Natural Hazards and Disaster

Class 3: Global Threats and Extraterrestrial Hazards

• Extreme Natural Hazards
• Global Risk Assessments
• Modern Global Change
• Major (Global) Risks
• Global Risk Governance
• Extraterrestrial Hazards
Extreme Events:

- **Extinction Level Events**: more than a quarter of all life on Earth is killed and major species extinction takes place.
- **Global Catastrophes**: more than a quarter of the world human population dies and that places civilization in serious risk.
- **Global Disasters**: global-scale events in which a few percent of the population die.
- **Major Disasters**: disasters exceeding $100 Billion in damage and/or causing more than 10,000 fatalities.

From Plag et al. (2015)
Extreme Events:

- **Extinction Level Events**: more than a quarter of all life on Earth is killed and major species extinction takes place.
- **Global Catastrophes**: more than a quarter of the world human population dies and that place civilization in serious risk.
- **Global Disasters**: global-scale events in which a few percent of the population die.
- **Major Disasters**: disasters exceeding $100 Billion in damage and/or causing more than 10,000 fatalities.

From Plag et al. (2015)

How can we assess risk for low-probability high-impact events?
“To decide how to allocate effort and resources, we must make **comparative judgements**. If we treat **risks singly**, and never as part of an overall threat profile, we may become **unduly fixated on the one or two dangers that happen to have captured the public or expert imagination of the day**, while neglecting other risks that are more severe or more amenable to mitigation.”

- Risks from Nature
- Risks from Unintended Consequences
- Risks from Hostile Acts
“We can roughly characterize the severity of a risk by three variables: its scope (how many people – and other morally relevant beings – would be affected), its intensity (how badly these would be affected), and its probability (how likely the disaster is to occur, according to our best judgement, given currently available evidence).”

Severity of a risk:
• its **scope** (how many people – and other morally relevant beings – would be affected),
• its **intensity** (how badly these would be affected),
• its **probability** (how likely is the disaster is to occur).
Extreme Natural Hazards

Scope (Cosmic?)

Trans-generational

Loss of one species of beetle

Drastic loss of biodiversity

Human extinction

Existential risks

Global catastrophic risks

Global warming by 0.001 °C

Spanish flu pandemic

Ageing

Local

Congestion from one extra vehicle

Recession in a country

Genocide

Personal

Loss of one hair

Car is stolen

Fatal car crash

Imperceptible

Endurable

Terminal

Intensity (Hellish?)
Extreme Natural Hazards

Casti (2012) defines ‘X-events’ as events that are rare, surprising, and have potentially huge impacts on human life. X-events are outliers that are found outside the ‘normal’ region and could lead to ‘the collapse of everything’.

The bell-shaped vs. fat-tailed distributions
How do we characterize risk in situations where probability theory and statistics cannot be employed?
How do we characterize risk in situations where probability theory and statistics cannot be employed?

Casti (2012) defines:

\[ X = \frac{\delta E}{E} \left(1 - \frac{U}{U + I}\right) \]

where:
- X is the X-ness of an event (a measure of the impact of the event),
- \(E\) the impacted ensemble (e.g. impact on the gross domestic product or the total annual deaths in the impacted region),
- \(\delta E\) the change in the ensemble due to the event,
- \(U\) the unfolding time of the event, and
- \(I\) the impact time.
Extreme Natural Hazards

**X-Event 1:** Digital Darkness: A Long-Term, Widespread Failure of the Internet

**X-Event 2:** When Do We Eat?: Breakdown of the Global Food-Supply System

**X-Event 3:** The Day the Electronics Died: A Continent-Wide Electromagnetic Pulse Destroys All Electronics

**X-Event 4:** A New World Disorder: The Collapse of Globalization

**X-Event 5:** Death by Physics: Destruction of the Earth Through the Creation of Exotic Particles

**X-Event 6:** Blown Away: Destabilization of the Nuclear Landscape

**X-Event 7:** Running on Empty: Drying Up of World Oil Supplies

**X-Event 8:** I’m Sick of It: A Global Pandemic

**X-Event 9:** Dark and Dry: Failure of the Electric Power Grid and Clean Water Supply

**X-Event 10:** Technology Run Amok: Intelligent Robots Overthrow Humanity

**X-Event 11:** The Great Unwinding: Global Deflation and the Collapse of World Financial Markets
Five warning signs of impending system state shifts

- An increasing rate of fluctuations
- High-amplitude fluctuations
- Critical slow down
- Skewness in distribution of system states
- Rapid changes in spatial patterns
Extreme Natural Hazards

Plag et al., 2015
Disaster Risk Reduction

Plag et al., 2015
Is modern climate (global) change the most extreme hazard?

Plag et al., 2015
Extreme Natural Hazards

![Graph showing the log of damage and fatalities against the chance of occurrence in any given year (percent).]

**Figure 1.2** Qualitative comparison of consequences of selected natural hazards. Also shown are the frequency of events with magnitudes similar to Mount St. Helens (1980) and Vesuvius (79 AD), super-eruptions, and large igneous province eruptions. An exceptionally rare but very large supervolcano and large igneous province eruptions would have global consequences. In contrast, the maximum size of earthquakes limits their impacts. Tsunamis can be generated by earthquakes, landslides, volcanic eruptions, and asteroid impacts. The slope of the curves, while qualitative, reflects the relationship between event size and probability of occurrence: Earthquakes, and to a lesser extent floods and drought, saturate at a maximum size. SOURCE: Adapted from Plag et al. (2015).
"To produce a civilization-disrupting event, an impactor would need a diameter of at least 1 or 2 km. A 10-km impactor would, it appears, have a good chance of causing the extinction of the human species. But even sub-kilometre impactors could produce damage reaching the level of global catastrophe, depending on their composition, velocity, angle, and impact site."
“To produce a civilization-disrupting event, an impactor would need a diameter of at least 1 or 2 km. A 10-km impactor would, it appears, have a good chance of causing the extinction of the human species. But even sub-kilometre impactors could produce damage reaching the level of global catastrophe, depending on their composition, velocity, angle, and impact site.”

