Direction de la Météorologie Nationale

Spatial Interpolation of Meteorological Data for crop forecasting: AURELHY

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E-AGRI Training Workshop: Crop yield forecasting based on remote sensing 12-14 October 2011, Rabat, Morocco

Outlines

- Origin and theoretical background
- Implementation for Morocco
- Aurelhy : Adaptation to crop yield forecasting
- Perspectives and summary

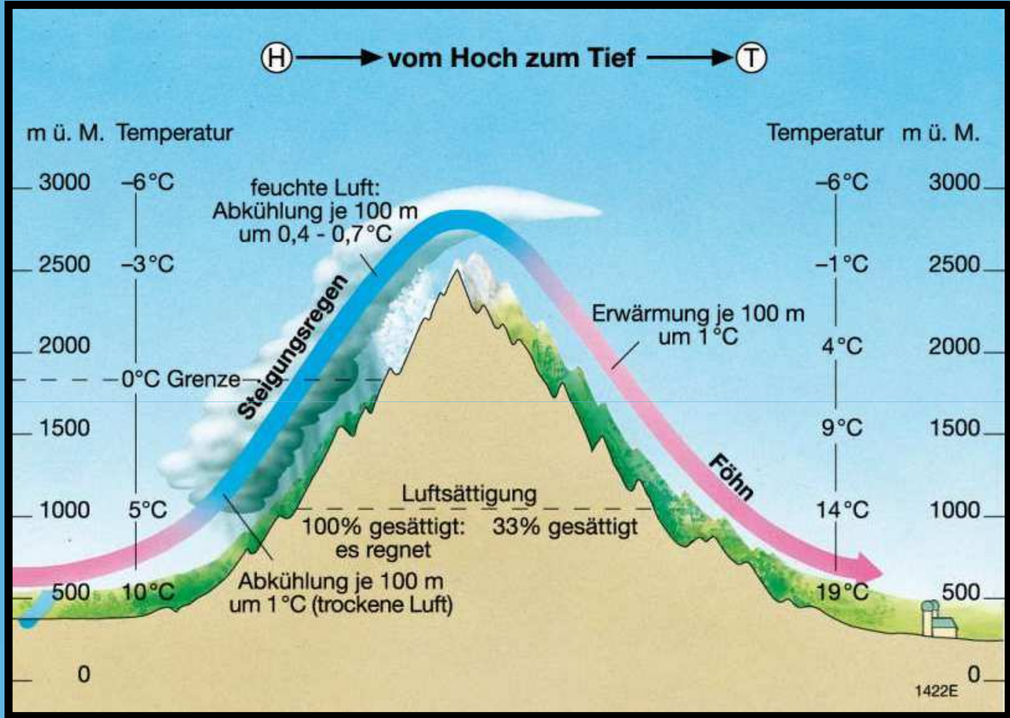
AURELHY: Origin

- **AURELHY:** <u>**A**</u>nalyse <u>**U**</u>tilisant le <u>**RE**</u>Lief pour les besoins de l'<u>**Hy**</u>drométéorologie

- **Authors:** (Patrick Bénichou and Odile Le Breton, 1986) from METEO FRANCE

Aurelhy: Basic Idea

- **Use of topography to guide the spatial interpolation of climatic variables (precipitation and others)**



$$\mathbf{P(Si) = P(xi, yi, Ri) = f(Ri) + \varepsilon(xi, yi)}$$

AURELHY: Suitability

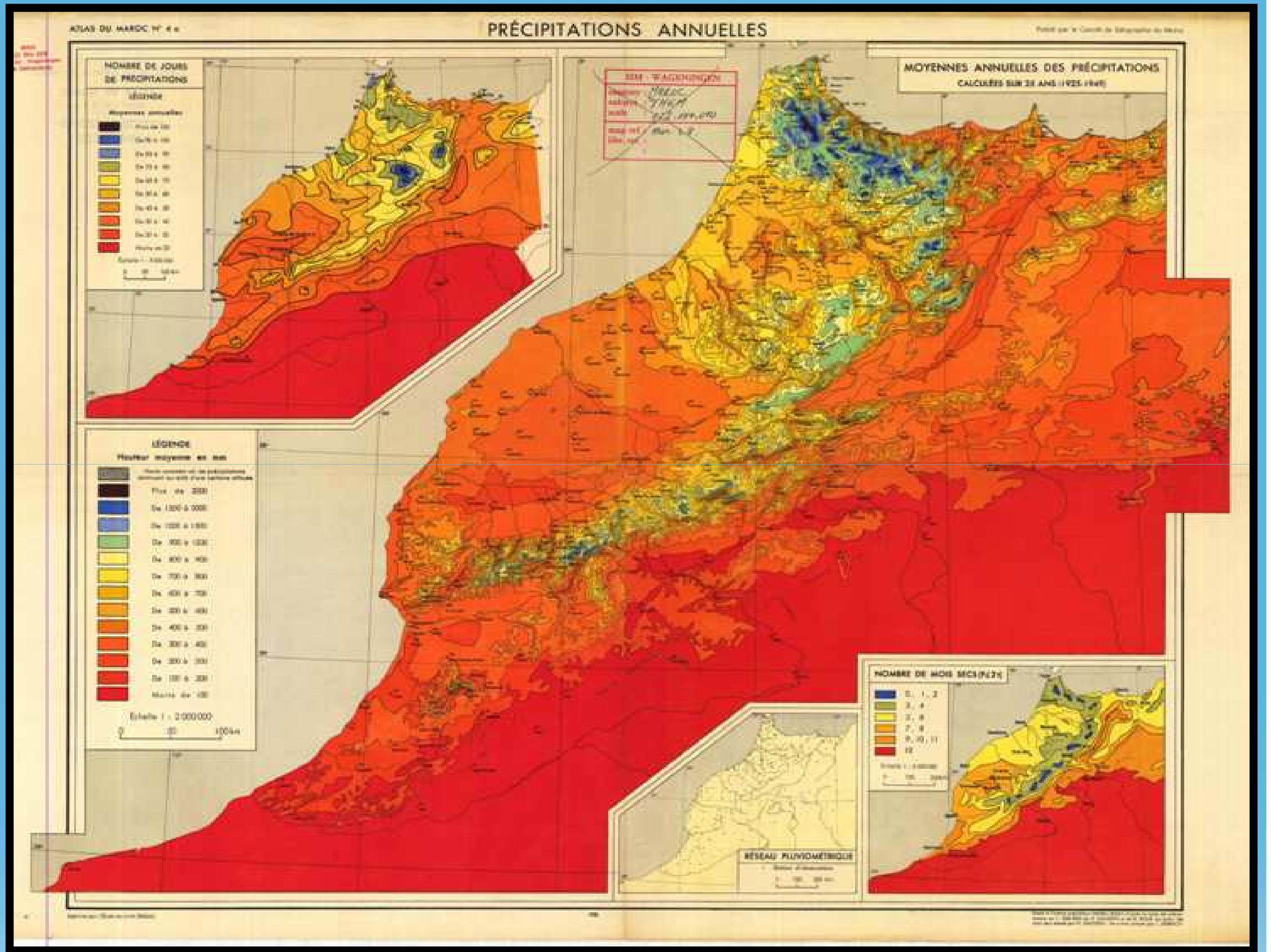
- More suitable for the interpolation of means, deciles, and other Monthly statistics of long time series

- Suitable for precipitation, number of rainy days, temperature (max, min, no. of frost days...)

Sources: Bénichou and Le Breton, 1986; Ecole nationale de la météorologie, without date; Regimbeau, 2008

