Master Thesis

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zum Thema

„Verification of vegetation in regard of greenvolume as potential for climate-adaption“

Using the example of the state-capital Potsdam

vorgelegt von

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Potsdam, den 14. Juli 2014 Steffen Tervooren

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Abstract

Reflecting expected Climate-heating (Potsdam about 2.5°C for 2050) and related extensive heat-periods (“tropical nights”), the search for adaptation is of interest. This includes health-challenging conditions. For Potsdam there are respective data available, addressing potentials for spatial- and landscape planning: detailed biotope mapping with connected data on green-volume (GV), soil sealing (VG) and other parameters like soil-types (for 1992, 1998, 2004 und 2010). Specifically GV indicating adaptation (cooling-possibilities) and VG as „contra-indicator“ (heat-risk), have been analysed.

Reflecting other studies, those data have been analysed to verify their relevance, using statistical, GIS- and geographical methods (e.g. regressions-analyses OLR / GWR). The target was to show relations between those data (variables to define indicators) and temperatures. Further similar, other study-results were to be verified and compared. To do this Landsat-data were processed to gain surface-temperatures. Thus were to be compared with the postulated indicators GV, VG and land-use (biotope-types).

The relevance of the postulated indicators were shown, specifically using 2010-data. Similarities with other study-results could be verified. In addition, Potsdam-analytics were showing local specifics and influences, which need to be confirmed and implemented.

VG and GVZ can be recommended to prepare for climate-adaptation and identify possibilities to do so. Results approve, that additional GV buffers temperatures, and rising VG most likely contributes to rising temperatures (method depending R^2: from 0.65-0.85 and 0.9). Thus, they can contribute to climate-adaptation-measures. Using the data, starting points for calculations are presented, which can be used caring about other influences (specifically: land-use, location). It is advised, that presented calculation-basics shall be specified and complemented. Reflecting the results $1m^3/m^2$ additional GV contributes to reduce temperatures for about 0.3°C, 1% additional VG leads to 0.03°C surface-temperature-rise.

Zusammenfassung

Vor dem Hintergrund anzunehmender Klimaerwärmung (Potsdam durchschnittlich 2,5°C bis 2050) und damit verbundener besonders ausgeprägter Hitzereignisse und –perioden („Tropennächste“) ist die Suche nach Möglichkeiten der Anpassung („adaptation“) an diese auch die Gesundheit fordernden Bedingungen von Interesse. Für Potsdam liegen Daten vor, die die Potenziale für eine Anpassung für den Bereich der Raum-, Stadt- und Landschaftsplanung definieren können: detaillierte Biotoptypenkartierung mit zugeordneten Daten zu Grünvolumen, Versiegelungsgrad und weiteren Parametern, wie Bodenarten (für 1992, 1998, 2004 und 2010). Insbesondere Grünvolumen als Indikator für eine Anpassung (Kühlungsmöglichkeit) und Versiegelung, praktisch als „Kontraindikator“ (Erwärmungsrisiko), wurden neben weiteren Nutzungseinflüssen untersucht.

Diese Daten wurden Ergebnissen anderer Studien folgend mit statistischen und GIS-technischen, geographischen Methoden (u.A. Regressionsanalyse OLR / GWR) auf ihre Wirksamkeit und Aussagekraft hin untersucht. Das Ziel war es neben dem Aufzeigen von Zusammenhängen zwischen Temperaturen und o.g. Parametern, die Ergebnisse anderer Studien zu verifizieren und zu verglichen. Hierfür wurden aus Landsat-Daten Oberflächentemperaturen ermittelt und den Parametern Grünvolumen, Versiegelung und Nutzung (Biotoptypen) gegenüber gestellt.

Dabei konnte die Eignung der Indikatoren speziell anhand der 2010-er Daten nachgewiesen werden. Bezüge zu anderen Studien ließen sich bestätigen, auch wenn die Potsdamer Analysen bezogen auf lokale Spezifika und Wirkungszusammenhänge aufzeigten, dass entsprechende Daten und abgeleitete Richtwerte vor einer Übertragung auf die lokale Ebene zu verifizieren und zu ergänzen sind. Versiegelung und Grünvolumen sind als Indikator geeignet, um eine Klimaanpassung vorzubereiten und Möglichkeiten hierfür abzuschätzen. Die Ergebnisse zeigen, dass zunehmendes Grünvolumen Temperaturen puffert und dass zunehmende Versiegelung meist zur Temperaturerhöhung beiträgt (methodenabhängig R^2: 0,65-0,85 / 0,9). Die Indikatoren können Klimaanpassungsmöglichkeiten aufzeigen. Anhand der Daten werden erste Berechnungsgrundlagen geliefert, deren Anwendung unter Berücksichtigung weiterer Parameter (insbesondere Nutzung, Lage) erfolgen kann. Eine Spezifizierung der Berechnungsgrundlagen wird aber empfohlen. 1m³/m² zusätzliches Grünvolumen führt nach den vorliegenden Analysen zu einer Reduktion von etwa 0,3°C, 1% zusätzliche Versiegelung führt zu 0,03°C Erhöhung der Oberflächentemperatur.

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Abbreviations:

AICc: Akaike Information Criterion
ALKIS: German - standard cadastral data for properties
ASCUE: Adaptation Strategies for Climate Change in the Urban Environment
ATKIS: German - standard cadastral data for topography
CEDT: Central European Daylight Saving Time
CEOS: Committee on Earth Observation Satellites
CEST: Central European Summer Time
CET: Central European Time = GMT+ 1h
CIR: Colour InfraRed (picture)
CLC: **C**ORINE-LandCover
CORINE *Coordination of Information on the Environment*
DEM: Digital Elevation Model
DSM: Digital Surface Model
DST: Daylight Saving Time
DTM : Digital Terrain Model
DWD: Deutscher Wetter Dienst (German Meteorological Service)

EOL: End Of Life
EOS: Earth Observation Sattelite
EROS: Earth Resources Observation and Science
ESA: European Space Agency
ETM: Enhanced Thematic Mapper
EU: European Union
EWP: **E**nergy and **W**ater **P**otsdam
ExWoSt: Experimenteller Wohnungs- und Städtebau (Experimental development for Housing and Settlement)
GMES Global Monitoring for Environment and Security
GLOVIS: Global Visualization Viewer
GV: Green Volume
GVZ/gvz: GrünVolumenZahl (Green Volume Number)
GWR: Geographically Weighted Regression
HH: High values clustered,
HL: High values surrounded by Low values clustered, then

HRSC: High Resolution Stereo Camera

I1-I6: Indicator 1-6
IPCC: Intergovernmental Panel on Climate Change
LH: Low values surrounded by High values clustered
LL: Low values clustered

MODIS: Moderate Resolution Imaging Spectroradiometer

NASA: National Aeronautics and Space Administration
OLR: Ordinary Least square Regression
OLS: Ordinary Least Square regression
pic picture
PIK: Potsdam Institute for Climate Impact Research
R^2: Regression coefficient of determination
StdDev: **St**an**d**ard **Dev**iation
TM: Thematic Mapper
VCID: Virtual Channel Identifier
VG/vg: VersieGelung (%) (share of soil sealing)

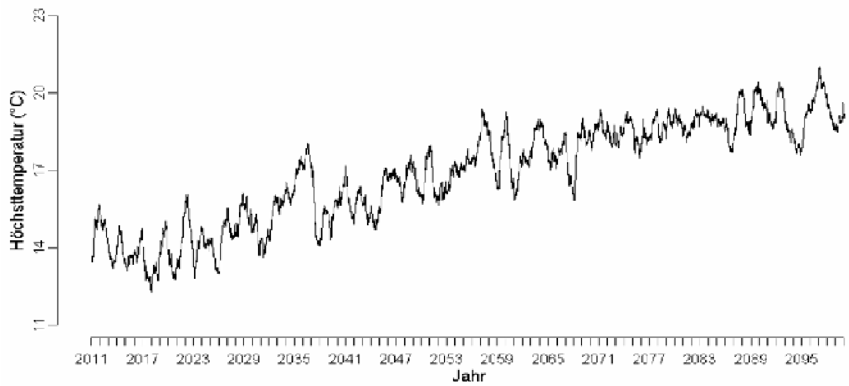
UcaHS: Urban climate and Heat Stress
UMTs: Urban Morphology Types
UN: United Nations
USGS: U.S. Geological Survey

1. Introduction and Definition

1.1 Introduction

The IPCC is indicating an rise of temperatures with an linear trend of 0.74°C [0.56 to 0.92°C] for 100-year-timespan 1906-2005 compared to 0.6°C for 1901-2000 [0.4 to 0.8°C]. Analyzing the last 50 years they see a linear warming trend from 1956 to 2005 of equivalent 1.3 °C [0.10 to 0.16°C] for a century (IPCC 2007_1, p30). Other sources and recent predictions go further, e.g.: An increase of the annual mean temperature across Europe between 2 and 5 °C, relative to the present-day climate, in combination with heat waves for the end of this century is predicted by the EEA-report on adaptation to climate change (EEA Report No 2/2012).

The PIK[1] is producing additional first results for Potsdam (see annex for further documentation of current research). Following a presentation of Mathias Lüdeke & Carsten Walther (PIK) on climate-adaptation strategies for Potsdam (13.05.2014[2]) some results for Potsdam were presented (Lüdeke and Walther, 2014):



Picture 2: expected temperature-development for Potsdam ("Jahr": year; "Höchsttemperatur": maximum temperature) - PIK (Lüdeke, Walther 2014)

1 Potsdam Institute for Climate Impact Research

2 Presentation: "Climate-trends for Potsdam: historical trends and climate-predictions" start up workshop climate-influences and vulnerability – Potsdam Institute for Climate research

- Mean temperatures are expected to rise in average till 2050 for about 2.5°C
- There will be more tropical – hot summer-nights and -days
- Extensive heat-periods will increase, will last longer and appear more often then today
- Years-precipitations will only slightly decrease
- But their pattern will change to less in Summer (dryer) and more in Winter (wetter)
- Extreme weather events will increase

The question beside activities to reduce climate change is how to adapt environments to the changing living conditions, specifically hot summer-days and –nights (e.g.: McCarthy et al., 2010, () Kiesel, Kristina et al. 2012). Especially for city-agglomerations it's a challenging question, only some guide-lines are established for yet[3], specifically few for the local level. Some samples reflecting the heat-stress-problems are given for Manchester (2008[4]) Berlin (in preparation from 2012[5]), Nürnberg (Nürnberg Stadt, Umweltamt, 2012), Dresden (2013[6]). The ExWoSt-project is presenting and collecting samples (Greiving Stefan et al., 2011). Vegetation is seen as one measure to support healthier living-environments buffering temperature-heights. Vegetation is often easy to implement – so to say a low-threshold action to support equalizing of temperatures and guarantee "balanced living-conditions". It's stabilizing living-conditions. If soil-sealing on the contrary is rising, as very often happens when agglomerations are growing, the risk increases that green is reduced and living-conditions are deteriorated.

As result of the Manchester - studies a reduction of 2.2 °C (1961-1990) to 2.5 °C (by the 2080th) is proposed if 10% green-volume is added. If 10% is subtracted an increase of 7-8.2°C (by the 2080th) is proposed (Gill et. al 2007).

For Potsdam (Germany) there are existing detailed data documenting quality and quantity of vegetation and other characteristics of land-use. Potsdam is covering about 140,000m² with almost 160,000 people living there in rising number.

In regard of defining effects of vegetation - "green" - on temperatures a valid and accepted indicator is green-volume or greenvolume (Großmann 1984, Whitford 2001,

3 Some collected inks on activities:: http://www.stadtklimalotse.net/english/ and Greiving Stefan et al., 2011()
4 Towards a Green Infrastructure Framework for Greater Manchester 1547.058 Final Report September 2008
5 DFG Research Unit 1736 "UcaHS": Urban climate and Heat Stress in mid-latitude cities in view of climate change: http://www.ucahs.org/index.php?page=over&lan=en
6 (REGKLAM-Partner, Dresden, 2013)

Kenneweg 2002, Arlt 2003, Gill et al 2007), even when data on green-volume are not widely access able, due to limited basic data-availability: DSM[7] including vegetation (Meinel, Hecht, Socher 2006; Hecht, Meinel, Buchroithner 2008).

Instead of green-volume (greenvolume) in some literature it's often spoken of greenspace[8] (Whitford et al 2001), green-infrastructure and green-cover(Gill et al 2007) and even green-canopy (beside urban canopy) as well (Rosenzweig et al., 2009). From the analytical point of view green-volume is a technical therm, indicating the space filled with green per ground-unit (Großmann 1984, Kenneweg 2002, Arlt 2003), when green-space and green-infrastructure is often addressing the more architectural and emotional part of green as well – this work won't concentrate on.

Potsdam in contrast to the general situation of limited availability of data deducing green volume is an exception. It is offering green-volume data even of different years (1992, 2004, 2010) in good quality – meaning relevant and good resolution. For the moment being, good resolution shall be defined as valid in regard of biotopes. Those biotope-, or in other words land-use-data are delivered as polygon-data reflecting real land-use-borders for which the green-volume was encountered as additional information beside biotope-value and surface-sealing. To allow a verification of the green-volume-data surface-sealing data was used as additional data-base related to the green-volume-information in a way that the existence of one factor – either green volume or surface-sealing – is limiting the respective other factor.

For Potsdam there are existing about 18275 biotopes (land-use-units) as pattern of about 5 m², as smallest indicated area, up to about more than 2 km² (lake-polygon), as largest part – founding on CIR-SAT data with a maximum resolution of about 0.5 m² (scale: 1:500 – 1:1,000[9] => see table annex and chapter 2 for further information).

Temperature is then the reference-parameter to be analysed.

The temperature to be related and be available should be the surface-temperature. It's beeing observed by many satellites as an mosaic covering all area in more or less high resolution (see chapter 2). Surface-temperatures are considered an appropriate indicator

7 DSM: Digital Surface Model to be substracted from DEM: Digital Elevation Model
8 As it is called in the ASCCUE-research 2007
9 Initially starting point for mapping for environmental data was a resolution of 1:10,000

for energy-exchange in urban areas (Wittford et al 2001, Gill et al 2007).

The scale of the back-ground data (biotopes, green-volume and surface-sealing) is initially the “mid-scale-range” of regional – local planning level (1:10.000) originating in service information for spatial- and landscape-planning. The mid-scale-data-background in Potsdam is exact in regard of land-use and vegetation-units up to at least 1:500. This meant to compare as high resolution temperature data as possible. Using low-resolution[10] data from satellites used for studies on national and continental level to show climate-impacts and change of land-use would be insufficient (=>EU / UN: Ms-Molina, MODIS -Land-change, CLC: CORINE-landcover, EUROSTAT, etc.), to understand local specifics and land-use-patterns.

Recent projects like geoland 2 (GMES)[11] with 1ha resolution followed the same track, as planned, documenting mid-scale data[12].

Temperature-information was finally deduced from Landsat-sensor[13] (surface-temperature).

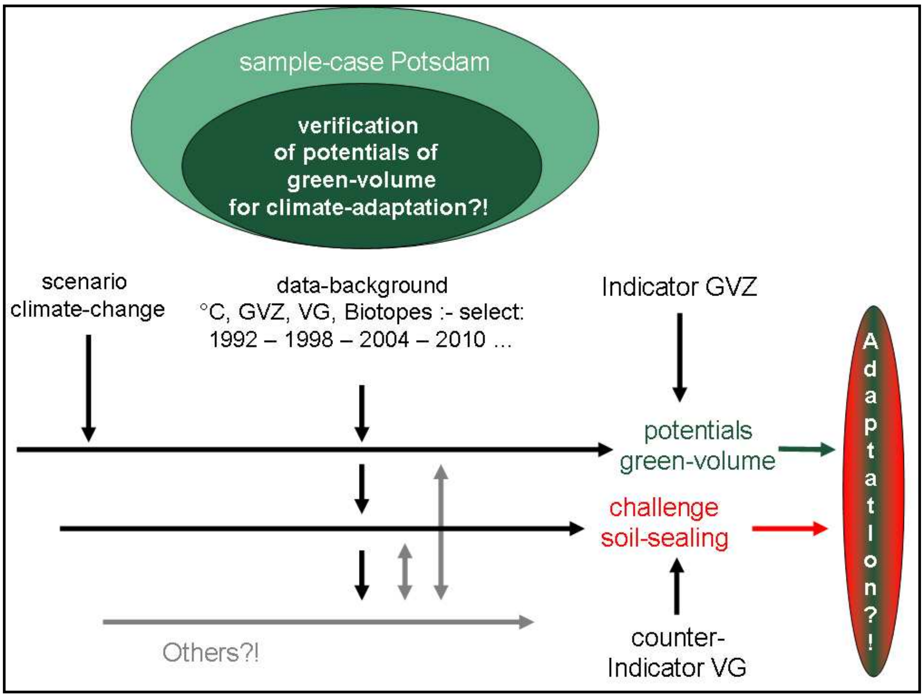
This was done to overcome problems like relying on a few or a single data-point, which needs to be used as starting point to calculate fully covering temperatures for a whole area. As long as temperatures are only measured at certain stations, data need to be extrapolated. Due to many influences on an model estimating temperatures there is a high risk of miss-calculating areas and so then to oversee special conditions (“reliability is only given at the measurement-point”, DWD- Behrens and Götschmann, 1993)

10 at least lower resolution

11 See e.g. http://www.d-gmes.de/sites/default/files/dokumente/geoland2-portfolio.pdf

12 Available from 2014

13 Originally it was planned to use the NASA-Satellite – Sensor – MODIS as part of the EOS-Programme allowing a resolution of about 250m² – finally decides to be not detailed enough ta address mid-scale-data



Picture 3: key idea of the theses putting green-volume in the centre of the research (GVZ for Green Volume Number, VG: for share of Soil Sealing

Using these data and especially green-volume-data and the Landsat-surface-temperatures it'll be tried to indicate differences focusing on climate-adaptation-potentials addressing temperature-stress or sensitive (reactive) conditions and temperature-constant, less reacting, less vulnerable environments through the following indicators:

- green-volume,
- surface sealing,
- biotopes (land-use),
- relation of the used parameters …

1.2 Definition in 5 steps

1:

The aim was, reflecting recent studies undertaken in Manchester (ASCCUE[14], (Gill et al., 2007), New York (Rosenzweig et al., 2009) and Berlin (2012f[15] and Meier, Fred, 2011), to verify the potential of vegetation to adapt to climate change and especially rising temperatures. Influences of green to buffer and in contrast soil-sealing to rise temperatures shall be analysed.

It's expected, that volume of green is the core-indicator for land-ecosystems to show

14 Adaptation Strategies for Climate Change in the Urban Environment undertaken in Greater Manchester which covers an area of approximately 1300 km²

15 DFG Research Unit 1736 "UcaHS": Urban climate and Heat Stress in mid-latitude cities in view of climate change: http://www.ucahs.org/index.php?page=over&lan=en

readiness to adapt environments to heat-stress-periods (the more green the more adaption)

It's expected, that soil-sealing is the core-indicator for land-ecosystems to show risk to adapt environments to heat-stress-periods (the more soil sealing the higher the risk of extensive heat-influences)

The sample of Potsdam shall reflect both effects and support further understanding of interactions.

2:

An other point was to present valid data to have good reasons to influence settlement-development for the future – especially in Potsdam - and reduce negative impacts due to climate change:

… the exposure and vulnerability of human and natural systems to climate change impacts is rising with an overall decrease in the number of cold days and nights (IPCC 2012).

If the change of green-patterns could influence such negative impacts - if it could be shown again - it would be a good argument to influence the spatial planning at least in Potsdam, to be more climate-change-adapted . Green-volume and soil-sealing could be established as accepted indicators for climate adaption-measures of local planning. They could guide the definition of healthier – temperature-buffered environments. Those aspects are regarded as crucial for future planning (Lenk, Thomas et al., 2008(), (Frommer, Birte and Schlipf, Sonja, 2008).

3:

If possible, the aim was then, to show different effects of green volume and soil sealing regarding local conditions represented with biotopes, local very specific land-use units (about 1,500 varieties). Green-volume- and soil-sealing-data are available for each biotope-unit. Those biotopes could assist finding additional influences, specific for a kind of land-use or spatial pattern, which influences temperatures as well. The findings shall assist using soil-sealing and green-volume-indications regarding different environments, when those indications are otherwise similar.

So Potsdam biotope-data-variety should be kept, to find indications for other temperature-influences as part of land-use-specifics, rather then summarizing their patterns directly.

4:

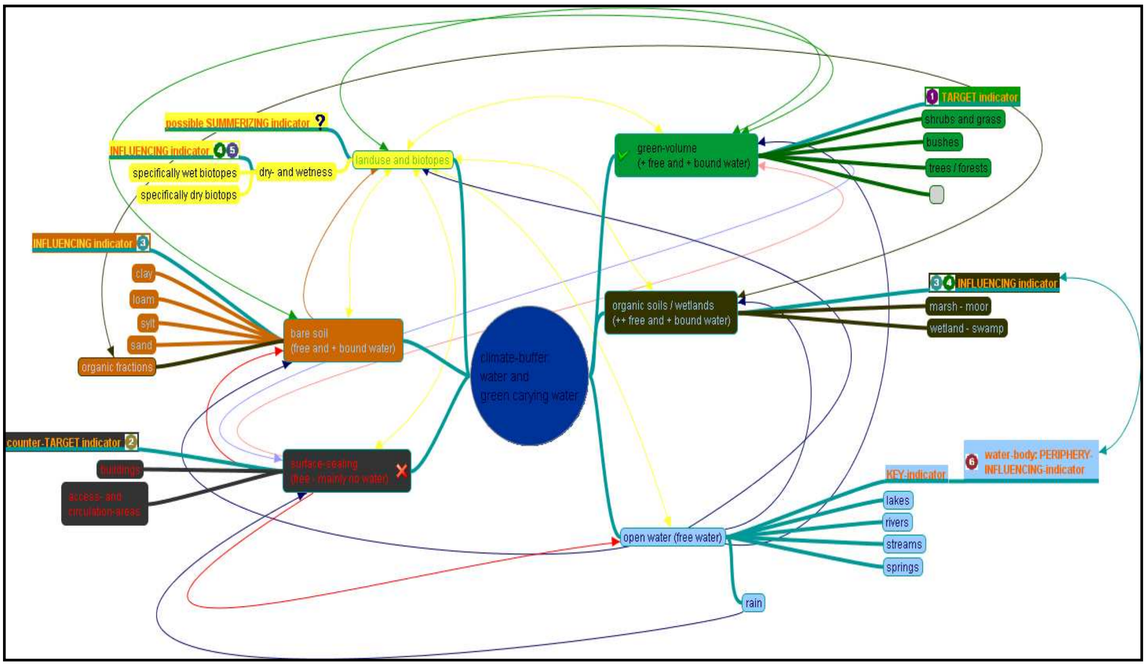
Some authors (e.g. Ripl and Ripl et.al. 1996, 2008, Hildmann 2002, 2013, Pokorny 2007) are committed to get the key-influence of water for the environment recognized and to opt for landuse-changes to have short-circled (and “closed”) water cycles. In the same moment they were showing the general cooling-effect of presence of water as well and defining it as essential for climate-adaptation. The effect could influence the focused correlation of green-volume, soil-sealing and surface-temperatures. Going through the available data it seemed possible to categorize and define those influences. This step was meant to support the understanding of environmental influences on temperatures detectable with the given data - if other influences could be detected - statistically significant (wetness and dryness).

The following mind-map is showing correlations which were in mind defining the later explained indicators 3-6. The mind-map distinguishes between free and bound water.

The effect of free-water to buffer surface heat was set as given, when on the other hand it was tried to define the influence of higher or lower water-contents of biotopes, soil and vegetation as such - on top of the green-volume and soil-sealing influences (I1-I2). After this research-widening step data and analysed target-indicators (green-volume and soil-sealing) should be presented.

5:

Summaries of biotope-types, addicted green-volume and soil-sealing values should be produced to find additions to other studies. Dealing with about 1500 biotope-types was different compared to research e.g. done in New York (Rosenzweig et al., 2009), Manchester with the UMT's[16] (Gill et. al 2007), more like in Dresden with the



Picture 4: mind-map trying to show linkages between different postulated indicators with water-related cooling-effects.

16 urban morphology types (UMTs) (LUC, 1993)

“FlächenMonitor”[17] and block-geometries (Meinel, Hecht, Socher 2006). Bigger and more complex landuse-units are difficult to be compared with other regions, national standards and research, as long as they don't share them. It was assumed that basic land-use units, as the biotopes could be matched better and compared with other researches, allowing different summaries of base-data. Still it's important to mention, that even biotopes in regard to be compared with other research-data, producing problems, due to the lack of comparable standards. But the code-structure is allowing simple summaries, which were planned to be used to compare results with the Manchester-study outcomes.

As outcome it's expected that, as e.g. found in Manchester (Withford et al 2001, Gill et al 2006[18]), Dresden 2006[19], Berlin 2011[20] New York 2009[21], the amount of green volume and soil-sealing is influencing the temperature, more specifically the local temperatures of environments. The same counts for “functional units” of land-use.

As mentioned under 3 and 4 the goal was finding additional impacts as well, specific for a kind of land-use or spatial pattern, which affect temperatures. This could lead to a better understanding of how far the first indicator green-volume and the second indicator soil-sealing are explaining temperature-varieties.

1.3 Key points

Since the development of temperatures is a quite complex issue many influences on temperatures won't be covered and discussed here.

- Not tackled here is e.g. the influence of relief (DEM / DSM) on temperature especially regarding cold-air-lakes, or exposition regarding infiltrating and buffering of solar-energy[22], etc..
- In the same direction, not covered here were settlement and housing-density: specifically not the space between buildings, resulting shade and possible cooling-effects, as well as construction materials[23].
- Missing too are temporary land-use-influences, like harvesting-time when e.g. grassland is, or is about to be cut. In regard of water-content bounded in the green – water bringing cooling - there is little information capable, leading to indicate reduced influences buffering temperatures: If e.g. grass tends to be dry, or is already harvested, it will still be mapped with high green-volume. High green-volume is supposed with “living green” and bound water (wetness) resulting in cooling. If it's dried the volume information is not adequate to indicate cooling any more.

17 Space monitoring: ATKIS / ALKIS – based => look for IÖR Dresden: http://www.ioer.de/1/ioer-overview/, G. Meinel
18 Compare as well the projects ASCCUE 2006, PLUREL2007
19 (REGKLAM-Partner, Dresden, 2013)
20 Meier 2011, (GEO-NET Umweltconsulting GmbH, 2011
21 (Rosenzweig et al., 2009)
22 Millward 2014 : Vegetation Placement for Summer Built Surface Temperature Moderation in an Urban Microclimate
23 having in mind: historical desert-settlements like e.g. Kasbahs - Morocco

Those additional influences were regarded as to complex and process-demanding to be included in the master-theses. The available material is allowing only limited indication for such influences. Still they would be of further interest to be investigated (e.g. DEM and DSM available for Potsdam addressing relief or soil-sealing-information differenced between construction and others available).

Starting the research the focus was on green-volume and soil sealing (in total). Green volume shall be as dense as looking at other demands is acceptable to allow maximum cooling-influence and adaptation to heat-stress. The ASCCUE – studies could be read like this.

Going through different publications tackling the issue, an other view was given, e.g. from ministry of traffic, building and urban development (Germany) published in a study on climate-fair - urban planning (Kuttler 2010), that on lawns and grassland there shall be only a few “large-crown” trees growing (… no woods / forests on free-lands). Reason was that the long-wave heat radiation shall not be hindered to emit at night (accepting possibly higher heating during day-time) (Kuttler 2010). Großmann (2012) is sensitizing in the same direction, presenting a climate and climate-change-scenario for Hamburg 2050. This will be a point for further studies and brief to be discussed at the end again.

In the following chapters it was tried, using the data-background of Potsdam, to:

- verify indicators influence on surface-temperatures:
- Green-volume
- soil-sealing both explained using biotopes (landuse-specifics)
- present additional influencing indicators, addressing:
- free and bound water

2. Sensors - data-background

2.1 Sensors Temperature-information

Reasons for used Sensors for temperature-data

The aim to use satellite-data was to get a full coverage of temperature-data to be related to the green-volume-, soil-sealing, land-use (biotopes) and later possible other data as part of the environmental monitoring of Potsdam. That meant to search for Summer-data where influence between temperature and vegetation is most likely high on one hand and close to the research-date of the pictures used for the land-use-classification and related indicators on the other hand. So temperature-information shall be gathered for the same moment the mapped environment was documented: the closer to the mapping-time, the better.

Doing the research on available and free-available data USGS (U.S. Geological Survey) offered reasonable sources to address the mid-scale monitoring-information of Potsdam as mentioned above. Several Sensors are offering surface-temperature-information suitable to be compared[24].

First in regard to generate temperature-data the MODIS-Sensor was recommended and focused. MODIS-data are offering an almost daily history, coverage and reasonable resolution. That seemed to be an advantage. The aim at the start was, to use temperature-data of the very same day as the data the green-volume and soil-sealing are based on. These are CIR-Satellite- and aerial images, as described beyond.

The MODIS-data in regard of resolution were not offering the expected target-resolution of 100m². MODIS-data carrying temperature-information are of a minimum-scale of 250m or less. The 100m² were already a compromise in regard of the much higher resolution of the green-volume, soil-sealing and land-use-data to be compared with the temperature-data. Also 1992-data were not available which were planned to be compared with the 1992 land-use-based data of Potsdam starting the evaluation of data for the following research. There were two options to follow:

- Find a sensor with higher resolution and the disadvantage of not being of the very same day as the land-use-data.
  This could produce misinterpretation due to change of land-use in regard of the time-gap between temperature and land-use data, especially if the land-use-data are of later dates. But it would offer a possibly better linkage between land-use-

24 esa updated 2014: Missions on surface temperatures – see graphic in annex – source: http://database.eohandbook.com/timeline/timeline.aspx?measurementCategoryID=14

data and temperature-data in terms of similar resolution.

- Keep the temperature-sensor and get less accurate data in relation to the land-use-data.
  This would lead to a loss of possible statistical dependencies between temperature and the land-use-classification due to generalisation (scale / resolution), but offer less miss-interpretation in regard of land-use-changes (data of same time).

The other sensor offered by the USGS was the in regard of temperature almost traditional Landsat-sensor. It offers a resolution of about 30x30m (resampled[25]) which is very suitable to be compared with the mid-scale-data available for Potsdam (reference-scale 1:10,000). After some research via the USGS Global Visualization Viewer “glovis”[26] there where found matching images for 1992, 2004 and 2010.

Mission Name (short)	**Launch Date**	**EOL[27] Date**	**Mission Status**	**Mission Instruments**
Landsat-5	01-Mar-84	31-Dec-12	active	TM
Landsat-7	15-Apr-99	01-Jan-17	active	ETM+
Terra	18-Dec-99	30-Sep-13	active	ASTER, MODIS
Aqua	04-May-02	30-Sep-13	active	AIRS, AMSU-A, MODIS

Table 1: sensors observed to be used to gain surface temperature-information[28] (st)

The above table is showing the available sensors. The Landsat-5 and -7 images were fitting looking at quality, cloud-cover and with very little disadvantage regarding time. As result option 1 was followed. Via Radiance both sensors were delivering surface-temperature-information.

