CREATION AND PRESERVATION OF A SEA ICE CLIMATE DATA RECORD

YEAR 1 PROGRESS REPORT

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SCIENTIFIC DATA STEWARDSHIP PROGRAM

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SUMMARY OF OVERALL PROJECT OBJECTIVES

The primary objective of this project is to lay the groundwork for the creation of a sea ice extent/area/concentration climate data record. The current standard sea ice fields are produced from passive microwave satellite brightness temperature fields. These provide complete daily coverage of the polar regions since late 1978. This nearly 30-year record is one of the longer satellite climate records and is a key indicator of climate change. The Arctic has experienced a precipitous decline in sea ice extent, particularly during summer, over the three decade record (e.g., Meier et al., 2007; Comiso and Nishio, 2008). Recent years have been particularly low, culminating in an extreme record minimum in September 2007, with extents 40% below normal and over 20% below the previous record low (Stroeve et al., 2008; Comiso et al., 2008).

However, for several reasons, the sea ice record is not yet at a sufficient level to be considered a true Climate Data Record (CDR). There is not a single authoritative and accepted sea ice product. The products lack grid cell-level or even granule-level error estimates or quality assessments (a granule refers to a coherent set of data, e.g., a daily field of a parameter). Intersensor calibration, while carefully conducted, could be improved. Finally, the metadata for the products is not comprehensive and does not meet the modern standards.

This project aims to address these deficiencies to allow the eventual production of a sea ice CDR. Specifically, the project objectives, as outlined in the original proposal are:

1. Intercalibrate the SMMR-SSM/I with the AMSR-E record to use the most recent, highest technology sensor as a basis for the record. This will also include implementing the NASA Team 2 algorithm over the SSM/I record, where the required high frequency channels (85.5 GHz) exist.
2. Develop data quality fields to accompany the data fields. This will be done through a variety of methods including temporal history and spatial correlation of the concentration fields, ancillary data (e.g., melt onset fields), and further comparisons with other basin-scale sea ice fields (such as AMSR-E concentrations from NSIDC processing).
3. Implement improved metadata and preservation standards. These standards will be FGDC/ISO 19115 compliant at both the file and data set level. The ability to distribute these products in data formats popular with specific user communities will be provided (e.g., NetCDF, GRIB2).

The end result will be higher quality sea ice concentration fields with associated data quality estimates and quality metadata information that will provide long-term preservation and reduce long-term maintenance costs. The production of these fields will provide a stable authoritative climate record into the NPOESS era and beyond.

BACKGROUND

Sea ice estimates are produced from two widely used algorithms, the NASA Team (Cavalieri and Gloersen, 1984) and the Bootstrap (Comiso et al., 1997), both developed at the NASA Goddard Space Flight Center. There are also several other, less widespread, algorithms in use. For the newer NASA Advanced Microwave Scanning Radiometer for EOS (AMSR-E), an enhanced NASA Team algorithm (Markus and Cavalieri, 2000), commonly referred to as NASA Team 2, is employed. Each sea ice algorithm uses combinations of passive microwave frequencies and polarizations to estimate sea ice concentration (percent ice cover within a grid cell), but the algorithms are formulated in different ways and use different combinations of channels. Evaluations of the algorithms have found that some algorithms perform better in some locations and some parts of the year, but that no single algorithm is optimal for all conditions (Comiso et al., 1997; Meier, 2005).

Another deficiency of the sea ice products in relation to CDR standards is that error estimates or quality assessments are lacking. There are only general error estimates based on a few local validation campaigns. Studies have shown that the quality of individual concentration estimates can vary dramatically, even over short distances and timescales (e.g., Meier, 2005).

Table 1. Characteristics of multichannel passive microwave sensors used in production of sea ice products and potential future sources. F8, F11, F13 denote DMSP satellites on which SSM/I was included. All frequencies include channels for both horizontal and vertical polarization, except 21.0/22.2, which has only a vertically polarized channel. MIS is currently planned for NPOESS. †Much of F8 85.5 GHz data missing or of low quality. ‡F15 is starting to be used operationally to replace the aging F13.

Sensor	Years of Operation	T_b Frequencies (GHz)	Min. Gridded Conc. Cell Size (km)
SMMR	10/25/78-8/20/87	6.6, 10.7, 18.0, 21.0, 37.0	25
SSM/I F8	7/9/87-12/31/91	19.3, 22.2, 37.0, 85.5†	25
SSM/I F11	12/3/91-9/30/95	19.3, 22.2, 37.0, 85.5	25
SSM/I F13	5/3/95-present	19.3, 22.2, 37.0, 85.5	25
SSM/I F15‡	12/18/99-present	19.3, 22.2, 37.0, 85.5	25
AMSR-E	6/18/02-present	6.9, 10.7, 18.7, 23.5, 36.5, 89.0	12.5
MIS	Planned ~2015	6.0-183.0	12.5 or less

The current widely-used sea ice timeseries employ the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) from 1978 to 1987 and a series of Special Sensor Microwave/Imagers (SSM/I) on the Defense Meteorological Satellite Program (DMSP) F- series satellites beginning with F8 in 1987 (Table 1). Thus, creation of the long-term sea ice timeseries has required intersensor calibration across numerous sensors. This has been carefully done to assure good consistency over the records (Cavalieri et al., 1999). However, there are some limitations in the intercalibrations. First, some overlap periods were extremely short, as little as three weeks (F8 to F11). Most of the overlap periods (all except F8 to F11) have been in the boreal summer (austral winter). Thus any seasonality effects on the intercalibration could not be accounted for. Ideally, a one-year overlap period should be used to cover the full range of annual variability. The sea ice products were not intercalibrated at the level of the sensor measurements (i.e., brightness

temperature). Such an approach was unable to yield consistent results, so the intercalibration was done at the final product level to produce consistent sea ice extents. However, though extents were matched, inconsistency has been found in ice area fields.

Finally, the sea ice products lack comprehensive metadata, particularly at the grid cell or granule level. Current metadata includes basic product-level documentation and, for only some products, rudimentary granule-level information consisting of basic parameter information (date, parameter name, units, scaling, flag values).

