SEASONAL SNOW EXTENT AND SNOW MASS IN SOUTH AMERICA USING SSMI/I PASSIVE MICROWAVE DATA (1988-2003)

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ABSTRACT

Seasonal snow cover in extra-tropical areas of South America was examined in this study using passive microwave satellite data from the Special Sensor Microwave Imagers (SSM/I) on board the Defense Meteorological Satellite Program (DMSP) satellites. For the period from 1988-2003, both snow cover extent and snow mass were estimated for the months of July, typically the coldest winter month. Most of the seasonal snow in South America is in the Patagonia region of Argentina. The average snow cover and snow mass for the 16-year period was 284,492 km^2 and 0.763 x 10^{13} kg, respectively. The year with the greatest average snow extent and snow mass during the 16-year period of record was 1992 -- 551,875 km^2 and 2.073 x 10^{13}, respectively. If the strong El-Nino years of 1991-1992 and 1997-1998 are excluded, the July snow mass shows a linear trend of 28% over the 16 years period, with a p-value of 0.0098, which is significant at the 85% level.

INTRODUCTION

Exclusive of Antarctica, seasonal snow in the Southern Hemisphere is mostly confined to southern South America, which is the only continent in the Southern Hemisphere where an extensive seasonal snow cover may occur. It should be noted that in mid winter, approximately 99% of the snow cover in the Southern Hemisphere is confined to Antarctica. Though snow may fall and even persist on the ground for several days in Africa and Australia, on those continents, its impact on climate and water resources is small in comparison to that of South America. In this study, using data from the SSM/I sensors on board DMSP satellites, seasonal snow extent and snow water equivalent (SWE) have been calculated in South America for the period from 1988-2003.

STUDY AREA

In the Patagonia region of Argentina and the Tierra del Fuego region of Argentina and Chile, a stable snow cover may form as early as May and remain as late as October. Each winter, snow is a feature south of about 45° latitude, and in the snowiest years, over 500,000 km^2 of snow has been measured -- during the coldest winter months (Dewey and Heim, 1983, Foster et al., 2002).

Typically, an extensive snow cover in southern South America results from disturbances embedded in the westerly air streams. East winds and heavy precipitation during the winter in southern South America are caused by quasi-stationary high pressure systems at high latitudes over the western South Atlantic Ocean (Kidson, 1988). These anticyclones block the more usual zonal airflow in such a way that normal sea level cyclonic systems are steered around the "high" toward Patagonia (the South American states of Rio Negro, Chubut, Santa Cruz and Tierra Del Fuego). In southeastern Brazil, snow can fall when incursions of polar air originating in the Antarctic (friajes or friagem) push rapidly north-northwestward (east of the Andes), coincident with a weakening of the normally dominant sub- tropical high-pressure belt.

PASSIVE MICROWAVE OBSERVATIONS

In this investigation, the 19 GHz and 37 GHz channel data of the SSM/I on board the DMSP satellites have been used to estimate seasonal snow cover extent and snow water equivalent (SWE) in South America. The nominal resolution for the 19 GHz (actually 19.35 GHz) channel is 69 x 43 km^2 and for the 37 GHz channel the resolution is 37x 28 km^2. The Equal Area SSM/I Earth Grid (EASE-grid) Southern Hemisphere projections (at a 25 km x 25 km pixel scale) used in this study were provided by the National Snow and Ice Data Center. Brightness temperature differences between the 19 and 37 GHz channels were multiplied by a coefficient related to the average snow grain size to derive SWE (Chang at al., 1987). For SSM/I, the algorithm is:

Paper presented Western Snow Conference 2007

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$$SWE = C\,[(T_{19} - T_{37}) + 5]\ \text{mm} \qquad [1]$$

Where SWE is in mm, C is the grain size coefficient and T_{19} and T_{37} are the brightness temperatures at the 19 and 37 GHz vertical polarizations, respectively. To determine snow depth, the quantity derived from [1] can be multiplied by 2.0 – using the assumption that average density of Patagonia snowpacks is approximately 200 kg m^{-3}. Snow mass is simply the total SWE for all snow covered pixels.

