ENHANCING SATELLITE IMAGERY THROUGH "MORPHING" TRANSITIONS

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1. INTRODUCTION

Morphing is a term that describes a broad category of digital image algorithms used to create smooth, seamless transitions between two or more images. In satellite imagery, morphing can be used to simulate image sequences at a temporal resolution that is higher than the original instrument capabilities. Here we present the latest developments in satellite image morphing applications that increase temporal resolution and substitute for missing data sectors, creating time sequences that have fewer impediments to interpretation than the raw imagery.

It is important to identify what morphing algorithms can and cannot do. The most valuable scientific application of morphing is the production of fluid, evenly spaced time series to aid in the interpretation of the original imagery, as the following examples will show. However, it is nearly impossible to capture through morphing the transitions between images of rapidly developing events, such as cumulus development, fine-scale motion along the jet stream, the initiation of fires or volcanic ejections. Thus, morphing is best suited to the interpolation of uniform motion (advection, stretching or rotation) and has difficulty interpolating the more noteworthy events that require high temporal sampling.

Morphing involves more than just a time-weighted pointwise interpolation of initial and final images (which is sometimes called a "fade" or a "cross-dissolve"). Rather, an initial and final image are warped with time such that their corresponding features advect, stretch, or rotate into one another. Only after the image transformations are the remaining differences between the images resolved through pointwise interpolation. Three separate morphing techniques are used on the examples that follow, explained sequentially in the next three sections.

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2. SIMULATING 5-MINUTE GOES IMAGERY

GOES IR imagery spaced at three hours were morphed into 5-minute resolution animations in order to simulate the proposed temporal resolution of the GOES-R Advanced Baseline Imager (ABI). (Figure 1). This morphing procedure was performed from a fully automated feature-matching of 16 image sub-sectors, based on Gao and Sederberg (1998). The original image is divided into 16 sub-sectors of four rows and four columns. The corners of these sectors are shifted around in all directions iteratively, and the original image distorted (warped) accordingly, in order to find an optimal distortion that minimizes the brightness temperature differences between the original and final images.

The morphed product of synthetic 5-minute resolution full-disk imagery shows that viewing transitions at the global scale are "too smooth" at 5-minute resolution to appreciate any significant changes, and that the full-disk animations are more desirable at approximately 15-minute resolution. However, morphing simulations that generate synthetic 5-minute imagery for synoptic-scale and smaller regions demonstrate that the 5-minute resolution is necessary to capture events such as rapid convection, which are merely blurred in the synthetic imagery.

3. SIMULATING 5-MINUTE, 2-KM RESOLUTION IR IMAGERY USING MODIS

A second approach for simulating the output of the GOES-R ABI was morphing sequential images from the Moderate Resolution Spectroradiometer (MODIS) on the Terra satellite. Original images are taken from sequential overpasses of the same area at high latitudes at 100 minute time gaps. The sequence in Figure 2 is a detail within a decaying cyclone east of Greenland. Rather than transforming the imagery by evenly divided subsectors, the images were transformed to match the motion of several hundred control points. These points were resolved from the "MODIS winds" program (Key et al., 2002), which is an automated satellite wind detection algorithm.

The use of satellite wind-detection control points is definitely more accurate than the automated sub-sector approach from the previous section. However, the greatest difficulty in using satellite winds is the projection of three-dimensional control points onto a two-dimensional image. Currently, the vertical height of the control points is ignored, causing features in the transformed images to artificially diverge (or converge) as an artifact of directional sheering with height. In the synthetic imagery, this phenomenon emerges as a smooth edge turning jagged with time. Normally, this is not pronounced over time gaps of 100 minutes or less.

4. APPLICATION OF MICROWAVE IMAGERY TO TROPICAL CYCLONES

The most challenging application of morphing to date has been the realistic interpolation of tropical cyclone (TC) imagery from passive microwave sounders. Imagery in the 85-89 GHz range from the Defense Meteorological Satellite Program Special Sensor Microwave Imager (DMSP SSM/I), Tropical Rainfall Measuring Mission Thematic Mapping Imager (TRMM TMI) and Aqua Advanced Microwave Scanning Radiometer-EOS (Aqua AMSR-E) provides a unique observation into convective intensity and eyewall structure, which can be used to predict future TC intensity. However, a tropical cyclone is encountered by one of these satellites only every 4-5 hours on average, although the time gaps are irregular, ranging from 30 minutes to as much as 25 hours. An additional complication is that activity in the imagery ranges can include both rapid advection and large-scale, stationary convective development, often overlapping. On the other hand, we can reasonably assume certain properties in the structure of a TC such as nearly axial symmetry of the windspeed and a “Holland profile” of windspeed as a function of radius (Holland, 1980).

