

AODT – Advanced Objective Dvorak Technique
USERS' GUIDE
(McIDAS Version 6.4.2)

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Users’ Guide

Table of Contents

1.)	Description of the AODT Algorithm	1
2.)	System Hardware and Software Requirements	1
3.)	AODT Acquisition and Installation	2
4.)	Using the AODT	3
A.)	Command Line Structure and Keywords	3
1.)	Description of Use	3
2.)	Special Keyword Notes	7
3.)	Examples	8
B.)	History File	10
C.)	UNIX Environment Arguments	11
D.)	Algorithm Output	12
1.)	Full AODT Analysis	13
2.)	Abbreviated AODT Analysis	15
3.)	Land Interaction	15
4.)	Automated Storm Center Determination	16
5.)	User Override Function	18
6.)	Remote Server Data Access	19
7.)	ATCF Record Output	19
E.)	History File Output	20
1.)	Text Output	20
a.)	Original Format Listing	20
b.)	ATCF Format Listing	21
2.)	Graphical Output	22
5.)	Background Information	23
A.)	Land Flag	23
B.)	Scene Classification	23
C.)	Eye and Surrounding Cloud Region Temperature Determination	24
D.)	Time Averaging Scheme	25
E.)	Weakening Flag (Dvorak EIR Rule 9)	26
F.)	Constraint Limits (Dvorak EIR Rule 8)	27
G.)	T# to MSLP Conversion Relationship Auto Determination	28
H.)	Automatic Storm Center Determination and Input File Formats	28
I.)	Maximum Curved Band Location Search	30
J.)	Sea Surface Temperature Information	31
K.)	Latitude Bias Adjustment	32
L.)	Estimate of Radius of Maximum Wind	32
6.)	Acknowledgments	33
7.)	References	34

1.) Description of the AODT Algorithm

The Advanced Objective Dvorak Technique (AODT) algorithm is a computer based technique, developed at the University of Wisconsin-Madison/Cooperative Institute for Meteorological Satellite Studies (UW/CIMSS), to objectively determine tropical cyclone intensity using geostationary satellite infrared imagery. The AODT can be used to classify storm intensity beginning from storm formation from development to dissipation. Previous versions of the ODT could only classify intensities once the storm being examined reached hurricane strength or greater (T# 3.5 or approximately 994/984mb in the Atlantic/Western Pacific).

The AODT is patterned after the Subjective Dvorak Enhanced Infrared 'EIR' Technique (SDT) (Dvorak, 1975, 1984) which made use of various pattern identification schemes and rules to determine tropical cyclone intensity. The AODT has been developed to closely mimic the SDT methodology in terms of intensity determination protocol and the incorporation of various rules and analysis methods. Some of the original SDT rules have been modified in the AODT as determined by in depth statistical analysis of AODT performance during application of these rules.

The AODT was originally derived from previous objective satellite estimation algorithms developed at the University of Wisconsin/Space Science and Engineering Center and Colorado State University/Cooperative Institute for Research Applications. Significant modifications and additions have been made to the AODT, resulting in an algorithm that bears little if any resemblance to its forerunners in terms of methodology, functionality, and content. The primary modifications from previous digital Dvorak methods include the addition of a history file (containing previous intensity estimates obtained during a storm lifecycle), utilization of a time-weighted averaging scheme, new definitions and determinations of various environmental temperature values, and implementation of various SDT rules governing the variability of the intensity estimates. These changes have led to more stable and statistically sound estimates of intensity.

For greater detail about the development process and statistical accuracy obtained with the current and previous ODT/AODT algorithm, please refer to Velden et al. (1998) and Olander et. al. (2004, 2002).

2.) System Requirements

The AODT was originally developed within the Man computer Interactive Data Access System (McIDAS) architecture. The algorithm utilizes McIDAS library functions and routines to ingest infrared satellite data, display textual and graphical results, read various input data files, and write various output files. The AODT has been tested and operated on a wide variety of UNIX/LINUX operating systems. Use of the GCC C-compiler is recommended, but the local system C-compiler can be used if the Makefile files in the two navcal directories are modified correctly.

3.) AODT Acquisition and Installation

The current version (6.4.2) of the AODT algorithm can be obtained via the UW-CIMSS AODT web page, along with the Users' Guide. All files required for installation of the AODT are contained within a single compressed UNIX tar file. The AODT web page is located at the following URL address:

<http://cimss.ssec.wisc.edu/tropic/aodt/aodt.html>

The downloaded AODT tar file for Version 6.4.2 can be uncompressed and unpacked using the following command :

gunzip NAODT-V6.4.2.tar.gz
tar -xvf NAODT-V6.4.2.tar

Once completed, the subdirectory "AODTV6.4.2" will be created and will contain the following directories and files:

- history : directory - output history files (suggested)
- inc : directory - include files
- lib : directory - library files
- odtapi : directory - application program interface (API) routines
- odtappl : directory - main application routine
- odtext : directory - external data handing routines
- odtplib : directory - AODT library routines
- odtmcidas : directory - McIDAS specific routines
- aodtENV : file - environment argument setup file (Section 4E)
- compileall : file - compile script
- Makefile : file - UNIX makefile (for compileall script)
- ProgMan : file - programmer's manual
- ProgMan-mcidas : file - programmer's manual (McIDAS specific)
- TOPOLRES : file - low resolution topography file
- Updates : file - version update notes

Please note that the AODT directory has been significantly reorganized. This was done to create a true AODT function library that will improve integration of the AODT code within non-McIDAS graphical interface platforms and make upgrades much easier to integrate in the future.

Prior to installation of the AODT, the current libmcidas.a library file must be located and linked to within the lib directory. The AODT requires this file for all text and graphical output within the McIDAS user interface windows. This file should reside in the ~mcidas/lib directory. The actual linking is performed within the "compileall" script using the variable MCLIB to define the location of the libmcidas.a file. The MCLIB variable should be modified in this file to reflect its location on the machine where the AODT is being installed. Note that the entire path name must be used instead of the "~mcidas/lib" designation (e.g. /home/mcidas/lib). Once the MCLIB variable has been defined, the AODT algorithm can be compiled using the "compileall" script file.

4.) Using the AODT

The AODT algorithm operates within the McIDAS architecture, utilizing the McIDAS text and graphics/image windows for command line input, data access, and image analysis. Runtime status and final analysis text output are displayed within the McIDAS text window, with image display and graphical output displayed within the McIDAS graphics/image window.

Use of the AODT algorithm is initiated via the McIDAS command line structure using a selection of keywords to control various functions of the AODT algorithm. All AODT keywords are defined in Section 4A1, with examples provided in Section 4A3.

A.) Command Line Structure and Keywords

The AODT is initiated and controlled with the following command line structure :

AODT <keywords> {comment}

Various keywords control different aspects of the AODT algorithm, many of which can be used in combination with other keywords to perform specific tasks. A short description of use for each keyword, along with several examples, will be presented in the following sections.

1.) Description of Use

HISTORY=filename (default=none)

History file used for the AODT analysis. If no history file is specified, no history file will be created/appended. History file names can be up to twelve total characters in length, including the suffix “.ODT”, which will be added to the end of all history file names. The directory where the history files are written to is defined with the ODTHISTORY environment argument. See Special Keyword Notes in Section 4A2 and Section 4B for additional information about the AODT history file.

LIST=YES/NO (default=NO)

List contents of history file within McIDAS text window. Can be used in conjunction with DATE, OUTPUT, and DOMAIN keywords. Pressure/wind units in terms of millibars/knots. If utilized in conjunction with the ATCF keyword, the listing produced will be in ATCF Fix File/DVTO format. AODT analysis will not be performed.

OUTPUT=SCREEN/FILE filename (default=SCREEN)

Direct LIST=YES keyword output to McIDAS text window or ASCII file *filename*. The default output filename is ODTDUMP.ASC. The directory where the FILE output is written is defined with the ODTOUTPUT environment argument (see Section 4C).

GRAPH=YES/NO/TEM (default=NO)

Plot intensity estimates from history file to McIDAS image window. Can be used in conjunction with DATE, PLOT, DOMAIN, and WIND keywords. Pressure/wind units in terms of millibars/knots. TEM value plots eye region, cloud region, and “coldest-warmest” cloud region temperatures, respectively. Temperature units in terms of degrees Celsius/Fahrenheit. AODT analysis will not be performed.

PLOT=c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 (default=1 2 0 0 0 0 6 0 1 7;0 to not display)

Defines graphic color level values for CI#, Adjusted MSLP, Final T# (6-hr time-weighted), Final T# (3-hr average), Adjusted Raw T#, Unadjusted Raw T#, 12-hour Average TIE Model value, Current TIE Model value, graphics boundaries, and graphics wording, respectively. If TEM keyword is used with GRAPH keyword, the color levels will be for the eye region temperature, cloud region temperature, and “coldest-warmest” cloud region temperature, respectively (the other four values will not be used). Graphics color level value of zero (0) will suppress plotting of desired intensity estimate value. Used in conjunction with GRAPH keyword.

DELETE=YES/NO (default=NO)

Allows for manual deletion of history file records. Must be used in conjunction with DATE keyword to define date/time limits to remove. Any records existing in history file after deletion of unwanted records will be updated as necessary (Final T# and CI values will be recalculated). See DATE keyword for default values associated with DELETE keyword. AODT analysis will not be performed.

