Chapter 2

Climate and Weather Forecasts and Downscaling

2.1 INTRODUCTION

A significant component of the INFORM integrated forecast-management system is the component that, first, ingests the operational climate and weather forecasts and, second, downscales them appropriately to the hydrologic accounting areas that contribute to reservoir inflow. This chapter discusses progress made in the design of climate and weather forecast ingest procedures in collaboration with national and regional forecast agencies, and summarizes the downscaling procedure implemented as part of the INFORM integrated system. Due to the unavailability of climate and weather forecasts for historical periods as of the time of this writing, no validation was possible for this class of data. Validation of the downscaling procedure is described for the historical period during the winter months. We start with a discussion of the extensive collaborative activities that led to the specific climate and weather data-use design in INFORM.

2.2 COLLABORATIVE ACTIVITIES

The California-Nevada River Forecast Center (CNRFC) of the NOAA National Weather Service has been identified as the primary agency for collaborative activities pertaining to ingesting and downscaling climate and weather data for INFORM (Figure 2-1). For sustainability and to utilize as much as possible operational products, it has been decided to use operational forecasts from the National Centers for Environmental Prediction (NCEP) of the NOAA National Weather Service to drive the INFORM downscaling procedures. INFORM representatives from HRC met with the Director and other members of the Environmental Modeling Center (EMC) of NCEP on the 16th of December 2003 in Washington to establish a collaboration plan regarding the availability of needed climate and weather forecast and retrospective analysis data for the implementation of the integrated forecast-management system for Northern California. In a subsequent meeting during January, 2004, CNFRC management was briefed concerning the discussions between HRC and NCEP in December 2003. The briefing passed on to CNRFC the information from NCEP concerning weather and climate forecast systems, data availability and acquisition. In turn, HRC personnel were briefed on communications methods available to CNRFC to acquire data from NCEP (principally in terms of bandwidth), and CNRFC perspective on data needs for the INFORM project.

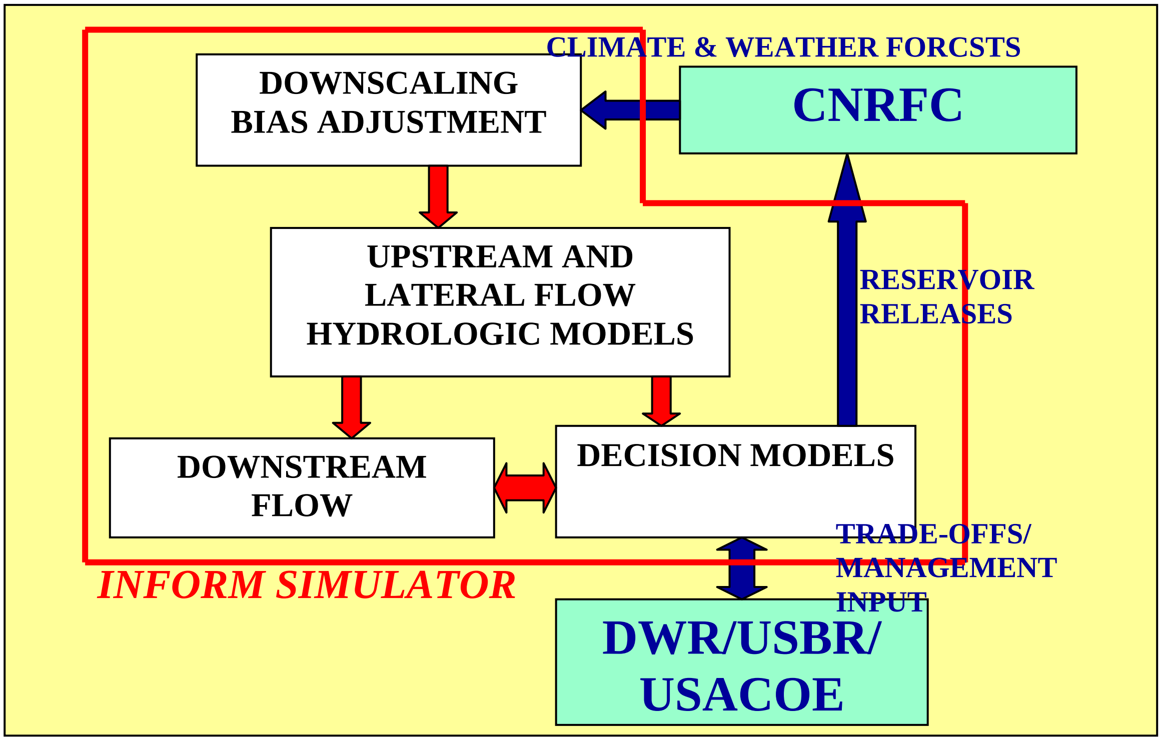


Figure 2-1: Schematic showing the main components of the INFORM simulator and its links to the main forecast (CNRFC) and management agencies (DWR/USBR/USACOE) in Northern California.

In January 2004 HRC personnel met again with NCEP EMC staff. These discussions covered the retrospective climate model forecast system and data availability in detail, the design, operational implementation and data availability for both short-range (GFS, Eta), and seasonal forecast systems. These discussions focused on the data required for the INFORM to produce probabilistic precipitation and snowmelt forecasts, and the means of acquiring those data. This latter point is an important practical matter, as ensemble forecast systems generate large volumes of data. In recognition of the fact that users were often required to download very large volumes of data in order to obtain the small fraction that they desired, NCEP has implemented a server/client system called NOMADS (NOAA Operational Model Archive Distribution System). The NOMADS system allows users to issue a request for specific model output data (e.g., specific time, level, latitude, longitude, variable). The actual preparation of this subset is carried out at NCEP on dedicated servers, and the subset is transmitted directly to the user, or is placed in a defined location for user retrieval. NCEP scientists briefed HRC personnel on the use of the NOMADS system.

