Correcting the radar rainfall forcing of a hydrologic model with data assimilation: application to flood forecasting in the Lez Catchment in Southern France

Abstract ID: H23G-1348

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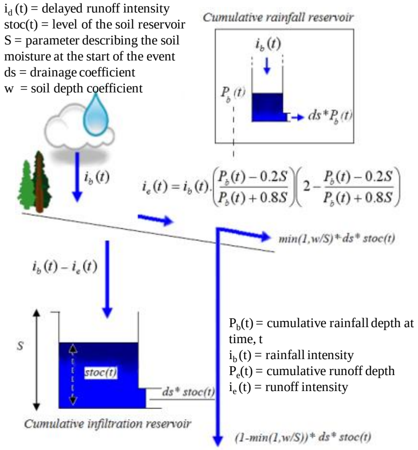
1. The Hydrologic Model

Runoff Production Function

$i_d(t)$ = delayed runoff intensity
stoc(t) = level of the soil reservoir
S = parameter describing the soil moisture at the start of the event
ds = drainage coefficient
w = soil depth coefficient

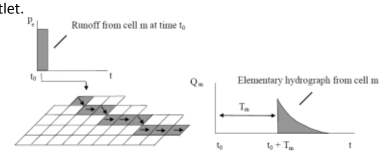


$P_b(t)$ = cumulative rainfall depth at time, t
$i_b(t)$ = rainfall intensity
$P_e(t)$ = cumulative runoff depth
$i_e(t)$ = runoff intensity

The MERCEDES platform of the ATHYS hydrological software enables the use of a **distributed, event-based parsimonious rainfall-runoff model** based on a derived form of the SCS equations (Coustau, 2011) and a lag and route transfer function. This model is appropriate for simulating discharge in **karstic catchments**.

Transfer Function

Runoff is transferred from independent grid cells to the watershed outlet.

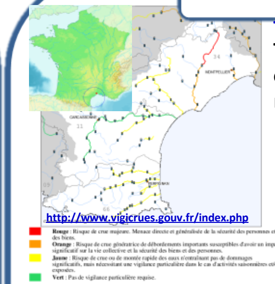


l_m = distance between a grid cell, m and the outlet
V_0 = propagation velocity
K_m = diffusion of velocities
T_m = propagation time
q(t) = elementary hydrograph discharge

$$T_m = \frac{l_m}{V_0}$$

$$\frac{q(t_m)}{A} = \frac{i_e(t_0)}{V_0}\exp\left(-\frac{t-(t_0+T_m)}{K_m}\right) \quad \text{if} \quad t \geq t_0 + T_m$$

2. The Lez Mediterranean Catchment



The Western Mediterranean

ARAMIS radar network

The Mediterranean Climate

The Western Mediterranean region receives heavy orographic rainfall during the autumn as warm, moist sea air reaches the Cévennes Mountains.

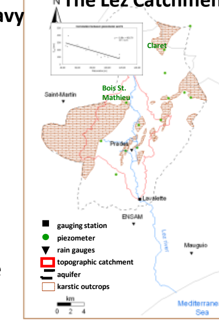
The Lez Catchment

The **114 km² Lez catchment** is located 15 km North of the town of Montpellier. It marks the start of the 26 km long Lez River. The watershed is composed mainly of limestone outcrops and marly plains. The Northwestern portion of the catchment is connected to a **380 km² karstic aquifer**. Discharge, rain gauge and piezometer data are available for a 10-15 year period(www.medycyss.org).

Improving flash flood forecasting

The genesis of **flash floods** in this region is often poorly understood due to high rainfall intensities and a karstic geology. The **increased time and spatial resolution of radar** imagery is critical for improving flood forecasting.

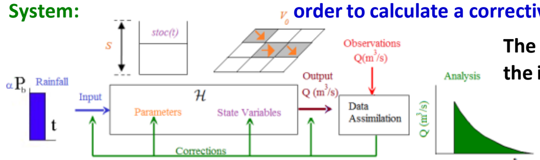
The Lez Catchment



Flood Event September 2005

3. Data Assimilation Methods

Schematic of the Assimilation System:



A simplified Kalman Filter was used to assimilate discharge data in order to calculate a corrective coefficient applied to rainfall inputs

The observation operator, $\mathcal{H}$, represents the integration of the hydrologic model

The control vector, x, contains the rainfall corrective coefficient

$$\mathbf{x} = (\alpha)$$

3D-var cost function with the non-linear observation operator, $\mathcal{H}$

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}^b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) + (\mathbf{y}^o - \mathcal{H}(\mathbf{x}^b))^T\mathbf{R}^{-1}(\mathbf{y}^o - \mathcal{H}(\mathbf{x}^b))$$

