# Using HYDRA2 to study new satellite data

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November 2015

# HYperspectral viewer for Development of Research Applications – HYDRA2

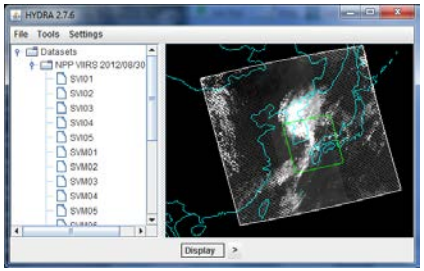
MODIS, AIRS, IASI, VIIRS, CrIS, ATMS

Freely available gui-driven software
For researchers and educators
Computer platform independent
Extendable to more sensors and applications
Uses Java-based technologies
Interactive, high-performance 2D/3D animations
derived from SSEC VisAD api
On-going development effort

Developed at CIMSS by
Tom Rink

With programming support from
Tommy Jasmin,
Ghansham Sangar (ISRO)

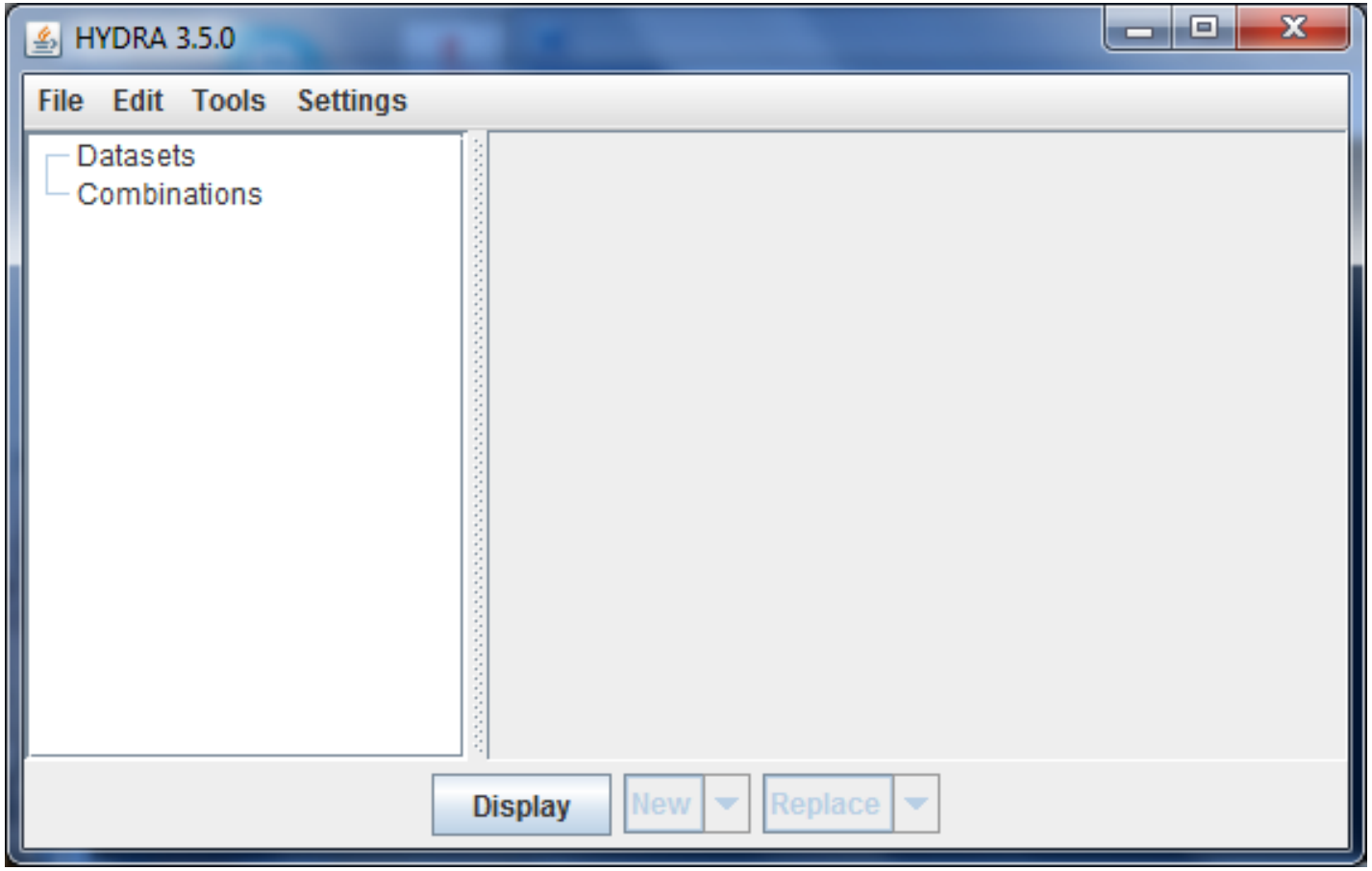
With guidance from
Liam Gumley
Kathy Strabala
Paul Menzel




CIMSS

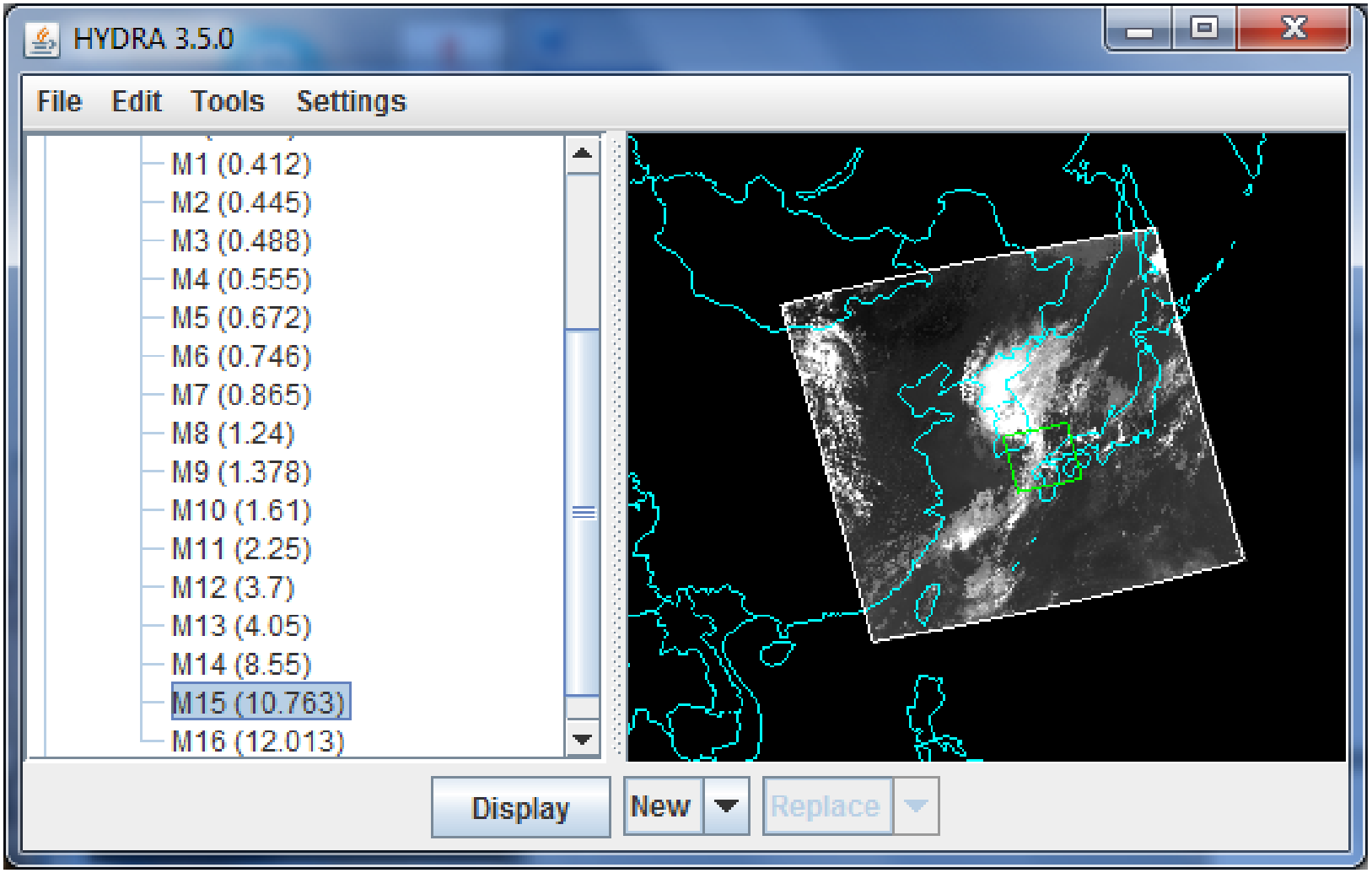
**ftp://ftp.ssec.wisc.edu/rink/HYDRA2**

# Opening HYDRA2




The installers for this release can be found at ftp://ftp.ssec.wisc.edu/rink/HYDRA2

# Selecting a File

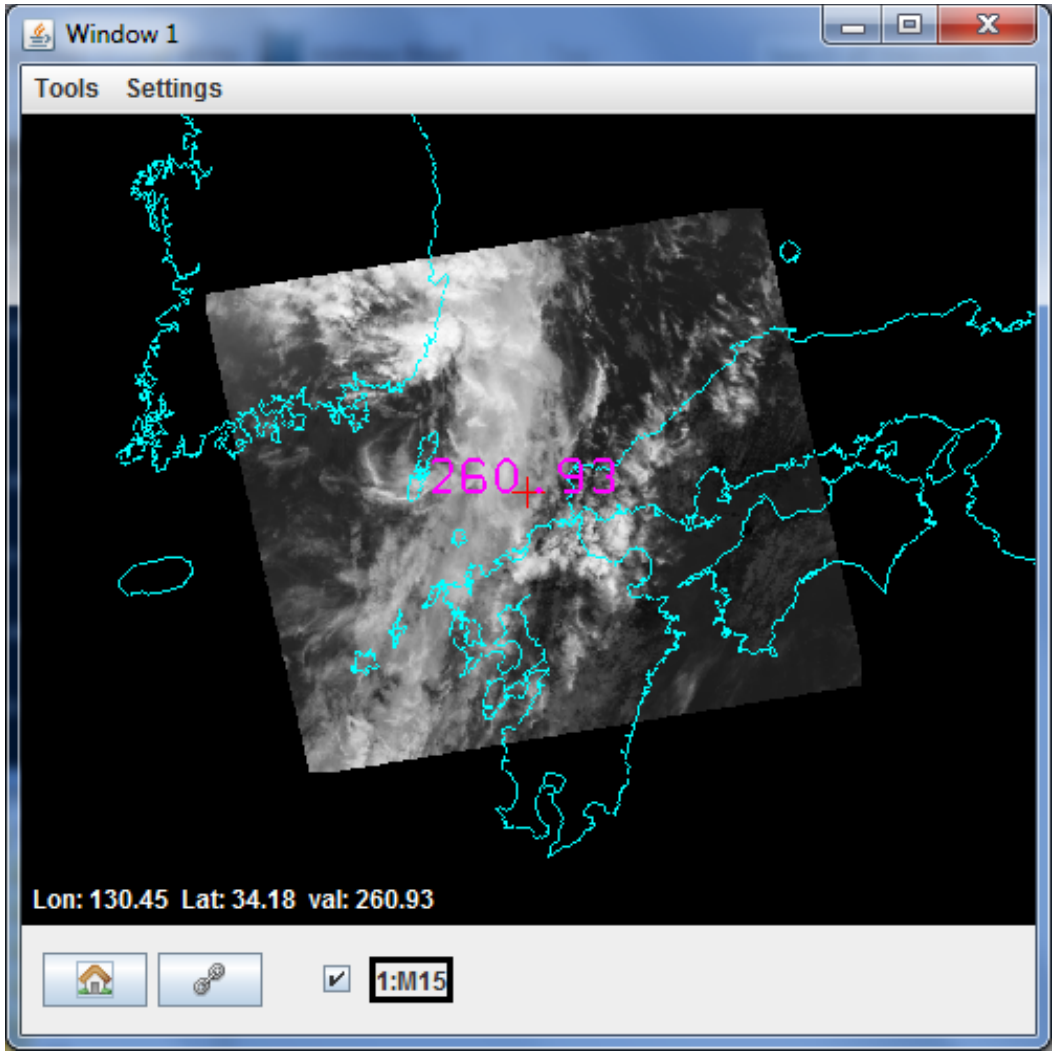


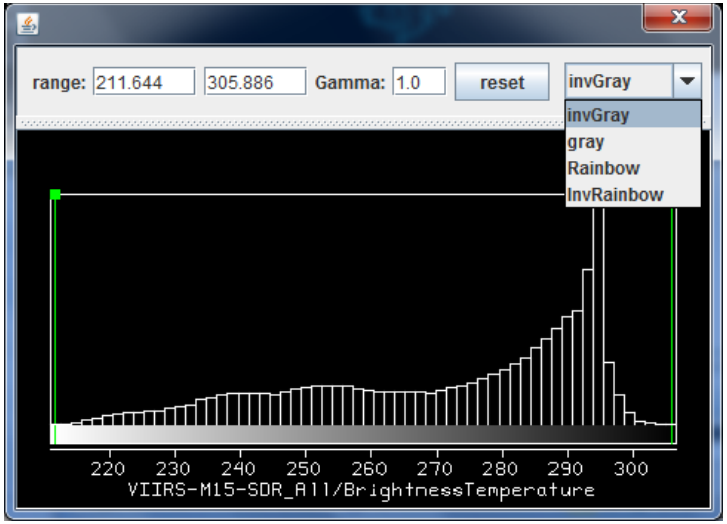
# VIIRS Examples

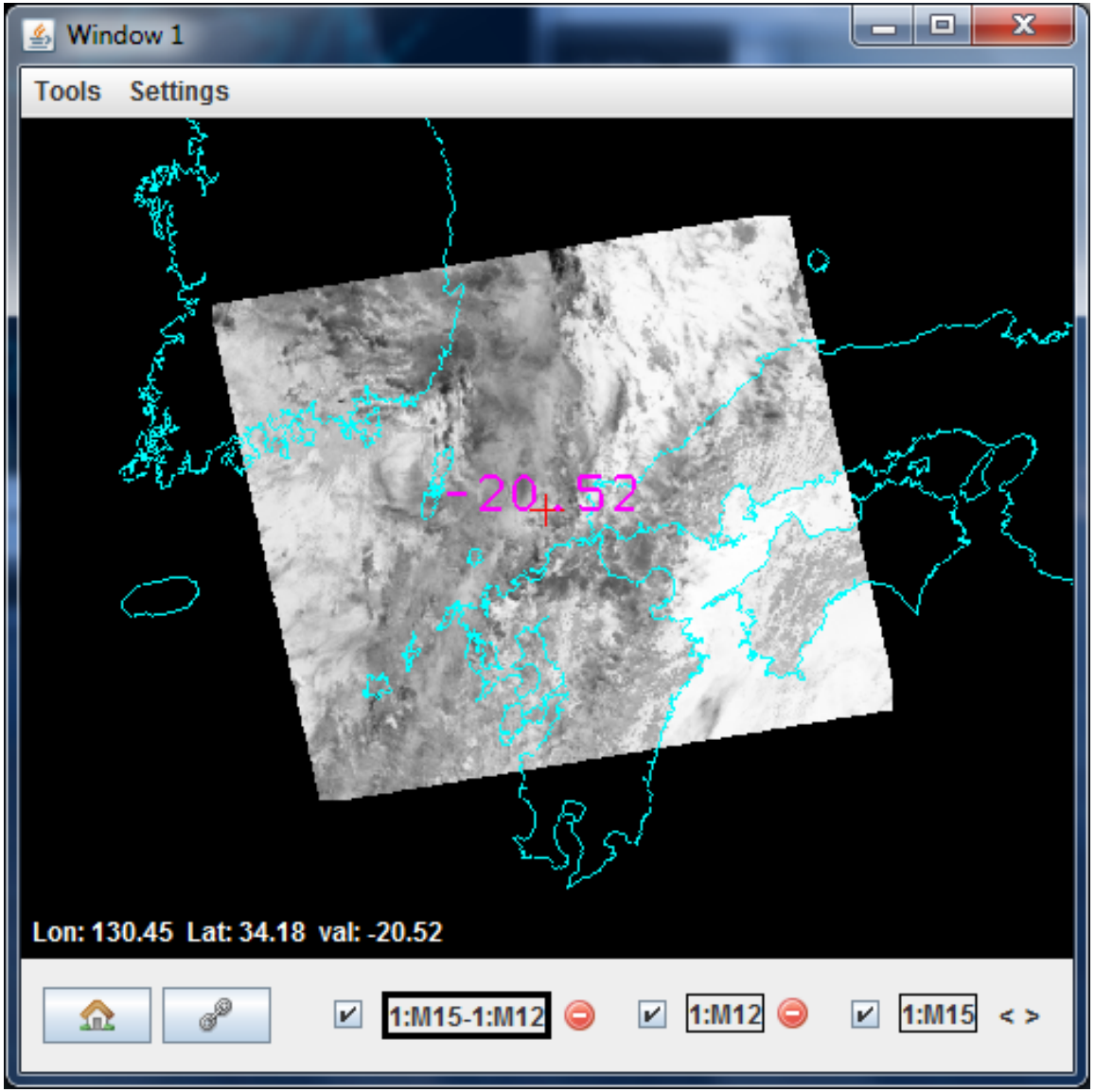
# VIIRS bands and bandwidths

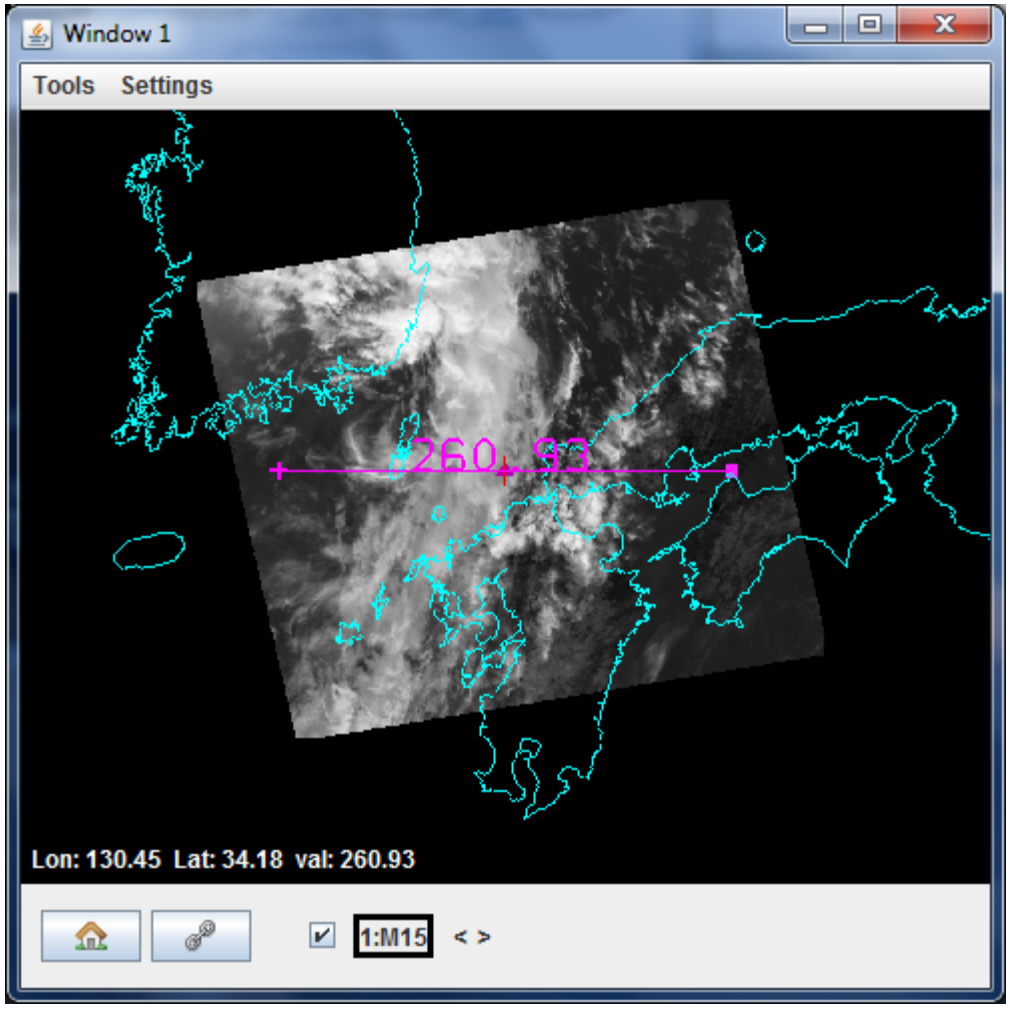
| VIIRS Band | Central Wavelength (µm) | Bandwidth (µm) | Wavelength Range (µm) | Band Explanation | Spatial Resolution (m) @ nadir |
|---|---|---|---|---|---|
| M1 | 0.412 | 0.02 | 0.402 - 0.422 | Visible/ Reflective | 750 m |
| M2 | 0.445 | 0.018 | 0.436 - 0.454 | | |
| M3 | 0.488 | 0.02 | 0.478 - 0.488 | | |
| M4 | 0.555 | 0.02 | 0.545 - 0.565 | | |
| M5 (B) | 0.672 | 0.02 | 0.662 - 0.682 | | |
| M6 | 0.746 | 0.015 | 0.739 - 0.754 | Near IR | |
| M7 (G) | 0.865 | 0.039 | 0.846 - 0.885 | | |
| M8 | 1.240 | 0.020 | 1.23 - 1.25 | Shortwave IR | |
| M9 | 1.378 | 0.015 | 1.371 - 1.386 | | |
| M10 (R) | 1.61 | 0.06 | 1.58 - 1.64 | | |
| M11 | 2.25 | 0.05 | 2.23 - 2.28 | | |
| M12 | 3.7 | 0.18 | 3.61 - 3.79 | Medium-wave IR | |
| M13 | 4.05 | 0.155 | 3.97 - 4.13 | | |
| M14 | 8.55 | 0.3 | 8.4 - 8.7 | Longwave IR | |
| M15 | 10.763 | 1.0 | 10.26 - 11.26 | | |
| M16 | 12.013 | 0.95 | 11.54 - 12.49 | | |
| DNB | 0.7 | 0.4 | 0.5 - 0.9 | Visible/ Reflective | 750 m across full scan |
| I1 (B) | 0.64 | 0.08 | 0.6 - 0.68 | Visible/ Reflective | 375 m |
| I2 (G) | 0.865 | 0.039 | 0.85 - 0.88 | Near IR | |
| I3 (R) | 1.61 | 0.06 | 1.58 - 1.64 | Shortwave IR | |
| I4 | 3.74 | 0.38 | 3.55 - 3.93 | Medium-wave IR | |
| I5 | 11.45 | 1.9 | 10.5 - 12.4 | Longwave IR | |

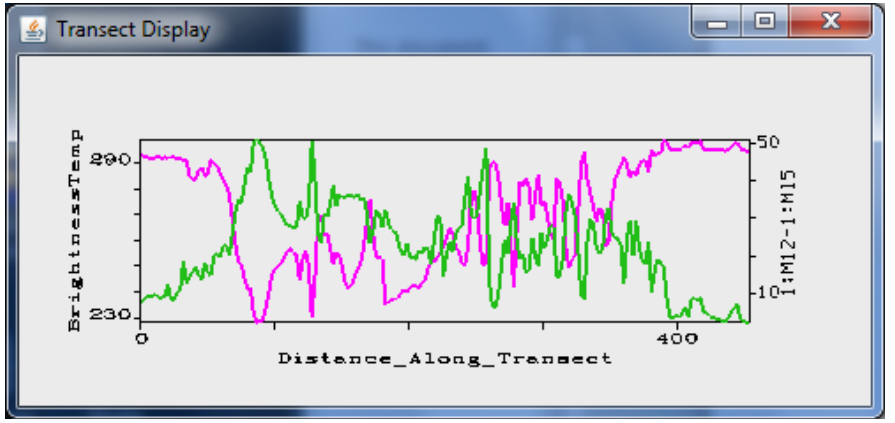
M = Moderate (750 m) resolution bands
I = Imagery (375 m) resolution bands
DNB = Day-Night Band (or Near Constant Contrast (NCC) band)

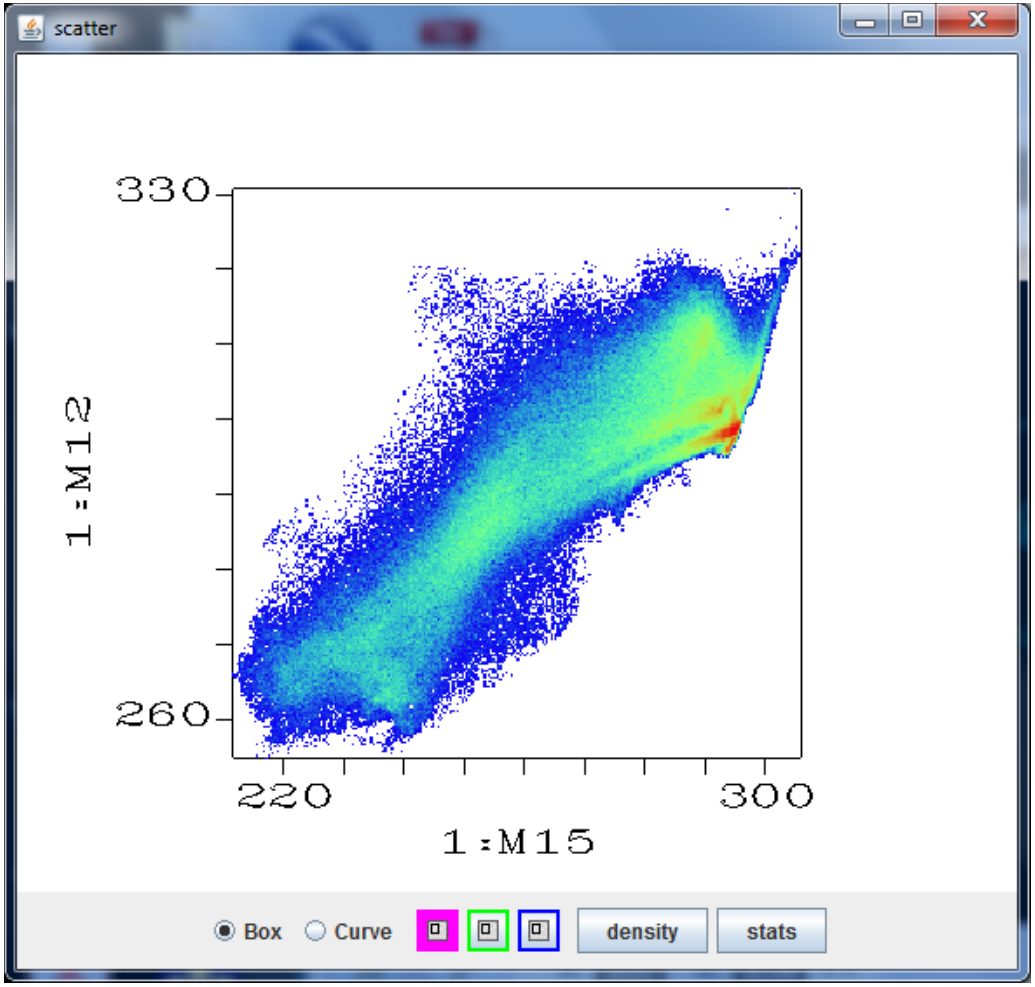

Window 1
Tools
Settings
260.93
Lon: 130.45 Lat: 34.18 val: 260.93
1:M15


range: 211.644
305.886
Gamma: 1.0
reset
invGray
invGray
gray
Rainbow
InvRainbow
220 230 240 250 260 270 280 290 300
VIIRS-M15-SDR_All/BrightnessTemperature


Window 1
Tools
Settings
-20.52
Lon: 130.45 Lat: 34.18 val: -20.52
1:M15-1:M12
1:M12
1:M15
< >

