Creating a Satellite Visible Image from Model Output

Visualizing Model Data Using a Fast Approximation of a Radiative Transfer Model

Valliappa Lakshmanan[1,2] Robert Rabin[2] Jason Otkin[3] John Kain[2]

[1]Cooperative Institute of Mesoscale Meteorological Studies
University of Oklahoma

[2]National Severe Storms Laboratory

[3]University of Wisconsin

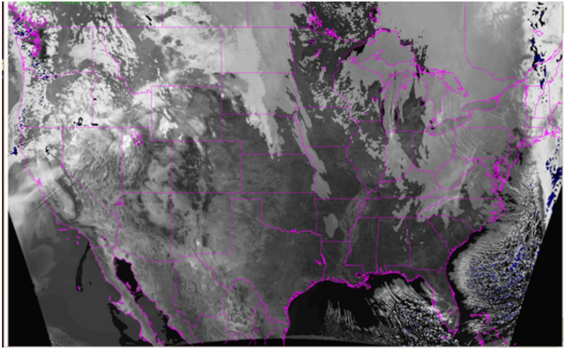
Jan. 2012

Visualizing Model Forecasts

- Model forecasts are often depicted as Radar Reflectivity.
- Good for convection/precipitation.
- NWP can now provide guidance about physical processes not currently associated with precipitation.

Synthetic satellite

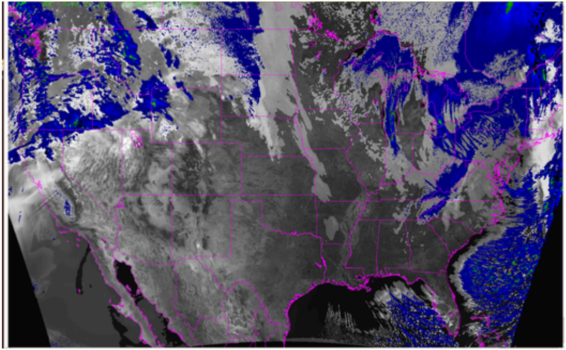
A synthetic satellite visible image can depict model guidance



(An 24-hour WRF forecast depicted as a satellite visible channel image)

More than just precipitation

Information beyond just the precipitation forecast:



Radiative Transfer Model

Radiative transfer models exist [Heidinger et al., 2006]
Approximately 13 hours are required to compute GOES $0.65\mu m$ reflectances for a single WRF output time (1200x800x35)

Approximate It!

Neural networks of a certain form can function as a universal approximator.

$$y = \sum_{j=1}^{M} w_j h(\sum_{i=0}^{d} w_{ji} x_i) \tag{1}$$

y is the output of the NN and the x_i are the inputs (there are d "true" inputs with x_0 fixed to be a constant value of 1). The w_{ji} are referred to as the weights and the "transfer function" $h(x)$ is given by:

$$h(x) = \frac{1}{1 + e^{-x}} \tag{2}$$

The idea

1. Pick a representative sample of WRF grids
2. Run forward model on them
3. Train NN to predict forward model output from WRF grids
4. In real time, input WRF to NN, obtain satellite visible output

Training dataset

- NSSL-WRF (4 km grid): 1200x800x35; time step=24s
- 18Z-23Z forecasts in one-hour increments on Apr. 3, 1974, July 1, 2009, Aug 12-16 2009 excluding Aug. 15, 2009
- 36 grids total
- 26.5 million pixels: way too many

Number of input parameters (WRF)

- Fourteen 3D fields such as temperature and perturbation geopotential
- 67 2D fields such as precipitation and soil moisture
- Total training set: 15 billion points.
- Completely unrealistic

How do we start to reduce the size of dataset?

How does the forward model do it?

- The forward model uses ice absorption and scattering properties to compute gas optical depths based on liquid and frozen hydrometeor species.
- Changes in reflectance due to waves and sun glint considered
- Simulated skin temperature, atmospheric temperature profiles used to compute simulated visible reflectances.

