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Observations and Projections: Cryosphere, Ocean Dynamics, and Hydrology

4. Observations and Projections: Cryosphere, Ocean Dynamics, and Hydrology

Introduction

The effects of climate change are visible in the cryosphere (places on Earth so cold that water is usually in solid form as snow or ice), in sea level change and other ocean dynamics, in patterns of precipitation, and in rivers and streamflow. Computer models have been used to project trends in each of these areas, while observations and data are available to test those projections.

According to the Intergovernmental Panel on Climate Change (IPCC), "recent decreases in ice mass are correlated with rising surface air temperatures. This is especially true in the region north of 65°N, where temperatures have increased by about twice the global average from 1965 to 2005" (IPCC 2007, p. 339). The IPCC goes on to report decreased snow cover "in most regions, especially in spring and summer," freeze-up dates in the Northern Hemisphere occurring later, breakup dates occurring earlier, declines in sea ice extent, and similar findings (ibid.).

In their 2009 Nongovernmental International Panel on Climate Change (NIPCC) report, Idso and Singer (2009) contended that many of the IPCC's findings on this subject were incorrect, the result of cherry-picking data or misrepresenting available research. The authors found,

> Glaciers around the world are continuously advancing and retreating, with a general pattern of retreat since the end of the Little Ice Age. There is no evidence of an increased rate of melting overall since CO_2 levels rose above their pre-industrial levels, suggesting CO_2 is not responsible for glaciers melting.
>
> Sea ice area and extent have continued to increase around Antarctica over the past few decades. Evidence shows that much of the reported thinning of Arctic sea ice that occurred in the 1990s was a natural consequences of changes in ice dynamics caused by an atmospheric regime shift, of which there have been several in decades past and will likely be several in the decades to come, totally irrespective of past or future changes in the air's CO_2 content. The Arctic appears to have recovered from its 2007 decline (Idso and Singer 2009, p. 4).

Similar disagreement between IPCC and NIPCC was found on ocean dynamics, with IPCC claiming "there is *high confidence* that the rate of sea level rise has increased between the mid-19th and the mid-20th centuries" (IPCC AR4, p. 387, emphasis in the original) while NIPCC found "the mean rate of global sea level rise has not accelerated over the recent past" (Idso and Singer 2009, p. 4). While the IPCC claimed "it is *likely* that … heavy precipitation events will continue to become more frequent" (IPCC AR4, p. 15), NIPCC said "global studies of precipitation trends show no net increase and no consistent trend with CO_2, contradicting climate model predictions that warming should cause increased precipitation" (Idso and Singer 2009, p. 4).

This chapter reinforces NIPCC's findings of 2009, with new research finding less melting of ice in the Arctic, Antarctic, and mountaintops than previously feared, no sign of acceleration of sea-level rise in recent decades, no trend over the past 50 years in changes to the Atlantic meridional overturning circulation (MOC), and no changes in precipitation patterns or river flows that could be attributed to rising CO_2 levels.

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4.1. The Cryosphere

4.1.1. Antarctica

The study of Antarctica's past, present, and expected future climate has provided valuable insights and spurred contentious debate over issues pertaining to global climate change. Although many individuals concerned about global warming expect Earth's polar regions to manifest the earliest and most severe responses to CO_2-induced climate change, real-world data from Antarctica do not support such expectations. In the 2009 NIPCC report, Idso and Singer (2009) discussed the results of several scientific analyses that demonstrated there is nothing unusual, unprecedented, or unnatural about the climate on this vast continent of ice. In this interim report we highlight the results of several more papers in support of their findings.

Starting with the Antarctic Peninsula, Hall (2009) offered "a summary of existing data concerning Holocene glacial extent and fluctuations within Antarctica and the sub-Antarctic islands." She begins by noting, "in several areas, ice extent was less than at present in mid-Holocene time," which suggests, in her words, "the magnitude of present ice recession and ice-shelf collapse is not unprecedented." She also reports "the first Neoglacial ice advances occurred at ~5.0 ka" and "glaciers in all areas underwent renewed growth in the past millennium." More specifically, Hall states, "the Antarctic Peninsula, along with the adjacent sub-Antarctic islands, yields one of the most complete Holocene glacial records from the southern high latitudes," and most of these locations "show an advance in the past few centuries, broadly coincident with what is known elsewhere as the Little Ice Age." Likewise, she reports "glaciers on most if not all" of the Indian/Pacific sector sub-Antarctic Islands "underwent advance in the last millennium, broadly synchronous with the Little Ice Age." And she notes "glaciers in all areas" have "subsequently undergone recession," but only in "the past 50 years."

In another study, Tedesco and Monaghan (2010) reviewed what has been learned about the melting of snow and ice over all of Antarctica since 1979, when routine measurement of the phenomenon via space-borne passive microwave radiometers first began. Their results revealed that over the course of the past three decades the continent-wide snow and ice melting trend was "negligible." They also observe that during the 2008–2009 austral summer, scientists from the City University of New York and the U.S. National Center for Atmospheric Research observed that snow and ice melt was "a record low for the 30-year period between 1979 and 2009," or as they alternatively describe it, "a new historical minimum." In addition, they note, "December 2008 temperature anomalies were cooler than normal around most of the Antarctic margin, and the overall sea ice extent for the same month was more extensive than usual."

Turning our attention to the West Antarctic Ice Sheet (WAIS), often described as the world's most unstable large ice sheet, it has been postulated that future global warming may cause the WAIS to disappear, resulting in a sea-level rise of several millimeters per year. Yet three groups of researchers have shown in recent papers that the WAIS is likely much more stable than the models predict.

Gomez et al. (2010) state that several studies (Oppenheimer, 1998; Meehl et al., 2007; Vaughan, 2008; Smith et al., 2009) have suggested "climate change could potentially destabilize marine ice sheets, which would affect projections of future sea-level rise." The studies specifically highlight "an instability mechanism (Weertman, 1974; Thomas and Bentley, 1978; Schoof, 2007; Katz and Worster, 2010)" which they say "has been predicted for marine ice sheets such as the West Antarctic ice sheet that rest on reversed bed slopes, whereby ice-sheet thinning or rising sea levels leads to irreversible retreat of the grounding line."

Noting existing analyses of this particular instability mechanism "have not accounted for deformational and gravitational effects that lead to a sea-level fall at the margin of a rapidly shrinking ice sheet," Gomez et al. go on to present "a suite of predictions of gravitationally self-consistent sea-level change following grounding-line migration," in which they "vary the initial ice-sheet size and also consider the contribution to sea-level change from various sub-regions of the simulated ice sheet."

The four researchers report their new results "demonstrate that gravity and deformation-induced sea-level changes local to the grounding line contribute a stabilizing influence on ice sheets grounded on reversed bed slopes," contrary to previously prevailing assumptions based on earlier analyses of the subject. In fact, they conclude, "local sea-level change following rapid grounding-line migration will contribute a stabilizing influence on marine ice sheets, even when grounded on beds of non-negligible reversed slopes."

In a terse statement describing the implications of their work, Gomez et al. write their new and more "accurate" treatment of sea-level change "should be incorporated into analyses of past and future marine-ice-sheet dynamics."

Introducing their study of the WAIS, Naish et al. (2009) write, "an understanding of the behavior of the marine-based West Antarctic ice sheet during the 'warmer-than-present' early-Pliocene epoch (~5-3 Myr ago) is needed to better constrain the possible range of ice-sheet behavior in the context of future global warming," and they thus undertook a project to provide such understanding. Specifically, as they describe it, they derived "a marine glacial record from the upper 600 meters of the AND-1B sediment core recovered from beneath the northwest part of the Ross ice shelf by the ANDRILL program," which demonstrated the "well-dated ~40-kyr cyclic variations in ice-sheet extent linked to cycles in insolation influenced by changes in the earth's axial tilt (obliquity) during the Pliocene." They state their data "provide direct evidence for orbitally induced oscillations in the WAIS, which periodically collapsed, resulting in a switch from grounded ice, or ice shelves, to open waters in the Ross embayment when planetary temperatures were up to ~3°C warmer than today and atmospheric CO_2 concentration was as high as ~400 ppm," the latter number being about 3 percent greater than what it is today.

An important implication of this last observation is that the much greater periodic warmth of the early-Pliocene was clearly not the primary result of periodic changes in the air's CO_2 concentration. The 56 researchers tacitly acknowledge that fact by attributing the variable warmth to periodic changes in the planet's axial tilt that produced 40,000-year cycles of insolation.

How long did it take for such warmth to bring about a total collapse of the WAIS? An answer to this question can be found in the companion paper of Pollard and DeConto (2009), who state projections of future WAIS behavior "have been hampered by limited understanding of past variations and their underlying mechanisms." With the findings of Naish et al. (2009), however, Pollard and DeConto gained important new knowledge that helped them frame a greatly improved "ice sheet/ice shelf model capable of high-resolution nesting with a new treatment of grounding-line dynamics and ice-shelf buttressing to simulate Antarctic ice sheet variations over the past five million years."

The two researchers report they modeled WAIS variations ranging "from full glacial extents with grounding lines near the continental shelf break, intermediate states similar to modern, and brief but dramatic retreats, leaving only small, isolated ice caps on West Antarctic islands." And they say their work suggests "the WAIS will begin to collapse when nearby ocean temperatures warm by roughly 5°C." In a "News & Views" story on Pollard and DeConto's findings, Huybrechts (2009) states, "the amount of nearby ocean warming required to generate enough sub-ice-shelf melting to initiate a significant retreat of the West Antarctic ice sheet ... may well take several centuries to develop." Once started, he concludes, the transition time for a total collapse of the West Antarctic ice sheet would range from "one thousand to several thousand years." This time period, he notes, "is nowhere near the century timescales for West Antarctic ice-sheet decay based on simple marine ice-sheet models," such as have been employed in the past.

The specter of sea-level rise being measured in meters can be seen to be receding ever further into the distance of unreality.

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4.1.2. Greenland and Eurasian Ice Caps

Murray et al. (2010) report that during the early 2000s, "the Greenland Ice Sheet's annual ice discharge doubled" and its outlet glaciers were dramatically "thinning, accelerating, and retreating." But as the scientists go on to show, the horror turned out to be short-lived. The 11 researchers "describe the oceanographic setting of the southeast Greenland region and then undertook two analyses to explore the relationship between oceanic processes and glacier dynamics," which helped put things in proper perspective.

Murray et al. report that in 2006, after the initial acceleration of ice loss, "two of the largest outlet glaciers in the sector, Helheim and Kangerdlugssuaq, were reported to have slowed down simultaneously (Howat et al., 2007), ceased thinning (Stearns and Hamilton, 2007; Howat et al., 2007), and readvanced (Joughin et al., 2008), and there was some indication that other glaciers in the region followed suit (Howat et al., 2008; Moon and Joughin, 2008)." In addition, their new work revealed, "the slowdown from 2006 was widespread and synchronized throughout southeast Greenland" and except for a minor reactivation at Helheim during 2007, "continued until at least 2008."

As for the mechanics of the oscillatory phenomenon, Murray et al. present evidence suggesting the original ice wastage speedup "was the result of warm ocean waters coming into contact with the glaciers" and that this speedup "was probably terminated in part by increased discharge from the glaciers themselves, which increased ice sheet runoff and iceberg calving," which in turn "introduced additional cold water strengthening the East Greenland Coastal Current." This slowed glacier melting until warmer water again began to dominate the current's waters.

Murray et al. write that their findings are suggestive of "a negative feedback that currently mitigates against continued very fast loss of ice from the ice sheet in a warming climate." They thus conclude "we should expect similar speedup and slowdown events of these glaciers in the future, which will make it difficult to elucidate any underlying trend in mass loss resulting from changes in this sector of the ice sheet."

Another attempt to assess the rapidity of Greenland ice melt was made by Wake et al. (2009). They write that the mass loss from the Greenland ice sheet over the last decade for which they had data (1995-2005) has caused the impression that "the ice sheet has been behaving anomalously" due to the warming of the 1990s and what has followed, the period the IPCC claims to have been the warmest such interval of the last one to two millennia (Mann et al., 1999; Mann and Jones, 2003). But was the ice sheet's mass loss really extraordinary?

