The Quantum Physics of Global Warming

Kavli Institute for Theoretical Physics
June 18, 2014

Brad Marston
Brown University
Lyell Glacier in 2013
“When we try to pick out anything by itself, we find it hitched to everything else in the Universe.” -- John Muir
“When we try to pick out anything by itself, we find it hitched to everything else in the Universe.” -- John Muir
Particles Come in Lumps
Particles Come in Lumps

\[ P_{12} = P_1 + P_2 \]
Particles Come in Lumps

Source: The Feynman Lectures on Physics
Waves Are Continuous
Waves Are Continuous

\[ I_1 = |h_1|^2 \]
\[ I_2 = |h_2|^2 \]
\[ I_{12} = |h_1 + h_2|^2 \]
Waves Are Continuous

"Interference"
Water Waves

Source: AAPT and Ztek “Physics: Cinema Classics”
Water Waves

Source: AAPT and Ztek “Physics: Cinema Classics”
Photons Demonstrated

Source: Brown University Department of Physics
Photons Demonstrated

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Photons Demonstrated
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Is it a particle? Wave? Both? Neither?
Photons Demonstrated

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“Like nothing you’ve ever seen before.”
Photons Demonstrated

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\[ E = h f \]
Photons Demonstrated

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Particles come in lumps (energy) \[ E = h \nu \]
Photons Demonstrated

Is it a particle? Wave? Both? Neither?

“Like nothing you’ve ever seen before.”

Particles come in lumps (energy) → $E = hf$ ← Waves have a frequency
Photons Demonstrated

Is it a particle? Wave? Both? Neither?

“Like nothing you’ve ever seen before.”

Particles come in lumps (energy) ————> \( E = h \cdot f \) ————> Waves have a frequency

Planck’s constant
albedo
$S = 1,361 \text{ W/m}^2$
Temperature of the Earth

\[ \sigma T^4 = \text{Heat Radiating To Space} \]
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\[ a \approx 30\% \]
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\[ a \approx 30\% \]

\[ T = 255\text{K} \]

\[ = -18^\circ\text{C} \]
Terrestrial Planets
## Terrestrial Planets

<table>
<thead>
<tr>
<th>Planet</th>
<th>Calculated Temperature</th>
<th>Actual Temperature</th>
<th>Greenhouse Warming</th>
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<tbody>
<tr>
<td></td>
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<table>
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<tr>
<th>Planet</th>
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</tr>
</thead>
<tbody>
<tr>
<td>calculated temperature</td>
<td>0</td>
</tr>
<tr>
<td>actual temperature</td>
<td>59</td>
</tr>
<tr>
<td>greenhouse warming</td>
<td>59</td>
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<tbody>
<tr>
<td>Earth</td>
<td>0</td>
<td>59</td>
<td>-69</td>
</tr>
<tr>
<td>Mars</td>
<td>-69</td>
<td>-63</td>
<td>6</td>
</tr>
</tbody>
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## Terrestrial Planets

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<th>Planet</th>
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<th>Mars</th>
<th>Venus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>calculated temperature</strong></td>
<td>0</td>
<td>-69</td>
<td>-38</td>
</tr>
<tr>
<td><strong>actual temperature</strong></td>
<td>59</td>
<td>-63</td>
<td>800</td>
</tr>
<tr>
<td><strong>greenhouse warming</strong></td>
<td>59</td>
<td>6</td>
<td>838</td>
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</tbody>
</table>
Water vapor
Water vapor
Water vapor
Water vapor

Carbon dioxide
Water vapor

Carbon dioxide

Oxygen & Nitrogen
$0^\circ F + \left( \frac{12^\circ F}{km} \right) \times 5 \text{ km} = 60^\circ F$
\[ 0^\circ F + \left( \frac{12^\circ F}{km} \right) \times 5 \text{ km} = 60^\circ F \]

\[ 2^{-\frac{1}{4}} \times 255K = 214K = -60^\circ C = -76^\circ F \]
Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

Source: Global Warming Art
Climate Sensitivity
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Feedbacks will amplify this temperature increase to 2 - 3 degrees C.
Variations of the Earth’s surface temperature: years 1000 to 2100

Departures in temperature in °C (from the 1990 value)

Observations, Northern Hemisphere, proxy data

Global instrumental observations

IPCC 2001
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Global instrumental observations

Projections

Several models all SRES envelope

Bars show the range in year 2100 produced by several models

Scenarios
- A1B
- A1T
- A1FI
- A2
- B1
- B2
- IS92a

IPCC 2001
Prof. J. D. Whitney (Harvard and chief of the California Geological Survey): Muir is an “ignoramus” and a “mere sheepherder.”
Atmospheric Dynamics

The northern polar jet stream, which can be up to 200 kilometers across, flows west to east at speeds of up to 400 km/hr, some 7 to 12 kilometers above Earth’s surface. It delineates colder and warmer air masses.

Source: *Science* 344, 250 (2014)
Declines in sea ice cover and other factors are driving “Arctic amplification,” or the more rapid warming of the Arctic than warming of the globe as a whole.

Jennifer Francis believes Arctic warming is altering the jet stream’s behavior, in particular by reducing the pressure gradient between the colder, thinner polar atmosphere and the warmer, thicker atmosphere to the south.