DATE=date1 time1 date2 time2 (default=see below)

Defines range of dates and times for LIST, GRAPH, and DELETE keywords. Format for date and time values are the same as those given within the text listing (LIST=YES option) :

date format : YearMonDy (e.g. 1998OCT17)

time format : HHMMSS (e.g. 131500)

Default values :

GRAPH and LIST : date1/time1 : first record
date2/time2 : last record

DELETE : date1/time1 : no default, must specify
date2/time2 : date1/time1

WIND=YES/NO (default=NO)

Intensity units given in terms of maximum wind speed (knots) instead of mean sea level pressure. Used in conjunction with GRAPH keyword to plot intensity estimates in terms of wind speed. Speed and pressure values are related to CI number values using empirical relationships defined in Dvorak (1984) and (Shewchuck and Weir, 1980).

DOMAIN=ATL/PAC (default=auto determination)

Define relationship “domain” for CI# to MSLP conversion. ATL should be used for storms within North Atlantic basin, while PAC should be used for storms within Western Pacific basin. If the oceanic basin is not explicitly defined with this keyword, a basin will be selected automatically (see Section 5G). Domain selection will affect Raw T# intensity estimate determination and corresponding CI number pressure value (empirical CI number/pressure relationship). Can be used with LIST and GRAPH keywords or with AODT analysis.

AUTO=YES/NO type filename atctype (defaults=NO 0 AUTOFIX OFCL)

Allow for completely automated operation of AODT, utilizing NHC/JTWC forecasts and Laplacian Analysis to objectively determine storm center position. ***Cannot be used with OVER keyword.***

type = 0 : ATCF Tropical Cyclone Forecast Record files.
type = 1 : TPC WTNT4? (North Atlantic) or WTPZ3? (East Pacific) storm specific DISCUSSION files.
type = 2 : JTWC WTPN3? (Western North Pacific) TROPICAL CYCLONE WARNING file.
type = 3 : Generic format (see Section 5H for format/example)
filename : Name of input file. The directory where the input files is located is defined with the ODTAUTO environment argument.
atctype : ATCF objective technique acronym (default is official forecast)

OVER=YES/NO (default=NO)

Allow user to manually override AODT scene identification. ***Cannot be used with AUTO keyword.*** See Section 4D5 for more information.

IC=value (default=1.0)

Allow user to override the initial Raw T# intensity classification value, as defined in the Subjective Dvorak Rules. The initial Raw T# classification value will be set to 1.0 unless explicitly defined by the user as another value. This keyword should only be used when analysis of a tropical cyclone is initiated at a time later than initial formation (storm has a Raw T# value greater than 1.0). If value is set to 0.0, this function will be turned off for the analysis, allowing for the AODT derived value to be displayed as the Raw T#.

REMOTE=YES/NO localserver localarea (default=NO ODTLSERVE ODTLDATA)

Utilize a remotely displayed/stored McIDAS image for AODT analysis. Subset of data image will be copied to the local server as defined by the *localserver* and *localarea* UNIX environment arguments. See Section 4C for more information.

localserver : ADDE dataset name (group/descriptor format or alias name).

The default is the environment argument ODTLSERVE.

localarea : ADDE dataset position (within local group/descriptor). The default value is the environment argument ODTLDATA.

LAND=YES/NO (default=YES)

Apply AODT land interaction rule. See Section 4D5 and 5A for more information.

SST=filename (default=SST.DAT)

Name of file containing SST information for TIE Model. Directory where SST file is located is defined using ODTSSST environmental variable. See Section 5K for more information.

SEARCH=YES/NO (default=YES)

Perform search for maximum curved band location if Curved Band scene type was automatically determined or manually selected. See Section 5J for more information.

COMM=YES/NO (default=NO)

Add comment field to history file at specified date/time (using DATE keyword). Comment can be up to 50 characters in length and must be enclosed within braces “{“ and “}” on the command line.

ATCF=stormID sourceID rawT finalT (default=-1 XXXX 0 0)

Produce ATCF format output listing for a current intensity estimate record or an entire history file listing. If ATCF keyword is used in conjunction with LIST keyword, output will consist of all records defined with DATE keyword. If ATCF keyword is defined when producing a tropical cyclone intensity estimate, an output file will be produced (in the directory defined with the ODTOUTPUT environmental variable) containing the ATCF format output for the current record. The naming convention for the output file is defined in Section 4A2.

stormID : Annual tropical cyclone number value (01-99)

sourceID : Fix site/WMO Identifier character string (e.g. NHC, PGTW, etc.)

rawT : Flag value indicating output of the Adjusted Raw T# (0) or Unadjusted Raw T# (1) value into the ATCF DVTO “T num (raw)” parameter output slot.

finalT : Flag value indicating output of the 6-hour weighted average Final T# (0) or 3-hour straight linear Final T# (1) value into the ATCF DVTO “T num (average)” parameter output slot.

2.) Special Keyword Notes

If no history file is provided, the AODT intensity bulletin and runtime output (see Section 4D) will be abbreviated, providing the user with only the intensity estimate value at the current time. No analysis flag values will be listed, and no history file will be created or modified.

If the GRAPH, LIST, or DELETE keywords are used, an AODT intensity analysis will not be performed. These functions are used to only investigate and modify the contents of the history file.

The AUTO and OVER keywords cannot be used in the command line at the same time. No user interaction is allowed during the automated operation of the AODT. If these keywords are used in the same command line entry, the override capability will be disabled, and an error message will alert the user of this fact.

The ATCF keyword can be utilized during an AODT intensity estimate analysis or in conjunction with the LIST keyword to output an ATCF Fix File format output (instead of the standard history file listing). If an ATCF format listing is desired with an intensity analysis, an output file will be created in the directory defined with the ODTOUTPUT environmental variable (Section 4C). The naming convention of this output file will be :

CIMSS_AODT_yyyymmddhhhh_ss_FIX

yyyy - year
mm - month (01-12)
dd - day (01-31)
hhhh - UTC time (12:15UTC = 1215)
ss - annual tropical cyclone number (input on command line)

3.) Examples

AODT

Perform abbreviated AODT analysis on current image. Only the current Raw T# will be displayed, with no time averaging or application of any being performed. Output will not be written to any history file.

AODT HISTORY=OPAL.ODT

Perform AODT analysis and add record to history file OPAL.ODT. All rules will be applied as necessary. If this is the first analysis in the OPAL.ODT history file, the initial Raw T# value classification will be set to 1.0.

AODT HISTORY=OPAL.ODT IC=2.5

Perform AODT analysis on the first record within the OPAL.ODT history file, however the initial intensity estimate (first record in history file) within the history file will be set to 2.5.

AODT HISTORY=OPAL.ODT ATCF=13 NHC 0 1

Perform AODT analysis and add record to history file OPAL.ODT. All rules will be applied as necessary. Output file containing intensity estimate for current analysis in ATCF format will be created with annual cyclone number of 13, Fix Center of "NHC, Adjusted Raw T# value, and 3-hour linear averaged Final T# value displayed.

AODT HISTORY=OPAL.ODT OVER=YES

Perform AODT analysis and add record to history file OPAL.ODT. User will be presented with the evaluated AODT Scene Type and prompted to accept or change this value.

AODT HISTORY=OPAL.ODT GRAPH=YES PLOT=3 4 5 0 1 2

Display graph of contents of history file OPAL.ODT in current graphic image using color level 3, 4, 5, 0, 1, and 2 for the CI#, Adjusted MSLP, Final T# (6-hr average), Final T# (3-hr), Adjusted Raw T#, and Unadjusted Raw T# plots, respectively. TIE Model output will not be displayed. Graph boundary and wording will utilize the default values. No intensity analysis is performed.

AODT HISTORY=OPAL.ODT LIST=YES

List contents of history file OPAL.ODT within McIDAS text window. No intensity analysis is performed.

AODT HISTORY=OPAL.ODT LIST=YES ATCF=13 NHC 0 1

List contents of history file OPAL.ODT within McIDAS text window in ATCF format. No intensity analysis is performed

AODT HISTORY=OPAL.ODT LIST=YES OUTPUT=FILE OPAL.TXT

Do NOT perform AODT analysis; provide listing of history file OPAL.ODT to output file OPAL.TXT within directory defined with the ODTOUTPUT environment argument.

AODT HISTORY=OPAL DELETE=YES DATE=1995OCT03 151500

Delete only the 1995OCT03/151500UTC record from the history file OPAL.ODT. No intensity analysis is performed, but all subsequent records in the history file are modified following the deleted record.

AODT HISTORY=OPAL DELETE=YES DATE=1995OCT03 151500 1995OCT03 191500

Delete all records between 1995OCT03/151500UTC and 1995OCT03/191500 UTC from the history file OPAL.ODT, inclusive. No intensity analysis is performed, but all subsequent records in the history file are modified following the deleted records.

AODT HISTORY=OPAL LIST=YES DATE=1995OCT03 1500

List all records between 1995OCT03/001500UTC and the end of the history file OPAL.ODT. No intensity analysis is performed.

AODT HISTORY=OPAL LIST=YES DATE=X X 1995OCT03 31500

List all records between the beginning of the history file OPAL.ODT and 1995OCT03/31500UTC. No intensity analysis is performed.

AODT HISTORY=OPAL.ODT AUTO=YES 2 wp2698.txt

Perform automated AODT analysis and add record to history file OPAL.ODT. AODT will read JTWC Tropical Cyclone Warning file wp2698.txt for forecast information, and is located in the directory defined by the ODTAUTO environment argument.

AODT HISTORY=OPAL.ODT REMOTE=YES

Perform AODT analysis on the remotely stored image currently displayed in the McIDAS image display window. A subset of the displayed image will be copied to the local server on the user's machine in a location defined using the environment arguments ODTLSERVER and ODTLDATA. See Sections 4C and 4D6 for more details.