Topography effect on Moroccan climate

- **W/E Gradient**
- **N/S Gradient**
- **Sea Effect**
- **Mountain Barrier**

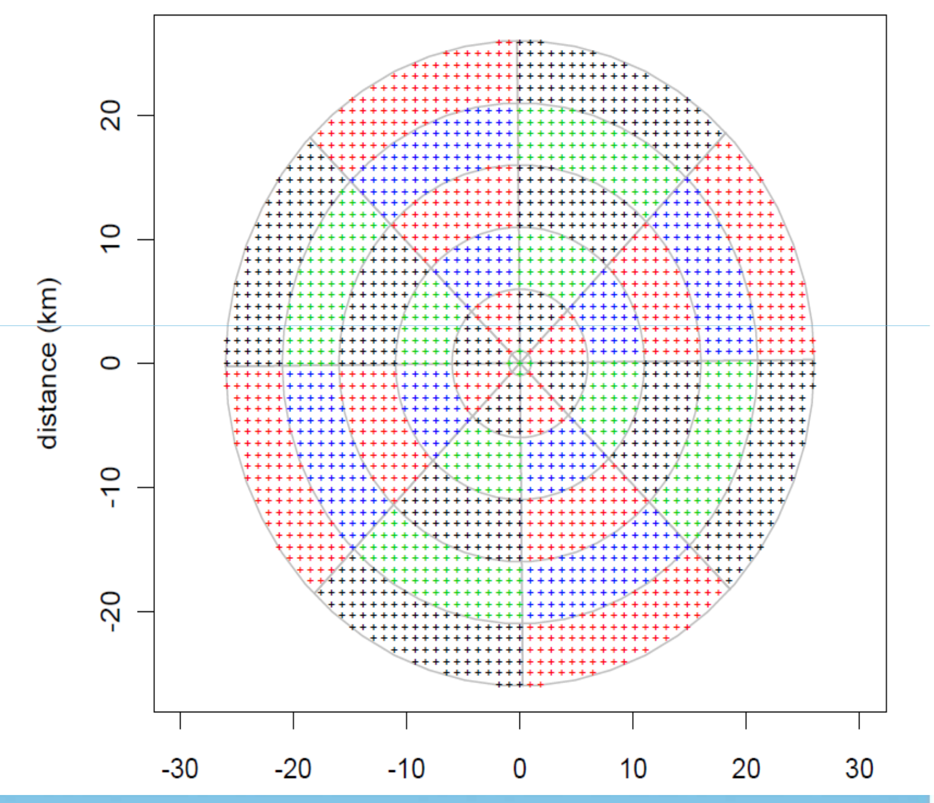


AURELHY: Steps involved

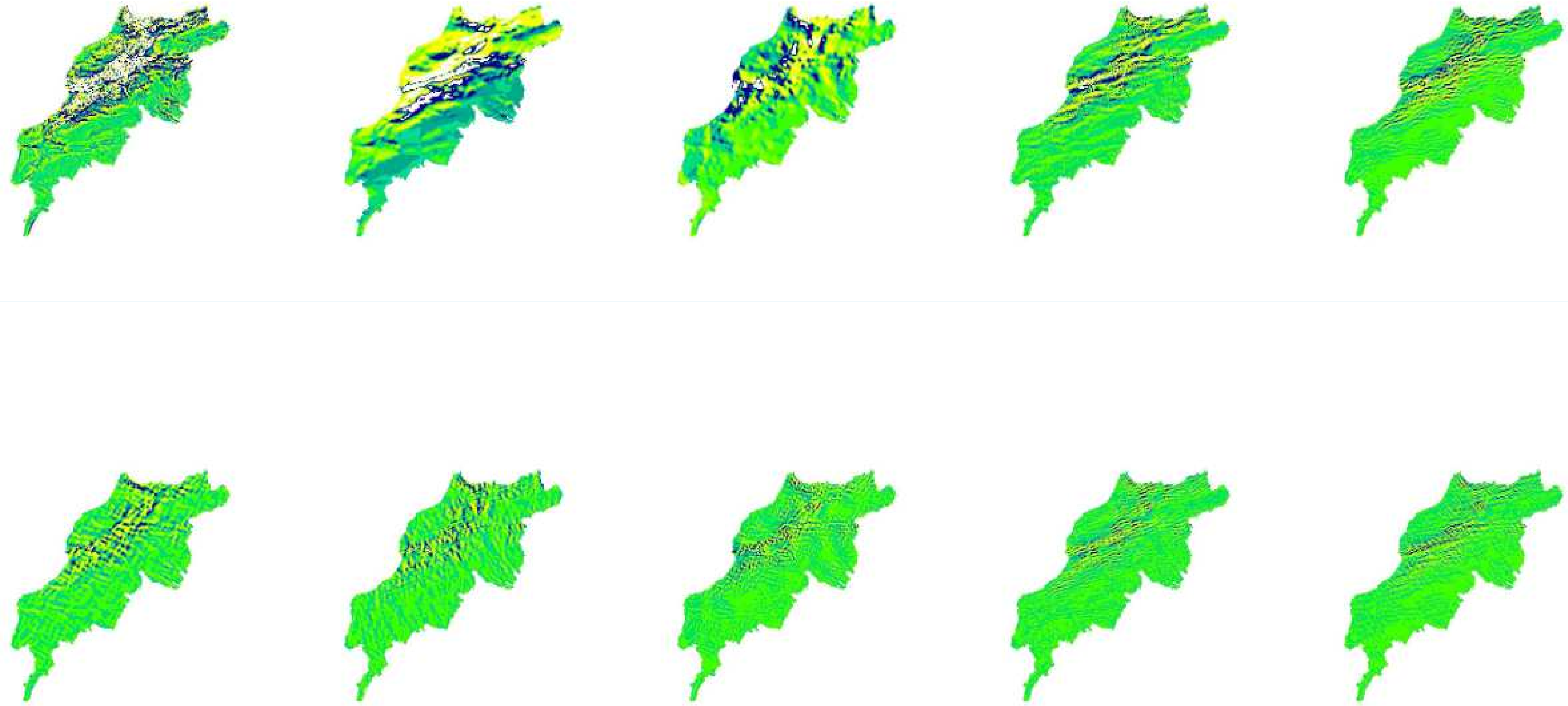
- Terrain analysis
  - Mapping relative altitude differences of smoothed local topographies
  - PCA of local topography variables
- Regression of climate variable against terrain
  - Surface predicted by regression
- Spatial interpolation of residuals by Kriging
- Adding surface of interpolated residuals to surface predicted by regression

Terrain analysis: New geometry adopted

- The landscape variables correspond to the difference in elevation between each grid point and neighbors points regularly distributed around the grid point (8 sectors and 5 distances from 6 to 26 km.

