JP1.14 MODIS/AIRS INSTRUMENT DIRECT BROADCAST PRODUCTS AND APPLICATIONS

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1. INTRODUCTION

The Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison, USA, has developed software for calibration and navigation of both polar and geostationary satellites for many years. Included in this work is collaboration with the International TOVS Working Group (ITWG) on the International TOVS/ATOVS Processing Packages (ITPP/IAPP). The package facilitates the use of satellite data by providing portable software for calibration, geolocation and product generation of satellite Level 0 data.

It is in this spirit of international cooperation that NASA has now funded the development of the International MODerate resolution Imaging Spectroradiometer (MODIS)/Atmospheric Infrared Sounder (AIRS) Processing Package (IMAPP). IMAPP provides freely distributed science production software that will transform Level 0 MODIS data into Level 1B (calibrated and geolocated) as well as a limited set of science data products. AIRS utilities will be added in early 2003. 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.

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. Nominal earth coverage is four times per day using both satellites. This paper focuses mainly on the MODIS portion of IMAPP and presents the current product suite and applications. AIRS data and products will be presented on the conference poster companion to this paper.

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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), and Level 2 science products. Distribution of IMAPP to the user community required that the production software be easy to install and use. With this in mind, the software package was developed with these requirements:

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) Overpasses of arbitrary size can be processed.
6) Downlinked spacecraft ephemeris and attitude data may be used for real-time geolocation.
7) The software must create products that are similar to those produced at the Goddard Space Flight Center (GSFC) DAAC.
8) The code must be efficient. A goal of end-to-end L0 to L1B to science product generation (Level 2) was set at 2 hours after overpass reception.

To download the software, please follow the directions found on the IMAPP web page at: http://cimss.ssec.wisc.edu/~gumley/IMAPP/ .

2.1 MODIS Level 1B

MODIS IMAPP geolocation and calibration modules were 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 pixel.
Calibration for every pixel in bands 1-2, 1-7, and 1-36 at 250, 500 and 1000 m resolution respectively.

In addition, the IMAPP Level 1 and Level 2 software were 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, Linux 2.2.12-20
Intel Pentium, Solarisx86 2.5.1

Since then, many more deliveries have been made, culminating in the latest release in first quarter 2003. For a complete history of releases, please see the CIMSS direct broadcast software web page at: http://cimss.ssec.wisc.edu/~gumley/IMAPP/ .

Implementation of the software involves execution of simple scripts and only the National Center for Supercomputing Applications (NCSA) Hierarchical Data Format (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 on an Intel Pentium, Solaris x86.

2.1.1 MODIS L1B Verification

In order to use MODIS IMAPP Level 1 software, the ingested satellite data must exist on one of the supported platforms mentioned above. At this point the data is in raw form; meaning not synchronized prior to protocol processing. The input required by IMAPP is Level 0 MODIS data, defined as reconstructed time-ordered Consultative Committee for Space Data Systems (CCSDS) packets with all communication artifacts (including duplicate packets) removed. This process includes decoding as well as re-assembly of the raw telemetry packets. Processing of the data stream to this stage is the responsibility of the user; however many X-band ground station vendors supply processing hardware and/or software that creates IMAPP compatible Level 0 files in Production Data Set (PDS) format (see the GSFC direct readout web page at http://directreadout.gsfc.nasa.gov/software_main.html).

MODIS Level-1B 1000 m radiance data for 21 November 2001 (day 325) from 1700 to 1705 UTC (203 earth scans) were acquired from the GSFC DAAC and compared to the corresponding direct broadcast data acquired at CIMSS. The GSFC data were processed with the operational calibration v3.0.0 on an IRIX 6.5 platform using the SGI compiler. The CIMSS data were processed with IMAPP v1.3 on a Solarisx86 platform using the gcc compiler. In operational processing at GSFC, each 5 minute Level-1A granule is accompanied by its neighboring granules to allow the Level-1B algorithm to average parameters such as black body temperature across granule boundaries. The averages are computed over 40 earth scans (400 lines at 100 meter resolution). In IMAPP processing, one typically processes the entire pass at once, and therefore neighboring granules are not available. Therefore differences in the calibrated radiances are seen in the first 40 and last 40 earth scans of the test granule. For this reason, we only show results from the middle 123 earth scans (203 - 40 - 40 = 123). All valid pixels in each band were compared in radiance units.

MODIS Level-1B radiances are stored as scaled 16-bit integers. Thus the smallest radiance difference that can be represented is the scale factor itself, which corresponds to one scaled integer. In the radiance comparison, pixels which differed by more than one scaled integer were considered 'different'. To allow for algorithm, platform, and compiler differences, pixels which differed by one scaled integer are considered to be the same. The results are shown in Table 1. The last column is the total number of all valid pixels which differed by more than one scaled integer. It can be seen that in all bands, every valid pixel agreed within one scaled integer.

Table 1. Radiance comparison (scaled integers) between a GSFC DAAC acquired MODIS granule and a MODIS direct broadcast granule collected at CIMSS from 21 November 2001 17:00 - 17:05 UTC.

