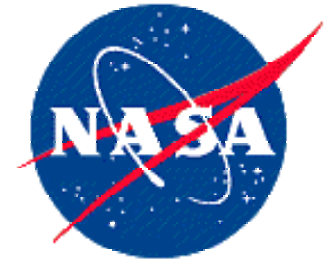


# Using 22 Years of HIRS Observations To Infer Global Cloud Cover Trends

Don Wylie, Darren Jackson, John Bates,  
& Paul Menzel



**Difficulties in studying clouds**

**22 year HIRS stats**

**Effects of orbit drift, CO2 increase, and sensor changes**

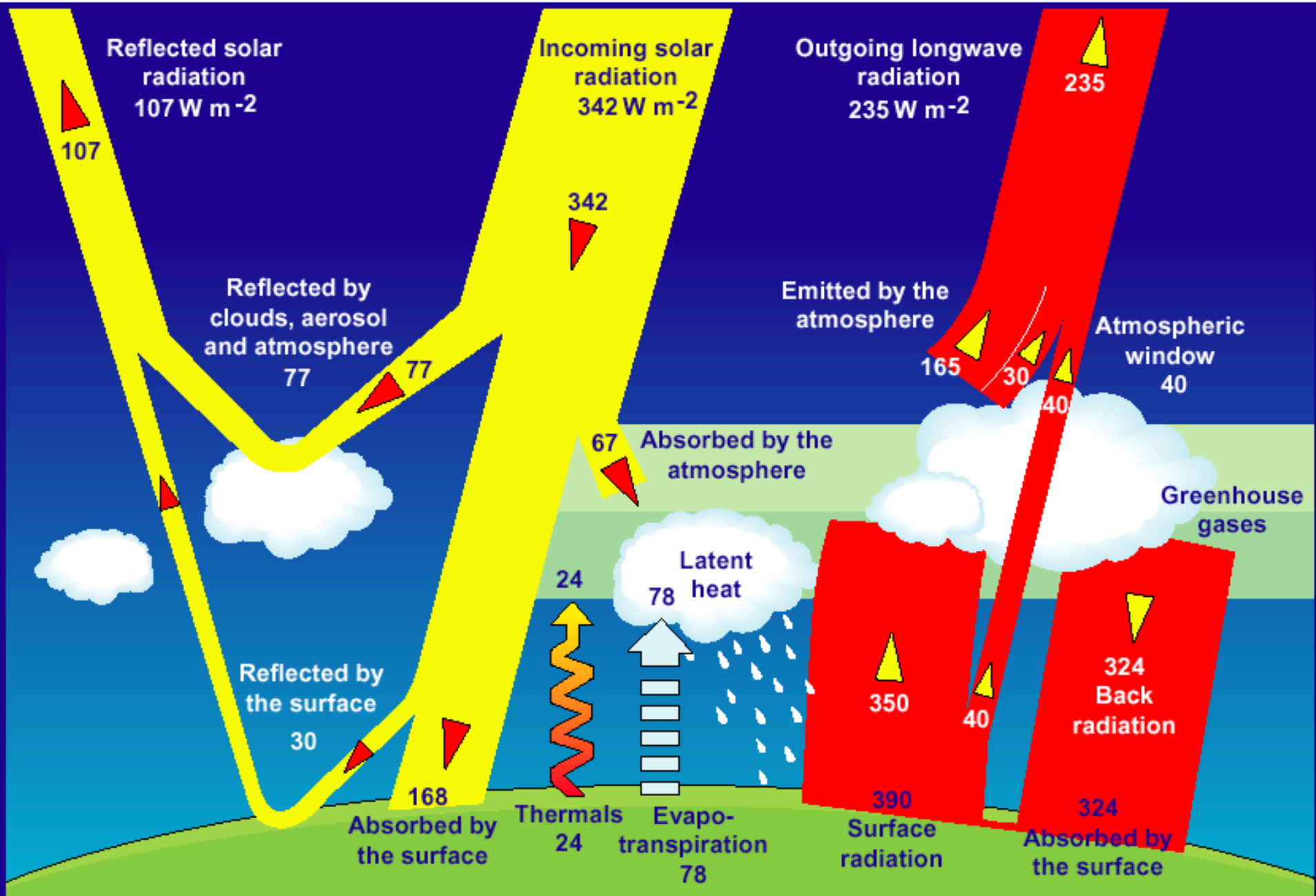
**Comparison with ISCCP and GLAS**

**Challenges for Climate Data Sets**

**Conclusions**

**May 2005**

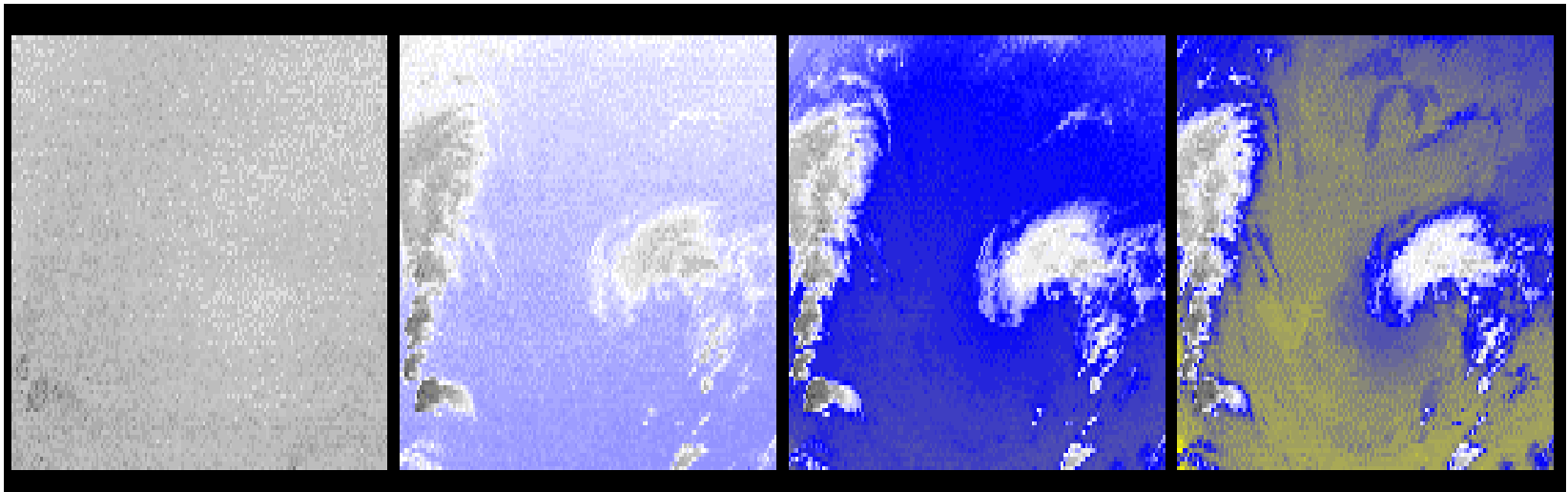
# Climate System Energy Balance



# 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

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	Current UW Pathfinder
Record length	22 years
Orbits processed	Both ascending and descending
Width 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 CO <sub>2</sub> channel screening of thin Ci
Channel Clear radiance estimate	Explicit forward radiance calculation with bias correction

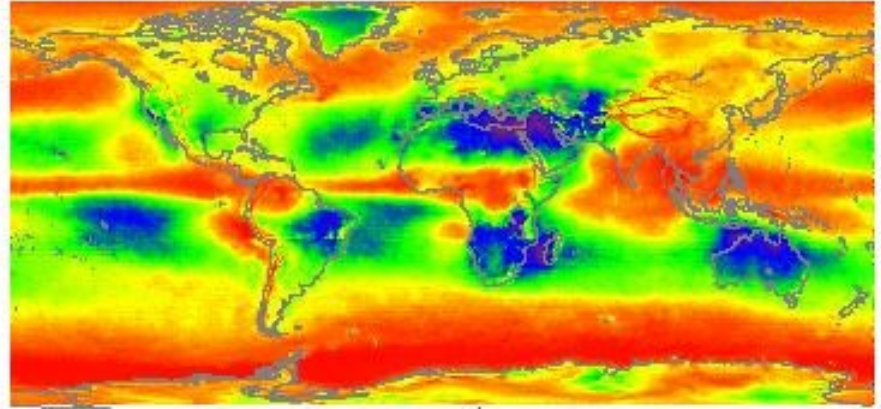
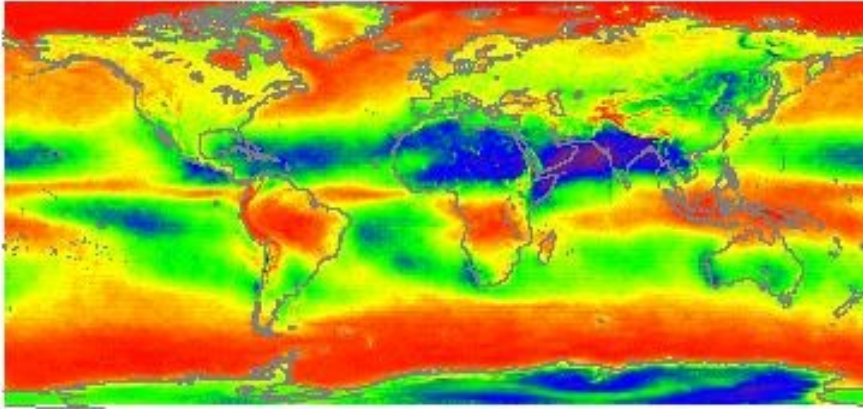
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# HIRS Cloud Observations since 1979