YEAR ONE ACCOMPLISHMENTS

Though this is a first-year progress report, the official start date of the project was 1 August 2007. Funds were transmitted to start the project in October 2007 and expenditures began in February 2008. Thus accomplishments for Year 1 are limited. However, some significant tasks have been completed or at least begun:

1. Acquired one year of overlap data from DMSP F13 and DMSP F15 SSM/I, and NASA AMSR-E for intersensor calibration
2. Performed intersensor calibration with F13 for both F15 and AMSR-E at the brightness temperature level
3. Compared sea ice extents from the NASA Team algorithm for F13, F15, and AMSR-E
4. Collaborated with EUMETSAT Satellite Application Facility on developing consistent standards for sea ice climate records
5. Discussed collaborating on CDR development with Sheldon Drobot, University of Colorado, and David Robinson, Rutgers University
6. Acquired NASA Team 2 algorithm
7. Began investigation of metadata standards

Details on each accomplishment are discussed below:

1) Acquired one year of overlap data from DMSP F13 and DMSP F15 SSM/I, and NASA AMSR-E for intersensor calibration

F13 and F15 SSM/I brightness temperatures (T_Bs) were acquired from the NASA Marshall Space Flight Center; AMSR-E T_Bs were acquired from NSIDC. All T_B products are daily composite fields on a polar stereographic projection at a 25 km gridded spatial resolution. However, the AMSR-E sensor has a much smaller instantaneous field of view for all channels and thus a higher effective spatial resolution than SSM/I. AMSR-E does have 12.5 km gridded fields at the same frequencies, but for consistency with SSM/I the 25 km products were employed here. Brightness temperatures for the 2007 calendar year have been acquired. This allows intercalibration over a full annual cycle in both the Arctic and Antarctic.

2) Performed intersensor calibration with F13 for both F15 and AMSR-E

SSM/I and AMSR-E brightness temperatures (19.3/18.7, 22.2/23.5, and 37.0/36.5 GHz – horizontal and vertical polarizations [except 22/23.5 GHz, for which SSM/I has only a vertical polarization channel]) were compared. First, a regression analysis was conducted for sea ice and near-sea ice regions. Slope and offsets for each channel were calculated for each day, as described by Equation 1 for F13 and F15.

$$T_BF13 = \text{Offset} + \text{Slope} * T_BF15 \quad [1]$$

A land mask and an ocean mask (masking out ocean areas where sea ice never occurs) was applied to the brightness temperatures to limit the regression to sea ice and near-sea ice regions. Inclusion of large areas of open water causes a large spread in the intersensor comparison and limits the effectiveness of the regression. However, some open water is necessary to encompass the full range of brightness temperatures encountered by the sea ice algorithms. Land grid cells were also excluded since they are not relevant to the sea ice intercalibration. An example regression between F13 and F15 for 31 May 2007 is shown in Figure 1.

Regressions were made for each day of 2007 (Figure 2). A strong seasonal effect on the quality of the regression is immediately noticeable. In summer (i.e., 1 June – 1 September), the regressions show large differences in slope and offset, meaning that a linear one-to-one relationship between the sensors is not as valid. This is due to surface melt, increased water vapor in the atmosphere, diurnal temperature variations, and potentially enhanced surface emission from the ocean. Winter shows much more consistent results and a higher correlation. This potentially has significant implications for previous intersensor calibrations, most of which took place during the boreal summer. Though not shown, the Antarctic showed similar characteristics as the Arctic, with good consistency in winter and larger variability in summer.

Another notable feature is the large offset in the 22 GHz channel between F13 and F15 (Figure 2a). This is due to a "radcal" beacon on the F15 satellite that was turned on 14 August 2006. This radcal beacon interferes with the 22 GHz retrievals. The 22 GHz channel is not directly used in sea ice concentration algorithms. However, because it is near a water vapor emission frequency, it is useful for discriminating weather effects that can produce false ice over the open ocean. Thus, the 22 GHz channel does have an important influence on sea ice extent and area estimates. The offset in the 22 GHz is ~10 K and is fairly consistent through most of the year (except summer where water vapor effects dominate), though there is an oscillation with about a one week period and a magnitude of ~1 K. The radcal beacon was turned on in August 2006 without warning and without notification of the climate community, presumably because the DMSP satellites are operational defense satellites and climate applications are secondary. This illuminates potential issues that can arise when attempting to create a high-quality CDR. It is also a consideration as we enter the combined operational/climate mission of the NPOESS era.

Conducting the regression with F13 on both F15 and AMSR-E T_Bs is useful because it allows us to gauge the effect of attempting intercalibration with a significantly different sensor. In Figure 2, it is clear that the correlations with F13 are much higher for F15 than for AMSR-E. This is due to: (1) sensor differences – particularly the different effective

spatial resolution between AMSR-E and the SSM/I sensors, (2) slightly different frequencies between AMSR-E and SSM/I (Table 1), and (3) greater difference in crossing times (F13 and F15 both have evening ascending node equatorial crossing times, while AMSR-E is early afternoon). Each of these factors will decrease the agreement between AMSR-E and F13 relative to the F13-F15 consistency. This has important implications for intersensor calibration. AMSR-E is a more advanced sensor than SSM/I, which seemingly makes it a better choice as a baseline for intersensor calibration. However, integrating AMSR-E into a CDR with the SSM/I record is more difficult because of these sensor and satellite orbit differences. AMSR-E is still likely to be valuable, but any intersensor calibration will need to be conducted with great care to assure consistency.

Comiso and Nishio (2008) have successfully intercalibrated AMSR-E with the SMMR-SSM/I timeseries for the Bootstrap algorithm and have produced consistent results. They however did not conduct regressions on the brightness temperatures, but rather adjusted tiepoints (coefficients for pure surface types, e.g., 100% ice or 100% water) so that sea ice extents are consistent between sensors. This is the approach that has been used in the past (Cavalieri et al., 1999). However, if ice extent consistency is optimized, ice area (fractional) coverage may not be consistent (Stroeve and Meier, unpublished research).

It can be difficult to compare sensors over sea ice because the ice is spatially and temporally variable, making it hard to discriminate sensor differences from differences in the character of the ice. Another way to investigate differences between sensors is through the use of stable targets, where selected regions are chosen for consistency, uniformity, with little seasonal variability. This approach has been implemented by NSIDC colleagues Mary Jo Brodzik and Richard Armstrong, though their focus is on improving land snow cover retrievals. Here we applied a simplified version of their method to examine approximately 250,000 square kilometer regions of Greenland and the Antarctic Plateau. Both are cold and dry high altitude regions that are uniform (snow covered over the whole regions) with little or no melt throughout the year. Thus the brightness temperatures remain stable.

For F13 vs. F15 (Figure 3a, top), the brightness temperatures show close agreement, with differences between +/- 1 K, which is on the order of the precision of the SSM/I instrument. The ~10 K offset, as well as the weekly periodicity of the F15 22 GHz channel is also clearly seen. AMSR-E shows greater disparity with F13 (Figure 3a, bottom), with several channels having differences of 2-4 K. The Antarctic Plateau shows similar characteristics (Figure 3b), though the AMSR-E has better agreement compared to its performance in Greenland.

This stable targets approach has potential usefulness for intersensor calibration for sea ice products. However, for now we have only applied the regression analysis for calculating sea ice extents, as discussion in the following section.

