Analysis of climate change effects on water and sediment cycle in a Mediterranean catchment

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Objectives

- Climate change impact on the sediment cycle of a high erodible catchment
  - Complexity: interactions between water balance, floods and sediments
  - Spatial variability of inputs and processes
  - Few sediment data: explore possibilities of using reservoir sedimentation volumes as a proxy of sediment yield

- Tool: global and distributed model for reproduction of the hydrological and sedimentological cycle
General methodology

Analysis of CO2 emission evolution:
- Selection of CO2 emission scenarios

Climatic models and downscaling
- Series of inputs (precipitation and temperature)

Hydrological model implementation
- Output series (discharge, snow and sediments)

Comparison of results between present and future scenarios
- Analysis and decision making

Comparison with observations in the control period
- Model selection and correction
Case study
The catchment: Ésera River

- Southern Central Pyrenees, Spain
- 1532 km²
- Mountain catchment
- Drained by a large reservoir
- Sediment gauged data: suspended sed. at Capella station (Isábena River)
The catchment: Ésera River

- Mountain – Mediterranean climate
  - Dry and cold winters
  - Stormy summers with frequent floods

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Annual precipitation</strong></td>
<td>642 mm</td>
</tr>
<tr>
<td><strong>Annual mean temp.</strong></td>
<td>10°C</td>
</tr>
<tr>
<td><strong>Annual ET0</strong></td>
<td>601 mm</td>
</tr>
</tbody>
</table>
The catchment: Ésera River

- Present land use:
  - Forest (34%)
  - Shrubland (27%)
  - Pasture (12%) and
  - Arable dryland (10%)

- Historical expansion of forest due to agricultural abandonment
The catchment: Ésera River

- **Geology:**
  - Limestone and sandstone in headwaters
  - Marls in the central part, **high erosion rates** and badland landscape
  - Conglomerates and sandstones in the south

- **Pedology:**
  - Shallow soils with low O.M. content
  - Silty clay and sandy silt soils
Daily monitoring with long series:
- 12 thermometers and raingauges (AEMET)
- Several stream gauges (CHE, CEH-CEDEX)
- Barasona reservoir data (CHE, CEH-CEDEX)

15-minute monitoring since 10/1997 (SAIH-CHE):
- 11 raingauges and 6 thermometers
- 3 stream gauges
- Barasona reservoir
Spain02: Regional interpolation of daily precipitation and temperature, ~ 20x20 km and from 1950 to 2008
The Barasona reservoir

- Regulation reservoir built in 1932 (70 Hm$^3$)
- Regrown in 1972 (92.2 Hm$^3$)
  - High siltation rates
  - 5 bathymetries available

Regrown in 1972 (92.2 Hm$^3$)
- High siltation rates
- 5 bathymetries available

Ésera River
Isábena River
The Barasona reservoir

- Construction (70 Hm$^3$)
- Re-growth (92.2 Hm$^3$)
- Bathymetry (87.2 Hm$^3$)
- Bathymetry (75.9 Hm$^3$)
- Bathymetry (75.8 Hm$^3$)
- Bathymetry (75.2 Hm$^3$)
- Bathymetry (84.8 Hm$^3$)

Key dates:
- 1932
- 1972
- 1973
- 1978
- 1986
- 1993
- 1995
- 1997
- 1998
- 2007

- Flushing (Vol = ?)
- Flushing (Vol ≈ 9 Hm$^3$)
Model implementation
- Developed in TU of Valencia since 1994 (version 8.2.7 on the web)
- Conceptual (tank structure) model, with **physically based parameters**
- **Global** model: water resources, floods, sediments, … dynamic vegetation, water quality, …
- **Distributed** in space:
  - reproduction of hydrological cycle spatial variability
  - Results at any point
- Split effective model parameter structure
  - It uses all spatial information available
  - Powerful **automatic calibration** algorithm
- 3 additional tanks

- Balance between water transport capacity and sediment availability

- Hillslope transport capacity: modified Kilinc – Richardson equation (Julien, 1995)

\[ Q_h = \frac{1}{\gamma_s} W \alpha S_o^{1.66} \left( \frac{Q}{W} \right)^{2.035} \frac{K}{0.15} C P \]
DEM
- Source: National DEM from IGN at 25m => re-scaled to 100 m and corrected

Derived from DEM
- Flow direction
- Slope
- Accumulated area
- Hillslope velocity
- Land cover (vegetation coef. and interception)
  - Source: Corine 2006 (1:100,000)
- Sustrate/aquifer permeability
  - Source: Litological Map from IGME (1:200,000)
- Upper soil permeability
  - Source: European Soil Database (1:1,000,000)

- Capillary storage capacity
  - Source: ESD + Corine land cover
Initial parameter estimation

- **Texture maps**
  - Source: European Soil Database (1:1,000,000)

- **USLE factors**
  - Source: previous scientific publication (Alatorre et al., 2010)
- Hydrological sub-model:
  - Calibration at Capella station (2005-2008)
  - Validation at Graus, Campo, Barasona and Capella (1997-2005)

