Matching observations to model resolution for future weather and climate applications

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ABSTRACT

High spatial resolution sounding observations will improve initialization and assimilation into the next generation forecast models and validation of the next generation of climate models. One such advanced sounder concept for low earth orbit is the Advanced Remote-sensing Imaging Emission Spectrometer (ARIES) which proposes to provide high spatial hyperspectral resolution observations in the mid to longwave infrared. This paper explores the effects of spatial resolution on the errors expected from the combined use of models and observations for representing scene information. We calculate the frequency response of the instrument and model and determine the error at any given spatial frequency. The results show that it is vital to have observations match the spatial resolution of models to minimize the uncertainty in the representation of the scene contents.

Keywords: Remote Sensing, Observations, Spatial Resolution, AIRS, ARIES

1. INTRODUCTION

The Atmospheric Infrared Sounder on the EOS Aqua Spacecraft measures the upwelling earth spectrum in 2378 channels in the infrared from 3.7-15.4 μm[1]. The AIRS spatial resolution is nominally 13.5 km at nadir and its radiance data are assimilated into the operational forecasts[2] and used for research in prediction of tropical cyclones, hurricanes[3] and regional weather[4]. Additionally, the AIRS Science Team has developed software to produce a wide range of geophysical products from AIRS including temperature and water vapor profiles, land and sea surface temperature, cloud products and a wide range of trace gases including ozone, carbon monoxide, methane and carbon dioxide[5]. This has made AIRS extremely valuable to scientists and researchers studying global climate change[6], particularly in the validation of climate models[7].

The Advanced Remote Sensing Imaging Emission Spectrometer (ARIES) is a measurement concept designed to improve upon the observations made from AIRS. Requirements for and science benefits of ARIES have been defined in earlier publications[8]. The argument for the higher spatial resolution has been made qualitatively in that it is generally recognized that as model spatial resolution increases, it is necessary to have observations that match the models to initiate them in the case of weather prediction models and for validation in the case of global climate models. Additionally, the models and observations together provide insight into the processes driving weather and climate and sufficient resolution on the order of the physical processes themselves is needed to adequately observe and represent them. Below we parameterize the expected error for a measured observable vs spatial frequency of the scene. It is assumed that the amount of information on processes is independent of frequency; i.e. there is just as much scene variability at high spatial frequencies as low spatial frequency.

2. THEORY

We ask the question, what is the degradation in the spatial frequency response of a model when data are assimilated from an observing system. If the spatial frequency of the observing system is higher than the model, usually, the degradation is minimal, however if the spatial response of the observing system is lower than the model, the degradation is substantial.

The spatial response of the observing system to the scene is given by the point spread function PSF. For this simple analysis, we consider a one-dimensional response function. Extrapolating the analysis to two dimensions is straightforward. The spatial frequency response of the observing system is the Fourier transform of the point spread function and is usually referred to as the Modulation Transfer Function.

$$MTF = F\{PSF(x)\}$$

The spatial frequency response of the model is simply the Fourier transform of the model spatial response, or a rectangle function of width equal to the model grid size. The combined response of the observing system and the model is the convolution of the spatial response function of each, or the product of their Fourier transforms.

$$R(f) = MTF(f) \bullet \frac{\sin(\pi df)}{\pi df}$$

Where d is the grid cell size of the model. The error at any frequency due to inadequate frequency response is given by

$$E(f) = 1 - R(f)$$

Figure 1 shows two examples of the effect of observations on the model response to scene information. Figure 1a shows a sensor resolution of 2 km on a 5 km grid size model. In this example, we assume the spatial response of the observation is a rectangle function whose resolution is defined by the width. We see a minimal degradation of the response of the combined system. Figure 1b shows the effect of a 14 km spatial resolution of the sensor on a 5 km grid model. In this figure we see the lower spatial resolution of the sensor dominates the spatial frequency response of the model, virtually reducing the sensitivity of the model to that of the observations.

The error , E(f) is shown in Figure 2 for varying sensor resolutions ranging from 1 km to 100 km.