3) Compared sea ice extents from the NASA Team algorithm for F13, F15, and AMSR-E

The NASA Team algorithm was implemented for F13, F15, and AMSR-E. The NASA Team algorithm was chosen for initial investigation because it is an algorithm NSIDC already has in-house and it is one of the two algorithms (along with the Bootstrap) most

widely-used for sea ice, including the primary sea ice climate records archived at NSIDC. We plan to also implement the NASA Team 2 algorithm, the standard algorithm for AMSR-E, in the coming year. One limitation of NASA Team 2 is that it requires high frequency channels (85.5/89.0 GHz), which were not on the SMMR sensor. This limits the beginning of a NASA Team 2 climate record to mid-1987.

The NASA Team algorithm was implemented using F13 tiepoints. Initially, these same tiepoints were used without correction for F15 and AMSR-E estimates. Not surprisingly, the discrepancies between the F13 and the F15 and AMSR-E estimates of total ice extent are quite extreme when simply applying the F13 tiepoints to the F15 and AMSR-E brightness temperatures (Figure 4). In the Arctic, the F15 differences can be over one million square kilometers (>10%) during summer. Much of this difference is due to the 22 GHz offset issue in F15. The AMSR-E differences are smaller, though they still approach 500,000 square kilometers during summer.

We accounted for the sensor differences in the algorithm by adjusting the F13 tiepoints based on the regression analysis. For F15, we also adjusted the 22 GHz brightness temperatures so that the weather filter threshold was consistent. We employed two approaches in adjusting the tiepoints. First, because we conducted daily regressions, we could adjust the tiepoints daily, based on that day's regression. This method in theory should be optimal. However, daily adjustments can be made only during overlap periods when data from both sensors are available; this makes it impractical for carrying on the new sensor's record after the old sensor's end of lifetime. The second approach is a simple and more conventional method, where the regressions are averaged over a time period (in this case the entire year) and essentially a constant tiepoint adjustment is made. This is the approach used in previous intersensor adjustments for the sea ice timeseries.

The difference in the results using the two methods is minimal, even during summer where the extent differences are largest. This is because there is significant spread in the regressions (see Figure 1), especially during summer. Thus, even when using regression coefficients for a given day, the slope and offset values may not be accurate for many of the individual cells. The annual average tiepoints are perhaps more stable through the year, yielding good results. We also investigated using seasonal, summer and non-summer, tiepoints (not shown), but found that, like the daily varying tiepoints, any improvement was minimal.

The tiepoint adjustment brought F15 and F13 into close agreement, with total extent differences on the order of 10,000 square kilometers through most of the year (Figure 4a, top), which NSIDC has found is on the order of the precision of the total extent estimates from the algorithm. Differences do increase in summer to a maximum of ~100,000 square kilometers, again due to melt, atmospheric moisture, and surface variability. The AMSR-E corrections are not as effective, with differences still generally in the 100,000-300,000 square kilometer range during much of the year. This again is due to the sensor and satellite orbit differences. It is likely that the largest contributor is the higher spatial resolution of AMSR-E. The higher spatial resolution yields a more precise ice edge than SSM/I, whose lower spatial resolution tends to "smear" out the ice edge. This leads to SSM/I typically yielding more ice, as we see here (Figure 4a, bottom); tiepoint adjustment based on the regression will not correct for this effect. Issues such as this are particularly relevant when attempting to integrate SSM/I and AMSR-E into a CDR. This

is one reason why the ice extent-matching approach used by Comiso and Nishio (2008) may be necessary, though again there can be inconsistencies with ice area. Results for the Antarctic show similar characteristics, though the corrected F15 extents do not show a particularly larger difference during summer as in the Arctic.

4) Collaborated with EUMETSAT Satellite Application Facility on developing consistent standards for sea ice climate records

As part of another funded project, NSIDC has collaborated with the European EUMETSAT Satellite Application Facility (SAF) to help develop improved sea ice climate records. SAF is developing reprocessed brightness temperature and sea ice fields for the passive microwave satellite record. NSIDC has contributed reprocessed SMMR data consistent with SAF formats for the project. In return, SAF has agreed to share their data with NSIDC and both have agreed to work together in developing format, archive, distribution, and metadata standards. While the SAF project is not directly related to this NOAA project, the collaboration will be potentially beneficial by developing uniform international standards for creation of sea ice CDRs. The SAF data may also be useful for some aspects of this project.

5) Discussed collaborating on CDR development with Sheldon Drobot, University of Colorado, and David Robinson, Rutgers University

In the past year, we have had discussions with Sheldon Drobot of the University of Colorado and David Robinson of Rutgers University. They and other co-investigators have been funded under the NASA MEaSUREs (Making Earth System data records for Use in Research Environments) program on the development of a snow CDR. Though focused on land snow cover, the planned project includes a snowmelt over sea ice component. Because melt significantly impacts the brightness temperature signal over sea ice and hence the quality of the sea ice concentration estimates, their snow melt product will be useful in our project for the development of quality flags. Their melt product requires a sea ice mask to detect melt only in ice-covered regions and they can take advantage of our concentration products to implement that mask.

Our two projects have informally agreed to share data products and we will also work to use common land masks, grids and projections, data formats, and metadata standards. Thus the two projects will be mutually beneficial to each other and will allow the development of the two CDR products to be as consistent as possible with each other.

6) Acquired NASA Team 2 Algorithm

The NASA Team 2 algorithm has been acquired. The next step in the project will be to complete regression and intersensor calibration of the high-frequency SSM/I and AMSR (85.5/89.0 GHz) channels and implement the NASA Team 2 algorithm over the 2007 overlap period. This will allow comparison between SSM/I fields and the AMSR-E standard sea ice concentration product.

7) Began investigation of metadata standards

In the months since this proposal was submitted, NOAA has initiated a transition away from FGDC CSGSM metadata towards the ISO 19115/19115-2 standards and accordingly the target metadata standard for the data created here will also be ISO. An

assessment of the detailed impact of this change is underway, but it should be noted that the FGDC community deems the transition to be manageable (see http://www.fgdc.gov/metadata/geospatial-metadata-standards). To ensure that the resulting data products are compatible with NOAA standards, investigator Duerr has joined NOAA's ITAT subgroup on metadata and attends monthly teleconferences with the NOAA community dealing with metadata issues.

Similarly, Version 2.0 of the PREMIS metadata standard was released earlier this year. The major changes to the standard are to increase its flexibility by permitting incorporation of metadata extensions and to improve the ability of the standard to include rights information. Neither change is expected to significantly impact this project, though we may choose to take advantage of the additional flexibility offered.

