Paleoclimate (Princeton Primers In Climate)

Synopsis

Earth's climate has undergone dramatic changes over the geologic timescale. At one extreme, Earth has been glaciated from the poles to the equator for periods that may have lasted millions of years. At another, temperatures were once so warm that the Canadian Arctic was heavily forested and large dinosaurs lived on Antarctica. Paleoclimatology is the study of such changes and their causes. Studying Earth's long-term climate history gives scientists vital clues about anthropogenic global warming and how climate is affected by human endeavor. In this book, Michael Bender, an internationally recognized authority on paleoclimate, provides a concise, comprehensive, and sophisticated introduction to the subject. After briefly describing the major periods in Earth history to provide geologic context, he discusses controls on climate and how the record of past climate is determined. The heart of the book then proceeds chronologically, introducing the history of climate changes over millions of years--its patterns and major transitions, and why average global temperature has varied so much. The book ends with a discussion of the Holocene (the past 10,000 years) and by putting manmade climate change in the context of paleoclimate. The most up-to-date overview on the subject, Paleoclimate provides an ideal introduction to undergraduates, nonspecialist scientists, and general readers with a scientific background.

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Customer Reviews

"The work is well-written, with just enough mathematics to add to the reader's understanding, without causing confusion."--Choice"The author has succeeded admirably in producing a clear, concise, yet detailed summary of a very important topic. The text is supplemented by an excellent selection of diagrams and data displays . . . and more than 300 references to the primary research literature. I found it easy to read yet thought provoking, consistently interesting and, perhaps best of all, not at all intimidating in bulk or style. Highly recommended!"--William R. Green, Leading Edge"Paleoclimate gives the reader a concise, clear view of how Earth's climate has changed over geologic time and the major drivers for this change. I heartily recommend the book for those interested in understanding Earth's rich climate complexity."--Jeffrey T Kiehl, Reports of the National Center for Science Education

"Michael Bender, a giant in the field, fits the excitement, rigor, and deep insights of paleoclimatology into a succinct text suitable for a semester-long course introducing this indispensable branch of environmental science."--Richard B. Alley, Pennsylvania State University"The history of Earth's climate is an essential context for understanding anthropogenic climate change in the future. Michael Bender pulls together this vast area of science and distills it to the essentials, delivering a comprehensive view of the evolution of Earth's climate at a level useful to scientists and the general reader."--Daniel Schrag, Harvard University"Paleoclimatology has been missing a concise, modern, overview textbook, and I think this book will fill that niche. There is much ground to cover and the text does a good job of bringing the reader up to speed on most of the important patterns and processes in Earth's climatic history. The book combines excellent coverage of basic physical and chemical aspects of the climate system with a long-term historical overview of the climate system in action."--Matthew Huber, Purdue University"This concise but comprehensive history of Earth's climate hits all the right points and will serve equally well as an introductory textbook or as an entry into the field of paleoclimate."--David W. Lea, University of California, Santa Barbara

The theory behind global warming is supported by evidence is in the climate history of the earth. This book offers a clear, non-polemic explanation.The hallmark of good science is a lack of dogmatism. Climate is a hugely complex subject. Some theories are agenda driven, but most are simply differences of opinion among capable scientists. The book appears to give an evenhanded treatment to the different theories.For the 99% who will want to get to the bottom line quickly, skip to the end of this review. I have included extensive quotes from the chapter on Anthropogenic Global Warming.Truly a five-star effort.Chapter 1: The Earth's Climate SystemOver the long-term, the amount of energy that the earth receives from outside must balance the amount reradiated back out into space. Any imbalance results in the accumulation or dissipation of