Assessing the Error in Calculated Outgoing Longwave Radiation due to Uncertainties in Surface Properties

using NASA AIRS, MODIS, and CERES Observations from EOS AQUA

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SSEC

THE UNIVERSITY of WISCONSIN MADISON

Objectives

- **Comparison of Ts and Infrared Emissivity derived from time and space coincident infrared imager and sounder observations.**

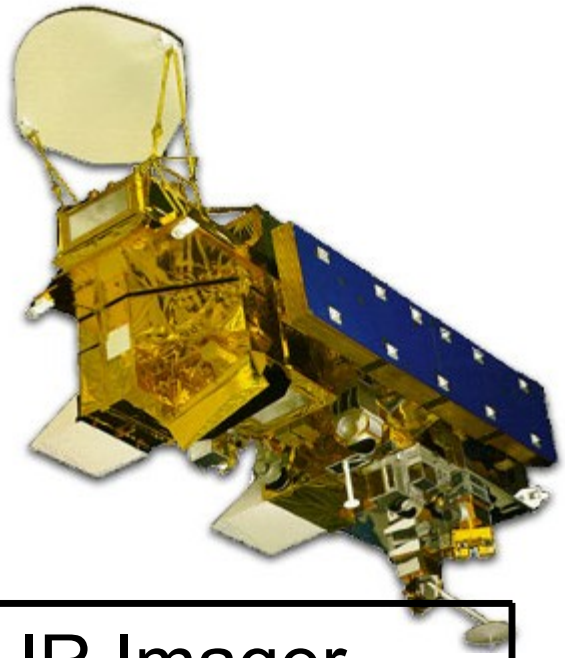
- **Comparison of computed OLR using Sounder derived Ts and Infrared Emissivity (and T(p), Q(p), O3(p)) to Top of Atmosphere flux measurements from a calibrated broadband radiometer satellite sensor.**

- **Compute sensitivity of OLR to surface parameters**

Why?

To answer the question, are remotely sensed IR surface temperatures of sufficient accuracy for climate studies?

Observations



NASA Aqua Research Platform

Sun synchronous: 1:30 pm *equator crossing time*

Aqua Sensors

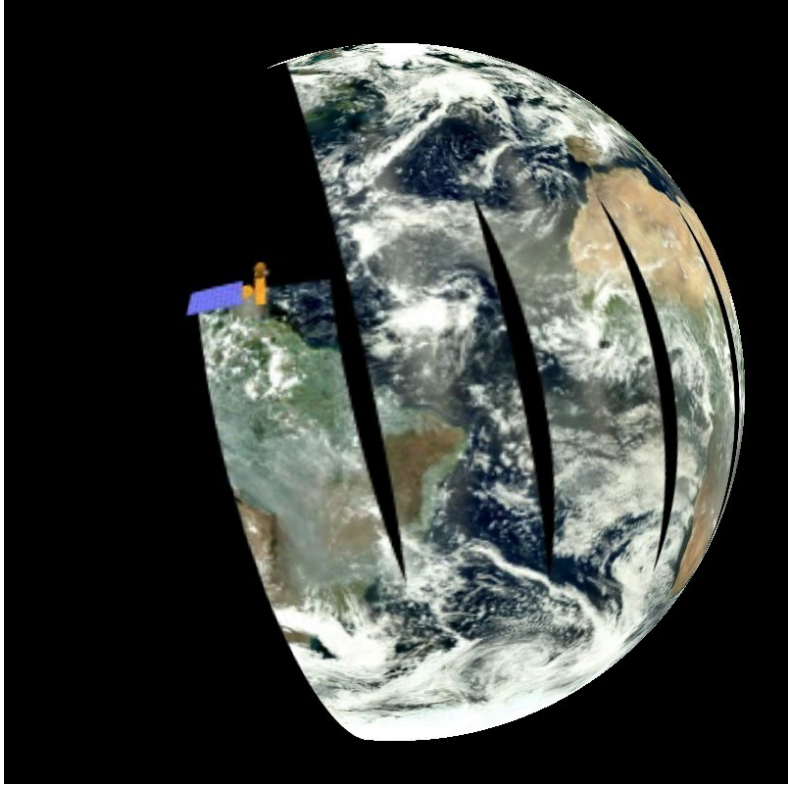
MODIS	SW and Mid-IR Imager
AIRS	Mid-IR Spectrometer
CERES	SW and LW Broadband Radiometer
AMSU	MW 50 GHz to 90 GHz
AMSR-E	MW 6.9 GHz to 89 GHz
HSB	MW 150 MHz to 183 MHz

NASA AQUA Research Satellite
Sept. 2002 – Current: > 6 years

MODIS ← Imager
LST and LSE

AIRS ← Sounder
T(p), Q(p), LST, LSE
== >> OLR

CERES ← Broadband flux
Total Flux–SW = OLR



MODIS Swath

Since all these instruments are on the same satellite platform and view the Earth *simultaneously*, we can inter-compare results while minimizing the error due to spatial and temporal sampling.

Longwave Outgoing Radiation

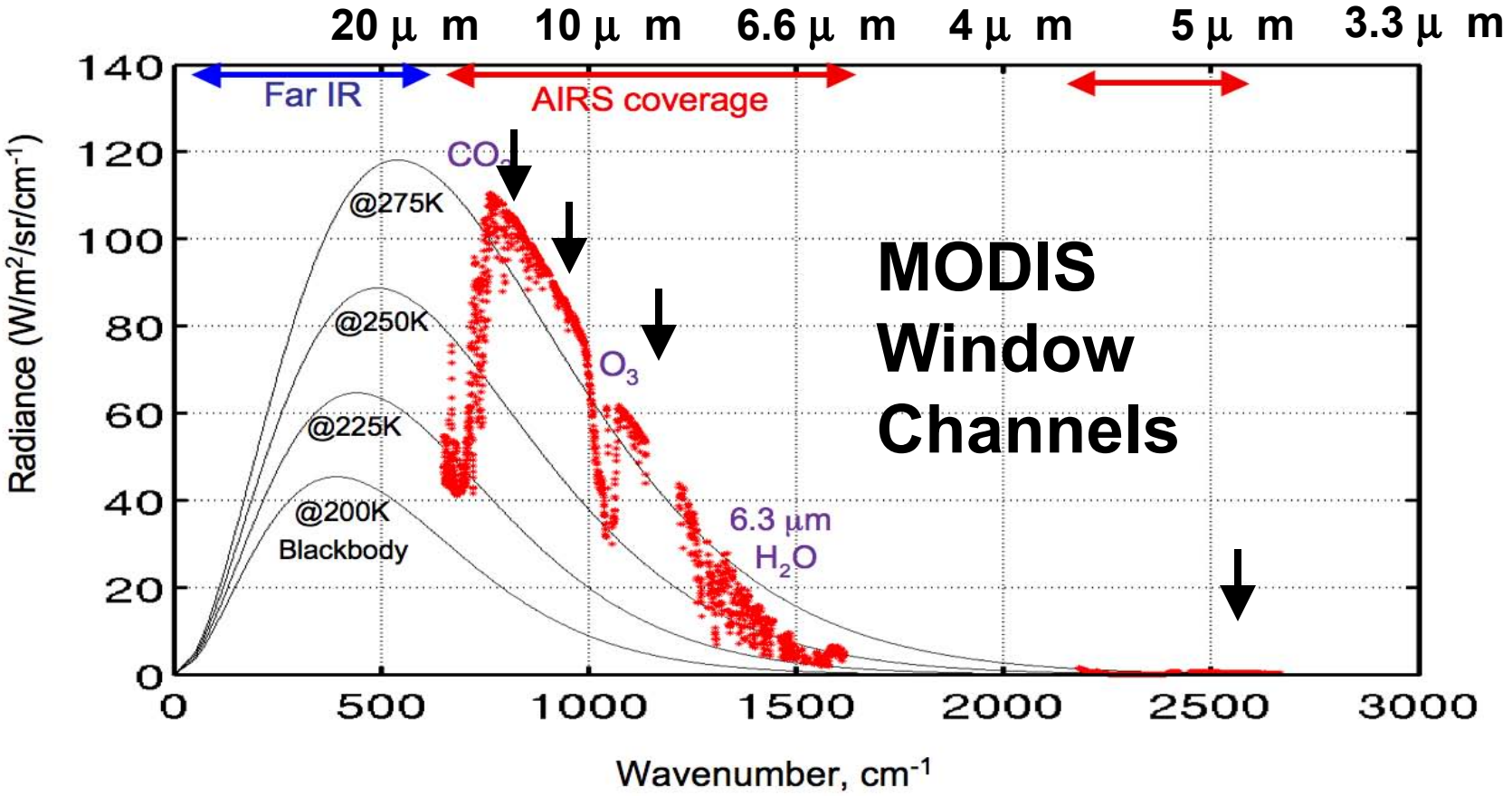


Illustration of the AIRS spectral coverage (shown in red) compared to plank radiance curves as a function of wave number for a range of blackbody temperatures. The Far IR region, defined here to be wavenumbers less than 650 cm^{-1}, i.e. λ>15.4 μm, contains the peak of atmospheric energy emission contributing to outgoing long wave radiation.

AIRS- MODIS Brightness Temperature Comparison (Tobin et al, 2006)

Good Agreement! Window Channels < 0.2 K

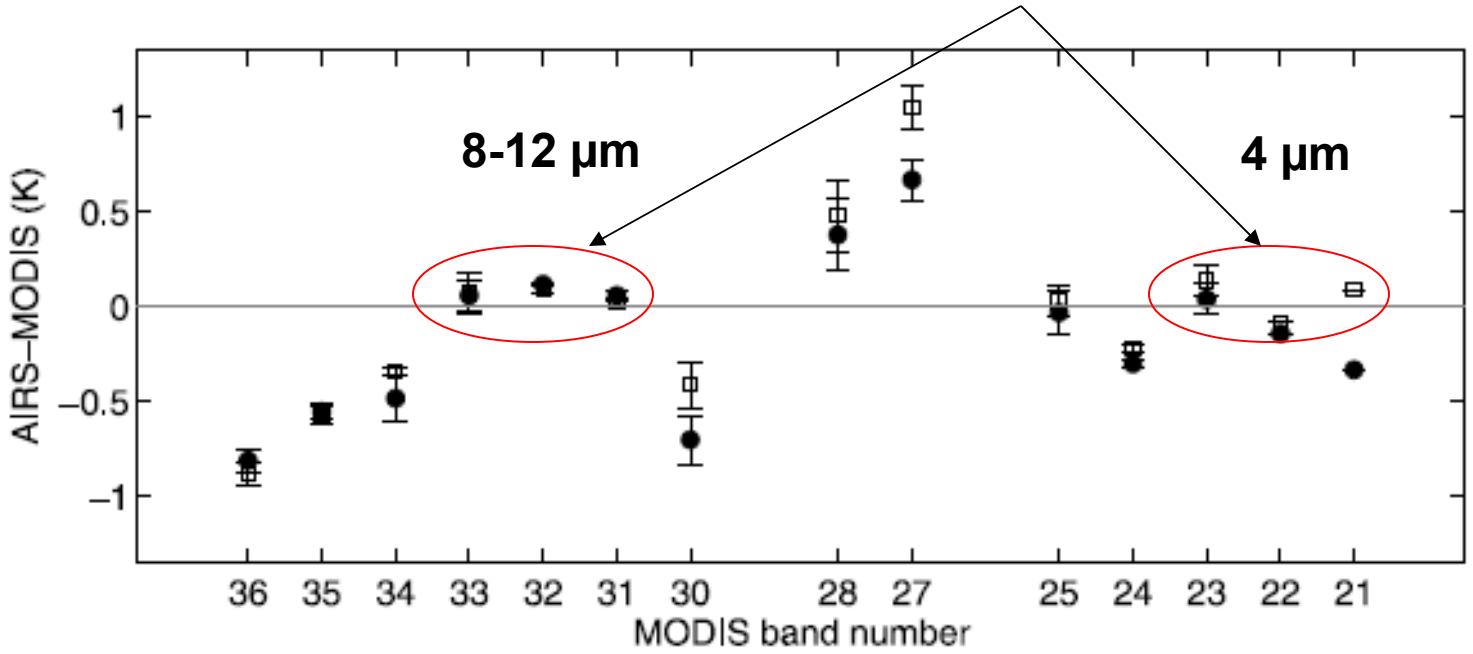


Figure 11. Mean AIRS minus MODIS brightness temperature differences and uncertainties for 6 September 2002 (open squares) and 18 February 2004 (solid circles).