“More than 20 super-eruption sites for the last 2 million years have been identified. This would suggest that, on average, a super-eruption occurs at least once every 50,000 years. However, there may well have been additional super-eruptions that have not yet been identified in the geological record.”
Extreme Natural Hazards

VEI 7 Eruptions

- Kurile, ~5550 BC
- Crater Lake, ~5680 BC
- Santorini, ~1610 BC
- Kikai, 2350 BC
- Tambora, 1815
- Changbai, ~970
- Taupo, 230

12 Billion by 2100
Extreme Natural Hazards

Population growth may offsets DRR efforts

VEI 7 Eruptions

- Tambora, 1815
- Changbai, ~970
- Santorini, ~1610 BC
- Crater Lake, ~5680 BC
- Kurile, ~5550 BC
- Kikai, 2350 BC
- Taupo, 230
- 12 Billion by 2100
Extreme Natural Hazards

**Recurrence Log (Years)**

**Energy Log (Joules)**

- **VEI 8** Toba-Type Eruption
  - $10^{16}$ W lasting $10^5$ s

- **VEI 7** Tambora-Type Eruption
  - $M = 9.5$ Earthquake
  - $10^{17}$ W lasting 100 s

- 2 km impactor
Extreme Natural Hazards

- **Homo sapiens**
  - Energy: $2 \times 10^{13}$ W

- **VEI 8 Toba-Type Eruption**
  - Energy: $10^{16}$ W
  - Duration: 100 s

- **VEI 7 Tambora-Type Eruption**
  - Energy: $10^{17}$ W
  - Duration: 100 s

- **2 km impactor**
  - Energy: $10^5$ s
Extreme Natural Hazards

Energy Log (Joules)

```
Recurrence Log (Years)
```

Homo sapiens: “Cataclysmic Virus (HCV) in the Earth’s Life-Support System”

- “Single-Species High-Energy Pulse”
  - Homo sapiens 2·10^{13} W

- VEI 8
  - Toba-Type Eruption
  - 10^{16} W lasting 10^5 s

- VEI 7
  - Tambora-Type Eruption
  - M = 9.5
  - Earthquake 10^{17} W lasting 100 s

- 2 km impactor

2 km impactor
Natural Hazards and Disaster

Class 3: Global Threats and Extraterrestrial Hazards
- Extreme Natural Hazards
- Global Risk Assessments
- Modern Global Change
- Major (Global) Risks
- Global Risk Governance
- Extraterrestrial Hazards
How to think and talk about possible futures, including worst cases?
What are the causes and consequences of unsustainability and how does this relate to our ethics?
Global Risk Assessments

Global Catastrophic Risks
2016

in association with

Global Challenges Foundation

Global Priorities Project

Future of Humanity Institute
UNIVERSITY OF OXFORD

OXFORD MARTIN SCHOOL
UNIVERSITY OF OXFORD
THE GLOBAL CHALLENGES FOUNDATION works to raise awareness of the Global Catastrophic Risks. Primarily focused on climate change, other environmental degradation and politically motivated violence as well as how these threats are linked to poverty and rapid population growth. Against this background, the Foundation also works to both identify and stimulate the development of good proposals for a management model – a global governance – able to decrease – and at best eliminate – these risks.

THE GLOBAL PRIORITIES PROJECT helps decision-makers effectively prioritise ways to do good. We achieve this both by advising decision-makers on programme evaluation methodology and by encouraging specific policies. We are a collaboration between the Centre for Effective Altruism and the Future of Humanity Institute, part of the University of Oxford.
"THE GLOBAL CHALLENGES FOUNDATION works to raise awareness of the Global Catastrophic Risks. Primarily focused on climate change, other environmental degradation and politically motivated violence as well as how these threats are linked to poverty and rapid population growth. Against this background, the Foundation also works to both identify and stimulate the development of good proposals for a management model – a global governance – able to decrease – and at best eliminate – these risks."

"THE GLOBAL PRIORITIES PROJECT helps decision-makers effectively prioritise ways to do good. We achieve this both by advising decision-makers on programme evaluation methodology and by encouraging specific policies. We are a collaboration between the Centre for Effective Altruism and the Future of Humanity Institute, part of the University of Oxford."
Global Risk Assessments

Global Catastrophic Risks

2016
Global Risk Assessments

Global Catastrophic Risks
2016

FIGURE 2.1. THE CHANCE OF EXTREME CLIMATE CHANGE
The probability of warming of 6°C for different atmospheric concentrations of greenhouse gases.
Global Risk Assessments

Global Catastrophic Risks
2016

2.5.2. GLOBAL TEMPERATURE ANOMALY FROM GEO-ENGINEERING FOLLOWED BY TERMINATION

Global average surface air temperature change from business as usual emissions, injection of 3 megatons/annum (Mt/a) of SO2 in the Arctic, 5 Mt/a of SO2 in the tropics, and 10 Mt/a SO2 in the tropics.\(^{39}\)

- Anthro Forcing
- +5 Mt/a Tropical
- +10 Mt/a Tropical
Food stockpiles and the ability to rapidly increase production of alternate sources of food would increase resilience to a broad range of risks.
The Global Risks Report 2017
12th Edition

Global Risk Assessments

Figure 2: The Evolving Risks Landscape, 2007-2017

Top 5 Global Risks in Terms of Likelihood
- Breakdown of critical information infrastructure
- Asset price collapse
- Severe income disparity
- Geopolitical conflict
- Chronic disease

Top 5 Global Risks in Terms of Impact
- Asset price collapse
- Asset price collapse
- Asset price collapse
- Geopolitical conflict
- Pandemics


Note: Global risks may not be strictly comparable across years, as definitions and the set of global risks have evolved with new issues emerging on the 10-year horizon. For example, cyber attacks, income disparity, and unemployment entered the set of global risks in 2015. Some global risks were reclassified: Water crises and rising income disparity were re-categorized first as societal risks and then as a trend in the 2015 and 2016 Global Risks Reports, respectively. The 2006 edition of the Global Risks Report did not have a risks landscape.
The Global Risks Report 2017
12th Edition
Reducing risk: Expert advice and citizen action. Technology continues to outpace humanity’s capacity to control it, even as many citizens lose faith in the institutions upon which they must rely to make scientific innovation work for rather than against them. Expert advice is crucial if governments are to effectively deal with complex global threats. The Science and Security Board is extremely concerned about the willingness of governments around the world—including the incoming US administration—to ignore or discount sound science and considered expertise during their decision-making processes.
The Bulletin of the Atomic Scientists moved the doomsday clock closer to midnight on Thursday morning, warning the world that it is as close to catastrophe in 2018 as it has ever been.

