A UNIFORM SPACE-TIME GRID FOR THE INTER-COMPARISON OF GLOBAL CLOUD TOP PRESSURE RETRIEVALS

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1. INTRODUCTION

While global cloud products are currently produced routinely from a number of satellite sensors and associated teams, trend and pattern analyses of cloud parameter products are hindered by the availability of cloud parameter data in a standard format. Instrument-specific characteristics such as equatorial crossing time, swath width, footprint size, and repeat cycle create problems for inter-comparison of data from different years, instruments and retrieval algorithms. Efforts are often limited to data from single instruments or groups of instruments with similar characteristics. One solution is to grid data from their non-uniform instrument domain to a uniform space-time domain. Many gridded data products exist but even then a lack of universal standards impede comparative research.

The goal of this work is to introduce a dynamic approach to gridding. Rather than relying on static gridded products, data are gridded as research needs arise. An algorithm is introduced with which to grid cloud parameter data from any instrument to a uniform space-time grid that is tailored to research-specific requirements for grid size, choice of cloud parameter, statistical representation and definition of time.

2. METHODS

The space-time gridding algorithm has two phases. First, data are physically resampled into nearest neighbor clusters during the *space gridding* phase. This follows a snap-to-grid routine in which the cloud parameter data are indexed into equal-angle latitude-longitude grid cells. Geophysical data filtering can be performed at this stage according to parameter-specific thresholds (e.g., cloud height), time of day or viewing angle. The only data stored per grid cell are the parameter values together with a scalar index for total number of observations. Most importantly, the gridded neighborhoods of data allow statistical data exploration that ultimately informs the second phase, namely *time gridding*.

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Statistical resampling is performed to reduce each neighborhood of data into a single value per grid cell. The result is a daily uniform space-time grid that can be aggregated into longer time frames, e.g., weekly or monthly grids.

The space-time gridding algorithm is demonstrated here for a month (1–31 August 2009) of Level 2 Terra/MODIS (Moderate Resolution Imaging Spectroradiometer) cloud top pressure (CTP) retrievals (MYD06, collection 5, King et al. 2003; Platnick et al. 2003; Menzel et al. 2008; available online: ladsweb.nascom.nasa.gov). Analysis is limited to daytime (solar zenith angle $< 84°$) high altitude cloud CTP retrievals (hCTP < 440 hPa) retrieved from near-nadir measurements (instrument viewing angle $< 32°$).

Data are gridded to a $1° \times 1°$ grid using a weighted average statistic that is calculated as follows:

$$\mathrm{CTP}_m = \frac{\sum_{days}\left(\% \times \mathrm{CTP}_d\right)}{\sum_{days}(\%)} = \frac{\sum_{days}\left(\frac{\mathrm{obs}_C}{\mathrm{obs}_T} \times \mathrm{CTP}_d\right)}{\sum_{days}\left(\frac{\mathrm{obs}_C}{\mathrm{obs}_T}\right)} \quad , \quad (1)$$

where CTP_m is the time average of weighted daily averages, CTP_d, obs_T the total number of instrument observations per grid cell per day, obs_C the number of hCTP retrievals per grid cell per day. Note that Eq. 1 is used in this paper as an example only. It can be replaced by any descriptive statistic relevant to the cloud parameter at hand.

To reduce statistical misrepresentation of data (and possible error propagation), obs_T is evaluated and the cell content is discarded if obs_T falls below a certain threshold. The following threshold was adopted:

$$\mathrm{obs}_T \geq \overline{m} - 1.5\sigma \quad , \quad (2)$$

where $\overline{m}$ is the average number of obs_T given all grid cells in the study region and σ is the standard deviation of obs_T. Eq. 2 can be rephrased; each grid cell must contain at least 93% of the average obs_T in the study region to be considered for phase two of the algorithm. This filters out those grid cells that fall on the edge of a swath and contain too few observations for robust statistical expression.

