The Vertical Structure of Cloud Radiative Forcing at the SGP ARM Site As Revealed by 8 Years of Continuous Data

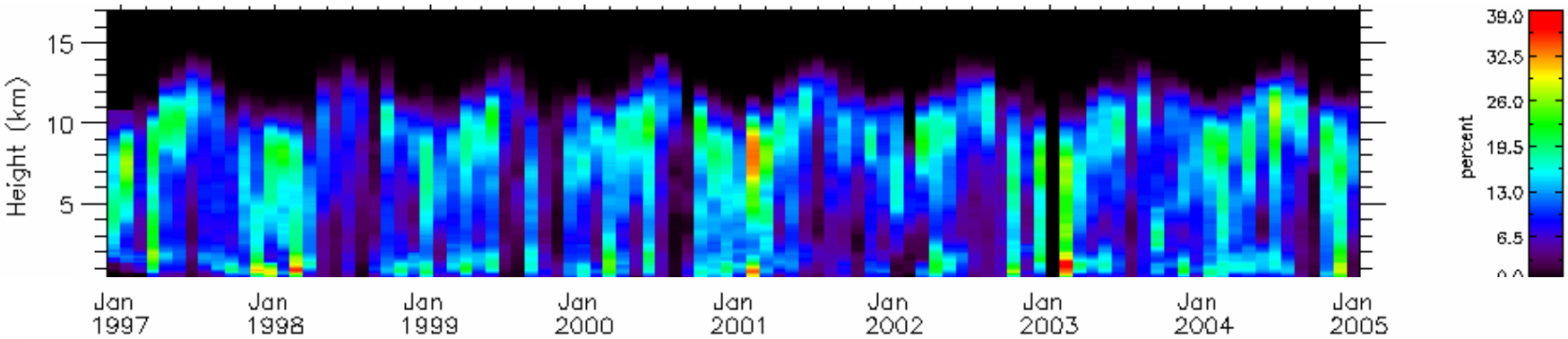
Jay Mace, Sally Benson

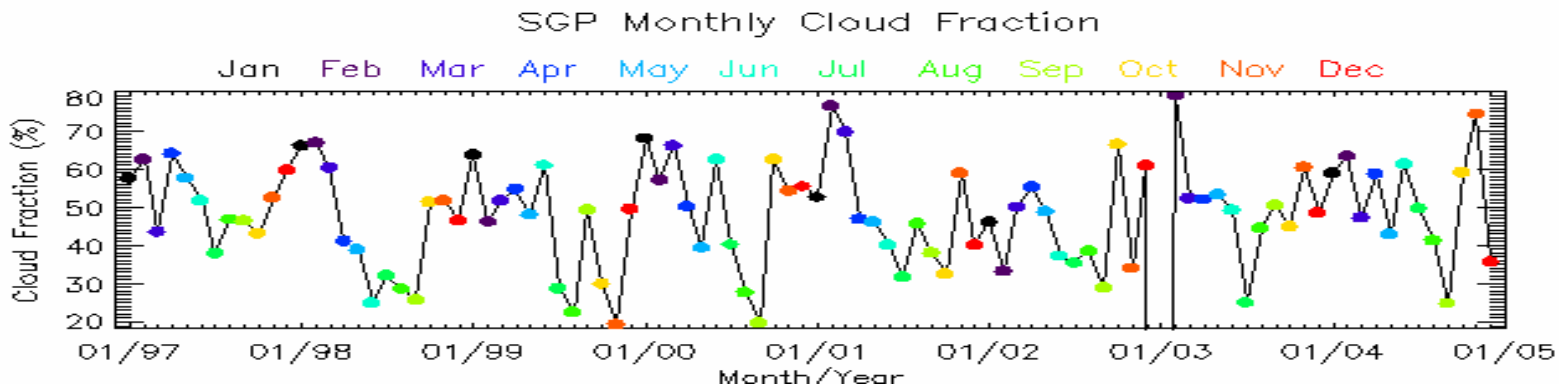
- The MMCR at the SGP ARM site began operation in late 1996 and has collected data nearly continuously since that time

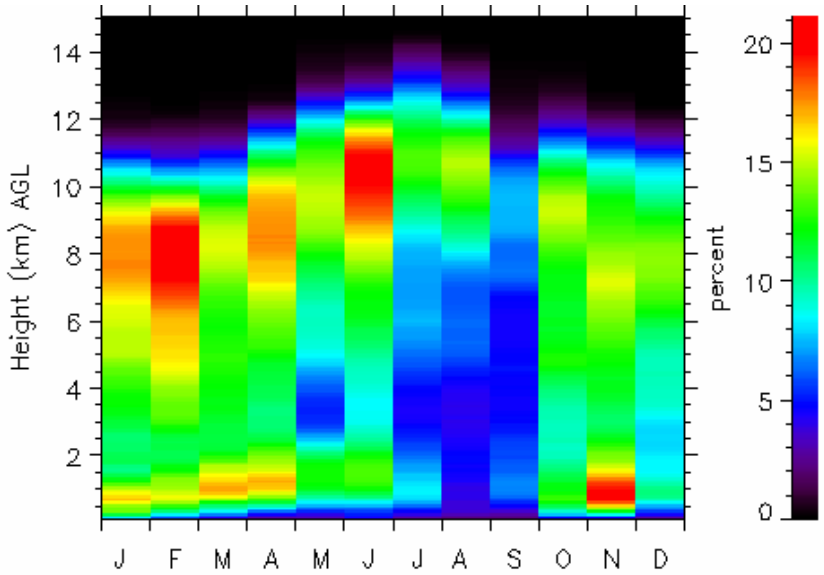
- Combined with other active and passive data at the ARM site, an unprecedented record of cloud vertical structure has been collected

- Goals:
    1. Document cloud occurrence, Cloud Radiative Effect (CRE) and the vertical structure of Cloud Radiative Forcing (CRF).
    2. Document the relationship of these quantities with the large-scale meteorological state.
    3. Use this information as metrics against which GCMs can be compared.

Monthly Cloud Occurrence Frequency







Toward Continuous Cloud Microphysics:

MACE ET AL.: CLOUD FORCING AT THE ARM CRF, 1
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D11S90, doi:10.1029/2005JD005921, 2006

Continuous thermodynamics are derived

Apply various microphysical retrieval algorithms to ARM data:

- Liquid Phase
- Ice Phase
- Mixed Phase scheme

Convert microphysics to radiative properties using various published schemes

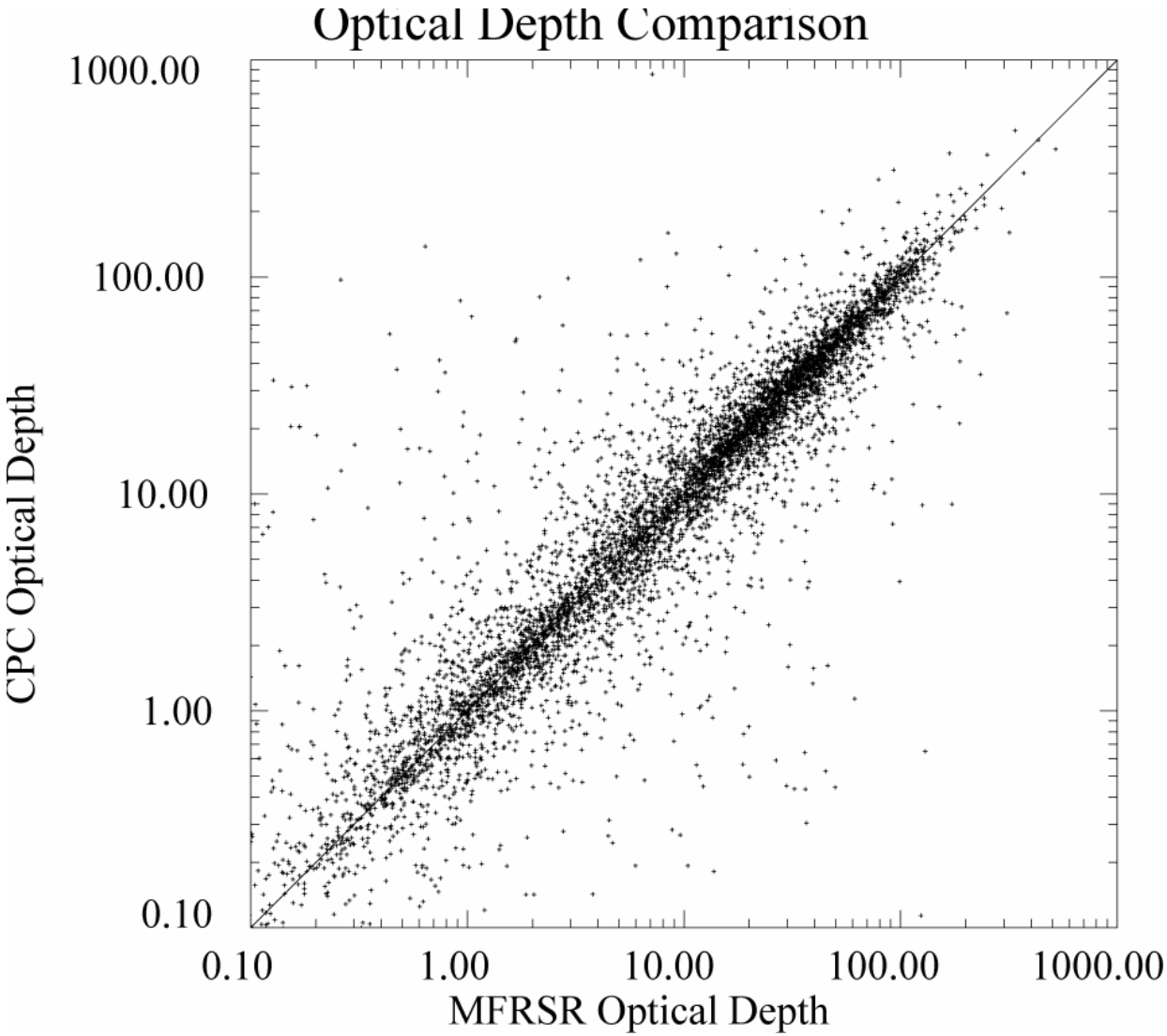
Compute Solar and IR Clear and Cloudy Fluxes