HRC personnel have familiarized themselves with the process of retrieving data from the NOMADS system, and have written and tested software necessary to automatically download defined subsets of numerical weather forecast data from NCEP. Thus the methodologies are in place for meeting the ensemble data requirements for the INFORM project. NCEP is currently in the process of placing the ensemble GFS data sets on the NOMADS servers.

HRC personnel met again with CNRFC staff (April 2004) to brief them concerning the January meeting with NCEP EMC, and to familiarize them with the capabilities of the NOMADS system. These meeting have been essential to the design of the INFORM ingest component for climate and weather data and have paved the way for a longer-term fruitful collaboration between operational global centers (NCEP), regional hydrologic forecast centers (CNRFC) and INFORM developers. In the next few sections we elaborate on the operational forecasts and ingest components of INFORM.

2.3 CLIMATE FORECASTS

Based on a number of discussions with regional and national forecast agencies, it was decided that the new National Centers for Environmental Prediction (NCEP) coupled model results will be used as the basis for INFORM climate time scale forecasts. The new NCEP climate forecast model is a true global dynamical coupled forecast model, and is thus a marked departure from the previous forecast system which contained numerous statistical/empirical corrections, and forecast sea surface temperatures over the tropical Pacific only (rather than globally). A 10-member retrospective forecast ensemble (out to a lead time of 9 months) is currently being generated by NCEP (Environmental Modeling Center) and is to be completed in the summer of 2004. These retrospective forecasts will cover the period from 1981 through 2003, with 10 forecasts initialized from each month and going out to a lead time of 9 months. The retrospective forecasts are essential to INFORM as they allow calibration of downscaling methods. Operational forecasts with this model will begin being issued in the summer of 2004.

The new NCEP operational model has the following positive attributes with respect to the INFORM project:

- *(a)* The model will be an operational NCEP forecasting system.
- *(b)* The use of NOAA products is necessary for the collaborating California Nevada River Forecast Center (CNRFC).
- *(c)* Initial evaluations (by NCEP) of the model performance show marked improvement over the earlier NCEP climate forecast model.
- *(d)* The former NCEP climate model will no longer be run.
- *(e)* As this model is improved, NCEP EMC is committed to performing new retrospective forecast simulations so that downscaling tools can be recalibrated.

Because the retrospective ensemble forecast simulations are not yet complete, the validation of the system is pending. At this stage HRC has generated a draft design of the operations associated with the climate model ingest and use in producing hydrologic model input. Table 2-1 shows the climate data types that are necessary for the INFORM system.

Other development activities regarding the coupled model are:

- *(a)* Met with NCEP EMC management and operational personnel in Camp Springs Maryland in December 2003 and January 2004 regarding the new climate model. These discussions covered details of the coupled modeling system, as well as schedules, model output (variables, time and space resolution), and matters relating to data acquisition, for both the retrospective forecast project and operational forecast activities.

(b) Sample datasets from ensemble retrospective forecasts for October 1982 and 1983 have been acquired from NCEP. The software necessary to read and process these data sets has been written and tested.

Table 2-1: Climate Forecast Data

(in all cases 9-month maximum lead time with 12-hr temporal resolution, T62 Gaussian spatial resolution, and 10 ensemble members)

At surface

Precipitation
2m air temperature (T)
2m specific humidity (Q)
10m wind vector components (U and V)
Net solar radiation
Net long-wave outgoing radiation
Sensible heat
Latent heat

At available upper levels (at least at standard pressure levels)

Wind vector components (U and V)
Air Temperature (T)
Specific humidity (Q)
Geopotential height

2.4 WEATHER FORECASTS

The NCEP operational global forecast system (GFS) ensemble forecasts out to 16 days (384 hours) maximum lead time with 6-hourly resolution are utilized to provide input to the downscaling procedure for producing short and medium term ensemble precipitation and temperature forecasts for the drainage basins of interest in the INFORM study region. Information about the GFS may be found in *Kanamitsu et al. (1991)* and more recently at http://www.emc.ncep.noaa.gov/gmb/moorthi/gam.html. Because the GFS and the climate forecasts mentioned in the previous section are based on essentially the same formulation, and given the low weather signal expected in 16-day forecasts, we plan to blend the ensemble GFS forecasts with the climate ensemble forecasts at 16 days lead time in order to produce a continuous ensemble stream for the downscaling procedure (Figure 2-2).

