# P1.53 ENHANCING THE GEOSTATIONARY LIGHTNING MAPPER FOR IMPROVED PERFORMANCE

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## 1. INTRODUCTION

The Geostationary Lightning Mapper (GLM) will be a single-channel, near-IR optical instrument designed to detect and locate lightning strikes from geostationary orbit (see Goodman, et. al, 2008). As a component of the new GOES-R spacecraft, the instrument will provide continuous full-disk lightning observations from a fixed, downward pointing telescope with a staring sensor based on a large 2-D CCD detector array.

The GLM Performance and Operational Requirements Document (PORD) calls for full-disk coverage, defined from the perspective of the GOES-R spacecraft as a square detection area (corresponding to the CCD array) centered at nadir and extending just under 53° in both the north-south and east-west directions (see Figures 1 and 2). The instrument's optics are also required to provide coverage out to a minimum of 59° from nadir (92% of the way from nadir to the edge of the visible earth disk). Going into the Formulation Phase design studies (e.g. Boccippio and Schaefer, 2006), the GLM's resolution target was to have a 10-km (Ground Sample Distance, GSD), or better, with a goal of 0.5 km. For the specified coverage area, a 1024 by 1024 CCD sensor array would provide a nadir resolution of just under 10-km.

Figure 3 illustrates the required coverage as seen from the GOES-EAST and WEST satellites. This figure also includes a depiction of the loss in resolution (GSD) with distance from nadir, based on a GSD of 10-km at nadir and with the GSD increasing to 25-km at a great-circle distance of 59° from nadir.

## 2. CORRECTING SATELLITE IMAGERY FOR EARTH CURVATURE EFFECTS

Johnson (2006 and 2007) discusses the possible use of an optical adapter (termed the GeoObs adapter) to correct for earth curvature effects and provide essentially uniform resolution imagery from a sensor in geostationary orbit. This adapter concept seems to be particularly well suited for likely GLM designs, but is a hardware enhancement that would have to be incorporated into the instrument design before launch.

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The GeoObs adapter would progressively stretch the earth image in a radial direction, with increasing stretching the further you get from nadir, at exactly the rate required to offset the natural foreshortening of earth features due to earth curvature (and to a lesser extent due to the increasing oblique viewing angles). The adapter would leave the regions near nadir unchanged, but would modify the overall proportions of the disk image so as to preserve essentially uniform resolution in any radial direction.

While Johnson (in both his 2006 and 2007 papers, as well as in the current discussion) places an emphasis on trying to generate uniform resolution imagery across the full earth disk (see following discussion), a similar stretching on a more modest scale could be used to minimize or restrict the normal loss in resolution as you move away from nadir without attempting a full correction.

## 3. WHAT DOES IT MEAN TO HAVE FULL DISK UNIFORM RESOLUTION IMAGERY?

Strictly speaking, it is impossible to provide truly "uniform resolution" imagery across a full disk image of a sphere (earth) as seen from geostationary orbit. This reflects a fundamental physical limitation which makes it impossible to simultaneously depict accurately the linear dimensions, area, and shape of features on a 3-dimensional object in a 2-dimensional image. This is a fundamental problem in cartography (Snyder, 1987).

Nevertheless, there are a wide variety of transformations (mappings) of the spherical earth that could reasonably be called "uniform resolution", whether through simple correcting for the loss in resolution in a radial direction due to earth curvature, or by more sophisticated transformations that can emulate standard map projections (in their equatorial implementations) such as Lambert Equal-area, Equidistant, or Stereographic. These specific map projections are all members of the azimuthal family of map projections, which differ from each other only in their treatment of distances from a reference point in the radial direction. Since the normal perspective view of the earth from geostationary orbit can also be considered to be a member of this same azimuthal family of map projections, the GeoObs adapter provides a potential functionality for transforming earth observations directly into a reference frame that emulates standard map projections.

The distinguishing feature of the desired transformations is a dramatic improvement over the normal satellite perspective images which experience extreme distortion and loss of resolution as you move away from nadir.

For this paper, the potential GeoObs transformations shown Figures 4-8 are all based on the Lambert Equal-area map projection. This means that each pixel of data collected by the CCD will cover an equal area on the earth's surface. One advantage of this particular transformation is the slightly more modest stretching requirements as compared with other possible transformations, coupled with the advantages of using a standard projection with well know properties.

