Developing Sub-Domain Verification Methods using GIS Tools

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Accurate Forecasting Essential

Benefits of accurate weather forecasting:

- Enhanced situational awareness of all battlefield commanders.
- Commanders and Soldiers can undertake weather risk mitigation.

Weather forecasting research

- WRF forecasts with a grid spacing of one-kilometer
- Comparison with observations using GIS

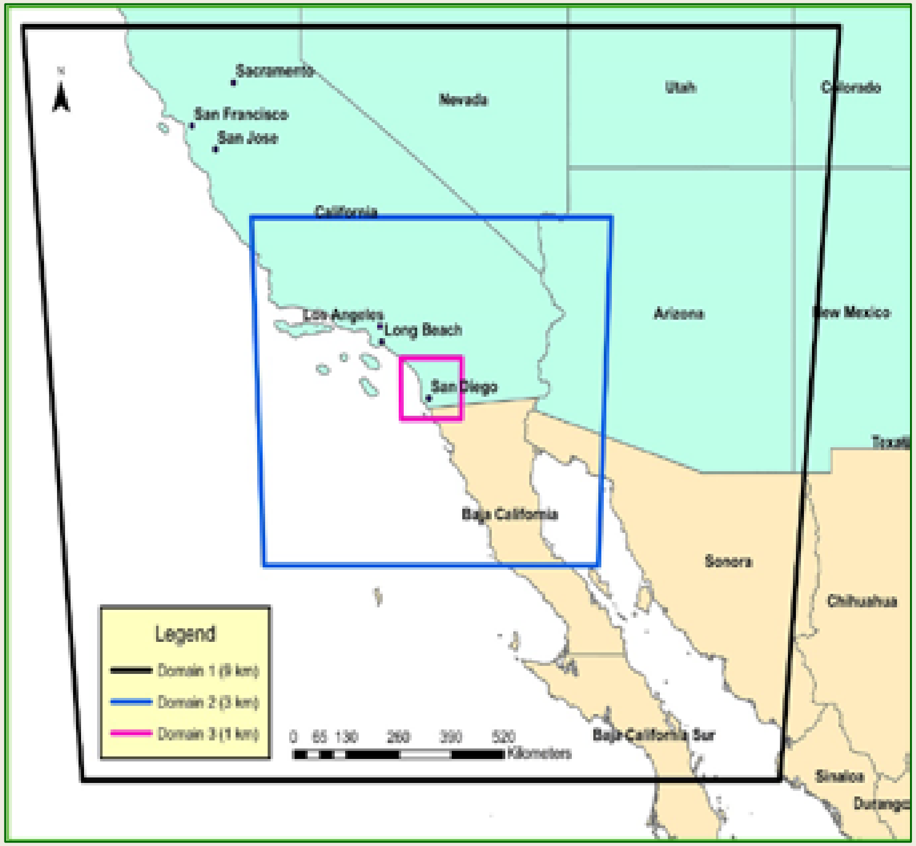
The Allies surprised the Germans on D-Day because they had more accurate weather forecasting.

Model Information

WRF (Weather Research and Forecasting)

- Numerical weather prediction model developed and maintained by the National Center for Atmospheric Research (NCAR).
- Includes parameterizations to represent unresolved atmospheric physics that create weather.
- Employs a triple nest with a grid spacing of 9/3/1-km.

WRF Domain Configuration



Use GIS for Validating WRF

The NCAR Model Evaluation Tools (MET) was used to calculate the model performance statistics over every matched pair (observed value and corresponding model forecast value) in a given domain.

GIS allows us to easily divide the model domain into smaller, more homogenous regions to better evaluate model performance.

