

Secondary

11–14

Measuring trees

Teacher guide and worksheets



**National Centre for
Earth Observation**

NATURAL ENVIRONMENT RESEARCH COUNCIL

Earth Observation science for a changing planet



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If you have any comments or questions about these materials, please email EODetective@NCEO.ac.uk We would love to hear about how you have used them and see what your students have produced!

Overview

Activity summary

Activity 1 (mostly maths) gives students the opportunity to approximate the volume of wood in local trees using simple equipment and mathematical ideas related to areas and volumes, proportionality and or the geometry of triangles. They are encouraged to discuss the accuracy of different methods.

Activity 2 (mostly science) describes the principles behind using airborne lidar to measure tree height and illustrates this with calculations. Students can carry out a practical modelling the technique to consider limitations. This leads to descriptions of the work of radar satellites and the Biomass satellite which allow students to consider the relationship between the type of radiation used and the detail of tree structure revealed.

Time needed

Activity 1

One to two hours for practical activity and related calculations depending on number of methods used and number of trees measured.

Activity 2

One hour if practical activity is demonstrated and calculations and evaluations are left for homework. More time will be needed for a class practical or/and groups who require more support.

Prior learning

Although the resource has been designed as a way of reinforcing the concepts or/and relationships below, it could be used to introduce one or more of them. If you are doing so, consider allowing extra time.

Activity 1

Method 1 uses direct proportionality; Method 2 uses Pythagoras' theorem; Method 3 requires awareness of complementary angles and uses either scale drawing or trigonometry.

Activity 2

Photosynthesis – plants use sunlight and CO₂ to build organic molecules; the relationship $speed = distance \div time$; standard form; rearranging equations.

Learning outcomes

- Describe the role of trees in the carbon cycle.
- Measure the approximate volume of a tree.
- Evaluate the method(s) you used to do this.
- Describe how active sensors are used to measure trees.
- List some advantages and disadvantages of various methods of assessing forest biomass.

Some of these are optional, and you may wish to add appropriate maths objectives, particularly if you are focussing on a single method.

Key words

carbon sink, biomass, volume, circumference, area, passive sensor, active sensor, satellite, proportionality, Pythagoras' theorem, clinometer, scale, tangent, lidar, radar

Curriculum coverage

These points may be touched on or emphasised depending on how you choose to use the materials. Some may be addressed through extension activities.

England

Maths

KS3 Working mathematically

- Pupils should substitute values in expressions, rearrange and simplify expressions, and solve equations.

KS3 subject content

- Pupils should interpret and compare numbers in standard form.
- Pupils should round numbers and measures to an appropriate degree of accuracy.
- Pupils should draw and measure line segments and angles in geometric figures, including interpreting scale drawings.
- Pupils should derive and use the standard ruler and compass constructions (constructing a perpendicular to a given line from/at a given point).
- Pupils should describe, sketch and draw using conventional terms and notations: points, lines, parallel lines, perpendicular lines, right angles.
- Pupils should use Pythagoras' theorem and trigonometric ratios in similar triangles to solve problems involving right-angled triangles.
- Pupils should use and interpret algebraic notation.
- Pupils should substitute numerical values into formulae and expressions, including scientific formulae.
- Pupils should apply formulae to calculate the volume of prisms (including cylinders).
- Pupils should calculate and solve problems involving the perimeters of 2-D shapes (including circles) and areas of circles.

Science

KS3 Working scientifically

- Pupils should pay attention to objectivity and concern for accuracy, precision, repeatability and reproducibility.
- Pupils should use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, paying attention to health and safety.
- Pupils should make and record observations and measurements using a range of methods for different investigations; and evaluate the reliability of methods and suggest possible improvements.
- Pupils should apply mathematical concepts and calculate results.
- Pupils should evaluate data, showing awareness of potential sources of random and systematic error.

KS3 Subject content

- Pupils should be taught about the carbon cycle.
- Pupils should be taught about the production of carbon dioxide by human activity and the impact on climate.
- Pupils should use the quantitative relationship between average speed, distance and time ($\text{speed} = \text{distance} \div \text{time}$).

- Pupils should be taught about light waves travelling through a vacuum; speed of light.
- Pupils should be taught about the transmission of light through materials: absorption, diffuse scattering and specular reflection at a surface.
- Pupils should use a ray model.
- Pupils should be taught about colours and the different frequencies of light, differential colour effects in absorption and diffuse reflection.

Scotland

Maths

- I can round a number using an appropriate degree of accuracy, having taken into account the context of the problem. (MNU 3-01a)
- Using simple time periods, I can work out how long a journey will take, the speed travelled at or distance covered, using my knowledge of the link between time, speed and distance. (MNU 3-10a)
- I can solve practical problems by applying my knowledge of measure, choosing the appropriate units and degree of accuracy for the task and using a formula to calculate area or volume when required. (MNU 3-11a)
- I can collect like algebraic terms, simplify expressions and evaluate using substitution. (MTH 3-14a)
- Having investigated a range of methods, I can accurately draw 2D shapes using appropriate mathematical instruments and methods. (MTH 3-16a)
- I can name angles and find their sizes using my knowledge of the properties of a range of 2D shapes and the angle properties associated with intersecting and parallel lines. (MTH 3-17a)
- I can apply my understanding of scale when enlarging or reducing pictures and shapes, using different methods, including technology. (MTH 3-17c)
- I have explored the relationships that exist between the sides, or sides and angles, in right-angled triangles and can select and use an appropriate strategy to solve related problems, interpreting my answer for the context. (MTH 4-16a)
- I can work collaboratively, making appropriate use of technology, to source information presented in a range of ways, interpret what it conveys and discuss whether I believe the information to be robust, vague or misleading. (MNU 3-20a)

Sciences

- I have collaborated on investigations into the process of photosynthesis and I can demonstrate my understanding of why plants are vital to sustaining life on Earth. (SCN 3-02a)
- By investigating renewable energy sources, I can discuss their benefits and potential problems. (SCN 3-04b)
- I can explain some processes which contribute to climate change. (SCN 3-05b)
- By exploring reflections, the formation of shadows I can use my knowledge of the properties of light to show how it can be used in a creative way. (SCN 2-11b)
- By exploring radiations beyond the visible, I can describe a selected application, discussing the advantages and limitations. (SCN 3-11b)

Wales

Maths (PS4)

- I can use standard index form to represent large and small numbers, performing calculations in context. I can use appropriate rounding methods, including significant figures.
- I can apply percentages and ratio to solve problems.
- I can use my knowledge of the equivalence of fractions, decimals and percentages to understand that numbers or proportions may be represented in different ways.
- I can explore and use efficient methods of solving equations, and I can apply this knowledge to rearrange formulae where the subject appears in one term.
- I can explore and calculate the areas and perimeters of two-dimensional shapes, including circles.
- I can derive and apply the formulae for the volume of simple prisms.
- I can apply my understanding of area to demonstrate and use the relationship between right-angled triangles and squares in the context of Pythagoras' theorem.
- I can use angle and shape facts to deduce further features and relationships of triangles and quadrilaterals.

Science and technology (PS4)

- I can evaluate and identify ways of improving the reliability of data, taking anomalies into account.
- I can select relevant scientific knowledge from a range of evidence sources to evaluate claims presented as scientific facts.
- I can predict the behaviour of waves in different circumstances.
- By applying simple rules, I can use waves in order to learn more about the world around me.

Humanities (PS4)

- I can understand and explain how human actions affect the physical processes that shape places, spaces, environments over time.
- I have an understanding of my own and others' environmental, economic and social responsibilities in creating a sustainable future.

