The Effect of Sensor Differences in Deriving Long-Term Trends from Satellite Passive Microwave Snow Extent

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Introduction

The extent and variability of seasonal snow cover are important parameters in climate and hydrologic systems due to effects on energy and moisture budgets. Northern Hemisphere snow cover extent, comprising about 98 percent of global seasonal snow cover, is the largest single spatial component of the cryosphere, with a mean maximum extent of 47 million square kilometers (nearly 50 percent of the land surface area). Satellite passive microwave sensors have operated on polar orbiting platforms since 1978, providing a long-term record of snow water equivalent (SWE) and snow extent that compares reasonably well with snow extent from visible-wavelength sensors. However, trend analysis on the passive microwave record is complicated by the change in passive microwave sensors from the Scanning Multichannel Microwave Radiometer (SMMR, operating from 1978 to 1987) to the Special Sensor Microwave/Imager (SSM/I, operating from 1987 to the present). The short duration of simultaneous operations of both sensors, in July and August of 1987, limits the amount of available intercalibration data. We present analysis of land surface "stable" targets as detected by SMMR and SSM/I brightness temperatures during the overlap period to quantify possible discontinuities in sensor observations and derived snow extent and SWE. We include trend analysis of hemispheric and continental snow extent derived from passive microwave and visible-wavelength satellite data.

	SMMR	SSM/I
Frequencies	18, 37 GHz	19, 37 GHz
Overpass Time	midnight	6 a.m.
Swath Width	~800 km	~1400 km
Operation	every other day	continuously
Repeat observations per month	5 days	10 days

Table 1: Differences between SMMR and SSM/I TBs used to derive SWE and snow extent.

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Differences between SMMR and SSM/I Sensors

Although SMMR and SSM/I are similar passive microwave sensors, they exhibit important differences in spatial and temporal coverage that affect the long-term record of snow extent (Fig. 1 and Table 1). To further complicate the long-term record, the sensors only operated simultaneously for a period that includes about 40 days during Northern Hemisphere summer, July and August of 1987.

