EUROPEAN COMMISSION

Community research

CLIPC DELIVERABLE (D -N°: 8.4)

Uncertainty assessment of climate impact indicators

File name:

Dissemination level: PU (public)

Author(s): ***Juliane Otto Elke Keup-Thiel (GERICS, HZG)***
PIK: Luis Costa, TUDO:Johannes Lückenkötter, Florian Hurth, JRC: Niall McCormick, SYKE: Kristin Böttcher, Stefan Fronzek, Juha Pöyry, Sari Metsamaki

Reviewer(s): ***Lars Bärring, Rob Swart***

Reporting period: *June 2015 –November 2016*

Release date for review: 18/11/2016

Final date of issue: ***25/11/2016***

Revision table			
Version	**Date**	**Name**	**Comments**
1	28 July 2016	First version	Outline circulated for discussion
2	14 Nov. 2016	Second version	Circulated for second internal review
3	18 Nov 2016	Third version	Circulated for external review
4	25 Nov 2016	Final version	Review comments addressed

Abstract

This deliverable is part of WP8 and presents the results of task 8.4 '*Development of tools specifying uncertainties of climate impact indicators*'.
A central and unique of part of the indicator toolkit is a new and innovative development of presenting expert-based confidence information for the climate impact indicators. A colour-code and a confidence-fact sheet provide the confidence information.
To help users to easily identify regions with robust projections of future climate change, the concept of the climate signal maps was implement in the CLIPC portal. Both methods are described in detail in this report.

Project co-funded by the European Commission's Seventh Framework Programme (FP7; 2007-2013) under the grant agreement n°607418

Table of contents

Executive Summary

Aim and Objective

This deliverables summarises how the CLIPC project dealt and engaged with the topic 'uncertainty[1]' and how it is presented and communicated in the final version of the CLIPC portal. This deliverable is a constituent part of Work Package 8 (WP8) summarising the results of task 8.4 'Development of tools specifying uncertainties of climate impact indicators'. The specific objectives of task 8.4 include:

a) Development of a methodology and tools to specify the uncertainty of climate change impact indicators developed in WP7 and WP8 with a tailor-made analysis to identify and communicate uncertainties of impact indicators
b) Statistical estimation of the robustness of tier 1 climate impact indicators based on different climate model scenarios covered in WP6

The development steps and first implementations of the methodology are described in detail in three previous milestones (MS34, MS37 & MS 39). Prime concept ideas of presenting uncertainty with confidence are described in MS34. The methodology of providing confidence information for the climate impact indicators is based on a questionnaire and user consultations as described in MS37. The subsequent MS39 presents the workflow of the implementation of the expert-based confidence information into the CLIPC portal.
The strategy how the CLIPC project engaged with uncertainties and how the management of confidence information is presented in the final version of the CLIPC portal is the main object of this deliverable 8.4.

[1] See Table 1 for the definition of the term‚uncertainty'

Introduction

The Climate Information Platform for Copernicus (CLIPC) project (http://www.clipc.eu) has developed an integrated web-portal of Climate Data Services to provide a single point of access for authoritative scientific information on climate variability and change, and their impacts. Data within the portal includes data from satellite and in-situ observations, climate models and data re-analyses, transformed data products enabling impact assessments, climate change impact[2] indicators and socio-economic data.

The CLIPC project aimed to provide a systematic treatment of uncertainty for the variety of climate impact indicators. A systematic and transparent management of uncertainty increases trust between the providers of climate impact indicators and users. Better understanding of uncertainty of climate impact indicators and how the level of uncertainty influences the confidence of a climate impact indicator is a prerequisite for better decision making.

For sake of clarity, we provide here the definitions of the terms '*uncertainty*', '*confidence*' and '*robustness*' that are used in this deliverable:

Uncertainty	is defined as an expression of the degree to which a value or relationship is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. Uncertainty may originate from many sources, such as quantifiable errors in the data, ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgment of a team of experts (IPCC SREX, 2012).
Confidence	comprises the validity of a finding, based on the type, amount, quality, and consistency of evidence and on the degree of agreement, as well as on the type of method used for the calculation of the climate impact indicator. Confidence is expressed qualitatively.
Robustness	is defined as agreement of simulations toward the projected changes as well as with the fraction of the simulations that project statistically significant changes.

Table 1: Overview of definitions of the terms 'uncertainty'*,* 'confidence' *and* 'robustness'.

[2] "Climate impact indicators" refer to tier 1, 2 and 3 indicators, noting that tier 1 indicators are derived from climate data and often only the terms "climate indicators" or "climate indices" are used for it. Tier 2 requires combination of climate information with biophysical information (e.g., flood risk or ecosystem impacts), and tier 3 also with socio-economic information (e.g., economic damage or health impacts).

The CLIPC portal is designed for expert users with comparatively high level of scientific understanding and technical skills to download and manipulate data (e.g., climate scientists, impact researchers, skilled consultants or other knowledge purveyors) as well as for non-expert users without the aforementioned characteristics (less skilled knowledge purveyors, policy makers, public and private sector decision makers). The complexity of the information provided makes the portal specifically attractive to the former category of users, but does not exclude the latter. The CLIPC portal's design speaks to both user categories, allowing them to navigate through the portal in a natural way by providing access to three main features:
(1) Data search: direct access to climate data from CLIPC but also central infrastructures, i.e. ESGF, EMODNET and others,
(2) Data processing: allows users to select, process, and download/upload datasets by making use of the tools in a personal MyCLIPC work space,
(3) Data exploration: the various climate impact indicators produced in CLIPC can be accessed, viewed and explored in separated section called ***indicator toolkit***.

A central and unique of part of the indicator toolkit is a new and innovative development of providing ***expert-based confidence information*** for climate impact indicators. An expert is a scientist (or group of scientists) who calculated and provided a climate impact indicator for the indicator toolkit. Special attention is placed on communicating this information about the confidence users can have in the various climate impact indicators in a qualitative and transparent way. The methodology development, implementation and application of the expert-based confidence information are described in section 'The new methodology: expert-based confidence assessment', page 7.

Besides providing expert-based confidence information for climate impact indicators, the CLIPC project aims to provide users with a visual presentation of robustness for a set of climate impact indicators. The ***climate signal map*** (Pfeifer et al. 2015) is a measure to present the robustness of an ensemble of climate projections where robustness is defined as the agreement of simulations with respect to the direction of the projected changes as well as with the fraction of the simulations that project statistically significant changes. To avoid overwhelming the user with the richness of information, only condensed information of the climate projection ensemble is selected for the visualisation. The development and application of the climate signal maps is described in section: 'Spatial visualisation of robustness: climate signal maps', page 12.

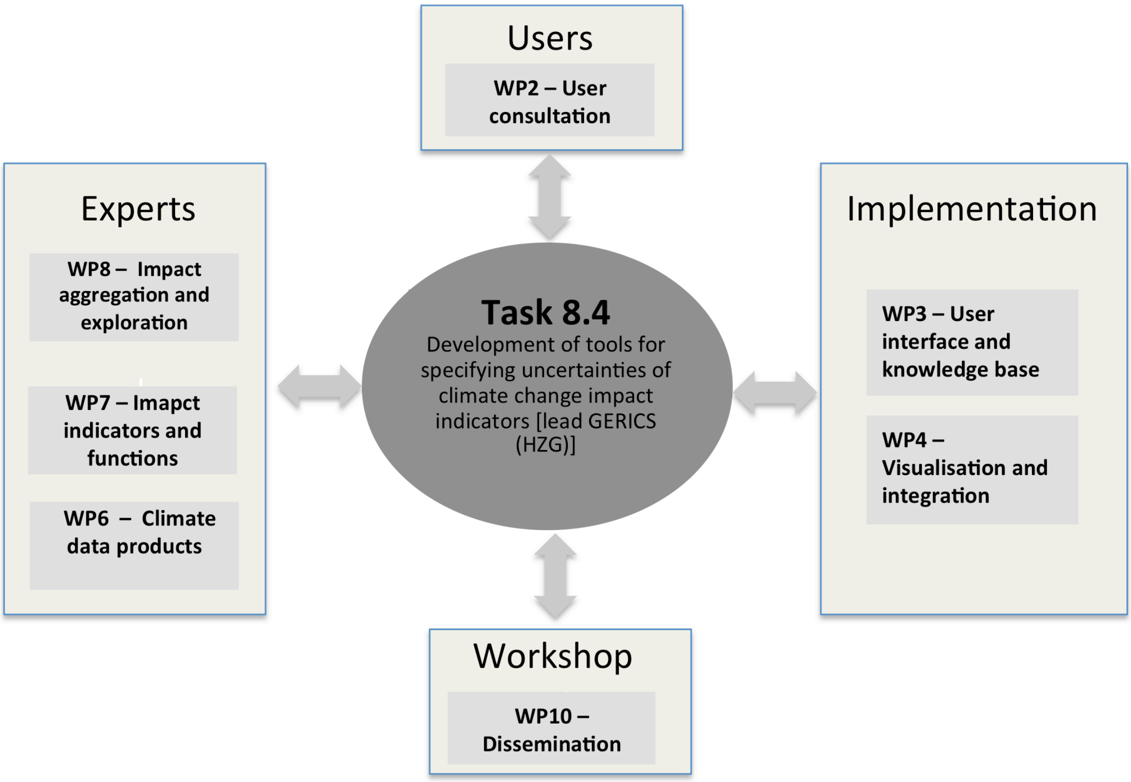


Figure 1: The methodology of the confidence assessment was developed and coordinated within Task 8.4. Various CLIPC partners from almost all work packages contributed to the various steps from the idea to the application of the expert-based confidence assessment: development (WP2, WP10), implementation (WP3,WP4), application (WP6,WP7,WP8). The implementation of the climate signal maps in the CLIPC was also done in close cooperation with WP3 and WP4.

The concept and methodology development of the confidence assessment was led by GERICS (HZG) and its implementation and application was a team effort of the CLIPC consortium (see Figure 1). The methodology for the expert-based confidence information was developed in WP8. During the development, three user consultations were organised with WP2 partners to take users needs about uncertainties into account in the methodology. Partners from WP6, WP7 and WP8 applied the method by providing expert-based confidence information for the climate impact indicators that they calculated. The design and implementation of the expert-based confidence information in the portal was done by WP3 and the processing of the data for the climate signal maps was done by WP4. Within the scope of the dissemination of CLIPC in WP10, a workshop was organised on the theme of how to present uncertainty with confidence.