Health and wellbeing (PS4)

- I can set appropriate goals and plan a course of action to achieve them.
- I can anticipate, assess and manage risks.

Northern Ireland

- Pupils should work effectively with others.
- Pupils should demonstrate self-management by working systematically, persisting with tasks, evaluating and improving own performance.
- Pupils should communicate effectively in oral, visual (including graphic), written, mathematical and ICT formats showing clear awareness of audience and purpose.

Environment and society: Geography (KS3)

- Pupils should demonstrate skills in using maps, fieldwork equipment and methods of data collection in undertaking geographical enquiry.

Science and technology: Science (KS3)

- Pupils should respect and co-operate with others in the process of scientific enquiry.
- Pupils should investigate the effects of specific measures to improve and protect the environment
- Pupils should demonstrate a range of practical skills in undertaking experiments, including the safe use of scientific equipment and appropriate mathematical calculations.
- Pupils should use investigative skills to solve problems.
- Pupils should research and manage information effectively, including using mathematics and using ICT where appropriate.

Learning for life and work: Local and global citizenship (KS3)

- Pupils should investigate an issue from a range of viewpoints and suggest action that might be taken to improve or resolve the situation,

Background information for teachers

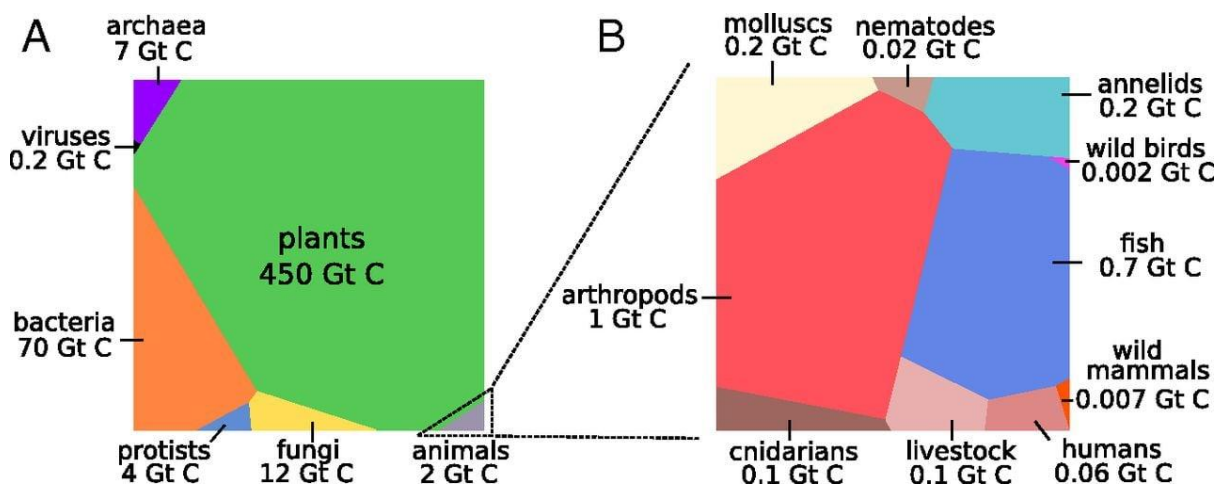
Biomass and climate

A living organism sequesters carbon in its tissues as it grows. The carbon is chemically combined with other elements and cannot get into the atmosphere until the compounds break down (e.g. in respiration) or the tissues decay or are burnt. Biomass is, therefore, an important part of the (fast) carbon cycle and, as such, has an impact on the Earth's climate.

However, the climate system is complex with many interdependent factors. If such a factor is not only a critical component of the climate system but something for which we can get reliable data over a suitably large area (often the whole world) and period of time in a financially feasible manner, it is known as an **essential climate variable (ECV)**.

Climate scientists usually think of biomass in terms of dry mass to make comparisons fairer: the ratio of water to carbon in, say, a jellyfish is much higher than in a tree. They may even express it in terms of mass of carbon: water, inorganic compounds – even the elements with which the carbon is chemically combined – don't matter in this context. Therefore, the only accurate way to determine the biomass of an organism is to kill it and completely dehydrate it (and maybe even reduce the material left behind to just carbon) – not a feasible measurement method!

In order to meet the criteria above, the biomass ECV relates only to the above-ground biomass (AGB) of trees, usually ignoring the short-lived, water-rich leaves. This is actually a reasonable thing to do since around 80% of the carbon stored by all living things on Earth is stored in plants, and about 70% of that is in (mostly) woody stems and tree trunks (see [this paper](#)). It is easy to find the density of wood using only samples, but finding the volume of a tree in order to calculate AGB is more tricky.



Global biomass distribution

The volume of a tree

In the late fifteenth century, Leonardo da Vinci suggested a rule relating the thickness of tree branches to that of the trunk (see [this paper](#)). The wording can be interpreted in various ways but is usually taken to mean that the total cross-sectional area is constant or, in other words, that we can model a tree as a cylinder. Results from destructive

measurements of sample trees and lidar scanning lead to more complex formulae that vary by species, but this first approximation is still widely used (see [here](#), for example).

Estimates of AGB in a forest generally involve detailed measurements of a sample of trees and then scaling the results up to the forest as a whole. The samples include trees of different species and ages growing in different conditions within the forest (e.g. among similar trees and among different trees, in dense and less-dense areas, in sheltered and more exposed areas and so on).

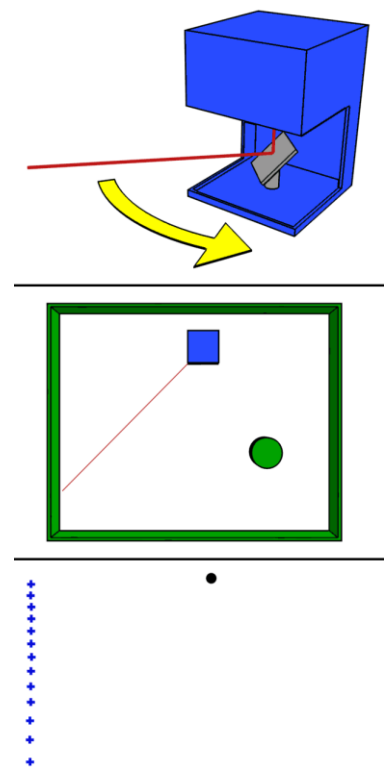
Lidar scanners and radar

Lidar and radar work in the same way although lidar uses light (although commonly used wavelengths of 905 nm and 1550 nm are in the near infrared rather than visible) and radar uses radio waves of various frequencies.

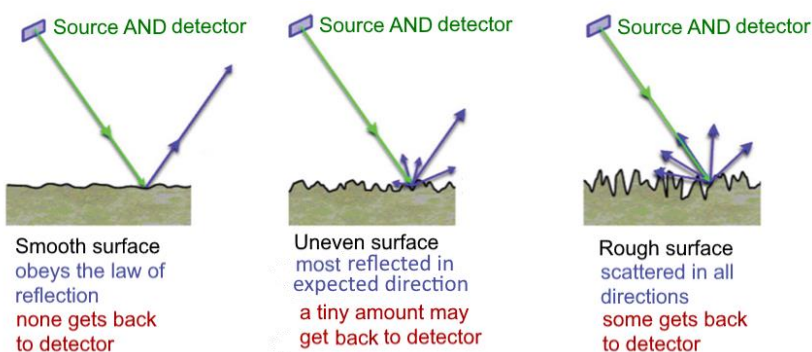
A transmitter produces pulses which may be absorbed or scattered as they travel, and may be reflected, scattered or/and absorbed when they reach an object. Which of these happens, and to what extent, depends on the wavelength used and the surface(s).