Incremental Approach
$$\delta\mathbf{x} = \mathbf{x} - \mathbf{x}^b$$

Taylor Expansion
$$\mathbf{H} = \frac{\partial\mathcal{H}}{\partial\mathbf{x}}\bigg|_{\mathbf{x}^{ref}} \approx \frac{\mathcal{H}(\mathbf{x}^{ref}+\delta\mathbf{x}) - \mathcal{H}(\mathbf{x}^{ref})}{\delta\mathbf{x}}$$

3D-var incremental cost function with linear approximation to $\mathcal{H}$

$$J_{inc}(\delta\mathbf{x}) = \delta\mathbf{x}^T\mathbf{B}^{-1}\delta\mathbf{x} + (\mathbf{y}^o - \mathcal{H}(\mathbf{x}^b) - \mathbf{H}\delta\mathbf{x})^T\mathbf{R}^{-1}(\mathbf{y}^o - \mathcal{H}(\mathbf{x}^b) - \mathbf{H}\delta\mathbf{x})$$

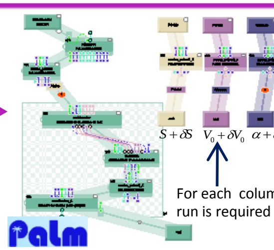
Optimal Correction, $\delta\mathbf{x}^a$ $\quad \nabla J_{inc}(\delta\mathbf{x}) = 0$

Kalman Filter Analysis

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}(\mathbf{y}^o - \mathcal{H}(\mathbf{x}^b))$$

$\mathbf{x}^b$ = background control vector
$\mathbf{y}^o$ = observation vector
$\delta\mathbf{x}$ = increment in x
$\mathcal{H}$ = observation operator
B = background error covariance matrix
R = observation error covariance matrix
K = the gain matrix
H = Jacobian of $\mathcal{H}$

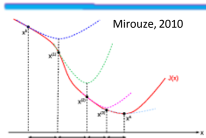
Thirel et al., 2011



Calculation of the Jacobian

A quadratic approximation is used to calculate the minimum of the true cost function.

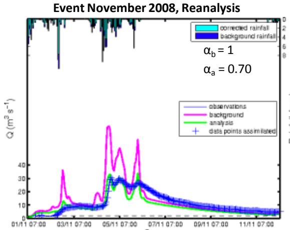
For each column of **H**, a perturbed model run is required to calculate $\mathcal{H}(\mathbf{x}^{ref} + d\mathbf{x})$.



External Loops Procedure

During iterations of the **External Loops** procedure, **H** is recalculated in the vicinity of $\mathbf{x}^a$ and a new minimum is estimated.

4. Results



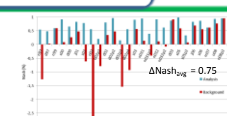
The rainfall is corrected by a factor of 0.70. $Nash_b$ = -0.52 and $Nash_a$ = 0.72.

Reanalysis Mode

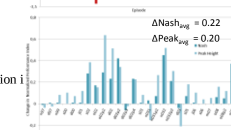
1. Radar Rainfall is corrected by assimilating discharges over the entire event period. Nash efficiency criteria are improved over the background state by 0.75 on average.
2. Radar rainfall corrected using DA were compared to rainfall corrected using ground rainfall measurements (MFB correction). DA showed improved results in most cases.

$$MFB = \frac{\frac{1}{n}\sum_i G_i}{\frac{1}{n}\sum_i R_i}$$

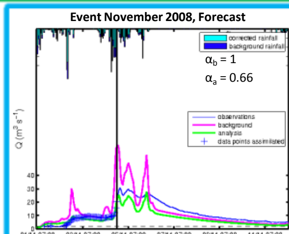
G_i = rain gauge measurement at location i
R_i = radar measurement at location i
n = the number of rain gauges



Nash Criteria Analysis vs. Background



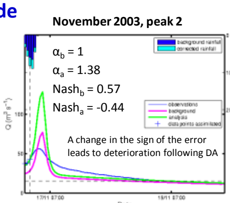
Nash and Peak Criteria Analysis vs. MFB



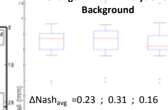
The rainfall is corrected by a factor of 0.66. $Nash_b$ = -0.10 and $Nash_a$ = 0.63.

Pseudo-Forecast Mode

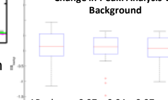
1. Discharges are assimilated until 3 hours before the event peak. S is parameterized using different physical indicators.
2. Between 62% and 67% of events have improved peak discharge criteria following assimilation. Average change in the peak criteria was between 0.07 and 0.04. Average change in Nash is between 0.16 and 0.31.



Change in Nash: Analysis vs. Background



Change in Peak: Analysis vs. Background



Assimilating discharge data can correct radar rainfall without the use of rain gauges.

References:

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