## 4. ENHANCEMENT OPTIONS FOR GLM

While 10-km resolution (at nadir) may often be adequate, resolutions of 20 to 25-km over CONUS will be a potentially serious limitation for many lightning applications. Optically transformed lightning imagery to provide full disk uniform resolution coverage should provide better data for model input and for integration with other data sources such as radars, and would be more appropriate for decision support systems (e.g., nowcasting of severe weather and tornados) and for long-term climate records. Uniform resolution observations are particularly well suited for many processing algorithms, such as Boccippio's radiance-weighted centroid approach for the analysis of lightning pixel clusters (see Boccippio and Schaefer, 2006). Enhancements of this sort are particularly valuable since they are applied before the observations are made and directly enhance the quality of the observation, and are not just a software remapping of the imagery after it is collected.

The optical adapter, depending on the overall system design, could be a lens, mirror, or other optical device. While the adapter could be a separate component within a satellite observing system, in many cases its functionality could be incorporated into other existing optical components.

A transformation to uniform resolution coverage across the full earth disk can improve lightning observations in terms of both area coverage and resolution, but with trade offs that need to be considered. Radial stretching of the normal perspective view of the earth while maintaining the image resolution at nadir makes the image larger. This reflects a real gain in resolution without over-sampling the equatorial areas near nadir, but at the cost of requiring a larger CCD sensor array. Most importantly, the transformed image will also maintain its resolution as you move away from nadir, resulting in a significant increase in the resolution over critical areas (such as CONUS) that are relatively far from nadir.

The improvement in the sensor resolution towards the edge of the earth disk also makes it attractive to expand the geographical coverage area to take additional advantage of the high resolution imagery. This extended area coverage can "fill in" the corners of the CCD array, or may justify a design change to incorporate a larger CCD sensor array.

An alternative to enlarging the CCD would be to shrink the transformed image to fit within a smaller, standard-sized CCD, trading off a small loss in nadir resolution for larger area coverage and higher overall resolution. Cutting back from an initially targeted 10-km nadir resolution to a transformed image with 12-km resolution across the full earth disk, for example, would still produce a significant improvement in the image resolution over CONUS, going from 20 or 25-km to 12-km.

## 5. EXAMPLES OF SIMULATED COVERAGE

Figures 4-8 illustrate the expected behavior and properties of the transformed imagery, and to highlight some of the design trade-offs that need to be considered. In all cases it is assumed that the starting reference point for the design is a 1024 x 1024 CCD with 10-km resolution at nadir.

Figure 4 shows the result of transforming the standard satellite perspective view of the earth through application of the GeoObs adapter, while preserving a pixel resolution of 10-km. As a result of stretching the image, while maintaining the original nadir resolution, the transformed image is larger, requiring a (most likely custom) 1225 by 1225 CCD sensor array. The transformation has a significant impact on the overall appearance of the continental areas with the obvious foreshortening seen in Figure 3 having been removed. The yellow arc seen in this figure, and in all subsequent figures as well, represents the PORD's 59° angular coverage specification.

The 59° PORD coverage requirement apparently represents an attempt to limit the GLM design to coverage areas for which quantitative applications of the data are possible. The threshold appears somewhat arbitrary, but seems to have been chosen, at least in part, because of the rapidly increasing GSD values this far from nadir. At the same time, the viewing angle from the earth to the satellite is becoming quite low, with a corresponding increase in the atmospheric path length and increasing parallax problems for assigning earth locations for targets in the middle or upper troposphere. At one time, the use of geostationary imagery was generally limited to areas within 60° of nadir, but with the improved resolution imagery available from the GOES-I and later satellites, quantitative applications have been routinely extended to 65° and beyond. A secondary result of using the GeoObs adapter to enhance the resolution of the GLM lightning locations may be to extend useful lightning observations further from nadir. In Figures 4-8 the 59° (minimum) requirement has been extended to a (possible) coverage area out to 70°. While this sounds like a very significant enlargement, it only represents an extension of the proportion of the earth disk that is analyzed from 92% of the way to the edge of the visible earth disk to 98%. The enlarged angular coverage area may require a slightly larger optical aperture, but doesn't necessarily require an increase in the size of the CCD arrays being used since the increased coverage can come from the previously empty "corners" of the CCD.

Figure 5 shows exactly the same transformation as in Figure 4, but has now been reduced in size to fit within a "standard" 1024 by 1024 CCD. The shrinking of the imager into a smaller CCD results in a small loss in pixel resolution, with the GSD now increased to just under 12-km.