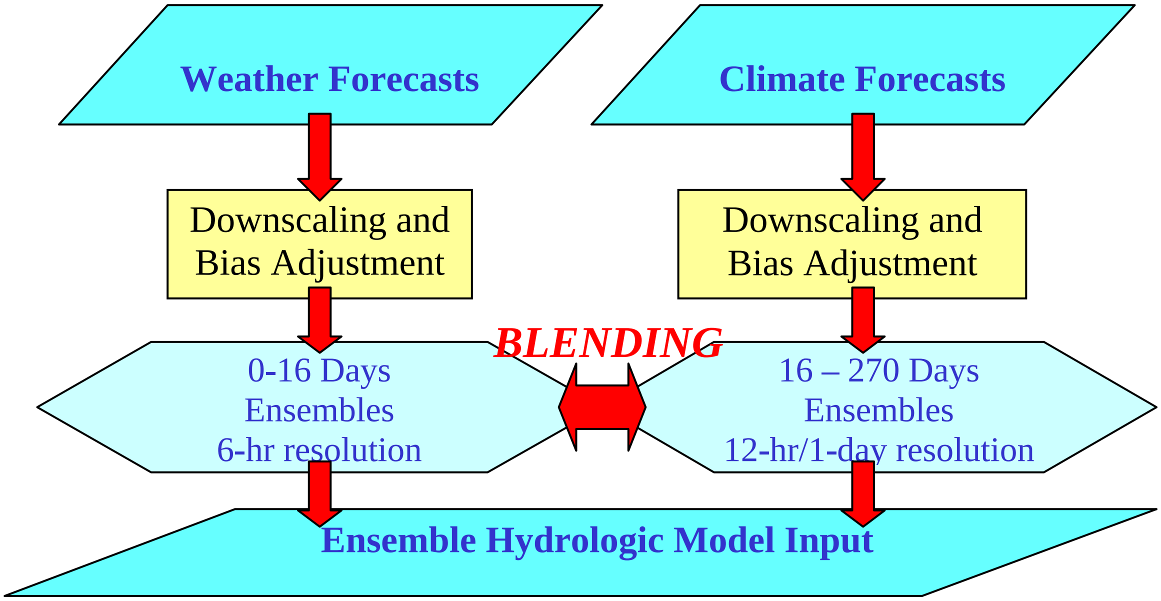


Figure 2-2: Schematic of the INFORM ingest components for NCEP climate and weather forecasts.

Table 2-2 shows the operational GFS ensemble forecasts that will be used by the INFORM system. There is a large volume of GFS data necessary for download during near real time operations. Download time is approximately 1 hour per ensemble forecast member. The total download time for all ten ensembles for near real time operations sets high computational resource demands. The INFORM demonstration period operations shown in Figure 2-3 are based on an 8-processor computational platform. The Figure shows two cycles of the INFORM ingest and downscaling process (i.e., the 00Z and 12Z forecast cycles). It is expected that in each cycle, the first 6 hours would be devoted to the production of the GFS ensemble forecasts by NCEP/EMC. A total of approximately 8 hours (until about 14Z) would be required to download these forecasts onto the INFORM computer through a normal FTP process. Assuming that the processing of the downscaling procedure would be done on an 8-CPU computer (each CPU processes one ensemble) and for the downscaling procedure described in section 2.5 of the present chapter with a 10-km x 10-km resolution, we estimate the downscaling procedure computation time to be approximately 4 hours. Thus the entire set of downscaled ensemble products based on the 00Z NCEP run will not be available for the hydrologic models and the reservoir management models earlier than 18Z. It is possible to have perhaps one downscaled forecast time series available 8 hours after the NCEP run (see asterisk in Figure) for short term forecast guidance. However, as proven in the INFORM feasibility studies, ensemble forecasts are necessary for improved reservoir management.

Table 2-2: GFS Forecast Data
(in all cases 16-day maximum lead time with 6-hourly temporal resolution, $1^o x 1^o$ spatial resolution out to a lead time of 84 hours and a $2.5^o x 2.5^o$ spatial resolution for greater lead times, and 12 ensemble members)

At surface

Precipitation
Snow accumulation
2m air temperature (T)
2m relative humidity (Q)
10m wind vector components (U and V)
Net solar radiation
Net long-wave outgoing radiation
Sensible heat
Latent heat

At available upper levels (at least at standard pressure levels)

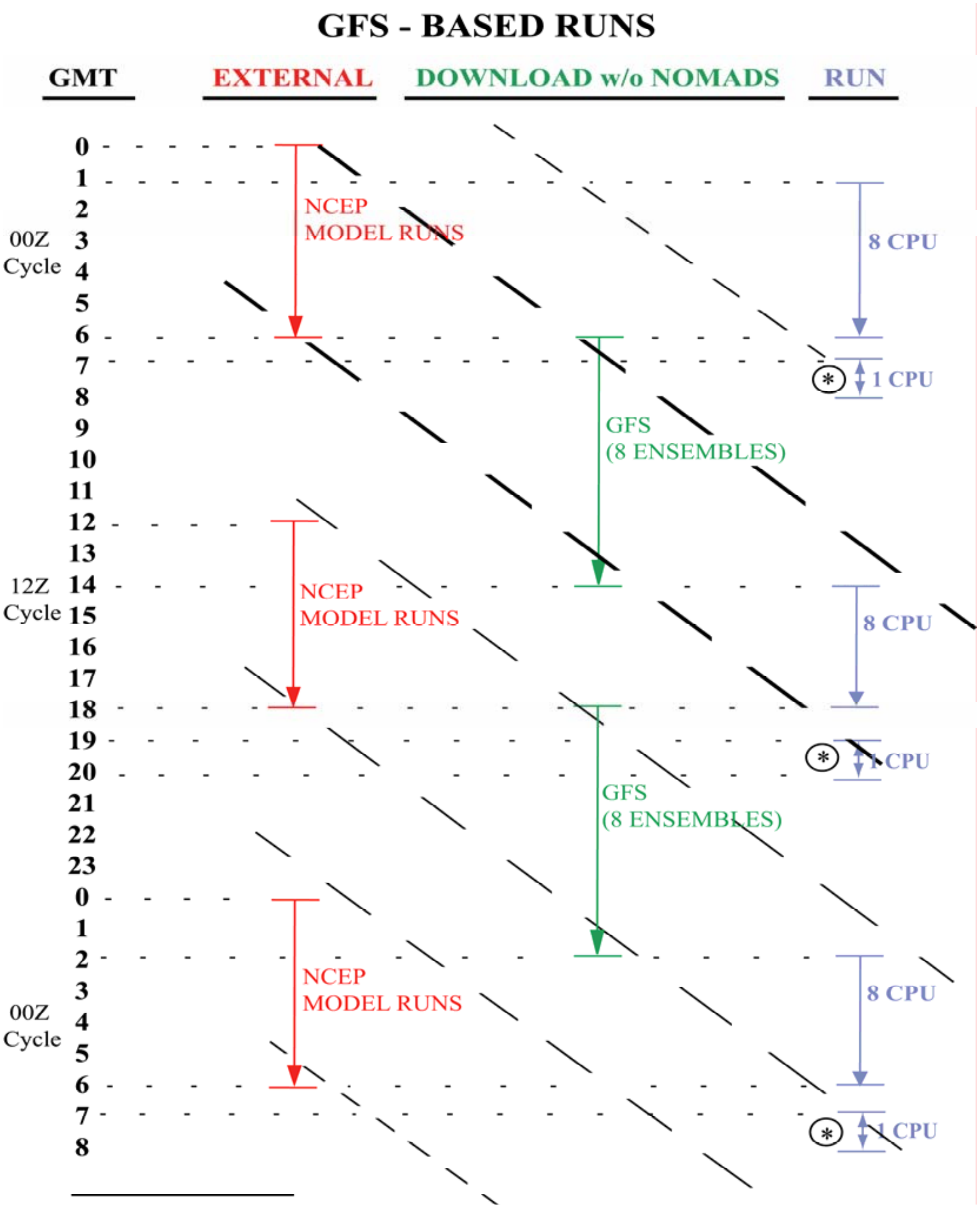
Wind vector components (U and V)
Air Temperature (T)
Relative humidity (Q)
Geopotential height

