Appendix 3 Data Day Definition

A3.1 Introduction

The basic products generated by both the AVHRR Pathfinder and the SeaWiFS projects are global daily fields of geophysical quantities such as sea surface temperature and chlorophyll concentration. This definition is proposed for use with global fields generated from MODIS products. The daily fields will be the basis of subsequent temporal compositing into weekly and monthly products. One basic question, however, is: what constitutes “a day’s worth” of data? This is the question we address in this document.

The need for a consistent definition of a data-day is only really relevant for the production or analysis of *global* data fields. If one is dealing with a limited area (although, in this case, “limited” means anything less than global, and can encompass entire ocean basins), one takes advantage of the fact that the satellite sensors usually sample a region at *approximately* the same time(s) every day. In this way, data separated by approximately 24-hour periods can be assigned to different data-days (a further separation into daytime and nighttime fields can be made with the AVHRR). Analyses of the resulting daily data fields will introduce a minimal amount of temporal aliasing, as the difference in sampling times is of the order of a couple of hours over an approximate repeat cycle of a few days.

In contrast, when daily global satellite data fields are to be constructed, a consistent definition of a data-day needs to be adopted. This definition should be easy to implement in practice and should minimize temporal aliasing and discontinuities in the resulting products. In the following paragraphs we explore some of the alternatives.

A3.2 A 24-hour data day

The most obvious definition of a data-day is a 24-hour period. For instance, a daily field would encompass all the data collected between 00:00:00 UTC (or any other arbitrary start of the day) and 23:59:59 UTC. This definition is simple, intuitive, and extremely easy to implement. Its negative aspects, however, become apparent when one considers the orbital characteristics of the spacecraft on which the sensors of interest are, or will be, flown.

To illustrate the problem, we present a plot of nadir tracks for the NOAA-11 spacecraft (Figure A3-1). To simplify the visualization we only display descending tracks (i.e., the spacecraft is flying from north to south). The NOAA descending tracks correspond to nighttime data, although, in the case of SeaWiFS, the descending tracks will correspond to the daytime data (the only data archived for this sensor, other than special calibration measurements).

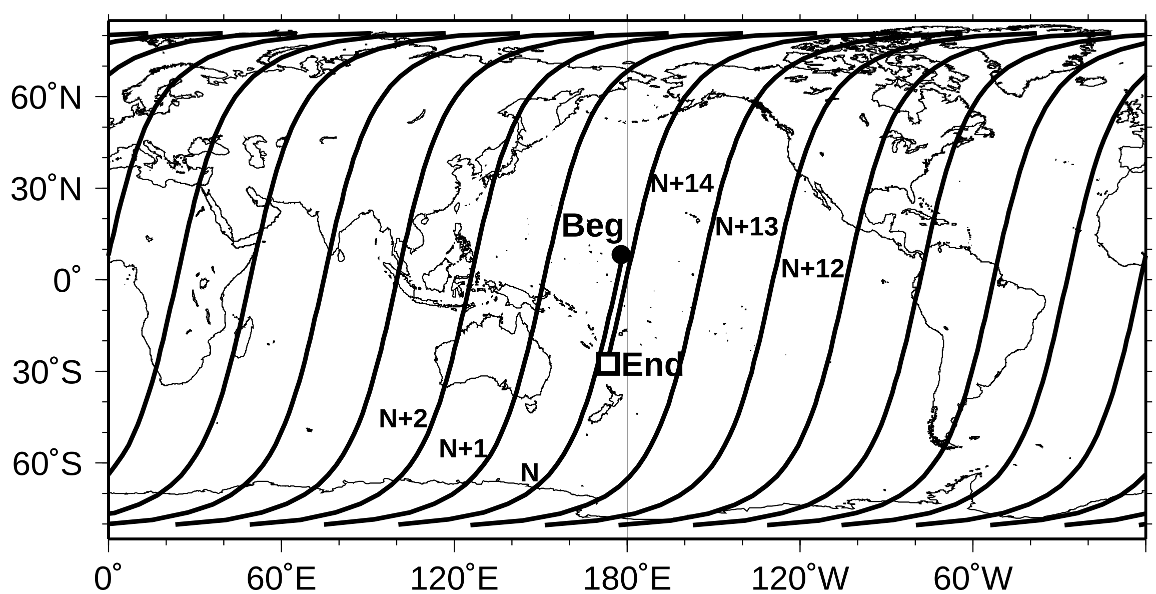

Figure A3-1. Descending NOAA-11 tracks for a 24-hour data-day beginning on July 26 1992 15:22:00 UTC. The data-day begins at the point labeled “Beg” and ends at the square labeled “End”. The first orbit after the beginning of the data-day is labeled “N”, and subsequent orbits are “N+1”…“N+14”.

