Need of 3-D Polar Cloud Climatology for Earth Radiation Budget Study

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Cloud radiative effect is a major climate concern and controls the global climate through earth radiation budget. Also, earth radiation budget is a good indicator of climate. Earth radiation budget is a key factor for discussing the role of polar region in global climate.

1. Earth radiation budget in the polar regions

In the polar regions, snow and ice as the Antarctic and Greenland ice sheets or as a sea ice with a large seasonal variation are strong controlling factors of radiation budget, but clouds also have a large effect on radiation budget. Radiative forcing of clouds is shown in Fig. 1, as a zonal annual average. It is found that the maximum cloud forcing appears in the high latitude, especially in the Southern Hemisphere around 60° S. Over the Antarctic Continent, cloud forcing lies near 0, but this is at the top of the atmosphere, and cloud forcing of each components at the surface becomes quite large. At the surface, shortwave and longwave cloud forcing are in the opposite direction, and the net cloud forcing is small positive (warming) throughout the year at the most region in Antarctica.

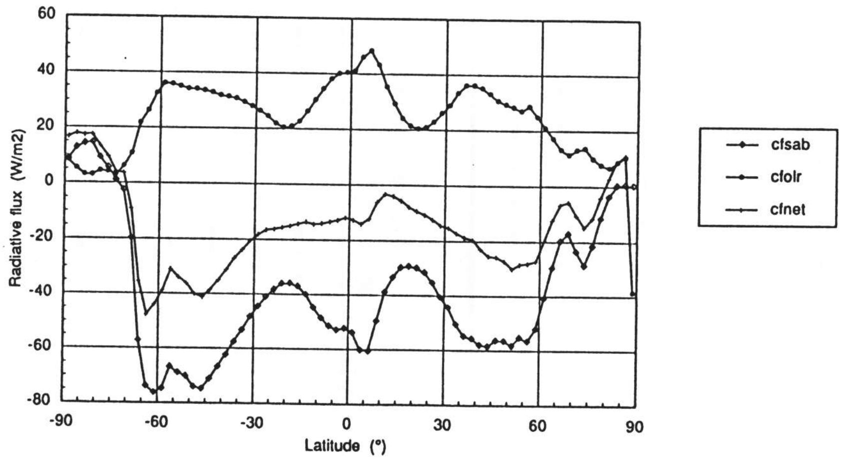

Fig. 1 Latitudinal variation of ERBE annual and zonal average of shortwave (cfsab), longwave (cfolr) and net (cfnet) cloud radiative forcing.

Fig. 2 shows the cloud amount dependence of radiative fluxes at the top of the atmosphere (TOA) and the surface at the South Pole. For the longwave fluxes, smaller dependence at the TOA and larger dependence at the surface, result in increase of cooling of the atmosphere by clouds. As for the shortwave, quite similar variation of fluxes are seen at the TOA and the surface, which means negligible effect for the atmosphere. The ratio R of the cloud shortwave effectiveness (CE) at the surface to that at the TOA is defined as R = CE(SFC) / CE(TOA). From this example at the South Pole, R = 1.0, while at Syowa Station, R = 1.2. There are many discussions about this relation (Li et al., 1995; Cess et al., 1995; Ramanathan et al., 1995; Hayasaka et al., 1995). From the present work, R does not show such a large value as 1.5 (large absorption) as reported for the low or mid latitudes. This estimate was just made with comparing the surface observation. In order to estimate the surface radiation budget from satellites, it is indispensable to have an information of cloud vertical distribution, especially of cloud bottom temperature/height. 3-D observation is necessary to proceed radiation budget study of the atmosphere.

2. Difficulties in estimating earth radiation budget fluxes

There are still large uncertainties for the radiative effect of clouds over the snow and ice surface of the Antarctic Continent. Ramanathan et al. (1989) estimated the shortwave cloud forcing to be positive from the ERBE results using clear sky fluxes. However, from the precise comparison with the surface observation, Yamanouchi and Charlock (1995)

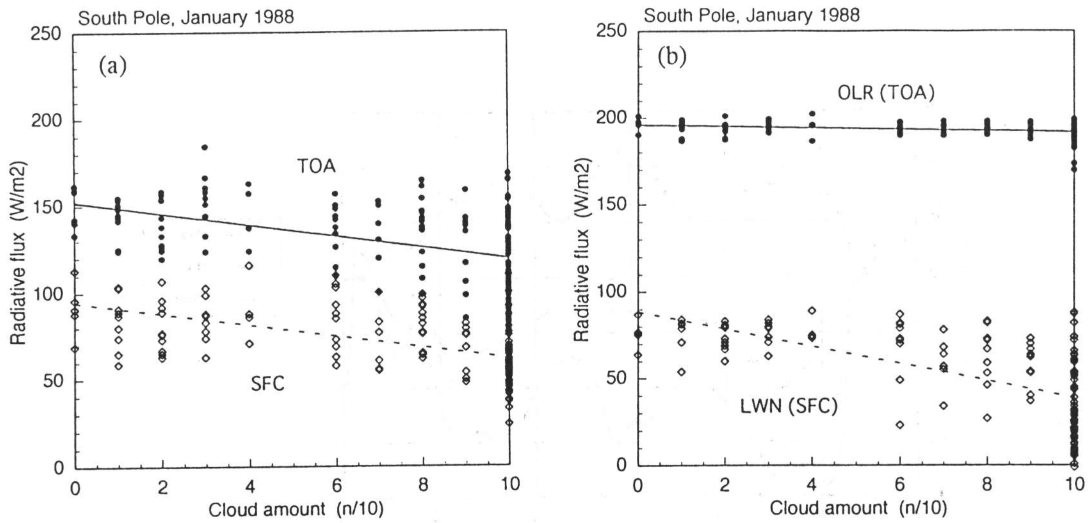

Fig. 2. (a) Cloud amount dependence of ERBE S-8 top of the atmosphere shortwave absorption (TOP) and shortwave absorption at the surface (SFC), (b) Cloud amount dependence of outgoing longwave radiation (OLR) and net longwave flux at the surface (LWN), South Pole, January 1988. Solid and dashed lines are regression lines.

obtained negative forcing. ERBE clear sky fluxes seem to be erroneous over the snow and ice surface.

Variations of the TOA shortwave absorption for ten days are shown in Fig. 3, from the whole data measured around the South Pole. Clear corresponding variation of the shortwave radiation at the TOA and the downward longwave radiation at the surface are seen for a time scale of about day, while there are some points which diverse greatly from other points. These points are estimated as "overcast" by the ERBE scene identification. Radiative fluxes of ERBE are calculated from the measured radiances using the ERBE angular distribution model following the scene identification of the target. The problem lies in the scene identification and also in the angular distribution model for the large solar zenith angle.

Cloud detection in the polar region is thus a urgent issue to be solved. Detection of polar clouds still encounters many difficulties only from the two dimensional image data. It is very important to have a reliable cloud detection from 3-D cloud observations.

3. Polar cloud climatology

Many efforts have been devoted to make a polar cloud climatology in the Arctic and Antarctic, still large uncertainties exist (Fig. 4). One of those efforts is ISCCP; however, the original analysis seems to have difficulties over snow and ice, especially over the Antarctic continent. Cloud distribution is also a large issue in winter Arctic, which is under the polar night. Even the surface cloud observation is suspicious and the contribution of clear sky precipitation is discussed (Wilson et al., 1993). Low level Arctic stratus, prevailing in summer Arctic, is also still a point of discussion. The relation of clouds and sea ice is a large

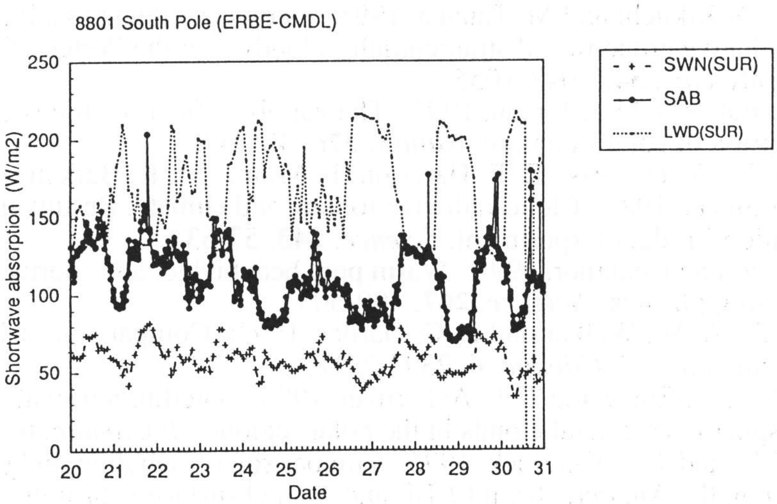

Fig. 3. ERBE S-8 TOA shortwave absorption (SAB), shortwave absorption at the surface (SWN(SUR)) and downward longwave radiation at the surface (LWD(SUR)), South Pole, January 1988.

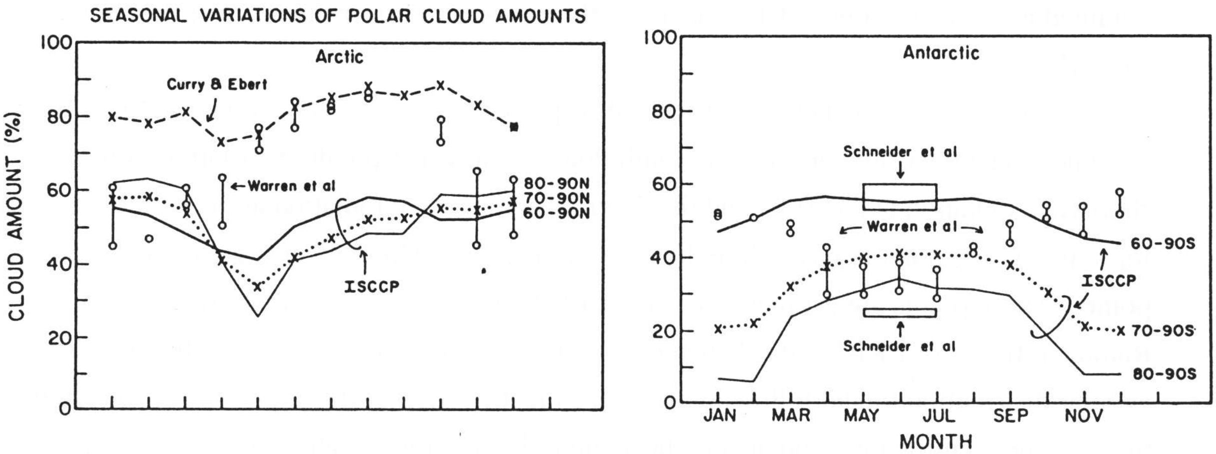

Fig. 4. Comparison of the seasonal variations of average cloud amount in the (a) Arctic and (b) Antarctic determined by ISCCP and other cloud climatologies (Rossow et al., 1993).

issue to be solved, since the radiative effects of sea ice and clouds are large, respectively, if they act independently. However, if there were some dependence of cloud distribution to the sea ice, then performance of the ice-albedo feedback should also be re-examined.