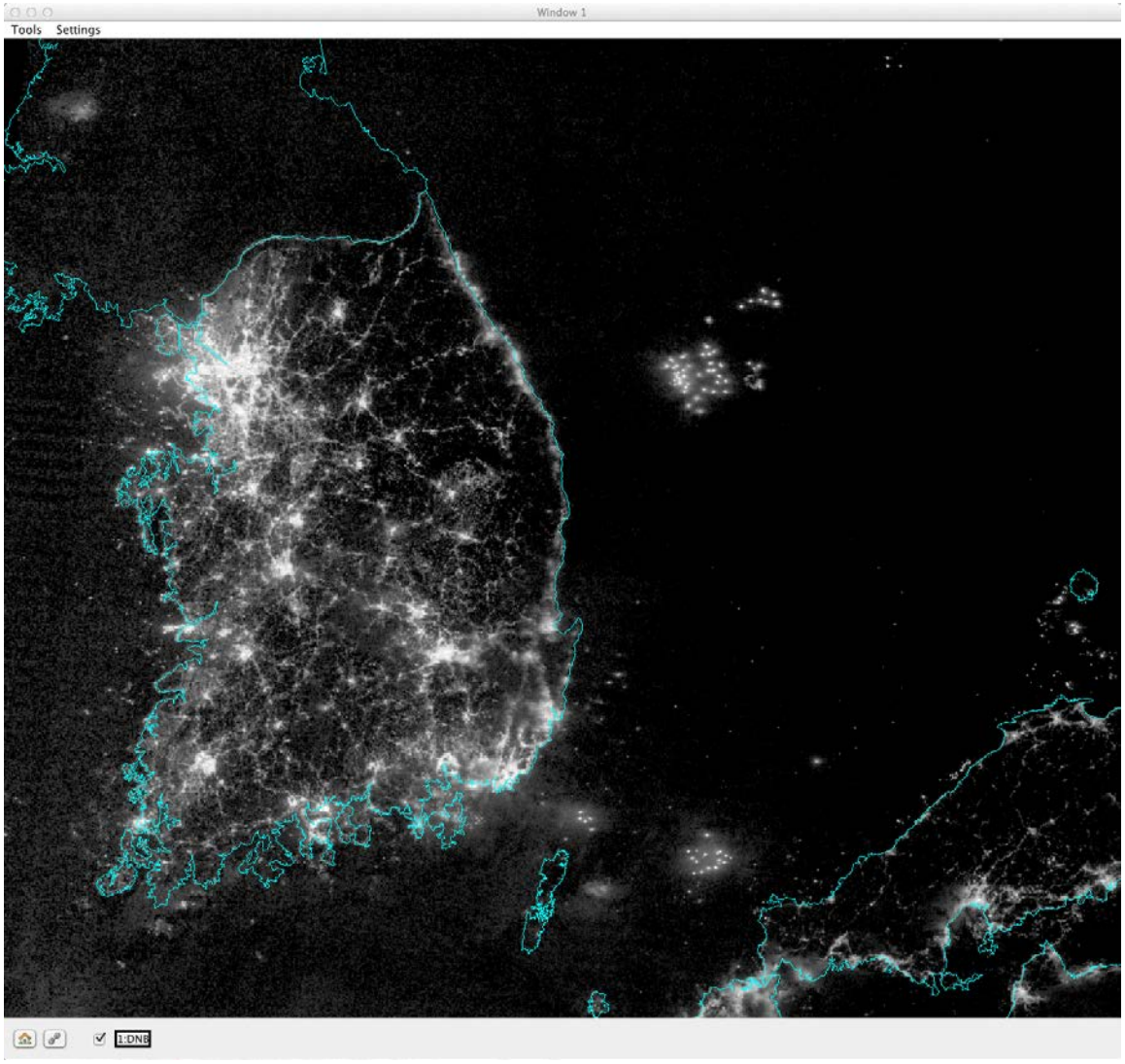

Window 1
Tools
Settings
260.93
Lon: 130.45 Lat: 34.18 val: 260.93
1:M15
< >

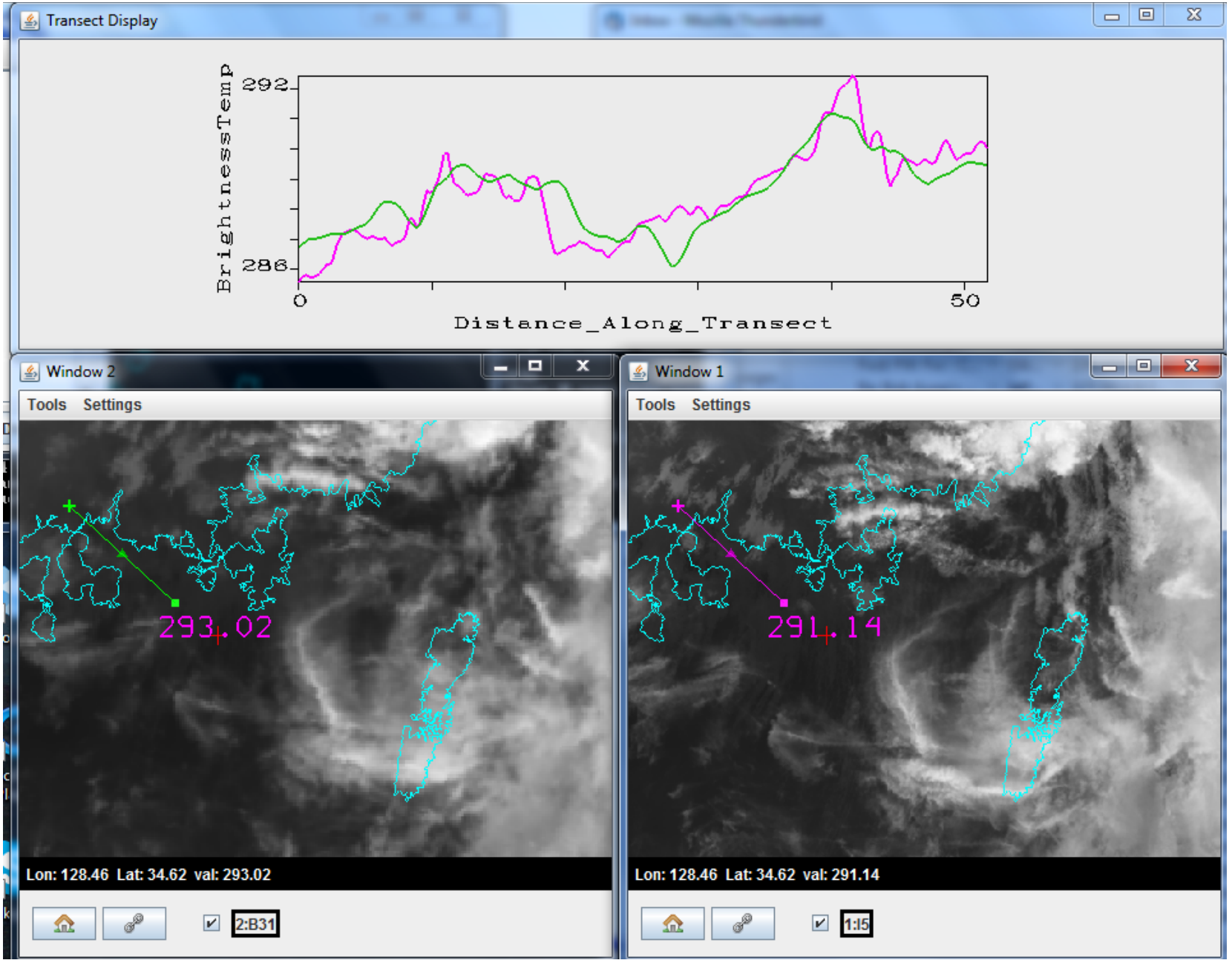

Transect Display
BrightnessTemp
290
230
0
400
Distance_Along_Transect
50
10
1:M12-1:M15

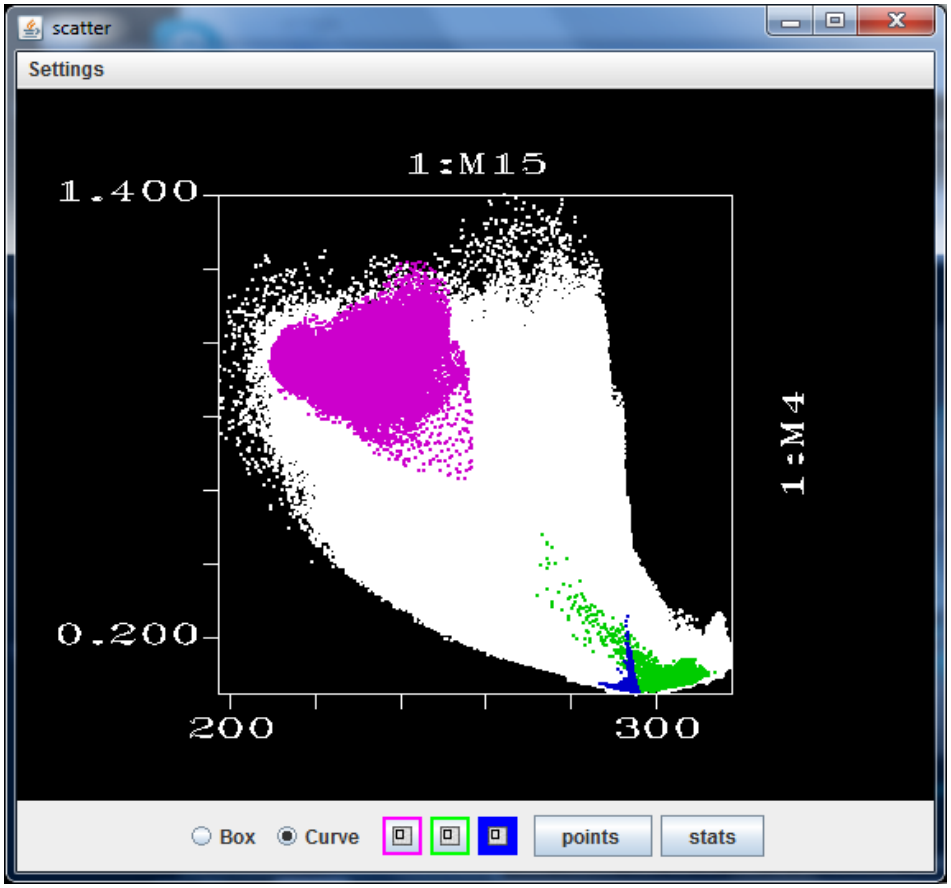


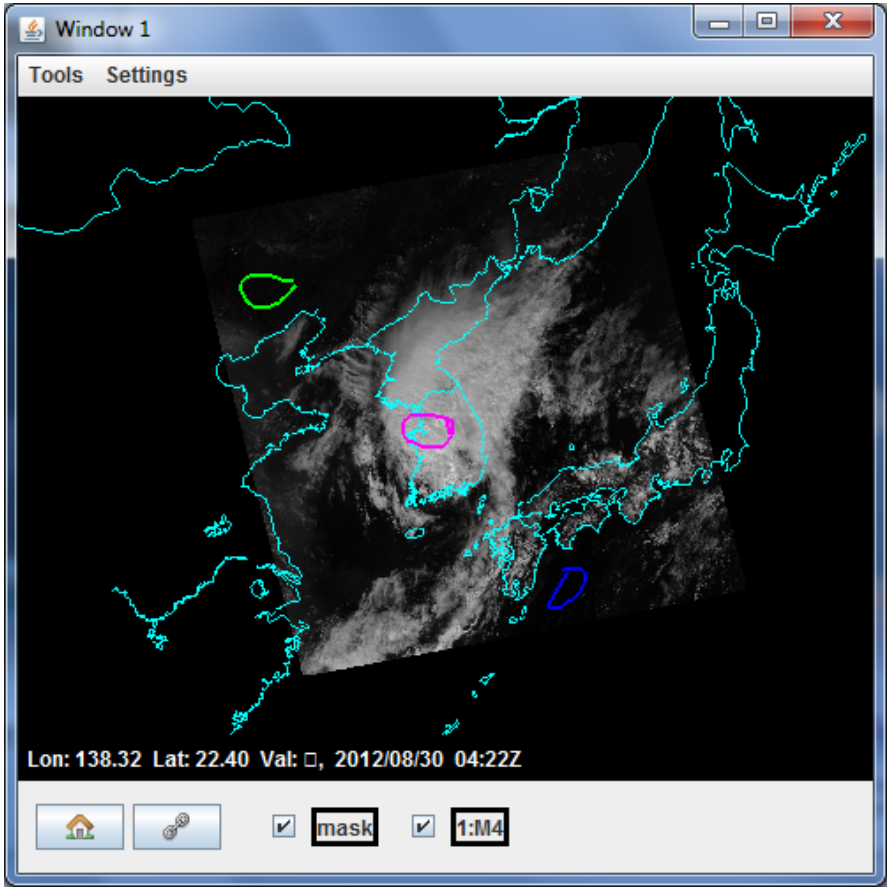

Scatter Statistics

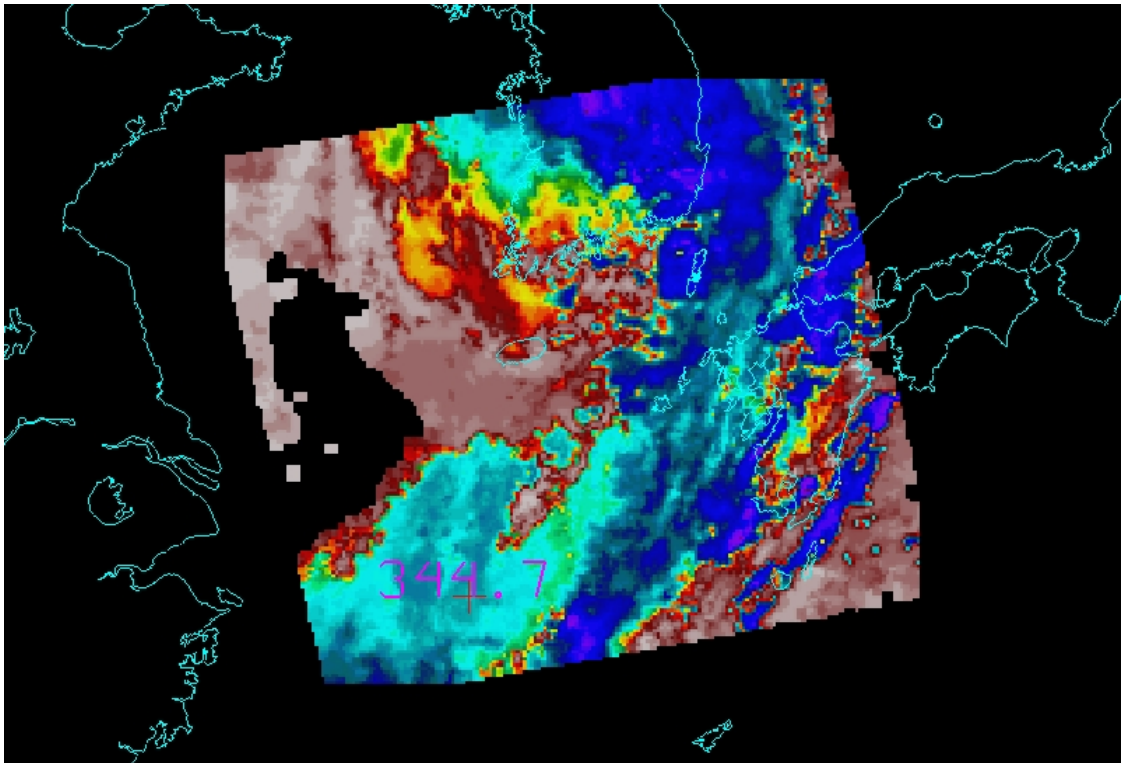
| Stats Parameter | NPP VIIRS 1:M15 2012/08/30 04:22Z | NPP VIIRS 1:M12 2012/08/30 04:22Z |
|---|---|---|
| Maximum | 305.89 | 330.77 |
| Minimum | 211.64 | 254.83 |
| Number of points | 592620 | 592620 |
| Mean | 272.28 | 294.40 |
| Median | 279.88 | 298.07 |
| Variance | 475.31 | 173.39 |
| Kurtosis | -0.71587 | -0.06323 |
| Std Dev | 21.80 | 13.17 |
| Correlation | 0.84746 | |
| Difference Maximum | -1.427 | |
| Difference Minimum | -78.91 | |
| Difference Mean | -22.11 | |
| Area [km^2] | | |

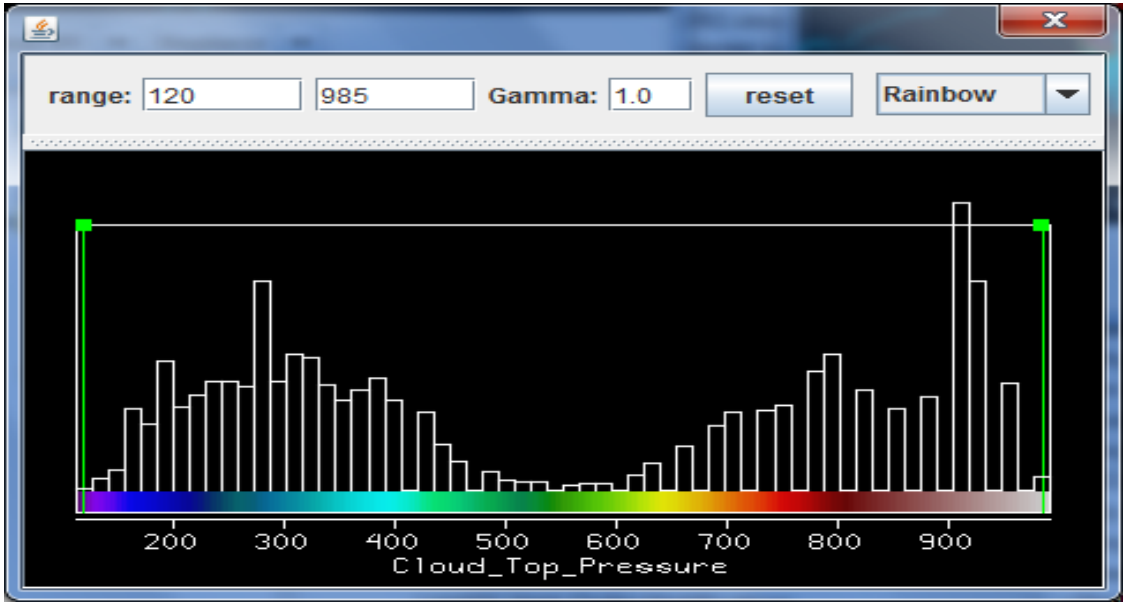

Window 1
Tools
Settings
1:DNB

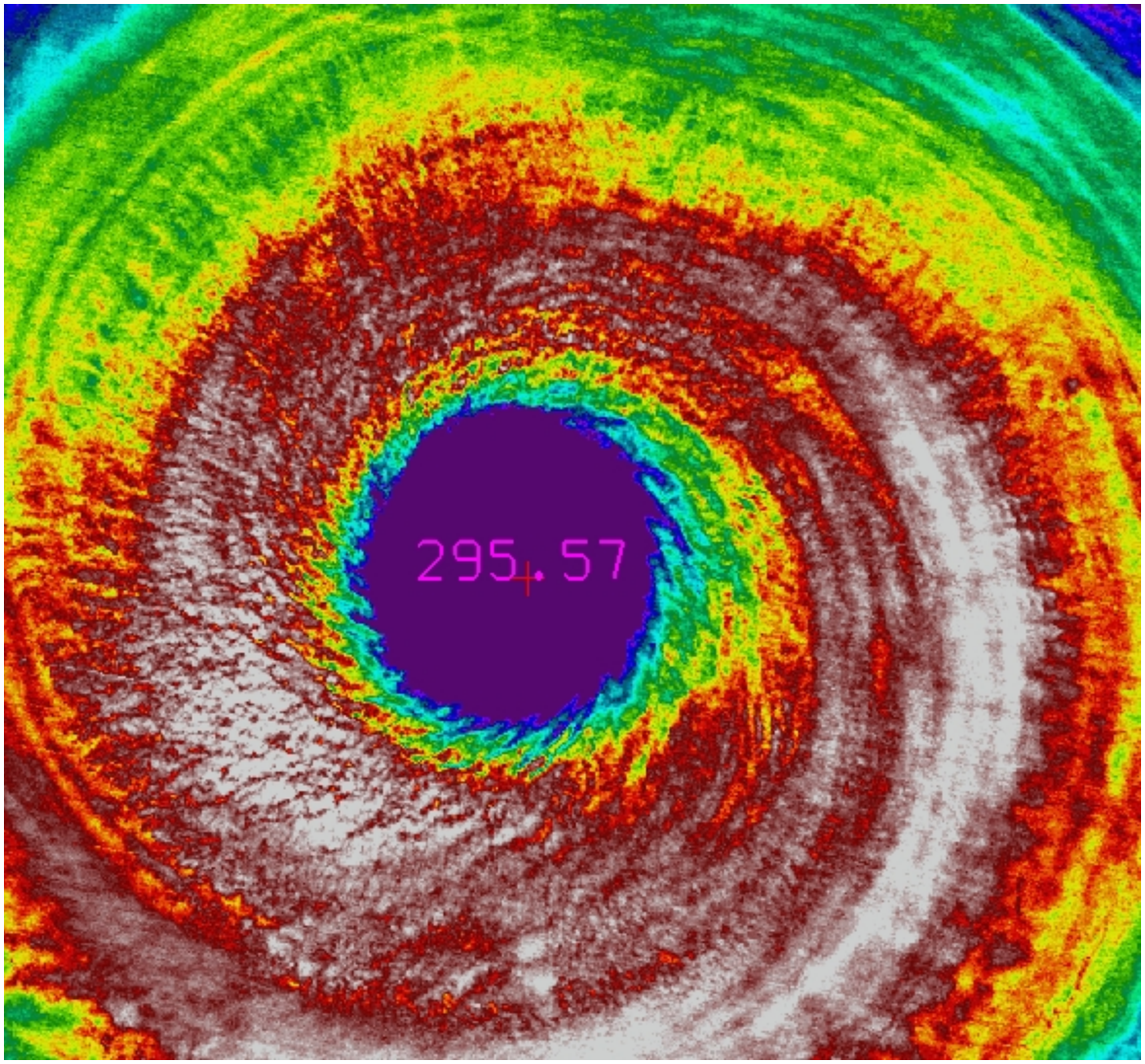

Transect Display
BrightnessTemp
292
286
0
50
Distance_Along_Transect
Window 2
Tools
Settings
293.02
Lon: 128.46 Lat: 34.62 val: 293.02
2:B31
Window 1
Tools
Settings
291.14
Lon: 128.46 Lat: 34.62 val: 291.14
1:15

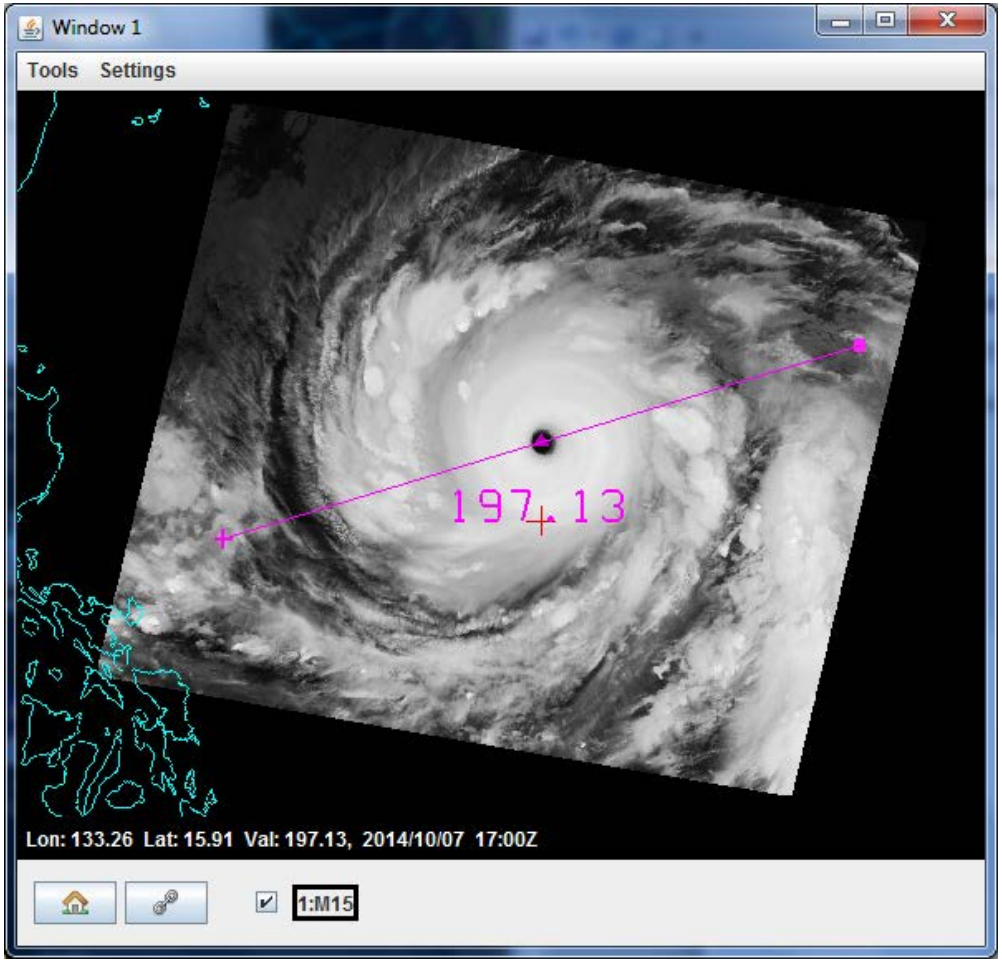

scatter
Settings
1:M15
1.400
0.200
200
300
1:M4
Box
Curve
points
stats

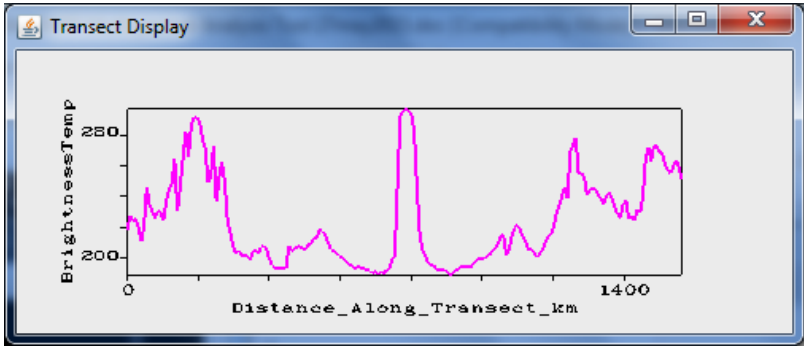

Window 1
Tools
Settings
Lon: 138.32 Lat: 22.40 Val: □, 2012/08/30 04:22Z
mask
1:M4

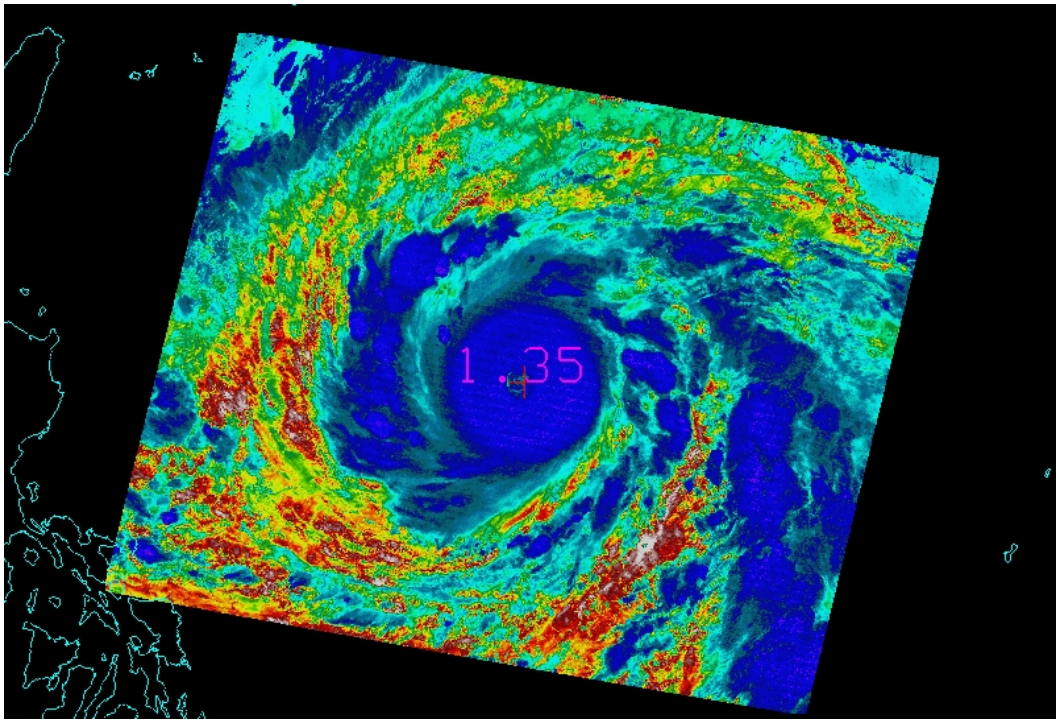

344.7

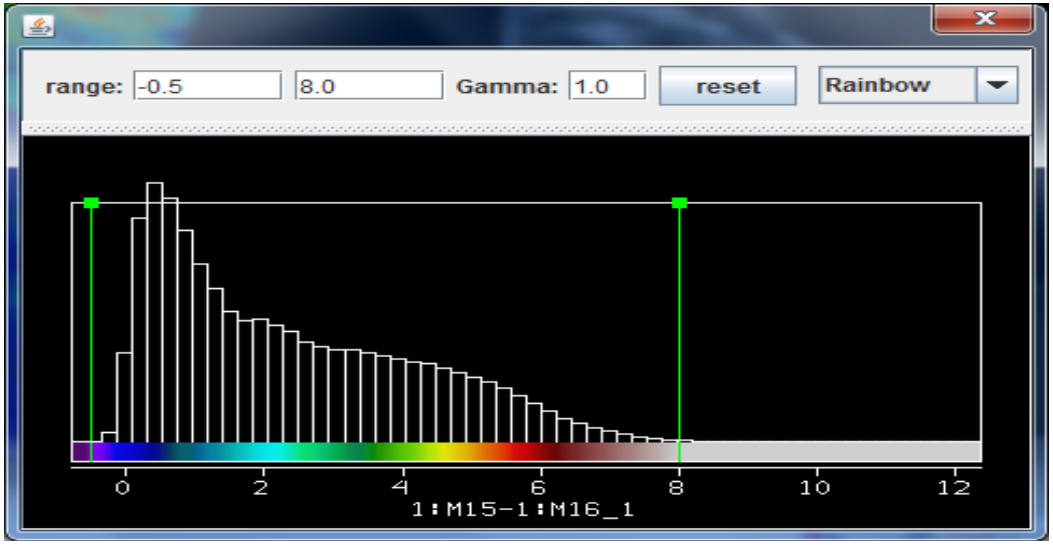

range: 120
985
Gamma: 1.0
reset
Rainbow
200
300
400
500
600
700
800
900
Cloud_Top_Pressure


295.57

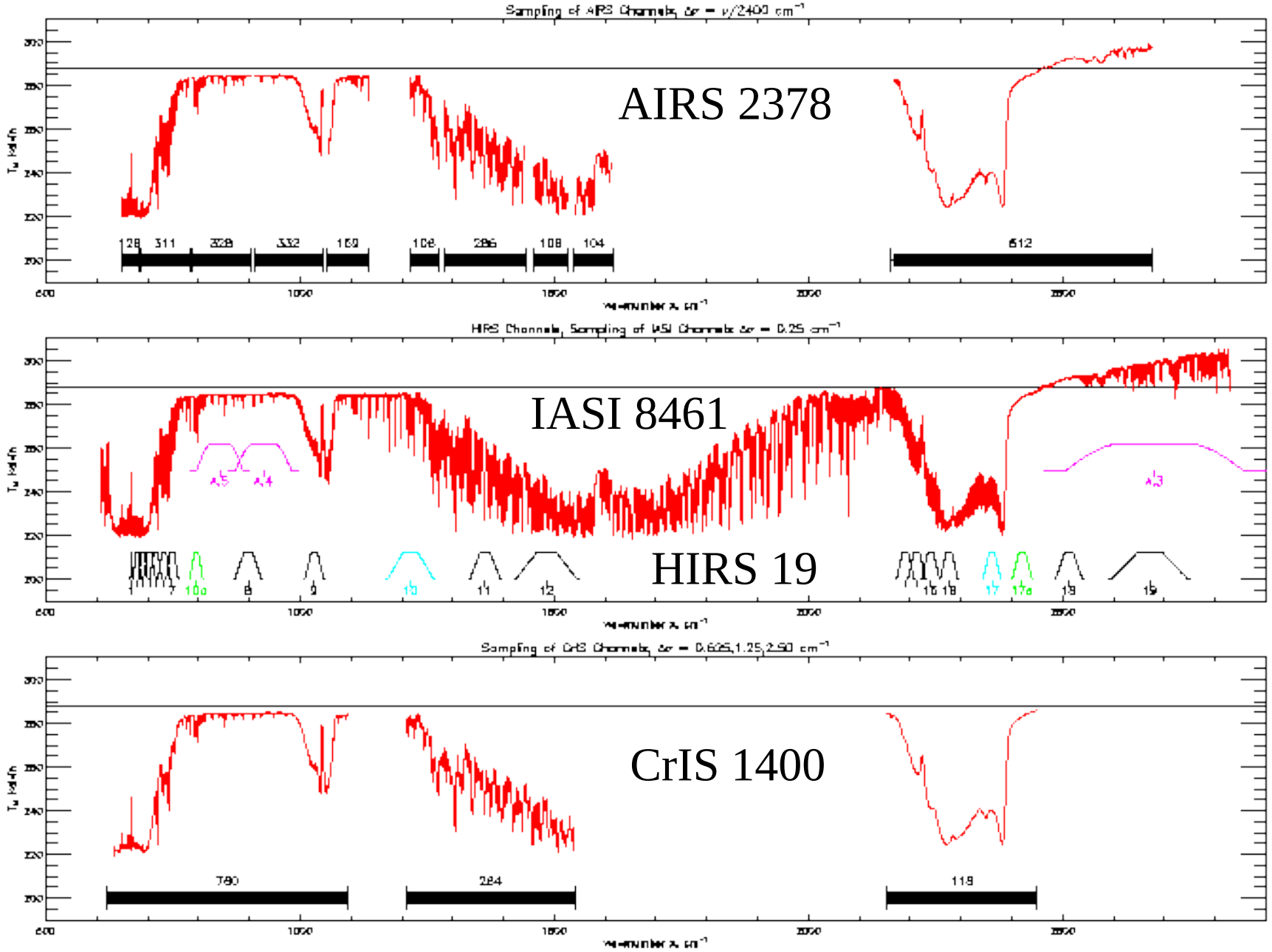

Window 1
Tools Settings
197.13
Lon: 133.26 Lat: 15.91 Val: 197.13, 2014/10/07 17:00Z
1:M15