Tobin, D. C., H. E. Revercomb, C. C. Moeller, and T. S. Pagano (2006), Use of Atmospheric Infrared Sounder high–spectral resolution spectra to assess the calibration of Moderate resolution Imaging Spectroradiometer on EOS Aqua, J. Geophys. Res., 111, D09S05,

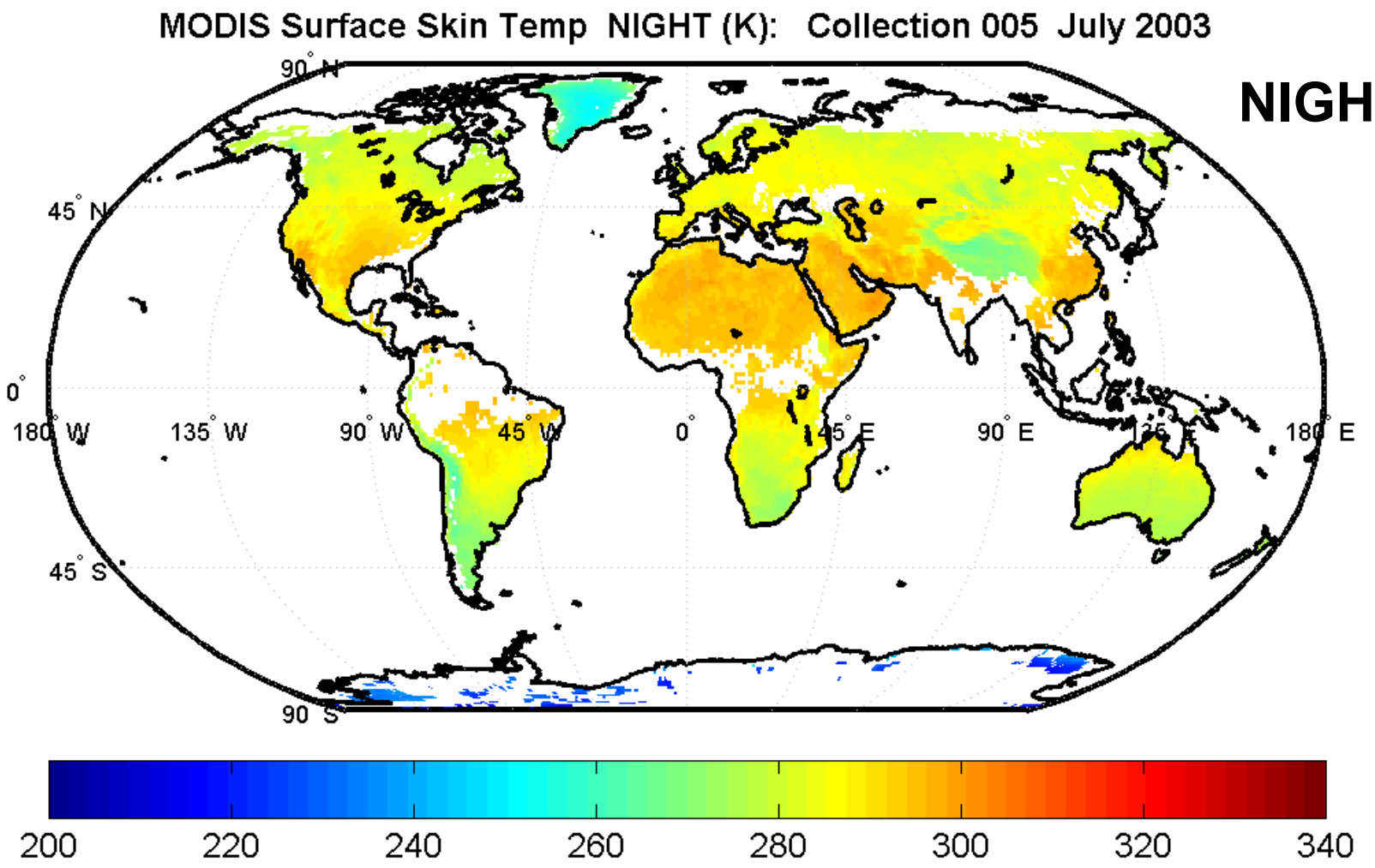
Comparison of

Ts and infrared Es

Between
AIRS (NASA Team Physical Retrieval)
and
MODIS (Land Team Day/Night Algorithm)

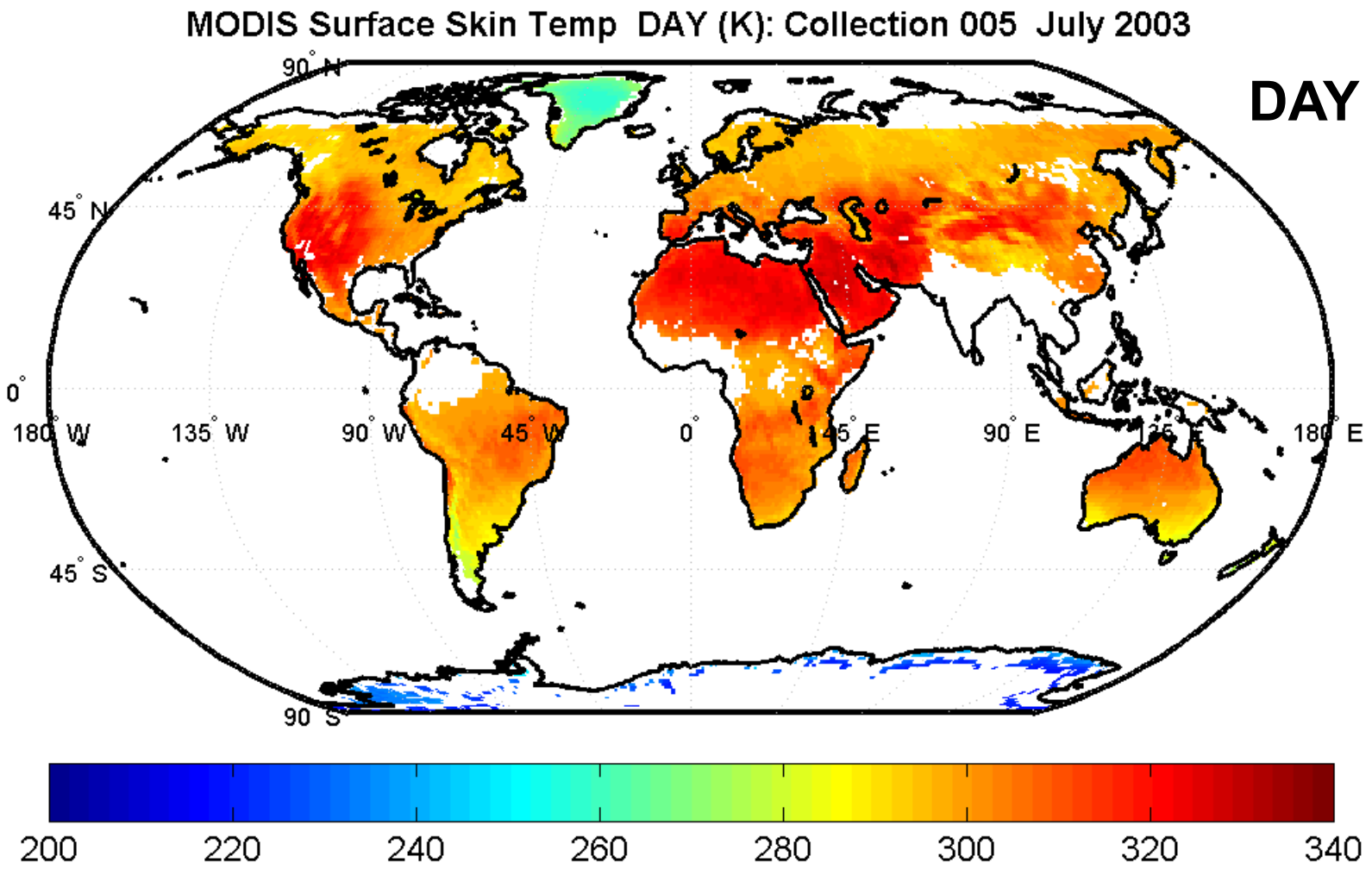
2002 - 2006

MODIS LST averaged to 1° x1° degree grid



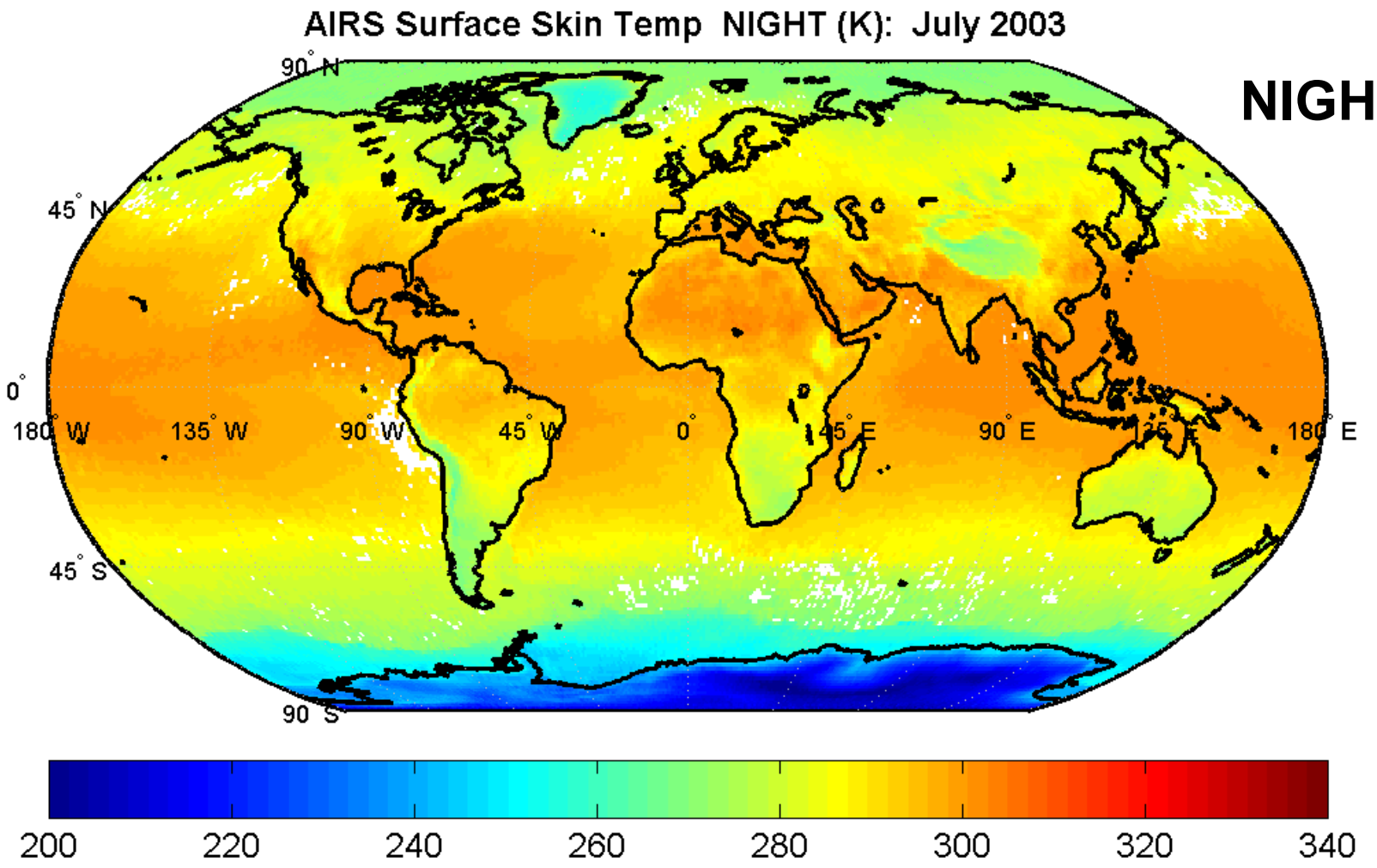
Monthly Average July 2003. Cloud-free.

MODIS LST averaged to 1° x1° degree grid



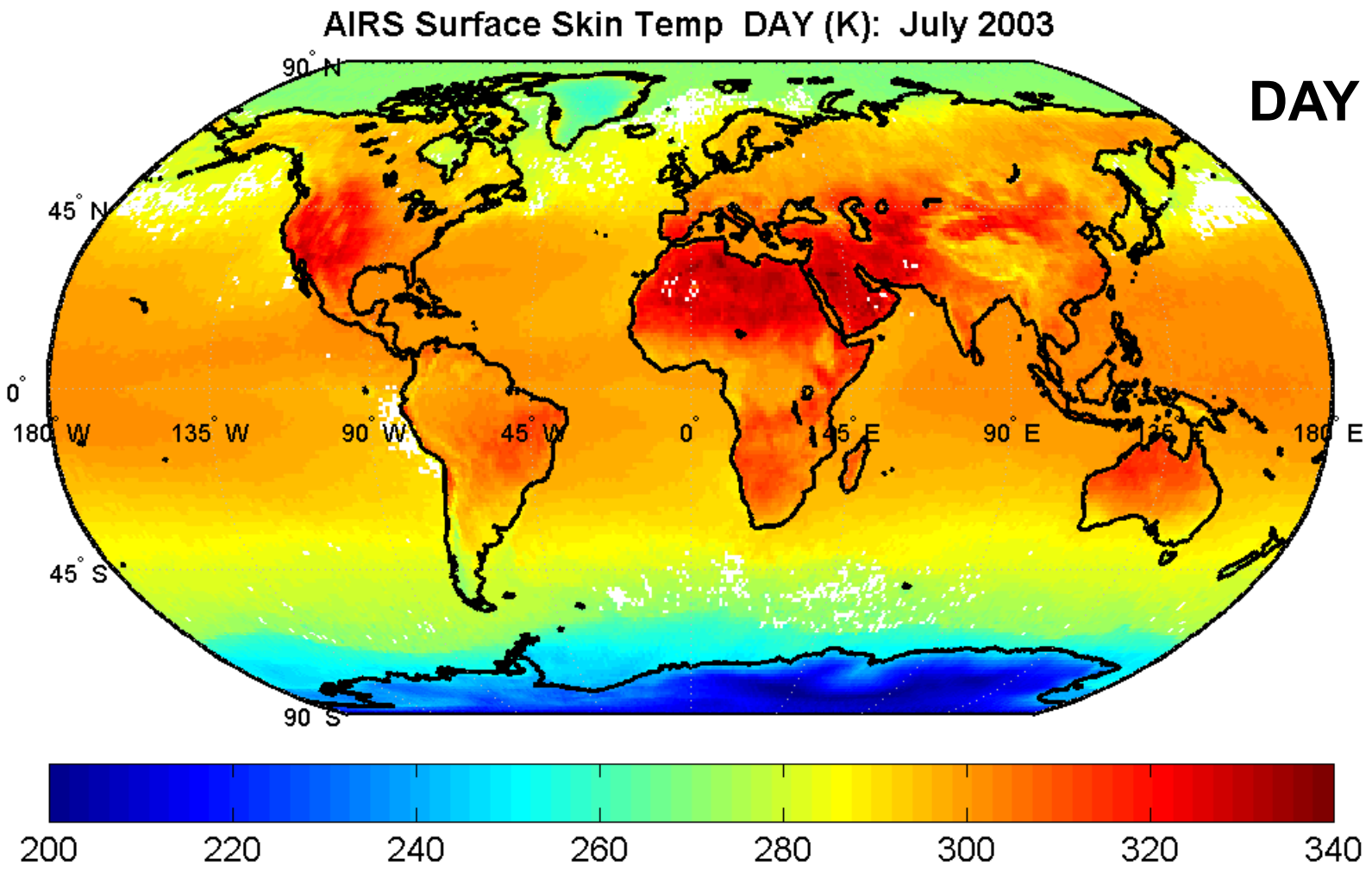
Monthly Average July 2003. Cloud-free.

