Scientific Consensus Statement on the
Likely Impacts of Climate Change on the Pacific Northwest

Executive Summary

The signatories of this statement seek to describe the state of scientific knowledge regarding likely impacts of climate change to the Pacific Northwest region. The intent is to assist Governor Kulongoski's Advisory Group on Global Warming in its task of developing a greenhouse gas emission reduction strategy for Oregon. The signatories agree that climate change is underway and that it is having global effects as well as impacts in the Pacific Northwest region. Climate-related changes to date, likely future changes, key questions to answer and research priorities are listed below.

Regional Climate Change Impacts in Recent Decades.
Temperature. Scientists are very certain that the Pacific Northwest is warming and that since 1975 the warming is best explained by human-caused changes in greenhouse gases.
Precipitation. Since the beginning of the 20th century, average annual precipitation has increased across the region by 10% with increases of 30–40% in eastern Washington and northern Idaho.
Sea Level. Land on the central and northern Oregon coast (from Florence to Astoria) is being submerged by rising sea level at an average rate of 0.06 – 0.08 inches (1.5–2 mm) annually, as inferred from data for the period 1930–1995.
Snowpack. Between 1950 and 2000, the April 1 snowpack declined. In the Cascades, the cumulative downward trend in snow-water equivalent is approximately 50% for the period 1950–1995. Timing of the peak snowpack has moved earlier in the year, increasing March streamflows and reducing June streamflows. Snowpack at low-to-mid elevations is the most sensitive to warming temperatures.

Regional Climate Change Projections over the Next 10-50 Years.
Temperature. Scientists have intermediate certainty that average temperatures in the Pacific Northwest will continue to increase in response to global climate change. Assessments suggest that the average warming will be approximately 2.7° F by 2030 and 5.4° F. by 2050. These projected increases are highly likely to result in a higher elevation treeline, longer growing seasons, longer fire seasons, earlier animal and plant breeding, longer and more intense allergy season and changes in vegetation zones.
Precipitation. Precipitation changes are very uncertain. The challenge will be to resolve scientific uncertainties about the interactions among atmosphere, land and ocean before significant climate change impacts occur. Oregon is expected to remain a wintertime-dominant precipitation regime (i.e., most precipitation will continue to occur in the winter). In addition, most precipitation will continue to occur in the mountains. Impacts on water resources due to low summer precipitation and earlier peak streamflow will likely include decreased summer water availability, changes in our ability to manage flood damage, shifts in hydropower

production from summer to winter, and decreased water quality due to higher temperatures, increased salinity and pollutant concentration.

Sea Level. Sea level is very certain to continue to rise although the impact will vary depending upon how fast the land is rising. In addition to increases in sea level, maximum wave heights will likely also increase, resulting in increasing erosion in coastal areas.

Snowpack. The April 1 snowpack will continue to decline corresponding to an earlier peak streamflow.

Marine Ecosystems. It is very certain that ocean circulation will continue to change in response to ocean-atmospheric processes. These changes suggest a likely increase in the magnitude and duration of upwelling, which will affect marine ecosystems. It is uncertain whether these changes will have adverse impacts such as more frequent occurrences of the low-oxygen ("dead zone") events seen in 2002 and 2004.

Terrestrial Ecosystems. The impact of changes in temperature and precipitation on terrestrial ecosystems is poorly known. Due to current biomass densities, the anticipated drier summers will likely increase drought stress and vulnerability of forests to insects, disease and fire.

Important Questions that could be Answered by Research.

What will be the trend and pattern of precipitation in the region?
What will be the patterns of coastal ocean winds?
What are the dynamics of large, decadal-scale patterns of ocean/atmosphere interactions?
Do thresholds exist for abrupt climate change and system shifts?
How will these patterns affect ecosystem patterns and resilience?
How will changes impact human health?
How will changes affect regional economic and social conditions?