4. Conclusion

Satellite observation of 3-D cloud distribution in the polar region is necessary for (1) cloud climatology, (2) discussion of radiation budget and (3) data processing of earth radiation budget.

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Need of 3-D Polar Cloud Climatology for Earth Radiation Budget Study

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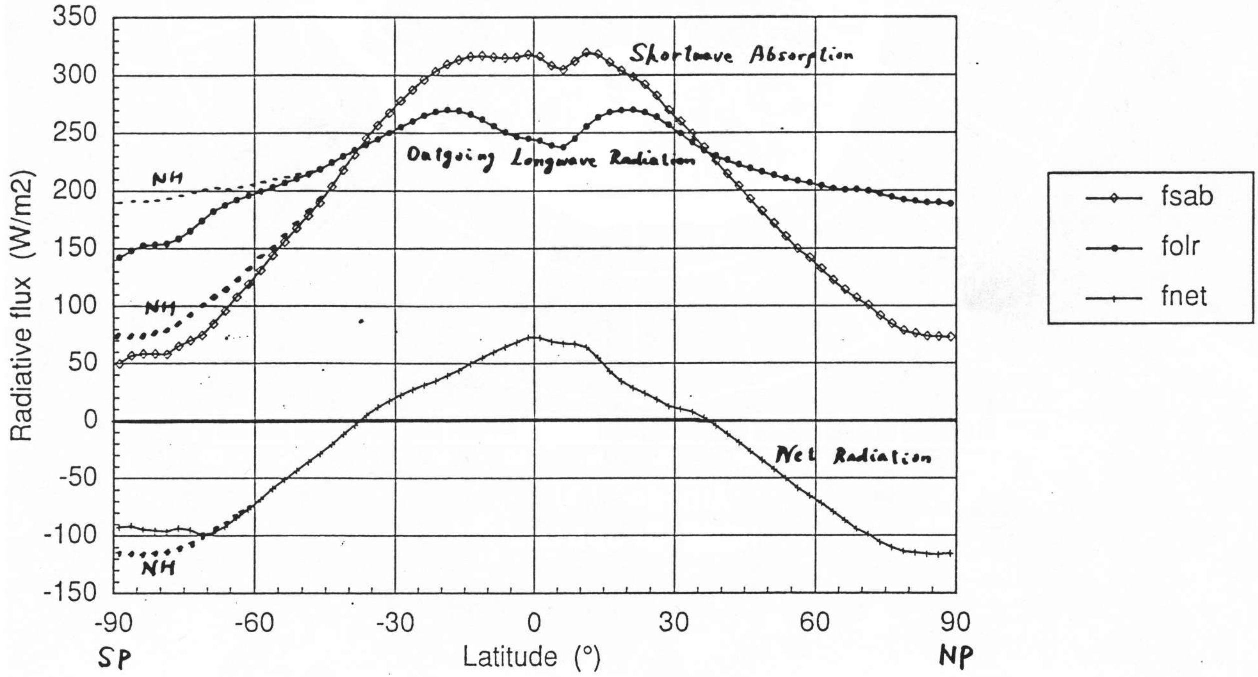
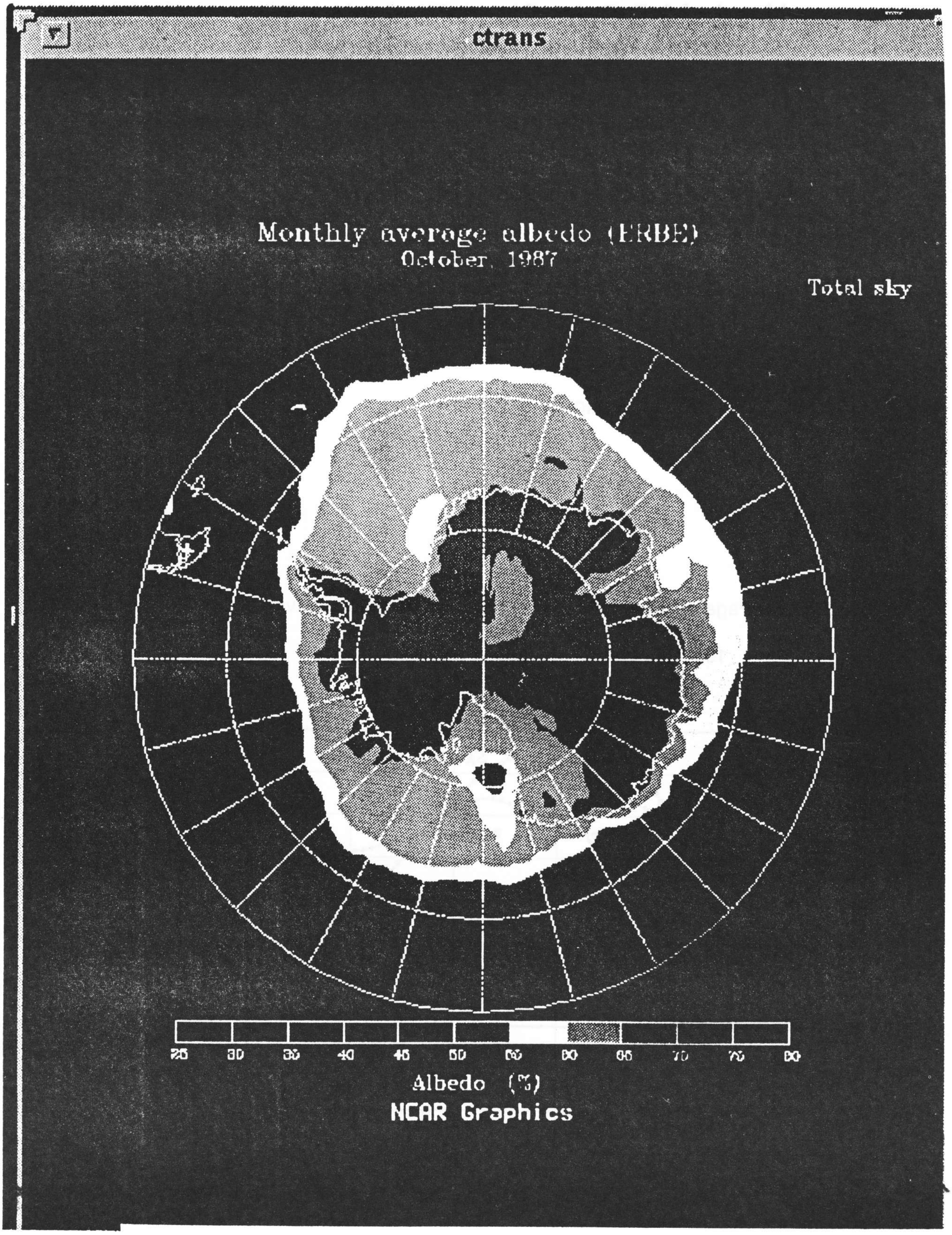
1. The role of polar regions in the earth radiation budget
2. Polar cloud climatology
3. Difficulties in scene identification and estimating earth radiation budget

