13.4 ANALYSIS OF POLAR SATELLITE DATA IN LAPS USING RTTOV

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1. INTRODUCTION

The Local Analysis and Prediction System (LAPS) was conceived in the late 1980s at the Forecast Systems Laboratory (FSL) (McGinley et al. 1991). LAPS fills an anticipated need in the future local forecast office. The large data volumes generated from current and planned data acquisition systems overwhelm forecasters because it is impractical to review all the available data in the time allowed to generate a timely forecast. An analysis system that integrates available real-time data will produce a timely comprehensive synopsis of the atmospheric state. Furthermore, LAPS goes beyond subjective application, and the feasibility of forecasting with local-scale numerical models initialized from LAPS analyses has been demonstrated (Stamus and McGinley 1997). This paper explores the application of infrared sounder data from polar satellites in LAPS using a radiative transfer (RT) model for television infrared orbiting satellite (TIROS) operational vertical sounder (TOVS), or RTTOV.

FSL's operational LAPS typically operates on a 10 km mesh approximately centered over Denver, Colorado. The square grid is 600 km on each side and the vertical coordinate is pressure with 50 hPa increments spanning 1100 hPa to 100 hPa.

LAPS background fields are interpolated from Rapid Update Cycle (RUC) or Mesoscale Analysis and Prediction System (MAPS) 60 km national scale forecasts (Benjamin 1991). LAPS fields routinely generated include state variables (*t, p, z, u, v, w*, and *q*); special fields such as clouds, cloud type, and precipitation; derived fields such as lifted index (*LI*), *LI* x *w*, and integrated precipitation over time. Many of the derived fields resolve aviation forecast problems.

LAPS is currently being integrated into AWIPS; soon a framework will exist within the forecast office to provide local analysis and forecasting capability (Schultz 1998). This work is targeted at improving the treatment of satellite data for National Weather Service (NWS) application.

Throughout its development history, the LAPS developers have concentrated on incorporating new data sources into its schemes with the most benefit for its intended application at the NWS local forecast office. Recently, interest has been shown in running LAPS in regions removed from the nominal set of familiar data sources; this need has arisen primarily from international efforts. To date, domains have been analyzed in Bosnia (Wagoner et al., 1996), China, and more are planned for other overseas applications (i.e., Sydney 2000 Olympic Games). With these activities external to the United States, we lack the Geostationary Operational Environmental Satellite (GOES) coverage that we have depended on for years for LAPS satellite data. GOES data have many advantages, such as the exceptional temporal continuity that is vital in local scale analysis and monitoring especially for severe weather. When using analyses for model initialization, we anticipate that polar satellite data can offer significant benefit in data-sparse areas especially if the model runs are scheduled at a time coincident with a polar pass. Polar data are also available at all locations on the globe, including our laboratory, making it an attractive data source for development, one that can be studied in-house to determine its value. We can then anticipate its performance to be the same overseas. Another advantage is that code maintenance becomes standardized since only one satellite (or instrument) is involved. Using our expertise with GOES, we can test the polar data along side GOES during development to verify that similar analysis adjustments occur.

The logical progression of our work is to follow TIROS high resolution infrared radiation sounder (HIRS) with TIROS microwave sounding unit (MSU) data and then progress to microwave applications with the defense meteorological satellite program (DMSP) data. Thus we will eventually be utilizing microwave satellite data in LAPS. This work is providing a foundation to exploit polar satellite data of all types given that the algorithms we develop to handle navigation and integration of data into the LAPS format is similar for all polar sensors.

2. USAGE OF SATELLITE DATA IN LAPS

TIROS data used in LAPS originate from high resolution picture transmission (HRPT) files. In particular, the TIROS ingest software processes the TOVS information. TOVS consists of radiation measurements in 19 IR spectral regions from the shortwave (4.3 μ) to the longwave regions, as well as, the visible wavelength (0.69 μ).

