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U.S. Army Research, Development and Engineering Command

Developing sub-domain verification methods based on Geographic Information System (GIS) tools

ARL

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Advantages of Geographic Information Systems (GIS)

- Other model performance tools (such as Model Evaluation Tools – MET) calculate the model performance statistics over every matched pair in a given domain.
- GIS allows us to divide the model domain into smaller, more homogenous regions to better evaluate model performance, for example we can consider:
  - Elevation in complex mountainous regions,
  - Valleys, and
  - Upslope and down slope flows.
- Incorporate other data into the analysis such as high-resolution terrain and land use data into a verification analysis.
- Make informative maps that place relevant information in a geospatial context.

ARL Nowcast Efforts

- Objective: The Army Research Laboratory (ARL) intends to provide a battlefield Nowcast (0 to 6 hour) capability to Army Brigade and below units that functions anywhere the Army fights with a minimum of localization.
- Expected benefits for the Warfighter include:
  – Enhancing situational awareness of all battlefield commanders.
  – Allowing commanders to use weather as a force multiplier.
  – Providing commanders and Soldiers a means to undertake weather risk mitigation.
- Foundation of ARLs modeling effort:
  – Extends the Advanced Research version of the Weather Research and Forecast (WRF-ARW) to create our “Weather Running Estimate – Nowcast (WRE-N)” model.
  – Includes observation nudging four dimensional data assimilation (FDDA).
  – Employs a 9/3/1-km triple nest configuration for the work described here: the finest grid utilized in WRE-N is typically 1-km grid spacing or finer.

Study Methodology

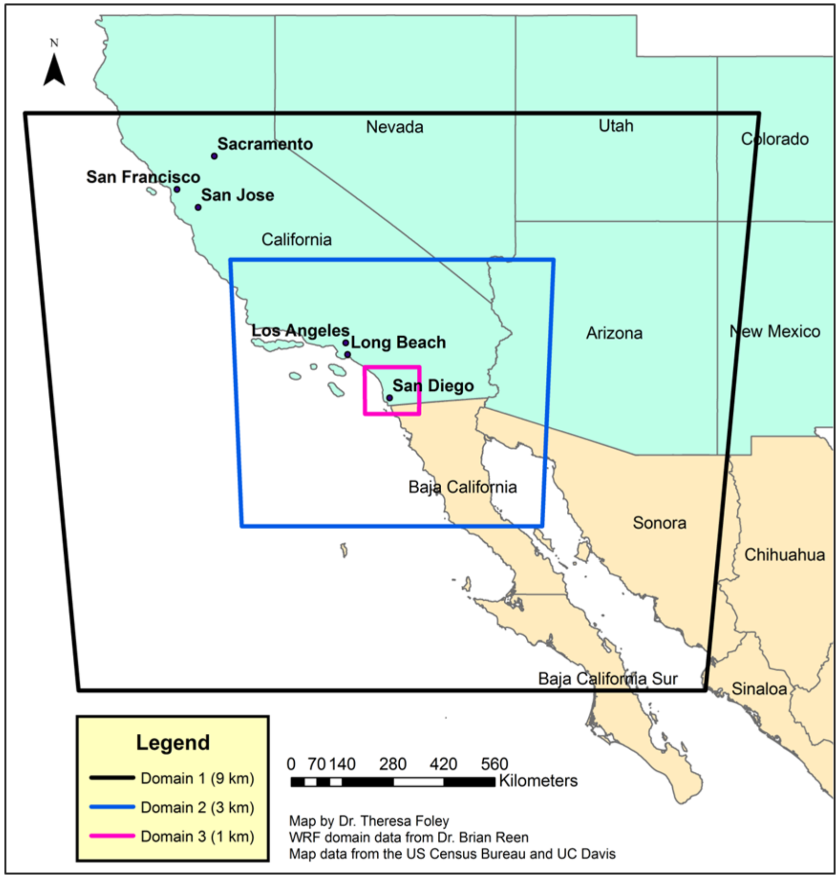
- Modeling:
  - We performed WRE-N modeling for five case study days, chosen for their varied synoptic conditions, in February and March of 2012. This talk will focus on Case 1: 7-8 February 2012.
  - We chose the southwest US because this area contains a wealth of weather observations and contrasting terrain types ranging from the Rocky Mountains to the Pacific Ocean, and that at least partially typifies areas of current Army operations from a meteorological standpoint.
- GIS Analysis:
  - We used MET Point-Stat to interpolate a forecasted value to each observation point (matched pair) from the WRF output data.
  - We analyzed the forecast error (forecasted minus observed) using GIS.
  - We used Empirical Bayesian Kriging on the inner domain matched pair data for all five case days to examine the forecast error.

Model Setup

WRF-ARW v3.4 Configuration

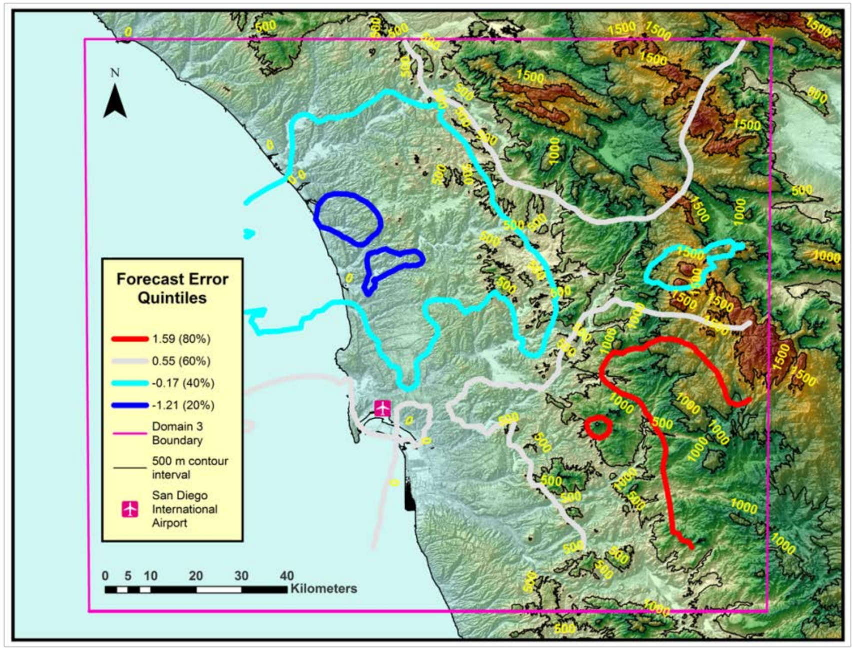
- Initialization:
  - Initial and boundary conditions from 0.5-degree GFS with observations analyzed onto initial conditions.
  - 1/12 degree (~9 km) RTG SST.
  - 1 km NOHRSC SNODAS snow where available (GFS snow elsewhere) .
- Data Assimilation
  - 6-h preforecast with observation nudging (12-18 UTC) Observation nudging uses TAMDAR aircraft data and various MADIS datasets (standard surface observations, mesonet surface observations, maritime surface observations, profiler data, rawinsondes, and ACARS (aircraft) data).
  - 18-h forecast (18-12 UTC).
- Parameterizations:
  - WSM-5 microphysics,
  - RRTM longwave,
  - Dudhia shortwave,
  - Noah land surface model,
  - Kain-Fritsch cumulus parameterization (only on 9-km outer domain), and
  - Modified MYJ PBL parameterization (lower background TKE and modified PBL depth diagnosis).