Landsat Sensor-data for temperature

For the data-search was used[29]:

1. Global Visualization Viewer “glovis” (http://glovis.usgs.gov/) and the
2. earthexplorer (http://earthexplorer.usgs.gov/) [30]
3. direct order for missing images of 1992

25 USGS set the pixel size for all thermal data at 30 meters as of February 25, 2010: http://landsat.gsfc.nasa.gov/?p=1349 - original TM Band 6 was acquired at 120-meter resolution, ETM+ Band 6 is acquired at 60-meter resolution http://landsat.usgs.gov/band_designations_landsat_satellites.php
26 http://glovis.usgs.gov/ last called 15.06.2013
27 EOL: end-of-life
28 esa 2013: Missions on surface temperatures – see graphic in annex
29 The search was simplified by the very helpful documentation and tools of the USGS (U.S. Geological Survey). See: http://www.usgs.gov/ last checked 15.06.2014
30 Introduction see: USGS 2012 Earth Explorer help documentation or Northwest Pacific Region Environmental Cooperation Center, pp 1-13, 2011

For preprocessing and suitability-check the following data were searched and downloaded (GeoTIFF file formats – Band 6[31]) :

discovery-dates	**ID: product/path /row/date/...** [32]	**Product / Sensor**[33]	**Cloud Cover (CC) CCPotsdam (CCP)**[34] **Quality (Qlty)**[35]	**Pass**[36] **GMT / Potsdam (GMT+2)**[37]
157st day – 1992: 5th June 1992	LT41930241992157XXX02	L4-5 TM	CC: 10% CCP: 0% Qlty: 9	09:09:38 / 11:09:38
205th day – 1992: 23th July 1992	LT41930241992205XXX02	L4-5 TM	**CC: 40%** CCP: 2% Qlty: 9	09:11:10 / 11:11:10
221st day – 1992: 8th August 1992	LT41930241992221XXX02	L4-5 TM	CC: 20% CCP: 2% Qlty: 9	09:11:39 / 11:11:39
222nd day – 2004: 9th August 2004	LE71930232004222ASN01 LE71930242004222ASN01	ETM+ L1T	CC: 1% CCP: 0% Qlty: 9	09:51:21 / 11:51:21 09:51:45 / 11:51:45
110th day – 2010: 20th April 2010	LE71930242010110ASN00	ETM+ L1T	**CC: 44%** CCP: 5-10% Qlty: 9	09:55:09 / 11:55:09
190th day – 2010: 9th July 2010[38]	LE71930232010190ASN00 LE71930242010190ASN00[39]	ETM+ L1T	CC: 0% CCP: 0% Qlty: 9	09:54:46 / 11:54:46 09:55:10 / 11:55:10
222nd day – 2010: 10th August 2010	LE71930242010222ASN00	ETM+ L1T	CC: 39% CCP: 20% Qlty: 9	09:55:09 / 11:55:09

Table 2: downloaded Landsat-scenes

For 1992 there were no data for the north of Potsdam available[40], as could be ordered for 2004 and 2010. So due to availability-problems some areas couldn't be covered for all years observed. Still the downloaded data was suitable for further processing and to be compared with the indicator-data of land-use, soil-sealing and green-volume.

The images need further processing to be used as temperature-information. Processing requires different steps in regard of research date and especially sensors used (Landsat 4-5: TM; Landsat 7: ETM+).

31 2004 and 2010-data with two values: 1. B6_VCID_1 = band 6L (low gain) (ETM+); 2. B6_VCID_2 = band 6H (high gain) (ETM+) as standard for Landsat-products from 2000

32 code see annex chapter 2 for explanation

33 ETM+ L1T: Landsat 7: ETM: enhanced thematic mapper plus (ETM+),
L4-5 TM: Landsat 4 and 5 satellites carries both the multispectral scanner (MSS) and the thematic mapper (TM)
XXX = Data held by EROS, Receiving station unknown
ASN = Data held by EROS, Receiving station, Alice Springs, Australia
see also "dictionary": http://earthexplorer.usgs.gov/resources/helpdocs/dict/landsat_dictionary.html (last called 27.06.2013) https://lta.cr.usgs.gov/landsat_dictionary.html

34 Cloud cover for Potsdam was estimated visually

35 Qlty: from -1 to 9: 9 meaning no errors – excellent quality – a perfect scene

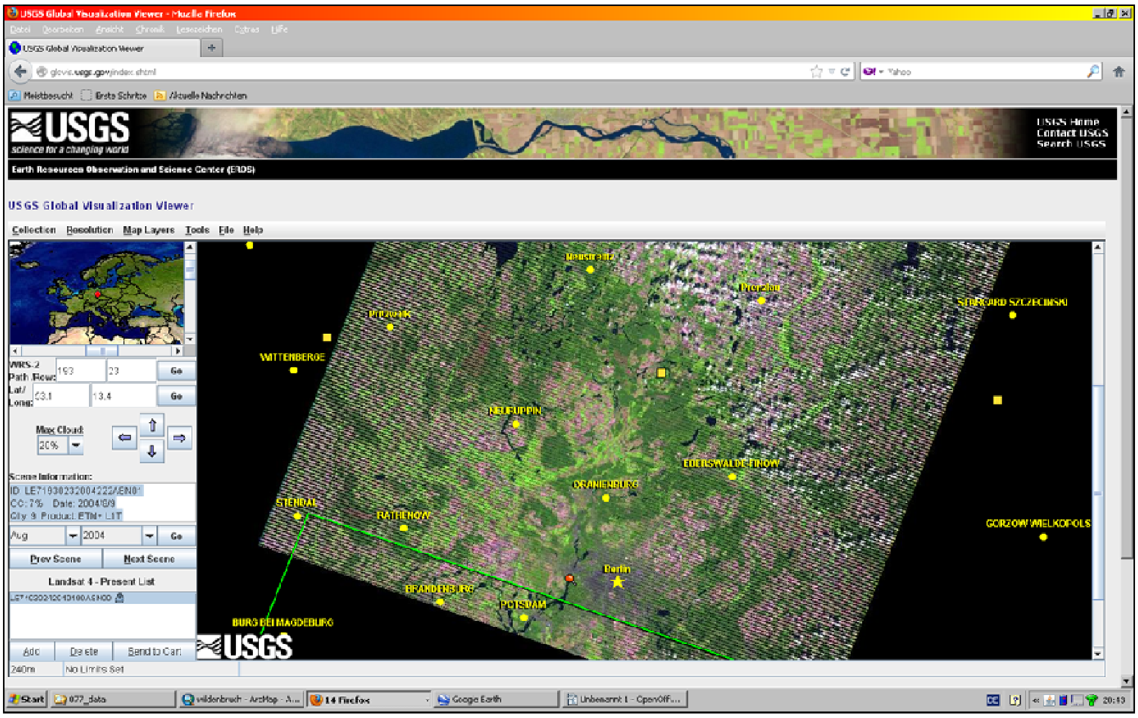
36 Center of scene

37 CEDT: Central European Daylight Saving Time or CEST: Central European Summer Time or DST Daylight Saving Time; CET: Central European Time = GMT+ 1h

38 Later First used dataset for detailed processing-steps – see chapter 3

39 Band 6 processed via VCID: Virtual Channel Identifier

40 Neither USGS nor ESA could make those data available! They wrote and turned down the request (2012 and beginning 2013)



Picture 5: Sample scene and of "glovis"-search-tool 24.06.2013 showing Potsdam on the South-edge

2.2 Sensors and data to address green-volume, soil-sealing, biotopes

It seems important to explain the Potsdam dataset-background to be able to rate the quality of input-materials, which is better than the average of usually available data of local governments or regional administration. The resolution of classifications and deepness of analysis is remarkable.

2.2.1 Sensors and basic datasets for land-use-data

For Potsdam there were data available from 1992 onwards in 6-year-steps, which are suitable and have been pre-processed[41] (CIR[42] towards land-use classification). They could be used and compared with temperature-data. Those remote-sensing-data, are based on :

1. 1992 -CIR-images - digitised airborne-pictures, resolution: 0.25 m
2. *1998 - CIR-images - digitised airborne-pictures* ***and*** *IRS satellite data, resol.: 5.8 m (both not used in the study due to the lack of full coverage of Potsdam and reliability)*
3. 2004 - QuickBird[43] satellite data, resolution: 0.6 m, reference - available surface sealing data - digital terrain model (DTM),

41 Not part of this theses: processed for city-administration of Potsdam from consulting LUP: Luftbild Umwelt Planung: see: http://www.lup-umwelt.de/en/kontakt/

42 CIR: **C**olour **I**nfra**R**ed: widely used image to map vegetation and vitality of green-cover: false-colour-image

43 Images offered by sattelite-image cooperation (US) http://www.satimagingcorp.com/satellite-sensors and Digital globe (EU): http://www.digitalglobe.com/about-us/content-collection#overview and technical details http://www.digitalglobe.com/sites/default/files/QuickBird-DS-QB-PROD.pdf – last 15.06.2014

4. 2006 DEM/DSM[44] from HRSC[45], resolution: 0.5 m (addressing specifically the surface-model to be built)[46]
5. 2010 – WorldView 2[47] satellite data, resolution: 0.5 m.
6. 2010 DEM/DSM[48] laser-scan-image 3pt/m² airborne-based, resolution 0.2 m [49]

The Sat-images were pre-processed in a way that they had been already sensor-corrected, calculated as radiance-value (W m^{-2} sr^{-1}) but without atmospheric correction. Then they were pass-point corrected. Due to the little relief-energy in Potsdam no hight-correction was applied. The CIR-airborne images were scanned and using histogram-correction mosicated (Tervooren, Frick 2010).

2.2.2 Land-use-data / indicators / generation of data

To gain soil-sealing and green-volume-data for the given years (1992, 2004, 2010) the same process was used altogether: regression-tree-modelling with CUBIST (Quinlan, 1993) and a hierarchical – decision-tree-modelling. Regression-tree-modelling being a tool of data-mining analysing complex and broad data-contents. Instead of an more or less simple linear regression-calculation, showing simple correlations, the regression-tree is able to identify corner-points and branches using a many times interacting model. An over-fitting can be avoided cutting back branches and through generalization[50] (Tervooren, Frick 2010 citing: Kearns, Mansour 1998, Quinlan 1993, Breimann 1984).

To support “first” results of environmental-monitoring information (surface-sealing, biotope-value and green-volume) different-sector-data had been used. Core-data were the biotope-mapping (land-use-classification) and the DEM/DSM.

To verify these information and possibly adjust values, cadastral data had been used (ATKIS, ALK, city-map[51]). The verification was again supported with other data, which were processed for local analysis (surface-sealing EWP: statistical data[52]).

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44 digital elevation model DEM, digital surface model: DSM

45 High Resolution Stereo Camera, of DLR – German air and aerospace agency: http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10364/548_read-400/#/gallery/657 (last called 10.06.2014) it was used air-borne as technical pre-check before the mission. One pre-check / test-area was Potsdam.

46 as result of difference between DEM/DSM

47 Images offered by sattelite-image cooperation (US) http://www.satimagingcorp.com/satellite-sensors and Digital globe (EU): http://www.digitalglobe.com/about-us/content-collection#overview and technical details: http://www.digitalglobe.com/sites/default/files/DG_WorldView2_DS_PROD.pdf – last 15.06.2014

48 DEM **D**igital **E**levation **M**odel / DSM **D**igital **S**urface **M**odel

49 DEM **D**igital **E**levation **M**odel / DSM **D**igital **S**urface **M**odel

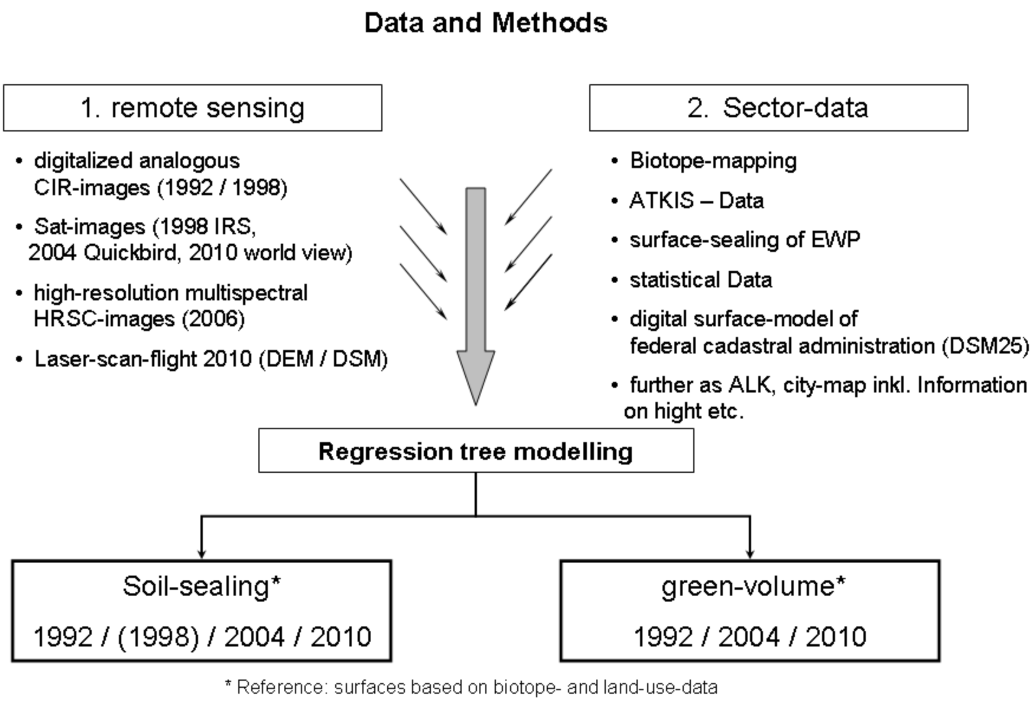
50 compare e.g. Kearns, Mansour 1998 or Quinlan 1993. For a more detailed explanation see Breiman et al. 1984

51 German - standard cadastral data here from “geobasis” Brandenbourg / ATKIS for topography and ALK (ALKIS) for propertie-borders etc. - see: http://www.geobasis-bb.de/GeoPortal1/produkte/aaa-allg.html only German – English (limited information): http://www.adv-online.de/Home/ and http://www.geodatenzentrum.de/isoinfo/iso_rahmen.iso_div?iso_menu=Produkt&iso_menu1=DEBKG00M00000081&iso_spr_id=1&iso_spr_web=2

52 Cadaster of local energy provider (**E**nergy and **W**ater **P**otsdam): holds detailed data of soil-sealing to account for water-run-off of properties (settlement)

The following picture is showing key-points of the process of producing soil-sealing and green-volume-data.

The fitting of the model was assessed using 10fold-cross-validation and independent test-areas. The correlation coefficient for soil-sealing reached 0.75 (for the 1998-model), more than 0.86 (for 1992) up to 0.96 (for 2004) and 0.99 for settlement-areas / 0.89 for landscape (for 2010), which was good or even very good. The average-errors laid



Picture 6: Used data and method to gain soil-sealing and green-volume data [1]

between 0.5-6 percent. To avoid mistakes due to different model-reports for all unchanged blocks the values of the best model were used.

For green-volume there were reached 0.89 (for 1992), 0.9 (for 2004) and 0.92 (for 2010) with average mistakes between 1.3 and 1.9, as very good. The 1998-results couldn't be used due to unsatisfying results regarding green-volume (Tervooren, Frick 2010).

2.2.3 Land-use-data / indicators / generated data

The following enumerations shall give an impression of the data-background used in this theses. The Indicators were later used as variables and generated from above explained sensors and other back-ground-data. Those data were ready processed when used for the research (values for each polygon available).

- **Indicator landuse-classification**[53] based on federal-states biotope-mapping standards (CIR)[54] and based on ATKIS-geometries [55] - method:

  1. visual on-screen mapping => and ,

     2. StdDev.[56] of original picture (Min, Max, Median)

     3. textures channels 1-4 multi-spectral / textures channels 1-4 sharpened,

     4. 20-class classification uncontrolled,

     5. 6-class classification controlled

  6. landuse-classes-validation

- **Indicator surface sealing** [%] - method:

  1. automated stepwise classification of remote sensing data (different sources).

  2. regression tree modelling, using classification results and various reference data sets.

  3. validation.

- **Indicator green-volume, density of vegetation** [m^3/m^2] – method:

  1. automated classification of multi-spectral data (SAT) to identify vegetation.

  2. height of identified vegetation, derived subtracting DTM / DSM

  3. calculation of green volume and 3D-reference values.

  4. regression tree modelling, remote sensing data and reference data.

  5. validation.

The above summarized information are part of every polygon and mapped biotope-unit. They're allowing statistical analysis. They didn't need further processing to be used when the land-sat-data needed further processing to be used and gain temperature-information (see following chapters).

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53 Not used here- but as standard-output available: Indicator biotope value of biotopes / land-use categories – method:
1. half-automated 1:1 definition of biotope-values.
2. Delphi-method definition of value-classes adapting German "Value-Standard" of (Kaule, 1991) => in 8 classes.
3. cross-check validation as visual check on plausibility and interview-feed back of different environmental experts, adaptation of results. ACCESS-data-bank coordinated validation

54 See annex: the there presented code (Alpha-code) is in regard of the mapped biotopes an 1:1 equivalent of the CIR-code which is a pure number-code

55 German - standard cadastral data here from "geobasis" Brandenbourg / ATKIS for topography - see: http://www.geobasis-bb.de/GeoPortal1/produkte/aaa-allg.html only German, English (limited information): http://www.adv-online.de/Home/ and http://www.geodatenzentrum.de/isoinfo/iso_rahmen.iso_div?iso_menu=Produkt&iso_menu1=DEBKG00M00000081&iso_spr_id=1&iso_spr_web=2

56 StdDev: **St**an**d**ard **Dev**iation here spectral differences later usually used in context of Residuals StdDev if not otherwise indicated!

3. Data processing

3.1. Data processing – preparation of source-data

The processing was done basically with Open-Office[57] and Microsoft-office[58] software-package, ARCGIS10[59]. Regression-analysis was then done with IBM-SPSS-STATISTICS Version 22[60] and initially open source PSPP-statistics (version 0.8.0-g693ac9) – all on a microsoft xp system. Few things were cross-checked with Linux OSGEO Live (version 6.0)[61].

They could be done with many other GIS- and statistic-software. The target ahead was to prepare data for statistical and GIS-analysis, to join the land-use-data with temperature-information to be extracted from the landsat-scenes.

Landsat-images:

The following downloaded scenes were used for processing (compare chapter 2: Table downloaded landsat-scenes - GEO-tif). The processing of the scenes was done to achieve good and fully covering regression results[62]. They were prepared for analysis with the following steps:

No.-set	processing: Date \	1. Convert DN to temp.	2. Extract Raster for Potsdam	3. Set no Data-values[63]	4. Zonal statist. table	5.Join Zonal statist. table - shp	6. initial regression	7. further regression
1	5th June 1992	X	X	X	X	X	Voted out	
2	23th July 1992	X	X	X	X	X	X	
3	8th August 1992	X	X	X	X			
4	9th August 2004	X	X	X	X	X	X	
5	20th April 2010	X	X	X	X	X	Voted out	
6	9th July 2010	X	X	X	X	X	X	X

Table 3: processing-steps Landsat-scenes with highlighted scene used for full analysis

1. processing step: Convert DN to temperature (*Raster-processing)*

For the given task of analysing the Landsat-temperature-information with the Potsdam-

57 Apache OpenOffice (http://www.openoffice.org) Copyright 2011, 2014 Apache Software version 4.1.0
58 Microsoft Windows XP Professional Version 5.1.2600 Service Pack 3 Build 2600 / Word Version11.0
59 ESRI ArcMap10.0 SP5, License ArcInfo Copyright © 1999-2010 ESRI
60 Local license for version 22.0 – GradPak IBM-cooperations and other's Copyright © 1999-2013
61 http://live.osgeo.org – September 2012 DVD-version
62 The 1992 – data were not covering the whole of Potsdam. Still they were initially processed to have an indication, if results were basically similar and one could expect similar results as processing the 2010-data finally used for all analysis. For results, see chapter 4.
63 For all pixel / mosaic with missing or missleading (e.g. effected by clouds) temperature-value

environmental-monitoring data the digital numbers of the images needed to be transferred to surface-temperature-information (most-likely in 3 steps):

I. Convert digital numbers (DN) to spectral radiance (L):

$L = LMIN + (LMAX-LMIN)*DN/255$ [64]

LMIN = DN of value 1

LMAX = DN of value 255[65]

II. convert L to temperature in Kelvin:

$T_B=K_2/\ln(K_1/L+1)$ [66] [67]

K_1 = Calibration Constant 1

K_2 = Calibration Constant 2

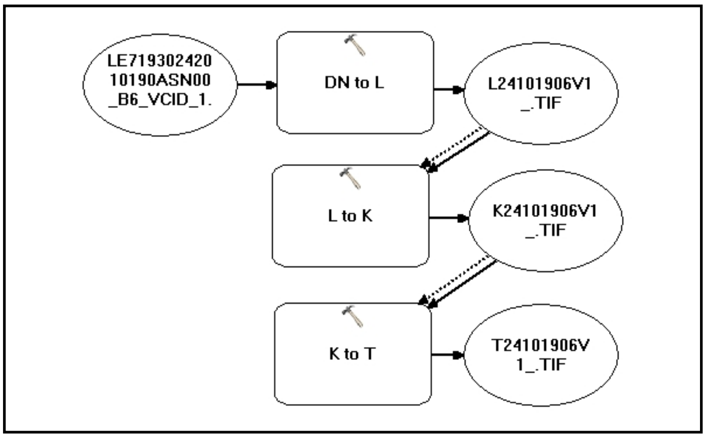
T_B = Surface-Temperature

	Landsat TM [68] / Landsat 5	**Landsat ETM [69] / Landsat 7**
K1:	607.76	666.09
K2:	1260.56	1282.71

III. convert temperature from K to temperature in °C:

$T_B = T_B -273$

- Out of the 2010 spectral bands an average of low and high gain-data70 was build for the further processed scenes.



*Picture 7: Steps converting initial landsat-image-information to temperature-information-image (incl. Image name: LE…) *.tif-format*

64 DN representing the pixel-value of the GEOTIF downloaded
65 USGS Frequently Asked Questions about the Landsat Missions 2013 http://landsat.usgs.gov/how_is_radiance_calculated.php – 28.06.2013
66 Logarithm for base "e" (meaning Eulers number: 2,7182818284590452…), same as natural logarithm: „ln"
67 The Emissivity as used in some literature (typically 0.95) wasn't used to further correct data. Due to that the aim wasn't to get highly correct temperature data, but to get temperature-data which show differences between each value in relation to Potsdams environmental monitoring.
68 Chander and Markham 2003, Table IV, page 2677
69 NASA 2013 – Landsat 7 handbook (pdf-download), Table 9.2 ETM+ Thermal Constants, page 101
70 2004 and 2010-data with two values: 1. B6_VCID_1 = band 6L (low gain) (ETM+); 2. B6_VCID_2 = band 6H (high gain) (ETM+) as standard for Landsat-products from 2000

The gaps of the ETM+ - data were left as “no data” areas[71]

4. processing step: Zonal statistic (*feature-raster-processing*)

All the raster-data-information were calculated regarding the land-use-units: every feature with an own ID was reference to calculate the mean[72] of “raster”-temperature-data for the respective area. After this for all unique ID's there was a temperature – value (mean surface-temperature) available to be compared with the other feature-information: 1:1 ...

5. processing step: Rejoin tables for zonal statistic with the land-use feature dataset

To analyse statistical patterns or significances the analytical outcome-tables were rejoined with the analysed datasets, to receive the full feature-data set-information.

All data (Landsat-scenes) of respective years mentioned above underwent the process up to this point (1992, 2004, 2010) to discover possible first hand unexpected[73] and expectable[74] values and as said above as preparation for possible further research was done. The regression results of cloudy scenes (6th processing step) e.g. were showing expectedly weak correlations, due to miss-leading (colder temperatures under clouds) and missing values.

3.2. Data processing – getting an overview

Visual overlay and discovery

To get a better understanding of the data-contents and expected relations (see chapter 1) some simple overlays of the data-sets were done. The main target was, to observe if temperature-information and

1. landuse (grouped biotopes),
2. green-volume,
3. soil-sealing,

had an obvious relation with the temperature-data, a spatial pattern.

After 5th preprocessing-step there was an average-temperature information (mean) available for every single polygon and as such with an own ID. This was the key point to analyse the data in regard of dependencies between green-volume, soil-sealing and as

71 The ETM-provided gap-masks were not used – no-data areas were identified without mask.

72 And all other statistical values provided with the Zonal Statistics as Table-tool from Arc-GIS10

73 like of the 1992-scenes when e.g. no data for the North of Potsdam results in regression-results with higher significance to be explained with other reasons rather then the landsat-scene-quality => here land-use-types – compare chapter 4!

74 like regression-results with little significance when e.g. high cloud-cover results in a lot of spreaded no-data-polygons and uncertain temperature-information.

planned in this stage regarding biotope-types to be compared with detected temperatures. Then an initial regeression (6th processing step: compare table 7 above), to indicate strength and weakness of the available data-sets, was done. As result forthcoming analyses were only done with the most suitable 2010-data (scene: LE71930232010190ASN00: 9th July 2010). Main reasons to use this scene were:

1. no disturbances (e.g. cloud-cover)
2. full coverage (compared e.g. to the 1992-data)
3. high-quality and reliability of indicator-data for the analysis (green-volume, soil-sealing)
4. best results after preprocessing and initial data analysis with regression

The core-processing started then as 7th step (compare table 7 above):
Two statistically regression-methods were used all through to detect dependencies and find explanatory influences of green volume and soil sealing on temperatures:

- OLR (OLS)[75] (processed with ESRI-ARC GIS or IBM-SPSS-STATISTICS)

followed by

- GWR[76] (processed with ESRI-ARC GIS)

As the aim of the work is to show the positive effects of green to buffer temperature or the negative effects of soil sealing, water[77] has been often excluded from regression, even when the effect of water to buffer temperatures is undisputed (see chapter 1). As water bodies are not showing vegetation or constructions (as soil sealing – the "counter-target indicator") the detection of temperature-influence and degrees of the effect of those could be miss-leading addressing the effects of green-volume, when including the water-bodies in the statistics. Green-volume buffers temperatures as water does as well (compare e.g.: Lang, Stefan et al., 2006, () Pokorný, Jan, 2010(), Clarc et al., 2010.).

The initial analysis was done with a somehow "a-spatial" analysis using OLR. Spatial influences were introduced only making use of Biotope-structures influencing the OLR-results. To finalize orientation on all-over-spatial distribution the standard-deviation-values (StdDev[78]) were grouped and detected (1st: no filter, 2nd: StdDev between -1.5 and 1.5 and 3rd: StdDev between -1.0 and 1.0). This was meant to find, indicate and understand possible influences on the the explanatory values in regard of temperature

75 OLS Ordinary Least Square, OLR Ordinary Least square Regression
76 GWR Geographically Weighted Regression
77 biotope-type-classes of water: 01 and 02
78 StdDev: **Stand**ard **Dev**iation and as such usually used in context of Residuals StdDev if not otherwise indicated!

and if already obvious land-use-classes (e.g. settlement, green-land or forests => results see chapter 4). The results of statistical significance of the processed data-filtering and structuring leaded to extracting data indicating influences of other factors. The biotope-code and available soil-mapping-information was used to detect those cases. It was tried to identify indicators (variables) characteristic for those cases: with higher standard-deviation (OLR). They were included in the analysis to detect other, then the primary focused factors (green-volume, soil-sealing). Focus was concentrated on dryness or wetness of structures: as far as information was available to indicate either further heating- or further cooling-effects adding to the cooling-effects of green-volume or heating-effects of surface-sealing.

So after detecting the explanatory value of green-volume (1st) and soil-sealing (2nd) on temperature – green-volume being the target-indicator of this thesis – further influencing indicators were included into the analysis, as long as OLR-processing was done – mainly to have the chance to address further influences of water rather then excluding it like done with the “free” water bodies on first hand. The general cooling-effect of the presence of water in the environments, essential for climate-adaptation, needed to be calculated. This was done with estimated indicators. The available data sugested the possiblity to categorize and define them with own indicators / variables (I3-I6 => see beyond and mind-map chapter 1). The step functioned as a review of the so far realized processing steps and to find an impression to present other influences on temperatures.

The main aim doing this, was 1st to recognize the specific share of green-volume affecting temperatures and 2nd to identify some possible further influences and their impact on temperatures and regression results regarding green-volume and soil-sealing.

The following indicators were used (OLR and GWR):

1. green-volume as introduced (m^3/m^2)
2. surface-sealing as introduced (%)

and further indicators[79] which were ranked on a scale representing their influence in an estimated way:

3. soil (organic and artificial influences - estimated weight: from “-100” to “+100”)
4. *organic soil [moor] (weight : included with weighting of indicators 3 and 5)*[80]
5. wetness or dryness of biotopes including artificial or cultivation-influences (estimated weight: from “-100” to “+100”)
6. water-periphery (estimated weight: “0” down to “-100”)

79 only OLR-processing!

80 The 4th point is marked “italic”, because it was processed only limited.

3.3. Data processing – details and data-specifications

Following the parameter-validations they are further explained. The common characteristic of the here now introduced indicators 3, 4 is that they are **not representing a specific time-period** – as green-volume, surface-sealing and correlated biotopes. Biotopes became recognized as indicator "I5" now: in form of wetness and dryness of biotopes. So Biotopes got a 2nd analytical-value beside the biotope code as such. So far they had only functioned to arrange Values of I1 and I2 to see spatial or statistical patterns.

The estimated ranking defines: "-" - values buffering temperatures, "+"-values heating influences. This was done on a scale minimum -100 to maximum 100.

Regarding 3.: soil (organic and artificial influences - estimated weight: from "-100" to "+100")

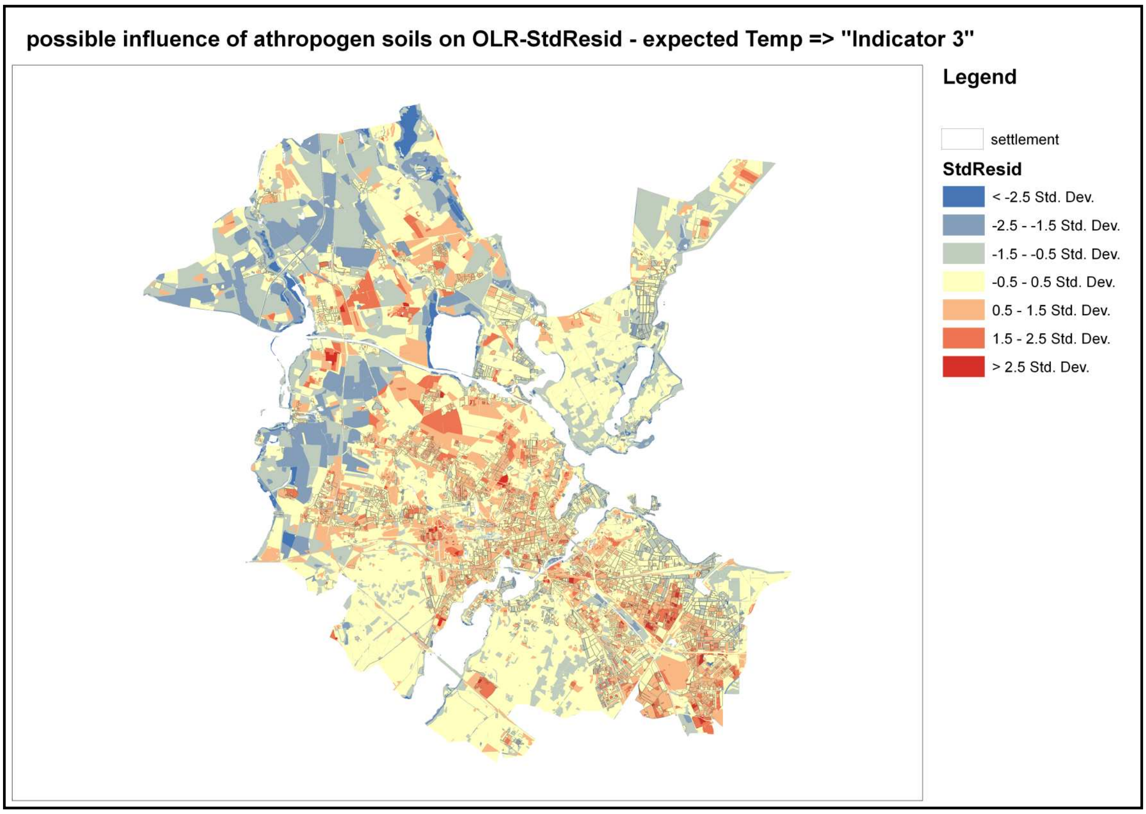
There is a soil-mapping available for the community of Potsdam[81]. As core-data it's informing about 4 types, which got a ranking in regard of their temperature-impacts:

main-type	value-classes
1. organic	-50
2. anthropogenic	50
3. mineral	0
4. (water)	(-100)

Free water is the most cooling medium, but was in fact left out calculating this processing-step to hinder cross-reliance with other indicators, specifically "I5". Most organic soils, as long as they're in natural condition are buffering temperatures as well[82]. To get this recognized they got negative values motivated from first OLR-processing (negative StdDev-residual-results). Reason to add a positive value for anthropogenic soils was, that first regression-results indicated positive StdDev-residual results, meaning higher temperatures in reality then expected. With organic soils, it was the other way around. To document the idea for the decision of the selection and further processing, the following picture is giving an impression (settlement-biotopes – here traffic network excluded – with black frame):

81 (Knothe/Geldmacher/Jacobi, 2002() compare: (Landeshauptstadt Potsdam, 2012.)

82 meaning with a high water content and not degenerated (Arge, 2010)(Trepel, Michael, 2008)



Picture 8: possible influences of ***anthropogenic*** *soils on temperatures: settlement-polygons with black frames*

Regarding 4.: organic soil [moor] (<u>weight : included with weighting of indicators 3 and 5</u>)

The available moor-information wasn't further processed but included with the indicator before (organic) and with the following one (see Biotope-code 04). Otherwise it would have resulted in a higher cross-reliance of indicators I3-I5 and redundant information[83].

