



Precision Measurements of Cloud Heights and Albedos Using Multiangle Remote Sensing

Implications for Detecting Trends and Feedbacks in the Climate System

Roger Davies

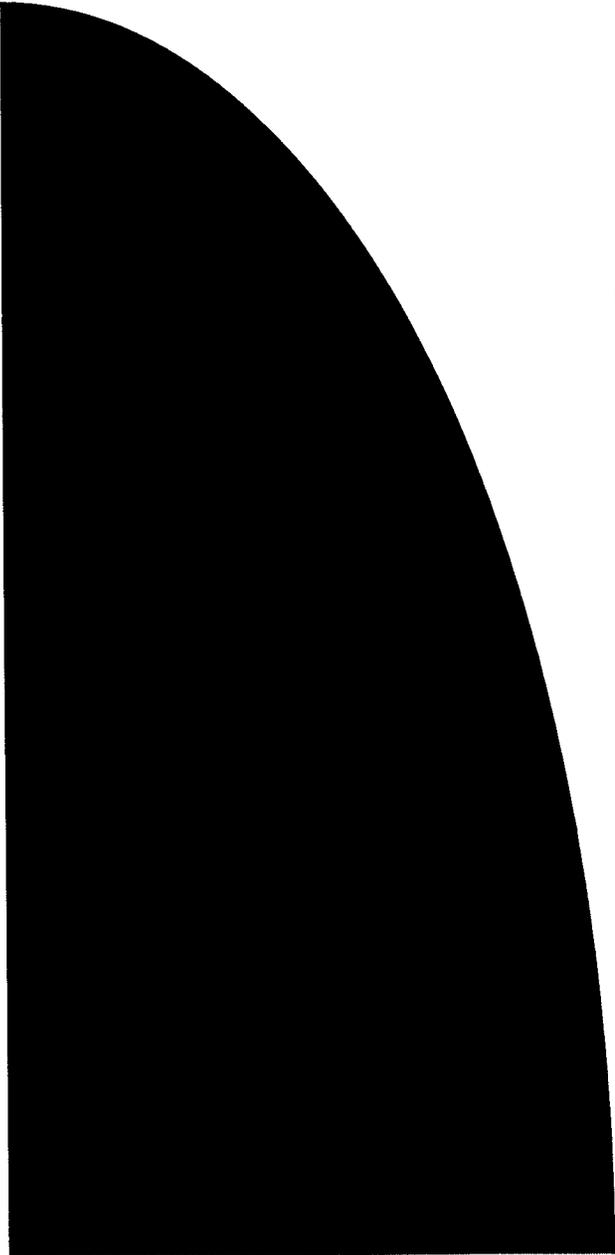
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MISR

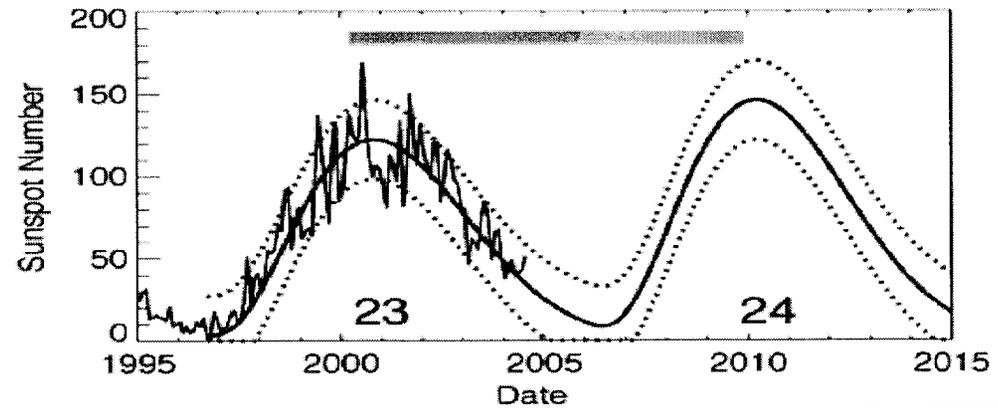
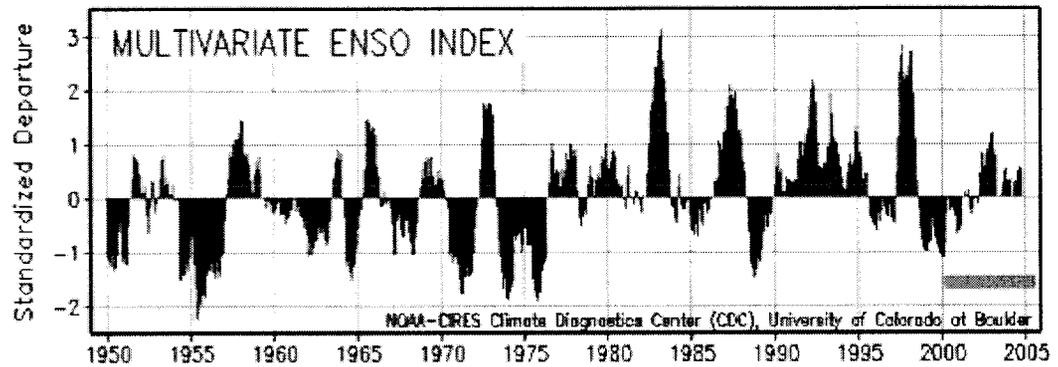
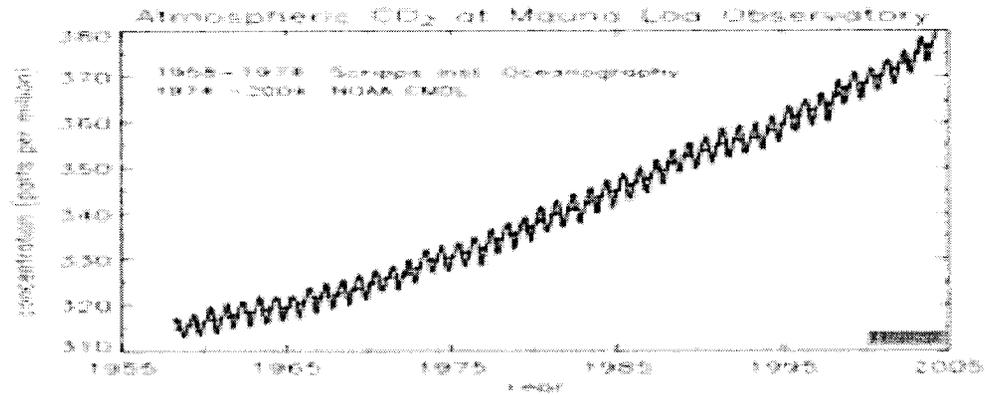
- Multiangle Imaging SpectroRadiometer
- on Terra satellite, launched Dec 1999
- sun synchronous, 10:30 am orbit
- measures reflected solar radiances at high spatial resolution from 9 directions
- first full month of data, March 2000
 - reprocessed for consistent calibration and algorithms to get albedos and cloud heights
- can now compare (March 2000–Feb 2001) with (March 2004–Feb 2005) to examine the 4-yr differences



motivation

- what can be learned, if anything, about cloud-radiative feedback?
 - ◆ measurement accuracy?
 - ◆ albedo changes?
 - ◆ longwave changes?
 - ◆ cloud amount changes?
 - ◆ regional and temporal relationships between these?

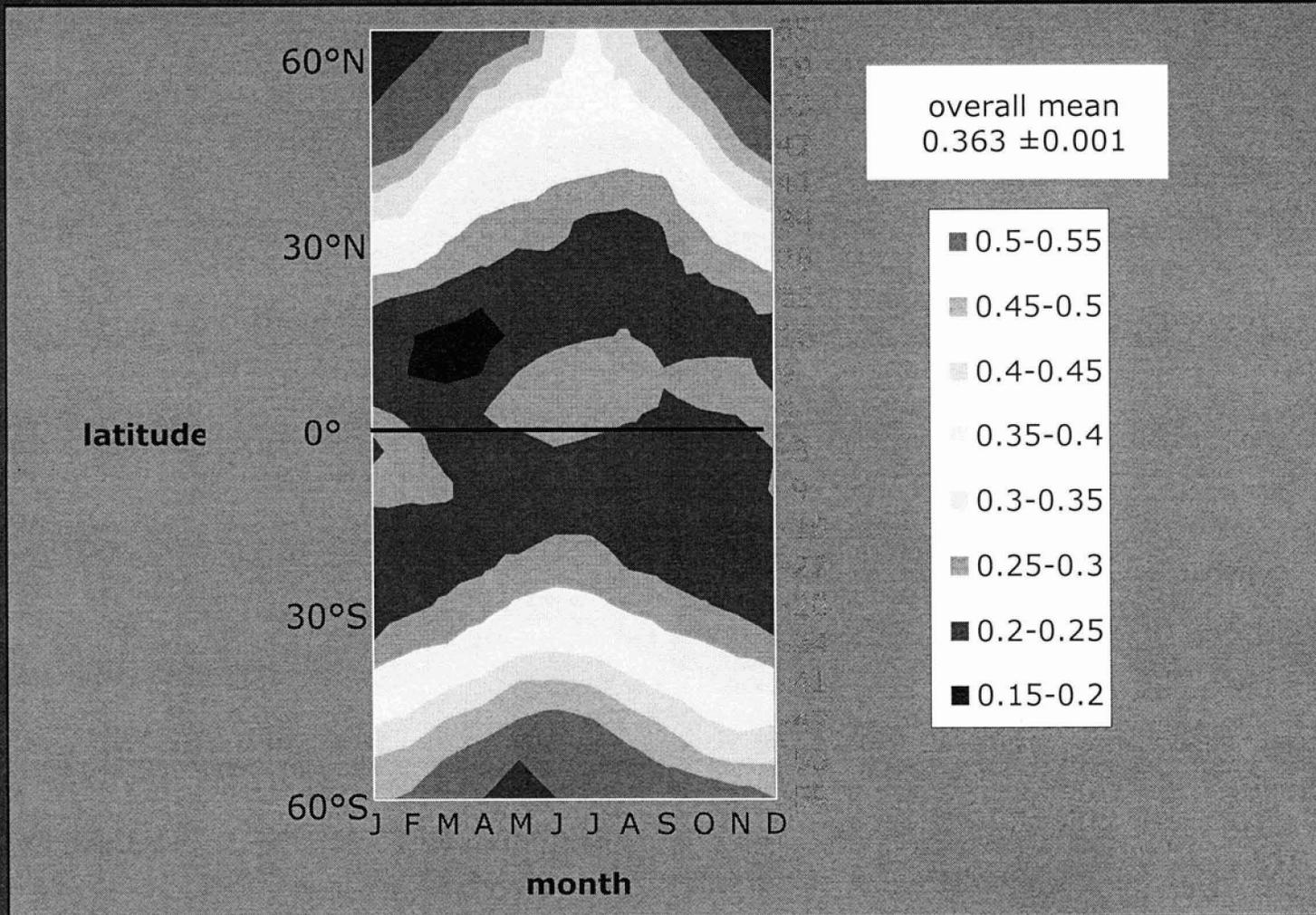
Terra prime (orange) and
extended (green)
mission durations
ended with
events.
paths
100 to



