Open Peer Review Journal

The physics of the Earth's atmosphere III. Pervective power.

Michael Connolly [1], ***Ronan Connolly*** [*1]

[1] *Connolly Scientific Research Group. Dublin, Ireland.*

Abstract

A previously-overlooked mechanism for energy transmission throughout the atmosphere is presented and characterised. This mechanism, which we have named *pervection*, involves the transmission of mechanical energy through a mass - in this case, the atmosphere. It is distinct from convection in that it does not require mass transport. It is also distinct from conduction in that conduction involves the transmission of thermal energy, not mechanical energy. The current atmospheric models assume that energy transmission in the atmosphere is dominated by radiation and convection, and have until now neglected pervection.

Experiments were carried out to measure the rate of energy transmission by pervection in air. It was found that pervection is rapid enough (up to at least 39.4 ± 0.9 m s^{-1}) to ensure the troposphere, tropopause and stratosphere remain in thermodynamic equilibrium. This contradicts a fundamental assumption of the current atmospheric models which assume the atmosphere is only in local thermodynamic equilibrium.

Citation:
M. Connolly, and R. Connolly (2014). *The physics of the Earth's atmosphere III. Pervective power.*, Open Peer Rev. J., 25 (*Atm. Sci.*), ver. 0.1 (non peer reviewed draft).
URL: http://oprj.net/articles/atmospheric-science/25

Version: 0.1 (non peer-reviewed)
First submitted: January 8, 2014.
This version submitted: February 4, 2014.

1 Introduction

This paper is the third in a series of three companion papers reassessing our understanding of the physics of the Earth's atmosphere. In Paper I[1], we identified a phase change associated with the transition from the troposphere (lower atmosphere) to the tropopause/stratosphere (middle atmosphere). We found when we accounted for this phase change (as well as changes in water content) we were able to quite accurately describe the atmospheric temperature profiles solely in terms of the thermodynamic properties of the bulk gases (nitrogen and oxygen). In Paper II[2], we concluded that this troposphere/tropopause phase change involved the partial multimerisation of the bulk gases.

A surprising implication of Papers I and II is that the tropopause and stratosphere appear to be in thermodynamic equilibrium with the troposphere. This contradicts a fundamental tenet of the current atmospheric models which assume that these parts of the atmosphere are only in *local* thermodynamic equilibrium, e.g., see Pierrehumbert, 2011[3].

If the atmosphere were only in local thermodynamic equilibrium then the air in one part of the atmosphere could gain or lose energy relative to the surrounding air through radiative processes. As a result, the atmospheric temperature profile would be strongly dictated by radiative physics. However, if the atmosphere is in thermodynamic equilibrium (as our findings suggest), then any radiative imbalances which develop in one part of the atmosphere would be rapidly redistributed throughout the atmosphere. As a result, the atmospheric temperature profile would be a mere consequence of the thermodynamic properties of the bulk atmospheric gases.

If the troposphere, tropopause and stratosphere regions are indeed in thermodynamic equilibrium with each other, as we concluded from our results in Papers I and II, then this implies that there is some overlooked rapid energy transmission mechanism operating in the atmosphere which has been neglected by the current models of the Earth's atmosphere.

*Corresponding author: ronanconnolly@yahoo.ie. Website: http://globalwarmingsolved.com

There are three standard mechanisms for energy transport which are usually considered - conduction, convection and radiation. Conduction involves the transport of thermal energy through a mass. The "conductivity" of a mass is a property which depends on the chemical nature of the mass[1]. Convection involves energy transport via mass transport, and is usually described in terms of the types of energy being transported - thermal, latent or kinetic. All matter radiates energy as a function of its temperature. But, the actual transmission of energy by radiation does not require mass, and can occur in a vacuum.

Since air is a good insulator (i.e., poor conductor), energy transport in the atmosphere by conduction is essentially negligible. Therefore, the current atmospheric models assume that energy is mostly transported throughout the atmosphere by either radiation or convection. Indeed, some early one- and two-dimensional atmospheric models were simply referred to as "radiative-convective models"[4, 5].

In this paper, we propose that there is an additional energy transmission mechanism, which is relevant for energy transport in the atmosphere, but appears to have been previously overlooked. This mechanism, which we have named *pervection*, involves the transmission of mechanical energy through a mass - in this case, the atmosphere.

Like the kinetic component of convection, pervection also involves the transmission of mechanical energy, however unlike convection, pervection does not require mass transport. Like pervection, conduction does not require mass transport, but unlike pervection, conduction involves the transmission of thermal energy.

In Section 2, we present the theoretical background necessary to describe energy transmission by pervection. In Section 3, we describe experiments we have carried out to characterise the rates of pervection through air. We present the results from these experiments in Section 4. Section 5 discusses the implications pervection has for our understanding of atmospheric physics, and in Section 6 we offer some concluding remarks, and suggest possible directions for future research into this energy transport mechanism.

[1] In this paper, "conduction" refers to thermal conduction, and not electrical conduction, although both mechanisms are related and substances that are good electric conductors are often good thermal conductors.

2 Theory: Mechanism for pervective transport

In this article, we will be considering the different mechanisms by which energy is transmitted throughout the atmosphere. Much of this discussion will also apply to other fluids (including the oceans), but since this series of papers is about the physics of the Earth's atmosphere, we will mostly focus here on energy transmission within the Earth's atmosphere.

Before we begin our discussion, it is important to define some of the terminology we will be using. This will mostly comprise the terminology used in general thermodynamics books, e.g., Lemons, 2009[6]. Although, in the context of this paper, our definitions will sometimes have a slightly different emphasis than usual.

2.1 Background terminology

A key concept in our discussion will be the distinction between *internal energy* and *mechanical energy*.

Let us consider a system of particles, e.g., a mole of atmospheric gas molecules.

The internal energy of the system is the total energy that the particles of the system have, relative to the centre of mass of the system. It is equal to the sum of the translational, rotational and vibrational energies of the particles in the system. The *temperature* of the system (T) is a function of its internal energy. If the system heats up, its average internal energy increases, while if it cools down, its average internal energy decreases. For this reason, we will also refer to internal energy interchangeably with *thermal energy*.

The mechanical energy of the system is the energy that the system has relative to its surroundings. It is equal to the sum of the *potential energy* of the system and the *kinetic energy* of the system. The potential energy of the system depends on its location in the different energy fields. In atmospheric models, the gravitational field is usually the only field considered, although the magnetic and electric fields are also of some importance[7]. Therefore, the potential energy of the system is usually defined as mgh, where m is the mass of the system; $g = 9.81$ m s^{-2} is the acceleration due to gravity; and h is the altitude of the system. The average kinetic energy of the system is a function of its mass and its net velocity relative to its surroundings (v), i.e., $\frac{1}{2}mv^2$.

We will use the term *heat* to refer to any process which alters the total internal energy of a system, and *work* to refer to any process which alters the total mechanical energy of a system.

As mentioned in Section 1, an important concept for this series of papers is that of *thermodynamic equilibrium*. A system is in thermodynamic equilibrium, if the average energy content of the particles is the same throughout the system.

If the rates of energy transmission throughout the system are too slow to maintain thermodynamic equilibrium, then the system might be only in *local thermodynamic equilibrium*. In such a case, substantial isolated pockets can develop within the system that have an average energy content that is either below average or above average for the system as a whole. In thermodynamic equilibrium, these pockets cannot exist, because as soon as one part of the system starts to go out of equilibrium, energy transmission will act to rapidly re-equilibrate the system.

In the conventional description of the atmosphere, it is assumed that the atmosphere is only in local thermodynamic equilibrium. As discussed in Papers I[1] and II[2], the greenhouse effect theory and stratospheric ozone heating theory are explicitly based on this assumption[3]. For instance, according to the greenhouse theory, radiative absorption and emission by infra-red active gases (e.g., water vapour, carbon dioxide, ozone) keeps the troposphere warmer and the stratosphere colder than would be the case under thermodynamic equilibrium.

A corollary of the local thermodynamic equilibrium assumption is that the energy transmission rates throughout the atmosphere are too slow to maintain thermodynamic equilibrium. Hence, if there is a fast energy transmission mechanism in the atmosphere, which has been overlooked (as we argue in this article), then this could explain why we found in Papers I[1] and II[2] that the atmosphere is *not* just in local thermodynamic equilibrium, but is actually in thermodynamic equilibrium.

Now, let us consider the different relevant mechanisms for energy transmission. *Power* is the rate of energy transmission (in units of Watts, W). Three mechanisms for energy transmission involving heat are known: *conduction*, *convection* and *radiation*. However, convection actually involves several components:

- Transport of thermal energy ($C_P T$, where C_P is the constant pressure heat capacity of the system)
- Transport of latent energy, e.g., due to changes in phase or chemistry, or dipole effects (magnetic or electric)
- Transport of the kinetic energy of the travelling air mass ($\frac{1}{2}mv^2$)

The first two components of convection involve changes in internal energy. But, the third component (kinetic energy transport) involves the transport of mechanical energy. To emphasise this distinction, in this discussion, we will refer to the first two components collectively as *enthalpic convection* and the third component as *kinetic convection* - although we recognise that some researchers prefer to categorise convection into "latent heat" and "sensible heat" components, e.g., Ref. [8].

Aside from radiation, which is a mass-less energy transmission mechanism and can operate in a vacuum (e.g., space), the other energy transmission mechanisms require mass to operate. However, the role that mass plays differs between mechanisms. In the convection mechanisms, the energy is transported with the mass, i.e., energy transport occurs via mass transport. We will refer to this type of mechanism as *with-mass* energy transmission. In conduction, on the other hand, energy is transported through the mass, without the mass itself having to move. We will call this type of mechanism *through-mass* energy transmission.