heat, changing the temperature on earth.The sun, practically speaking, is the source of all heat on earth. Solar radiation has grown over geological time. In the Earth’s infancy it was only 70% as powerful.Earth receives solar energy at 1368 W per square meter. A sphere’s surface is four times its cross-sectional area, so average insolation is 1/4, 342 W per square meter.A fraction of the 342 W, is reflected back out into space, a process called albedo. Major causes are cloud cover, snow and ice cover, and deserts. Vegetation makes the Earth’s surface darker so it absorbs more solar energy.Light arrives to the earth in wavelengths commensurate with the temperature of the sun, 6000Ãƒâ Ã Â C. Most passes unhindered through the Earth’s atmosphere. However, the wavelength of energy reradiated by the earth is much longer, appropriate to about 15Ãƒâ Ã Â C, 278Ãƒâ Ã Â Kelvin. This radiation excites gases in the atmosphere, capturing reradiated heat. "Greenhouse gases" include carbon dioxide, water vapor, methane, fluorochlorocarbons and others. Carbon dioxide is the most significant.Increases in greenhouse gases force temperatures up. Conversely, an increase in the albedo forces them down. The argument about global warming concerns the balance between these forcings, and hence the prognosis for future temperatures.The Earth’s temperature will always move towards equilibrium. If the earth heats up, it will reradiate more heat back out into space as the amount of incoming energy remains constant.Energy absorbed by CO2 increases as a logarithmic function. Doubling of carbon dioxide raises temperature by 2.5Ãƒâ Ã Â C. Other greenhouse gases follow different formulas.Circulation of air and water have indirect but significant impacts on temperature. They affect vegetation and snow and ice cover. These affect albedo, which affects warming.The Coriolis effect is the primary driver for wind and ocean currents. The earth rotates once every 24 hours, about 1000 mph along the equator. Inertia makes air and the water want to spin a bit less quickly, though friction with the earth tends drags them along at close to the Earth’s speed.Evaporation is a major factor in circulation. Water evaporates around the equator, rising in the atmosphere. Rising air forces winds poleward. At 30Ãƒâ Ã Â North and South latitude it falls again. The same pattern is repeated at 60Ãƒâ Ã Â and northwards. The middle latitudes, 30 to 60Ãƒâ Ã Â , experience an opposite effect.The result is prevailing easterly winds along the equator, westerlies in the temperate latitudes, and easterlies towards the poles. It also affects precipitation. As the warm air rises over the equator it cools and drops rain. Hence the rain forests over the equator. Conversely, the dryer air falling around 30Ãƒâ Ã Â latitude causes deserts. Note the location of the Sahara, the Sonora, the Alticama, and other major deserts.Natural barriers ÃƒÂ¢Ã â ¬Ã â œ mountains for winds, continents for ocean currents ÃƒÂ¢Ã â ¬Ã â œ constrain these flows. Therefore geological events such as the closing of the Isthmus of Panama can have a major effect on climate.These major forces have a significant impact on local weather.

Monthly temperatures in San Francisco vary over a range of 6Ãƒâ Ã Â ; Baltimore, at the same latitude, 24Ãƒâ Ã Â . Air is brought to San Francisco by prevailing westerlies is coming off the ocean, whereas air in Baltimore has traveled over an entire continent.The density of ocean water depends on salinity and temperature. Heavy water sinks, most notably in the North Atlantic. Therefore, contends the book, the deep oceans all over the world tend to contain water that sank in the North Atlantic. The geology of the Pacific Ocean doesn't force the same effect.A major theme of the book concerns the chemistry of carbon and carbon dioxide. Mobile carbon dioxide continually taken out of the system by chemical processes, but continually restored by other processes such as respiration and of course burning fossil fuels. It is worth looking at where the carbon on earth is located to understand what a small fraction is really involved in this question of global warming. If CO2 in the atmosphere is 1, the relative abundance of CO2 elsewhere is:As CO2 in atmosphere...............1Carbon in biomass incl. soil......2.5Fossil fuels left.........................6.25Carbon in oceans....................50In earth's crust...................6,250Total carbon................5,449,450As you can see, there is almost a thousand times more carbon locked in the interior of the earth than is present in the crust and atmosphere where it can be chemically active. Carbon dioxide continues to be