The new methodology: expert-based confidence assessment

A CLIPC user consultation about the user experiences of existing portals (D2.1: http://www.clipc.eu/project-information/deliverables-and-milestones) has recognised that climate data portals provide insufficient information about uncertainties, resulting in one of the major weaknesses of existing climate data portals. Therefore, the CLIPC project aimed to provide the users with a systematic and transparent treatment of uncertainty for all climate impact indicators to enhance trust between the users and the data providers.

Three WPs in CLIPC were dedicated to produce climate impact indicators that are defined as an observed or projected measure that indicates a 'relevant' environmental/human/economic impact that can be linked to changes in the climate. The challenge for the CLIPC project was that the portal was designed to act as a single point of access for this variety of climate impact indicators that are derived from a variety of underlying climate, climate impacts and non-climate data sources with different associated sources of uncertainty.

The CLIPC project developed an innovative method to systematically collect and present expert-based confidence information of the different climate impact indicators in the CLIPC portal. The expert-based confidence assessment was conceived of assembling and combining relevant uncertainty information, then translating the aggregated result into a degree of confidence - this comprises not only the quantifiable fraction of uncertainty, but also additionally the degree to which one trusts an outcome. The CLIPC partners who calculated and provided the climate impact indicators for the portal performed this confidence assessment. After a review and a final check from GERICS, the expert-based confidence information was published via a content management system.

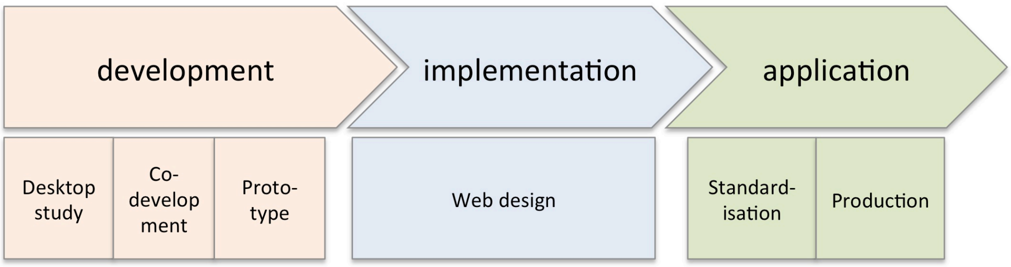
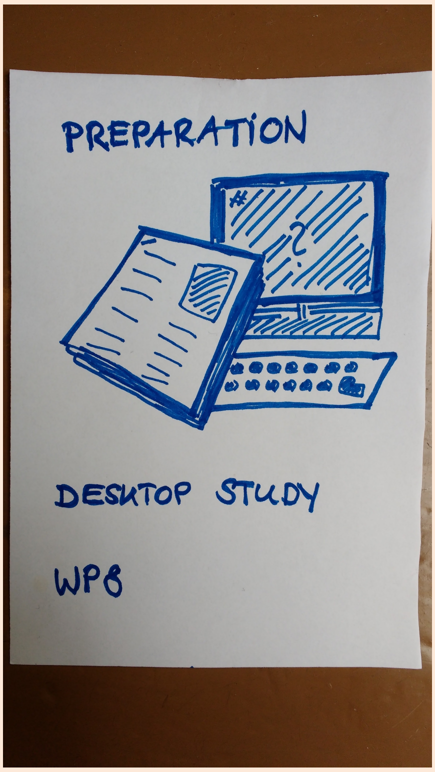


Figure 2: Three phases from the development to the application of the expert-based confidence assessment. The single steps are explained below.

The development of the methodology how to collect and present expert-based confidence information of climate impact indicators in the CLIPC portal comprised three main phases during the duration of the project: the development phase consisting of three steps, the implementation phase and the application consisting of two steps. These phases are described in detail in three previous MS34, MS37 & MS 39. Although the description of the methodology (MS37) was only required as a Milestone, we initiated a review process by two

CLIPC partners to receive feedback on the development of this new methodology. A summary of the three phases is presented below:

Development

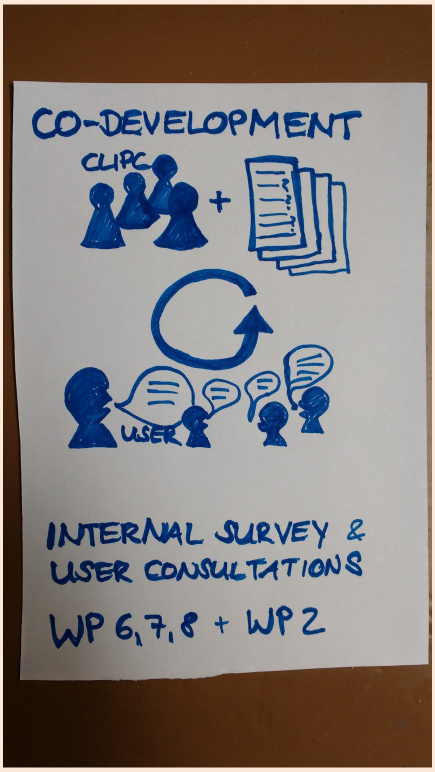


STEP I – Desktop study

The aim was to identify the current status of presenting uncertainties in climate portals and to gain an overview of uncertainty frameworks.

- Existing uncertainty assessments are developed for very specific purposes, e.g. modelling of ecosystems (Warmink et al., 2010) or water sector (Refsgaard et al., 2007, 2012). They are not directly transferable to the CLIPC portal's aims of covering the uncertainties associated with a variety of climate and non-climate data.
- Scanning of more than 15 climate portals showed that none of the climate data portals provide the users with systematic confidence guidance on the displayed data.

For more information: see M34 and M37 → http://www.clipc.eu/project-information/deliverables-and-milestones



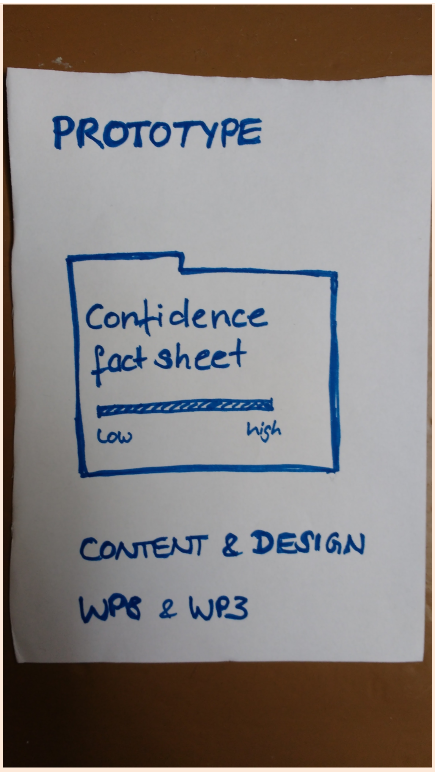
STEP II – Co-Development

To meet user needs, a survey with CLIPC partners and consultations with CLIPC users were performed.

The methodology for providing confidence information developed for CLIPC is based on two main components:

- a questionnaire filled-in by CLIPC partners to identify sources of uncertainty for each selected climate impact indicator
- engagement with potential CLIPC users to test development steps and to determine most important components for providing confidence information
-

For more information: see M37 → http://www.clipc.eu/project-information/deliverables-and-milestones.



STEP III – Prototype

Based on step I and II a prototype for presenting the confidence information was developed.

The prototype presents the confidence information in two-step approach:

- **scale**: translation of degree of confidence in a level ranging from * (low) to ****(high) determined by the expert
- **confidence factsheet**: a description of the degree of confidence and a list of sources of uncertainty related to a climate impact indicator - complied by the expert

For more information: see M37 → http://www.clipc.eu/project-information/deliverables-and-milestones.

Implementation

STEP I - Web design
From the prototype stage the expert-based confidence information was transferred and implemented in the indicator toolkit of the CLIPC portal.

The ***indicator toolkit*** allows users to view and explore climate impact indicators that are viewed via a map viewer. The confidence information appears in the indicator toolkit in two steps: a selected dataset is viewed on a map, next to the map a button indicates the degree of confidence by a four-fold colour code. By clicking on it, the confidence-fact sheet appears with detailed information on the confidence, underpinned by a list of sources of uncertainties (see Figure 3 below).

