TOWARDS A STRATEGY FOR INFRARED EMISSIVITY

Thomas J. Kleespies
NOAA/NESDIS
Camp Springs, MD USA

1. INTRODUCTION

Radiative transfer calculations are becoming so accurate that variations of infrared emissivity from unity are now important. In the context of numerical weather prediction, emissivity is required for accurate cloud detection and clearing, and to determine land skin temperature for surface energy flux calculations. The problem is that emissivity is bound with skin temperature in the surface term of the radiative transfer equation. There are additional difficulties with inhomogeneities in the field of view, and variations of the emissivity of some materials with wavelength.

Figure 1 gives an estimate of the impact of ignoring the emissivity problem. This figure shows the difference in brightness temperature for HIRS channels 7, 8 and 9 for the US Standard Atmosphere with the emissivity set to unity, and the emissivity set to that specified by the Surface and Atmospheric Radiation Budget (SARB) working group of the Clouds and the Earth's Radiant Energy System (CERES) mission. The biggest differences are in the regions of desert and high terrain, with differences in excess of 3K for channel 8. Note that the SARB emissivity is assumed constant over oceans. It is clear that one can not assume a fixed emissivity over the entire world. This paper will suggest several ways of dealing with the surface emissivity problem.

2. OCEAN EMISSIVITY

Estimation of ocean emissivity is a relatively easy problem. There is a good estimate of the skin temperature from the sea surface temperature analysis. The surface within the field of view is relatively uniform. A number of methods have been presented to model ocean emissivity, including Cox and Munk (1954), Saunders (1968), Sidrin (1981), Masuda et al. (1988), and Watts (1996). These are all summarized in Watts (1996), who presents the most sophisticated model, including multiple reflections and anisotropy, but the model is specific to the Along Track Scanning Radiometer. A more general model is given by Masuda et al. (1988), who have tabulated emissivity as a function of zenith angle and wind speed for the mid- and near-IR window channels. We have performed a functional fit to the Masuda et al. tables, and generated the Jacobian for potential use in NWP. The Environmental Modeling Center of the National Centers for Environmental Prediction is presently using this fit to the Masuda model in the operational assimilation of GOES and HIRS radiances. An example of the difference in computing GOES radiances with fixed and Masuda emissivities is given in Figure 2.

3. LAND EMISSIVITY

Estimation of land emissivity is quite problematic. The skin temperature estimate is poor, and the surface within the field of view can be quite heterogeneous. In addition, there can be shadow effects in the daytime. Figure 3 illustrates the shadow effect. When two GOES satellites view the same sun lit location at the same time, they often yield different window channel brightness temperatures. This is because one satellite is seeing shadows of vegetation and structures, and the other is viewing the sunlit side, with a correspondingly warmer physical temperature. Both observations are correct, but they are different, and it is not clear how to handle this in an NWP environment. In a more general sense, the NOAA satellites are also affected, since the instruments view both the antisolar and the solar side of the scan. While the shadow effect may prove to be intractable, the following sections details some possible approaches for treating land emissivity.

3.1 Retrieve emissivity directly along with other parameters.

A simultaneous retrieval can retrieve emissivity along with other parameters. The advantages are that the solution satisfies the radiances, the code is relatively fast and compact, and that other data such as microwave channels can be included. However, it suffers from a lack of uniqueness of the solution. Errors in the lower atmospheric profile can manifest themselves as errors in emissivity, and vice versa. The potential for this technique perhaps lies with high spectral resolution instruments such as AIRS, IASI and CrIS.

3.2 Emissivity Retrieval

Considerable work has been done in the land science community in the arena of direct emissivity retrievals. However, most of this work has been done in the near-infrared. Very little work has been done in the mid-infrared. Some work presently being done at the Cooperative Institute for Meteorology and Space Science at the University of Wisconsin attempts to reduce the influence of emissivity on temperature and moisture estimation.

3.3 Retrieval skin temperature directly

This approach is usually some variation of the split window technique (McMillin, 1975). The technique is fast and computationally inexpensive. However, one of the underlying assumptions is that the emissivity is invariant between the two channels of the split window. This assumption is violated for some natural materials, particularly those containing quartz.

3.4 Static Emissivity Mapping

Emissivity could be determined by *a priori* data, such as that which produced Figure 1, which will eventually be available at 1 km resolution (K. Gallo, personal communication). This would be fairly inexpensive, only requiring a weighed average of the emissivities within the instrument field of view. However, the vegetation cover in most climates changes with the season, revealing the underlying surface, which can change the emissivity.

