A-Train Data Depot - Bringing Atmospheric Measurements Together

Andrey Savtchenko, Robert Kummerer, Peter Smith, Arun Gopalan, Steven Kempler, and Gregory Leptoukh

Abstract— This paper describes the satellite data processing and services that constitute current functionalities of the A-Train Data Depot. We first provide a brief introduction to the original geometrical intricacies of the platforms and instruments of the A-Train constellation, and then proceed with description of our A-Train collocation processing algorithm that provides subsets that facilitate synergistic use of the various instruments. Finally, we present some sample image products from our web-based Giovanni tool which allows users to display, compare and download coregistered A-Train related data.

Index Terms— Aerosols, Clouds, Precipitation, Remote sensing, Satellite applications.

I. INTRODUCTION

IT BECAME clear in recent years, that achieving qualitative progress in understanding and forecasting changes on synoptic-to-climate scales will not be possible without a synergistic approach to the multitude of measurements coming from different instruments and platforms [1,2]. The existence of the Earth Observing System and the more-focused Earth System Science Pathfinder (ESSP) missions opened a unique opportunity towards materialization of the **A-Train** formation and accomplishing these goals. A-Train is a constellation of five satellites flying in a tight formation, Fig. 1 and Table 1, and a sixth one is scheduled for launch in late 2008.

The A-Train is addressing broad aspects of radiation budget, aerosols, clouds, atmospheric water in all phases, trace gases, stratospheric ozone, and interaction among them.

The A-Train Data Depot (**ATDD**) project at the Goddard Earth Sciences Data and Information Services Center (GES DISC) seeks to maximize its impact by addressing the differences in spatial, vertical and horizontal, as well as temporal scales of coverage of different instruments participating in the A-Train, and providing applications that shorten the bridge between data exploration and data utilization. ATDD is achieving these goals by providing collocated subsets, user-friendly search and visualization web tools, and A-Train focused web content.

Based on preliminary analyses by late 2007, the A-Train

mission formulated a proposal to reconfigure the flying formation, which would clearly elevate the significance of the scientific results. A brief discussion of the essence of the proposed changes to the original configuration is presented at the end of section II. At the time we were preparing this publication for press, the Aura phasing part of the reconfiguration was still in a planning stage. Regardless of that outcome though, our discussion here is addressing the original configuration which does not lose on value - these data will still be utilized, and hence the need to understand the configuration at which they were acquired.

II. SPATIAL AND TEMPORAL DIFFERENCES

It is essential to understand the differences in the orbital configuration of various platforms and instruments en Route to the accurate co-location and co-interpretation of data from them.

A. Lateral Separation

A frequently seen rendering is the one where all A-Train satellites are attached to the same track. However, it is important to note that they are actually not in the same orbital plane, i.e. not on identical right ascension nodes, Fig. 1. Further, the satellite positions in the right ascension coordinate system do not project similarly onto ground tracks, following the combined effect of the time lag between satellites on one hand, and planetary rotation that amounts to ¼ degree per minute, on the other. Originally, the A-Train orbits are such that the **spatial** (lateral) separation between ground tracks at the Equator is largest between CloudSat, carrying the CPR (Appendix A) [2,3], and Aura, carrying four instruments: OMI, MLS, HIRDLS, and TES (Appendix A). This defeats the intuition if looking superficially at Fig. 1, where Aura is only slightly east from CloudSat. Nonetheless, if OMI nadir is taken as a close proxy of Aura track, then the latter could be seen to be crossing the Equator about 3.68° (408 km) west from CloudSat, Fig. 2. This is a combined result of Aura lagging 15 minutes behind CloudSat but being on a very close right ascension node, and the Earth's rotation that amounts to 3.7° turn for that time. Also in Fig.2, OMI/Aura is seen 1.7 degrees west from MODIS/Aqua — yet another non-intuitive result from the Aura time lag and the Earth rotation.

B. Temporal Separation

In terms of the original **temporal** differences, Aqua leads while Aura trails the pack, Fig.1, and thus the time lag is largest between these two, amounting to about 16 minutes. In spite of the substantial spatial and temporal separation between Aura and Aqua spacecrafts, however, the Aura's MLS instrument pointing is such that its retrieval footprint are spatially collocated with the Aqua platform ground track for many practical purposes, and hence with its MODIS and AIRS (Appendix A) instruments nadir. This formidable outcome is a result of the 3000-km bore sight of MLS. Thus, MODIS nadir and the ground track of MLS retrievals show as one track in Fig. 2, while the time lag of the MLS column retrieval of about 9 minutes behind MODIS (or Aqua) contrasts the 16-minutes lag between OMI nadir (or Aura) and Aqua, Fig. 2. The time lag between platforms should always be kept in mind. For instance, the same atmospheric column is seen by OMI 15 minutes after CloudSat, and 16 minutes after Aqua. (Recall that CloudSat is inserted right behind Aqua, Fig.1). The inset in Fig.2 shows the orbital convergence of MODIS nadir and CloudSat, between 81.7N and 81.8N latitudes. In this inset, MODIS 1-km footprints are shown, relative to the points where CPR reports retrievals. In summary, Fig. 2 should be interpreted as an example of separation of ground tracks of CPR footprint and just a sample of other A-Train instruments, while the numbers reflect the particular separation at the Equator, in terms of arc-distance, longitudinal angle, and UTC time for this particular ascending node.

