Realtime Level-1 Processing

EOS Direct Broadcast

Terra (10:30 am local descending)

• Direct broadcast of MODIS only

• Deep Space Network outages (Canberra, Goldstone, Madrid)

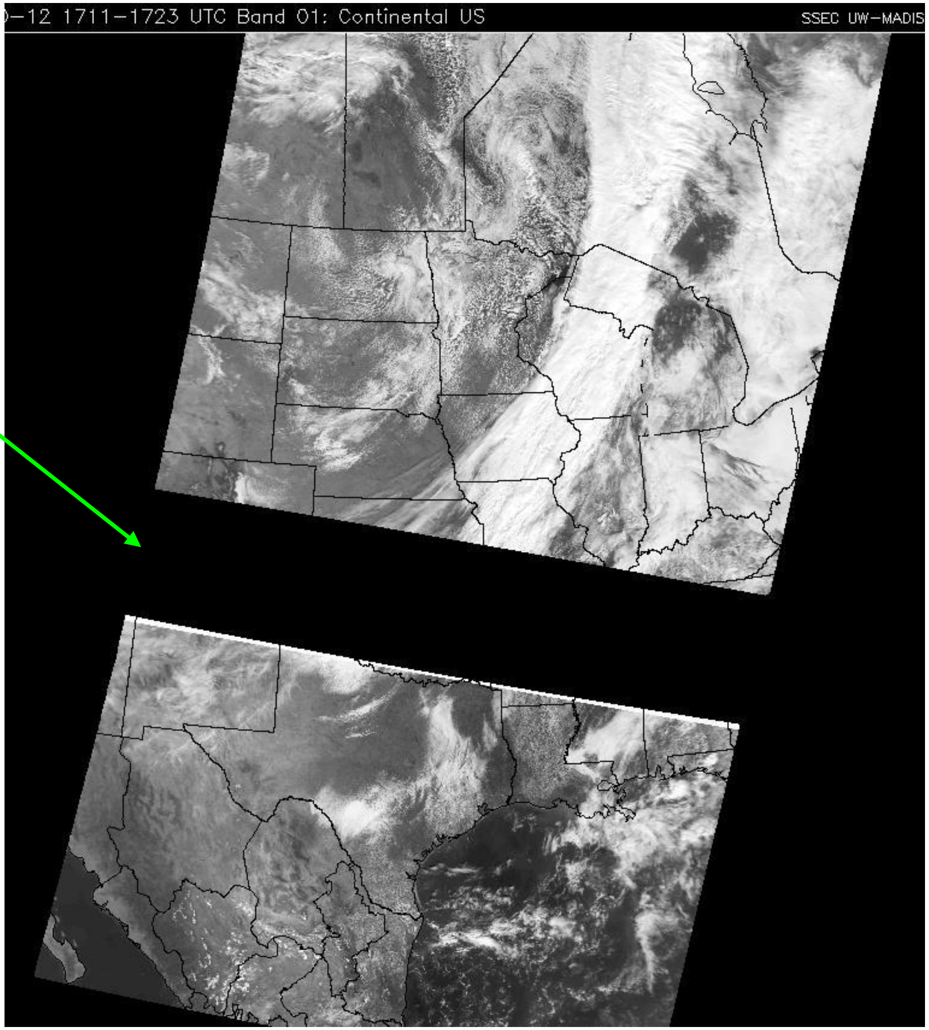
• 13.125 Mb/sec data rate

Aqua (10:30 am local ascending)

• Direct broadcast of all data

• Polar Ground Station outages (Svalbard, Alaska)

• 15 Mb/sec data rate



EOS Direct Broadcast Groundstation

TeraScan SX-EOS 4.4 m antenna: First data acquired 2000/08/18

International MODIS/AIRS Processing Package

Goal:

Transform direct broadcast Level-0 data (initially from MODIS) to calibrated & geolocated radiances (Level-1B).

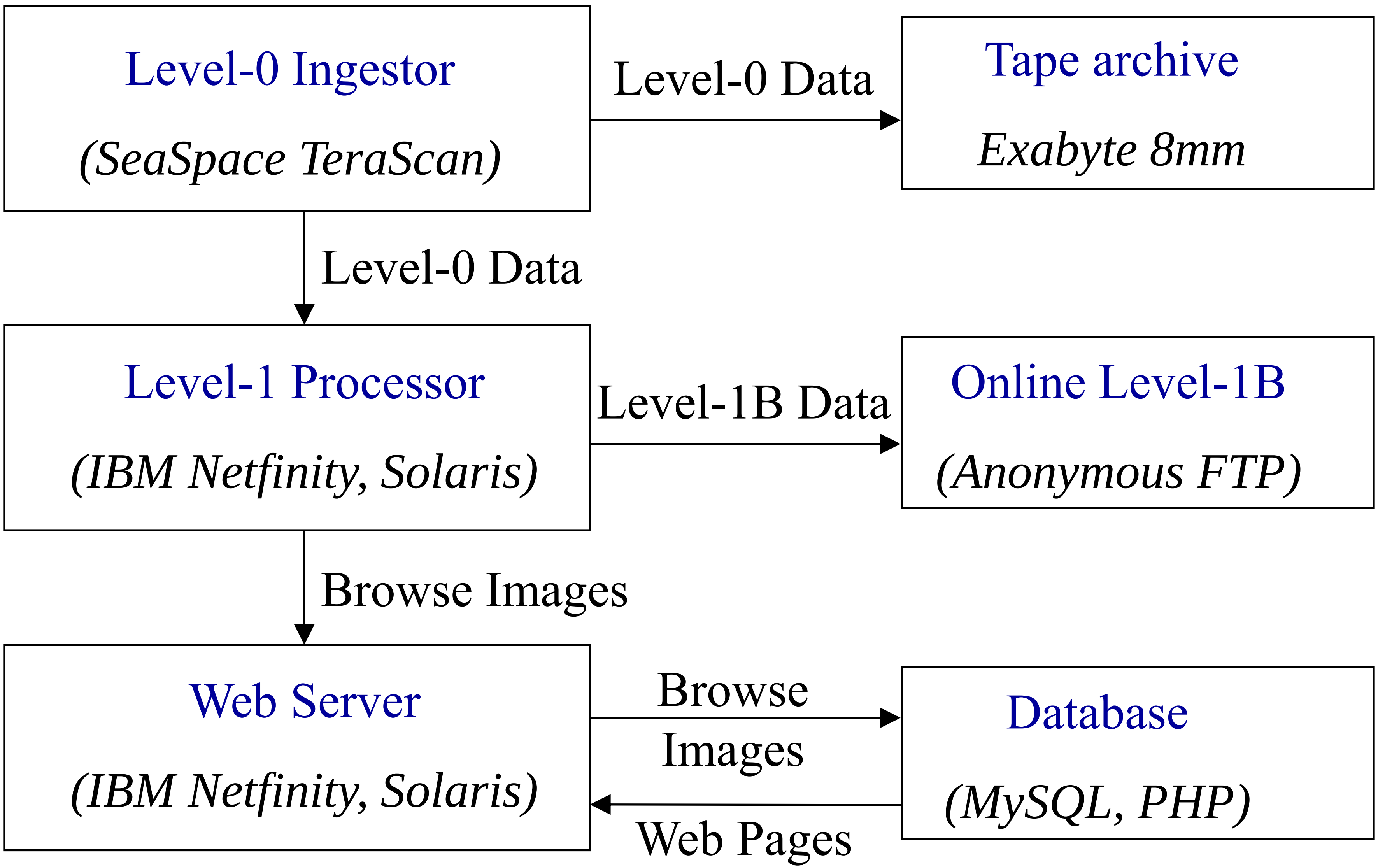
IMAPP Features:

- Ported to a range of platforms (IRIX, SunOS, AIX, HPUX, Linux),
- Only tool kit required is NCSA HDF 4.1r3,
- Processing environment is greatly simplified,
- Downlinked or definitive ephemeris/attitude data may be used,
- Passes of arbitrary size may be processed,
- Available at no cost; licensed under GNU GPL.

Available from:

http://cimss.ssec.wisc.edu/~gumley/IMAPP/

SSEC Realtime MODIS Processing



MODIS Direct Broadcast at SSEC - Netscape

File Edit View Go Communicator Help

Bookmarks Location: http://eosdb.ssec.wisc.edu/modisdirect/ What's Related

MODIS Direct Broadcast at SSEC 2001/09/04 (day 247) Historical

Terra - September 04, 2001

		Start UTC	End UTC	Quicklook	Browse Images
1	Predicted	03:10:40	03:23:10		
	Actual	03:10:59	03:23:07		Graphical, Text Only, Coverage
2	Predicted	04:48:30	05:00:50		
	Actual	04:48:21	05:00:48		Graphical, Text Only, Coverage
3	Predicted	15:10:40	15:18:20		
	Actual	15:10:56	15:18:18	VIS-02	Graphical, Text Only, Coverage
4	Predicted	16:46:20	16:59:40		
	Actual	16:46:14	16:59:36	VIS-02	Graphical, Text Only, Coverage
5	Predicted	18:24:50	18:35:20		
	Actual	18:25:02	18:35:18	VIS-02	Graphical, Text Only, Coverage

Information current as of September 4, 2001 23:57:48 UTC

http://eosdb.ssec.wisc.edu/modisdirect/

Realtime MODIS Processing

Required Input: Level-0 MODIS data (time ordered CCSDS packets)

Ancillary Data: None for Terra; GBAD packets for Aqua

Terra geolocation: Uses ephemeris and attitude information obtained from sensors onboard spacecraft

Aqua geolocation: Uses attitude information from spacecraft and uploaded predictive ephemeris (good to 300 meters over 36 hours)

Terra and Aqua can also use post-processed definitive ephemeris and attitude files from GSFC (available via FTP from SSEC)

MODIS Level-1 Processing: IMAPP vs. GSFC

	IMAPP	GSFC
Platforms	Solaris, IRIX, HP-UX, AIX, Linux	IRIX, Linux
Toolkits required	HDF 4.1	HDF 4.1, HDF-EOS, SDPTK
Output format	HDF	HDF-EOS
Installation	Easy	Difficult

Level-1A File Contents

1. Global metadata (e.g. Date, No. of scans, Orbit No.)

2. Scan-level metadata (e.g. Mirror side, Scan start time)

3. Pixel quality data (Missing or discarded packet, Bad CRC)

4. Scan data (e.g. Earth view, Space View, OBC view)

5. Discarded packets

6. Engineering data (e.g. S/C attitude, OBC temperature)

Geolocation File Contents

1. Geodetic position (latitude, longitude, and height above*) for center of each 1000 m pixel; WGS84*

2. Sun and satellite bearings (zenith and azimuth) for center of each 1000 m pixel

3. Land/sea mask for center of each 1000 m pixel

4. Terrain elevation for each 1000 m pixel

5. Instrument information sufficient to permit geolocation for specific bands and sub-pixel ground location.

Level-1B File Contents

1. Earth view image data (radiance/reflectance units)
    - 250 m resolution file contains bands 1-2
    - 500 m resolution file contains bands 1-7
    - 1000 m resolution file contains bands 1-36
    - Radiance (Watts / square meter / steradian / micron)
    - Reflectance (dimensionless)

2. Geolocation data for every 5th 1000 m pixel on every 5th line (3, 8, 13, …)

3. Global metadata (e.g. Date, Time, Number of scans, Day/night mode, LUT serial numbers)

Level-1B File Sizes
(per 5 minute granule)

Day mode (all bands):

MOD021KM	345 MB
MOD02HKM	275 MB
MOD02QKM	285 MB
MOD03	60 MB
	965 MB

Night mode (bands 20-36 only):

MOD021KM	142 MB
MOD03	60 MB
	202 MB

Scaled Integer Missing Value Codes

Reason for unusable data	SI
Fill Value (includes reflective band data at night and completely missing L1A scans)	65535
L1A DN is missing within a scan	65534
Detector is saturated	65533
Cannot compute zero point DN	65532
Detector is dead	65531
RSB dn** below the minimum of the scaling range	65530
TEB radiance or RSB dn** exceeds the maximum of the scaling range	65529
Aggregation algorithm failure	65528
Rotation of Earth-View Sector from nominal science collection position	65527
(Reserved for future use)	65501-65526
NAD closed upper limit	65500

Converting Scaled Integers to Physical Quantities

First, search for missing or fill values that are defined in terms of scaled 16-bit unsigned integers (e.g.65531 means dead detector)

Then apply scale and offset values as follows:

$$\text{result} = \text{scale} \cdot (\text{integer} - \text{offset})$$

where

scale is band dependent scale factor,

offset is band dependent offset.

