The MISR Cloud Fraction by Altitude Product and the GEWEX Cloud Assessment

Larry Di Girolamo

Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign

Guangyu Zhao

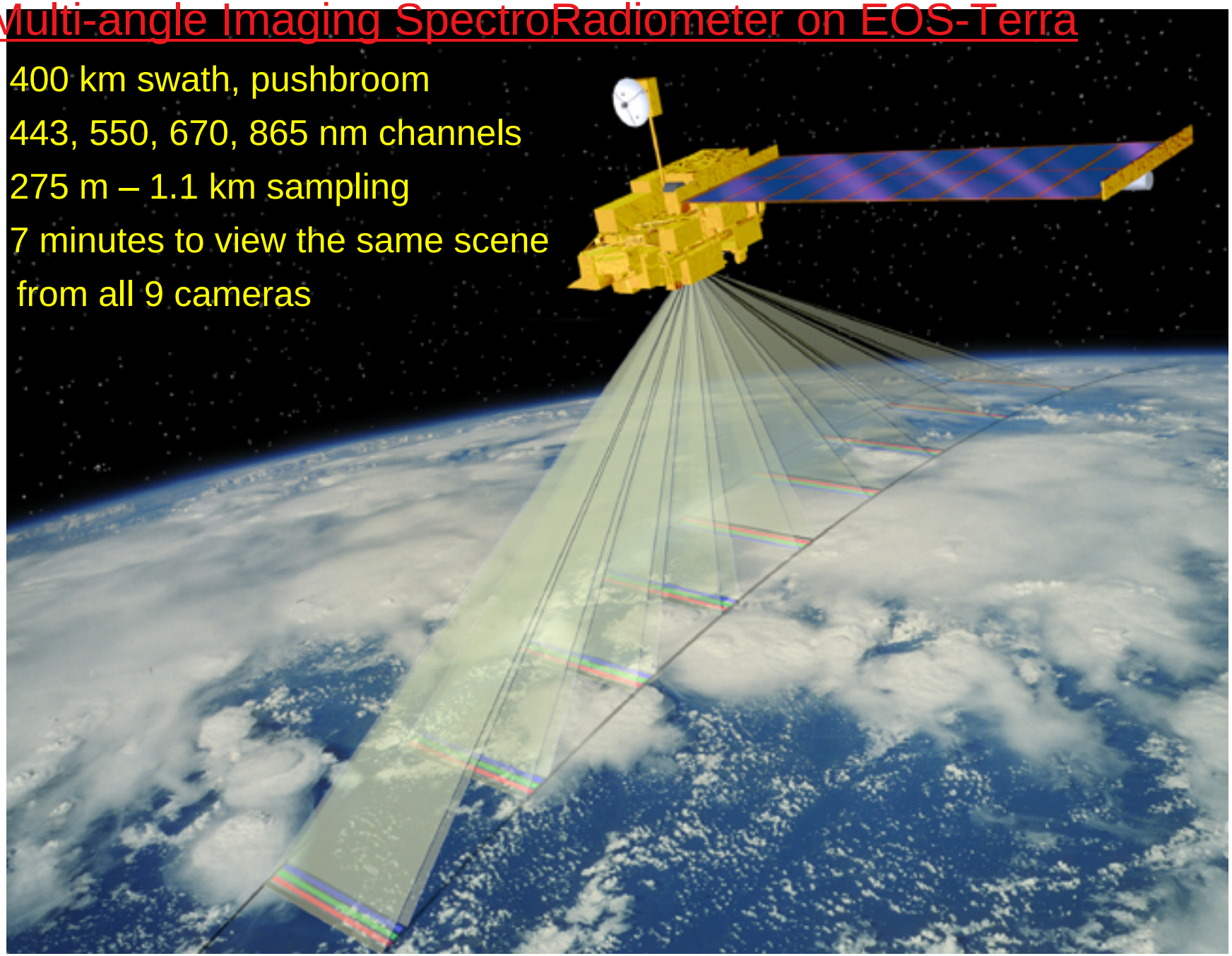
Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign

Alex Menzies

Jet Propulsion Laboratory

Multi-angle Imaging SpectroRadiometer on EOS-Terra

- 400 km swath, pushbroom
- 443, 550, 670, 865 nm channels
- 275 m – 1.1 km sampling
- 7 minutes to view the same scene from all 9 cameras



The MISR Cloud Fraction By Altitude Product

JPL D-62358

Earth Observing System

Multi-angle
Imaging
Spectro-
Radiometer

Level 3 Cloud Fraction by Altitude Algorithm Theoretical Basis

Larry Di Girolamo[1]
Alex Menzies[2]
Guangyu Zhao[1]
Kevin Mueller[2]
Catherine Moroney[2]
David J. Diner[2]

[1]University of Illinois at Urbana-Champaign
[2]Jet Propulsion Laboratory, California Institute of Technology

Di Girolamo, L., A. Menzies, G. Zhao, K. Mueller, and D.J. Diner, 2010: MISR Level 3 cloud fraction by altitude algorithm theoretical basis. *JPL D-62358, Jet Propulsion Laboratory, Pasadena, CA, 23 pp.*

Jet Propulsion Laboratory
California Institute of Technology

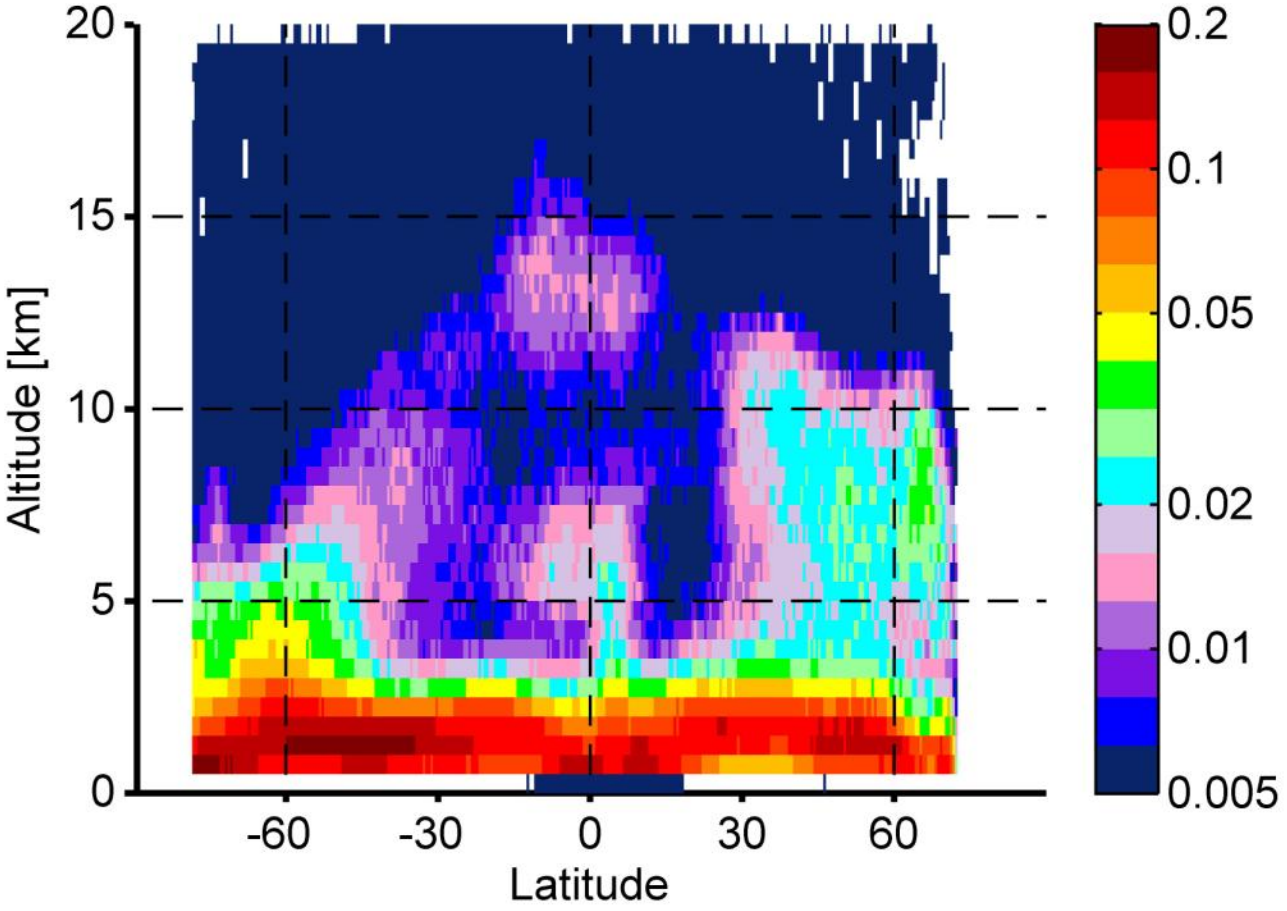
January 25, 2010

The MISR Cloud Fraction By Altitude Product

- Daily and Monthly cloud top fraction in 500 m vertical resolution bins
- 0.5° equal angle grid
- 10 years +
- Publically available through Langley: http://eosweb.larc.nasa.gov

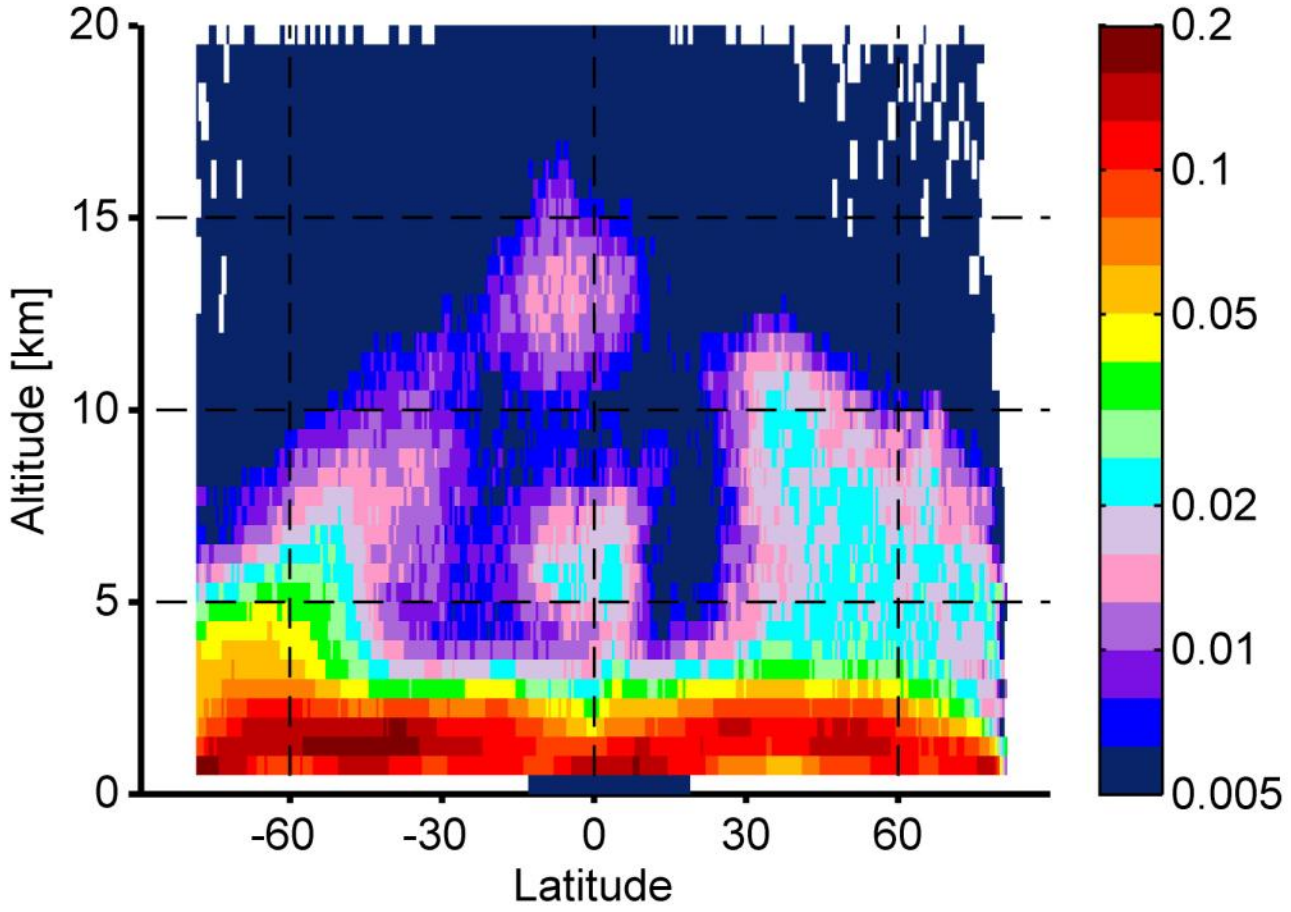
Zonal Monthly Mean (2000 – 2009; ocean only)

Jan



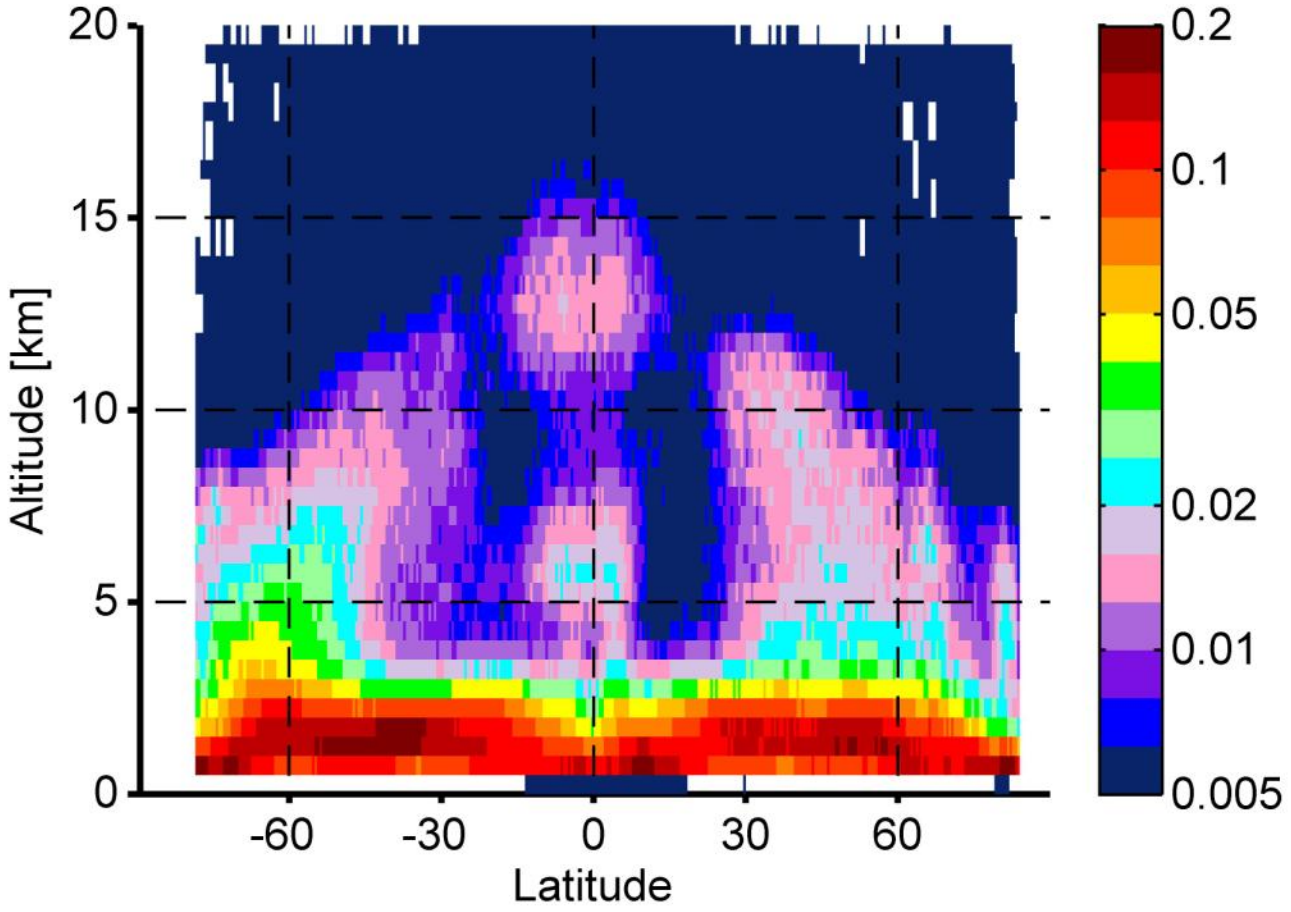
Zonal Monthly Mean (2000 – 2009; ocean only)

Feb



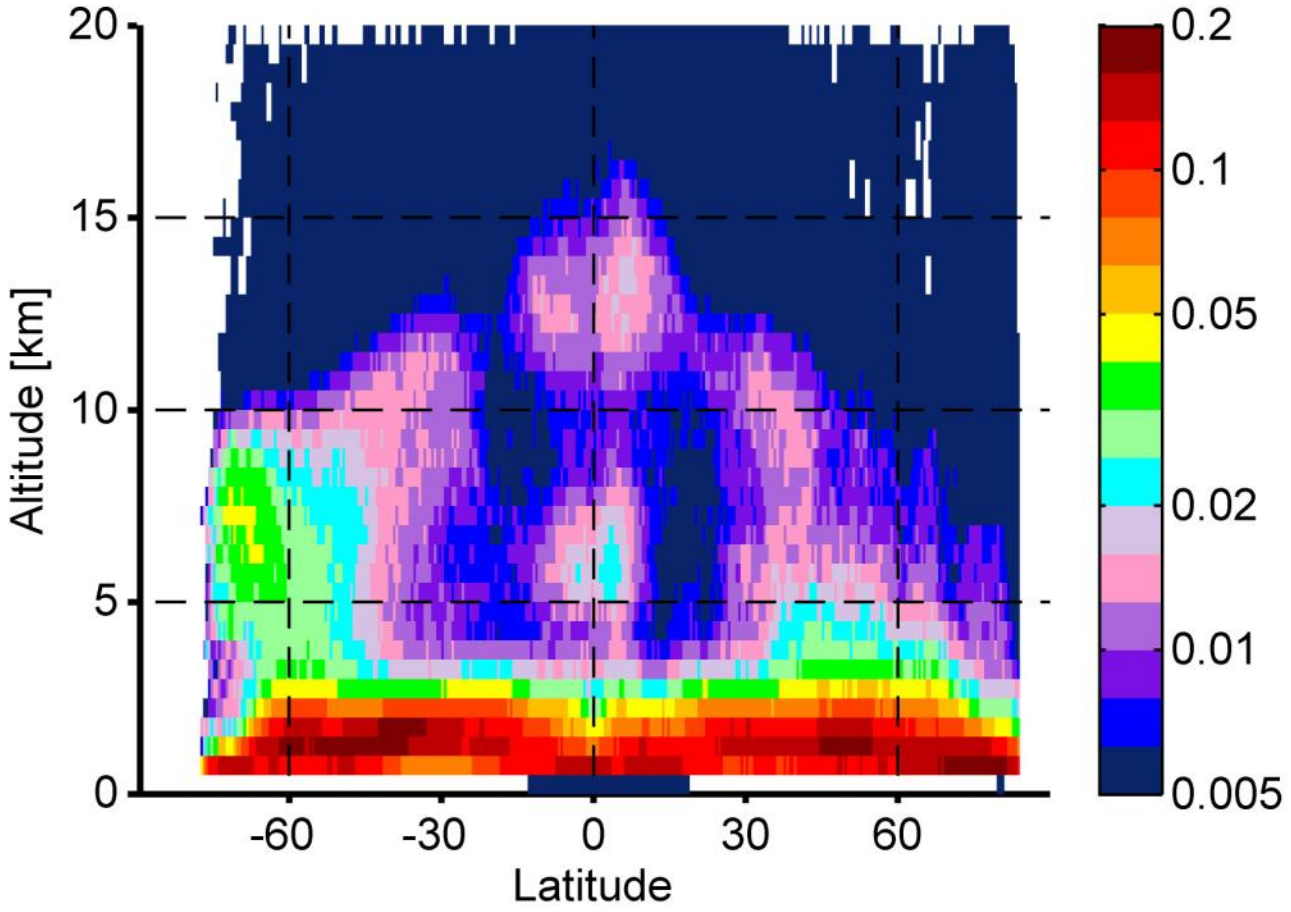
Zonal Monthly Mean (2000 – 2009; ocean only)

Mar



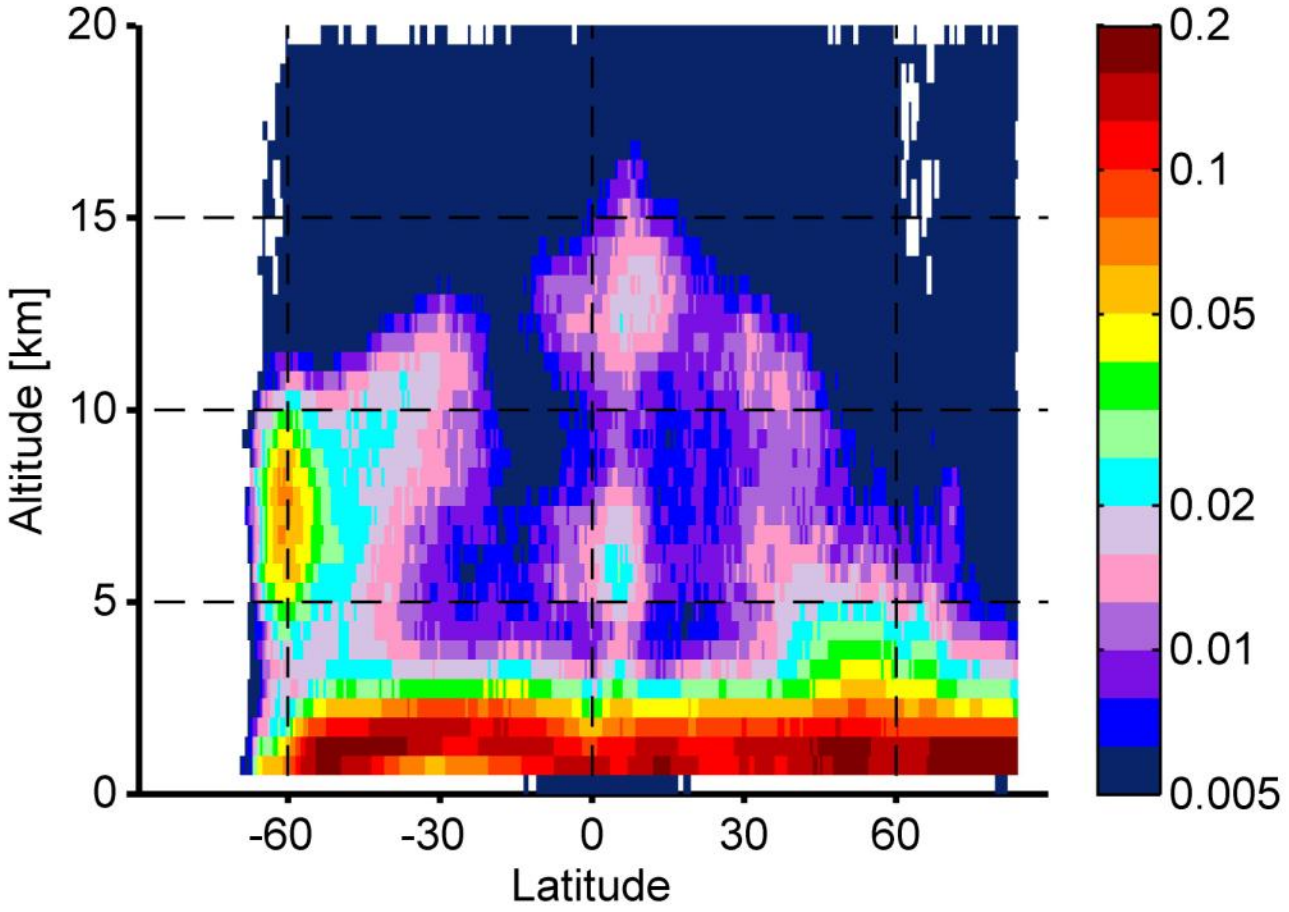
Zonal Monthly Mean (2000 – 2009; ocean only)

Apr



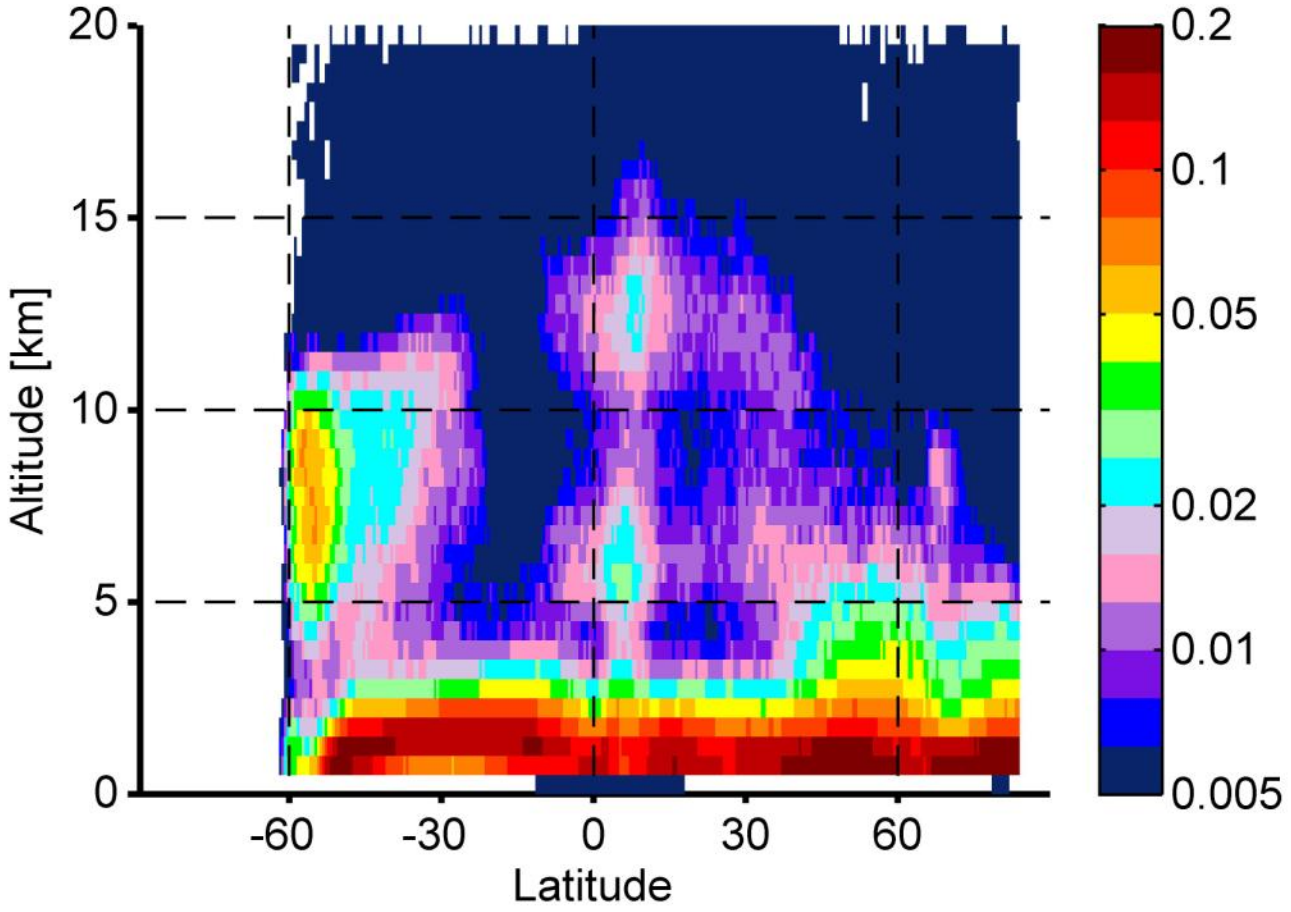
Zonal Monthly Mean (2000 – 2009; ocean only)

May



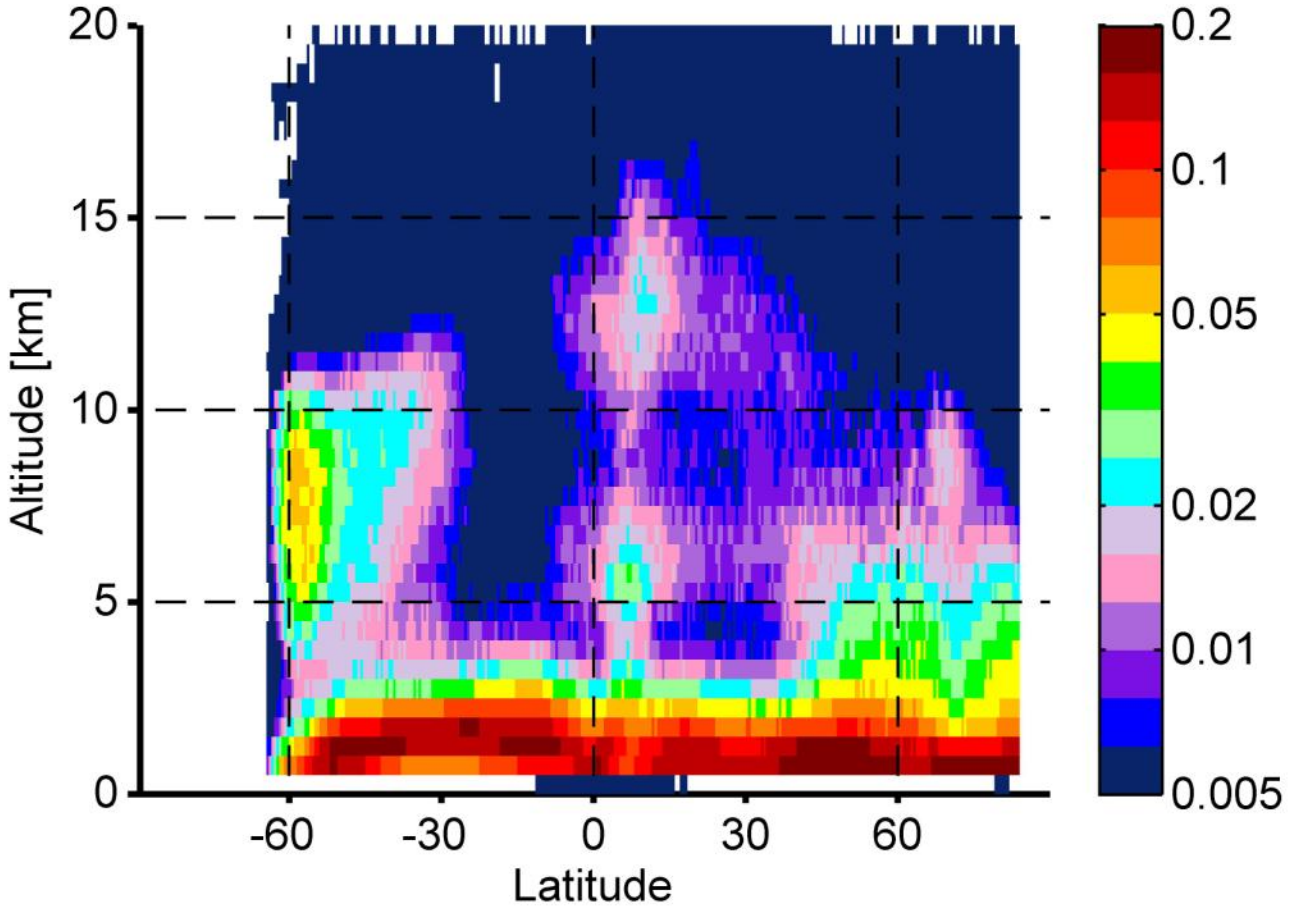
Zonal Monthly Mean (2000 – 2009; ocean only)