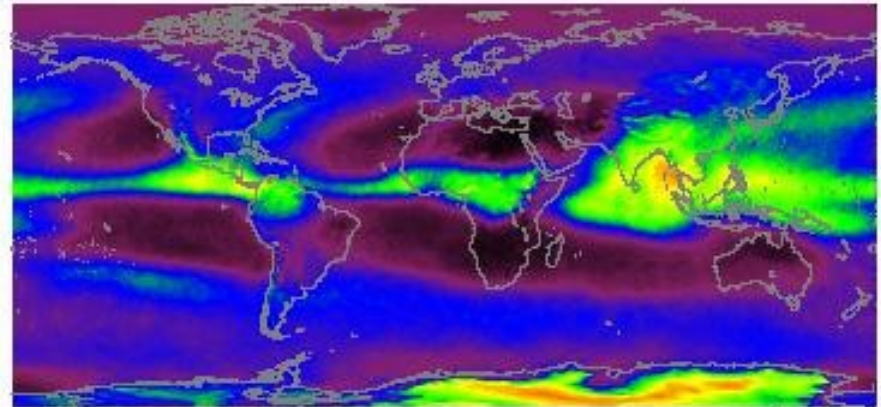
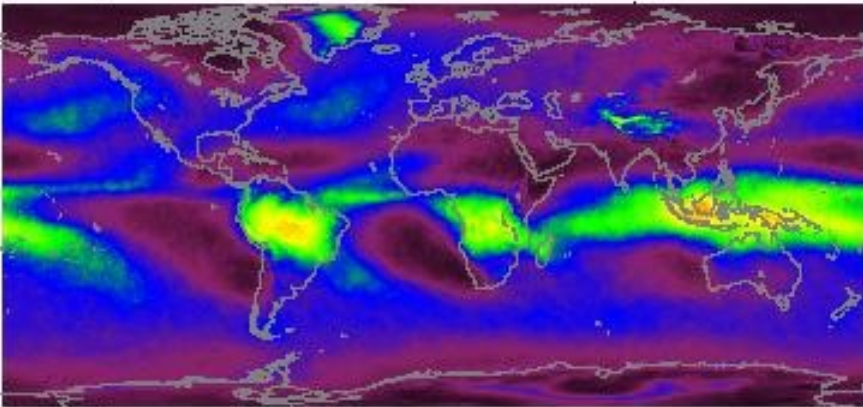
December, January, February

All Clouds

June, July, August



High Clouds



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

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

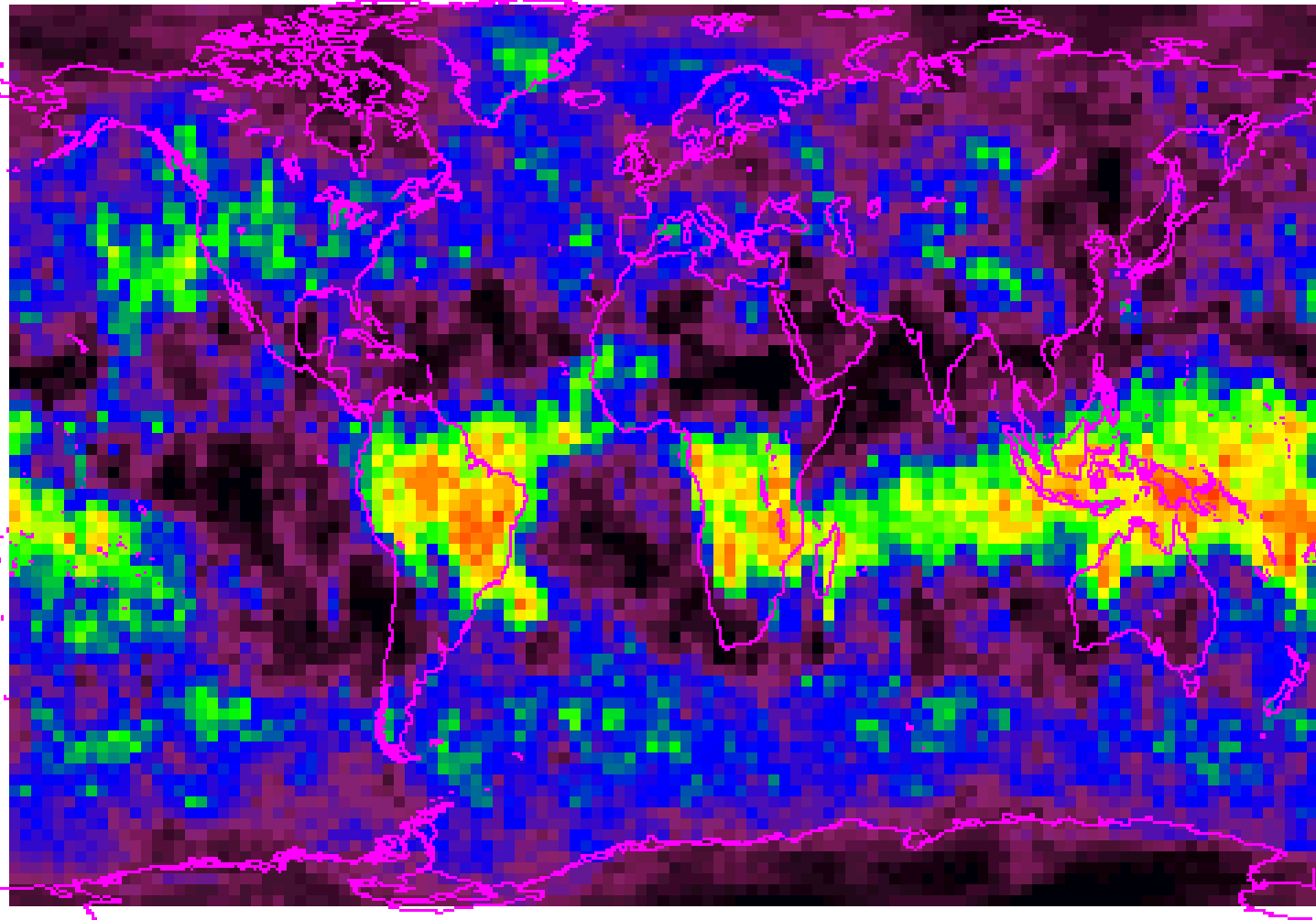
**UW NOAA Pathfinder HIRS global cloud statistics from  
December 1978 through December 2001**

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

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



NOAA 14 Jan 1997 High Clouds



Frequency of Clouds

0

20

40

60

80

100%

# **Inferring Decadal HIRS Cloud Trends requires corrections for**

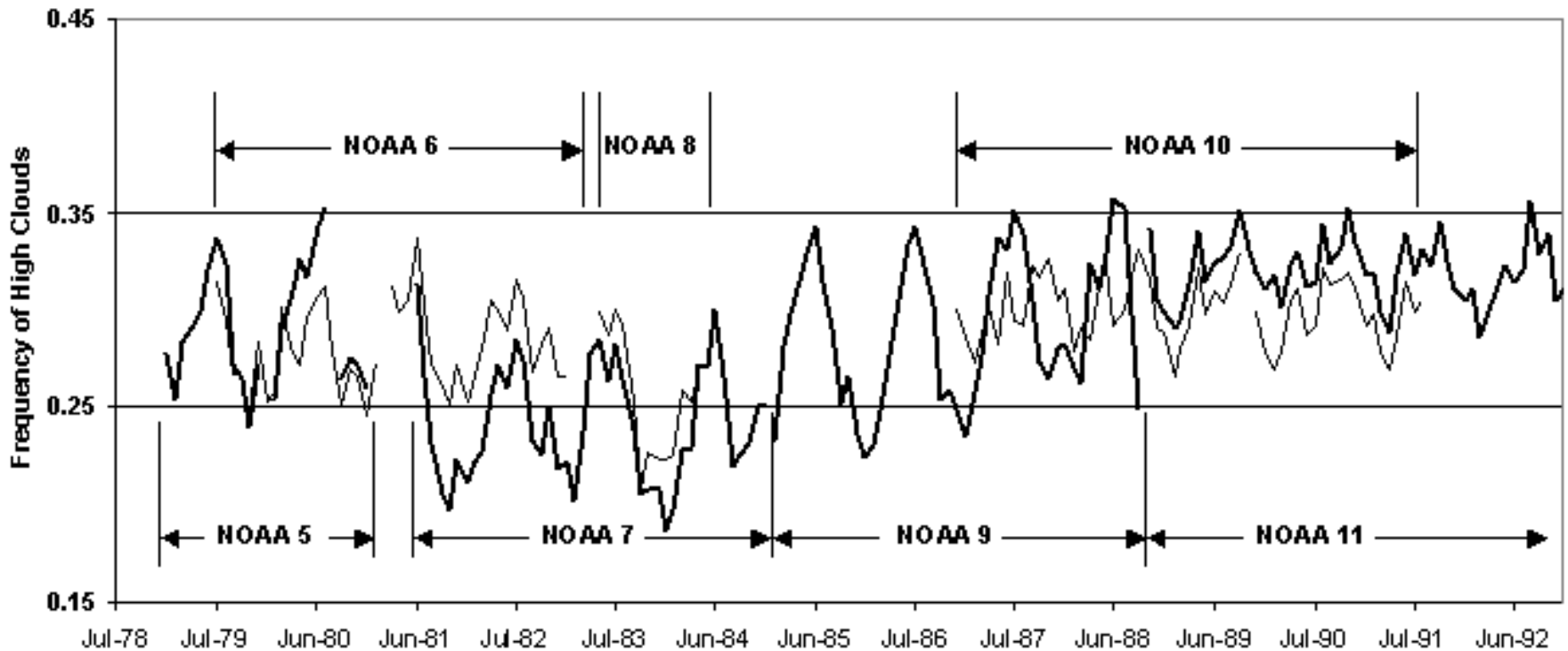
- (1) anomalous satellite data or gaps**
- (2) orbit drift**
- (3) CO<sub>2</sub> increase**