Domain Configuration



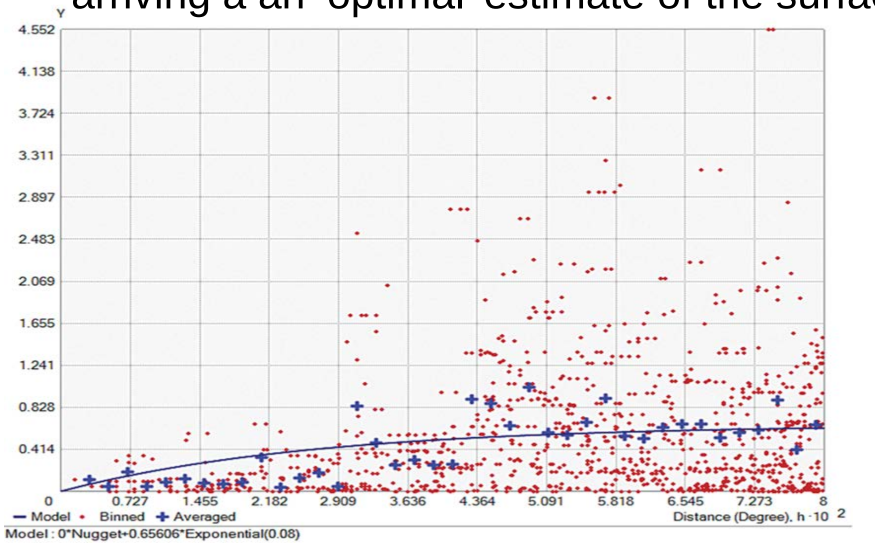
An overview of how we used kriging

- Meteorological variables such as temperature and wind speed, and model derived forecasts of these variables, are point measurements or predictions of what can be mathematically modeled as spatially continuous random processes.
- Empirical Bayesian Kriging is a statistical technique that uses point valued error data derived from these variables to optimally predict a surface model of that error as a continuous spatial random process.
- In the figure to the right, this error surface is represented by contour intervals that correspond to the quintiles of the error distribution over a portion of the domain.
- The surface does not completely fill the domain because there is insufficient error data in those areas with which to reliably estimate a surface.

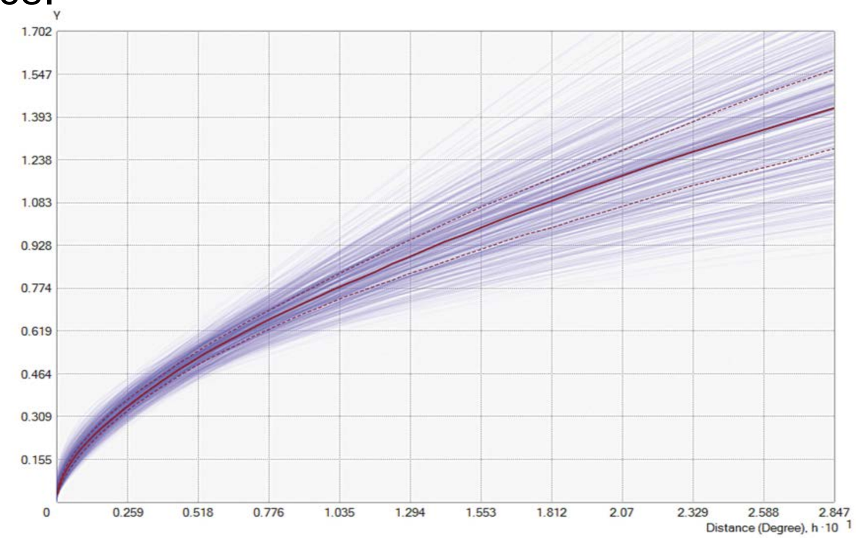


Empirical Bayesian Kriging in ArcGIS

- 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).
- Bayes rule is used to iteratively adapt the semivariogram to create a new surface estimate that is compared to errors values at points not used in the estimate; ultimately arriving a an 'optimal' estimate of the surface.

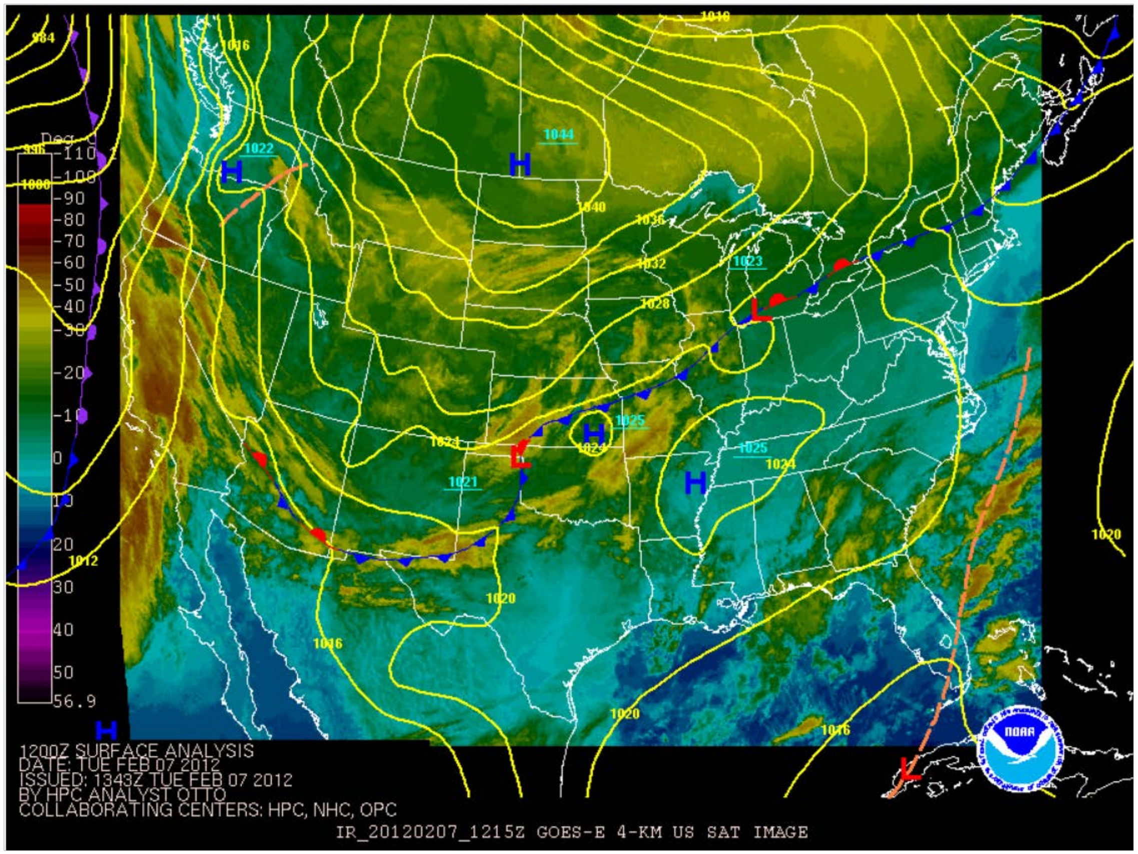


An example semivariogram that depicts values for pairs of points (red), their averages (blue crosses), and the estimated semivariogram model (blue line).