Band	Number of Valid Pixels	Scale	Number of Pixels that differ
1	1665420	0.0271	0
2	1665420	0.0104	0
3	1665420	0.0206	0
4	1665420	0.0178	0
5	1665420	0.0052	0
6	1665420	0.0025	0
7	1665420	0.0008	0
8	1665420	0.0077	0
9	1585322	0.0048	0
10	1506567	0.0036	0
11	1474221	0.0028	0
12	1424943	0.0022	0
13	1138656	0.0011	0
14	1116022	0.0011	0
15	541400	0.0009	0
16	606652	0.0009	0
17	1665420	0.0067	0
18	1665420	0.0091	0
19	1665420	0.0066	0
20	1665420	0.0001	0
21	1665420	0.0031	0
22	1665420	0.0001	0
23	1665420	0.0001	0
24	1665420	0	0
25	1665420	0.0001	0
26	1665420	0.0029	0
27	1665420	0.0001	0
28	1665420	0.0002	0
29	1665420	0.0005	0
30	1665420	0.0004	0
31	1665420	0.0008	0
32	1665420	0.0007	0
33	1665420	0.0003	0
34	1665420	0.0002	0
35	1665420	0.0002	0
36	1665420	0.0001	0

Comparisons between the operational DAAC L1B products and the IMAPP L1B products have been made. By default, IMAPP uses the platform ephemeris and attitude information encoded in the Level-0 PDS files to geolocate each 1000 meter pixel, while the operational MODIS processing system at GSFC uses definitive post-processed spacecraft ephemeris and attitude. Therefore near real-time geolocation in IMAPP will give different results than the operational geolocation. However IMAPP does give results which are close to the operational values. MODIS geolocation data for 25 November 2001 from 1635 to 1640 were obtained from the GSFC DAAC and compared to the corresponding direct broadcast data acquired at CIMSS and processed using IMAPP v1.3 with terrain correction enabled. The results are shown in Fig. 1. The top histogram shows the difference between the DAAC and IMAPP latitudes for the entire scene (1354 x 2030 pixels), while the bottom histogram shows the longitude differences. The x-axis units are degrees, and the y-axis units are number of pixels. It can be seen that the majority of latitude and longitude differences are within +0.0025 degrees.

These results show that acceptable geolocation accuracy can be obtained in near real-time by using just the Level-0 PDS input to IMAPP. For greater accuracy, the definitive attitude and ephemeris data may be used. For those users wishing to input the definitive data, we have established an online repository of the most recent files at ftp://terra.ssec.wisc.edu/pub/terra/ephemeris/. There is typically at least a 24 hour delay before the post-processed attitude and ephemeris are available. The Aqua MODIS geolocation algorithm requires that ephemeris and attitude files must be used, since spacecraft position is not encoded in the Aqua MODIS Level 0 PDS files. For real time processing, the Ground Based Attitude Determination (GBAD) data (APID 957) transmitted as part of the X-band downlink

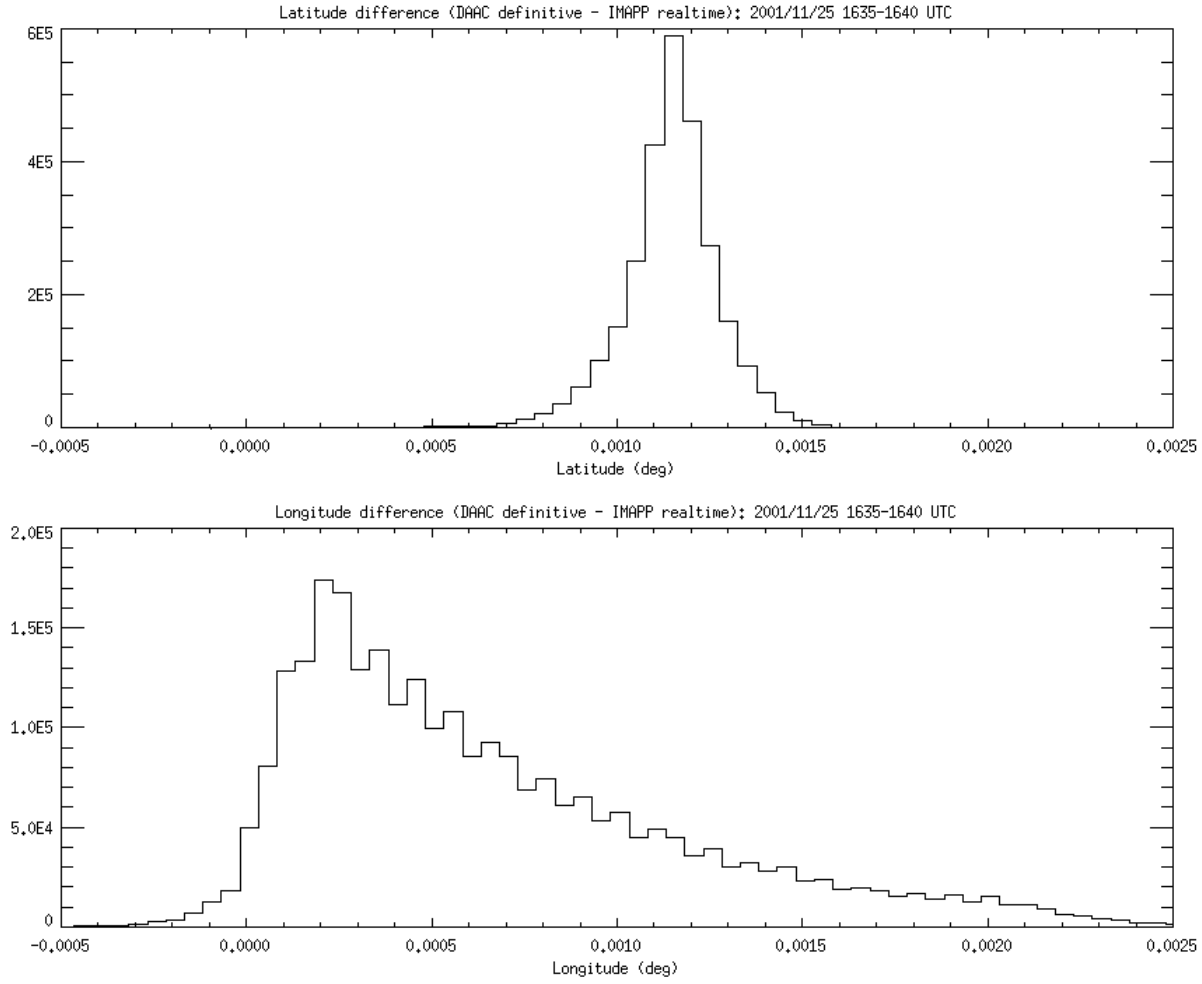

Figure 1. Histogram of latitude and longitude differences between a GSFC DAAC acquired MODIS granule and a MODIS direct broadcast granule collected at CIMSS from 25 November 2001 16:35 - 16:40 UTC.

