EVALUATION OF HYDROLOGIC AND WATER RESOURCES RESPONSE TO METEOROLOGICAL DROUGHT IN THESSALY, GREECE

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OBJECTIVES

- to identify different types of drought (agricultural, hydrological and water resources) using the meteorological drought index SPI in selected small, medium and large watersheds in the region of Thessaly, Greece.
- to identify the relationship between meteorological, hydrological and soil moisture drought, and water resources drought
- to identify the operational timescale of SPI for soil moisture hydrological and water resources drought
- to develop a drought preparedness plan in the region

HYDROLOGICAL DROUGHT IDENTIFICATION

- Assessment of hydrological drought severity using a water balance derived drought index (Vasiliades and Loukas, 2010)
- Use of a monthly water balance model to produce watershed runoff and soil moisture for small, medium and large watersheds
- Normalize and standardize the produced runoff and soil moisture timeseries for hydrological and soil moisture drought assessment
- Calculation of Standardized Precipitation Index at multiple timescales as meteorological drought index
- Identify the relationship between meteorological, hydrological and soil moisture drought with the response of respective indices
- Identify the response of drought indices to selective drought episodes

METHODOLOGY

- Use of a monthly water balance model to simulate hydrological cycle components (AET, soil moisture, runoff) in the seven (7) watersheds (the study watersheds have intermittent discharge observations at their outlets)

- Normalize and standardize the produced runoff and soil moisture timeseries for:
  - hydrological drought assessment → water balance derived drought index (Z_{WBI}) and
  - soil moisture drought assessment → soil moisture derived drought index (Z_{SMI})

- Comparison with calculated SPI at multiple timescales to find the operational drought index

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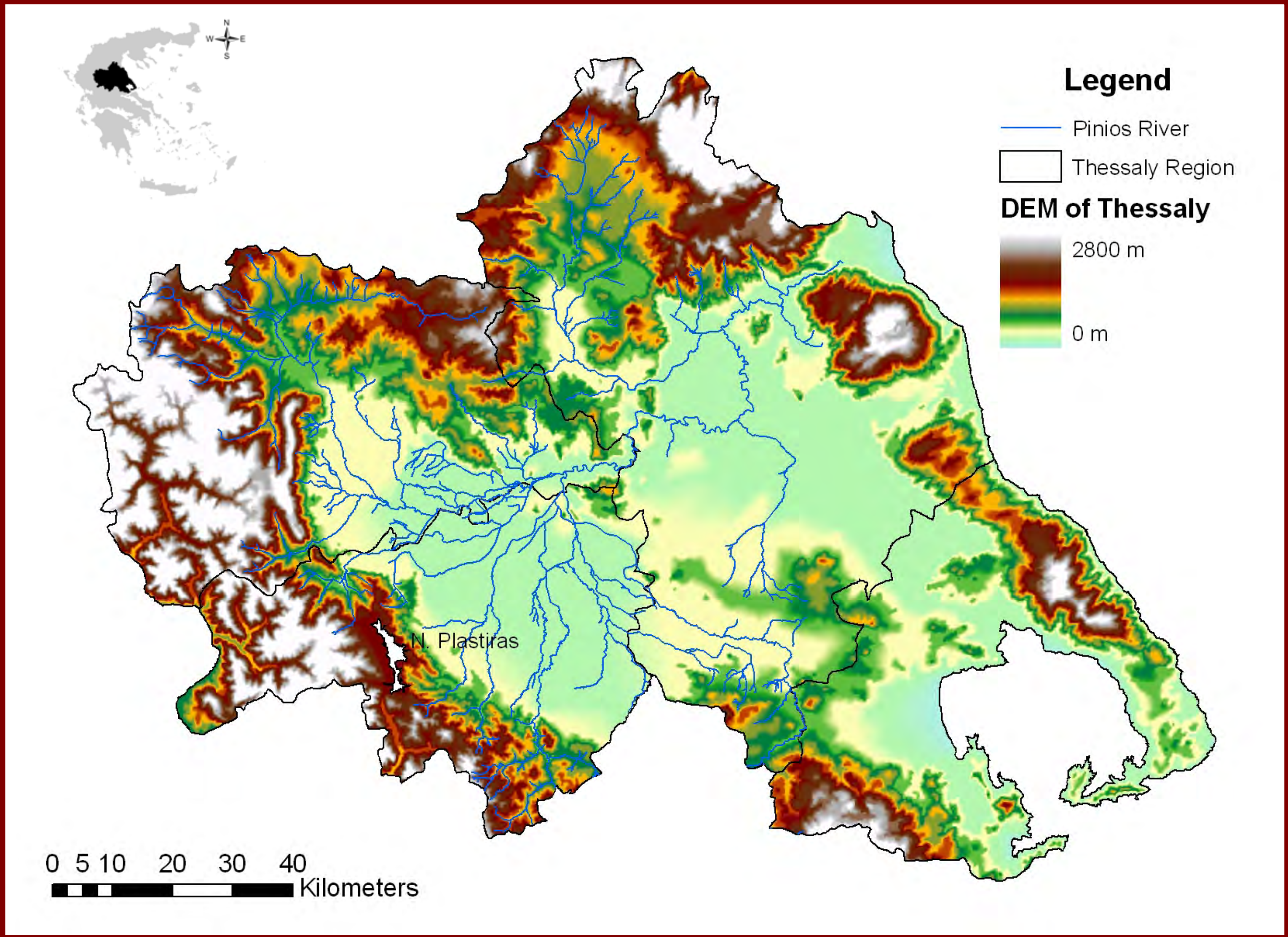
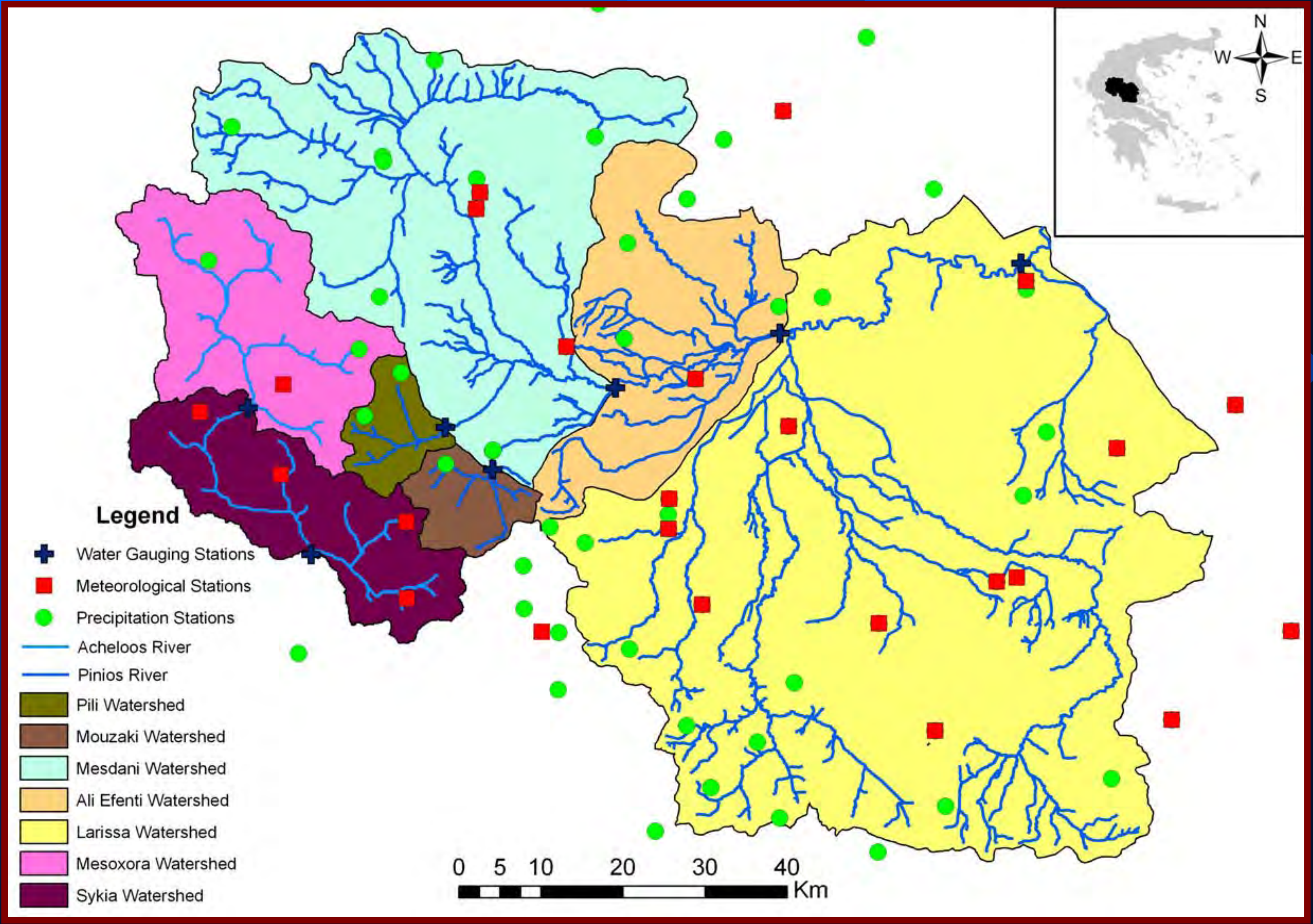
DEM OF THESSALY REGION