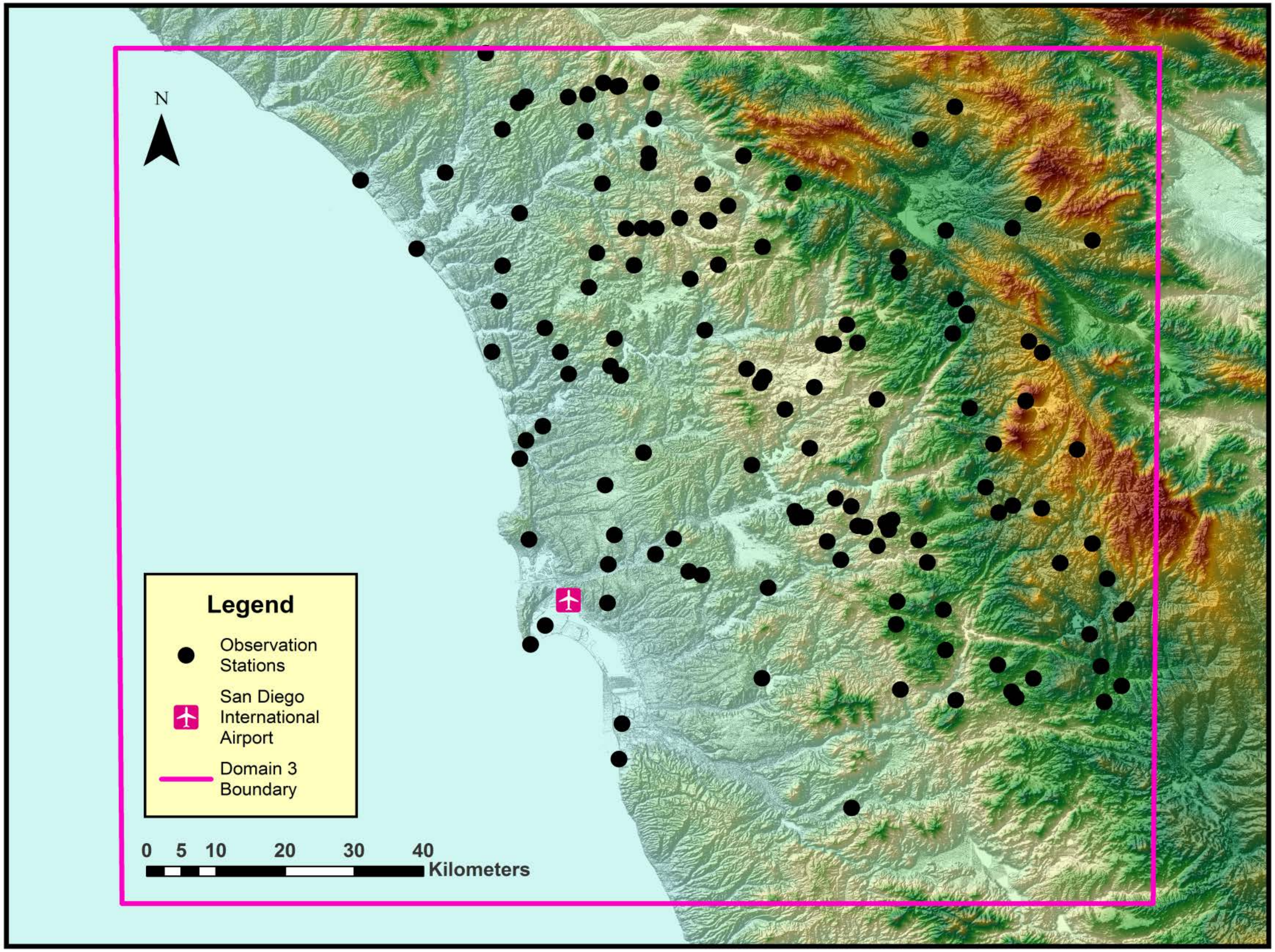
The spectrum of semivariograms produced by iteratively adapting an initial semivariogram using Bayes rule.

Synoptic Conditions (1200 UTC Surface Analysis)