Note: data type of result is determined by data type of scale and offset (e.g., float, double etc.)

Differences between IMAPP and GSFC L1B formats

Product	**IMAPP**	**GSFC**
File format	HDF 4.1	HDF-EOS 2.6 (subset of HDF 4.1)
Science data objects are stored as	Scientific Data Sets	Scientific Data Sets
Metadata objects are stored as	Global Attributes formatted as text	Global Attributes formatted as ODL*

* ODL: Object Description Language

Object Description Language (ODL)

ODL consists of name/value pairs containing metadata information:

```
:CoreMetadata.0 = "\n",
    "GROUP                       = INVENTORYMETADATA\n",
    "  GROUPTYPE                 = MASTERGROUP\n",
    "\n",
    "  GROUP                       = ECSDATAGRANULE\n",
    "\n",
    "    OBJECT                      = LOCALGRANULEID\n",
    "      NUM_VAL                   = 1\n",
    "      VALUE                     =
\"MOD021KM.A2001153.1645.003.2001159005738.hdf\"\n",
    "    END_OBJECT                  = LOCALGRANULEID\n",
    "\n",
    "    OBJECT                      = PRODUCTIONDATETIME\n",
    "      NUM_VAL                   = 1\n",
    "      VALUE                     = \"2001-06-08T00:57:39.000Z\"\n",
    "    END_OBJECT                  = PRODUCTIONDATETIME\n",
    "\n",
    "    OBJECT                      = DAYNIGHTFLAG\n",
    "      NUM_VAL                   = 1\n",
    "      VALUE                     = \"Day\"\n",
    "    END_OBJECT                  = DAYNIGHTFLAG\n",
    "\n",
```

Why is ODL Metadata so Painful?

- Metadata fields formatted in ODL are required by the EOSDIS Core System (ECS) in order for a product to be archived.

- Files with missing or incorrectly formatted ODL metadata are not archived, and cause ECS to become very upset!

- ODL is created by accessing a specialized API that is part of the ECS toolkit.

- Many MODIS developers depend on the ODL metadata fields when reading input files. If a field is not present, their code quits (nobody ever imagined it wouldn’t be there).

Reconciling IMAPP and GSFC Metadata

- Most metadata fields do not change from granule to granule.

- A template (text file) containing the correct metadata fields can be used to copy information into IMAPP product files.

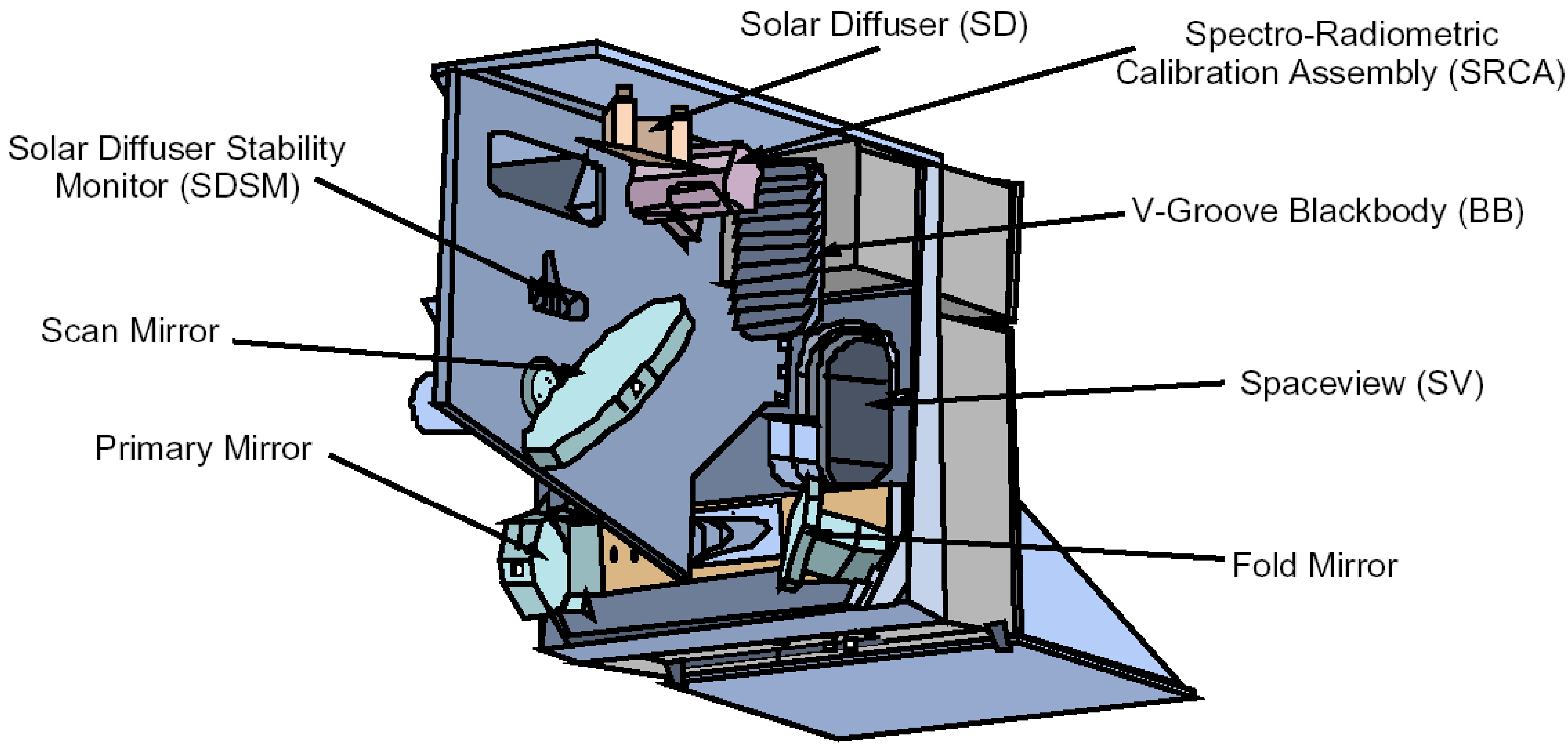
- Only a few metadata fields (e.g. date, time, geographic extent) then need to be modified to make the metadata identical to GSFC format.

- University of Wisconsin is testing this approach and plans to include it in the next IMAPP Level-1 release (1Q 2003).

- Result should be IMAPP Level-1B files which are essentially identical to GSFC format.

MODIS Calibration

On-Board Calibrators in MODIS Scan Cavity



Emissive Band Calibration Algorithm

$$L_{EV} = (a_0 + b_1 \, . \, DN_{EV} + a_2 \, . \, DN_{EV}{}^2) \, / \, \rho_{SM(EV)}$$

$$- \left[(\rho_{SM(SV)} - \rho_{SM(EV)}) \, / \, \rho_{SM(EV)} \right] . \, L_{SM}$$

L_{EV} at aperture radiance; earth view

a_0, a_2 pre launch calibration coefficients

b_1 on-orbit linear response (gain)

DN_{EV} digital counts; earth view

$\rho_{SM(EV)}$, $\rho_{SM(SV)}$ scan mirror reflectivity; earth and space views

L_{SM} scan mirror radiance

Reflective Band Calibration Algorithm

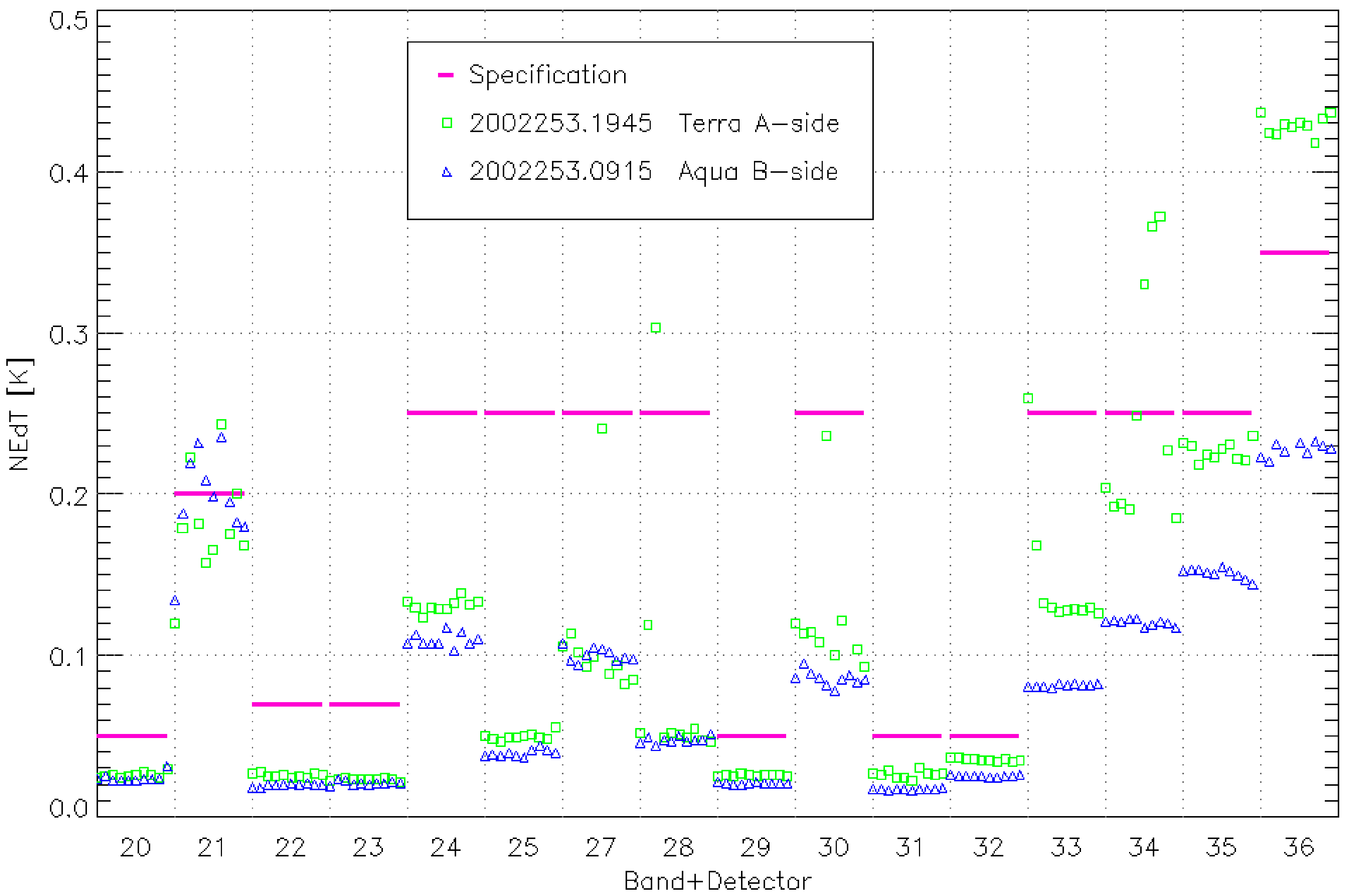
$$[\rho\cos(\Theta)\ ]_{EV} = m_0 + m_1 \,.\, d_{ES}^{\ 2} \,.\, dn^*$$

m_0 and m_1 are derived from Solar Diffuser

d_{ES} is the Earth-Sun distance (varies for each 5 minute granule)