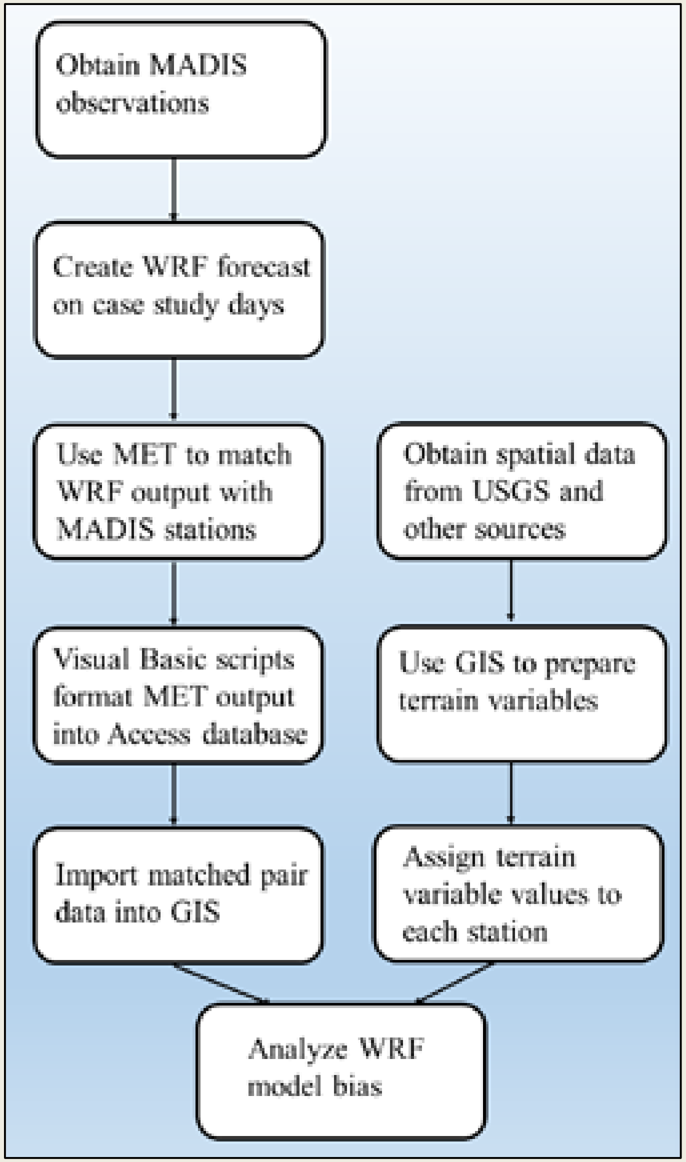
- Elevation in complex mountainous regions,
- Valleys, and
- Upslope and down slope flows.

Incorporate other information into the verification analysis such as high-resolution terrain and land use data.

Research Protocols

Weather Forecast Validation

1. Ran WRF for 5 case study days.
2. Used MET to interpolate WRF output at each weather station.
3. Assigned NAD1983 datum/GCS North American 1983 projection.
4. Classified stations by land use, elevation and distance to coastline.
5. Created terrain variables.
6. Interpolated model bias using Empirical Bayesian Kriging.
7. Used kriging surfaces and terrain variables to analyze model performance.



Importing WRF Output into GIS

Before ArcMap Version 10.3, WRF model output could not be imported directly into GIS

- WRF NetCDF output has staggered wind fields.
- WRF GRIB output was not a supported GIS file format.
- Version 10.3 can now import Gridded Binary (GRIB) files directly using Add Data!

When importing data into GIS, it is necessary to assign a datum and projection

- WRF assumes a perfect sphere (no datum) and Lambert Conic Conformal.
- Assigning this projection and no datum put the matched pair data way out into the Pacific Ocean.
- Assigned NAD1983 datum/GCS North American projection to WRF output.

