

# International MODIS/AIRS Processing Package (IMAPP) MODIS Overshooting Top Detection Software

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Version 1.1

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This document explains how to install and use the IMAPP MODIS Overshooting Top (OT) Detection Software. The OT software identifies portions of MODIS data that contain convective cloud tops that have broken through into the lower stratosphere because of a strong updraft. Convective storms with OTs have the potential to produce severe weather at the ground (heavy rain, damaging winds, hail and tornadoes) as well as aviation hazards including lightning and turbulence. For more information about the algorithm, and the relationship between OTs and surface and aviation hazards, please see:

## **Algorithm Reference:**

K.M. Bedka, J.C. Brunner, R. Dworak, W.F. Feltz, J. Otkin, T. Greenwald, 2010:

“Objective satellite-based overshooting top detection using infrared window channel brightness temperature gradient”. *J. Appl. Meteorol. Climatol.*, 49, pp. 181–202.

## **What’s New in Version 1.1**

IMAPP\_OT execution scripts and Numerical Weather Prediction fetching logic scripts have been updated, as well as improvements made to the python plotting scripts. The GEOCAT and Overshooting Top Detection Science executables have not changed.

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## **DISCLAIMER**

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## **1) Introduction**

The IMAPP Overshooting Top (OT) software consists of binary executables, static ancillary data, execution bash shell scripts and Python image creation scripts. The algorithm source code is not included with this release. It does include the GEOstationary Cloud Algorithm Test-bed (GEOCAT) geocat executable, which was modified for use with MODIS data. The GEOCAT software was developed by Michael Pavlonis of NOAA/STAR, and serves as a framework for running the OT software. It is expected that other algorithms will be added to the IMAPP GEOCAT suite in the future. The IMAPP OT software package also includes python code to create images that display the location of the Overshooting Tops on a map, as well as images indicating the likelihood of turbulence and lightning surrounding these areas for aviation interests.

Inputs are the MODIS Aqua or Terra 1 km file in either NASA archive format or IMAPP direct broadcast format (MOD021KM, MYD021KM, t1 or a1\*1000.hdf), the 1 km geolocation file (MYD03, MOD03, a1 or t1\*geo.hdf), and ancillary Global Forecast System Numerical Weather Prediction (NWP) files. One output HDF4 file at 1km resolution is produced containing the locations of the OTs and information relevant to the algorithm.

## **2) Requirements**

System requirements for the IMAPP Overshooting Top software are as follows:

- Intel or AMD CUP.
- 4 GB RAM,
- Red Hat Enterprise Linux 5.5 64-bit (or other compatible 64-bit Linux distribution),
- 15 GB of disk space,
- Internet connection (for downloading the packages and the dynamic ancillary data).

### 3) Installing and Executing the Software

#### 3.1 Download the software and test data through the IMAPP website:

[http://cimss.ssec.wisc.edu/imapp/tops\\_v1.1.shtml](http://cimss.ssec.wisc.edu/imapp/tops_v1.1.shtml)

#### 3.2 Unpack and install the software

Uncompress the installation file. In this example, I will unpack in  $\${HOME}$ :

```
cd  $\${HOME}$ 
tar -zxvf IMAPP_OVERSHOOTING_TOPS_V1.1.tar.gz
```

This will unpack the software into  $\${HOME}/imapp_ot$

Change your directory to the env sub-directory:

```
cd imapp_ot/env
```

Set the top level OT home directory of your installation in the imapp\_otenv.bash script by modifying the

```
export OTHOME= (path to your installation)
```

entry if necessary. Then set the environmental variables by sourcing the bash file:

```
source imapp_otenv.bash
```

This will also add the /scripts and /bin directories to your \$PATH.

#### 3.3 Run the verification test data set

Unpack the test data in whatever directory you wish:

```
cd  $\${HOME}$ 
tar -zxvf IMAPP_OVERSHOOTING_TOPS_DATA_V1.1.tar.gz
```

this will create a test\_input and test\_output directory containing MODIS input data and the IMAPP OT verification output file. Change to the test\_input directory, create a work directory and change to that directory.

```
cd test_input
mkdir work
cd work
```

Then execute the software by typing in the following command.

```
process_modis_ot.bash ../a1.15218.0737.1000m.hdf ../a1.15218.0737.geo.hdf
```

The processing script can be executed from any directory once you have sourced the imapp\_otenv.bash script.

The output file (geocatL2.Aqua.2015218.074958.hdf) will be created in the execution directory.