dn* is the digital signal corrected for instrumental effects

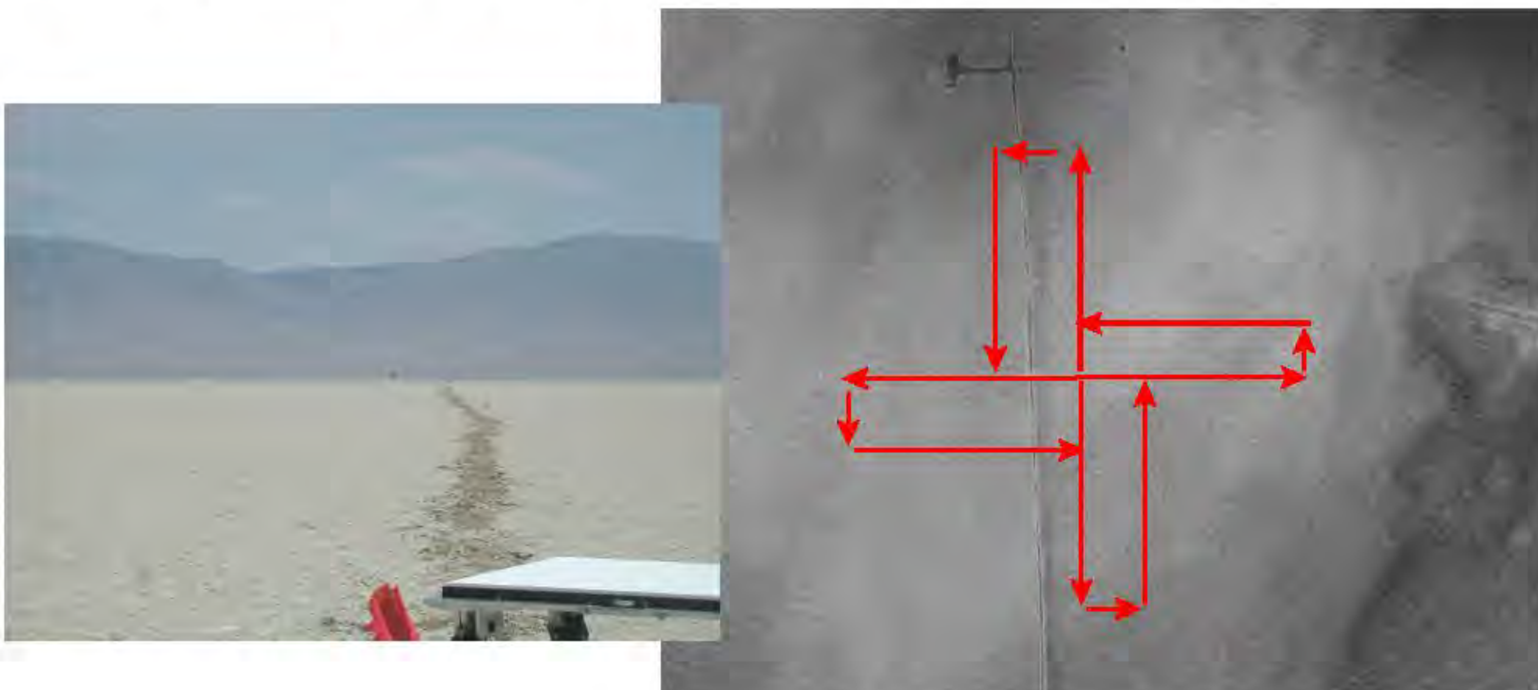
NOTE: To convert to at-sensor reflectance, you must divide by the cosine of the solar zenith angle.



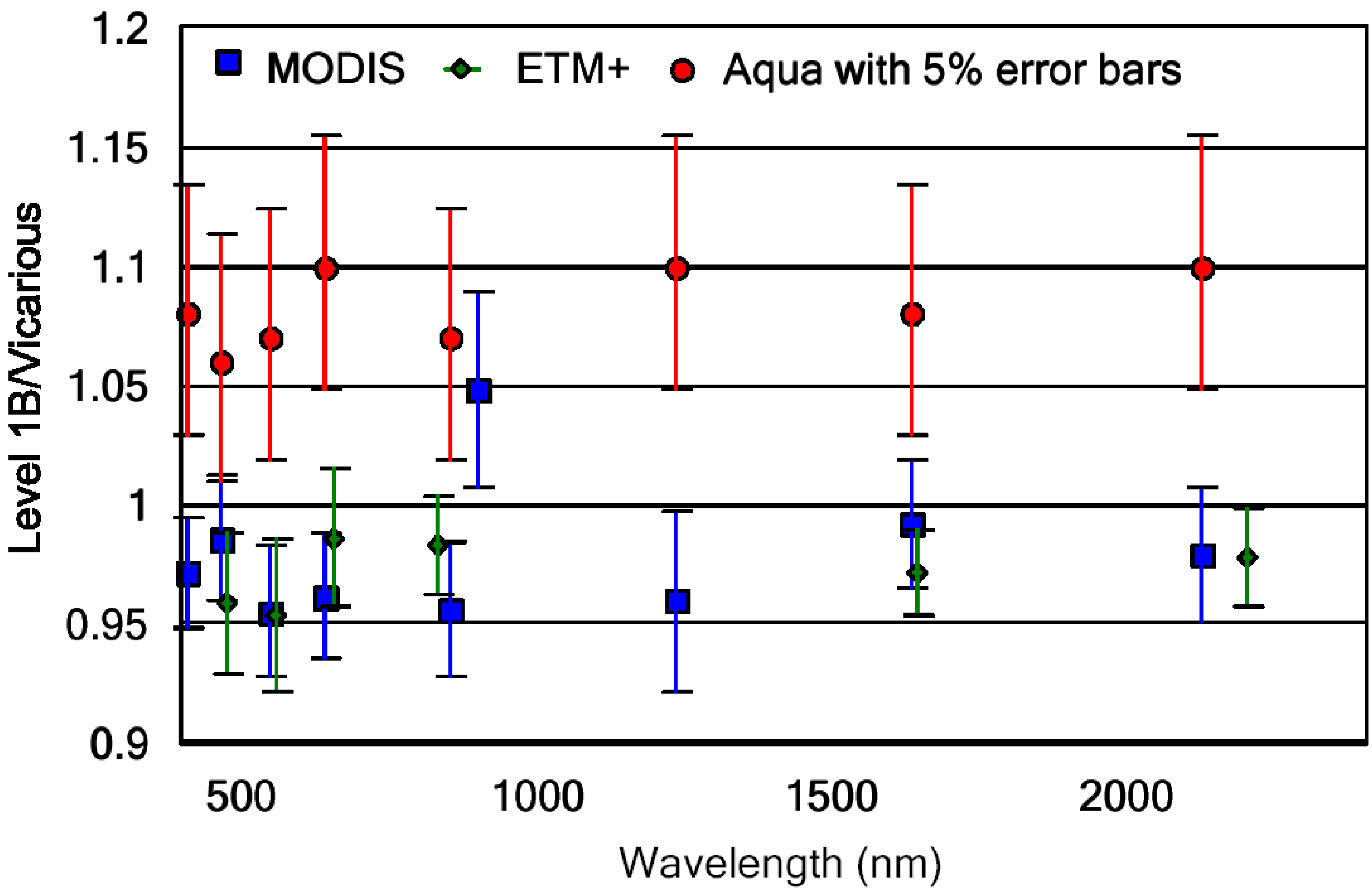
Specification
2002253.1945 Terra A–side
2002253.0915 Aqua B–side
NEdT [K]
0.0
0.1
0.2
0.3
0.4
0.5
20
21
22
23
24
25
27
28
29
30
31
32
33
34
35
36
Band+Detector

Surface reflectance retrieval

- Surface reflectance is found by referencing measurements of upwelling radiance from the test site to those of a panel of known reflectance
  - Reference panels are Spectralon
  - Radiometer reports data at 1-nm intervals from 350 to 2500 nm
- Directional reflectance effects are ignored (assume lambertian surface which is good to 2% for view angles out to 20 degrees and solar incident angles)
- Sampling strategy has 8 paths of 500 m in length separated by 100 m



Comparison with ETM+ results



Radiance to Brightness Temperature Conversion: 1

For a given brightness temperature, a spectral response weighted integral is computed:

$$I_b(T) = \frac{\int B(\lambda, T) F(\lambda) d\lambda}{\int F(\lambda) d\lambda}$$

where

$I_b(T)$ is the equivalent Planck radiance for the band,
$B(\lambda, T)$ is the Planck function,
$F(\lambda)$ is the spectral response for the band,
λ is wavelength,
T is temperature.

Radiance to Brightness Temperature Conversion: 2

For efficiency, the integral is computed for a range of scene temperatures (e.g., 180 K to 320 K) and a fit is computed:

$$I_b(T) = B(\lambda_b, \alpha_1 T + \alpha_0)$$

where
α_1 and α_0 are linear fit coefficients,
λ_b is the effective central wavelength.

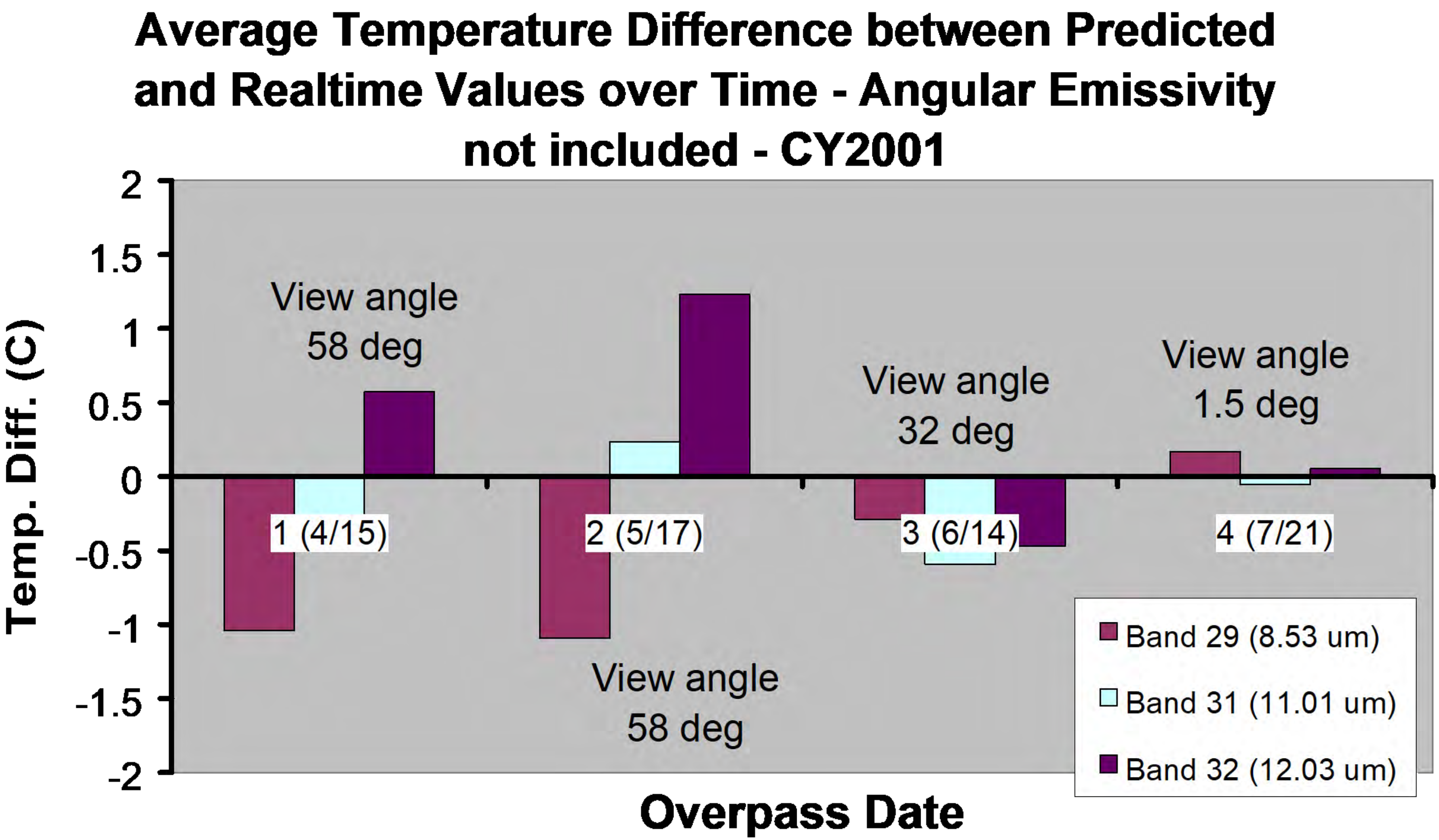
Tables of α_0, α_1, and λ_b are maintained for each spectral band on Terra and Aqua.