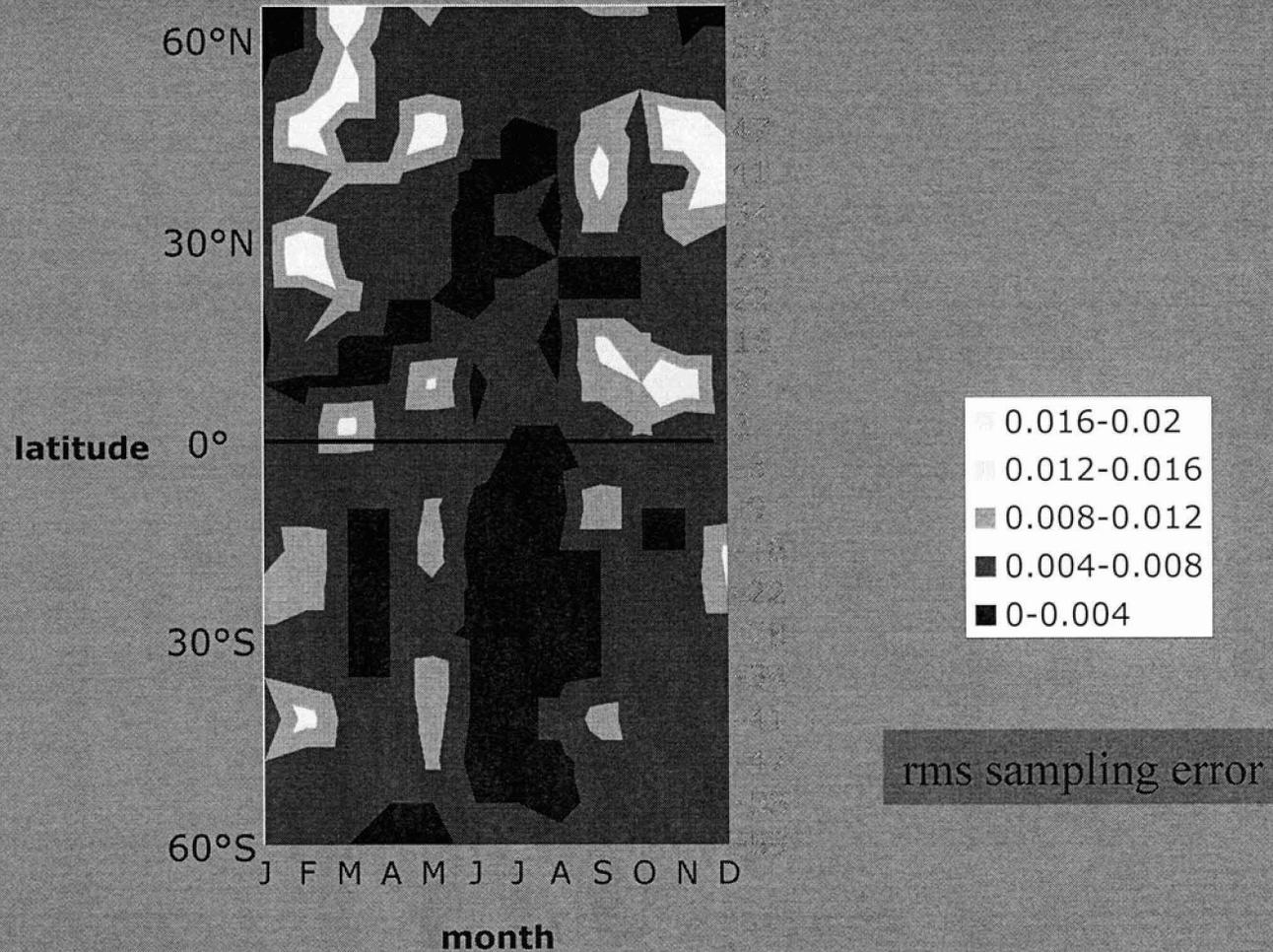
MISR and TOA albedo

- 4 spectral bands (blue, green, red, near infrared)
 - ◆ highly correlated with coincident broadband radiances from CERES
 - ★ can use green band as proxy for broadband (assumes any changes in sw absorption by water vapor or ozone are second order to changes in cloud and surface reflection)
- careful onboard and vicarious calibration
 - ◆ relative uncertainty $\pm 1\%$ over mission life
- 9-angles allow albedo to be estimated at high spatial resolution
- massive amounts of data $\approx 10^5$ independent samples/month (from ≈ 10 Tbytes of measurements)

