Climatic tourism potential in the North Sea and Black Forest region – a comparison between REMO and DWD data

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Abstract

Within the project CAST *("climate trends and sustainable tourism development in coastal and mountain regions")*, the climatic tourism potential will be analysed for present and future climate conditions for two different climatic sensitive regions in Germany: the North Sea and the Black Forest. Furthermore, analysing tourism trends, developing new products for sustainable tourism as well as establishing a communication and knowledge platform including e.g. adaptation to climate change are focussed in the project CAST and realized in collaboration with stakeholders. For the time being the analysis of the climatic tourism potential is based on the regional climate simulations (A1B) carried out by the regional climate model REMO from the Max-Planck-Institute for Meteorology in Hamburg with a spatial resolution of 10 km. Challenges and difficulties in modelling the extensive physics of the atmosphere and its interactions with the climate system are known. The question, how well can REMO simulate the present climate, will initially be answered by the evaluation with climate data of the German Weather Service (DWD) for Norderney, Titisee, and Freiburg for the reference periods 1961-1990 and 1971-2000, respectively. Besides precipitation and air temperature REMO offers some difficulties in modelling wind, cloud cover, and relative humidity. Orographical regions are characterized by an underestimation of precipitation and fog conditions and an overestimation of stormy days, whereas lowlands are characterized by an overestimation of precipitation, stormy days, and fog conditions. The analysis of DWD data allows a careful interpretation of the modelled data and an evaluation of model uncertainties.

Klimatisches Tourismuspotenzial für die Regionen Nordsee und Schwarzwald – ein Vergleich zwischen REMO und DWD Daten

Zusammenfassung

Im Rahmen des Projektes KUNTIKUM *(„Klimatrends und nachhaltige Tourismusentwicklung in Küsten- und Mittelgebirgsregionen")* wird das klimatische Tourismuspotenzial für das gegenwärtige und zukünftige Klima für zwei verschiedene klimatisch sensible Regionen Deutschlands untersucht: Nordsee und Schwarzwald. Weiterhin werden in Zusammenarbeit mit Tourismusakteuren Tourismustrends analysiert und Strategien sowie neue Produkte für den nachhaltigen Tourismus entwickelt. Ein zusätzlicher Schwerpunkt des Projektes KUNTIKUM ist die Erstellung einer Wissens- und Kommunikationsplattform, die u. a. Anpassungsstrategien an den Klimawandel beinhalten. Für die Analyse des klimatischen Tourismuspotenzials werden vorerst die regionalen Klimasimulationen (A1B) des Regionalmodells REMO vom Max-Planck-Institut für Meteorologie in Hamburg, mit einer räumlichen Auflösung von 10 km, verwendet. In der Modellierung ist bekannt, dass Modelle die komplexe Physik der Atmosphäre und die Wechselwirkungen im Klimasystem nur teilweise realistisch abbilden können. Wie gut REMO das heutige Klima simulieren kann, wird zunächst mit Hilfe der Klimastationsdaten des Deutschen Wetterdienstes (DWD) für Norderney, Titisee und Freiburg für die Referenzperioden 1961-1990 bzw. 1971-2000 evaluiert. REMO offenbart neben Niederschlag und Lufttemperatur einige Schwierigkeiten in der Modellierung von Wind, Bewölkung und relativer Luftfeuchte. Dabei werden im orografisch strukturierten Gelände Niederschlag und Nebel unterschätzt und stürmische Tage überschätzt. In der Tiefebene hingegen werden Niederschlag, stürmische und neblige

Tage überschätzt. Die Analyse der DWD Daten ermöglicht eine sorgfältige Interpretation der Modellergebnisse und eine Abschätzung der Modellunsicherheiten.

1. Introduction

To simulate past, present, and future climate conditions, dynamical models are necessary. Numerical partial differential equations reproduce – as well as possible - the interactions of several subsystems of the climate system. Nowadays, the grid mesh is about 250 to 500 km and 9 to 20 layers in the vertical. Physical-chemical micro- and meso scale processes like cloud formation, turbulence effects or land breeze effects are not primary modelled as processes but parameterized. The IPCC report 2001 stated the need for a substantial reduction of uncertainties in regional climate modelling and an increase of the spatial resolution of the results.