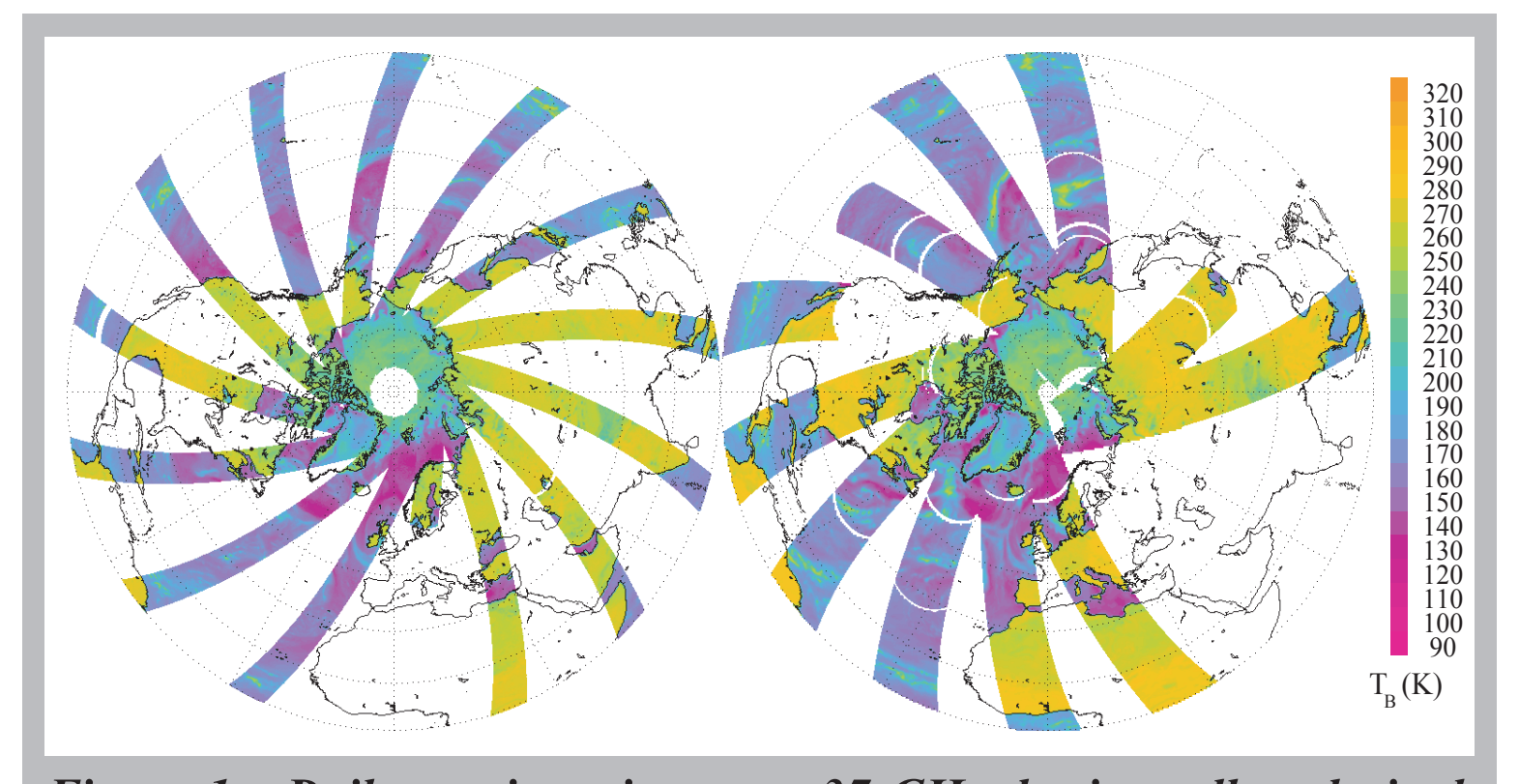

Figure 1: Daily passive microwave 37 GHz, horizontally-polarized, brightness temperatures, July 19, 1987, showing smaller coverage area of SMMR (left) vs. SSM/I (right).

To derive a temporally consistent map of snow cover from the two sensors, we chose fixed Earth targets with a range of physical characteristics. Individual targets were chosen for temporal and spatial stability, and together include a range of brightness temperatures representing the cold through warm end of the emission range. During the summer of 1987, we examined the (temporally) closest overpasses from both SMMR and SSM/I sensors, and derived regression equations for the brightness temperatures (Fig. 2).