LOCATION OF THE STUDY WATERSHEDS AND DATABASE



CHARACTERISTICS OF THE STUDY AREAS

Attribute	Area (km^2)	Elevation range (m)	Mean Elevation (m)	Mean Annual Precipitation (mm)	Mean Annual Runoff (mm)	Runoff Coefficient
Pili	133	300 - 1800	949	1820	1130	0.62
Mouzaki	145	200 - 2000	838	1450	830	0.57
Mesdani	2055	180-2000	660	985	600	0.61
Ali Efenti	2869	150-2000	555	890	420	0.47
Larissa	6591	70-2000	451	720	290	0.40
Mesoxora	615	700 - 2300	1400	1860	1150	0.62
Sykia	1155	500 – 2300	1288	1875	1290	0.69

THE UTHBAL MODEL

- A monthly conceptual water balance (UTHBAL) model was developed by Loukas et al., (2007)
- Three inputs: Areal precipitation, mean areal temperature and potential evapotranspiration
- The precipitation is separated into rainfall and snowfall
- The rain/snow percentage have been estimated using a logistic relationship based on mean monthly air temperature
- The snowmelt is estimated with the simple degree-day method
- Total watershed runoff is divided into three components: the surface runoff, the medium runoff, and the baseflow runoff using a soil moisture mechanism
- Outputs: AET, soil moisture, groundwater and surface runoff

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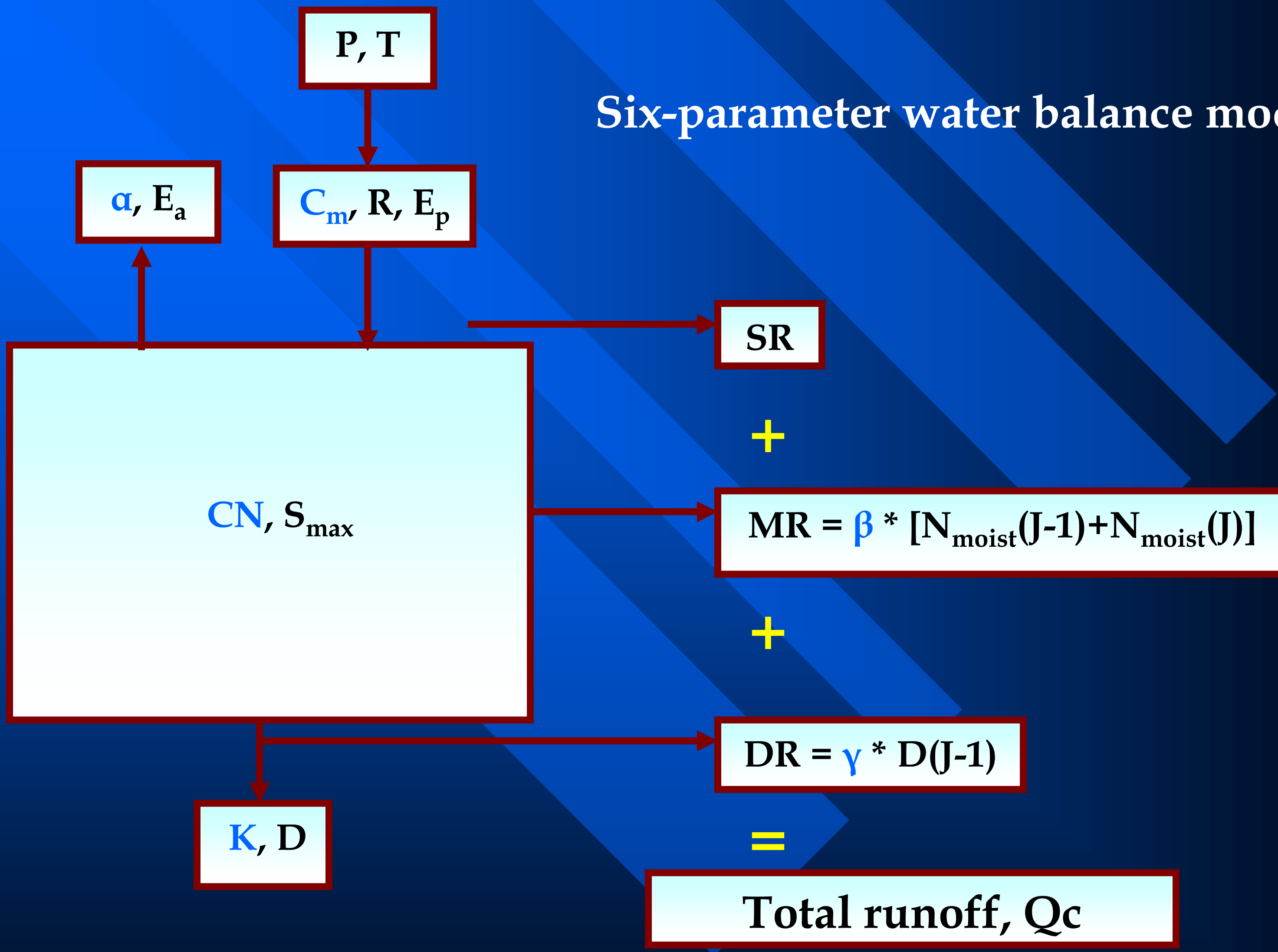
WATER BALANCE MODEL (UTHBAL)

Six-parameter water balance model



HYDROLOGICAL MODEL PROCEDURE

- Six (6) parameters of the water balance model have to be optimized
- Optimization was done using the global multistart Generalised Reduced Gradient Algorithm
- The objective function of the above calibration procedure was defined as:

$$Eff = 1 - \frac{\sum_{i=1}^{n} \left(Qobs_i - Qsim_i\right)^2}{\sum_{i=1}^{n} \left(Qobs_i - \overline{Qobs}\right)^2}$$

where,

$Qobs_i$ is the observed flow on month i,

$Qsim_i$ is the simulated flow on month i, and

$\overline{Qobs}$ is the average observed flow for the simulation period

ESTIMATION OF INPUT DATA SETS

- **Mean monthly basin wide temperature:** temperature lapse rate from 27 meteorological stations adjusted for the mean elevation

- **Potential evapotranspiration:** Thornthwaite method (based on mean monthly basin wide temperature)

- **Areal Precipitation: Modified Thiessen method**
    - The weighted coefficients of the Thiessen method were calculated in the GIS
    - Adjusted with the precipitation gradient for the mean elevation of each watershed
    - Linear relationship between precipitation and elevation (high correlation values in all watersheds, $r > 0.90$)

RECONSTRUCTION OF RUNOFF AND SOIL MOISTURE

- UTHBAL optimisation results

Watershed	Eff	DV(%)	R	Calibration Period
Pili	0.72	0.96	0.85	Oct 60 - Sep 94
Mouzaki	0.72	-0.80	0.85	Oct 60 - Sep 85, Oct 87 - Sep 94
Mesdani	0.80	-1.98	0.90	Oct 60 - Sep 71
Ali Efenti	0.78	-1.28	0.89	Oct 60 - Dec 69, Feb 72 - Jun 94
Larissa	0.76	0.39	0.87	Oct 60 - Feb 67, Jan 69 - Mar 91
Mesoxora	0.71	-0.75	0.84	Oct 60 - Sep 94
Sykia	0.72	-0.99	0.85	Oct 60 - Sep 94

- Extension of calculated (synthetic) runoff and soil moisture timeseries for the period Oct 1960 to Sep 2002
- Normalization through Box-Cox transformation

$$Y = \begin{cases} \dfrac{X^{\lambda} - 1}{\lambda}, & \lambda \neq 0 \\ \ln(X), & \lambda = 0 \end{cases}$$