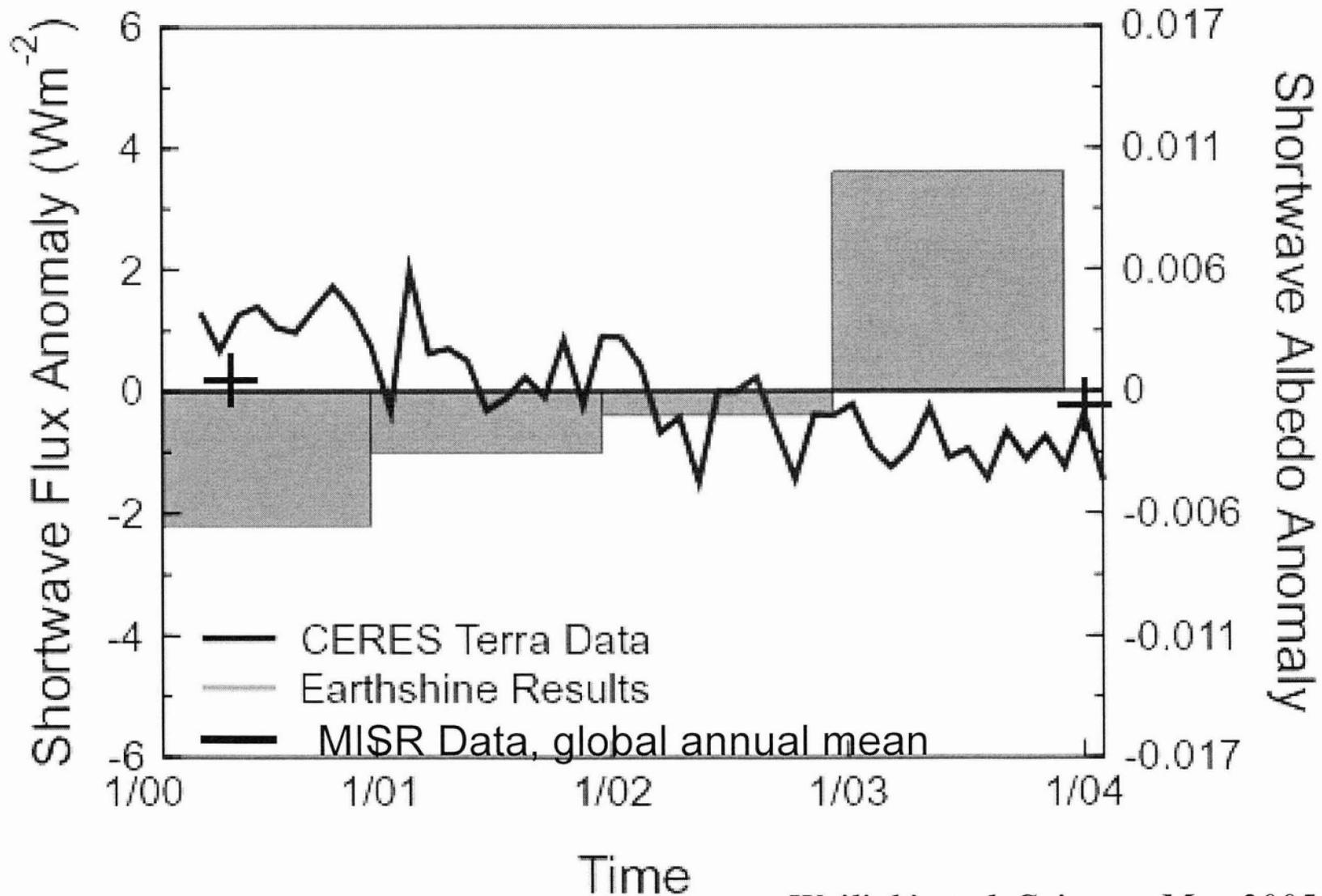
MISR monthly mean green albedo



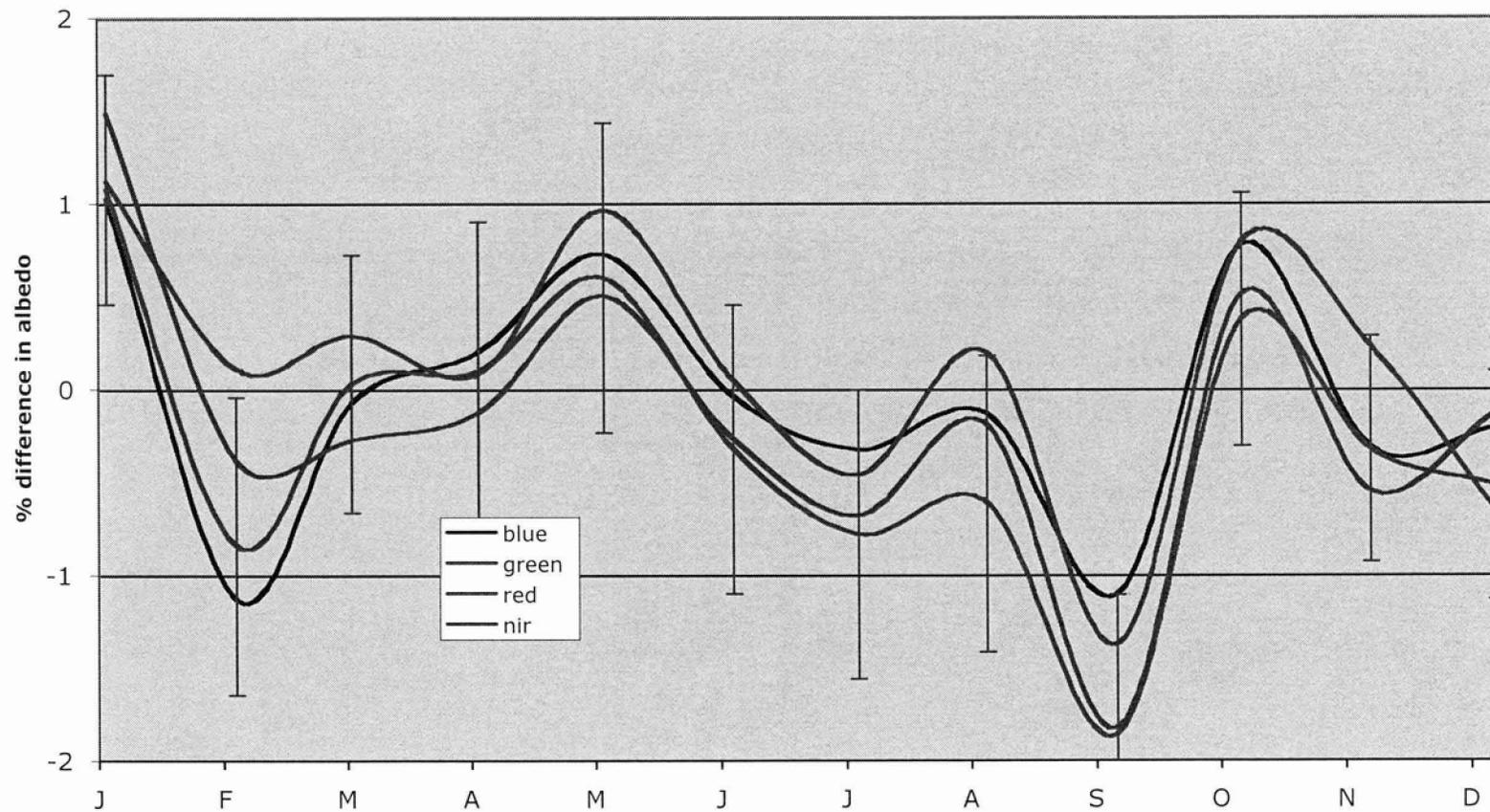
green albedo uncertainty



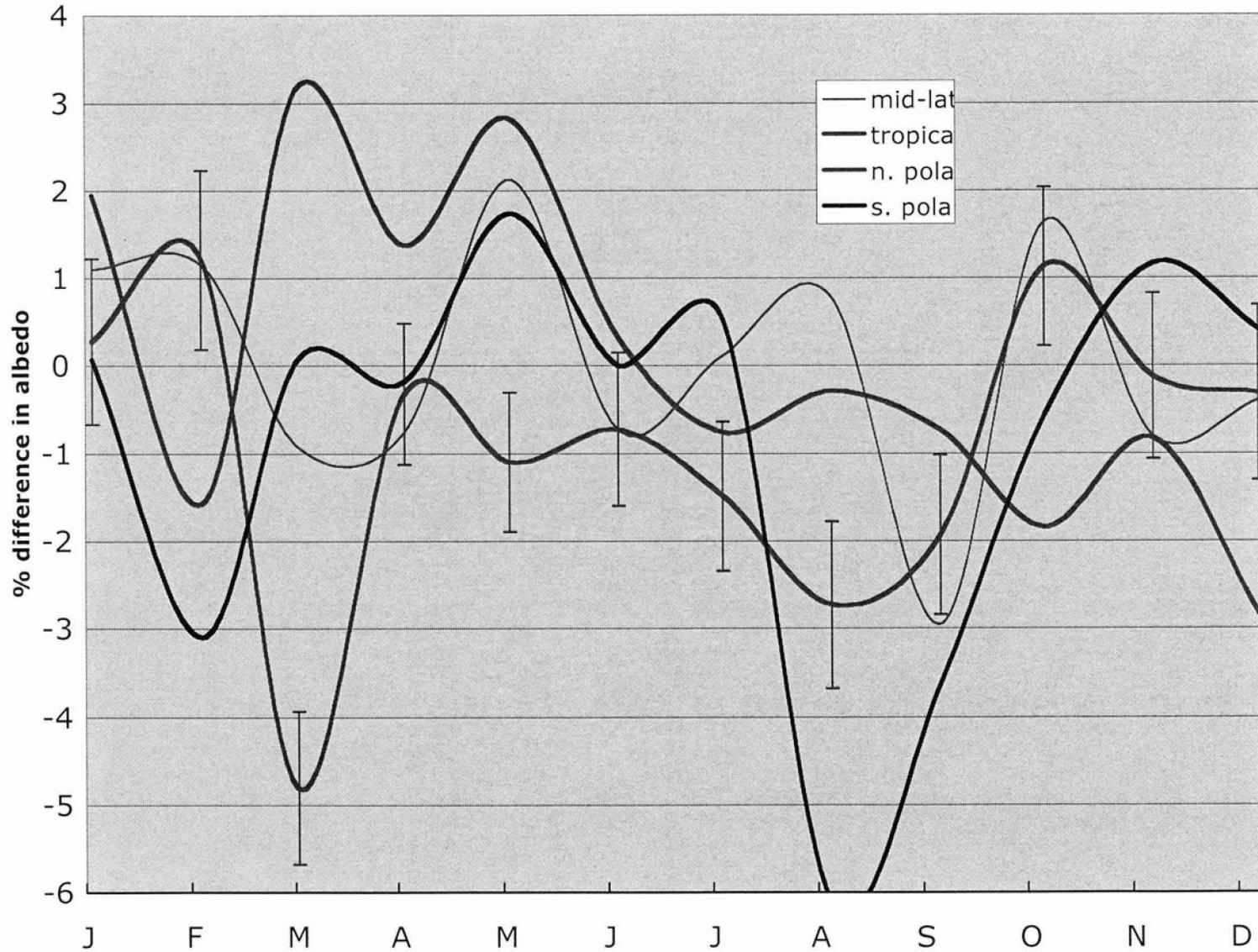
Earthshine Results versus CERES: 2000 to 2004



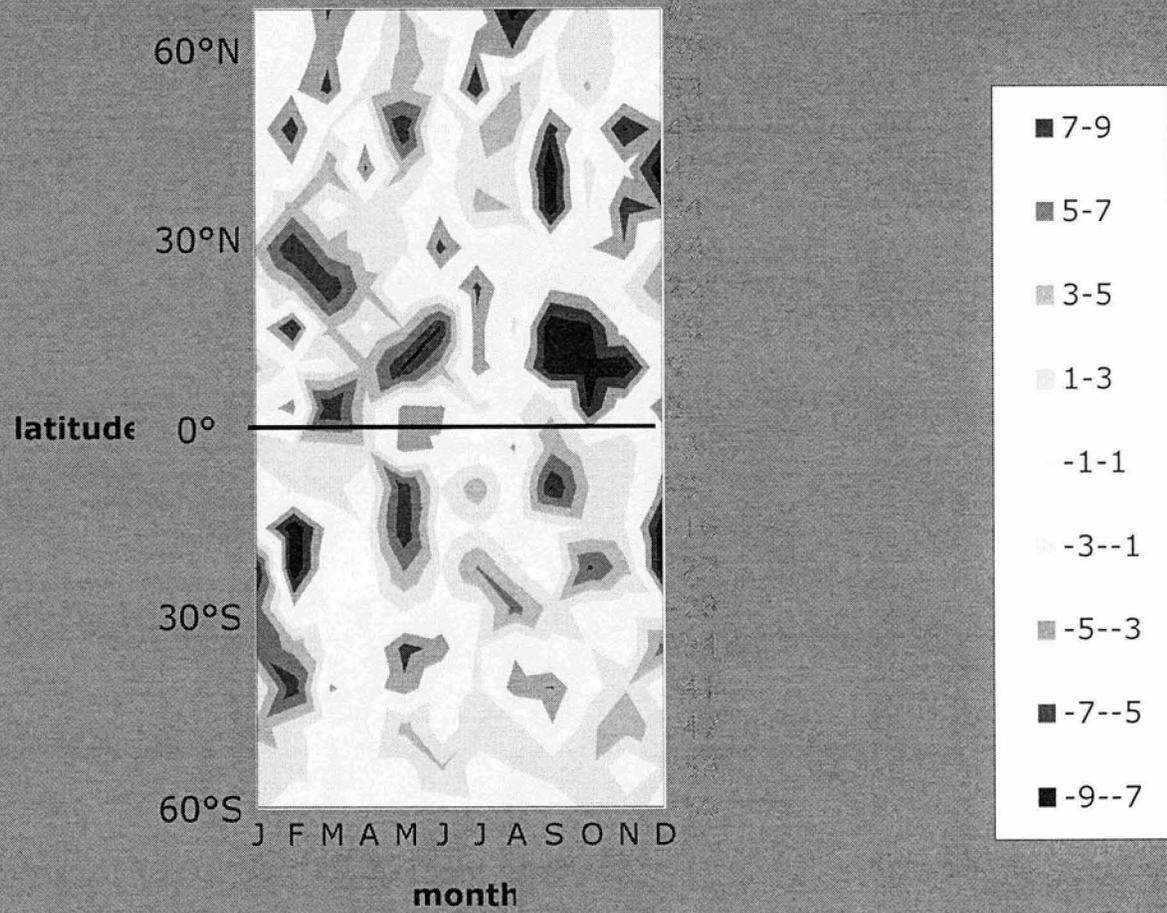
%difference in albedo, 2004-2000, global



