Climate, economics, and statistical thermodynamics

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Introduction

- Earth system modelling: coupling of the physical climate with biogeochemical processes
- Inclusion of socioeconomic processes: adds another layer of complexity and unpredictability
  - Particularly since economic actors are 'self-aware': can read scientific papers and model code . . .
- Nevertheless, both the climate system and economies are subject to physical laws
  - Large and complex systems, statistical mechanics and thermodynamics should be applicable
  - Some form of maximum entropy principle?
- 'Dissipative' system: maximum entropy *production* [Dewar 2003; Martyushev & Seleznev 2006].

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The Big Questions?

- Is coupled modelling of climate and socioeconomic systems possible?
- What can we learn from history?
- How can we analyse and/or specify physical constraints on the system?

‘Maximum entropy production’

- Maximum entropy S for an isolated system in equilibrium:

  $$dS \geq dQ/T \qquad S = k \log W$$

  S is entropy, Q is heat supplied to system, k is Boltzmann constant, W is volume in phase space.

- For a dissipative system subject to appropriate constraints, the most ‘probable’ state should be that of maximum entropy *production* (MaxEP) [e.g., Dewar 2003].
- Maximum volume in the phase space of ‘paths’.

MaxEP—applications

- Transition to turbulence
- Climate of Earth and other planets [e.g., Lorenz et al. 2001]
- Effect of large-scale wind power production on the atmospheric circulation [Miller et al. 2011]
- Feedback between climate and ecology (optimal radiation balance) [Kleidon et al. 2000]

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[Lorenz et al. 2001]

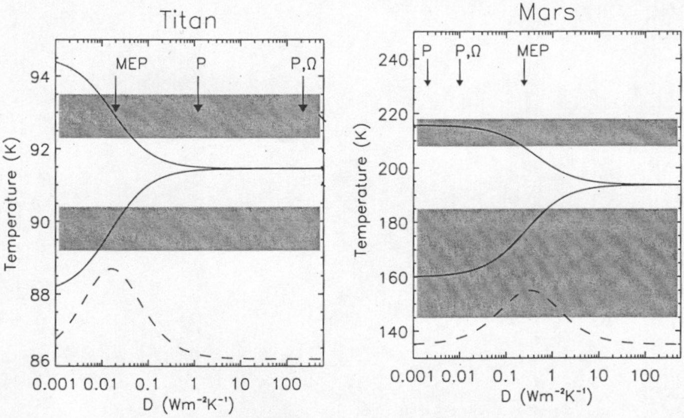

Figure 2. Observed temperature contrasts on Titan (a) and Mars (b) agree with predictions at maximum entropy production. Shading indicates observed annually-averaged temperature ranges for the regions 10- 20 deg and 40-60 deg latitude. Solid curves are model temperatures (upper curve tropics; lower curve polar regions) as a function of D : dashed curves at bottom are the entropy production $dS/dt=(F/T_1-F/T_0)$ in arbitrary units. It is seen that the temperatures are successfully predicted where dS/dt has a maximum. Values of D predicted from scaling pressure (P), or pressure and rotation rate (P,Ω) are marked: the arrows marked MEP correspond to the maximum entropy value inferred from the simple expression $D=\sigma T^3/2$. High ($>10 Wm^{-2}K^{-1}$) values for D predict near-isothermal conditions and do not agree with observations. Low ($<0.01 Wm^{-2}K^{-1}$) D values appear compatible for Mars but not for Titan, but see text for discussion of the failure of small D for the Mars case. Note that the temperature slopes are steepest at MEP.

'Thermodynamics' / MaxEP in economic modelling

- Human society consumes energy, raw materials, and the products of biological processes, so can be regarded as a dissipative system.
- Some economic models consider the 'information entropy' of economic networks
- But I consider the 'real' thermodynamic entropy, generated by the dissipation of mechanical, chemical energy etc.
- Examples: Georgescu-Roegen [1971], Lorenz [2003], Jenkins [2004, 2005, 2009], Annila & Salthe [2009], Hermann-Pillath [2010], Woollacott [2011].
- 'Rebound effect', see Woollacott [2011] and references therein.
  - MaxEP may explain *increasing* energy consumption after processes become more energy-efficient.

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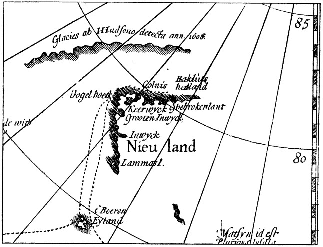
‘History’

- It is instructive to consider the entropy production in historical economic systems (agricultural, hydraulic, industrial).
- It may be valuable to consider the transitions which occurred between different systems (changes in technology, exhaustion of resources, conflict periods, climate change, epidemics, etc.)
- This speaker [Jenkins 2004, 2009] performed some preliminary calculations for the early whaling activities on Spitsbergen (exhaustion of a non-renewable biological resource).

THE MUSCOVY COMPANY'S MAP OF SPITSBERGEN (1625).



SPITSBERGEN FROM HONDIUS' CHART (1611).

17th-century Svalbard whaling

[Conway 1906]

- In a good year (1697), 201 ships caught 1968 whales and obtained 63883 casks of blubber (perhaps 13000 tonnes)
- Lipid content corresponds to 570×10^{12} J, spread over the year this is 18 MW, entropy prod. 63 kW K^{-1}
- Compare with the size of a ‘typical’ country’s economy: England 1688 (Gregory King, in Laslett 1971), population 5.5 M, food consumption ≈530–1000 MW, entropy prod. ≈1.9–3.2 MW K^{-1}.
- Whale oil was largely used in the making of soap, used to launder fine linen for the elite, thus acting as a ‘social catalyst’ for the political economy
- Elite population of England was about 100k, food consumption ≈10–15 MW this is of the same order of magnitude as the energy content in the supply of whale lipid to NW Europe

17th-century Svalbard whaling

Effect on the marine ecosystem:

- From Sakshaug 1997, new primary production in Barents Sea is 60 g C m^{-2} a^{-1}
- Krill and Calanus production is 9.5 g C m^{-2} a^{-1}
- If 5 g of this is available for whales, and they use it with 10% efficiency to produce lipid for ‘harvesting’, we get 0.58 g lipid m^{-2} a^{-1}
- A production of 13000 tonnes thus requires a primary production area of 22000 km^2

Was this sustainable?

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What do economists *need* from climate scientists? and *v.v.*?

- Physical, chemical, biological conditions
  - Temperature, precipitation, wind, sea level, ...
  - Conditions for agriculture, fisheries, transport, building, health
  - Access to water, minerals and raw materials
  - Disposal of waste

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What do climate scientists *need* from economists?

- Social conditions, leading to
  - Changes in radiation and water balance
  - Changes in biological environment
  - Amount of raw material extraction
  - Amount of environmental pollution

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Discussion points

- Economic models should be physically consistent
  - Energy and raw material pathways
  - Pollution dispersion
  - Feedback on radiation balance
- Allow for (potentially sudden) changes in energy and material flows
  - Alternative pathways with greater entropy production?
- Scope for analysis of past (historical, archaeological) processes and events?

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