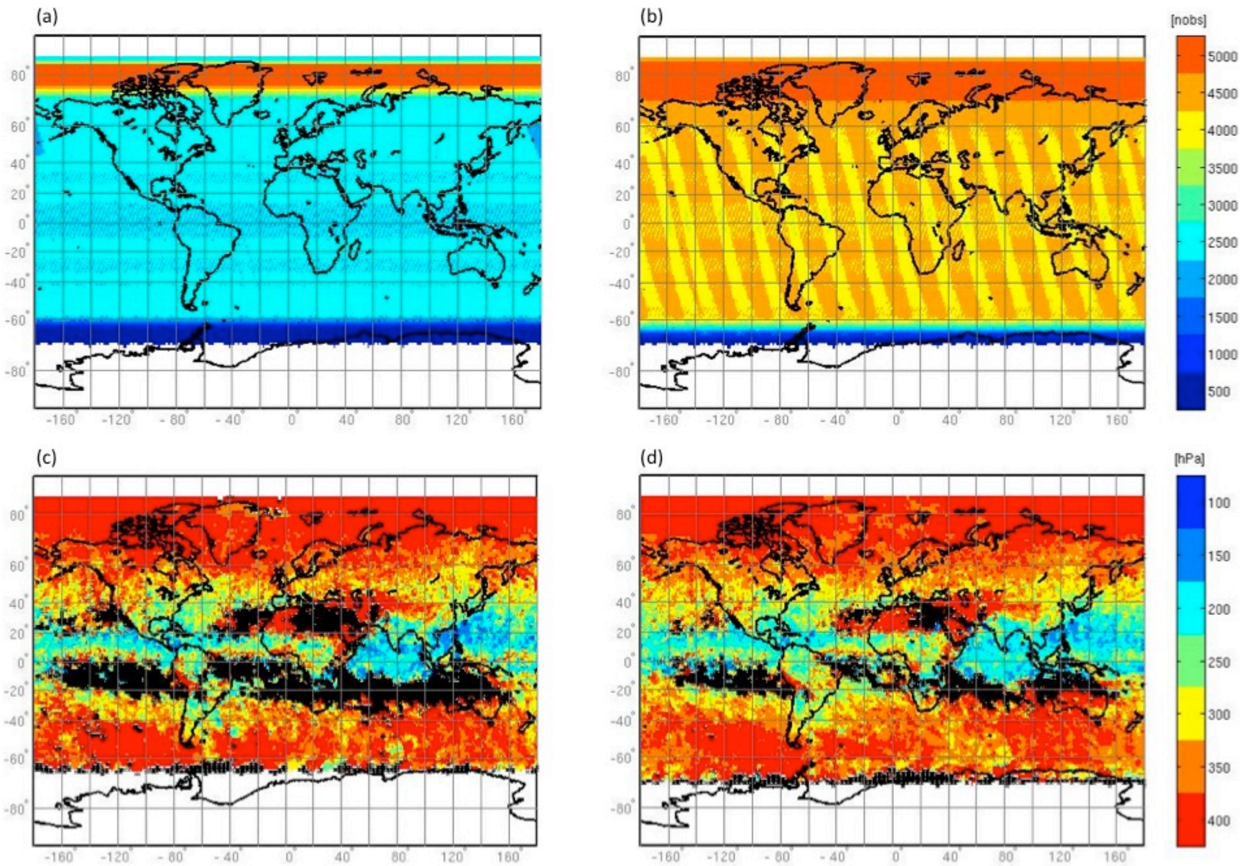

Fig. 1. Space-time algorithm sensitivity to time considerations. Results are shown for 5 km MODIS cloud top pressure (CTP < 440 hPa) retrievals (MOD06, coll.5). [Top] Total number of observations on a $1^{\circ} \times 1^{\circ}$ grid for (a) 1–16 August 2009 and (b) 1–31 August 2009. [Bottom] High CTP average (Eq. 1) for (a) 1–16 August 2009, (b) 1–31 August 2009. White spaces indicate data absence and black spaces indicate absence of high clouds.

3. RESULTS AND DISCUSSION

Polar-orbiting instruments sample roughly 70% of the globe per day. MODIS has a repeat cycle of 16 days. A comparison of the total number of observations per grid cell for an aggregate of 16 and 31 days (number of days in August) highlights the problem (Figs. 1a–1b); i.e., the definition of a typical month is a couple of days short from being an even latitudinal/longitudinal sample. This raised the question as to how the uneven sampling frequency affects monthly statistics. A CTP_m calculation for 1–16 August 2009 versus 1–31 August shows that the method of calculating time statistics from daily statistics is quite robust (Figs. 1c–1d). The pattern of monthly cloud features is not a result of infrequent orbital sampling, but the result of statistics on individual days. High clouds may not be present at a specific location every day of the month, which means that a monthly statistic is calculated from a few daily statistics only, i.e., $ndays < 31$. It remains to be determined how sensitive the time average is to the magnitude of *ndays*.