Scientists cited growing nuclear threats, climate change and a lack of trust in political institutions as they set the doomsday clock at two minutes to midnight — 30 seconds closer than it was last year.

“The world is not only more dangerous now than it was a year ago; it is as threatening as it has been since World War II,” Lawrence Krauss and Robert Rosner of the Bulletin of the Atomic Scientists wrote in a Washington Post column on Thursday, referencing President Trump’s repeated threats of war against North Korean leader Kim Jong Un, as well as his reversal of the Obama Administration’s efforts to stop climate change.

Time, January 25, 2018
Reducing risk: Expert advice and citizen action continues to outpace humanity's capacity to control it, even as many citizens lose faith in the institutions upon which they must rely to make scientific innovation work for rather than against them. Expert advice is crucial if governments are to effectively deal with complex global threats. The Science and Security Board is extremely concerned about the willingness of governments around the world—including the incoming US administration—to ignore or discount sound science and considered expertise during their decision-making processes.

By KATIE REILLY

The Bulletin of the Atomic Scientists moved the doomsday clock closer to midnight on Thursday morning, warning the world that it is as close to catastrophe in 2018 as it has ever been. Scientists cited growing nuclear threats, climate change and a lack of trust in political institutions as they set the doomsday clock at two minutes to midnight — 30 seconds closer than it was last year.

"The world is not only more dangerous now than it was a year ago; it is as threatening as it has been since World War II," Lawrence Krauss and Robert Rosner of the Bulletin of the Atomic Scientists wrote in a Washington Post column on Thursday, referencing President Trump's repeated threats of war against North Korean leader Kim Jong Un, as well as his reversal of the Obama Administration's efforts to stop climate change.

Time, January 25, 2018

https://clock.thebulletin.org
Global Risk Assessments

Clock Changes

- **2018**: It is 2 minutes to midnight
- **2017**: It is two and a half minutes to midnight
- **2016**: It is still 3 minutes to midnight
- **2015**: It is 3 minutes to midnight
- **2012**: It is 5 minutes to midnight
- **2010**: It is 6 minutes to midnight
- **2007**: It is 5 minutes to midnight
- **2002**: It is 7 minutes to midnight
- **1998**: It is 9 minutes to midnight
- **1995**: It is 14 minutes to midnight
Global Risk Assessments
THINKING THE UNTHINKABLE
Successful risk management requires thinking “outside the box” to avoid a failure of imagination, but this is a skill rarely found at the senior levels of government and global corporations. (Spratt and Dunlop, 2018)

THE UNDERESTIMATION OF (MAJOR) RISKS
“When all the new knowledge that challenges the old is on the more worrying side, one worries about whether the asymmetry reflects some systematic bias... I have come to wonder whether the reason why most of the new knowledge confirms the established science or changes it for the worse is scholarly reticence.”

Prof. Ross Garnaut, 2011
THINKING THE UNTINKABLE
Successful risk management requires thinking “outside the box” to avoid a failure of imagination, but this is a skill rarely found at the senior levels of government and global corporations. (Spratt and Dunlop, 2018)

THE UNDERESTIMATION OF (MAJOR) RISKS
“When all the new knowledge that challenges the old is on the more worrying side, one worries about whether the asymmetry reflects some systematic bias... I have come to wonder whether the reason why most of the new knowledge confirms the established science or changes it for the worse is scholarly reticence.”

Prof. Ross Garnaut, 2011
Natural Hazards and Disaster

Class 3: Global Threats and Extraterrestrial Hazards

• Extreme Natural Hazards
• Global Risk Assessments
• Modern Global Change
• Major (Global) Risks
• Global Risk Governance
• Extraterrestrial Hazards
The Holocene was a “safe operating space for humanity”
Modern Global Change

The Holocene was a “safe operating space for humanity”

Rockström and Klum, 2015
Modern Global Change

The Holocene was a “safe operating space for humanity”
Modern Global Change

The Holocene was a “safe operating space for humanity”

Current extinction rates:
300 times background rate for birds
80,000 times background rate for mammals

Rockstrom and Klum, 2015
Modern Global Change

The Holocene was a “safe operating space for humanity”

Current extinction rates:
300 times background rate for birds
80,000 times background rate for mammals

“We are the asteroid …”

Rockstrom and Klum, 2015
Modern Global Change

The Holocene was a “safe operating space for humanity”

Rockstrom and Klum, 2015
Modern Global Change

The Holocene was a “safe operating space for humanity”
Modern climate change is a symptom, not the cause, not the “sickness.” It is a symptom of a single-species, high-energy pulse.

Rockstrom and Klum, 2015
Modern Global Change

The Holocene was a “safe operating space for humanity”

Growth in Asia
As the economies in Asia grow, so does demand for consumer products—and plastics. Half the world’s plastics are made there, 29 percent in China.

Global plastic production by industry
in millions of tons

Legacy of World War II
Shortages of natural materials during the war led to a search for synthetic alternatives—and to an exponential surge in plastic production that continues today.

1973 oil crisis
2008 recession

The urgent challenge of plastics

The largest market for plastics today is for packaging materials. That trash now accounts for nearly half of all plastic waste generated globally; most of it never gets recycled or incinerated.

Total
448 million tons produced in 2015

Other
52 million
includes health care and agriculture

The average time plastics are used before they're discarded.

Building and construction
72 million
35 years

Industrial machinery
3 million
20 years

Transportation
30 million
13 years

Electrical
19 million
8 years

Textiles
65 million
5 years

Consumer products
46 million
3 years

Packaging
161 million
Less than six months

Below boundary (safe)
In zone of uncertainty (uncertainty)
Beyond zone of uncertainty (dangerous)
Modern Global Change

The Holocene was a “safe operating space for humanity”

Modern climate change is a symptom, not the cause, not the “sickness.” It is a symptom of a single-species, high-energy pulse.