may be used in conjunction with the GSFC GBAD processor to produce IMAPP-compatible ephemeris and attitude input files. Early results show that realtime geolocation using GBAD derived ephemeris and attitude data is accurate to within 500 meters. For non-realtime processing, the definitive Aqua ephemeris and attitude may be used, providing the same geolocation accuracy as the operational processing at GSFC.

2.1.2 MODIS L1B File Formats

The format of the MODIS IMAPP Level 1B output files is very similar, but not identical, to the format of the GSFC DAAC Level-1B 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.

2.2 MODIS Level 2 Products

The initial release of IMAPP MODIS Level 2 science products took place in May 2002 and consisted of the Terra Cloud Mask (MODIS product MOD35) and Terra Cloud Top Properties and Cloud Phase (Part of MODIS product MOD06). The suite of products now includes the Terra MODIS atmospheric profiles and water vapor product (MODIS product MOD07). The product releases consist of an ancillary data extractor, a set of flat file radiance/geolocation extractors, and the science data software. The extractors serve as data preprocessors for the science software packages; inputs to the extractors are either a DAAC L1B or an IMAPP L1B file. Production scripts also exist as part of the science data packages which will execute the extractors and product software in sequence. The only required external libraries are NCSA HDF4.

The packages are supported on the same UNIX/PC platforms as described in the L1B section 1.1. In addition, an ftp site has been set up (ftp://terra.ssec.wisc.edu/pub/terra/ancillary/) which contains the current and previous 6 days of ancillary data required by all of the science software packages. This will allow the direct broadcast community to one-stop shop for all the ancillary data that they will need 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 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.

Processing times for products varies with the complexity of the algorithm and the processing platform. On an Intel Pentium Sun, running Solaris x86, the cloud mask IMAPP software takes ~30 minutes to process a 15 minute overpass; the cloud top properties software ~15 minutes and the atmospheric profiles ~15 minutes.

2.2.1 MODIS Level 2 Product Verification

Identical product results have been confirmed by directly comparing the IMAPP products with the operational cloud mask (MOD35) version 3.1.1, which was delivered to the GSFC DAAC on 25 February 2002, production cloud top property and cloud phase (MOD06) version 3.1.0 delivered on 15 March 2002 and atmospheric profiles (MOD07) version 3.1.0 delivered on 4 March 2002.

2.2.2 MODIS Level 2 File Formats

For the sake of simplicity, the IMAPP MODIS science data product output files are not in HDF format. They consist of 8-bit unsigned integer (cloud mask) or 32-bit floating point (cloud top properties, atmospheric profiles) files plus header files. Quality assurance (QA) files are also included as part of the cloud mask and cloud top properties and cloud phase products, similar to the production QA product arrays. The extracted radiance/reflectance/geolocation and product flat files can be displayed using the freely distributed FreeLook application or with the commercial ENVI application.

2.2.2.1 Cloud Mask (MODIS product MOD35)

The MODIS cloud mask product consists of a 6 byte output array at 1 km resolution. This 48 bits per pixel of information includes 4 levels of confidence that a given view of the earth is obstructed by clouds or aerosols, along with ancillary data information (background ecosystem, sunglint, etc.) and results of individual tests that went into creating the mask for that scene. The product also contains a 10 byte per 1km pixel array containing information on quality assurance.

Although the structure of the output 48 bit cloud mask array is identical to the operational DAAC product, there are other product differences. The IMAPP version differs from the DAAC cloud mask version in that:

1) It is a flat binary file instead of HDF. No toolkits are required to open or extract data from the file.
2) There are two .img and two .hdr files representing the operational MOD35 HDF Cloud_Mask and Quality_Assurance HDF Science Data Sets (SDS).
3) There are no geolocation or solar and viewing geometry parameters included as part of the direct broadcast product.

For a description of the MODIS cloud mask algorithm please see Ackerman, et al., 1998. A detailed description of the production DAAC MOD35 HDF file can be found at: http://modis-atmos.gsfc.nasa.gov/_specs/MOD35_L2.CDL.fs ; the IMAPP cloud mask Level 2 file description is accessible from: ftp://origin.ssec.wisc.edu/pub/IMAPP/MODIS/Level-2/v1.1/Cloud_Mask_Bit_Description.txt .

2.2.2.2 Cloud Top Properties and Cloud Phase (MODIS product MOD06)

Cloud top temperature, cloud top pressure, cloud top effective emissivity, cloud top fraction and cloud phase are the key parameters included in the MODIS cloud top properties and cloud phase product. The product requires the cloud mask to identify when cloud retrievals should be performed as well as the GDAS model as inputs. Results are provided at 5 km resolution.

