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A MODIS SEA SURFACE TEMPERATURE COMPOSITE PRODUCT

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1. INTRODUCTION

Short term forecasts of meteorological parameters (including precipitation) over the oceans is often difficult because of the lack of observations used to initialize the forecast models in these regions. While sea surface temperature (SST) fields derived from satellite and in situ data currently provided to the models provide some large scale information on surface forcing, the small scale gradients in SST that are important for regional forecast models, particularly in coastal regions, are not.

The mission of the NASA's Short-term Prediction and Research Transition (SPoRT) program (Goodman et al. 2004) is to accelerate the infusion of NASA Earth Science Enterprise observations, data assimilation and modeling research into NWS forecast operations and decision-making at the regional and local level. In support of this, a 1 km MODIS SST composite product has been developed to use in numerical weather prediction modeling to study the possible forecast improvement the high-resolution SST data provides.

In order to provide a high-resolution, spatially continuous SST product for assimilation into regional forecast models, daily MODIS SST data from the Aqua satellite were temporally composited and interpolated to a 1000 x 1000 km grid for the coastal region surrounding Florida. For the case study period of May 2004, the daily SST composites were assimilated into the SPoRT version of the Weather Research and Forecasting (WRF) predication system to study the improvement in short-term regional forecasts. This paper presents a description of the SPoRT Aqua MODIS SST compositing method, a comparison of the composite to independently produced GOES SST composites and the real-time global SST analysis field, and validated against GOES SST data and in situ buoy data. The results of the WRF forecasts are presented in the companion paper by LaCasse et al. (2006). Although only Aqua MODIS composites are discussed and used in this paper, the same method can be applied to Terra data with similar results.

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2. BACKGROUND

The May 2004 period was selected because of the predominately clear-sky conditions and the weather events associated with strong SST gradients that occurred doing this time. This produced optimal observing conditions for satellite remote sensing of the ocean surface in which to develop and test a compositing strategy with the satellite data. The applicability of the compositing method is currently being tested in an operational framework as part of SPoRT.

2.1 EOS MODIS SST

The Earth Observing System (EOS) Science Team MODIS Level 2 global SST (MOD28) is a daily global 1 km clear-sky infrared SST product (Brown and Minnett 1999) available from the Goddard Distributed Active Archive Center (DAAC) and in real-time from the University of South Florida, Tampa. The MOD28 SST product uses a linear retrieval equation based on the AVHRR algorithm. SST is calculated using two infrared channels of MODIS which are regressed to reference SSTs, normally Reynold's SST or the brightness temperature at 3.7 μm, and corrects for the effects of the atmosphere on the spectral radiances. For the May 2004 period SST data was obtained from the DAAC, and cloud contaminated pixels of SST were removed by applying the EOS MOD35 cloud mask product.

2.2 RTG-SST Analysis

The real-time global (RTG) SST analysis (Thiébaux et al. 2003) provides 0.5° x 0.5° resolution SST fields to operational weather prediction models. The RTG-SST is a two-dimensional variational interpolation analysis of in situ and satellite data collected in the 24 hours prior, which is generated once a day. On a global or large scale, the RTG-SST analysis is sufficient in depicting both the absolute SST values and the spatial changes, or gradients, of SST. However, on a regional scale the approximately 50 km resolution of the RTG does not provide the details needed by high spatial resolution forecast models.

2.3 GOES SST

The GOES SST data is provided by NOAA National Environmental Satellite, Data, and Information Service (NESDIS). The product combines 30 minute GOES-12

Imager data that uses two of the five available channels (3.9 and 11µm) to produce hourly SST files.

Removal of both cloud-contaminated radiances (via a cloud mask) and radiances that are affected by sun glint at 3.9 µm, precede application of a regression-based SST retrieval algorithm (Maturi et al. 2004). The resulting files are sub sampled (Maturi, personal communication) to produce the 6 km horizontal resolution lat/lon grids ranging from 60°N to 45°S latitude and from 180°W to 30°W longitude.

