Understanding Climate Science

Prof. Mike Mauel

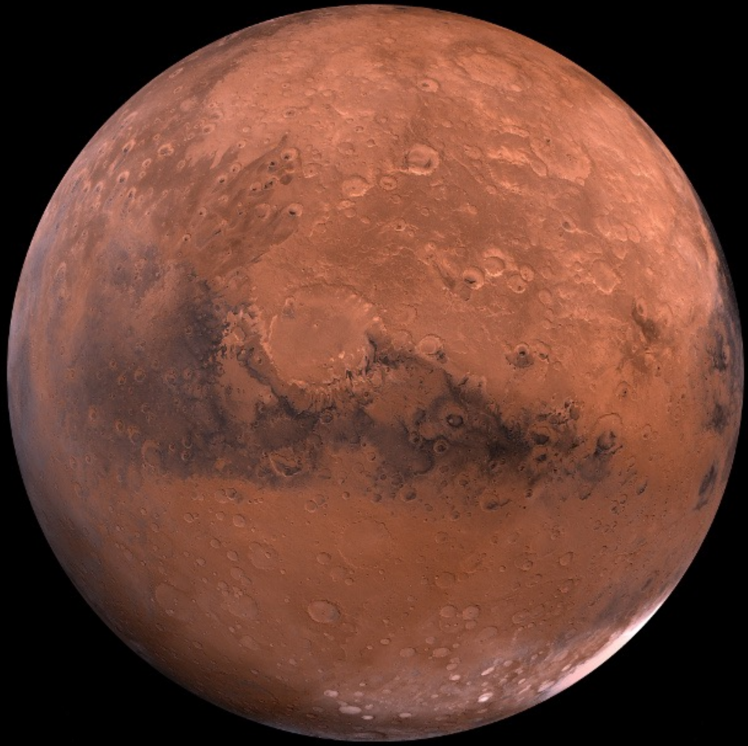
Applied Physics Lunch-Time Seminar

Fall 2015

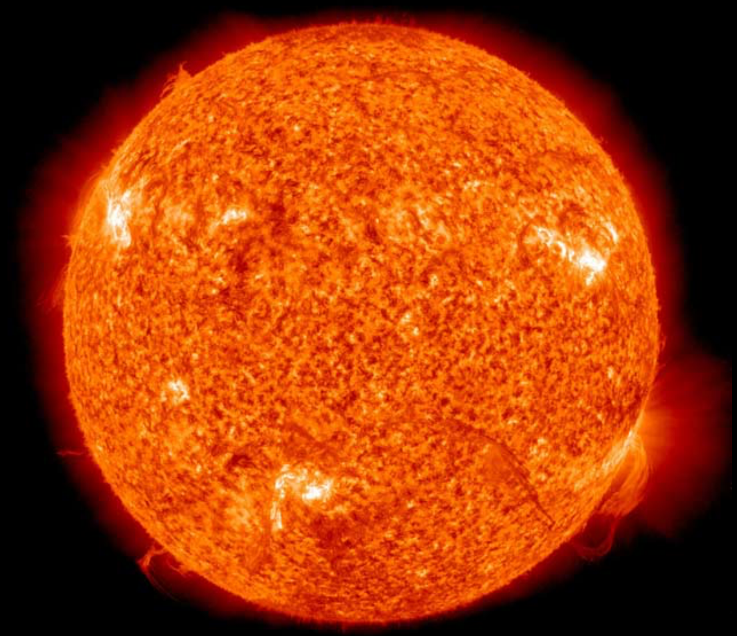
Current Events (9/16/2015)

- (Monday) White House announces $160M for "smart cities" (https://www.whitehouse.gov/the-press-office/2015/09/14/fact-sheet-administration-announces-new-"smart-cities"-initiative-help)
- (Tuesday) DOE announces "technologist in residence program" and "high performance computing for manufacturing program" (http://energy.gov/eere/articles/energy-department-announces-two-new-actions-spur-clean-energy-manufacturing-growth-and)
- (Today) Columbia's Center of Global Energy Policy presents "The New Geopolitics of Energy" Wednesday at 6pm (Live: http://energypolicy.columbia.edu/watch)
- (Next week) Columbia hosts 2015 International Conference on Sustainable Development, free for students (http://ic-sd.org)

Average Temperature of Planets



Our Sun



5,778 °K

3.8×10^{26} W (21 trillion × avg world power consumption)