Exception:

- Precipitating Systems

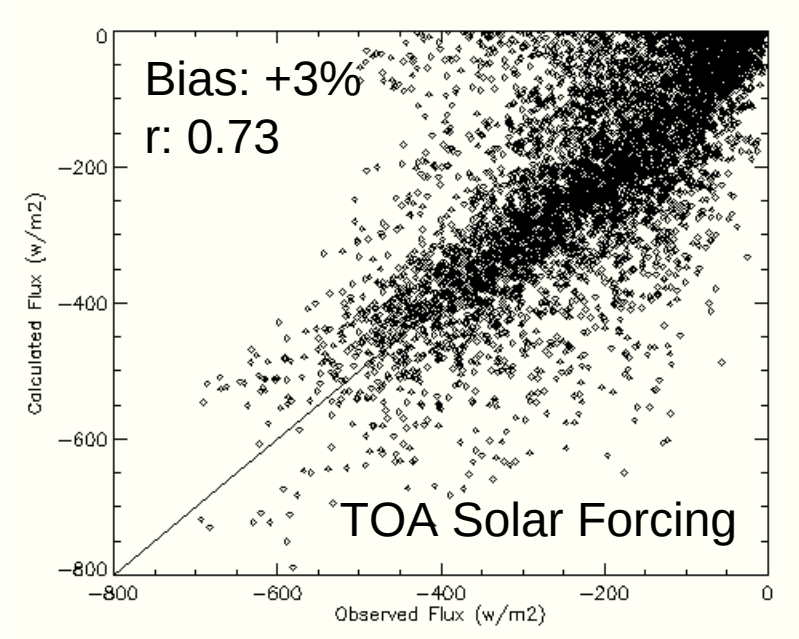
Validation of Microphysics and Radiation:

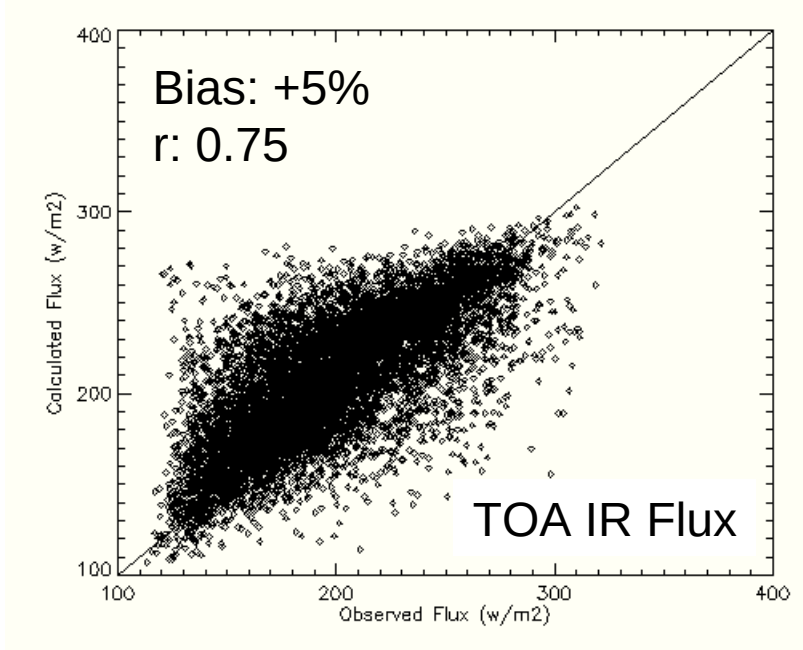
Comparison of derived optical depth with Qilong Min's MFRSR optical depth

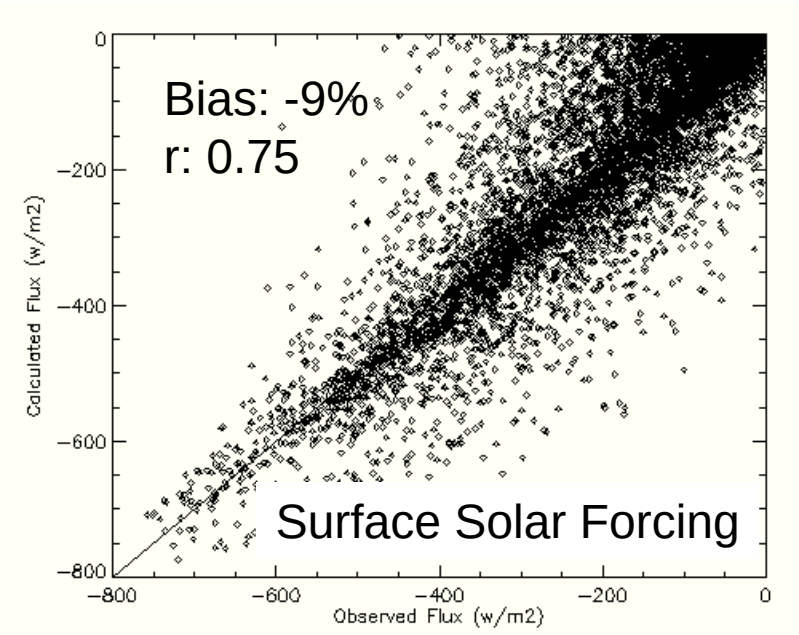


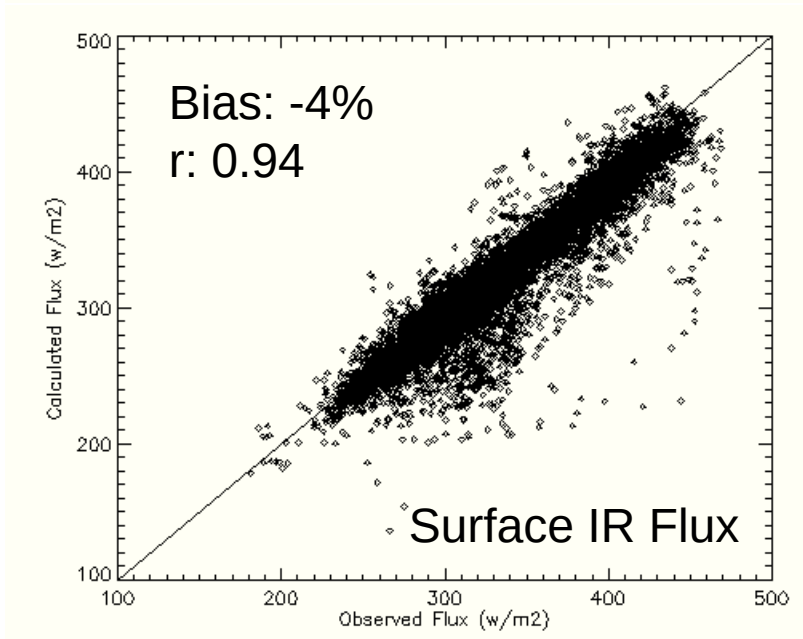
> 6000 observations show no bias and have a correlation coefficient of 0.6.

Radiative Closure: Comparison to TOA (Minnis) and Surface Fluxes (Long)





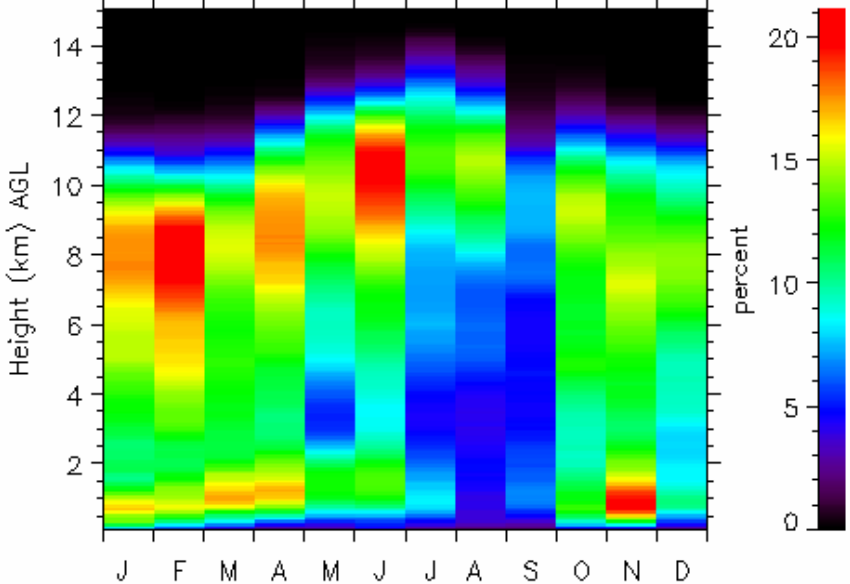


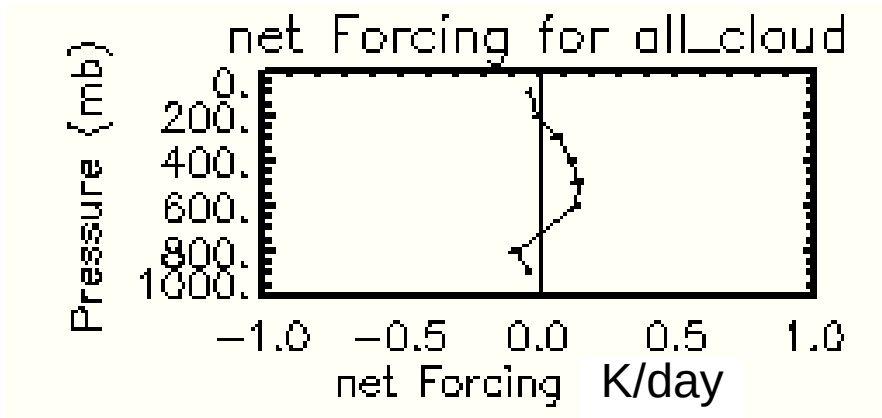


To what precision can we derive CRF and CRE with present suite of retrievals?