%difference in green albedo, 2004-200



%difference in green albedo



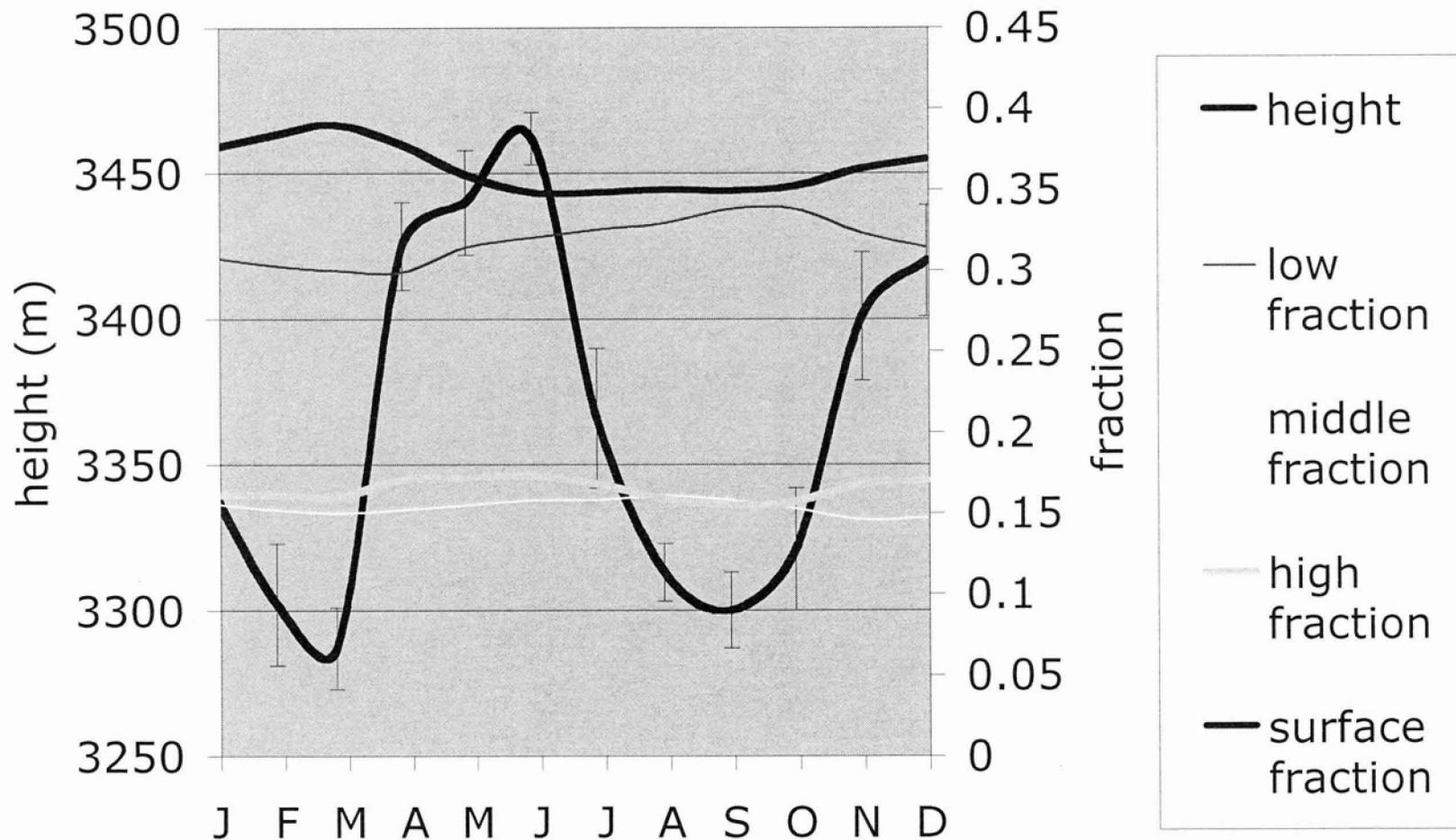
albedo summary

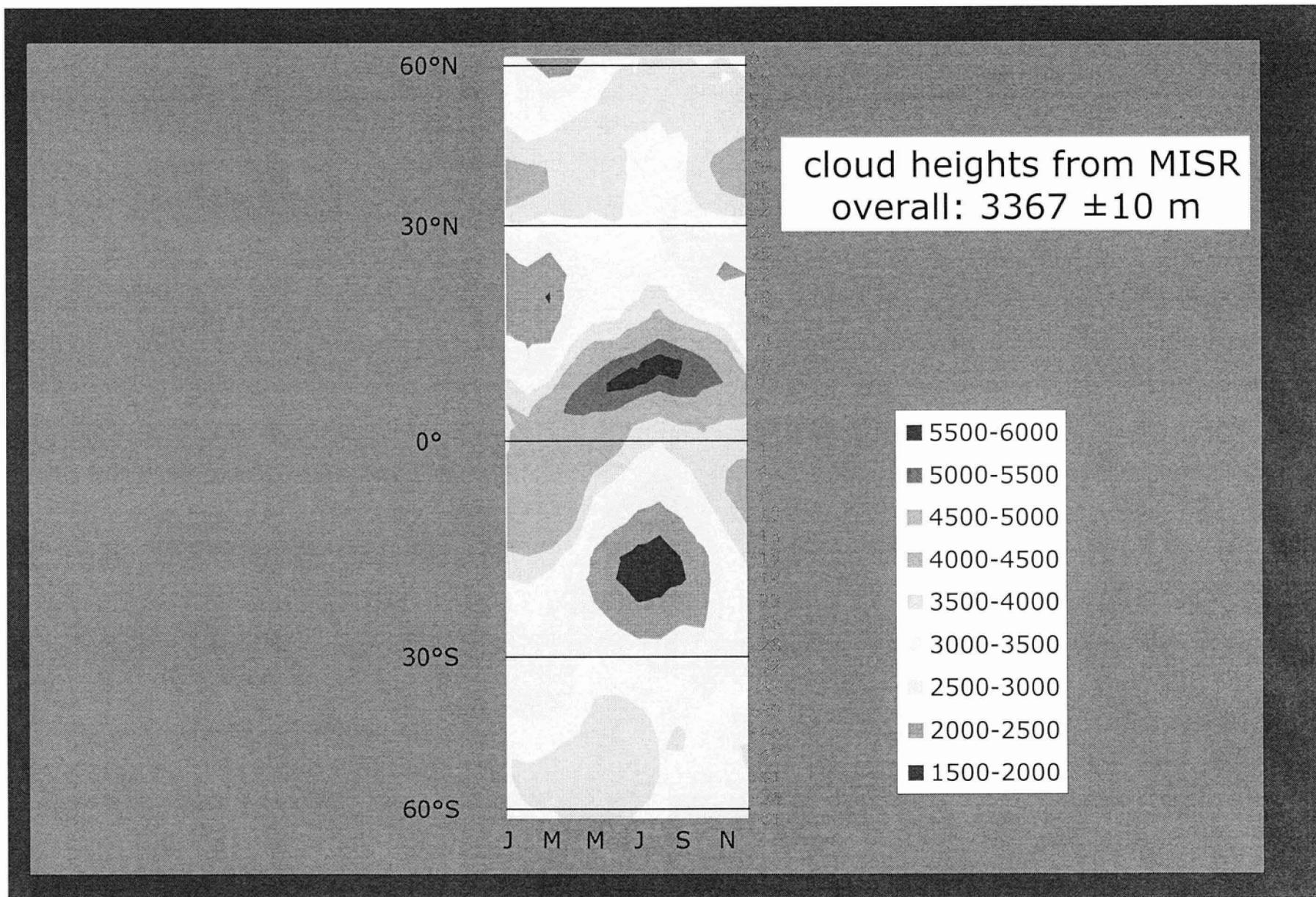
- MISR shows that the annual global average green band albedo of 2004 was lower than 2000 by 0.2 ± 0.2 %.
 - converting to broadband, this is equivalent to an extra 0.3 ± 0.3 W m⁻² of absorbed energy
- this is less than the reduction measured by CERES
 - which is true broadband and calibrated differently
- it is inconsistent with the Earthshine results
 - which use a very different technique, and are not limited to 10:30 am local time sampling
- largest regional, seasonal differences noted
 - polar springs(esp. north polar) were darker in 2004 (less snow/ice?)
 - tropical clouds were seasonally different in 2004, but effects cancel on annual average

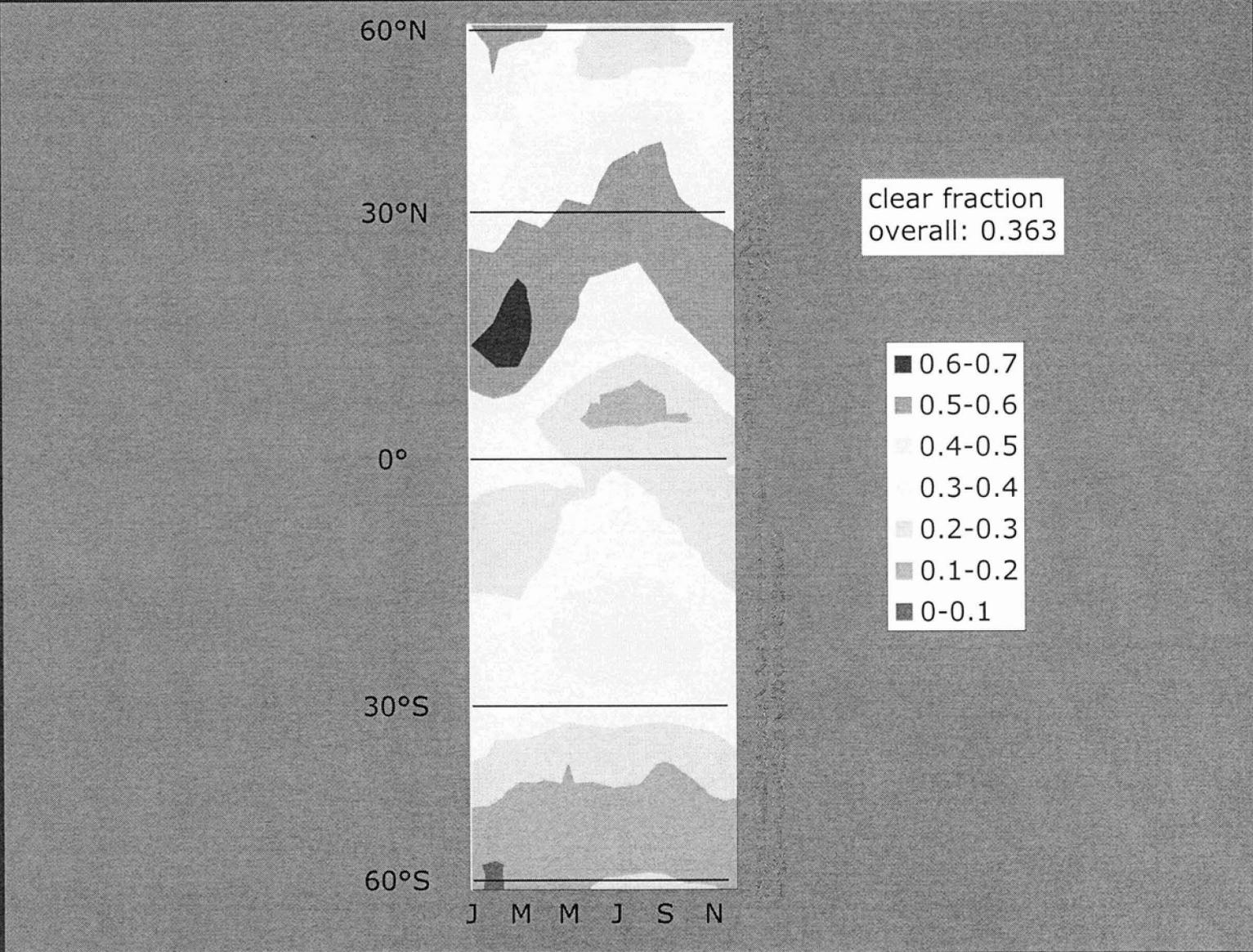
MISR cloud heights

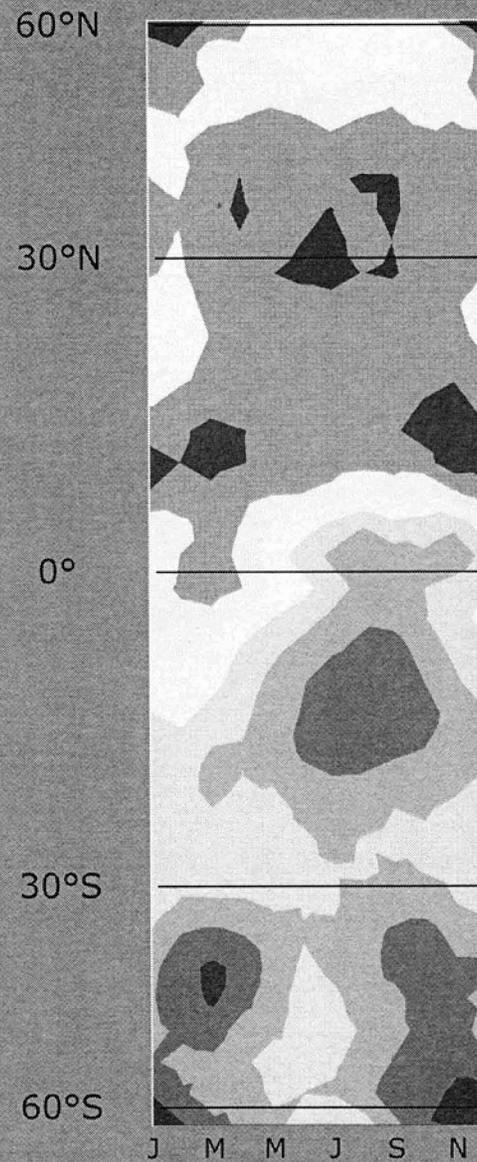
- operational stereo gives 80% global coverage of reflecting layer altitude
 - ◆ average to get mean height, normalized by coverage
 - ◆ classify coverage by
 - ★ near surface ($z < 500$ m)
 - ★ low cloud ($500 < z < 3000$ m)
 - ★ mid-level cloud ($3000 < z < 7000$ m)
 - ★ high cloud ($z > 7000$ m)
- insensitive to radiometric calibration
- consistent retrieval algorithm allows accurate differences to be measured in heights and cloud fraction

