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Supplementary Material

Assessment of observed changes and responses in natural and managed systems

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This Supplementary Material is in support of Chapter 1. The headings correspond to the sections of the main chapter. The Supplementary Material cannot and should not be read in isolation. It can only be read in association with the chapter.

1.3.2 Hydrology and water resources

Table SM-1.1. *Examples from the literature of observed changes in (a) runoff/streamflow and (b) lake levels.*

Location	Time period	Observed change	Reference
(a) Runoff/streamflow			
Arctic Ocean	1936-2002	Increasing annual discharge from six largest Eurasian rivers to Arctic Ocean by 7% due to Arctic Oscillation NAO and warming climate (this increase is not entirely consistent with apparent trends in temperature and precipitation, due to data limitations)	Peterson et al., 2002; Shiklomanov and Shiklomanov, 2003
Sweden	1807-2002	No trend in runoff due to increasing temperature offsetting the increasing precipitation	Lindstrom and Bergstrom, 2004
UK	Last 50 years	No trend in annual runoff	Hannaford and Marsh, 2005
Finland	Last 20 years	Increase in discharge	Hyvarinen, 2003
(b) Lake levels			
Bosten Lake, Xinjiang, China	1980-2000	Rise in lake level ~4 m due to increasing precipitation and snow-ice melt flow from 3.08×108 m^3 to 9.6×108 m^3	Yuan et al., 2003
Daihai Lake, China	1700-1996	From 1960 to 1996 lake level decreased 3.85 m due to combined effects of drought and human activities	Zhang and Ruijin, 2001
Lakes, central Italy	Last 20 years	Decline in lake level due to rainfall decrease and water withdrawal	Capelli and Mazza, 2005
Vortsjarv, Estonia	1884-2000	Strong water level fluctuation related to the North Atlantic Oscillation (NAO)	Noges et al., 2003

Table SM-1.2. *Examples from the literature of observed changes in (a) floods and (b) droughts.*

Location	Time period	Observed change	Reference
(a) Floods			
Global	1865-1999	Increase in frequency of floods with discharges exceeding 100-year levels from 29 large river basins more than 200,000 km^2	Milly et al., 2002
Elbe and Dresden, Germany	1997-2002	Catastrophic events much larger than 100-year flood, but no increasing trend in flood magnitude in a record from 1827	Becker and Grunewald, 2003; Kundzewicz et al., 2005
Bangladesh	1980s-1998	>50-to-100-year floods from strong monsoons	Chowdhury and Ward, 2003
Yangtze River, China	1990-1999	>50-year floods due to El Niño events	Qian and Zhu, 2001
(b) Droughts			
Much of UK	20th century	No evidence of significant increase in the occurrence of low river flows	Hannaford and Marsh, 2005
Much of Europe	1911-1995	No evidence of significant increase in droughts (defined as streamflow below a certain threshold). However, recently Europe has suffered prolonged drought associated with the severe summer heatwave	Hisdal et al., 2001; Hannaford and Marsh, 2005; van der Schrier et al., 2005
Eastern USA	1941-1999	Significant increase in annual minimum (202 out of 395 sites) and median (219 sites) daily streamflow around 1970 as a step change related to precipitation increase and NAO	Douglas, 2000; McCabe, 2002; Groisman, 2004
New England, USA	20th century	No evidence of significant increase in droughts (defined as streamflow below a certain threshold)	Hodgkins et al., 2005
Australia	2002-2003	Severe drought due to record high temperature	Karoly et al., 2003; Nicholls, 2004
Sahelian drought	1981-1993; 1994-2005	(a) 1981-1993 marked by below average Normalised Difference Vegetation Index (NDVI) and persistence of drought (b) 1994-2005 marked by a trend towards 'wetter' condition, but still far below the pre-1980s wetter condition	Hisdal et al., 2001; Hannaford and Marsh, 2005; Hodgkins et al., 2005; van der Schrier et al., 2005

Table SM-1.3. *Examples from the literature of observed changes in physical and chemical water properties.*