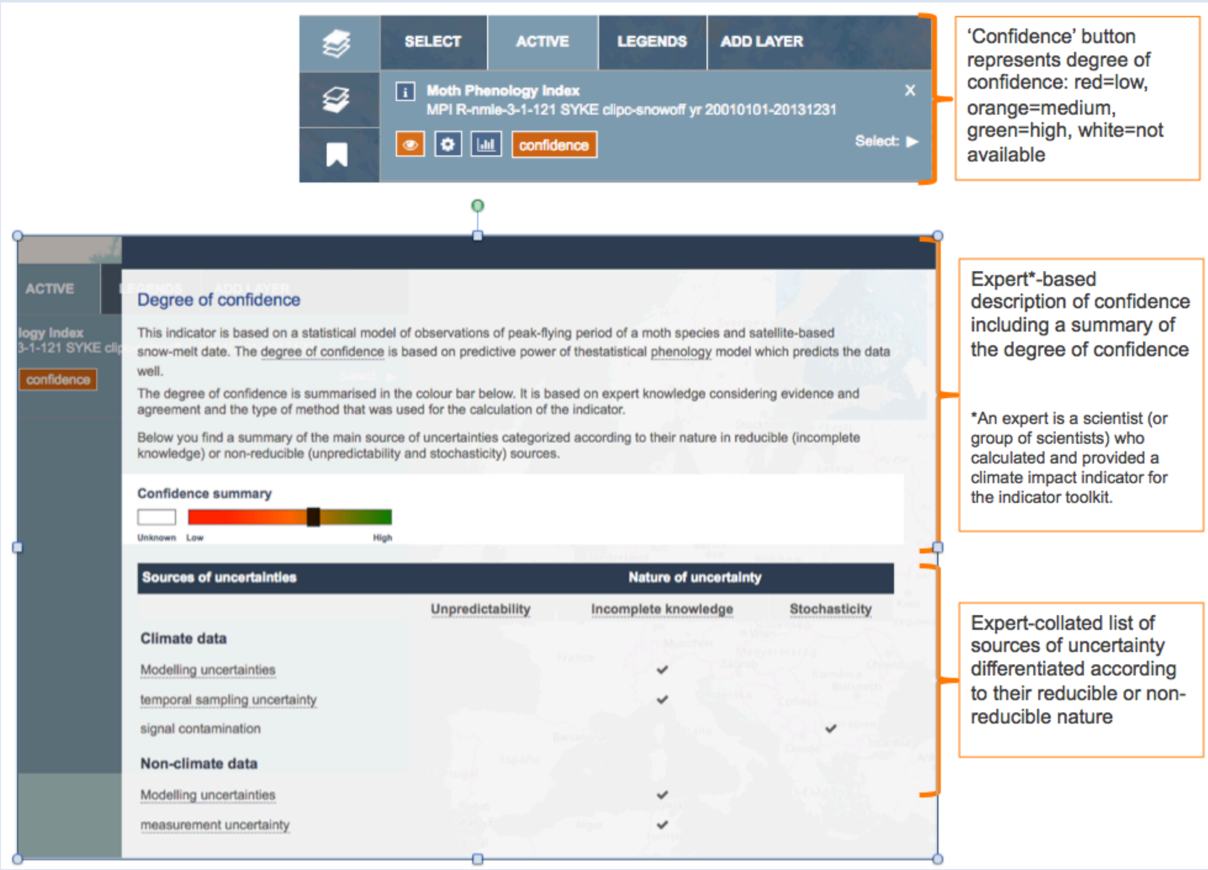
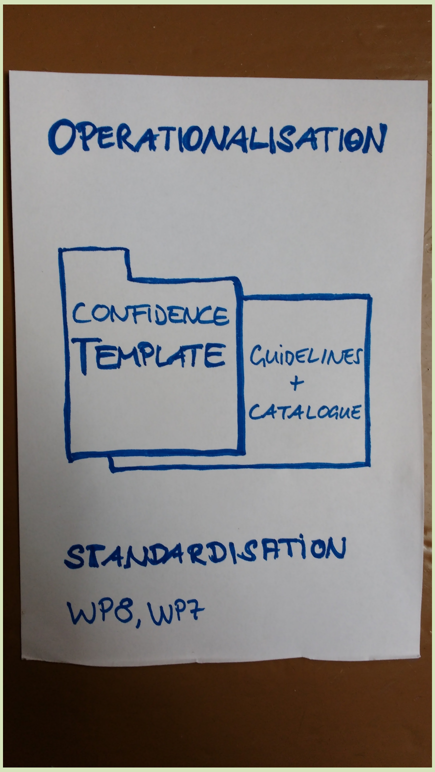


Figure 3: The expert-based confidence information illustrated on the basis of the climate change indicator 'moth phenology' (MPI_R-nlme-3-1-121_SYKE_clipc-snowoff_yr_20010101-20131231). The confidence information is displayed in two-step approach. First a confidence button is shown which colour depends on the degree of confidence. A popup window contains the detailed information about the confidence information.

For more information: see M39 → http://www.clipc.eu/project-information/deliverables-and-milestones.

Application

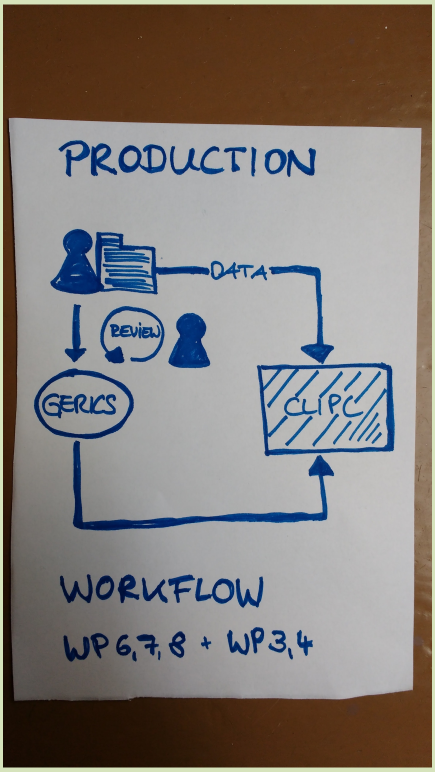


STEP I – Standardisation

To apply the method to a variety of climate impact indicators, a standardisation of the process was required.

- Template and protocol how to assess the confidence information was developed and provided to the CLIPC partners
- A catalogue of main sources of uncertainty (see Appendix A) was established. The sources were grouped depending on the input datasets: modelling, in-situ, remote sensing, bias adjustment and re-analysis, and categorized by their nature into reducible or non-reducible sources of uncertainty.

For more information: see M39 → http://www.clipc.eu/project-information/deliverables-and-milestones.



STEP II – Production

A workflow was established to publish the expert-based confidence information in the CLIPC portal.

- When a CLIPC partner calculated a new climate impact indicator for the indicator toolkit, he/she filled in the confidence template (developed at step I) and sent it to GERICS (HZG). An internal review by a CLIPC partner was initialized. After a final check from GERICS(HZG), the confidence information was published by GERICS(HZG) via a content management system. The archiving of the confidence templates was done at GERICS(HZG).

For more information: see M39 and D7.3→ http://www.clipc.eu/project-information/deliverables-and-milestones

Result: Published expert-based confidence information in final version of CLIPC portal

During the development phase, it was decided that only for a small selection of ten to twelve climate impact indicators the expert-based confidence information would be made available in the indicator toolkit. In the final version of the CLIPC portal, now in total more than two-third of the climate impact indicators are provided with expert-based confidence information. The close cooperation between Task8.4 and WP3, the CLIP web developers, and the other CLIPC partners providing climate impact indicators allowed us to establish an efficient work flow to publish the expert-based confidence information in the indicator toolkit. There are in total 59 climate impact indicators available in the indicator toolkit (November 2016). For 43 of these climate impact indicators expert-based confidence information is available. For the remaining climate impact indicators the user receives a notification that expert-based confidence information is not available - due to the end of the project time.

A climate impact indicator can be derived from different underlying data sets. For example, the climate impact indicator ‘frost days’ is available in the indicator toolkit for a lower and higher spatial resolution, for the historical and future time periods, for two Representative Concentration Pathways, for non-bias adjusted and bias-adjusted data sets. Each dataset is provided with separated expert-based confidence information.

Some expert-based confidence information relates to several climate impact indicators. This is the case if they are derived from the same underlying data set. For example, the expert-based confidence information of the datasets for ‘frost days’ are also valid for other temperature-related climate impact indicators derived from the same ensemble of climate change projections, i.e. ‘ice days’, ‘summer days’, ‘tropical nights’.

In the final version of the CLIPC portal, in total 161 datasets related to 43 climate impact indicators are provided with expert-based confidence information. See the full list in Appendix B: Overview of climate impact indicators and datasets with expert-based confidence information.

Spatial visualisation of robustness: climate signal maps

The variety of climate impact indicators, based on different underlying data sets, may lead to an overwhelming flood of information. In addition, climate impact indicators derived from an ensemble of climate change projections consisting of different model simulations and/or different scenarios span a wide range of possible climate changes. It is not always directly evident from the range of possible climate changes whether and how robust information can be derived from the data. The CLIPC project aimed to provide users not only with expert-based confidence information to help interpreting the climate impact indicators but also to support them with a visual presentation of robustness for a set of climate impact indicators.

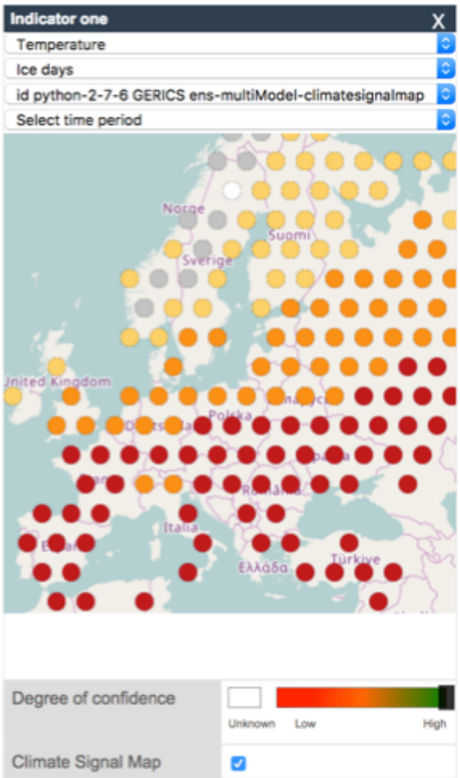
To evaluate the robustness of projected changes in climate projection ensembles and to make the results of such evaluations quickly comprehensible and spatially visible, the climate signal map method was developed (Pfeifer et al., 2015). "Robust" is thereby defined as the agreement of simulations toward the projected changes as well as with the fraction of the simulations that project statistically significant changes. To avoid overwhelming the user with the richness of information, only condensed information of the climate projection ensemble is selected for the visualisation. Only one direction of change is always examined, either the increase or decrease of a climate impact indicator.

A three-fold colour code with individual thresholds is assigned to demonstrate the robustness of the climate change signal. These thresholds are based on practical relevance and categorise the climate change signal into a low, medium or strong magnitude depending on the purpose of the climate signal map. For example, if we are interested in the change in tropical nights for Europe, we select the increase in tropical nights because a higher occurrence of tropical nights in the future would require adaptation. If for a region no robust information can be derived from the ensemble of model projections, the region is marked in grey. Regions in white are those areas in which the climate ensemble would project no change or the opposite direction of the climate change signal. Following the example of displaying the increase of tropical nights, areas with a decrease of tropical nights get the colour white.

Climate signal maps are calculated for the mean projected change of climate parameters averaged for the time period 2070-2099 compared to the average for the time period 1971 to 2000. The number of climate change projections per climate signal map depends on the resolution. The climate signal maps for the lower resolution (about 50 km, EUR-44) are based on a set of 10 climate change projections, whereas the climate signal maps for the higher resolution (about 12 km, EUR-11) are based on a set of 15 climate change projections. All climate change projections are based on one Representative Concentration Pathway (RCP8.5).

In the final version of the CLIPC portal, climate signal maps are available the following climate impact indicators: wet days, heavy precipitation days, tropical nights, ice days, frost days, heating days, summer days. The datasets contain the facet ‘climatesignalmap’ and are accessible via the ‘compare function’ in the indicator toolkit.

How the digital climate signal maps are presented in the CLIPC portal, is demonstrated below by the means of the climate impact indicator ‘ice days’.