global mean heights and cloud fractions

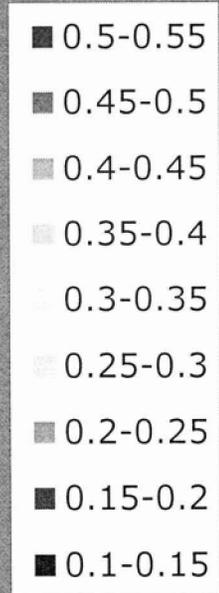


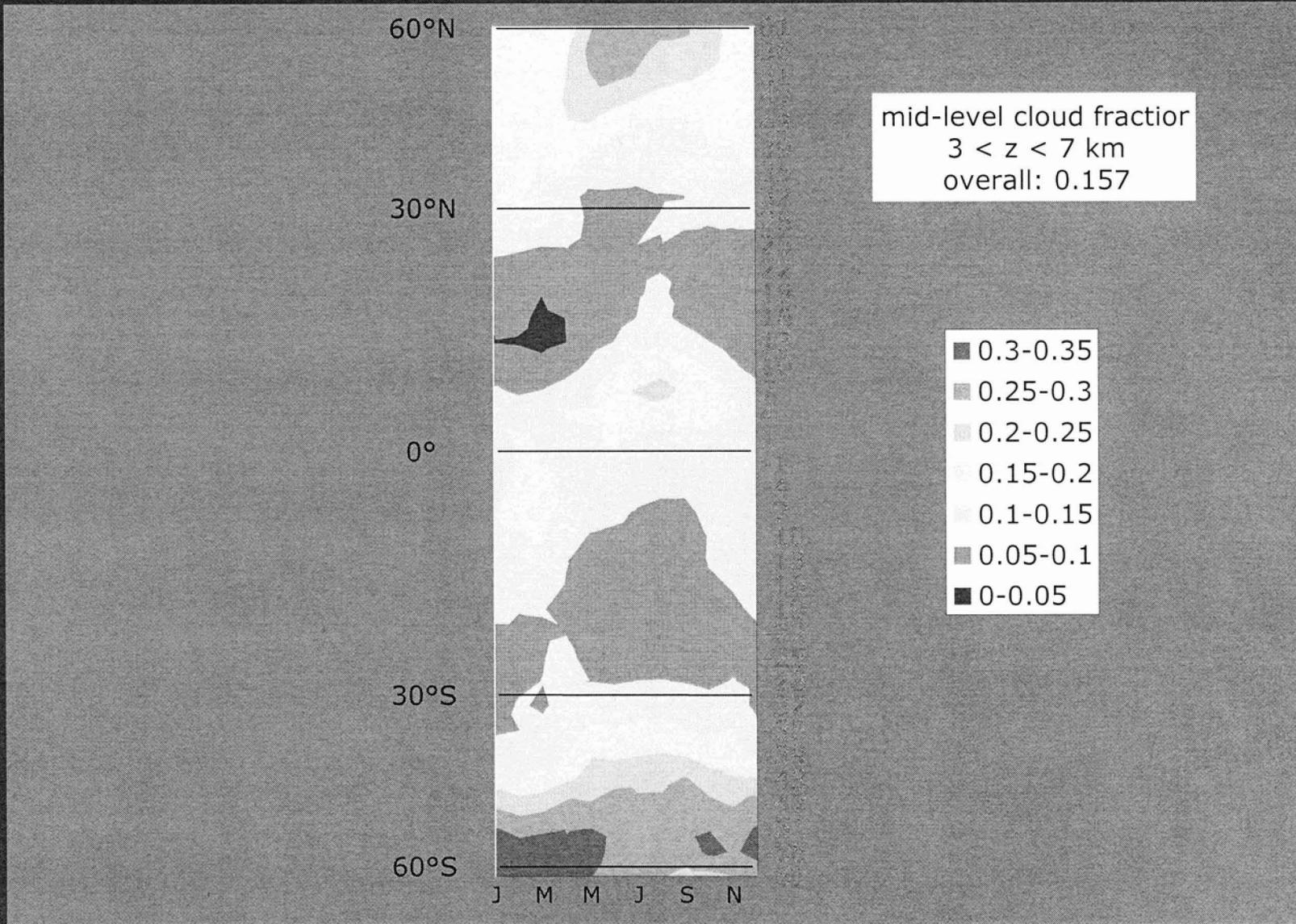


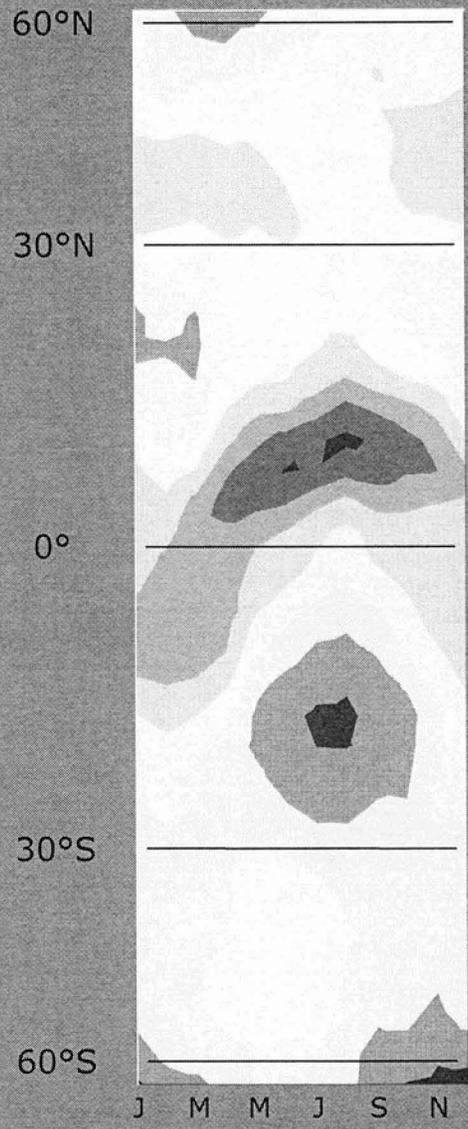




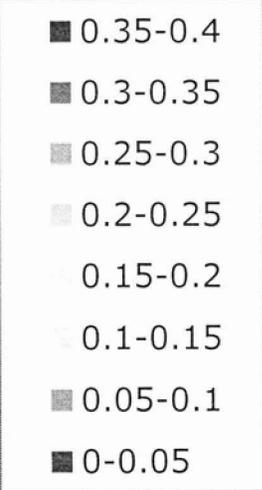
low cloud fraction
 $z < 3$ km
 overall: 0.317