For comparison with subsequent cases, we choose to begin the 24-hour data-day on July 26, 1992 at 15:22:00 UTC, when the nadir track intersects the 180° meridian (Marked

“Beg” on Figure A3-1). The descending orbit immediately after the beginning of the data-day is labeled N. Subsequent descending tracks pass to the west, and are offset by a distance of about 25 degrees of longitude at the Equator. The swaths viewed by the AVHRR in consecutive orbits have an increasingly larger overlap with latitude. This means that areas at intermediate and high latitudes may be sampled twice or more during a data-day (ignoring, for the time being, the ascending orbits). When an area is sampled in two consecutive descending orbits, measurements will be separated by about an hour and a half. Unless one is concerned with features with very small scales, it is probably safe to assume that the ocean fields will not change significantly between consecutive passes, thus temporal aliasing should be negligible.

The NOAA polar platforms that carry the AVHRR have an orbital period of approximately 102 minutes. The actual period depends on the spacecraft altitude, and, therefore, will be slightly different for each NOAA spacecraft. The orbital period may also vary with time, as the altitude of a satellite changes. Given an orbital period of about 102 minutes, the number of revolutions that the NOAA spacecraft will complete in a 24-hour period is approximately 14.12. The last descending orbit of the 24-hour data day is labeled N+14. It is apparent from Figure A3-1 that there is along-track overlap between descending tracks N and N+14. The areas in which there is overlap will have been sampled twice (ignoring the smaller overlap between consecutive orbits) in a data-day, and the output will be the average of measurements taken almost 24 hours apart. The 24-hour definition of a data-day, therefore, may result in temporal aliasing in areas near the beginning and end of the 24-hour period, due to the inclusion in a given day of overlapping orbit tracks sampled almost 24 hours apart.

A second problem of the temporal definition of a data-day is the existence of areas on the global fields with large temporal discontinuities in sampling times, even though they may be spatially contiguous. For instance, in Figure A3-1, one can see descending track N+14, the last track of the data-day. To the north of that track (i.e., over the Arctic Ocean north of Alaska), data are contributed by track N+1 and, possibly, N+2. These two tracks, however, were sampled near the beginning of the data-day, more than 20 hours before track N+14. The daily fields, then, will contain large temporal discontinuities along the boundaries between data swaths from tracks N+14 and N+1. If there is overlap between the two swaths, data collected far apart in time may be averaged, once again introducing potential aliasing. Similar problems occur in the area south of track N (south of New Zealand), which is sampled by tracks N+13 and N+12 much later in the day.

The aliasing and temporal discontinuity effects are further complicated by the fact that the locations where they occur change in time. Figure A3-2 shows the locations along the nadir tracks of the boundaries between 24-hour data-days for a 10-day period beginning on July 26, 1992 (for the NOAA-11 spacecraft). The dot labeled “1” corresponds to the beginning of the cycle on July 26, 1992 at 15:22:00 UTC. The dot labeled “2” indicates the beginning of the second 24-hour data-day, and so forth. The shift in the location of the daily boundaries is a direct result of the difference between the 24-hour data-day and the shorter time it takes the spacecraft to complete a number of revolutions that would ensure global coverage.

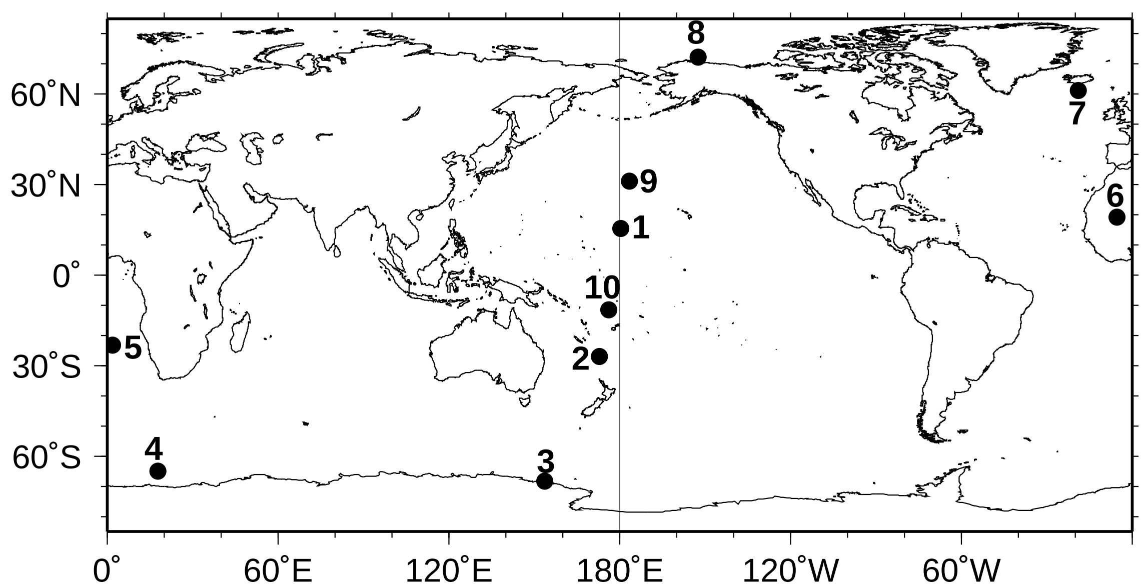

Figure A3-2. Locations of the boundaries of 24-hour data days for a 10-day period beginning on July 26, 1992 15:22:00 UTC (dot labeled “1”).