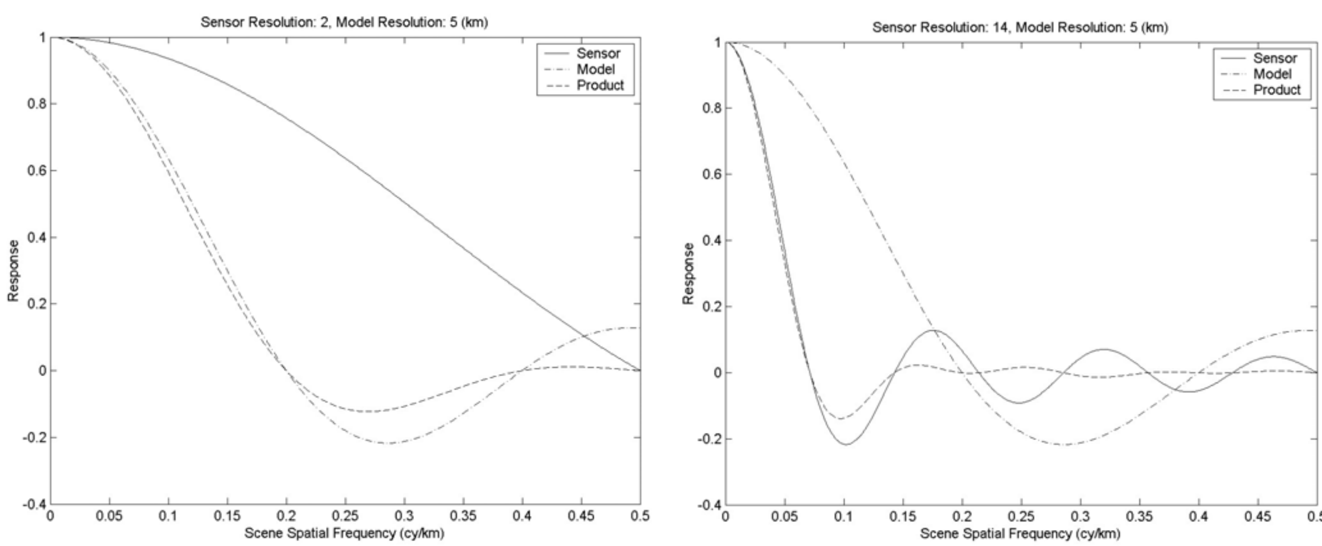

Figure 1a (left). Sensor resolution of 2km convolved with a model grid response of 5 km. 1b (right). Sensor resolution of 14 km on a model grid response of 5 km. Assimilation of observations of lower resolution greatly reduces the spatial frequency sensitivity of the model.

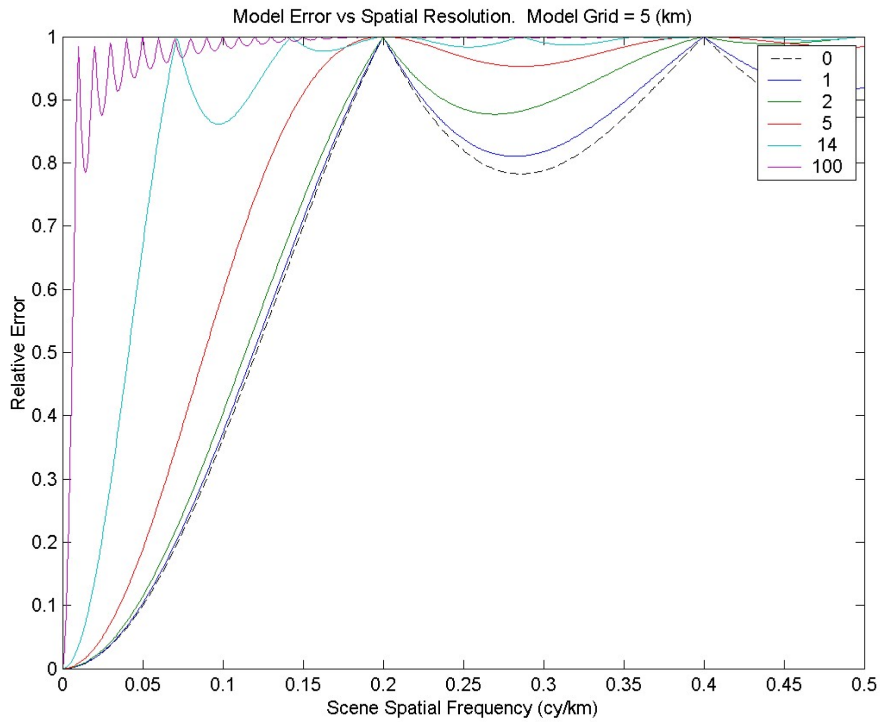

Figure 2. Residual error of convolved scene with resolution of 1km to 100 km and model with grid size 5 km. To minimize effects of assimilating observations, the resolution of the observation must be at least as good as the model itself.

3. RESULTS

For a 5 km grid size, Table 1 gives the frequency response and the resulting error at the model Nyquist frequency of 0.1 cy/km for the model alone and the model after assimilating data from the observing system. The model error at the Nyquist frequency is approximately 36%. For a matched model and observing system, the error is approximately 60%, but for an observing system of spatial resolution 2/5 of the model we see only 40% error, a reduction of only 4% in error.

