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|---|---|
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# CLIMATE AND WATER:

# Presentation of climate change and its impacts on quantity and quality of water

By

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**WMO RA VI WGH Climate and Water**

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Report/ WMO RA VI, Working Group on Hydrology, Climate and Water, 2009.

## Abstract

The predicted climate change may have significant environmental and ecological impacts worldwide. For assessing future behaviour of climate, different scenarios of development of the population and production, emissions to the atmosphere, and their consequences to the climate have been produced. Climate change scenarios are available to experts in different disciplines for assessing how projected changes are reflected in their own field. Information about the climate change and the risks related to its impacts is relevant and valuable for authorities and decision makers. This all raises the question how the available information on the effects of climate change can be presented to facilitate easy delivery of relevant information. CLIME-DSS is a web-based decision support system that was designed to summarise and visualise results available from climate and environmental model simulations to decision makers in an easily digestible form. In this study the WMO RA VI contacts were used to distribute an internet survey for eliciting user opinions on the clarity of the CLIME-DSS tools. The survey demonstrated that a map based tool where one can either view large areas at a same time, or select a point of interest for detailed examination, is well suited for disseminating results of regional climate models. The respondents found coloured visualisations, as well as tabulated information about mean values of the variables to be equally informative and useful. The respondents pointed out that the methods behind the visualisations and tables should be made more transparent. Many users expressed the need to have access to detailed information about emission scenarios related to model simulations, structure and parameterisation of climate and environmental models, and methodology applied in aggregating model results in CLIME-DSS. While visualisation of changes in climatic variables was judged to be fairly straightforward and understandable, it was more challenging to illustrate how the climate change is reflected in chemical and biological variables describing the state of the environment.

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# 1. Introduction

The predicted climate change along with its potential impacts on physical, chemical, and biological lake processes sets a challenge to the management of water resources. Meteorological forcing, such as precipitation, evaporation, and air temperature, exert a significant control on catchment hydrological processes, loadings of dissolved and suspended material to surface waters, residence time of water in lakes and reservoirs, and ecology of aquatic habitats. According to the predictions of the Intergovernmental Panel on Climate Change (IPCC) (http://www.ipcc.ch/), in case of an increasing population and an insufficient extent of emission control technologies, greenhouse gas and aerosol emissions will lead to a large increase in air temperature and to altered precipitation patterns. Computational methods are needed for quantifying how quantity and quality of water resources respond to these changing conditions. It is essential to present and communicate the anticipated climate change and its consequences in an easily accessible and comprehensible manner to interest groups outside of the research community.

The Terms of Reference as defined by the WMO RA VI in 2005 for this report was the following:

> *Considering the potential impacts of climate variability and change on water resources, as well as uncertainties involved in assessing the impacts*
>
> *(a) To study and report how scenarios provided by regional climate models should be presented to the end users dealing with water resources management*
>
> *(b) To study and report how assessments based on environmental simulation models and regional climate scenarios can be condensed and presented to the end-users in a readily comprehensible form*
>
> *(c) To liaise with and receive feedback from those experts of the Association working on assessing the effects of climate change on water resources*

Thrust for this work was an EU funded project CLIME (Climate and Lake Impacts in Europe, http://clime.tkk.fi/) where a suite of methods was developed to manage lakes and catchments under future as well as current climatic conditions. In CLIME, regional climate scenarios, and existing catchment and lake models were combined to support lake management in the light of the water quality criteria prescribed in the European Union Water Framework Directive (Samuelsson, 2004, Jennings and Naden, 2004). Expert knowledge and simulation model results were integrated in a form of a decision support system (CLIME-DSS) that illustrates and summarises the main results of the project to interest groups outside the research community (Jolma et al., 2005; Kokkonen et al., 2005; Koivusalo et al., 2005a).

CLIME-DSS (http://clime.tkk.fi/?page=dss) is a web application that provides the user with tools for illustrating the predicted climate change and its impacts on lake variables (Kokkonen et al., 2004). The user can view maps showing differences in climatic variables across the Europe between the reference (1960 – 1990) and the future (2070 – 2100) periods. The user can select a location to see, where in Europe the current climate most resembles the future climate in the selected location. CLIME-DSS also provides an interface where the user can apply causal Bayesian networks to characterize how changes in climate variables are reflected in variables related to catchment and lake processes (Koivusalo et al, 2005b).

While the CLIME-DSS incorporates presentation tools for communicating results on predicted climate change and its impacts for a wide audience it is not clear how well the CLIME-DSS meets the objective of providing the results in an easily comprehensible form. In this work the WMO RA VI contacts were used to distribute a survey for eliciting user opinions on the clarity of the CLIME-DSS tools. We were also interested to explore whether opinions of persons having a different background and / or place of residence show significant differences. Finally, new ideas were requested in the survey for further improvement of the way of presenting climate change and its impacts to a wide audience.

## 2. Survey method

Survey was carried out as a web poll that was created using the Esurveyspro survey service (http://www.esurveyspro.com). CLIME-DSS is a web application that can be accessed over the Internet but firewalls can block the use of CLIME-DSS at some institutes and companies. To ensure that all recipients have access to CLIME-DSS results key visualisations and tables were copied as screen shots to the web poll itself, and the recipients were not requested to use CLIME-DSS.

Survey comprised nine topics, and questions related to each topic were presented in the same page. Questions were given as multiple choices, with the possibility to add free form comments related to each question. Figure 1 shows an example of a question. In the last page the background (profession, area of expertise) of recipients was elicited.