A3.3 A spatial data-day definition

Because of the problems associated with a temporal definition of a data-day, we explored the implications of adopting a spatial definition. In this case, the boundary between data-days is not defined by time but, instead, by a fixed geographic reference. A similar criterion is commonly used for designating orbit numbers in several spacecraft: the orbit number usually is incremented upon crossing the Equator. For the initial investigations, we selected the 180° meridian as the boundary between data-days.

Figure A3-3 shows NOAA-11 nadir tracks for a spatially-defined data day. Because the nadir tracks crosses the reference line several times during a day, one of the crossings must be selected as the beginning of a data-day. An operational definition of this is presented below. For this discussion, we define the day to begin on July 26, 1992 at 15:22:00 UTC, when the spacecraft crosses the 180° meridian flying from north to south (i.e., at the same time at which the 24-hour data-day shown on Figure A3-1 started). The first descending track of the day is labeled N.

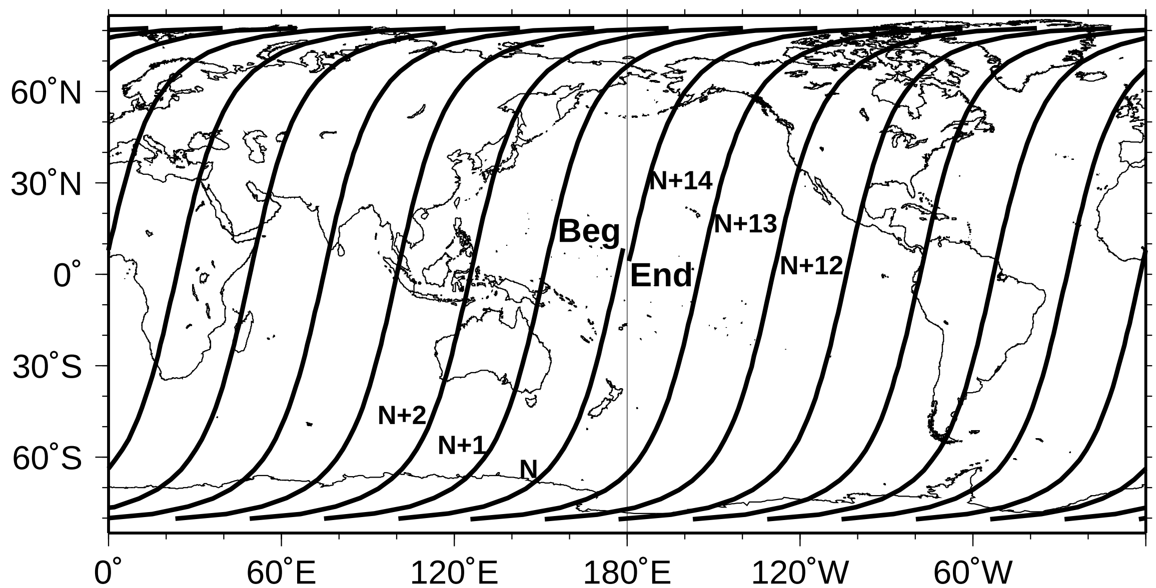

Figure A3-3. NOAA-11 descending orbits for a spatially-defined data-day beginning on July 26 1992, 15:22:00 UTC. At this time, the nadir track crosses the 180° meridian.

As almost 24 hours worth of data are required to ensure global coverage, we define the data-day as ending when the nadir track crosses the 180° meridian during revolution N+14. This happens approximately on June 27, 1992 at 15:14:00 UTC. The most immediate observation, then, is that a spatial definition results in a data-day that does not necessarily correspond to a 24-hour day: in this case the data-day is approximately 23 hours and 52 minutes long. This figure is only approximate for two reasons. In the first place, it is sometimes necessary to include an additional revolution in order to ensure global coverage (that is, the last orbit of the day would be N+15). Secondly, the spatial definition is applied on a pixel-by-pixel basis. That is, pixels along the same scan line on a given orbit can be assigned to different days depending on whether they are on one side or the other of the 180° meridian.

