Advancing CATS, The **C**limate **A**ware **T**ask **S**cheduler, for high performance- and throughput-computing application

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Motivating question

Image credits: https://i.imgflip.com/208mpa.jpg, from IT Crowd (Channel 4)

(High performance) computing *always requires energy* (electricity etc.) - how can we do it in a sustainable way to not exacerbate the climate crisis?

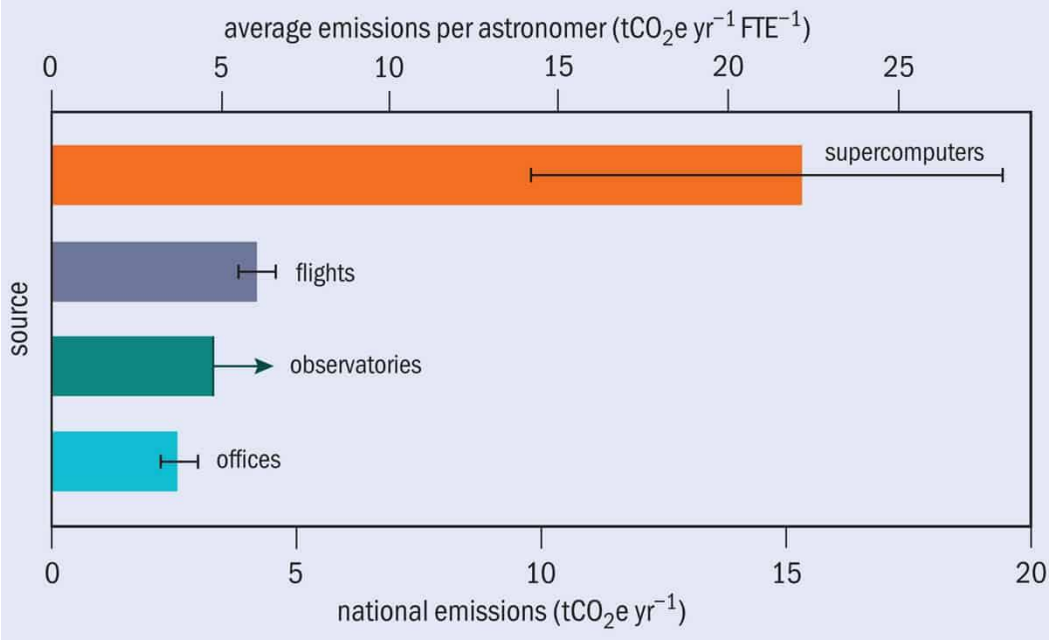
The *operational* (not *embodied*) consumption of HPC

- More need for HPC → more systems built, at larger scale → higher carbon footprint of HPC:

"For example, the *Summit supercomputer built in 2017 has a peak power consumption of 13 MW, while in 2021, the next-generational Frontier supercomputer has more than doubled the peak power to 29MW*"*

- Energy demands of data centers and HPC systems are expected to continue to increase significantly over the next few decades, driven partly by growing use of cloud services, AI, and machine learning models plus more need for data centers which are power hungry:

"*It is estimated that by 2030, datacenters and HPC systems may account for up to 8% of the worldwide emissions if not intervened*"*



*Breakdown of the four sources of **Australian astronomers' emissions** considered in one study from 2019 †*

**Source*: B. Li et al., 2023, Toward Sustainable HPC: Carbon Footprint Estimation and Environmental Implications of HPC Systems

† Source: A. Stevens et al, 2019, The imperative to reduce carbon emissions in astronomy

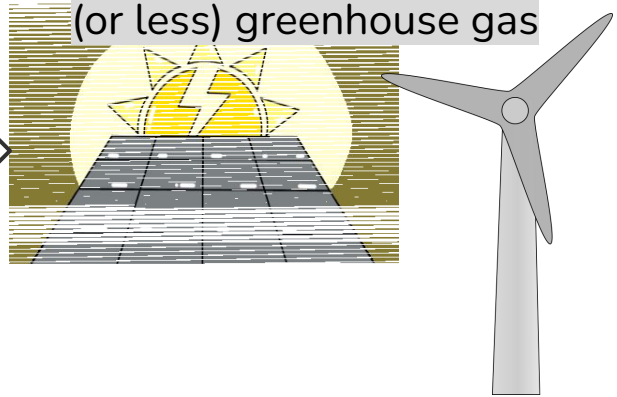
The underlying idea

We can (and should) work to reduce our energy consumption from the computing we do. But we can *also* reduce our climate impact by being *more clever* with the *set energy we do use* so that we end up using **more energy from renewables (clean) over fossil fuels (dirty)**