released from the Earth's interior by volcanic activity.The chapter closes with the mention of weathering. Carbon dioxide combines with water in the air to form carbonic acid H2CO3. It enters into chemical reactions with rocks on the earth. The carbon is locked into molecules such as calcium carbonate and swept into the oceans where it gets buried in deep sediments. It is not necessarily totally out of circulation ÃƒÂ¢Ã â ¬Ã â œ extremely long term geological processes circulate that carbon back up to the surface over millions of years ÃƒÂ¢Ã â ¬Ã â œ but it is out of the way. Weathering, like most chemical processes, speeds up with increased heat. This is a beneficial feedback loop. The warmer the earth, the more carbon dioxide gets removed from the air.Chapter 2 ÃƒÂ¢Ã â ¬Ã â œ The Faint Young SunThe central question for global warming is "how do you know?" How do we know that human activity is going to lead to higher temperatures?The questions about what the Earth's climate history has been are just as fascinating, and delightfully apolitical. The techniques by which scientists are able to estimate past climates, atmospheres and temperatures are truly ingenious.One major technique involves isotopes. Carbon has an atomic weight of 12: six protons and six neutrons. Electrons weigh nothing. However, there is a stable isotope, carbon 13, with seven neutrons and an unstable one, carbon-14, with eight.We know about carbon-14 dating. Carbon-14 decays, with a half-life of 5700 years. Carbon-14 remaining in a specimen gives an approximation of its age. Strontium 90 decays to rubidium in a like manner with a half-life of 30 years; the Rb/Sr ratio gives an approximate age. But these are only good back through the last ice age. The primary technique involves stable isootopes.Stable isotopes of carbon and oxygen are available in the atmosphere in known ratios. Molecules incorporating these different isotopes have different weights. Since lighter molecules are a bit more chemically active than heavier ones, the fraction of heavier isotopes tends to be less in some chemical compounds than in the surrounding environment.How much less is a function of the chemical environment. When carbon is readily available, the preference for lighter carbon 12 will be more strongly expressed. If carbon is not so abundant, the chemical reactions take what they can. The ratio of carbon 12 to carbon 13 will be closer to that of the pool from which the carbon is taken. Scientists are clever at using the ratios of isotopes to deduce the chemical makeup and the ambient temperatures of ancient atmospheres. Read the book for details.Scientists use these techniques to answer a baffling question. If the sun was only 70% is bright early in the Earth’s history, the planet should have been permanently frozen. Yet it was not. There is evidence of glacial activity and liquid water. They use a variety of devices to infer that there were other major gases in the Earth’s atmosphere, among them methane (CH4) and carbonyl sulfate (OCS, or COS) which served as greenhouse gases.Chapter 3: Precambrian glaciationsThis chapter discusses the "Snowball Earth" theory. The geological record of glaciations, metabolic activities by single celled plants, and chemical reactions involving carbon, silicon and other elements indicate four or so glaciations, some of which may have covered the entire earth, in the Precambrian era, prior to 540 million years ago, when oceanic multicellular life was just getting started.This about feedback mechanisms. If the earth was totally frozen over, albedo would be so high that it would tend to stay frozen. However, carbon dioxide would continue to enter the atmosphere from volcanic activity. At such low temperatures there would be little chemical activity to remove it. This chapter discusses the theories as to the various glaciations and their reversals.Chapter 4: Regulation Of The Earth System And Global TemperatureTerrestrial plants appeared 400 million years ago. Obviously, there would be no animals without plants to eat.CO2 levels were higher over much of this period; 1500 to 3000 ppm. Some put the figure as high as 7000 ppm. The most authoritative figure, Robert Berner, incorporated a vast database of geological observations and chemical formulas into a model called GEOCARB, which would support a lower figure.Ceteris paribus, temperature goes up 2.5Ãƒâ Ã Â for every doubling in carbon dioxide. By this formula the temperature should have been 7 to 10Ãƒâ Ã Â C warmer in the ages of the amphibians and dinosaurs. It was not. Why not?There is an extensive discussion of the GEOCARB model. It shows CO2 levels varying significantly, from