AIRS LST on 1° x1° degree grid



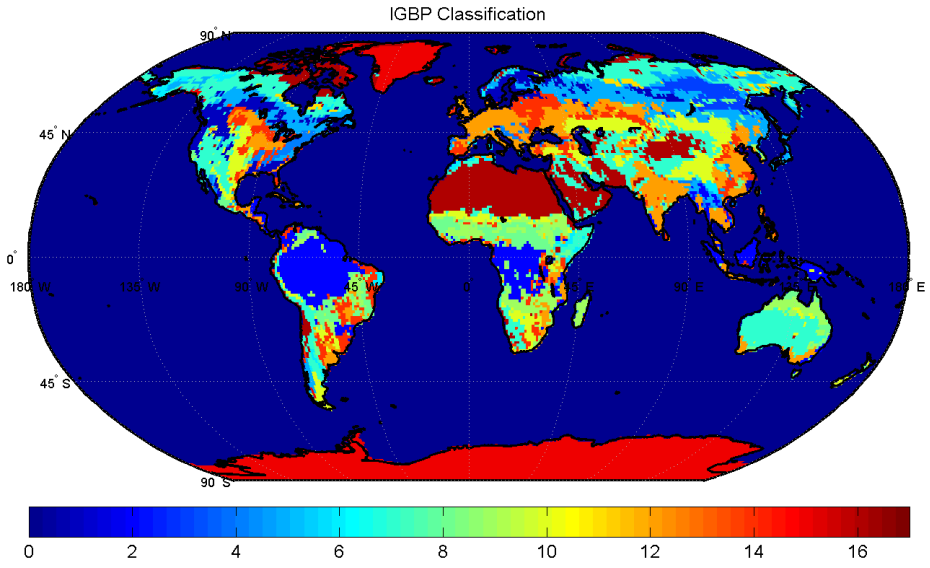
Monthly Average July 2003. Cloud-cleared.

AIRS LST on 1° x1° degree grid



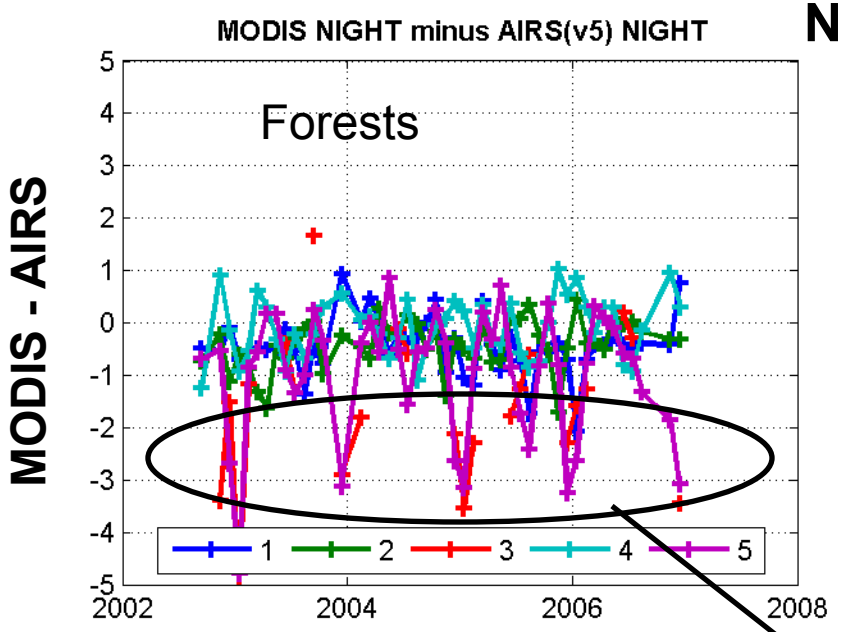
Monthly Average July 2003. Cloud-cleared.

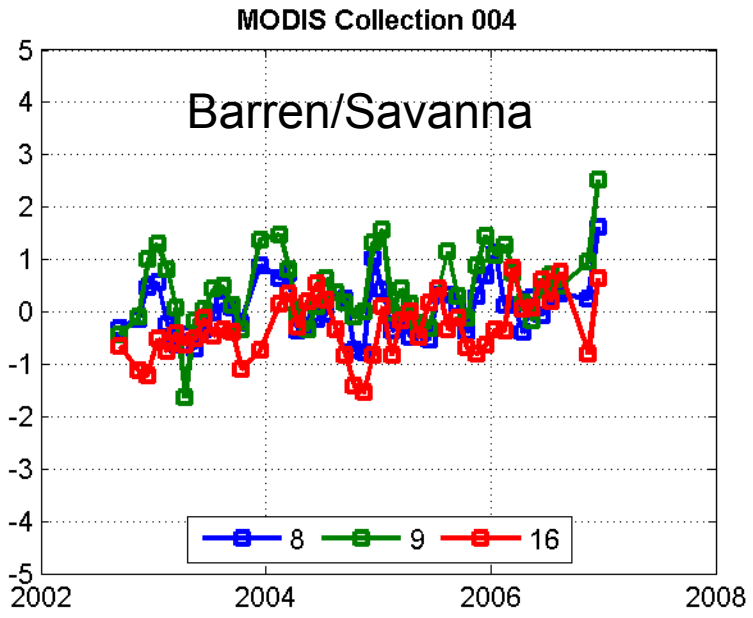
Use Land Classes (IGBP) to group the global data by land type for statistical analysis.



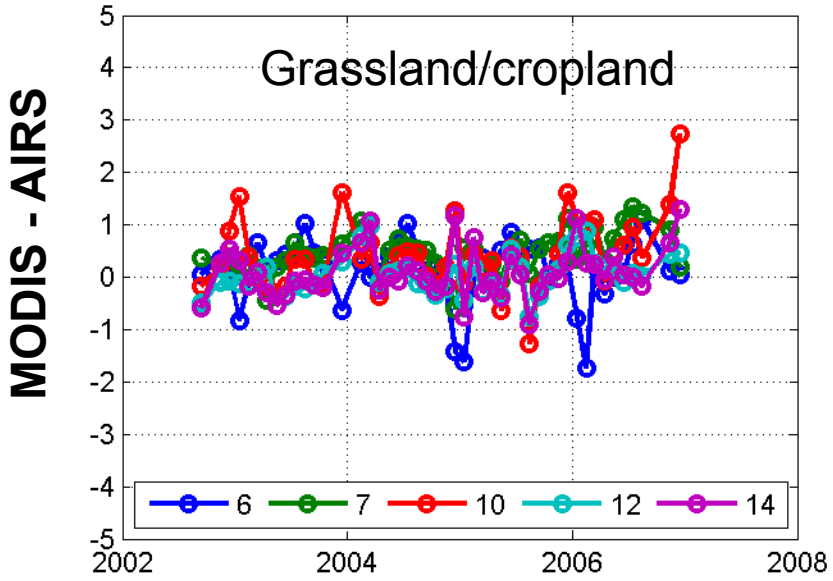
IGBP CLASS ID	IGBP CLASS Description
0	Water Bodies
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland/Natural Vegetation Mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Missing Data

