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AN EXAMINATION OF SOUTH AMERICAN SNOW COVER EXTENT AND SNOW MASS FROM 1979-2002 USING PASSIVE MICROWAVE SATELLITE DATA

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1. INTRODUCTION

Exclusive of Antarctica, seasonal snow in the Southern Hemisphere is, for the most part, confined to South America. Though snow may fall and even persist on the ground for several days in Africa and Australia, on those continents, snow is basically a novelty. Using data from the SSMR instrument on board the Nimbus-7 satellite and from the SSMI sensors on board DMSP satellites, seasonal snow extent and snow depth (snow mass) have been calculated for the period from 1979-2001 in the middle latitudes of South America. The objectives of this study are to measure the seasonal snow cover and snow mass during the late fall and winter months using passive microwave satellite data. Using this data, a snow record will be generated that is comparable to the snow record for North America and Eurasia.

2. STUDY AREA

In the Patagonia region of Argentina and the Tierra del Fuego region of Argentina and Chile, snow may accumulate as early as May and as late as October. Each winter, snow is a regular feature south of about 45 degrees latitude, and in the snowiest years, snow can cover the ground for several weeks in succession. A single storm may cover the ground with several hundred thousand km^2 of snow. Snow can fall at locations much further north than expected, and it can even lay on the ground for a few days as far north as 27 degrees south latitude. Snow here is usually confined to elevations greater than 1,000 meters above sea level (Prohaska, 1976). However, in most seasons, the non mountainous snow cover varies from year-to-year. This is to be expected when accumulations are shallow.

3. PASSIVE MICROWAVE DATA

The SMMR instrument operated from November 1978 until August of 1987. The first SSMI was launched in late 1987, thus there is no overlap period for these two sensors, and therefore a serious validation between them is lacking.

Whereas SMMR was fitted with an 18 GHz sensor, a 19 GHz sensor was employed on the SSMIs. The nominal resolution for the 19 GHz (actually 19.35 GHz) channel is 69 x 43 km^2 and for the 37 GHz channel it is 37x 28 km^2 . For this investigation, brightness temperature differences between the 19 GHz (for SSMI) and 37 GHz channels were multiplied by a coefficient related to the average grain size (4.8 for SSMI and 4.77 for SMMR) to derive the snow water equivalent of snow (Chang at al., 1987). The simple algorithm is then

SWE = 4.8 [(19 GHz - 37 GHz) –5] mm [1]

where SWE is snow water equivalent in mm, and 19 GHz and 37 GHz are the brightness temperatures at 19 GHz and 37 GHz vertical polarizations, respectively. If the 18 GHz channel is less than the 37 GHz channel, then the SWE is defined to be zero.

To derive snow depth, the above algorithm can be divided by 3.0 – the average density of mid winter, mid latitude snowpacks is approximately 300 kg^{-3} . This is expressed as follows:

SD = 1.6 [(19 GHz - 37 GHz) –5] cm [2]

Where SD is snow depth in cm, and 19 GHz and 37 GHz are the brightness temperatures at 19 GHz and 37 GHz vertical polarizations, respectively.

Using data from a study by Van Der Veen and Jezek (1993), it was found that a -5 K offset exists between SMMR data and SSMI observations over Antarctica. The above equations for the SSMI include this offset. For SMMR, however, this offset was not used.

Passive microwave remote sensing is particularly advantageous in Patagonia, not only because clouds and darkness do not preclude snow detection, but also because Patagonia has few forests. The emission from trees can confound the scattering signal of snowpacks, and thus if forests are present, adjustments would need to be made to the retrieval algorithms in order to account for the forest emission and resulting increase in brightness temperature.

4. DATA ANALYSIS

SSMR and SSMI snow data were acquired from May through August for the years 1979-2001. Note, that 1999 data have not as yet been processed due to a programming problem. In order to construct snow maps, 19 GHz (18GHz in the case of SMMR) and 37 GHz (horizontal) radiances were converted to brightness temperatures. Both average monthly and monthly maximum maps of snow cover extent and snow depth (mass) were generated for the period using equations 1 and 2. Average monthly snow depth is given as ½ of the maximum observed on any day. Thus, if 24 mm of snow was the maximum daily snow for any given pixel during the month, the average snow depth for the month was 12 mm. This procedure was used because, while the snow in Patagonia is generally quite shallow and transient, the snow thickness seems to be rather consistent – pixel-to-pixel variance is low.

If the 37 H brightness temperature is greater than 250 K or if the 37 GHz and 19 GHz frequency gradient is greater than 10 K, then no snow is assumed. Furthermore, if the snow water equivalent (SWE), from equation 1, is less than 10 mm, the surface is considered snow free.

Our estimates of snow extent (Table 1) were less than the values measured by Dewey and Heim (1983) for the late 1970s through the early 1980s. However, their measurements included snow in the Andes Mountains, south of 10 degrees south latitude. For our measurements, we included only snow cover south of 25 degrees south latitude. Moreover, if any of the large microwave pixels contained a fragment of ocean water, it was not used since the cold ocean water would considerably lower the brightness temperatures, thus adversely affecting the performance of our algorithms. Consequently, pixels mixed with water, such as in the vicinity of Tierra del Fuego, are not mapped as snow covered, even though they are, in fact, likely to be at least partially snow covered It should be mentioned that, thus far, there have been no field campaigns or airborne overflights to conclusively validate the passive microwave snow extent and snow mass estimates.

