Using 22 Years of HIRS Observations To Infer Global Cloud Cover Trends

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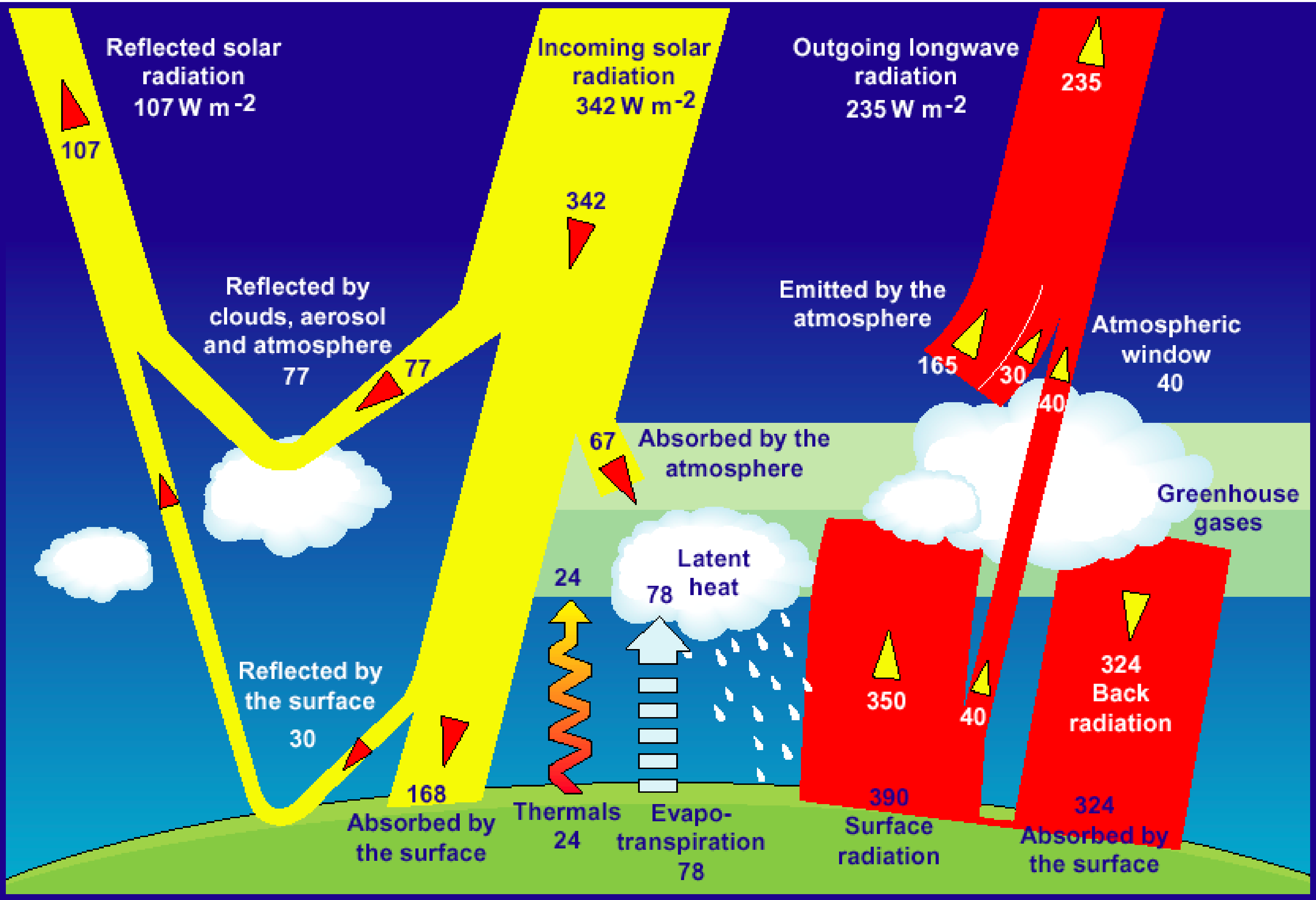
Difficulties in studying clouds
22 year HIRS stats
Effects of orbit drift, CO2 increase, and sensor changes
Comparison with ISCCP and GLAS
Challenges for Climate Data Sets
Conclusions

May 2005

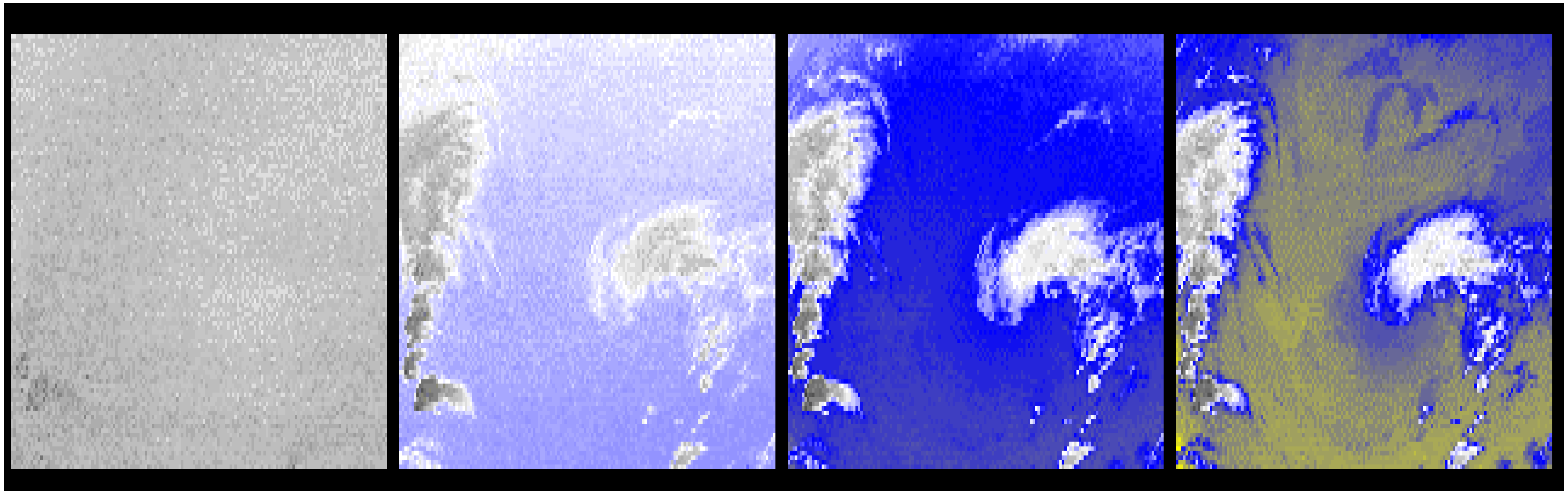
Climate System Energy Balance



Why are clouds so tough?

- Aerosols <0.1 micron, cloud systems >1000 km
- Cloud particles grow in seconds: climate is centuries
- Cloud growth can be explosive:
  1 thunderstorm packs the energy of an H-bomb.
- Cloud properties can vary a factor of 1000 in hours.
- Few percent cloud changes drive climate sensitivity
- Best current climate models are 250 km scale
- Cloud updrafts are a 100 m to a few km
- Clouds can be invisible but have infrared impact

CO2 channels see to different levels in the atmosphere;
CO2 Slicing identifies cirrus and infers its height

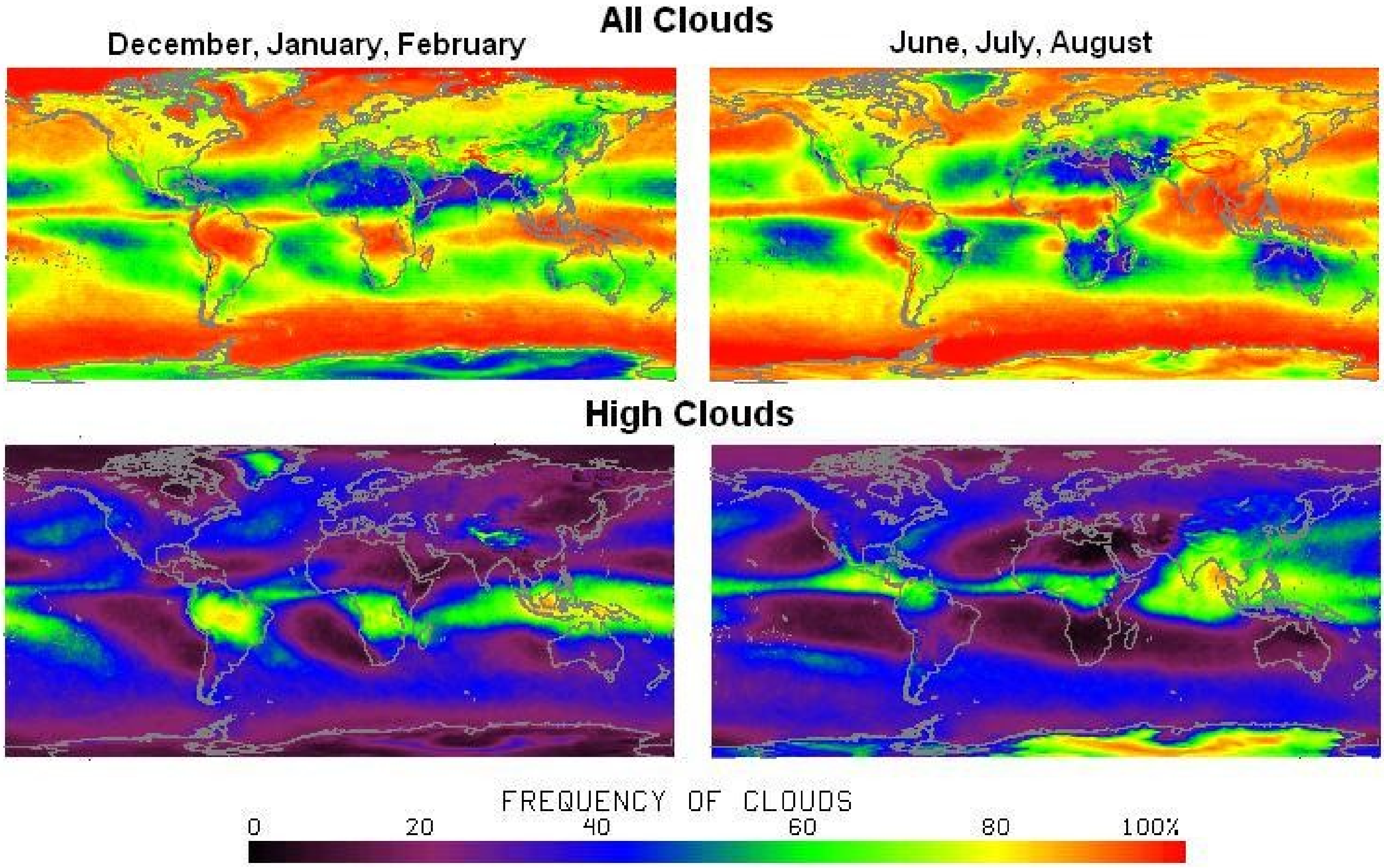


14.2 um 13.9 um 13.6 um 13.3 um

UW HIRS Pathfinder Processing

	Current UW Pathfinder
Record length	22 years
Orbits processed	Both ascending and descending
With of scan swath	18° from nadir
Coverage	Contiguous FOVS over whole globe
Basis of Cloud Mask	Spatial and temporal variances of window channel data plus CO2 channel screening of thin Ci
Channel Clear radiance estimate	Explicit forward radiance calculation with bias correction