With a transformed image projected onto a 1024 by 1024 CCD while maintaining a GSD of 10-km, the coverage area has to shrink. Figure 6 shows two examples of the reduced coverage areas under these conditions, but with the CCD imaging arrays offset from the optical center to provide better coverage over CONUS, the Gulf of Mexico and the Caribbean. Zooming in further, Figure 7 illustrates one possible GOES-EAST coverage window with 6.5 km resolution, using the same 1024 by 1024 CCD imaging array. This transformation would give excellent North American coverage, but at the cost of the highly desirable full disk coverage. In principle, it may be possible to split the near-IR imagery into two parallel image paths, simultaneously providing a lower resolution data set with full disk coverage area, while also monitoring CONUS (or other critical areas) at a higher resolution.

Figure 8, somewhat dramatically, shows an extended coverage area — even larger than the PORD requirements — combined with a high resolution GSD of 6.5 km. This combination, however, would require a larger 2048 by 2048 CCD sensor.

## 6. REFERENCES


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## ACKNOWLEDGEMENTS

This work was supported, in part, by NASA through their Applied Sciences Program and the Advanced Satellite Aviation-weather Products (ASAP) initiative. Additional support was provided by the University Corporation for Atmospheric Research (UCAR). The GeoObs Adapter is a registered intellectual property of the UCAR (patent pending).

The National Center for Atmospheric Research is sponsored by the National Science Foundation (NSF).

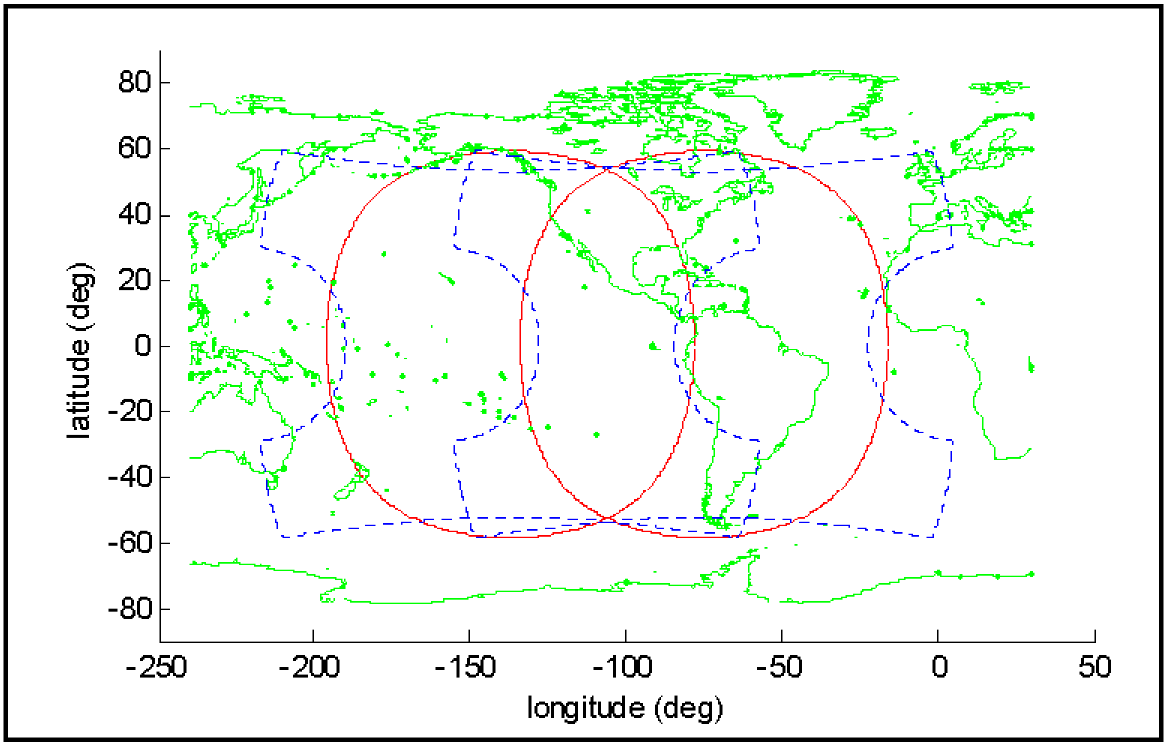



Fig. 1: Full-disk coverage definition from the GLM Performance and Operational Requirements Document (PORD).

