P6.7 PHYSICAL RETRIEVAL FOR PRECISE SATELLITE SST MEASUREMENTS - GOES-R RISK REDUCTION STUDY

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1. Introduction

A physical algorithm is developed to allow precise sea surface temperatures to be derived from a combination of satellite Hyperspectral Sounder (HS) and Multi-spectral Imager (MI) data, as one of the Geostationary Operational Environmental Satellite-R (GOES-R) Risk Reduction studies. The physics of the algorithm involves the formulation of the radiative transfer equation, including the surface emission, the upwelling atmospheric emission, and the surface reflected sky radiation. The accuracy goal is 0.2 C, which requires the solution to accurately account for the surface emissivity and reflectivity and the atmospheric temperature, water vapor, and trace gas contributions to the observed upwelling radiance. In order to account for these contributions, high spectral resolution HS radiance spectra, as will be measured by future operational satellites, are required. However, HS observations will be at a spatial resolution where cloud contamination will often affect the measured radiance spectra. Under these conditions, low spectral, but high horizontal, resolution radiances, from a companion MI must be used, both to detect HS cloud contamination and to infer the sea surface temperature in geographical regions where the HS data are affected by partial cloudiness. The multi-sensor sea surface temperatures are combined in such a manner that the transition from clear field of view HS to partly cloudy HS field-of-view MI sea surface temperature determinations is relatively seamless (i.e., partly cloudy HS fields-of-view MI determinations possess approximately the same accuracy as the HS clear fields-of-view). This characteristic is accomplished by adjusting the partly clouded HS field-of-view MI sea surface temperature for local differences in the HS and MI sea surface temperatures obtained for surrounding HS clear sky fields of view. This paper provides a description of the multi-sensor algorithm and presents results from applying this algorithm to Aqua satellite Atmospheric Infrared Sounder (AIRS) (HS) and the Moderate Resolution Imaging Spectroradiometer (MODIS) (MI) measurements. These algorithms will be applied to the GOES-R Hyper-spectral Environmental Suite (HES) and Advanced and Baseline Imager (ABI) data to achieve precise sea surface temperature measurements during the next generation satellite era.

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2. Sea Surface Temperature Algorithms

Considerable progress is being made in the development and demonstration of a physical algorithm for the determination of Sea Surface-skin Temperature (SST) and emissivity. The algorithm is being developed for use with simultaneous GOES-R HES and ABI radiance measurements. The algorithm can be used for model independent SST retrieval and/or in the NWP model radiance assimilation process. SST accuracy better than 0.2 K, depending upon sky condition (i.e., clear or partly cloudy), is the goal. In order to achieve this very high accuracy goal, the sea surface emissivity and atmospheric profiles of temperature and moisture must be simultaneously derived in order to account for viewing angle and sea state (i.e., surface wind speed), and the atmospheric temperature and moisture profile dependence of the observed radiances.

In brief, the inverse solution of the non-linear radiative transfer equation, in its variational form, is obtained (Rogers, 2000). The true surface emissivity is assumed to be a constant percentage of the nominal sea surface emissivity spectrum for nadir viewing of calm sea conditions (Wu and Smith, 1997). To account for sea state and view angle variability a dynamical solution for the emissivity constant will be performed. The final iteration of the inverse solution includes on-line/off-line radiance residuals as the input radiance measurements. This step provides a final adjustment to the surface temperature and emissivity that produces a tight radiance fit to the amplitude of the weak line absorption lines across the window region, thereby accounting precisely for the surface reflected sky radiation. A final check of the solution is provided by the computation of surface emissivity and surface temperature using the on-line/off-line radiance equations provided by Xie (1993). If agreement exists between the on-line/off-line solution and the inverse solution of the radiative transfer equation, convergence is assumed; otherwise, the inverse solution is iterated until convergence is achieved.

The methodology is being tested using the Aqua satellite Atmospheric Infrared Sounder (AIRS) and Moderate Resolution Imaging Spectro-radiometer (MODIS) 10-14 μm radiance observations. The European Centre for Medium-Range Weather Forecasts (ECMWF) model atmospheric state data is being used as the initial state. The two areas selected for this study are the Gulf of Mexico and the western Atlantic coastal region of the eastern US for February 5, 2005. A precise Line-By-Line Radiative Transfer Model (LBLRTM) is being used (Clough et al., 1992, 1995). However, before applying this methodology to actual radiance observations, the method needs to be thoroughly tested using simulated AIRS radiances for sample atmospheric and surface conditions. An example of such a simulation is presented here.