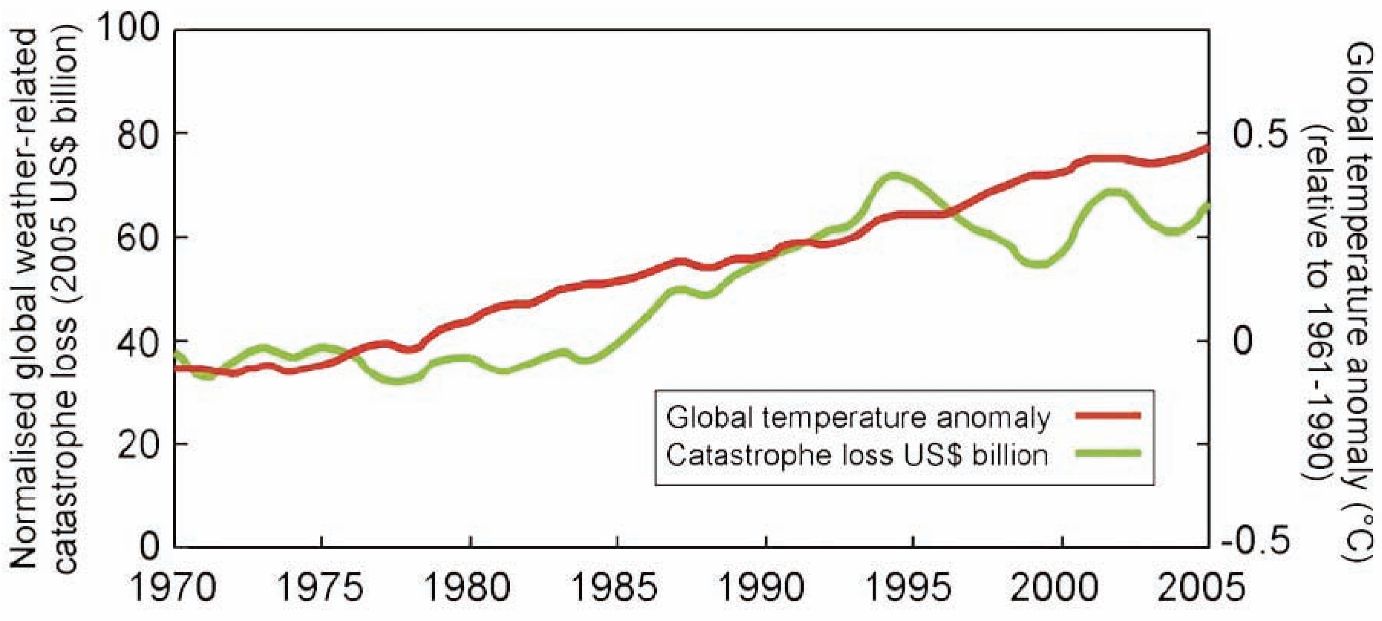
Location	Time period	Observed change	Reference
64 lakes/rivers in Europe, North America and Asia	Last 40 years	Surface water temperature warming by 0.2-1.5°C for 17 lakes. Stratified period has advanced by up to 20 days and lengthened by 2-3 weeks with increased thermal stability	Adrian and Deneke, 1996; King et al., 1998; Livingstone and Dokulil, 2001; Carvalho and Kirika, 2003; Livingstone, 2003; Straile et al., 2003; Arhonditsis et al., 2004; Dabrowski et al., 2004; Winder and Schindler, 2004
8 lakes/rivers in North America, Europe and East Africa	1991-2003 1939-2000	Decreases in nutrients in surface water and corresponding increases in deep-water concentration because of reduced upwelling due to greater thermal stability	Hambright et al., 1994; Adrian and Deneke, 1996; Straile et al., 2003
Lake Baikal, Russia	Recent decades	Decrease in silica content of 30% related to regional warming	Shimaraev et al., 2004
27 rivers, Japan	Recent decades	Increase in biological oxygen demand and suspended solids, and decrease in dissolved oxygen due to increase in air temperature	Ozaki et al., 2003

1.3.3 Coastal processes and zones

Table SM-1.4. *Examples from the literature of changes in storm surges, flood heights and areas, and waves.*

Type of change	Period	Location	References
More frequent and higher floods due to subsidence, hydrodynamic changes and relative sea-level rise	1830-2000	Venice, Italy	Camuffo and Stararo, 2004
Decreasing surges due to shifts in wind direction	1890s-1910s and 1950s-1997	Brittany, France	Pirazzoli et al., 2004
Increasing extreme high water levels due to climate variability and sea-level rise	1975-present	Global	Woodworth and Blackman, 2004
Decrease in mean winter significant wave height	1958-2001	Mediterranean Sea	Lionello et al., 2005

1.3.8 Disasters and hazards



Errata Figure SM-1.1. *An example from the literature of one study analysing rising costs of normalised weather-related catastrophes compared with global temperatures. Data smoothed over ±4 years = 9 years until 2001 (Muir Wood et al., 2006).*

1.4 Larger-scale aggregation and attribution to anthropogenic climate change

Table SM-1.5. *Characteristics of the data used in the aggregation and attribution assessment of Section 1.4.*

1. Database constructed of observations from studies, including information such as:
   a. category and region (according to WGII Chapters),
   b. longitude and latitude of study,
   c. study dates and duration,
   d. direction of change, consistent or not consistent with warming,
   e. statistical significance,
   f. type of impact and system,
   g. whether or not land use was a driving factor.

2. Criteria for inclusion of study in synthesis assessment:
   - published peer-reviewed study,
   - statistically significant trend in change in system related to temperature or related climate variable,
   - changes observed in systems between 1970 and 2004; studies may extend after 2004,
   - studies ending in 1990 or later,
   - duration of study period 20 years or longer.

