INFERRING CLOUD PROPERTIES

(T, Pc, N, E, and phase)

FROM MODIS OBSERVATIONS

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RATIONALE FOR CLOUD INVESTIGATIONS

Clouds are a strong modulator of shortwave and longwave components of the Earth radiation budget

Knowledge of cloud properties and their changes in time and space are crucial to studies of weather and climate

Global climate change models need accurate estimation of cloud cover, height, emissivity, thermodynamic state, particle size

- high clouds give positive feedback to greenhouse effect, low clouds give negative feedback

- climate induced changes in optical properties may be negative feedback, eg. clouds created from anthropogenic aerosols exhibit higher albedo

There is a need for consistent long term observation records to enable better characterization of the statistics of weather and climate variability

GLOBAL CLOUD STATISTICS

Effect of clouds on global radiative processes large

- 1% change in global cloud cover equivalent to about 4% change in CO_2 concentration

Accurate determination of global cloud cover has been elusive

- semi transparent clouds often underestimated by 10%

CO_2 Technique uses multispectral approach to better characterize global semi-transparent clouds

- Over 15 million observations processed from nearly four years of HIRS data (Jun 89 through Apr 93)

OUTLINE

DIFFICULTY ESTIMATING CIRRUS CLOUD PARAMETERS

CO2 ALGORITHM (THEORY AND PERFORMANCE)

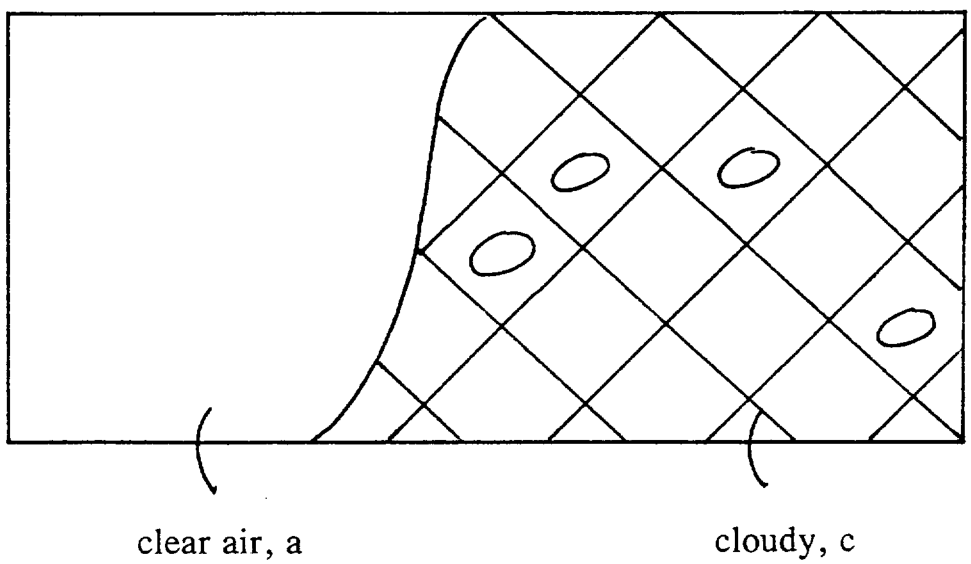
HIRS APPLICATION

FOUR YEAR HIRS CLOUD STATISTICS

TRENDS

CONCLUSIONS

Cloud Parameter Determinations from Satellite Measured Radiances for a given field of view (FOV) partly clear and partly cloudy



$$R = [1 - N] R_a + N R_c$$

but if b indicates opaque "black" cloud

$$R_c = [1 - E] R_a + E R_b(p_c)$$

so together

$$R = [1 - NE] R_a + NE R_b(p_c)$$

BASIS FOR THE CO2 CLOUD ALGORITHM

Radiation sensed for a cloudy FOV is given by

$$R = (1\text{-}NE)\,[B_s\, t_s + \int_{p_s}^{p_c} B\, dt] \qquad \text{below cloud}$$

$$+\ NE\, B_c\, t_c \qquad \text{cloud}$$

$$+\int_{p_c}^{0} B\, dt \qquad \text{above cloud}$$

For clear sky indicated by the subscript a

$$R_a = B_s\, t_s + \int_{p_s}^{0} B\, dt$$

Integrating by parts yields the radiation cloud forcing in
a partly cloudy field of view is characterized by two unknowns NE and p

$$R - R_a = NE \int_{p_s}^{p_c} t\, dB$$

or

$$R - R_a = NE\, [R_b(p_c) - R_a]$$

where

a indicates clear air

b indicates opaque "black" cloud

NE is effective emissivity of the fov

p_c is the cloud pressure

BASIS FOR THE CO2 CLOUD ALGORITHM

Radiation cloud forcing sensed in a given spectral band in
a partly cloudy field of view is characterized by two unknowns NE and p

$$R - R_a = NE\,[R_b(p_c) - R_a]$$

where

a indicates clear air
b indicates opaque "black" cloud
NE is effective emissivity of the fov
p_c is the cloud pressure