Regarding 5.: wetness or dryness of biotopes including artificial or cultivation-influences (estimated weight: from "-100" to "+100")

The available biotope-code allows detailed linking between biotope-types and wetness or dryness of them (negative values indicating wetness, positive once dryness):

Biotope-code	Biotopes (groupes)	Factor – Value
01 / 02	water-body	-100
** * * tr *	Fallen dry	50
03 10 * * *	Vegetation-free / bare-soil	50
03 ** 1 * *	dry habitat	75
03 ** 3 * *	wet habitat	-25
04	Moor and Swamp	-50
05 ** 1 * * * *	Grass and shrubs-dry	25

[83] The 4th point is still mentioned here, because there were data present, which allowed a separated processing of the factor which was done once. Once to see if the concept of including them in the indication of I3 and I5 covered the influence (which succeeded – so it didn't needed to be used on it's own).

Biotope-code	Biotopes (groupes)	Factor – Value
05 ** 3 * * * *	Grass and shrubs-wet	-25
05 15/16	Intensive grass / pasture[84]	25
05 1 * * * *	dry	30
05 2 * * * *	moistures	20
05 3 * * * *	wet	10
06 10 1 * * *	heather-dry[85]	25
07 10 3 *	Wet woods (willows)[86]	-25
08	Wood and Forest	
08 1 * * * *	Car / fen-wood / meadows	-25
08 26 1 *	Cleared woodland / reforestation - dry	50
08 26 3 *	Cleared woodland / reforestation - wet	-25
08 28 1 *	Pioneer-forest - dry	25
08 28 3 *	Pioneer-forest - wet	-25
08 * * 6 * *	Wet chracteristic	-25
L/N/LN/NL * * 6 * *[87]	Forest wet chracteristic	-25
L7*	Black alder	-25

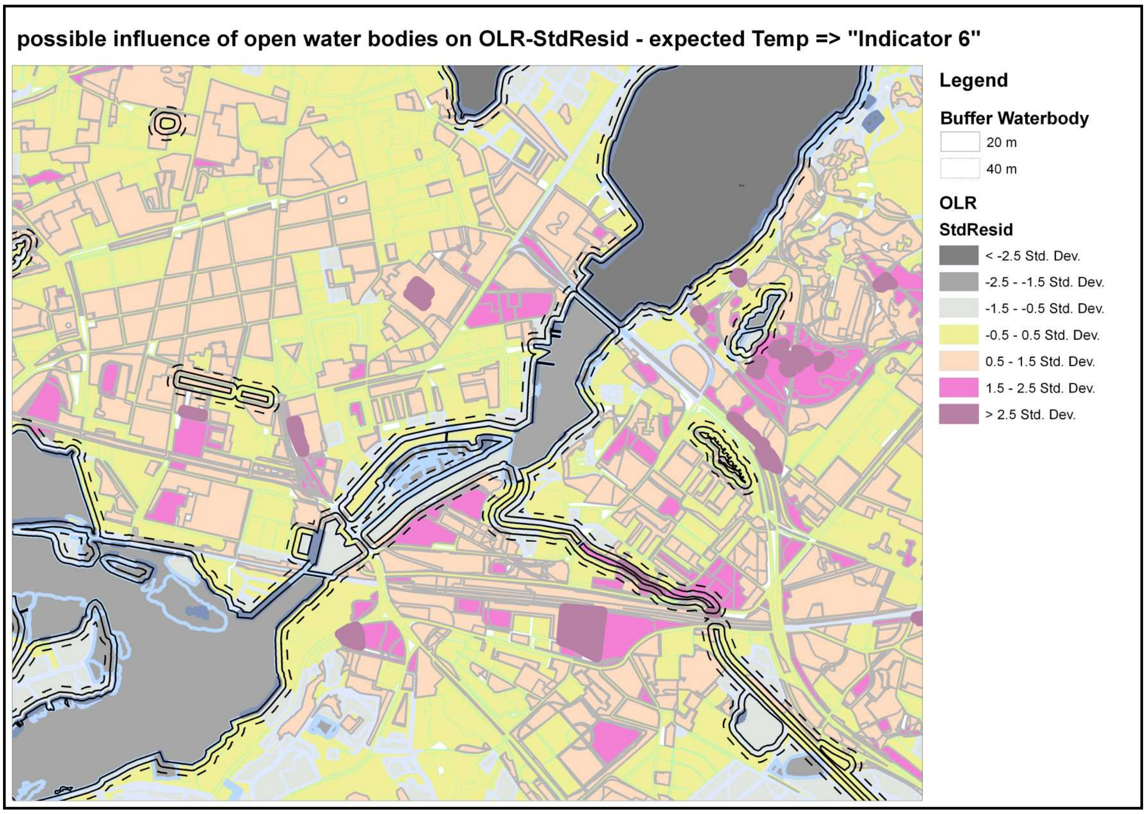
Table 4: estimated influence-ranking of biotopes on temperatures ("-" - values buffering temperatures, others heating influences

The biotopes offer a broader range of ranking then the other indicators, still beeing an estimate. Water-bodies as most cooling element are now included with the highest score of buffering heat (-100). They are not ranked as part of the other indicators to hinder cross-reliance.

Regarding 6.: water-periphery (estimated weight: "0" down to "-100")

As can be seen on the image below (after first regression-results), it seems that the influence of open water on expected temperatures (negative influence) is declining with decreasing distance from the water body (full black line to dotted black line and beyond). Most water-bodies are framed with black lines followed of a small striped line towards the land-side. Adding: the influence of some water bodies (e.g. pounds in parks[88]), they're in fact disturbing the picture regarding the used data. They can be expectedly linked to areas of low standard deviation (StdDev[89]) of residuals after OLR / OLS-processing[90]. Those will stay unrecognised within this study. In the same moment influences of water-bodies may not be that strong seeing the overlapping of yellow

84 Industrial land-use types where ranked as relatively warm spots, due to the visual comparison following the OLR-StdDev and due to the expectation that they show more open water-cycles with dryness on the soil-top.
85 Others e.g. wet (**3* *) not mapped in Potsdams territory
86 Others e.g. dry (**1* *) not part of coding
87 'L': leaf-tree, 'N': conifer
88 which are not mapped but which are known
89 StdDev: **St**an**d**ard **Dev**iation and as such usually used in context of Residuals StdDev if not otherwise indicated!
90 OLR as in the image or OLS used for Ordinary Least Squere-function: OLS Ordinary Least Square, OLR Ordinary Least square Regression



Picture 9: possible influences of open water bodies on temperatures of the surrounding indicated with StdDev of residuals: buffer 20m and 40m

towards pinkish colours in the lower right parts of the picture where a small river – the "Nuthe" (smaller river) is approaching the bigger Havel-waters (grey and white colours). It seems that other influences addressing the temperatures are stronger[91]. Still the possible influence was further detected and processed.

The following influence-weights were defined:

distance	**value-classes**
"0"m: water-bodies	*-100*[92]
0-20m:	-90
20-40m:	-45
>40m:	0

The distance of water-body-influences on buffering temperature was estimated using the landsat-temperature-data comparing it with the buffer-zones of certain distances around the waters [93].

91 The less explaining value of small especially linear structures (beyond 30 m: land-SAT-resulution) was later recognized and used.

92 Calculated only with indicator 5 (biotopes) and not as water-periphery-weight.

93 It was tried to use information from a profile-temperature-drive from 1993 of the German weather service (DWD, Behrens and Götschmann, 1993) to indicate water-body-influences. But there was only a little hint in the data to give further orientation on measuring possible influences.

Indicating statistical outliers (OLR)

The influence of above postulated indicators where not seen satisfying-explaining the indicator-temperature-correlation (see results chapter 4). So the dataset as such was analysed regarding less **the residuals** explaining data[94]. Outlier-detection was defined that beyond +/- 1.5 the StdDev (respective +/- 1 the StdDev) deviation of the residuals they were indicating **possible** model-miss-fits and outliers.

As introduction – more general steps - two datasets excluding **all data** with standard-deviation smaller and as small as -1.5 and lower and as high as 1.5, respectively -1 and 1 were processed. This step was done to indicate **possible spatial patterns** beside and in regard of mostly influenced land-use-patterns. A table of respective biotopes effected was produced. This step assisted to get a better view on less explaining data for the further processing.

The exclusion of datasets leading to an improvement of regression-results indicated structures and situations where other influences might be stronger then the examined once. ´**First then linear biotopes** like tracks, streets etc. which were almost all showing unusual high StdDev were excluded, together with the first unique values of Biotope-codes[95]. The further **indication of statistical outliers** was done with a procedure concentrating on land-use patterns (Biotope-codes) which showed higher StdDev[96], as follows:

1. homogeneous biotope-code with all cases StdDev beyond +/- 1.5 (and incl. linear biotopes)
2. homogeneous biotope-code with most cases StdDev beyond +/- 1.5 and mean beyond +/- 1.5
3. homogeneous biotope-code with mean beyond +/- 1 StdDev and range ≥ 4 (later sorted out – not used / unsatisfying)
4. Biotope-group code 05 (grass-land and meadows) and 09 (acres / farm-land) all single cases (polygons) StdDev beyond +/- 1.5.

Geographically weighted regression (GWR) and indicating statistical outliers with GWR

The influence of above postulated indicators where not fully satisfying / explaining (see results chapter 4). On the other hand the work with different land-use-classes (here biotopes) suggested already further influences and land-use-specific influences (variable / indicator 5, etc.). The clustering of data was a sign for this too (see chapter 4). So the

94 or in other words data with higher or lower standard-deviation (StdDev: **St**an**d**ard **Dev**iation and as such usually used in context of residuals - if not otherwise indicated!)

95 See chapter 4: Linear structures (10-15m) are often influenced by neighbour-structures, especially looking at the land-SAT-data-resolution of about 30m/30m at its best. This counts for smaller structures in general (only an little influence – filtering out polygons either ≤ 30, 45 and 60 m² was detected).

96 StdDev: **St**an**d**ard **Dev**iation and as such usually used in context of Residuals StdDev if not otherwise indicated!

dataset as such was analysed regarding less explaining data[97] with a technique, allowing the detection of specific spatial-related influences: geographically weighted regression - "GWR". GWR is increasingly used to address geographically motivated phenomena (Yu, Danlin and Wei, Yehua Dennis, 2004() (Matthews, Stephen A. and Yang, Tse-Chuan, 2012 () Bruna, Fernando a and Yu, Danlin b, 2013). It seemed that similar conditions of the used independent variables caused different response, provoking a model-miss-fit of the OLR-technique. (Matthews, Stephen A. and Yang, Tse-Chuan, 2012()p. 152, 2012) stating that: "*Spatial nonstationarity exists when the same stimulus provokes a different response in different parts of the study region. If nonstationarity exists then there is a suggestion that different processes are at work within the study region.*" Addressing such OLR is showing limits indicating these relations. They proceed, that "*Geographically Weighted Regression (GWR) is a statistical technique that allows variations in relationships between predictors and outcome variable over space to be measured within a single modeling framework*" (citing: Fotheringham, Brunsdon, and Charlton 2002; National Centre for Geocomputation 2009).

Then summarizing the technique as follows (Matthews, Stephen A. and Yang, Tse-Chuan, 2012() p. 153, 2012): "*Briefly, GWR extends OLS linear regression models by accounting for spatial structure and estimates a separate model and local parameter estimates for each geographic location in the data based on a 'local' subset of the data using a differential weighting scheme. The GWR model can be expressed as*[98]*:*

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{k} \beta_j(u_i, v_i)x_{ij} + \varepsilon_i$$

where y_i is the value of the outcome variable at the coordinate location i where (v_i, u_i) denotes the coordinates of i, β_0 and β_j represents the local estimated intercept and effect of variable j for location i, respectively". They then reformulate the "Tobler"-statement[99] (Tobler Waldo R., 1970, page 136) regarding GWR: "The locations near to i have a stronger influence in the estimation of β_j (u_i, v_i) then locations farther from i." (Matthews and Yang p. 153, 2012).

The formula given here reflects the ESRI-ARC-GIS used GWR model, used for the present analysis. GWR brought satisfying improvements to detect the relations between temperatures, green-volume and soil-sealing (see chapter 4).

97 or in other words data with higher or lower standard-deviation (StdDev)
98 Adaptive with Akaike Information Criterion (AIC)
99 "everything is related to everything else, but near things are more related then distant things'' (Tobler 1970).

During GWR-processing first StdDev of residuals beyond -1.5 and 1.5 were, similar to OLR-processing, excluded and then second StdDev of residuals beyond -1.0 and 1.0 excluded and further interpreted (same as with OLR-processing).

Summaries of processing-outcomes and comparison with other studies

In general and first results were summarized regarding land-use structures (biotopes). This was made possible by re-joining the regression-results with the processed data-sets so that the regression-results (OLR and GWR) could better be compared with the input-data in regard of the indicators or factors like green-volume and soil-sealing as well as with the biotope-structures and certain coding. Especially regarding the OLR-processing this lead to above explained outlier-detection which was transparent in the way that possible explanations through certain land-use patterns were possible, too.

As such it was tried joining statistical methods with possible reasons of ecosystem and land-use influences. Reasons were not present with the impacts of the independent variables (green-volume and soil-sealing) on the dependent variable (temperature).

To allow statistical comparison especially in regard of other studies (Manchester: ASCCUE 2007,Gill 2007; Dresden: Meinel 2006, 2010; New York: Rosenzweig et al., 2009) the data-sets were summarized alongside the biotope-code (only OLR):

- reduction of the biotope-code block to 4 digits (instead of 8-11 – depending on the Biotope-class) including mean of green-volume, soil-sealing and temperatures.
- reduction of the code block to 2 digits (the Biotope-class) including mean of green-volume, soil-sealing and temperatures.

The first reduction of the biotope-code was done to adapt the in other studies used land-use-classes with estimated and defined green-volume and soil-sealing.

This meant a reduction to a 10^{th} of the cases from about 1500 cases of the original-full code to about 150 and then 12 cases (Biotope-classes). In the same moment this meant a homogenization of independent and dependent variables of the statistical analysis being summarized (mean).

4. Findings and results

This chapter is giving an data-overview presenting results and first findings. It's chronologically presented following the processing-steps (compare chapter 3).

Temperature-control

The transformation of radiance-values of the Landsat-data to surface-temperatures was cross-checked with the available German Meteorological Service (DWD[100])-information (here for the 9th July 2010). The station in Potsdam offered temperature data (air and air directly at the soil-surface):

9th July 2010:							
DWD[101] 12:00 h		Polygon[102] 11:55 h	Landsat[103] 11:55 h (single mosaic 30x30m)[104]				
DWD air-temperature	DWD Air-temperature at soil-surface	Mean Temperature	North [105]-low	North - high	South [106]-low	South - high
37.3	31.9	29.0357	29.664	29.703	30.146	29.954

Table 5: comparision of temperature-informations: air, air above surface and surface

The calculated Landsat-temperatures seeming to be accurate and close to the real situation, measured from DWD. Keeping in mind, that specifically the measured air-temperature of the DWD above surface (a measured value for the full hour 12:00[107]) is very close to the calculated temperature via radiance of the landsat-scene (pass 11:55 h). The air-temperature at soil-surface is somehow mediating between air-temperature and surface-temperature. The mean-temperature was the further used temperature. The landsat-values are grid-values of 30X30 m -resolution. The mean-value is showing some influence of cooler neighbor-structures.

The measure-ground is a lawn-structure with no shade surrounded by forest-areas (see following picture 27th Nov. 2013, 12:28pm). There is a little north-facing slope bordering the measuring field, which can be identified looking at the rime (or tiny snow-spots) in the front of the picture (looking from the South to the North). The bordering bush-structures may be able to reduce temperatures of the environment a little bit.

100 DWD – German: **D**eutsche **W**etter**D**ienst 2013
101 delivered data of DWD: 11:00 "Wintertime" – CET: Central European Time = GMT+ 1h
102 Of biotope-/ land-use-unit meaning the average of grid-values (30X30m) Landsat-scene
103 2004 and 2010-data with two values: 1. B6_VCID_1 = band 6L (low gain) (ETM+); 2. B6_VCID_2 = band 6H (high gain) (ETM+) as standard for Landsat-products from 2000
104 Two Landsat-scenes: a northern and a southern scene, both covering Potsdam and being calculated
105 See 5
106 See 5
107 See 2

Picture 10: measure ground and station-equipment Potsdam – Telegrafenberg 27th Nov. 2013

The table beyond is giving an impression about the temperature-development of the respective day (DWD). It's showing the gradient of temperatures of an typical hot summer-day where the adaption of environments to keep air-temperatures low would benefit a lot to support well-being of inhabitants.

DWD 9th July 2010:					
GMT+2	Air-tempera-ture (AT)	AT above surface	GMT+2	AT	AT above surface
00:00:00	18.9	20.1	13:00:00	37.7	32.2
01:00:00	18.1	19.3	14:00:00	37.2	33.1
02:00:00	17.6	19.1	15:00:00	38.8	32.9
03:00:00	17.1	18.4	16:00:00	36.8	33.3
04:00:00	15.9	18.5	17:00:00	36.3	33.6
05:00:00	15.6	18.2	18:00:00	34.1	32.8
06:00:00	17.2	19.1	19:00:00	30.1	31.2
07:00:00	22.9	22.1	20:00:00	26.1	28.6
08:00:00	29.7	26	21:00:00	23.9	27
09:00:00	33.1	28.1	22:00:00	23.9	26
10:00:00	36.5	29.6	23:00:00	22.9	24.9
11:00:00	37.3	30.2	00:00:00	22.3	24.9
12:00:00	**37**	**31.9**	01:00:00	20	21.1

Table 6: temperature-development secular-station Potsdam

4.1 Introduction - Visual overlay and discovery

To get a better understanding of the data-contents and expected relations (see chapter 1) some simple overlays of the data-sets were done. The main target was to observe if temperature-information and green-volume, soil-sealing and landuse (grouped biotopes: main 12 land-use classes[108]) had an obvious relation or spatial pattern.

The following pictures are only meant to give an impression of results

Findings 1.: temperature-information and landuse (grouped biotopes)

The temperature-information is shown in color, the land-use-information in symbols.

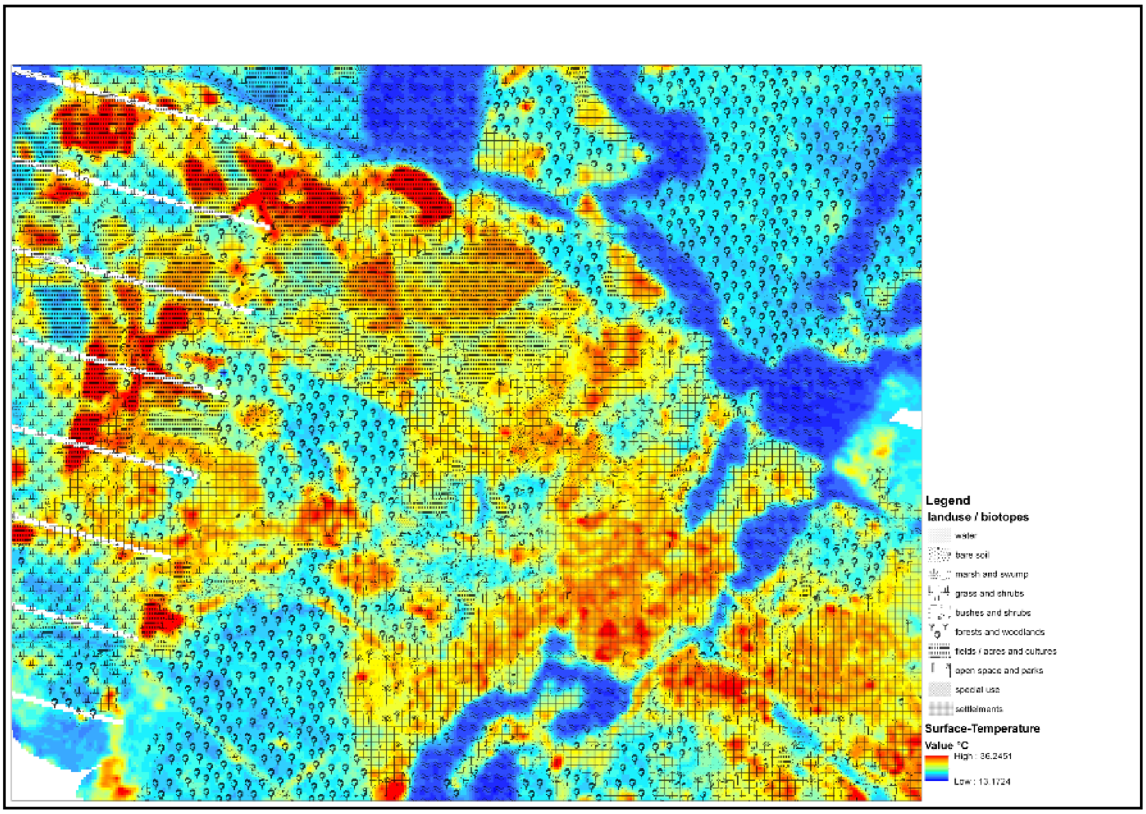
The surface-temperature - land-use overlay is in short showing the following:

1. water is the most cooling factor – most-preventing or buffering in regard of reaction-time heating of surfaces (dark-blue colors in picture) => starting with **15°C leading to about 22°C**
2. second are trees / forests (light-blue / turquoise) and marshes => about **22-24°C**
3. followed third by grass- and shrub-vegetation (still light-blue / turquoise) => about **22-25°C**
4. Then there are gardens and parks or mixed structures which form the switch from blue to yellow-orange colors of Temperature => **23-28°C**
5. and then are coming settlement areas **and** agriculture (acres) with orange to red colors => **27-36°C**

So there can be observed differences even between the land-eco-systems of more than 14°C, the types less heated characterized by higher vegetation-shares. Including water-bodies, the span is covering more than 20°C (23°C: 13.2-26.2) for the same moment in time.

Compared to the in regard of land-use-units further summarized temperature-data, the very low values of water-bodies (°C as pixel-value) can't be detected any more. The rest of the temperature-spectrum is still visible, even after summarizing the pixel-values of temperature to averages regarding land-use-units (biotopes as polygons). Main explanation is the area-size of the water-bodies (up to 2 km² for the biggest lake-polygon) resulting in a leveling of single values like with the about 14°C-lowest pixel-value (=> compare annex – chapter 4: Data-spectrum Biotope-classes and regression-processing with added values of biotope-class-separated OLR and GWR-processing).

108 Class/Group 1:Flowing water-bodies; Class/Group 2:Standing water-bodies; Class/Group 3:bare soil / brown fields; Class/Group 4:marshland swamp; Class/Group 5:grassland and meadows (incl. Argiculture); Class/Group 6:Hay + shrubs; Class/Group 7:bushes and woods; Class/Group 8:Forests; Class/Group 9:Acres – agriculture; Class/Group 10:parks and open spaces; Class/Group 11:special biotopes; Class/Group 12:settlements



Picture 11: overlay of temperature-data with landuse- / biotopeclasses (Potsdam Center-North, with visible white stripes for "no data" areas: left)

Findings 2.: temperature-information and green-volume

The temperature-green-volume sample is showing (green-volume in the map-picture beyond in green-stripes):

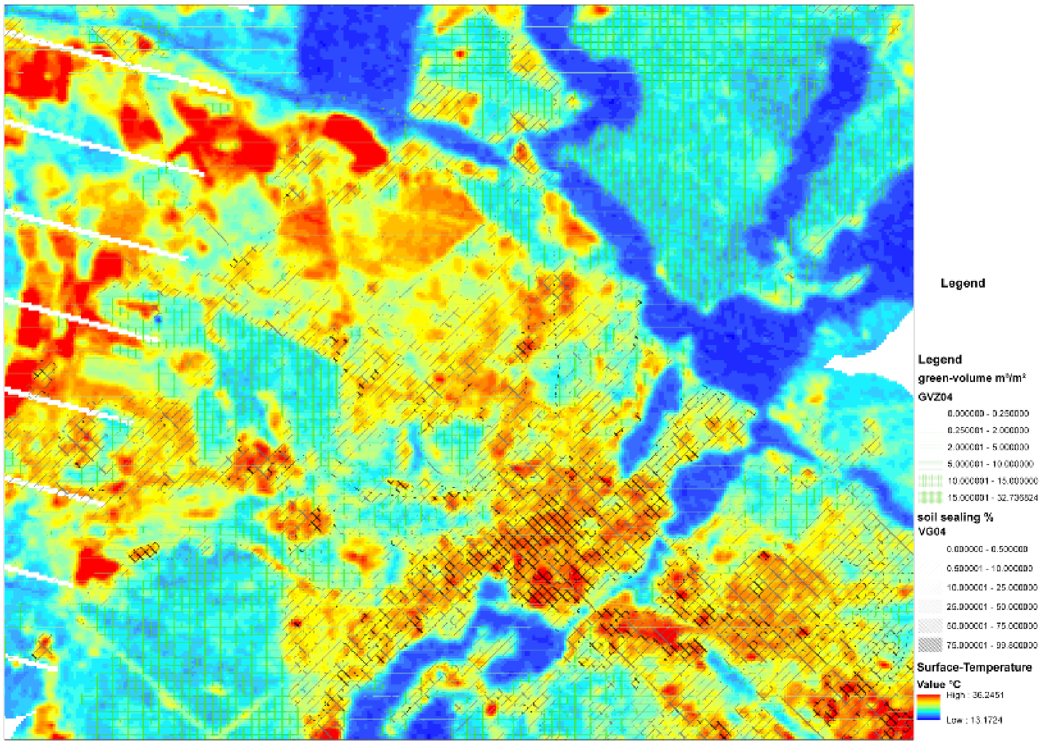
- the more green-volume the more cooling-effect
- true even in combination with soil-sealing

It seems green-volume makes a difference in regard of temperature of minimum about 12°C.

Findings 3.: temperature-information and soil-sealing

The temperature-soil-sealing case (soil-sealing in the map-picture beyond in black-grey-stripes):

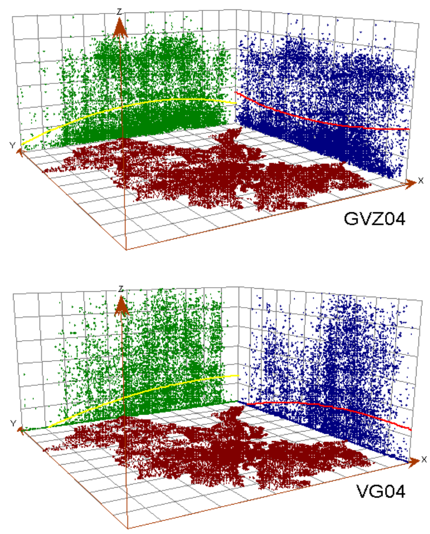
- the more soil-sealing the more heating-effect
- but not necessarily: not in combination with agrarian land (north on the map-sample)



Picture 12: overlay of temperature-data with green-volume and soil-sealing-classes (Potsdam Center-North, with visible white stripes for "no data" areas). The denser the stripes the higher the values (green for GVZ and black for VG)

To get a better picture detailed statistic is advised.

Before doing this, Potsdams spatial distribution of the key indicators shall be shown using in this case a sample of 2004-data, green volume (GVZ04) and soil sealing (VG04): The shape of Potsdam-territory is shown on the ground (brown) and the West-



Picture 13: green-volume (GVZ) and soil-sealing (VG) pattern for 2004 (04) – ARCGIS-graphic–

East spreading on top in green. The North-South spreading in blue can be seen on the right. Green-volume is almost equally distributed from North to South and rising from West almost to the East, when soil sealing is showing an increase from the West to the East and from the North to the South. The tiny hole on the GVZ04-graph in the middle from the North to the South can be explained with the city-center of Potsdam. Looking at the point-density of the GVZ-picture, diverging versus the graph, there is a variety, but with tinier pattern. Main settlement-areas are placed from the middle towards the South-East.

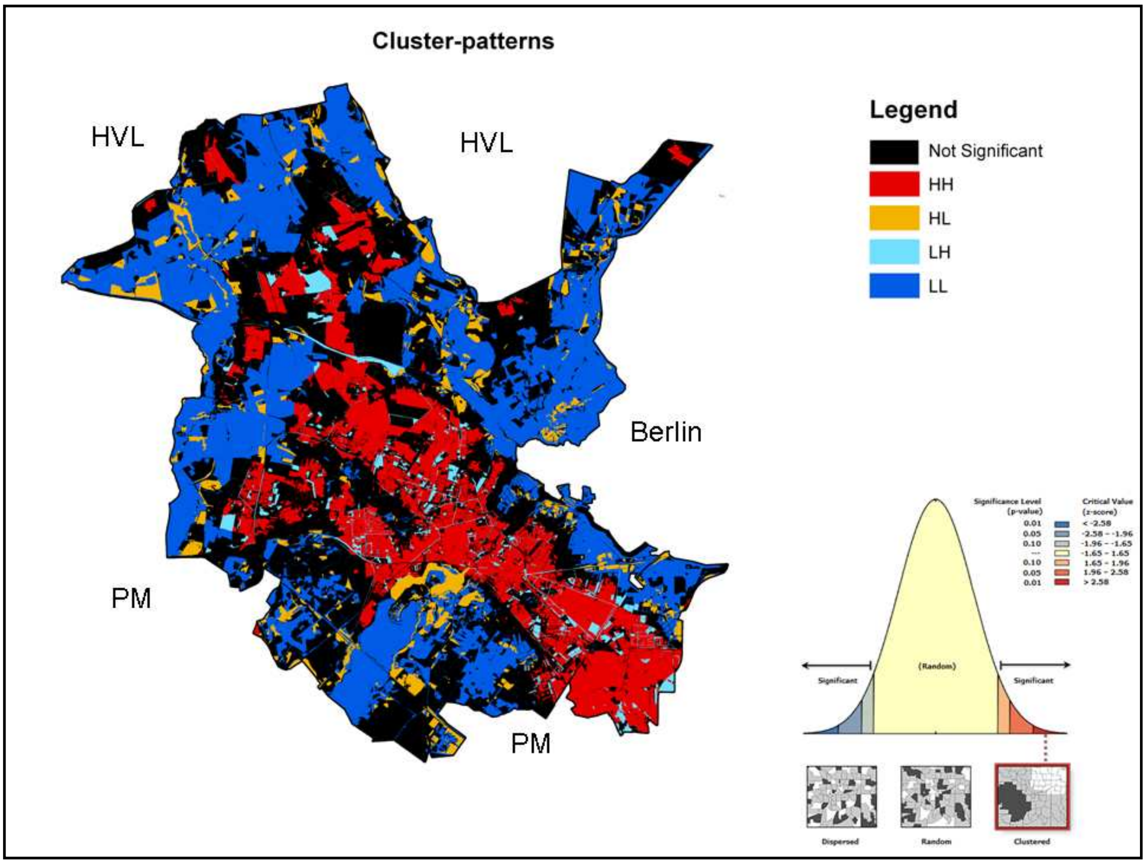
4.2 Statistics

After step 4 of the preprocessing[109] there is an average-temperature information (mean) available for every single polygon with an own ID including green-volume, soil-sealing values and biotope-codes. This is the key point to analyze the data in regard of dependencies between green-volume, soil-sealing and as planned at this stage regarding biotope-types (land-use-patterns). They were assisting to detected and understand unexpected temperatures.

As the aim of the work was to show the positive effects of green (green-volume: GVZ or GV) to buffer temperature or the negative effects of soil sealing (VG), water will be often excluded (biotope-type-groups of water: 01 and 02). Still the effect of water to buffer temperatures is undisputed. As water bodies are not showing relevant vegetation or constructions (soil sealing), the detection of temperature-influencing patterns and degrees of the effect of those could be spoiled when including the water-bodies in the statistics. Free water disturbs the visibility of effects of green-volume and soil-sealing on temperatures.

The next question to observe was about spatial relations of the processed data and data-background, regarding landuse / biotopes, green-volume and soil-sealing.

[109] (see chapter 3 pages 21-22)



Picture 14: Clustering of data (bordering communities: PM: Potsdam Mittelmark, HVL: Havelland)

The picture is showing different cluster-groups:

1. HH: High values clustered,
2. HL High values surrounded by Low values clustered, then
3. LH: Low values surrounded by High values clustered and
4. LL: Low values clustered

As long as they're significant: statistically significant (0.05 level). The local values of polygons are detected “clustered” with “Local Moran's I” (Getis 1992[110]). The “Local Moran's I”-tool was indicating for most of the data with more than 95% confidence:

- significance, z-score <-2, > 2 of Local Moran's I and as such clustering of values
- only 15918 data of 67756 are between -1 and 1 and so not significantly clustered
- The model is not random (compare annex for map Z-score – StdDev-values).