An intermediate processing step exists between the LAPS ingest and the raw HPRT files. The primary function navigates the data to earth locations (latitude and longitude) and computes the brightness temperatures for each IR channel using the interactive TIROS processing package (ITPP). The LAPS ingest software directly reads the ITPP-produced files and computes the map transformation information for each

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HPRT file. Because the TOVS data resolution is approximately 42 km along the satellite track, this mapping is not time-consuming it only takes about 2 minutes to process each intermediate file.

Because the TIROS sounder data resolution is more than four times the LAPS grid spacing, decisions were made on how to handle the disparity in analysis grid versus sensor resolution (see section 4 below). The ingest software also processes swaths that only partly cover the domain; however, this experiment used a swath that completely covers the domain (Fig 1.).

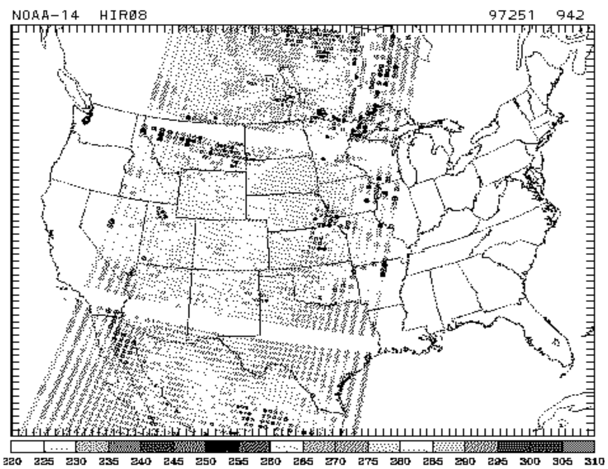

Fig 1. Plot of a typical NOAA 14 HIRS data swath over North America for the date studied, 8 September 1997 at 0940 UTC.

3. RTTOV

The forward model/variational solution was selected to be RTTOV, a radiative transfer model obtained from ECMWF. RTTOV solves both the forward model problem plus the gradient matrix "K matrix," adjoint, and tangent linear operators. Here the gradient matrix is used to solve a one-dimensional (1D) or three-dimensional (3D) variational solution to reconcile the analyzed thermal and moisture profiles with measured satellite radiances. The 1D variational (1Dvar) minimum variance solution of the vertical profile, *x,* is solved by Eyre (1989) using

$$x = x^b + CK^T(E + KCK^T)^{-1}(y^m - y(x^b)) \tag{1}$$

where x^b is the background vertical profile vector containing thermal and moisture data from modified model background data along with climatology above 100 mb. C is the covariance error matrix of the background, K is the gradient matrix from RTTOV, E is the covariance error matrix for the HIRS channel data, y^m is the measured radiance vector, and $y(x^b)$ is the forward modeled radiance vector computed from the background vertical profile using RTTOV.

The solution is only applied in clear areas even though methods exist to handle clouds in the model. We selected this approach for convenience, since we are using the model for the first time. For cloud detection we rely on the LAPS cloud analysis that uses GOES data in its current formulation.

4. LAPS MOISTURE ANALYSIS

In practice, the forward model was run for each clear grid point, and corrections were made to *x*. For this experiment, only the moisture profile was used in the subsequent LAPS analysis, but eventually thermal and cloud adjustments can be made. For each TIROS grid point at each LAPS level, a scale factor is computed as

$$s = \frac{q_t}{q_i} \tag{2}$$

where q_t is the TIROS corrected specific humidity (SH) and q_i is the initial SH before the variational step (i.e., value corresponding to the vector x^b at the grid point in question).

After working through all of the clear grid points a sparse 3D set of scale factors is generated. A two-dimensional continuous Barnes analysis is then computed for the scale factors at each LAPS level. These scaling fields are used to derive the adjusted SH for the entire field in cloud clear areas from the initial LAPS SH. The Barnes step allows application to regions outside of the TIROS swath (partial domain coverage case), and for regions initially rejected by the HIRS channel 8 filter step (discussed in the next section), or data dropouts.