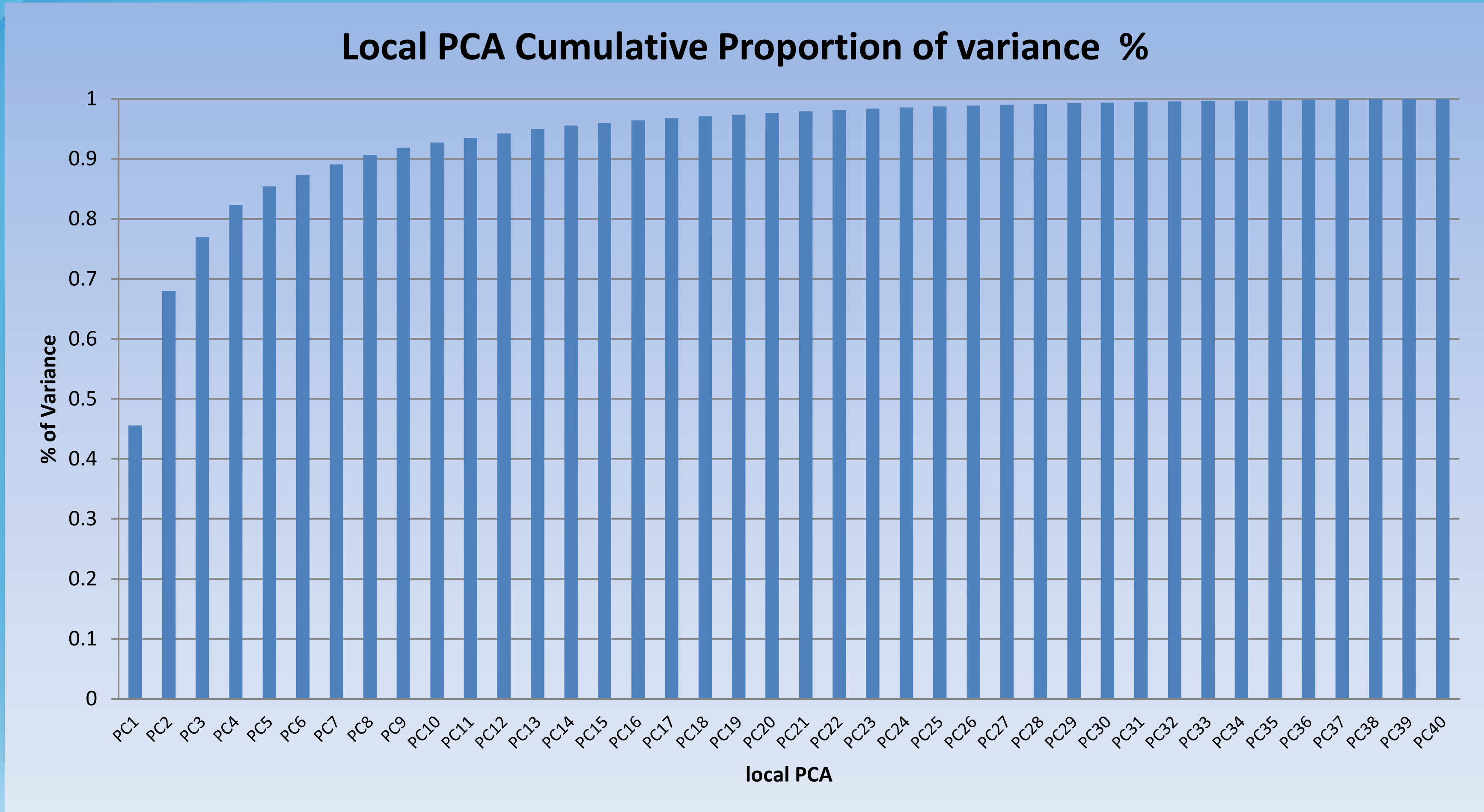


Terrain analysis: PCA of Local Topography variables

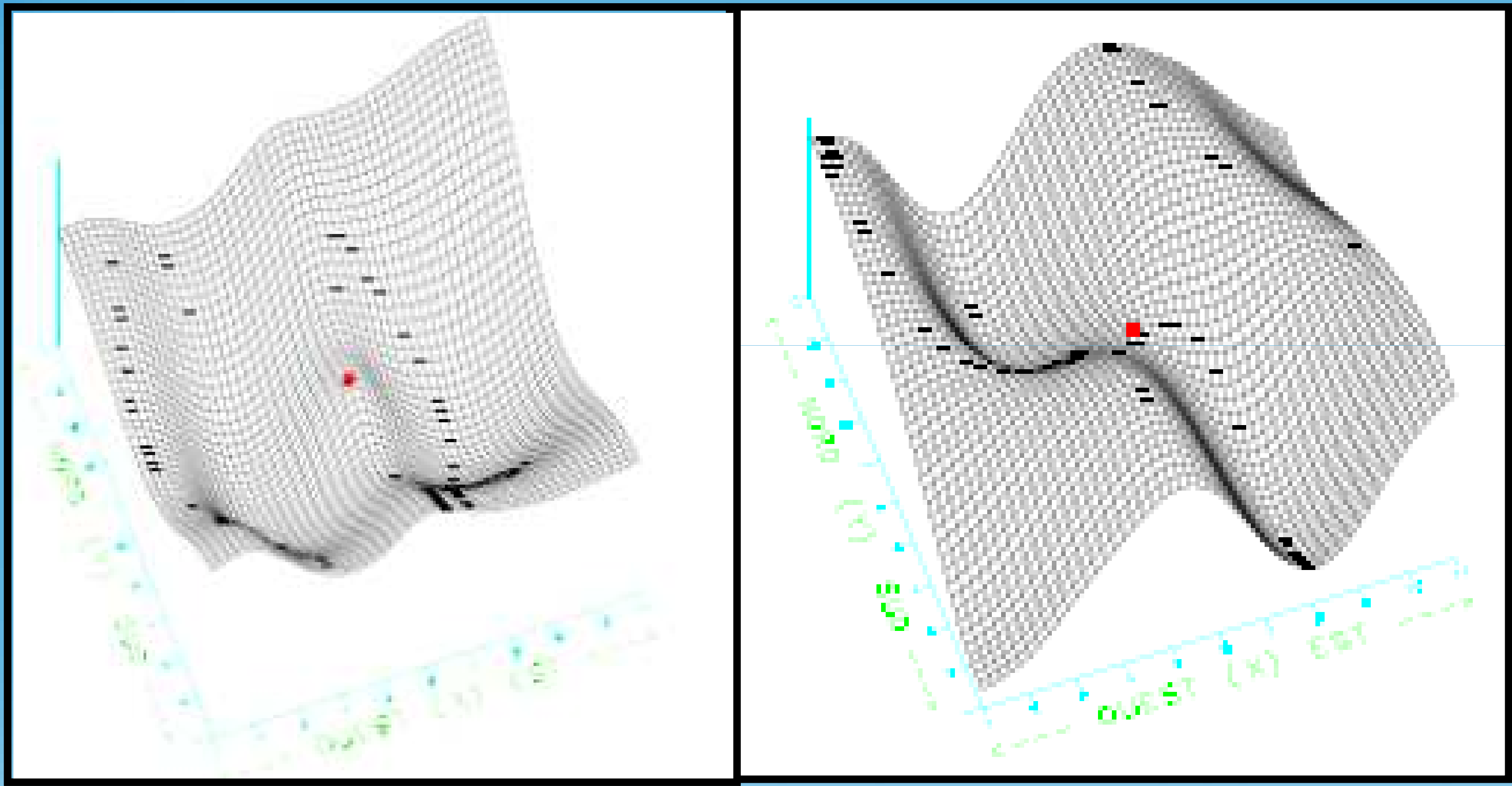


From left to right respectively Pc1 to Pc10

Terrain analysis: 10 Pcs explain more than 92% of total variance



Terrain analysis: straightforward interpretation as terrain form



Source: Huard, 1990

Regression Issues: Predictors

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
x	47	-17.088	2.246	-6.392	4.508
y	47	19.412	36.329	31.584	4.316
z	47	1.000	1494.000	427.596	447.693
seadist	47	7.517	817.026	124.748	156.043
PC1	47	-3489.414	1667.763	260.993	763.855
PC2	47	-918.187	2029.593	298.656	592.849
PC3	47	-770.923	800.999	-22.698	336.256
PC4	47	-295.293	705.233	100.296	210.094
PC5	47	-324.262	690.799	75.871	159.035
PC6	47	-630.096	489.101	-0.737	205.595
PC7	47	-284.001	403.841	5.757	126.310
PC8	47	-367.884	311.565	-6.073	125.335
PC9	47	-480.227	203.080	3.933	120.388
PC10	47	-421.230	258.358	2.755	108.250

Table 1: Description of predictors

Regression Issues: Co linearity

Variables	x	y	z	seadist	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
x	1	**0.771**	**0.478**	0.194	-0.068	0.076	0.230	0.197	0.227	0.178	0.107	-0.242	-0.005	0.135
y	**0.771**	1	0.162	**-0.335**	0.092	0.228	0.217	**0.290**	0.192	0.108	0.121	-0.234	-0.047	0.152
z	**0.478**	0.162	1	**0.455**	-0.093	0.088	-0.016	0.054	0.084	0.016	0.242	-0.239	-0.176	-0.173
seadist	0.194	**-0.335**	**0.455**	1	0.018	-0.102	-0.096	-0.043	-0.207	0.008	-0.042	0.051	-0.063	-0.182
PC1	-0.068	0.092	-0.093	0.018	1	**0.595**	0.123	**0.381**	**-0.354**	**-0.325**	**-0.315**	-0.002	**-0.305**	-0.237
PC2	0.076	0.228	0.088	-0.102	**0.595**	1	0.085	**0.354**	0.158	0.051	-0.059	-0.207	**-0.458**	-0.235
PC3	0.230	0.217	-0.016	-0.096	0.123	0.085	1	0.111	-0.079	-0.271	0.092	**-0.326**	-0.083	0.031
PC4	0.197	**0.290**	0.054	-0.043	**0.381**	**0.354**	0.111	1	0.224	0.134	-0.015	-0.053	-0.070	-0.081
PC5	0.227	0.192	0.084	-0.207	**-0.354**	0.158	-0.079	0.224	1	**0.431**	0.135	0.132	0.285	0.197
PC6	0.178	0.108	0.016	0.008	**-0.325**	0.051	-0.271	0.134	**0.431**	1	-0.174	**0.337**	0.237	0.209
PC7	0.107	0.121	0.242	-0.042	**-0.315**	-0.059	0.092	-0.015	0.135	-0.174	1	**-0.397**	-0.237	-0.095
PC8	-0.242	-0.234	-0.239	0.051	-0.002	-0.207	**-0.326**	-0.053	0.132	**0.337**	**-0.397**	1	**0.491**	0.182
PC9	-0.005	-0.047	-0.176	-0.063	**-0.305**	**-0.458**	-0.083	-0.070	0.285	0.237	-0.237	**0.491**	1	**0.768**
PC10	0.135	0.152	-0.173	-0.182	-0.237	-0.235	0.031	-0.081	0.197	0.209	-0.095	0.182	**0.768**	1

Table 2 Correlation matrix Between predictors *Values in bold are different from 0 with a significance level alpha=0.05*