The authors reconstructed the 1866-2005 surface mass-balance (SMB) history of the Greenland ice sheet on a 5 x 5 km grid "using a runoff-retention model based on the positive degree-day method," which accounts "for the influence of year-on-year surface elevation changes on SMB estimates" while being "forced with new datasets of temperature and precipitation patterns dating back to 1866." They did this, they state, in order to compare "the response of the ice sheet to a recent period of warming and a similar warm period during the 1920s to examine how exceptional the recent changes are within a longer time context."

The six scientists determined that present-day SMB changes "are not exceptional within the last 140 years." In fact, they found the SMB decline over the decade 1995-2005 was no different from that of the decade 1923-1933. "Based on the simulations of these two periods," Wake et al. observe, "it could as well be stated that the recent changes that have been monitored extensively (Krabill et al., 2004; Luthcke et al., 2006; Thomas et al., 2006) are representative of natural sub-decadal fluctuations in the mass balance of the ice sheet and are not necessarily the result of anthropogenic-related warming."

In another study, Sharp and Wang (2009) turned their attention to Eurasian ice caps east of Greenland. They report, "Enhanced resolution Ku-band scatterometer data from the Quick Scatterometer were used to map the timing of annual melt onset and freeze-up, and the duration of the summer melt season on the large glaciers and ice caps of Svalbard [Norway], Novaya Zemlya [Russia], and Severnaya Zemlya [Russia] for the 2000-04 period." To place the observations of their five-year study period in a longer-term context, they used "regression relationships between melt season duration and annual (June + August) mean 850-hPa air temperature over each region from the NCEP-NCAR Reanalysis to predict the annual melt duration for each year in the 1948-2005 period."

The two researchers report that with respect to all discrete five-year periods (pentads) between 1950 and 2004, "the 2000-04 pentad has the second longest mean predicted melt duration on Novaya Zemlya (after 1950-54), and the third longest on Svalbard (after 1950-54 and 1970-74) and Severnaya Zemlya (after 1950-54 and 1955-59)." These findings clearly reveal the 1950-54 pentad to have experienced the longest melt season of the past 55 years on all three of the large Eurasian Arctic ice caps.

In one final paper of note, Nick et al. (2009) concentrated their attention on the outlet glaciers that occur around the margins of the Greenland ice sheet. They report "the recent marked retreat, thinning and acceleration of most of Greenland's outlet glaciers south of 70°N has increased concerns over Greenland's contribution to future sea level rise," because, as they continue, "these dynamic changes seem to be parallel to the warming trend in Greenland." The authors developed "a numerical ice-flow model that reproduces the observed marked changes in Helheim Glacier," which they describe as "one of Greenland's largest outlet glaciers." They used the model to study the glacier's dynamics and determine what they might imply about the future mass balance of the Greenland Ice Sheet and subsequent global sea levels.

The four researchers report their model simulations show "ice acceleration, thinning and retreat begin at the calving terminus and then propagate upstream through dynamic coupling along the glacier." They find "these changes are unlikely to be caused by basal lubrication through surface melt propagating to the glacier bed," a phenomenon often cited as a cause of great concern with respect to its impact on sea level. The authors observe that "tidewater outlet glaciers adjust extremely rapidly to changing boundary conditions at the calving terminus," and conclude that "the recent rates of mass loss in Greenland's outlet glaciers are transient and should not be extrapolated into the future."

Despite concerns expressed over the past two decades about global warming becoming ever more intense, especially in the Arctic, conditions during the middle of the twentieth century seem to have been in this respect even more extreme than at any subsequent time, especially on these three major ice caps and their associated glaciers.

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4.1.3. Montane Glaciers

Achieving a proper perspective on the advance and retreat of glaciers located on mountaintops and in mountain valleys requires that data be viewed in the context of the known extent of Holocene (last 10,000 years) glacial advance and older ice limits during the Pleistocene (last 2.5 million years). Using Alaska as their study area, Barclay et al. (2009) provide an extensive and up-to-date review of what is known about Holocene glacial activity there and its relationship to temperature.

Barclay et al. report the "termini of land-based valley glaciers were in retracted positions during the early to middle Holocene" but "neoglaciation was underway in some areas by 4.5-4.0 ka and major advances of land-based termini occurred by 3.0 ka." Most dramatic, however, were the Little Ice Age (LIA) glacial advances, which culminated in two phases in the 1540s-1710s and in the 1810s-1880s, of which they state, "moraines of these middle and late LIA maxima are invariably the Holocene maxima in coastal southern Alaska," adding, "LIA advances are also recognized as major expansions in all glacierized mountain ranges in Alaska." In addition, they state researchers have determined that "Holocene fluctuations of Alaskan land-terminating glaciers have primarily been forced by multi-decadal and longer timescale changes in temperature."

These several observations suggest changes in glaciation as experienced in Alaska during the twentieth century likely started at the end of the coldest portion of the current interglacial period. It is valuable to note the Earth descended into that wretched state without any help from declining atmospheric CO_2 concentrations.

A second Holocene glacial study was conducted by Rodbell et al. (2009) in South America. These authors updated "the chronology of Andean glaciation during the Lateglacial and the Holocene from the numerous articles and reviews published over the past three decades," noting the Andes "offer an unparalleled opportunity to elucidate spatial and temporal patterns of glaciation along a continuous 68-degree meridional transect." Results indicated "all presently glacierized mountain ranges contain multiple moraines deposited during the last 450 years" and "these correlate with the Little Ice Age as defined in the Northern Hemisphere." In addition, they note most Andean regions "reveal a nearly continuous temporal distribution of moraines during the Little Ice Age."

The temporal correspondence of the Little Ice Age in essentially all of the glacierized portions of the Northern Hemisphere and the great meridional expanse of most of Andean South America, as well as the similar glacial activity of both parts of the planet during this time period, provide strong support for the proposition that montane glaciation began to retreat when much of the world commenced its return to its current, milder climatic state from what could be called the Holocene's "thermal basement."

In a third study of Holocene glacier change, Nesje (2009) compiled, assessed, and evaluated "evidence of Late Glacial and Holocene glacier fluctuations in Scandinavia as deduced from ice-marginal features, marginal moraines, proglacial terrestrial and lacustrine sites, using especially new information that has become available since the review paper published by Karlen (1988)." Nesje reports his data compilation indicates "significant Lateglacial ice-sheet fluctuations, glacial contraction and disappearance during the early and mid-Holocene and subsequent Neoglacial expansion, peaking during the 'Little Ice Age'." These observations, in his words, are "in good agreement with other presently glaciated regions in the world," as he states has been described by Solomina et al. (2008) and "references therein."

Other authors confirm that the Little Ice Age in Scandinavia, as in most parts of the world where glaciers formed and grew during that period, was a depressing and dangerous time (Luckman, 1994; Villalba, 1994; Smith et al., 1995; Naftz et al., 1996). Alpine glaciers advanced in virtually all mountainous regions of the globe during that period, eroding large areas of land and producing masses of debris. Like an army of tractors and bulldozers, streams of ice flowed down mountain slopes, carving paths through the landscape, moving rocks, and destroying all vegetation in their paths (Smith and Laroque, 1995).

Continental glaciers and sea ice expanded their ranges as well during this period (Grove, 1988; Crowley and North, 1991). Near Iceland and Greenland, in fact, the expansion of sea ice during the Little Ice Age was so great that it isolated the Viking colony established in Greenland during the Medieval Warm Period, leading to its eventual abandonment (Bergthorsson, 1969; Dansgaard et al., 1975; Pringle, 1997).

Two closely associated phenomena that often occurred during the Little Ice Age were glacial landslides and avalanches (Porter and Orombelli, 1981; Innes, 1985). In Norway, an unprecedented number of petitions for tax and land rent relief were granted in the seventeenth and eighteenth centuries because of the considerable damage caused by landslides, rockfalls, avalanches, floods, and ice movement (Grove, 1988). In one example of catastrophic force and destruction, the Italian settlements of Ameiron and Triolet were destroyed by a rockfall of boulders, water, and ice in 1717. The evidence suggests the rockfall had a volume of 16–20 million cubic meters and descended 1,860 meters over a distance of 7 kilometers in but a few minutes, destroying homes, livestock, and vegetation (Porter and Orombelli, 1980). Other data suggest rockslides and avalanches were also frequent hazards in mountainous regions during this period (Porter and Orombelli, 1981; Innes, 1985).

Flooding was another catastrophic hazard of the Little Ice Age, with meltwater streams from glaciers eroding farmland throughout Norway (Blyth, 1982; Grove, 1988). In Iceland, flooding also wreaked havoc on the landscape when, on occasion, subglacial volcanic activity melted large portions of continental glaciers (Thoroddsen, 1905–06; Thórarinsson, 1959). Peak discharge rates during these episodes have been estimated to have been as high as 100,000 cubic meters per second—a value comparable in magnitude to the mean discharge rate of the Amazon River (Thórarinsson, 1957). During one such eruption-flood in 1660, glacial meltwater streams carried enough rock and debris from the land to the sea to create a dry beach where fishing boats had previously operated in 120 feet (36.6 m) of water (Grove, 1988). Flooding from a later eruption carried enough sediment seaward to fill waters 240 feet (73.2 m) deep (Henderson, 1819).

Another Holocene study, this time of European glacial activity by Ivy-Ochs et al. (2009), presented "a summary of the evidence for suggested periods of glacier advance during the final phase of the Alpine Lateglacial and the Holocene," interweaving "data obtained from ^{10}Be surface exposure dating, radiocarbon dating of wood and peat washed out from the presently melting glacier tongues, dendrochronological investigations on wood from the glacierized basins, tree-line studies and archaeological evidence."

Results indicated "the earliest Holocene (between 11.6 and about 10.5 ka) was still strongly affected by the cold climatic conditions of the Younger Dryas and the Preboreal oscillation," but "at or slightly before 10.5 ka rapid shrinkage of glaciers to a size smaller than their late 20th century size reflects markedly warmer and possibly also drier climate." After 3.3 ka, however, "climate conditions became generally colder and warm periods were brief and less frequent." Finally, they indicate "glaciers in the Alps attained their Little Ice Age maximum extents in the 14th, 17th and 19th centuries, with most reaching their greatest Little Ice Age extent in the final 1850/1860 AD advance."

Like their alpine glacier counterparts in Scandinavia described by Nesje (2009), glaciers of the European Alps also reached their maximum Holocene extensions close to the end of the Little Ice Age. This means that at that time there existed the greatest potential for significant warming of the entire Holocene interglacial, for in an oscillatory climatic regime, the point of lowest temperature decline also represents the point of the greatest potential for a significant temperature increase. It should only have been expected, then, that the subsequent temperature recovery of the Earth would likely be quite substantial, as there was much prior cooling to be overcome in order to return the planet to a climatic state more characteristic of the bulk of the Holocene.

Considering glacial change over a shorter timeframe, Vincent et al. (2007) analyzed the impact of climate change over the past 100 years on high-elevation glaciated areas of the Mont Blanc range, including the ice fields that cover the Mont Blanc (4,808 m) and Dôme du Goûter (4,300 m) peaks. Surface ablation is negligible for these high-elevation areas, and the surface mass balance is mainly controlled by snow accumulation.

At Dôme du Goûter, ice fluxes were calculated through two transversal sections by two independent methods in order to assess long-term surface accumulation. A comparison between these results and recent accumulation observations, together with the strong relationship between valley precipitation and snow accumulation, suggests surface accumulation rates did not change significantly over the entire twentieth century.

Vincent et al. state “the most striking features ... are the small thickness changes observed over the twentieth century. For both areas, thickness variations do not exceed ±15 m. The average changes are +2.6 m at Dôme du Goûter and -0.3 m at Mont Blanc. Considering the uncertainty interval, i.e., ±5 m, it can be concluded that no significant thickness change is detectable over most of these areas.” These findings show these high-elevation glaciated areas have not been significantly affected by climate change over the last 100 years.

