC, HP-UX B.10.20
Intel Pentium, Linux 2.2.12-20
Intel Pentium, Solarisx86 2.5.1

The entire MODIS suite of IMAPP software products now includes calibration, geolocation, a software correction for the spectral leak of band 5 into band 26 detectors, cloud mask, cloud top properties (height, temperature, emissivity), cloud phase, atmospheric profiles (temperature, moisture, total precipitable water vapor, stability indices), sea surface temperatures, and a tutorial on how to create MODIS true color images.

Working with the AIRS Team at the NASA Jet Propulsion Laboratory (JPL), CIMSS released the first version of the AIRS/AMSU/HSB Level 1 software to the direct broadcast community on 5 November 2003. This set of binaries has been ported and tested on both Linux and Sun Solaris (SPARC) platforms.

Most recently, CIMSS developed AIRS Level 2 software for release as part of IMAPP in August 2004. The software consists of a regression algorithm providing vertical profiles of temperature, moisture and ozone at 101 levels, surface pressure, skin temperature, surface reflectivity and emissivity, total precipitable water vapor and total ozone for every AIRS pixel (~14 km resolution). The only input required is the AIRS Level 1B radiance product, using a set of 1688 selected channels.

IMAPP has been downloaded and used in every continent except Antarctica. Countries where IMAPP software is used routinely include the USA, Australia, Spain, Italy, China, Russia, South Korea, Brazil, Mexico, Thailand, Germany and Australia. It is also included as a standard feature by some ground station manufactures including SeaSpace and Integral Systems of the United States, Kongsberg Spacetec of Norway, and Environmental Systems and Services of Australia.

## 4. APPLICATIONS

IMAPP products are used in a wide variety of research and environmental applications. A few examples will now be given.

Water quality is studied in near-real time over the mid-west United States using direct broadcast IMAPP MODIS Level 1B products. The Environmental Remote Sensing Center (ERSC) at the University of Wisconsin – Madison utilizes the data to determine characteristics such as Total Suspended Solids (TSS) concentration over Green Bay, Wisconsin. With the cost of dredging the Bay for navigation as high as $8.4 million per year, it is vitally important to keep track of sediment amounts in order to track sediment sources and keep them under control. Figure 1 shows true color MODIS direct broadcast observations, along with derived products over Green Bay in the summer of 2001.

