2/2/2021



Submission to. Climate change Commissioner panel, Parliament WELLINGTON.

Mesdames/Sirs.

My two points of interest, raised in the attached newspaper outline are:-

LPG gas bottles will still need to be available to the large number of folk who now live permanently in mobile homes owing to the severe housing shortage which will continue for years in New Zealand.

Relying exclusively on electricity for everything. Vix home and transport power is wrong. A second source MUST be available to Joe Public otherwise those in charge of electric power supply will monopolise prices and have no competition. Perhaps if the N.Z. Government decide to return to a sole N.Z.E.D. government department getting rid of the S.O.E. model would be a step in the right direction. As regards transport electric for rail, hydrogen based fuel for road.

Constant electric power 'outages' would cripple N.Z. economy.



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CAL PARK

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		page 1 of 3
Submissions Analysis Team,		
Climate Change Commission		
PO Box 24448		
WELLINGTON 6142		
1 st February 2021		
Prepared by Mobile	Auckland E Mail —	

PURPOSE: I was unable to use your system to respond on line, hence the need to submit a written response.

CHEMICAL PROBLEMS: Your report was intended for politicians, not chemists. Example:

BIOFUELS: This correctly refers to the production of combustible fuels made from natural products such as plants, oil seeds, waste food fats and similar. Biofuels in this context are not low gas emitters — they are an attempt to replace fossil fuels with renewable resources. Adopting Biofuels will NOT reduce our emission of carbon dioxide, methane or minor gases.

c + 02 -Y c02

You should cease using this "remedy" in your proposal to reduce Global Warming.

NASTY TARGET GASES: Carbon Dioxide is the chief culprit. This gas is claimed to trap solar heat and contribute to global warming. The evidence of reduced consumption of airline and transport fuels, supports this concept — during the CV19 pandemic, the world reduced emission of carbon dioxide although the growth in temperature was not as depressed as expected.

The reasons are complex — the greatest contributor to global warming is gaseous water (a product of combustion). The warmer our atmosphere, the more water vapour is held. More rain helps, but this is a difficult problem to solve.

Other gases such as Freon affect our atmosphere ability to absorb ultra violet radiation — there is no evidence that this influences global warming, although reducing the level of fluorocarbon gases in our atmosphere is known to reduce skin cancer in humans.

Nitrous oxide gas produces acid rain — this damages plants but there is no evidence that it causes global warming.

It would be wise to avoid using these minor gas reductions as part of the "solution" to global warming.

METHANE: is known to increase global warming. it is sourced from decaying plant matter. Decreasing our number of cows by an "estimated" 15% will lead to severe economic damage for New Zealand. Most of our income comes from selling milk & related products. Our economy thrives on the sale of meat.

Points to note:

- Pasture absorbs more carbon dioxide per hectare than plantation forests. This supports continuance of our dairy industry.
- Our agri scientists are able to develop grasses and herbs that yield lower amounts of methane when ingested by animals. This gives New Zealand a key global advantage and ensures that our most valuable industry is thriving.
- Most of the pine plantations in NZ are owned by foreigners. They seek carbon credits and tax benefits. There is no effort made by foreign owners to support downstream use of harvested pine trees. Most trees are processed at the plantation and exported. Increasing the number of pines to reduce carbon dioxide only makes sense if the pines are owned by NZ and they are mandated to be further processed into lumber for export. This plan will take 25 years and in the interim foreign owners will accelerate deforestation. Only steep land, restricted to NZ owners and unsuited for animals should be planted.

TRANSPORT: Switch to electric power vehicles makes sense, but do not underestimate the huge cost involved. Infrastructure to distribute electricity is essential — we need fast charge points otherwise our roads will be chocked with vehicles waiting to charge up.

- To encourage the switch, the government must support thousands of charge points, New Zealand wide.
- Abused power generation must stop once we switch to electric vehicles, NZ will increase its consumption of electricity and selling electricity to produce aluminium must stop. • Build more wind turbines
- Build more tidal turbines
- Build more solar power
- Build train wagons able to self-load/unload shipping containers so that short run trucks can be used to deliver and pick up from customers. Rail is more energy efficient than road. Dismiss the management of the Port of Auckland and employ capable staff. The port was very efficient many years ago installing more cranes improved turnaround. Now the port is a failure and complaints are a waste of time take action. It will take 2 years to renew and train a better team.

VEHICLE IMPORT TAXES: Offer attractive taxes to switch from fossil fuels to electricity. Start NOW

page 3 of 3

MEASURE RESULTS: No more fairy tales about how wonderful it will be when we reduce global warming. Measure every day and analyse the results. If the efforts are not producing results, change or switch to other options.

CHANGE GRADUALLY: NZ cannot afford a massive change. Instead we should stop fossil fuel vehicle imports immediately, so that the gradual replacement using electric vehicles creates demand. Within 5 years, half the NZ fleet will be switched (at no extra cost). Partner with firms able to handle installation, service and support of re-charge outlets. Work with power companies, fuel distributors, not retailers. Appoint capable industry groups and make them responsible for achieving goals. No political appointments — use NZ government auditors only.





CLIMATE COMMISSION ADVICE: COMMENTS AND SUGGESTED ACTIONS

Distinguished Professor

ONZ, DBE, CBE, CFBA, FANAS, FRSNZ, FNZAH

1.0 INTRODUCTION

In most areas, the Climate Change Commission's report is based on solid evidence, but this is not the case when it comes to the costs and benefits of native afforestation vs. exotic pine plantations. This is not the fault of the Commission, but arises from an almost exclusive bias in silvicultural research, teaching, policy and practice in New Zealand towards exotic species, especially pinus radiata, grown in monocultural industrial plantations.

Because of this systemic bias, there has been comparatively little research into the dynamics of natural forests in New Zealand, including their ability as living communities to sequester carbon across a range of different forest types and regions; and the optimal management of indigenous forests for commercial uses, including timber production.

It also means that advice from contemporary silviculture 'experts' is often blinkered, given their lack of research-based knowledge of indigenous silviculture (apart from those associated with Tane's Tree Trust and a few others).

Perhaps for these reasons, many of the statements in the Commission's advice to government about the comparative values of native vs. exotic forests for particular purposes in New Zealand — and in the ETS - are not evidence-based. Many of the costs of exotic monoculture forestry production to local ecosystems, communities and economies are understated, while their benefits are overstated. The reverse is true of indigenous forests.

Industrial forestry in New Zealand is at least as damaging to soils and freshwater and marine ecosystems as industrial dairying; and - as is argued below - its potential contribution to carbon sequestration as compared with permanent native forests must be seriously questioned.

It is vital that in responding to the climate emergency, Government adopts strategies that at the same time address challenges to soil health, the health of waterways and the ocean, biodiversity losses and collapsing ecosystems. A shift towards regenerative approaches to land use across all fronts — agriculture, forestry, tourism, urban and rural planning — is urgently needed if its people are to survive and thrive.

In relation to commercial forestry, our country has been a laggard in adopting regenerative approaches, including 'nature-based' forestry on the German and Scandinavian models (see attachments), in which multi-age, multi-species production forests of locally adapted species

are reproduced mainly by regeneration, managed without sprays, open to the public by law and harvested in small coups to produce high value timbers.

The Commission's advice to government fails even to mention this possibility for forestry in New Zealand. When it recommends a continued expansion of exotic monoculture plantations (albeit less than formerly planned), it looks backwards, rather than forwards.

Rather than reflecting 'legacy effects' in silvicultural research, teaching, policy and practice in New Zealand, the government needs to take urgent action to shift the country's approach to forestry in more sustainable directions.

In what follows, I offer comments and suggested actions on particular sections of the Commission's advice in relation to forestry.

2.0 QUOTE FROM ADVICE

p. 6: "Small areas of trees and vegetation on other land, such as riparian planting along waterways or shelterbelts on farms, also remove carbon dioxide and store carbon, but to a much lesser degree. This is partly due to the small areas planted and partly because they are generally smaller tree species which cannot store large amounts of carbon.

Although they do provide benefits, these small areas of vegetation often do not contribute to the overall 'net' emissions of Aotearoa in the same way as forests. This is for several reasons, such as the ability to reliably count small areas of planting, as well as track their harvesting and/or deforestation."

2.1 COMMENT:

The current approach to riparian planting in New Zealand is often crude and ineffective. To effectively protect highly erodible headwaters and eroding gullies as well as the banks of waterways, more land is required than is often allocated for riparian plantings at present, and a more evidence-based mix of species. Larger trees are needed to shade and cool the water; their roots help to stabilise the banks and bases of waterways; and a good mix of species helps to restore biodiversity, including healthy underground fungal communities.

It should not be assumed that the narrow, discontinuous strips of land and smaller species (eg cabbage trees and flax) that are currently often used for riparian plantings represent best practice. More research is needed into optimal approaches to riparian restoration in different parts of the country; and it is likely that best practice, once devised, will be much more effective in contributing to carbon sequestration as well as freshwater restoration, soil health and biodiversity.

This will require incentives and practical support, however, both on farms and in communities. This includes the financial recognition of the contribution of riparian plantings and reversion to carbon sequestration. The use of LIDAR and drone technologies should make it much easier and cheaper to reliably count smaller areas of forest, and in any case, it is

argued here that effective riparian protection will often require more land and a better mix of species than at present — in many cases, the restoration of riverside forest.

This topic needs more inquiry and analysis by the Commission. It is vital that New Zealand's climate change policies work effectively in conjunction with Government initiatives to foster freshwater restoration, rather than work against them; and the evidence base and thinking here seems weak.

2.2 SUGGESTED ACTIONS

The government should

- Invest in research into optimal approaches (including scale, location, species mix and management) to riparian plantings for carbon sequestration, soil health and biodiversity as well as freshwater restoration, as a means of contributing to its climate change as well as freshwater and regenerative agriculture and forestry objectives;
- Actively encourage the use of LIDAR, drone technology etc to improve the measurement and monitoring of forest (including smaller areas) for carbon sequestration etc.

3.0 QUOTE FROM ADVICE

p. 9: "There is limited information on native plantation carbon dioxide removal rates, which vary with the species planted. The NZ ETS lookup tables have one value covering native forests, which indicate 323 tC02 is removed after 50 years.

When the planted forest area is larger than 100 ha and registered for ETS, forest managers are required to do field measurements so that the actual tree growth is registered. Under certain circumstances using species such as Kauri, native plantation forests remove carbon dioxide at greater rates, instead of values from the look-up value."

3.1 COMMENT

Carbon dioxide removal values for forests vary by forest type, age and region as well as individual species. This is recognised in the look-up tables for pine plantations, but not for native forests. Some native species grow very fast in some parts of the country, but the research here is limited and needs to be urgently upgraded.

In addition, current methods for measuring carbon sequestration (eg. the destruction of sample trees) work much better for monocultures, where the measurement of an individual tree can be simply multiplied, than for natural forests, where complex communities of plants and fungi contribute to carbon sequestration.

The process of carbon sequestration in natural forests in New Zealand is not well understood. Here the combination of many different species, including underground mycorhizzal fungal communities, in different types of native forests in different regions may lead to very different rates of carbon sequestration than are currently allowed for in the ETS look-up tables.

Landowners investing in native forest restoration are currently faced with a 'double penalty' of low and poorly researched carbon dioxide removal rates for native forests in the ETS look-up tables, as compared with pine plantations (where the rates can be as much as ten times higher, without a reliable evidence base to support this disparity); and the cost of field measurement, which is not required if they invest in pine plantations.

For pine plantation investors, the cost of field measurement has been carried by the taxpayer over many years, so that the ETS look up tables already reflect differences in carbon sequestration by forest age and region.

This financial double penalty is a major disincentive to landowners investing in native forest restoration, and will have to be addressed urgently if the Commission's goal of increased native plantings is to be met.

3 SUGGESTED ACTIONS

The government should

- Invest in an urgent research programme to improve the evidence on rates of carbon sequestration by native forests of different types and ages in different regions; and
- Carry the cost of field measurement for native forests, as it has done for those establishing pine plantations over many years.

4.0 QUOTE FROM ADVICE

p. 10."Native plantation forests are more expensive to establish compared to pines because of the cost of seedlings and management required to ensure survival rates."

4.1 COMMENT

The relatively low cost of pine seedlings is based on large scale plantings, with forward contracts and deposits that allow nurseries to invest in high end technologies for growing high quality seedlings, without an undue risk of contract defaults.

By contrast, the cost of seedlings for native species is generally based on relatively small scale plantings, low tech methods, and contracts that are often insecure and don't include deposits etc.

Geoff Thorpe of Riversun Nurseries, one of the biggest horticultural nurseries in New Zealand, says that if native seedlings were treated contractually like pine seedlings, with forward contracts for large quantities of seedlings, with deposits, growers would have the incentive to invest in the technology that enables them to produce large volumes of higher

quality native seedlings at a much lower cost. This could happen very quickly, and would improve survival rates in the field.

At the same time, the need for eco-sourced plantings of a much wider variety of species for native forests will still require a price premium — but this would be much lower than at present

4.2 SUGGESTED ACTION

- The use of large scale forward contracting with deposits should be instituted for native plantings.
- The use of eco-sourced seeds from local species for these seedlings should be actively fostered.

Without such incentives, it is unlikely that growers will invest in the high tech approaches required for the production of large volumes of high quality native seedlings, increasing supply and reducing prices.

There is also the risk (which is happening at present) of generating native forests that are no longer well adapted to local conditions, because the seedlings provided are massproduced like pine trees, rather than eco-sourced.

5.0 QUOTE FROM ADVICE

p. 10 'In theory, if these forests are actively managed, some exotic species could act as a nurse crop and accelerate the establishment of native forests.' See also p.ll.

5.1 COMMENT

While this strategy is being actively promoted by the forestry industry as a means of maintaining volumes of exotic plantings, the evidence that pine plantations will naturally revert to native forests over time is lacking; and the costs of a managed process of reversion are likely to be high — see current experience in the Malborough Sounds, ¹ where those costs are in any case carried by the wider community, rather than the forestry industry.

The risk of wildlings from permanent pine plantations is also likely to be high, with the costs again being carried by taxpayers and ratepayers, rather than the forestry industry. These trees are highly flammable and relatively short-lived, so their long-term contribution to carbon sequestration is likely to be limited, compared with permanent native forests.

¹ https://www.marlborough.govt.nz/repository/libraries/id: 1 w 1 mps0ir17q9sgxanf9/hierarchy/

Documents/Environment/Biodiversity/Guidelines%20for%20Pine%20Plantations%20List/B %20Pines to Native Guidelines Website PV.pdf

There is no good evidence to suggest that establishing new 'carbon forests' of exotics will be beneficial. The most probable outcome of this strategy is hybrid forests of natives and exotics, with unknown impacts on tourism, community enjoyment of local landscapes, biodiversity and ecosystem health.

The long-term costs associated with permanent exotic forests, especially of pine trees, are likely to far outstrip the short-term benefit of relatively rapid carbon sequestration in the initial phase.

The positive long-term benefits associated with permanent native forests for tourism, local enjoyment of local landscapes, biodiversity and ecosystem health are likely to far outstrip those for permanent exotic forests.

Furthermore, if some permanent native forests are managed as 'nature-based' commercial forests, with harvesting in small coups, no spraying, regeneration by reversion rather than planting etc, they will provide good prospects for high quality, long term employment based on the harvesting of sustainable supplies of unique, high value timbers eg. beech, totara, rimu, kahikatea, tawa, kauri etc.

5.2 SUGGESTED ACTIONS

- A cost-benefit analysis for the use of permanent native forests for carbon sequestration as compared with permanent exotic forests should be carried out, taking all these factors into account.
- The 'permanent forest' category in the ETS should be restricted to permanent native forests, given the limited evidence in favour of permanent exotic forests, and the likely long-term costs.
- The Government should make a significant investment in research, teaching and policy development for 'nature based' forestry in New Zealand. This would be a popular initiative, and is highly recommended.

6.0 p. 14: 'Carbon is not released to the atmosphere at harvest but remains in the products made with the timber. Harvested wood products (HWP) in Aotearoa are an important pool of carbon stocks in our GHG inventory.'

6.1 COMMENT

While the life cycle of timber products is one important factor in measuring the carbon stored by different kinds of forests, another is the carbon released in the process of establishing and managing these forests, and producing and transporting timber products to market.

The life-cycle of carbon stocks in New Zealand should include a measurement of the carbon emissions involved in industrial forestry, eg. the preparation of land with earthworks and helicopter spraying; the production, transport and planting of seedlings; the management of forests with trimming etc; the harvesting of trees (earthworks, the use of chainsaws, heavy

machinery etc); the treatment of logs (de-barking, treatment with chemicals etc); the transport of logs (to local ports and international markets); and the manufacture and transport of timber products to market.

The carbon emissions involved in establishing permanent native forests, especially by natural reversion, should also be analysed. These will include the production, transport and planting of seedlings (in the case of planted native forests), fencing, pest and weed control.

If the emissions involved in the production process are included (as they should be) in assessing the overall contribution of industrial vs permanent native forests to reducing the nation's carbon debt, the cost-benefit assessment is likely to be overwhelmingly in favour of permanent native forests — especially those established and managed by assisted regeneration.

6.2 SUGGESTED ACTION:

The cost-benefit analysis suggested in 4.3 for the use of permanent native forests for carbon sequestration as compared with permanent exotic forests should include an analysis of \bullet the life-cycle of timber products, AND \bullet the carbon emissions involved in industrial forestry as compared with those involved in establishing and managing permanent native forests, including those established by assisted regeneration.

7.0 QUOTE FROM ADVICE: p. 14 "The science and measurement of soil carbon is still developing and long-term monitoring programmes have been established in Aotearoa."

7.1 SUGGESTED ACTION

As suggested above, • the science and measurement of soil carbon should include a comparative study of the soil carbon sequestered by natural forests vs. monoculture exotic plantations, including the role of different types of mycorrhizal fungal communities under these different types of forest.

8.0 QUOTE FROM ADVICE: p. 18: ¹ RMA legislation prevents commercial forestry activities on some steep slopes to avoid environmental impacts such as erosion and flooding.'

8.1 COMMENT

This statement is incorrect. It is clear from recent catastrophic failures associated with industrial forestry and consequent court cases in Tairäwhiti (eg Tolaga Bay), the West Coast of the South Island and elsewhere, that while RMA legislation should have prevented commercial forestry activities on many steep, highly erodible slopes, this has not happened in many regions — and is still not happening.

Lobbying over the NES for Plantation Forestry and Regional Plans, and the use of lawyers by the forestry industry to intimidate local councils who seek to limit forestry plantings or penalise RMA breaches has contributed to these failures. Regional councils have often lacked the expertise and will to set evidence-based limits on forestry plantings, or the resources to counteract lobbying and legal intimidation.

This weakness in the drafting, monitoring and enforcing of regional restraints on the environmental damage caused by industrial forestry is systemic and well-attested (see recent damning judgements in the Environment Court), and should not be underestimated.

Exotic production forests are still being planted in the 'wrong places' and managed in ways that are environmentally and socially damaging, a trend that is accelerating as carbon prices rise. It is a matter of direct observation that many of the management practices condemned by the Environment Court continue unabated.

The Climate Change Commission must acknowledge and seek to counteract such systemic failures.

By increasing the commercial incentives for forestry companies to plant pine plantations in inappropriate places, and to harvest them in ways that cause severe environmental damage, the Climate Commission itself might make this situation much worse. There is evidence that as carbon prices rise, this is already happening.

To give one example, in Tairäwhiti, where various community groups are seeking to restore local rivers (the Waiapu, the Uawa, the Waimatä, for instance), and working with local farmers to achieve this, they are finding that some landowners, including those who own very large farms, are deciding to plant all or much of their productive land in pine trees, even in catchments which are already severely damaged by industrial forestry, purely because of the financial incentives to do this under the ETS, and given the prospect of rapidly rising carbon prices.