Finally, Kaser et al. (2010) examined the ice fields that top Mt. Kilimanjaro’s highest peak, Kibo. Kaser et al. write these features have garnered “particular attention” since Irion (2001) attributed modern changes in them to “increased air temperature in the context of global warming” and Thompson et al. (2002) reported on what they described as the “near extinction of the ice on Kibo,” which they characterized as being “unprecedented over the last 11,700 years.” Shortly thereafter, however, Kaser et al. (2004) developed an alternative hypothesis, namely that atmospheric moisture primarily controls the modern-time glacier changes on Kibo, as Kaser et al. (2010) indicate is also suggested by the work of Molg and Hardy (2004), Cullen et al. (2006, 2007) and Molg et al. (2003, 2006, 2009a,b). This finding, in their words, “not only rules out rising local air temperature (i.e. on the peak of Kibo) as the main driver of observed changes during the last 120 years, but also puts the currently accepted 11,700 years age in question.”

Based on their review of a compilation of all available information on present-day phenomena that control the glaciers on Kilimanjaro, and after what the five researchers describe as “a careful glaciological evaluation,” Kaser et al. (2010) conclude “minor changes in thickness have no impact on the changing surface area of the tabular plateau glaciers,” while noting “plateau glacier area decrease has been strikingly constant over the twentieth century” and “ablation rates of the ice walls are [also] persistently constant.” In addition, their analyses suggest the mountain’s plateau ice “may have come and gone repeatedly throughout the Holocene” and the reduction of plateau ice in modern times “is controlled by the absence of sustained regional wet periods rather than changes in local air temperature on the peak of Kilimanjaro.”

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4.1.4. Sea and Lake Ice

Though semi-permanent sea ice exists around the North Pole, fringing sea ice in both the Arctic and Antarctic is an annual, seasonal feature. Fringing sea ice is therefore particularly susceptible to fast advance or retreat depending upon local oceanographic and atmospheric changes. Even quite major sea-ice changes are not necessarily due to climatic change.

This dynamic, rather than climatic, aspect of sea-ice change is well documented in a recent study by Scott and Marshall (2010), two scientists with the British Antarctic Survey. They found “over the last four decades there has been a trend to earlier summer breakup of the sea ice in western Hudson Bay, Canada" and "the trend to earlier sea-ice breakup has been linked to the long-term effect of warming in the region (Stirling et al., 1999; Gagnon and Gough, 2005)." Subsequently, however, they report "the existence of a sufficiently long-term regional warming trend was disputed by Dyck et al. (2007)," and, therefore, they decided to explore the subject in more detail, to see if they could resolve the controversy.

Working with passive microwave data obtained from the Scanning Multichannel Microwave Radiometer onboard the Nimbus 7 satellite, plus three Special Sensor Microwave/Imager instruments onboard Defense Meteorological Satellite Program satellites, as well as Canadian Ice Service sea-ice charts considered to be "more accurate than passive microwave data for estimates of ice concentration, particularly in the presence of surface melt," as described by Agnew and Howell (2002) and Fetterer et al. (2008), Scott and Marshall performed several new analyses on both datasets, "bringing the time series up to date" (to 2007, from a starting date of 1971) while looking at "temperature trends in the area around the time of breakup in more detail than was [done] in previous studies."

With respect to the chief point of controversy, the researchers found "there has clearly not been a continuous trend in the [time of sea-ice breakup] data, and the change is best described by a step to 12 days earlier breakup occurring between 1988 and 1989, with no significant trend before or after this date." In addition, they remark, "an increase in regional southwesterly winds during the first three weeks of June and a corresponding increase in surface temperature are shown to be likely contributing factors to this earlier breakup."

Proponents of the theory of CO_2-induced global warming have long publicized what they characterize as the gradual development, over the past four decades, of an earlier occurrence of the date of yearly sea-ice breakup in Canada's Hudson Bay, claiming it was a manifestation of anthropogenic climate change that was negatively affecting the region's polar bears. The newer findings of Scott and Marshall argue against that conclusion. Nevertheless—and correctly—the two researchers conclude their analysis by stating "it remains to be seen whether these changes in atmospheric circulation [which appear to be the proximate cause of the significant step-change in the date of sea-ice breakup] might be ascribed to human actions or simply to natural climate variability."

Clearly, the science pertaining to this matter is not settled.

Floating ice pack that is responsive to climatic fluctuations forms on large, intra-continental lakes as well as on the ocean, and Wang et al. (2010) provide an analysis of 70 years of such floating ice for the Great Lakes of North America. Their study covers the winters of 1972–73 to 2008–09 and comprises an analysis of time series of annual average ice area and basin winter average surface air temperature (SAT) and floating ice cover (FIC) for the Great Lakes, which they remind us "contain about 95% of the fresh surface water supply for the United States and 20% of the world."

The primary data of interest are depicted in Figure 4.1.1 below, where after an initial four years of relative warmth and lower annual average ice area, SATs declined and FIC area rose. Then, there began a long period of somewhat jagged SAT rise and FIC decline, which both level out from about 1998 to 2006, after which SAT once again slowly declines and FIC slowly rises. Both parameters terminate at about the same value they exhibited initially.

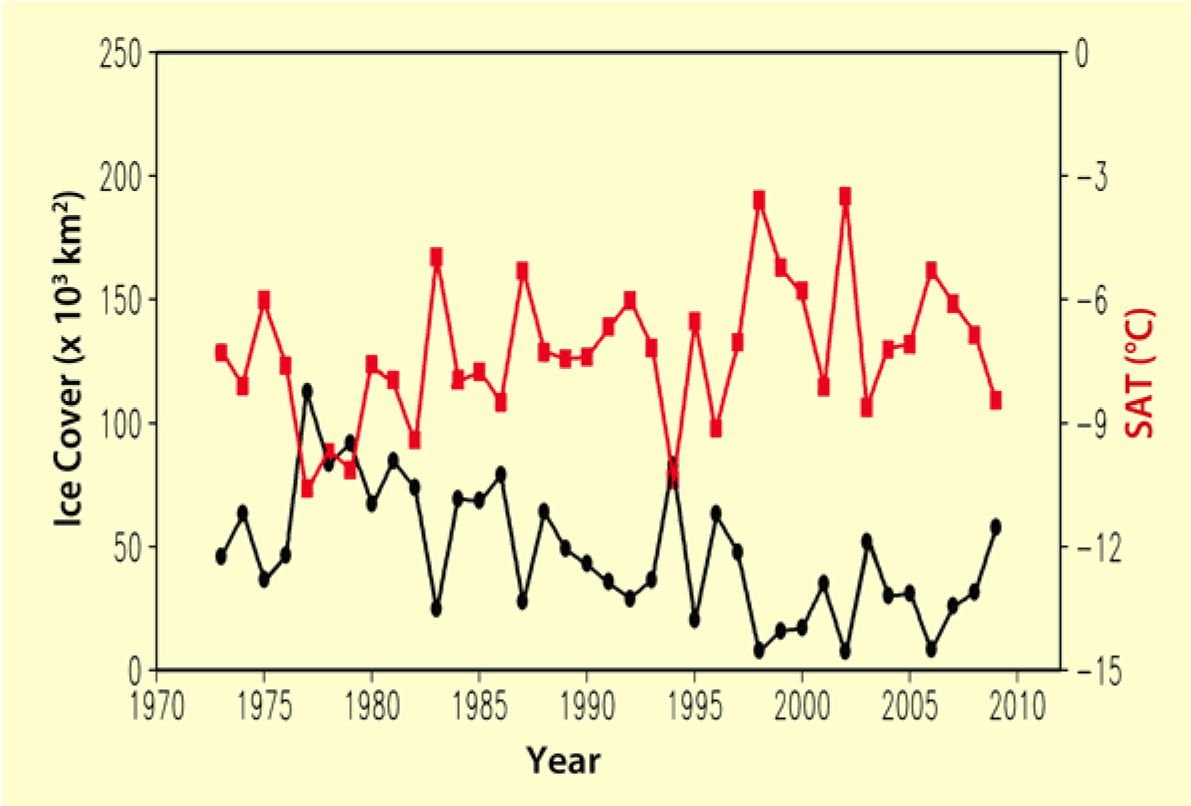

Figure 4.1.1. Annual average ice area of the North American Great Lakes and basin winter average surface air temperature (SAT) vs. time. Adapted from Wang et al. (2010).

Wang et al. conclude from their study that "natural variability dominates Great Lakes ice cover," and that any trend in the data—of which there are some of a few years and one that is lengthier—"is only useful for the period studied." Given this finding, there is no reason to attribute any change in the annual average ice area of the North American Great Lakes to anthropogenic global warming.

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4.2. Ocean Dynamics

4.2.1. Sea Level Change

In an analysis of the tide gauge record for Brest, a city in north-western France, Woppelmann et al. (2008) examined "the issue of a possible tide gauge datum discontinuity … caused by the bombing of the city in August 1944" via "a detailed analysis of historical levelling information, and comparison of sea level data between adjacent stations."

The Brest tide gauge was found to be "'stable' over the 1889–1996 period." The authors say their work "led to an accurate datum connection between recently rediscovered 18th century sea level data (back to 1711) and those of the present day." In addition, they claim "an interesting by-product" of their work, "the close matching of the Brest and Liverpool [UK] time series over more than 200 years." Both instrumental records "show a roughly coincident increase in the rate of relative sea-level rise around the end of the 19th century," as does the sea-level record of Newlyn in the UK. From 1890 to the ends of the records, which appear to extend to about 2007, all three datasets define similar linear increases with time.

If one splits the period of linear sea-level rise into two equal 57-year parts centered on the middle of the twentieth century—1893 to 1950 and 1950 to 2007—it can be determined from various atmospheric trace gas records that the air's CO_2 concentration rose about 3.8 times faster over the last of these periods than it did over the first period. Since mean sea level rose at a constant rate over the entire 114 years, it is unlikely the historical increase in the atmosphere's CO_2 content was the ultimate cause of the steady mean sea-level rise.

In another study, this time of coastal wetlands in the eastern United States, Langley et al. (2009) discovered, "tidal wetlands experiencing increased rates of sea-level rise (SLR) must increase rates of soil elevation gain to avoid permanent conversion to open water." As for how that might happen, they note "root zone expansion by accumulation of plant material is essential to maintaining a constant surface elevation relative to rising sea level."

In Kirkpatrick Marsh—a microtidal subestuary of Chesapeake Bay, where each of several 200m^2 plots was outfitted with a surface elevation table (SET) to measure soil elevation change—Langley et al. exposed half the plots to an extra 340 ppm of CO_2 for two years, while "data from a greenhouse mesocosm experiment (Cherry et al., 2009) were used to examine how elevated CO_2 might affect elevation response under simulated SLR scenarios."

The five researchers report the extra CO_2 of their marsh experiment increased fine root productivity by an average of 36 percent over the two-year study, and that above-ground biomass production was increased by as much as 30 percent, "consistent with a 20-year record of elevated CO_2 treatment in a previous CO_2 study on the same marsh (Erickson et al., 2007)." In addition, they state the elevated CO_2 caused an increase in root zone thickness of 4.9 mm/year compared with only 0.7 mm/year in the ambient CO_2 treatment, with the result that there was "a slight loss of elevation in ambient CO_2 (-0.9 mm/year) compared with an elevation gain (3.0 mm/year) in the elevated CO_2 treatment." Furthermore, they report the greenhouse mesocosm experiment of Cherry et al. (2009) "revealed that the CO_2 effect was enhanced under salinity and flooding conditions likely to accompany future SLR."

Langley et al. conclude, "by stimulating biogenic contributions to marsh elevation, increases in the greenhouse gas, CO_2, may paradoxically aid some coastal wetlands in counterbalancing rising seas." In this regard, they state their findings "bear particular importance given the threat of accelerating SLR to coastal wetlands worldwide," citing the recent Environmental Protection Agency report of Reed et al. (2008), which suggests "a 2-mm increase in the rate of SLR will threaten or eliminate a large portion of mid-Atlantic marshes." This research suggests the positive growth-promoting effect of atmospheric CO_2 enrichment more than compensates for its hypothetical sea-level-raising effect.