Rockstrom and Klum, 2015
Scaling law for metabolic rate:
\[ Y = Y_0 \times M^{(3/4)} \]

human: \[ Y = 50 \text{ - } 100 \text{ Watt} \]
Scaling law for metabolic rate:
\[ Y = Y_0 \times M^{(3/4)} \]

human: \( Y = 50 \text{ - } 100 \text{ Watt} \)
Scaling law for metabolic rate: 
\[ Y = Y_0 \times M^{3/4} \]

human: \( Y = 50 \text{ -100 Watt} \)

Extended metabolic rate: 
\[ Y_E = Y + C_E \]
\((C_E: \text{total energy consumption})\)

Energy consumption per capita: 
Global Average: \( Y_E = 2,735 \text{ Watt} \) 
\( M = 10 \text{ metric tons} \)
Scaling law for metabolic rate:
\[ Y = Y_0 \times M^{(3/4)} \]

human: \[ Y = 50 \text{ - 100 Watt} \]

Energy consumption per capita:
Global Average: \[ Y_E = 2,735 \text{ Watt} \]

Mass = 10 metric tons

Extended metabolic rate:
\[ Y_E = Y + C_E \]

\( C_E \): total energy consumption

Metabolic Rate

Being out of Scale

Humanity has an extended metabolic rate equivalent to 14 Billion elephants (2.7 Billion for the U.S. alone)

14 Billion elephants: a heavy “load” for Earth
Changes in flows in the Earth’s life-support system:
Modern Global Change

Changes in flows in the Earth’s life-support system:

- Energy flows from fossil fuels => humanity => life-support system.
- Impacts other flows in a “re-engineered” system
- Changes Earth’s Energy Imbalance:
Modern Global Change

Changes in flows in the Earth’s life-support system:

- Energy flows from fossil fuels => humanity => life-support system.
- Impacts other flows in a “re-engineered” system
- Changes Earth’s Energy Imbalance:

\[10^{-10}\] Incoming Solar

Outgoing Radiation

Storage in fossil fuels

Imbalance on the order of \(10^{-10}\)

Last 200 Million years
Modern Global Change

Changes in flows in the Earth’s life-support system:

- Energy flows from fossil fuels => humanity => life-support system.
- Impacts other flows in a “re-engineered” system
- Changes Earth’s Energy Imbalance:

\[
\text{Incoming Solar} \quad 10^{-10} \quad \text{Outgoing Radiation} \\
\text{Storage in fossil fuels}
\]

Imbalance on the order of $10^{-10}$
Last 200 Million years

\[
\text{Incoming Solar} \quad 10^{-3} \quad \text{Outgoing Radiation} \\
\text{Storage in heat}
\]

Imbalance on the order of $10^{-3}$
Last 70 years
Modern Global Change

Imbalance: 300-320 TW;
Greenhouse
Modern Global Change

Greenhouse

[Image of a greenhouse in a natural setting]

[Distant landscape image]
Modern Global Change

Greenhouse
Volumetric heat capacity of water compared to air:
About 3300 time higher
Modern Global Change

Greenhouse

Poolhouse
Is there a connection to climate change? Well, a warmer atmosphere can hold more water vapor, and the region’s main moisture source — the Gulf of Mexico — has reached record-warm levels in recent years, helping to spur an increase in precipitation intensity. Since the 1950s, the amount of rain falling in the heaviest storms has increased by 37 percent in the Midwest.

But there’s more to it than that. Decades of development have also paved over land that used to soak up rainwater. Earlier this year, Wisconsin took controversial steps to loosen restrictions on lakeside development.
They also saw what could be a perilous future for low-lying airports around the world, increasingly vulnerable to the rising sea levels and more extreme storms brought about by climate change. A quarter of the world’s 100 busiest airports are less than 10 meters, or 32 feet, above sea level, according to an analysis of data from Airports Council International and OpenFlights. Twelve of those airports — including hubs in Shanghai, Rome, San Francisco and New York — are less than 5 meters above sea level.

Climate change is driving worldwide glacial retreat and thinning\(^1\) that can expose unstable hillslopes. The removal of glacial ice supporting steep slopes combined with the thawing of permafrost in alpine regions\(^2\) increases the likelihood of landslides.
Modern Global Change

We know about the threat of modern climate change since more than 100 years, but …

“Humans, as individuals, as groups, and together as a society, seem to be hard-wired to respond quickly and effectively to a sudden threat, but not to a menace that makes itself known stealthily and over an extended period of time.”

We reacted in the past to extreme events, but …

“Despite our increasingly desperate predicament, climate change has not prompted anything like this sort of response, and initiatives designed to cut carbon emissions, such as the Kyoto Protocol, have made no impression at all on the steadily rising concentrations of greenhouse gases in the atmosphere.”
Natural Hazards and Disaster

Class 3: Global Threats and Extraterrestrial Hazards

- Extreme Natural Hazards
- Global Risk Assessments
- Modern Global Change
- Major (Global) Risks
- Global Risk Governance
- Extraterrestrial Hazards
Major Global Risks (My Assessment)

Even if carbon emissions are reduced, the ocean is still set for centuries of warming, acidification, deoxygenation, and sea level rise. Photo by Ethan Daniels/Alamy Stock Photo

When It Comes to Climate Change, the Ocean Never Forgets
Even if carbon emissions are reduced, the ocean is still set for centuries or more of warming, acidification, deoxygenation, and sea level rise.
Even if carbon emissions are reduced, the ocean is still set for centuries or more of warming, acidification, deoxygenation, and sea level rise.

Major Global Risks (My Assessment)

• Overload of the ocean with nutrients
• Reduction of oxygen
• Ocean acidification
• Overload with plastics
• Overfishing
....

When It Comes to Climate Change, the Ocean Never Forgets
Major Global Risks (My Assessment)

Land use

Percentage of Earth's terrestrial ecosystems that show state shifts

Critical transition as increased emergent global forcings reach threshold values that rapidly change all of Earth's ecosystems

(Generally increases with human population size)
Major Global Risks (My Assessment)

Land use

95% in extreme poverty

Adam Smith:
The purpose of economy is to create human wealth.

Critical transition as increased emergent global forcings reach threshold values that rapidly change all of Earth’s ecosystems

(Generally increases with human population size)
Land use

95% in extreme poverty

Adam Smith:
The purpose of economy is
to create human wealth.