PLANS FOR YEAR TWO OF THE PROJECT

There are several planned accomplishments for Year 2, including:

1. Complete intersensor calibration studies, including the high-resolution channels required to implement NASA Team 2.
2. Implement NASA Team 2 algorithm and compare extents between F13, F15, and AMSR-E. Also, compare NASA Team 2 fields with NASA Team fields.
3. Begin developing grid cells- and granule-level error estimates and quality assessments. An initial quality assessment will employ a melt flag, indicating decreased reliability of the retrieval. This will be developed to be consistent with the Drobot/Robinson project. Other potential quality flags will included coastal grid cells (possible land contamination), edge grid cells (limitation of sensor resolution), and grid cells with new ice (possible underestimation of thin ice concentration). Other quality fields and error estimates will be investigated and considered in the coming years of the project.
4. Continue development of metadata standards.
5. Present initial results at the American Geophysical Union Fall 2008 Meeting in San Francisco in December.
6. Begin writing of a peer-reviewed journal article describing notable results of the project.

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LIST OF FIGURES

Figure 1. Sample regression plots for 19 and 37 GHz brightness temperatures for F13 (y-axis) and F15 (x-axis) for the Arctic sea ice region on 31 May 2007. Units are in tenths of Kelvin. Dashed lines are 1:1 correspondence; the solid line is the actual regression line for F13 and F15.

Figure 2a. Regression offset (y-intercept) in Kelvin for F13-F15 (top) and F13-AMSR (bottom) for the five low-resolution passive microwave channels. In general, the F15 channels have a much smaller offset than the AMSR-E channels. Differences are larger during summer.

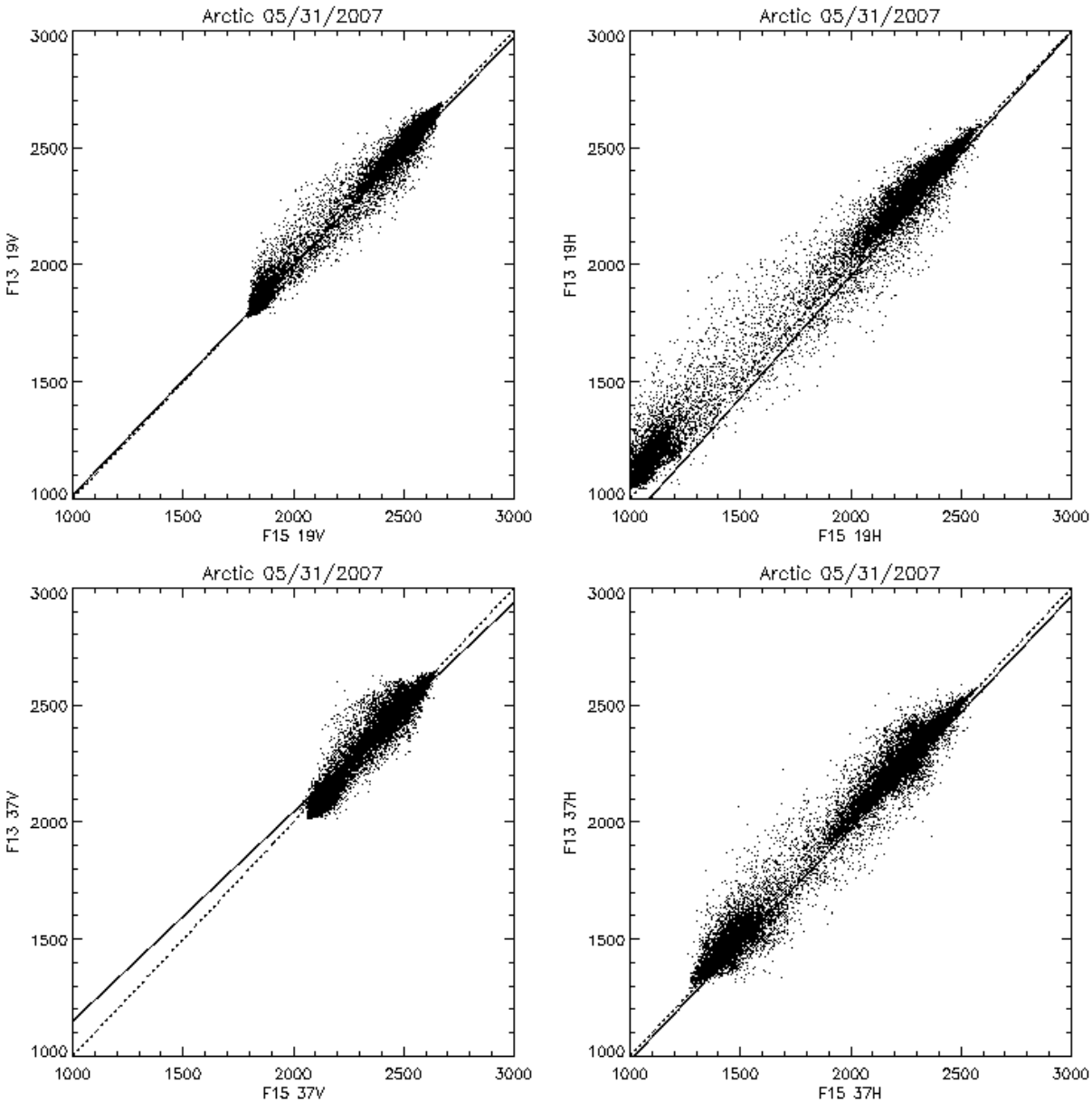
Figure 2b. Regression slope in Kelvin for F13-F15 (top) and F13-AMSR (bottom) for the five low-resolution passive microwave channels. In general, the F15 channels have a much smaller offset than the AMSR-E channels. Differences are larger during summer.

Figure 3a. Brightness temperature differences between F13 and F15 (top) and F13 and AMSR-E (bottom). F15 shows closer agreement than AMSR-E, except for the 22 GHz channel due to the beacon interference.

Figure 3b. Brightness temperature differences between F13 and F15 (top) and F13 and AMSR-E (bottom) over a region of the Antarctic Plateau. F15 shows closer agreement than AMSR-E, except for the 22 GHz channel due to the beacon interference.

Figure 4a. Arctic total sea ice extent differences between F13 and F15 (top) and AMSR (bottom). The uncorrected F15 has larger differences due to the large offset of the 22 GHz channel, but the corrected F15 matches F13 more closely.

Figure 4b. Antarctic total sea ice extent differences between F13 and F15 (top) and AMSR-E (bottom). The uncorrected F15 has larger differences due to the large offset of the 22 GHz channel, but the corrected F15 matches F13 more closely.