Spectral response data files:

ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/

Simon Hook's (JPL) MkIV Raft on Lake Tahoe with Radiometer, Meteorological Station and Temperature Loggers

MODIS radiances are sent automatically for every Tahoe pass



Average Temperature Difference between Predicted and Realtime Values over Time - Angular Emissivity not included - CY2001
Temp. Diff. (C)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
View angle 58 deg
View angle 58 deg
View angle 32 deg
View angle 1.5 deg
1 (4/15)
2 (5/17)
3 (6/14)
4 (7/21)
Band 29 (8.53 um)
Band 31 (11.01 um)
Band 32 (12.03 um)
Overpass Date

Infrared Validation

MODIS L1B Validation Sources
Thermal Bands

- GOES and other Satellite Platforms
- ER-2 Aircraft Based Campaigns
- Ground Based AERI measurements
- Special Radiosondes / IOPs

ER-2 Based MODIS L1B Validation

- Payload:
  - **SHIS**: < 0.5 cm^{-1} spectral res.; < 0.5°C accuracy
  - **MAS**: 50 m spatial res.; +/- 43° view
  - **CPL**: nadir viewing lidar to validate clear sky
- Procedure:
  - transfer SHIS calibration to MAS observations
  - integrate MODIS spatial function over MAS radiances
  - remove spectral, altitude, viewing geometry dependence
- Field Campaigns

Field Campaigns	Dates	Location
– WISC-T2000	Feb 27 - Mar 13, 2000	Madison, WI
– SAFARI-2000	Aug 13 - Sep 25, 2000	Pietersburg, SA
– TX-2001	Mar 14 - Apr 05, 2001	San Antonio, TX
– TX-2002	Nov 20 - Dec 11, 2002	San Antonio, TX

2000

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Terra MODIS first light Side A

WISC-T2000

SAFARI-2000

Switch to Side B

S/MWIR bias adjustment to 79/110

2001

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

TX-2001

Side A

S/MWIR bias at 79/190

2002

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

Aqua
MODIS
first light
Side B

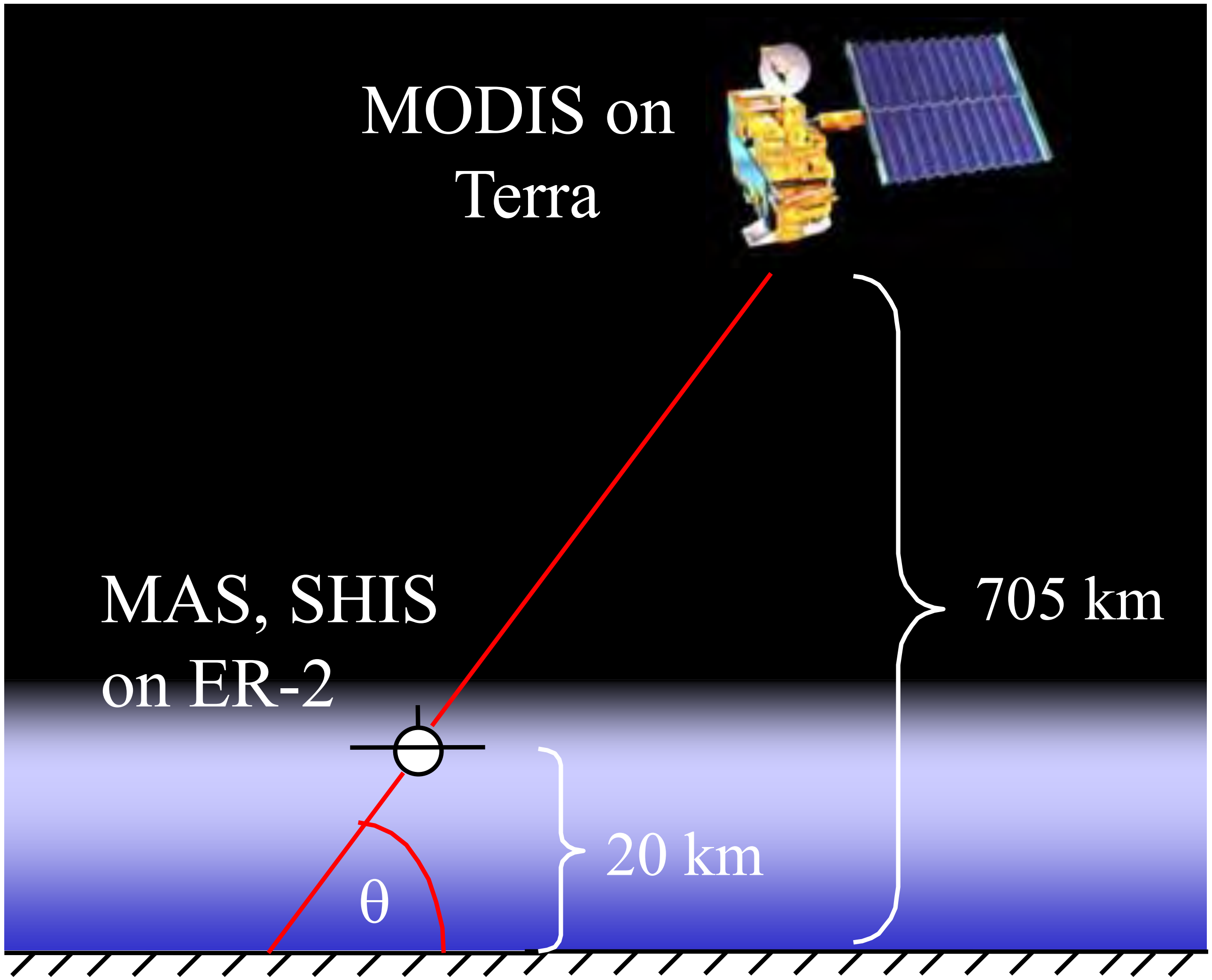
TX-2002

2003

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

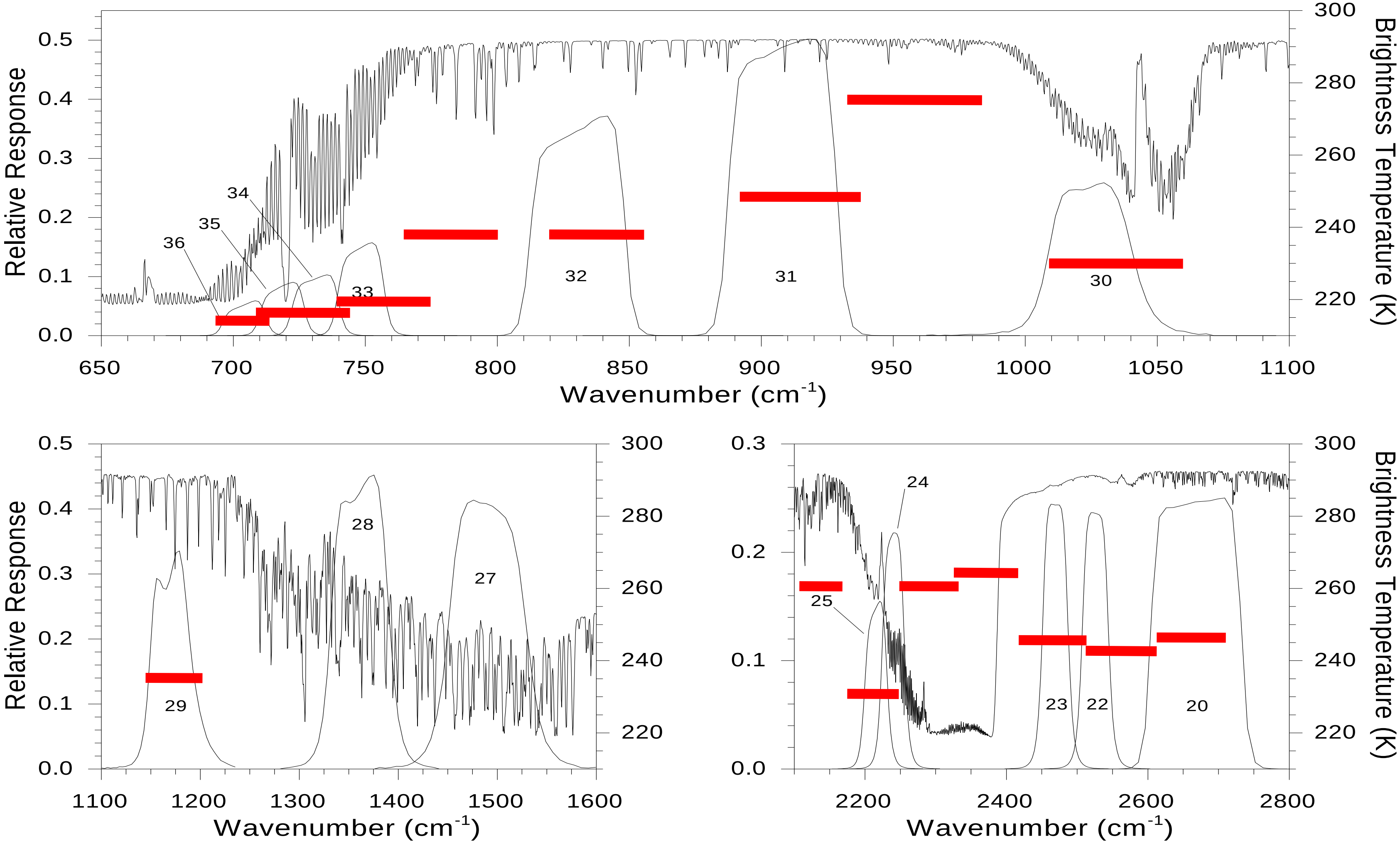
THORPex
(planned)