C. Difference in Footprints

Another dominating factor in data coregistration is the relationship between the resulting footprints of retrievals from different instruments. For instance, one footprint of MLS retrievals strides over 166 km along-track (1.5 deg at the Equator), whereas it is only about 10 km across-track. Thus, over one hundred of MODIS 1-km or CPR retrievals can be collocated with one MLS retrieval, Fig. 3. Note that because of the CPR aggregation that lasts while the satellite travels 1.1 km, the resultant CPR retrieval footprint has a long axis (along-track) of 2.5 km, and a short axis (cross-track) of 1.4 km, which results in overlaps of retrievals along the track. Fig. 3 also zooms into the spatial (lateral) separation between MLS and CloudSat, and clearly shows the 1.94° reported in Fig. 1, that amounts to more than 200 km at the Equator. However, their tracks are converging towards the Poles, Fig. 4. Even though full overlap occurs for a short period only, in general beyond 81 deg of latitude, various mesoscale phenomena are still feasible to be co-registered by both, MLS and CloudSat. In this regard, Fig. 4 can serve as guidance to the atmospheric phenomena scales that can be co-registered by both instruments at a given latitude.

D. Original MODIS/Aqua-MLS collocation

The case of MODIS/Aqua and MLS is more favorable. For many practical purposes, MODIS/Aqua nadir and MLS retrieved columns are spatially collocated, and in particular for the 5-10 km MODIS science retrievals, Fig. 5. The variations of the spatial separation are due to orbital adjustments and drifts, and are within ±6 km in terms of standard deviation from the mean separation at the Equator, where the impact of adjustments is maximal. Apart from the obvious convenience for any sort of MLS-Aqua subsets, this fact can be exploited anytime Aqua track can be used as proxy predictor of MLS track. It should be noted that the spatial collocation should not be confused with temporal – the time at the MLS-retrieved column is on average 8.5 minutes past MODIS/Aqua nadir.

E. CloudSat and CALIPSO

CloudSat and CALIPSO (Appendix A) were launched on the same vehicle, and placed on a very close right ascension nodes, Fig.1, about 12 seconds apart. Both satellites are kept in this tightly controlled box, which ensures that the CPR and CALIPSO lidar (CALIOP) footprints are practically overlapping along their orbits. A summary of the Equatorial crossings of the ground tracks of MLS retrievals and a sample of other instruments at nadir, relative to Aqua, is given in Table 1.

F. OCO

The last instrument to be inserted into the A-Train formation will be the Orbiting Carbon Observatory, OCO, which is expected to be launched in late 2008. It is expected to be 15 minutes ahead of Aqua.

G. A-Train Reconfiguration

To maximize the scientific benefits from the mission, an optimization of the A-Train formation was proposed by the science teams. The proposed modifications to the A-Train configuration include phasing of the Aura and CloudSat platforms, and a pitch change to the CALIPSO. It is envisioned that Aura will be left to drift about 7 minutes ahead, i.e. closer to Aqua. The sought effect is to relocate the MLS footprint under CPR and CALIOP, as well as to reduce the time lag between Aura and Aqua observations. The CALIPSO pitch change amounts to 3°, which requires a 5-seconds increase of the CloudSat separation, in order to maintain their footprints overlapped. These changes will bring numerous benefits, among them are: reducing of ambiguities associated with the time difference; better combining of multi-instrument retrievals of atmospheric water vapor, temperature, clouds and aerosols; and better understanding of the microphysics of clouds and their interactions with aerosols. The CALIPSO-CloudSat reconfiguration was accomplished by the end of November, 2007, whereas the Aura phasing is a longer process that is expected to be finalized by the summer of 2008.

III. ATDD MODIS/AQUA SUBSETS

At the time of this publication, ATDD operationally collocates and subsets data from MODIS/Aqua, OMI, and AIRS (interactively, through Giovanni, see below).

MODIS/Aqua collocated subsets are the most extensive collection of subsets. They are used in the CloudSat operational science retrieval algorithms, at the Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University. MODIS/Aqua collocated subsets are available in two groups. While one is collocated with CloudSat, the other is collocated with MLS. (If Aura phasing takes place within the A-Train reconfiguration, the MODIS-MLS subset will be discontinued.) The CloudSat-collocated subsets are produced and available in two swath widths: ±100-km and ±5-km across-track. Subset are all MODIS/Aqua Atmospheres Level 2 products (aerosols, atmospheric water vapor, clouds, profiles, and cloud mask), and certain geolocation and radiance products.

On the OMI side, as of the time of this publication, ATDD subsets a ±100-km wide OMI swath collocated with CloudSat. ATDD provides four OMI subset products: two cloud products (O2-O2 absorption and Raman Ring scattering), the aerosol extinction and absorption optical depth, and the total column ozone (TOMS-like algorithm).