The Climate Commission and the government need to recognise the urgency of this situation, and act accordingly. Once productive land is planted in pine trees, this has irreversible long-term impacts on local rural and urban communities, landscapes, biodiversity, waterways and marine environments.

Urgent action must be taken to shift current incentives that encourage landowners to establish exotic plantations, often in inappropriate locations (eg river catchments that are already suffering severe impacts from industrial forestry), and to penalise those who wish to restore native forests.

8.2 SUGGESTED ACTIONS

Effective practical incentives to encourage landowners to establish, regenerate and restore native forests rather than to establish pine plantations in inappropriate locations should be put in place as a matter of urgency. These include

- ' A Billion Trees programme purely focused on the establishment, regeneration and active restoration of native forests, as suggested by the Commission;
- Urgent inquiries into and remedies to address non-evidence based disparities under the ETS between landowners investing in pine plantations vs those who wish to invest native forests; and in contractual arrangements for growers of pine vs. native seedlings, as suggested in 2.2, 3.2 and 4.2 above;
- Restricting the 'permanent forest' category under the ETS to native forests;
 Greater support for the costs of fencing and pest and weed control for native forests, as suggested by the Commission; and
- Ensuring that the long-term carbon sequestered by permanent native forests yields financial rewards at least competitive with those for short-term carbon sequestered by industrial plantations.

Without taking such actions as a matter of urgency, the shift recommended by the Climate Change towards the establishment of permanent or 'nature-based' native forests in appropriate places, and away from increased plantings of exotic plantations in inappropriate places and managed in ecologically damaging ways, is unlikely to be achieved.

This would be a significant failure, with highly damaging long term effects, for which the Climate Commission and the government would be responsible.

9.0 OVERALL STRATEGY

While the Commission acknowledges the superior sequestration and co-benefits of indigenous forests, it still proposes several hundred thousand more hectares of new pine plantations and only a smaller area of natives.

Given the points raised above, it is clear that such a strategy is not based on reliable evidence. It makes little sense, ecologically, economically or socially, for New Zealand in the years ahead.



Submission to climate Change Commission

from

Inis submission from one of the general populus of New Zealand with a real concern for the welfare of our planet and hence the welfare of all its inhabitants. I was born in the mid 1950's and in our country I have been witness to many changes, locally, nationally & globarly. For me, whispers that all was not well with 90me human activities relating to Earth's welfare, was being noticed by the time I was In my early teenage years, with the older generation speaking of books echoing early warnings. The books I recall being, Soil & Civilizetion · Edward Hyams (1952) The Breakdown of Nations- Leopold Kohr (1957), On the Beach - Nevil Shute (1957) The Silent Spring - Rachel Carson (1962).

#5

23 [06202]

Being made aware of the implications of our activities is the first step in dealing with the problems they create. Albert Einstein was often quoted as saying "I cannot believe God played dice with the Universe" Well I think that we humans are playing dice with planet Earth. We simply must eer on the side of caution and act now in every conceivable way to reduce our impact on the environment and ask ourselves - do we think that we are a part of nature, or are we apart from nature? Thinking this over should lead us to respect and act responsibly toward the very soil under our feet.

My view as to some of the changies we can make to contribute to reducing the deplorable wastage of the Earth's resources and reduce climate change is to try to reduce the number of cars & trucks from our roads and really promote the use of rail for both freight and passenger movements. Much of the rail infrastructure is already in place but under utilised here in New Zealand

There should be a real incentive to replace internal combustion powered cars, when they reach the end of their life, with electric powered vehicles.

fromoting of 'real' cycle ways-separate from vehicular traffic to safer accomodate cylists to their destinations

A real effort must be made to reduce the throw-away packaging. Glass re-useable containers instead of plastic being a good start. My feelings, since Cavid pandemic set in, is the value of purchasing as van as possible, goods that are sold as close to the point of manufacture production ince to byy local thereby reducing transport a associated costs. Recently I ind the purchase linseed (to add to our home-made breakfast muesti) only to ind the kinseed for sale was imported from China. After investigating, I liscovered that a large shipment of our locally grown kinseed was being exported to Australia. I cannot see the merit in this type of activity from the planets welfore point of view. wirtually non-existent. Now our market is flooded with synthetic fibres that now is revealed to be so domaging to the environment as it ages and breaks down. Wedo need to re-establish our natural fibre industries again (wool - Alpaca - Abssum - Hemp) and thereby create jobs for further clothing manufacture.

Witnessing our population having local holidays and spending money in New Realand instead of overseas is helping aspects of local economy, reducing jet geoplane travel & returning to the New Realand of So years ago - not a bad thing.

Generally I feel we must 'throttle back' our consumption of the Farth's resources a simply be content with less a care for what we have. Much greater care of our fishing stocks with exclusions from other countries wanting to poach the stocks from our 200 mile exclusion zone.

our schools must include the teaching of the importance of the use of our resources and care of the planet.

I think the term land ownership "should be replaced by the term 'land guardianship". Have a look at thugh Wilson's wonderful example at the term a look at thugh Wilson's wonderful example at the term and the term and the see a living example of good land care.

Give a copy of the book "Blue Print for a Green Planct" (with some updated additions) to every person charged with making decisions in the planets best interests.

We collectively have to act now to do some real positive moves for Farth's well being or we may find the old North American Cree saying might be a phrophecy after all -

only when the last tree has died, & the last liver been poisoned and the last fish been caught, will we realize we cannot eat money '

Duted 15th February, 2021

Kind Recyards

Page 10 + 5 #6 Submission on Climate Change Commissio Attn: Submission Analysis Team Name: email: Name: email: perspective: personal Area : Wairarapa Age group: 75+ years My submission: I commend the Commission's wise scientific reasearch. A huge task. A key statement is, 'Aotearoa can transition in a way that considers the Well being of people, the land and the environment' which says to me all of us need to pull together to make sure our emissions are contributing to the global efforts to limit warming to 1.5°C above pre-industrial levels and to do this by 2050. 2050. I am looking specifically at the Agriculture sector. To start with, as I read, the word To start with, as I read, ... fairness to farmers was uppermost in my mind and the collaboration between the Government and the Agricultural sector I Pin and inst outcomes. to reach fair and just outcomes.

Page 20f5

In this first emissions reduction plan where the focus will need to identify areas where early action is needed to unlock potential for significant emissions reduction in the future, I commend the Commissions recommendations in the following as it applies to the Agricultural Sector taken from the Summary of the Seven Key Areas: // changing on-farm management practices can reduce biological emissions now and will be enough to meet the 2030 biogenic methane target target // do this by in centivising and enabling farmers to make the necessary efficiency improvements I bring all farmers to the level of the best farmers upgrade rural broad band to gain technologies // invest in R and D e.g. to develop a methane injection early action on methane emissions ensuring new technologies are rapidly deployed as they are developed

2

Page 3 of 5 Seven Key Areas cont. / policies needed to encourage new, permanent native plantings, for emissions sequestration on currently unproductive land, with provisions for a system of fire breaks in our increasing fire danger hazards. I would like to particularly note the huge tasks already undertaken by our farmers in the areas of freshwater and climate change: * boof and lamb farmers have already reduced stock numbers since the mid 1990's * riparean plantings along streams and rivers * wetland development and enhancement * Farmer catchment hubs-working to restore water clarity. Here, aovernment could support

Page 4 of 5 * Work already done by farmers cont. and extend the catchment group movement with catchmen groups in every catchment to support the work of Regional Councils to repair hotspots on Fivers (quote NZ FW Feb. 15, interview by Neal Wallace with Laurie Patterson). The following are my concerns: Covernment and Agriculture must work in collaboration recognising the following factors: Farms in many cases, are individually or family owned entities, and are being asked in many ways to finance e.g. consents, F.E.P.S, mitigations, whereas City or District, Councils going through the same processes are able to draw from a wider fund base recognise the work of Federated

Paga 5 of 5 Concerns cont Vationa their armers, and President oggard to work co Government o me farmers' being aware of ment ita these extrem times, of c ely st hange 2201

Submission to the New Zealand Climate Change Commission 8/3/2021

The carbon cycle and the science of biogenic methane is easily understood. Every atom of carbon that is emitted by a cow whether by respiration as CO2 or digestion as CH4 for production of high protein meat and milk has recently been captured from the atmosphere by photosynthesis

Photo synthesis 6 CO2 + 6 H2O + sunlight energy > C6 H12 06 + 6O2 $^{\circ}$. Anaerobic digestion or decay C6 H12 O6 > 3 CH4 + 3 CO2 + energy. Methane Decay CH4 + 2O2 > CO2 + H2O + energy

It is accepted that methane breaks down in the atmosphere in a short space of time, say a ten year half life.

It is accepted that it breaks down in to CO2 and H2O that is recaptured by photosynthesis and that at a constant rate of production will remain at a constant level. The science here is simple and well understood however the politics is not. From the Green and Labour party government in the early 2000's people unfamiliar with science compared the gross emissions of methane with the net emissions of internal combustion engines and fossil fuel burning powered stations and said that in New Zealand 48% of our climate changing greenhouse gases were produced by farm ruminant animals burping methane.

It's like steam out of a kettle the steam cloud only gets bigger if you turn up the heat and boil the water faster producing more steam the 'cloud', lets call it a cloud, of methane only gets bigger if you run more cows or other ruminants producing . As ruminant animals have stabilised the biogenic methane levels in the atmosphere from New Zealand are stable and we are already at carbon zero. As I said the science is simple and well understood but the politics is not.

Before the election I questioned a senior politician at a election meeting, he was a candidate in rural electorate. I asked him if he understood that methane breaks down in the atmosphere into CO2 and H2O and was recaptured by photosynthesis which would leave a constant level of methane in the atmosphere. He stated he did understand that. I asked him why he did not come out and support his farmers, his answer explained all. He said that if he explained that methane was not 48% of New Zealand's greenhouse gases and was actually at carbon zero (they) would think him a climate change denier and anti environment.

How did we get to here, living with the big New Zealand lie? Ignorance by the Labour and Green party of 2006, 2007, 2008 rural envy, wishful thinking (tax the farmer not the fuel). Someone did the numbers comparing gross methane production with net fossil fuel consumption and came up with 48% However although it was obvious to anyone with a scientific mind that this was absurd it was decided by the Labour and Greens to investigate, to start a world research project in to biogenic methane production. They spent 30 million and had 22 Wellington embassies represented at the grand opening in Palmerston North.

I am generally in favour of blue sky research but found it embarrassing to think of all that money being poured in to an absurdity and the head of steam that the project had developed. At the explanatory meeting I asked the project leader if he knew methane had a very short life in the atmosphere, and how did carbon dioxide that it was being compared with breakdown except by photosynthesis. His reply, by radiation, he did not say what the CO2 broke down in to. Looking back it is easy to see how New Zealand's big lie was perpetuated and how it spread from the World Centre at Palmerston North right around the world. The spokesmen for the fatally flawed research were dealing with a difficult conflict of interest when answering questions, to tell the truth and your job would not last long or

try to keep your job going. No scientist that understood the situation would take a job with methane research unless he was prepared to go along with the myth that methane was a serious green house gas problem. This meant that journalists with an arts education rather than science would turn to the world research body in Palmerston North if they wanted reassurance that we had a big problem. 12 years later we are still to defeat New Zealand's big lie. The irony that New Zealand the most reliant of all wealthy countries on its pastoral industry here in the goldilocks climate of the maritime south pacific, are the only country intending to tax pastoralist for ruminant greenhouse gas production, is ludicrous.

We must vanquish the wishful thinking, envy and embarrassment that has allowed the big lie to have lasted these last 15 years. I ask the Climate Change Committee to tell the whole truth and nothing but the truth in this matter.

I claim the Commissions suggestion to reduce ruminant agriculture by 15% is simply a political face saver by people who already know it is a nonsense.

Finally some advice. If you are going to spend millions employing scientists to solve a problem that does not exist you will create a conflict of interest between the science and the salaries. If the problem does not exist obviously the solution does not exist and you have a good chance of being embarrassed and supping on seaweed.

Question, is it possible to complete anaerobic decay or digestion of carbohydrates without the production of hydrocarbons, natural gas or methane being the main one?

I ask again that the Commission tell the truth, admit the mistake made 15 years ago and give our hardworking farmers a break. Help reduce anti farmer negativity and help reduce rates of farm suicide. Help promote NewZealand pure pastoral protein production with the lowest carbon footprint in the world and get your knee off my neck. Vaccinate the New Zealand economy against the damage of New Zealand's big lie, our conspiracy theory. Base your policy on science rather than sentiment, on fact rather than foolishness and tax any increase in farmed ruminant animals which do increase atmospheric levels of methane, so people will undertand the principles involved. You have important work to do, don't destroy your credibility with face saving mumbo jumbo.

I wish to be heard to present this submission in person at a time to be mutually agreed.

Yours Faithfully,

Global Warming

From Climate Change Commission <helloi@climatecommission.go0vt.nz>
Date \$08-03-2021 09:50

Hello

I am a NZ born person that has resided in this country for over 75 years plus another five years in the Northern Hemisphere and comment¹

On the emission side, you HAVE NOT included the important primary assisted cause of the warming. That is people. The World population is exploding at an uncontrolled rate. There is no point trying to control what people do if their expansion is not controlled. They go together. With all your research. much of it from overseas and the North Hemisphere does little to show if the Earth's biggest warmers Have been researched enough.

The sun is top. Has our planet got closer? has the sun got more fierce? Has the earth's tilt varied? has the movement of millions of tons of magnetic iron ore from the south to north hemisphere affected our position? have any other planets moved to affect the position of the earth? have volcano activities both under the ocean and on land increased?

Have smaller things that contribute been researched. I mean here things that can be changed at almost nil cost like banning all dark coloured roofs and buildings, cars, maybe tar seal roads and airports. Dark colours absorb double the energy of light colours.

From a very simple formula, I question the rising of the oceans. Very roughly the ratio of oceans to land is 2 :1 So for the oceans to rise half a metre all earth landmass would need 1.1metre of ice on it, land ice contains 10% air. Also as the sea rises its area increases due to land edges and river mouths. Has the effect of earthquakes affected the ratio of Earth to Oceans. The Earth is a malleable mass is it shrinking or expanding due to milieu cooling? Will the effect of huge acreage of solar panels in deserts that absorb the sun in lieu of the earth under it have any overall effect of global warming?

I believe the commission is following too soon conditions that affect the Northern Hemisphere much much more than the Southern Hemisphere and want us to pay the price. Yes, we can do a lot more than we are at present with more research that applies to our own country and give us time to readjust. Start on the population side.

Thank You





sitivity: General

Climate Change submission

ANON-NZPP-D77C-W 1D Unique ID: 307125490

New Zealand has declared its support for Global strategies to reduce carbon emissions and to do so as a matter of urgency.

It is apparent that, in NZ, there is wide support for action. It is acknowledged that we will have a very small impact on global results but as a matter of principle we should play our part.

It is vital that we recognise that we can only make predictions of the effectiveness of our strategies and of the strategies adopted by others. There is nothing more certain than realising the limitations of all predictions. There is also a likelihood that some of our efforts may be less effective than current predictions. For this reason, the Commission must add to its recommendations a requirement to continually review the global progress and to calibrate NZ performance and strategies against what is taking place elsewhere. NZ strategies should be adjusted accordingly.

The Climate Change Commission should recommend strategies that take into account the certainty that the direction of our efforts as proposed today will need to be kept aligned to global efforts.

l list below points that are of concern to me at the moment.

- Reduction of some of NZ emissions may result in those same emissions increasing in other countries with the effect that NZ reductions make no difference in Global emissions and in some instances increase them. I offer 2 examples.
- Closure of the Tiwai Point aluminium smelter is a case in point. NZ production will be replaced by production in plants that use coal to generate electricity. Net global emissions will increase.
- 3. Reduction of agricultural emissions by altering the production of methane in animal digestion processes is a promising prospect and research to advance that result is worthy. However, as illustrated a few years ago with milk production, several less efficient producers built milk powder plants to profit from very high global prices This illustrated that if milk demand remains the reduction of NZ production will result in immediate increases in production elsewhere in the World-the net emissions from this source could increase in other countries where agricultural emissions are not subject to control and production less efficient.
- 4. NZ has to respond to the call for emission reductions but reduction has to be at a global level. The Commission must monitor not just NZ emissions. It must calibrate those efforts against global consequences for the same emissions. If NZ fails to do this it will sacrifice the strength of its economy. A weakened NZ economy will put the country at risk. One of these risks could be to become more dependent on others. Supply of goods could come from less efficient sources. NZ could become dependent for economic success on others who are not likely to have NZ interests at heart.
- 5. For these reasons I consider the Commission has a responsibility to ensure that NZ's changes in emissions do, in fact, help to reduce global emissions and it should be explicit in recommending this in its final report.

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March 10 - 2021

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Climate Change Submission to the Climate Change Commission (due by 28th March 2021)



Pace of Change

WAIRARAPA

I support urgent action to reduce the contribution Aotearoa makes to global climate change. This means rapid reductions in all greenhouse gases, including carbon dioxide from transport and energy, and methane and nitrous oxide from agriculture.

I agree when the Commission says that transformational work must start now. This term of Parliament is critical for key decisions that will shape the following decades. A more ambitious target would be achievable for people walking, cycling, and taking public transport, not only the substitution of electric vehicles for internal combustion.

I'd also like to see faster action to reduce agricultural emissions, including more farms moving to regenerative and organic farming. The Government can support this by funding farmers to change the ways they farm and using appropriate regulations to reduce industrial fertiliser over-use.

Future Generations

The longer we wait to reduce emissions, the more dramatic the shift needed. We need to start now. Future generations will benefit from greener investment made this decade. Therefore Government must urgently set up the systems, structures, and policies to make reducing emissions easy, affordable and fair for everyday people.

Coordinated action for Aotearoa to reduce emissions can also help address other long-term challenges for future generations. These include building affordable, energy-efficient homes close to schools and jobs, with good public transport, walking and cycling connections, and in well-serviced communities with parks and trees. I would also like to see more focus on enhancing nature in our towns and cities. Urban trees and parks help reduce emissions, cool urban temperatures, and improve peoples' quality of life. Designing green roofs and walls for new buildings improves the interior atmosphere and people's mental health. Policy changes have a long lead time in their effects.

Our contribution

Aotearoa New Zealand has significant economic wealth (although it's often not shared fairly). As a developed country, we have a responsibility to act quickly and help lead the global effort. We can do this in a way that raises living standards for our disadvantaged communities.

We have significant potential for more low emissions renewable electricity including geothermal, wind, marine and solar, and this should be used to power industry, homes and transport. Energy conservation including insulation is even cheaper than new renewable sources and should be accelerated.

We need to do this not just for ourselves, but also for our Pacific neighbours at the frontline of changing climate.

I support the Commission's approach of focusing on reducing emissions within Aotearoa, not relying on buying overseas carbon credits. Reducing our emissions can help create local jobs in green industries.

Pine grows fast to sequester carbon out of the atmosphere, but in the longer term it has some environmental problems, especially when it's planted on steep land. We need to encourage more indigenous forestry, which supports native birds and healthier ecosystems. Shifting the balance to more indigenous forestry with differential carbon pricing may be useful. Pine does have a place in building construction, and we need more housing. However, I don't support pine being planted with no intention of harvesting. The landscape effects of pine monoculture and the lack of local jobs compared to other land-use are both negative. We have seen this in the Wairarapa electorate.

Policy priorities to reduce emissions

Focusing on energy and transport first makes sense because clean energy and clean transport options are available. Agriculture accounts for almost half of the emissions in Aotearoa so it needs urgent action too, while retaining our ability to have rural jobs and feed our people.