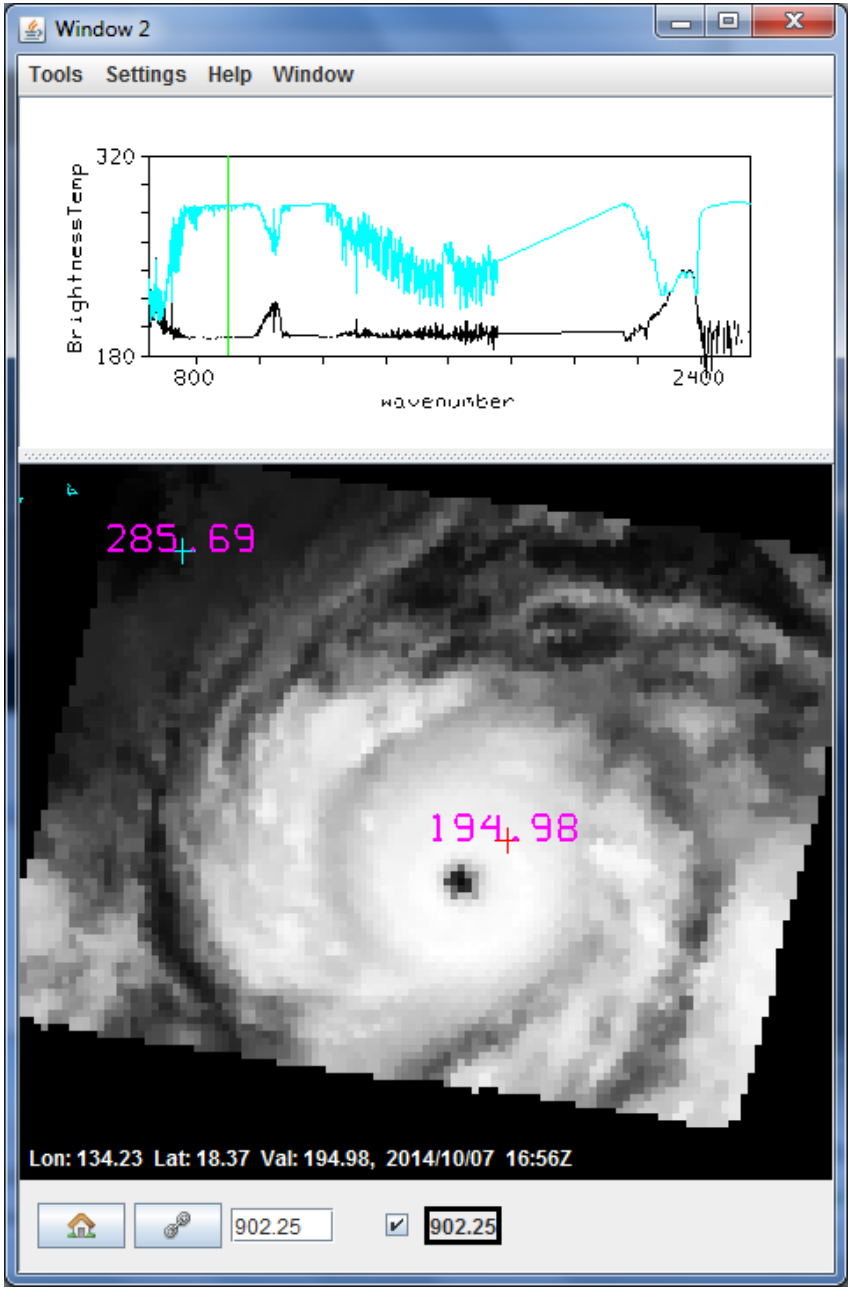

Transect Display
BrightnessTemp
280
200
0
1400
Distance_Along_Transect_km

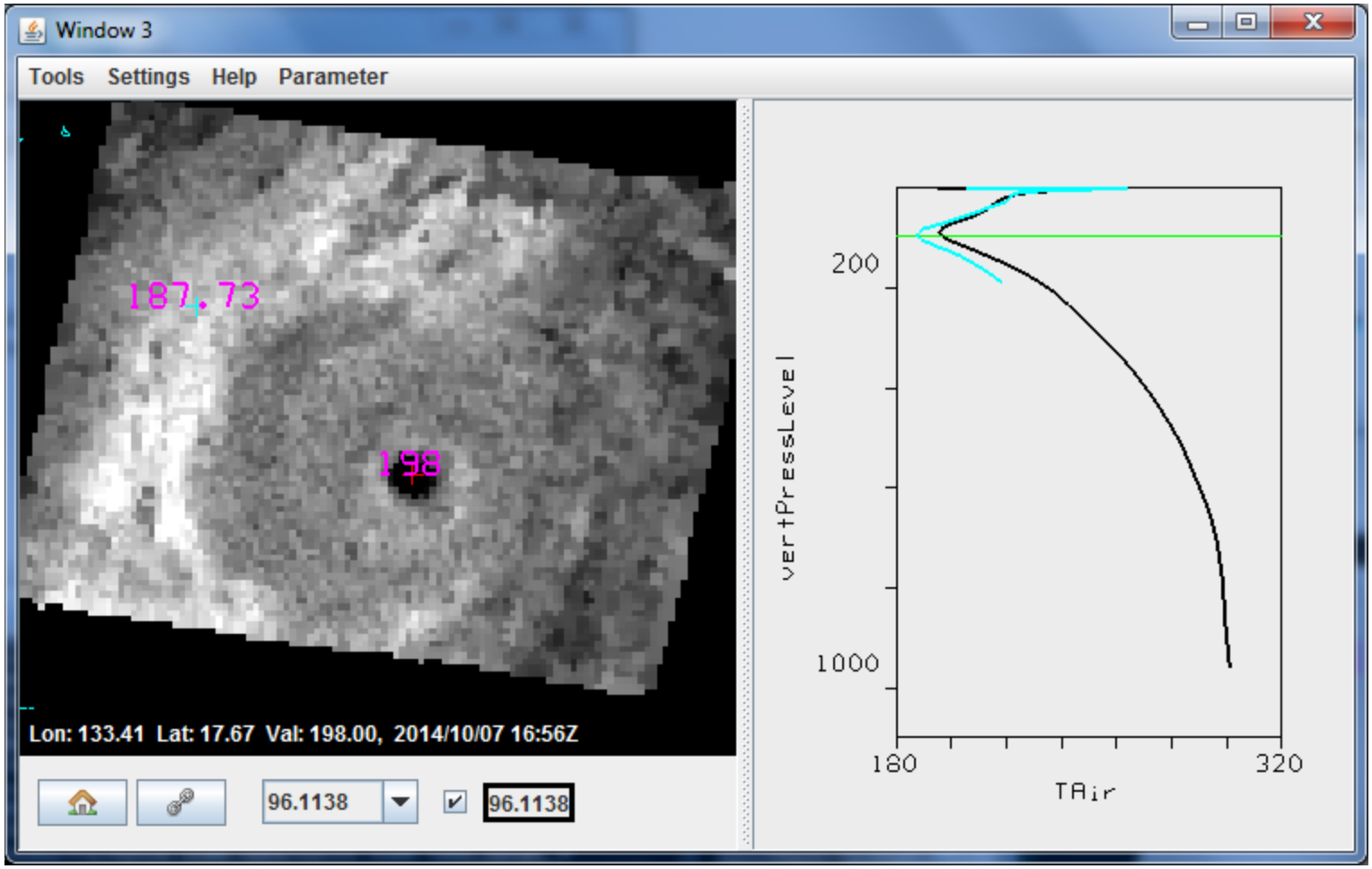

1.35

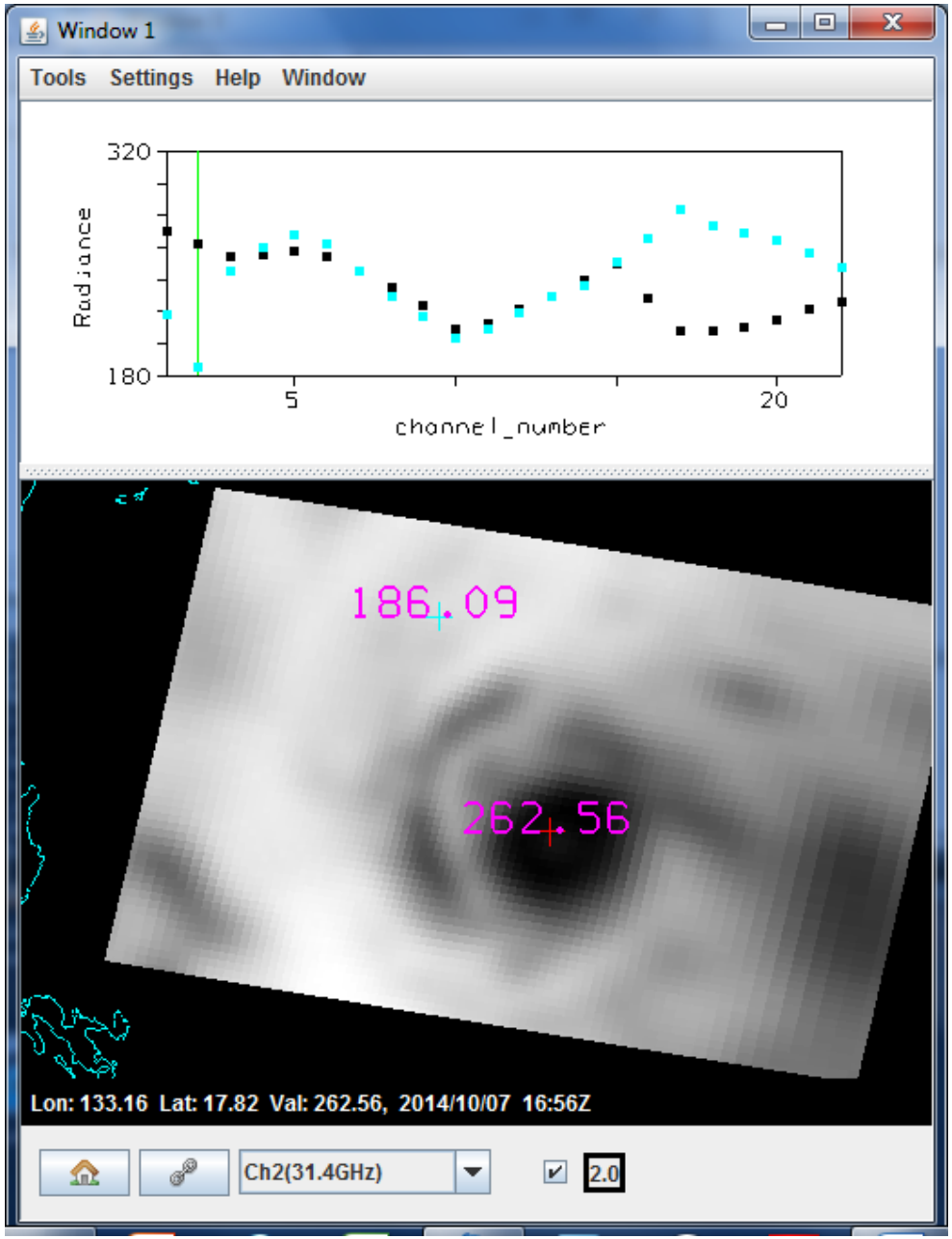

range: -0.5
8.0
Gamma: 1.0
reset
Rainbow
0
2
4
6
8
10
12
1:M15-1:M16_1

# Adding CrIS and ATMS


AIRS 2378
IASI 8461
HIRS 19
CrIS 1400


Window 2
Tools
Settings
Help
Window
320
180
BrightnessTemp
800
2400
wavenumber
285.69
194.98
Lon: 134.23 Lat: 18.37 Val: 194.98, 2014/10/07 16:56Z
902.25
902.25


Window 3
Tools
Settings
Help
Parameter
187.73
198
Lon: 133.41 Lat: 17.67 Val: 198.00, 2014/10/07 16:56Z
96.1138
96.1138
200
1000
vertPressLevel
180
320
TAir

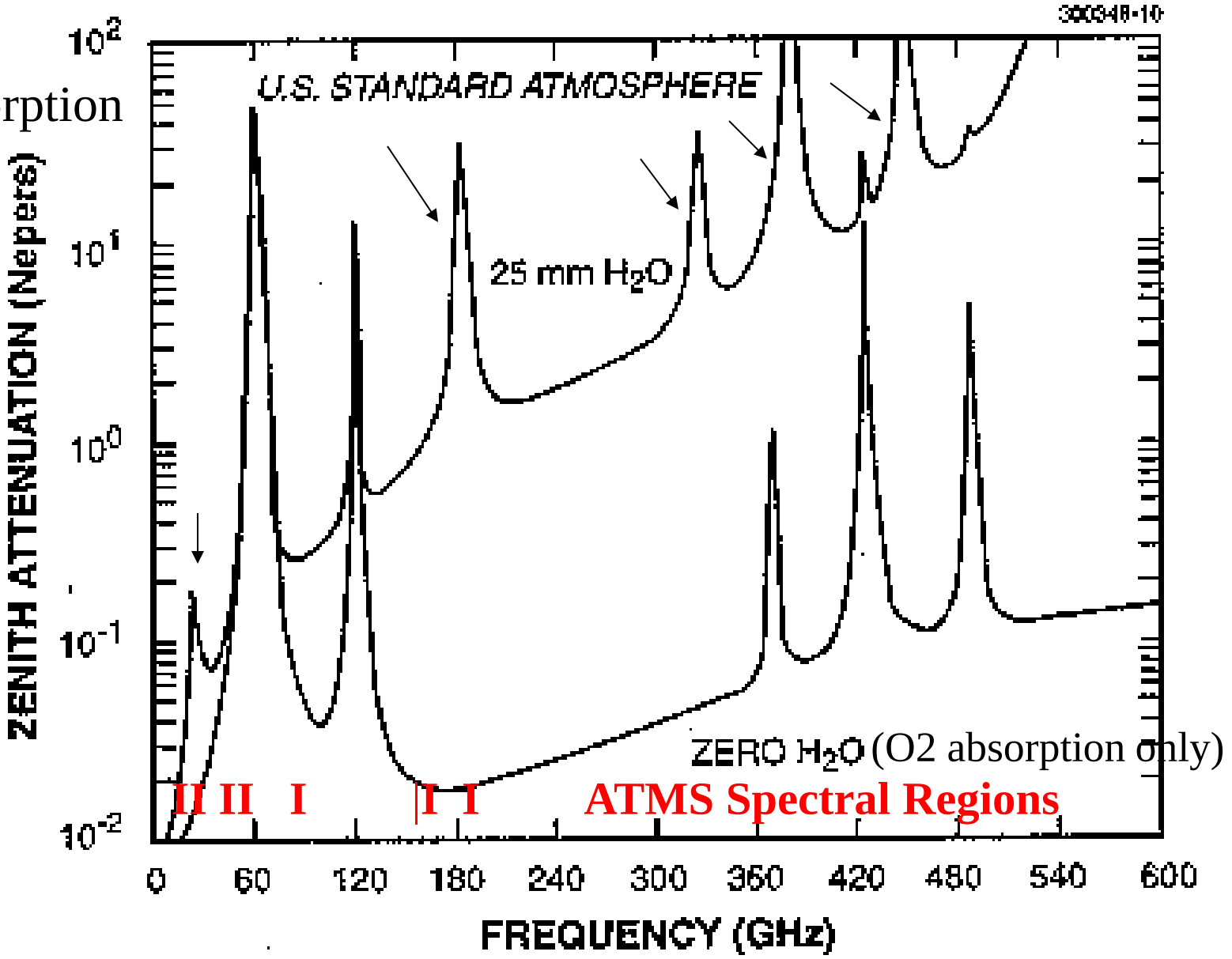

Window 1
Tools
Settings
Help
Window
320
180
Radiance
5
20
channel_number
186.09
262.56
Lon: 133.16 Lat: 17.82 Val: 262.56, 2014/10/07 16:56Z
Ch2(31.4GHz)
2.0

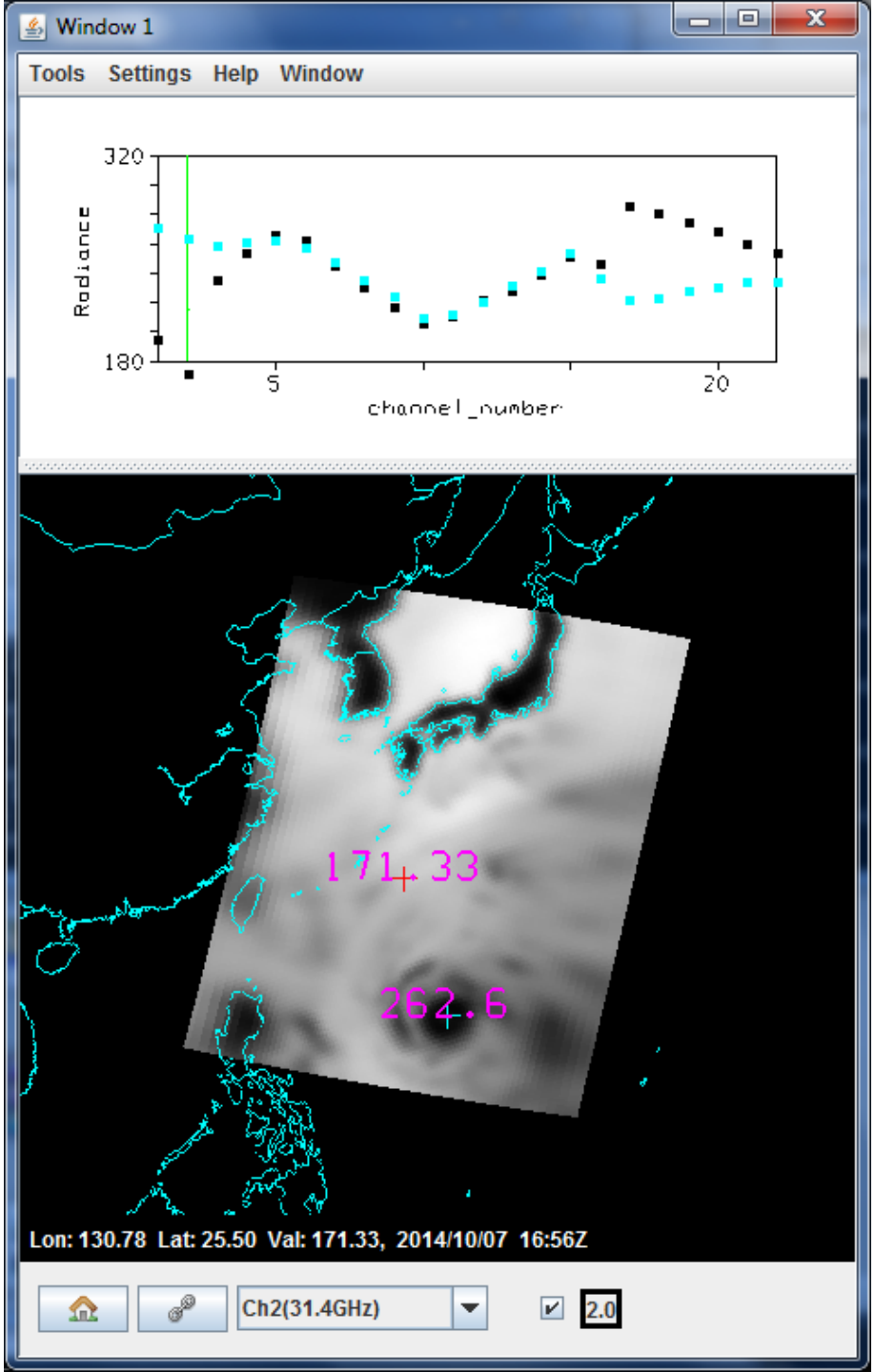
# Suggested ATMS Channels

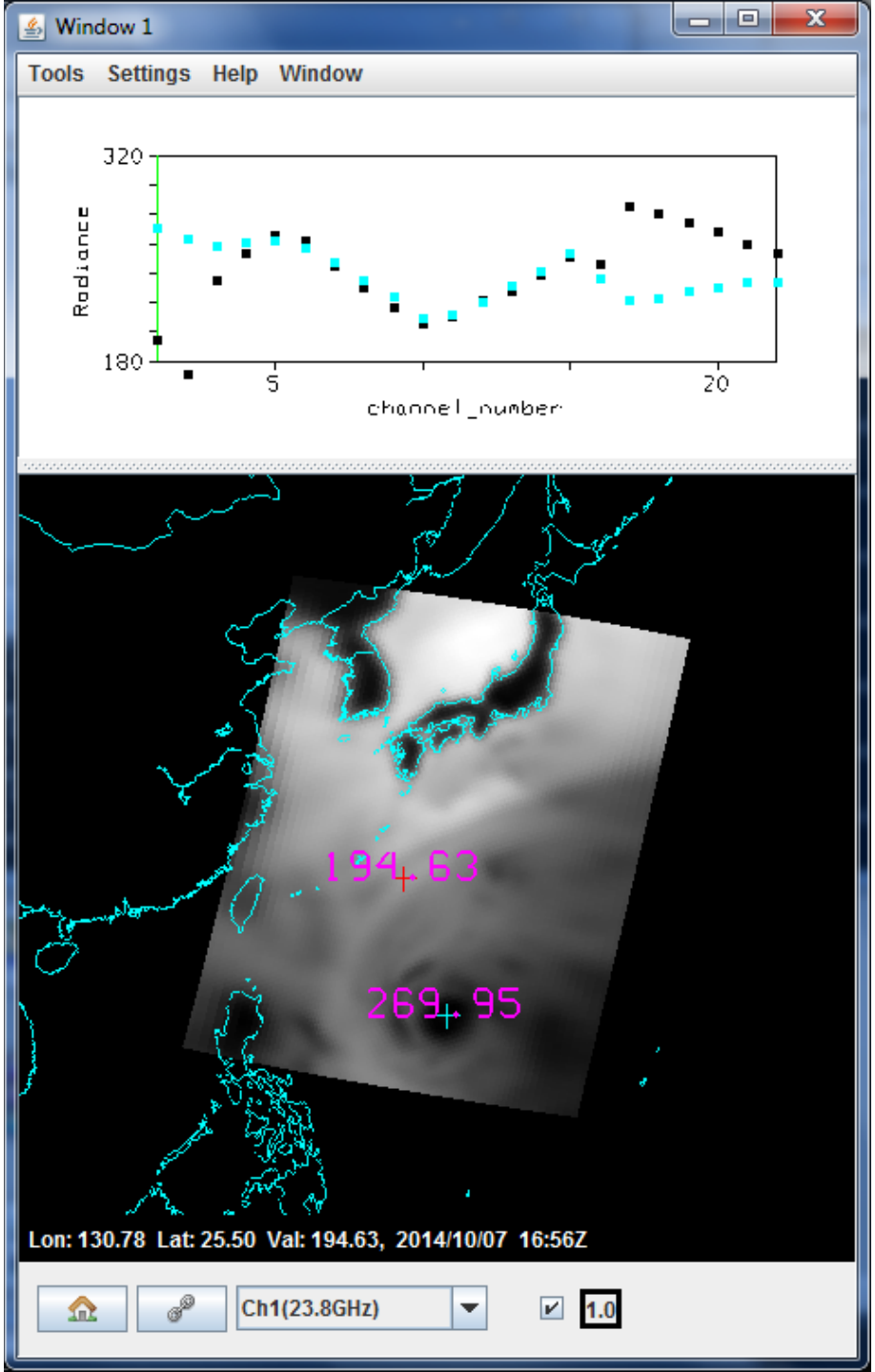
| Ch | ν(GHz) | BW(GHz) | Characteristic |
|---|---|---|---|
| 1* | 23.8 | 0.27 | split window-water vapor 100 mm |
| 2* | 31.4 | 0.18 | split window-water vapor 500 mm |
| 3* | 50.3 | 0.18 | window-surface emissivity |
| 4 | 51.76 | 0.40 | window-surface emissivity |
| 5* | 52.8 | 0.40 | surface air |
| 6* | 53.596±.115 | 0.17 | 4 km ~ 700 mb temp and precip |
| 7* | 54.4 | 0.40 | 9 km ~ 400 mb temp and precip |
| 8* | 54.94 | 0.40 | 11 km ~ 250 mb |
| 9* | 55.5 | 0.33 | 13 km ~ 180 mb |
| 10* | 57.2903 | 0.33 | 17 km ~ 90 mb |
| 11* | 57.2903 ±.217 | 0.078 | 19 km ~ 50 mb |
| 12* | 57.2903 ±.322 ±.048 | 0.036 | 25 km ~ 25 mb |
| 13* | 57.2903 ±.322 ±.022 | 0.016 | 29 km ~ 10 mb |
| 14* | 57.2903 ±.322 ±.010 | 0.008 | 32 km ~ 6 mb |
| 15* | 57.2903 ±.322 ±.004 | 0.03 | 37 km ~ 3 mb |
| 16* | 89.0 | 6.0 | window-precip and water vapor 150 mm |
| 17 | 166.31 | 4.0 | $H_2O$ 18 mm |
| 18* | 183.31±7 | 2.0 | $H_2O$ 8 mm |
| 19 | 183.31±4.5 | 2.0 | $H_2O$ 4.5 mm |
| 20* | 183.31±3 | 1.0 | $H_2O$ 2.5 mm |
| 21 | 183.31±1.8 | 1.0 | $H_2O$ 1.2 mm |
| 22* | 183.31±1 | 0.5 | $H_2O$ 0.5 mm |

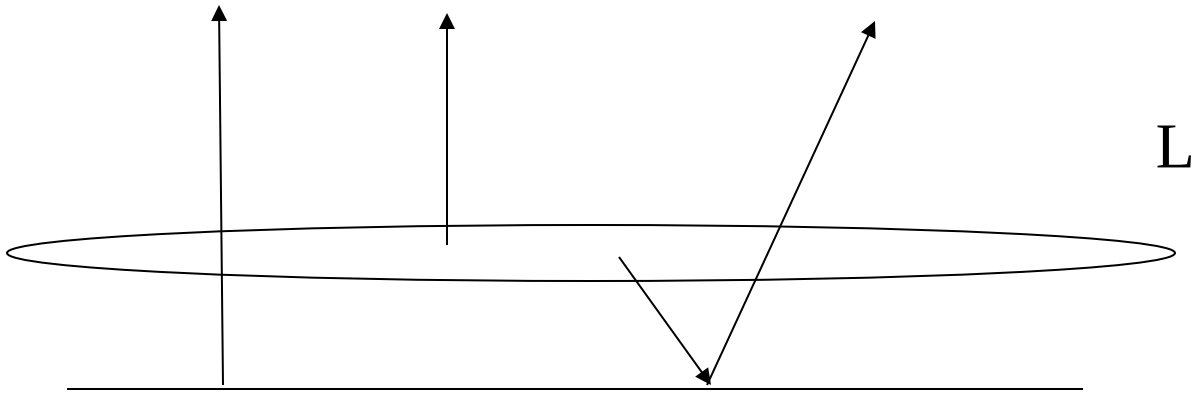
* In common with AMSU/HSB

absorption


U.S. STANDARD ATMOSPHERE
25 mm $H_2O$
ZERO $H_2O$ (O2 absorption only)
ZENITH ATTENUATION (Nepers)
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
0
60
120
180
240
300
360
420
480
540
600
FREQUENCY (GHz)
II II I I I
ATMS Spectral Regions


Window 1
Tools Settings Help Window
320
180
Radiance
5
20
channel_number
171.33
262.6
Lon: 130.78 Lat: 25.50 Val: 171.33, 2014/10/07 16:56Z
Ch2(31.4GHz)
2.0


Window 1
Tools Settings Help Window
320
180
Radiance
5
20
channel_number
194.63
269.95
Lon: 130.78 Lat: 25.50 Val: 194.63, 2014/10/07 16:56Z
Ch1(23.8GHz)
1.0



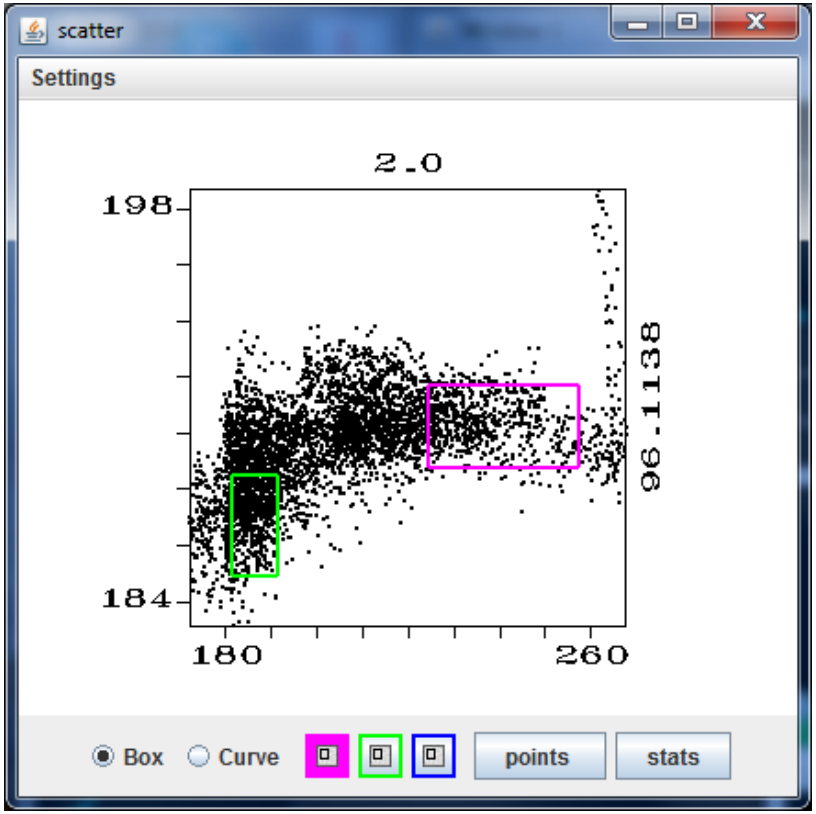
Low mist over ocean

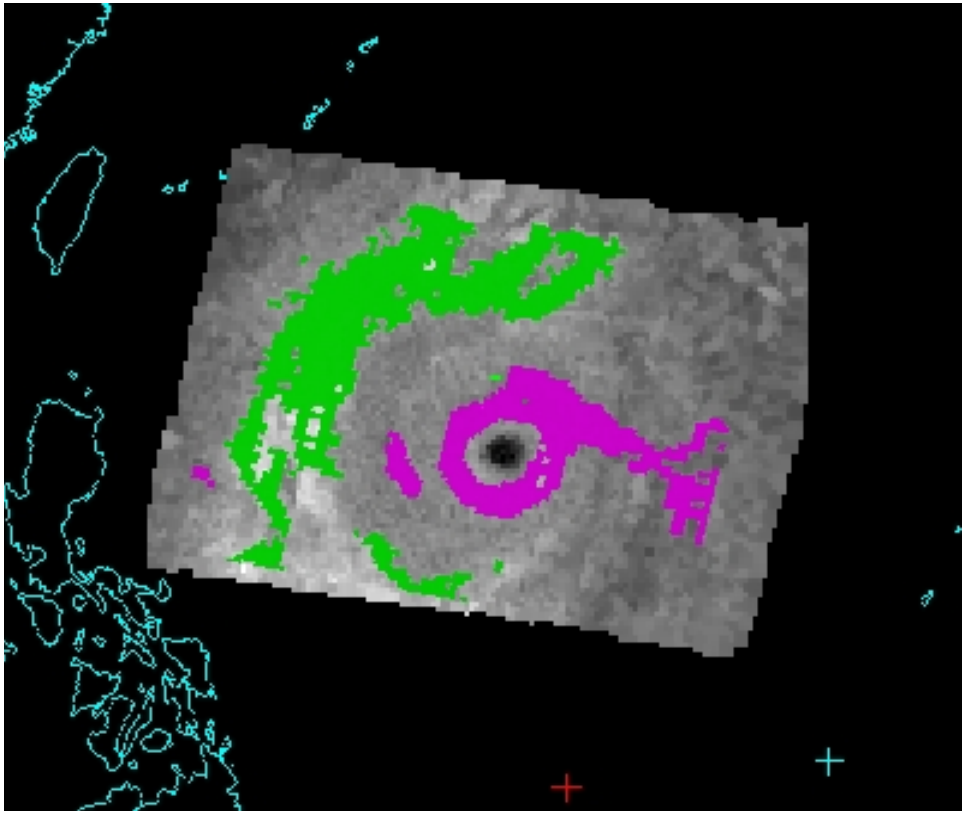
$T_b = \varepsilon_s T_s (1-\sigma_m) + \sigma_m T_m + \sigma_m (1-\varepsilon_s) (1-\sigma_m) T_m$

