Simple Tests of Simple Climate Models on More Than One Planet

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Overview

* Why design simple climate models?

* Focus on variation with latitude of annually averaged temperatures

* Surface temperatures on Venus, Earth, Mars, and Titan

* Effective temperatures on Venus, Earth, Mars, and Jupiter

* Seasonal effects on Earth

* Conclusions

Complicated Climate Models

* General Circulation Models (GCMs)

* Years to develop, almost as long to run…

* Require huge amounts of actual data to make predictions

* Mountains of output may obscure understanding

* Generally accepted to work

Simple Climate Models

* One-dimensional energy balance models

* Cheap, fast to design, fast to run

* Require minimal actual data to make predictions

* Simple response to “parameter-tweaking” aids understanding

* Not as accurate as a GCM

* Are they at all useful?

Why should a simple climate model work?

* Can a simple model describe a complex climate system?

* Simple models can describe other physical systems

* Thermodynamics is a simple tool of unrivalled power for describing complex systems

* Simple extremum principles abound in physics, including the field of fluid dynamics

* Such extremum principles are usually found by guesswork

Uses of simple climate models

* Extra-solar planets

* Comparative planetology within our own solar system

* Successful simple models are always best for developing understanding

Proposed Simple Climate Models

* One dimensional annual average:

* Dynamic Heat Flux = Absorbed Solar Radiation - Emitted Thermal Radiation

$J(x) = F(x) - I(x)$ where $x =$ sine(latitude) and $I = \sigma T^4_{effective}$

* May parameterize I(x) by $I(x)=A + BT_{surface}(x)$ in some models

* Simple model for F(x) is easy given orbit and albedo

* Climate is all about J(x)

Getting at J(x)

Traditional approach

Use diffusion model $J(x) \quad {}^2T_s(x)$

$(1-x^2)\, d^2I/dx^2 - 2x\, dI/dx - I/D + F/D = 0$

D from fit to current Earth and scaling

D α $(P_s c_p / g^2 m^2 \Omega^2 R^2)$

Nontraditional approach

Extremisation of some functional

$$\int_{-1}^{1} (F(x) - I(x))(T_{s,e} - < T_{s,e} >)\,dx$$

$$\int_{-1}^{1} \frac{(F(x) - I(x))}{T_{s,e}}\,dx$$

$I = \sigma T_e^4 = A + BT_s$ and energy balance

Model Requirements

F(x) requires stellar luminosity, planetary orbital elements, and a planetary albedo

Traditional approach

$D \propto (P_s c_p / g^2 m^2 \Omega^2 R^2)$

Extremisation approach

Sometimes nothing more, sometimes $I=A+BT_s$ parameterization

Does not formally depend on atmospheric composition or planetary rotation rate

Surface Temperature Summary

Predictions of the extremisation models are basically equivalent

	Extremisation	Traditional
Venus	Bad	Adequate
Earth	Good	Good
Mars	Bad	Bad
Titan	Adequate	Bad
Scores	2/4	2/4

Both classes of models seem to do equally well, despite the huge amount of extra information needed by the traditional models.

Endmember models for Effective Temperature Predictions

No heat transport
$I(x) = F(x)$

Infinite heat transport
$I(x) = \langle F(x) \rangle$

Still to come…

* Effective temperature predictions

* Seasonal predictions

Effective Temperature Summary

Venus - accurate ~ 10%

Earth - accurate ~ 5%

Mars - accurate ~ 10%

Jupiter - Large internal heat source

Both rotation rate and surface pressure vary by orders of magnitude between the three rocky planets studied here.

Seasonal Variations on Earth

Caused by obliquity and, in the general case, orbital eccentricity.

What temporal and spatial scales are appropriate for these models?

Annual, seasonal, or daily?

…What if a planet's day is not a small fraction of its year…?

Seasonal Summary

Failure

Predictions vary by too much over a year. In reality, heat is transported from the sunlit tropics to the dark winter pole to buffer temperatures.

Water boils at the summer poles…

Conclusions

* A valid simple climate model would be a good thing.

* Proposed extremisation models work just as well as traditional models for predicting annually averaged equator-to-pole surface and effective temperature differences on planets without internal heat sources.

* Proposed extremisation models are basically equivalent in their predictions.

* Both traditional and extremisation models fail to reproduce seasonal variations correctly.