MODIS DAAC product MOD06 combines the output of two executables into one file. The direct broadcast version does not include the daytime cloud optical properties at 1km that the DAAC version includes. There are plans to add these remaining parameters in the future. The cloud top properties direct broadcast output file differs from the operational DAAC version in that:

1) It is a 32 bit binary flat file instead of HDF. All parameters (bands) are of type 4 byte float. No toolkits are required to open and read the files.
2) There are two .img and two .hdr files representing the 48 operational MOD06 HDF SDS's, and the cloud top properties and cloud phase MOD06 HDF SDS Quality_Assurance_5km.
3) There are no geolocation or solar and viewing geometry parameters included as part of the direct broadcast product.
4) The output product consists of 48 band interleaved parameters instead of individual HDF file SDS's.
5) The output product does not include several operational MOD06 SDS's. These are:
   Effective_Particle_Radius
   Cloud_Optical_Thickness
   Effective_Radius_Difference
   Water_Path
   Cirrus_Reflectance
   Cirrus_Reflectance_Flag
   Cloud_Mask_5km
   Cloud_Mask_1km
   Quality_Assurance_1km
6) The Quality_Assurance_5km array indices are ordered differently. The IMAPP mod06qa.img order is (element,line,qa_byte), while the DAAC operational HDF SDS is ordered (qa_byte,element,line). The array order was changed to be compatible with the cloud mask byte order.

For a description of the MODIS cloud top properties and cloud phase algorithm, please see the Algorithm Theoretical Basis document at: http://modis-atmos.gsfc.nasa.gov/_docs/atbd_mod04.pdf. A detailed description of the production DAAC MOD06 HDF file can be found at: http://modis-atmos.gsfc.nasa.gov/_specs/MOD06_L2.CDL.fs ; the IMAPP atmospheric profiles Level 2 file description is accessible from: ftp://origin.ssec.wisc.edu/pub/IMAPP/MODIS/Level-2/v1.1/Cloud_Top_Property_Description.txt .

2.2.2.3 Atmospheric properties (MODIS product MOD07)

Retrievals of vertical profiles of atmospheric temperature and moisture, total column ozone, total column water vapor, stability parameters (lifted index, K index, total totals), as well as low level moisture (water vapor between surface and 700 hPa) and high level moisture (water vapor between 400 and 100 hPa) are produced as part of the IMAPP atmospheric profiles software at 5 km resolution. The IMAPP atmospheric profiles and water vapor product differs from the operational product in that:

1) It is a 32 bit binary flat file instead of HDF. All parameters (bands) are of type 4 byte float.
2) There are two .img and two .hdr files representing the 83 operational MOD07 HDF SDS's.
3) There are no geolocation or solar and viewing geometry parameters included as part of the direct broadcast product.
4) The output product consists of 83 band interleaved parameters instead of individual HDF file SDS's.
5) The output product does not include several operational MOD07 SDS's. These are:
   Cloud_Mask
   Processing_Flag
   Tropopause_Height

Guess_Temperature_Profile
Guess_Moisture_Profile
Quality_Assurance_Infrared

There is no quality assurance array or file included with this delivery. In operational processing, the quality is always set to good if a retrieval was performed.

For a description of the MODIS atmospheric profiles retrieval algorithm please see Li, et al., 2002. A detailed description of the production DAAC MOD07 HDF file can be found at http://modis-atmos.gsfc.nasa.gov/_specs/MOD07_L2.CDL.fs ; the IMAPP atmospheric profiles Level 2 file description is accessible from: ftp://origin.ssec.wisc.edu/pub/IMAPP/MODIS/Level-2/v1.2/Profiles_Output_Description.txt .

3. DATA

MODIS Terra and Aqua data are being collected by X-band receiving stations around the world; many of these sites are using IMAPP as the tool to calibrate, navigate and create science data products from MODIS data. CIMSS at the University of Wisconsin-Madison, USA, has created a direct broadcast processing system which automatically creates IMAPP Level 1 and Level 2 products from ingested MODIS data and places the resultant files on a web site for public access. These data sets are utilized by both CIMSS and others for a wide range of applications to be discussed below. In addition, other global receiving stations have documented their use of IMAPP in support of their own investigations. An example is given in the next section.

4. RESULTS

University of Wisconsin CIMSS ingests and processes MODIS Terra and Aqua through Level 1 and Level 2 using automated scripts. The product files are placed on an ftp server for open access (ftp://terra.ssec.wisc.edu/pub/terra/modis/). 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 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 Fig. 2.