CO2 Slicing Solution

(1) measure ratio of cloud forcing for two CO2 channels,
and calculate p_c assuming NE is same

$$\frac{R(i) - R_a(i)}{R(j) - R_a(j)} = \frac{NE(i) \int_{p_s}^{p_c} t(i,p)\, dB[i, T(p)]}{NE(j) \int_{p_s}^{p_c} t(j,p)\, dB[j, T(p)]}$$

where

t is transmittance
B is Planck function
T(p) is the temperature at pressure p
LHS is measured and RHS is calculated

(2) measure longwave infrared window channel cloud forcing,
and calculate NE given p_c

$$NE(w) = [R - R_a] / [R_b(p_c) - R_a]$$

CO_2 TECHNIQUE PERFORMANCE

Radiative transfer formulation independent of cloud cover

Heights have been proven with VAS and HIRS CO_2 channels against lidar, stereo, and radiosonde (within 50 mb)

Effective emissivity compares within 20% with lidar observations

CO_2 technique detects cirrus reliably (begins missing when radiative attenuation is less than 10%)

Ground observations of clear sky agree 80% of the time

FOUR YEARS OF GLOBAL CLOUD STATISTICS

Processing procedure unchanged from before

HIRS data from NOAA 10, 11, and 12 used

zenith angle less than 10 degrees

every third field of view (FOV) on every third line

half of Earth sampled each day with two satellites

morning orbits over land rejected

Arctic and Antarctic satellite detection of surface temperature inversions assumed to indicate clear sky

CO2 slicing algorithm

CO2 cloud top pressures calculated when the cloud forcing (clear minus cloudy radiance) greater than instrument noise

otherwise the IR window used to get opaque cloud top pressure

fields of view determined clear or cloudy if moisture IR window temperature within 2 K of $T_{surface}$

(LST from the NMC MRF; SST from NMC SST analysis)

Table 1: HIRS four year global cloud statistics (June 1989 to May 1993). The frequency of cloud observations for different heights and effective emissivities. Percentages are of the total number of observations, clear and cloudy combined. Clouds were not detected in 23 % of the observations.

	ALL CLOUDS	EFFECTIVE EMISSIVITY					
LEVEL		<0.25	<0.50	<0.75	<0.95	>0.95	
<200 mb	3.5%	1.2%	0.4%	0.3%	0.7%	0.9%	
<300 mb	9.6	2.3	1.9	1.6	2.1	1.7	hi 23.9%
<400 mb	10.8	2.5	2.3	2.2	2.4	1.4	
<500 mb	11.0	2.3	2.5	2.6	2.5	1.1	
<600 mb	8.2	1.4	2.2	2.5	0.7	1.4	mid 27.0%
<700 mb	7.8	0.6	1.2	1.7	0.7	3.6	
<800 mb	7.6	0.2	0.4	0.4	0	6.6	
<900 mb	11.5	0	0	0	0	11.5	lo 25.9%
<1000 mb	6.8	0	0	0	0	6.8	
Total	76.8%	10.5%	10.9%	11.3%	9.1%	35.0%	

clear 23.2% semitransparent 41.8% opaque 35.0%

freq clouds over land 67% ocean 79%

cirrus over land 39% ocean 43%

thin clouds (NE <.50) over land 18% ocean 22%

Table 2a: The change in HIRS global cloud cover from year 1 (June 1989 - May 1990) to year 2 (June 1990 - May 1991). Numbers are frequency of cloud cover in summer and winter of year 2 minus the the same in year 1; negative numbers indicate a decrease in cloudiness while positive numbers indicate an increase.