Regression Issues: Multi Co Linearity

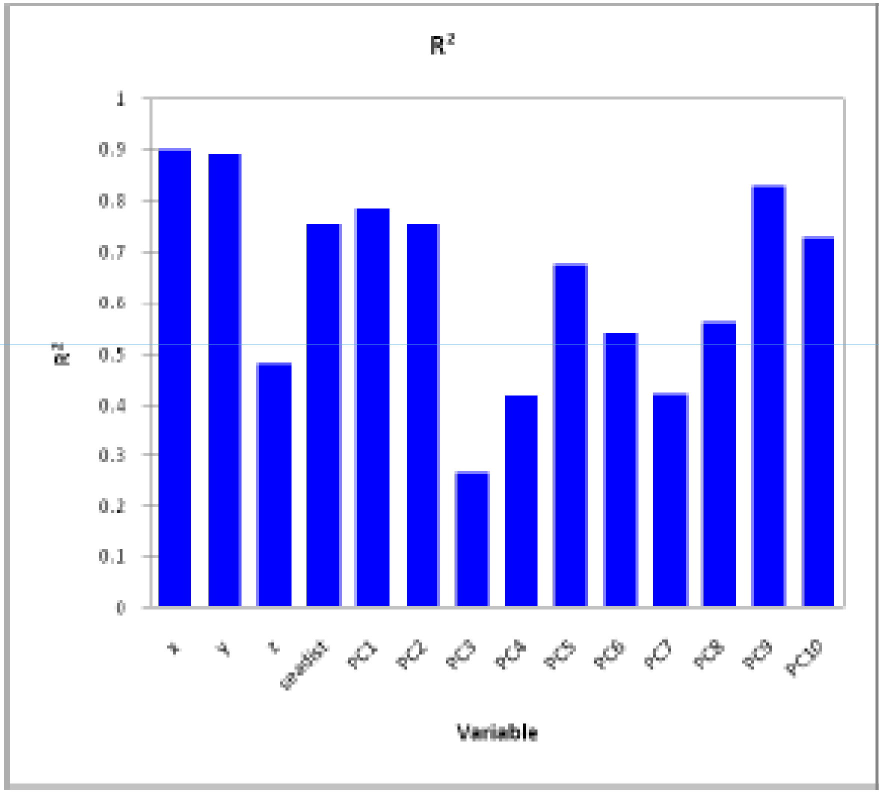


Figure 1-a: R2 between predictors

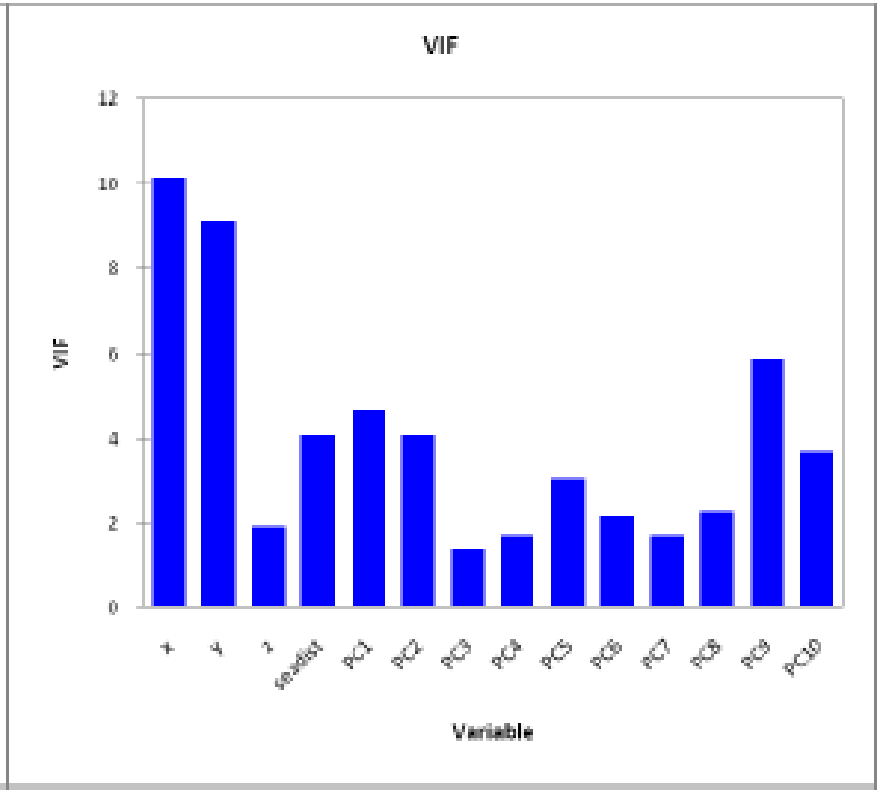


Figure 1-a: VIF

Regression Issues: Avoiding Multi Co linearity

- **Use of Stepwise Regression : Backward and Forward elimination**

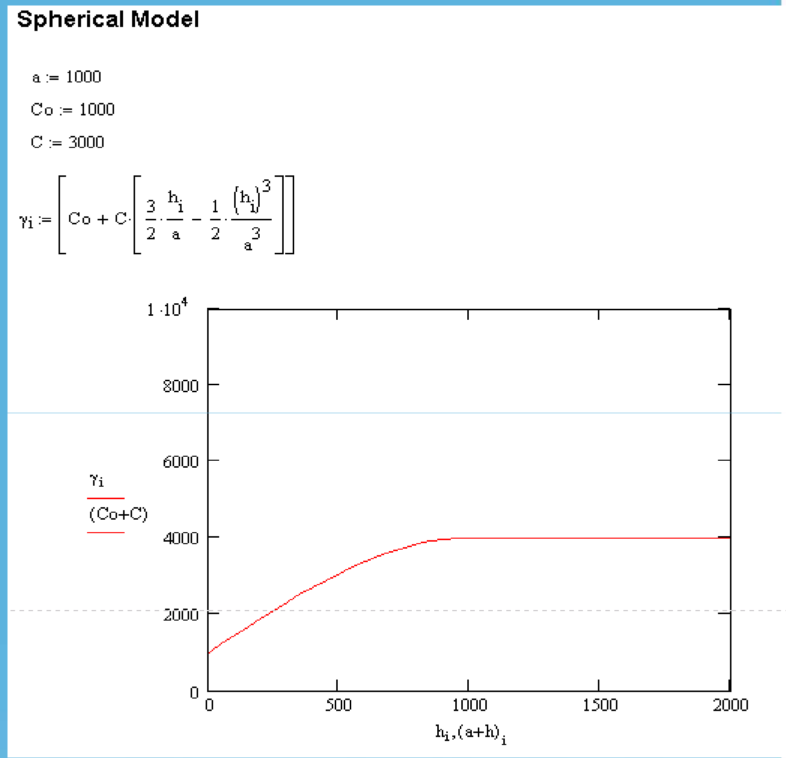
- Reduction of predictors number

- Ensuring The significance of regression Coefficients

- Ensuring The normality of residuals which is an important condition for kriging

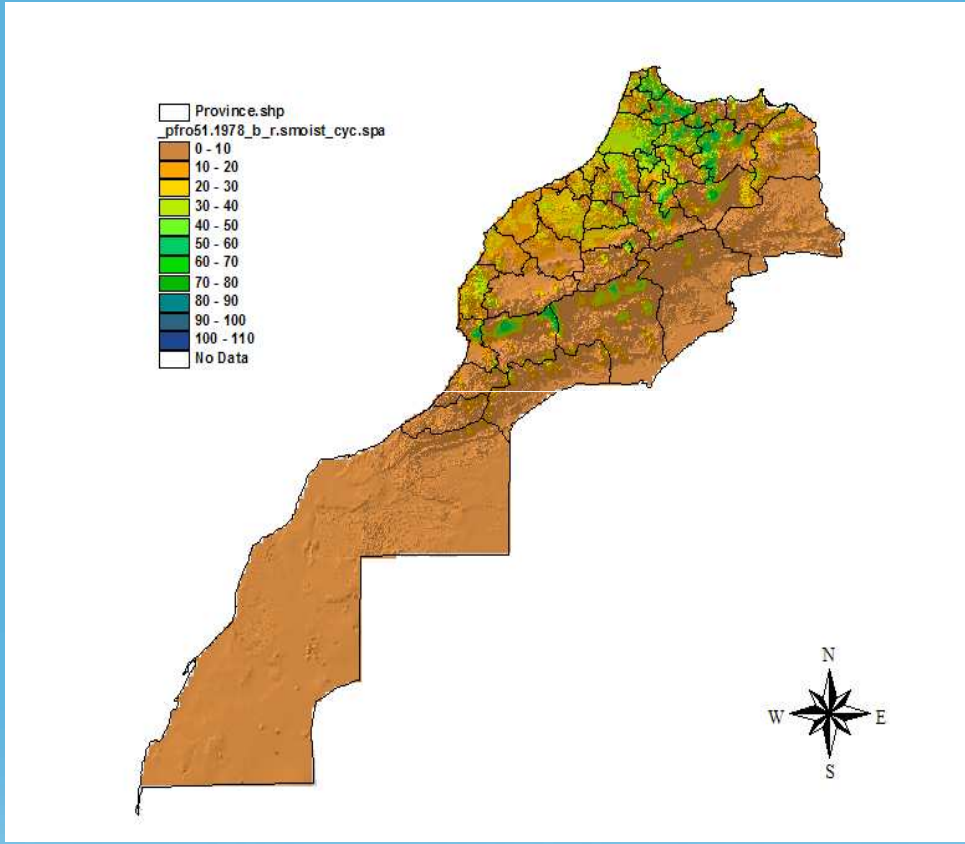
Residuals kriging

- Compute regression residues and spatially interpolate them with a kriging algorithm to a resolution of 0.1 degree:
- Detrend the quadratic drift from regression residues;
- Interpolate the detrended term with an ordinary Kriging using a spherical semivariogram;



Final mapping

- Final mapping by addition of :
  - Grid predicted by regression
  - Grid obtained through kriging of residuals