The second part of the sensor is a receiver that detects any part of the signal that is 'backscattered' (returns in the same direction). Because some is scattered in other directions, or/and absorbed en route or at the surface, the return pulse will have a lower amplitude (power). The time it takes for a return pulse to arrive can be used to calculate the distance between the instrument and the reflecting surface.

A lidar or radar system also includes instruments that can capture the precise position and orientation of the sensor as each measurement is made. In a scanning system, moving mirrors or prisms direct the pulses to different places at different times (see gif, right) to build up a '**point cloud**' that can build a **detailed picture**.



A basic lidar system



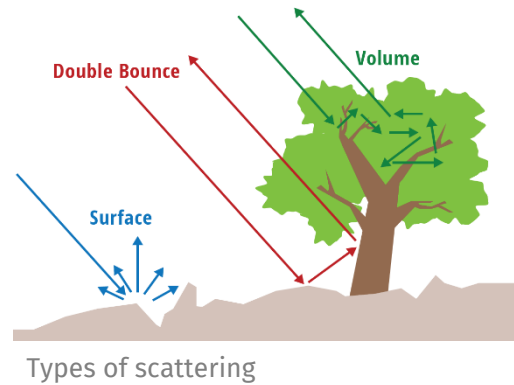
How surface affects backscatter from an angled beam

The examples in this resource consider a sensor that sends a single pulse in one direction (straight down) so the smoother the surface, the stronger the reflection. However, the opposite is true for images from many satellite and airborne radar systems because the beam is angled.

Using an angled beam also means that a signal can get back to the detector after a double reflection or multiple reflections. Each type of scattering affects a property of the return signal (the polarisation) in a different way. This makes it possible to find out more about the type of object or surface.

The Biomass satellite mission

The European Space Agency (ESA) Biomass satellite mission is the brainchild of science lead Shaun Quegan (NCEO, University of Sheffield). The satellite was built by Airbus in the UK and launched on 29 April 2025 from Kourou in French Guiana. It is the first Earth observation (EO) science satellite to use P-band radar ($\lambda \approx 70$ cm) which can pass through not only cloud but also dense canopies such as those in tropical forests.

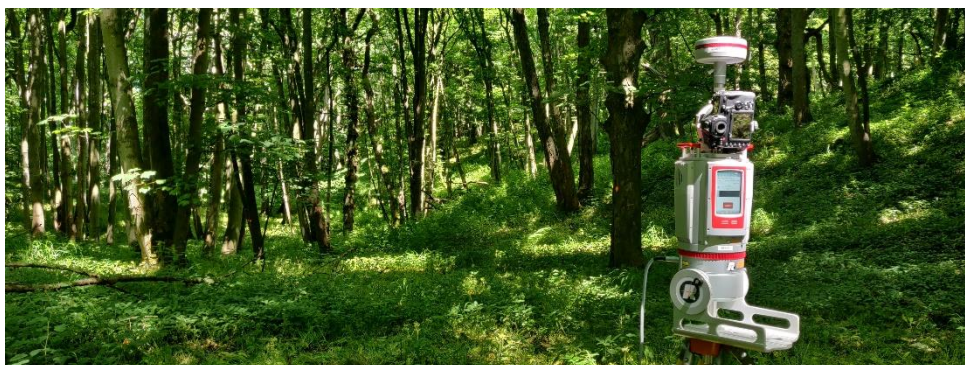


The satellite travels around the Earth every 100 minutes in a **low-Earth Sun-synchronous orbit** (SSO). However, to build up a 3D picture, it needs to collect a stack of several images of each place from a slightly different angle each time. It then needs to 'twist' the orbit to look at a different strip of the Earth. These videos show how **Sentinel 1** (a C band radar satellite) and **Biomass** orbits provide global coverage by imaging a strip at a time as the Earth turns beneath them.

During the first part of its mission, lasting about 18 months, Biomass will collect stacks of seven images from each strip to show forest structure in detail. Every nine months or so after that, it will collect stacks of three images for each strip until the mission ends in 2030. This will give us more information about how forests change over time.

Geo-trees

Meanwhile, an international team including Mat Disney (NCEO, UCL) is working on a project called **Geo-trees**. They are mapping and collecting data on tree type and distribution, using terrestrial (ground-based) laser scanning (TLS) and airborne laser scanning (ALS) to measure individual trees, and recording changes in selected areas of tropical forest across the world.



A terrestrial laser scanner used for mapping a forest

When Biomass has collected information about these same sites, scientists will be able to compare the two sets of data. They can then 'fine-tune' the satellite results (calibrate) and check that they agree with those made by other methods (validate).

Practical notes

- Worksheets are designed for single use and can be copied in black and white.
- Resource sheets may contain larger images for you to insert into your classroom presentations, additional information for students, or data for them to work with. These are best printed or copied in colour but may be reused.
- Students may need a pen/pencil, a calculator and their exercise book or paper as well as the materials listed for each activity.
- You will need to print sufficient copies of any worksheets and resource sheets you plan to use in advance and, in some cases laminate or/and cut into separate cards. If any additional preparation is required, it is given below the resources list.
- The presentation to go with this activity can be downloaded, along with any additional supporting files, by following the links to this pack on **STEM Learning** or the **NCEO website**. The presentation may include slides in addition to those referenced in the activities (e.g. one listing the learning outcomes). You can edit these as required.
- Suggestions for differentiation, home learning and assessment are included at appropriate points in the description of each activity

Health and safety

In all activities, we have assumed you will continue to follow your usual procedures relating to, for example, movement within the learning environment, use of equipment, trips and spills, first aid and online safety. Since the details of these vary, even within an individual school, we have not listed them every time. However, we have highlighted any additional specific hazards to inform your risk assessment.

Activity 1: Measuring individual trees

Resources

- Slide pack: Measuring trees
- Worksheet 1* (per student)

Method 1, per group

- Resource sheet 1* (2 pages)
- 30 cm ruler
- metre rule
- tape measure – the sort used for measuring in long jump is best
If a suitable measuring tape is not available, then students could record the distance using string that they can later measure with the metre rule.

Method 2, per group

- Resource sheet 2* (2 pages)
- laser distance measure – these are available from £10 or so online or in DIY stores
- tape measure or string and metre rule (as above)
- metre rule (optional)

Method 3, per group

- Resource sheet 3* (3 pages)
- protractor with a hole at the centre point – you can easily make a hole in a plastic protractor using an awl or large needle (held in a cork) heated in a flame (make sure the protractor is stable and on a suitable surface if you need to do this)
- thin string that can be threaded through the hole
- weight (a slotted mass, mass hanger, washer, nut, lump of clay ...)
- drinking straw (paper or metal – silicone ones may bend)
- sticky tape or glue – if you use sticky tape, the clinometers can be dismantled so the protractors are available for later use
- tape measure or string and metre rule (as above)
- metre rule (optional)
- protractor and ruler (method A) or calculator (method B) per student

*Alternatively, you could describe the tasks to students and display questions, asking them to record their results and carry out the calculations in their exercise books.

Preparation

For equipment preparation, see above.

Identify suitable tree(s) in school grounds or local area.

Health and safety

- If students are working offsite, follow your institution's rules for trips and fieldwork.
- Although most cheaper laser measures are low power and relatively safe, students should be told to avoid looking into the beam or directing it near others' eyes.
- Check the area around the trees to be measured for hazards: for example, ditches or streams students should be aware of when moving to an appropriate distance from the tree.