1.5×10^{11} m distance to Earth

62 MW/m^2 (surface)

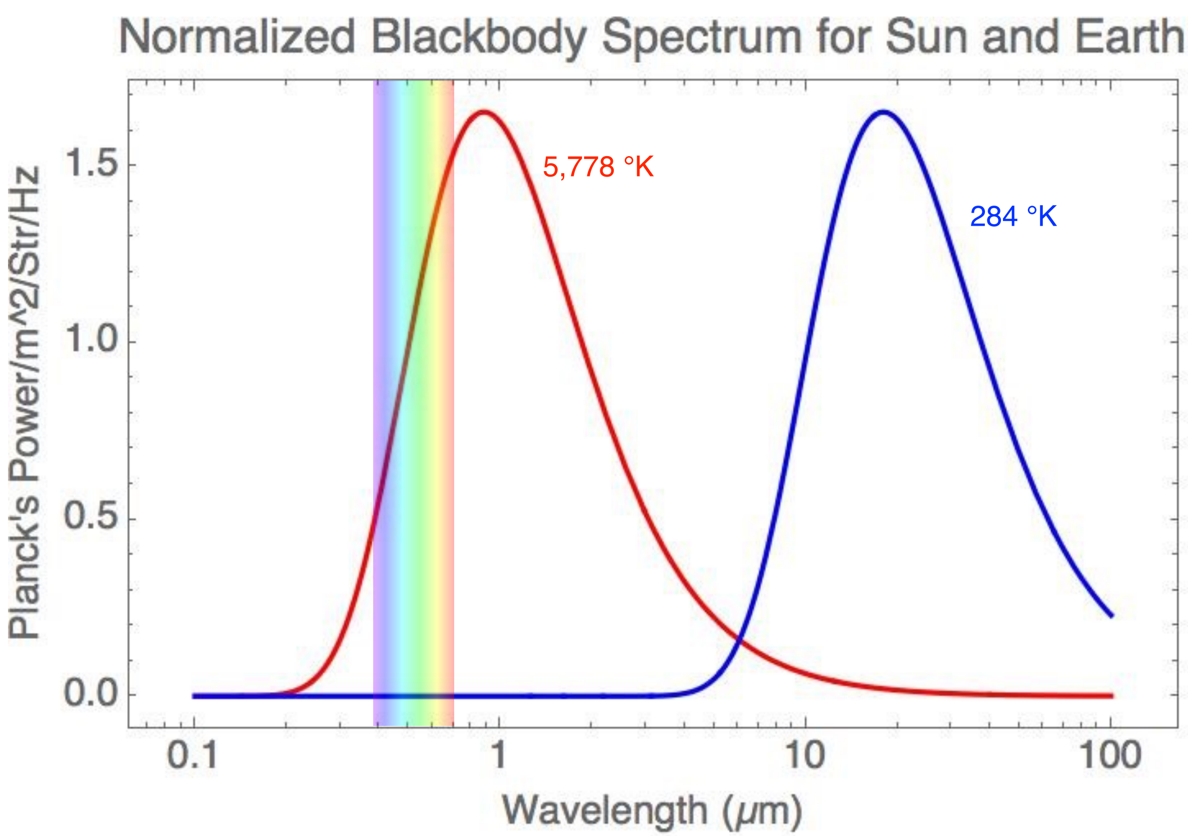
1.34 kW/m^2 (at Earth)

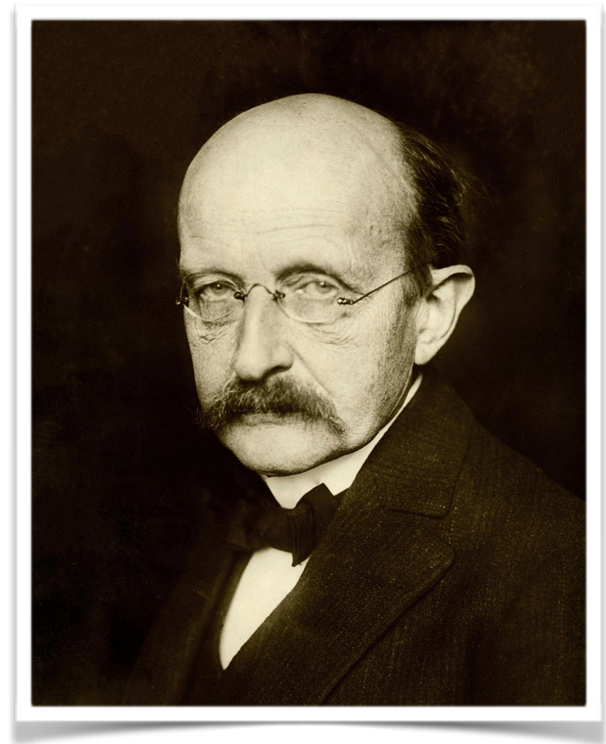
1.7×10^{17} W (170,000 × avg world power consumption)

Planck's Law for Blackbody Spectrum

$$\delta P(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}, \ \ [\mathrm{W/sr\,m^3}]$$