Since that time the computer power increased substantially and the model physics and dynamics have been further developed in order to simulate the climate change at spatial resolutions substantially below 50 km. The new generation of non-hydrostatic regional climate models even has the potential to simulate the regional climate at space scales down to 1 km. However, the dynamics of the earth system at higher spatial scales has to be taken into account adequately. Initially, we used the regional climate model REMO in a high resolution of 10 km for Germany. These model calculations have been conducted on behalf of the Federal Environment Agency (Umweltbundesamt, UBA) (ZEBISCH et al., 2005). Hence, UBA would like to support positively the research topics concerning climate change and adaptation. Thus, the model runs are available for interested applicants. In order to derive the model results for application purposes, to avoid error propagation, and to interpret model uncertainties an evaluation of these results is necessary.

One application field is the tourism industry. Tourism is one the determining factor for economy. Tourism and climate are closely linked. Climate and climate changes influence the tourism industry, respectively. Consequently, demand and supply depend on given climate conditions. Policy makers have to act accordingly and adapt to modified economical and ecological conditions under climate change. Therefore, scientific information has to be produced in a useful and easy understandable way (DE FREITAS, 2003; MATZARAKIS et al., 2004).

Within our project we calculate the climatic tourism and recreation potential for the two investigation areas North Sea and Black Forest. Background of the computed tourism and recreation potential for the presence are climate data from the German Weather Service (DWD). These data shall be compared to data carried out by REMO (JACOB, 2001; JACOB et al., 2007) and CLM (Climate Local Model) (BÖHM et al., 2006). Within our project REMO data as well as CLM data will be used for the analysis of tourism potential for 1961-1990 and 1971-2000, respectively, and for future climate trends (2021-2050). Hence, the SRES scenarios A1B, B1, and A2 will be considered. REMO and CLM data build the base for thermal, physical, and aesthetic computations being used for the validation of both thermal comfort and tourism and recreation potential. Moreover, frequency classes and frequencies of extreme weather events are generated based on monthly and 10-day-intervals. The derived results, in terms of climate tourism information schemata (CTIS), and maps shall be allocated for stakeholders (MATZARAKIS, 2007).

2. Data and Methods

For this study the A1B scenario carried out by REMO (JACOB, 2001; JACOB et al., 2007) is initially used. The model region covers Germany and the Alps. The data has a spatial resolution of 10 km and a temporal resolution of hours. The data are available from 1950 to 2100. Thereby, the periods 1961-1990 as well as 1971-2000 of the A1B scenario are used as reference periods for future climate changes. Furthermore, climate data for exclusive stations are available from mid 20th century up to now. We have chosen the time span from 1961-2000 for comparison. The following parameters of REMO and DWD data, respectively, are the basis for the computation of physiologically equivalent temperature (PET) being background for thermal comfort and discomfort (HÖPPE, 1999; MATZARAKIS et al., 1999):

- date,
- longitude, latitude and elevation,
- air temperature,
- vapour pressure,
- wind velocity,
- cloud cover (DWD) and global radiation (REMO).

PET is computed by the model RayMan (MATZARAKIS et al., 2007). Additionally, precipitation and snow cover are also included in the analysis. The values refer to 14 and 14:30 CET for REMO and DWD, respectively, except precipitation being the total annual precipitation amount. The snow cover carried out by DWD refers to 6 UTC.

For the analysis of the climatic tourism potential particular thresholds based on meteorological parameters are defined (Table 1).