To resolve this issue a request was submitted to NCEP to make the GFS products available on the NOMADS server in which case a very small fraction of the original data needs be downloaded to the INFORM computer at a fraction of the time (estimated in less than 1 hour). In such a case, the full set of downscaled ensembles would be available in less than 12 hours after the time of NCEP run initiation. NCEP is currently in the process of making GFS products available on NOMADS. A computer code to control the data retrieval through the NOMADS system is shown in Appendix A.

2.5 DOWNSCALING

2.5.1 Overview

A simplified orographic precipitation model is the means of dynamic downscaling of weather and climate forecasts to precipitation rates over scales of 10-km x 10-km. The simplified orographic precipitation model is based on decoupling the momentum from the moisture conservation equations in the atmosphere. Estimation of three dimensional air velocities is accomplished via analytical potential theory flow solutions (e.g., *Georgakakos et al. 1999*) over complex terrain driven by 700mbar wind velocities from numerical weather and climate prediction model fields. Forecast fields also provide the boundary conditions for a three-dimensional moisture conservation model based on *Kessler (1969)*, which uses the potential theory flow velocities to produce precipitation rates over complex terrain. The formulation differs from earlier simplified approaches (e.g., *Pandey et al. 2000; Rhea 1978*) in that it produces consistent three dimensional velocity fields over complex terrain, and in that it has explicit microphysical parameterizations for the generation of cloud and precipitation. Compared to full non-hydrostatic mesoscale models, its computational efficiency allows the generation of ensemble downscaled forecasts in reasonable time while it preserves the deterministic signal in orographic rainfall (see earlier examples in *Georgakakos et al. 1999* for the tropics and in *Tateya et al. 1991* for the mid latitudes). The model has been used in a recent HRC study funded by the U.S. Army Corps of Engineers for reconstructing the deterministic signal in Sierra Nevada rainfall from historical radiosonde observations and analysis fields. In the next sub-sections we outline the basis of the formulation and provide validation results from sensitivity studies pertaining to the Folsom watershed.



NOTES:
- 8 PC Processors
- 8 ENSEMBLE GFS (1° x 1° – 84 hrs MFLT / 2.5° x 2.5° – 16 days MFLT)
- 1 SHORT RANGE FORECAST RUN ⊛ with ETA or GFS
- 4 min / 6 hrs / 1 CPU / 1 ENS

Figure 2-3: Scenario of INFORM system generation of ensemble downscaled products for the hydrologic and reservoir management models. NCEP run times, GFS ensemble forecast download times and downscale processing times are shown for two full cycles of demonstration project operation. Downloading of GFS products is done with normal FTP process without the NOMADS system.

2.5.2 Potential Theory Updrafts

Fundamental assumptions for applicability are:

(a) the atmosphere is near saturation;

(b) the atmosphere has a steady uniform flow for the time interval of interest;

(c) the scale of the flow fluctuations is longer than the topographic fluctuations considered;

(d) the Coriolis effect is assumed negligible for the spatial scales of interest.

With those conditions and for incompressible and irrotational flow without momentum sources or sinks, the following holds true:

$$\nabla \times U = 0 \tag{2-1}$$

and

$$\nabla \bullet U = 0 \tag{2-2}$$

In the previous two equations, ∇ represents the gradient vector and U represents the three-dimensional velocity vector. The first equation shows the vector (or cross) product and the second equation shows the scalar (or inner) product of the two vectors. The first condition of zero curl implies that there exist a scalar single-valued velocity potential ϕ so that the velocity field is given by:

$$U = \nabla \phi \tag{2-3}$$

This when substituted in the incompressible condition (2-2) of zero divergence (absence of momentum sources and sinks) yields:

$$\nabla \bullet \nabla \phi = 0 \tag{2-4}$$

or

$$\nabla^2 \phi = 0 \tag{2-5}$$

The last equation is *Laplace's* equation and its solutions are called *harmonic functions*. This equation constitutes the basis for the potential theory flow estimation of three dimensional air velocities over complex terrain. The expanded constitutive equation and boundary conditions are written in the following for a rectangular domain (*LxKxH*) whose lower boundary is the complex terrain, whose upper boundary is located in the upper troposphere, and with the free air stream velocity (700mbar upstream velocity u_o) aligned with the x-axis.