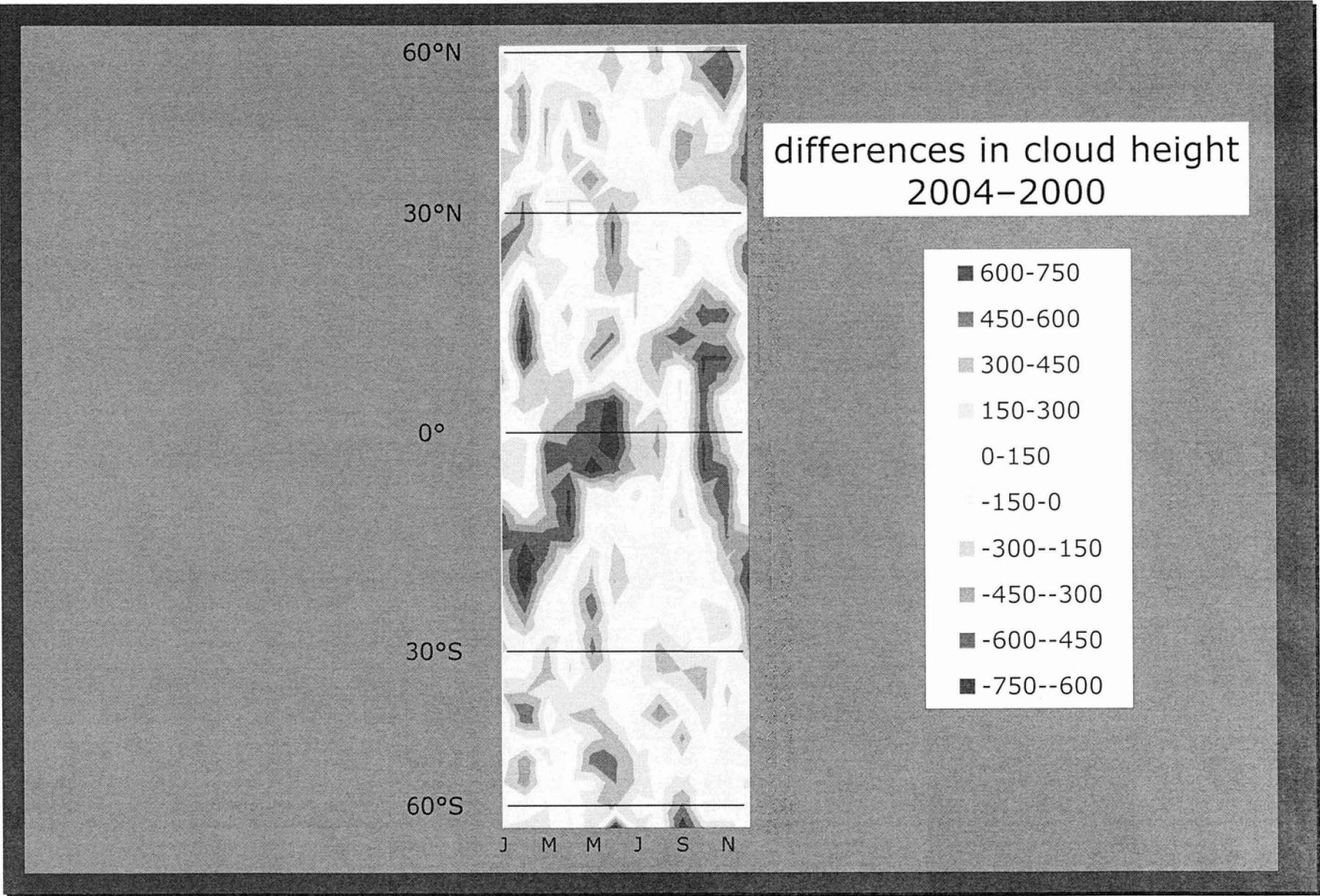


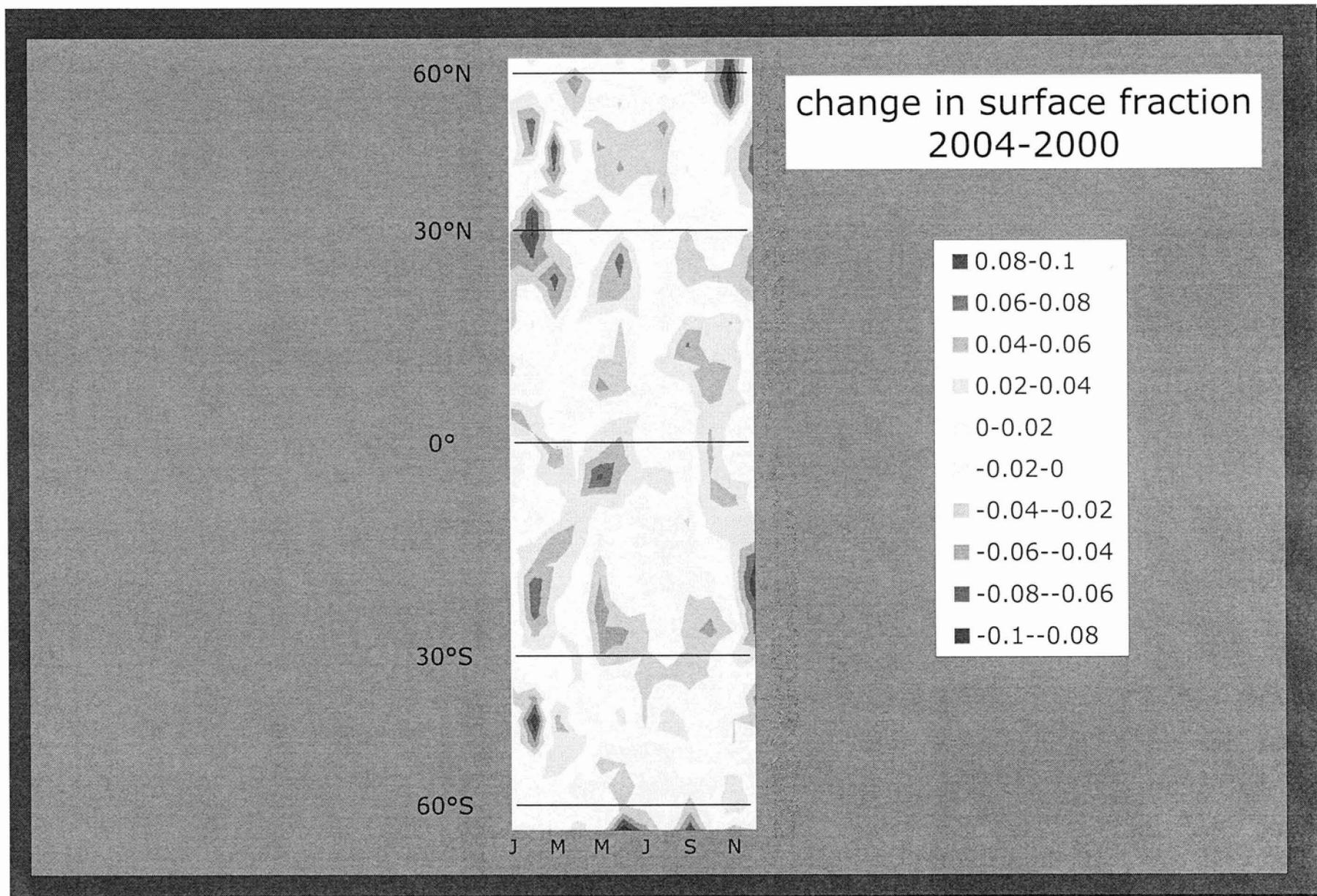
high cloud fraction
z > 7 km
overall: 0.163



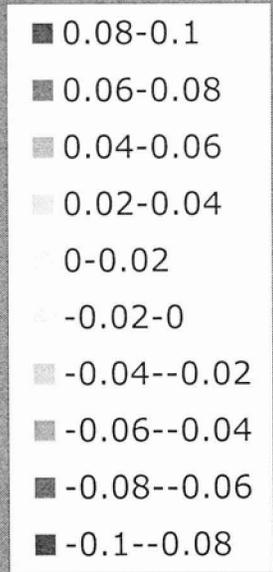
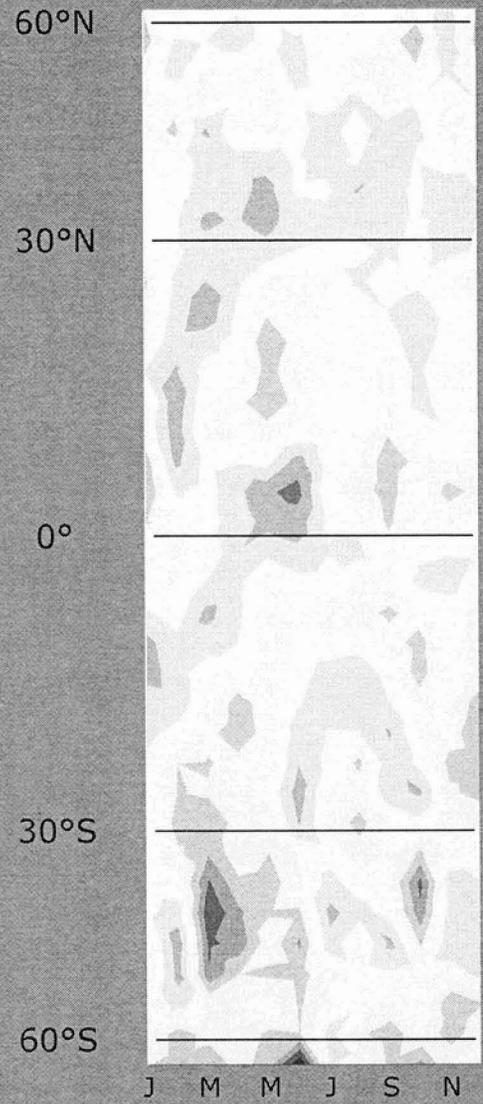
changes in global, annual mean height and cloud fraction 2004–2000

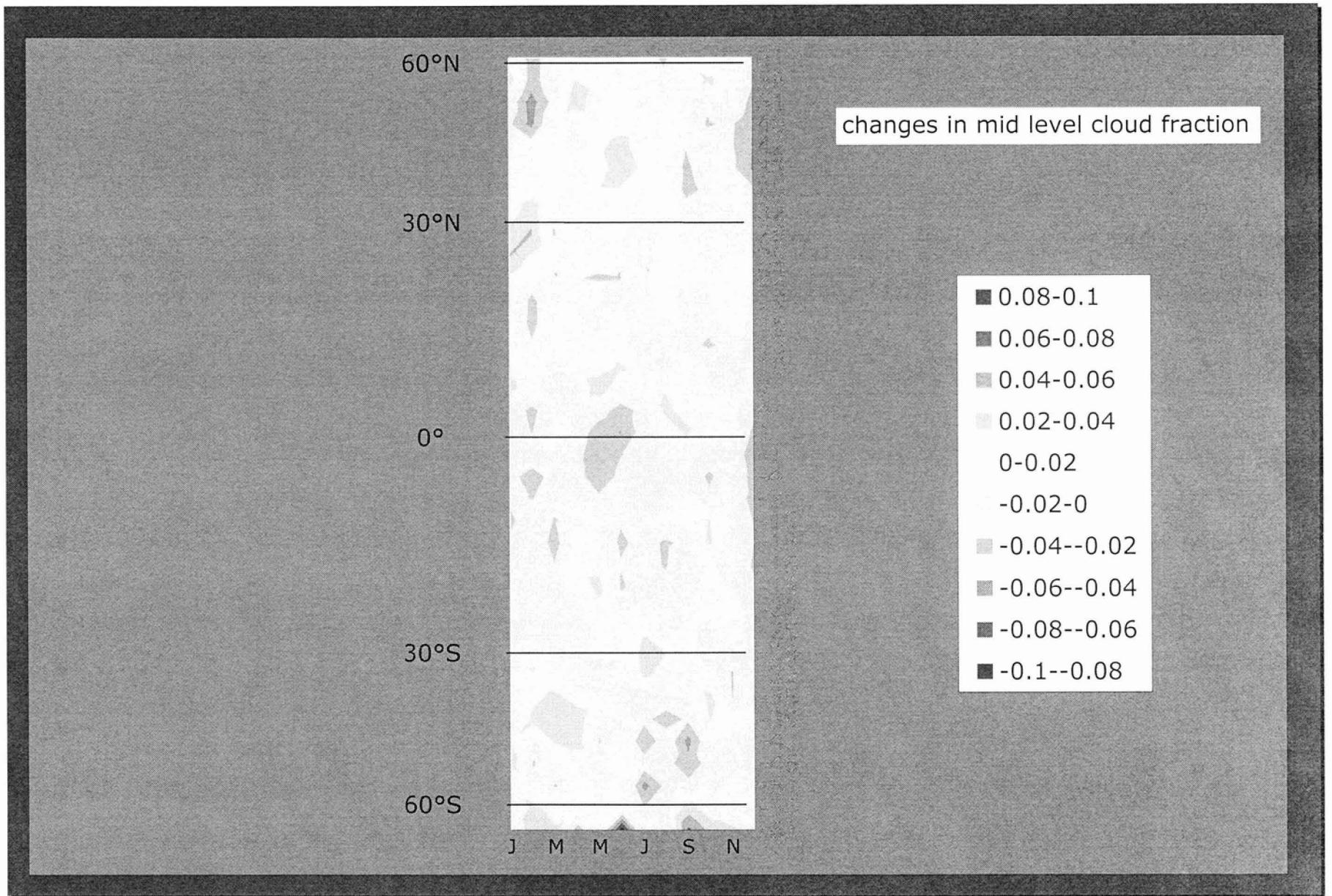
height (m)	-40 ± 13
clear (near surface) fraction	0.000 ± 0.002
low cloud ($z < 3$ km)	0.005 ± 0.002
mid-level cloud ($3 < z < 7$ km)	-0.002 ± 0.002
high cloud ($z > 7$ km)	-0.002 ± 0.002