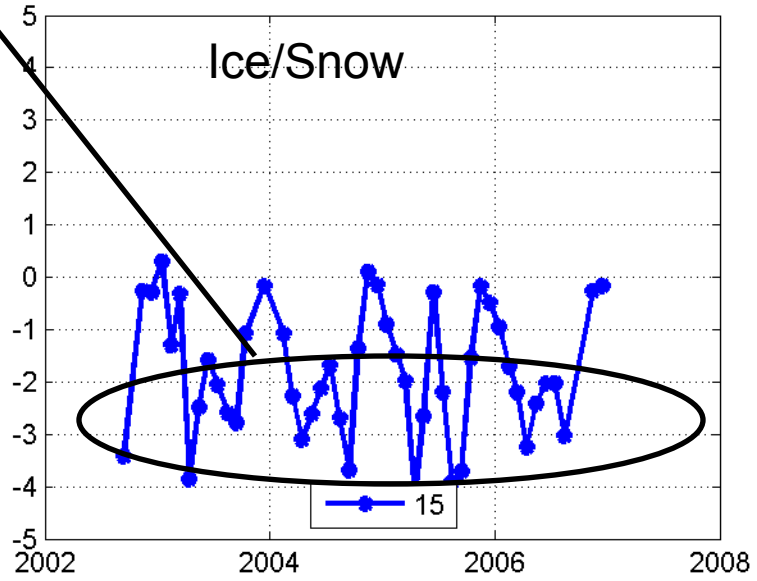
NIGHT





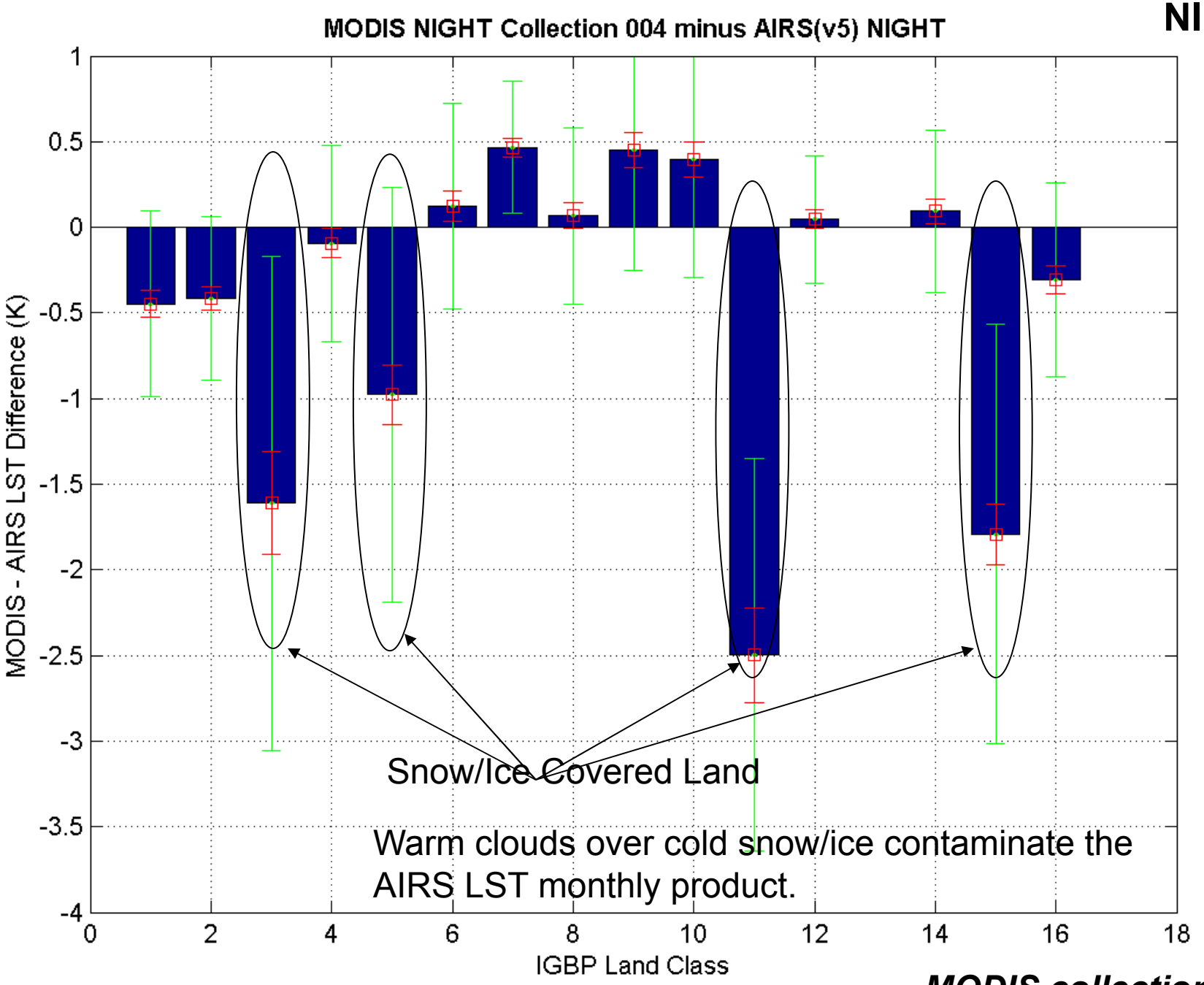
Cloud Contamination over Ice/Snow





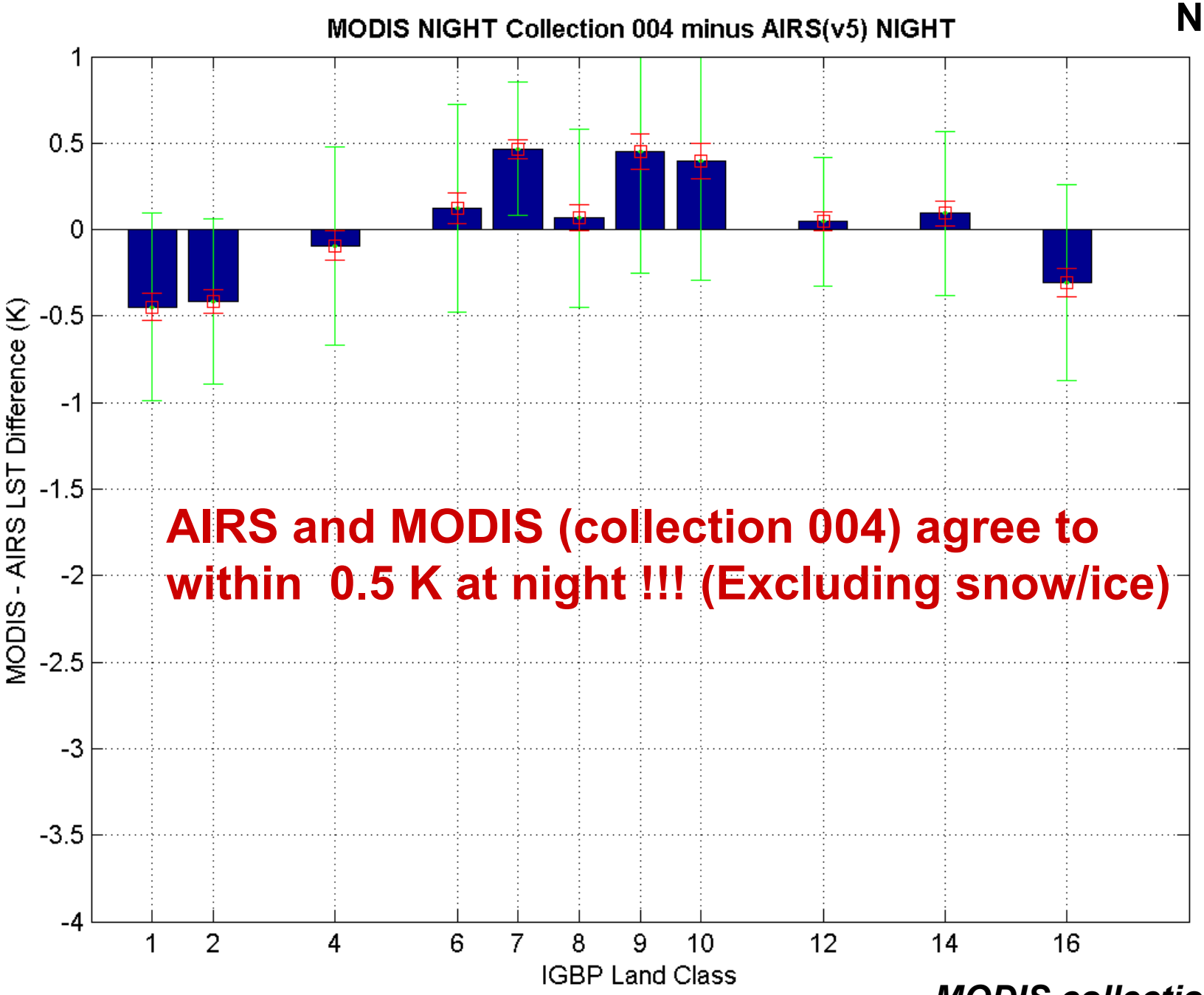
MODIS collection 4

NIGHT



MODIS collection 4

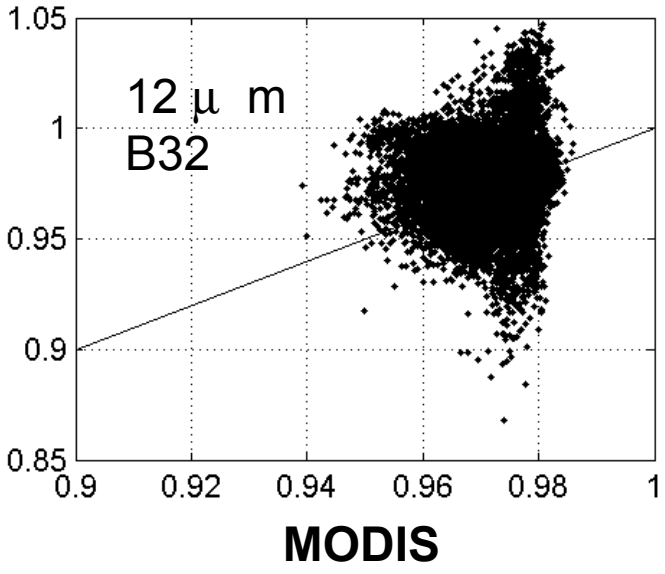
NIGHT



MODIS collection 4

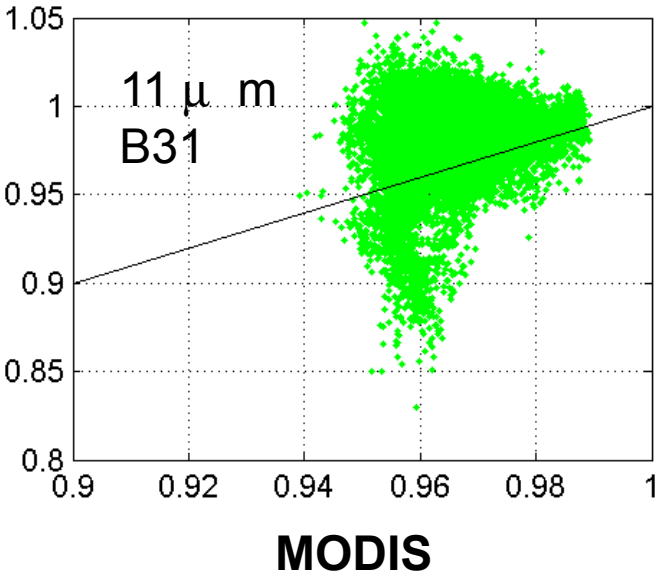
Infrared Emissivity Comparison: AIRS vs MODIS

NIGHT



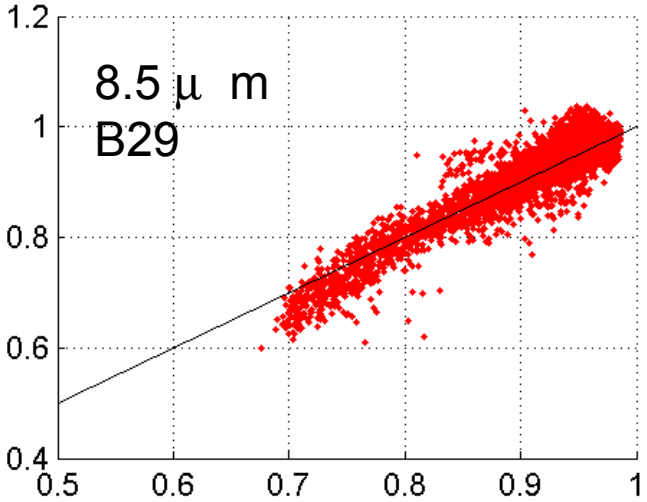
AIRS

MODIS



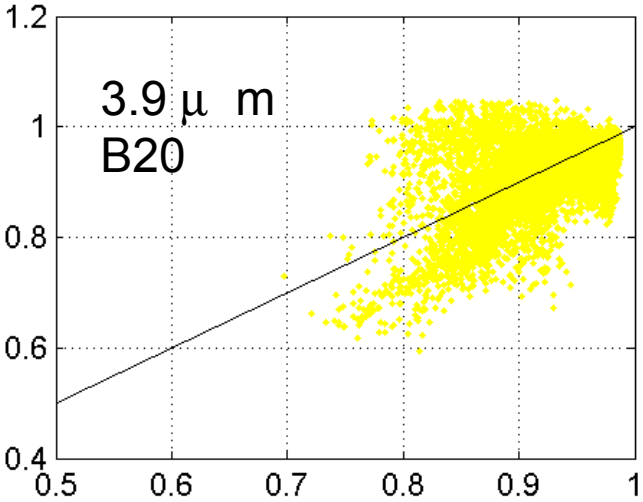
MODIS

Monthly Composite



AIRS

MODIS

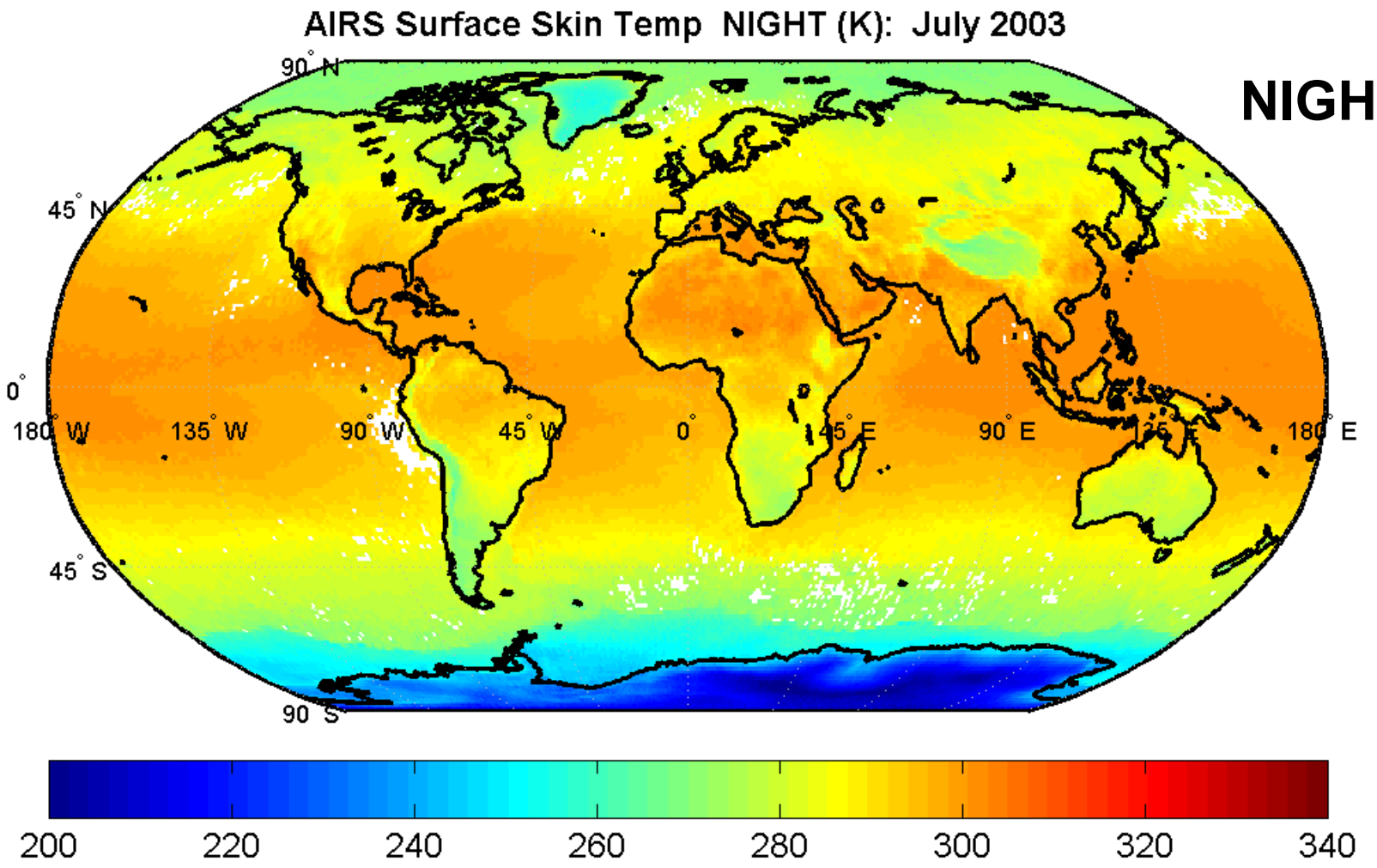


MODIS

MODIS Collection 004

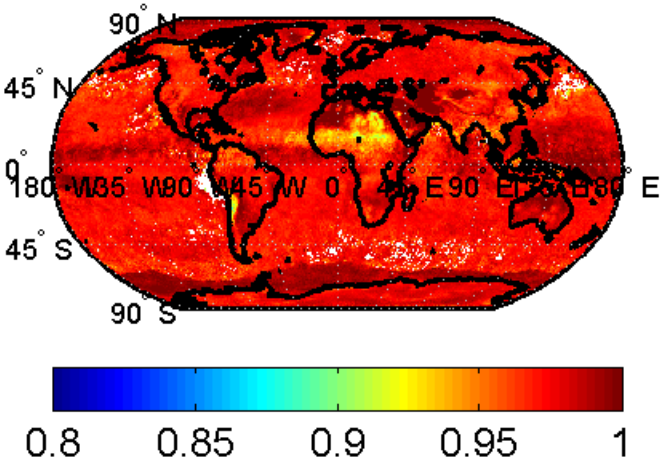
Comparison of
AIRS Calculated OLR and CERES Measured OLR