Jun



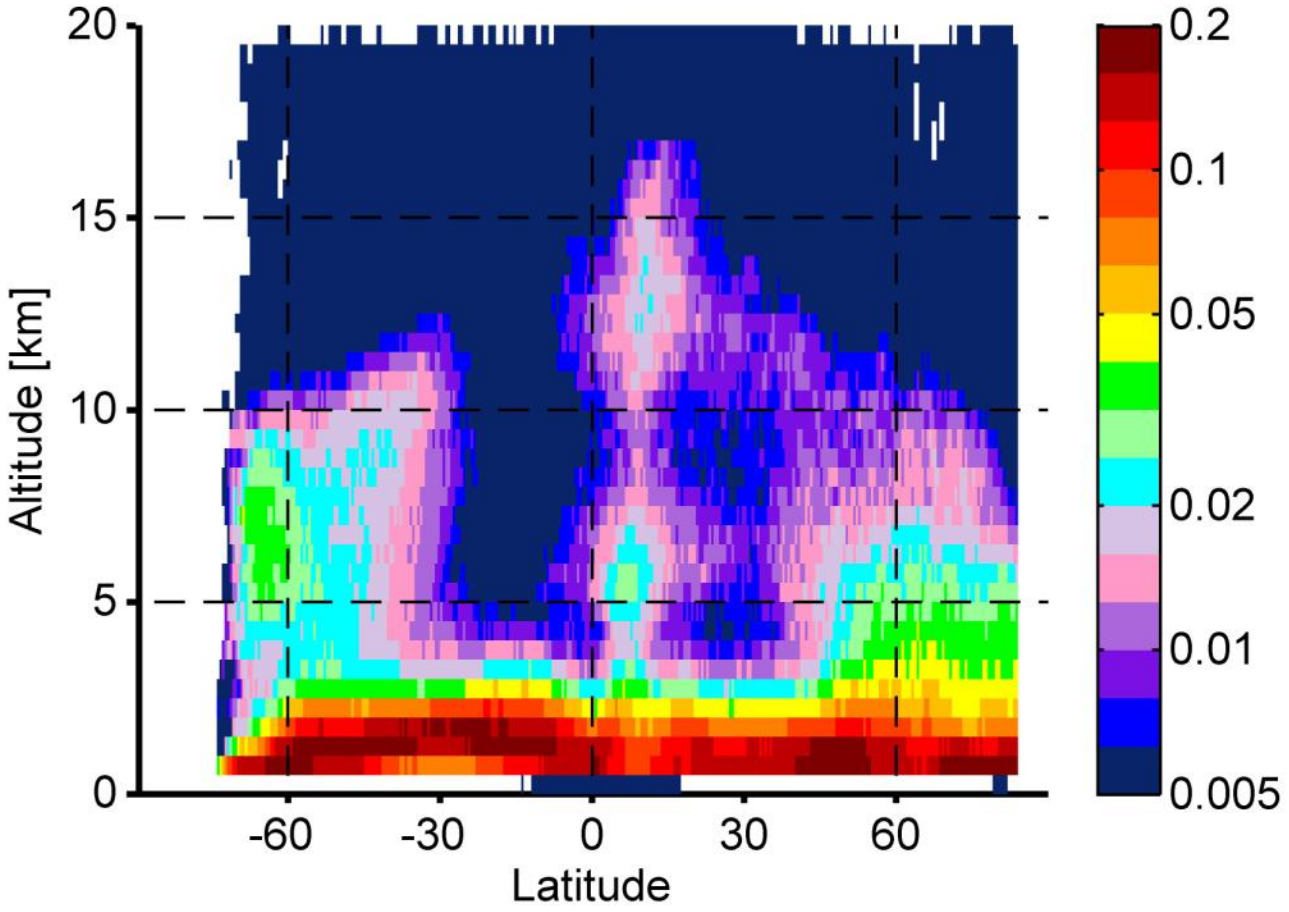
Zonal Monthly Mean (2000 – 2009; ocean only)

Jul



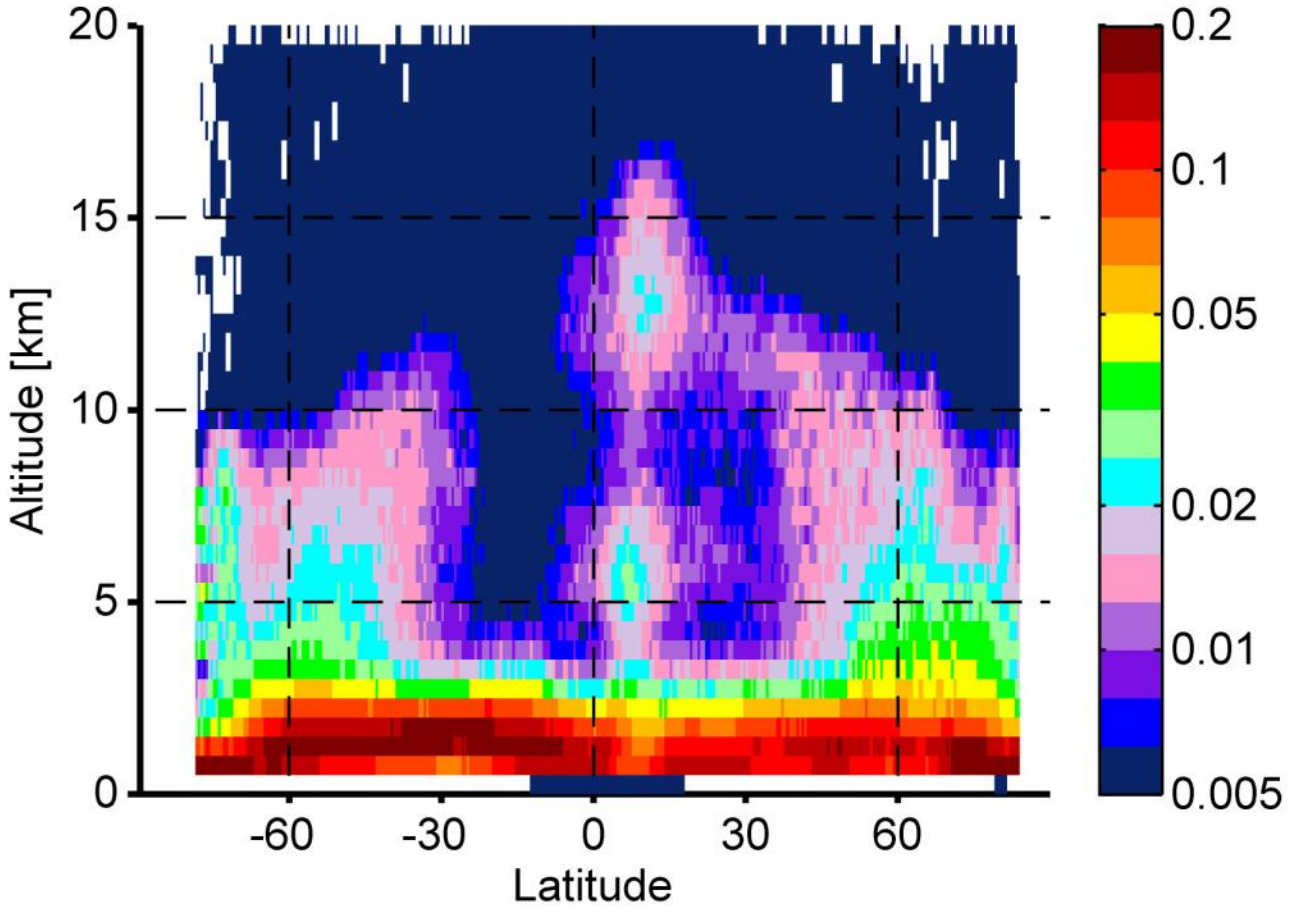
Zonal Monthly Mean (2000 – 2009; ocean only)

Aug



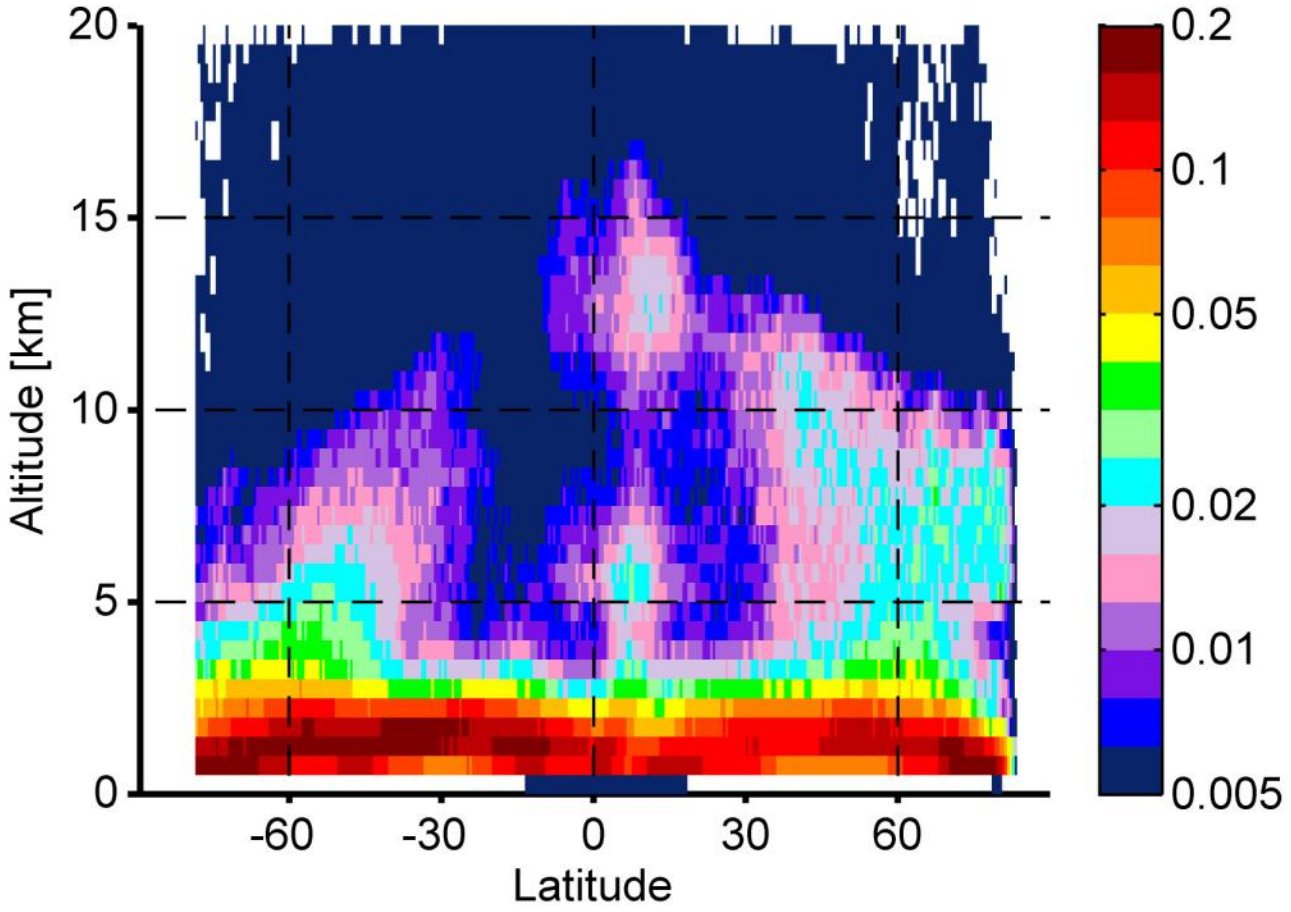
Zonal Monthly Mean (2000 – 2009; ocean only)

Sep



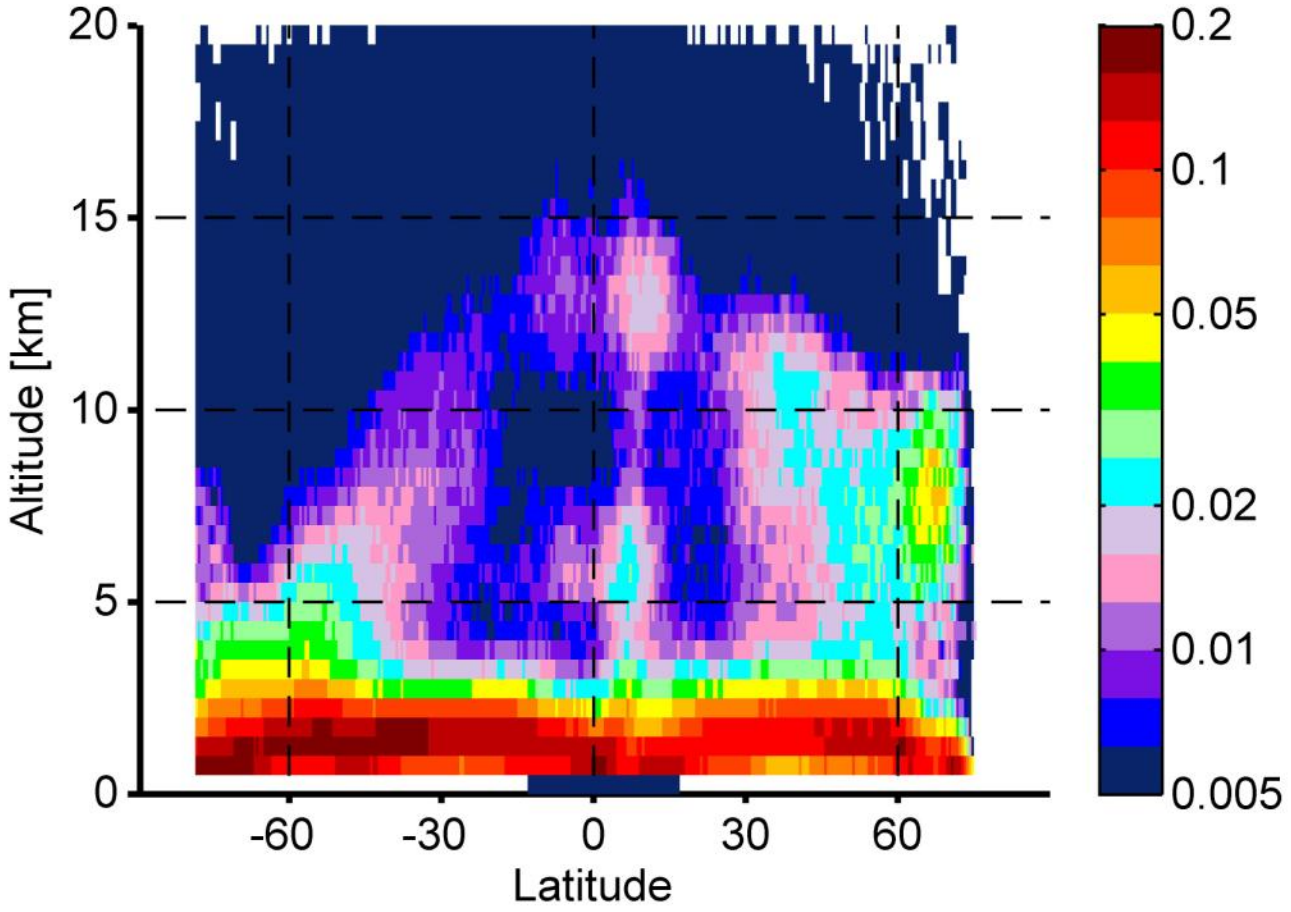
Zonal Monthly Mean (2000 – 2009; ocean only)

Oct



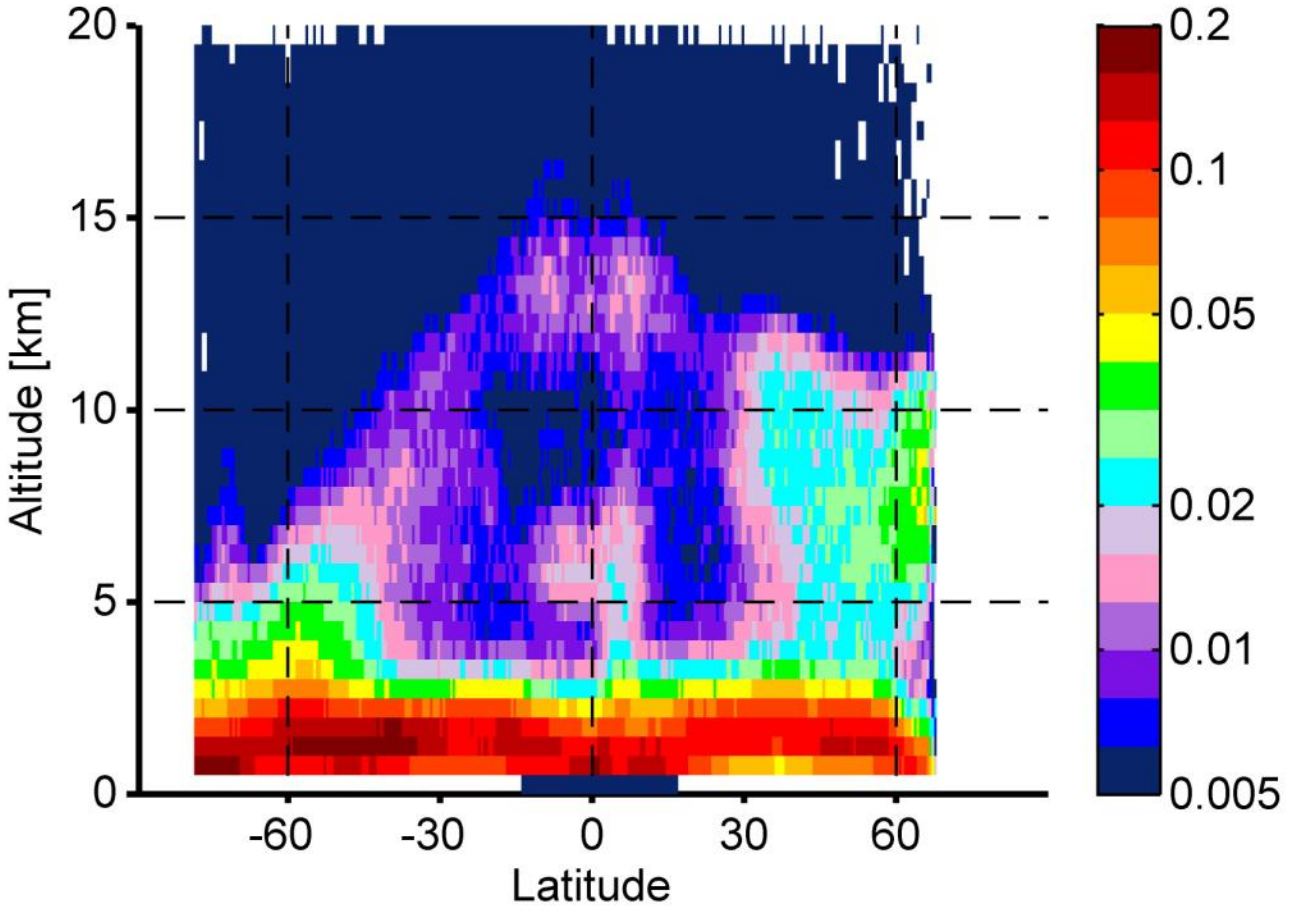
Zonal Monthly Mean (2000 – 2009; ocean only)

Nov

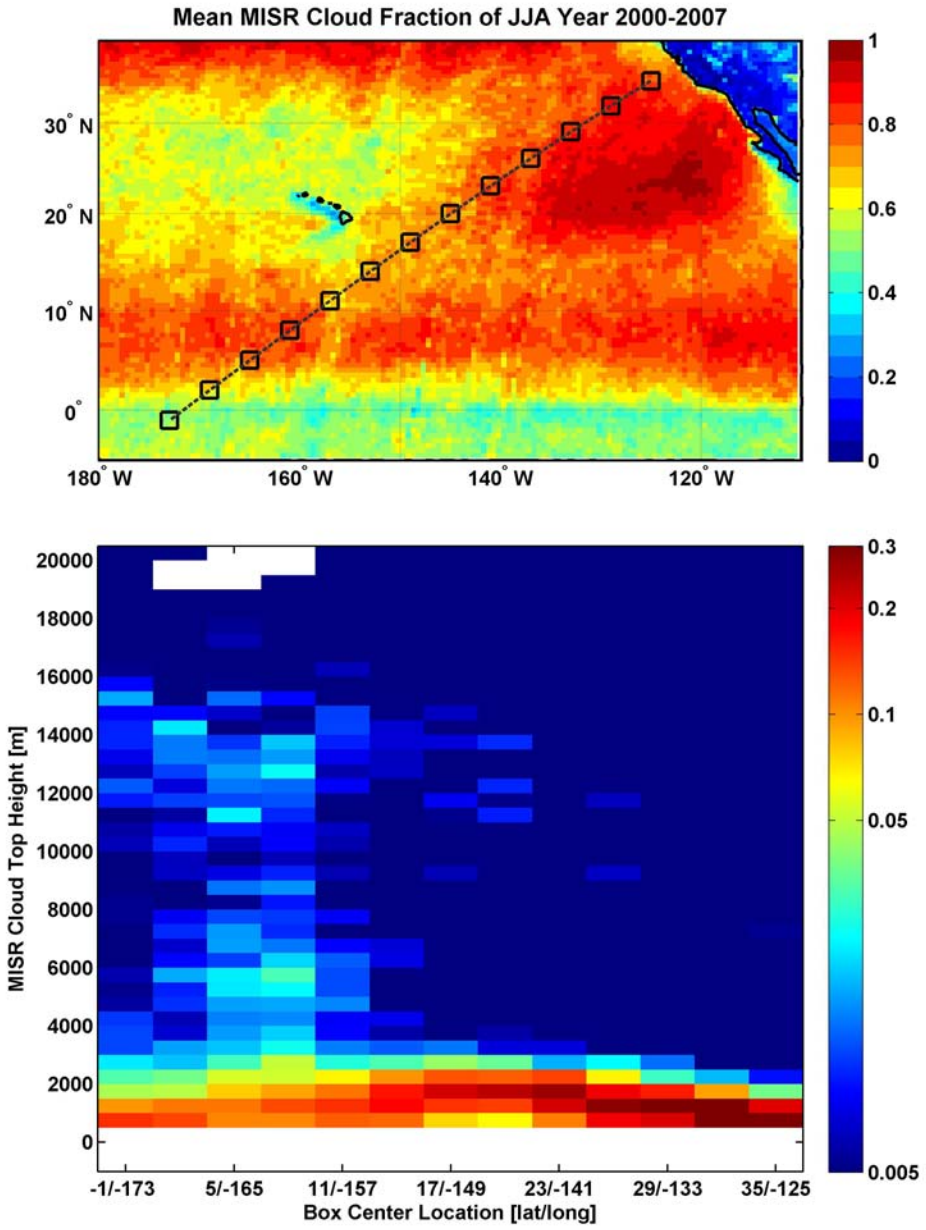


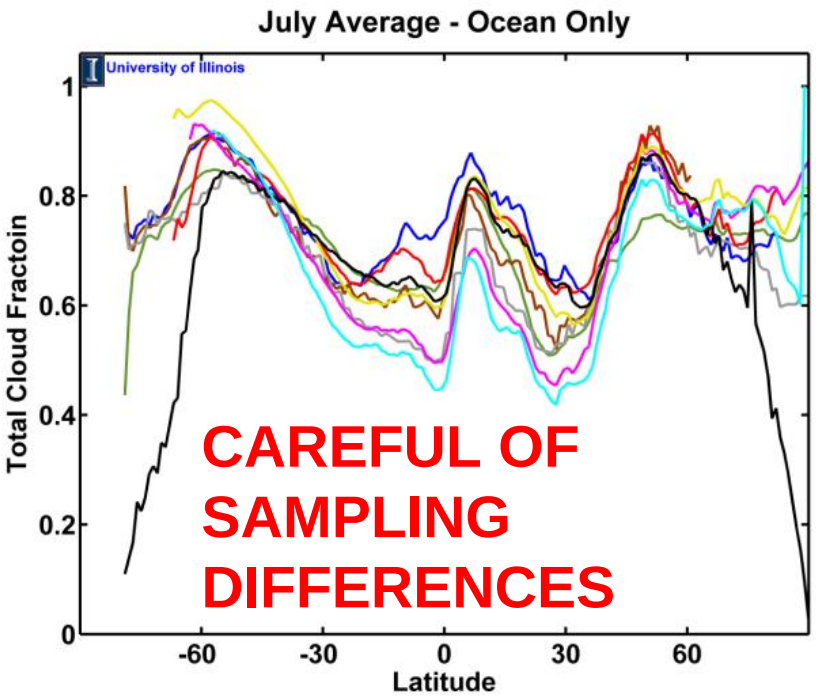
Zonal Monthly Mean (2000 – 2009; ocean only)

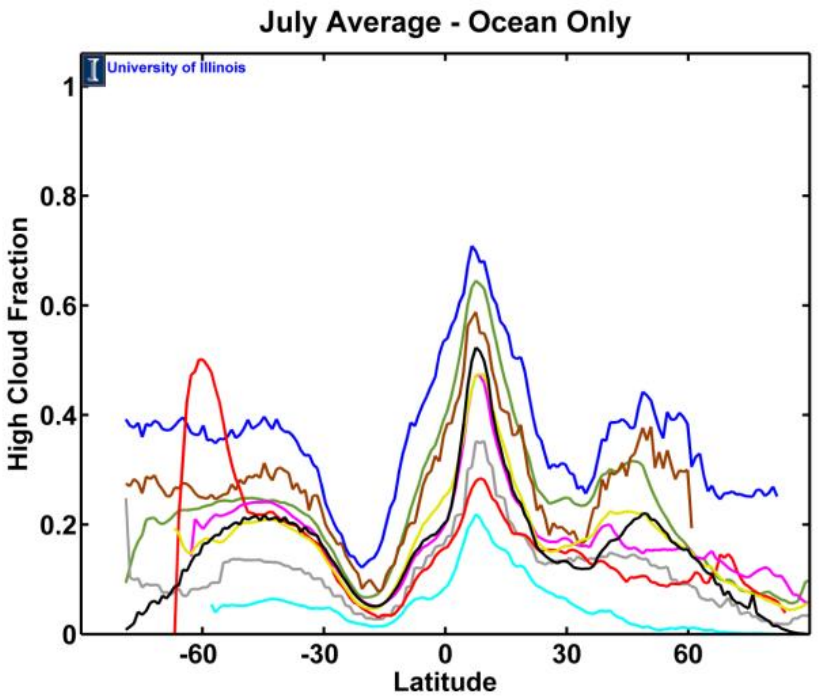
Dec

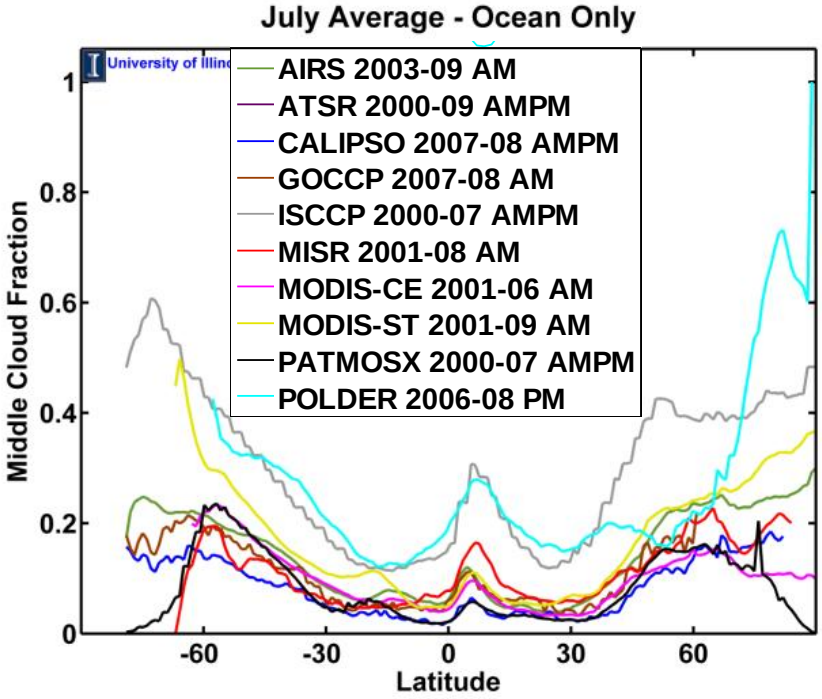


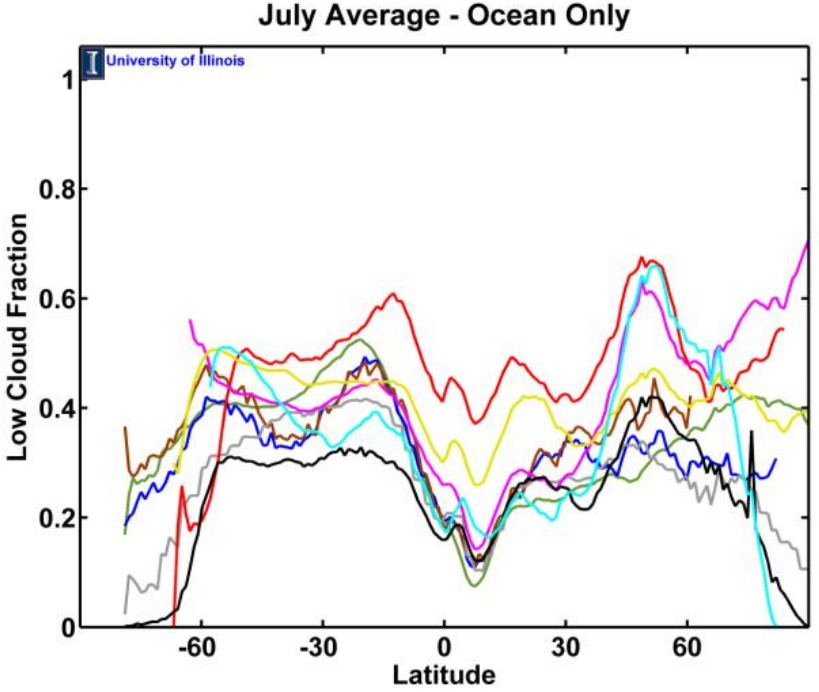
MISR GPCI (JJA 2000 – 2009)