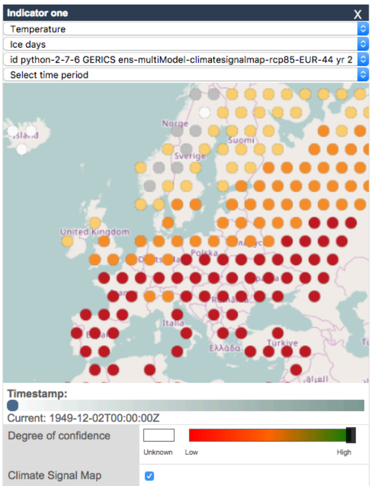
Digital climate signal map - view

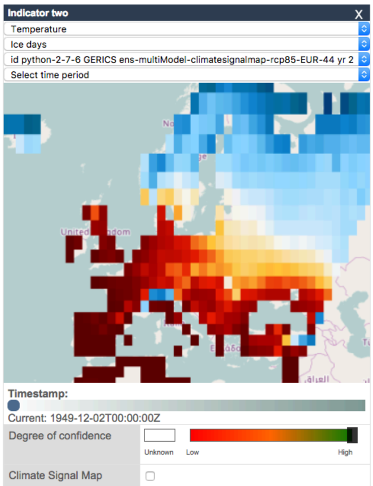
The climate signal maps are accessible via the 'compare function' in the indicator toolkit.

Example 'Decrease in ice days' for spatial resolution of about 50 km x 50 km grid cell (EUR-44).
Each circle represents the climate change signal average over 4x4 grid cells.

The colour of the circles indicate:
yellow - small robust decrease (< 5 days)
orange- medium robust decrease (5 – 30 days)
red - large robust decrease (> 30 days).

Grey circles present regions where the climate change information is not robust. Regions white circles show an increase or no change in ice days.





Digital climate signal map - compare

The compare function allows to view the same dataset next to a climate signal map which allows a direct comparison with 'raw' climate change signal without the robustness assessment.

The visual method of assessing the robustness of climate change projections was adapted for the purpose to be used and to be publishable in the CLIPC portal. The main new developments are listed here:

- climate signal maps are stored as netcdf including legend information
- fast grid-independent interpolation
- speeding up of code and improved plotting
- script-based setting of CLIPC metadata information

For more detailed information, please contact juliane.otto@hzg.de

Guidance in CLIPC portal on confidence information and robustness

To create a well-functioning climate information portal that meets the requirements of diverse users, a user consultation process has been organised by WP2 (see D2.3 http://www.clipc.eu/project-information/deliverables-and-milestones). A frequent request by users was to provide more guidance in accessing and interpreting data as well as in using the different functionalities. The CLIPC portal now provides the user with different types of guidance: 'How to get started,' 'FAQs', 'Glossary', and training videos on how to use the portal and the indicator toolkit.

To support the users interpreting the climate impact indicators by taking into account the information that is available about confidence and robustness, a webpage with guidelines will be established before the end of the project. The users are guided to the confidence fact sheets of climate impact indicators and to the climate signal maps for assessing the robustness of climate change information. The content for the guideline webpage is presented in 'Appendix C: Concept of guidance about confidence information and robustness in CLIPC portal' and will be available online under http://www.clipc.eu/getting-started/presenting-uncertainty-with-confidence.

Workshop: "Confidence in Climate Services - Presenting Uncertainty with Confidence"

The objective of WP10 was to ensure that the project outcomes of CLIPC are communicated effectively to the scientific community and appropriate user communities. One task to fulfil this objective was to organize a workshop on the topic of uncertainty.

Beginning of 2016 a workshop entitled "Confidence in Climate Services (CiCS) - Presenting Uncertainty with Confidence" was hosted at the Climate Service Center Germany (GERICS) in Hamburg (Germany). Invited were 25 delegates from ten on-going and finished European Union FP7 and H2020 projects (CLIPC, EUCLEIA, EUPORIAS, FIDUCEO, GAIA-CLIM, IMPACT2C, IMPRESSIONS, QA4ECV, SPECS), the European Space Agency SST CCI project and two European institutions (C3S, EEA). The objective was to share information about uncertainty of data in climate science and to discuss how to contribute to establishing confidence in the role of uncertainty related to climate service products.

The report about the outcome of the CiCS workshop was accepted as Meeting Summary in Bulletin of the American Meteorological Society. The report is expected to be online available in January 2017. A pre-print version is available in 'Appendix D: Workshop report – preprint of BAMS meeting summary'.

The lessons learned of the CiCS workshop were discussed during a follow-up workshop by the remote sensing and re-analysis community. This workshop, in which the FP7/H2020 Copernicus Climate Change projects shared their expertise and increased convergence on how to define, assess, and communicate uncertainties and data quality, was held in September 2016. The European Commission in Brussels hosted the workshop. See for more information: http://uerra.eu/project-meetings/uncertainty-c3s-workshop.html.

Conclusions and lessons learned

A unique aspect of the CLIPC portal is the systematic presentation of expert-based confidence information for climate impact indicators for which a quantitative analysis is not always possible. With that the CLIPC project paid special attention on communicating information about the confidence users can have in the various data sets and indicators in a qualitative and transparent way.

In addition to the expert-based climate information, the users can explore the robustness of a set of climate impact indicators derived from an ensemble of climate change projections. By means of the climate signal maps user can easily identify regions with robust projections of future climate change and regions for which projected climate changes are strongest.

Despite the value and importance of this information about confidence and robustness, the CLIPC portal does not aim to replace expert consultancy – it is a decision-support system that still may require tailoring to satisfy specific user needs.

The presentation of expert-based confidence information and robustness seem to be highly appreciated by users (see D2.3 http://www.clipc.eu/project-information/deliverables-and-milestones). Nevertheless, their implementation in the CLIPC portal is a compromise between what users asked for and what was feasible. For example, users requested not only for a listing of sources of uncertainties associated with a climate impact indicator but also for a ranking of these sources in terms of importance. A solution for the latter request depends strongly on the case and the user's intention. It is not possible within a project like CLIPC that develops a climate data portal that is designed to reach a variety of users to address such a request.

The expert-based climate information reflects the judgement of a limited number of project experts and the provided confidence information by the CLIPC partners varied in the level of detail. In some assessments a long list of potential uncertainty sources are listed but the description is lacking information about the confidence assessment. This was criticised by the MS40 about 'Testing WP8 tools' (see for more information: http://www.clipc.eu/project-information/deliverables-and-milestones). A further development of the method could be to include a more formalised way of expert elicitation of confidence information (see i.e. Zickfeld et al. (2010) or the NUSAP method) - a broader peer review may further improve the confidence estimates of the CLIPC experts.

The application of the expert-based confidence assessment is time consuming. A climate data portal with sustained operation would need to allow for enough time and human resources for applying this expert-based confidence method and expanding it to all data and information made accessible through the portal. A central contact for the coordination of this task is essential. This comprises monitoring the collection of expert-based confidence information, including the review process, publishing and archiving the expert-based confidence information.

References

IPCC SREX: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp, 2012.

Maxim, L. and van der Sluijs, J. P.: Quality in environmental science for policy: Assessing uncertainty as a component of policy analysis, Environ. Sci. Policy, 14(4), 482–492, doi:10.1016/j.envsci.2011.01.003, 2011.

Pfeifer, S., Bülow, K., Gobiet, A., Hänsler, A., Mudelsee, M., Otto, J., Rechid, D., Teichmann, C. and Jacob, D.: Robustness of Ensemble Climate Projections Analyzed with Climate Signal Maps: Seasonal and Extreme Precipitation for Germany, Atmosphere (Basel)., 6(5), 677–698, doi:10.3390/atmos6050677, 2015.

Refsgaard, J. C., van der Sluijs, J. P., Højberg, A. L. and Vanrolleghem, P. a.: Uncertainty in the environmental modelling process – A framework and guidance, Environ. Model. Softw., 22(11), 1543–1556, doi:10.1016/j.envsoft.2007.02.004, 2007.

Refsgaard, J. C., Arnbjerg-Nielsen, K., Drews, M., Halsnæs, K., Jeppesen, E., Madsen, H., Markandya, a., Olesen, J. E., Porter, J. R. and Christensen, J. H.: The role of uncertainty in climate change adaptation strategies—A Danish water management example, Mitig. Adapt. Strateg. Glob. Chang., 18(3), 337–359, doi:10.1007/s11027-012-9366-6, 2012.

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluijs, J. P., van Asselt, M. B. A., Janssen, P. and Krayer von Krauss, M. P.: Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support, Integr. Assess., 4(1), 5–17, 2003.

Wardekker, J. A., van der Sluijs, J. P., Janssen, P. H. M., Kloprogge, P. and Petersen, A. C.: Uncertainty communication in environmental assessments: views from the Dutch science-policy interface, Environ. Sci. Policy, 11(7), 627–641, doi:10.1016/j.envsci.2008.05.005, 2008.

Warmink, J. J., Janssen, J. a. E. B., Booij, M. J. and Krol, M. S.: Identification and classification of uncertainties in the application of environmental models, Environ. Model. Softw., 25(12), 1518–1527, doi:10.1016/j.envsoft.2010.04.011, 2010.

Zickfeld, K., Morgan, M. G., Frame, D. J. and Keith, D. W.: Expert judgments about transient climate response to alternative future trajectories of radiative forcing., Proc. Natl. Acad. Sci. U. S. A., 107, 12451–12456, doi:10.1073/pnas.0908906107, 2010.

Appendix A: Complied list of sources of uncertainties

List of sources of uncertainty that was developed together with the CLIPC partners and serves as a basis for the expert-based confidence assessment. This list is part of the guidelines how to do the confidence assessment and can for be found online: http://tiny.cc/clipc_confidence_template.