HIRS Cloud Observations since 1979



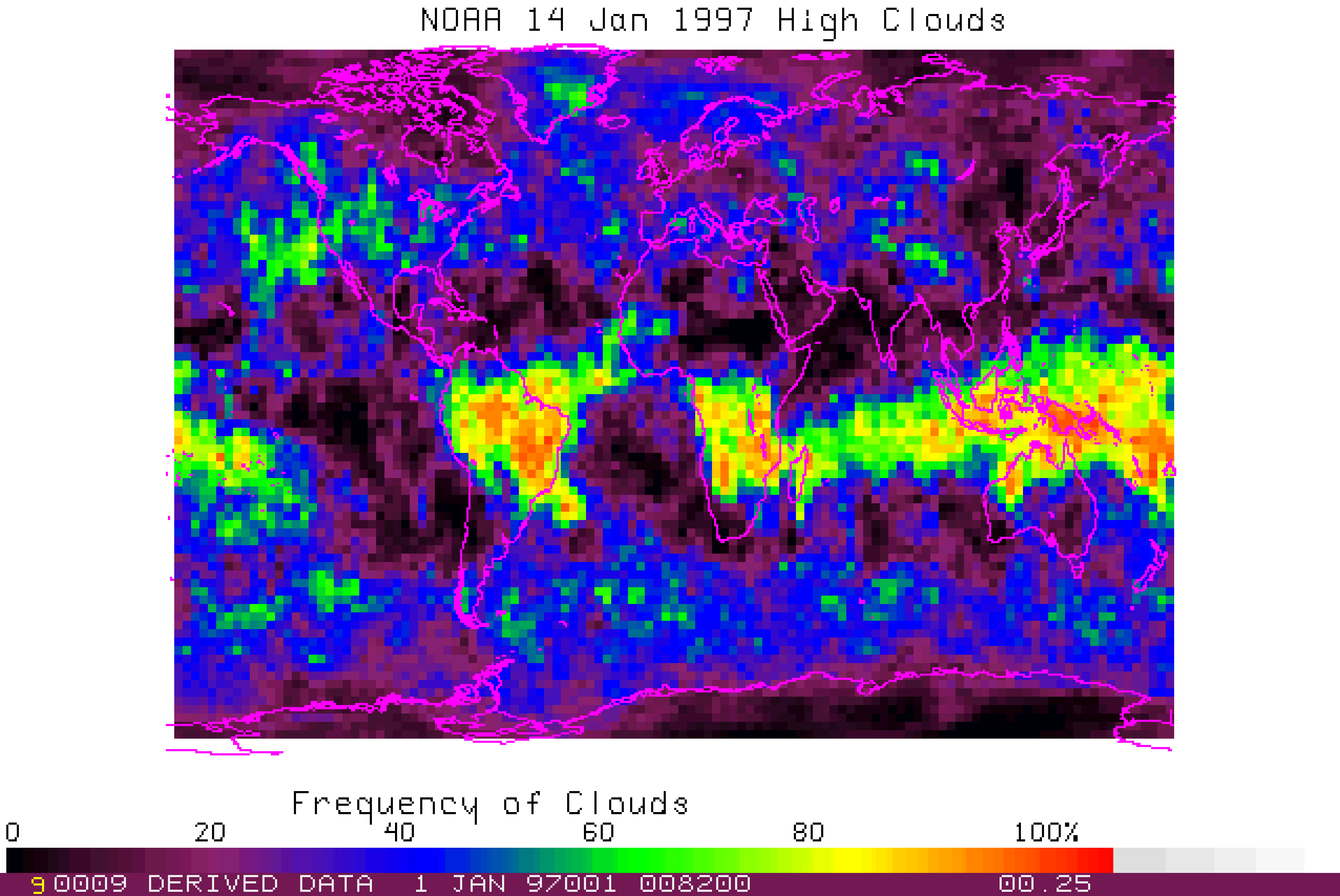
UW NOAA Pathfinder HIRS global cloud statistics from December 1978 through December 2001

	All Clouds	Thin Clouds NE<0.5	Thick Clouds	Opaque Clouds NE>0.95
Vis Optical Depth	0.1<	<1.4	<6	>6
High (<400 hPa)	33%	15%	15%	3%
Mid (400 → 700 hPa)	18%	5%	7%	6%
Low (>700 hPa)	24%	-	1%	23%
All Clouds	75%	20%	23%	32%

UW NOAA Pathfinder HIRS global cloud statistics from December 1978 through December 2001

(corrected for higher cloud obstruction of lower clouds using random overlap assumption)

	All Clouds	Thin Clouds NE<0.5	Thick Clouds	Opaque Clouds NE>0.95
Vis Optical Depth	0.1<	<1.4	<6	>6
High (<400 hPa)	33%	15%	15%	3%
Mid (400 → 700 hPa)	26%	7%	10%	9%
Low (>700 hPa)	49%	-	2%	47%
All Clouds	75%	20%	23%	32%


NOAA 14 Jan 1997 High Clouds
Frequency of Clouds
0
20
40
60
80
100%
9 0009 DERIVED DATA 1 JAN 97001 008200 00.25

Inferring Decadal HIRS Cloud Trends requires corrections for

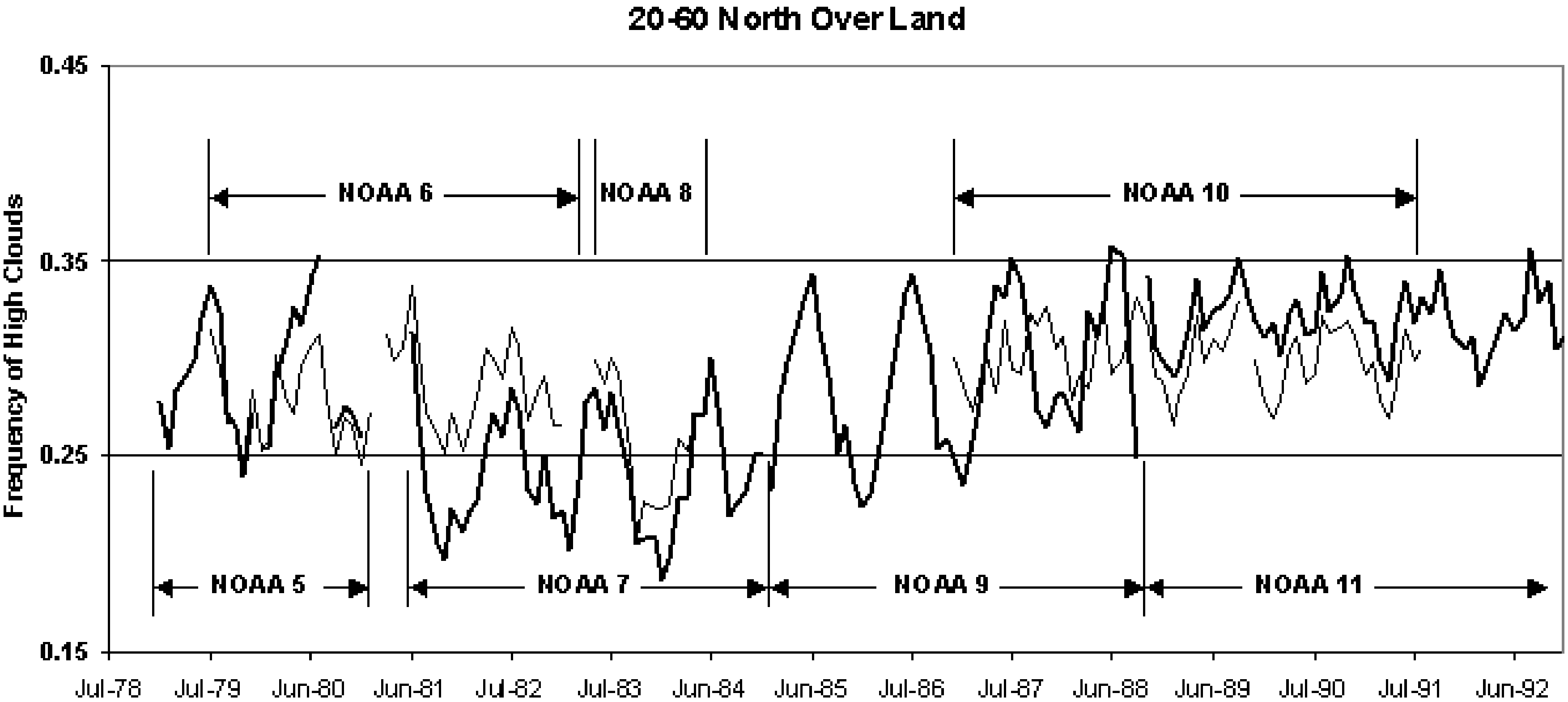
(1) anomalous satellite data or gaps
(2) orbit drift
(3) CO_2 increase

constant CO_2 concentration was assumed in analysis

Satellite by satellite analysis

Gap in 8am/pm orbit coverage between NOAA-8 and -10

HIRS cloud trends show unexplained dip with NOAA-7 in 2 am/pm orbit.



Monthly average frequency of high clouds from 20-60 N showing time periods of individual satellites. Heavy lines are satellites in 2 pm/am orbit and thin lines are in 8 am/pm orbit.