A key issue in understanding eustatic (global) sea-level change is the degree to which glacial meltwater is causing an increase in ocean mass. In a study of Alaskan and nearby Canadian glaciers, Berthier et al. (2010) comment that earlier estimates of mass loss from Alaskan and nearby glaciers "have relied on extrapolating site-specific measurements to the entire region," citing in support the studies of Arendt et al. (2002), Meier and Dyurgerov (2002), and Dyurgerov and Meier (2005).

Berthier et al. Say the "landmark study" of Arendt et al. (2002) used laser altimetry to measure elevation changes on 67 glaciers, but those glaciers represented only 20 percent of the area of the ice field. Therefore, in an attempt to expand the areal coverage and overcome several other methodological deficiencies, Berthier et al. calculated ice elevation changes for nearly three-quarters of the ice-covered areas in the Alaskan glacier range by combining "a comprehensive glacier inventory with elevation changes derived from sequential digital elevation models," the first set having a median date of 1962 and the latter having a date of 2006.

Results indicated "between 1962 and 2006, Alaskan glaciers lost 41.9 ± 8.6 km^3 per year of water, and contributed 0.12 ± 0.02 mm per year to sea-level rise," which they note was 34 percent less than estimated by Arendt et al. (2002) and Meier and Dyurgerov (2002). In discussing this large difference, they say the reasons for their lower values include "the higher spatial resolution of [their] glacier inventory as well as the reduction of ice thinning underneath debris and at the glacier margins, which were not resolved in earlier work." Thus, in addition to significantly revising what was previously believed about the magnitude of ice wastage in Alaska and northwest Canada in recent decades, Berthier et al. say their results suggest "estimates of mass loss from glaciers and ice caps in other mountain regions could be subject to similar revisions." This work calls into serious question claims that Earth's mountain glaciers and ice caps are wasting away rapidly and thereby contributing to global sea level rise.

As glacial melt supplies water that may cause sea-level rise, measurement of that rise may be made by means of its effect on coral reefs, the upper limit of which is closely controlled by mean sea level. "Accepting current IPCC scenarios of eustatic sea-level rise," Webb and Kench (2010) note, "it is widely anticipated that low-lying reef islands will become physically unstable and be unable to support human populations over the coming century." They also write, "it is also widely perceived that island erosion will become so widespread that entire atoll nations will disappear, rendering their inhabitants among the first environmental refugees of climate change."

To draw attention to this perceived threat, members of the Maldives Cabinet donned scuba gear on 17 October 2009 and used hand signals to conduct business at an underwater meeting. During this meeting they signed a document calling on all nations to reduce their carbon emissions. However, Webb and Kench's study of this situation found the theatrics were entirely unnecessary.

Webb and Kench examined the morphological changes of 27 atoll islands located in the central Pacific in four atolls spanning 15 degrees of latitude from Mokil atoll in the north (6°41.01'N) to Funafuti in the south (8°30.59'S). They did this using historical aerial photography and satellite images over periods ranging from 19 to 61 years, during which time interval they say instrumental records indicated a rate of sea-level rise of 2.0 mm per year in the central Pacific.

Based on their analysis, the two researchers—one from Fiji and one from New Zealand—state, "there is no evidence of large-scale reduction in island area despite the upward trend in sea level" and the islands "have predominantly been persistent or expanded in area on atoll rims for the past 20 to 60 years." More specifically, they find 43 percent of the islands "increased in area by more than 3% with the largest increases of 30% on Betio (Tarawa atoll) and 28.3% on Funamanu (Funafuti atoll)." The results of this study, they observe, "contradict widespread perceptions that all reef islands are eroding in response to recent sea level rise." Quite to the contrary, the authors note, "reef islands are geomorphically resilient landforms that thus far have predominantly remained stable or grown in area over the last 20–60 years" and, "given this positive trend, reef islands may not disappear from atoll rims and other coral reefs in the near-future as speculated."

The views of the Maldives cabinet and its supporters notwithstanding, it is evident from first principles that on low-lying shorelines, an incremental increase in sea level will most likely lead to an expansion of reef area.

In a similar study of the Great Barrier Reef (Australia), Dawson and Smithers (2010) note low-lying reef islands are widely perceived to be particularly sensitive to ongoing and projected sea-level increases, but they add "a number of geomorphologists have argued that rising sea levels do not always cause reef islands to erode." They state, "a rise in sea level may promote reef island growth by: i) increasing accommodation space for new sediment; ii) reinvigorating carbonate production on reef flats where further reef growth has been inhibited by a stable sea level; and iii) increasing the efficiency of waves to transport new and stored sediment to an island depocentre (Hopley, 1993; Hopley et al., 2007; Smithers et al., 2007; Woodroffe, 2007)."

Working on Raine Island (11°35'28"S, 144°02'17"E) at the northwest end of a planar reef on the outer edge of Australia's Great Barrier Reef—one of the world's most important nesting sites for marine turtles—Dawson and Smithers employed three historic survey maps and five topographic survey datasets of earlier researchers, supplementing them with digital elevation data collected in 1998, 2006, and 2007, to reconstruct a 40-year (1967–2007) shoreline history of the island. The two Australian researchers report their "detailed quantitative surveys and analyses demonstrate that Raine Island increased in area (~6%) and volume (~4%) between 1967 and 2007," and that "in the 40 years between 1967 and 2007 Raine Island underwent a net accretion of 68,400 ± 6,700 m^3."

In summing up their findings, Dawson and Smithers write, "contrary to perceptions, Raine Island did not erode but instead modestly accreted during the 40-year study period." They therefore conclude, "future management strategies of Raine Island and other islands of the Great Barrier Reef should recognize that perceptions of reef island erosion can arise from large short-term seasonal and storm-derived sediment redistribution from one part of the island to another or to a temporary storage on the adjacent reef flat" but these phenomena do not necessarily lead to "a net permanent loss from the island sediment budget." Considering also the similar findings of Webb and Kench (2010), it can therefore be concluded that the most likely effect of a rising sea level is to add to the area and volume of low-lying reef islands.

Moving on to geophysical studies of sea-level change, Quinn and Ponte (2010) write, "ocean mass, together with steric sea level, are the key components of total observed sea level change" and "monthly observations from the Gravity Recovery and Climate Experiment (GRACE) can provide estimates of the ocean mass component of the sea level budget, but full use of the data requires a detailed understanding of its errors and biases." This belief is true in principle, but the complex operational corrections that often need to be applied to spaceborne geophysical datasets mean "at best, the determination and attribution [in this way] of global-mean sea level change lies at the very edge of knowledge and technology" (Wunsch et al., 2007).

In an effort to provide some of that "detailed understanding" of GRACE's "errors and biases," Quinn and Ponte conduct what they describe as "a detailed analysis of processing and post-processing factors affecting GRACE estimates of ocean mass trends," by "comparing results from different data centers and exploring a range of post-processing filtering and modeling parameters, including the effects of geocenter motion, PGR [postglacial rebound], and atmospheric pressure."

The two researchers report the mean ocean mass trends they calculated "vary quite dramatically depending on which GRACE product is used, which adjustments are applied, and how the data are processed." They state "the PGR adjustment ranges from 1 to 2 mm/year, the geocenter adjustment may have biases on the order of 0.2 mm/year, and the atmospheric mass correction may have errors of up to 0.1 mm/year," while "differences between GRACE data centers are quite large, up to 1 mm/year, and differences due to variations in the processing may be up to 0.5 mm/year."

In light of the fact that Quinn and Ponte indicate "over the last century, the rate of sea level rise has been only 1.7 ± 0.5 mm/year, based on tide gauge reconstructions (Church and White, 2006)," it seems a bit strange that one would question that result on the basis of a GRACE-derived assessment, with its many and potentially very large "errors and biases." In addition, as Ramillien et al. (2006) have noted, "the GRACE data time series is still very short" and results obtained from it "must be considered as preliminary since we cannot exclude that apparent trends [derived from it] only reflect inter-annual fluctuations." And as Quinn and Ponte also note, "non-ocean signals, such as in the Indian Ocean due to the 2004 Sumatran-Andean earthquake, and near Greenland and West Antarctica due to land signal leakage, can also corrupt the ocean trend estimates."

Clearly, the GRACE approach to evaluating ocean mass and sea level trends still has a long way to go—and must develop a long history of data acquisition—before it can be considered a reliable means of providing assessments of ocean mass and sea-level change accurate enough to detect an anthropogenic signal that could be confidently distinguished from natural variability.

Despite the inherent uncertainty of the results, GRACE satellite data nonetheless have been used in several studies to estimate sea-level rise and ice loss due to global warming. A particularly confounding factor in these studies is that continents and ocean basins respond to past and recent mass loss or additions by rising or sinking. Thus the surface of an ice sheet could be rising due to Glacial Isostatic Adjustment (GIA) even though it is currently losing ice mass, or vice versa.

Earlier studies have used an estimated GIA model to adjust for this effect, but these models are not independent of ice accumulation/loss rates. Wu et al. (2010) used the alternative method of simultaneously estimating GIA and present-day surface mass trend (PDMT) for the globe. They use three sources of data: GRACE data, ocean bottom pressure data from the Jet Propulsion Laboratory, and the three-dimensional surface velocities (from GPS data) of a network of 664 globally distributed sites, the goal being to obtain with high accuracy global surface maps of both GIA and PDMT.

The most prominent result of this analysis is a reduction by about a factor of two in the estimate of current rates of ice loss for Greenland and Antarctica compared to previous GRACE estimates based on the *a priori* GIA model, due partly to clear evidence for ice accumulation in the interior of Greenland (accompanied by ice loss around the margins of Greenland). Parts of West Antarctica also show rapid loss and others rapid gain of ice mass, while East Antarctica seems relatively stable. The current (2002–2008) global non-steric (not due to ocean warming and water expansion) sea-level rise attributable to ice mass loss is estimated in the study to be 0.54 mm/yr (about 2 inches per century). This suggests almost none of the ongoing background sea-level rise of about 1.7 mm/yr, as measured by tide gauges worldwide, is due to glacial ice loss.

That sea level has been rising gently for the past 100+ years has been demonstrated by numerous real-world measurements and observations. An important open question, however, is whether the rate of rise has accelerated in recent decades, because an acceleration is implied by greenhouse theory.

Normally, the approach to answering such a question would be to turn to measurements of the phenomenon, but in the case of sea-level rise, there is a major problem in that tide gauge stations rise or fall as the land they sit on rises or falls, thereby confounding the data. In addition, newer satellite measurements do not extend very far back in time. Wenzel and Schroter (2010) adopt a novel technique in order to attempt to overcome these issues: They use neural nets for infilling of missing data at individual stations and for estimating weights for individual gauges.

Using 56 stations with at least 50 years of data each, these authors adjusted the data before use by correcting it for land movement up or down. The training data for the neural net were three sets of altimetry data for recent decades, and all three results were shown. By basin, they indicated no net trend for the South Atlantic and tropical Indian Oceans, and a net decline in sea level for the Southern Indian Ocean. The Pacific Ocean showed an approximate 70-year oscillation in sea level that correlates (with lag) with the Pacific Decadal Oscillation (PDO), while the Atlantic showed cycles of 23 and 65 years. Overall, ocean basin changes showed correlations with the PDO and Southern Annular Mode indices, with lags. Wenzel and Schroter say this work—along with the clear annual cycles in sea level they discern—shows their final result correctly reflects the effects of water temperature on sea level.

For the globe as a whole, the two researchers found a linear upward sea-level trend of 1.56 mm/year, with no sign of acceleration in recent decades. This result is consistent with previous tide gauge estimates, but only about one-half of the value used by the IPCC, and if the rate of rise continued it would produce about one-half foot of sea level rise over the next century. These results agree with those of Hagedoorn et al. (2007) of 1.46 mm/year and Woppelmann et al. (2009) of 1.61 mm/year, as well as several other recent studies that give only slightly higher values around 1.7–1.8 mm/year.