Figure A3-4 illustrates the pixel-by-pixel assignment of data to a given day. The figure shows the sampling pattern of the AVHRR onboard NOAA-11 between 15:12:00 and 15:32:00 UTC on July 26, 1992 (i.e., ± 10 minutes from the start of the data-day at 15:22:00 UTC). The scan lines shown on Figure A3-4 are separated by one minute (in a one-minute interval there are 360 LAC scans or 120 GAC scans). Pixels along a given scan line that are located east of 180° are assigned to day N. If pixels along the same scan line are west of 180°, those pixels are assigned to the following day (N+1). It is apparent from Figure A3-4 that, even before the nadir track crosses the 180° meridian, pixels are already being assigned to day N+1. Conversely, after the nadir track has crossed the reference meridian (at 15:22:00 UTC), pixels east of the meridian are still being allocated to day N. It is this allocation mechanism that makes it difficult to define precisely the duration of a data-day.

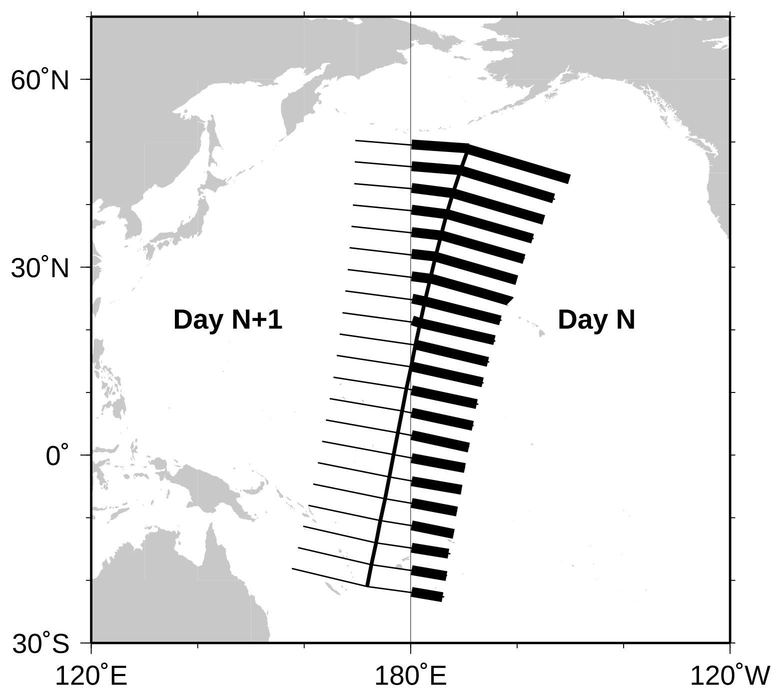

Figure A3-4. AVHRR nadir track and scan lines for a 20-minute period between 15:12:00 and 15:32:00 UTC on July 26, 1992. Pixels to the east of the 180° meridian (marked in a thicker line) get assigned to data-day N, whereas the pixels to the west of the meridian correspond to data-day N+1.

A3.4 How is the beginning of a data-day defined?

How is the spatial definition of a data-day implemented in routine processing of global satellite data fields? The first step is to define a meridian which will serve as the reference for the data-day definition. The 180° meridian used in the previous examples is a good alternative, as this choice minimizes differences between actual dates and the dates assigned to the data-days. As the spatial data-days are not 24-hours long, a suitable naming convention will have to be established.

A second step in defining a data-day is to decide which of the descending (or ascending) crossings of the reference meridian will mark the beginning of the descending (or ascending) data-days. As mentioned above, there are several (usually seven to nine) descending crossings of the reference meridian in a day; the same is true for ascending orbits. This is illustrated in Figure A3-5, which shows the latitude of descending crossings of the 180° meridian as a function of time for the NOAA-11 spacecraft, beginning on July 26, 1992; a 10-day span is shown. Most of the crossings (shown as dots) take place at high latitudes, and one or two crossings per day occur at tropical to intermediate latitudes.

Any of the crossings of the 180° meridian shown on Figure A3-5 can be potentially selected as the one marking the beginning of a data-day for descending and ascending orbits. For operational purposes, we propose the following definition: *a data-day for descending orbits is defined to begin at the descending crossing of the 180° meridian closest to the Equator.* A similar definition can be applied to ascending crossings, yielding data-days for ascending orbits. Such definition is the easiest to implement because there is always only one crossing in a day that fulfills the condition (although consecutive crossings may sometimes have very similar absolute latitudes of intersection, one on the Southern hemisphere, and the other on the Northern hemisphere).