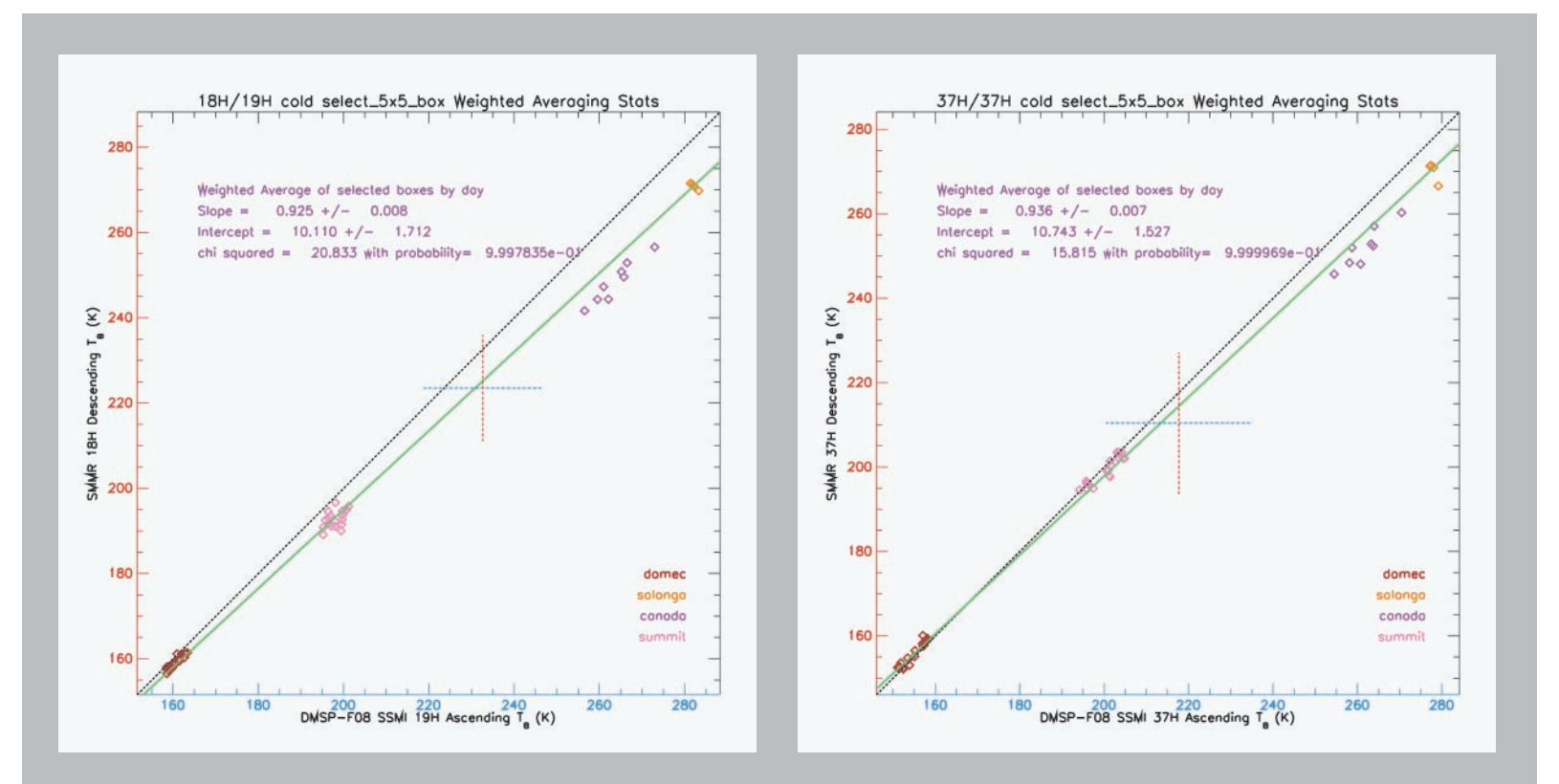

Figure 2: Scatter plots of SSM/I vs. SMMR brightness temperatures (19/18 GHz, left, and 37 GHz, right) at Earth targets selected for spatial stability (Dome C (Antarctic ice sheet), Salonga (African tropical forest), Canada (plains), Summit (Greenland ice sheet)). The large plus sign in each plot represents the typical range (+/- 1 standard deviation) of wintertime brightness temperatures in seasonally snow-covered regions.

Daily passive microwave data are not available at all typically snow-covered locations. We produced a simulated daily map of SWE, by piece-wise interpolation of non-zero SWE on a pixel-by-pixel basis through the period of record. We composited daily maps into weekly maximum extent maps for comparison with NOAA weekly snow extent maps (Robinson, 2000). Available since 1966, the NOAA snow charts are derived from visible sensors on earth-observing satellites. Robinson and Frei (2000) have noted that the mean snow extent in the NOAA maps displays a significant step change in 1987 that is apparent during late winter, spring and summer. This further complicates interpretation of the SMMR-SSM/I record (Fig. 7, far right panel).