$$P(T) = \sigma T^4 = \int_0^\infty d\lambda \delta P(\lambda, T)$$





Earth

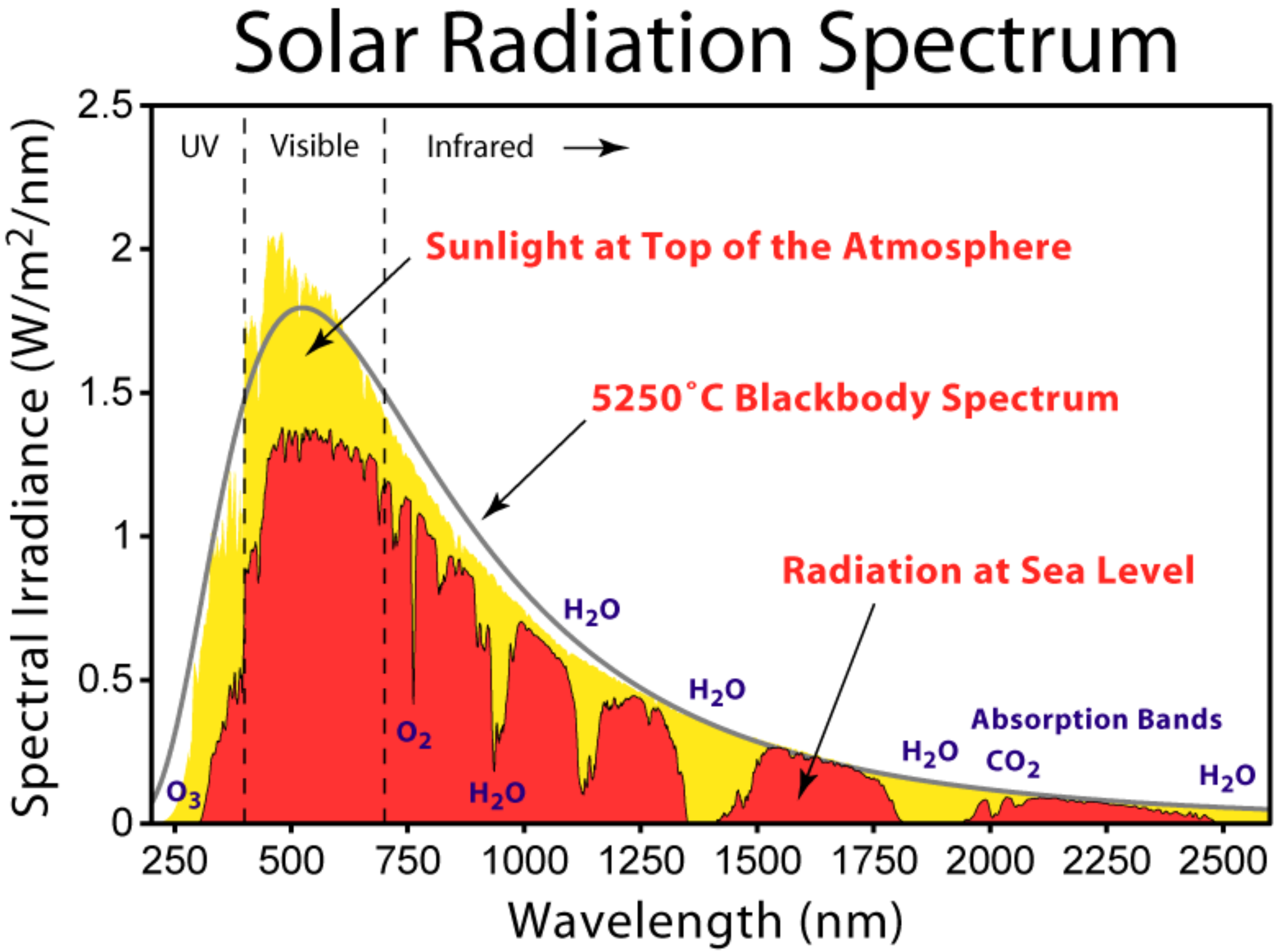
$R = 6.37 \times 10^5$ m

$P_{in} = \pi R^2 (1-\alpha) \times 1.3$ kW/m^2

$P_{rad} = 4 \pi R^2 \varepsilon \sigma T^4$

$T = 253$ °K (- 4 °F)

$\sigma = 5.67 \times 10^{-8}$ W / m^2 °K^4 $\alpha = 0.3$ $\varepsilon = 0.975$



Solar Radiation Spectrum
Spectral Irradiance (W/m²/nm)
2.5
2
1.5
1
0.5
0
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250˚C Blackbody Spectrum
Radiation at Sea Level
H_2O
H_2O
Absorption Bands
H_2O
CO_2
H_2O
O_2
H_2O
O_3
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)

$$R = 6.37 \times 10^5 \text{ m}$$
$$P_{in} = \pi R^2 (1-\alpha) \times 1.3 \text{ kW/m}^2$$
$$P_{rad} = 4 \pi R^2 \varepsilon \sigma T^4$$
$$T = 284 \text{ °K } (53 \text{ °F})$$

