P1.26 CLOUD COVER CLIMATOLOGY FOR THE SOUTH POLE FROM SURFACE-BASED INFRARED RADIATION MEASUREMENTS

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1. INTRODUCTION

Cloud cover at high latitudes is not well known (Hahn et al. 1995; Rossow and Schiffer 1999). Visual observations of fractional cloud cover (FCC_{vis}) are acceptable during times of daylight but are unreliable during the polar night because of the difficult nature of the observation. Observers are forced to estimate the FCC of optically thin clouds in the dark and extreme cold. Hahn et al. (1995) concluded that at the South Pole during the winter there may not even be enough moonlight when the moon is above the horizon for observers to adequately estimate FCC.

Satellite retrievals of polar FCC have a completely different set of caveats. During the polar day, satellites must radiatively distinguish clouds and snow of similar temperatures and albedos. The task becomes a little easier during the polar night due to the persistent near-surface temperature inversion which raises the brightness temperature (T_B) of some clouds above the snow surface temperature. ISCCP retrievals of FCC (FCC_{ISCCP}) over the poles are notoriously low during the polar day (Rossow and Schiffer 1999). In fact, Hahn et al. (1995, Figure 13) showed that the climatological retrievals of FCC_{ISCCP} over the South Pole have a seasonal cycle opposite that of FCC_{vis}.

Until recently there has been no reliable ground truth for wintertime FCC in Antarctica. There is now evidence that FCC estimated from satellite retrievals may not be as poor as suspected (Town et al. 2004). Town et al. (2004) compared one year of FCC retrieved from Polar Atmospheric Emitted Radiance Interferometer (PAERI) data (FCC_{PAERI}) and pyrgeometer data (FCC_{pyr}) taken at the South Pole during 2001 with climatological FCC_{ISCCP} and FCC estimated from AVHRR Polar Pathfinder data (FCC_{APP-x}) (Key 2002, Pavolonis and Key 2003) over that region with some success.

Here we present FCC from ground-based pyrgeometer measurements taken at the South Pole for 9 years (1994-2003). Monthly mean FCC_{pyr} is compared with concurrent measurements of FCC_{PAERI}, FCC_{vis}, FCC_{ISCCP} and FCC_{APP-x}. It is concluded that FCC_{pyr} gives consistently good estimates of cloud cover at the South Pole.

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2. SURFACE-BASED FRACTIONAL CLOUD COVER

FCC was estimated using three different ground-based data sets for this study: infrared radiances from the PAERI, infrared irradiances from pyrgeometer measurements made by NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL), and visual observations made by the South Pole Meteorological Office (SPMO).

2.1 *Polar Atmospheric Emitted Radiance Interferometer (PAERI)*

FCC_{PAERI} was determined by a radiance-ratio method described in Town et al. (2004) using data taken at the South Pole during 2001. Briefly, the radiance-ratio method involves integrating each zenith spectrum over wavelength and dividing by the integral of a blackbody radiance spectrum of the same bandwidth as the PAERI. The T_B of the blackbody spectrum is set to the mean T_B of the zenith spectrum between 630-640 cm^{-1}.

A monthly clear-sky radiance-ratio threshold was modeled using the Line-by-Line Radiative Transfer Model (LBLRTM) (Clough et al. 1992) and monthly mean temperature and humidity profiles (Town et al. 2004) plus the radiative effects of near-surface ice crystals estimated from the South Pole PAERI data set. Figure 1 shows the monthly FCC_{PAERI} for 2001.

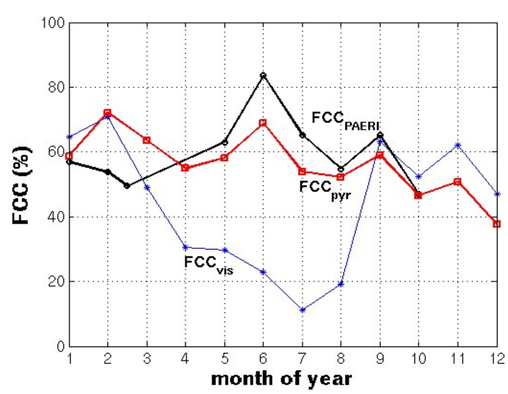

Figure 1. Monthly estimates of FCC over the South Pole during 2001 from radiance (FCC_{PAERI}), irradiance (FCC_{pyr}) and visual observations (FCC_{vis}).