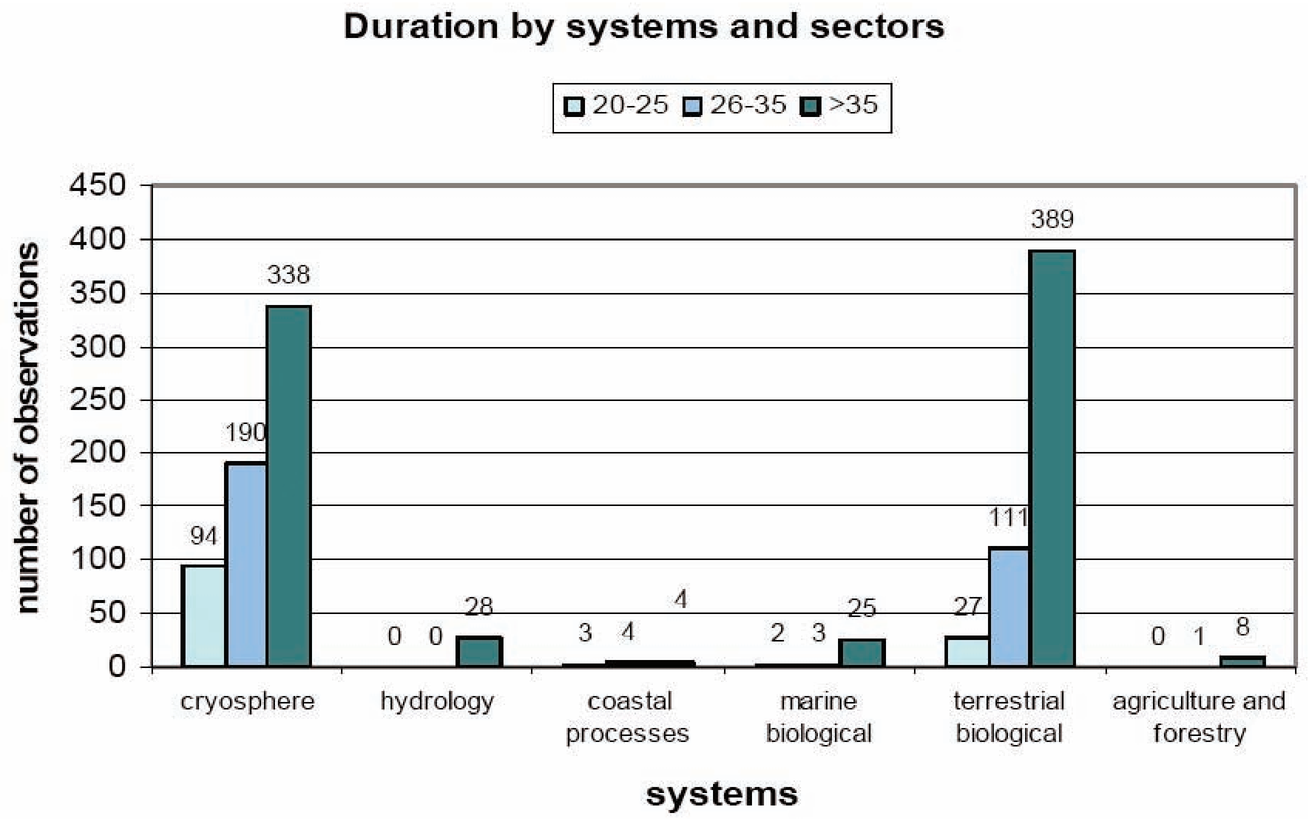


Figure SM-1.2. *Duration of time-series (years) of observed changes in natural and managed systems used in statistical analysis of synthesis assessment in Section 1.4.*

Table SM-1.6. *Summary of observed impacts of temperature-related regional climate change in chapter synthesis assessment in Section 1.4.*

Cryosphere	Changes in glaciers, lake and river ice break-up, snow cover and permafrost active layer
Hydrology	Changes in spring peak discharge and lake levels
Coastal processes	Changes in storminess and coastal vegetation, shoreline retreat, coastal erosion
Marine, freshwater and terrestrial biological systems	Changes in phenology, community composition, productivity and synchrony; shifts in latitude/altitude ranges and breeding sites; genetic adaptation

Table SM-1.7. *Comparison of significant observed changes in physical and biological systems with regional temperature changes at the global scale in chapter synthesis assessment in Section 1.4.*

Temperature cells	Cells with significant observed change consistent with warming*	Cells with significant observed change not consistent with warming	Cells with significant observed change consistent with warming**
Significant warming	49% (2.5%)	9% (2.5%)	56% (5%)
Warming	31% (22.5%)	4% (22.5%)	36% (45%)
Cooling	6% (22.5%)	0% (22.5%)	6% (45%)
Significant cooling	2% (2.5%)	0% (2.5%)	2% (5%)
Chi-squared value (significance level)		350 (<<1%)	104 (<<1%)

* assuming three-fold null hypothesis; ** assuming two-fold null hypothesis; see text for full explanation

Note: Fraction of 5°×5° cells with significant observed changes in systems (from studies considered in this chapter) and temperature changes (over 1970-2004 from HadCRUT3 – Brohan et al., 2006) in different categories (significant warming, warming, cooling, significant cooling). Expected values shown in parentheses are for the null hypotheses:

(i) significant observed changes in systems are equally likely in each direction,
(ii) temperature trends are due to natural climate variations and are normally distributed,
(iii) there is no relationship between significant changes in systems and co-located warming.

