Six-Month (May 1 2012 – Oct 31 2012) Report for

NOAA CDR Project (Award No. NA10NES4400004)

Creating UTH-Related FCDRs from IR and Microwave Sensors Cross Calibrated by In Situ Measurements from Commercial Aircraft

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1. Overview

As stated in the original proposal, the objective of this project is to "*bring together all the upper-tropospheric humidity (UTH)-relevant radiance data from multiple satellites and process them to establish a long-term, global radiance record from which a climate data record (CDR) of UTH can be retrieved and UTH research may be conducted*". Since IR-based UTH CDR (from HIRS) has already been developed and is now operational at NCDC (Shi and Bates 2011), emphasis of this project is placed on microwave sensors, especially SSM/T2, that have not been well archived and calibrated before.

During the last six months, our research has been focused on the following areas:

1. Completed the merge of ISCCP cloud data with the SSM/T2.

2. Further inter-calibrate the NGDC version SSM/T2 data using methods discussed in John et al (2012), including: 1) SNO, 2) natural targets, and 3) zonal averages.

3. Inter-compare water vapor channel radiances from AMSU-B and SSM/T2. This part is still ongoing.

2. Research Progress

2.1 Completed the merge of ISCCP cloud data with the SSM/T2.

SSM/T2 UTH radiances are influenced by thick high clouds with large ice particles (e.g., cirrus anvil spawning from deep convection). Figure 1 shows an example. The whole CDR will be much more useful if cloud information is appended so that future users can decide to include or reject certain measurements when calculating UTH. Also, appending collocated cloud information will help future research concerning the influence of deep convection on UTH (e.g., Luo et al. 2012). Since early this year, we have started to write up code to merge ISCCP pixel-level data (30km and 3 hourly) with SSM/T2. Now, the work was completed. When newer version of ISCCP data (10km and 3 hourly) become available early next year, we will re-do the job. But it should be fairly straightforward, given the software has already been developed.

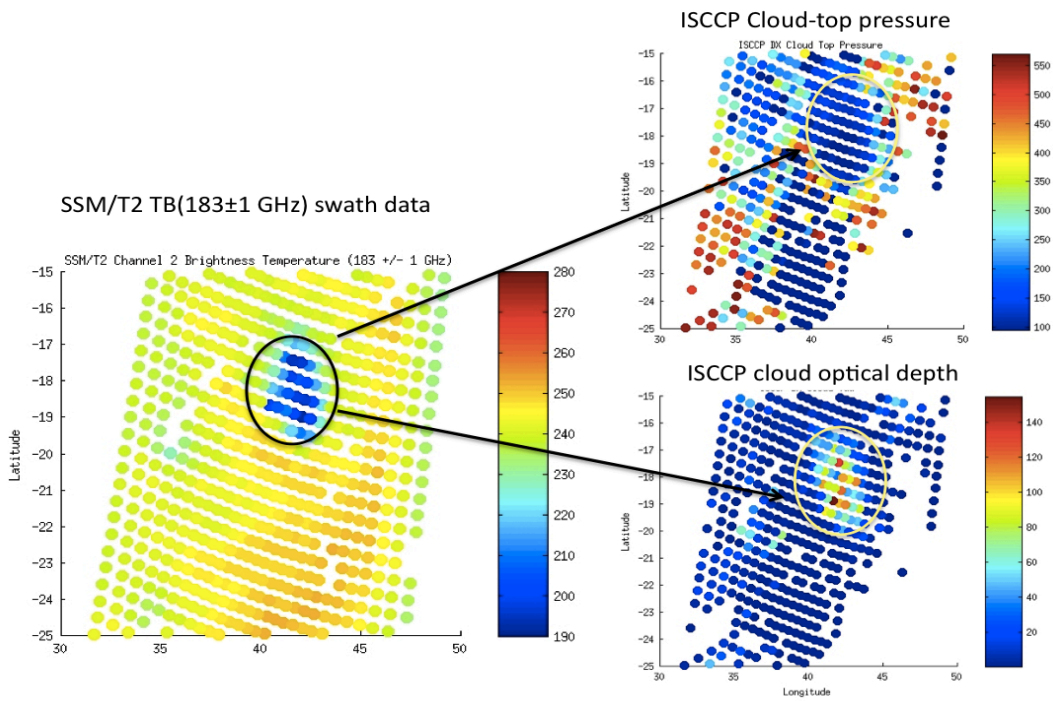

Figure 1. An example of contamination of SSM/T2 radiances by deep convection. As the yellow ovals on the right panels show, these clouds have cloud-top pressure < 200 hPa (upper right) and optical thickness > 50 (lower right). Such clouds can only be deep convection. They need to be labeled in order to generate a meaningful UTH CDR.