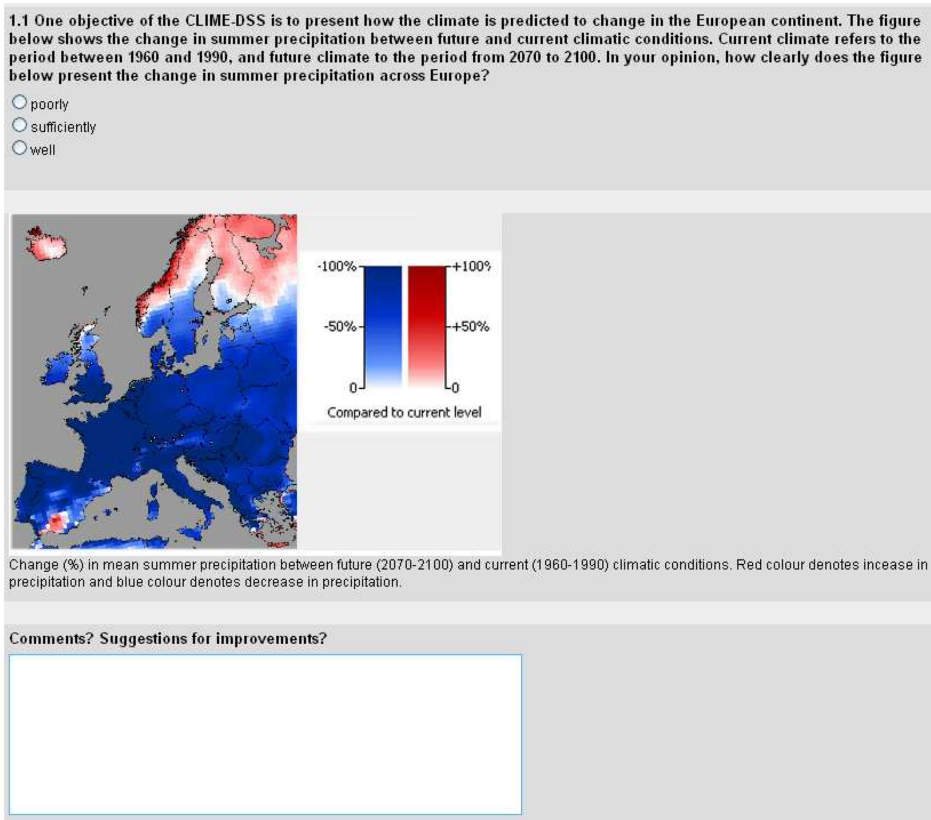



**Figure 1.** An example question in the web poll.

## 3. Results

### 3.1 Respondent profile

In June 2008 the survey request was emailed to 160 persons within the RA VI countries. As these persons were encouraged to forward the survey request to potential respondents the total number of recipients is not known. By October 8 2008 the number of persons having returned the survey totalled 37. The geographical distribution, the profession, and the area of expertise of respondents are listed in Figure 2. Figure 3 shows a map defining six regions for eliciting the place of residence. We received responses from all five regions with the highest number of respondents residing either in northern or southern Europe. With respect to profession the majority of respondents worked in governance and/or research. The most common areas of expertise were hydrology and meteorology. It is worth noting that respondents were allowed to give multiple choices for profession and area of expertise.

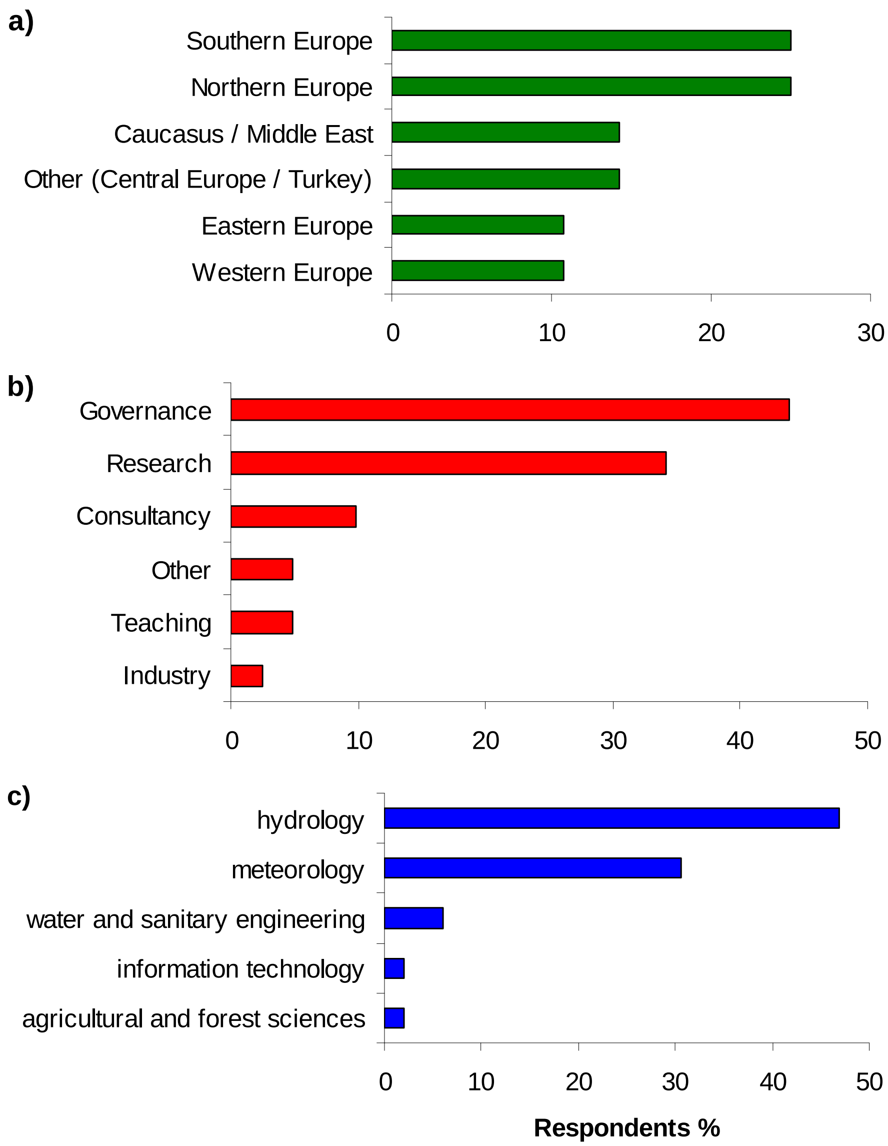
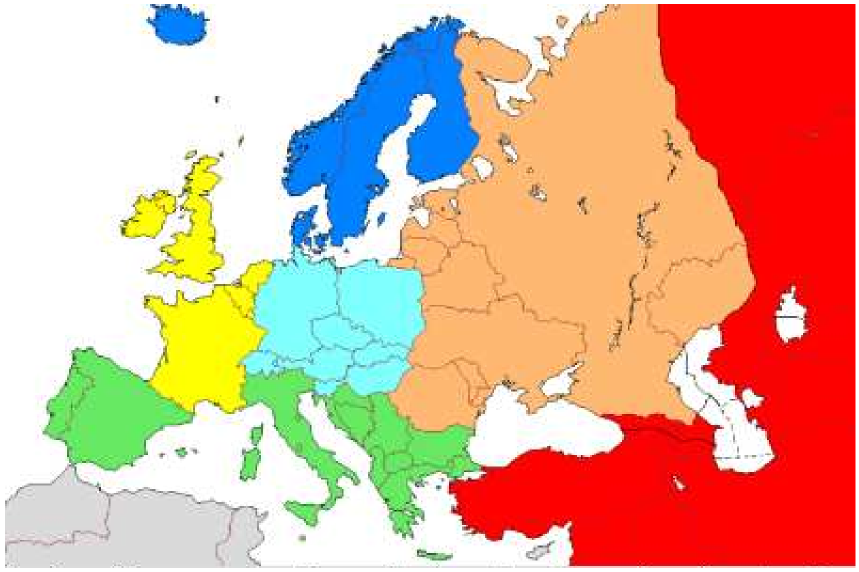
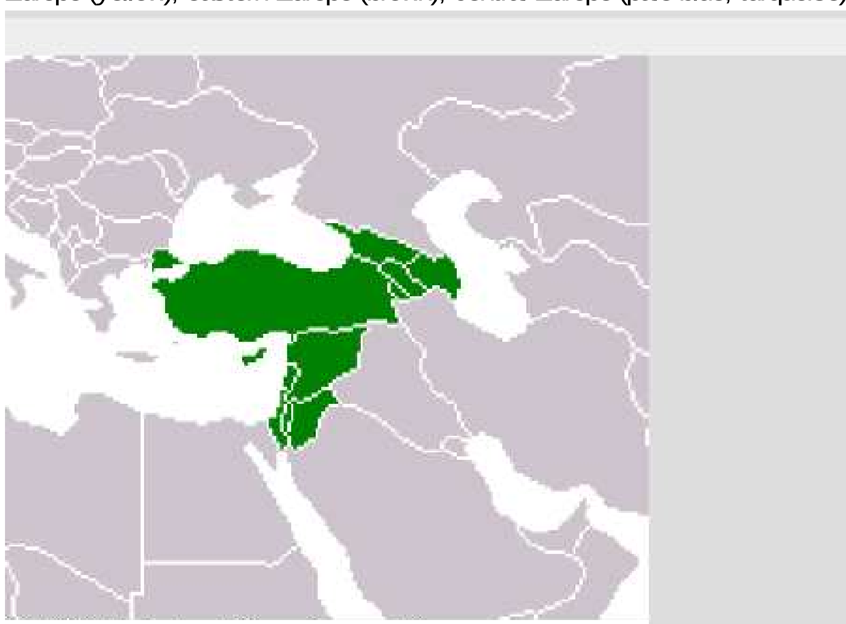