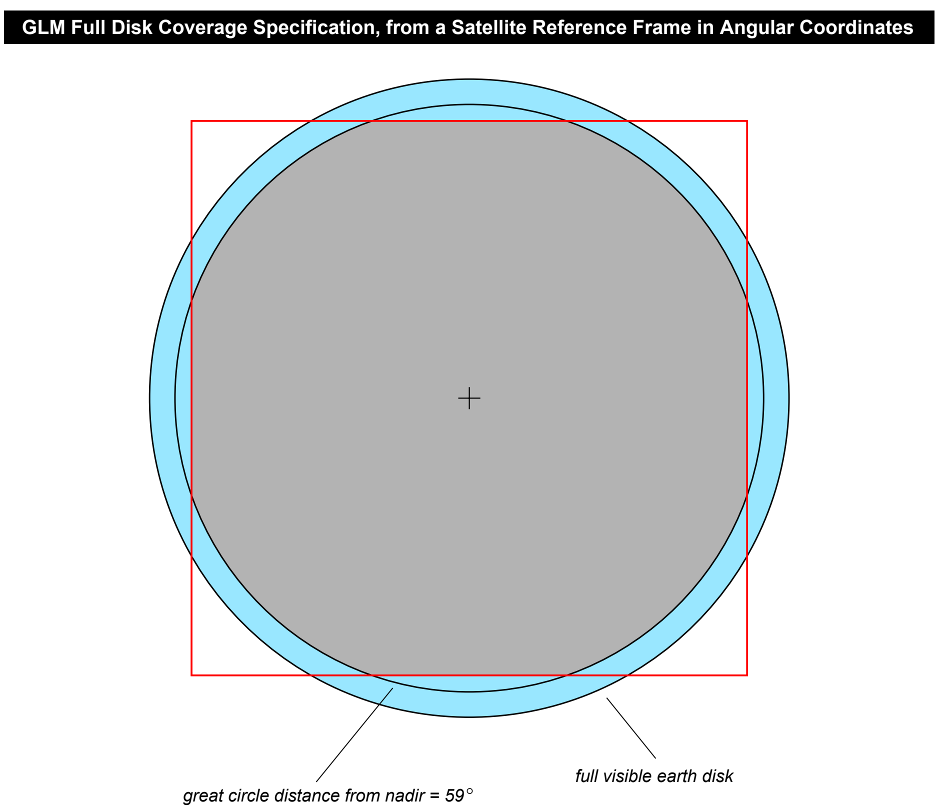



Fig. 2: PORD coverage requirement translated into a satellite perspective view of the earth disk (see text for discussion).