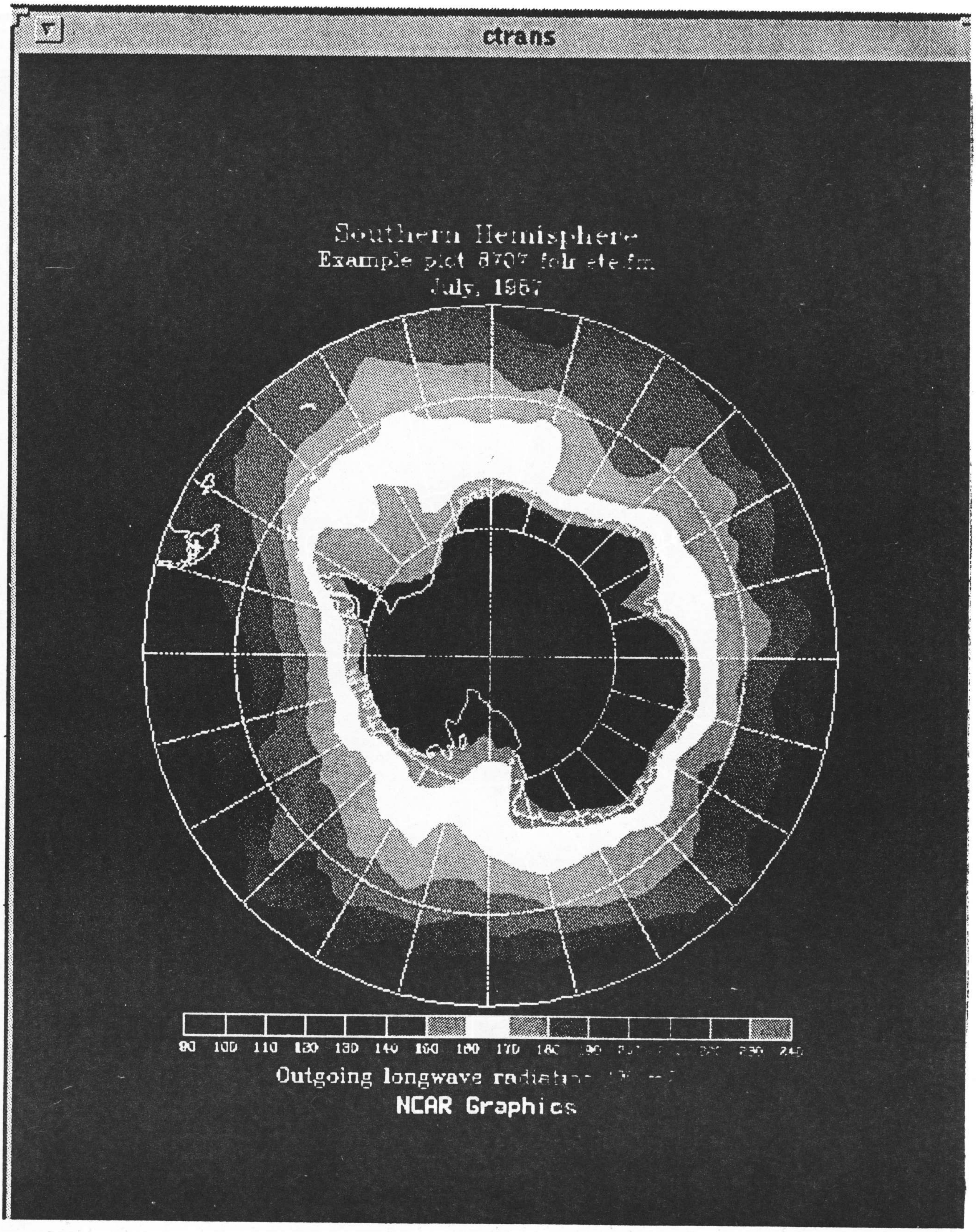
- Need of 3-D cloud distribution

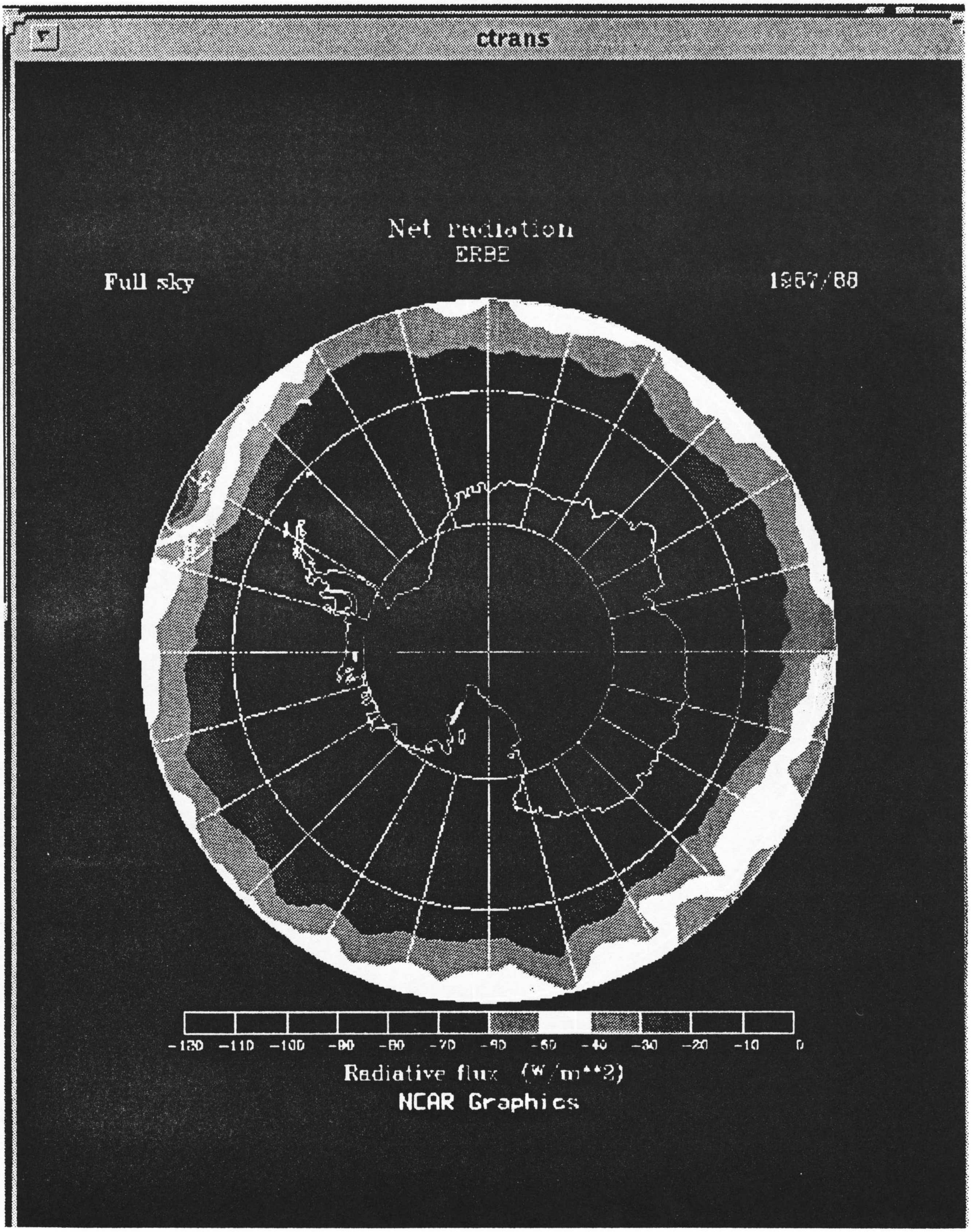
Zonal average of shortwave absorption, outgoing longwave and net radiation
1987/88c annual average (4 months)

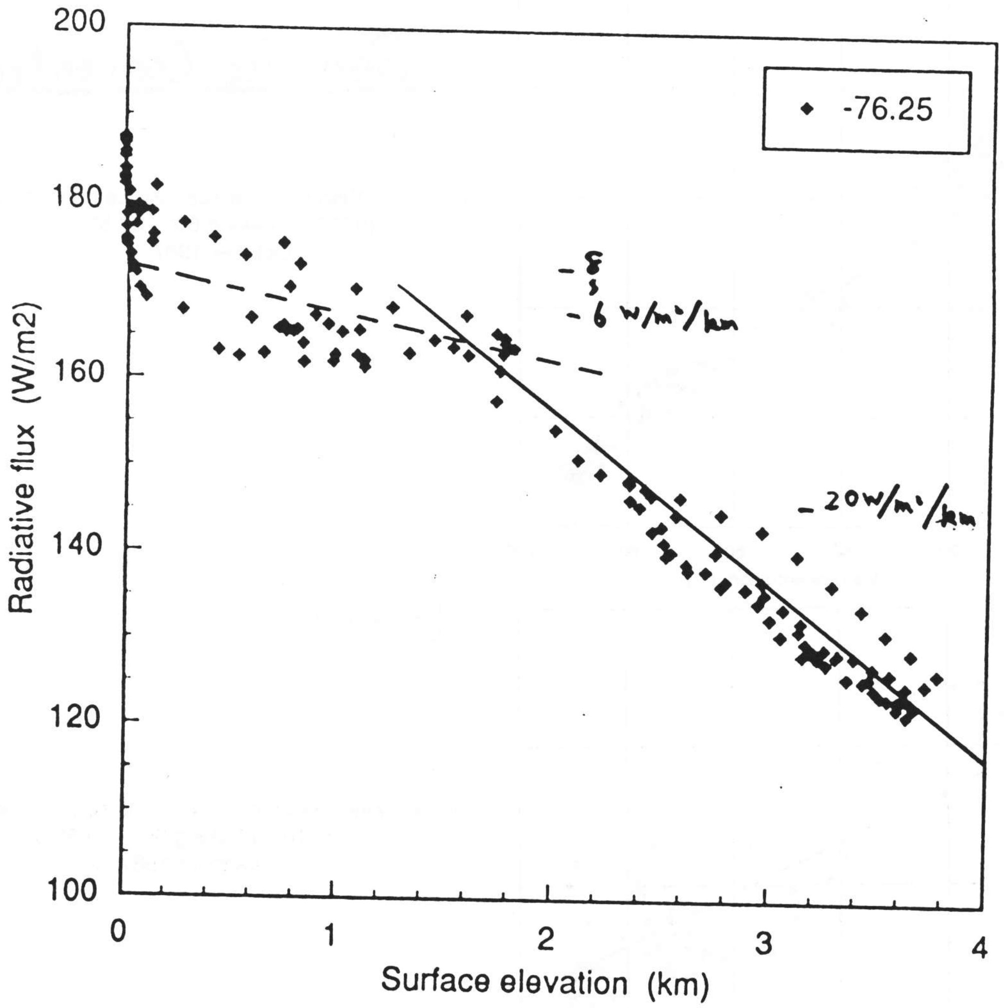




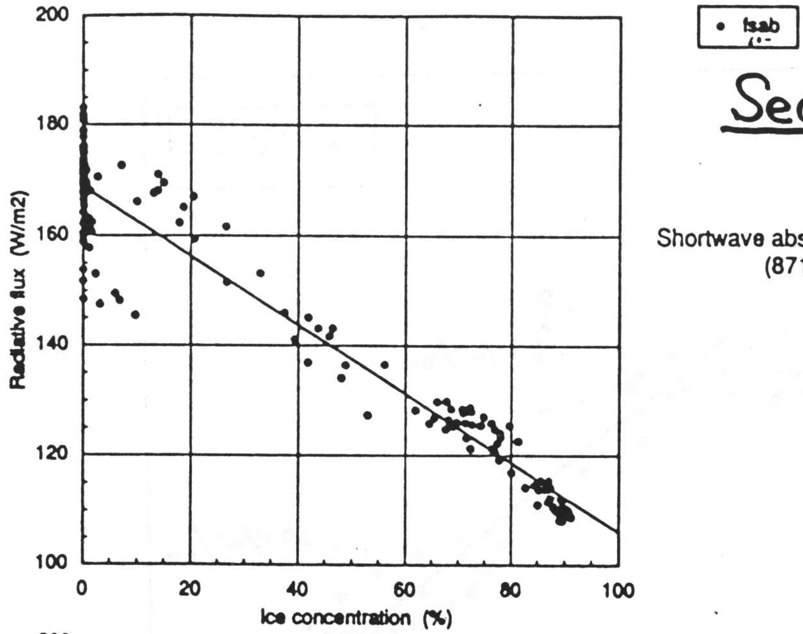
ERBE 月平均アルベード（大気上端）、
1987年10月、全天候


ctrans
Southern Hemisphere
Example plot 8707 folr ete.fm
July, 1987
90 100 110 130 130 140 160 160 170 180 230 240
Outgoing longwave radiat
NCAR Graphics


ctrans
Net radiation
ERBE
Full sky
1987/88
-120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0
Radiative flux (W/m**2)
NCAR Graphics