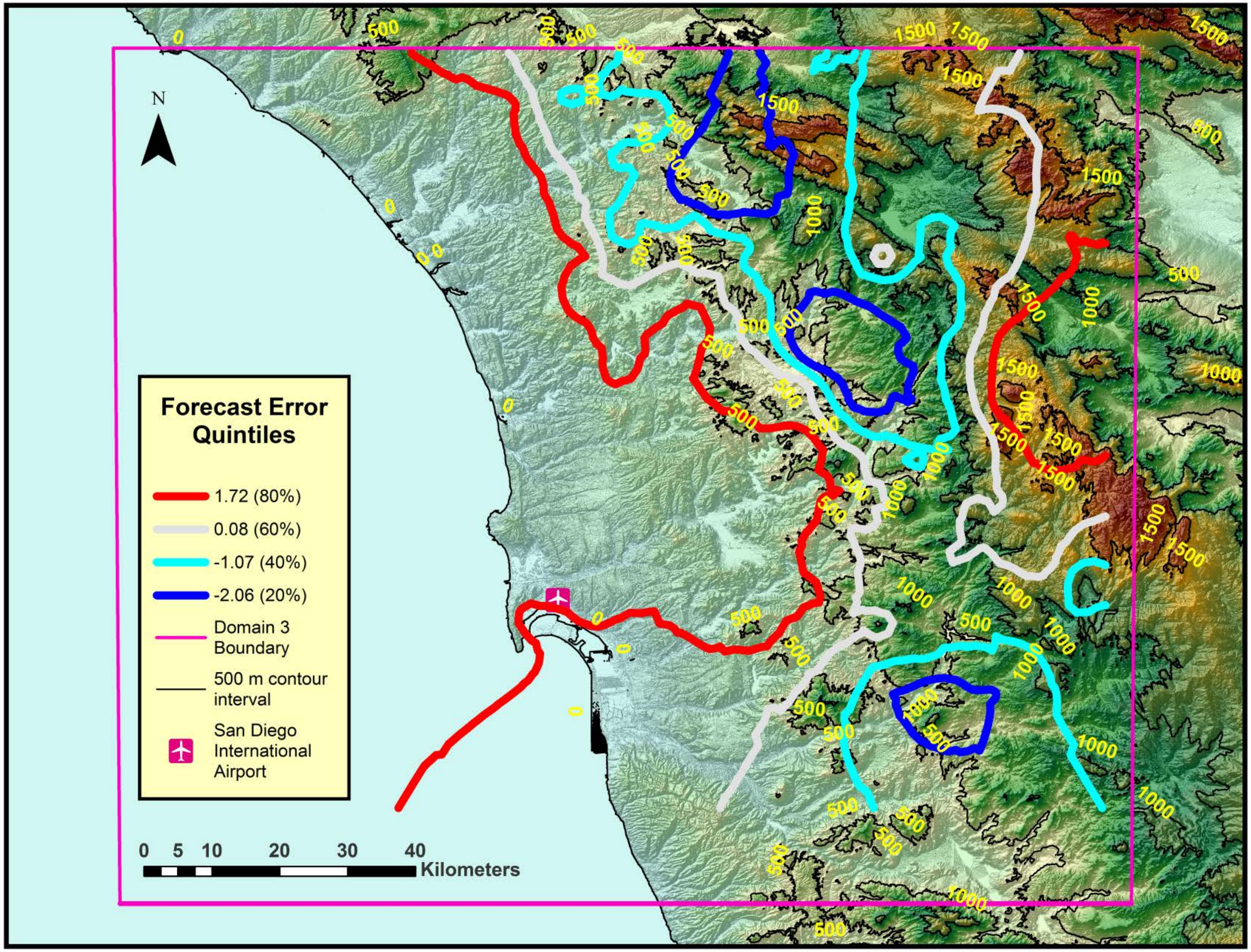


Surface troughing along the California coast, out ahead of an approaching strong Pacific upper level disturbance/trough, caused an extended and widespread period of precipitation over the region. Much of southern California experienced strong diffluent flow at upper levels as the day progressed, as well as mainly an east to southeast surface flow regime (although more southerly along or just off shore later in the day).

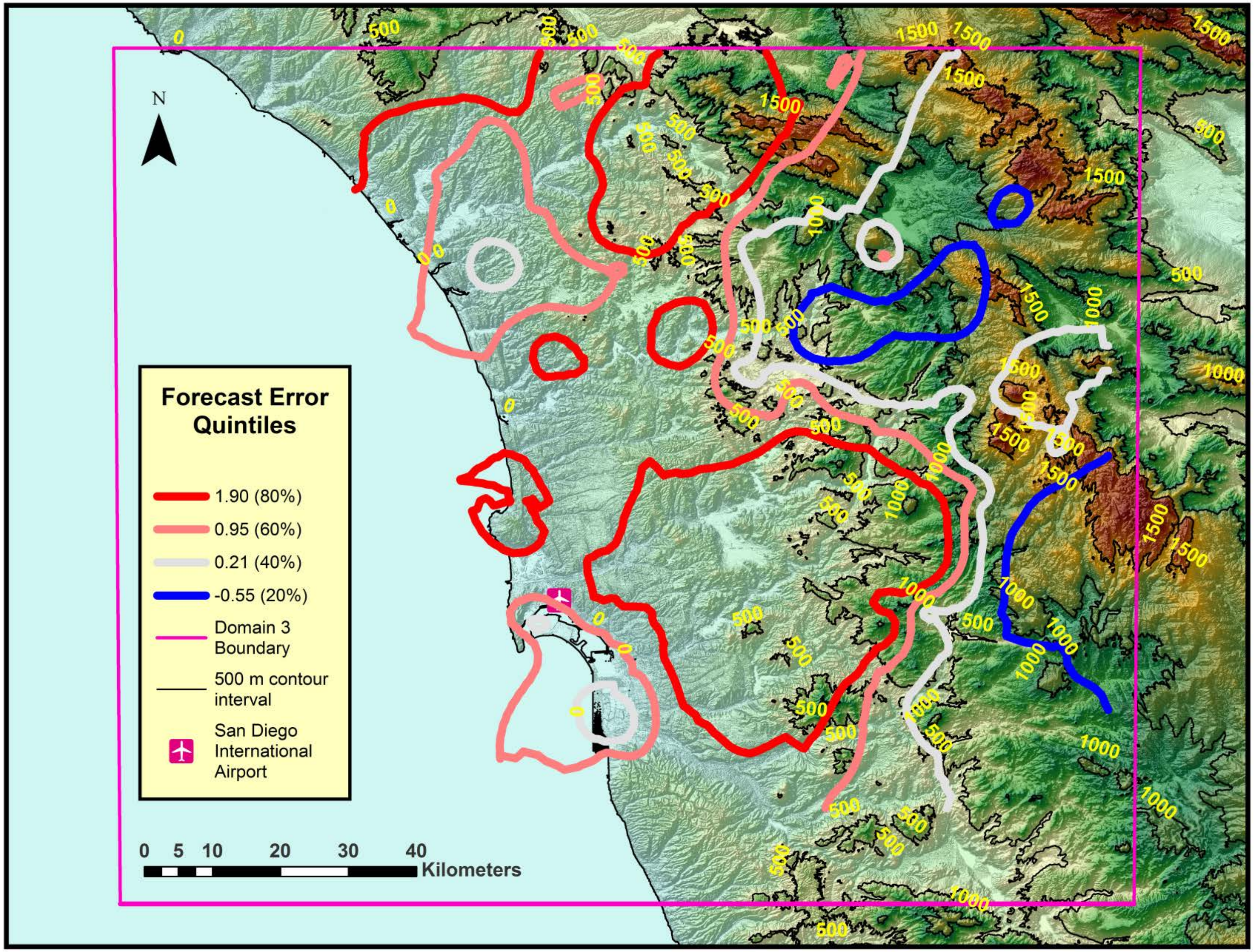
Observation Stations reporting Temperature at 2 meters AGL in Domain 3 (1 km grid spacing)