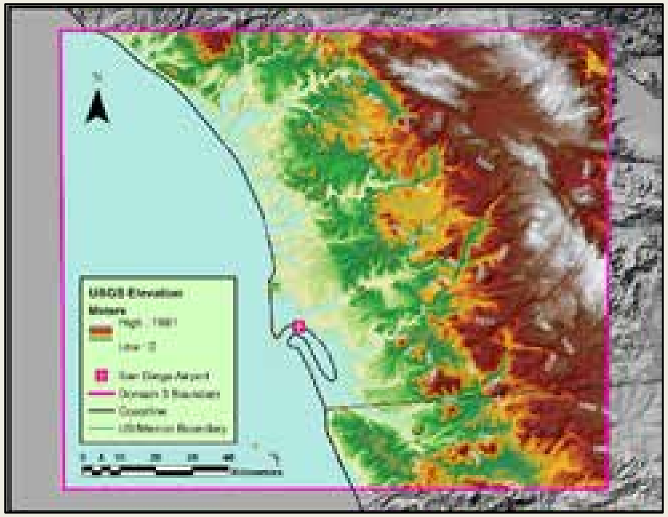
Terrain Variables for Analysis

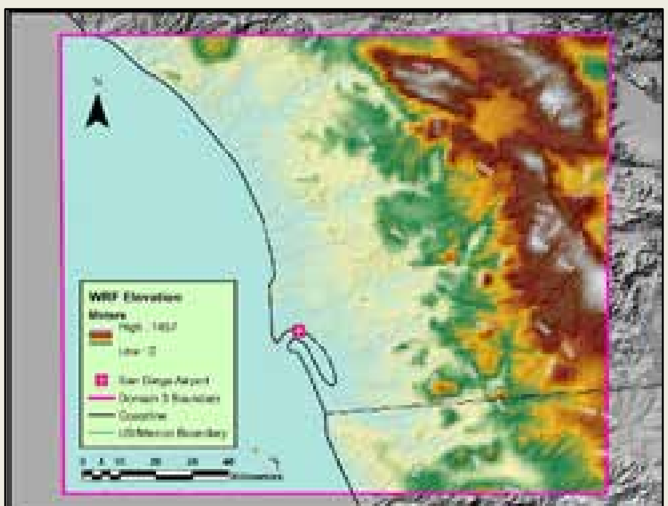
Here are the candidate terrain variables for the analysis of WRF model bias.

Terrain Variable	GIS Tool	Data Source
Elevation	Add Rasters to Mosaic Dataset (Data Management)	MADIS[b]
Latitude	Create Feature Class/From xy Table	MADIS[b]
Longitude	Create Feature Class/From xy Table	MADIS[b]
WRF Elevation Difference	Add Data	WRF GRIB output and USGS DEM
Slope	Slope (3D Analyst)	USGS DEM
Coast Distance	Near (Analysis)	CEC[c] Coastline
NDVI[a]	Extract Subset (Data management)	MODIS Terra satellite

[a]Normalized Difference Vegetation Index.
[b]Meteorological Assimilation Data Ingest System, weather observations source.
[c]Commission for Environmental Cooperation.