Analyzing a scaling term has advantages and disadvantages. Scale factor products will never go negative (the main reason this approach was selected). Unknown are possibly the error characteristics of analyzing scale factors as opposed to bias differences with Barnes. However, the current LAPS analysis that employs a GOES variance solution works well with this approach.

A number of spatial considerations must be addressed. Initially we thought we could assign radiances to represent all grid points encompassed by the field of view (FOV). However, clouds in LAPS can be of better resolution than attainable from HIRS alone (indeed advanced very high resolution radiometer (AVHRR) imagery can be used for better cloud characterization and is being investigated by others, but the current LAPS system here does not yet use AVHRR). Furthermore, we find ourselves in a very diverse terrain area. Great terrain discontinuities within a FOV can have dramatic consequences in modeling radiative transfer. Consider a FOV that straddles the Colorado Front Range containing both 14,000 ft mountains juxtaposed with plains that are almost 9,000 ft lower in elevation. The way to reconcile the effects of terrain variability is difficult when the forward model is designed to simulate the atmosphere above a location with uniform surface characteristics. It is unlikely that averaging the surface characteristics over such FOVs will match observations due to terrain effects alone (even given uniform moisture and an adiabatic temperature distribution). This is further complicated when one considers applying TOVS to the 3D variational scheme with a grid resolution like LAPS. Unless we are careful, large FOV satellite data could wipe out the horizontal spatial detail provided by a sensor with a high spatial resolution.

Our approach assigns the FOV (typically 900 km^2) to only one LAPS grid point central to the FOV, while at the same time tightening the radiometric constraints that had to be met in order to accept the data into the scheme.

5. FORWARD MODEL AGREEMENT

As an initial step in applying the RTTOV system to LAPS, we checked modeled against measured radiances to demonstrate proper navigation and to determine if the model formulation was functioning correctly. Figure 2 shows a typical plot of modeled and measured brightness temperature for NOAA 14 using a combination of LAPS thermal and moisture profiles with climatology data (for regions above 100 hPa and ozone). The comparison in the window channel was also used as a sanity and additional cloud check. If the absolute modeled and measured channel 8 HIRS brightness temperature difference was more than 4 K, that FOV was excluded from variational computation. Such measures illustrate the conservative nature of our approach. Indeed, a tight rejection criteria will disallow correction to large LAPS-satellite differences, but should work most of the time assuming LAPS reasonably describes the atmospheric state. On the other hand, we are safe-guarding against radical solutions that are perhaps due to terrain or cloud-caused effects. Until this is better understood, a conservative approach is preferred.

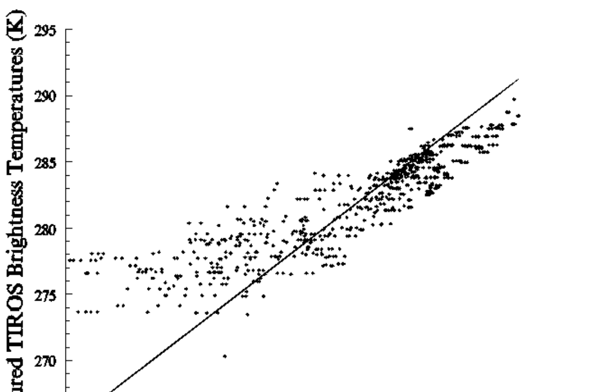

Fig. 2. Plot showing measured vs. computed brightness temperatures for HIRS channel 8 for the same pass as Fig 1. Radiances differing by more than 4 K have been filtered at this point.

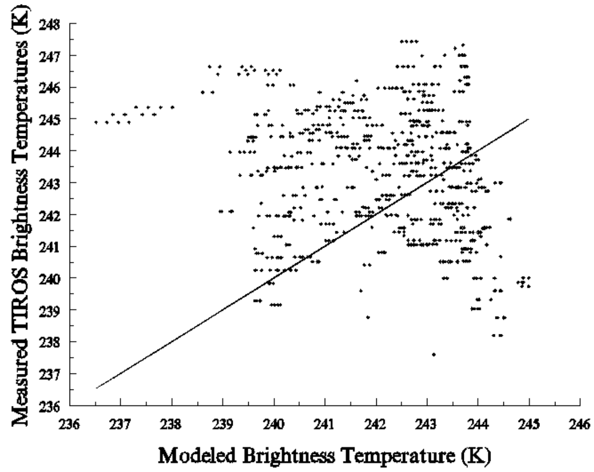

Fig. 3. Plot showing measured vs. computed brightness temperature for HIRS moisture channel 12 for the same sample set as Fig. 2.