Research Priorities

1. Improved and sustained observation of critical processes that can resolve interannual/decadal-scale variability.
2. Focused process experiments and studies of critical processes, such as impacts of increased CO_2 on forest dynamics.
3. Improved numerical and statistical models focused on coupled atmosphere/ocean/land processes that include ecological as well as geophysical dynamics.
4. Modeling and analysis of the effects of economics and management policies interannual/decadal-scale processes in the region.

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History and Objective

This Consensus Statement was drafted by a subcommittee of participants in the scientific meeting "Impacts of Climate Change on the Pacific Northwest" convened at OSU on June 15, 2004. The statement has been reviewed and signed by XX meeting participants. The objective of the statement is to assist Governor Kulongoski's Advisory Group on Global Warming (GAGGW) by describing the state of scientific knowledge and uncertainty regarding climate change impacts in the Pacific Northwest. The GAGGW is charged with recommending strategies for reduction of greenhouse gas emission for the State of Oregon. For more information about the consensus process and participants, see Appendix A.

Global Effects of Climate Change

The signatories of this consensus statement agree with the scientific findings about climate change as reported in the Third Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change (IPCC), published in 2001. The IPCC finds that

- over the last century, the global average surface temperature increased about 1° F, and
- sea level rose between 4 and 8 inches.

The IPCC predicts that if current trends continue, by 2100

- the global average temperature will increase 2.5–10.4° F and
- sea level will rise 4–35".

The IPCC report concludes that

> "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."

An overview of these and other findings from the IPCC Third Assessment Report is attached in Appendix B.

Regional Impacts of Climate Change

Climate change is also affecting important parameters and processes on a regional scale. This Consensus Statement addresses the following key questions related to the impacts of climate change on the Pacific Northwest:

- What are the areas of consensus on the impacts of climate change on the Pacific Northwest based on scientific findings and observed changes?
- What are the projections for impacts of climate change on the Pacific Northwest over the next 10–50 years?
- What are the areas of uncertainty affecting our ability to understand and predict likely climate change?
- What are the most important questions to be answered in the next 5–10 years?
- What are the priorities for future research?

What are the areas of consensus on the impacts of climate change on the Pacific Northwest, based on scientific findings and observed changes?

Some major parameters and processes in the Pacific Northwest affected by climate change are described below. Areas of consensus on these topics, based on scientific findings and observed changes, were gathered and synthesized from a variety of sources, including the U.S. Global Change Research Program Report (USGCRP 2001), papers in peer-reviewed scientific publications, and scientific presentations and breakout group summaries from the June 2004 Impacts of Climate Change in the Pacific Northwest meeting at OSU.

Temperature

Scientists are very certain that the Pacific Northwest is warming. The USGCRP Report indicates that the annual average temperature has increased 1–3° F (0.6–1.7° C) over most of the region in the last century. Temperature change during this time is characterized by a steep rise from 1900 to 1940, a decline from 1940 to 1975, and a rise thereafter. Model simulations suggest that the earlier warming was largely due to natural causes, whereas the most recent warming is best explained by human-caused changes in greenhouse gases (Water Resources Breakout Group 2004). Since 1920, nearly every temperature monitoring station in the Pacific Northwest—both urban and rural—shows a warming trend (Mote 2003).

Precipitation

While there is little evidence of a consistent global warming signal for precipitation in the West since 1915, precipitation has increased modestly from 1916 to 1997 (Water Resources Breakout Group 2004). Since the beginning of the 20th century, the USGCRP Report indicates that annual precipitation has increased across the region by 10% on average, and the level of increase has reached 30–40% in eastern Washington and Northern Idaho.

Sea Level

During the period 1930–1995, land on the southern Oregon coast between Florence and Coos Bay has generally risen faster than worldwide changes in sea level by about 1 mm per year (Abbott 2004). However, the same data, which are based on geodetic leveling and tide-gauge records, indicate that land on the central and northern coast of Oregon (from Florence to Astoria) is being submerged by rising sea level at a rate of 1.5–2 mm per year.

