Cloud detection from Satellites: What I learned from Bill Rossow

Steve Ackerman

Rossow Symposium June 6-8 2017

Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin - Madison

Outline

- The 1980's
- The 1990's
- The 2000's
- Looking forward

Cloud detection and an algorithm that generates a publicly available product.

Radiative Energy Budget Estimates for the 1979 Summer Monsoon – Ackerman and Cox JAS 1987

The region of study and surface type.

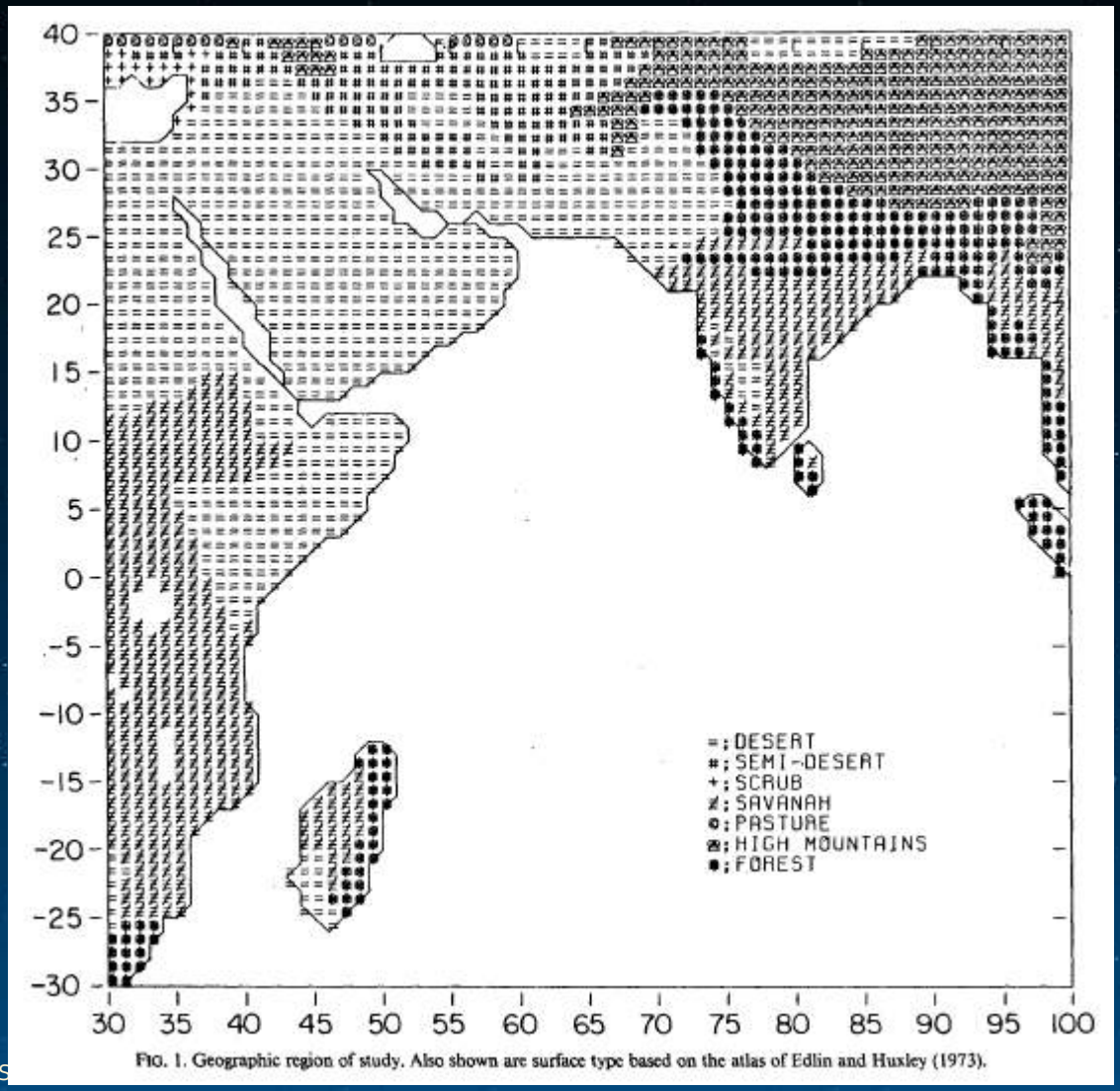


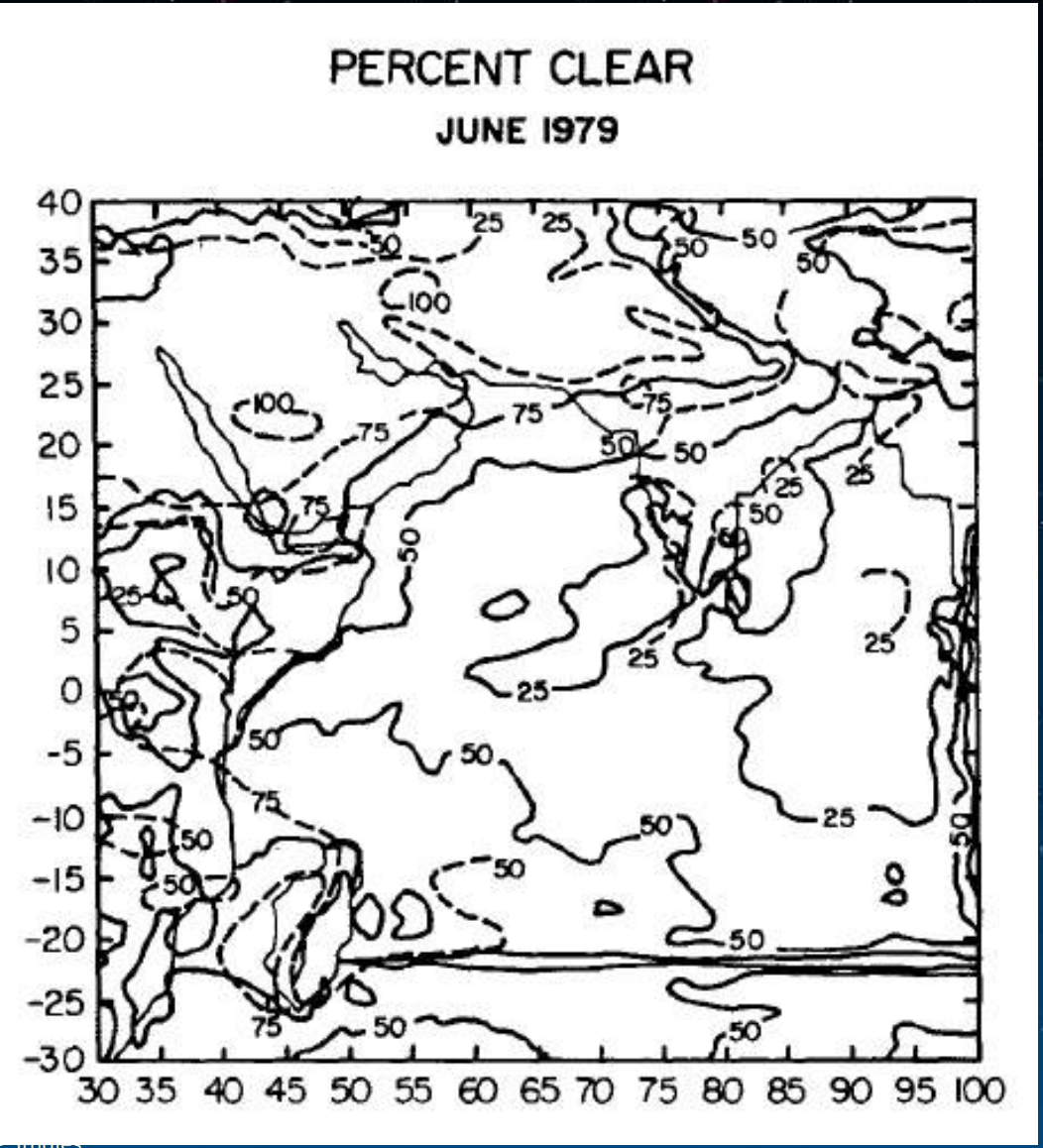
FIG. 1. Geographic region of study. Also shown are surface type based on the atlas of Edlin and Huxley (1973).

Percent Clear June 1979

Determined from GOES-1 Visible – IR bispectral thresholding

(similar to ISCCP)

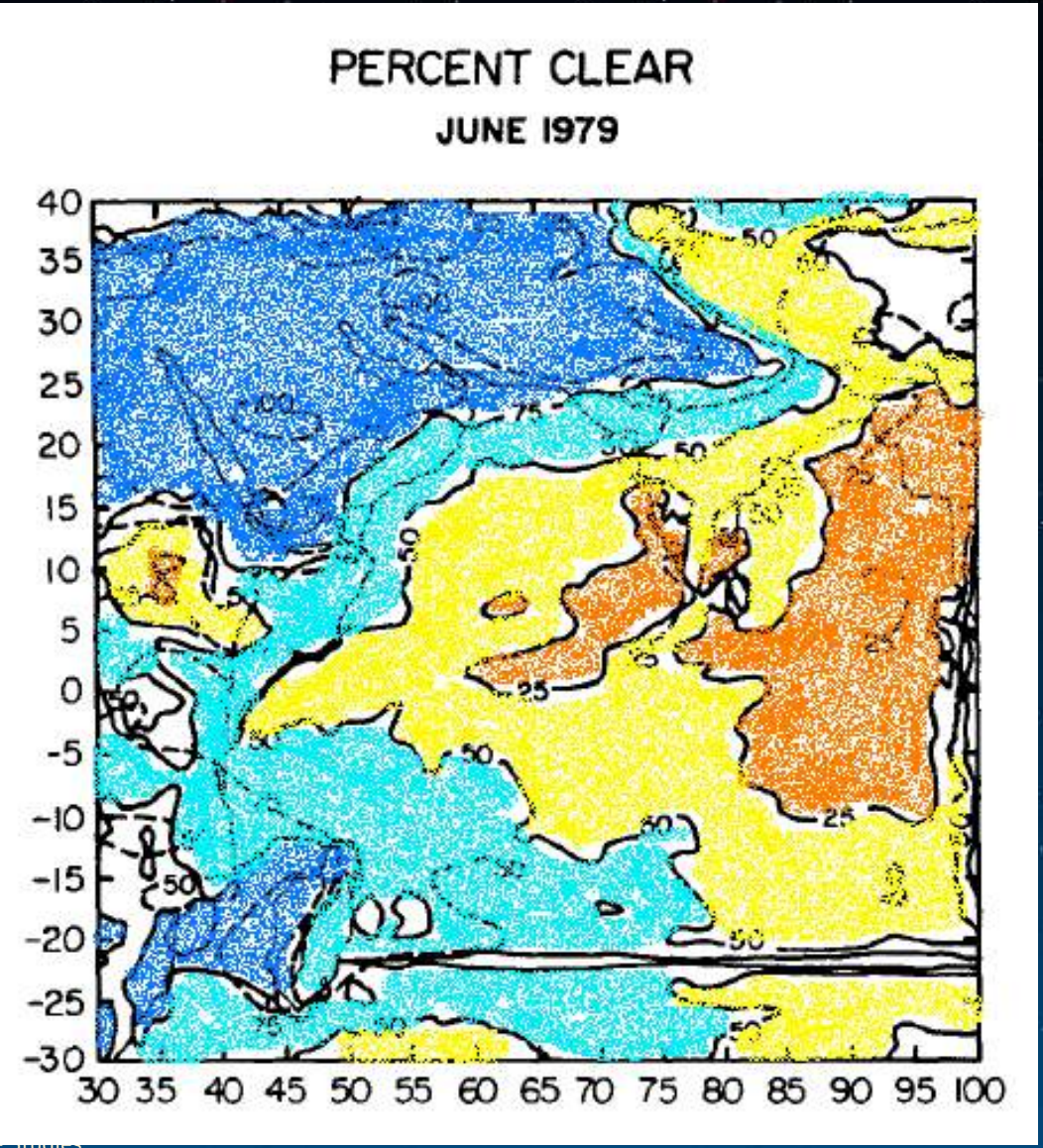
(TIROS-N as well)



Percent Clear June 1979

Determined from GOES-1… color coded….

Visible and IR bi-spectral yes/no decision



Mid 1990s – MODIS cloud mask

Used up to 20 spectral tests which was a function of scene type and some variability

Rather than yes/no decision – yes, probably, uncertain, no

Global application

Finer spatial resolution

What is a cloud?

I know one when I see one…

Our philosophy

Our approach to the MODIS Cloud Mask, is for each pixel to provide a confidence flag that indicates how certain we are that the pixel is clear.

