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Know Your Footprint!
- A yHEP Initiative

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Sustainable HEP 2024

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Atmospheric CO_2 and Ground Temperature

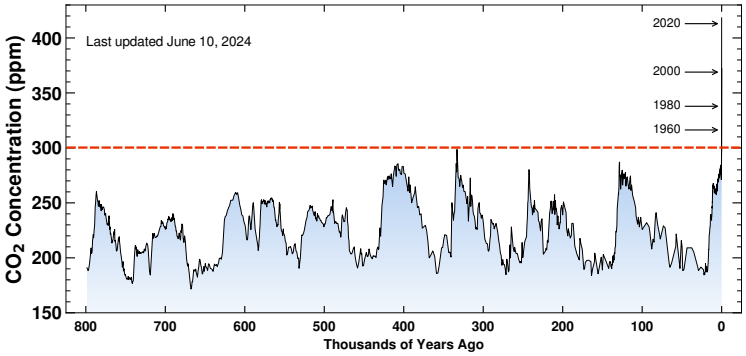
- First publication on the relation between atmospheric CO_2 and ground temperature ▸ S. Arrhenius, 1896
  - Increase in CO_2 levels by factor of 2 $\rightarrow$ temperature increase of $\approx 6^\circ C$
  - Surprising accuracy already 128 year ago
  - Confirmed and refined since then in a multitude of studies $\rightarrow$ e.g. ▸ Nobel Prize 2021

TABLE VII.—*Variation of Temperature caused by a given Variation of Carbonic Acid.*

	Latitude.	Carbonic Acid = 0·67.					Carbonic Acid = 1·5.					Carbonic Acid = 2·0.					Carbonic Acid = 2·5.					Carbonic Acid = 3·0.				
		Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
Europe	70	−2·9	−3·0	−3·4	−3·1	−3·1	3·3	3·4	3·8	3·6	3·52	6·0	6·1	6·0	6·1	6·05	7·9	8·0	7·9	8·0	7·95	9·1	9·3	9·4	9·4	9·3
	60	−3·0	−3·2	−3·4	−3·3	−3·22	3·4	3·7	3·6	3·8	3·62	6·1	6·1	5·8	6·1	6·02	8·0	8·0	7·6	7·9	7·87	9·3	9·5	8·9	9·5	9·3
	50	−3·2	−3·3	−3·3	−3·4	−3·3	3·7	3·8	3·4	3·7	3·65	6·1	6·1	5·5	6·0	5·92	8·0	7·9	7·0	7·9	7·7	9·5	9·4	8·6	9·2	9·17
	40	−3·4	−3·4	−3·2	−3·3	−3·32	3·7	3·6	3·3	3·5	3·52	6·0	5·8	5·4	5·6	5·7	7·9	7·6	6·9	7·3	7·42	9·3	9·0	8·2	8·8	8·82
	30																									

Trends in Atmospheric CO_2 Concentration

- Keeling curve using measurements since 1958 at Mauna Loa Observatory
  - Combined with data from ice cores over last 800k years
    $\Rightarrow$ Composition of air trapped in ice from Antarctica



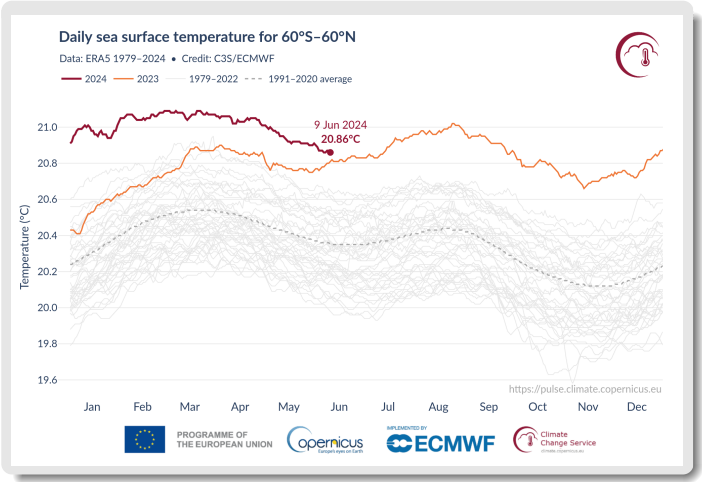
https://keelingcurve.ucsd.edu/

Latest reading: $427.44\,\text{ppm}$

- Currently $40\,\%$ higher than the maximum in past 800k years
- Extremely significant deviation from the observed variation

Trends in Ground Temperature

- Data from Copernicus Satellite → daily sea surface temperature since 1979
  - Strongest anomaly observed in January 2024 ⇒ March 2024 hottest month