Dirty energy: produces (more) greenhouse gas

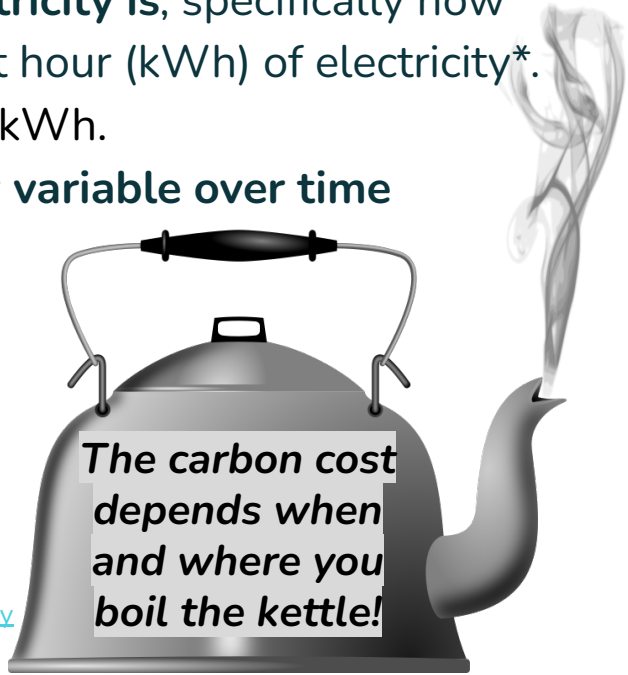
Aim to shift our energy consumption this way

Clean(er) energy: produces no (or less) greenhouse gas



How do we measure the ‘cleanliness’ of energy we use?

- Because renewable sources aren’t available in a steady manner, and demand on a given electricity grid varies, CO_2 emissions from a given task requiring a set amount of electricity *depend on when (datetime) and where (location) the task happens*
- **Carbon intensity is a measure of how clean our electricity is**, specifically how many grams of CO_2 are released to produce a kilowatt hour (kWh) of electricity*. This becomes our metric of interest. Units are gCO_2e/kWh.
- The **carbon intensity of electricity (in the UK) is very variable over time**
  - Windy and/or sunny weather ⇒ lower carbon
  - Generally between 0 and 400 gCO_2e/kWh
  - EU average 251 gCO_2e/kWh in 2022 †

