

**International MODIS and AIRS Processing Package (IMAPP) –
Package Status and Features**

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1. Introduction

The National Aeronautics & Space Administration (NASA) Earth Observing System (EOS) spacecrafts Terra and Aqua are providing a new generation of sensor observations of planet Earth. The instruments onboard these platforms provide a wealth of information on ocean, atmosphere, and land processes that are of global environmental importance. A critical component of the data distribution system for Terra and Aqua is the direct broadcast service on the spacecraft. The International MODIS/AIRS Processing Package (IMAPP) (Huang et al. 2004) provides researchers, governmental, educational, and commercial sector users with the capability of receiving and processing raw data in real-time (i.e., as observations are acquired) and creating environmental products which provide immediate information in areas as diverse as severe weather monitoring, forest fire detection, fisheries management, weather forecasting, aviation safety, and ice forecasts, to name a few.

In anticipation of these activities, NASA funded IMAPP in 2000, to provide freely distributed science production software that will transform Level 0 MODIS/AIRS data into calibrated and geolocated radiances and reflectances (level 1B) as well as a limited set of environmental products (level 2). Both Terra (MODIS am) and Aqua (MODIS pm and AIRS) platforms have a direct broadcast X-band downlink that allows data to be received in real time by sites having the proper reception hardware. IMAPP is derived from the operational processing software developed by NASA, and is modified to be compatible with direct broadcast data.

2. Software Package

Distribution of IMAPP to the user community means that the production software must be easy to install and use. With this in mind, the software was developed with these requirements:

- IMAPP must be portable to a wide range of UNIX/PC platforms.
- The number of required toolkits must be kept to a minimum.
- Ancillary data sets must be easily accessible.
- Software must be able to process overpasses of any size.
- Downlinked spacecraft ephemeris and attitude data may be used for real-time geolocation.
- Distributed products must be similar to those produced at the Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC).
- The code must be efficient.

2.1 MODIS

Following the requirements outlined above, MODIS IMAPP v1.1 geolocation and calibration L1B software modules were developed and first released in May 2000 and included the following functionality for Terra MODIS:

- Reformatting from time-ordered CCSDS Level-0 packets to Level-1A.
- Geolocation for every 1000 m pixels.
- Calibration for every pixel in bands 1-2, 1-7, and 1-36 at 250, 500 and 1000 m resolution respectively.

The first international user was the University of Dundee, where IMAPP was used to process the first Terra MODIS pass collected by the institution on May 8th, 2000 (Dundee served as a beta test site for IMAPP v1.0).

To date, SSEC has released IMAPP versions for MODIS level 1 geolocation (Barbieri 1997) and a selection of MODIS level 2 geophysical products. Versions 1.1, 1.2, 1.3, and 1.4 of IMAPP MODIS level 1 were released in November 2000, April 2001, December 2001, and September 2003, respectively. These updates allowed EOS direct broadcast users to keep pace with improvements to the calibration for Terra and Aqua MODIS in a systematic fashion. IMAPP MODIS level 2 version 1.1 was released to the community in May 2002 (version 1.0 was not released to the public). The first products released were the cloud mask (Ackerman, et al 1998) and cloud top properties (King et al 1992, and Menzel et al 2002) and cloud phase (Baum et al 2000) algorithms. Version 1.2 followed in October 2002, and included the MODIS atmospheric profile algorithm, and version 1.3 was released in February 2003 and contained Aqua compatible versions of the aforementioned algorithms. Most recently, Version 1.4 was released in September 2003 containing scientific updates to the atmospheric profiles algorithm.

All IMAPP released software has been ported and tested on the following UNIX/PC platforms:

- 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, Red Hat Linux 7.2 (2.4.7-10) (with gcc/g77 2.96)
- Intel Pentium, Solaris8 x86 5.8 (with gcc/g77 2.95.2)

All IMAPP source code and test data are freely available for download from <http://cimss.ssec.wisc.edu/~gumley/IMAPP/>. Top level README files provide detailed installation instructions. Implementation of the software involves execution of simple scripts and only the National Center for Supercomputing Applications (NCSA) Hierarchical Data Format 4 (HDF4) toolkit is required. The processing environment has been greatly simplified from the DAAC environment and overpasses of any size may be processed. The software runs efficiently taking ~45 minutes to process a 10 minute MODIS overpass through level 1B on an Intel Pentium, Solaris x86.