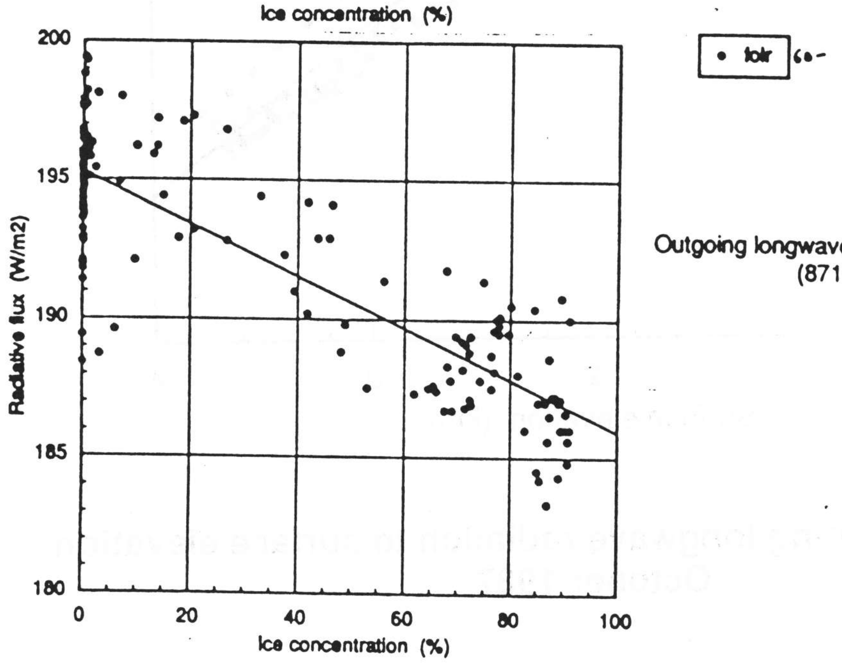


Relation of outgoing longwave radiation to surface elevation
October 1987

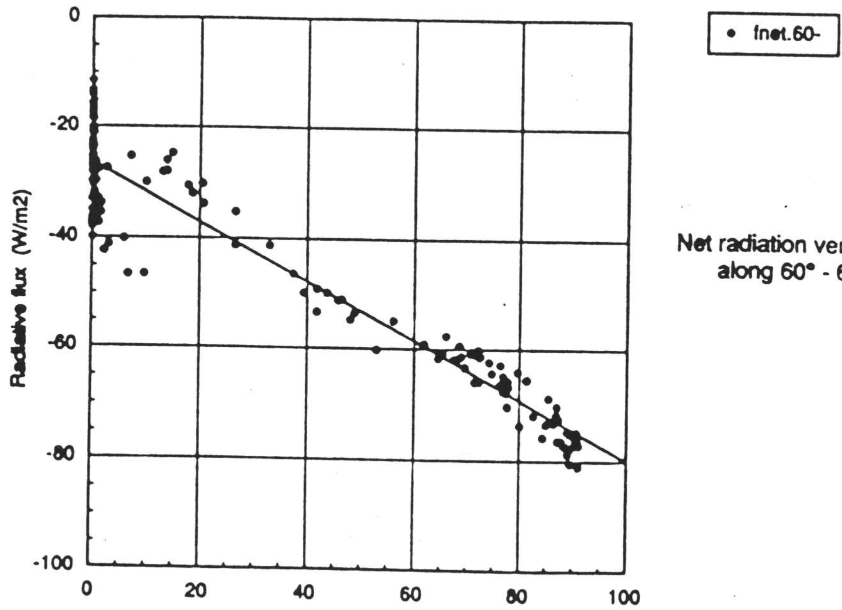


Sea Ice Concentration

Shortwave absorption versus sea ice concentration
(8710mm) along 60° - 62.5° S
October 1987

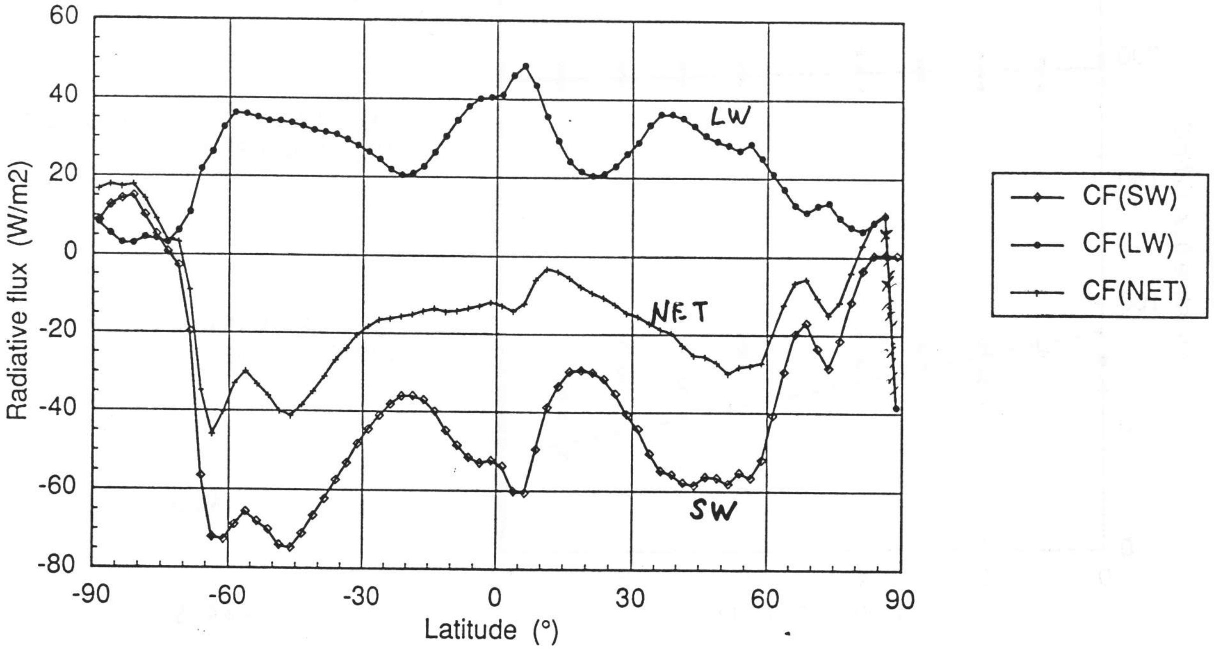


Outgoing longwave radiation versus sea ice concentration
(8710mm) along 60° - 62.5° S
October 1987

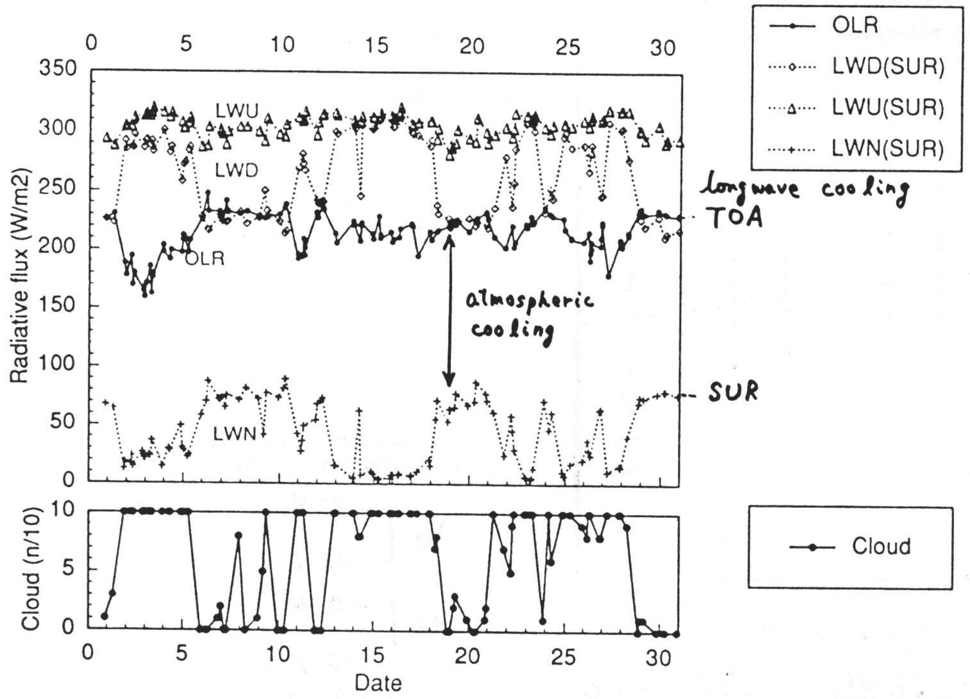


Net radiation versus sea ice concentration
along 60° - 62.5° S, October 1987

Zonal average of cloud radiative forcing shortwave, longwave and net
1987/88c annual average (4months)

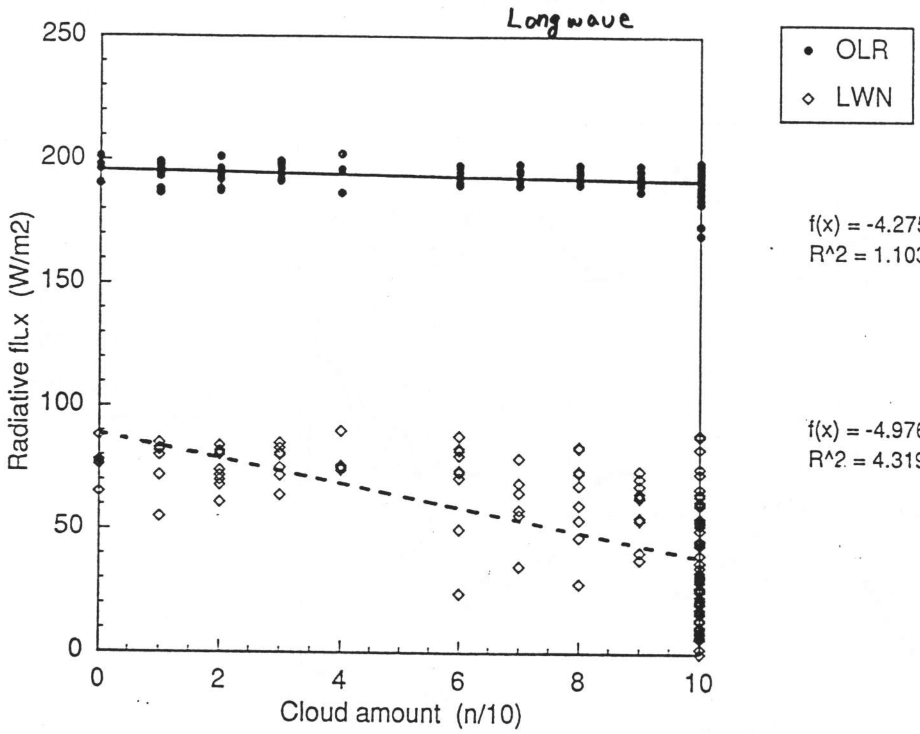


8801 Syowa (69° 00' S, 39° 35' E)



Variation of longwave radiation at the top of the atmosphere (TOA) and surface (SUR)

8801 South Pole (ERBE CMDL NCDC)



f(x) = -4.275468E-1*x + 1.959535E+2
R^2 = 1.103518E-1

f(x) = -4.976451E+0*x + 8.851013E+1
R^2 = 4.319158E-1

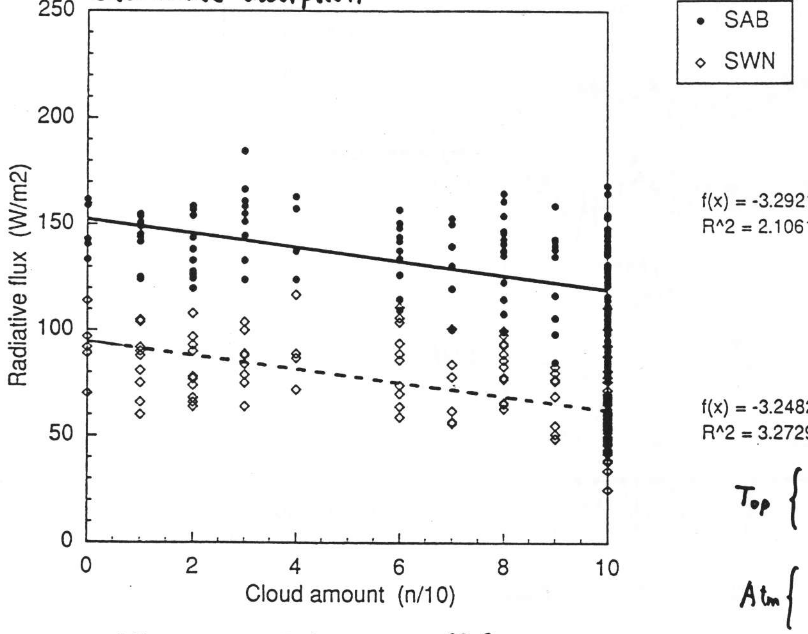
4.3

-45.5

49.8

8801 South Pole (ERBE CMDL NCDC)

Shortwave absorption



f(x) = -3.292129E+0*x + 1.521811E+2
R^2 = 2.106178E-1 (SAB)

f(x) = -3.248283E+0*x + 9.451124E+1
R^2 = 3.272942E-1 (SRFSAB)