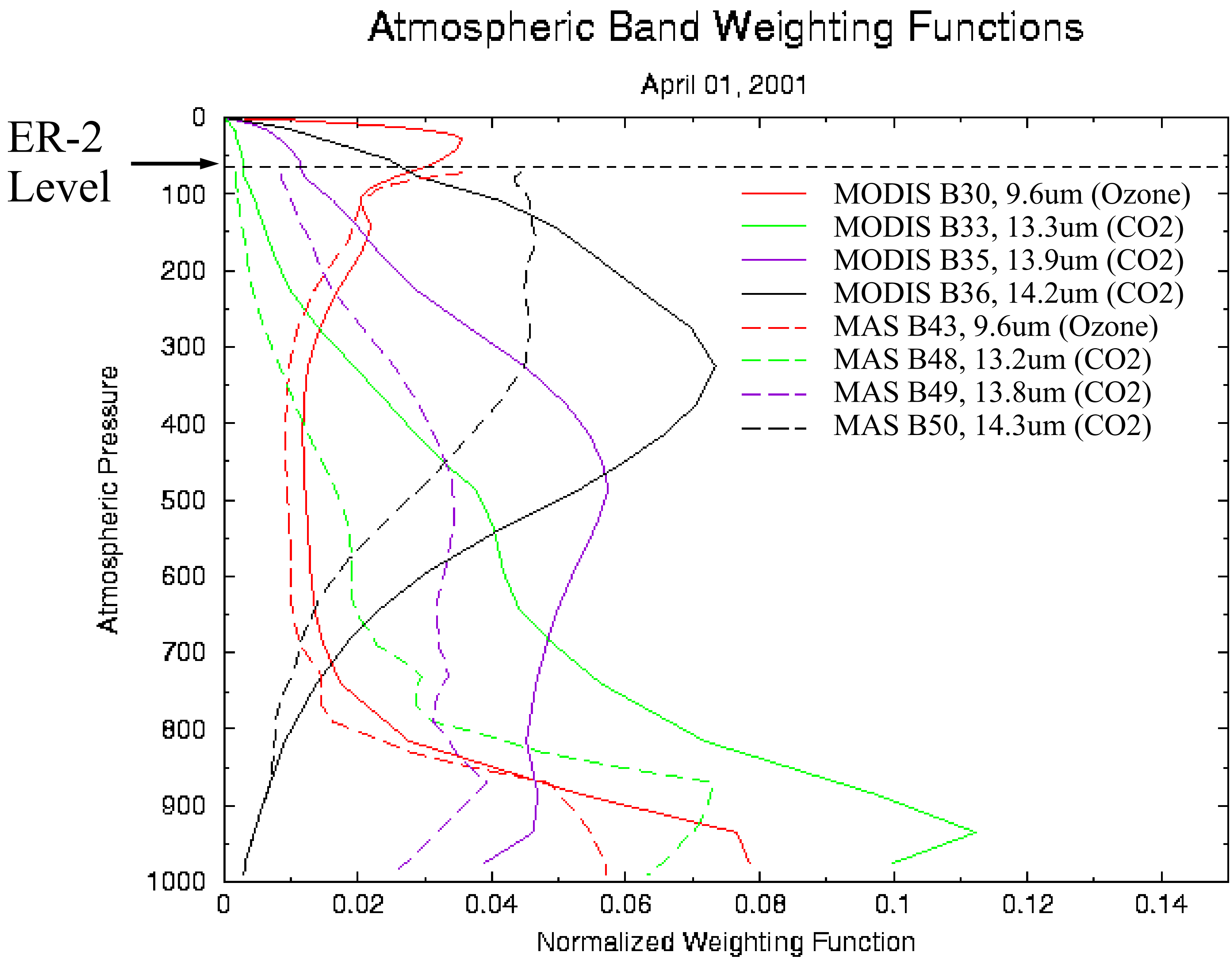
MAS data collected at same viewing geometry as MODIS



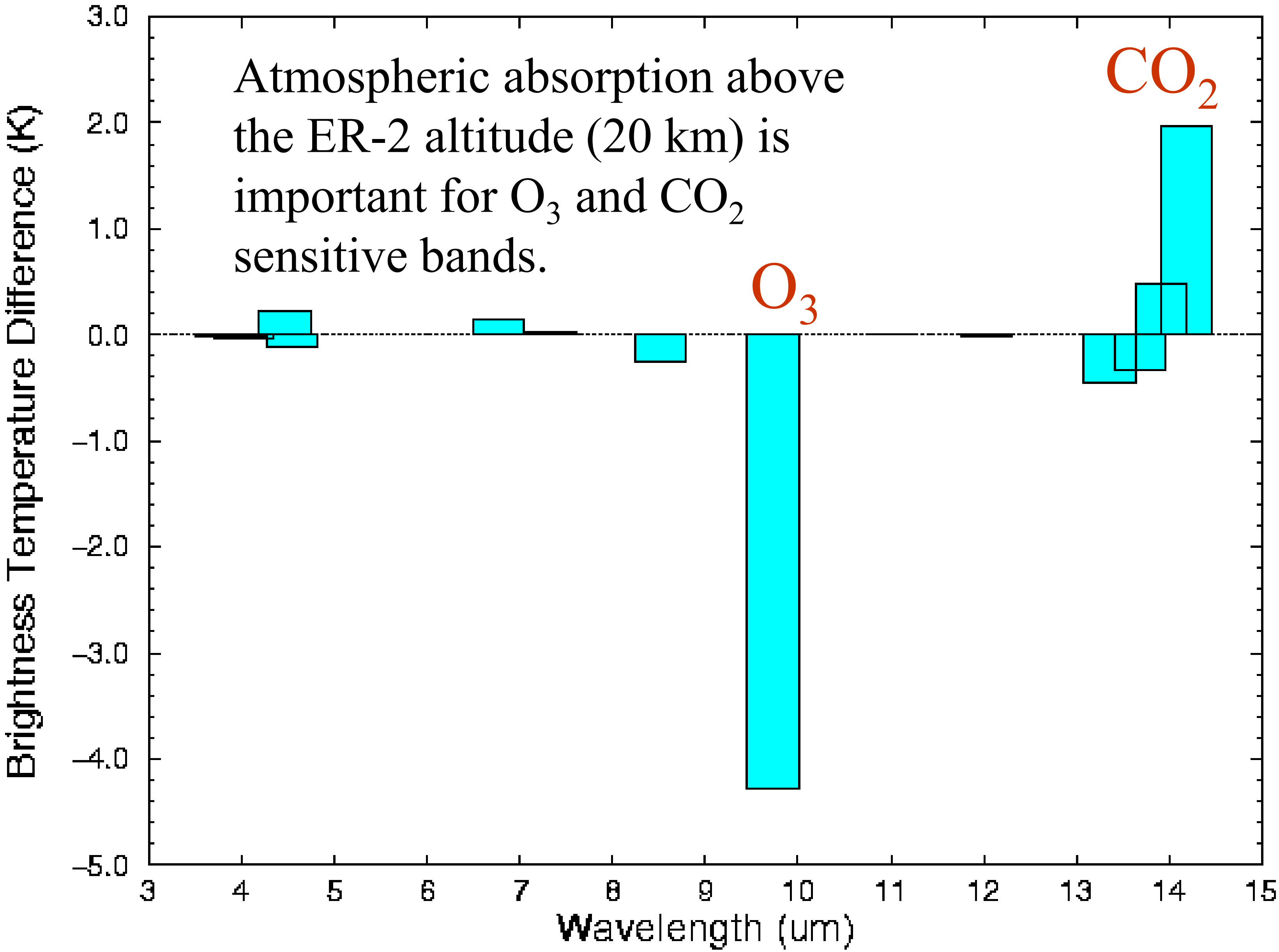
MODIS IR Spectral Bands, MAS FWHM

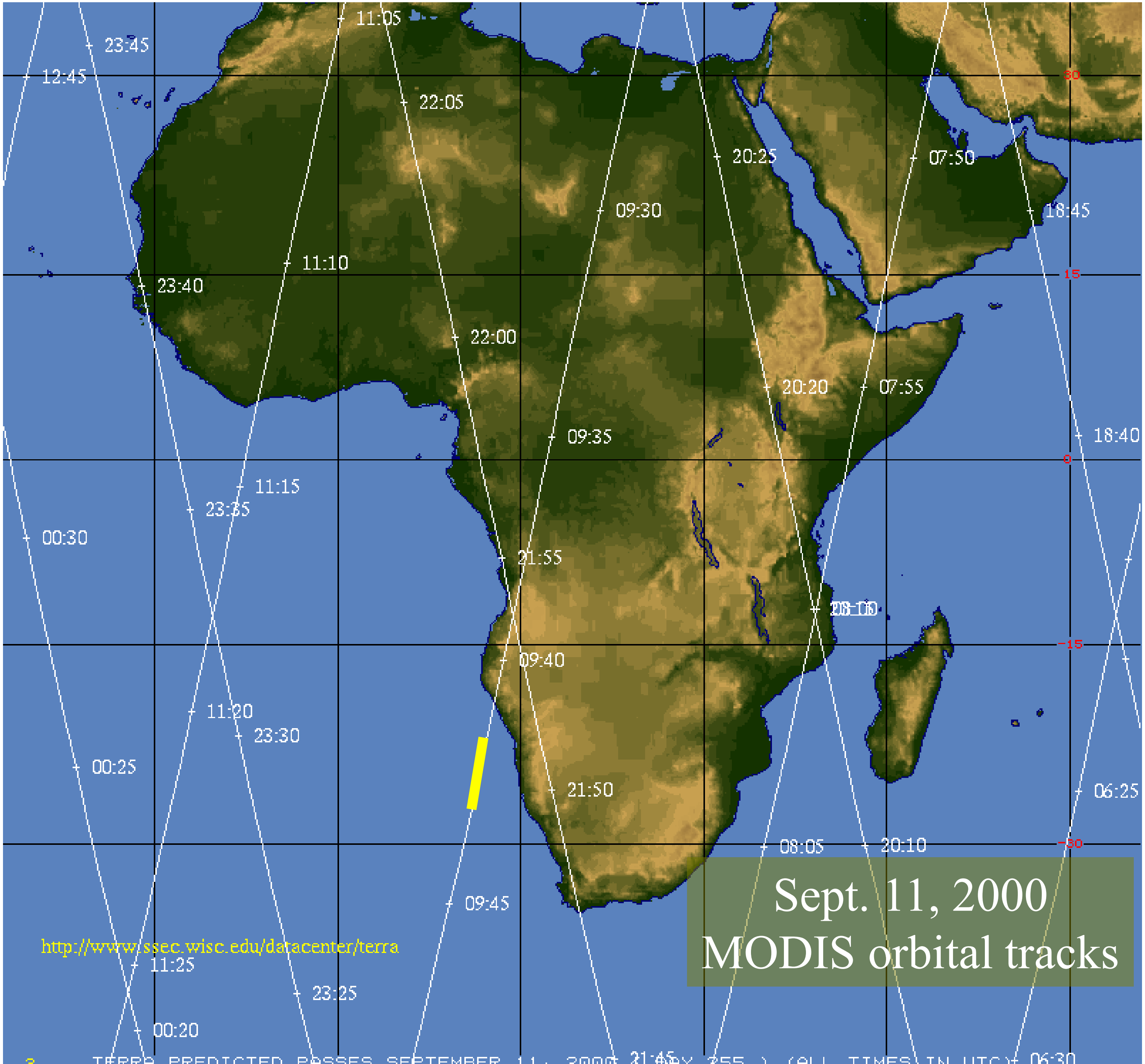
MODIS Spectral Response Functions and FASCOD3P Brightness Temperature Spectrum at HIS Resolution (U.S. Standard Atmosphere; 0-30km)