**constant CO<sub>2</sub> 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.

## 20-60 North Over Land



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)

NOAA 6 HIRS/2

NOAA 8 HIRS/2

NOAA 10 HIRS/2

NOAA 12 HIRS/2

afternoon (2 pm LST)

NOAA 5 HIRS

NOAA 7 HIRS/2

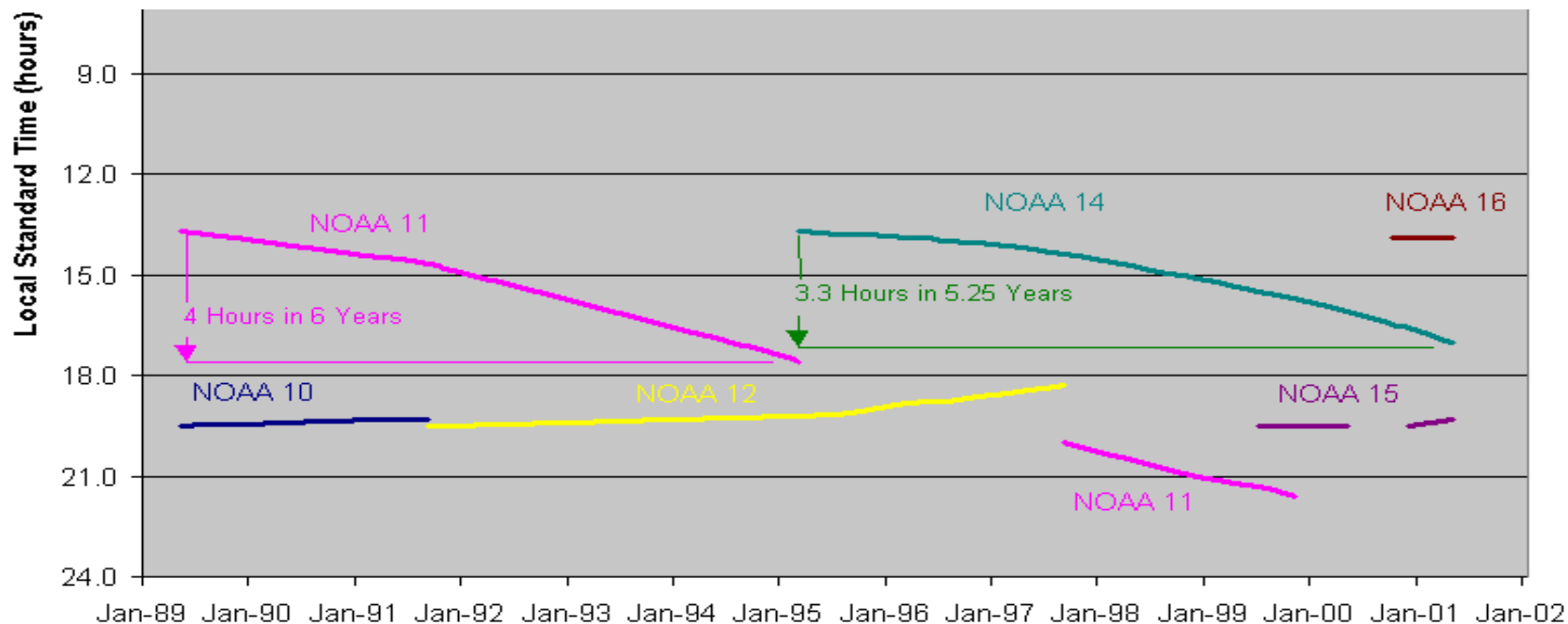
NOAA 9 HIRS/2

NOAA 11 HIRS/2I \*

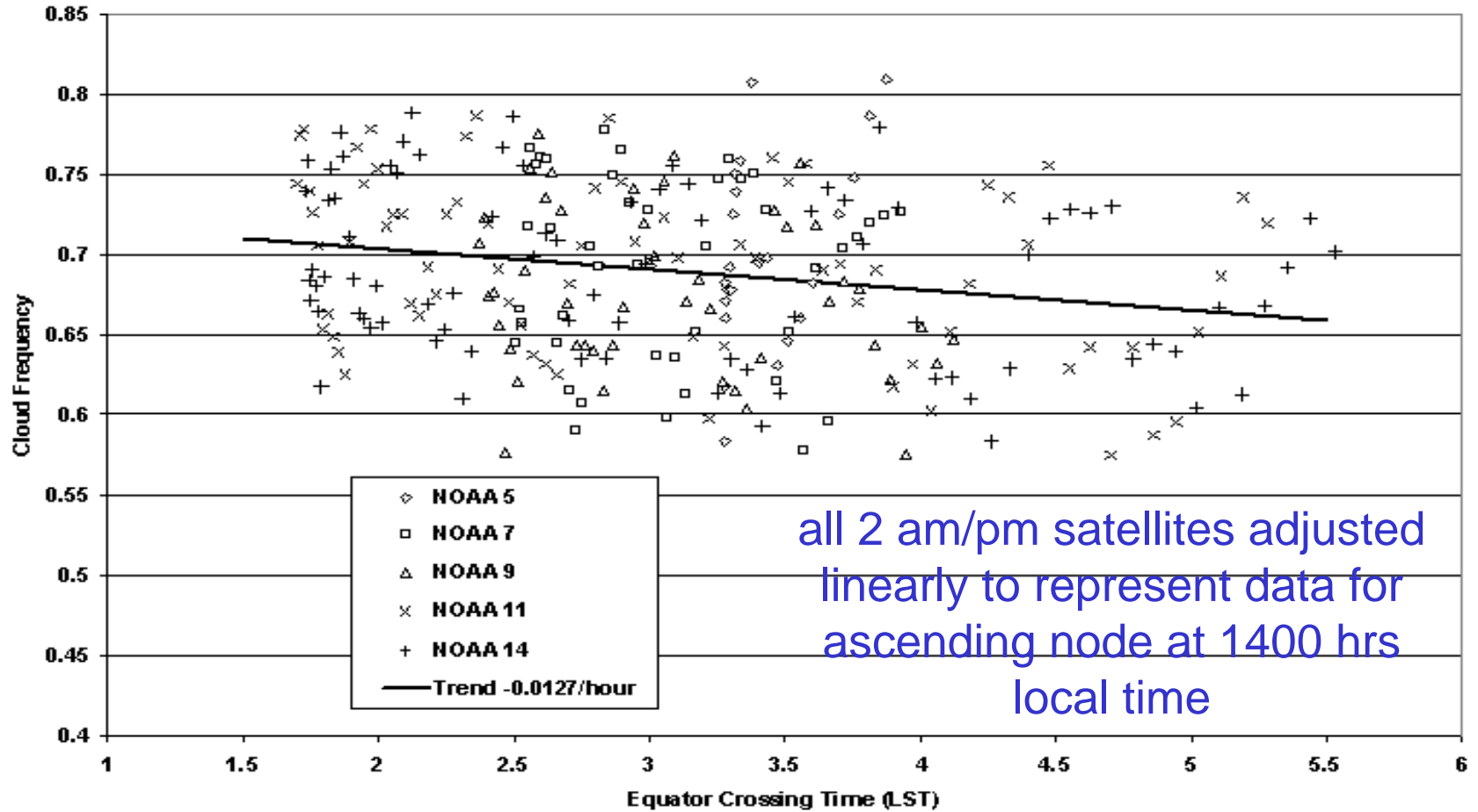
NOAA 14 HIRS/2I \*

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 the Frequency of All Clouds Over Land from 20-60 South Latitude  
with Equator Crossing Time for the 2 am/pm Orbit**



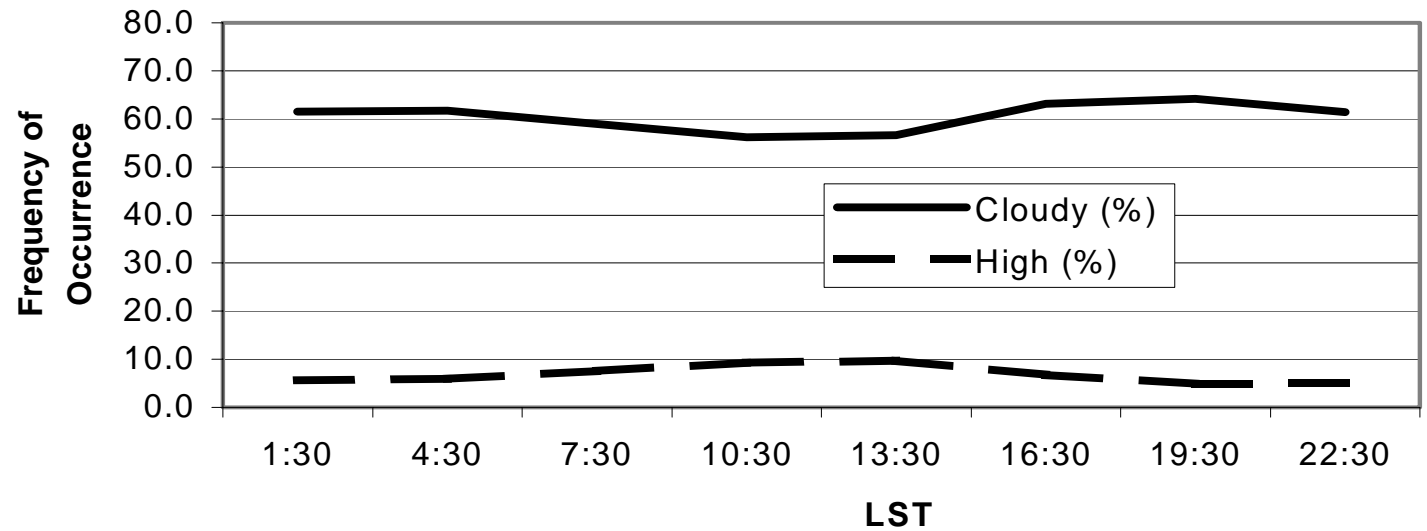
Change in cloud frequency per hour of orbit drift (cloud fraction per hour)

Orbit drift corrections.