Table 1: Parameters relevant for tourism and recreation concerning their thresholds and authors

Parameter	Thresholds	Author
thermal comfort	18 °C < PET < 29 °C	MATZARAKIS (2007)
heat stress	PET > 35 °C	MATZARAKIS and MAYER (1996)
cold stress	PET < 0 °C	MATZARAKIS (2007)
sunshine	cloud cover < 5/8	GÓMEZ MARTÍN (2004)
fog	relative humidity > 93 %	MATZARAKIS (2007)
"sultriness"	vapour pressure > 18 hPa	SCHARLAU (1943)
dry day	precipitation < 1 mm	MATZARAKIS (2007)
rainy day	precipitation > 5 mm	MATZARAKIS (2007)
stormy day	wind velocity > 8 m/s	BESANCENOT (1990), GÓMEZ MARTÍN (2004)
ski potential	snow cover > 10 cm	BENISTON (1997), KULINAT and STEINECKE (1984), BREILING and CHARAMZA (1999), ROTH et al. (2005)

Evaluating REMO data with selected DWD data additional parameters are included (shown in Table 2 to 7). Keeping in mind that REMO has a spatial resolution of 10 km the averaging influences the values. The exclusive DWD stations are located in the corresponding grid box. Thereby it is not focused on the definite consistence of the values rather on the validation.

3. Results and Discussion

The comparison of REMO and DWD data is realized for exclusive regions and stations for both the North Sea (Norderney) and Black Forest (Titisee and Freiburg). The elevations of the DWD stations compared to REMO vary concerning the grid mesh of 10 km.

Table 2: Comparison of different selected parameters concerning REMO and DWD data for the periods 1961-1990 and 1971-2000 for Norderney; corresponding notations are: PETa: annual PET, Tmrt: mean radiant temperature, RR: precipitation, RH: relative humidity, VP: vapour pressure, V: wind velocity

Norderney	**1961-1990**		**1971-2000**	
Parameter	**REMO**	**DWD**	**REMO**	**DWD**
PETa [°C]	5.0	5.1	5.1	5.6
PETmax [°C]	33.3	32.5	34.4	32.1
PETmin [°C]	-14.3	-19.0	-14.3	-19
PET < 0 [d]	115	119	113	109
PET = 18-29 [d]	13	19	14	23
PET > 30 [d]	0	0	0	0
PET > 35 [d]	0	0	0	0
mean air temperature [°C]	9.9	9.0	9.9	9.3
Tmax [°C]	23.0	25.8	23	26.4
Tmin [°C]	-5.7	-11.4	-5.7	-11.4
mean radiant temperature [°C]	18.1	25.4	18.2	25.8
Tmrt_max [°C]	48.9	54.6	49.3	53.6
Tmrt_min [°C]	-15.7	-21.0	-15.7	-21.0
annual precipitation amount [mm]	1013.8	769.5	1014.7	742.9
RR < 1 mm [d]	196	235	197	238
RR > 1 mm [d]	169	130	169	127
RR > 5 mm [d]	66	52	65	50
averaged relative humidity [%]	82.9	83.7	83.0	83.2
RH > 93 % [d]	88	48	90	47
averaged cloud cover [octas]	5.3	5.3	5.3	5.2
cloud cover < 5 octas [d]	144	132	145	136
averaged vapour pressure [hPa]	10.5	10.2	10.6	10.3
VP > 18 hPa [d]	8	10	10	11
averaged wind velocity [m/s]	7.2	6.9	7.1	6.5
Vmax [m/s]	23.4	26.5	23.4	26.5
V > 8 m/s [d]	142	115	137	94

Norderney has an actual and modelled height of 11 m asl and 1 m asl, respectively. Titisee offers an actual height of 846 m asl and a modelled height of 984 m asl. Freiburg has an actual and modelled height of 268 and 228 m asl, respectively. Especially in highly orographical areas like the Black Forest significant elevation differences can occur.

The exclusive comparative parameters for REMO and DWD data for the two periods 1961-1990 and 1971-2000 for Norderney are given in Tables 2 and 3.