3. SST COMPOSITING METHODS

3.1 SPoRT MODIS Composite

The SPoRT MODIS SST composite uses the EOS 1 km SST product to produce a detailed and spatially continuous SST field while minimizing cloud contamination and latency effects. Although the case study investigation did not require a time-efficient algorithm, a quick compositing approach was employed to support future real-time data assimilation activities for Florida coastal National Weather Service offices as part of the SPoRT program. Note that the real-time SPoRT SST composite product uses the SPoRT MODIS cloud mask (Haines et al. 2004). Work is still under way to refine the SST composite algorithm for real-time use.

The compositing approach is based on the assumption that day-to-day changes in SST values are relatively small and that for a given region SST values from a preceding day will represent the actual (current day's) values quite well. The validity of this assumption may vary spatially and seasonally as oceanic and atmospheric forcing create higher frequency changes in SST values and can be examined by measuring the accuracy of the SST composite as a function of data latency. Several versions of the compositing method were evaluated during the development process. These methods are described below and evaluated in section 4.

The compositing approach begins with the collection of the five most recent clear SST values (as determined by a cloud mask) for each pixel within the domain separately for daytime Aqua passes (approximately 1:30 p.m. local time) and nighttime Aqua passes (approx. 1:30 a.m. local time). Figure 1(a-e) shows images of the five most recent SST values used for the daytime May 8th 2004 composite, with (a) showing the most recent values, and (e) the oldest. Each image can contain data from several different days, sometimes resulting in large pixel-to-pixel variations. Cloud contamination can also cause erroneous values to be included. The key to creating a useful composite SST image lies in the combination of these most recent values to produce a continuous and accurate SST field while maintaining the fine spatial gradients observed in the individual SST fields.

An initial approach discarded the coldest and warmest of the five most recent, and averaged the remaining three. By not using the extremes, that is the coldest and warmest, the hope was to remove anomalies and cloud contamination in the data. However, it was found by not using the warmest, much of the most recent data was lost. An improved approach which included the warmest values (version 2) is presented in Fig. 1(f). Version 2 averages the warmest three of the five, discarding the coldest two, and thus removing a significant number of cloud contaminated pixels. Version 2 was the composite assimilated into the WRF for the May 2004 period (LaCasse et al. 2006).

Version 2 generated an excellent representation of the true SST field for the May 2004 period, but limitations for real-time applications are readily apparent. In particular, with the frequent occurrence of hurricanes during the summer of 2005, the version 2 product did not capture the cooling of the SSTs after the hurricanes had passed over the water until much later, and therefore was also not capturing the magnitude of the cooling. A modification to the compositing approach was developed to help reduce the latency of the product and alleviate this problem (version 3; Fig. 1(g)). Version 3 takes the three most recent, discards the coldest because of cloud contamination, and averages the remaining two. The two versions look very similar and both provide a spatially consistent SST image with detail horizontal structure, but differences can be seen. For example, version 3 has slightly warmer regions, particularly noticeable in the southwest region of the domain, but also has some cloud contamination off the west coast of Florida.

For each of the products, latency information is also computed. The latency is provided in units of days, and is computed by averaging the dates of the SSTs values used for the composite. The latency images of versions 2 and 3 are shown in Figs. 1 (h) and 1 (i), respectively. The improved latency of version 3 over version 2 can easily be noted by the increase in red, orange and yellow colors across the image.

3.2 FIT GOES Composite

The Florida Institute of Technology (FIT) produced a GOES SST composite using the NESDIS GOES SST for the May 2004 period (Lazarus et al. 2006). The composites were generated by overwriting a previous SST with a new hourly value. Cloud and/or sun glint contaminated values were not overwritten and the SSTs from the previous hourly GOES file were retained. Processing a sufficient number of hourly files resulted in a product containing no data voids. Although the SSTs were updated hourly, persistent cloud cover did, at times, lead to SST composites that were unrepresentative. For this reason, latency information was calculated so that it was possible to identify areas containing old data. The latency is defined as the amount of time, in hours, since a given grid point was updated with a new value. The GOES SST composite at 19 UTC for May 8th 2004 is shown in Fig. 1(k). The latency of this product is shown in Fig. 1(l). The GOES latency is presented in units of hours, with black representing values older than 40 hours.