Restrictions

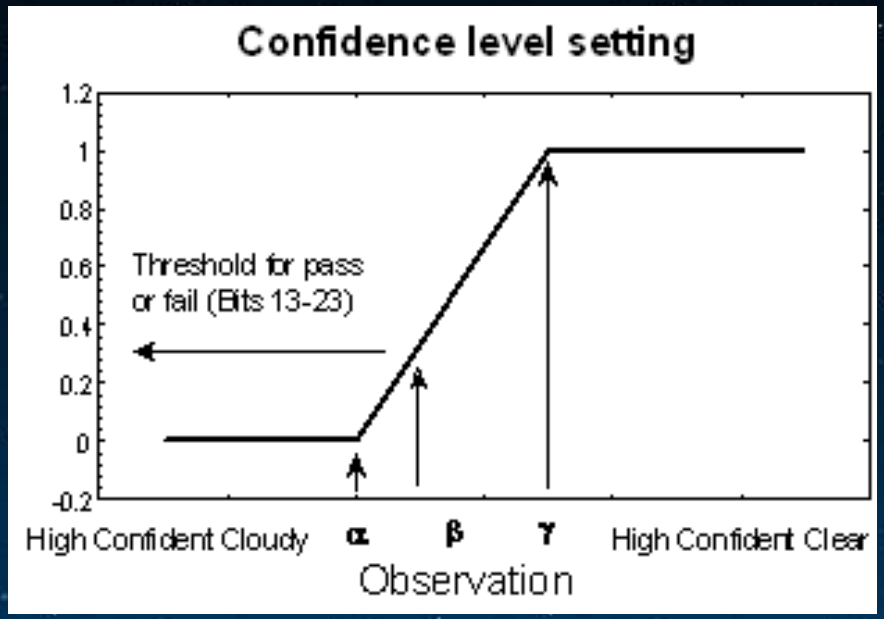
Real time execution

Computer storage (4.8 g bytes per day)

Comprehension

Restrictions in the 1990s

Cloud detection Threshold approach



- Each test returns a confidence (F) ranging from 0 to 1.
- Similar tests are grouped and minimum confidence selected [min (F_i)]
- Quality Flag is

$$Q = \sqrt[N]{\prod_{i=1}^{N} \min(F_i)}$$

- Four values; , >.66, >.95 and >.99

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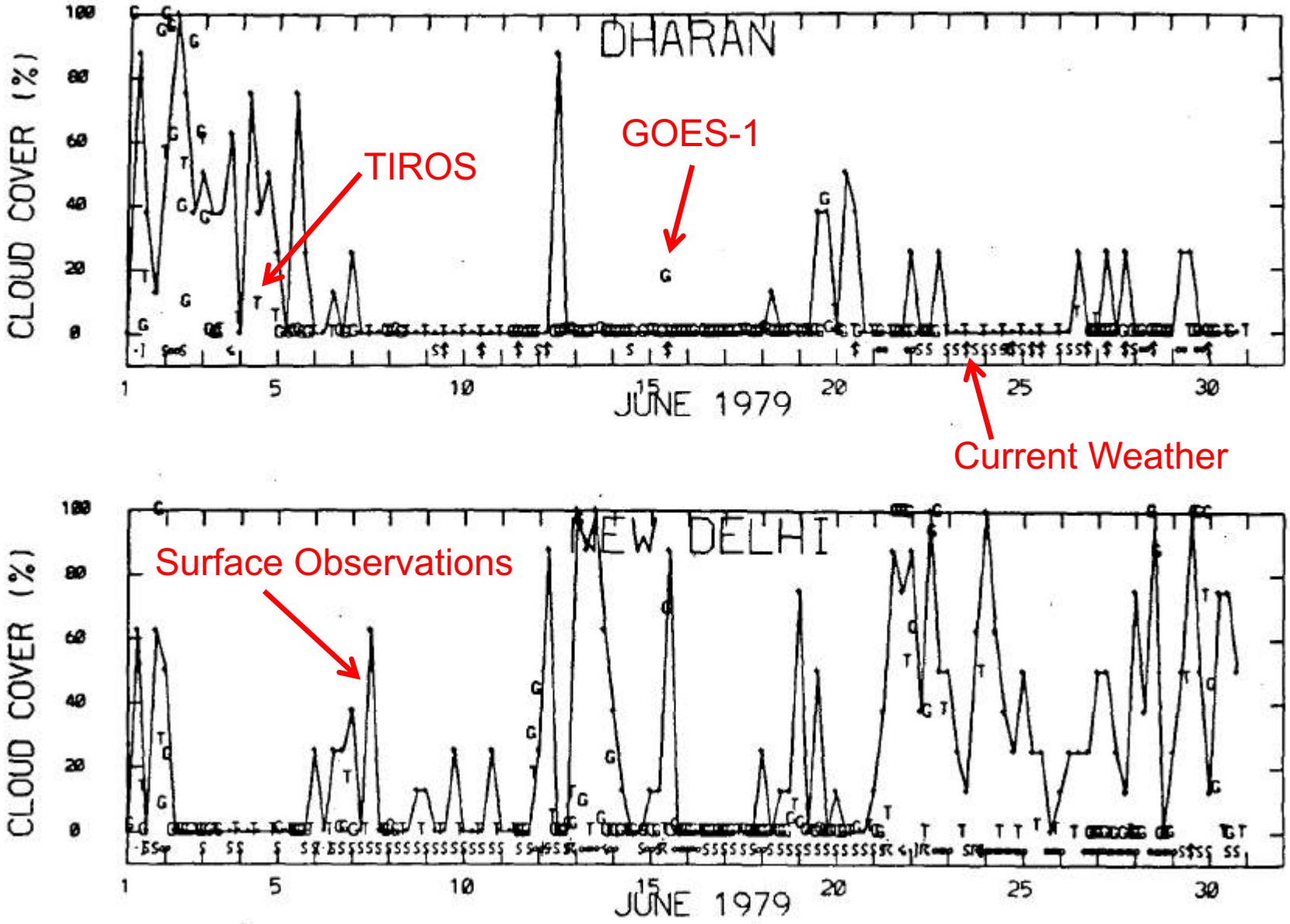
The 48 bit cloud mask

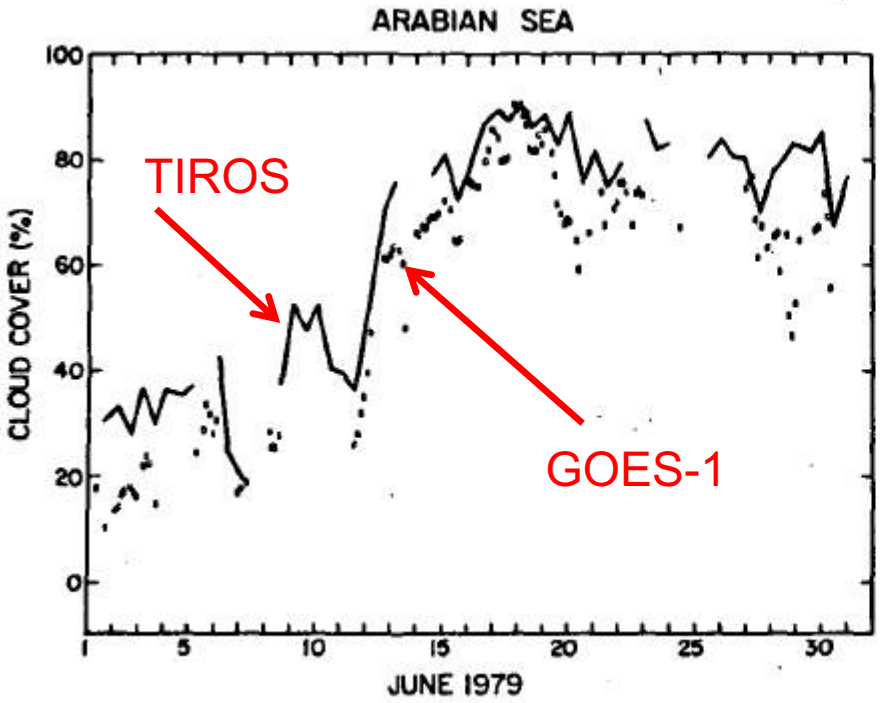
BIT FIELD	DESCRIPTION KEY	RESULT
0	Cloud Mask Flag	0 = not determined 1 = determined
1-2	Unobstructed FOV Confidence Flag	00 = cloudy 01 = probably cloudy 10 = probably clear 11 = confident clear
	smoke, other thick non-dust aerosol	
9	Thin Cirrus Detected (solar)	0 = Yes / 1 = No
10	Snow cover from ancillary map	0 = Yes / 1 = No
11	Thin Cirrus Detected (infrared)	0 = Yes / 1 = No
12	Cloud Adjacency (cloudy, prob. cloudy, plus 1-pixel adjacent)	0 = Yes / 1 = No
13	Cloud Flag – Ocean IR Threshold Test	0 = Yes / 1 = No
14	High Cloud Flag - CO_2 Threshold Test	0 = Yes / 1 = No
15	High Cloud Flag – 6.7 μm Test	0 = Yes / 1 = No
16	High Cloud Flag – 1.38 μm Test	0 = Yes / 1 = No
17	High Cloud Flag – 3.9-12 μm Test (night only)	0 = Yes / 1 = No
18	Cloud Flag - IR Temperature Difference Tests	0 = Yes / 1 = No
19	Cloud Flag - 3.9-11 μm Test	0 = Yes / 1 = No
20	Cloud Flag – Visible Reflectance	0 = Yes / 1 = No
28	Suspended Dust Flag	0 = Yes / 1 = No
29	Cloud Flag - Night Ocean 8.6 – 7.3 μm Test	0 = Yes / 1 = No
30	Cloud Flag – Night Ocean 11 μm Variability Test	0 = Yes / 1 = No
31	Cloud Flag – Night Ocean "Low-Emissivity" 3.9-11 μm Test	0 = Yes / 1 = No
	250-m CLOUD FLAG	
32	Element(1,1)	0 = Yes / 1 = No
33	Element(1,2)	0 = Yes / 1 = No
34	Element(1,3)	0 = Yes / 1 = No
35	Element(1,4)	0 = Yes / 1 = No
36	Element(2,1)	0 = Yes / 1 = No
37	Element(2,2)	0 = Yes / 1 = No
38	Element(2,3)	0 = Yes / 1 = No
39	Element(2,4)	0 = Yes / 1 = No
40	Element(3,1)	0 = Yes / 1 = No
41	Element(3,2)	0 = Yes / 1 = No
42	Element(3,3)	0 = Yes / 1 = No
43	Element(3,4)	0 = Yes / 1 = No
44	Element(4,1)	0 = Yes / 1 = No
45	Element(4,2)	0 = Yes / 1 = No
46	Element(4,3)	0 = Yes / 1 = No

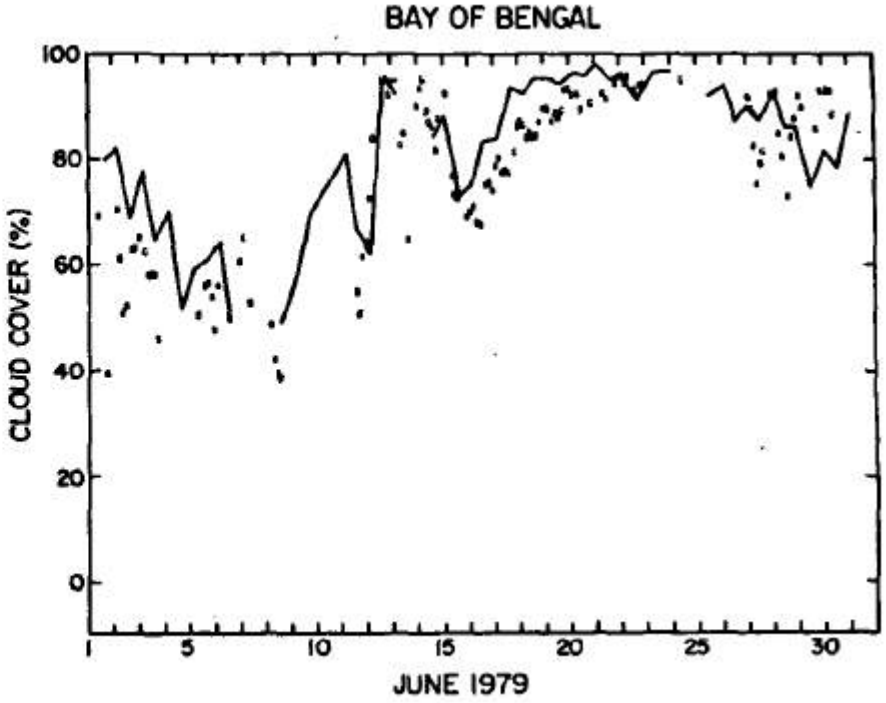
The issue of Validation

1980s: Compare with surface observations of cloud cover.