Many water-bodies and wet areas were indicating negative values. Surroundings of bigger streets were often indicating little confidence (meaning they were detected with no clustering). The land-use-patterns of Potsdam are clustered (keeping the resolution and test-area of Potsdam in mind). So the attached values of temperatures, green volume-values and soil-sealing are influenced and clustered as well. The large forest-plots (most LL), lakes and settlement-centers (HH) are each provoking specific

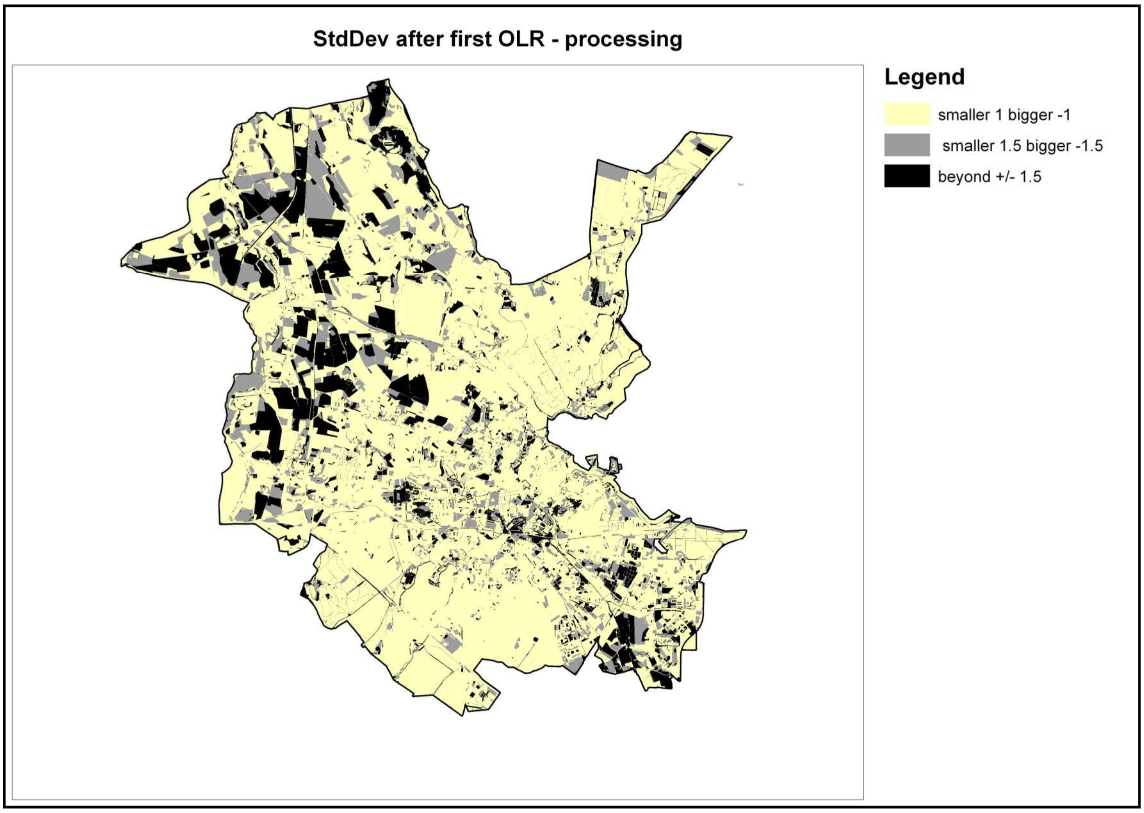
110 corner-points compare: http://help.arcgis.com/de/arcgisdesktop/10.0/help

conditions depending on e.g. soil sealing, green-volume and other factors, typical for the land-use-types and classes.

In regard of further steps the “LL”-situation of villa and family-home-settlements (middle-East) at the southern border to Berlin (all eastern parts) – possibly indicating more green and bordering water, needs to be remembered. Not to forget are the “LL”-areas in regard of always included bigger water-bodies almost in their centre. This may be indicating relief-influences as well (Northwest) here addressing low-land (depression). Spatial correlations were given – one reason not to only work with OLR but as well with GWR-models. The clustering is showing patterns, that suggest effects if a certain space is covered with similar structure. Then a more global influence in the respective direction can be expected (HH and LL from 1km²-1.5km² and bigger onwards).

To finalize orientation on over-all-spatial distribution the standard-deviation-values (standard deviation: StdDev[111]) of the residuals were grouped and regression-values (R^2 for R^2-adjusted) detected:

- all values (black) $R^2 = 0.42$ (incl. other colours)
- StdDev -1.5 – 1.5 (grey) $R^2 = 0.58$ (incl. light-yellow)
- StdDev -1.0 – 1.0 (light-yellow) $R^2 = 0.69$



Picture 15: standard-deviation – of the residuals - categorised in 3 groups: 1. “little” (-1 – 1), “medium” (-1.5 – 1.5) and bigger (smaller -1.5 and bigger 1.5)

111 StdDev: **St**an**d**ard **Dev**iation and as such usually used in context of Residuals StdDev if not otherwise indicated!

It can bee seen that:

- The higher deviation-values (larger patterns) are concentrated in the North-West and an other smaller spot in the South-East, which are often green-land and agriculture-areas – the very southern spots industry as well.
- Then there are smaller patterns in the centre which are settlement areas – typically more diversified. It seems that the water-bodies are not disturbing the picture.
- Then there can be indicated a lot of linear structures with higher StdDev (including water-bodies like the smaller river "Nuthe" a side branch of the Havel-catchment from the South-East towards the centre). Forest-areas like in the South-West and North-East are seeming more explanatory, disturbed only by some linear structures (here tracks).

The following explanations are possible, even when due to the lack of material[112] an uncertainty remains using green-volume data for a short moment of time (especially 1st point):

- In regard of agrarian land and the data-background it can be estimated that green-volume-data are not as reliable as in other areas, due to e.g. harvest-influences
- In settlement-areas a lot of artificial influences can disturb the used green-volume-estimates, e.g. watering, excessive cultivation
- Linear structures (10-15m) are often influenced by neighbor-structures, especially looking at the land-sat-data-resolution of about 30m/30m at its best. This counts for smaller structures in general (only an little influence – filtering out polygons either ≤ 30, 45 and 60 m² was detected and no significant change of regression-results achieved).
- The forest-green-volume-data should reach better results, due to that they are less estimated (as e.g. green-land). They are measured as outcome of DEM/DSM[113] - subtraction and less vulnerable about variations of short-time artificial influences (e.g. harvest).

During the following statistical analysis, using differing ways to indicate phenomena, those points need to be remembered and verified.

4.2 Key-points of the processing

To help to oversee the forthcoming results, key-values are shown to introduce the range of processed data. The results looking on statistical significance of the processed data (R^2 – water-bodies excluded if not indicated other-ways):

112 e.g. high resolution -pictures of the very same time as the used Land-Sat-data of July 2010 to detect e.g. cutting of grass or other harvest leading to the loss of green-volume. The green-volume-indication was based on data of the end of May 2010 – Landsat-temperature from 10th of July 2010 – see decision to use Landsat rather then MODIS chapter 2.

113 digital elevation model DEM, digital surface model: DSM

OLR-analysis	R^2 adjusted
1st	0.39-0.51 (results of all processed data from 1992 – 2010)
2nd	0.075-0.756 (regarding separated processing of biotope-classes[114])
After including other possible valid indicators	
3rd	0.526: including moor
4th	0.579: including moor, wetness of biotopes and water-periphery (indicators 3, 5, 6)
After excluding linear biotopes (significant heights regarding outliers)	
5th	0.596
After further outlier-detection in 3 steps	
6th	0.606 (water-bodies included)
7th	0.613 (water-bodies included)
8th	0.655 (water-bodies included)
9th	0.626 (water bodies excluded)
GWR-analysis (based only on green-volume and soil-sealing)	
10th	0.71 – 0.78 (total – full data-sets / 0.664 only GVZ)
11th	0.78 – 0.79 (water excluded / 0.858 only GVZ)
12th	0.914 (StdDev residuals beyond -1.5 and 1.5 excluded)
Then in regard of summarized data-sets (Biotope-code and only variables GVZ[115] and VG[116]	
13th	0.774 Biotope-Code (weights based on frequency)
14th	0.841 Biotope-Code reduced to 4 digits[117] (weights based on frequency)
15th	0.886 Biotope-Code reduced to 2 digits[118] (weights based on frequency)
16th	Summaries regarding green-volume and soil-sealing

Table 7: overview of processing steps and results

In general the data were significant. All P-values were smaller 0.0001 (if not mentioned otherwise). Green-volume is negative correlated to temperatures, soil-sealing positive.

4.3 Detailed analysis and results

4.3.1 ORL-processing and spatial data-structure

To remind on the selection of the data-sets (chapter 3) it's important to recognize, that the 1992-datasets are not covering the whole of the research area (Potsdam-administration). All data-sets in statistical regards are significant. Processing the datasets with IBM-SPSS the scatter-plot of the 2010 data in regard of different regression-models didn't show highly significant differences regarding linear, quadratic or exponential models. When e.g. the quadratic function is addressing low green-

114 See annex chapter 4
115 Green-volume-number an equivalent for green-mass in m³/m² - GVZ for German Grün Volumen Zahl in m³/m²
116 and soil-sealing VG for German Versiegelung in %
117 instead of 8-11 – depending on the Biotope-class. This meant a reduction to a 10th of the cases from around 1500 cases of the original-full code to about 150 => here including mean of green-volume, soil-sealing and temperatures
118 the Biotope-class: 12 cases => here including mean of green-volume, soil-sealing and temperatures

volume numbers (gvz10) slightly better than the linear, the difference is not as obvious in the high-volume-scale – especially taking out-breakers in mind[119]. The data-sets evaluated and presented at this stage are not yet cleaned of outbreakers! The details of processing-steps are presented using the key-points presented above (chap. 4.2).

1st 0.39-0.51 (results of all processed data from 1992 – 2010):

The table next page is showing the results in detail. The table is summarizing first regression-results before further detection of outliers and before concentrating the regression-analysis on one representative data-set with best pre-processing results (July 2010).

It can be seen that there is a high correlation between the core-indicators of the theses (green volume (here as "GV") and soil sealing (here as "VG") and a significant dependency of GV and VG explaining temperatures.

It's higher in the 2010 and 2004-datasets then in the 1992-datasets. A reason could be the more trustful data-background of these indicators[120]. An additional explanation could be the risen soil-sealing of Potsdam from 1992 to 2004 and 2010 in total[121]:

- **1.** 1992:9.2%, **2.** 2004:10.6%, **3.** 2010: 11.3 %

… together with a change in land-use-patterns. From 1992 towards 2004 a lot of new settlement-areas were built ("on green fields") – including tree-plantings, which spatially seen bringing the indicators (green volume and soil sealing) together, influencing each another immediate and explaining temperatures.

The April 2010-dataset indicates an expected result, that as soon as a widespread cloud-cover (44% and estimated 5-10% regarding Potsdam territory) is disturbing the quality of input-data (calculated temperature-values), the results are unreliable, even when the cloud-covered datasets are tried to be sorted out before regression-processing.

Even when the July 1992-dataset was producing good results, the dataset couldn't be used further, because, as mentioned already, it didn't cover the whole research-area. On the other hand it made a spatial pattern visible beforehand. It gave a first sign, that regression-results in the city-center-area were better than in the remote parts of the North of Potsdam.

119 this counted for later checks after the outbreaker-elimination as well
120 Unpublished report for Potsdam city-adminstration: further information: http://www.lup-umwelt.de/en/kontakt/
121 Keeping in mind that about 10% are water-surfaces without any soil-sealing or green-volume: Results not fully officially published study for Potsdam: Environmental monitoring Potsdam, Dec. 2010 :see: www.lup-umwelt.de / some results (German): http://vv.potsdam.de/vv/Umweltmonitoring_-_Flyer_Jan2014.pdf + http://www.ioer-monitor.de/fileadmin/Dokumente/Symposium_2010/TERVOOREN-FRICK_Umweltmonitoring-Potsdam.pdf + http://www.ioer.de/fileadmin/internet/IOER_schriften/Buch_IOER_Schriften_Band_52_Meinel.pdf

IBM / SPSS OLR[122]		**Correlations – regression**		
Landsat		Unstandardised Coefficients[123]		
Dataset		total R²-adjusted	Mean °C	GV (green-volume)
5th June 1992	Constant[124]	0.387	1	
	vg[125]		0.471	-0.397
	gv		-0.561	1
23th July 1992	Constant	0.507	1	
	vg		0.599	-0.394
	gv		-0.59	1
9th August 2004	Constant	0.465	1	
	vg		0.486	-0.429
	gv		-0.64	1
20th April 2010	Constant	0.114	1	
	vg		0.333	-0.469
	gv		-0.203	1
9th July 2010[126]	Constant	0.49	1	
	vg		0.507	-0.467
	gv		-0.663	1

Table 8: Regression-results of processed data-sets (Landsat-image-scenes) => constant for - surface-temperatures, vg for soil-sealing and gv for green-volume - Significance of the checked variables and correlation was always given: P<0.001: P-value / Sig. 1-tailed / Sig. F-change all calculated (IBM-SPSS / ARC_GIS ESRI): 0.000.

Here again: when green volume is showing a negative correlation towards Temperatures, soil sealing is showing a positive one. Both effects are partly compensating each another (=> further interpretation see 3rd and 4th beyond!). Regarding the OLR-models it was preliminary further worked with a linear model.

2nd 0.075-0.756 (regarding separated processing of biotope-classes[127])

The separate processing of biotope-classes was initially meant to detect land-use-correlations (in a simple way) and to get a deeper understanding of the data. Regarding GWR-processing a detailed discussion will follow later (10th step ff – presented results). Still the numbers for single GWR-processing are presented here, to see the different influences in respect of spatial values and correlations recognized or let out of the analytic:

122 OLR **O**rdinary **L**east square **R**egression / OLS ordinary least square
123 Pearson correlation
124 Gv : green-volume and vg: soil sealing towards mean-surface-temperature
125 VG/vg: soil sealing %, GV/gv: green-volume m³/m²
126 is a processed data-set representing the mean of the ETM-data-bands: 2004 and 2010-data with two values: 1. B6_VCID_1 = band 6L (low gain) (ETM+); 2. B6_VCID_2 = band 6H (high gain) (ETM+) as standard for Landsat-products from 2000
127 See annex chapter 4

Processed with ARC-GIS-Esri	Biotope-class	OLR[128]		GWR[129]	
		R^2-adjusted	rank	R^2-adjusted	rank
"All"[130]- land	total	0.49		0.779	
bare soil / brown fields	Group 3	0.215	5	0.403	4
marshland swamp	Group 4	0.23	4	0.365	8
grassland and meadows [131]	Group 5	0.149	8	0.397	5, 6
Hay + shrubs	Group 6	0.355	2	0.355	9
bushes and woods	Group 7	0.756	1	0.396	7
Forests	Group 8	0.194	6	0.440	3
Acres – agriculture	Group 9	0.075	9	0.235	10
parks and open spaces	Group 10	0.192	7	0.477	2
special biotopes	Group 11	0.038	10	0.397	5, 6
settlements	Group 12	0.353	3	0.537	1
	Group 12 – without traffic	0.347		0.477	
"All"-land	Without 11	0.491		0.761	
"All"-land	Without 9, 11	0.498		0.765	
"All"-land	Without 5, 9, 11	0.554		0.764	

Table 9: data-spectrum of separated processing of respective biotope-classes

Loosing band-width of the processed data when splitted in sub-groups weakens the over-all result of the regression – visible dependencies between green volume, soil sealing and surface-temperatures. The influences of outliers are rising.

It's difficult to explain the high correlation R^2-result for group 7 compared to the other results – e.g. of group 8. But during further processing regarding the group-8 results a lot of outliers were detected and are disturbing the otherwise strong correlation here (specifically tracks within the forests). The much more significant GWR-values of group 8 are indicating more explaining data. The Group 12 is generally indicating its relevance (OLR rank 3, GWR rank 1) which is in regard of possible measurements based on the study results (heat-adaptation with green) of high interest.

A summary of the StdDev-values of residuals in regard of biotope-classes is given in the annex. As additional information originating from a full dataset processed which can be compared with the OLR-results of the separate processing here.

OLR results could be positively influenced excluding the groups with poorest relations (5, 9, 11). The information was used to search specifically here for outliers and explanations of them not fitting with the estimates.

All groups with more spread structures and / or little frequency (fewer samples) provoking already as such less significant GWR-results most likely influenced by

128 OLR **O**rdinary **L**east square **R**egression
129 GWR geographically weighted regeression
130 Only water-bodies excluded
131 (incl. Argiculture)

missing correlation to neighbor-units (group 4, 6). Group 12 is suggesting the opposite effect, almost everywhere a lot of neighbors to compare with available[132]. The less explaining results of GWR and OLR regarding acres (group nine) seems to be an indicator for the difficult interpretation of this land-use type. A reason again could be the already mentioned harvest-influence.

3rd 0.526: including moor (indicators 4) and

4th 0.579: incl. moor, wetness of biotopes water-periphery (indicators 3, 5, 6)

As the indicators (3-6) were defined in an estimated way (see chapter 3) to represent the influence of the presence or absence of water, it was a good sign that the implementation showed improvement of the regression-model. The 3rd and 4th step of the processing are basically showing the influence of other factors (other independent variables) on the temperature (dependent). The 3rd step (introduction of one additional variable / indicator) only being a preparation for step 4. The check of results of single indicator 4 [moor] processing compared with indicators 3 and 5-processing indicated that indicator 4 (moor) was sufficiently covered with those.

The performance is shown in detail in the following table (IBM-SPSS-output) for 3rd R^2: 0.526:

Correlations (IBM-SPSS)		Temp. °C mean	moor	gvz10	vg10
Pearson Correlation	Temp. °C	1.000	.339	-.679	.480
	moor	.339	1.000	-.182	.314
	gvz10	-.679	-.182	1.000	-.471
	vg10	.480	.314	-.471	1.000
Sig. (1-tailed) / Sig.F-change	0.000 always 0.000 always for whole model				
N	66260		Std. Error of the Estimate		1.75

Table 10: Correlations between each of the independent variables (vg10: soil sealing 2010and gvz 2010 for green volume 2010), moor: for indication of wetness of organic soils and others[133]

Adding another variable as moor[134] adds positive to the overall model-fit. The correlations between the variables is indicating some cross-correlations which was accepted due to that the aim was indicating valid variables (indicators) contributing to the explanation of surface-temperatures and indicating influences rather then gaining for a specifically statistically optimized model. Still the cross-correlations were not that strong. As shown later, the influence of green-volume on temperatures is relevantly higher than of soil sealing and moor.

132 for the effect see e.g. pp 10f, Gang Cheng 2011
133 See chapter 3 on indicator 4 – later transferred to indicator 3 and 5
134 moor: processed only at this stage – later transferred to indicator 3 and 5 - see chapter 3

Result OLR (ESRI-ARCGIS) for 4th R^2: 0.579:

When adding other variables the explanatory part could be risen – but not in a way to improve the over all model-fitting to focus on those in general. Results and dependencies between the main variables (dependent and independent: indicators 1-2) and between other variables (indicators 3-6) will be presented with the following processing steps, representing the influences sufficiently.

5th - 9th outlier-detection

The next steps, from 5th - 9th, are concentrating on outlier-detection via biotope-codes. The aim was to find reasons (e.g. through land-management-specifics, sizes, …) to exclude certain polygons and regression-results with a higher standard-deviation of the residuals (StdDev). It was tried to **detect** them **via the biotope-codes**, due to that it was expected that certain land-use-specifics are indicating possible influences for a miss-fit beside the statistical indication. Those could be understood then in an eco-systematic context.

Before the outlier-detection a short reminder on presented numbers regarding StdDev:

- **negative Values** are indicating an **overestimation** of values (measured values / temperatures are lower than the estimated once regarding the use of independent variables)
- **positive values** are indicating an **underestimation** of values (measured values / temperatures are higher than the estimated once regarding the use of independent variables)
- **beyond +/- 1.5 StdDev** (respective +/- 1 the StdDev) of the residuals, they were seen as significant in regard of **possible model-miss-fit**s and outliers.

5th 0.596 After excluding linear biotopes (significant height regarding outliers)

The exclusion brought a small Regression-strengthening (R^2-adjusted) result of almost 0.02. Detecting specific outliers it was obvious, that linear biotopes caused a weakening of the explaining part (see picture on standard deviation-categories – above and beyond after the 9th processing-step). As written above linear structures (of 10-15m width or less) are often influenced by neighbor-structures especially looking at the land-sat-data-resolution of about 30m/30m at its best. So the processed temperatures (mean per polygon) are of higher risk to be miss-calculated when not including full landsat-pixels and / or small fractions of pixels dominated from other land-use-influences rather then the linear biotope. Many of the linear structures were showing significant higher standard-deviation (positive or negative) and as such excluded as outliers (for biotopes see: table annex chapter 4 together with 6th processing step beyond).

In the same moment explaining variables: green-volume and soil-sealing data, tend to be miss-interpreted, looking e.g. at trees covering a street where soil sealing-information could be easy underestimated, resulting in a less fitting model. Or in cases where the green-volume is covering high soil-sealing, it won't necessarily be reflected with higher temperature data as the soil sealing suggests[135]. The landsat-data-input is as such delivering inaccurate temperature-information for many linear biotopes. A more specific example about dependence of neighbor-biotopes: an alley is influencing e.g. a street (with almost 100% soil -sealing) and neighboring biotopes (e.g. forests), leaving the street unexpectedly cool. The other way around: when a street is covered with green but alongside hot – sealed settlement-structures (e.g. industry), it will be detected unexpectedly hot.

After outlier-detection in 3 further steps

6th 0.606 (water-bodies included)
7th 0.613 (water-bodies included)
8th 0.655 (water-bodies included)

6th 0.606 (water-bodies included)

Exclusion of homogeneous biotope-code with all cases of the codex standard deviation (StdDev[136]) of the residuals beyond +/- 1.5: The following main structures and biotopes were sorted out – 130 codes all-together with the 5th processing-step:

- 5th linear biotopes like streets, tracks ...
- other: small water-bodies
- bare soils or grass-land with initial growth of encroaching woods which could have cooled down the environment already but having not detected as expected green-volume for such cooling.
- fallen idle grass-land under ruderal vegetation (cooler then expected).
- intensive grassland incl. new planted grassland (hotter then expected)
- grassland with cultivation influences through e.g. harvesting?
- artificial influences like in parks and under military use, where temporary influences of e.g. cuttings, watering could have influenced the results – leaving a question-mark still.
- new plantings.

7th 0.613 (water-bodies included)

Exclusion of homogeneous biotope-codes with most cases StdDev beyond +/- 1.5 and mean beyond +/- 1.5: The main following structures and biotopes were sorted out (31 codes all-together):

135 This counts even more, due to that the soil-sealing values for linear structures like streets were to a high degree calculated based on topographic-cadaster data and not through the usual indication via-Sat-images due to that those were limited in the same way as the landsat-images to produce the soil-sealing information in this case, e.g. streets covered with green.

136 StdDev: **St**an**d**ard **Dev**iation and as such usually used in context of Residuals StdDev if not otherwise indicated!

- Pounds,(positive StdDev) due to may be heating-effects of the environment.
- again encroaching wood / vegetation on bare soil or grassland (negative StdDev – cooler then expected)
- again grassland and intensive acres – arable land (hotter then model-expected)
- a- / reforestation (cooler then expected) may be due to already effective green
- sport-grounds and distance-green space (hotter then expected) – most likely due to intensive green-care and for the last influence of neighbor biotopes (e.g. hot streets)
- (Dense) settlements may be due to effects of exposition and resulting cooling or heating of buildings and environment (both directions).
- Modern city-centre (hotter then expected)
- castles (cooler then expected) may be due to good embedding with vegetation or watering or an other aspects like exposition and design.

It's important to highlight the conditions of intensive agriculture (arable land, acres, grassland) which leads to an exclusion of those datasets. The hotness of the structures is a most-likely sign for unsustainable conditions (absence of bound water).

The indication of homogeneous biotope-codes with mean beyond +/- 1 standard deviation (StdDev[137]) of the residuals and **range** ≥ 4, originally planned as next processing step, **didn't lead no significant improvements** of the model and wasn't used. [138]

After 8th 0.655 (water-bodies included) / 9th 0.626 (water bodies excluded)

8th 0.655 (water-bodies included):

Exclusion of Biotope-group code “05” (grass-land and meadows) and “09” (acres / farm-land / arable land). **All single cases** (polygons) StdDev beyond +/- 1.5.

Since grass-land and acres were still causing many cases with outliers most likely due to cultivation and other artificial influences, difficult to detect, the step of excluding affected data-sets was gone to optimize regression-results. The rise from 7th: 0.613 to 8th: 0.655 was showing most effective results of all processing-steps. It can be, to some extend, “justified” with ecosystem-related arguments then only with statistical processes.

137 See 137

138 The big range of residuals within one biotope-code seemed not to be an indication as such. Green-volume and soil-sealing seeming to be a stronger influences and could, doing further research, deliver an answer for poor improvement of the model in detail, which wasn't focused any more.

9th 0.626 (water bodies excluded):

The less good OLR-results (0.626 compared to 0.655) processing excluding water bodies contrary to results, achieved before outlier-detection and introduction of further variables, showed the effect of the newly implemented variables (3-6). Water-bodies are as good addressed and explained with the indicators that the regression is more optimized then water-bodies would be still weakening the regression-results.

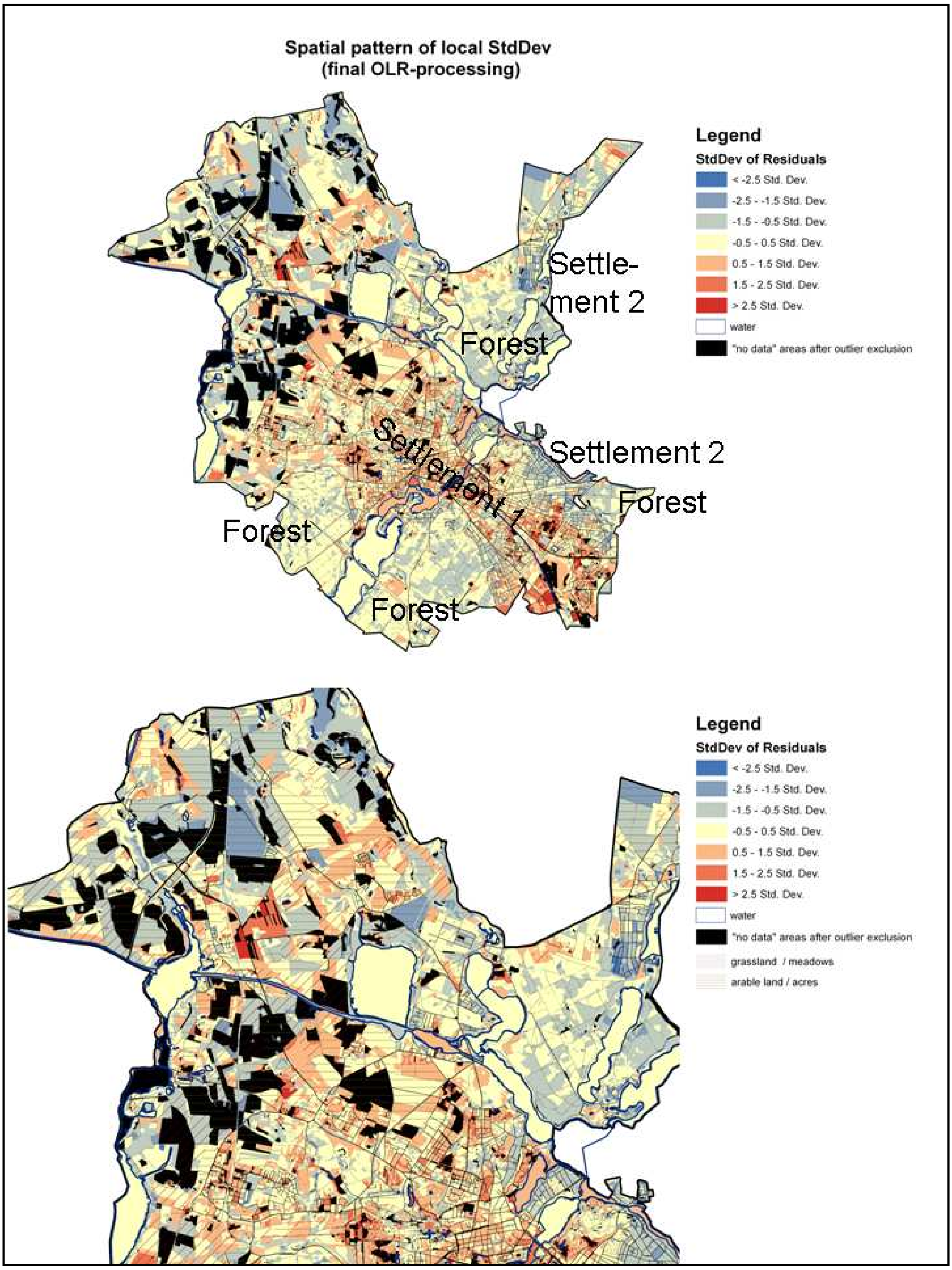
Regarding OLR-processing this is the final point. It wasn't worked further with the data to optimize the model-fit. Further processing with the whole set was done with GWR (see 10thf), to care about the spatial dimension. Otherwise data were summarized (beyond: GWR 12th). Key-points being observed till this stage here were:

- artificial or cultivation-influences are disturbing regression-results in regard of the used and available data.
- Water including water-bodies can be addressed with the newly implemented - “estimated” variables, what leaves space for further studies and possible optimization defining variables
- initial vegetation can be an explanation for unexpected cooler temperatures then estimated - mainly on bare soil and grass-lands and with space for further studies
- There are some unexplained phenomena producing outliers in regard of the used model. This counts specifically for settlement-biotopes (class 12 - 11) which on the other side are showing significant better model-fits then other biotope-classes like grasslands.

StdDev:

- Temperatures in forests and woods tend to be slightly (0.5-1.5 StdDev) underestimated (see 1st pic following side)
- Temperatures in settlement-areas tend to be slightly overestimated (see 1st pic following side: “settlement 1”) and in other parts with tendency to more green underestimated (see 1st pic following side: “settlement 2”)
- areas under cultivation with little relevant green volume / soil-sealing are heterogeneous (see brown stripes 2nd pic following side: 0°: arable land, 45°: greenland)

It seems that bigger settlement-areas are influencing smaller water bodies to be hotter then expected and bigger water bodies effecting smaller settlement-areas to be cooler then expected. The cluster-analysis of data was showing same patterns. The clustering was showing patterns, which suggested effects when a certain space was covered with similar structures. Then a more global influence in the respective direction can be expected (settlements provoking hotness and lakes and forest provoking cooling from 2 minimum edges 1km-1.5km [1km²] and bigger onwards) It looks like, that from a certain space covered with similar structures a more global influence in the respective direction can be expected.



Picture 16: StdDev after OLR-processing (here including water-bodies)
Brown stripes 0°: arable land, 45°: greenland

After OLR-processing some few, single areas with higher StdDev (+/- 1.5 and even 2.5 and beyond) were remaining in the dataset and not removed, especially.

1. bare soils
2. moor / swamps
3. hay
4. woods
5. special biotopes – sewage farm
6. settlement-areas – industry and trade

They are all indicating specific land-use-influences (artificial influences) looking at the biotope-code already, which could be addressed with further research. Special interest could be given to moors and swamps due to that they may of special interest in regard of climate-change beside adaptation-influence, when intact (having enough water / wetness[139]). These 6 land-use-patterns were not further addressed here – only indicated as outliers, due to the interest of the work less on optimizing the OLR-model as such. Focus was on the variables and postulated indicators green-volume and soil-sealing and to describe them and their influences and on an "overview" for the local level (midscale – 1:10,000).