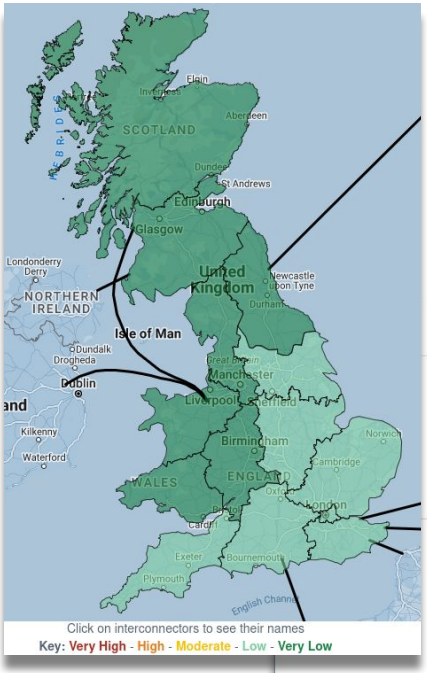


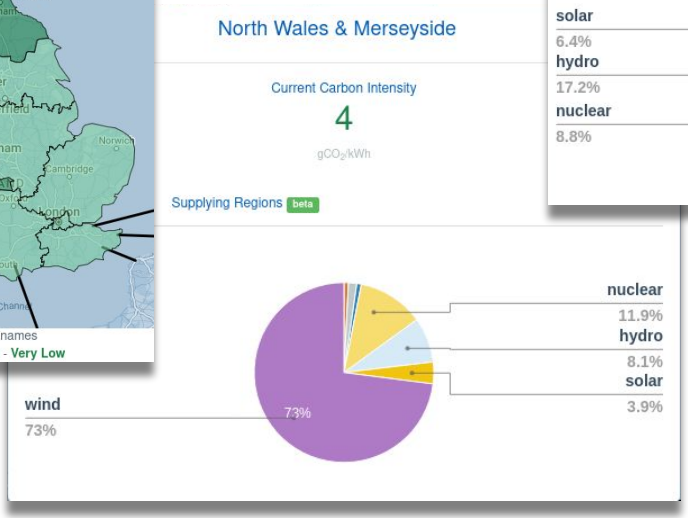
* *Source of definition*: https://www.nationalgrid.com/stories/energy-explained/what-is-carbon-intensity

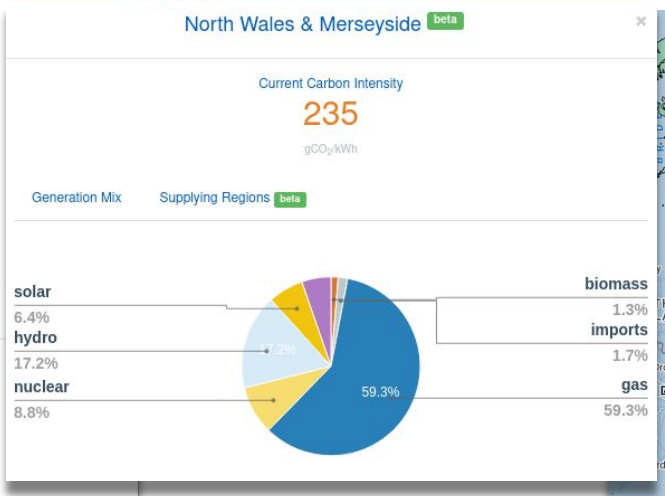
† https://www.eea.europa.eu/en/analysis/maps-and-charts/co2-emission-intensity-15

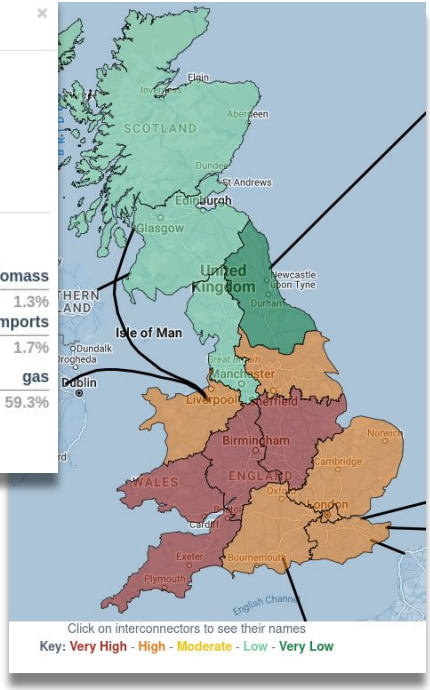
Regional & weather-based influence on carbon intensity

- Left: windy & quite sunny day across UK, right: neither windy nor sunny across UK
- For example showing regional carbon intensity factors for North Wales & Merseyside