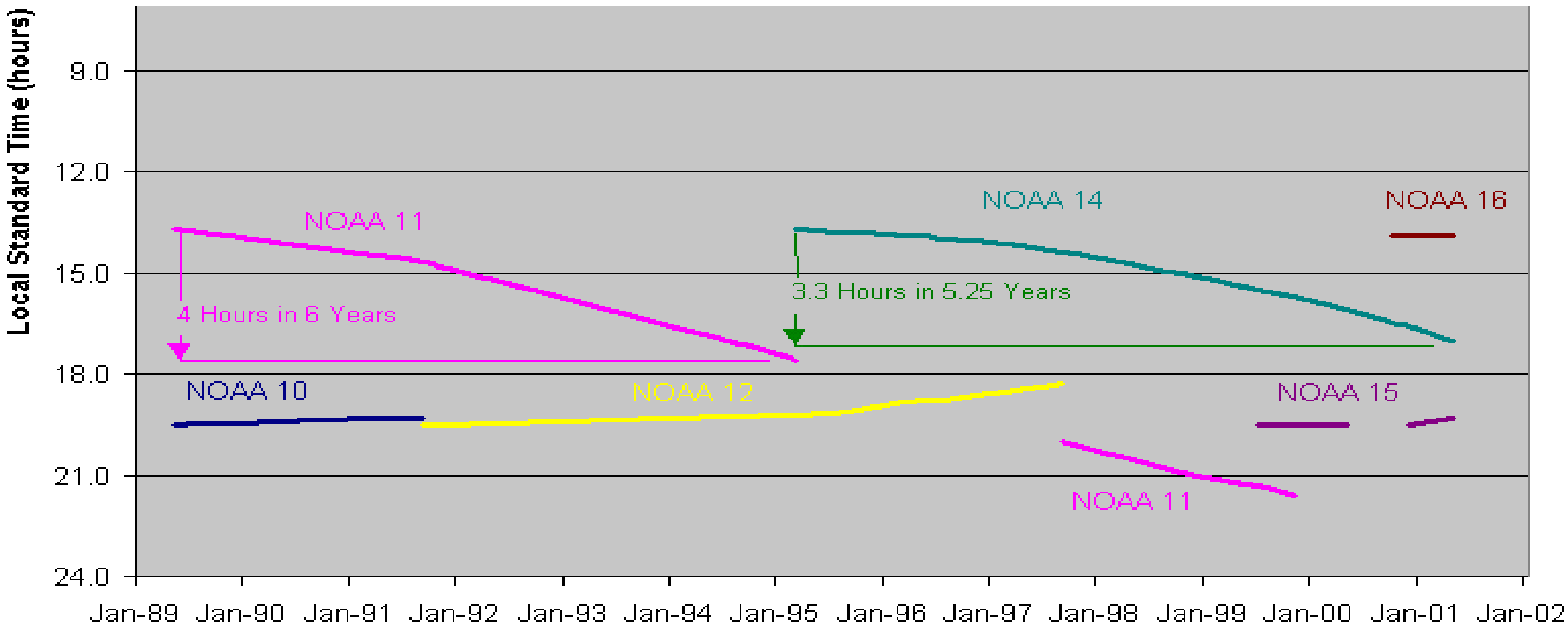
Used only 2 am/pm orbit data after 1985 in cloud trend analysis for continuity of data and satellite to satellite consistency

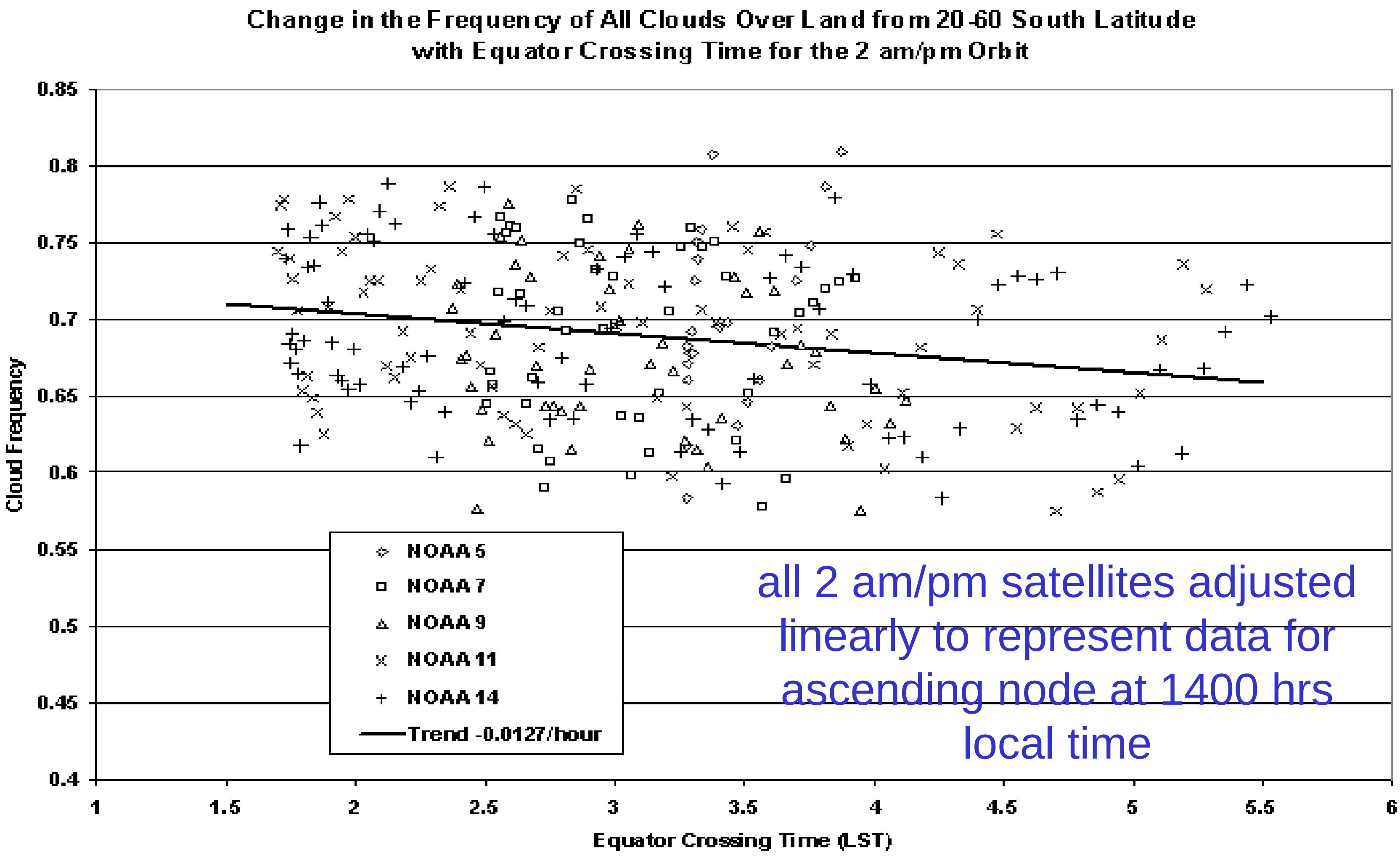
Measurements from 9 sensors used in 22 year study of clouds

morning (8 am LST)	afternoon (2 pm LST)
NOAA 6 HIRS/2	NOAA 5 HIRS
NOAA 8 HIRS/2	NOAA 7 HIRS/2
NOAA 10 HIRS/2	NOAA 9 HIRS/2
NOAA 12 HIRS/2	NOAA 11 HIRS/2I *
	NOAA 14 HIRS/2I *

HIRS/2I ch 10 at 12.5 um instead of prior HIRS/2 8.6 um. Asterisk indicates orbit drift from 14 UTC to 18 UTC over 5 years of operation