DHARAN
CLOUD COVER (%)
TIROS
GOES-1
Current Weather
JUNE 1979
NEW DELHI
Surface Observations
CLOUD COVER (%)
JUNE 1979

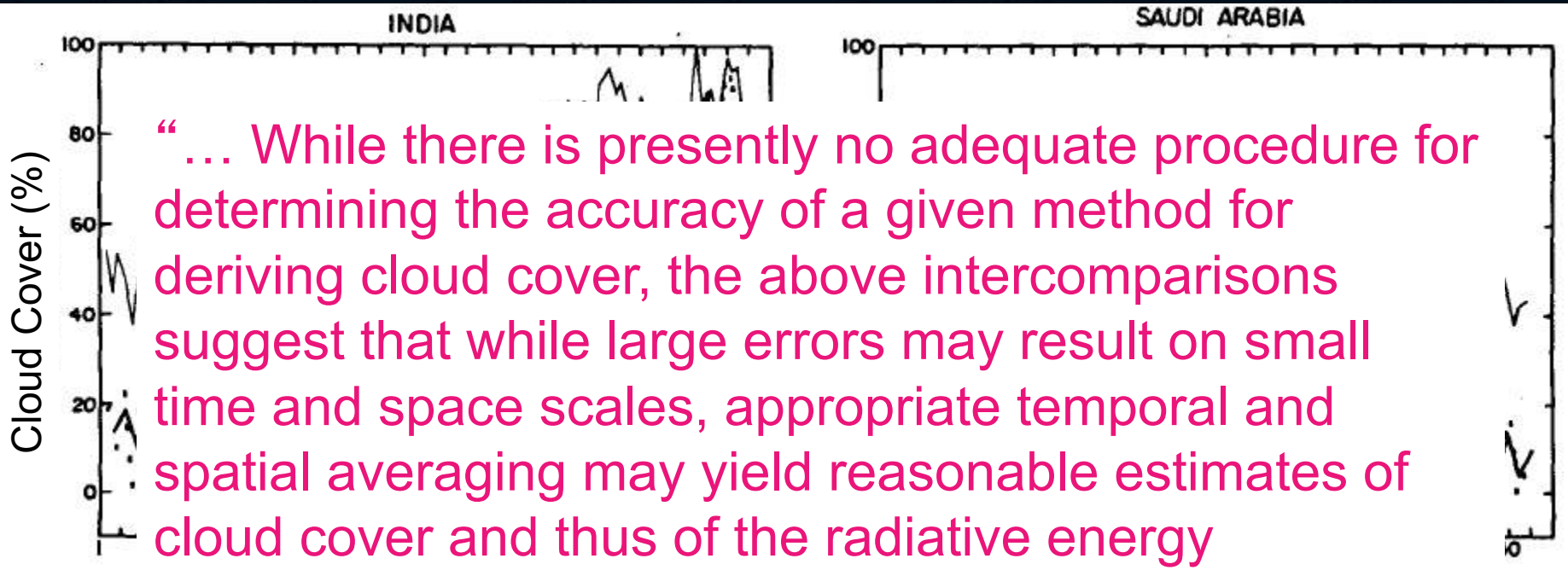
Compare two satellite products





"… point out the excellent agreement between the two satellite-retrieved cloud cover estimates…"

Compare with Ground Observations



"… While there is presently no adequate procedure for determining the accuracy of a given method for deriving cloud cover, the above intercomparisons suggest that while large errors may result on small time and space scales, appropriate temporal and spatial averaging may yield reasonable estimates of cloud cover and thus of the radiative energy budgets…."

The issue of Validation (1990s)

- Compare with surface observations of cloud cover (active and passive).
- Compare with aircraft observations using simulators.
- Compare with satellite observations of cloud cover (active and passive).

The issue of Validation (the 21st Century)

Compare with visual observations, lidar ground based observations, CALIOP, CloudSat, other satellites.

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Comparison to ground-based radar/lidar combined observations

	ARCL clear	**ARCL cloudy**
MODIS clear	Terra: 146 Aqua: 117	Terra: 45 Aqua: 58
MODIS cloudy	Terra: 38 Aqua: 12	Terra: 298 Aqua: 185

MODIS and radar/lidar detection agree 85% of the time.

Time period 2003 through 2005 – three years

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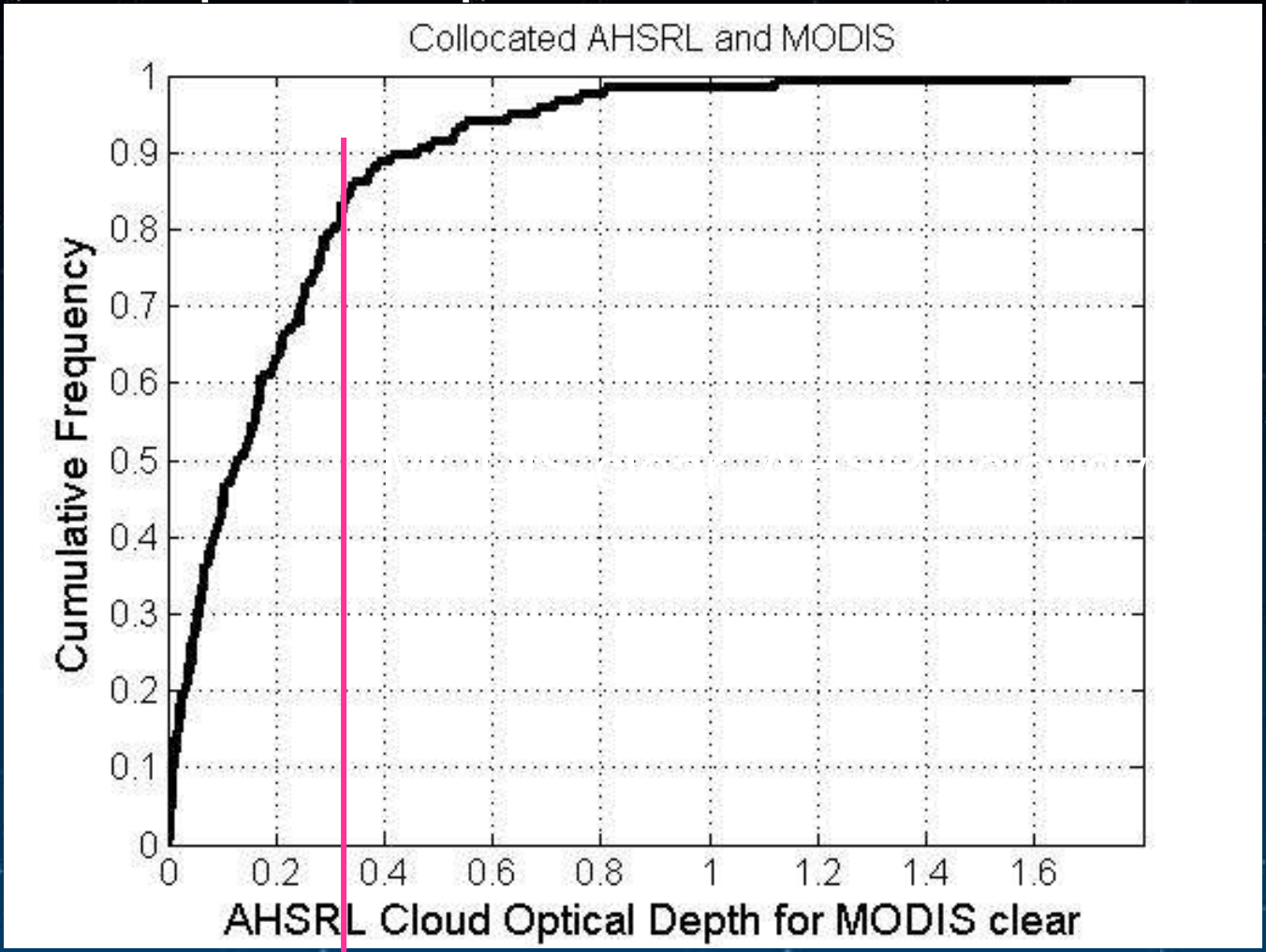
MODIS optical depth threshold: over Wisconsin



Ackerman et al 2008

MODIS optical depth threshold ~ 0.3

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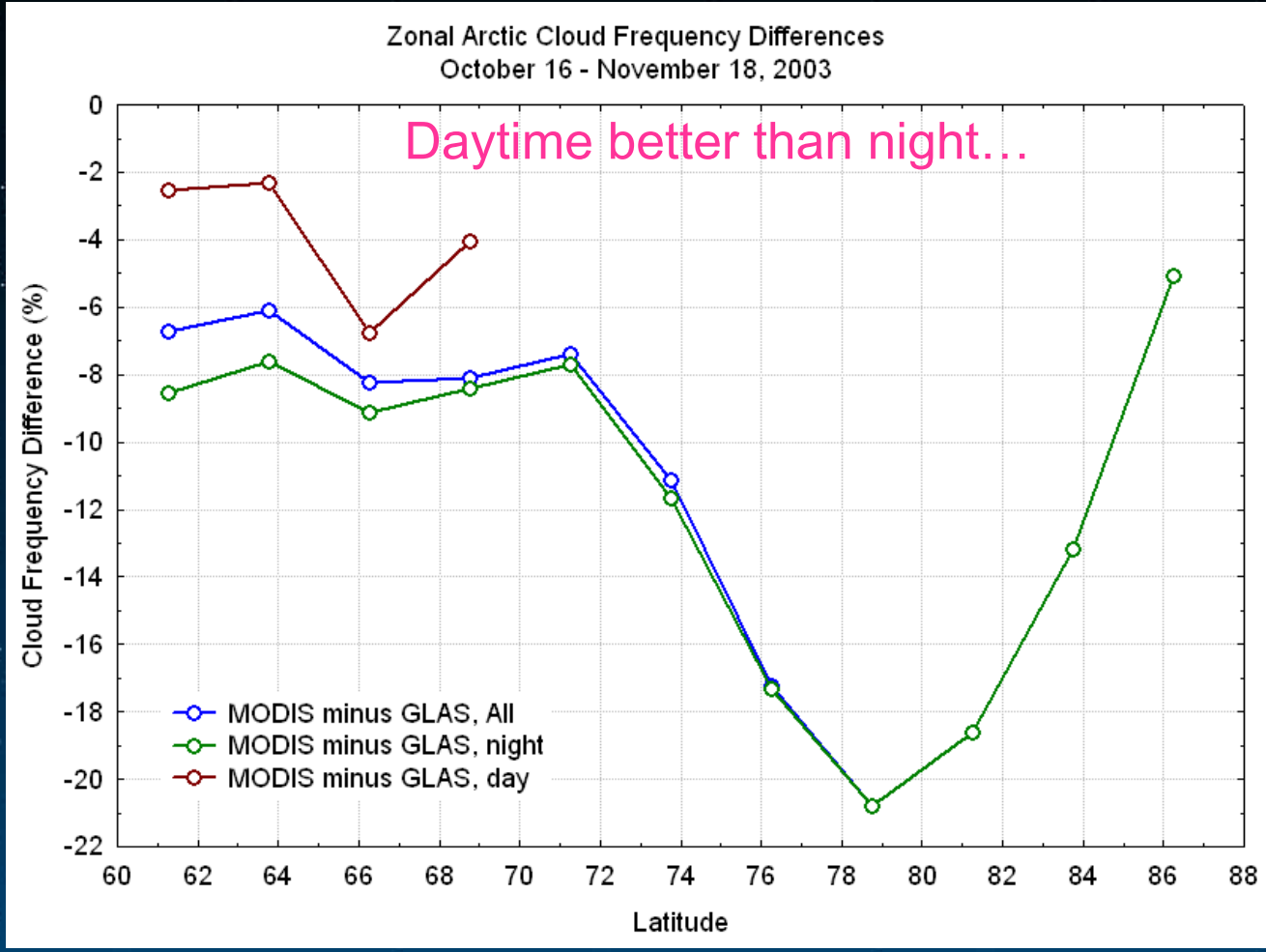
What is a cloud?