AODT HISTORY=OPAL.ODT DATE=1995OCT03 81500 COMM=YES {great estimate}

The comment "great estimate" will be added to the 1995OCT03/08150 UTC intensity analysis record in the OPAL.ODT history file.

B.) History File

The AODT history file is an ASCII format file containing AODT intensity estimates, locations, and other specific information for each image analysis. The AODT algorithm utilizes records in the history file for the determination of the intensity estimate values as well as the application of various rules utilized within the intensity estimate routines. Each analysis stored in the history file will contain the following values :

Value 1	: date (YYYYMMDD format : YYYY=year, MM=month, DD=day)
Value 2	: time (hhmmss format)
Value 3	: Julian day and partial day
Value 4	: raw T# unadjusted
Value 5	: raw T# adjusted by Rule 8 rules
Value 6	: final T# value (6-hour time-weighted average)
Value 7	: final T# value (3-hour average)
Value 8	: final CI# value
Value 9	: eye region temperature (°C)
Value 10	: mean cloud region temperature (°C) – movable annulus
Value 11	: mean cloud region temperature (°C) – set region (old method)
Value 12	: “coldest-warmest” cloud region temperature (°C)
Value 13	: storm center latitude (+/- = North/South Hemisphere)
Value 14	: storm center longitude (+/- = West/East Hemisphere)
Value 15	: eye diameter or shear distance (in km)
Value 16	: eye region temperature standard deviation value
Value 17	: satellite ID value
Value 18	: cloud region symmetry value
Value 19	: eye region scene type (original value)
Value 20	: cloud region scene type (original value)
Value 21	: eye region scene type (original value if user override performed)
Value 22	: cloud region scene type (original value if user override performed)
Value 23	: Dvorak Weakening (Dvorak EIR Rule 9) flag
Value 24	: Dvorak Constraint Limits (Dvorak EIR Rule 8) flag
Value 25	: latitude bias application flag
Value 26	: land/ocean flag
Value 27	: eye region FFT value
Value 28	: cloud region FFT value
Value 29	: curved band analysis – BD curve gray scale value
Value 30	: curved band analysis – convection curvature amount (out of 25)
Value 31	: distance from center to “coldest-warmest” temperature value
Value 32	: automated center determination flag
Value 33	: MSLP latitude bias adjustment value
Value 34	: TIE Model output flag
Value 35	: TIE Model current pressure value – if SST value available
Value 36	: TIE Model 12-hour averaged pressure value – if SST value available
Value 37	: sea surface temperature value (in °C) – if available
Value 38	: radius of maximum wind (in km)
Value 39	: user comment – if available

History files should not be modified directly. Any modifications, such as reanalysis or removal of individual records, should only be done using the AODT command line entry with select keywords, such as DELETE and DATE, in order to assure correct modification to the remaining history file entries.

Due to McIDAS keyword entry constraints, with origins dating back to the initial DOS-based systems, history file names are limited to 12 characters in total length, including the “.ODT” suffix. History file names provided in the command line without the “.ODT” suffix will have it appended automatically, with the prefix name truncated to eight characters if necessary. For example, the command line entered history file name of JOSEPHINE will result in a file name of “JOSEPHIN.ODT”, while “OPAL.ODT” or “OPAL” will result in “OPAL.ODT”. The directory location of the history files is defined with the ODTISTORY environment variable.

C.) UNIX Environment Arguments

In order to provide more control regarding various AODT input/output file and directory definitions, the AODT utilizes seven UNIX environment arguments to define specific variables used within the AODT algorithm. This provides the user greater ability to personalize the AODT to the local machine on which it is operating.

<u>Variable</u>	<u>Description</u>
ODTTOPO	Directory where TOPOHRES topography file is located
ODTHISTORY	Directory where AODT history files are stored
ODTAUTO	Directory for forecast files for AODT auto mode
ODTOUTPUT	Directory for LIST/ATCF output
ODTSST	Directory for the external SST input file
ODTLSERVER	Name of local ADDE server dataset name
ODTLAREA	ID number of local ADDE server dataset position

ODTTOPO, ODTHISTORY, ODTAUTO, ODTOUTPUT, and ODTSST are directory names. The default value for the base directory for these variables is defined using the \$ODTHOME environmental variable, which is defined on line one of the aodtENV file. If any of these variable names are not defined in the aodtENV file explicitly, the value will default to the \$HOME environment variable value.

The ODTLSERVER and ODTLAREA variables will copy a remotely stored image to the local server using the standard McIDAS ADDE dataset name and position identification scheme. ODTLSERVER is the dataset name, in either *group/descriptor* format or an ADDE alias name (using AKA), with ODTLAREA being the *position* variable. Please refer to the McIDAS Users’ Guide for details on specific McIDAS ADDE server definitions and topics.

To install these variables within the UNIX environment, use the following command on the UNIX command line:

. aodtENV

D.) Algorithm Output

During AODT operation the algorithm will display various text outputs within the McIDAS text window, consisting of various runtime information and error messages, interactive prompts for user override options, and the final intensity estimate bulletin.

1.) Full AODT Analysis

Full AODT analysis of an image requires the use of a history file and may use various combinations of specific keywords. Below is sample intensity bulletin output :

```
Utilizing history file /home/odt/history/TEST.ODT
Performing full AODT analysis
Using USER-SELECTED center position : LAT: 22.99 LON: 66.21
Ocean basin automatically selected as ATLANTIC
Utilizing SST GRIB file /home/odt/data/sst/SST.DAT
Error accessing SST GRIB file - No TIE Model estimate available
Invalid SST value - No TIE Model estimate available
Utilizing image data file /home/odt/mcidas/data/AREA2010
```

```
                UW - CIMSS
      ADVANCED OBJECTIVE DVORAK TECHNIQUE
      AODT - Version 6.4.2
Tropical Cyclone Intensity Algorithm
```

```
      ----- Current Analysis -----
Date : 12 SEP 1999      Time : 124500 UTC
Lat  : 22:59:26 N      Lon  : 66:12:49 W
```

```
      CI# /Pressure/ Vmax
      6.5 / 934.8mb/127.0kt
```

Latitude bias adjustment to MSLP : -0.2mb

Estimated radius of max. wind base on IR : 31.4km

```
      6hr-Avg T#    3hr-Avg T#    Adj T#    Raw T#
      6.3           6.4           6.5       7.1
```

Eye Temp : 18.6C Cloud Region Temp : -74.2C

Scene Type : CLEAR EYE

Positioning Method : MANUAL

Ocean Basin : ATLANTIC
Dvorak CI > MSLP Conversion Used : ATLANTIC

Tno/CI Rules : Constraint Limits : 1.5T/6hr
Weakening Flag : OFF

```
ADDED RECORD TO END OF HISTORY FILE /home/odt/history/TEST.ODT
WROTE 66 RECORDS TO HISTORY FILE /home/odt/history/TEST.ODT
Successfully completed AODT analysis
```

The first section of the AODT intensity bulletin output includes the runtime messages, which provide general information about the history file being used and various other parameters used in the derivation of the current intensity estimate. The history file utilized will be displayed first, and thus a full AODT analysis will be performed on the image. This will be indicated by the following message :

```
Performing full AODT analysis
```

The path and file name of the current image file being analyzed will be listed prior to the intensity estimate bulletin. In this example the locally stored image file is named AREA2010. The path to this image is defined by the \$MCPATH environment variable, and is defined in the local “.mcenv” file. For an example of remotely stored data, and its corresponding output messages, see Section 4D6.

Within the intensity estimate bulletin, all vital information relating to the current image analysis will be displayed. The date, time, and location are presented first, followed by the four intensity estimate values; the current unadjusted Raw T#, adjusted Raw T#, Final T# (6-hour time-weighted average), Final T# (3-hour average), and CI#.

The “Raw T#” value is the unadjusted Raw “DT” number determined using the current scene type and measured environmental parameters for the selected scene type (cloud curvature, eye/cloud temperatures, etc.). The “Adj T#” value represents the current intensity of the storm after any Constraint Limit (Dvorak “Rule 8”) rules have been applied (see Section 5F). The “6hr-Avg T#” value is the 6-hour time-weighted averaged intensity of the storm. The time averaging scheme is explained in greater detail in Section 5D. The “3hr-Avg T#” value is the average of the current and previous three hour analyses values. Finally, the “CI#” value represents the 6-hour time-weighted averaged value after various AODT rules and constraints governing its variability, listed next to the Constraint Limits and Weakening Flag labels at the end of the intensity bulletin, have been applied. For more details on these rules, see Sections 5E and F.

Adjacent to the “CI#” value are the corresponding estimated mean sea level pressure (MSLP) and maximum wind (Vmax) values. The MSLP value displayed for the derived CI# intensity estimate may have been modified by a latitude bias adjustment, which is a linear regression-based equation which adjusts the original CI# based upon the current storm latitude. The amount of any adjustment will be listed below the CI#/Pressure/Vmax information next to the “Latitude Bias Adjustment to MSLP” label. A positive/negative adjustment will increase/decrease the MSLP value obtained from the specific CI#/MSLP relationship for the scene being investigated. Please see Sections 5G and 5K for more information on this adjustment.

Following the eye and cloud temperature information (Section 5C), the specific Scene Type and Positioning Method information is listed. The example above obtained a CLEAR EYE scene for a manually selected storm center location. The storm center selection method is provided in both the intensity bulletin and the preceding runtime messages section. A discussion of an automatically selected storm center location will be

provided in section 4D4. The scene type will be determined automatically using various image analysis methods (Section 5B). Manual selection of the storm scene type can be performed using the OVER keyword described in Section 4A1.