2.1.1 File Formats

The format of the IMAPP MODIS level 1B output files is very similar, but not identical, to the format of the GSFC DAAC (B output files. In particular, IMAPP output

files are written using HDF only (not HDF-EOS), and IMAPP output files store metadata in separate global attributes. The difference can best be seen by comparing an alphabetized listing of the HDF SDS and Vdata objects in an IMAPP Level 1B 1000 meter file and the corresponding DAAC file. Similarly, the format of the geolocation files produced by IMAPP is very similar, but not identical to, the GSFC DAAC format, as seen in the alphabetized listing of the HDF SDS objects in an IMAPP geolocation file and the corresponding DAAC file.

The level 2 product file formats are not HDF. For simplicity, a straight binary file format and ascii header file that is compatible with ENVI and freelook, a freely distributed visualization tool, were selected as the output file format. For those desiring HDF, simple IDL routines to convert from binary to HDF are included with each MODIS level 2 software release.

2.1.2 Ancillary Data

External data sets are required as input in order to successfully run the MODIS IMAPP level 2 product software. All required ancillary data sets are staged together in real-time on an anonymous ftp site: (<ftp://aqua.ssec.wisc.edu/pub/aqua/ancillary>) which contains the current and previous 4 days of ancillary data. This facilitates the use of MODIS product software by providing a one-stop shop for all the ancillary data needed to run the algorithms. The files included at the site are:

(1) Near Real-Time SSM/I EASE-Grid Daily Global Ice Concentration and Snow Extent (NISE) file from the National Snow and Ice Data Center (NSIDC) in Colorado, USA for providing help in identifying cloud mask snow backgrounds.

(2) Daily SSMI sea ice concentration from the National Center for Environmental Prediction (NCEP). This provides help in identifying cloud mask sea ice backgrounds.

(3) 6 hourly Global Data Assimilation System T126 resolution profiles of temperature and moisture analyses from NCEP. These profiles are required in order to run the CO₂ slicing portion of the cloud top properties and cloud phase algorithm as well as perform retrievals of atmospheric temperature and moisture profiles.

2.2. AIRS

Working in conjunction with the AIRS Team at NASA Jet Propulsion Laboratory (JPL) (Aumann et al 1999, and Hofstadter et al 1999), SSEC received the first post-launch delivery of the AIRS/AMSU/HSB level 1 software package in September 2002. In January 2003, SSEC demonstrated the ability to transform locally acquired direct broadcast AIRS Level 0 data to Level 1. Due to the complexity of the calibration software for the more than 2300 spectral bands of the AIRS instrument, NASA agreed upon a strategy for level 1 IMAPP release whereby JPL would create the software and SSEC would test and distribute the binaries. SSEC is currently finalizing the beta testing of this package; the first version of AIRS/AMSU/HSB level 1 software is released on 5 November 2003.

3 Imagery and Products

IMAPP software has been successfully downloaded and installed by users all over the world. Correspondence from IMAPP users indicates that the software is in use in the USA, UK, Germany, Italy, Norway, Japan, China, Russia, South Korea, Singapore, Thailand, Vietnam, Brazil, South Africa, Australia and Mexico. In addition, the released operational automated products that are generated at SSEC in real-time (MODIS level 1 through all level 2 products), are placed on an ftp site for open access (<ftp://aqua.ssec.wisc.edu/pub/>). Quick look images are automatically generated for each captured overpass and placed on a web page in real-time: <http://eosdb.ssec.wisc.edu/modisdirect/>. The total end-to-end processing time between ingest and placement of MODIS level 1 to level 2 product files on the ftp site for distribution is ~ 1 1/2 - 2 hours on a Sun Intel Pentium, Solarisx86 2.5.1. An example of the CIMSS IMAPP automated product suite for MODIS Terra is shown in figure 1.