1950 Syndrome

1700
~650 million people

1800
~1 billion people

1900
1.65 billion

1950
2.52 billion

2011
7.00 billion

2025
8.20 billion

? 2045
9.00 billion

Percentage of Earth’s terrestrial ecosystems that show state shifts

Percentage of lightly affected ecosystems

Critical transition as increased emergent global forcings reach threshold values that rapidly change all of Earth’s ecosystems

Major Global Risks (My Assessment)

(Generally increases with human population size)
Major Global Risks (My Assessment)

Extinction

Terrestrial Vertebrate Biomass

- **Millions of Tonnes**
  - Global Carrying Capacity
  - 10,000 BCE: 200
  - 1900: 200
  - 1950: 400
  - 2000: 1200
  - 2050: 1400

Data:
- 1900, 2000: Vaclav Smil
- 10,000 BCE, 1950, 2050: Paul Cheffins
Major Global Risks (My Assessment)

Exceeding Earth’s Carrying Capacity (ECC)
Major Global Risks (My Assessment)

Exceeding Earth’s Carrying Capacity (ECC)

Unsustainable (transient) ECC

Energy Usage

Population

Carrying Capacity

Time
Exceeding Earth’s Carrying Capacity (ECC)

Unsustainable (transient) ECC

Population exceeds ECC

Energy Usage

Population

Carrying Capacity

Time
Exceeding Earth’s Carrying Capacity (ECC)

- Unsustainable (transient) ECC
- Population exceeds ECC
- Social collapse or change in morality of procreation?
Lovelock: Carrying Capacity will be down to 1 Billion in 2050

Major Global Risks (My Assessment)

Exceeding Earth’s Carrying Capacity (ECC)

Unsustainable (transient) ECC

Population exceeds ECC

Energy Usage

Social collapse or change in morality of procreation?

Carrying Capacity

Time
Class 3: Global Threats and Extraterrestrial Hazards

- Extreme Natural Hazards
- Global Risk Assessments
- Modern Global Change
- Major (Global) Risks
- (Global Risk Governance)
- Extraterrestrial Hazards
Natural Hazards and Disaster

Class 3: Global Threats and Extraterrestrial Hazards
• Extreme Natural Hazards
• Global Risk Assessments
• Modern Global Change
• Major (Global) Risks
• Global Risk Governance
• Extraterrestrial Hazards
Natural Hazards and Disaster

Class 3: ... Extraterrestrial Hazards

• Threats from Space
• Near-Earth Objects (NEOS)
• Meteoroids and Asteroids
• Comets
• Bolides
• Space Weather, Solar Storms, Gamma Rays
Threats from Space

- Near-Earth Objects: Meteoroids, asteroids and comets with orbits that intersect Earth’s orbit.
- Meteoroids and asteroids: Fragments of rock and/or metal in space. The smaller fragments generate light as meteors as they pass through Earth's atmosphere. Larger fragments land as meteorites.
- Comets: Balls of ice, dust, and rock that normally reside beyond the orbit of Neptune.
- Bolllides: Meteoroids and cometary fragments that explode on entering Earth’s atmosphere.
- Solar storms and space weather: Solar flares and coronal mass ejections occur frequently and can disrupt telecommunications or have more severe consequences for electrical and electronically infrastructure.
- Gamma Ray bursts: Extremely energetic explosions that have been observed in distant galaxies
- Extraterrestrial intelligence:
- Human space debris: debris of satellites and rockets
Class 3: Extraterrestrial Hazards

- Threats from Space
- **Near-Earth Objects (NEOS)**
- Meteorides and Asteroids
- Comets
- Bolides
- Space Weather, Solar Storms, Gamma Rays
Near-Earth Objects (NEOS)

- Near Earth Objects (NEOs) are meteoroids, asteroids or comets that pass close to the Earth.
- Potentially hazardous NEOs are estimated to be greater than 20 m in diameter.
- Asteroids reside in the asteroid belt within the inner solar system.
- Comets originate from the Kuiper belt in the outer solar system.
- NEOs greater than 1 km in diameter have the potential to severely disrupt and destroy life.
Near-Earth Objects (NEOS)

The Torino Scale

- **Global**
- **Regional**
- **Local**
- **No Consequence**

**KINETIC ENERGY (MT)**
- $10^8$ (5 km)
- $10^6$ (1 km)
- $10^5$ (100 m)
- $10^4$ (1 km)
- $10^3$ (100 m)
- $10^2$ (1 km)
- $10^1$ (20 m)
- $10^0$ (1 m)

**COLLISION PROBABILITY**
- $10^{-8}$
- $10^{-6}$
- $10^{-4}$
- $10^{-2}$
- $>0.99$

Legend:
- **No hazard.**
- **Normal.**
- **Meriting attention.**
- **Threatening.**
- **Certain collisions.**

Binzel, 2000
## Near-Earth Objects (NEOS)

### NO HAZARD (white)

- The likelihood of a collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bodies that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.

### NORMAL (green)

1. A routine discovery in which a pass near Earth is predicted, that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to reassignment to Level 0.

### MERITING ATTENTION BY ASTRONOMERS (yellow)

2. A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to reassignment to Level 0.

3. A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to reassignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.

4. A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to reassignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.

### THREATENING (orange)

5. A close encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.

6. A close encounter by a large object posing a serious but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted.

7. A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether a collision will occur.

### CERTAIN COLLISIONS (red)

8. A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several thousand years.

9. A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years.

10. A collision is certain, capable of causing global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

---

Binzel, 2000
Near-Earth Objects (NEOS)

The United States of America leads discovery and tracking survey programs using optical telescopes. NASA and the European Space Agency determine the likelihood of an impact with the Earth.
Near-Earth Objects (NEOS)

CNEOS is NASA’s center for computing asteroid and comet orbits and their odds of Earth impact.

Top News Stories

Radar Reveals Two Moons Orbiting Asteroid Florence
2017-09-01
Radar images of asteroid 3122 Florence obtained at the 70-meter antenna at NASA's Goldstone Deep Space Communications Complex between August 29 and September 1 have revealed that the asteroid has two small moons, and also confirmed that main asteroid Florence is about 4.5 km (2.8 miles) in size. Florence is only the third triple asteroid known in the near-Earth population out of more than 16,400 that have been discovered to date. All three near-Earth asteroid triplies have been discovered with radar observations and Florence is the first seen since two moons were discovered around asteroid 1994 CC in June 2009.