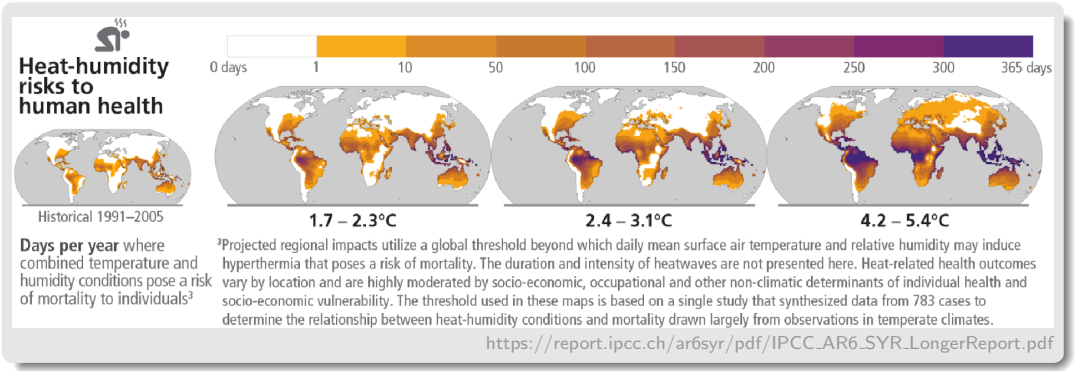


- Comparing last 12 months with 1850–1900 average:
  - Global average $1.63^{\circ}\mathrm{C}$ higher
  - Europe average $1.76^{\circ}\mathrm{C}$ higher

Already reached and surpassing the ideal target of $1.5^{\circ}\mathrm{C}$ set by Paris climate agreement 2015!

https://climate.copernicus.eu/surface-air-temperature-may-2024

- Projections for impact of climate change on natural and human systems:
  - With $> 2^{\circ}\mathrm{C}$ rise in temperature, risks posed in regions around the equator:
    - $\Rightarrow$ Risk of losing $100\,\%$ of animal species
    - $\Rightarrow$ Risk of Hyperthermia* due to heat-humidity conditions *throughout the year*



https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf

*Hyperthermia: Failure of heat-regulating mechanisms of the body due to extreme external heat

Remaining Carbon Budget

- Excerpt from the Paris Agreement 2015

> (a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
>
> https://treaties.un.org/doc/Treaties/2016/02/20160215%2006-03%20PM/Ch_XXVII-7-d.pdf

- Temperature targets set to $1.5^\circ\mathrm{C}$ ($2.0^\circ\mathrm{C}$) above pre-industrial levels (1850–1900)
  $\Rightarrow$ Translates to global carbon budget* of $400\,\mathrm{GtCO_2}$ ($1150\,\mathrm{GtCO_2}$)
- Naively assuming equal yearly emissions from 2020–2050 for a static population of 8 billion people:

$$\text{Annual per person carbon budget} = \frac{400 \times 10^9\,\mathrm{tCO_2}}{30\,\text{years} \times 8 \times 10^9\,\text{people}} \quad \left(\frac{1150 \times 10^9\,\mathrm{tCO_2}}{30\,\text{years} \times 8 \times 10^9\,\text{people}}\right)$$

$$= 1.7\,\mathrm{tCO_2} \quad (4.8\,\mathrm{tCO_2})$$

*Carbon budget defined from the beginning of 2020 until global carbon neutrality is achieved

Relevance for High Energy Physics

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In order to mitigate climate change, *ALL* areas of society need to contribute towards reducing emissions
$\Rightarrow$ This includes HEP!

- HEP has significant CO_2 emissions
  $\Rightarrow$ Seen in recent environmental reports
- But how large per-researcher? $\Rightarrow$ **Know your footprint!**
  - Estimate professional CO_2 footprint per researcher
    $\Rightarrow$ Allows comparison with private and target footprints
  - Identify dominant sources of emissions
  - Devise strategies to address biggest sources first

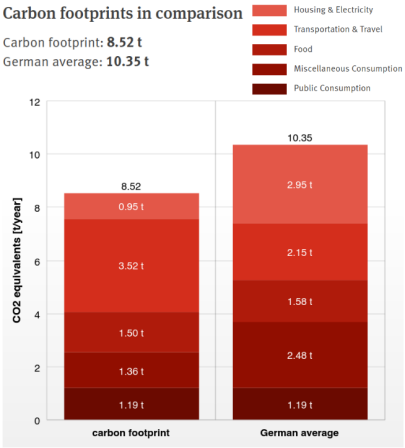
Steps to solve a problem: Acknowledge $\rightarrow$ Identify $\rightarrow$ Strategise $\rightarrow$ Implement

Know Your Footprint Calculator

- Know your footprint (Kyf) calculator → tool to estimate carbon emissions for researchers
  - Private emissions in Germany: Carbon Calculator by German Federal Environment Ministry (UBA)*
  - Professional emissions in HEP and related fields → split into 4 categories:
    ⇒ Experiment
    ⇒ Institute
    ⇒ Computing
    ⇒ Travel

  - Each category configurable for an individual, i.e. for your individual research situation
  - Investigate the impact of each category

- Know your footprint calculator now live: Kyf calculator
- Paper discussing the basis of Kyf calculator available online on arXiv: arXiv:2403.03308



*Permission duly granted by UBA

Experiment, Collaboration or Project

- Possible choices offered:
  - Large LHC experiment
  - Small LHC experiment

  } CERN environmental report(s) and LHCb technical design report

  - Small HEP experiment* → DESY electricity consumption
  - Astrophysics experiment → ESO annual report

Image generated by Deep AI, Inc.