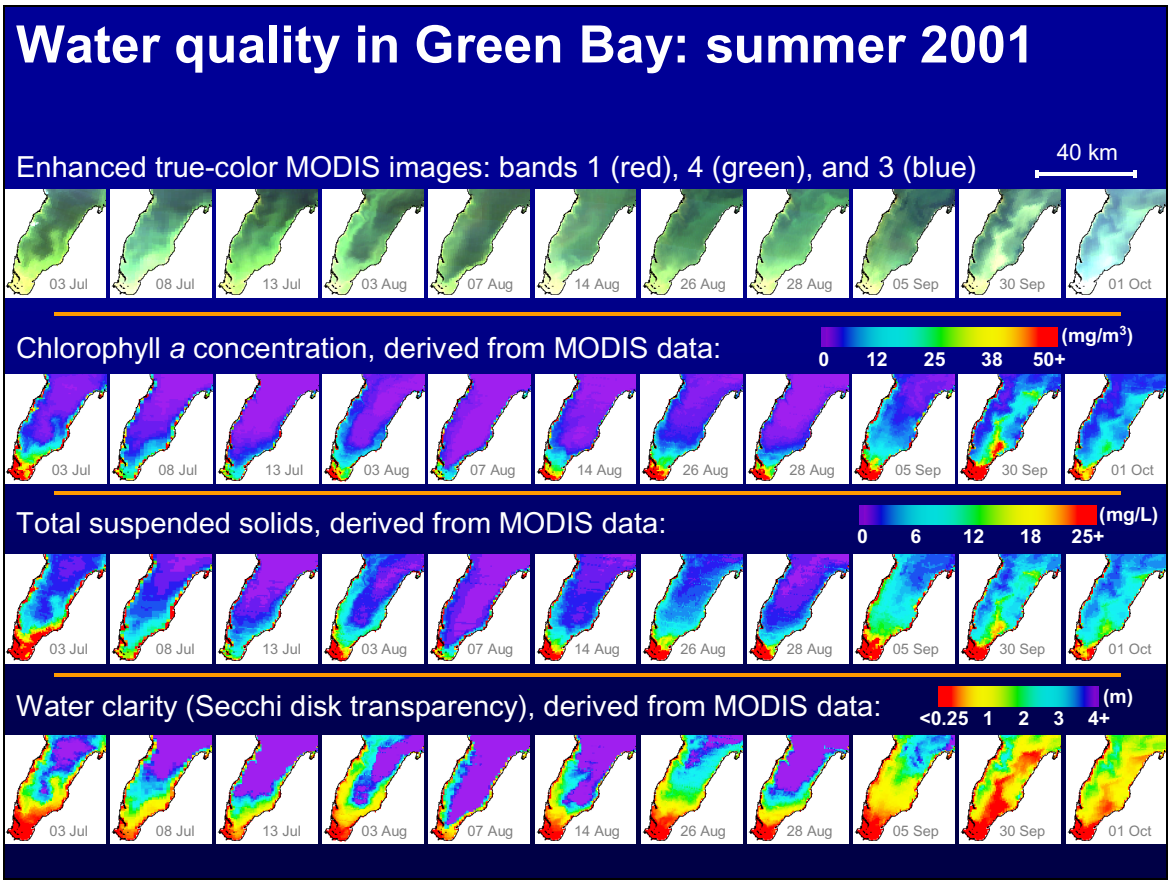


**Figure 1**. Example of Regional direct broadcast MODIS IMAPP application. MODIS Level 1B data is used to monitor water quality over Green Bay, Wisconsin. Courtesy of Jonathan W. Chipman, UW-Madison ERSC.

The US National Weather Service (NWS) is using direct broadcast MODIS products as a forecasting tool through NASA's Short-Term Prediction Research and Transition (SPORT) program (http://wwwghcc.msfc.nasa.gov/sport/sport_featured.html). The timeliness of the high resolution products allows them to be useful to forecasters, in contrast to the official DAAC products, which are often 12 hours or more behind real-time. Figure 2 shows the SPORT IMAPP cloud top pressure image from 27 July 2004.

International users are also implementing IMAPP products as an environmental monitoring tool. As an example, the National Satellite Meteorological Center in China uses direct broadcast MODIS data for a wide variety of uses, including fog monitoring. Fog regions identified by MODIS direct broadcast IMAPP Level 1B images are entered into a GIS to help public traffic officials in alerting the public to dangerous road conditions. An example of this strategy is depicted in Figure 3.

Other regional applications are acknowledged as well. Chinese agencies use IMAPP products for disaster monitoring, including flooding and fires, forecasting and investigations of dust storms and aerosol composition, along with cloud classifications and cloud composition monitoring. (see EOS DB web site at: http://www.eos.hawaii.edu/eos_db.html. )

Cloud top properties and cloud phase IMAPP direct broadcast products are used as part of the CLOUDMAP2 research program (http://www.npm.ac.uk/rsg/projects/cloudmap2/ ). The objective of this research effort is to assimilate water vapor above land and above clouds into the European High Resolution Limited Area Model (HRLAM). Data sets are collected and generated in near-real time using IMAPP in both Germany and the Plymouth Marine Laboratory (PML) in England.

AIRS radiances produced by IMAPP software are being used to determine wavelength selection for bands on future satellites. AIRS radiances are being convolved using spectral response functions for proposed Advanced Baseline Imager (ABI) bandwidths. Those involved with making the decisions will have a wide range of datasets with which to base their choice. A real-time web page of ABI like channels simulated from AIRS radiances can be found at this site:
http://cimss.ssec.wisc.edu/goes/abi/airs_broadcast/aniairs.html .