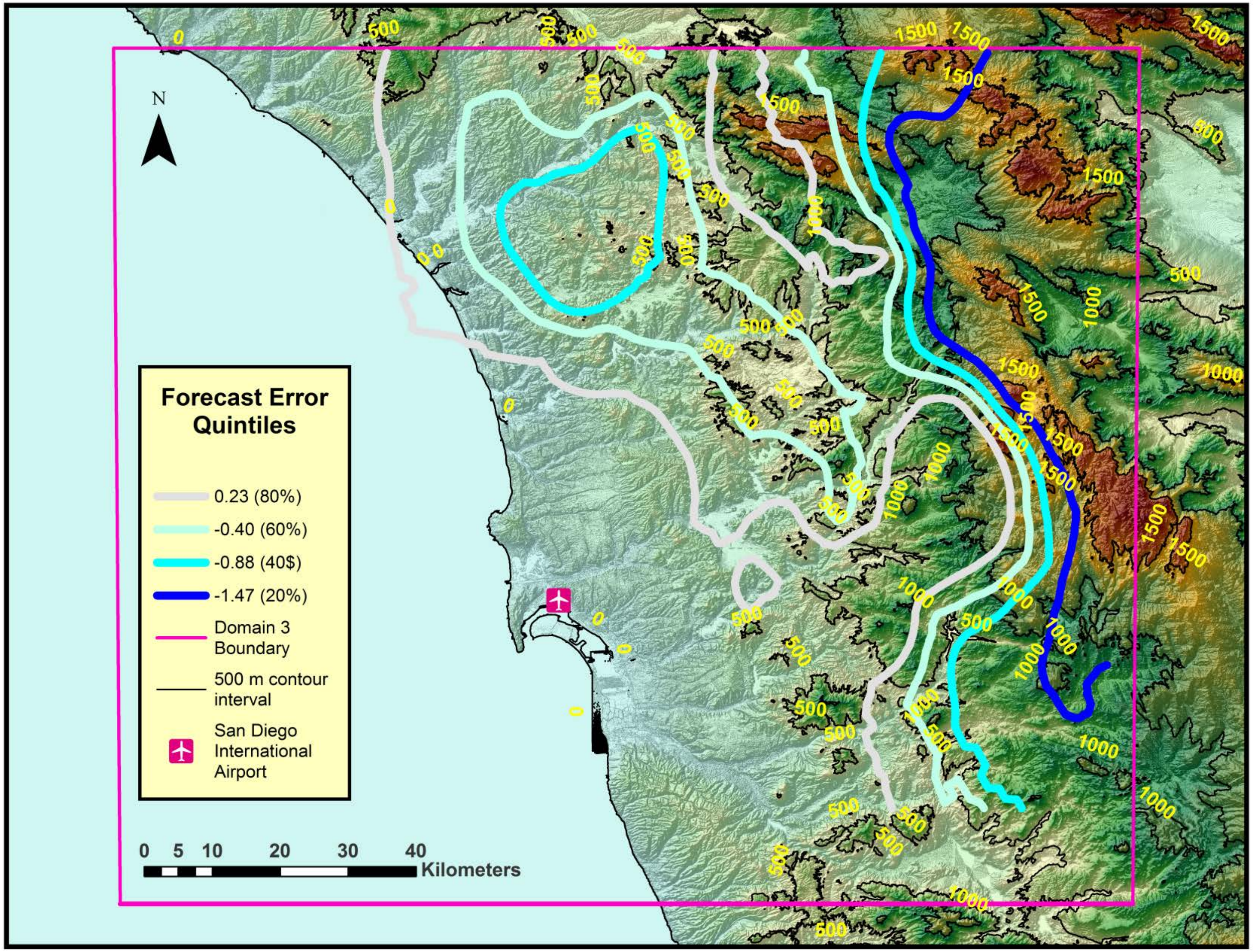
Model Temperature Error (K) for 04 PST / 12 UTC (-6 h analysis)



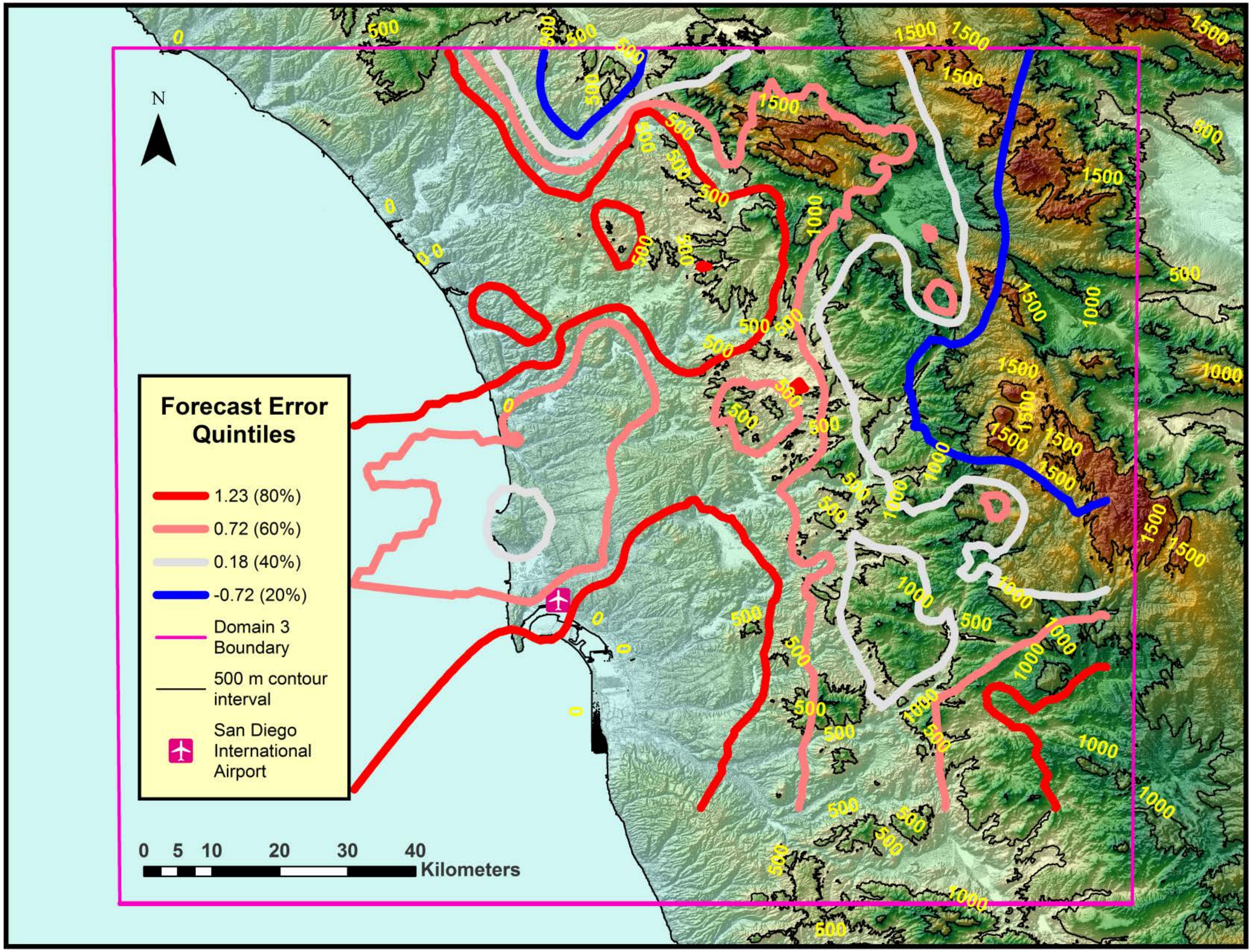
Model Temperature Error (K) for 10 PST / 18 UTC (0 h forecast)