Output text written to standard output includes statistics on the resulting scene analysis and actual number of overshooting tops found. If this number is zero, then no overshooting tops were identified in the data set. Below is the first few lines and the last few lines of the text output generated from executing the software on the test data.

```
#####  
IMAPP MODIS Overshooting Tops Detection started at Thu Aug 6 18:44:34 UTC 2015  
#####
```

Input Arguments:

```
Input MODIS L1B File: ../a1.15218.0737.1000m.hdf  
Input MODIS Geolocation File: ../a1.15218.0737.geo.hdf  
-----
```

Getting ancillary data from NCEP for day 218

Beginning extraction of fields from file 1 gfs.t18z.pgrb2.0p50.f012

Beginning extraction of fields from file 2 gfs.t00z.pgrb2.0p50.f012

GFS NWP fetch and conversion completed successfully.

Executing GEOCAT Command

```
/data3/kathys/test/ot/imapp_ot/bin/geocat -f MYD021KM.A2015218.0737.temp.hdf -area_dir  
/data3/kathys/test/ot/test_input/work -file_type modis -read_nav MYD03.A2015218.0737.temp.hdf -  
nav_input_dir /data3/kathys/test/ot/test_input/work -nwp gfs -nwp_dir  
/data3/kathys/test/ot/imapp_ot/ancillary -akey ot -nscans 9999 -l2_dir  
/data3/kathys/test/ot/test_input/work -verbose -time_report  
-----
```

GEOCAT 0.8

Algorithms

Overshooting Top Detection (version unknown)

```
geocat>> Reading satellite meta data...
```

```
geocat>> Printing directory block information...
```

SSEC sensor #: 111  
Image yyyydd: 115218

.....

geocat>> Processing elements 1 - 1354 with xstride = 1 and lines 1 - 2290 in 1 scan line segments

Number of Cold Channel 14 Pixels: 903 1000  
Number of Overshooting Candidate Pixels: 27  
Number of Overshooting Tops: 10  
Number of Total Overshooting Pixels: 532

geocat>> Printing time report for each algorithm processed

Overshooting Top Detection

geocat>> Total processing time:dd=0, hh=0, mm=0, ss=0

geocat>> Destroying input pointers...  
geocat>> Destroying Level 2 output pointers...  
geocat>> Destroying NWP pointers...  
geocat>> Destroying local pointers...

geocat>> Total processing time:  
Days = 0  
Hours = 0  
Minutes = 0  
Seconds = 6

geotime= 49

Output GEOCAT file name: ./geocatL2.Aqua.2015218.074958.hdf

Beginning Overshooting Top Image Creation.

#####  
IMAPP MODIS Overshooting Tops Detection completed normally  
at Thu Aug 6 18:47:33 UTC 2015 .  
#####

To verify a correct installation, use the 'hdiff' command to compare your results with the test\_output benchmark file:

**hdiff -b -S geocatL2.Aqua.2015218.074958.hdf ../../test\_output/geocatL2.Aqua.2015218.074958.hdf**

There should be few if any differences found. There will also be three images created that show the locations of the overshooting tops and potential aviation hazards. **See section 10 for more information about product images.**

### 3.4 Software package contents

The contents of the MODIS OT Detection tar archive are as follows:

- **ancillary** – dynamic ancillary data will be downloaded here. (See section 6.)
- **bin** – contains statically linked executables.
  - **geocat** – This is a statically-linked executable that invokes the geocat system which runs the OT detection algorithm. (See Section 7.)
  - **convert\_grib\_hdf** – This is a statically-linked executable for converting GFS GRIB2 data into geocat-compatible HDF files. (See Section 6.)
- **config** – contains the geocat configuration file.
  - **geocat.default** – contains the default setting settings for geocat. These setting should not be changed.
- **env** – contains the environmental setting script.
- **geocat\_ancillary** – large file containing all of the static ancillary files that are used by geocat.
- **scripts** – contains Bourne shell scripts used to call the executables
  - **process\_modis\_ot.bash** – main driver script for processing the MODIS data. (See Section 2.)
  - **nwpfetch\_newservers.bash** – data retrieval script for grabbing GFS NWP GRIB2 data from NCDC. (See Section 6.)
  - **wgrib2** – National Center for Environmental Prediction (NCEP) program that unpacks Numerical Weather Prediction GRIB2 files.
- **src** – contains source code
  - **convert\_grib** – Software to convert the NWS GFS grib2 file to HDF4 format, which can be read in by the geocat software.
- **ShellB3** – Python based set of software that is used to create product images.