3.5 Dynamic Emissivity Mapping

The idea behind this approach is to us a data base of land classification, with accompanying emissivity data. The AVHRR could be used to determine the NDVI/ greenness fraction. The greenness fraction could be used to weight the emissivity between the fraction of the FOV covered by vegetation, versus the underlying soil type. Potentially this could be extended to multiple surface types. The use of *a priori* data has both positive and negative implications. It certainly makes the problem more tractable, but it also locks the solution into a partially fixed database. This approach can also be memory and computationally expensive.

3.6 Assimilate Effective Temperature Directly

This is the easiest and least expensive approach. Once the brightness temperatures are corrected for the atmospheric contribution, the result would be close to the skin temperature, but not exact. However, this approach does not help with the cloud clearing problem.

4. SUMMARY

The suggestions presented in this paper are in no means intended to give a comprehensive solution to the problem of infrared emissivity determination, but rather to identify some possible approaches for attacking the problem. There may be no ultimate solution to the problem, and any solution that is found to be workable may incorporate several of these proposed solutions, and others that were not proposed. None of what has been discussed here obviates the need for quality control. The intent here is to make better use of the infrared data in the future.

5. ACKNOWLEDGEMENTS:

The global emissivity maps were obtained from the CERES Surface Properties Home Page: http://tanalo.larc.nasa.gov:8080/surf_htmls/SARB_surf.html

6. REFERENCES

Cox, C., and W. Munk, 1954: Measurements of the roughness of the sea surface from photographs of the sun's glitter. J. Opt. Soc. Amer., 44, 838-350.

Masuda, K., T. Takashima, and Y. Takayama, 1988: Emissivity of pure and sea waters for the model sea surface in the infrared window regions. Remote Sens. Environ., 24, 313-329.

McMillin, L. M., 1975: Estimation of sea surface temperatures from two infrared window measurements with different absorption, J. Geophys. Res., 80, 5113-5117.

Saunders, P. M., 1968: Radiance of sea and sky in the infrared widow 800-1200 cm^{-1}. J. Opt. Soc. Amer., 58, 645-652.

Sidrin, M., 1981: Broadband reflectance and emissivity of specular and rough water surfaces. Appl. Opt., 20, 3176-3183.

Watts, P. D., M. R. Allen, and T. J. Nightingale,1996: Wind speed effects on sea surface emission and reflection for the along track scanning radiometer, J. Atmos. Ocean. Tech, 13, 126-141.

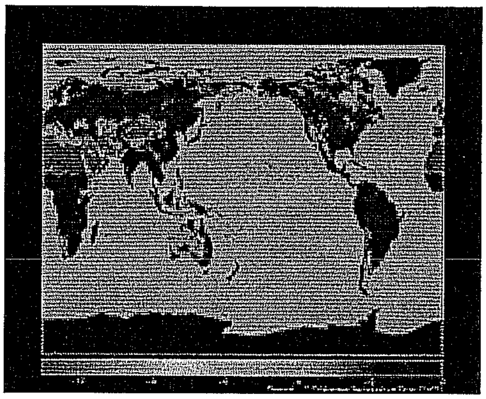

Fig. 1a Brightness temperature difference for HIRS channel 7 for unit emissivity minus SARP emissivity. Range is –1 to 0 K.

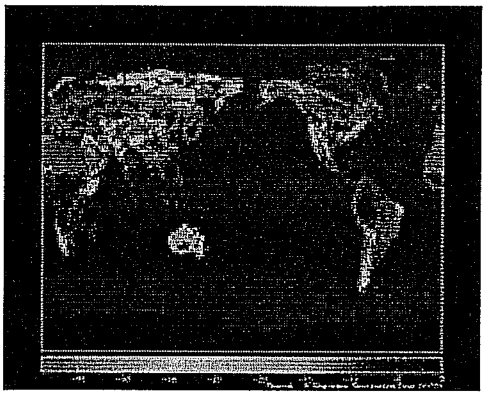

Fig. 1b Brightness temperature difference for HIRS channel 8 for unit emissivity minus SARP emissivity. Range is –4 to 0 K.

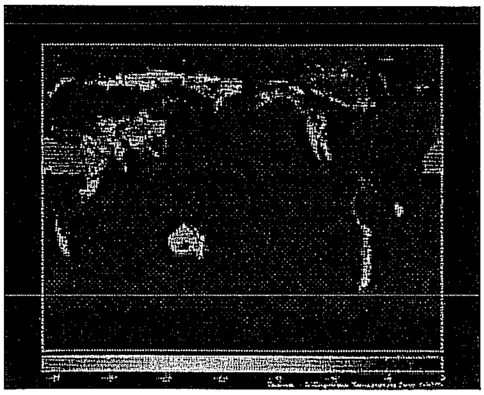

Fig. 1c Brightness temperature difference for HIRS channel 9 for unit emissivity minus SARP emissivity. Range is –3 to 0 K.