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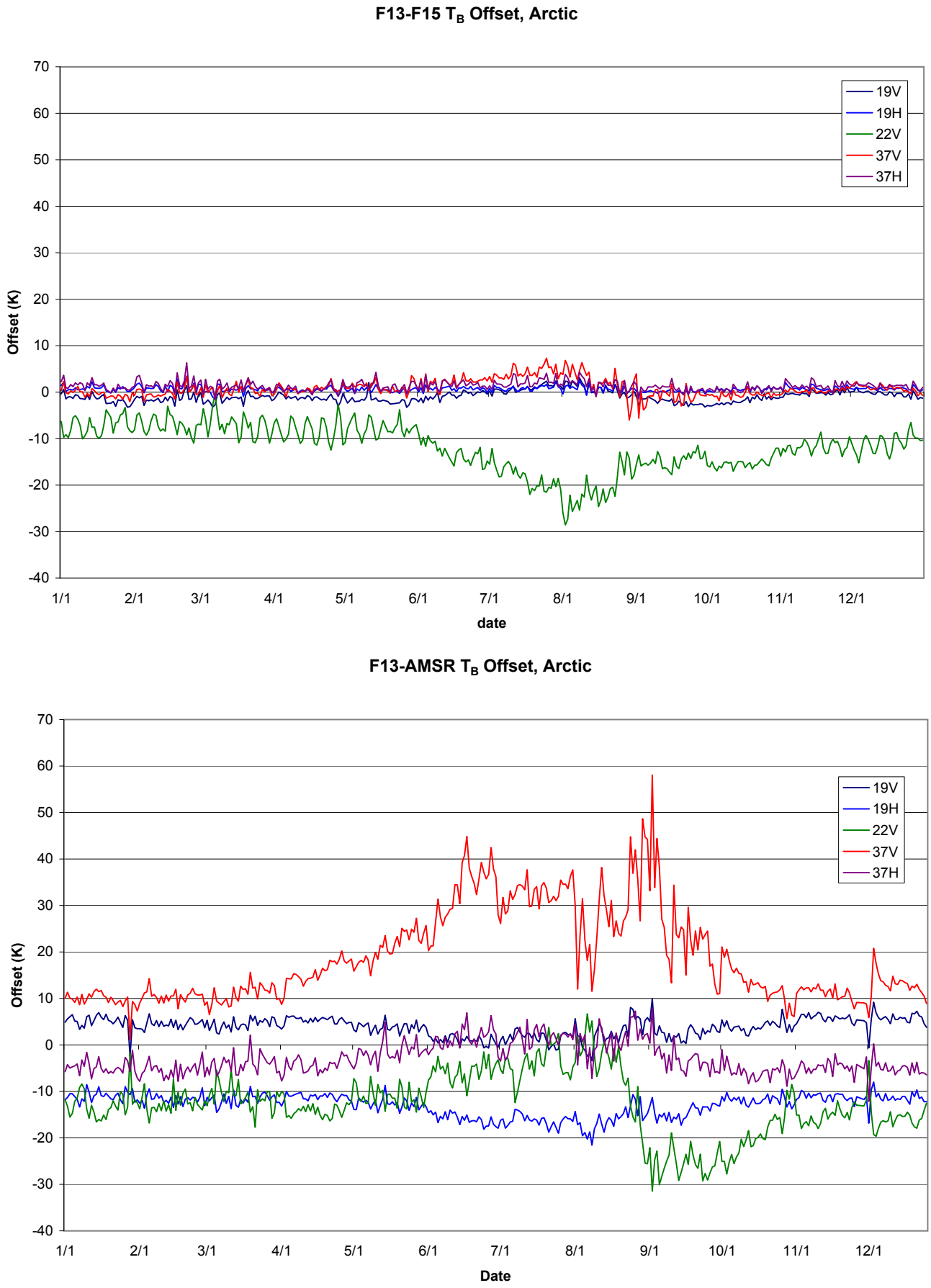

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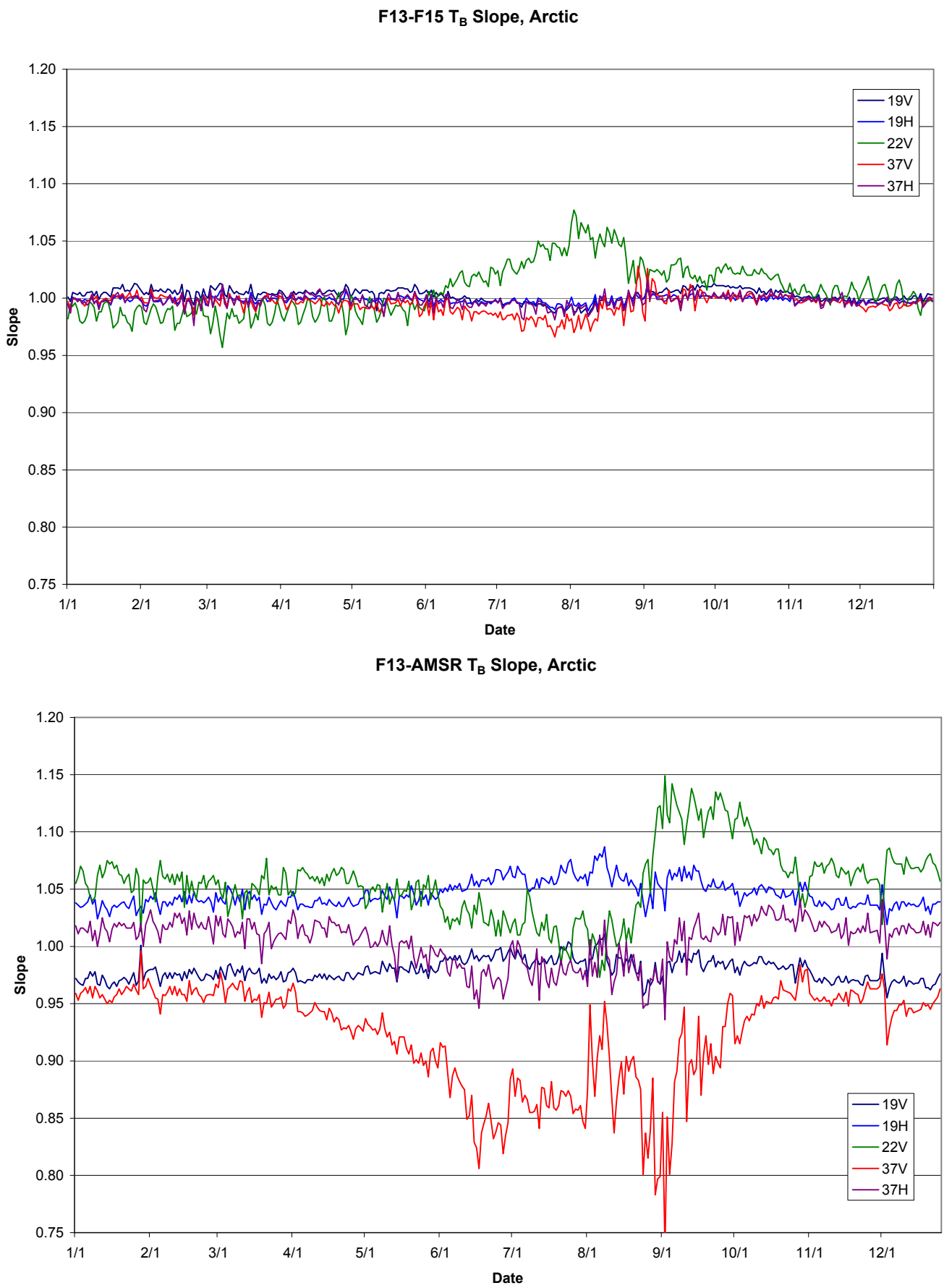