The explaining part of the single independent variables after processing looked as follows (IBM-SPSS-results): **For R^2-adjusted (8^{th}) 0.655**

Correlations (IBM-SPSS)		**Temp °C**	I1	I2	I3	I5	I6
		mean	gvz10	vg10	soil	Bio.wet	waterpery
Pearson Correlation	**mean °C**	**1.000**	**-.610**	**.537**	**.388**	**.536**	**.373**
	I1_gvz10	**-.610**	1.000	-.475	-.153	-.146	-.012
	I2_vg10	**.537**	-.475	1.000	.329	.354	.114
	I3_soil	**.388**	-.153	.329	1.000	.298	.226
	I5_Bio.wet	**.536**	-.146	.354	.298	1.000	.374
	I6_waterpery	**.373**	-.012	.114	.226	.374	1.000
Sig. (1-tailed) / Sig.F-change	0.000 always 0.000 always for whole model						
N	50307 always						

Table 11: Correlations for R^2-adjusted for (8^{th}) 0.655. The correlation of wetness of biotopes (I5) and gvz for 2010 (I1) is highlighted – here weak compared to the 9th processing step (water excluded)

When the overall-dataset is delivering a better regression-result then the dataset with water-bodies excluded, explaining surface-temperatures green volume is loosing influence (0.708-0610). The expected influence of water-bodies (with little green-volume / soil-sealing) is becoming visible with the correlation-values.

In the same moment I5 and I6 are winning value regarding the dependent variable (mean °C) and showing the strength of the explaining part of the biotope-component (I5). The correlation between I1 and I5 looses lots of its value (highlighted blue), which counts, but not so obvious for I2 and I5 as well, whereas the relation between I5 and I6 is getting stronger.

139 Compare recent studies wichtmann joosten 2012: and 2014 using the sample of Potsdam "Koordinierungsstelle Klimaschutz" (Arge, 2010)

For R²-adjusted (9th) 0.626 (green volume alone here 0.501) => no water-bodies

Between the used variables there was always an obvious correlation detected (this sample presented as an equivalent for all other processing steps). Green-volume (I1, gvz10) always being calculated as negative factor. It can be seen that it is the strongest explaining variable (-0.708) followed of soil sealing (I2, vg10)[140]. Their relation (-0.500) is almost as strong as the one of vg and temperatures (0.533). The influence of the variables I3, I5, I6 is obvious and with some strength of especially I5 (Bio.wet[141]) in relation to temperatures. During all processing-steps it was of relevant benefit, to process at least I1 and I2 together, rather then only one variable / indicator.

Correlations (IBM-SPSS)		**Temp °C**	I1	I2	I3	I5	I6
		mean	gvz10	vg10	soil	Bio.wet	waterpery
Pearson Correlation	**mean °C**	**1.000**	**-.708**	**.533**	**.364**	**.481**	**.292**
	I1_gvz10	**-.708**	1.000	-.500	-.196	-.453	-.065
	I2_vg10	**.533**	-.500	1.000	.329	.457	.074
	I3_soil	**.364**	-.196	.329	1.000	.289	.184
	I5_Bio.wet	**.481**	-.453	.457	.289	1.000	.159
	I6_waterpery	**.292**	-.065	.074	.184	.159	1.000
Sig. (1-tailed) / Sig.F-change	0.000 always 0.000 always for whole model						
N	49009 always						

Table 12: Correlations for R²-adjusted (9th) 0.626: The correlation of wetness of biotopes (I5) and gvz for 2010 (I1) is highlighted – here strong compared to the 8th processing step (water included)

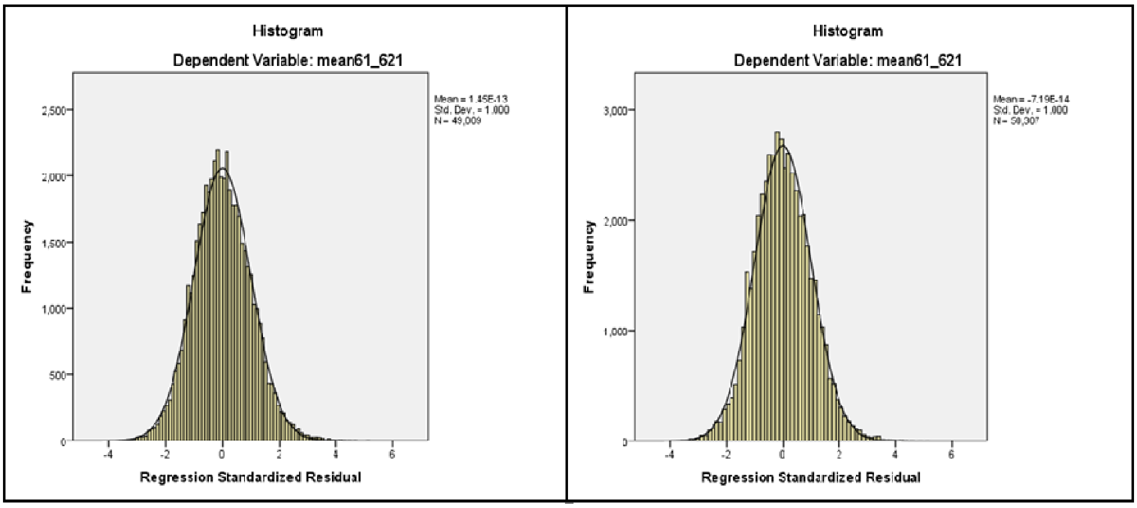
But still the cutting out of water-bodies is showing influence. The left graph (beyond) is loosing some values on the left side, of cooler temperatures (cooling effects of water-bodies leading to lower Values then the average residuals and lower StdDev-values: “negative” once).

If the set is processed only with variables green-volume I1 and soil-sealing I2 R² is remaining at 0.451 including water and 0.544 excluding water-bodies. The result is again showing the weakness of the model addressing water-bodies (without I3-I5). Compared to 0.49 before outlier-detection (water excluded) the improvement is little more than 5%. This suggests using the additional variables I3-I6 specifically when addressing the whole data-set and when not concentrating specifically on the value of green-volume and may be soil-sealing as it is the main aim of this work.

140 The housing and other construction related splitted value of soil sealing didn't bring relevant-better results and isn't presented here. If there is an interest am ready to send further information => see contact-details

141 Compare chapter 3 regaring the variable / indicator and it's shape => values indicating room for further research

Temperature-variations after outlier-detection are still almost normally distributed (Gaußian).



Picture 17: data-variation mean61_62_=> surface-temperatures °C (IBM-SPSS- Ggraph)
left: for R²-adjusted (9th) 0.626 / water excluded
right: for R²-adjusted (8th) 0.655 / water included [142]

4.3.2 GWR-processing

GWR-analysis (based only green-volume and soil-sealing)

10th <u>0.71</u> – 0.78 (total – full data-sets) (0.664 only GVZ)

11th <u>0.78 – 0.79</u> (water excluded) (0.858 only GVZ)

12th <u>0.914</u> (StdDev residuals beyond -1.5 and 1.5 excluded)

The adaptive Kernel type[143] and AICc[144] reached best results of the ESRI-ARC-GIS available GWR-spectrum (shown above). The adaptive type is better taking care of the geographic patterns of e.g. smaller polygons in settlement areas and in the same moment bigger once in forest- ore agricultural areas. The following results are not presented in detail regarding different GWR-techniques, due to that it's of no benefit to understand the general data-situation and values of GVZ and VG.

Based on the "First Law of Geography": everything is related with everything else, but closer things are more related GWR employs a spatial weighting function with the assumption that near places are more similar then distant ones (geography matters) (Tobler 1970, Matthews and Yang 2012[145]). As such the results show, that

- GWR is improving the results of Potsdam-data in regard of detecting dependencies between green-volume / soil-sealing and surface-temperatures.

142 See annex for data- variations in regard of biotope-groups and gvz, vg, temperatures
143 Adaptive: Spatial context (Gaussian kernel) a function of a specified number of neighbours reacting that: 1. where feature distribution is dense, the spatial context is smaller; 2. where feature distribution is sparse, the spatial context is larger. — Instead of fixed: spatial context with defined fix distance (ESRI: ARC-GIS10 help, Matthews and Yang 2012)
144 the Akaike Information Criterion, mostly used (Matthews and Yang 2012)
145 References as well in ESRI-ARC-GIS-10 help

- GWR is confirming OLR-results looking at land-use-classes and geographic position, making them visible.

10th   0.71 – 0.78 (total – full data-sets) (0.664 only GVZ):

For this group only the last dataset[146] will be discussed. 0.7748 R^2 [147] was reached, as output of GWR-processing of the outlier-cleaned OLR-processing. Using only green-volume for the model the R^2 is 0.664, indicating again the weakness of the green-volume-variable when free water is influencing temperatures (see 8th -9th processing-step above). Summarizing the values. The mean-values presented in the following table could be possibly miss-leading, but they fit to the geographical image (=> see picture next page). It seems acceptable presenting them to highlight tendencies within the dataset related to land-use-classes (biotope-classes).

Bio-Class		Fre-quency	MEAN Local R²	MEAN °C predicted [148]	MEAN °C intercept [149]	MEAN °C	MEAN VG	MEAN GVZ	MEAN Std-Residual
01	Flowing water	704	0.29	27.82	27.98	24.61	0.00	1.28	-2.25
02	Standing water	792	0.28	28.24	28.61	24.96	0.01	2.23	-2.31
03	bare soil / brown fields	2186	0.38	30.61	31.33	30.97	9.42	3.18	0.26
04	marshland swamp	540	0.28	28.12	28.81	26.02	0.13	3.93	-1.47
05	grassland meadows [150]	7278	0.29	29.94	30.56	30.12	2.34	2.97	0.12
06	Hay + shrubs	53	0.13	27.30	27.61	29.27	0.07	2.89	1.39
07	bushes woods	5213	0.32	28.79	30.61	29.28	4.38	9.24	0.35
08	Forests	10272	**0.41**	27.07	29.41	27.01	0.93	13.16	-0.04
09	Acres – agriculture	1981	0.31	30.66	30.87	30.52	2.05	0.88	-0.10
10	parks open spaces	6229	0.35	30.70	31.35	30.93	18.65	3.59	0.16
11	special biotopes	96	0.36	30.94	31.67	31.78	2.25	3.25	0.59
12	settlements	32412	0.36	31.19	31.36	31.12	47.73	3.11	-0.05

Table 13: GWR-results Local R² summarized alongside biotope-classes incl. frequency of all biotpes (GVZ: green volume, VG: soil sealing)

Compared with the overall GWR-result the mean of local R^2 seems to be weak but those mean-values are assisting to understand differences. They are not any more representing local cross-reliance as the GWR does. The mean of Std.-Error is 1.43. The negative Std.-Residuals of water-bodies (Biotope-class 1 +2) is indicating absence of VG and

146 furthest OLR-processed dataset and polygon-set
147 Reminder – it's always meant the R²-adjusted value, speaking of R²
148 Predicted for values (°C) calculated on base of independent variables
149 Intercept for values (°C) calculated regardless independent variables: the expected value for the dependent variable if all the independent (explanatory) variables are zero...
150 incl. argicultural grass-land

GVZ of an cool environment. Moors (04) indicating cooling-effects of water as well, here not adjusted using indicators 3-6 (see above OLR-processing). The higher difference between predicted (mean!) and intercept values (mean!) of forests and woods is even in regard of mean-values reflecting the high influence of detected GV to buffer heat-influences. The effect isn't prominent looking at the other Biotope-classes. It's indicating the influence of other variables and effects (presence of soil-sealing, absence of green).

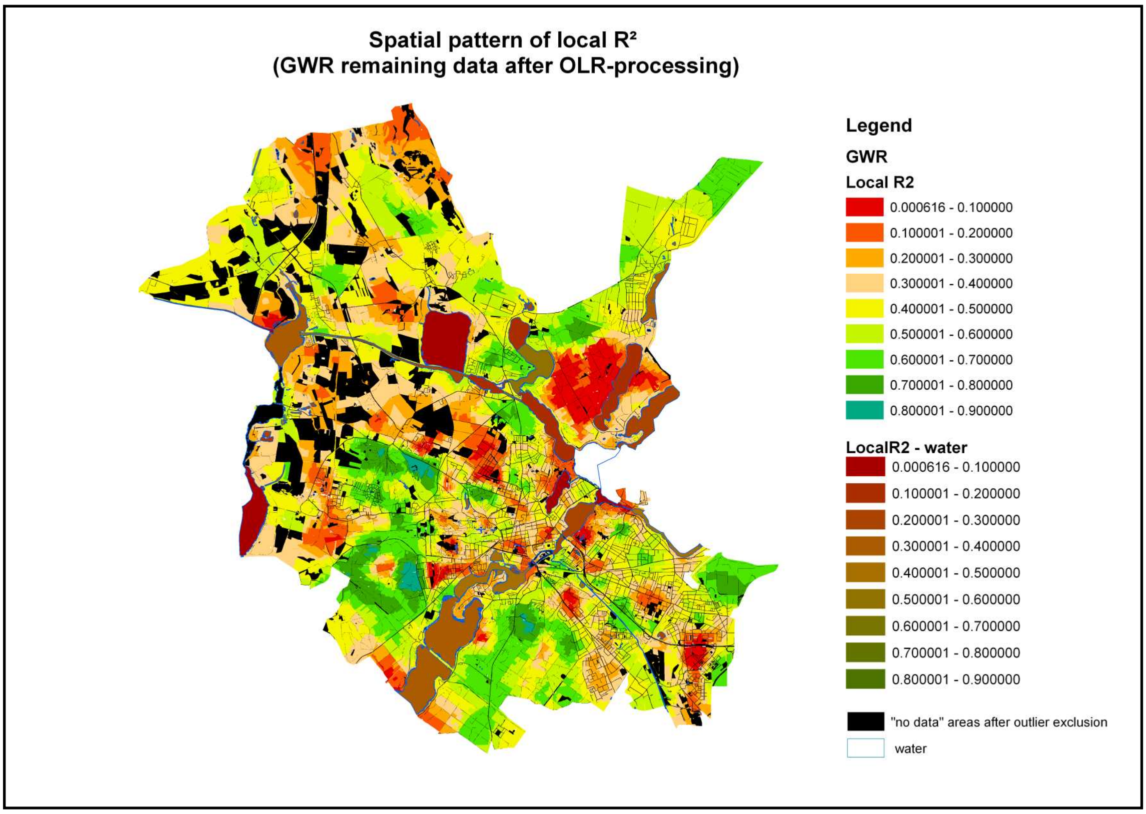
Some of the GWR-results contradict OLR-results or focusing on larger areas, giving space for further research (see picture next side):

- large forest in the East (middle) and some parts in the West are showing weak results in regard of local R^2. This counts if both variables are used or if they are used independently
- many settlement-areas are showing weak results (not obvious with mean of local R^2 – above in the table) but to some extent a sign for other influences like the water-bodies
- North: agricultural and forest-mix-areas with weak results compared to
- strong results in NW (N of Wublitz-Area) agriculture and greenland and
- center West: mix of settlement, forest and agriculture (W of park Sanssouci)

Some of the GWR-results confirm OLR-results

- Water bodies are showing weak results (brown colors - obvious with mean of local R^2 – above in the table)

In regard of OLR-processing the influence of other factors on the model were mentioned. Looking at the GWR-outcomes and samples above as geographic pattern this is becoming more obvious.



Picture 18: GWR-results with fulll data-background (brownish colours) and without water-bodies (bright colours)

11th 0.78 -0.79 (water excluded) (0.858 only GVZ):

When the water-bodies were excluded the same effect as with the initial OLR-processing (without further indicators I3-I6) appeared. The model-fit was rising. The explanatory value of GVZ for surface-temperatures rose.

Interesting was, that the single use of GVZ leaving out VG accounted for even better results then the use of both variables (Aic-adaptive cernel: 0.850 GVZ, 0.707 VG; Aic-fixed cernel: 0.798 only GVZ, 0.757 VG included). As such VG is a contributing and influencing factor on temperatures, but it seems advised 1st to focus on GVZ to achieve a fitting over-all picture as long as water-bodies are left out, but the results could be miss-leading as well.

Looking at the map, the areas with high local regression-results are concentrated on unsealed areas and land-use-types. So the first idea was, as long as unsealed areas are addressed, calculating only with GVZ would be sufficient. When on the other hand – and for biotopes of most interest in regard of climate-adaptation: “settlement-biotopes”, it's advised not to let VS out of processing.

Following this point the settlement-biotopes were extracted showing R^2: 0.858 only GVZ and 0.799 for VG-only compared to R^2: 0.784 for both variables (GVZ and VG).

So the results of soil-sealing were strengthened most likely due to a denser data background of soil sealing data. But the tendency of separate processed data in relation to together processed (GVZ and VG) is not linear. In some cases they are showing almost same results when in other cases, they differ. Processing with spatial reduction (e.g. on settlement-biotopes: biotope class 12) the picture gets even more complex and diversified. In some cases the result of 2 variables can be seen as average of the single variables, in others there can't be seen an obvious relation.

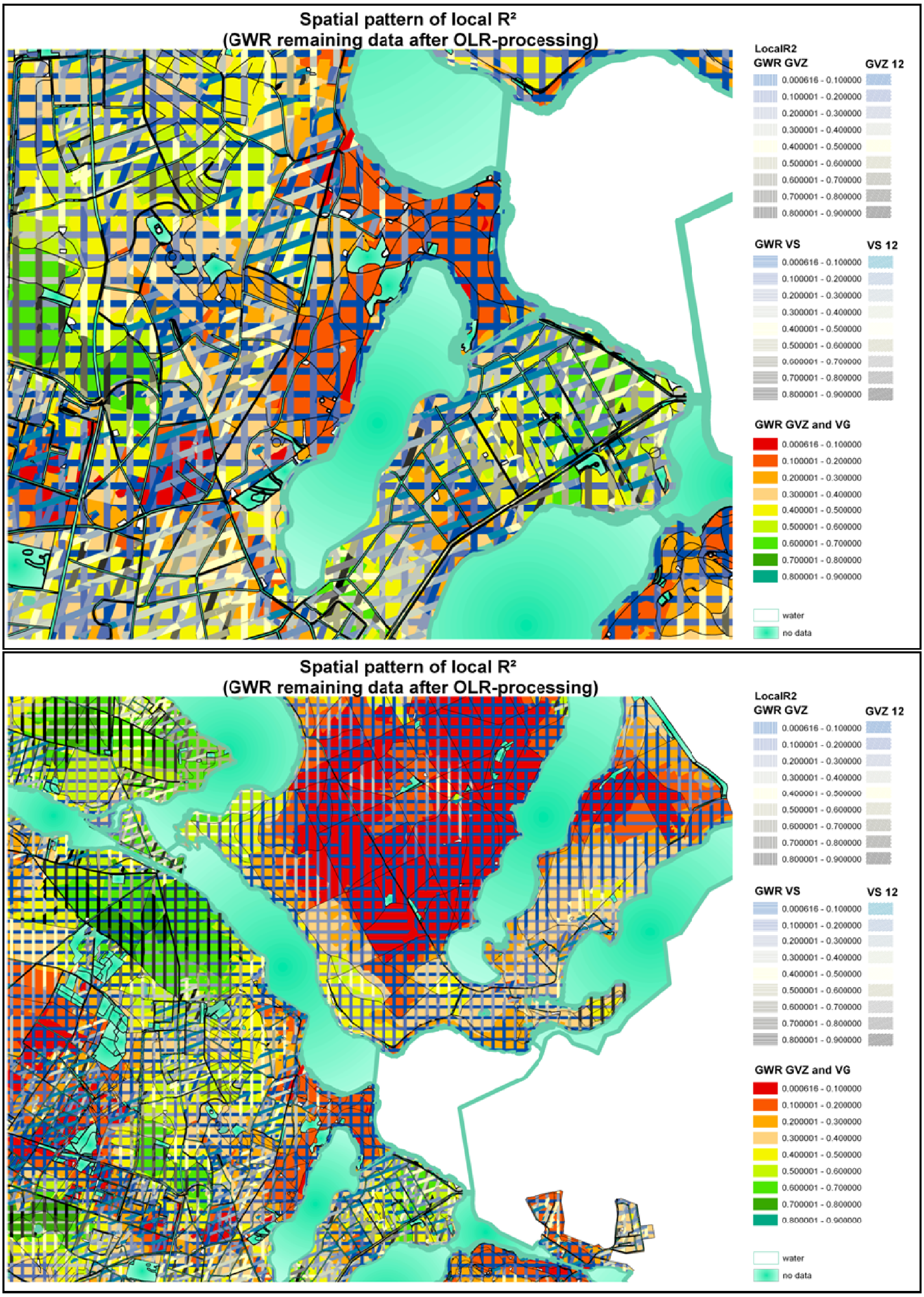
The GWR-results of different variables are leading to different local Regression strength and weaknesses, different patterns, even between spatially full and part-data processing (12 here for biotope-class of settlement-biotopes), see pictures next page: 1st – zoom city-center, 2nd Potsdam-East, Legend: GVZ (90° stripes): green-volume, VS (0° stripes): soil-sealing, GVZ12 (70° stripes) / VS12 (20° stripes): values for settlement biotopes. The big red spot (2nd picture beyond - overview) indicating e.g. weak GWR-regression results for a forest-dominated area. It’s showing a similar tendency of single-variable-processing compared to the two-variable processing.

Observing the first picture beyond (zoom), the difference between spatially limited and almost full covering data is obvious (0° compared with 20° VG and 90 with 70° GVZ).

- Checking the green areas on the left side it seems that GVZ is the dominating factor driving the 2 variable-result in the direction of the single-GVZ-result (grey 90° - GVZ on blue 0° - VG in front of green overall result).
- Small areas whith blue stripes (weak) of both single processed variables in front of yellow-overall (medium) were not first-hand expected.

But looking at the model behind GWR (see chapter 3) the phenomena was expectable, even when not compelling. The variety and sum of single results is not linear-related connecting either variables or spaces.

Cross-correlation between GVZ and VG could be seen all the time processing the data, but it never resulted in a weakening of the model-fits (R^2-adjusted) in the way that a single-variable regression result was weaker then the two- ore more variable processing. As said in the introduction the two variables need, may be, to be seen additional rather then combined.

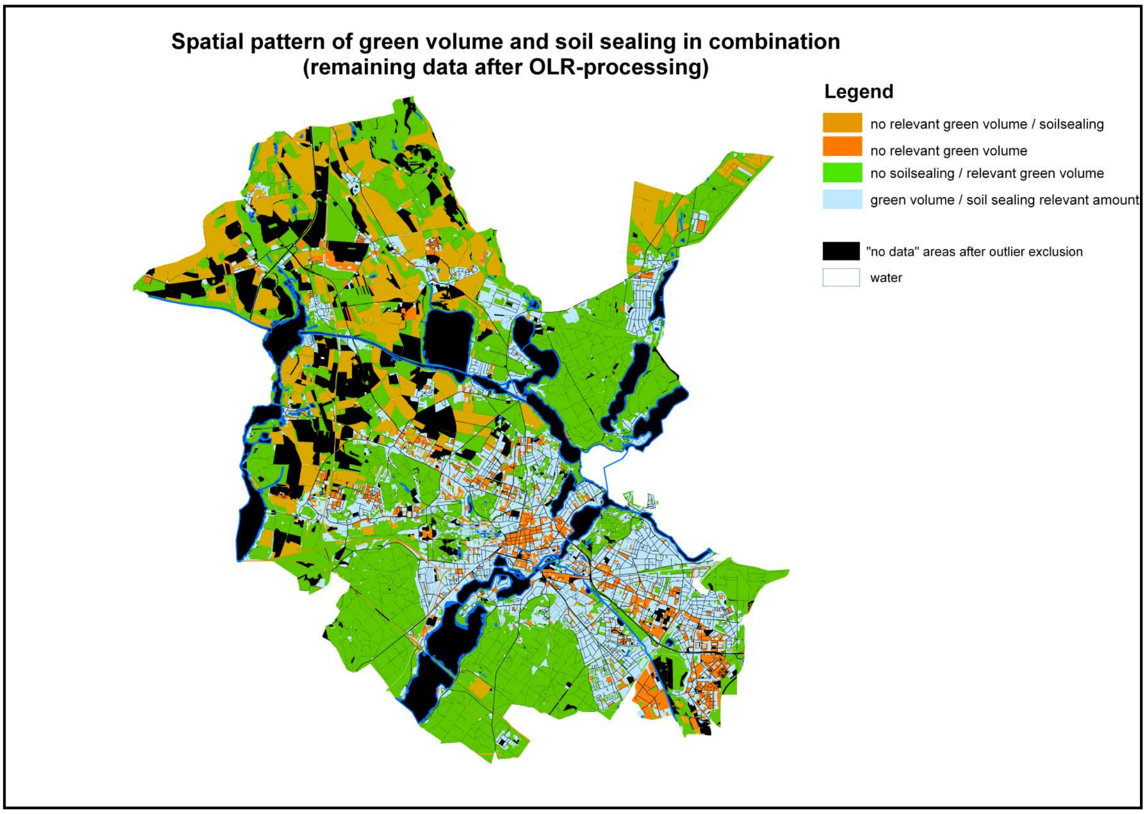


Picture 19: The GWR-results of different variables are leading to different local Regression strength and weaknesses, different patterns even between spatially full and part-data processing ("12" here for biotope-class of settlement-biotopes): 1st – zoom city-center, 2nd Potsdam-East, Legend of stripes: GVZ (90°): green-volume, VS (0°): soil-sealing, GVZ12 (70°) / VS12 (20°): values for settlement biotopes. Blue stripes for little values, than from white stripes to black stripes for high values.

Regarding the single variables influence the results were difficult to identify.

The picture beyond was produced to give a further hint before GWR-processing –

presentation is finished, to understand and see areas were either green-volume or soil-sealing is showing no relevant amount to influence temperatures (GVZ less than 1m³/m², Soil-sealing less than 1%). Still the "0"-information of missing influence of variables was influencing the R^2-result.



Picture 20: Spatial pattern of variables (water excluded) with indication of datasets regarding presence of relevant numbers of indicators to predict temperatures.

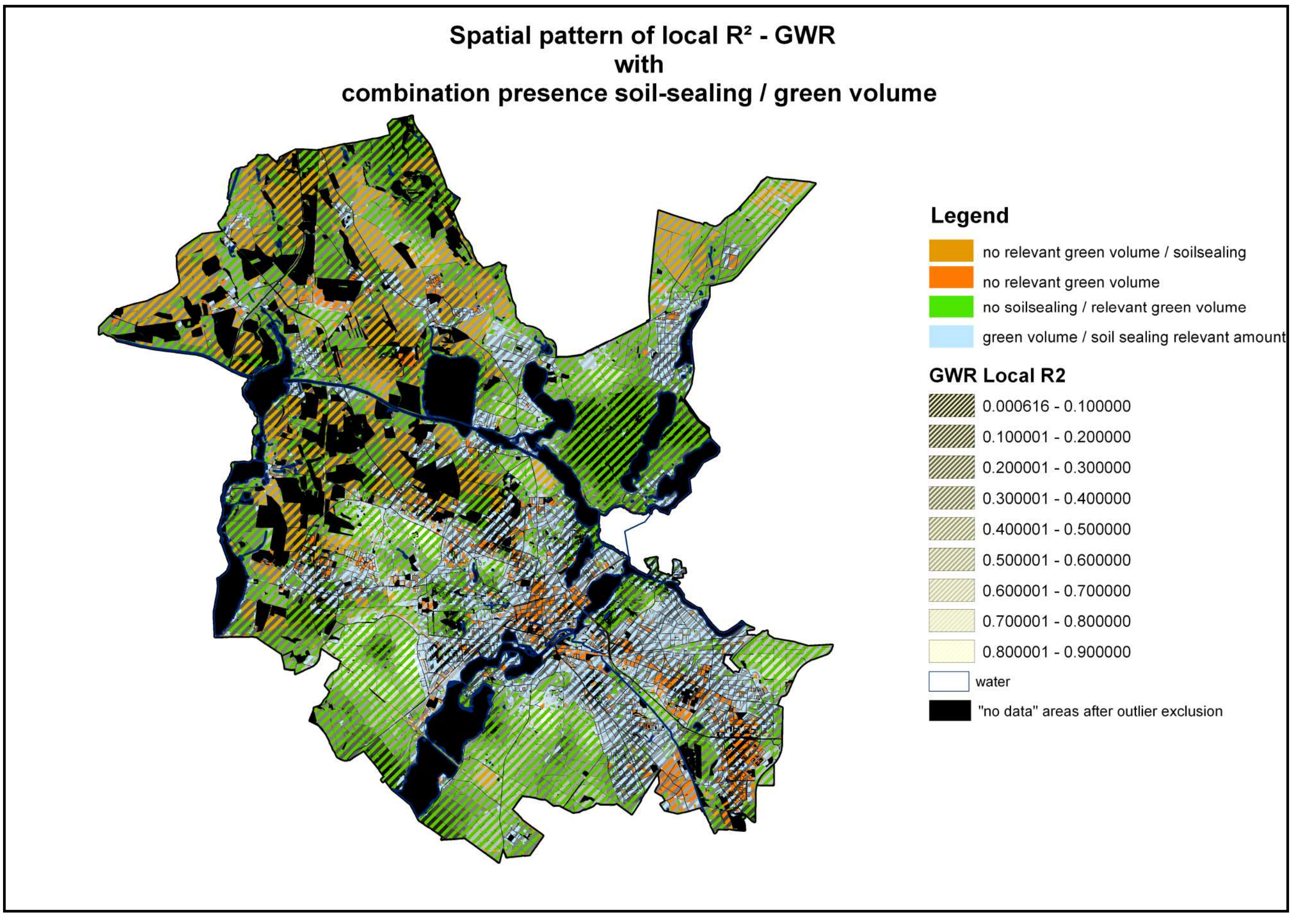
The spatial pattern is showing:

- brown (neither relevant green volume nor soil-sealing): mostly agricultural areas – acres – agrarian land (including sandpit in the south, .
- orange (no relevant green-volume): dense settlement and specifically industry-areas
- green (no relevant soil-sealing): mostly forests and lowlands along waterbodies, most of the parks
- light-blue (both relevant): settlement-areas (incl. allotments/garden-plots, graveyards, brown fields) – very prominent.

12th 0.914 (StdDev residuals beyond -1.5 and 1.5 excluded)

The next result is more an evident and expected one. As soon as outliers are excluded in general via StdDev of residuals, the results improved. The picture beyhond was using the before introduced pattern of **presence of relevant values of green-volume or soil sealing** to see different strength of local R^2. The additional information reflects the local GWR-R^2 results. The darker the stripes the higher the local R^2 (black low / white: high).

The pattern is not indicating explicitly a strong link regarding local R² and the variables value or combination.



Picture 21: GWR-results local R² combined with presence and absence of green-volume or soil-sealing

At this point GWR analysis was stopped, a different branch of research needed to find mechanisms between land-use-influences and basic parameters GV and VG on temperatures.. Basically the explaining value of green-volume and surface-sealing was shown (with complex and diversified relations). It's still advised to get the indicators green-volume and soil-sealing accepted as standard-indicator to adapt to climate-change. To further justify this, it was tried to define some core-points to be able to use the indicators.

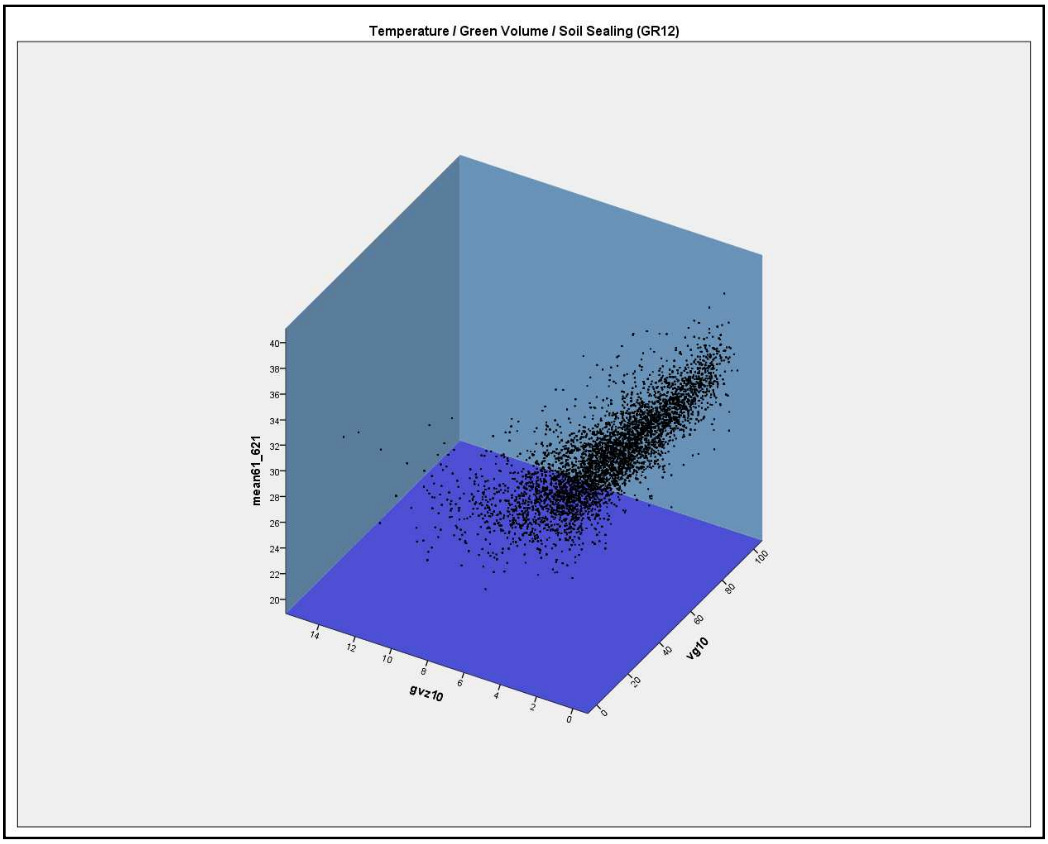
The relation of findings in comparison with other studies will follow, too (for more see as well chapter 5).