AIRS LST on 1° x1° degree grid

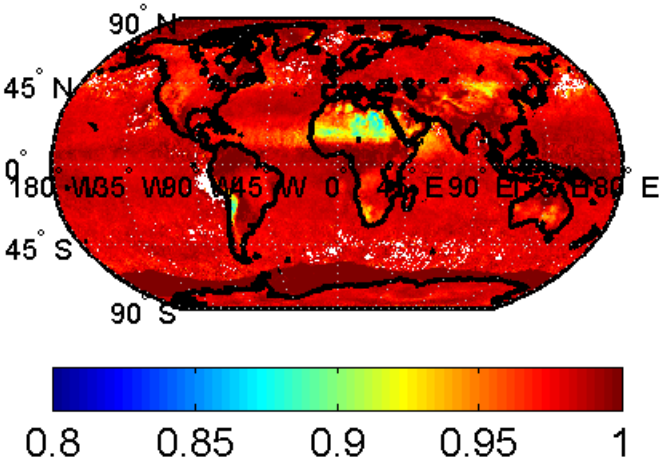


AIRS Emissivity on 1° x1° degree grid

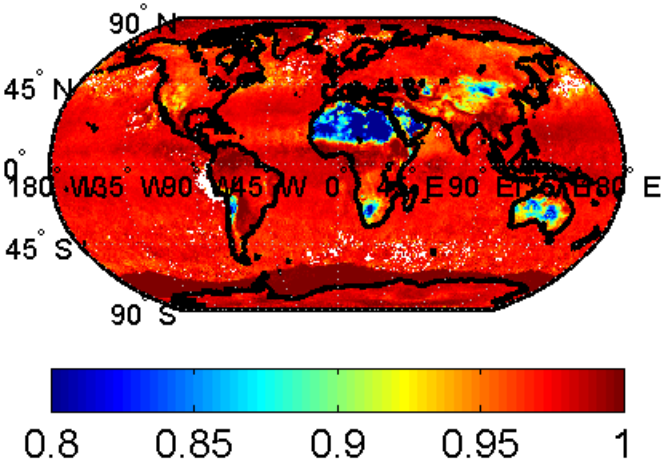
12 μm Night: July 2003



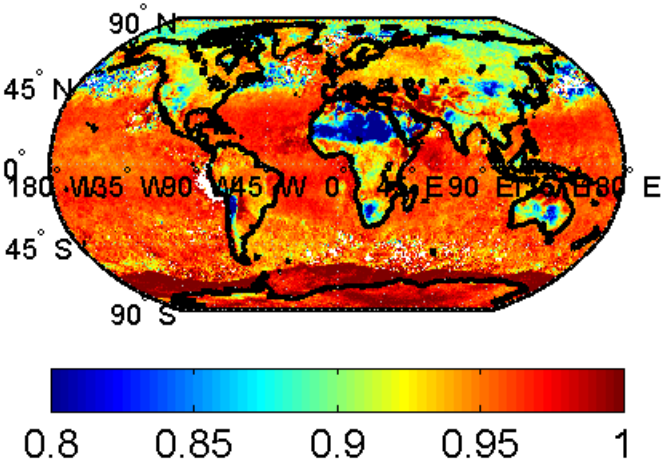
11 μm Night: July 2003



9 μm Night: July 2003



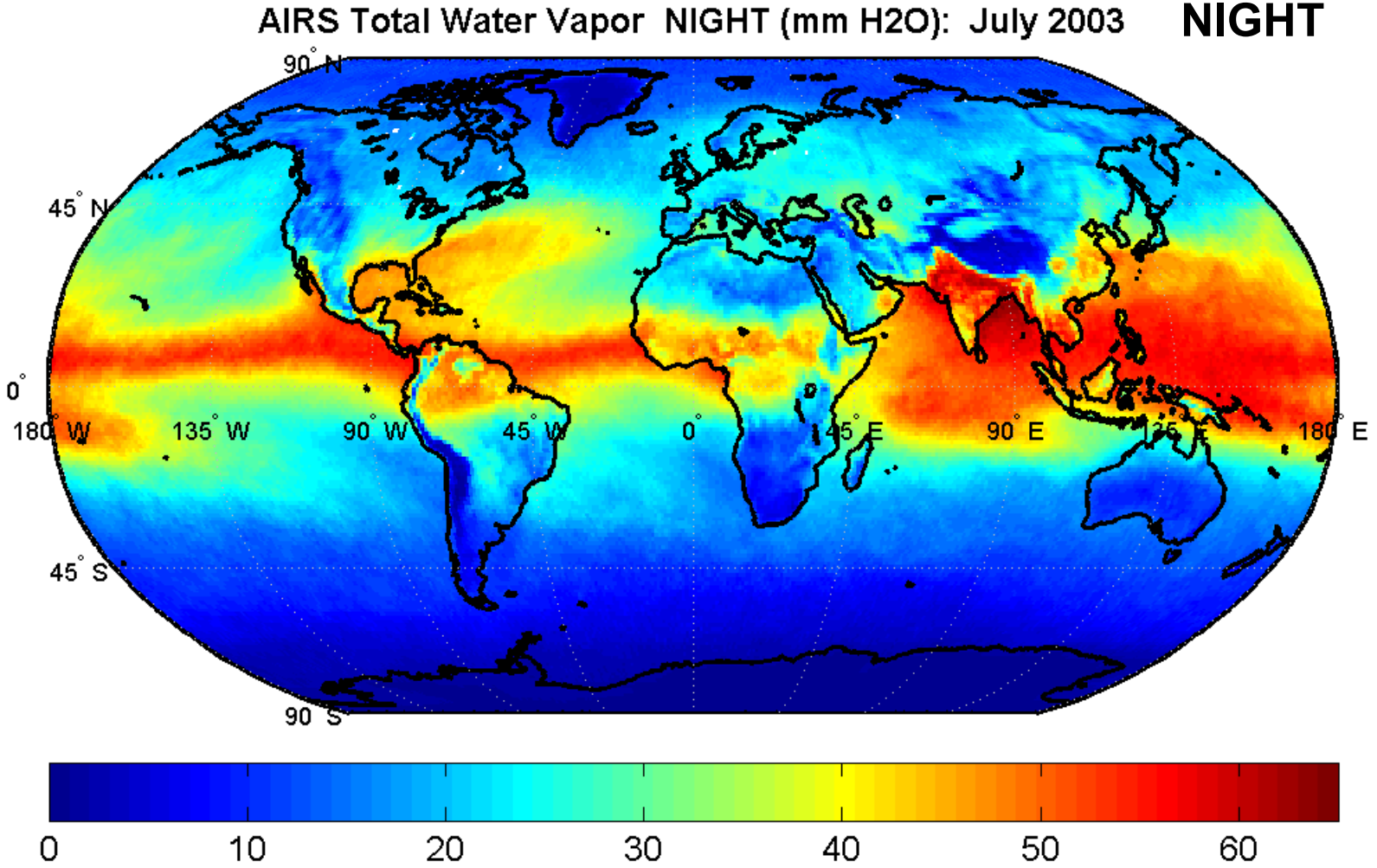
4 μm Night: July 2003



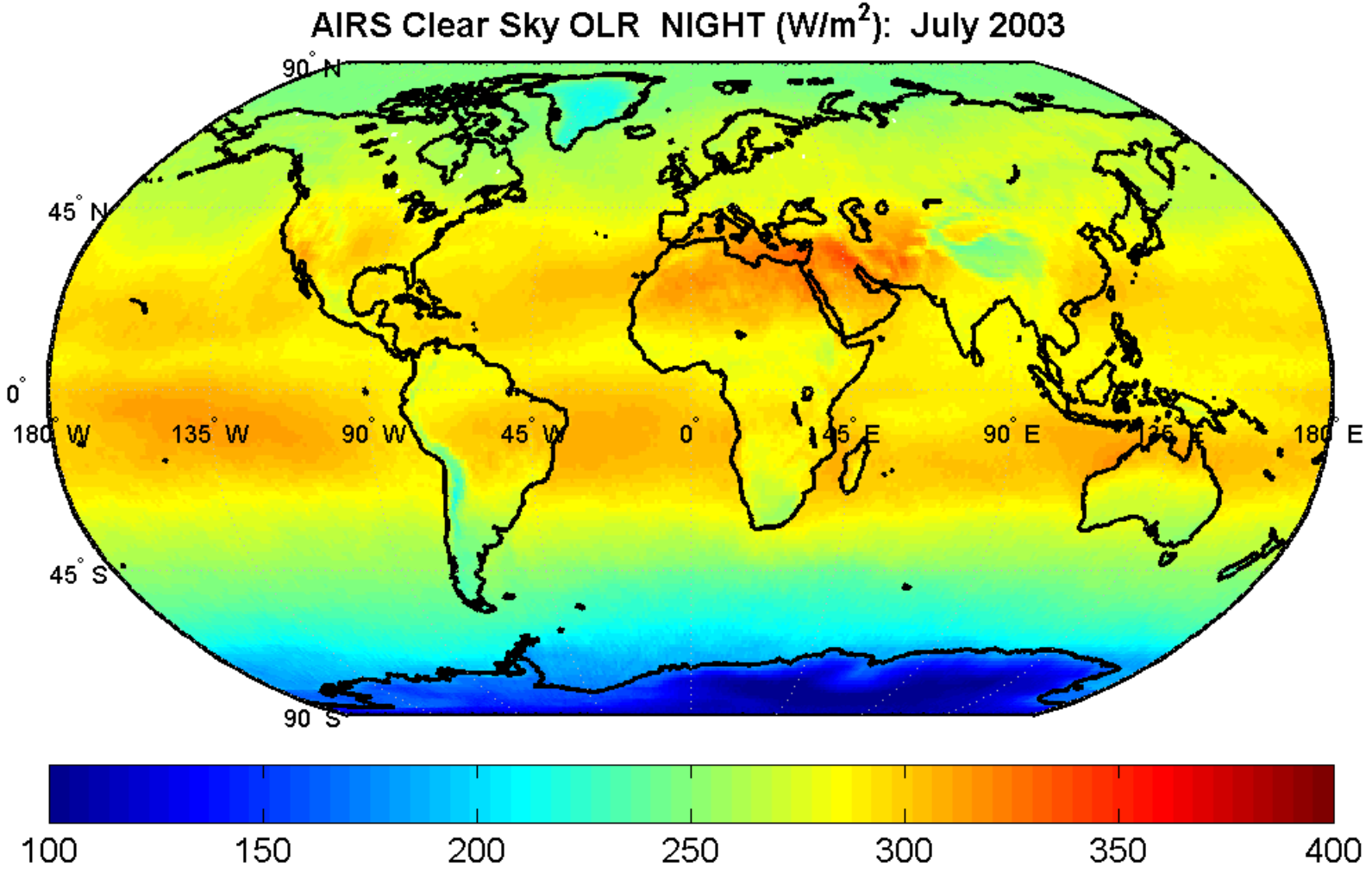
AIRS

AIRS Water Vapor

Total Column Water Vapor NIGHT



AIRS Clear Sky OLR: NIGHT

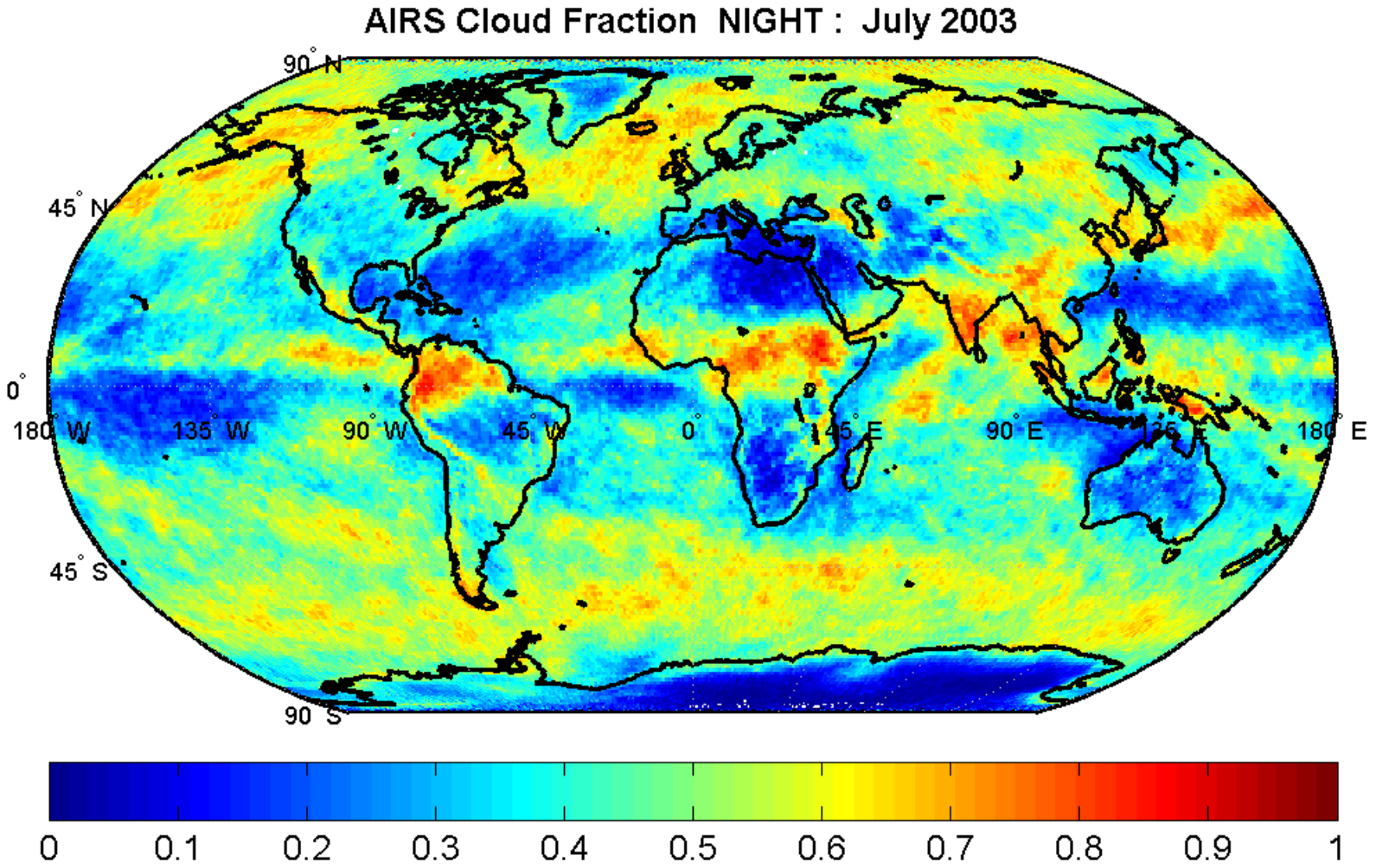


This is the product that we will compare to CERES Clear Sky OLR.