It would appear careful analyses of tide gauge records by multiple teams do not show the acceleration of sea-level rise proposed by the IPCC.

This result notwithstanding, Rahmstorf (2007) has proposed the existence of "a linear relationship between the rate of global mean sea-level rise and the global mean near-surface air temperature deviations," which he claims can be "calibrated with observed data, thus incorporating in a somewhat realistic and condensed manner all known and unknown mechanisms modulating the global sea-level height." The concept sounds reasonable, but does it work? In an intriguing study published in *Ocean Dynamics*, von Storch et al. (2008) find it does not.

One way of addressing Rahmstorf's assertions—which von Storch et al. employ—is "to test the statistical methods in the virtual reality produced in simulations with state-of-the-art climate models." Following that strategy, these authors examined "several hypotheses concerning the relationship between global mean sea level and other thermal surface variables in a long climate simulation of the past millennium with the climate model ECHO-G driven by estimations of past greenhouse gas, volcanic and solar forcing."

The three researchers report the linear link between global mean temperature and the rate of change of global mean sea level proposed by Rahmstorf "turned out to be not reliable over the full time period." They continue, "instead, for some periods, even inverse relationships were found to describe the simulated data best." Likewise, they state the second predictor—the rate of change of temperature—"did not show markedly better results." For both predictors, they report, "there exist periods in the simulation where the prediction errors are very large."

In discussing their own findings, von Storch et al. acknowledge the type of test they performed in the "virtual reality" produced by climate models "cannot prove whether a certain hypothesis, in this case the different statistical relationships, will hold in the real world." However, they continue, "they can be used to falsify a particular hypothesis," noting "if it is not fulfilled in a simple virtual reality, it will probably also fail in a more complex real world."

The IPCC should therefore take note: There is currently no known way to predict with any reasonable and demonstrable degree of confidence what mean global sea level will do over the twenty-first century, even if mean global air temperature begins to rise once again.

Another attempt to assess the global sea-level change "budget" was made by Leuliette and Miller (2009). They assert, "Global mean sea level change results from two major processes that alter the total volume of the ocean." These processes are (1) changes in total heat content and salinity, which produce density or steric changes and (2) the exchange of water between the oceans and other reservoirs (such as glaciers, ice caps, and ice sheets, plus land-based liquid water reservoirs), which result in mass variations. In regard to these several components, they note that although satellite radar altimeters have provided global observations since the early 1990s, only since 2002 have satellite gravity observations allowed for global estimates of mass variations, and not until 2007 did the Argo Project achieve its goal of 3,000 floats measuring truly global steric changes.

Using appropriate data to ascertain whether the sum of global steric and global mass contributions to global sea-level rise were indeed equal to the observed global sea-level rise (within the error bounds of each side of the equation), two prior attempts to close the global sea-level-rise budget were performed by Lombard et al. (2007) and Willis et al. (2008). Both of these attempts were unsuccessful. Consequently, and with a little more data, Leuliette and Miller attempted to obtain closure (and, therefore, greater confidence in the final result) one more time.

The two U.S. researchers state their "new analysis of the sea level rise budget for the period January 2004 to December 2007 used corrected Jason-1 and Envisat altimetry observations of total sea level, improved upper ocean steric sea level [data] from the Argo array, and ocean mass variations inferred from GRACE gravity mission observations." This effort yielded success, as they closed the global sea-level-rise budget by finding that the sum of steric sea level and ocean mass components had a trend of 1.5 ± 1.0 mm/year over the period of their analysis, which they state is "in agreement with the total sea level rise observed by either Jason-1 (2.4 ± 1.1 mm/year) or Envisat (2.7 ± 1.5 mm/year) within a 95% confidence interval."

Of course, there is still the question of which of the three mean results lies closest to the truth, which is of great importance given that the last of the three results is fully 80 percent greater than the first. In this regard, Woppelmann et al. (2009) recently obtained a result of 1.58 ± 0.03 mm/year by analyzing GPS observations from a global network of 227 stations over the period January 1997 to November 2006, and they cite a result of 1.7 mm/year obtained by both Church and White (2006) and Holgate (2007).

We draw attention a second time to the wise caution of Wunsch et al. (2007) that "at best, the determination and attribution of global-mean sea level change lies at the very edge of knowledge and technology." Nonetheless, it would appear researchers are gradually closing in on the truth, which is that we have yet to see any of the catastrophic sea-level rise predicted by the IPCC.

It is, of course, a truism that highly accurate measurements of historic and modern sea-level change have no particular value in their own right but only when they are considered in the proper context of sea-level change over geological time. Knowledge about changes in past (pre-instrumental) sea level comes from measurements of geological proxies and is abundant around the world. Members of the PALeo SEA Level Working Group (PALSEA 2009) recently looked to some of these records of past sea-level change in order to identify the natural contextual limits (both high and low) within which future sea-level rise will occur.

Starting with the IPCC's most recent estimate that global warming of somewhere between 1.1 and 6.3°C will occur in the twenty-first century, the PALSEA group writes, "the last time that a global warming of comparable magnitude occurred was during the termination of the last glacial period," which consisted of "a series of short, sharp steps on millennial to centennial timescales." Hence they looked at what is known about sea-level change during the Bolling-Allerod and post-Younger Dryas/early Holocene periods, noting "the magnitude and rate of warming during these periods are most closely analogous to the magnitude and rate of anthropogenic warming [that is predicted to occur] over the coming centuries." This comparison immediately rules out any type of exponentially increasing sea-level response, pointing more toward an asymptotic response where the sea-level rise is high initially but gradually levels off.

For even greater realism, the PALSEA team next turned to warm periods of the Holocene, since they assert the Earth is now at a much higher "starting" temperature than during the termination of the last great ice age. (This somewhat strange belief conflicts with the gently declining Holocene temperatures recorded in both Greenland and Antarctic ice cores.) Considering what is known about eustatic sea level between 9 and 8.5 ka BP and between 7.6 and 6.8 ka BP (increases of 1.3 and 0.7 m per century, respectively), the PALSEA scientists state, a "rapid demise of ice sheets in a climate similar to today is certainly a possibility," but "an improved understanding of ice sheet dynamics is required before one can conclude that the Greenland or West Antarctic ice sheets will behave in a similar fashion in the future."

Turning finally to previous interglacials, the 32-member research group notes some studies have placed peak sea levels during the last interglacial period somewhere in the range of 3–6 m above modern sea level about 126 ka BP, but only "several thousand years after proxy records of temperature reached interglacial levels."

In considering all of the above lines of argument, the PALSEA scientists conclude, "using palaeo-data and direct observations, it is possible to put loose limits on just how rapidly we might expect sea-level rise to occur over the next century" if the worst-case warming scenario of the IPCC were actually to occur. PALSEA places the projected rise somewhere between the lower limit of twentieth-century sea-level rise (0.12 m per century) and the sea-level rise at the conclusion of the termination of the last glacial period (1 m per century). Interestingly, this range significantly exceeds (at the high end) that reported in the IPCC's Fourth Assessment Report (-0.01 to 0.17 m over the current century); but it is still a far cry from the multiple "meters" suggested by some commentators.

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4.2.2. Ocean Heat

The Earth's climate is not controlled solely by the atmosphere but instead to a large degree by the heat store represented by the ocean, which has a 3,300 times greater heat capacity than the atmosphere. Furthermore, with a global circulation time of roughly

1,000 years, compared with one year for the atmosphere, changes in ocean heat release or uptake operate over the longer multidecadal, centennial, and millennial time scales associated with climate (as opposed to weather) change.

Despite its critical importance for climatic studies, we have a poor record of ocean heat observations, and it is only since the inception in 2004 of the ARGO global network of more than 3,000 drifting and diving ocean probes that we have an adequate estimate of ocean temperatures and heat budget. Though ARGO data are in their infancy and still subject to adjustment for errors, early indications are that the oceans are currently cooling (Loehle, 2009).

In an important paper, Shaviv (2008) has explored some of the key issues relating to change in ocean heat as a driver of climate change, particularly in response to solar variations. As background, Shaviv writes, “climatic variations synchronized with solar variations do exist, whether over the solar cycle or over longer time-scales,” citing numerous references in support of this fact. However, many scientists decline to accept the logical derivative of this fact: that solar variations are driving climate changes. Their prime objection is that measured or reconstructed variations in total solar irradiance seem too small to be capable of producing observed climate change.

One way of resolving this dilemma would be to discover some amplification mechanism, but most attempts to identify one have been fraught with difficulty and met with much criticism. In his 2008 paper, however, Shaviv makes a good case for the existence of such an amplifier, as well as providing a potential mechanism that might fill that role.

Specifically, Shaviv’s study aimed to “use the oceans as a calorimeter to measure the radiative forcing variations associated with the solar cycle” via “the study of three independent records: the net heat flux into the oceans over 5 decades, the sea-level change rate based on tide gauge records over the 20th century, and the sea-surface temperature variations,” each of which can be used “to consistently derive the same oceanic heat flux.”

In pursuing this logic, Shaviv demonstrated “there are large variations in the oceanic heat content together with the 11-year solar cycle.” In addition, he reports the three independent datasets “consistently show that the oceans absorb and emit an order of magnitude more heat than could be expected from just the variations in the total solar irradiance,” thus “implying,” as he describes it, “the necessary existence of an amplification mechanism, although without pointing to which one.”

Finding it difficult to resist pointing, however, Shaviv acknowledges his affinity for the solar-wind modulated cosmic ray flux (CRF) hypothesis, which was suggested by Ney (1959), discussed by Dickinson (1975), and championed by Svensmark (1998). Based on “correlations between CRF variations and cloud cover, correlations between non-solar CRF variations and temperature over geological timescales, as well as experimental results showing that the formation of small condensation nuclei could be bottlenecked by the number density of atmospheric ions,” this concept, according to Shaviv, “predicts the correct radiation imbalance observed in the cloud cover variations” that are needed to produce the magnitude of the net heat flux into the oceans associated with the 11-year solar cycle. Shaviv thus concludes the solar-wind modulated CRF hypothesis is “a favorable candidate” as the primary instigator of many climatic phenomena.

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4.2.3. Ocean Circulation

The global thermohaline system of circulation of ocean currents, also sometimes called the meridional overturning circulation, provides links for the transfer of heat across, between, and vertically through ocean basins, with complete mixing taking up to 1,000 years and more. Physical forcing of the system is provided by the westerly wind belts of the southern circum-Antarctic Ocean and by the sinking of dense, saline water in the North Atlantic Ocean. Past changes in the flow of this ocean circulation system can be shown to be linked to major climate change; for example, flow speeds of the cold-water Pacific Deep Western Boundary Current increased during past glacial periods (Hall et al., 2001). The IPCC, noting such facts, therefore argues global warming will change the speed of ocean circulation phenomena such as the Gulf Stream in ways that will make the world's climate less hospitable.

In setting out to assess this argument, Baehr et al. (2007) investigated how quickly changes in the North Atlantic meridional overturning circulation (MOC) could be detected by projecting simulated observations onto a time-independent spatial pattern of natural variability, which was derived by regressing the zonal density gradient along 26°N against the strength of the MOC at 26°N within a model-based control climate simulation, which pattern was compared against observed anomalies found between the 1957 and 2004 hydrographic occupations of this latitudinal section.

Looking to the future, this exercise revealed that Atlantic MOC changes could likely be detected with 95 percent reliability after about 30 years, using continuous observations of zonal density gradients that can be obtained from a recently deployed monitoring array. Looking to the past, they report, "for the five hydrographic occupations of the 26°N transect, none of the analyzed depth ranges shows a significant trend between 1957 and 2004, implying that there was no MOC trend over the past 50 years." The finding is significant because to this point in time, over which the IPCC claims the Earth has warmed at a rate and to a level of warmth that is unprecedented over the past two millennia, there has been no observable change in the rate of the North Atlantic MOC, suggesting either the IPCC is significantly in error in its characterization of Earth's current level of warmth or the North Atlantic MOC is not nearly as sensitive to global warming as many climate models employed by the IPCC have suggested it is.