Terrain variables derived from USGS DEM and WRF output

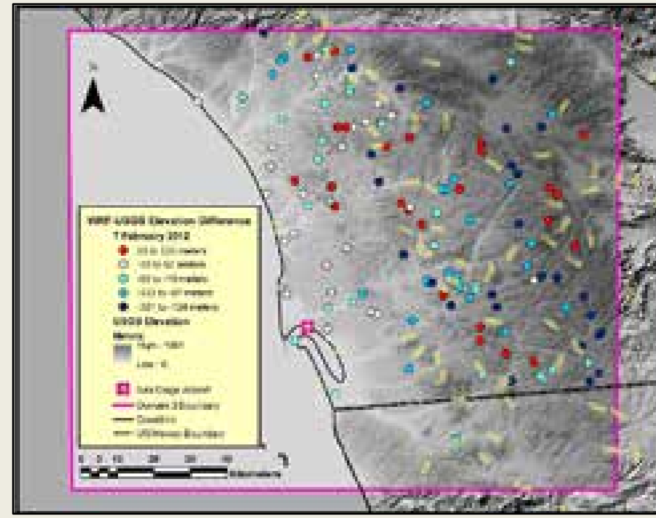


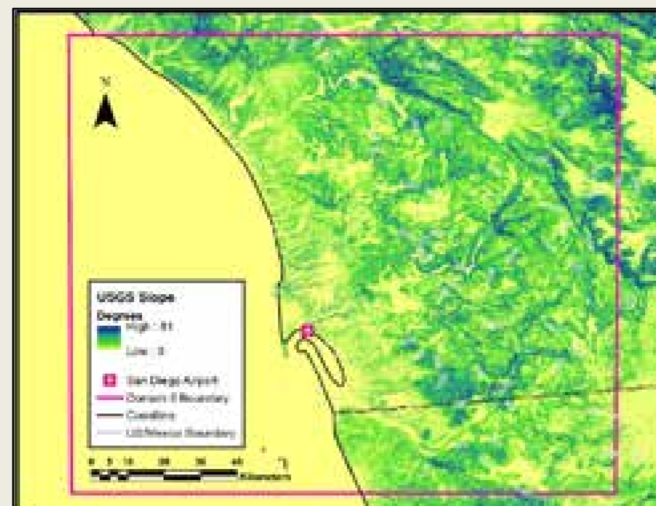


Left
USGS DEM (top)
+
WRF Terrain (bottom)

Right
WRF Elevation Difference (top)

Slope(bottom)