If the scene type of the current analysis is a CLEAR EYE, PINHOLE EYE, or a LARGE CLEAR EYE, an estimate of the radius of maximum wind will be provided under the Latitude Bias Adjustment line in the intensity bulletin. For more information on the derivation of this maximum wind value see Section 5L.

The ocean basin in which the storm is located will be displayed next. This value will either be ATLANTIC, PACIFIC, or INDIAN. Following the ocean basin designation, the empirical T# to MSLP relationship method used to determine the MSLP value for the given T/CI# is presented. This value will either be listed as ATLANTIC or PACIFIC, indicating the Atlantic or West Pacific empirical relationship conversion is used. The conversion will automatically be determined unless manually overridden using the DOMAIN keyword. See Section 5G for more information on the automatic ocean basin determination process and T# to MSLP conversion relationship.

Once the intensity analysis has completed, the current analysis information will be written to the history file. In this example the current analysis was appended at the end of the history file TEST.ODT and was the last of 66 records written to the history file.

Most frequently an intensity analysis will be performed on the most current image available. If analysis of a missed image or reanalysis of a previously examined image is performed, one of the following message groups will be displayed, respectively:

```
Inserting record X in history file <history file>  
Modified X subsequent records in history file <history file>  
Wrote X record(s) to history file <history file>
```

or

```
Overwrote record X in history file <history file>  
Modified X subsequent records in history file <history file>  
Wrote X record(s) to history file <history file>
```

When a record is overwritten or inserted into an existing history file, all subsequent records after the current analysis will be automatically recalculated as needed.

The final section of the intensity estimate bulletin, if displayed, is the experimental Tropical Cyclone Intensity Estimate (TIE) Model output. An estimate will only appear if a valid sea surface temperature (SST) (Section 5K) can be obtained from an external data file. Also, the TIE Model estimate will not be displayed until the TIE Model estimate and AODT estimate difference is less than or equal to 0.5 T#. A message in the intensity estimate bulleting will be displayed indicating this condition has not been met. Once this condition has been met, all subsequent TIE Model estimates will be displayed within the intensity estimate bulletin and available for output with the GRAPH option. See the TIE Model Users' Guide, available on the AODT homepage, for more specific information about the TIE Model.

2.) Abbreviated AODT Analysis

If a history file is not specified on the command line when utilizing the AODT, an abbreviated analysis will be performed. Much of the output will be the same, however a few modifications to the runtime messages and intensity bulletin will exist. First, the intensity bulletin will contain only one intensity estimate value. This estimate will be listed at the "CI#", representing the intensity estimate at the analysis time only. Second, the two "Rule Flags" values will not be listed since they are only utilized when a history file is present. A sample abbreviated output is presented below :

```
Performing abbreviated AODT analysis
Using USER-SELECTED center position : LAT: 22.99 LON: 66.21
Ocean basin automatically selected as ATLANTIC
Utilizing SST GRIB file /home/odt/data/sst/SST.DAT
Error accessing SST GRIB file - No TIE Model estimate available
Invalid SST value - No TIE Model estimate available
Utilizing image data file /home/odt/mcidas/data/AREA2010
```

```
                UW - CIMSS
      ADVANCED OBJECTIVE DVORAK TECHNIQUE
        AODT - Version 6.4.2
Tropical Cyclone Intensity Algorithm
```

```
      ----- Current Analysis -----
Date : 12 SEP 1999      Time : 124500 UTC
Lat  : 22:59:26 N      Lon  : 66:12:49 W
```

```
      CI# /Pressure/ Vmax
      7.1 / 917.8mb/143.0kt
```

```
Latitude bias adjustment to MSLP : -0.2mb
```

```
Estimated radius of max. wind base on IR : 31.4km
```

```
Eye Temp : 18.6C      Cloud Region Temp : -74.2C
```

```
Scene Type : CLEAR EYE
```

```
Positioning Method : MANUAL
```

```
Ocean Basin : ATLANTIC
```

```
Dvorak CI > MSLP Conversion Used : ATLANTIC
```

```
Successfully completed AODT analysis
```

3.) Land Interaction

If the storm center is over a land region (as defined in Section 5A), a warning will be presented in the runtime output and intensity bulletin. No intensity estimate will be calculated unless explicitly requested by the user with the LAND keyword. A sample output for a storm center over land is presented below :

```

Performing abbreviated AODT analysis
Using USER-SELECTED center position : LAT: 22.93 LON: 66.04
Ocean basin automatically selected as ATLANTIC
Utilizing SST GRIB file /home/odt/data/sst/SST.DAT
Error accessing SST GRIB file - No TIE Model estimate available
Invalid SST value - No TIE Model estimate available
Utilizing image data file /home/odt/mcidas/data/AREA2010
Utilizing topography file /home/odt/TOPOLRES
Tropical cyclone is over land

```

```

                UW - CIMSS
      ADVANCED OBJECTIVE DVORAK TECHNIQUE
        AODT - Version 6.4.2
Tropical Cyclone Intensity Algorithm

```

```

      ----- Current Analysis -----
Date : 12 SEP 1999      Time : 124500 UTC
Lat  : 22:56:18 N      Lon  : 66:02:56 W

```

```

      TROPICAL CYCLONE OVER LAND
      NO AODT ANALYSIS AVAILABLE

```

4.) Automated Storm Center Determination

The AODT algorithm can be executed in a completely automated mode, utilizing an interpolated tropical cyclone forecast and three storm center determination analysis techniques to obtain a completely objective storm intensity estimate. See Section 5H for specific information on the formats allowed for the input forecast files.

The automated storm center location is determined using one of the following methods; polynomial interpolation of a forecast, linear extrapolation of previous history file positions, or a combination analysis approach using a Spiral Centering, Eye Ring Fitting, and/or Laplacian analysis scheme to determine the best storm center location. The polynomial interpolation scheme determines the current position of the storm using three positions (the current, 12 hour, and 24 hour forecast positions) from a TPC/NHC or JTWC forecast in conjunction with two previous positions from the history file (6 and 12 hour old positions), if available. If the forecast interpolation scheme fails, a linear extrapolation of the previous 12 hours of storm positions stored in the history is determined.

If the Final T# value for the previous entry in the history file is greater than 3.5 and either the interpolation or extrapolation methods are successful, a full objective analysis search for the storm center location is performed using a combination of three image analysis routines. The first method is a Spiral Centering analysis centered at the interpolation/extrapolation position. Once completed, an Eye Ring Fitting analysis, which attempts to fit different size rings to cloud temperature gradients, is performed. A Laplacian analysis of the cloud top temperature field, which searches for large cloud top

temperature gradients concentrated in small regions (e.g. eye regions), is then performed. Once all three methods have been completed, an empirically based determination scheme selects the center point from the three methods (or a combination of the Spiral Centering and Eye Ring Fitting routines). For a more detailed discussion of the entire auto-location methodology, refer to Section 5H.

In the following examples, a TPC/NHC forecast was used in the polynomial interpolation scheme. The data points used in the polynomial interpolation scheme are displayed prior to the interpolated position. The Spiral Centering, Eye Ring Fitting, and Laplacian analyses were then attempted. In this example a strong eye region was not found, but the Spiral Analysis routine was able to find a center point successfully:

```
Accessing forecast file /home/odt/forecasts/storm01-15.txt
CURRENT ANALYSIS TIME : 01/OCT/2000 0715UTC
      DATE      TIME      LAT      LON
T0 01/OCT/2000 0300UTC   18.10   87.10
T1 02/OCT/2000 1200UTC   18.30   87.40
T2 02/OCT/2000 0000UTC   19.00   87.50
FORECAST INTERPOLATION successful -- LAT: 18.16 LON: 87.27
Utilizing image data file /home/odt/mcidas/data/AREA2030
Warmest pixel temperature of 12.6C at LAT: 18.34 LON: 87.55
Will utilize SPIRAL ANALYSIS position -- LAT: 17.96 LON: 87.28
```

If the polynomial interpolation scheme fails, and the linear extrapolation of the previous 12 hour storm center locations, stored within the history file, will be used as the first guess for the three auto-centering techniques:

```
Accessing forecast file /home/odt/forecasts/storm01-15.txt
Error accessing forecast file /home/odt/forecasts/storm01-15.txt
FORECAST INTERPOLATION failed
LINERAR EXTRAPOLATION successful -- LAT: 18.09 LON: 87.22
Will utilize SPIRAL ANALYSIS position -- LAT: 17.96 LON: 87.28
```

If both the polynomial interpolation and linear extrapolation schemes fail, the three auto-centering techniques will not be attempted and the AODT will quit and the user will be notified in the runtime message output section with the following message :

```
Error with autopositioning
Exiting AODT
```

As mentioned previously, the automated center determination scheme cannot be used in conjunction with the manual override capability (see next section). If both the AUTO and OVER keywords are entered on the same command line, the override capability will be disabled, and the following message will be presented :

```
OVER and AUTO keywords cannot be used at same time
Disabling override ability
```

5.) User Override Function

The user override function allows the user to modify the automatically determined scene type classification prior to the AODT storm intensity estimate calculation. This is performed utilizing mouse button inputs to toggle through the various scene types. After the scene type has been automatically determined, the user will be prompted either accept or modify the scene type. If the user desires to modify the scene type, a sequence of scene type classifications will be presented to the user. Once the desired scene type is chosen, the program will proceed with the determination of the current storm intensity estimate using the user-selected scene type. Two example sessions are below :

The user agrees with the scene type :

```
AODT has classified the EYE SCENE as CLEAR
Do you agree with this scene classification?
TOGGLE : Press MIDDLE mouse button
ACCEPT : Press RIGHT mouse button
  <user presses RIGHT mouse button>
CLOUD AND EYE SCENES have not been changed
User accepted scene type
```

The user does not agree with the scene type :

```
AODT has classified the EYE SCENE as RAGGED
Do you agree with this scene classification?
TOGGLE : Press MIDDLE mouse button
ACCEPT : Press RIGHT mouse button
  <user presses MIDDLE mouse button>
Change eye scene to OBSCURED
  <user presses MIDDLE mouse button>
Change eye scene to NONE
  <user presses RIGHT mouse button>
Change cloud scene to UNIFORM CDO
  <user presses MIDDLE mouse button>
Change cloud scene to EMBEDDED CENTER
  <user presses RIGHT mouse button>
CLOUD SCENE has been changed to EMBEDDED CENTER
User modified scene type
```

In the second example, the user selected NONE for the eye scene. The scene types switched from eye scene to cloud (no-eye) scenes, and the user resumed scrolling through the different cloud scene type options until the desired scene was presented. The opposite switch can be performed, from cloud to eye scene types, by selecting the cloud scene type of EYE during the override process.