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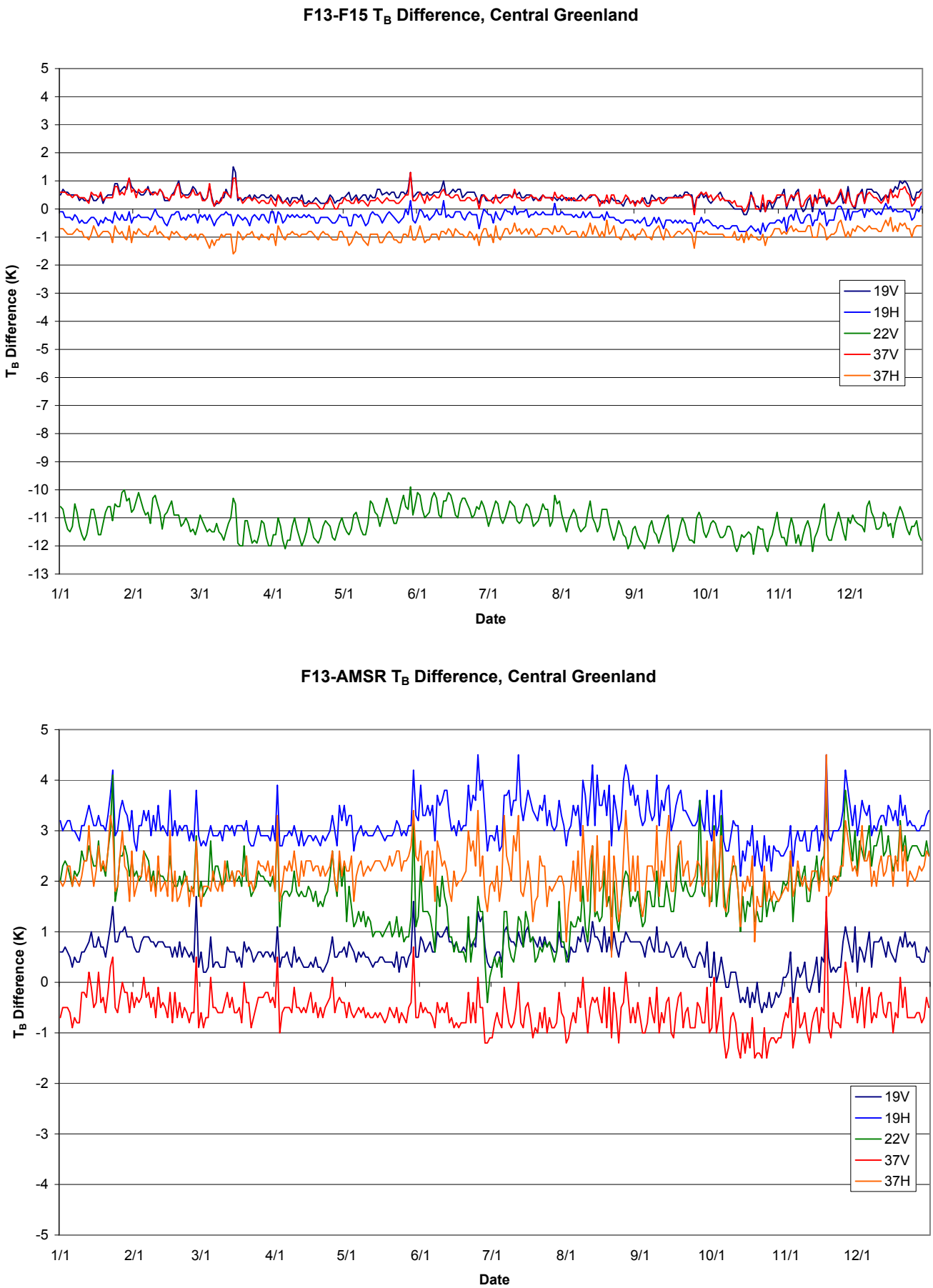