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NDVI Terrain Variable

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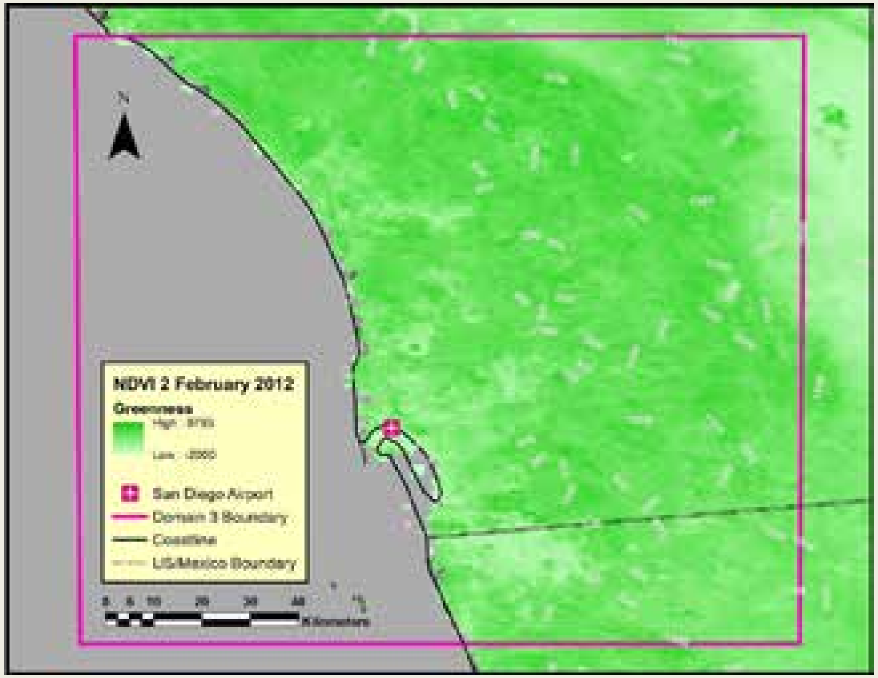
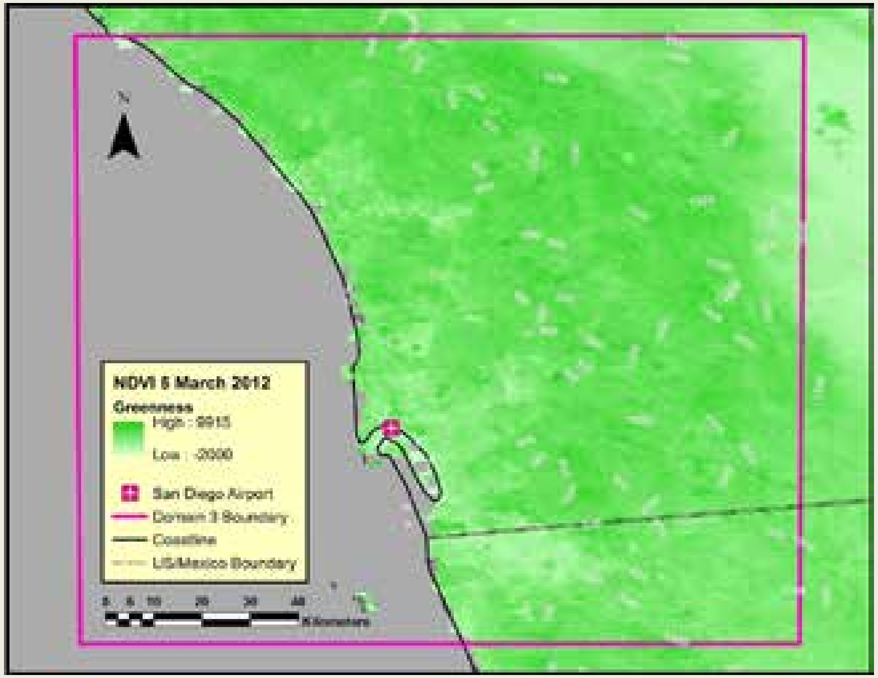
NDVI is a measure of greenness