## 4) RUNNING THE MODIS OT DETECTION ALGORITHM

The MODIS OT Detection algorithm is invoked via the following command line calling sequence:

```
process_modis_ot.bash <1km resolution MODIS file> <MODIS geolocation file>
```

where

**<1km resolution MODIS file>** is the path and name of the input MODIS Level 1B 1000m HDF file,  
**<MODIS geolocation file>** is the path and name of the input MODIS Geolocation HDF file.

Within the main processing script (`process_modis_ot.bash`) is a user-editable section of directory paths and a NWP repository choice for input and output data. We suggest that you do not change these. The paths are:

- area\_dir** -> This is the location of input satellite data. (See Section 3 for information about satellite data retrieval.)
- nav\_dir** -> This is the location of the satellite geolocation data. (See Section 3 for information about satellite navigation retrieval.)
- nwp\_dir** -> This is the location of the input GFS NWP HDF files. (See Section 4 for information about GFS NWP data retrieval.)
- geocat\_ancillary\_dir** -> This is the location of GEOCAT's static ancillary data necessary for running the GEOCAT system. (See Section 5 for more information about GEOCAT ancillary data.)
- geocat\_l2\_dir** -> This is the location of the output GEOCAT Level 2 file in HDF format containing the MODIS OT detection locations.
- geocat\_working\_dir** -> This is the location where GEOCAT is called and executed.
- nwp\_repo** -> This is the repository from which the GFS NWP GRIB2 files will be retrieved. (See Section 6 for information about GFS NWP data retrieval.)

Most directory paths are set to the default present working directory (`$PWD`).

Example MODIS IMAPP OT software execution:

```
process_modis_ot.bash ${OTHOME}/data/a1.15218.0737.1000m.hdf  
${OTHOME}/data/a1.15218.0737.1000m.hdf
```

## 5) RETRIEVING MODIS DATA

The MODIS Overshooting Top Detection Algorithm requires the use of MODIS Level 1B 1km Infrared Window Brightness Temperatures and MODIS Geolocation Data stored in HDF4 format. The software accepts either **NASA MODIS standard naming conventions**:

- MOD021KM.A<yyyyjjj>.<hhmm>.\*.\*.hdf -> Terra 1000m (1km) Level 1B data file
- MOD03.A<yyyyjjj>.<hhmm>.\*.\*.hdf -> Terra Geolocation data file
- MYD021KM.A<yyyyjjj>.<hhmm>.\*.\*.hdf -> Aqua 1000m (1km) Level 1B data file
- MYD03.A<yyyyjjj>.<hhmm>.\*.\*.hdf -> Aqua Geolocation data file

where yyyy is the four digit year, jjj is the day of the year, hh is the hour, and mm is the minute, **or the IMAPP standard naming conventions**:

- t1.<yyjjj>.<hhmm>.1000m.hdf -> Terra 1000m (1km) Level 1B data file
- t1.<yyjjj>.<hhmm>.geo.hdf -> Terra Geolocation data file
- a1.<yyjjj>.<hhmm>.1000m.hdf -> Aqua 1000m (1km) Level 1B data file
- a1.<yyjjj>.<hhmm>.geo.hdf -> Aqua Geolocation data file



where yy is the last two digits of the year, jjj is the day of the year, hh is the hour, and mm is the minute. This repository is available in near real-time with data coverage over most of North America. It can be retrieved via anonymous FTP from the UW SSEC direct broadcast repository:

```
ftp://ftp.ssec.wisc.edu/pub/eosdb/<satellite name>/modis/<yyyy_mm_dd_jjj>
```

where <satellite name> is either 'aqua' or 'terra,' and <yyyy\_mm\_dd\_jjj> is the date of interest in the given format where y, m, d, and j represent the number of characters necessary for year, month, day and julian day, respectively.

## 6) RETRIEVING GFS NWP DATA

The MODIS Overshooting Top Detection Algorithm requires the use of two NOAA NCEP Global Forecast System (GFS) NWP 12-hour forecasts that bound the MODIS satellite pass time. One 12-hour forecast must be the latest forecast valid before or at the beginning satellite scan line time and the other must be the latest 12-hour forecast valid immediately following the ending MODIS satellite scan time. The GEOCAT framework requires that the GFS data be in HDF4 format. As part of the IMAPP OT execution, the correct GFS files are automatically identified based upon the input MODIS L1B file date and time, the necessary GFS GRIB2 forecasts files are then downloaded from the NCDC (archive) or NCEP FTP (real-time) server and converted to HDF4 format.