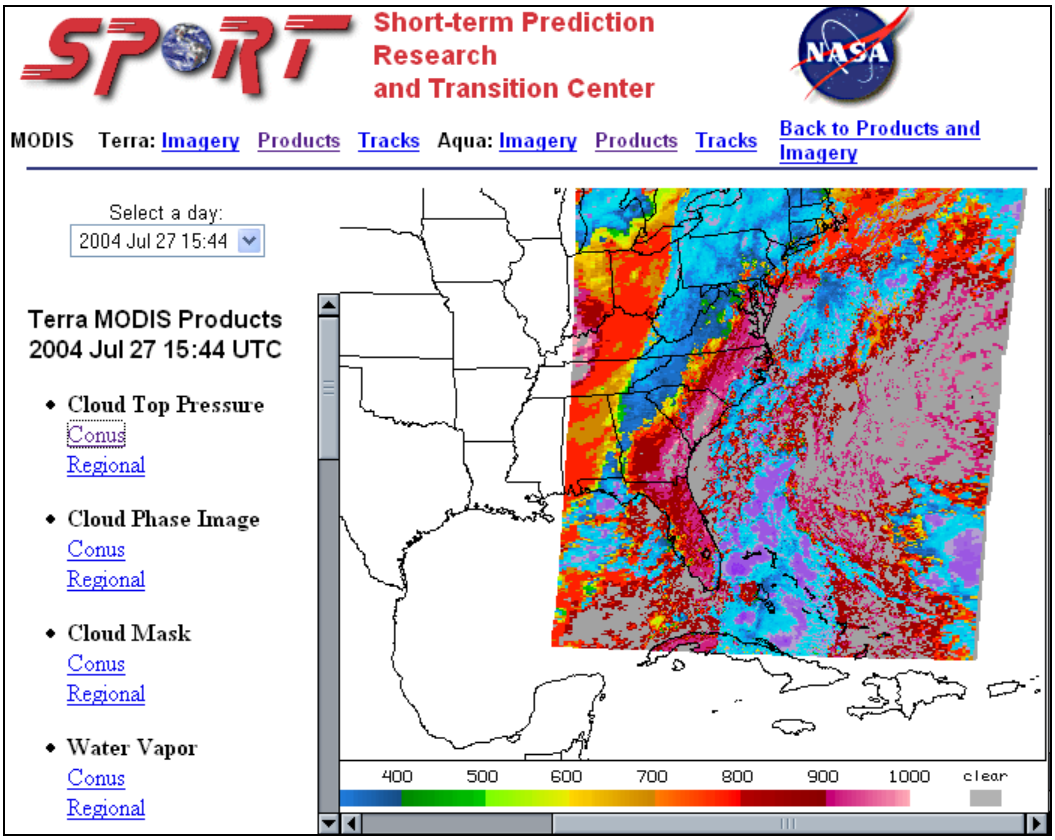


**Figure 2**. Example of the MODIS cloud top pressure IMAPP product as displayed on the SPORT page from the 15:44 UTC overpass on 27 July 2004.