Top { -32.9, -28.6 }

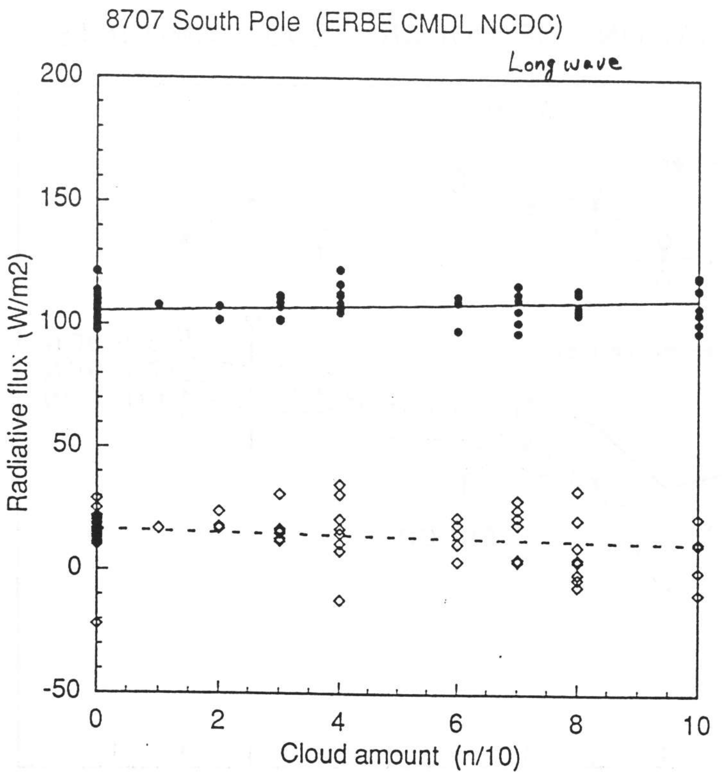
Atm { -0.4, -45.9 }

Sfc { -32.5, +17.3 }

$$R = \frac{CF\,(SFC)}{CF\,(TOA)} = \frac{CE\,(SFC)}{CE\,(TOA)} = \frac{-32.9}{-32.5} \approx 1.0$$

cf) $R \approx 1.2$ at Syowa S9.

CE : Cloud radiative effectiveness



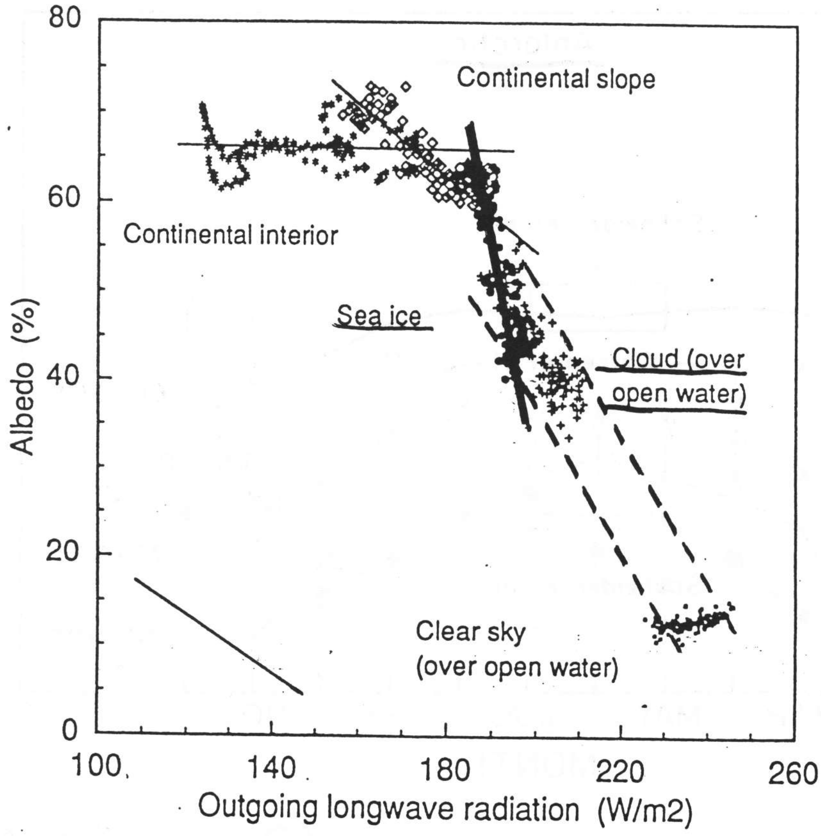
f(x) = 5.215210E-1*x + 1.053913E+2
R^2 = 1.047623E-1

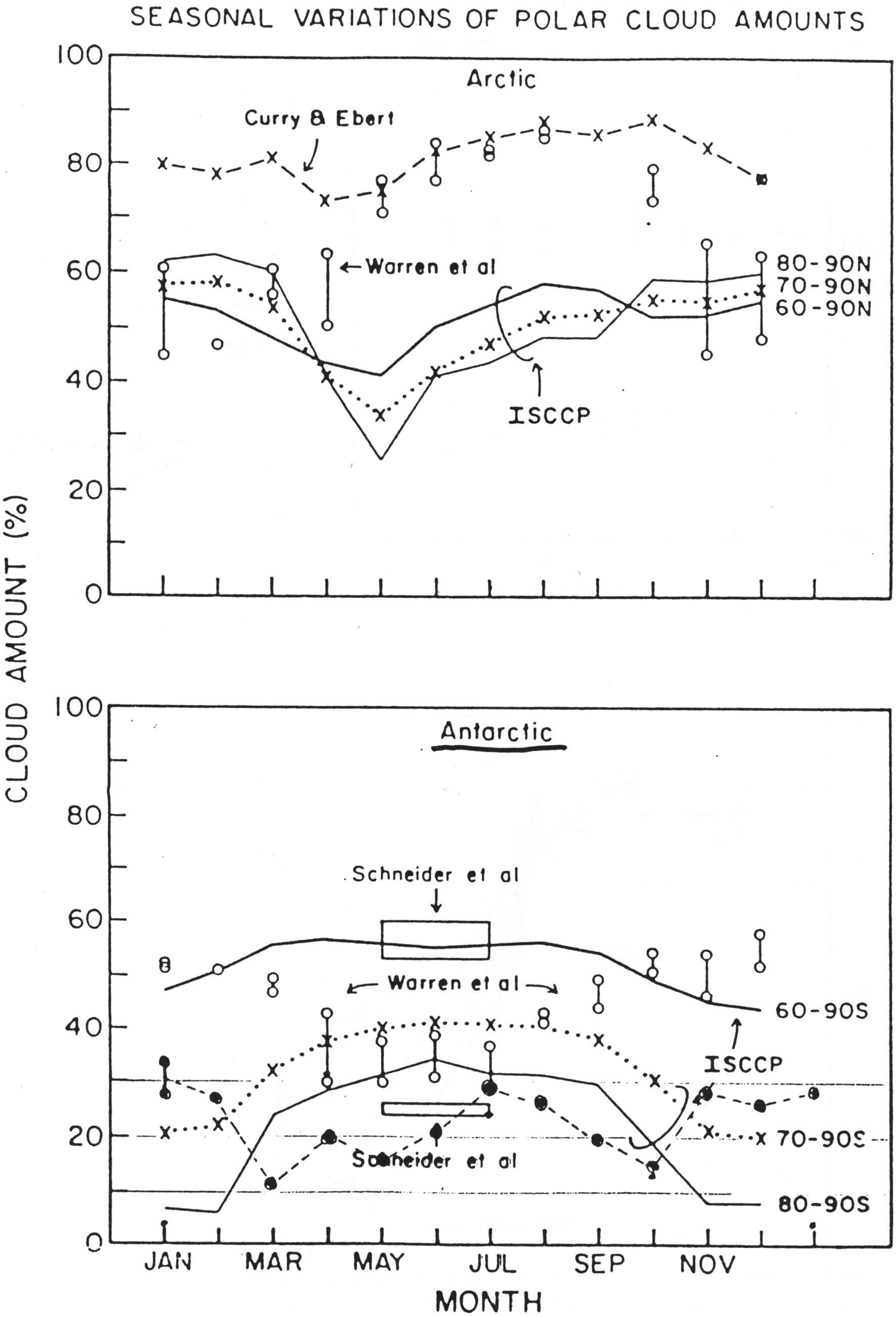
Top : −5.2 W/m²

Atm : −10.4

Sfc : +5.2

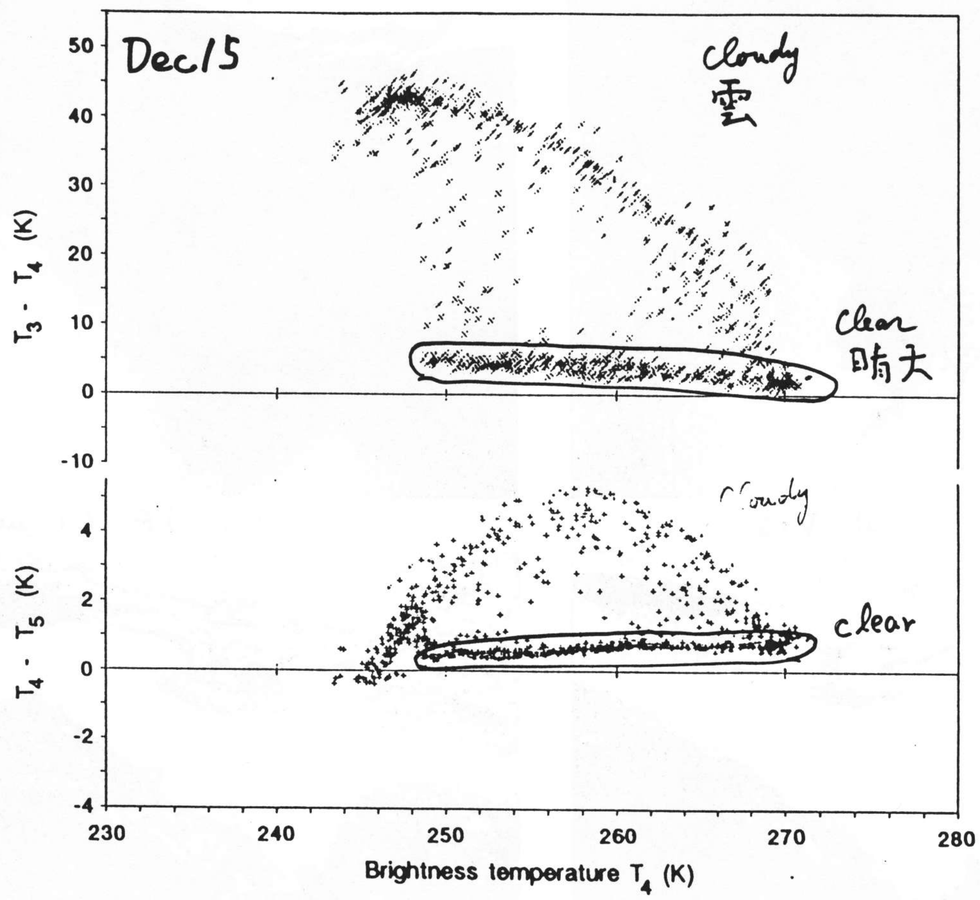
f(x) = -5.215303E-1*x + 1.651704E+1
R^2 = 4.367309E-2