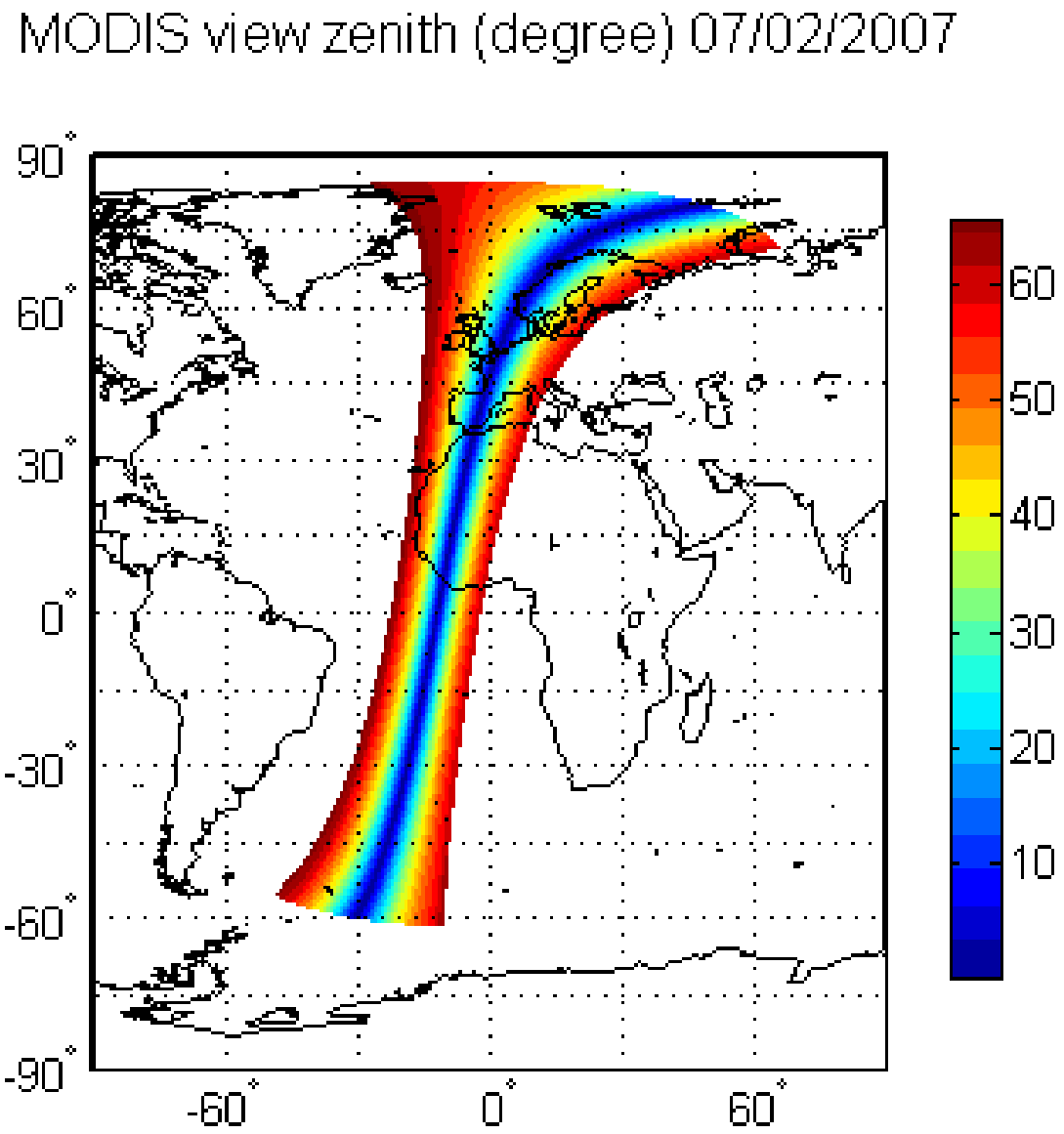

July Average - Ocean Only
University of Illinois
Total Cloud Fractoin
Latitude
CAREFUL OF SAMPLING DIFFERENCES


July Average - Ocean Only
University of Illinois
High Cloud Fraction
Latitude


July Average - Ocean Only
University of Illinois
Middle Cloud Fraction
Latitude
AIRS 2003-09 AM
ATSR 2000-09 AMPM
CALIPSO 2007-08 AMPM
GOCCP 2007-08 AM
ISCCP 2000-07 AMPM
MISR 2001-08 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-09 AM
PATMOSX 2000-07 AMPM
POLDER 2006-08 PM


July Average - Ocean Only
University of Illinois
Low Cloud Fraction
Latitude

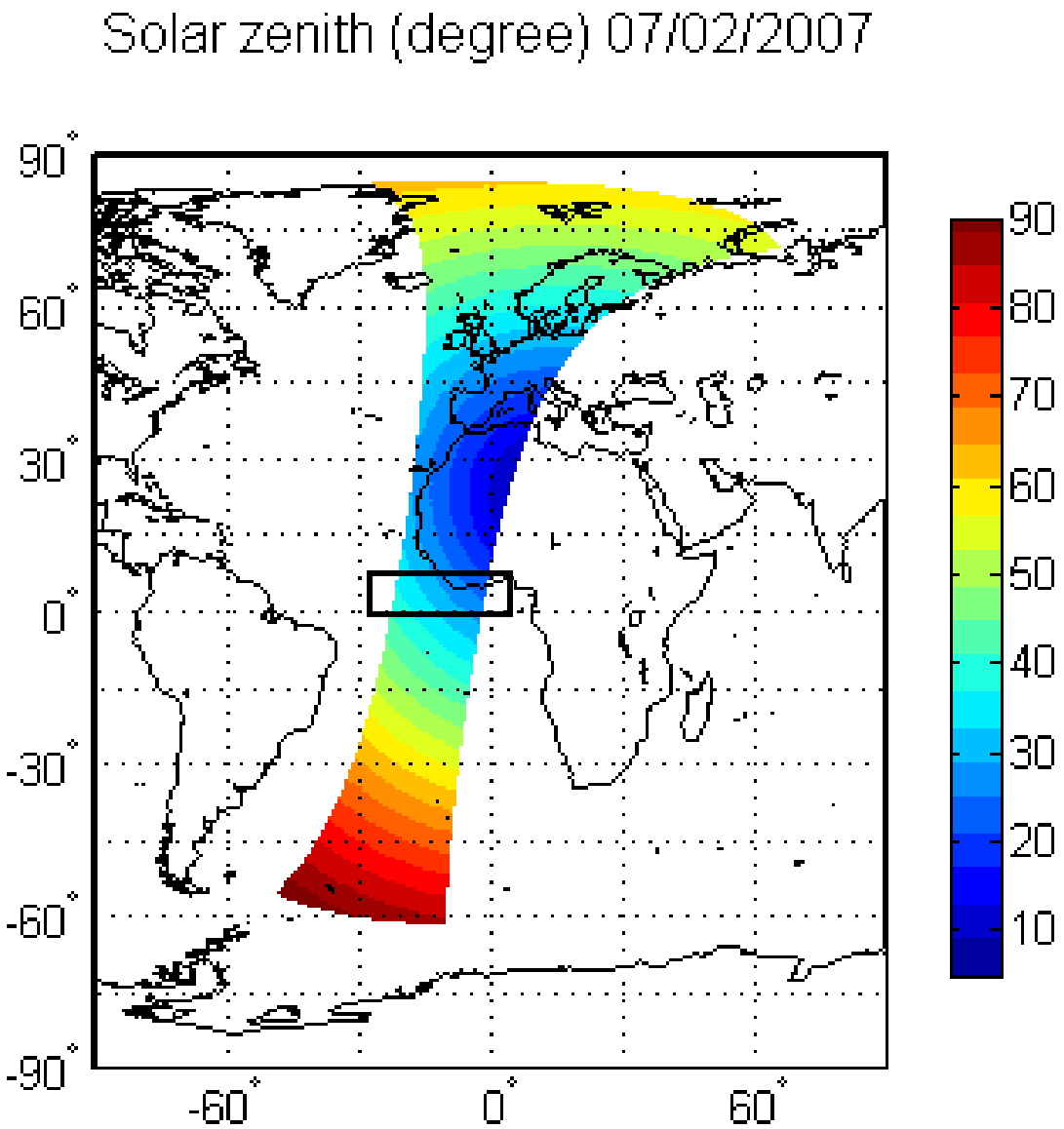
A few MISR-MODIS sampling issues to keep in mind…



Monthly binning assumes view zenith angle invariant cloud properties

GOES:	**Minnis (1989)**
MISR:	**Zhao and Di Girolamo (2004)**
MODIS:	**Ackerman et al. (2008)**

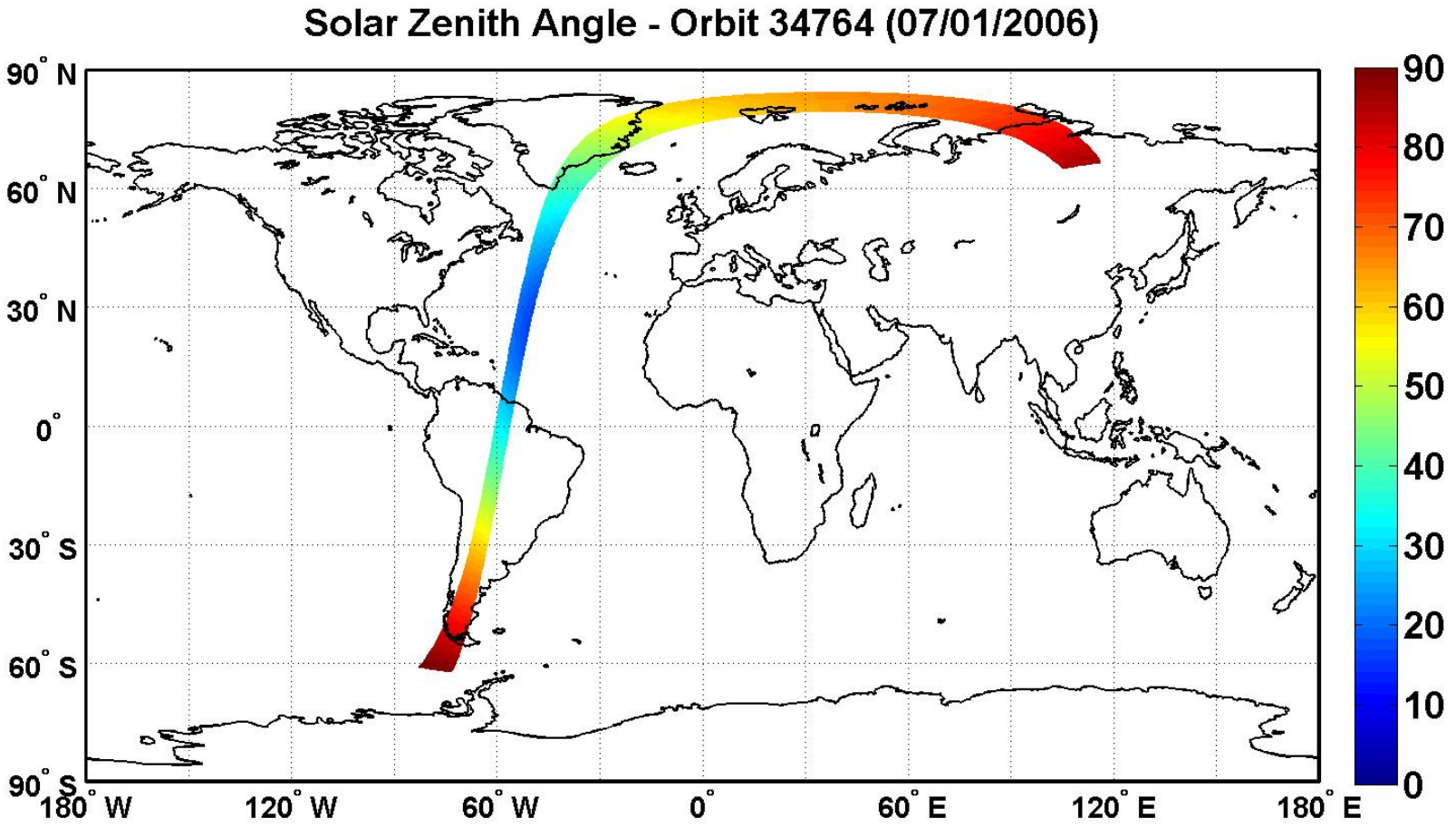
A few MISR-MODIS sampling issues to keep in mind…



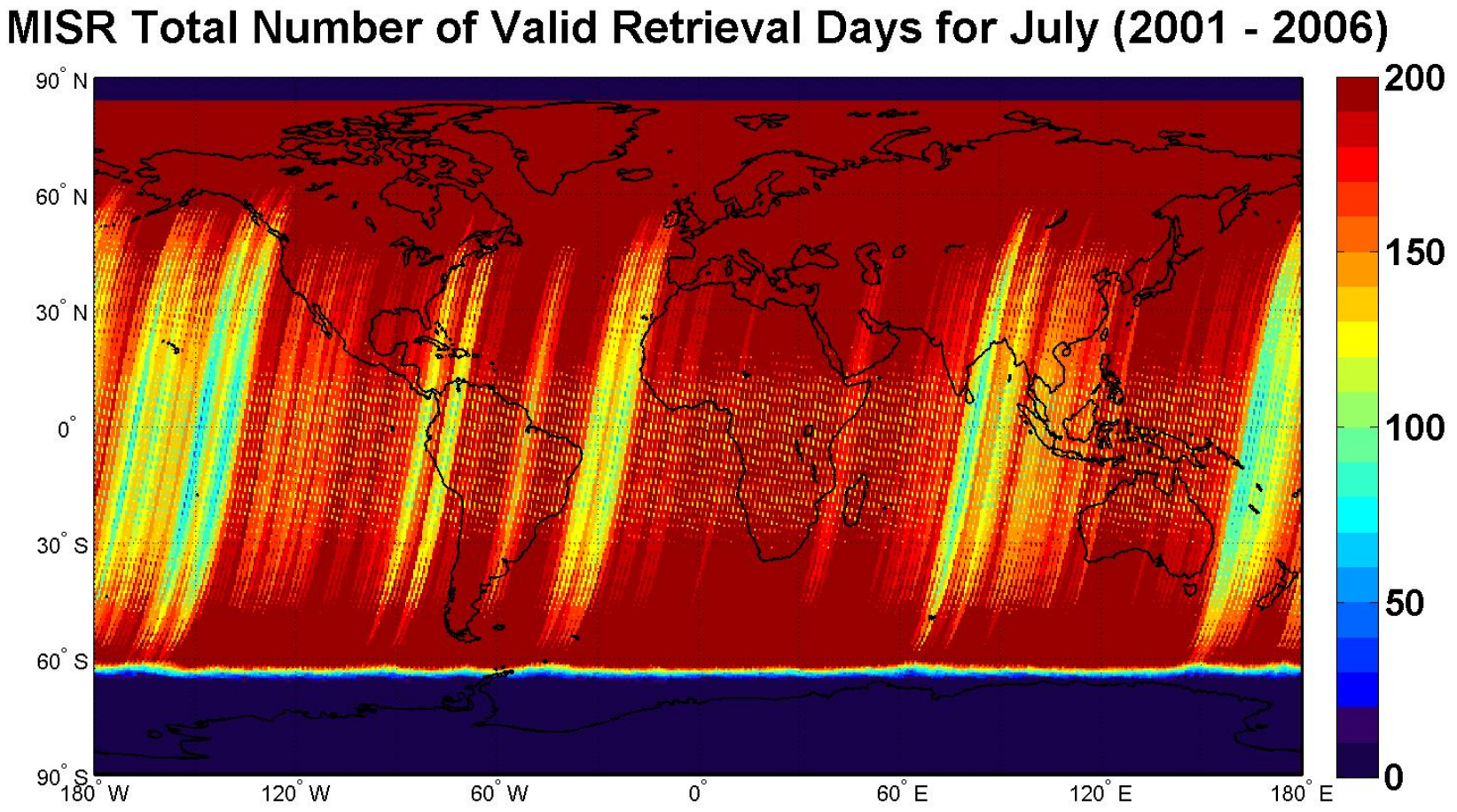
Monthly binning assumes solar zenith angle invariant cloud properties

A few MISR-MODIS sampling issues to keep in mind…

“Daytime” high latitude summer hemisphere lat/long grids can have multiple solar zenith angles.



A few MISR-MODIS sampling issues to keep in mind…



The MISR Cloud Fraction By Altitude Product

- Daily and Monthly cloud top fraction in 500 m vertical resolution bins
- 0.5° equal angle grid
- 10 years +
- Publically available through Langley: http://eosweb.larc.nasa.gov

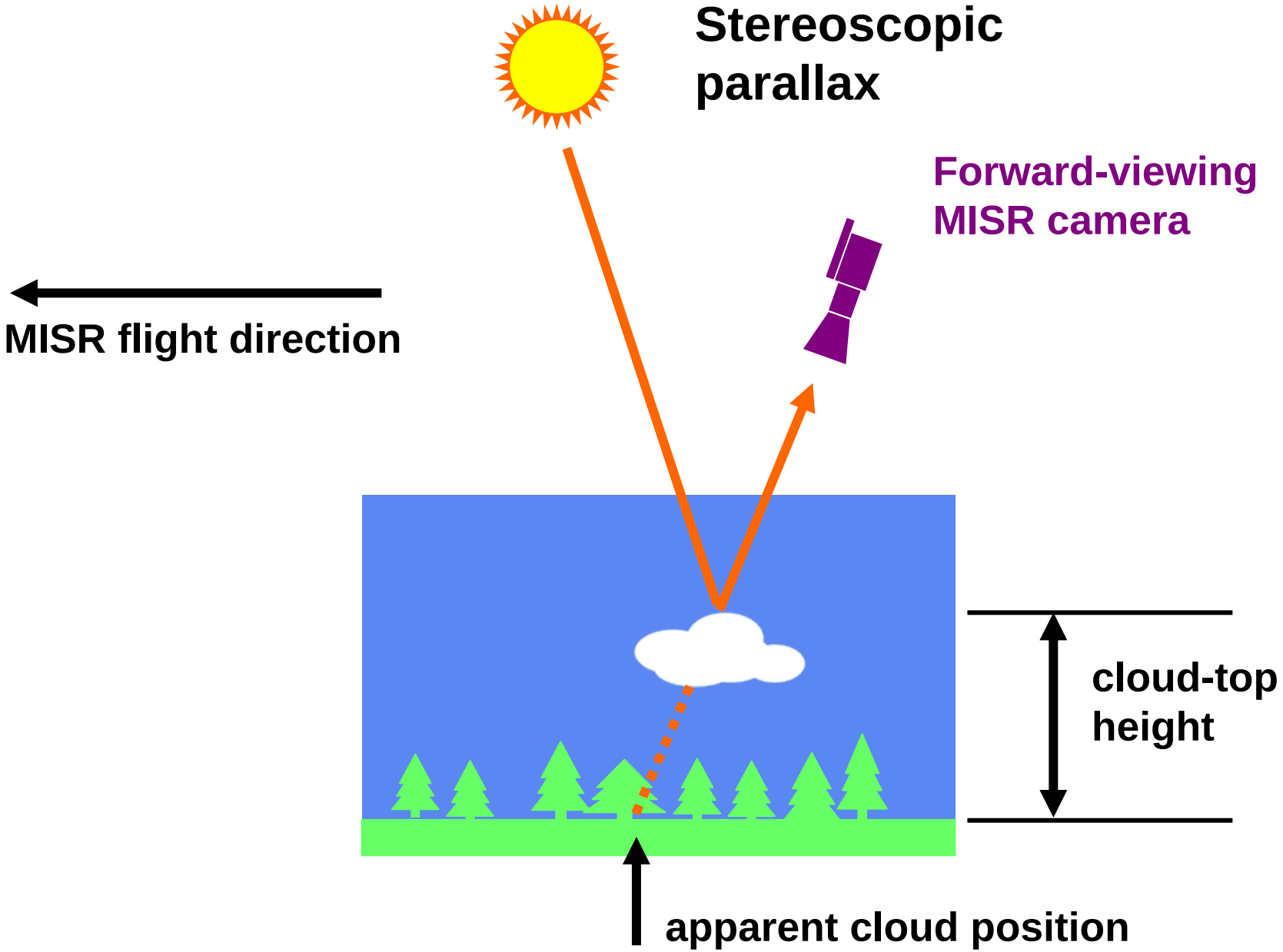
- Features:

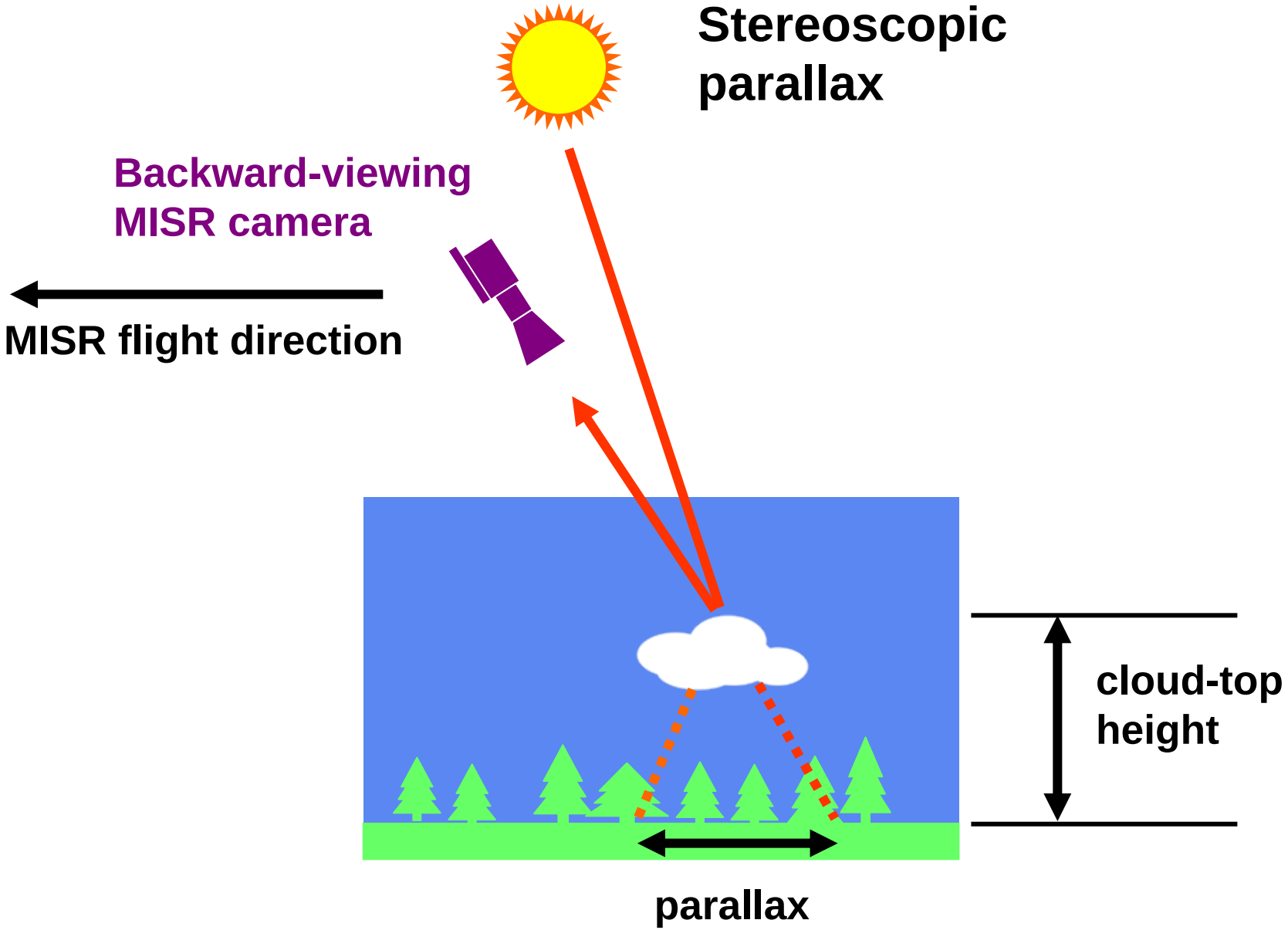
  Combines strengths of various MISR cloud masking approaches

  Avoids sunglint by using nearest nadir camera that is free of sunglint

  Unique and independent cloud detection and cloud heights

  Highest vertical resolution cloud climatology from passive instrument


Stereoscopic parallax
Forward-viewing MISR camera
MISR flight direction
cloud-top height
apparent cloud position


Stereoscopic parallax
Backward-viewing MISR camera
MISR flight direction
cloud-top height
parallax

MISR Stereo Publications

Algorithm:

Diner et al. (1999, ATBD)
Horvath and Davies (2001a,b)
Moroney et al. (2002)
Muller et al. (2002)
Davies et al. (2007)

Validation:

Naud et al. (2002, 2004, 2005, 2007)
Davies et al. (2007)
Marchand et al. (2007)
Genkova et al. (2007)
Garay et al. (2009)
Harshvardhan et al. (2009)
Hinkelman et al. (2009)

Cloud-top height:

RMS ~ 560 m; unbiased

Cloud-track wind:

MVD ~ 5 m/s;
Southward bias < 1.5 m/s?

An upcoming implementation of sub-pixel correspondence, based in part on Mueller et al. (2008), will cut these uncertainties in half

MISR Cloud Masking Approach

1) Stereo-Derived Cloud Mask (SDCM)

If stereo feature > 562 m above surface, then cloud

2) Radiometric Camera-by-camera Cloud Mask (RCCM):

Per camera cloud mask using one spectral and one spatial metrics (different for land and ocean) for thresholding

Space-time dependent thresholds

3) Angular Signature Cloud Mask (ASCM)

Single threshold operation to Band Differenced Angular Signature

MISR Cloud Mask Publications

Algorithm:

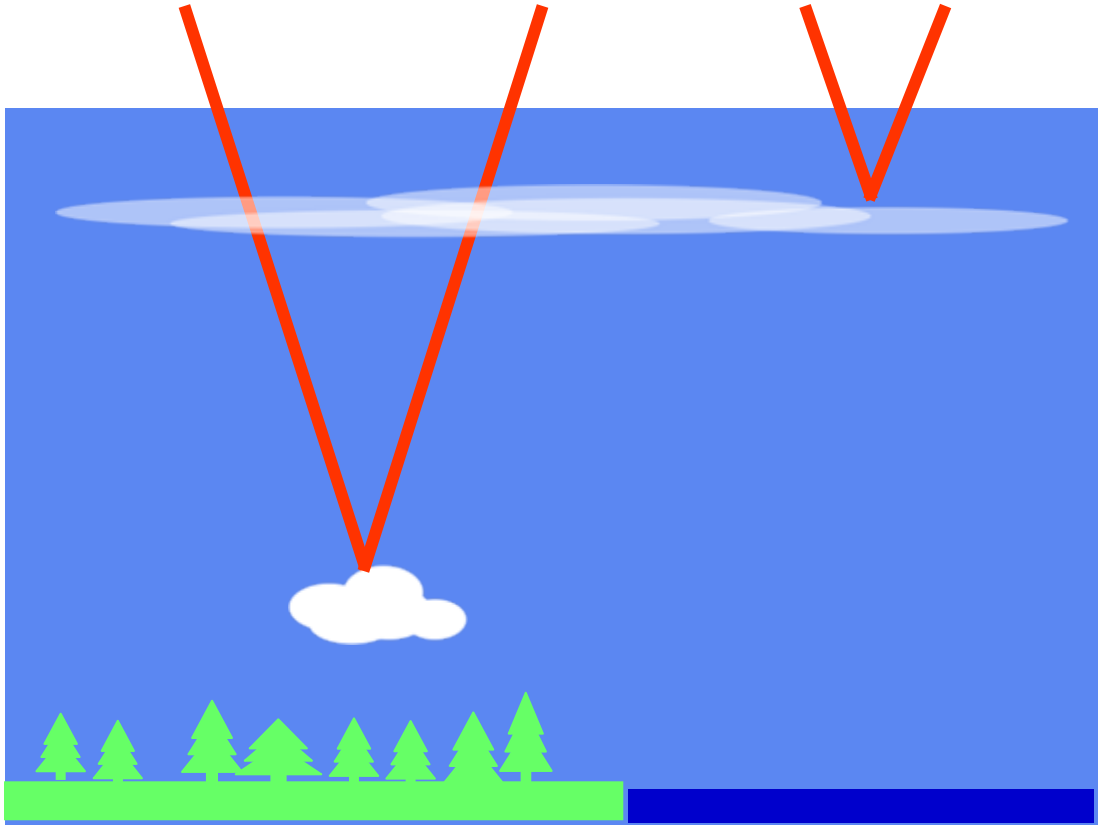
Di Girolamo and Davies (1994; ASCM)
Di Girolamo and Davies (1995; RCCM)
Diner et al. (1999a,b, ATBD; RCCM, ASCM, SDCM)
Di Girolamo and Wilson (2003; ASCM)
Zhao and Di Girolamo (2004; RCCM – Ocean)
Zhao (2006, Ph.D. thesis; RCCM – Ocean)
Yang and Di Girolamo (2007; RCCM – Land)
Yang (2007, Ph.D. thesis; RCCM – Land)
Wilson (2008, Ph.D. thesis; ASCM)

Validation:

Zhao and Di Girolamo (2004; RCCM – Ocean)
Zhao and Di Girolamo (2006; RCCM – trade cumuli over ocean)
Zhao (2006, Ph.D. thesis; RCCM – Ocean)
Yang and Di Girolamo (2007; RCCM – Land: dynamic thresholding)
Yang (2007, Ph.D. thesis; RCCM – Land)
Wilson (2008, Ph.D. thesis; ASCM)
Di Girolamo et al. (in preparation)

Major MISR things to keep in mind for GEWEX CA Comparisons

1) Stereo returns the altitude of maximum spatial contrast as viewed from MISR



In the situation of thin cirrus over low clouds, the cloud top heights of the low clouds are retrieved without any degradation in accuracy.