The current TC morphing algorithm strikes a balance between these different kinds of motion and imposes an advection on the microwave signal that is a function of radius and reported maximum wind. The algorithm works by blending purely interpolated images into one another, but by rotating the interpolated images throughout the blending process. This creates an effect of rapidly-emerging cells inside large, slower moving areas of convection, which is observed in surface radar imagery but is not apparent at the original temporal resolution of the microwave imagery. The final result is an improved visualization of the evolution of a TC.

5. ADDITIONAL REMARKS

As a means of visualizing high-temporal resolution satellite imagery, morphing is a simple and computationally inexpensive operation. Compared to the alternatives, such as numerical modeling with a radiative transfer function, the functional inputs are minor (only an initial and final image, and sometimes a set of control points) and the processing time is very fast. After computing an initial transform function (several minutes on a desktop PC), the “synthetic” image product can be computed at a rate of less than one minute per image, and at any temporal resolution desired.

6. REFERENCES

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7. ACKNOWLEDGMENTS

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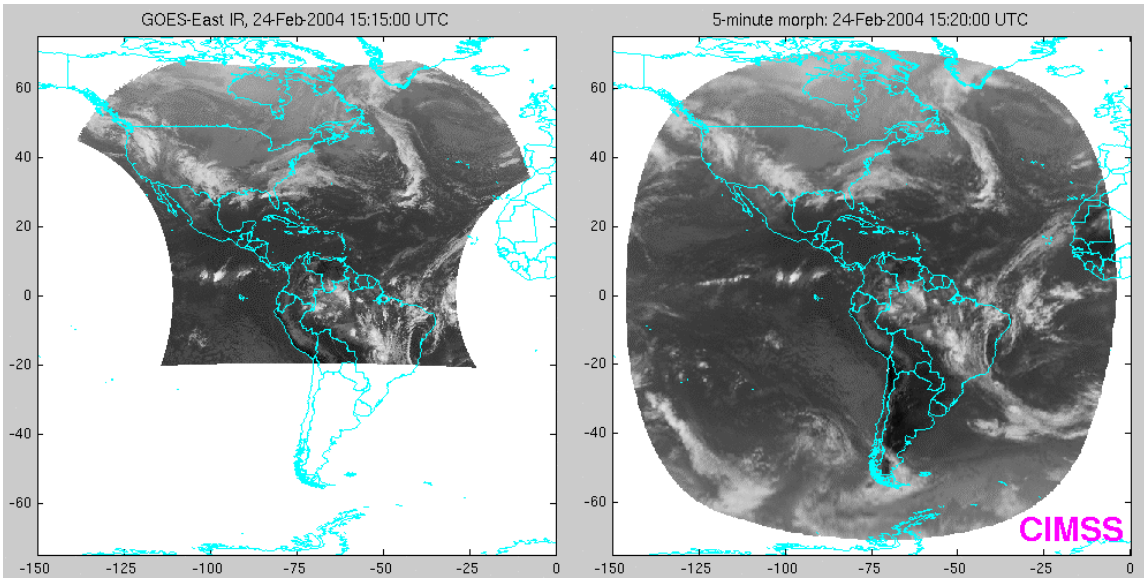

Figure 1. Frame from an animated comparison between the current GOES-12 coverage in a three-hour cycle (left) and a simulated 5-minute resolution time series over the same three hours (right).