- MODIS is sensitive to OD ~0.3

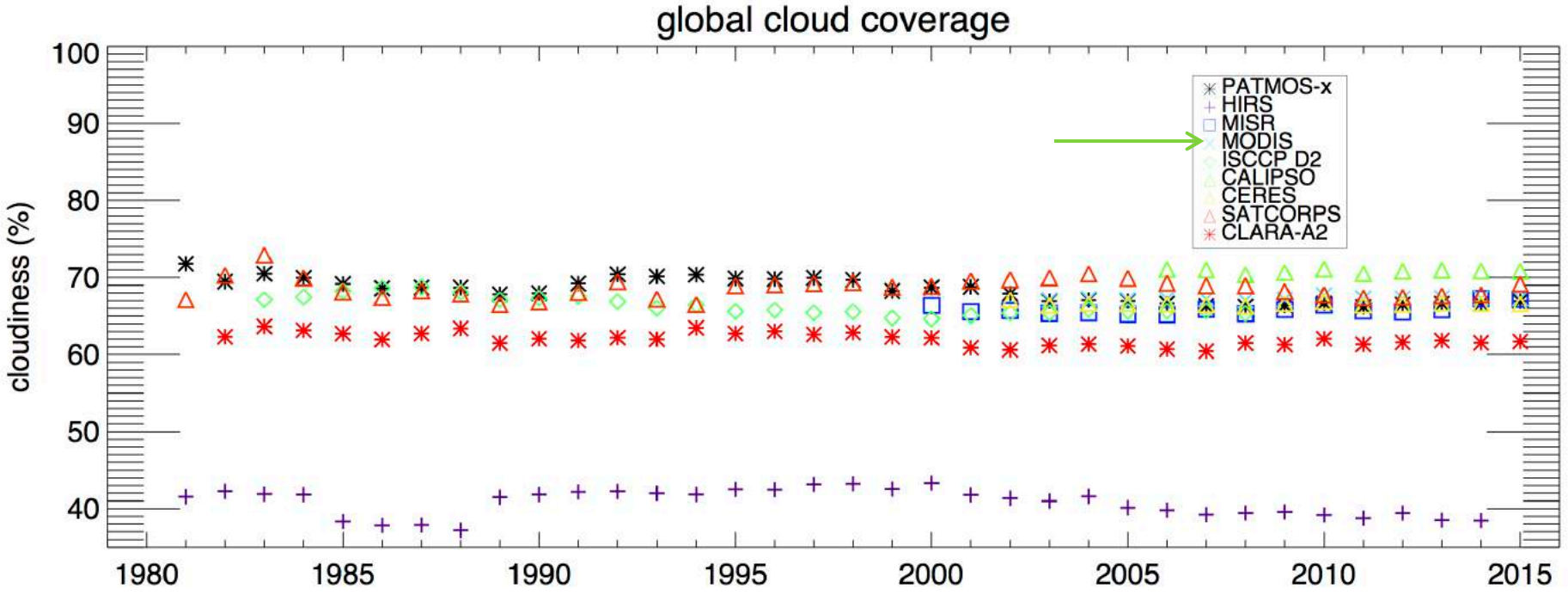
Comparison with GLAS

Difference, MODIS minus GLAS cloud amount

Frey et al 2008



Global Cloud Time Series



After Foster et al, 2016

Comparison with collocated CALIOP

excellent agreement is 87% - 91% agreement in clear and cloud cases with lidar – worse situation is polar during night

	August 2006 Clear	August 2006 Cloudy	February 2007 Clear	February 2007 Cloudy
Global CALIOP 1-km (5-km)	0.85 (0.75)	0.87 (0.85)	0.86 (0.77)	0.87 (0.84)
Non-Polar Ocean CALIOP 1-km (5-km)	0.87 (0.83)	0.92 (0.86)	0.88 (0.79)	0.92 (0.86)
Non-Polar land CALIOP 1-km (5-km)	0.90 (0.86)	0.85 (0.78)	0.82 (0.74)	0.85 (0.81)
Northern Mid Latitude CALIOP 1-km (5-km)	0.89 (0.82)	0.88 (0.85)	0.78 (0.68)	0.91 (0.89)
Tropics CALIOP 1-km (5-km)	0.88 (0.84)	0.90 (0.83)	0.89 (0.86)	0.87 (0.80)
Southern Mid Latitude CALIOP 1-km (5-km)	0.87 (0.81)	0.94(0.92)	0.88 (0.81)	0.93 (0.90)
Arctic > 60 deg Latitude	0.74 (0.62)	0.91 (0.92)	0.83 (0.66)	0.72 (0.76)
Antarctic < -60 Latitude	0.79(0.57)	0.71 (0.75)	0.92 (0.87)	0.88 (0.86)
Northern Mid Latitude Day/Night CALIOP 1-km	0.91 / 0.87	0.88 / 0.88	0.77 / 0.80	0.92 / 0.89
Tropics Day/Night CALIOP 1-km	0.89 / 0.86	0.89 / 0.90	0.90 / 0.86	0.86 / 0.87
Southern Mid Latitude Day/Night CALIOP 1-km	0.91/ 0.84	0.93 / 0.94	0.91 / 0.86	0.93 / 0.94

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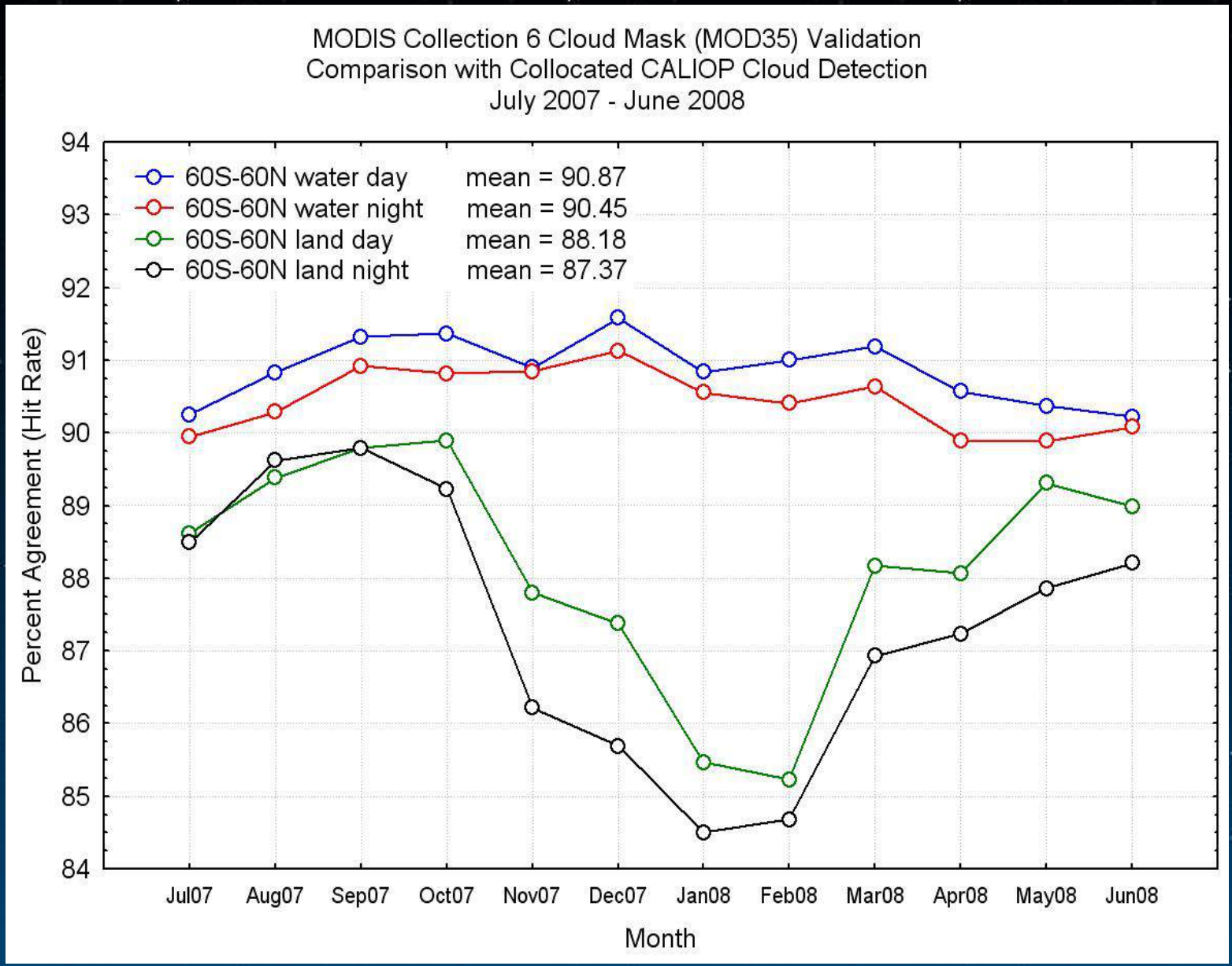

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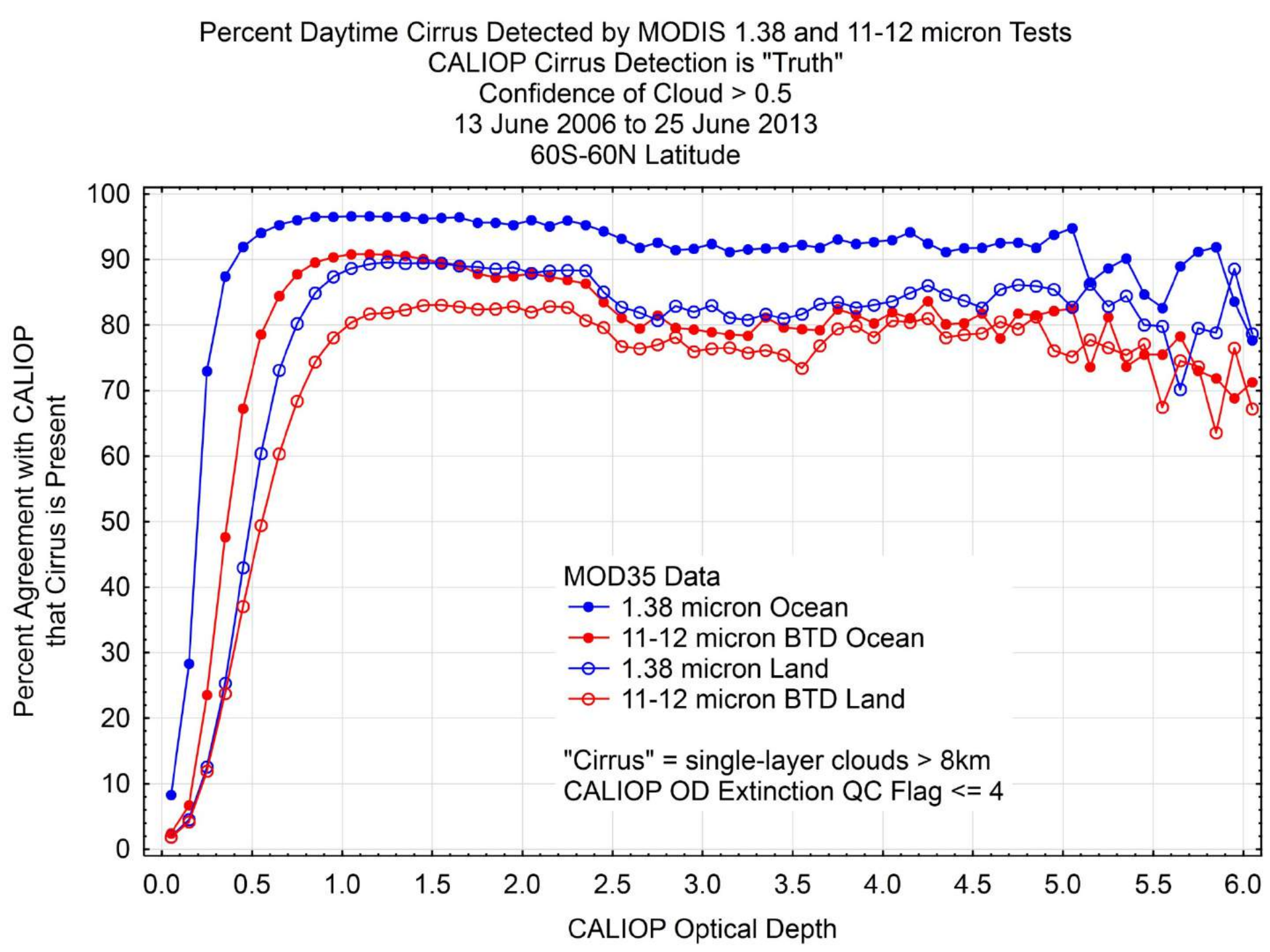

Percent Daytime Cirrus Detected by MODIS 1.38 and 11-12 micron Tests
CALIOP Cirrus Detection is "Truth"
Confidence of Cloud > 0.5
13 June 2006 to 25 June 2013
60S-60N Latitude
Percent Agreement with CALIOP that Cirrus is Present
100
90
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
CALIOP Optical Depth
MOD35 Data
1.38 micron Ocean
11-12 micron BTD Ocean
1.38 micron Land
11-12 micron BTD Land
"Cirrus" = single-layer clouds > 8km
CALIOP OD Extinction QC Flag <= 4

What is a cloud?