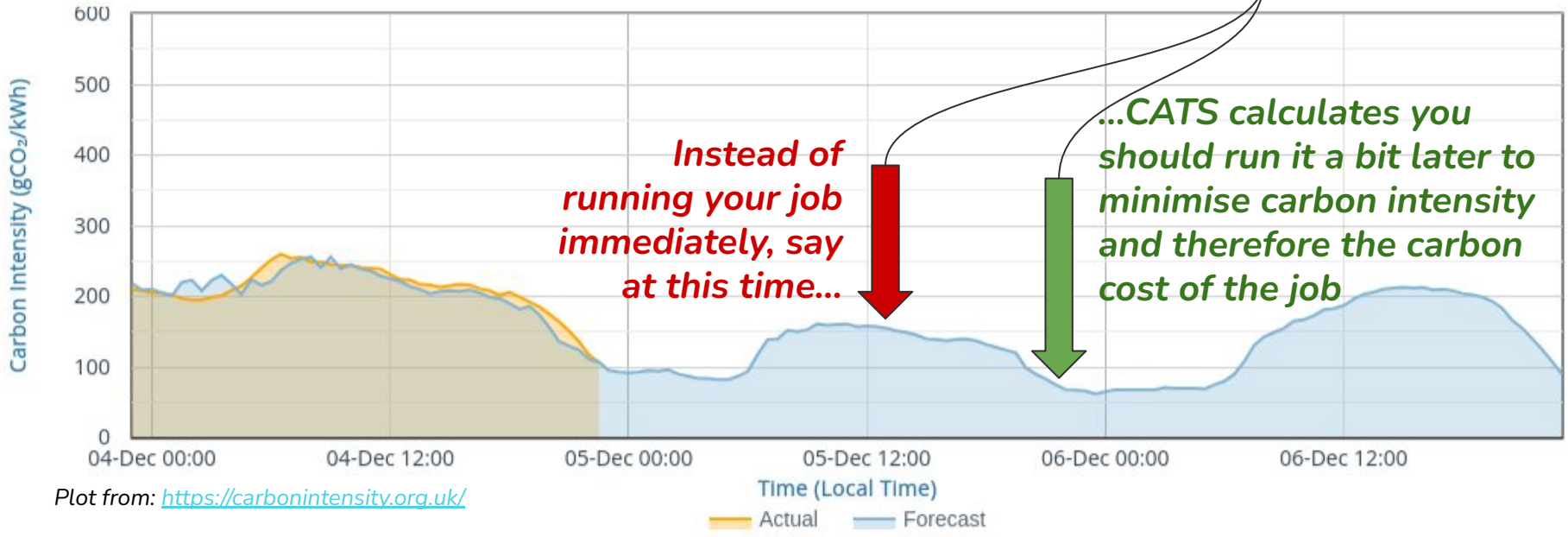




Diagrams and pie charts from: https://carbonintensity.org.uk/

Introducing our tool CATS to manage time-shifting of jobs

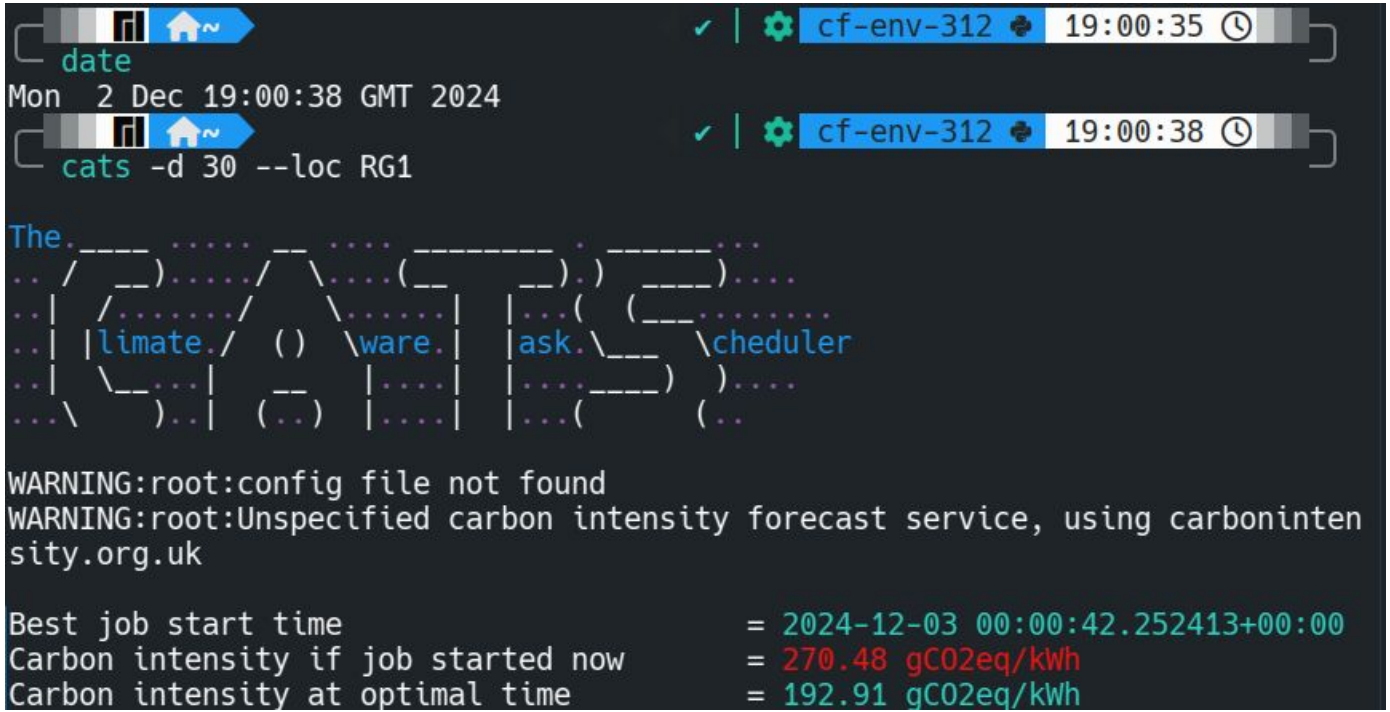
The **C**limate **A**ware **T**ask **S**cheduler (https://github.com/GreenScheduler/cats) calculates the optimal time to run a job to minimise its carbon intensity