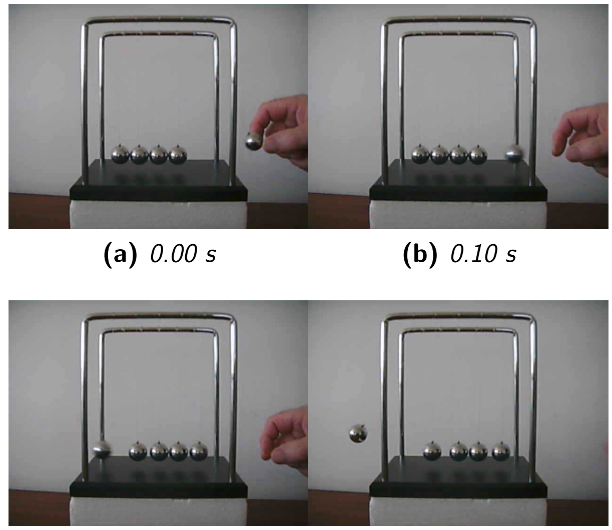
The previously-overlooked energy transmission mechanism which we consider in this article is a *through-mass*, *work transfer* mechanism. In keeping with the Latin etymology of the term "convection"[2], we propose using the term *"pervection"*[3] to describe this "through-mass" mechanical energy transmission mechanism (as opposed to the "with-mass" mechanism of convection). The term pervection has already been used in soil science for describing the movement of phytoliths (microscopic opaline silica particles) through interconnecting soil pores, e.g., Hart & Humphreys, 2003[9] (citing Paton, 1978[10]), however we do not envisage the overlap between these two fields will cause much confusion. The relationships between pervection, conduction and the different convection mechanisms are shown in Table 1.

It is quite straightforward to visualise how the with-mass mechanisms occur - if a molecule has energy (internal or mechanical), and it moves, then it can carry that energy with it. We can also understand the through-mass mechanism with a few simple

[2] Latin *com-* (with); Latin *vehere* (to carry)
[3] Latin *per-* (through); Latin *vehere* (to carry).

	Transfer by heat	**Transfer by work**
With-mass	Enthalpic convection	Kinetic convection
Through-mass	Conduction	Pervection

Table 1: *Mechanisms for energy transport in the atmosphere, which involve mass as a medium for transmission.*



(a) *0.00 s* **(b)** *0.10 s*

(c) *0.17 s* **(d)** *0.33 s*

Figure 1: *Snapshots from a video of the Newton's cradle executive toy after the sphere on the right is lifted and released.*

analogies.

Figure 1 shows the popular "Newton's cradle" executive toy in action. When the sphere on the far right is manually lifted out of the cradle, it gains mechanical energy (in the form of potential energy). When it is released, the sphere falls back into the cradle and transfers most of this mechanical energy (now in the form of kinetic energy) to its neighbouring sphere. Shortly afterwards, the sphere on the far left acquires most of this mechanical energy (still in the form of kinetic energy), and leaves the cradle. The mechanical energy has been transmitted from the sphere on the far right of the cradle to the sphere on the far left. However, at no stage did the two outer spheres come into direct contact with each other. This means that the mechanical energy has been transmitted *through* the mass of the inner spheres, even though the inner spheres have themselves remained in approximately the same place.

As another analogy, let us consider a stonemason working on stone with a mallet and steel chisel. By placing the chisel in contact with the stone, the mason is able to transmit mechanical energy to the stone *through the mass* of the steel chisel, by hammering the chisel with the mallet.

Those two analogies illustrate how, in principle, energy can be transmitted through the medium of a mass, even if the mass remains in roughly the same spot. Still, it might seem that this is of little relevance for the atmosphere, since the atmosphere comprises a mixture of randomly colliding gas molecules, and gases are of a much lower density than liquids or solids. Therefore, initially, the well-constrained system of solid metal spheres in the Newton's cradle might appear to have little in common with the gaseous mixture of the atmosphere. However, as we will discuss in Section 2.2, under certain conditions, the atmosphere behaves like a rigid (technically, "incompressible") body. So, under these conditions, through-mass energy transmission mechanisms such as pervection may be important. Although, since air is a good insulator, energy transmission via conduction is essentially negligible within the atmosphere.

Before discussing the incompressibility of air, it is worth elaborating on one aspect of our Newton's cradle analogy. Although the three inner spheres remained in roughly the same location throughout Figure 1, they were *not* static. A close inspection of the different frames in Figure 1 reveals that there was some "jostling" between the three inner spheres throughout the process, as energy was transmitted between the spheres.

So, it is important to stress that, just like the with-mass mechanisms, the through-mass mechanisms do involve the movement of particles. However, in with-mass mechanisms, the energy has to remain with the moving particles. In through-mass mechanisms, the particles involved in the energy transmission can remain roughly where they were, after the energy has been transmitted. In other words, net mass transport is not necessary.

2.2 Incompressibility of air

All materials are *compressible* to some extent, in that when you "squeeze" or apply pressure to them, their density will change. In general, this compressibility is greatest for gases, much less so for liquids, and almost negligible for solids. Like most gaseous fluids, air can be *compressible*. Indeed, sound is able to propagate through air (and other fluids) because of this compressibility.

Despite this, if the air temperature and composition remains constant, the compressibility of air is actually quite small. Unless the air is moving at a high speed, it can be surprisingly well approximated as *incompressible*. As a rule of thumb, aeronautical engineers typically approximate the atmosphere as being an "incompressible fluid" when the speed of air (relative to its surroundings) is less than Mach 0.3. The Mach Number (M) is the ratio of the air velocity (v) to the speed of sound for equivalent conditions (v_{sound}),

$$M = \frac{v}{v_{sound}} \tag{1}$$

It is only when $M \gtrsim 0.3$ that air is considered a "compressible fluid". Since the conditions for incompressibility are important for our discussion, it may be helpful to briefly justify this approximation. For a detailed discussion of the basis for this approximation, the interested reader is referred to a standard aerodynamics textbook, e.g., Anderson, 1991[11].

Consider a fluid at rest with a density of ρ_0. If the fluid is compressible, then as the velocity of the fluid increases, the density, ρ, should decrease. The relative change in density ($\frac{\rho_0}{\rho}$) with increasing Mach number can be calculated from the following equation:

$$\frac{\rho_0}{\rho} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{1/(\gamma-1)} \tag{2}$$

Where γ is a constant which relates the total energy capacity of a fluid (in this case, air) to the internal energy capacity of the fluid. For dry tropospheric air, $\gamma = 1.4$. For a discussion of how γ is derived, and how it varies under different conditions, see the Appendix of Paper I[1].

Taking the reciprocal of Equation 2, we plot the reduction in $\frac{\rho}{\rho_0}$ with increasing Mach number in Figure 2. We can see that when $M < 0.3$, the reduction in $\frac{\rho}{\rho_0}$ is less than 5%, i.e., the air is *approximately* incompressible. For higher values of M, the reduction becomes quite substantial, and the air is better treated as compressible. However, if $M \lesssim 0.3$ (~ 100 m s^{-1} for dry air at room temperature), then air can be approximated as a semi-rigid fluid, i.e., energy transmission by pervection is plausible.

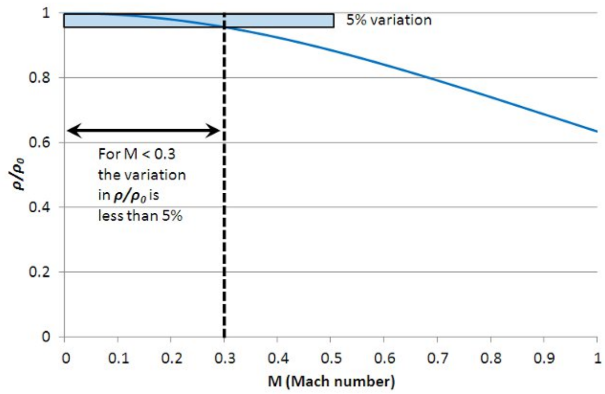


Figure 2: *Changes in density (ρ) with increasing fluid velocity (in terms of Mach number) for dry tropospheric air, i.e., $\gamma = 1.4$. Adapted from Anderson, 1991's Figure 8.5[11].*

2.3 Pervective energy transmission

We saw in Section 2.2 that, if the air composition and temperature are constant and the velocity of the air $\lesssim$Mach 0.3, it is nearly incompressible. Obviously, the air temperature varies throughout the atmosphere, e.g., temperature decreases with altitude in the troposphere and increases with altitude in the stratosphere. The air composition also varies, e.g., due to changes in water content, or as we discuss in Paper II[2], multimerization of the bulk gases. So, the density of air is not just dependent on air velocity and pressure[2], i.e., it is a "baroclinic fluid"[4].

Nonetheless, let us consider an arbitrary parcel of air in the atmosphere, which receives extra energy (e.g., by incoming solar radiation), thereby creating an energy imbalance, relative to its surroundings. If part of the atmosphere has more energy than its surroundings, then that extra energy will have a tendency to flow towards regions with less energy, i.e., tending back towards thermodynamic equilibrium. We suggest that *provided that the extra energy does* **not** *significantly alter the density profile of the surrounding air*, then we can treat the surrounding air as being *effectively* incompressible, at least with respect to the extra energy.

If a fluid is incompressible, any energy that is added or subtracted to the fluid has to be in the form of mechanical energy (i.e., the internal energy of the system does not change). Therefore, a work trans-

[4] A fluid whose density depends on factors other than pressure is known as a *"baroclinic"* fluid, as opposed to a *"barotropic"* fluid.

fer mechanism, such as pervection, should be able to transmit excess mechanical energy from one region to another. We propose that pervection is a significant mechanism for energy transmission in the atmosphere. Unfortunately, unlike conduction, radiation and convection, humans do not seem to have evolved senses for detecting pervection. This might explain why it seems to have been overlooked until now. However, in Section 3, we will describe experiments that can be used to demonstrate pervective energy transmission.