The name of the script is 'nwpfetch\_newservers.bash' and is automatically invoked from within the main processing script (process\_modis\_ot.bash) with the following call:

```
nwpfetch_newservers.bash <year> <julian day> <time> <nwp directory> <nwp repository>
```

where <year> is in yy format, <julian day> is in jjj format, <time> is in hhmm format, <nwp directory> is the location where the HDF files will be stored and <nwp repository> is the repository, 'NCDC' or 'NCEP,' from which the GFS GRIB2 files will be retrieved. It is recommended that the NCEP repository be used for real/near-real time applications as the NCDC server is updated less frequently. Within the 'nwpfetch\_newservers.bash' script two executables are called, 'convert\_grib\_hdf' and 'wgrib2,' and used in the conversion of the GFS GRIB2 files to HDF4.

## 7) GEOCAT

The GEOCAT framework provides an interface to a variety of commonly used radiances, ancillary data, fast models, etc. for the development of satellite retrieval algorithms. The software was initially developed by Michael Pavolonis for the GOES-R Algorithm Working Group (AWG). The GEOCAT framework source code is publically available from this ftp site:

```
ftp://ftp.ssec.wisc.edu/pub/geocat/stable
```

The framework does not include any product retrieval software. For more information, there is a GEOCAT Manual available at the above ftp site.

This IMAPP OT software consists of a geocat binary executable that includes the IMAPP OT algorithm execution, however no source code is included. This distribution also includes the required large geocat ancillary data set. It is located within the imapp\_ot/geocat\_ancillary directory.

## 8) COMPUTING ENVIRONMENT ISSUES

Since the size of the MODIS passes may be large, your stack memory will be highly utilized. Therefore, the main script (process\_modis\_ot.bash ) will ensure that the stack size is set to a large number with this entry:

```
ulimit -s 64000000
```

## 9) OUTPUT FILES

### 9.1 NAMING CONVENTION

A successful execution of the process\_modis\_ot.bash script will result in the creation of an output HDF4 file at 1 km resolution. The naming convention of the MODIS OT Detection output data file is as follows:

**geocatL2.<satellite name>.<yyyyddd>.<hhmmss>.hdf**

where:

- <satellite name> is either 'Aqua' or 'Terra',
- <yyyyddd> is the year and day of the year of the data set,
- <hhmmss> is the hour, minute and second of the data set.

### 9.2 LOCATION OF THE OUTPUT DATA FILE

The location of the MODIS OT Detection output data file is set by default to \$PWD, the directory the program is executed in, the present working directory. This location can be modified by changing the variable 'geocat\_l2\_dir' in the process\_modis\_ot.bash script.

### 9.3 CONTENTS OF THE OUTPUT DATA FILE

The contents of the MODIS OT Detection output data file can be split into three different categories. Each category of data is denoted by a specific prefix appended to the array name within the output file. These categories and prefixes are:

Category	Prefix
1. Pixel characteristics,	<b>pixel</b>
2. NWP model characteristics, and	<b>NWP</b>
3. MODIS OT Detection Algorithm output.	<b>ot</b>

For descriptions of those arrays pertaining to pixel and NWP characteristics, the user is referred to the current GEOCAT Reference Manual which is available from the following FTP location:

<ftp://ftp.ssec.wisc.edu/pub/geocat/stable/>

The MODIS OT Detection Algorithm output arrays contained within the data file are as follows:

- **ot\_overshooting\_top\_grid\_magnitude**  
This data set contains the magnitude of the overshooting top, which is described as the difference in 11-micron infrared channel brightness temperature between the overshooting top and the surrounding cloud shield.
- **ot\_overshooting\_top\_grid\_bt14**  
This data set contains the 11-micron infrared channel brightness temperature of the overshooting top.
- **ot\_overshooting\_top\_grid\_flag**  
This data set contains a boolean value (0 or 1) identifying whether a particular pixel is considered part of an overshooting top (1) or not (0).
- **ot\_overshooting\_top\_qa\_flag**  
This data set contains the MODIS Overshooting Top Detection Algorithm-related quality assurance value of a pixel. The values used for this data set along with their respective descriptions are as follows:

0 - The pixel is an overshooting top center.

1 - The pixel is classified as part of an overshooting top via a fill procedure. The pixel is 50% colder than the mean surrounding anvil brightness temperature.

2 - The pixel is not classified as an overshooting top because its IR-window brightness temperature is warmer than 215 K.

3 - The pixel is not classified as an overshooting top because its IR-window brightness temperature is warmer than the NWP tropopause temperature.

4 - The candidate pixel is not classified as an overshooting top because it is located less than 15 km from another colder overshooting candidate pixel.