Large Asteroid Florence Will Fly by Earth on September 1
Large Asteroid to Safely Pass Earth on Sept. 1

Asteroid Florence, a large near-Earth asteroid, will pass safely by Earth on Sept. 1, 2017, at a distance of about 4.4 million miles.
Near-Earth Objects (NEOS)
Near-Earth Objects (NEOS)

Fireballs

Fireball and Bolide Data

The following chart shows reported fireball events for which geographic location data are provided. Each event's calculated total impact energy is indicated by its relative size and by a color. Hover over an event to see its details.

Fireballs Reported by US Government Sensors

1988-Apr-15 to 2017-Jul-31
Near-Earth Objects (NEOS)

Planetary Defense Coordination Office

NASA's Planetary Defense Coordination Office (PDCO) is managed in the Planetary Science Division of the Science Mission Directorate at NASA Headquarters in Washington, D.C.

The PDCO is responsible for:

- Ensuring the early detection of potentially hazardous objects (PHOs) – asteroids and comets whose orbits are predicted to bring them within 0.05 Astronomical Units of Earth, and of a size large enough to reach Earth's surface – that is, greater than approximately 30 to 50 meters;
- Tracking and characterizing PHOs and issuing warnings about potential impacts;
- Providing timely and accurate communications about PHOs; and
- Leading the coordination of U.S. Government planning for response to an actual impact threat.

The PDCO relies on data from projects supported by NASA's Near-Earth Object (NEO) Observations Program. The PDCO also coordinates NEO observation efforts conducted at ground-based observatories sponsored by the National Science Foundation and space situational awareness facilities of the United States Air Force. In addition to finding, tracking, and characterizing PHOs, NASA's planetary defense goals include developing techniques for deflecting or redirecting PHOs, if possible, that are determined to be on an impact course with Earth. In the event that deflection or redirection is not possible, the PDCO is responsible for providing expert input to the Federal Emergency Management Agency for emergency response operations should a PHO be on an impact course or actually impact the Earth.
Near-Earth Objects (NEOS)

In 1998, NASA established a goal to discover 90% of the NEOs larger than one kilometer in diameter and in 2005, Congress extended that goal to include 90% of the NEOs larger than 140 meters. There are thought to be about 1000 NEAs larger than one kilometer and roughly 15,000 larger than 140 meters.

All of the NEO discovery teams currently use so-called charged couple devices (CCDs) rather than photographic images. These CCD cameras are similar in design to those used in cell phones and they record images digitally in many electronic picture elements (pixels).
Large Asteroid to Safely Pass Earth on Sept. 1

Asteroid Florence, a large near-Earth asteroid, will pass safely by Earth on Sept. 1, 2017, at a distance of about 4.4 million miles.
Near-Earth Objects (NEOS)

Asteroid Watch - August 17, 2017

Large Asteroid to

Asteroid Florence, a large near-Earth asteroid, will come within 4.4 million miles.

Read more.
Class 5: Extraterrestrial Hazards

• Threats from Space
• Near-Earth Objects (NEOS)
• Meteoroids and Asteroids
• Comets
• Bolides
• Space Weather, Solar Storms, Gamma Rays
Meteoroids and Asteroids

A meteoroid is a small rocky or metallic body traveling through outer space. Meteoroids are significantly smaller than asteroids, and range in size from small grains to 1 meter-wide objects. Most are fragments from comets or asteroids, whereas others are collision impact debris ejected from bodies such as the Moon or Mars.

Asteroids are small, airless rocky worlds revolving around the sun too small to be called planets. They are also known as planetoids or minor planets. In total, the mass of all the asteroids is less than that of Earth's moon. Many asteroids have hit Earth in the past, and more will crash into our planet in the future. If an asteroid is headed our way, we want to know that.

A comet is a very small solar system body made mostly of ices mixed with smaller amounts of dust and rock. The main body of the comet is the nucleus, which can contain water, methane, nitrogen and other ices. Most comets are smaller than a few kilometres in diameter. When passing close to the Sun, a comet warms and its ices begin to release gas (outgasing). The mixture of ice crystals and dust blows away from the comet nucleus in the solar wind, creating a pair of tails.
Meteoroids and Asteroids

- Meteorites are rock and/or metal fragments that land on Earth after entering the Earth’s atmosphere at an average speed of about 64,000 km/h.
- Roughly 44,000 kg of meteoritic material falls onto Earth each day, almost all as fragments a millimeter or smaller in diameter.
- Larger pieces do fall, including a few in North America in recent times.
- Very large meteoroids and asteroids are extremely rare, but have caused catastrophic damage in the geological past.

Meteor streak photographed on August 12, 2016, with the Andromeda Galaxy in background. Green color is from vaporized meteor gas flares.

A 12 kg stony-iron meteorite (seen on floor), estimated as 4.4 billion years old, landed on this car in Peekskill, NY on October 9, 1992.

The Willamette iron (+nickel) meteorite found in Oregon, is the largest ever found in the U.S.A. at 14,000 kg.
Meteoroids and Asteroids

More than 8,000 asteroids and meteoroids orbit in the asteroid belt, between Jupiter and Mars.

- The asteroid belt, located in the orbital plane between Jupiter and Mars, contains at least 8,000 asteroids that are 10 to 20 km in diameter and millions of smaller ones.
- The orbits of asteroid belt objects are generally stable, although they are often much more elliptical than those of Earth or Mars.
- Not all of the asteroids are in the same orbital plane, which can lead to asteroid-asteroid collisions.
- A few dozen of the objects in the asteroid belt are over 100 km across.
- Ceres is the largest at 960 km diameter, a little less than 1/4 the size of the Moon.

View looking down onto Earth's orbital plane shows the elliptical orbits of 4 of the main asteroids in the asteroid belt.

Small asteroids in the asteroid belt, shown to scale with Mars. Most are irregular in shape, but Ceres is large enough to have self-gravitated into a roughly spherical shape. Besides impact craters on its surface, Ceres shows evidence of geological activity, including landslides and cryovolcanoes (ice volcanoes) up to 4 km in height.