$$\varepsilon = 0.975 \rightarrow 0.612$$

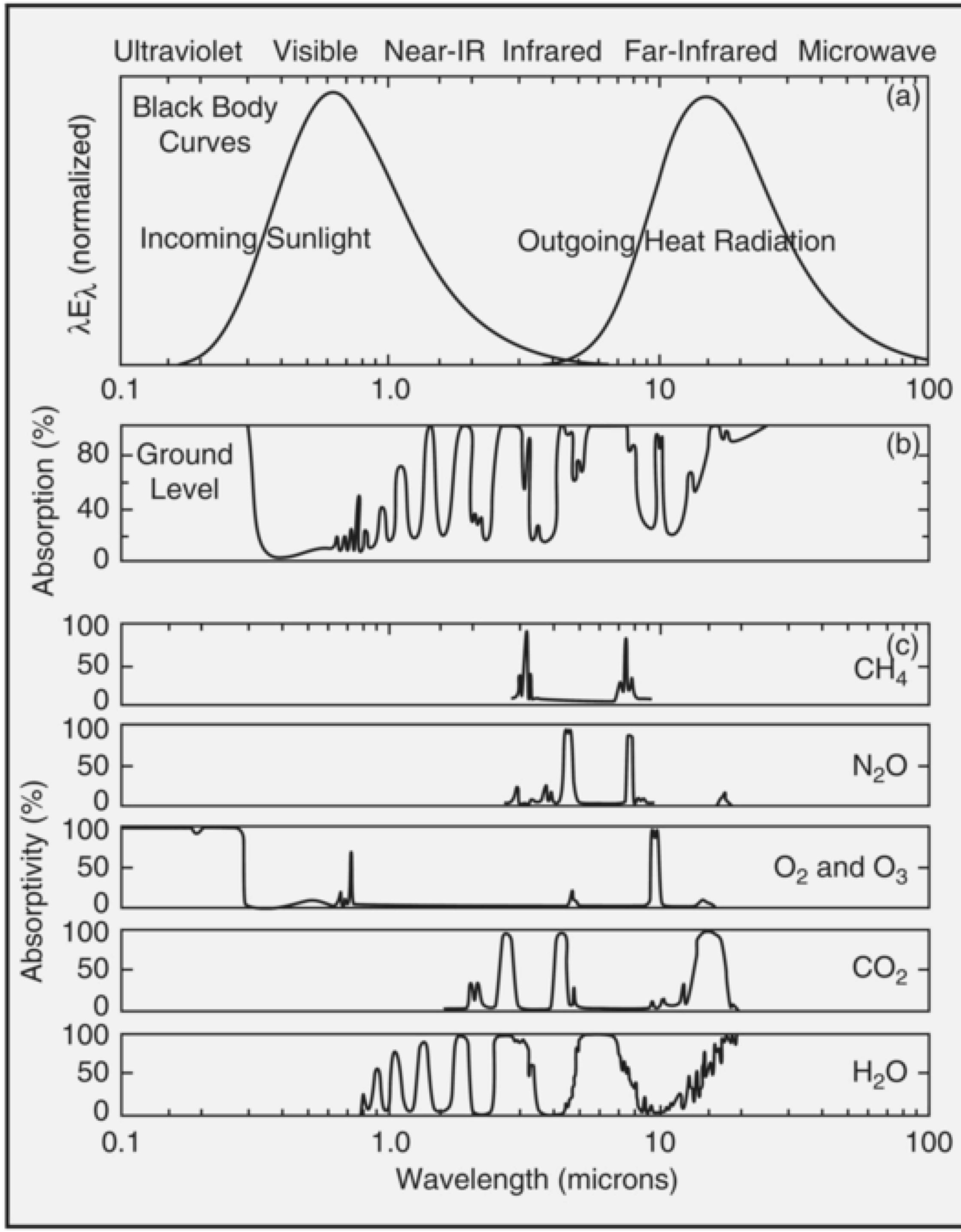
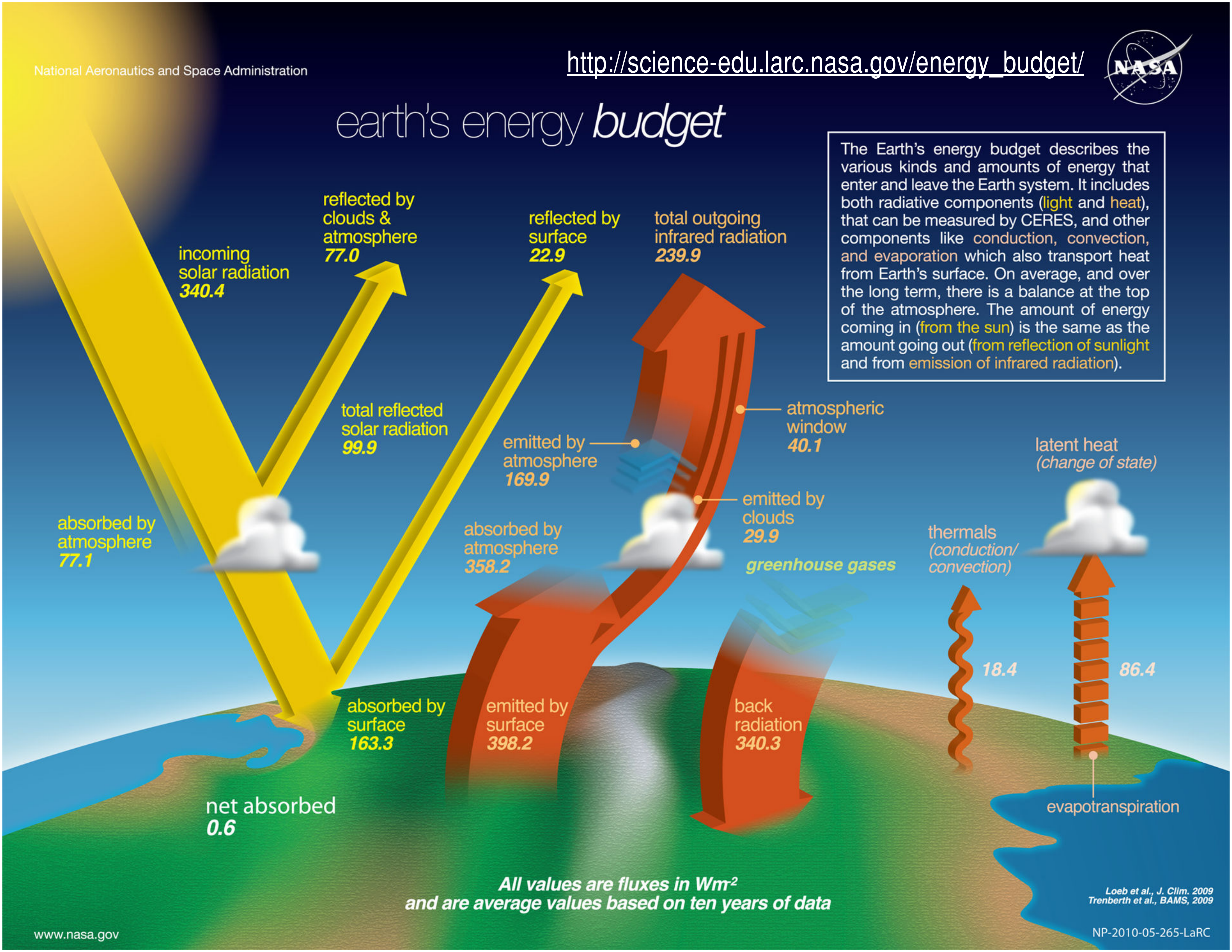


Fig. 2.1 (a) Spectrum of incoming sunlight and outgoing heat radiation for a surface temperature of 60


National Aeronautics and Space Administration
http://science-edu.larc.nasa.gov/energy_budget/
NASA
earth's energy budget
The Earth's energy budget describes the various kinds and amounts of energy that enter and leave the Earth system. It includes both radiative components (light and heat), that can be measured by CERES, and other components like conduction, convection, and evaporation which also transport heat from Earth's surface. On average, and over the long term, there is a balance at the top of the atmosphere. The amount of energy coming in (from the sun) is the same as the amount going out (from reflection of sunlight and from emission of infrared radiation).
incoming solar radiation 340.4
reflected by clouds & atmosphere 77.0
reflected by surface 22.9
total outgoing infrared radiation 239.9
total reflected solar radiation 99.9
atmospheric window 40.1
emitted by atmosphere 169.9
latent heat (change of state)
absorbed by atmosphere 77.1
emitted by clouds 29.9
absorbed by atmosphere 358.2
thermals (conduction/ convection)
greenhouse gases
18.4
86.4
absorbed by surface 163.3
emitted by surface 398.2
back radiation 340.3
net absorbed 0.6
evapotranspiration
All values are fluxes in Wm-2 and are average values based on ten years of data
Loeb et al., J. Clim. 2009
Trenberth et al., BAMS, 2009
www.nasa.gov
NP-2010-05-265-LaRC