Name of source	Description	Nature of source			Guidance help: it is indicated the source applies for type of underlying data				
		Unpredictability …is caused by the variable behaviour of human beings or social processes. It differs from 'incomplete knowledge' because it concerns what 'we cannot know' and therefore cannot be reduced or changed by further research. 'Unpredictability' is therefore non-reducible.	**Stochasticity** … is an inherent property of the system and it describes the degree to which the system's evolution is not predictable, even given perfect understanding of the system. For example, it refers to the evolution of the climate system that is due to chaotic behaviour or (quasi-)random events. This source of uncertainty is non-reducible**.**	**Incomplete knowledge** …arises from the imperfection of our knowledge. It concerns what 'we do not know' at this moment but might know in the future, if sufficient time and resources are available to perform additional research or collect more data. 'Incomplete knowledge' is therefore reducible.	**modelling**	**in-situ**	**remote sensing**	**bias adjustment**	**re-analysis**
external natural forcing	Externally forced climate variations due to changes in natural factors, such as solar	yes			**x**			**x**	

external human forcing	It stems from many possible trajectories that future emission rates of greenhouse gases and aerosol precursors might take, and from future trends in land use.	yes			**x**			**x**	
modelling uncertainty	This comprises all uncertainties resulting from incomplete understanding and representation of the system modelled, including chosen parameters in models and algorithms.This can also include uncertainty from imperfect calibration, the choice of statistical techniques and missing or simplified processes in the algorithms used to retrieve a geophysical quantity from the signal detected by a satellite sensor.			yes	**x**		**x**	**x**	
processing uncertainty	Any steps taken in the transformation from raw data to an end product. This includes homogenisation, averaging, interpolating, computing indices/trends etc.			yes	**x**	**x**	**x**	**x**	**x**
measurement uncertainty	This includes the precision of the instrument, and inhomogeneity due to changes in the observing system over time, and any bias of one observing system or sensor versus another. Related to satellite measurements, the position of the sensor plays a role which can lead to errors of the retrieved value. Moreover, the instrument calibration and ageing of the instrument lead to additional uncertainties.			yes		**x**	**x**		
temporal sampling uncertainty	Missing data at the hourly, daily and monthly scales are very common. This will affect any analyses of daily/monthly/seasonal/annual maxima and minima, as well as averages.			yes		**x**			
spatial representativeness	Any region of the Earth is unlikely to be evenly or densely sampled. Stations may also drop in			yes		**x**	**x**		

	and out over time. Regional averages can only represent the stations they are made up of. The comparison of data measured at ground stations with data collected by satellites may introduce scaling errors. The coarser the grid cell of the remotely sensed data, the more of this variability is lost. This may lead to scaling errors between remotely retrieved and in-situ observations.								
sampling uncertainty	Temporal and spatial sampling characteristics will vary depending on the type of orbit, the width of the instrument swath and its field-of-view. For example a single sensor might provide an under-sampled view in space and time and thus, the measurements may or may not capture the true variability of the observed quantity. The position of the sensor which is related to the viewing geometry plays can also lead to errors of the retrieved value.			yes			**x**		
signal contamination	Depending on the quantiy of focus, atmospheric effects like clouds or aerosols, or unwanted signals from the Earth's surface can significantly influence or alter the retrieved signal. For example, for optical data, a robust surface image classification can be very challenging, given the fact that approximately 50% of the Earth is covered by clouds at any time.		yes				**x**		
data assimilation uncertainty	The changing mix of observations, and biases in observations and models, can introduce spurious variability and trends into reanalysis output. Variables relating to the hydrological cycle, such as precipitation and evaporation, should be used with extreme caution. More			yes					**x**

	information: https://climatedataguide.ucar.edu/climate-data/atmospheric-reanalysis-overview-comparison-tables								
calibration uncertainty	The choice of the calibration period introduces uncertainty. The length but also the choice of years for the calibration relate to the relationship which is build between observation and simulation data. This issue is related to the non-stationarity of the bias - it can be changing over time. Statistical methods, however, assume stationarity of biases over time. Therefore, there is a need to maximise the calibration period in order to reduce this part of the uncertainty.			yes				**x**	
observational constraints	Observational constraints, and therefore the reliability of the output, can considerably vary depending on the location, time period, and variable considered.			yes				**x**	**x**

Appendix B: Overview of climate impact indicators and datasets with expert-based confidence information

List of all climate impact indicators and their respective datasets that are available in the CLIPC portal with expert-based confidence information. Sorted by name of institution that provided the expert-based confidence information. The right column specifies the tier of the climate impact indictor (tier :1,2 or 3, nc=non climate). Bold indicates the name of the climate impact indicator and the dataset name the CLIPC partners provided the confidence information for, the datasets listed below relate to the same expert-based confidence information. The completely filled-in confidence templates for these climate impact indicators and a short description of the climate impact indicator can be retrieved under this link: ***http://tinyurl.com/CLIPCDel8-4-confidence-archive*** *or upon request from juliane.otto@hzg.de*

Indicator name	DRS	Tier
HZG		
Temperature		
Tropical nights (EUR11 historical)	**tr_cdo-1-6-3_GERICS_ens-multiModel_historical_mixed_ens-multiModel_v1_EUR-11_yr_19700101-2005123**	1
Ice day	id_cdo-1-6-3_GERICS_ens-multiModel_historical_mixed_ens-multiModel_v1_EUR-11_yr_19700101-2005123	
Frost day	fd_cdo-1-6-3_GERICS_ens-multiModel_historical_mixed_ens-multiModel_v1_EUR-11_yr_19700101-2005123	
Heating days	hd17_cdo-1-6-3_GERICS_ens-multiModel_historical_mixed_ens-multiModel_v1_EUR-11_yr_19700101-2005123	
Summer days	su__cdo-1-6-3_GERICS_ens-multiModel_historical_mixed_ens-multiModel_v1_EUR-11_yr_19700101-2005123	
Tropical nights (EUR11 future)	**tr_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231**	1
Ice day	id_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Frost day	fd__icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Heating days	hd17_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Summer days	su_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Tropical nights (EUR44 historical)	**tr_ icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231**	1

Ice day	id_ icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Frost day	fd_ icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231...	
Heating days	hd17 icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Summer days	su icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Minimum temperature	tn icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Maximum temperature	tx icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Tropical nights (EUR44 future rcp4.5/rcp8.5)	**tr icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231**	1
Ice day	id_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Frost day	fd_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Heating days	hd17_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Summer days	su_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Minimum temperature	tn_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Maximum temperature	tx_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Tropical nights	tr_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Ice day	id_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	

Frost day	fd_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Heating days	hd17_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Summer days	su_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Minimum temperature	tn_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Maximum temperature	tx_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Tropical nights (EUR44 historical bias-adjusted)	**tr_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231**	1
Ice day	id_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Frost day	fd_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Heating days	hd17_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Summer days	su_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Minimum temperature	tn_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Maximum temperature	tx_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Tropical nights (EUR44 future rcp4.5/rcp8.5 bias-adjusted)	**tr icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231**	
Ice day	id_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	

Frost day	fd_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	1
Heating days	hd17_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Summer days	su_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Minimum temperature	tn_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum temperature	tx_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Tropical nights	tr icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Ice day	id_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Frost day	fd_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Heating days	hd17_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Summer days	su_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Minimum temperature	tn_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum temperature	tx_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Tropical nights (EUR11 climate signal maps)	**tr python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-11 yr 20700101-20991231 1971-2000**	1
Ice days	id python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-11 yr 20700101-20991231 1971-2000	
Frost days	fd_ python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-11 yr 20700101-20991231 1971-2000	

Heating days	hd17_ python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-11 yr 20700101-20991231 1971-2000	
Summer days	su_ python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-11 yr 20700101-20991231 1971-2000	
Tropical nights (EUR44 climate signal maps)	**tr python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-44 yr 20700101-20991231 1971-2000**	1
Ice days	id_python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-44 yr 20700101-20991231 1971-2000	
Frost days	fd_python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-44 yr 20700101-20991231 1971-2000	
Heating days	hd17_python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-44 yr 20700101-20991231 1971-2000	
Summer days	su__python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-44 yr 20700101-20991231 1971-2000	
Precipitation		
Wet days (EUR11 historical)	**r1mm_cdo-1-6-3 GERICS ens-multiModel historical mixed ens-multiModel v1 EUR-11 yr 19700101-20051231**	1
Number of Heavy Precipitation Days	r10mm_cdo-1-6-3 GERICS ens-multiModel historical mixed ens-multiModel v1 EUR-11 yr 19700101-20051231	
Wet days (EUR11 future rcp 8.5)	**r1mm_cdo-1-6-3_GERICS_ens-multiModel_rcp85_mixed_ens-multiModel_v1_EUR-11_yr_20060101-20991231**	1
Number of Heavy Precipitation Days	r10mm_cdo-1-6-3_GERICS_ens-multiModel_rcp85_mixed_ens-multiModel_v1_EUR-11_yr_20060101-20991231	
Wet days (EUR44 historical)	**r1mm icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231**	
Number of Heavy Precipitation Days	r10mm_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Maximum 1-day precipitation	rx1day_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	

Very wet days	r95p_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	1
Number of Very Heavy Precipitation Days	r20mm_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Total wet- day precipitation	prcptot_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Maximum Consecutive Wet Days	cwd_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Maximum Consecutive Dry Days	cdd_icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 yr 19700101-20051231	
Wet days (EUR44 future rcp8.5 / rcp4.5)	**r1mm icclim-4-2-3 KNMI ens-multiModel rcp845 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231**	
Number of Heavy Precipitation Days rcp4.5	r10mm icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Maximum 1-day precipitation	rx1day icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231_...	
Very wet days	r95p_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Number of Very Heavy Precipitation Days	r20mm_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Total wet- day precipitation	prcptot_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Maximum Consecutive Wet Days	cwd_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	1

Maximum Consecutive Dry Days	cdd_ icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Wet days (EUR44 future)	r1mm icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Number of Heavy Precipitation Days rcp8.5	r10mm icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Maximum 1-day precipitation	rx1day icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231_...	
Very wet days	r95p_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Number of Very Heavy Precipitation Days	r20mm_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Total wet- day precipitation	prcptot_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Maximum Consecutive Wet Days	cwd_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Maximum Consecutive Dry Days	cdd_ icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 yr 20060101-20991231	
Wet days (EUR44 historical bias-adjusted)	**r1mm icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231**	
Number of Heavy Precipitation Days	r10mm icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Maximum 1-day precipitation	rx1day_ icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Very wet days	r95p icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	1