**Figure 2**. Place of residence (a), profession (b), and area of expertise (c) of respondents.



Regions of Europe: northern Europe (blue), southern Europe (green), western Europe (yellow), eastern Europe (brown), central Europe (pale blue, turquoise)



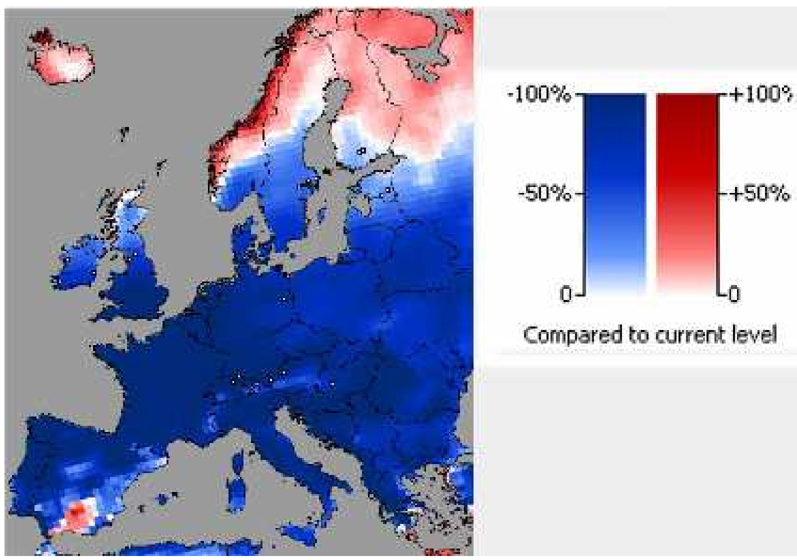
RA VI Middle East and Caucasian countries

**Figure 3**. Six regions used for eliciting the place of residence of respondents.

## 3.2. Predicted change in precipitation

One objective of the CLIME-DSS is to present how the climate is predicted to change in the European continent. Figure 4 shows the change in summer precipitation between future and current climatic conditions. Current climate refers to the period between 1960 and 1990, and future climate to the period from 2070 to 2100. In the survey the respondents determined whether the change in precipitation was presented poorly, sufficiently or well (Figure 4). Overall the majority of respondents regarded the presentation to be sufficient or good. There were no clear differences neither between persons working in research or governance, nor between persons having their background in meteorology or hydrology. Respondents residing in northern Europe regarded the presentation to be clearer than persons from elsewhere. Three main points were raised in the freeform comments given by the respondents. Firstly, the blue colour should denote increasing, instead of decreasing, precipitation. The red colour should denote drier conditions, as commonly used in describing precipitation quantities. Secondly, the extent of summer should be explicitly defined. And finally, respondents commented on the lack of some countries belonging to the RA VI region. The reason for not including Middle Eastern and Caucasian countries to the maps is that CLIME as an EU funded project focused on European countries.

**a)**




**b)**

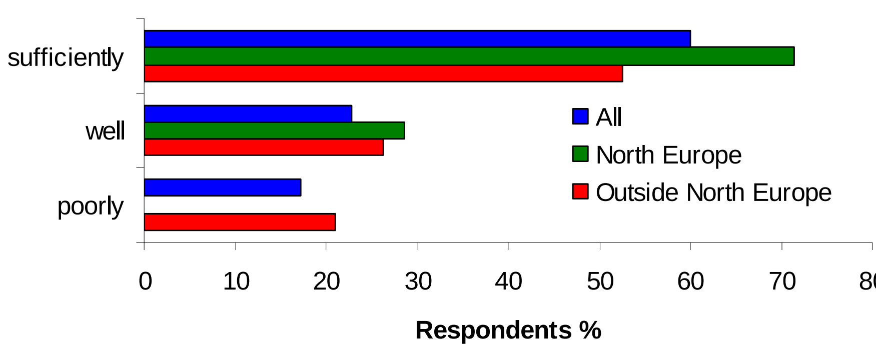



**Figure 4**. CLIME-DSS presentation of change in summer precipitation between future and current climatic conditions (a). The respondents' opinion about clarity of presentation (b).

In Figure 4 the change in precipitation is defined as the change in mean seasonal precipitation. There are several other options for representing the change, and it is also possible to present the predicted absolute values of precipitation in the future. In the respondents' opinion the change in the precipitation between future and control periods and the predicted future precipitation were equally interesting (Figure 5). All information about precipitation was regarded important. However, respondents were more interested in mean and maximum values than minimum values. The freeform comments pointed out that the future prediction is subject to greater inaccuracies than the change in (modelled) precipitation. Also, temporal variability and frequency analysis were suggested as ways of studying the changed precipitation conditions.