MISR+MODIS
Multi-layer detection?

Consequences:

1)Thinner clouds can be retrieved over ocean compared to land
2)MISR will have smaller High CA and larger Low CA relative to IR-retrieved heights but total cloud amount should be the same.

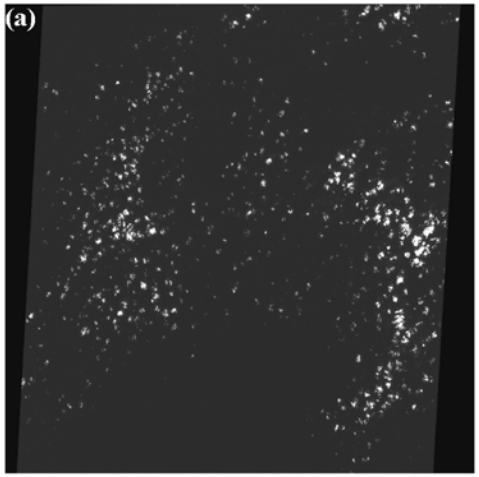
Major MISR things to keep in mind for GEWEX CA Comparisons

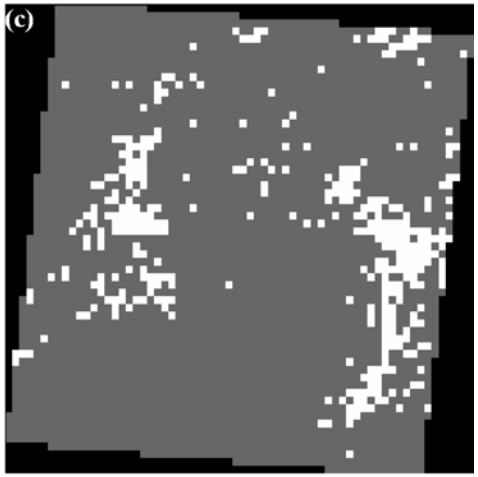
2) MISR is very good at detecting sub-pixel clouds

CA = # cloudy pixels / total # pixels

Zhao and Di Girolamo (GRL 2006)

ASTER VIS BRF



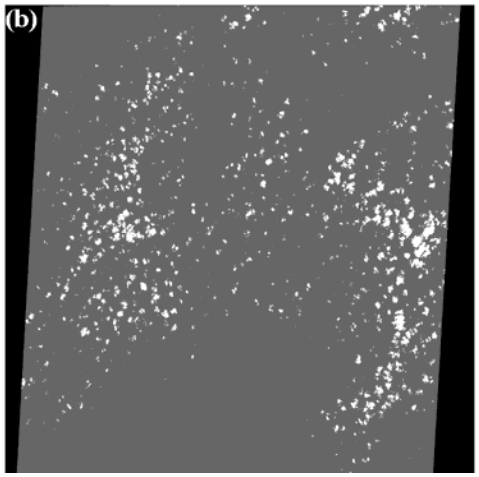


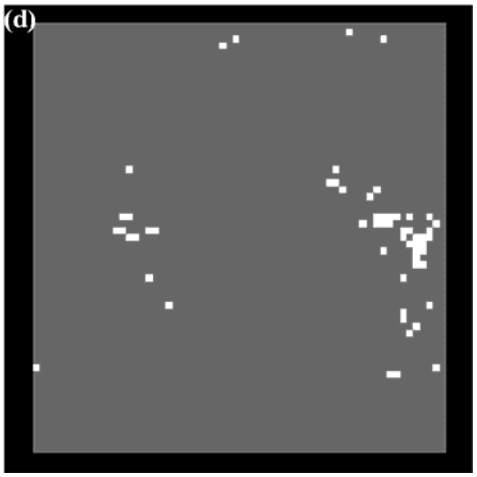
MISR RCCM

CA = 0.11

ASTER CM

CA = 0.04





MOD35

CA = 0.01

Consequence: MISR will overestimate the cloud fraction in regions dominated by small cumulus clouds (MODIS also overestimates, but less so).

Major MISR things to keep in mind for GEWEX CA Comparisons

3) How thin and impact on cloud amount?

- Relative to lidars... τ_{min} ~ 0.3 over ocean; ~ 0.6 over land

- Relative to supervised SVM cloud masks on random scenes… CA too low by ~ 2% over ocean and ~ 7% over land because of thin cirrus

Consequence: Understanding how to quantitatively deal with thin cirrus within GEWEX CA comparisons will be challenging

Major MISR things to keep in mind for GEWEX CA Comparisons

4) ASCM is cloud conservative over snow and ice

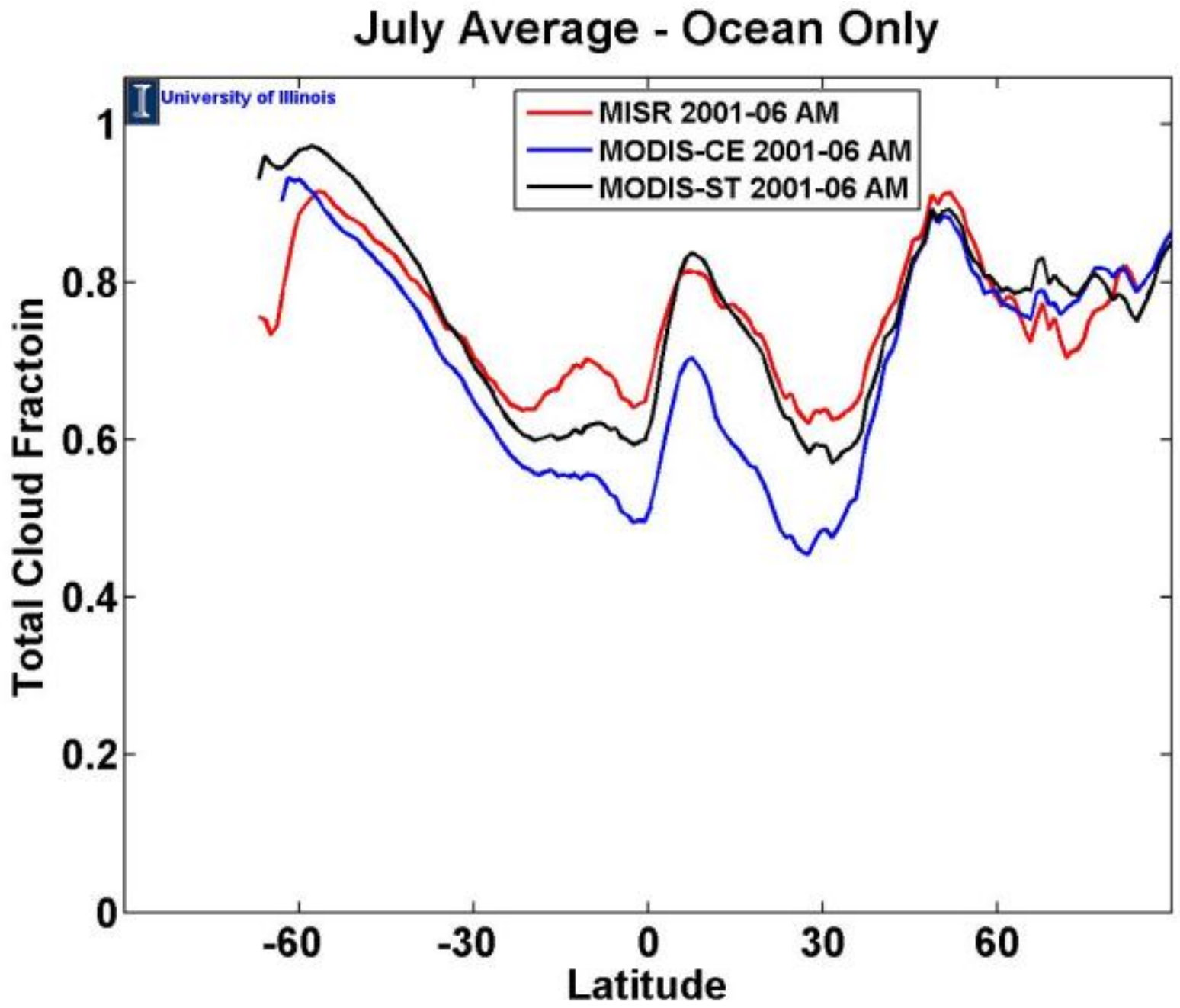
- Cloud-on-cloud shadows are classified as clear

- **Monthly** sea ice masks at 1 degree resolution is labeled snow/ice if > 5% of the region has snow/ice for more than 4 days of the month based on SSM/I. Where labeled snow-ice covered, snow/ice thresholds are used, causing a cloud conservative mask over the snow/ice-free pixels.

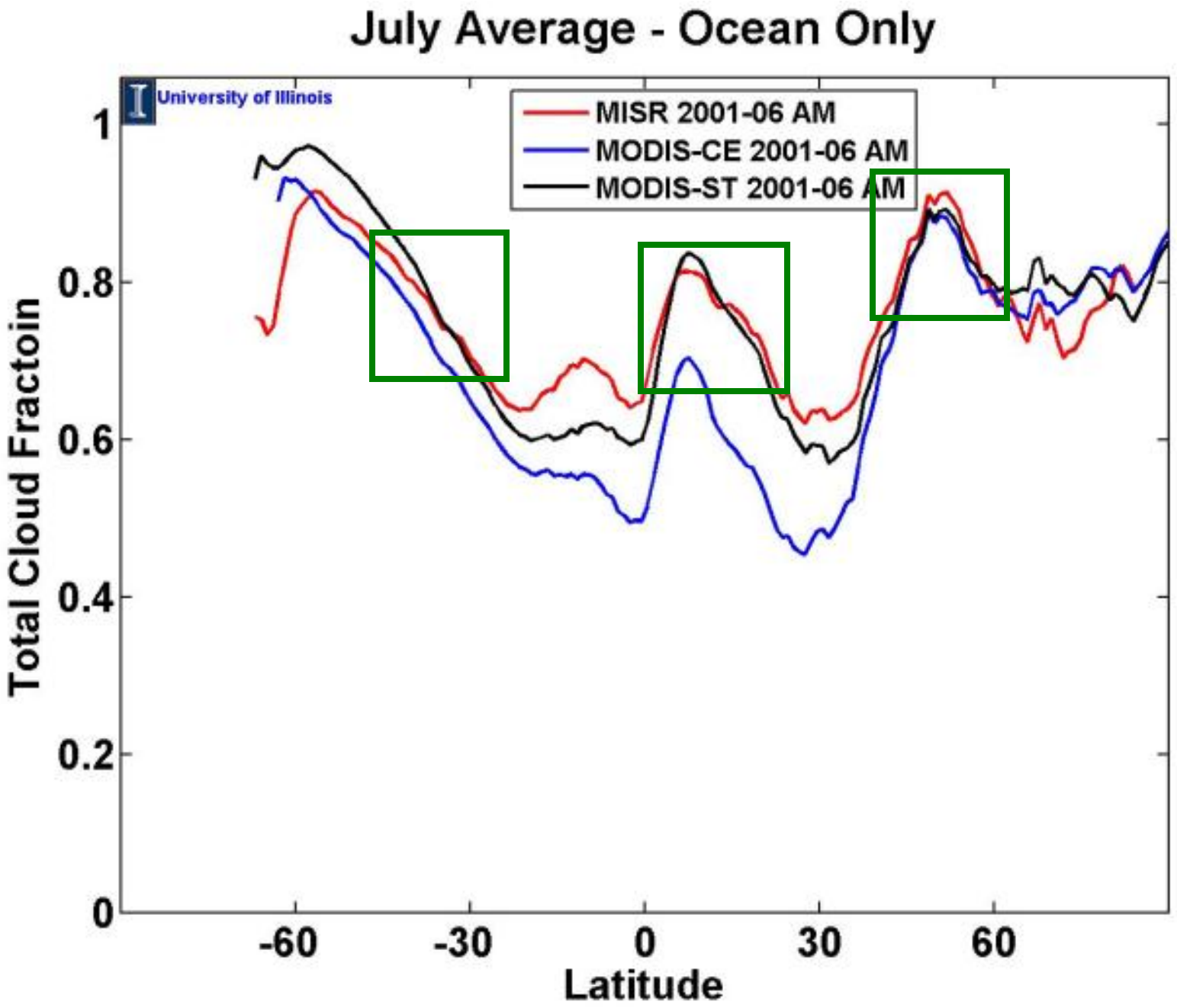
Consequence: MISR will underestimate cloud fraction in polar regions, especially in regions near the snow/ice – snow/ice-free boundaries.

Future action: replace existing snow-ice mask with higher resolution, daily snow/ice mask; source TBD.

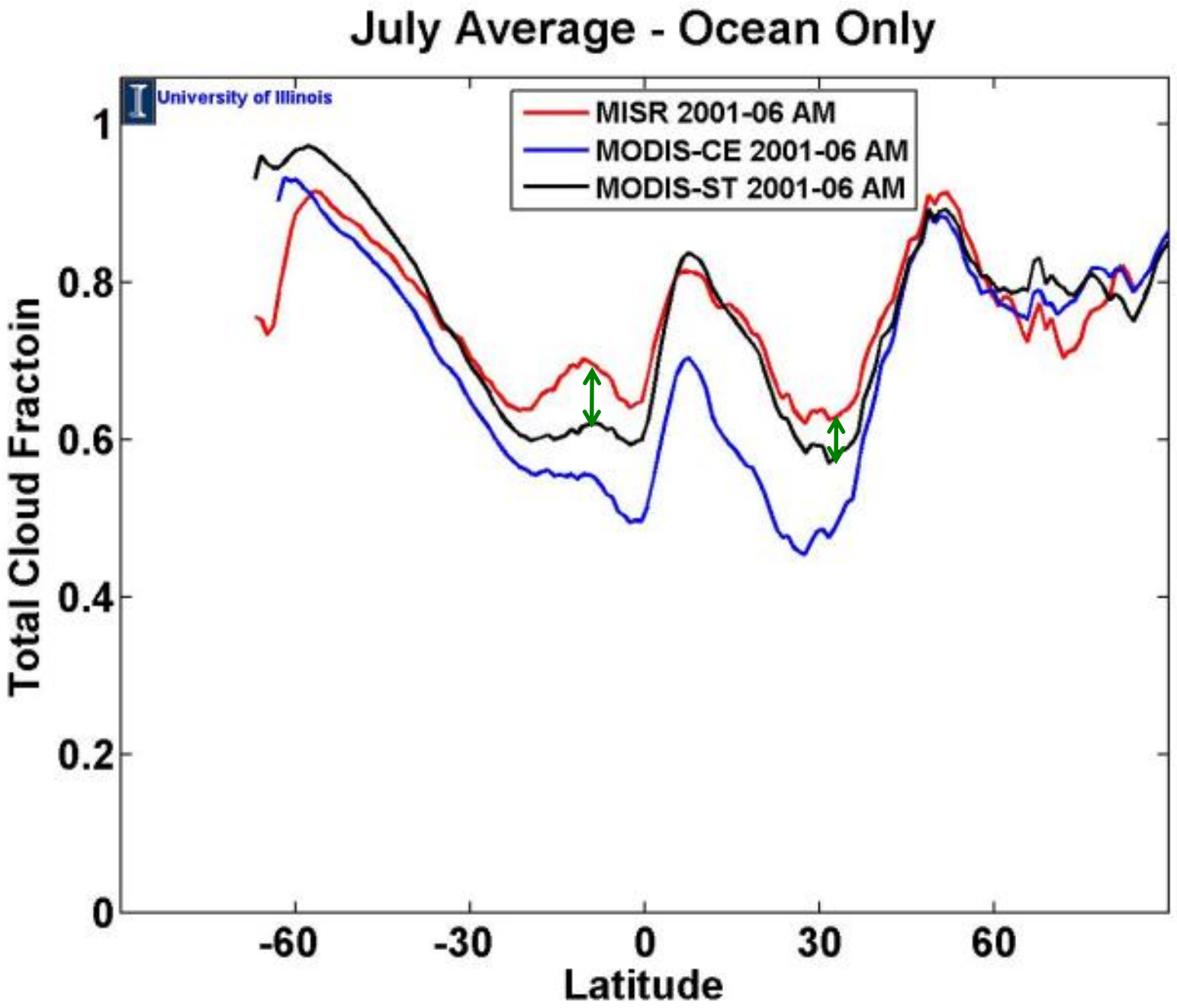
July 2001-2006 Zonal Cloud Amount (Ocean)



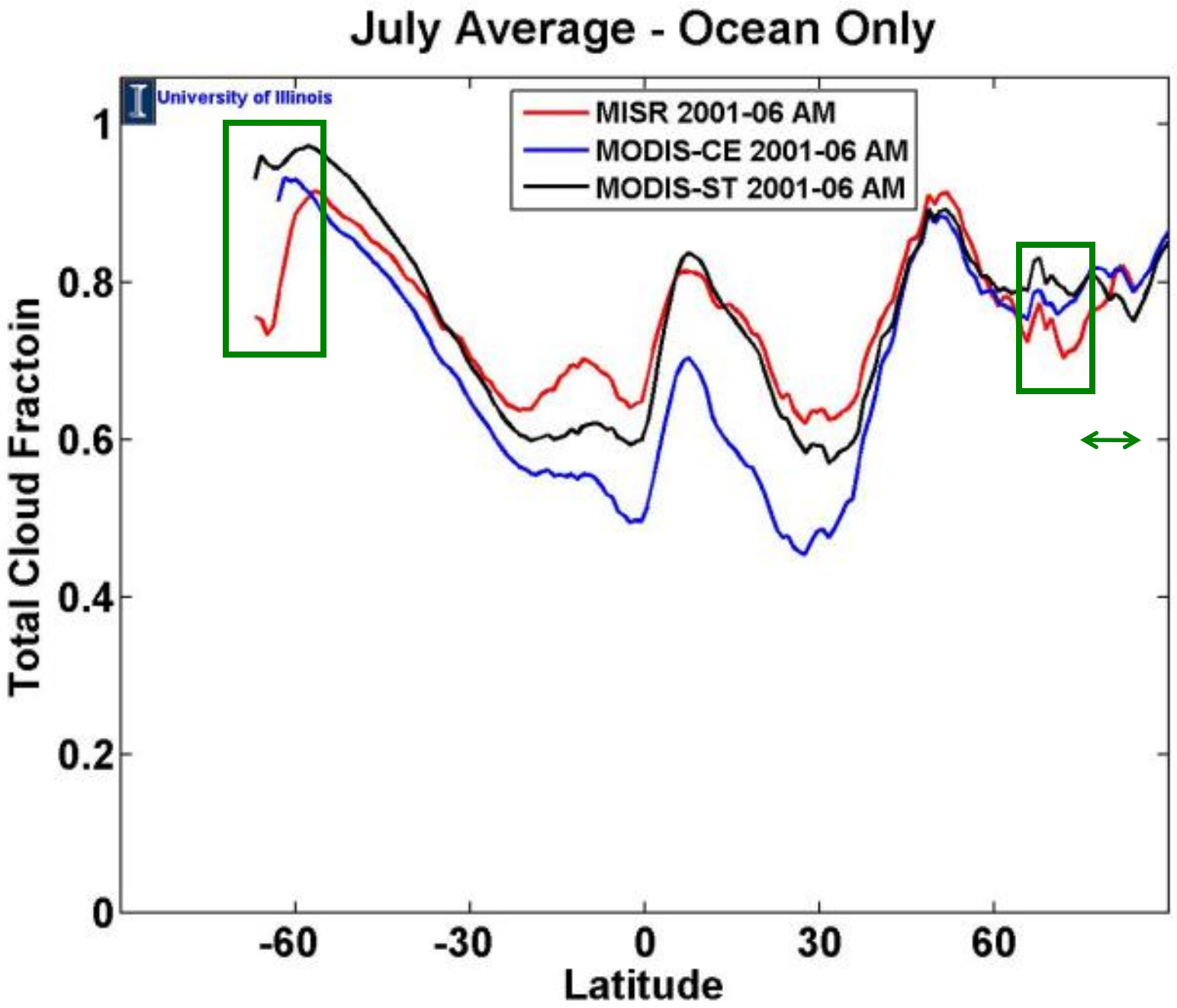
July 2001-2006 Zonal Cloud Amount (Ocean)



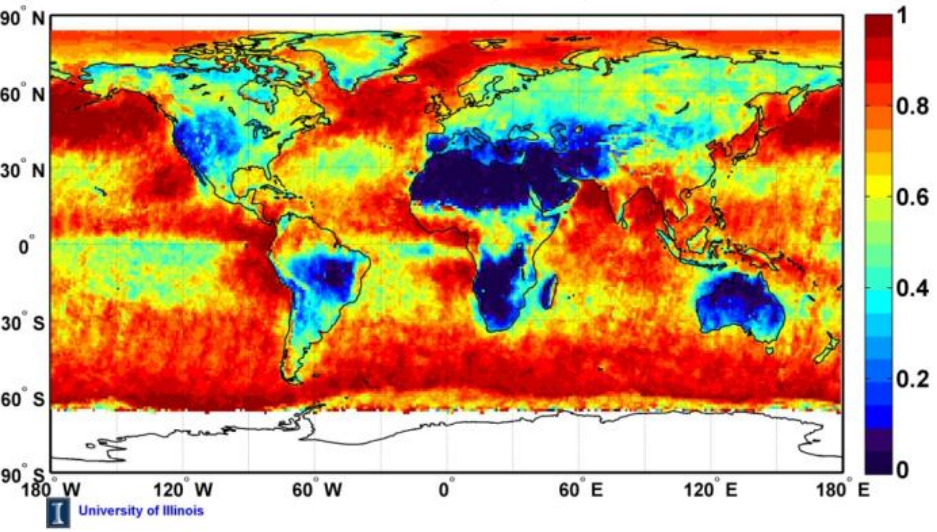
July 2001-2006 Zonal Cloud Amount (Ocean)



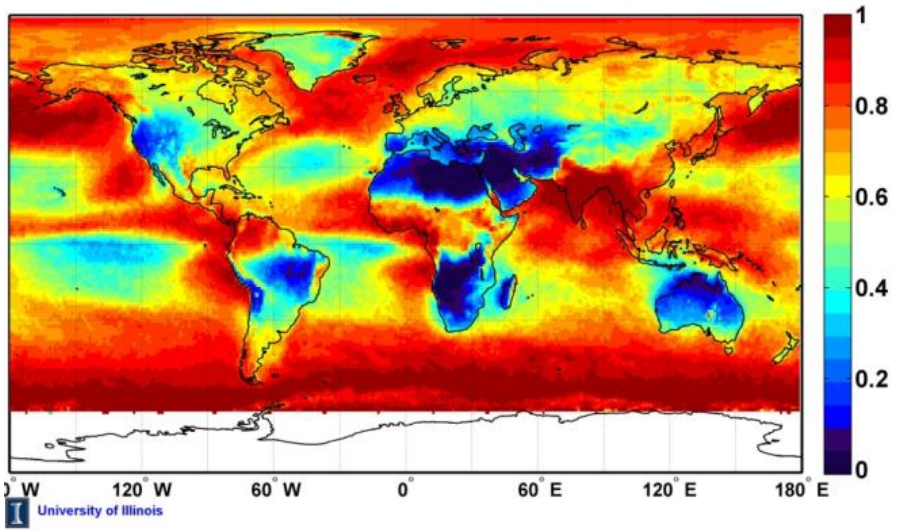
July 2001-2006 Zonal Cloud Amount (Ocean)



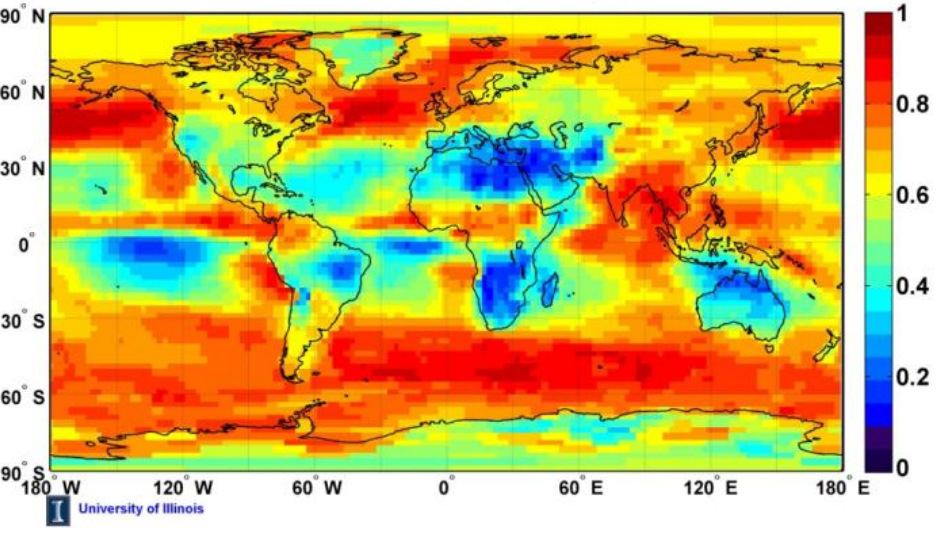
MISR Total Cloud Fraction July Average (2001-2006)



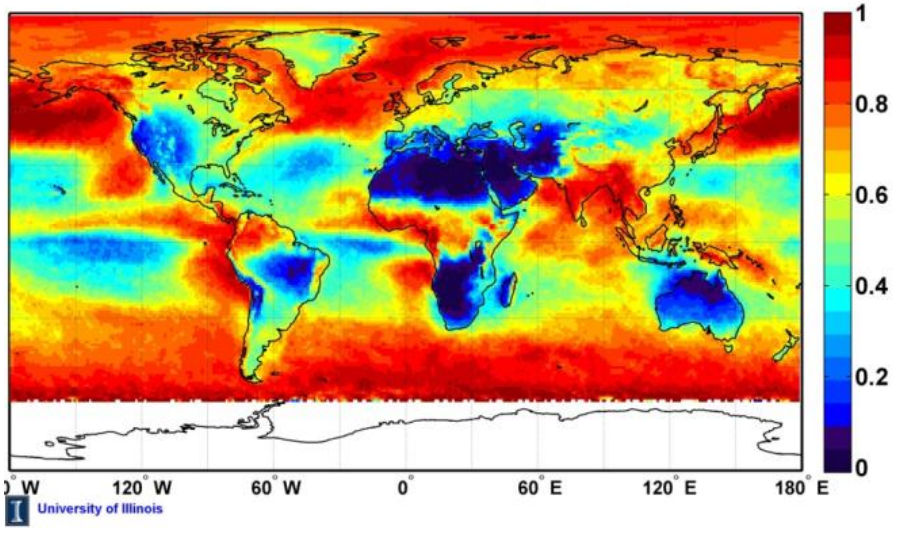
MODIS-ST-Terra-AM Total Cloud Fraction July Average (2001-2006)



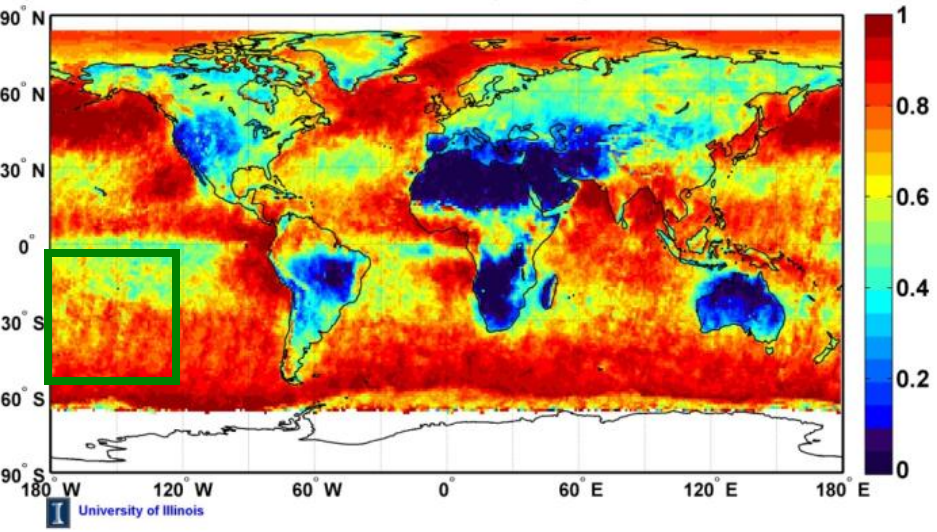
ISCCP Total Cloud Fraction July Average (2001-2006)



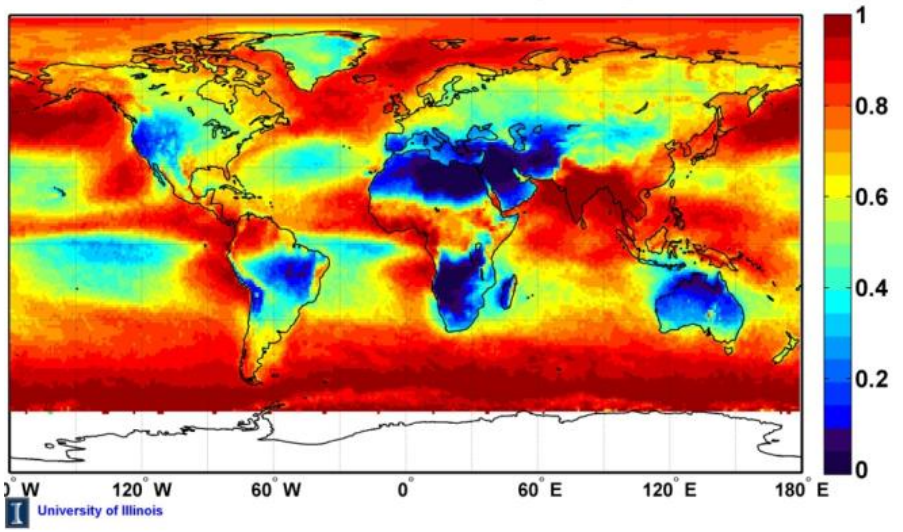
MODIS-CE-Terra-AM Total Cloud Fraction July Average (2001-2006)