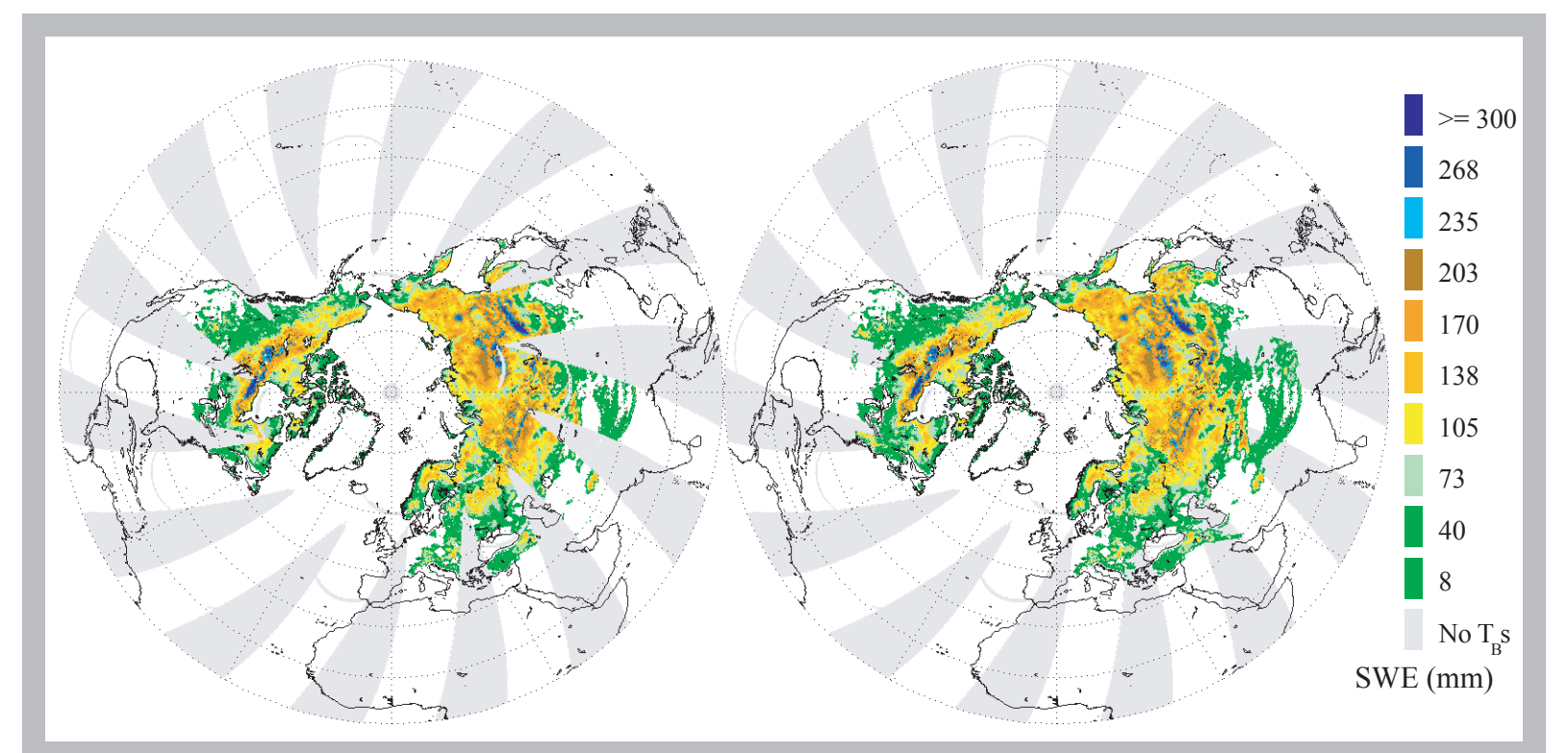

Figure 3: Northern Hemisphere passive-microwave-derived SWE, March 1, 2003, from daily observations only (left) and interpolated from surrounding days (right) to produce a more complete snow-covered area for the day.

Passive Microwave vs. Visible Snow-Covered Area

The time series comparison of hemispheric snow extent derived from passive microwave and visible sensors (Fig. 4) shows general agreement in the interannual signal, although microwave tends to underestimate snow extent in the fall and early winter periods, underestimating by as much as 20% in November (Armstrong and Brodzik, 2001). The underestimate is most likely due to microwave's relative insensitivity to shallow or patchy snow and the large microwave footprint size. Scatter plots of visible snow extent versus the respective microwave sensors (Fig. 5) display the characteristic undermeasure of microwave during fall and early winter. The scatter plot patterns show well-defined seasonal differences in the SSM/I that are not as distinguishable in the SMMR. At this time we do not have an explanation for the differences, but we suspect this may be due to the different sensor overpass times (6 am vs. midnight).