2.2 Further inter-calibrate the NGDC version SSM/T2 data

Ever since the beginning of the project, we've tried several calibration methods to inter-calibrate SSM/T2 data, including relative calibrations such as SNO and absolute calibration using collocated MOZAIC sounding data during takeoff and landing which were then fed into the Community Radiative Transfer Model (CTRM) to calculate the SSM/T2 brightness temperatures. Recently, we decided to follow a publication by John et al. (2012) and run three inter-calibration methods through the NGDC version SSM/T2 data simultaneously, with the purpose of seeking mutually consistent conclusions. These methods include: 1) SNO, 2) natural targets (such as Antarctica and tropical oceans), and 3) zonal averages.

While we are still trying to consolidate the results, a few robust conclusions already emerge. Taking the 183 ± 1 GHz radiances as an example, if we use F14 as the calibration base, F11 needs to be shifted downward by about 0.5K and F12 shifted upward by 1K. F14 and F15 seem to agree with each another fairly well until 2004, after which some weird disagreement is observed, which is still being investigated.

2.3 Inter-compare vapor channels from AMSU-B and SSM/T2 (ongoing)

In addition to SSM/T2, AMSU-B also provides UTH radiances. Our ongoing effort is to inter-calibrate AMSU-B against SSM/T2. This part has just started. We've

downloaded some AMSU-B data from CLASS website and made some straightforward comparisons. This task will continue and will be finished during the upcoming 6-month cycle.

3. Future plans

3.1 Research plans

As we are entering into the final 6 months of the project, we plan to wrap up the CDR. A few tasks that remain to be finished are:

1) Apply the same calibration procedures to ASMU-B water vapor channels
2) Finish inter-comparison/calibration between AMSU-B and SSM/T2
3) Merging ISCCP with AMSU-B water vapor channel radiances

3.2 Special request: 1-year no-cost extension

We request a no-cost extension of the project for one year (i.e., from May 2013-April 2014) to ensure a smooth closure and transition to NCDC. A few unexpected situations led to delays of the project. First, it took longer than expected to obtain raw SSM/T2 data and make out the data format (SSM/T2 data are poorly archived). At the beginning of the project, it took us some time to find and train a research associate who can work on the programming part of the project. Another important reason for the extension is to wait for the newer version of ISCCP (10km and 3-hourly) to become available so that the merged cloud-water vapor data will be up to date.

References:

John, V. O., R. P. Allan, W. Bell, S. A. Buehler and A. Kottayil, 2012: Assessment of inter-calibration methods for satellite microwave humidity sounders, J. Geophys. Res. *in press*

Luo, Z. J. , D. Kley, R. H. Johnson, G. Y. Liu, S. Nawrath, and H. G. J. Smit, 2012: Influence of sea surface temperature on humidity and temperature in the outflow of tropical deep convection, J. Climate, 25,1340-1348

Shi, L. and J. J. Bates, 2011: Three decades of intersatellite-calibrated high-resolution infrared radiation sounder upper tropospheric water vapor, J. Geophys. Res., 116, D04108, doi: 1029/2010JD014847

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A no-cost extension of our CDR project has been approved by NOAA CDR program which will extend the project to April 30 2014. Here we briefly summarize what have been achieved so far and the plan toward the completion of the project (delivery).

2. Research Progress

Researches of the past 2.5 years have focused on SSM/T2 UTH radiances. Just recently we start to analyze AMSU-B UTH data. Research activities fall into the following four categories:

1. Obtaining SSM/T2 data from multiple sources

2. Inter-calibrating SSM/T2 data across different satellites

3. Comparing SSM/T2 radiances with sounding data from MOZAIC

4. Merging SSM/T2 with ISCCP cloud product

Here we briefly summarize these activities:

<u>1. Obtaining SSM/T2 data from multiple sources</u>

At the beginning of the project, we received the first version of SSM/T2 data from NESDIS archive, which covers 1994-2001. Data files exist until 2005 but due to a metadata problem, no useful information can be retrieved from 2001 to 2005. The metadata problem has to do with changes of scaling factor and offset that are not documented. This is a common problem for SSM/T2, namely, very poorly documented. We worked on this version of data for a year and a half, testing various calibration methods.