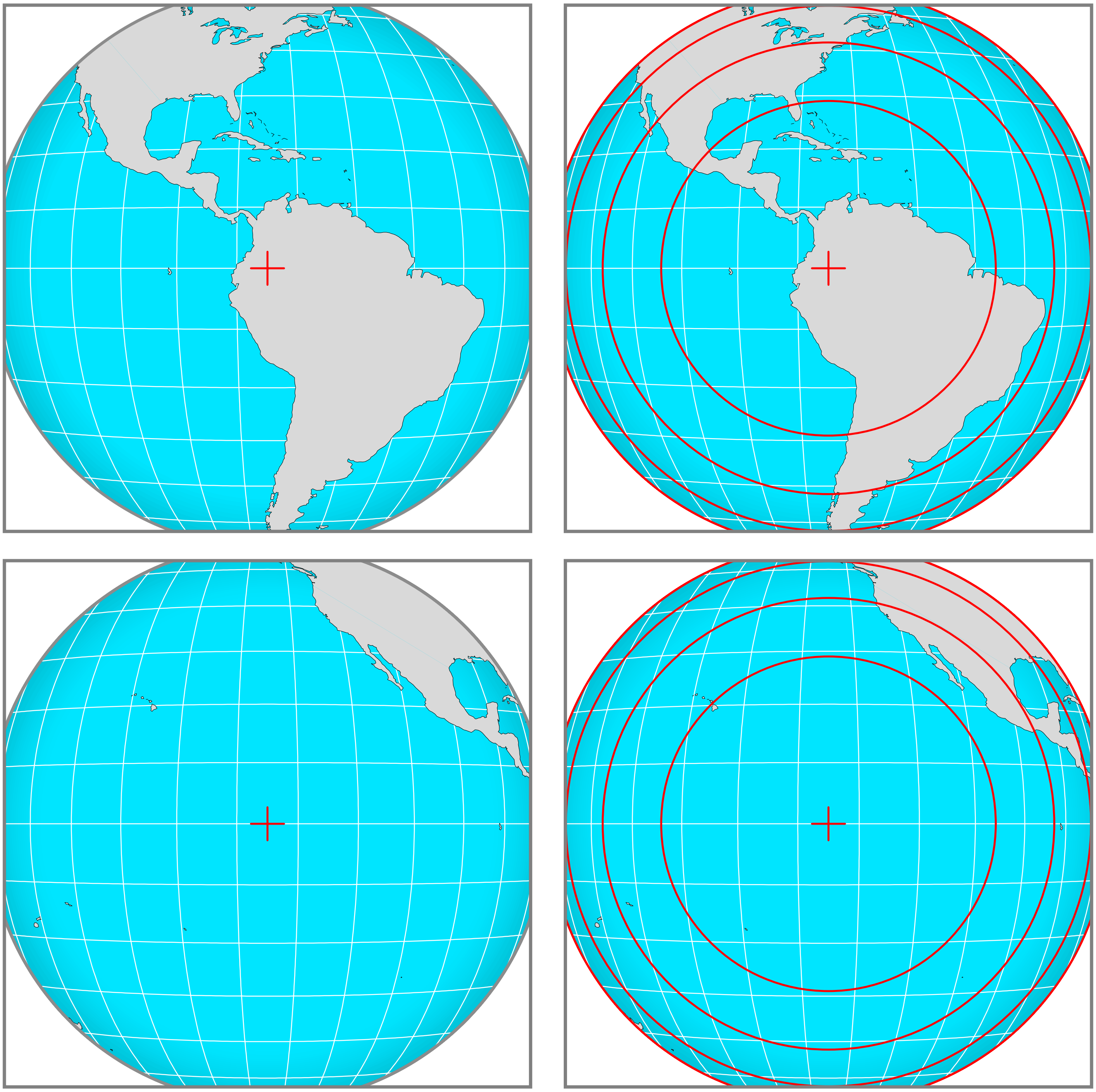


Figure 3: The GLM area coverage requirement for both GOES-EAST (top pair) and GOES-WEST (bottom pair). The right hand figures add lines of equal resolution (i.e. GSD). For a nadir resolution of 10-km, the red circles show the reduction in resolution with distance from nadir, with GSD values of 12-km, 15-km, 20-km, and 25-km respectively.