5 - The candidate pixel is not classified as an overshooting top because of an insufficient number (less than five) of valid anvil pixels present within an 8 km radius from the overshooting candidate.

6 - The candidate pixel is not classified as an overshooting top because of an insufficient IR-window brightness temperature difference (less than 6.5 K) between the overshooting candidate and mean surrounding anvil brightness temperature.

7 - The candidate pixel is not classified as an overshooting top because it is located at a greater than 70-degree viewing zenith angle.

8 - The pixel is not classified as an overshooting top because its IR-window brightness temperature is colder than 173 K, which is an indicator of a bad pixel.

9 - The pixel is classified as a space pixel.

10 - The pixel is greater than or equal to 15 K colder than its neighboring pixels, implying that the pixel may be affected by noise, and is considered a bad pixel.

11 - The pixel is not classified as an overshooting top because it is located in an area with no CAPE.

- **ot\_overshooting\_top\_pqi\_flag**  
This data set contains the boolean value (0 or 1) of a pixel representing a product quality indicator identifying whether the algorithm output at the pixel is good (1) or bad (0).
- **ot\_overshooting\_top\_grid\_ID\_number**  
This data set contains the ID number of the overshooting top that a particular pixel is associated with.
- **ot\_overshooting\_top\_grid\_number\_of\_anvil\_pixels**  
This data set contains the number of pixels that were used in computing the mean brightness temperature of the anvil cloud surrounding the overshooting top. This value is stored at each pixel location that comprises an overshooting top.