Note that the original and user override values for the scene type are both stored in the history file for the storm being analyzed. The override values will be used, if the scene was manually changed for the specific history file record, in any history file listings or intensity estimate recalculations if previous record(s) is/are modified/inserted/deleted.

The capability to override the automatically determined storm center location has been disallowed since it defeats the purpose of executing the AODT in fully automatic mode (without manual intervention). Thus, the concurrent use of the OVER and AUTO keywords is not allowed, resulting in a runtime text error message and the disabling of the override capability for the analysis being performed.

6.) Remote Server Data Access

The AODT has the ability to utilize remotely stored and displayed McIDAS imagery. The AODT will assume the data is stored locally unless the keyword REMOTE is used. The REMOTE keyword utilizes two AODT environment arguments to describe the name and location of the data file being examined. These variables can be defined in the aodtENV file (Section 4C) or with two REMOTE keyword entries (Section 4A1).

If a remotely stored McIDAS image is investigated by the AODT, a subsection of the image displayed within the McIDAS image display window will be copied to the local machine. The McIDAS server dataset and position variables, defined with the ODTLSERVER and ODTLAREA AODT environment arguments, will be used to define the location and name where the image will be copied. The variable ODTLSERVER defines the ADDE *group/descriptor* name (or alias name) while ODTLAREA defines the *position* number within the *group/descriptor*. The size of the image copied will be 480x640 pixels and will be centered at the user-selected storm center position. An example output text message when using the REMOTE keyword follows :

```
DOWNLOADING REMOTE IMAGE EAST/NH.5 TO LOCAL IMAGE LOCAL/IMAGES.7777
  WITHIN LOCAL DIRECTORY AT /home/aodt-v6.3/mcidas/data/AREA7777
Utilizing image data file /home/aodt-v6.3/mcidas/data/AREA7777
```

In the example above, the AODT user was investigating a remotely stored image within the ADDE dataset name of “EAST/NH” at position “5”. It was copied to the local server defined with the ADDE dataset name of “LOCAL/IMAGES” into position 7777. The local ADDE image in this example was located in the /home/aodt-v6.3/mcidas/data directory in the file AREA7777. The AODT algorithm then utilized this locally stored image in the derivation of the intensity estimate for the storm image being examined.

7.) ATCF Record Output

An ATCF Fix File format record can be produced for each individual intensity estimate using the ATCF keyword. The output file location will be automatically determined using the ODTOUTPUT environmental variable. The file name will also be automatically determined using the date and time information of the image being investigated. See Section 4A2 for more information about the file naming structure.

If an ATCF file is produced, an information message will be displayed at the end of the intensity bulletin indicating the location and name of the file created :

```
WROTE ATCF OUTPUT TO FILE home/odt/output/CIMSS_AODT_199909102115_08_FIX
```


The text output displays time, date, all intensity values (CI# with corresponding adjusted MSLP and wind values, Final T#s (both 6 and 3 hour averaged values), and the Adjusted and Initial/Unadjusted Raw T# values), T#/CI# constraint and weakening rules, eye and cloud region temperatures, scene type, estimated radius of maximum wind value, storm position, and storm center fix method (manual or automated technique). Any comments that have been entered will be displayed at the end of each history file entry.

If an external ASCII output file is desired, the AODT keyword command "OUTPUT=FILE <filename>" is used. The directory location where the output text file is written is defined with the AODT environment argument ODTOUTPUT. For example, an output file defined as "listing.txt" will produce the following output message :