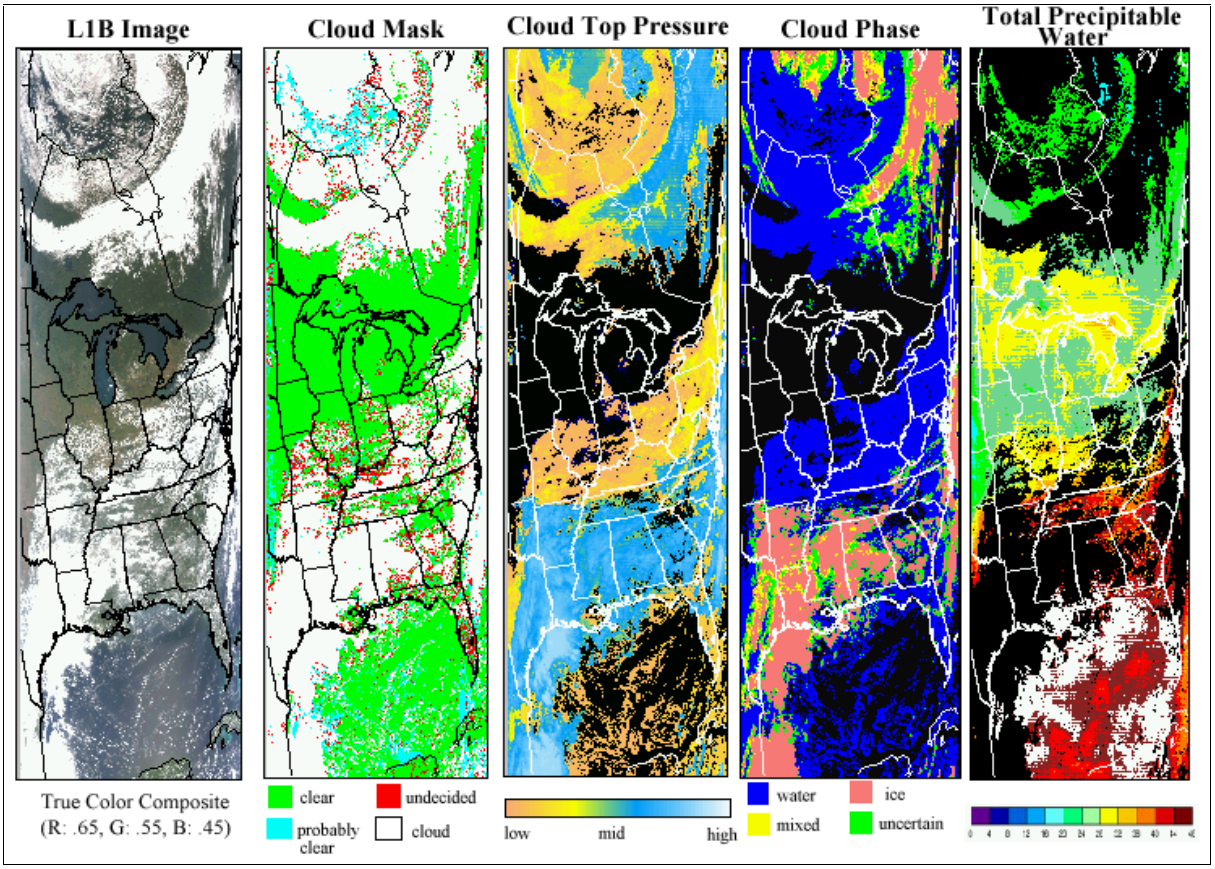

Figure 2. MODIS Terra IMAPP produced L1B true color image, cloud mask, cloud top pressure, cloud phase and total precipitable water from data received at CIMMS on 16 September 2002.

CIMSS is using the data 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 (Li et al., 2002). 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).

The real-time product files that are staged on the CIMSS direct broadcast ftp site are being used by NASA's Short-term Prediction Research and Transition Center (SPORT) to provide real-time high spatial resolution products for use by the meteorologists at the USA National Weather Service (NWS). Fig. 3 is a screen shot of the SPORT web page that is generated and updated automatically displaying MODIS direct broadcast images and products. The page can be found at: http://wwwghcc.msfc.nasa.gov/sport/modis_products.html .

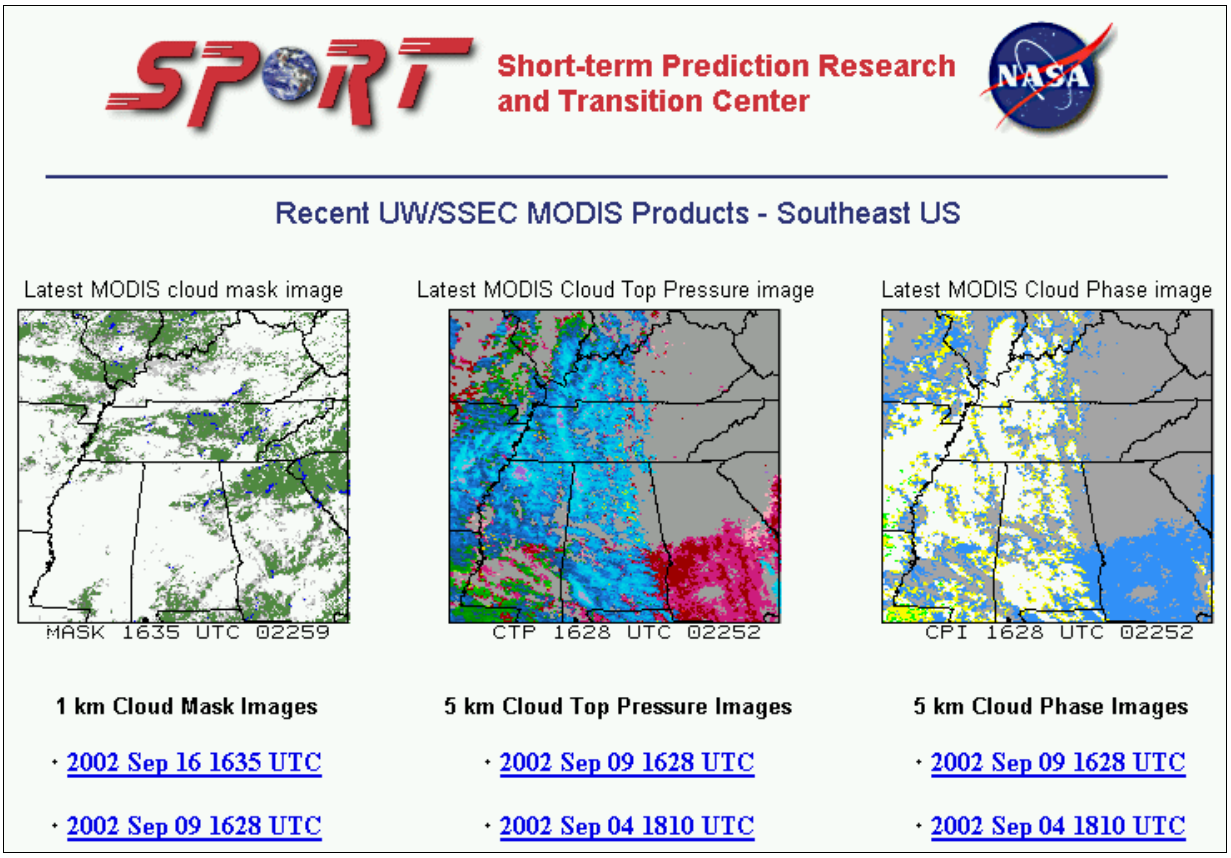

Figure 3. Screen shot of the SPORT web page displaying real-time MODIS direct broadcast products for use by the USA National Weather Service forecasters. This particular display is from 16 September 2002.