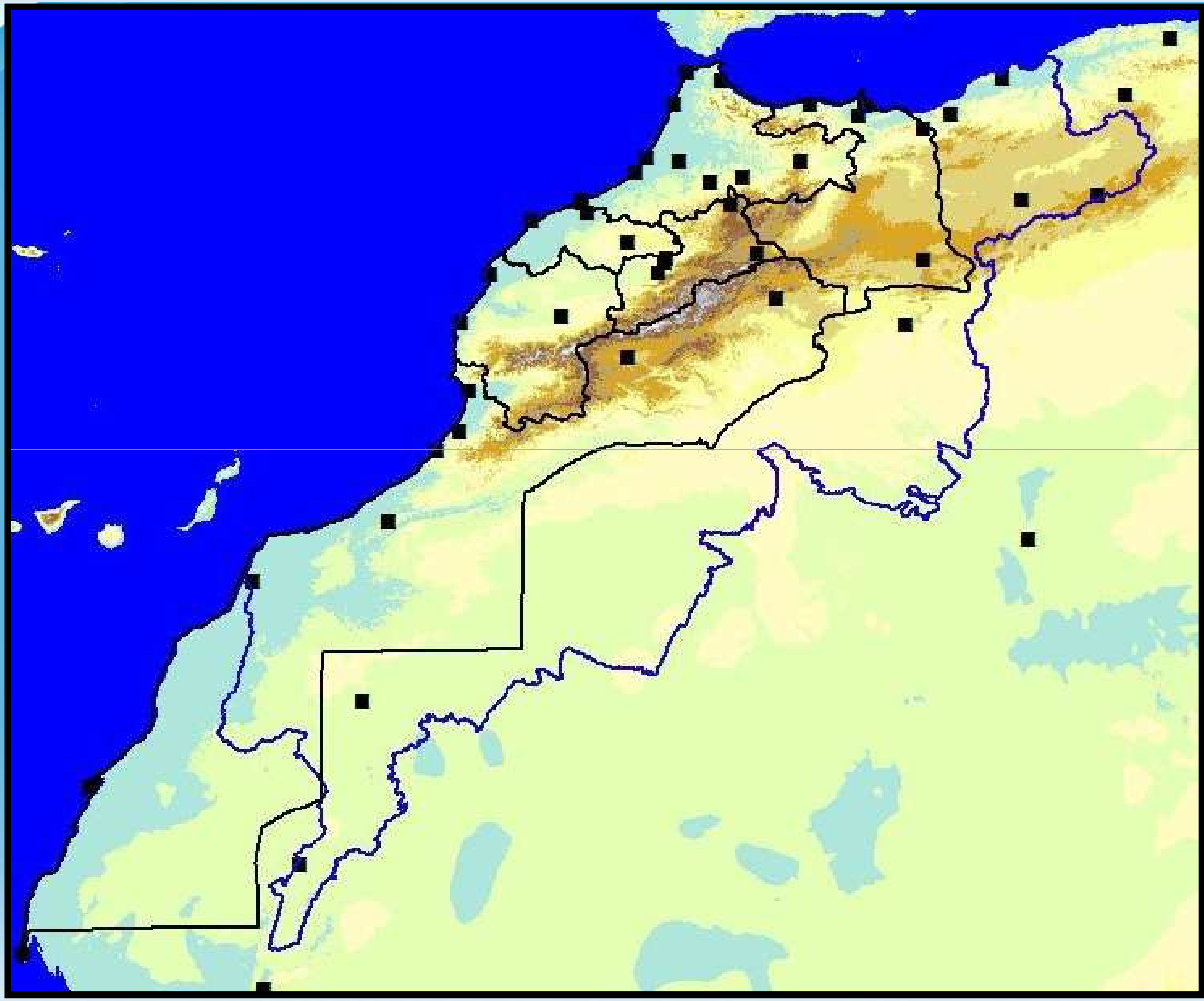
AURELHY Implementation: R package

- R Version(>= 2.10.0)
- Dependents R Package: stats, graphics, shapefiles, gstat, Mass
- Author: Philippe Grosjean
- Download: http://r-forge.r-project.org/projects/aurelhy/

AURELHY R package: Utilities

- DEM Resampling to 0.1°
- Local Topography components
- SEA Distance Calculation
- Principal Component Analysis of Local Topography components
- FITTING Variogram

Data Needed: DEM and geo referenced Data records

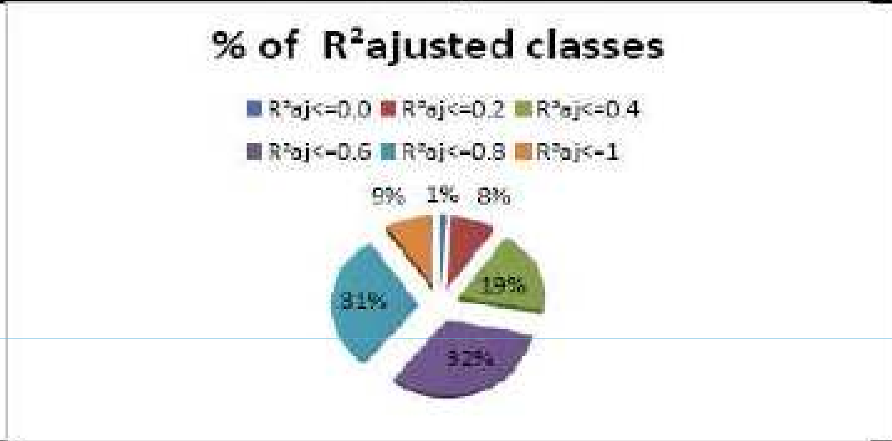
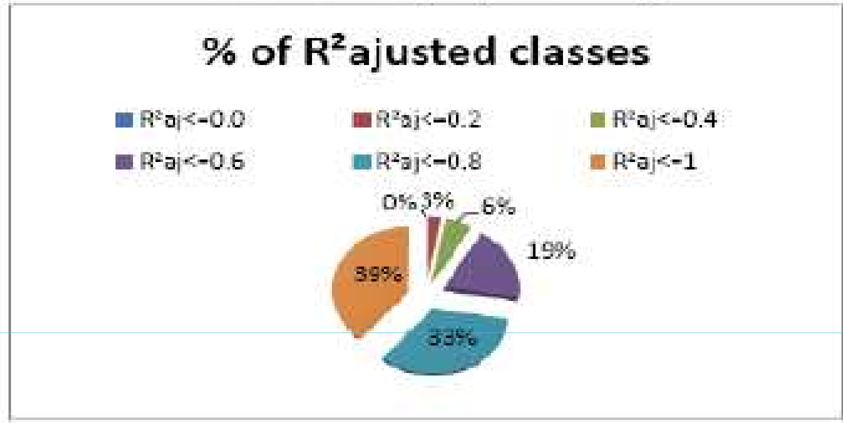
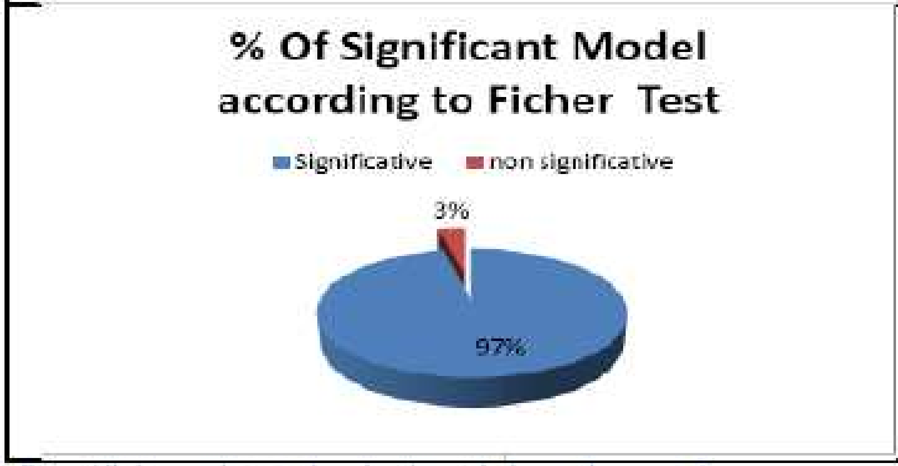
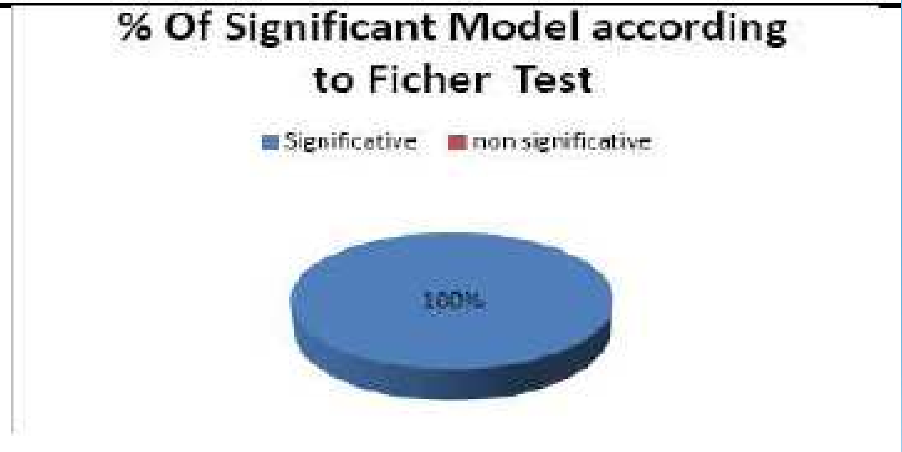