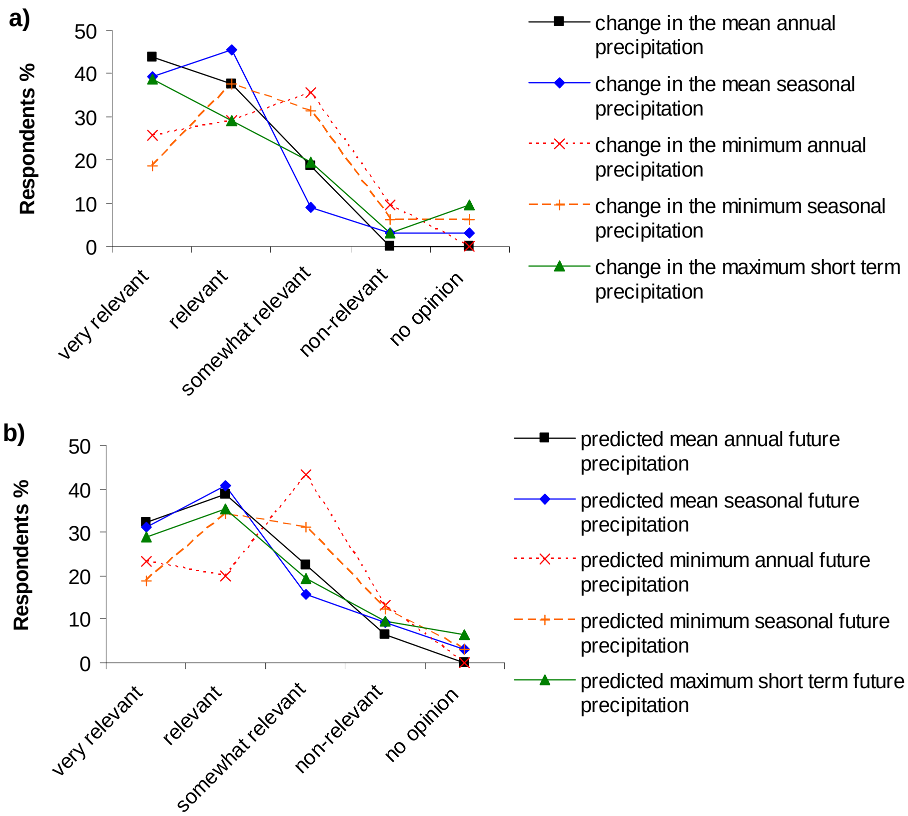
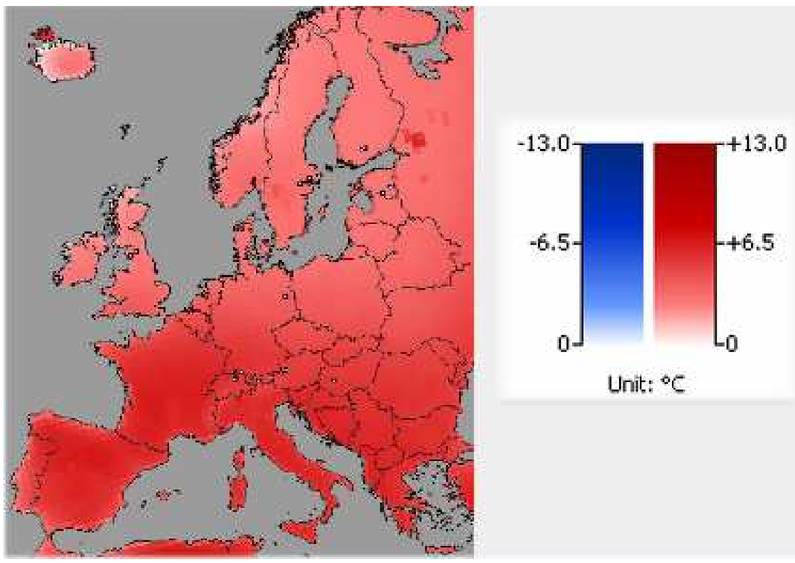



**Figure 5**. Relevance of different ways representing the change in precipitation between the future and control scenarios (a) and relevance of different ways representing the predicted future values of precipitation (b).

### 3.3. Predicted change in air temperature

Figure 6 shows the change in summer air temperature between future and current climatic conditions. The presentation of temperature change was predominantly regarded as sufficient or poor. Hydrologists were more critical about the presentation than persons working in the meteorology (Figure 6). The major critics considered the use of shades of a single colour in the colour palette for presenting increase in temperature. The mismatch between the map and the RA VI region was raised again.

**a)**




**b)**

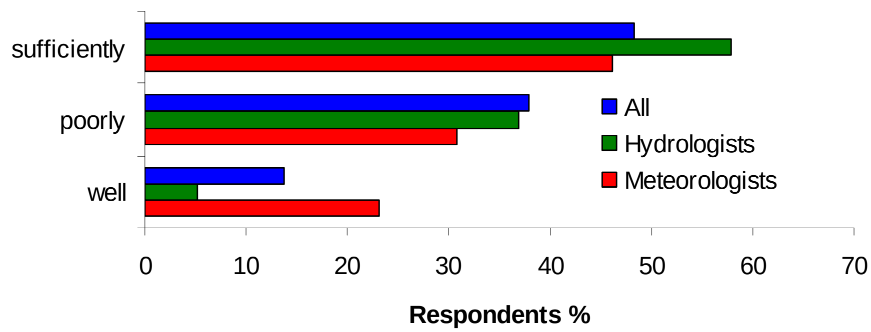



**Figure 6**. CLIME-DSS presentation of change in summer air temperature between future and current climatic conditions (a). The respondents' opinion about clarity of presentation (b).

Figure 6 presents the change in air temperature as the change in mean seasonal temperature. There are other options for representing the change (e.g. minimum or maximum temperature over a year or a specific season), and it is also possible to present the predicted absolute values of temperature in the future. The respondents considered all ways of describing the change in air temperature and the predicted future temperature almost equally relevant (Figure 7). Freeform comments called for information about temporal distribution of future air temperature, e.g. the number of days when the air temperature is below or above given threshold values.

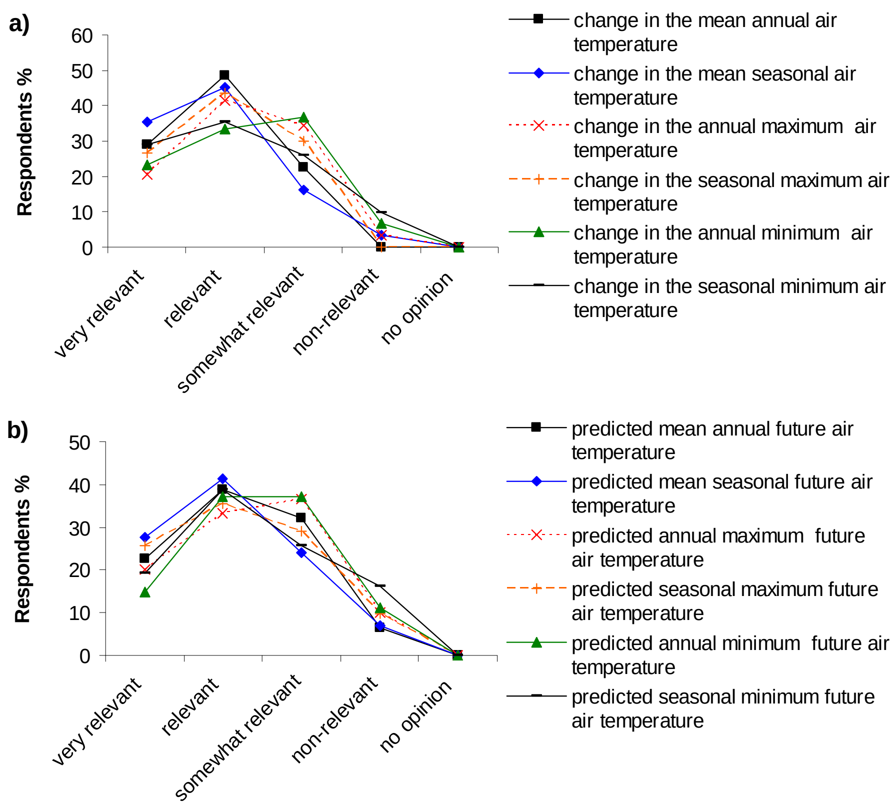



**Figure 7**. Relevance of different ways representing the change in air temperature between future and control scenarios (a) and relevance of different ways representing the predicted future values of air temperature (b).