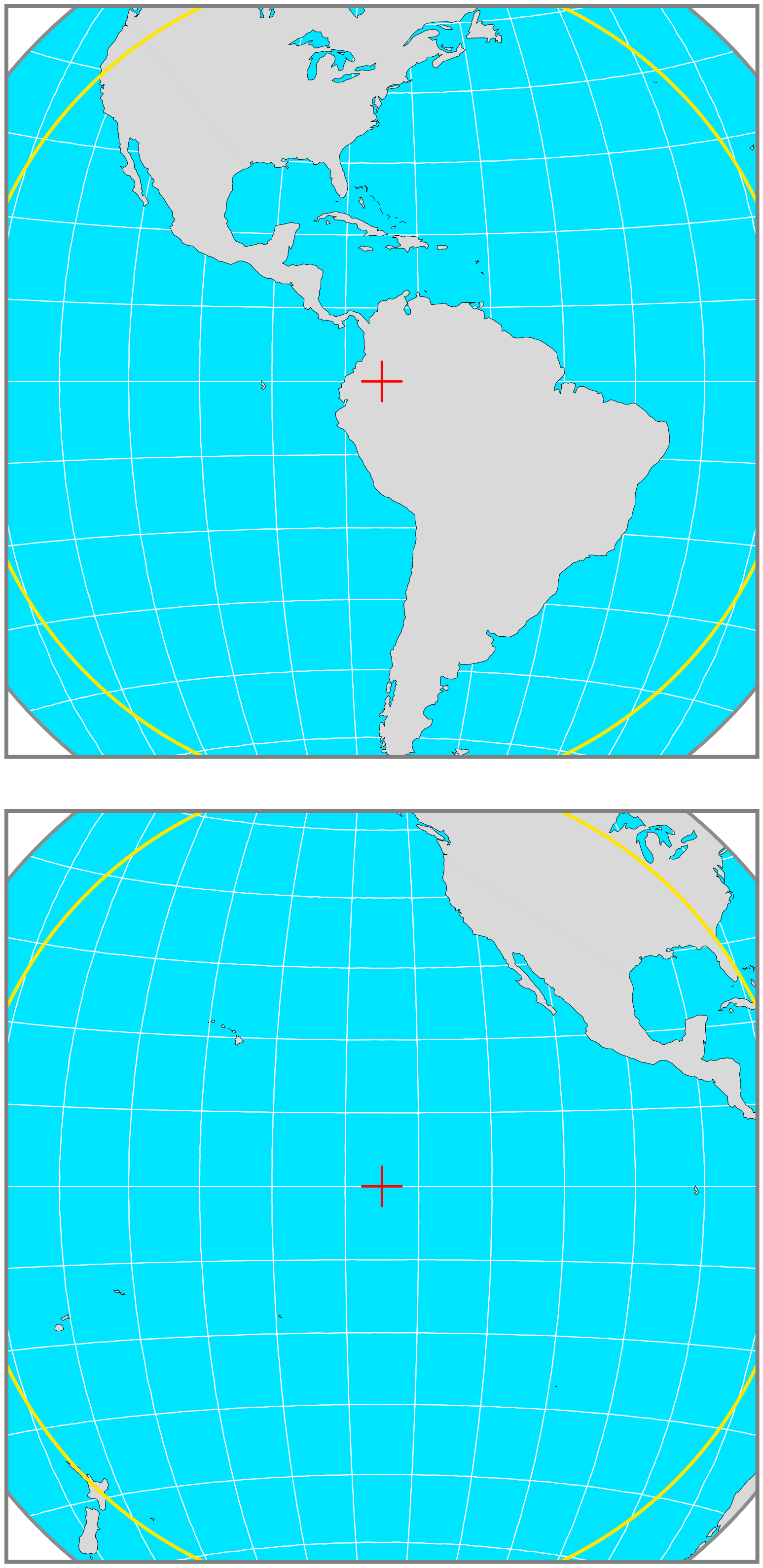
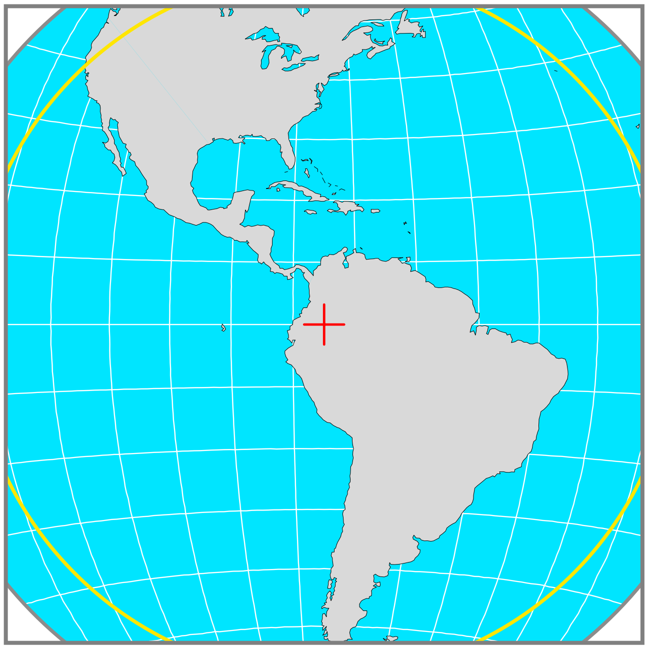


Fig. 4: GOES-EAST and WEST coverage areas as transformed by the GeoObs adapter (see text for discussion). The optical stretching creates a larger image which reflects the overall net increase in image resolution and requires a custom 1225 by 1225 CCD array to provide a uniform 10-km resolution over the entire coverage area.