Some sensors experienced significant orbit drift



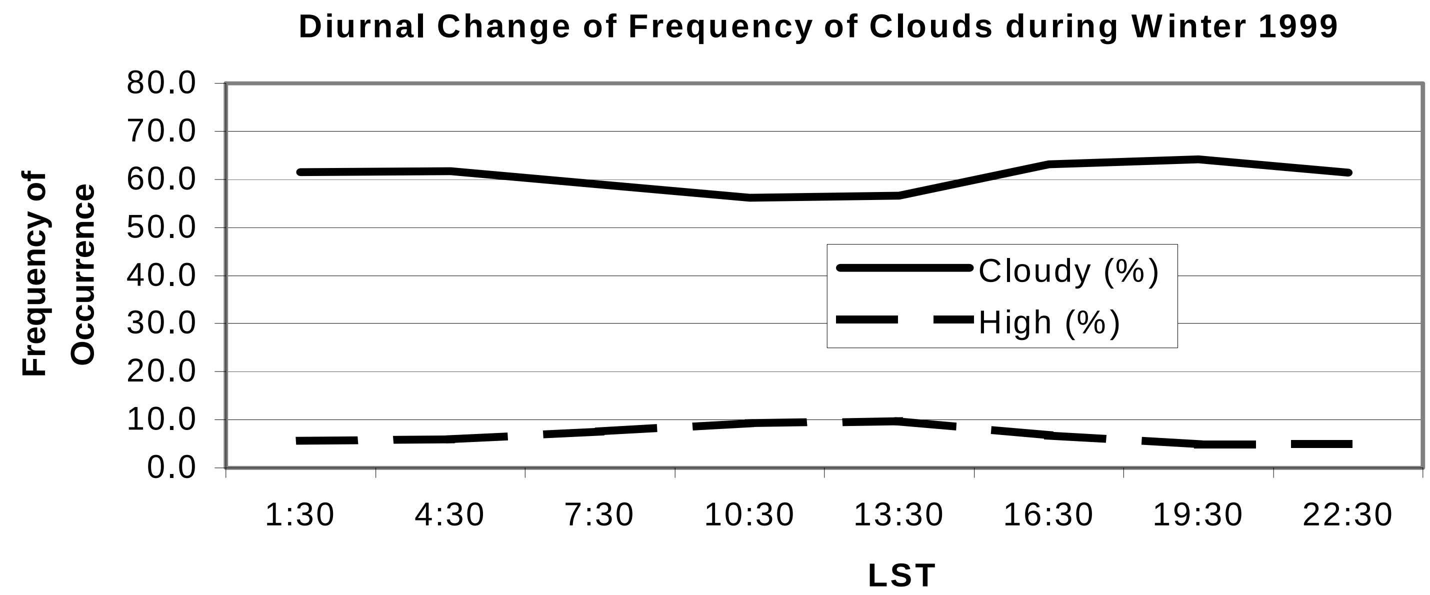


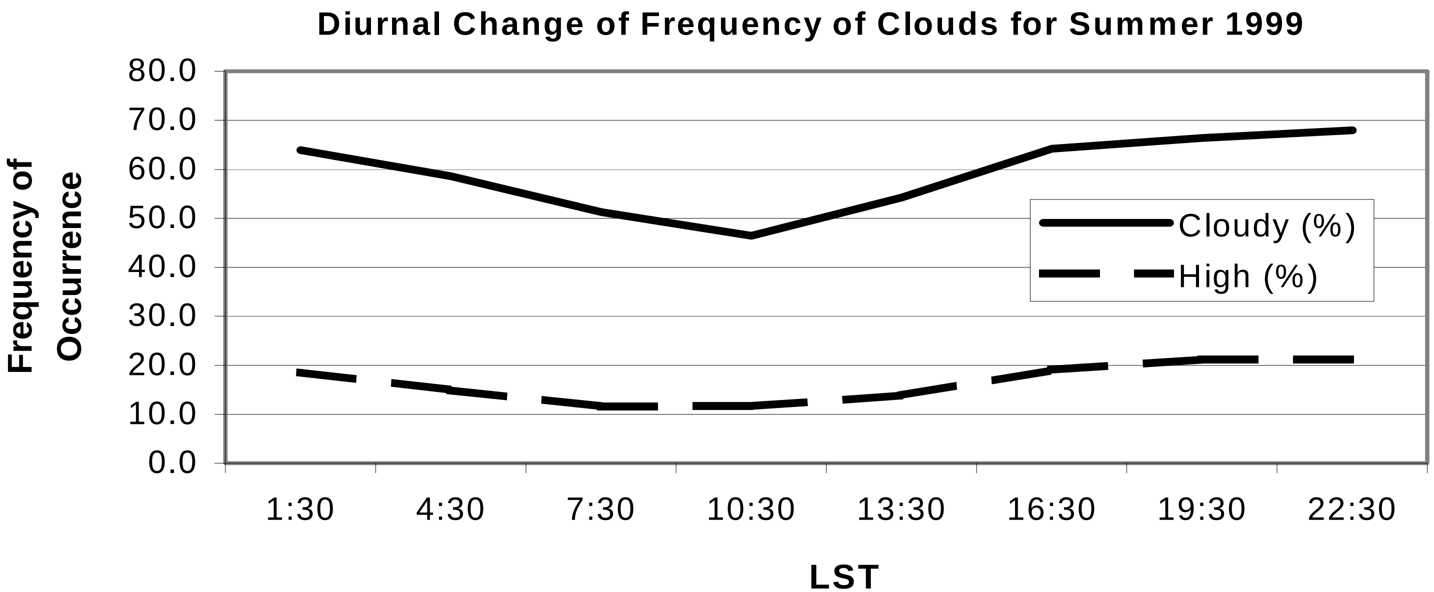
Change in cloud frequency per hour of orbit drift (cloud fraction per hour)

Orbit drift corrections.

	All Clouds		High Clouds	
	Land	Ocean	Land	Ocean
20-60 North	-0.004	0.002	0.007	0.004
Tropics 20 S - 20 N	-0.010	0.006	0.010	0.004
20-60 South	-0.013	0.003	0.006	0.000

GOES Sounder sees >5% increase of summer cloud detection as observations drift later in day from 14 to 18 LST





Atmospheric CO2 has not been constant

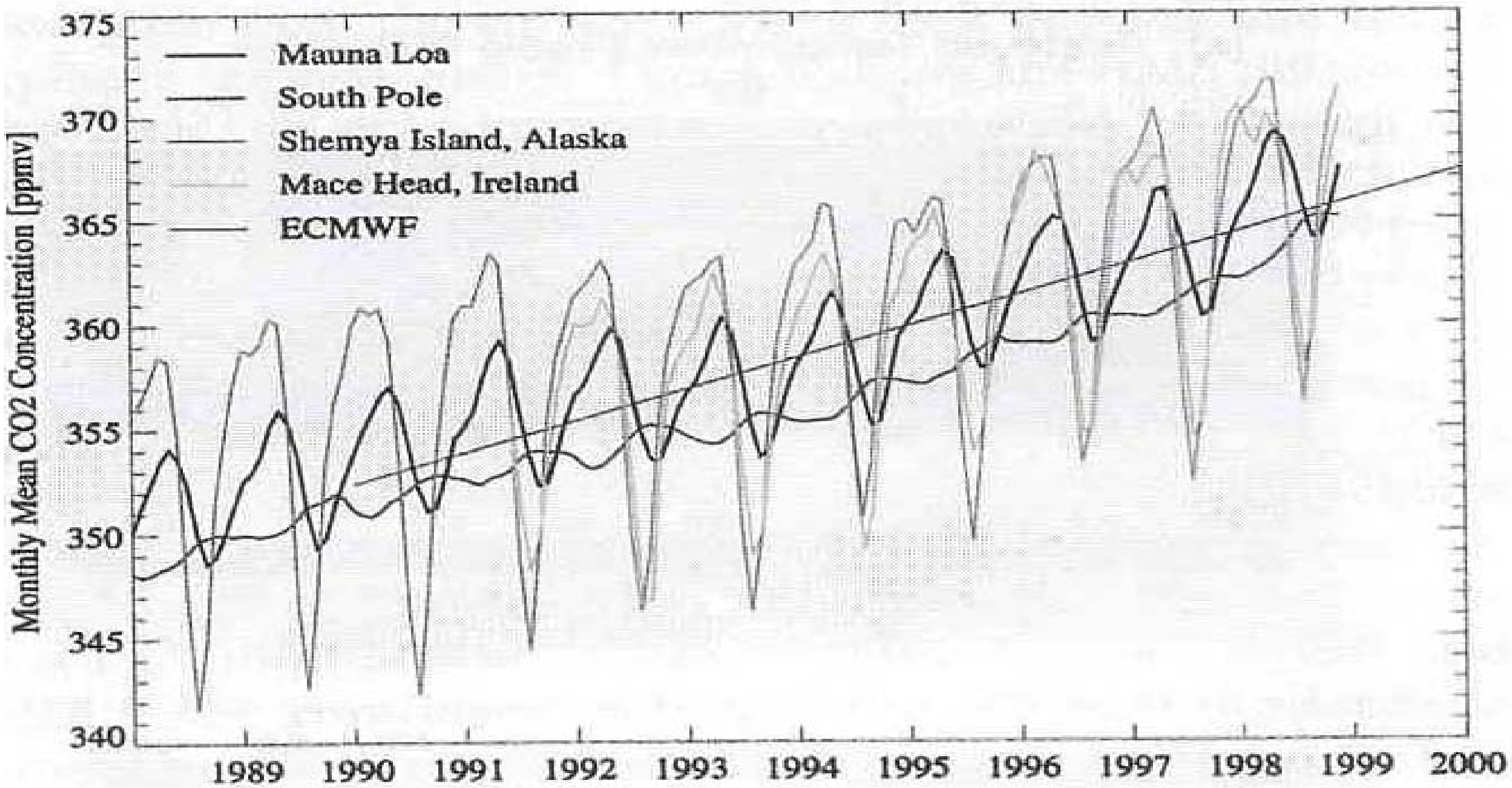
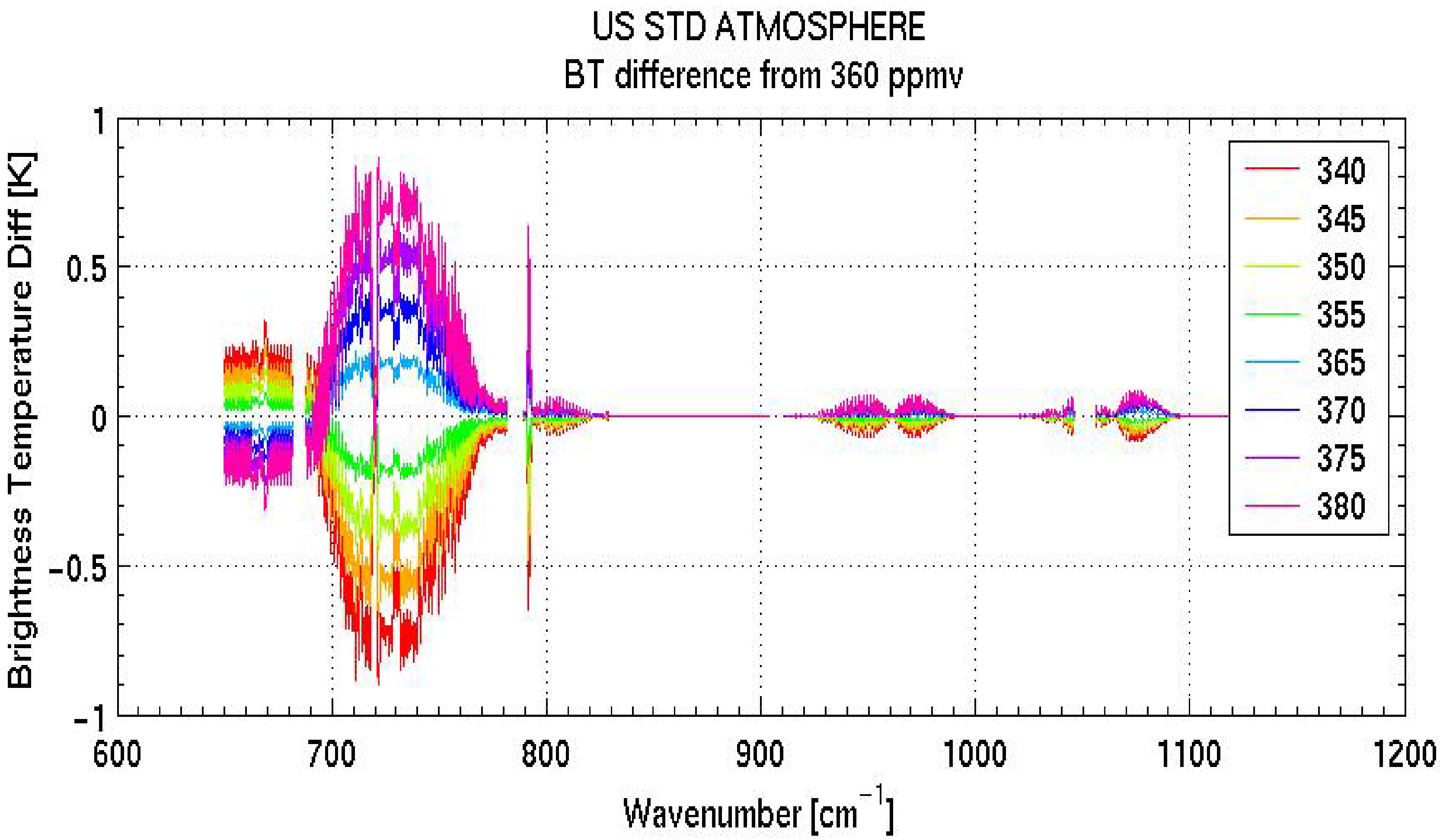


Figure 1. Time series of monthly mean surface CO_2 volume mixing ratios for 4 flask stations. The red line represents the values used by ECMWF.