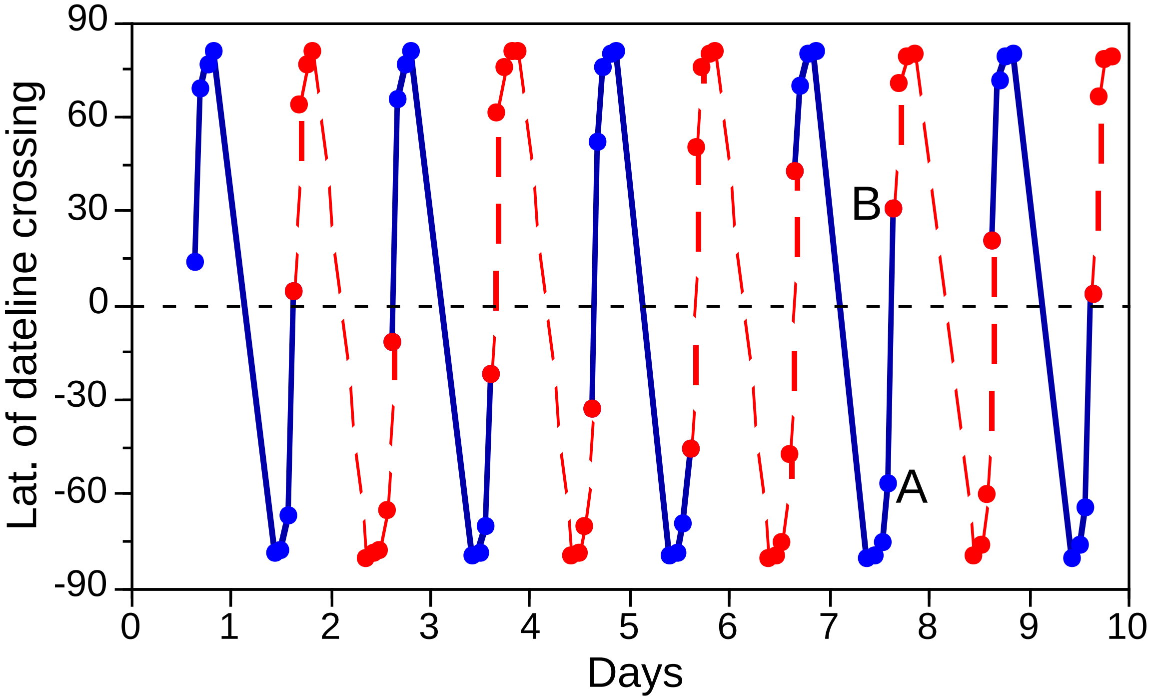

Figure A3-5. Latitude of crossing of the 180° meridian for NOAA-11 descending orbits. Data shown for a 10-day period beginning on 26 July 1992, 15:22:00 UTC. The alternating solid and dashed lines indicate consecutive data-days.

The alternating solid and dashed lines in Figure A3-5 indicate consecutive data-days. Initially, the latitude of the data-day beginning seems to follow a regular progression to the south. For instance, the first two data-day boundaries in Figure A3-5 are on the Northern hemisphere, and the next four are progressively further south on the Southern hemisphere. Note, however, that the southward progression is interrupted near the end of data-day 6 (the point labeled A). In this case, the next descending crossing (point labeled B) is actually closer to the Equator, so the data-day is extended until this next crossing (located in the Northern hemisphere). That is, the data-day is slightly longer (one more revolution) in this case. The southward progression of the crossings subsequently resumes. For ascending orbits, the progression of the latitude of the crossings is reversed, that is, it occurs from south to north.

Table A3-1 contains a list of start times of descending data-days for a 15-day period beginning on July 26, 1992, as well as the latitude at which the crossing of the 180° meridian occurs.

Date	Beginning time	Latitude of 180° crossing
07 / 26 / 92	15:22:04	13.85
07 / 27 / 92	15:13:39	0.67
07 / 28 / 92	15:05:14	-12.52
07 / 29 / 92	14:56:34	-24.81
07 / 30 / 92	14:47:28	-35.52
07 / 31 / 92	14:37:51	-44.37
08 / 01 / 92	15:43:42	39.33
08 / 02 / 92	15:34:24	29.34
08 / 03 / 92	15:25:35	17.60
08 / 04 / 92	15:17:06	4.63
08 / 05 / 92	15:08:42	-8.64
08 / 06 / 92	15:00:08	-21.29
08 / 07 / 92	14:51:11	-32.58
08 / 08 / 92	14:41:43	-41.99
08 / 09 / 92	15:47:31	41.94

Table A3-1. Beginning times of fifteen data-days for descending orbits , NOAA-11 spacecraft. The latitude of the 180° meridian crossing is also shown.

We must stress that, because of the pixel-by-pixel allocation described above, parts of the field will include data collected both before and after the times listed in Table A3-1. Notice the jump in the southward progression of crossing latitudes (e.g., from July 31 to August 1), which is associated with a slightly longer data-day.

A3.5 Advantages of the Spatial Definition of a Data-Day

In previous sections we proposed a spatial definition for a data-day, together with an objective definition for the temporal “beginning” and “end” of such a data-day. So far, however, we have not discussed the advantages or disadvantages of the proposed definitions.

Some problems associated with a temporal definition of the data-day were the potential presence of aliasing and large temporal discontinuities, and the fact that the day boundaries changed with time. The spatial definition avoids temporal changes in the location of boundaries, as the boundary is fixed (e.g., the 180° meridian). Furthermore, because there is no overlap of swaths at the beginning and end of a data-day, the spatial definition reduces the aliasing resulting from averaging data sampled almost 24 hours apart. The presence of large temporal discontinuities among adjacent areas is still present, however.