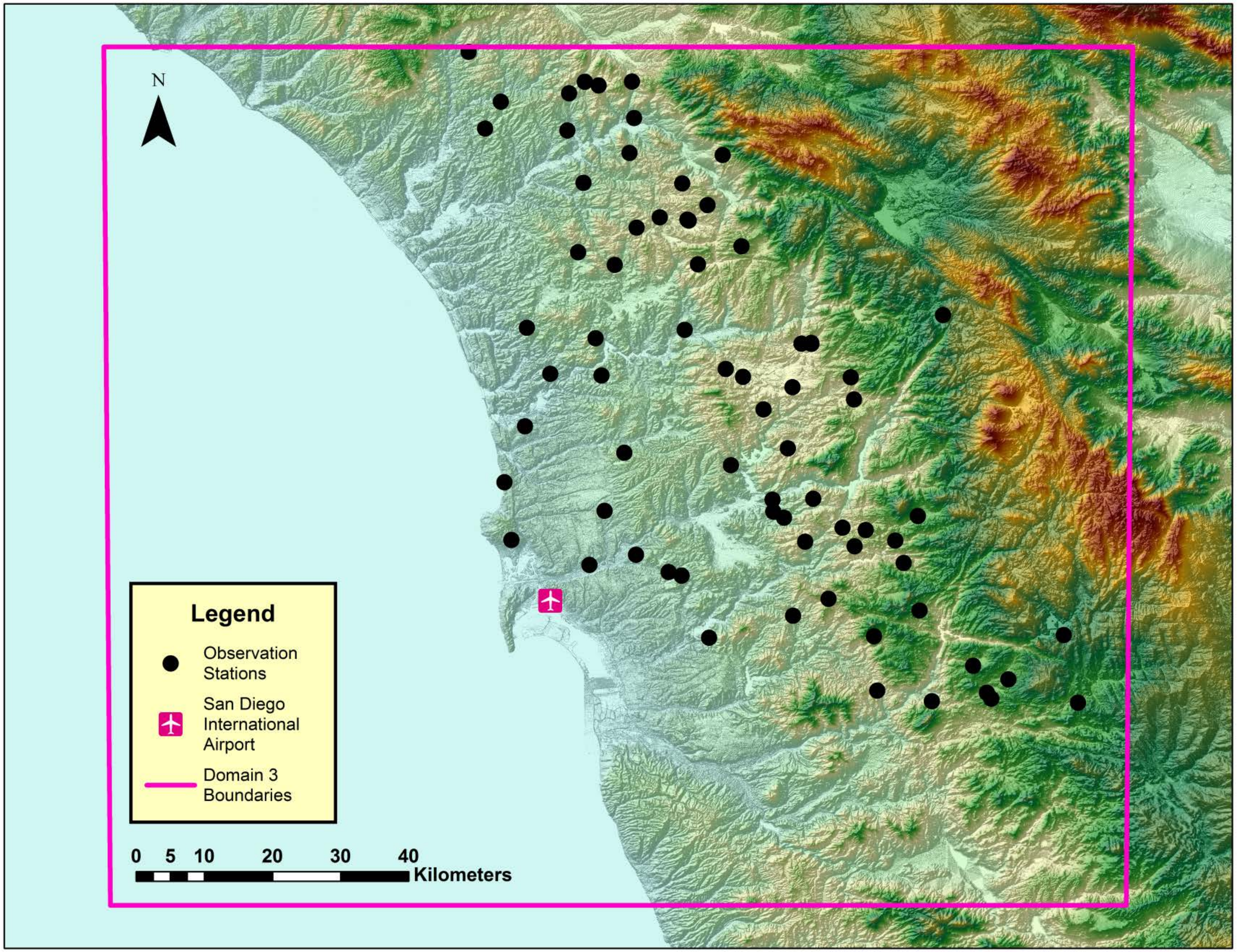
Model Temperature Error (K) for 16 PST / 00 UTC (6 h forecast)



Model Temperature Error (K) for 04 PST / 12 UTC (18 h forecast)