Oblique view shows the orbits of Pallas and Juno are at a significant angle to those of Earth and Mars.
Meteoroids and Asteroids

**Meteorite Impact Frequency**

- Meteor showers occur frequently, but large meteorite falls are very rare.
- Today, at least one meteorite of several cm to a meter in size, with velocities of 15 km/s or more, lands on Earth each year, but larger meteorite falls are rare.
- Meteor showers occur when Earth passes through locally high concentrations of space, e.g. mid-August Perseid Shower.
- Meteor showers are usually harmless events, although in 2003 a meteoroid impact that occurred during a meteor shower destroyed two houses and injured several people in India.

Meteor showers occur when Earth's orbit enters the dust and debris left behind by a comet.

Meteorite fragments of 1 mm or less in diameter fall all the time onto Earth. Larger pieces fall less often, but are potentially very dangerous. A meteorite tens of meters in diameter, although rare, would cause a tsunami if it landed in an ocean and would devastate the region around a landfall.
Meteoroids and Asteroids

**Impact Crater Formation**

- Impact bodies release energy as a shock wave.
- The kinetic energy $E_k$ of the impact shock depends upon the mass $m$ and velocity $v$ of the impactor.
- The shock wave radiates outward and fractures the surrounding rock into pieces, called breccia.
- The shock also melts rock at the impact site and blasts tiny globules of molten rock, along with pulverized rock fragments and meteoritic material, high into the atmosphere.
- The blasted-away material is called ejecta and it leaves behind a circular crater.
- Rock in the crater’s center rebounds almost instantaneously, creating a central uplift in the crater.
- The molten ejecta globules can be carried far in the atmosphere before they are strewn as glassy objects, called tektites, over a very wide region around impact sites.

A meteorite impact releases kinetic energy $E_k$ as a shock wave according to $E_k = m \cdot v^2$. Top: The shock wave creates a crater by pulverizing and melting rock strata, which is ejected high into the atmosphere. Bottom: Rebounded rock beneath the crater’s center forms a central uplift, surrounded by an inner ring of breccia and an outer rim of upturned rock and ejecta.

Two tektites that originated from a 35.5 million year old impact in Chesapeake Bay, eastern U.S.A. Each specimen is just a few cm long. Left: Tektite found in Georgia, U.S.A. Right: Tektite found in east Texas, U.S.A.
Meteoroids and Asteroids

Earth’s Impact Craters
- Earth’s erosional and tectonic forces have removed much of the evidence for asteroid impact craters.
- There are presently 190 confirmed impact craters on Earth, ranging from about 50 m to 300 km in diameter.
- This is a tiny number compared to the thousands of craters, large and small, that are visible on the Moon.
- Reasons for the lack of impact craters on Earth include: (i) tectonic processes; (ii) there is no oceanic crust older > 270 million years; (iii) erosion by wind, water and/or ice; (iv) younger sediment and volcanic rock cover; (v) the friction of passing through Earth’s atmosphere.
Meteoroids and Asteroids

Large Terrestrial Impacts

- The largest confirmed meteorite impact on Earth is the Vredefort Dome in South Africa, which was formed 2.02 billion years ago by a 10 km diameter impactor.
- The Vredefort crater is at least 120 km in diameter now, although some estimates put the crater’s original diameter at 300 km.
- Rocks from Earth’s lower crust are exposed in its center along with a large volume of impact-generated melt rock called pseudotachylyte.
- Earth’s second-largest impact crater formed near Sudbury, Canada. The originally circular, 1.85 billion year-old crater has been deformed into a roughly elliptical shape by younger tectonic events, but still contains shatter cones and other shock features, as well as high amounts of nickel, platinum, copper, and gold.
Chicxulub Impact And The End-Cretaceous Mass Extinction

- Several mass extinctions of biota on Earth may have been caused by asteroid impacts.
- The most famous is the demise of dinosaurs at the end of the Cretaceous Period, 65.5 million years ago.
- The Chicxulub asteroid, estimated as 12–14 km in diameter, made a crater 170–180 km across on the edge of the Yucatán Peninsula. The estimated energy released was equivalent to $5 \cdot 10^{23}$ J (about 100 times the energy released during the last eruption of the Yellowstone super volcano).
- Enormous tsunami waves would have been generated.
- The timing of the Chicxulub impact coincides with the extinction of 85% of Earth’s animal and plant species, including almost all species of dinosaurs.
- However, the concept of an impact origin for this mass extinction event is still controversial.
Class 5: Extraterrestrial Hazards

- Threats from Space
- Near-Earth Objects (NEOS)
- Meteoroids and Asteroids
- Comets
- Bolides
- Space Weather, Solar Storms, Gamma Rays
Comets are balls of ice, dust, and rock that normally reside beyond the orbit of Neptune.

- Some comets have a rocky center and many also contain small amounts of CO₂, CO, ammonia, and methane.
- They only become visible when, as they approach the Sun, their frozen surfaces emit gas that streams behind them as they travel.
- Some comets reside in the Kuiper Belt, beyond the orbit of Neptune, but most are in the Oort Cloud, well beyond Pluto.
- Some are occasionally perturbed into eccentric orbits.
- Comets that take less than 200 Earth-years to orbit the Sun have well-documented orbits, such as Halley’s Comet.
- Others take much longer to complete one orbit, are less well mapped.

Halley’s Comet as photographed on March 12, 1986 from Australia. The bright ‘head,’ also called ‘coma,’ of the comet is caused by expanding gases that are swept into a ‘tail’ by solar radiation pressure. Comet Halley’s next appearance will be in 2062.
Natural Hazards and Disaster

Class 5: Extraterrestrial Hazards
• Threats from Space
• Near-Earth Objects (NEOS)
• Meteoroids and Asteroids
• Comets
• Bolides
• Space Weather, Solar Storms, Gamma Rays
Bolides are meteoroids and cometary fragments that explode on entering Earth’s atmosphere.

- Asteroids, meteoroids, and fragments of comets that explode in Earth’s atmosphere before reaching the surface are called bolides.
- The explosions are seen as very bright meteors, sometimes called ‘fireballs.’
- In a 20-year period, more than 500 bolides with diameters > 1 m are typical.
- Tunguska Bolide: An object thought to be at least 60 m in diameter and weighing $10^8$ kg exploded in Earth’s atmosphere on June 30, 1908, high above a remote forested region of the Tunguska River in Siberia. Roughly 80 million trees were flattened by the blast. Energy estimates are between $1.3 \times 10^{16}$ and $2.1 \times 10^{16}$ J.