I strongly support; urgently ending the use of coal for industry, phasing out the use of gas in industry, government action to reduce the cost of electric cars, and phasing out imports of new petrol and diesel cars, building more wind, solar, and geothermal electricity generators and electrifying rail for freight and passengers.

For transport priorities, the Commission could be more ambitious about enabling people to walk, cycle, and take public transport more often. In the Wairarapa there is an existing line that could be more heavily used and improved to Woodville and connect to the Palmerston North – Napier line, both for freight and passengers. Covid-19 as shown how New Zealanders enjoy exploring our own country. Making these journeys by train with walking and cycling connections would make our tourism industry more sustainable.

Technology and Behaviour Change

It's time Government and businesses make it easier for people to choose low-emissions options. I support the Government taking specific, immediate actions to improve clean transport and energy options, not just relying on the Emissions Trading Scheme to encourage businesses to change their technologies.

I agree there are lots of clean energy options currently available, so we don't rely on future "magic" technologies. Online meetings can reduce travel costs, but computers and search engines are huge energy users. Government can use and promote search engines that plant trees to offset emissions or choose ones that use renewable energy. People sometimes need to meet kanohi-ki-te-kanohi whether as families, businesses or interest groups so we support Government investment in new fuels, such as algae, for aviation and shipping as well as land transport.

It's essential that we have a just transition in Aotearoa. I support new training and job opportunities in lowemissions industries and working alongside communities who are affected by change. Waste is an area where behaviour change can complement technology and create jobs. For example, we need better recycling technologies but the manufacturers of products also need to create less waste. Repairing creates more jobs than trashing but design must facilitate repair.

There's no point in encouraging people to walk to school if the journey is too far so encourage school locations to be central, with safe access and consider zoning rather than putting pressure on individual families. Similarly, people won't cycle more without safe separated cycleways. Bus and train fares must be made competitive with car travel and frequent reliable services will do far more than behaviour change campaigns. In this rural electorate, many will still need individual transport. Transitional support for EVs for rural and on-farm use is important.

Climate Change Commission Attention: Submissions analysis team PO Box 24448 Wellington 6142

Dear Climate Change Commission,

Submission on 2012 Draft Advice for Consultation

This consultation document has many strengths, as has been widely acknowledged. We found it inspiring to see how much solid, careful work has already been accomplished by the Commission.

While there is much in this document which we are not competent to assess, we would make the following comments:

- We particularly support the emphasis on reducing emissions, rather than just trying to offset them.
- While doing its best to maintain multi-party support, we hope that the Commission speaks out <u>forcefully</u> about the urgency of climate action. There is a need to push for really ambitious practical policies, and a faster pace in implementing them.
- The government should be encouraged to take bold action and not shy away from measures such as out-and-out regulation to achieve climate policy targets
- People and businesses must be effectively supported in concrete ways to undertake the necessary changes. The whole notion of 'just transition' is an excellent guiding principle.



29 March 2021

Attn: Submissions Analysis Team

Climate Change Commission PO Box 24448 Wellington 6142

Your recent publication regarding all aspects of climate change action presents sobering conclusions for the state of our planet.

Few would doubt (myself included) the need for action and you have presented many valid ways to tackle these problems.

However, I am left wondering, isn't the basic premise of all these actions that may have to be taken, that NZ is doing its part, not just for NZ's sake but as our part of the global effort, both as contributors to the problem and as contributors to the solution?

If that is the case, in my opinion, what seems to be lacking in all this debate and in these reports, is the degree of perspective when comparing NZ's contribution to global warming with the rest of the world.

NZ's declared goal to reduce our emissions by 2030 sounds honourable, and as a nation we should expect to play our part, set an example and wear our share of the cost.

But in most of the suggested actions in this report the costs that we will bear and the amount we contribute to the problem are highly disproportionate compared to what the rest of the world is contributing.

From what I can research our share of world emissions is somewhere between 0.10% and 0.17% of the total. By comparison China is about 27%. The maths on that suggest we are contributing 0.63 % of what China produces! If we were to reduce our contribution to ZERO the impact that will have on the rest of the world is but a drop in the bucket compared to the bigger nations.

This disparity seems to get little mention in any of the areas mooted in this report. What is stated is that our omissions per capita are higher than the global average. But what sort of comparison is that? We only have a population of 5 million, that's 0.063% of the world's 7.9 Billion! Arguments based on per capita are not relevant to this debate, they are almost a smokescreen.

This lack of perspective appears in many of the main topics suggested for change:

The transport sector:

The report suggests that we should ban all petrol and diesel vehicles by 2030.

NZ has 4.2 million vehicles. How many are there in the world...1.4 Billion? Our proportion is .29% of the worlds fleet! If we were to make every vehicle in the country an electric one, the effect will be insignificant if we compare that to say the USA's 290 Million vehicles.

If the recommendation to ban all cars by 2030 became law, our countries transportation will grind to a halt.

Why is this unrealistic?

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- 1. Much of the population wont be able to afford an electric car. To overcome that its suggested government subsidies will be needed. Where's that money going to come from? The only way to get cheap electric cars will be to bring in thousands of used Japanese off castes. That will result in our streets being full of poor-quality vehicles, that five years later will need replacement batteries or will be scrapped, with all the resultant pollutant from that and their batteries. Remember the 1980's when we bought in thousands of Japanese imports, how many of those vehicles do you see on the road now? Most of the electric cars currently coming into NZ now are used Japanese cars like the Nissan leaf. Already we are seeing some workshops specializing in repairing the batteries because they don't last, look on Trade me and see the number listed for sale at \$5000 because replacing the batteries costs more than the value of the vehicle.
- 2. Many people don't want to drive electric cars. This ban will mean we will be keeping our old petrol vehicles going longer as we hang on to them.
- 3. A large portion of our recent new vehicle fleet are light commercials, about 32%, last year, these are used by tradies for their work and for often leisure in the weekend. A tradesman needs his vehicle mobile all of his working day, he cant stop for two hours to charge it up. How does a taxi driver or a courier van driver run a 10 hour shift driving an electric car?
- 4. The investment required the infrastructure for charging stations will be millions of dollars. And that will have to be spent before people will consider buying electric. So if we invest that money and there isn't the uptake what a waste that will be. And if there is uptake, if half the fleet are replaced with electric cars, many of which will be charging at home at non peak hour cost, if two million cars were on charge at night, that will possibly become peak hour pricing, imagine how that will go down. And will the national grid cope, probably only by alternative forms of generation, eg. coal or gas?
- 5. Has the sheer logistics of charging all these proposed electric cars been considered? If you need to fill your car with petrol, today it might take five minutes to do so, maybe 10 minutes if there is a queue, and you're on your way. Driving an electric car and your batteries are low, you will have to wait around even if only to top up, for an hour for rapid charging. We fill our cars with petrol maybe once week? Charging all these cars daily at the supermarket, at your work or a charging station, we will need huge car parks for these thousands of vehicles to wait in.
- 6. This report suggests, along with many other countries that we should not sell any more non electric vehicles after the 2030 to 2035 year time frame. If many other countries have a similar goal the worldwide production of new electric vehicles won't be able to meet that demand. Take the USA as an example, the number of EVs on U.S. roads is only projected to reach 18.7 million in 2030. This is about 7 percent of the 259 million vehicles driving in the U.S. in 2030. This proposed goal target date seems to be totally unrealistic.

The agricultural sector:

The report suggests sheep and beef numbers be reduced by 15% by 2030. NZ is reported to have about 10.1 million cattle. Reducing that figure by 15% suggests a drop of about 1.5 million. The total number of cattle in the entire world is reported to be about 1.4 billion. Therefore, the drop of NZ's cattle numbers is a little over 0.11% of the world total. Considering the agriculture sectors earnings contribution to our economy and the lowering of export dollars as a result of the suggested drop of

15% of cattle, this again seems to me to be entirely disproportionate to the worldwide, hoped for lowering of emissions. Brazil is reported to have the most cattle in the world at 211 million compared to our 10 million, this implies we are being a martyr for a cause for an insignificant gain.

New technologies.

In clause 3.8.6 of the draft advise it is stated "we have conservatively assumed that no new technologies to reduce methane emissions are available before 2035." Why has this path been omitted from your calculations? Surely this is one of the answers to the problem. Much work has already been done in this area, gains have been made, why not focus all our efforts on those areas, improving grass types, cattle breeding technologies etc rather than a slash and burn approach to our numbers of cattle. If we can develop a Covid vaccine in six months, surely focus on those technological improvements over 14 years will be the answer. Yet your report ignores that.

I hope the tone of what I have written isn't taken as negative. We are a small nation and we must play our part. But the sacrifices that will have to be made under these suggestions, the impact on our standard of living and the costs financially, that we will incur as a nation are out of whack when we compare our part to the rest of the world.

Please reconsider this imbalance in your final reports.





8 March 2021

The Climate Change Commission,

Dear Commissioners,

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I attach herewith my submission to yourselves concerning various aspects of climate change and actions which may be taken against it.

The first part consists of two recent technical papers that demonstrate that the almost religious demonization of carbon-dioxide and redemption by eliminating it is a false god. One by demonstrating that there is a gross error in the modelling process which results in temperature rises some 3 times higher than is actually measured, the other by demonstrating that the "global warming" effect of carbon-dioxide is already at maximum and that further emission of same will have no measureable effect.

The second part consists of questions that must be faced and answered should the Government decide to reject the solid science indicating that there is no climate crisis and continue believing in inaccurate models.

Vours fé	aithfully			
		cal En	gineer}	
e-mail:				

Climate has always changed, ever since climate began billions of years ago. It is changing today, and will continue to change regardless of efforts by humans to overcome natural forces.

I attach two very recent technical papers showing that there is a gulf between modelled temperature rise and reality.

The first, *How an Error by Climate Scientists Created the Climate Emergency*, is a summary of a longer paper which has Viscount Monckton of Brenchley as lead author, backed by nine others who are experts in their particular fields. Climate science is not a singular subject, but an agglomeration of many disciplines who must work together. The longer paper is with the editor of a major scientific journal for review, so is not yet available for publication. Viscount Monckton has provided me with the summary with permission to submit it to yourselves for consideration.

The paper demonstrates that, in the early days of the present climate discussion, an error was made in the application of the routine calculations surrounding the operation of feedback loops, resulting in a tripling of the projected temperature rise with a doubling of carbon-dioxide concentration as compared with the result of correct application. Control system design theory and associated feedback loops were mature technology by that time but, as the error was made almost 30 years ago, the reason for misapplication cannot be ascertained.

As you study the summary paper, you will note that the recalculation uses the latest accepted data, so "cherry-picking" is absent.

As the paper is based upon System control theory, you may wish to have the work verified by a Control Systems Engineer. The author has said that he would welcome any properly-science-based correction of his position. A review of the temperature changes associated with El Nino / La Nina cycles shows a <u>natural variation</u> of half of the corrected 1.2K temperature change. Indeed, the satellite temperature measurement shows a decline in global mean temperature of half a degree in just 2 months of La Nina conditions. This effectively demolishes any argument that there is minimal natural variation and everything is caused by humans.

The effect of carbon-dioxide on global warming is logarithmic, meaning that a tonne of CO_2 last week has greater effect than a tonne of CO_2 now, and a tonne of CO_2 next week will have less effect than a tonne now. In terms of its effect, it follows a law of diminishing returns. The effect is therefore asymptotic to a final level beyond which additional CO_2 will have no measurable result. This is the *saturation level*.

The attached paper, *Dependence of Earth's Thermal Radiation on Five Most Abundant Greenhouse Gases*, by Professors Wijngaarden and Happer, is submitted to the Comission with permission, investigates five of the most abundant greenhouse gases at the molecular level, detail which is not evident in such publications as IPCC assessment reports where parameterization is used in preference.

The paper deals mainly with a clear sky to avoid the effect of water vapour, the main greenhouse gas. In an interview, Professor Wijngaarden stated that clouds [water vapour] are so complex that there is insufficient computer capacity to reasonably model them. The Professors indicate that the CO₂ absorption wavelengths are either saturated or close to it. It follows that additional CO₂ will have minimal effect.

Discussion at equal scientific and mathematical rigour will be considered.
<u>Computer models</u> in general are, by definition, inaccurate because they are only mathematical approximations to reality and are therefore, at best, only as good as the mathematicians constructing them. Additionally, many of them contain "parameterisations", the politically-correct word for fudge-factors, guesses, etc covering for what is actually unknown. Without knowing the factors used, and the reasons for selecting those particular factors, no model can be reasonably assessed.

<u>Climate models</u> are well known to "run hot" compared to actual measurements such as the satellite system operated by the University of Alabama, Huntsville. The reason is probably because of a combination of the problems found by the above authors. Such information as has become available re IPCC Assessment Report 6 indicates that the discrepancy is even larger than AR5. Indeed, the Commission will recall that, at the time of AR5, the models were "re-zero'd" back to reality as they had become embarrassingly hot. It will further be noted that models by different investigative groups also differ in their outputs, indicating that the "science is most definitely not settled" as each investigating group has its own ideas on the parameterisations. The IPCC method of taking the average of a set of wrong numbers and proclaiming that to be the correct answer despite not even closely matching real measurements cannot be considered a satisfactory base for political and strategic planning.

There is one model that very closely matches reality. It has been constructed by the Marchuk Institute of Numerical Mathematics, part of the Russian Academy of Sciences. Before dismissing it as "Russian and therefore unreliable" as many do, it must be noted that an American scientist spent his 2020 sabbatical there, and reported afterwards on the freedom of academic investigation and no Government or political interference.

Both the Marchuk model and extrapolation of the satellite record show that there is no forthcoming disaster.

There is a lot of propaganda about the imminent melting of the Arctic ice. Since 2003, it has regularly been given another 5 years of life until 2018 when Alexandria Ocasio-Cortez extended the life to 2030. Russia obviously believes its own climate model and is in the process of building a new fleet of icebreakers, including 5 nuclear-powered units capable of breaking 3 metres of ice. The first is in service, 2 are fitting out, and 2 are on the stocks. A design contract has been let for the design of larger icebreakers capable of breaking 4.3 metres of ice, to be sailing by 2030.

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Moral matters.

Food.

 $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

This equation is what guarantees the continuation of life on Earth. It is the equation of photosynthesis allowing plants to grow. It will be noted that carbon-dioxide is at the very base of planetary life, and the rate of plant growth is directly linked to the concentration of CO_2 in the atmosphere. Recent satellite photography shows an increase in green-leaved areas of 10% in the past 20 years.

The UN estimates that, by 2100, there will be 11 billion mouths to feed. The question must be faced, "What concentration of atmospheric CO₂ will be necessary in order to grow sufficient food?"

In the years that I have been following these matters, I have seen only one technical paper that addresses the matter. That paper estimated a requirement of 625 ppmv of CO_2 for sufficient growth. An annual increase of 2.625 ppmv worldwide would suffice.

What is the position of the Commission on increasing CO₂ in order to help feed the burgeoning population?

Environment

An average Tesla battery includes :-

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11.5 kg lithium, source brine typically 0.1% Li, = 11.5 tonnes of brine

13.5 kg cobalt, ore averages 0.1% Co = 13.5 tonnes of ore

27.3 kg nickel, ore averages 1% Ni = 2.73 tonnes of ore

50 kg graphite, ore averages 10% graphite = 0.5 tonnes of ore

41 kg copper, ore averages 0.6% Cu = 6.33 tonnes of ore.

To produce *1* tesla battery it is necessary to excavate and process 23 tonnes of ore, plus pump out and evaporate 11.5 tonnes of brine. It is also necessary to excavate the overburden to access the various ores. The overburden varies, approximately between 3 and 20 tonnes per tonne of ore. Taking 11 as an average, accessing 23 tonnes of ore requires a total excavation of $23 \times 11 = 253$ tonnes. Internationally, the Green movement has recognized that mining and excavation on the scale required to meet the demands of Western nations going all-electric will inevitably cause severe damage to ecological and environmental areas. Technical papers have already been appearing warning of such problems.

Lithium is mainly sourced from South America, although Australia has begun hard rock excavation. In South America, the Li is held in underground brines which must be brought to the surface. Trouble has arisen with subsequent lowering of the water table forcing farmers to abandon their land because of lack of water.

Although New Zealand will not suffer the degradations mentioned above because we import everything for electrification, the Commission must consider whether we have the moral right to force other countries to accept that degradation and loss of livelihood for our benefit, not to mention the child-miners of cobalt ore in the Democratic Republic of Congo.

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<u>Wind turbines</u> have a finite life as do all machines. Whilst a lot of the parts are reclaimable for recycling, the blades are not, neither are they degradable in landfill. Some developing countries are cutting the blades up and using the result as road-building material. What does the Commission recommend for the disposal of end-of-life wind turbines, especially the thousands of tonnes of reinforced concrete bases?

Infrasound from wind turbine blades is coming more and more to the fore despite outrage from their proponents. Modern research, including from a scientist with Auckland University connections, is showing physical health problems arising from prolonged exposure, although not all people and animals appear to be affected. In the USA, the utility companies often just rehouse affected families and bulldoze their old house rather than fight the case.

What does the Commission recommend for the protection of humans and animals from infrasound?

<u>Silicon chips</u>, in order to make them generate electricity under sunlight, have to be doped with a poisonous substance such as arsenic, gallium, or germanium, of which arsenic is the safest. Consequently, solar panels cannot safely be cut up and dumped in landfill without risking contamination of the groundwater. There is, at present, no useful method of removing the poisons, although a joint pilot-plant has been trialed by Germany and the Czech Republic. Reports are that it works, but is very expensive, time-consuming and power consuming, and that no commercial enterprise would even consider it because the returns would be negative.

What is the Commission's proposal for the disposal of expired solar panels?

Electric vehicles

A matter rarely, if ever, considered is the requisite supply of electricity. In summary, either the private vehicle fleet must be severely rationed, or the generation capacity must be greatly increased along with the charging stations. Consider the following thought experiment.

There are reported to be 2000 urban buses in NZ, plus school and tour buses. The most recent overseas reports indicate that urban buses use between 1.5 and 2.44 kWh per km run, so use 2 kWh per km run on average. At an average run of 200 km per day, the urban bus charging load would be 800,000 kWh per day.

Tiwai Point closes, and the whole output of Manapouri power station is designated for vehicle charging. By the time that the power goes through the various transformers en-route, plus the AC – DC – AC across Cook Strait, there may be 725 MW available into the various batteries on charge, = 17,400.000 kWh per day.

Subtract 800,000 kWh for buses, leaves 16,600,000 kWh for other vehicles.

Consider an average electric car such as the Kia e-Niro, about Corolla size 5seater, as the general electric family / urban transport. It has a 64 kWh battery capacity. Assume, on average that, over a 24-hour period, the electric car fleet requires a 50% recharge, i.e. 32 kWh per car.

Over a 24 hour period, Manapouri can support 518,750 cars in addition to the urban buses. There are reported to be 3.5 million registered light vehicles in NZ, so Manapouri can support 14.8% of light vehicles plus the urban bus fleet.

A modern 7MW wind turbine, with a blade circle size larger than the parking area of a jumbo jet, and on a pole some 200 metres high could support some vehicles. The world average for wind turbine capacity factor is 22%, However, NZ is in the roaring 40' so assume that we can get 40%. The same proportional system losses would accrue, except possibly the Cook Strait cable, so the batteries could expect about 2.4 MW to be available, = 57,600 kWh per 24 hours. Each wind turbine could therefore support another 1800 light vehicles. Another 1650 7MW wind turbines should do it at 10 blade diameters apart, and foundations measured in the thousands of tonnes of concrete.

From *Fueling Freedom* by Moore and Hartnett, the average wind farm requires 460 tonnes of steel and 870 cubic metres of concrete per MW installed. Those are American numbers, so NZ numbers will be higher because of seismic requirements.