With the help of Hilawe Semunegus (NCDC) and Daniel Kowal (NGDC), we were able to obtain the NGDC archive of the SSM/T2 in late 2011, a more complete version that spans from April 1992 to May 2008. Much of the work since then has focused on analyzing this longer data record.

<u>2. Inter-calibrating SSM/T2 data across different satellites</u>

Three methods were used to inter-calibrate SSM/T2 from F-11, F-12, F-14 and F-15: 1) SNO, 2) natural targets (such as Antarctica and tropical oceans), and 3) zonal averages. A few robust conclusions can be drawn from multiple analyses. Taking the 183 ± 1 GHz radiances (a UTH channel with weighting function peak near

400 hPa) as an example, if we use F14 as the calibration base, F11 needs to be adjusted downward by about 0.5K and F12 be adjusted upward by 1K. F14 and F15 are found to agree with each another fairly well until 2004.

3. Comparing SSM/T2 radiances with sounding data from MOZAIC

MOZAIC take-off and landing measurements provide high-accuracy humidity sounding data. The Community Radiative Transfer Model as provided by NCEP and NESDIS colleagues (ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM/) was used to convert sounding profiles to microwave brightness temperatures (TBs). Then, we matched up MOZAIC data with SSM/T2 measurements and made comparisons between the simulated and observed UTH (183 GHZ) TBs. This exercise can be interpreted as an attempt of absolute calibration of SSM/T2 UTH radiances. Results showed that for F-14 (the basis of our relative calibration), the observed TBs are warmer than the simulated TBs by 1-3K. The colder end has larger bias than the warmer end.

4. Merging SSM/T2 with ISCCP cloud information

A unique aspect of our UTH CDR product is: we take into account cloud information to facilitate future research. SSM/T2 UTH radiances are influenced by thick high clouds with large ice particles (e.g., cirrus anvil spawning from deep convection). The whole CDR will be much more useful if cloud information is appended so that future users can decide to include or reject certain measurements when calculating UTH. Also, appending collocated cloud information will help future research concerning the influence of deep convection on UTH. To this end, we have merged ISCCP pixel-level data (30km and 3 hourly) with SSM/T2. When newer version of ISCCP data (10km and 3 hourly) become available later this year, we will re-do the job.

3. Future plans

Two major tasks remain to be finished before we consolidate all research activities and deliver the final CDR product: 1) fully incorporating AMSU-B and constructing a complete microwave-based UTH CDR, and 2) update ISCCP cloud data.

1) Fully incorporating AMSU-B data

Since last winter, we have started analyzing AMSU-B data. At first, we downloaded a few months of AMSU-B data that overlap with SSM/T2 and built up analysis code. With the help of Drs. Huan Meng and Ralph Ferraro of NESDIS, we have now obtained a complete archive of AMSU-B. We plan to finish inter-calibration of AMSU-B and compare with the work by Ralph Ferraro's group. Also, we plan to inter-calibrate SSM/T2 and AMSU-B.

2) Update ISCCP cloud data

ISCCP H-series data (10km and 3 hourly) will be available later this year. We plan to update the match ISCCP pixel-level data.

References:

Shi, L. and J. J. Bates, 2011: Three decades of intersatellite-calibrated high-resolution infrared radiation sounder upper tropospheric water vapor, J. Geophys. Res., 116, D04108, doi: 1029/2010JD014847

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We focus on the microwave measurements, especially SSM/T2, because IR-based UTH CDR (from HIRS) has already been developed and is now operational at NCDC (Shi and Bates 2011). AMSU-B UTH radiances have been analyzed by another CDR team as part of a bigger project (Ralph Ferraro), but we will incorporate them into our CDR. GEO-version of UTH is being calibrated by the ISCCP team in parallel.

A no-cost extension of our CDR project has been approved by NOAA CDR program which will extend the project to April 30 2014. Here we briefly summarize what have been achieved so far and the plan toward delivery.

2. Research Activities

Our analysis and calibration of SSM/T2 focus on the following areas: 1) Obtaining SSM/T2 data from multiple sources; 2) Inter-calibrating SSM/T2 data across different satellites; 3) Calibrating SSM/T2 radiances against sounding data from MOZAIC; 4) Appending SSM/T2 with ISCCP cloud product. The following paragraphs summarize these activities:

<u>1. Obtaining and archiving SSM/T2 data</u>

We first worked on SSM/T2 data from NESDIS archive, which covers 1994-2001. Although data files exist until 2005, no useful information can be retrieved from 2001 to 2005 due to a metadata problem. The metadata problem has to do with changes of scaling factor and offset that are not documented. This is a common problem for SSM/T2, namely, poor documentation. We used this version of data to test various calibration methods. With the help of Hilawe Semunegus (NCDC) and Daniel Kowal (NGDC), we were able to obtain the NGDC archive of the SSM/T2, a more complete version that spans from April 1992 to May 2008. Much of the work since then has focused on analyzing this longer data record.

