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CO-LOCATION ALGORITHMS FOR SATELLITE OBSERVATIONS

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1. Introduction

Agreement for a 10-year implementation plan for a Global Earth Observation System of Systems, known as GEOSS, was reached by member countries of the Group on Earth Observations at the Third Observation Summit held in Brussels. The goal of GEOSS is to integrate and coordinate different observing systems to provide integrated observations that provide the best available observation. An important component of implementing the GEOSS is the development of scientific algorithms to integrate observations. The Office of Research and Applications of NESDIS is contributing to the GEOSS in many activities. These activities include the development of algorithms and tools to characterize and understand differences between different sensors and the development of algorithms and processing systems to integrate imager and sounder observations from multiple sensors. A product generation system is currently being developed to integrate multiple observations on AQUA, METOP and NPOESS to produce improved atmospheric temperature and water vapor soundings, cloud properties retrievals, and surface parameter characterization.

2. Background

In a system composed of multi-sensor and multi-platform satellites, a given point is observed by different sensors onboard either the same or different satellite platforms with different observation characteristics at different times. Integration data processing is to co-locate simultaneous observations or successive observations and assimilate those data with comparable spatial representation if needed. Quantitative integration of remote sensing data requires accurate co-location of the sensor observations.

Two existing papers describe co-location algorithms. Aoki (1980) computed a table for use in matching HIRS and AVHRR observations. This table works for HIRS and AVHRR co-location processing and the two sensors must be aboard on the same observation platform. Nagle (1998) proposed a general algorithm that can be used to co-locate the observation from two different sensors; the two sensors can be aboard the same or different vehicles. This algorithm has been used to co-locate the Moderate Resolution Imaging Spectrum radiometer (MODIS) and the Atmospheric Infrared Sounder (AIRS) observations. One key part of this algorithm is a time based searching algorithm in which the time satellite overpass the master observation is used to locate the possible collocation slaver observation. The master observation is the instrument onto whose footprints the slave views are to be overlain. The master field of view (MFOV) is simplified as a large dish with orientation along the vector slant range between the satellite and the center of the MFOV while the slaver sensor must be a cross-scanning instrument. The solid angle between the two vectors (from the master platform to the center of the MFOV and from the master platform to the slaver field of view (SFOV)) is used to make the collocated data selection and weighting function computation.

The observed radiance of the remote sensing instrument is contributed by all the points within the effective field of view (EFOV) of the sensor. The weight of the individual point of the observation is the convolution product of the spatial response function (SRF) of instantaneous field of view (IFOV) and the integration time. The shape of the EFOV is defined by the IFOV shape and the scan pattern. This shape will be bias from circle (more like an ellipse) for most cases, especially for cross-scanning instruments at large scan angles. The solid angle between the MFOV pointing vector and the SFOV pointing vector does not provide enough information to make the correct collocated slaver observation selection and weighting function computation for a non-spherical MFOV.

Basing on Nagle's co-location algorithms, an adjusted scheme is proposed. In the adjusted algorithm, the time based searching algorithm is revised to speed up the co-locations. EFOV's SRF is introduced to address the problems that are introduced by the no spherical master EFOV. The algorithm has also been expanded to include co-locations between instruments that do not cross scan.

3. Methods

In Nagle's algorithms, master and salver are used to represent two sensors to be co-located. Master is the instrument onto whose footprints the slave views are to be overlaid. Generally, a master is chosen with a large spot size while the slaver is cross-scanning sensor. The collocation algorithm can be divided into three steps:

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The first step finds the time at which a slaver satellite platform is directly abeam of a given point (MFOV) on the ground. In the case of a cross-scanning instrument, the moment, at which the point is abeam can be determined by equation 1.0.

$$S(t) \times G(t) * O(t) = 0 \qquad (1.0)$$

In which S(t) is the slaver satellite position vector at time t, G(t) is the given MFOV position vector at time t, and O(t) is slave satellite platform orbit plane vector. This time is also assumed as the observation time of the MFOV center by slaver instrument (t_{mc}).

In the second step, the slaver observation is co-located to the master observation. Given the knowledge of the slaver instrument observation time sequence, the slaver point that is closest to the center of the master spot can be found with the MFOV center observation time(t_{mc}). An outward search is used from this nearest slaver point to find other collocated slaver points. The angle between the vector from the satellite to center of the collocated SFOV and the vector from the satellite to the center of the MFOV should be less than a set selection criteria.

The third step is to determine the weight of the slaver observation in regards to the MFOV. The angle between the vector from the satellite to center of the collocated SFOV and the vector from the satellite to the center of the MFOV are used to evaluate the weight of slaver observation to master observation.