The Commission will be aware that Hyundai has recalled its electric cars because of battery fires. In Germany a case has recently been reported that a VW Golf 8 suffered a battery explosion that blew out all the windows. The occupants got out with minor injuries immediately before the battery exploded. 28 firefighters attended, but could not fully extinguish the battery fire. Temperatures generated were so high that the battery fire kept re-igniting. The answer was to immerse the entire car in a tank of water.

The German town of Kulmbach has refused entry of electric vehicles into its car park building. The building is of steel, and could suffer strength degradation under the heat of a car battery fire. A recommendation, seemingly by VW, is to leave electric vehicles parked outdoors or on the street instead of in the garage.

Lithium burns at 2000 degrees, but steel melts at 1500 degrees.

A lithium - ion battery fire is a low-risk-high-consequences event.

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What is the advice of the Commission on parking and firefighting of electric vehicles?

<u>Grid stability</u> has been in the news recently, ranging from South Australia to California to Texas. Load swings occasioned by renewable energy sources not providing power reasonably evenly leads to variations in grid frequency which, if not corrected swiftly, will allow the automation to take over and shed load in order to protect the heavy rotating machinery. In the case of South Australia, it took 0.85 seconds from first failure to black-out as the automation shed the entire state to protect the remainder of the East Coast grid. In the other two recent instances, the operators reacted by load-shedding in time to prevent total black-out, although in Texas, the operators didn't think through their actions. They managed to include in the black-out the electric motors driving the gas compressors providing gas to the thermal power stations which, of course, shut down because of lack of fuel, thus worsening the situation.

{ Originally, the compressors were driven by internal combustion engines using gas as fuel, making the gas supply system self-supporting. Obama – Biden regulation combatting climate change forced the conversion to electric motors to drive the compressors. The Law of Unintended Consequences is immutable .} <u>**Grid-scale batteries</u>** are often touted as the answer to maintaining grid stability. However, nobody has actually built one yet, so the truth of the statement is unknown. The most recent numbers out of the USA on large battery costs are US\$1.5M per MWh capacity.</u>

As a thought experiment, consider replacing Huntly coal-fired station of 1000 MW with a battery to keep the grid up in dark windless conditions, say for 12 hours.

12,000 MWh X 1.5M = US\$18 billion.

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Generation sufficient to recharge the battery plus power the grid would also be required.

What is the Commission's recommendation on battery back-up?

How an error by climate scientists created the climate 'emergency'

An astonishing but welcome discovery: The Argonauts, an international team of ten eminent climate researchers, among them a former Director of the US Government's Global Change Research Program and a Professor of Control Theory, have made the astonishing but welcome discovery that concern about substantial and thus dangerous global warming arose from an elementary but disastrous error of physics made by climate scientists when they borrowed feedback theory from engineering physics in the 1980s without understanding it. The error tripled climate scientists' expectations, and then their predictions, of how much global warming we may cause. After correction, eventual warming by doubled CO_2 will be just 1.2 Celsius degrees, not 4 degrees, ending the climate "emergency".



How climate scientists forgot the Sun was shining: They forgot that feedbacks, chiefly from more water vapour in warmer air, amplified not only the 10 degrees' direct warming by preindustrial greenhouse gases but also the 25-times-greater 255 K temperature from the Sun's warmth even without greenhouse gases.

The error: Climate scientists imagined that the natural greenhouse effect in 1850 comprised just two components: 8-10 degrees' direct warming by preindustrial greenhouse gases driving 22-24 degrees' additional, indirect warming called feedback response, chiefly caused by more water vapour in warmer air. For instance, a mainstream study by the Goddard Institute for Space Studies and Columbia University concluded that –

"Noncondensing greenhouse gases, which account for 25% of the total terrestrial greenhouse effect, ... provide the stable temperature structure that sustains the current levels of atmospheric water vapor and clouds via feedback processes that account for the remaining 75% of the greenhouse effect" (Lacis+ 2010).

What climate scientists missed: They overlooked the third component in the natural greenhouse effect, far larger than the other two: the substantial feedback response to the temperature driven by the Sun's warmth even without any noncondensing greenhouse gases like CO_2 . The larger the feedback response to the Sun's warmth, the smaller the feedback response from preindustrial greenhouse gases – and the smaller the expected feedback response to direct warming by greenhouse gases today.

How the error influenced climate scientists' expectations: The error led climate scientists to expect that today's feedbacks (IPCC, the Intergovernmental Panel on Climate Change, mentions "feedback" more than 1000 times in its 2013 *Fifth Assessment Report*) would add as much as 3 degrees' feedback response to the 1-degree direct warming from doubled CO_2 in the air, turning a non-event into an "emergency". IPCC embedded the error in its 2013 report, and will do so again in its forthcoming *Sixth Assessment Report*. If climate scientists had not been misled by their error, they would not have expected anything like as much as 4 degrees' eventual warming by doubled CO_2 in the air, known as equilibrium climate sensitivity (ECS).

Verification in the lab: A national laboratory commissioned by the Argonauts replicated a test apparatus designed by one of them and confirmed that even without direct warming by greenhouse gases there would be a large feedback response to the input signal, which, in climate, is the temperature from the Sun's warmth.

Correcting climate scientists' error: Once the Argonauts had realized and verified that climate scientists' error had greatly inflated their expectations of global warming, they used just seven up-to-date, mainstream, real-world measurements (D1-D7) to carry out six simple steps S1-S6 to calculate the corrected ECS (S6):

	Equilibrium	CO2 sensitivity (ECS)	deriv	ved from 7 mainstream	quantities
D1	1850-2020	NGHG + O ₃ + aerosol + BC	Δ01	AGGI; Gaudel; Dittus; IPCC	2.9 W m ⁻²
D2	1850-2020	Observed global warming	ΔT_1	HadCRUT5 (Morice+ 2020)	1.1 K
D3	1850-2020	Earth energy imbalance	ΔN_1	Schuckmann+ 2020	$0.87 \mathrm{W}\mathrm{m}^{-2}$
D4	2020-2xCO2	Doubled-CO ₂ forcing	ΔO_2	Zelinka+ 2020	3.52 W m ⁻²
D5		Anthropogenic fraction	M	Wu+ 2020	0,7
D6		Exponential-growth factor	H	Wentz+ 2007	1.07 K ⁻¹
D7		Planck sensi. parameter	P	Schlesinger 1988; Roe 2009	$0.3 \mathrm{K} \mathrm{W}^{-1} \mathrm{m}^2$
S1	1850-2020	Energy imbalance ratio	Г	$\Delta O_1 / (\Delta O_1 - M \Delta N_1)$	1.266
S2	1850-2020	Anthro. equilibrium sensi.	ΔE_1	$M \Delta T_1 \Gamma$	0.975 K
S 3	1850-2020	Unit feedback response	$\dot{v_i}$	$\Delta E_1/(P \Delta \hat{Q}_1) - 1$	0.127
S4	2020-2xCO2	Response ratio $U_2/U_1 =$, X	$\exp(P \Delta Q_2 \ln H)$	1.074
S 5	2020-2xCO2	Unit feedback response	U,	Ū1 X	0.136
S6	2020-2xCO2	ECS	ΔE_2	$P \Delta Q_2(U_2+1)$	1.2 K
F1	CMIP6 ECS	ΔE_2 on 3.7 [2.0, 5.7] K	X	$[\Delta E_2/(P \Delta Q_2) - 1]/U_1$	20 [7, 35]
F2		Extreme ECS 10 K	X	$[10/(P \Delta Q_2) - 1]/U_1$	67

The mathematics, like the data, is mainstream: S1-S3 for the industrial era from 1850-2020; S4-S6 for the period from 2020 to doubled CO₂ (415 to 830 ppmv). First, the unit feedback response U_1 from 1850-2020 is derived from real-world data, and is found to be small. X increases U_1 a little to allow for growth in specific humidity and hence in water vapour feedback response with warming by doubled CO₂ after 2020. Thus, U_1 becomes the doubled-CO₂ unit feedback response U_2 . Direct warming $P \Delta Q_2$ from doubled CO₂ is multiplied by (U_2+1) to yield the eventual warming after feedback response – equilibrium CO₂ sensitivity (ECS) ΔE_2 .

The true ECS – roughly equal to the entire warming we may cause this century – is just 1.2 degrees (S6). That is less than a third of the 3.7-3.9 degrees that climate models currently predict. That small warming is well within natural variability. It will be net-beneficial, ending the imagined (and imaginary) climate "emergency".

Falsification (F1-F2): The unit-feedback-response ratio X, a yardstick of how much more feedback response to expect after 2020 than from 1850-2020, was found to be just 1.074. Realistically, X cannot reach 2. However, climate scientists' current low, midrange and high predictions of 2, 3.7 and 5.7 degrees ECS imply impossible X of 7, 20 and 35 (F1), rising to 67 (F2) if, as some extreme papers predict, ECS is 10 degrees.

The economic damage from the pandemic need no longer be compounded by further damage from costly interventions intended to abate greenhouse-gas emissions and mitigate global warming. Though trillions have been spent on expensive, intermittent, environmentally-destructive wind farms, solar panels and other pointless mitigation policies over the past 25 years, the share of global energy use contributed by coal, oil and gas fell by only 1% in that time, from 88% to 87% – while global energy consumption rose by two-thirds. Yet CO_2 is greening the Earth, crop yields are at record highs and extreme-weather deaths continue to plummet.

The Argonauts include a professor of climatology who was a former director of the United States Government's Global Change Program; a professor of control theory, the branch of engineering physics misunderstood by climate scientists; an award-winning solar physicist from the Harvard-Smithsonian; a physicist from MIT; two control engineers, a former adviser to the British Prime Minister on scientific questions; an environmental consultant who once sold wind farms; a nuclear engineer who wrote the award-winning control program for a nuclear station; and an expert on the global electricity industry.

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Dependence of Earth's Thermal Radiation on Five Most Abundant Greenhouse Gases

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The atmospheric temperatures and concentrations of Earth's five most important, greenhouse gases, H₂O, CO₂, O₃, N₂O and CH₄ control the cloud-free, thermal radiative flux from the Earth to outer space. Over 1/3 million lines having strengths as low as 10^{-27} cm of the HITRAN database were used to evaluate the dependence of the forcing on the gas concentrations. For a hypothetical, optically thin atmosphere, where there is negligible saturation of the absorption bands, or interference of one type of greenhouse gas with others, the per-molecule forcings are of order 10^{-22} W for H₂O, CO₂, O₃, N₂O and CH₄. For current atmospheric concentrations, the per-molecule forcings of the abundant greenhouse gases H_2O and CO_2 are suppressed by four orders of magnitude. The forcings of the less abundant greenhouse gases, O₃, N₂O and CH₄, are also suppressed, but much less so. For current concentrations, the per-molecule forcings are two to three orders of magnitude greater for O_3 , N_2O and CH_4 , than those of H_2O or CO_2 . Doubling the current concentrations of CO_2 , N_2O or CH_4 increases the forcings by a few per cent. These forcing results are close to previously published values even though the calculations did not utilize either a CO_2 or H_2O continuum. The change in surface temperature due to CO_2 doubling is estimated taking into account radiative-convective equilibrium of the atmosphere as well as water feedback for the cases of fixed absolute and relative humidities as well as the effect of using a pseudoadiabatic lapse rate to model the troposphere temperature. Satellite spectral measurements at various latitudes are in excellent quantitative agreement with modelled intensities.

1 Introduction

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The temperature record from 1850 to the present shows the average surface temperature of the Earth has increased by about one degree Celsius[1]. The Interovernmental Panel on Climate Change (IPCC) attributes most of this temperature rise due to increasing greenhouse gas concentrations associated with anthropogenic activity. The average concentration of CO_2 in the atmosphere has increased from 280 ppm to over 400 ppm largely due to the combustion of fossil fuels. Concentrations of N_2O and CH_4 have also risen substantially since the start of the industrial revolution [2].

Greenhouse warming of Earth's surface and lower atmosphere is driven by radiative forcing, the difference between the flux of thermal radiant energy from a black surface through a hypothetical, transparent atmosphere, and the flux through an atmosphere with greenhouse gases, particulates and clouds, but with the same surface temperature [3, 4]. This paper examines the effect of greenhouse gas concentrations on thermal radiation for the case of a clear sky. It considers the five most important naturally occurring greenhouse gases: H_2O , CO_2 , O_3 , N_2O and CH_4 .

The spectra of greenhouse gases consists of hundreds of thousands of individual rovibrational spectral lines whose strengths and transition frequencies can be downloaded from the HITRAN database [5, 6]. The earliest global warming estimates approximated the multitude of lines by various absorption bands [7, 8, 9]. The most accurate forcings are found by performing line by line calculations [10, 11, 12, 13, 14, 15]. Here, we use line by line calculations to estimate the effects of doubling CO_2 , N_2O and CH_4 concentrations from current levels. The forcings are strongly affected by saturation of the absorption bands and spectral overlap with other greenhouse gases. Recently, this was found to significantly affect methane forcing [16].

This work downloaded over 1/3 million rovibrational lines from the most recent HITRAN database to calculate the per-molecule forcings. The concentration of each greenhouse gas was varied from the optically thin limit where there is negligible saturation or interference of one type of greenhouse gas with others; to current levels where the per-molecule forcings are suppressed by up to four orders of magnitude. The "instantaneous" forcings resulting from doubling concentrations of CO₂, N₂O and CH₄ were compared to those published in the literature. The change to the temperature profile was estimated taking into account radiative-conective equilibrium of the atmosphere as well as water feedback. Finally, the intensities modelled at the top of the atmosphere were compared to satellite spectral measurements at various latitudes.

2 Altitude Profiles of Temperature and Greenhouse Gases

Radiation transfer in the cloud-free atmosphere of the Earth is controlled by the temperature T = T(z) at the altitude z and the number densities, $N^{\{i\}} = N^{\{i\}}(z)$ of the *i*th type of molecule. Representative midlatitude altitude profiles of temperature [17], and greenhouse gas concentrations [18], are shown in Fig. 1. Altitude profiles directly measured by radiosondes in ascending balloons are always more complicated than those of Fig. 1, which can be



Figure 1: Left. A standard atmospheric temperature profile[17], T = T(z). The Earth's mean surface temperature i T(0) = 288.7 K. Right. Standard concentrations[18], $C_{\rm sd}^{\{i\}}$ for greenhouse molecules versus altitude z.

thought of as appropriate average profiles for the year 2020.

We divided the atmosphere into 500 altitude segments, 100 segments for each layer: the troposphere, lower stratosphere, mid stratosphere, upper stratosphere and mesosphere. The segment midpoints are labeled by the integers i = 1, 2, 3, ..., 500. We characterize the initial temperature profile of the atmosphere, with six breakpoints, with temperatures θ_{α} and altitudes ζ_{α} , where $\alpha = 0, 1, ..., 5$. Between the breakpoints, the atmosphere is assumed to have constant temperature lapse rates $L_{\alpha} = -dT/dz = -(\theta_{\alpha} - \theta_{\alpha-1})/(\zeta_{\alpha} - \zeta_{\alpha-1})$. For a midlatitude standard atmosphere, the breakpoint temperatures and altitudes are

$$\theta = \begin{bmatrix} 288.7\\ 217.2\\ 229.2\\ 271.2\\ 187.5 \end{bmatrix} \text{ K, and } \zeta = \begin{bmatrix} 0\\ 11\\ 20\\ 32\\ 47\\ 86 \end{bmatrix} \text{ km.}$$
(1)

The lapse rates are L = [6.5, 0, -1, -2.8, 2.1] K km⁻¹. The temperature profile determined by (1) is shown as the solid blue line in the left panel of Fig. 1.

In the troposphere, convective transport of sensible and latent heat of water vapor, especially near the equator, is as important as radiant heat transfer. Above the troposphere is the stratosphere, which extends from the tropopause to the stratopause, at a typical altitude

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i	Molecule	$\hat{N}_{ m sd}^{\{i\}}~({ m cm}^{-2})$
1	H ₂ O	$4.67 imes10^{22}$
2	$\rm CO_2$	$8.61 imes10^{21}$
3	O ₃	$9.22 imes 10^{18}$
4	N_2O	$6.61 imes 10^{18}$
5	CH_4	3.76×10^{19}

Table 1: Column densities, $\hat{N}_{sd}^{\{i\}}$, of the 5 most abundant greenhouse gases obtained using the standard altitudinal profiles [18] of Fig. 1.

of $z_{\rm sp} = 47$ km, as shown in Fig. 1. The temperature in the stratosphere is nearly constant at low altitudes, but increases at higher altitudes due to the heating of ozone molecules that absorb ultraviolet sunlight. The stratosphere is much more stable to vertical displacements of air parcels than the troposphere and negligible moist convection occurs because of the very low water vapor concentration.

Above the stratosphere is the mesosphere, which extends from the stratopause to the mesopause at an altitude of about $z_{\rm mp} = 86$ km. With increasing altitudes, radiative cooling, mainly by CO₂, becomes increasingly more important compared to heating by solar ultraviolet radiation. This causes the temperature to decrease with increasing altitude in the mesosphere.

The vertical radiation flux changes rapidly in the troposphere and stratosphere compared to the mesosphere where the atmospheric density is very low. Changes in flux above the mesopause are negligible and the mesopause is therefore referred to as "the top of the atmosphere" (TOA), with respect to radiation transfer.

The standard concentrations for the ith greenhouse gas, $C_{\rm sd}^{\{i\}}$, based on observations[18], are shown as functions of altitude on the right of Fig. 1. The sea level concentrations are 7,750 ppm of H₂O, 1.8 ppm of CH₄ and 0.32 ppm of N₂O. The O₃ concentration peaks at 7.8 ppm at an altitude of 35 km, and the CO₂ concentration was 400 ppm at all altitudes. Integrating the concentrations over an atmospheric column having a cross sectional area of 1 cm² yields the column number density of the *i*th type of molecule $\hat{N}_{\rm sd}^{\{i\}}$ which are listed in Table 1.

3 Greenhouse Gas Lines

A line by line calculation of radiative forcing utilizes various parameters that are now briefly discussed.

3.1 Line Intensities

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Fig. 2 illustrates the greenhouse gas lines considered in this work. The Bohr frequency ν_{ul} for a radiative transition from a lower level l of energy E_l to an upper level u of energy E_u of the same molecule is denoted by

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$$\nu_{ul} = \frac{E_{ul}}{hc}, \quad \text{where} \quad E_{ul} = E_u - E_l. \tag{2}$$

where the energy of a resonant photon is E_{ul} , h is Planck's constant and c is the speed of light.