History file listing written to ASCII file /home/odt/output/listing.txt

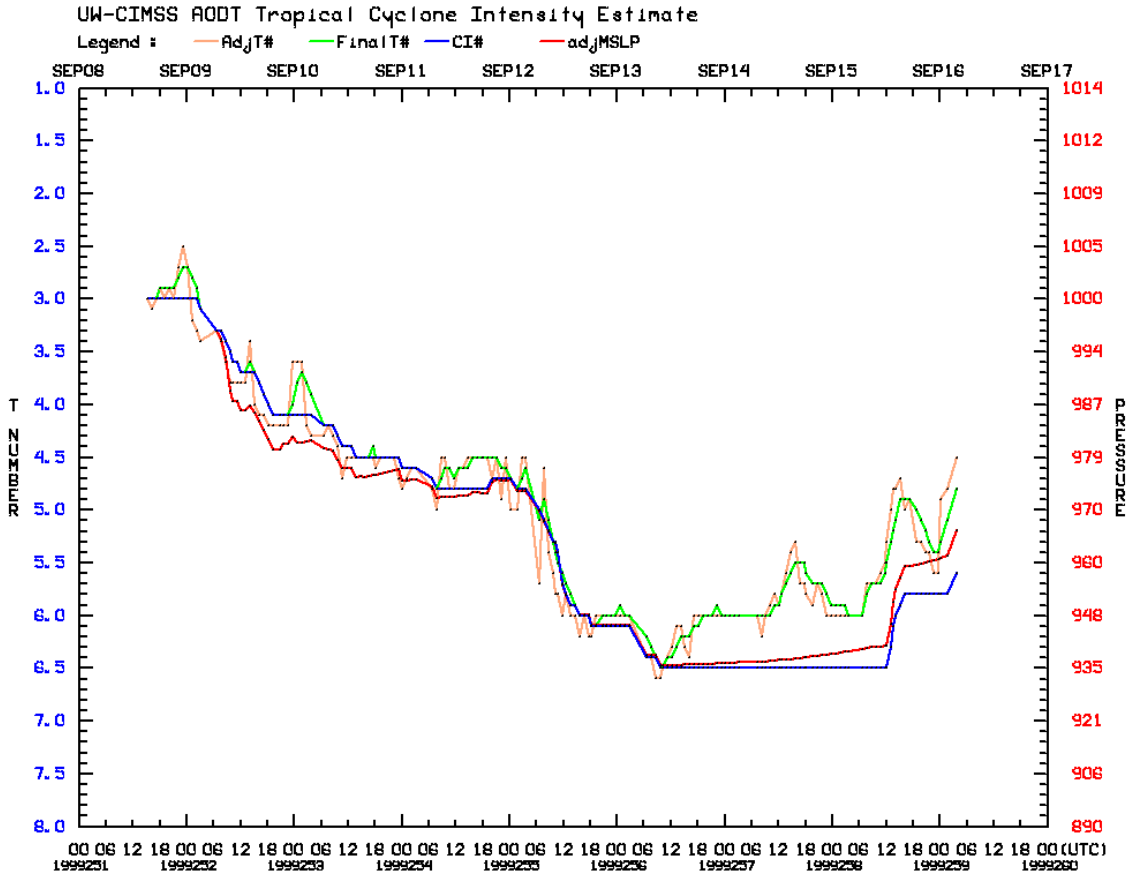
b.) ATCF Format Listing

Any or all records a history file can be displayed in ATCF format using the ATCF keyword in conjunction with the LIST command. The output will be displayed in the text output window unless specifically requested to be stored in an output file using the OUTPUT keyword. A sample ATCF format file is displayed below :

```
==== AODT-Version 6.4.2 =====
AL, 08, 199909081515, 20, DVTO, , CI, , 1581N, 5006W, , 3, 45, 2, 1000, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 30, 2, 30, 6, T, 30, -158, -276, SHER, , GOESS, T,
AL, 08, 199909081615, 20, DVTO, , CI, , 1585N, 5027W, , 3, 45, 2, 1000, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 30, 2, 30, 6, T, 31, -61, -288, SHER, R8, GOESS, T,
AL, 08, 199909081715, 20, DVTO, , CI, , 1590N, 5050W, , 2, 45, 2, 1000, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 30, 2, 30, 6, T, 30, -55, -338, ICDO, R8, GOESS, T,
AL, 08, 199909081815, 20, DVTO, , CI, , 1596N, 5072W, , 2, 45, 2, 1000, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 30, 2, 29, 6, T, 29, -199, -365, ICDO, R8, GOESS, T,
AL, 08, 199909081915, 20, DVTO, , CI, , 1602N, 5095W, , 3, 45, 2, 1000, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 30, 2, 29, 6, T, 30, -415, -340, CBND, , GOESS, T,
AL, 08, 199909082015, 20, DVTO, , CI, , 1606N, 5118W, , 2, 45, 2, 1000, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 30, 2, 29, 6, T, 29, -293, -354, ICDO, R8, GOESS, T,
AL, 08, 199909082115, 20, DVTO, , CI, , 1662N, 5175W, , 3, 45, 2, 1000, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 30, 2, 29, 6, T, 30, -349, -451, CBND, R8, GOESS, T,
<records deleted from listing>
AL, 08, 199909101445, 20, DVTO, , CI, , 1956N, 5963W, , 2, 77, 2, 975, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 45, 2, 45, 6, T, 45, -651, -685, CDO, , GOESS, T,
AL, 08, 199909101545, 20, DVTO, , CI, , 1950N, 5947W, , 2, 77, 2, 975, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 45, 2, 45, 6, T, 45, -601, -648, EMBC, , GOESS, T,
AL, 08, 199909101645, 20, DVTO, , CI, , 1965N, 6004W, , 2, 77, 2, 975, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 45, 2, 45, 6, T, 45, -655, -646, CDO, , GOESS, T,
AL, 08, 199909101745, 20, DVTO, , CI, , 1993N, 5988W, , 2, 77, 2, 975, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 45, 2, 44, 6, T, 45, -664, -656, CDO, , GOESS, T,
AL, 08, 199909101815, 20, DVTO, , CI, , 1986N, 5984W, , 2, 77, 2, 975, 2, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 45, 2, 45, 6, T, 46, -612, -658, EMBC, , GOESS, T,
<records deleted from listing>
AL, 08, 199909131015, 20, DVTO, , CI, , 2400N, 7105W, , 1, 127, 1, 935, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 65, 1, 65, 6, T, 65, 194, -704, EYE, , GOESS, T,
AL, 08, 199909131115, 20, DVTO, , CI, , 2404N, 7127W, , 1, 127, 1, 935, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 65, 1, 64, 6, T, 64, 191, -698, EYE, , GOESS, T,
AL, 08, 199909131215, 20, DVTO, , CI, , 2407N, 7151W, , 1, 127, 1, 935, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 65, 1, 64, 6, T, 63, 194, -683, EYE, R9, GOESS, T,
AL, 08, 199909131315, 20, DVTO, , CI, , 2412N, 7173W, , 1, 127, 1, 935, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 65, 1, 63, 6, T, 61, 191, -658, EYE, R9, GOESS, T,
AL, 08, 199909131415, 20, DVTO, , CI, , 2417N, 7194W, , 1, 127, 1, 935, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 65, 1, 62, 6, T, 61, 187, -654, EYE, R9, GOESS, T,
<records deleted from listing>
AL, 08, 199909152245, 20, DVTO, , CI, , 3179N, 7841W, , 1, 109, 1, 960, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 58, 1, 54, 6, T, 56, 28, -607, EYE, R9, GOESS, T,
AL, 08, 199909152345, 20, DVTO, , CI, , 3209N, 7837W, , 1, 109, 1, 960, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 58, 1, 54, 6, T, 56, 20, -602, EYE, R9, GOESS, T,
AL, 08, 199909160015, 20, DVTO, , CI, , 3234N, 7833W, , 1, 109, 1, 960, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 58, 1, 53, 6, T, 49, -77, -608, EYE, R9, GOESS, T,
AL, 08, 199909160145, 20, DVTO, , CI, , 3279N, 7826W, , 1, 109, 1, 961, 1, DVRK, , , , , , , , , , , , , , , , ,
, , NHC, AUT, I, 58, 1, 51, 6, T, 48, -72, -602, EYE, R9, GOESS, T,
Utilizing history file /home/odt/output/FLOYD.ODT
Successfully completed listing
```

2.) Graphical Output

A time series graph of intensity estimates and environmental temperature values stored within history files can be displayed within the McIDAS image/graphics window. Graphic capabilities are controlled using the AODT keywords GRAPH, PLOT, and DATE. Below is an example :



18

In the example above, the CI#, 6-hour time-weighted average Final T# (FinalT#), Adjusted Raw T# (AdjT#), and the latitude bias-adjusted MSLP value (adjMSLP) are all displayed. Any combination of the seven intensity estimate values can be plotted using the PLOT keyword (Section 4A1).

The intensity estimate values are plotted along the ordinate; CI#/T# values along the left hand side and corresponding pressure/wind values along the right side. Time is plotted along the abscissa, with Julian date and time (UTC) displayed at the bottom and the corresponding calendar day (month and day) plotted along the top of the graph. Any portion of the history file can be plotted using the DATE keyword. The legend of the displayed variables presented along the top of the graphics window. The various environmental temperature values calculated and used by the AODT in the intensity estimate calculations can also be graphed.

5.) Background Information

A.) Land Flag

Tropical cyclone land interaction is determined utilizing the low-resolution topography map TOPOLRES provided. The resolution of the map file is 1.0° X 1.0° latitude/longitude. If the storm center is positioned over a grid box with an average height greater than sea level (and more than 50% covered by land), the land flag will be triggered. If the land flag is triggered, no intensity estimate will be produced unless specifically requested by the user using the LAND keyword. The history file will still include an entry for any intensity estimate attempted while over land. The latitude, longitude, and land flag parameters will contain their assigned values, however the values for the intensity estimates and the remaining parameters will be assigned a “missing value” (mostly 0’s). Calculation of both Final T# values and the CI# value will exclude all “over land” entries once the storm resumes movement over open water (non-land grid points).

B.) Scene Classification

Objective scene identification is performed using Fast Fourier Transform (FFT) analysis, 10° log spiral analysis, and/or other statistical analysis techniques. Scene classifications are performed separately for the eye (0-24km from storm center) and surround cloud (24-136km) regions. Determinations of certain scene types are dependent upon past intensity estimates stored in the history file of a particular storm, closely mirroring the thresholds defined in the subjective Dvorak EIR technique. The six eye region scene types and five cloud region scene types are described below :

Eye Region

<u>Scene Type</u>	<u>Description</u>
CLEAR	Clear, well-defined eye
PINHOLE	Very small eye/pronounced warm spot
LARGE CLEAR	Clear, well-defined eye greater than 40 km diameter
LARGE RAGGED	Ill-defined eye region greater than 40 km diameter
RAGGED	Ill-defined (cloudy or oblong) eye region
OBSCURED	Very cloudy/cloud covered warm region
NONE	No eye

Cloud Region

<u>Scene Type</u>	<u>Description</u>
UNIFORM CDO	Overcast cloud region with uniform temperature structure
EMBEDDED CENTER	Arc of convection within central overcast cloud region
IRREGULAR CDO	Cloud region over storm center, but large shift in coverage
CURVED BAND	Curved cloud region surrounding circulation center
SHEAR	Displaced convection and exposed circulation center

Eye scene types are derived by examining the eye region FFT harmonics, variability of temperature values in the eye region, and “BD enhancement curve” categorical differences between the eye and surrounding cloud region temperature values. Eye size is derived by measuring the distance across the eye between BD-curve “Dark Gray” temperature range edges. Distances are measured at 90° angles outward from the manual/auto-selected center location and are averaged to give an approximate eye size.

Cloud region scene types are determined by examination of the entire cloud region FFT harmonics, the average difference between opposing 15° arc average temperatures (convective symmetry value), and by differencing the average and “coldest-warmest” cloud region temperature values. If the cloud scene is thought to be a “Curved Band” type scene, a 10° Log Spiral analysis will be performed to determine the curvature extent of the convective cloud region around the selected center position. The algorithm will first target the BD-curve “Light Gray” temperature range to define the convective region of the curved band area. If this temperature region is devoid of significant activity/completely surrounds the selected storm center position, analysis of warmer/colder ranges BD-curve temperature levels will be performed. Once a Curved Band scene is determined, an additional search will be performed to look for a location that yields a greater amount of curvature in the cloud region, and thus a higher intensity estimate (Section 5I). If the scene is determined to be a “Shear” scene, the distance between the center position and the closest BD-curve “Dark Gray” temperature range pixel will be determined.

Once the scene type has been automatically or manually determined, the value is used in conjunction with the eye and surrounding cloud top temperatures, oceanic basin type, and other history file information to calculate the intensity estimate for the image being investigated.

C.) Eye and Surrounding Cloud Region Temperature Determination

Proper determination of the storm center is paramount for an accurate storm intensity estimate since the eye and cloud region temperature value calculations are heavily dependent on this location.

Determination of the eye region temperature is straightforward. This temperature is assigned the value of the warmest pixel within a 24 km radius from the user or automated storm center location. Since an incorrect eye temperature can lead to an incorrect intensity estimate, proper selection of the storm center location is essential.

Calculations of the two surrounding cloud region temperature values are a bit more complicated than for the eye temperature. The first cloud region temperature value computed is centered at the storm center location and lies between 24 and 136 km from the center location. Individual analysis rings are selected, and are dependent upon the resolution of the satellite imagery. Thus for a 4 km resolution infrared image, there will be $(136 - 24)/4 = 28$ rings. On each ring the warmest temperature will be found. The

coldest of these values will be used as the cloud top temperature value. This value is referred to as the “coldest-warmest” temperature, and it is used only in the determination process for the cloud region scene type. The ring number (CWRN) distance (in km from the storm center location) on which the “coldest-warmest” temperature value is located is used in the determination of the “mean” cloud region temperature discussed below. For more information about this value, see Velden et al. (1998) and Zehr (1989).