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}$$





Each satellite image is a 16 day composite.

Correlation Analysis

Eliminated coast distance and longitude from analysis

- North-south coastline means longitude duplicates coast distance information.
- Strong 1:1 relationship between elevation and coast distance.

Correlation analysis between terrain variables and model bias

- Calculated Pearson correlation coefficient (r).
- Calculated percent total model bias variance explained (R^2 or the square of r).

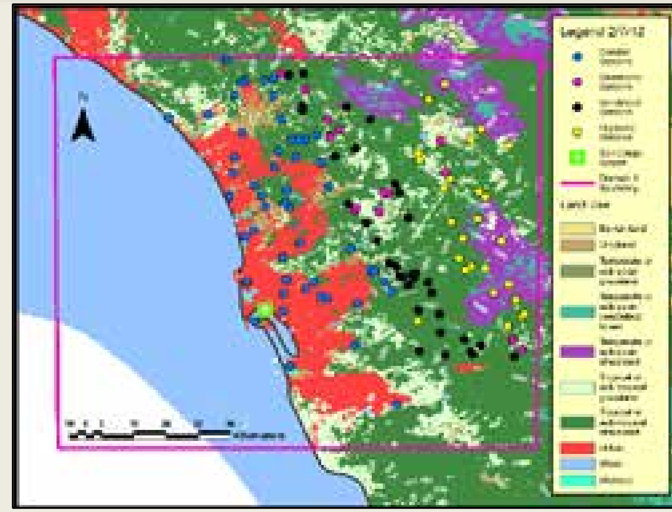
Terrain Classification

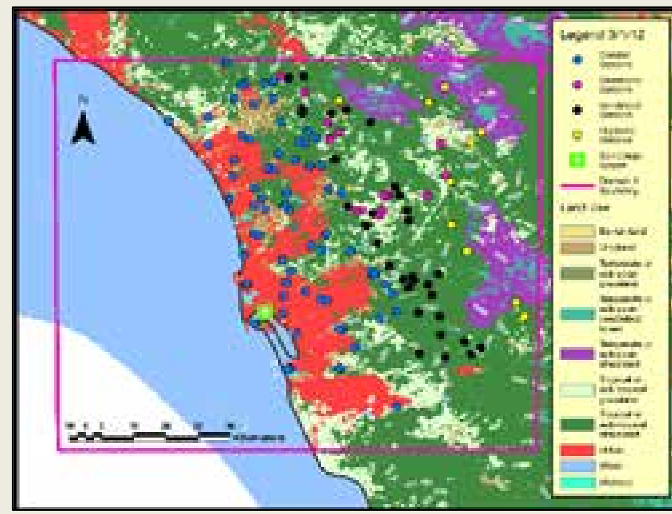
Created 4 terrain-based classes

- Within 30 km of the coast.
- Elevation greater than 900 m.
- Shrub land use with an elevation less than 900 meters.
- Grass land with an elevation less than 900 meters.

Model bias analysis

- Compared overall model bias to model bias of land use classes.





Weather stations classified by land use. 7 February 2012 (top) and 1 March 2012 (bottom).

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Results of Model Bias Analysis

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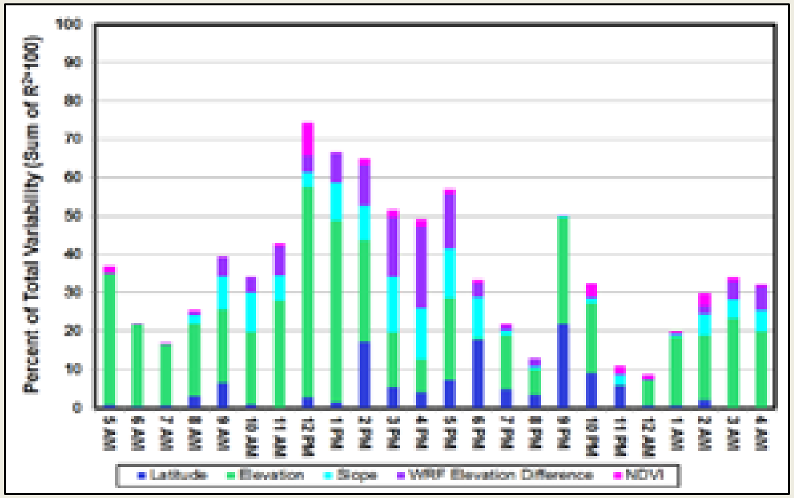
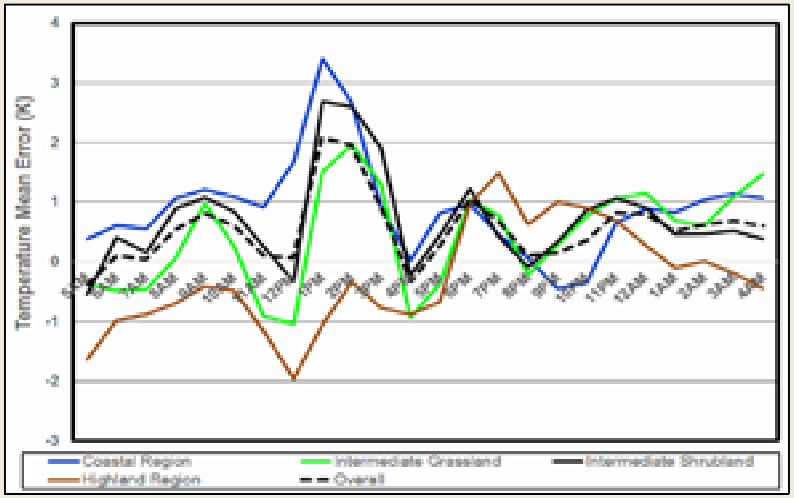
Correlation between terrain variables and model bias

- Overall elevation explains as much as 50% of model bias variability.

Terrain Classification and model bias

- Performed an analysis of variance (ANOVA).
- Statistically significant 51 of 75 hours.