### 3.4. Climate variables in a selected location

In addition to visualising climate change across Europe, in CLIME DDS the user can select a location by clicking on a map and see average seasonal values of some hydrometeorological variables (Figure 8) for the selected location - and for both current and future conditions. Air temperature and precipitation were clearly considered as the most important variables regarding the climate change in a selected location. Runoff and snow water equivalent (SWE) were seen as the next important variables. Hydrologists gave more weight to runoff and SWE than meteorologists. Similarly, north European respondents assigned a higher importance to these variables than respondents from elsewhere. All respondents considered wind speed, soil moisture and the number of frost days to be of significance, too, although they received less weight than the previously mentioned variables.

In freeform comments several respondents called for inclusion of evapotranspiration in the group of assessed climate variables. Radiation, sunshine hours, cloudiness, temperature sum, soil temperature, snow cover duration, and groundwater level were also suggested as additional variables. Respondents also raised the issue of downscaling in presenting the climatic variables. The variables are currently presented as grid (ca. 50 x 50 $km^2$) averages available from regional climate models (RCM), and a downscaling would be necessary to allow users assess climatic variables in a point of interest within a single grid cell.

More than half of the respondents regarded presenting seasonal average values of climatic variables for different climate scenarios in a table as informative or very informative (Figure 8). However, it was pointed out in the comments that extreme phenomena should also be considered in addition to seasonal averages. The comments also revealed that it is important to recognise what the climate scenarios are behind the presented values, as well as what the time period of the model simulation is. Definition of different scenarios (control, A2, B2) was not clear in the context of this question. Although they were explained in the beginning of the survey, scenario definitions should have been repeated here. Comments also raised the issue of uncertainty in predicted climate variables. The issue of the effect of RCM grid resolution on model results was mentioned.

**a)**

**Average values of variables at selected location in summer according to RCAO-E**

| Variable / Scenario | A2 | B2 | Control |
|---|---|---|---|
| Frost days, d | 0 | 0 | 0 |
| Precipitation, mm/season | 86.6 | 140 | 227.4 |
| Runoff, mm/season | 8.5 | 16.2 | 48.9 |
| Snow, mm | 0 | 0 | 0 |
| Soil moisture, mm | 80.5 | 111.3 | 159.2 |
| Air temperature, °C | 21 | 18.5 | 13.8 |
| Wind speed, m/s | 3 | 2.9 | 3.2 |

**b)**

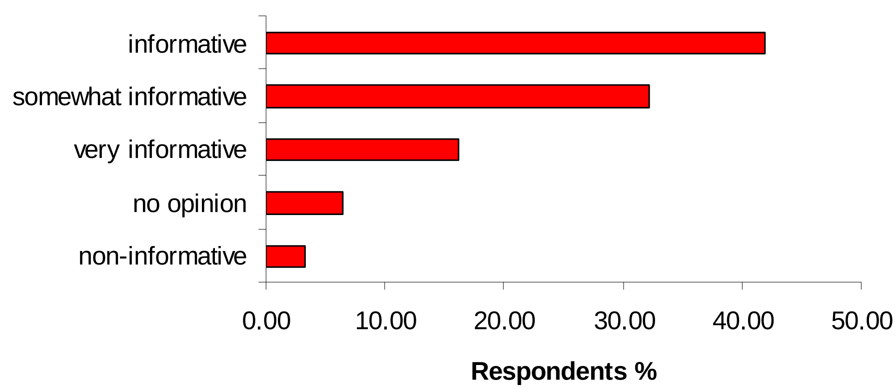
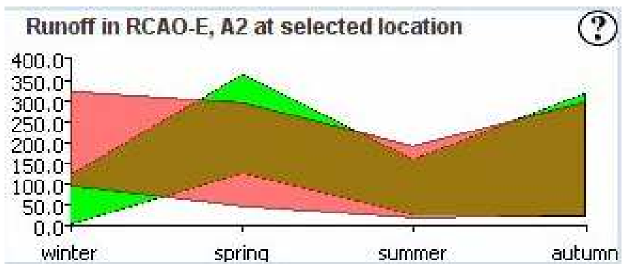



**Figure 8**. CLIME-DSS presentation of average seasonal values of hydrometeorological variables in Brussels (a). The respondents' opinion about how informative the presentation is (b).

## 3.5. Range of variability in seasonal climate variables in a selected location

The graph (Figure 9) showing the range of a single climate variable (here seasonal runoff) was regarded to be informative or very informative by ca. 60% of the respondents (Figure 9). It was noted in the comments, however, that the graph presentation may not be as informative for other variables than runoff. As in Section 3.4., respondents emphasized the importance of better clarifying the emission scenario and the prediction time period. The unit of the variable was accidentally missing from the graph, as aptly remarked by respondents.

**a)**

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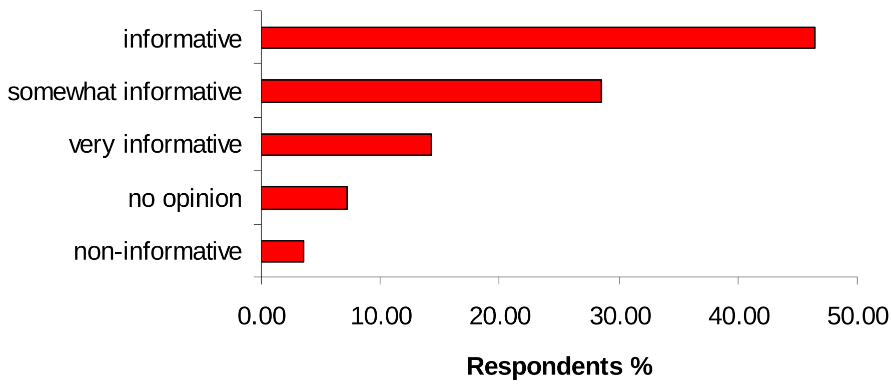
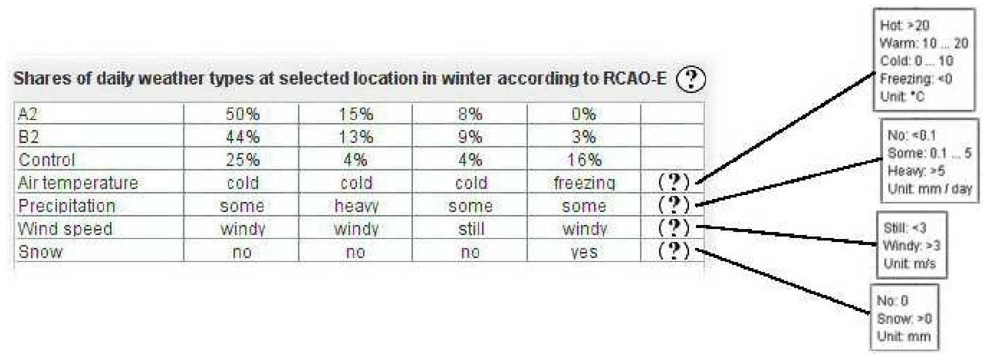



**Figure 9**. CLIME-DSS presentation of range of seasonal runoff in Umeå, Sweden (a). The respondents' opinion about how informative the presentation is (b).