4.3.3 Summarizing ORL-processing-results through biotope-code-reduction

The settlement biotopes are the biotope-group or biotope-class (GR12) which provoke a special interest in regard of climate-adaptation and more specific healthy living-conditions.

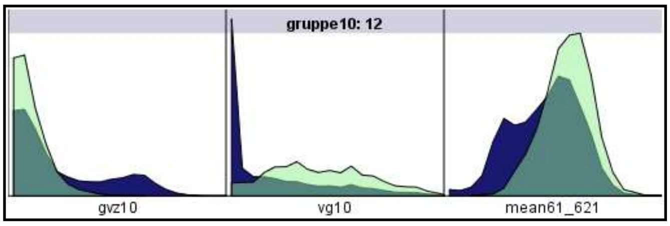
Other biotope-classes could be addressed, like agricultural biotopes, but the focus in regard of possible climate adaptation would most likely then first address cultures and their management and less permanent green-volume.

The effects of green-volume and soil-sealing were initially planned to be observed looking at climate-adaptation potentials regarding settlement-biotopes. The following 3D-scatter plot is giving an additional impression of the relation between the factors and surface-temperatures after outlier-detection for settlement-biotopes (GR12).



Picture 22: Relation between surface temperatures (mean61_621), green-volume (gvz10) and soil sealing (vg10) for settlement-Areas (GR12 for settlement-biotope-class)[1]

It's possible to see temperature-rising influences of soil sealing and temperature-reducing effects of green-volume, when still showing the variety of single datasets (points). Summarizing data assists to get a better picture and will be presented beyond (13th processing step beyond).



Picture 23: data-variation (left low values – right high values) of settlement-biotopes ("gruppe12" light-green-transparent) compared to the mean of all data (dark-blue graph): gvz10=> green-volume, vg10=> soil sealing, mean61_62_=> surface-temperatures °C (IBM-SPSS-GGraph)

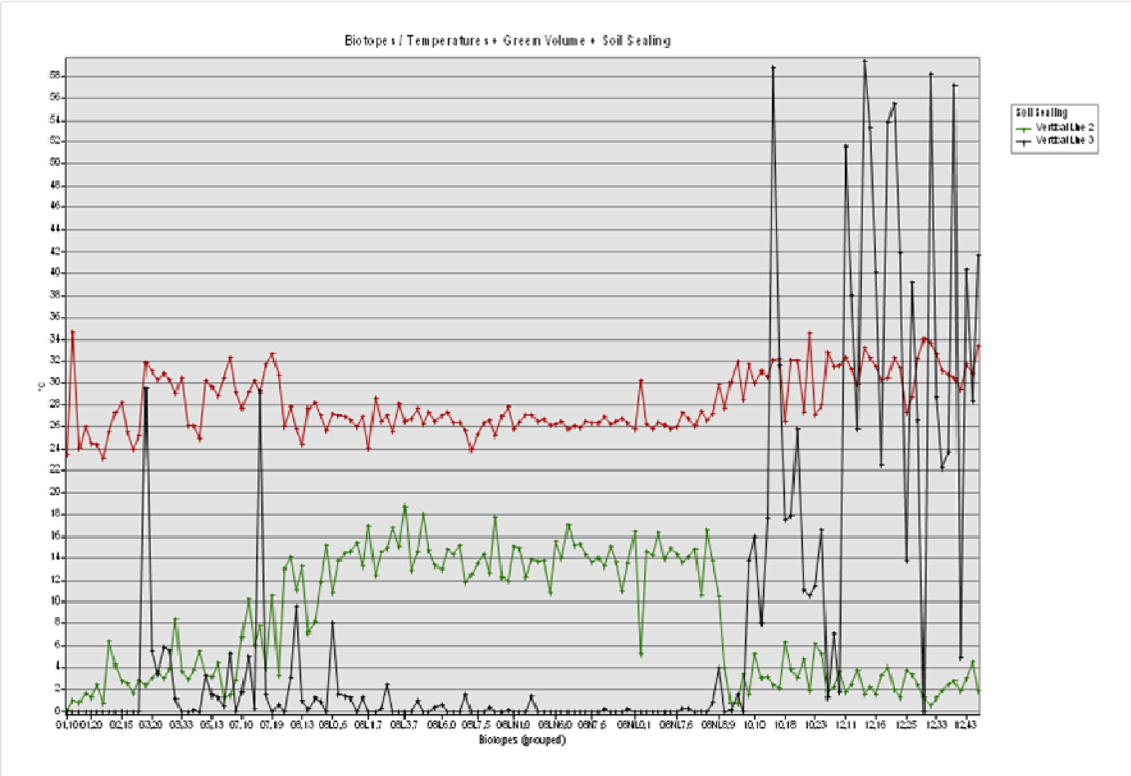
The data-variation (light-green-transparent graph) compared to the mean of all data variations (dark-blue graph) is showing the typical pattern for settlement-areas with less green, high soil-sealing and higher temperatures, here compared to the average of Potsdam. It helps to understand the relation between surface temperatures (mean61_621), green-volume (gvz10) and soil sealing (vg10) for settlement-areas in a way, that to buffer temperatures and compensate higher soil-sealing-shares, relatively little space for green is available (for more and the other biotope-groups: see annex!).

It's postulated: If there is more green-volume it buffers temperatures even, when there is relevant soil-sealing. The graph following shall broaden the view from settlement-biotopes to all biotopes. The numbers on the base line (X) are indicating the biotope-groups following from left to the right from 01* to 12* as follows:

1 Flowing water-bodies	7 bushes and woods
2 Standing water-bodies	8 Forests
3 bare soil / brown fields	9 Acres – agriculture
4 marshland swamp	10 parks and open spaces
5 grassland and meadows [151]	11 special biotopes
6 Hay + shrubs	12 settlements

Between right hand on the graph Forests (8.NL.89152) and Parks and graveyards (10.10) green-volume is significantly low (green graph). Behind is the agricultural biotope-class (09) – agrarian land. It's showing significant height of temperatures (red graph) and low of soil-sealing (black). So without relevant soil-sealing influences the temperatures are high when there is little green-volume. Tendencies lowering temperatures when there is green and soil-sealing can be seen on the right part of the graph from 10-12, where a little + of green is reducing temperatures even when soil-sealing (black) is higher – assuming that green-volume is the temperature-buffering factor behind.

151 incl. argicultural grass-land
152 N (Nadel) for conifer-trees –, L for leaf-trees, 8 here pine 9 for different other trees



Picture 24: Relation between: surface temperatures (Y-axis) "red" graph (Vertical line 1), green-volume (gvz10) "green" graph (Vertical line 2) and soil sealing (vg10) "black" graph (Vertical line 3) following biotopes (X-axis) [1]

Biotope-code (variables only GVZ[153] and VG[154]) in regard of summarized data-sets addressing:

13th 0.774 Biotope-Code (weights based on frequency)

14th 0.841 Biotope-Code reduced to 4 digits[155] (weights based on frequency)

15th 0.886 Biotope-Code reduction of the code block to 2 digits[156] (weights based on frequency)

The first step to summarize data started joining all data with the same code, doing the regression still taking the frequency in account. The 2nd step, 1st reduction of the biotope-code was done then with a reduction to a 10th of the cases of the original-full code to 150 and then with the 3rd step, as 2nd reduction to 12 cases (Biotope-classes).

This meant a homogenization of independent and dependent variables of the statistical analysis being summarized (mean) (see chapter 3). Doing this, the outliers are equalized. The expected relation crystallized. In the same moment the biotope-related indicators became more obvious and didn't get level, showing the strong correlation

153 Green-volume-number GVZ for German Grün Volumen Zahl in m³/m²
154 and soil-sealing VG for German VersieGelung in %
155 instead of 8-11 – depending on the Biotope-class. This meant a reduction to a 10th of the cases from around 1500 cases of the original-full code to about 150 => here including mean of green-volume, soil-sealing and temperatures
156 the Biotope-class: 12 cases => here including mean of green-volume, soil-sealing and temperatures

between biotopes and the variables (here green-volume and soil-sealing remaining[157]). The focus in other studies on land-use-classes detecting influences of green-volume and soil-sealing was, as indicated in the introduction, reason to go this processing-step.

13th. R²: 0.774 Biotope-Code (weights based on frequency)

Correlations (IBM SPSS)		Temp. °C mean	I1 gvz10	I2 vg10
Pearson Correlation	Mean °C	1.000	-.840	.700
	gvz10	-.840	1.000	-.578
	vg10	.700	-.578	1.000
Sig. (1-tailed) / Sig.F-change	0.000 always 0.000 always for whole model			
N	1314 always (based on 49009 frequency)			

Table 14: Correlations for R²-adjusted (10th -1.) 0.744 and weights based on frequency of all biotpes

The weight of each independent variable is rising, as well as the cross-correlations, compared to the processing-steps before. Still the negative cross-correlations between the two independent variables were weakening the overall result. If frequency is not taken into account the R^2 goes down to 0.710 and cross-correlation is weakened, indicating that the numbers of more the model explaining cases (e.g. settlement-biotopes) are present to a higher degree in the data.

The result is showing as well, that as soon as green-volume is estimated for certain land-use-types or more specifically, as an average for certain-land-use-units, as e.g. done in Manchester - studies (ASCCUE, 2013() ASCCUE Local Advisory Group, 2004() Gill Susannah Elizabeth, 2006() Gill et al., 2007) and New York (Rosenzweig et al., 2009), the over all-model-fit tends to improve. This picture is crystallizing when the Potsdam-landuse units are more summarized, as done in Manchester[158] too. The estimation of about 150 biotopes in regard of a reduced biotope-code and 12 Biotope classes is highlighting this (almost similar to the ASCCUE-Manchester-studies => see chapter 5 – discussion).

157 The others (I3-I6 =>see chapter 3) couldn't be processed, due to that they were not in a state to be summarized.
158 => urban morphology types (UMTs): primary 12 and detailed 29 resulting in 9 surface-cover-types in regard of estimated green volume / in other words land-use-units (Gill 2006)

14th. R^2: 0.841   Alpha-Code reduced to 4 digits[159] (weights based on frequency)

Correlations (IBM-SPSS)		Temperature mean_°C	I1 mean_gvz10	I2 mean_vg10
Pearson Correlation	mean_°C	1.000	-.879	.743
	mean_gvz10	-.879	1.000	-.605
	mean_vg10	.743	-.605	1.000
Sig. (1-tailed) / Sig.F-change	0.000 / 0.000			
N	135 (based on 49009 frequency)			

Table 15: Correlation for R²: 0.841 with Alpha-Code reduction of the code block to 4 digits and weights based on frequency of all biotpes

Following the approach with an estimated green-volume the reduction of the code to 4 digits is a first step approaching comparable conditions as in the ASCCUE-set-up. Coming from R^2 0.544 excluding water-bodies[160], this is a huge step to reach R^2 0.841 (from about 54% to 84% - fit). The dependencies between the variables here again increasing.

15th. R^2: 0.886   Alpha-Code reduction of the code block to 2 digits[161] (weights based on frequency)

Correlations (IBM-SPSS)		Temperature mean_°C	I1 mean_gvz10	I2 mean_vg10
Pearson Correlation	mean_°C	1.000	-.924	.788
	mean_gvz10	-.924	1.000	-.656
	mean_vg10	.788	-.656	1.000
Sig. (1-tailed)	mean_°C		0.000	0.003
	mean_gvz10	0.000		0.020
	mean_vg10	0.003	0.020	
Sig.F-change	0.000			
N	10 (based on 49009 frequency)			

Table 16: Correlation for R²: 0.886 with Alpha-Code reduction of the code block to 2 digits and weights based on frequency of all biotpes.

Still the 0-hypotheses can be rejected (up to 0.05), but the 0.020 significance between green-volume (gvz) and soil sealing (vg) is indicating a beginning weakening of the model, probably due to summarizing-effects. Since water-bodies were excluded the biotope-classes reduced from 12 to 10.

159 instead of 8-11 – depending on the Biotope-class. This meant a reduction to a 10^{th} of the cases from around 1500 cases of the original-full code to about 150 => here including mean of green-volume, soil-sealing and temperatures

160 From 0.451 including water and 0.656 (N 146) using the reduced code. The result is again showing the weakness of the model addressing water-bodies (without I3-I5) – see above.

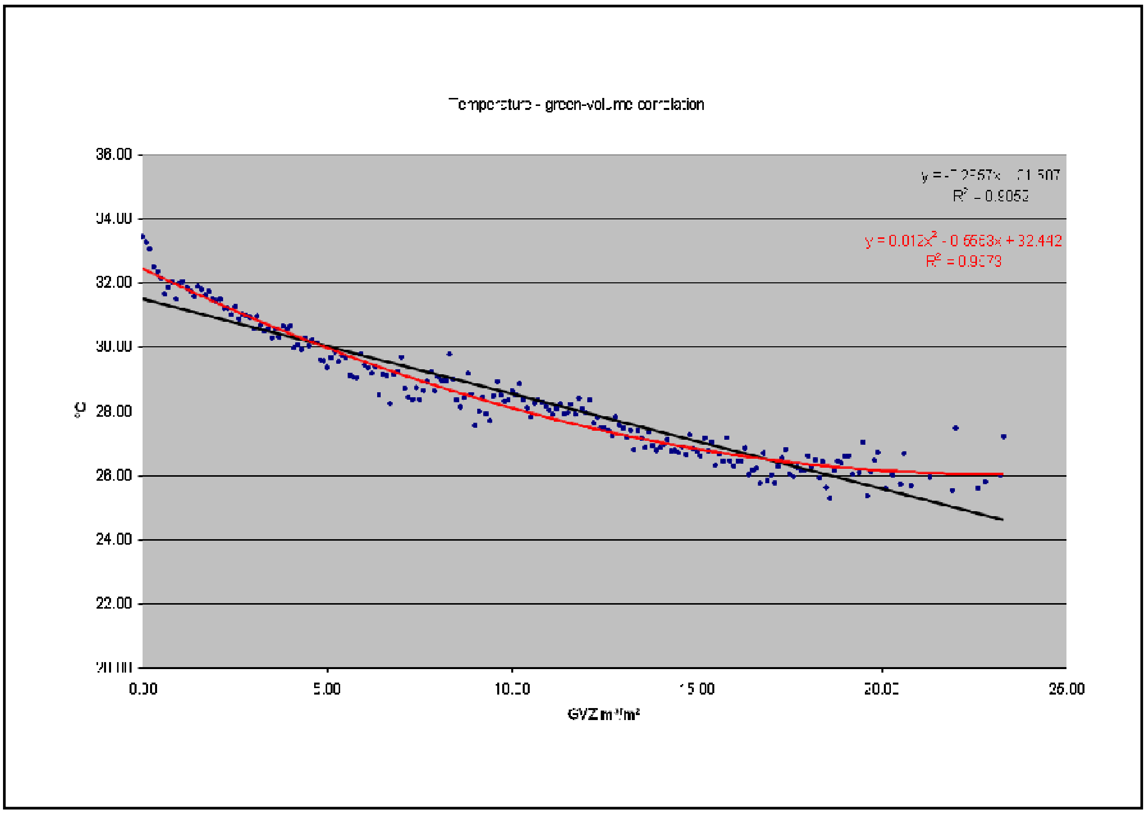
161 the Biotope-class: 12 cases => here including mean of green-volume, soil-sealing and temperatures

If water-bodies are included, R^2 is reduced to 0.641 and cross-correlation is reduced from 0.020 to 0.016. Very strong is the loss in the model-fit taking in water-bodies, due to that – as said already – and especially in regard of summarized data, no relevant variables are available (only“I1” green-volume and “I2” soil-sealing) to address water-bodies. All “water”-cases then are weakening the explanation of surface temperatures via “I1” and “I2”.

4.3.4 More summarized data (GVZ / VG)

Green-volume <u>summarized to 1 digit</u>: R^2 0.952 if frequency is recognized (IBM-SPSS-OUTPUT)

If the green-volume data are summarized limiting the cases to one decimal-digit (independent) and the mean of temperatures (dependent) is to be explained, the Regression result is very strong (IBM linear R^2 0.952 **including frequencies**), showing the effect of generalization on a different scale. It meant a reduction from 49,009 cases to 211 cases .



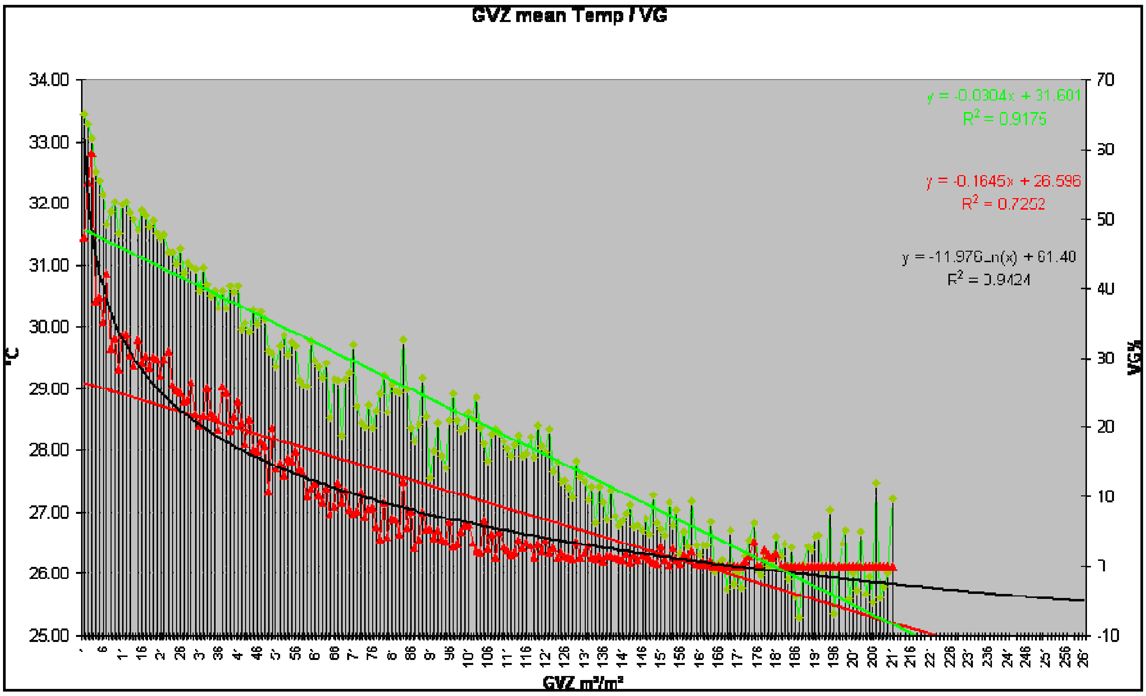
Picture 25: graph of green-volume and temperature-correlation - here without recognizing frequencies linear R^2 0,905, quadratic R^2 0.957 (Microsoft-EXEL-graph)

The mean of correlated soil sealing[162] is reaching an explaining value of $R^2$0.906 and using both variables (GV / VG) in the given set: $R^2$0.974 (IBM-SPSS). The cross-

162 with the same data-background and summarized regarding the 211 cases GV

correlation, if both indicators are processed, VG explaining GV is then -0.913 (equivalent to R^2 0.833 if set in relation GVZ explaining VG). All those data only presented to show the strength of the relation after summarizing. The only accountable and usable result to assist defining a simplified measure as an indicator is the change of temperatures in addition to a certain GV.

Following the formula in the picture above (and IBM-SPSS-results – including frequency of the over-all dataset), adding **1m³/m² green-volume** leads to a **reduction of about 0.3°C surface temperature** (linear regression) - 1°C to buffer needs $3^1/_3$ m³/m²GV. This count in fact only for conditions of the 10th July 2010 with for this case resulting **mean**-temperatures 25-33°C (about the bandwidth of all polygon-related mean-temperatures see 2nd picture beyond). If to the green-volume – temperature-correlation (see graph above) is added the mean of soil sealing the picture seems still more or less obvious. There are only a few out-breakers: Since the pure scatter-plot is difficult to read (see annex), the variables were cross-checked, to find a more cumulative graphical image:



Picture 26: graph of GVZ and temperature-correlation (green) with added mean values of addicted soil sealing-values (red). R²-values included as function (frequency unrecognised). GVZ-index base line multiplied X10 (1 is equivalent 0.1 in reality, 261 = 26.1). Regression-function / respective graph (green for GV and black and red for VG)

The tendency of both indicators summarized in regard of green-volume seems obviously influencing temperatures. The soil-sealing-values related to green-volume then very much better to explain with an exponential function.

Looking at specific (geographical) places conditions the relation could easy mislead interpreting local circumstances. The variety of data of each variable behind is too heterogeneous, to be used without further research of other influencing factors. Still – if planned to be used as an estimate for orientation:

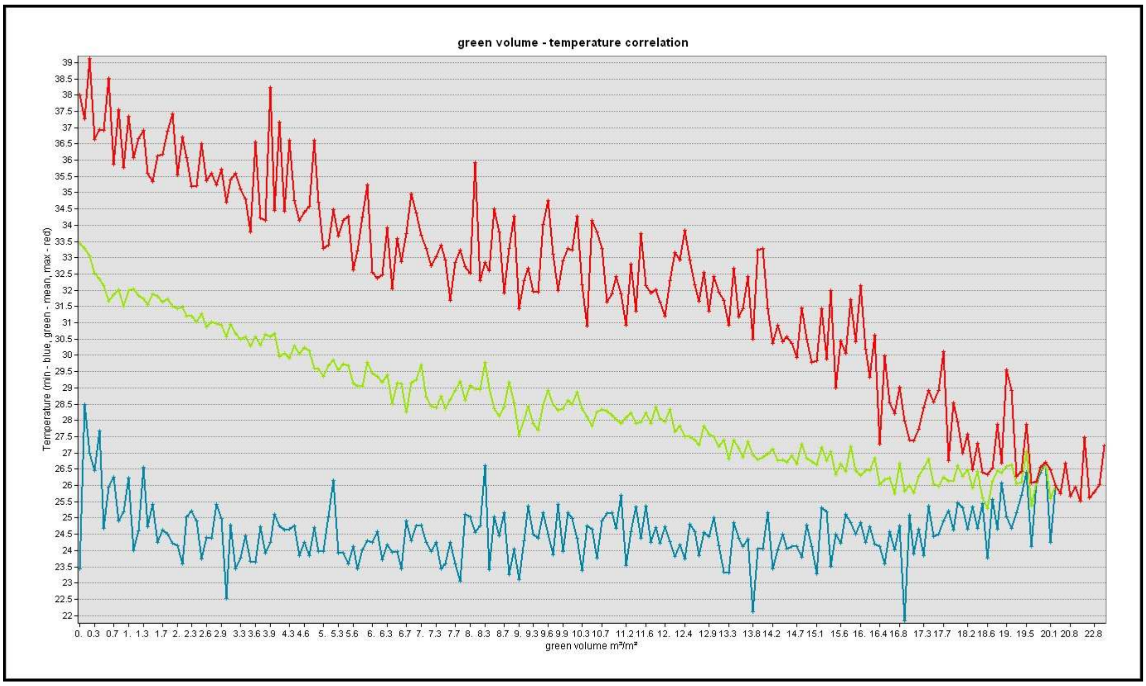
- it could be recommended to be used relative to better results
- specifically in Potsdam and similar climate-regions

To see the range of temperatures related to each GV-case they were summarized in a graph. The following picture is showing the influence of green-volume on temperatures, now based on the summarized green-volume to one digit (49009 cases summarized to 211 cases with frequency-information / number and range of all cases – the mean temperature of each polygon still available).

The 3 lines are indicating the spectrum of data:

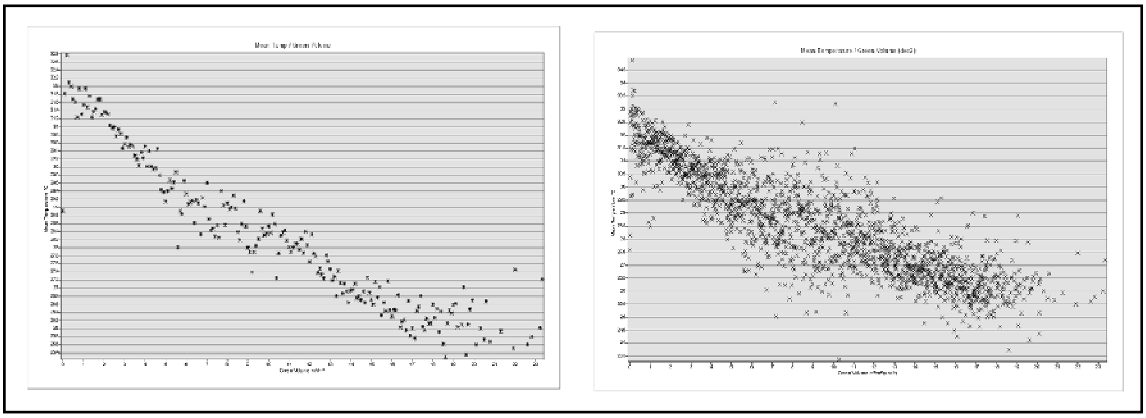
- red for maximum values,
- green for mean of values and
- blue for minimum of values.

The lines meet more the higher the green-volume is (from left to right). This indicates that with rising green-volume the influence on temperatures is increasing as well. At least the correlation of green-volume and temperatures is strengthened. Important is, that on the very end on the right side green-volume-values are as well less in number, beginning with about 15m³/m² (bandwidth: from 16m³/m² less than 100 cases to 19.2m³/m² with less than 10 cases: see green-volume-graph annex 4). The data-range of related temperatures (**mean-values**) covers about **33-26°C**, **maximum** from about **39-27°C –** more or less following the steepness of the mean-values-graph. The **minimum** varies around **25-23°C** indicating other influences (cooling environments).



Picture 28: GVZ – temperature – correlation with mean values °C: maximum (red), mean (green), minimum (blue)

The influence of reducing data-sets summarizing can be seen comparing the case on the left, summarized green-volume-values to one digit (211 cases) with the summary on the



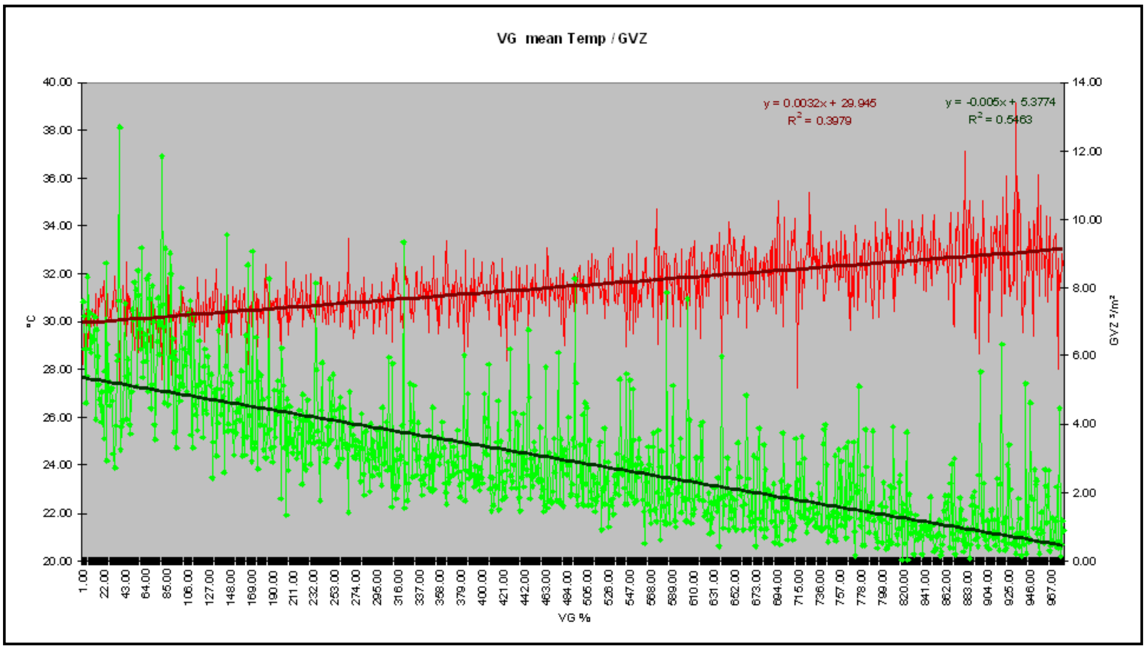
Picture 27: GVZ – temperature – correlation data-spectrum summarized to 211 (one digit) cases (left) and 1843 (two digit) cases (right)

right, summarized to 2 digits (1843 cases). Green-volume-values are on the base-line (X) and temperatures on (Y). Even on the right side graphic - the tendency of green-volume, influencing temperatures stays obvious.

Soil-sealing (1 decimal-digit reduction to about 1000 cases): R^2 0.753 if frequency is recognized (IBM-SPSS)

The pure regression between mean of soil-sealing (based on a 1 decimal-digit-reduction to about 1000 cases from 49009) produces a R^2 of 0.753 (0.389 without frequency recognized! - as in the graph beyond) and R^2: 0.813 including the addicted GV (R^2

0.808 only GV, 0.519 processed without frequency). Quadratic or other functions, like exponential functions, are not improving the adaptation of the relation, as it was the case with VG related to GV-classes (see above). Including frequency in the function is the main strengthening factor. This recognizes most likely the many settlement-areas (high frequency) and cases summarized with valid influences of soil sealing on temperatures (scatter-plot with frequencies in annex4).

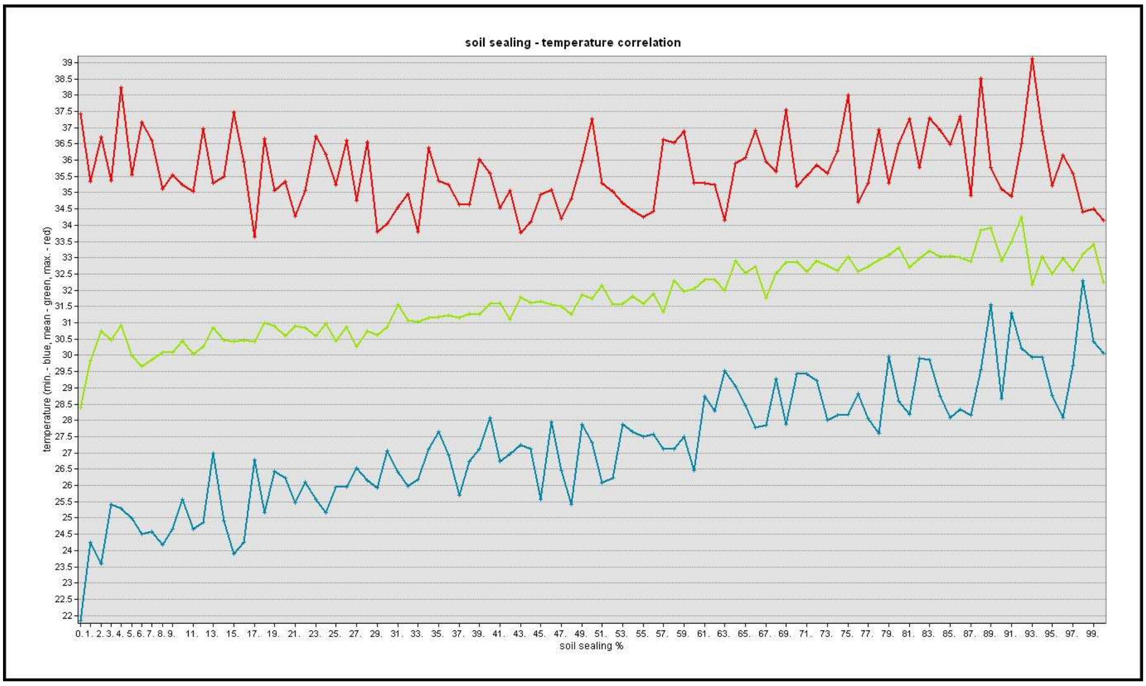


Picture 29: graph of VG and temperature-correlation (red) with added mean values of correlated GV-temperature-correlation (green). R^2-values included as function (frequency unrecognised). The index of soil sealing (%) base line is multiplied X10 (1.00 is equivalent 0.1 in reality, 967.00 = 96.7%). The regression-functions / graphs (green for GV and red for VG)

Both indicators summarized in regard of soil-sealing (1 decimal-digit reduction to about 1000 cases) still indicating influence on temperatures, even when weaker then with the GV-based graphs before. The GV in this case sufficiently explained with a linear regression-function. An increase of 10% soil sealing leading to a temperature-rise of 0.3°C. Again the results are based on conditions of the 10th July 2010 with and related mean-temperatures 27-39°C (bandwidth of polygon-related mean-temperatures see 2nd picture beyond). The relation of green-volume addicted to soil-sealing-categories with temperatures is weakened about 15% then compared to the relation of GV directly with temperatures (see above).