3 Experimental: Measurement of pervection

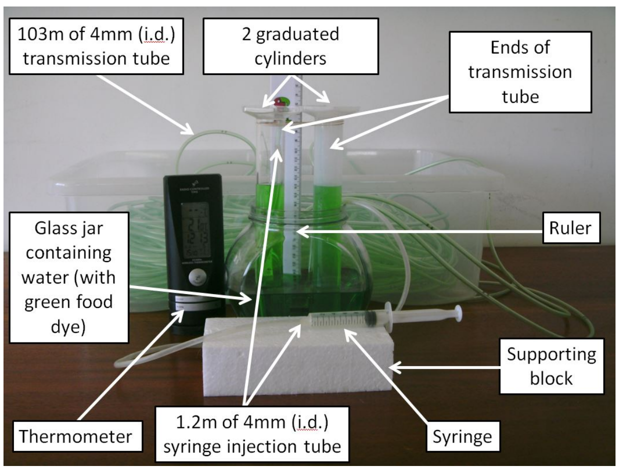


Figure 3: *Labelled photograph of our experimental set-up.*

The apparatus we used for the experiment in this study are shown in Figure 3. We used the following materials:

- Two 100 cm^3 graduated cylinders.
- A 10 cm^3 plastic syringe.
- About 100 m of 4 mm (internal diameter) plastic tube (we used 102.925 m) - the "transmission tube"[5].
- A short length of the same tube to connect the syringe to the cylinder (we used 1.185 m) - the "syringe injection tube".
- A glass jar, containing about 1L of water. We added some green food dye to the water for visual clarity.
- A ruler attached to the graduated cylinders for measuring water levels
- A digital camera and tripod which could record video, for frame-by-frame analysis.
- (Optional) A transparent plastic box for storing the transmission tube.
- (Optional) A digital thermometer for measuring the air temperature at the time of experiment.
- (Optional) A polystyrene supporting block for lifting the syringe into the view of the camera.

Throughout the experiment, the air temperature of the laboratory was in the range 294.00 ± 0.05K (20.85 ± 0.05°C) and the laboratory atmospheric pressure was 1.00095×10^5 Pa.

In one cylinder, we placed one end of the syringe injection tube and one end of the transmission tube. In the other cylinder, we placed the other end of the transmission tube. The ends of the tubes were placed *near* the base of the graduated cylinders[6]. The two graduated cylinders, together with the tubes, were then inverted and placed upside-down into the glass jar.

In Figure 3, the graduated cylinder containing the syringe injection tube is on the left hand side of the photograph and the other cylinder is on the right hand side. For this reason, we will henceforth refer to the graduated cylinder with the syringe injection tube as the "left cylinder", and the graduated cylinder without a syringe injection tube as the "right cylinder".

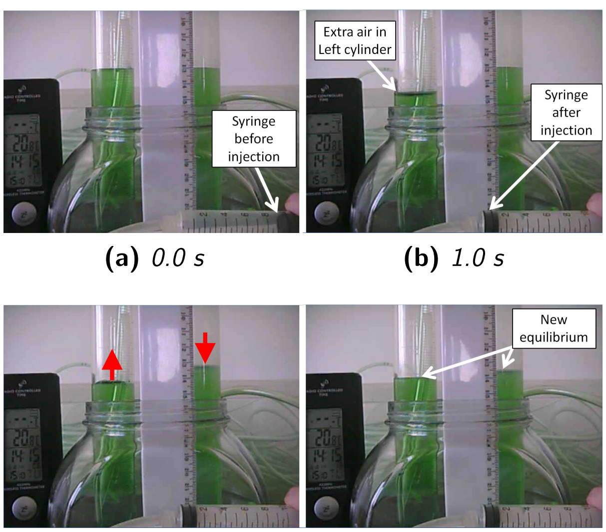
Initially, there was no water in the two graduated cylinders. Before attaching the syringe, we used the syringe injection tube to suck some of the air out of the left cylinder. This increased the water level in the left cylinder. Temporarily covering the syringe end of the tube with a finger, we waited a few seconds until the water levels in both cylinders equilibrated (by pervection). We then sucked some more air out of the left cylinder, and repeated the process until the water levels were at a suitable height. We chose 11.5 cm (0.115 m) above the water level in the jar as a suitable height. This corresponded to air gaps of

[5]The transmission tube had an internal volume of 1293 cm^3.

[6]Care was taken to ensure the tube inlets were not in actual contact with the cylinders, to avoid restricting the air flow.

about 35 cm^3 at the top of both cylinders. We then attached the syringe to the tube (with the plunger extended to 10 cm^3).

The basic idea behind this experiment is to measure the transmission of mechanical energy from the left cylinder to the right cylinder (and vice versa), through the $\sim$ 100 m transmission tube. To ensure that the only way for this energy to be transmitted between the two cylinders is by the transmission tube, the graduated cylinders were placed upside-down in water. The water then traps the air at the top of the graduated cylinders, i.e., the air gaps were not in contact with the surrounding air. However, since we placed the two ends of the transmission tube in these air gaps, the two air gaps were still in contact with each other via the 102.925 m transmission tube. We also placed one end of the syringe injection tube into the air gap of one of the cylinders, and attached the other end to the syringe, which could then be used in order to inject/extract air into/from the system.



(a) *0.0 s* **(b)** *1.0 s*

(c) *6.0 s* **(d)** *19.0 s*

Figure 4: *Snapshots from our experiment demonstrating the changes in water level in the two cylinders which occur after the syringe handle is plunged.*

Figure 4 demonstrates how the system behaved after we used the syringe to push a volume of air into the air gap at the top of the cylinder on the left. Before the syringe handle had been plunged (Figure 4a), the water levels in both cylinders were at the same height. After the syringe handle was plunged, an extra 10 cm^3 of air is pushed into the air gap of the left cylinder (Figure 4b). Because of the increase in air pressure, the water level in the left cylinder fell. The water level in the left cylinder then started to rise again. Initially, there was no detectable change in the water level of the right cylinder. But, after a short lag, the water level in the right cylinder started to fall (Figure 4c). Eventually, the water levels stopped changing, and the water levels settled at a new equilibrium (Figure 4d). The reverse process could then be carried out by extracting 10 cm^3 of air from the air gap using the syringe.

For the experiment in this study, we carried out the following cycle five times:

1. Push air into air gap with syringe.
2. Wait approximately 30 s.
3. Extract air from air gap with syringe.
4. Wait approximately 30 s.

The video footage of the experiment ($\sim$ 5 minutes duration) is available on-line as Supplementary Information at http://www.youtube.com/watch?v=d_J1jr281as.

In our experiment, we used a digital camera to monitor the changes in the water levels after using the syringe in a video. The digital camera we used was a Traveler UW 8 Outdoor-Sports camera. This camera had a relatively low screen resolution for video capture (640 $\times$ 480 pixels, 30 frames s^{-1}) compared to other cameras on the market at the time of writing. It was satisfactory for the purposes of this study, but we would recommend a higher quality camera for future research.

We then analysed this video using video editing software. We used a freeware computer program for Microsoft Windows called ImageGrab (developed by Paul Glagla). But, any video player/editor which allows frame-by-frame analysis should also work.

Clicking through the frames of the video, we recorded the changes in water level measured using the ruler, and the times at which they occurred for both cylinders. We also recorded the changes in volume for the syringe. During periods of rapid change, measurements were made frame-by-frame. However, when the changes were relatively slow, it was often sufficient to only take measurements second-by-second.

In Section 4, we will present and discuss the results from this set of experiments. However, it is worth first noting that the experiment described above should be easily adaptable for measuring pervection rates in other fluids. We suspect this could be a productive avenue for future research.

If the fluid being tested is a gas then, in some cases, the air in the two tubes (i.e., transmission tube and syringe injection tube) and the graduated cylinders could be simply replaced with the gas in question. However, obviously, if the gas reacts with water, then a more appropriate liquid should be used, and if the gas reacts with plastic, then a more suitable material for the tubes would probably be required.

If the fluid being tested is a liquid, then the same apparatus could also be used with minor adjustments. For instance, to measure pervection in water, the transmission tube could be filled with water[7]. However, it might be appropriate to continue using air as the medium for injecting/extracting mechanical energy, i.e., maintain air gaps in the two graduated cylinders and fill the syringe and syringe injection tube with air.

4 Results

As the first step in our analysis of the results from our experiment, we calculated the changes in air pressure in both cylinders from the recorded water levels. The air pressure in each cylinder at any time is equal to the laboratory air pressure minus the pressure of the raised water column.

The laboratory air pressure at the time of the experiment was $P_{lab} = 1.00095 \times 10^5$ Pa. The pressure exerted on the raised water column relative to the laboratory air pressure is $\rho_w gh$, where ρ_w is the density of water (998 kg m^{-3} at 294.0 K) and h is the height of the water level in the cylinders above the water level in the jar (in m). We were therefore able to calculate the air pressures in the cylinders, P_{cyl}, from our measurements for h, using the following equation,

$$P_{cyl} = P_{lab} - \rho_w gh \tag{3}$$

At the start of the experiment, the water level in both cylinders was 0.115 m above the water level in the jar, corresponding to cylinder pressures of 98969 Pa. However, after injecting/extracting air from the cylinders using the syringe, the air pressures in both cylinders underwent a series of changes, as shown in Figure 5.

After the syringe pushes air into the left cylinder air gap, the pressure in the left cylinder increases, and as a result the water level in the left cylinder rapidly falls (Figure 4). Then, the pressure starts to decrease, and the water level starts to rise again. After a brief lag, the right cylinder pressure begins to increase, and the water level in the right cylinder starts decreasing. Eventually, the pressures (and, hence, water levels) in both cylinders reach fairly constant values, and the system returns to equilibrium, albeit a different equilibrium from the one before the injection. We can see from Figure 5 that extracting air from the left cylinder with the syringe has similar effects, although the changes in pressure (and, hence, water levels) are of the opposite sign.