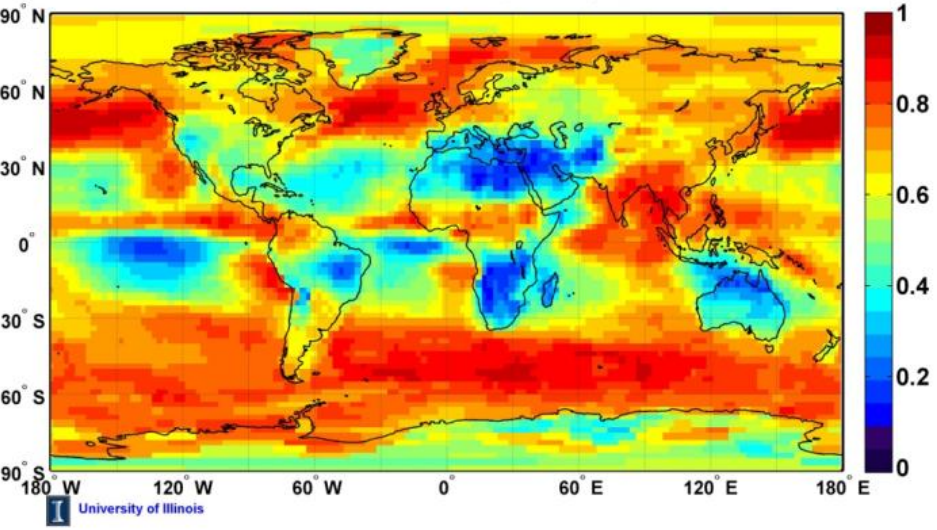
MISR Total Cloud Fraction July Average (2001-2006)



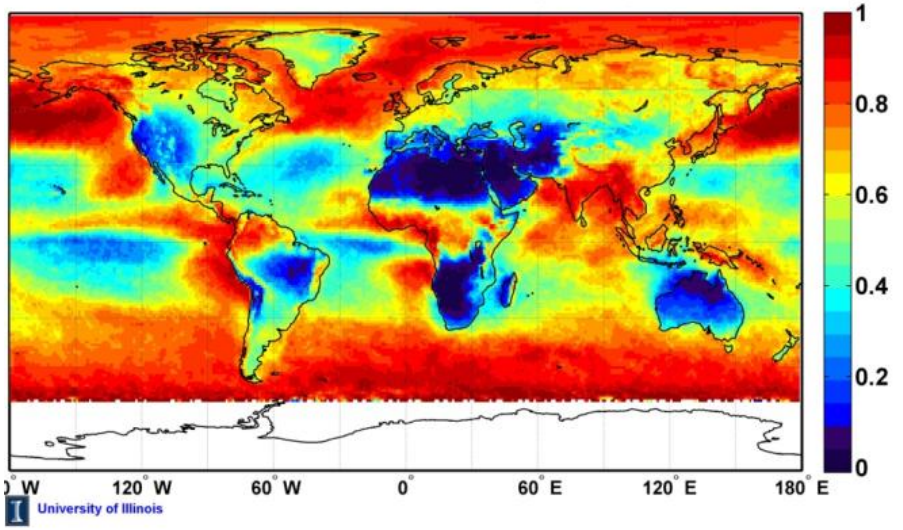
MODIS-ST-Terra-AM Total Cloud Fraction July Average (2001-2006)



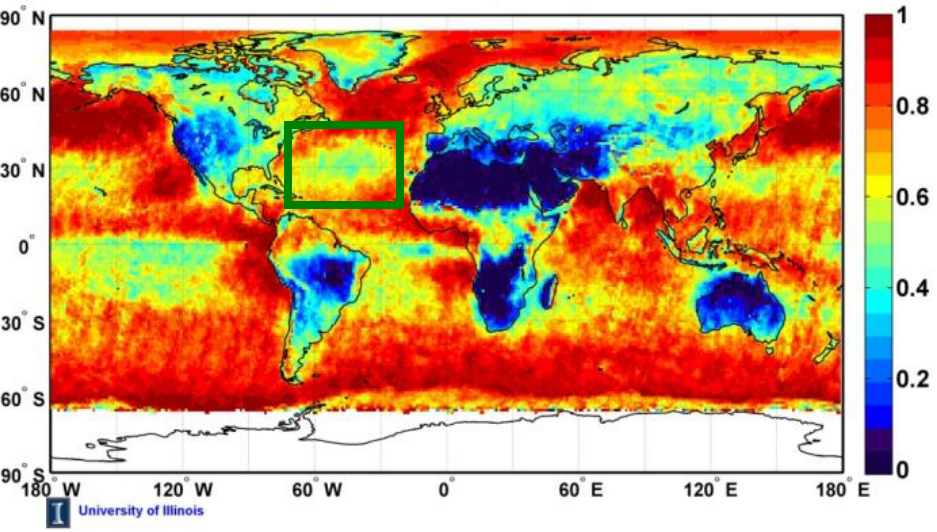
ISCCP Total Cloud Fraction July Average (2001-2006)



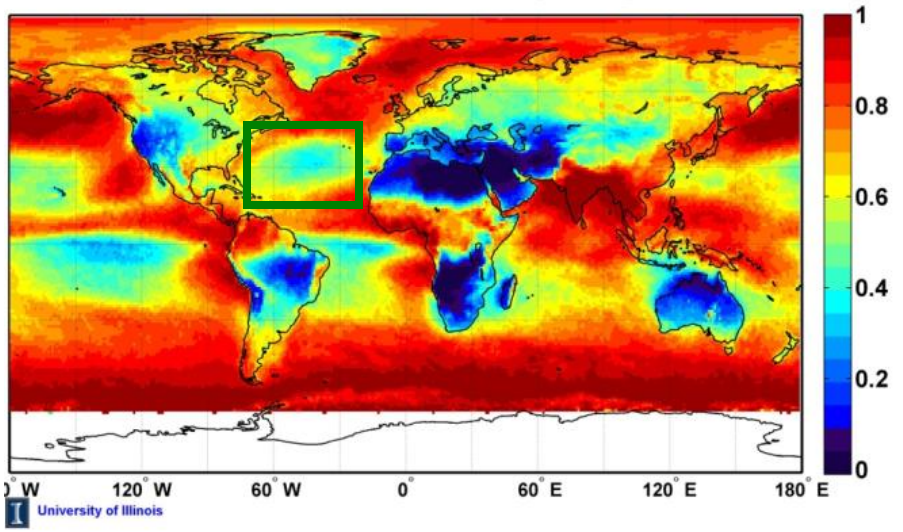
MODIS-CE-Terra-AM Total Cloud Fraction July Average (2001-2006)



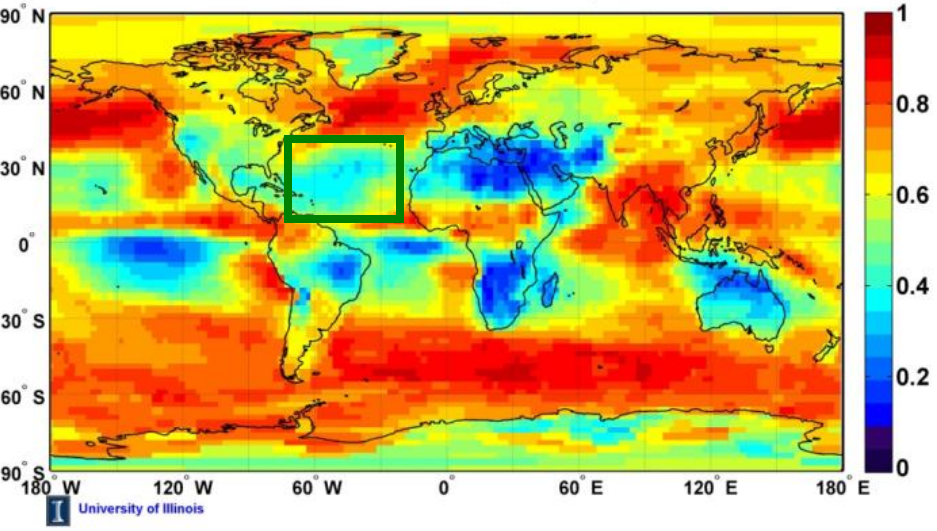
MISR Total Cloud Fraction July Average (2001-2006)



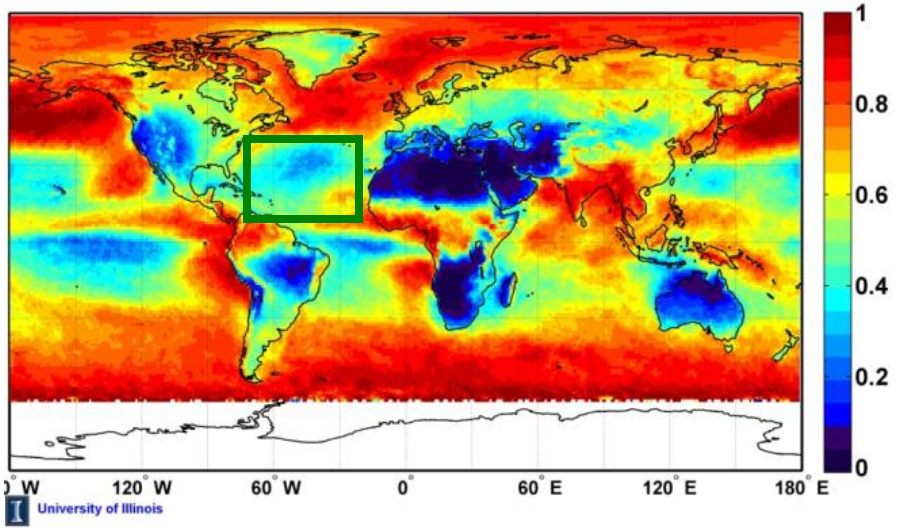
MODIS-ST-Terra-AM Total Cloud Fraction July Average (2001-2006)



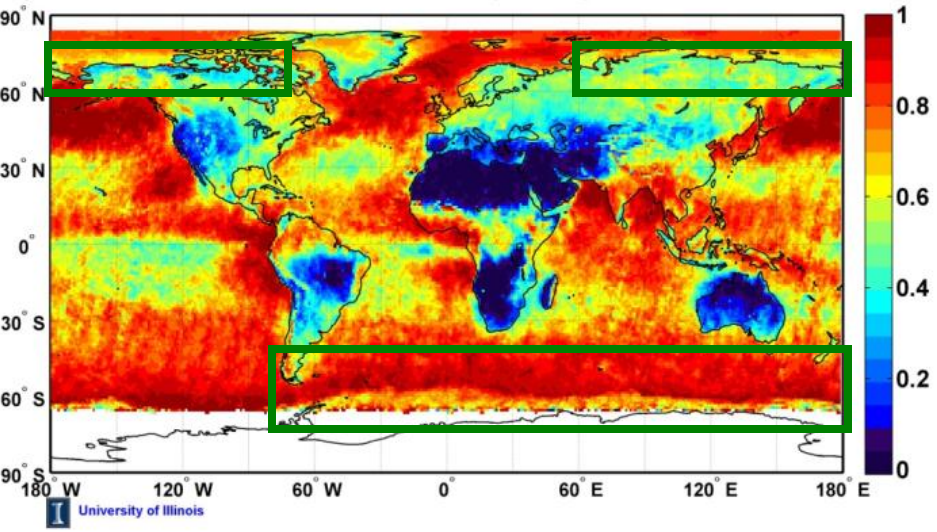
ISCCP Total Cloud Fraction July Average (2001-2006)



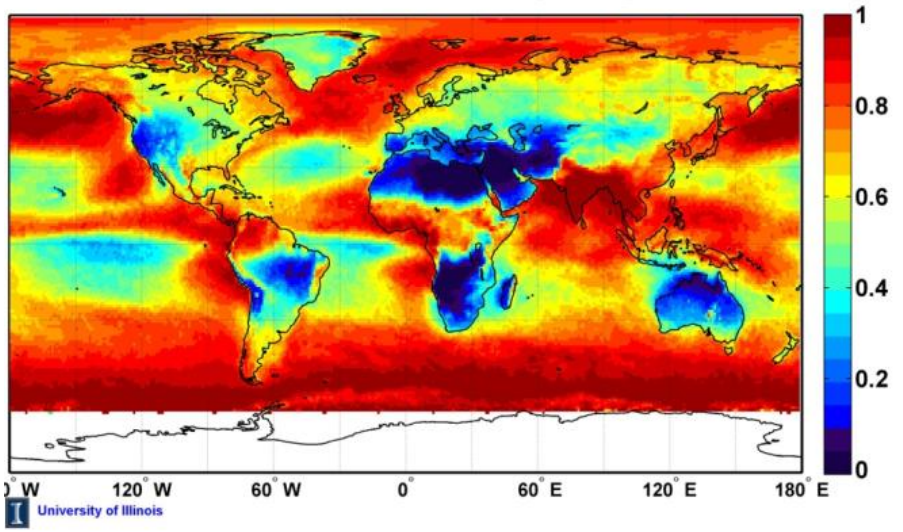
MODIS-CE-Terra-AM Total Cloud Fraction July Average (2001-2006)



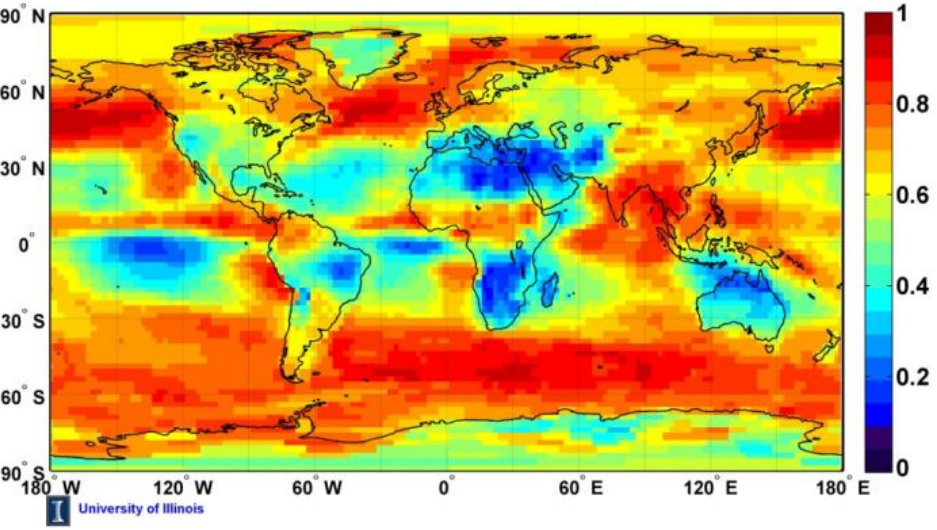
MISR Total Cloud Fraction July Average (2001-2006)



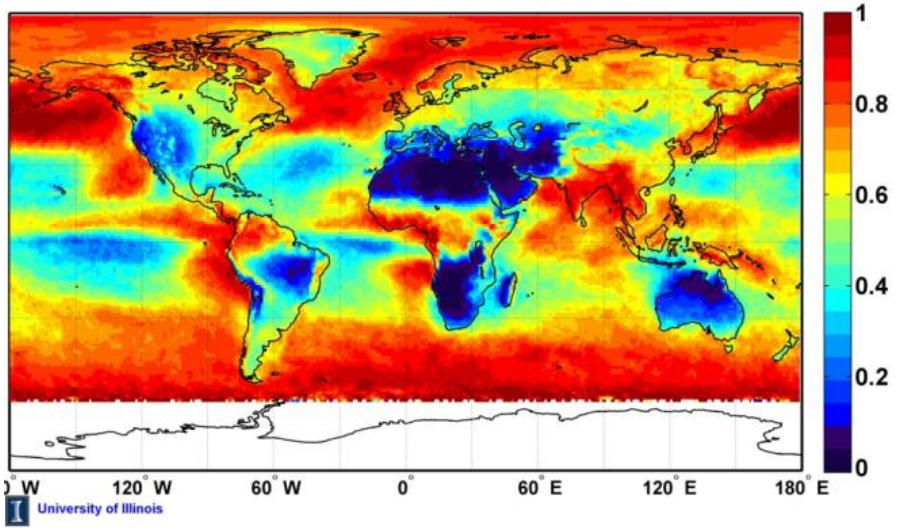
MODIS-ST-Terra-AM Total Cloud Fraction July Average (2001-2006)



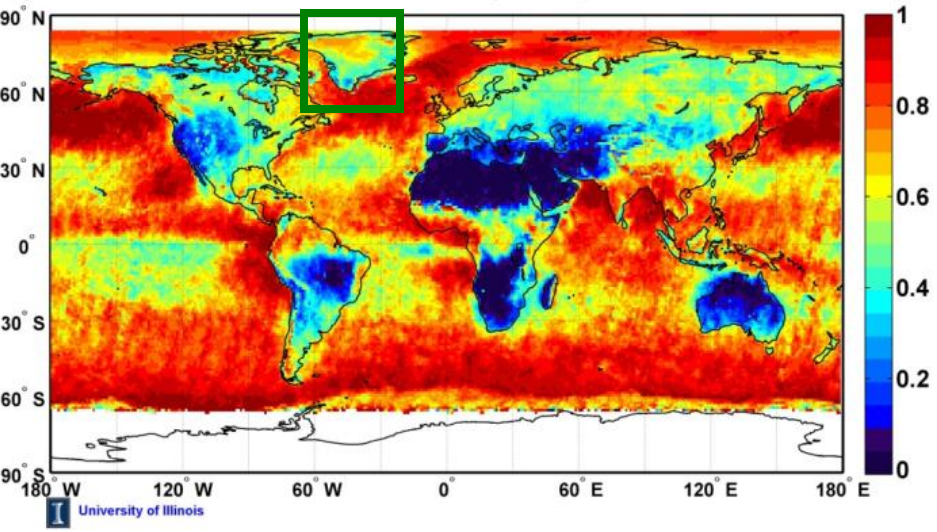
ISCCP Total Cloud Fraction July Average (2001-2006)



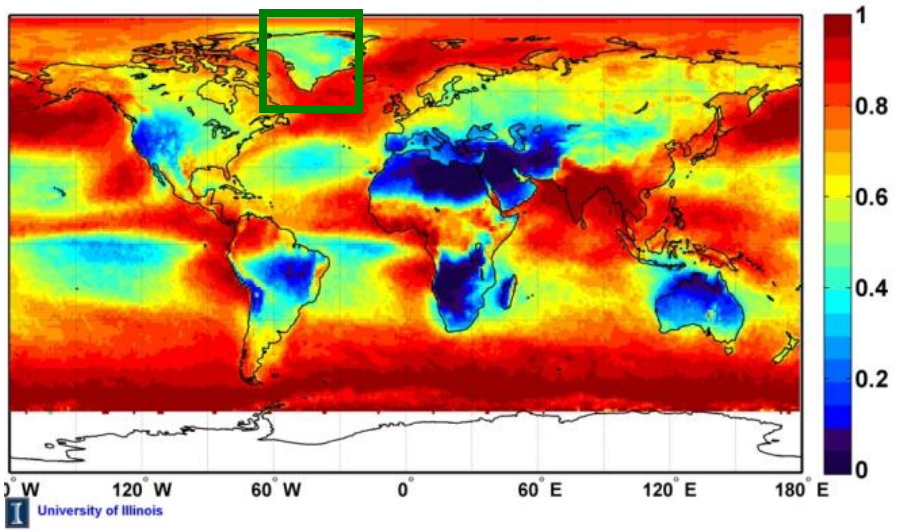
MODIS-CE-Terra-AM Total Cloud Fraction July Average (2001-2006)



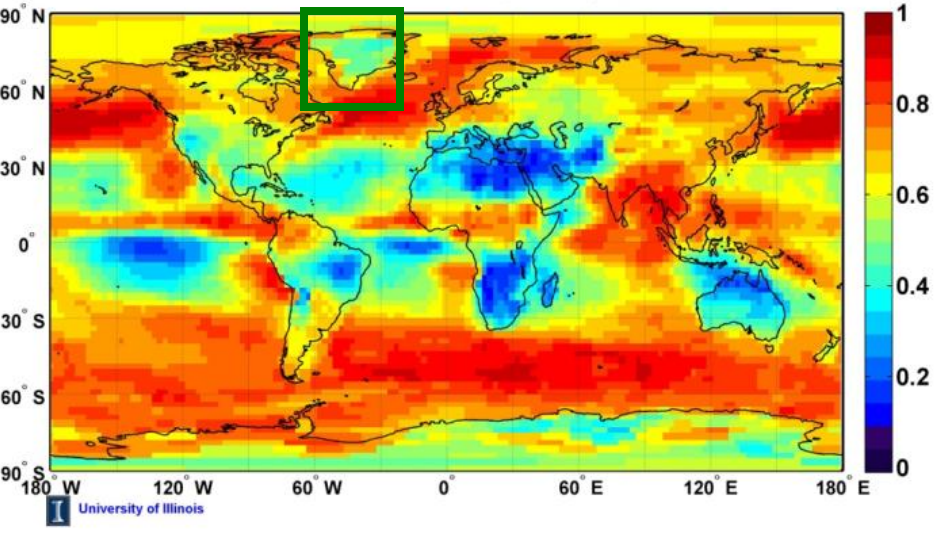
MISR Total Cloud Fraction July Average (2001-2006)



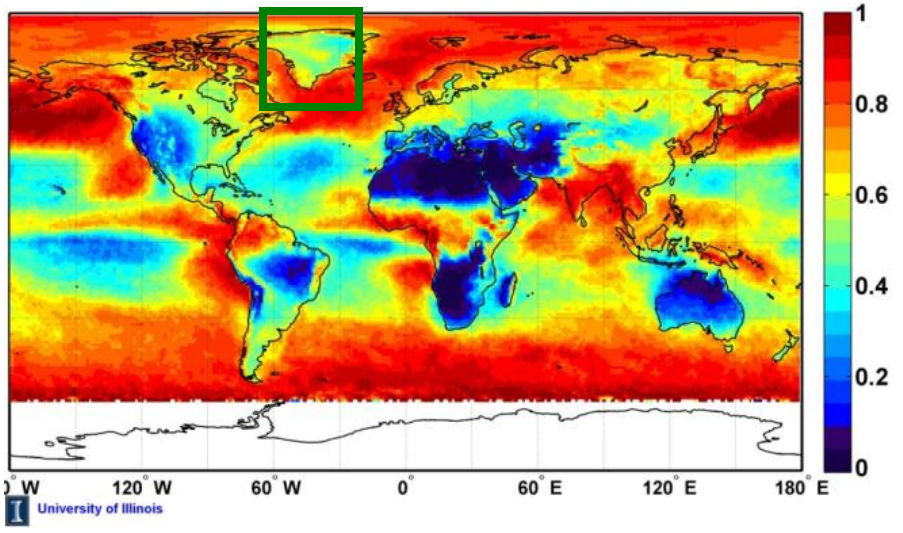
MODIS-ST-Terra-AM Total Cloud Fraction July Average (2001-2006)



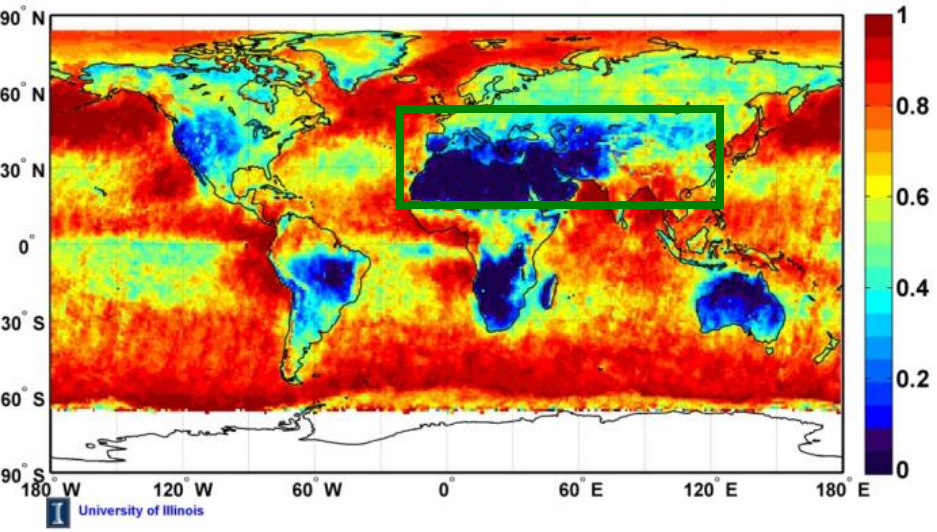
ISCCP Total Cloud Fraction July Average (2001-2006)



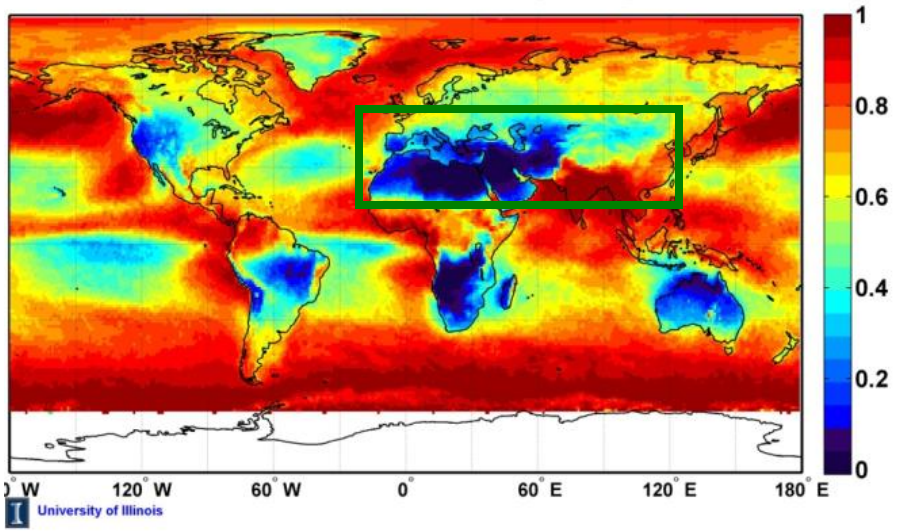
MODIS-CE-Terra-AM Total Cloud Fraction July Average (2001-2006)



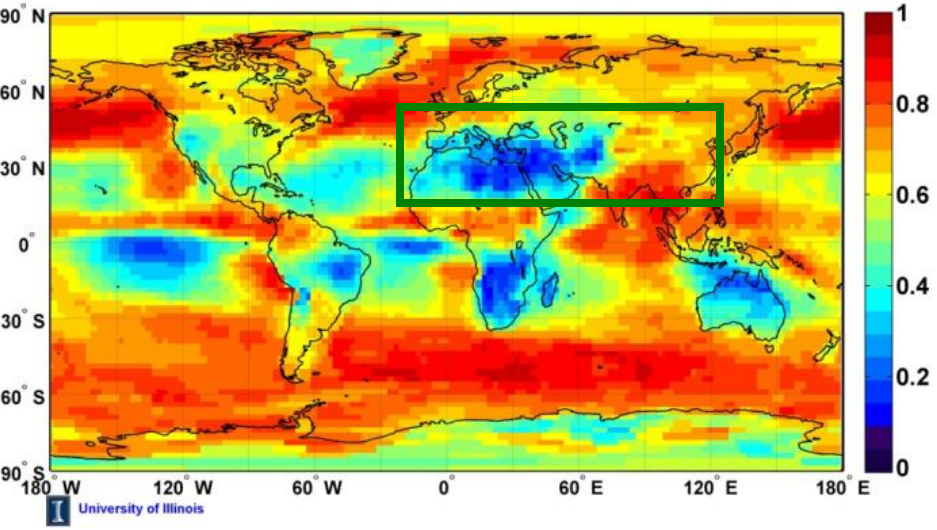
MISR Total Cloud Fraction July Average (2001-2006)



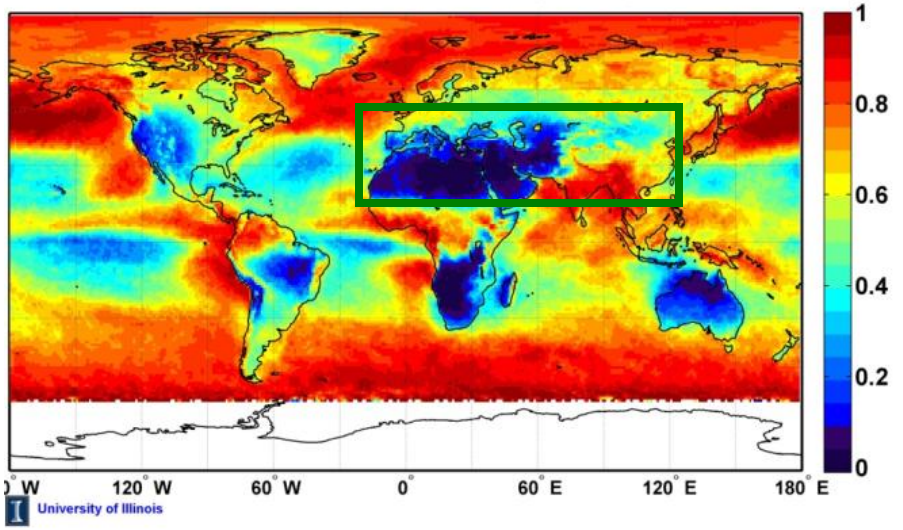
MODIS-ST-Terra-AM Total Cloud Fraction July Average (2001-2006)



ISCCP Total Cloud Fraction July Average (2001-2006)



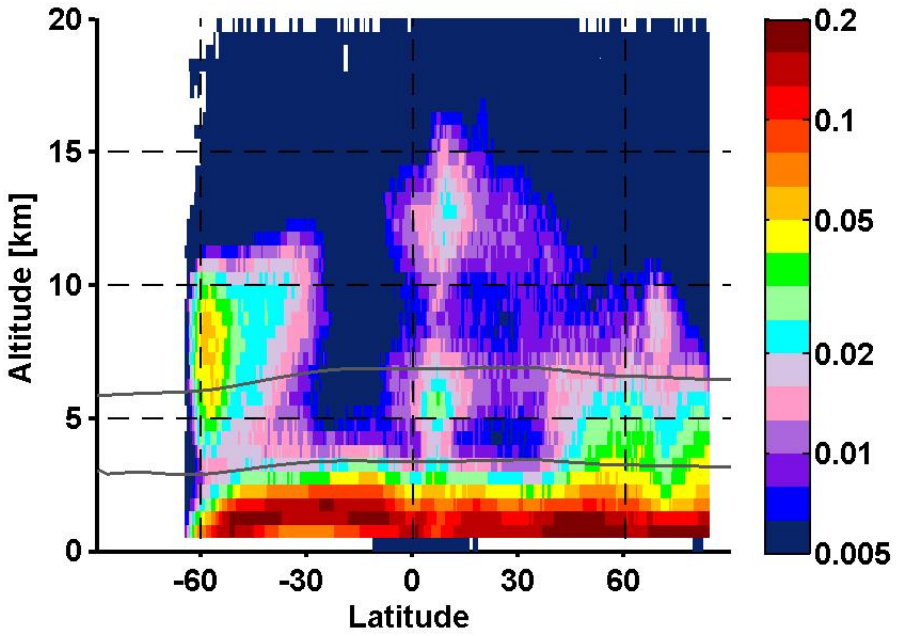
MODIS-CE-Terra-AM Total Cloud Fraction July Average (2001-2006)