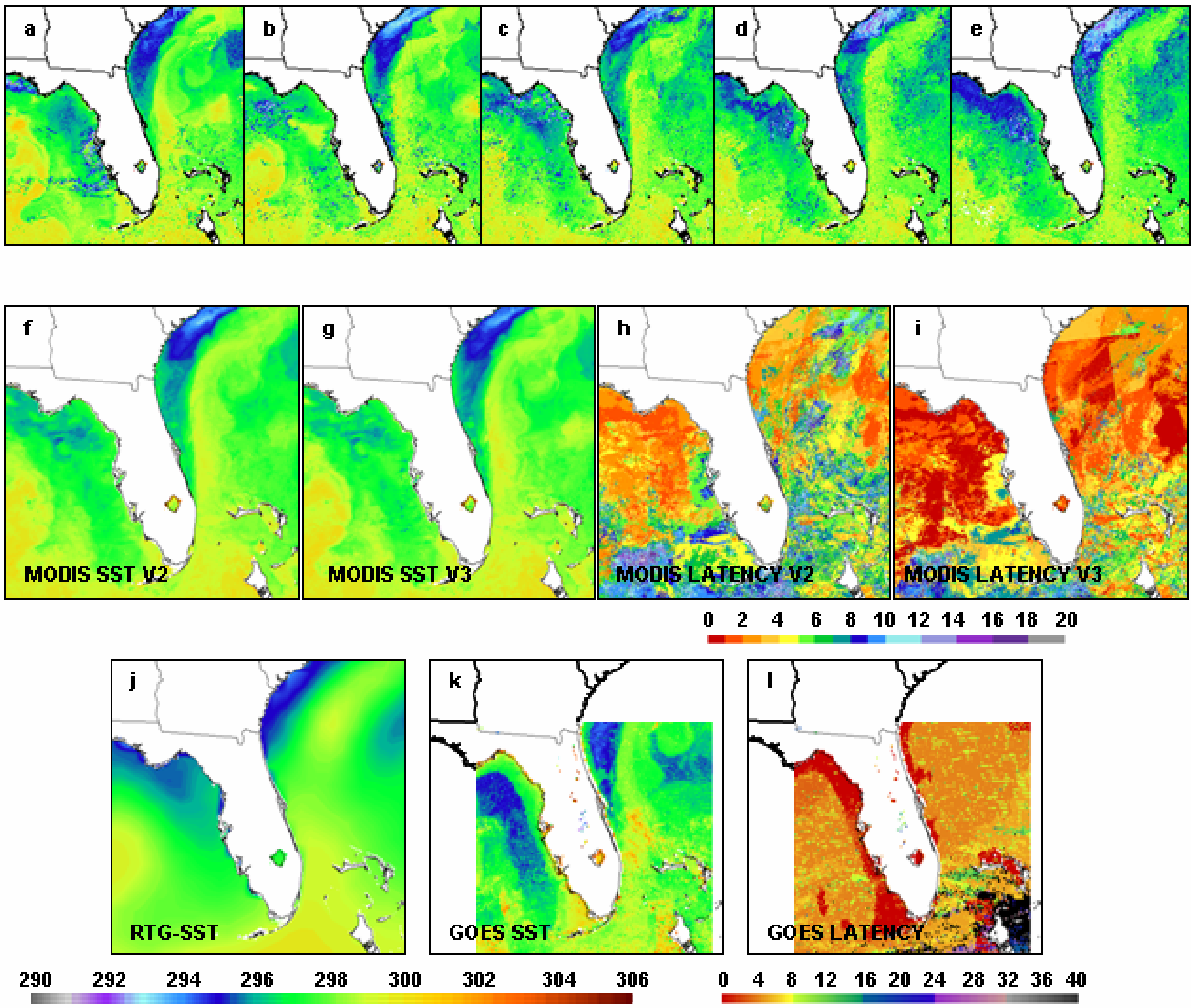

FIG. 1. The five most recent clear values (a – e) used to generated the daytime version 2 (f) and version 3(g) MODIS SST composites (in Kelvin) for May 8th 2004. The latency images (in days) of the MODIS composites are shown in (h) and (i). The RTG-SST analysis for May 8th is shown in (j), and the GOES 19 UTC May 8th composite image and corresponding latency image (in hours) are shown in (k) and (l).