Number of Very Heavy Precipitation Days	r20mm_ icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Total wet- day precipitation	prcptot icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Maximum Consecutive Wet Days	cwd_ icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Maximum Consecutive Dry Days	cdd_ icclim-4-2-3 KNMI ens-multiModel historical r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 19700101-20051231	
Wet days (EUR44 future rcp8.5 / rcp4.5 bias-adjusted)	**r1mm icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231**	
Number of Heavy Precipitation Days rcp4.5	r10mm_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum 1-day precipitation	rx1day_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Very wet days	r95p_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	1
Number of Very Heavy Precipitation Days	r20mm_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Total wet- day precipitation	prcptot_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum Consecutive Wet Days	cwd_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum Consecutive Dry	cdd_icclim-4-2-3 KNMI ens-multiModel rcp45 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	

Days		
Wet days (EUR44 future)	**r1mm icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231**	1
Number of Heavy Precipitation Days rcp8.5	r10mm_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum 1-day precipitation	rx1day_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Very wet days	r95p_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Number of Very Heavy Precipitation Days	r20mm_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Total wet- day precipitation	prcptot_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum Consecutive Wet Days	cwd_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Maximum Consecutive Dry Days	cdd_icclim-4-2-3 KNMI ens-multiModel rcp85 r1i1p1 SMHI-RCA4 v1 EUR-44 SMHI-DBS43 EOBS10 bcref-1981-2010 yr 20060101-20991231	
Wet days (EUR11 Climate signal maps)	**r1mm python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-11 yr 20700101-20991231 1971-2000**	1
Number of Heavy Precipitation Days	r10mm python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-11 yr 20700101-20991231 1971-2000	
Wet days (EUR44 Climate signal maps)	**r1mm python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-44 yr 20700101-20991231 1971-2000**	1
Number of Heavy Precipitation Days	r10mm python-2-7-6 GERICS ens-multiModel-climatesignalmap-rcp85-EUR-44 yr 20700101-20991231 1971-2000	

SYKE		
moth phenology indicator	**MPI_R-nlme-3-1-121_SYKE_clipc-snowoff_yr_20010101-20131231**	2
moth phenology indicator	**MPI_R-nlme-3-1-121_SYKE_gdd5-133_yr_20010101-20131231**	2
Snow melt-off date	**snowoff_MATLAB-8-1_SYKE_CryoLand-FSC_yr_20010101-20151231**	1
JRC		
Length of Growing Season	**gsl_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015**	2
Start of growing season	sgs_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015	
End of growing season	egs_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015	
Heatwave Duration Index	hwdi_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015	1
Coldwave Duration Index	cwdi_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015	1
Number of Frost-Free Days	ffd_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015	1
Annual mean temperature	tm_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yrClim_19750101-20151231_1975-2015	1
Winter mean temperature	tm_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_djfClim_19750101-20151231_1975-2015	
Spring mean temperature	tm_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_mamClim_19750101-20151231_1975-2015	
Summer mean temperature	tm_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_jjaClim_19750101-20151231_1975-2015	
Autumn mean temperature	tm_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_sonClim_19750101-20151231_1975-2015	

Annual mean precipitation	prcp_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yrClim_19750101-20151231_1975-2015	1
Winter mean precipitation	prcp_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_djfClim_19750101-20151231_1975-2015	
Spring mean precipitation	prcp_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_mamClim_19750101-20151231_1975-2015	
Summer mean precipitation	prcp_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_jjaClim_19750101-20151231_1975-2015	
Autumn mean precipitation	prcp_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_sonClim_19750101-20151231_1975-2015	
Annual Standardized Precipitation Index	spi_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yrClim_19750101-20151231_1975-2015	1
Winter Standardized Precipitation Index	spi_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_djfClim_19750101-20151231_1975-2015	
Spring Standardized Precipitation Index	spi_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_mamClim_19750101-20151231_1975-2015	
Spring Standardized Precipitation Index	spi_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_jjaClim_19750101-20151231_1975-2015	
Summer Spring Standardized Precipitation Index	spi_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_sonClim_19750101-20151231_1975-2015	
Maximum Consecutive Dry	cdd_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015	1

Days		
Maximum 5-Day Precipitation Total	r5d_induce-1-0-0_EC-JRC_MARS-AGRI4CAST_yr_19750101-20151231_1975-2015	1
Annual vegetation condition	avc_induce-1-0-0_EC-JRC_FAPAR_yr_20030101-20141231_2003-2014	2
End of growing season	EGS pheno JRC 1.0 EC-JRC FAPAR JRC yr 19980101-20111231 1998-2011	
Length of Growing Season	GSL pheno JRC 1.0 EC-JRC FAPAR JRC yr 19980101-20111231 1998-2011	
Start of growing season	SGS pheno JRC 1.0 EC-JRC FAPAR JRC yr 19980101-20111231 1998-2011	
TUDO		
Population	**pop_arcgis-10-4-0_IRPUD_Eurostat_EUROPOP2013-Trend_5yr_20151231-20601231**	nc
forest, transitional woodland-shrub	**forest_arcgis-10-4-0_IRPUD_JRC-LUISA-Landuse_10yr_20100101-20501231**	nc
urban area	urban_arcgis-10-4-0_IRPUD_JRC-LUISA-Landuse_10yr_20100101-20501231	
industry, commercial and services area	indust_arcgis-10-4-0_IRPUD_JRC-LUISA-Landuse_10yr_20100101-20501231	
agricultural area	agri_arcgis-10-4-0_IRPUD_JRC-LUISA-Landuse_10yr_20100101-20501231	
natural land	natland_arcgis-10-4-0_IRPUD_JRC-LUISA-Landuse_10yr_20100101-20501231	
new energy crops	ecrops arcgis-10-4-0 IRPUD JRC-LUISA-Landuse 10yr 20201231-20501231	
PIK		
Storm surge flood depth	**fldd_R-raster-2-5-2_PIK_multi-mixed-historical_clim_19691211-20041130_00001**	2
Minimum mortality	**mmt_R-raster-2-5-2_PIK_multi-mixed_clim_20101231**	2

temperature		
Storm surge level historical	**ssl_R-raster-2-5-2_PIK_ens-multiModel-mean-historical_clim_19691201-20041130**	2
Storm surge level rcp4.5	**ssl_R-raster-2-5-2_PIK_ens-multiModel-mean-rcp45_clim_20091201-20991130**	2
Urban heat island	**uhi_R-raster-2-5-2_PIK_multi-mixed_avg_20130831_00001**	2

Appendix C: Concept of guidance about confidence information and robustness in CLIPC portal

"Presenting uncertainty with confidence"

A systematic and transparent management of uncertainty increases trust between the providers of climate impact indicators and users. Better understanding of uncertainty of climate impact indicators and how the level of uncertainty influences the confidence of a climate impact indicator is a prerequisite for better decision making.

A unique aspect of the CLIPC portal is the systematic presentation of expert-based confidence information for climate impact indicators for which a quantitative analysis is not always possible. With that the CLIPC project paid special attention on communicating information about the confidence users can have in the various data sets and indicators in a qualitative and transparent way. See: **"Expert-based confidence information" (**An expert is a scientist who calculated and provided the climate impact indicator for the portal.)

In addition to the expert-based climate information, the users can explore the robustness of a set of climate impact indicators derived from an ensemble of climate change projections. See **"Climate Signal Maps"**

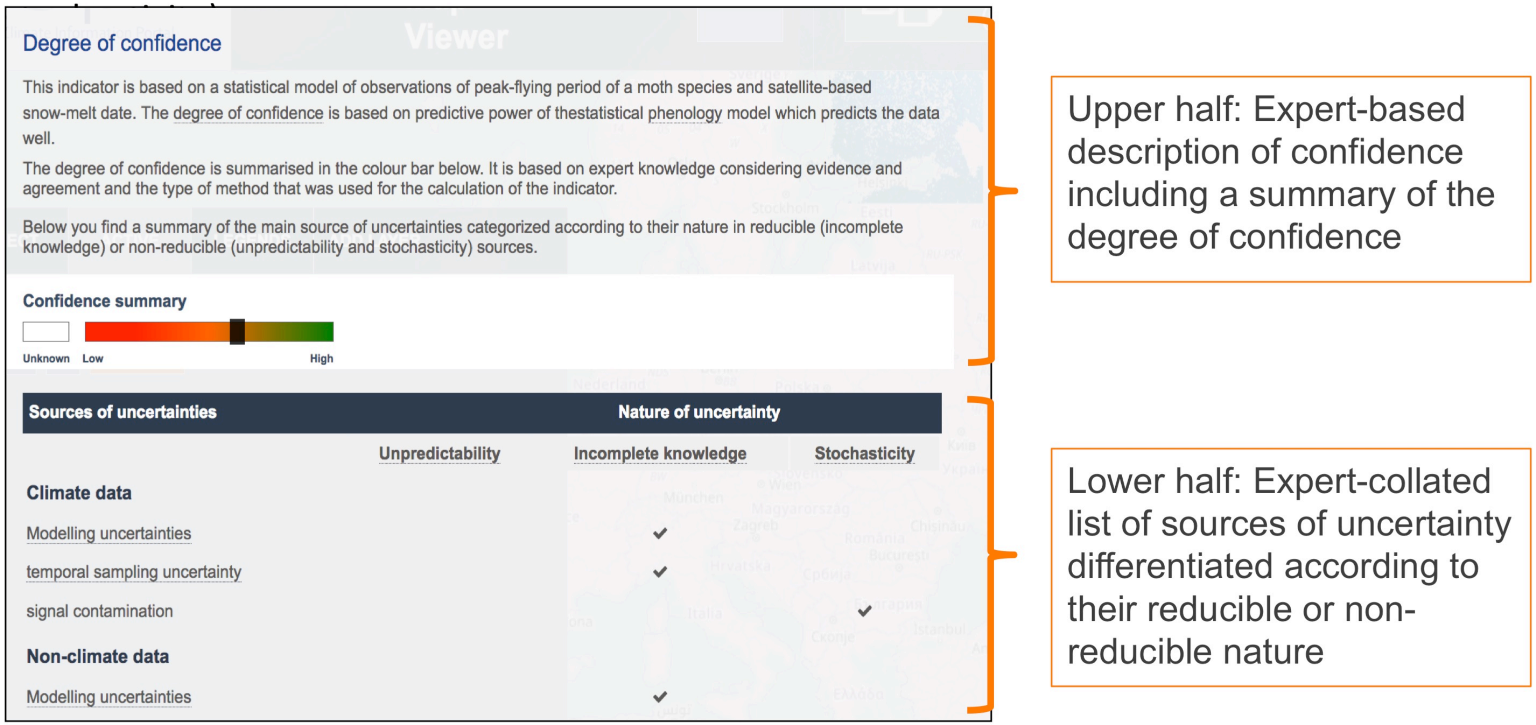
"Expert-based confidence information"

The indicator toolkit allows the user to view and explore climate impact indicators. When you select a dataset for a climate impact indicators, a button called 'confidence' is highlighted under the "active" tab. The colour of the ‚confidence' button summarises the degree of confidence ranging from red (='low') to green (='high'). By clicking on it detailed information about the degree of confidence and the sources of uncertainties are presented in the confidence fact sheet.