... contd.

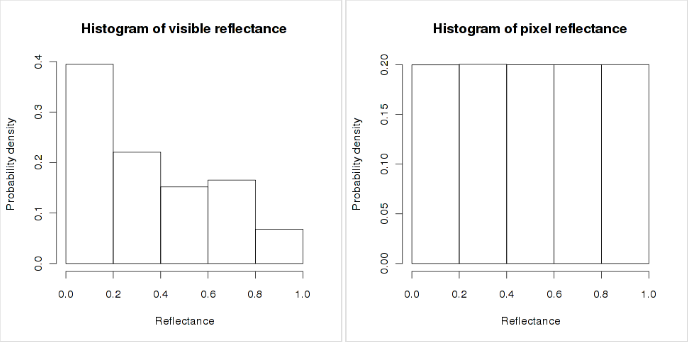
Some of those things are, of course, irrelevant.
Turn off sun angle, glint, etc. Run forward model assuming local noon everywhere (advantage: we'll get satellite visible forecasts even at night!)
But use the idea of integrating optical depth.

Neural network inputs

1. Mixing ratios (kg/kg) of water vapor, cloud water, rain, cloud ice, snow and graupel vertically integrated by weighting each layer's value with the thickness of that model layer in meters.
2. Mixing ratios above, but using only the top 17 model layers for the vertical integration.
3. Mixing ratios vertically integrated by weighting each layer's value by $pressure/temperature$ instead of by the thickness of the layer
4. minimum temperature, height of minimum temperature
5. Skin surface temperature (TSK)
6. windspeed

Histogram equalization and downsampling

Downsample 5 million non-zero points to 1 million using probabilistic sampling



... contd. ...

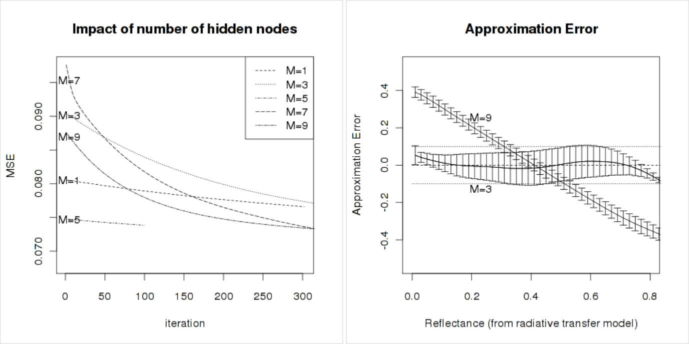
- The likelihood of a grid point with brightness value b being selected depends on r, the repeat ratio, given by:

$$r = nS/P(b) \tag{3}$$

  where n is the number of non-zero bins in the histogram, S the subsampling ratio is 0.2 and $P(b)$ the probability density of that brightness value
- If the r is, say 0.3, the grid point is selected with a probability of 0.3.
- If the r is 2.3, the grid point is selected twice and a third time with a probability of 0.3.

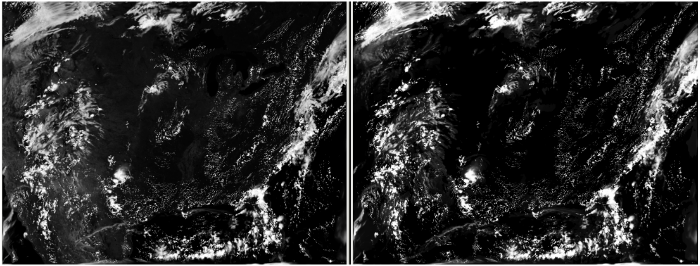
Neural network training

31 input variables, 3 hidden nodes

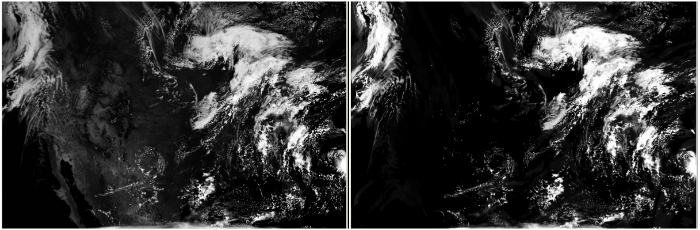


With 3 hidden nodes, all errors bounded within 0.1.