Venus

$$P_{in} = \pi R^2 (1-\alpha) \times 2.6\ kW/m^2$$
$$P_{rad} = 4 \pi R^2 \varepsilon \sigma T^4$$
$$T = 303\ °K\ (85\ °F)$$
(actually 737 °K, hotter than Mercury)

$\sigma = 5.67 \times 10^{-8}\ W / m^2\ °K^4$ $\alpha = 0.3$ $\varepsilon = 0.975$

Mars

$$P_{in} = \pi R^2 (1-\alpha) \times 0.62 \text{ kW/m}^2$$
$$P_{rad} = 4 \pi R^2 \varepsilon \sigma T^4$$
$$T = 212 \text{ °K} (- 78 \text{ °F})$$

$\sigma = 5.67 \times 10^{-8}$ W / m^2 °K^4 $\alpha = 0.25$ $\varepsilon = 0.975$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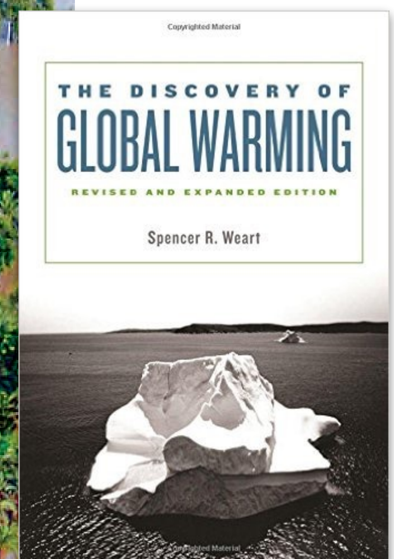
Climate change impacts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THE DISCOVERY OF
GLOBAL WARMING
REVISED AND EXPANDED EDITION
Spencer R. Weart

The peculiar history of climate change: the main actors are committees and no seminal papers or scientific giants emerge

We are now quite certain that over the next century the world will warm up by a few degrees. A few degrees—the difference between early morning and mid morning—doesn't sound like much. But, in fact, the impacts turn out to be dire. … We need to convince the public of the threats we face; yet how can we convince them if we don't explain how scientists came to know what they know?

The history of any scientific development can address general questions of how scientists do their work and reach their conclusions. **But the history of climate change impact studies turns out to be a peculiar kind of history, not at all the sort of story that historians of the physical sciences are used to telling.**

Svante Arrhenius

(1859-1927)

Nobel Prize Chemistry 1903

http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1903/

"in recognition of the extraordinary services he has rendered to the advancement of chemistry by his electrolytic theory of dissociation".

To be sure, the study of impacts began like most histories of science: **in the realm of speculation.** And poor speculation at that. Through the first half of the 20th century, when global warming from the greenhouse effect was itself only a speculation, the handful of scientists who thought about it supposed any warming would be for the good. For example, Svante Arrhenius (figure 1) published the first calculations in 1896 and claimed that the world ***"may hope to enjoy ages with more equable and better climates."*** Others tended to agree that global warming, or any effect of the progress of human industry, could only lead to a beneficent future.

Rise of Environmentalism

(≈1970 to ≈1985)

- **The rise of environmentalism was raising public doubts about the benefits of human activity for the planet**; smoke in city air and pesticides on farms were no longer tokens of progress but instigators of regional or even global harm. A landmark study conducted at MIT in 1970 covered a variety of environmental problems and included a section on greenhouse warming. The experts concluded it might bring "widespread droughts, changes of the ocean level, and so forth," but they could not get beyond such vague worries.

- **Governments were now putting some of the environmental movement's demands into law**; thus arose a practical need for formal environmental impact assessments. A new industry was born with expert consultants who strove to forecast effects on the natural environment of everything from building a dam to regulating factory emissions.

- All those committees managed to reach a consensus on what they were saying: **Everybody signed off on the conclusions.** They could do that because in most areas they agreed to tell the public that they were uncertain—except they were certain there were risks, serious possibilities that needed to be addressed with dedicated research efforts.

Detailed Studies Emerge

- By the early 1980s the studies were starting to look less like seat-of-the-pants guesses; they had numbers, equations, and references to a growing peer-reviewed scientific literature. **The key developments were computer projections** of future temperature rise along with changes in precipitation, soil moisture, and so forth.

- Studies of how climate change might affect human health expanded particularly swiftly in the 1990s, catching the attention of both experts and the public. **As in some other categories, the health-effects work was increasingly supervised not by a particular government but by international organizations**, including the venerable World Health Organization and the new Intergovernmental Panel on Climate Change (IPCC), established in 1988.

- Yet with health, as in other arenas, it was becoming clear that **global generalizations were of much less value** than studies at a regional level.

Scenarios and Probabilities

- The future state of the climate would depend crucially on what emission controls nations chose to impose—and that was the biggest uncertainty of all. Thus was exposed a problem with the standard way of predicting impacts. **Scientists had tried to look into the future by looking to a most likely outcome within a range of possibilities**
- The IPCC got **increasingly specific about just what the consensus of experts meant.** The panel reported whether they judged a given impact to be "more likely than not," or "likely," or "very likely," and so forth.
- In the panel's 2001, 2007, and 2013 reports, the most impressive parts resembled the earlier reports; they simply laid out a variety of the possible impacts.
- **In fact, all the major impacts of climate change as we now understand them were well understood on the global scale by 2001.** The later IPCC reports were mainly distinguished by their increasing regional specificity and their increasing certainty that the impacts were well on their way.

"A Peculiar Kind of Science"

- This brief summary of the history of scientific understanding of the impacts of climate change is a peculiar history, as histories of science go. **Since the real work began in the 1960s, I have not had occasion to mention a single name of an individual: My actors were committees.** I have not even cited any single landmark discovery paper; the committees were looking over dozens of papers, then hundreds, each contributing a little bit to the overall picture.