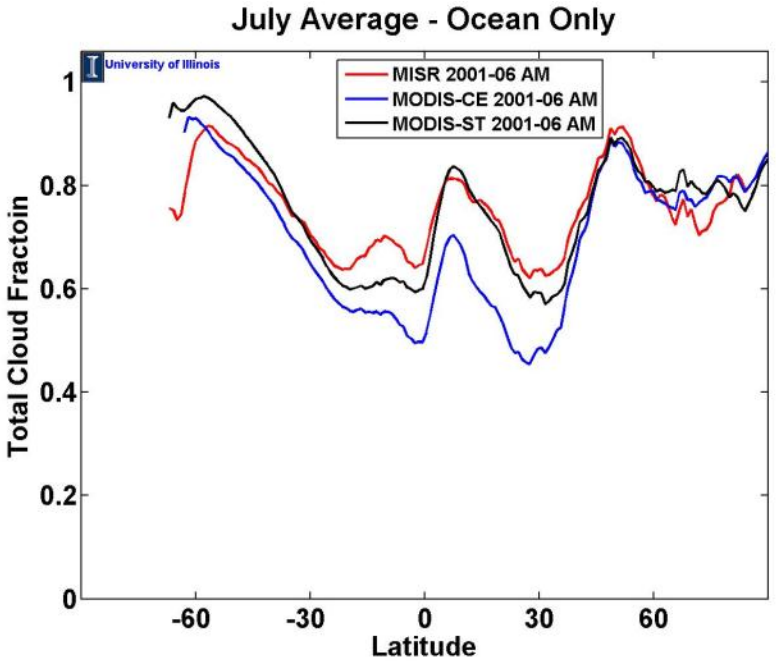
Low/Middle/High Clouds

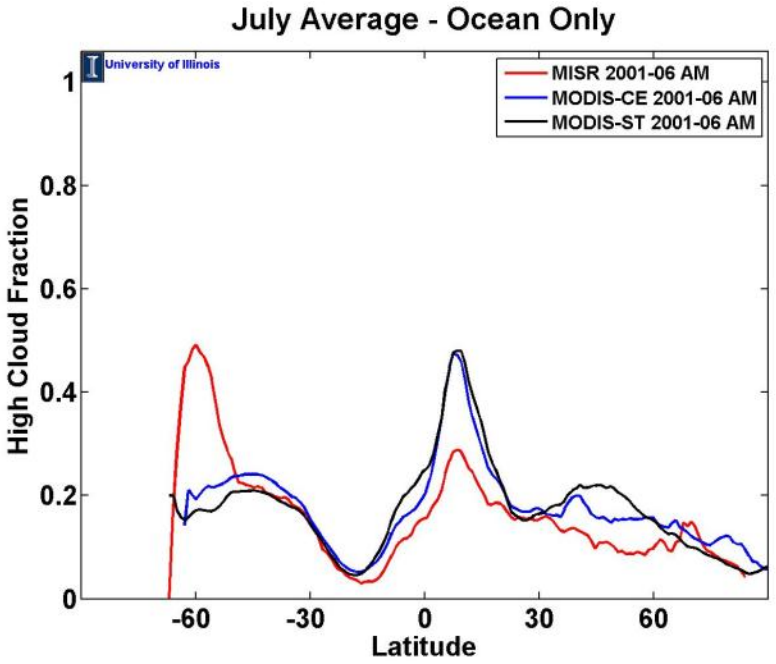
- MISR retrieves **altitude**… not pressure.
- Converting MISR altitudes to pressure requires assumptions that **degrade** the quality and vertical resolution of the original data.
- Height to 680 and 440 hPa pressure conversion based on GEOS-5 monthly averages for 2007
- Conversion done only for GEWEX CA comparison

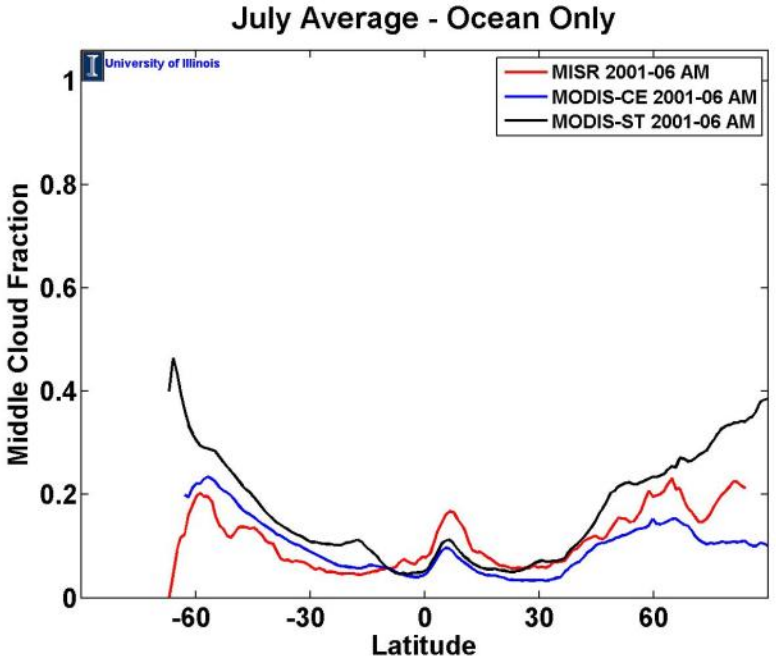
JUL

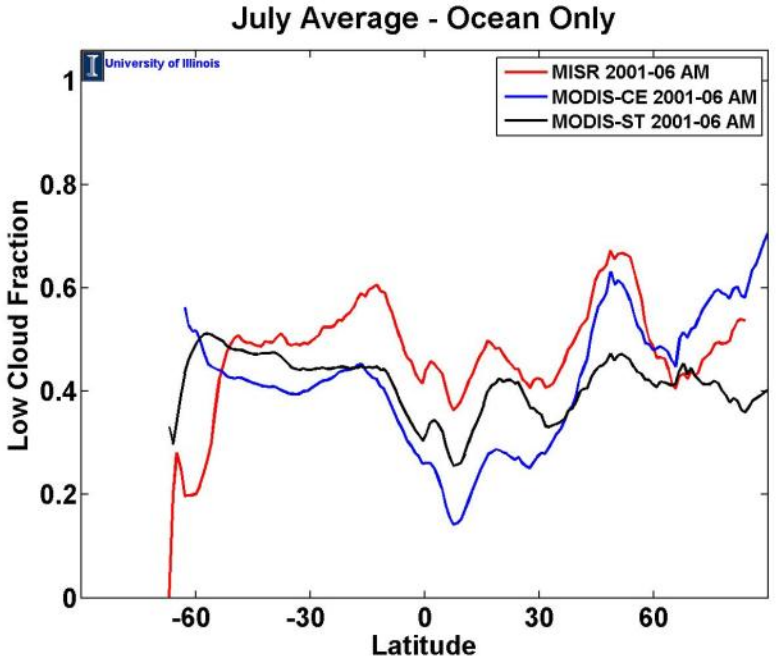


July 2001-2006 Zonal Cloud Amount (Ocean)

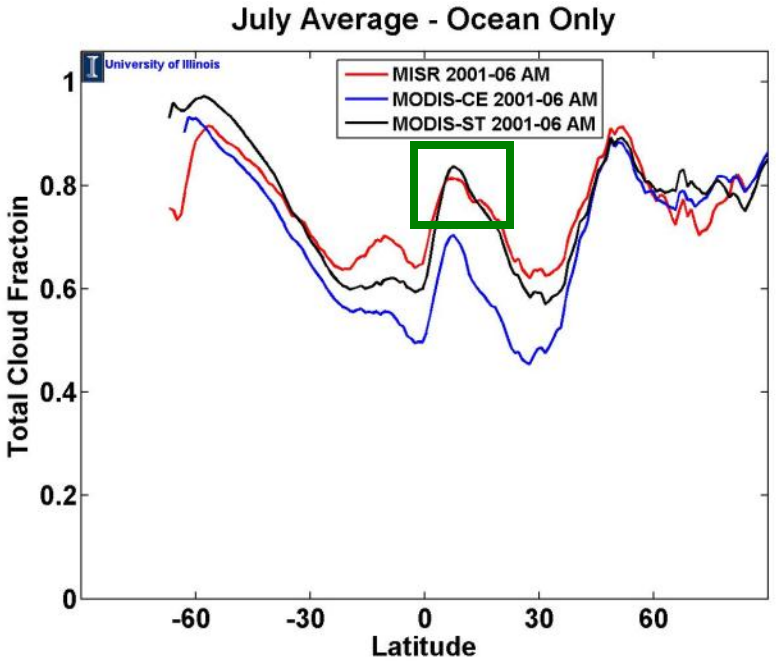


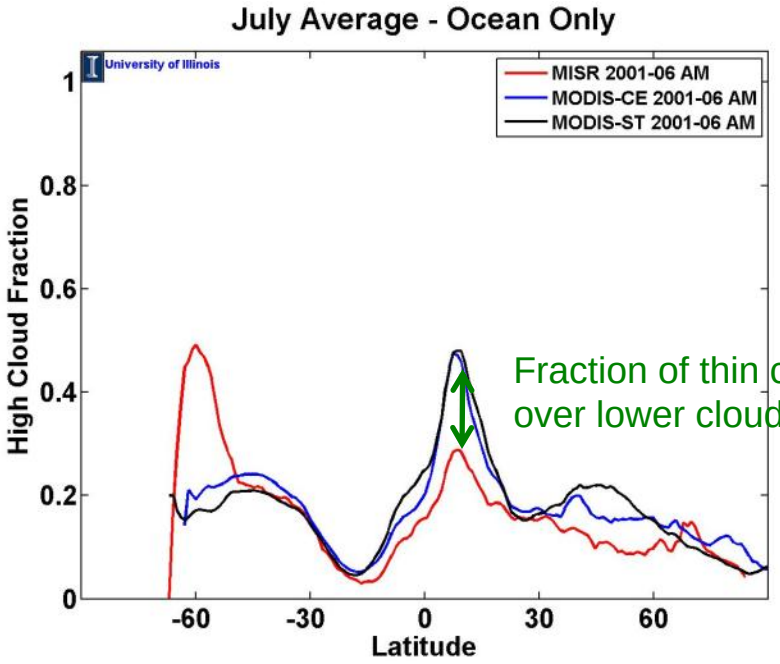


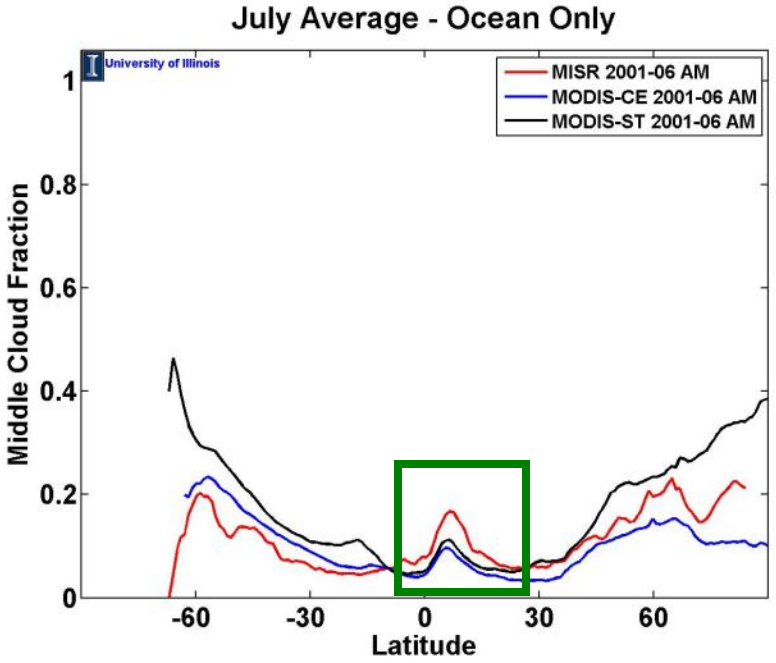


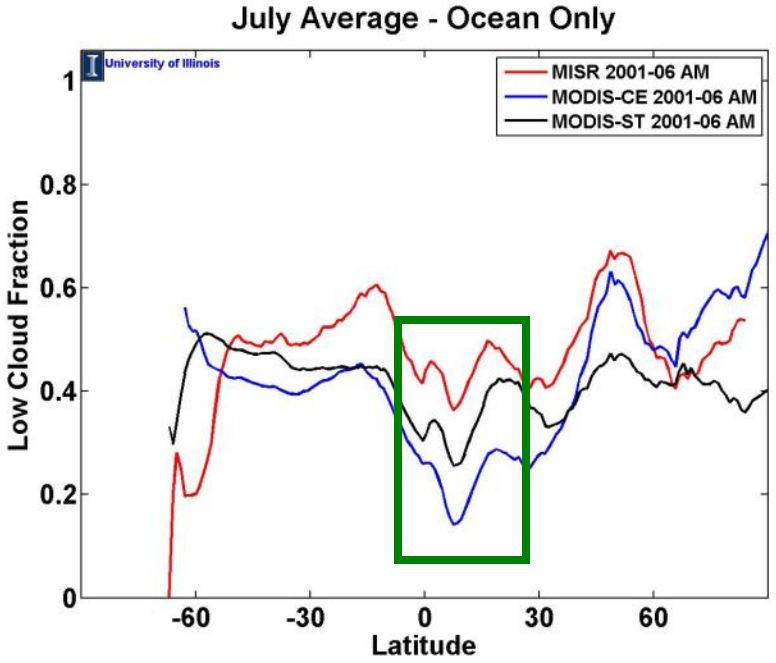


July 2001-2006 Zonal Cloud Amount (Ocean)

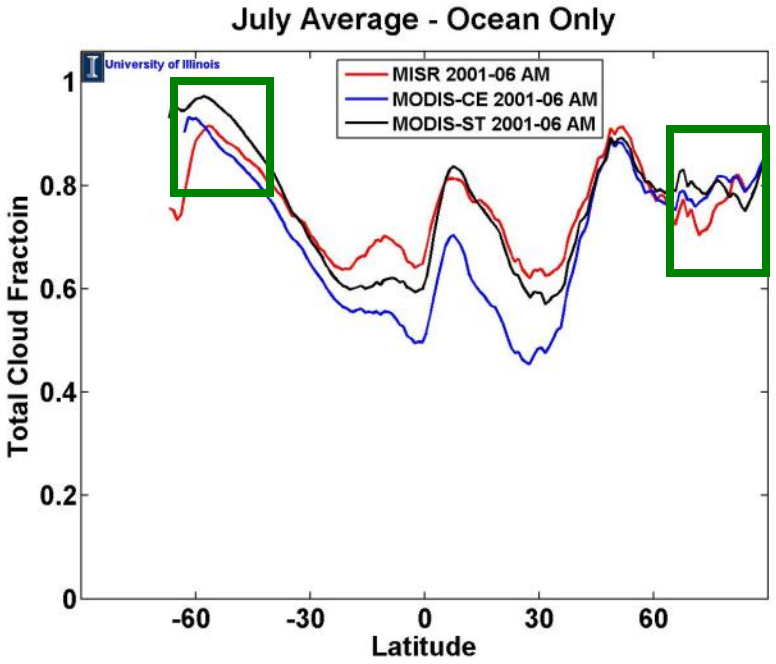


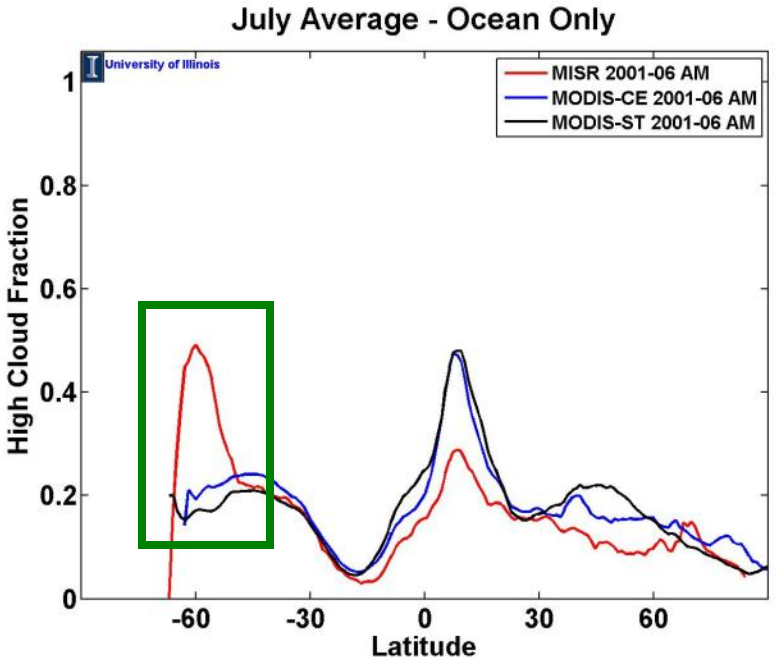


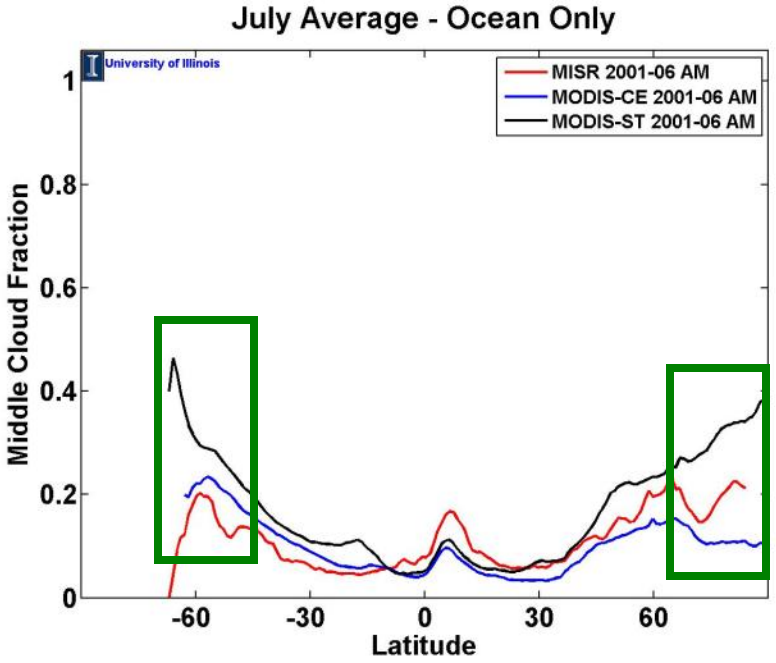


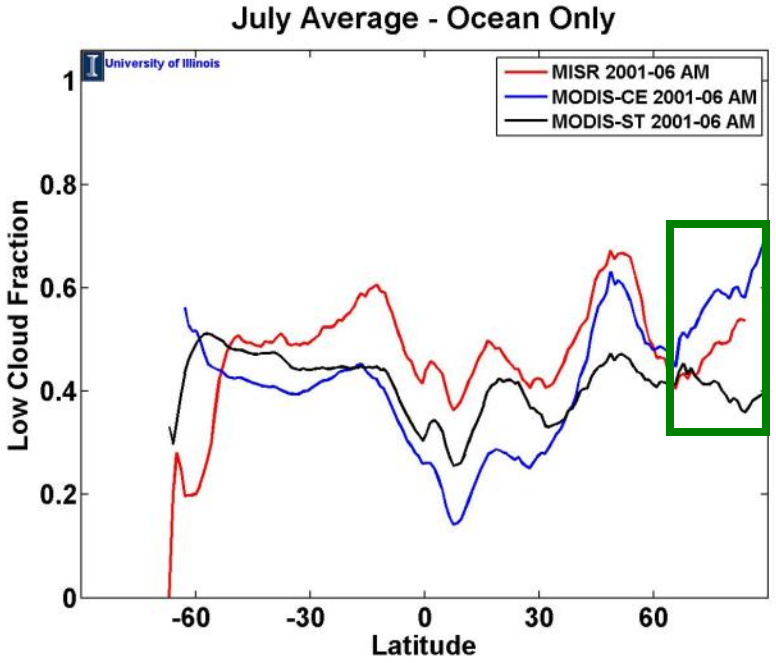


July 2001-2006 Zonal Cloud Amount (Ocean)

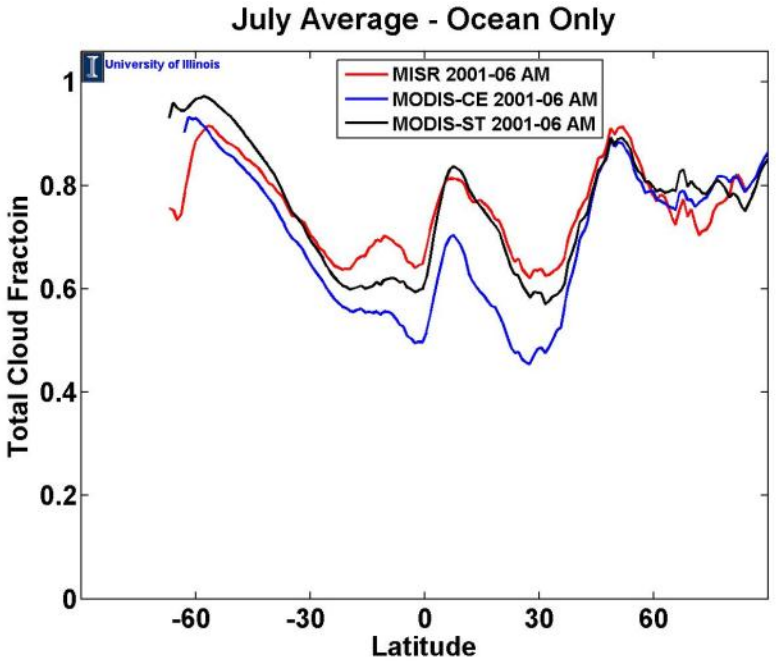


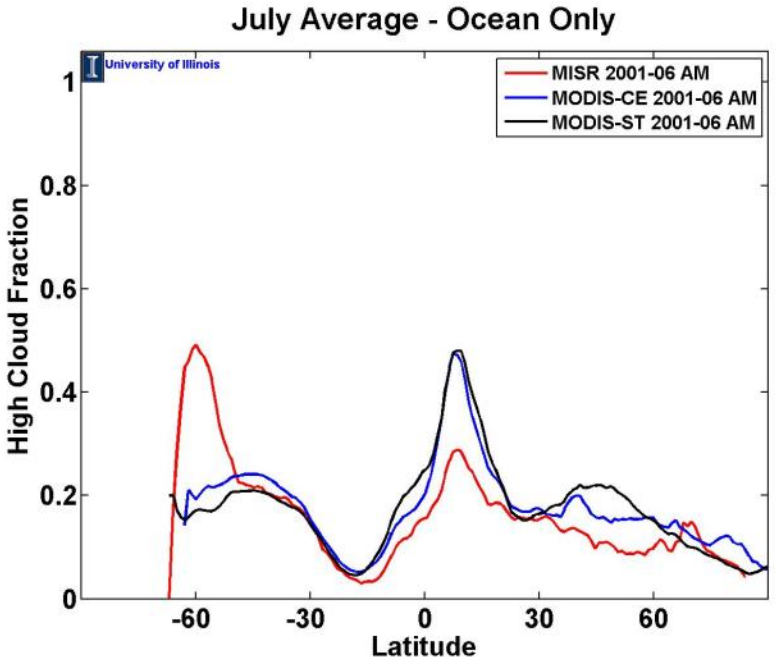


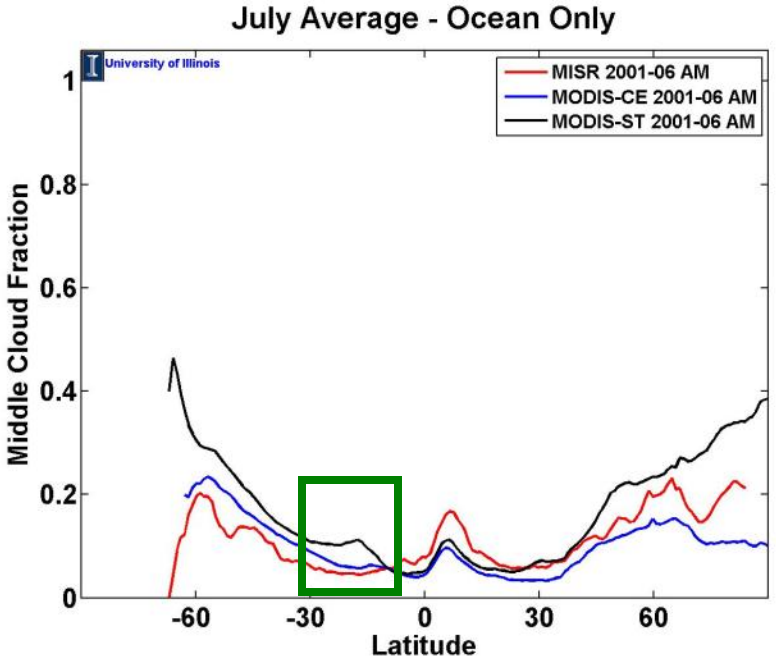


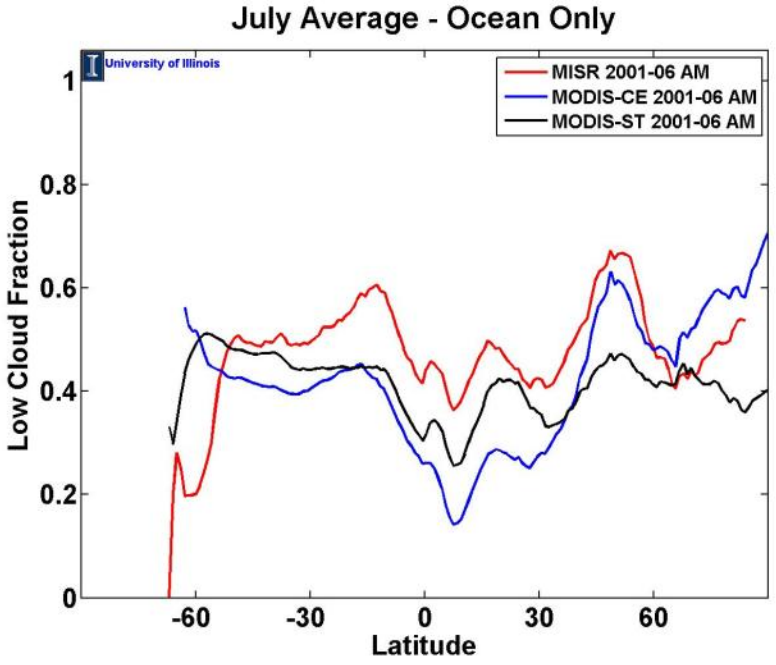


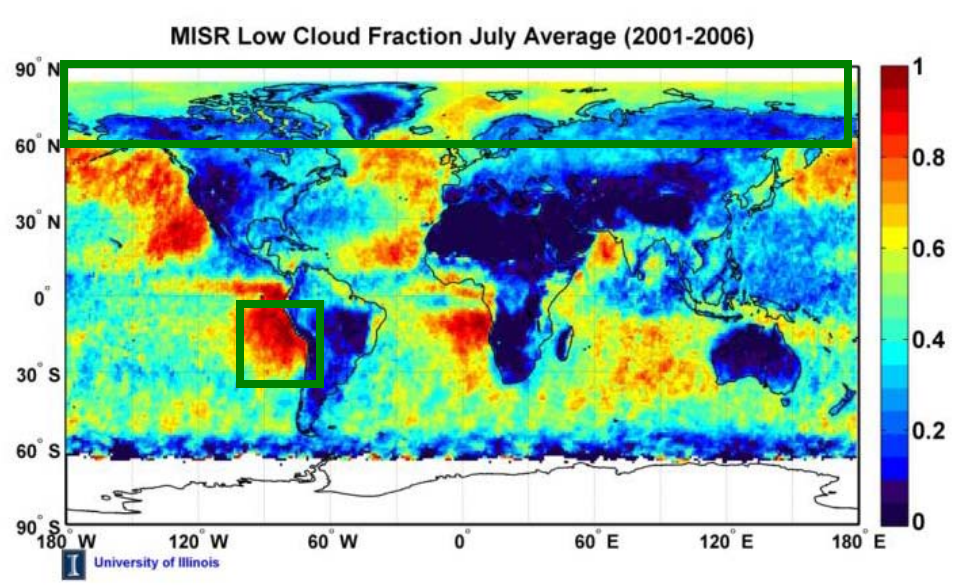
July 2001-2006 Zonal Cloud Amount (Ocean)