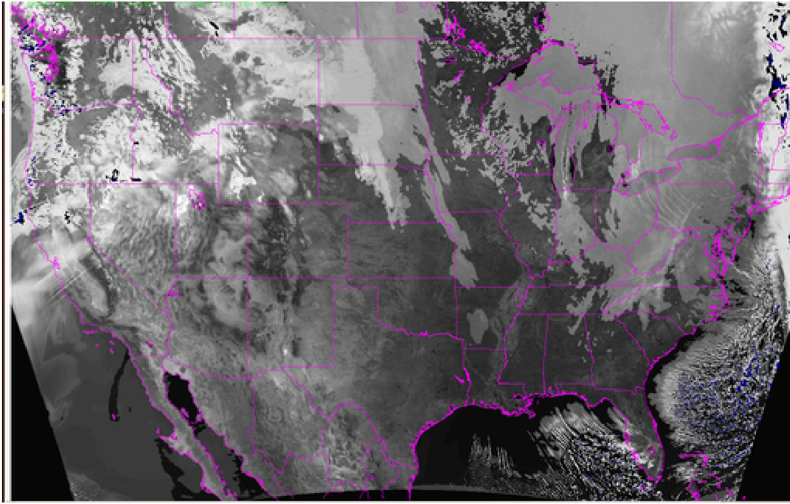
Forward model vs. Approximation (train)



Forward model vs. Approximation (test)

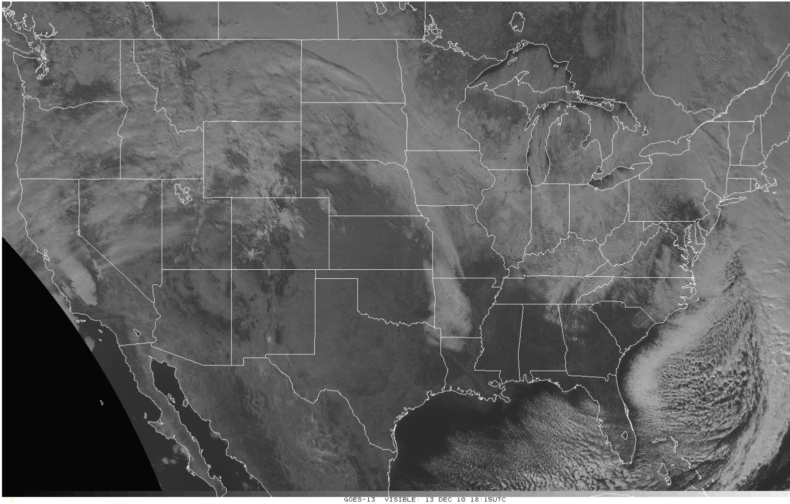


Real-time: 24-hour Forecast



Dec. 13, 2010

Real-time: What happened



Links

Real-time images:
http://www.nssl.noaa.gov/users/rabin/public_html/vis_wrf
Full paper: V. Lakshmanan, R. Rabin, J. Otkin, and J. Kain, "Visualizing model data using a fast approximation of a radiative transfer model," J. Atmos. Ocean. Tech., InPress

Acknowledgements

Funding for this research was provided under NOAA-OU Cooperative Agreement NA17RJ1227.

References

Heidinger, A., O'Dell, C., Bennartz, R., and Greewald, T. (2006).
The successive order-of-interaction radiative transfer model. part i: Model development.
J. Appl. Meteor. Clim., 45:1388–1402.