AIRS

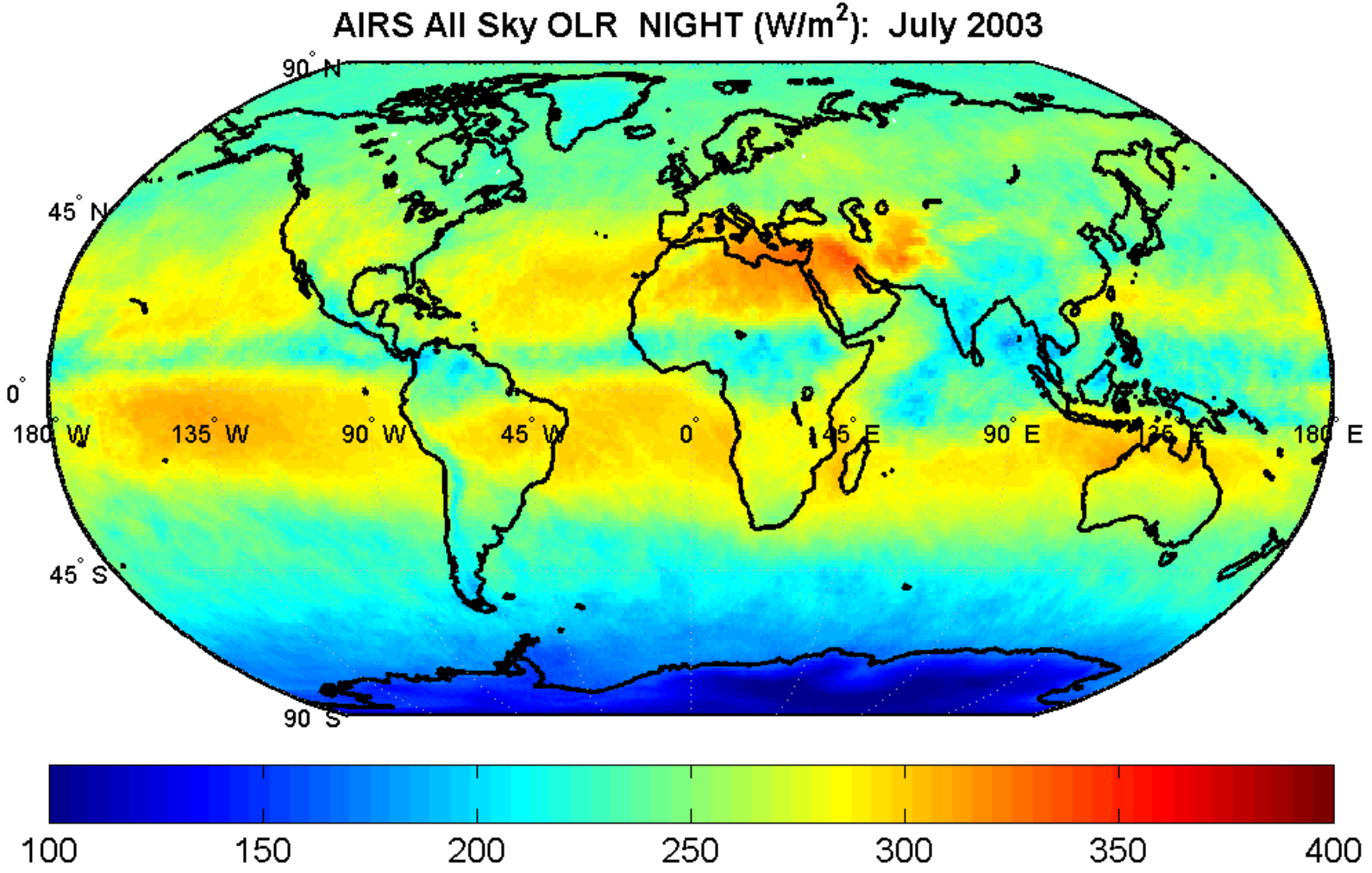
AIRS Cloud Fraction

Cloud Fraction
Night



NASA/NOAA AIRS Team Uses Cloud Clearing Algorithm to estimate clear column radiance in broken cloud fields.

AIRS All Sky OLR: NIGHT



Clouds suppress the Outgoing Longwave Radiation.

AER, Inc. Radiative Transfer Model

www.aer.com

HITRAN Line Spectroscopy Database

"Clough" CKD H2O Continuum

LBLRTM (FASCODE) Line-by-Line RTM

Correlated K-distribution Database

AIRS NASA Retrievals (T,q, Ts, Es)

Rapid Radiative Transfer Model (RRTM)

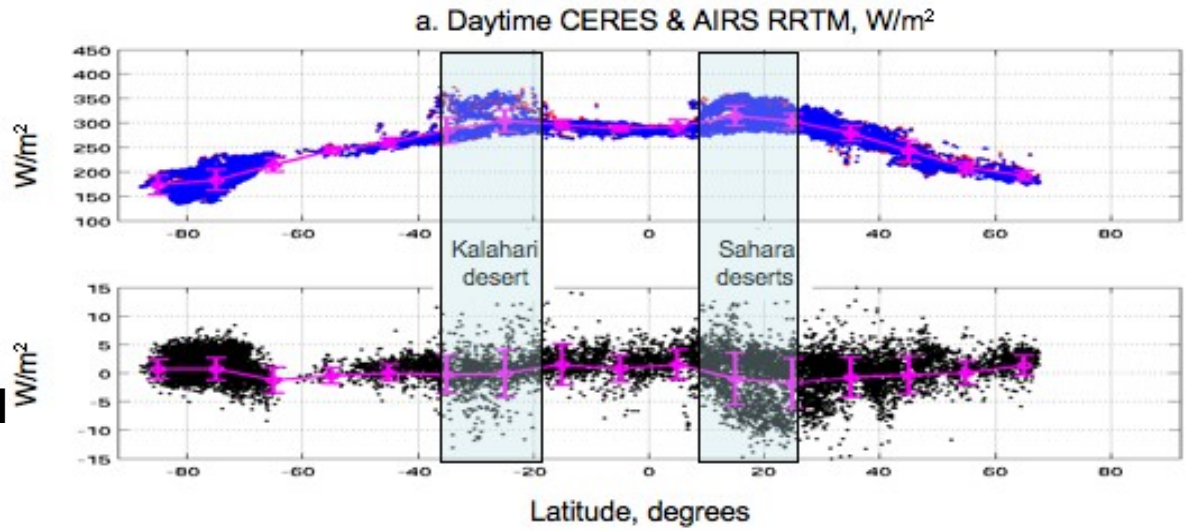
Net Flux Profile
Cooling Rate profile
Surface Flux
TOA Flux (OLR)

Claimed accuracy < 1% in OLR.