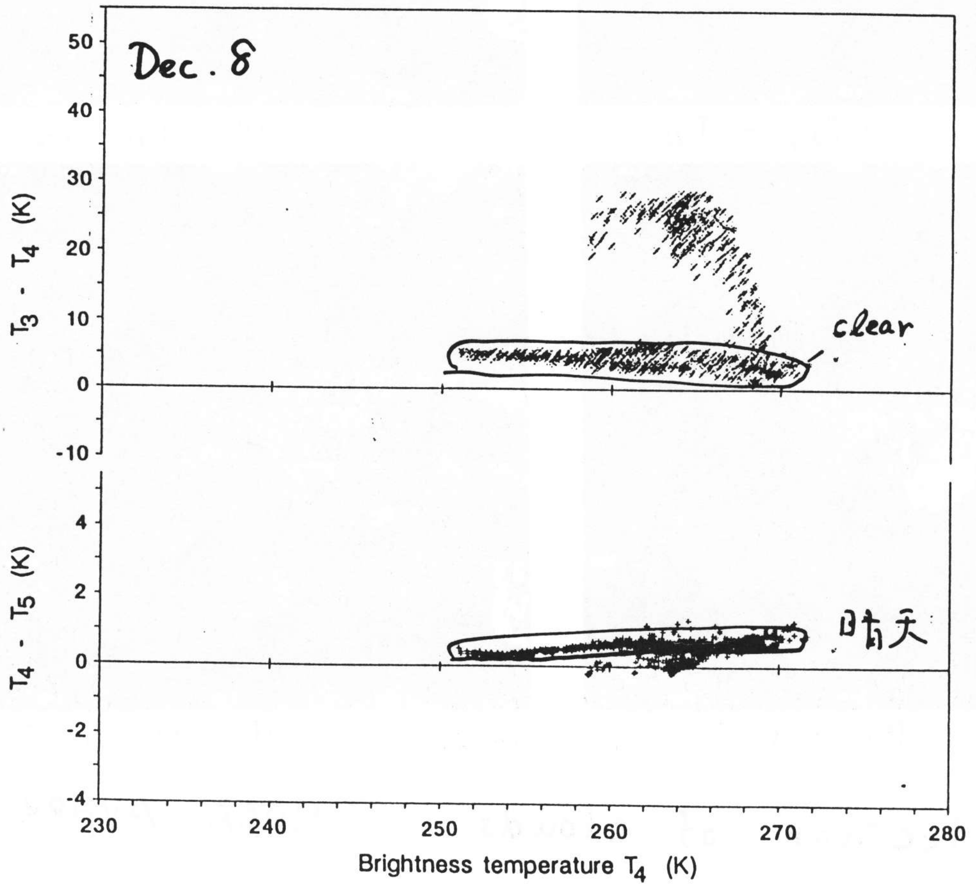


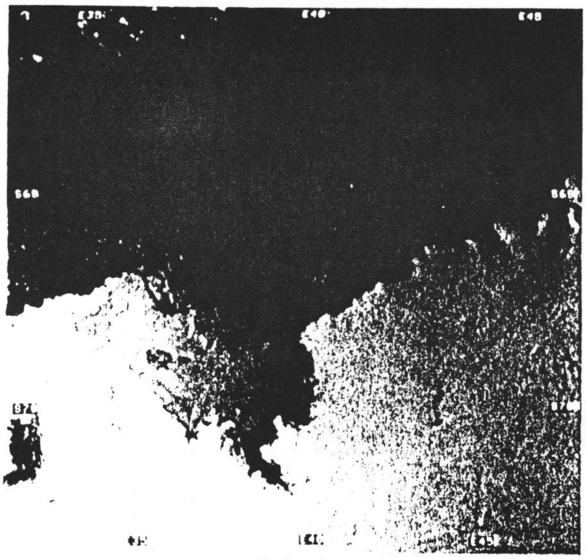


(Rossow et al., 93)

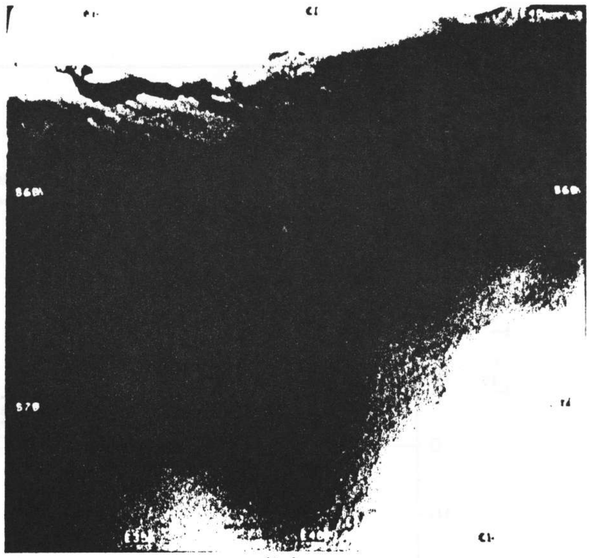
FIG 36


Dec15
Cloudy
雲
Clear
晴天
Cloudy
clear
$T_3 - T_4$ (K)
$T_4 - T_5$ (K)
Brightness temperature T_4 (K)

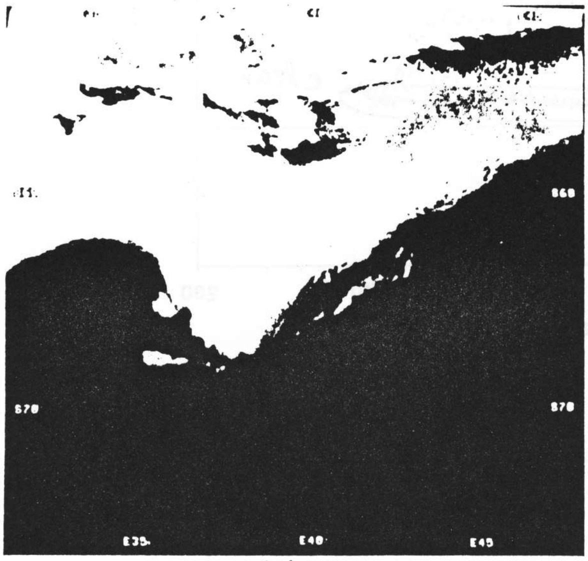

Dec. 8
clear
晴天
$T_3 - T_4$ (K)
$T_4 - T_5$ (K)
Brightness temperature T_4 (K)



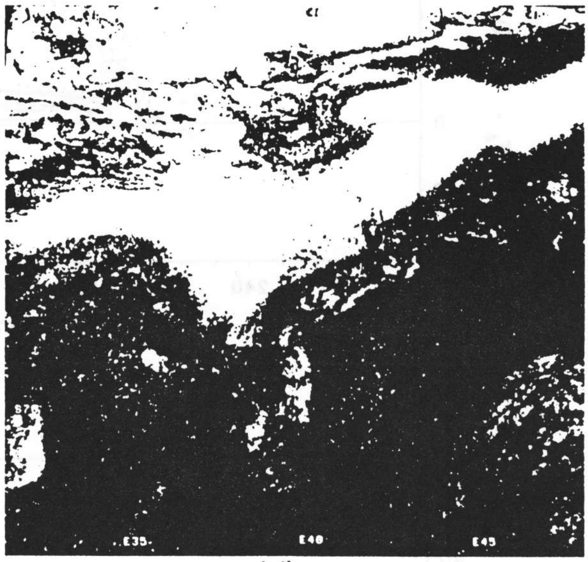
(a) Vis



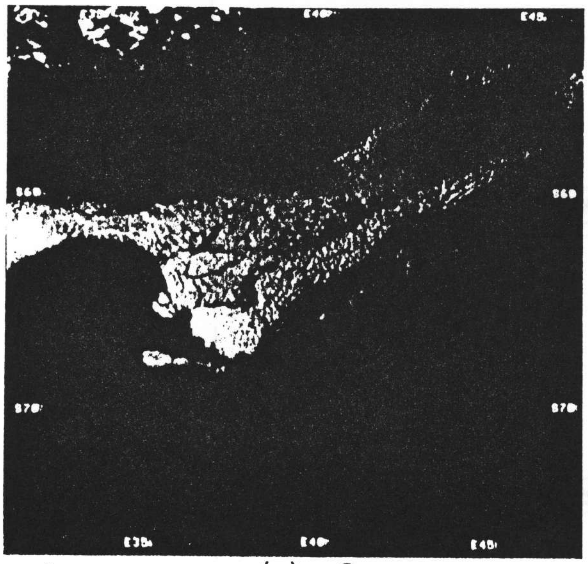
(b) IR (11 μm)