Basing on above algorithms, an adjusted three step scheme is proposed. It is applied in the celestial frame of reference (CFR) and it keeps the same definition for master and slaver where the slaver can be cross-scanning or conical-scanning instrument.

This time based nearest observation searching algorithms is designed for cross-scanning slaver instruments. The algorithm is based on the two assumptions: 1:) A slaver sensor is abeam of a ground point when the crossing product of the satellite position vector with the ground vector has no component along the orbit plane that can be obtained from the satellite data 2:) slaver view vector points to the nearest SFOV at the abeam time. Generally, the abeam time is decided by orbit characteristic and given point location. At abeam time, the slaver view vector is decided by instrument scan time sequence pattern and can point to any direction within the slaver cross-scaning plane, not necessarily limited to the nearest SFOV direction. As in figure 1.0, the time t_G is given by the solution of equation 1.0. Even If t_G is within the earth observation period (t1< t_G <t2), the slaver sensor may still be possible to pointing in a different direction. In this case, the point determined with t_G will lead to unnecessary calculations for the rest of the points co-located to the MFOV.

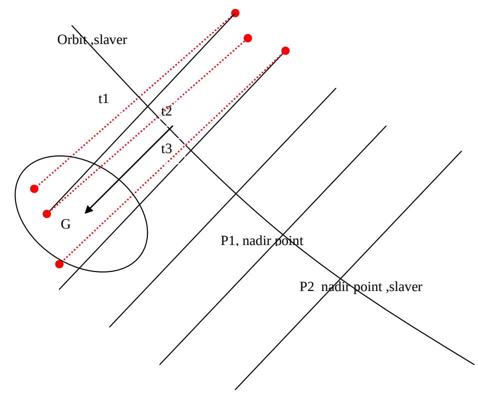

Figure 1.0 Cross-Scanning Observation

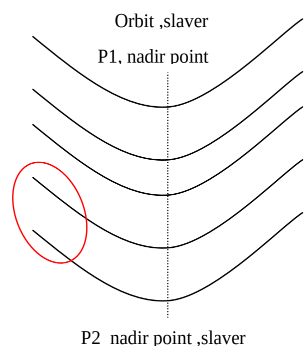

Figure 2.0 Conical-Scanning Observation

To avoid the problem motioned above, the nearest SFOV point searching algorithm has been adjusted and two separate schemes were developed to process both cross-scanning slaver instruments and conical-scanning slaver instruments. Operationally, the nearest SFOV position can be defined by the scan line index in the data set and the footprint index within the scan line. The slaver instrument observation time sequence is not used . For the cross-scanning instrument, the nadir observation time of each slaver scan line is processed to find the scan line with the nadir observation time t_{nadir_i} at which the minimum $P(t_{nadir})$ is determined:

$$P(t_{nadir}) = (S(t_{nadir}) \times G(t_{nadir}))^\wedge * O(t_{nadir})^\wedge \qquad (2)$$

where $S(t_{nadir})$ is the slaver satellite position vector at the time when the slaver sensor points at the nadir position, $G(t_{nadir})$ is the MFOV position vector at the same time, $O(t_{nadir})$ is slaver satellite orbit plane vector determined from the geolocation data of the slaver satellite nadir points,^ is the unit vector operator and $P(t_{nadir})$ represent the cosine of the angle between orbit plane vector and the plane defined by $S(t_{nadir})$ and $G(t_{nadir})$. This scan line include the SFOV whose position center is nearest to the MFOV position center along the orbit direction.

For conical-scanning slaver, the observation times of the middle point in slaver scan lines are processed to find the scan line which include the nearest SFOV observation with:

$$P(t_{mid}) = (S(t_{mid}) - G(t_{mid}))\hat{} * S(t_{mid})\hat{} - \cos(\Phi) \quad (3)$$

where t_{mid} is the time of the middle earth observation in each scan line, Φ is the nadir angle determined by the conical-scanning instrument , $S(t_{mid})$ is slaver satellite position vector, $G(t_{mid})$ is the MFOV position vector at the same time, the point product of $(S(t_{mid}) - G(t_{mid}))$ and $S(t_{mid})$ is the cosine of the nadir angle of the MFOV from the slaver satellite at $t_{mid.}$ The scan line with minimum $P(t_{mid})$ include the nearest SFOV observation.