(From Engelen et al., Geophys Res Lett, 2001)

SARTA calculations: BT with 360 ppmv minus BT with 340,345,…380 ppmv



HIRS cloud trends have been calculated with CO_2 concentration assumed constant at 380 ppm.

Lower CO_2 concentrations increase the atmospheric transmission, so radiation is detected from lower altitudes in the atmosphere.

$$\tau dry(335,p,ch) = \tau dry(380,p,ch)^{**}\{335/380)$$

$$\tau(p,ch) = \tau dry(p,ch)^{*}\tau H2O(p,ch)^{*}\tau O3(p,ch).$$

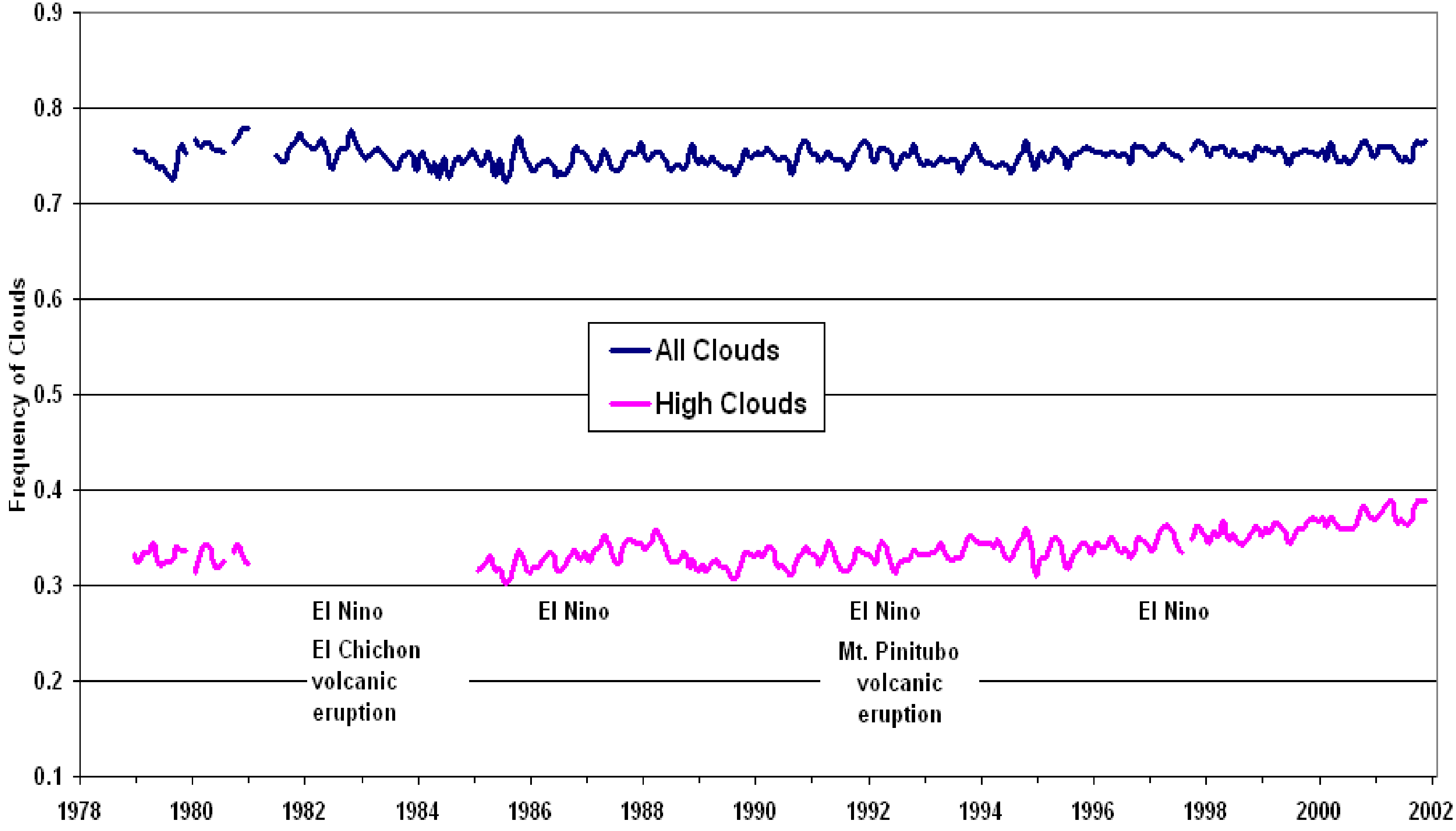
For January and June 2001 the clouds detected by NOAA 14 in the more transparent atmosphere (CO2 at 335 ppm) are found to be lower by 15-50 hPa

More transparent atmosphere (CO2 at 335 ppm) results in HIRS reporting 2% less high clouds than in the more opaque atmosphere (CO2 at 380 ppm); this implies that the frequency of high cloud detection in the early 1980s should be adjusted down.

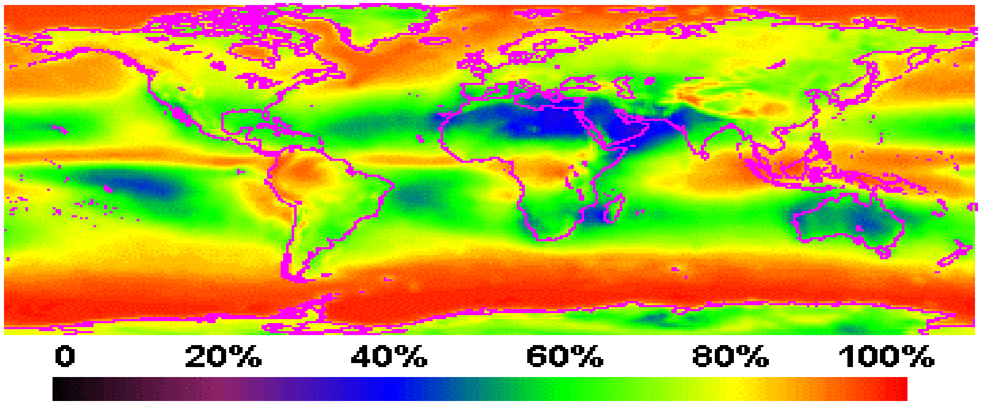
Cloud time series was adjusted to represent a linear increase of CO2 from 335 ppm in 1979 to 375 ppm in 2001

The statistically significant trends in cloud frequency change per decade from 1985-2001

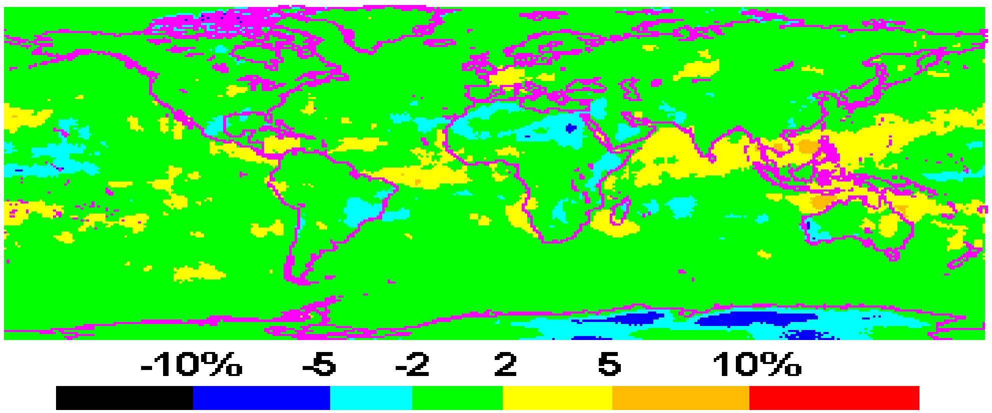
	20-60 N		20 S - 20 N		20-60 S	
	Ocean	Land	Ocean	Land	Ocean	Land
	HIRS uncorrected					
High Clouds	0.013	0.014	none	0.017	0.014	0.021
All Clouds	none	none	0.018	None	none	none
	HIRS corrected					
High Clouds	0.023	0.021	none	0.017	0.027	0.029
All Clouds	none	none	0.014	None	none	none
	ISCCP					
High Clouds	none	-0.015	none	None	none	-0.020
All Clouds	-0.042	-0.031	-0.037	-0.021	-0.017	-0.010



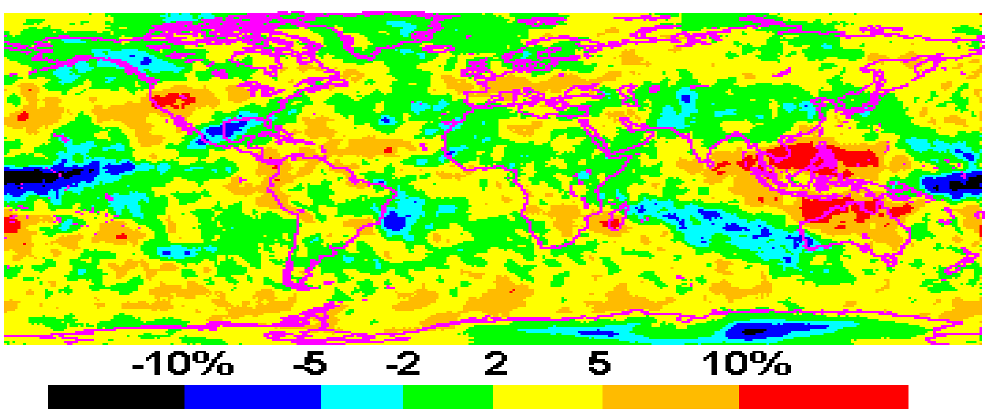
The monthly average frequency of clouds and high clouds (above 6 km) from 70 south to 70 north latitude from 1979 to 2002; Wylie et al 2005.