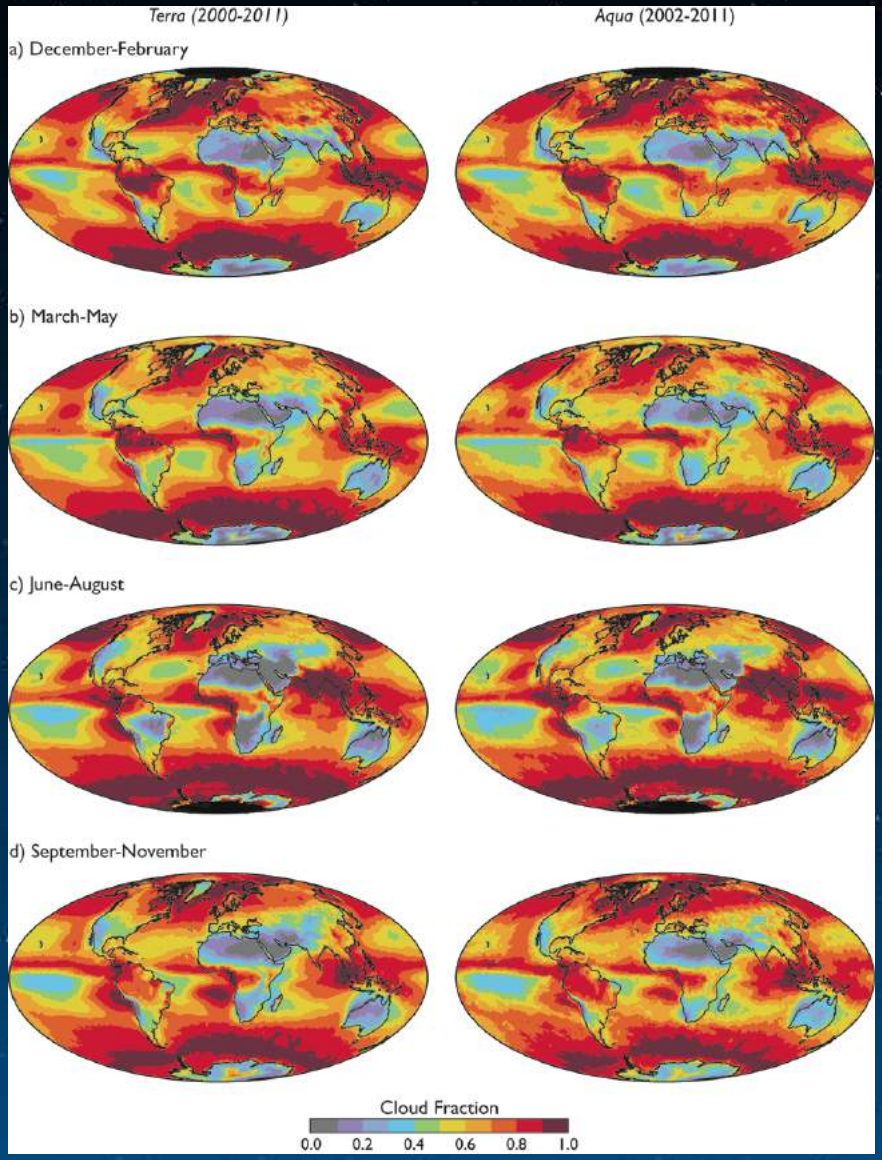
Depends on detection objective….

Applications…

Global Cloud Cover

Global Cloud cover from the two MODIS instruments.

King et al 2013



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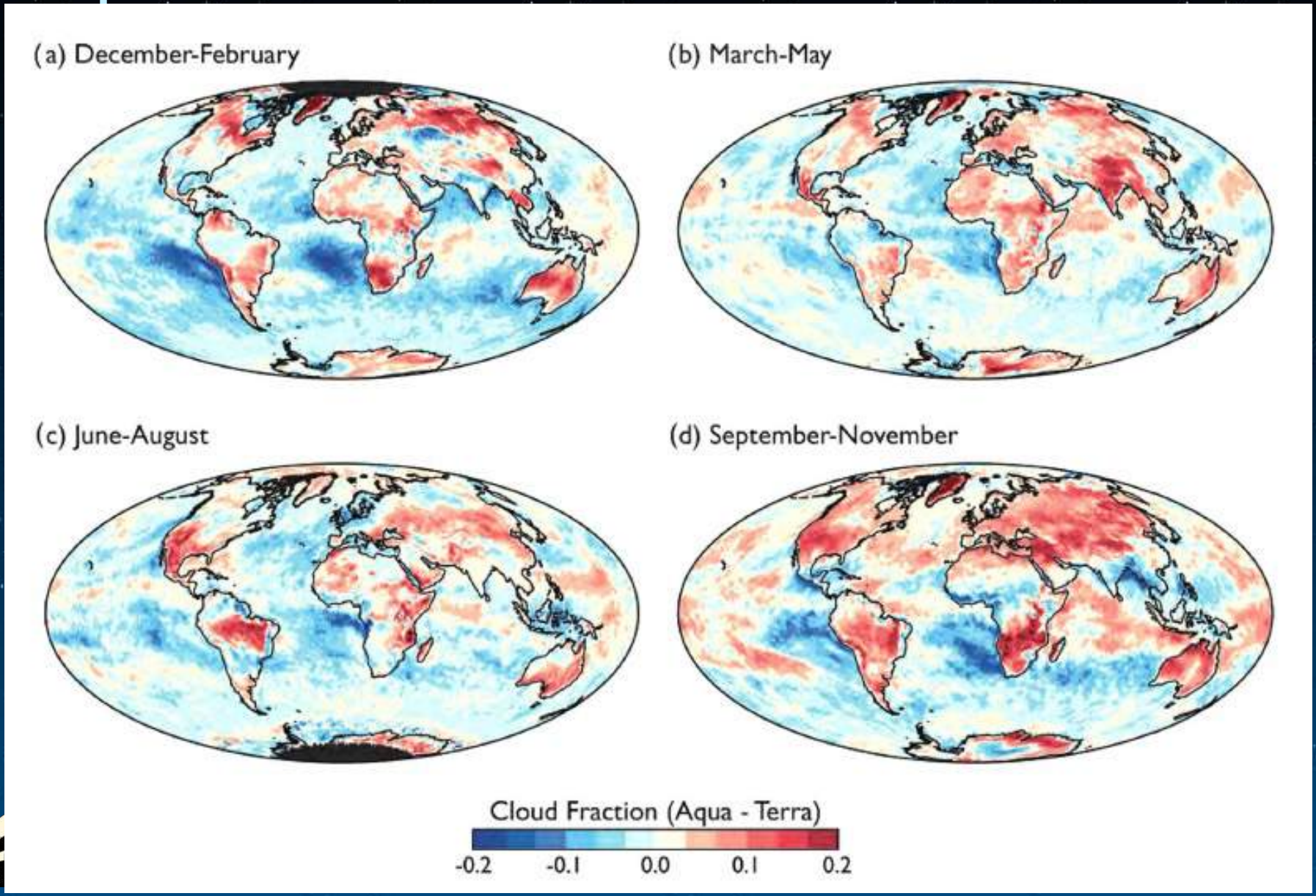
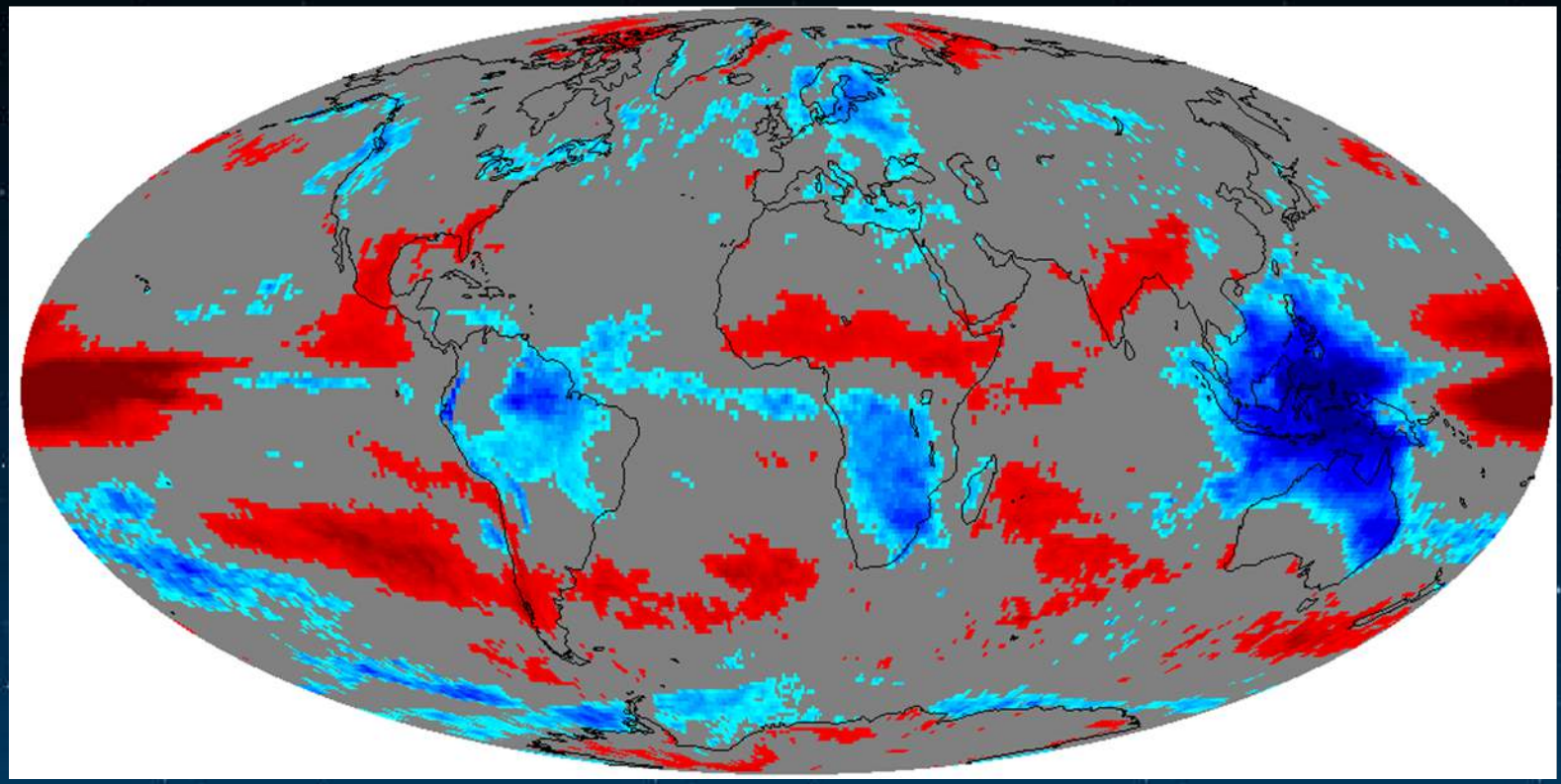
Aqua – Terra cloud fraction…



Correlations with indices (ENSO)

Correlation of ENSO and Cloud Fraction



Correlation is significant >± .15 for a p-value of .05

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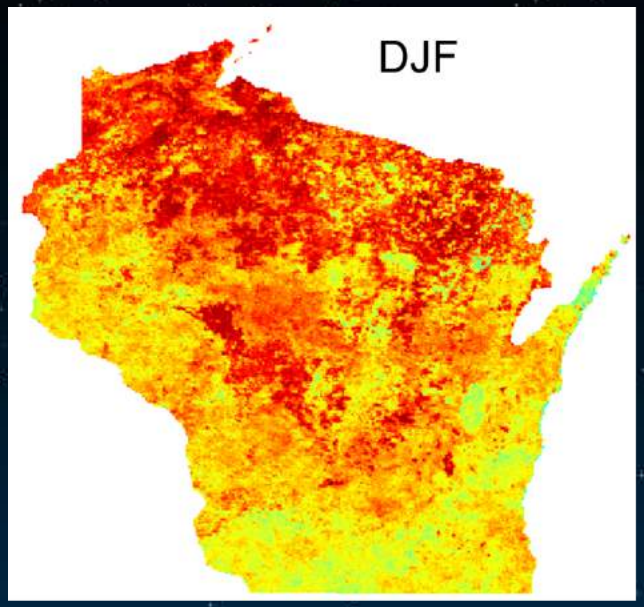
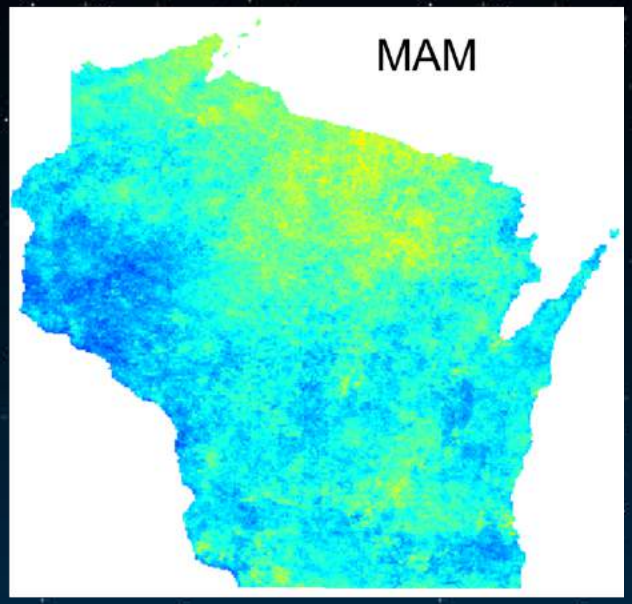
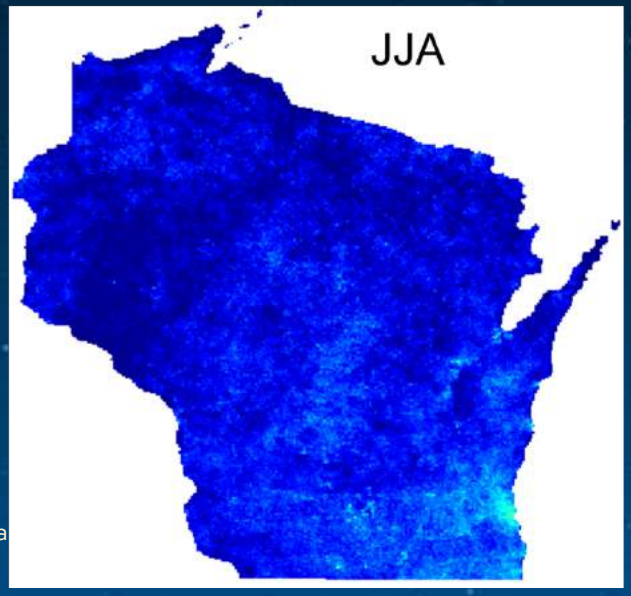
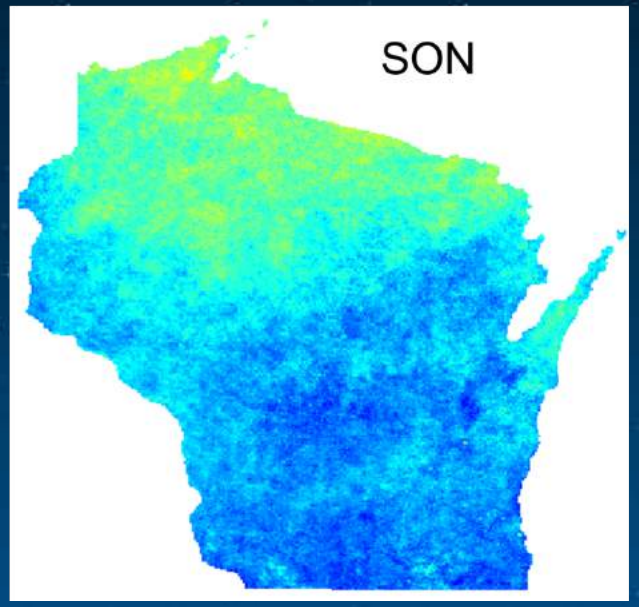
Regional Scale Analysis

The seasonal mean cloud amount at high spatial resolution enable regional studies.