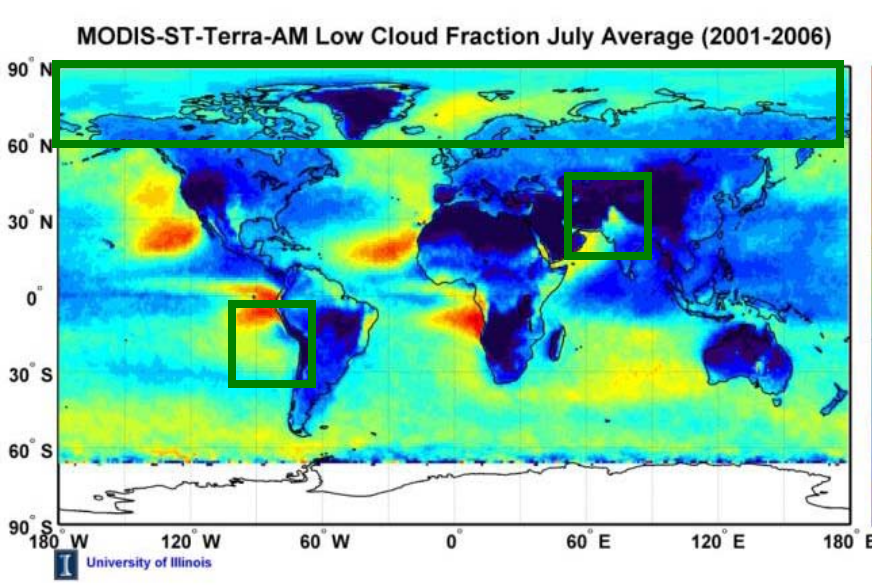


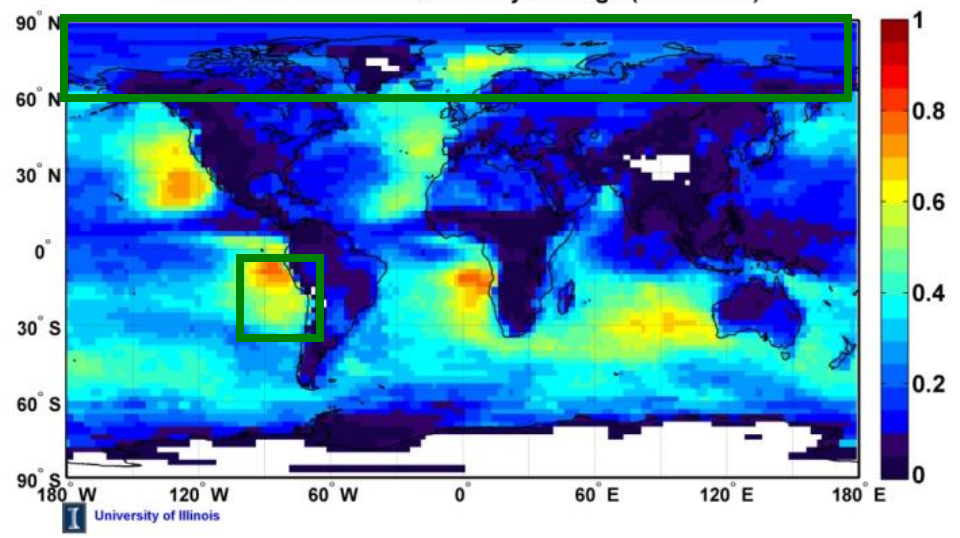


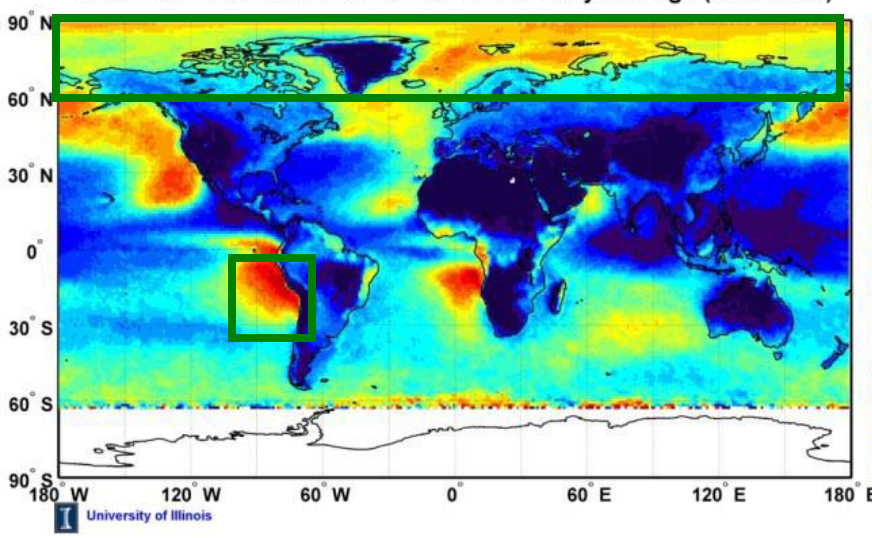




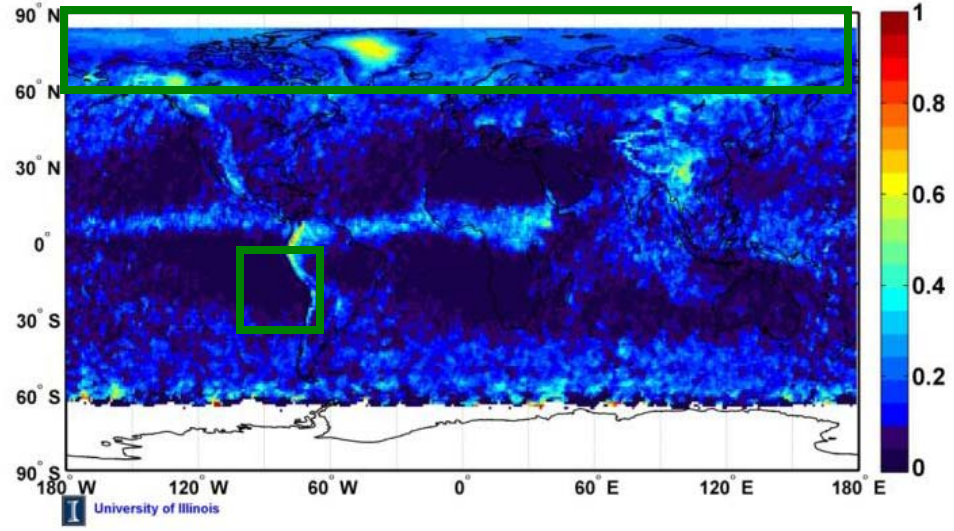

MISR Low Cloud Fraction July Average (2001-2006)
90° N
60° N
30° N
0°
30° S
60° S
90° S
180° W
120° W
60° W
0°
60° E
120° E
180° E
1
0.8
0.6
0.4
0.2
0
University of Illinois


MODIS-ST-Terra-AM Low Cloud Fraction July Average (2001-2006)
90° N
60° N
30° N
0°
30° S
60° S
90° S
180° W
120° W
60° W
0°
60° E
120° E
180° E
University of Illinois

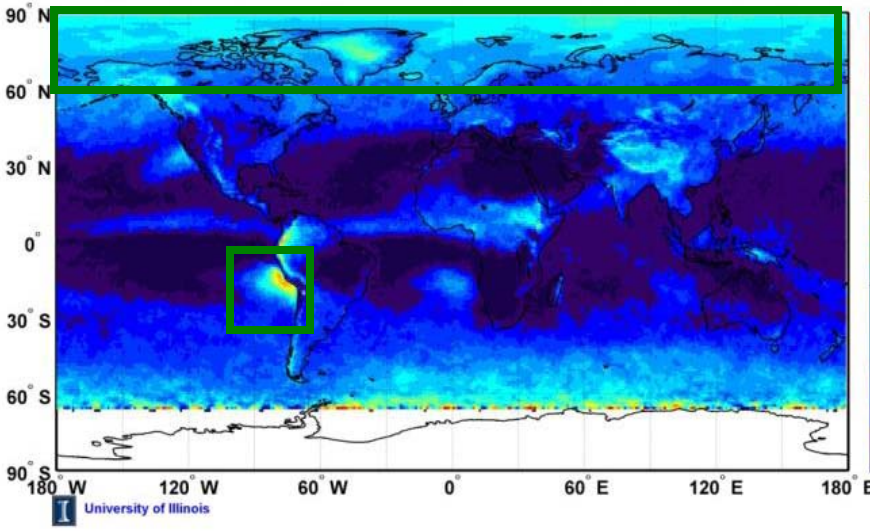

ISCCP Low Cloud Fraction July Average (2001-2006)
90° N
60° N
30° N
0°
30° S
60° S
90° S
180° W
120° W
60° W
0°
60° E
120° E
180° E
1
0.8
0.6
0.4
0.2
0
University of Illinois


MODIS-CE-Terra-AM Low Cloud Fraction July Average (2001-2006)
90° N
60° N
30° N
0°
30° S
60° S
90° S
180° W
120° W
60° W
0°
60° E
120° E
180° E
University of Illinois

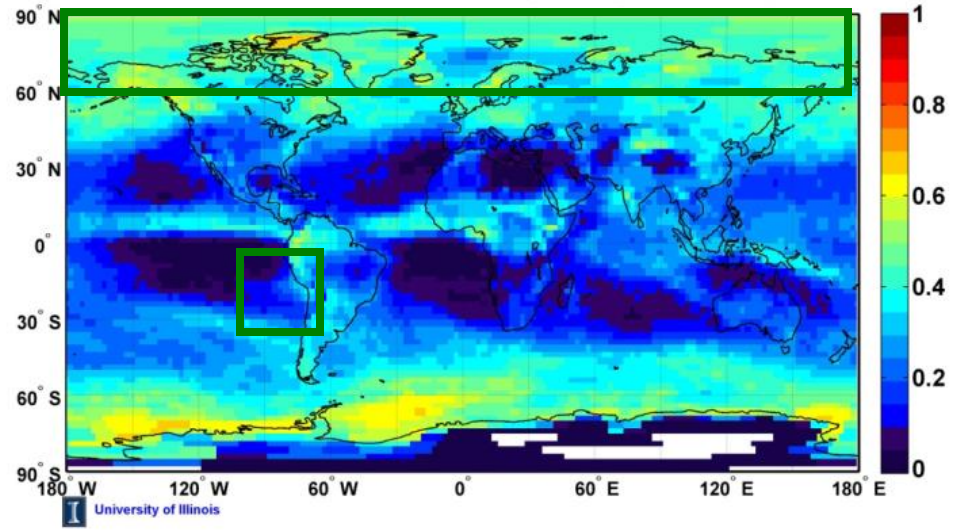
MISR Middle Cloud Fraction July Average (2001-2006)



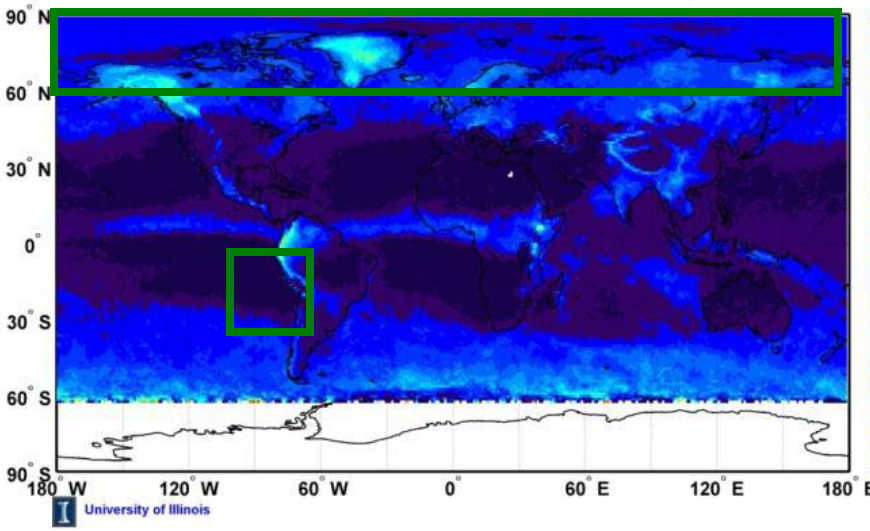
MODIS-ST-Terra-AM Middle Cloud Fraction July Average (2001-2006)



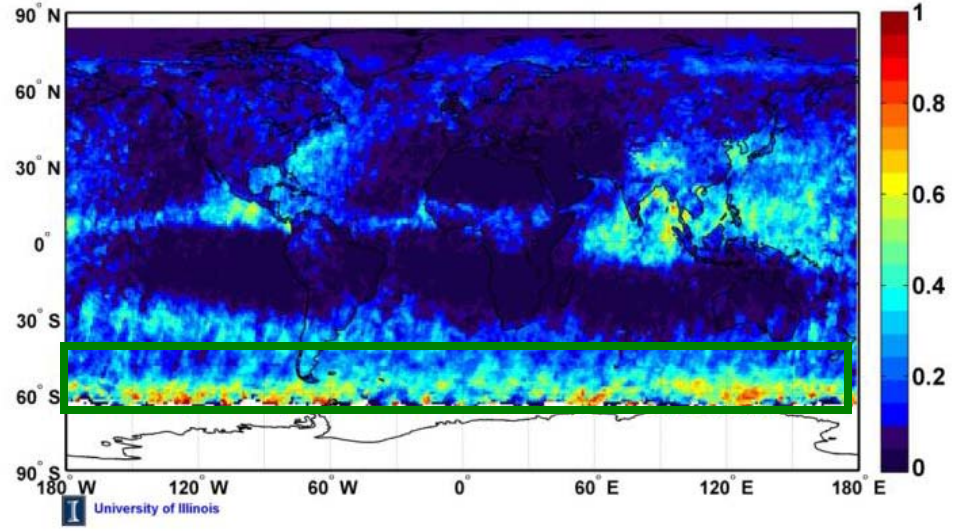
ISCCP Middle Cloud Fraction July Average (2001-2006)



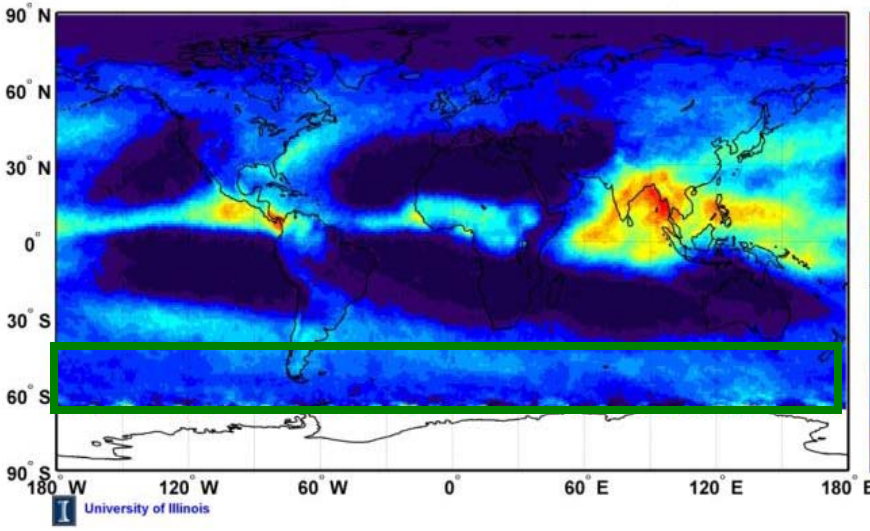
MODIS-CE-Terra-AM Middle Cloud Fraction July Average (2001-2006)



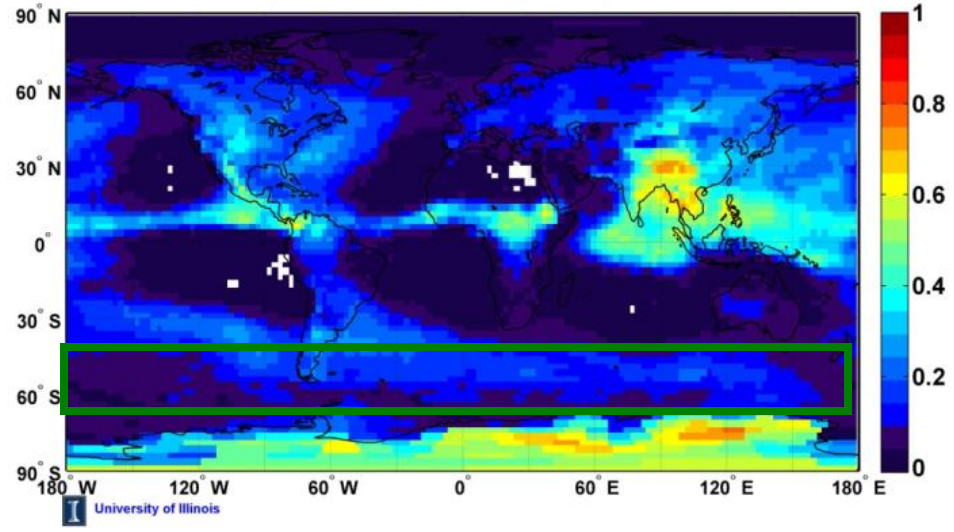
MISR High Cloud Fraction July Average (2001-2006)



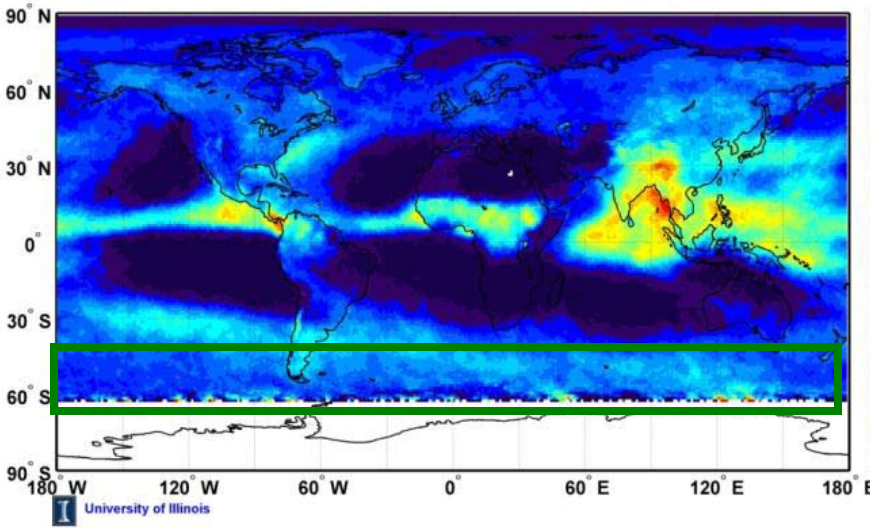
MODIS-ST-Terra-AM High Cloud Fraction July Average (2001-2006)

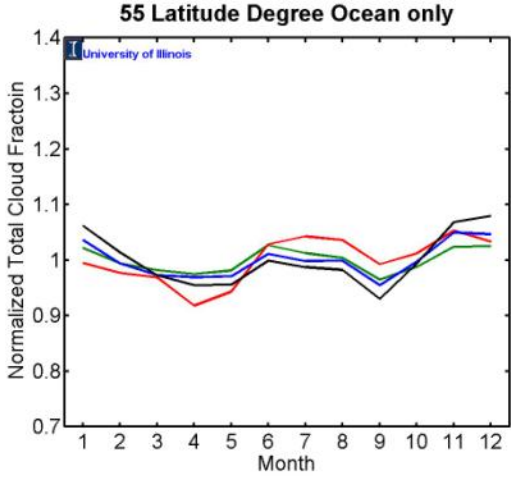


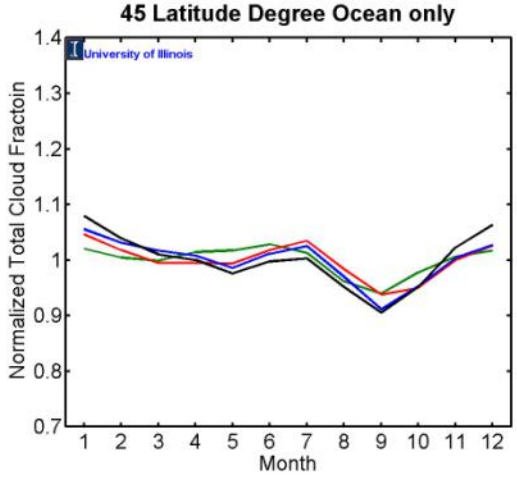
ISCCP High Cloud Fraction July Average (2001-2006)

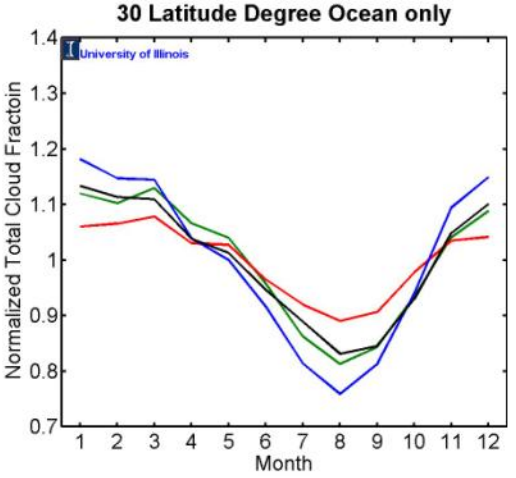


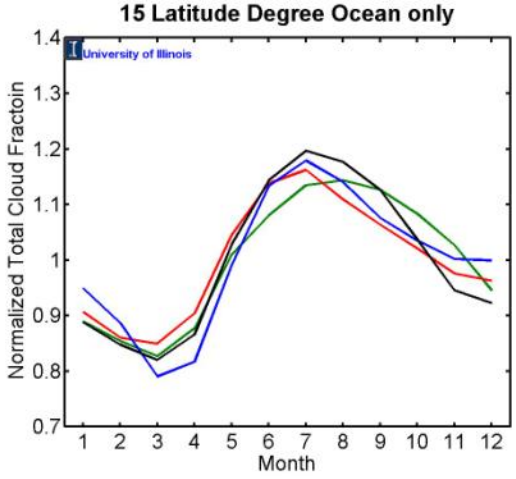
MODIS-CE-Terra-AM High Cloud Fraction July Average (2001-2006)





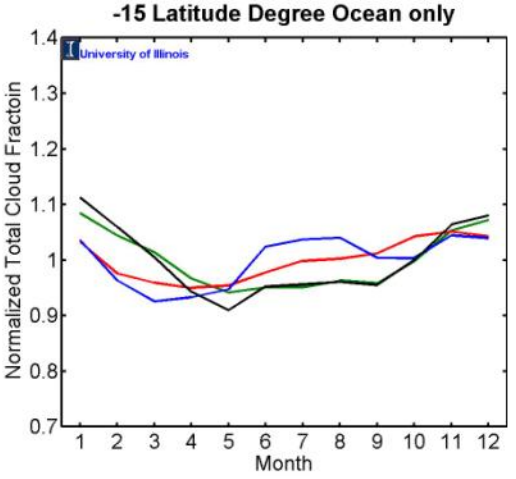


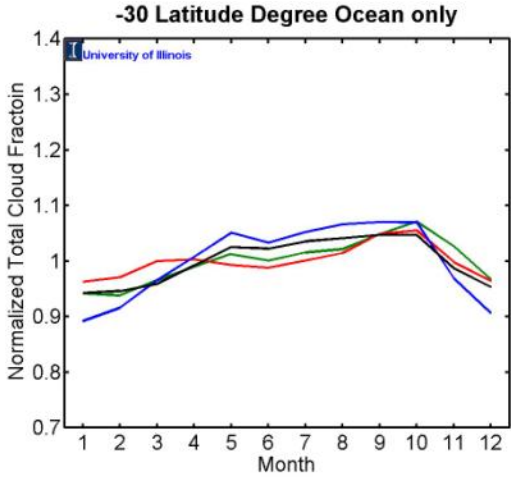


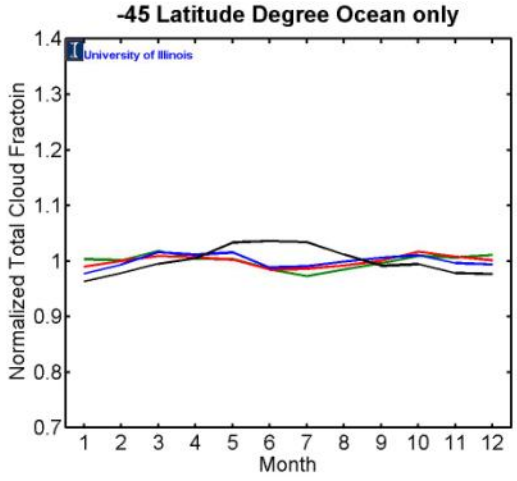


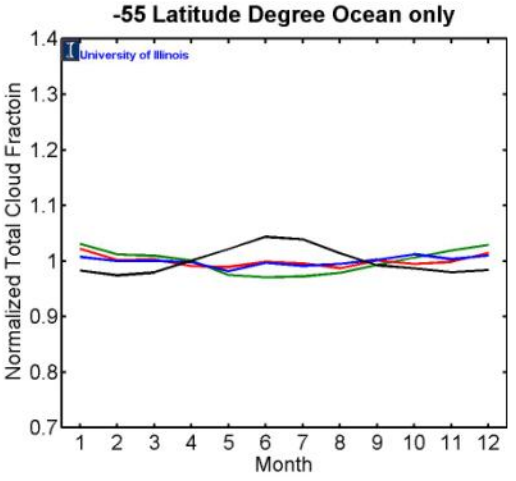
ISCCP 2001-06 AMPM
MISR 2001-06 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-06 AM

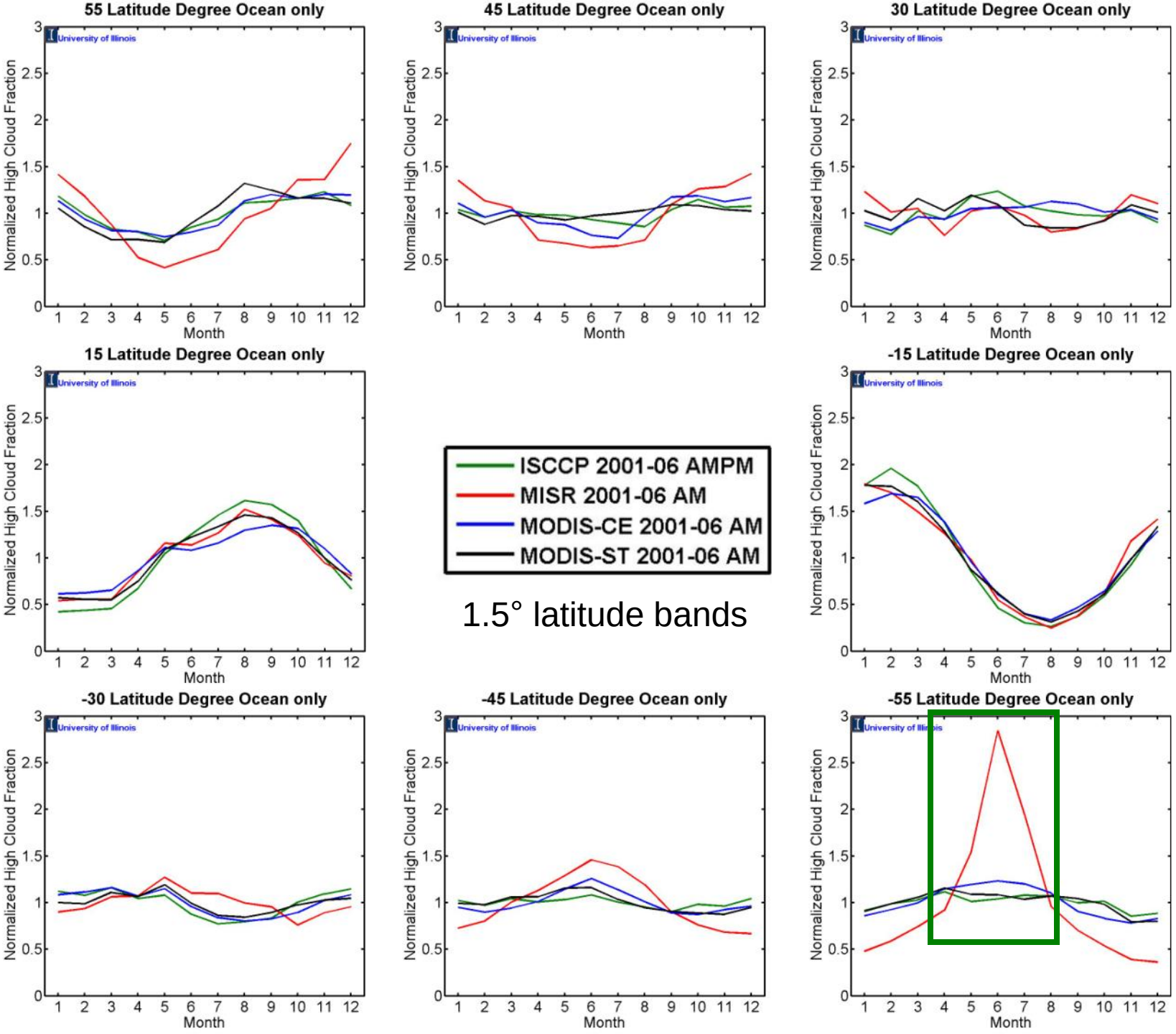
1.5° latitude bands

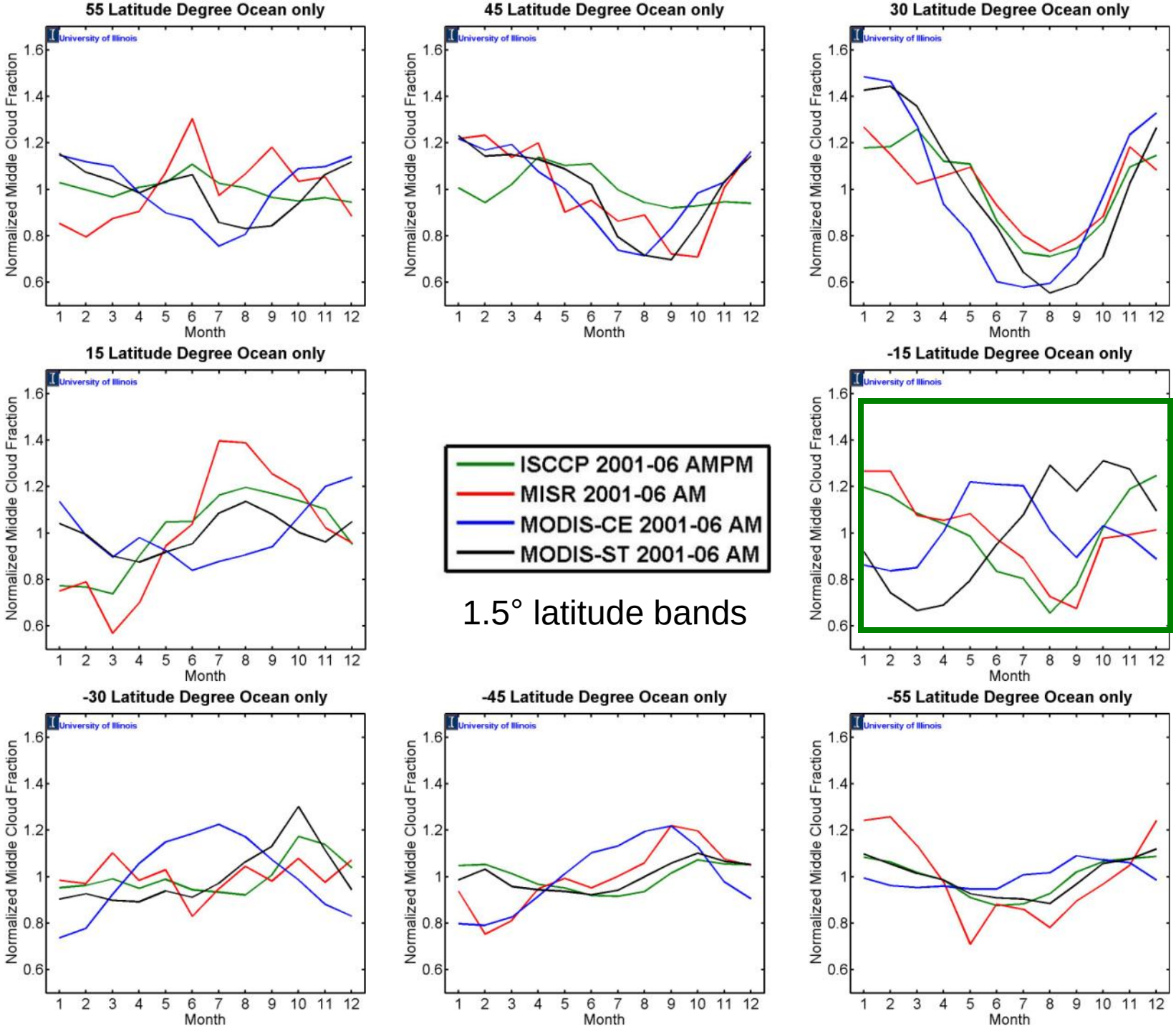


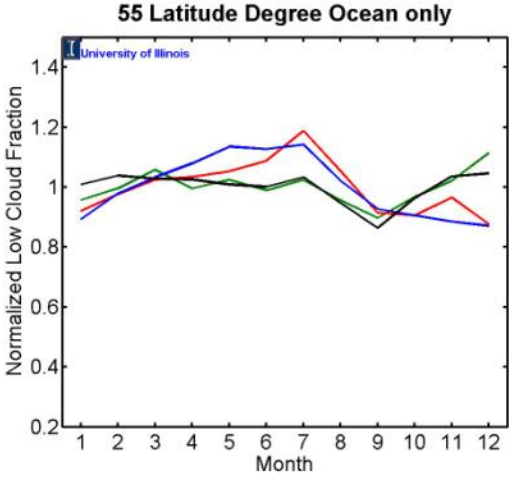


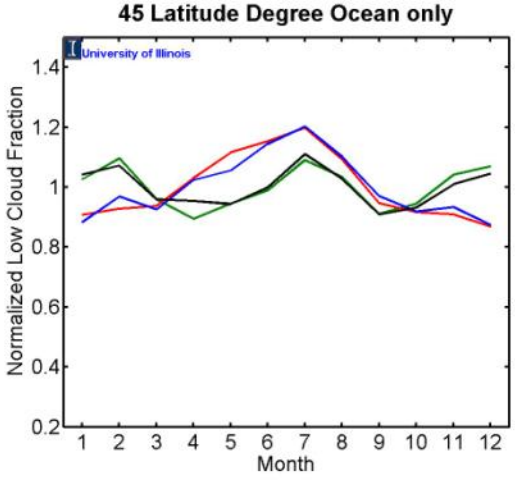


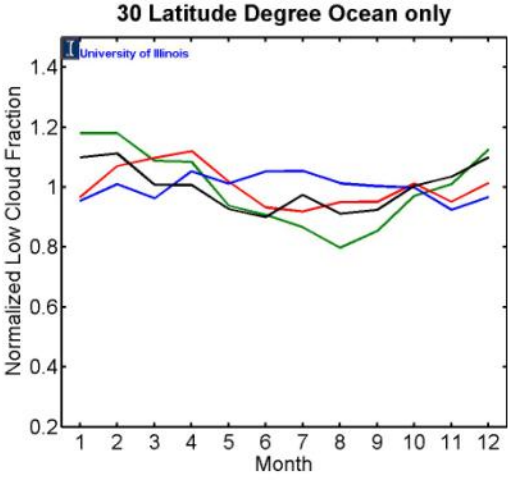


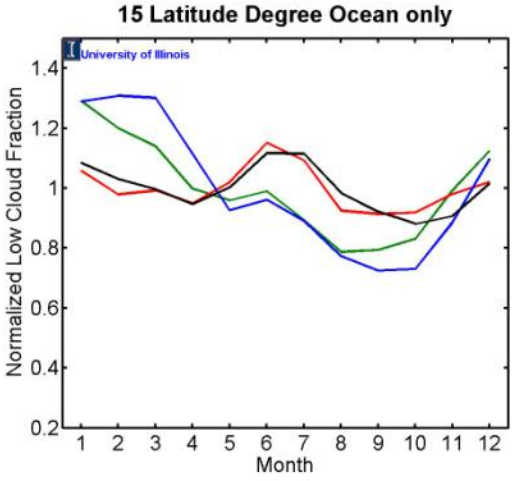

55 Latitude Degree Ocean only
45 Latitude Degree Ocean only
30 Latitude Degree Ocean only
15 Latitude Degree Ocean only
-15 Latitude Degree Ocean only
-30 Latitude Degree Ocean only
-45 Latitude Degree Ocean only
-55 Latitude Degree Ocean only
University of Illinois
Normalized High Cloud Fraction
Month
ISCCP 2001-06 AMPM
MISR 2001-06 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-06 AM
1.5° latitude bands