## 3.6. Daily weather types in a selected location

One way to characterise the weather is to classify climatic variables with qualitative terms (Figure 10). For example, air temperature was classified to be hot, warm, cold or freezing according to prescribed temperature ranges. Any combination of classes of different climatic variables constitutes one weather type. Figure 10 presents the four most typical daily weather types and their percentages of occurrence in winter in Berlin. The occurrence percentages are listed for three different climate scenarios. In the survey it was requested to assess how informative this type of way representing the predicted climate change is. Approximately half of the respondents rated the representation to be informative or very informative, while one fifth of the respondents regarded it to be non-informative (Figure 10). Free-form comments confirmed the impression that opinions on the clarity and significance of the day type approach was strongly divided. Several respondents experienced the table in Figure 10 as incomprehensible without additional clarification.

**a)**


Shares of daily weather types at selected location in winter according to RCAO-E (?)

| | | | | | |
|---|---|---|---|---|---|
| A2 | 50% | 15% | 8% | 0% | |
| B2 | 44% | 13% | 9% | 3% | |
| Control | 25% | 4% | 4% | 16% | |
| Air temperature | cold | cold | cold | freezing | (?) |
| Precipitation | some | heavy | some | some | (?) |
| Wind speed | windy | windy | still | windy | (?) |
| Snow | no | no | no | yes | (?) |



**b)**

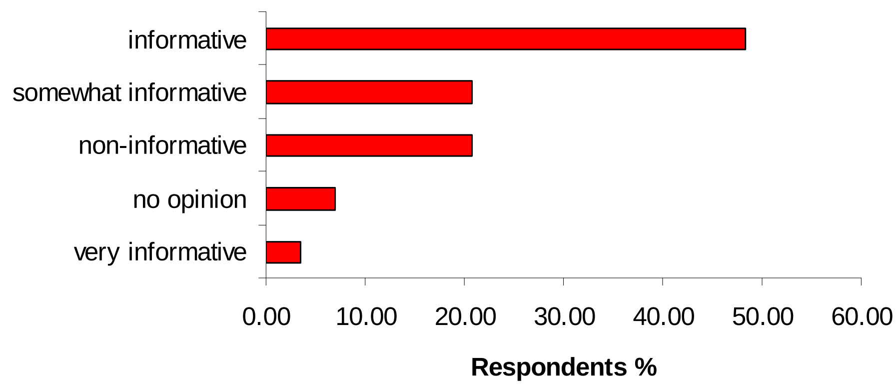
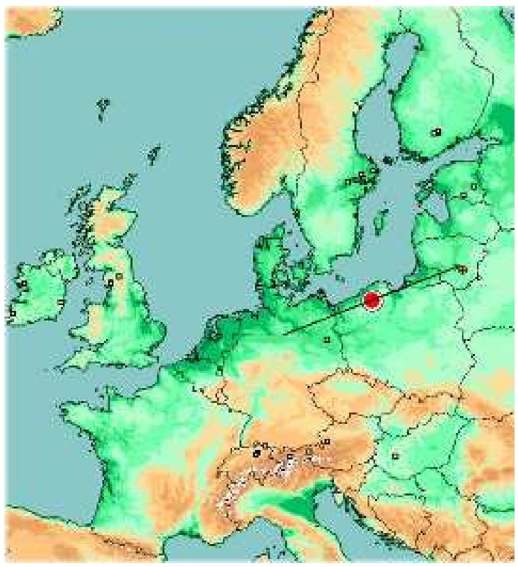



**Figure 10**. CLIME-DSS presentation of shares of daily weather types in Berlin in winter (a) according to the RCAO-E regional climate model. The respondents' opinion about how informative the presentation is (b).

### 3.7. Climate migration

The idea of the climate migration tool is to visualise the predicted climate change by identifying the region where the present climate most closely resembles the future climate in the studied location. The arrow on a map shown in Figure 11 identifies the place in Europe where the current climate (northern Germany) most resembles the future climate at the clicked location (southern Lithuania). In other words, the climate migration arrow indicates from where the climate is going to "migrate" to the selected location. The resemblance between the two climates is determined by comparing the distribution of daily weather types (Jolma et al., 2006). Current climate refers to the period between 1960 and 1990, and future climate to the period from 2070 to 2100. Half of the respondents viewed the representation to be informative or very informative, and 10% of the respondents regarded it to be non-informative (Figure 11). Respondents working in research were less satisfied about the climate migration visualization than persons working in governance. Freeform comments revealed that while the presentation itself may have been illustrative the respondents raised doubts about the soundness of the methodology for quantifying the resemblance between different climates.

**a)**



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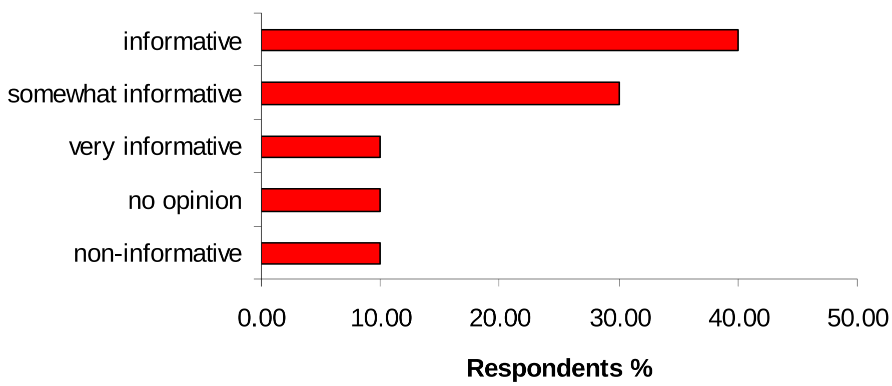


**Figure 11**. CLIME-DSS presentation of change in climate depicted as climate migration from one region to another (a). The respondents' opinion about how informative the presentation is (b).

### 3.8. Climate impacts on lakes

The CLIME-DSS was designed to visualise how climate change predictions are reflected in key environmental variables characterising physical, chemical and biological properties of lakes in Europe. The respondents were requested to assess the relevance of a set of given lake variables (Table 1). While all listed variables were seen as relevant the duration of ice cover was assigned with the highest significance. However, approximately one third of the respondents expressed no opinion about the relevance of most of the variables. The high share of 'no-opinion' replies and freeform comments indicated that the expertise of the respondents lied mostly in water quantity instead of water quality. Also, in free form comments it became apparent that lakes are not an issue in all RA VI countries.

There are several options for representing a change in an environmental variable of a lake (e.g. with respect to minimum, mean or maximum value), and it is also possible to present the predicted absolute values of a variable in the future. The respondents assessed the relevance of the way of presenting future nutrient load and algae concentration values. No preference was expressed in presenting the change of a variable or the absolute future value of a variable (Figures 12 and 13). It appeared that use of mean values was slightly preferred over use of maximum values, and using minimum values received least significance. The fraction of 'no-opinion' replies was notably high for all ways of describing the climate change impact on environmental variables (up to 55%). Free form comments stated that the uncertainty in the prediction of the environmental impacts of climate change is very high.

