545057

On the use and validation of mosaic heterogeneity in atmospheric numerical models

Michael G. Bosilovich

NASA Data Assimilation Office, Greenbelt, Maryland

Short title: VALIDATION OF MOSAIC HETEROGENEITY

Submitted to Geophysical Research Letters

Abstract.

The mosaic land modeling approach allows for the representation of multiple surface types in a single atmospheric general circulation model grid box. Each surface type, collectively called 'tiles' correspond to different sets of surface characteristics (e.g. for grass, crop or forest). Typically, the tile space data is averaged to grid space by weighting the tiles with their fractional cover. While grid space data is routinely evaluated, little attention has been given to the tile space data. The present paper explores uses of the tile space surface data in validation with station observations. The results indicate the limitations that the mosaic heterogeneity parameterization has in reproducing variations observed between stations at the Atmospheric Radiation Measurement Southern Great Plains field site.

Introduction

High resolution observations of surface characteristics can yield the fractional cover of surface types for the relatively coarse atmospheric numerical model grid. Often, several distinct characteristics can exist within one model grid box. *Avissar and Pielke* [1989] and *Koster and Suarez* [1992] presented methods of including multiple surface types in the land parameterization of atmospheric numerical models. This is known as the mosaic or tile approach to land surface heterogeneity parameterization. Typically, most model diagnostics include the grid space average of the tile space data. Beyond the grid space average of tiles, there has been little or no use of the tile space data in process or validation studies.

In the Goddard Earth Observing System (GEOS) Data Assimilation System (DAS), tile space surface output diagnostics have been included as an option to users. The near surface data come from the atmospheric general circulation model(AGCM) portion of the GEOS DAS. While the assimilation controls the large scale meteorology, the near surface processes are more closely determined by the model simulation. The effect of different surface characteristics can be important in the numerical simulation of the surface energy budget [*Sun and Bosilovich*, 1996]. The GEOS DAS includes the Mosaic land surface model [*Koster and Suarez*, 1992]. In this paper, we develop a metric for evaluating the tile space heterogeneity, and compare the tile space data to surface observations of the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) field experiment [*Stokes and Schwartz*, 1994].

Model and Methodology

GEOS DAS

The GEOS DAS [*Schubert et al.*, 1993] provides a global data analysis for July 1998. While significant observations are analyzed in the troposphere, neither surface observations nor precipitation are included in this analysis. Hence, surface data and precipitation are mostly related to the model forecast. The comparison of the analysis grid point data at the surface with observations can provide valuable information on the model system [*Betts et al.*, 1996; *Betts et al.*, 1998].

The ARM SGP experiment was designed to provide observations to for the development and validation of sub-grid cloud parameterizations. Several surface stations are spread across a region with an area that corresponds to an AGCM grid box (Figure 1). Similarly, we can use the surface observations to better understand the Mosaic parameterization of sub-grid land processes. Figure 1 shows the ARM SGP surface meteorology and surface flux stations relative to the GEOS DAS grid boxes (at 2° × 2.5° horizontal resolution). With several observing stations within the 36N, 97.5W grid box, we can compare the model simulated mosaic heterogeneity with the observed spatial heterogeneity. At the surface, the GEOS DAS has several tiles in the grid box at 36N, 97.5W (Figure 2). It is important to note that the tiles represent a homogeneous portion of the area and do not have a spatial distribution within the grid box.

Figure 1

Figure 2

Stokes and Schwartz [1994] reviewed the development of the ARM project. For updated instrumentation information, quality control and data types, the reader is referred to the ARM Data Archive site (http://www.archive.arm.gov). In this study, we will focus on the near-surface atmospheric temperature and specific humidity (at 2 m), precipitation, sensible heat flux and latent heat flux (using the meteorology and Bowen ratio stations). Each different observing station will be compared with each tile. Only a limited number of the surface meteorology and Bowen ratio station are used in this study. The observing stations near the central grid box are generally characterized as a crop (wheat or alfalfa) or pasture.

Mosaic Heterogeneity

In the Mosaic approach, each surface type (e.g. forest, grassland or barren), called a 'tile', has a prescribed fractional cover. The fractional cover is a linear weight, relative to the total area of the surface (as in Figure 2). The tiles do not have any associated spatial location. Therefore, the mosaic heterogeneity only represents the differences of the surface characteristics, and not the spatial heterogeneity that may result from sub-grid variations in topography or precipitation.