The result, she hypothesizes, is a slower, more sinuous jet stream with tips that stretch farther north.

The “wavier” jet stream causes longer lasting weather patterns, such as the southward bend that brought record cold to much of eastern North America this past winter.
Idealized General Circulation Models (GCMs) of planetary atmospheres, solved by a variety of methods.

What's New in Version 1.0.4
New wave lifecycle model, better organized menu. Bug fixes to CE3 (now conserves 3rd Casimir) and the calculation of the eddy diffusivity.

Free
Category: Education
Updated: May 23, 2013
Version: 1.0.4
Size: 1.4 MB
Language: English
Seller: Brad Marston
© 2013 M3 Research
Rated 4+

Requirements: OS X 10.8.3 or later, 64-bit processor

Customer Ratings
We have not received enough ratings to display an average for the current version of this application.
All Versions: 8 Ratings
Wave-Flow Interaction in Geophysics, Climate, Astrophysics, and Plasmas

**Coordinators:** James Cho, Patrick Diamond, Brad Marston, Steve Tobias

**Scientific Advisors:** Oliver Bühler, David Dritschel, Rick Salmon

Waves that interact strongly with the flowing media in which they propagate are fundamental to many systems. Examples of such wave-flow systems are gravity waves in atmospheres and oceans, planetary waves in weather and climate, tides and inertial waves in planets and stars, density waves in planetary rings and accretion disks, and Alfvén waves in tokomaks and solar wind. However waves and background flows are often characterized by very different spatial and temporal scales. Hence, modeling their interaction poses considerable technical and conceptual challenges.

Significant advances in wave-flow interaction theory, simulation, experiment, and observation over the past decade make this KITP program timely. For example, there is now a better understanding of the role of the interaction in the long-term behavior of the atmosphere and oceans. The program will bring together international researchers with expertise in wave-flow interactions to help solve critical problems across the disciplines of applied mathematics, geophysics, climate, astrophysics, and plasma physics. The program will begin with a week-long **conference** (March 24 - 27, 2014) that will include overviews and perspectives on eddy - mean-flow interactions in fluids.

**DATES:**

Mar 24, 2014 - Jun 20,
Quantum physics is statistical
Quantum physics is statistical
Quantum physics is statistical

Climate is the statistics of weather: “Climate is what we expect; weather is what we get.” Can we use tools borrowed from quantum physics?
Physics of Climate Change

Coordinators: Jean M. Carlson, Gregory Falkovich, John Harte, J. Bradley Marston, Raymond Pierrehumbert

Scientific Advisors: Paul Kushner

Climate change is upon us. The need for accurate and detailed predictions is pressing, but even the most sophisticated models running on the world’s fastest computers are far from directly capturing crucial physics such as cloud formation and deep convection. First-principles models of ecosystem dynamics are even further out of reach, yet ecosystems respond to and affect climate in a wide variety of ways.

The basic equations governing climate variables such as wind velocity and soil moisture were assembled by Lewis Fry Richardson nearly a century ago. The program is premised on the idea that the science of climate can again be advanced by an infusion of ideas from modern physics. As our central goal we seek to identify outstanding questions that would benefit from physics input, and to determine the most intelligent ways to go about answering these questions. Large-scale atmospheric and oceanic circulation, cloud physics, and ecosystems are three broad areas of interest. In addition connections will be made between experts in different fields, enabling the solution of outstanding open problems. Coordination is planned with the National Center for Ecological Analysis and Synthesis (<http://www.nceas.ucsb.edu>).

A secondary goal is to inform other physicists as well as the public (through a forum) about the science of climate change.

To focus attention on key questions, a conference will be held near the beginning of the workshop, scheduled for Tuesday through Saturday, May 6 to 10, 2008. Please see Conference Page for details.
Fire in the Earth System


Fire is a worldwide phenomenon that appears in the geological record soon after the appearance of terrestrial plants. Fire influences global ecosystem patterns and processes, including vegetation distribution and structure, the carbon cycle, and climate. Although humans and fire have always coexisted, our capacity to manage fire remains imperfect and may become more difficult in the future as climate change alters fire regimes. This risk is difficult to assess, however, because fires are still poorly represented in global models. Here, we discuss some of the most important issues involved in developing a better understanding of the role of fire in the Earth system.

Emission of atmospheric carbon dioxide levels (9). Fire also influences the geological cycling of other elements, such as phosphorus, by volatization and leaching (10).

Fire’s occurrence throughout the history of terrestrial life invites conjecture that fire must have had pronounced evolutionary effects on biotas. However, the evolution of adaptations to fire remains a difficult topic to explore because traits that increase the rate of occurrence of fire, or of recovery following burning, are not unambiguously the result of natural selection by fire regimes (11) (table S1). Nonetheless, flammable vegetation types leave distinct signatures in the fossil record, chronicling changes in their abundance and geographic range. For example, tropical grasses produce large quantities of fine, aerated fuels that become highly flammable during dry periods, and their C3 photosynthetic pathway...
Climate Change Impacts in the United States

U.S. National Climate Assessment
U.S. Global Change Research Program
Stevens and Bony, Science 340, 1053 (2013)