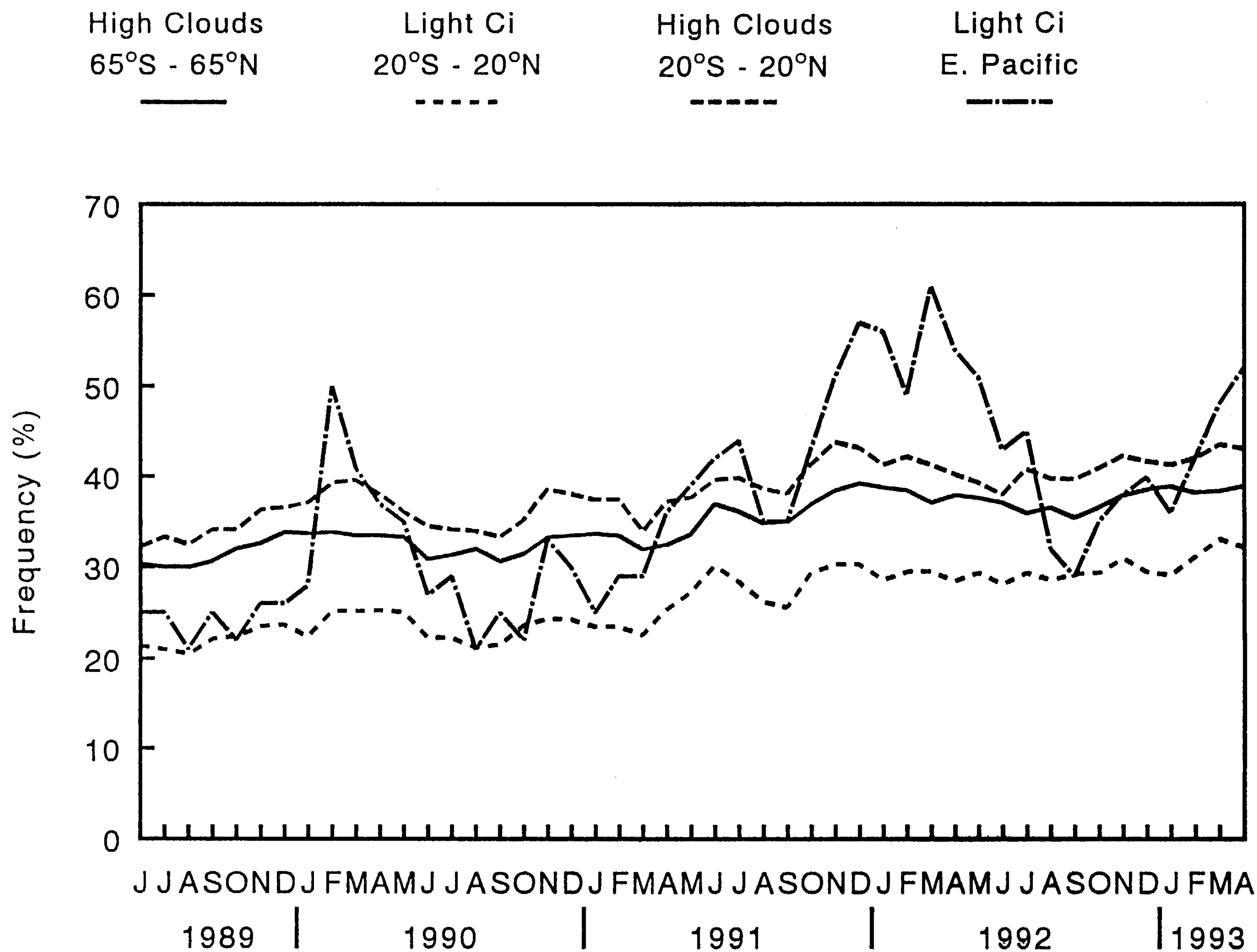
	EFFECTIVE EMISSIVITY		
LEVEL	thin<0.50	thick>0.50	opaque>0.95
hi < 400 mb	0	1	-1
mid <700 mb	0	-1	0
low <1000 mb	0	0	0
Total	0	0	-1

Table 2b: The change in HIRS global cloud cover from year 2 (June 1990 - May 1991) to year 3 (June 1991 - May 1992). Numbers are frequency of cloud cover in summer and winter of year 3 minus the same in year 2.

	EFFECTIVE EMISSIVITY		
LEVEL	thin<0.50	thick>0.50	opaque>0.95
hi < 400 mb	4	1	0
mid <700 mb	2	1	-2
low <1000 mb	0	0	-5
Total	6	2	-7

Table 2c: The change in HIRS global cloud cover from year 3 (June 1991 - May 1992) to year 4 (June 1992 - Apr 1993). Numbers are frequency of cloud cover in summer and winter of year 4 minus the same in year 3.

	EFFECTIVE EMISSIVITY		
LEVEL	thin<0.50	thick>0.50	opaque>0.95
hi < 400 mb	0	0	0
mid <700 mb	2	-1	0
low <1000 mb	0	0	2
Total	2	-1	2



High Clouds
65°S - 65°N
Light Ci
20°S - 20°N
High Clouds
20°S - 20°N
Light Ci
E. Pacific
Frequency (%)
70
60
50
40
30
20
10
0
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A
1989
1990
1991
1992
1993

CONCLUSIONS FROM FOUR YEAR HIRS CLOUD STUDY

Global Averages

* clouds are found in 76% of all observations
67% over land and 79% over oceans

* global preponderance of semi-transparent high clouds continue
42% on the average between June 1989 and May 1992

* ITCZ shows high frequency of cirrus (greater than 50%)

* large seasonal changes in the storm belts at midlatitudes

* little seasonal change in cirrus is found between
45 -75 latitude

* more cirrus in summer tham winter in each hemisphere

Four year trends

* changes in cirrus cloud cover from year 1 to year 2 were small

* changes from year 2 to year 3 were large
opaque cloud down by 7% globally, while cirrus up by 8%

* changes from year 3 to 4 were small again

* changes in global cloud cover not yet understood
Mt. Pinatubo??? El Nino??

MODIS Opportunity

High spatial resolution with good S/N

Better determination of cloud properties
(cleaner Ra, separate N and E, spatial continuity checks)

Algorithm heritage with HIRS, AVHRR, and VAS

Testing with MAS at high spatial resolution

MODIS processing will use boxes of 5 x 5 FOV to determine cloud properties

Gridded global product at .5 deg

Coverage from AM andd PM platforms