4. RESULTS

4.1 SST Composite Comparisons

The SST composite images in Fig. 1 can be compared both to each other and to the RTG-SST field shown in Fig. 1(j). The MODIS composites (f and g) compare well to the RTG-SST field, but contain much more spatial variation as a result of the increase in resolution. The GOES product shows similar SST patterns and spatial information as the MODIS products, although striping is noticeable, particularly in the north-east region of the domain, but has much larger variations of SST across the domain. This can be explained by the difference in latency (Fig. 1 (l)) across the domain as explained below. One of the most important features seen in these images is the strong SST gradient off the east coast of Florida. Convection often occurs in this region because of the strong SST gradient, and is therefore very important for model input, but the gradient is not present in the RTG analysis.

Figure 2 provides image examples of the MODIS versions 2 and 3 composites, the GOES composites, their three corresponding latency images, and the RTG analysis for both (a) daytime, and (b) nighttime on May 29th, 2004. Again, the MODIS composites exhibit the most spatial variation, and the strong SST gradient off the east coast is again easily distinguished in the GOES and MODIS images but not seen as far south in the RTG image.

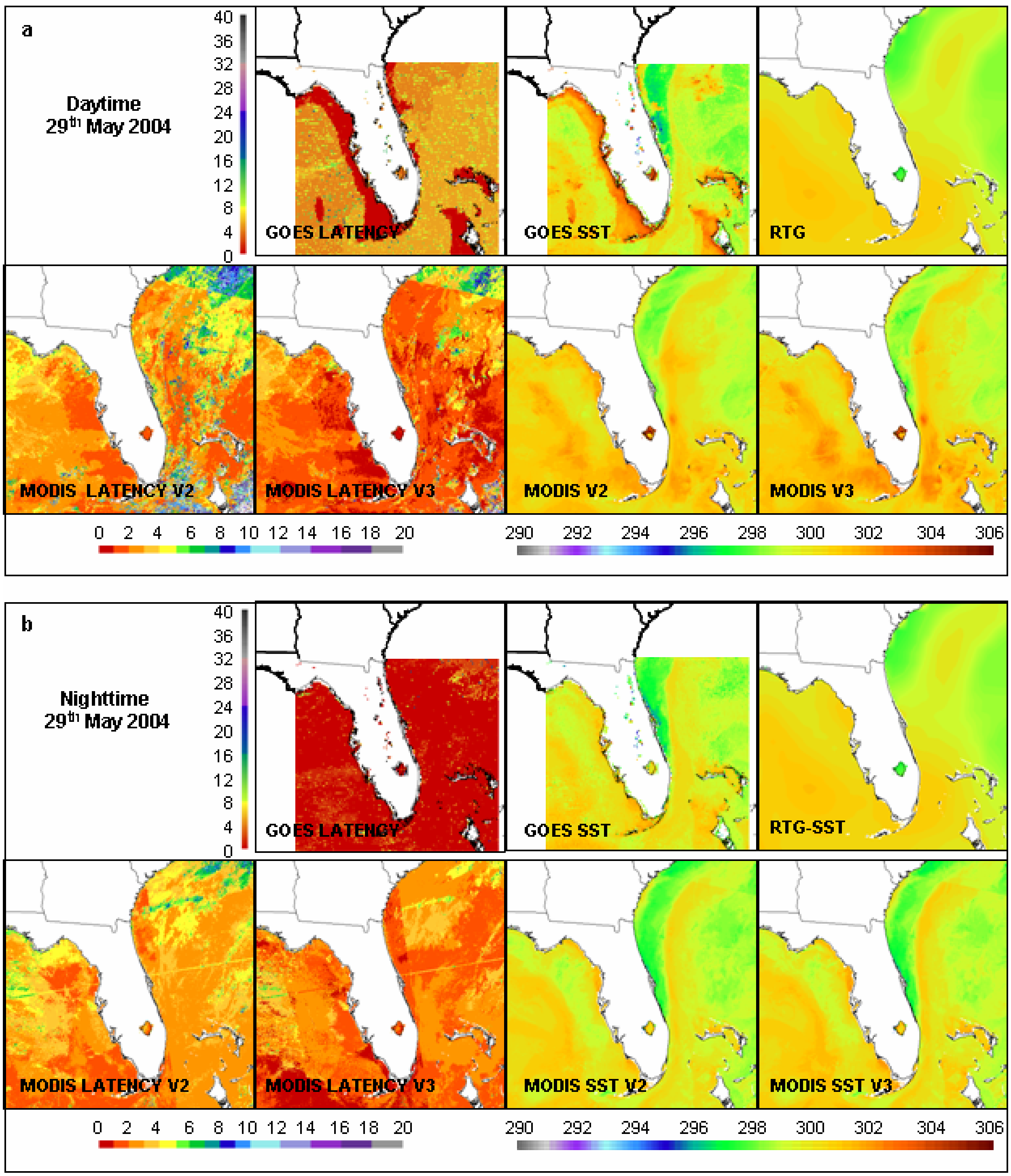

FIG. 2. SST daytime (a) and nighttime (b) composites for May 29th 2004. The images on the top rows, starting from the left, are the GOES composite latency image (in hours), the FIT GOES composite, the RTG composite. On the bottom row, starting fro the left, are the MODIS versions 2 and 3 latency images (in days) and the MODIS SST versions 2 and 3 composites.

Comparing the two MODIS composites, version 3 contains more recent data than version 2 for both day and night, as indicated by the latency images, but only small changes can be seen in the composites, indicating that the SST fields do not change dramatically from one day to the next.

Notice that the latency of the GOES nighttime product is almost all 0 – 2 hours, resulting in a composite containing just the most recent data and should therefore be a close representation of the actual SST field at that time (obviously dependent on the accuracy of the GOES SST product itself). Even though the MODIS composites contain data that is days older, the magnitudes of the MODIS SSTs compare very well to the GOES nighttime product. However, the GOES daytime images (Fig. 1 and Fig. 2) contain both much warmer (sun glint contaminated pixels off the coast), and much cooler values (recent data removed by cloud masking) than seen in the RTG and MODIS images (work is currently being done at FIT to correct these issues with the GOES composites). The GOES daytime composites comprise of data as much as 6 - 8 hours old, as well as the current hour's data, resulting in much larger spatial variations. The diurnal change in SST, as seen in the GOES composites, can therefore cause more spatial differences in the composites than daily changes, as seen in the MODIS composites.