- Standardization to the normal distribution (Z_{WBI} and Z_{SMI})

$$Z_{WBI} = \frac{Y - \bar{Y}}{\sigma_Y}$$

COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPHS

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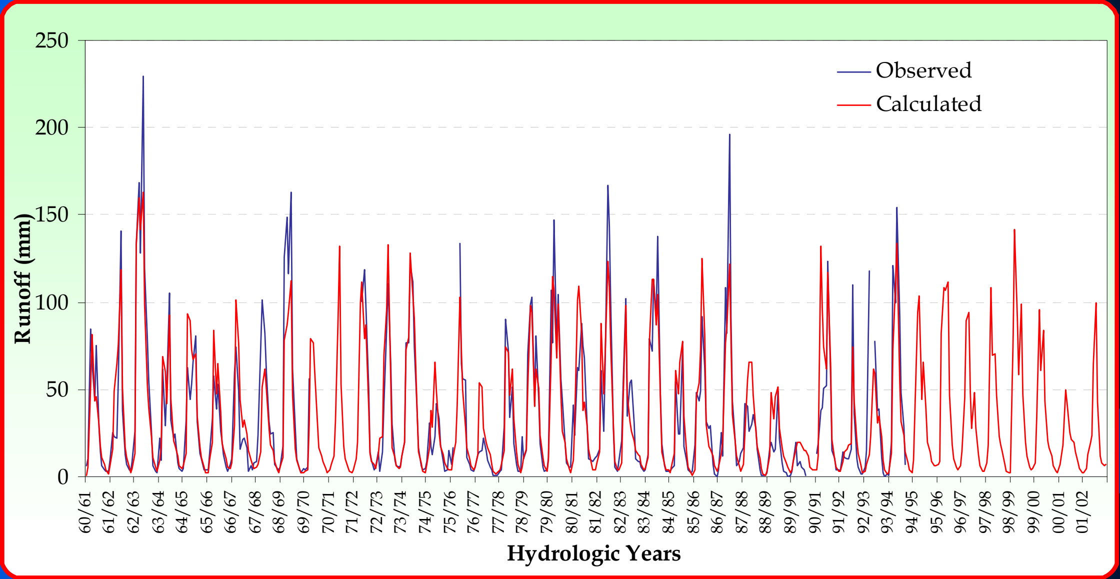
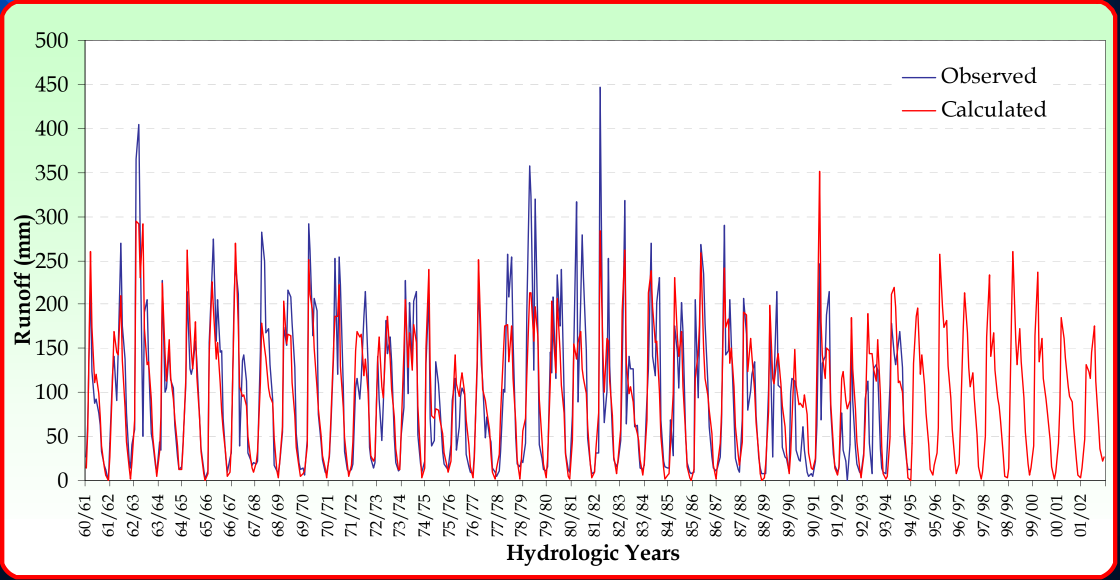
ALI EFENTI WATERSHED



MESOXORA WATERSHED



THE STANDARDIZED PRECIPITATION INDEX

- The SPI calculation for any location is based on the long-term precipitation record for various time scales
- Wetter and drier climates can be represented in the same way, because SPI is a standardized index
- This long-term record is fitted to a Gamma probability distribution, which is then transformed into a Normal distribution with mean SPI zero (0) and SPI variance one (1)
- Maximum likelihood solutions were obtained for estimation of Gamma distribution parameters
- Areal precipitation was used for estimation of SPI at 1-, 2-, 3-, 4-, 5-, 6-, 9-, 12-, and 24-month time scales in all study watersheds

RESULTS

Best correlations between meteorological-hydrological and soil moisture drought indices

SPI – Runoff Z_{WBI}

Watershed	Time scale of SPI (r)
Mouzaki	SPI-3month (0.76)
Pili	SPI-2month (0.79)
Mesdani	SPI-3month (0.90)
Ali Efenti	SPI-3month (0.86)
Larissa	SPI-4month (0.85)
Mesoxora	SPI-2month (0.84)
Sykia	SPI-2month (0.85)

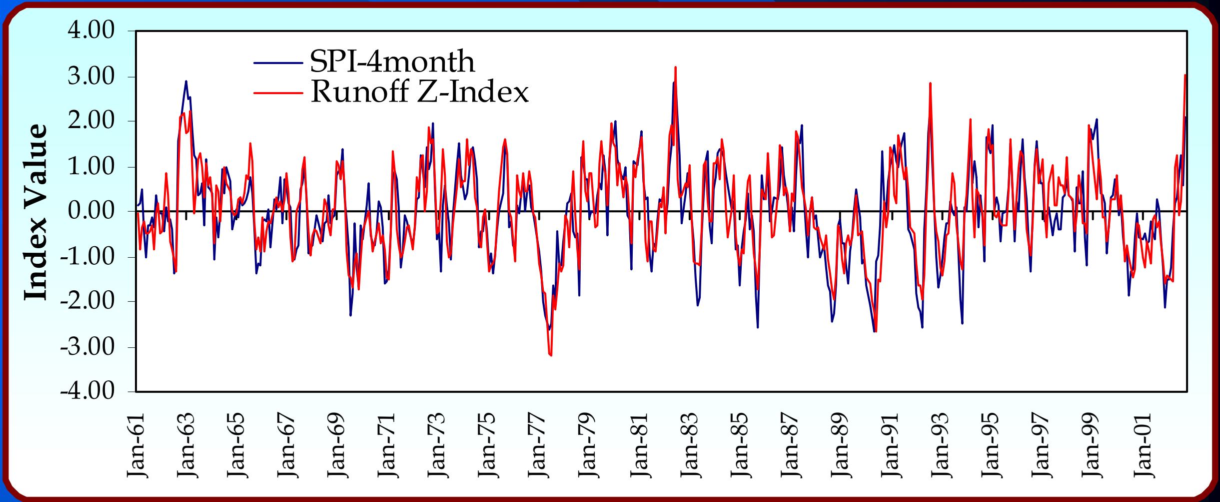
SPI – Soil Moisture Z_{SMI}

Watershed	Time scale of SPI (r)
Mouzaki	SPI-1month (0.76)
Pili	SPI-1month (0.78)
Mesdani	SPI-2month (0.88)
Ali Efenti	SPI-2month (0.85)
Larissa	SPI-3month (0.84)
Mesoxora	SPI-1month (0.84)
Sykia	SPI-1month (0.84)

