Data Science in Academic Research
& Physics of Wind Energy

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Data Science in Academic Research & Physics of Wind Energy

Data Science: Computer Programming, Mathematical Modelling, Visualization

Mechanism: Thermodynamics, Fluid Dynamics

Assimilated Meteorological Data: GEOS-5 DAS

Wind Energy
Data:
The study is based on meteorological data from the MERRA compilation GEOS-5 DAS. Wind speeds, air temperature, and other variables were obtained on the basis of retrospective analysis of global meteorological data. I use the standard 3-hourly output available for 42 pressure levels with a horizontal resolution of 1.25 ° latitude × 1.25 ° longitude.
The atmosphere: a non-equilibrium thermodynamic system
The atmosphere: a non-equilibrium thermodynamic system

(a) Zonal-Average Temperature (K)
(b) Vertical profile of heating (unit: 10^{-3} W/kg)
(C) Vertically integrated heating in the atmosphere (unit: W/m^2)
The atmosphere: a non-equilibrium thermodynamic system

Schematic diagram indicating the transfer of entropy across the boundaries and the production of entropy within the atmosphere.

\[
\frac{dS_{\text{atm}}}{dt} = \frac{dS_i}{dt} + \frac{dS_e}{dt} > 0
\]

\[
(\Delta S)_{\text{max}} = \int_{t_0}^{\infty} \frac{dS_{\text{atm}}}{dt} \cdot dt = \int_{t_0}^{\infty} \frac{dS_i}{dt} \cdot dt
\]
The atmosphere: a non-equilibrium thermodynamic system

Schematic diagram indicating the transfer of entropy across the boundaries and the production of entropy within the atmosphere.

Isolate this system and then connect it with a thermal engine

\[
\frac{dS^{\text{atm}}}{dt} = \frac{dS_i}{dt} + \frac{dS_e}{dt} \quad \frac{dS_i}{dt} > 0
\]

\[
W_{\text{max}} = \int_{-\infty}^{+\infty} dW_{\text{reversible}} \, dt
\]
If a system is in thermodynamic equilibrium, its entropy, $S_{eq}$, and temperature, $T_{eq}$, are functions of its total energy, $E_{eq}$.

Namely: \[ S_{eq} = S_{eq}(E_{eq}) \] \[ T_{eq} = T_{eq}(E_{eq}) \]

The continuous line in the figure defines the behavior of the function $S_{eq}=S_{eq}(E_{eq})$.

Transition b-to-a: $(\Delta S)_{\text{max}}$  
Transition b-to-c: $W_{\text{max}}$
The thermodynamic condition, \(( E^\text{atm}, S^\text{atm} )\), of the atmosphere on May 30, 2002 displayed in an Entropy-Energy Diagram. The \(\Delta E\) in the figure represents the maximum work, \(W_{\text{max}}\), that can be performed in a thermally reversible process; \(\Delta S\) represents the maximum increase in entropy, \((\Delta S)_{\text{max}}\), that can arise in a thermally irreversible process with zero work.
The seasonality of the thermodynamic conditions, \((E_{\text{atm}}, S_{\text{atm}})\), of the atmosphere in an Entropy-Energy Diagram.
The Creation of Kinetic Energy
The Creation of Kinetic Energy

Total kinetic energy of the atmosphere: \[ KE = \int \frac{1}{2} \rho (u^2 + v^2) dV \]
(a) The departure of global kinetic energy from its 32 years' mean value 1.50 MJ/m². The seasonality of the departure is removed via 365-day running average. (b) The time series of the multivariate ENSO index from January 1979 to December 2010. Positive values correspond to the warm events of the ENSO phenomena, while the negative ones correspond to the cold events.
The rate for production of kinetic energy in a fixed unit of volume:

\[ \frac{\partial \rho K}{\partial t} = - \nabla \cdot (K \rho \nu) - \nu \cdot \nabla p + \rho \nu \cdot F - g \rho \omega \]

The destiny of kinetic energy in the atmosphere from a mechanical perspective:

\[ \text{lifetime} = \frac{KE}{D} = 6.9 \text{ days} \]
The Creation of Kinetic Energy

Efficiency: $\eta = \frac{W}{Q_{in}}$

$Q_{f} = \int \rho Q_i dV = -\int \tau : \nabla \vec{v} dV$

$Q_{out} = \int \rho Q_e dV_{Q_{h}<0}$

$Q_{in} = \int \rho Q_e dV_{Q_{e}>0}$
The changing patterns of wind in the U.S.
The changing patterns of wind in the U.S.

Snapshot of the geopotential height at 500 hPa (Time: December 1\textsuperscript{st} 2011)
The changing patterns of wind in the U.S.

Video: The changing patterns of the variations in geopotential height and wind speed at 500hPa together with the time and spatial variation of the wind and related values for CF values at 100m for winter 2008 (Dec 1st ~ Feb 28st). In calculating the potential electricity generated from wind, we chose to use power curves and technical parameters for the GE 2.5 MW turbines.
Data Science in Academic Research & Physics of Wind Energy

- Observation
- Raw Data Collected
- Clean the Raw Data
- Models & Algorithm
- Data Product
- Investigate the Data
- Communicate the results
Thanks !