**Table 1**. Relevance of selected lake variables.

| | No opinion | Non relevant | Somewhat relevant | Relevant | Very relevant |
|---|---|---|---|---|---|
| Lake surface temperature | 20% (6) | 0% (0) | 10% (3) | 41% (12) | 27% (8) |
| Lake residence time | 28% (8) | 0% (0) | 10% (3) | 53% (15) | 7% (2) |
| Duration of ice cover | 10% (3) | 0% (0) | 10% (3) | 44% (13) | 34% (10) |
| Mixing depth of a lake | 31% (9) | 0% (0) | 10% (3) | 44% (13) | 13% (4) |
| Phosphorous load into the lake | 27% (8) | 0% (0) | 13% (4) | 44% (13) | 13% (4) |
| Nitrogen load into the lake | 31% (9) | 0% (0) | 10% (3) | 48% (14) | 10% (3) |
| Dissolved organic carbon load into the lake | 31% (9) | 0% (0) | 10% (3) | 48% (14) | 10% (3) |
| Phytoplankton concentration | 31% (9) | 0% (0) | 6% (2) | 44% (13) | 17% (5) |
| Blue green algae concentration | 31% (9) | 0% (0) | 6% (2) | 41% (12) | 20% (6) |

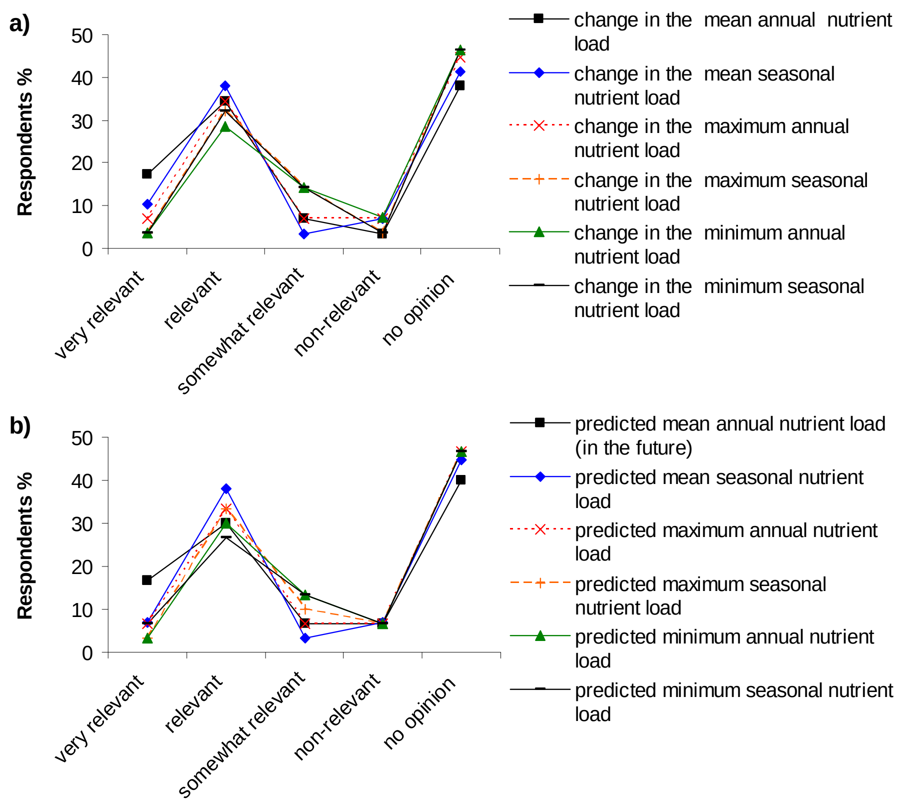


**Figure 12**. Relevance of different ways representing the change in nutrient load between future and control scenarios (a) and relevance of different ways representing the predicted future values of nutrient load (b).

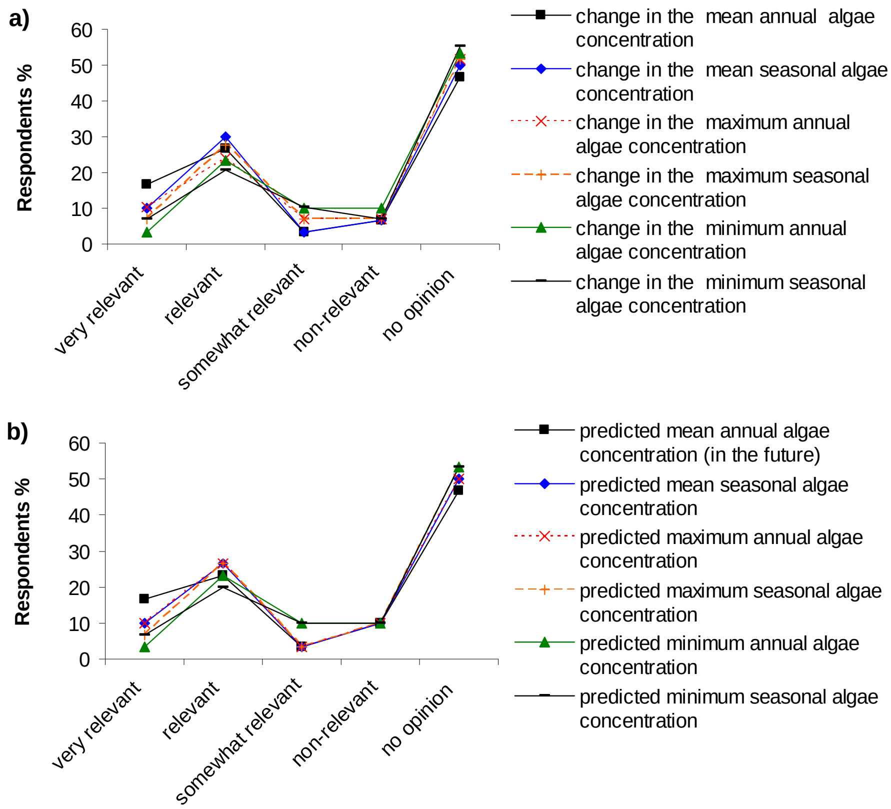


**Figure 13**. Relevance of different ways representing the change in algae concentration between future and control scenarios (a) and relevance of different ways representing the predicted future values of algae concentration (b).

### 3.9. Visualisation of lake response

The lake response to climate change is calculated with the aid of a Bayesian network that characterizes the interrelations between climate and lake variables. The Bayesian network is constructed using simulation model results from several research catchments and lakes (Koivusalo et al., 2005a, 2005b). CLIME-DSS can regionalize results from the research sites to any location in Europe by utilising the predicted climate change at the given location. In the Bayesian network application lake variables are described using discrete probability distributions having five classes (Figure 14). The user defines the ‘current’ distribution of the seasonal average value for the lake variable of interest, and CLIME-DSS generates the future (‘predicted’) distribution by adding the climate change impact to the current distribution.

Approximately two thirds of the respondents found the graph in Figure 14 to be sufficient in indicating the direction of change in an environmental variable, and nearly one third considered that detecting the direction is easy (Figure 14). Detecting the change in the variability of an environmental variable based on the same graph was deemed more complicated. Only 14% were of the opinion that it was easy to see the change in variability, and 39% expressed ‘no opinion’ regarding this question (Figure 14).