The cross section, $\sigma^{\{i\}} = \sigma$, for the *i*th type of greenhouse molecule is written as the sum of partial cross sections σ_{ul} , corresponding to each Bohr frequency ν_{ul} ,

$$\sigma = \sum_{ul} \sigma_{ul}.$$
 (3)

The partial cross section, σ_{ul} , is assumed to be the product of a lineshape function, $G_{ul} = G_{ul}(\nu, \tau)$, and a line intensity, $S_{ul} = S_{ul}(T)$,

$$\sigma_{ul} = G_{ul} S_{ul}.\tag{4}$$

The lineshape functions, G_{ul} , are normalized to have unit area,

$$\int_{0}^{\infty} G_{ul} d\nu = 1 \tag{5}$$

and have units of cm. The line intensity is

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$$S_{ul} = \eta_u \pi r_e f_{ul} W_l \left(1 - e^{-\nu_{ul}/\nu_T} \right) = \frac{\eta_u W_u \Gamma_{ul} E_{ul}}{4\pi \tilde{B}_{ul}}.$$
 (6)

In (6), S_{ul} has the units of cm, $r_e = e^2/(m_e c^2)$ is the classical electron radius, where e is the elementary charge and m_e is the electron mass. The isotopologue fractions are η_u . For the most abundant isotopologues of CO₂,

$$\eta_{u} = \begin{cases} 0.9843 & \text{for } {}^{16}\text{O} {}^{12}\text{C} {}^{16}\text{O} \\ 0.0110 & \text{for } {}^{16}\text{O} {}^{13}\text{C} {}^{16}\text{O} \\ 0.0040 & \text{for } {}^{16}\text{O} {}^{12}\text{C} {}^{18}\text{O} \\ 0.0007 & \text{for } {}^{16}\text{O} {}^{12}\text{C} {}^{17}\text{O}. \end{cases}$$

$$(7)$$

The last term of (6) contains the spectral Planck intensity evaluated at the frequency ν_{ul} ,

$$\dot{B}_{ul} = \dot{B}(\nu_{ul}, T). \tag{8}$$

The Planck intensity is given by

$$\tilde{B}(\nu,T) = \frac{2hc^2\nu^3}{e^{\nu c h/(k_{\rm B}T)} - 1}$$
(9)

The radiation frequency, $\nu = 1/\lambda$ is the inverse of the wavelength λ and has units of cm⁻¹. The probability W_n (with n = u or n = l) to find a molecule in the rovibrational level n is

$$W_n = \frac{g_n e^{-E_n/k_{\rm B}T}}{Q}.$$
(10)



Figure 2: Reference line intensities, $S_{ul}^{\{r\}}$ of (15) for H₂O, CO₂, O₃, N₂O and CH₄ from the HITRAN data base [6]. The horizontal coordinate of each point represents the Bohr frequency ν_{ul} of a transition from an upper level u to a lower level l. The vertical coordinate of the point is the line intensity. For greater clarity we have plotted only 1/10, chosen at random, of the extremely large number of O₃ line intensities. The numbers of lines (in parenthesis) used for this work were: H₂O (31,112), CO₂ (20,569), O₃ (210,295), N₂O (43,152) and CH₄ (43,696). The smooth line is the Planck spectral intensity, \tilde{B} of (9) in units of mW cm m⁻² sr⁻¹ for the HITRAN reference temperature, $T^{\{r\}} = 296$ K.

Here g_n is the statistical weight of the level n, the number of independent quantum states with the same energy E_n . For molecules in the level n, the statistical weight can be taken to be

$$g_n = (2j_n + 1)k_n, (11)$$

where j_n is the rotational angular momentum quantum number, and k_n is the nuclear degeneracy factor, that depends on whether the spins of the nuclei are identical or not. The partition function, Q = Q(T), of the molecule is

$$Q = \sum_{n} g_n e^{-E_n/k_{\rm B}T}.$$
(12)

The oscillator strength, f_{ul} , of (6) is related to the matrix elements of the electric dipole moment **M** of the molecule, between the upper energy basis state $|j_u m_u\rangle$ with azimuthal quantum number m_u and the lower energy basis state $|j_l m_l\rangle$, by

$$f_{ul} = \frac{4\pi\nu_{ul}}{3g_l c r_e \hbar} \sum_{m_u m_l} \langle u \, m_u | \mathbf{M} | l \, m_l \rangle \cdot \langle l \, m_l | \mathbf{M} | u \, m_u \rangle. \tag{13}$$

The quantum numbers m_u label the various degenerate substates of the upper level u and the m_l label the substates of the lower level l. If the levels are characterized by rotational quantum numbers j_u and j_l , the quantum numbers m_u and m_l can be thought of as the corresponding azimuthal quantum numbers, for example, $m_u = j_u, j_u - 1, \ldots, -j_u$.

The rate of spontaneous emission of photons when the molecule makes transitions from the upper level u to the lower level l is Γ_{ul} , the same as the Einstein A coefficient, $\Gamma_{ul} = A_{ul}$ [19, 20]. The spontaneous emission rate is related to the oscillator strength by

$$\Gamma_{ul} = \frac{8\pi^2 c \, r_e \nu_{ul}^2 f_{ul} g_l}{g_u}.$$
(14)

From inspection of (6) we see that the line intensity $S_{ul} = S_{ul}(T)$ at some arbitrary temperature T is related to the intensity, $S_{ul}^{\{r\}} = S_{ul}(T^{\{r\}})$ at a reference temperature $T^{\{r\}}$ where the partition function of (12) is related to $Q^{\{r\}} = Q(T^{\{r\}})$ by

$$S_{ul} = S_{ul}^{\{r\}} \frac{Q^{\{r\}}}{Q} \left(\frac{e^{-E_l/k_B T}}{e^{-E_l/k_B T^{\{r\}}}} \right) \left(\frac{1 - e^{-\nu_{ul}/\nu_T}}{1 - e^{-\nu_{ul}/\nu_T \{r\}}} \right).$$
(15)

This work considered all lines in the HITRAN database of the five gases under consideration in having intensities greater than 10^{-25} cm. For H₂O, lines having intensities greater than 10^{-27} cm were included since water vapor has an order of magnitude greater density than any other greenhouse gas near the Earth's surface.

3.2 Lineshapes

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It is convenient to write the lineshape function as the product of a "core" profile $C_{ul} = C_{ul}(\nu)$ and a wing-suppression factor, $\chi_{ul} = \chi_{ul}(\nu)$,

$$G_{ul} = C_{ul}\chi_{ul}.\tag{16}$$

Core functions The core function is normally taken to be a Doppler broadened Lorentzian, often called a Voigt profile[21]. If we average over a Maxwellian distribution of velocities v for molecules of mass m at the temperature T we find that the core function has the form

$$C_{ul} = \frac{\mu_{ul}}{\pi} \sqrt{\frac{m}{2\pi k_{\rm B}T}} \int_{-\infty}^{\infty} \frac{e^{-mv^2/2k_{\rm B}T} dv}{\mu_{ul}^2 + (\nu - \nu_{ul}[1 + v/c])^2}$$
(17)

The half width at half maximum of a purely Doppler broadened line is

$$\Delta \nu_{ul} = \nu_{ul} \sqrt{\frac{2k_{\rm B}T\ln 2}{mc^2}} \approx 0.0005 \ {\rm cm}^{-1} \tag{18}$$

Here, the representative Doppler half width is for a resonance frequency ν_{ul} of the 667 cm⁻¹ band of a CO₂ molecule near the cold mesopause.

The half width at half maximum, μ_{ul} , of the Lorentzian function in (17) is almost entirely due to collisions. The contribution to μ_{ul} from spontaneous radiative decay is negligible at altitudes below the mesopause. For the bending mode of CO₂, representative values[5] of μ_{ul} at atmospheric pressure p are

$$\mu_{ul} \approx 0.07 \frac{p}{p_0} \text{ cm}^{-1}.$$
 (19)

Here $p_0 = 1$ bar, the approximate atmospheric pressure at mean sea level. The pressure broadening coefficients depend somewhat on temperature and on the particular resonance, ul, involved.

For (17), a small, temperature dependent pressure shift[5] must be added to the free molecule Bohr frequency of (2), which we denote by $\nu_{ul}^{\{0\}}$, to define the resonance frequency

$$\nu_{ul} = \nu_{ul}^{(0)} + \delta_{ul} \, p/p_0. \tag{20}$$

The magnitude of the pressure shift coefficient δ_{ul} is of order

$$|\delta_{ul}| \approx 0.001 \text{ cm}^{-1},\tag{21}$$

comparable to the Doppler half width (18). The small pressure shifts have negligible influence on radiative forcing calculations, but the pressure broadening coefficients of (19) have a large effect. Collisions significantly broaden absorption lines in the troposphere and stratosphere.

Wing-suppression functions Lorentz profiles give far too much absorption for large detunings $|\nu - \nu_{ul}|$, so it is necessary to include wing suppression factors χ in the expression (16) for the lineshape function [22, 23]. Lorentzian lineshapes result from assuming an infinitely short collision duration, but in fact collisions take a few ps for completion. The collisional interactions that lead to wing suppression are not known well enough for reliable theoretical calculations, so we use the empirical wing suppression factor

$$\chi_{ul}(\nu) = \operatorname{sech}^2([\nu - \nu_{ul}]/\varpi).$$
(22)

Measurements on bands of CO₂, for example by Edwards and Strow [24], suggest that the far wings decrease approximately exponentially with detuning, $|\nu - \nu_{ul}|$, as does the wing suppression function (22). We used the width parameter $\varpi = 2 \text{ cm}^{-1}$, corresponding to a collision duration of a few picoseconds.

4 Radiation

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In cloud-free air where scattering is negligible, radiation transport is governed by the Schwarzschild equation [25],

$$\cos\theta \frac{\partial \tilde{I}}{\partial \tau} = -(\tilde{I} - \tilde{B}) \tag{23}$$

where $\tilde{I} = \tilde{I}(\nu, z, \theta)$ is the spectral intensity of a pencil of radiation of frequency between ν and $\nu + d\nu$ at altitude z. The pencil makes an angle θ to the vertical. In thermal equilibrium, the spectral intensity \tilde{I} equals the Planck intensity given by (9). The optical depth is defined by

$$\tau(z,\nu) = \int_0^z dz' \kappa(z',\nu), \qquad (24)$$

where the net attenuation coefficient due to molecules absorbing and remitting light of frequency ν at altitude z is given by

$$\kappa(z,\nu) = \sum_{i} N^{\{i\}}(z)\sigma^{\{i\}}(z,\nu).$$
(25)

Here $N^{\{i\}}(z)$ is the density of greenhouse gas molecule of type *i* and $\sigma^{\{i\}} = \sigma^{\{i\}}(z,\nu)$ is its absorption cross section for radiation of frequency ν at the altitude *z* given by (3). The cross section can depend strongly on altitude because temperature and pressure are functions of altitude. Temperature controls the distribution of the molecules between translational, rotational and vibrational states. Pressure, together with temperature, determines the width of the molecular resonance lines.

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The optical depth from the surface to the top of the radiative atmosphere, the altitude $z_{\rm mp}$ of the mesopause, is

$$\tau_{\infty} = \tau_{\rm mp} = \int_0^{z_{\rm mp}} dz' \kappa(z', \nu).$$
(26)

As indicated by the notation (26), we have assumed that the optical depth $\tau_{\rm mp}$ at the mesopause altitude $z_{\rm mp}$ differs negligibly from the optical depth τ_{∞} at infinite altitude since there is so little opacity of the atmosphere above the mesopause.

The Schwarzschild equation (23) can be solved to find the intensity [26, 27]

For
$$\varsigma > 0$$
: $\tilde{I}(\tau,\varsigma) = +\varsigma \int_0^\tau d\tau' e^{-\varsigma(\tau-\tau')} \tilde{B}(\tau') + e^{-\varsigma\tau} \tilde{I}(0,\varsigma)$ (27)

For
$$\varsigma < 0$$
: $\tilde{I}(\tau,\varsigma) = -\varsigma \int_{\tau}^{\tau_{\infty}} d\tau' e^{-\varsigma(\tau-\tau')} \tilde{B}(\tau')$ (28)

where $\varsigma = \sec \theta$. For simplicity, we assume the surface intensity is the product of $B_s = B(T_s)$, the Planck intensity (9) for a temperature T_s , and an angle independent emissivity $\epsilon_s = \epsilon_s(\nu)$,

$$\tilde{I}(0,\varsigma) = \epsilon_s \tilde{B}_s. \tag{29}$$

Over most of the Earth's surface the thermal infrared emissivity ϵ_s , is observed to be in the interval $[0.9 < \epsilon_s < 1]$ [28]. Negligible error is introduced by setting $\epsilon_s = 1$ in spectral regions of high atmospheric opacity, with $\tau_{\infty} >> 1$. With only radiative heat transfer from the surface and with negligible conduction or convection, there can be a discontinuous jump between the surface temperature T_s and the temperature T_0 of the air just above. For the rest of this paper we assume that any temperature jump is negligibly small, and $T_s = T_0$ and $\tilde{B}_s = \tilde{B}_0$.

For discussions of greenhouse gas forcing, we will be particularly interested in the upward flux

$$\tilde{Z} = \int_{4\pi} d\Omega \, \cos\theta \, \tilde{I}. \tag{30}$$

Using (27) and (28) in (30), we find

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$$\frac{\tilde{Z}}{2\pi} = \int_0^\tau d\tau' E_2(\tau - \tau') \tilde{B}(\tau') - \int_{\tau}^{\tau_{\infty}} d\tau' E_2(\tau' - \tau) \tilde{B}(\tau') + \epsilon_s \tilde{B}_s E_3(\tau)$$

$$= -\int_0^{\tau_{\infty}} d\tau' E_3(|\tau - \tau'|) \frac{\partial \tilde{B}(\tau')}{\partial \tau'} + \tilde{B}(\tau_{\infty}) E_3(\tau_{\infty} - \tau) + [\epsilon_s \tilde{B}_s - \tilde{B}(0)] E_3(\tau). \quad (31)$$

In this work, we have assumed that $\epsilon_s \tilde{B}_s = \tilde{B}(0)$. Equation (31) is the fundamental expression for the net upward flux in an atmosphere with negligible scattering and has been known for a long time. For example, the first line can be found in the NASA reports: Equation (2a) of Yoshikawa [29], or Equation (3.19) of Buglia [26]. Equation (31) contains exponential-integral functions, $E_n(\tau)$, that account for slant paths of radiation between different altitudes. They are defined for integers $n = 1, 2, 3, \ldots$ by

$$E_n(\tau) = \int_1^\infty d\varsigma \,\varsigma^{-n} \,e^{-\varsigma\tau},\tag{32}$$

as discussed in Appendix 1 of Chandrasekhar [7], or Section 5.1.4 of Abramowitz and Stegun [30].

For frequencies where the atmosphere is not too optically thick, with $\tau_{\infty} \leq 10$, we evaluate \tilde{Z} from the first line of (31). Fast Fourier transforms are used to calculate a discretized version of the convolution with \tilde{B} . For frequencies where the atmosphere is thicker, we use the expression on the first line of (31) to calculate \tilde{Z} for 10 e-foldings of optical depth down from the top of the atmosphere, $\tau_{\infty} - \tau < 10$. We use a fast and accurate analytic approximation of the second line to evaluate \tilde{Z} when $\tau_{\infty} - \tau \geq 10$. For example, in the lower troposphere,

$$\frac{\tilde{Z}}{2\pi} = -\frac{d\tilde{B}(\tau)}{d\tau} \Big[\frac{4}{3} - 2E_4(\tau)\Big].$$
(33)

The spectral forcing, \tilde{F} , is defined as the difference between the spectral flux $\pi \tilde{B}_s$ through a transparent atmosphere from a black surface with temperature T_s , and the spectral flux \tilde{Z} for an atmosphere with greenhouse gases,

$$\tilde{F} = \pi \tilde{B}_s - \tilde{Z}.\tag{34}$$

The frequency integrals of the flux (30) and the forcing (34) are

$$Z = \int_0^\infty d\nu \,\tilde{Z},\tag{35}$$

$$F = \int_0^\infty d\nu \,\tilde{F} = \sigma_{\rm SB} T_0^4 - Z, \qquad (36)$$

(37)

where σ_{SB} is the Stefan Boltzmann constant.

5 Intensity and Flux

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In this section we discuss model atmospheres with greenhouse gas concentrations comparable to those of the year 2020. The spectral flux has a complicated dependence on frequency ν , the altitude profiles of the temperature T and greenhouse gas concentrations $C^{\{i\}}$, and latitude.

For the standard atmosphere, the optical depths of (26) can be extremely large i.e. $\tau_{\infty} >> 1$ at so called "blanket" frequencies ν near the centers of the absorption lines. For blanket frequencies a photon emitted near the surface is unlikely to escape the Earth's atmosphere because it has a high probability of being reabsorbed by a greenhouse gas molecule. The extreme opposite of a blanket frequency is a "window" frequency, where there is little absorption, and $\tau_{\infty} \approx 0$. For window frequencies most radiation reaching space comes from the surface, with minor contributions from greenhouse gases.

From the first line of (31), we see that for frequencies where the atmosphere is optically thick, with $\tau_{\infty} >> 1$, the flux at the top of the atmosphere is very nearly $\tilde{Z}(\tau_{\infty}) = \int_{0}^{\tau_{\infty}} d\tau' E_{2}(\tau_{\infty} - \tau')\tilde{B}(\tau')$. For an isothermal atmosphere, with constant brightness \tilde{B} , half of the flux at the top of the atmosphere will come from altitudes above an emission optical depth τ_{e} , defined by

$$\int_{\tau_e}^{\tau_{\infty}} d\tau' E_2(\tau_{\infty} - \tau') = \frac{1}{2} \int_0^{\tau_{\infty}} d\tau' E_2(\tau_{\infty} - \tau').$$
(38)

Recalling that $E_2(\tau) = -dE_3(\tau)/d\tau$ and that $E_3(0) = 1/2$, we see that (38) implies that the value of the emission optical depth τ_e is given by

$$E_3(\tau_{\infty} - \tau_e) = 1/4, \text{ or } \tau_{\infty} - \tau_e = 0.41904.$$
 (39)

Fig. 3 shows a plot of upwards flux as a function of altitude at four different frequencies. Fig. 3(a) shows a moderate blanket frequency $\nu = 500.5 \text{ cm}^{-1}$, where the optical depth, $\tau_{\infty} = 2.82$. The emission height $z_e = 2.80 \text{ km}$ is in the lower troposphere. From inspection of Fig. 2, we see that transitions of the pure rotation spectrum of H₂O dominate the atmospheric opacity at the frequency, $\nu = 500.5 \text{ cm}^{-1}$.

Fig. 3(b) shows an extreme blanket frequency $\nu = 667.4 \text{ cm}^{-1}$ coinciding with a peak in the CO₂ absorption cross section where the optical depth is $\tau_{\infty} = 51,688$, and where the emission height is $z_e = 84.8 \text{ km}$, just below the mesopause.

Fig. 3(c) shows an extreme window frequency, $\nu = 971 \text{ cm}^{-1}$, where the optical depth is only $\tau_{\infty} = 0.029$. At this frequency, and in the absence of clouds, surface radiation reaches space with negligible attenuation by greenhouse gases. The band centered on the wavelength $\lambda = 1/(971 \text{ cm}^{-1}) = 10.3 \,\mu\text{m}$, is therefore called the "clean infrared window."

Fig. 3(d) shows a blanket frequency, $\nu = 1016.2 \text{ cm}^{-1}$, with a moderate optical depth $\tau_{\infty} = 7.54$ in the O₃ band. Not surprisingly, the emission height, $z_e = 33.0$ km, is in the upper stratosphere, where Fig. 1 shows that the O₃ concentration is maximum.

High resolution spectrometers on satellites seldom provide measurements of intensity I with resolutions less than 1 cm⁻¹. For comparison of modeled spectral intensity or flux, it is useful to plot filtered spectral quantities.