- **Nor have I described any grand false leads, dead ends, or controversies, which are so common in the history of science. The seat-of-the-pants guesses that scientists started with in the 1960s turned out to be roughly correct;** the story was one of adding to the list of impacts, putting numbers to each item, and becoming ever more certain that the things foreseen would indeed come to pass.

- And in this short article **I have certainly not been able**—any more than the IPCC in its lengthy reports—to present a convincing case, based on logic and observations, of **why anyone should believe the consensus statements.**

http://www.ipcc.ch

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Languages | IPCC web pages | Searc

Phone: +41-22-730-8208 /84/54
Email: IPCC-Sec@wmo.int

Fifth Assessment Report (AR5)

AR5 provides a clear and up to date view of the current state of scientific knowledge relevant to climate change. It consists of three Workir Group (WG) reports and a Synthesis Report (SYR). Information about how the AR5 was prepared can be found here.

Synthesis Report

The Synthesis Report distils and integrates the findings of the three working group contributions to the IPCC Fifth Assessment Report -- the most comprehensive assessment of climate change yet undertaken, produced by hundreds of scientists -- as well as the two Special Reports produced during this cycle.

- Summary for Policymakers
- Factsheets
- Synthesis Report website
- Quick link to report PDFs

News and Sessions

Announcements

- Vacancy: Secretary of the IPCC

Recent Reports

AR5 (Fifth Assessment Report)

More than 830 Authors and Review Editors from over 80 countries were selected for the IPCC's Fifth Assessment Report (AR5) from about 3,600 nominated individuals. In the course of the assessment process Lead Authors enlisted Contributing Authors to prepare technical information in the form of text, graphs or data for assimilation by the Lead Authors into the draft sections.

The IPCC AR5

Summary Statistics

Total Number of Coordinating Lead Authors, Lead Authors and Review Editors: **+830**

Total Number of Countries Represented on Writing Teams: up to **85**

Developing Country and Economy-in-Transition Writing Team Members: **301 (36%)**

Female Writing Team Members: **179 (21%)**

Writing Team Members New to the IPCC Process: **529 (63%)**

Regional Distribution (all AR5 author teams by WMO region): **8%** from Africa, **16%** from Asia, **6%** from South America, **28%** from North America, Central America and Caribbean, **7%** from South West Pacific, and **34%** from Europe.

- "New" connotes an expert not engaged in the AR4 or one of the two IPCC Special Reports released in 2011

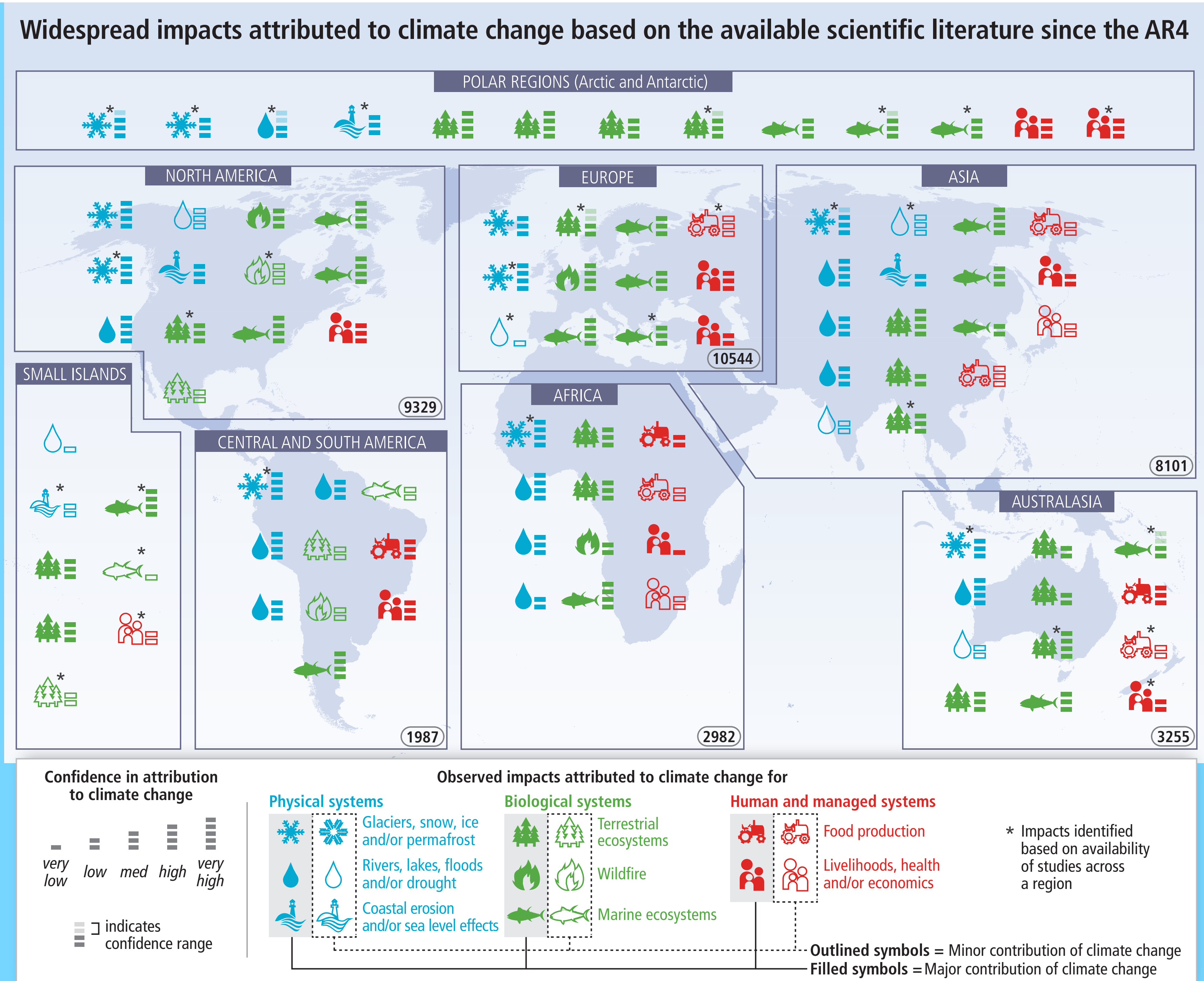

Figure SPM.4 | Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Figure SPM.10). In most scenarios without additional mitigation efforts (those with 2100 atmospheric concentrations