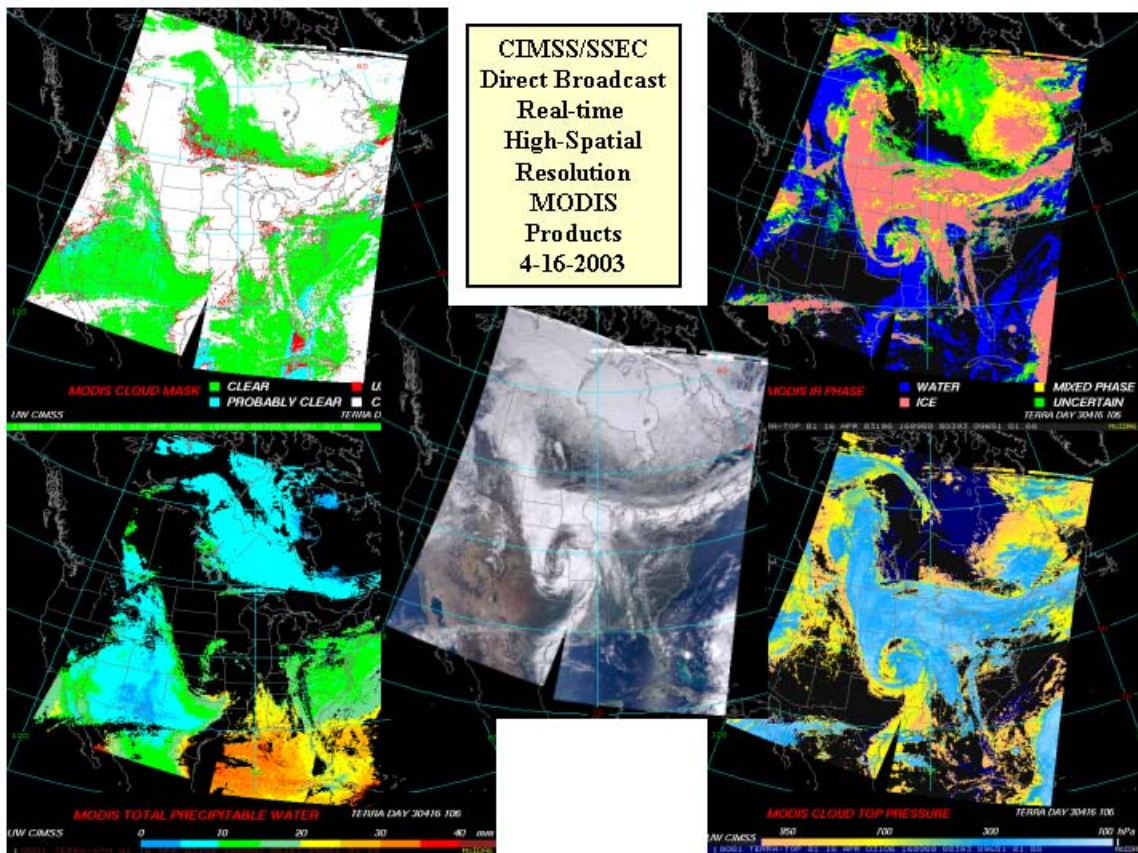


Figure 1. IMAPP products from Terra MODIS, 16 April 2003. Middle panel: true color image, upper left: cloud mask, upper right: cloud phase, lower left: total precipitable water, lower right: cloud top pressure.

Retrieval algorithms for AIRS level 2 products have been developed using a focus data set provided by the JPL AIRS science team. Figure 2 shows a sample of the AIRS/AMSU and HSB level 1 imagery from the focus data. AIRS color composite image and cloud phase are shown in figure 3.