comparison of Two variants of Aurelhy

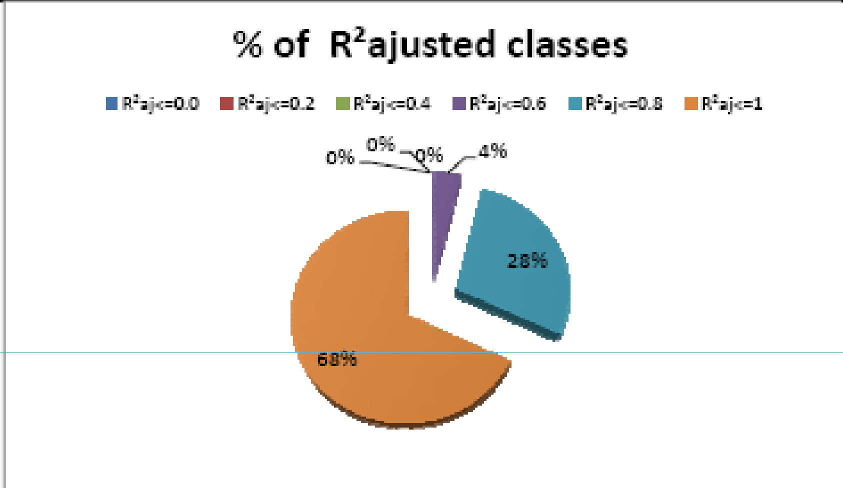
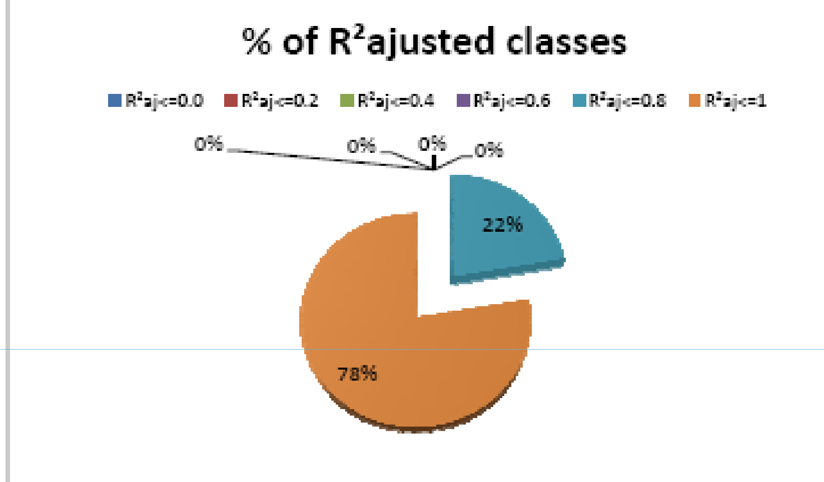
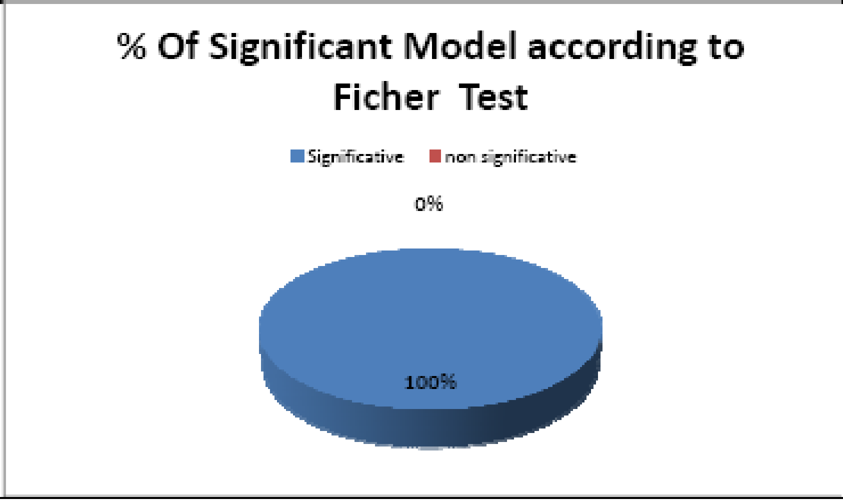
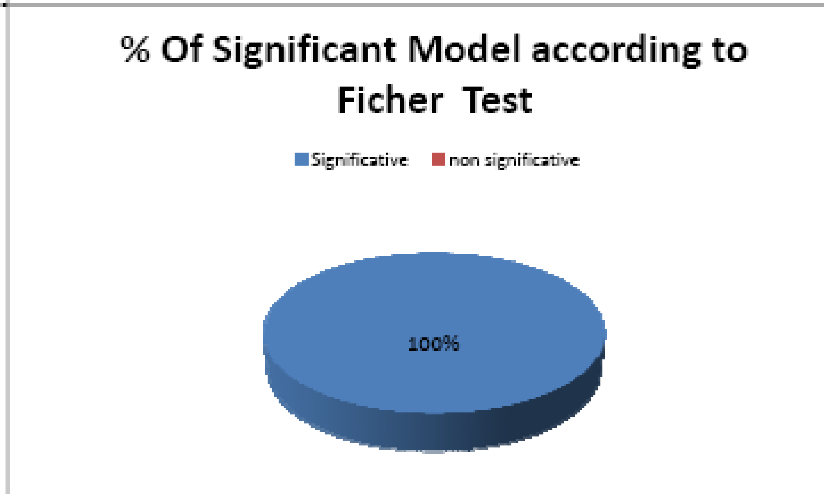
- **Variant 1:**
  - Regression of each decadal climatic variable against PCs and kriging residuals

- **Variant 2:**
  - Regression of long term average of climatic variable and kriging differences

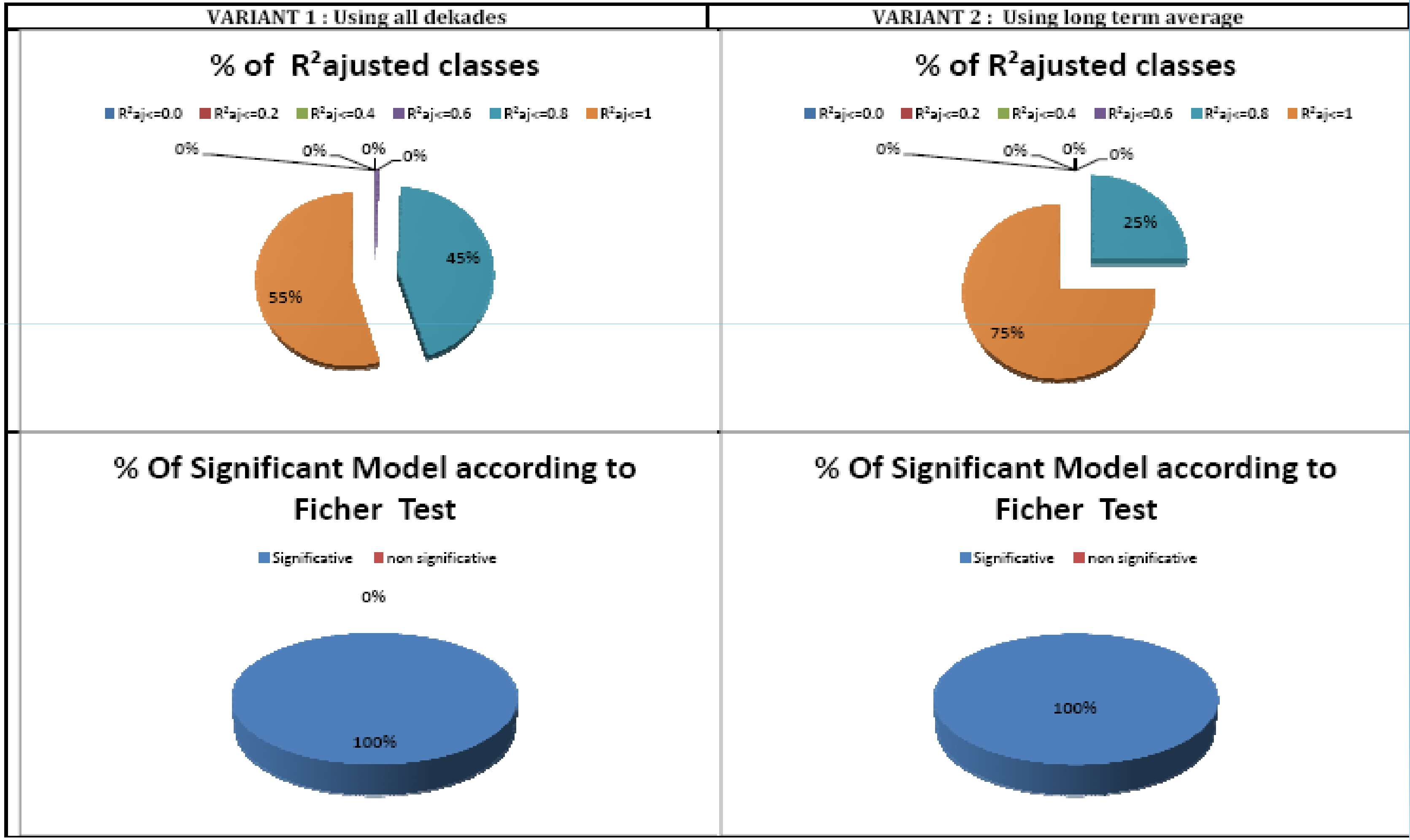
comparison of Two variants of Aurelhy (Rain)