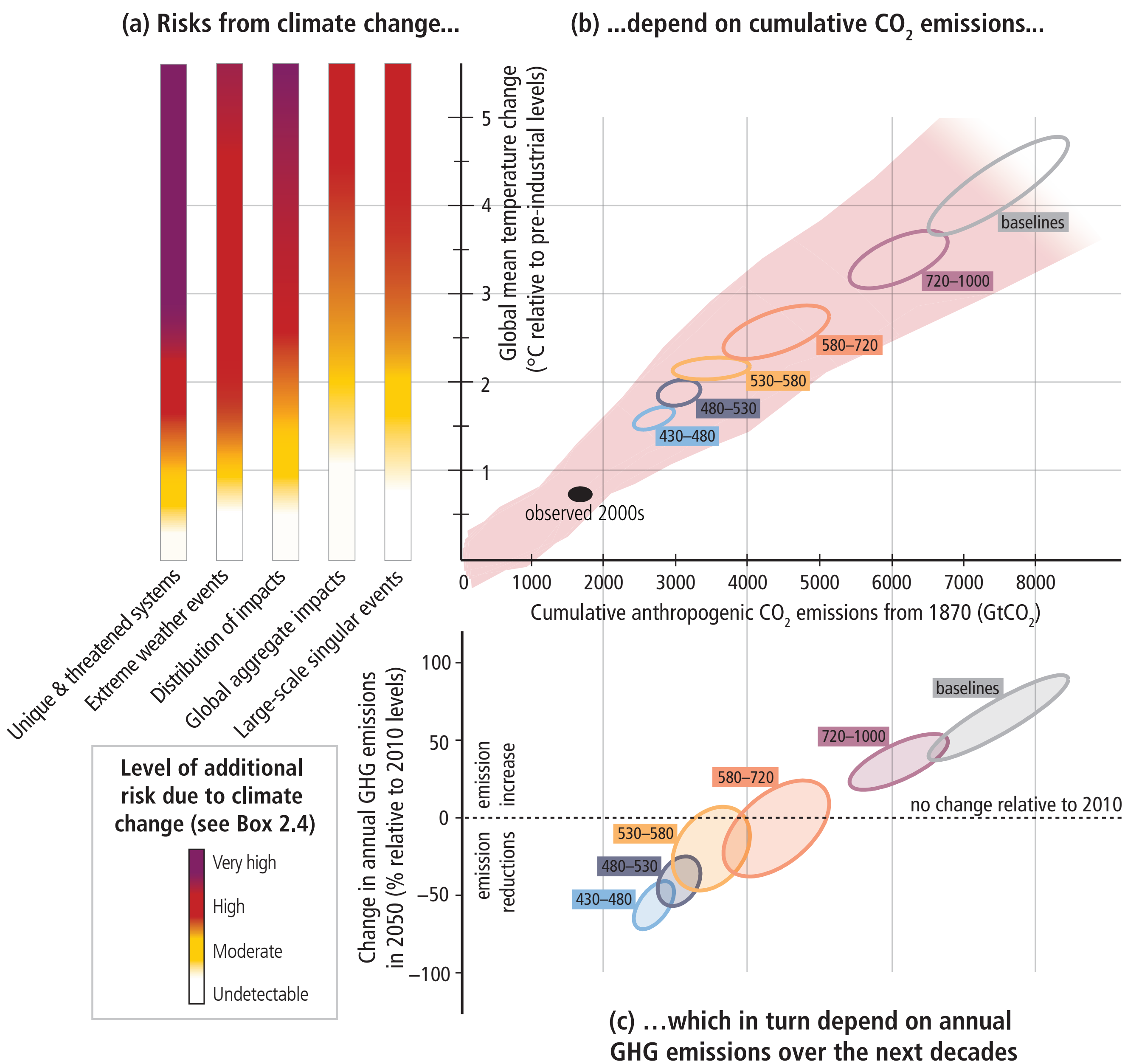

Figure SPM.10 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)**

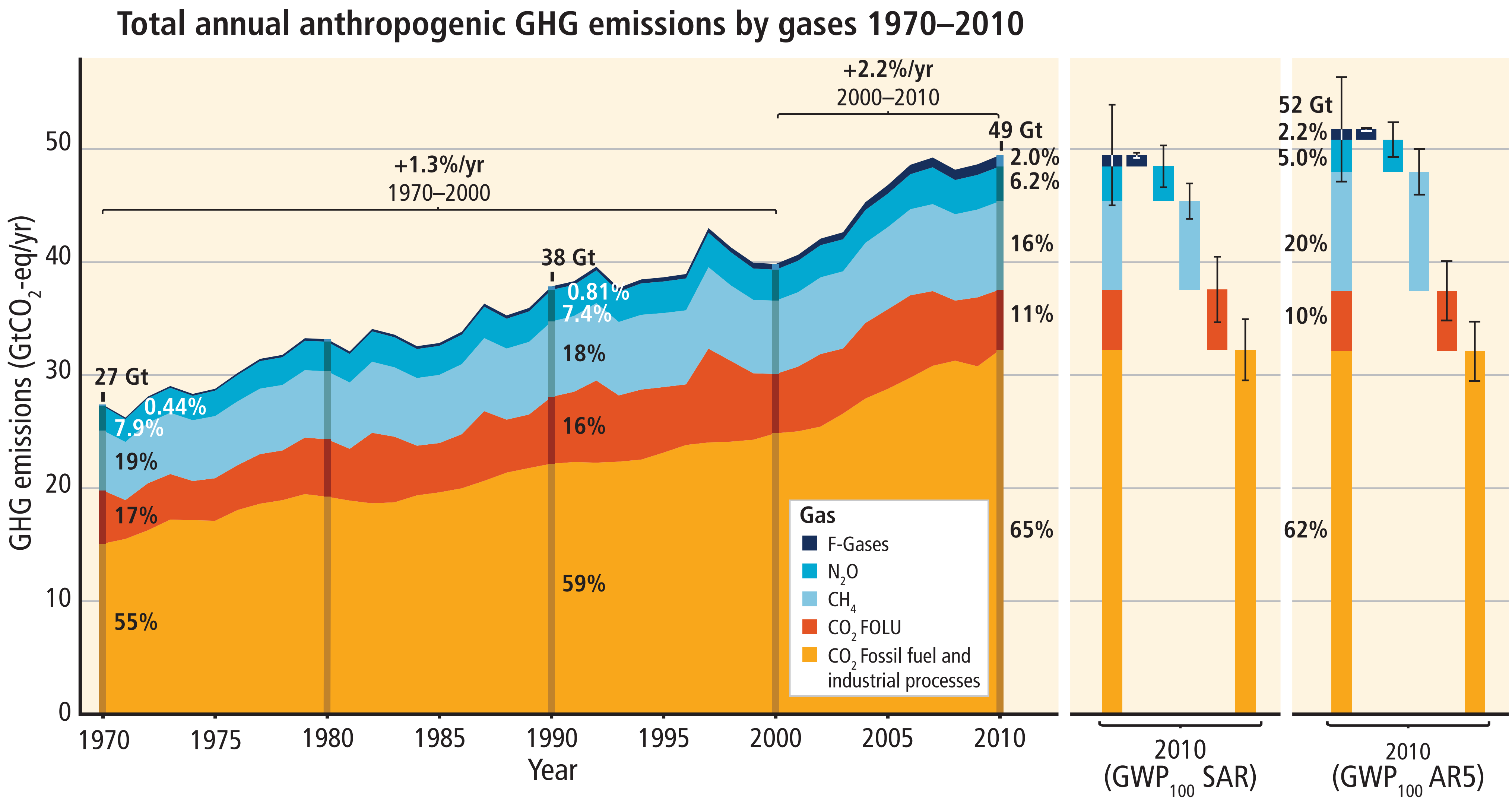

Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO_2-equivalent emissions in this report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the SAR (see Glossary). Using the most recent GWP_{100} values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 $GtCO_2$-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. *{Figure 1.6, Box 3.2}*

Assignment for Next Week

- What motivates your interest in applied physics?
- Name three (potentially) innovative science or technology ideas that may contribute to our national energy and/or climate goals? (no more than three)
- If you were part of an energy technology "start-up", what role(s) would you like to play?

Send by email to mauel@columbia.edu
before C.O.B. next Tuesday

Many common motivations, ideas, and ambitions.

Team	Motivation	Idea 1	Idea 2	Idea 3	Start-up Role
	understand the Universe in all its elegance	battery	Increasing ocean albedo	CCS	scientific advisor
	basic science can advance technologies in leaps and bounds rather than incrementally	CCS	fusion and molten salt fission	Requirements relating to emissions, recycling, etc.	CTO
	seeing some new technology or applied physics principle be used in the real world	massive collection of data that makes unintelligible information and data useful/inspiring to the public	cheap cube-sat (in large numbers) for a low cost weather constellation	harvest the untapped power of the ocean	CTO
	quest to understand the universe and interests in engineering, practical problem solving, and a scientific/technical career	meat substitute	Optimize transportation routing	Harness the gravitational potential energy of orbiting planets	Data computation and presentation or, scientific evaluation of creative proposals
	how things in the world to work	fusion	solar panels in space	batteries	product design and development
	high-energy theoretical Physics; energy and transportation	more cost-effective collection of solar power using planar light guides	use the earth's magnetic field to generate current	desert into a giant field on windmills.	theoretician and spokesperson