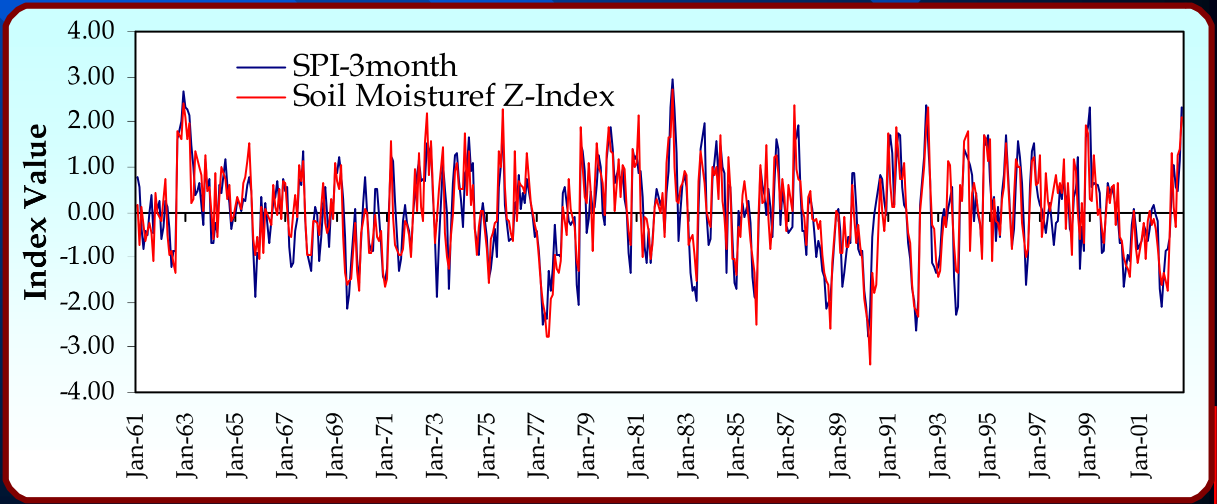
Timeseries of meteorological, hydrological and soil moisture drought indices

LARISSA WATERSHED

SPI – Runoff Z-Index (Z_{WBI})



SPI – Soil Moisture Z-Index (Z_{SMI})



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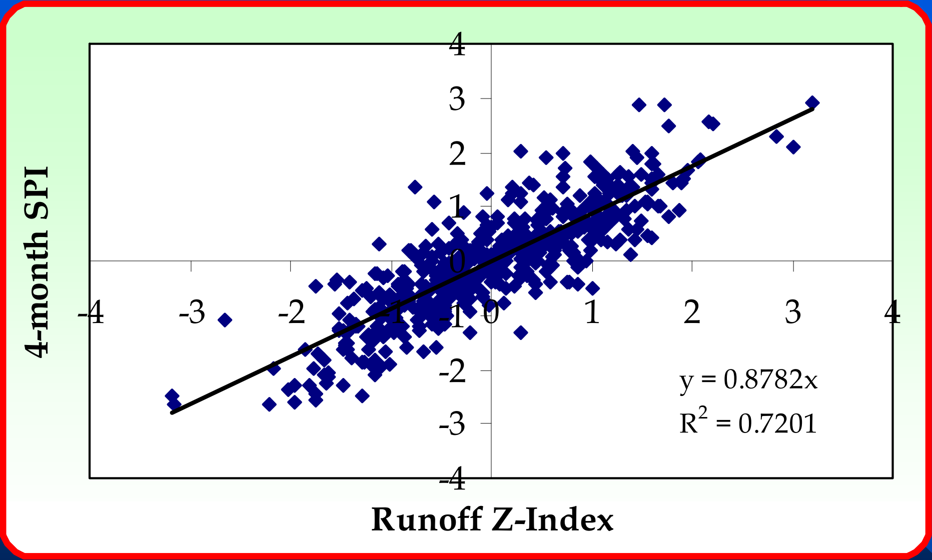
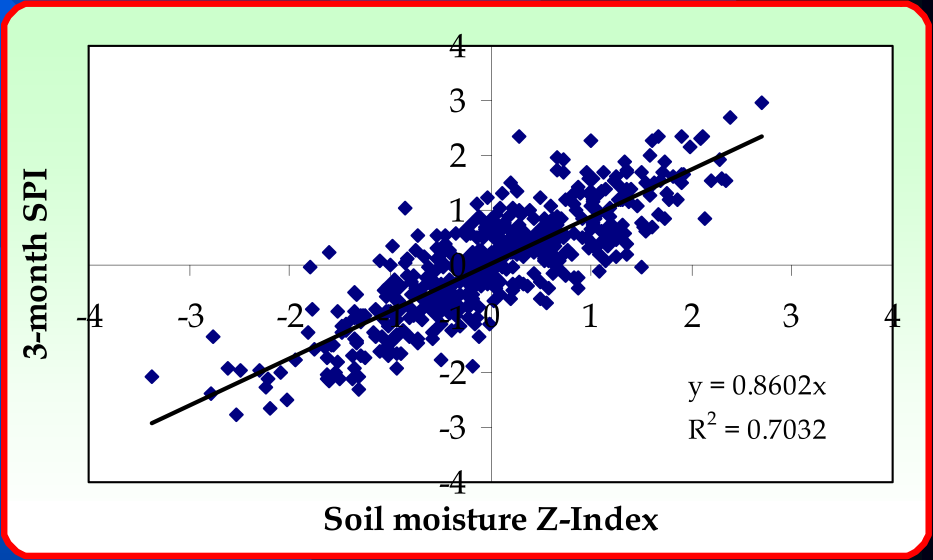
Scattergraphs of meteorological-hydrological and soil moisture drought indices

LARISSA WATERSHED

SPI – Runoff Z-Index (Z_{WBI})



SPI – Soil Moisture Z-Index (Z_{SMI})



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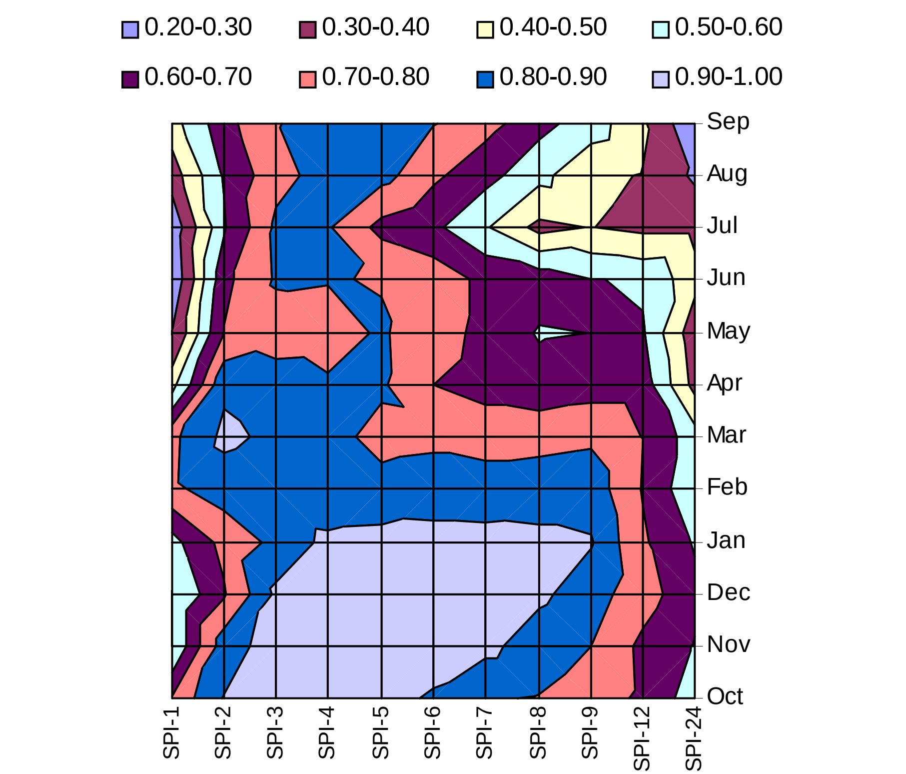
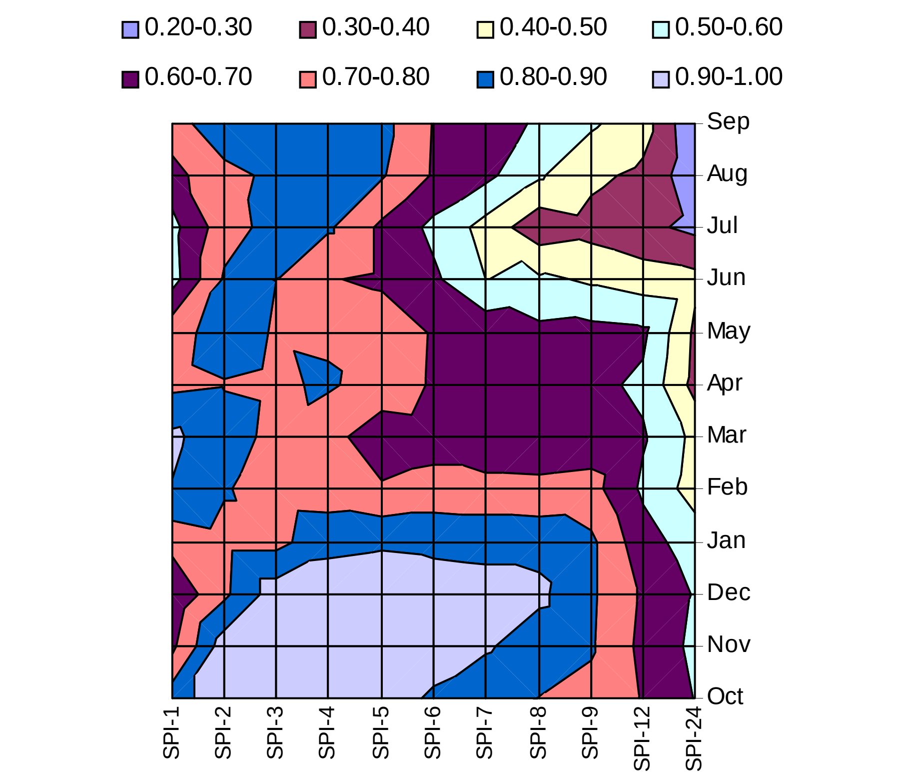
Monthly correlations between meteorological-hydrological and soil moisture drought indices