For the ARIES system, this would indicate that the 1 km observing allowing for 2 km cloud cleared products would match well for models of grid size 5 km with minimal frequency response error.

Table 1. Response at $F_{Nyquist}$ = 0.1 cy/km for Model resolution of 5 km/.

IFOV (km)	Model (km)	MTF_{IFOV} (cy/km)	MTF_{MODEL} (cy/km)	R_{Conv} (cy/km)	E_{Model} (cy/km)	E_{Conv} (cy/km)
1	5	0.9836	0.6366	0.6262	0.3634	0.3738
2	5	0.9355	0.6366	0.5956	0.3634	0.4044
5	5	0.6366	0.6366	0.4053	0.3634	0.5947
14	5	-0.2162	0.6366	-0.1377	0.3634	0.8623
100	5	0.0000	0.6366	0.0000	0.3634	1.0000

4. SCENE FREQUENCY DEPENDENCE

The above analysis is relatively straightforward and not surprising. The question remaining is how will this ultimately affect the ability to extract information of geophysical processes in the scene. For this, it depends on the spatial frequency dependence and information content of the parameters of interest. It is not possible for us to examine the global spatial frequency dependence of all possible geophysical parameters, but we do illustrate here one example just to give us an idea of what to expect.

For this analysis, we take a sample MODIS Level 1B granule from September 1, 2004, granule 1840. The window channel, band 31, at 11 μm was analyzed for frequency dependence. Figure 3a shows an image of the granule, and Figure 3b shows the frequency content within the granule. For this analysis, the Fourier transform was acquired for each scan line, and then averaged for the entire granule. What we see is that after we get beyond the low frequency components of the scene and the granule boundaries, that there is a continuum of information at all frequencies up to the Nyquist frequency of the MODIS observation (approximately 0.5 cy/km). This is consistent with the assumption that the scene can contain a significant amount of information content at all frequencies.

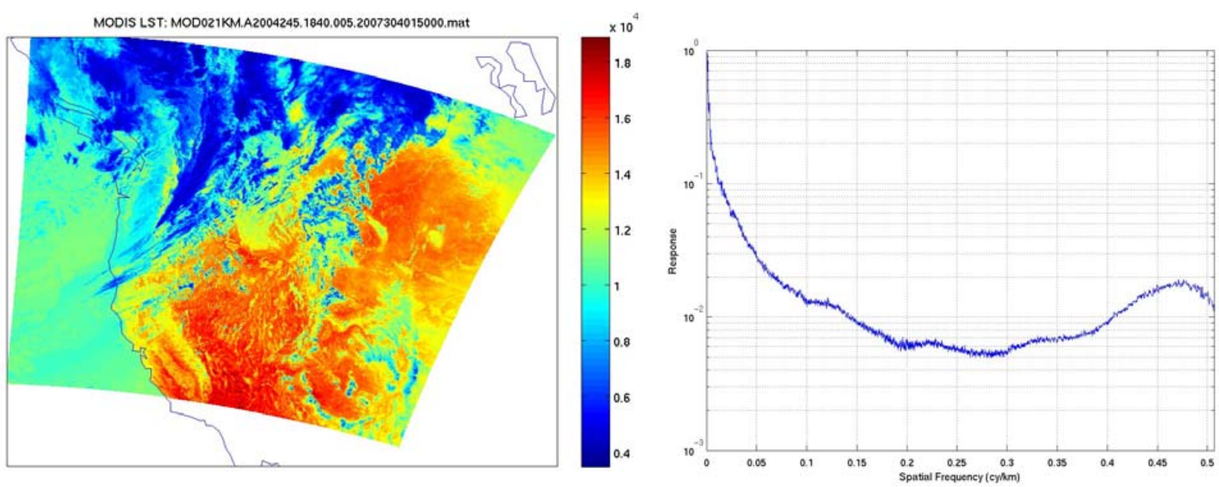

Figure 3a (left). MODIS L1B Granule 1840 from September 1, 2004. 3b (right) Average frequency dependence of the information in the granule.

5. CONCLUSIONS

The spatial resolution selected for ARIES must match the resolution of weather and climate models that will use the data. A spatial resolution requirement for ARIES of 1 km to 2 km will easily allow assimilation into and validation of weather forecasting and climate models respectively of 5 km or greater resolution. This is consistent with "regional" scale models and in particular will greatly benefit hurricane forecast models. The performance improvements achieved at the global level with weather and climate models from the AIRS can therefore be expected at the regional scale from ARIES.

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7. REFERENCES

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