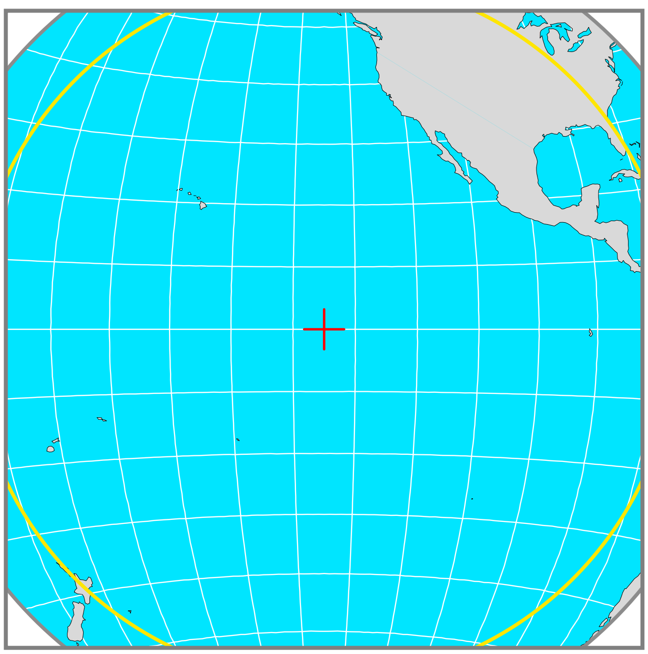


Fig. 5: In this figure, the transformed earth images as shown in Fig. 4 have been reduced in size so as to fit within the coverage area of a 1024 by 1024 CCD, while preserving the image transformation provided by the GeoObs adapter. While the area coverage is identical, the effective resolution of each pixel has been decreased to just under 12-km. In this example, the transformation to provide uniform resolution across the entire image necessitates a modest loss in nadir resolution. In spite of the reduction in the size of the CCD, however, areas well away from nadir (such as CONUS) still show a significant improvement in pixel resolution when compared to untransformed images with 10-km nadir resolution.

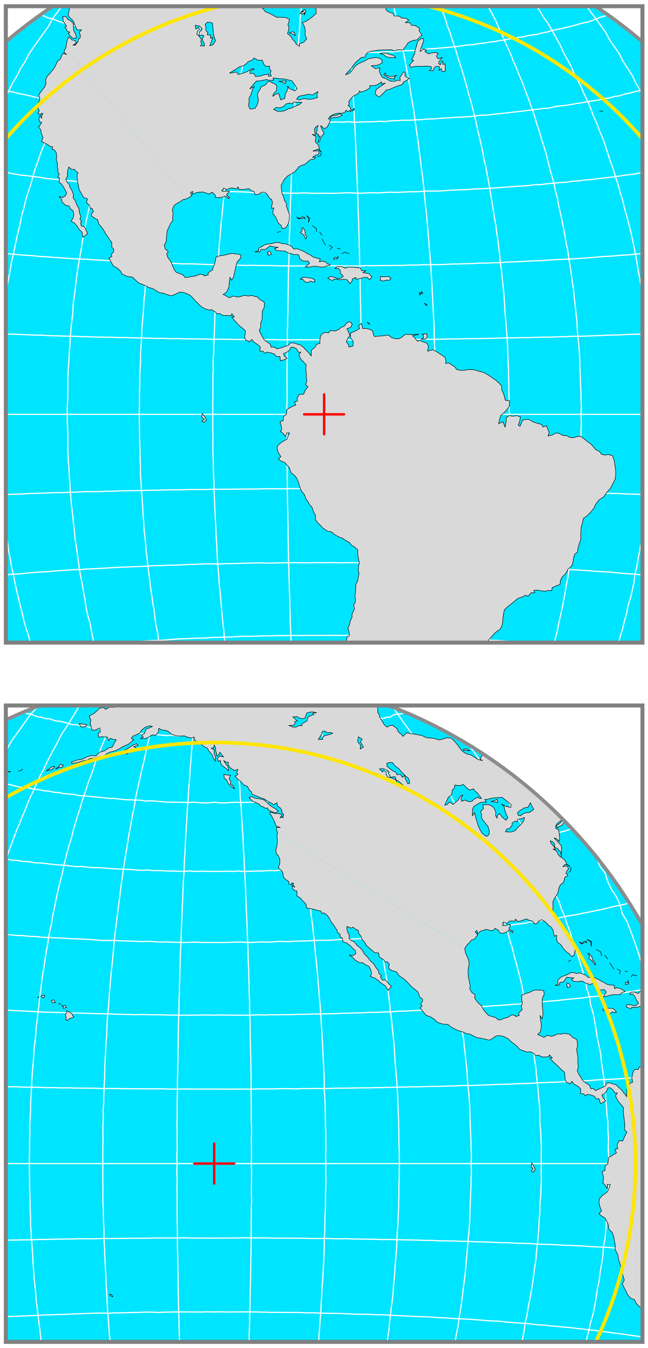


Fig. 6: This example shows another possible application of the GeoObs adapter with GLM, in this case preserving the 10-km pixel resolution at nadir (instead of the 12-km resolution shown in Fig. 5) in conjunction with a “standard” 1024 by 1024 CCD. This means that there is a significant shrinking of the overall coverage area, but by moving the CCD to an off-center location we can get very good coverage over CONUS, the Gulf of Mexico, and the Caribbean (both satellites) and much of South America (GOES-EAST only).