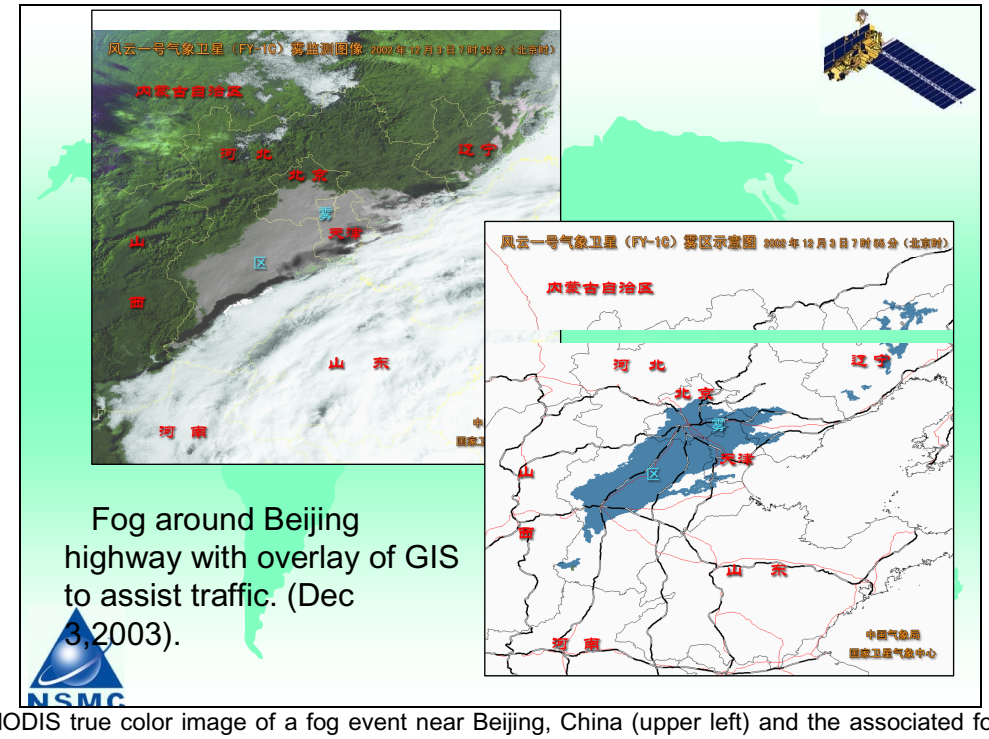


**Figure 3**. MODIS true color image of a fog event near Beijing, China (upper left) and the associated fog region overlaid on a road map (bottom right). The MODIS image was produced using IMAPP software. Courtesy of Dr. Wenjian Zhang.

The first IMAPP Remote Sensing Workshop was held at the Nanjing Institute of Science and Technology in Nanjing, China on 6-8 June 2004. CIMSS personnel taught direct broadcast users through lectures and labs about the remote sensing basis of IMAPP products, the techniques used in the product retrievals and their applications. Attendees of the workshop included scientists and students from China, Taiwan, Thailand and South Korea. Student reviews were very positive, and more workshops are planned for the future.

## 5. FUTURE WORK

NASA funding for IMAPP development was recently renewed through 2006. An ambitious schedule of software releases is projected throughout the funding period. A list of IMAPP activities in the near future are listed in Table 2.

Table 2: Planned IMAPP activities through April 2006.

| MODIS | AIRS/AMSU/HSB | AMSR-E |
|---|---|---|
| Aerosol Optical Depth | Cloud Detection | Soil Moisture |
| Surface Reflectance | Cloud Properties | Precipitation |
| Snow Detection | Cloud Height/Emissivity | |
| Sea Ice Detection | Cloud Liquid Water | |
| Scene Classification (Clouds and Land Surface) | AMSU Precipitation Estimate | |
| Cloud Particle Size | | |
| Cloud Optical Thickness | | |
| Ocean Color | | |
| Suspended Sediment | | |
| MODIS/AIRS Collocation | | |
| MODIS/AIRS Cloud Clearing | | |
| MODIS/AIRS Cloud Properties | | |
| MODIS/AIRS Visualization Tool (hydra) | | |
| IMAPP Remote Sensing Workshops | | |
| Real-time Air Quality Monitoring System | | |

One new feature that will be included in future IMAPP releases will be visualization software to view the MODIS and AIRS Level 1 and Level 2 products. This is considered to be an important aspect of making the data easier to use. To date, no freely available software has been found which will provide platform independent tools to visualize, interpret and manipulate IMAPP data sets in binary and/or HDF formats. This will complete the circle of end-to-end IMAPP tools that allow the user to acquire, process, visualize, investigate and manipulate direct broadcast IMAPP data sets.

## 6. CONCLUSIONS

IMAPP continues to evolve by developing and releasing software that meets users' demands for near real-time regional environmental products. Portability, reliability and usability continue to be the primary directives driving the project.

The software has proven to be effective in the monitoring and understanding of the Earth system. Global international applications range from cloud research in Europe, to road hazard alerts due to detection of fog in China to IMAPP products aiding forecasters in the United States National Weather Service.

The number of products within IMAPP continues to grow. The list now includes MODIS/AIRS calibrated/navigated radiances, MODIS cloud mask, cloud top properties and cloud phase, and retrievals of atmospheric profiles (temperature, moisture) and total precipitable water, and Sea Surface Temperatures. AIRS Level 2 products have recently been added including retrievals of temperature and moisture at 101 levels in the atmosphere.

It is anticipated that IMAPP will continue to be an integral part of the real-time downlink and processing systems for the international direct-broadcast community in NASA EOS, and will play a key role in the NASA/NOAA National Polar-Orbiting Operational Environmental Satellite System Preparatory Project (NPOESS/NPP) epoch. It is expected that the future follow-on to IMAPP, the International NPP/NPOESS Processing Package (INPP), will continue to allow direct broadcast users maximum utilization of data.

## 7. ACKNOWLEDGEMENTS

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