We seek solutions of the velocity potential $\phi(x,y,z)$ for the following boundary value problem:

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=0 \qquad (2\text{-}6)$$

with the Neumann boundary conditions specified:

$$\frac{\partial\phi}{\partial y}=u_o \quad at \quad y=0 \qquad (2\text{-}7)$$

$$\frac{\partial\phi}{\partial y}=u_o \quad at \quad y=L \qquad (2\text{-}8)$$

$$\frac{\partial\phi}{\partial x}=0 \quad at \quad x=0 \qquad (2\text{-}9)$$

$$\frac{\partial\phi}{\partial x}=0 \quad at \quad x=K \qquad (2\text{-}10)$$

$$\frac{\partial\phi}{\partial z}=0 \quad at \quad z=0 \qquad (2\text{-}11)$$

$$\frac{\partial\phi}{\partial z}=u_o\frac{\partial s}{\partial y} \quad at \quad z=\text{-}H \qquad (2\text{-}12)$$

It is noted that dependence of ϕ on the spatially independent variables is not shown for notational convenience. The boundary conditions represent conditions on the velocity field, such that the free stream velocity u_o is specified at the boundaries ($y=0$ and $y=L$) in the y-direction under the assumption of flat terrain there; zero velocity is specified in the x-direction at the boundaries ($x=0$ and $x=L$); and zero velocity is specified at the upper boundary ($z=0$) in the z-direction, while the lower boundary vertical velocity is forced by the boundary topographic gradient function ($\partial s/\partial y$) along the direction of u_o. By definition, the velocity components are:

$$\text{(along } x\text{-axis)} \quad v = \frac{\partial\phi}{\partial x} \qquad (2\text{-}13)$$

$$\text{(along } y\text{-axis)} \quad u = \frac{\partial\phi}{\partial y} \qquad (2\text{-}14)$$

$$\text{(along } z\text{-axis)} \quad w = \frac{\partial \phi}{\partial z} \qquad \text{(2-15)}$$

The solutions of *Georgakakos et al. 1999* were used in this work to obtain analytical expressions for the three-dimensional velocity vector at each point in the three dimensional rectangular domain. The horizontal resolution in x and y is set to 10 km.

We used existing HRC software (e.g., *Sperfslage et al. 1999*) to produce the numerical solution of the potential theory flow equations (2-6 through 2-15) for terrain aligned with the 700-mbar wind velocity. Rotated terrain coordinates are produced from original Northings and Eastings of 1 km resolution for Northern California to accommodate incoming wind from different directions. A resolution of $\pi/8$ in the interval $(0 – 2\pi]$ was used, with 0 and 2π signifying wind from the North and with a clockwise convention for the angles in between (e.g., $\pi/2$ signifies wind from the East, while $3\pi/2$ signifies wind from the West). The solutions for each of 16 angles in the interval $(0, 2\pi]$ and for unit upstream 700 mbar wind were produced in rotated coordinates and were used to provide the three dimensional wind vectors to the atmospheric moisture conservation component described in the next subsection. There is strong dependence of the watershed-averaged updraft strength on the 700-mbar wind direction for the Folsom Lake watershed. The compass plot in Figure 2-4 shows this dependence for a unit 700-mbar wind with direction that spans the interval $(0,2\pi]$ clockwise with resolution of $\pi/8$.

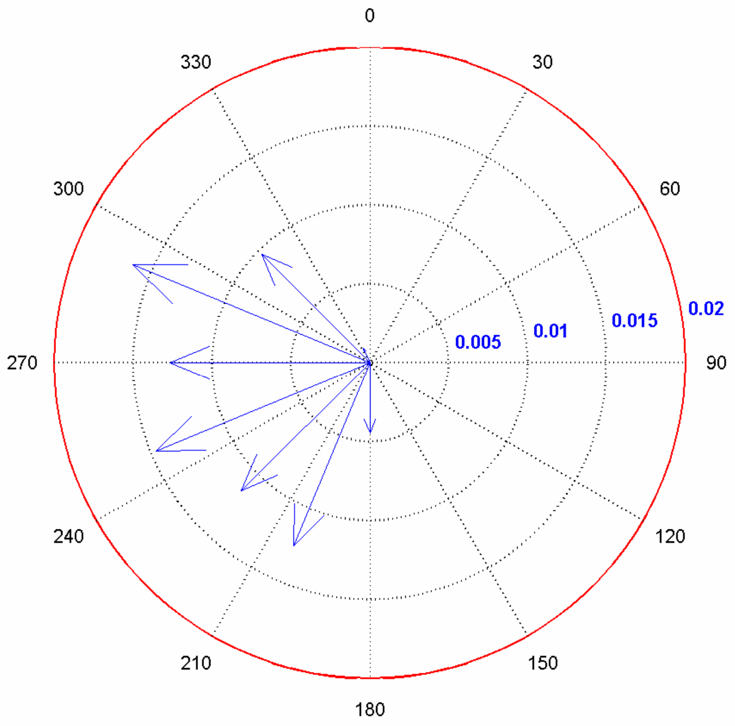


Figure 2-4: Mean areal updraft for Folsom Lake watershed as a function of direction angle from North (shown in degrees) for a unit 700-mbar wind inflow. The arrows indicate the direction from where the 700-mbar wind is blowing, and the magnitude of the mean areal updraft as a fraction of the incoming wind magnitude (contours of equal mean areal updraft are shown as concentric circles with indicated magnitude). Terrain slope is averaged over 10km intervals.