Suggested sequence

1. Start by asking students about the links between trees and carbon. Show slides 4 and 5, which summarise key points relevant to this activity.
2. Perhaps using Think–Pair–Share, ask students for ideas about how to measure the volume of a tree to work out how much carbon it can store long term in trunk and branches (i.e. not including leaves or roots).
3. Show the drawing from Leonardo da Vinci's notebook (slide 6). Use the updated version of it (slide 7) to explain his theory that the combined thickness of all branches remains the same as they split off. State that we take 'thickness' to mean cross-sectional area, or use slide 8 to explain the relationship in more detail depending on the ability of the class and time available. This means we can model the tree as a cylinder, so we need only measure the height and cross-sectional area.
4. All the resource sheets include sample data and calculations as well as instructions so, if members of the class work confidently when self-directed, you can simply distribute worksheets, resource sheets and equipment so students can use the instructions to find the volume of one or more trees.
 - If your aim is to deliver a practical application of a particular concept, then ask all students to use the same method as follows: method 1, proportionality; method 2, Pythagoras' theorem; method 3A, complementary angles and scale drawing; method 3B, complementary angles and trigonometry.
 - If you wish to focus on evaluation of techniques, or consolidate previous work, allocate different methods to different groups of students. If time allows, you could rotate equipment and methods between groups.

Alternatively, you can take students through the method(s) they are to use, or/and the related sample calculations using:

- slides 9–10 for calculation of cross-sectional area from circumference
 - slides 11–13 for method 1
 - slides 14–16 for method 2
 - slides 17–19 for method 3
 - slide 20 for method 3A
 - slide 21 for method 3B.
5. Students could carry out calculations in the field, on their return to class, or as homework depending on how many trees they are to measure, time available and ability.
 6. Ask students to check the calculations of others in their group or/and look at the results of other groups. They can compare values obtained for the same tree using different methods, or sense-check results for different trees: are they consistent with what common sense tells them about which trees are most bulky? You could use their calculations to assess students against objectives from the maths curriculum.
 7. The evaluation questions (slide 22, task 6 on worksheet 1) can be used to support class discussion or set as homework. The answers can be used to assess students against practical objectives from relevant curriculum areas.

Sample results

See resource sheets 1–3 / slides 10, 13, 16, 20 and 21.

Activity 2: Measuring trees in a forest

Resources

- Slide pack: Measuring trees
- Graph paper
- Worksheet 2* (one per student)
- Worksheet 3 * (one per student) – optional extension
- Resource sheet 4* (2 sides)
- Items listed below for demo; per group of 4 or 6 students if class practical
 - 2 clamps and retort stands (or put the ends of the rule on two stools)
 - a metre rule (or use e.g. a broom handle and measure distances directly)
 - a laser distance measure
 - a small piece of card
 - sticky tape and scissors
 - blocks
 - a large piece of card to make a screenSee step 5, below, for an alternative.

*Alternatively, you could describe the tasks to students and display questions, asking them to record their results and carry out the calculations in their exercise books.

Preparation

You could set up the stands, metre rule and laser measure in advance if space allows.

Health and safety

Although most cheaper laser measures are low power and relatively safe, students should be told to avoid looking into the beam or directing it near others' eyes.

Suggested sequence

1. Show slide 23. Ask students how they could measure the heights of the trees in this forest, referring back to Activity 1, if appropriate.
2. Draw out the idea that, unless we cut down or climb the tree, we measure the height by detecting light reflected from the tree. Use slide 24 to introduce the idea of active and passive sensors and ask students to decide if each of the sensors on slide 25 are active or passive. The slide reveals one answer at a time, so this can be a voting exercise rather than a written one, if you prefer.
3. Use slide 26 to bring discussion back to the original question. What can we do when we cannot see or clearly distinguish the top of an individual tree?
4. Use slides 27 and 28 to explain how airborne lidar is used to determine canopy height. Worksheet 2.1 guides students through the calculations so you could leave these for homework and give only a qualitative explanation at this stage. Scientists can create a map like that on slide 29 by flying back and forth across an area.
5. Carry out the modelling ALS practical as described on Resource sheet 4 and slides 30–37 (note that the slides also include sample results).
 - You could do this as a class practical, or demo with you (or one or two students) setting up the blocks and operating the measure and the class recording results.

- If you cannot access appropriate equipment, use the sample results.
 - If you have access to dataloggers with appropriate sensors, you might like to speed up the analysis by using these instead (see [this STEM Learning video](#)).
6. Having discussed any potential limitations of this model (see evaluation questions), show slide 38. What additional problem does this image illustrate?
Clouds will scatter and partly or completely absorb light. A small aircraft may not have enough fuel to get to the centre of a large forest, fly around collecting data, and then return safely.
 7. Explain that we therefore collect data using satellites, such as that shown on slide 39, that pass over the forest every week or so. These satellites carry active sensors that emit and detect radar waves rather than light. Radar can pass through clouds and some wavelengths can also pass through the leaves of trees, instead of reflecting from them, as shown on slide 40.
If your students are familiar with the idea of wavelength, you can shift the text box on slide 40 down to show how each radar band reveals structures of a size similar to its own wavelength.
 8. These pictures of a single tree are built up using measurements from radar beams ‘fired’ at the tree from various angles, not just straight down. Ask students which type of radar would be most useful if we wanted to work out:
 - The height of the tree?
VHF has fewest distractions, but L or P band might show a branch growing higher than the main stem.
 - How much carbon is being captured from the air at a particular time?
X band shows the leaves and the rate of photosynthesis will be linked to the total area of leaves.
 - How much carbon is stored in the woody, above-ground, parts of the tree?
L band shows every little twig and leaf stem, so calculating the volume from this data would be really tricky; VHF omits a lot of wood; P band is just right.
 9. Slides 41 & 42 show the ESA Biomass satellite (see page 9) which will build up a picture of the woody parts of trees in tropical forests. This will give us more detailed information about the volume of these trees (and therefore their mass, and the amount of carbon they store) than we have ever had before. It will take more than a year to gather data from across the world. It will then repeat measurements to see how forests are changing.
 10. Slide 43 is one of the first images sent back from the satellite. It does not show real colours, nor does it yet give tell us anything about tree structure, but we can still work things out from it. Ask students to identify features shown in the diagram: you could offer suggestions (river, lake, forests) to students who need more support (or show them the image [alongside a true-colour picture here](#)); and ask more able students to justify their answers by relating them to the information given about what each colour represents (see inset and notes on slide 43).
 11. As a plenary activity or homework, ask: What’s the best way to measure how much wood there is in a forest? Introduce the question by referring back to the advantages (e.g. accurate) and disadvantages (e.g. destroys the forest) of cutting down the trees and chopping them into measurable pieces to measure the volume directly.

Ask students to create a spider diagram showing different ways of measuring the heights of trees to calculate their volume (slide 44). You could encourage more able students to carry out more research on lidar systems and the Biomass satellite before completing their diagram, and support less able students by giving further examples or a list of possible advantages and disadvantages for them to match to each method (see answers, below).

Students can then use their spider diagram to help them write a paragraph to answer the question that you can use to assess their understanding.

Sample results

See slide 33 and analysis on slide 36

Answers

Active and passive sensors (slide 25)

- **Active:** the parking sensor on a car, a laser measurer used for DIY, an ultrasound machine in a hospital, a speed camera
- **Passive:** your eyes, an infrared thermometer, a camera, a microphone, the pressure sensor under an object in a museum

The best way to measure how much wood there is in a forest

This list is not exhaustive, but gives some possible ideas. Students who have carried out Activity 1 could also include different methods of measuring height from the ground, referring back to their evaluation. As is often the case, there is no single 'best' method: one method, or a combination, may be more appropriate in a particular situation.