**a)**

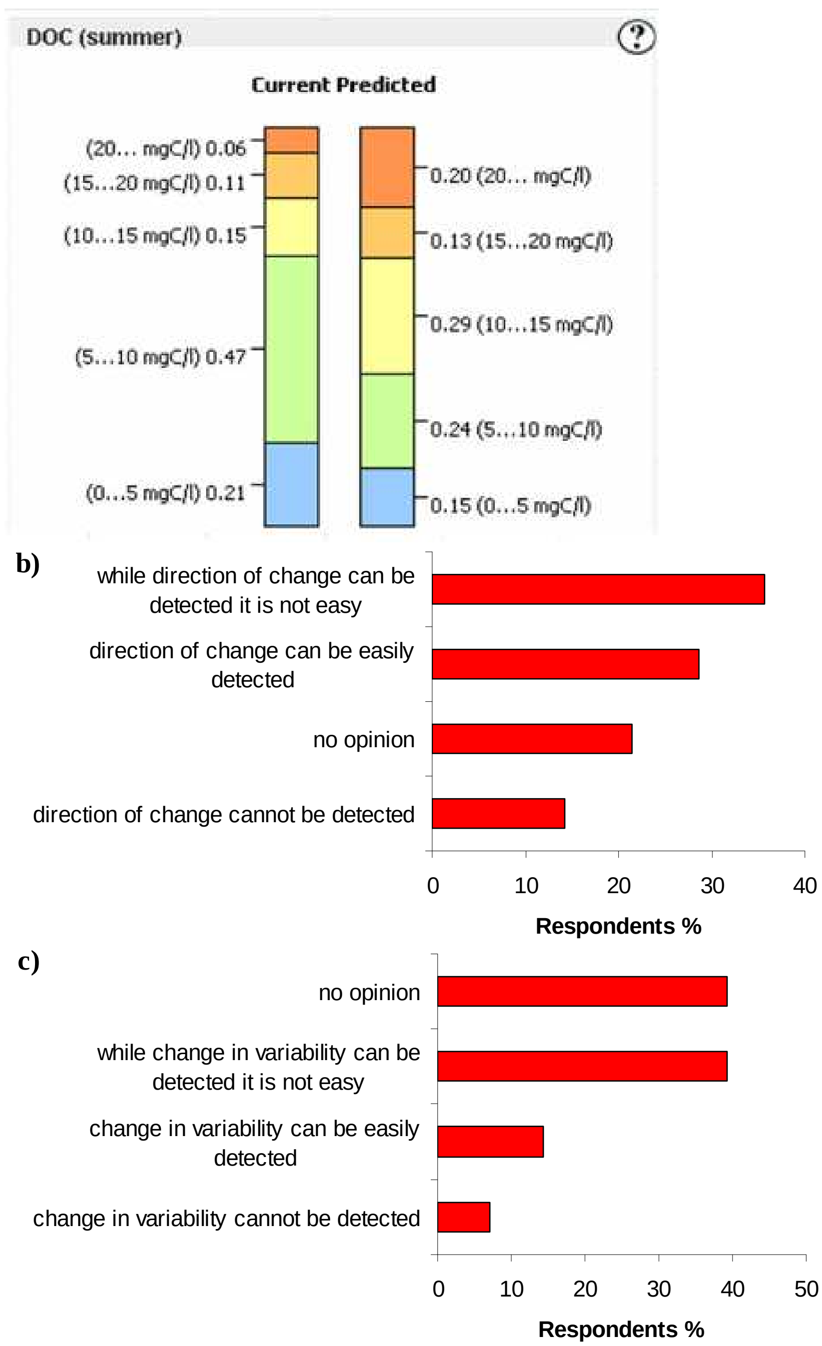


**Figure 19**. CLIME-DSS presentation of current and predicted distributions for average summer time DOC concentration (a). The respondents’ opinion about the clarity of the presentation in showing the direction of change (b) and change in variability (c).

### 3.10. Level of user control

Climate change predictions are based on different scenarios describing greenhouse gas emissions, which again are dependent on economic development, population growth etc. Also, climate change results are available from several simulation models, which differ in their structure and parameterisation. Moreover, the time period for which the prediction has been made has an impact on the results. While all the factors mentioned above have an important role in affecting the magnitude of the predicted climate change, only one third of the respondents express willingness to have control over them.

## 4. Conclusions

There is now a strong consensus among the scientific community that the predicted climate change may have significant environmental and ecological impacts worldwide. Researchers have prepared scenarios related to future development of the population and production, emissions to the atmosphere, and their consequences to the climate (e.g., Christensen et al., 2002; Räisänen et al., 2004; Carter et al., 2005). Furthermore, experts in different disciplines have then assessed how climate change is reflected in their own field (e.g., Kaivo-oja et al., 2004; Silander et al., 2006). There is a great need among decision makers to receive information about the risks posed by the climate change. This all raises the question how the available information on the effects of climate change should be presented to facilitate easy delivery of relevant information to decision makers. CLIME-DSS is a web application that was designed to summarise and visualise results available from climate and environmental model simulations to decision makers in an easily digestible form.

WMO RA VI experts were involved in assessing how CLIME-DSS succeeds in delivering key information on the predicted climate change and its impacts on lakes. The survey was carried out as a web poll to which we received 37 replies. The whole region of WMO RA VI was well represented among the respondents. Most respondents worked in research and/or governance and gave meteorology and/or hydrology as their area of expertise. None of the respondents considered themselves as limnologists, biologists or chemists. This explains why presentation methods of CLIME-DSS related to climate characteristics and water quantity receive more attention among the respondents than lake and water quality variables.

Coloured visualisations presenting changes of meteorological variables shown on a map, as well as tabulated information about mean values of the variables in a selected location, were regarded equally informative and useful by the majority of recipients. The respondents, however, pointed out that the methods behind the visualisations and tables should be more transparent. In order to assess the credibility of results the users need to have access to more detailed information about emission scenarios related to model simulations, structure and parameterisation of climate and environmental models, and methodology applied in aggregating model results in CLIME-DSS. The respondents also noted that the grid scale (ca. 50 x 50 $km^2$) of CLIME-DSS does not allow consideration of results at a point scale in a certain location. To achieve this the grid average should be downscaled to the point of interest. Also, respondents called for inclusion of uncertainty in the presentation of simulation model results.

Respondents regarded air temperature and precipitation as the most important variables in presenting the changing climate. Runoff and snow water equivalent (SWE) were seen as the next important variables. Particularly hydrologists acknowledged the importance of runoff and SWE. The lack of evaporation and net radiation balance in the results was raised by the respondents. CLIME-DSS illustrates the effect of climate change on several physical, chemical and biological variables related to lakes. The respondents considered all these variables almost equally relevant, with a slight emphasis on the duration of ice cover. This result is probably explained by the background of the respondents.

This survey demonstrated that a map based tool where one can either view large areas at a same time, or select a point of interest for detailed examination, is well suited for disseminating results of regional climate models – despite the deficiencies discussed above. However, it seems to be more challenging to illustrate how the climate change is reflected in chemical and biological variables describing the state of the environment. This may be partly explained by the increasing uncertainty and decreasing confidence in the results as climate model simulations – that are already subject to substantial uncertainty – are used as an input to yet another uncertain model describing the state of the environment. The methods applied in condensing simulation model results (such as climate migration tool and Bayesian networks) in CLIME-DSS appeared to be useful provided that sufficient information about how the results have been processed is available.

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