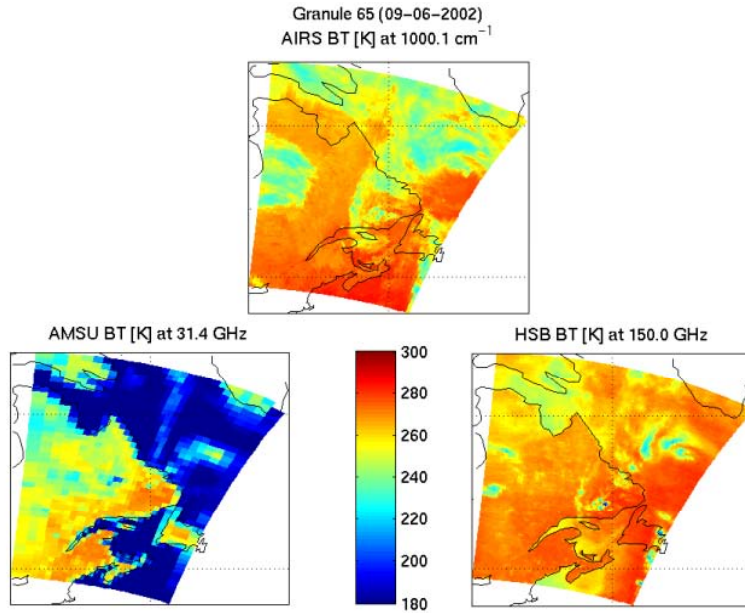


Figure 2. AIRS, AMSU and HSB level 1 brightness temperatures as produced by IMAPP software over North America on 20 July 2002.

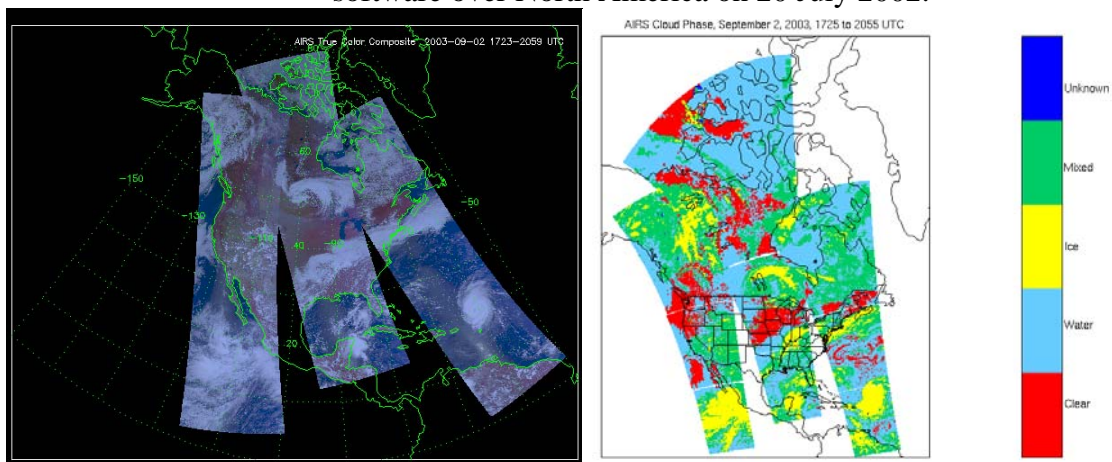


Figure 3. AIRS level 1B color composite and cloud mask derived from MODIS single filed of view (spatial resolution of ~ 1km at nadir) cloud mask pixels.

Figure 4 displays level temperature and water vapor retrievals derived from AIRS, MODIS and GOES, respectively. The retrieval differences are due to factors such as spectral and spatial measurement information content, data signal to noise ratio, and temporal discrepancy. All retrieval products are currently undergone validation. Retrieval algorithm refinement is expected once products validation suggests the need of product performance improvement.