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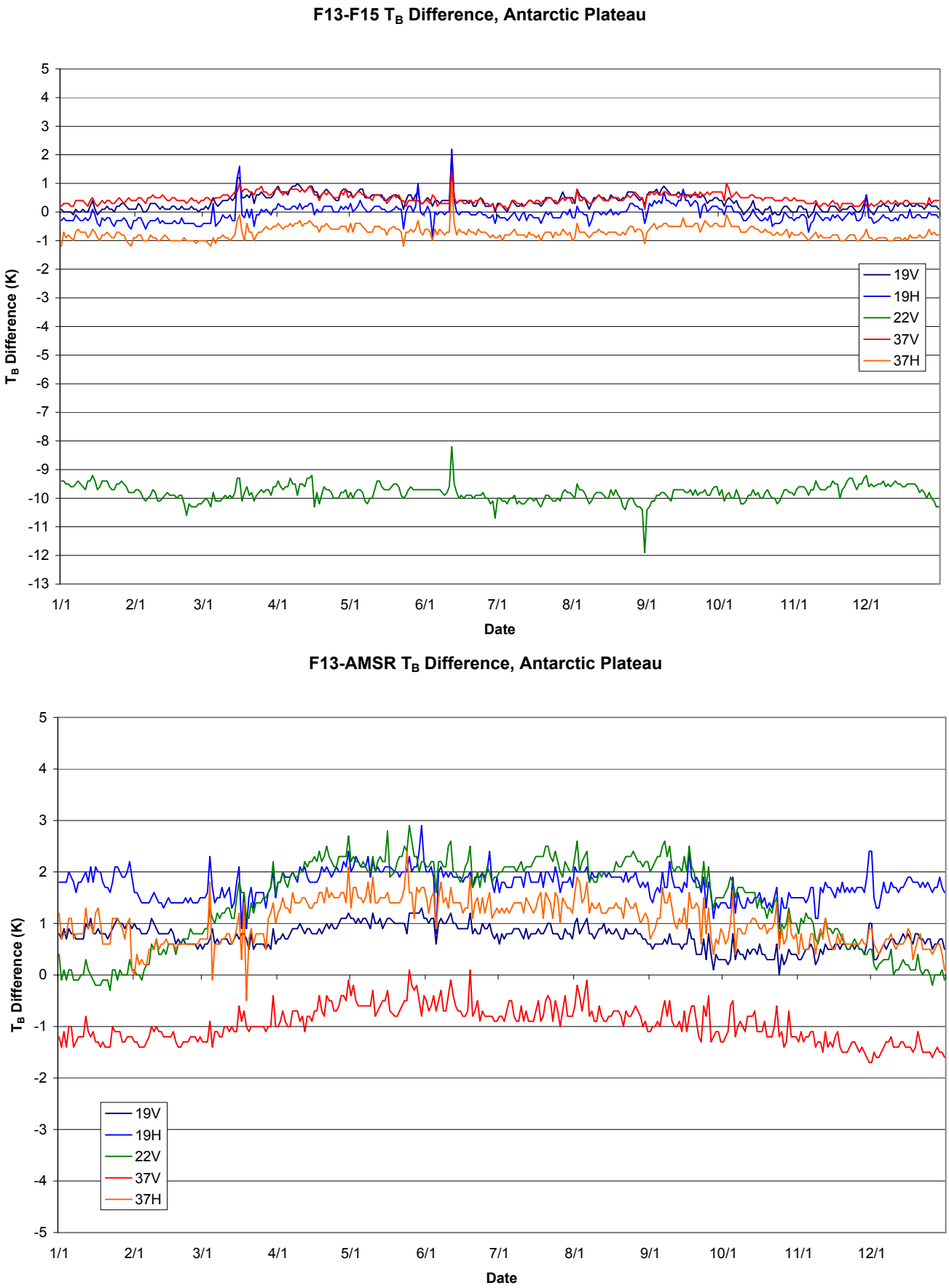
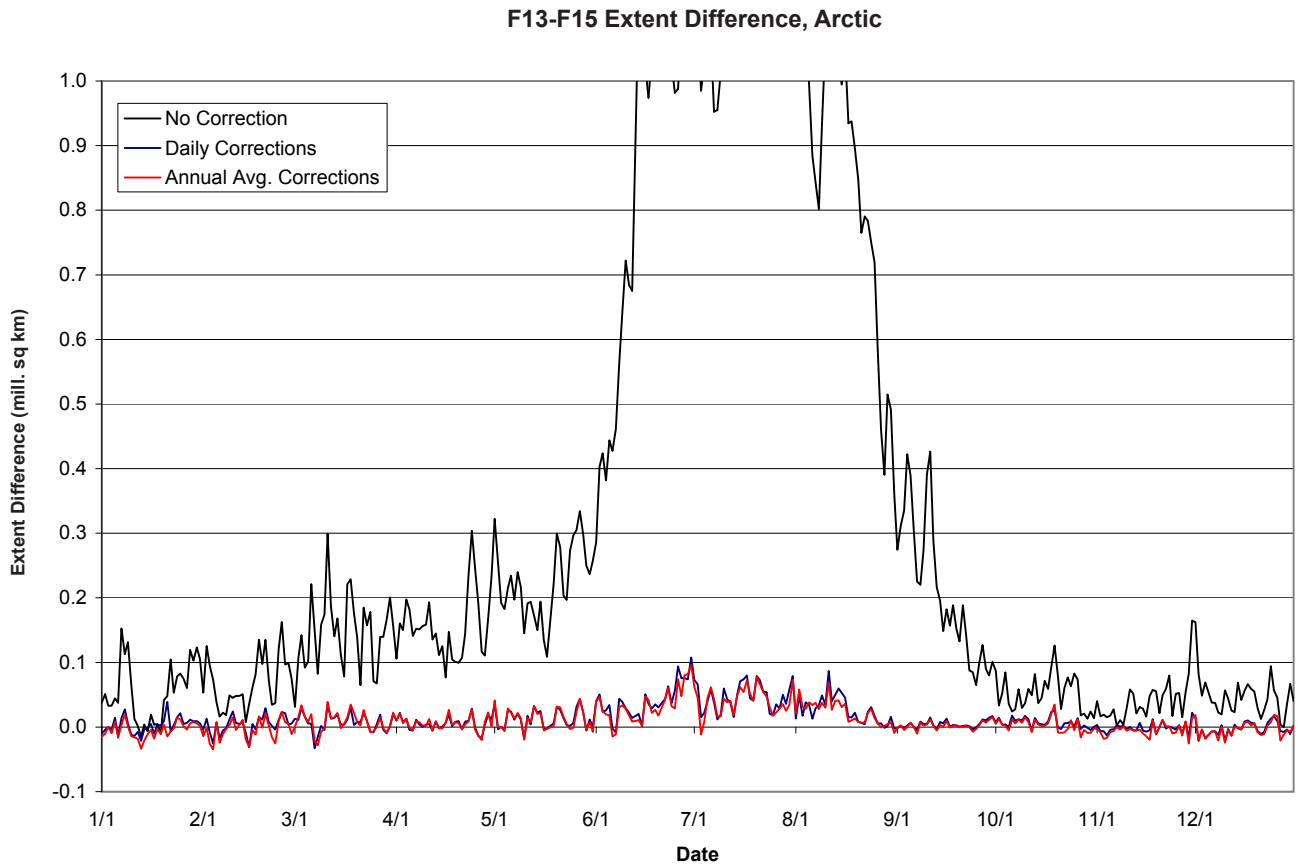


Figure 3b. Brightness temperature differences between F13 and F15 (top) and F13 and AMSR-E (bottom) over a region of the Antarctic Plateau. F15 shows closer agreement than AMSR-E, except for the 22 GHz channel due to the beacon interference.