Finally, the Canadian Ice Service has requested that CIMSS routinely produce a MODIS quick look image covering Hudson Bay so they can monitor ice cover for shipping concerns.

A partial list of current users of the digital MODIS Level-1B data acquired and processed at CIMSS includes:

Environmental Remote Sensing Center, University of Wisconsin-Madison, USA
Naval Research Laboratory, Monterey, California, USA
Short-term Prediction Research and Transition (SPoRT) Center, NASA/MSFC, USA
Satellite Services Division, NOAA/NESDIS, USA
Atmospheric and Environmental Research, Inc, Lexington Massachusetts, USA

Upper Midwest Aerospace Consortium, University of North Dakota, USA
National Center for Environmental Prediction (NCEP), NOAA, USA
MODIS Snow and Sea Ice Global Mapping Project, NASA/GSFC, USA

Other groups have also used IMAPP to generate real-time products for their interests. 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". The quote was taken from the CLOUDMAP 2 web site located at http://www.npm.ac.uk/rsdas/projects/cloudmap2/ . An example of the IMAPP cloud top temperature product taken from the PML web site is displayed in Fig. 4.

Correspondence from IMAPP users around the world indicates that the software is used in the USA, UK, Germany, Italy, Norway, Japan, China, Russia, S. Korea, Singapore, Thailand, Vietnam, Brazil, South Africa, Australia and Mexico.

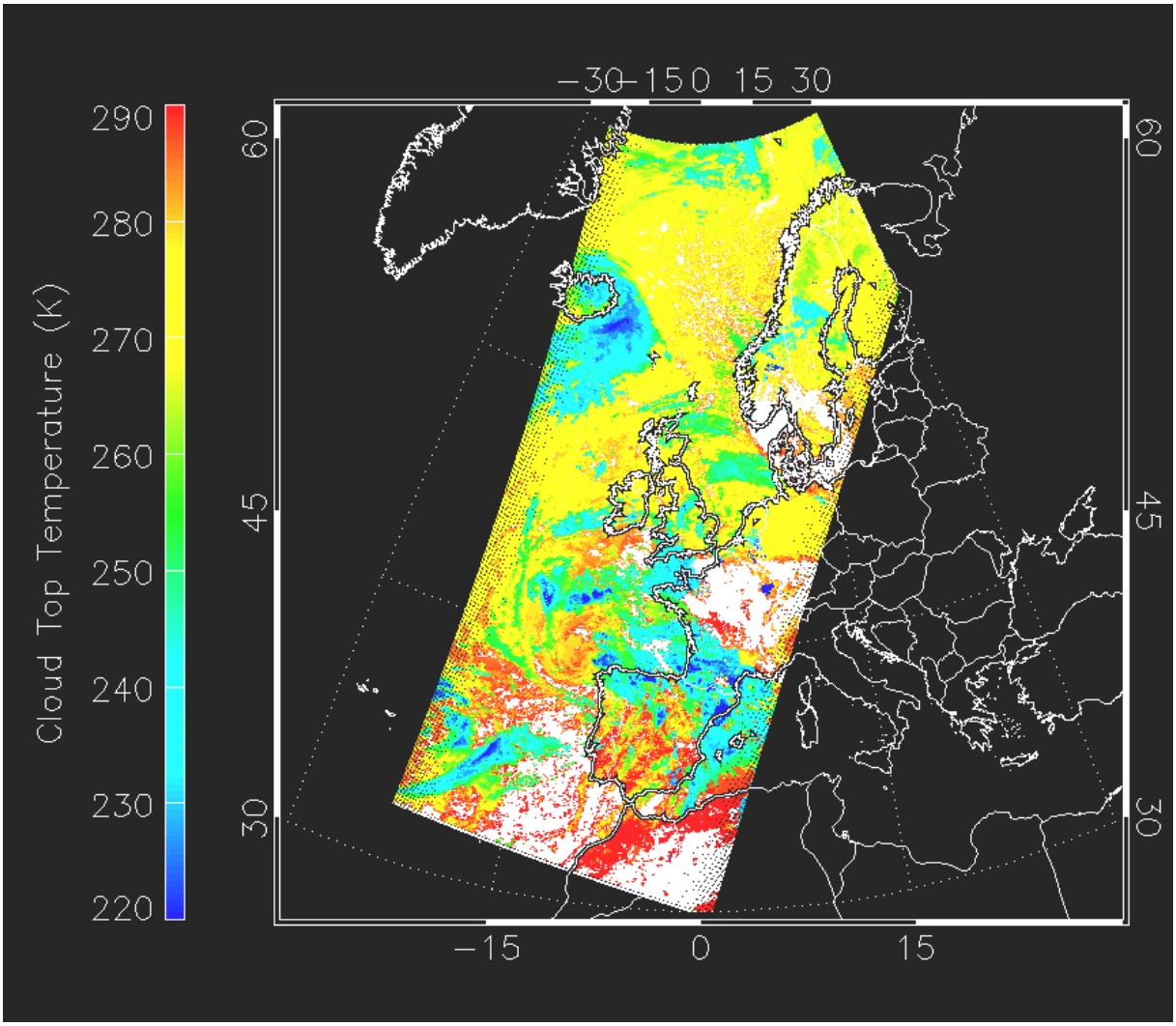

Figure 4. IMAPP MOD06 cloud top temperature product created by the Plymouth Naval Laboratory, UK as part of the CLOUDMAP2 program. The image is from the 18 September 2002, 11:51:26 - 13:11:59 UTC overpass.