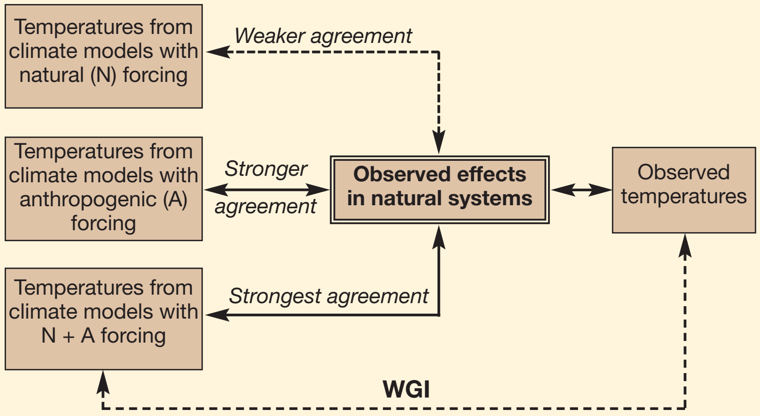
The right-hand column repeats the analysis without assuming point (i) above and only considers significant observed changes in systems that are consistent with warming, in order to avoid the possible effects of publication or research biases.

The significance levels for the chi-squared values relative to the expected distribution are obtained by comparing the locations of the significant observed system changes with regional temperature trends over 35-year periods due to natural climate variability from long control simulations with 5 different coupled climate models; 192 independent 35-year periods were sampled from the control runs, allowing estimation of chi-squared values at about the 1% significance level due to natural variability.

The analysis was repeated using a second global gridded temperature dataset (GHCN-ERSST) and there were no significant differences in the results.

Footnote 1, continued from below Box SM.1 on next page. At each location, all of which are in the Northern Hemisphere, the changing trait is compared with modelled temperatures driven by: (a) Natural forcings (pink bars), (b) anthropogenic (i.e., human) forcings (orange bars), and (c) combined natural and anthropogenic forcings (yellow bars). In addition, on each panel the frequencies of the correlation coefficients between the actual temperatures recorded during each study and changes in the traits of 83 species, the only ones of the 145 with reported local-temperature trends, are shown (dark blue bars). On average the number of years species were examined is about 28 with average starting and ending years of 1960 to 1998. Note that the agreement: a) between the natural and actual plots is weaker (K=60.16, P>0.05) than b) between the anthropogenic and actual (K=35.15, P>0.05), which in turn is weaker than c) the agreement between combined and actual (K=3.65, P<0.01). Taken together, these plots show that a measurable portion of the warming regional temperatures to which species are reacting can be attributed to humans, therefore showing joint attribution (see Chapter 1).

Box SM.1. Linking the causes of climate change to observed effects on physical and biological systems. In chapter synthesis assessment in Section 1.4



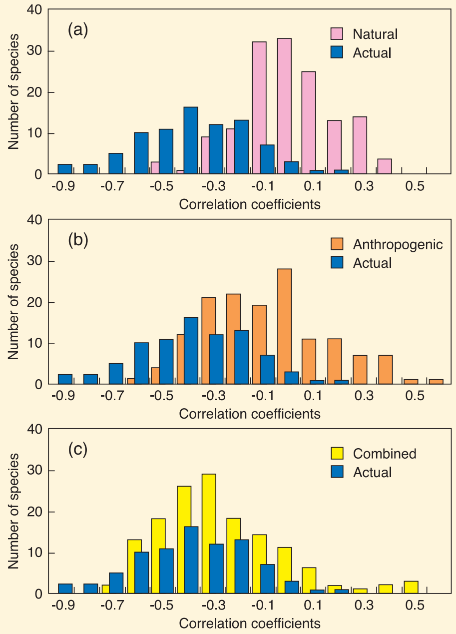
The figure to the left demonstrates the linkages between observed temperatures, observed effects on natural systems, and temperatures from climate model simulations with natural, anthropogenic, and combined natural and anthropogenic forcings. Two ways in which these linkages are utilised in detection and attribution studies of observed effects are described below.

1. Using climate models

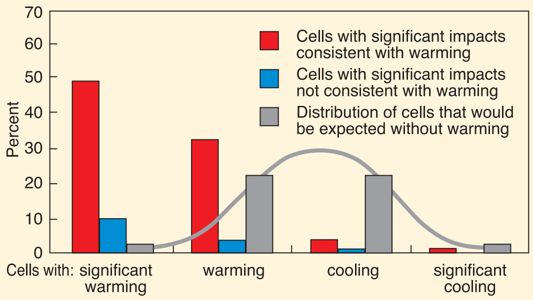
The study of causal connection by separation of natural and anthropogenic forcing factors compares observed temporal changes in animals and plants with changes over the same time periods in observed temperatures as well as modelled temperatures using (i) only natural climate forcing; (ii) only anthropogenic climate forcing; and (iii) both forcings combined.

The panel to the right shows the results from a study employing this methodology[1]. The locations for the modelled temperatures were individual grid boxes corresponding to given animal and plant study sites and time periods.