So

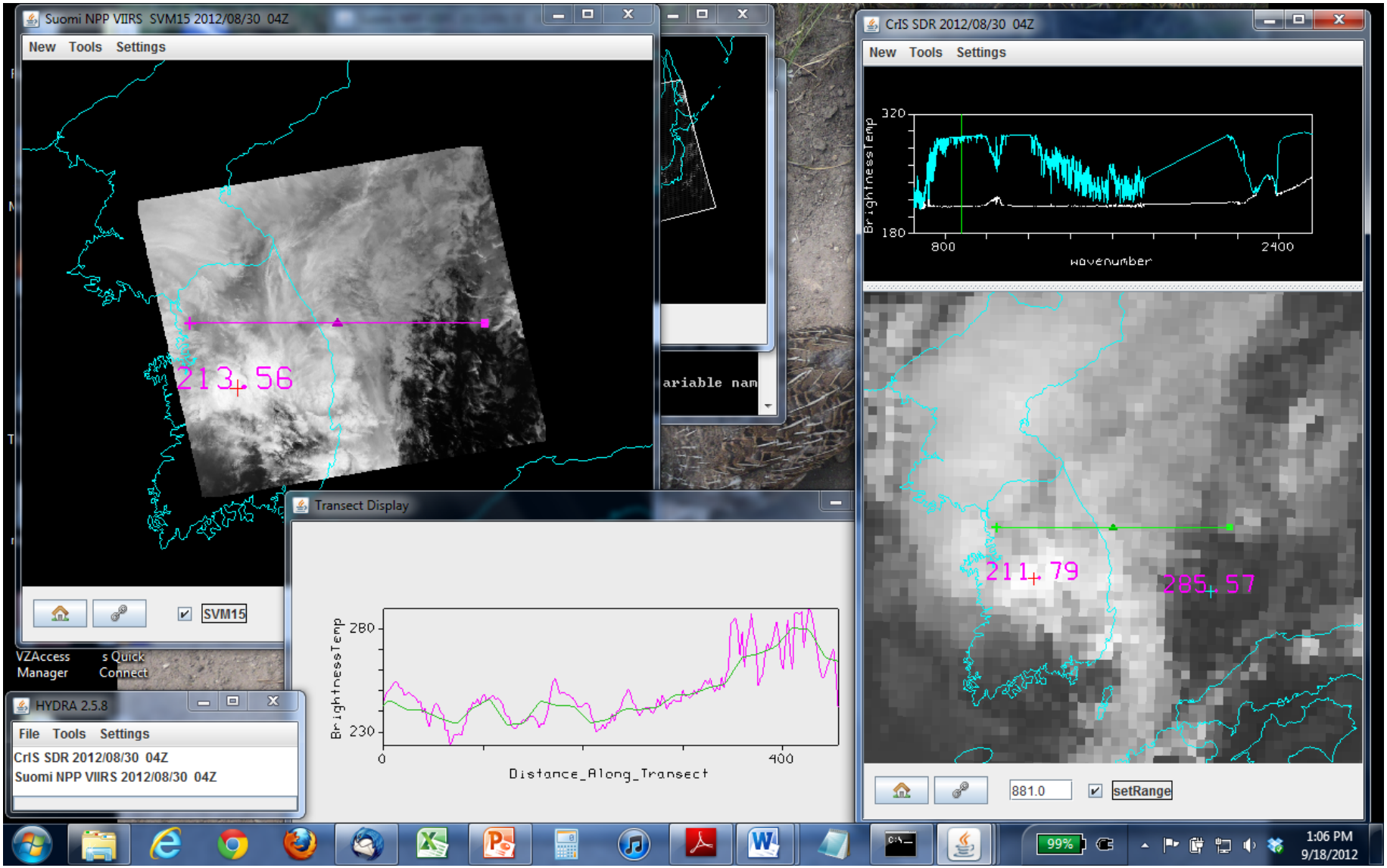
$\Delta T_b = - \varepsilon_s \sigma_m T_s + \sigma_m T_m + \sigma_m (1-\varepsilon_s) (1-\sigma_m) T_m$

For $\varepsilon_s \sim 0.5$ and $T_s \sim T_m$ this is always positive for $0 < \sigma_m < 1$


scatter
Settings
2.0
198
184
180
260
96.1138
Box
Curve
points
stats

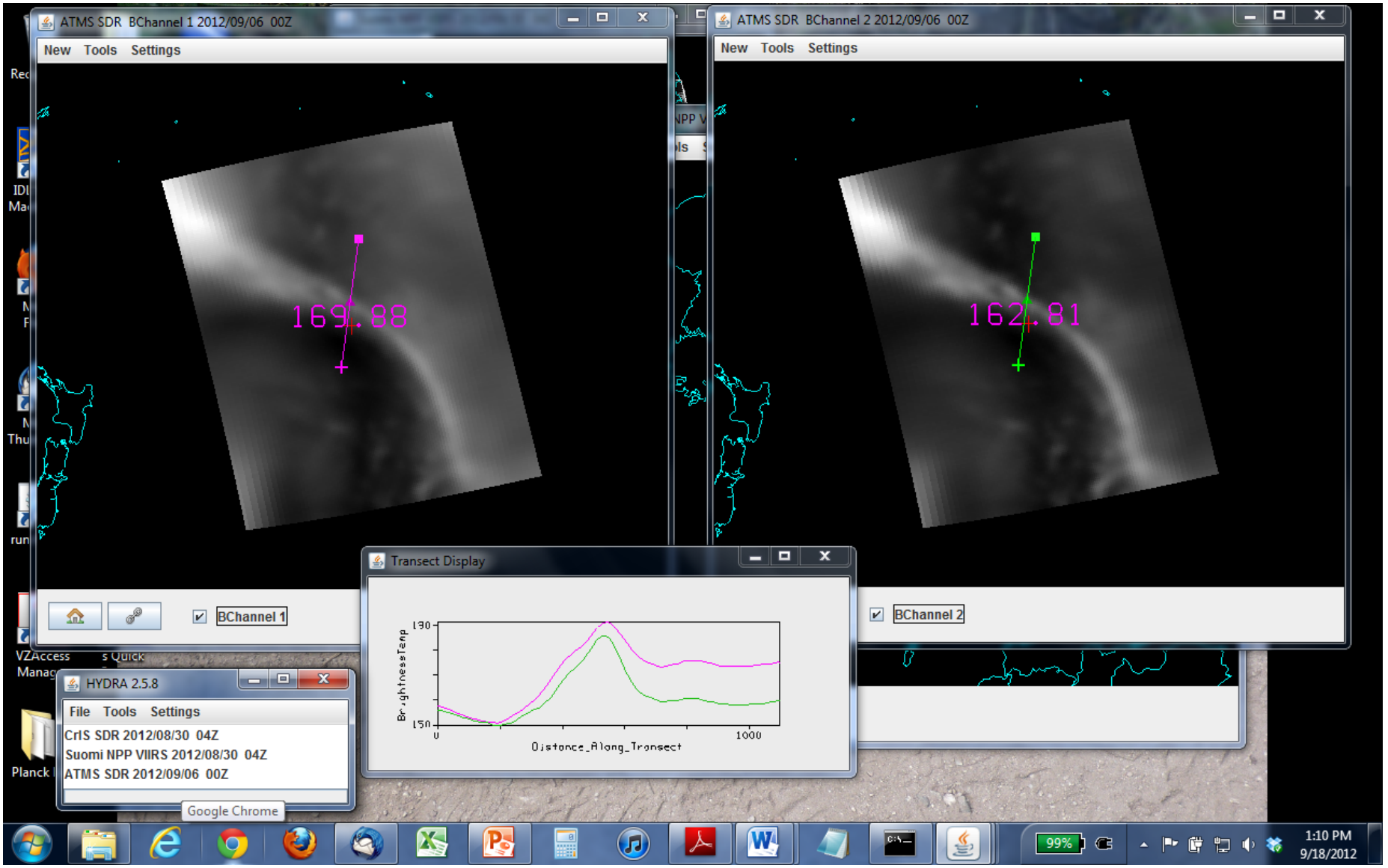


# Comparing SNPP sensor measurements




**VIIRS and CrIS**

# ATMS Ch1 vs Ch2

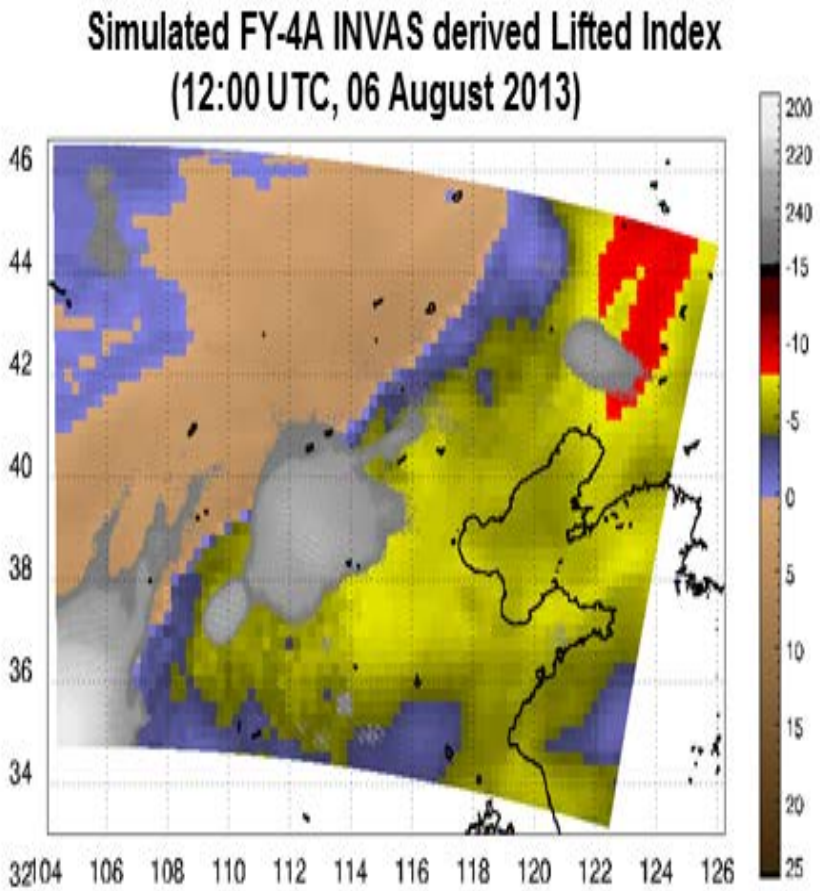


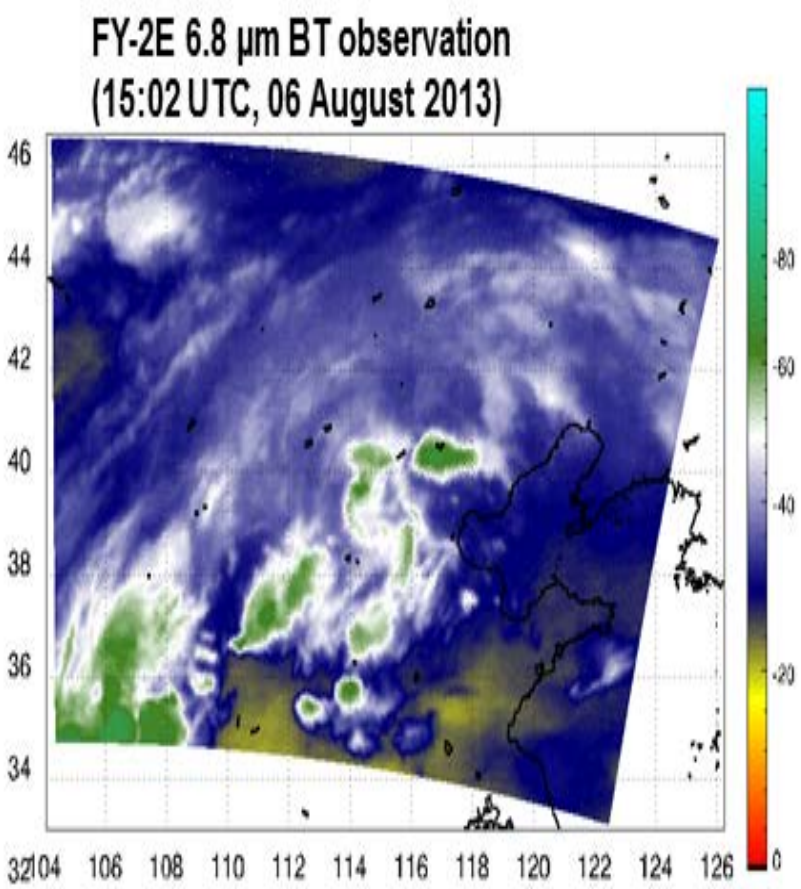
# AIRS, CrIS, and 2 IASIs

Multiple overpasses per day

- often more than ten for mid-lats
- enables trending of atm and sfc trends

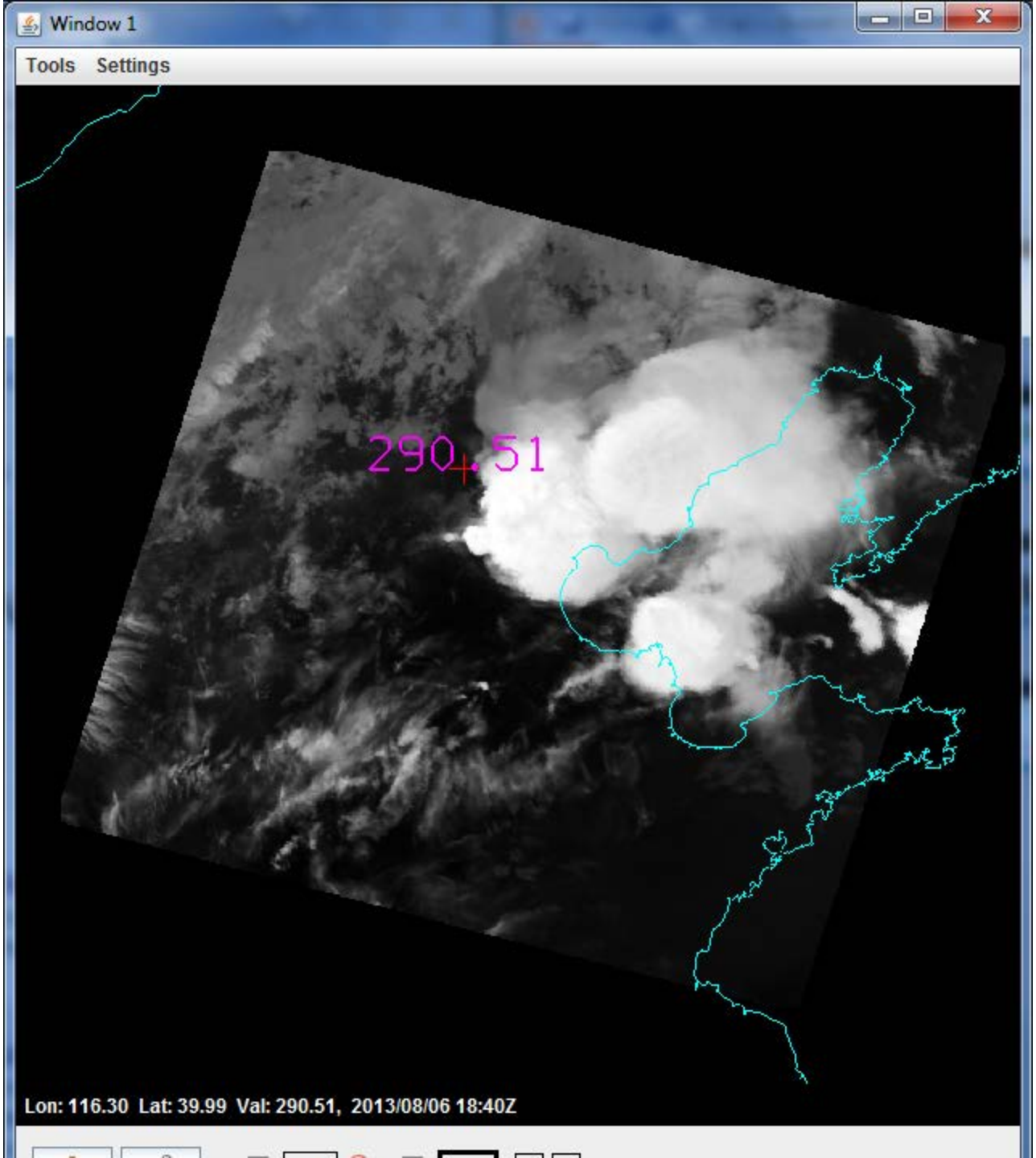
# 06 Aug 2013 Beijing Storm



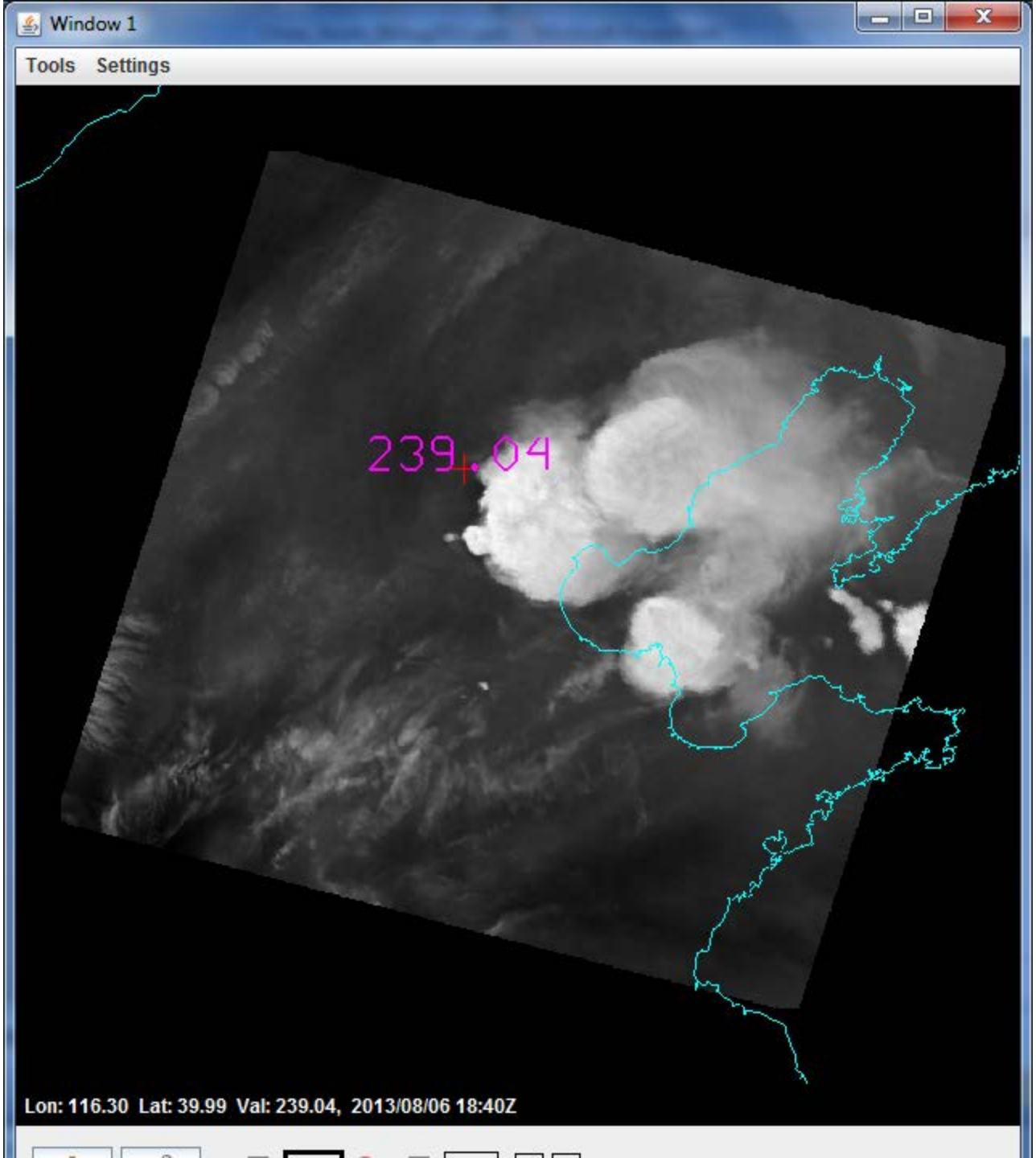
MODIS IRW

1700 UTC
6 Aug 2013



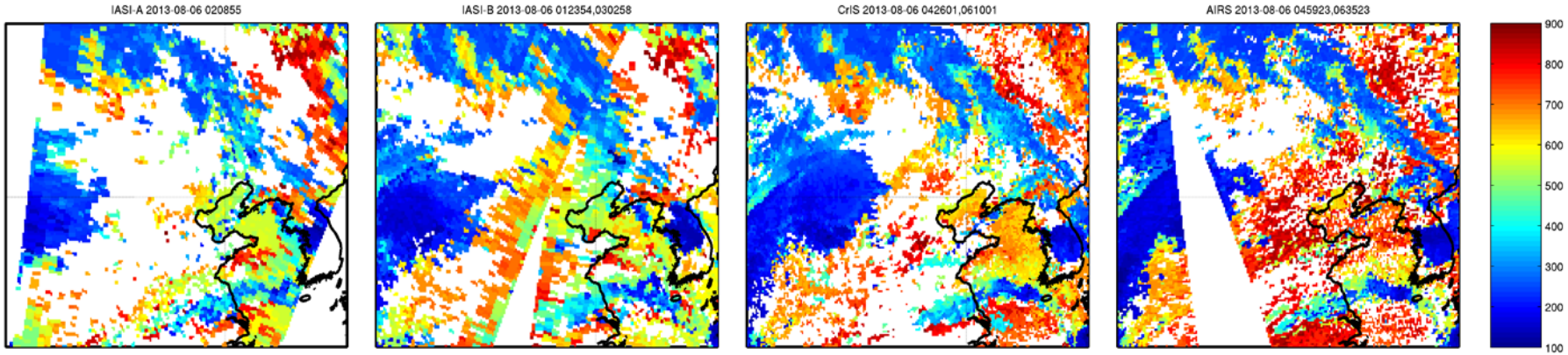
MODIS WV

1700 UTC
6 Aug 2013



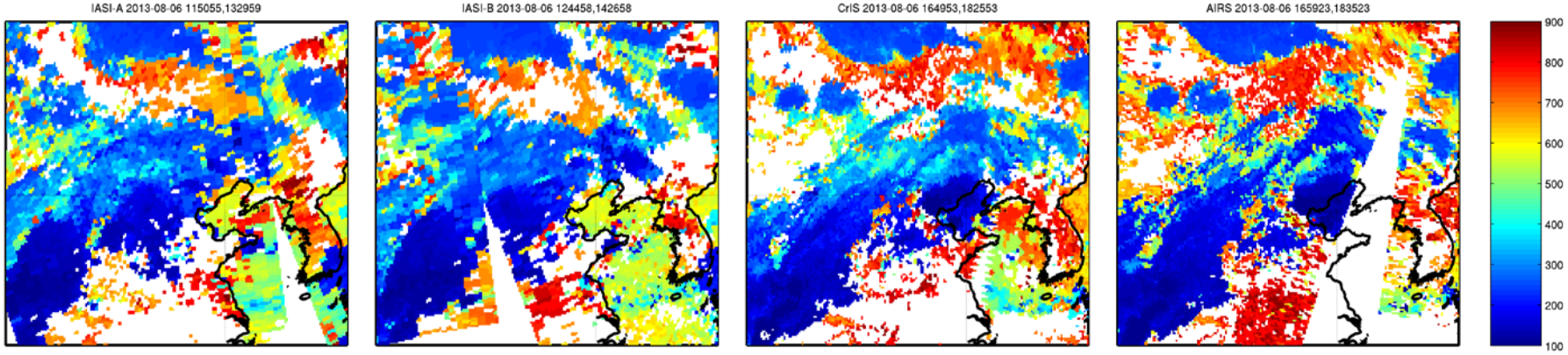
# CTOP 6 Aug 2013

IASI-A | IASI-B | CrIS | AIRS




0209 | 0124&0303 | 0426&0610 | 0459&0635 GMT

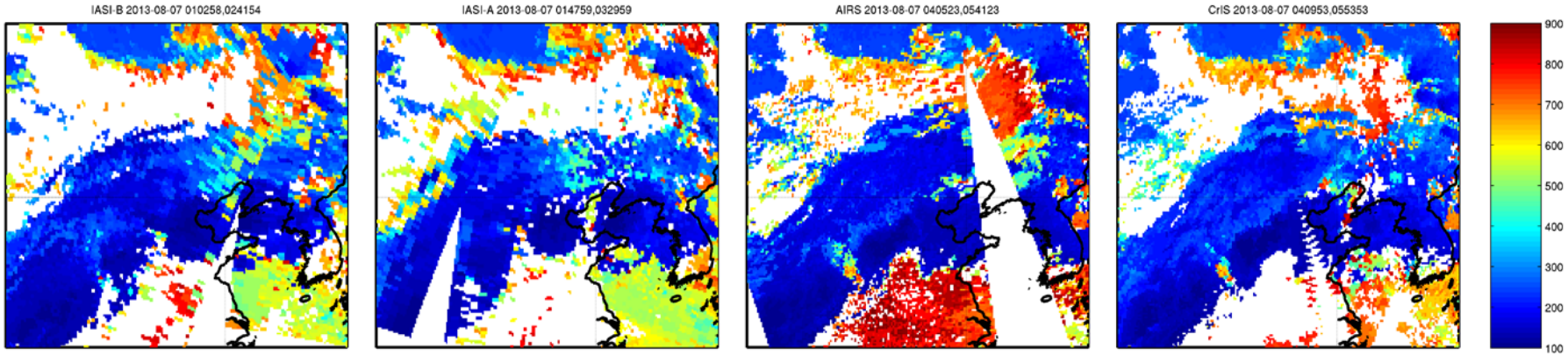
IASI-A | IASI-B | CrIS | AIRS




1151&1330 | 1245&1427 | 1650&1826 | 1659&1836 GMT

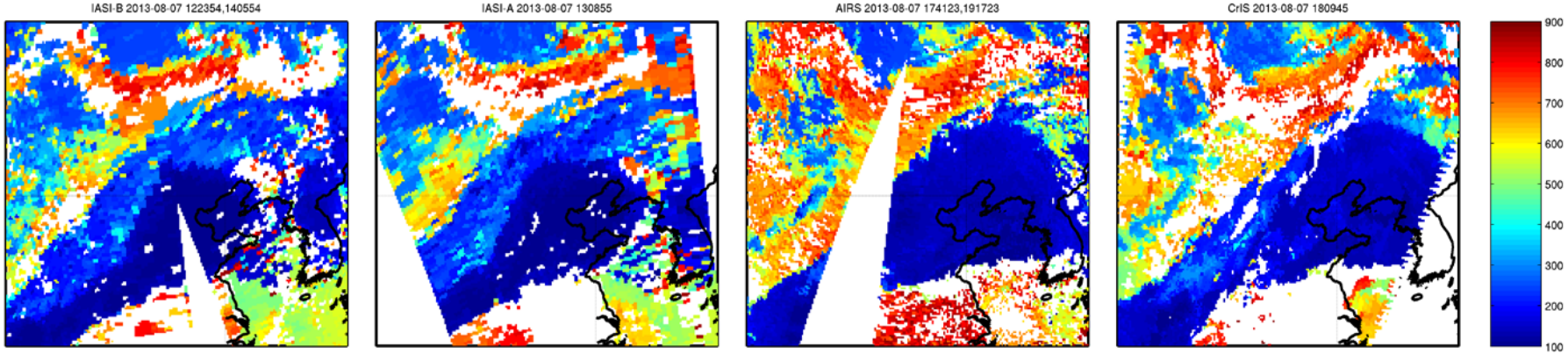
# CTOP 7 Aug 2013

IASI-B | IASI-A | AIRS | CrIS




0103&0242 | 0148&0330 | 0405&0541 | 0410&0554 GMT

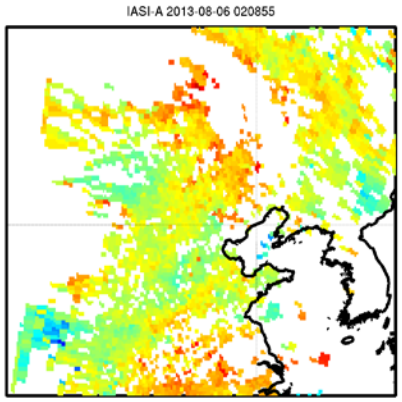
IASI-B | IASI-A | AIRS | CrIS




1224&1406 | 1309 | 1741&1917 | 1810 GMT

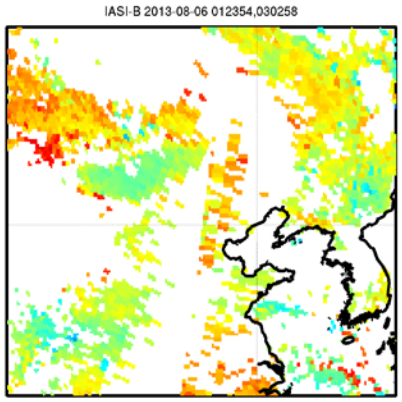
# Lifted Index 6 Aug 2013

IASI-A



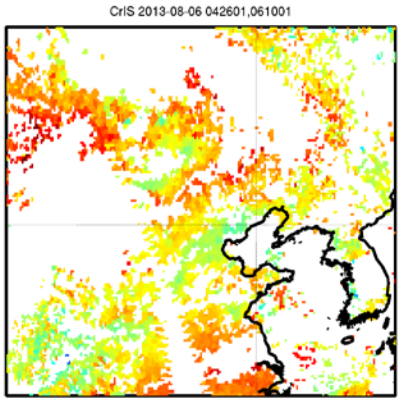

0209

IASI-B



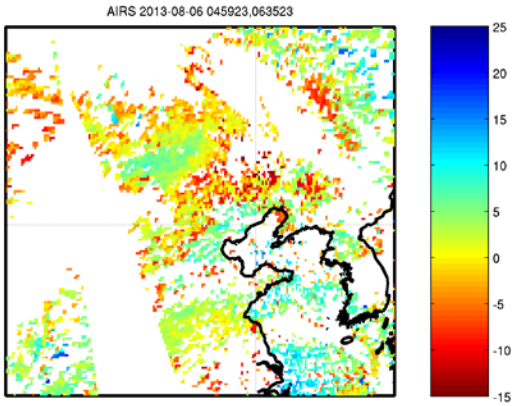

0124&0303

CrIS




0426&0610

AIRS




0459&0635 GMT

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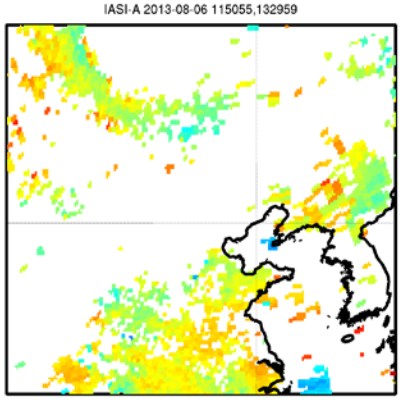