Figure 3 shows the HIRS moisture channel 12 which peaks near 500 hPa from the same dataset screened in figure 2. Generally, points show more scatter indicating that moisture first guess is not as close as the thermal first guess, with some points showing the measured brightness as cooler (more moist) or warmer (drier).

The Barnes analyzed scaling field for the 600-hPa level is shown in Figure 4. The field extends over the entire LAPS domain but it is applied only in cloud-free areas. Moisture in cloudy regions is a function of cloud fraction. Recall the cloud information is from GOES. For this level the scaling factor ranges from 0.32 to 1.68.

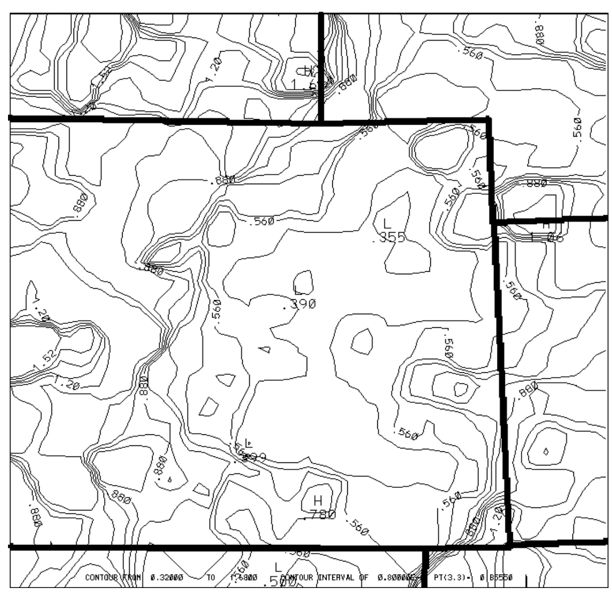

Fig 4. Contour plot of the 600 hPa *s* value from (2) over the LAPS domain from same NOAA 14 pass in earlier figures.

6. SUMMARY AND PLANS

Modeling tests similar to that done for GOES moisture studies (Birkenheuer 1998) will be conducted for one or two case studies, drawing upon the techniques presented. The progress of this work will be reported at the time of the conference.

We remain committed to utilizing polar satellite radiance data in LAPS. Further work will follow along the current lines, with these known exceptions. RTTOV will likely be replaced with the optical transmittance (OPTRAN) model. This work was intended to use OPTRAN when started last spring, but OPTRAN was not made available to us until the summer of 1997. Since the work was begun with RTTOV, we decided to see it through for the first phase. The switch to OTPRAN, now scheduled for the fall of 1997, will become our forward radiance model to use with both polar and GOES data. OPTRAN will enable us to maintain one radiance model for a variety of satellites, an approach we hope will reduce software maintenance.

Other enhancements are planned including the exploration of modifying both thermal and moisture profiles using satellite data. 3Dvar solutions will be examined, along with better error descriptions for the covariance matrices used. A nonlinear cloud solution may be attempted, but that is farther down the list of priorities already mentioned. We will likely investigate the use of HIRS or AVHRR data for cloud identification since porting LAPS overseas will end possibilities of using GOES data for cloud screening. However, we will not rule out using Meteosat or geostationary meteorological satellite (GMS) data for IR window band applications in our cloud and surface analyses, especially if these data are readily available where we port LAPS.

Finally, whether to use large FOV data with domains containing topographical extremes will need more study. Effective ways to approach this problem will likely be examined when 3Dvar experiments are conducted.

7. REFERENCES

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