Snowpack

From 1950 to 2000, warming temperatures across the West have diminished snowpacks. During this period, most monitoring stations in the Pacific Northwest show a decline in April 1 snowpack (or "snow water equivalent") (Miles 2004). In the Cascades, the cumulative downward trend in snow water equivalent is approximately 50%. Model simulations for the period 1950–1995 show that roughly half the reductions in the Cascades are due to warming trends, and half are due to downward trends in precipitation. Trends for the period 1916–1995 show smaller trends due to warming (a 20% decrease in 82 years) and little effect from precipitation (Water Resources Breakout Group 2004).

Simulations of snow-water equivalent from 1916–1997 show that the timing of peak snow accumulation and 90% snowmelt have both moved toward earlier calendar dates across the West (Water Resources Breakout Group 2004; Miles 2004). In sensitive areas like the Cascade, for

example, the date of peak snowpack has shifted by as much as 40 days earlier in the year. These simulations are supported by studies of observed snowpack, along with observations of stream flow from 1950–2003 which show systematic reductions in April 1 snowpack and June flow, and increases in March flow, over much of the West (Water Resources Breakout Group 2004; Stewart et al. in review).

Snowpack at low-to-mid elevations is the most sensitive to warming temperatures. Watersheds in the Cascades have shown significant losses of summer water availability due to warming over the last 55 years. The fraction of annual streamflow from May to September in the Cedar River watershed, for example, has declined by 30% in 55 years (Miles 2004). These observed changes in streamflow are not explained by trends in precipitation.

Climate Variability at the Scale of Years to Decades

The USGCRP Report indicates that the climate of the Pacific Northwest shows significant recurrent patterns of year-to-year variability. Warm years tend to be relatively dry with low streamflow and light snowpack, which lead to summer water shortages, less abundant salmon, and increased probability of forest fires. Conversely, cool years tend to be relatively wet with high streamflow and heavy snowpack. Scientists conclude with high certainty that variations in Pacific Northwest climate show clear correlations with the large-scale ocean-atmosphere patterns associated with the El Nino/Southern Oscillation (ENSO) on scales of a few years (interannual) (Abbott 2004). Because of uncertainty about underlying dynamics and lack of predictability about other large-scale ocean-atmosphere patterns, such as the Pacific Decadal Oscillation (PDO), understanding the effects of such patterns on climate variability in the Pacific Northwest is problematic at present.

What are the projections for climate change and its impacts in the Pacific Northwest over the next 10-50 years?

Temperature

There is intermediate certainty that average temperatures in the Pacific Northwest will continue to increase in response to global climate change. The slope of the trend over the last 20 years should continue in the next few decades. The USGCRP Pacific Northwest assessment predicts that there will be average warming over the region of approximately 2.7° F (1.5° C) by 2030 and 5.4° F (3° C) by the 2050s. This change translates into a 0.18 to 0.9° F (0.1–0.5° C) increase per decade. However, the rate of increase may be even higher in the eastern portion of the region. The exact magnitude and rate of increase are difficult to predict, particularly beyond 50 years.

These projected temperature increases are highly likely to result in:

- An increase in elevation of the upper tree line,
- Longer growing seasons,
- Increased length of fire season,
- Earlier breeding by animals and plants,
- Longer and more intense allergy season, and
- Possible changes in vegetation zones.

Other changes, such as prevalence of insect infestations and expansion of woody vegetation, are less certain (Terrestrial Ecosystems Breakout Group 2004), in part because they are affected by additional factors such as precipitation and land use.

Precipitation

Changes in precipitation regimes are generally acknowledged to be very uncertain in comparison with the temperature changes described above. Existing models are unable to make consistent projections of precipitation on regional scales. Recent IPCC global climate model scenarios have suggested the likelihood of modest increases in winter precipitation and decreases in summer precipitation for the Pacific Northwest. These effects are broadly consistent with the expected consequences of an intensified hydrologic cycle at the global level.