Forcing for each tile comes from the AGCM grid space meteorology and radiative fluxes. The prognostic variables for each tile are saved for the next time step. Each tile will react differently to the forcing, but only the grid space average of the tile fluxes will feed back to the atmosphere. The grid space average (for either feedback to the AGCM, or diagnostic averaging) is computed by,

$$\bar{X} = \sum_{i=1}^{n_c} C_{fr_i} X_i \qquad (1)$$

C_{fr_i} is the fractional cover of tile i, X_i is any tile space variable, overbar indicates the weighted average in grid space, n_c is the number of tiles in the grid box.

While tile space data must be saved for restarting the model simulation, it is generally not saved for diagnostic purposes. In the present GEOS DAS, the tile space data is archived as a third dimension for surface data (longitude, latitude and number of tiles). Because visualization of three dimensional data is difficult, it is advantageous to develop a two dimensional representation of the degree of heterogeneity. Considering the weighted average (equation 1), it follows that the standard deviation of the tile average can be computed by,

$$SD(X) = \sqrt{\sum_{i=1}^{n_c} C_{fr_i} (\bar{X} - X_i)^2}. \qquad (2)$$

This equation provides a grid space estimate of the variability of tiles. Given these equations and the tile space model diagnostic data, we can evaluate the mosaic heterogeneity compared to the ARM SGP field observations.

Results

All the GEOS DAS data presented here has been taken from the center grid cell of Figure 1. Figure 3 compares the July monthly mean diurnal cycle from the GEOS DAS to different stations observations of 2m temperature and specific humidity. The error

Figure 3

bars indicate ± one standard deviation due to the Mosaic heterogeneity (equation 2). For this particular grid point the variability of the 2 meter temperature and moisture reach a magnitude of 0.5 K and 0.5 g/kg respectively in the mean diurnal cycle. However, the values can also be quite small at some times of the day. While the GEOS DAS grid cell mean diurnal cycles are comparable to the observations in each figure, the observations exhibit more variability from station to station. This particular grid cell is dominated by the grassland tile, with less fractional cover from the other tiles. This weakens the magnitude of the standard deviation, as compared to grid cells to the east (figure not shown). Station altitude could also play a role in differences between the model and observations. In this case, however, these observing stations range form 318 - 418 m altitude. In this simple comparison, no corrections for the variation of altitude have been applied.

The main interaction between the land surface and atmosphere occur through the surface turbulent heat and water flux. Figure 4 shows the mean diurnal cycles of July latent and sensible heat flux. The variability of tiles in sensible and latent heat fluxes appears to be more substantial than in temperature and specific humidity (values around 50 Wm^{-2}). While the mosaic variability appears to encompass some of the variability between different observing stations, some significant differences can exist between observing stations.

Figure 4

Because several observing stations are located in close proximity to a model grid point, we can compare each station's observations with each model tile data. Typically, there would be no need to compare grassland observations with forest or shrub tiles, but in this paper, the goal is to understand the differences of the tiles. Figure 5 shows the 2m air temperature mean difference and the standard deviation of the hourly differences between each tile and each station (in addition to the grid space mean). For station E24, all tiles standard deviations and biases are very close to each other, but notably different from the other stations' error (especially station E11). In general, the error for any tile at each station show only small variations compared to the variation of error from station to station.

Figure 5

This result also extends to the near surface specific humidity standard deviations and mean differences (Figure 6). In Figure 6, the mean difference between model precipitation and each station's precipitation is also included. Note that the precipitation is a forcing parameter that does not have any variation with tiles. A reasonable correspondence exists between the mean differences of precipitation and specific humidity for each station. Therefore, the effect of real spatial variability of precipitation greatly influences the meteorology at each station and the differences between observation and model simulation. The mosaic parameterization was not designed to handle sub-grid variability of precipitation.