- **Ground-based measurements** *Advantages:* can easily repeat measurements; can get independent check. *Disadvantages:* most methods involve having a clear line of sight to top of tree so not suitable for dense forest; not feasible to do a whole forest/large forest directly, so need to choose a suitable sample and scale up; sample may not be truly representative if parts of the forest are inaccessible.
- **Airborne lidar** *Advantages:* can easily measure heights of many trees; may also give more detail of tree structure. *Disadvantages:* limited by cloud cover; in dense forest, may be difficult to make out top of a low tree among trees whose branches are above it, expensive and polluting, difficult to access middle of .
- **Radar satellites** *Advantages:* (near) global coverage; works for any size forest; 'sees through' cloud. *Disadvantages:* initial cost is huge; data difficult to analyse, especially if want detail on structure; computing power required may not be available; radar may have to be switched off over some areas.

Worksheet 2

- | | |
|---|-----------|
| 1. 2x | 3. 2100 m |
| 2. $14 \mu\text{s} = 14 \times 10^{-6} \text{ s}$ | 4. 22.5 m |

Worksheet 3

- | | |
|-------------------------------|----------------------------------|
| 1. The top of the tree/canopy | 4. tree height = 11.25 m |
| 2. (b) | top branch to ground = 7.50 m |
| 3. 300 m | bottom branch to ground = 3.00 m |

Additional activities and questions

- The questions on Worksheet 3 (also on slide 46) involve the analysis of multiple reflections from a single tree. There is less guidance than for the questions on the first page of the worksheet so this is suitable as homework or extension work for students who are more confident with maths. You may wish to use slide 45 to introduce the principles involved before distributing the worksheet.
- Students could **survey trees** in the school grounds, in their street or a local park, adding them to (or updating data on) **Treezilla**. Students could use field guides or an app (such as **this one**) to identify trees in situ or take photographs to help them determine species in class or at home when they have access to the internet. The **Woodland Trust Tree ID for kids' series** is a set of free guides that show twigs, blossom and fruit as well as leaves for common trees. Links on the page lead through to more detailed descriptions of a wider variety of trees.
- Using the **UK Ward Canopy Cover Map** and maps of the local area, students could explore if the school (and, if appropriate, their home) meets the **3+30+300 principle**. If not, can they develop a plan to improve the situation? They could start by identifying sites where trees could be planted and research which species would be appropriate for these locations given local environmental conditions including proximity to buildings. Can they cost their proposal? Are there any other benefits they could quantify? Who would they need to involve in order to put their plan into action? How could they do this?
- The **ESA Eduspace radar technology page** explains other ways in which data from radar satellites can be used. You could use this as the basis of a reading exercise or challenge students to summarise the information from it in a presentation, limiting the number of slides and words they may use as appropriate to ability. To increase challenge, ask them to find alternative relevant images to illustrate their slides. (Note that tools linked to from this page have been moved or deprecated.)
- An alternative for more visual learners is to show this **ESA video (Radar vision)**, and ask students to list the uses of data from Sentinel-1.
- 'Wood, and other forms of biomass, are carbon neutral. We can reduce overall emissions by just using these instead of fossil fuels.' Ask students to investigate this proposition, perhaps asking different groups to focus on different issues depending on ability. Possible sub-questions might be related to biomass use by country, types and production of biomass-based fuel, relative energy density, and impacts on food supply, biodiversity and health. This research could be preparation for a formal class debate or a large display to which everyone contributes.
- Are pictures that follow Leonardo's 'rule' more realistic? Are they perceived as better? Collect non-photographic images of bare trees (clip-art, drawings, paintings and perhaps some AI-generated images) or ask everyone in the class to draw/create one. Survey the class to rank or group the drawings by how much they seem like a real tree. Find a way to make measurements to see how well each tree fits Leonardo's 'rule' (e.g. use a ruler on enlarged printed copies or use vector graphics software to draw lines across branches) and use this to rank or group the images. How do the two sets of groups or rankings compare? What can you conclude from this? (This idea is based on **this paper**.)

Measuring trees

Name _____

1. What method will you use to measure the height of the tree?

2. Draw a table to record the circumference of the trunk and your other measurements. Make sure your headings include units. Remember to include space for repeated measurements and averages.

3. What is the cross-sectional area of the tree you measured?

cross-sectional area of tree trunk = _____ m²

4. What is the height of the tree you measured? Include a diagram in your answer if it is helpful.

height of tree = _____ m

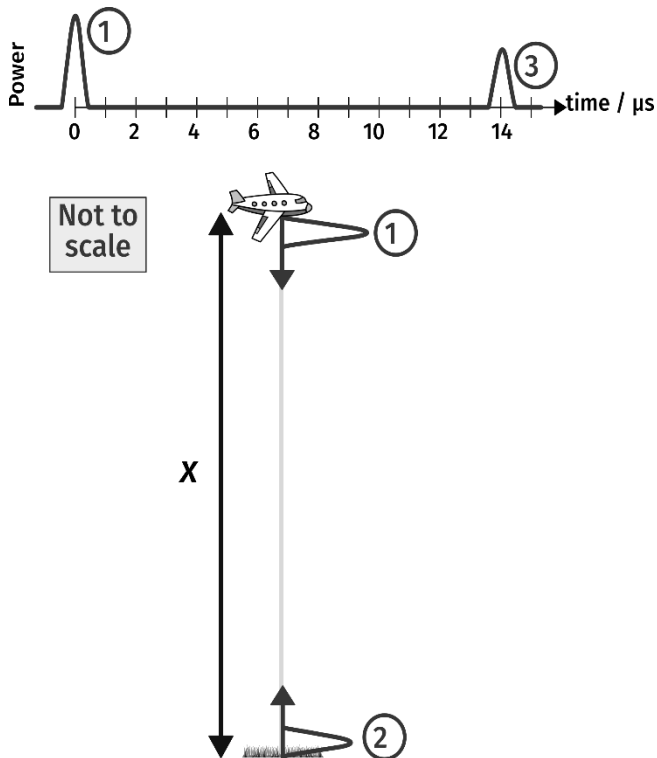
5. What is the volume of wood in the tree you measured?

volume of wood in tree = _____ m³

6. Evaluate your result. Use the questions below to help.
- How easy was the method you used?
 - How reliable was it? (Would someone else get the same results?)
 - What errors might there be in your measurements? (Give values if possible.)
 - What effect might they have on your final answer?

Measuring trees from above

Name _____



- An instrument on the aircraft sends out a pulse of light ①.
- The light pulse travels at $3 \times 10^8 \text{ m/s}$.
- When it hits a surface a distance x from the aircraft, it is reflected back ②.
- The instrument detects the reflected pulse when it arrives back at the aircraft ③.