Frequency of all clouds found in HIRS data since 1979



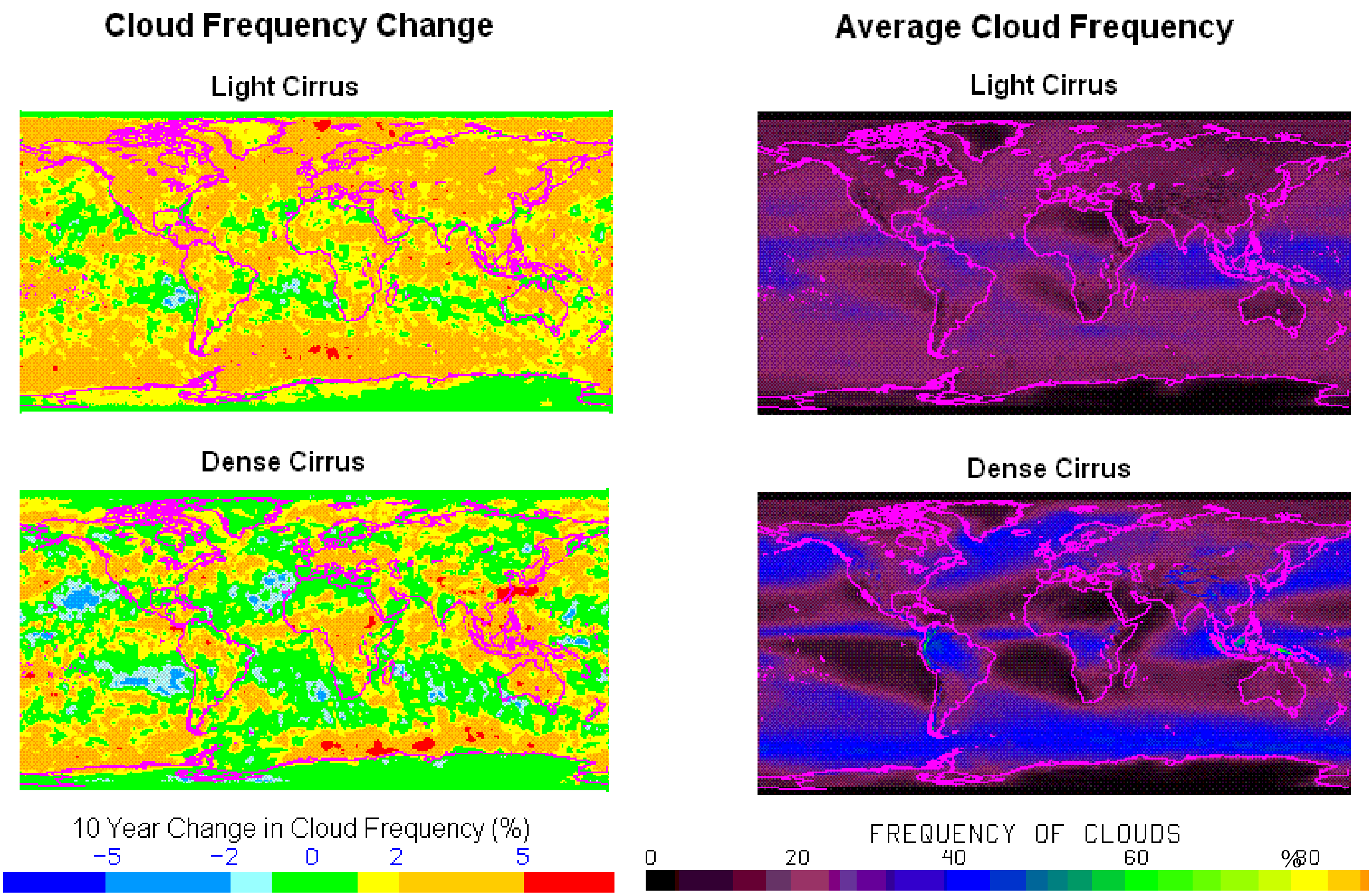
Change in cloud frequency from the 1980s to the 1990s

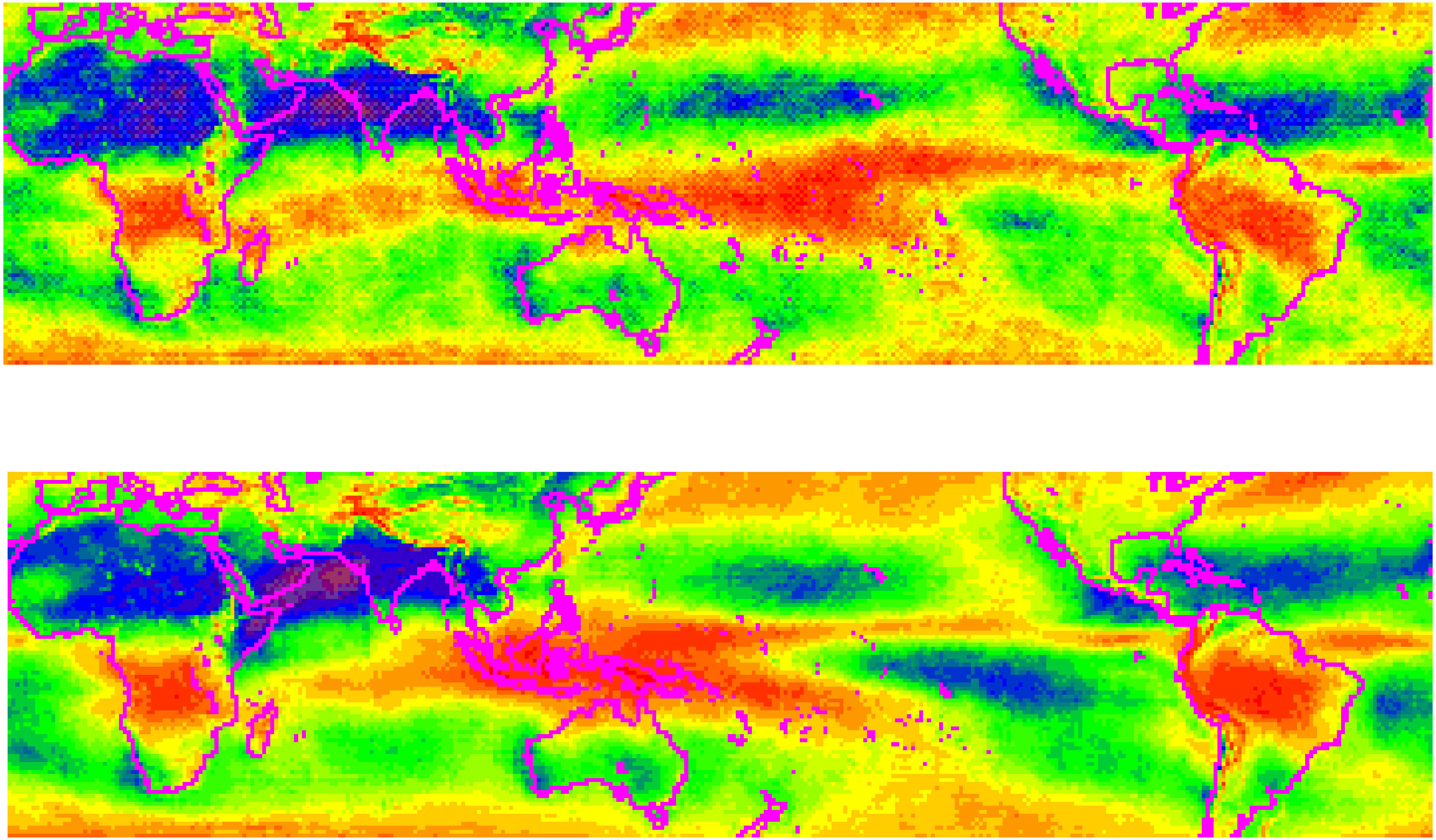


Change in high cloud (above 6 km) frequency during northern hemisphere winters

Wylie et al 2005

Change in Light and Dense Cirrus from 1980s to 1990s





High cloud (above 6 km) frequency in El Nino years (top) and all other years (bottom) during northern hemisphere winters (Dec, Jan, and Feb) from 1980s to 1990s.

Comparing with ISCCP and GLAS

(1) using GLAS as a sanity check
(2) understanding ISCCP
and algorithm differences

How Cloudy is the Earth?

	All Clouds			High Clouds		
Source	**Land**	**Sea**	**Both**	**Land**	**Sea**	**Both**
ISCCP	**56 %**	**70 %**		**25 %**	**20 %**	
HIRS Pathfinder	**71**	**77**		**34**	**32**	
Surface Reports	**52**	**65**		**54**	**43**	
SAGE			**73**			**53**
CLAVR			**60**			
GLAS	**66**	**80**		**34** *	**31** *	

**GLAS High Cloud Frequencies adjusted because HIRS reported more high clouds during the GLAS period than its 21 year average.*

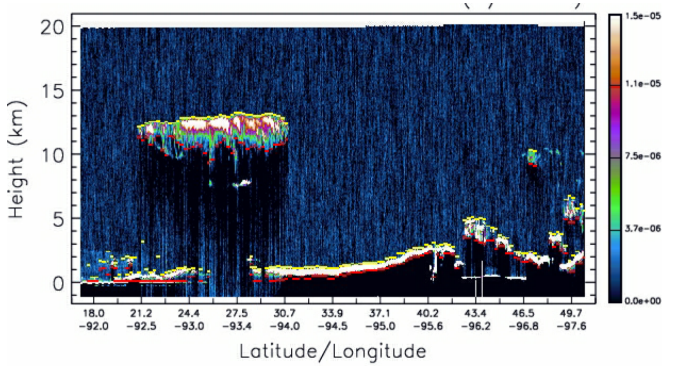
GLAS 22 Feb – 28 Mar 2003, HIRS 1979 – 2001, ISCCP 1983 – 2001, SAGE 1985-89, Surface Reports 1980-89, CLAVR 1982 - 2004

ISCCP reports 7-15% less cloud than HIRS because it misses thin cirrus.