<u>2. Inter-calibrating SSM/T2 data across different satellites</u>

Three inter-calibration methods were used to analyze SSM/T2 from F-11, F-12, F-14 and F-15: 1) SNO, 2) natural targets (such as Antarctica and tropical oceans), and 3) zonal averages. A few robust conclusions can be drawn from multiple analyses. Taking the 183 ± 1 GHz radiances (a UTH channel with weighting function peak near 400 hPa) as an example, if we use F14 as the calibration base, F11 needs to be adjusted downward by about 0.5K and F12 be adjusted upward by 1K. F14 and F15 are found to agree with each another fairly well until 2004.

<u>3. Calibrating SSM/T2 radiances against sounding data from MOZAIC</u>

MOZAIC take-off and landing measurements provide high-accuracy humidity sounding data. The Community Radiative Transfer Model as provided by NCEP and NESDIS colleagues was used to convert sounding profiles to microwave

brightness temperatures (TBs). Then, we matched up MOZAIC data with SSM/T2 measurements and made comparisons between the simulated and observed UTH (183 GHZ) TBs. This exercise can be interpreted as an attempt of absolute calibration of SSM/T2 UTH radiances. Results showed that for F-14 (the basis of our relative calibration), the observed TBs are warmer than the simulated TBs by 1-3K. The colder end has larger bias than the warmer end.

4. Appending SSM/T2 with ISCCP cloud information

A unique aspect of our UTH CDR product is: we take into account cloud information to facilitate future research. SSM/T2 UTH radiances are influenced by thick high clouds with large ice particles (e.g., cirrus anvil spawning from deep convection). The whole CDR will be much more useful if cloud information is appended so that future users can decide to include or reject certain measurements when calculating UTH. Also, appending collocated cloud information will help future research concerning the influence of deep convection on UTH. To this end, we have merged ISCCP pixel-level data (30km and 3 hourly) with SSM/T2. When newer version of ISCCP data (10km and 3 hourly) become available later this year, we will re-do the job.

3. Remaining research and plan for delivery

We are working toward delivery of the CDR product to NCDC by next summer. A couple of tasks remain to be finished: 1) incorporating AMSU-B and constructing a complete microwave-based UTH CDR, and 2) update ISCCP cloud data and include GEO-version of UTH radiances (which is part of ISCCP data). The first task is moving steadily. The second part depends on the schedule of the new ISCCP data production. We will be in touch with the NCDC CDR program manager early next year to discuss the plan for delivery.

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We focus on the microwave measurements, including SSM/T2 and AMSU-B (i.e., radiances from near 183 GHz). IR-based UTH CDR (around 6.7 μm) from HIRS has already been developed and is now operational at NCDC (Shi and Bates 2011). The GEO-based of IR UTH radiances are being calibrated by the ISCCP team in parallel and will be merged with the microwave data.

2. Work Accomplished

Over the past several years, we have completed the following work: 1) Obtaining SSM/T2 data and re-archiving them; 2) Inter-calibrating SSM/T2 data among F-11, F-12, F-14 and F-15; 3) Calibrating SSM/T2 radiances against collocated aircraft measurements (MOZAIC); 4) Appending ISCCP cloud products to SSM/T2. The following paragraphs summarize these activities:

<u>1. Obtaining and archiving SSM/T2 data</u>

We first worked on SSM/T2 data from NESDIS archive, which covers 1994-2001. Although data files exist until 2005, no useful information can be retrieved from 2001 to 2005 due to a metadata problem. The metadata problem has to do with changes of scaling factor and offset that are not documented. This is a common problem for SSM/T2, namely, poor documentation. We used this version of data to test various calibration methods. With the help of Hilawe Semunegus (NCDC) and Daniel Kowal (NGDC), we were able to obtain the NGDC archive of the SSM/T2, a more complete version that spans from April 1992 to May 2008. Much of the work since then has focused on analyzing this longer data record.

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our relative calibration), the observed TBs are warmer than the simulated TBs by 1-3K. The colder end has larger bias than the warmer end.