Regarding soil-sealing the effects summarizing data (min, mean, max =>see beyond) are similar as with green-volume, even, when the over-all picture is standing for a less strong influence of soil-sealing on temperatures. Now the maximum-values (related to 36-37°C) are indicating other heating-influences. Mean (30-34°C) and minimum (23-

30°C) are indicating stronger influences of soil-sealing (%-scale) on temperatures. Mean and minimum values are unlike GV with mean and maximum -graph following a similar steepness.



Picture 30: VG – temperature – correlation with mean values °C: maximum (red), mean (green), minimum (blue)

Results – summary

After processing	**Key results are** **(addressing 30m resolution-units of landsat-data)**

using different methods of regression-analysis
• OLR /
• GWR
detected with
• checking spatial-patterns by view
• summarizing statistics
and datasets of different shape in regard of
• land-use-units,
• StdDev
and variables (I1-I6) in different combinations
• I1 -green-volume as introduced
• I2 surface-sealing as introduced
• I3 soil
• I4 organic soil [moor]
• I5wetness or dryness of biotopes
• I6 water-periphery
	• Relevant explanation of surface temperatures is given via:
	    ○ GVZ: “I1”
	    ○ VS: “I2”
	    ○ Land-use as “complex criterion”
	• High negative correlation between variables green-volume and soil sealing
	• Possible other influences on surface-temperatures are:
	    ○ Artificial – short-time influences of land-use are disturbing regression-correlation
	    ○ Processed: “I3”-”I6” (free and bound water - water-content and wetness) and found relevant
	    ○ Unprocessed, e.g.: exposition, border-effects between different areas, summarizing effects
	• On a range of mean-temperatures 25-35°C[163] every m³/m² is reducing temperatures for about 1/3 (0.3-0.4)°C. As such it's a good contribution to climate-adaptation.
	• 1% (1m²/100m²) of soil-sealing is then[164] provoking a rise of temperatures for about 0.03°C.
	• Summarizing data leads to improvement of regression and prediction[165]

163 Single cases 22-40°C resulting in a mean of almost 25-35°C (water-bodies excluded)
164 Single cases 22-40°C resulting in a mean of 30-33°C (water-bodies excluded)
165 More a general then a specific phenomena – but could have weakened results as well

5. Findings and discussion

After *Potsdam-data* and regression-analysis it can be confirmed that GV and VG are influencing temperatures and relevant as indicators addressing temperature-development – specifically adaptation to rising temperatures. Defining differences focusing on climate-adaptation-potentials, addressing temperature-stress or sensitive (reactive) and temperature-constant, less reacting, less vulnerable environments, it can be said that:

1. Green-volume is a reactive factor buffering temperatures
2. Surface sealing is a reactive factor contributing to temperature rise
3. Biotope- and land-use-information is an assisting factor to understand and address local specifics, including water as cooling parameter
4. The different parameters are influencing the effects of each another on temperatures …

But it needs to be said, that:

- It's difficult to indicate an specific amount of green volume and possibly other conditions of the researched parameters, to guarantee maximum adaptation-potential to rising temperatures
- Still - if a defined temperature change shall be adapted, required dimensions of e.g. green can be estimated (see beyond)

Basically the explaining value of green-volume and surface-sealing was shown - with complex and diversified relations (R^2 fits of 0.65-0.85). It's reasonable, reflecting the findings of the analyzed *Potsdam-data*, to get the indicators green-volume and soil-sealing accepted as standard-indicator to prepare adaption to climate-change. To do this, some core-points before defining the indicators shall be mentioned and recent study-results addressing GV and VG shall be reflected again.

5.1 First reflecting of other study results regarding Potsdam

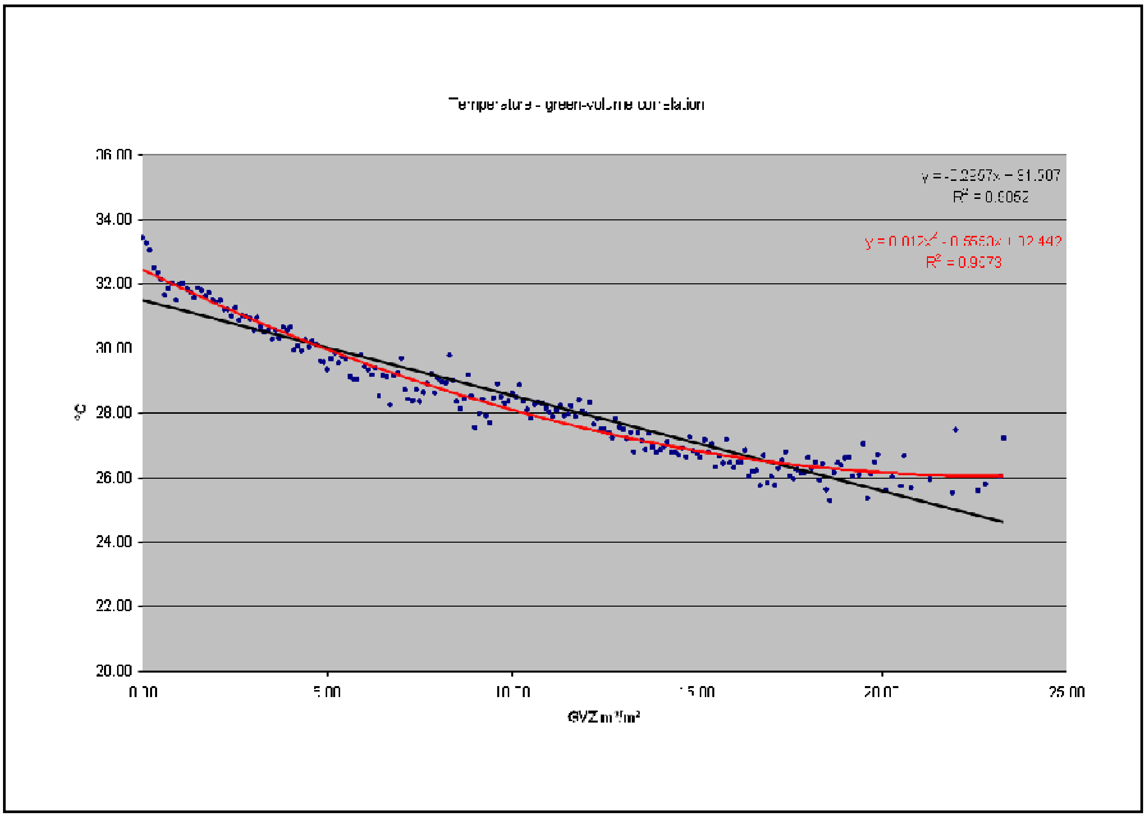
In other studies and research (as presented: e.g. for Manchester: Gill 2006, ASCCUE 2007, Dresden: Meinel 2006; Meinel, Hecht 2008, New York: Rosenzweig et al., 2009) data were often summarized in regard of land-use-structures. For Manchester e.g. into the urban morphology types (UMTs): primary 12 and detailed 29 resulting in 9 surface-cover-types in regard of estimated green volume - in other words land-use-units (Gill 2006, 2007). So to process the GV and VG-parameters they were summarized into a very few categories.

The visual estimation in regard of green-volume and soil-sealing is as Frick (2008) could show analyzing data for Potsdam in many cases miss-leading to achieve accurate results. Extreme values are preferred and medium values are less present (Frick, Annett, 2006(), Luftbild Umwelt Planung GmbH and Frick, Annett, 2008). For Potsdam very accurate data are available and used (many processed automatically – see chapter 2), which is outstanding. The data are fulfilling demand on high quality for the local level. The issue is pointed out here to mention needs to address local specifics and demand of processing-requirements and standards, Thus they're not always achievable if local conditions shall be addressed and sometimes even best technical proceedings are not sufficient to understand all local interactions as analyzed here regarding land use-influences. If the aim is to define measurements less accurate data can still achieve success to promote a certain development e.g. in regard of climate-adaptation via GV.
Adding to this issue, it's difficult to compare data of different localizations (e.g. Potsdam, Manchester, New York, Dresden) since the units are usually measured and defined in very specific ways and towards complex units. Even when it is possible to adapt those, they're not easy to be used when other standards are common. Looking at Germany where even the standards for cadastres of land-use are limited to be compared (e.g. in Germany the standard for ATKIS: Krüger p. 79-93 and Walz, Schuhmacher p. 201-217; 2010).

Thus summarized data are helping to highlight an overall trend. The smoothing of data-varieties, which was done with the Potsdam-data, too is leading then possible to a definition of a simple indicator. As presented: depending on the way of the processing, green-volume can reach an explaining value for temperatures of up to 0.9R^2, when as done with the sample-data of Potsdam is summarized in blocks of values with one decimal-digit and the related mean-temperatures (still representing 211 cases). In regard of other factor-influences this image is miss-leading and provoking overestimation of green-volume-influences. Out-breakers are already not visible any more, with a summary to a number worth 0.02% of the original data.

Findings based on estimated green-volume and soil-sealing-data are as such helping to reflect the overall-situation and defining demand for e.g. masses of health-supporting green-volume to adapt to climate change and expected rise of temperatures. So it's very helpful to develop a reliable sizing of indicators. The GWR results, based on spatial relations, with up to 85% model-fit justify using the indicator, regardless estimated for certain landuse-patterns or more specific local conditions.

A calculation based on estimated green-volume and soil-sealing-data as done for Manchester (ASCCUE, Gill 2006, 2007) and at least for Dresden (Meinel, Hecht 2006, 2008), too is benefiting to adapt to climate change and expected rise of temperatures.



Picture 31 - repeating Picture: graph of GV temperature-correlation - here without recognizing frequencies linear R² 0,905, quadratic R² 0.957 (Microsoft-EXEL-graph)

5.2 GVZ/VG- formula for Potsdam

Following the formula in the picture above (y = -0.2957x + 31.507 for R^2 = 0.9052 - IBM linear R^2 0.952 **including frequencies**) – shown already, adding 1m³/m² green-volume leads to a reduction of about 0,3°C surface temperature[166].

As the **average green-volume of settlement-biotopes** is little more than 3m³/m² (in average on a space almost 50% soil sealed) someone would need to little more than double the green-volume to reduce temperatures for about 1°C. This is equivalent adding at least (good) **6 m³/m² on the remaining free-space,** what is already the volume of a little tree (5-6m height and about 2 m width) or bigger bush (Großmann Max, 1984(), Großmann Max and Schulze, 1987). For wooden vegetation it can be expected that it's possible to implement such volume. Other vegetation would be viewed as additional support, but not leading to a significant change and adaptation-possibility to higher temperatures, as long as using the GVZ-parameter. Still other vegetation is of

166 - based on a temperature range from about 25-33°C: measured conditions of the 10th July 2010

even high benefit to reduce heat-influences (e.g.: Rosenzweig et al., 2009(), Meier, Fred, 2011).

Based on the Potsdam 2010-data, locations e.g. 50% sealed are showing a Green-volume from 0.14-8.13 m^3/m^2 and temperatures of little more than 27°C to 37°C. The trend between more green and less heat is visible controlling the data, even when not only indicating green-volume-influences to reduce the temperature. The GV-values are showing, that there is quite a span on many locations to implement more green (0.14-8.13 m^3/m^2). **To add a small tree, soon reaching 6m^3/m^2 to reduce temperature for about 1°C, seems realistic at many locations.**

Looking at specific (geographical) localities conditions, the picture could easy mislead interpreting circumstances. The variety of data of many factors influencing temperatures and the variables behind is to some extend too heterogeneous, to be used without further research of other influencing factors.

On the other hand if planers are cross-checking with local specifics and influences, the findings of effects of GV could be used as an estimate for orientation to implement an effective amount of green:

- it can be recommended to be used relative to better results
- specifically in Potsdam and similar climate-regions

Since the PIK[167] was expecting a rise in average Temperature till 2050 for about 2.5°C and specifically a health-challenging rise of days with extensive heat and tropical nights (Lüdeke and Walther, 2014), it would be of benefit to cut the heat-peaks, too.

To define a first starting-point to address climate adaptation-measures via green-volume (for Potsdam) and to be used as indicator relative to better results, the following estimation-formula could be used:

$$(1)\ GV_{eq} = 3^{1}/_{3}\ m^3/m^2 \triangleq \Delta V = 1m^3$$

- "GV_{eq}" being the GV-equivalent to adapt to 1 unit temperature-rise (1°C) and V for volume m^3
- "GV_{ad}" would be the needed GV to reduce a postulated temperature-rise [Δ°Temp] meaning the "GV-adaptation-mass" in m^3
- The GV to adapt to a certain heating effect for a certain space could be defined

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then as follows:

(2) $GV_{ad} = \Delta Temp * GV_{eq} * 100/VG$

- VG being the % of soil-sealing of the addressed area

Calculating GV_{ad}, it's possible to see if GV_{ad} as postulated GV is realistic to be implemented on a certain area. If it's not feasible the adaptation and production of healthier living-environments via GV is not possible and the environment is in that regard unsustainable, if not other measurements like e.g. implementing cooling water can be considered. The formula (2) could be used with negative values for decreasing temperatures as well.

The formula needs verification especially in regard of soil-sealing. The processing of VG related with temperatures produced a linear correlation and a possible formula to calculate it. A rise of soil-sealing is provoking a certain rise of temperatures. If $\Delta Temp_{VG}$ is defined as the VG-related temperature-change, it needs to be added to the calculation of GV_{ad} :

(3) $GV_{ad} = \Delta Temp_{VG} + \Delta Temp * GV_{eq} * 100/VG$

- When ΔVG [%] is defined as the change of soil-sealing per unit (equivalent to the total max. 100%: total sealing of a given space and min. 0%: no soil sealing), the formula for the soil-sealing-change related temperature would be:

(4) $\Delta Temp_{VG} = 0.03 * \Delta VG$

- … as long as model-results detected so far are used, where 1% soil sealing is leading to a temperature-rise of 0.03°C[168].

For the formula which is based on a 75%-model fit of the summarized data or up to 80% fit of GWR-outcome counts even more than for the GV formula:

- it can be recommended to be used relative to better results
- specifically in Potsdam and similar climate-regions

It's strongly recommended to verify the results and to adjust the formulas. As mentioned at the beginning of chapter 4, presenting the DWD-measured temperatures for the given day (9th July 2010), the day was representing a hot summer-day with air-temperatures of

168 Temp. = 0.03x : e.g. 10% soil sealing leading to a temperature-rise of 1°C

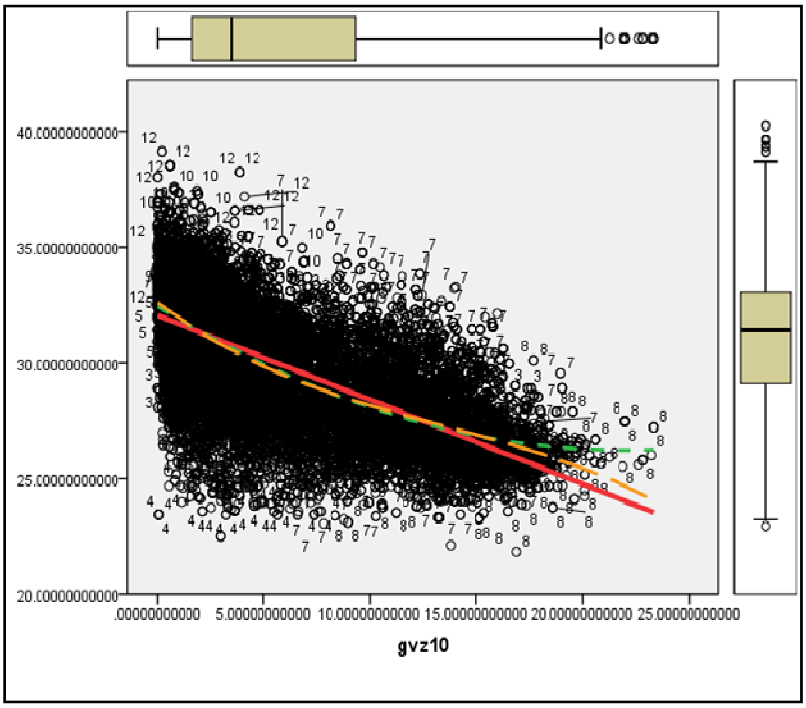
up to almost 39°C. Given the temperatures of the calculated model-results they are based on a day which is suitable to address high and health- challenging summer-temperatures. As such the adaption-degrees of GV and risk-degrees of VG presented here are accounting for to be used as a valid measure to address climate change-related effects on living-environments.

Cross-correlation between GV and VG could be seen all the time processing the data. It even resulted in a weakening of the model-fits (R^2-adjusted) in the way that a single-variable regression result was stronger then the two- ore more variable processing (GWR). When calculating influences, as said in the introduction and still after the presented analysis, the two variables currently need to be seen additional rather then combined. The presented formula follows this finding. On the other hand it will be of interest, if to address local conditions and if to allow an accountable monitoring, that the relation between the two indicators is further clarified. To produce a simple indicator-formula would be of high benefit for spatial and land-use-planning. Some first tests during the presented research, to bring the indicators green-volume and soil sealing together in one formula, couldn't achieve the results (model-fit) processing them independent. Best results were reached multiplying green volume by 2, subtracting it from soil-sealing values. For this **further research** could be interesting to define a “full covering” or complex (combined VG and GV) indicator, helping to find the balance between construction (VG) and additional structures like green (GV) and if possible water in one step.

5.3 Further reflecting of other study results

Gill (2006, p 122) postulated a temperature reduction for Manchester of up to 2.2-2.5°C if 10% GV is added to a high-density environment: *In high-density residential areas, for example, maximum surface temperatures in 1961–1990 with current form are 27.9°C. Adding 10 per cent green cover decreases maximum surface temperatures by 2.2°C in 1961–1990, and 2.4°C to 2.5°C by the 2080s Low and High emissions scenarios, respectively … if no change was made to surface* cover.

10% rise of GV as indicated for Manchester (Gill 2006) wouldn't be enough to compensate the e.g. PIK-defined temperature-rise of 2.5°C for Potsdam for 2050 (Lüdeke, Walther 2014). In the case of average-settlement-areas for Potsdam: 50% sealed environments with an average green of $3m^3/m^2$ present one would need $8^1/_3$ m^3 which is a much higher percentage GV-rise. If one focuses more sealed environments with less GV the effect calculating in added GV% is even worse. The only sign of Potsdam-data fitting with the Manchester-data can be observed looking at scatter-plots of the whole Potsdam-data-set, where quite some data points suggest a stronger influence of initial – first green on temperatures then compared to cases where some green is already present (see graph beyond and data range of little gvz compared to temperatures – left scale). Regarding the Potsdam-data the uncertainty of the amount of how much already little GV is influencing temperatures higher than the definition of influence of higher GV (compare chapter 4 graphs on range of temperatures correlated to GV).



Picture 32: band-width of data addressing GV (gvz10: bottom) and temperature (left) – correlation incl. different regression graphs (linear, exponential …)

Findings of many studies like for New York (Rosenzweig et al., 2009), Berlin (e.g. Meier, Fred, 2011) and Stuttgart (Reuter, Ulrich, 2013) and others (Smith and Lindley, 2008(), Stocker, 2014(), Snover, A.K., L. Whitely Binder, J. Lopez, E. Willmott, J. Kay, D. Howell, and J. Simmonds., 2007.) suggest a high influence of green-cover like roof-greening or vertical greening. The given parameters couldn't be covered with the Potsdam data-background.

Calculating with a %-background like for Manchester is making it complicate to compare results, when on the other hand it contributes the implementation of measures. The GV needed for a 10%-rise would be easy to be implemented in many environments – and still benefit living-conditions.

If heterogeneous structures shall be addressed to define measurements on local ground there is a difference compared to measurements on regional level. The same counts comparing a total-community with a specific settlement-area or “living-block”. Measures defined in Manchester (Handley and Carter, 2006), Dresden (REGKLAM-Partner, Dresden, 2013) and possible for Potsdam would, using the current data-background, address the regional to community-level and would need adjustments on local level (support with further expertise to take care about specifics “on the ground”).

The present research was addressing land-use-specifics (biotopes) in relation to GV and VG as well. When the land-use units are more summarized, as done in Manchester[169] effects are similar as presented above. When presenting summarized dependencies between soil-sealing, green-volume and surface-temperatures (with an estimated GV, VG) which was done with the reduction of the Biotope-code to 4 digits, it lead from about 55% for all data (OLR) to a 84% - model-fit. Different Influences for this effect were mentioned in chapter 4 already, like density of construction resulting either in heating or cooling. First now before coming back to other influences on temperatures not covered in detail with the research, the specifics found out and related to land-use shall be shown again and discussed.

5.3 Specific land-use-patterns and influences on regression-results:

Smaller and tinier structures

Linear biotopes like streets, tracks, streams and small rivers as well as smaller structures as such, like pounds are often influenced by neighbour-structures and biotopes. Structures of about only 10-15m width or less are effected. The calculated and expected temperature-effects of indicators are often not fitting with measured values. Looking at the land-sat-data-resolution of about 30m/30m at its best 1st the mean-temperature-calculation is likely to be wrong, covering the whole environment around including the small structure with in many cases different GV, VG and other parameters then the surrounding dominating the Landsat image-values. 2nd if calculations on a spot are all right, linear structures are likely summarizing influences of many neighbours, so that the results are accidentally fitting rather then due to real coherence. Both effects count for smaller structures in general. Filtering out polygons either ≤ 30, 45 and 60 m² detected no significant change of regression-results. They need to be addressed with different methods.

169 See above => urban morphology types (UMTs): primary 12 and detailed 29 resulting in 9 surface-cover-types in regard of estimated green volume / in other words land-use-units (Gill 2006)

Undetected green

Bare soils or grass-land with initial growth of encroaching woods, fallen idle grass-land under ruderal vegetation and reforestations or new plantings - all cooler then expected: Upcoming vegetation could have cooled down the environment already but having not detected as expected green-volume for such cooling.

Artificial influences

Agriculture: It's important to highlight the conditions of intensive and other agriculture (arable land, acres, grassland) which lead to an exclusion of those datasets: Hotter then expected, green-volume-data are not as reliable as in other areas. The rise from 7^{th}: 0.613 to 8^{th}: 0.655 OLR-step and outlier-exclusion were showing most effective results of all OLR-processing-steps. The land-use-structures are suggesting land-use-related influences: Due to cultivation influences through e.g. harvesting (where detected green is not present any more biotopes and calculated green volume based on end of may data – temperatures mid of July – data) and possible draining (dryer then biotopes and soil are suggesting). It can be a sign for unsustainable conditions (absence of bound water).

Other artificial influences: Parks and structures under military use, where temporary influences of e.g. cuttings and watering could have influenced the results were detected with high StdDev of residuals. Such artificial influences could have lead to detect full biotope-code-groups (biotopes of same coding). Further research could produce explanations leaving a question mark now.

Almost stable estimates (Forests and wooden vegetation):

The forest-green-volume-data are more accurate due to that they are less estimated (as e.g. green-land). They are measured as outcome of DEM/DSM[170] - subtraction and less vulnerable about variations of short time artificial influences (e.g. harvest). The relatively weak local regression-results of some forest-areas need further research (specifically GWR). There was no satisfying explanation found so far. The wood-dominated biotopes are often showing no soil sealing. So the Regression-analysis is limited to one factor, thus allows to set the focus on the GV-temperature-correlation. The average of local R^2 of GWR-processing is better than of other biotope-classes (compare chapter 4.3.2 on GWR and Table 17). The forest (group-8) GWR-values are indicating well explaining data.

170 digital elevation model DEM, digital surface model: DSM

Settlements and other artificial special structures:

Separated processing for the group 12-biotopes (settlements) is generally indicating their relevance (OLR rank 3, GWR rank 1) which is in regard of possible measurements based on the study results (heat-adaptation with green) of high interest. A lot of artificial influences can disturb the used green-volume-estimates, e.g. watering, excessive cultivation (see above). There are prominent samples of under- and overestimating the temperature-influencing factors (GV, VG...).

Hotter then expected are: sport-grounds and distance-green space – most likely due to intensive green-care and for hotter situations the influence of neighbour biotopes (e.g. hot streets). Modern city-centres are hotter then expected, may be because of building and construction- influences, primarily provoked in combination with high soil sealing.

Dense settlement and specifically industry-areas can be indicated as well. They shall be addressed, today showing very little green and high soil sealing (compare Picture 33 f – orange areas and see about the "general phenomenon": Benden, Jan and Riegel, Christoph, 2012 () and Greiving Stefan et al., 2011[171]). They can be defined as risk areas to adapt to hotter living conditions, many people being active there during daytime.

Both directions: Dense settlements occur because of effects of exposition and resulting cooling or heating of buildings and environment. The influences behind were not detected as part of the present study and need research for other influences (some explanations, se e.g.: Greiving Stefan et al., 2011() ,Baumüller, Nicole, 2012).

Cooler then expected are Castles may be due to good embedding with vegetation or watering or another aspects like exposition and design / construction (copying Mediterranean design).

Bound and free water:

Above is mentioned that for intensive agriculture (arable land, acres, grassland) the day-time-hotness of the structures is a most-likely sign for unsustainable conditions and absence of bound water (Pokorný, Jan, 2010 (), Kovářová, Milena, 2011). GV and VG as indicators were not covering those influences.

The less good OLR-results (0.626 compared to 0.655) when excluding water bodies contrary to results, achieved before outlier-detection and introduction of further variables, showed the effect of alternative implemented variables (I3-I6: see chapter 4 and 3). Water-bodies are addressed and explained with the indicators 3-6 that the regression is more optimized, then that water-bodies would be still weakening the

[171] With English summary!

regression-results. Wooden vegetation then tends to hold water within the vegetation more than the shrub- and grass-vegetation or crops. The last tend to loose bound water when hotter temperatures and harvest-time come close. The same counts for lawns (more beyond). The water is assisting cooling the environment (Kravčík Michal et al., 2007).

Other effects (and more on water):

After OLR-processing some few areas with higher StdDev were remaining in the dataset which are all indicating specific land-use-influences (artificial influences) looking at the biotope-code already. They could be addressed with further research. Special interest could be given to moors and swamps due to that they may of special interest in regard of climate-change beside adaptation-influence, when intact (having enough water / wetness[172] :(Wichtmann, Wendelin and Haberl, Andreas, 2012(), Arge Integriertes Klimaschutzkonzept für die Landeshauptstadt Potsdam, 2010).

This is a statement to use the additional variables I3-I6 specifically when addressing the whole data-set and when not concentrating specifically on the value of green-volume and may be soil-sealing as it is the main aim of this work. Some of the GWR-results contradicted OLR-results or focusing on larger areas, giving space for further research (see chapter 4), where a further research regarding water-influences in the direction of indicators 3-6 could help.

The Clustering was suggesting bordering water-influences. Not to forget the cooler areas in regard of always included bigger water-bodies, almost in their centre. Additional this may be indicating relief-influences as well (Northwest), addressing low-land (depression).

- Global influence leading to patterns where
- around water conditions are cooler then the average environment
- in settlement-areas where with increasing density and space covered conditions tend to be even hotter- then model-expected. Bigger settlement-areas are even influencing smaller water bodies to be hotter then expected

The effect is known from bigger agglomerations where spatial planning is addressing the effects (e.g. Berlin STEP-Klima 2012, pages 14ff: GEO-NET Umweltconsulting GmbH, 2011() and (Brandl et al., 2010). Then a more global influence in the respective direction can be expected (settlements provoking hotness and lakes and forest provoking cooling from width of 1km-1.5km and bigger onwards). It seems that bigger

172 Compare recent study wichtmann joosten 2012: http://www.potsdam.de/sites/default/files/documents/Leitfaden-Paludikultur_2012.12_21%5B1%5D.pdf and unpublished 2014 using the sample of Potsdam “Koordinierungsstelle Klimaschutz”: Koordinierungsstelle-Klimaschutz@rathaus.potsdam.de

homogeneous areas are influencing smaller once. Research from which space onwards covered with similar structures a more global influence in the respective direction can be expected or not would be of interest.

5.4 General patterns – independent variables – indicators towards further steps

Biotope-information assists to identify local specifics. Water and other land-use specific influences can assist green-volume-effects reducing temperatures. When combined as in the Arabic and Mediterranean gardens, where water is often part of the gardens, it's cooling the local environment (Baumüller, Nicole, 2012). For spatial planning, this leads to the question or even concept of availability of water as cooling effect in combination with green.

The in the introduction postulated limitation of especially trees on public and open spaces, to allow faster cooling at night isn't generally advised, reflecting the results of the analyses and shall be limited to cold-air-influx-areas, which have a special role to guarantee a change of air in settlement-areas (slopes, hillsides, lakes, riverbeds…). If those steps are to be gone, focus could be on otherwise cooler environments (e.g. lake, meadow- and forest-surroundings). The guide line would be to address local specifics to produce locally to climate-change adopted environments, e.g. local wind-exchange-systems … (Baumüller, Nicole and Baumüller, Jürgen, 2010).

From which point onwards one could speak of relevance of green influencing temperatures was described above. Many factors are contributing to influence temperatures. Reflecting the study-results, especially wooden vegetation is effective, even when other vegetation is contributing as well. Wooden vegetation is as well holding the water most likely for longer periods then other vegetation ("is sustainable"). An estimate to define a potential to adapt to rising temperatures with vegetation (GV) and to calculate rising risk (VG) was given, but needs further reflexion. VG is a risk factor, reflecting the present research, which needs further attention addressing local specifics.

The summarizing of data like in Manchester helps to define corner-points for development addressing effects for climate adaption and -risk.
Local patterns can vary a lot but still the direction to understand and address circumstances counts (GV hindering warming, VG increasing heat). Possible indicators to identify general or better regional potentials have been presented here with VG and

GV. The biotope-structures can assist to specify possible local demands and potentials – including water. Potsdam spatial planning could do a lot of benefit, proceeding with systematic steps to address climate adaption as done successfully at other places as well (e.g. Lenk, Thomas et al., 2008(), (Frommer, Birte and Schlipf, Sonja, 2008 (), Lang Markus, 2012)(Baumüller, Nicole, 2012). In some areas of spatial planning Potsdam was pushing hard to implement more green into working- and industrial environments. This track needs to be followed when those structures shall be sustainable for the future – ready for climate change – in the coming years may be benefiting on top as well of experiences of other communities like Aachen as part of the ExWoSt-project (Benden, Jan and Riegel, Christoph, 2012). Aspects addressing water management and keeping it save within the settlement areas shall not be left out than (Fink, Johanna, etal., 2012). This will benefit and stabilize green (temperature-buffering) structures as well.