Figure 3: Spectral fluxes \tilde{Z} for representative frequencies, ν indicated: (a) $\tau_{\infty} = 2.82$, $z_e = 2.80 \text{ km}$, $\tilde{B}_s = 134.2 \text{ i.u.}$; (b) $\tau_{\infty} = 51688$, $z_e = 84.8 \text{ km}$, $\tilde{B}_s = 131.8 \text{ i.u.}$; (c) $\tau_{\infty} = 0.029$, $z_e = 0 \text{ km}$, $\tilde{B}_s = 86.4 \text{ i.u.}$; (d) $\tau_{\infty} = 7.54$, $z_e = 33.0 \text{ km}$, $\tilde{B}_s = 79.3 \text{ i.u.}$ Here the spectral intensity unit is 1 i.u. = 1 mW m⁻² cm sr⁻¹.

$$\langle \tilde{X} \rangle(z,\nu) = \int_0^\infty d\nu' J(\nu,\nu') \tilde{X}(z,\nu').$$
(40)

The filter function $J(\nu, \nu')$ smooths out sharp changes with frequency. It is normalized so that

$$\int_{-\infty}^{\infty} d\nu J(\nu,\nu') = 1.$$
(41)

From (40) and (41) we see that the unfiltered spectral flux \tilde{Z} and filtered spectral flux $\langle \tilde{Z} \rangle$ have the same frequency integral

$$Z = \int_0^\infty d\nu \tilde{Z} = \int_0^\infty d\nu \,\langle \tilde{Z} \rangle,\tag{42}$$

and represent the same total flux Z. We found it convenient to use a Gaussian filter function with a width parameter $\Delta \nu$,

$$J(\nu,\nu') = \frac{e^{-(\nu-\nu')^2/2\Delta\nu^2}}{\sqrt{2\pi}\Delta\nu}.$$
(43)



Figure 4: Effects of changing concentrations of carbon dioxide, CO₂ on the filtered spectral flux $\langle \tilde{Z}^{\{i\}}(\nu, z_{\rm mp}, f) \rangle$ of (44) at the mesopause altitude, $z_{\rm mp} = 86$ km. The width of the filter (43) was $\Delta \nu = 3 \text{ cm}^{-1}$. The smooth blue line is the spectral flux, $\tilde{Z} = \pi \tilde{B}(\nu, T_0)$ from a surface at the temperature $T_0 = 288.7$ K for a transparent atmosphere with no greenhouse gases. The green line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{\rm mp}, 0) \rangle$ with the CO₂ removed but with all the other greenhouse gases at their standard concentrations. The black line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{\rm mp}, 1) \rangle$ with all greenhouse gases at their standard concentrations. The red line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{\rm mp}, 2) \rangle$ for twice the standard concentration of CO₂ but with all the other greenhouse gases at their standard concentration of CO₂ (from 400 to 800 ppm) would cause a forcing increase (the area between the black and red lines) of $\Delta F^{\{i\}} = 3.0$ W m⁻², as shown in Table 2.

The effects on radiative transfer of changing the column density of the *i*th greenhouse gas to some multiple f of the standard value, $\hat{N}_{sd}^{\{i\}}$, can be displayed with filtered spectral fluxes

$$\langle \tilde{Z}^{\{i\}}(\nu, z, f) \rangle = \langle \tilde{Z}(\nu, z, \hat{N}_{\rm sd}^{\{1\}}, \dots, \hat{N}_{\rm sd}^{\{i-1\}}, f \hat{N}_{\rm sd}^{\{i\}}, \hat{N}_{\rm sd}^{\{i+1\}}, \dots, \hat{N}_{\rm sd}^{\{n\}}) \rangle.$$
(44)

Figs. 4 and 5 show how varying the concentrations of CO_2 and CH_4 affect the filtered spectral fluxes at the mesopause altitude, $z_{\rm mp} = 86$ km. Expanded views of the differences between the flux for standard and doubled concentrations of greenhouse gases are shown in Fig. 6, where we display

$$\langle \Delta \tilde{F}^{\{i\}}(z_{\rm mp},2) \rangle = \langle \tilde{Z}^{\{i\}}(\nu, z_{\rm mp},1) \rangle - \langle \tilde{Z}^{\{i\}}(\nu, z_{\rm mp},2) \rangle.$$

$$\tag{45}$$



Figure 5: Effects of changing concentrations of methane, CH_4 , on the filtered spectral flux $\langle \tilde{Z}^{\{i\}}(\nu, z_{mp}, f) \rangle$ of (44) at the mesopause altitude, $z_{mp} = 86$ km. The blue and black lines have the same meanings as for Fig. 4. The green line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{mp}, 0) \rangle$ with the CH_4 removed but with all the other greenhouse gases at their standard concentrations. The red line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{mp}, 2) \rangle$ with twice the standard concentration of CH_4 but with all the other greenhouse gases at their standard concentration of CH_4 would cause a forcing increase (the area between the black and red lines) of $\Delta F^{\{i\}} = 0.7$ W m⁻², as shown in Table 2.

Integrating spectral fluxes, \tilde{Z} , like those of Fig. 4, over all frequencies in accordance with (35) gives Z, the frequency integrated flux shown in the right panel of Fig. 7. The calculations used the temperature profile of Fig. 1, which is shown in the left panel of Fig. 7. A doubling of CO₂ concentration results in a 3 W/m² decrease in the top of the atmosphere flux. This positive forcing changes the temperature profile as is discussed in Section 7.

Thermal radiative fluxes depend on latitude. They are larger near the equator where the surface is relatively warm than near the poles, where the surface is colder and where wintertime temperature inversions often form in the lower troposphere. For example, Fig. 8 is the analog of Fig. 7 for Antarctica. For Fig. 8 we used a five segment temperature profile with altitude breakpoints at $\zeta = [0, 2.5, 8, 25, 47, 86]$ km. The low tropopause at 8 km and the strong, wintertime temperature inversion, peaking at 2.5 km, are both characteristic of the nighttime poles. The lapse rates between the break points were L = [-12.5, 2.3, 0, -1.5, 2.1]K km⁻¹. The surface temperature in Antarctica was taken to be $T_0 = 190$ K and the surface pressure was set to be $p_0 = 677$ hPa, because of the high elevation of the ice surface, about 2.7 km above mean sea level. Doubling CO₂ causes the negative forcing in the Antarctic



Figure 6: Spectral forcing increments (45) for doubled concentrations of CO_2 , N₂O and CH₄. These are the magnified differences between the black and red curves of Figs. 4 and 5. For most frequencies $\langle \Delta \tilde{F}^{\{i\}}(z_{\text{mp}}, 2) \rangle$ is positive. This is because doubling the concentrations of greenhouse gases shifts the emission heights z_e of (38) to higher, colder altitudes in the troposphere. An exception is the band of frequencies near the center of the exceptionally strong bending-mode band of CO₂ at 667 cm⁻¹. Here doubling CO₂ moves the emission heights to higher, warmer altitudes of the stratosphere, where molecules can more efficiently radiate heat to space. Also shown are forcing increments for halved concentrations of H₂O and O₃. Halving ensures that the relative humidity does not exceed 100%, and reduces the clutter of the graph.

opposite that shown in Fig. 1. This is due to the temperature inversion which means an increase in CO_2 causes more infrared radiation to escape to space, creating a negative greenhouse effect [31].

6 Concentration Dependence of Forcing

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The frequency integrated forcing, F, of (36) depends on the altitude z and on the column densities of the five greenhouse gases given in Table 1.

$$F = F(z, \hat{N}^{\{1\}}, \dots, \hat{N}^{\{5\}}).$$
(46)

We assume the temperature T and densities $N^{\{i\}}$ have the same altitude profiles as in the midlatitude example of Fig. 1. An important special case of (46) is the forcing, F_{sd} , when



Figure 7: Left. Midlatitude standard temperature profile. Right. Altitude dependence of frequency integrated flux Z of (35). The flux for three concentrations of CO₂ are shown, the standard concentration, $C_{\rm sd}^{\{i\}} = 400$ ppm of Fig. 1, twice and half that value. The other greenhouse gases have the standard concentrations of Fig. 1. The vertical dashed line is the flux $\sigma_{\rm SB}T_0^4 = 394$ W m⁻² for a transparent atmosphere with a surface temperature $T_0 = 288.7$ K. The forcings F_s that follow from (36) at 0 km, 11 km and 86 km are 252, 137 and 117 W m⁻² respectively.

each greenhouse gas i is present at its standard column density $\hat{N}_{sd}^{\{i\}}$ of Table 1,

$$F_{\rm sd}(z) = F(z, \hat{N}_{\rm sd}^{\{1\}}, \dots, \hat{N}_{\rm sd}^{\{5\}}).$$
(47)

A second special case of (46) is the hypothetical, per molecule standard forcing, $F_{sd}^{\{i\}}$, when the atmosphere contains only molecules of type *i* at their standard column density, $\hat{N}^{\{i\}} = \hat{N}_{sd}^{\{i\}}$, and the concentrations of the other greenhouse vanish, $\hat{N}^{\{j\}} = 0$ if $j \neq i$,

$$F_{\rm sd}^{\{i\}}(z) = F(z, 0, \dots, 0, \hat{N}_{\rm sd}^{\{i\}}, 0, \dots, 0).$$
(48)

We define the forcing power per added molecule as

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$$P^{\{i\}}(z, \hat{N}^{\{1\}}, \dots, \hat{N}^{\{n\}}) = \frac{\partial F}{\partial \hat{N}^{\{i\}}}.$$
(49)

The densities of greenhouse gases j with $j \neq i$ are held constant in the partial derivative of (49). If the units of F are taken to be W m⁻² and the units of $\hat{N}^{\{i\}}$ are taken to be molecules m⁻², then the units of $P^{\{i\}}$ will be W molecule⁻¹.



Figure 8: Quantities analogous to those of Fig. 7 at the South Pole. There is a strong temperature inversion at an altitude of 2.5 km above the ice surface. The flux for three concentrations of CO_2 are shown, the standard concentration, $C_{sd}^{\{i\}} = 400$ ppm of Fig. 1, twice and half that value. The other greenhouse gases have the standard concentrations of Fig. 1. The relatively warm greenhouse-gas molecules in the atmosphere above the cold surface cause the Earth to radiate more heat to space from the poles than it could without greenhouse gases [31].

We define a finite forcing increment for the *i*th type of greenhouse molecule as

$$\Delta F^{\{i\}}(z,f) = F(z,\hat{N}_{\rm sd}^{\{1\}},\ldots,\hat{N}_{\rm sd}^{\{i-1\}},f\hat{N}_{\rm sd}^{\{i\}},\hat{N}_{\rm sd}^{\{i+1\}},\ldots,\hat{N}_{\rm sd}^{\{n\}}) - F_{\rm sd}.$$
(50)

Differentiating (50) with respect to f we find

$$\frac{\partial \Delta F^{\{i\}}}{\partial f}(z,f) = \hat{N}_{\rm sd}^{\{i\}} P_{\rm sd}^{\{i\}}(z,f),\tag{51}$$

where $P_{\rm sd}^{\{i\}}(z, f)$ is the forcing power per additional molecule of type *i* when these molecules have the column density $\hat{N}^{\{i\}} = f \hat{N}_{\rm sd}^{\{i\}}$ and all other types of greenhouse molecules have their standard column densities.

The forcing increments (50) for the five greenhouse gases considered in this paper are shown as a function of f in Fig. 9. Forcing increments are also tabulated at representative altitudes z and multiplicative factors f in Table 2. At both the top of the atmosphere and at the tropopause, we see that the forcing increment (50) is largest for abundant water molecules, H₂O, and is relatively small for the much more dilute greenhouse gases CH₄ and



Figure 9: Dependence of partial forcing increments $\Delta F^{\{i\}}$ of (50) on greenhouse gas multiplicative factor, $f = N^{\{i\}}/N_{sd}^{\{i\}}$. At the standard column densities, with f = 1, the incremental forcings are well into the saturation regime, with $d\Delta F^{\{i\}}(1)/df < d\Delta F^{\{i\}}(0)/df$ for all 5 gases. For the most abundant greenhouse gases, H₂O and CO₂, the saturation effects are extreme, with per-molecule forcing powers suppressed by four orders of magnitude at standard concentrations (f = 1) with respect to the low-concentration, optically thin limit (f = 0). For CO₂, N₂O, and CH₄, the areas bounded by the green and black curves of Figs. 4 and 5 give the values, $-\Delta F^{\{i\}}$ for f = 0, and the areas bounded by the black and red curves give $\Delta F^{\{i\}}$ for f = 2, as discussed for Fig. 6. See the text and Table 2 for more details.

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N₂O. The incremental forcings are all in the saturation regime, with $\partial \Delta F^{\{i\}}/\partial f$ diminishing with increasing f.

In Table 2, the forcing decrements from removing H_2O , CO_2 , O_3 , N_2O and CH_4 , -62.2, -30.2, -8.1, -2.2 and -2.1 W m⁻², are reasonably close to those calculated by Zhong and Haigh [32]. In their Table 1 they cite forcing decrements at the top of the atmosphere of -70.6, -25.5, -7.0, -1.8 and -1.7 W m⁻². Zhong and Haigh seem to have taken the concentrations of N_2O and CH_4 to be independent of altitude. The altitude dependence of Fig. 1 were used in our calculations.

Note from Table 2 that doubling or halving the column density of CO₂ changes the forcing F by almost the same amount, either at the tropopause or at the mesopause. This dependence of forcing increments on the logarithm of the CO₂ column density was first pointed out by Arrhenius [33]. Wilson and Gea-Banacloche [34] explain how the approximate dependence of the CO₂ absorption cross section on frequency ν , $\sigma^{\{i\}} = \sigma_e e^{-\lambda_e |\nu - \nu_e|}$, leads to

	$F_{ m sd}^{\{i\}}(z)$		$\Delta F^{\{i\}}(z,0)$		$\Delta F^{\{i\}}(z,1/2)$		$\Delta F^{\{i\}}(z,2)$	
$i \setminus z$	$z_{ m tp}$	$z_{ m mp}$	$z_{ m tp}$	$z_{ m mp}$	$z_{ m tp}$	$z_{ m mp}$	$z_{ m tp}$	$z_{ m mp}$
H ₂ O	81.6	71.6	-72.6	-62.2	-10.4	-7.8	11.2	8.1
CO_2	52.4	38.9	-44.6	-30.2	-5.3	-3.0	5.5	3.0
O ₃	6.1	10.5	-4.7	-8.1	-1.8	-2.2	2.5	2.5
N ₂ O	4.4	4.7	-2.2	-2.2	-0.8	-0.8	1.2	1.1
CH ₄	4.2	4.4	-2.1	-2.1	-0.6	-0.6	0.8	0.7
\sum_{i}	148.7	130.1	-126.2	-104.8				
$F_{ m sd}(z)$	137	117	137	117				

Table 2: Partial forcings $F_{\rm sd}^{\{i\}}(z)$ of (48) and partial forcing increments $\Delta F^{\{i\}}(z, f)$ of (50), all in units of W m⁻², at the altitudes $z_{\rm tp} = 11$ km of the tropopause and $z_{\rm mp} = 86$ km of the mesopause. The last row contains the forcings $F_{\rm sd}(z)$ of (47), shown in Fig. 7, when all greenhouse molecules are present simultaneously at their standard column densities $\hat{N}_{\rm sd}^{\{i\}}$. Because of the overlapping absorption bands, $\sum_i F_{\rm sd}^{\{i\}}(z) > F_{\rm sd}(z)$, and $-\sum_i \Delta F^{\{i\}}(z, 0) < F_{\rm sd}(z)$.

the logarithmic forcing law. Here σ_e is the maximum cross section at the center frequency, $\nu_e = 667 \text{ cm}^{-1}$, of the bending mode band.

The forcing increments in Table 3 are comparable to those calculated by others. For example, in column 3 we give the increments $\Delta F^{\{i\}}(z, f)$ calculated by Collins et al [13], as estimated from their Tables 2 and 8. These are the results of averaging five separate line by line calculations. In addition to line intensities, three of the calculations used a continuum CO₂ opacity, and all five used a continuum H₂O opacity. The physical origin of these continua is unclear. They are added to make the calculations agree better with observations [10, 13]. The forcings calculated in this paper, summarized in column 4, used only lines for the HITRAN data base and no continua. Our values are fairly close to those of Collins et al.[13], with the largest discrepancy for H₂O. The mesopause spectral intensities, calculated with only HITRAN lines and with no continuum contributions, are in excellent agreement with satellite measurements over the Sahara Desert, the Mediterranean Sea and Antarctica, as discussed in Section 8.

The three mesopause flux increments $\Delta F^{\{i\}}$ in the fourth column of Table 3 for doubled concentrations of CO₂, N₂O and CH₄ sum to 4.8 W m⁻². The calculated flux increment from simultaneously doubling CO₂, N₂O and CH₄ is the slightly smaller value, $\Delta F = 4.7$ W m⁻². Similarly, the four mesopause flux increments $\Delta F^{\{i\}}$ in the fourth column of Table 3 for doubled concentrations of CO₂, N₂O and CH₄ as well as a factor of f = 1.06 increase of H₂O concentration sum to 5.5 W m⁻². The calculated flux increment from simultaneously doubling CO₂, N₂O and CH₄, and increasing the H₂O concentrations by a factor of f = 1.06, is the slightly smaller value 5.3 W m⁻². The "whole" is less than the sum of the parts, because of the interference of greenhouse gases that absorb the same infrared frequencies.

Table 4 summarizes the forcing powers (49) per additional molecule in units of 10^{-22} W at the tropopause altitude, $z_{tp} = 11$ km and at the mesopause altitude, $z_{mp} = 86$ km. The

		$\Delta F^{\{i\}}(z, f)$ in W m ⁻²					
		Ref.	[13]	This	Work		
i	\int	$z_{ m tp}$	$z_{ m mp}$	$z_{ m tp}$	$z_{ m mp}$		
H ₂ O	1.06	1.4	1.1	0.9	0.7		
CO_2	2	5.5	2.8	5.5	3.0		
O ₃	1.1			0.3	0.3		
N ₂ O	2	1.3	1.2	1.2	1.1		
CH ₄	2	0.6	0.6	0.8	0.7		

Table 3: Comparison of the forcing increments $\Delta F^{\{i\}}(z, f)$ of Collins *et al.*[13] in column 3, and the results of Table 2 and (50) in column 4, at the altitude $z_{\rm tp} = 11$ km of the tropopause and $z_{\rm mp} = 86$ km of the mesopause. For H₂O, the relative increase, f = 1.06, of the column density is approximately that caused by a 1 K increase of the surface temperature.

surface temperature was $T_0 = 288.7$ K, and the altitude profiles of temperature and number density were those of Fig. 1. The first column lists the molecules we considered. The numbers in the second column are forcing powers, $P_{ot}^{\{i\}}(z)$, of (54) in the optically thin limit. The numbers of the third column are forcing powers $P_{sd}^{\{i\}}(z,0)$ from (51) for an atmosphere that previously had no molecules of type i (so $\hat{N}^{\{i\}} = 0$) but all other greenhouse molecules had standard concentrations, $\hat{N}^{\{j\}} = \hat{N}_{sd}^{\{j\}}$ if $j \neq i$. The forcings of the third column are less than those of the second because of interference between absorption by different greenhouse gases. The numbers in the fourth column are the forcing powers $P_{sd}^{\{i\}}(z,1)$ from (51) when a single molecule of type i is added to an atmosphere that previously had standard densities for all greenhouse gases, $\hat{N}^{\{j\}} = \hat{N}_{sd}^{\{j\}}$. Saturation of the absorption suppresses the per-molecule forcing by about four orders of magnitude for the abundant greenhouse gases H₂O and CO₂. Saturation causes less drastic suppression of per-molecule forcings for the less abundant O₃, N₂O and CH₄.