4.2 SST Composite Validation

Limited validation of the MODIS SST composites is made by comparisons to buoy data, which are considered ground truth. As is always the issue with the validation of satellite products against ground truth, there are limitations to consider. Namely, the comparison of point data to areal data, and the comparison of SST measurements taken approximately 0.6 m below the surface to retrievals derived from satellite signals from the surface (skin) of the water.

Two buoy comparisons are discussed in this paper; buoy 41012 in the Atlantic Ocean 75 km east northeast of St. Augustine, Florida, and buoy 42036 in the Gulf of Mexico 200 km west northwest of Tampa, Florida. Figures 3 and 4 show the daytime and nighttime, respectively, plots of SST at these two buoy locations at times close to the average pass time of Aqua for May 2004. The correlation values of the RTG, the GOES SST and the MODIS composites to the buoy data are included on the plots. Also included in the figures are plots of the latency of the two MODIS composites. GOES SST data was not available for the daytime plots because of an over determination of clouds in the GOES SST processing. The GOES data on the nighttime plots (Fig. 4) are the actual derived GOES SST values, not values from the GOES SST composite.

Figure 3(a) shows the daytime SST values for buoy 41012. Notice the large change in the buoy SST that occurs between days 139 and 143. The MODIS and RTG products exhibit a warming the following day (day 140), with the MODIS version 3 product coming closest to the buoy values. The MODIS products also have the highest correlation to the buoy during this time as well as for the whole period. The improvement in latency from version 2 to version 3, as shown in Figs. 3(b) and 3(d), directly relates to an improvement in SST as compared to the buoy values.

Figure 3(c) shows the daytime values for buoy 42036. The RTG and MODIS products are very similar to the buoy values (as indicated by the correlation values), except after the peak in temperature that occurred on day 129. Both the MODIS products capture the increase in temperature without a delay, but take several days to recover to the lower temperature. Again the reduced latency plays a large role, with version 3 representing the cooling sooner because of the inclusion of newer data.