LARISSA WATERSHED

SPI – Runoff Z-Index (Z_{WBI})

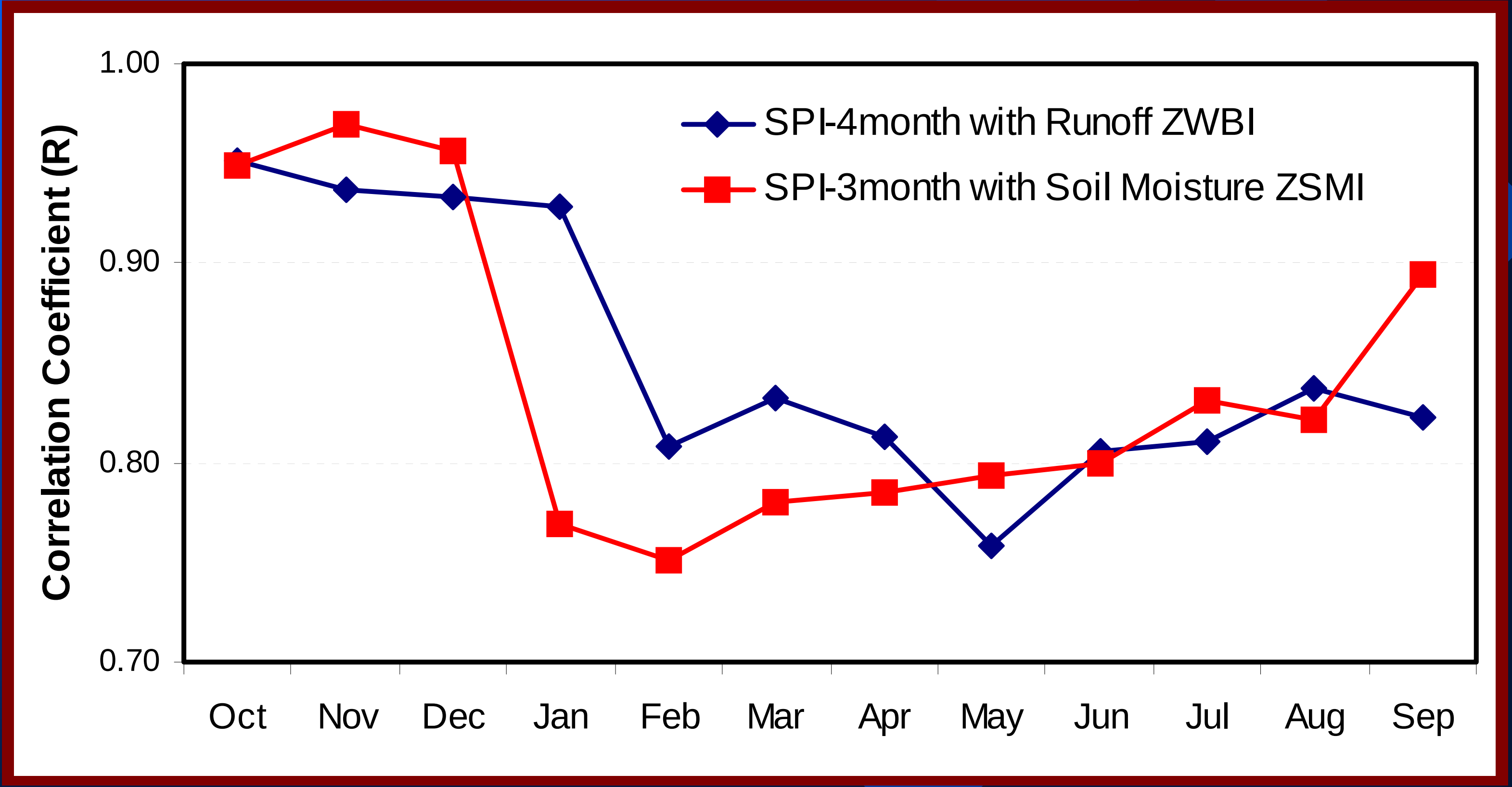


SPI – Soil Moisture Z-Index (Z_{SMI})



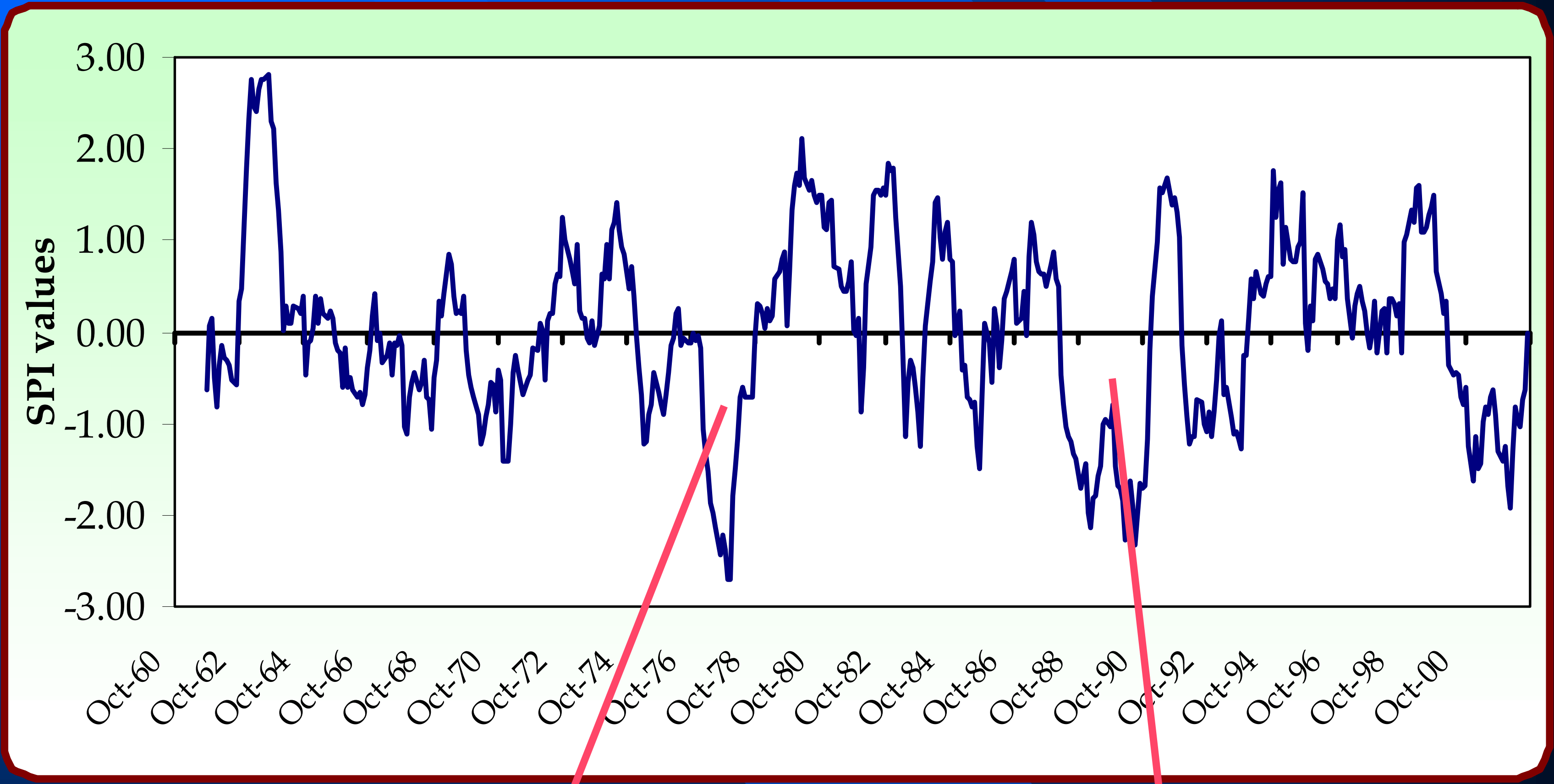
Best monthly correlations between meteorological-hydrological and soil moisture drought indices