When the syringe injects or extracts air to/from the left cylinder, there is a change in mechanical energy, which can be seen visually by the changes in water level (video footage of the experiment is provided on-line as Supplementary Information at http://www.youtube.com/watch?v=d_J1jr281as). However, after a lag, changes in the water level *also* occur in the right cylinder. Clearly, some energy is being transmitted from the left cylinder to the right cylinder. In this section, we will show that the conventional energy transmission mechanisms are actually unable to explain this energy transmission, and argue that the observed changes are due to pervection.

First, let us characterise the pressure behaviour in more detail. The pressure behaviour in the cylinders is fairly similar for all five injection/extraction cycles of the experiment. With this in mind, let us consider in detail the pressure behaviour for the 30 s after the first injection.

Figure 6 compares the pressures in the two cylinders during this period. Before the injection, the water levels and pressures are the same in both cylinders (98969 Pa). However, the pressure changes which occur after the injection are different in the two cylinders.

As soon as the syringe handle is plunged, the pressure in the left cylinder rapidly increases (regime L1 on Figure 6). After 0.90 s, the pressure in the left cylinder reaches a maximum (99136 Pa), and then starts to decrease (regime L2). The rate of pressure decrease is not linear, but the pressure does monotonically decrease. After about 10-11 s, the rate of pressure decrease has slowed down, and the left cylinder pressure seems almost constant. But, at around 14-15

[7] In this study, we only consider pervection rates for air, but our preliminary measurements for water suggest that pervection is considerably slower in water than air, with one cycle taking at least 50 times as long to complete as the experiment described here, for a transmission tube of only 25m.

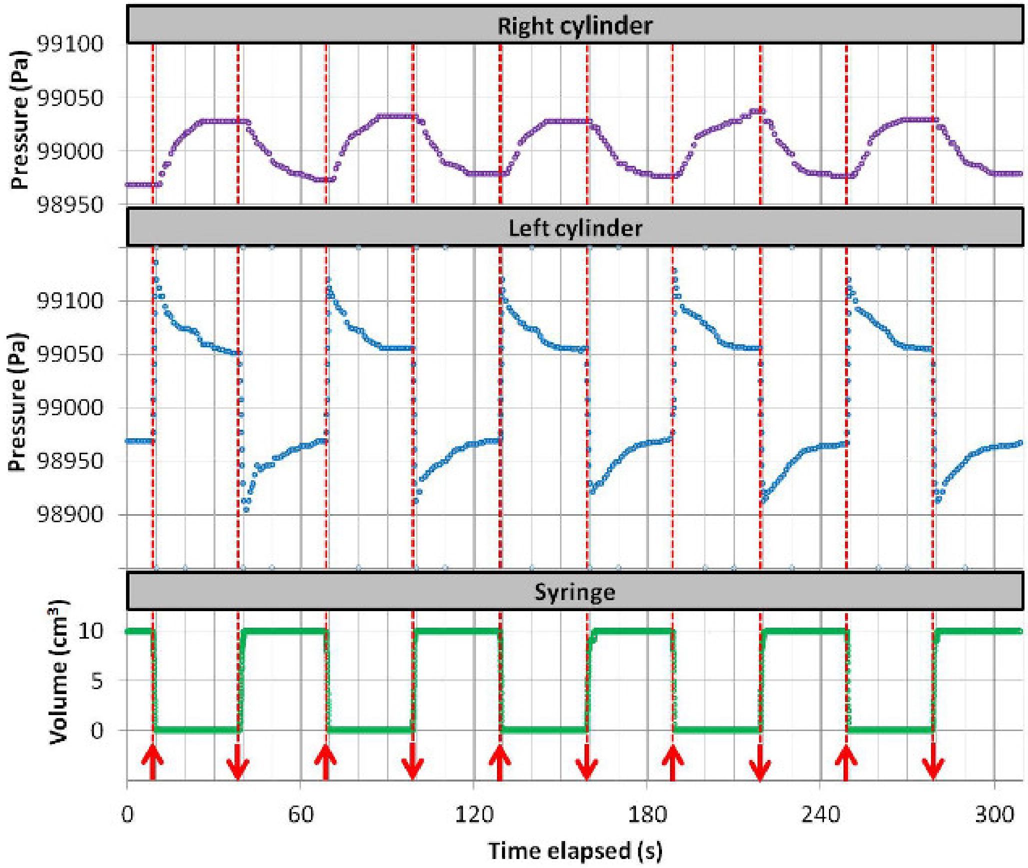


Figure 5: *Air pressures in the left and right cylinders during the experiment, calculated from the measured water levels of each cylinder using Equation 3. The red dashed lines at roughly 30 s intervals correspond to the injection or extraction of 10 cm^3 air using the syringe.*

s, another regime seems to start (regime L3), and the pressure starts decreasing at a faster rate. By 28-30 s, the pressure seems to reach a fairly constant value roughly halfway between the initial pressure and the maximum pressure (99051 Pa).

As for the right cylinder, after the injection there is a lag of 2.57 s during which there is no pressure change. But, after this lag, the pressure begins increasing at an almost linear rate (regime R1), until 8-9 s. After this time, the pressure still continues to increase, but at a slower linear rate (regime R2). 17.29 s after the injection, the pressure stops changing and remains constant (99028 Pa) for the duration of the period.

Due to the low resolution of the camera we used, the accuracy with which we could estimate the water levels in each frame of the video was somewhat limited. With a higher resolution camera, it might be possible to discern more gradual changes, and make more accurate measurements. Nonetheless, the general features of the pressure changes in Figure 6 were repeated after all of the injections, and similar features were observed after the extractions, although of the opposite sign - see Figure 5. For this reason, we believe that the presence of different "regimes" of pressure changes is probably real and worthy of further investigation. We will return to a discussion of these regimes at the end of this Section.

Let us now consider the energy changes in the system over the 30 s time period in Figure 6. When the syringe injects 10 cm^3 of air into the left cylinder, this pushes an equivalent volume of water out of the cylinder into the jar.

The change in potential energy (ΔPE) associated with a change in the water levels in the cylinders (Δh) can be calculated from,

$$\Delta PE = mg\Delta h \tag{4}$$

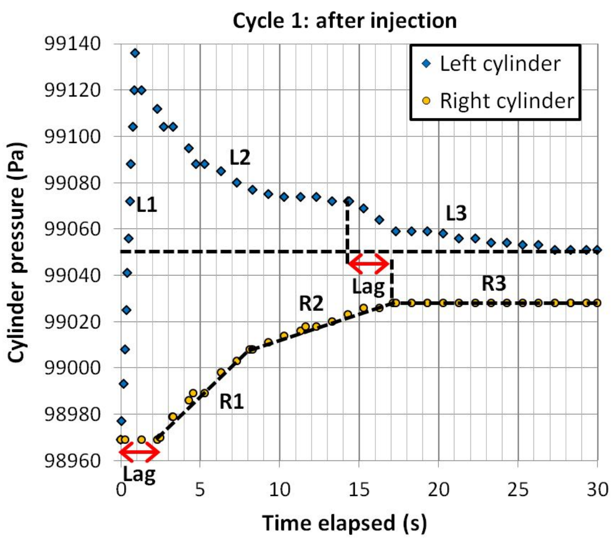


Figure 6: *Changes in the air pressure in the two cylinders for the 30 s after the first injection with the syringe. L1/2/3 correspond to different regimes of pressure change in the left cylinder, while R1/2/3 correspond to different regimes for the right cylinder.*

	Change in potential energy	
Time after injection	**Left cylinder**	**Right cylinder**
0.00 s	0.0×10^{-3} J	$0.0\ \times10^{-3}$ J
0.90 s	1.74×10^{-3} J	0.0×10^{-3} J
17.29 s	1.04×10^{-3} J	0.87×10^{-3} J
30.00 s	0.87×10^{-3} J	0.87×10^{-3} J

Table 2: *Distribution of additional potential energy in both cylinders after injection for the time period discussed in Figure 6.*

Where m is the mass of the displaced water. Since we know the density of water at 294.0K is 998 kg m^{-3}, we can calculate m from the volume of the displaced water, which can be measured using the graduated cylinders.

In this way, we can monitor the changes in potential energy in the air gaps of both cylinders throughout the cycle. Table 2 lists these changes at various times during the part of the experiment in Figure 6.

We can see from Table 2 that 17.29 s after injection, 8.7×10^{-4} J of energy has been transmitted from the left cylinder to the right cylinder. Could this have occurred via conduction, convection or radiation?

In order for the energy to be transferred from the left cylinder to the right cylinder by conduction, there must be a temperature difference between the two cylinders, ΔT. Before the syringe was injected, the air in both cylinders would have been at the laboratory temperature, T_1=294.0 K. However, when the syringe was injected, this supplied extra energy to the left cylinder (in the form of work). Some of this energy would have been converted into thermal energy, thereby slightly raising the temperature of the air in the left cylinder.

We can calculate the change in the left cylinder air temperature after the injection using the ideal gas law, $PV = nRT$. Let us define t_1 as the time before injection and $t_2 = 0.90$ s as the time at which all of the air in the syringe had been injected into the left cylinder. Although the volume of air in the air gap of the left cylinder increased after the syringe handle was plunged, the air gap was only separated from the syringe by the 1.2 m syringe tube. So, if we treat the total volume of air in the left cylinder and the syringe tube and the syringe as a single volume, V, then the volume at times t_1 and t_2 was the same, i.e., $V_1 = V_2 = V$. Similarly, $n_1 = n_2 = n$. Hence, it is only the changes in P and T that are relevant.