Since Baehr et al. (2007) have used real-world hydrographic transect data to demonstrate "there was no MOC trend over the past 50 years," we will probably have more time to prepare for any undesirable consequences of a drastic decline in the Atlantic MOC than did the unfortunate folks in the non-award-winning film *The Day After Tomorrow*.

In a second paper addressing North Atlantic deep water formation and circulation, Vage et al. (2008) write, "in response to global warming, most climate models predict a decline in the Meridional Overturning Circulation, often due to a reduction of Labrador Sea Water" (which is produced in the Labrador and Irminger Seas of the North Atlantic Ocean), noting further, "since the mid-1990s, convection in the Labrador Sea has been shallow—and at times nearly absent."

This confluence of observations might be interpreted as strengthening claims of an impending climatic disaster. However, Vage et al. document "the return of deep convection to the subpolar gyre in both the Labrador and Irminger seas in the winter of 2007–2008," using "profiling float data from the Argo program to document deep mixing" as well as "a variety of *in situ*, satellite and reanalysis data" to provide context for the phenomenon.

The Canadian, Danish, French, and U.S. scientists observed winter mixing to depths of 1,800 m in the Labrador Sea, 1,000 m in the Irminger Sea, and 1,600 m south of Greenland, whereas base-period (the winters of 2001–2006) mixing depths are less than 1,000 m. They also determined, via analyses of heat flux components, "the main cause of the enhanced heat flux was unusually cold air temperatures during [the 2007–2008] winter."

More specifically, the scientists tell us, "the air temperature recorded at the Prins Christian Sund meteorological station near Cape Farewell was 2.8°C colder in the winter of 2007–2008 than the corresponding mean of the base period." Furthermore, they say the cooling was "not a local phenomenon," noting "the global temperature dropped 0.45°C between the winters of 2006–2007 and 2007–2008" and that across northern North America "the mean winter temperature was more than 3°C colder." In addition, they report "storm tracks, the flux of freshwater to the Labrador Sea and the distribution of pack ice all contributed to an enhanced flux of heat from the sea to the air, making the surface water sufficiently cold and dense to initiate deep convection." This phenomenon was aided by "very strong westerly winds off the Labrador ice edge" that "boosted the advection of cold air towards the region of deep convection," thereby providing a sort of perfect storm situation in which everything came together to create an oceanic overturning the likes of which had not been seen since the late 1980s to early 1990s.

In the words of the nine scientists of the research team, "the return of deep convection to the Labrador and Irminger seas in the winter of 2007–2008 was a surprise." One reason for this reaction, as they describe it, was that "contrary to expectations the transition to a convective state took place abruptly, without going through a phase of preconditioning."

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4.3. Precipitation

4.3.1. Rainfall

The IPCC contends extreme weather events of all types should become both more frequent and more intense when the world warms. It claims this is particularly true with respect to events having to do with rainfall. Others follow suit. For example, in their popular book *Dire Predictions: Understanding Global Warming*— subtitled "The Illustrated Guide to the Findings of the IPCC"—Mann and Kump (2008) write that as temperatures rise "increases are to be expected in the frequency of very intense rainfall events" and "individual storms will be associated with more severe downpours ... due to the greater amount of water vapor that a warmer atmosphere can hold." But have such things actually been happening in the real world? This is an especially testable proposition in light of the global warming of the last two decades of the twentieth century, which the IPCC describes as having been unprecedented over the past one to two millennia.

Giambelluca et al. (2008) have reported Hawaii warmed recently at a rate of 0.163°C per decade. In a study designed to assess whether this warming caused additional rainfall in Hawaii, Chu et al. (2010) write, "for the first time, five climate change indices for extreme precipitation (four related to wetness and one related to dryness) in Hawaii have been calculated," based on "daily observational records from the 1950s to 2007." These specific indices are (1) the simple daily intensity index, (2) the total number of days with precipitation ≥25.4 mm, (3) the annual maximum consecutive five-day precipitation amount, (4) the fraction of annual total precipitation from events exceeding the 1961–1990 95th percentile, and (5) the number of consecutive dry days.

The three University of Hawaii at Manoa scientists determined that "since the 1980s, there has been a change in the types of precipitation intensity, resulting in more frequent light precipitation and less frequent moderate and heavy precipitation intensity," as well as a "shorter annual number of days with intense precipitation and smaller consecutive 5-day precipitation amounts and smaller fraction of annual precipitation due to events exceeding the 1961–1990 95th percentile in the recent epoch [1980–2007] relative to the first epoch [1950–1979]." They add, "long-term upward trends are observed for consecutive dry days." Thus, Chu et al. show that not only were the excess precipitation predictions of the IPCC not realized throughout the Hawaiian Islands, but in fact just the opposite occurred there.

In a parallel analysis of rainfall patterns in Southern Italy, but over a longer time period, Diodato et al.(2008) studied "Calore River Basin (South Italy) erosive rainfall using data from 425-year-long series of both observations (1922–2004) and proxy-based reconstructions (1580–1921)." The more recent of the two series was based on a scheme that employed the Revised Universal Soil Loss Equation, and documentary descriptions provided the basis for the earlier series.

The authors report the climate history of the Calore River Basin shows pronounced interdecadal variations, with multidecadal erosivity reflecting the mixed population of thermo-convective and cyclonic rainstorms with large anomalies, and they note "the so-called Little Ice Age (16th to mid-19th centuries) was identified as the stormiest period, with mixed rainstorm types and high frequency of floods and erosive rainfall."

In the concluding section of their paper, the three researchers write, "in recent years, climate change (generally assumed as synonymous with global warming) has become a global concern and is widely reported in the media." One of the chief concerns is that extreme weather phenomena, such as droughts and floods, will become both more frequent and more severe as the planet warms. According to Diodato et al., however, the real world data they studied indicate "climate in the Calore River Basin has been largely characterized by naturally occurring weather anomalies in past centuries (long before industrial CO_2 emissions), not only in recent years."

In a geomorphological study, Stankoviansky (2003), working in the Myjava Hill Land of Slovakia (in the western part of the country, near the Czech Republic border), employed topographical maps and aerial photographs, field geomorphic investigation, and the study of historical documents from local municipal and church sources to determine the spatial distribution of gully landforms and trace the history of their development.

Stankoviansky's results indicate "the central part of the area, settled between the second half of the 16th and the beginning of the 19th centuries, was affected by gully formation in two periods, the first between the end of the 16th century and the 1730s and the second roughly between the 1780s and 1840s." He infers the gullies were formed "during periods of extensive forest clearance and expansion of farmland," but "the triggering mechanism of gullying was extreme rainfalls during the Little Ice Age." More specifically, he writes, "the gullies were formed relatively quickly by repeated incision of ephemeral flows concentrated during extreme rainfall events, which were clustered in periods that correspond with known climatic fluctuations during the Little Ice Age." Subsequently, from the mid-nineteenth century to the present, he reports, "there has been a decrease in gully growth because of the afforestation of gullies and especially climatic improvements since the termination of the Little Ice Age."

Stankoviansky's observations suggest extreme and destructive rainfall events were much more common throughout the Myjava Hill Land of Slovakia during the Little Ice Age than in the centuries since. This view, in his words (and in many references he cites), "is often regarded as generally valid for Central Europe."

The Tibetan Plateau, sometimes termed the "roof of the world," also has been called the "world's water tower" because of the strong influence it exerts on northern hemisphere mid-latitude moisture, precipitation, and runoff. In a recent study, Xu et al. (2008) analyzed 50 years (1957–2006) of upper-air Chinese radiosonde observations along with concomitant surface air temperature and precipitation data.

The results indicate that in the summer half of the year, "the Tibetan Plateau acts as a strong 'dynamic pump' [that] continuously attracts moist air from the low-latitude oceans." When reaching the plateau, some of these flows rise along its south side and cause "frequent convections and precipitations," which feed its mid- and low-latitude glaciers, snowpacks, and lakes, from whence originate many of Asia's major rivers. This flow system constitutes "the largest river runoff from any single location in the world." In further analysis of their datasets, the four researchers found "recent warming in the plateau started in the early 1970s, while the water vapor content showed an upward trend in the early 1980s and continues to the present time," a pattern similar to that found in the annual precipitation data.

Xu et al. write their findings "suggest several possible consequences." First, they note, "owing to the combined effect of the rapid melting of glaciers and increased precipitation in the Tibetan Plateau due to global warming, the downstream transport of water from the Tibetan water tower would increase in volume," and "this may cause an increase in severe flooding problems for countries along the major rivers that discharge this water." Alternatively, "the rapid retreat of glaciers over the plateau's mountains may pose a serious socio-economical issue for the water resources that feed 40% of the world's population." A third scenario, which seems more likely in view of Xu et al.'s results, is that, as these authors describe it, "the increased atmospheric [moisture] supply may alleviate the problem of rapid depletion of water resources arising from the melting of glaciers." This more optimistic view is perhaps akin to seeing doomsday on the left and doomsday on the right, but salvation in the middle.

Over a longer period, a climate history for the Tibetan Plateau for the past 1,700 years has been developed by Zhao et al. (2009). These authors studied carbonate percentages and ostracode abundances in sediment cores from Hurleg Lake, in the arid Qaidam Basin of the Northeast Tibetan Plateau. They compared their lacustrine history with a contemporaneous history of tree-ring-derived precipitation over nearby mountainous terrain, as well as with changes in solar activity manifest in solar proxy residual $\Delta^{14}C$ data.

Zhao et al. discovered "carbonate percentage and ostracode abundance show a consistent pattern with ~200-year moisture oscillations during the last 1000 years." In addition, the moisture pattern in the Qaidam Basin being "in opposite relation to tree-ring-based monsoon precipitations in the surrounding mountains" suggested "that topography may be important in controlling regional moisture patterns as mediated by rising and subsiding air masses in this topographically-complex region." Cross-spectral analysis between their moisture proxies and the solar activity proxy "shows high coherence at the ~200-year periodicity which is similar to Chinese monsoon intensity records, implying the possible solar forcing of moisture oscillations in the NE Tibetan Plateau."

These findings provide another example of cyclical solar activity controlling parallel precipitation cycles. In the words of the researchers, "higher solar output corresponds to a stronger monsoon, which intensifies the uplift of air mass on the high Tibetan Plateau and strengthens the subsidence of air mass over the Qaidam Basin," while "the reverse is true during the period of lower solar output." They conclude, "high solar activity is correlated with dry climate in the Qaidam Basin and increased precipitation in monsoonal areas." This does not leave a lot of room for CO_2 to control precipitation in this important part of the world.

Lastly, Kim et al. (2009) analyzed a 200-year history of precipitation measured at Seoul, Korea (1807 to 2006). This study is highly relevant to the common allegation that droughts and floods will become more frequent or severe because of global warming. One important way to test this prediction is to study precipitation over the period of time when the planet transited from what was one of the coldest intervals of the current interglacial period (the Little Ice Age) to the end of the twentieth century.

Kim et al. use "progressive methods for assessing drought severity from diverse points of view," starting with (1) the Effective Drought Index (EDI) developed by Byun and Wilhite (1999), which Kim et al. describe as "an intensive measure that considers daily water accumulation with a weighting function for time passage," (2) a Corrected EDI that "considers the rapid runoff of water resources after heavy rainfall" (CEDI), (3) an Accumulated EDI that "considers the drought severity and duration of individual drought events" (AEDI), and finally (4) a year-accumulated negative EDI "representing annual drought severity" (YAEDI).

The researchers' precipitation history and two of their drought severity histories are presented, in that order, in Figures 4.3.1 and 4.3.2.

It is obvious from these results that the only major deviation from long-term normality is the decadal-scale decrease in precipitation and ensuing drought, with both phenomena achieving their most extreme values (low in the case of precipitation, high in the case of drought) around AD 1900. Hence, it is very clear that the significant post-Little Ice Age warming of the planet had essentially no effect on the long-term histories of either precipitation or drought at Seoul, Korea. Similar results are known from around the world.