3. Validation

After considerable investigations of the sensitivity of surface temperature retrieval to atmospheric state and surface emissivity uncertainties, using very time consuming line-by-line radiative transfer calculations, a retrieval methodology was developed which enables the surface temperature and emissivity to be retrieved with the desired accuracy of 0.2 C. As an example, this accuracy is demonstrated from simulated AIRS radiance data, for an initial surface skin temperature error of -1K, an initial surface emissivity error of -1%, an initial atmospheric temperature error of +2 K, and an initial atmospheric water vapor volume mixing ratio error of -5 %, error magnitudes approximating those expected to be inherent in oceanic analyses of assimilated surface, satellite, aircraft, and radiosonde observations. Figure 1 shows the radiance residuals associated with this case.

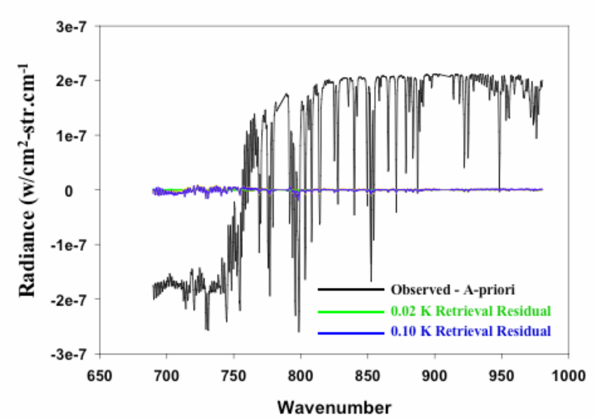

Figure 1: Radiance residuals (observed minus calculated) for the a-priori initial state and after surface temperature/emissivity and atmospheric profile retrievals assuming random measurement brightness temperature errors of 0.02 K and 0.1 K, representing nearly noise free and realistic radiance observation error conditions, respectively.

As can be seen, the solutions, which were obtained in three iterations, closely satisfy the observed radiance spectrum. Figure 2 below shows the retrieved emissivity and surface temperature for the 0.02 K (~ noise free) and 0.1 K (realistic) radiance measurement error conditions, respectively. As can be seen, the surface skin temperature is retrieved accurately, with an error less than 0.1 K, for realistic errors in the radiance brightness temperature and initial surface and atmospheric state conditions. This very high degree of sea surface temperature accuracy is attributed to the ability of the retrieval model to account for the actual atmospheric profile and surface emissivity conditions associated with the radiance measurement spectrum. Of course, the accuracy that will be achieved with actual radiance observations will be somewhat lower than that demonstrated here, due to uncertainties in the forward radiative transfer model used and due to spectral calibration errors which impact the on-line/off-line determinations of surface emissivity.

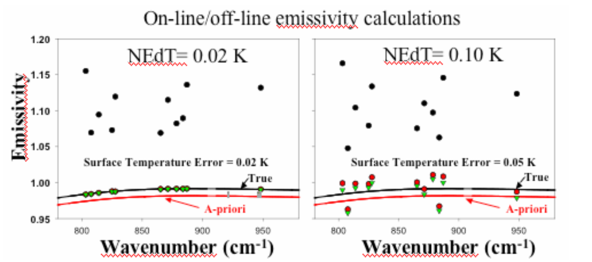

Figure 2: On-line/off-line calculations of surface emissivity from the observed radiances for the a-priori atmospheric state (black circles) and atmospheric retrievals obtained with and without the use of the on-line/off-line radiance differences in the inverse solution (red circles and green triangles, respectively).

4. Future Work

In spite of the apparent success of the retrieval algorithm developed under this project, there is much more work that needs to be accomplished to demonstrate the ability to achieve the desired accuracy when much larger atmospheric state errors and forward model errors exist, although we believe the retrieval methodology should handle these larger uncertainty situations. In order to minimize the amount of calculation time required, we only considered the spectral region from 690 - 1000 cm^{-1} for the retrieval. We believe that by including the water vapor band (i.e., 1200 - 1600 $cm^{-1)}$ and the shortwave N_2O/CO_2 and window bands (i.e., 2000 - 2700 cm^{-1}), the impact of initial state water vapor profile, surface temperature/emissivity, and temperature profile errors on the sea surface temperature retrieval will be further reduced; however, for the case of the shortwave observations, the contribution by surface reflected sunlight must be modeled. The technique will be applied to actual AIRS and National Polar-Orbiting Environmental Satellite System (NPOESS) Airborne Sounder Testbed Interferometer (NAST-I) radiance data to assess the accuracy under real measurement conditions. Simulations will be performed for a wide variety of surface and atmospheric condition initial state errors in order to provide a statistical assessment of the robustness of the algorithm under varying surface, atmospheric, and radiance measurement conditions.

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