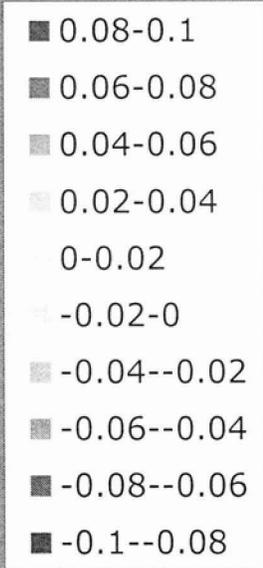
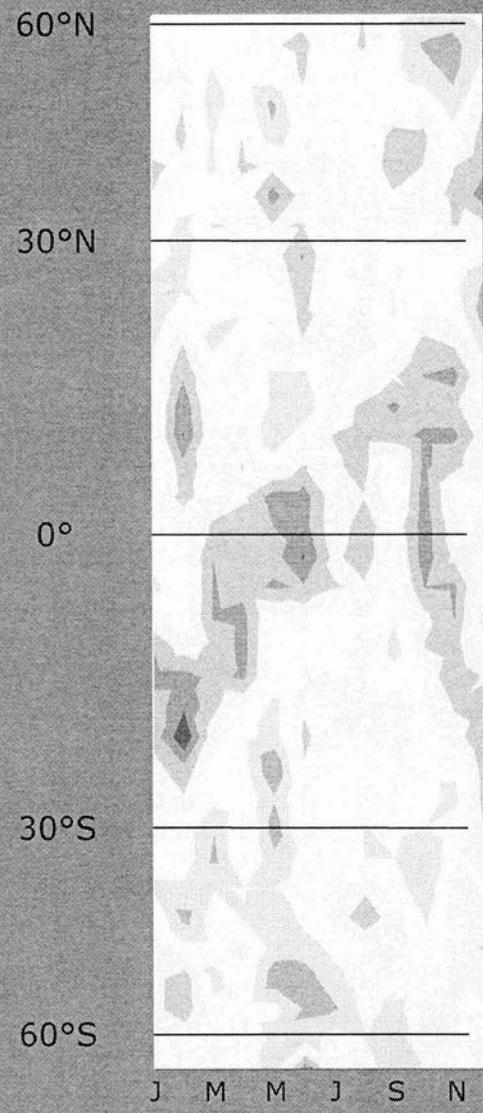


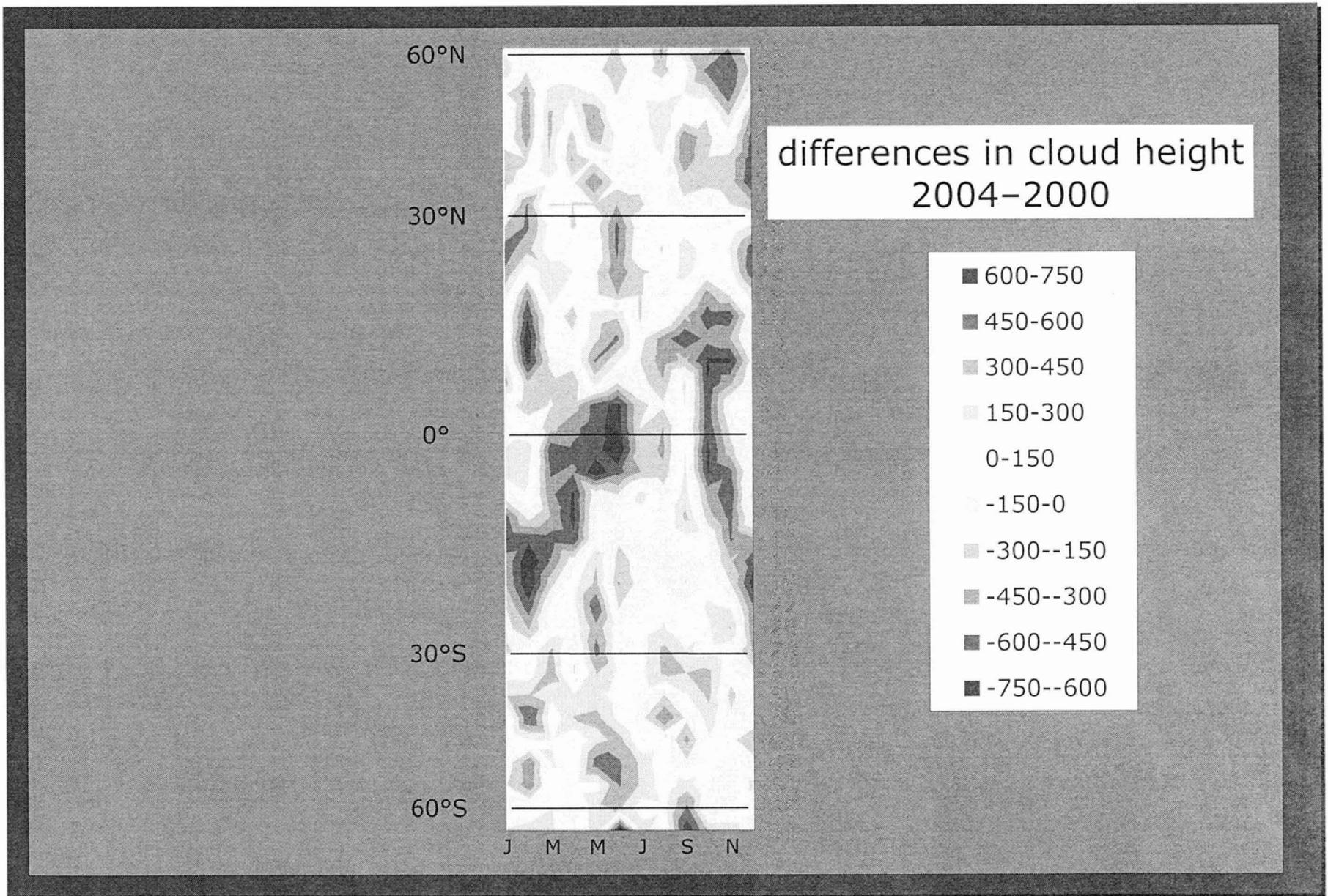
changes in low cloud fraction





change in high cloud fraction





height and fraction summary

- can measure interannual differences
 - in cloud height to ± 10 m on a global basis
 - in cloud fraction to ± 0.002
- biggest changes in cloud height occur in tropics, associated with the ITCZ
 - directly correlated with changes in high cloud fraction

interpretation of height changes

- statistically more significant than the albedo changes
- clouds have a strong greenhouse effect

longwave forcing (i.e., sfc-TOA)

adapted from Kiehl and Trenberth BAMS 97

clouds	45%
water vapor	33%
carbon dioxide	15%
other	7%

- based on 65 g m^{-2} global average cloud water
- Pruppacher and Klett, 1995:
 - 380 g m^{-2} more likely

interpretation of height changes

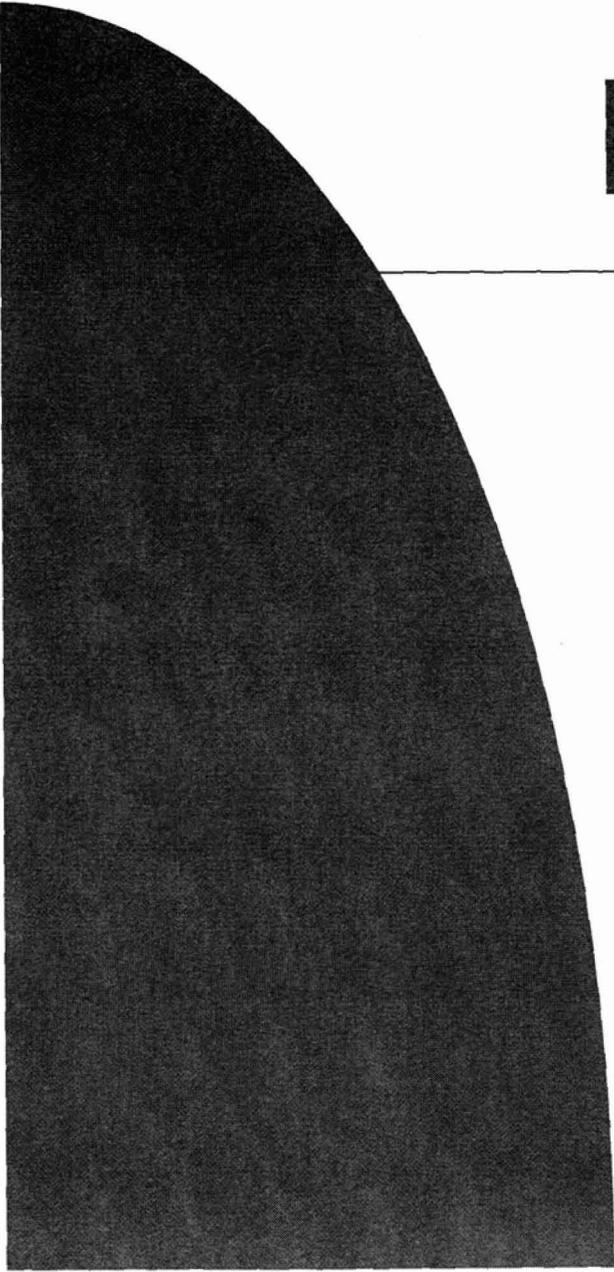
- statistically more significant than the albedo changes
- clouds have a strong greenhouse effect
- radiative-convective models show a strong dependence of equilibrium temperature on cloud height
 - ◆ a change of +300 m \approx 2x CO₂
 - ◆ -40 m \approx 0.5 W m⁻² cooling

overall differences between beginning and current Terra data

- additional absorption of $0.3 \pm 0.3 \text{ W m}^{-2}$ shortwave radiation
 - ◆ primarily at polar latitudes
 - ◆ positive feedback
- reduction in cloud height of $40 \pm 13 \text{ m}$
 - ◆ comparable in forcing to $-0.5 \pm 0.15 \text{ W m}^{-2}$
 - ◆ negative feedback
 - ◆ primarily due to fewer high clouds in ITCZ