about 20 times today’s level 550 million years ago clear down to just about today’s level 300 million years ago, then back up to five times as much before returning to the current low level. Fossil evidence includes the stomata of leaves. When carbon dioxide is scarce leaves have many shallow stomata; when it is abundant they have fewer and deeper ones. This correlates with the other evidence. Previous chapters dealt extensively with the action in shallow seas, in which a great deal of photosynthesis takes place in CO2 exchange with the atmosphere. Patterns of waves and sediments and in seabeds tell that story.The GEOCARB model includes tectonic plate movements. More plate movement means more outgassing (volcanic emission) of CO2 from inside the earth. The evidence of outgassing is in the form of warmer seas. Therefore, sea level and ocean temperature are proxies for tectonic movements. The formation of sedimentary rocks supports this analysis: black slate when it's cold, gray slate when it's warm.The isotope ratios discussed above are useful in analyzing the remains of plants. Plants discriminate against the heavier carbon 13 by about 27%.Bender compares the output of the model with other analysis. They don't agree entirely, but enough to give a general picture. Interestingly, he cites a sharp CO2 minimum about 65 million years ago in the fossil record but not in the model. This is the time of the great extinction. Is it possible that without animals to eat the vegetation, it depleted most of the CO2 in the atmosphere?Lastly, CO2 in the atmosphere decreased over the past 55 million years. There is a fair amount of discrepancy in the analysis of how much and when. Some analysts put the peak level at about 2000 ppm compared to the base rate of 280 just prior to the industrial age.Chapter 5: The Late Paleozoic Ice AgesPaleozoic means early life. It embraces the Cambrian, Ordovician, Silurian, Devonian, Mississippian Pennsylvanian in Permian ages, stretching from 542 to 251million years ago. The earth was glaciated from about 370 to 260 million years ago. The evidence is that CO2 concentrations were low.The evidence for glaciation is direct: glacially polished and striated pavement. Striated stones. Glacial debris embedded in sedimentary rock called drop stones. Some deposits show seasonal variations, with fine deposits throughout the year book and coarse stones being dropped in the spring thaws.This was a time in geological history when all of the large continents were united in Gondwanaland, centered around the South Pole for the most part. This Continental configuration lent itself to the accumulation of ice and a general cold climate.Bender concludes that there is still a lot to be known. There are conflicting theories as to how warm the tropics were and how far into the temperate latitudes the warmth might have extended.Chapter 6 Equable Climates of the Mesozoic and PaleogeneThe earth was substantially unglaciated from the upper Permian through the Triassic, Jurassic and Cretaceous periods leading to the great extinction 65 million years ago. This warmth continued through the Paleocene and Eocene periods of the Cenozoic era, up to about 34 million years ago.Not only was it warmer, but the distribution of warmth was different. It was warmer at high latitudes. There is also discussion of the warmth of the deep oceans, inferred from the isotope ratios of plankton skeletons. They conclude that the deep oceans were about 10Ãƒâ Ã Â C warmer.Chapter 7. The Paleocene Eocene Thermal MaximumThe duration was about 200,000 years, at the beginning of the Eocene era 55 million years ago. Massive amount of CO2 ÃƒÂ¢Ã â ¬Ã â œ comparable to all fossil fuels now in the Earth’s endowment ÃƒÂ¢Ã â ¬Ã â œ entered the atmosphere and the oceans. Global temperatures rose about 6Ãƒâ Ã Â C and the oceans became acidified, attacking many organisms with calcium shells.The observation is supported by isotope readings. Oxygen indicates a 5Ãƒâ Ã Â rise in temperature; carbon indicates a vast increase in the abundance of CO2. Also the source ÃƒÂ¢Ã â ¬Ã â œ biological, because organisms discriminate against carbon 13.The event was sudden: the change in isotope distributions is abrupt (10,000 yrs), with no intermediate stages.The temperature rise was about 5Ãƒâ Ã Â C in the tropics, 8Ãƒâ Ã Â C at high latitudes, with considerable uncertainty. It came on suddenly, and then died back at a rate consistent with the rate at which outgassed CO2 from volcanic activity dissipates via weathering, discussed above.There are several theories as to where the carbon came from. It could have been fires, uplift of shallow oceans exposing organic