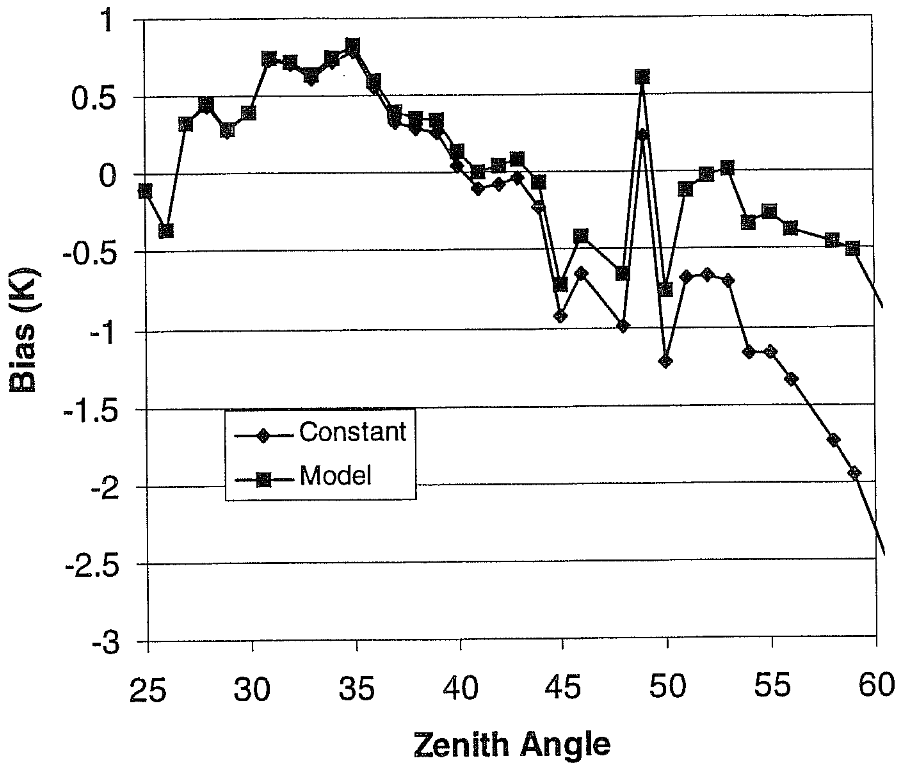

Fig 2. Bias between observed and computed GOES brightness temperatures as a function of Zenith angle for a constant emissivity, and for the Masuda et al. emissivity model. The large local variations are due to different populations within the zenith angle bins.

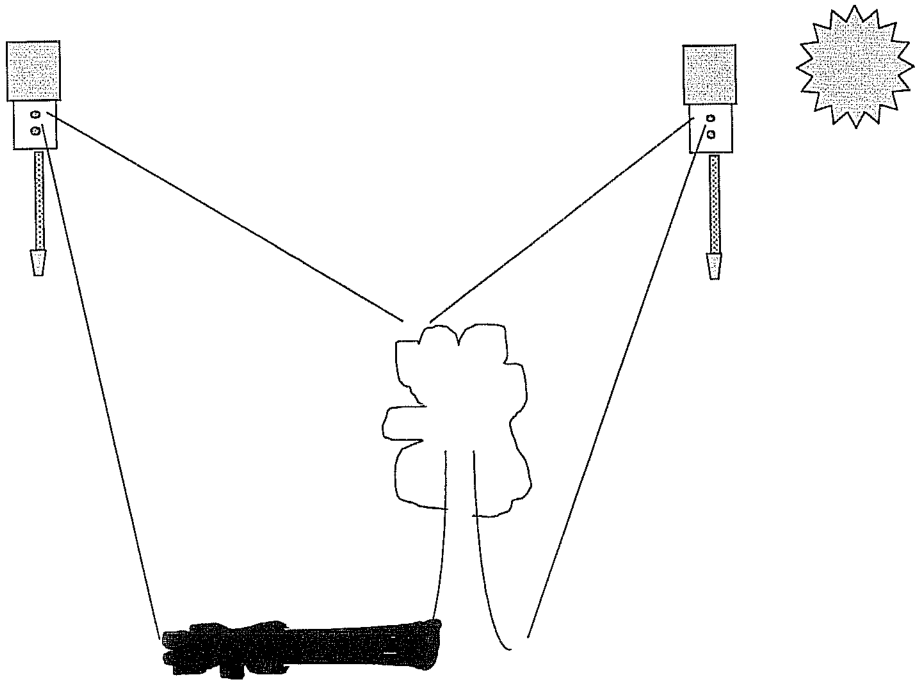

Fig 3. Illustration of the shadow effect for the GOES constellation