The agreement (in overlap and shape) between the observed (blue bars) and modelled plots is weakest with natural forcings, stronger with anthropogenic forcings, and strongest with combined forcings. Thus, observed changes in animals and plants are likely responding to both natural and anthropogenic climate forcings, providing a direct cause-and-effect linkage [F1.7, 1.4.2.2].



2. Using spatial analysis



The study of causal connection by spatial analysis follows these stages: (i) it identifies 5° × 5° latitude/longitude cells across the globe which exhibit significant warming, warming, cooling, and significant cooling; (ii) it identifies 5° × 5° cells of significant observed changes in natural systems that are consistent with warming and that are not consistent with warming; and (iii) it statistically determines the degree of spatial agreement between the two sets of cells. In this assessment, the conclusion is that the spatial agreement is significant at the 1% level and is very unlikely to be solely due to natural variability of climate or of the natural systems.

Taken together with evidence of significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica [WGI AR4[2] SPM], this shows a discernible human influence on changes in many natural systems [1.4.2.3].

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[1] Plotted are the frequencies of the correlation coefficients (associations) between the timing of changes in traits (e.g., earlier egg-laying) of 145 species and modelled (HadCM3) spring temperatures for the grid-boxes in which each species was examined. (Continues at bottom of previous page).

[2] IPCC, 2007: *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 996 pp.