Plot from: https://carbonintensity.org.uk/

Basic usage of CATS: via a command-line interface

- Terminal use, with configuration via YAML file and/or CLI options & arguments
- Minimal use: `cats -d <job duration in mins> --loc <postcode>`
- Example: shows savings of >75 gCO2e/kWh by waiting ~6h to run a job



Further usage: direct scheduling & estimating carbon footprint

- **To directly schedule a job with the CATS calculation**, use the argument `--scheduler`. We currently support the UNIX `at` command, for example to run a Python script `work.py` expected to take an hour or so: `cats -d 60 --loc RG1 --scheduler at --command 'python work.py'`

- **You can go further than carbon *intensity* information and extract the estimated carbon *footprint* reduction** from delaying the compute if you provide memory consumption and a hardware profile for the relevant machine: `cats --duration 480 --location "EH8" --footprint --memory 16 --profile my_gpu_profile --gpu 4 --cpu 1`

Example YAML config file, profiles section (only)

```yaml
profiles:
  my_cpu_only_profile:
    cpu:
      model: "Xeon Gold 6142"
      power: 9.4 # in W, per core
      nunits: 2
  my_gpu_profile:
    gpu:
      model: "NVIDIA A100-SXM-80GB GPUs"
      power: 300
      nunits: 2
    cpu:
      model: "AMD EPYC 7763"
      power: 4.4
      nunits: 1
```

Use cases for CATS: from small- to large-scale compute

- History: conception on May 2023 at the SSI's Collaborations Workshop, CW23, winning First Prize in the Hack Day with further funding from the SSI
- **Version 1.0** (July 2024): first stable/mature release, designed for 'small-scale' computing e.g. a few hours on a workstation/desktop or laptop overnight
    - Note: JOSS paper for CATS under submission, in review stages
- **Work towards Version 2.0 is in progress, which aims to target the more pressing source of carbon emissions, HPC and HTC**
    - Includes work to test CATS on a 'mini HPC' (Raspberry Pi cluster, funded by the SSI and built by CATS team members Sadie and Colin) with thanks to Jannetta Steyn for the inspiration!

Further work and upcoming HPC/HTC-focused version 2!

- Work underway for integration with the batch scheduler SLURM (https://slurm.schedmd.com/) which will be in CATS version 2
  - Simplest approach: using `sbatch` to offset start time
  - Our ideal result: HPC systems can implement ‘green’ queues to use CATS to delay jobs that users are happy to in return for reduced carbon footprint (and/or incentives)
  - Integrating carbon accounting as a Slurm plugin (will need rewrite in C)
  - SSI funding provided a few months of developer time, coming to the end of this and approaching completion of work
- Now have support for single-user case with `sbatch`. Work in progress as present: plugin development to create a queue managed by CATS.