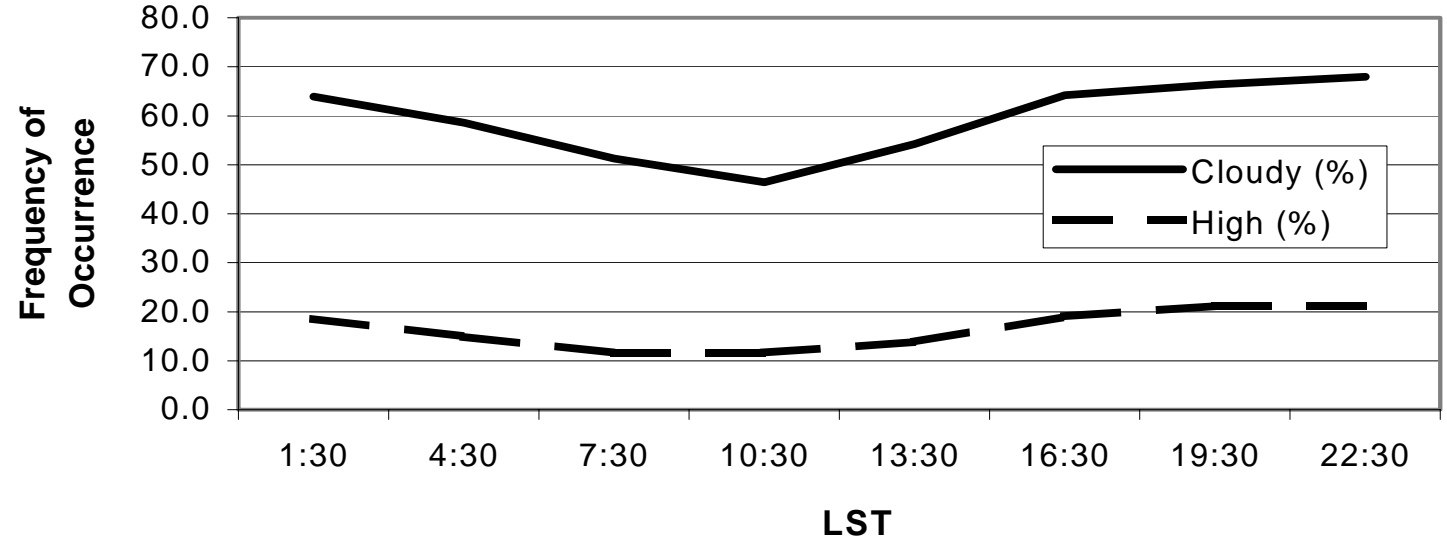
	All Clouds		High Clouds	
	Land	Ocean	Land	Ocean
20-60 North	-0.004	0.002	0.007	0.004
Tropics 20 S - 20 N	-0.010	0.006	0.010	0.004
20-60 South	-0.013	0.003	0.006	0.000

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

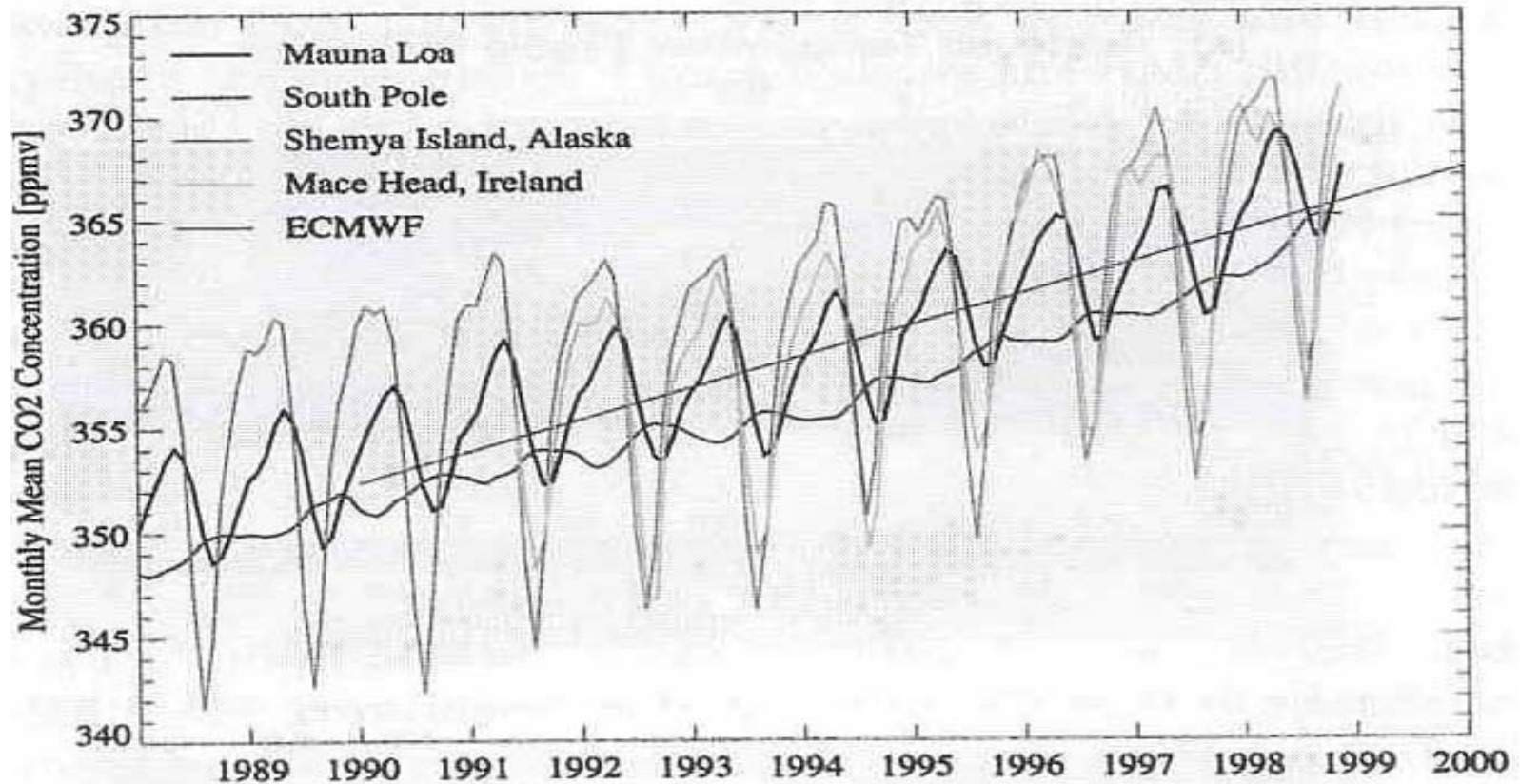
## Diurnal Change of Frequency of Clouds during Winter 1999



## Diurnal Change of Frequency of Clouds for Summer 1999



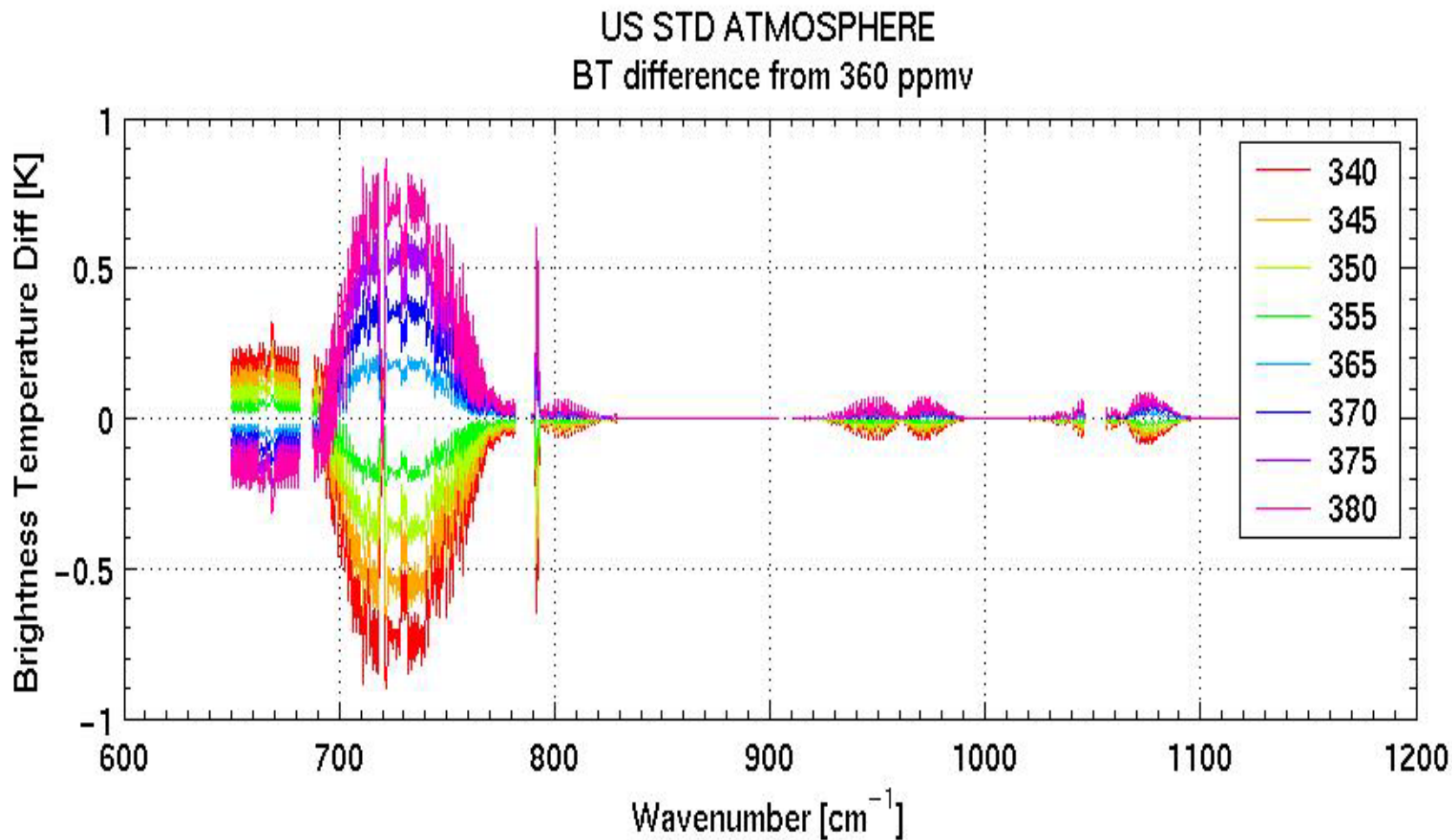
# Atmospheric CO<sub>2</sub> has not been constant