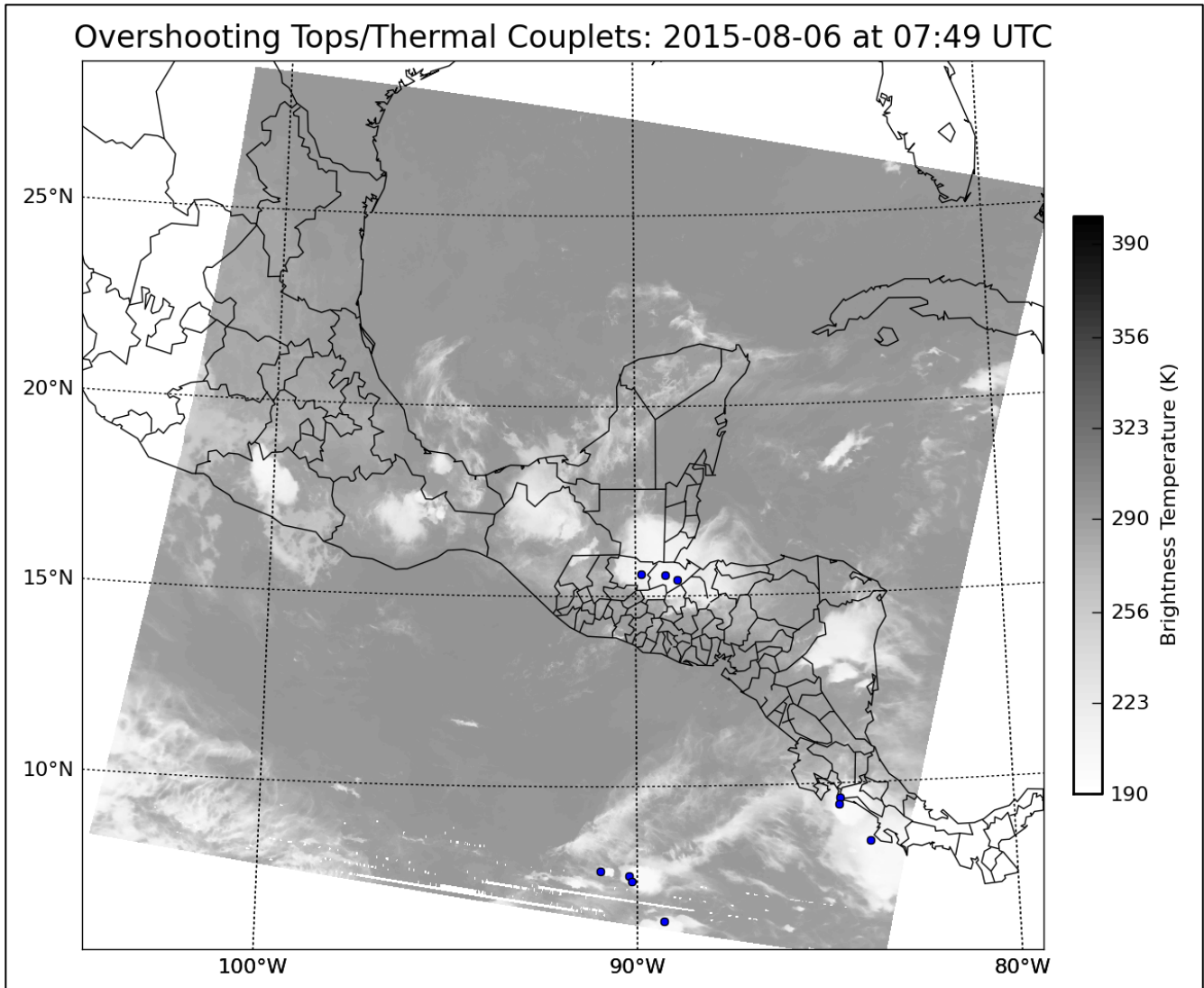
## 10) OUTPUT IMAGES

Python based software is included with the package that will generate product images. The software is executed automatically from within the main IMAPP OT code processing script `process_modis_ot.bash`. The image software is packaged in the `imapp_ot/ShellB3` directory. Three images are created with each script execution. The area plotted is dependent upon the size of the data pass. You can change the domain that is plotted using the options defined in the section **10.4 - Execution of the Image Generation Software**. For example, the MAXVIEW parameters can be defined for a stationary domain. The 3 images that are created include overshooting tops, lightning risk and turbulence risk.