We now consider the optically thin limit, where the concentrations of greenhouse gases are sufficiently low that the optical depths τ of (24) will be small, $\tau \ll 1$, for all frequencies ν and at all altitudes z. The frequency integral of the spectral forcing (35) at altitude z can then be written as

$$F_{\rm ot}(z) = \sum_{i} \hat{N}^{\{i\}} P_{\rm ot}^{\{i\}}(z)$$
(52)

where the forcing power per greenhouse molecule of type i is

$$P_{\rm ot}^{\{i\}}(z) = \frac{1}{2} \int_0^z dz' \frac{N^{\{i\}'}}{\hat{N}^{\{i\}}} \left[\Pi^{\{i\}}(T', T_0) - \Pi^{\{i\}}(T', T') \right] + \frac{1}{2} \int_0^z dz' \frac{N^{\{i\}'}}{\hat{N}^{\{i\}}} \Pi^{\{i\}}(T', T').$$
(53)

Here $N^{\{i\}'} = N^{\{i\}}(z')$, T' = T(z') and $T_0 = T(0)$. The mean power absorbed by a greenhouse gas molecule of temperature T from thermal equilibrium radiation of temperature T' is

	$P_{ m ot}^{\{i\}}(z)$		$P_{\rm sd}^{\{i\}}(z,0)$		$P_{ m sd}^{\{i\}}(z,1)$		
$i \setminus z$	$z_{ m tp}$	$z_{ m mp}$	$z_{ m tp}$	$z_{ m mp}$	$z_{ m tp}$	$z_{ m mp}$	
H ₂ O	1.49	1.49	1.16	1.19	$3.3 imes 10^{-4}$	$2.5 imes 10^{-4}$	
CO_2	2.73	3.45	2.24	2.53	$9.0 imes 10^{-4}$	$4.9 imes 10^{-4}$	
O ₃	2.00	5.69	1.68	4.57	3.3×10^{-1}	3.8×10^{-1}	
N_2O	1.68	2.24	0.73	0.91	2.1×10^{-1}	2.0×10^{-1}	
CH_4	0.51	0.71	0.21	0.27	2.8×10^{-2}	$2.6 imes 10^{-2}$	

Table 4: Forcing powers (49) per additional molecule in units of 10^{-22} W at the altitude $z_{\rm tp} = 11$ km of the tropopause and $z_{\rm mp} = 86$ km of the mesopause. The surface temperature was $T_0 = 288.7$ K, and the altitude profiles of temperature and number density were those of Fig. 1. $P_{\rm ot}^{\{i\}}(z)$ of (54) is for the optically-thin limit. $P_{\rm sd}^{\{i\}}(z,0)$ from (51) is for an atmosphere that previously had no molecules of type i (so $\hat{N}^{\{i\}} = 0$) but all other greenhouse molecules had standard concentrations. $P_{\rm sd}^{\{i\}}(z,1)$ from (51) is for a single molecule of type i added to an atmosphere that previously had standard densities for all greenhouse gases.

$$\Pi^{\{i\}}(T,T') = 4\pi \sum_{ul} S^{\{i\}}_{ul}(T) \tilde{B}(\nu_{ul},T').$$
(54)

For the special case of T' = T we can substitute (6) into (54) to find

$$\Pi^{\{i\}}(T,T) = \sum_{ul} W_u^{\{i\}}(T) \Gamma_{ul}^{\{i\}} E_{ul}^{\{i\}}.$$
(55)

Since we are considering a single isotopologue, we have set $\eta_u = 1$ in (6). The three factors in the summed terms of (55) are the probability $W_u^{\{i\}}(T)$ to find the molecule in the upper state u, the radiative decay rate $\Gamma_{ul}^{\{i\}}$ from the upper level u to the lower level l and the mean energy $E_{ul}^{\{i\}}$ of the emitted photon. This is obviously the total power radiated by a molecule of temperature T. For a molecule of temperature T in thermal equilibrium with radiation of the same temperature, the radiative power absorbed by the molecule is equal to the spontaneous radiative power it emits. The forcing powers per molecule are summarized graphically in Fig. 10.

7 Temperature and Forcing

The forcings due to instantaneous changes of greenhouse gas concentrations can be calculated quite accurately. Temperature changes induced by the forcings are less clearly defined because various feedbacks change the temperature profile of the atmosphere. After doubling CO_2 concentrations, a new, steady state will eventually be established by these feedback processes.

As shown in Fig. 7, we have computed the upwards flux $Z = Z(C_g, C_w, T)$ where C_g and C_w are the initial concentrations of some greenhouse gas and water vapor respectively, and T is the temperature. The flux depends on altitude z because C_g , C_w and T are each functions



Figure 10: A graphical display of the per-molecule forcing powers of Table 4. At standard column densities the (red) powers, $P_{\rm sd}^{\{i\}}(z,1)$, for H₂O and CO₂ are suppressed by four orders of magnitude from their values in the optically thin limit (blue) where the powers are $P_{\rm ot}^{\{i\}}(z)$. This is due to strong saturation of the absorption bands. Saturation effects (difference between the blue and red lines) are much less for the minor gases, O₃, N₂O and CH₄. The green lines are the powers per molecule, $P_{\rm sd}^{\{i\}}(z,0)$, of the *i*th greenhouse gas in its low-concentration limit, but when the forcing power is suppressed by other gases at their standard densities. Interference effects (difference between the blue and green lines) are more pronounced for N₂O and CH₄ than for H₂O and CO₂. Fig. 2 shows the strongest bands of O₃ overlap little with those of other greenhouse molecules, minimizing interference effects.

of altitude. In the right panel of Fig. 7 we showed that changing the concentration C_g of the greenhouse gas CO_2 to twice its value, $C'_g = 2C_g$, while holding all other atmospheric properties the same, changed the flux from its initial value $Z(C_g, C_w, T)$ to a slightly smaller value, $Z(C'_g, C_w, T)$. In this hypothetical "instantaneous" process there is no change in the atmospheric temperature T = T(z). The concentrations of all other greenhouse gases, most notably, the concentration $C_w = C_w(z)$ of water vapor, also remain the same. The difference between the flux before and after addition of the greenhouse gas is called the *instantaneous forcing increment*, and can be written as

$$\Delta F = -\Delta Z = Z(C_g, C_w, T) - Z(C'_g, C_w, T).$$
(56)

The flux increment ΔZ for doubling CO₂ concentrations is too small to be seen clearly in Fig. 7 so we have plotted an expanded version in the right panel of Fig. 11. The magnitude of the flux increment is somewhat greater in the lower atmosphere than at higher altitudes.



Figure 11: Temperature and Flux Adjustments. Left. An initial temperature profile T (continuous blue line), which is characteristic of mid latitudes, and the adjusted profile $T' = T + \Delta T$ (dotted red line), from (69). Right. The continuous blue line is the altitude profile of the instantaneous flux decrease ΔZ of (56) caused by increasing CO₂ concentrations from 400 ppm to 800 ppm, with no change in the profiles T of temperature or C_w of water-vapor concentration. The dotted red line shows the residual flux change δZ of (59) for the adjusted temperature profile T' of the left panel, together with the adjusted water-vapor concentration C'_w to keep relative humidity constant at all altitudes. These adjustments restore the flux as nearly as possible to its original value for altitudes above the tropopause, the criterion for maintaining radiative-convective equilibrium.

In steady state the atmosphere is commonly assumed to be in radiative-convective equilibrium, described in 1967 by Manabe and Wetherald[35]. If the concentration C_g of a greenhouse gas other than water vapor instantaneously changes to a new value $C'_g = C_g + \Delta C_g$, the atmosphere will no longer be in equilibrium. To restore radiative-convective equilibrium the temperature profile will change to $T' = T + \Delta T$ and the water-vapor concentration will change to $C'_w = C_w + \Delta C_w$.

The first criterion for radiative-convective equilibrium is no change in thermal flux at the top of radiative atmosphere, which we take to be the mesopause altitude $z_{\rm mp} = \zeta_5$,

$$Z_{\rm mp}(C'_g, C'_w, T') = Z_{\rm mp}(C_g, C_w, T), \quad \text{for} \quad z = \zeta_5.$$
(57)

This criterion assumes that net solar heating remains the same and is balanced by thermal radiation to space.

Above the tropopause, vertical convection is negligible. Thermal radiation carries off heat resulting from the absorption of solar ultraviolet radiation by ozone, and also any heating by horizontal convection. In radiative equilibrium, the volume heating rate is balanced by the thermal-radiation cooling rate, dZ/dz. So a second criterion for radiative-convective

equilibrium is no change in either the heating or cooling rates

$$\frac{dZ(C'_{g}, C'_{w}, T')}{dz} = \frac{dZ(C_{g}, C_{w}, T)}{dz} \quad \text{for} \quad \zeta_{1} < z < \zeta_{5}.$$
(58)

We can integrate (58) down in altitude from the top of the atmosphere, using (57) as a boundary condition. This gives a combined criterion for radiative equilibrium above the tropopause,

$$\delta Z = Z(C'_g, C'_w, T') - Z(C_g, C_w, T) = 0 \quad \text{for} \quad \zeta_1 < z < \zeta_5.$$
(59)

Below the tropopause, much of the heat is transported by vertical convection rather than radiation. Manabe and Wetherald suggested that for convective equilibrium in the troposphere, the temperature lapse rate, $-\partial T/\partial z$ should equal (or not exceed) an equilibrium value, L, that is a known function of the altitude z and of the surface temperature θ_0 . Formally, the criterion is

$$-\frac{\partial}{\partial z}T(z,\theta_0) = L(z,\theta_0) \quad \text{for} \quad z < \zeta_1.$$
(60)

Integrating (60) we see that the tropospheric temperature is a function of altitude z and surface temperature θ_0 , given by

$$T(z,\theta_0) = \theta_0 - \int_0^z dz' L(z',\theta_0).$$
 (61)

Tropospheric lapse rates measured by radiosondes are often quite complicated [36]. Simplified functions are normally used to approximate lapse rates. Manabe and Wetherald[35] made extensive use of the altitude-independent tropospheric lapse rate

$$\bar{L} = 6.5 \text{ K km}^{-1}$$
. (62)

This can be thought of as the average, over the troposphere, of a more complicated lapse rate

$$\bar{L} = -\frac{1}{\zeta_1} \int_0^{\zeta_1} dz \frac{\partial T}{\partial z} = \frac{\theta_0 - \theta_1}{\zeta_1}.$$
(63)

Pseudoadiabatic temperature profiles result if air with 100% relative humidity is adiabatically decompressed, with liquid or solid phases of water removed as they form. But no heat is exchanged with the environment during the decompression. Fig. 12 shows various pseudoadiabatic temperature profiles that can be found using the Clausius Clapeyron equation [37]. Also shown as black, dashed lines are representative profiles with altitude-independent lapse rates. The pseudoadiabat with a surface temperature of $\theta_0 = -50$ C has very little water vapor and cannot be distinguished from a profile with a fully adiabatic, dry-air lapse rate of 9.8 K/km.

7.1 Temperature adjustment

Setting $z = \zeta_1$ in (61) we see that the breakpoint temperature at the tropopause is

$$\theta_1 = T(\zeta_1, \theta_0) = \theta_0 - \int_0^{\zeta_1} dz' L(z', \theta_0).$$
(64)



Figure 12: Temperature profiles for lapse rates that are altitude-independent (black dashed lines) and pseudoadiabatic (colored continuous lines). The dashed black line that starts at a surface temperature of -50 C, has an altitude-independent lapse rate of $\Gamma_W = 9.8$ K/km, the dry adiabatic lapse rate of (87). Little condensible water is available to slow the cooling along the pseudoadiabat that starts from a surface temperature of -50 C, so the dry adiabat and the pseudoadiabat are almost indistinguishable. The dashed black line that starts from a surface temperature of 15.5 C (288.7 K) has an altitude-independent lapse rate of 6.5 K/km. Representative tropopause altitudes are 8 km (polar latitudes), 11 km (temperature latitudes) and 18 km (tropical latitudes).

If the surface temperature increases by a small increment $\Delta \theta_0$, the tropopause breakpoint temperature will increase by $\Delta \theta_1 = \mu \Delta \theta_0$. From (64) we see that the tropopause temperature magnification factor

$$\mu = \frac{\partial \theta_1}{\partial \theta_0} = 1 - \frac{\partial}{\partial \theta_0} \int_0^{\zeta_1} dz' L(z', \theta_0).$$
(65)

Some illustrative magnification factors μ for pseudoadiabatic lapse rates are shown in Fig. 13.

From (61) we see that a surface temperature increase $\Delta \theta_0$, will cause the tropospheric temperature to increase by ΔT , where

$$\Delta T = \mu \Phi_1 \Delta \theta_0 = \Phi_1 \Delta \theta_1. \tag{66}$$

The temperature-adjustment basis function $\Phi_1(z)$ is

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$$\Phi_1(z) = \frac{1}{\mu} \frac{\partial T}{\partial \theta_0} = \frac{1}{\mu} \left(1 - \frac{\partial}{\partial \theta_0} \int_0^z dz' L(z', \theta_0) \right), \quad \text{for} \quad z \le \zeta_1.$$
(67)

For altitudes above the trop pause we extend the definition (67) to

$$\Phi_1(z) = \begin{cases} (\zeta_2 - z)/(\zeta_2 - \zeta_1) & \text{if } \zeta_1 < z < \zeta_2, \\ 0 & \text{if } \zeta_2 < z. \end{cases}$$
(68)



Figure 13: Magnification factor μ versus Surface Temperature for three tropopause altitudes as indicated. The left kink occurs at the surface freezing temperature while the right kink occurs when the tropopause temperature $\theta_1 = 0$ C.

Guided by (66) we will assume that the temperature adjustment ΔT that best restores radiative-convective equilibrium from the surface to the top of the atmosphere is parameterized by the breakpoint temperature adjustments $\Delta \theta_{\lambda}$, for $\lambda = 1, 2, 3, 4, 5$. We represent the temperature adjustment by the expansion on temperature-adjustment basis functions Φ_{λ} .

$$\Delta T = \sum_{\lambda=1}^{5} \Delta \theta_{\lambda} \Phi_{\lambda}.$$
 (69)

We already defined Φ_1 with (67) and (68). For $\lambda = 2, 3, 4$ we write the temperatureadjustment basis functions as

$$\Phi_{\lambda} = \begin{cases} (\zeta_{\lambda+1} - z)/(\zeta_{\lambda+1} - \zeta_{\lambda}) & \text{if } \zeta_{\lambda} < z < \zeta_{\lambda+1}, \\ (z - \zeta_{\lambda-1})/(\zeta_{\lambda} - \zeta_{\lambda-1}) & \text{if } \zeta_{\lambda-1} < z < \zeta_{\lambda}, \\ 0 & \text{otherwise.} \end{cases}$$
(70)

For the highest altitudes we take the temperature-adjustment basis function to be

$$\Phi_5 = \begin{cases} (z - \zeta_4)/(\zeta_5 - \zeta_4) & \text{if } \zeta_4 < z, \\ 0 & \text{otherwise.} \end{cases}$$
(71)

Representative temperature-adjustment profiles, Φ_{λ} and flux-adjustment profiles, V_{λ} for an altitude-independent lapse rate, $L = 6.5 \text{ K km}^{-1}$ are shown in Fig. 14.

7.2 Flux adjustments

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The breakpoint-temperature adjustments, $\Delta \theta_{\lambda}$, can be used to find the flux that restores radiative-convective equilibrium as


Figure 14: The temperature basis functions Φ_{α} are shown as dashed red lines with scales at the tops of the panels. Altitudes at the maxima of the temperature perturbations are given in km next to the short red lines. Multiples of the flux basis functions V_{α} in units of W m⁻² K⁻¹, and with constant relative humidity water vapor feedback, are shown as solid blue lines, with scales at the bottoms of the panels. The dashed blue line is for flux perturbation V_1 without water vapor feedback (with $C'_w = C_w$). The flux perturbations V_2, \ldots, V_5 are the same with or without water vapor feedback.

$$Z(C'_g, C'_w, T') = Z(C'_g, C_w, T) + \sum_{\lambda} \Delta \theta_{\lambda} V_{\lambda}.$$
(72)

The flux-adjustment basis vector for $\lambda = 1$ is

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$$V_{1} = \lim_{\Delta\theta_{1} \to 0} \frac{Z(C'_{g}, C'_{w}, T + \Delta\theta_{1}\Phi_{1}) - Z(C'_{g}, C_{w}, T)}{\Delta\theta_{1}}.$$
(73)

Manabe and Wetherald [35] pointed out that one plausible way for atmospheric water vapor to respond to a temperature increase would be for the relative humidity to remain constant at all altitudes. Observational support for this hypothesis is ambiguous. For example, over 70 years of radiosonde observations indicate relative humidity has decreased slightly in the upper atmosphere [38].

We assume that changes in water-vapor concentration have negligible effect at altitudes above the troposophere, so that the flux-adjustment basis vectors for $\lambda = 2, 3, 4, 5$ are defined by

$$V_{\lambda} = \lim_{\Delta\theta_{\lambda}\to 0} \frac{Z(C'_{g}, C_{w}, T + \Delta\theta_{\lambda}\Phi_{\lambda}) - Z(C'_{g}, C_{w}, T)}{\Delta\theta_{\lambda}}.$$
(74)

Then the adjusted forcing of (59) is

$$\delta Z = \Delta Z + \sum_{\lambda} \Delta \theta_{\lambda} V_{\lambda}. \tag{75}$$

7.3 Optimum temperature adjustments

Between breakpoint altitudes ζ_{λ} and $\zeta_{\lambda+1}$ we have taken 100 evenly spaced altitude segments. Using (72) in (59) for each of the 400 altitude samples z above the tropopause would give 400 linear equations in the five unknowns, $\Delta \theta_1, \Delta \theta_2, \ldots \Delta \theta_5$. This grossly overdetermines the $\Delta \theta_{\lambda}$. However, we can find values of $\Delta \theta_{\lambda}$ that give the best approximate solution to (59) by minimizing

$$Q = \sum_{i=1}^{500} W_i (\delta Z_i)^2.$$
(76)

where $\delta Z_i = \delta Z(z_i)$. The adjustments $\Delta \theta_{\lambda}$ are not very sensitive to the weights W_i , and we used

$$W_i = \begin{cases} \Delta z_i & \text{if } z_i \ge \zeta_1, \\ 0 & \text{if } z_i < \zeta_1. \end{cases}$$
(77)

The altitude interval size is $\Delta z_i = z_{i+1} - z_i$.

The temperature adjustments $\Delta \theta_{\lambda}$, that minimize (76) are the simultaneous solutions of the five linear equations ($\lambda = 1, 2, 3, 4, 5$)

$$\frac{\partial Q}{\partial \Delta \theta_{\lambda}} = 2 \sum_{i} V_{\lambda i} W_{i} \, \delta Z_{i} = 0, \tag{78}$$

where $V_{\lambda i} = V_{\lambda}(z_i)$ was defined by (73) and (74). We can write (75) as the 5 × 5 matrix equation

$$\sum_{\lambda} A_{\kappa\lambda} \Delta \theta_{\lambda} = \Delta S_{\kappa}.$$
(79)

The adjustment matrix of (79) is

$$A_{\kappa\lambda} = \sum_{i} W_i V_{\kappa i} V_{\lambda i}.$$
(80)

The source vector is

$$\Delta S_{\kappa} = -\sum_{i} \Delta Z_{i} W_{i} V_{\kappa i}, \qquad (81)$$

where $\Delta Z_i = \Delta Z(z_i)$ was defined by (56). We assume that the adjustment matrix A of (80) has an inverse A^{-1} . Then we can multiply both sides of (79) by A^{-1} to find

$$\Delta \theta_{\lambda} = \sum_{\kappa} A_{\lambda \kappa}^{-1} \Delta S_{\kappa}. \tag{82}$$

The temperature adjustment (82) will slightly affect the breakpoint altitudes. The pressure will not change for the air segment initially at the altitude z_i since it is due to the weight per unit area of all higher air segments. The ideal gas law implies that the height increment of the *i*th interval becomes

$$\Delta z_i' = \Delta z_i \frac{T'(z_i)}{T(z_i)}.$$
(83)

The adjusted breakpoint altitudes at the top of the λ th layer, with $\lambda = 1, 2, 3, 4, 5$, will be

$$\Delta \zeta_{\lambda} = \sum_{i=1}^{100\lambda} \Delta z_i'. \tag{84}$$

The surface altitude adjustment obviously is $\Delta \zeta_0 = 0$.

7.4 Representative Calculations

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7.4.1 Anderson H₂O profile for L = 6.5 K km⁻¹

For the temperature profile and standard greenhouse-gas concentrations of Fig. 1, doubling the CO_2 concentration changes the flux Z as shown in the right panel of Fig. 11. The adjustments given by (82) and (84) are as follows.