**Figure 1.** Time series of monthly mean surface CO<sub>2</sub> 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<sub>2</sub> concentration assumed constant at 380 ppm.

Lower CO<sub>2</sub> concentrations increase the atmospheric transmission, so radiation is detected from lower altitudes in the atmosphere.

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

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

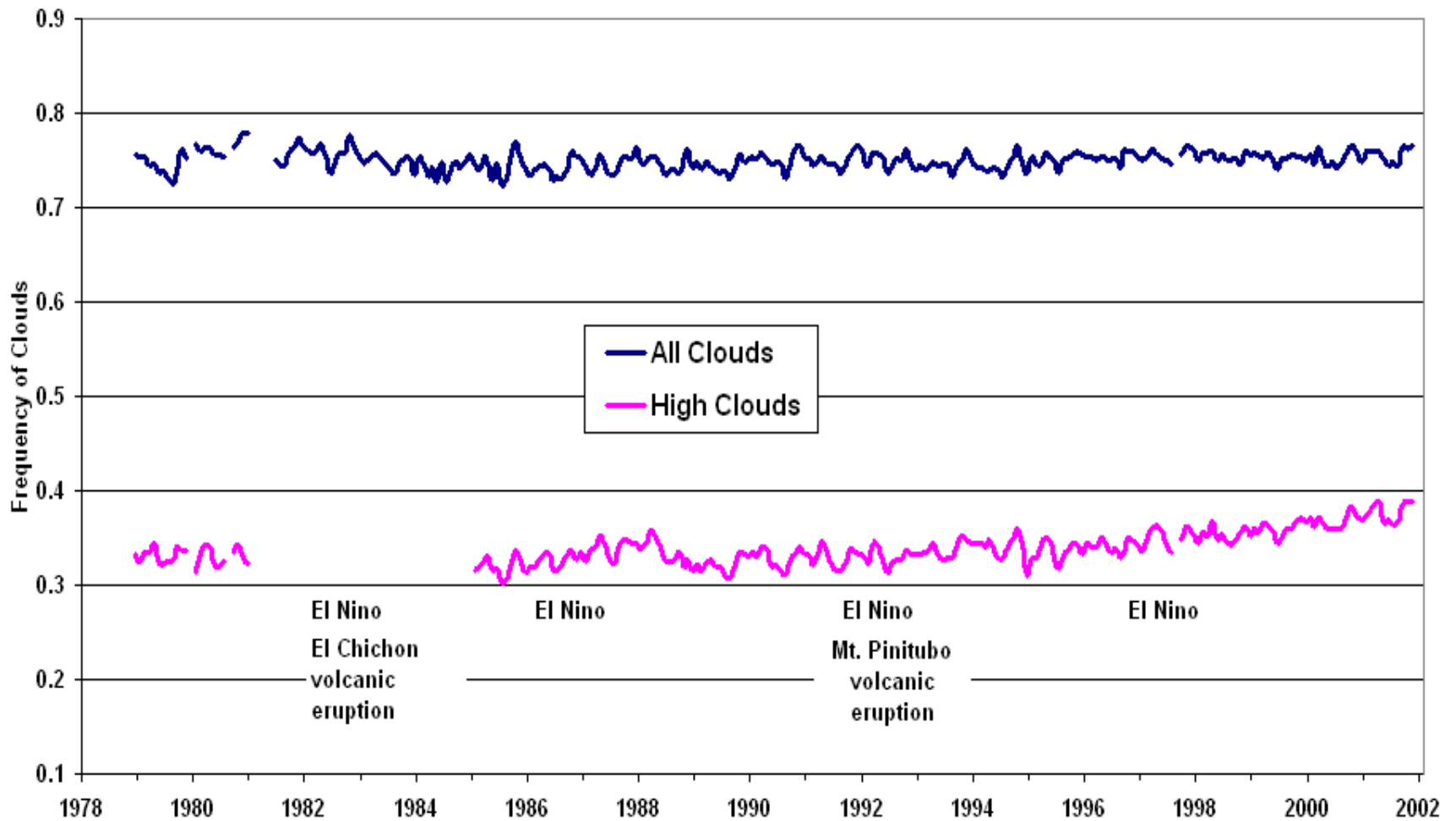
For January and June 2001 the clouds detected by NOAA 14 in the more transparent atmosphere (CO<sub>2</sub> at 335 ppm) are found to be lower by 15-50 hPa

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

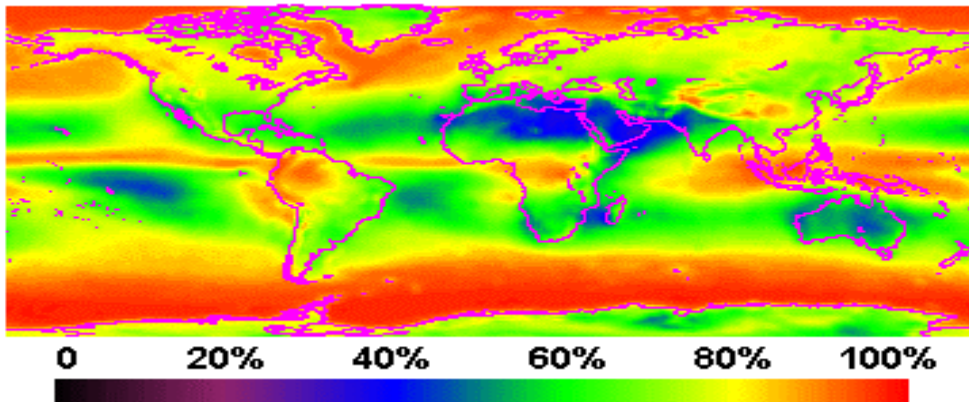
Cloud time series was adjusted to represent a linear increase of CO<sub>2</sub> from 335 ppm in 1979 to 375 ppm in 2001

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

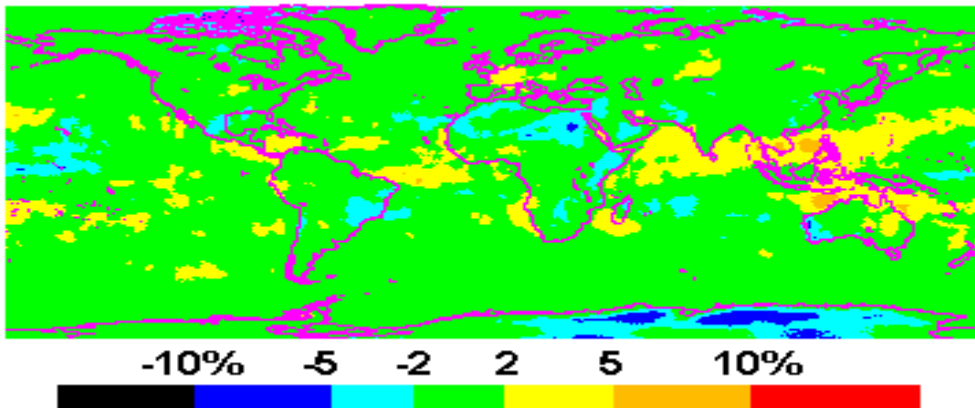
	20-60 N		20 S - 20 N		20-60 S	
	Ocean	Land	Ocean	Land	Ocean	Land
	<b>HIRS uncorrected</b>					
High Clouds	0.013	0.014	none	0.017	0.014	0.021
All Clouds	none	none	0.018	None	none	none
	<b>HIRS corrected</b>					
High Clouds	0.023	0.021	none	0.017	0.027	0.029
All Clouds	none	none	0.014	None	none	none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



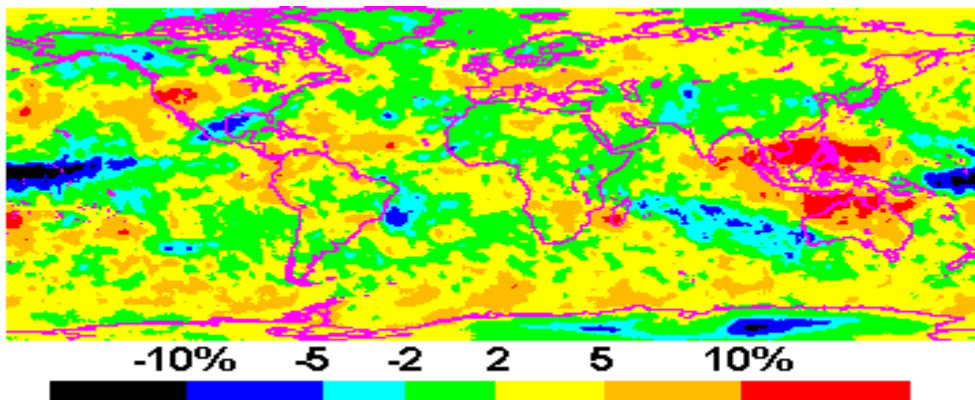
The monthly average frequency of clouds and high clouds (above 6 km) from 70 south to 70 north latitude from 1979 to 2002; Wylie et al 2005.