In the above algorithm, if T_{19} is >252 K and T_{37} is >245 K, SWE is assumed non-detectable and considered to be zero. For prairie or steppe landscapes, C is set at 4.0, whereas for alpine conditions C becomes 4.25. These values are based largely on results for similar landscapes in North America. For more on this see Foster et al. (2005). Since the snowpacks in Patagonia are usually rather unstable (snow does not often accumulate throughout the winter), the coefficients are static rather than dynamic – remaining constant through the snow accumulation and snowmelt seasons.

RESULTS AND VALIDATION

SSM/I snow data for July (1988-2003), typically the coldest and snowiest month, is presented in Table 1 -- showing the average monthly snow cover and snow mass for the 16-year period. The average snow cover and snow mass for this period was 284,492 km^2 and 0.763 x 10^{13} kg, respectively. The year with the greatest average snow extent and snow mass during the 16-year period of record was 1992 -- 551,875 km^2 and 2.073 x 10^{13} kg, respectively.

Table 1. Snow Cover and Snow Mass for South America from SSM/I during July

	average snow extent (10^5 km^2)	average snow mass (10^{13} kg)
1988	145,635	0.282
1989	111,250	0.210
1990	121,875	0.234
1991	178,125	0.413
1992	551,875	2.073
1993	306,875	0.616
1994	336,875	1.078
1995	358,750	0.847
1996	233,750	0.386
1997	318,750	1.015
1998	193,125	0.304
1999	262,500	0.575
2000	483,125	1.750
2001	363,125	0.838
2002	331,875	0.970
2003	254,375	0.506

Table 2 shows snow depth as measured at two meteorological stations and derived from SSM/I for the period July 11-15, 2000. Despite the fact that a point value (station) is being compared to a large satellite pixel (25 km x 25 km), which includes the station, the observed and estimated values compare quite well.

Table 2. Snow depth (in cm) measured from meteorological stations and derived from SSM/I observations for the period from July 11-15, 2000

	Lago Argentino		Esquel	
day	station	satellite	station	satellite
11	8	5	8	13
12	8	5	8	18
13	15	8	5	13
14	15	10	10	10
15	13	10	10	10

Figure 1 shows the time series of the July snow cover extent and snow mass (SWE). A linear trend analysis was found of the form SWE = α t +β, where t is time in steps of years and α is the slope and β the intercept of the regression. The linear trend is considered significant if α is significantly different from zero. Two analyses were performed. The first analysis considers all data and α is found to be 0.00955 with a standard error of 0.006, which is not significantly different from zero. We next consider the effect of natural variability, such as the effect of El Nino/Southern Oscillation (ENSO), on the snow data. Consensus estimates of strong ENSO years during our period of investigation include the 1991-1992 and 1997-1998 events. If the data for the years 1992 and 1998 were excluded from our trend analysis, the slope becomes $\alpha = 0.0138$ with standard error of 0.0045 and a p-value of 0.00987. This trend is significant at 95% level and translates into an increase of 28% of the mean snow mass over the 16-year period.

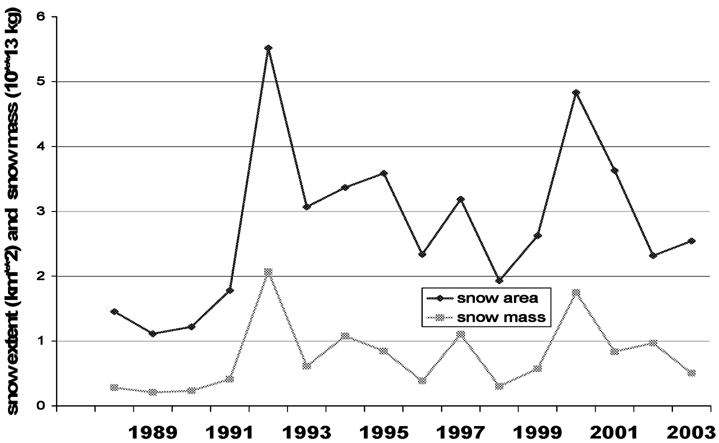

Figure 1. SSM/I derived snow cover and snow mass for South America

CONCLUSIONS

This study demonstrates that passive microwave radiometry is especially useful in estimating the snow cover extent and snow mass in the Patagonia region of South America where clouds are a major mapping problem and where the snow is often ephemeral in nature. The passive microwave observations show sharp year-to-year differences in the seasonal snow extent over the Patagonia region of South America. Average extent in the month of July, the month having the greatest snow cover, varied during the 16-year period from a high of 551,875 km^2 to a low of 111,250 km^2.

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