Since $P_1V = nRT_1$ and $P_2V = nRT_2$, this means that,

$$\frac{P_1}{T_1} = \frac{nR}{V} = \frac{P_2}{T_2} \tag{5}$$

Rearranging, this yields,

$$T_2 = \frac{T_1P_2}{P_1} \tag{6}$$

$$\therefore T_2 = \frac{(294.0)(99136)}{(98969)} = 294.5\text{K} \tag{7}$$

$$\Delta T = T_2 - T_1 = 294.5 - 294.0 = 0.5\text{K} \tag{8}$$

For a temperature difference of $\Delta T = 0.5$ K between the left and right cylinders, the average temperature gradient (∇T) along the transmission tube (of length, l=102.925 m) is,

$$\nabla T = \frac{\Delta T}{l} = \frac{0.5}{102.925} = 4.86\times10^{-3}\text{K m}^{-1} \tag{9}$$

According to Fourier's law of heat conduction, the rate of thermal conduction along a temperature gradient, i.e., the power rate, Q, is,

$$Q = -kA\nabla T \tag{10}$$

A is the cross-sectional area through which the energy is transmitted, and in this case is the cross-sectional area of the interior of the transmission tube, i.e., $A = 1.25 \times 10^{-5}$ m^2. k is the conductivity of the material, in this case air. For wet air, $k = 0.028$ W m^{-1} K^{-1}, while for dry air, $k = 0.025$ W m^{-1} K^{-1}. If we use the highest value (wet air), this still only gives us a power rate of $Q = -(0.028)(1.25 \times 10^{-5})(4.86 \times 10^{-3}) = -1.85 \times 10^{-9}$ W.

At this rate, the length of time it would take to transmit $8.7{\times}10^{-4}$ J from the left cylinder to the right cylinder by conduction along the transmission tube would be,

$$\text{Time taken} = \frac{8.7 \times 10^{-4}}{1.85 \times 10^{-9}} = 4.7 \times 10^5 \text{s} \qquad (11)$$

4.7×10^5 s is approximately 5.4 days, which is obviously considerably longer than the 17.29 s actually observed. Therefore, we conclude that the contribution of conduction to the observed energy transmission is negligible.

Now let us consider energy transmission via radiation. Radiation can only travel around corners if it is reflected. It can be seen from Figure 3 that the transmission tube was coiled on itself many times in order to fit the $\sim$ 100m of tube into the storage box. So, the amount of energy transmitted from the left cylinder to the right cylinder *along* the transmission tube must have been negligible.

One might argue that some of the energy could be transmitted by radiation directly from the left cylinder to the right cylinder, since they were placed beside each other in the same water jar. However, there are several problems with this suggestion. For instance, it is true that, if the air in the left cylinder heats up, some of the increase in thermal energy will be lost to its surroundings by radiation. But, there is no reason why that lost thermal energy would *preferentially* be absorbed by the air in the right cylinder. In other words, radiative cooling of the left cylinder cannot explain how the energy is transmitted to the right cylinder. Also, in earlier versions of our experiment, the left and right cylinders were kept far apart, but we obtained similar results.

The only remaining *conventional* mechanisms for energy transmission in air are the convection mechanisms. For energy to be transmitted by convection (whether enthalpic or kinetic), the energy must be accompanied by mass flow (Table 1). So, we can estimate an upper bound for the time taken to transmit the energy by convection, by estimating the maximum mass flow rates.

After the energy has been transmitted to the right cylinder, the volume of air in the right cylinder has increased by about half of the volume of air injected by the syringe, i.e., ~ 5 cm^3. Let us suppose that 5.0 cm^3 of air was physically transported directly from the left cylinder over the course of the 17.29 s. If this were the case, then the average volume of air leaving the left cylinder would be,

$$\text{Volume leaving} = \frac{5.0}{17.29} = 0.29\text{cm}^3\text{s}^{-1} \qquad (12)$$

In S.I. units, the volume leaving would be 2.9×10^{-7}m^{3}s^{-1}. Since the internal area of the transmission tube is 1.25×10^{-5}m^2, the average velocity of the air leaving the left cylinder (v) would be,

$$v = \frac{2.9 \times 10^{-7}}{1.25 \times 10^{-5}} = 2.32 \times 10^{-2} \text{m s}^{-1} \qquad (13)$$

At this speed, it would take 4436 s ($\sim$74 minutes) for the air to physically travel the full length of the 102.925 m transmission tube. Clearly this is too slow to explain the transmission of the energy from the left cylinder to the right cylinder by convection.

From Table 1, this leaves us with pervection. Like in our analogy of the Newton's cradle (Figure 1) and the stonemason's chisel, energy can be transmitted from the left cylinder to the right cylinder along the transmission tube without the air mass itself having to be transferred. Instead, the energy is transmitted *through* the air mass.

Now that we have established that pervection is probably the main mechanism by which energy is transmitted from the left cylinder to the right cylinder in our experiment, let us consider what our experiment reveals about pervection.

As we discussed earlier, we can see from Figure 6 that the rates of pressure change in the cylinders go through several "regimes" before equilibration is reached.

After the initial increase in the pressure in the left cylinder (regime L1 in Figure 6), the pressure decreases until it reaches a value halfway between the initial and maximum pressures. In the right cylinder, the pressure increases until it reaches a pressure slightly less than the final left cylinder pressure. That is, the pressures in both cylinders tend towards their new equilibrium values. However, the process by which the cylinders reach the new equilibrium is different for the left and right cylinders.

One difference between the two cylinders is that the change in pressure with time is reasonably linear for the right cylinder (although the slope of the line is different for regimes R1 and R2), while the changes for the left cylinder are quite non-linear.

A possible explanation for the non-linear changes in the left cylinder could be due to the interchange between thermal and mechanical energy. We mentioned earlier that when the air is injected into the left cylinder by the syringe, some of the mechanical energy is converted into thermal energy. Pervection transmits mechanical energy and not thermal energy. Therefore, most of this thermal energy probably remains in the left cylinder. Some of this thermal energy might be lost to the surroundings, e.g., by radiative cooling, and some of the thermal energy might be reconverted back into mechanical energy. Both of these processes could explain the non-linear pressure changes associated with the left cylinder.

Now let us consider the pressure changes in the right cylinder. There is a lag of a few seconds after the air is injected by the syringe before mechanical energy starts to reach the cylinder on the right. We list the lags for all five of the cycles in Table 3.

After injection		
Cycle	**Peak of left cylinder**	**Start of right cylinder rise**
1	0.90 s	2.57 s
2	0.87 s	2.77 s
3	0.81 s	2.57 s
4	0.84 s	2.73 s
5	0.61 s	2.43 s
Mean	0.81 s	2.61 s
S.E.	0.05 s	0.06 s
After extraction		
Cycle	**Trough of left cylinder**	**Start of right cylinder fall**
1	2.19 s	3.08 s
2	0.84 s	3.30 s
3	0.84 s	3.83 s
4	1.10 s	3.73 s
5	1.68 s	3.73 s
Mean	1.33 s	3.54 s
S.E.	0.26 s	0.15 s

Table 3: *The top part of the table lists the times after injection at which the left cylinder pressure reached its maximum, and the lag before the right cylinder pressure began to change for the experiment described in Figure 5. The bottom part of the table lists the equivalent times for the parts of the cycles after extraction.*

We can see that on average the lag is 2.61 ± 0.06 s. This means that pervection was not able to transmit the mechanical energy to the right cylinder any faster than that. Since we know that the transmission tube connecting the left cylinder to the right cylinder is 102.925m long, this gives us an upper bound for the speed of pervective transmission in air of 39.4 ± 0.9 m s^{-1}.

Although the pressure in the right cylinder increases during both the R1 and R2 regimes, the rate of increase drops sharply at the transition between the two regimes. As we mentioned above, the rate of increase in both regimes seem reasonably linear. This suggests the possibility that there is a fundamental change in the energy transmission mechanism which is associated with this transition.

Muriel and others have argued that the laminar-turbulent transition with increasing velocity for fluid flow in a pipe is quantum in nature (e.g., see Refs. [12–15] and references therein). They argue that laminar flow occurs when the average kinetic energy of the molecules is too low to cause inelastic collisions. But, once the molecules gain sufficient kinetic energy to excite at least one of the non-translational degrees of freedom of the particles (e.g., rotational or vibrational degrees of freedom), inelastic collisions can take place. The quantum theory for the laminar-turbulent transition argues that turbulent flow occurs once the average kinetic energy of the molecules reaches this threshold.

The quantum theory for the laminar-turbulent transition has been controversial, e.g., Refs. [16, 17]. Nonetheless, we suggest that a similar transition could be associated with pervection. Perhaps the sharp decrease in the rate of pressure increase for R2 relative to R1 is due to such a transition.

Let us consider a fluid which does not undergo any change in phase, chemistry or composition and is at a constant temperature. The density of this fluid is a function of the translational energy of the particles. If all of the particles are only interacting with each other via *elastic collisions*, then this translational energy will remain constant, and the fluid will be incompressible. Therefore, if the fluid is compressible, some of the particles must be involved in *inelastic collisions*. As we discussed in Section 2.3, pervection acts through incompressible fluids[8]. So, there

[8] Unlike pervection, sound requires a compressible fluid for transmission. In some senses, sound might be considered a compressible version of pervection. However, the speed of sound is relatively fast (i.e., $M = 1$), and the amounts of energy transmitted throughout the atmosphere by sonic energy transmission are generally quite small, except perhaps when there is a loud noise.

may also be a similar transition between pervective transmission and non-pervective transmission to the laminar-turbulent transition.

In that context, it is interesting that Novopashin & Muriel, 2002[15] found the laminar-turbulent transition for nitrogen to correspond to a Mach number of 0.105. The upper bound for pervective transmission in air of 39.4 ± 0.9 m s^{-1} that we calculated above corresponds to a Mach number of $\simeq 0.11$ (from Equation 1), since the speed of sound is 343.2 m s^{-1} for dry air at room temperature. These values seem quite similar, and it is possible that they are related.