Lastly, thanks to the small size of AIRS final retrieval, its collocation and subset along CloudSat is implemented on-the-fly in the web tool Giovanni that will be described shortly. The advantages of this approach are: i) AIRS data are stitched, collocated, and trimmed dynamically to the size of the CloudSat portion of the orbit as requested by users on a simple web interface; ii) Trimmed AIRS data can be previewed along CloudSat, CALIOP, MODIS and OMI, and immediately downloaded.

More details on the available subsets can be found at: http://disc.gsfc.nasa.gov/atdd. All subsets are stored in an online archive and are available for ftp download. They are also searchable, per user-input temporal, spatial and event gazetteer constrains, through Mirador: http://mirador.gsfc.nasa.gov . The events include hurricanes, hail, air pollution, aerosols, winds, and others described at the latter url.

The subset algorithm, used in collocating MODIS and AIRS from Aqua platform, and OMI from Aura platform, with CloudSat, is an iterative approach. Even though the algorithm is universally applied to all of these instruments, we will use MODIS as an example of our application. The orbital planes of CloudSat and Aqua are such that the shortest arc distance between their ground tracks is a function of time, or latitude as shown in Fig.4. Thus, the goal of the algorithm is to find in a MODIS granule the pixels that are closest to the CloudSat radar footprints falling within that granule. The algorithm can be summarized as a processing where an initial solution is found first, and then it is subsequently refined to the MODIS pixel closest to the radar footprint. Without leaving the close neighborhood of the previous solution, the process then continues along the portion of the CloudSat track that falls within the subject granule. Because of the size of MODIS data arrays in the standard granules (files), the very first initial search of solution per granule is constrained to a much smaller

subset in the center of the granule. This, and the fact that the algorithm "locks" to and progresses along the CloudSat track, drastically minimizes the amount of calculations thus making the processing very efficient and operationally feasible.

The operational subset processing is asynchronous and decoupled from the availability of CloudSat data - it uses two-line elements (TLE) and predicts the CloudSat track at finer spatial and temporal grid, and thus is ensuring excellent accuracy of collocation. Nominally, the TLE are updated every day, and even though orbital-adjustments do occur, they are on the scale of once per several months and their impact is not substantial.

Fig. 6 presents the collocation algorithm, as well as the approximate spatial relation between CloudSat track and one MODIS swath granule. It typifies a situation on Aqua ascend, close to the Equator, where MODIS nadir is about 200 km west from the CloudSat track. We use the following notations, and use nominal values where appropriate:

T_b, T_e MODIS granule beginning and end time, $T_e - T_b = 300$ sec

X, Y Number of MODIS 1-km frames and detector lines, correspondingly. $X = 1354$, $Y = 2030$.

Δ Time interval

$\mathbf{g}_m(i_m, j_m)$ MODIS geolocation vectors; $i_m \in [1, Y]$, $j_m \in [1, X]$

$\mathbf{g}_c(i_c)$ CloudSat predicted geolocation vectors; $i_c \in [1, 9000]$

$\mathbf{g}_m \mathbf{g}_c$ Arc distance between MODIS and CloudSat geolocation vectors.

$\mathbf{a} = \mathbf{g}_c(i_{c0})$, $\mathbf{b} = \mathbf{g}_c(i_{c1})$ Vectors that represent "entry" and "exit" points of CloudSat track, and that happen to be at indices i_{c0}, i_{c1}.

The algorithm is initiated by the temporal interval, T_b, T_e, of the MODIS granule we need to subset. Given CloudSat lag behind Aqua of about a minute, $\Delta = 300$ sec is added and subtracted to that interval, and the extended time interval is used to compute the CloudSat ground track. Thus, there is an ample contingency that the 900-sec predicted CloudSat track, $\mathbf{g}_c$, will cover the 300-sec MODIS granule. The CloudSat ground positions are calculated at 0.1 sec intervals, which results in $i_c \in [1, 9000]$.

Once the CloudSat track is computed, the algorithm detects $[i_{c0}, i_{c1}]$ where the track intersects the first and the last MODIS detector line. The intersect points $\mathbf{a}$ and $\mathbf{b}$ are resolved by finding the $\mathbf{g}_c$ vectors that are inside the MODIS granule box and closest to the tangent vectors of the first and last scan planes.

Given the CloudSat locations are computed at 0.1sec intervals, they appear at finer than MODIS spatial sampling rate. Thus the algorithm builds a cross-reference $i_m = f(i_c)$ for $i_c \in [i_{c0}, i_{c1}]$ that will be used during the search process. From the pair $[i_{c0}, i_{c1}]$, the initial index is set at the midpoint $i_{cc} = (i_{c1} - i_{c0})/2$, which will serve as a starting point on the CloudSat track from where the search procedure will start.

To expedite the search procedure, a sub-box of MODIS

geolocations is cut out at i_{mb}=Y/2, j_{mb}= X/2, with dimensions 800x100 (shaded inset box, Fig. 6). This sub-box discards immediately millions of MODIS geolocations, while at the same time it is sufficiently large to enclose $\mathbf{g}_c(i_{cc})$. Next, the algorithm checks the arc-distances between vector $\mathbf{g}_c(i_{cc})$ and all vectors $\mathbf{g}_m(i_m,j_m)$ from the box, $i_m \in [i_{mb}$-50,i_{mb}+50], $j_m \in [j_{mb}$-400,j_{mb}+400], until it finds an arc distance $\mathbf{g}_m\mathbf{g}_c$<1 km.