5. FUTURE WORK

AQUA was launched in May 2002. Direct broadcast MODIS Aqua compatible products will be released before the end of 2002.

At press time, AIRS data was just beginning to be collected and processed by the AIRS Science Team. It is expected that L1B AIRS direct broadcast products will be released in early 2003. Examples will be shown on the poster companion to this paper.

6. CONCLUSIONS

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 MODIS data into valuable science products. The number of products within IMAPP continues to grow. The list now includes calibrated/navigated radiances, cloud mask, cloud top properties and cloud phase, and retrievals of atmospheric profiles (temperature, moisture) and total precipitable water. AIRS products will be added early in 2003. Some IMAPP products may differ from the operational DAAC MODIS products; however all of the IMAPP released products have been verified against the NASA production products.

The utility of the package has been confirmed both through historical experiences with ITPP and through the wide variety of applications already in use today. CIMSS direct broadcast IMAPP automated processing has proven useful in several ways:

- For MODIS product validation; including Level 1 and Level 2 products.
- Testing of MODIS algorithm product changes.
- Quick look display for identifying regions of spectral or meteorological interest.
- Automated data extraction over a given geographical region for comparison with other instruments or for long term climate studies.
- Provides real-time support for field experiments.

In addition, the real-time IMAPP products that CIMMS provides are used by others. These uses include:

- MODIS calibration validation over Lake Tahoe, USA
- Assisting the USA National Weather Service by providing forecasters with real-time high spatial resolution imagery and products.
- Aiding the Canadian Ice Service in monitoring the amount of ice on Hudson Bay for shipping concerns.

Finally, IMAPP is being utilized globally; scientists at the Plymouth Marine Laboratory in the UK are using IMAPP to provide cloud information as part of the CLOUDMAP 2 project. Although no formal records are kept on the number of users and the nature of IMAPP use, correspondence suggests that IMAPP is being used in every continent except Antarctica.

A series of examples of the high quality of MODIS data is provided in Figure 5. These images were created using IMAPP L1B MODIS Terra data collected by the direct broadcast receiver at CIMSS.

7. ACKNOWLEDGEMENTS

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Hook, S. J, F. J. Prata, and G. S. Schladow, 2001: Validation of Thermal Infrared Data and Products from MODIS and ASTER over Land. NASA progress report. See http://eospso.gsfc.nasa.gov/ftp_docs/validation/Hook.01.report.pdf .

Figure 5a. MODIS Terra L1B true color image (red: band 1 (.65 μm), green: band 4 (.55 μm), blue: .band 3 (.46 μm) processed with IMAPP from data collected at the University of Wisconsin - Madison over the Bahamas on 6 November 2001.

Figure 5b. MODIS Terra L1B true color image (red: band 1 (.65 μm), green: band 4 (.55 μm), blue: .band 3 (.46 μm) processed with IMAPP from data collected at the University of Wisconsin - Madison over forest fires in Saskatchewan, Canada on 27 June 2002.