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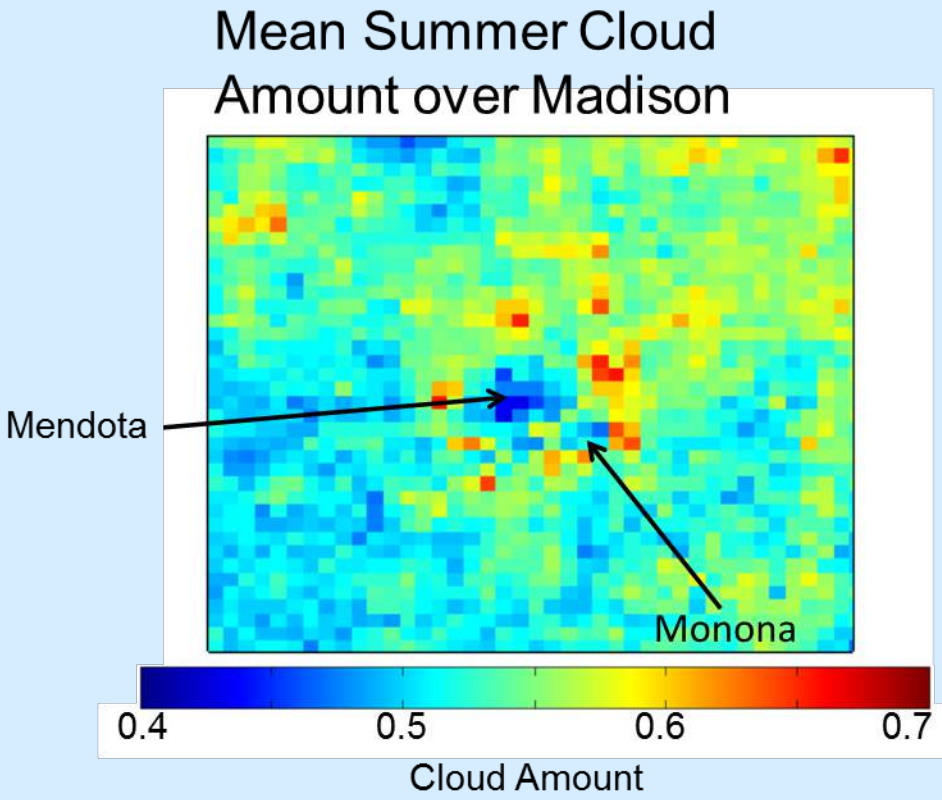
Regional Satellite Climate Studies



Extremely high resolution data shows the suppression of clouds over the lakes during the summer in Madison. The increase in summer cloud cover over other developed areas is also evident in the MODIS data record

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Going forward: MODIS & VIIRS

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Continuity

"..high-quality data set requires measurements made by well-characterized, calibrated, and stable instruments, validated algorithms, and consistent auxiliary data."

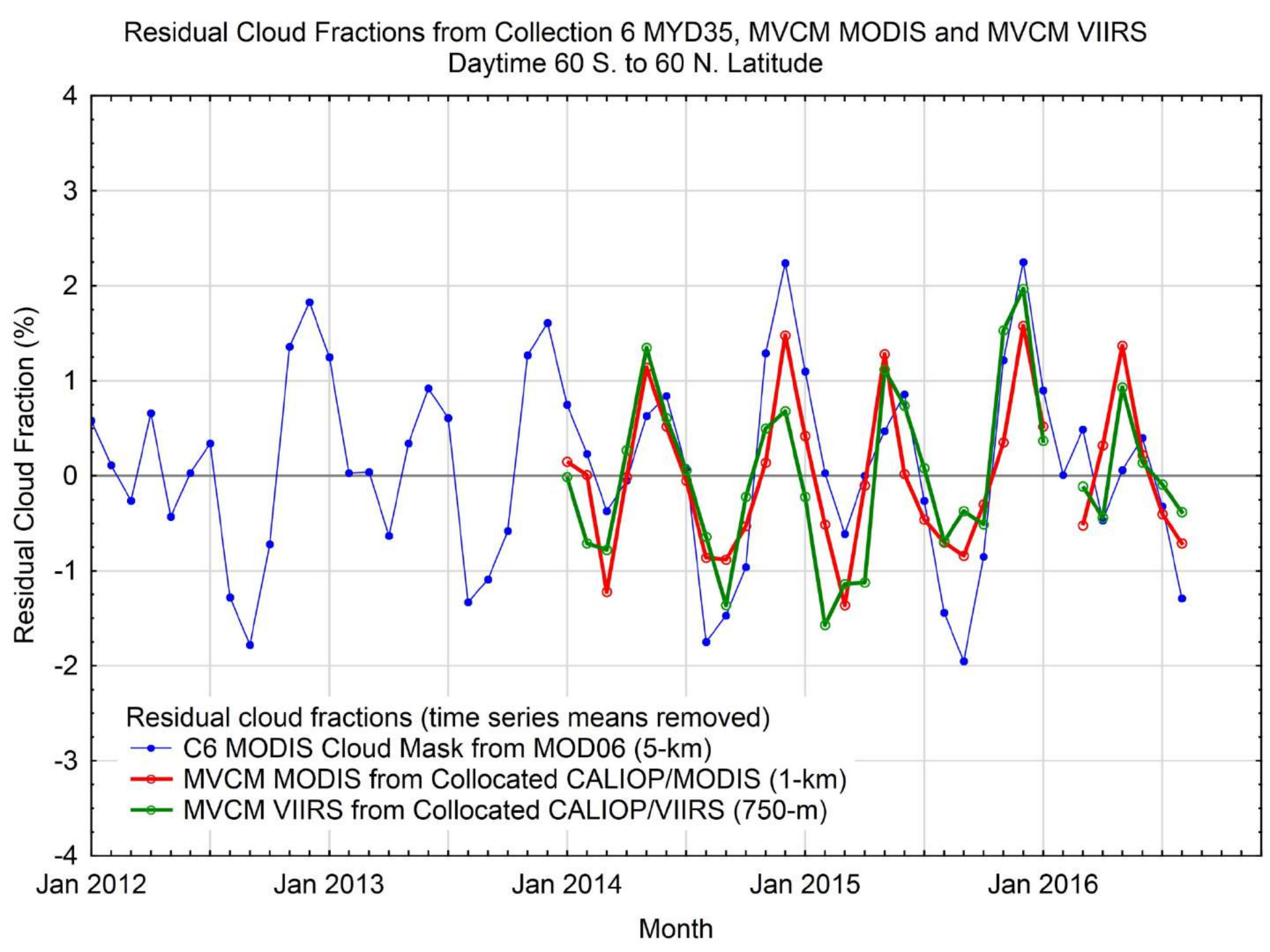
Continuity of NASA Earth Observations from Space: A Value Framework (A National Academy Study)

Instruments

Make continuous climate records from MODIS (2000-20xx) and VIIRS (2012-2030), using same algorithm and similar channels.

- MYD35: Cloud mask for MODIS Terra and Aqua (also from MYD06)
- MVCM-MODIS: Common cloud mask applied to MODIS observations
- MVCM-VIIRS: Common cloud mask applied to VIIRS observations

Common algorithm run and comparison of results made with collocated CALIOP observations


Residual Cloud Fractions from Collection 6 MYD35, MVCM MODIS and MVCM VIIRS
Daytime 60 S. to 60 N. Latitude
Residual Cloud Fraction (%)
4
3
2
1
0
-1
-2
-3
-4
Jan 2012
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Month
Residual cloud fractions (time series means removed)
C6 MODIS Cloud Mask from MOD06 (5-km)
MVCM MODIS from Collocated CALIOP/MODIS (1-km)
MVCM VIIRS from Collocated CALIOP/VIIRS (750-m)

January 2013	MYD35 vs. CALIOP				MVCM Aqua vs. CALIOP				MVCM NPP vs. CALIOP (5 minute filter)			
Scene Type	HR Cloud	HR Clear	HR Comb	H-K SS	HR Cloud	HR Clear	HR Comb	H-K SS	HR Cloud	HR Clear	HR Comb	H-K SS
Global	87.8	87.8	87.8	75.6	86.9	85.9	86.5	72.7	87.4	82.5	85.8	69.9
60N-60S	92.0	85.1	89.9	77.1	91.5	84.6	89.4	76.1	91.4	82.1	88.4	73.5
Global Day	91.1	88.7	90.3	79.8	91.4	87.1	89.9	78.5	89.8	85.3	88.2	75.1
60S-60N Day	92.6	86.4	90.5	79.8	93.2	84.8	90.3	78.0	92.8	82.4	89.2	75.2
Global Night	84.8	86.8	85.4	71.6	82.7	84.5	83.3	67.2	85.3	79.4	83.4	64.7
Water Nt	87.6	86.3	87.2	73.9	87.4	86.4	87.1	73.8	88.1	81.6	86.4	69.7
60S-60N Water Nt	93.2	82.8	90.8	76.0	92.9	84.0	90.8	76.9	91.4	81.7	89.1	73.1
Global Land	79.5	88.8	83.7	68.2	74.0	87.9	80.4	61.9	77.0	83.5	79.8	60.5
Global Land Day	81.9	89.6	85.7	71.5	78.8	92.4	85.5	71.2	76.8	89.4	82.6	66.2
60S-60N Land Day	87.9	83.1	85.8	71.0	83.8	89.3	86.2	73.1	85.7	81.5	84.0	67.2
Global Land Nt	77.1	87.6	81.4	64.7	69.2	81.7	74.4	50.9	77.3	76.0	76.8	53.4
60S-60N Land Nt	85.6	84.2	85.1	69.8	79.8	84.9	81.8	64.7	85.9	81.9	84.3	67.8
Polar	77.1	92.6	83.2	69.6	75.1	88.1	80.2	63.2	78.3	83.1	80.0	61.4
Polar Day	86.7	93.8	89.5	80.5	86.4	92.1	88.7	78.5	82.5	92.0	86.0	74.5
Polar Nt	69.2	91.6	78.0	60.8	65.8	84.8	73.3	50.6	74.8	75.9	75.2	50.7
Arctic Nt	63.2	92.3	75.9	55.5	58.0	89.4	71.7	47.4	67.7	82.8	73.9	50.5
Antarctic Day	86.2	94.9	89.7	81.1	87.3	92.3	89.3	79.5	83.3	94.3	87.3	77.7
Desert Day	81.7	86.8	84.5	68.5	79.7	88.4	84.8	68.1	82.4	84.8	83.7	67.2
Desert Nt	78.4	86.3	82.5	64.5	73.4	85.4	79.8	58.9	81.1	84.9	83.1	66.0