The large temporal discontinuities identified on Figure A3-1 north of Alaska and south of New Zealand are still present in Figure A3-3. It is clear that the large temporal discontinuities occur in two places near the meridian that defines the separation between data-days. The first place is the area south of the first track of the data-day and west of the reference line. The second area with discontinuities occurs north of the last track of the data-day, east of the reference line. In addition to the large temporal discontinuities between adjacent swaths, when the swaths overlap at higher latitudes once again data will be averaged that were sampled far apart in time. Elsewhere on the global fields, any given track is surrounded by tracks sampled one orbital period (about 100 minutes) earlier or later.

The presence of temporal discontinuities or the averaging of data collected at very different times may not be too important for many applications, although users should certainly be made aware of the occurrence of these events. In other situations, however, the temporal discontinuities may cause significant problems. Examples of such applications may be the estimation of the translation speed of certain features, or the computation of fluxes.

In order to limit the large meridional temporal discontinuities near the data-day boundary, the short track segments north and south of the first and last tracks of the data-day could simply be eliminated (e.g., parts of N+1, N+2, N+12 and N+13). This approach is illustrated in Figure A3-6, which shows descending tracks between July 27 1992, 15:14:00 UTC and July 28 1992, 15:05:00 UTC (the data-day following the one shown on Figure A3-3). The map is now centered at 0°, rather than at 180° as in Figure A3-3. Note that the nadir tracks for which segments were eliminated seem to end a bit before or after the 180° line. This is because positions were predicted at one-minute increments.

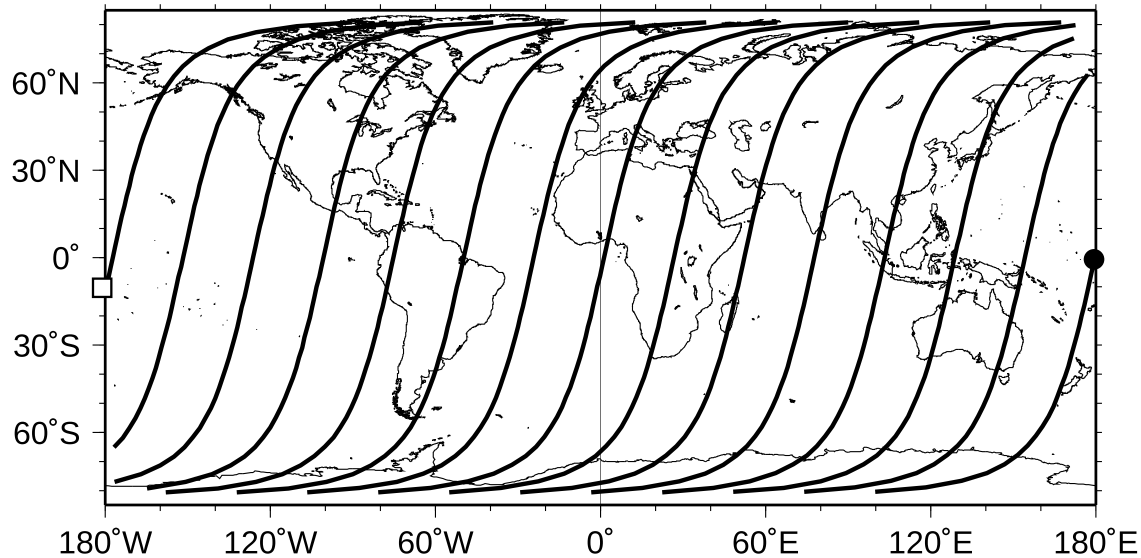

Figure A3-6. NOAA-11 descending orbits for spatially-defined data-day beginning on July 27, 1992 15:14:00 UTC. Segments that introduce large north-south temporal discontinuities (see text) are excluded.

The elimination of segments may result in areas not being sampled (e.g., upper left and lower right corners of the map). These gaps may possibly be filled by the wide swath of the first and last tracks of the data-day (tracks N+14 and N in the north and south, respectively). However, the size of the gaps is a function of the latitude of the reference line crossing which defines the beginning of the data-day. As shown above (Figure A3-5), this latitude changes with time, moving north and south approximately between 60°N and 60°S. When the crossing is further north, the gap to the south of the first track will be larger. Conversely, when the crossing is further south, the gap north of the last track will get larger. We propose that two additional swaths be added at each end of the data-day, in order to replace the eliminated segments. Experience has shown that two additional swaths are enough to fill each of the gaps and ensure complete coverage. The added swaths would be temporally continuous with the first and last tracks of each data-day, thus eliminating the problems of temporal discontinuities. An operational scheme would involve the following steps:

1. The times of the beginning and end of a spatially-defined data-day are found following the definition suggested above. These times will be referred to as the “beginning” and “end” of the data-day.