If condition $\mathbf{g}_m\mathbf{g}_c$<1 km is met, the search has identified sufficiently close, but not necessarily the best, frame and detector line solution for collocated MODIS geolocations, $\mathbf{g}_m(i_a,j_a)$. Apparently then, there is no need to continue to search throughout the entire shaded box, and hence, that solution is used to confine the search to a yet smaller vicinity of $\mathbf{g}_m(i_a,j_a)$, that further expedites finding the best solution. This vicinity is small indeed: it is on the same MODIS detector line, i_a, and it consists of just three MODIS frames, $j_m \in [j_a$-1,j_a+1], and five CloudSat ground positions. This step will either confirm that $\mathbf{g}_m(i_a,j_a)$ is the best solution, or will find the final best one, $\mathbf{g}_m(i_a,j_s)$.

At this point the algorithm is certain that it has identified a MODIS frame, at certain detector line, that is no farther than one kilometer from the CloudSat track. Now the algorithm needs to only move one detector line, and to use the previously found frame, j_s, as the center of the new search. The five CloudSat ground positions move along, exploiting the cross-reference i_m=f(i_c) established earlier. This cycle repeats up- and down-track, until all MODIS detector lines are exhausted.

While CloudSat ground positions are computed (predicted) from the TLE, the MODIS geolocations are taken from the standard geolocation product MYD03 where data gaps (missing or incomplete scan lines) are not uncommon. To prevent the algorithm to "lose the track" in these gaps, there are two conditions that must be met: $\mathbf{g}_m\mathbf{g}_c$<1 km, and the geolocations must not be fill values. In case either of these tests fail, the algorithm moves the sub-box to a new location, starts the search over, and repeats the cycle until condition $\mathbf{g}_m\mathbf{g}_c$<1 km is met, or all detector lines are exhausted.

Since MODIS/Aqua nadir and MLS retrieval footprints are sufficiently close (Fig. 5) along their tracks, this iterative procedure is not applied for the MODIS-MLS collocated subset. Rather, a simple MODIS center frame extraction is executed, and a ±100km across-track swath width is stored in the output subset. The accuracy of the assumption that MODIS/Aqua and MLS are collocated varies in time, Fig. 5, as the platforms are adjusted in their orbital control boxes [2]. If, for a given study, this accuracy is not sufficient, users can relatively easily perform refined collocation using the ATDD subset for input. This operation would be greatly facilitated by the already drastically reduced volume of the subsets available from ATDD.

IV. GIOVANNI TOOL FOR A-TRAIN DATA DISCOVERY

To meet the needs to visualize by simple means high resolution local scenes (swath) data along the A-Train tracks, and CloudSat in particular, ATDD employs the Giovanni tool [5]. The latter is a Web-based application developed at GES DISC, that provides a simple and intuitive way to visualize and access Earth science remote sensing data. Visualizations of vertical profiles, as well as horizontal swaths, of data collocated with CloudSat (and thus CALIPSO) are at the core of its goals for the purposes of ATDD. Giovanni adds to ATDD subsets the ability of on-the fly AIRS collocation with CloudSat, as well as interactive stitching and trimming of collocated OMI, AIRS, MODIS, CPR and CALIOP data to a common length, as requested by users from the web interface.

Since retrievals from various sounders are reported on different vertical grids, which is of inconvenience for fast inter-comparisons of relevant measurements, Giovanni tool offers optional vertical regridding too. E.g. CloudSat and CALIOP can be regrided on-the-fly to a pressure grid and thus compared with relevant retrievals from MODIS, AIRS, OMI, and MLS. For this purpose, Giovanni is using the National Centers for Environmental Prediction (NCEP) Global Data Assimilation group product (GDAS) [6]. It serves as ancillary data that provides standard reference mapping between atmospheric pressures and geopotential heights. Giovanni extracts grid cells from GDAS that are closest to CloudSat, and uses the extracted pressure/height mapping to place CPR and CALIOP altitude bins at the appropriate pressures. This procedure is very fast, and sufficiently accurate, to satisfy the needs of a web-based application.

Produced in just one run, Fig. 7 demonstrates Giovanni ability to easily bring multiple (but relevant) measurements from various A-Train instruments together in one plot for quick data discovery. Data from August 23, 2006, are used, when CloudSat flew directly over hurricane Ileana. Fig. 7 depicts vertical profiles from CPR and CALIOP, with line overplots representing collocated cloud pressure retrievals from MODIS, AIRS and OMI. In contrast to MODIS and AIRS, OMI effective cloud pressure retrievals do not correspond to geometrical cloud tops. CALIOP vertical feature mask, envisioned for cloud and aerosol classification, complements CPR information by revealing clouds and their tops where the radar return is below the noise level. CPR complements CALIOP by revealing the vertical structure of deep convective clouds where CALIOP experiences full attenuation (the black fill). MODIS cloud top pressures follow remarkably well the cloud tops as seen by the CPR. In addition to vertical structures, Giovanni offers further perspective into the A-Train environment by providing simultaneous views of underlying surfaces and atmospheric columns. The four strips at the bottom of Fig. 7 depict collocated swaths of cloud top pressures and temperatures from MODIS, total cloud liquid content from AIRS, and effective cloud pressure from OMI. The latter data have been screened from pixels that do not meet mandatory criteria for cloud fraction and quality.