The strengths of this method are the narrow field-of-view (FOV) of the PAERI and the sensitivity of the radiance-ratio to changes in the thermal infrared window region. A weakness is the estimate of the radiative effects of near-surface ice crystals in the thermal infrared spectrum.

2.2 *Pyrgeometer*

FCC is retrieved from the routine pyrgeometer measurements made at the South Pole by taking a twenty-minute time series of downwelling irradiances and assigning it into clear and cloudy categories using a predetermined standard deviation threshold. The threshold was set based on inspection of the entire standard deviation time series. The same threshold is used for the entire pyrgeometer data set.

To prevent times of stable, optically-thick, warm clouds from being categorized as clear, an absolute irradiance threshold was also determined. Climatological clear-sky downwelling irradiances were modeled using LBLRTM, and monthly mean radiosonde temperature and humidity profiles as in Town et al. (2004). The threshold was increased by 20 W m^{-2} to account for natural interannual variability in monthly mean clear-sky downwelling irradiances and pyrgeometer calibration drift.

Figure 2 is a scatter plot of standard deviation vs. irradiance for December 2001. It is clear from this plot that both filters are necessary for an accurate estimate of FCC.

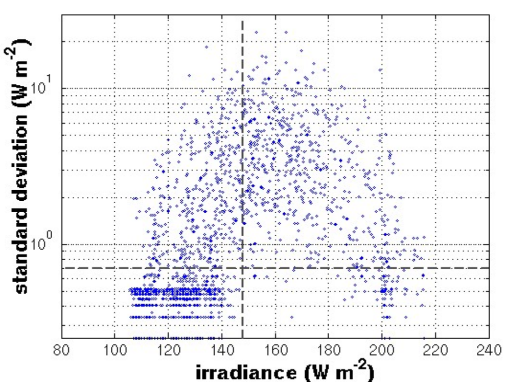

Figure 2. Standard deviation vs downwelling irradiance over the South Pole for December, 2001. The horizontal dashed line is the predetermined standard deviation threshold. The vertical dashed line is the irradiance threshold for December.

Figure 3 is a frequency distribution of sunlit FCC_{vis} observations in octas. It is clear from Figure 3 that it is usually within one octa of being clear or cloudy at the South Pole. Thus, the threshold method employing the binary categories of clear and cloudy is a reasonable approximation in the case of FCC over the South Pole. In other words, FCC_{pyr} does not suffer greatly from the wide FOV of the pyrgeometers.

The monthly estimates of FCC_{pyr} over the South Pole for 2001 are shown in Figure 1. Figure 4 shows monthly estimates of FCC_{pyr} for the time period of 1994-2003.

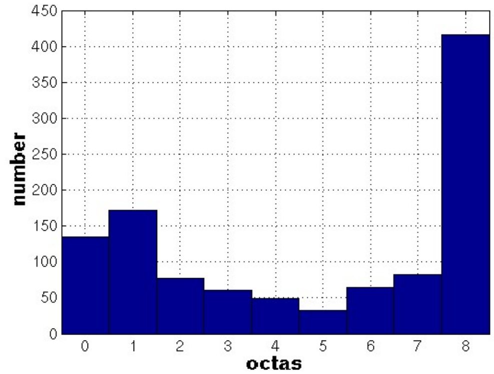

Figure 3. Frequency distribution of all sunlit FCC_{vis} estimates over the South Pole from 1994-2003 in octas.

2.3 *Visual Observations*

Also shown in Figures 1 and 4 are time series of the FCC_{vis} for the periods of 2001-2002 and 1994-2003, respectively. There is a clear seasonal cycle similar to the FCC_{vis} climatology presented in Hahn et al. (1995), with less cloud cover reported during winter.