Figure 4 presents the same plots as Fig. 3 but for nighttime, and with the inclusion of GOES SST values on clear nights. The MODIS composite values for buoy 41012 are generally too cold compared to the buoy, probably because of both the latency of the MODIS products and the difference between the surface temperature and the temperature measured at 0.6 m below the surface by the buoy. Version 3 is slightly warmer than version 2, and therefore has a higher correlation to the buoy data. The RTG is too warm, as would be expected because it is a daily product. Also, as expected because it is a real-time product derived at the time and location of the ground truth data, the GOES values compare well to the buoy values.

At the buoy 42036 location (Fig. 4(c-d)), both of the MODIS SST composite trends are very similar to the buoy values, except during the 140 -144 day period. When the latency of the MODIS composites decreased on day 145, the comparison to the buoy data significantly improved, highlighting the need to reduce the latency as much as possible.

For each of the examples in Figs. 3 and 4, the correlation coefficients of the MODIS composites to the buoy data either improve upon or compare very well to both the RTG and the GOES correlation values. Considering that the RTG draws heavily on the buoy data in its analysis and that the GOES data were instantaneous values (i.e. no latency), the performance of MODIS composites during the May 2004 period was excellent.

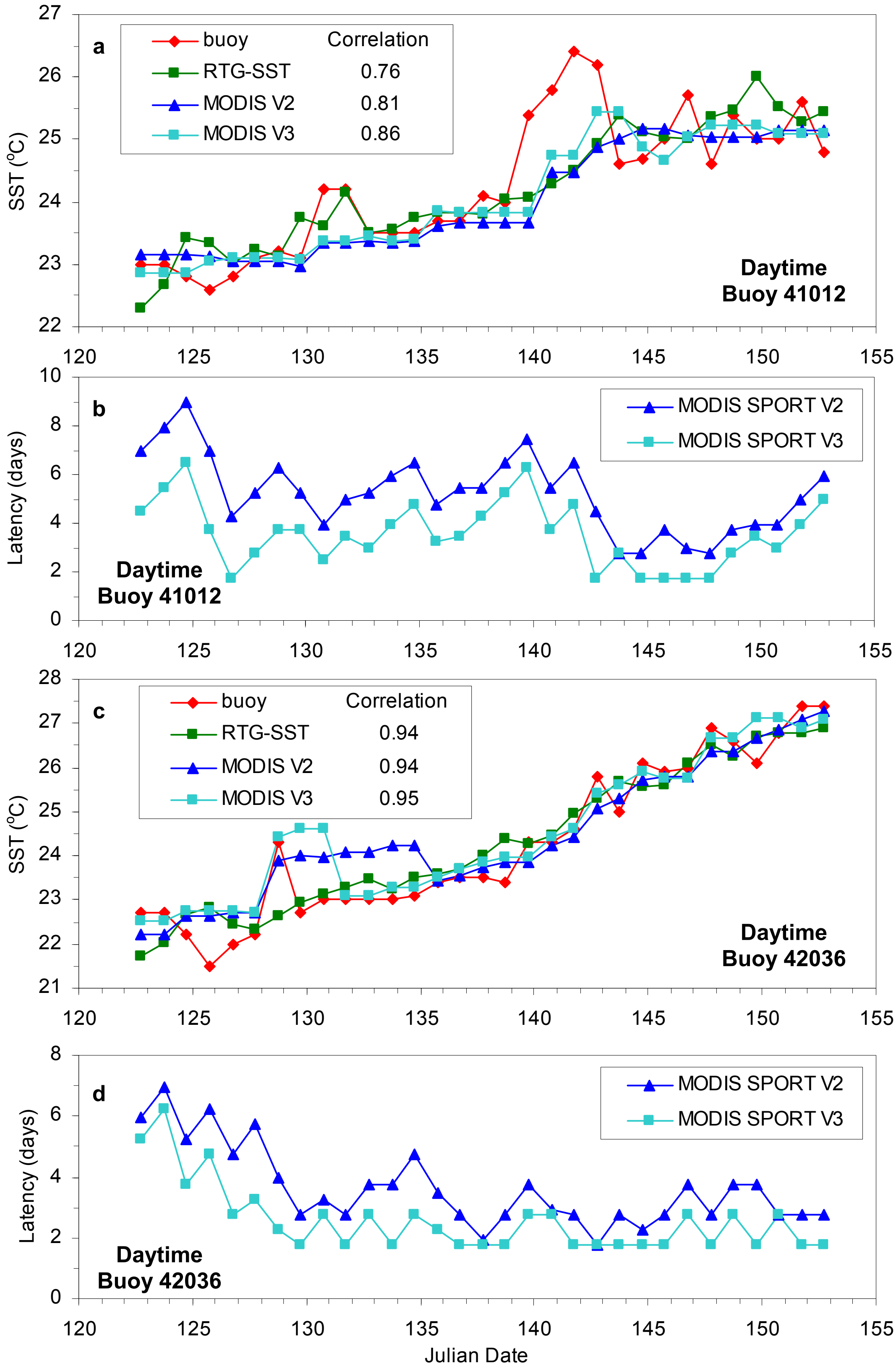

FIG. 3. Plots of daytime SST from the RTG analysis and the MODIS SST composites for buoys 41012 (a) and 42036 (c). The latency plots of the MODIS composites are shown in (b) and (d).