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Final Report for NOAA CDR Project (Award No. NA10NES4400004)

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The main contributions of this project are as follows. In the following section, detailed descriptions will be given.

- Re-archived and inter-calibrated raw SSM/T2 data
- Matched IR UTH radiances from GEOs to SSM/T2
- Appended ISCCP cloud properties (so that one can better interpret UTH radiances in future applications)

2. Microwave-based UTH FCDR

Figure 1 shows the flowchart for building the SSM/T2 UTH CDR. Here, we briefly describe them:

1) Obtaining raw data: we first obtained raw, uncalibrated SSM/T2 data from NGDC (thanks to Hilawe Semunegus and Dan Kowal for help).

2) Granularizing the data files: the raw data are intended to be saved one orbit per file. However, sometimes the beginning or ending part of an orbit is not clearly cut (e.g., the raw file may extend to the next orbit). So, we process them in such a way that each file is strictly set for one orbit.

3) Intercalibration: this is a critical step and took much of our time to finish. All four satellites that carry SSM/T2 share some overlaps in time (see Fig. 1) so a direct comparison between them is possible. We tried different calibration methods including simultaneous nadir overpass (SNO), use of natural targets (e.g., tropical ocean) for comparison, comparing zonal averages, and using matched MOZAIC taking-off landing "sounding" profiles coupled with a radiative transfer model. We look for consistency between these different methods. Conclusions are generally robust. Taking 183 ± 1 GHz radiances as an example, if we use F14 as the calibration base, F11 needs to be shifted downward by about 0.5K and F12 shifted upward by 1K. Calibration coefficients are saved as slopes and intercepts (i.e., one satellite against another).

4) Appending ISCCP cloud data and IR UTH radiances from GEOs: SSM/T2 UTH radiances are influenced by thick high clouds with large ice particles (e.g., cirrus anvil spawning from deep convection). Figure 2 shows an example of such contamination. The whole CDR will be much more useful if cloud information is appended so that future users can decide to include or reject certain

measurements depending on their applications. Also, appending collocated cloud information will help future research concerning the influence of deep convection on UTH (e.g., Luo et al. 2012). Since IR UTH radiances from GEOs are also archived by ISCCP, we appended them as well.

