A KALMAN FIELTER APPROACH TO INTEGRATE PRECIPITATION INFORMATION FROM SATELLITE AND GAUGE OBSERVATIONS OVER THE GLOBE

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1. INTRODUCTION

Over the past decade, systematic efforts have been made at the NOAA Climate Prediction Center (CPC) to construct high quality, high-resolution global precipitation analyses through integrating information from multi-sensor, multi-platform satellite observations. Called CPC Morphing technique (CMORPH, Joyce et al. 2004 [1]), an innovative algorithm was developed that combines estimates of instantaneous precipitation rates derived from passive microwave (PMW) observations of all available LEO satellites through propagating and morphing them via the cloud advection vectors derived from consecutive infrared (IR) images from geostationary platforms. The CMORPH satellite precipitation analysis has been produced on an 8kmx8km resolution over the globe (60^oS-60^oN) for an 11-year period from November 1998 to the present [2]. Intercomparison and validation studies illustrated excellent performance of the CMORPH estimates in capturing precipitation variations of various time / space scales [3].

The second generation CMORPH is under development to further improve the performance through a) adopting the Kalman Filter (KF) technique for refined accuracy and enhanced flexibility in incorporating additional inputs, and b) adjusting the all-satellite combined estimates against gauge observations to remove biases. The objective of this paper is to report the progress of the development of this new blending technique.

2. THE KALMAN FILTER BASED CMORPH

Under the Kalman Filter framework, precipitation analysis defined at step (k+1) Z_{k+1} is computed from the analysis at the previous step (Z_k) and the additional observations (O_k) through the following equation:

$$Z_{k+1} = Z_k + K_k \cdot (O_k - Z_k)$$

where K_k is the Kalman gain defined from error for the previous analysis (σ_k) and the observations (σ_o):

$$K_k = \sigma_k^2 / (\sigma_k^2 + \sigma_o^2)$$

In our application, PMW estimates from multiple LEO platforms are first propagated backward and forward to produce the ‘predicted’ analysis at the target analysis time. The prediction is then refined by incorporating information from IR-based estimates at the target time to form the final analysis.

The PMW precipitation estimates used in this study include those from TRMM/TMI, AQUA/AMSR-E, SSM/I aboard DMSP satellites and NOAA/AMSU-B. The IR-based estimates used here are from the IRFREQ developed at CPC through PDF matching of the IR cloud top temperatures against that of the collocated PMW estimates and are available globally at 30-min intervals.

Key to the development of the KF CMORPH is the definition of error structure for the propagated PMW and IR-based estimates as a function of instrument type, propagation time, location, and season. A preliminary test is first performed to define the error (expressed as correlation) through comparing the IR-based precipitation estimates and the PMW estimates propagated through various length of time against the Stage-II radar observations over CONUS for summer 2007.

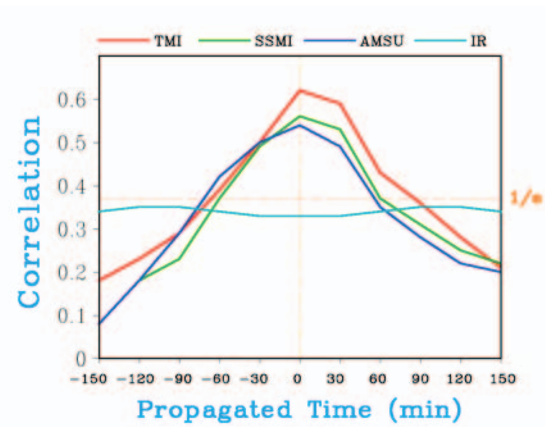

Figure 1:
Correlation for the IR-based and PMW propagated precipitation estimates as a function of instrument type and propagation time computed by comparisons with Stage-II radar data over CONUS for JJAS 2007. Positive and negative propagation times indicate forward and backward propagation, respectively.

Correlation for the PMW estimates degrades shapely as they are propagated from their observation time (figure 1). The magnitude and the degradation rate of the correlation, however, differ for different instruments, indicating the importance of defining the error separately for estimates from different platforms. The IR-based precipitation estimates outperform the PMW estimates when the propagation time is longer than 90 minutes or so, suggesting potential improvements in the final analysis through the inclusion of IR estimates to fill in PMW observation gaps.

Using these error statistics, a conceptual model for KF-CMORPH is developed to construct high-resolution precipitation estimates over CONUS. The precipitation analysis produced by the KF-CMORPH is re-calibrated through PDF matching against the original PMW and IRFREQ precipitation estimates to reduce the damping in high precipitation intensity caused by linear processing of the Kalman Filter. The final analysis is compared against the radar observations to examine their quantitative accuracy. Precipitation estimates generated by the KF-CMORPH present consistently improved accuracy compared to those from the original CMORPH (figure 2).