The time series comparisons of hemispheric and continental-scale monthly standardized anomalies (Fig. 6) display some correlation in the 12-month running means, although the correlation appears to be better during the SSM/I era.

Since there is significant autocorrelation in both time-series (> 0.5 lag-1 autocorrelation, $p < 0.01$), we chose to examine the long-term trend using the method described by Weatherhead et al. (1998). In addition to solving for the respective trend values, we calculated the number of years of data required to detect a real trend of the calculated magnitude (for $p < 0.1$). While both passive microwave and visible time-series exhibit negative trends at these scales, none of the trends are significant at a 90% level. The Northern Hemisphere visible data require at least 21 more years than the 25 years included in this series, and the microwave data require at least 30 more years, to detect a significant trend of the magnitude found.

It is interesting to note, however, that the NOAA snow charts are in fact available for the 39 years since 1966, and a similar analysis on the full time-series of the visible data (1966-2004) yields a trend of -0.217 +/- 0.075 s.d./decade. This trend is significant at a 99% level.

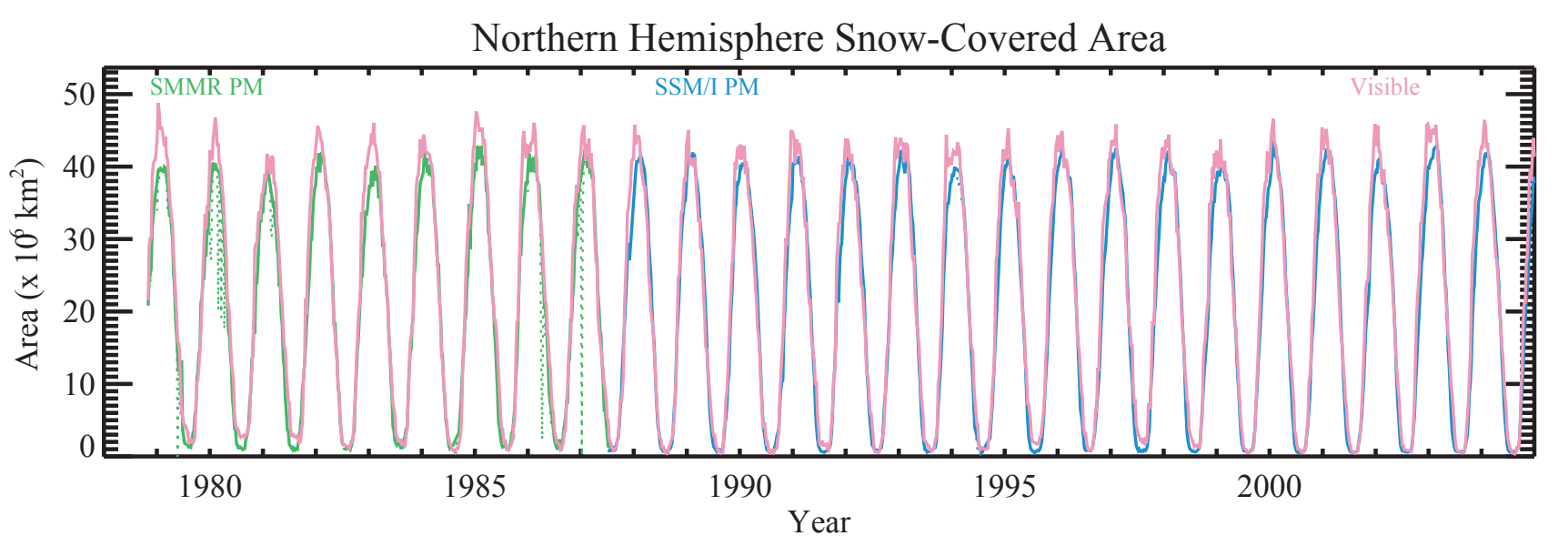

Figure 4: Time series of Northern Hemisphere snow-covered area derived from passive microwave (green/blue) and visible (pink) sensors, 1978-2004.