Figure 6

Summary and Conclusions

Simulated sub-grid heterogeneity data from the Goddard Earth Observing System (GEOS) Data Assimilation System (DAS) has been compared with several observing stations in the Atmospheric Radiation Measurement (ARM) program Southern Great Plains (SGP) field experiment. Given that many stations exist in close proximity to a model grid box, we can validate the heterogeneity parameterization. The results indicate that the mosaic heterogeneity represents only a portion of the real spatial variability that can exist. In the present case study, the observed surface meteorology is strongly affected by sub-grid variability of precipitation. While the mosaic parameterization was not designed to include this kind of sub-grid variability, there needs to be more quantitative investigation of the degree to which it does represent subgrid heterogeneity. Mosaic heterogeneity remains to be a useful parameterization in AGCMs, by allowing the for effect of different surface characteristics on the energy and water balances. This analysis provides a quantified estimate of the limitations of the mosaic heterogeneity parameterization.

Acknowledgments. Paul Houser, Randy Koster, Andrea Molod, Jared Entin, Dave Toll, Jiun-Dar Chern and Guiling Wang offered useful discussions and assistance in preparing and assessing the tile space data.

References

Avissar, R. and R. Pielke, A parameterization of heterogeneous land surfaces for atmospheric numerical models and its impact on regional meteorology, *Mon. Weather Rev., 117,* 2113-2136, 1989.

Betts, A., S.-Y. Hong, and H.-L. Pan, Comparison of the NCAR-NCEP reanalysis with 1987 FIFE Data, *Mon. Weather Rev., 124,* 1480-1498, 1996.

Betts, A., P. Viterbo, and A. Beljaars, Comparison of the land-surface interaction in the ECMWF reanalyses model with 1987 FIFE data, *Mon. Weather Rev., 126,* 186-198, 1998.

Koster, R., and M. Suarez, Modeling the land surface boundary in climate models as a composite of independent vegetation stands, *J. Geophys. Res., 97,* 2697 - 2715, 1992.

Schubert, S. D., J. Pfaendtner and R. Rood, An assimilated data set for Earth science applications, *Bull. Am. Meteorol. Soc., 74,* 2331-2342, 1993.

Stokes, G. M., and S. E. Schwartz, The Atmospheric Radiation Measurement (ARM) Program: Programmatic background and design of the Cloud and Radiation Test Bed, *Bull. Am. Meteorol. Soc., 75,* 1201-1221, 1994.

Sun, W.-Y., and M. G. Bosilovich, Planetary boundary layer and surface layer sensitivity to land surface parameters, *Boundary Layer Meteorol., 77,* 353-378, 1996.

M. G. Bosilovich, NASA Data Assimilation Office, GSFC Code 910.3, Greenbelt, MD 20771. (e-mail: mikeb@dao.gsfc.nasa.gov)

Received XX; revised YY; accepted ZZ.

Figure 1. ARM Southern Great Plains observing stations used in this study. X - Surface meteorology and box - Bowen Ratio fluxes.

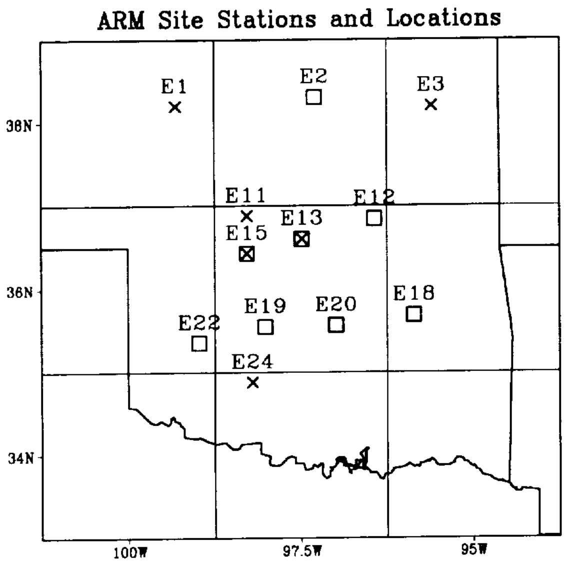
Figure 2. GEOS fractional coverage by different surface types at 36N, 97.5W.

Figure 3. July 1998 monthly mean diurnal cycles of 2m temperature and specific humidity. The error bars denote the standard deviation of the tile space weighted mean (as computed in equation 2).