Error in calculated CRF and CRE (w/m2)

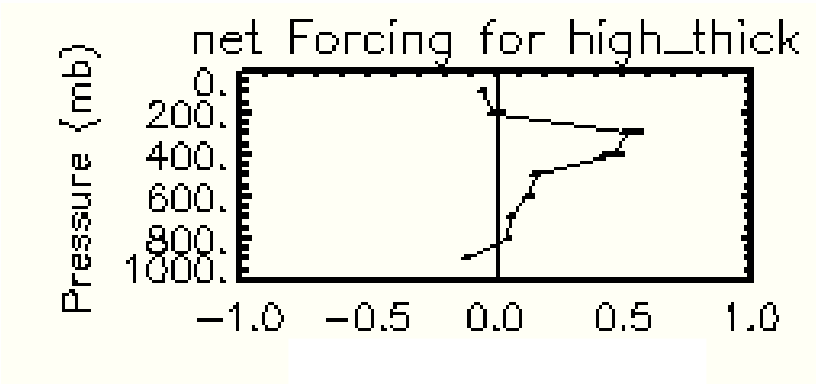
	1 hour	1 day	1 Week	1 Month
TOA Solar CRE (w m^{-2})	53	11	4.1	0.75
TOA IR CRE (w m^{-2})	16	3.3	1.2	0.22
Atm Solar CRE (w m^{-2})	55	11	4.2	0.78
Atm IR CRE (w m^{-2})	21	4.5	1.6	0.30
Sfc Solar CRE (w m^{-2})	15	2.8	1.0	0.23
Sfc IR CRE (w m^{-2})	14	2.9	1.1	0.20
Solar Heating Rate (K day^{-1})	16	3.4	1.2	0.23
IR Heating Rate (K day^{-1})	25	5.1	1.9	0.35

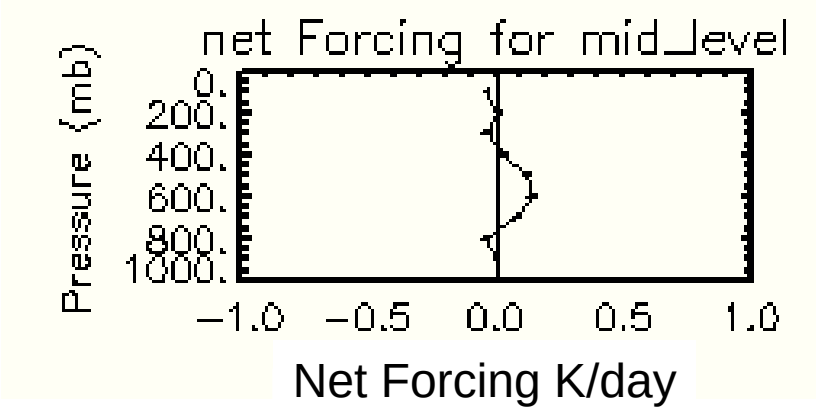


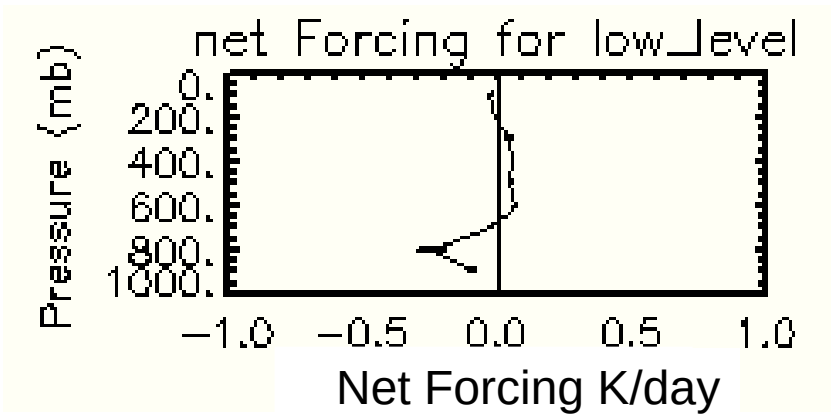


CRE (W/m2)

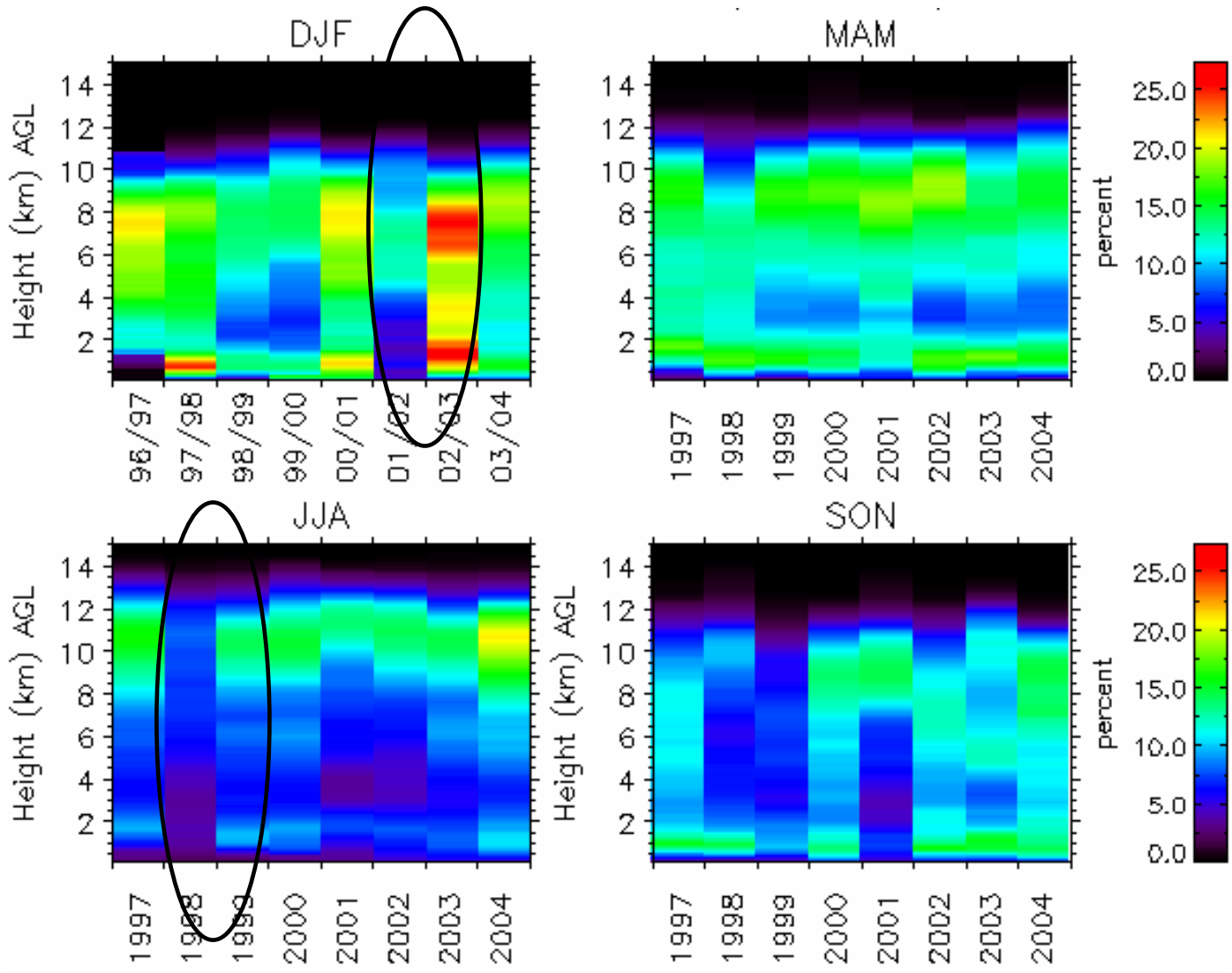
	Solar	IR	Net
TOA	−37.9	16.9	−21.0
ATM	2.2	1.3	3.5
SFC	−40.0	15.5	−24.5