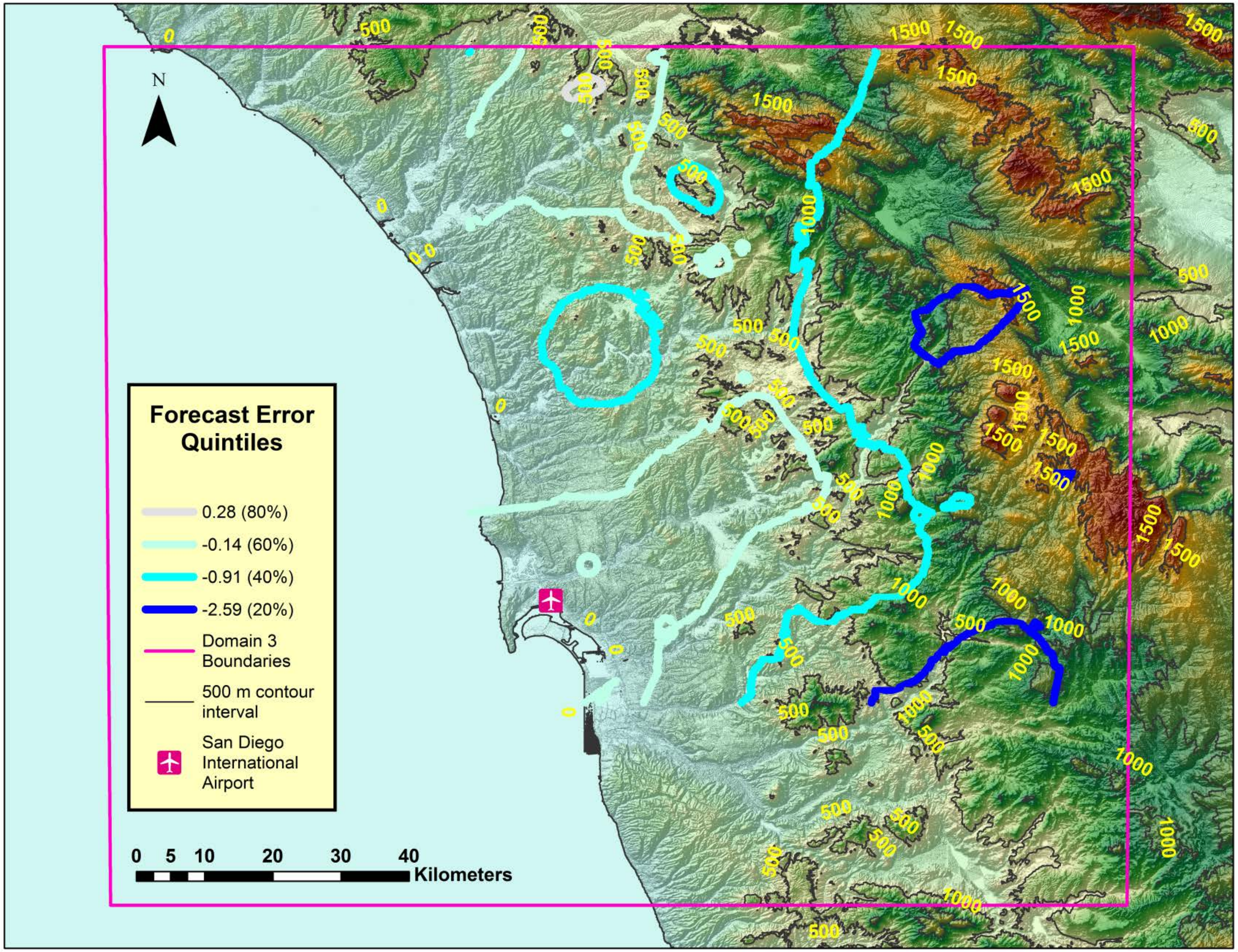


Observation Stations reporting Wind Speed (magnitude) at 10 meters AGL

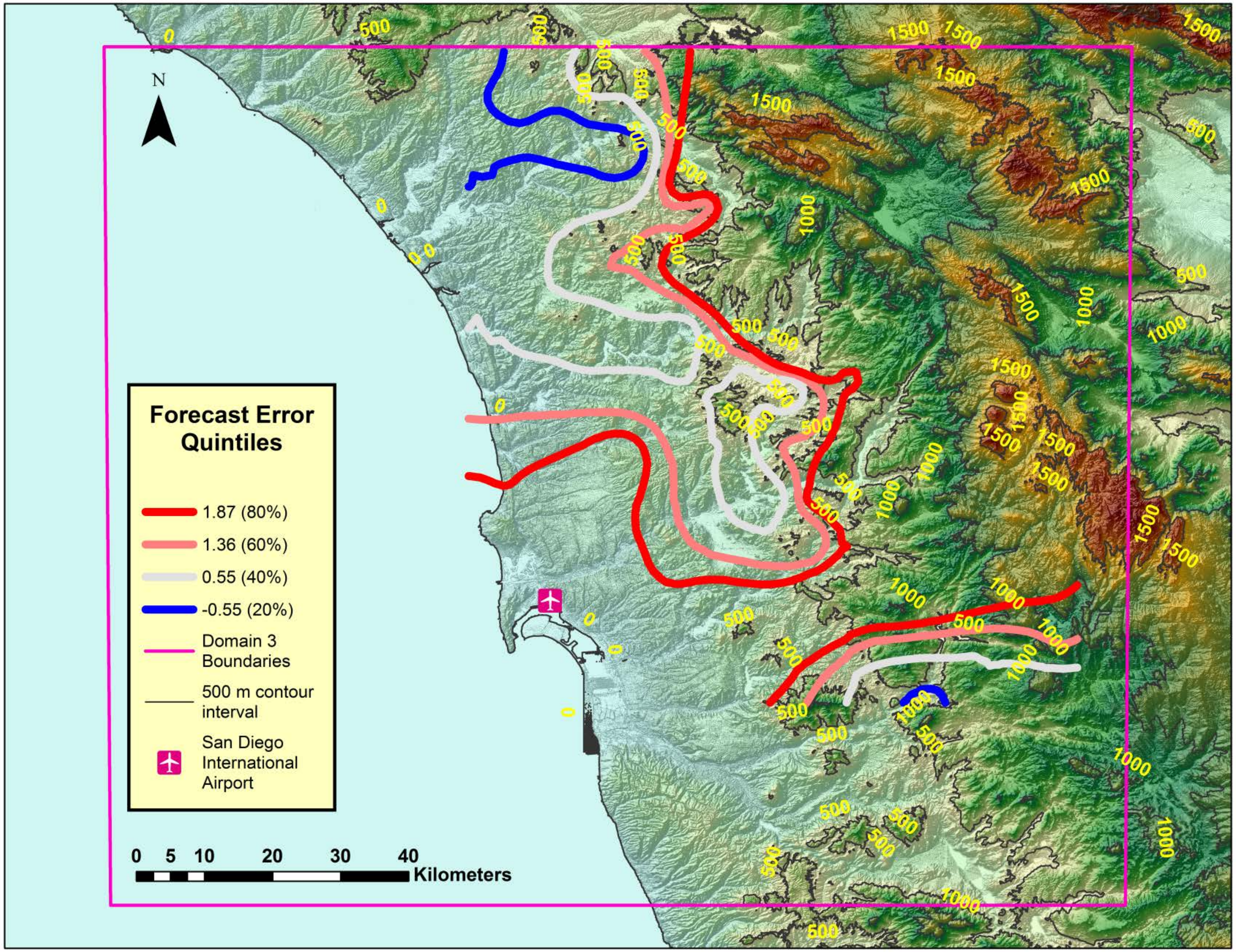


August 21, 2014

Model Wind Speed Error (m/s) for 04 PST / 12 UTC (-6 h analysis)



Model Wind Speed Error (m/s) for 10 PST / 18 UTC (0 h forecast)