### 10.1 Thunderstorm Overshooting Tops Image

Thunderstorm Overshooting Tops

Filename: **OverShootingTops\_MODIS\_<Sat\_name>.<yyyyddd>.<hhmm>.png**

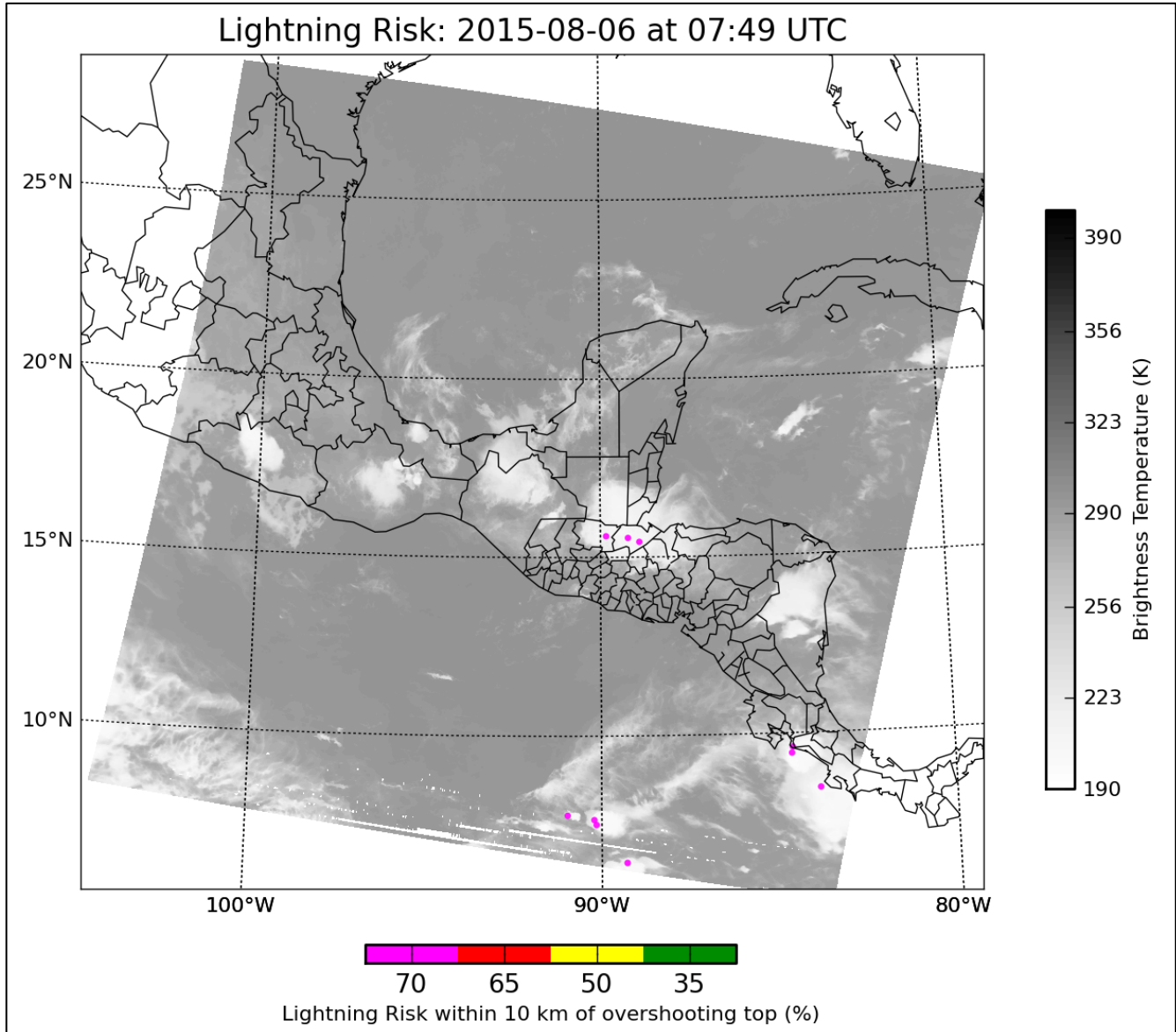


This image displays the overshooting top center location depicted by the blue circles overlaid on MODIS 11 micron (Band 31) Brightness Temperatures. The blue circles may or may not encompass the entire overshooting top area as this image is meant to purely identify the presence of an overshooting top. In addition, the title of the plot states ‘Overshooting Tops/Thermal Couplets;’ however, in the current state of the IMAPP algorithm the only detection is overshooting tops.