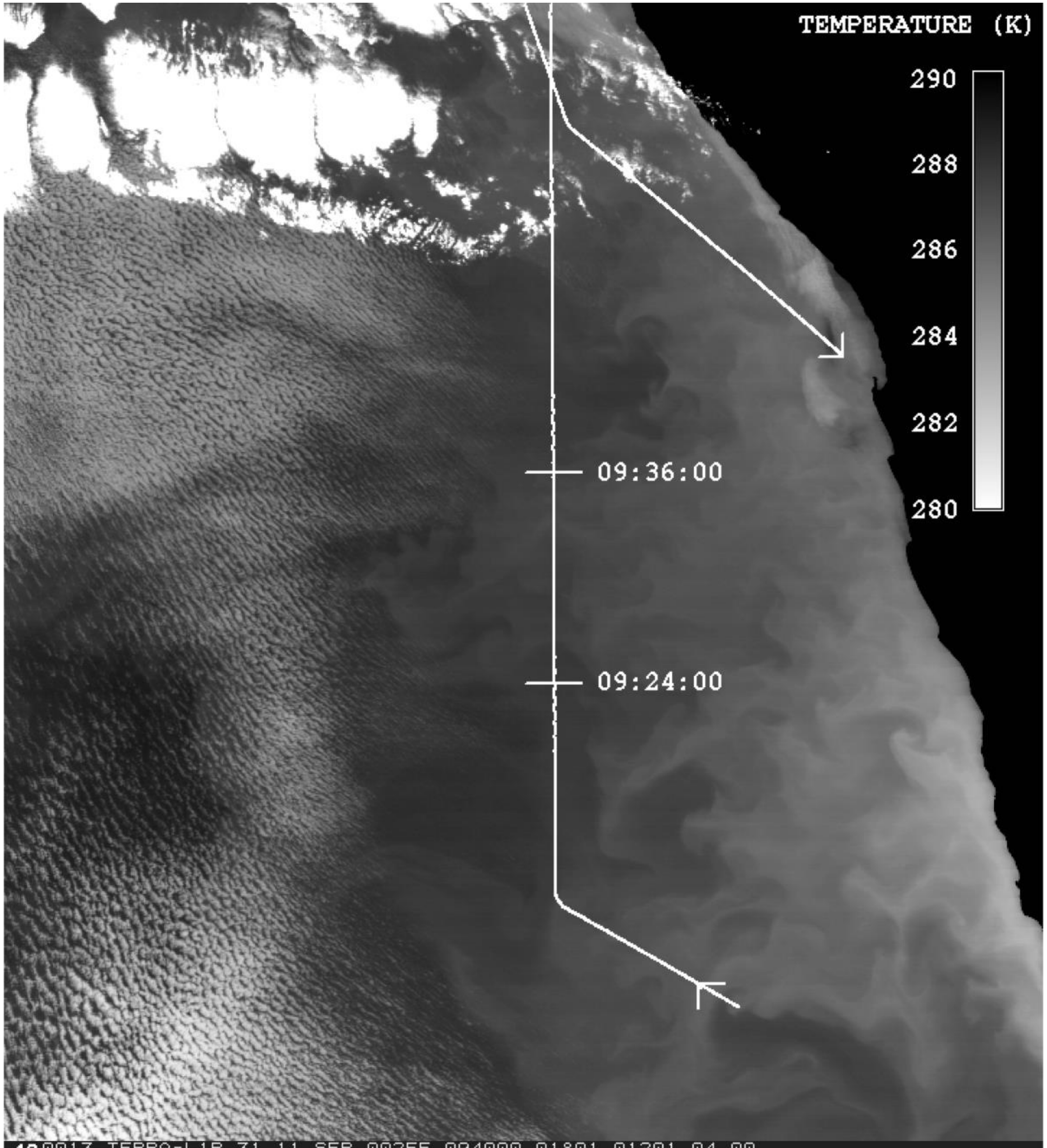

Atmospheric Band Weighting Functions
April 01, 2001
ER-2
Level
MODIS B30, 9.6um (Ozone)
MODIS B33, 13.3um (CO2)
MODIS B35, 13.9um (CO2)
MODIS B36, 14.2um (CO2)
MAS B43, 9.6um (Ozone)
MAS B48, 13.2um (CO2)
MAS B49, 13.8um (CO2)
MAS B50, 14.3um (CO2)
Atmospheric Pressure
0
100
200
300
400
500
600
700
800
900
1000
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Normalized Weighting Function

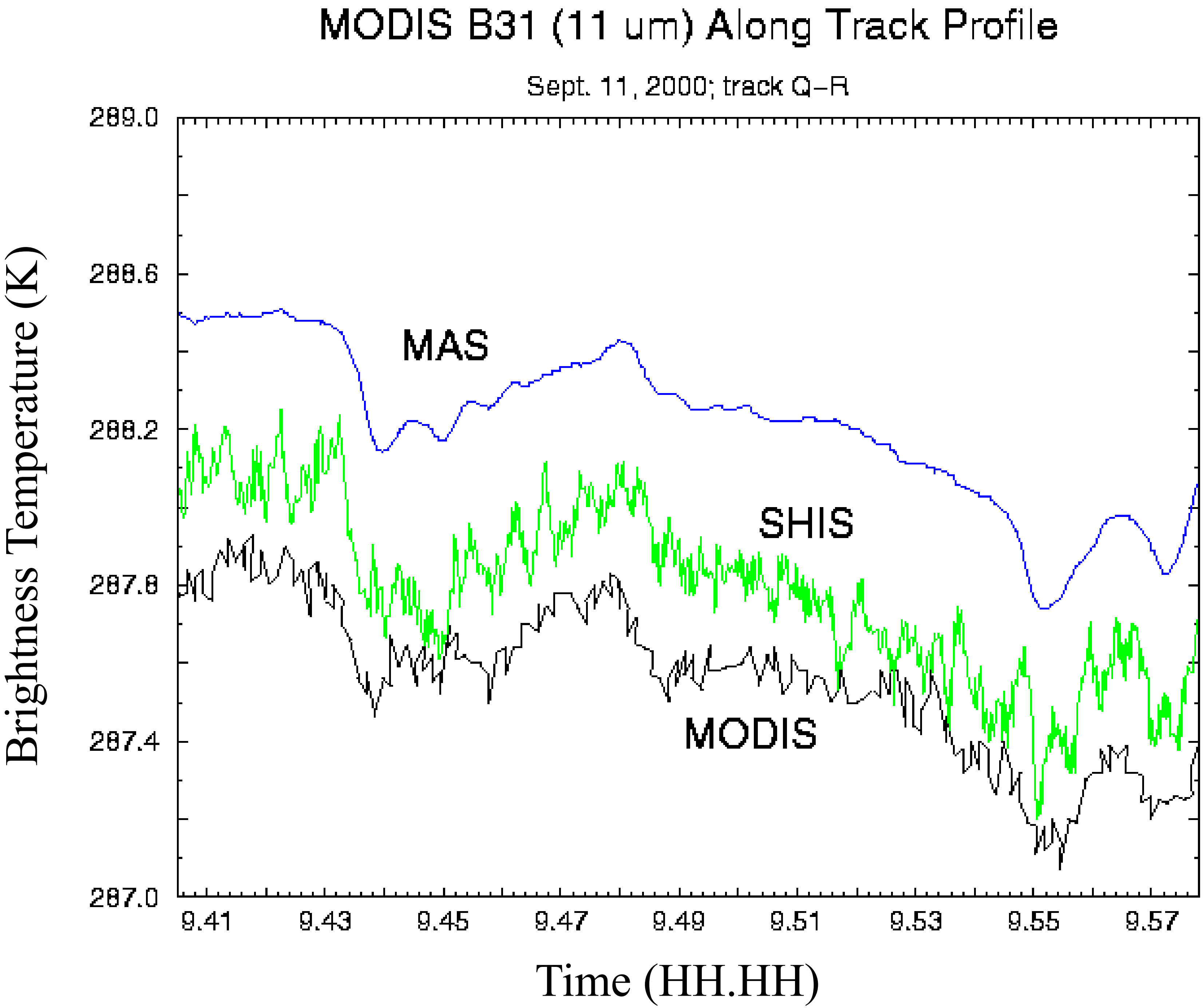
Influence of Altitude Difference between MODIS and MAS