Frequency of all clouds found  
in HIRS data since 1979



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



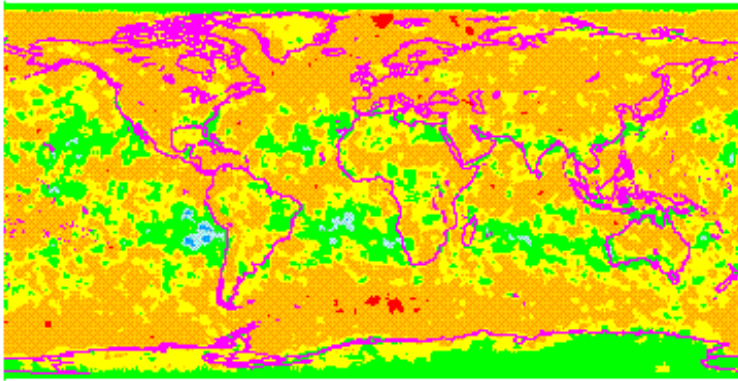
Change in high cloud (above 6  
km) frequency during northern  
hemisphere winters

Wylie et al 2005

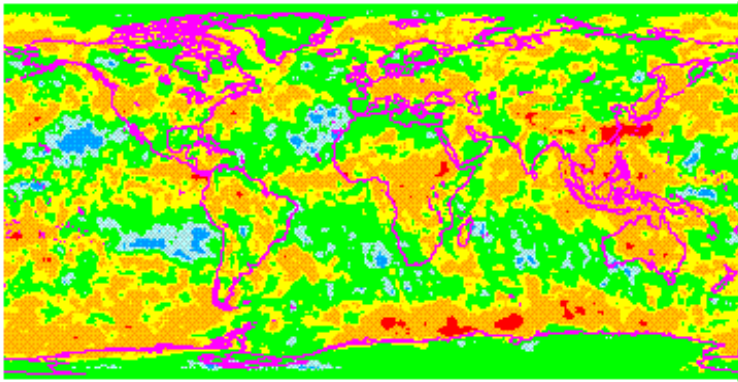
# Change in Light and Dense Cirrus from 1980s to 1990s

## Cloud Frequency Change

### Light Cirrus



### Dense Cirrus



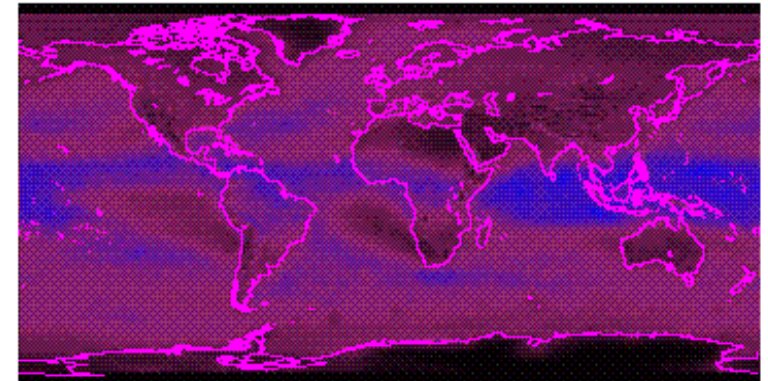
10 Year Change in Cloud Frequency (%)

-5      -2      0      2      5

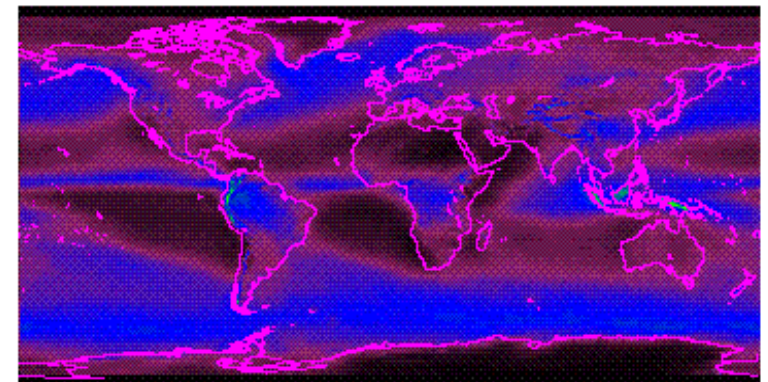


## Average Cloud Frequency

### Light Cirrus



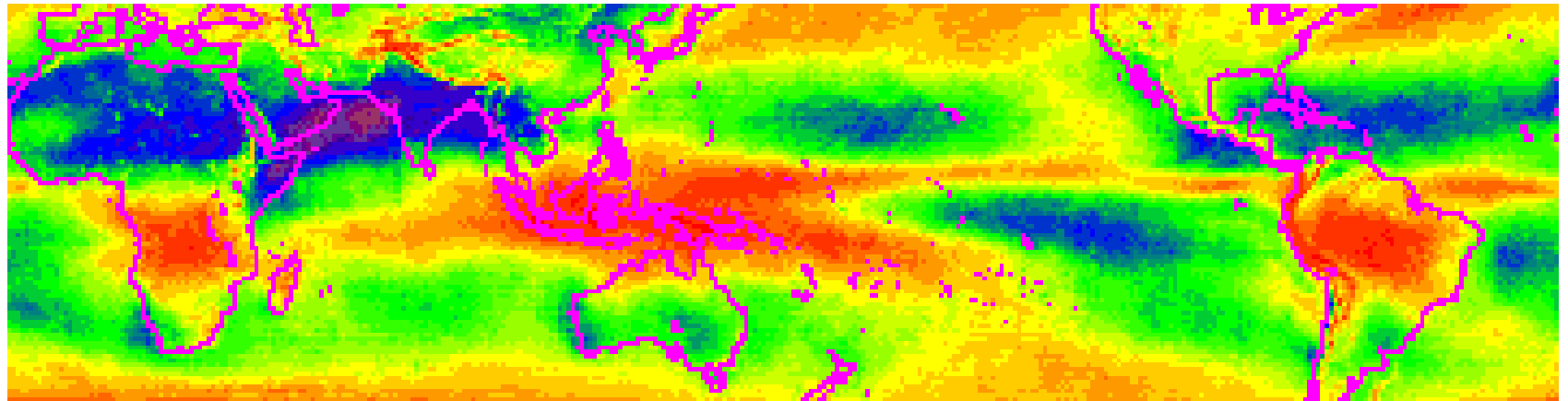
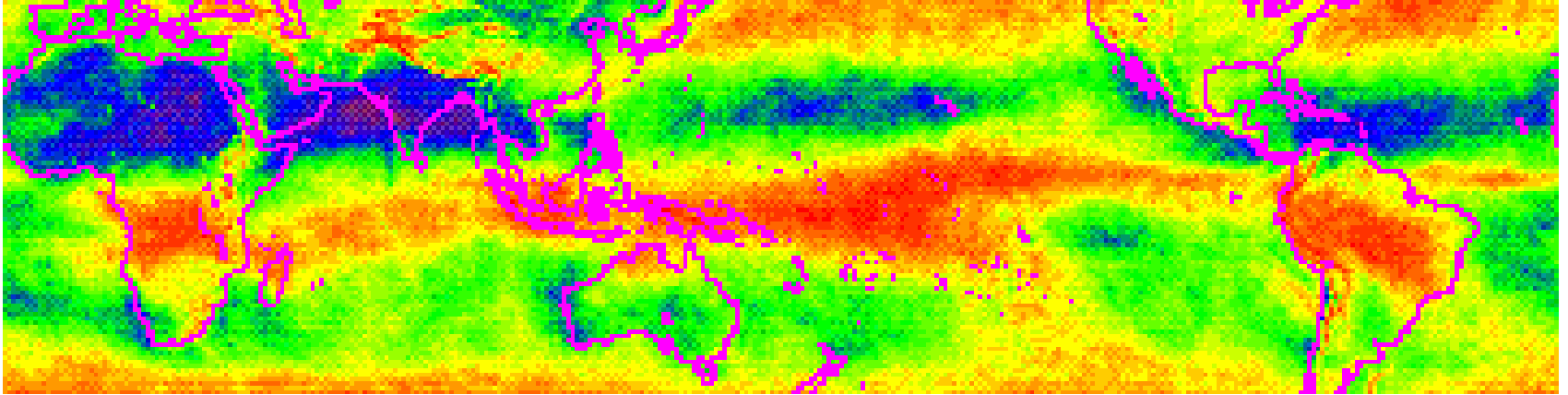
### Dense Cirrus



FREQUENCY OF CLOUDS

0      20      40      60      %80





High cloud (above 6 km) frequency in El Niño 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?