material, the dying of forests, or have been related to volcanic action and outgassing. Two lesser events following at about 2 million year intervals are equally unexplained.Chapter 8. Long Cooling of the CenozoicThe last 50 million years of Earth’s history have shown a gradual cooling, including some dramatic ice ages.There may have been ice in the paleogene, but certainly not as extensive as today. There may have been some transient ice sheets on Antarctica proceeding the permanent glaciation that began 34 million years ago.Vegetation changed. Temperate forests were replaced by grassland and steppe. Ugulate animals were replaced by ruminants. Smaller species of animals became more prevalent. Not all of the evidence goes the same direction, but this is the predominant trend. The deep oceans show the same pattern. The depth at which the calcium shells of plankton ceased to be dissolved in seawater continues to grow deeper, indicating that the water got colder.Some changes attributable to changes in the Earth’s orbit (100 and 400 thousand year cycles), the tilt of the earth (41,000 year cycle) and precession (21,000 years). The interesting fact is that the biological record is sensitive enough to accurately record these changes. There was a minor cooling 23 1/2 million years ago in the major cooling of 14 million years ago. The latter marked a point of no return, leading to the intense glaciations over the period of man’s evolution.The most obvious reason for cooling in the Oligocene and Miocene periods was falling carbon dioxide. CO2 was significantly more abundant in the Eocene than the more recent times. There was a large decrease about the time of the Oligocene boundary, and CO2 probably didn’t vary much during the Miocene... up to 5 million years ago.Vegetation on earth changed near the end of the Cretaceous (65 million years ago). Back then high latitude areas that are now covered by tundra and ice sheets were forested. Second, the planet was wetter, with more forest and less desert. Lastly, the chemistry of photosynthesis changed. All Cretaceous vegetation fixed carbon via what’s called the C3 pathway, but now 25% use the C4 pathway. This resulted in profound changes in animals.Grasses evolved in the Cretaceous and Paleocene ÃƒÂ¢Ã â ¬Ã â œ bracketing the extinction of the dinosaurs. Grasses replaced forests. Grasses are seasonally arid and prone to fires, destroying trees, favoring grasses. Animals evolved to eat grass. Grasses got tougher; teeth got stronger. Plants that metabolize carbon dioxide via the C4 path are more efficient with lower concentrations of CO2. Going back to isotopes again, C3 and C4 plants take up different ratios of isotopes. These isotopes are preserved in the teeth of the animals that eat them, providing a proxy for the replacement of forest by grass. This was recent ÃƒÂ¢Ã â ¬Ã â œ about 9 million years ago.The Asian monsoons appeared about this time. The air gets hotter over land, rising and squeezing out precipitation, and drawing more precipitation and off the oceans. The Himalaya Mountains rose, with rain on the south and east and a rain shadow to the west.By 5.3 million years ago, the beginning of the Paleocene era, the earth had been transformed from a wet planet with equitable climates to a cooler, dryer planet with a massive permanent ice sheet on the antarctic continent. Grazing animals replace browsing animals. In aggregate, these changes set the stage for increasingly intense cyclical glaciations in the northern hemisphere.Chapter 9: The Origin of Northern Hemisphere Glaciation and the Pleistocene Ice Ages.Two factors driving the ice ages of the last 2.6 million years were increased albedo from the ice sheets themselves, and lower greenhouse gas concentrations. There were feedback loops: lower CO2 led to ice sheet growth and greater albedo, which led to changes in ocean circulation that further lowered atmospheric CO2.We are currently living in the warm phase of a 100,000 year glacial cycle. Bender now tightens the timeframe of his reportage. Whereas it has been in millions of years, he focuses on the height of the last Ice Age 20,000 years ago, when our ancestors inhabited most of Eurasia.Nine ice sheets covered the earth: East and West Antarctica, and seven around the North Pole stretching down into the United States and France. The snow line descended on the mountains in temperate and tropical climes. Bender gives a very rough average figure of about 6Ãƒâ Ã Â C per thousand meters descent in elevation.Summertime temperatures went down 5 to 10Ãƒâ Ã Â C; wintertime 12 to 20Ãƒâ Ã Â ÃƒÂ¢Ã â ¬Ã â œ with considerable uncertainty. Tropical temperatures may have dropped 3 to 5Ãƒâ Ã Â C.CO2 can be measured directly for such recent geological periods through gases trapped in ice cores. Bender cites a rise of 80 ppm, from 185 to 265 x 10,000 years ago. It continued to rise to 280 preindustrial. Methane doubled, from