Example of v2 carbon footprint saving for a fictional HPC

- For an example of a fictional HPC, with hardware as follows:
  - 64 core AMD EPYC 7773X (Milan) CPUs
    - 10 nodes, 2 CPUs per node, 20 CPUs total, 1280 cores
  - Fully loaded CPU = 255 W, Idle CPU = 37.5 W (from https://www.phoronix.com/review/amd-epyc-7773x-linux/9)
  - Idle saving = 217.5 W per CPU
  - Cluster idle vs peak = 4.35 kW
- Time shifting reduces grid intensity from:
  200 to 50 g/kWh = 150 g/kWh reduction
- The calculation:
  - 12 hour job using all cores
  - 12h * 4.35 kW = 52.2 kWh
  - 52.2 kWh * 0.15 kg = 7.83 kg
- Comparable to driving an average car (150 g/km) 50 km (7.5 kg)!

Limitations of CATS and notes regarding value

- Some HPC systems are already powered by 100% renewables e.g. ARCHER2 is supplied by 100% certified renewable energy (zero ‘scope 2’ emissions)! ☺️
- Restrictions due to API:
  - Only works for the UK (at present) due to lack of APIs like the National Grid ESO's Carbon Intensity one used, for other countries/regions (open Issue https://github.com/GreenScheduler/cats/issues/22)
  - Can’t handle jobs expected to take more than 2 days due to forecast cutoff of the National Grid ESO API
- Relies on user specifying the job length correctly - and this can be hard to estimate and *might require pre-run(s) to estimate well (enough)*
- HPC: won’t be able to do much on systems at/near 100% load
- Important notes:
  - the UK electricity grid is planned to be net-zero by 2035, but that’s quite optimistic and besides, if we can do something now, then *why wait*?
  - *reducing operational emissions is* not the only thing you can/should do to reduce the climate impact of your computing! You can look to also reduce emissions from scope 3 (manufacturing), cooling, storage & networks (e.g. see blog post ‘Tracking the environmental impact of research computing’ SSI blog post covering useful background: https://www.software.ac.uk/blog/tracking-environmental-impact-research-computing)

Summary of CATS, The Climate Aware Task Scheduler

- Computing uses (a lot of!) energy - HPC, HTC, data centers and AI in particular. One approach to reduce our impact on the climate crisis from greenhouse gas emissions resulting from our energy consumption is to shift to **using more of the 'clean' renewable sources over 'dirty' sources like fossil fuels**
- We can do this by **using the local electricity when it is lower in carbon intensity**
- By **intelligently time shifting compute jobs** to run them at the time that minimises carbon footprint across their expected duration, using real-time carbon intensity data from the National Grid ESO API, CATS can contribute to more sustainable computing
- CATS was **first developed for small-scale compute jobs, but work is underway for v.2 to support HPC & HTC applications** via SLURM integration. The single-user case is working for sbatch now and we are ultimately aiming for a CATS managed queue
- Until v.2 is out, please **try out CATS v.1**! See https://github.com/GreenScheduler/cats

Border image credits: 'Climate Stripes' infographic designed by Prof. Ed Hawkins (University of Reading), see showyourstripes.info

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Thanks for listening.

For more info. about CATS and/or other aspects from this talk, please ask me anything now or you can explore such resources as:

- the CATS codebase, OSS on Github: https://github.com/GreenScheduler/cats
- the CATS package documentation: https://greenscheduler.github.io/cats/
- a recent episode of the 'Code for Thought' podcast in which myself and Colin talk about CATS: https://www.buzzsprout.com/1326658/episodes/15766448-en-bonus-green-computing-at-the-rse-conference-2024-in-newcastle?t=0
- 'Tracking the environmental impact of research computing' SSI blog post covering useful background: https://www.software.ac.uk/blog/tracking-environmental-impact-research-computing