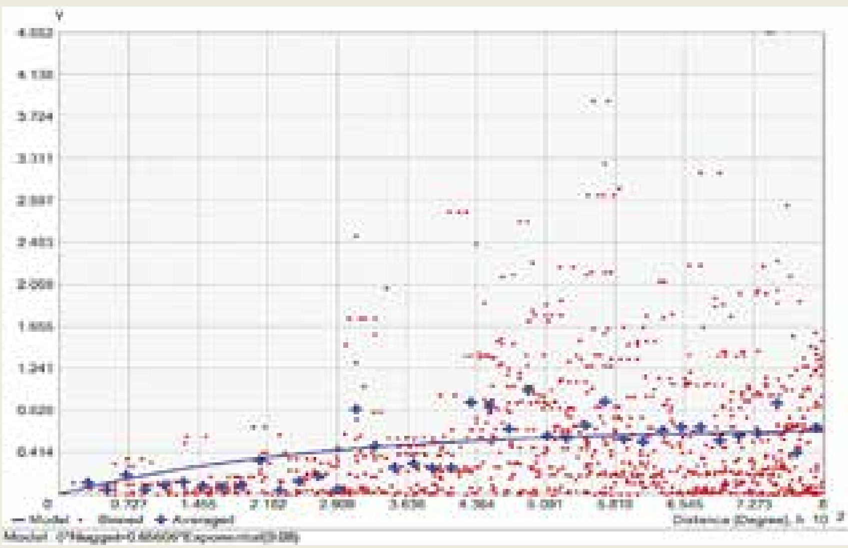




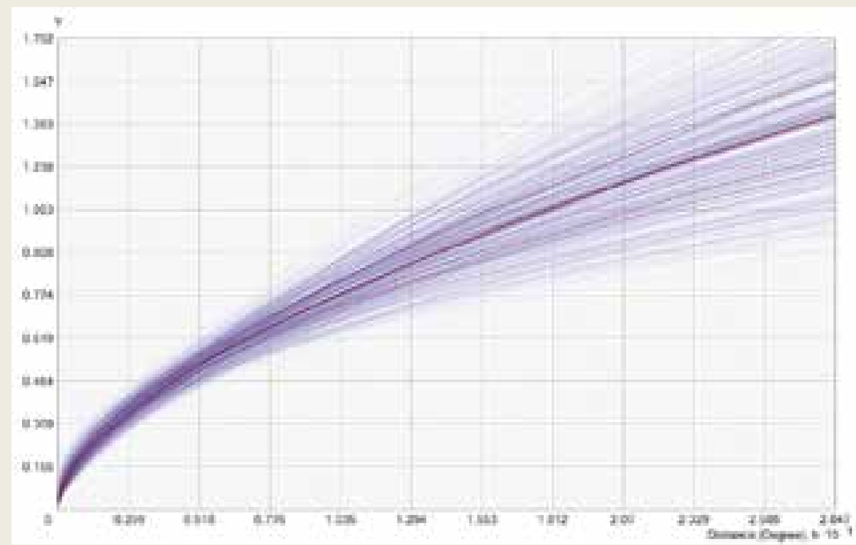
Spatial and Temporal Variability of WRF SurfaceTemperature Bias Errors.

Empirical Bayesian Kriging

Kriging estimates the degree of spatial correlation (or spatial dependence) between pairs of given data points. This correlation is depicted as a semivariogram whose ordinate (y) value is one half the average squared difference between errors at all pairs of locations within a radius h (abscissa or x).