The second cloud region temperature computed is the “mean” cloud region temperature value, and is the actual value that is assigned as the cloud region temperature. First, an annulus region is determined around the storm center location. The annulus will be a total of 80 km wide and is centered on the CWRN distance explained above. The minimum inner/maximum outer radius of the annulus will be the CWRN distance minus/plus 40 km. The minimum inner radius cannot be less than 24 km from the storm center location, but there is no maximum limit on the outer radius distance. For example, if the CWRN distance is 48 km, the inner distance will be a minimum of 24 km (not 8 km), and the outer distance will be 104km. Once the annulus is defined, it is divided into 24 arc regions (15° each) and the average temperature of each arc is calculated. The average of the 24 average arc temperature values is computed and assigned to the “mean” cloud region temperature value.

The “coldest-warmest” temperature value was replaced with the “mean” temperature value after close examination of both values, and their respective Raw T# intensity values, in relation to aircraft reconnaissance intensity measurements. The “coldest-warmest” temperature value varied significantly more than the “mean” values, and their corresponding intensity estimates. The intensity estimate values computed using the coldest-warmest temperature values were found to be inferior to the intensity estimates using the mean temperature values, thus the change was implemented.

D.) Time Averaging Scheme

The Final T# (6-hour average) value is calculated using a linear-weighted time averaging scheme, which places greater weight on the current intensity estimate value and less weight upon each preceding intensity estimate. The time averaging scheme uses the current Raw T# value and all available Raw T# values obtained within the last 6 hours. The current value is given a weight of 6.0, with all other values given weights directly proportional to their time difference from the current analysis time.

Determination of the time-weighted Final T# value previously utilized a 12-hour time period, but it was found that by changing the analysis period to 6 hours coupled with the use of the Dvorak EIR Rule 8 (see Section 5F) provided a statistically superior intensity estimate. In addition, utilizing a 6-hour time averaging period eliminates the need for the Rapid Deepening flag and corresponding time-averaging period change (from 12 hours to 3 hours). The rapid deepening flag had been a documented source of error in the analysis of some tropical cyclones where it had been (incorrectly?) triggered.

E.) Weakening Flag (Dvorak EIR Rule 9)

The AODT Weakening Flag is modeled after the Dvorak EIR Rule 9 (Dvorak, 1984). This rule is used in the determination of the CI# after a storm has reached its maximum intensity and is weakening. The EIR Rule 9 will hold the CI# at values 0.5 to 1.0 higher in value than the current Final T#. Subjective application of this rule (e.g. how and when to apply it) varies between forecasters and is the focal point of much debate. The value of 1.0 is utilized in the AODT since it provides the most statistically accurate estimates of storm intensity when compared with reconnaissance pressure measurements.

In the AODT algorithm the Weakening Flag is a merger of two separate Dvorak EIR “weakening event” rules, one that is specifically defined within the EIR Rule 9 and a second defined via personal communication with several tropical cyclone forecasters.

The first AODT Weakening Flag rule is performed when the storm has undergone a “significant strengthening event” and begins to weaken. A significant strengthening event is identified by computing a least squares fit to the current and all Final T# values during the past 24. If the slope of this fit is greater than or equal to 1.0 (increasing 1.0 T# in the last 24 hours), a significant strengthening event is said to be occurring. Once the Final T# (6-hour average) begins to decrease, the Dvorak EIR Rule 9 guidelines are applied to calculate the CI#. The Weakening Flag in the intensity bulletin will indicate that this rule is being applied by the flag value “ON”. A constant value of 1.0 is added to the Final T# value to obtain the CI# until the storm begins to strengthen again, the storm dissipates, or the storm encounters a land feature for more than 12 hours consecutively. The CI# cannot be more than the maximum Final T# value obtained prior to the onset of the weakening cycle. The CI# will then be held at a value of 1.0 greater than the Final T# during weakening. If the Final T# begins to increase again, the CI# will be held constant until the Final T# is equal to the CI# or the Final T# becomes less than the CI# by 1.0.

For example, if the Final T# reached a maximum intensity of 6.8 and then begins to decrease, the CI# will be held at 6.8 until the Final T# falls below 5.8. If the Final T# is 5.4 the corresponding CI# will be 6.4. If the Final T# begins to increase after reaching a “minimum” of 5.4, the CI# will be held at 6.4 until the Final T# either becomes greater than 6.4 (the CI# and Final T# will increase in tandem) or once again becomes less than 5.4 (The CI# will again be held at a value 1.0 greater than the Final T#).

The second AODT Weakening Flag rule affects the calculation of the Final T# and CI# during weakening prior to a “significant strengthening event” being noted (e.g. during the formation stages). This rule is as follows: “Always hold the CI# to the highest Final T# in the last 12 hours (but never greater than 1.0 for the CI#) in all cases”. This rule will hold the CI# equal to the highest Final T# (6-hour averaged) obtained during the previous 12 hours. For example, if the Final T# value obtains a value of 5.2 then decreases, the CI# value will be held at 5.2 until the T# falls below 5.2. The “Weakening” flag indicator in intensity estimate bulletin (Section 4D1) will display either “WEAK” or “ON” depending on which weakening rule is being applied.

F.) Constraint Limits (Dvorak EIR Rule 8)

The AODT Constraint Limits is a modification of the Dvorak EIR Rule 8 which constrains the rate of increase or decrease of the Raw T# intensity estimate value based upon specified rates of change over specific time periods. The rate of change comparisons are performed against the Final T# (6-hour average) values stored in the history file at various times prior to the current analysis time, with the rate of change constraints being dependent upon the “current” intensity of the storm, as defined in the Dvorak EIR technique. The Final T# (6-hour average) value of the record immediately prior to the current analysis time is used as a proxy for the “current” intensity estimate. When current intensity of the storm is less than 4.0, the current Raw T# rate of change cannot exceed ± 0.5 T# over 6 hours. If the current intensity estimate value is greater or equal to 4.0, the rate of change of the Raw T# value cannot exceed the following rates : 1.0 over 6 hours, 1.5 over 12 hours, 2.0 over 18 hours, and/or 2.5 over 24 hours.

The AODT employs a modified version of this rule based upon the current scene type analyzed. This modification was developed from extensive statistical analysis of AODT performance of over 3500 individual intensity estimates. The rate of change is constrained/increased by 0.5 during all scene types of non-shear/eye scenes for all time periods. For a non-shear/eye scenes (such as Curved Band, CDO, Embedded Center) the amount of change is limited to 0.5/1.0/1.5/2.0 T# over 6/12/18/24 hours, while for eye scenes the amount of allowed change is increased to 1.5/2.0/2.5/3.0 T# over 6/12/18/24 hours. The latter modification will allow the Final T#/CI# to increase at a quick enough and realistic rate during “rapid intensification” events. For shear scenes only, the rate of change rule is unmodified from the original Dvorak EIR Rule 8.

If one of the criteria is exceeded, the Adjusted Raw T# will be assigned the maximum/minimum value allowed by the criteria in question and will be used in the determination of the corresponding Final T#/CI# values. The unadjusted Raw T# value is also stored in the history file for reference.

As a final “gross error check” for the Raw T# values derived by the AODT, a supplementary Rule 8 rule has been added to the Constraint Limits listed above. This additional rule will limit the growth of the Raw T# value by 0.5 over 1 hour. Implementation of this rule was found to be necessary due to the inherent variability of the AODT during “scene type transitions”, especially between eye and non-eye cases. Due to the completely objective nature of the scene determination scheme, and the threshold values that are used to define the different scene types, changes between scene types can result in unrealistic jumps in Raw T# values from one intensity estimate to another. The addition of this rule will produce estimates that are reasonable when these types of scene changes occur, but still will allow the Raw T# values to change at a rate greater than observed in nature. The largest MSLP change we found in our test data set was with Hurricane Opal, which had a decrease in observed MSLP (from reconnaissance aircraft) of 17mb (933mb to 916mb) over about two and a half hours (07:20UTC to

09:45UTC). This corresponds to a change of about 0.6 T# (933mb \approx 6.6 T#; 916mb \approx 7.2 T#) in 2.5 hours, or approximately 0.25 T#/hour.

Implementation of this modified rule has allowed for the time-weighted Final T# calculation to be changed from 12 hours to 6 hours, with the 6-hour weighted average proving to be slightly more accurate statistically than the previous 12-hour methodology. By utilizing the 6-hour scheme, the rate of change of the time-weighted Final T# value is greater than with the 12-hour scheme, allowing for more rapid increase in intensity over time, especially in conjunction with the modified constraint limit rules for eye scenes, and has resulted in more realistic intensity changes and estimates over time.

G.) T# to MSLP Conversion Relationship Auto Determination

The AODT intensity estimates are presented in terms of T/CI#, mean sea level pressure (MSLP), and wind speed values. The pressure values are derived from one of two empirical conversions relating CI# to MSLP for the North Atlantic (Dvorak, 1984) and Northwest Pacific (Shewchuck and Weir, 1980) ocean basins. Also, proper determination of the initial Raw T# is dependent upon use of the correct storm basin conversion relationship. Thus, proper identification of the correct relationship to use is essential for conversion of T# to MSLP, especially outside of the Atlantic and West Pacific regions. The AODT can automatically determine the conversion method “basin” based upon the longitude value of the selected storm center location. A storm west of the international dateline (180° E/W) and east of the Prime Meridian (0° E/W) is designated as a Northwest Pacific storm (regardless of N/S hemisphere), with all other storms designated as an Atlantic storm. The user can override this automated determination process with the DOMAIN keyword if desired.