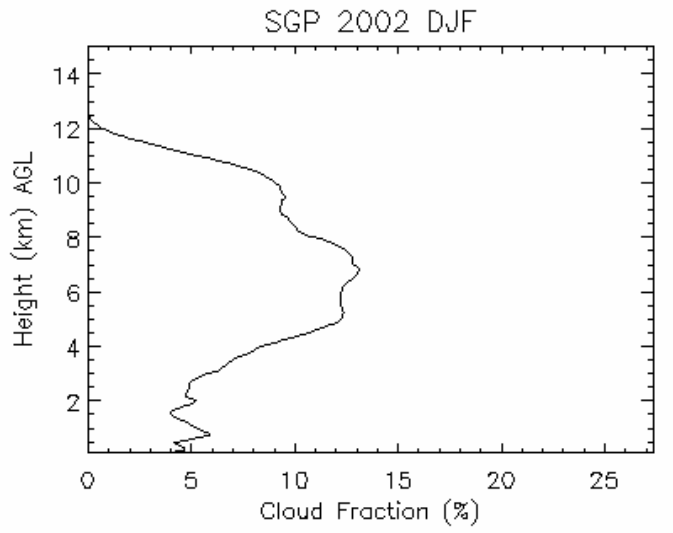


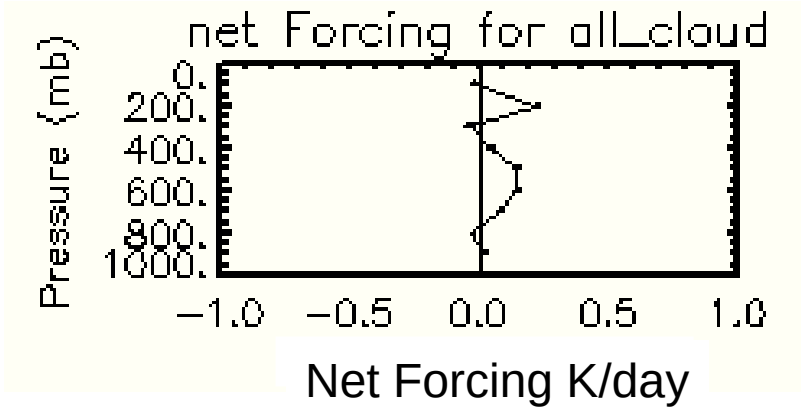


Seasonal Variability in Cloud Occurrence Frequency

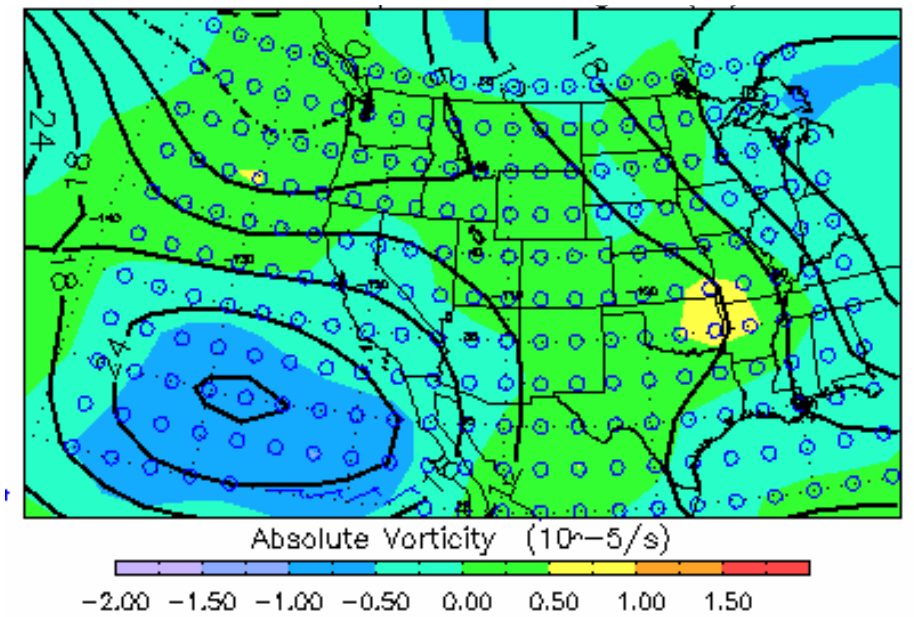


December 2001-February 2002



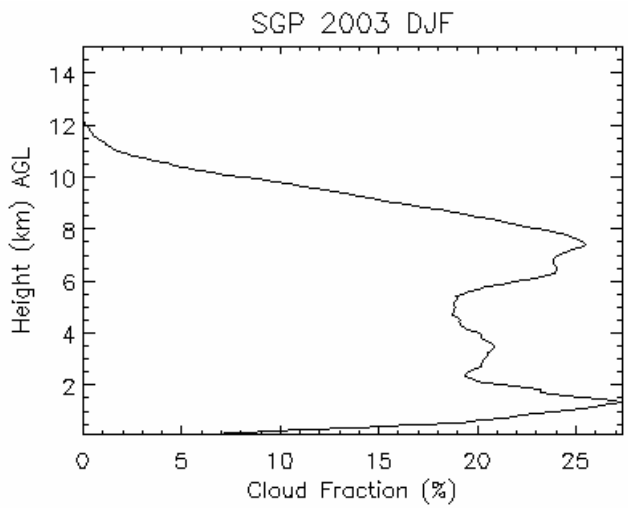


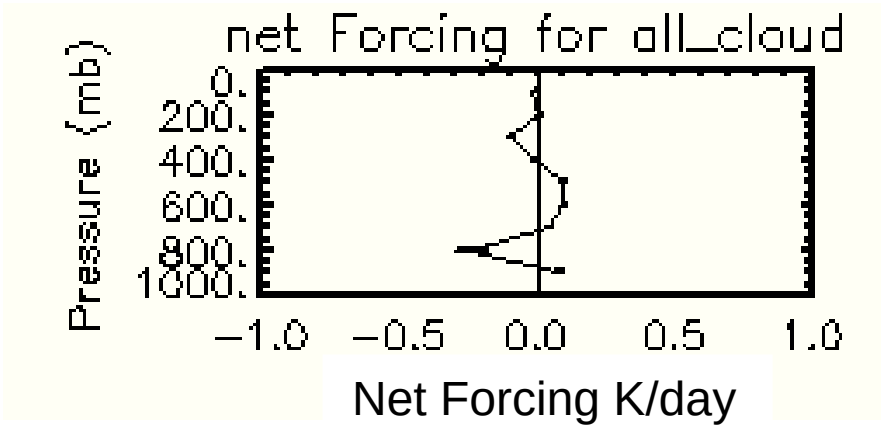
500 mb Geopotential Heights Anomaly (m)



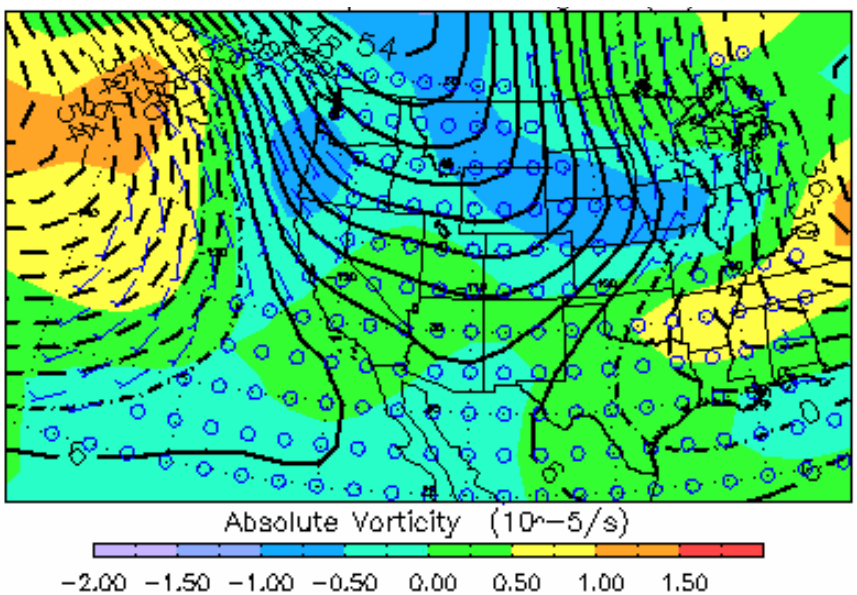
	Solar	IR	Net
TOA	−21.6	14.3	−7.3
ATM	0.9	3.2	4.1
SFC	−22.6	11.1	−11.4

December 2002-February 2003





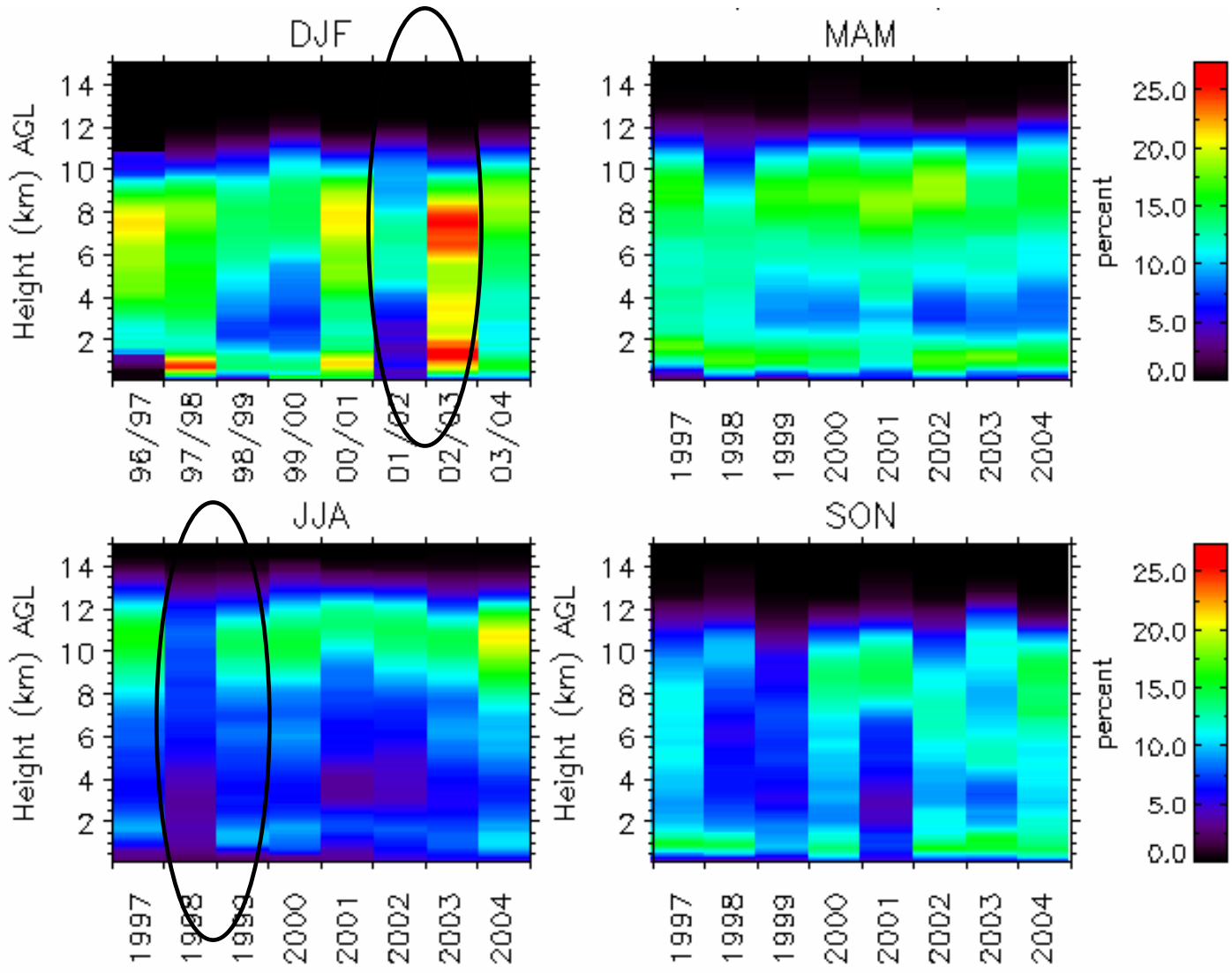
500 mb Geopotential Heights Anomaly (m)