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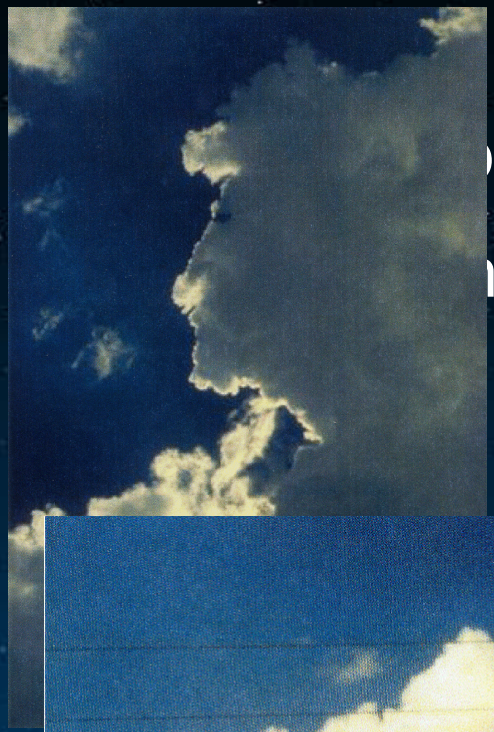
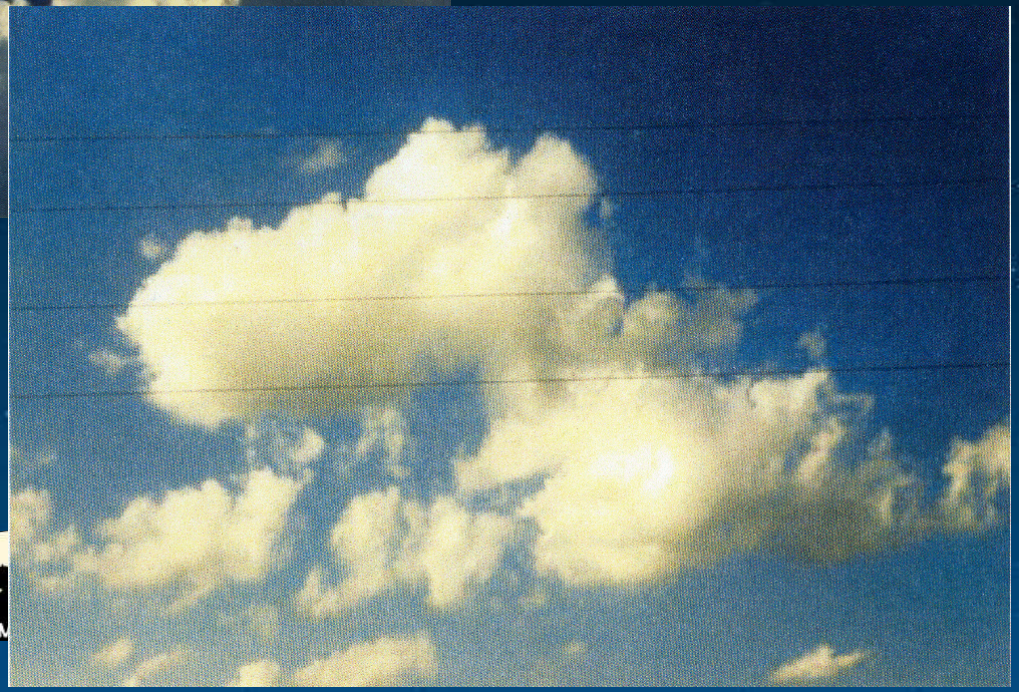
Summary – What I learne



ost everything..

hanks and congra



Thanks….

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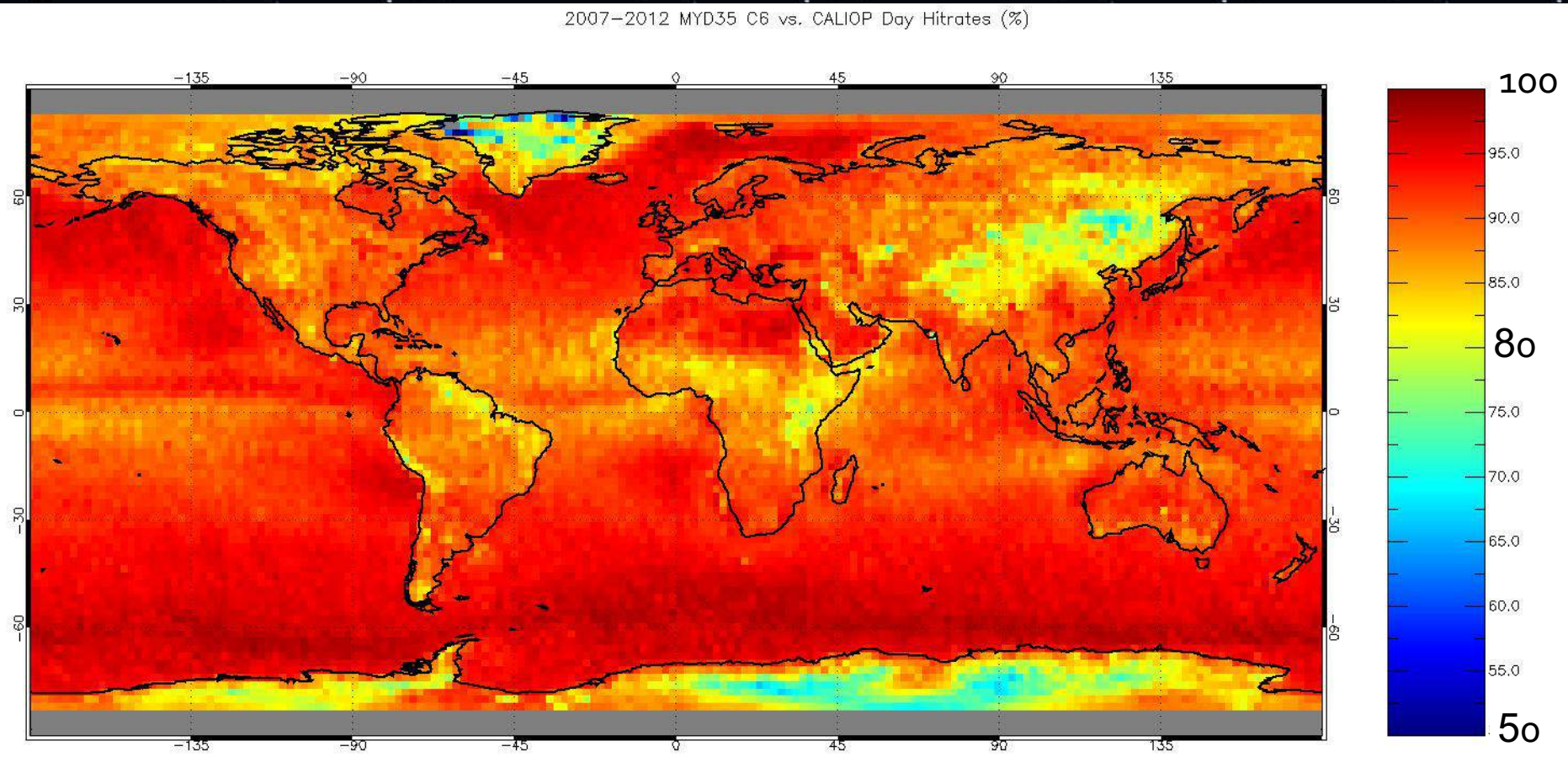
DAYTIME MYD35 VS. CALIOP (2007-2012)



confident clear and probably clear = “clear”, confident cloud and probably cloud = “clou

dy”

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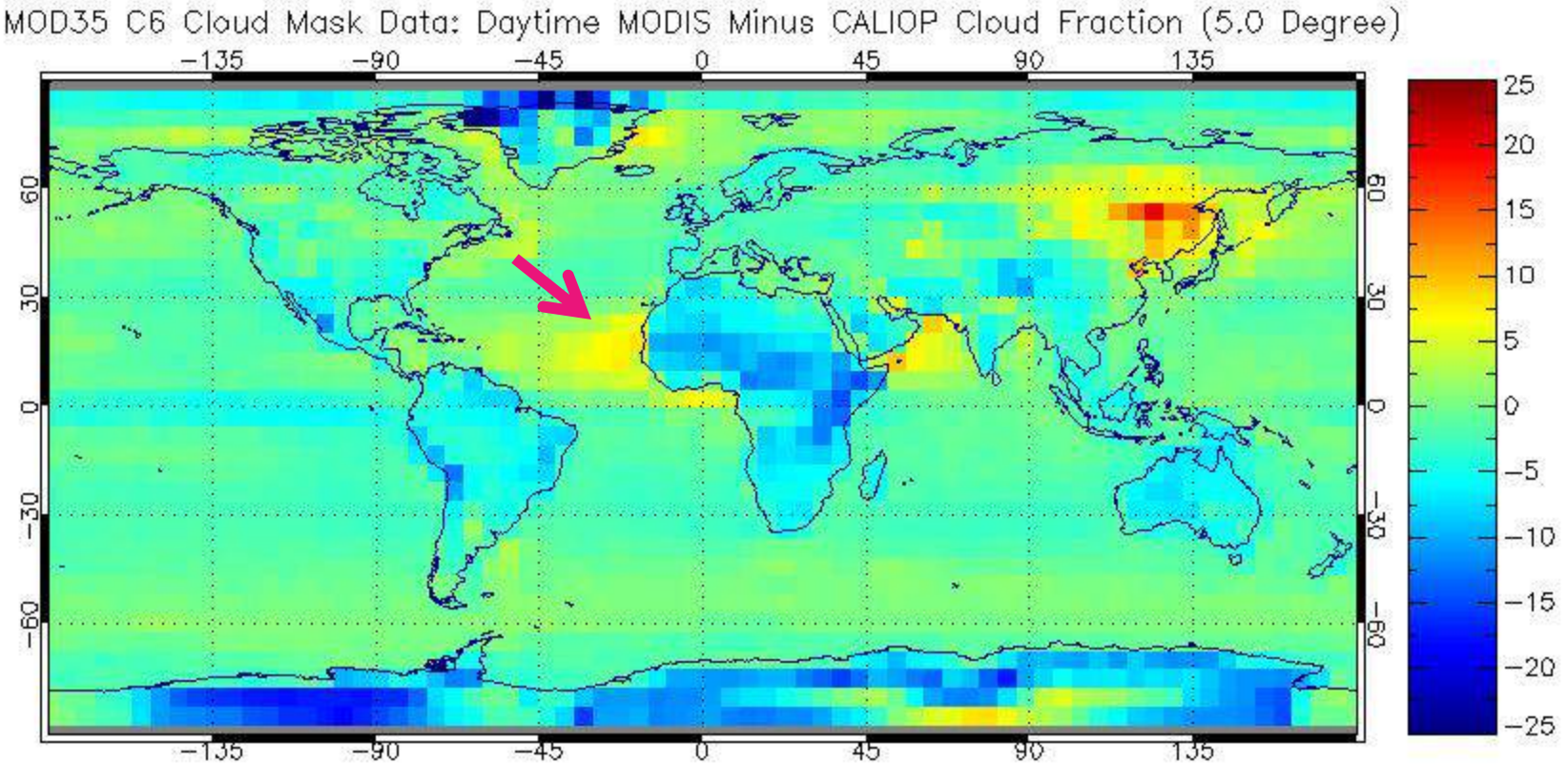
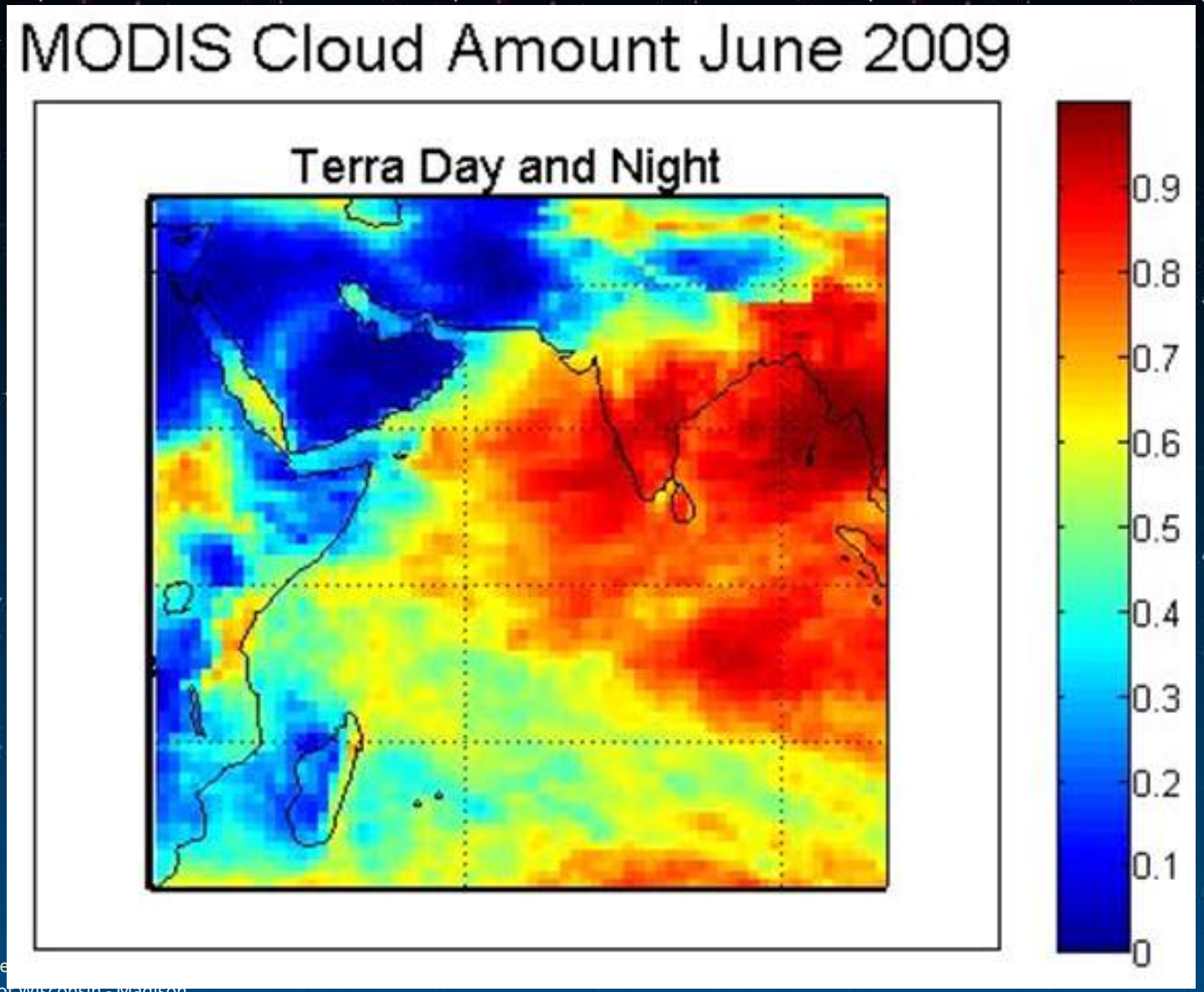
DAYTIME 5-DEGREE MEAN MODIS CLOUD FRACTIONS MINUS DAYTIME 5-DEGREE MEAN CALIOP CLOUD FRACTIONS.