The division point in the Pacific Ocean was chosen to match the “areas of responsibility” for the Joint Typhoon Warning Center and Central Pacific Hurricane Center. Use of either CI#/pressure conversion in the Eastern Pacific Ocean is a topic for debate since specific rules defining the use of one of the conversions for this or other regions, such as Indian Ocean or Southern Pacific Ocean, have not been documented.

H.) Automatic Storm Center Determination and Input File Formats

The automated storm center location algorithm approximates tropical storm position using four methods : polynomial interpolation of NHC/JTWC forecasts, warmest pixel search, Laplacian Analysis of the cloud region temperature values, and linear extrapolation of the history file positions.

As a first guess, the forecast positions from NHC or JTWC are used in conjunction with previous storm locations in the polynomial interpolation routine. This routine interpolates the position at the time desired using three forecast positions (current, 12 hour, and 24 hour positions). The four types of input file formats are :

- ATCF Forecast Record file (“OFCL” forecast is default)
- NHC Tropical Storm/Hurricane Discussion files (WTNT4? or WTPZ4?)
- JTWC Tropical Cyclone Warning files (WTPN3?)
- Generic Entry file (see below for format)

Each line in the Generic Entry file contains either the initial/current position of the storm or a forecast position at 12-hours or 24-hours, and are formatted as follows :

dd mm yyyy tttt aa.a bbb.b

<u>parameter</u>	<u>value</u>	<u>format</u>
dd	date	two digit integer
mm	month	two digit integer
yyyy	year	four digit integer
tttt	UTC time	HHMM format : HH-hour MM-minute
aa.a	latitude	floating point (+/- : north/south)
bbb.b	longitude	floating point (+/- : west/east)

An example file for Floyd using the 12 September 1999/03:00UTC forecast product :

```
12 09 1999 0300 22.7 64.5
12 09 1999 1200 22.9 66.0
13 09 1999 0000 23.2 68.3
```

The first line contains the “initial” position, with the second and third lines containing the 12-hour and 24-hour forecast positions. Use of a forecast file older than 24 hours will result in a failure with the auto-positioning routine.

If the forecast interpolation fails, a linear extrapolation of storm positions for the previous 12 hours (stored in the history file) is attempted. Once a valid interpolated forecast or extrapolated history file position is obtained, the Final T# intensity estimate of the record immediately preceding the current analysis time in the history file found. If this value is less than 3.5, the interpolated/extrapolated point is used as the final automated storm position. However, if this value is greater or equal to 3.5, a more thorough analysis of the image is conducted to determine a better storm center location.

The first two methods are new additions to the auto-centering scheme. The methods were developed at UW-CIMSS by Anthony Wimmers to aid in determining the storm center position when the previous AODT techniques were less reliable. These methods are quite labor intensive and may take a significant amount of time to complete, especially if the satellite image being investigated is not in a rectilinear projection and needs to be remapped to this projection internally before proceeding.

The first technique, the Spiral Centering routine, determines a center point in the image where there is a maximum alignment between the image gradient field and a 5-

degree log spiral vector emanating from the center point. This approach has the advantage of using the composition of the whole image instead of just the orientation of the spiral bands. Also, by using only the curvature of the image, the algorithm is not drawn to high-temperature “moats”, but rather uses their curved shape as a guide to the optimal center. The technique closely mimics the method used by experienced meteorologists to determine a center of rotation because it naturally assigns appropriate weights to the rotation-induced gradients of all sizes. However, the algorithm is quite sensitive to the effects of upper-level shear in IR imagery, leading to center estimates driven by patterns in the cirrus clouds rather than low-level clouds.

Further calculation beyond the Spiral Centering method is needed to resolve the exact center of rotation in storms with a well-defined eye. Although finding the eye of a storm is a simple task for the meteorologist to perform subjectively, it is made objectively and computationally difficult by partial obscurations and nearby, oddly shaped high-temperature moats. To address this issue the second technique is employed. The Eye Ring Fitting analysis method performs a search around the spiral center point for the most intense gradients in a small ring-shaped area defining the storm eyewall.

The third technique, the Laplacian analysis, targets those eye scenes where the eye may not be symmetrical and readily identified by the Eye Ring Fitting analysis scheme. This technique begins by searching for the warmest satellite image pixel within 75km of the forecast interpolated/history file extrapolated point. A Laplacian Analysis is then performed over a 90km radius analysis region, which identifies temperature gradients exceeding various threshold values. The gradient threshold fields are then statistically analyzed, with an empirically defined “confidence factor” derived based upon the scatter and cohesiveness of the gradient points for each of the thresholds.

Once all three analyses techniques have successfully completed, their derived center points and corresponding confidence factors are used to determine the “best” storm position for the scene being analyzed. If the previous Final T# intensity was between 3.5 and 4.5, the Spiral Centering and Eye Ring Analysis positions will be used if three or more eye or embedded center scene types have been identified for previous intensity estimates prior to the current analysis date/time. This will ensure that the storm organization is sufficient for the different techniques to work properly and correctly estimate the storm center location. If less than three eye/embedded center scenes have been found, only the Laplacian Analysis position will be examined for possible use. Once the Final T# value has exceeded 4.5, all of the three methods will be examined.

I.) Maximum Curved Band Location Search

If a Curved Band scene type has been determined automatically, or was selected manually during a scene override, an additional search will be performed to locate a storm center position possessing a greater cloud curvature measurement than obtained at the original selected storm center location. The search will examine the same BD-curve temperature range as obtained with the automatic scene type determination scheme. A 2°

latitude/longitude box, centered at the originally selected storm center location, will be examined at a 0.2° spacing between search points. At each search point, the 10° Log Spiral will be examined to determine the maximum arc length of the BD-curve temperature range being targeted. The spiral will then be rotated 15° and the measurement is performed again. Once the spiral has been rotated 360°, the spiral is moved to the next search point and the process is repeated. The search point possessing the maximum arc length measurement will then be shown in the intensity analysis output.

This feature was incorporated, in response to user feedback, due to the high degree of subjectivity inherent to the curved band analysis technique. It was added to provide an objectively determined location with the greatest curvature, however this location may or may not be the best location, due to limitations inherent to the technique. The storm center location produced by this method should be used as a suggestion, and should be examined closely to determine its applicability to the current scene analysis over the original storm center location.

J.) Sea Surface Temperature Information

The sea surface temperature (SST) information is used in conjunction with various parameters in the AODT history file in the determination of the TIE Model intensity estimate for the current scene being analyzed. Details on the usage of the SST values and the derivation of the TIE-Model intensity estimates are discussed in the TIE Model User's Guide, obtained at the following website:

<http://cimss.ssec.wisc.edu/tropic/aodt>

The SST data used for the TIE Model intensity estimate within the AODT package can be obtained from various FTP sites listed on the following website :

<http://polar.wwb.noaa.gov/sst/>

The SST files obtained from the above website are real-time, global, one-degree resolution GRIB format files (RTG_SST) distributed by the National Centers for Environmental Prediction/Marine Modeling and Analysis Branch (NCEP/MMAB). Significant detail on the derivation process for the RTG_SST files can also be found at the above website.

Once obtained, the SST files should be placed in the directory defined in the "aodtenv" file with the ODTSSST environmental variable. The name of the file to be used is obtained by the AODT algorithm using the SST keyword, as described in Section 4A1. If the SST file is available, the TIE Model intensity estimate will be appended to the end of the AODT intensity estimate bulletin after the first clear eye scene has been identified. An example of the TIE Model intensity estimate is shown in Section 4D1.

K.) Latitude Bias Adjustment

The MSLP value displayed in the AODT intensity estimate bulletin is adjusted using a linear regression-based adjustment equation. This equation is designed to eliminate a pronounced intensity estimate bias noted in the derived CI# value of the AODT and underlying Dvorak Technique. The equation used for this adjustment is:

$$CI\#_{adj} = CI\#_{orig} - (-20.60822 + (0.88463)*ABS(latitude))$$

This equation requires the CI#_{orig} value to be entered in units of pressure (millibars). Since the AODT produces estimates in terms of T# values, the CI#_{orig} value must be converted to millibars before the adjustment equation is applied. The pressure adjustment value is stored in a history file.

The latitude bias adjustment is only applied to scene types that utilize eye and cloud temperature values to determine the strength of the storm since the adjustment is related to tropopause height and the corresponding temperature changes associated with a higher/lower tropopause height. In order for the adjustment to be turned “on” six hours of continuous “EIR-type” scenes must be present. These types of scenes are CDO, embedded center, and eye scenes, while non-EIR scenes include shear, curved band, and irregular CDO. Once the criteria has been met, the lat-bias adjustment will be blended into use over the next six hours using a time-weighted multiplication factor with the determined latitude bias adjustment value.

For more specific information about the latitude bias adjustment, please refer to the following online document (Kossin and Velden, 2003) at :

http://www.ssec.wisc.edu/~kossin/articles/kossin_velden_MWR.pdf

L.) Estimate of Radius of Maximum Wind (RMW)

An estimate of RMW using geostationary IR data was derived using a simple linear regression analysis of cloud temperature fields and collocated reconnaissance aircraft radius of maximum wind measurements. If the derived AODT cloud top temperature is determined to be colder than -50°C , the distance from the storm center to the -45°C cloud top temperature isotherm is measured in four directions and averaged to produce a final distance measurement. The RMW location (in kilometers from the storm center position) is then determined from this distance using the equation :

$$RMW = 2.8068 + (0.8361*dist)$$

If the AODT derived cloud top temperature value is warmer than -50°C , the distance to the isotherm defined by the equation $(ERT + 2.0*CRT)/3.0$, where ERT is the eye temperature and CRT is the cloud top temperature, is used in the above equation to determine the RMW value.

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