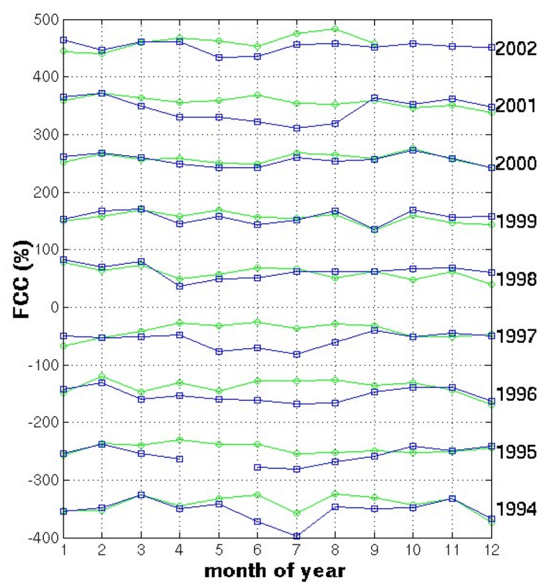

Figure 4. Estimates of FCC_{pyr} (green circles) and FCC_{vis} (blue squares) by month from 1994-2003. Each year is offset from neighboring years by 100%.

3. SATELLITE RETRIEVALS OF FRACTIONAL CLOUD COVER

FCC_{ISCCP} is described in Rossow and Schiffer (1999). The FCC_{ISCCP} retrievals presented here are from the D-2 data set. The APP-x data set and FCC_{APP-x} are described in detail in Key (2002). Both data sets are shown in Figure 5 along with FCC_{pyr}.

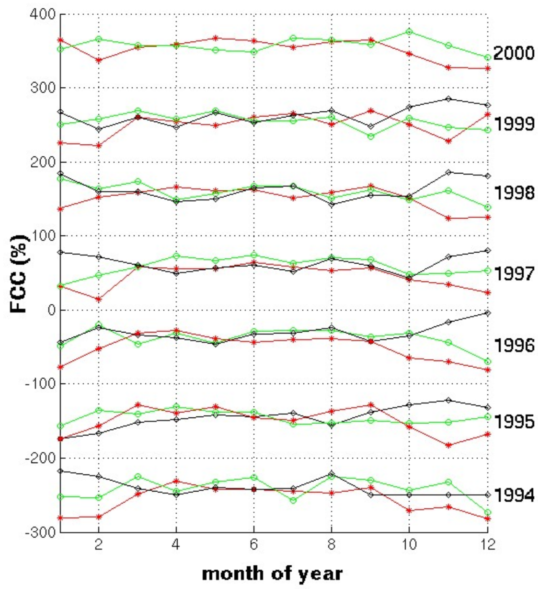

Figure 5. Estimates of FCC_{pyr}, (green circles), FCC_{APP-x} (black diamonds), and FCC_{ISCCP} (red stars) by month from 1994-2001. Each year is offset from neighboring years by 100%.

4. COMPARSION OF FRACTIONAL CLOUD COVER RETRIEVALS

Figure 1 shows FCC_{PAERI}, FCC_{pyr} and FCC_{vis} for 2001. Both FCC_{PAERI} and FCC_{pyr} have similar month-to-month variations but are offset from each other by approximately 10% during the winter. This could be due to the thin nature of the clouds during that time of year, which may elude the FCC_{pyr} algorithm, or the uncertainty in the radiance-ratio threshold employed in the FCC_{PAERI} retrieval.

Figure 4 shows both the FCC_{pyr} and FCC_{vis} monthly time series for the South Pole. From Figure 4 it is clear that the two methods are more or less in agreement during times of daylight, but much less so during times of darkness. Figure 6 is a scatter plot of the entire data set separated into daytime (October-March) and nighttime (April-September) estimates. The daytime FCC_{vis} correlate very well with FCC_{pyr} (R^2 = 0.59). However, the nighttime FCC_{vis} are completely uncorrelated with the FCC_{pyr}.

Figure 7 shows the nighttime FCC_{APP-x} and FCC_{ISCCP} plotted against concurrent monthly estimates of FCC_{pyr}. Nighttime FCC_{APP-x} correlates with FCC_{pyr} with an R^2 = 0.29, but nighttime FCC_{ISCCP} is uncorrelated with FCC_{pyr}.

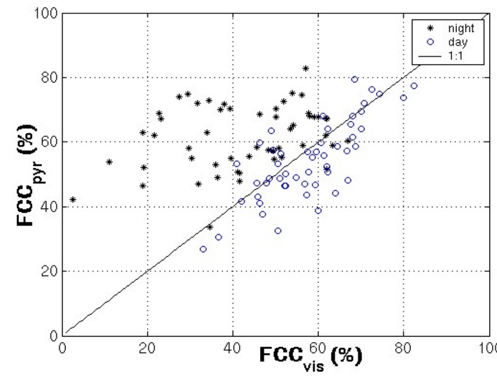

Figure 6. Scatter plot of FCC_{vis} vs. FCC_{pyr} for 1994-2003. Black stars represent nighttime (April-September) estimates and blue circles represent daytime (October-March) estimates.