It is clearly shown that the Folsom watershed terrain generates updrafts for winds with angles of approach in the interval [π, $7\pi/4$] or for S to NW winds. It is also shown that the mean areal updraft strength depends non-linearly on the direction angle due to the terrain morphology (local slopes and Coastal and Sierra Nevada mountain alignment along the 700mbar wind direction). Most significant mean areal updrafts are generated for SSW to WNW winds with magnitudes of about 1.5 percent of the 700-mbar wind speeds (e.g., 0.45m/s averaged over the Folsom watershed for a 30 m/s 700-mbar wind). These updrafts are responsible for the generation of orographic precipitation even in the absence of convection in the region. The model for computing surface precipitation on the basis of the derived three-dimensional air velocities and microphysical parameterizations is described next.

2.5.3 Simplified Orographic Precipitation (SIMOROP) Model

The atmospheric moisture model for cloud and precipitation first proposed by *Kessler (1969)* is the basis of the orographic precipitation computations (see also microphysical formulation in *Tsintikidis and Georgakakos 1999*). The model equations describe the response of the water content of air to the air motions and microphysical processes:

$$\frac{\partial M}{\partial t} = -v\frac{\partial M}{\partial x} - u\frac{\partial M}{\partial y} - (V+w)\frac{\partial M}{\partial z} - M\frac{\partial V}{\partial z} + Mw\frac{\partial \ln \rho}{\partial z} + k_1(m-a) + \\ k_2 E N_0^{1/8} m M^{7/8}\exp(kz/2) + k_3 N_0^{7/20} m M^{13/20} \qquad (2\text{-}16)$$

$$\frac{\partial m}{\partial t} = -v\frac{\partial m}{\partial x} - u\frac{\partial m}{\partial y} - w\frac{\partial m}{\partial z} + wG + mw\frac{\partial \ln \rho}{\partial z} - k_1(m-a) - \\ k_2 E N_0^{1/8} m M^{7/8}\exp(kz/2) - k_3 N_0^{7/20} m M^{13/20} \qquad (2\text{-}17)$$

The model states are m and M, with the first being the cloud content if positive and the amount of moisture required to saturate the air if negative, and the second being the precipitation content (both in units [gm m^{-3}]). The velocities u, v and w are as defined earlier for y, x and z directions, and ρ represents the air density. The derivatives dM/dt and dm/dt are in [gm m^{-3} s^{-1}], $k = 10^{-4}$ [m^{-1}] if compressibility of air is taken into account, otherwise zero; k_1 = constant (usually 10^{-3} [s^{-1}]) when $m > a$, otherwise, $k_1 = 0$; $k_2 = 6.96 \times 10^{-4}$ when $m > 0$, otherwise, $k_2 = 0$; $k_3 = 1.93 \times 10^{-6}$ when $m < 0$, otherwise, $k_3 = 0$; $V = -38.3\, N_0^{\;1/8} M^{9/8} exp(kz/2)$ [m s^{-1}]; G is treated as a constant at a given altitude; and a, E and N_o are parameters (Kessler used the values of 0.5 [gm m^{-3}], 1, and 10^7 [m^{-4}], respectively).

The main assumptions implicit in this system are (adopted from *Kessler 1969*):

(a) Cloud is condensed water that fully shares the air motion.

(b) Cloud forms in saturated rising air and evaporates in saturated descending air at the rate $wG = -\ w\rho(dQ_s'/dz)$ where Q_s' is the saturation mixing ratio of water in air computed from radiosonde or embedding model information. Cloud-containing air is always saturated, and unsaturated air never contains cloud.

(c) Cloud changes to raindrops that are distributed in size according to an inverse exponential distribution at the rate $k_1(m - a)$, where the magnitude of k_1 and a may be selected to simulate various processes and rates.

(d) Precipitation particles once formed are assumed to be distributed in size according to an inverse exponential law and to collect cloud particles or evaporate in sub-saturated air according to approximations to the natural accretion and evaporation processes.

(e) Precipitation shares the horizontal motion of the air, but the vertical mass transport of precipitation is based on the fall speed of the median-diameter precipitation particle. The change of shape of a distribution by virtue of differing fall speeds within it, and by evaporation, condensation and accretion processes is omitted.

As part of the downscaling procedure, the numerical code simulates the system of Equations (2-16) and (2-17) using as boundary conditions vertical profiles of temperature, pressure, humidity, and utilizing the potential theory flow solutions of the previous subsection for a given speed and direction of the boundary 700-mbar wind. The code uses a non-diffusive spline-interpolation method for the computation of three-dimensional advection (see *Pielke 1984; cf. Mahrer and Pielke, 1978*) and a fourth order Runge–Kutta integration method for the computation of the source and sink contributions of Equations (2-16) and (2-17) due to microphysical terms. A series of numerical sensitivity studies was conducted to determine appropriate temporal discretization intervals for advection (Δt_a) and for source/sink term integration (Δt_s). The ranges of the intervals examined in each case were: $56 \text{ s} \leq \Delta t_a \leq 900 \text{ s}$; $1 \text{ s} \leq \Delta t_s \leq 300 \text{ s}$. It was found that Δt_a=112 s and Δt_s=11 s are adequate to reproduce the surface precipitation magnitude and pattern obtained by a very accurate integration (Δt_a=56 s; Δt_s=1 s). The sensitivity studies were conducted with boundary conditions taken from the operational ETA analysis data obtained for the recent significant storm in Northern California that occurred on the 7th and 8th of November 2002. Once the three dimensional wind computations are done as described in the previous subsection for various 700-mbar wind angles, it takes approximately 2.5 min of CPU time on a 1GH PC running Windows 2000 to produce a three-hourly surface precipitation field for Northern California (from 37°N to 42°N and from 118°W to 125°W) with a 10 km resolution in rotated coordinates. This is a small fraction of the time it takes a full mesoscale numerical weather prediction model to complete the same integration. In the following sub-section we discuss the validation of the simplified orographic precipitation (SIMOROP) model.