Where appropriate, the top axis shows the UTC time, and it comes as a convenient validation check. Indeed, it can be seen from the begin time of the strip plots that OMI is trailing

MODIS by more than 16 minutes. It should be recalled, however, that the time lag between platforms, and thus their instruments, is not a constant because of the orbital adjustments, Fig. 5. Since MLS and OMI are attached to Aura, the variations of the MLS time lag actually reflect the variations of Aura and thus OMI lag as well, and thus the magnitude of the time lag variations between OMI and MODIS can be deduced to be on the order of one minute, Fig. 5.

Concluding this section, we would like to note that while quick visualizations may work for data discovery, users should be vigilant about data specifics. For example, unlike for MODIS and AIRS, cloud pressures from OMI should not be associated with geometrical cloud tops [7]. Also, OMI cloud retrievals in particular should be carefully screened with regard of cloud fraction and quality masks. In general, science retrievals from all instruments are accompanied by description of known problems and quality arrays which should be carefully observed and applied as recommended by algorithm developers. This would ensure that Giovanni is used reasonably within the appropriate limits, as a data preview and download stage an Route to scientifically sound conclusions.

V. SUMMARY

The A-Train mission opens a unique opportunity towards improving our understanding of wide range of atmospheric science issues, for instance physics of clouds, their vertical structure and interaction with their environment and aerosols in particular, and the role they play in the climate system [4]. The expected impact is encompassing, and not limited to, improved weather forecasting and climate prediction.

As no single instrument is the perfect tool to address all science goals, among the biggest challenges are the differences in the spatial definitions of various instruments and retrievals, their spatial and temporal collocation, as well as the various formats of data. The A-Train Data Depot efforts are focused on these issues and are aiming at shortening the bridge between data discovery and usage on one hand, and scientific analysis and conclusions on the other. This is evidenced by the following major ATDD achievements. MODIS/Aqua collocated subsets are operationally produced and made publicly available. They are searchable by temporal, spatial, as well as by events (like hurricanes and air pollution) constrains. Other subsets, like OMI/Aura and AIRS/Aqua are also available through operational production or on-the-fly processing in Giovanni. Apart from collocating and subsetting capabilities, the Giovanni tool provides simple vertical regridding and visualizations for quick data discovery and comparisons. Our future Giovanni goals encompass expanded selection of measurements, enhanced visualizations, addition of analytical functionalities like quality and class filtering, horizontal gridding to a uniform grid, and data merging.

APPENDIX A

Names of deployed A-Train satellites and their instruments, as of 2007.

Aqua
AIRS=*Atsmopsheric InfraRed Sounder*
AMSR-E=*Advanced Microwave Scanning Radiometer for the Earth Observing System*
CERES=*Clouds and the Earth's Radiant Energy System*
MODIS=*Moderate Resolution Imaging Spectroradiometer*

CloudSat
CPR=*Cloud Profiling Radar*

CALIPSO
CALIPSO=*Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation*
CALIOP=*Cloud Aerosol Lidar with Orthogonal Polarization*
IIR=*Imaging Infrared Radiometer*
WFC=*Wide Field Camera*

PARASOL
PARASOL=*Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from Lidar*
POLDER=*POLarization and Directionality of the Earth's Reflectances*

Aura
HRDLS=*High Resolution Dynamic Limb Sounder*
MLS=*Microwave Limb Sounder*
OMI=*Ozone Monitoring Instrument*
TES=*Tropospheric Emission Spectrometer*

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Andrey Savtchenko received his M.S. in physics from Sofia University, Sofia, Bulgaria, in 1981, M.S. in radar remote sensing from the Bulgarian Academy of Sciences, Sofia, Bulgaria, in 1983, and Ph.D. in applied ocean sciences from the University of Delaware, USA, in 1997.

He is currently Principal Support Scientist with RSIS, at NASA Goddard Space Flight Center, and is leading integration efforts related with the A-Train Data Depot. His current interests are in air-sea interactions, boundary layer turbulent exchanges, physics of clouds, and application of satellite data in advancing of the existing understanding of the processes in the atmospheric boundary layer.

Dr. Savtchenko is a member of AGU.
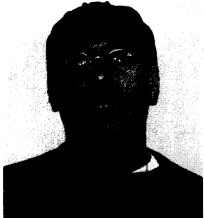
Robert Kummerer received his B.S. in astronomy from the Pennsylvania State University, State College, Pennsylvania, in 1980.

He is currently Senior Programmer/Analyst with ADNET Systems, Inc., at the NASA Goddard Space Flight Center, and is engaged in software development for the A-Train Data Depot. His current interests are in development and optimization of spatial collocation and subset algorithms for remotely sensed satellite data.

Arun Gopalan received his B.S. in mechanical engineering from the Victoria Jubilee Technical Institute, University of Bombay, India, in 1991, and his M.S. from SUNY, Stony Brook, NY in 1993.