5. RESULTS AND DISCUSSION

Since the snow cover in Patagonia is generally quite shallow, the month having the maximum snow coverage can vary from one year to the next. With few exceptions, however, the coldest month is the month with the greatest snow cover extent. Consequently, July is the month that usually has the greatest snow cover and snow thickness. In many years, a storm will deposit a layer of snow that melts before another storm arrives.

For the 20 plus years studied, the average maximum snow thickness per SSMR or SSMI pixel was approximately 11.0 cm (July, 2002). Approximately 5% (352 pixels) of South America was snow covered during the month having the maximum snow extent, also July, 2000. In contrast, for the month of maximum snow extent in North America (January) and Eurasia (February), the maximum snow extent encompasses approximately 62% and 53% of the land area, respectively. Of course, the land mass configurations are very different in the Northern and Southern Hemisphere (Foster at al., 2001).

From Table 1, it can be seen that the most snow for any month occurred in July of 2000 – the maximum snow extent was over 800,000 sq. km, and the snow mass was more than 2.8 x 10^{13} kg. The biggest snow season occurred in 1992. Other relatively big snow seasons include 1994, 1997, 1991, 1993 and 1984. The least snow occurred during 1985. The snow extent was more than 4.5 times greater in July of 2000 compared to July of 1985. Other years with relatively little snow include, 1979, 1980, 1981, 1983, 1987, 1996, and 1998. Interestingly, the biggest snow years occur after 1990 while the smallest snow years occurs prior to 1990. This is in contrast to the Northern Hemisphere where during the 1990s, there was less snow than during the 1980s.

The reason for this is unclear at present, but before looking at climate-induced or human-induced causes, more work needs to be done to assure that the SMMR and SSMI sensors are in accordance. As mentioned earlier, because there was no overlap in observing times between these two sensors, there was no formal verification program. A closer look will be taken at the SSMR and SSMI-derived algorithms to determine if the offset used for the SSMI is in fact valid.

For the 20 plus-year period of this study, the average snow cover extent (May-August) was approximately 3.5 x 10^5 km^2 and the average monthly snow mass (May-August was approximately 0.90 x 10^{13} kg. However, during the SMMR period (1979-1987), the average monthly snow extent was 1.93 x 10^5 km^2 compared to 4.56 x 10^5 km^2 during the SSMI years (1988-2001). The average monthly snow mass as derived from SMMR was 0.55 x 10^{13} kg compared to 1.13 x 10^{13} kg for SSMI. Because the seasonally snow covered area of South America is relatively small, large changes in snow extent could result during a cooler climatic regime. Nonetheless, it is much more likely that such large changes between the SSMR and SSMI data sets are due to algorithm differences - the –5 K SSMI offset.

7. REFERENCES

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Table 1

Snow cover and snow mass in South America (1979-2001)

		Snow Extent (x 10^5 km^2)	Snow Mass (X 10^{13} kg)			Snow Extent (x 10^5 km^2)	Snow Mass (X 10^{13} kg)
1979	May	0.55	0.13	1990	May	2.16	0.38
	June	1.5	0.53		June	3.3	0.65
	July	1.55	0.39		July	4.02	0.81
	August	1.72	0.47		August	4.18	0.98
1980	May	1.11	0.28	1991	May	3.5	0.73
	June	2.64	0.67		June	5.48	1.41
	July	2.36	0.64		July	6.99	1.79
	August	2.08	0.54		August	6.11	1.46
1981	May	0.68	0.16	1992	May	4.26	0.85
	June	2.31	0.69		June	7.08	1.7
	July	1.76	0.41		July	7.96	2.58
	August	1.32	0.3		August	6.95	2.36
							0.63
1982	May	0.78	0.24	1993	May	2.94	0.63
	June	1.8	0.42		June	5.32	1.24
	July	4.45	1.33		July	5.7	1.36
	August	1.75	0.47		August	4.01	0.93
1983	May	1.17	0.2	1994	May	3.87	0.94
	June	2.36	0.54		June	5.26	1.7
	July	2.43	0.59		July	6.44	2.01
	August	2.07	0.6		August	5.21	1.55
1984	May	1.39	0.27	1995	May	1.89	0.39
	June	4.43	1.13		June	5.6	1.17
	July	5.34	2.05		July	6.54	1.6
	August	2.72	1.02		August	6.59	1.8
1985	May	0.57	0.13	1996	May	1.53	0.27
	June	1.06	0.3		June	3.19	0.62
	July	1.77	0.41		July	3.07	0.62
	August	1.19	0.26		August	3.46	0.68
1986	May	no data		1997	May	2.17	0.42
	June	no data			June	5.2	1.34
	July	2.82	1.05		July	7.34	2.12
	August	1.74	0.76		August	5.67	1.49
1987	May	0.33	0.06	1998	May	1.99	0.43
	June	0.69	0.18		June	2.43	0.56
	July	2.44	0.79		July	3.45	0.76
	August	2.62	0.75		August	3.55	0.82
1988	May	2.08	0.36	1999		data not processed	
	June	4.25	0.82				
	July	5.49	1.17	2000	May	2.59	0.49
	August	4.19	0.8		June	6.18	1.56
					July	8.08	2.83
1989	May	2.51	0.48		August	6.27	1.98
	June	4.09	1				
	July	4.5	0.95	2001	May	3.29	0.63
	August	4.76	1.01		June	5.43	1.23