	a very flexible skill set that allows you to do anything	mass amount of data we have about climate change and makes it readily available and easily decipherable to the public	solar and ocean hydrothermal		Project Manager
	practice of science can motivate important social and political change in the world	climate scientists motivate political change	education initiative		New technology adoption leader
	understand the universe and help make the world a better place	Solar roads	Roof top gardens		researcher
	interests in energy, plasma physics, law and sustainable development	Attachments to siphon carbon out of the ocean	Coat the smoke stacks of GHG emitters with CO2 absorbers	Cover the ice caps with tin foil	CEO, or R&D
	see the world change, education	hyperloop	synchrophasors in electrical grids	CCS	project manager
	fundamentals of nature	consumer metadata to determine beneficial patterns	Mitigation extended cloud seeding	machine learning algorithms for advanced fusion	R & D
	applied math & learning how the universe works	easier/more accessible way to charge phones/ electronic devices	breakthrough renewable energy sources	make carbon dioxide do something useful	technological developer
	love of problem solving	"smart grid"	organic photovoltaic cells	carbon geosequestration	data scientist
	love for physics and alternative sources of energy	Nuclear reactors	solar powered plants	"Artificial plants"	advisor to the CEO
	Hands on experience and applying physics for a better planet.	Roads for energy	Human motion for energy	Revamping the culture of alternative energy	organizing and leading
	lasting impact on the future of humanity	Self-Driving Electric Cars	Garbage Incineration	Small-scale Nuclear Energy	engineer or product designer
	physics for the "benefit of mankind in future"	4th gen fission reactors	Public outreach to reverse, the negative image of nuclear energy	nuclear fusion	Scientist and/or Engineer
	Learn physics and Aerospace	Nano-structured clothing for enhanced IR cooling	convert kinetic energy of people's daily motion to electric energy / batteries	volcano's geothermal heat energy	tester or an examinator