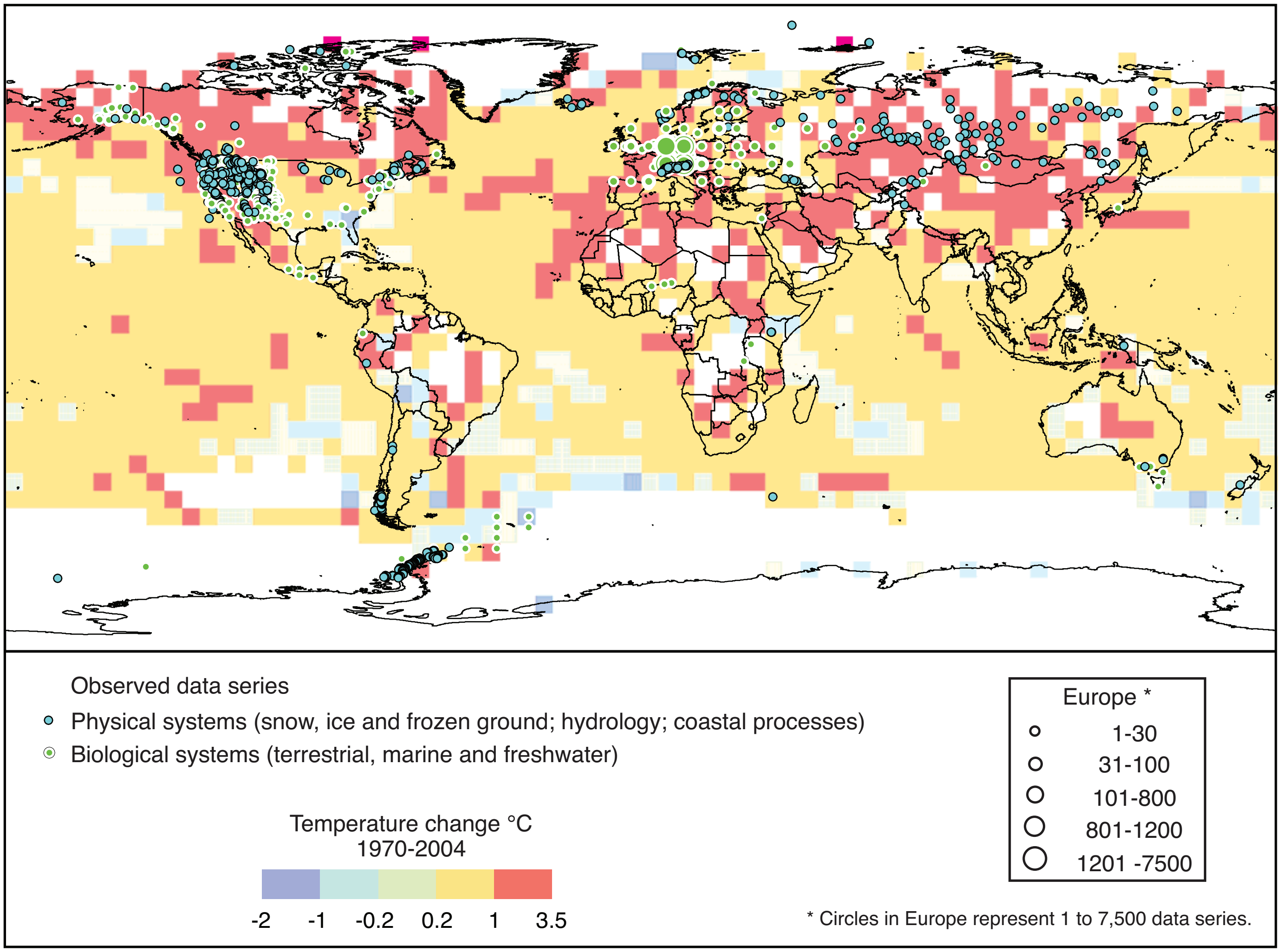
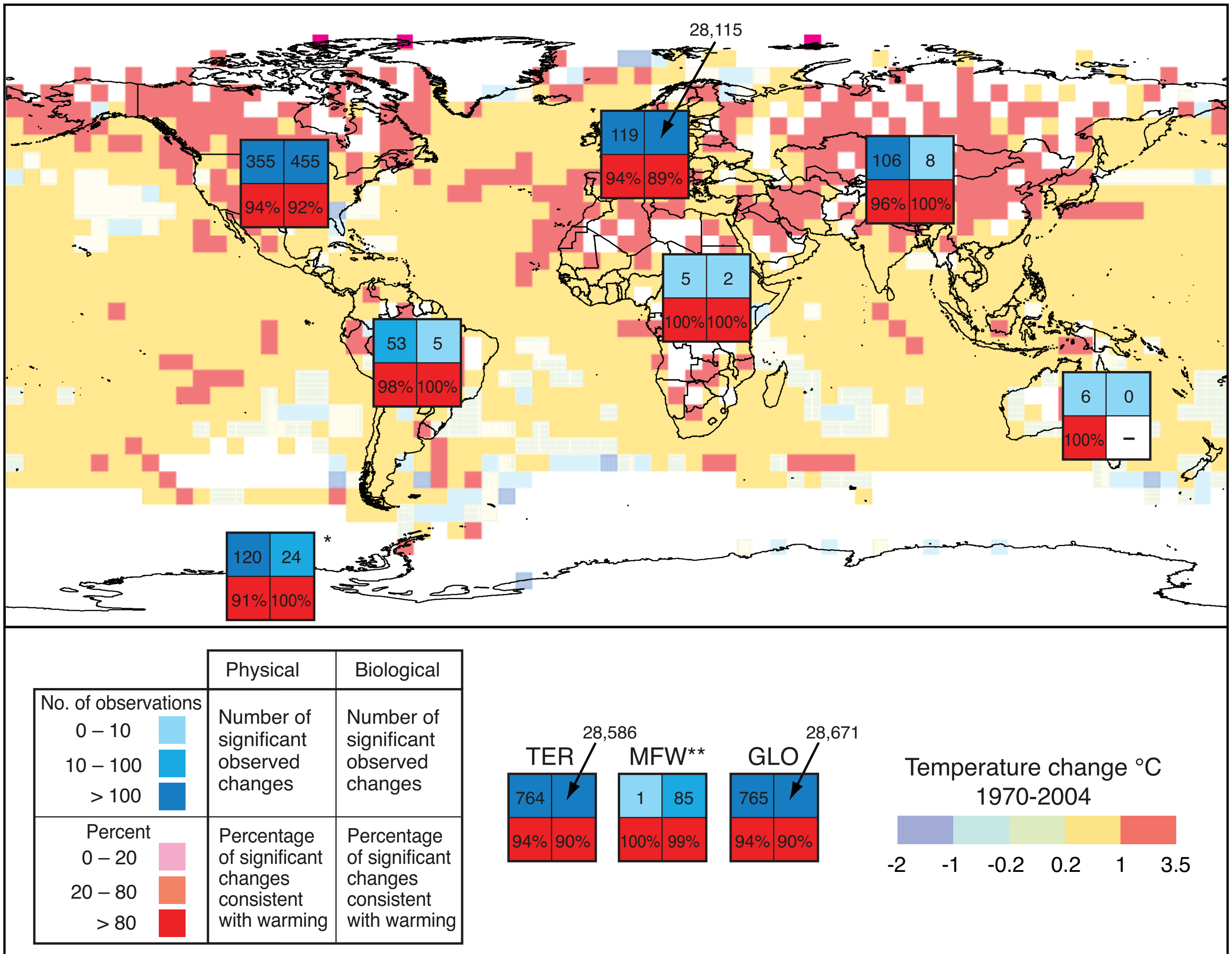


Figure SM-1.3. *Observed changes in physical systems (cryosphere, hydrology and coastal processes) and biological systems (marine and freshwater biological systems, terrestrial biological systems) for studies ending in 1990 or later with at least 20 years of data used in chapter sysnthesis assessment in Section 1.4. Dots represent about 75 studies, which have >29,000 data series (of which ~27,800 are from European phenological studies of flora and fauna). Observed trends in surface air temperature and sea-surface temperature 1970-2004 (HadCRUT3 Brohan et al., 2006). White regions do not contain sufficient observational climate data to estimate a trend.*



* Polar regions include also observed changes in marine and freshwater biological systems.