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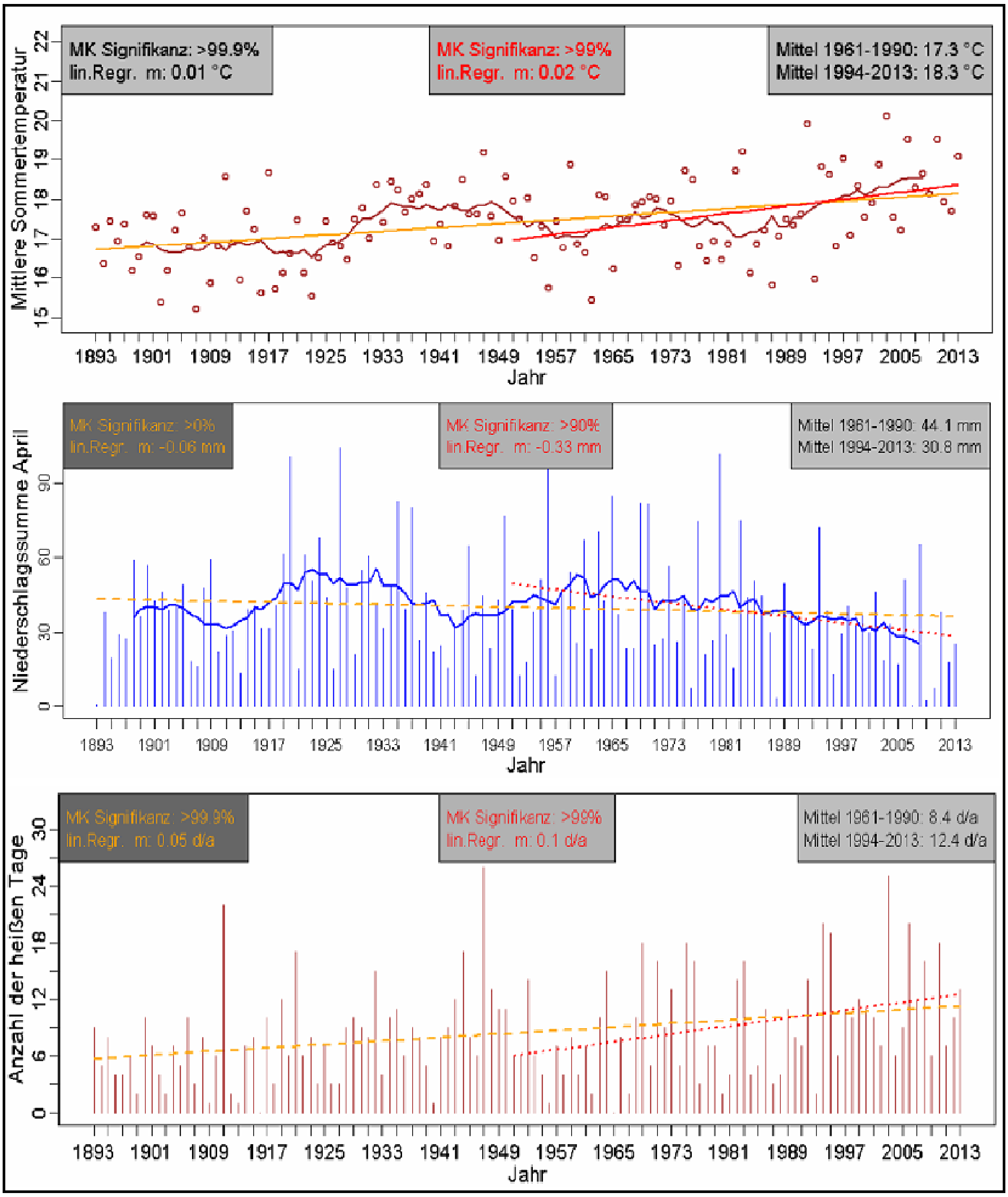
Annex

Annex chapter 1:

Biotope-Class	**Bio-Class No.**	**COUNT**	**MEAN_Area**	**MIN_Area**	**MAX_Area**	**RANGE_Area**	**SUM_Area**
Flowing open water-body	01	275.00	32130.01	31.11	1894990.94	1894959.83	8835752.45
Stagnant open water-body	02	342.00	28393.72	12.45	2124433.46	2124421.01	9710652.98
Bare-soil (Veg.-free)	03	771.00	4288.15	3.32	252563.48	252560.16	3306164.72
Moor and Swamp	04	290.00	9503.48	3.50	139762.15	139758.65	2756008.30
Grassland and pasture	05	2511.00	12114.23	6.03	295968.21	295962.18	30418829.79
Heather	06	19.00	41501.71	2961.44	225708.03	222746.59	788532.49
Woods ("bushes")	07	1780.00	4193.67	14.78	323991.63	323976.86	7464732.39
Wood and Forest	08	3627.00	13743.14	1.84	315786.94	315785.10	49846366.94
Fields and farmland	09	453.00	60510.88	28.00	835681.18	835653.18	27411426.67
Green space and parks	10	1549.00	4721.14	5.66	48219.35	48213.69	7313043.51
Special landuse	11	35.00	8047.32	62.34	70774.41	70712.07	281656.08
Settlement	12	6623.00	6049.68	0.00	755664.41	755664.41	40067053.25
SUM		18275.00					
m²			18766.43		2124433.46		**188200219.57**
ha			1.88		212.44		**18820.02**
km²			0.02		2.12		**188.20**

Table 18: Biotope-classes of Potsdam – core-values



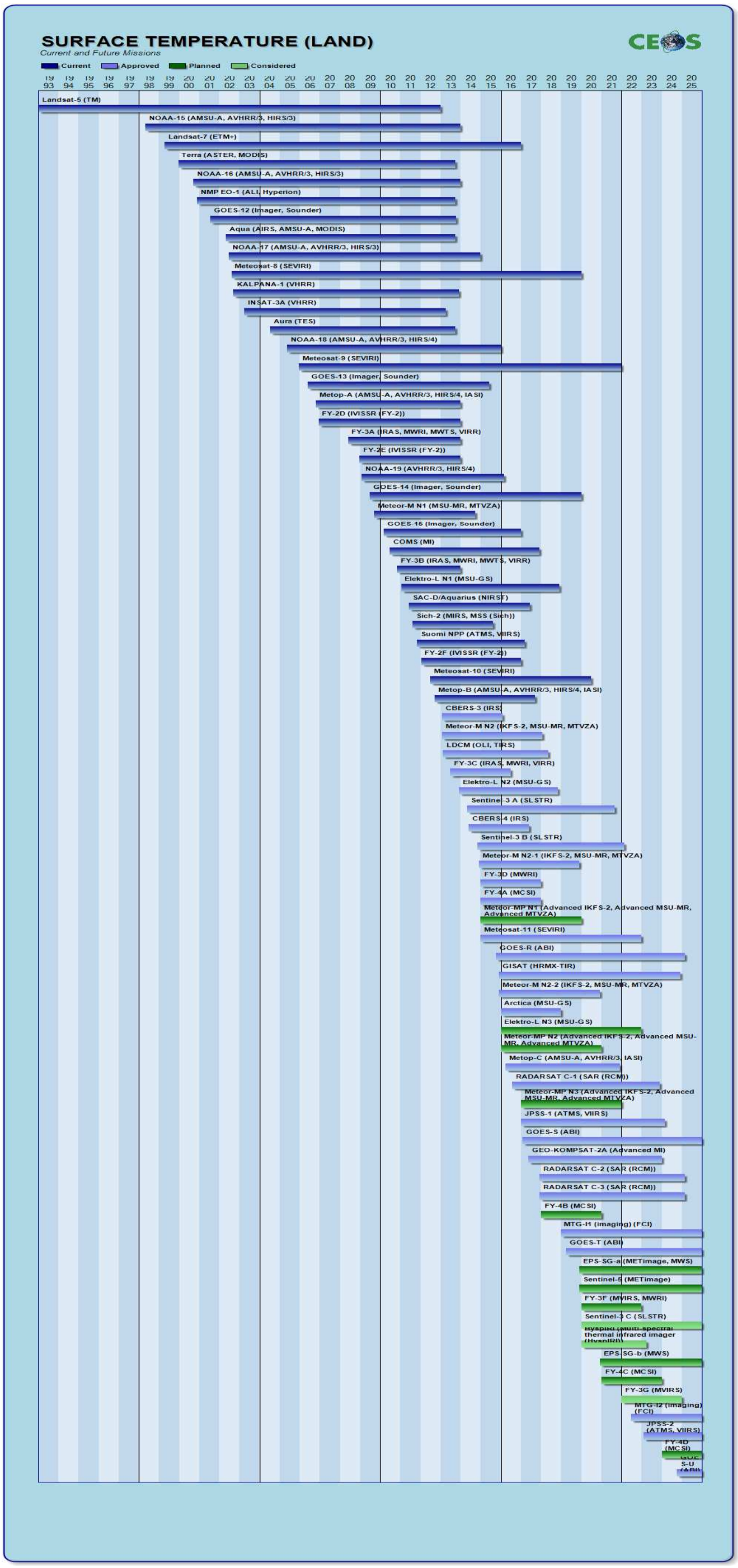
Picture 34: first results of research regarding climate-developmentfor Potsdam (Lüdeke and Walther, 2014)

1. *Median (Mittel) summer-temperatures for a specific year (Jahr) with rising tendency*
2. *rainfall sums (Niederschlagssumme) April for a specific year (Jahr) with declining tendency*
3. *number of hot days (Anzahl der heißen Tage) per year (Jahr) with increasing tendency*

Annex chapter 2:

Data files and names as described in "README.GTF" are added to every scene-download of NASA (GEOTIF-level1 -product). Further Info: NASA 2013: Landsat 7 Science Data Users Handbook (USGS U.S. Geological Survey, NASA, 2013a) Additional in the USGS - documentations and specifications regarding the provision of Landsat-images.(USGS U.S. Geological Survey, NASA, 2013b)

CEOS[173]:



Picture 35: missions on surface-temperature CEOS

173 *CEOS*: the Committee on Earth Observation Satellites: esa 2013/14: Missions on surface temperatures – (esa and CEOS, 2013)

Annex chapter 3:

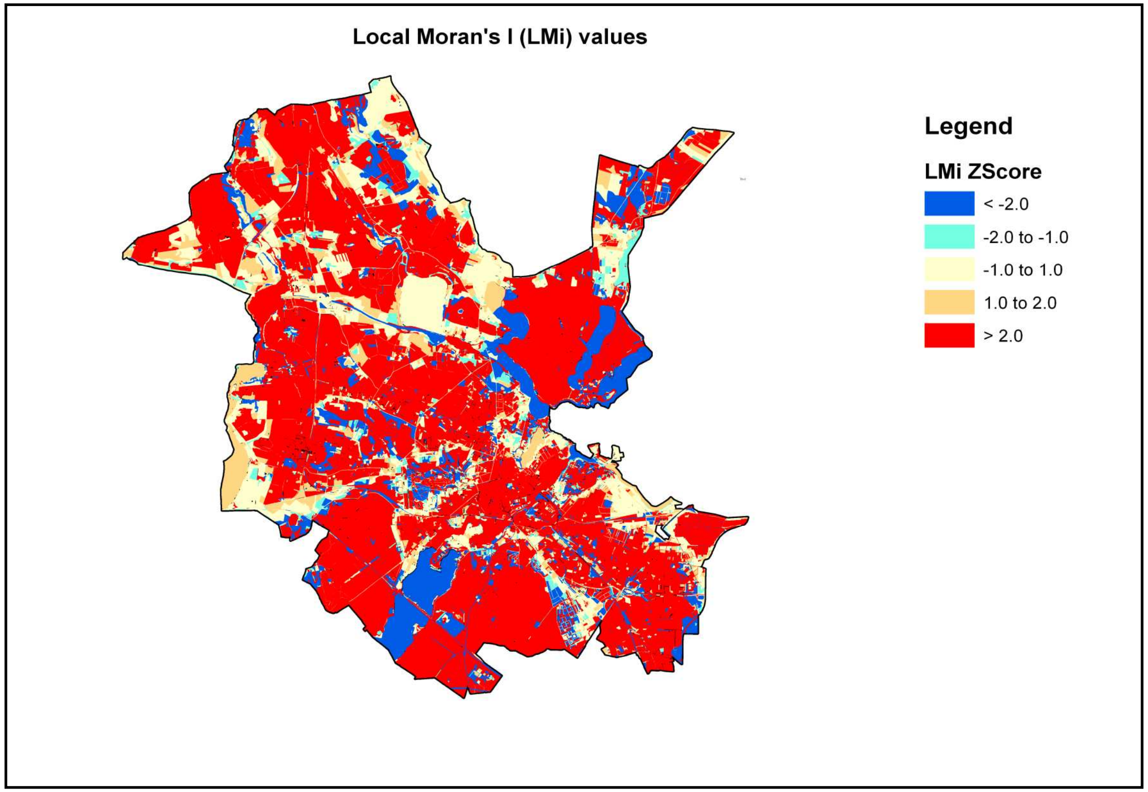
Indicator 6 (I6) – Biotopes: Biotope-codes used supposing influences regarding temperature-data after detecting OLR-deviation (processing-stage based only on I1 and I2)

Biotope-code	**Biotopes (groupes)**	**Factor – Value**
01	Flowing open water-body	-100
01 ** * * tr *	Fallen dry	50
02	Stagnant open water-body	-100
02 ** * * tr *	Fallen dry	50
03 10 * * *	Vegetation-free / bare-soil	50
03 ** 1 * *	dry habitat	75
03 ** 3 * *	wet habitat	-25
04	Moor and Swamp	-50
05 ** 1 * * * *	Grass and shrubs-dry	25
05 ** 3 * * * *	Grass and shrubs-wet	-25
05 15	Intensive grass	25
05 15 1 * * * *	Intensive Grass dry	30
05 15 2 * * * *	Intensive Grass moistures	20
05 15 3 * * * *	Intensive Grass wet	10
05 16	pasture	25
05 16 1 * * * *	pasture dry	30
05 16 2 * * * *	pasture moistures	20
05 16 3 * * * *	pasture wet	10
06 10 1 * * *	heather-dry[174]	25
07 10 3 *	Wet woods (willows)[175]	-25
08	Wood and Forest	
08 10 * * * *	Car / fen-wood	-25
08 11 * *	alder / ash - meadow	-25
08 12 * *	poplar / willow - softwood-meadow	-25
08 13 * *	Oak / elm - hardwood-meadow	-25
08 26 1 *	Cleared woodland / reforestation - dry	50
08 26 3 *	Cleared woodland / reforestation - wet	-25
08 28 1 *	Pioneer-forest - dry	25
08 28 3 *	Pioneer-forest - wet	-25
L/N/LN/NL * * 6 * *[176]	Forest wet chracteristic	-25
L7*	Black alder	-25
Checked but left out:		
08 10 * e * *	drained	25
09 13 * * *	field	25
09.13.1	Intensive used field	25
11 23 * * * *	sewage-farm	-25
*ri	Idle - left open sewage-farm	-25
12	Settlement / Industry	25
12 26	Harbour / port	-25

Table 19: Indicator 6 (I6) – Biotopes

174 Others e.g. wet (**3* *) not mapped in Potsdams territory
175 Others e.g. dry (**1* *) not part of coding
176 'L': leaf-tree, 'N': conifer

Annex chapter 4:



Picture 36: Local Moran I – Z-score map Potsdam (Border-areas with little score)

First OLR-results before and after outlier-detection

Biotope-Class		Green-volume m^3/m^2 GVZ10				Soil-sealing % VG10				surface Temperature °C				StdDeV				OLR[177]	GWR[178]
GROUPE	FREQUENCY	Mean	Min	MAx	Range	Mean	Min	MAx	Range	Mean	Min	MAx	Range	Mean	Min	MAx	Range	R^2-adjusted	R^2-adjusted
01	704	1.28	0.00	6.86	6.86	0.00	0.00	0.00	0.00	24.61	22.20	34.63	12.43	-0.51	-3.40	4.67	8.07		
02	792	2.23	0.01	14.00	13.99	0.01	0.00	3.60	3.60	24.96	**21.91**	33.29	11.38	-0.40	-2.94	5.22	8.16		
03	2186	3.18	0.00	17.40	17.40	9.42	0.00	97.40	97.40	30.97	24.97	36.66	11.69	-0.33	-3.47	3.11	6.58	0.215	0.403
04	540	3.93	0.05	14.26	14.21	0.13	0.00	12.60	12.60	26.02	23.45	33.33	9.88	-0.79	-2.83	3.73	6.56	0.23	0.365
05	7278	2.97	0.00	14.94	14.94	2.34	0.00	74.80	74.80	30.12	23.59	38.25	14.66	0.05	-3.57	4.23	7.81	0.149	0.397
06	53	2.89	0.30	7.53	7.23	0.07	0.00	0.30	0.30	29.27	26.95	34.01	7.07	-0.53	-2.07	1.93	4.00	0.355	0.355
07	5213	9.24	0.14	19.73	19.59	4.38	0.00	65.40	65.40	29.28	22.52	35.92	13.40	0.62	-2.92	4.12	7.04	0.756	0.396
08	10272	**13.16**	0.49	23.34	22.85	0.93	0.00	48.30	48.30	**27.01**	**21.84**	34.14	12.30	-0.06	-3.32	3.46	6.78	0.194	0.44
09	1981	0.88	0.00	5.47	5.47	2.05	0.00	88.70	88.70	30.52	25.02	35.69	10.67	-0.09	-2.75	2.92	5.67	0.075	0.235
10	6229	3.59	0.09	17.67	17.58	18.65	0.00	100.0	100.00	30.93	23.59	38.83	15.24	0.38	-2.98	4.05	7.03	0.192	0.477
11	96	3.25	0.80	6.48	5.68	2.25	0.00	19.40	19.40	31.78	27.41	34.25	6.84	0.83	-2.07	2.05	4.11	0.038	0.397
12	32412	**3.11**	0.00	17.19	17.19	**47.73**	0.00	100.0	100.00	**31.12**	24.25	**39.12**	14.87	-0.10	-3.90	4.60	8.51	0.353	0.537

Table 20: Data-spectrum Biotope-Classes and Regression-processing with added values of biotope-class-separated OLR and GWR-processing ***before outlier-detection***

1 Flowing water-bodies
2 Standing water-bodies
3 bare soil / brown fields
4 marshland swamp
5 grassland and meadows [179]
6 Hay + shrubs
7 bushes and woods
8 Forests
9 Acres – agriculture
10 parks and open spaces
11 special biotopes
12 settlements

177 OLR **O**rdinary **L**east square **R**egression
178 GWR **G**eographically **W**eighted **R**egression
179 incl. agicultural grass-land

Biotope Class		GVZ				VG				Surface-Temperature °C			
	FREQ.	MEAN	MIN	MAX	RANGE	MEAN	MIN	MAX	RANGE	MEAN	MIN	MAX	RANGE
03	2105	3.14	0.00	17.40	17.40	9.57	0.00	97.40	97.40	31.08	24.97	36.66	11.68
04	538	3.94	0.05	14.26	14.21	**0.13**	0.00	12.60	12.60	26.02	23.45	33.33	9.88
05	5601	3.16	0.00	14.94	14.94	**2.30**	0.00	71.40	71.40	30.03	24.26	34.01	9.75
06	53	2.89	0.30	7.53	7.23	**0.07**	0.00	0.30	0.30	29.27	26.95	34.01	7.07
07	5196	**9.24**	0.14	19.73	19.59	4.37	0.00	65.40	65.40	29.27	22.52	35.92	13.40
08	10178	**13.22**	0.65	23.34	22.69	**0.94**	0.00	48.30	48.30	**27.00**	**21.84**	34.14	12.30
09	1438	0.97	0.00	5.47	5.47	**2.02**	0.00	88.70	88.70	30.59	26.57	33.81	7.24
10	5960	3.62	0.11	17.67	17.56	18.19	0.00	100.00	100.00	30.84	23.59	37.46	13.87
11	96	3.25	0.80	6.48	5.68	**2.25**	0.00	19.40	19.40	**31.78**	27.41	34.25	6.84
12	17844	2.35	0.00	14.07	14.07	**42.80**	0.00	100.00	100.00	**31.60**	24.25	**39.12**	14.87

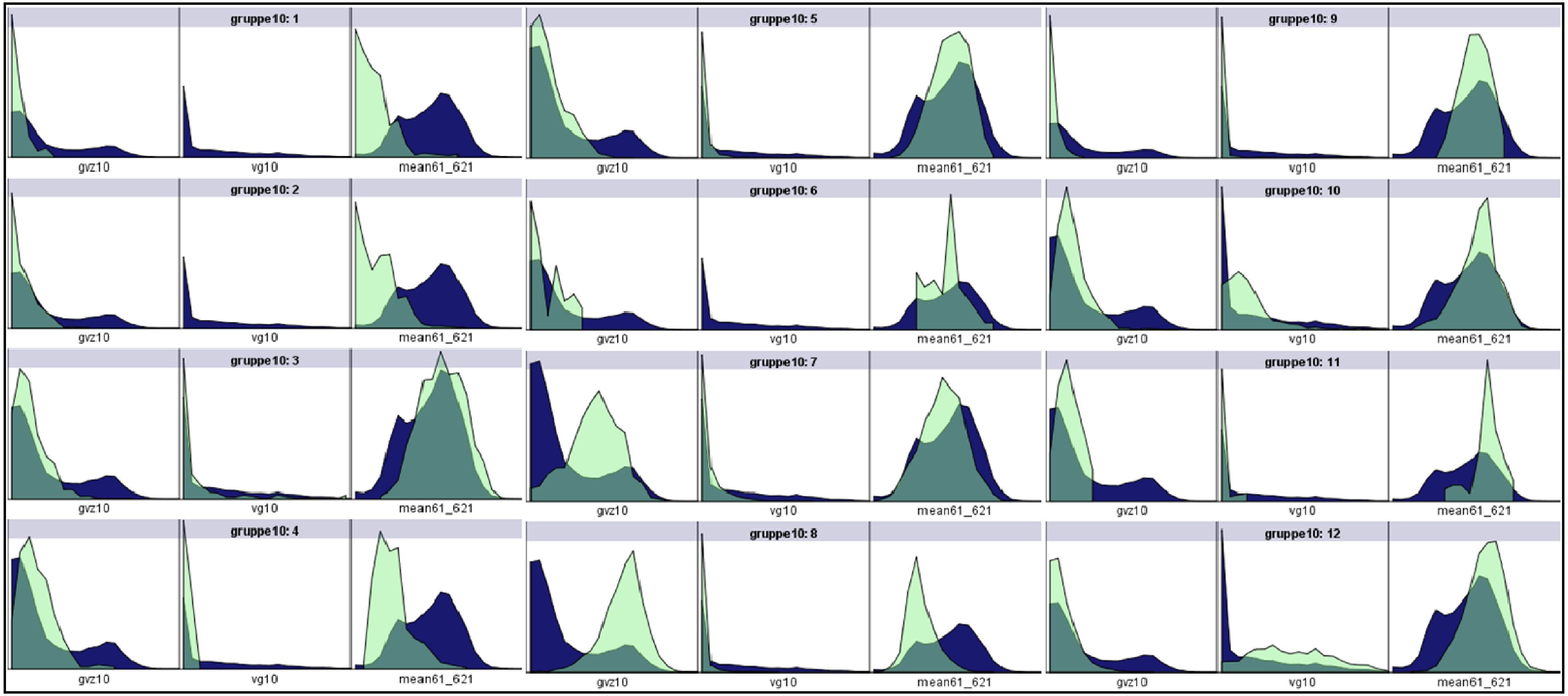
Table 21; Biotope-Classes ***after*** *OLR-processing and outlier-detection (9th step) regarding key-variables:*

Biotope-classes:

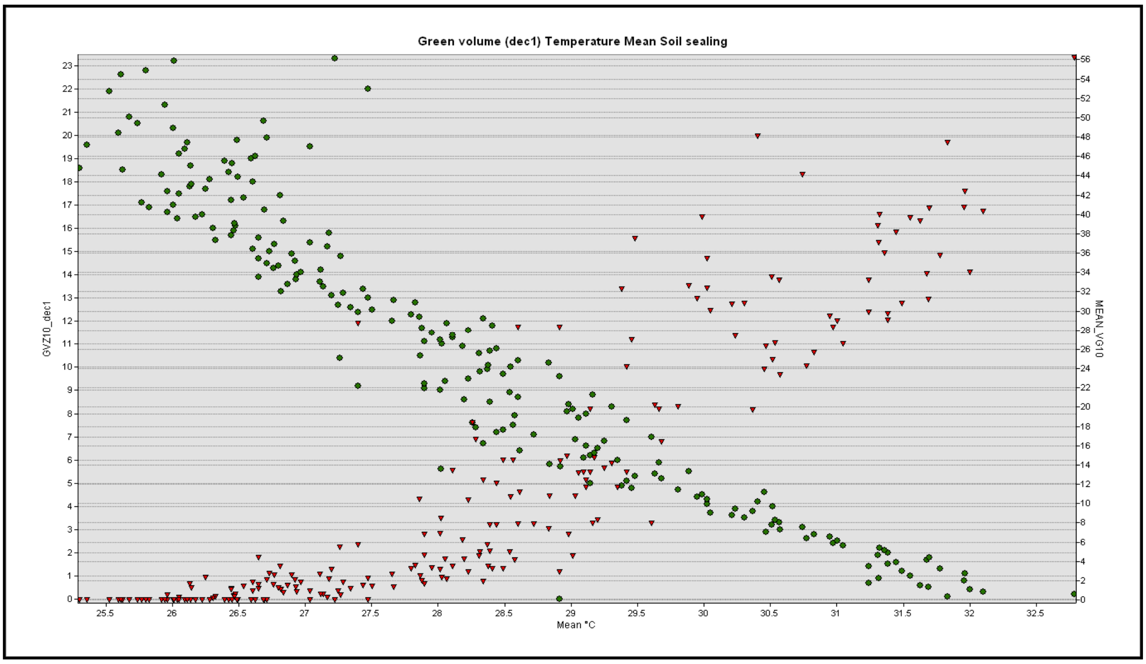
1 Flowing water-bodies	7 bushes and woods
2 Standing water-bodies	8 Forests
3 bare soil / brown fields	9 Acres – agriculture
4 marshland swamp	10 parks and open spaces
5 grassland and meadows [180]	11 special biotopes
6 Hay + shrubs	12 settlements

180 incl. agicultural grass-land

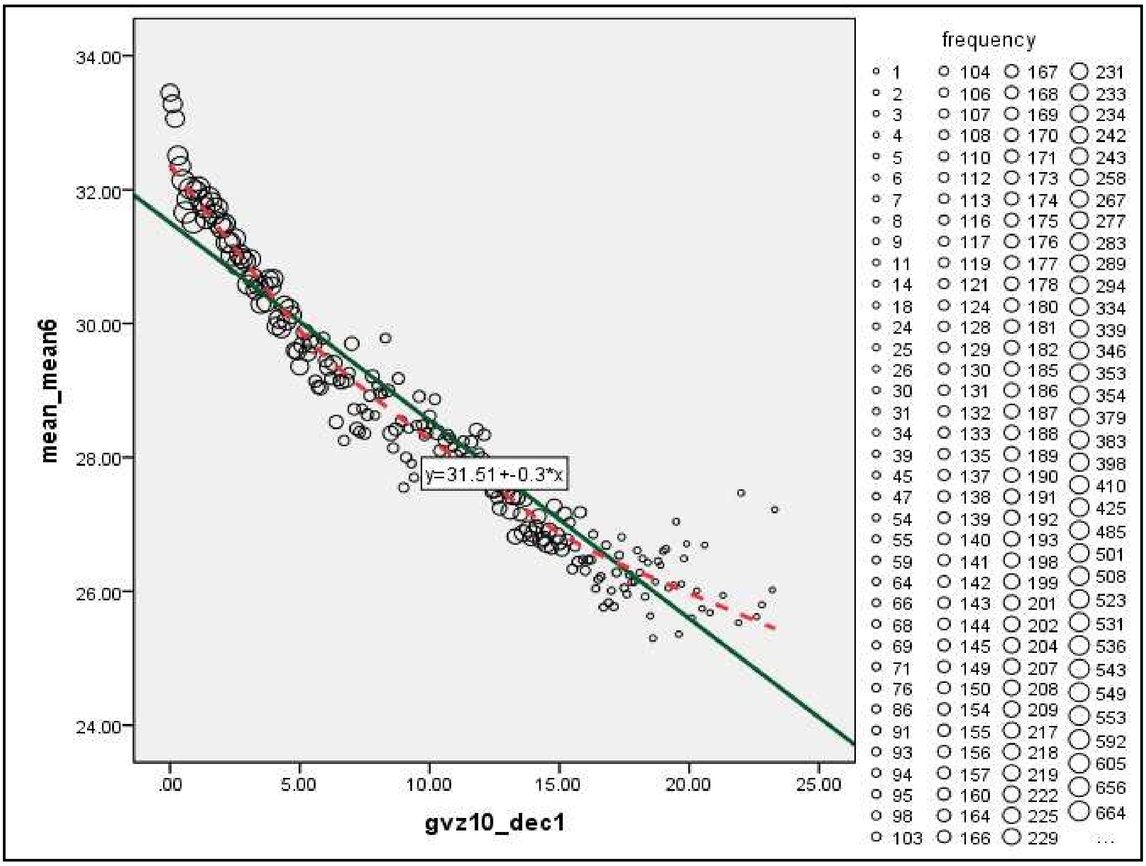
Results after OLR-processing and outlier-detection:



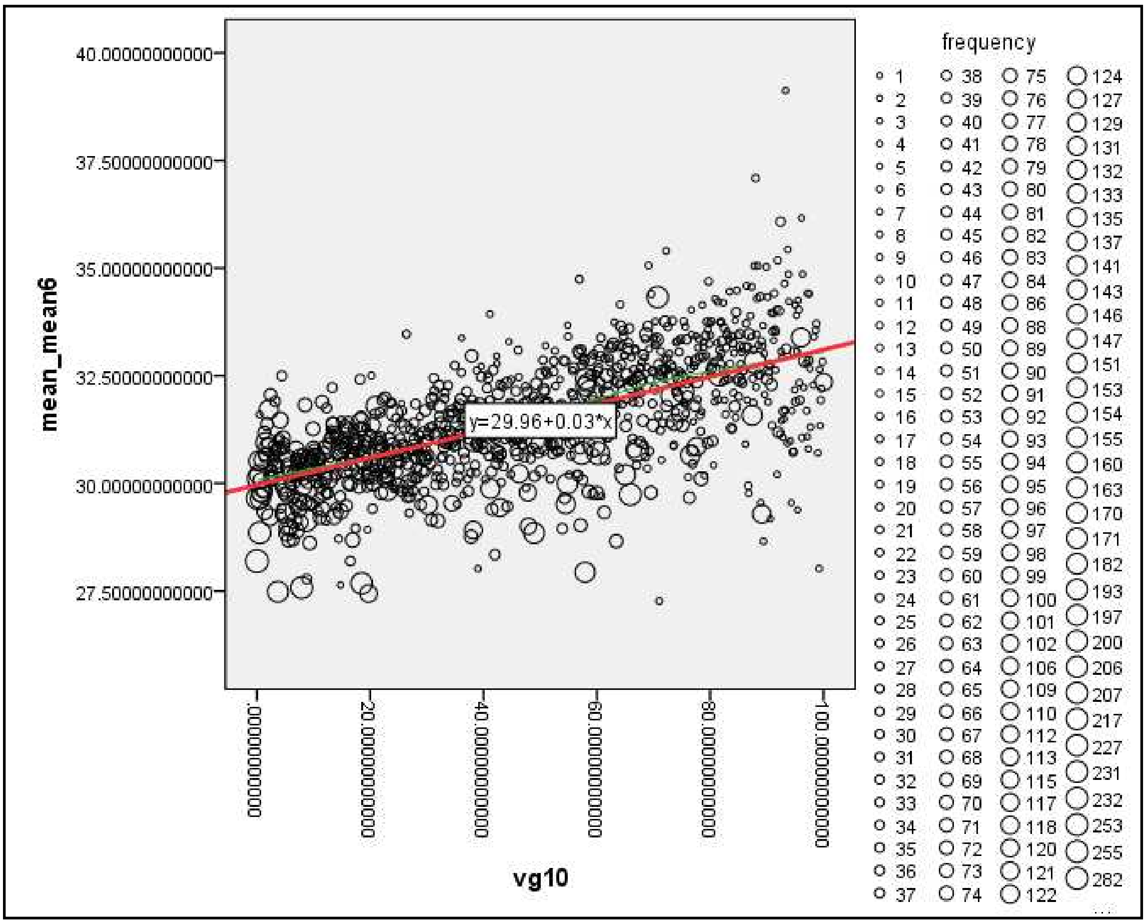
Picture 37: Data-spectrum Biotope-Classes looking at variables gvz (green-volume), vg (soil-sealing), mean61_62_ (temperature °C)
(graphs produced after 8th processing-step) highlighting the conditions overall (dark-blue) compared to group-specific conditions (transparent-green).
For group-numbers/ biotope-classes (gruppe 10:1-12) see one page above 1-12!



Picture 39: graph of green-volume (green dots) and temperature-correlation with added mean values of soil sealing (red triangle-dots) - ESRI-ARCGIS10-graph



Picture 38; graph of green-volume (gvz10) and temperature(mean) °C -correlation with added sample number (frequency) as dot-sizes. - IBM-SPSS-graph



Picture 40: graph of soil-sealing (green dots) and temperature-correlation with added regression-function soil sealing-temperature-correlation (dot-sizes standing for frequencies) - IBM-SPSS-graph