Some current research, however, suggests that these scenarios could be wrong for the Pacific Northwest because other factors may influence the outcome. For example, systematic changes in global sea surface temperature patterns, or in other fundamental drivers of global atmospheric circulation, could create systematic changes in storm-track behavior (Water Resources Breakout Group 2004). Based on this hypothesis, the Pacific Northwest could conceivably become drier, despite an intensification of the hydrologic cycle on a global level. These alternate hypotheses underscore the current uncertainty even about the direction of trends (i.e., increasing or decreasing) in precipitation. Better understanding of the interactions among atmosphere, land, and ocean are critical to predicting changes to and patterns of precipitation. The challenge will be to resolve these scientific uncertainties before significant climate change impacts occur.

Regarding specific projections, Oregon now experiences most of its precipitation during winter, with the greatest precipitation occurring in the mountains. The expectation is that this pattern will continue, and that the greatest precipitation (in the form of snow) will remain at high elevations. Changes in cool-season (i.e., October–March) climate are, therefore, likely to have the greatest effect on river flow and water resources.

Due to relatively little precipitation in summer and an earlier summer streamflow recession associated with earlier snowmelt, intensified impacts on water resources likely will include:

- Increased summer water demand (because of population growth) coupled with decreased water availability due to warmer temperatures, systematic reductions in summer streamflow, and limited reservoir storage.

- Changed ability to mitigate flood damage (which could result from increased unpredictability associated with extreme weather events and streamflow forecasting) that may warrant reconsideration of current management schemes for storage reservoirs and flood protection to account for this altered flow regime.

- Increased winter flows (if precipitation remains the same or increases in winter) that enhancement hydropower production in winter months and reductions in summer streamflow that diminish hydropower production in summer months may challenge the current approach to hydropower production in the Columbia River (Water Resources Breakout Group 2004).

- Decreased summer water availability and late-summer flows that may further decrease the overall ability water of water regulators and users to meet instream flow targets using storage reservoirs, and intensify the conflict between winter hydropower production and summer water supply.

- Exacerbated water-quality issues, including increased water temperatures in lakes and rivers, increased salinity and pollutant concentration (because water withdrawals decrease water quantity and concentrate pollutants in remaining water), lower dissolved oxygen content with increasing temperature, increases in certain pathogens that thrive at higher temperatures, and changes in the ecosystem and food web—all of which would stress fish including salmon.

Sea Level

Sea level is very certain to continue to rise. The impacts of sea-level rise, however, will vary because of differences in tectonic processes throughout the Pacific Northwest. In some areas where tectonic processes exceed sea-level rise, land will rise faster than increased sea level. Where tectonic processes do not exceed sea-level rise, the region's shoreline will move landward. Maximum wave heights also will likely increase. This increase in wave height, in association with sea-level rise, has the potential to increase erosion in coastal areas.

Snowpack

It is highly certain that the April 1 snowpack will continue to decline in response to increasing global greenhouse-gas emissions. This decline in snowpack will correspond with an earlier peak runoff of snowmelt, and increased streamflows earlier in the year (see above).

Other effects of warmer temperatures on snowmelt hydrology have been well understood for decades, and the effects of global warming on Pacific Northwest rivers has been quantified in a number of published studies. In basins with significant snow accumulation in winter, warmer temperatures systematically reduce peak snow accumulation, producing more runoff in winter, earlier peak flows in spring, and reduced water availability in summer. Snowpack at high elevations is generally less sensitive to temperature changes and more sensitive to precipitation changes. Thus, at high elevations, snowpack could increase if winter precipitation increases over time. However, even if there is an increase in snowfall at high elevations, the area covered by high elevations is small relative to the area of an entire river basin and consequently the total snow pack in a river basin typically declines if temperatures rise (even if precipitation increases by a modest amount).