** Marine and freshwater includes observed changes at sites and large areas in oceans, small islands and continents.

Figure SM-1.4. *Changes in physical and biological systems and surface temperature used in chapter synthesis assessment in Section 1.4. Background shading, and the key to the bottom right, show changes in gridded surface temperatures over the period 1970-2004. The boxes, and the key to bottom left, show the continental-scale changes in physical (left-hand column) and biological (right-hand column) systems calculated from individual series with at least 20 years data in the 1970-2004 period; the top row shows the number of observed series matching the length criterion that show a significant trend and the bottom row shows the percentage of these in which the trend is consistent with warming. At the global scale TER = Terrestrial; MFW = Marine and Freshwater, and GLO = Global.*

Table SM-1.8. *References of studies that fit the criteria selected for global synthesis assessment in Section 1.4.*

Database Reference List

	Year	Short reference	Full reference
1	2001	Abu-Asab et al. (2001)	Abu-Asab, et al., 2001: Earlier plant flowering in spring as a response to global warming in the Washington, DC, area. *Biodiversity and Conservation*, **10**, 597-612.
2	2002	Ahas et al. (2002)	Ahas, R., et al., 2002: Changes in European spring phenology. *International Journal of Climatology*, **22**, 1727-1738.
3	2006	Allan and Komar (2006)	Allan, J. C. and P. D. Komar, 2006: Climate controls on U.S. west coast erosion processes. *Journal of Coastal Research*, **3**, 511-529.
4	2002	Arendt et al. (2002)	Arendt, A.A., et al., 2002: Rapid wastage of Alaska glaciers and their contribution to rising sea level. *Science*, **297**, 382-386.
5	2004	Atkinson et al. (2004)	Atkinson, A., et al., 2004: Long term decline in krill stock and increase in salps within the Southern Ocean. *Nature*, **432**, 100-103.
6	2001	Barbraud and Weimerskirch (2001)	Barbraud C. and H. Weimerskirch, 2001: Emperor penguins and climate change. *Nature*, **411**, 183-186.
7	1995	Barry et al. (1995)	Barry, J.P., et al., 1995: Climate-related, long-term faunal changes in a California rocky intertidal community. *Science*, **267**, 672-965.
8	2000	Beaubien and Freeland (2000)	Beaubien, E.G. and H.J. Freeland, 2000: Spring phenology trends in Alberta, Canada: links to ocean temperature. *International Journal of Biometeorology*, **44**, 53-59.
9	2002	Beaurgrand et al. (2002)	Beaugrand, G., et al., 2002: Reorganization of North Atlantic marine copepod biodiversity and climate. *Science*, **296**, 1692-1694.
10	2004	Both et al. (2004)	Both, C., et al., 2004: Large-scale geographical variation confirms that climate change causes birds to lay earlier. *Proceedings of the Royal Society of London Series B – Biological Sciences*, **271**, 1657.
11	2001	Bradshaw, and Holzapfel (2001)	Bradshaw, W.E. and C.M. Holzapfel, 2001: Genetic shift in photoperiodic response correlated with global warming. *Proceedings of the National Academy of Sciences of the USA*, **98**, 14509.
12	2004	Brooks and Birks (2004)	Brooks, S.J. and H.J.B. Birks, 2004: The dynamics of Chironomidae (Insecta: Diptera) assemblages in response to environmental change during the past 700 years on Svalbard. *Journal of Paleolimnology*, **31**, 483-498.
13	1999 (cited in TAR)	Brown et al. (1999)	Brown, J.L., et al., 1999: Long-term trend toward earlier breeding in an American bird: a response to global warming? *Proceedings of the National Academy of Sciences of the USA*, **96**, 5565-5569.
14	2002	Bunce et al. (2002)	Bunce, A., et al., 2002: Long-term trends in the Australasian gannet (Morus serrator) population in Australia: the effect of climate change and commercial fisheries. *Marine Biology*, **141**, 263-269.
15	2003	Butler (2003)	Butler, C.J., 2003: The disproportionate effect of global warming on the arrival dates of short-distance migratory birds in North America. *Ibis*, **45**, 484.
16	2005	Chambers (2005)	Chambers, L.E., 2005: Migration dates at Eyre Bird Observatory: links with climate change? *Climate Research*, **29**, 157-165.
17	2004	Chuine et al. (2004)	Chuine, I., et al., 2004: Grape ripening as a past climate indicator. *Nature*, **432**, 289-290.
18	2005	Cook et al. (2005)	Cook, A.J., et al., 2005: Retreating glacier fronts on the Antarctic Peninsula over the past half-century. *Science*, **308**, 541-544.
19	2004	Corn (2003)	Corn, P.S., 2003: Amphibian breeding and climate change: importance of snow in the mountains. *Conservation Biology*, **17**, 622-625.
20	2001	Dafila and Clot (2001)	Dafila, C. and B. Clot, 2001: Phytophenological trends in Switzerland. International Journal of *Biometeorology*, **45**, 203-207.
21	2001	D'Arrigo et al. (2001)	D'Arrigo, R., et al., 2001: 1738 years of Mongolian temperature variability inferred from tree-ring chronology of Siberian pine. *Geophysical Research Letters*, **28**, 543-546.
22	2003	Daufresne et al. (2003)	Daufresne, M., et al., 2004: Long-term changes within the invertebrate and fish communities of the Upper Rhone River: effects of climatic factors. *Global Change Biology*, **10**, 124-140.
23	2005	Dyurgerov and Meier (2005)	Dyurgerov, M.B. and M.F. Meier, 2005: Glaciers and the changing earth system: a 2004 snapshot. Occasional Paper No. 58. INSTAAR, University of Colorado at Boulder, Colorado.
24	2004	Edwards and Richardson (2004)	Edwards, M. and A.J. Richardson, 2004: Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature*, **430**, 881- 884.
25	2006	Field et al. (2006)	Field, D.B., et al., 2006: Planktonic foraminifera of the California current reflect 20th-century warming. *Science*, **311**, 63-66.
26	2002	Fitter and Fitter (2002)	Fitter, A. H. and R.S.R. Fitter, 2002: Rapid changes in flowering time in British plants. *Science*, **296**, 1689-1691.
27	2004	Forbes et al. (2004)	Forbes, D.L., et al., 2004: Storms and shoreline retreat in the southern Gulf of St. Lawrence. *Marine Geology*, **210**, 169-204.
28	2003	Forister and Shapiro (2003)	Forister, M.L. and A.M. Shapiro, 2003: Climatic trends and advancing spring flight of butterflies in lowland California. *Global Change Biology*, **9**, 1130-1135.
29	2004	Frauenfeld et al. (2004)	Frauenfeld, O.W., et al., 2004: Interdecadal changes in seasonal freeze and thaw depths in Russia. *Journal of Geophysical Research*, **109**, D5101.
30	2004	Georges (2004)	Georges, C., 2004: 20th-century glacier fluctuations in the tropical Cordillera Blanca, Peru. *Arctic, Antarctic and Alpine Research*, **36**, 100-107.
31	2001	Gibbs and Breish (2001)	Gibbs, J.P. and A.R. Breish, 2001: Climate warming and calling phenology of frogs near Ithaca New York, 1900-1999. *Conservation Biology*, **15**, 1175-1178.
32	2005	Hampton (2005)	Hampton, S.E., 2005: Increased niche differentiation between two Conochilus species over 33 years of climate change and food web alteration. *Limnology and Oceanography*, **50**, 421-426.