**IMAPP AIRS Single FOV RTV vs MODIS and GOES RTV:
T and q at 620 mbar (09-02-2003, 192, Day)**

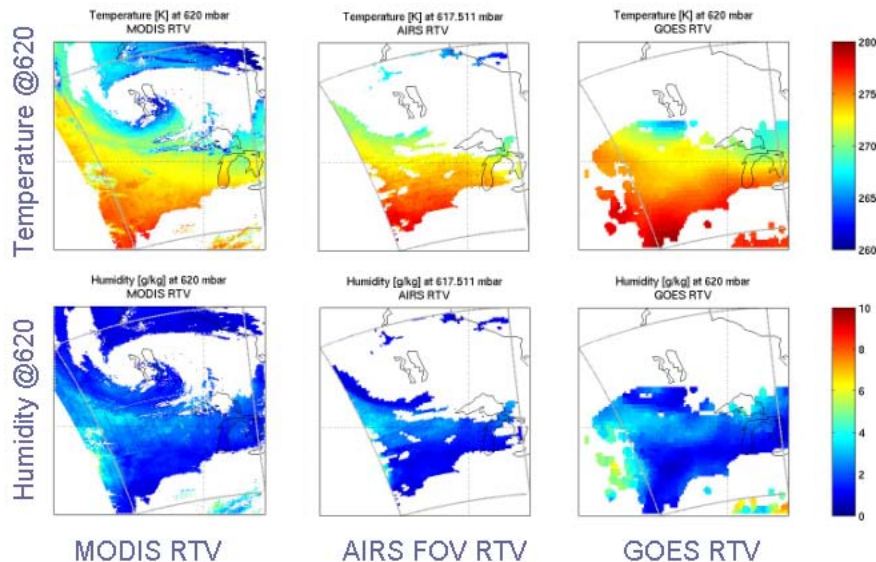


Figure 4. IMAPP AIRS single FOV, MODIS and GOES retrieval of temperature and water vapor of 620 mb on 2 September 2003.

CIMSS is using the real time products for many purposes. These include validation of MODIS products, testing new MODIS algorithms and changes to existing production software. Real-time data collection and processing allow us to routinely sample the data sets over pre-determined regions for investigations. For instance, MODIS water vapor retrievals from the direct broadcast atmospheric profiles product, along with MODIS radiances are being extracted and saved for all overflights of the Oklahoma, USA, Cloud and Radiation Testbed (CART) site. These are used for comparisons with other instrument retrievals made at the site (Seeman et al., 2003). Data is also being routinely extracted and shared with other collaborators such as Dr. Simon Hook of NASA's Jet Propulsion Laboratory (JPL), who is using the data for MODIS calibration and product validation over Lake Tahoe, Nevada, USA (Hook et al., 2001).

Real-time IMAPP products are also supporting the US National Weather Service as a forecasting tool under the NASA supported Short-term Prediction Research and Transition (SPORT) program. Other users of MODIS data acquired and processed by IMAPP at SSEC include:

- Naval Research Laboratory, Monterey
- Satellite Services Division, NOAA/NESDIS
- Atmospheric and Environmental Research, Inc, Lexington MA
- Upper Midwest Aerospace Consortium, University of North Dakota
- National Center for Environmental Prediction (NCEP), NOAA
- MODIS Snow and Sea Ice Global Mapping Project, NASA/GSFC

IMAPP is also used globally to generate real-time products of local interest. As an example, Plymouth Marine Laboratory's Remote Sensing Data Analysis Service (RSDAS) in the UK posts real-time IMAPP MODIS products on their web site for use in the CLOUDMAP2 European program. One of the goals of CLOUDMAP2 is "to produce and exploit value-added remote sensing data products on macroscopic (e.g. cloud-top height) and microscopic (e.g. cloud droplet radius) properties and water vapor distributions to characterize sub-grid scale processes within Numerical Weather Prediction Models (NWP) through validation and data assimilation".

4 Future Work

Table 1 briefly summarizes the current IMAPP product algorithms, along with those planned for production during the three-year continuation phase. MODIS algorithms released for Terra and Aqua have received the most attention during the initial phase.

Table 1. Summary of current and upcoming IMAPP MODIS and AIRS product algorithms.

	MODIS	AIRS/AMSU/HSB
Current	Geo-location/Navigation Cloud mask Cloud Phase Cloud top Property Clear T/Q Sounding Total Precipitable Water	Geo-location/Navigation
Planned	Cloud Particle Size Cloud Optical Thickness Aerosol Optical Thickness Surface Reflectance Sea Surface Temperature Snow Detection Sea Ice Detection Scene Classification (Clouds and Land Surface)	Clear/Cloudy T/Q Sounding Cloud Detection Cloud Clearing Cloud Height/Emissivity Surface Skin Temperature Cloud Liquid Water AMSU Precipitation estimate
	MODIS/AIRS Collocation	

5. Summary

The International MODIS/AIRS Processing Package has been successful in providing a portable, relatively easy to install and use software package for converting direct broadcast EOS Terra and Aqua data into valuable environmental products. The number of products within IMAPP continues to grow. The list now includes MODIS calibrated/navigated radiances, cloud mask, cloud top properties and cloud phase, and retrievals of atmospheric profiles (temperature, moisture) and total precipitable water. AIRS products are in beta test mode and will be added to the IMAPP suite in early 2004. All IMAPP released products have been verified against the NASA production counterparts.