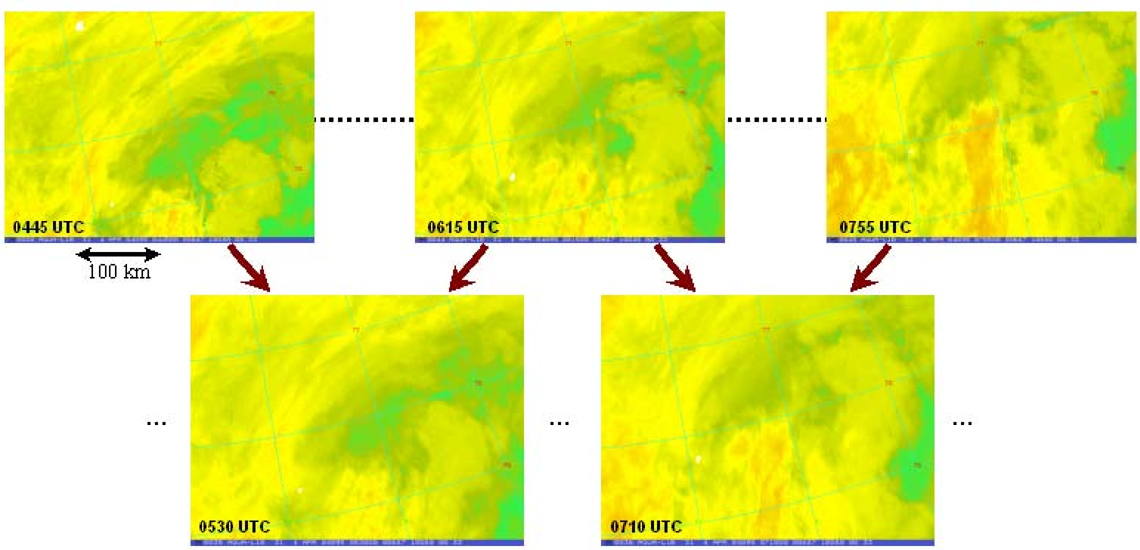

Figure 2. Top row: MODIS channel 31 (longwave infrared) imagery from sequential overpasses in the high latitudes east of Greenland (~100 minute time gaps); bottom row: synthetic ABI imagery at middle times created by morphing the real images directly before and after.

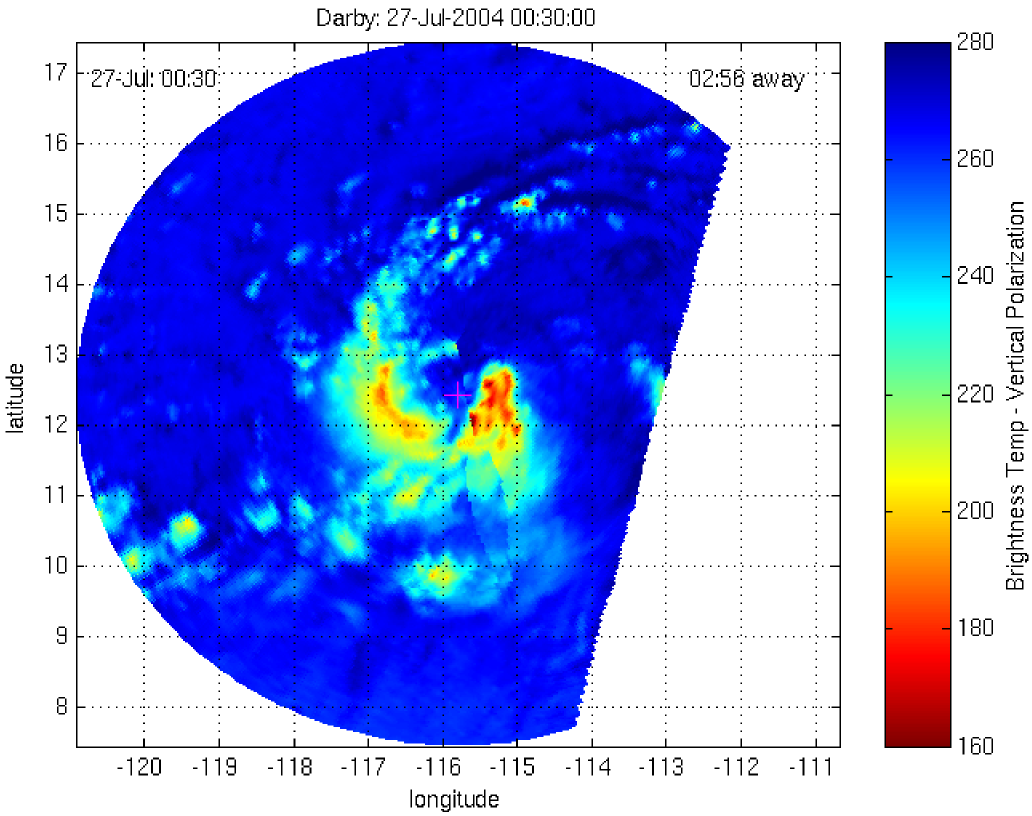

Figure 3. Frame from an animated morph of Hurricane Darby in the East Pacific basin. The text “02:56 away” indicates that the nearest real microwave image is 2 hours and 56 minutes away, either before or after the represented time (whichever is closer).