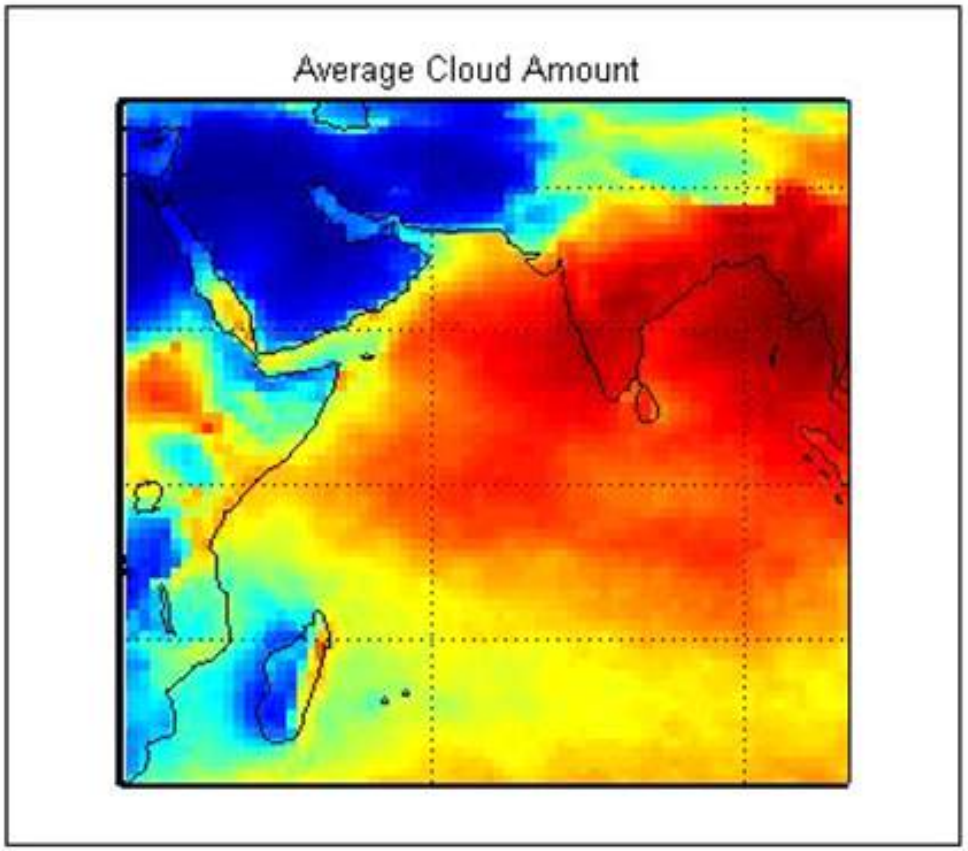


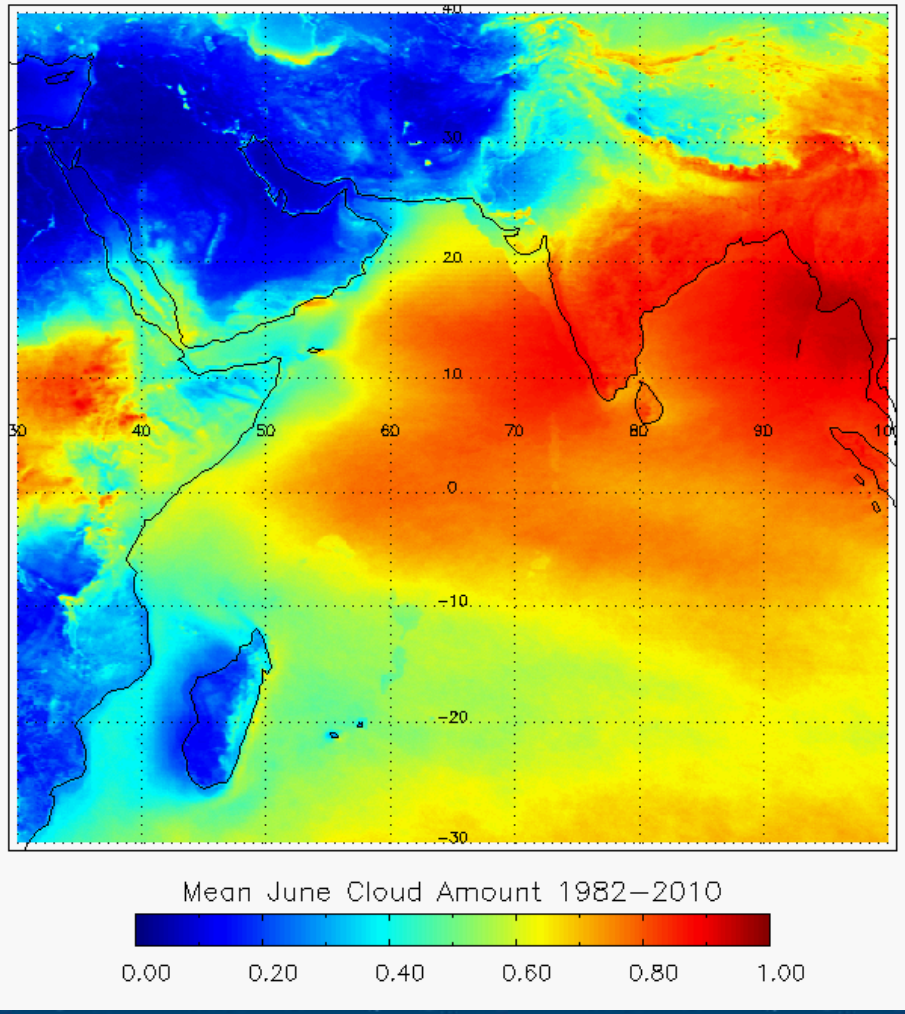
Percent Cloudy June 2009



MODIS Cloud Fraction in Compared to 1982-2010 from NOAA's PATMOS-x AVHRR Data Set. Month of JUNE

MODIS Cloud Amount 2000-2010





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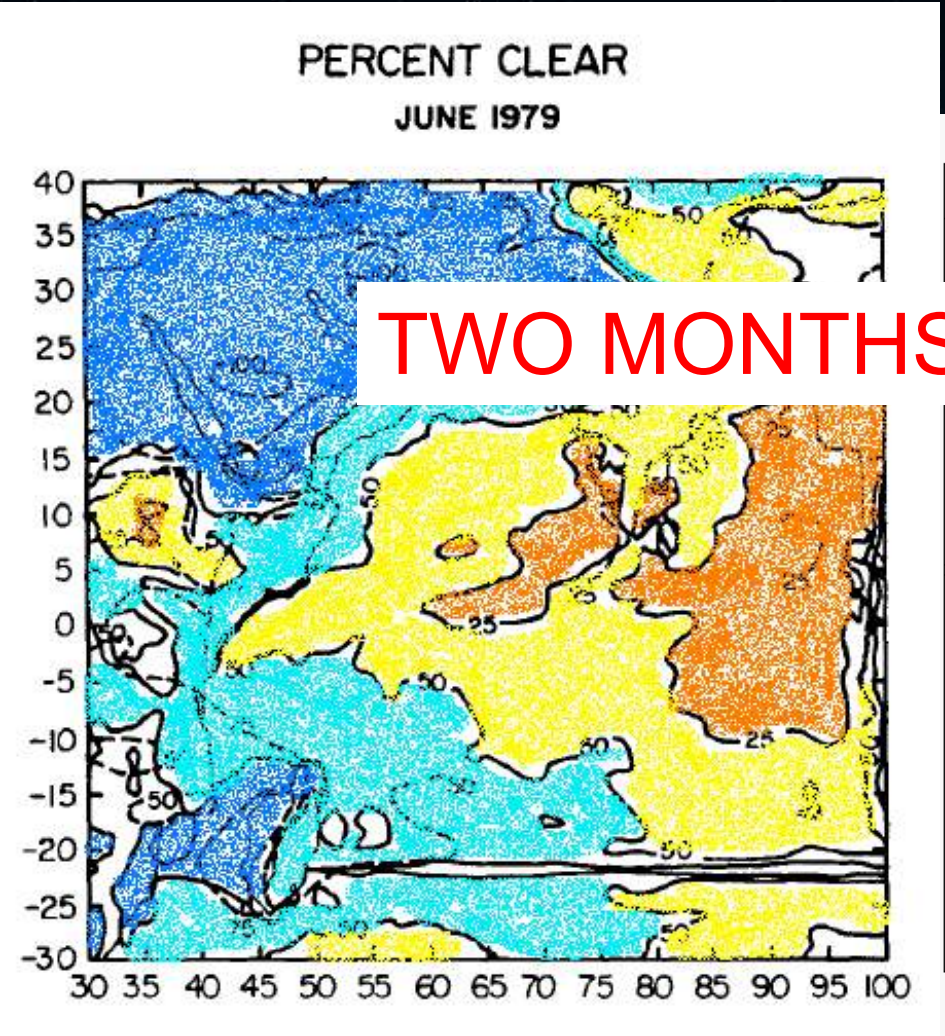
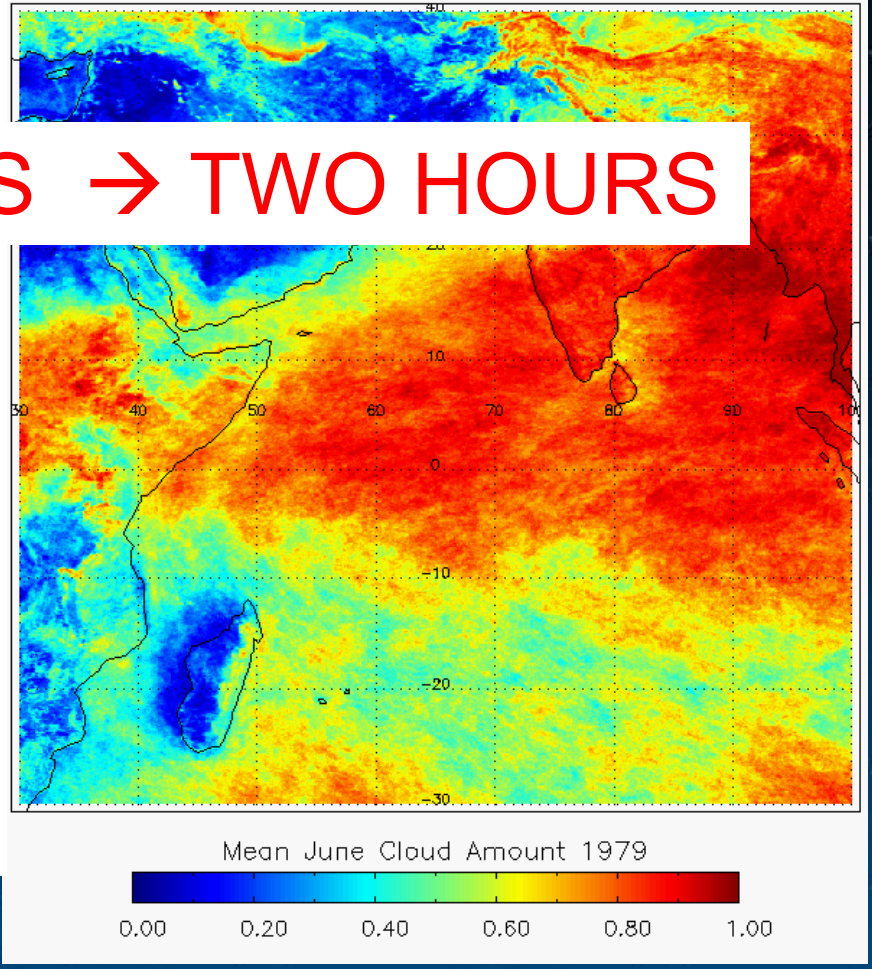
0.1 degree spatial resolution

Cloud Fraction in June 1979 Compared to 1979 NOAA's PATMOS-x AVHRR Data Set.



0.1 degree spatial resolution

TWO MONTHS → TWO HOURS



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