1151&1330

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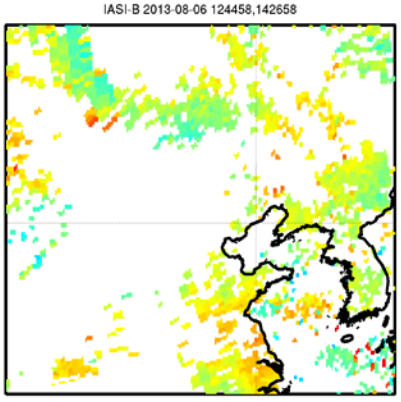
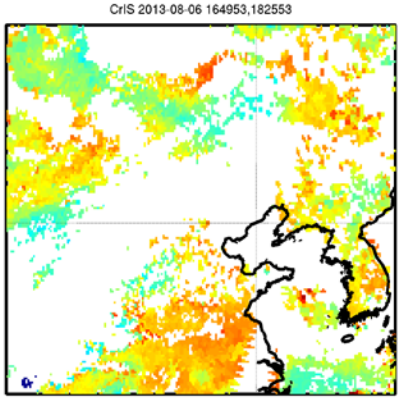


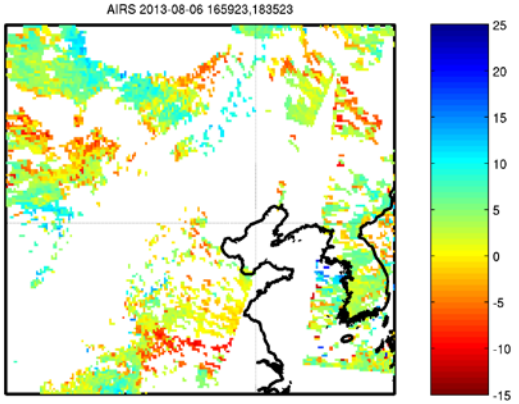

1245&1427

CrIS




1650&1826

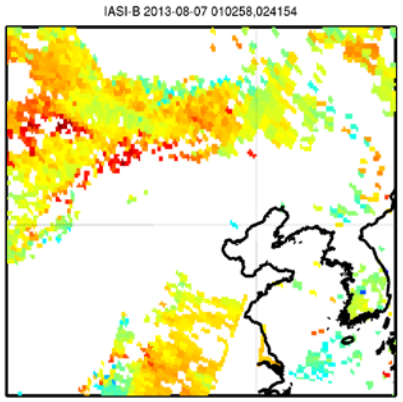
AIRS




1659&1836 GMT

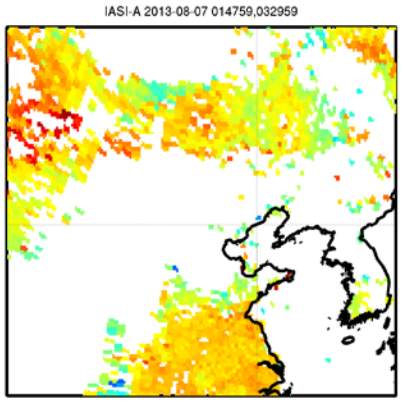
# Lifted Index 7 Aug 2013

IASI-B



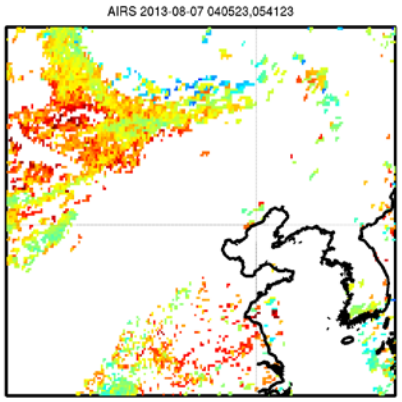

0103&0242

IASI-A



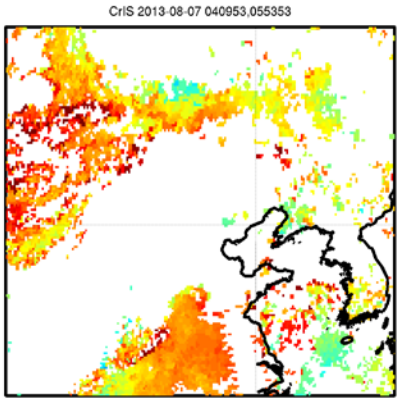

0148&0330

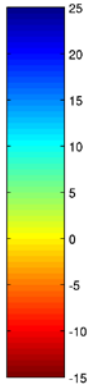
AIRS




0405&0541

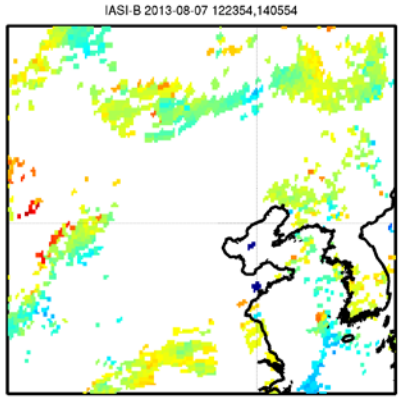
CrIS



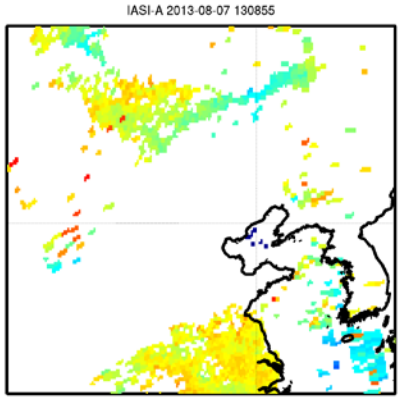

0410&0554 GMT

IASI-B



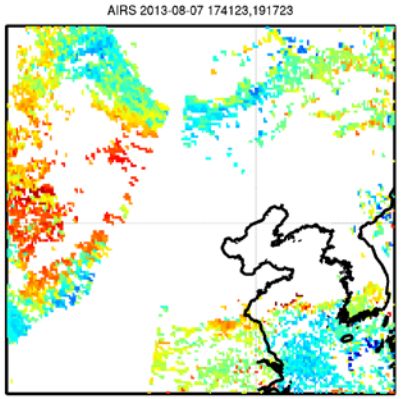

1224&1406

IASI-A



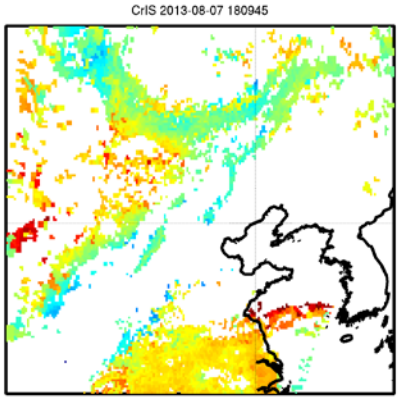

1309

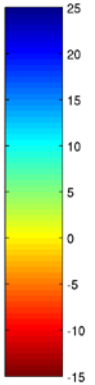
AIRS




1741&1917

CrIS




1810 GMT

LST = GMT + 8

# Access to visualization tools and data

**For HYDRA2 ftp://ftp.ssec.wisc.edu/rink/hydra2/**

**For MODIS data http://ladsweb.nascom.nasa.gov/**

**For AIRS data http://daac.gsfc.nasa.gov/**

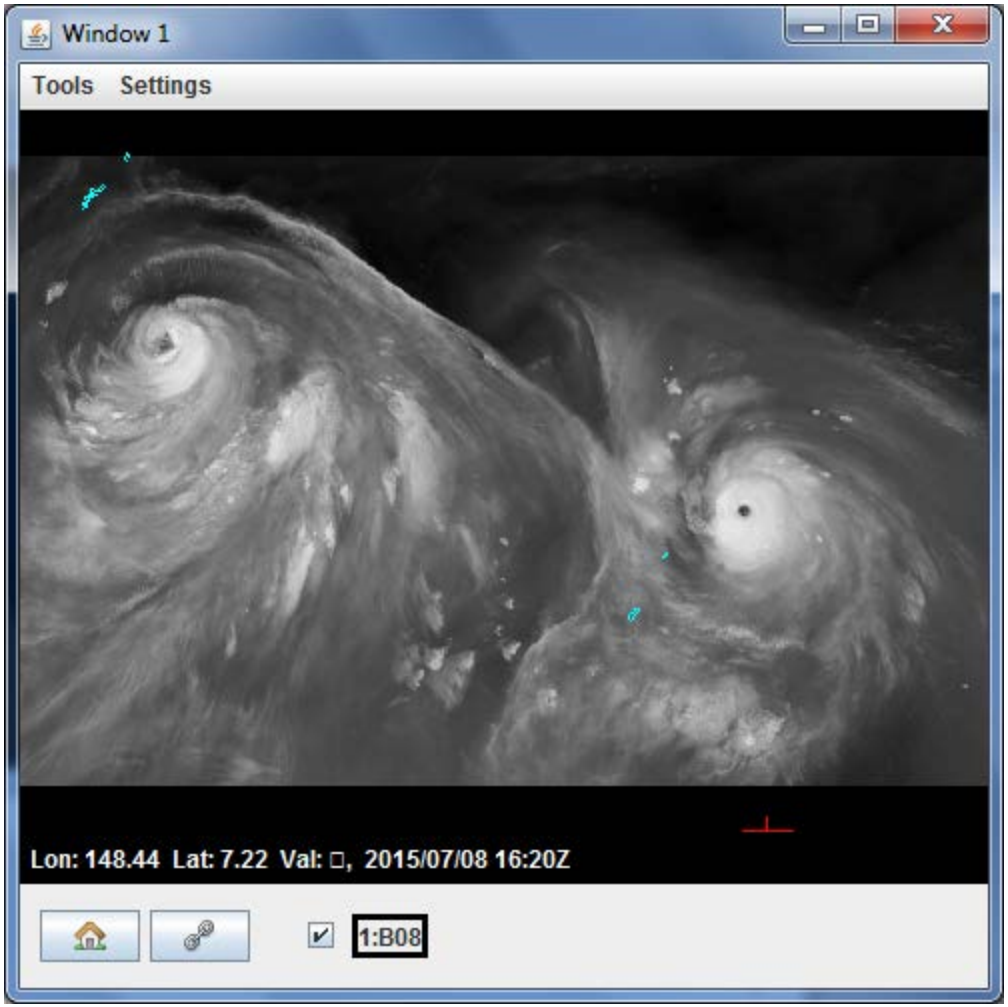
**For IASI, connect with EUMETSAT archive**
**http://www.eumetsat.int/website/home/Data/DataDelivery/OnlineDataAccess/index.html**

**For VIIRS, CrIS, and ATMS data, orbit tracks, guide**
**http://www.nsof.class.noaa.gov**
**http://www.ssec.wisc.edu/datacenter/npp/**
**http://www.class.ncdc.noaa.gov/notification/faq_npp.htm**
*See tutorial "How do I order NPP data in CLASS (11/28/11)"*

**For AHI data**
**Contact rink@ssec.wisc.edu with request to convert file to NetCDF**

# AHI Example

Chan-hom
8 Jul 2015




Nangka

AHI

| Band | Bandwidth | SNR | Res | Objectives |
|---|---|---|---|---|
| 1 | 455 nm | 50 nm | ≤ 300 @ 100 % albedo | 1.0 km | Daytime aerosol over land, coastal water mapping |
| 2 | 510 nm | 20 nm | ≤ 300 @ 100 % albedo | 1.0 km | Green band – to produce color composite imagery |
| 3 | 645 nm | 30 nm | ≤ 300 @ 100 % albedo | **0.5 km** | Daytime vegetation/burn scar and aerosols over water, winds |
| 4 | 860 nm | 20 nm | ≤ 300 @ 100 % albedo | 1.0 km | Daytime cirrus cloud |
| 5 | 1610 nm | 20 nm | ≤ 300 @ 100 % albedo | 2.0 km | Daytime cloud-top phase and particle size, snow |
| 6 | 2260 nm | 20 nm | ≤ 300 @ 100 % albedo | 2.0 km | Daytime land/cloud properties, particle size, vegetation, snow |
| 7 | 3.85 μm | 0.22 μm | ≤ 0.16 @ 300 K | 2.0 km | Surface and cloud, fog at night, fire, winds |
| 8 | 6.25 μm | 0.37 μm | ≤ 0.40 @ 240 K | 2.0 km | High-level atmospheric water vapor, winds, rainfall |
| 9 | 6.95 μm | 0.12 μm | ≤ 0.10 @ 300 K | 2.0 km | Mid-level atmospheric water vapor, winds, rainfall |
| 10 | 7.35 μm | 0.17 μm | ≤ 0.32 @ 240 K | 2.0 km | Lower-level water vapor, winds and $SO_2$ |
| 11 | 8.60 μm | 0.32 μm | ≤ 0.10 @ 300 K | 2.0 km | Total water for stability, cloud phase, dust, $SO_2$, rainfall |
| 12 | 9.63 μm | 0.18 μm | ≤ 0.10 @ 300 K | 2.0 km | Total ozone, turbulence, winds |
| 13 | 10.45 μm | 0.30 μm | ≤ 0.10 @ 300 K | 2.0 km | Surface and cloud |
| 14 | 11.20 μm | 0.20 μm | ≤ 0.10 @ 300 K | 2.0 km | Imagery, SST, clouds, rainfall |
| 15 | 12.35 μm | 0.30 μm | ≤ 0.10 @ 300 K | 2.0 km | Total water, ash, SST |
| 16 | 13.30 μm | 0.20 μm | ≤ 0.30 @ 300 K | 2.0 km | Air temperature, cloud heights and amounts |

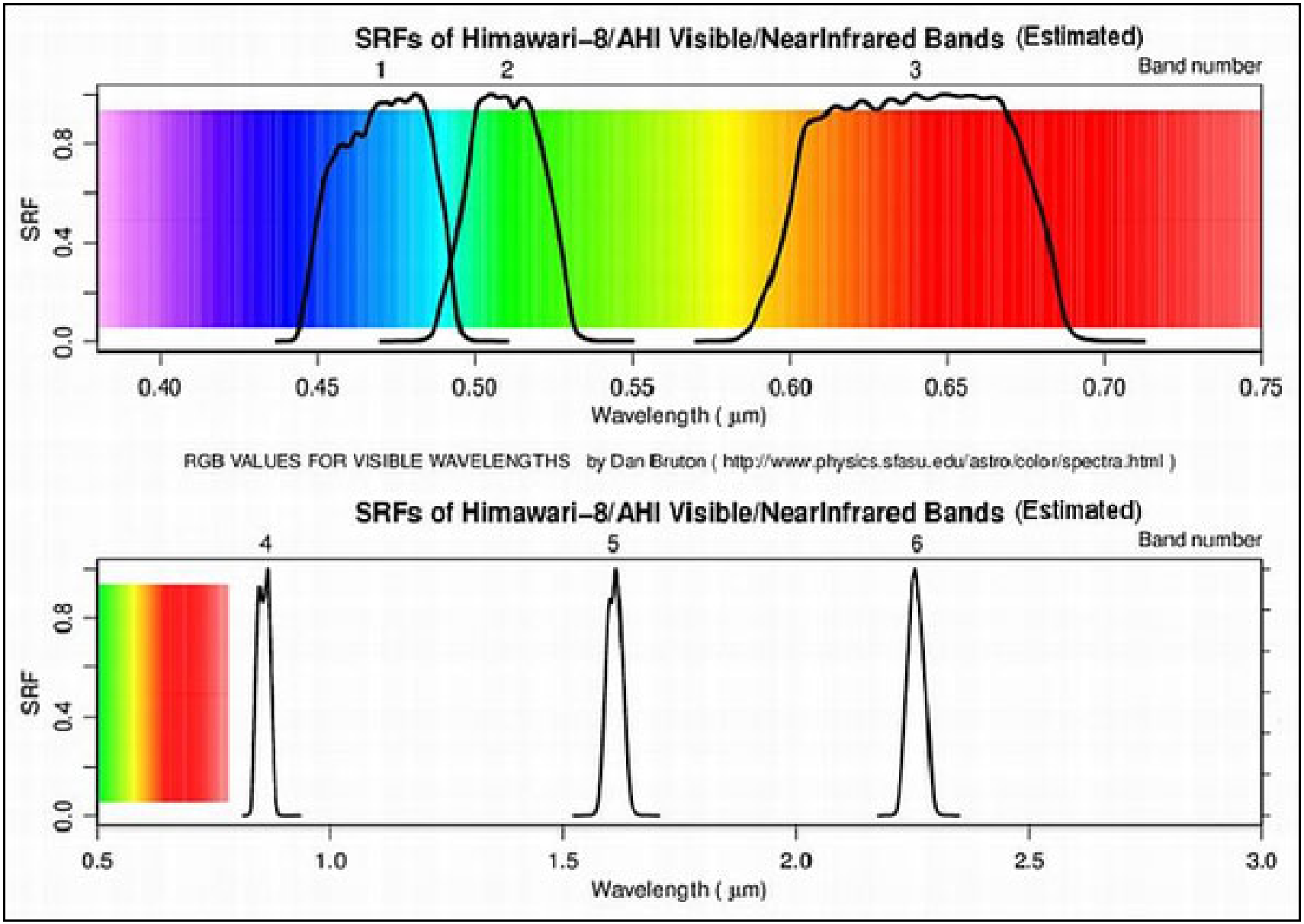



Figure 7: SRF (Spectral Response Functions) of AHI in the VNIR bands (image credit: JMA)

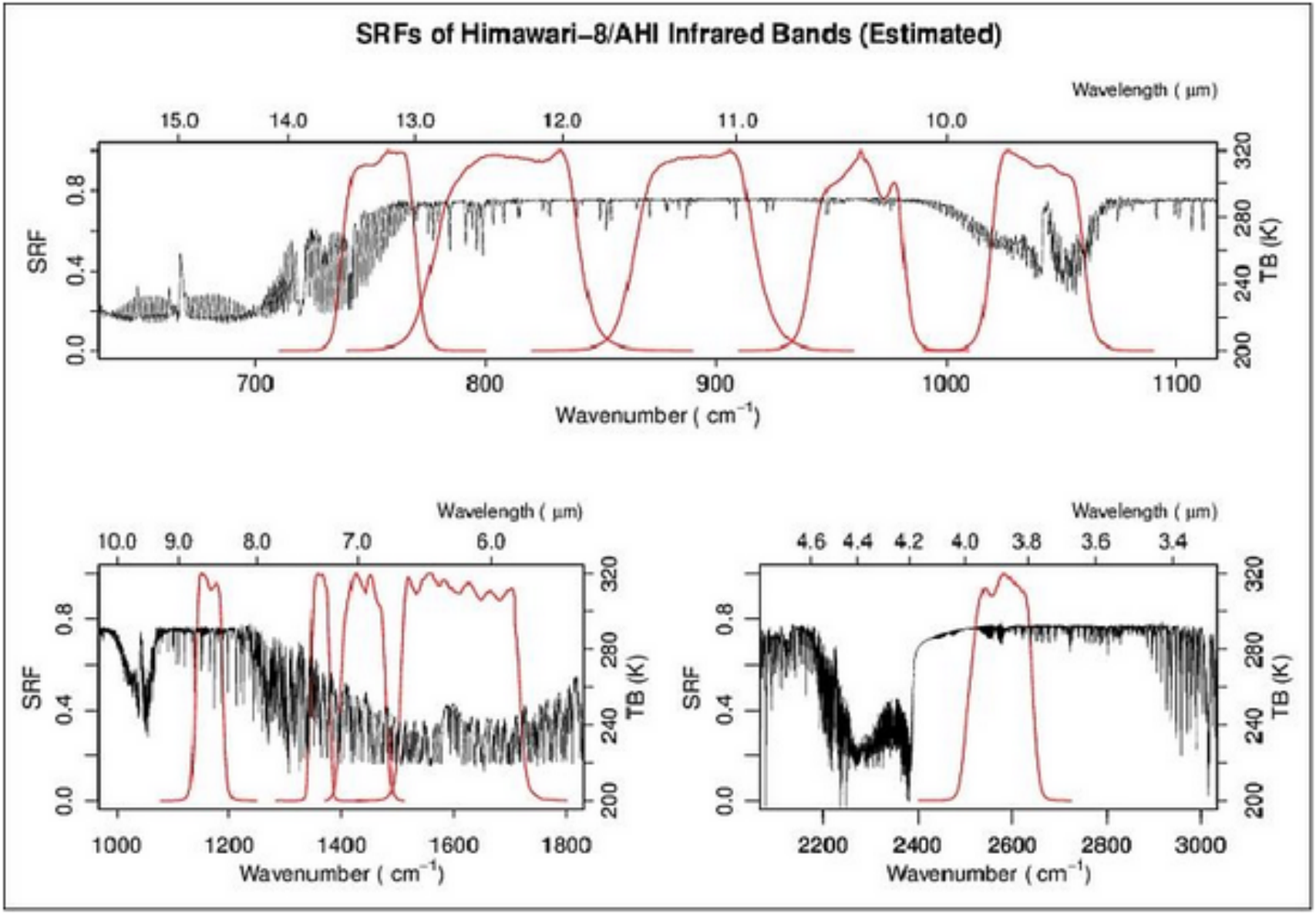


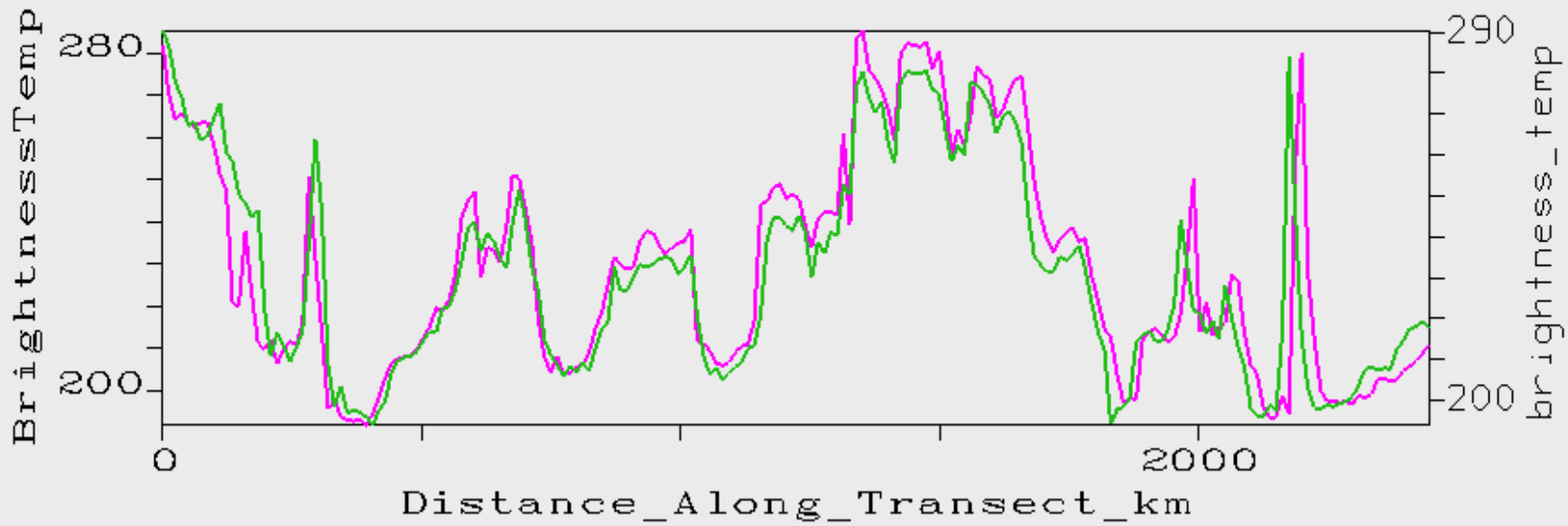

Figure 8: SRF (Spectral Response Functions) of AHI in the IR bands (image credit: JMA)

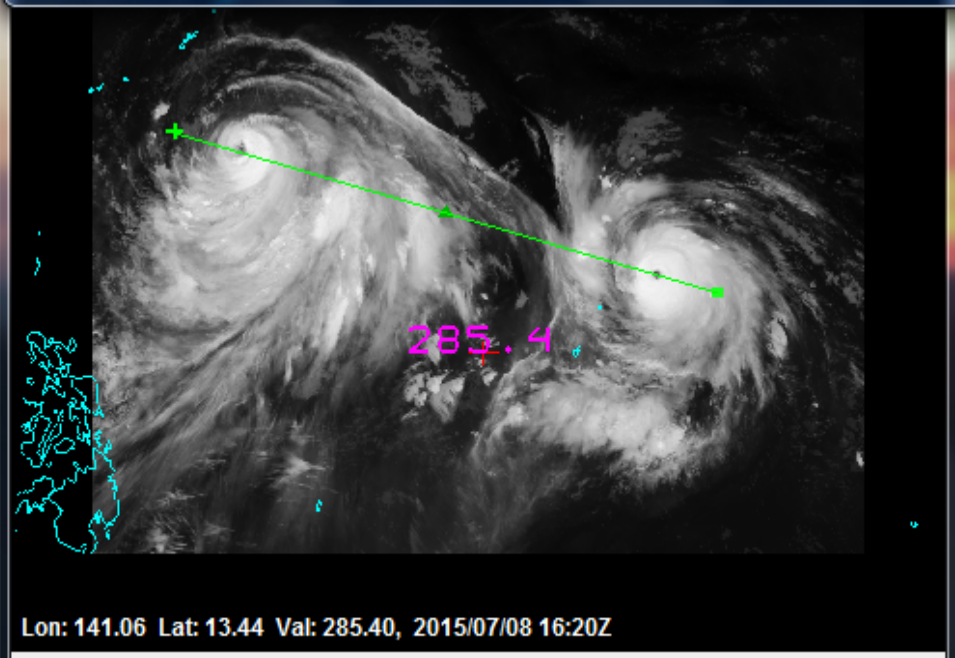
# VIIRS bands and bandwidths

| VIIRS Band | Central Wavelength (µm) | Bandwidth (µm) | Wavelength Range (µm) | Band Explanation | Spatial Resolution (m) @ nadir |
|---|---|---|---|---|---|
| M1 | 0.412 | 0.02 | 0.402 - 0.422 | Visible/ Reflective | 750 m |
| M2 | 0.445 | 0.018 | 0.436 - 0.454 | | |
| M3 | 0.488 | 0.02 | 0.478 - 0.488 | | |
| M4 | 0.555 | 0.02 | 0.545 - 0.565 | | |
| M5 (B) | 0.672 | 0.02 | 0.662 - 0.682 | | |
| M6 | 0.746 | 0.015 | 0.739 - 0.754 | Near IR | |
| M7 (G) | 0.865 | 0.039 | 0.846 - 0.885 | | |
| M8 | 1.240 | 0.020 | 1.23 - 1.25 | Shortwave IR | |
| M9 | 1.378 | 0.015 | 1.371 - 1.386 | | |
| M10 (R) | 1.61 | 0.06 | 1.58 - 1.64 | | |
| M11 | 2.25 | 0.05 | 2.23 - 2.28 | | |
| M12 | 3.7 | 0.18 | 3.61 - 3.79 | Medium-wave IR | |
| M13 | 4.05 | 0.155 | 3.97 - 4.13 | | |
| M14 | 8.55 | 0.3 | 8.4 - 8.7 | Longwave IR | |
| M15 | 10.763 | 1.0 | 10.26 - 11.26 | | |
| M16 | 12.013 | 0.95 | 11.54 - 12.49 | | |
| DNB | 0.7 | 0.4 | 0.5 - 0.9 | Visible/ Reflective | 750 m across full scan |
| I1 (B) | 0.64 | 0.08 | 0.6 - 0.68 | Visible/ Reflective | 375 m |
| I2 (G) | 0.865 | 0.039 | 0.85 - 0.88 | Near IR | |
| I3 (R) | 1.61 | 0.06 | 1.58 - 1.64 | Shortwave IR | |
| I4 | 3.74 | 0.38 | 3.55 - 3.93 | Medium-wave IR | |
| I5 | 11.45 | 1.9 | 10.5 - 12.4 | Longwave IR | |

M = Moderate (750 m) resolution bands
I = Imagery (375 m) resolution bands
DNB = Day-Night Band (or Near Constant Contrast (NCC) band)