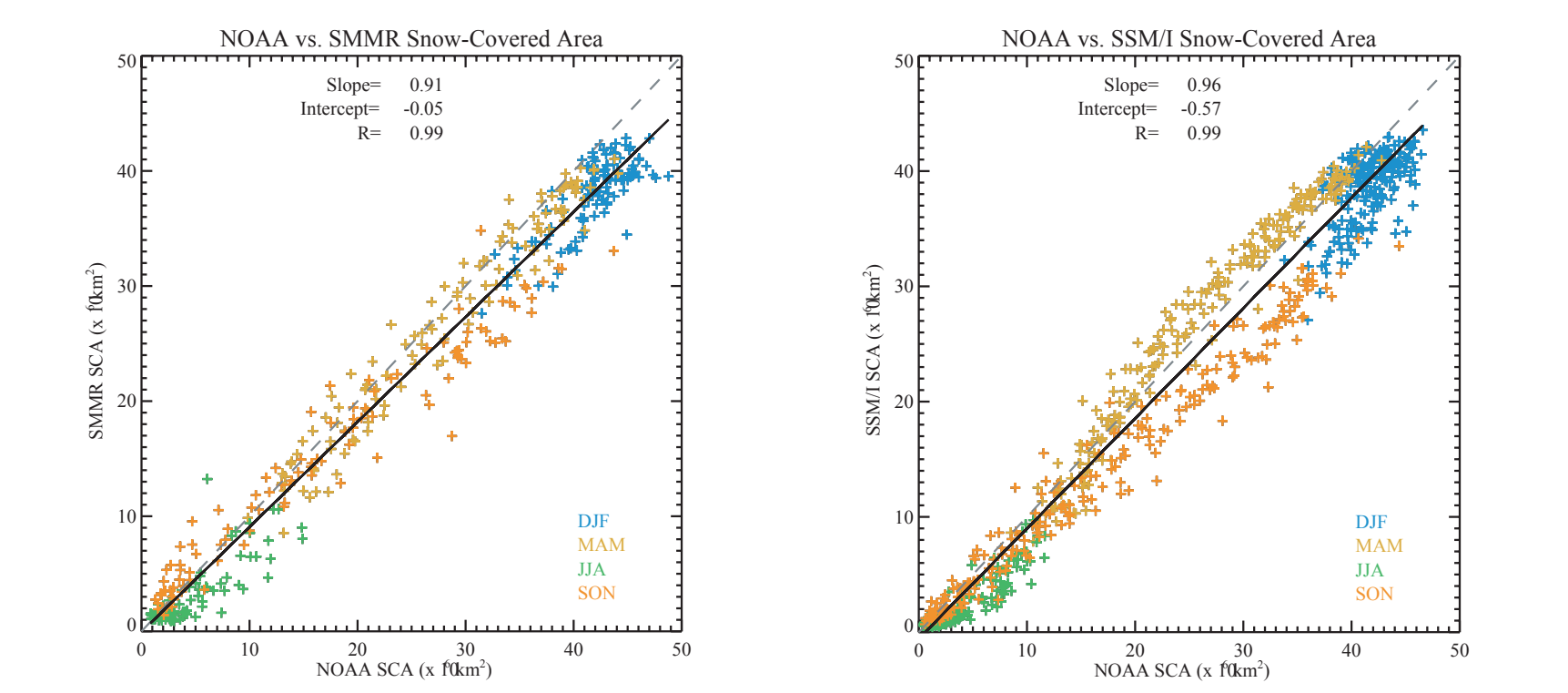

Figure 5: Scatter plots of Northern Hemisphere snow-covered area derived from SMMR vs. visible sensors, 1978-1987, (left) and SSM/I vs. visible sensors, 1987-2004 (right).