Table 3: Comparison of monthly and seasonal precipitation concerning REMO and DWD data for the periods 1961-1990 and 1971-2000 for Norderney

Norderney	**1961-1990**			**1971-2000**		
precipitation [mm]	**REMO**	**DWD**	**[%]**	**REMO**	**DWD**	**[%]**
monthly						
January	82.0	58.9	0.7	81.2	58.9	0.7
February	70.4	40.7	0.6	76.8	41.4	0.5
March	49.3	52.7	1.1	51.5	53.5	1.0
April	44.3	40.9	0.9	41.5	36.5	0.9
May	55.4	49.0	0.9	54.1	47.0	0.9
June	62.0	62.4	1.0	66.0	60.5	0.9
July	84.8	75.9	0.9	89.7	66.1	0.7
August	107.9	73.3	0.7	101.0	65.2	0.6
September	115.9	72.1	0.6	126.8	80.1	0.6
October	111.7	80.1	0.7	103.7	79.2	0.8
November	131.3	88.0	0.7	122.5	82.7	0.7
December	98.6	75.4	0.8	99.8	71.7	0.7
seasonal						
winter (DJF)	83.7	58.3	0.7	105.8	65.3	0.6
spring (MAM)	49.7	47.5	1.0	49.0	45.7	0.9
summer (JJA)	84.9	70.5	0.8	85.6	63.9	0.7
autumn (SON)	119.6	80.1	0.7	117.7	80.7	0.7

Keeping in mind that the data modelled by REMO are too warm and wet, the mean air temperature differs from DWD data by 0.9 K (1961-1990) and 0.6 K (1971-2000), respectively. The annual PET does not show distinctive deviations in both periods. Despite a warmer air temperature and underestimation of cloud cover, the thermal comfort and mean radiant temperature are underestimated. However, the averaged cloud cover has the same magnitude. REMO obviously overestimates wind velocities and fog conditions. The latter is based on the relative humidity. The distribution of precipitation (Table 3) shows an overestimation of winter and autumn precipitation, whereas the spring and summer precipitation are consistent with DWD data.

The exclusive comparative parameters for REMO and DWD data for the two periods 1961-1990 and 1971-2000 for Titisee are given in Table 4 and 5.

Table 4: Comparison of different selected parameters concerning REMO and DWD data for the periods 1961-1990 and 1971-2000 for Titisee; corresponding notations are: PETa: annual PET, Tmrt: mean radiant temperature, RR: precipitation, RH: relative humidity, VP: vapour pressure, V: wind velocity, SN: snow cover

Titisee	**1961-1990**		**1971-2000**	
Parameter	**REMO**	**DWD**	**REMO**	**DWD**
PETa [°C]	8.9	9.1	9.1	9.7
PETmax [°C]	47.3	42.9	47.3	44.1
PETmin [°C]	-23.7	-26.7	-23.7	-26.2
PETd < 0 [d]	108	100	107	93
PETd 18-29 [d]	63	74	65	74
PETd > 30 [d]	20	18	22	22
PETd > 35 [d]	7	7	8	10
mean air temperature [°C]	11.0	5.8	11.2	6.1
Tmax [°C]	32.8	24.0	33.5	24
Tmin [°C]	-16.5	-25.2	-16.5	-25.2
mean radiant temperature [°C]	25.5	23.3	25.8	24.0
Tmrt_max [°C]	62.6	54.4	62.6	55.6
Tmrt_min [°C]	-23.1	-31.6	-23.1	-28.5
annual precipitation amount [mm]	1046.1	1328.6	1032.4	1384.2
RR < 1 mm [d]	205	219	205	217
RR > 1 mm [d]	160	147	160	149
RR > 5 mm [d]	70	83	68	85
averaged relative humidity [%]	64.4	83.7	64.4	82.6
RH > 93 % [d]	13	94	13	86
averaged cloud cover [octas]	4.1	5.5	4.0	5.4
cloud cover < 5 octas [d]	199	134	201	137
averaged vapour pressure [hPa]	8.9	8.3	9.0	8.3
VP > 18 hPa [d]	9	1	11	2
averaged wind velocity [m/s]	4.2	1.3	4.2	1.3
Vmax [m/s]	14.0	22.6	14	22.6
V > 8 m/s [d]	17	4	17	4
SN > 10 cm [d]	18	70	21	59