Apart from time, gridding is also sensitive to space considerations. First, a comparison is made of CTP_m (Eq. 1) for retrievals from near nadir (viewing angle < 32º) and all observations (Figs. 2a–2b). These results indicate that CTP_m is very sensitive to viewing angle filtering such that a CTP_m with no filtering has a higher spatial correlation. A near-nadir filter is typically applied to cloud fraction retrievals with error that increases exponentially with viewing angle. These results indicate the importance of careful decision making in gridding; each parameter should be individually assessed, a general set of filters cannot be applied in an ad hoc fashion.

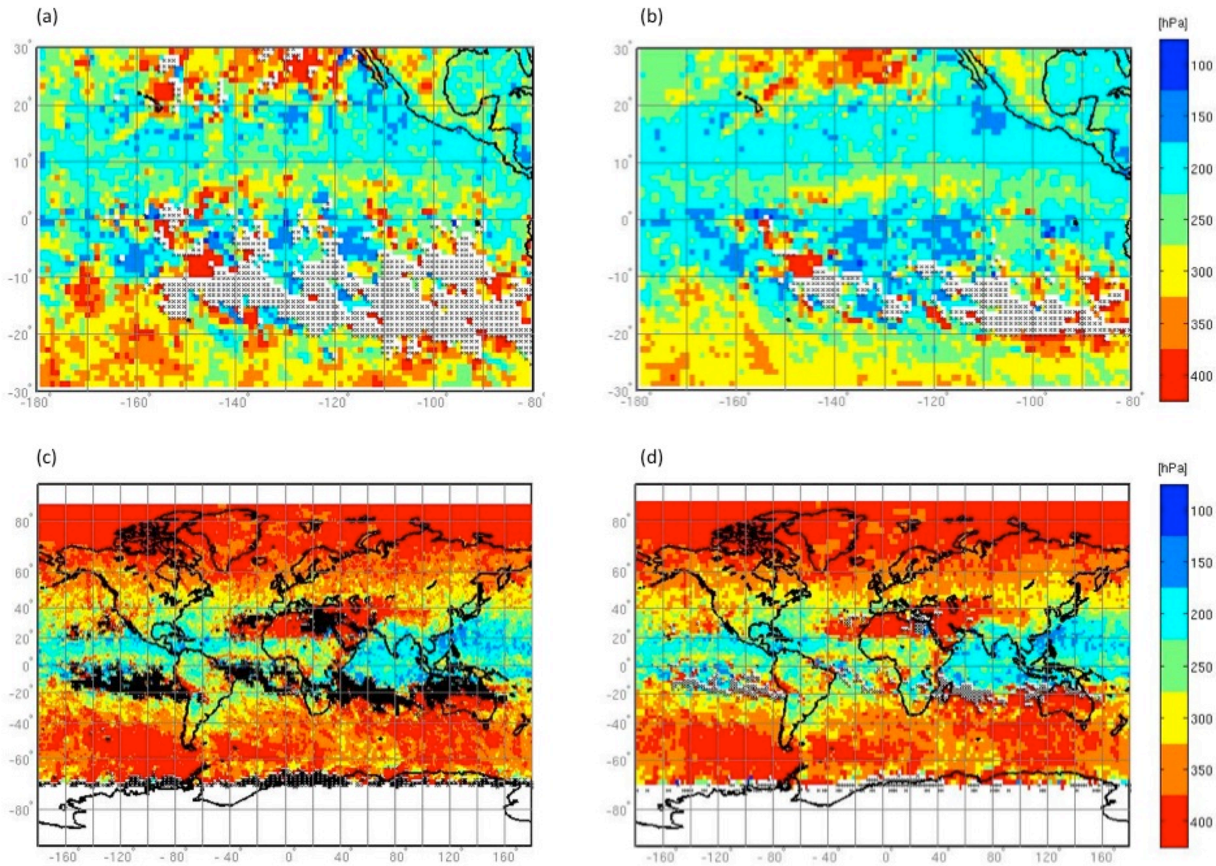

FIG. 2. Space-time algorithm sensitivity to space considerations. Results are shown for a monthly average (1–31 August 2009) of 5 km MODIS high cloud top pressure (hCTP < 440 hPa) retrievals (MOD06, coll.5, Eq. 1). [Top] hCTP average (Eq. 1) for retrievals from (a) near-nadir observations (viewing angle < 32°) and (b) all observations. [Bottom] hCTP average (Eq. 1) on a (c) 1° × 1° grid, and (d) 2° × 2° grid. White spaces indicate data absence and black spaces indicate absence of high clouds.