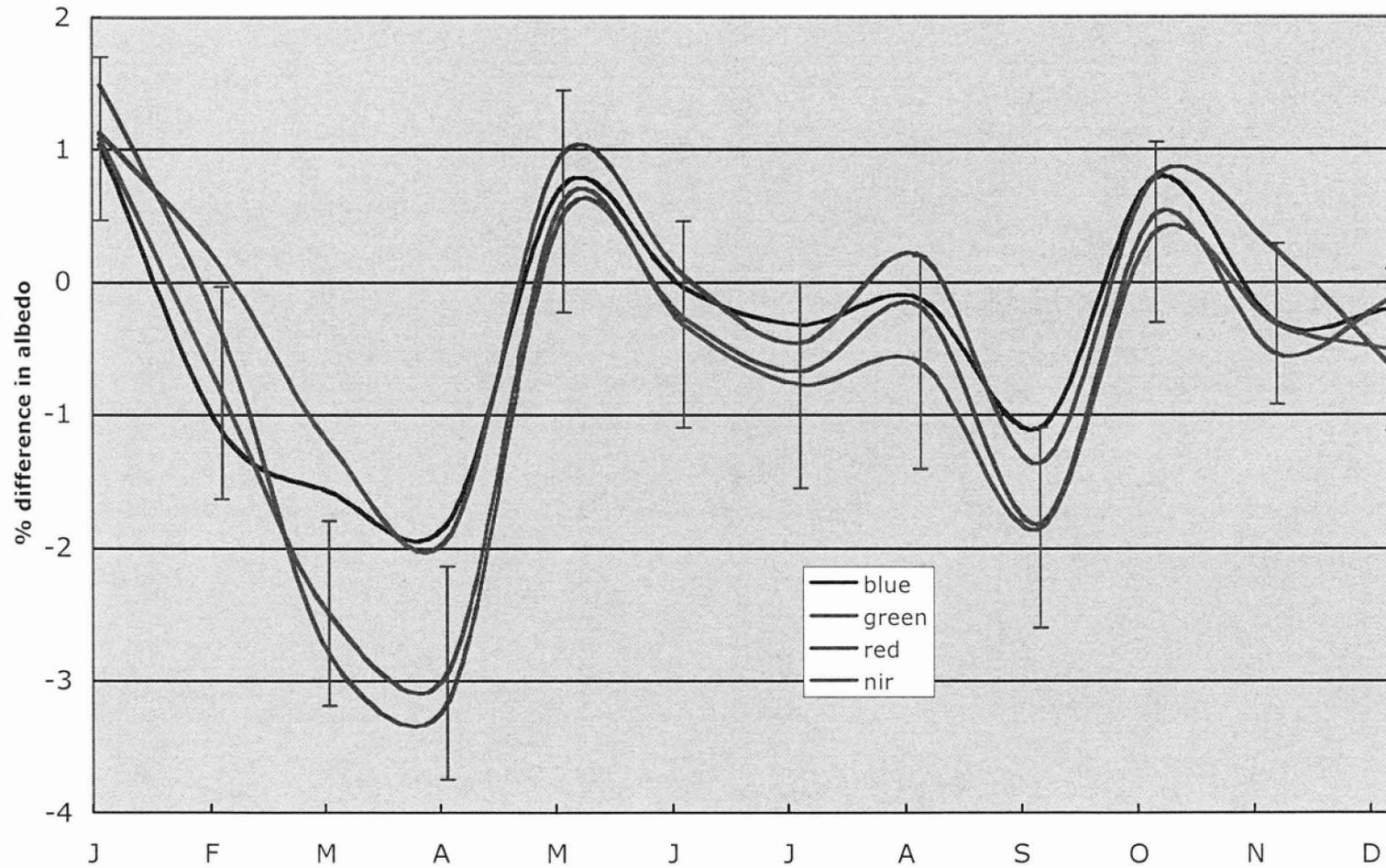
points to ponder

- IPCC suggests $+0.6 \text{ W m}^{-2}$ /decade CO_2 forcing
- our shortwave difference is well within the sampling uncertainty, and close to zero
- our cloud height difference appears larger than the sampling uncertainty
 - ◆ need to revisit the r-c equilibrium modeling implications
- analysis of intervening years is underway as reprocessed data becomes available
- the next few years should be very interesting!

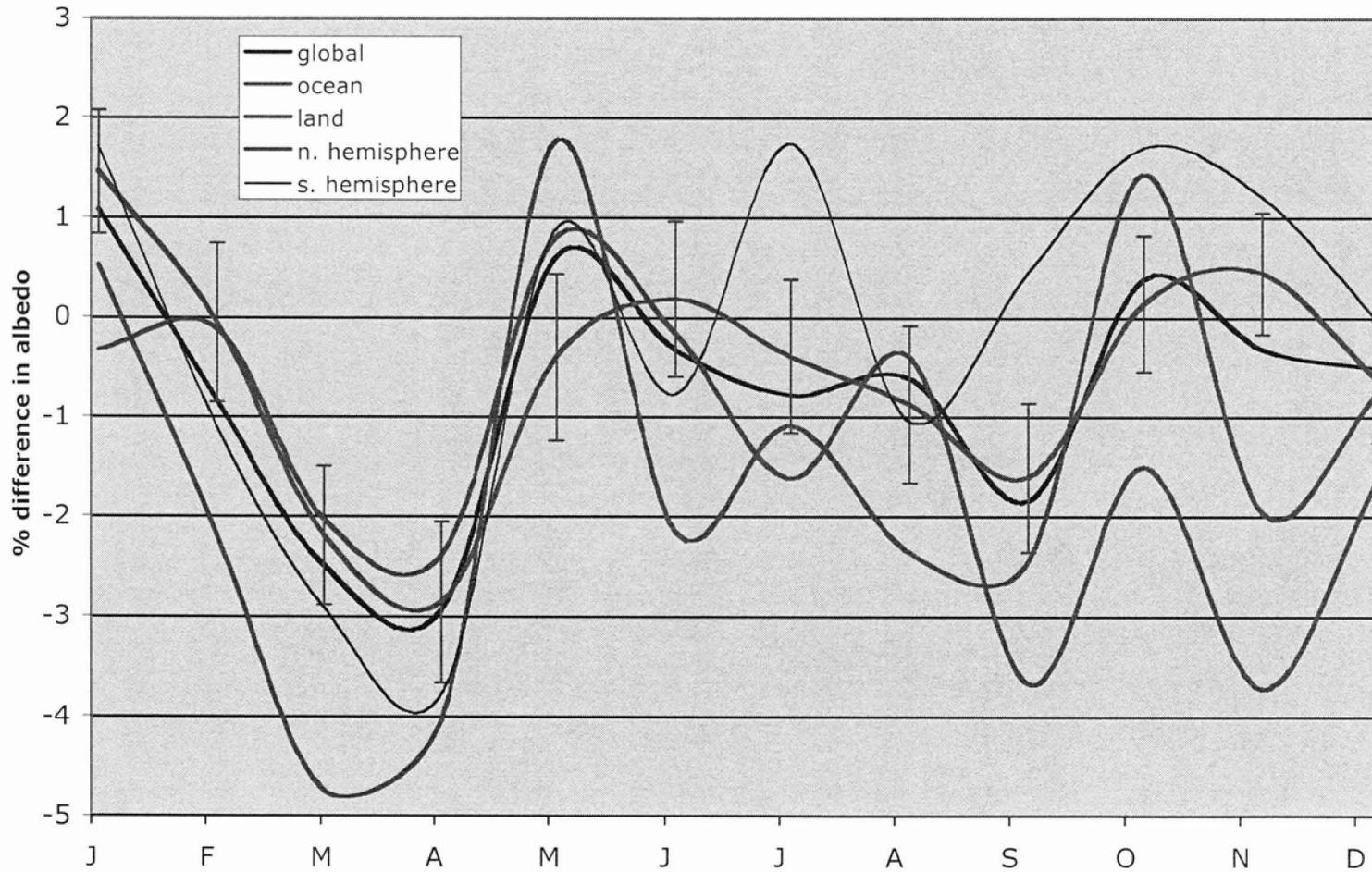


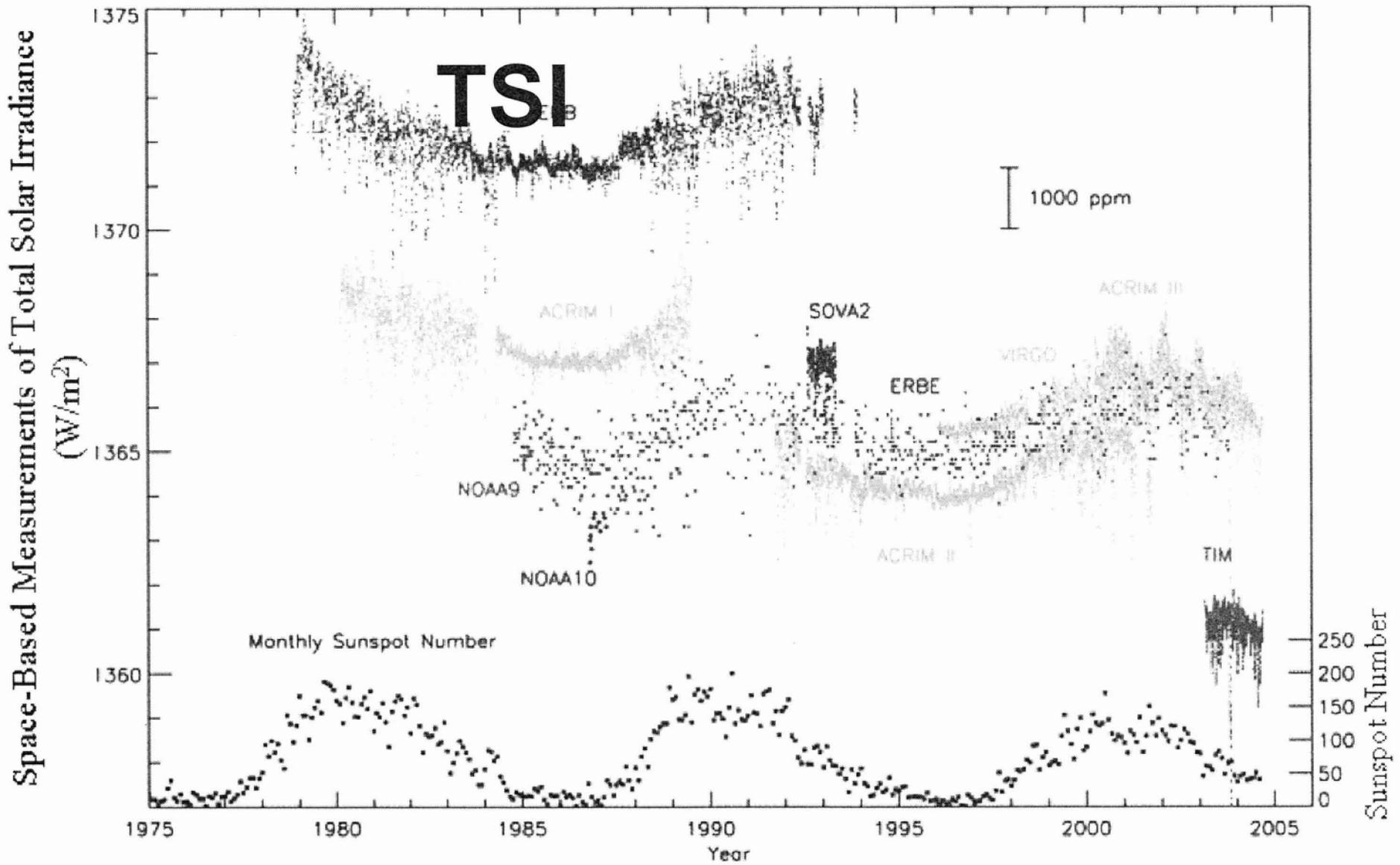
backup slides

%difference in albedo, 2004-2000, global



%difference in green albedo, 2004-2000, global





9/22/05