352 to 700 ppb.Six factors contribute to the glacial Ãƒâ¢Ã â ¬Ã â œ interglacial difference in atmospheric CO2:Ãƒâ¢Ã â ¬Ã â¢ ocean temperatureÃƒâ¢Ã â ¬Ã â¢ ocean salinityÃƒâ¢Ã â ¬Ã â¢ mass of carbon and the land biosphere and soil carbonÃƒâ¢Ã â ¬Ã â¢ strength of the biological "pump" that fixes organic matter and they ocean surface, sinks it and oxidizes it, lowering CO2Ãƒâ¢Ã â ¬Ã â¢ residence time of water in the deep oceanÃƒâ¢Ã â ¬Ã â¢ changes in deep sea calcium carbonate saturationWorking together, these factors decrease CO2 and thereby lower the temperature.There is a strong connection between the change in insolation due to Milankovitch orbital forcing and deglaciation. As changes in the Earth's orbit and tilt bring the northern hemisphere closer to the sun in summer, the glaciers melt. Smaller glaciers mean greater albedo, creating a positive feedback loop that continues until it reaches a cyclical maximum."Eventually, orbital changes will induce cooling and the opposite feedback loops will push the planet back toward a glacial mode. Whether the earth is heading toward warmer or cooler extremes, the feedbacks run out of steam and limit the extremes to something like today's world that the warm and, or at the other end, the world of the last glacial maximum."The mechanics of the 100,000 year cycle are quite complex. They involve CO2 exchange in the southern oceans; the salinity of the North Atlantic and hence the formation of new deep ocean waters; geothermal heating under glaciers, in which the glacier itself ironically acts as a blanket, protecting the rock from cold air masses.The take-home point from this chapter are that the earth is close to the temperature maximum in the 100,000 year cycle.Chapter 10. Rapid Climate Change During the Last Glacial PeriodThe chapter includes a diagram of five different indicators of historical climate, ice core studies and isotope analyses. All of them show rapid warming starting about 20,000 years ago after a period of gradual cooling starting 60,000 years ago.There were more than 12 times within the Ice Age when Greenland temperature, represented by ice cores, warmed very rapidly Ãƒâ¢Ã â ¬Ã â œ on the order of decades Ãƒâ¢Ã â ¬Ã â œ followed by slow cooling back to the baseline glacial temperatures. Swings of 20Ãƒâ Ã Â C occurred. Antarctica show similar cycles, not necessarily synchronized with Greenland. Continental areas were affected as indicated by the abundance of methane. Wetlands and rain were more extensive when Greenland was warm. Counterintuitively, when Greenland was at its coldest, sea ice and sea levels rose.The best studied warming occurred 11,600 years ago, ending the Younger Dryas cold episode. The warming reached its full magnitude in two decades or less.The evidence, once again, consists of isotope studies and sediment dropped from glaciers. A major source of glaciers was the Hudson Bay flowing east through the Hudson Strait ; they dropped sediments they had scoured into the Atlantic.Polar regions appear throughout this book to be the most intensely studied for two reasons: they experienced

greater climate change than equatorial regions, and glacial action leaves better historical traces. Changes in the tropics largely affect the biomass, which does not leave as much of a geological record. The deep oceans, like the polar regions, are a good source because of their stability. Calcium carbonate remains of plankton on the surface and formifera on the ocean bottom accumulate continually.Lake levels in the great basin region of the United States, centered in Nevada, correlate to the Greenland record.There is a 1500 year cycle of interstadial events. It is likely that Bender mentions this to refute Singer's book "Unstoppable Global Warming ÃƒÂ¢Ã â ¬Ã â œ Every 1500 Years." Bender offers the opinion that if it were caused by the sun, there would be evidence in the form of beryllium 10, a product of cosmic rays striking atmospheric carbon.Bender summarizes that rapid climate change events were permanent features of Ice Age earth. There were major shifts in temperature in the upper latitudes, and changes in precipitation in the lower latitudes. The hemispheres were somewhat out of phase. And ultimately, there is no complete explanation of rapid climate change.Chapter 11: The HoloceneThe Holocene era begins with the end of the Younger Dyass cold episode 11,700 years ago.The earth tilts