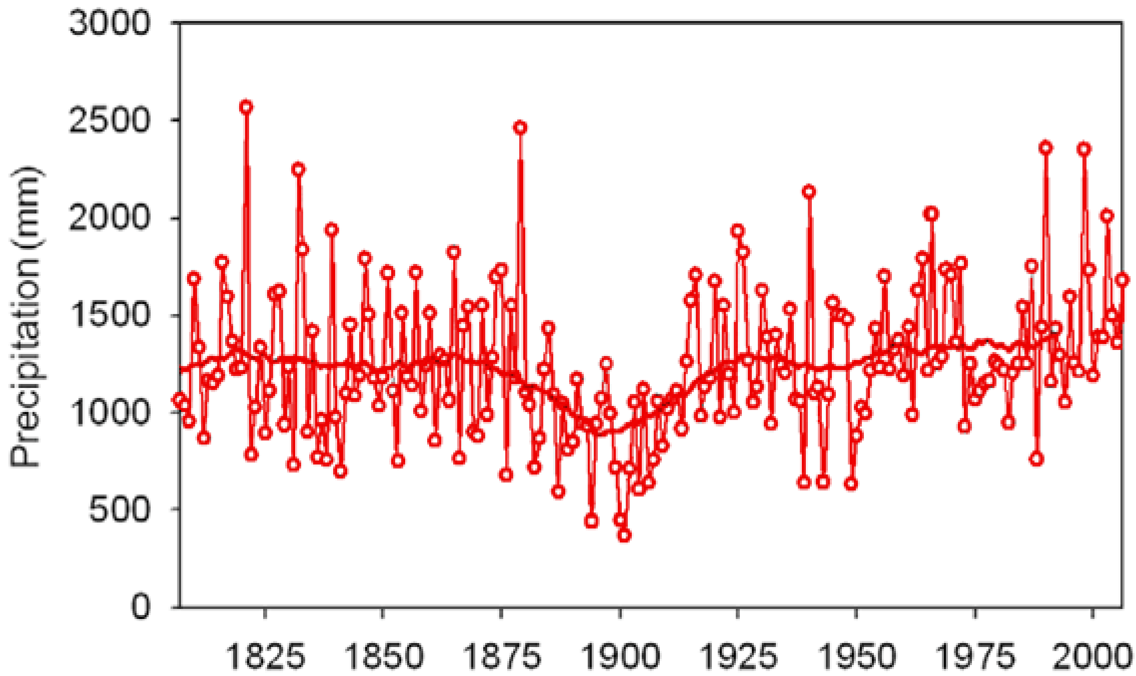

Figure 4.3.1. Annual precipitation history at Seoul, Korea, where the solid line represents a thirty-year moving-average. Adapted from Kim et al. (2009).

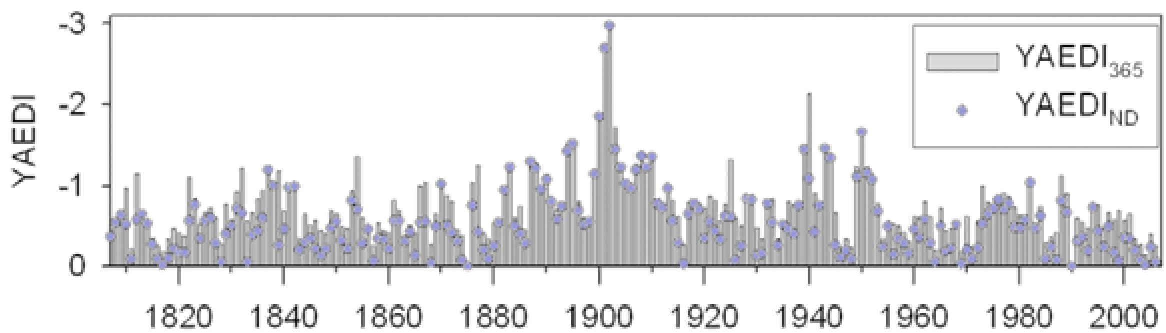

Figure 4.3.2. Annual “dryness” history at Seoul, Korea, represented by YAEDI365 (sum of daily negative EDI values divided by 365, represented by bars) and YAEDIND (sum of daily negative EDI values divided by total days of negative EDI, represented by open circles). Adapted from Kim et al. (2009).

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4.3.2. Snow

In their analysis of the record of snow avalanches from the French Alps, Eckert et al. (2010) comment, "understanding the response of dangerous natural phenomena to variations in corresponding constraining factors can reveal signals of climate change." They add, "since snow avalanches are mainly governed by temperature fluctuations, heavy precipitation and wind regimes, they are likely to be strongly influenced by climatic fluctuations." This reasoning is similar to that used by the IPCC.

Eckert et al. compared several different ways of analyzing snow avalanche data contained in the *Enquete Permanente sur les Avalanches—EPA*, which they say "is a chronicle describing the avalanche events on approximately 5,000 determined paths in the French Alps and the Pyrenees."

The four researchers report finding "no strong modifications in mean avalanche activity or in the number of winters of low or high activity over the last 60 years," and they point out "a similar result was obtained for Switzerland over the second half of the twentieth century by Laternser and Schneebeli (2002) using avalanche indexes and comparison with meteorological data." Eckert et al. also report "Schneebeli et al. (1997) and Bader and Kunz (2000) have seen no change in extreme snowfalls and in the associated number of catastrophic avalanches around Davos, Switzerland during the twentieth century," and "in the Maurienne Valley in France, Jomelli et al. (2007) found no correlation between the fluctuations in avalanche activity between 1978 and 2003 and large-scale atmospheric patterns." And in one final study, which had a slightly different result, they note Jomelli and Pech (2004) "suggest that at low altitudes, avalanche magnitude has declined since 1650 in the Massif des Ecrins in the French Alps."

After considering all they learned from their many analyses and comprehensive review of the work of other scientists, Eckert et al. concluded "climate change has recently had little impact on the avalanching rhythm in this region."

Analyzing a slightly longer record from the Unites States, this time of annual snowfall, and based on the dataset described by Kunkel et al. (2009a), Kunkel et al. (2009b) used 440 long-term, homogeneous snowfall records to examine "temporal variability in the occurrence of the most extreme snowfall years, both those with abundant snowfall amounts and those lacking snowfall" (defined as the highest and lowest tenth percentile winter snow amounts). The analyzed data came from the conterminous United States over the 107-year period from 1900–01 to 2006–07.

Kunkel et al. (2009b) found there were "large decreases in the frequency of low-extreme snowfall years in the west north-central and east north-central United States," but they were "balanced by large increases in the frequency of low-extreme snowfall years in the Northeast, Southeast and Northwest." All in all, therefore, Kunkel et al. determined "the area-weighted conterminous United States results do not show a statistically significant trend in the occurrence of either high or low snowfall years for the 107-year period."

Kilpelainen et al. (2010) report on the degree to which Finnish forests are damaged by snow load on their branches. They write, "within Europe's forests, snow-induced damage"—due to "accumulation of snow load on tree branches"—"has accounted for a mean annual amount of almost one million cubic meters of damaged wood in managed forests over the period 1950–2000." The damage that occurs is primarily to "stem breakage or bending when the soil is frozen," although Kilpelainen et al. also point out "trees can also be uprooted if the soil is not frozen" and damage "by insects or fungal attacks are also common in trees suffering from snow damage."

To calculate risk of snow-induced damage, Kilpelainen et al. employed a snow accumulation model in which cumulative precipitation, air temperature, and wind speed were derived from the A2 scenario of the FINADAPT project (Ruosteenoja et al., 2005), where the air's CO_2 concentration was estimated to rise to 840 ppm by 2100 and mean air temperatures were projected to increase by almost 4°C in summer and more than 6°C in winter. The model was first tested and trained using real-world data obtained by the Finnish Meteorological Institute (Venalainen et al., 2005) for the 30-year baseline period of 1961–1990.

Defining the risk of snow-induced forest damage as proportional to the number of days per year when the accumulated amount of snow exceeds 20 kg m^{-2}, the six scientists calculated the mean annual number of risk days in Finland declined by 11 percent, 23 percent, and 56 percent relative to the 1961–1990 baseline period for the first, second, and third 30-day simulation periods they modeled (1991–2020, 2021–2050, and 2070–2099), respectively. For the most hazardous areas of northwest and northeast Finland they also report "the number of risk days decreased from the baseline period of over 30 days to about 8 days per year at the end of the century," which represents a warming-induced decrease in risk of snow damage to forests on the order of 75 percent.

In another study, from Northern China, Peng et al. (2010) used snow-depth measurements collected at 279 meteorological stations, plus colocated satellite-derived Normalized Difference Vegetation Index (NDVI) data, to investigate spatio-temporal changes in snow depth over the period 1980–2006, and to analyze the effects of those changes on vegetative growth during the following spring and summer.

The five researchers report "over the past three decades, winter snow depth overall increased in northern China, particularly in the most arid and semiarid regions of western China where desert and grassland are mainly distributed." Peng et al. report that in these specific areas, positive correlations existed between mean winter snow depth and spring NDVI data. In addition, they note Piao et al. (2005) determined the net primary productivity of the same desert and grasslands during 1982–1999 "increased by 1.6% per year and 1.1% per year, respectively" and that "desertification has been reversed in some areas of western China since the 1980s," citing Runnstrom (2000), Wu (2001), Zhang et al. (2003), and Piao et al. (2005).

Discussing the implications of their findings, Peng et al. note the "increase in vegetation coverage in arid and semiarid regions of China, possibly driven by winter snow, will likely restore soil and enhance its antiwind-erosion ability, reducing the possibility of released dust and mitigating sand-dust storms." They note, further, that the frequency of sand-dust storms has indeed "declined in China since the early 1980s (Qian et al., 2002; Zhao et al., 2004)."

Thus, as the world has warmed over the past three decades, the concomitant climatic change across China above 40°N latitude has been an increase in winter snow depth that, in turn, promoted increased vegetative growth in desert areas and grasslands and resulted in a reduction in sand-dust storms. These three climate-related changes would be recognized by most rational people as environmentally positive developments.

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4.3.3. Monsoon

Bombardi and Carvalho (2009) evaluated the ability of ten IPCC global coupled climate models (with distinct physics and resolutions) to simulate characteristics of the real-world South American Monsoon System (SAMS). For comparison with model outputs, they used real-world data pertaining to the onset, end, and total rainfall of SAMS, as characterized by precipitation data for the period 1979–2006, which they derived from the Global Precipitation Climatology Project.

Bombardi and Carvalho report that over northern South America the annual precipitation cycle "is poorly represented by most models." More specifically, they found "most models tend to underestimate precipitation during the peak of the rainy season." They attribute the lack of success of their model runs to "the misrepresentation of the Inter-Tropical Convergence Zone and its seasonal cycle," noting also that "poor representation of the total monsoonal precipitation over the Amazon and northeast Brazil is observed in a large majority of the models." Finally, they note, "simulations of the total seasonal precipitation, onset and end of the rainy season diverge among models and are notoriously unrealistic over [the] north and northwest Amazon for most models."

This is another demonstration of the failure of computer-model output to correspond to real-world data, giving little confidence in the models' ability to correctly simulate future climatic trends.

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4.3.4. Evaporation

Climate scientists have a particular interest in the process of evaporation, because evaporation is the primary source of atmospheric water vapor, a powerful greenhouse gas.

Recognizing the importance of near-surface wind speed for evaporation, McVicar et al. (2010) note "the occurrence of widespread declining trends of wind speed measured by terrestrial anemometers at many mid-latitude sites over the last 30-50 years," citing papers by Roderick et al. (2007), McVicar et al. (2008), Pryor et al. (2009), and Jiang et al. (2010) in support.

McVicar et al. assert that this "stilling," as it has come to be called, is "a key factor in reducing atmospheric evaporative demand," which drives actual evapotranspiration when water availability is not limited, as in the case of lakes and rivers. In addition, they note (1) near-surface wind speed (u) nearly always increases as land-surface elevation (z) increases (as demonstrated by McVicar et al., 2007), (2) increasing wind speeds lead to increases in atmospheric evaporative demand, and (3) decreasing wind speeds do the opposite.

