



What's New in Climate Change?

Original (2010)

Section 1: Why does Climate Change Matter?

- **Global Warming: A Hot Topic**
 - Data from diverse biological systems demonstrate the importance of temperature on performance across scales:
 - Molecules (enzymes)
 - Individuals (adult body size)
 - Populations (population growth rate)
 - Regions (species richness)

Revised (2018)

Section 1: Why does Climate Change Matter?

- **Temperature is Critical**
 - Temperature impacts important biological processes, e.g., spread of disease vectors, species richness
 - Temperature can affect performance at population level (New Simulated Experiment adapted from butterfly exercise previously in Section 5)
 - Key elements of a performance curve (New Test-Your-Understanding Interactive)
- **Temperature Drives Performance Across Biological Scales**
 - Performance curves from other biological scales:
 - Organismal (adult body size)
 - Molecular (enzymes)

OTHER CHANGES TO SECTION 1: Edited text and questions throughout. Added 4 instant-feedback questions and 2 graded questions.

Original (2010)

Section 2: Detecting Climate Change

- **The Earth's Climate is Dynamic**
- **Climate vs. Weather**
- **Detecting a Trend...**
 - Signal Strength
 - Extension: Regression analysis
 - Noise
 - Series Length
- **Where to Seek Evidence of Climate Change?**
 - Predicted changes
- **The Temperature Instrumental Record**
 - Spatial patterns
 - Extension: measuring temperature
 - Global Mean
 - Extension: time series
 - 1,300 Years of Temperature
 - Introduction to proxies
 - Other Indicators of Climate Change
 - A Coherent Picture of Climate Change

Revised (2018)

Section 2: Detecting Climate Change

- **The Earth's Climate is Dynamic**
- **Climate vs. Weather**
 - Anomalies (**New**)
- **Detecting a Trend...**
 - Noise
 - Series Length
 - Signal Strength
 - Eliminated data collection
 - Simplified by removing p-values
 - Climate variability across scales (**New**)
- **Is Earth's Climate Warming?**
 - The climate system (**New Interactive Diagram**)
 - Predicting climate system responses to warming. (**New Interactive Diagram**)
- **Best Evidence of Change: Surface Temperature**
 - Instrumental record, global means (**Updated**)
 - Instrumental record, spatial patterns (**Updated**)
- **More Evidence of Change from Proxies**
 - Comparing proxy records (**New Interactive Diagram**)
- **What Do Other Components of the Climate System Show?**
 - Cryosphere (sea ice, glaciers, snow) (**Updated**)
 - Extension: snow cover decline (**New**)
 - Hydrosphere/hydrologic cycle (**New interactive diagram**)
 - Sea level rise (**Updated**) and ocean heat content (**New**)
 - Changes in biosphere - growing season changes in U.S. (**New interactive map**)
- **A Coherent Picture of Climate Change**

OTHER CHANGES TO SECTION 2: Edited text and questions throughout.

Original (2010)

Section 3: Earth's Climate and Climate Models

- **A Simple Climate Model**
 - Black-body model for Planet X
 - Distance
 - Solar Output
 - Albedo
 - Greenhouse gases
 - Extension: sister planets
- **Feedbacks to the Climate System**
 - Ice-albedo feedback
 - Long-term C cycle
- **More Complex Physical Models**
 - Key features of General Circulation Models
- **Putting it All Together**
 - Model refinements
 - Extension: El Niño / La Niña
- **Model Verification**
 - Reconstructions versus observations

Revised (2018)

Section 3: Earth's Climate and Climate Models

- **Climate Models: Why and How**
 - Black-body, defined (**New Interactive Diagram**)
 - Extension: Shortwave vs. longwave radiation (**New**)
- **Modeling Temperature: Irradiation**
 - Black-body model for Earth (**Revised**)
 - Distance
 - Solar output
- **Modeling Temperature: Albedo**
 - Albedo of ice vs. forests (**New Interactive Diagram**)
 - Extension: Drivers of albedo
- **Modeling Temperature: Greenhouse Gases**
 - Greenhouse gases, defined (**New Narrated Video**)
 - Extension: Venus, Mercury and Mars compared (**Revised**)
- **Feedbacks to the Climate System**
 - Ice-albedo feedback (**New Interactive Diagram**)
 - Cloud feedbacks (**New**)
 - Extension: Additional Feedbacks (**New**)
- **Earth's Energy Budget**
 - Earth's Energy Budget (**New Narrated Video**)
- **Sophisticated Climate Models**
 - GCMs summarized (**New Narrated Video**)
 - Emergent properties of GCMs (**New Narrated Video**)
 - Extension: El Niño / La Niña
 - Extension: Polar vortex (**New**)
 - Eliminated text on multiple components of GCMs
- **Recreating Historic Climate**
 - Model verification (**Updated**)