- Estimate annual per-researcher footprint:
  - (Total annual experiment footrint)/(Total experiment members)
  - Experiment member → collaboration members or users (and operators) as per applicability
  - Do not consider indirect benefits to society → too vague and diffuses responsibility
  - We researchers designing, building and operating detectors, and analysing data must take responsibility

*Choice between green and conventional electricity

Image generated by Deep AI, Inc.

- Possible choices offered:
  - Research centre → CERN environmental report(s)
  - University* → University of Freiburg environmental report
    (Cross check with Leibniz University Hannover)
- Estimate annual per-researcher footprint:
  - (Total annual institute footrint)/(Effective number of institute members)
  - One year outside COVID-19 pandemic considered representative
    ⇒ 2019 for University of Freiburg, 2022 for CERN
  - University of Freiburg preferred over Leibniz University Hannover as default university footprint:
    ⇒ Procurement information omitted by Leibniz University Hannover
    ⇒ Decent agreement in overlapping categories

*Choice between green and conventional electricity

Computing

- Focus on high-performance computing (HPC)
  - Specify researcher's individual computing workload in core hours
  - Distinguish between CPU and GPU → based on computational task
    - ⇒ Several possibilities to tune configuration
    - ⇒ Assume optimal core utilisation

Image generated by Deep AI, Inc.

- Potential to add footprint for large external data storage resources
- Personal computers, small institute clusters, etc.
  ⇒ Assumed to be covered personal or institute electricity and procurement
- Benchmark scenarios provided for user-friendliness

Business Travel

- Only considering business travel
  $\Rightarrow$ Private travel included in private footprint
- International research environment
  $\Rightarrow$ Travel important for personal connections
  - Most notably missed during COVID-19 pandemic
- But travel leads to CO_2 emissions
  $\Rightarrow$ Need to reconsider which trips are essential
  - Avoid air travel if possible
  - Consider extending business trips to combine with vacations

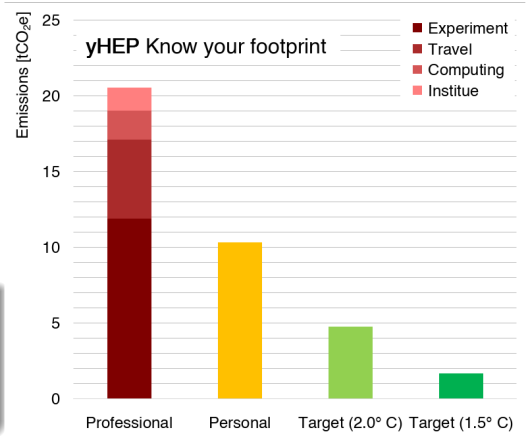
Image generated by Deep AI, Inc.

- Possibility for detailed calculations for business trips in Kyf calculator
- Alternatively, also possible to configure with benchmark trips

Benchmark Researcher

- Doctoral researcher as a benchmark case:
  - Working on a large LHC experiment
  - Employed by a university (conventional electricity)
  - Medium computing level (conventional electricity)
  - Annual travel:
    - ⇒ Two 1-week trips by train in Germany
    - ⇒ One 1-week flight travel in Europe
    - ⇒ One 2-week transcontinental travel

- Professional footprint double of private footprint
- Both far above the targets set in Paris agreement
- HEP researchers urgently need to address this
  ⇒ Become part of the solution to the climate crisis!



Summary

- Climate crisis progressing and intensifying each year
  - Relation between atmospheric CO_2 and ground temperature known since ≈ 130 years
  - Human activities drive temperature increase
    - $\Rightarrow$ Increase of $> 2^\circ\mathrm{C}$ will have dire consequences in tropical regions
      - $\rightarrow$ Risk of $100\,\%$ loss of biodiversity
      - $\rightarrow$ Inhabitable heat-humidity conditions throughout the year
  - However, targeted action still missing today!
- HEP and related fields contribute to global emissions
  - Estimate per-researcher emissions $\rightarrow$ Know your footprint
  - Four categories: Experiment, Institute, Computing, Travel
  - Evaluation of benchmark researcher:
    $\Rightarrow$ Total footprint ≈ 6 (≈ 18) times larger than what is needed for the $2.0^\circ\mathrm{C}$ ($1.5^\circ\mathrm{C}$) target

$\Rightarrow$ Know your footprint to know where to start!

$\Rightarrow$ Every gram of CO_2 not emitted counts!

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Please consider submitting your results $\Rightarrow$ provides us better statistics to understand trends

Backup