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Extra slides

A brief history of CATS

May 2023 (SSI CW23) → ***The future***

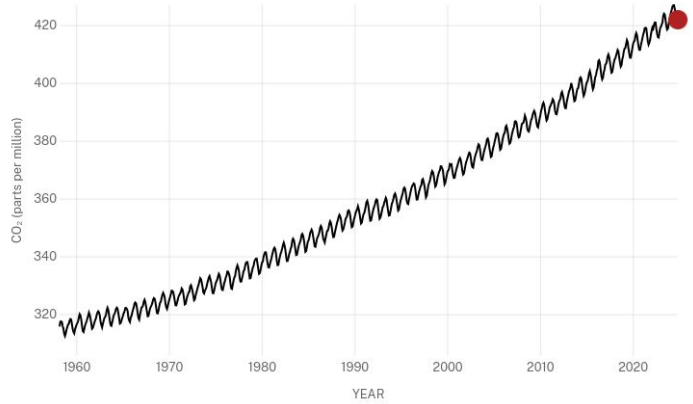
- Devised & prototyped at the Software Sustainability Institute's Collaborations Workshop 2023 Hack Day (winning first prize!), proof of concept intended for small-scale compute
- Original hackathon team took the project forward together to continue developing CATS
- Version 1.0 released in July this year, marking the first release of a stable tool (full documentation, improved CLI, test coverage & output formats for humans & machines)
- Work in progress with further support from the SSI, including integration with SLURM, testing on real HPCs & submitting a publication to the Journal of Open Source Software

Motivating issue: the climate crisis

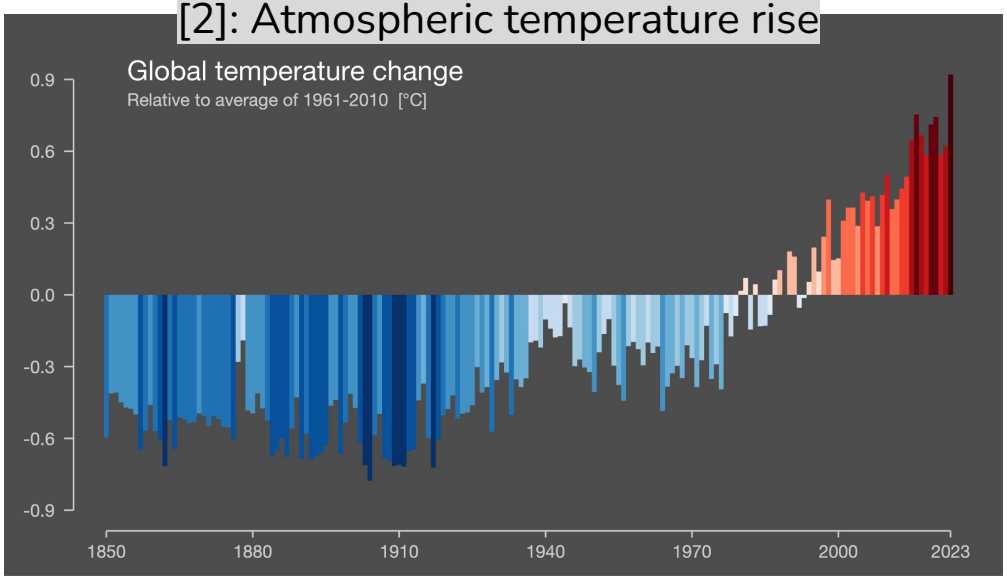
Human activities, notably fossil fuel burning to generate energy, are (largely) responsible for accumulation of greenhouse gases (e.g. CO_2 [1]) in the Earth's atmosphere causing rise in global temperatures [2] and sea levels [3] etc. - **activities including computing**