LARISSA WATERSHED



SELECTIVE HISTORICAL DROUGHT EVENTS

12-month SPI for Larissa Watershed (Loukas & Vasiliades, 2004)



The 1977-1978 drought episode

The 1988-1990 drought episode

Best correlations between meteorological and hydrological drought indices for the selective historical events

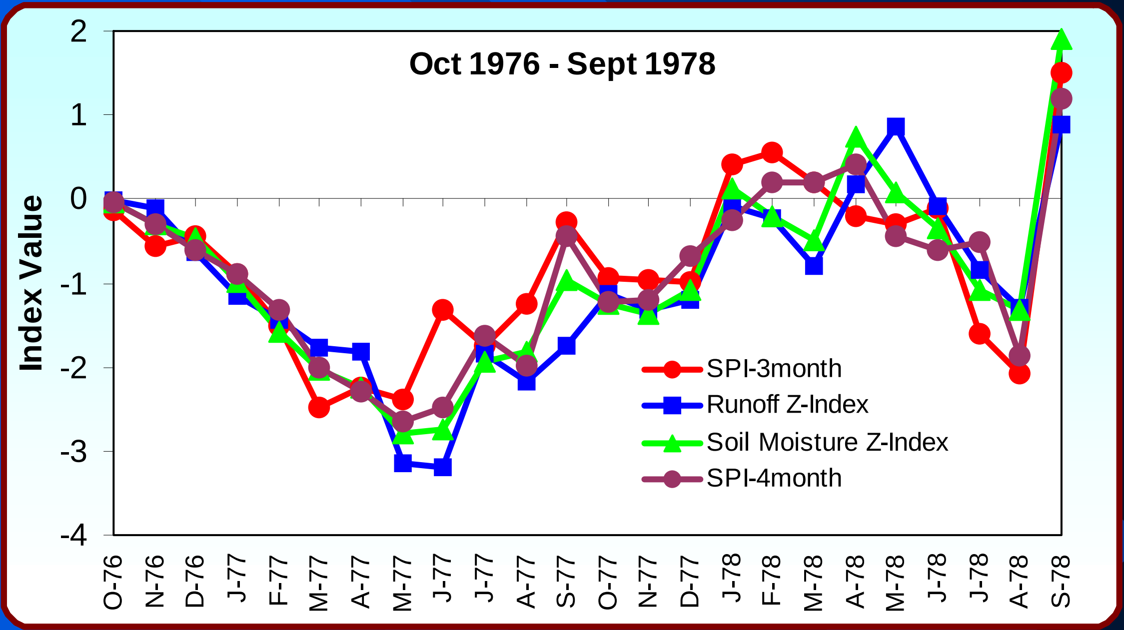
Watershed	Period Oct 60-Sep 02 Time scale of SPI (r)	Period Oct 76-Sep78 Time scale of SPI (r)	Period Oct87-Sep90 Time scale of SPI (r)
Mouzaki	SPI-3month (0.76)	SPI-4month (0.85)	SPI-3month (0.87)
Pili	SPI-2month (0.79)	SPI-3month (0.77)	SPI-3month (0.83)
Mesdani	SPI-3month (0.90)	SPI-4month (0.92)	SPI-5month (0.90)
Ali Efenti	SPI-3month (0.86)	SPI-5month (0.93)	SPI-5month (0.92)
Larissa	SPI-4month (0.85)	SPI-5month (0.93)	SPI-6month (086)
Mesoxora	SPI-2month (0.84)	SPI-4month (0.87)	SPI-3month (0.87)
Sykia	SPI-2month (0.85)	SPI-3month (0.83)	SPI-3month (0.90)

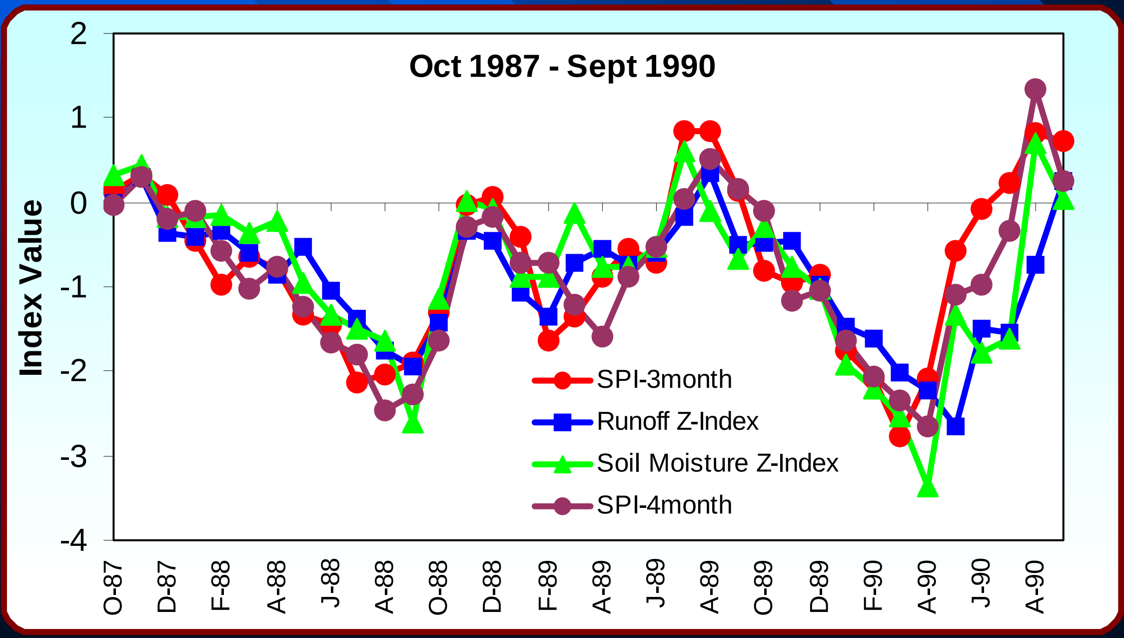
Best correlations between meteorological and soil moisture drought indices for the selective historical events

Watershed	Period Oct 60-Sep 02 Time scale of SPI (r)	Period Oct 76-Sep78 Time scale of SPI (r)	Period Oct87-Sep90 Time scale of SPI (r)
Mouzaki	SPI-1month (0.76)	SPI-3month (0.85)	SPI-3month (0.84)
Pili	SPI-1month (0.78)	SPI-1month (0.79)	SPI-2month (0.83)
Mesdani	SPI-2month (0.88)	SPI-3month (0.91)	SPI-4month (0.87)
Ali Efenti	SPI-2month (0.85)	SPI-4month (0.91)	SPI-4month (0.88)
Larissa	SPI-3month (0.84)	SPI-5month (0.95)	SPI-5month (089)
Mesoxora	SPI-1month (0.84)	SPI-3month (0.86)	SPI-3month (0.86)
Sykia	SPI-1month (0.84)	SPI-2month (0.85)	SPI-2month (0.87)