'Confidence' button represents degree of confidence: red=low, orange=medium, green=high, white=not available

The confidence fact sheet is divided in two parts. The upper part is related to the expert-based description of what contributes to the degree of confidence. It is based on expert knowledge considering evidence and agreement and the type of method that was used for the calculation of this indicator. The degree of confidence is summarised in a colour bar.

In the lower part of the confidence fact sheet, you find a summary of the main sources of uncertainty related to the selected dataset. These sources of uncertainty belong either to a source that is reducible (incomplete knowledge) or that is non-reducible (unpredictability and

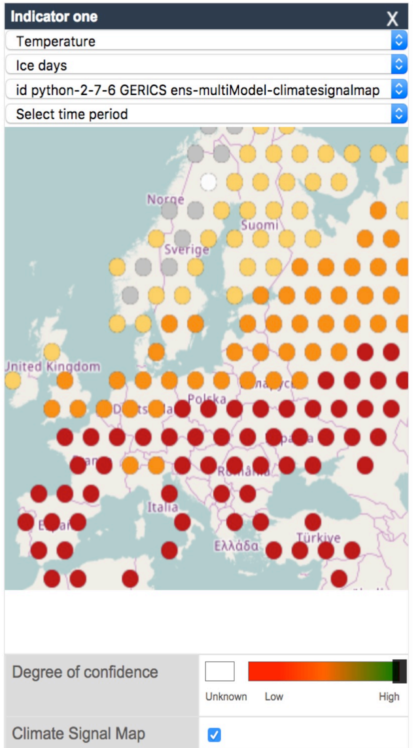


“Climate signal maps”

Under the ‘compare function’ you can select a spatial visualisation of the robustness for a set of climate impact indicators. These 'climate signal maps' help you to identify regions where robust climate changes are derived from an ensemble of multi-model climate simulations. "Robust" is thereby defined as the agreement of simulations toward the projected changes as well as with the portion of the simulations that project statistically significant changes.

Climate signal maps are available for the ‘worst case scenario’ RCP8.5 and the following climate impact indicators: wet days, heavy precipitation days, tropical nights, ice days, frost days, heating days, summer days. Select the dataset named ‘climatesignalmap’ and tick the box ‘Climate Signal Map’ below the map viewer.

For more information about the method: see D8.4 under http://www.clipc.eu/project-information/deliverables-and-milestones and Pfeifer et al. (2015): Robustness of ensemble climate projections analyzed with climate signal maps: seasonal and extreme precipitation for Germany. *Atmosphere*, *6*(5), 677-698; doi:10.3390/atmos6050677



Example of decrease in ice days for spatial resolution of about 50 km x 50 km grid cell.

Each circle represents the climate change signal average over 4x4 grid cells.

The colour of the circles indicate:

- yellow- small robust decrease (less then 5 days)
- orange- medium robust decrease (between 5 and 30 days)
- red - large robust decrease (more then 30 days)

Grey circles present regions where the climate change information is not robust. Regions white circles show an increase or no change in ice days.

Appendix D: Workshop report – preprint of BAMS meeting summary

Uncertainty: Lessons learned for climate services

Juliane Otto, Calum Brown, Carlo Buontempo, Francisco Doblas-Reyes, Daniela Jacob, Martin Juckes, Elke Keup-Thiel, Blaz Kurnik, Jörg Schulz, Andrea Taylor, Tijl Verhoelst, and Peter Walton

Confidence in Climate Services - Presenting Uncertainty with Confidence

What: 25 participants from ten European Union FP7 and H2020 projects (CLIPC, EUCLEIA, EUPORIAS, FIDUCEO, GAIA-CLIM, IMPACT2C, IMPRESSIONS, QA4ECV, SPECS), the European Space Agency SST CCI project and two European institutions (C3S, EEA) met to share information about uncertainty in climate science and to discuss how to contribute to establishing confidence in the role of uncertainty in climate services.

When: 15-17th February 2016

Where: Climate Service Center Germany (GERICS), Hamburg, Germany

AFFILIATIONS: Otto – Climate Service Center Germany (GERICS), Helmholtz-Zentrum Geesthacht, Hamburg Germany; Brown -- University of Edinburgh, Edinburgh, UK; Buontempo-- Met Office, Exeter, UK; Doblas-Reyes --Institució Catalana de Recerca I Estudis Avançats (ICREA) and Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS), Barcelona, Spain; Jacob -- Climate Service Center Germany (GERICS), Helmholtz-Zentrum Geesthacht, Hamburg Germany; Juckes -- Science and Technology Facilities Council (STFC), Didcot, UK; Keup-Thiel -- Climate Service Center Germany (GERICS), Helmholtz-Zentrum Geesthacht, Hamburg Germany; Kurnik -- European Environment Agency (EEA), Copenhagen, Denmark; Schulz -- European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Darmstadt, Germany; Taylor -- Leeds University Business School & School for Earth and Environment, University of Leeds, Leeds, UK; Verhoelst -- Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium; Walton -- Environmental Change Institute, University of Oxford, Oxford, UK.
CORRESPONDING AUTHOR: Juliane Otto, Climate Service Center Germany (GERICS) Helmholtz-Zentrum Geesthacht Chilehaus, Eingang B Fischertwiete 1 20095 Hamburg, Germany
E-mail: juliane.otto@hzg.de

Introduction

Enhancing trust in climate services is a fundamental challenge being faced by providers. Complicating this challenge is how best to communicate uncertainty to different sectors that handle it in different ways depending on their decision-making frameworks. To address this problem for the first time a workshop was held to engage with, and understand the different perspectives of European research projects, institutions and climate service providers.

The workshop targeted European funded projects (FP7 and H2020) that specifically related to the delivery and/or support of climate data, in particular providers of observational and modeled climate data (e.g. FIDUCEO, SPECS), of climate impact data (e.g. IMPACT2C) and service delivery (e.g. EUPORIAS). The assessment and communication of uncertainty is critical in developing confidence in climate services. The delegates presented their strategies in their projects or institutions, followed by in-depth discussions in six breakout groups.

Assessing uncertainty

One step towards building confidence in the role of uncertainty is to reflect on how uncertainty can be assessed. Previous workshops have focused separately on observational (Matthews et al., 2013) and modeling (Qian et al., 2016) approaches, however, it was felt that by considering them together it might be possible to identify common challenges and opportunities. To facilitate this, three breakout groups discussed: methods for the quantification of uncertainty; if temporal and spatial scales matter for quantifying uncertainty; and how to categorize uncertainty.

Methods group: An overview of methods on how to assess uncertainty revealed three frameworks applied by the observation and modeling communities: verification and validation through comparison with a trusted standard reference; evaluation by testing the usefulness of a product to the user; and through expert judgment**.** Within these frameworks there are several methods for quantifying, describing and propagating uncertainty. As each method has its advantages and limitations it is suggested that there is a need to apply a variety of methods to engender confidence. The discussion revealed though that this is not yet common practice. Climate services could benefit from more mutual cooperation between observational and modeling communities. It was suggested that something analogous to the metrological traceability chain documenting the processing steps taken to produce remote sensing data sets (i.e. by QA4ECV) could be attractive for climate service products ensuring that no uncertainty information gets lost in the chain while being tailored to the subsequent user needs.

Scale group: Depending on the temporal and spatial scale of the study, different sources of uncertainty dominate, e.g. random effects might be averaged out at longer temporal and larger spatial scales but systematic effects, such as imperfect instrument calibration, will persist. Appropriate methods to propagate the observational uncertainty estimates when averaging or accumulating a variable are urgently required. Some projects are trying to address this problem (e.g. GAIA-CLIM, FIDUCEO , CCI-SST) but more work is needed. As with the methods group above, any solutions to build more trust requires a better interaction between modelers and observational teams. This will include identifying clear specifications of user requirements on different temporal and spatial scales (Figure 1) in terms of observational uncertainty estimates, and the application of existing practices to as many observational datasets as possible.

Simulations are not exempt from problems of uncertainty estimation either as there is no general agreement on what constitutes an adequate uncertainty estimate. Earth system models are becoming more sophisticated and extensive through the addition of new components and processes. While these reflect an increase in knowledge and therefore reduced levels of uncertainty, it does not directly lead to a quantifiable estimate of uncertainty.

Category group: To disentangle the multiple layers of uncertainty, a mapping exercise was conducted to identify examples across four categories of uncertainty made popular by Donald Rumsfeld: known knowns, known unknowns, unknown knowns and unknown unknowns. It is a ‘known known’ that a certain fraction of the spread of climate projections is irreducible owing to internal variability in the climate system. Whereas the emissions scenarios used in climate projections are dependent on future policy implementations and therefore can be considered 'known unknowns'. 'Unknown knowns', however, are areas of uncertainty we can explain or model but we don't recognize the importance of them to users. This category could be seen as service providers not fully understanding users' needs but could be resolved through dialogue between the different parties. 'Unknown unknowns' reflect areas of uncertainty that may be important to climate change but have not yet been identified and can therefore only be speculated about. Hindsight has revealed examples though such as the depletion of stratospheric ozone as a result of anthropogenic pollutants. From these discussions it was possible to see that there are known components of uncertainty that can be used to outline the knowledge gaps.

Communicating uncertainty

The workshop determined that the communication of uncertainty is critical in developing confidence in climate services and this was explored using three questions: how best to engage with users; what are users' communication preferences; and what role does vocabulary play in understanding uncertainty.

User engagement group: The importance of user engagement is widely acknowledged in building trust, but rather than a need for more engagement *per se*, there is an identifiable need for more targeted and efficient forms of engagement. The group discussed a range of successful strategies they experienced such as developing an on-going user engagement that creates close working relationships and allows for the efficient management of users' input. Creating dedicated user engagement programs independent of any one project could support this last point, along with ensuring consistency of relationships and availability of responses (e.g. in shared databases). Responsive forms of user-led engagement (e.g. online FAQs) have also proved successful in improving usage and allowing the co-development of novel approaches. The incidental availability of broad statistics describing the kinds of user (e.g. geographical location, professional affiliation) engaging with available products can also be helpful.