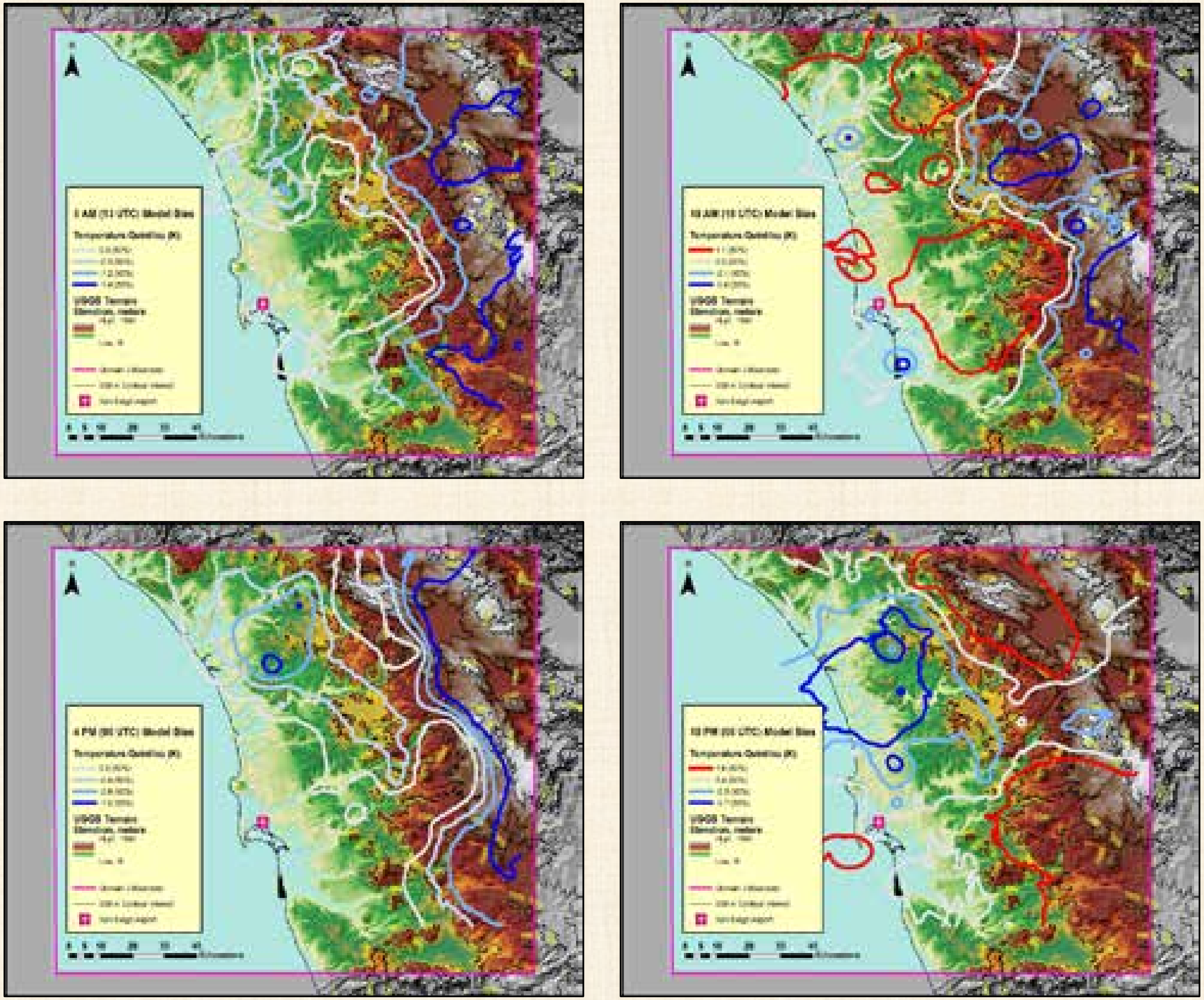


An example semivariogram that depicts values for pairs of points (red), their averages (blue crosses), and the estimated semivariogram model (blue line).



The spectrum of semivariograms produced by iteratively adapting an initial semivariogram using Bayes rule.

2-7-12 EBK Model Bias Surfaces



Conclusions

WRF performance varies spatially over the domain

- The four terrain classes have statistically different model biases.
- The 5 terrain variables (elevation, latitude, slope, distance from coast, and NDVI) explain 8-73% of the model bias variance for 7 February 2012 surface temperature.

GIS is a useful tool for analyzing WRF performance.

- Standard WRF analysis packages only analyze entire domain.
- GIS gives us information on sub-domain spatial variability