Response of Drought Indices to selective historical events

LARISSA WATERSHED





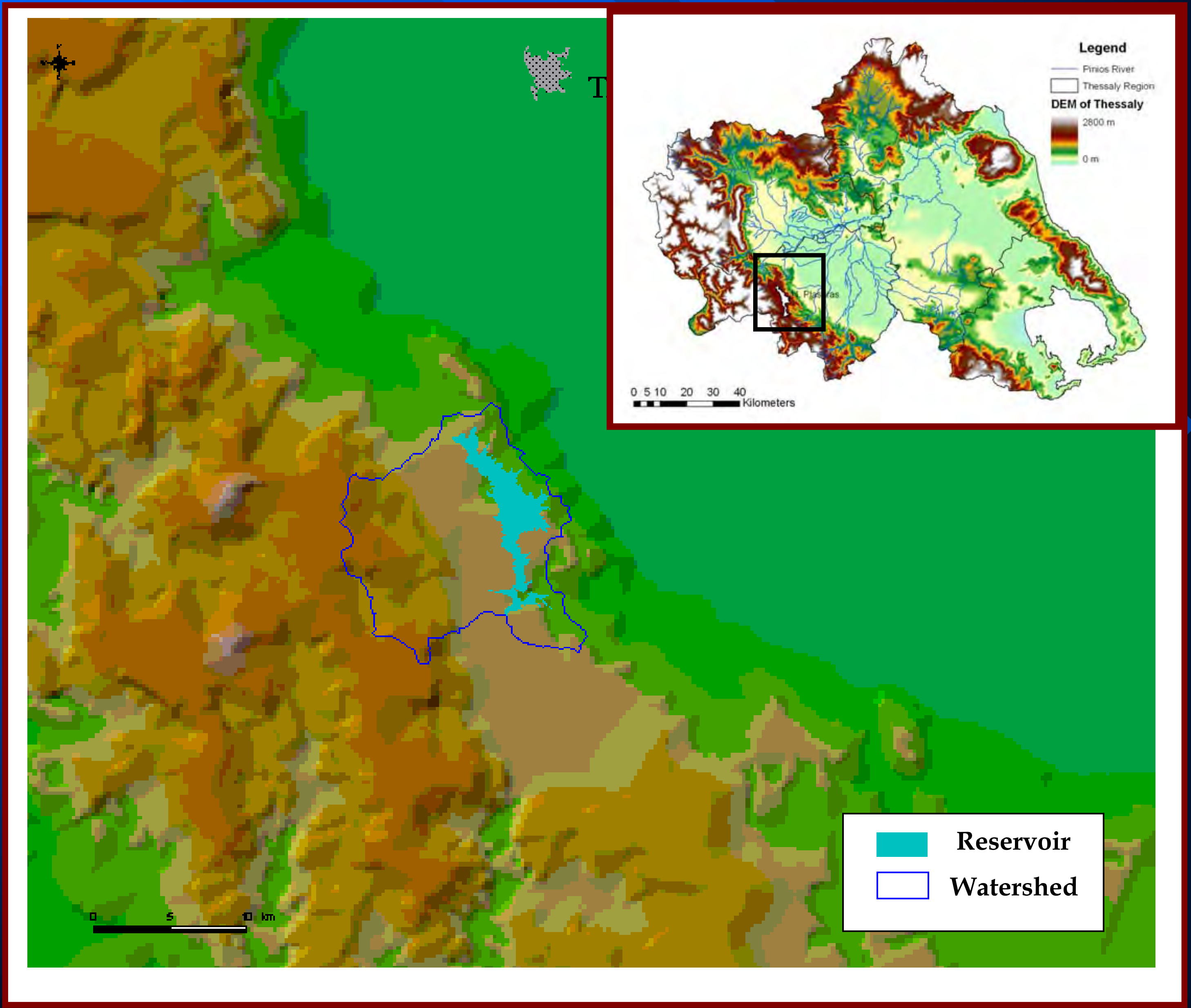
WATER RESOURCES DROUGHT IDENTIFICATION

- The Plastiras Lake, situated in a mountainous part of Western Thessaly, is a multipurpose reservoir used for hydropower, irrigation, water supply and recreation. These competitive uses raise various conflicts between groups of different interests (farmers, residents, ecologists, hotel owners).
- Use of reservoir storages as water use index
- Normalize and standardize the reservoir storages for water resources drought assessment
- Calculation of Standardized Precipitation Index at multiple timescales as meteorological drought index

Plastiras basin and reservoir characteristics

- Basin area 161.3 km^2
- Maximum basin altitude 2140 m, mean altitude 1459 m
- Mean annual runoff 147 hm^3 (1029 mm)
- Arch dam, height 83 m
- Reservoir capacity 362 hm^3, net capacity 286 hm^3, maximum area 25 km^2
- Intake level +776 m, spill level +792 m
- Installed power capacity 130 MW, hydraulic head 577 m
- Annual water demand 160 hm^3
  - 145 hm^3 for irrigation, 15 hm^3 for water supply

DEM


Legend
Pinios River
Thessaly Region
DEM of Thessaly
2800 m
0 m
0 5 10 20 30 40
Kilometers
Reservoir
Watershed
0 5 10 km

VIEW OF THE SOUTHERN PART OF PLASTIRAS LAKE

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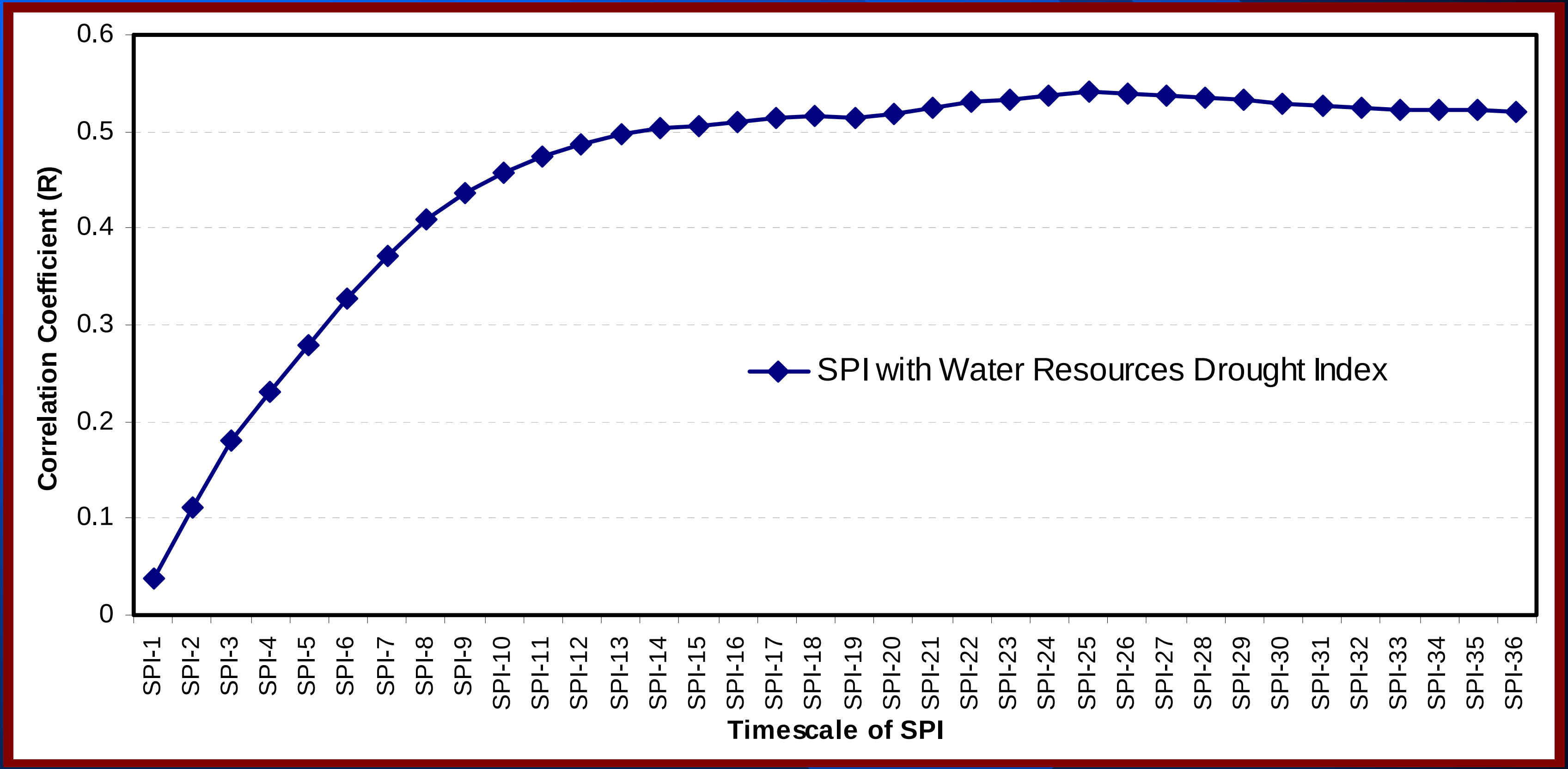
Correlations between meteorological and water resources drought indices