5 Discussion

The experimental results in Section 4 suggest that pervection could be a major mechanism for energy transmission in the atmosphere. Indeed, in our laboratory experiment for pervection in air, energy transmission by pervection was orders of magnitude faster than either convection *or* radiation.

Obviously, under different conditions than those in our experiment, the relative rates of pervection, convection and radiation will vary. So, the results described in this article only mark the beginning in understanding the relative roles of the three mechanisms in distributing energy throughout the atmosphere. However, even at this stage, it seems apparent that pervection plays an important role (at the very least) in atmospheric energy distribution.

With this in mind, it is a serious concern that pervection, until now, appears to have been neglected from the conventional textbook descriptions of the physics and dynamics of the Earth's atmosphere, e.g., Barry & Chorley, 2009[18]. Instead, the current descriptions of energy transport throughout the atmosphere are dominated by radiation and convection (enthalpic and kinetic).

We must stress that we agree both radiation and convection are important mechanisms within the atmosphere. However, since the current descriptions of atmospheric energy transport do not even consider the role of pervection, it is quite likely that many of the current theories are inadequate, or even plain wrong. For this reason, it may be necessary to revisit many of the assumptions in the so-called "textbook" explanations for atmospheric phenomena that many of us have learnt (or even taught). We note that more than two decades ago, Lorenz, 1991 anticipated the possibility that improving our understanding of energy transport within the Earth's atmosphere might well involve a revisiting of our fundamental assumptions[19].

As well as revisiting our theories to describe the physics of the atmosphere, we will probably have to reassess our current climate models (usually called *Global Climate Models*, or GCMs for short). The current climate models are, of course, based on the same "textbook" theories for atmospheric energy transport we mentioned above. So, they also assume that energy transmission is dominated by convection and radiation, and neglect pervection, e.g., see Edwards, 2011 for a review of the historical development of climate models[5] and Neelin, 2011 for a useful textbook introduction to current climate modelling techniques[20]. Therefore, the current Global Climate Models will probably require a major overhaul, in order to adequately account for pervection. For this reason, we suspect that many of the climate model results up to now will need to be discarded.

In recent years, climate models and their results have played a major role in climate science, particularly for studying climate change. For instance, in the 4th Assessment Report of Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC)[21], four of the eleven chapters (Chapters 8-11) are devoted exclusively to the discussion of climate models and their results. In each of the remaining seven chapters, climate model results comprise a substantial part of the discussion[9]. The purpose of that IPCC report was to describe *"... those aspects of the current understanding of the physical science of climate change that are judged to be most relevant to policymakers"*[21]. Therefore it seems that much of the current understanding of climate change relevant to policymakers is based on the results of climate models, and as a result, might need to be revisited.

It is disappointing that such a large body of work looks like it will need to be revisited. However, we also see room for optimism. If new models can be developed (or old models updated) to account for pervection, then they should provide more realistic results. These new models might significantly improve our understanding of the climate, and climate change.

As a first step in revisiting the conventional descriptions for atmospheric energy transport, let us consider the implications pervection has for a few aspects of atmospheric physics.

[9] At the time of writing (October 2013), an on-line draft of the 5th Assessment Report had been just released. From our initial reading, it appears that discussions of climate models and their results played a similarly large role in the 5th report.

5.1 Revisiting the poleward energy transport problem

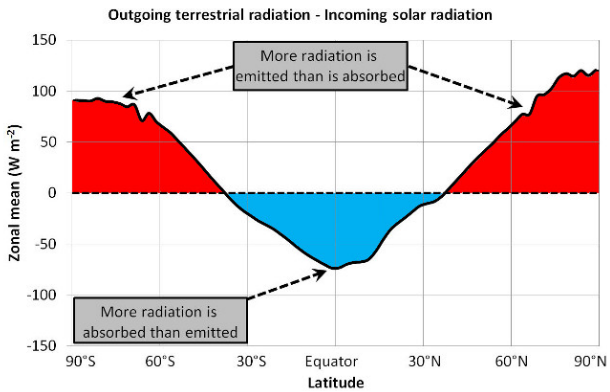


Figure 7: *Annual mean net radiative flux (outgoing longwave radiation - incoming shortwave radiation) at the "Top Of Atmosphere" (tropopause/stratosphere), as estimated by the Earth Radiation Budget Experiment (ERBE) satellite over the period January 1986-December 1988. Data obtained from the on-line supplement for Pierrehumbert, 2011b[22] at http://geosci.uchicago.edu/~rtp1/PrinciplesPlanetaryClimate/index.html.*

An example of a problem which has, until now, been considered only in terms of convection (enthalpic and kinetic) is the so-called *"poleward energy transport problem"*. Figure 7 shows the zonally-averaged annual mean net radiative flux at different latitudes, as measured by the Earth Radiation Budget Experiment (ERBE) satellite over the period January 1986-December 1988.

We can see that, averaged over the year, the poles emit more radiation than they absorb, while the tropics emit less radiation than they absorb. This means that some of the energy that is absorbed in the tropics throughout the year must be somehow transported towards the poles. Figure 8 shows an estimate of the average poleward energy transport (also called "meridional heat transport") which is required to account for the different radiative fluxes at each latitude (adapted from Trenberth & Caron, 2001's Figure 2[23]).

Until now, it has been assumed that most of this energy must be transported through convection (either enthalpic or kinetic). Some of the energy might be transported through the ground by conduction or through surface and groundwater transport[23]. But, it is generally believed that it mostly occurs through

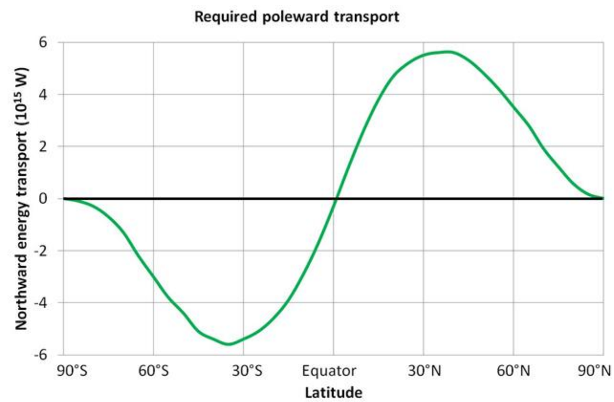


Figure 8: *Estimated poleward energy transport required to account for the net radiative flux in Figure 7. Adapted from Trenberth & Caron, 2001's Figure 2[23]. Positive values correspond to northward transport, while negative values correspond to southward transport*

convection by the atmosphere[19, 24, 25] as well as the oceans[26–31]. Several studies have attempted to estimate the relative ratio of the oceanic and atmospheric convective components to this poleward transport, e.g., Trenberth & Caron, 2001[23]; Held, 2001[32]; Huang, 2005[33]; Wunsch, 2005[34]; Czaja & Marshall, 2006[35]; Fasullo & Trenberth, 2008[36].

We agree that convection probably plays a major role in poleward energy transport. However, it is plausible that pervective processes may *also* be involved in the poleward transport. If this is so, then some fraction of the required transport in Figure 8 which has previously been attributed to convection is probably a result of pervection instead.

The poleward energy transport problem is of interest, not only because it tells us about how energy is transported throughout the atmosphere, but because of its relevance for long-term climate change. As summarised by Lindzen, 1994[37], changes in globally-averaged surface temperatures often seem to be greater at the poles than at the equator, a phenomenon known as *"polar amplification"*[38, 39]. Essentially, during periods of global cooling, the cooling often seems to be greatest at the poles, and during periods of global warming, the warming also seems to be greatest at the poles.

There are several possible factors which might be involved in polar amplification. For instance, warming or cooling at the poles could cause changes in sea ice, ground ice or cloud cover, leading to feedback processes which might amplify the original temperature changes[39]. Perhaps the amplification is related to changes in the incoming solar radiation[37]. Soon & Legates, 2013 have found that the equator-pole temperature gradient is inversely proportional to solar activity (at least in the Northern Hemisphere)[40]. However, another potential factor would be if the poleward energy transport mechanisms change over time. If this latter factor is substantial, then understanding the ratios between pervection and convection in poleward energy transport might help us to better understand the causes of long term climate changes.

5.2 Revisiting the local thermodynamic equilibrium assumption

As we mentioned in Section 1, the current atmospheric models assume that energy is mostly transported throughout the atmosphere by either convection or radiation. The rates of energy transport via convection[19, 23–25, 32–36] do not appear to be rapid enough to keep the atmosphere in thermodynamic equilibrium. As a result, the current models assume that the atmosphere is only in *local* thermodynamic equilibrium.

The distance from the bottom of the troposphere to the top of the stratosphere is only about 50km. Our experiments in this article suggest that pervection can transmit energy at speeds of $\sim 39.4 \pm 0.9$ m s^{-1}. Therefore, it should only take about 21 minutes (1269 s) for pervection to transport excess energy from the bottom of the troposphere to the top of the stratosphere, or vice versa. In other words, pervective transport seems to be fast enough to maintain thermodynamic equilibrium over the required distances. This is in keeping with our results from Papers I[1] and II[2] which suggested that the troposphere/tropopause/stratosphere *are* in thermodynamic equilibrium.

Having said that, over longer distances, pervective transport might not be fast enough to maintain thermodynamic equilibrium. For instance, the equator-to-pole distance (which we discussed in Section 5.1) is 10^7 m. If pervection transmits energy at a speed of 39.4 m s^{-1}, to cover such a distance it would take $\sim$ 254000 s, i.e., $\sim$70.5 hours (nearly 3 days). So, probably, the equator is *not* in thermodynamic equilibrium with the poles. This is not too surprising, since we know that the poles are considerably colder than the tropics.