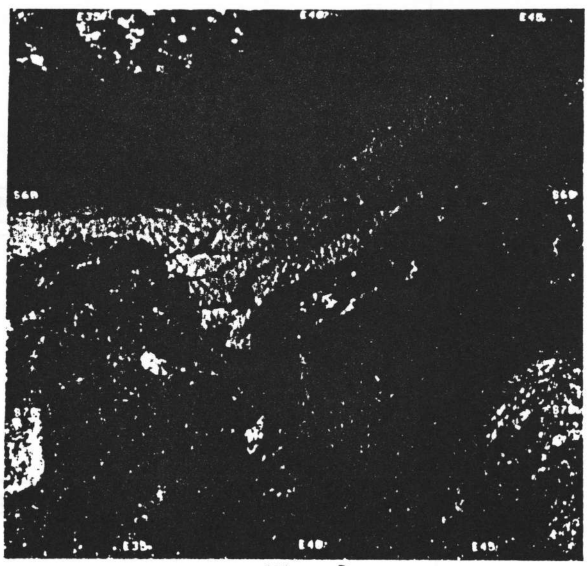
(c) $T_{3.7} - T_{11}$



(d) $T_{11} - T_{12}$

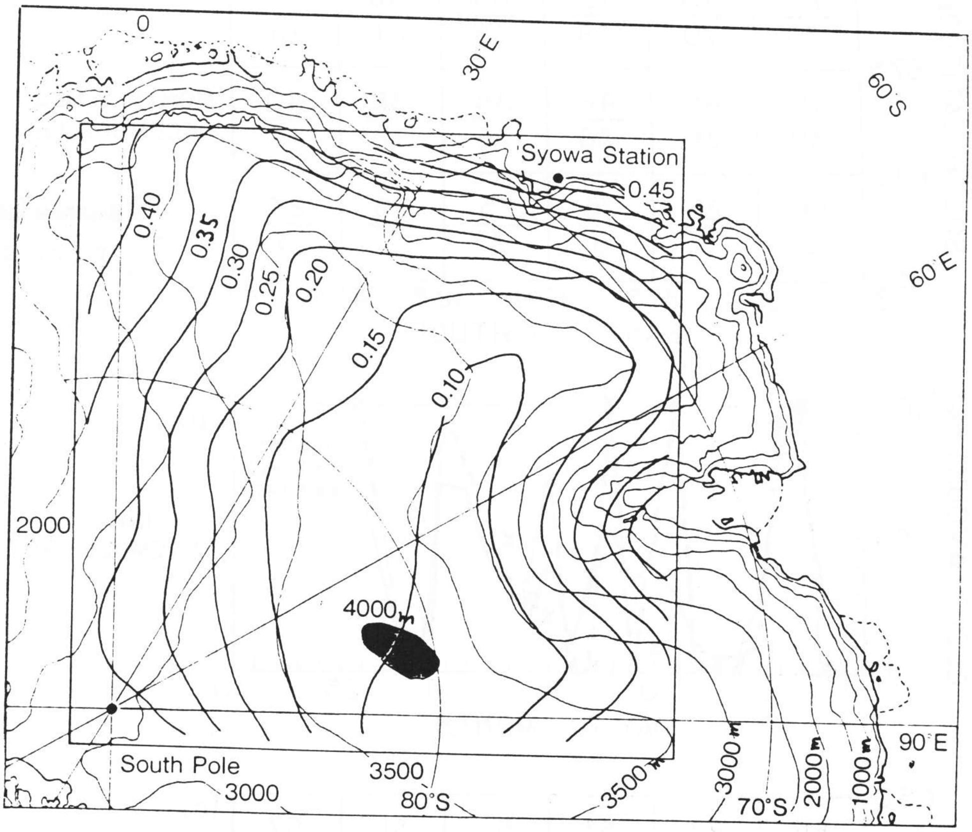


Composite (e) Red : $T_{3.7} - T_{11}$ ← clouds



(f) Red : $T_{11} - T_{12}$

Fig. 8 Detection of clouds NOAA AVHRR



Annual mean cloud amount 1987

Seasonal variation of cloud amounts 1987/88

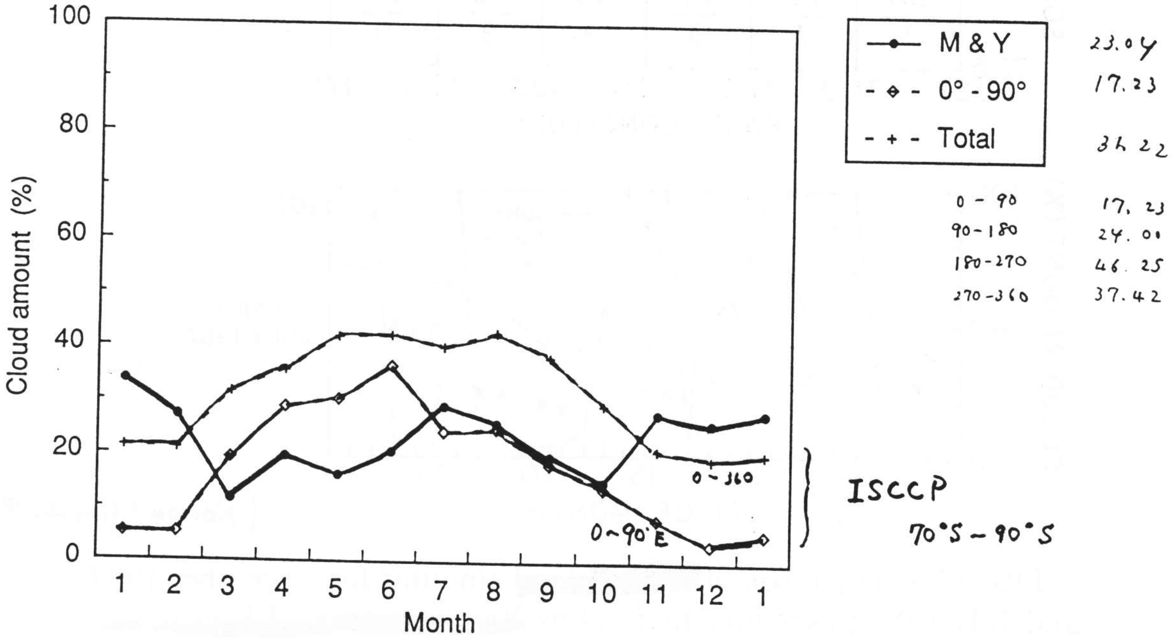


Fig. 7

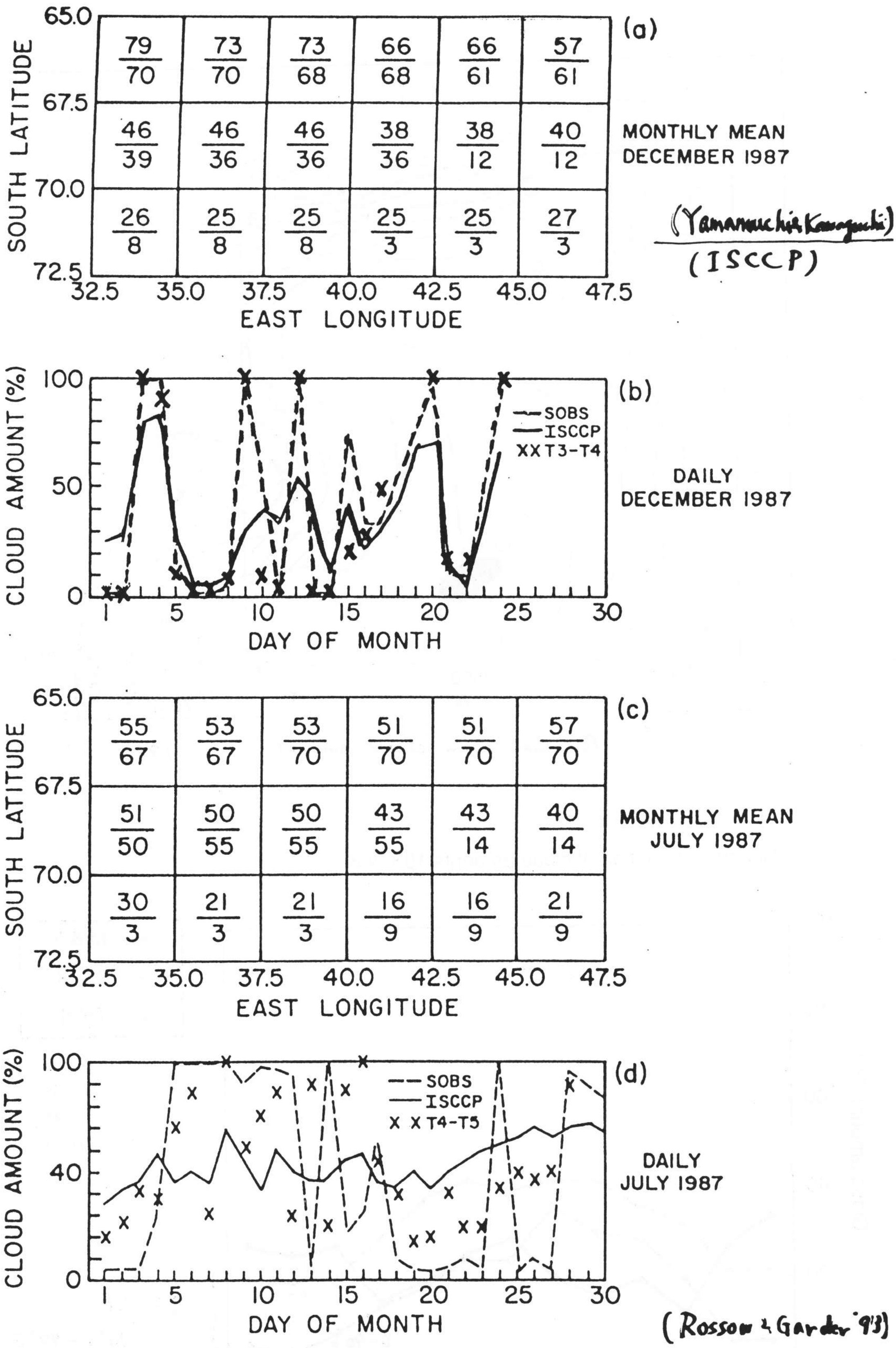


FIG. 17. Comparison of [redacted] amounts for December 1987 and July 1987 to satellite analyses by [redacted] (1992) and to surface reports from Svowa station in Antarctica. The