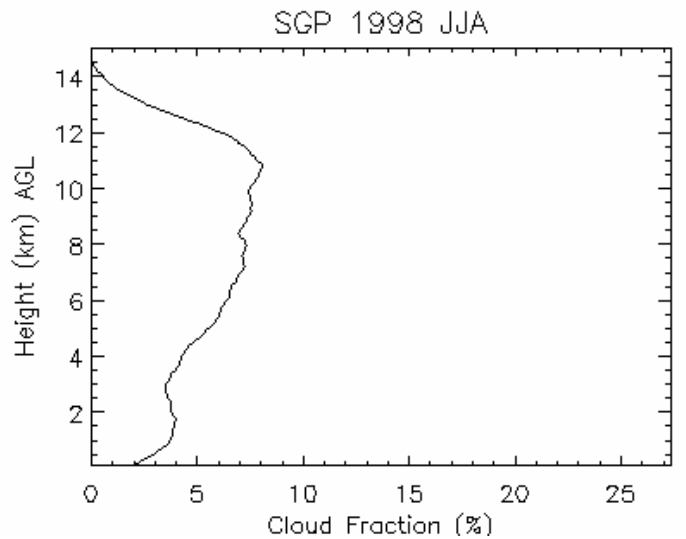
CRE (W/m2)

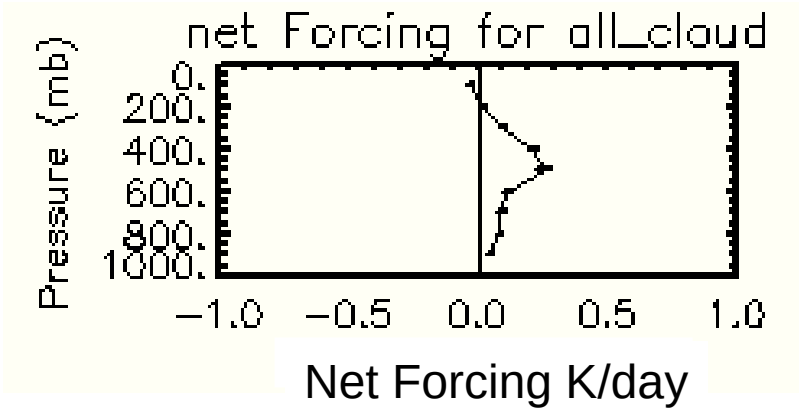
	Solar	IR	Net
TOA	−31.5	12.0	−19.5
ATM	4.1	−4.9	−0.8
SFC	−35.6	16.9	−18.7

Seasonal Variability in Cloud Occurrence Frequency

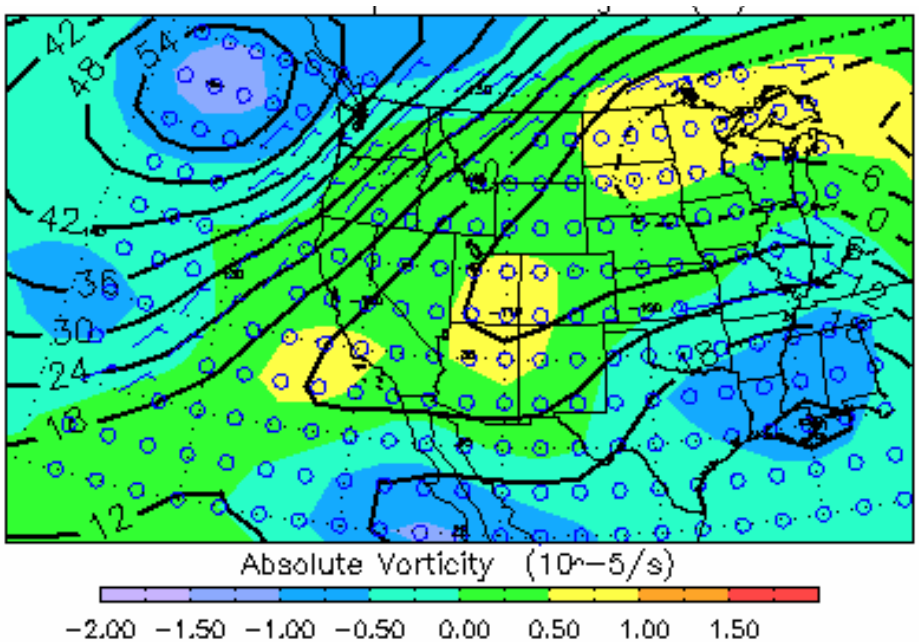


June-August 1998





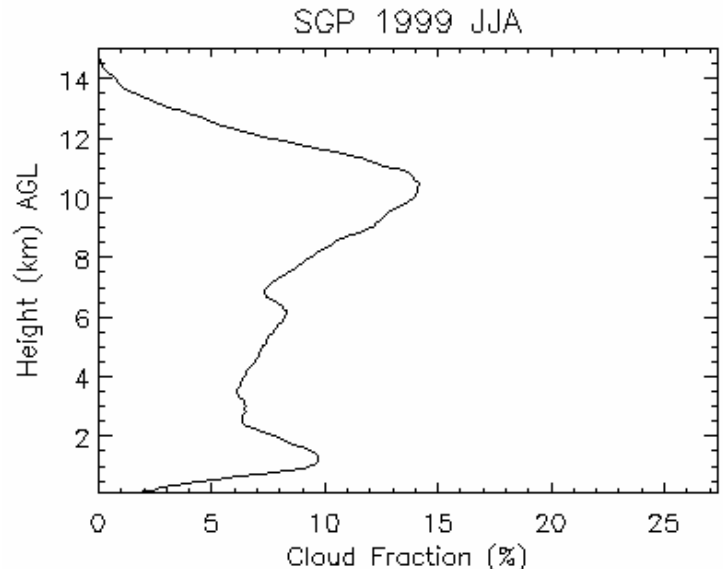
500 mb Geopotential Heights Anomaly (m)

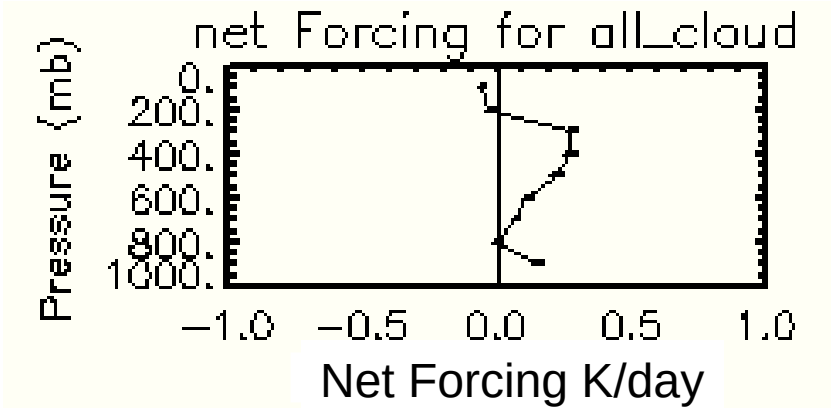


CRE (W/m2)

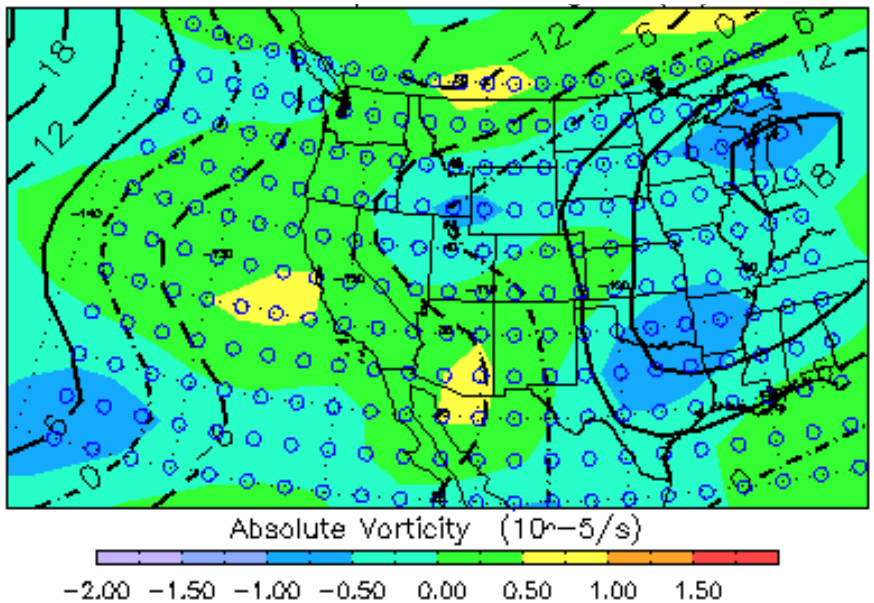
	Solar	IR	Net
TOA	−19.9	14.2	−5.7
ATM	0.4	9.9	10.4
SFC	−20.4	4.3	−16.1

June-August 1999





500 mb Geopotential Heights Anomaly (m)



CRE (W/m2)

	Solar	IR	Net
TOA	−29.9	18.1	−11.8
ATM	3.0	9.6	12.6
SFC	−32.8	8.5	−24.4

Summary:

- Long records of vertically pointing ground-based remote sensing data appear reasonably capable of providing cloud forcing information with reasonable uncertainties on monthly timscales.