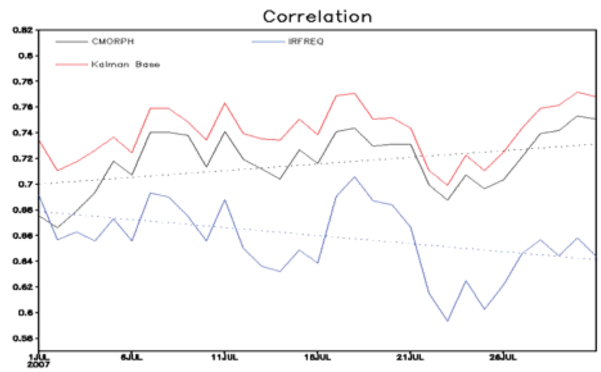

Figure 2:
Time series of correlation between radar-estimated precipitation and satellite precipitation estimates derived from a) IR observations (blue); b) the original CMORPH (black); and c) the prototype Kalman Filter (KF) CMORPH over CONUS (red).

This conceptual model is further modified and implemented for constructing the precipitation estimates over the global domain from 60°S to 60°N. Error statistics for PMW and IR-based precipitation estimates are defined for individual instruments as a function of region and season through comparisons with the concurrent estimates from the TRMM/TMI. Evolution of estimation error over the propagation period presents strong regional variations, indicating differences in the time scales of the target precipitation systems.

The prototype Kalman Filter based CMORPH is applied to generate high-resolution precipitation analysis for a 6-month period from April – September, 2009 for further tests and examinations.

3. REMOVING BIAS IN SATELLITE ESTIMATES

As shown in many validation studies, CMORPH and all other satellite-based precipitation estimates contain regionally dependent and seasonably changing biases. One way to remove the bias is to combine information from gauge observations. To this end, we have developed a prototype algorithm to remove the CMORPH bias through matching the probability density function (PDF) of the daily CMORPH with that of a daily gauge analysis produced routinely at NOAA/CPC [4].

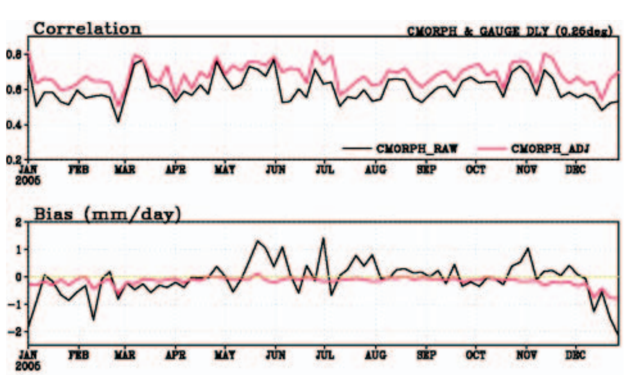

Figure 3:
Time series of correlation between the daily gauge-based analysis of precipitation and the daily estimates from a) the CMORPH (black), and b) the bias-corrected CMORPH over the global land.

This bias correction is performed for each 0.25°lat/lon grid box over the global land and updated daily on a real-time basis. First, co-located daily CMORPH and gauge analysis data are collected over grid boxes with at least one gauge over a spatial domain centering at the target grid box and a 30-day time period ending at the target date. The PDF for the CMORPH is then created and matched against that of the gauge analysis to correct the biases. To examine the effects of this procedure, the bias corrected CMORPH estimates are compared against gauge analyses over the entire global land. As shown in figure 3, seasonally changing biases in the original CMORPH are removed substantially after the correction, and the correlation for the bias-corrected CMORPH is improved by ~0.05 upon that for the original CMORPH.

4. SUMMARY AND FUTUREWORK

A prototype algorithm has been developed for the second generation CMORPH. First, the Kalman Filter technique is adopted to integrate the PMW and IR precipitation estimates using error statistics computed as a function of instrument type, propagation type, location and season. The blended satellite precipitation estimates are then adjusted against a gauge-based analysis through PDF matching to remove the bias. The prototype algorithm is applied to produce 30-min precipitation analysis on an 8kmx8km resolution over the globe for a six months period from April – September 2009. The results showed substantial improvements of the new analysis compared to the previous version. Further work is underway to fine tune the error statistics, include information from additional sources (e.g. radar observations and model simulations), and to extend the domain to the entire global domain from pole to pole. Detailed results will be reported at the conference.

5. REFERENCES

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