Threshold values based on PET like cold stress, heat stress, and thermal comfort are reproduced well by REMO. High discrepancies occur in mean air temperature ($\Delta T=5.2$ K and $\Delta T=5.1$ K for 1961-1990 and 1971-2000, respectively) in fog, sunshine, wind, and snow conditions. The relative humidity is underestimated about 20% by REMO and thus the number of days with fog is sevenfold underestimated. The number of days less than 5 octas is overestimated due to a reduction of the averaged cloud cover by 0.6 octas (1961-1990) and 1.4 octas (1971-2000), respectively. The averaged wind velocity is tripled by REMO. Moreover, the snow cover is marginally simulated. This discrepancy may be due to an underestimation of precipitation and an overestimation of air temperature by REMO. The distribution of precipitation shown in Table 5 indicates all-seasonally an underestimation.

Table 5: Comparison of monthly and seasonal precipitation concerning REMO and DWD data for the periods 1961-1990 and 1971-2000 for Titisee

Titisee	**1961-1990**			**1971-2000**		
precipitation [mm]	**REMO**	**DWD**	**[%]**	**REMO**	**DWD**	**[%]**
monthly						
January	92.3	129.4	1.4	96.9	146.0	1.5
February	85.7	106.1	1.2	83.4	104.9	1.3
March	62.0	108.7	1.8	61.3	110.0	1.8
April	75.3	102.3	1.4	71.1	99.1	1.4
May	99.2	112.7	1.1	95.3	109.9	1.2
June	98.9	112.8	1.1	95.5	123.0	1.3
July	91.0	102.3	1.1	87.2	105.3	1.2
August	86.2	112.2	1.3	88.5	95.2	1.1
September	78.3	79.3	1.0	81.3	91.9	1.1
October	81.1	93.0	1.1	67.3	111.4	1.7
November	96.9	131.6	1.4	98.2	138.8	1.4
December	99.1	138.2	1.4	106.5	148.7	1.4
seasonal						
winter (DJF)	92.4	124.6	1.3	109.1	132.9	1.2
spring (MAM)	78.8	107.9	1.4	75.9	106.3	1.4
summer (JJA)	92.0	109.1	1.2	90.4	107.8	1.2
autumn (SON)	85.4	101.3	1.2	82.3	114.0	1.4

The exclusive comparative parameters for REMO and DWD data for the two periods 1961-1990 and 1971-2000 for Freiburg are given in Table 6 and 7.

The parameters measured by DWD and modelled by REMO are inconsistent for the mean air temperature, relative humidity, days with sunshine, fog and sultriness. While thermal comfortable conditions and cold stress agree well, heat stress is overestimated by REMO. The annual PET varies about 2 K and indicates the greatest difference of the studied stations. The modelled mean air and radiant temperature of Freiburg differs about 4 K for both time spans as well. While averaged wind velocity and relative humidity show almost the magnitude, the number of stormy and foggy days differs. Cloud cover is underestimated by 1.4 octas in both time spans as well, thus heat stress, sunshine and sultriness can be overestimated. Although the precipitation is overestimated the numbers of dry and rainy days are consistent. The monthly distribution of precipitation shown in Table 7 denotes predominately an overestimation of winter and slightly of summer and autumn precipitation.

Table 6: Comparison of different selected parameters concerning REMO and DWD data for the periods 1961-1990 and 1971-2000 for Freiburg; corresponding notations are: PETa: annual PET, Tmrt: mean radiant temperature, RR: precipitation, RH: relative humidity, VP: vapour pressure, V: wind velocity, SN: snow cover