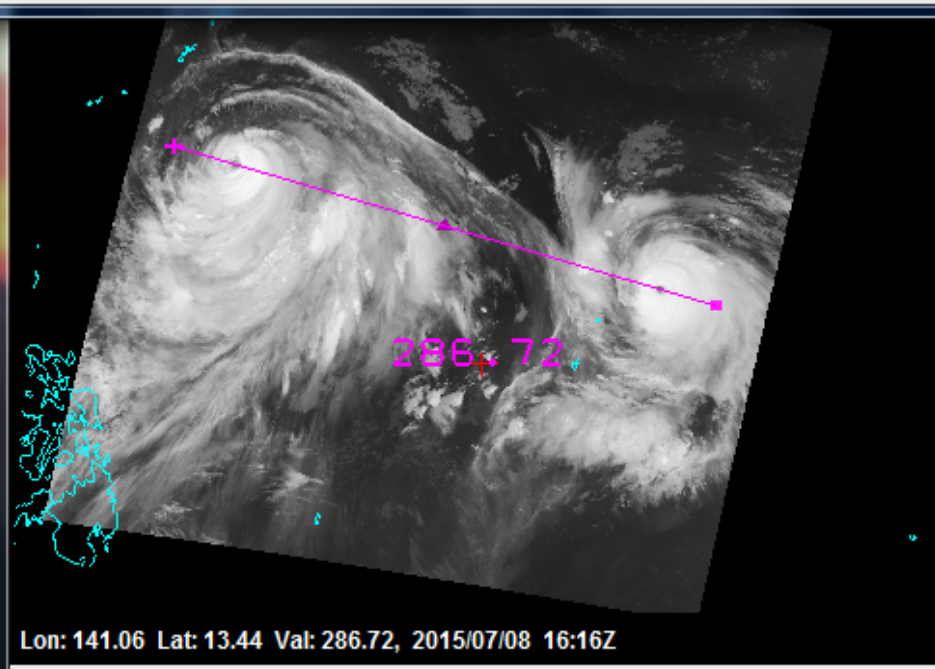
Transect Display




Lon: 141.06 Lat: 13.44 Val: 285.40, 2015/07/08 16:20Z

1:B14

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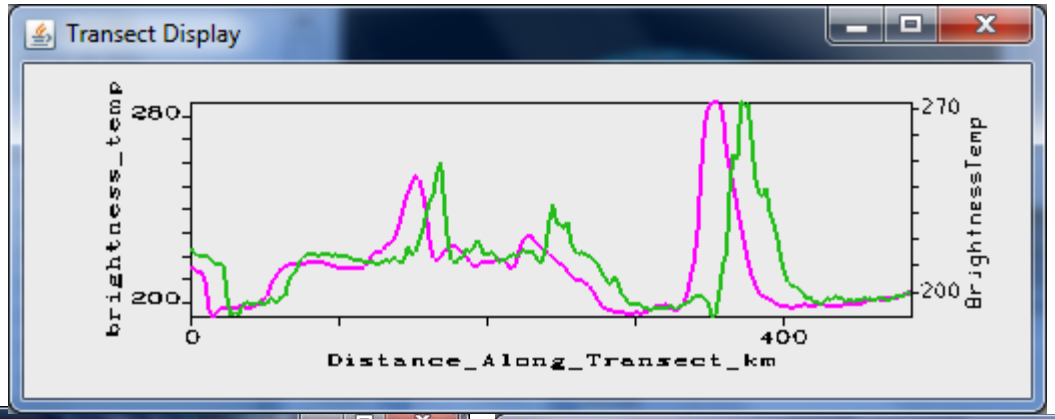
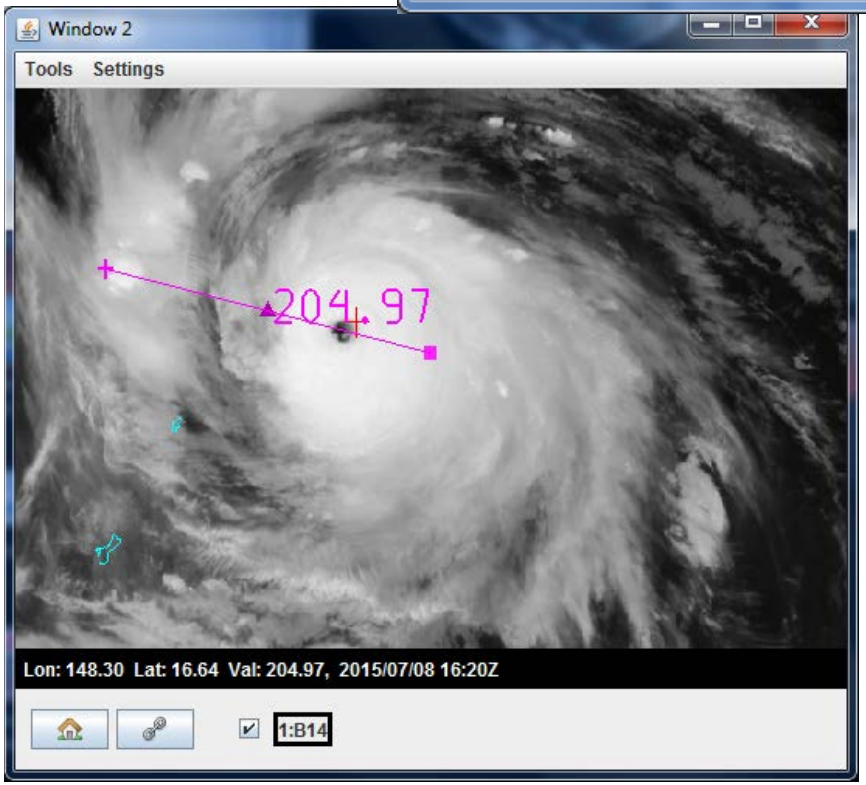
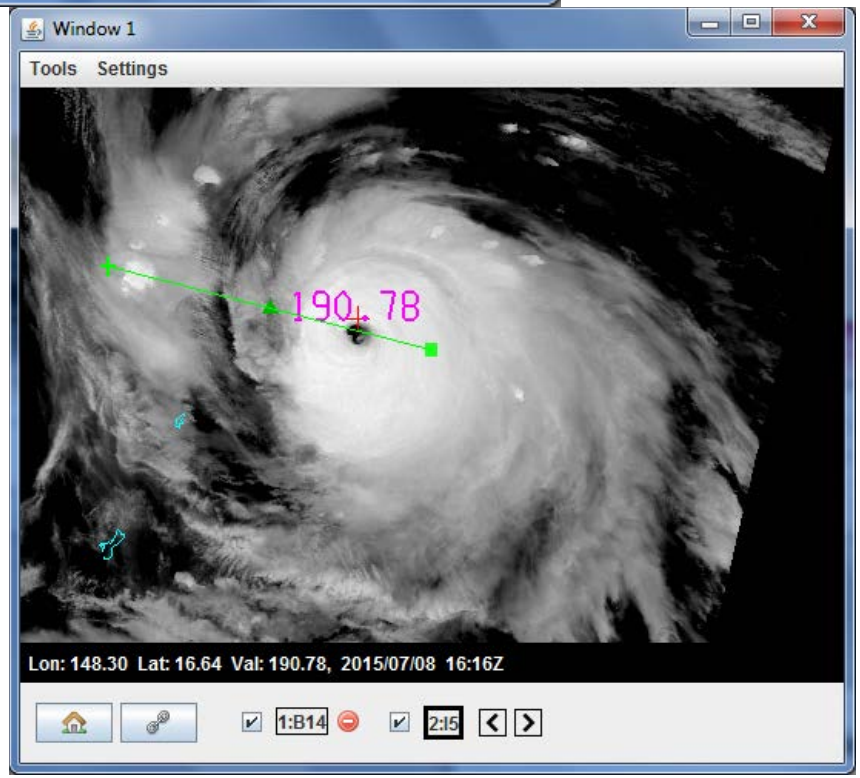
2:M15

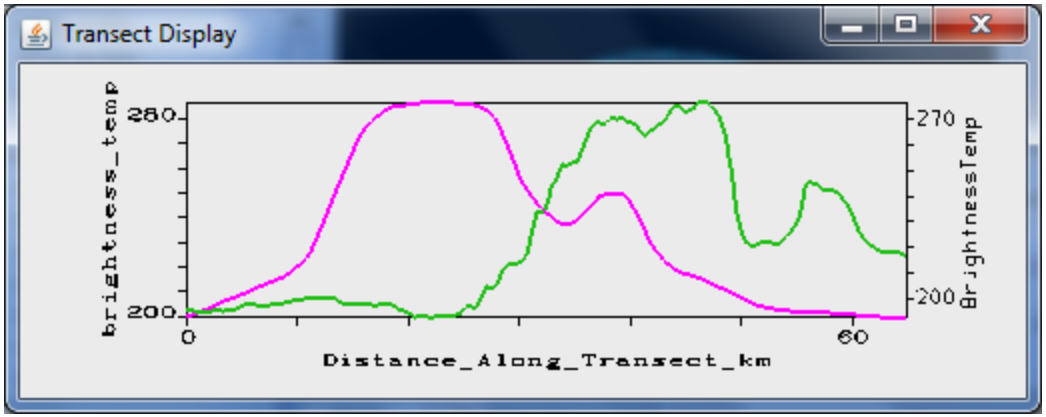
# IRW AHI (left) & VIIRS (right)

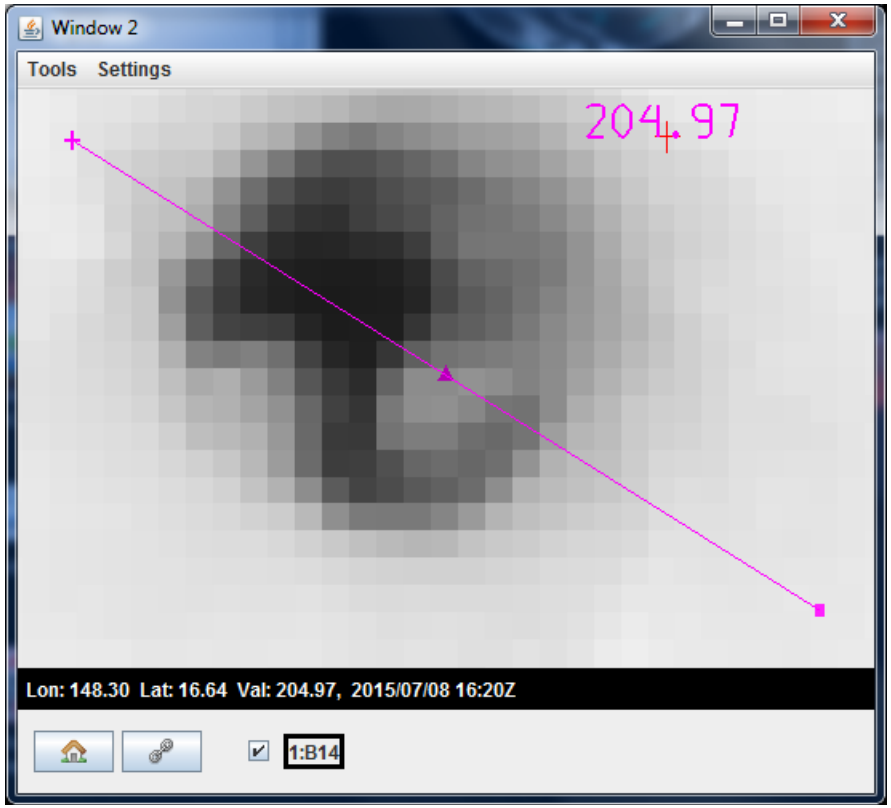


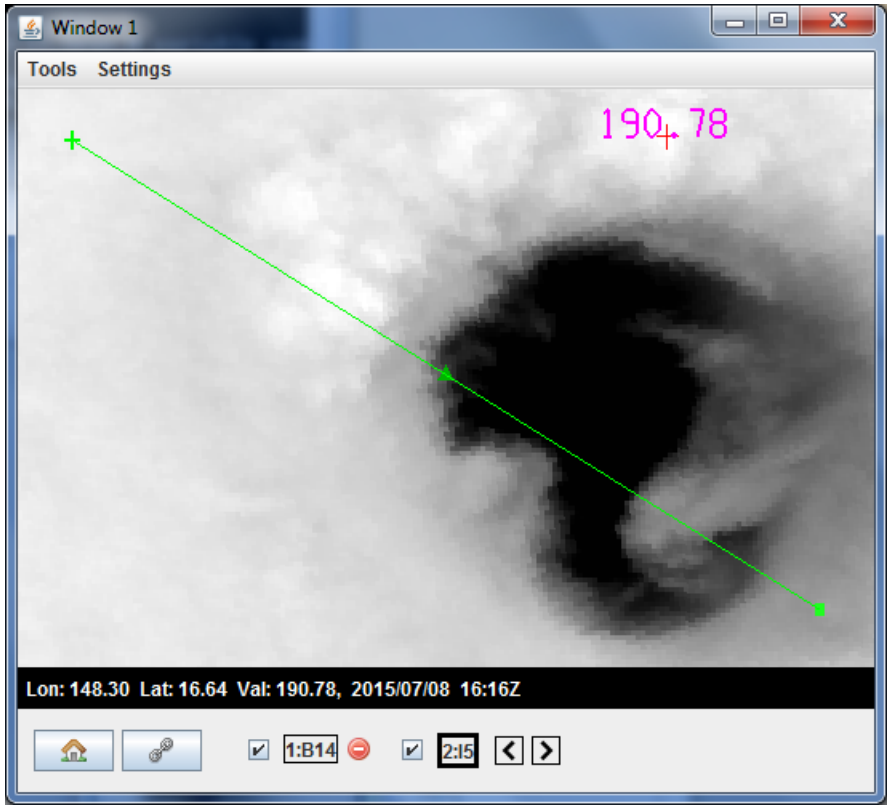



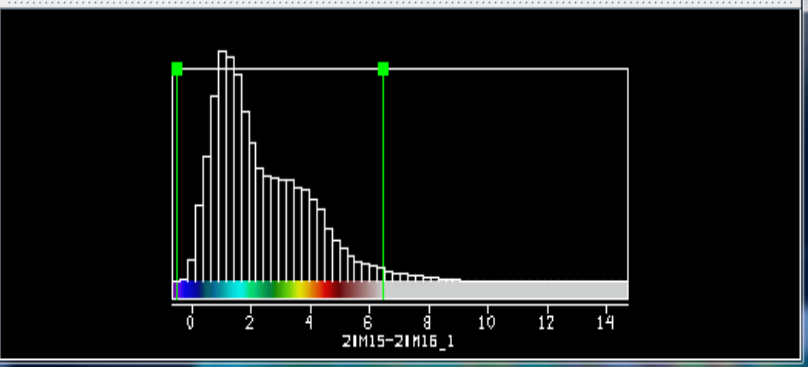
# IRW AHI (left) & VIIRS (right)



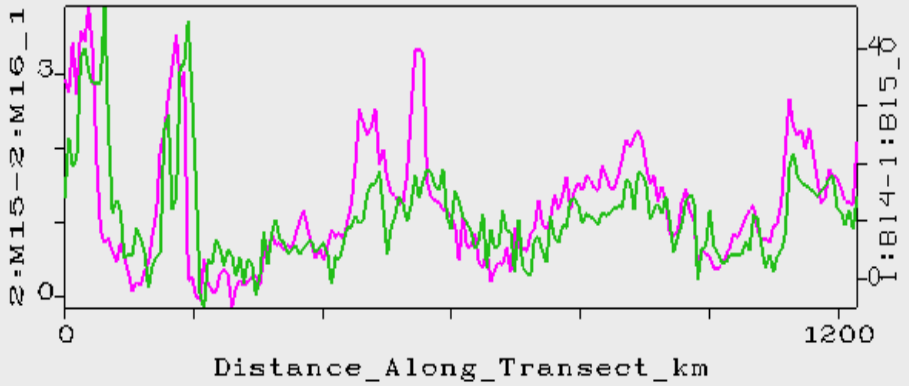



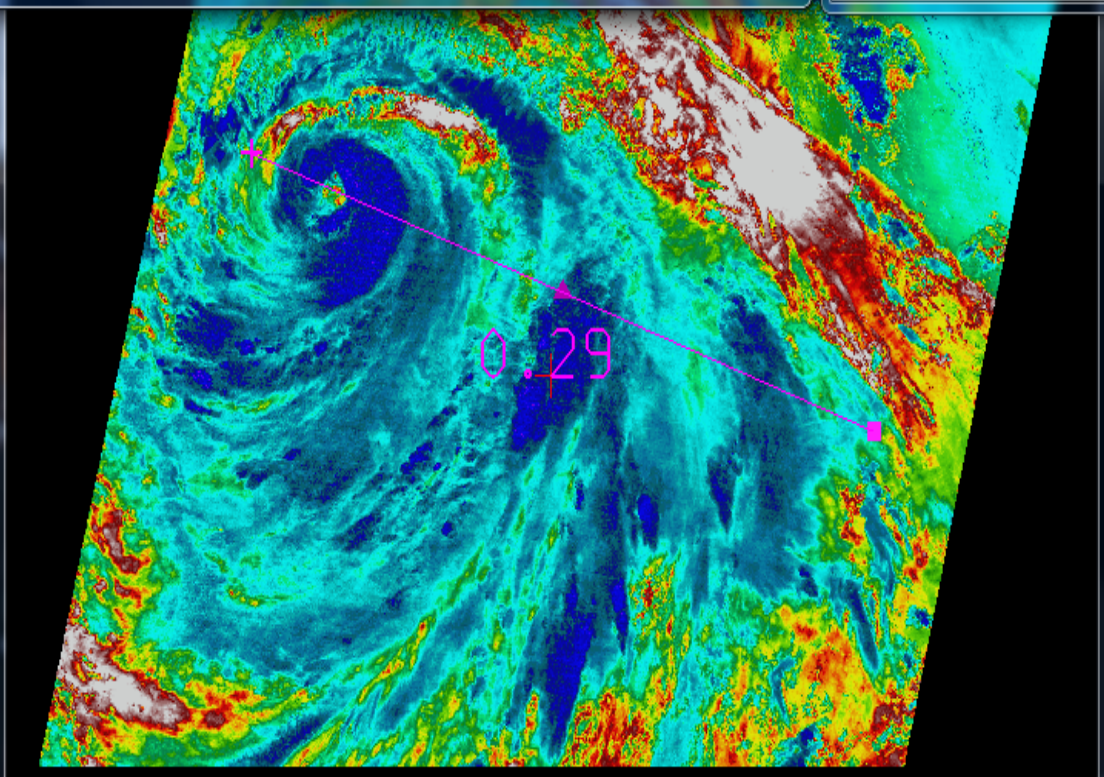



range: -0.507 6.479 Gamma: 1.0 reset Rainbow




Transcect Display

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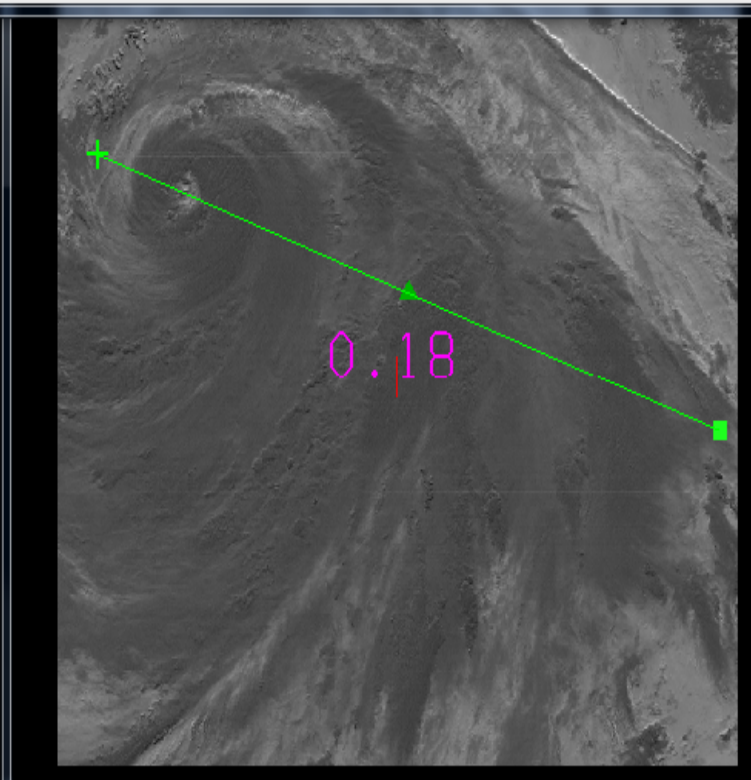


8.97 Val: 0.18, 2015/07/08 16:20Z

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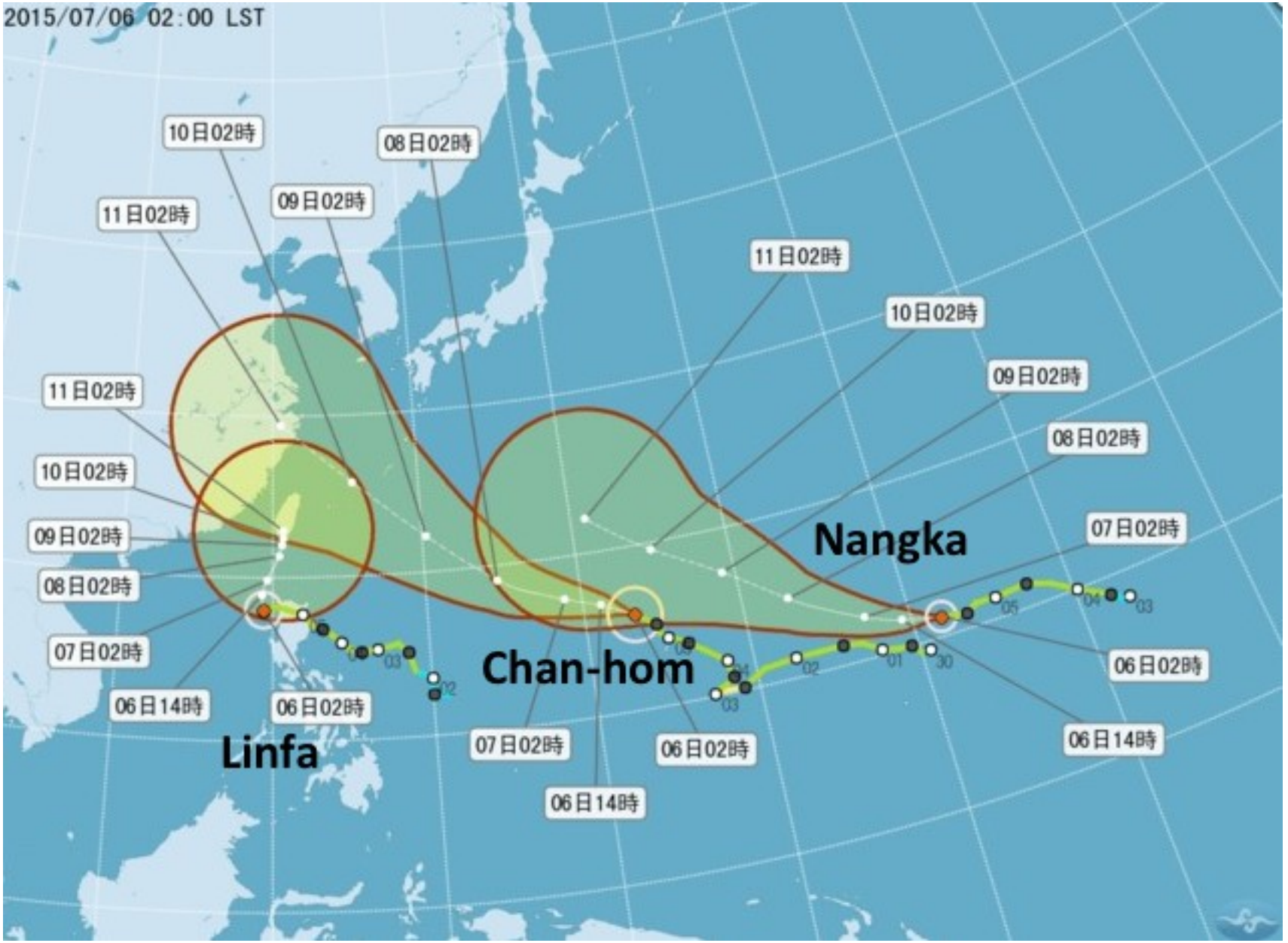
1:B14-1:B15 1:B14


2015/07/06 02:00 LST
10日02時
08日02時
11日02時
09日02時
11日02時
10日02時
09日02時
08日02時
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10日02時
09日02時
08日02時
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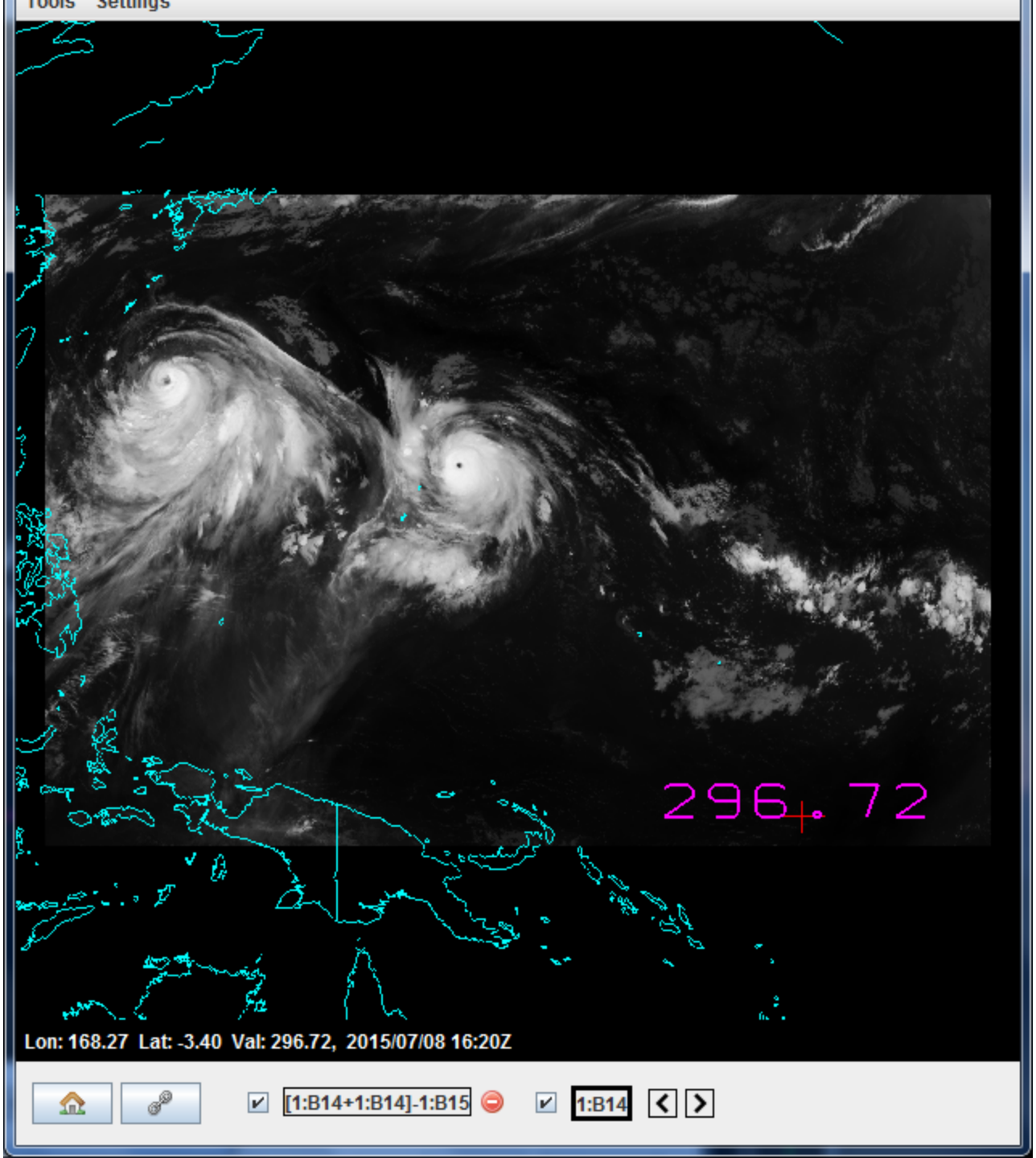
06日02時
06日14時
Nangka
Chan-hom
Linfa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296.72
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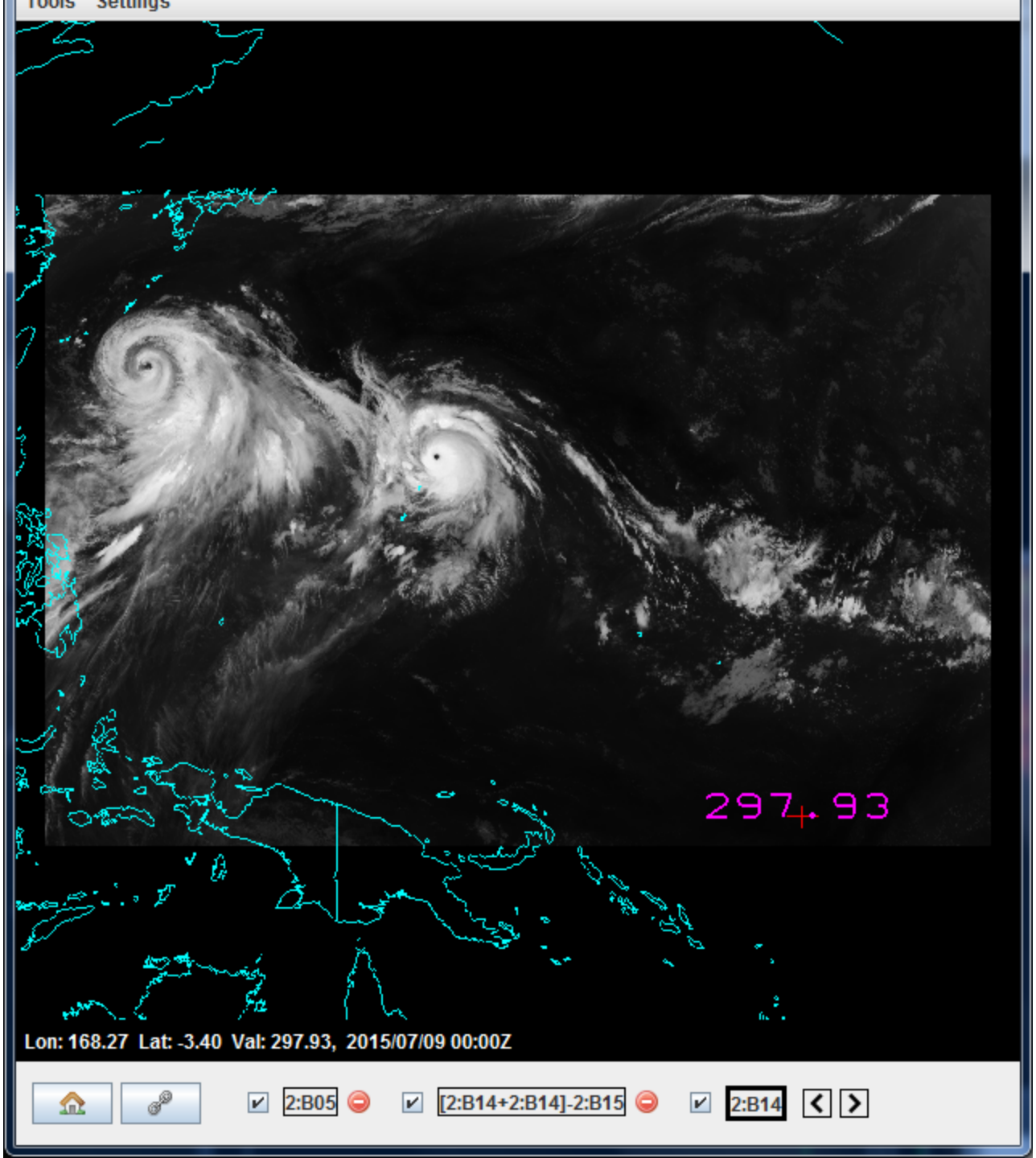
1:B14