All of these changes are significant to people dependent on water resources derived from mountainous headwater catchments. It would therefore be advantageous to learn how this latter phenomenon (the change in near-surface wind speed with ground elevation) might have varied over the last few decades of global warming, because, as the authors point out, "over half the global population live in catchments with rivers originating in mountainous regions (Beniston, 2005), with this water supporting about 25% of the global gross domestic product (Barnett et al., 2005)."

Defining u_z as change in wind speed with change in elevation—$u_z = \Delta u/\Delta z$, where $\Delta u = u_2 - u_1$, $\Delta z = z_2 - z_1$, and $z_2 > z_1$—McVicar et al. calculated monthly averages of u_z, using monthly average u data from low-set (10-meter) anemometers maintained by the Chinese Bureau of Meteorology at 82 sites in central China and by MeteoSwiss at 37 sites in Switzerland from January 1960 through December 2006. Their research constitutes, in their words, "the first time that long-term trends in u_z in mountainous regions have been calculated." The seven scientists determined, "for both regions u_z trend results showed that u has declined more rapidly at higher than lower elevations."

This double-benefit—a general decline in wind speed at many mid-latitude sites and a further decline in wind speed at higher elevations—should act to reduce water loss via evaporation from high-altitude catchments in many of the world's mountainous regions, thus providing more water for people who obtain it from such sources. Finally, McVicar et al. note the "reductions in wind speed will serve to reduce rates of actual evapo-transpiration partially compensating for increases in actual evapo-transpiration due to increasing air temperatures."

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4.4. Rivers and Streamflow

The IPCC claims that global warming will lead to the occurrence of both more floods and more droughts. As a check on this hypothesis, Zhang et al. (2010) analyzed twentieth century streamflow changes within the Susquehanna River Basin. This basin includes parts of the states of Maryland, New York, and Pennsylvania and is the largest freshwater contributor to Chesapeake Bay in the eastern United States, comprising 43 percent of the bay's drainage area and providing 50 percent of its water.

Zhang et al. studied long-term, continuous, daily streamflow records for eight unregulated streams. The records start at slightly different times, but all end in 2006 with record-lengths ranging from 68 to 93 years and an average length of 82.5 years. These data were subjected to repeated monotonic trend tests, each using different beginning and ending times, to search for trends and to detect changes in annual minimum, median, and maximum daily streamflow.

The four researchers, who are members of the Susquehanna River Basin Commission, report there was "a considerable increase in annual minimum flow for most of the examined watersheds and a noticeable increase in annual median flow for about half of the examined watersheds." However, they found annual maximum streamflow "does not show significant long-term change."

Predicting that global warming will lead to more frequent and/or more intense flooding *and* drought, as the IPCC does, would seem almost to ensure predictive success nearly all the time and nearly everywhere. The Susquehanna River Basin study, however, yields no support for this contention. This is because the increases in minimum streamflow should be accompanied by less severe and/or less frequent drought, whereas the lack of change in annual maximum streamflow shows there has been no significant long-term change at the opposite end of the spectrum, where floods might be expected.

Mauas et al. (2008) conducted a similar study of the Parana River in South America. They write that streamflows "are excellent climatic indicators," especially in the case of rivers "with continental scale basins" that "smooth out local variations" and can thus "be particularly useful to study global forcing mechanisms." The Parana River is the world's fifth-largest in terms of drainage area and fourth-largest with respect to streamflow. Mauas et al. analyzed streamflow data that have been collected continuously on a daily basis since 1904.

The three researchers looked for any trends or periodicities that might be present. They found "the flow of the Parana is larger in the last three decades, with a mean value almost 20% larger than that of the first 70 years of the twentieth century." Even more importantly, they state, "the stream flow during the last 30 years has increased in the months in which the flow is minimum, while the flow remains more or less constant during the months of maximum," noting "the same trend is also found in other rivers of the region."

With respect to periodicities, they report that detrended time series of streamflow data are correlated with detrended times series of both sunspot number and total solar irradiance, with Pearson's correlation coefficients between streamflow and the two solar parameters of 0.78 and 0.69, respectively, at "a significance level higher than 99.99% in both cases."

In a study of United Kingdom rivers, Hannaford and Marsh (2008) write, "recent flood events have led to speculation that climate change is influencing the high-flow regimes of UK catchments, and projections suggest that flooding may increase in [the] future as a result of human-induced warming." Utilizing the UK "benchmark network" of 87 "near-natural catchments" (as identified by Bradford and Marsh, 2003), Hannaford and Marsh conducted "a UK-wide appraisal of trends in high-flow regimes unaffected by human disturbances" to test such speculation.

The two researchers report "significant positive trends were observed in all high-flow indicators ... over the 30–40 years prior to 2003, primarily in the maritime-influenced, upland catchments in the north and west of the UK." However, they write, "there is little compelling evidence for high-flow trends in lowland areas in the south and east." They also note, "in western areas, high-flow indicators are correlated with the North Atlantic Oscillation Index (NAOI)," so "recent trends may therefore reflect an influence of multi-decadal variability related to the NAOI." In addition, they state longer river flow records from five additional catchments they studied "provide little compelling evidence for long-term (>50 year) trends, but do show evidence of pronounced multi-decadal fluctuations." Lastly, they add, "in comparison with other indicators, there were fewer trends in flood magnitude" and "trends in peaks-over-threshold frequency and extended-duration maxima at a gauging station were not necessarily associated with increasing annual maximum instantaneous flow."

Hannaford and Marsh conclude, "considerable caution should be exercised in extrapolating from any future increases in runoff or high-flow frequency to an increasing vulnerability to extreme flood events." This word to the wise is something climate policymakers, especially those residing within the U.K., would do well to consider carefully.

Lloyd (2010) provides another study of historical trends in riverine flow trends, this time from the Breede River, which "is the largest in South Africa's Western Province, and plays a significant part in the province's economy." Modeling studies of the Breede River have predicted that flows into it could be seriously affected by climate change. For example, Steynor et al. (2009) used "a form of neural network" that was "trained on historical climate data" that were "linked to historical flow data at five stations in the Breede River valley," in order to "downscale from a global climate model to the typical area of a catchment" and thereby determine the consequences of predicted future global warming for Breede River flows. The Steynor et al. modeling results indicated Breede River flows will decrease if temperatures rise over the next 60 years in the fashion predicted by climate models.

As a check upon this approach to divining the region's hydrologic future, the Steynor et al. authors—who include a researcher based at the Energy Institute of the Cape Peninsula University of Technology in Cape Town—used flow data for five sites in the Breede Valley to compute historical flow-rate trends over prior periods of warming that ranged from 29 to 43 years in length.

All of the future flow rates calculated by Steynor et al. exhibited double-digit negative percentage changes, averaging -25 percent for one global climate model and -50 percent for another. The mean past trend of four of Lloyd's five stations also was negative (-13 percent); one station had a positive trend (+14.6 percent). But in a vital piece of additional research, by "examination of river flows over the past 43 years in the Breede basin" Lloyd was able to demonstrate that "changes in land use, creation of impoundments, and increasing abstraction have primarily been responsible for changes in the observed flows" of all the negative-trend stations.

Interestingly, Steynor et al. presumed warming would lead to decreased flow rates, as their projections suggested, and they thus assumed their projections were correct. However, Lloyd was able to demonstrate that those results were driven primarily by unaccounted-for land use changes in the five catchments, and that in his newer study the one site that had "a pristine watershed" was the one that had the "14% increase in flow over the study period," which was "contrary to the climate change predictions" and indicative of the fact that "climate change models cannot yet account for local climate change effects."

Lloyd concluded, "predictions of possible adverse local impacts from global climate change should therefore be treated with the greatest caution" and "above all, they must not form the basis for any policy decisions until such time as they can reproduce known climatic effects satisfactorily."

It is apparent from the conclusions of Lloyd's work that a vital aspect of analyzing river flow time series for climatic signals is to normalize the studies for vegetation and groundwater recharge change while remembering that such changes may be of either human or natural origin.

In a study designed to explore that point, Texas A&M researchers Wilcox and Huang (2010) analyzed the long-term (85-year) trends of both baseflow (groundwater-derived) and stormflow (precipitation-derived) streamflow components of four major rivers in the Edwards Plateau region of Texas (USA)—the Nueces, Frio, Guadalupe, and Llano Rivers. Over the period of study, this region experienced a significant increase in the presence of woody plants, indicating that "contrary to widespread perceptions," streamflows in the study region "have not been declining."

In a review of all large free-air carbon-enrichment (FACE) studies conducted over the prior 15 years, Ainsworth and Long (2005) had previously reported the greatest CO_2-induced benefits were accrued by trees, which experienced a mean biomass increase of 42 percent in response to a 300 ppm increase in the atmosphere's CO_2 concentration. In comparison, they found that C_4 sorghum posted a yield increase of only 7 percent and the C_3 crops rice and wheat exhibited yield increases of 16 percent and 22 percent, respectively. Thus, it is natural to presume that as the air's CO_2 content continues to climb higher, Earth's woody plants will gradually encroach upon areas where herbaceous plants previously ruled the landscape. That is typically observed to be the case.

However, as noted by Wilcox and Huang, trees typically use deeper water than grasses, and consequently, they write, the "prevailing belief is that woody plant encroachment leads to declining groundwater recharge and, therefore, to lower groundwater contributions to streams," which typically would be viewed as an undesirable outcome. Noting their findings "run counter to current thinking in both lay and scientific circles," the Texas researchers speculate that "baseflows are higher now than in pre-settlement times, because rooting by trees has facilitated groundwater recharge." In addition, the transpiration-reducing effect of atmospheric CO_2 enrichment may also have played a role in this regard, as has been suggested by several prior studies of river basin hydrology (Idso and Brazel, 1984; Gedney et al., 2006; Betts et al., 2007).

In any event, and whatever the answer or answers may be, it would appear good things have been happening to degraded grasslands throughout the world, as the atmosphere's CO_2 concentration has been gradually rising and woody plants have been extending their ranges and growing where they previously had been unable to survive, thereby helping to make more water available for many other uses by man and nature alike.

Finally, in a riverine geomorphological and archaeological study, Panin and Nefedov (2010) write, a "long-term decrease in seasonal peaks of water levels allows the [human] settling of relatively low geomorphic locations, such as river and lake floodplains, while a rise in flood levels causes settlements to be shifted to higher elevations." They base this assumption on the logic that "ancient settlements could not persist under the impact of regular inundations."

The authors studied regions of the Upper Volga and Zapadnaya Dvina Rivers (Russia) in order to document "the geomorphological and altitudinal positions of [human] occupational layers corresponding to 1224 colonization epochs at 870 archaeological sites in river valleys and lake depressions in southwestern Tver province." In the process they identified "a series of alternating low-water (low levels of seasonal peaks, many-year periods without inundation of flood plains) and high-water (high spring floods, regular inundation of floodplains) intervals of various hierarchial rank" associated with periods of warming and cooling.

The two Russian researchers report "low-water epochs coincide with epochs of relative warming, while high-water epochs [coincide] with cooling epochs," because "during the climate warming epochs, a decrease in duration and severity of winters should have resulted in a drop in snow cover water equivalent by the snowmelt period, a decrease in water discharge and flood stage, and a decrease in seasonal peaks in lake levels." They note, too, that "a model of past warming epochs can be the warming in the late 20th century, still continuing now." They also report, "in the Middle Ages (1.8–0.3 Ky ago), the conditions were favorable for long-time inhabiting [of] river and lake floodplains, which are subject to inundation nowadays." In addition, their results overall indicate that over the total time period studied, the interval AD 1000–1300 hosted the greatest number of floodplain occupations.

One of Panin and Nefedov's main conclusions is that the interval AD 1000–1300 and other "epochs of floodplain occupation by humans in the past can be regarded as hydrological analogues of the situation of the late 20th-early current century," which, they add, "is forming under the effect of directed climate change." This relationship implies that the current level of warmth in the portion of Russia that hosts the Upper Volga and Zapadnaya Dvina Rivers is not yet as great as it was during the AD 1000–1300 portion of the Medieval Warm Period.

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