Temperature adjustments but no water-vapor adjustment.

$$\Delta \theta = \begin{bmatrix} 1.4\\ 1.4\\ -2.0\\ -7.2\\ -7.9\\ -2.0 \end{bmatrix}$$
 K, and $\Delta \zeta = \begin{bmatrix} 0\\ 0.06\\ 0.05\\ -0.19\\ -0.65\\ -1.10 \end{bmatrix}$ km, for $\Delta C_w = 0.$ (85)

The breakpoint temperature and altitude adjustments show the lower atmosphere warms and expands slightly after doubling the CO_2 concentration while the upper atmosphere cools and contracts.

Both temperature and constant relative humidity water-vapor adjustments.

$$\Delta \theta = \begin{bmatrix} 2.3 \\ 2.3 \\ -2.8 \\ -7.0 \\ -8.6 \\ 3.8 \end{bmatrix}$$
 K, and $\Delta \zeta = \begin{bmatrix} 0 \\ 0.10 \\ 0.09 \\ -0.17 \\ -0.64 \\ -0.98 \end{bmatrix}$ km. (86)

The temperature and altitude adjustments of (86) are shown in the left panel of Fig. 11. Doubling CO₂ concentrations with water vapor feedback increases the surface temperature warming to $\Delta \theta_0 = 2.3$ K from $\Delta \theta_0 = 1.4$ K, or by a factor of 1.6.

7.4.2 Manabe H₂O profile for L = 6.5 K km⁻¹

The sensitivity of the results to the water vapor profile were checked by considering the altitude dependence of relative humidity $\Phi(z)$, used by Manabe and Wetherald [35].

$$\Phi = \Phi_s \left(\frac{p/p_s - 0.02}{1 - 0.02} \right) \tag{87}$$

Here, p is the pressure at altitude z while p_s denotes the surface pressure. Manabe and Wetherald set the surface relative humidity Φ_s to 77%. Equation (87) fails at high altitudes where it gives negative relative humidity values. The minimum H₂O mixing ratio was therefore set to 3×10^{-6} gm per gm of air which corresponds to a concentration of 4.8 ppm. Equation (87) gives a higher surface H₂O concentration of 13,396 ppm than 7,750 ppm found using the H₂O profile observed by Anderson [18] shown in Fig. 1. The H₂O concentration obtained using equation (87) decreases faster with altitude than that observed by Anderson and corresponds to a column density about 20% higher than that given in Table 1.

The adjustments given by (82) and (84) are as follows.

Temperature adjustments but no water-vapor adjustment.

$$\Delta \theta = \begin{bmatrix} 1.4 \\ 1.4 \\ -1.8 \\ -6.7 \\ -8.9 \\ 0.5 \end{bmatrix}$$
 K, and $\Delta \zeta = \begin{bmatrix} 0 \\ 0.06 \\ 0.05 \\ -0.17 \\ -0.64 \\ -1.33 \end{bmatrix}$ km, for $\Delta C_w = 0.$ (88)

Both temperature and constant relative humidity water-vapor adjustments.

$$\Delta \theta = \begin{bmatrix} 2.2 \\ 2.2 \\ -2.7 \\ -6.8 \\ -10.0 \\ 2.8 \end{bmatrix}$$
 K, and $\Delta \zeta = \begin{bmatrix} 0 \\ 0.10 \\ 0.09 \\ -0.17 \\ -0.67 \\ -1.23 \end{bmatrix}$ km. (89)

These results for both cases without and with water vapor feedback differ very little from (85) and (86) that were obtained using the Anderson H₂O profile.

7.4.3 Anderson H₂O profile with Pseudoadiabatic Lapse Rate

The effect of a temperature profile determined using a pseudoadiabatic lapse rate illustrated in Fig. 12 was considered. For a surface at 288.7 K, the temperature decreases to 211.2 K at 11 km altitude. This is slightly lower than the tropopause breakpoint temperature $\theta_2 = 217.2$ K given by (1). The higher altitude temperatures were determined using the same breakpoint temperatures as given by (1) and all of the breakpoint altitudes remained unchanged.

The adjustments given by (82) and (84) are as follows.

Temperature adjustments but no water-vapor adjustment.

$$\Delta \theta = \begin{bmatrix} 1.0 \\ 3.0 \\ -2.0 \\ -7.7 \\ -8.1 \\ 2.1 \end{bmatrix}$$
 K, and $\Delta \zeta = \begin{bmatrix} 0 \\ 0.13 \\ 0.15 \\ -0.11 \\ -0.58 \\ -1.05 \end{bmatrix}$ km, for $\Delta C_w = 0.$ (90)

Both temperature and constant relative humidity water-vapor adjustments.

$$\Delta \theta = \begin{bmatrix} 2.2 \\ 6.2 \\ -4.2 \\ -7.3 \\ -10.2 \\ 8.9 \end{bmatrix}$$
 K, and $\Delta \zeta = \begin{bmatrix} 0 \\ 0.28 \\ 0.32 \\ 0.01 \\ -0.52 \\ -0.53 \end{bmatrix}$ km. (91)

In (90) and (91), the surface warming was found using the magnification factor $\mu = 3.0$ at a midlatitude tropopause altitude of 11 km.

7.5 Climate Sensitivity

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A comparison of our result for the climate sensitivity defined as the surface warming due to doubling the CO_2 concentration from 400 to 800 ppm, to other work is given in Table 5. These calculations considered the case of a clear sky one dimensional atmosphere in radiative-convective equilibrium. All groups get nearly the identical value for the case of fixed absolute humidity for a constant lapse rate of 6.5 K/km in the troposphere. Additional significant surface warming occurs for the case of fixed relative humidity. Our result of 2.2 K is substantially lower than the value obtained by the pioneering work of Manabe and Wetherald [35] who obviously did not have access to the current line by line information. In a later publication [39] the authors explained that their 1967 result for the surface warming decreased by about 20% when they replaced their radiation transfer scheme by that used by Rodgers and Walshaw [27] which they felt was superior. A 20% reduction of their climate sensitivity result of 2.9 K gives the value of 2.3 K closer to that of the other groups. Hunt and Wells [40] refined the earlier model used by Manabe and Hunt [41] to encompass 18 altitudinal levels up to 37.5 km. Kluft et al [42] calculated radiative fluxes using the Rapid Radiative Transfer Model which is used for global climate models [43]. Their temperature adjustments show stratospheric cooling of about 10 K similar to our results but greater surface warming. All groups obtain similar surface warming for the case of fixed relative humidity using a pseudoadiabatic lapse rate in the troposphere. Some variation of the results is to be expected since the calculations used different water vapor concentration profiles as well as temperature profiles that differ slightly near the tropopause.

Model Configuration	Manabe et al [35][39]	Hunt et al [40]	Kluft et al [42]	This Work
Fixed absolute humidity, constant lapse rate (6.5 K km^{-1})	1.4 (1.4)		1.3	1.4
Fixed relative humidity, constant lapse rate (6.5 K km^{-1})	2.9 (2.2)	2.2	2.7	2.3
Fixed relative humidity, pseudoadiabatic lapse rate	2.0	1.8	2.1	2.2

Table 5: Climate sensitivity in Kelvins for different model configurations. The bracketed numbers next to the results found by Manabe and Wetherald [35] are the results of our calculation using their relative humidity profile given by (87). Our result for the case of fixed relative humidity with a pseudoadiabatic lapse rate in the troposphere was found using the temperature profile shown in Fig. (12) which is further discussed in the text.

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8 Comparison of Model Intensities to Satellite Observations

An important test is to compare calculations to observations. Fig 15 shows vertical spectral intensities, $\tilde{I}(0)$, measured with a Michaelson interferometer from a satellite over the Sahara Desert, the Mediterranean Sea and Antarctica [44]. The figure also shows values of the vertical intensity, \tilde{I} , calculated with (27).

For the Mediterranean, we used the five segment temperature profile of Fig. 1. For the Sahara and Antarctica analogous profiles with different parameters were used. The altitude breakpoints for the Sahara were at $\zeta = [0, 18, 20, 32, 47, 86]$ km. The high tropopause at 18 km is characteristic of near equatorial latitudes. For Antarctica, the altitude breakpoints were $\zeta = [0, 2.5, 8, 25, 47, 86]$. The low tropopause at 8 km is characteristic of the nighttime poles, as is the strong, wintertime temperature inversion, peaking at 2.5 km. The lapse rates between the breakpoints were L = [6.5, 0, -1, -3.8, 2.145] K km⁻¹ for the Sahara and L = [-12.5, 2.33, 0, -1.5, 2.145] K km⁻¹ for Antarctica. The surface temperature in the Sahara was taken to be $T_0 = 320$ K (very hot) and the surface temperature in Antarctica was taken to be $T_0 = 190$ K (very cold). The surface pressure in the Sahara and the Mediterranean was taken to be $p_0 = 1013$ hPa and the surface pressure in Antarctic was taken to be $p_0 = 677$ hPa, low because of the high elevation of the ice surface, about 2.7 km above mean sea level.

For convenience, we modeled the dependence of the water vapor concentrations $C^{\{i\}}$ on the height z above the surface as

$$C^{\{i\}} = C_0^{\{i\}} e^{-z/z_w},\tag{92}$$

with a latitude independent scale height $z_w = 5$ km and with surface concentrations $C_0^{\{i\}} =$



Figure 15: Vertical intensities I(0) at the top of the atmosphere observed with a Michaelson interferometer in a satellite [44], and modeled with (27): over the Sahara desert, the Mediterranean and Antarctica. The intensity unit is 1 i.u. = 1 mW m⁻² cm sr⁻¹. Radiative forcing is negative over wintertime Antarctica since the relatively warm greenhouse gases in the troposphere, mostly CO₂, O₃ and H₂O, radiate more to space than the cold ice surface, at a temperature of T = 190 K, could radiate through a transparent atmosphere.

31,000 ppm for the Sahara, $C_0^{\{i\}} = 12,000$ ppm for the Mediterranean, and $C_0^{\{i\}} = 2,000$ ppm Antarctica. For the year 1970 when the satellite measurements were made, we used surface concentrations, in ppm, for CO₂, N₂O and CH₄ of 326, 0.294 and 1.4, with the same relative altitude profile as those in Fig 1. The altitude profile of Fig. 1 for O₃ was used for the Sahara, the Mediterranean and Antarctica.

As can be seen from Fig. 15 the modeled spectral intensities can hardly be distinguished from the observed values. We conclude that our modeled spectral fluxes would also be close to observed fluxes, if a reliable way to measure spectral fluxes were invented.

9 Conclusions

This work examined the transmission of infrared radiation through a cloud-free atmosphere from the Earth's surface to outer space. A line by line calculation used over 1/3 million lines of the five most important naturally occurring greenhouse gases, H₂O, CO₂, O₃, N₂O and CH₄. This included considerably more weaker rovibrational line strengths, for H₂O as small as 10^{-27} cm, than other studies. The calculation of forcings took into account the observed altitudinal concentrations of the various gases as well as several temperature profiles.

The upward spectral flux, \tilde{Z} , "breaks out" at an emission height z_e , given by (38). Emission heights can be near the top of the atmosphere for frequencies in the middle of strong absorption lines. For frequencies with little absorption, the emission heights can be close to, or at the surface as shown in Fig. 3.

The most striking fact about radiation transfer in Earth's atmosphere is summarized by Figs. 4 and 5. Doubling the current concentrations of the greenhouse gases CO_2 , N_2O and CH_4 increases the forcings by a few percent for cloud-free parts of the atmosphere. Table 3 shows the forcings at both the top of the atmosphere and at the tropopause are comparable to those found by other groups.

Radiative forcing depends strongly on latitude, as shown in Figs. 7 and 8. Near the wintertime poles, with very little water vapor in the atmosphere, CO_2 dominates the radiative forcing. The radiation to space from H₂O, CO_2 and O_3 in the relatively warm upper atmosphere can exceed the radiation from the cold surface of the ice sheet and the TOA forcing can be negative.

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Fig. 9 as well as Tables 2 and 4 show that at current concentrations, the forcings from all greenhouse gases are saturated. The saturations of the abundant greenhouse gases H_2O and CO_2 are so extreme that the per-molecule forcing is attenuated by four orders of magnitude with respect to the optically thin values. Saturation also suppresses the forcing power per molecule for the less abundant greenhouse gases, O_3 , N_2O and CH_4 , from their optically thin values, but far less than for H_2O and CO_2 .

Table 2 and Fig. 10 show the overlap of absorption bands of greenhouse gases causes their forcings to be only roughly additive. One greenhouse gas interferes with, and diminishes, the forcings of all others. But the self-interference of a greenhouse gas with itself, or saturation, is a much larger effect than interference between different gases. Table 4 shows that for optically thin conditions, the forcing power per molecule is about the same for all greenhouse gases, a few times 10^{-22} W per molecule.

Doubling the CO_2 concentration will cause a temperature decrease of the upper atmosphere of about 10 K as shown in Fig. 11 to restore hypothetical radiative-convective equilibrium. For the case of fixed absolute humidity, the surface warms by 1.4 K which agrees very well with other work as shown in Table 5. The surface warming increases significantly for the case of water feedback assuming fixed relative humidity. Our result of 2.3 K is within 0.1 K of values obtained by two other groups as well as a separate calculation where we used the Manabe water vapor profile given by (87). For the case of fixed relative humidity and a pseudoadiabatic lapse rate in the troposphere, we obtain a climate sensitivity of 2.2 K. The corresponding climate sensitivities determined by other groups differ by about 10% which can be expected using slightly differing temperature and water vapor profiles. The issue of water feedback would undoubtedly be greatly clarified if additional observations of water vapor concentration as a function of altitude were available.

Fig. 15 shows that the integral transform (27) used to calculate TOA intensities \tilde{I} with HITRAN line intensities and with no CO₂ nor H₂O continuum absorption gives results in very close agreement with spectral intensities observed from satellites over climate zones as different as the Sahara Desert, the Mediterranean Sea and Antarctica. One can therefore have confidence in the calculations of spectral fluxes. The negligible effect of the H₂O continuum on the top of the atmosphere radiative flux has also been found by Zhong and Haigh [45]. It

would be interesting to examine comparable data for the tropics where atmospheric moisture is highest to determine the effect of a H_2O continuum. One would need to be careful that any "observed continuum" not be confused with a layer of cloud like haze which can be prevalent at high humidities. In conclusion, the combination of one dimensional radiativeconvective models and observations such as TOA intensities are invaluable for furthering our understanding of how increasing greenhouse gas concentrations will affect the Earth's climate.

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Tēnā koutou katoa,

Waiheke Resources Trust (WRT) supports more ambitious climate change commitments than listed in the Climate Change Commission's draft advice. We must act swiftly and aspire towards meeting the proposed 2050 emissions targets in 2030, making reductions immediately as per the Intergovernmental Panel on Climate Change's 1.5 degree report. We feel that it is important to do the mahi now and create an equitable transition as fast as possible by using the ideas, tools and knowledge that already exist within our communities and across the globe.

Waiheke Resources Trust

WRT is a well-established sustainability trust which has operated on Waiheke Island since 1998. A Charitable Trust since 2008, WRT is a member of Environmental Hubs of Aotearoa and has received funding from a variety of sources including the Foundation North, Auckland Council, Waiheke Local Board contracts, and central government grants such as Jobs for Nature. Our vision is that Waiheke's diverse community is connected, empowered, skilled and supported to actively protect and enhance the natural and social fabric of our island and the planet for future generations. We work closely with the community to deliver projects that offer employment and education to locals.

An Inclusive Approach to Climate Change is Needed

The Commission must consider the interconnectivity of the whenua (land), wai (water) and āngi (air), and the intersection between climate change and the biodiversity crisis when looking at solutions to reduce our carbon footprint. It's especially important to focus on the health of our moana, as 70% of all carbon is sequestered through our oceans and as of 2014, only 0.4% of Aotearoa's marine environment is a fully protected marine reserve under a Type 1 MPA.

Just as we need a holistic mountain to sea approach, it is crucial that Aotearoa's approach to climate change is intersectional across all forms of marginalisation and oppression. A collective response is necessary, but the Commission must recognise that actions must be adaptable and work to restore equity for those who are disabled, living in poverty or are in a low socio-economic class, and experience discrimination because of their gender, sexuality, age and/or race. With respect to te ao Māori, the articles of Te Tiriti should be integrated throughout the policy recommendations as well as using the Treaty Principles. Our climate solutions must ensure that everyone, including vulnerable communities, has the resources they need to thrive and participate in mitigating and adapting to climate change.

Similarly, the Commission must undertake meaningful youth engagement programmes to evaluate the intergenerational impacts of their advice. Whether they can vote yet or not, the youth of today will be participating in our climate plan, and future generations will have to live with the policies proposed in this report and their consequences. It is only right that they fully understand what this means and have the chance to give their input.

Emissions Targets Need to be More Ambitious

Aotearoa's government has acknowledged that we are in the midst of a climate crisis. We must act accordingly, and recognise the high cost of inaction.

An NDC target under the Paris Agreement for Aotearoa that reflects our historical pollution and outsized carbon footprint would be far beyond 35% below 2005 levels by 2030, and our targets must reflect our position as a developed nation. Additionally, the NDC target should not rely on offshore mitigation and carbon credits, which are not sustainable to Aotearoa's mauri and don't create the same opportunities in creating long-term adaptations and lasting societal changes around how we think about our carbon footprint as individuals, families, communities, cities and as a country.

The Commission's proposed budgets need to be reversed so that larger emissions cuts are made over the next decade, and we are better aligned with efforts to keep global warming to 1.5 degrees.

We Need More Holistic and Systems-changing Solutions

- We need better climate education and nation-wide policies so that each sector of Aotearoa can confidently and knowledgeably transition to more sustainable practices, with simple accessible milestones.
- The cost of transitioning to a low-carbon future must fall on the industries most responsible so that policies do not regressively impact low socio-economic demographics.
- Agricultural climate pollution must be reduced further and faster and agriculture should enter the Emissions Trading Scheme in 2021 with no subsidies.
- We need more new native forests, wetland restoration, salt marshes, kelp and sea grasses and mangroves, and as land and marine areas are protected we need to make sure that mana whenua are involved in the kaitiakitanga of these taonga.
- We need to encourage biodiversity, with regenerative agriculture being prioritised instead of monoculture.
- Organic waste reduction targets should be 100% by 2030, paired with a mindshift that realises it is a resource that can be used to create compost and regenerate our soils.
- A mindshift to circular economy must be prioritised. Long-lived greenhouse gas emissions are generated from the extraction, production, transport and

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consumption of packaging and goods, which is intrinsic to our current linear economy.

- We need policy interventions that phase out products that cannot be effectively reused, repaired, recycled or composted, and extend the lifespan of our products.
- The Waste Strategy and the Waste Minimisation Act should set binding reduction targets for all waste streams, whether organic or inorganic.
- We need to transform infrastructure for an equitable transition into non-carbon transport, making walking, cycling, shared transport and public transport options accessible and safe for everyone, including disabled people and low socio-economic classes.
- We need an active and public transport mode shift. Car dependence and urban sprawl is one of the biggest contributors to climate change, road deaths, social exclusion and isolation. Furthermore, it entrenches socioeconomic inequalities and restricts access to opportunities.
- No new ICE vehicles should be imported into Aotearoa.
- There should be an immediate ban on any new coal mining on conservation land.
- Energy efficient homes must be financially affordable and physically accessible.
- The Commission needs to explore the health savings from co-benefits.

In conclusion, WRT disagrees with the Climate Commission's draft advice as it stands because we believe that in order to prevent Earth from reaching the tipping point, we need to act faster, be more bold in our targets, and create more long-lasting, sustainable change that improves the lives of everyone in Aotearoa.

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on behalf of the Waiheke Resources Trust whanau



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