VARIANT 1 : Using all dekades	VARIANT 2 : Using long term average
	
	

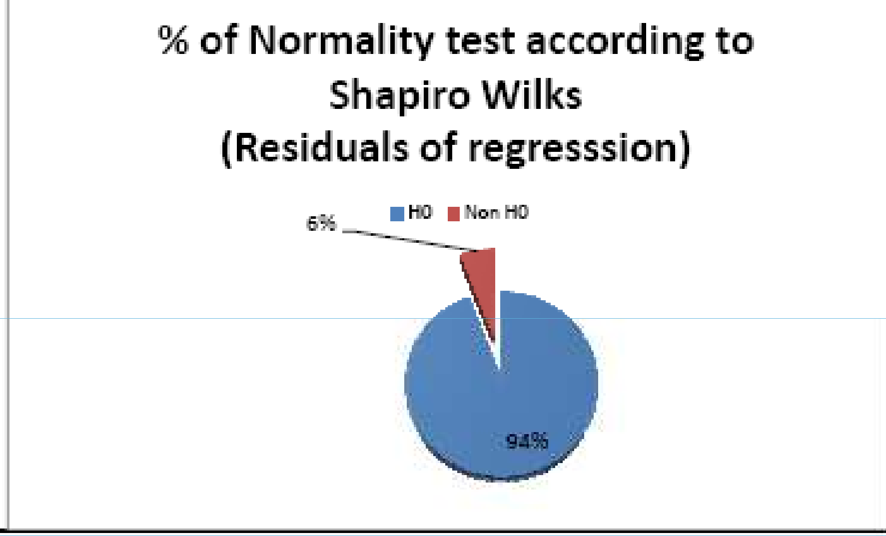
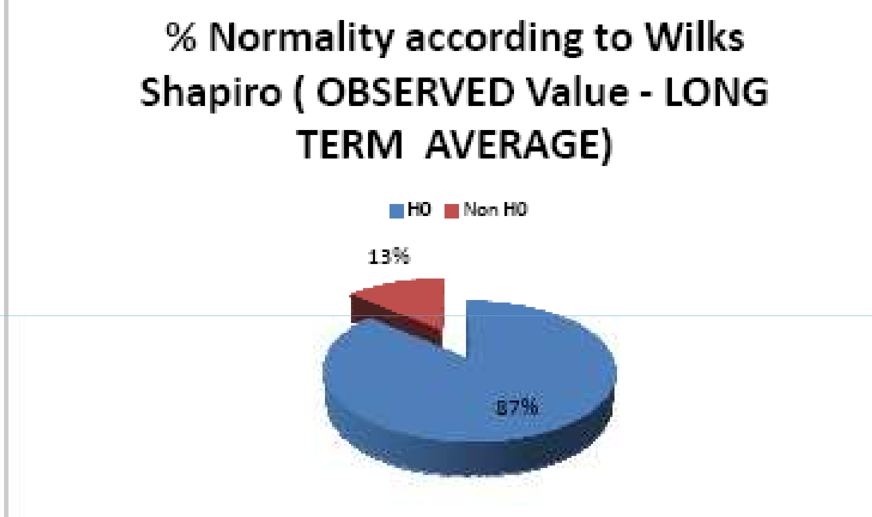
comparison of Two variants of Aurelhy (Tmax)

VARIANT 1 : Using all dekades	VARIANT 2 : Using long term average
	
	

comparison of Two variants of Aurelhy (Tmin)



Regression Residuals analysis (Tmin)

Variant 1 : Using All dekades	Variant 2 : Using long Term Average
	

- **Regressions in using long term average gives significant models but generates more Fields not following a normal distribution.**
- **GOOD REGRESSIONS BUT VERY LIKELY BAD KRIGING**

leave one out Cross Validation (Temperatures)

- **Both Variants Presents good and similar results for Temperatures (Tmax and Tmin)**

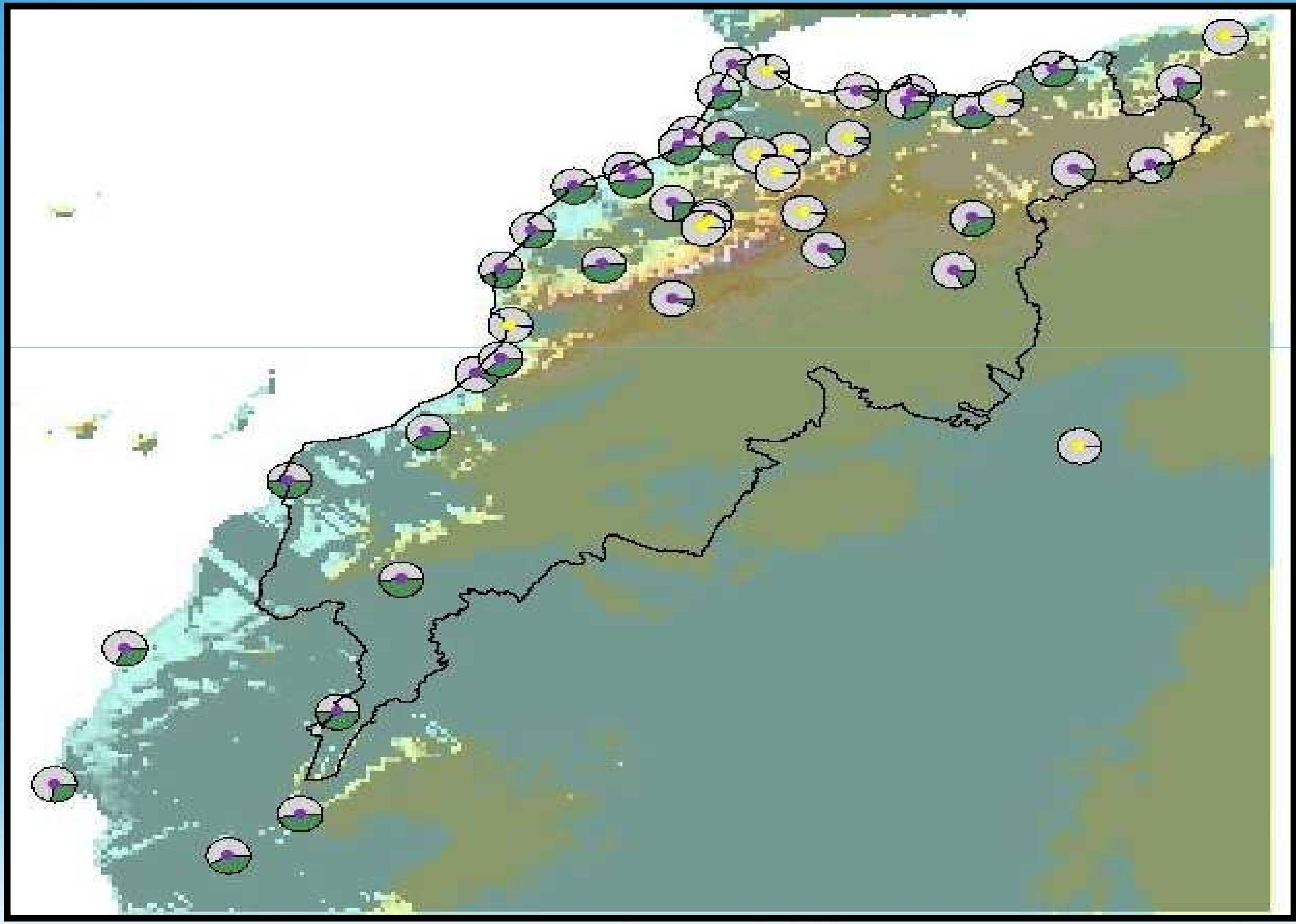
Variable	Variants	R^2 adj	Slope	MSE
Tmin	Variant 1	0.95	0.951	2.23
	Variant 2	0.93	0.9	2.16
Tmax	Variant 1	0.92	0.998	7.32
	Variant 2	0.91	0.996	7.21

leave one out Cross Validation (Rainfall)