OTHER CHANGES TO SECTION 3: **Edited text and questions throughout.**

Original (2010)

Section 4: Humans and Climate Change

- **Attribution of Recent Climate Change**
 - Natural vs. anthropogenic forcings
 - SimBio's simple attribution model
- **Can Solar Variation Explain Recent Warming?**
 - SimBio model vs. observations
- **Can Greenhouse Gases Explain Recent Warming?**
 - Keeling curve
 - SimBio model vs. observations
- **Can Human Actions Explain Recent Warming?**
 - Extension: Milankovitch cycles
- **Climate Change in the 21st Century**
 - SimBio model forecast
 - Model uncertainties
 - Extension: El Niño / La Niña
 - Extension: North Atlantic Oscillation
- **Future Drivers of Climate Change**
 - IPCC emission scenarios
 - Projected changes
- **Spatial Distribution of Temperature Change**
 - Extension: Predicted precipitation changes

Revised (2018)

Section 4: Humans and Climate Change

- **Attribution of Recent Climate Change**
 - Extension: Attribution vs. detection (**Revised**)
 - Attribution relies on models (**New**)
 - Removed SimBio's simple model
- **How Do Natural Forcings Affect Climate?**
 - Volcanic emissions, variation in solar output and orbital variations as forcings (**Updated**)
 - Extension: Milankovitch cycles (**Updated**)
 - Drivers of glacial cycles (**New**)
 - Natural forcings role evaluated with NASA's GISS model output (**New Interactive Diagram**)
- **How Do Anthropogenic Forcings Affect Climate?**
 - Land-use change, aerosols, ozone, and greenhouse as forcings (**Updated**)
 - Keeling curve
- **Why is Earth's Climate Warming?**
 - All potential forcings evaluated with NASA's GISS model output (**New Interactive Diagram**)
 - Extension: Summary of recent climate forcings (**New**)
 - Human fingerprints on climate change (**New Interactive Diagram**)
- **Projection Future Changes**
 - Key sources of uncertainty, projected changes in mean temperature (**New Narrated Video**)
 - Spatial patterns (**Updated**)
- **Effects of Warming Cascade Through Climate System**
 - (**New Interactive Diagram**)
- **Feedbacks Suggest Tipping Points**
 - Extension: Critical tipping points (**New**)

OTHER CHANGES TO SECTION 4: Edited text and questions throughout. Moved discussion of effects on people to Section 5.

Original (2010)

Section 5: Biological Consequences of Climate Change

- **Species Must Respond to Climate Change**
- **Can Changes in Phenology Affect Population Growth?**
 - Simulation: Trophic Mismatch
- **Climate Change and Fitness**
- **How Does Climate Change Affect Species Distribution?**
- **Evolutionary Responses**
 - Simulation: rate of environmental change
 - Extension: Performance curves evolve
 - Simulation: initial genetic variation
 - Generation time
- **Climate Change will Affect Life**
 - Extension: Evolutionary constraints

Revised (2018)

Section 5: Biological Consequences of Climate Change

- **Climate Change Will Pose Grave Threats for Many Species (New)**
 - Altered phenology (Revised)
 - Predict potential phenotypic mismatch of caribou and forage (**New Interactive Diagram**)
 - Compare predictions to data (**New**)
- **Direct and Indirect Effects of Climate Change**
 - Effects on species, people (**New**)
 - Extension: Fertilization effect
 - Extension: Ocean acidification
 - Cascading effects of sea-ice decline (**New Interactive Diagram**)
- **How will life respond? (New)**
 - Four potential responses (**Updated**)
 - Risk to tropical vs. temperate species (**New Interactive Diagram**)
- **Individuals May Acclimate (New)**
- **Species Ranges May Shift (Revised)**
 - Latitudinal Range Shifts (**New Narrated Video**)
- **Who Can “Keep Up” With Climate Change?**
 - Climate Velocity (**New Narrated Video**)
- **Populations May Evolve (New)**
 - Salmon example replaces fruit fly
- **Which Populations Can Evolve Fast Enough?**
 - Simulation: rate of environmental change (**Revised**)
 - Extension: Performance curves evolve
 - Simulation: initial genetic variation (**Revised**)
 - Simulation: generation time (**New**)
- **The Changes to Come (New)**

OTHER CHANGES TO SECTION 5: Edited text and questions throughout. Deleted butterfly phenology simulation and fitness discussion. Moved simulation in which performance curve is generated to Section 1.