Why are there seasons?

How does the climate respond to the radiative annual cycle?

How does the climate respond to changes in radiative forcing (year-to-year timescales?)
Why are there seasons?

Figures from Aguado and Burt (2004) 2/e; Not to Scale!
Annual cycle: Net (incoming-outgoing @ surface) short wave radiation

Net Short-Wave Radiation

Dec

Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

J. Shinker, University of Oregon and Digital Library for Earth Science Education, http://climvis.net/content/global.htm, acc. 1/30/13
Annual cycle: Net (incoming-outgoing @ surface) long wave radiation
Annual cycle: Net (incoming-outgoing @ surface) long wave+short wave radiation

Net Radiation

Dec

Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

J. Shinker, University of Oregon and Digital Library for Earth Science Education, http://climvis.net/content/global.htm, acc. 1/30/13
What are the consequences for the climate system?

IPCC AR4 (2007) WG1 FAQ, Fig. 2 (http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_FAQs.pdf)
Annual cycle: surface air temperature

Air Temperature

Dec

Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

J. Shinker, University of Oregon and Digital Library for Earth Science Education, http://climvis.net/content/global.htm, acc. 1/30/13
Annual cycle: precipitation-evaporation

Animation courtesy J. Shinker, University of Oregon Geography Dept. (http://geography.uoregon.edu/envchange/clim_animations/), accessed 2/4/09

Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000
Annual cycle: soil moisture (in top 10cm)

J. Shinker, University of Oregon and Digital Library for Earth Science Education, http://climvis.net/content/global.htm, acc. 1/30/13

Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000
Annual cycle: sea level pressure and vector winds

Sea-Level Pressure and Surface Winds

Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

J. Shinker, University of Oregon and Digital Library for Earth Science Education, http://climvis.net/content/global.htm, acc. 1/30/13
Annual cycle: biological productivity

SeaWiFS chlorophyll-a retrieval animation for 1997-2003
Annual cycle: sea ice

Sea ice climatological extremes, from passive microwave remote sensing data archived at the National Snow and Ice Data Center (http://nsidc.org/sotc/sea_ice.html), accessed 2/4/09
The annual cycle is a big deal!

Power spectrum of temperature estimates from a variety of instrumental and proxy data sources; from Huybers and Curry (2006)
Perturbations to atmospheric composition: The Pinatubo eruption (1991)

before...

And during the 1991 eruption.

From the Wikipedia entry on Mt. Pinatubo (http://en.wikipedia.org/wiki/Mount_Pinatubo; based on references therein), accessed 2/4/09
Perturbations to atmospheric composition: The Pinatubo eruption (1991)

Sulfur dioxide converts to tiny persistent sulfuric acid (H2SO4) aerosols. These aerosols reflect energy coming from the sun, thereby preventing the sun's rays from heating Earth's surface. NASA Earth Observatory, “What are aerosols?” http://earthobservatory.nasa.gov/Features/Aerosols/aerosol2.php, accessed 2/4/09; graphic by R. Simmon, Goddard DAAC.
Perturbations to the mean climate: The Pinatubo eruption (1991)

Space Shuttle (Mission STS 43) photograph of the Earth over South America taken on August 8, 1991, showing double layer of Pinatubo aerosol cloud (dark streaks) above high cumulonimbus tops. From the Wikipedia entry on Mt. Pinatubo (http://en.wikipedia.org/wiki/Mount_Pinatubo), accessed 2/4/09
Perturbations to the mean climate: The Pinatubo eruption (1991)

Model prediction for -4W/m² radiative forcing at top of tropopause:
B = linear CO2 increase
P1 = Pinatubo + B
P2 = P1 + noise

IPCC total net anthropogenic radiative forcing, 1750-2011: 1.1-3.4 W/m²

Hansen et al. (1992) simulation of the effect on global temperature of the eruption of Mt. Pinatubo (1991); GISTEMP global average temperature estimates updated through 2017 (http://data.giss.nasa.gov/gistemp/), accessed 1/25/18; IPCC AR5WG1 Tech. Summ, Fig TS.6, p 54 (2013)
What are the consequences for the climate system?

IPCC AR4 (2007) WG1 FAQ, Fig. 2 (http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_FAQs.pdf)
Summary

• The annual cycle in solar radiation received at Earth's surface results from the tilt of the Earth on its rotational axis, and its orbital period about the Sun.

• The annual cycle in solar radiation drives annual variations in the climate: heating, circulation, biosphere, and cryosphere. This accounts for a lot of observed climate variation.

• If episodic volcanic eruptions can eject aerosols into the stratosphere, they can cool the climate substantially for a few years at a time, and temporarily rival the climate forcing resulting from anthropogenic greenhouse gas emissions.

• Next: ocean and atmospheric circulation (readings: Kump et al., ch 4, pp 55-66); interannual variation (Thompson and Wallace, 2001).