<table>
<thead>
<tr>
<th>Station</th>
<th>Calibration period NSE</th>
<th>Calibration period VE%</th>
<th>Validation period NSE</th>
<th>Validation period VE%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capella</td>
<td>0.720</td>
<td>-6%</td>
<td>0.686</td>
<td>-39%</td>
</tr>
<tr>
<td>Graus</td>
<td>0.581</td>
<td>-28%</td>
<td>0.704</td>
<td>-61%</td>
</tr>
<tr>
<td>Campo</td>
<td>0.294</td>
<td>-44%</td>
<td>0.455</td>
<td>-35%</td>
</tr>
<tr>
<td>Barasona</td>
<td>0.708</td>
<td>-10%</td>
<td>0.529</td>
<td>-22%</td>
</tr>
</tbody>
</table>
Sediment sub-model:
- Calibration and validation vs Barasona volumes:

<table>
<thead>
<tr>
<th>Period</th>
<th>Accumulated sediments Hm$^3$</th>
<th>Specific sediment yield t km$^{-2}$ year$^{-1}$</th>
<th>Simulated volume Hm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998-2006</td>
<td>9.02</td>
<td>820</td>
<td>9.02</td>
</tr>
<tr>
<td>2006-2007</td>
<td>0.60</td>
<td>435</td>
<td>0.76</td>
</tr>
</tbody>
</table>

- Reconstruction of the storage evolution
Sediment sub-model: validation in experimental station at Capella

- Model results (total load) vs gauged data (suspended load);
- Measurement errors: turbidimeter measurements can be misleading with high concentrations (Regües & Nadal-Romero 2012, CATENA)
Sediment sub-model:

- Erosion zones: central marl strip and headwater:

- Annual sediment yield:

![Graph showing annual sediment yield from 1972 to 2007 with a 3-year moving average.](image-url)

Map showing erosion rates in t/km² for the study area.
Climate Change Scenarios
Scenario A2: Very pessimistic
- Growing world population, growing economy, but no coordination: heterogeneous world and independent countries
- Slow and odd technological changes.

Scenario B2: Less pessimistic
- Growing world population (less than A2), intermediate economic development.
- Local solutions to environmental and social sustainability
In the area at daily time scale 3 models from PRUDENCE project, with the same global circulation model, but different regional downscaling:

- **UCM** University of Castilla la Mancha, Spain (hadAM3+ PROMES)
- **CRNM** National Center for Meteorological Research, France (hadAM3+ARPEGE)
- **ETH Zurich** Swiss Federal Institute of Technology (hadAM3+ CHRM)

Selection by comparison with observations (Spain02) during the control period 1961-1990:
Climatic model selection

CNRM
Input correction

- Uncorrected climatological output
- Corrected climatological output
Effect of correction on seasonality
**Effect of correction on extremes**

![Graphs showing precipitation and flow rate](image)

- **Precipitación diaria máxima anual (mm/día)**
  - Observado
  - Climático
  - Climático corregido

- **Caudal diario máximo anual (m3/s)**
  - Observado
  - Climático
  - Climático corregido
Results and discussion
### Mean values

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>A2</th>
<th>B2</th>
<th>Variation A2</th>
<th>Variation B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (mm/year)</td>
<td>655</td>
<td>571</td>
<td>581</td>
<td>-13%</td>
<td>-11%</td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>6.9</td>
<td>10.7</td>
<td>9.7</td>
<td>+3.8°C</td>
<td>+2.8°C</td>
</tr>
<tr>
<td>Soil saturation (%)</td>
<td>66%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Snowpack (mm eq.)</td>
<td>0.573</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Water yield (Hm³/year)</td>
<td>594</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment yield (ton/ha/year)</td>
<td>5.23</td>
<td></td>
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</tbody>
</table>
Precipitation

![Graph showing precipitation over months and return period vs precipitation](image)

- Precipitation (mm month\(^{-1}\))
- Month
- Return period (years)
- Precipitation (mm)
Soil moisture and snowpack

![Graphs showing soil moisture and snowpack trends over months.](image)
Floods
Sediment
Reservoir useful life (higher than 10 Hm³):
Spatial variability of soil erosion

- Difference between future and control period erosion:

<table>
<thead>
<tr>
<th>Soil erosion diff.</th>
<th>-150 - -50 ton/ha/year</th>
<th>-50 - -5 ton/ha/year</th>
<th>-5 - 5 ton/ha/year</th>
<th>5 - 50 ton/ha/year</th>
<th>50 - 500 ton/ha/year</th>
</tr>
</thead>
</table>

A2

B2
Model implementation:

- Distributed sediment model implementation without direct sediment data (reservoir sedimentation can be used as proxy data for model calibration and validation)
- The methodology can be extended to all catchments drained by a reservoir with bathymetries
- The TETIS water sub-model behaves very good, and the sediment sub-model result are satisfactory
- The main sediment source is the central marl area
Conclusions

- Climate change scenarios: precipitation decreases, although its torrentiality increases; mean temperature increases;
  - High uncertainty => selection and correction
- Significant decrease in water yield
- Significant change in snow: amount and seasonality
- Compensation effects for floods and sediment yield, especially for A2 scenario:
  - Soil moisture decreases => drier initial soil moisture
  - less snow melting
Thank you for your attention!

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