He is currently a Research Scientist with SSAI Inc., at NASA Goddard Space Flight Center. His research interests include remote sensing data processing, retrieval algorithms, aerosol-cloud-climate feedback mechanisms, visualization of large atmospheric science data sets and data mining.
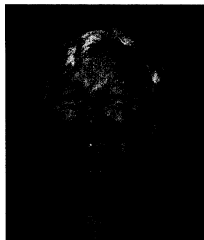
Peter Smith received his B. Sc. in chemistry and M. Sc. in spectroscopy from Manchester University, England in 1966, 1967 and his Ph. D. in physical chemistry from Georgetown University, Washington DC, USA in 1971.

He is currently a Computer Scientist with NASA Goddard Space Flight Center, where he is responsible for overseeing development of the ATrain Data Depot. His research interests encompass the management, graphical analysis and distribution of remotely sensed atmospheric data sets.

Steven Kempler received his B.A. in geography from SUNY, Cortland, in 1976, and his M.A. in physical geography (atmospheric science) from Ohio State University in 1979.

He is currently with NASA Goddard Space Flight Center, and is Manager of the Goddard Earth Sciences Data and Information Services Center (GES DISC), as well as PI of the A-Train Data Depot project at the GES DISC. His interests encompass the development of techniques, tools and protocols for enhancing the use and usefulness of science data, and the development of new markets for Earth observing remote sensing data.

Gregory Leptoukh received his M.S. in theoretical physics and Ph.D. in cosmic ray physics from Tbilisi State University, Tbilisi, Georgia (USSR), in 1975 and 1985, respectively.

He is currently with NASA Goddard Space Flight Center, and is Science Data Manager at the GES DISC. His current interests are in statistical aspects of multi-sensor data intercomparison, aerosol data fusion, and in design and development of web-based data access and manipulation tools.

Dr. Leptoukh is IEEE and AGU member.

TABLE 1
APPROXIMATE EARTH EQUATOR CROSSINGS RELATIVE TO AQUA NADIR, ON
ASCEND (ORIGINAL CONFIGURATION). "-"AND "+" INDICATE RESPECTIVELY
WEST AND EAST FROM AQUA NADIR.

Instrument	Arc-distance (deg)	Arc-distance (km)	Time lag (sec)
CloudSat	+2	222	50
CALIPSO	+2	222	62
PARASOL	-1	111	120
MLS/Aura	0	0	510
OMI/Aura	-1.7	189	960
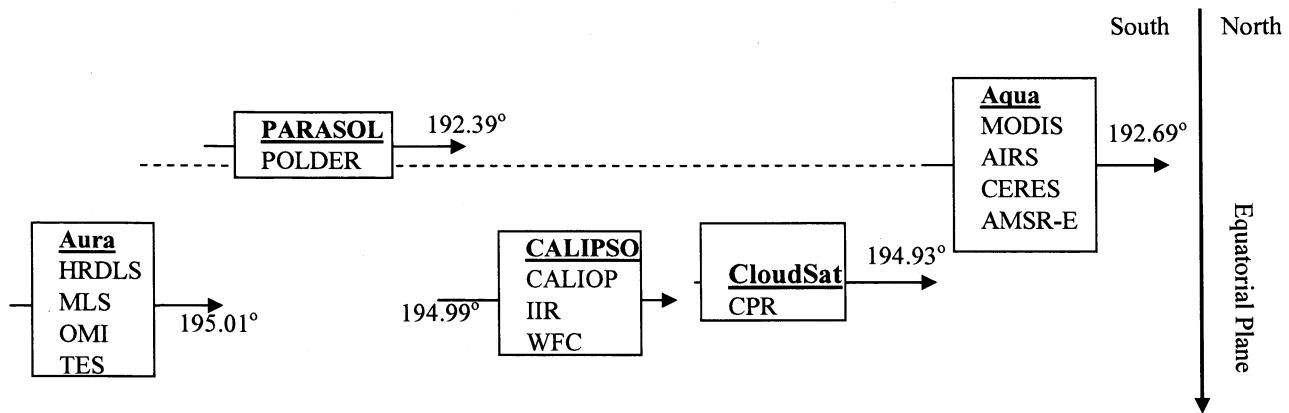
Fig. 1. Relative positions of orbital planes of A-Train **satellites** on ascend, for an observer making a snapshot from "above" and fixed to right ascension coordinate system. The names of instruments mounted on corresponding **satellites** are listed in the boxes (see Appendix A for names expansions). Numbers reflect the Right Ascension of Ascending Node of the satellites, in degrees, for **September 10, 2007**.
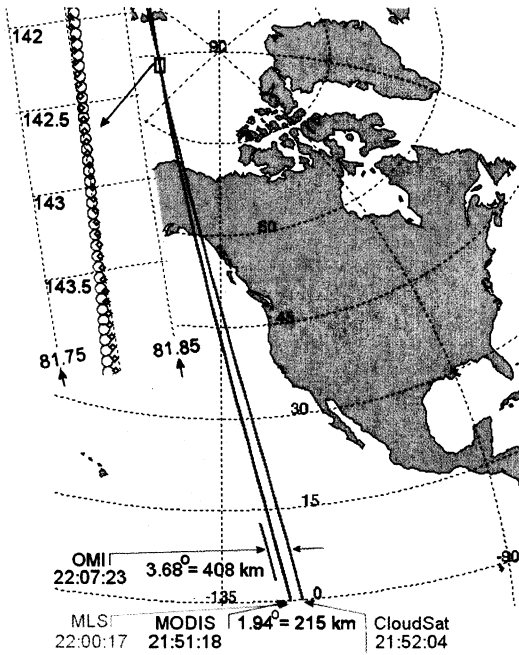
Fig. 2. Separation between CloudSat on one hand, and MODIS and OMI nadir, and MLS retrieval footprints on the other, on ascend. The times shown reflect the corresponding Equatorial crossings for these particular orbits. OMI nadir footprint ground track is 3.68° (408 km) west from CloudSat on ascend, and is shown as a portion only for clarity. See Table 1 for more details.
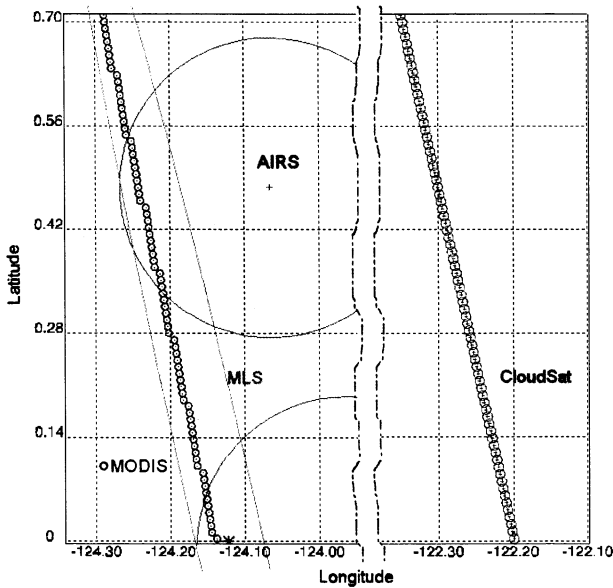