IMAPP is going to evolve to adopt, adapt and develop new processing algorithms to meet global users' demands for regional real time multi-disciplinary applications. Most of all, with open source architecture and rigorous documentation standards, IMAPP can be easily implemented on almost any computing platform. In the near future, the International NPP/NPOESS Processing Package (INPP) as the next generation of IMAPP can continue to optimize the global utilization of earth observation data to improve our ability to monitor and understand the natural environment.

Acknowledgements

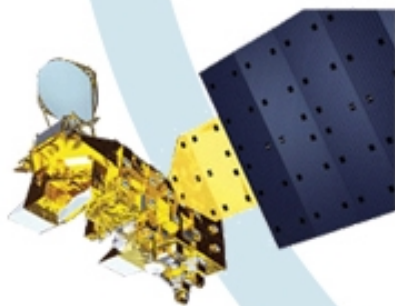
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References

- ACKERMAN, S. A., STRABALA, K. I., MENZEL, W. P., FREY, R. A., MOELLER, C. C., and GUMLEY, L. E., 1998, Discriminating clear sky from clouds with MODIS. *Journal of Geophysical Research*, **103**, 32141–32157.
- AUMANN, H., GAISER, S., TING, D., and MANNING, E., 1999, AIRS Algorithm Theoretical Basis Document Level 1B Part 1: Infrared spectrometer. EOS Project Science Office, NASA Goddard Space Flight Center.
- BARBIERI, R., 1997, MODIS Level 1B Algorithm Theoretical Basis Document. EOS Project Science Office, NASA Goddard Space Flight Center, 70 pp.
- BAUM, B. A., P. F. Soulen, K. I. Strabala, M. D. King, S. A. Ackerman, W. P. Menzel, and P. Yang, 2000: Remote sensing of cloud properties using MODIS Airborne Simulator imagery during SUCCESS. II. Cloud thermodynamic phase. *J. Geophys. Res.*, **105**, 11,781-11,792.
- HOFSTADTER, M., AUMANN, H., MANNING, E., GAISER, S., GAUTIER, C., and YANG, S., 1999, AIRS Algorithm Theoretical Basis Document Level 1B Part 2: Visible/Near-Infrared Channels. EOS Project Science Office, NASA Goddard Space Flight Center.
- HOOK, S. J., PRATA, F. J., and SCHLADOW, G. S., 2001, Validation of Thermal Infrared Data and Products from MODIS and ASTER over Land. NASA progress report. See http://eospsso.gsfc.nasa.gov/ftp_docs/validation/Hook.01.report.pdf.
- HUANG, H.L., L.E. Gumley, K. Strabala, J. Li, E. Weisz, T. Rink, K.C. Baggett, J. E. Davies, W.L. Smith, J. C. Dodge, 2004: International MODIS and AIRS Processing Package (IMAPP) – A Direct Broadcast Software Package for the NASA Earth Observing System. American Meteorological Society Bulletin, February 2004, 17-19.
- KING, M. D., KAUFMAN, Y. J., MENZEL, W. P., and TANRE, D. 1992, Remote sensing of cloud, aerosol, and water vapor properties from the Moderate Resolution Imaging Spectrometer (MODIS). *IEEE Transactions on Geoscience and Remote Sensing*, **30**, 2-27.
- MENZEL, W. P. SEEMAN, S. W., LI, J., and GUMLEY, L. E., 2002, MODIS Atmospheric Profile Retrieval Algorithm Theoretical Basis Document. EOS Project Science Office, NASA Goddard Space Flight Center, 39 pp.
- SEEMAN, S. W., LI, J., MENZEL, W. P., and GUMLEY, L. E., 2003, Operational retrieval of atmospheric temperature, moisture, and ozone from MODIS infrared radiances. *Journal of Applied Meteorology*, **42**, 1072-1091.

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