Lecture 4.2, Consequences of scale invariance [2]

* Temperature scales differently than passive scalars (tracers) and differently to wind speed.

* The intermittency of $T$ is correlated with $J[O_3]$ - what does it imply?

* Example: what does the scaling of $T$ imply for stratospheric water?

* Temperature implies a relevance to climate - what has scaling to say?
ATMOSPHERIC TEMPERATURE

* Intermittency of $T$ is correlated with $O_3$ photodissociation rate.***
* Horizontally, $H_1(T) = 0.52 \pm 0.02$
* Vertically, $H_1(T) = 0.986 \pm 0.002$

***Will the same thermometer be measuring the same average over molecular speeds in the troposphere and stratosphere? At the surface now as 100 years ago, when the ozone was a factor of 2 to 5 less?

$T$ is well defined operationally, but the implied fat-tailed molecular speed distributions will have consequences (no LTE) for radiation, turbulence and chemistry. $T$ may not be proportional to mean square most probable velocity of air molecules; are molecular and macroscopic $T$ consistent?

Heat flux and the hydrostatic relation are central. Generalized Scale Invariance has linkages at smallest and largest scales.

If $J[O_3]$ is correlated with $T$ and $C_1[T]$, what does this mean?
Dropsonde from NOAA G4: (15°N, 166°W), 20040304
Temperature & its $H$ scaling exponent

$H_1 = 0.98 \pm 0.01$
Dynamical stability $[\text{Ri}>0.25]$ at 500 & 150 m(left), 50 & 10 m(right)
Dropsonde (25°N, 157°W) on 20040229. The ‘Russian doll’ structure.
Long-tailed PDFs of temperature, Arctic winter & summer, trop. trop.
Scaling & intermittency of temperature, ER-2, Arctic, 19970506

\[ K(q) = c_1 + c_2 q \]

\[ H_a = 0.56 \pm 0.03 \]

\[ C_1 = 0.051 \pm 0.003 \]
Evans & Searles (2002), *Adv. Phys.*, 51, 1529-1585. The high speed molecules, a minority, produce order (‘flow’) while the average majority produce dissipation (‘temperature’).

*The Fluctuation Theorem*

\[
t = 0.1, \gamma = 0.5
\]

\[
p(\overline{P}_{xy,t} = A) \over p(\overline{P}_{xy,t} = -A) = \exp[-AV\beta\gamma t]
\]
PDFs of O₃ and CH₄ from WB57F flights at (10° N, 84° W)
Jan - Feb 2004, for H₂O vapour ≤ 10 ppmv
Water vapour and $T, \ H_2O \leq 10 \ \text{ppmv}, \ WB57F, \ (10^\circ \ N, 84^\circ \ W), \ Jan - Feb \ 2004$
PDF of tropopause temperatures, NCEP Analysis, 30° N to 30° S, 20031201 to 20040229 UTC.
An example showing that over tropical Central America in January 2004 the water vapor minimum was 200-300 metres above an underlying saturated or apparently supersaturated layer; this was the case on every profile. Small ice particles evaporated, and the resulting water vapour condensed on larger particles, leaving a vapour minimum above a saturated layer. This mechanism can account for the final stage in the dehydration of air entering the stratosphere.
Absorption efficiency factor for ice spheres, spectral dependence

![Graph showing absorption efficiency factor for ice spheres across different wavelengths and diameters.](image)
Radiative heating/cooling as a function of particle size, cloud top, 190 K, 0° solar zenith angle

* The small ones absorb and evaporate quickly, the water molecules distilling over to the 10 - 100 micron particles. Accounts for the observed water vapour profiles.
Mean profiles of CH$_4$ and $\theta$, WB57F, (10° N, 84° W, Jan - Feb 2004)
Stratospheric water and scaling at the tropical tropopause

* The lowest water mixing ratios are attained in the lower stratosphere, via distillation of water molecules from small ice particles on to larger ones, which fall under gravity.

* This air is recirculated into the upper troposphere, where the lower methane and water content have influence on climate via their infrared spectra. There will be no one-to-mapping of tropopause temperature to stratospheric water content, the PDFs of $T$ and $H_2O$ have long tails from their scale invariance.

* The methane variability and back trajectories below 12 km indicate a methane source over northern South America [jungle? petroleum industry?].
Transition from ‘weather’ to ‘climate’ in scaling régimes, Lovejoy & Schertzer book. Composite Greenland ice core data.
Greenland ice core (GRIP & 20CR) compared to GCM (IPSL)
Transition region: atmosphere (upper) and ocean (lower) compared.

\[ \log_{10} E(\omega) \]

\( \beta = 0.6 \)

\( \beta = 0.2 \)

\( \beta = 1.8 \)

Air over land

France, daily
**THEORY:** Nonlinear interaction among high speed molecules subject to an anisotropy sustains vortices and the overpopulation of fast molecules in the PDF - fluid flow emerges from the Maxwellian ‘billiard balls’. Temperature remains defined but is not the mean of the Maxwell-Boltzmann distribution. The high speed molecules produce larger scale order (negative entropy), the ones near the mean are responsible for dissipation (positive entropy).

**EVIDENCE:** Correlation of $H_1$(windspeed) with horizontal and vertical measures of jet stream strength. Correlation of temperature intermittency with ozone photodissociation rate. Jet stream speeds reach Mach 0.7 - half the speed of the most probable speed of $N_2$ molecules.

* Natural definition of ‘weather’ and ‘climate’ appears to emerge from generalized scale invariance analysis of Greenland ice core data, with a transition region between about 10 days and 10 - 100 years mediated by the ocean. [Lovejoy & Schertzer, 2012]