Fig. 3. Relative horizontal sizes of footprints of MLS, and of AIRS and 1-km MODIS final science retrievals at nadir. CloudSat track is depicted as a sequence of points corresponding to locations at every 1.1 km where final retrievals are reported, with circles representing the raw antenna footprint (effective radius on the surface 0.7 km). However, as a result of each aggregation that lasts 1.1 km, the resultant CPR retrieval footprint has a long axis (along-track) of 2.5 km, and a short axis (cross-track) of 1.4 km, thus resulting in overlaps of retrievals along-track.
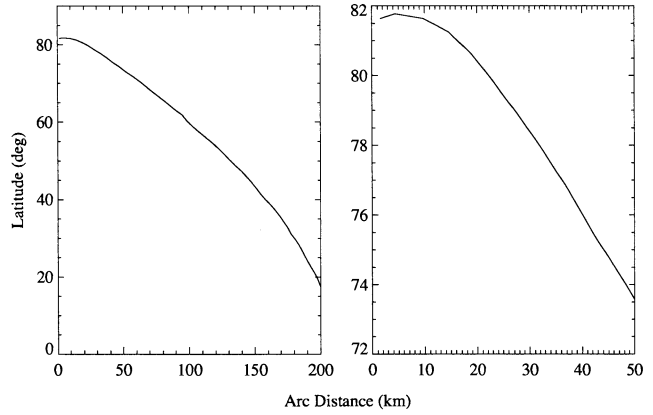

Fig. 4. The latitudinal dependence of the lateral separation between MLS and CloudSat in terms of arc distance between their tracks. Instantaneous, "snapshot", comparisons of smaller mesoscale atmospheric phenomena (10-30 km), as retrieved by both profilers, is apparently possible at high latitudes, in general beyond 78 deg.
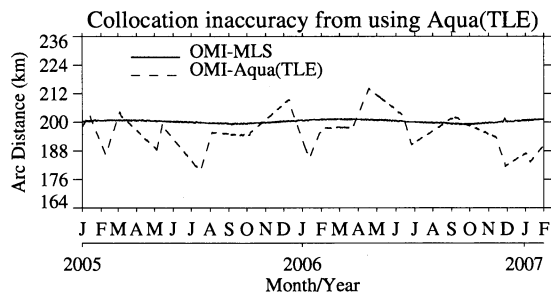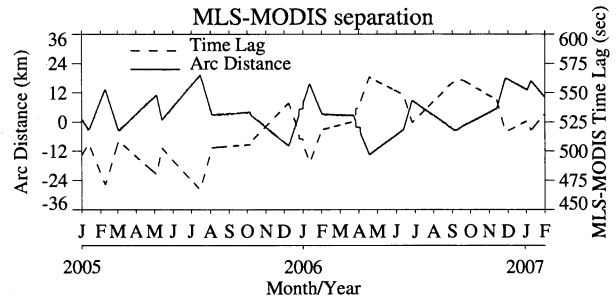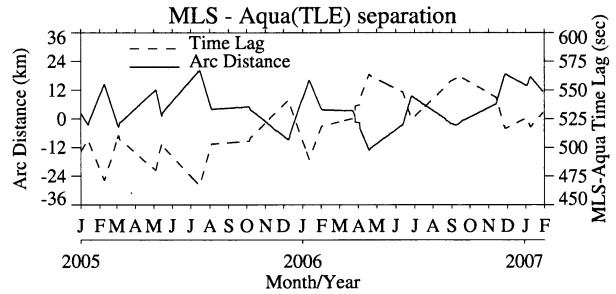