Fig. 7:  This example is similar to the case shown in Fig. 6, but zooming in even further to provide 6.5-km resolution over CONUS, the Gulf of Mexico, and the Caribbean (from the GOES-EAST orbital position).

**2048 by 2048 CCD Mosaic**

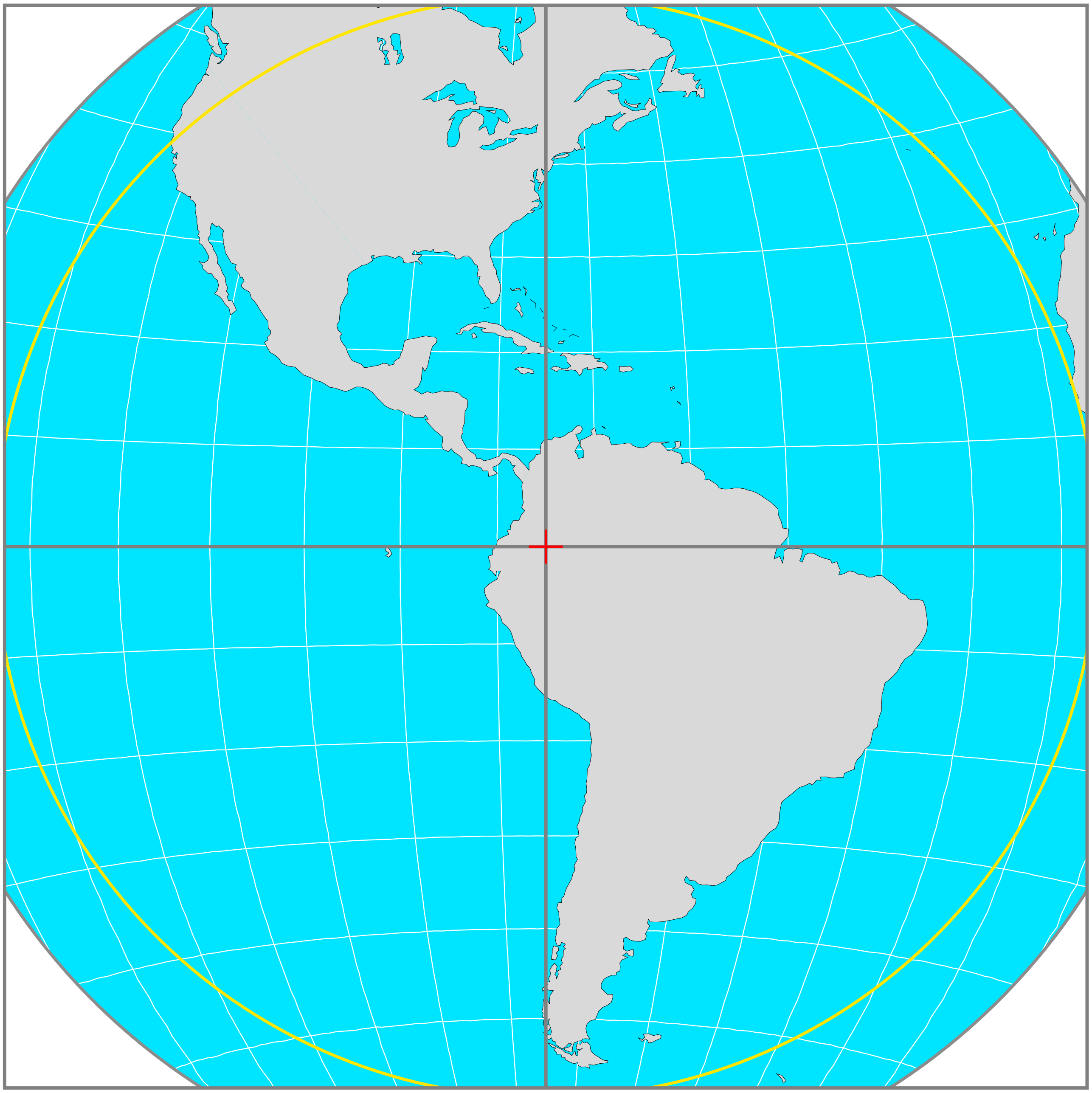


Fig. 8: This last example shows an enlarged coverage area, including all of South American and the waters south of Cape Horn at the south, as well as good Canadian coverage at the north. By making use of a 2048 by 2048 mosaic CCD, the imaging system can provide uniform 6.5-km pixel resolution imagery over the entire enlarged domain.