- Combining the point measurements with reanalyses allows for documentation of the relationship between cloud forcing and the large-scale atmosphere – a critical element of correct cloud feedback simulation.

- The cloud occurrence and heating anomalies we find seem to be associated with regional anomalies in the large-scale forcing.

- Challenges:
    - Improve the precision and accuracy of the cloud microphysics
    - To the modeling community….

Approach to non-cirrus ice phase:

Assume the radar reflectivity and Doppler velocity record information only about the ice phase.

We require a relationship that provides the IWC in such layers.

March 2000 IOP: the Citation was instrumented with the CVI and PMS probes.

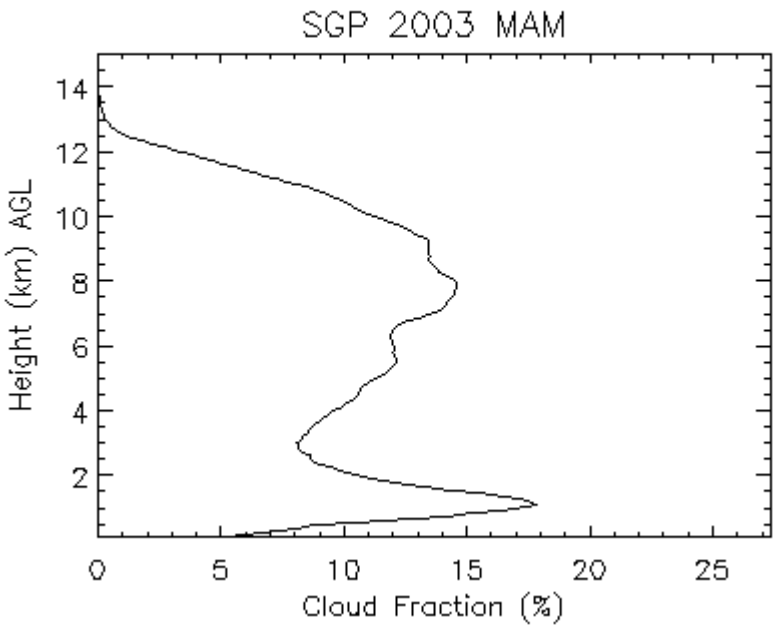
We use data from deep altostratus and mixed phase layers to define a regression relationship relating the radar reflectivity and the Doppler velocity calculated from the PMS size distributions to the observed condensed water:

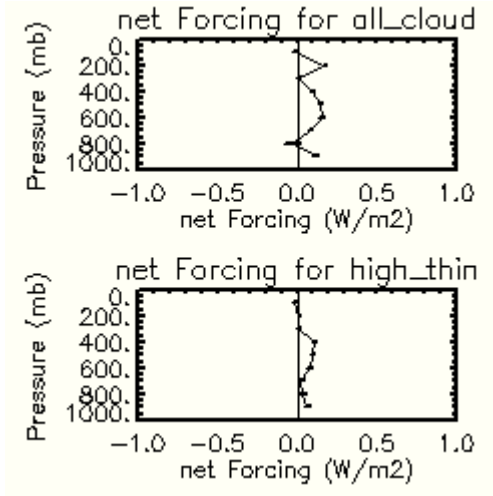
$$IWC = a + bF_1\left(Z_e, V_d\right) + cF_2\left(T\right)$$

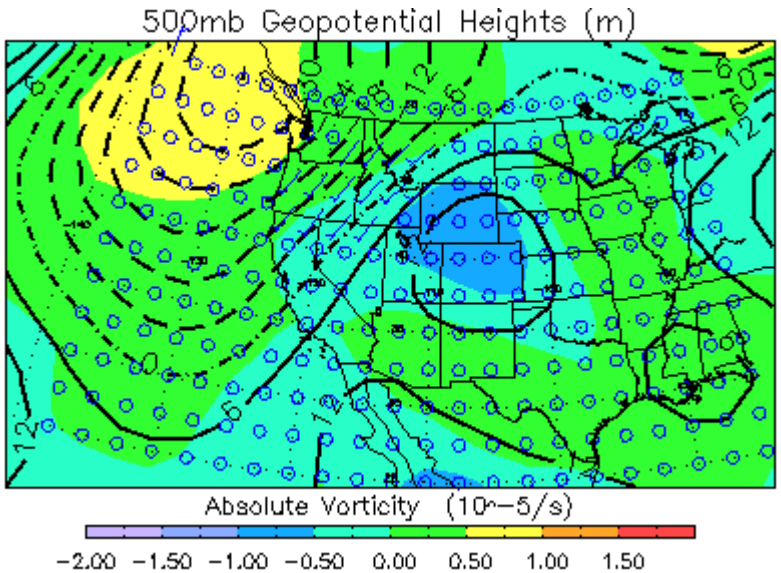
$$F_1\left(Z_e, V_e\right) = V_d Z_e^{b_A/(6+b_Z)} \qquad F_2\left(T\right) = \exp\left[\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right]$$

1560 5-second averages, the Bias in the fit is 0.2 mg/m3, the median fractional error is 0.33, and the normal deviation is 3.4 mg/m3.

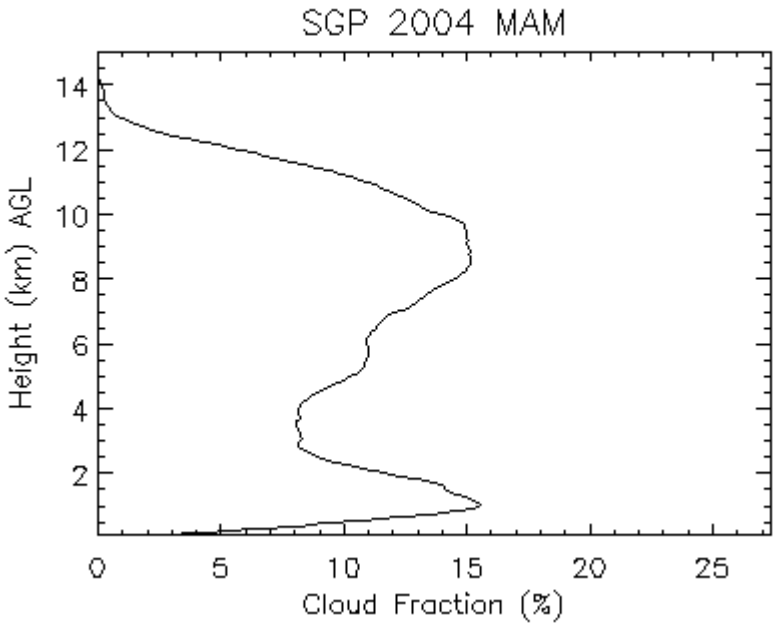
a	b	c
-1.52e-8	8.76e-8	2.28e-10

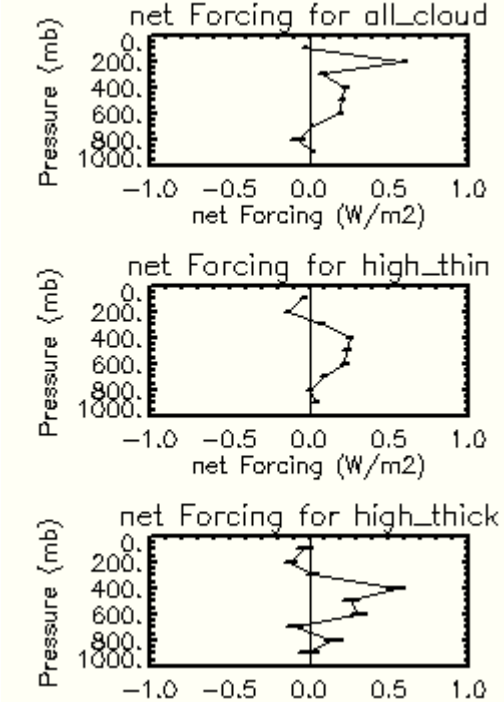


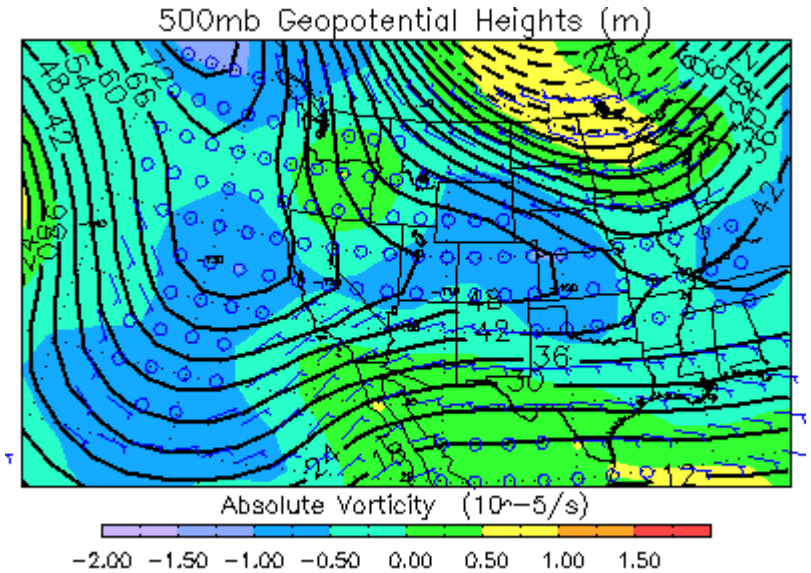




		Solar	IR	Net
all_cloud				
	TOA	−42.6	14.0	−28.5
	ATM	5.7	0.5	6.2
	SFC	−48.3	13.5	−34.8
high_thin				
	TOA	−18.2	8.8	−9.4
	ATM	2.4	2.6	5.0
	SFC	−20.6	6.2	−14.4
high_thick				
	TOA	−71.7	17.0	−54.7
	ATM	10.2	9.2	19.4
	SFC	−82.0	7.8	−74.2