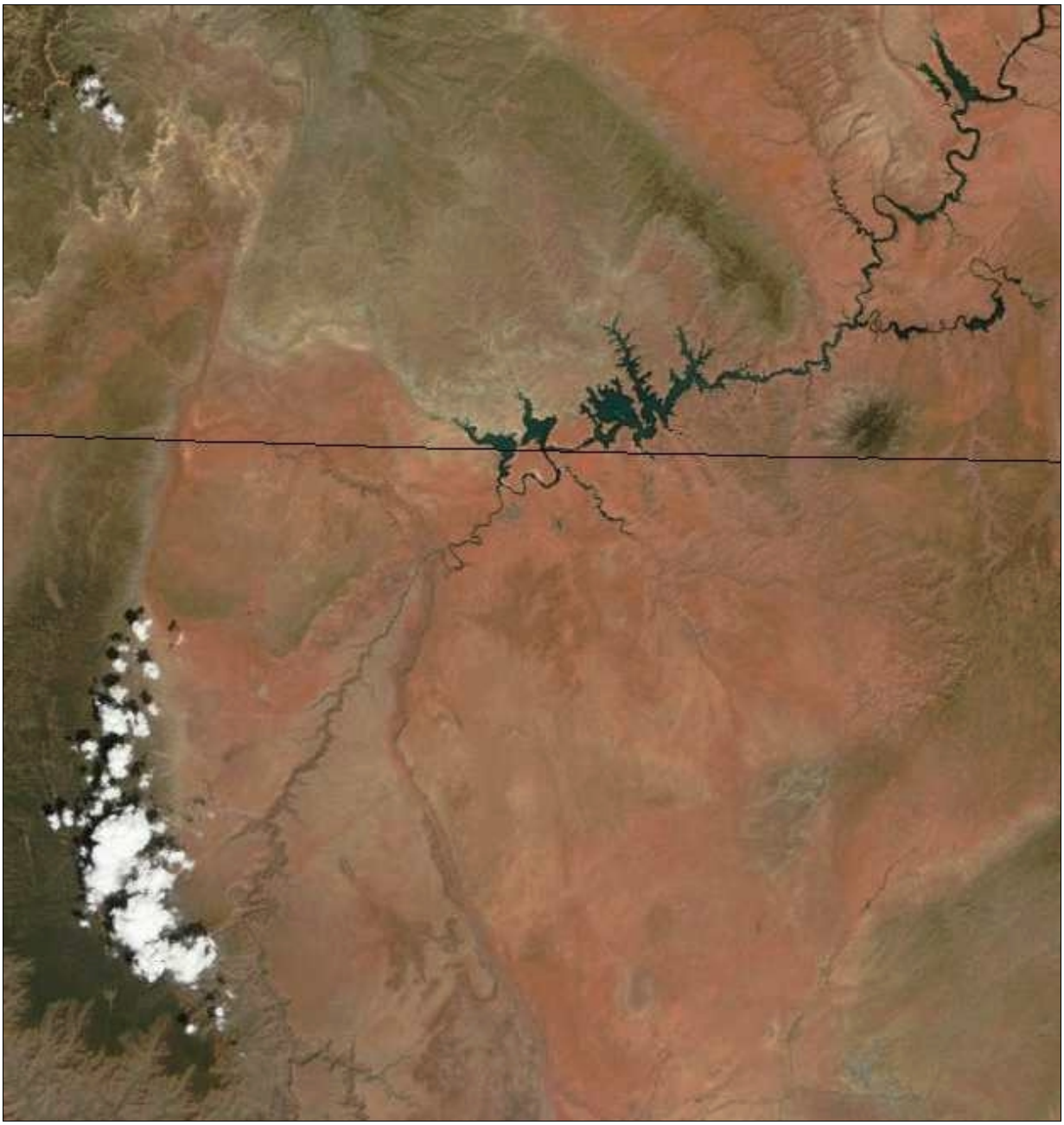

Figure 5c. MODIS Terra L1B true color image (red: band 1 (.65 μm), green: band 4 (.55 μm), blue: .band 3 (.46 μm) processed with IMAPP from data collected at the University of Wisconsin - Madison over the Colorado River in Utah and Arizona, USA on 15 August 2002.

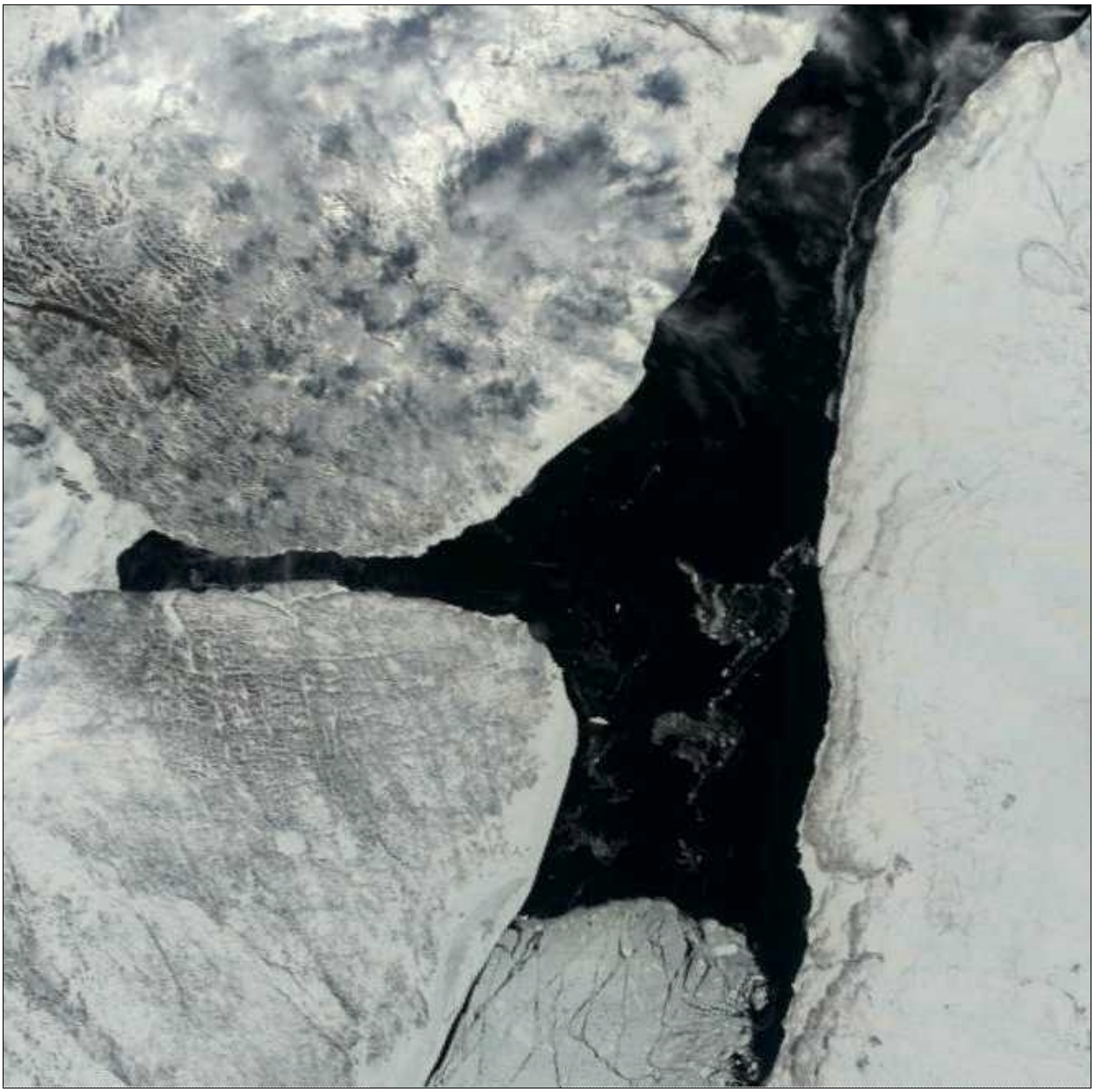

Figure 5d. MODIS Terra L1B true color image (red: band 1 (.65 μm), green: band 4 (.55 μm), blue: .band 3 (.46 μm) processed with IMAPP from data collected at the University of Wisconsin - Madison over Hudson Bay, Canada on 3 June 2002.