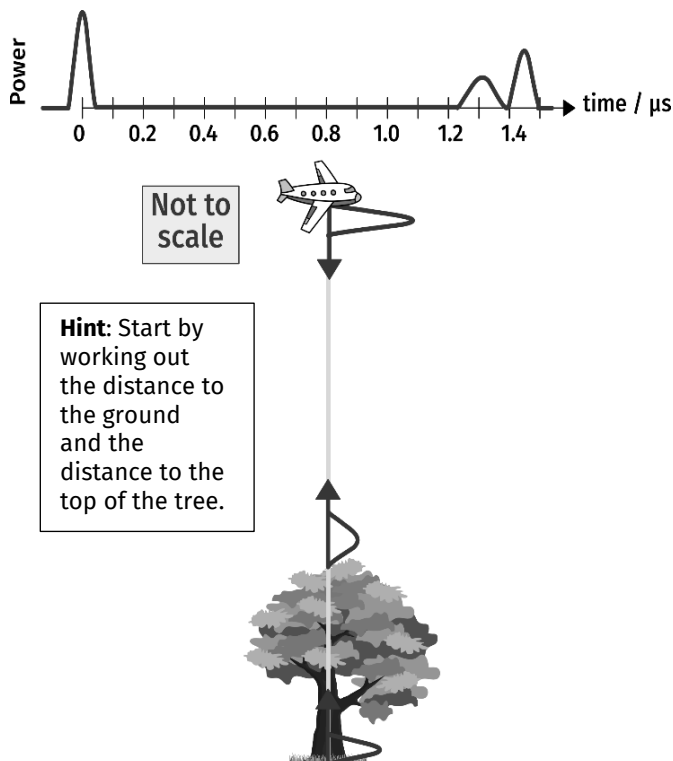
1. What is the total distance the pulse travels?
Give your answer in terms of x .

distance = _____ m

2. From the graph, how long does the pulse take to return ? ($1 \mu\text{s} = 1 \times 10^{-6} \text{ s}$)

time = _____ s

3. Use the equation **speed = distance $\div$ time** to work out the distance x .



The aircraft is _____ m above the ground.

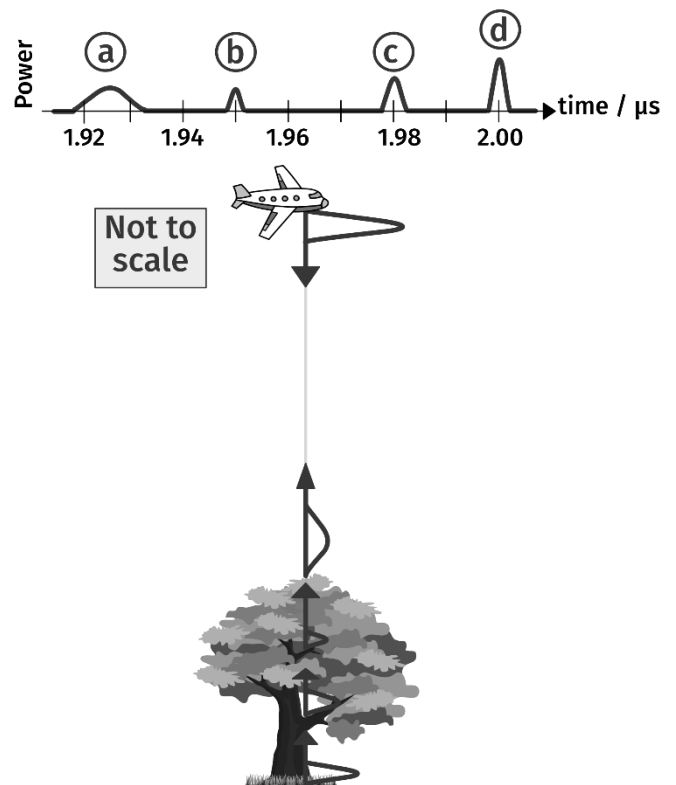
4. How tall is the tree in the second picture?

The tree is _____ m tall.

Using airborne sensors to see tree structure

Branches in the tree may also reflect the signal from an active sensor, as in this example.

Notice that the graph does not show the pulse sent out by the aircraft at time $t = 0 \mu\text{s}$.

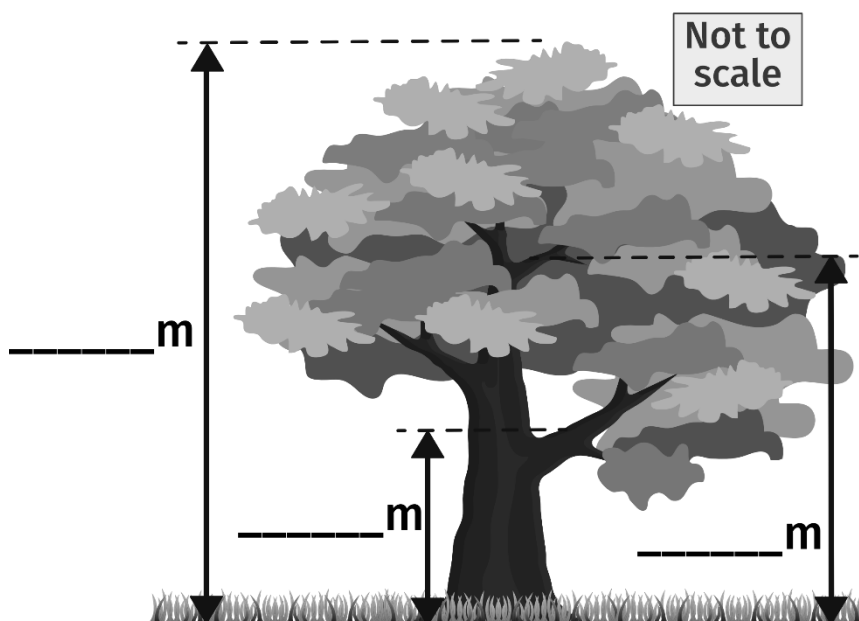


1. What reflects the light to make the pulse labelled (a)?

2. Which pulse, (b) or (c), is made by a reflection from a branch higher up in the tree?
Pulse _____
3. How high above the ground is the aircraft carrying the lidar?

The aircraft is _____m above the ground.

4. Use information from the graph to calculate the heights labelled below.
Add your answers to the diagram.



Measuring trees: Method 1

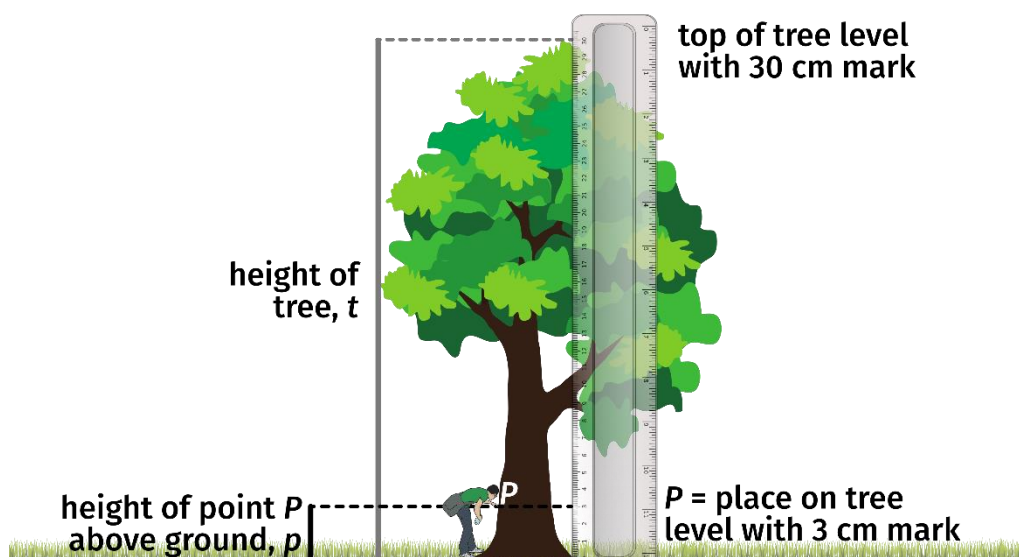
Two people using rulers and proportionality