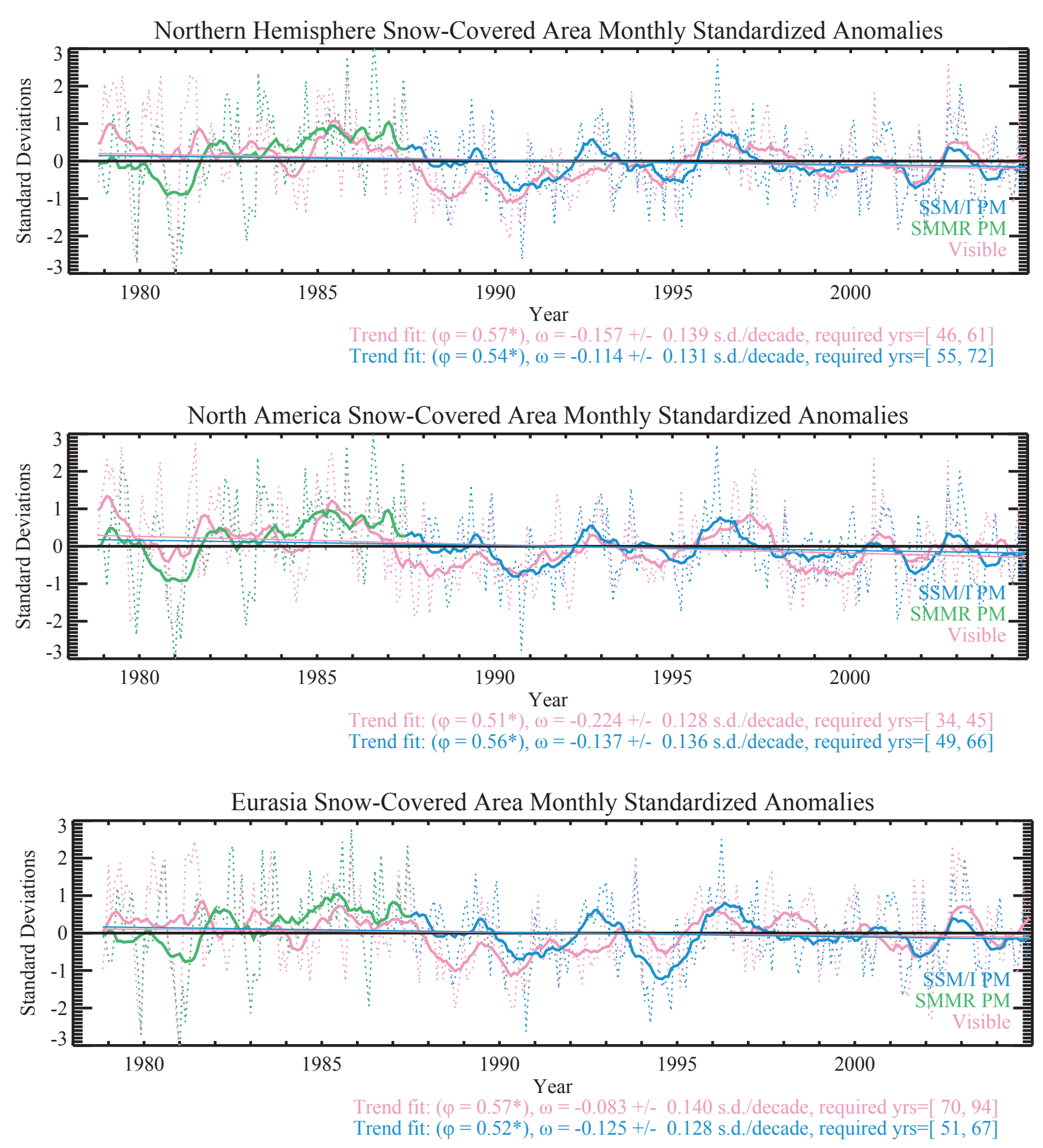

Figure 6: Time series of Northern Hemisphere (top), North American (center) and Eurasian (bottom) snow-covered area monthly standardized anomalies derived from passive microwave (green/blue) vs. visible (pink) sensors, 1978-2004. Respective trend lines are included, and autocorrelation (φ) and trend (ω) estimates are listed, including the confidence interval describing the range of years required to detect significant ($p < 0.1$) trends of this magnitude.