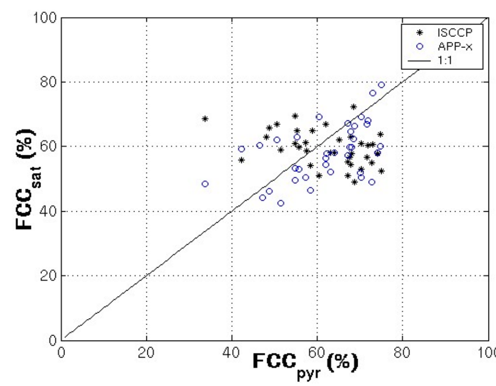

Figure 7. Scatter plot of nighttime (April-September) FCC_{ISCCP} (black stars) and FCC_{APP-x} (blue circles) vs FCC_{pyr} for their respective time periods (shown in Figure 5).

Table 1 contains a summary of seasonal cloud cover by FCC source. The traditional way of defining the seasons for Antarctica is 2 months for Spring, Summer and Autumn and 6 months for Winter. This results in Spring being defined as October and November, Summer being defined as December and January, Autumn as February and March, and Winter as April through September. Summer is set to be an adjacent December and January. It is named for the year of January (e.g. "Summer 1994" refers to December 1993 and January 1994).

Table 1. Seasonal means of FCC for the South Pole from 5 different methods. Residuals in the seasonal means relative to the pyrgeometer method are in parentheses to the right of each seasonal mean.

Method	Su	Au	Wi	Sp	Time Period
Pyr	46	63	63	55	1994-2003
Vis	54(+8)	60(*-3*)	44(*-19*)	60(+5)	1994-2003
PAERI	57(+11)	52(*-11*)	66(+3)	47(*-8*)	2001-2002
ISCCP	30(*-16*)	47(*-16*)	60(*-3*)	35(*-20*)	1994-2001
APP-x	72(+25)	60(*-3*)	58(*-5*)	68(+13)	1994-2000

The wintertime means of FCC_{APP-x} and FCC_{ISCCP} are similar to the FCC_{PAERI} and FCC_{pyr} retrievals. Thus, it may be that the wintertime ISCCP and APP-x data sets are only reasonable on a climatological basis.

Figure 8 shows the FCC_{pyr} interannual variations by season and year. There does not seem to be a trend in any of the seasonal or annual FCC_{pyr} means for this time period.

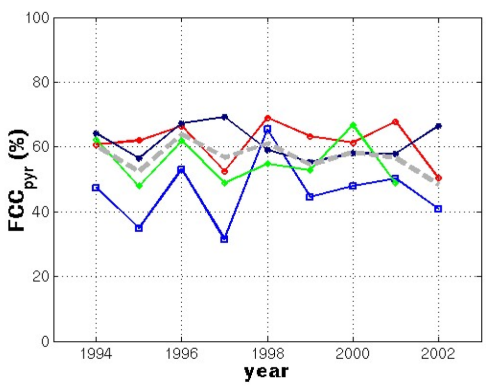

Figure 8. Annual and seasonal interannual variations in FCC_{pyr} over the South Pole. Gray dashed line = annual mean; blue squares = Summer mean; red circles = Autumn mean; dark blue stars = Winter mean; green diamonds = Spring mean.

5. CONCLUSIONS

FCC for the South Pole over the period 1994-2003 from 5 different sources are presented here. FCC_{pyr} compares well with FCC_{vis} during sunlit times and FCC_{PAERI} throughout the year. Discrepancies between FCC_{pyr} and FCC_{PAERI} most likely stem from the insensitivity of FCC_{pyr} to thin cirrus clouds, but they could be due to uncertainties in the FCC_{PAERI} algorithm. FCC_{APP-x} and FCC_{ISCCP} agree with FCC_{pyr} on long-term averages in winter but not in summer. However, they do not compare well with FCC_{pyr} on a month-to-month basis, even in winter.

6. ACKNOWLEDGMENTS

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