Equipment

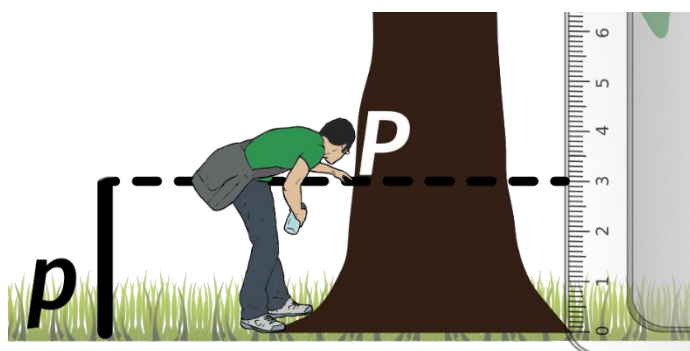
- a 30 cm ruler
- a metre rule
- a tape measure

Instructions

1. Use the tape measure to find the circumference of the trunk.
2. Person 1: Stand by the tree with the metre rule.
3. Person 2: Stand a few metres away from the tree. Hold the 30 cm ruler at right angles to the ground. Move the ruler until the bottom of the tree seems to be at the 0 cm mark and the top of the tree at the 30 cm mark. You might need to move to a different distance from the tree.



4. Person 1: Point to somewhere on the trunk of the tree.
5. Person 2: Tell Person 1 to move their hand up or down slowly. Ask them to stop when their hand is level with the 3 cm mark* on the ruler.
6. Person 1: Use the metre rule to measure the distance between this point and the ground.



Do anything else you need to do to make your measurement as accurate as possible.

*You could use another point – 2 cm or 5 cm, say. If you do, look carefully at how to calculate the height: you will need to change the figures in red.

Measuring trees: Method 1 continued

Sample results

circumference of trunk, c (average)	2.64 m
apparent height of tree (on 30 cm ruler)	30 cm
apparent height of point P above ground (on 30 cm ruler)	3 cm
actual height of point P above ground, p (average)	1.04 m

Calculation

If we treat the tree as a cylinder of radius r and height t , we know that $c = 2\pi r$ ①

the cross-sectional area $A = \pi r^2$ ②

and the volume of the tree $V = At$ ③

Rearranging ① gives $r = \frac{c}{2\pi}$

Substituting this into ② gives $A = \pi \left(\frac{c}{2\pi} \right)^2 = \pi \frac{c^2}{4\pi^2} = \frac{c^2}{4\pi}$ ④

The ratio of the apparent heights is the same as the ratio of the actual heights, so:

$$\frac{30 \text{ cm}}{3 \text{ cm}} = \frac{\text{height of tree, } t, \text{ in m}}{\text{actual height of point P above ground, } p, \text{ in m}}$$

This simplifies to: $10 = \frac{t}{p}$

Which can be written as: $t = 10p$ ⑤

Using the sample results

$c = 2.64 \text{ m}$, $p = 1.04 \text{ m}$, so:

Using ④ $A = \frac{c^2}{4\pi} = \frac{2.64^2}{4\pi} = \frac{2.64^2}{4 \times 3.14} = \frac{6.9696}{12.568} = 0.554$

The cross-sectional area of the tree is 0.554 m^2 (to 3 s.f.).

Using ⑤ $t = 10 \times 1.04 = 10.4$

The height of the tree is 10.4 m

Using ③ $V = At = 0.554 \times 10.4 = 5.7616$

The volume of wood in the tree is 5.76 m^3 (to 3 s.f.).

Measuring trees: Method 2

Laser distance measure and Pythagoras' theorem

Equipment

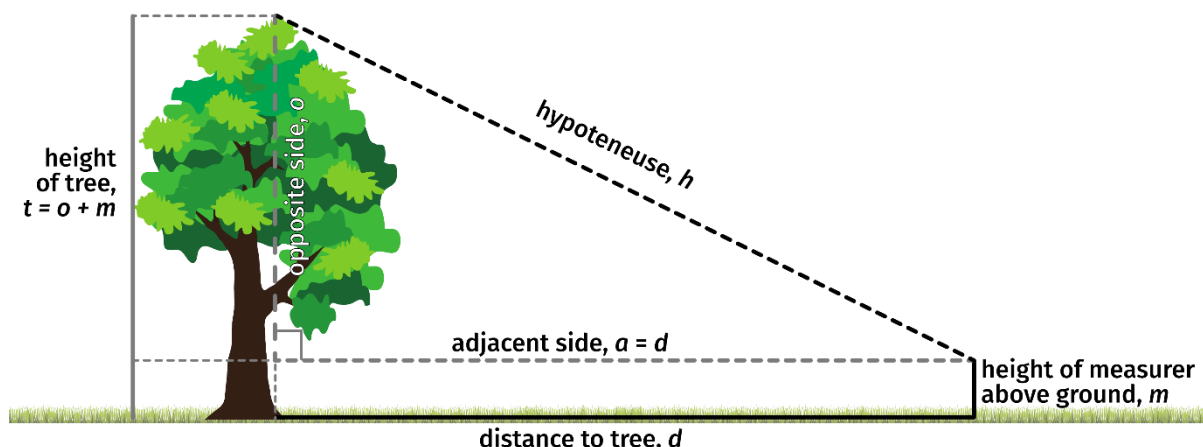
- a laser distance measure
- a tape measure
- metre rule (optional)

Health and safety

Make sure the beam from laser measure can never go into someone's eye.

Instructions

1. Use the tape measure to find the circumference of the trunk.
2. Stand several metres from the tree. Measure the distance to the tree, d .



3. Hold the laser measure at a comfortable height. Measure the distance between this position and the ground, m . (You might want to use a metre rule for this.)
4. Use the laser measure to find the distance to the top of the tree. You will probably need a bit of practice to get consistent readings. Record this as distance h .

Do anything else you need to do to make your measurement as accurate as possible.

Sample results

circumference of trunk, c (average)	2.64 m
distance to tree, d	6.00 m
height of measurer above ground, m	1.23 m
distance to top of tree from laser measure, h	10.57 m

Calculation

If we treat the tree as a cylinder of radius r and height t , we know that $c = 2\pi r$ ①

the cross-sectional area $A = \pi r^2$ ②

and the volume of the tree $V = At$ ③

Rearranging ① gives $r = \frac{c}{2\pi}$

Substituting this into ② gives $A = \pi \left(\frac{c}{2\pi} \right)^2 = \pi \frac{c^2}{4\pi^2} = \frac{c^2}{4\pi}$ ④

Measuring trees: Method 2 continued

The diagram shows how most of the tree forms one side of a right-angled triangle.

The length of the hypotenuse is h and the lengths of the other two sides are o and a .

We know from Pythagoras' theorem that $h^2 = o^2 + a^2$

But $a = d$, the distance to the tree, so $h^2 = o^2 + d^2$

We can rewrite this as $o^2 = h^2 - d^2$

so $o = \sqrt{h^2 - d^2}$

However, line AB is a distance m above the ground, so the height of the tree, $t = m + o$

Substituting for o gives us: $t = m + \sqrt{h^2 - d^2}$ ⑤

Using the sample results:

$c = 2.64$ m, $m = 1.23$ m, $h = 10.57$ m, $d = 6.00$ m so:

Using ④ $A = \frac{c^2}{4\pi} = \frac{2.64^2}{4\pi} = \frac{2.64^2}{4 \times 3.14} = \frac{6.9696}{12.568} = 0.554$

The cross sectional area of the tree is 0.554 m^2 (to 3 s.f.)