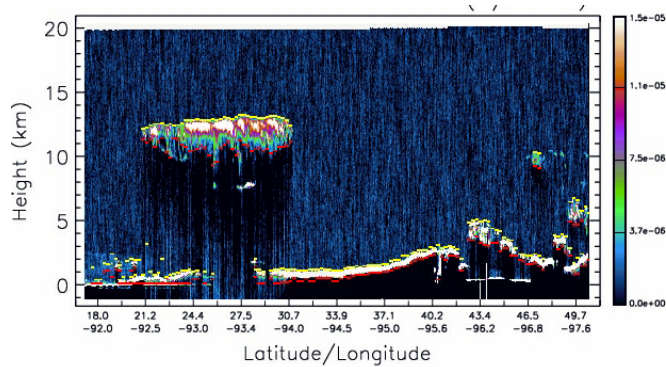
Source	All Clouds			High Clouds		
	Land	Sea	Both	Land	Sea	Both
<b>ISCCP</b>	<b>56 %</b>	<b>70 %</b>		<b>25 %</b>	<b>20 %</b>	
<b>HIRS Pathfinder</b>	<b>71</b>	<b>77</b>		<b>34</b>	<b>32</b>	
<b>Surface Reports</b>	<b>52</b>	<b>65</b>		<b>54</b>	<b>43</b>	
<b>SAGE</b>			<b>73</b>			<b>53</b>
<b>CLAVR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

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

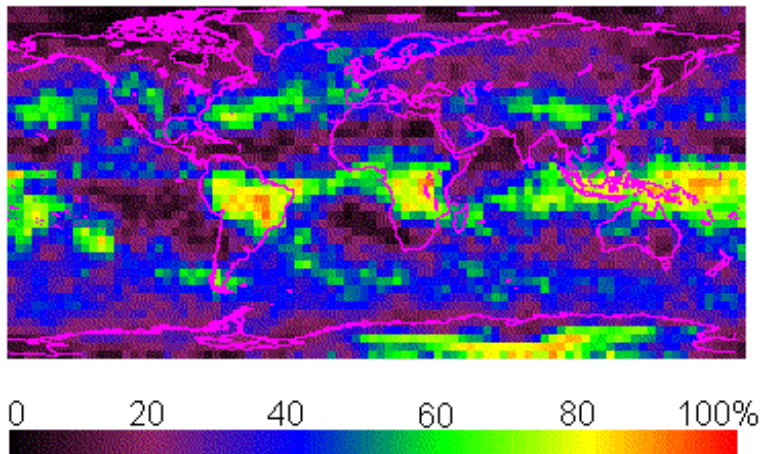
GLAS 22 Feb – 28 Mar 2003, HIRS 1979 – 2001, ISCCP 1983 – 2001,  
 SAGE 1985-89, Surface Reports 1980-89, CLAVR 1982 - 2004  
 ISCCP reports 7-15% less cloud than HIRS because it misses thin cirrus.  
 HIRS and GLAS report nearly the same high cloud frequencies.  
 HIRS reports more clouds over land than GLAS probably because GLAS  
 sees holes in low cumulus below the resolution of HIRS.