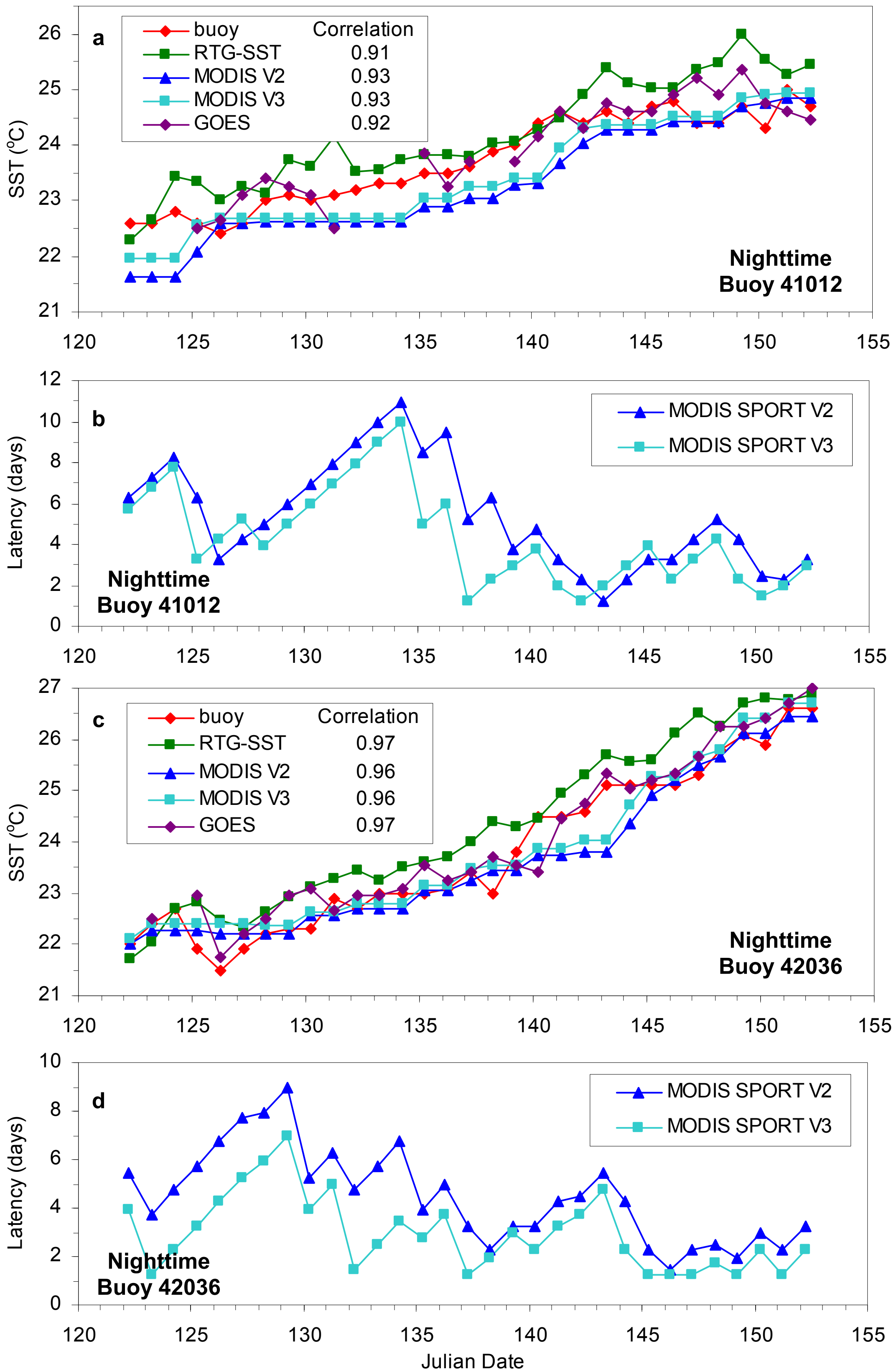

FIG. 4. Plots of nighttime SST from the RTG analysis and the MODIS SST composites for buoys 41012 (a) and 42036 (c). The latency plots of the MODIS composites are shown in (b) and (d).

5. CONCLUSIONS AND FUTURE WORK

An Aqua MODIS SST composite was generated for the month of May 2004 for assimilation into the SPoRT WRF forecast model. Various compositing methods were considered, with the second and third being discussed and validated in this paper. The two SPoRT MODIS composites were compared to the RTG-SST field, and a GOES SST composite. It was found that hourly changes, as least for this case study, have a bigger effect on the SST fields than daily changes such as seen in the MODIS composites. The MODIS composites were also found to contain the most spatial variation with few erroneous values. A limited validation of the composites was performed with comparisons to buoy data.

Overall the MODIS SST composites compare well to the buoy data, but with some deviations. By looking at just the plots in Figs. 3 and 4, the argument could be made that the RTG (and maybe the GOES composite) do as well or better than the MODIS composites and therefore the MODIS composites are not needed. However, the validation against the buoys only provides limited validation of the products, and also doesn't convey the spatial variation in SST that can be so important and is the obvious advantage of the MODIS composites.

Considering the two MODIS composite methods discussed in this paper, version 3 improved the latency of the product and therefore improved the performance. However, because the composite is relying upon clear-skies and the coverage of MODIS data, the latency can still be too high. Therefore, a version 4 technique is currently being worked on that will include AMSR-E SST data that, although is at a coarser resolution, will improve the latency of the product without significantly reducing the high spatial information provided by the MODIS data.