HIRS and GLAS report nearly the same high cloud frequencies.

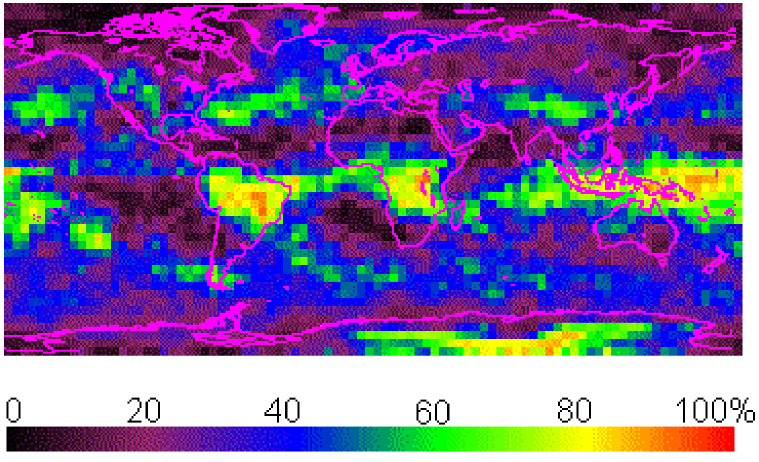
HIRS reports more clouds over land than GLAS probably because GLAS sees holes in low cumulus below the resolution of HIRS.

