Noname manuscript No.
(will be inserted by the editor)

Supplementary Material: The challenge to detect and attribute effects of climate change on human and natural systems

Dáithí Stone · Maximilian Auffhammer · Mark Carey · Gerrit Hansen · Christian Huggel · Wolfgang Cramer · David Lobell · Ulf Molau · Andrew Solow · Lourdes Tibig · Gary Yohe

Received: date / Accepted: date

D. Stone
Lawrence Berkeley National Laboratory, 1 Cyclotron Road, MS-50F1650, Berkeley, CA, 94720, USA
Tel.: +1-510-495-8160
Fax: +1-510-486-5812
E-mail: dstone@lbl.gov

M. Auffhammer
University of California, Berkeley & National Bureau of Economic Research, Cambridge, USA

M. Carey
University of Oregon, Eugene, OR, USA

G. Hansen
Potsdam Institute for Climate Impact Research, Potsdam, Germany

C. Huggel
University of Zürich, Zürich, Switzerland

W. Cramer
Mediterranean Institute for Biodiversity and Ecology (IMBE), Aix-Marseille University / CNRS / IRD, Bat. Villemin, Europol de l'Arbois – BP 80, F-13545, Aix-en-Provence cedex, France E-mail: wolfgang.cramer@imbe.fr

D. Lobell
Stanford University, Stanford, CA, USA

U. Molau
University of Gothenburg, Gothenburg, Sweden

A. Solow
Woods Hole Oceanographic Institution, Woods Hole, MA, USA

L. Tibig
The Manila Observatory, Quezon City, Philippines

G. Yohe
Wesleyan University, Middletown, CT, USA

Table 1 Definitions of detection given in various climate change-related literature. In order to reflect active usage, the definitions listed here are taken directly from the texts and not from any associated glossaries.

Source	Definition of detection
Merriam-Webster (2013)	Detection: the act of detecting; the state or fact of being detected. To detect: to discover the true character of; to discover or determine the existence, presence, or fact of.
Wigley et al (1990) (IPCC FAR WGI)	The word detection has been used to refer to the identification of a significant change in climate. . . . To claim detection in a useful and practical way, we must not only identify a climatic change, but we must attribute at least part of such a chance to the enhanced greenhouse effect. . . . Detection requires that the observed changes in climate are in accord with detailed model predictions of the enhanced greenhouse effect. . . .
Santer et al (1996) (IPCC SAR WGI)	. . . detection of change is the process of demonstrating that an observed change in climate is highly unusual in a statistical sense, but does not provide a reason for the change.
Watson et al (1996) (IPCC SAR WGII)	Not defined.
Mitchell et al (2001) (IPCC TAR WGI)	Detection is the process of demonstrating that an observed change is significantly different (in a statistical sense) than can be explained by natural internal variability.
Ahmad et al (2001) (IPCC TAR WGII)	Assessment of the impacts on human and natural systems that already have occurred as a result of recent climate change. . . . An important component of the detection process is the search for systematic patterns of change across many studies that are consistent with expectations. . .
Hegerl et al (2007) (IPCC AR4 WGI)	Detection is the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change. . . . An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small.
Rosenzweig et al (2007) (IPCC AR4 WGII)	Considered synonymous with attribution.
Hegerl et al (2010) (IPCC GPGP)	Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small.

References

Ahmad QK, Warrick RA, et alii (2001) Methods and tools. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Climate change 2001. Impacts, adaptation, and vulnerability, Cambridge University Press, Cambridge, U.K., pp 105–143

Hegerl GC, Zwiers FW, Braconnot P, Gillett NP, Luo Y, Marengo Orsini JA, Nicholls N, Penner JE, Stott PA, et alii (2007) Understanding and attributing climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press,

Table 2 List of definitions of attribution given in various climate change-related literature. In order to reflect active usage, the definitions listed here are taken directly from the texts and not from any associated glossaries.

Source	Definition of attribution
Merriam-Webster (2013)	Attribution: the act of attributing. To attribute: to explain by indicating a cause.
Wigley et al (1990) (IPCC FAR WGI)	Not defined.
Santer et al (1996) (IPCC SAR WGI)	Attribution is the process of establishing cause and effect, i.e. that changes in anthropogenic emissions are required in order to explain satisfactorily the observed change in climate.
Watson et al (1996) (IPCC SAR WGII)	Not defined.
Mitchell et al (2001) (IPCC TAR WGI)	Detection and attribution of climate change to anthropogenic causes (i.e. the isolation of cause and effect) ... involves statistical analysis and the careful assessment of multiple lines of evidence to demonstrate, within a pre-specified margin of error, that the observed changes are: unlikely to be due entirely to internal variability; consistent with the estimated responses to the given combination of anthropogenic and natural forcing; and not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combination of forcings.
Ahmad et al (2001) (IPCC TAR WGII)	Attribution of observed changes in natural systems to the effects of climate change is analogous to attribution of anthropogenic greenhouse gases as causal factors of recent climate trends.
Hegerl et al (2007) (IPCC AR4 WGI)	Attribution of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence.
Rosenzweig et al (2007) (IPCC AR4 WGII)	Detection and attribution of observed changes and responses in systems to anthropogenic forcing is usually a two-stage process. First, the observed changes in a system must be demonstrated to be associated with an observed regional climate change within a specified degree of confidence. Second, a measurable portion of the observed regional climate change, or the associated observed change in the system, must be attributed to anthropogenic causes with a similar degree of confidence.
Hegerl et al (2010) (IPCC GPGP)	Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence.

Table 3 Examples of response time scale in various impacts systems.

System	Driver	Time scale
Snow	Temperature	Days to weeks
	Precipitation	Hours to days
Glaciers	Temperature and precipitation	Years to several decades to a century
Ice sheets of Greenland and Antarctica	Temperature and precipitation	Centuries to millennia
Runoff	Precipitation	Minutes to hours
River streamflow	Precipitation	Days to months
	Temperature	Months

Cambridge, U.K., pp 663–745

Hegerl GC, Hoegh-Guldberg O, Casassa G, Hoerling MP, Kovats RS, Parmesan C, Pierce DW, Stott PA (2010) Good practice guidance paper on detection and attribution related to anthropogenic climate change. In: Stocker TF, Field CB, Qin D, Barros V, Plattner GK, Tignor M, Midgley PM, Ebi KL (eds) Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Detection and Attribution of Anthropogenic Climate Change, IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland

Merriam-Webster (2013) Merriam-webster online. Http://www.merriam-webster.com/dictionary/. Accessed 30 January 2013

Mitchell JFB, Karoly DJ, Hegerl GC, Zwiers FW, Allen MR, Marengo J, et alii (2001) Detection of climate change and attribution of causes. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom, 881pp

Rosenzweig C, Casassa G, Karoly DJ, Imeson A, Liu C, Menzel A, Rawlins S, Root TL, Seguin B, Tryjanowski P, et alii (2007) Assessment of observed changes and responses in natural and managed systems. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., pp 79–131

Santer BD, Wigley TML, Barnett TP, Anyamba E, et alii (1996) Detection of climate change and attribution of causes. In: Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K (eds) Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., pp 407–443

Watson RT, Zinyowera MC, Moss RH (eds) (1996) Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Cambridge University Press, 889pp

Wigley TML, Barnett TP, et alii (1990) Detection of the greenhouse effect in the observations. In: Houghton JT, Jenkins GJ, Ephraums JJ (eds) Climate Change. The IPCC Scientific Assessment,, Cambridge University Press, Cambridge, U.K., pp 241–255