## 10.2 Thunderstorm Overshooting Tops Lightning Risk Image

Overshooting Tops Lightning Risk

Filename: **LightningRisk\_<Sat\_name>.<yyyyddd>.<hhmm>.png**

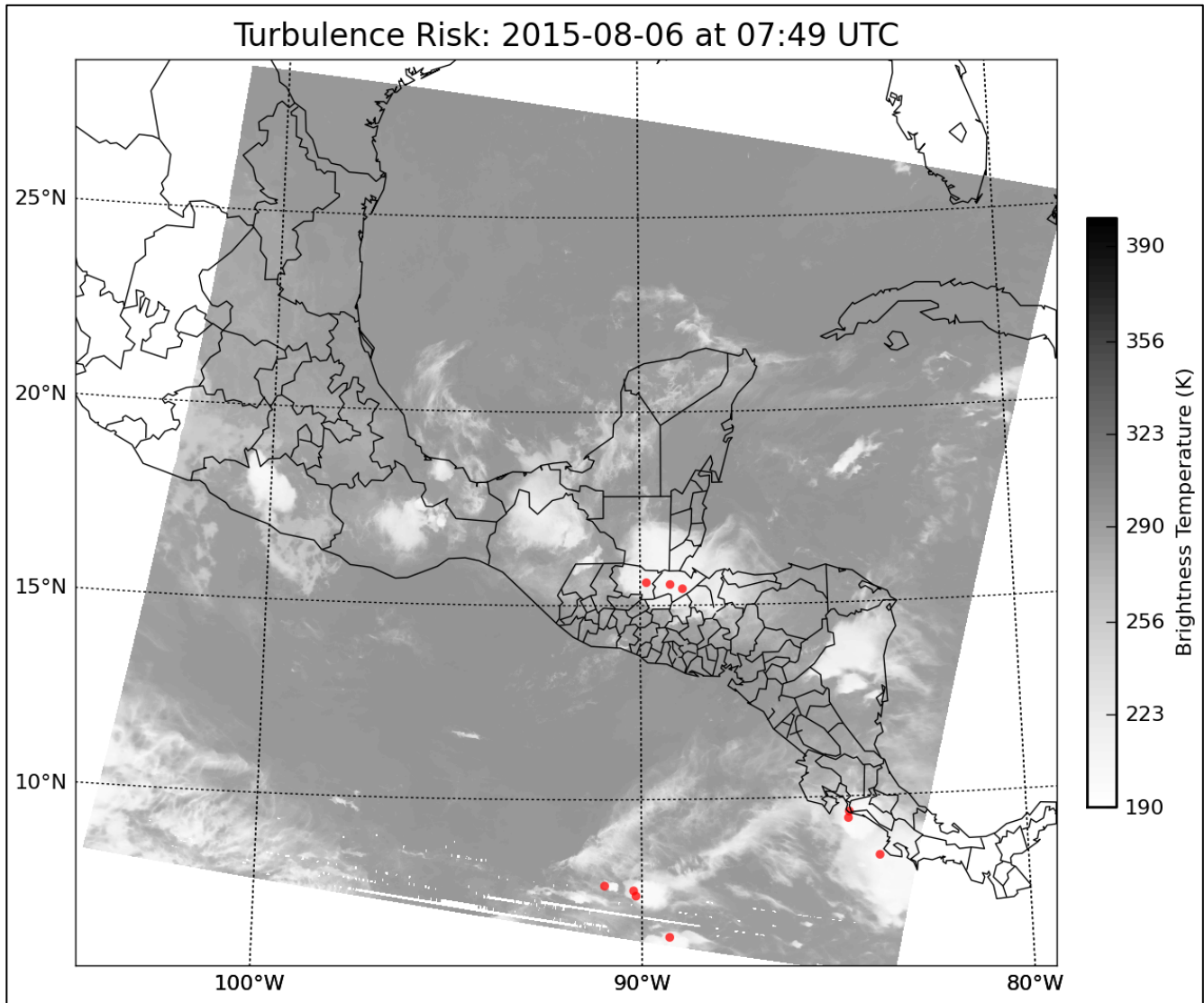


This image displays the areas of potential Cloud-to-Ground (CG) lightning activity due to the presence of an overshooting top overlaid on MODIS 11 micron (Band 31) Brightness Temperatures. According to the study by Bedka et al. 2010 (JAM), with the presence of an overshooting top, there is a 35% chance or greater, 50% chance or greater, 65% chance or greater, or 70% chance or greater of experiencing CG lightning within 10 km of the overshooting top center depending on the brightness temperature of the overshooting top, respectively. The colder the overshooting top brightness temperature is, the greater the chance of CG lightning. These relationships are shown on this image with each colored region identifying the area within a 10 km radius of the overshooting top center.

### 10.3 Thunderstorm Overshooting Tops Turbulence Risk Image

Overshooting Tops Atmospheric Turbulence Risk -

Filename: **TurbulenceRisk\_MODIS\_\_<Sat\_name>.<yyyymmdd>.<hhmm>.png**



This image displays the areas of potential convectively induced atmospheric turbulence due to the presence of an overshooting top, overlaid on MODIS 11 micron (Band 31) Brightness Temperatures. According to the study by Bedka et al. 2010 (JAM), with the presence of an overshooting top there is a 25% or greater chance of experiencing turbulence within 25 km of the overshooting top center. This relationship is shown on this image with each red region representing the area within a 25 km radius of the respective overshooting top center.

## 10.4 Execution of the Image Generation Software

The software can also be executed manually after adding the `/${OTHOME}/ShellB3/bin` to your path. To do this you can source the `imapp_ot/env/imapp_otenv.bash` script after setting the top level `OTHOME` environmental variable for your system. The software uses both the output `geocatL2` file as well as the input `MODIS Level 1B 1km` and the `1km MODIS geolocation` file.

Use the following command to create the images manually.

```
python -m glance.imapp_plot otPlot <IMAPP output OT file> <modis 1km file> <modis geo file>
```

Options:

- `-h, --help` show this help message and exit
- `-q, --quiet` only error output
- `-v, --verbose` enable more informational output
- `-w, --debug` enable debug output
- `-p OUTPATH, --outpath=OUTPATH`  
set path to output directory
- `-m MERIDIANWIDTH, --meridianWidth=MERIDIANWIDTH`  
the width in degrees between displayed meridians.
- `-r PARALLELWIDTH, --parallelWidth=PARALLELWIDTH`  
the width in degrees between displayed parallels.
- `-a MINVIEWLON, --minViewLongitude=MINVIEWLON`  
the minimum longitude that will be visible; if unset will auto-detect from file or data.
- `-z MAXVIEWLON, --maxViewLongitude=MAXVIEWLON`  
the maximum longitude that will be visible; if unset will auto-detect from file or data.
- `-b MINVIEWLAT, --minViewLatitude=MINVIEWLAT`  
the minimum latitude that will be visible; if unset will auto-detect from file or data.
- `-y MAXVIEWLAT, --maxViewLatitude=MAXVIEWLAT`  
the maximum latitude that will be visible; if unset will auto-detect from file or data.

`otPlot` Plot 3 overshooting tops frames.

```
Example: python -m glance.imapp_plot -a -92 -z -87 -b 14 -y 17 otPlot \  
geocatL2.Aqua.2015218.074958.hdf ../a1.15218.0737.1000m.hdf ../a1.15218.0737.geo.hdf
```

When you execute the software manually, it will always generate images with the same 3 filenames:

```
coupletCentersOT.png  
lightningRiskOT.png  
turbulenceRiskOT.png
```

An example of the Turbulence Risk image created from executing this command using the test data set is show below.



Turbulence Risk: 2015-08-06 at 07:49 UTC