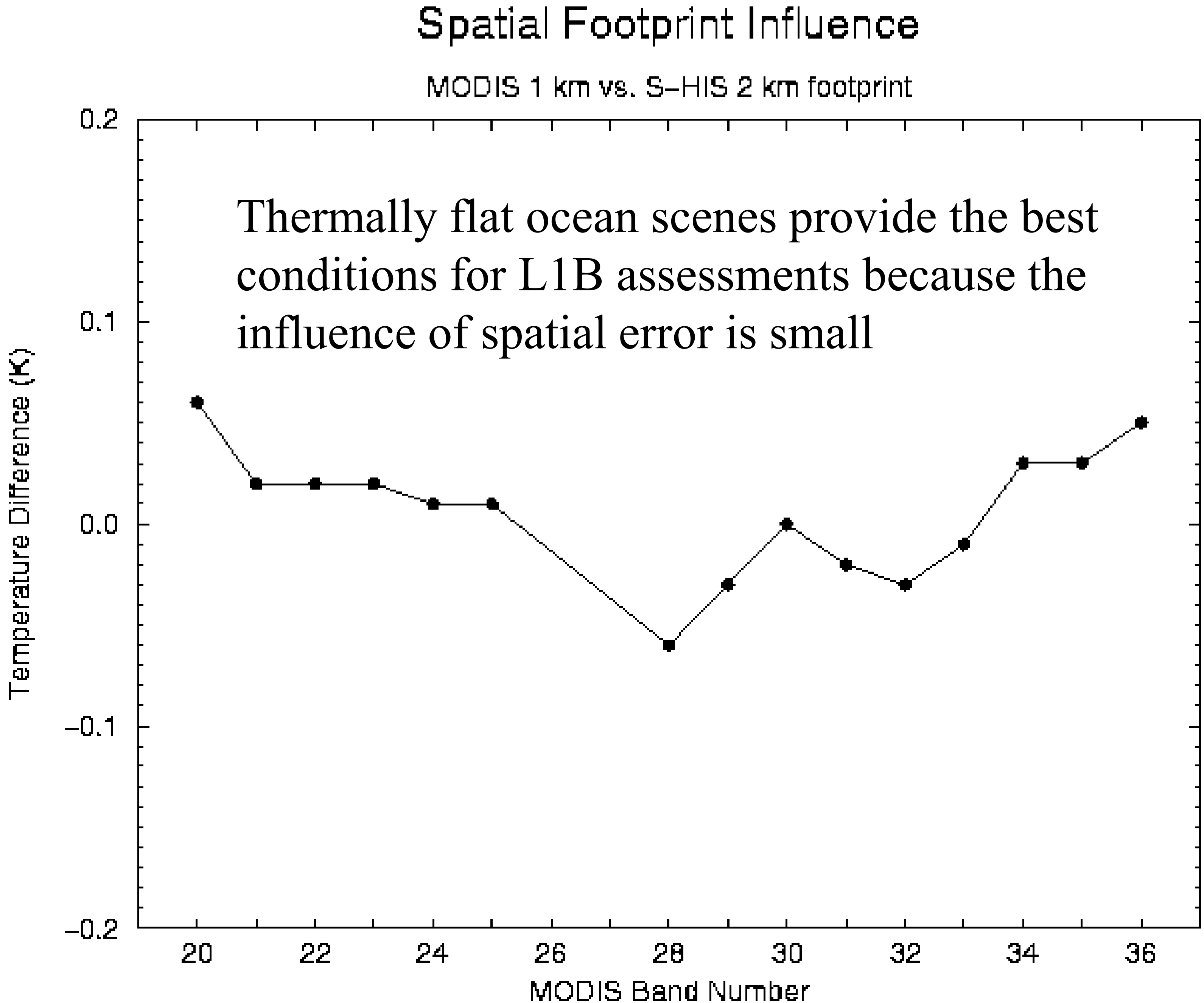


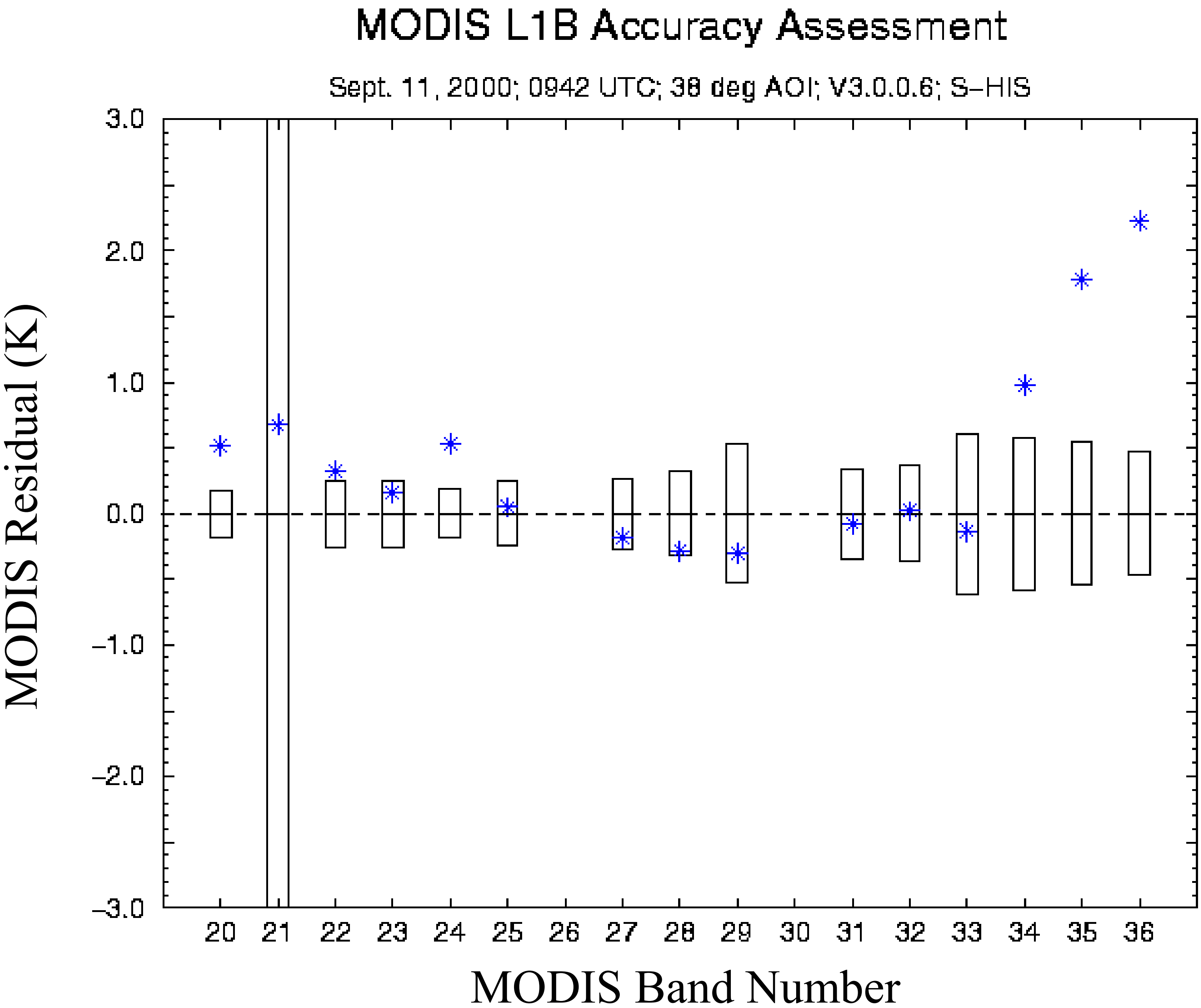


Sept. 11, 2000
MODIS orbital tracks


TEMPERATURE (K)
290
288
286
284
282
280
09:36:00
09:24:00
13 00013 TERRA-L1B 31 11 SEP 00255 094000 01801 01201 04.00

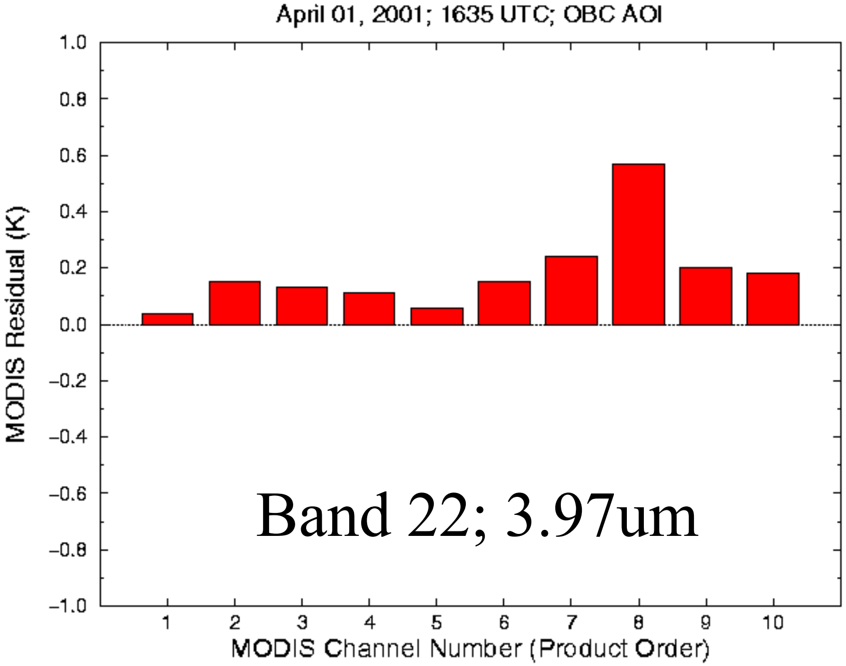

MODIS B31 (11 um) Along Track Profile
Sept. 11, 2000; track Q-R
Brightness Temperature (K)
289.0
288.6
288.2
287.8
287.4
287.0
MAS
SHIS
MODIS
9.41
9.43
9.45
9.47
9.49
9.51
9.53
9.55
9.57
Time (HH.HH)


Spatial Footprint Influence
MODIS 1 km vs. S–HIS 2 km footprint
Thermally flat ocean scenes provide the best conditions for L1B assessments because the influence of spatial error is small
Temperature Difference (K)
0.2
0.1
0.0
–0.1
–0.2
20
22
24
26
28
30
32
34
36
MODIS Band Number

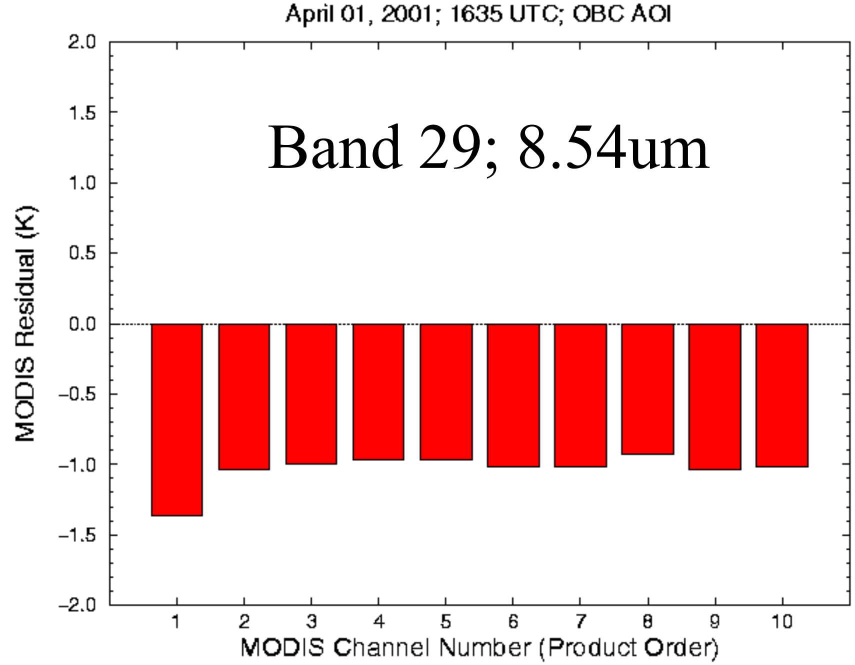


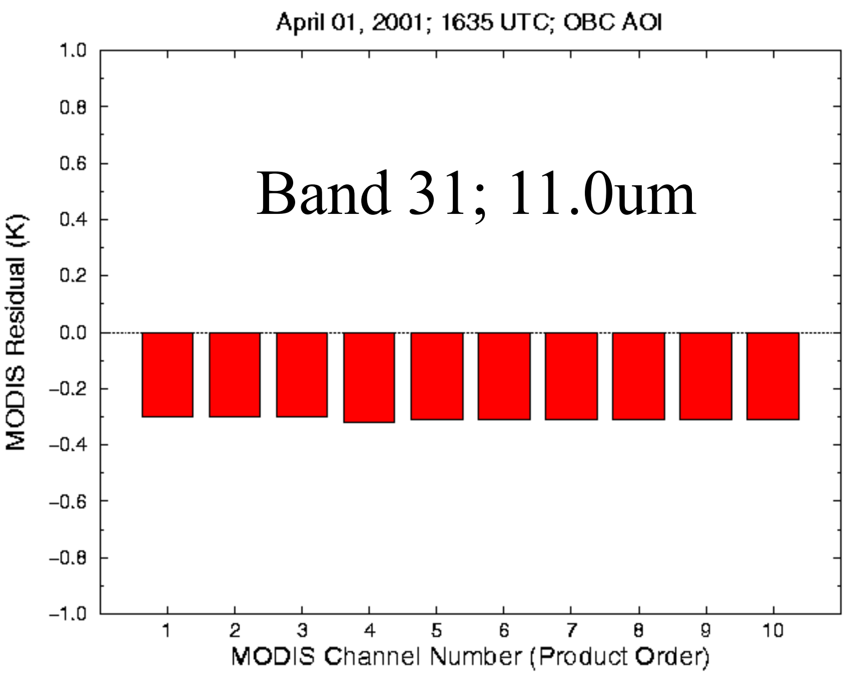
MODIS L1B Accuracy Assessment
Sept. 11, 2000; 0942 UTC; 38 deg AOI; V3.0.0.6; S–HIS
3.0
2.0
1.0
0.0
–1.0
–2.0
–3.0
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
MODIS Residual (K)
MODIS Band Number