at about 23 1/2Ãƒâ Ã Â as it spins on its axis. The angle of the tilt changes on a 40,000 year cycle and the orientation of the axis of the spin changes on a 26,000 year cycle. The net effect is that in some parts of the cycles the earth is closer to the sun in the northern hemisphere summer than in others.10,000 years ago northern summers occurred when the earth was closest to the sun; now they occur when it is farthest from the sun. They have gotten cooler and tropical precipitation is changed. As always there complicating factors. The Laurentide ice sheet covering northern Canada lasted until 7000 years ago, adding greatly to the Earth's albedo.The cycles had effects all over the world. The Indian monsoons, monsoon that used to exist in North Africa, ocean salinity, rainfallÃƒÂ¢Ã â ¬Ã Â¦ all sorts of indicators.Within the Holocene there are millennium long cycles of fairly rapid climate change. It looks like they are driven by variability in the brightness of the sun.Here is a typical paragraph from the book, an example of the author's style and just one of many indications of the complexity of explaining the climate."Solar forcing may have contributed to the two major climate excursions of the last millennium, the Medieval Warm Period and the Little Ice Age (Bard and Frank 2006). The Medieval Warm Period was an interval around 1000 BP when the global climate was somewhat warmer than during the previous millenium. The Little Ice Age was an interval from about 1300 to 1850 when global climate was somewhat cooler. Evidence for these temperature changes comes primarily from tree ring records, data on advances and retreats of mountain glaciers, borehole temperature studies (described in chapter 10), studies of ocean temperatures, and studies of ice-rafted detritus in the North Atlantic (Bond et al. 2001; Bradley 2000;

Broecker 2001; Cook et al. 2004; Mayewski et al. 2004; Wanner et al. 2008). In the Bond cosmology, the Medieval Warm Period and the Little Ice Age are the latest warm and cold periods of the current solar cycle, and since about 1850 Earth has been recovering from the Little Ice Age.""Was solar variability an important cause of Holocene climate variability? We can look at the evidence, but at the present time we just don't know."There are geological explanations for a lot of phenomena. A huge ice dam broke in northern Canada 8000 years ago, flooding the Atlantic with so much freshwater that the North Atlantic no longer fed the deep oceans with saltwater for a while. The dustbowl in the depression era of the United States was due to cool sea surface temperatures in the Pacific and warm ones in the Atlantic. The droughts in the great basin of the United States appear to have been caused by sea surface anomalies. The drought and the Sahel during the 80s and 90s the same way. There is a lot of evidence, but it has yet to be combined in a story powerful enough to explain it all.Chapter 12 ÃƒÂ¢Ã â ¬Ã â œ Anthropogenic Global Warming in the Context of PaleoclimateClimate change had a profound effect on human migrations. Asians could live in the Bering Straits area, then cross to the Americas on a land bridge 14,000 years ago. This was followed shortly by the extinction of most North American large animals.Our ancestors discovered farming 10,000 years ago. CO2 rose to its preindustrial level (280 ppm) 10,000 years ago. Farming might not have been possible if CO2 were more scarce.The primary way we are contributing to climate change is by adding CO2 to the atmosphere. The planet had already warmed by almost 1Ãƒâ   Ã Â C and sea level is rising at the rate of 30 cm per century. It is likely to accelerate as the planet warms."The present world is good enough for human habitation. However, it would improve of Greenland and Antarctica were unglaciated and habitable, if there were more rainfall and areas that are currently deserts. For humans, in other words, the world might be more habitable if conditions resembled a high CO2 equitable climates of the Cretaceous, Paleocene, and Eocene.""The problem of anthropogenic global change, then, is not necessarily that we are heading for a less habitable planet. The problem is that both natural ecosystems and civilizations are aligned to historical patterns of climate and water resources. Global warming will destroy this alignment in some regions.""If we burn all available fossil fuels in the next few hundred years, we are likely to drive the atmospheric CO2 concentration up to 1500 ppm or so, five times the preindustrial level. This estimate takes into account that over hundreds of years, a large fraction of CO2 is taken up rather quickly by the growth of