For both cross-scanning and conical scanning slaver instruments, the footprint index of can be calculated from the scan angle. The scan angle for a cross scanning instrument is given by:

$$\mathrm{Cos}(\theta(t_{obs})) = (S(t_{obs}) - G(t_{obs}))\hat{} * S(t_{obs})\hat{} \quad (4)$$

where $S(t_{obs})$ is satellite position vector at time t_{obs}, $G(t_{obs})$ is the position vector of MFOV, and t_{obs} is given by the solution of equation 1, The point product of $S(t_{obs})$ - $G(t_{obs})$ and $S(t_{obs})$ is the cosine of the view angle at abeam time.

For a conical-scanning slaver instrument, the scan angle is given by:

$$\cos(\theta(t_{obs})) = (S(t_{obs}) \times G_{MFOV}(t_{obs}))\hat{} * (S(t_{obs}) \times G_{MID}(t_{obs}))\hat{} \quad 5.0$$

where $S(t_{obs})$ is satellite position vector at time t_{obs}, $G_{MFOV}(t_{obs})$ is the position vector of MFOV, the cross product $S(t_{obs}) \times G_{MFOV}(t_{obs})$ is the normal vector of plane defined by $S(t_{obs})$ and $G_{MFOV}(t_{obs})$. $G_{MID}(t_{obs})$ is the position vector of the middle observation in the scan line, the cross product $S(t_{obs}) \times G_{MID}(t_{obs})$ is the normal vector of plane defined by $S(t_{obs})$ and $G_{MID}(t_{obs})$, t_{obs} is middle observation time defined by the equation 3.0. The point product, $\theta(t_{obs})$ is the cosine of angle between two planes normal vector. The footprint index can be calculated with $\theta(t_{obs})$.

Collocation Algorithms

In collocating slaver observations to the master observation, the integrated master observation weight over the SFOV (IMWSFOV) area is adopted in selecting the collocated slaver observation. The IMWSFOV can be obtained from integration of the master spatial response function (SRF) over the SFOV. The master observation SRF is expressed on an earth surface coordinate where the reference point is at the master observation center (x is the radian angle relative to earth center along the scan direction and y is the radian angle relative to earth center along orbit direction). The observed radiance of remote sensing instrument is contributed by all points within the effective field of view (EFOV). The EFOV is the effective area swept by the sensor observation beam during the observation integration time. The IMWSFOV can be used to quantitatively describe the close relationship of the two observations and therefore quantitatively evaluate the 'distance' of these two observations. If IMWSFOV equals zero, that means that the slaver observed area contribute nothing to the master observation. If the master and slaver observation have the same EFOV size and width, IMWSFOV equals to 1 and the slaver observation observed the exact same target as master observation.

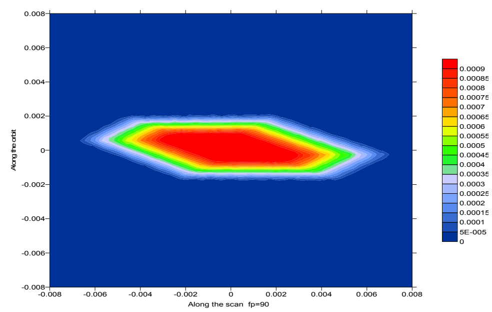

Figure 3.0 AIRS SRF: Footprint 1

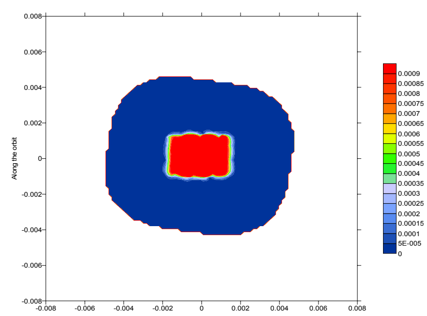

Figure 4.0 AIRS SRF: Footprint 45

For cross-scanning instruments with a circle observation bore-sight and continuously scanning mode, the sensor's EFOV is a perfect circle only when it is lies directly beneath the satellite or platform. For large nadir angles, the sensor's EFOV approximates an ellipse and for very large nadir angles, the view is an egg-shaped spot (due to the movement of the IFOV during the observation integration time and the curving earth surface effect). The SRF of the EFOV is directly affected by the shape of the observation EFOV and is a function of the observation scan angle. Figure 3 is the AIRS EFOV SRF for footprint 1 (at the edge of each scan line) and Figure 4 is for footprint 45 (close the nadir point). For conical scanning instruments, the SRF of an EFOV stays the same for different footprints.

Comparing with the collocation algorithms that use the angle between the view vector from the satellite to the MFOV and view vector from the satellite to the SFOV, the algorithm using IWMSFOV will have a better selection for collocated slaver observations when the master SRF of the EFOV is not spherical, which is generally the case. As in Figure 5.0, the collocation selection base on the view vector angle difference will miss the slaver observation 2 and wrongly choose observation 1.