2. Data east of the 180° meridian and collected up to 216 minutes (about two orbits) after the beginning of the data day will be excluded. Data west of the 180° meridian

sampled up to 216 minutes before the end of the data-day will be similarly excluded. The net result of these actions is similar to the elimination of segments shown on Figure A3-6.

3. To ensure full coverage, data collected up to 216 minutes before the beginning of the data-day and west of the 180° meridian are added to the data-day. This fills the gap to the south of the first track of the day. Data collected up to 216 minutes after the end of the data-day and east of 180° are also added. These data fill the gap north of the last track of the data-day. The end result is illustrated on Figure A3-7. Note that only the descending (AVHRR night or ascending day) portions of the extra orbits are included in the fields.

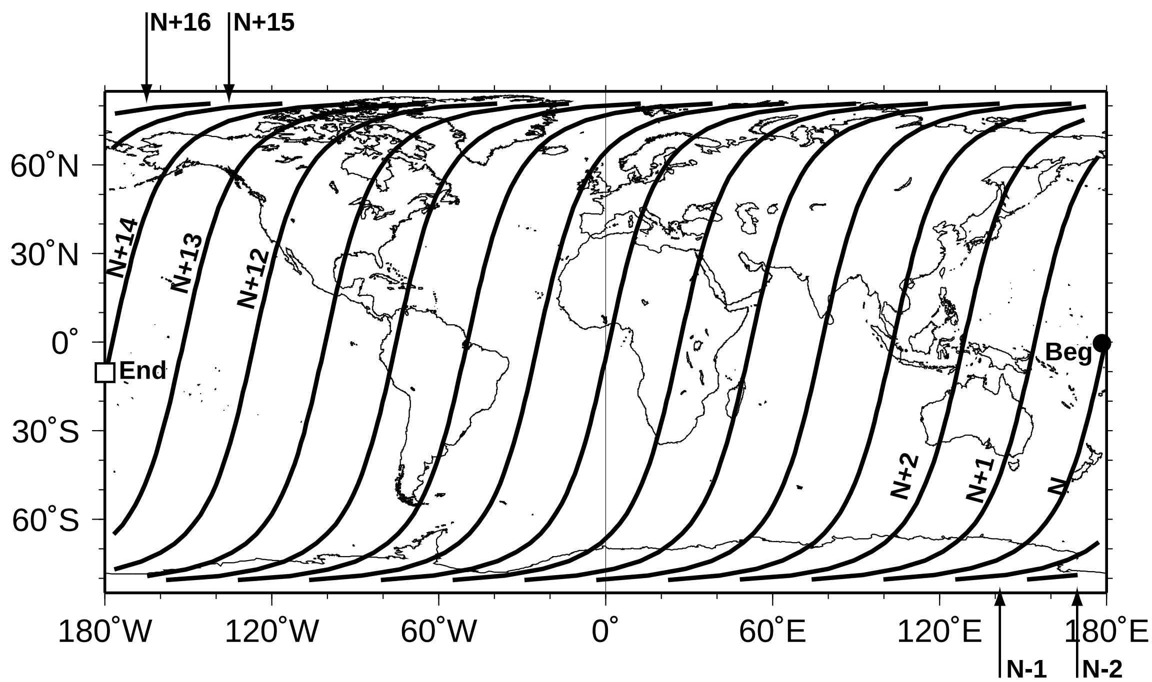

Figure A3-7. Data-day beginning on July 27 1992 15:14:00 UTC, showing the addition of four segments (indicated by arrows) in order to minimize temporal discontinuities. The first track sampled after the estimated beginning time of the day ("Beg") is track N. The two segments to the south correspond to the two previous orbits (N-1, N-2). The last track before the estimated end time of the data-day ("End") is track N+14. The two segments to the north correspond to the next two orbits (N+15, N+16).

Figure A3-7 shows the descending orbits for the data-day beginning approximately on July 27 1992, 15:14:00 UTC. The gaps shown on Figure A3-6 have been filled by the addition of four short segments, indicated by arrows on Figure A3-7. Note that these segments have been sampled before (N-1, N-2) and after (N+15, N+16) the times estimated for the beginning and end of this data-day (see Table A3-1). However, because the added segments are close in time to orbits N and N+14, the large temporal discontinuities have been eliminated. The segments excluded from this data-day are the first portion of tracks N+1 and N+2, east of 180°, and the last portion of tracks N+12 and N+13, west of 180°.

Admittedly, it is somewhat difficult to grasp the methodology proposed. To facilitate comprehension, we may present a simple analogy. Envision a continuous strip chart on which the continents are drawn. Above the chart recorder there is a clock showing UTC time and date. As the chart moves from left to right, a pen draws descending tracks, one at a time. The speed of the chart movement is appropriate to ensure that the nadir track's latitude and longitude corresponding to any given UTC time are correct. That is, the nadir tracks should look similar to those on Figures A3-6 and A3-7.