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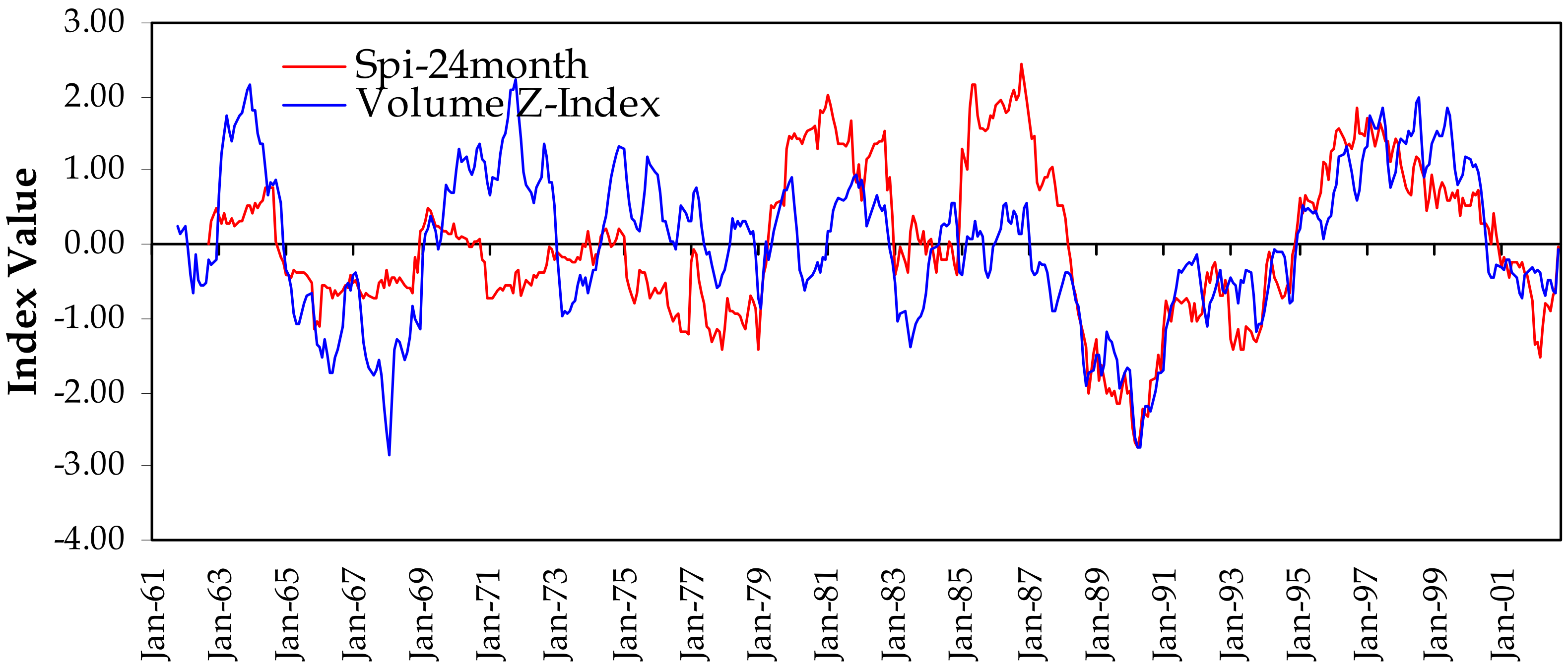
Timeseries of meteorological, and water resources drought indices



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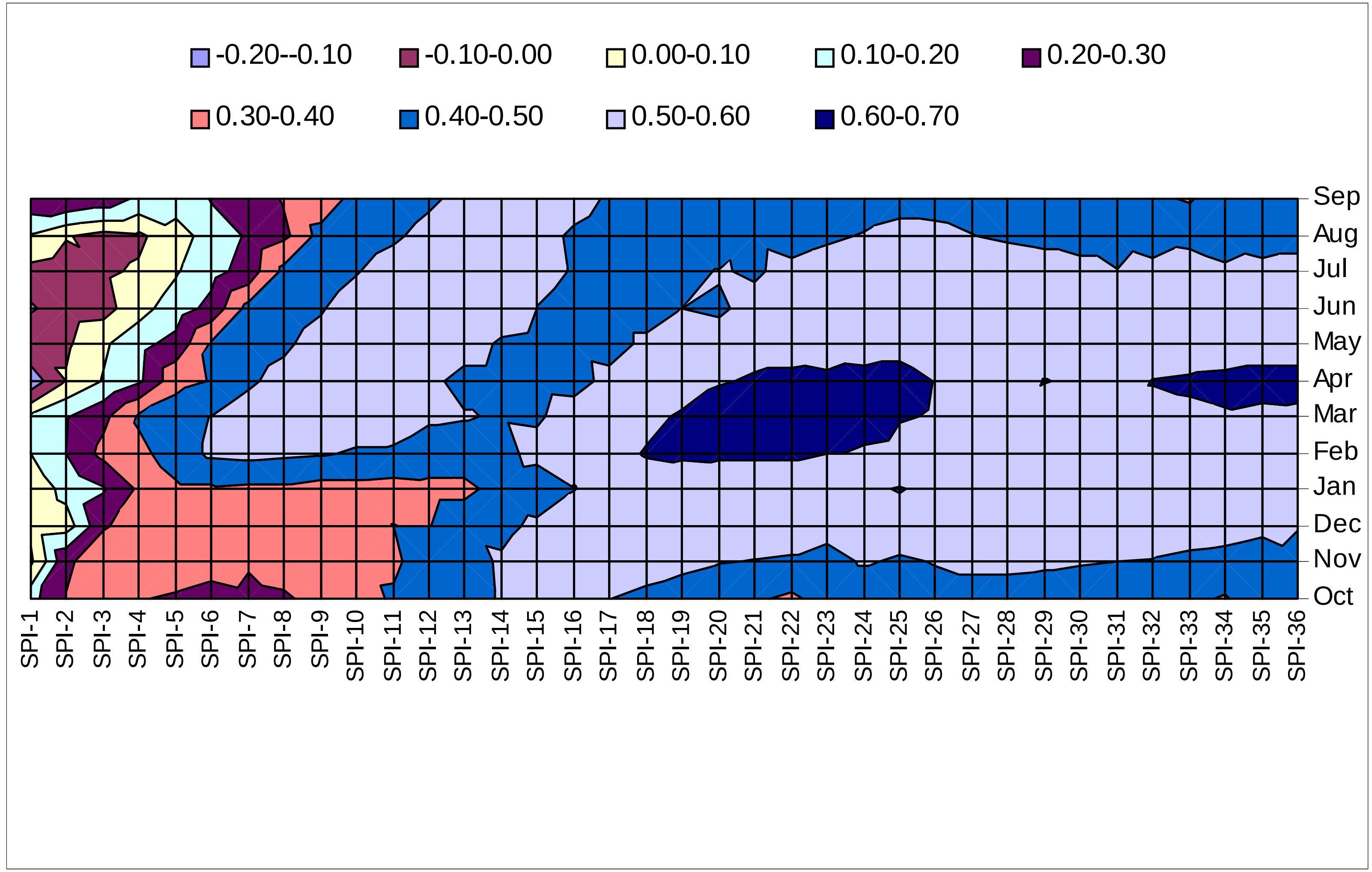
Monthly correlations between meteorological and water resources drought indices



CONCLUDING REMARKS

- Soil moisture is more responsive to meteorological dry conditions than runoff
- Care should be given in the choice of SPI timescale for drought identification (it depends on the size and characteristics of the watershed and the runoff processes)
- The Standardized Precipitation Index could be used as operational tool to identify hydrological, soil moisture and water resources drought

FUTURE RESEARCH

- Use of geomorphological watershed characteristics (area, basin slope, wetness index etc.) and runoff generation processes to establish an independent stable relationship for identification of SPI timescale in a given watershed

- Consideration of snow hydrology processes in the development of a drought index (very important for mountainous areas)

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- Loukas, A., Vasiliades, L., 2004. Probabilistic analysis of drought spatiotemporal characteristics in Thessaly Region, Greece. *Natural Hazards and Earth System Sciences*, 4(5-6), 719-731.

- Loukas, A., Mylopoulos, N., Vasiliades, L., 2007. A modeling system for the evaluation of water resources management strategies in Thessaly, Greece. *Water Resources Management*, 21(10), 1673-1702.

- Vasiliades, L., Loukas, A., Liberis, N., 2010. A water balance derived drought index for Pinios river basin, Greece. *Water Resources Management* (submitted).