Mean cloud cover

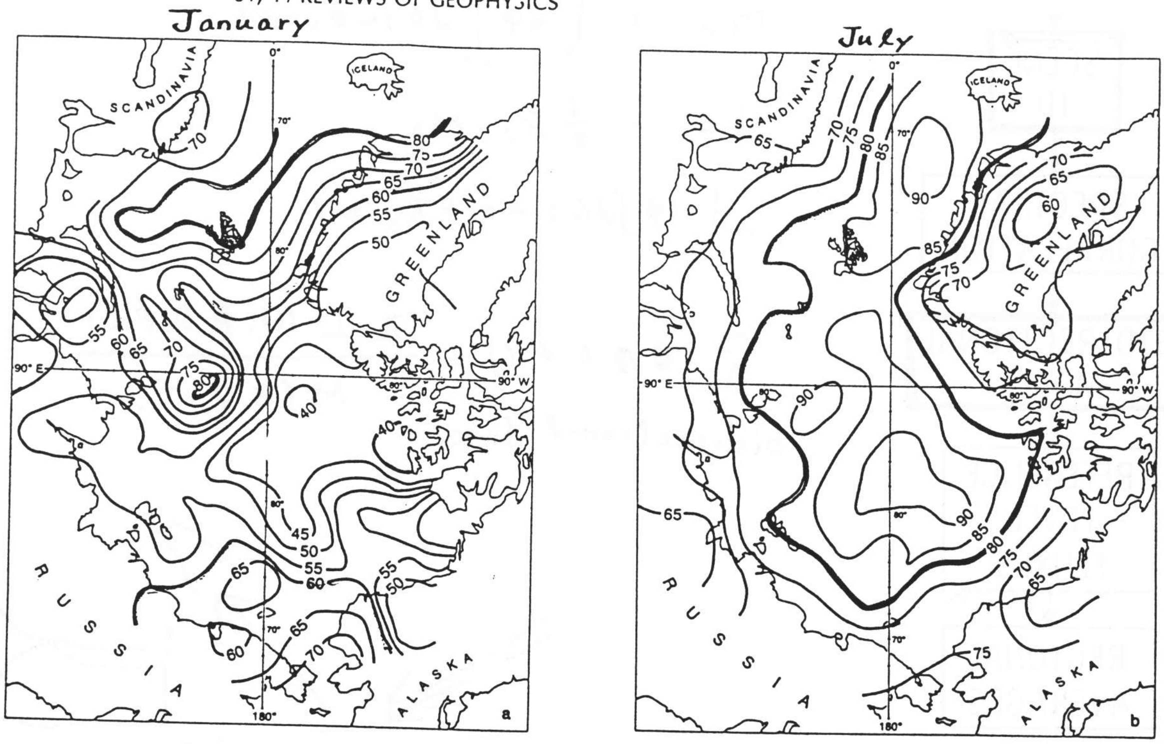
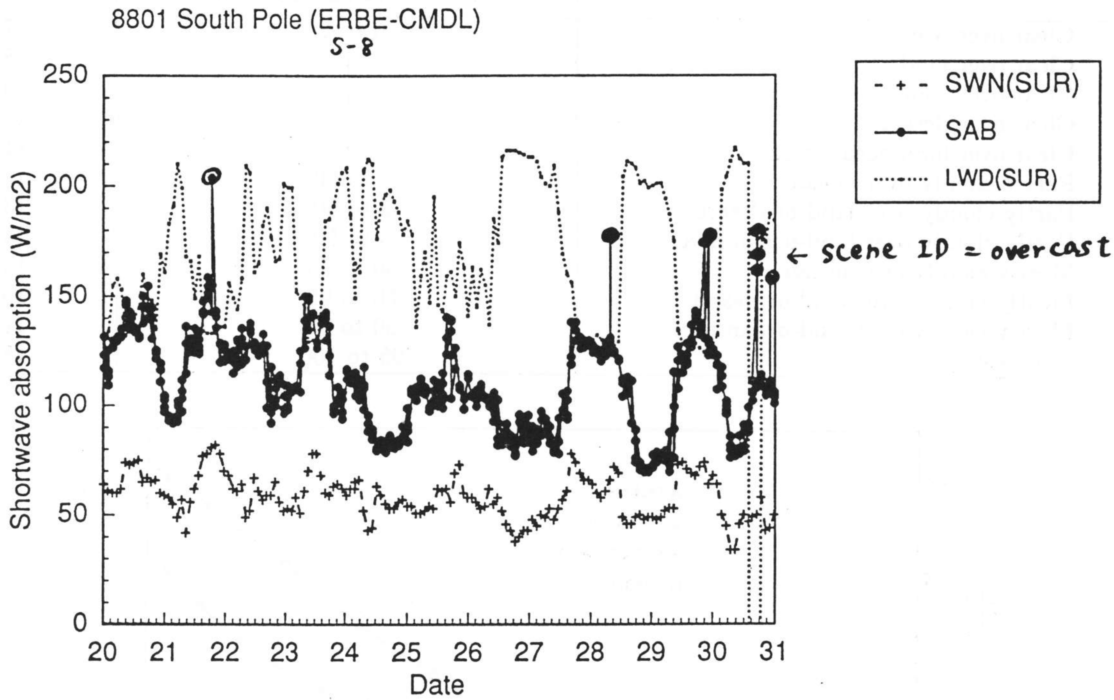


Figure 7. Mean cloud cover (in percent) for (*a*) January and (*b*) July, based on surface and ship observations (from *Schweiger and Key* [1992], based on data from *Warren et al.* [1989]).



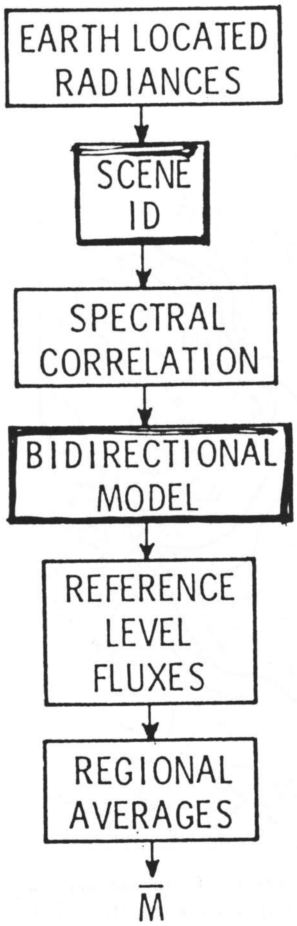


Fig. 13. Inversion processing steps.

$$M_\lambda = \int_0^{2\pi} d\phi \int_0^{\frac{\pi}{2}} d\theta \sin\theta \cos\theta \, L_\lambda$$

$$L_\lambda = \frac{1}{\pi} R_\lambda \cdot M_\lambda$$

$$\frac{1}{\pi} \int d\phi \int d\theta \sin\theta \cos\theta \, R_\lambda = 1$$

$$R(\Theta,\Phi,\theta,\phi,t) = \frac{\pi L(\Theta,\Phi,\theta,\phi,t)}{M(\Theta,\Phi,t)}$$

bidirectional func.

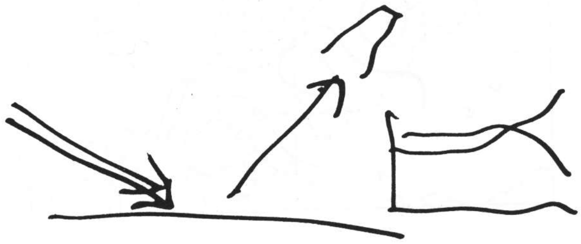


Table 1. Scene Types for Angular Models

Scene	Cloud coverage, percent	Figure
Clear over ocean	0 to 5	7
Clear over land	↓	8
Clear over snow		9
Clear over desert		10
Clear over land-ocean mix		11
Partly cloudy over ocean	5 to 50	12
Partly cloudy over land or desert	5 to 50	13
Partly cloudy over land-ocean mix	5 to 50	14
Mostly cloudy over ocean	50 to 95	15
Mostly cloudy over land or desert	50 to 95	16
Mostly cloudy over land-ocean mix	50 to 95	17
Overcast	95 to 100	18

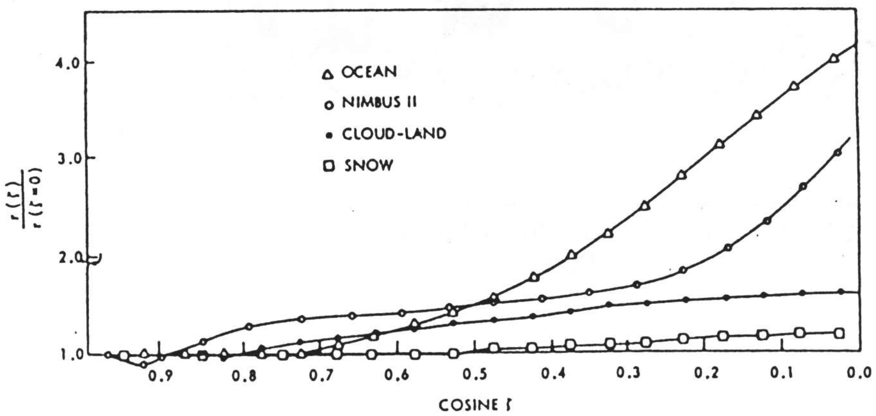
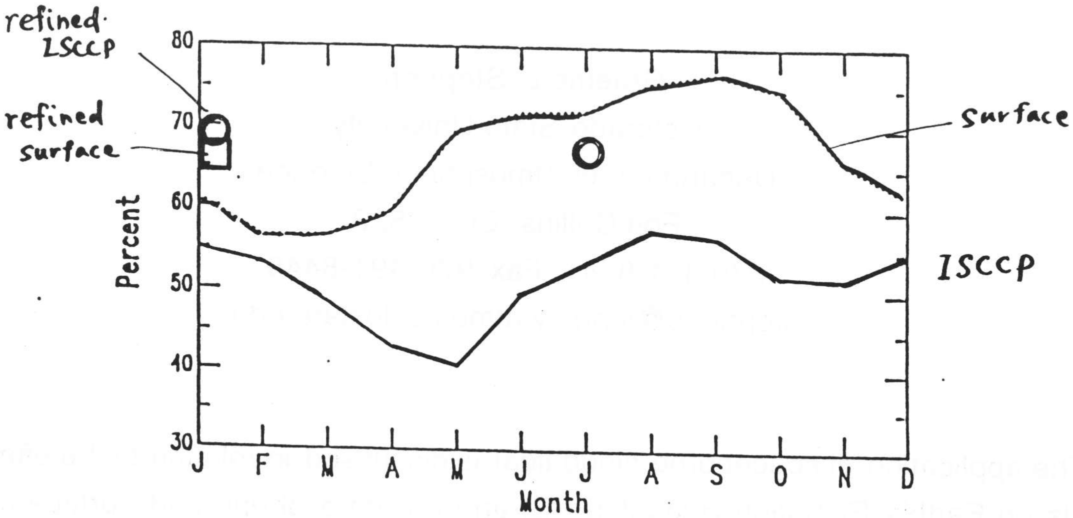


Fig. 5. Relations used to account for dependence of directional reflectance of the earth-atmosphere system on the sun's zenith angle.

Arctic (60-90°N) total cloud cover



(Curry et al., 1995)

Need of 3-D Polar Cloud Climatology

New Satellite Mission: ATMOS-B1 (Cloud-Aerosol-Radiation)

Sensor
- LIDAR

- Cloud Profiling Radar (CPR)

- Imager (VIS, IR, MW)

- Earth Radiation Budget (ERBE, CERES?)

Orbit
- Low altitude (< 500 km)

- { Diurnal variation -----> ~~Solar asynchronous~~ Non-sun-synchonous } ? <.... incl. ≤ 55° rec cick 60 days
  { Global coverage -----> Polar orbit <.-- diurnal variation by multiple satellite (Int. Coop.)