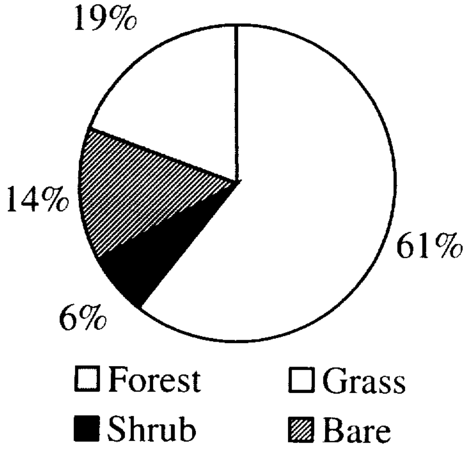
Figure 4. July 1998 monthly mean diurnal cycles of surface latent and sensible heat flux. The error bars denote the standard deviation of the tile space weighted mean (as computed in equation 2).

Figure 5. Standard deviation of the hourly differences and mean of the hourly differences for 2m temperature (K) from each tile and the grid average to several ARM SGP surface meteorology stations.

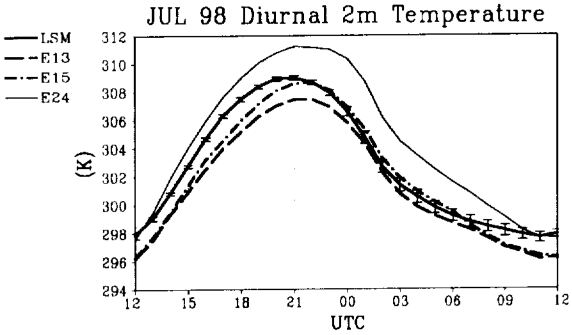
Figure 6. Standard deviation of the hourly differences and mean of the hourly differences for 2m specific humidity ($g\ kg^{-1}$) from each tile and the grid average to several ARM SGP surface meteorology stations. The bias of grid space precipitation for each station is included ($mm\ day^{-1}$, shown on the right axis).


ARM Site Stations and Locations
E1
E2
E3
E11
E12
E13
E15
E18
E19
E20
E22
E24
38N
36N
34N
100W
97.5W
95W