2.5.4 *Validation for Folsom Watershed*

Six-hourly mean areal precipitation data were made available through the California Nevada River Forecast Center (CNRFC) for the period 1969 - 1992. The data are based on precipitation gauge measurements and standard National Weather Service procedures for producing mean areal precipitation values from point data in mountainous terrain. The simplified orographic precipitation model was run for the period from 1 November to 15 May (wet season of the year) for each of the water years from 1969 through 1992. Six-hourly National Centers for Environmental Prediction (NCEP) reanalysis data were used as input to the model with a resolution of about 2.5^o x 2.5^o (about 250 x 250 km^2). In this case, the orographic model was used as a means of downscaling the reanalysis data. The domain of analysis covered the INFORM domain in Northern California with a resolution of 10 x 10 km^2. On the basis of available digital catchment boundaries, mean areal precipitation estimates over the North, Middle and South Fork and the entire Folsom Lake drainage were computed by averaging the gridded output of the simplified orographic model within each of these catchments.

Appendix B contains plots of six hourly observed and downscaled mean areal precipitation estimates for all the catchments considered and for the period 1 November through 15 May for each water year of record. Visual inspection shows that in most cases the downscaled estimates capture the variability of the observed six-hourly rainfall for the entire 3,300-km^2 Folsom Lake catchment and in each of the three sub-catchments (areas from 800 to 1,400 km^2). That is, the simplified orographic model, while parsimonious, generates skillful downscaled estimates for this catchment. There is a tendency to overestimate the low six-hourly precipitation rates, especially in the Middle and the South Fork.

Table 2-3 shows the values of statistical performance indices for the period of record and for six-hourly and daily time intervals. The indices computed are the cross correlation coefficient between observed and downscaled mean areal precipitation estimates (ρ_c), the ratio of the residual mean to the observations mean (r_m), and the ratio of the residual standard deviation to the observed standard deviation (r_s). Perfect performance is indicated by values of 1, 0, and 0 for these three performance indices respectively. The analysis was performed for those time steps for which the observed mean areal precipitation was greater than 0.1 mm/6hrs for the six-hourly time step case or 0.5 mm/day for the daily time step case. It is apparent that the downscaled estimates exhibit high cross correlation with the observations even at the 6-hour time step for all the catchments examined. The downscaled estimates have low bias and residual variability that is lower than that of the observations, especially for the North Fork and the entire Folsom Lake catchment.

Table 2-3: Statistical Performance of Simplified Orographic Model in Wet Season (1969-1992)

	Folsom Lake	*North Fork*	*Middle Fork*	*South Fork*
Six-Hourly Data				
ρ_c	0.52	0.49	0.48	0.46
r_m	-0.46	-0.02	-0.74	-1.00
r_s	0.96	0.91	1.10	1.15
Daily Data				
ρ_c	0.67	0.66	0.65	0.64
r_m	-0.66	-0.11	-0.97	-1.30
r_s	0.86	0.78	1.00	1.09

These results support the use of the orographic model as the component for downscaling large scale weather and climate information for INFORM. Prior to the use of the downscaled data for hydrologic and water resources analysis, adjustment of the downscaled estimates is necessary to account for the model bias and residual errors as indicated in Table 2-3. This may be done by regressing the observed mean areal precipitation values on the downscaled precipitation values, and estimating the linear regression parameters from the historical data shown in Appendix B. This was done, and Figures 2-5 and 2-6 show the scatter plots of observed and downscaled mean areal precipitation (MAP) together with the regression lines and the regression equation for six-hourly and daily data, respectively. The observations are denoted by “O” and the downscaled estimates are denoted by “D” in the regression equations of these two Figures. Thus, after downscaling the weather and climate information to the level of the catchments, these equations may be applied to the downscaled estimates to yield unbiased estimates for use by the hydrologic models. On-going analysis aims to develop these regression equations by month and possibly by magnitude of downscaled precipitation. Furthermore use of the adjusted precipitation in hydrologic models is planned to study the effects of the downscaling errors on the catchment outflows.