Marine Ecosystems

It is very certain that ocean circulation will continue to change in response to ocean-atmospheric processes occurring at the scale of years to decades (see discussion of ENSO and PDO above). These changes in ocean circulation include the intensity and character of upwelling winds, as well as changes in freshwater input (Water Resources Breakout Group 2004). While the patterns of these variations and their impacts on marine ecosystems (e.g., persistent changes in ecosystem structure, directional changes in productivity, etc.) are unknown, paleological records and quantified physical dynamics help to shed light on potential projections. Paleo-records suggest

that over long time scales, warm regimes are associated with strong upwelling. It also is known that a warmer continent results in stronger equator-ward winds that fuel upwelling. In combination, these two trends suggest a likely increase in the magnitude and duration of upwelling along the Pacific Northwest coast (Water Resources Breakout Group 2004).

The emergence of a mass of hypoxic (low oxygen) water (a so-called "dead zone") appearing off the central coast of Oregon in 2002 and 2004 may signal an unanticipated consequence of climate change mediated through changes in ocean circulation.

Projections about climate change in the region also indicate the potential for:

- Influx of seawater into estuaries and lower reaches of rivers due to sea-level rise,
- An earlier influx of freshwater into estuarine and coastal areas,
- Greater seasonal variation, and
- Increased stress on estuarine and nearshore species that are physiologically adapted to particular patterns in physical characteristics of their habitats (e.g., salinity).

Terrestrial Ecosystems

Changes in temperature and precipitation patterns are likely, but the manner in which these changes will affect the terrestrial ecosystems of the Pacific Northwest is poorly known. Likely impacts include shifts in species composition and timing of the growing season, but the details are unpredictable. For example, temperature changes and loss of snowpack are expected to affect forests, particularly those in southwest, central, and eastern Oregon that rely on snowpack for water. Given current biomass densities, the anticipated drier summers will increase drought stress and vulnerability of forests to insects and diseases, and may ultimately lead to widespread fires that may systematically alter the hydrologic response in river basins over time.

What are the greatest areas of uncertainty affecting our ability to understand and predict likely climate change in the Pacific Northwest?

Shifts in regional-scale climate forcing, such as precipitation and winds, are the fundamental processes that affect ecosystems. We have little certainty in the projections about these key processes for the Pacific Northwest, and their effects on outcomes such as extreme events (e.g., flooding and large fires). The next level of uncertainty is the response of marine and terrestrial ecosystems to changes in the patterns of variability as well as long-term trends. Lastly, shifts in management practices, urban development, and other human activities will be convolved with changes in the natural environment and will impact ecosystems.

What are the most important questions to be answered in the next 5-10 years?

- What will be the trend and pattern of precipitation in the Pacific Northwest?
- What will be the patterns of coastal ocean winds and associated upwelling events?
- What are the dynamics of large, decadal-scale patterns of ocean/atmosphere interactions?
- Do thresholds exist for abrupt climate change and system shifts?
- How will the aforementioned patterns affect ecosystem patterns and resilience (including the maintenance of processes and patterns in the face of variability)?

What are the priorities for future research?

The priorities should be based on answering the four questions listed above. To accomplish this, we need to invest in four areas of research.

1. Improved and sustained observations of critical processes that can resolve interannual/decadal-scale variability. These observing systems should be focused on both physical and biological variables, and should be of sufficient quality to resolve local, small-scale processes relative to climate signals.
2. Focused process experiments and studies of critical processes, such as the impacts of increased CO_2 on forest dynamics and the impact of changes in the upwelling regime on coastal marine ecosystems and fisheries.
3. Improved numerical and statistical models focused on coupled atmosphere/ocean/land processes that include ecological as well as geophysical dynamics. Particular emphasis should be on developing regional-scale projections. Close interaction between modeling and analysis and the observing programs should be ensured.
4. Modeling and analysis of the effects of economic and management policies interannual/decadal-scale processes in the Pacific Northwest. This could include forest management, land use changes, fishery management, coastal zone management and water policy.