Tools Settings
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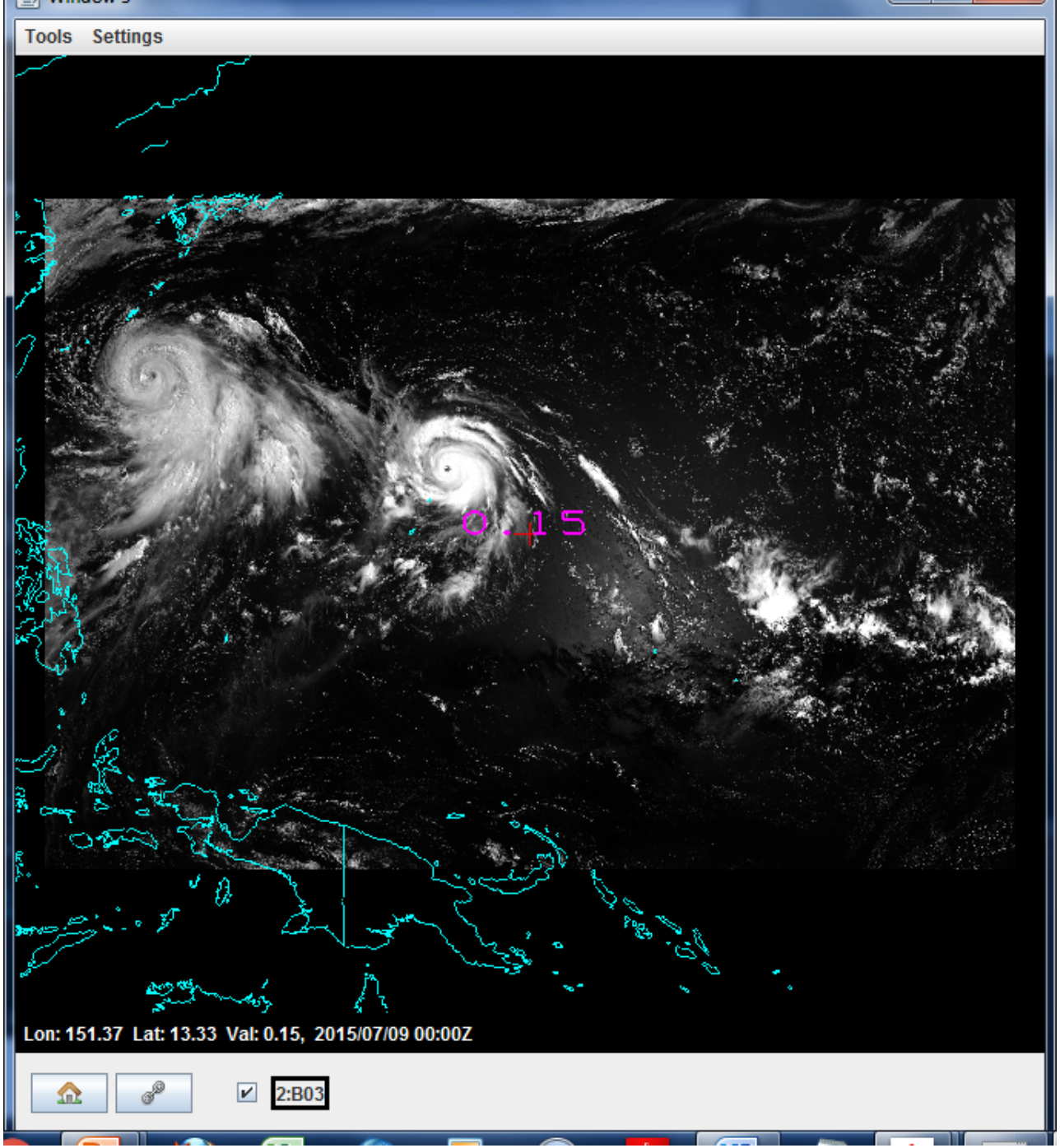
2:B14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Settings
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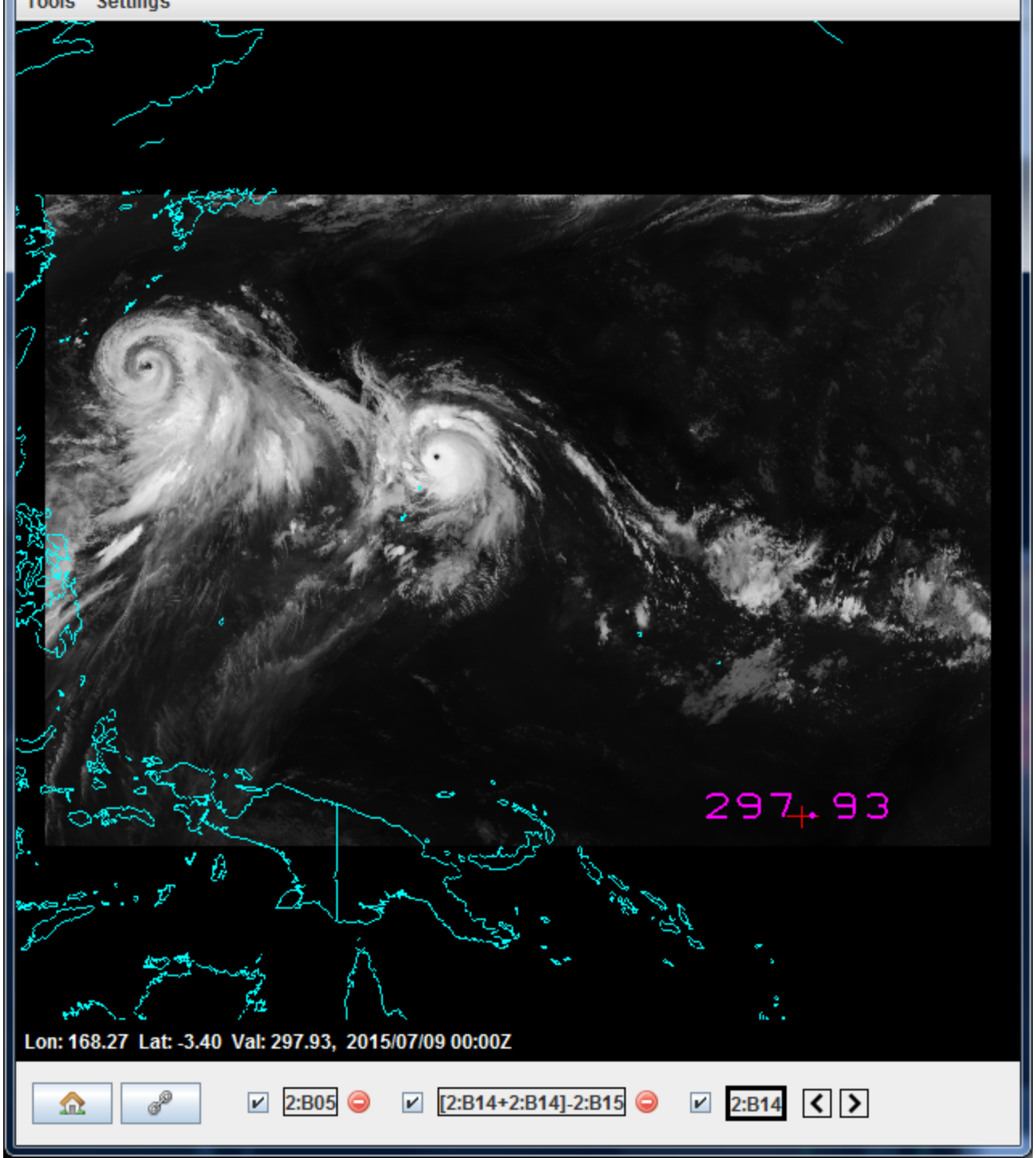
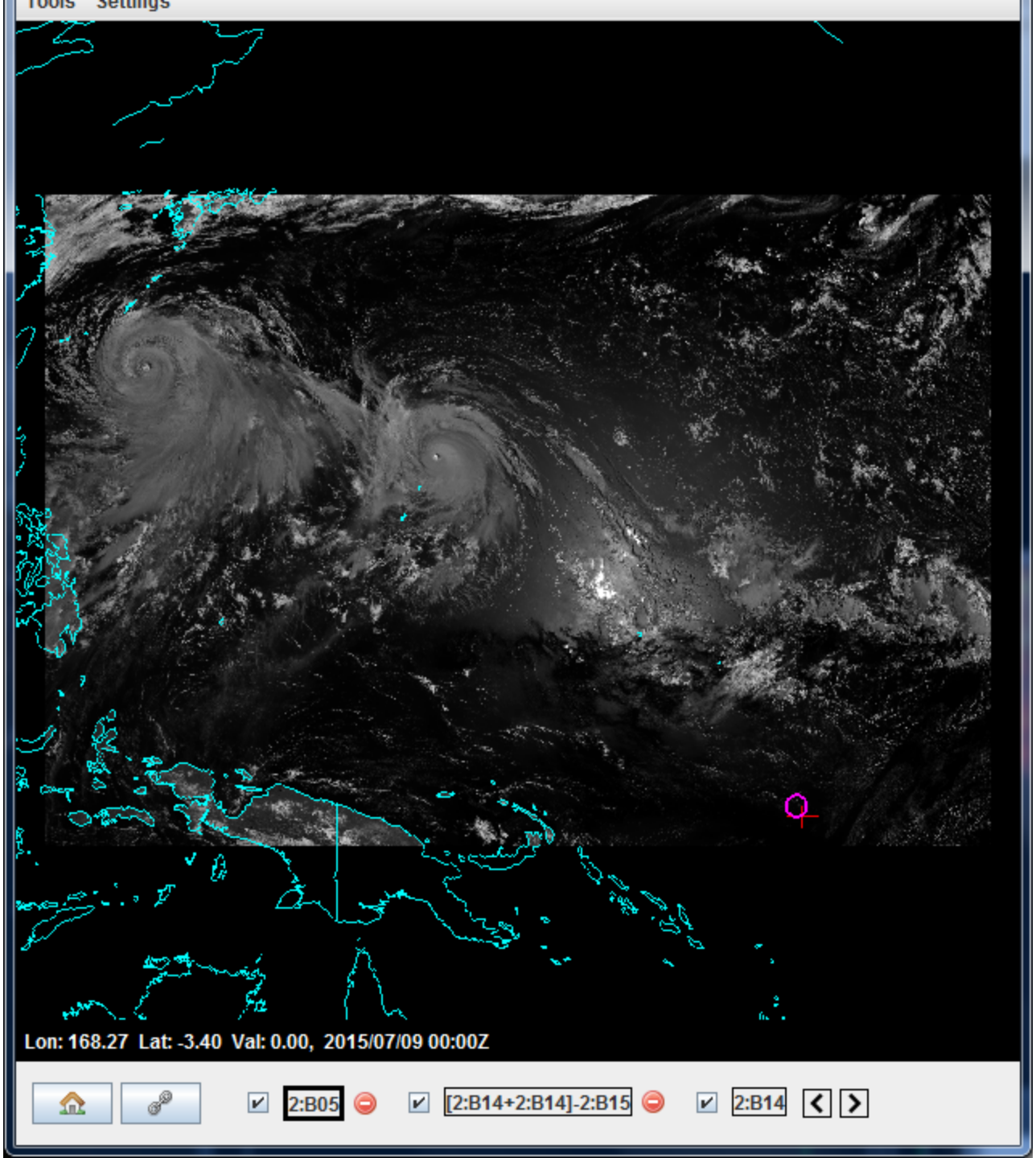
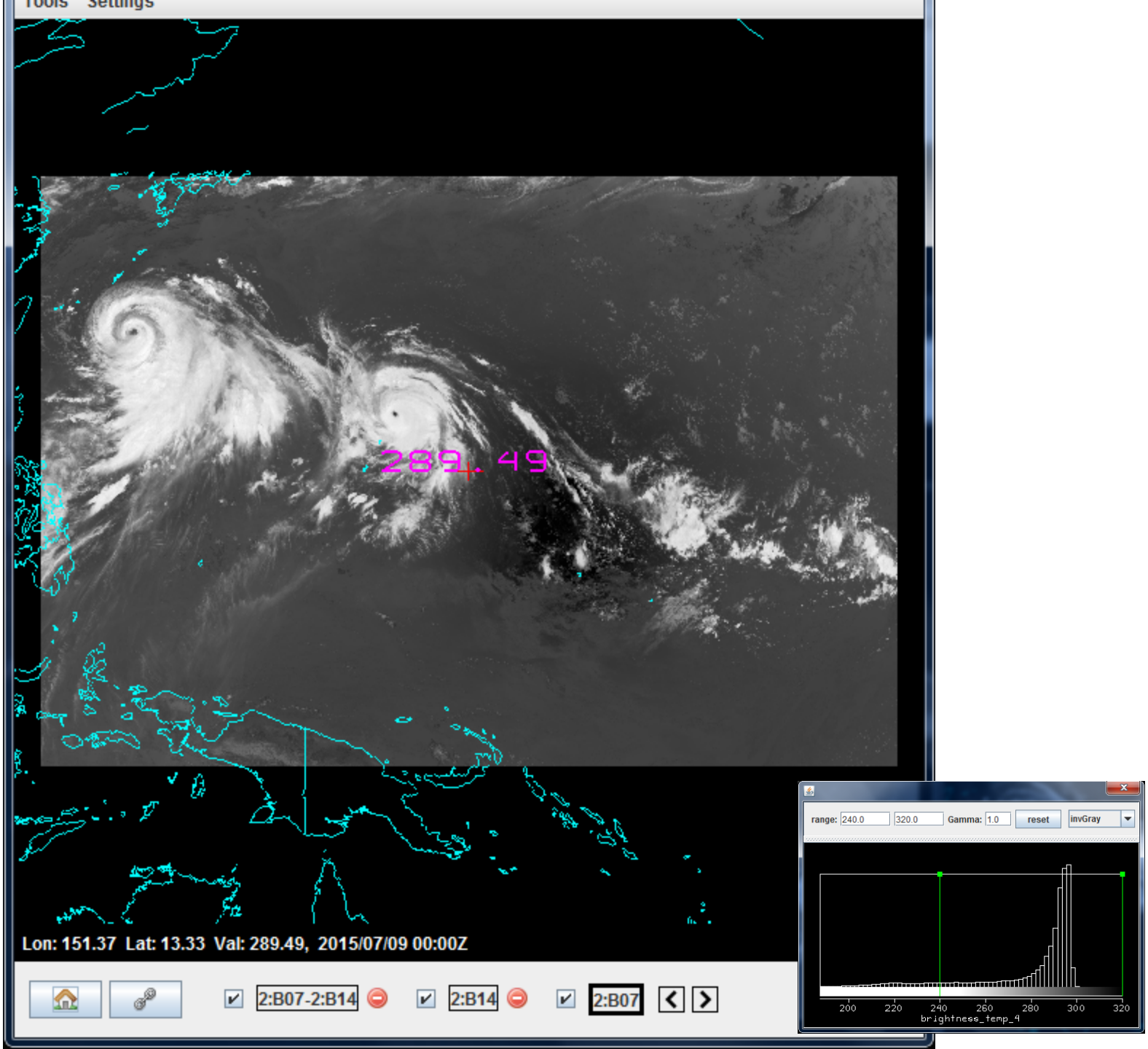
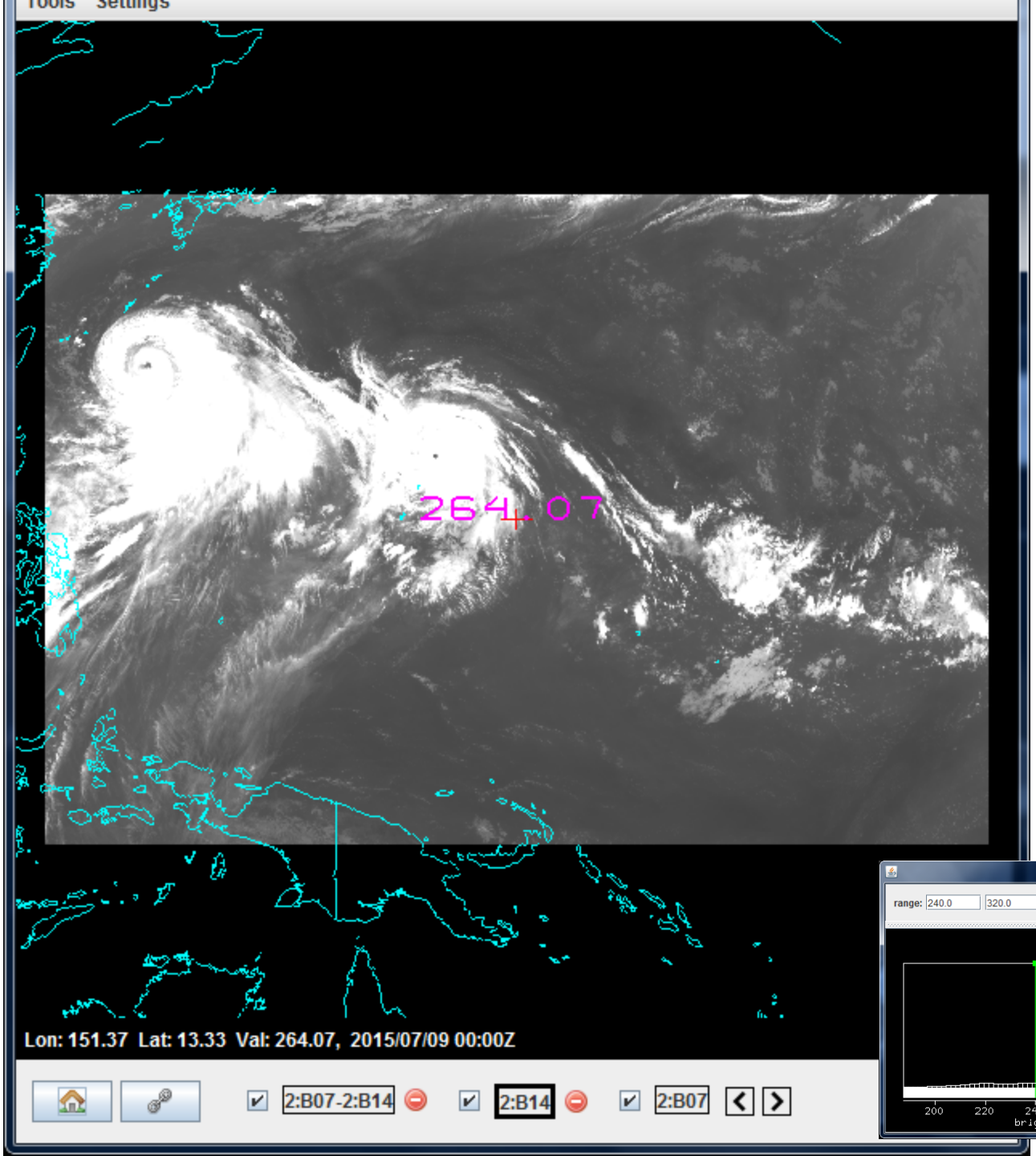
2:B03

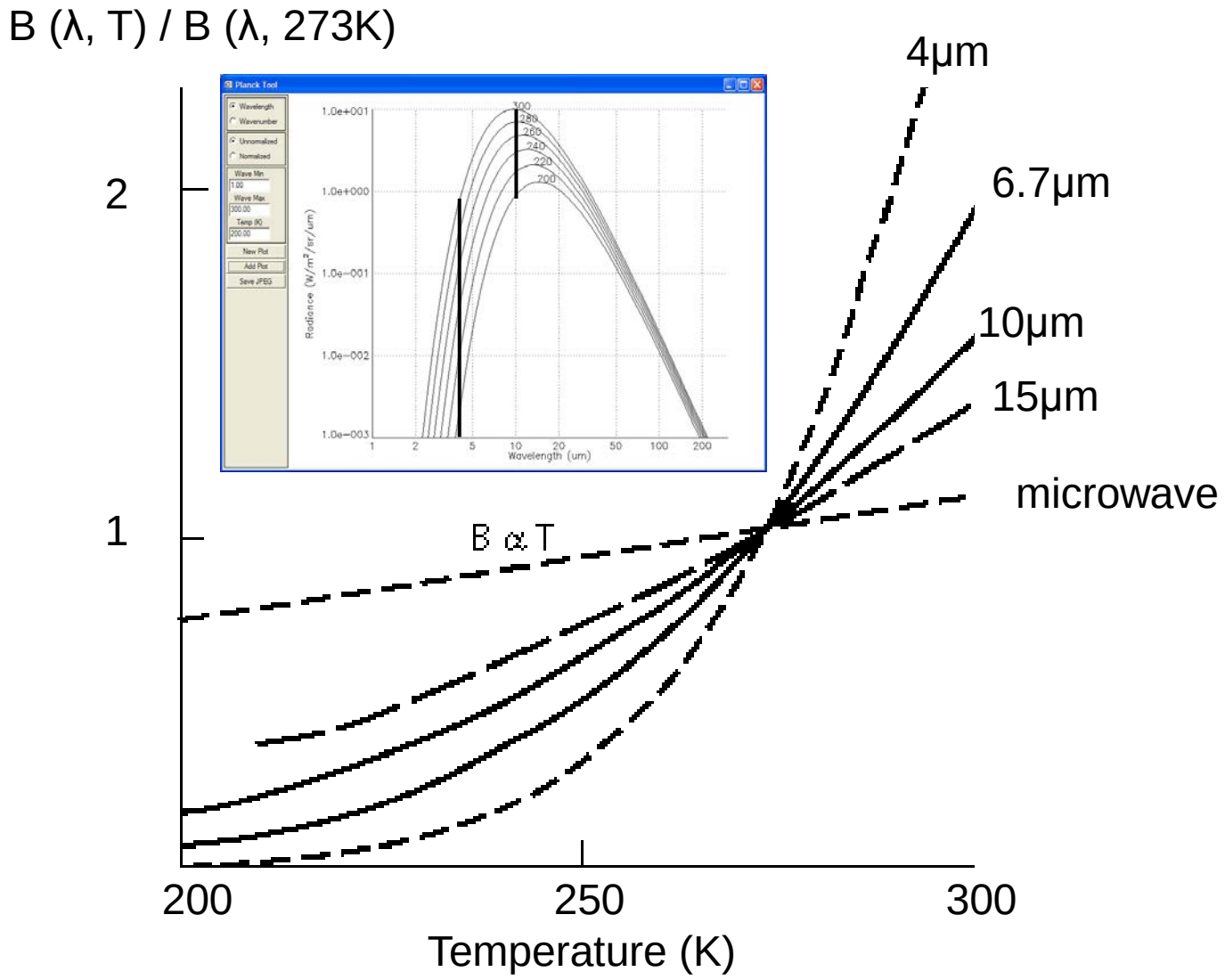

Tools Settings
297.93
Lon: 168.27 Lat: -3.40 Val: 297.93, 2015/07/09 00:00Z
2:B05
[2:B14+2:B14]-2:B15
2:B14


Tools Settings
Lon: 168.27 Lat: -3.40 Val: 0.00, 2015/07/09 00:00Z
2:B05
[2:B14+2:B14]-2:B15
2:B14

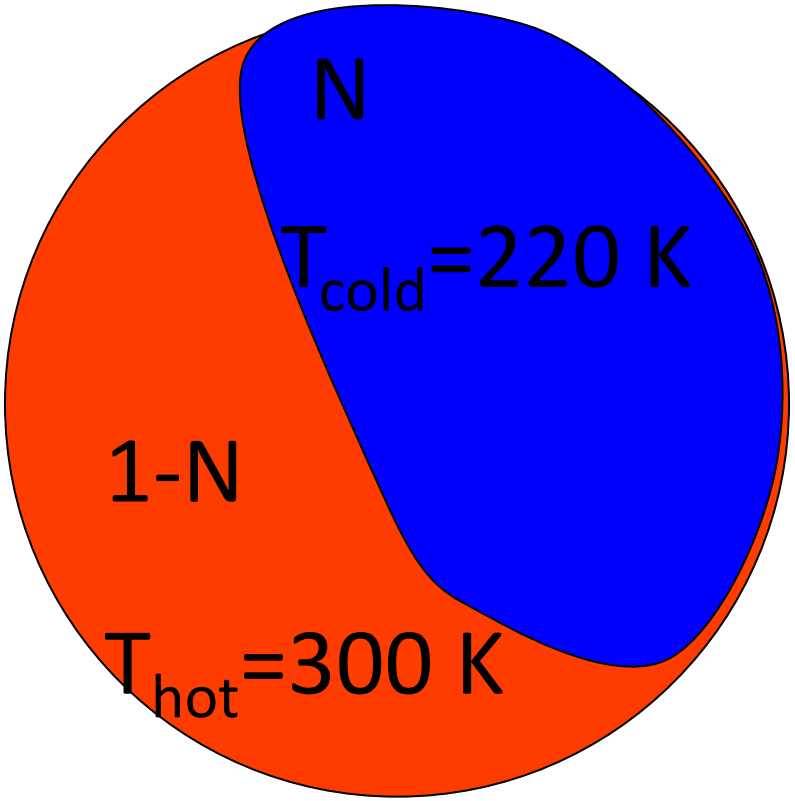

Tools Settings
289.49
Lon: 151.37 Lat: 13.33 Val: 289.49, 2015/07/09 00:00Z
2:B07-2:B14
2:B14
2:B07
range: 240.0 320.0 Gamma: 1.0 reset invGray
200 220 240 260 280 300 320
brightness_temp_4


Tools Settings
264.07
Lon: 151.37 Lat: 13.33 Val: 264.07, 2015/07/09 00:00Z
2:B07-2:B14
2:B14
2:B07
range: 240.0 320.0 Gamma: 1.0 reset invGray
200 220 240 260 280 300 320
brightness_temp_4

# Temperature Sensitivity of B(λ,T) for typical earth temperatures

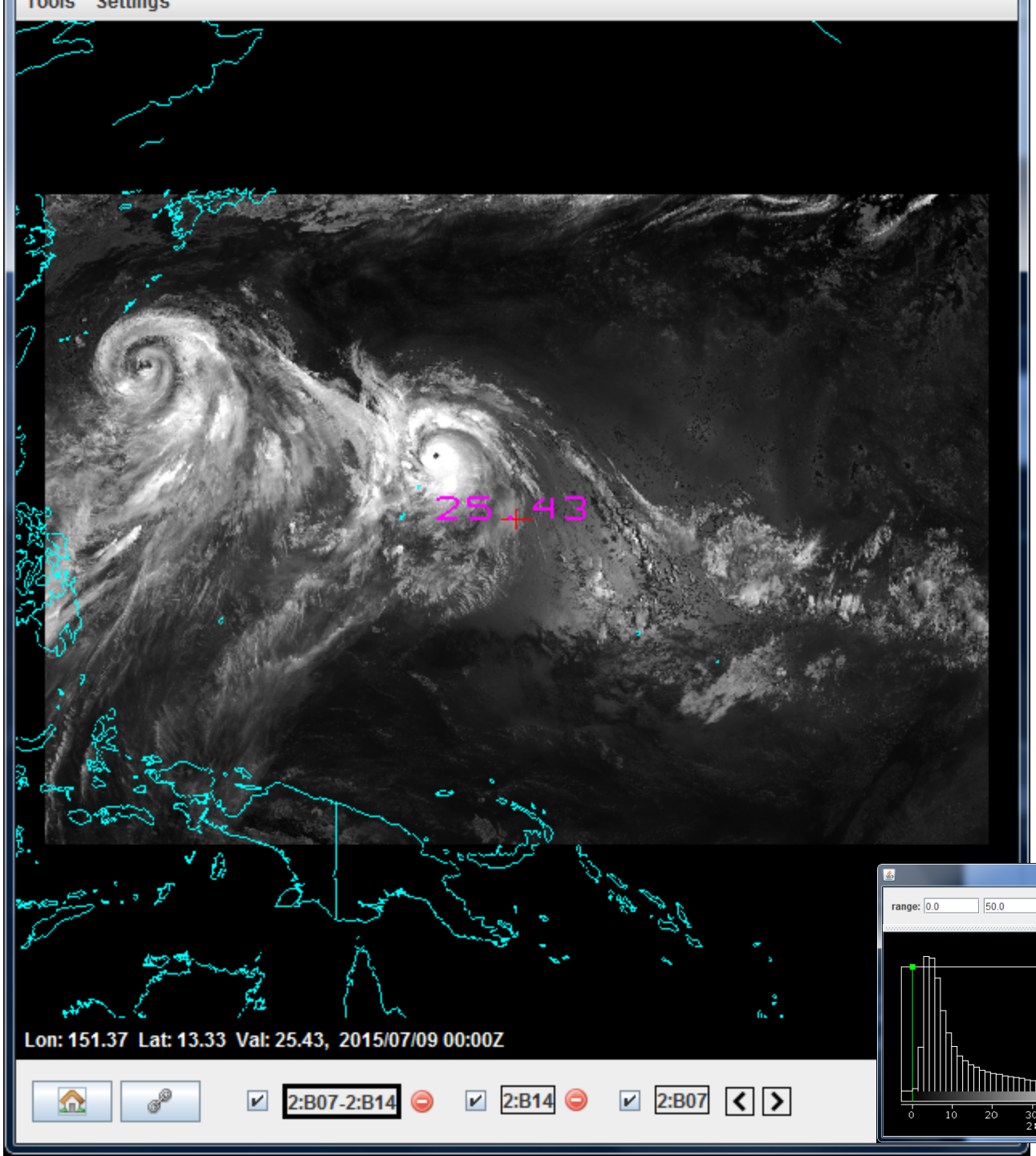


# Non-Homogeneous FOV




$$B=N*B(T_{cold})+(1-N)*B(T_{hot})$$

$$BT=N*T_{cold}+(1-N)*T_{hot}$$


Tools Settings
25 43
Lon: 151.37 Lat: 13.33 Val: 25.43, 2015/07/09 00:00Z
2:B07-2:B14
2:B14
2:B07
range: 0.0 50.0 Gamma: 1.0 reset gray
0 10 20 30 40 50 60 70 80
2:B07-2:B14_5

BT11=265K and BT4=290K.

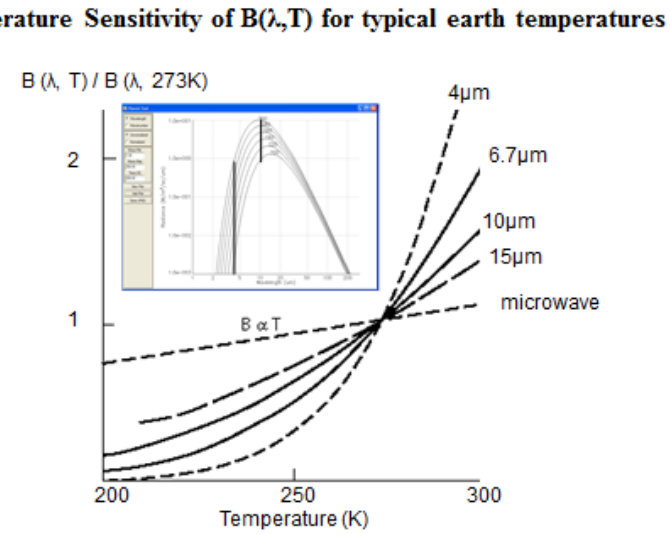
What fraction of R4 is due to reflected solar radiance?