Freiburg	**1961-1990**		**1971-2000**	
Parameter	**REMO**	**DWD**	**REMO**	**DWD**
PETa [°C]	13.1	11.2	13.3	11.3
PETmax [°C]	52.2	41.9	52.2	39.2
PETmin [°C]	-21.3	-20.2	-21.3	-20.2
PET < 0 [d]	59	61	59	56
PET = 18-29 [d]	84	90	84	90
PET > 30 [d]	38	13	42	12
PET > 35 [d]	19	2	21	1
mean air temperature [°C]	14.6	10.7	14.8	11.2
Tmax [°C]	38.1	30.8	38.1	30.8
Tmin [°C]	-13.8	-15.0	-13.8	-15.0
mean radiation temperature [°C]	26.3	30.5	26.5	31.0
Tmrt_max [°C]	65.7	55.7	65.7	55.7
Tmrt_min [°C]	-18.5	-25.8	-18.5	-18.5
annual precipitation amount [mm]	1150.0	954.8	1130.5	929.5
RR < 1 mm [d]	232	235	234	238
RR > 1 mm [d]	133	130	131	127
RR > 5 mm [d]	68	62	66	61
averaged relative humidity [%]	62.3	72.4	62.3	71.2
RH > 93 % [d]	7	24	7	18
averaged cloud cover [octas]	4.1	5.5	4.1	5.5
cloud cover < 5 octas [d]	196	121	196	117
averaged vapour pressure [hPa]	10.9	9.9	11.0	10.0
VP > 18 hPa [d]	33	11	36	12
averaged wind velocity [m/s]	3.3	2.9	3.3	3.1
Vmax [m/s]	10.7	12.3	11.7	12.3
V > 8 m/s [d]	3	12	4	12
SN > 10 cm [d]	10	3	13	3

4. Conclusions

The difficulties in modelling air temperature and precipitation by REMO are known. Surprisingly, REMO simulates the climate for Norderney (North Sea) well. Regional discrepancies may be due to averaging (10 km x 10 km area) as well. The North Sea is characterized by lowland and by little differences in elevation. Thus, the radiation budget is rather consistent and uniformly distributed and not affected by orography. Consequently, derived parameters do not vary enormously.

Table 7: Comparison of monthly and seasonal precipitation concerning REMO and DWD data for the periods 1961-1990 and 1971-2000 for Freiburg

Freiburg	**1961-1990**			**1971-2000**		
precipitation [mm]	**REMO**	**DWD**	**[%]**	**REMO**	**DWD**	**[%]**
monthly						
January	94.1	60.1	0.6	100.2	53.1	0.5
February	84.3	54.5	0.6	80.5	54.0	0.7
March	50.3	64.4	1.3	54.0	58.3	1.1
April	72.9	80.3	1.1	61.1	73.7	1.2
May	123.9	105.7	0.9	121.1	102.8	0.8
June	145.6	116.1	0.8	138.7	109.0	0.8
July	116.7	95.6	0.8	113.3	99.2	0.9
August	96.0	102.6	1.1	105.4	84.0	0.8
September	80.3	71.9	0.9	78.0	75.9	1.0
October	75.4	65.6	0.9	58.7	75.3	1.3
November	94.7	72.3	0.8	97.2	70.8	0.7
December	115.7	65.8	0.6	122.3	73.6	0.6
seasonal						
winter (DJF)	98.0	60.1	0.6	99.9	64.8	0.6
spring (MAM)	82.4	83.5	1.0	78.7	78.2	1.0
summer (JJA)	119.4	104.8	0.9	119.1	97.4	0.8
autumn (SON)	83.5	69.9	0.8	78.0	74.0	0.9

An underestimation of thermal comfort and overestimation of precipitation and stormy days are modelled by REMO. Concerning orographical areas like the Black Forest, more difficulties in reproducing the climate conditions occur. In higher levels precipitation and snow depth are underestimated, whereas wind velocity is overestimated. In lower regions the precipitation and threshold values based on PET overestimated. A general model problem is the relative humidity. The relative humidity and derived fog conditions are notably underestimated in orographical areas and overestimated in lowlands. The parameters considered in this study are derived from the raw data by REMO. Therefore, these derived parameters show uncertainties as well. The analysis of DWD data allows thus a careful interpretation of the modelled data and an evaluation of model uncertainties.

The presented study represents the first step in comparison of climate condition for tourism and recreation approaches. Additionally, analysis and comparison of the climatic tourism potential are planned using CLM data as well.

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