55 Latitude Degree Ocean only
45 Latitude Degree Ocean only
30 Latitude Degree Ocean only
15 Latitude Degree Ocean only
-15 Latitude Degree Ocean only
-30 Latitude Degree Ocean only
-45 Latitude Degree Ocean only
-55 Latitude Degree Ocean only
University of Illinois
Normalized Middle Cloud Fraction
Month
ISCCP 2001-06 AMPM
MISR 2001-06 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-06 AM
1.5° latitude bands



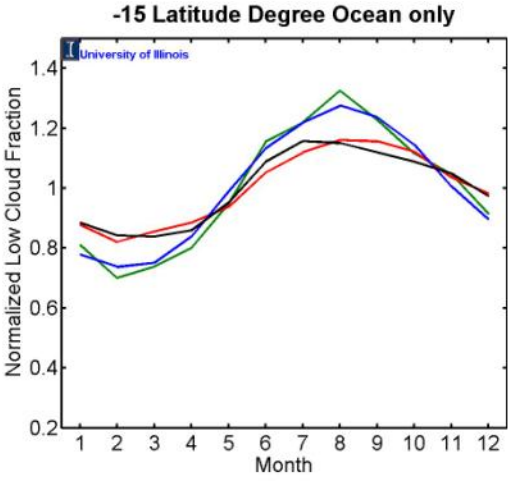


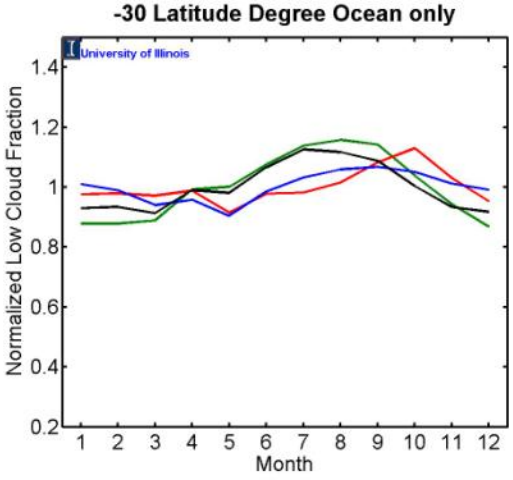


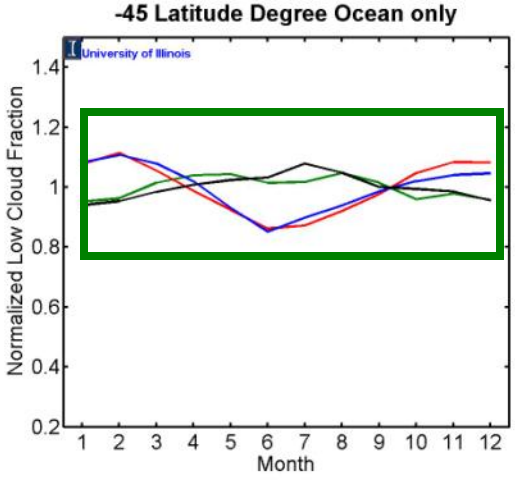


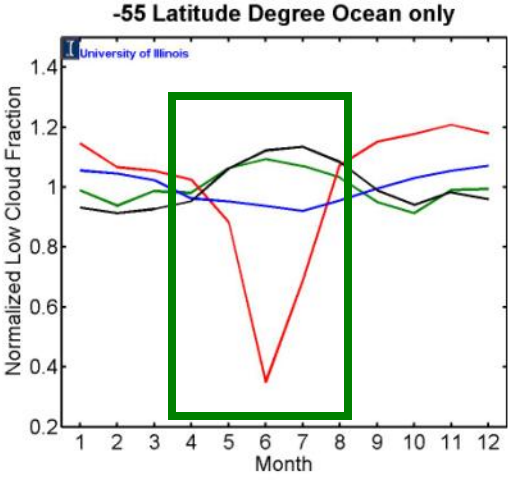
ISCCP 2001-06 AMPM
MISR 2001-06 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-06 AM

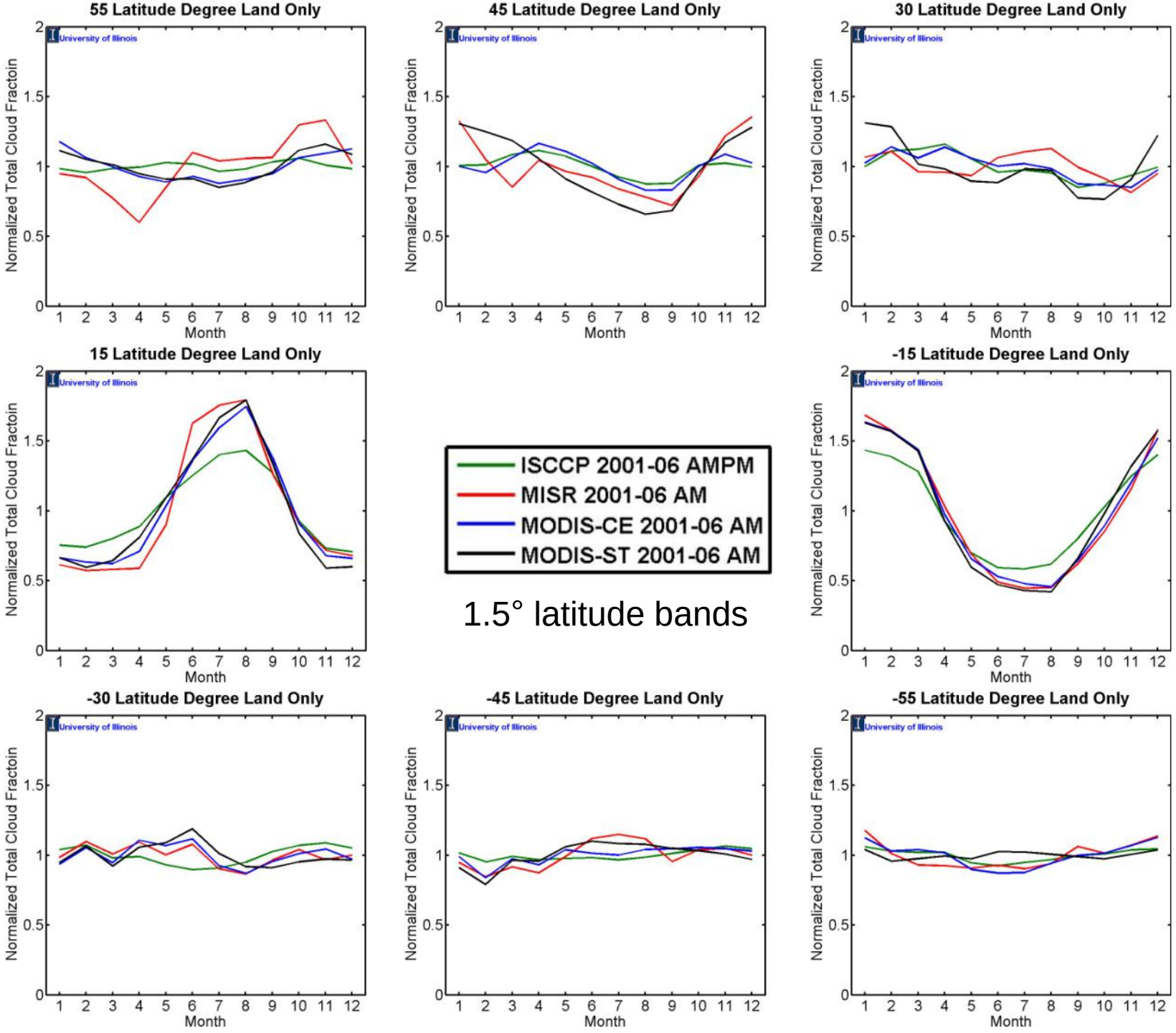
1.5° latitude bands

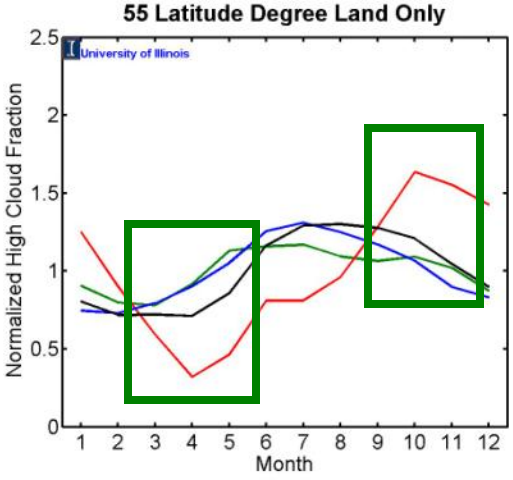


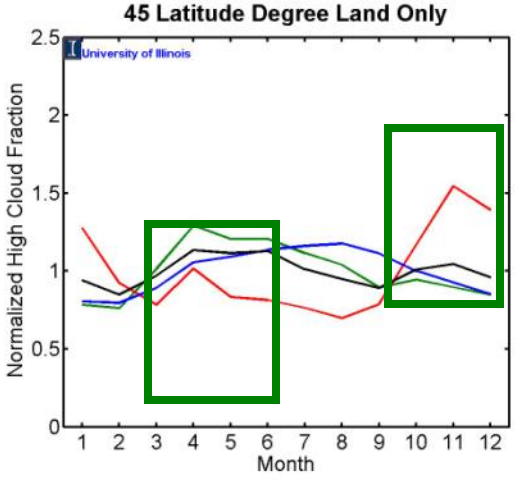


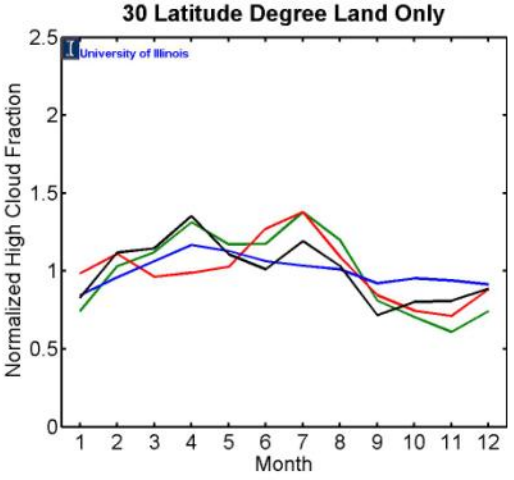


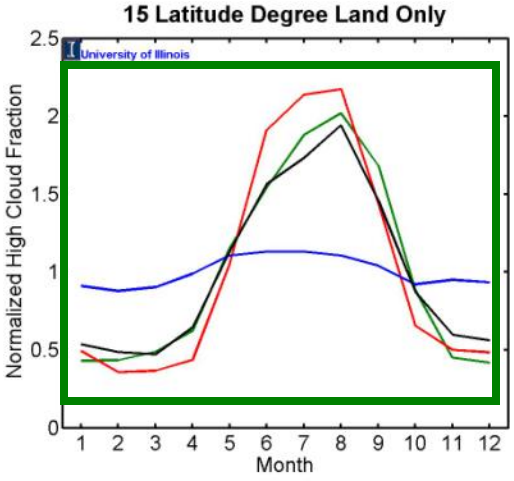



55 Latitude Degree Land Only
45 Latitude Degree Land Only
30 Latitude Degree Land Only
15 Latitude Degree Land Only
-15 Latitude Degree Land Only
-30 Latitude Degree Land Only
-45 Latitude Degree Land Only
-55 Latitude Degree Land Only
University of Illinois
Normalized Total Cloud Fractoin
Month
ISCCP 2001-06 AMPM
MISR 2001-06 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-06 AM
1.5° latitude bands



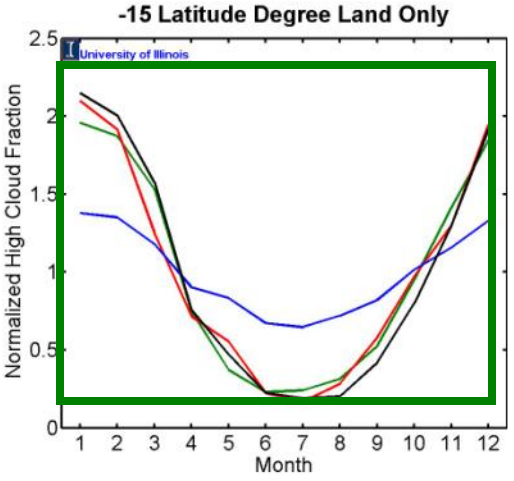


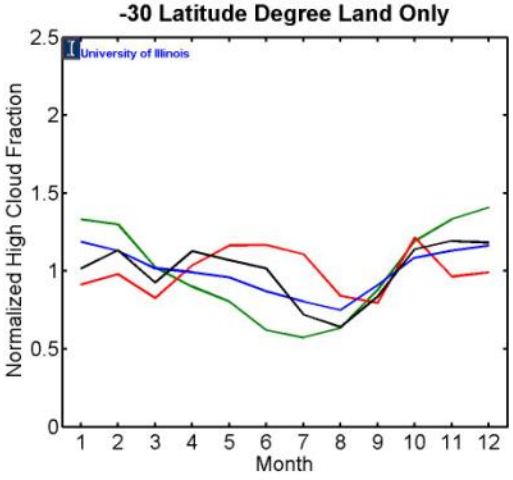


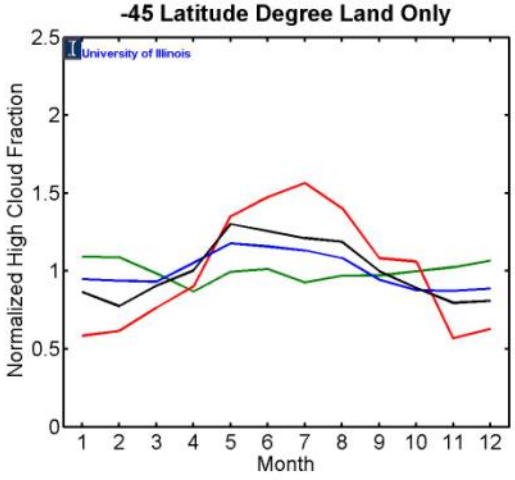


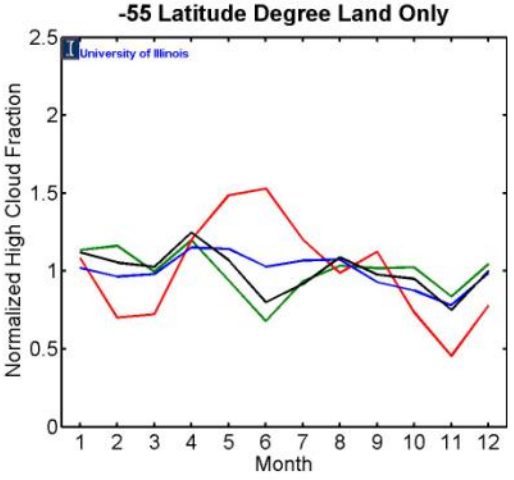
ISCCP 2001-06 AMPM
MISR 2001-06 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-06 AM

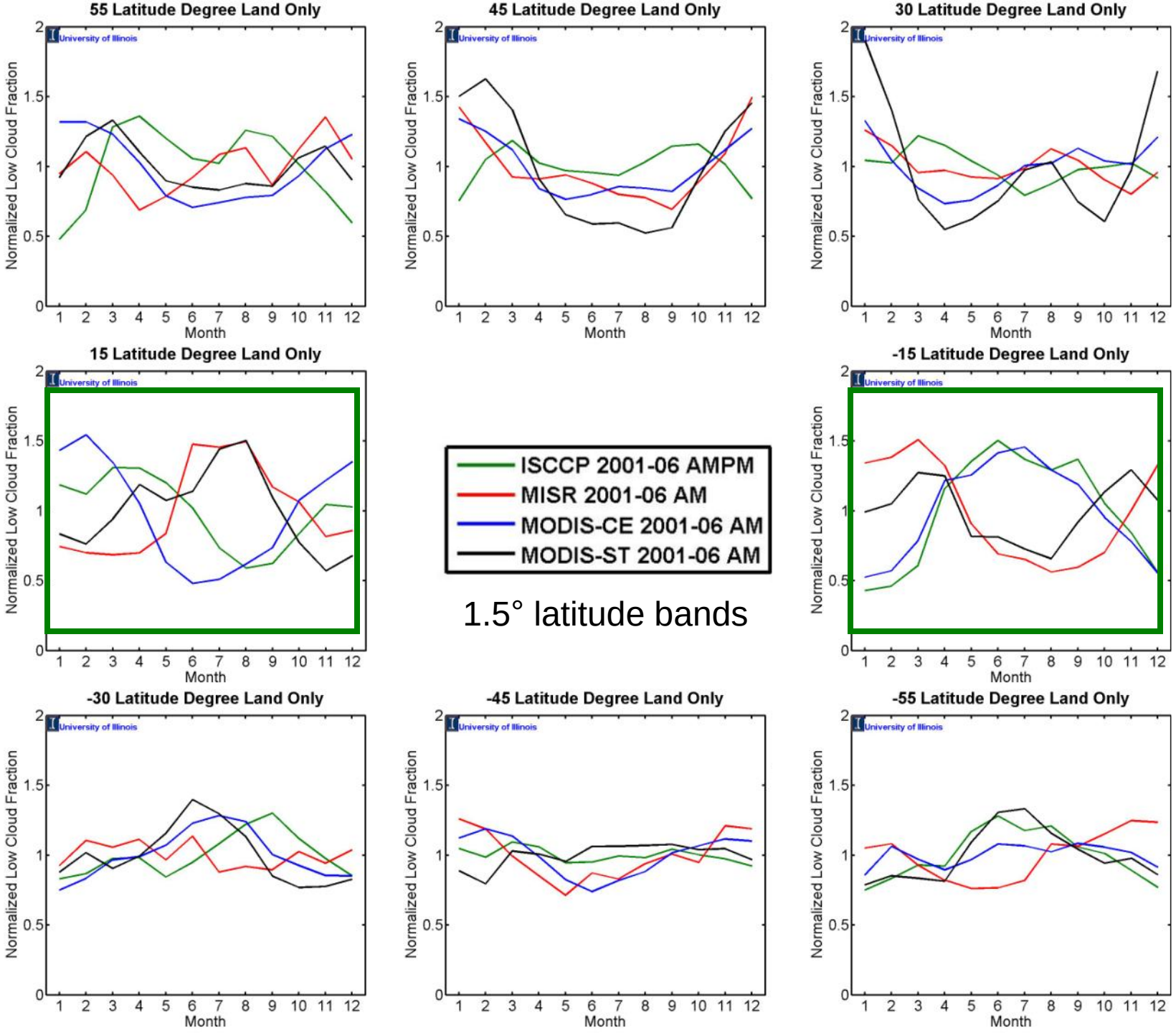
1.5° latitude bands

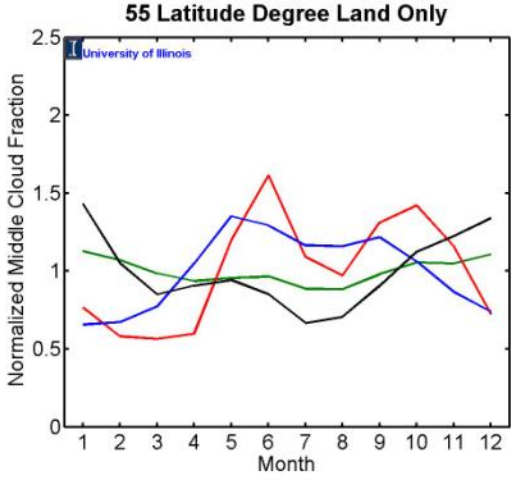


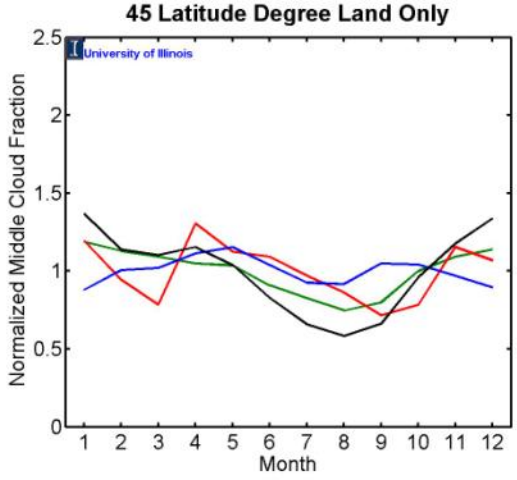


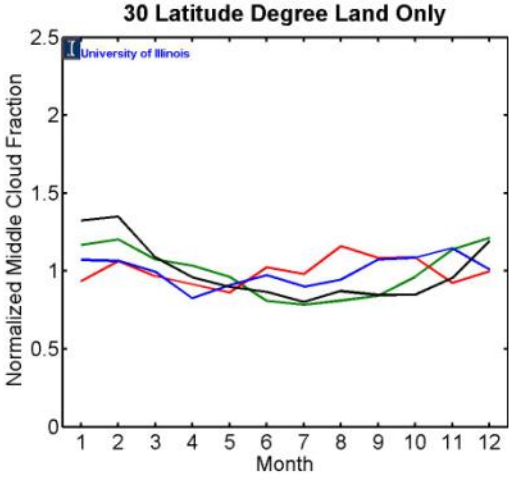


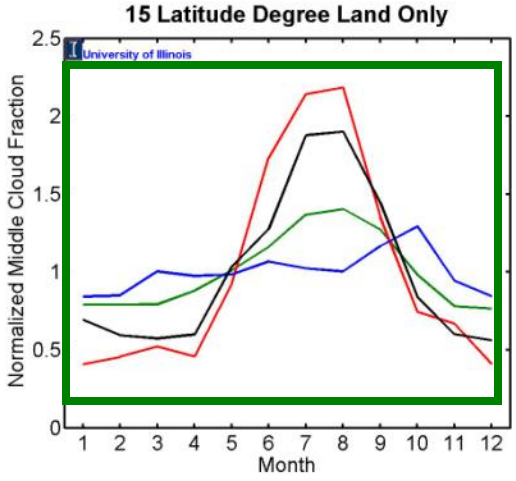


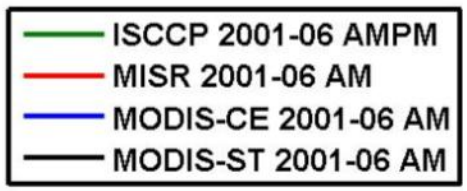

55 Latitude Degree Land Only
45 Latitude Degree Land Only
30 Latitude Degree Land Only
15 Latitude Degree Land Only
-15 Latitude Degree Land Only
-30 Latitude Degree Land Only
-45 Latitude Degree Land Only
-55 Latitude Degree Land Only
University of Illinois
Normalized Low Cloud Fraction
Month
ISCCP 2001-06 AMPM
MISR 2001-06 AM
MODIS-CE 2001-06 AM
MODIS-ST 2001-06 AM
1.5° latitude bands



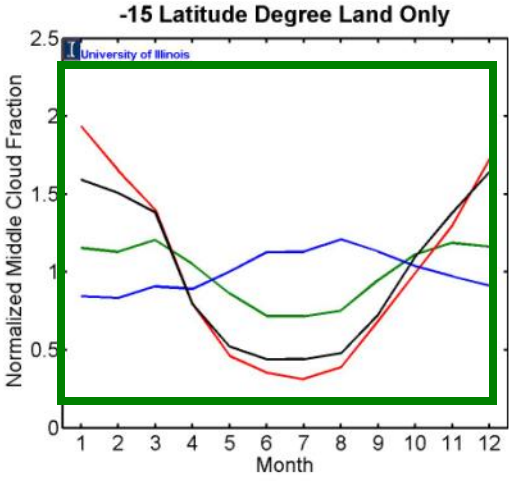


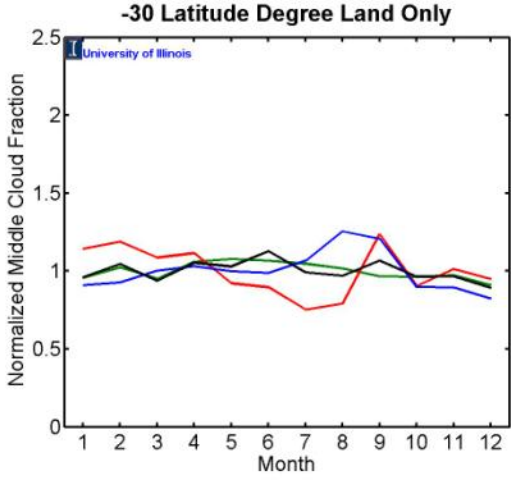


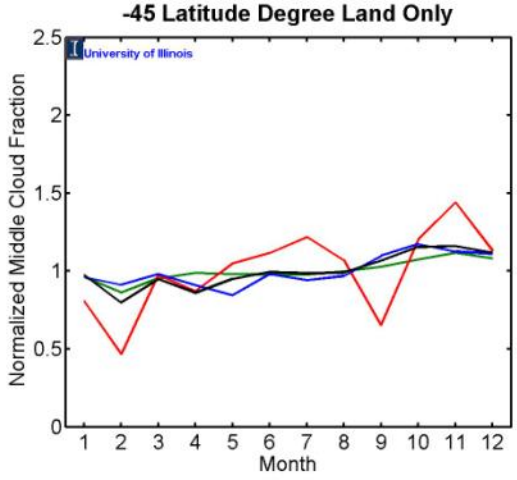


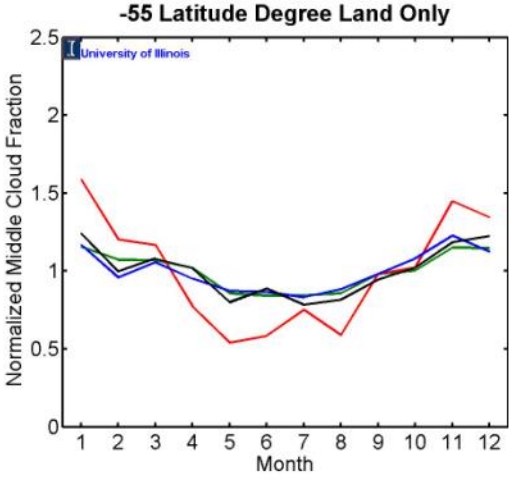


1.5° latitude bands









Summary

- MISR provides 10+ years of CFBA data.
- MISR provides unique and independent cloud detection and heights with well understood error characteristics.
- Be mindful of sampling differences amongst GEWEX CA datasets.
- Low, middle, high CA differences between GEWEX datasets may be more of a Height assignment issue rather than a detection issue.
- Differences between datasets provide complimentary information (e.g., fraction of thin cirrus over lower altitude clouds) and demonstrate potential of multi-instrument retrievals (fusion).
- MISR CFBA improvements in the next version (~18 months):
  - correcting CA for sub-pixel clouds (Jones and Di Girolamo 2010)
  - reducing height uncertainty by half
  - applying a daily snow/ice mask