Sources of plots: showyourstripes.info, https://climate.nasa.gov/vital-signs/

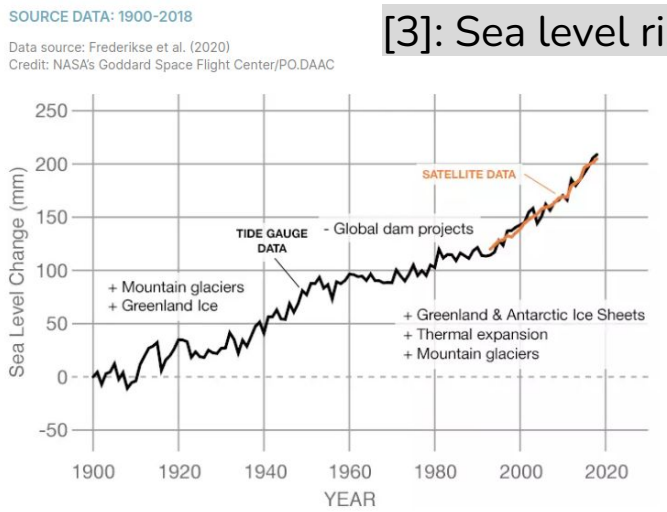
[1]: CO_2 level rise



[2]: Atmospheric temperature rise

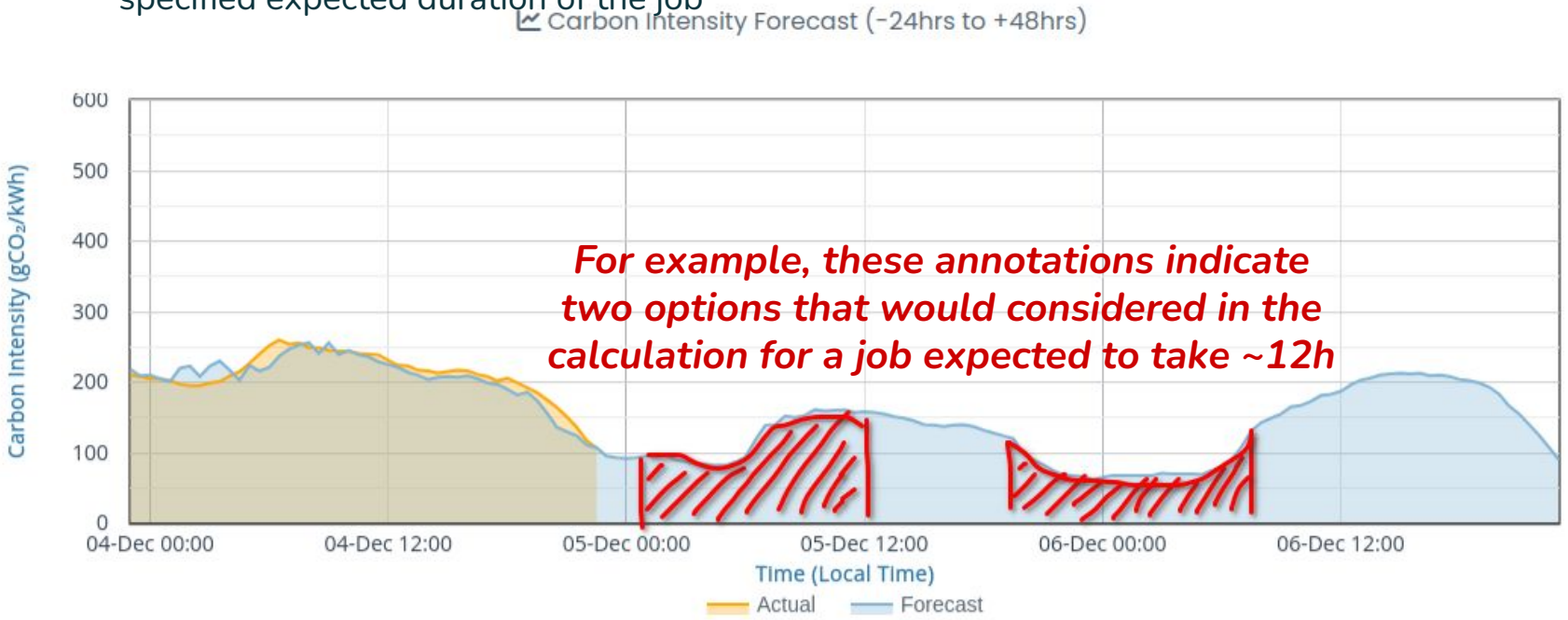


[3]: Sea level rise



How does CATS work?

- To run software when renewable sources of energy are most plentiful, CATS:
  - uses National Grid ESO's Carbon Intensity API (carbonintensity.org.uk) for carbon intensity forecast
  - takes such data appropriate to the local region (found from a given postcode as proxy for location)
  - calculates to effectively minimise the area under the curve (as illustrated on the plot here) for the specified expected duration of the job



Plot from https://carbonintensity.org.uk/, with SB annotations added (drawn lines in red)