Each bolide on the map was visible as a meteor; circle sizes represent their optical radiated energy in GJ.

Flattened trees in Tunguska, Siberia, after a bolide blast on June 30, 1908. Trees over an area of about 2,000 km$^2$ were downed in a radial pattern, pointing inward toward the blast source.
Bolides

Chelyabinsk, Russia, 2013

- An unexpected bolide blast over southern Russia shattered windows and caused multiple injuries.
- On February 15, 2013, an object at least 17 m in diameter exploded at a height of about 20 km in the atmosphere above Chelyabinsk, Russia.
- The bolide had an estimated energy release equivalent to over $2 \cdot 10^{15} \text{ J}$.
- The blast was recorded by seismic stations around the world.
- There were no direct fatalities from the bolide, but 1,500 people were injured, some seriously, by flying glass and debris.
- By coincidence, NASA had predicted that a different asteroid, they had named 2012DA14, would make a close approach to Earth on about the same day, however they were unaware of the Chelyabinsk asteroid; the two were on completely different and unconnected orbits.

The Chelyabinsk bolide explosion in 2013, as seen by a Russian driver's Dash Cam.

Orbits of the inner planets and those of the Chelyabinsk asteroid & 201DA14. Both asteroids crossed Earth's orbit within hours of each other. Only the Chelyabinsk object came close enough to become a bolide.
Class 5: Extraterrestrial Hazards
• Threats from Space
• Near-Earth Objects (NEOS)
• Meteoroids and Asteroids
• Comets
• Bolides
• Space Weather, Solar Storms, Gamma Rays
Space Weather

• Solar flares and coronal mass ejections occur frequently and can disrupt telecommunications.
• Streams of electrically charged particles are constantly emitted by the Sun as a ‘solar wind.’
• Effects on the upper atmosphere cause Aurora Borealis.
• Variations in the Sun’s magnetic field produce intense, localized solar X-ray and proton flares; frequency and strength are often correlated with sunspot activity.
• A solar X-ray burst disturbs the ionosphere and can jam both high- and low-frequency radio signals.
• Many solar flares trigger coronal mass ejections (CMEs), which blast billions of tons of charged gas into space at speeds of hundreds to thousands of km/s.
• A CME can take from one to four days to reach Earth, where it can cause serious disruption to telecommunications and power grids.
• CME’s are monitored as part of NASA’s Space Weather program.
Space Weather and Solar Storms

**Earth’s Safety Shield**

- Earth’s magnetic field deflects the solar wind, shielding the planet from harmful ions.
- Earth is protected from much of the ionized solar wind and from most solar emissions by its magnetosheath, which is the result of the magnetic field generated by electrical currents in Earth’s core.
- The magnetosheath is not symmetrical, but is compressed on the daylight side of Earth (the side facing the solar wind) and extended on the dark, night-time side into a long tail, called the magnetotail.
- Large solar flares and very fast-moving CMEs further distort Earth’s magnetosheath and cause geomagnetic storms that can seriously disrupt satellites and telecommunications.

Where the solar wind interacts with Earth’s magnetic field, at a distance of about 90,000 km, a bowshaped boundary forms, called a ‘bow shock’ because of the abrupt reduction in the solar wind’s speed. The approximate symmetry of Earth’s local magnetic field (inset) is distorted, becoming compressed on the side facing the Sun and stretched on the night side of Earth.
Space Weather and Solar Storms
OBSERVATIONS

SWPC utilizes an array of observed data sets in their Space Weather forecast operations and related research. Many of these data sets are available in near-real-time, and come from a variety of sources, ranging from solar imaging satellites to ground magnetometer stations. SWPC also provides these data sources to the external community.

- Boulder Magnetometer
- GOES Electron Flux
- GOES Magnetometer
- GOES Proton Flux
- GOES Solar X-ray Imager
- GOES X-ray Flux
- LASCO Coronagraph
- Planetary K-index
- Real Time Solar Wind
- Satellite Environment
- Solar Synoptic Map
- Space Weather Overview
- Station K and A Indices
Solar Flares

- Records of major solar flares and their associated coronal mass ejections first began in 1859.
- Solar flares are classified today according to their strength in watts per square meter reaching Earth, using a lettered scale in which each level is 10 times greater than the next lower rating.
- For example, an M0 flare is ten times greater than a C9, and an M3 is ten times greater than an M2.
- The strongest, most damaging flares are given X values, with no upper limit.

NASA’s letter-scale rating of solar flare strength. The logarithmic scale goes from 1 to 9 within each letter, and extends beyond 20 for X-level flares.
Space Weather and Solar Storms

The Carrington Superstorm
- On September 1, 1859, an intense white-light solar flare was observed by British astronomer Richard Carrington.
- This was the first recorded observation of a solar flare, which lasted for about 5 minutes and is now classified as an X15 Super Geomagnetic Storm.
- When the intense burst of energy reached Earth it caused aurora-induced electrical currents in telegraph wires that were sufficient to give electric shocks to telegraph operators.
- In the hours before dawn next morning, bright auroras were visible as far south as Cuba.

Other Solar Flares
- A powerful geomagnetic storm occurred in May 1921, burning out telephone and telegraph wires across Europe and North America.
- On March 10, 1989, an X15 solar flare and CME caused a geomagnetic storm three days later that disrupted weather satellites and shut down the power grid of Quebec province, Canada, for over 9 hours.
At least 350 of the U.S.A.'s largest electrical transformers, affecting over 130 million people, could be damaged by a geomagnetic storm of the same magnitude as that of May 1921.
More Recent Solar Flares

- A large solar flare on August 4, 1972, disrupted telephone communication across the state of Illinois and caused AT&T to redesign its power system for transatlantic cable.
- On April 2, 2001, an X20 flare became the largest so far on record; it generated a 2,000 km/s CME blast that, fortunately, was not directed toward Earth.

NOAA's GOES-13 satellite recorded this X-ray image of a solar flare on December 5, 2006. The flare was not as intense as the Carrington flare, but it still damaged the satellite's imaging instruments.