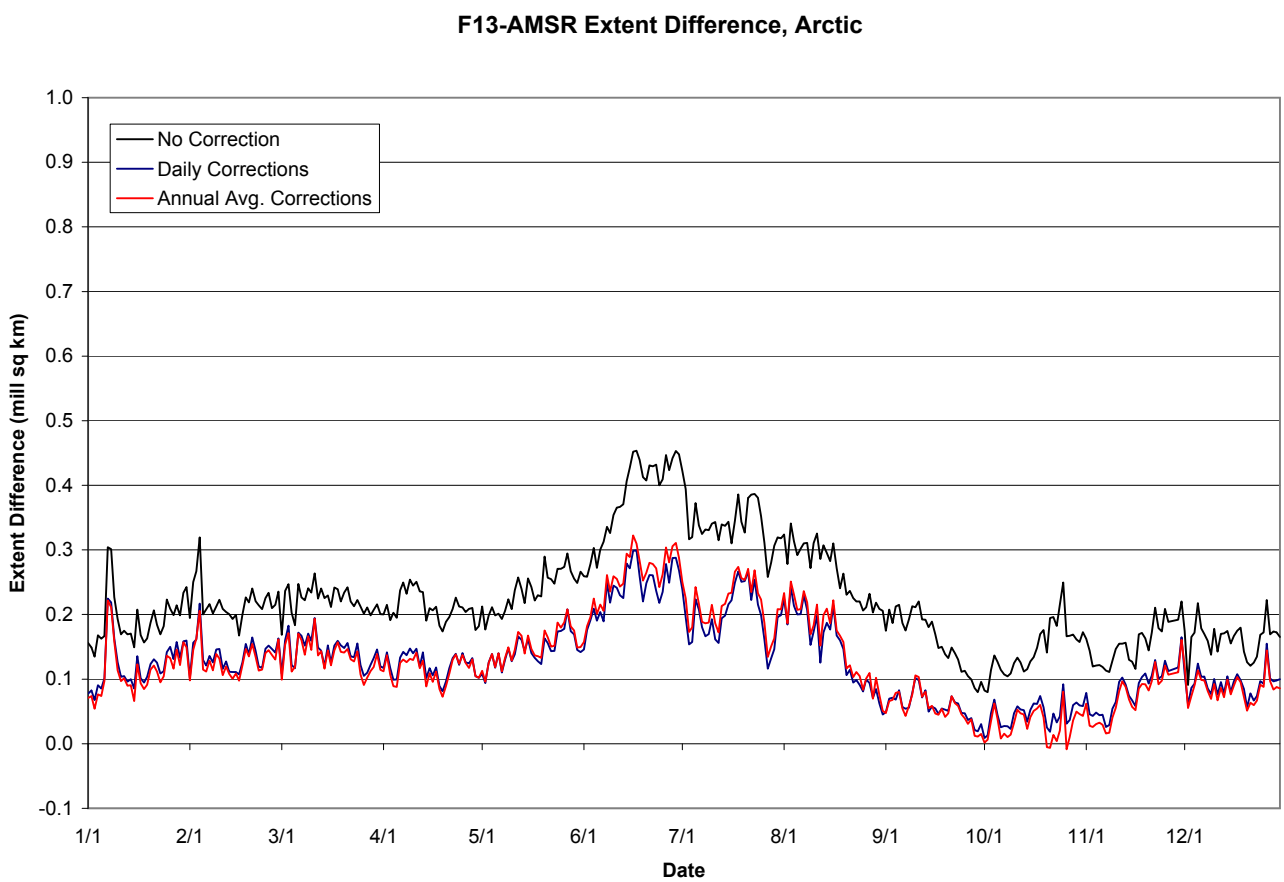


Figure 4a. Arctic total sea ice extent differences between F13 and F15 (top) and AMSR-E (bottom). The uncorrected F15 has larger differences due to the large offset of the 22 GHz channel, but the corrected F15 matches F13 more closely.

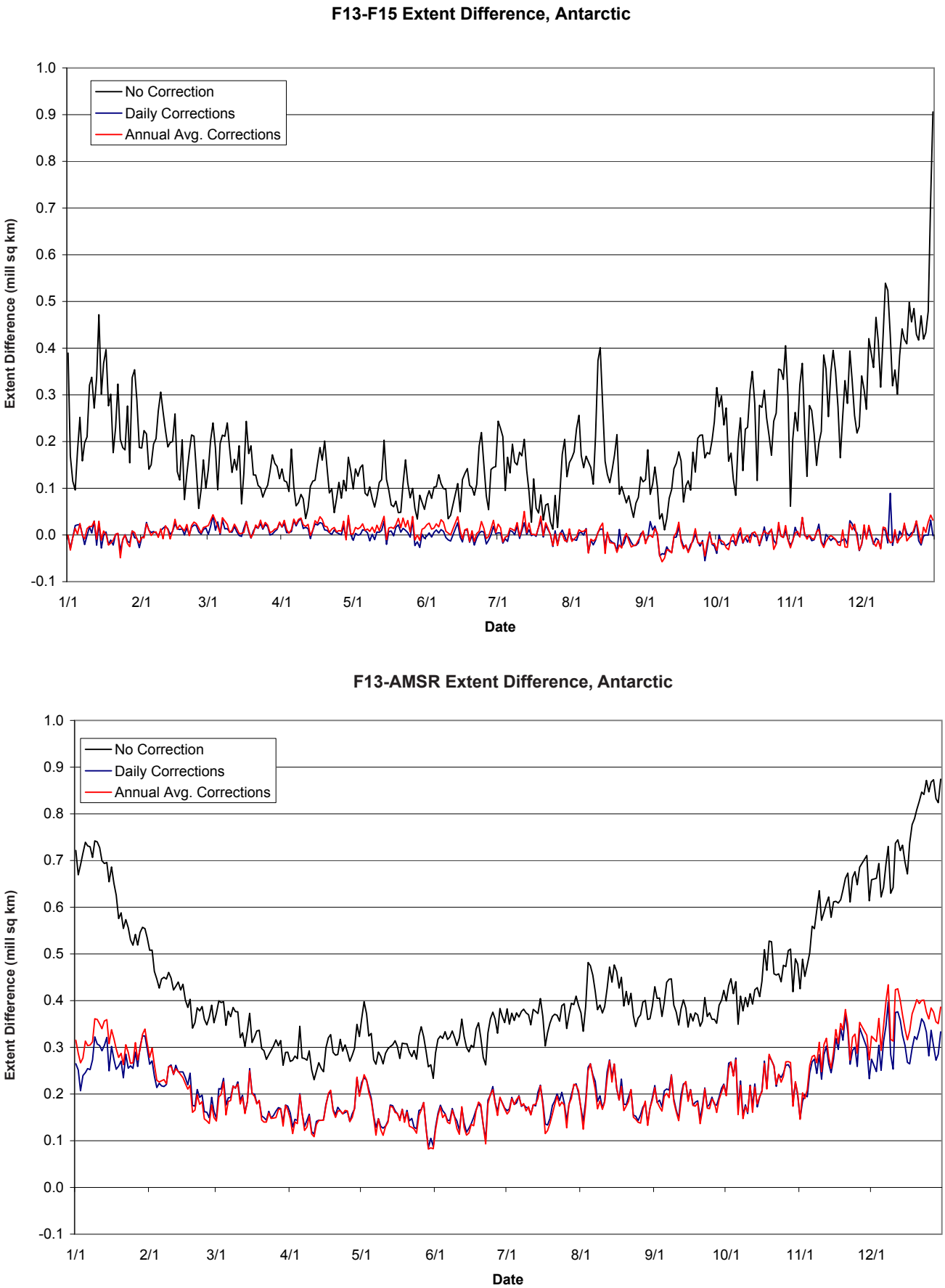


Figure 4b. Antarctic total sea ice extent differences between F13 and F15 (top) and AMSR-E (bottom). The uncorrected F15 has larger differences due to the large offset of the 22 GHz channel, but the corrected F15 matches F13 more closely.