Comparison of Calculated OLR (AIRS/RRTM) and CERES Measurement

OLR

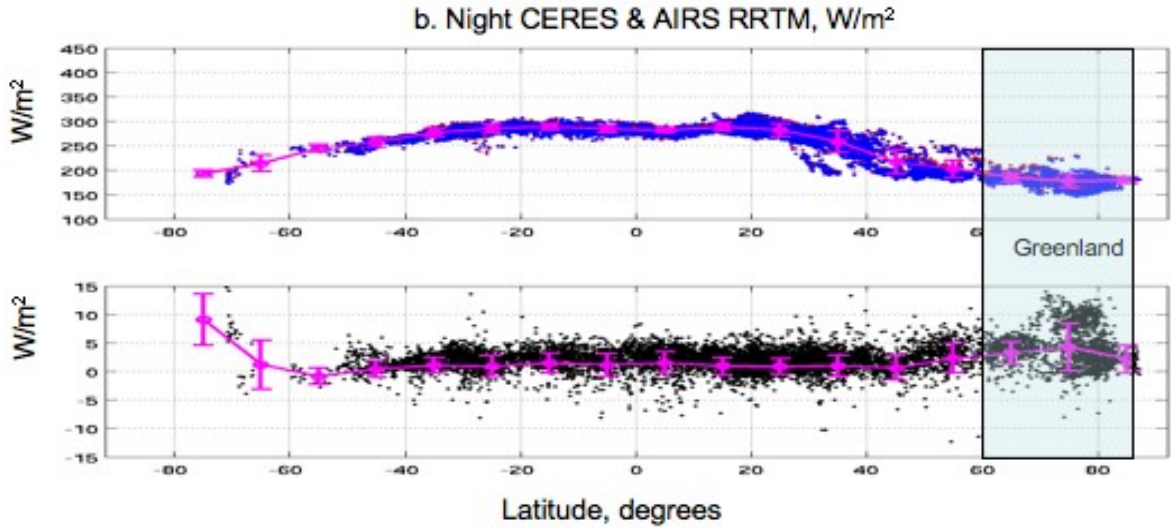
CERES – AIRS/RRTM



DAY

OLR

CERES – AIRS/RRTM

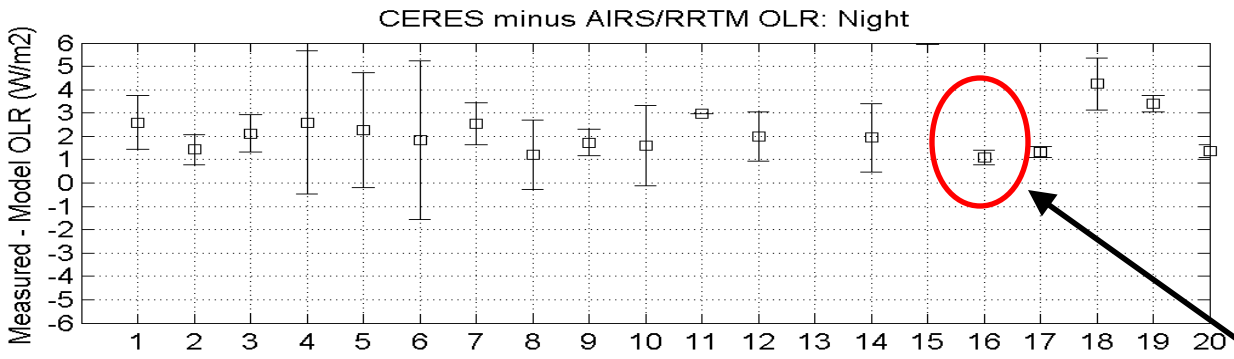


NIGHT

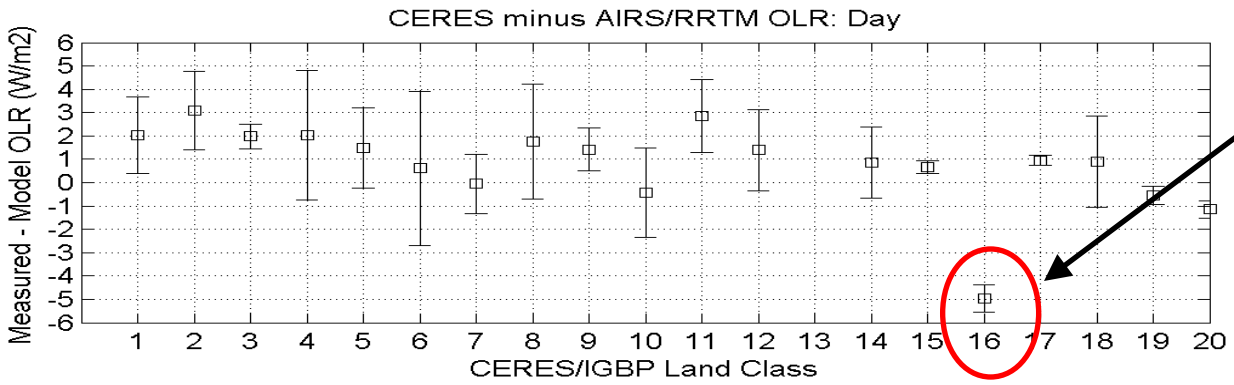
OCEAN and LAND Combined

Good Agreement for all IGBP land classes at Night

NIGHT



DAY



< 1 % Night

BARREN LAND

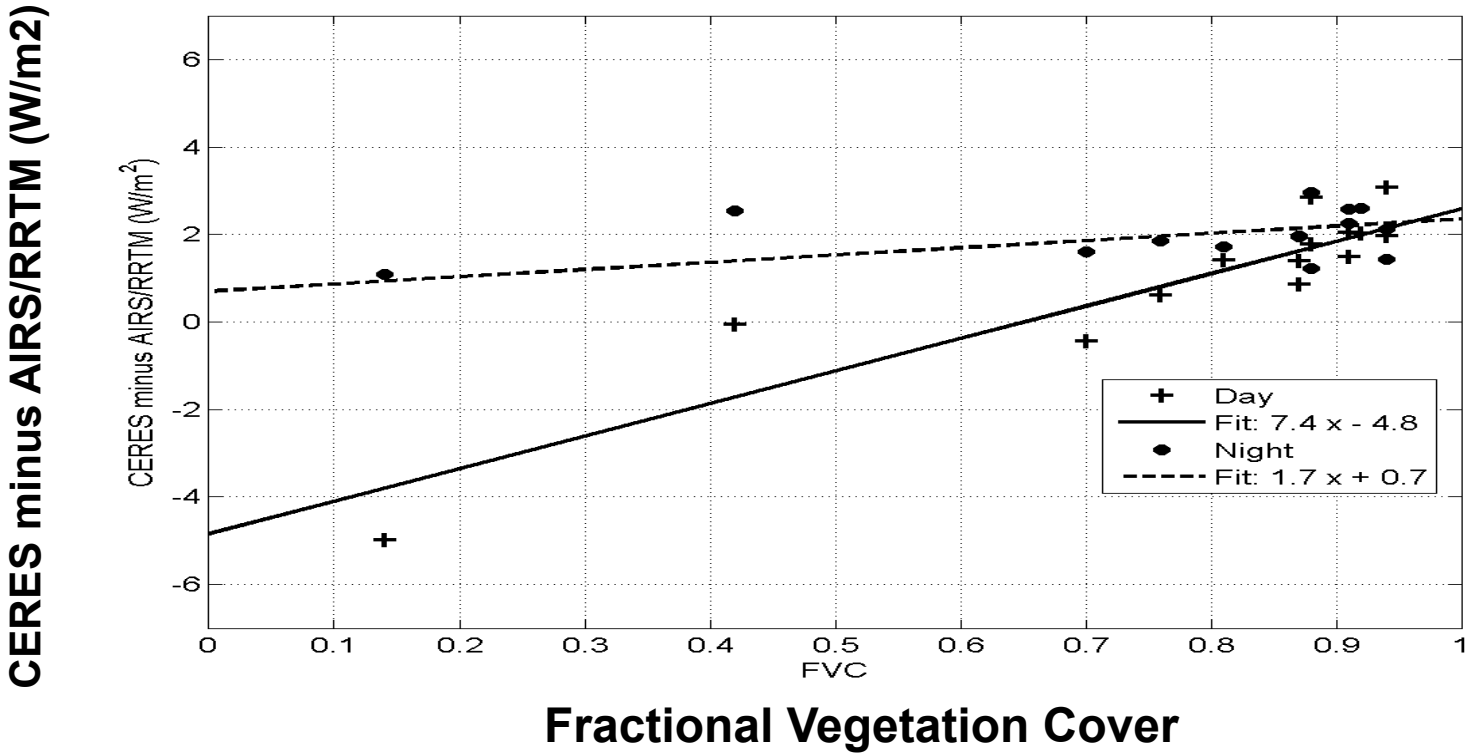
< 3 % Day

Agreement degrades in Daytime for land scenes with lower vegetation fractions.

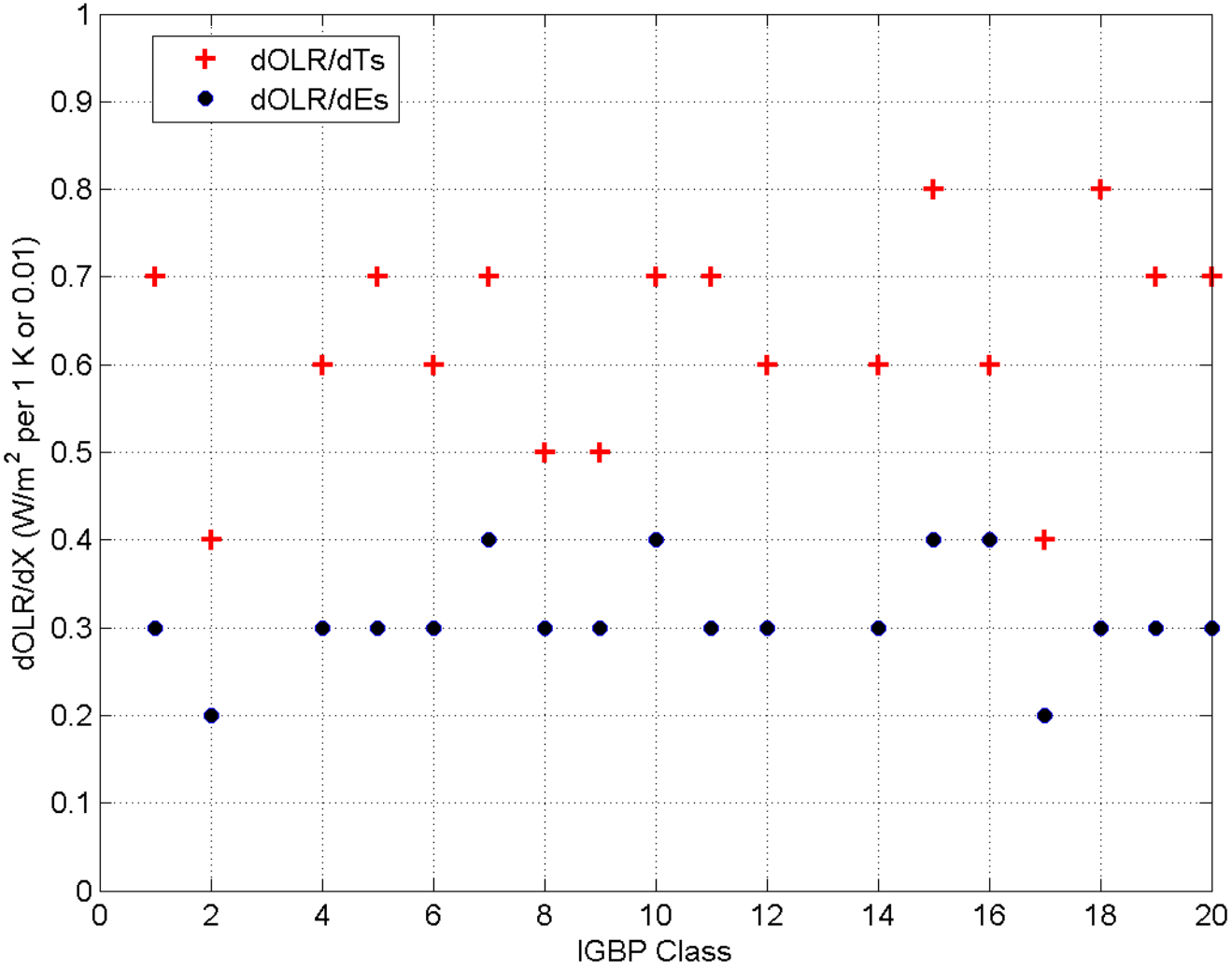
This may be an error in the CERES SW BRDF since OLR = Total – SW during the daytime.

Possible Problem with CERES Daytime OLR

Land classes, excluding snow/ice and ocean, shown as a function of mean fractional vegetation cover from Zeng et al. [2003]. The solid and dashed lines are a weighted linear fit to the measured minus modeled OLR as a function of fractional vegetation cover. The daytime dependence of CERES minus AIRS/RRTM OLR on FVC is significantly greater than the nighttime tendency. This may be a problem with the CERES SW BRDF.



OLR Sensitivity to Surface Parameter for Observed Atmospheric States by IGBP Land Class.



0.7 W/m²
per degree K Skin Temperature

0.3 W/m²
Per 0.01 emissivity

IGBP CLASS

Conclusions

- AIRS Sounder Surface temperature has been validated against MODIS (collection 4) LST with agreement for all IGBP land classes (excluding snow/ice classes) at

  < 0.5 K bias (Nighttime)

  < 1.5 K bias (Daytime)

- This agreement give confidence in the use of sounder surface temperatures over land for NWP and climate studies.

Conclusions (continued)

- Clear Sky OLR calculated using AIRS Ts, Es, T(p), q(p), O3(p) agree with CERES observations to
  - **< 0.5% over the ocean (70S to 70N)**
  - **< 1% over Nighttime land (excluding snow/ice)**
  - **< 1-3% over Daytime land (excluding snow/ice)**
- This agreement give confidence in the use of sounder retrieved parameters in constraining the TOA outgoing longwave radiation in NWP and climate models.

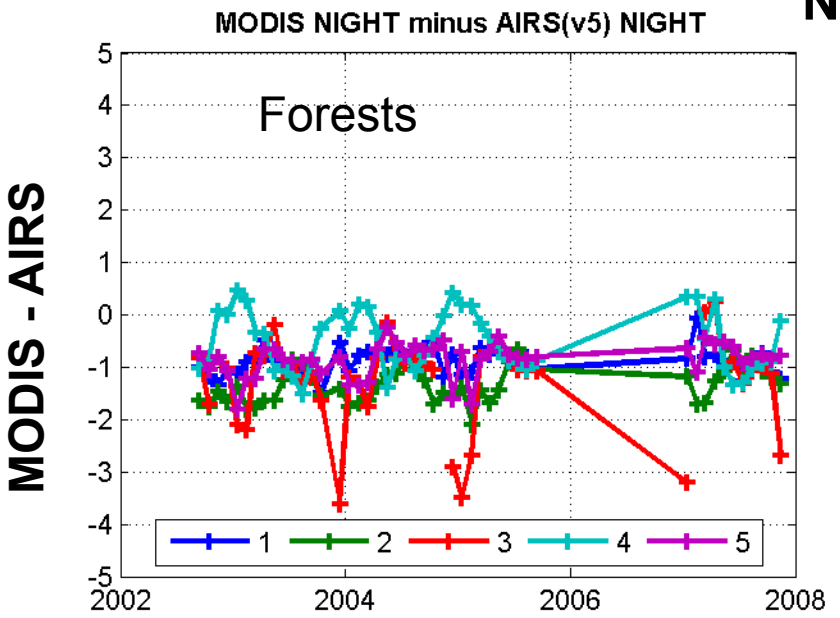
Conclusions (continued)

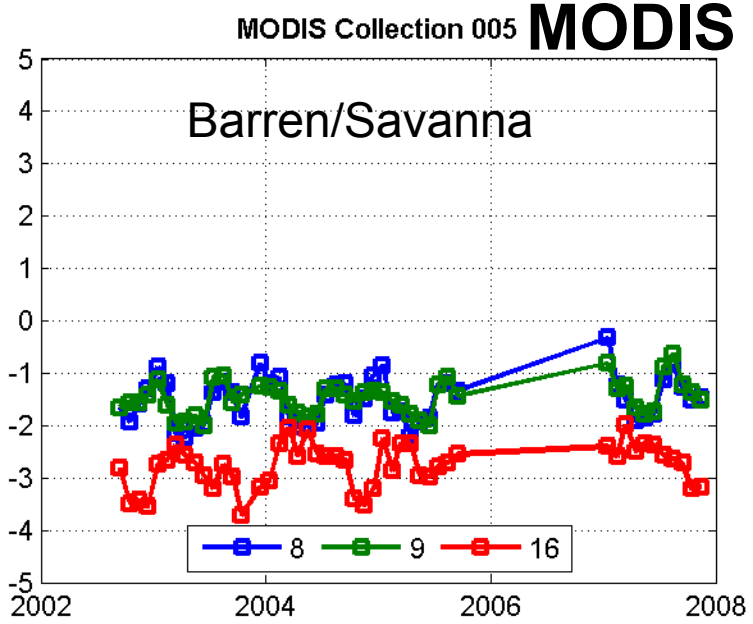
- A **sensitivity study** on the AIRS RRTM OLR due to errors in land surface parameters and vertical profiles has been performed by IGBP land class. The results show that an error of
  +1 K in the surface temperature can lead to a change in OLR of about 0.7 W/m^2 (<0.5%) while a
  0.01 increase in emissivity leads to a change in OLR of about 0.3 W/m^2 (<0.3%).