Conclusions and Future Plans

The full record of available visible data (1966-2004) is sufficient to detect a significant (99% level) decreasing trend in hemispheric snow cover. There is not a sufficiently long record of passive microwave data to determine a significant trend at a 90% level in hemispheric or continental snow cover. However, passive microwave sensors can potentially measure SWE in addition to snow extent. This underscores the need to continue production of a consistent passive microwave record.

We are currently investigating regional-scale SWE trends, using the methods described here.

Monthly Snow-Covered Area Trends

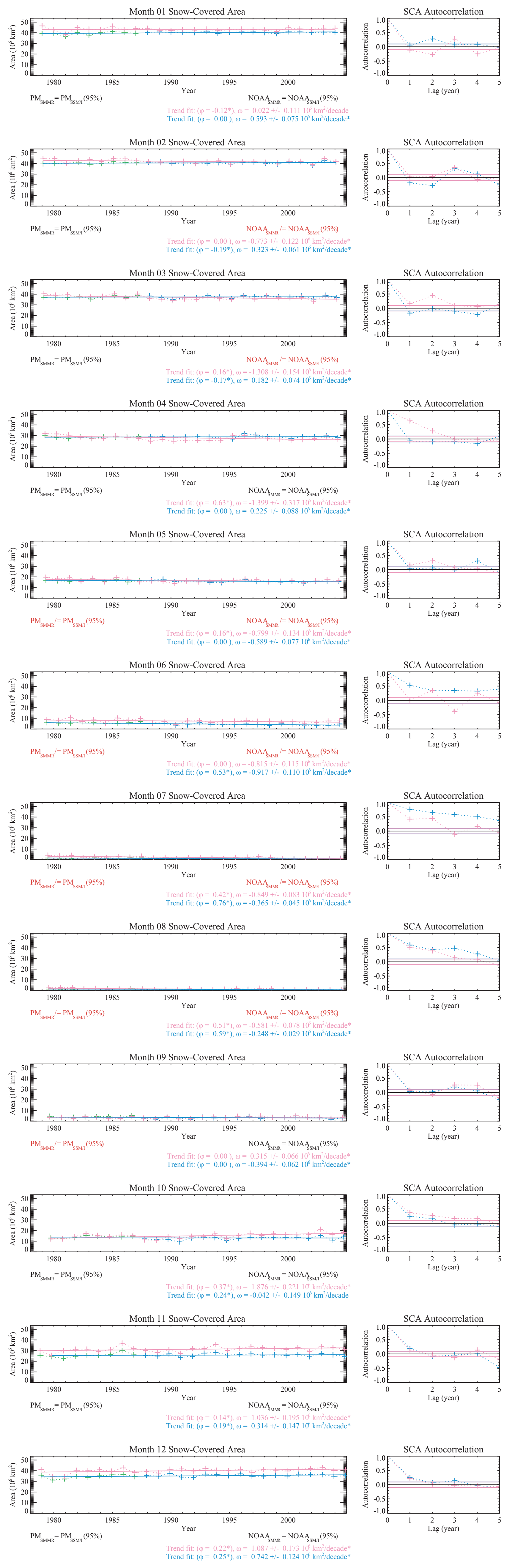

Figure 7: Time series of Northern Hemisphere monthly (top to bottom) snow-covered area (left) derived from passive microwave (green/blue) vs. visible sensors (pink), 1978-2004, and interannual autocorrelations (right). Respective trend lines are plotted. Autocorrelation (φ) and slope (ω) estimates are listed. Significantly different means in pre- and post-1987 periods are indicated in red.