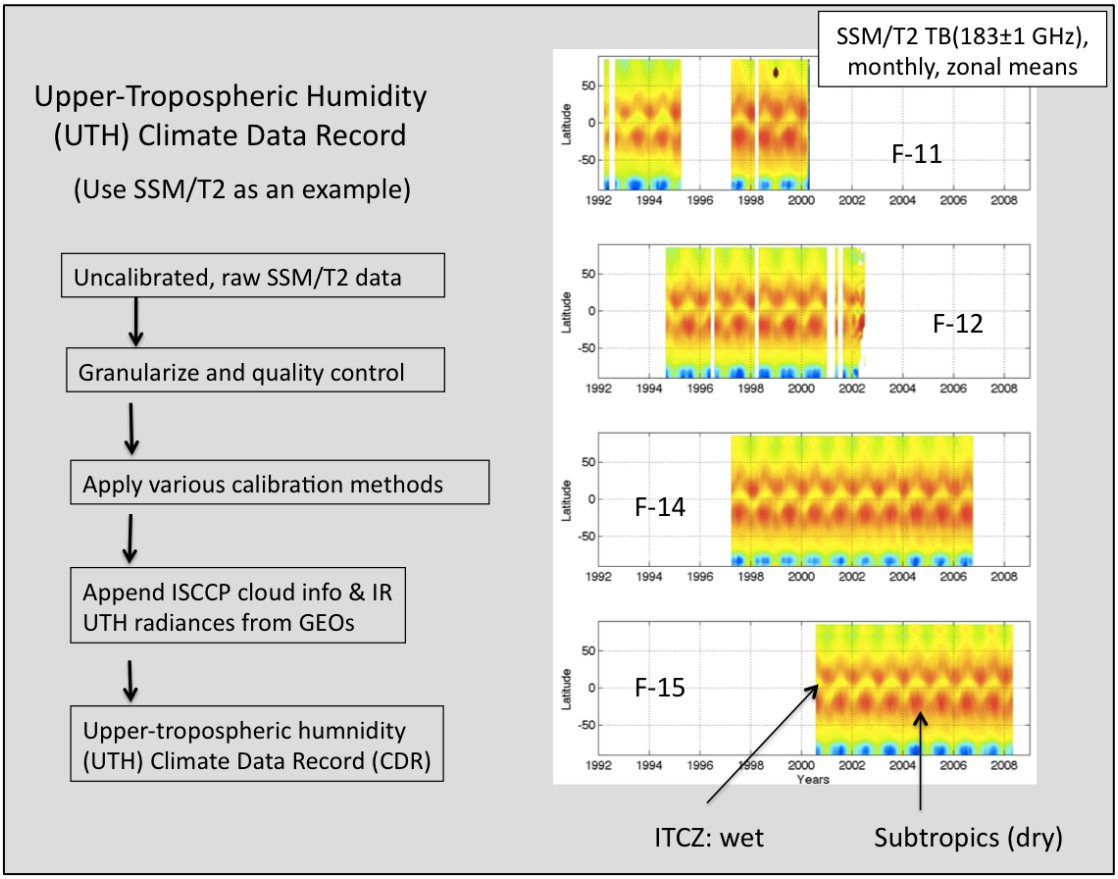

Figure 1. Flowchart for preparing the microwave-based UTH CDR

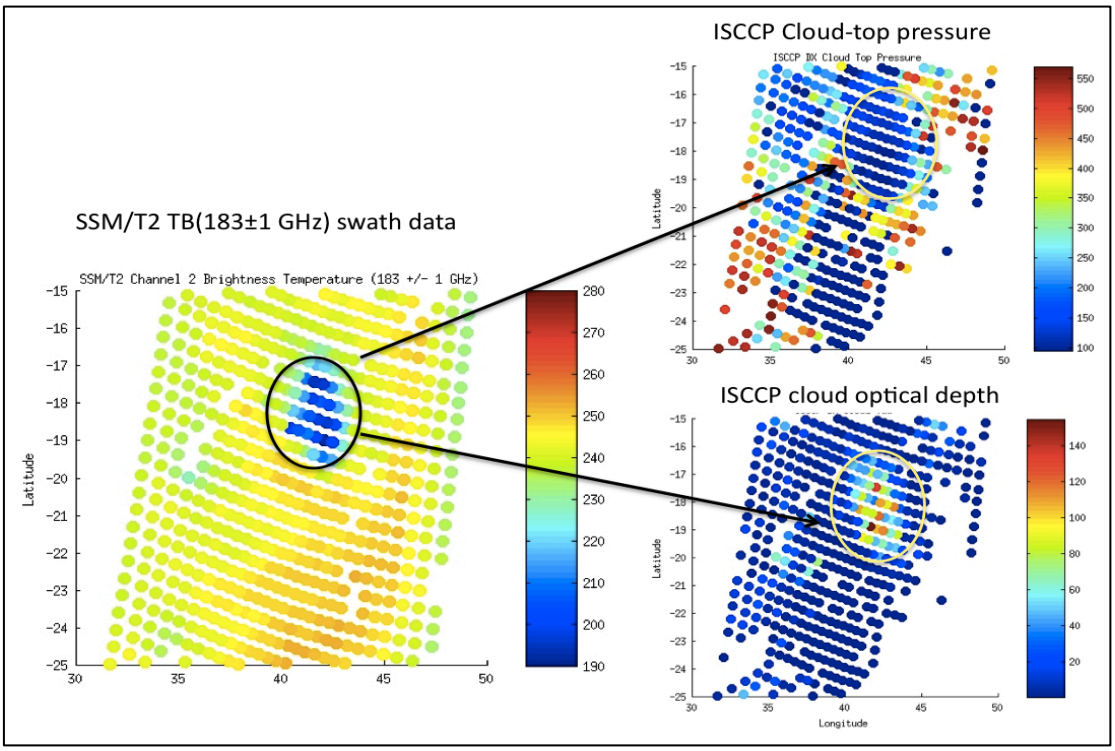

Figure 2. An example of contamination of SSM/T2 radiances by deep convection. As the yellow ovals on the right panels show, these clouds have cloud-top pressure < 200 hPa (upper right) and optical thickness > 50 (lower right), which are obviously deep convective clouds. They need to be labeled in order to generate a meaningful UTH CDR.

2. Publication and delivery of the product

We are in the process of writing up a journal article to describe this new dataset, to present a few initial results and to discuss possible applications. In terms of delivery, we are working with NOAA NCDC (Dr. Xuepeng "Tom" Zhao and Mr. Terry Mcpherson) to ensure a smooth transition of the dataset to NCDC for archive. This process is ongoing and we agreed that some extra features will be added.

References:

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