33	2003	Hennessy et al. (2003)	Hennessy, K., et al., 2003: *The Impact of Climate Change on Snow Conditions in Mainland Australia*. CSIRO, Aspendale.
34	2003	Hodgkins et al. (2003)	Hodgkins, G.A., et al., 2003: Changes in the timing of high river flows in New England over the 20th century. *Journal of Hydrology*, **278**, 244-252.
35	2000	Inouye et al. (2000)	Inouye, D.W., et al., 2000: Climate change is affecting altitudinal migrants and hibernating species. *Proceedings of the National Academy of Sciences of the USA*, **97**, 1630.
36	2002	Jacobs et al. (2002)	Jacobs, S.S., et al., 2002: Freshening of the Ross Sea during the late 20th century. *Science*, **297**, 386-389.
37	2001	Jones et al. (2001)	Jones, R.N., et al., 2001: Modelling historical lake levels and recent climate change at three closed lakes, Victoria, Australia (c. 1840-1990). *Journal of Hydrology*, **246**, 159-180.
38	2004	Juanes et al. (2004)	Juanes, F., et al., 2004: Long-term changes in migration timing of adult Atlantic salmon (Salmo salar) at the southern edge of the species distribution. *Canadian Journal of Fisheries and Aquatic Sciences*, **61**, 2392-2400.
39	2005	Karst-Riddoch et al. (2005)	Karst-Riddoch, T.L., et al., 2005: Diatom responses to 20th century climate-related environmental changes in high-elevation mountain lakes of the northern Canadian Cordillera. *Journal of Paleolimnology*, **33**, 265-282.
40	2002	Kozlov and Berlina (2002)	Kozlov, M.V. and N.G. Berlina, 2002: Decline in length of the summer season in the Kola peninsula, Russia. *Climatic Change*, **54**, 387-398.
41	2002	Kullman (2002)	Kullman, L., 2002: Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. *Journal of Ecology*, **90**, 68.
42	2004	Ledneva et al. (2004)	Ledneva, A., et al., 2004: Climate change as reflected in a naturalist's diary, Middleborough, Massachusetts. *Wilson Bulletin*, **116**, 224-231.
43	2004	Lips et al. (2004)	Lips, K.R., et al., 2004: Amphibian population declines in montane southern Mexico: resurveys of historical localities. *Biological Conservation*, **119**, 555-564.
44	2000 (Cited in TAR)	Magnuson et al. (2000)	Magnuson, J. J., et al., 2000: Historical trends in lake and river ice cover in the Northern Hemisphere. *Science*, **289**, 1743-1746.
45	2003	Matzumoto et al. (2003)	Matsumoto, K., et al., 2003: Climate change and extension of the Ginko biloba L. growing season in Japan. *Global Change Biology*, **9**, 1634-1642.
46	2006	Menzel et al. (2006)	Menzel, A., et al., 2006: European phenological response to climate change matches the warming pattern. *Global Change Biology*, **12**, 1969-1976.
47	2003	Michelutti et al. (2003)	Michelutti, N., et al., 2003: Diatom response to recent climatic change in a high arctic lake (Char Lake, Cornwallis Island, Nunavut). *Global and Planetary Change*, **38**, 257-271.
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