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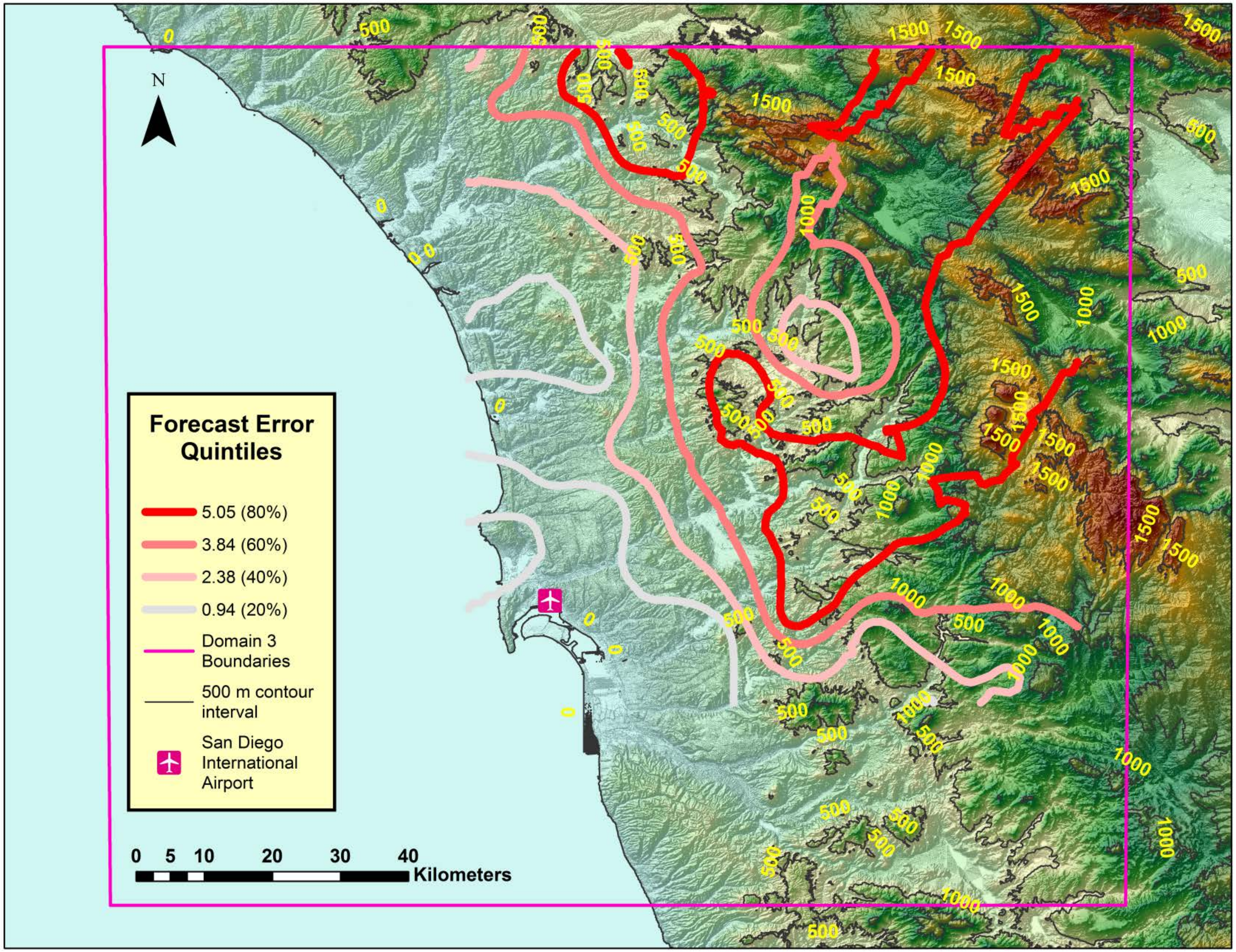
Model Wind Speed Error (m/s) for 16 PST / 00 UTC (6 h forecast)

ARL



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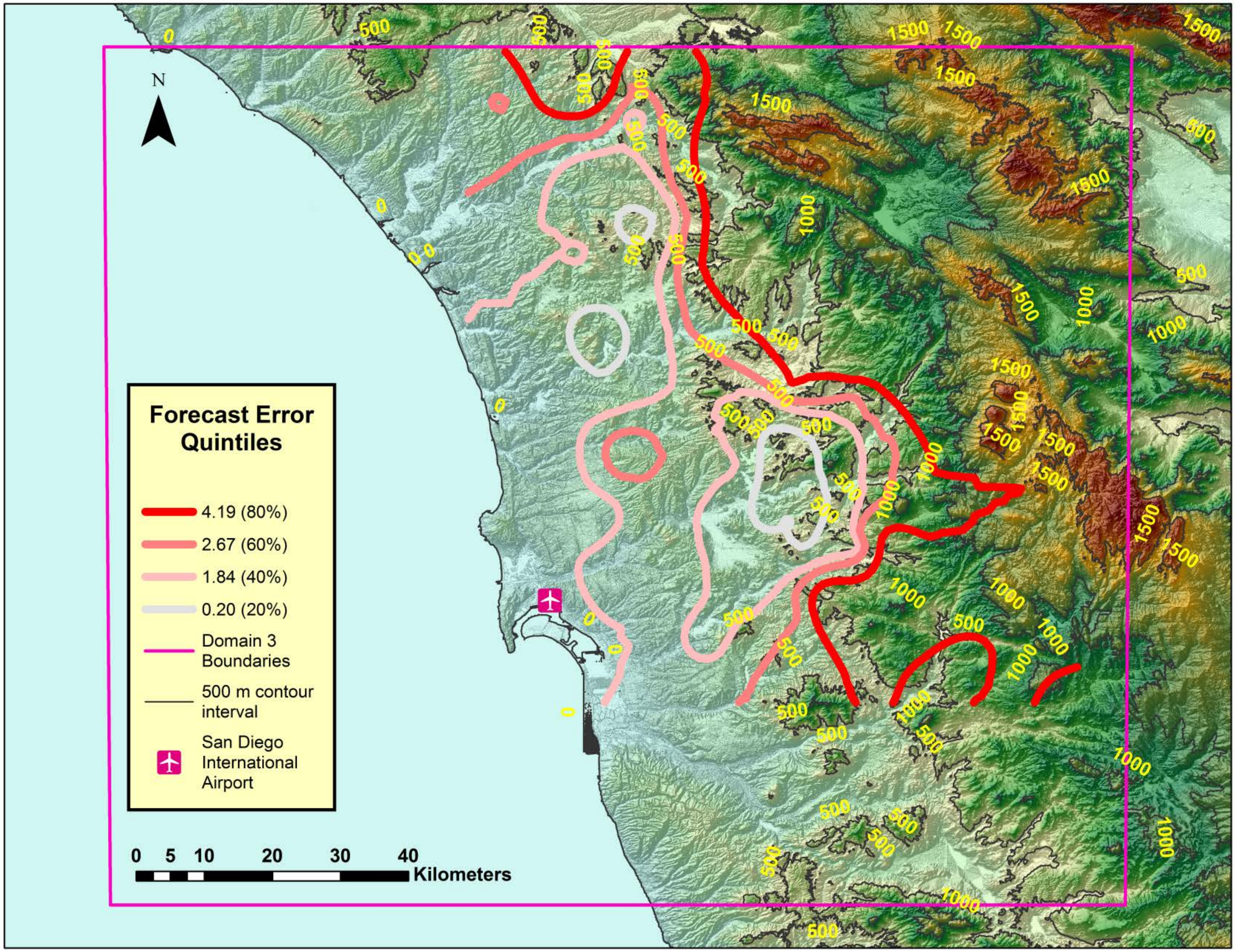
Model Wind Speed Error (m/s) for 22 PST / 06 UTC (12 h forecast)



Conclusions

- GIS extends the use of MET as a post processing tool, and has enhanced ARL model assessment capabilities by allowing the:
  - Display of the spatial distribution of forecast errors at a specified forecast hour.
  - Analysis of the spatial distribution of errors over very high resolution terrain background information.
  - Analysis of the temporal variation of errors from multiple forecasts in the context of the terrain variability and synoptic conditions.
  - Segmentation of the domain into similar sub-domains to better determine relationships between the terrain characteristics and the errors.

Future Efforts

- Cross-validate the kriging model based on sub-sampling the observation stations to produce a surface, and use the remaining un-sampled points to validate the kriged surface.
- Use GIS to analyze forecast errors over other terrain characteristics such as land-use to discover possible spatial and temporal relationships between land-use and errors.
- Use GIS capabilities to perform K-means clustering for determining sub-domains for analysis.
- Expand our capability to perform spatial and temporal analysis of forecast data, through, for example, the use of random fields to account for spatial and temporal error.

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