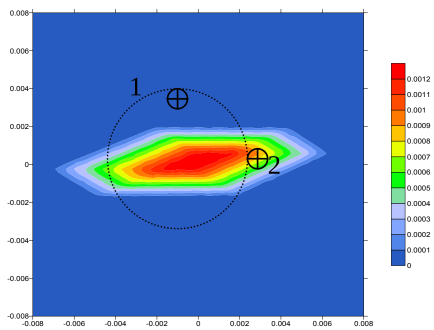

Figure 5.0 Co-location Selection

The EFOV SRF for the master observation has to be calculated before it can be used in the co-location algorithm. It is an integrated IFOV SRF over observed time. The EFOV SRF is a function of the scan angle and latitude if oblate earth is assumed for a cross-scanning instrument. If spherical earth used, latitude has no effect and the EFOV SRF set for different scan positions within one scan line can be calculated and used for other scan lines. For conical scanning instrument, only one EFOV SRF needs to be calculated. The collocation algorithms is applied in CFR, the surface coordinate system of MFOV SRF rotate with the scan direction in CFR, The scan direction can be determined with neighboring footprint geolocation information. Figure 6.0 give an AIRS scan line geolocation pattern and Figure 7.0 is the SRF of the first footprint in two different scan lines, which with two different orient angle in CFR.

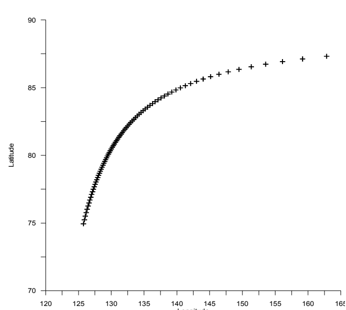

Figure 6.0 AIRS Scan Line

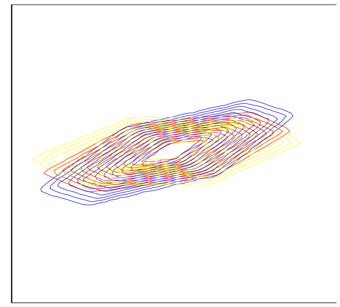

Figure 7.0 AIRS SFR in CFR

The IWMSFOV criteria using to determine whether the slaver observation is co-located with the master observation can be set according to the characteristic of the SLOV and the purpose of the co-location processing.

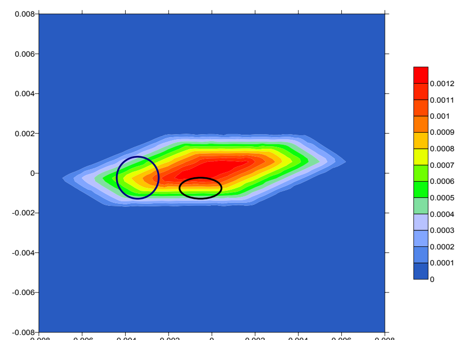

Figure 8.0 IMWSFOV

The master observation SRF gives the high spatial resolution weight distribution within the footprint. The IMWSFOV is the integration of master SRF over the SFOV, as shown in Figure 8.0. A mathematical description of the slaver EFOV is necessary for accurate IMWSFOV calculations. Generally, the slaver chosen has a much smaller FOV size compared with master observation. IWMSFOV can be calculated using the area of the SFOV and the master observation weight at the center point of the SFOV. In the application where the high spatial resolution slaver observation is co-located to the low spatial resolution master observation, the weight of each collocated SFOV can be calculated by integrating all the grid weights within SFOV. Hence, normalization with all the co-located SFOV will give the weight for each of the SFOV that will be used in the MFOV.

5.0 Summary

A remote sensing data co-location scheme is proposed in this paper. This scheme is developed basing on the Nagle's collocation algorithm and can be used to collocate the observation from two different sensors (either aboard the same or different vehicles) where the slaver sensor can be cross scanning instrument or conical scanning instrument. In this scheme, the algorithm that finds the closest slaver observation is a revised and expanded version of Nagle's algorithm. The revised algorithms can avoid the bias registration of closest slaver observation and can be applied to master-slaver collocation problem when conical scanning is the slaver instrument. The master observation spatial response function is introduced in the collocation algorithm where the SRF is applied to the collocated slaver observation selection and a quantitative relationship between the master observation and the slaver observation is obtained. The application of the SRF in collocation algorithms will avoid the problem when a non spherical EFOV master observation is concerned.

6. REFERENCES

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