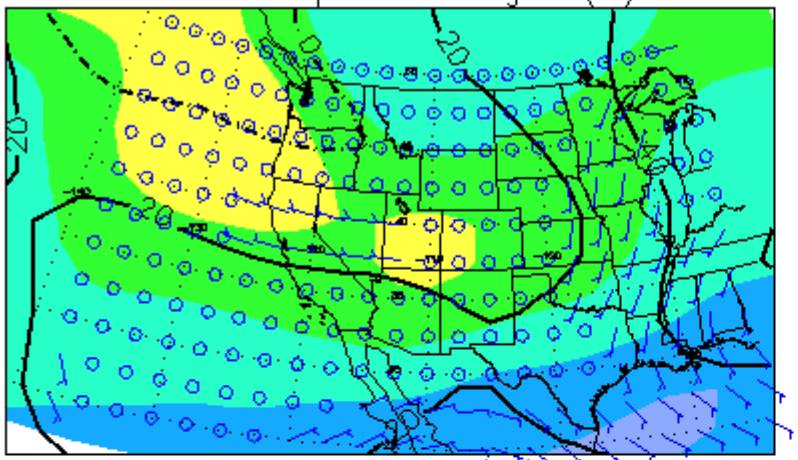
all_cloud		Solar	IR	Net
	TOA	−55.1	21.3	−33.7
	ATM	6.2	0.5	6.7
	SFC	−61.3	20.9	−40.4

high_thin		Solar	IR	Net
	TOA	−39.2	23.0	−16.2
	ATM	3.2	5.5	8.8
	SFC	−42.4	17.4	−25.0

high_thick		Solar	IR	Net
	TOA	−45.9	16.3	−29.6
	ATM	6.6	5.8	12.4
	SFC	−52.5	10.5	−42.0

2001dec_to_2002feb – sgpNCEP_30yrClimotology.djf

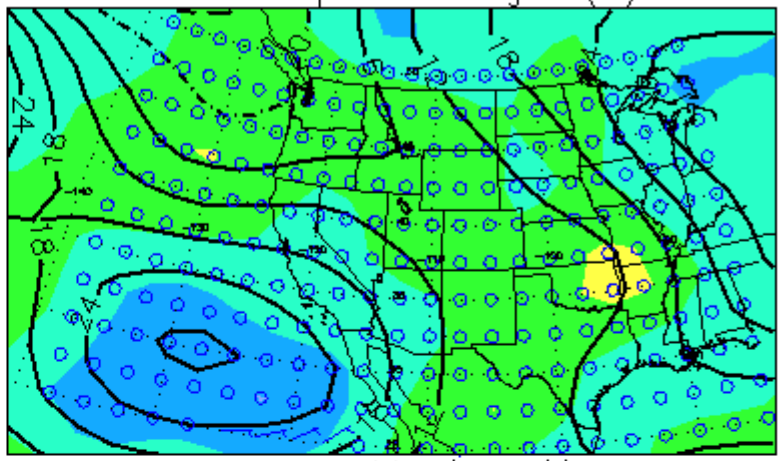
300mb Geopotential Heights (m)



300mb Wind Speed (m/s)

−8 −4 0 4 8 12 16 20

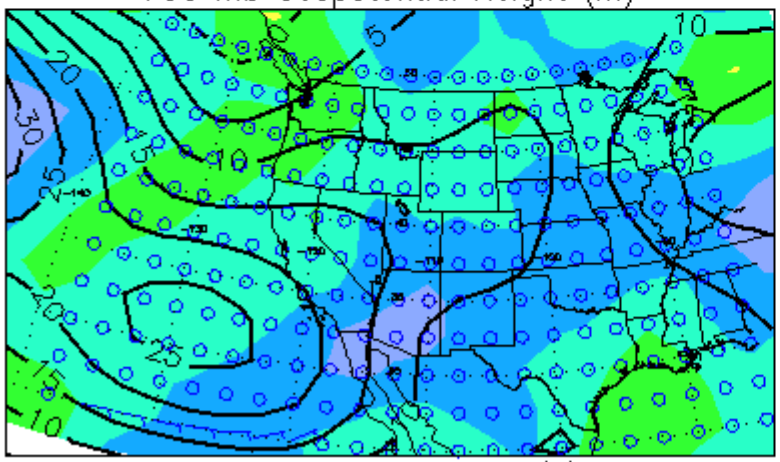
500mb Geopotential Heights (m)



Absolute Vorticity (10^−5/s)

−2.00 −1.50 −1.00 −0.50 0.00 0.50 1.00 1.50

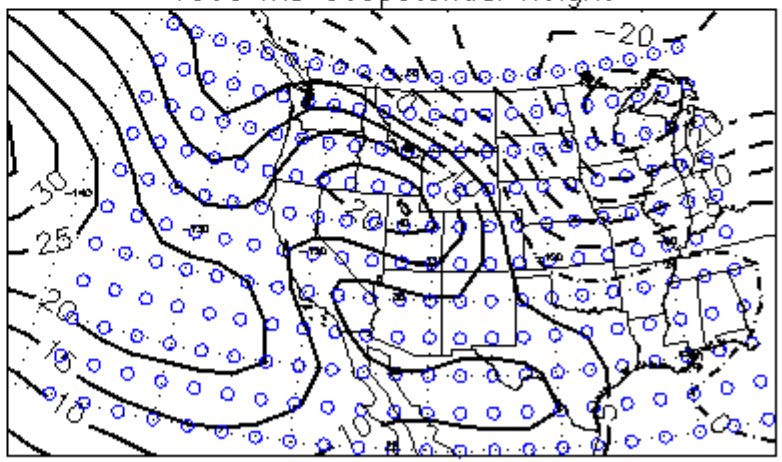
700 mb Geopotential Height (m)



700 mb Relative Humidity (%)

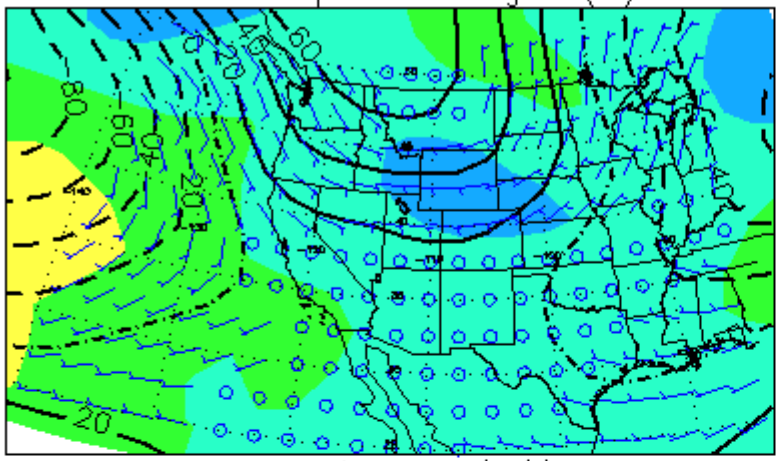
−16 −12 −8 −4 0 4 8 12

1000 mb Geopotential Height



2002dec_to_2003feb – sgpNCEP_30yrClimotology.djf

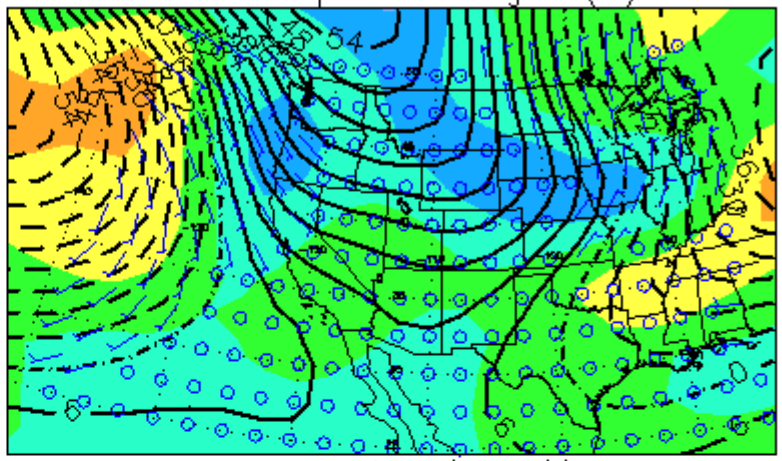
300mb Geopotential Heights (m)



300mb Wind Speed (m/s)

−8 −4 0 4 8 12 16 20

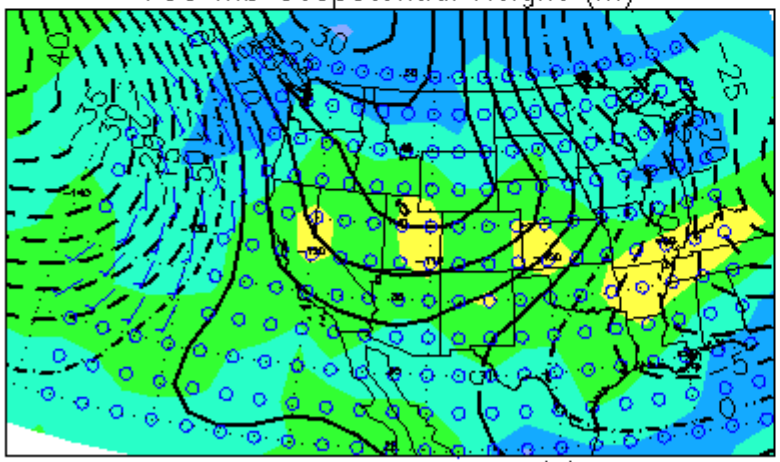
500mb Geopotential Heights (m)



Absolute Vorticity (10^−5/s)