Appendix A – Consensus Process and Participants

On June 15, 2004, a symposium entitled "Impacts of Climate Change on the Pacific Northwest" was held to provide invited Oregon and Washington-based scientists an opportunity to: 1) share knowledge concerning the present status of global climate change research and regional greenhouse gas emission reduction strategies, 2) share findings on scenarios for climate change and possible impacts in the Pacific Northwest, and 3) identify areas of consensus and uncertainty. Sixty-five people attended the meeting. Participants were primarily scientists working in a variety of fields related to climate change in the Pacific Northwest, such as oceanography, forest ecology, forest economics, agriculture and resource economics, hydrology, paleoclimatology, marine ecology, fisheries biology, estuarine ecology, population biology, geography, ornithology, climatology, and meteorology. Attendees also included a diversity of observers, such as members of the Advisory Group and agency staff providing technical support to the Advisory Group, media, and other individuals working on issues related to climate change policy.

Pre-meeting questionnaires were distributed to participants. Four experts presented overview of scientific understanding in key areas. Responses to the pre-meeting questionnaires, the slideshow presentations, extended abstracts of the presentations, and summaries of four breakout group sessions (terrestrial ecosystems, marine ecosystems, water resources, and the Pacific Northwest as a system) are available as part of the meeting proceedings online at http://inr.oregonstate.edu/policy/climate-change.html.

This Consensus Statement, drafted by a subcommittee of participants and circulated to other participants for review and sign-on, is also part of the proceedings. The statement is signed by 46 Ph.D.-level scientists with expertise on the impacts of climate change in the Pacific Northwest. Names of the signatories appear below.

Peter Clark, Professor
OSU/Geosciences

Ronald Mitchell, Professor
U of O/Political Science

Tim Cowles, Professor
OSU/College of Oceanic and Atmospheric Sciences

Alan Mix, Professor
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Richard Hildreth, Director
U of O/Env. & Natural Resources Law Program

Brent Steel, Professor
OSU/Political Science

Mark Hixon, Professor
OSU/Zoology

David Turner, Assoc. Professor
OSU/College of Forestry

Dave Lytle, Professor
OSU/Zoology

Richard Vong, Professor
OSU/College of Oceanic & Atmospheric

Jane Lubchenco, Professor
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Patrick Bartlein, Professor
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Edward Miles, Professor
U of W/School of Marine Affairs

Sherm Bloomer, Dean
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Appendix B – Overview of Findings from the Third Assessment Report of the Intergovernmental Panel on Climate Change

(Excerpted from *Climate Change 2001: Synthesis Report – Summary for Policymakers, an Assessment of the Intergovernmental Panel on Climate Change*. This summary, approved in detail at IPCC Plenary XVIII (Wembley, United Kingdom, 24-29 September 2001), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Third Assessment Report.)

Table SPM-1 20th century changes in the Earth's atmosphere, climate, and biophysical system.[a]