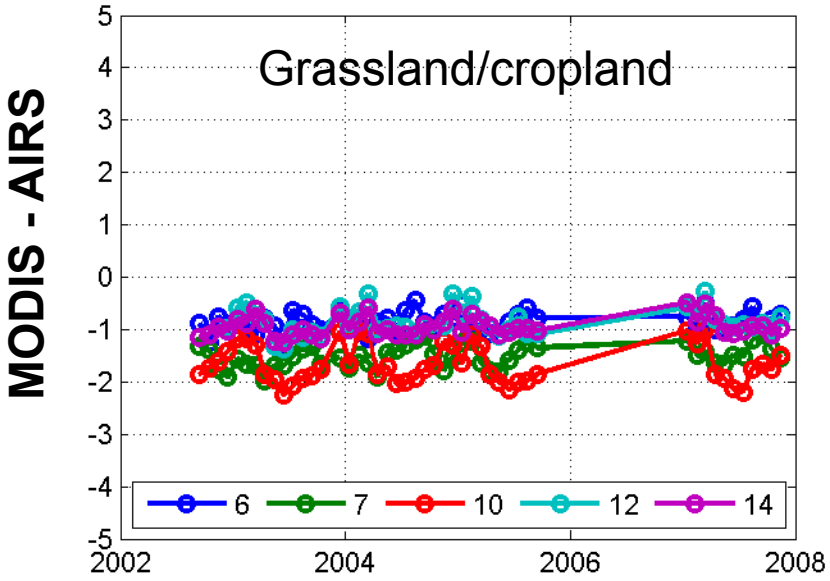
- Hence the measured error of AIRS sounder surface temperature (< 1.5 K) corresponds to an **OLR error** of better than **0.5%** for all land classes which is less than the uncertainty of the radiative transfer model (of about 1%).

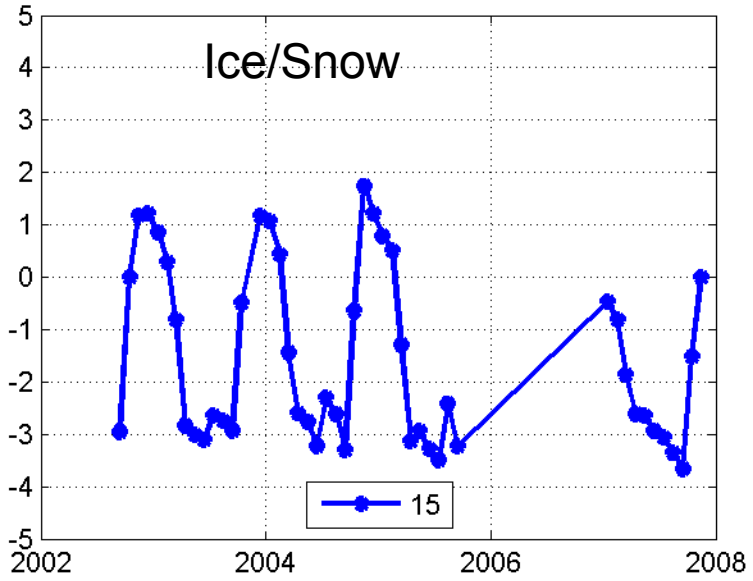
BACKUP SLIDES

NIGHT

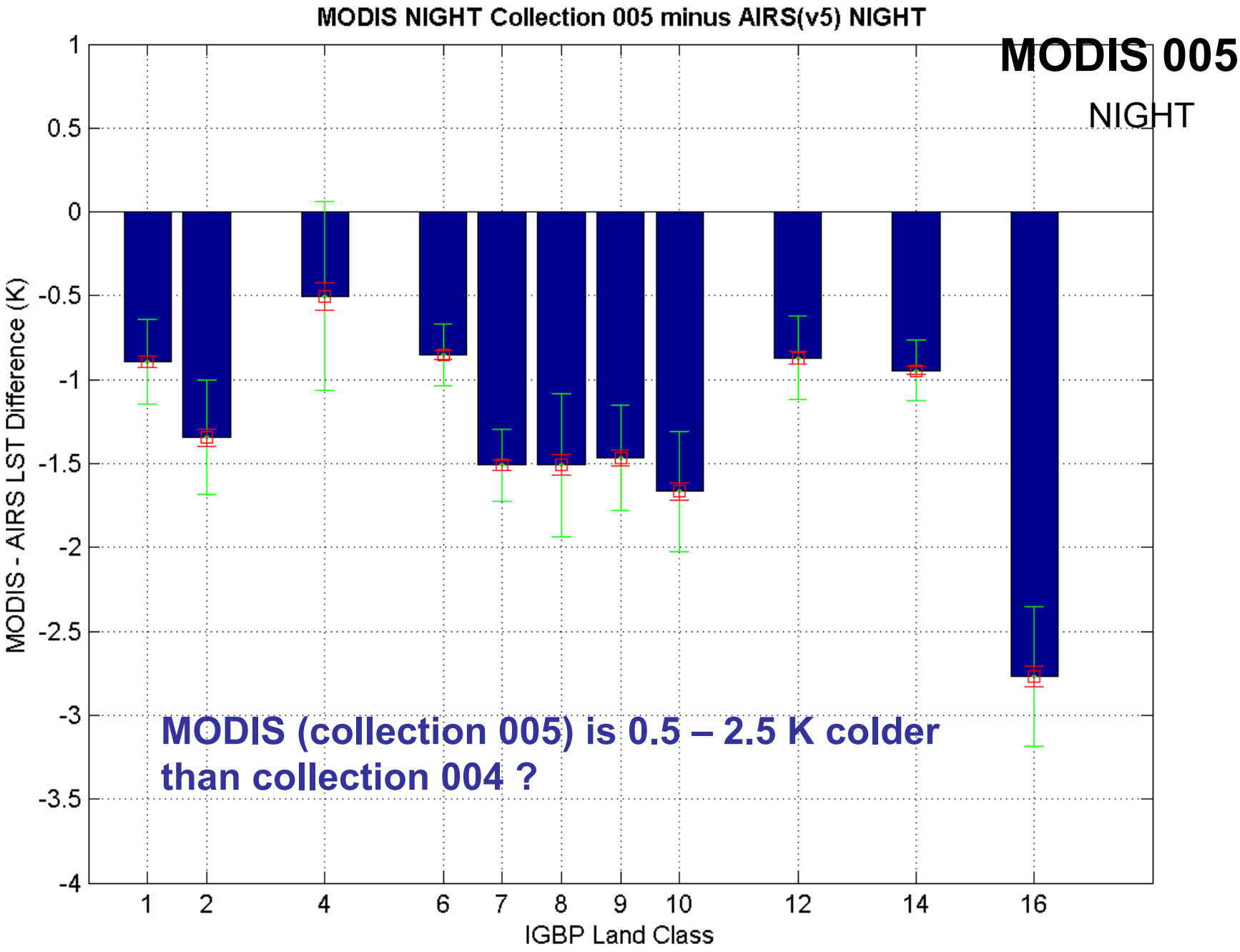


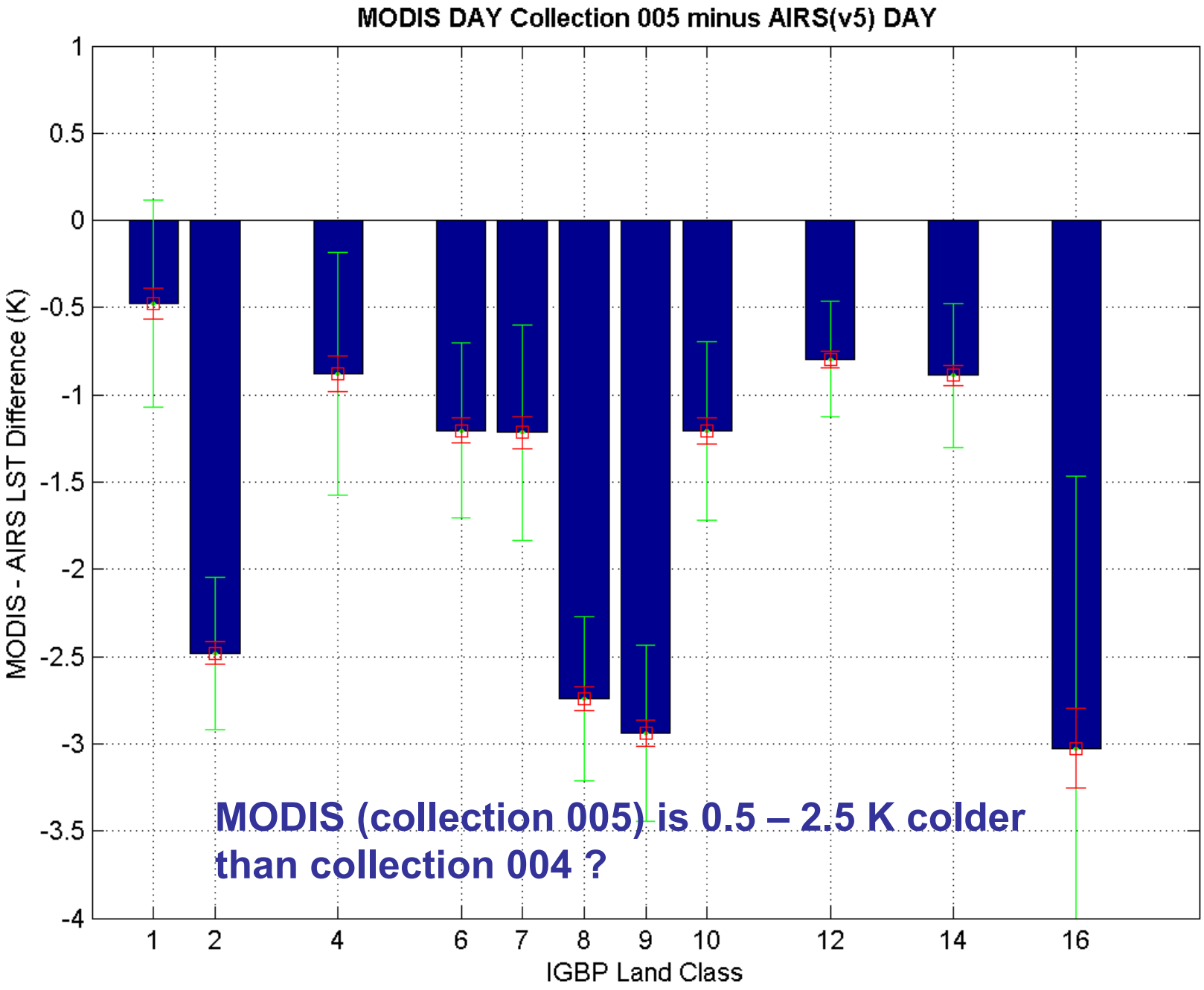






- Note artifacts (“noise”) is reduced in monthly timeseries.


MODIS NIGHT Collection 005 minus AIRS(v5) NIGHT
MODIS 005
NIGHT
MODIS - AIRS LST Difference (K)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
2
4
6
7
8
9
10
12
14
16
IGBP Land Class
MODIS (collection 005) is 0.5 – 2.5 K colder than collection 004 ?


MODIS DAY Collection 005 minus AIRS(v5) DAY
MODIS - AIRS LST Difference (K)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
2
4
6
7
8
9
10
12
14
16
IGBP Land Class
MODIS (collection 005) is 0.5 – 2.5 K colder than collection 004 ?

MYD11C3

Aqua
MODIS
(Early PM orbit)

Monthly Average
Clear Day/Night

0.05 degree grid
(5 km x 5 km)

QC Flag = '00'

Collection 004
Sep 2002 –
Dec 2006

Collection 005
Sep 2002 –
Sep 2005 &
Jan 2007 –
Nov 2007

AIRS and MODIS

Collection 004	Collection 005
15-Sep-2002	15-Sep-2002
15-Nov-2002	15-Oct-2002
15-Dec-2002	15-Nov-2002
15-Jan-2003	15-Dec-2002
15-Feb-2003	15-Jan-2003
15-Mar-2003	15-Feb-2003
15-Apr-2003	15-Mar-2003
15-May-2003	15-Apr-2003
15-Jun-2003	15-May-2003
15-Jul-2003	15-Jun-2003
15-Aug-2003	15-Jul-2003
15-Sep-2003	15-Aug-2003
15-Oct-2003	15-Sep-2003
15-Dec-2003	15-Oct-2003
15-Feb-2004	15-Dec-2003
15-Mar-2004	15-Jan-2004
15-Apr-2004	15-Feb-2004
15-May-2004	15-Mar-2004
15-Jun-2004	15-Apr-2004
15-Jul-2004	15-May-2004
15-Aug-2004	15-Jun-2004
15-Sep-2004	15-Jul-2004
15-Oct-2004	15-Aug-2004
15-Nov-2004	15-Sep-2004
15-Dec-2004	15-Oct-2004
15-Jan-2005	15-Nov-2004
15-Feb-2005	15-Dec-2004
15-Mar-2005	15-Jan-2005
15-Apr-2005	15-Feb-2005
15-May-2005	15-Mar-2005
15-Jun-2005	15-Apr-2005
15-Jul-2005	15-May-2005
15-Aug-2005	15-Jun-2005
15-Sep-2005	15-Jul-2005
15-Oct-2005	15-Aug-2005
15-Nov-2005	15-Sep-2005
15-Dec-2005	15-Jan-2007
15-Jan-2006	15-Feb-2007
15-Feb-2006	15-Mar-2007
15-Mar-2006	15-Apr-2007
15-Apr-2006	15-May-2007
15-May-2006	15-Jun-2007
15-Jun-2006	15-Jul-2007
15-Jul-2006	15-Aug-2007
15-Aug-2006	15-Sep-2007
15-Nov-2006	15-Oct-2007
15-Dec-2006	15-Nov-2007

AIRS / MODIS Matched Months

Month	004	005
Jan	3	4
Feb	4	4
Mar	4	4
Apr	4	4
May	4	4
June	4	4
July	4	4
Aug	4	4
Sept	4	5
Oct	3	4
Nov	4	3
Dec	5	3
Total	**47**	**47**