5.3 Is the climate "sensitive" to infra-red active gas concentrations?

A consequence of the current climate models assuming the atmosphere is in local thermodynamic equilibrium is that they also assume that atmospheric temperature profiles are strongly dictated by radiative physics, specifically the rates of infra-red cooling[41] and radiative heating[42]. Indeed, current climate models are only able to simulate long-term climate changes by altering the *"radiative forcing"* of the system[43–46], where the radiative forcing is an estimate of the net impact that a factor has on the radiative flux of the atmosphere.

The types of factors which are assumed to alter the radiative forcing are changes in (1) the incoming solar radiation, (2) amounts and types of reflective substances in the atmosphere (e.g., aerosols, clouds) or on the Earth's surface (e.g., ice, vegetation), or (3) in the atmospheric distribution and total concentrations of infra-red active gases (e.g., water vapour, carbon dioxide, ozone, methane)[43].

An implied corollary of this approach to climate modelling is that changes in the average concentrations of infra-red active gases (*"greenhouse gases"*) would substantially alter the atmospheric temperature profile of the Earth's atmosphere. This has led to considerable concern[47] that increasing atmospheric concentrations of carbon dioxide from fossil fuel usage will lead to (or has already led to) an increase in the average temperature of the troposphere (*"anthropogenic global warming"*) and a corresponding decrease in stratospheric temperatures (*"stratospheric cooling"*). As a result, a substantial amount of research has been carried out in an attempt to estimate the so-called *"climate sensitivity"*[37, 44–46], which is typically defined as the expected increase in the global average surface temperature for a doubling of atmospheric carbon dioxide, e.g., see Edwards et al., 2007[48] for a review of 2001-2007 studies, and Refs. [46, 49–55] and references therein for some more recent studies.

The widespread popularity of the assumption that increasing atmospheric carbon dioxide concentrations must cause at least some global warming is apparent from the fact that the term "climate sensitivity" is explicitly *defined* in terms of the expected global warming from increases in atmospheric carbon dioxide. However, the concentration of infra-red active gases can *only* alter the troposphere/tropopause/stratosphere temperature profiles if the atmosphere is in *local* thermodynamic equilibrium[3]. The radiative properties of the atmospheric gases are only relevant if prolonged radiative imbalances can occur.

If the atmosphere is in thermodynamic equilibrium, then any local energy imbalances that are formed by radiative processes will be rapidly redistributed throughout the atmosphere. The proposed "greenhouse effect" is in fact a series of energy imbalances at different altitudes of the atmosphere, i.e., the troposphere is supposed to be heated at the expense of the tropopause/stratosphere. So, if the atmosphere is in thermodynamic equilibrium, then it cannot exist.

As we mentioned in Section 5.2, our analysis suggests that pervective transport is fast enough to keep the troposphere, tropopause and stratosphere in thermodynamic equilibrium. With this in mind, we suggest that the so-called "climate sensitivity" is exactly zero, i.e., doubling the relative concentration of infrared active gases in the atmosphere will *not* alter the atmospheric temperature profile.

6 Conclusions and further research

In this article, we identified and characterised a previously-overlooked energy transmission mechanism which can take place in the atmosphere. This mechanism, which we named "pervection" involves the *through-mass* transmission of mechanical energy. It is different from the convection mechanisms which are *with-mass* energy transmission mechanisms, i.e., they require mass to be transported along with energy. It is also different from the through-mass mechanism of conduction, in that conduction involves the transmission of thermal energy.

We devised a simple laboratory set-up to investigate the rates of pervection through a ∼100m plastic tube. Under these (admittedly fairly specific) laboratory conditions, energy transmission via pervection was orders of magnitude faster than by radiation, conduction or convection.

In the atmosphere, changes in temperature, or in the phase, chemistry and composition of different regions of the atmosphere might act to reduce the rates of pervective energy transport. An important avenue for future research will be investigating how these factors affect pervection.

Nonetheless, in the current textbook descriptions of atmospheric physics, energy transport throughout the atmosphere is assumed to be dominated by convection and radiation. In other words, pervection has been neglected. For this reason, we suspect that many of the so-called "textbook" explanations for different atmospheric phenomena might need to be revisited to take into account pervection.

Similarly, energy transport in the current Global Climate Models is predominantly modelled in terms of radiation and convection, and neglects the role of pervection. For this reason, the current climate models will probably require a major overhaul, and many of the climate model results up to now may need to be discarded. This has implications for policymakers who have been devising policy approaches on the basis of reports by groups such as the Intergovernmental Panel on Climate Change (IPCC)[21], since these reports rely heavily on climate model results.

A fundamental assumption in the current atmospheric models is that the troposphere/tropopause/stratosphere are only in *local* thermodynamic equilibrium, since energy transmission by convection is not sufficient to maintain thermodynamic equilibrium[3]. This assumption has led to the belief that atmospheric temperatures are strongly influenced by radiative processes. In turn, this has led to the expectation that increasing the relative atmospheric concentrations of infra-red active gases (e.g., water vapour, carbon dioxide) would lead to "global warming" of the troposphere along with global "stratospheric cooling"[41]. However, in Papers I[1] and II[2], we found that the troposphere/tropopause/stratosphere are actually in thermodynamic equilibrium, *not* just local thermodynamic equilibrium.

Our preliminary measurements of pervection suggest that it is a rapid enough energy transmission mechanism to keep the troposphere in thermodynamic equilibrium with the tropopause and stratosphere. So, this could explain why the current atmospheric models (which neglect pervection) appear to be contradicted by the data. However, pervection is probably too slow to maintain thermodynamic equilibrium over longer distances, such as the distance from the equator to the poles. It would be interesting to investigate the maximum distances and regions over which thermodynamic equilibrium conditions hold for the atmosphere.

Our study in this paper was mainly just an exploratory assessment of pervection, and further research is necessary to develop a more comprehensive characterisation of the energy transmission mechanism. In particular, we note that the rates of pervection were not constant in our experiment, which suggests that several factors are involved in the transmission of energy by pervection.

In general, we would expect that atmospheric changes which reduce the incompressibility of air would limit the rates of pervective energy transport. If the average kinetic energy of air becomes large enough to activate non-translational degrees of freedom (i.e., rotational/vibrational degrees of freedom), this reduces the incompressibility of air. For this reason, we suspect that quantum effects may be important for pervection, and so the study of pervection may involve parallels with the debate over whether the laminar/turbulent transition for fluid flow in pipes is classical or quantum in nature[12].

The experimental set-up we used in this study could be easily adapted to investigate pervection rates in other fluids, either liquid or gas. Determining how pervection in air compares and contrasts with pervection in other fluids might provide further insight into the pervection mechanism.

Determining pervection rates in the oceans might help to address some of the questions on energy distribution and transmission in the oceans which have not yet been satisfactorily resolved, e.g., Wunsch & Ferrari, 2004[56]. With this in mind, it is worth noting that our preliminary (*unpublished*) investigations suggest that pervection in water is considerably slower than in air, but is not insignificant.

Acknowledgements

No funding was received for this research.

We would like to thank Don Zieman and Dr. Imelda Connolly for some useful comments.

References

[1] M. Connolly and R. Connolly. "The physics of the Earth's atmosphere I. Phase change associated with tropopause". 19 (Atm. Sci.). Ver. 0.1 (non peer reviewed draft). 2014. URL: http://oprj.net/articles/atmospheric-science/19.

[2] M. Connolly and R. Connolly. "The physics of the Earth's atmosphere II. Multimerization of atmospheric gases above the troposphere". 22 (Atm. Sci.). Ver. 0.1 (non peer reviewed draft). 2014. URL: http://oprj.net/articles/atmospheric-science/22.

[3] R. T. Pierrehumbert. "Infrared radiation and planetary temperature". *Phys. Today* 64 (2011), pp. 33–38. DOI: 10.1063/1.3541943.

[4] V. Ramanathan and J. A. Coakley Jr. "Climate modeling through radiative-convective models". *Rev. Geophys.* 16 (1978), pp. 465–489. DOI: 10.1029/RG016i004p00465.

[5] P. N. Edwards. "History of climate modeling". *WIRES Clim. Change* 2 (2011), pp. 128–139. DOI: 10.1002/wcc.95.

[6] D. S. Lemons. *Mere thermodynamics*. 1st. John Hopkins University Press, Maryland (USA)., 2009, 207pp. ISBN: 978-0801890154.

[7] M. M. Lam, G. Chisham, and M. P. Freeman. "The interplanetary magnetic field influences mid-latitude surface atmospheric pressure". *Environ. Res. Lett.* 8 (2013), p. 045001. DOI: 10.1088/1748-9326/8/4/045001.

[8] J. T. Kiehl and K. E. Trenberth. "Earth's annual global mean energy budget". *Bull. Amer. Meteor. Soc.* 78 (1997), pp. 197–208. DOI: 10.1175/1520-0477(1997)078<0197:EAGMEB>2.0.CO;2.

[9] D. M. Hart and G. S. Humphreys. "Phytolith depth functions in surface regolith materials". In: *Advances in regolith*. Ed. by I. C. Roach. 4th. CRC LEME, 2003, pp. 159–163. URL: http://www.crcleme.org.au/Pubs/Advancesinregolith/Hart_Humphreys.pdf.

[10] T. R. Paton. *The formation of soil material*. 4th. Allen & Unwin. London, 1978, 143pp. ISBN: 978-0046310097.

[11] J. D. Anderson Jr. *Fundamentals of aerodynamics*. 2nd. McGraw-Hill, Inc., 1991, 772pp. ISBN: 978-0073398105.

[12] W. Wong, Zh. Yang, and A. Muriel. "Internal energy level population redistribution of carbon dioxide in laminar and turbulent flow". *ISRN Spectroscopy* 2013 (2013), p. 681654. DOI: 10.1155/2013/681654.

[13] A. Muriel and M. Dresden. "Projection techniques in non-equilibrium statistical mechanics III. A microscopic theory of turbulence". *Physica D* 81 (1995), pp. 221–236. DOI: 10.1016/0167-2789(94)00191-R.