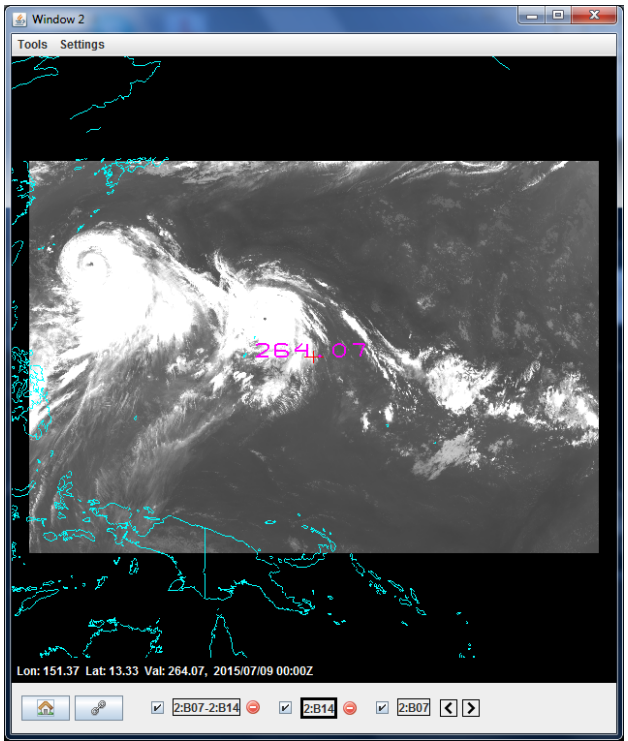
R4 = R4 refl + R4 emiss

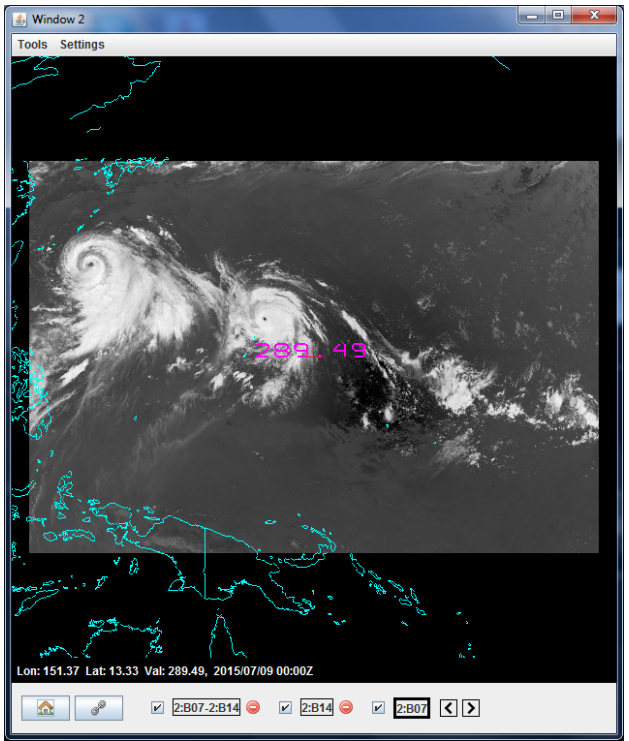
BT4 emiss = BT11

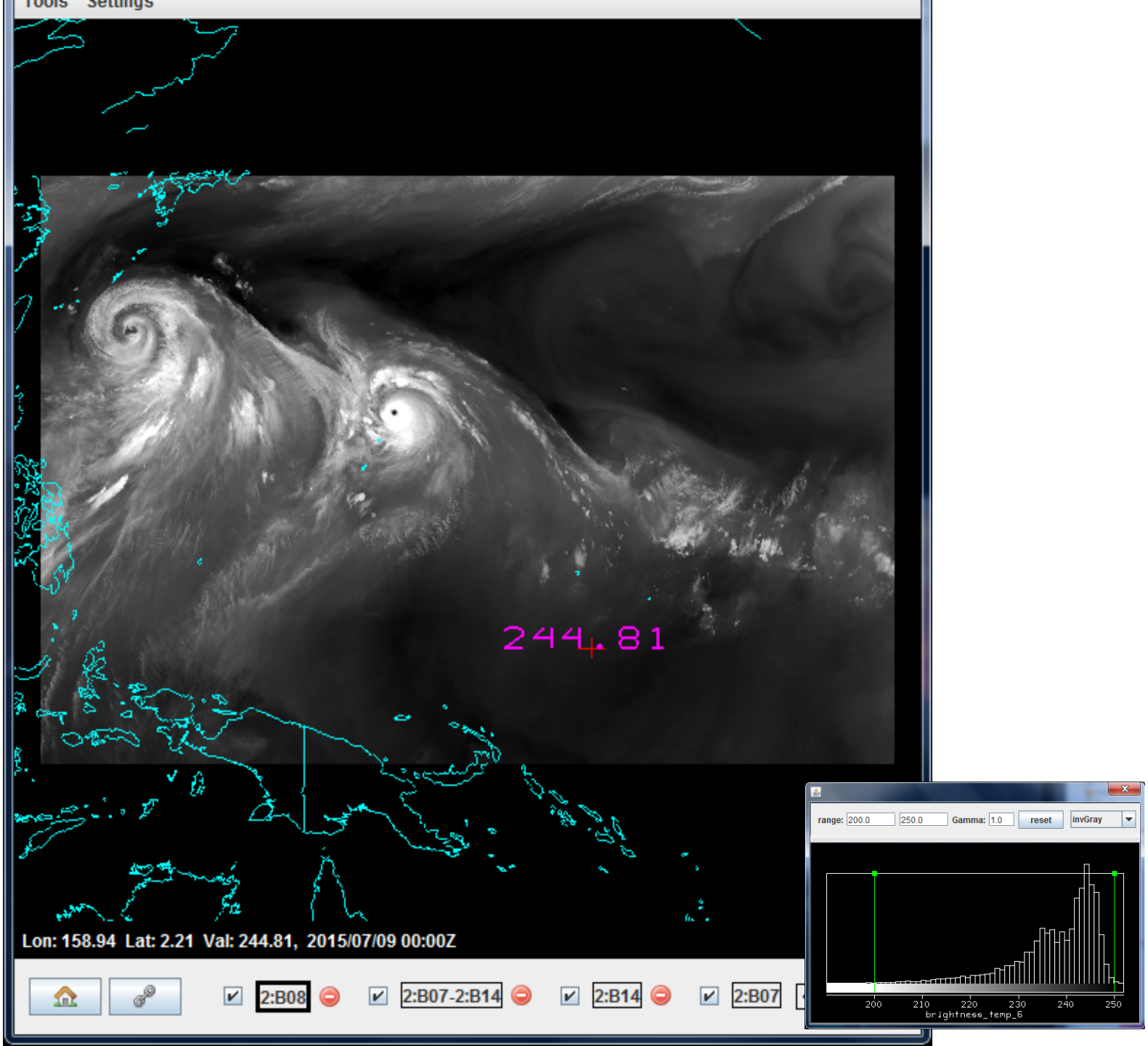
R4 ~ T**12

Fraction = [$290^{12}$–$265^{12}$] / $290^{12}$ ~ .66




Tools Settings
244.81
Lon: 158.94 Lat: 2.21 Val: 244.81, 2015/07/09 00:00Z
2:B08
2:B07-2:B14
2:B14
2:B07
range: 200.0 250.0 Gamma: 1.0 reset invGray
200 210 220 230 240 250
brightness_temp_6

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T_{sfc}) \tau_\lambda(sfc - top) + \sum_{layers} \varepsilon_\lambda^{layer} B_\lambda(T_{layer}) \tau_\lambda(layer - top)$$

The emission of an infinitesimal layer of the atmosphere at pressure p is equal to the absorption (1 - transmission). So,

$$\varepsilon_\lambda(layer)\, \tau_\lambda(layer \text{ to } top) = [1 - \tau_\lambda(layer)]\, \tau_\lambda(layer \text{ to } top)$$

Since transmission is multiplicative

$$\tau_\lambda(layer \text{ to } top) - \tau_\lambda(layer)\, \tau_\lambda(layer \text{ to } top) = -\Delta\tau_\lambda(layer \text{ to } top)$$

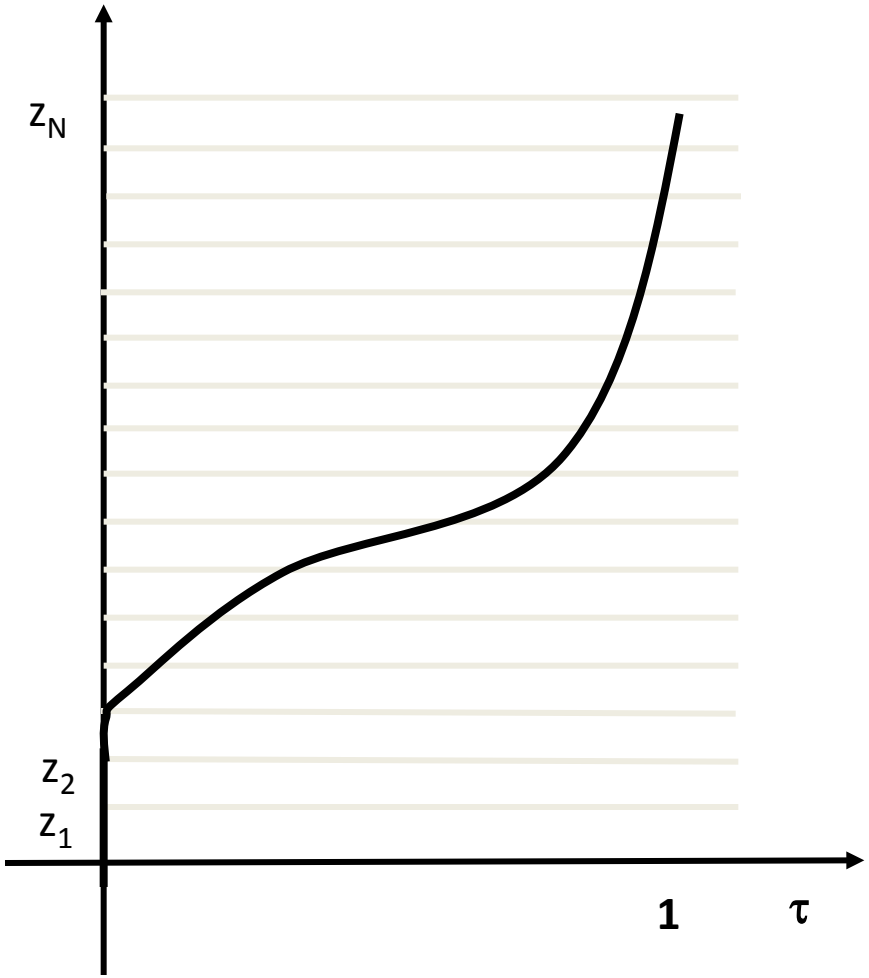
So we can write

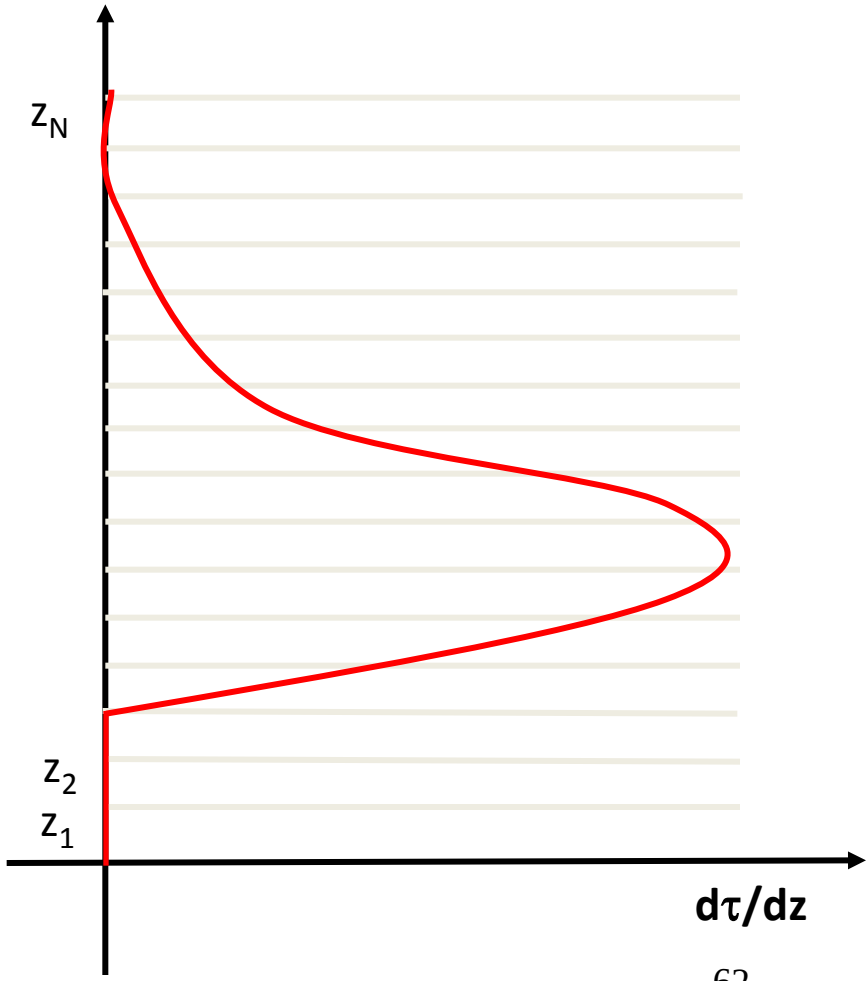
$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \sum_{p} B_\lambda(T(p))\, \Delta\tau_\lambda(p) .$$

which when written in integral form reads

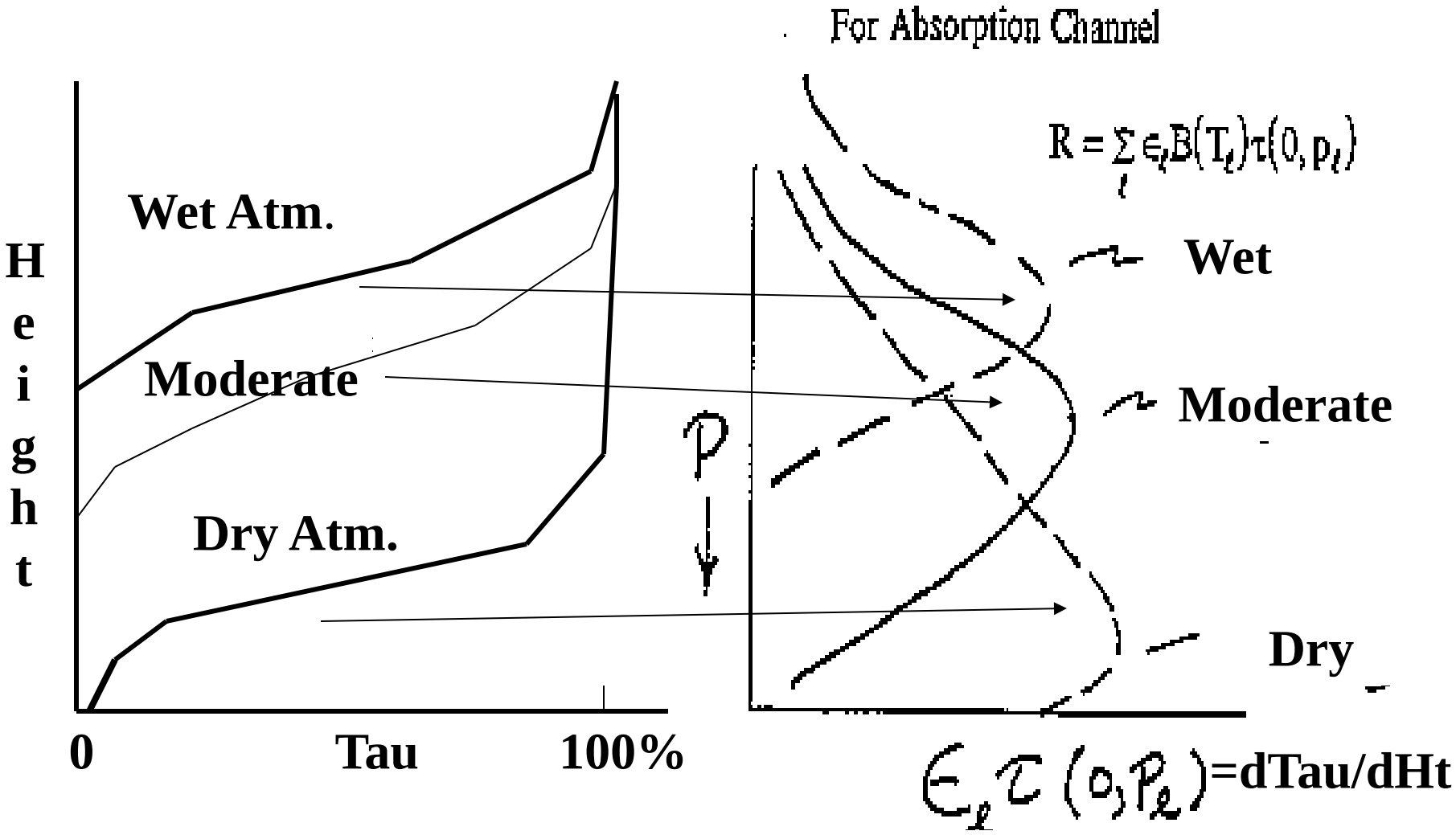
$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \int_{o}^{p_s} B_\lambda(T(p))\, [\, d\tau_\lambda(p) / dp \,]\, dp .$$

# Weighting Functions

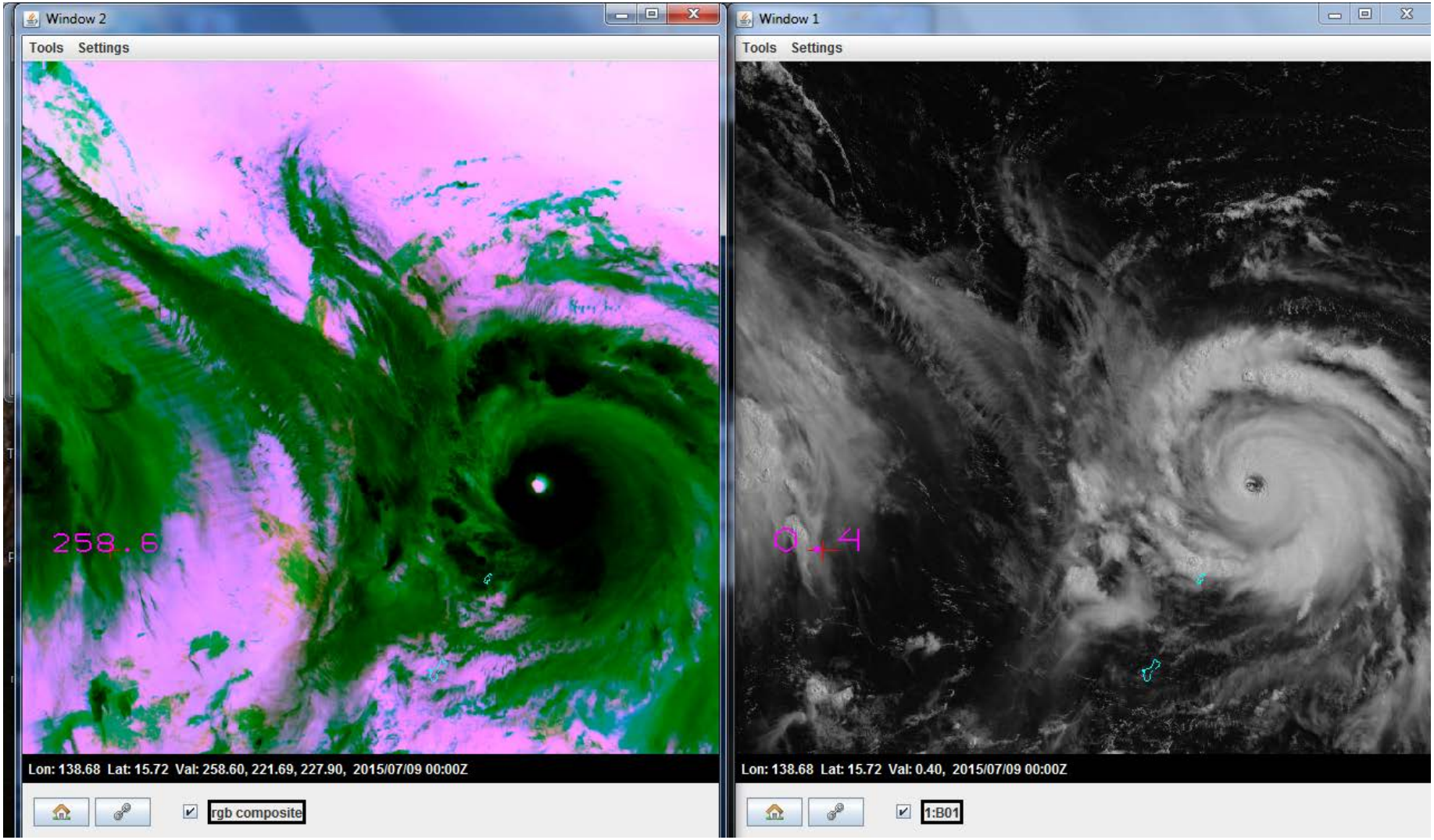


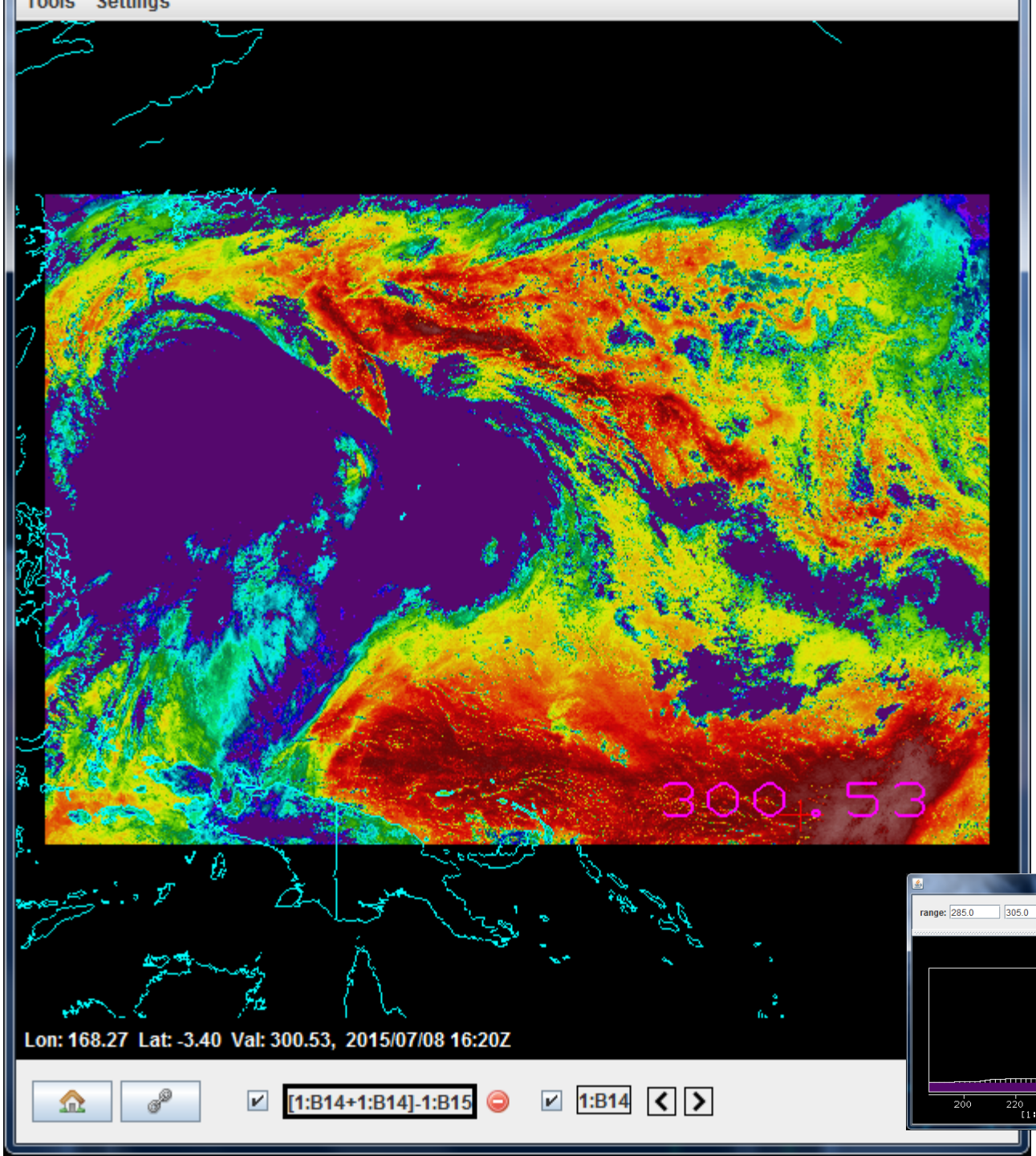
**For a given water vapor spectral channel the weighting function depends on the amount of water vapor in the atmospheric column**

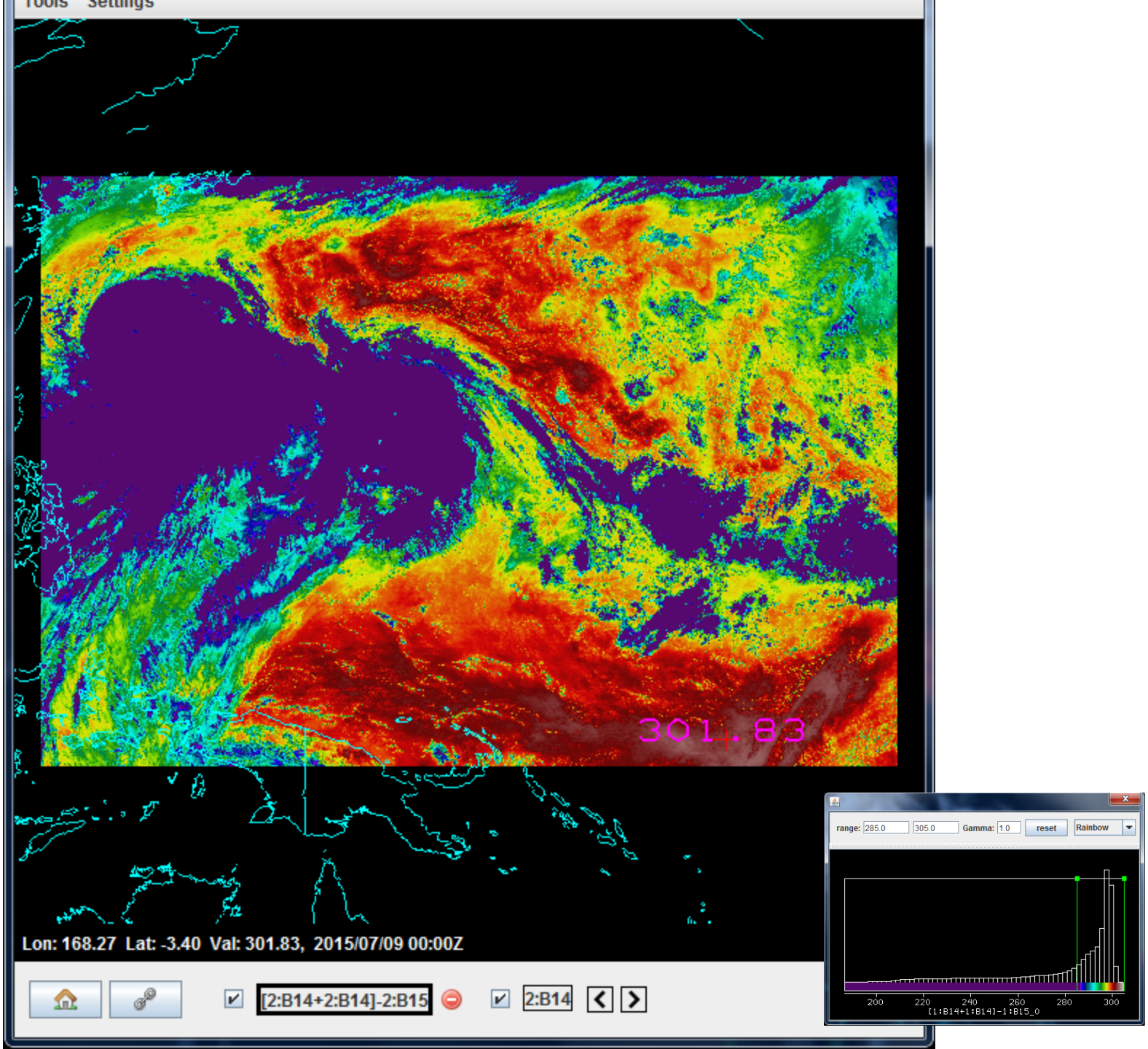



**CO2 is about the same everywhere, the weighting function for a given CO2 spectral channel is the same everywhere**




# R-SWIRW, G-WV, B-LWIRW


Tools
Settings
300.53
Lon: 168.27 Lat: -3.40 Val: 300.53, 2015/07/08 16:20Z
[1:B14+1:B14]-1:B15
1:B14
range: 285.0 305.0 Gamma: 1.0 reset Rainbow
200 220 240 260 280 300
[1:B14+1:B14]-1:B15_0


Tools
Settings
301.83
Lon: 168.27 Lat: -3.40 Val: 301.83, 2015/07/09 00:00Z
[2:B14+2:B14]-2:B15
2:B14
range: 285.0
305.0
Gamma: 1.0
reset
Rainbow
200
220
240
260
280
300
[1:B14+1:B14]-1:B15_0

## First Order Estimation of SST

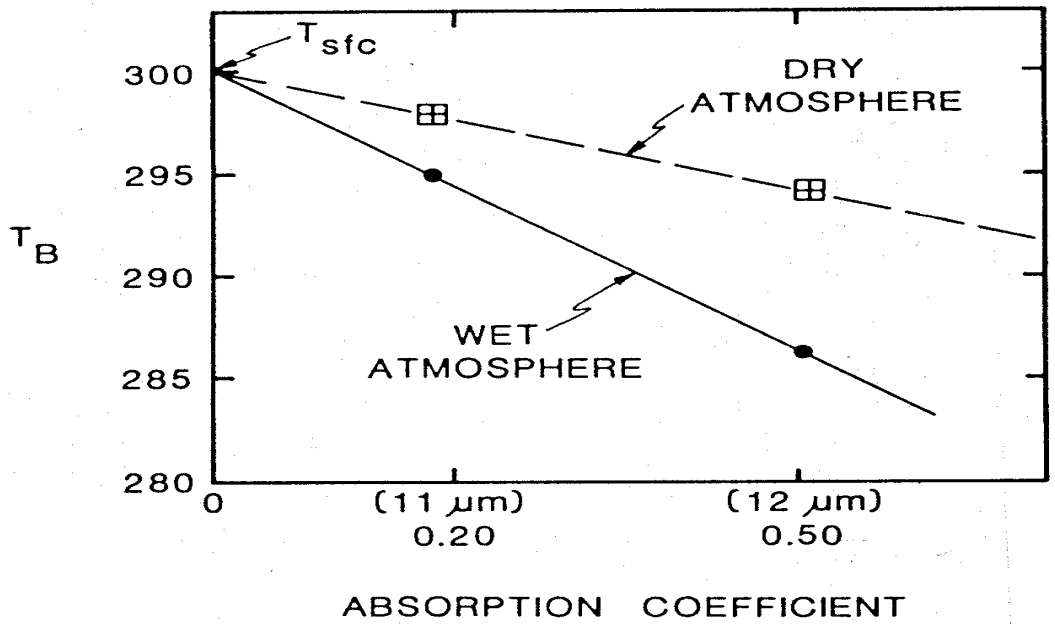
Moisture attenuation in atmospheric windows varies linearly with optical depth.

$$\tau_\lambda = e^{-k_\lambda u} = 1 - k_\lambda u$$

For same atmosphere, deviation of brightness temperature from surface temperature is a linear function of absorbing power. Thus moisture corrected SST can inferred by using split window measurements and extrapolating to zero $k_\lambda$

$$T_s = T_{bw1} + [\, k_{w1} / (k_{w2} - k_{w1}) \,] [T_{bw1} - T_{bw2}] = a0 + a1\, T_{bw1} + a2\, T_{bw2} .$$

Moisture content of atmosphere can be inferred from slope of linear relation.



# REMOTE SENSING APPLICATIONS WITH METEOROLOGICAL SATELLITES

by

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University of Wisconsin
Madison, WI

November 2012



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# Arigatō

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