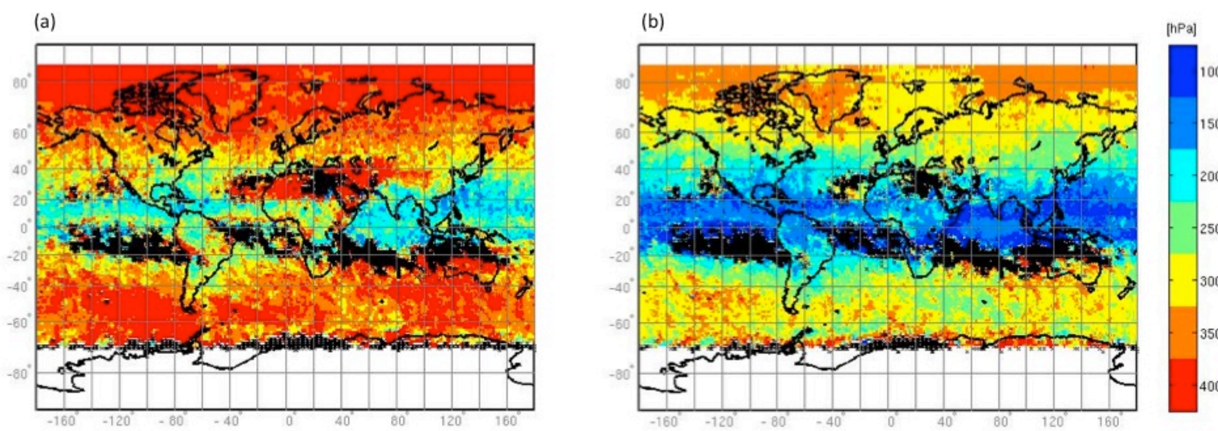

FIG. 3. Space-time algorithm inter-comparisons. Results are shown for a monthly average (1–31 August 2009) of high cloud top pressure (hCTP < 440 hPa) retrievals from two different polar-orbiting instruments, the (a) Moderate resolution imaging spectroradiometer (MODIS, MOD06, coll.5), and (b) Atmospheric infrared sounder (AIRS, Level 2 operational product). White spaces indicate data absence and black spaces indicate absence of high clouds.

Second, the sensitivity to grid size is tested (Figs. 2c–2d). Dependence on grid size may vary with resolution of source instrument but for the MODIS CTP retrieval product the difference in CTP_m between a 1° and 2° grid is minimal. Apart from a degree of smoothing, cloud features are preserved at the coarser resolution.

Finally, the usefulness of the gridding algorithm for multi-instrument comparisons is demonstrated (Fig. 3). Near-nadir daytime retrievals from a polar-orbiting imager, MODIS, and sounder, AIRS (Atmospheric Infrared Sounder), are compared on a $1° \times 1°$ grid. The operational Level 2 retrieval product from AIRS was employed (Susskind et al. 2003, available online at daac.gsfc.nasa.gov).

The number of observations per grid cell varies per instrument as the spatial resolution and swath width changes. For example, the 5 km MODIS cloud product (MYD06) has approximately 500 observations per 1° grid cell, whereas the 45 km AIRS product averages 55. The value of Eq. 2 becomes all the more meaningful in these circumstances, since a statistically robust gridded product can be derived irrespective of sampling size. With the data projected onto the same space-time grid, differences in instrument capability and retrieval algorithms are highlighted. Note that no statement is made about the accuracy of these products.

4. CONCLUSION

Gridding is a method for data standardization and reduction. It promotes the accessibility and inter-comparison of data records, both of which are important in environmental and climate research. As presented in this paper, the implementation of a gridding algorithm instead of static gridded product generation, has distinct advantages; gridded products are (i) tailored to research requirements; (ii) generated on the fly as research needs arise, thus eliminating the need for long-term storage, (iii) comparable, irrespective of source instrument, and (iv) generated in a fast and transparent manner for both research and operational use.

Future work will focus on gridded inter-comparisons of cloud products, the production of multi-instrument blended products, and studying the characteristics of different cloud properties and their correlation with each other over space and time.

5. REFERENCES

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