Fig. 5. Variations of the separation of the retrieved MLS and MODIS/Aqua nadir footprints at the Equator, for 2005-2007, in terms of arcdistance and time lag. Aqua Two-Lines Elements (TLE) are used to compute the Aqua subsatellite track in the top and bottom pannels. For comparison, the middle pannel shows the arcdistance and time lag computed from the geolocation data available in the products. Aqua TLE-computed track can be sufficiently good proxy for the MLS track.
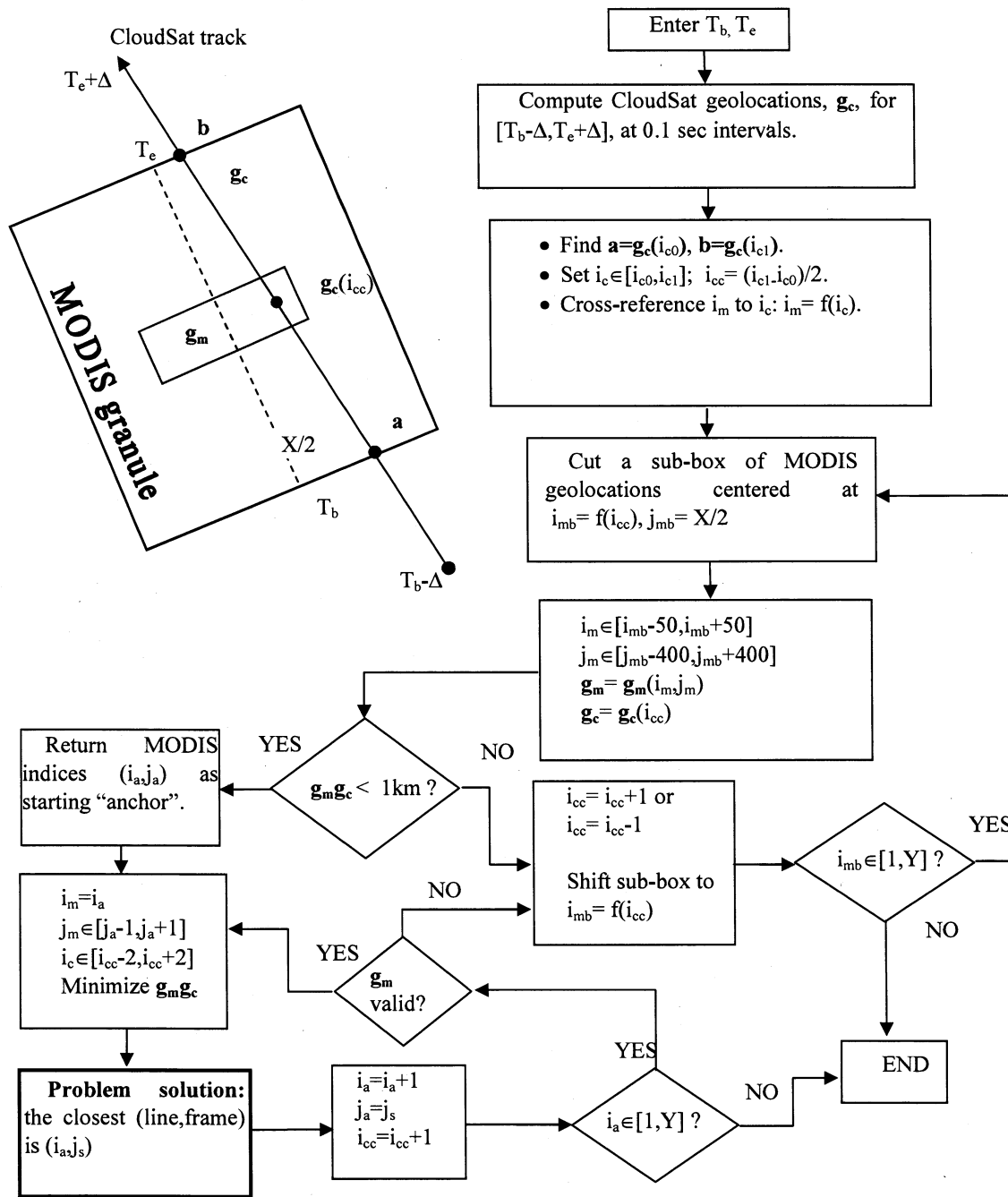
Fig. 6. Schematic layout of CloudSat track intersecting MODIS granule on ascend in the Northern hemisphere, and the collocation algorithm that extracts the MODIS pixels closest to the CloudSat track.

Fig. 7. Example plot output from Giovanni. Vertical profiles (curtains) from CALIOP and CPR can be combined with collocated and subset horizontal strips of cloud properties from MODIS, AIRS, and OMI. Other parameters, like cloud pressures, can be added as line overplots in the curtain plot. Shown is Hurricane Ileana, August 23, 2006.