HIRS vs GLAS High Clouds

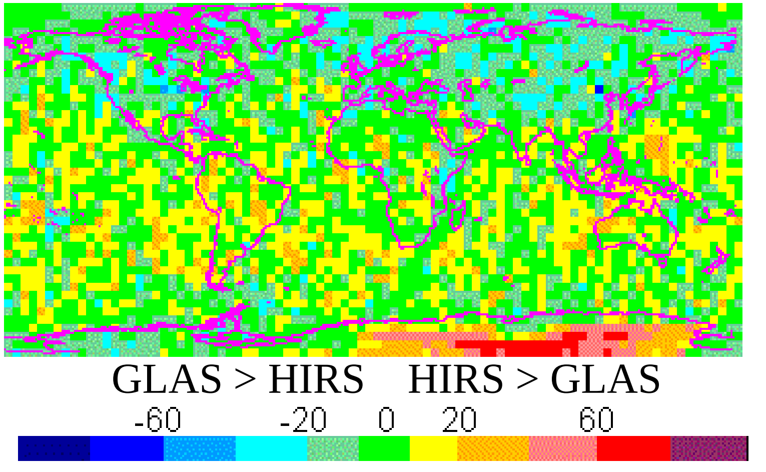


GLAS
Geoscience Laser Altimeter System

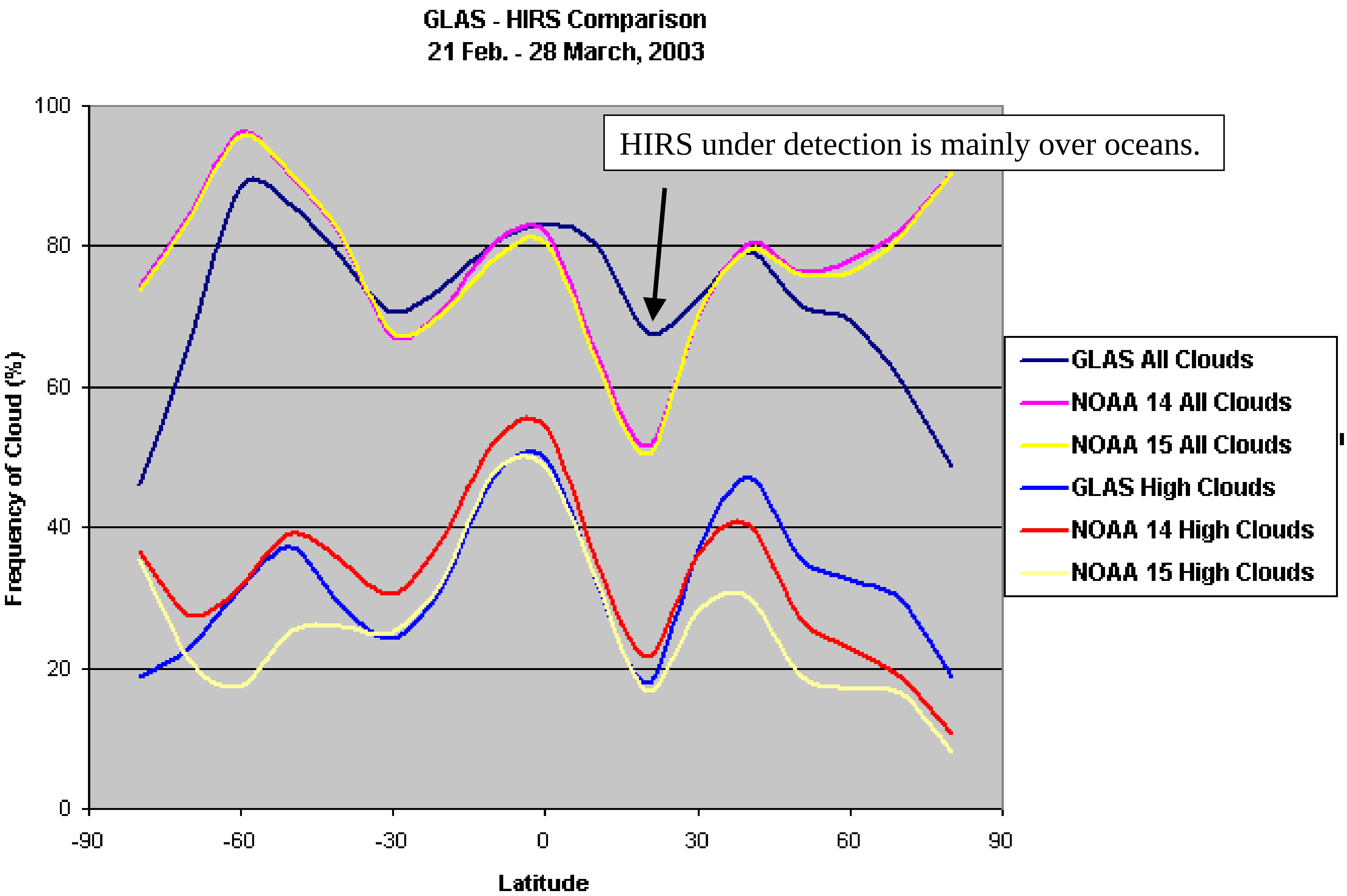
HIRS Frequency of High Cloud

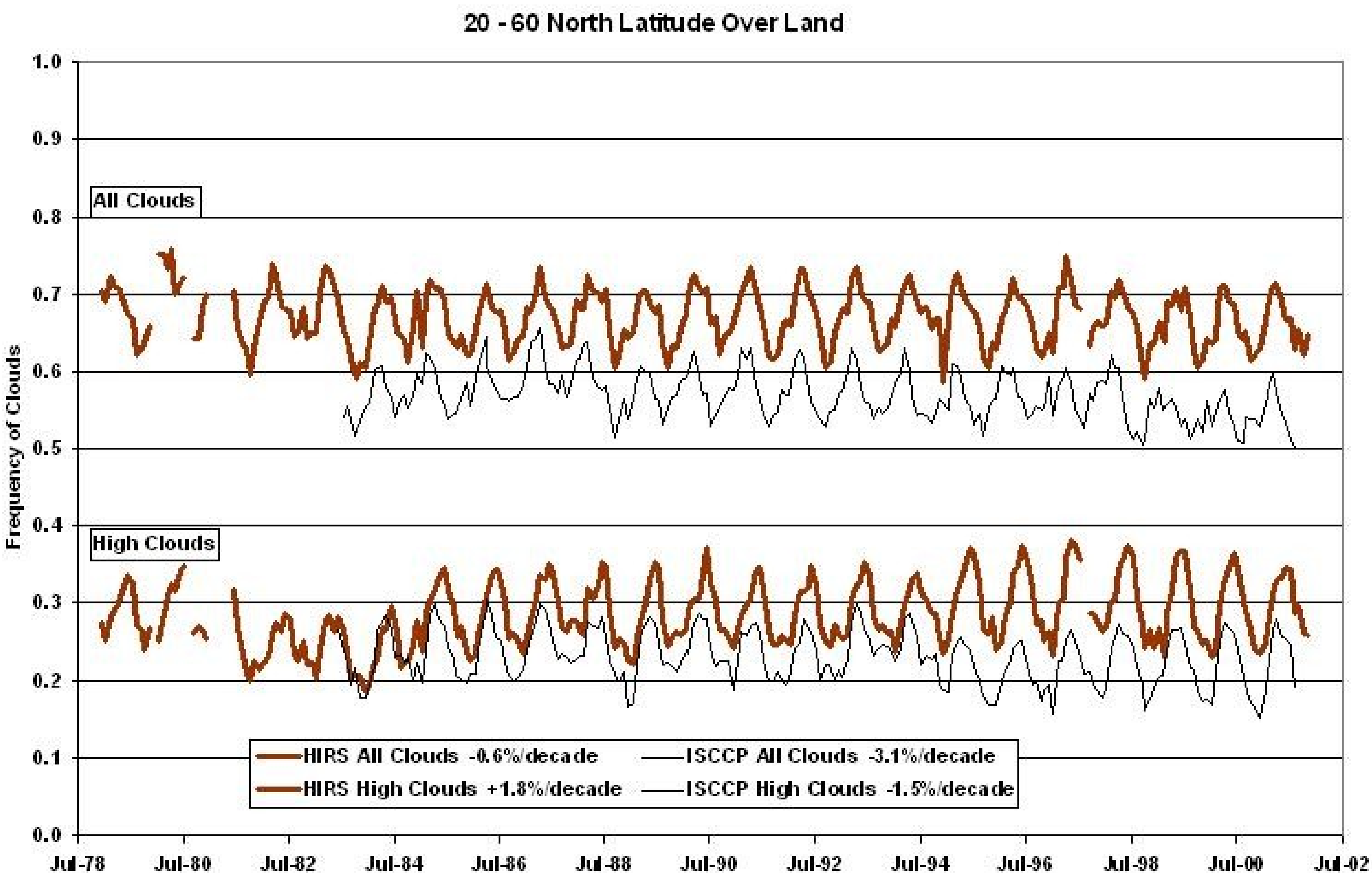


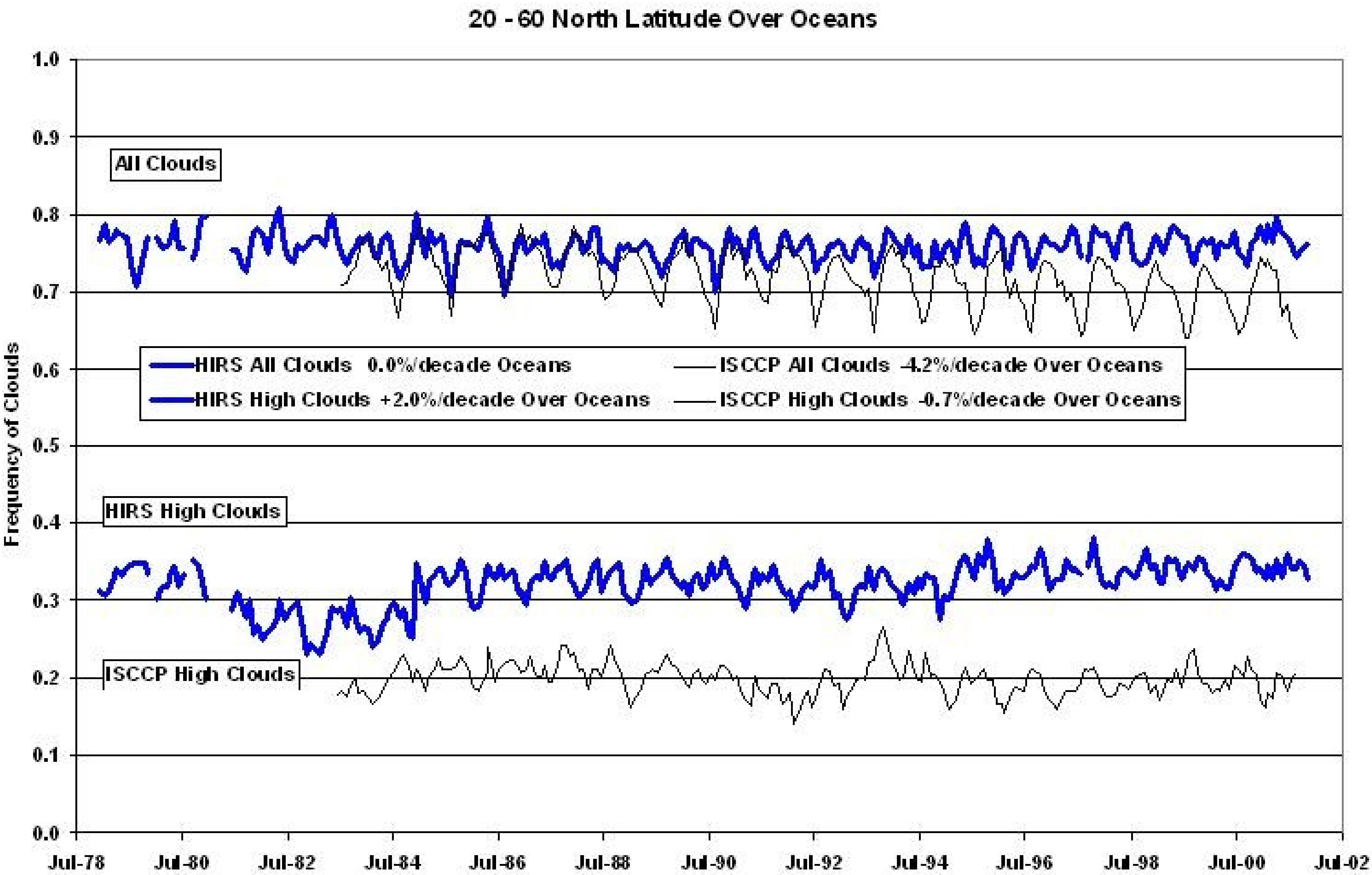
HIRS – GLAS Difference



HIRS reports more high clouds in parts of tropics and southern hemisphere, but areas of differences are scattered and not meteorologically organized.


GLAS - HIRS Comparison
21 Feb. - 28 March, 2003
HIRS under detection is mainly over oceans.
Frequency of Cloud (%)
100
80
60
40
20
0
-90
-60
-30
0
30
60
90
Latitude
GLAS All Clouds
NOAA 14 All Clouds
NOAA 15 All Clouds
GLAS High Clouds
NOAA 14 High Clouds
NOAA 15 High Clouds


20 - 60 North Latitude Over Land
Frequency of Clouds
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
All Clouds
High Clouds
HIRS All Clouds -0.6%/decade
ISCCP All Clouds -3.1%/decade
HIRS High Clouds +1.8%/decade
ISCCP High Clouds -1.5%/decade
Jul-78
Jul-80
Jul-82
Jul-84
Jul-86
Jul-88
Jul-90
Jul-92
Jul-94
Jul-96
Jul-98
Jul-00
Jul-02

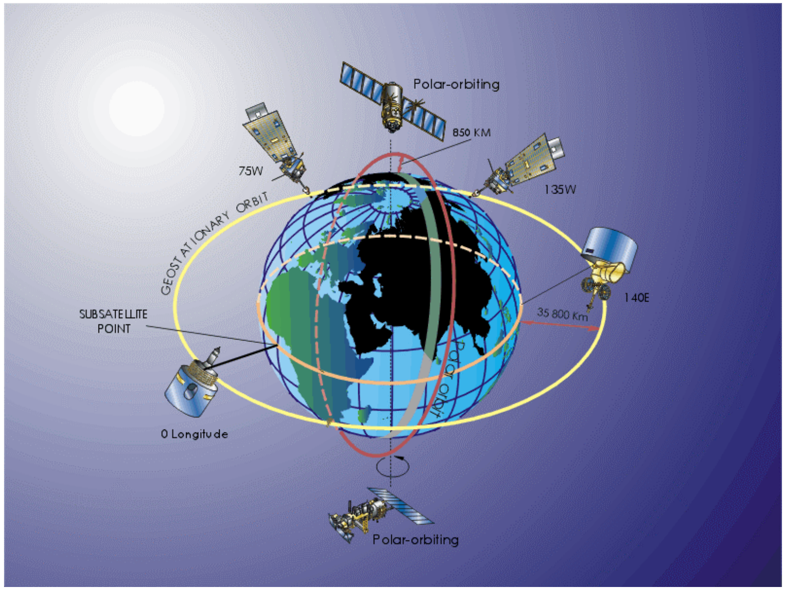

20 - 60 North Latitude Over Oceans
All Clouds
HIRS High Clouds
ISCCP High Clouds
HIRS All Clouds 0.0%/decade Oceans
HIRS High Clouds +2.0%/decade Over Oceans
ISCCP All Clouds -4.2%/decade Over Oceans
ISCCP High Clouds -0.7%/decade Over Oceans
Frequency of Clouds
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Jul-78
Jul-80
Jul-82
Jul-84
Jul-86
Jul-88
Jul-90
Jul-92
Jul-94
Jul-96
Jul-98
Jul-00
Jul-02

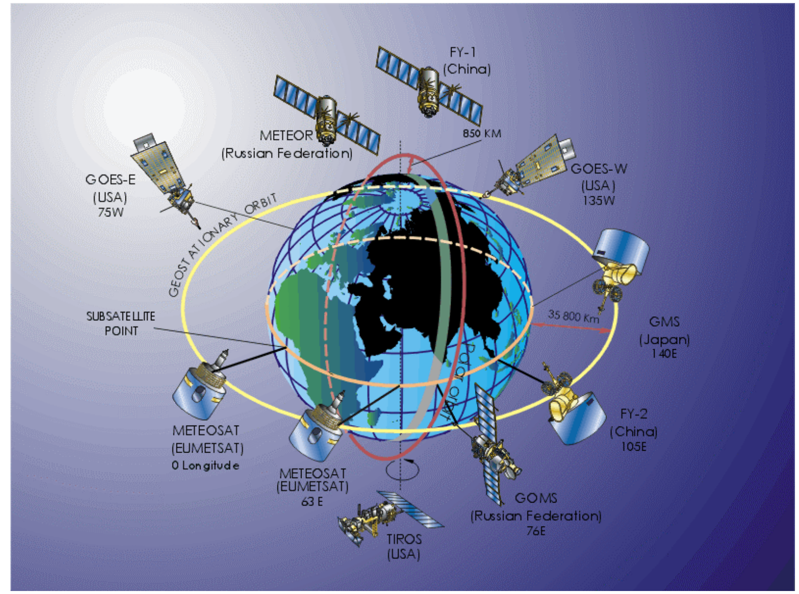
Wylie et al

Differences between UW HIRS analysis and the ISCCP are primarily (a) ISCCP uses visible reflectance measurements with the infrared window thermal radiance measurements, which limits transmissive cirrus detection to only day light data; (b) UW HIRS analysis uses only longwave infrared data from 11 to 15 μm which is more sensitive to transmissive cirrus clouds, but is relatively insensitive to low level marine stratus clouds

Campbell and VonderHaar

ISCCP may be showing fewer clouds as satellite coverage (and hence more nadir viewing coverage) increases in later years.





Satellite Observing System in 1978 (left) and 200 (right)

Challenges for Climate data sets

Spectral consistency
(if not possible at least spectral knowledge)

Accurate radiative transfer
(accommodating seasonal and interannual CO_2 changes)

Orbit constancy
(maintain equator crossing times for leos)

Consistency with the Global Observing System
(using NWP data assimilation)

Reprocessing opportunities
(adjusting algorithms with experience)

Sustained Validation
(cal/val from ground & airborne instrumentation)

Conclusions

- clouds were found in 75% of HIRS observations since 1978 (hi clouds in 33%)
- loop of monthly means shows latitudinal cloud cover follows the sun
- good agreement with GLAS, but ISCCP finds 10-15 % fewer high and all clouds
- 16 yr trends in HIRS reveal modest 2% increase in high clouds during last decade compared with previous decade
- orbit drift, CO_2 increase, and satellite to satellite differences were mitigated
- ISCCP shows decreasing trends in total cloud cover of 3 to 4 % per decade but little high cloud trend

International TOVS Study Conference, 14th, ITSC-14, Beijing, China, 25-31 May 2005. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2005.