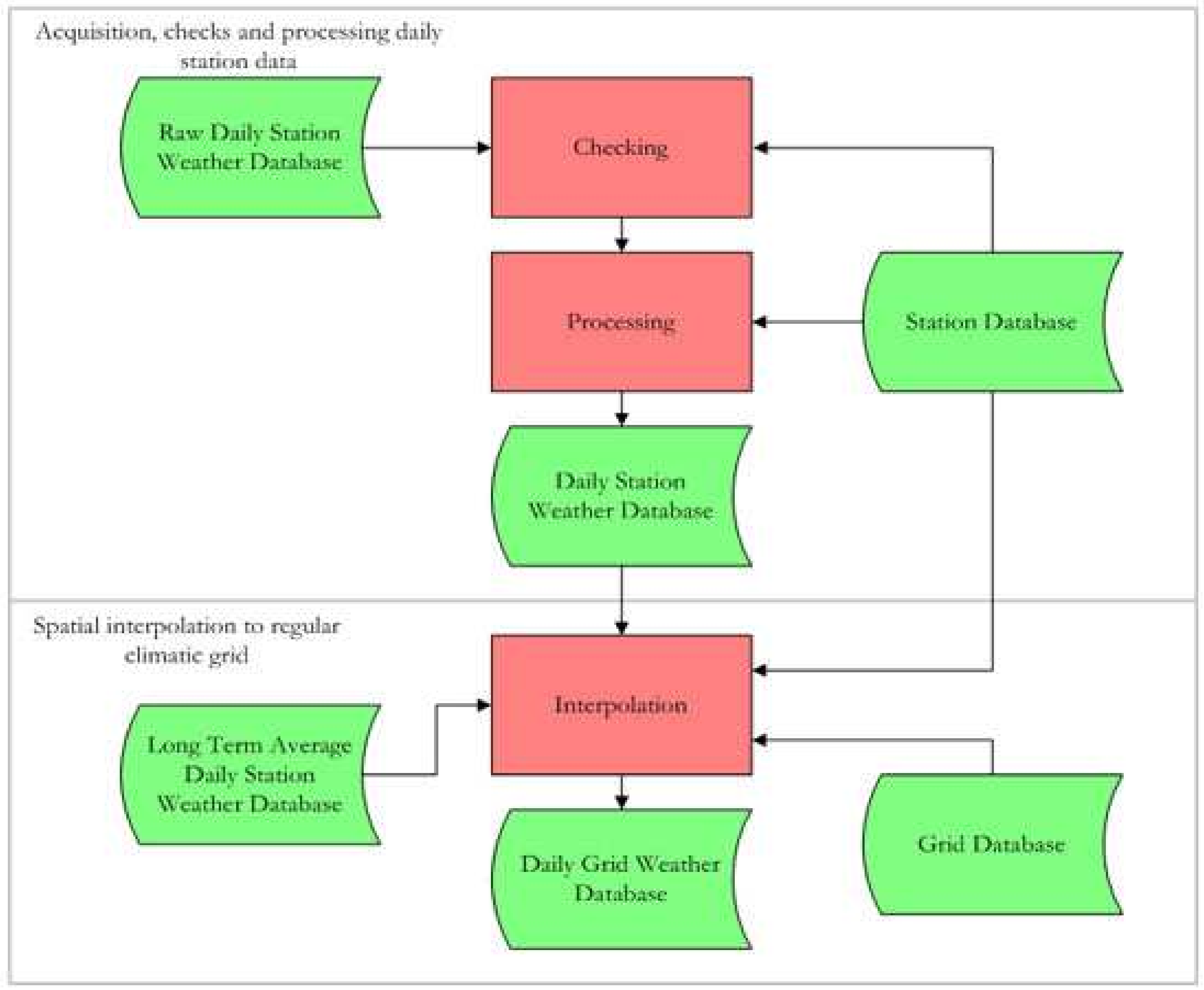
Rainfall: Variant 2 is more stable

	STANDART DEVIATION OF ERRORS	
	Variant1	**Variant2**
MEAN	1.06E+14	16.9
MINIMUM	5.01	4.4
MAXIMUM	5.03E+15	264.24

leave one out sensitivity



Role of interpolation in CGMS level 1



Daily Data needed for feeding CGMS

maximum temperature (°C)
minimum temperature (°C)
mean daily vapour pressure (hPa)
mean daily windspeed at 10m (m/s)
mean daily rainfall (mm)
Penman potential evaporation from a free water surface (mm/day)
Penman potential evaporation from a moist bare soil surface (mm/day)
Penman potential transpiration from a crop canopy (mm/day)

daily global radiation in $KJ/m^2/day$
daily mean snow depth in cm

Alternative entry for grid weather data

- CGM Version 9.2:

1. Integration of Decadal grids of temperatures , rainfalls and number of rainy days by decade or month;
2. Downscaling to Daily time step

Pseudo Penman Formula for ET0 Calculation

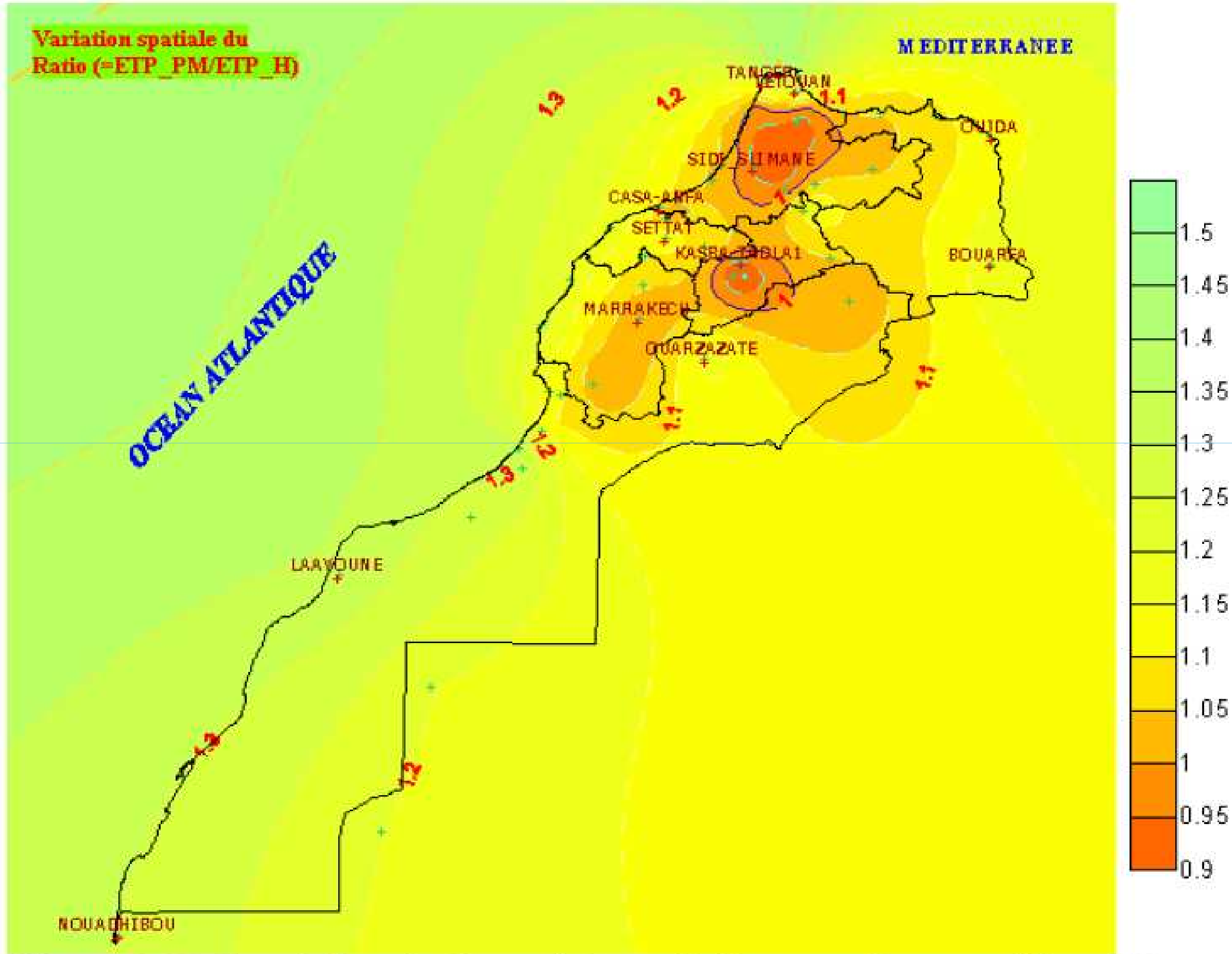


Figure 2.05: Spatial variations of the ratio between Penman-Monteith and Hargreaves estimations of evapotranspiration.

Summary

- Aurelhy has the potential to integrate the effect of topography for Tmin and Tmax interpolation at 10 days scale. Both variants are reliable.
- Using Long term average for precipitations gives stable results.
- Interpolation by Aurelhy needs more development especially for punctual/convective rain events.
- Aurelhy is sensitive to the number of stations and their geographic position
- Aurelhy is sensitive to Data quality and Data missing

Aurelhy Perspectives for CGMS

- Generating decadal grids of Tmax, Tmin , Rain and number of rainy days;

- Using the calibrated Hargreaves formula for ET0;

THANK YOU !