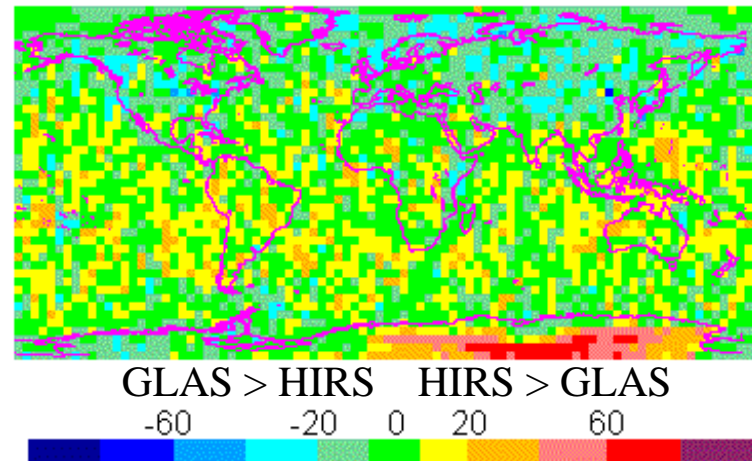
# HIRS vs GLAS High Clouds



## HIRS Frequency of High Cloud

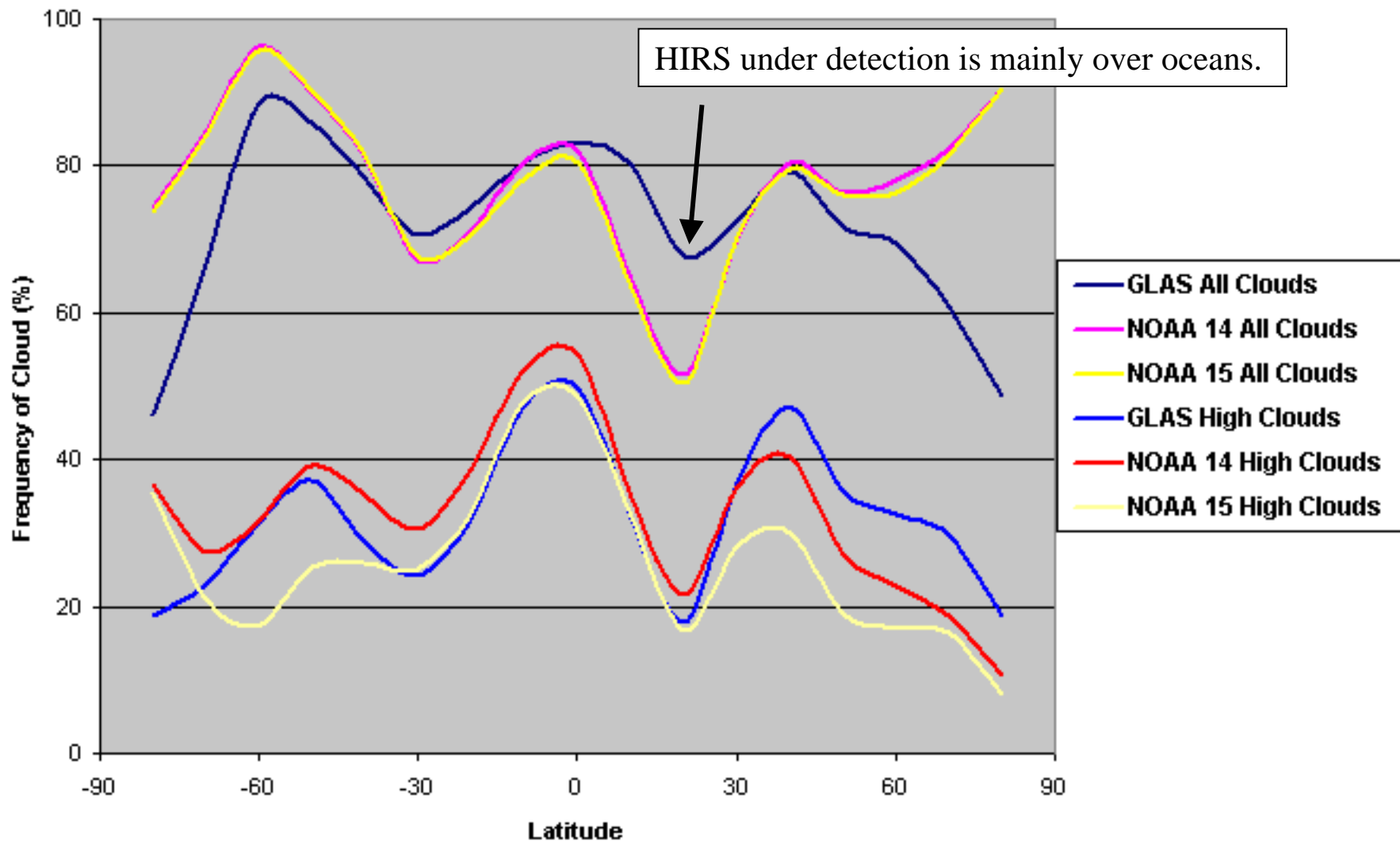


## HIRS – GLAS Difference

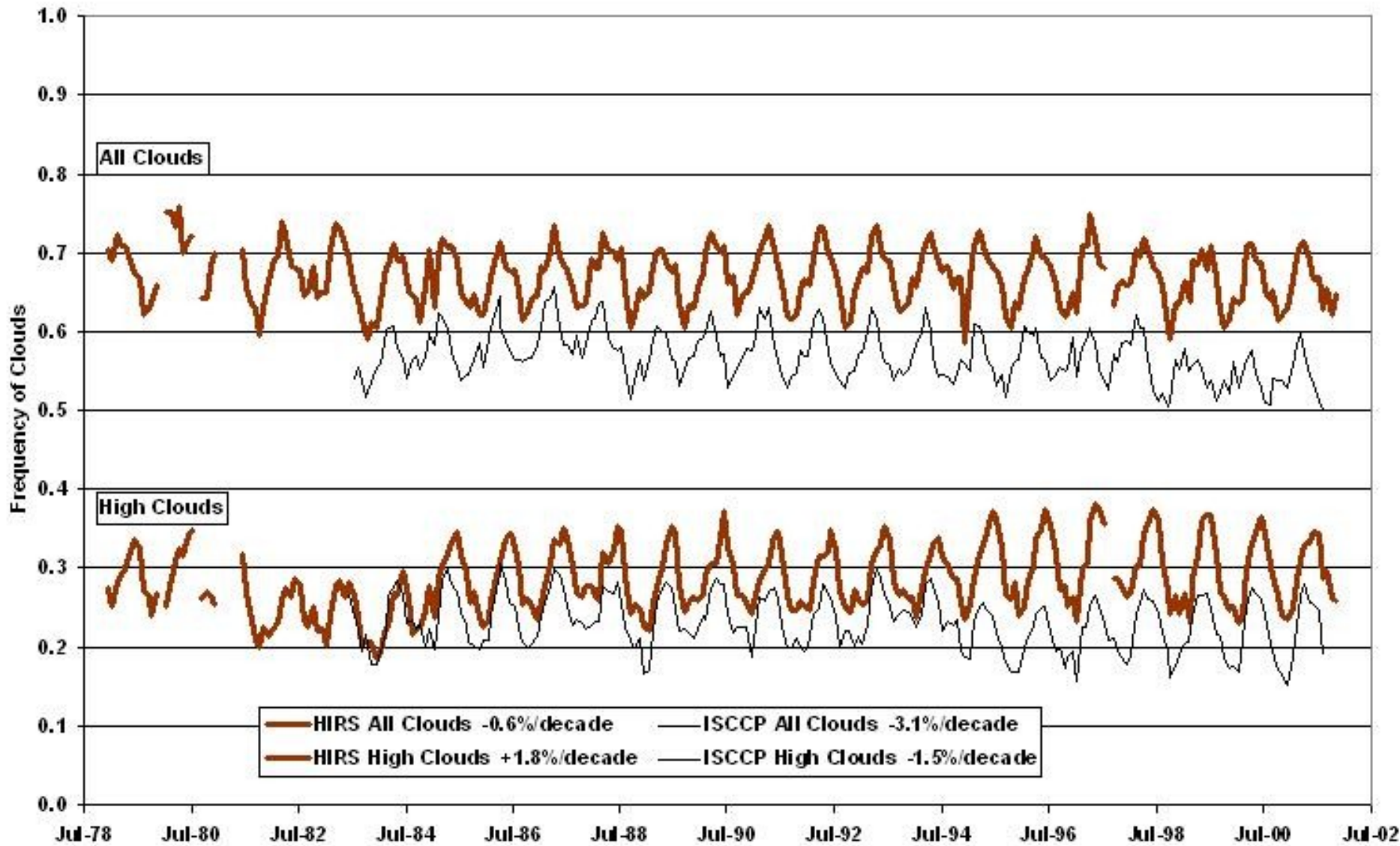


HIRS reports more high clouds in parts of tropics and southern hemisphere, but areas of differences are scattered and not meteorologically organized.

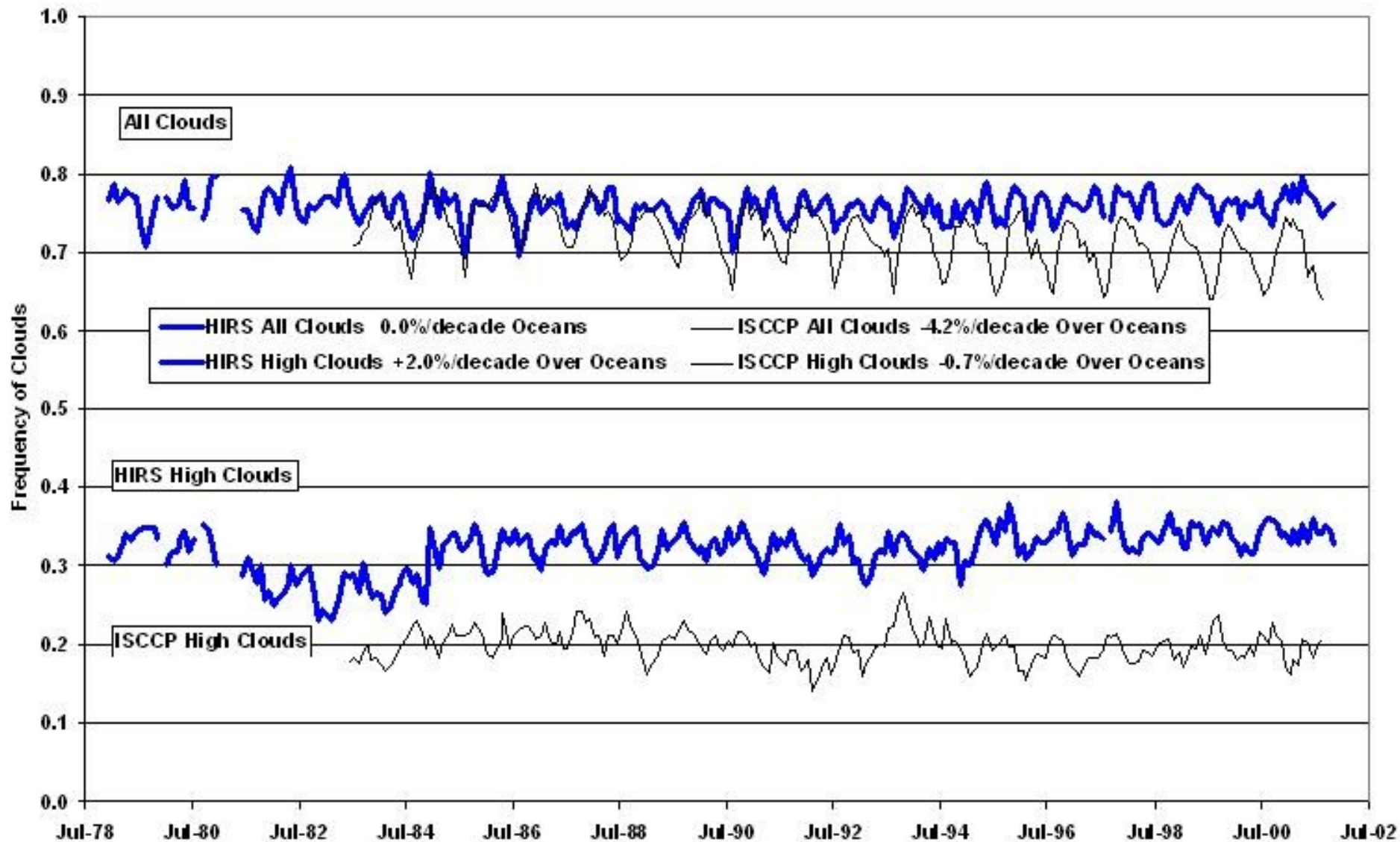
**GLAS - HIRS Comparison**  
**21 Feb. - 28 March, 2003**



### 20 - 60 North Latitude Over Land



### 20 - 60 North Latitude Over Oceans



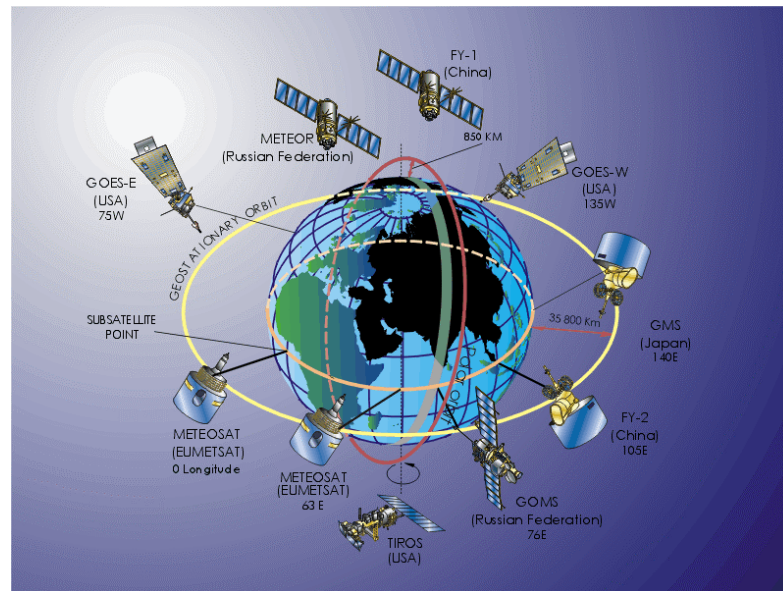
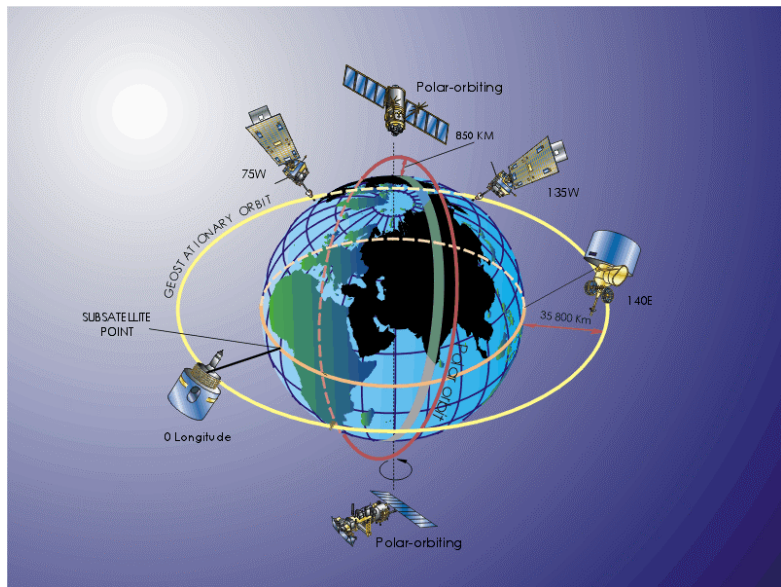
Wylie et al

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  $\mu\text{m}$  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 2000 (right)

# **Challenges for Climate data sets**

**Spectral consistency**

**(if not possible at least spectral knowledge)**

**Accurate radiative transfer**

**(accommodating seasonal and interannual CO<sub>2</sub> 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<sub>2</sub> 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