[14] A. Muriel. "A molecular basis for the onset of turbulence". *Trans. Natl. Acad. Sci. & Tech., Philippines* 23 (2001), pp. 21–29. URL: http://www.nast.ph/index.php?option=com_content&view=article&id=454.

[15] S. Novopashin and A. Muriel. "Is the critical Reynolds number universal?" *J. Exp. Theor. Phys.* 95 (2002), pp. 262–265. DOI: 10.1134/1.1506433.

[16] C. M. White and K. R. Sreenivasan. "Does molecular rotation affect the transition Reynolds number?" *Phys. Lett. A* 238 (1998), pp. 323–327. DOI: 10.1016/S0375-9601(97)00765-2.

[17] C. J. Swanson et al. "Pipe flow measurements over a wide range of REynolds numbers using liquid helium and various gases". *J. Fluid Mech.* 461 (2002), pp. 51–60. DOI: 10.1017/S022112002008595.

[18] R. G. Barry and R. J. Chorley. *Atmosphere, weather and climate*. 9th. Routledge. London. New York., 2009, 536 pp. ISBN: 978-0415465700.

[19] E. N. Lorenz. "The general circulation of the atmosphere: an evolving problem". *Tellus A* 43 (1991), pp. 8–15. DOI: 10.1034/j.1600-0870.1991.t01-3-00003.x.

[20] J. D. Neelin. *Climate change and climate modeling*. 1st. Cambridge University Press, 2011. ISBN: 978-0521602433.

[21] S. Solomon et al. *Climate change 2007: The physical science basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Cambridge. New York., 2007, 1056pp. ISBN: 978-0521-70596-7. URL: http://www.ipcc.ch/.

[22] R. T. Pierrehumbert. *Principles of planetary climate*. 1st. Cambridge University Press, 2011, 680pp. ISBN: 978-0521865562.

[23] K. E. Trenberth and J. M. Caron. "Estimates of meridional atmosphere and ocean heat transports". *J. Clim.* 14 (2001), pp. 3433–3443. DOI: 10.1175/1520-0442(2001)014<3433:EOMAAO>2.0.CO;2.

[24] R. S. Lindzen and B. Farrell. "The role of polar regions in global climate, and a new parameterization of global heat transport". *Mon. Wea. Rev.* 108 (1980), pp. 2064–2079. DOI: 10.1175/1520-0493(1980)108<2064:TROPRI>2.0.CO;2.

[25] D. E. Waliser et al. "The Hadley circulation: assessing NCEP/NCAR reanalysis and sparse in-situ estimates". *Clim. Dyn.* 15 (1999), pp. 719–735. DOI: 10.1007/s003820050312.

[26] S. Hastenrath. "On meridional heat transports in the world ocean". *J. Phys. Oceanogr.* 12 (1982), pp. 922–927. DOI: 10.1175/1520-0485(1982)012<0922:OMHTIT>2.0.CO;2.

[27] L. Talley. "Meridional heat transport in the Pacific Ocean". *J. Phys. Oceanogr.* 14 (1984), pp. 231–241. DOI: 10.1175/1520-0485(1984)014<0231:MHTITP>2.0.CO;2.

[28] W. S. Broecker. "The great ocean conveyor". *Oceanography* 4 (1991), pp. 79–89. DOI: 10.5670/oceanog.1991.07.

[29] A. M. Macdonald and C. Wunsch. "An estimate of global ocean circulation and heat fluxes". *Nature* 382 (1996), pp. 436–439. DOI: 10.1038/382436a0.

[30] A. Ganachaud and C. Wunsch. "Large-scale ocean heat and freshwater transports during the World Ocean Circulation Experiment". *J. Clim.* 16 (2003), pp. 696–705. DOI: 10.1175/1520-0442(2003)016<0696:LSOHAF>2.0.CO;2.

[31] L. D. Talley. "Shallow, intermediate, and deep overturning components of the global heat budget". *J. Phys. Oceanogr.* 33 (2003), pp. 530–560. DOI: 10.1175/1520-0485(2003)033<0530:SIADOC>2.0.CO;2.

[32] I. M. Held. "The partitioning of the poleward energy transport between the tropical ocean and atmosphere". *J. Atmos. Sci.* 58 (2001), pp. 943–948. DOI: 10.1175/1520-0469(2001)058<0943:TPOTPE>2.0.CO;2.

[33] R. Huang. "Contribution of oceanic circulation to the poleward heat flux". *J. Ocean Uni. China* 4 (2005), pp. 277–287. ISSN: 1672-5182. URL: http://www.ouc.edu.cn/xbywb.

[34] C. Wunsch. "The total meridional heat flux and its oceanic and atmospheric partition". *J. Clim.* 18 (2005), pp. 4374–4380. DOI: 10.1175/JCLI3539.1.

[35] A. Czaja and J. Marshall. "The partitioning of poleward heat transport between the atmosphere and ocean". *J. Atmos. Sci.* 63 (2006), pp. 1498–1511. DOI: 10.1175/JAS3695.1.

[36] J. T. Fasullo and K. E. Trenberth. "The annual cycle of the energy budget. Part II: Meridional structures and poleward transports". *J. Clim.* 21 (2008), pp. 2313–2325. DOI: 10.1175/2007JCLI1936.1.

[37] R. S. Lindzen. "Climate dynamics and global change". *Annu. Rev. Fluid Mech.* 26 (1994), pp. 353–378. DOI: 10.1146/annurev.fl.26.010194.002033.

[38] R. V. Bekryaev, I. V. Polyakov, and V. A. Alexeev. "Role of polar amplification in long-term surface air temperature variations and modern Arctic warming". *J. Clim.* 23 (2010), pp. 3888–3906. DOI: 10.1175/2010JCLI3297.1.

[39] M. M. Holland and C. M. Bitz. "Polar amplification of climate change in coupled models". *Clim. Dyn.* 21 (2003), pp. 221–232. DOI: 10.1007/s00382-003-0332-6.

[40] W. Soon and D. R. Legates. "Solar irradiance modulation of equator-to-pole (Arctic) temperature gradients: Empirical evidence for climate variation on multi-decadal timescales". *J. Atm. Sol.-Terr. Phys.* 93 (2013), pp. 45–56. DOI: 10.1016/j.jastp.2012.11.015.

[41] S. B. Fels et al. "Infrared cooling rate calculations in operational general circulation models: Comparisons with benchmark computations". *J. Geophys. Res.* 96D (1991), pp. 9105–9120. DOI: 10.1029/91JD00516.

[42] M.-D. Chou. "A solar radiation model for use in climate studies". *J. Atmos. Sci.* 49 (1992), pp. 762–772. DOI: 10.1175/1520-0469(1992)049<0762:ASRMFU>2.0.CO;2.

[43] P. Forster et al. "2. Changes in atmospheric constituents and in radiative forcing". In: *Climate change 2007: The physical science basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Ed. by S. Solomon et al. Cambridge University Press. Cambridge. New York., 2007, 1056pp. URL: http://www.ipcc.ch/.

[44] J. Hansen, M. Sato, and R. Ruedy. "Radiative forcing and climate response". *J. Geophys. Res.* 102D (1997), pp. 6831–6864. DOI: 10.1029/96JD03436.

[45] J. M. Gregory et al. "A new method for diagnosing radiative forcing and climate sensitivity". *Geophys. Res. Lett.* 31 (2004), p. L03205. DOI: 10.1029/2003GL018747.

[46] R. Knutti and G. C. Hegerl. "The equilibrium sensitivity of the Earth's temperature to radiation changes". *Nature Geosci.* 1 (2008), pp. 735–743. DOI: 10.1038/ngeo337.

[47] A. Gore. *An inconvenient truth.* 1st. Rodale Books, 2006. ISBN: 978-1594865671.

[48] T. L. Edwards, M. Crucifix, and S. P. Harrison. "Using the past to constrain the future: how the palaeorecord can improve estimates of global warming". *Prog. Phys. Geogr.* 31 (2007), pp. 481–500. DOI: 10.1177/0309133307083295.

[49] P. M. Forster et al. "Evaluating adjusted forcing and model spread for historical and future scenarios in the CMIP5 generation of climate models". *J. Geophys. Res. Atmos.* 118 (2013), pp. 1139–1150. DOI: 10.1002/jgrd.50174.

[50] J. D. Annan and J. C. Hargreaves. "On the generation and interpretation of probabilistic estimates of climate sensitivity". *Clim. Change* 104 (2011), pp. 423–436. DOI: 10.1007/s10584-009-9715-y.

[51] M. J. Ring et al. "Causes of the global warming observed since the 19th century". *Atm. Clim. Sci.* 2 (2012), pp. 401–415. DOI: 10.4236/acs.2012.24035.

[52] M. Aldrin et al. "Bayesian estimation of climate sensitivity based on a simple climate model fitted to observations of hemispheric temperatures and global ocean heat content". *Environmetrics* 23 (2012), pp. 253–271. DOI: 10.1002/env.2140.

[53] A. Otto et al. "Energy budget constraints on climate response". *Nature Geosci.* 6 (2013), pp. 415–416. DOI: 10.1038/ngeo1836.

[54] R. S. Lindzen. "Climate physics, feedbacks, and reductionism (and when does reductionism go too far?)" *Eur. Phys. J. Plus* 127 (2012), p. 52. DOI: 10.1140/epjp/i2012-12052-8.

[55] N. Lewis. "An objective Bayesian improved approach for applying optimal fingerprint techniques to estimate climate sensitivity". *J. Clim.* 26 (2013), pp. 7414–7429. DOI: 10.1175/JCLI-D-12-00473.1.

[56] C. Wunsch and R. Ferrari. "Vertical mixing, energy and the general circulation of the oceans". *Annu. Rev. Fluid Mech.* 36 (2004), pp. 281–314. DOI: 10.1146/annurev.fluid.36.050802.122121.