forests and the dissolution of the oceans.""This high atmospheric CO2 level would be unsustainable. The warm temperature and high CO2 burden mean that once fossil fuels were exhausted, weathering would consume CO2 faster than it is added by natural sources. The excess CO2 would thus be slowly consumed and dissipated by weathering, exactly as for the Paleocene Eocene thermal maximum.""With such a long horizon, two other factors would come into play. The first is orbital change in the natural climate cycle, which would push the earth back into a glacial mode at some point. The second is additional transformations of the environment by humans. These transformations are likely to be severe, and cannot now be predicted.""As for the past 4 1/2 billion years, Earth’s climate in the near geologic future will be determined by changes in greenhouse gases, albedo, Milankovitch forcing, and perhaps solar variability. However, we cannot now know the four things that will dominate climate change hundreds of thousands of years or more in the future, and hence cannot judge how climate will respond. Stay tuned."

This book provides an excellent foundation for a person interested in understanding the global climate system and what drives it, how climate changes over time, and the key measurements or proxies used in the climate literature. It is written in a clear way (I only had to use Google to pursue clarifying material once, in the discussion of the fate of organic carbon as a function of depth in the ocean) and does not read like a textbook."Paleoclimate" should serve as a model for educational scientific writing for non-climate scientists and the general public interested in scientific and technological issues. I would mention two aspects in particular. First, while the concepts are presented clearly and using a minimal amount of specialist terminology or jargon, they are not oversimplified. This is critical, because oversimplification usually ends up being perceived as "dumbing down" or as propaganda advocating for a point of view. Second, the author makes clear the uncertainties and contradictions in the evidence, and the variety of interpretations that have been put forward to explain the record we have. This also tends to be uncommon in general scientific writing, and especially in climate science, where it seems that knowledgeable scientists believe that explaining or admitting that alternative viewpoints exist somehow undercuts their arguments. The material must in the end stand on its own merits, can’t be oversimplified without being compromised, and as the data accumulates and the methodology improves, the interpretation will evolve.For individuals who are interested in reading articles in the scientific literature, "Paleoclimate" gives clear explanations of the frequently used proxy measures, which goes a long way in making them understandable. I didn’t realize until reading this book how much of the interpretation of the climate history of the earth depends on analysis of atomic isotopes!

This is a good reference on paleoclimate. I found chapter 12 disappointing and chapter 11 was rushed through, leaving out a lot of important details on Holocene climate that I think should have been discussed. In chapter 12 unsubstantiated statements such as a 30 cm/century rate of rise in sea level will endanger millions of people is silly. They would be underwater at high tide if that were true. In chapter 11 of my Kindle version "Box 4" explaining the precession cycle is missing. I would have liked to see more human historical events tied into chapter 11, like the Greek Dark Age, the rise of Egypt at the end of the Sahara Savannah period, etc. But, I am criticizing around the edges, overall it is a good reference on paleoclimate.

Paleoclimate is one of the best introductions I’ve seen for the scientifically literate (i.e. a little college science background) non-specialist. Bender does a remarkable job in explaining complex concepts clearly, without over-simplification and with just minimal mathematics. He must be an awesome instructor in the classroom! Bender covers past global climates from the early "snowball earth" glaciations some 600 - 700 MYA, and continues onward to the present. About a third of the book focuses on the Ice ages and modern climates. For those who wish to investigate further, bender provides a reference list at the end of each chapter. Overall, a remarkable job of explaining complex ideas to en educatred lay-person. I strongly recommend this book as a primer for anybody interested in past climates and as a spring-board for more advanced studies

Pulse Sequences Work (Oxford Chemistry Primers)