Indicator	*Observed Changes*
Concentration indicators	
Atmospheric concentration of CO_2	280 ppm for the period 1000–1750 to 368 ppm in year 2000 (31±4% increase).
Terrestrial biospheric CO_2 exchange	Cumulative source of about 30 Gt C between the years 1800 and 2000; but during the 1990s, a net sink of about 14±7 Gt C.
Atmospheric concentration of CH_4	700 ppb for the period 1000–1750 to 1,750 ppb in year 2000 (151±25% increase).
Atmospheric concentration of N_2O	270 ppb for the period 1000–1750 to 316 ppb in year 2000 (17±5% increase).
Tropospheric concentration of O_3	Increased by 35±15% from the years 1750 to 2000, varies with region.
Stratospheric concentration of O_3	Decreased over the years 1970 to 2000, varies with altitude and latitude.
Atmospheric concentrations of HFCs, PFCs, and SF_6	Increased globally over the last 50 years.
Weather indicators	
Global mean surface temperature	Increased by 0.6±0.2°C over the 20th century; land areas warmed more than the oceans (*very likely*).
Northern Hemisphere surface temperature	Increase over the 20th century greater than during any other century in the last 1,000 years; 1990s warmest decade of the millennium (*likely*).
Diurnal surface temperature range	Decreased over the years 1950 to 2000 over land: nighttime minimum temperatures increased at twice the rate of daytime maximum temperatures (*likely*).
Hot days / heat index	Increased (*likely*).
Cold / frost days	Decreased for nearly all land areas during the 20th century (*very likely*).
Continental precipitation	Increased by 5–10% over the 20th century in the Northern Hemisphere (*very likely*), although decreased in some regions (e.g., north and west Africa and parts of the Mediterranean).
Heavy precipitation events	Increased at mid- and high northern latitudes (*likely*).
Frequency and severity of drought	Increased summer drying and associated incidence of drought in a few areas (*likely*). In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades.

Box SPM-1 Confidence and likelihood statements.

Where appropriate, the authors of the Third Assessment Report assigned confidence levels that represent their collective judgment in the validity of a conclusion based on observational evidence, modeling results, and theory that they have examined. The following words have been used throughout the text of the Synthesis Report to the TAR relating to WGI findings: *virtually certain* (greater than 99% chance that a result is true); *very likely* (90–99% chance); *likely* (66–90% chance); *medium likelihood* (33–66% chance); *unlikely* (10–33% chance); *very unlikely* (1–10% chance); and *exceptionally unlikely* (less than 1% chance). An explicit uncertainty range (±) is a *likely* range. Estimates of confidence relating to WGII findings are: *very high* (95% or greater), *high* (67–95%), *medium* (33–67%), *low* (5–33%), and *very low* (5% or less). No confidence levels were assigned in WGIII.

Table SPM-1	20th century changes in the Earth's atmosphere, climate, and biophysical system.[a] (continued)
Indicator	***Observed Changes***
Biological and physical indicators	
Global mean sea level	Increased at an average annual rate of 1 to 2 mm during the 20th century.
Duration of ice cover of rivers and lakes	Decreased by about 2 weeks over the 20th century in mid- and high latitudes of the Northern Hemisphere (*very likely*).
Arctic sea-ice extent and thickness	Thinned by 40% in recent decades in late summer to early autumn (*likely*) and decreased in extent by 10–15% since the 1950s in spring and summer.
Non-polar glaciers	Widespread retreat during the 20th century.
Snow cover	Decreased in area by 10% since global observations became available from satellites in the 1960s (*very likely*).
Permafrost	Thawed, warmed, and degraded in parts of the polar, sub-polar, and mountainous regions.
El Niño events	Became more frequent, persistent, and intense during the last 20 to 30 years compared to the previous 100 years.
Growing season	Lengthened by about 1 to 4 days per decade during the last 40 years in the Northern Hemisphere, especially at higher latitudes.
Plant and animal ranges	Shifted poleward and up in elevation for plants, insects, birds, and fish.
Breeding, flowering, and migration	Earlier plant flowering, earlier bird arrival, earlier dates of breeding season, and earlier emergence of insects in the Northern Hemisphere.
Coral reef bleaching	Increased frequency, especially during El Niño events.
Economic indicators	
Weather-related economic losses	Global inflation-adjusted losses rose an order of magnitude over the last 40 years (see Q2 Figure 2-7). Part of the observed upward trend is linked to socio-economic factors and part is linked to climatic factors.

[a] This table provides examples of key observed changes and is not an exhaustive list. It includes both changes attributable to anthropogenic climate change and those that may be caused by natural variations or anthropogenic climate change. Confidence levels are reported where they are explicitly assessed by the relevant Working Group. An identical table in the Synthesis Report contains cross-references to the WGI and WGII reports.

Appendix C – References

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