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REFERENCES

Brown, O. B., and P. J. Minnett, 1999: MODIS infrared sea surface temperature algorithm - Algorithm Theoretical Basis Document. Products: MOD28. ATBD Reference Number: ATBD-MOD-25.

Goodman, S. J., W. M. Lapenta, G. J. Jedlovec, J. C. Dodge, and T. Bradshaw, 2004: The NASA Short-term Prediction Research and Transition (SPoRT) Center: A collaborative model for accelerating research into operations. Preprints, *20th Conf. on Interactive Information Processing Systems (IIPS)*, Seattle, WA, Amer. Meteor. Soc., CDROM, P1.34.

Haines, S. L., G. J. Jedlovec, and F. J. LaFontaine, 2004: Spatially varying spectral thresholds for MODIS cloud detection. Preprints, *13th Conf. on Satellite Meteorology and Oceanography*, Norfolk, VA, Amer. Meteor. Soc., CDROM, P7.9.

LaCasse, K., M., W. M. Lapenta, S. M. Lazarus, and M. E. Splitt, 2006: The impact of MODIS SST composites on short-term regional forecasts. Preprints, *10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, Atlanta GA, Amer. Met. Soc., CDROM, 1.3.

Lazarus, S. M., C. G. Calvert, and M. Splitt, 2006: Multi-platform real-time sea surface temperature analysis for the initialization of short-term operational forecasts. Preprints, *10th Symp. on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, Atlanta GA, Amer. Met. Soc., CDROM, 6.12.

Maturi, E., A. Harris, N. Nalli, C. Merchant, S. McCallum, R. Meiggs, and R. Potash, 2004: NOAA's Operational Geostationary Sea Surface Temperature Products. Preprints, *20th Conf. on Interactive Information Processing Systems (IIPS)*, Seattle, WA, Amer. Met. Soc., CDROM, P2.4.

Thiébaux, J., E. Rogers, W. Wang, and B. Katz, 2003: A New High-Resolution Blended Real-Time Global Sea Surface Temperature Analysis. *Bull. Amer. Met. Soc.*, **84**, 645–656.