−2.00 −1.50 −1.00 −0.50 0.00 0.50 1.00 1.50

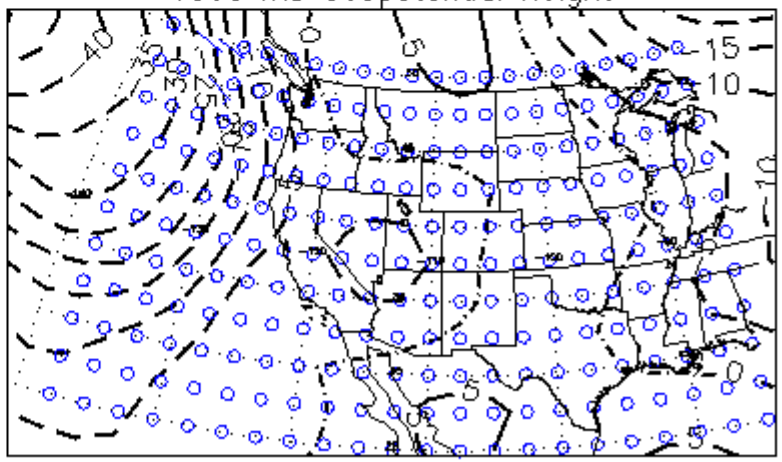
700 mb Geopotential Height (m)

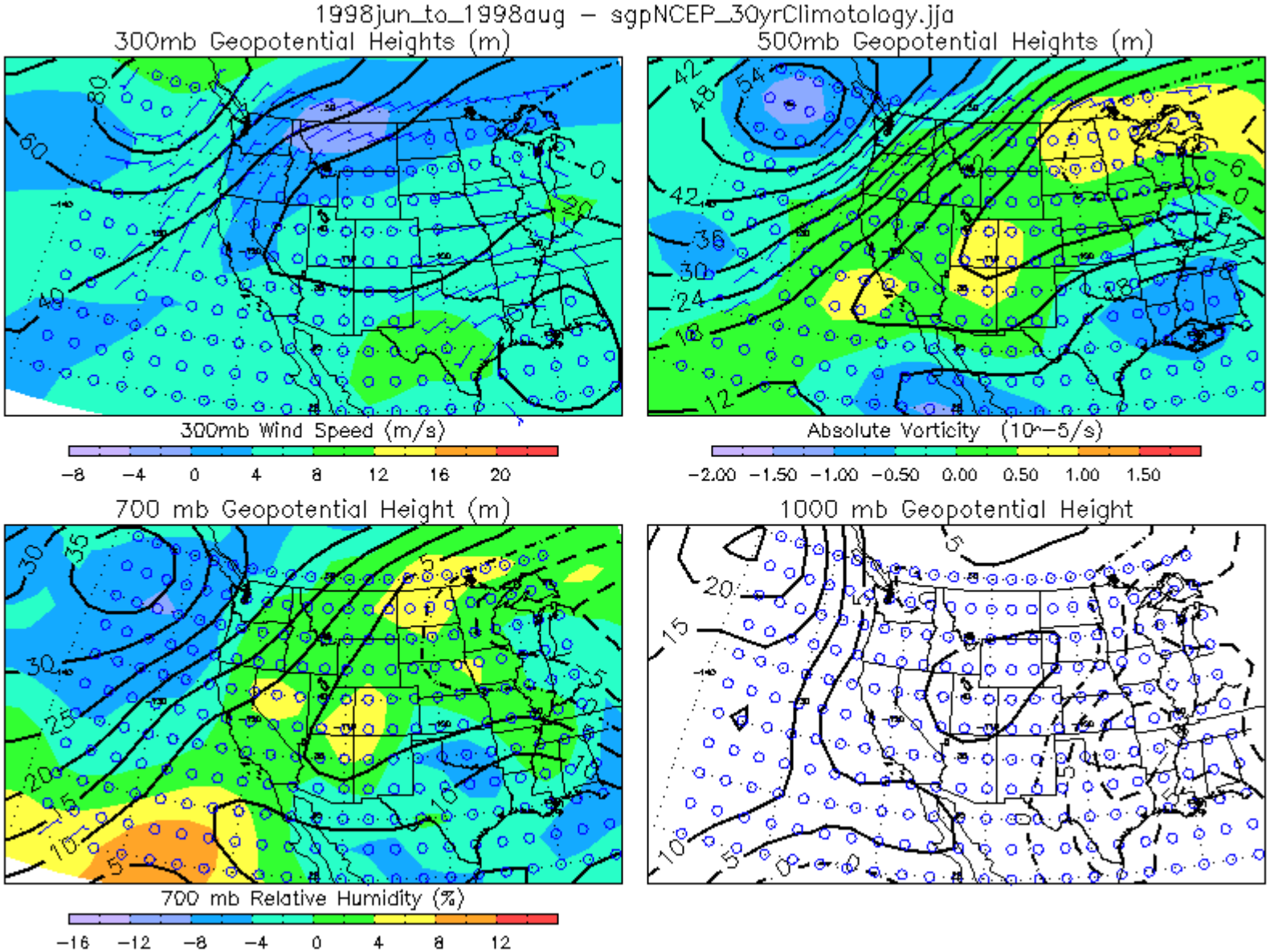


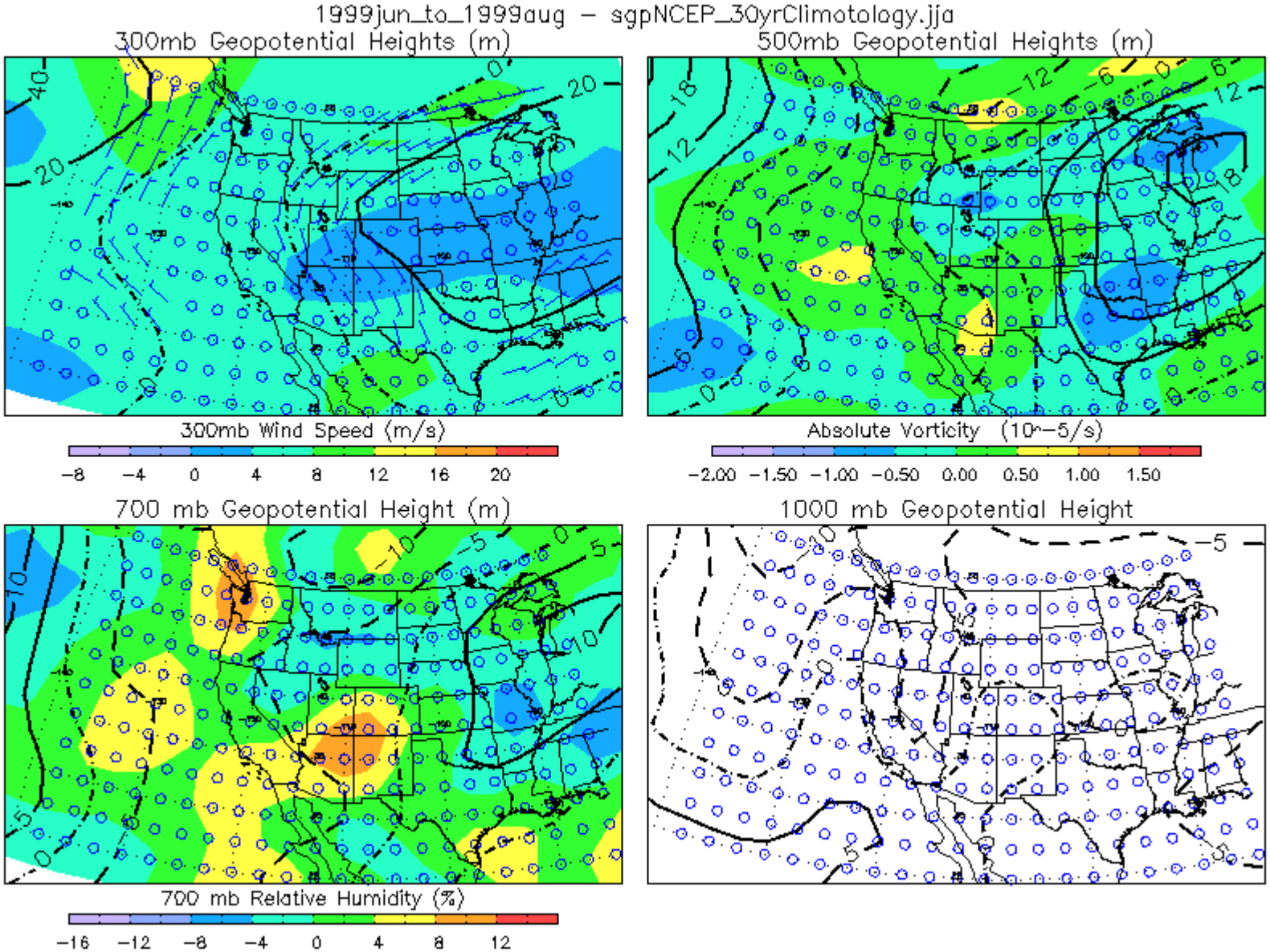
700 mb Relative Humidity (%)

−16 −12 −8 −4 0 4 8 12

1000 mb Geopotential Height




1998jun_to_1998aug – sgpNCEP_30yrClimatology.jja
300mb Geopotential Heights (m)
300mb Wind Speed (m/s)
−8 −4 0 4 8 12 16 20
500mb Geopotential Heights (m)
Absolute Vorticity (10^−5/s)
−2.00 −1.50 −1.00 −0.50 0.00 0.50 1.00 1.50
700 mb Geopotential Height (m)
700 mb Relative Humidity (%)
−16 −12 −8 −4 0 4 8 12
1000 mb Geopotential Height


1999jun_to_1999aug – sgpNCEP_30yrClimatology.jja
300mb Geopotential Heights (m)
300mb Wind Speed (m/s)
−8 −4 0 4 8 12 16 20
500mb Geopotential Heights (m)
Absolute Vorticity (10^−5/s)
−2.00 −1.50 −1.00 −0.50 0.00 0.50 1.00 1.50
700 mb Geopotential Height (m)
700 mb Relative Humidity (%)
−16 −12 −8 −4 0 4 8 12
1000 mb Geopotential Height