Suppose we position the chart so that the pen is just crossing the 180° meridian near the Equator on July 27 1992. The time shown by the clock should be about 15:14:00 UTC. We then allow the chart recorder to run for almost 24 hours, until a track crosses the 180° meridian again very close to the Equator. The time should be about 15:04:00 UTC on July 28, 1992. If we cut the chart along the two 180° meridians drawn (left and right), the tracks on the chart should look exactly like Figure A3-6. As in Figure A3-6, there will be some gaps in the coverage. On the right side of the chart, there is a gap south of the first track (N) of the day. This gap should have been filled by the last portion of tracks N+12 and N+13, which have been drawn to the left of the 180° meridian on the left side of the chart. These lines, however, were eliminated when we cut the chart along the left 180° line. Similarly, the gap north of the last track of the day should have been filled by the initial portions of tracks N+1 and N+2. These segments were drawn east of the 180° meridian on the right side of the plot. However, as we cut along the 180° line on the right, these segments were excluded. It is apparent, then, that the chart recorder analogy reproduces the action of eliminating tracks which cause large temporal discontinuities, as the end result looks exactly like Figure A3-6. Let us see if we can fill the gaps in the global fields using the same chart recorder analogy.

Suppose that we do not start the chart recorder at 15:14:00 UTC on July 27 1992 but, rather, we move the chart backwards and start about 216 minutes earlier. If we start the recorder then, a few additional tracks (e.g., N-1 and N-2) will be drawn before the nadir track of orbit N crosses the 180° meridian at 15:14:00 UTC (defined as the temporal beginning of the data-day). The southern segments of tracks N-1 and N-2 will fall west of the 180° meridian, filling the gap previously existing in the south. We let the recorder run up to 216 minutes past the time estimated for the end of the day (July 28 1992, 15:04:00 UTC) and, again, a few additional tracks will be drawn. If the last track of the day is N+14, the northern portions of tracks N+15 and N+16 will fill the northern gap. Once we have allowed the recorder to run for about 24 hours plus the additional 216 minutes on either end, we take a pair of scissors and cut the chart along both 180° meridians. That is, we are applying the spatial pixel-by-pixel assignment of data to a given data-day. The end result should look exactly like Figure A3-7. Finally, we could envision running the recorder for long periods and repeatedly cutting the long chart along the 180° meridians. Each of the maps would correspond to one data-day.

When discussing the elimination of segments that caused large temporal discontinuities, we could have given the impression that the data in these segments would be unused, and therefore wasted. However, if one follows the analogy presented above, it is easy to see that the data will not be deleted but, rather, they will be assigned to the previous or the following data-days. For instance, the northern portions of tracks N+1 and N+2 (not labeled) in Figure A3-6 would be plotted to the east of the right 180° meridian on the chart. When we cut the chart, these portions get assigned to the previous data-day, which begins on July 26 1992, 15:22:00 UTC. In the same way, the southernmost portions of tracks N+12 and N+13 are plotted to the west of the left 180° meridian, thus being assigned to the next data-day after the chart is cut along the meridian. The end result of the scheme proposed is a daily global field where all parts of a field are temporally separated from adjacent areas by, at most, one orbital period.

A similar scheme can be implemented for ascending tracks. The definitions of the temporal beginning and end of an ascending data-day were discussed above. The chart recorder analogy can also be similarly formulated for ascending nadir tracks.

A3.6 Other Issues

An aspect that we have not discussed so far is that at both the extreme north and south of the fields, data from several tracks will be averaged for a data-day. At high latitudes, the spacecraft is flying almost in an east-west direction and, thus, the scan lines have a north-south orientation. For instance, there are seven to nine passes a day at high latitudes (see Figure A3-5). Near the 180° meridian, where some of the passes are excluded at high latitudes, as described above. In other high latitude regions, however, the fields will contain the average of several passes. This should not have too many consequences on ocean products, as the areas affected will be mostly on land in the southern hemisphere and under permanent ice cover in the northern hemisphere.

One final issue that needs to be pointed out is that the spatial scheme proposed above will result in temporal discontinuities in areas that straddle the reference line. Suppose that an oceanographer is studying an area of the North Pacific Ocean encompassed between 150°W and 150°E, straddling the 180° line. If the oceanographer obtains a global field for a given data-day, he/she must realize that the portion of the study area west of 180° has been sampled much earlier than the portion to the east. Again, this may not be relevant for some research, but it could be in some cases. A solution would be to place the reference line elsewhere, for instance along 0°, but there will always be some location where areas on either side of the line will be sampled far apart in time. Alternatively, a user might obtain product fields for two consecutive data-days and paste the appropriate portions. Going back to the Pacific example presented above, the eastern part of the study area would be extracted from data-day X and the western part would be taken from day X+1. This can be accomplished without reprocessing and without introducing any spatial or temporal aliasing.