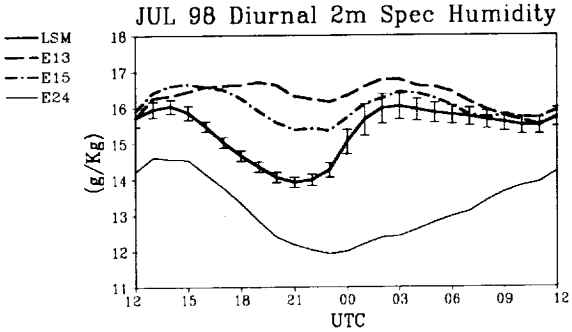
f1


Mosaic at 36N, 97.5W

f2

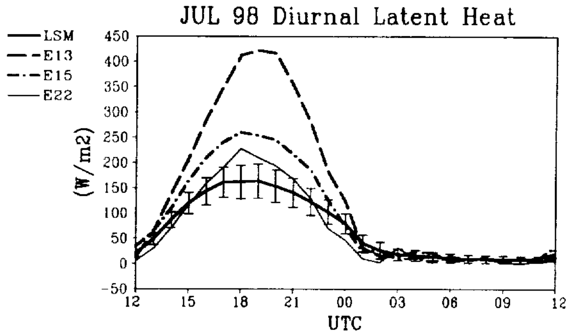


JUL 98 Diurnal 2m Temperature

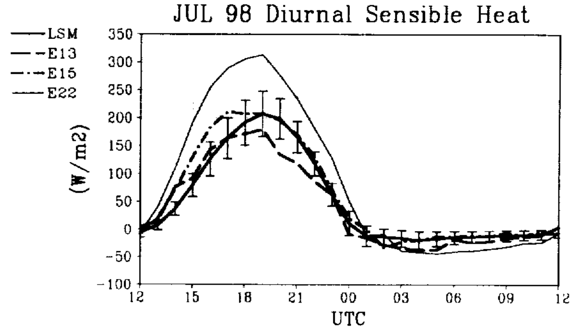


JUL 98 Diurnal 2m Spec Humidity

43

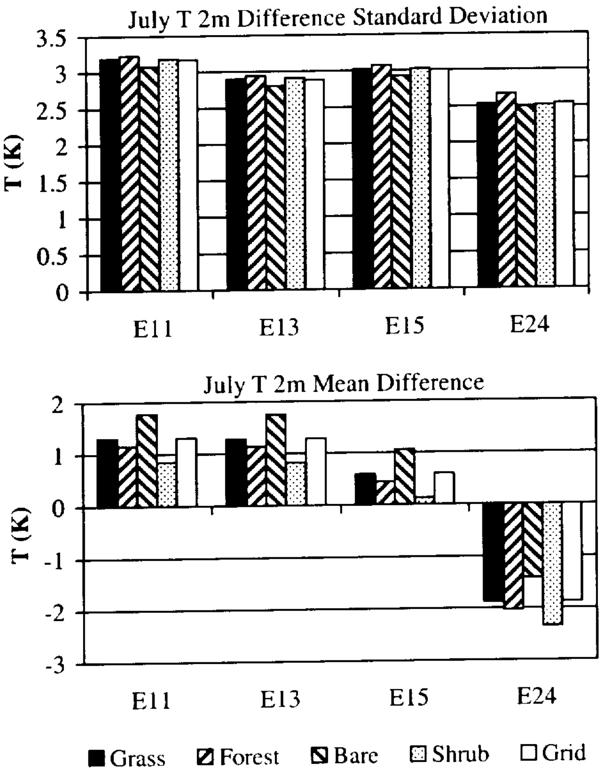


JUL 98 Diurnal Latent Heat

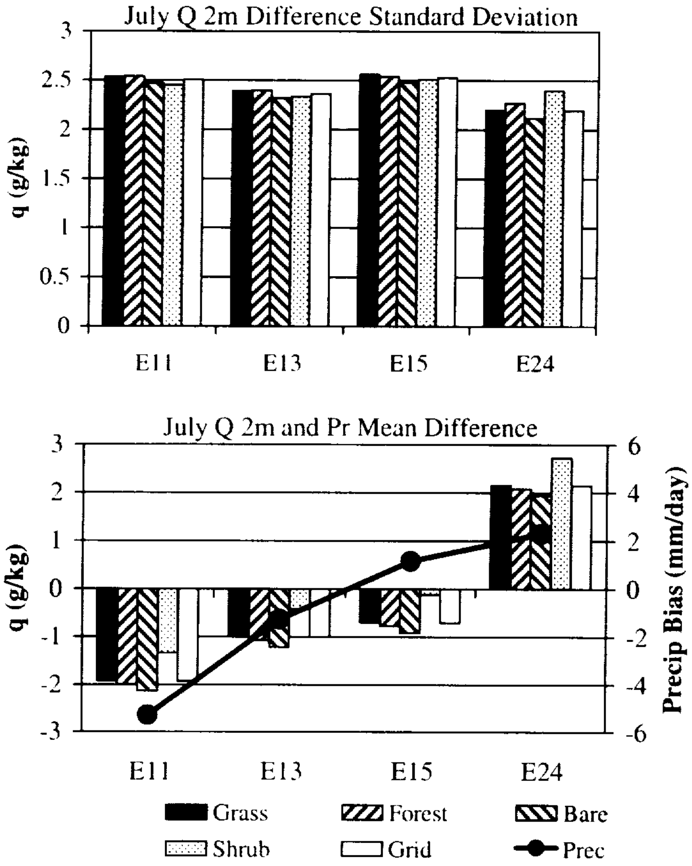


JUL 98 Diurnal Sensible Heat

#4


July T 2m Difference Standard Deviation
3.5
3
2.5
2
1.5
1
0.5
0
T (K)
E11
E13
E15
E24
July T 2m Mean Difference
2
1
0
-1
-2
-3
T (K)
E11
E13
E15
E24
■ Grass
▨ Forest
▧ Bare
▒ Shrub
□ Grid

f5


July Q 2m Difference Standard Deviation
q (g/kg)
3
2.5
2
1.5
1
0.5
0
E11
E13
E15
E24
July Q 2m and Pr Mean Difference
q (g/kg)
3
2
1
0
-1
-2
-3
Precip Bias (mm/day)
6
4
2
0
-2
-4
-6
E11
E13
E15
E24
Grass
Forest
Bare
Shrub
Grid
Prec

f6