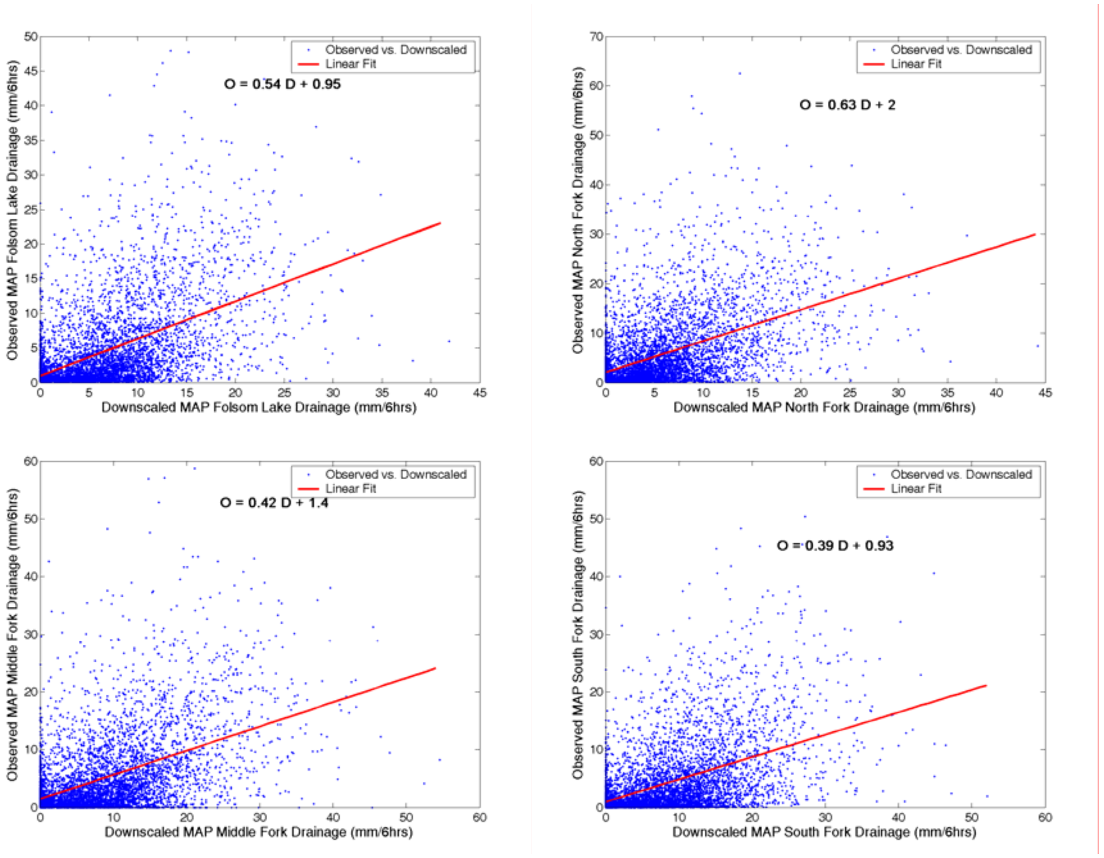


Figure 2-5: Linear regression equations between six-hourly downscaled (predictor) and observed estimates (predictant) of mean areal precipitation for the Folsom Lake sub-basins.

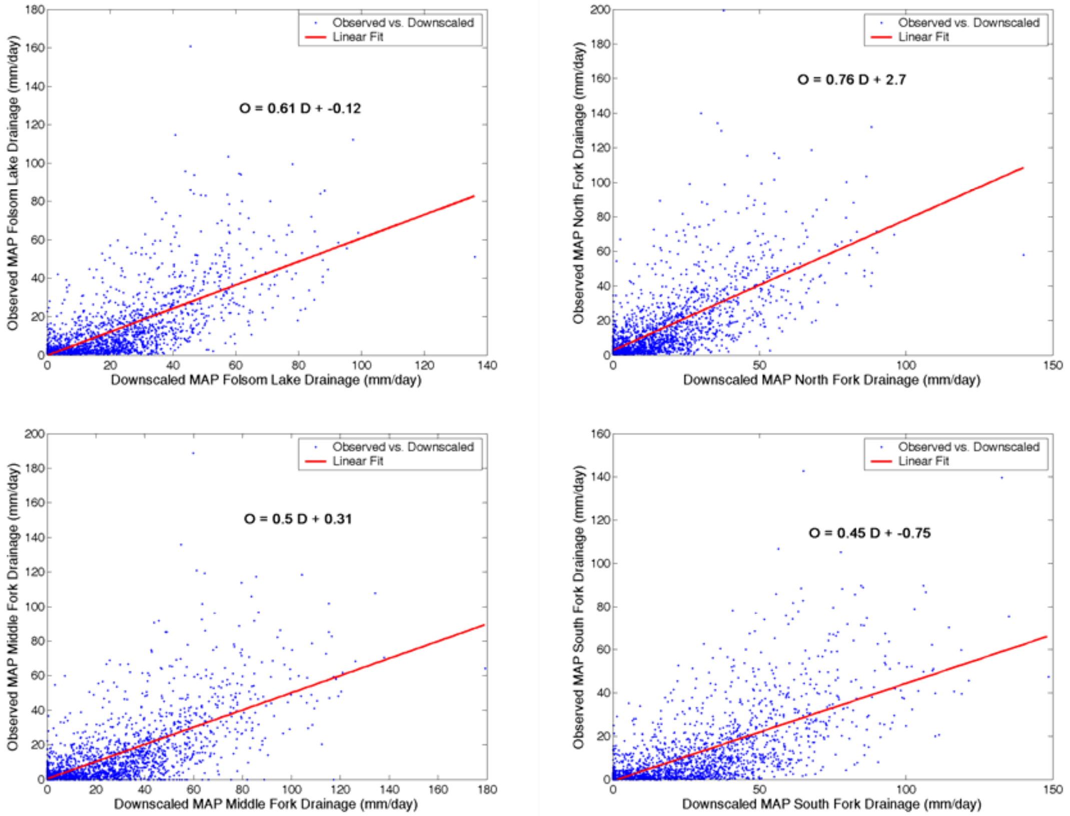


Figure 2-6: As in Figure 2-5 but for daily data.

2.6 REFERENCES

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