User preferences group: Using a mapping exercise inspired by Dowell et al. (2013), the chain of providers and users lying between climate data and climate service provision was explored (Figure 1). While not exhaustive, this exercise highlighted a) multiple points at which uncertainty must be summarized and communicated; b) that communication between the various "links" need not be unidirectional; and c) that in the chain of providers and users, end-user preferences are not the only ones that must be considered. Communication challenges across the chain predominantly fell into two interlinked categories of 'traceability' and 'tailoring'. Traceability was seen as the need to maintain clarity about sources of uncertainty from observation to end-user. The chain should not become an avalanche, cascading an unmanageable and unusable compendium of uncertainty details onto an overwhelmed user, but it should provide the links back to all the information for those who elect to follow them. While information about uncertainty may need to be condensed, a traceable chain of documentation is needed to provide full transparency. Tailoring encourages the climate service provider to recognize the differing information requirements of users at different stages of 'the chain', as well as end-users' diverse needs. The importance of appropriately tailoring uncertainty information was stressed, as was a need for greater bi-directional communication between providers and subsequent users.

Language group: It is of particular importance to convey the uncertainty information to different levels of decision makers in understandable 'language'. Two examples of well-proven practices in communicating confidence were identified: a) for a scientific audience: the definition of confidence through an amalgamation of level of evidence and agreement by the Intergovernmental Panel on Climate Change (Mastrandrea et al., 2011); b) for a broader non-scientific audience: using serious gaming to help local policy makers understand climate hazard and risk (Suarez and Bachofen, 2013). As seen by the user preference group, it is essential to maintain and improve an interactive communication between service providers and decision makers (Figure 1). And where appropriate providing training on the presentation of climate and impact information with the necessary uncertainty information is seen as being decisive. This can be strengthened by climate services with focus on traceability and the development of targeted guidance. The distribution of information through translation of e.g. policy briefs into different languages needs to be done carefully as any lack of clarity in the initial description of uncertainty is liable to be amplified in translation.

Barriers and potential solutions

A large part of the discussions centered on the barriers in building confidence in climate services and, where possible, their potential solutions. The ones noted here are far from being exhaustive but represent the key barriers and solutions highlighted at the workshop:

Barrier: Uncertainty is often seen as a barrier to action. **Solution**: The framing and integration of user needs at early stages of data product design is essential. On the one hand this avoids unrealistic expectations by the users but it also adds knowledge about which sources of uncertainty are most relevant.

Barrier: Each community has its own methods for treating uncertainty. **Solution**: Continued collaboration between communities in their role as users and providers (Figure 1) sharing information and learning from each other was recognized as key for developing best practices.

Barrier: Presenting uncertainty in a clear, user-focused manner is a challenge**. Solution**: Lessons can be learned from other sectors as how to communicate uncertainty to users (e.g. finance or insurance) though care needs to be taken when applying other strategies in a new context.

Lessons learned for best practices

During the workshop, three core lessons emerged from the group discussions that could be considered for best practice:

Transparency: the need to maintain traceability about sources of uncertainty was emphasized across all groups. While information about uncertainty may need to be condensed when it is communicated from provider to subsequent users, a traceable chain of documentation is necessary for full transparency. This assumes documentation of all processing steps (Figure 1).

Layering: a layered approach allows tailoring the amount of information on uncertainty under different decision frameworks. This can only be achieved by a bi-directional communication between providers and users, to ensure that the user needs are understood and that appropriate and accurate information is provided and appropriately interpreted (Figure 1).

Disclosure: a tailored approached is not meant to hide uncertainty but rather aims to detect and document all known components of uncertainty, including knowledge gaps and issues relating to methodology and processing of data. When communicating uncertainty it is important to emphasize what we understand and to recognize that as research improves knowledge, some uncertainty sources may reduce.

Future challenges

During the workshop two main challenges in the role of uncertainty for climate services were identified:

Validation of communication: the discussion of how to communicate uncertainty is often centered on how to transport information from providers to users. However, there is a great need for climate services to develop methods for testing the efficacy of communication strategies to ensure that appropriate and accurate uncertainty information is provided and that this is interpreted correctly.

Guidance: There is a clear need for guidance and standards on the methods of uncertainty assessment and communication. These do not yet exist for climate services. Noting that this was the first of its kind, similar workshops, preferably together with users, can serve as a good basis to share information between communities and to collect lessons learned that could be turned into best practices, which could then be developed into climate service standards.

Acknowledgements

The three-day workshop was funded and initiated by the FP7 project CLIPC (Grant 607418) and organized jointly with the FP7 projects EUPORIAS, EUCLEIA and QA4ECV and hosted by GERICS in Hamburg, Germany.

References

M. Dowell, P. Lecomte, R. Husband, J. Schulz, T. Mohr, Y. Tahara, R. Eckman, E. Lindstrom, C. Wooldridge, S. Hilding, J.Bates, B. Ryan, J. Lafeuille, and S. Bojinski, 2013: Strategy Towards an Architecture for Climate Monitoring from Space. **Pp. 39**, [Available online at: http://www.wmo.int/pages/prog/sat/documents/ARCH_strategy-climate-architecture-space.pdf].

Mastrandrea, M. D., Mach, K. J., Plattner, G.-K., Edenhofer, O., Stocker, T. F., Field, C. B., Ebi, K. L. , and Matschoss, P. R.: The IPCC AR5 guidance note on consistent treatment of uncertainties: a common approach across the working groups, Clim. Change, **108(4)**, 675–691, doi:10.1007/s10584-011-0178-6, 2011.

Matthews, J. L., Mannshardt, E. and P. Gremaud, 2013: Uncertainty Quantification for Climate Observations, Bull. Am. Meteorol. Soc., **94(3)**, ES21–ES25, doi:10.1175/BAMS-D-12-00042.1.

Qian, Y., Jackson, C., Giorgi, F., Booth, B., Duan, Q., Forest, C., Higdon, D., Hou, Z. J. and G. Huerta, 2016: Uncertainty Quantification in Climate Modeling and Projection, Bull. Am. Meteorol. Soc., **97(5)**, 821–824, doi:10.1175/BAMS-D-15-00297.1.

Suarez, P. and Bachofen, C., 2013: Using games to experience climate risk: Empowering

Africa's decision makers, **27** [Available online at:
http://www.climatecentre.org/downloads/File/Games/CDKNGamesReport.pdf].

Figure Captions List

Figure1: Between the provision of data and the application of climate services, a "chain" of providers and subsequent users/providers exists. For instance, one pathway through the chain may involve observational data and information being passed to data assimilation, to post-processing, to climate modeling, to impact modeling, to climate service providers, with new details of information on uncertainty being added at each step (striped area). Hence, the question of how to best address user preferences is not only restricted to end-users only. While information about uncertainty may need to be condensed at each knot (tailoring), a traceable chain of documentation is needed to provide full transparency (traceability) on all aspects of uncertainty. This requires that the flow of communication needs to be bi-directional. Both sides benefit from this bi-directional flow: providers learn about users' needs and users understand how to handle uncertainty with confidence.

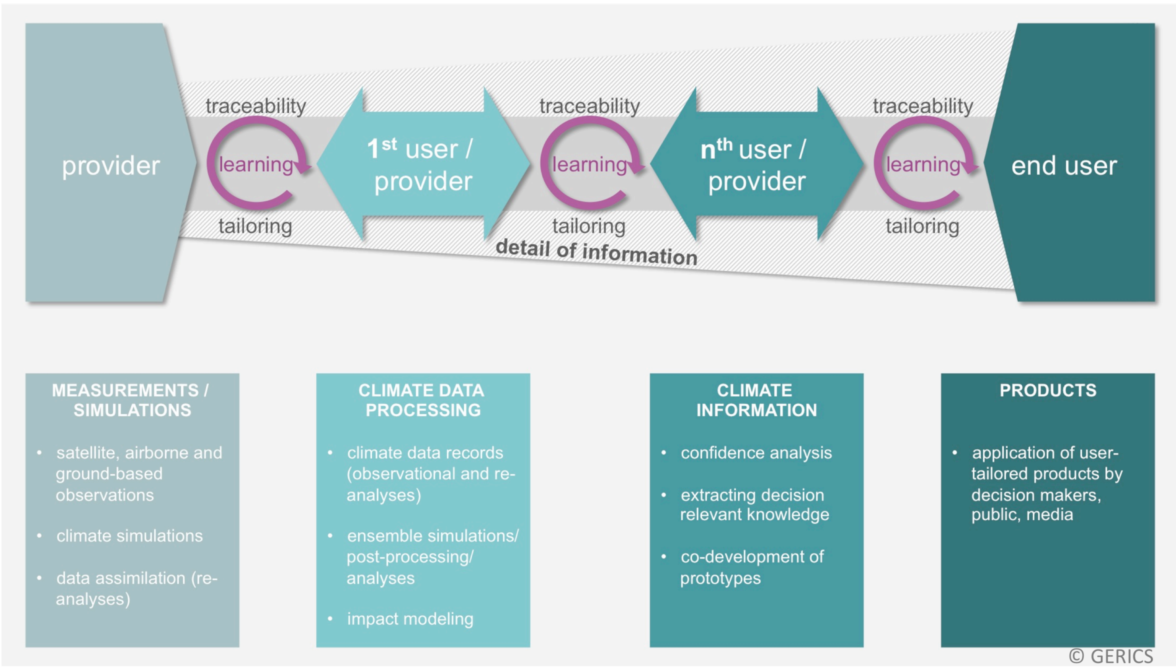


Figure 1: Between the provision of data and the application of climate services, a "chain" of providers and subsequent users/providers exists. For instance, one pathway through the chain may involve observational data and information being passed to data assimilation, to post-processing, to climate modeling, to impact modeling, to climate service providers, with new details of information on uncertainty being added at each step (striped area). Hence, the question of how to best address user preferences is not only restricted to end-users only. While information about uncertainty may need to be condensed at each knot (tailoring), a traceable chain of documentation is needed to provide full transparency

(traceability) on all aspects of uncertainty. This requires that the flow of communication needs to be bi-directional. Both sides benefit from this bi-directional flow: providers learn about users' needs and users understand how to handle uncertainty with confidence.