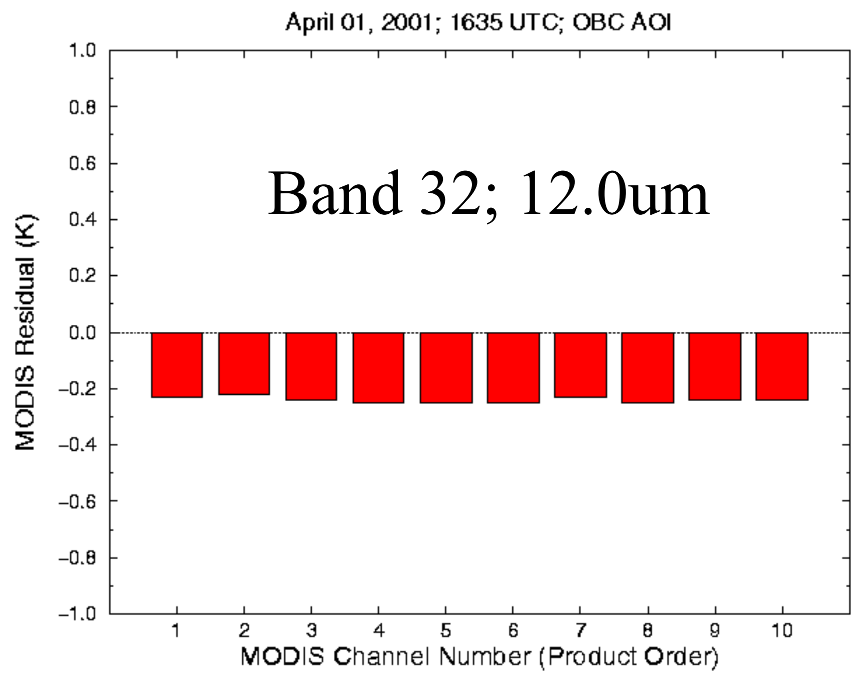
MODIS L1B Accuracy Assessment

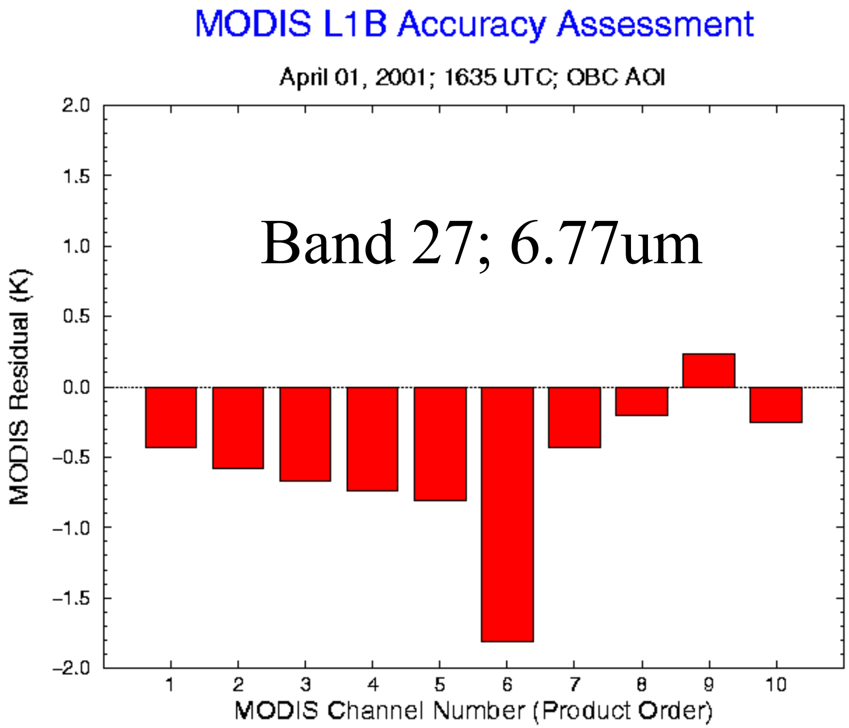


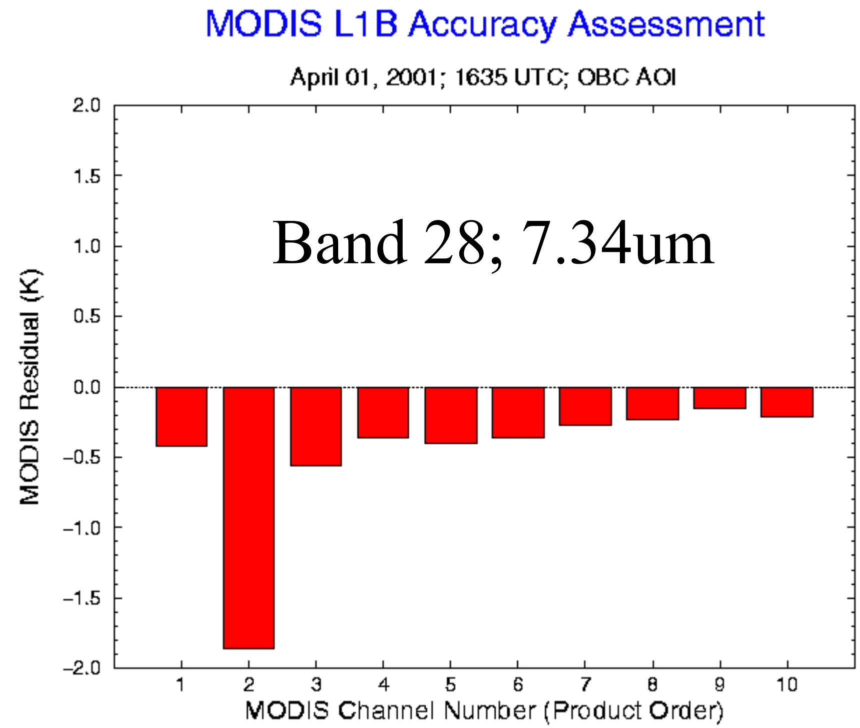
MODIS L1B Accuracy Assessment

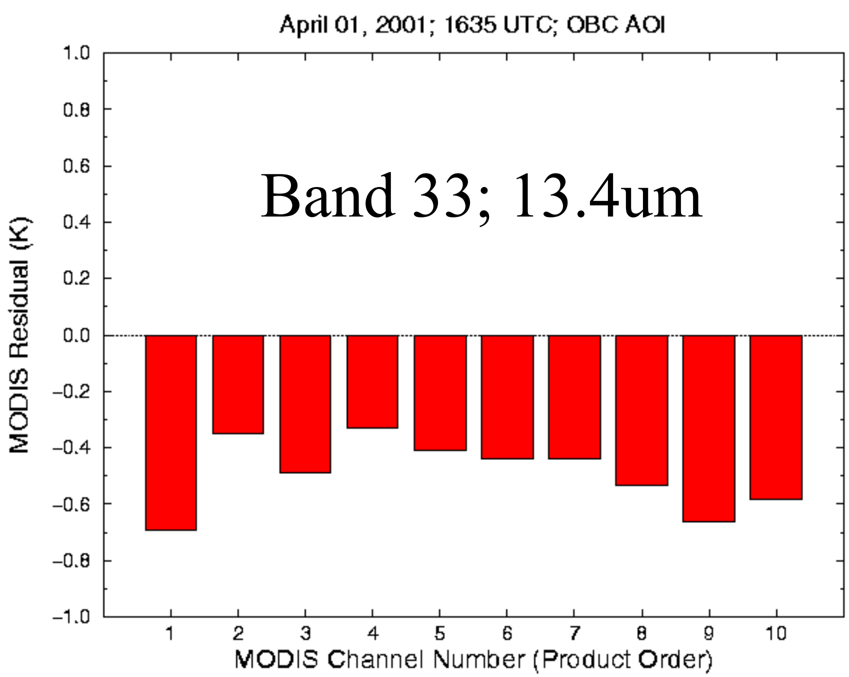


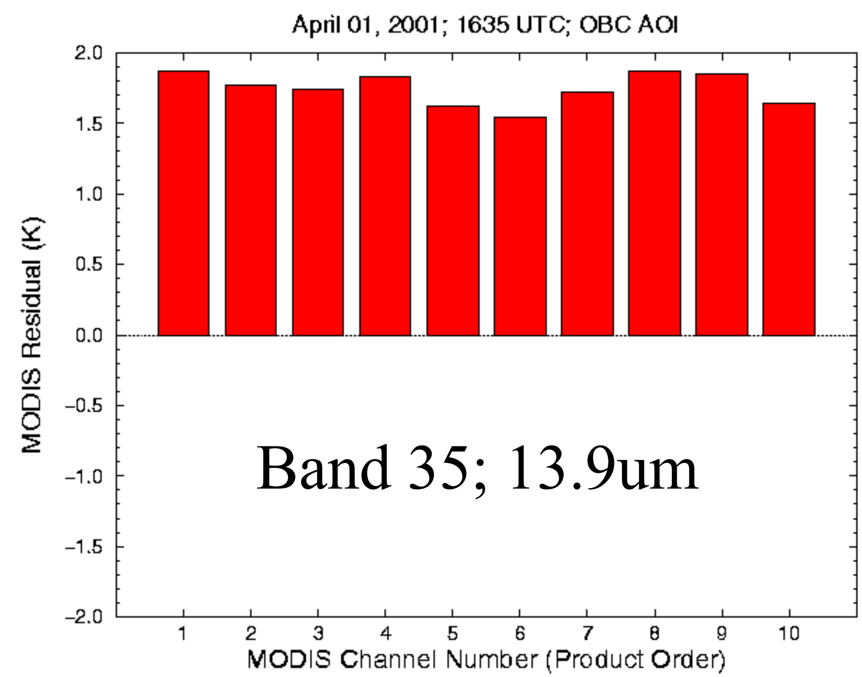


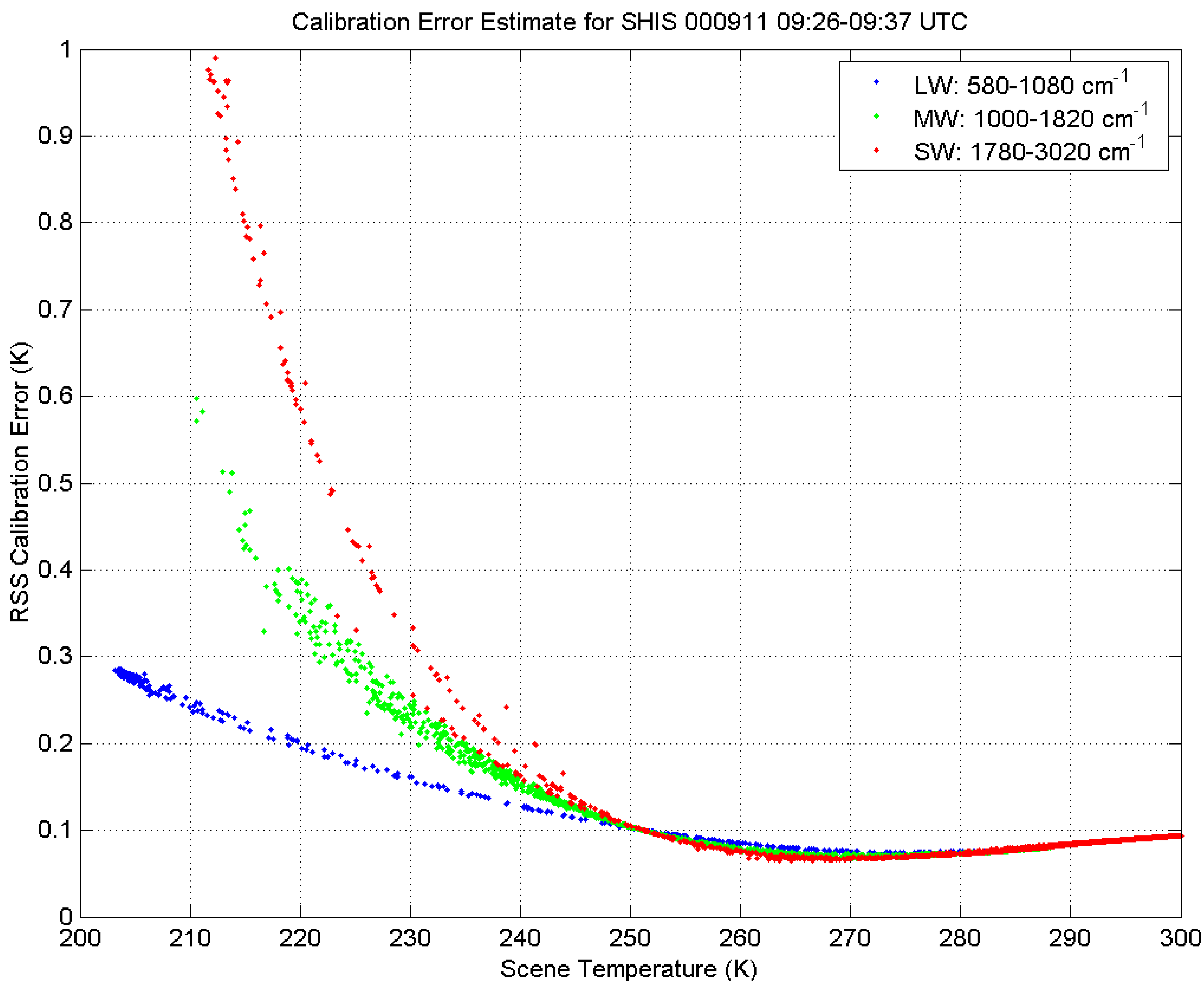



MODIS L1B Accuracy Assessment
April 01, 2001; 1635 UTC; OBC AOI
Band 27; 6.77um
MODIS Residual (K)
MODIS Channel Number (Product Order)


MODIS L1B Accuracy Assessment
April 01, 2001; 1635 UTC; OBC AOI
Band 28; 7.34um
MODIS Residual (K)
MODIS Channel Number (Product Order)


April 01, 2001; 1635 UTC; OBC AOI
Band 33; 13.4um
MODIS Residual (K)
MODIS Channel Number (Product Order)


April 01, 2001; 1635 UTC; OBC AOI
Band 35; 13.9um
MODIS Residual (K)
MODIS Channel Number (Product Order)


Calibration Error Estimate for SHIS 000911 09:26-09:37 UTC
LW: 580-1080 cm-1
MW: 1000-1820 cm-1
SW: 1780-3020 cm-1
RSS Calibration Error (K)
Scene Temperature (K)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
200
210
220
230
240
250
260
270
280
290
300

Summary

- MODIS TIR band radiometric accuracy is being assessed by high altitude aircraft based instruments.
- Spectral, spatial, geometric and altitude dependence is removed by convolving MODIS spectral and spatial characteristics over S-HIS and MAS data.
- SHIS radiometric accuracy must be very good for results to be meaningful.
- ER-2 deployed 2-3 times per year.
- Limited to clear scene (i.e. warm scene) cases for window bands. Cold scenes addressed by land based instruments (P-AERI at S. Pole).