Using ⑤ $t = 1.23 + \sqrt{10.57^2 - 6.00^2}$

$$t = 1.23 + \sqrt{111.7249 - 36}$$

$$t = 1.23 + \sqrt{75.7249} = 1.23 + 8.70200... = 9.93200...$$

The height of the tree, to the nearest cm, is 9.93 m

Using ③ $V = At = 0.554 \times 9.93 = 5.50122$

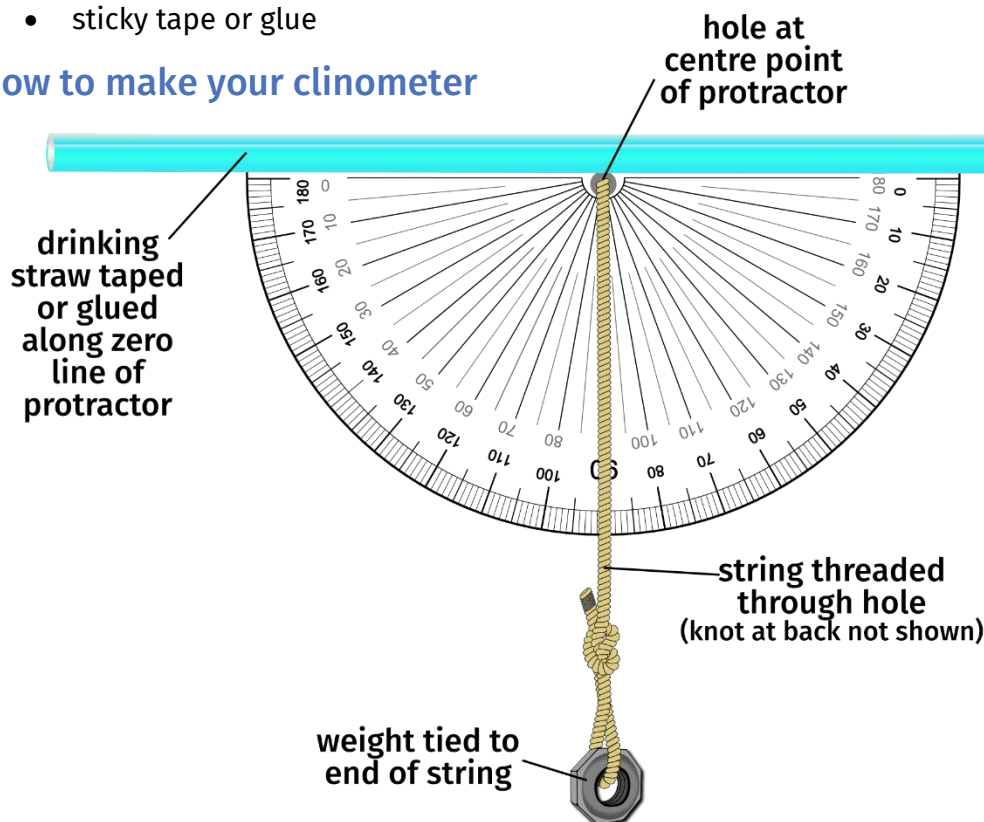
The volume of wood in the tree is 5.50 m^3 (to 3 s.f.)

Making a clinometer

Equipment

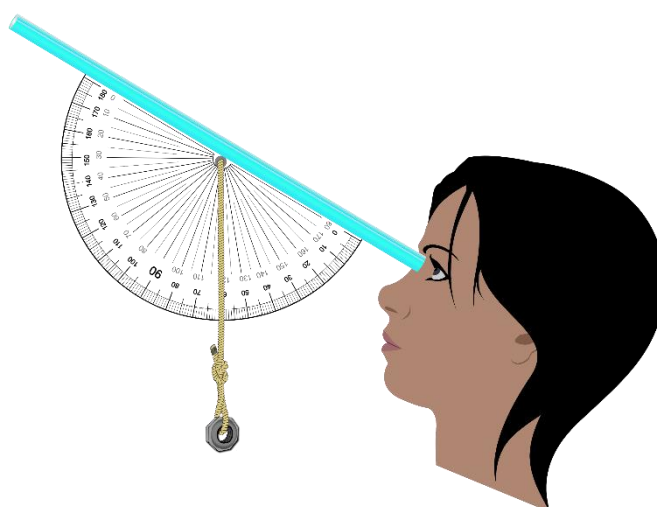
- a protractor with a hole at the centre point
- thin string
- a weight
- a drinking straw
- sticky tape or glue

How to make your clinometer



How to use your clinometer

1. Hold the clinometer so the string can move freely.
2. Look through the straw and tilt the clinometer until you can see the top of the tree.
3. Read the angle the string shows on the protractor. This is the angle between the straw and the **vertical**.
In this example it is 60°
4. To measure the height of a tree, we want the angle between the straw and the **horizontal**, 90° – the reading.
(Can you draw a diagram to explain why?)
In this example it is $90^\circ - 60^\circ = 30^\circ$



Measuring trees: Method 3

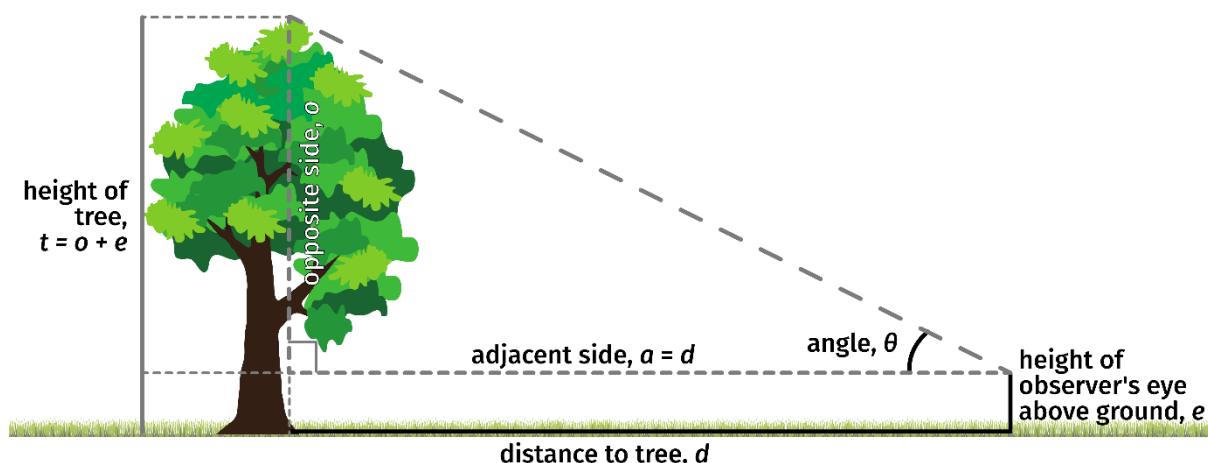
Clinometer and scale drawing or trigonometry

Equipment

- a clinometer
- a laser distance measure
- a tape measure
- metre rule (optional)

Instructions

1. Use the tape measure to find the circumference of the trunk.
2. Stand several metres from the tree. Measure the distance to the tree, d .



3. Measure the distance between your eye and the ground, e . (You might want to use a metre rule instead of the tape for this.)
4. Use the clinometer to find the angle between the **horizontal** and the top of the tree. Record this as angle θ .

Do anything else you need to do to make your measurement as accurate as possible.

Sample results

circumference of trunk, c (average)	2.64 m
distance to tree, d	6.00 m
height of eye above ground, e	1.54 m
Angle between horizontal and top of tree, θ	64°

Calculation

If we treat the tree as a cylinder of radius r and height t , we know that $c = 2\pi r$ ①

the cross-sectional area $A = \pi r^2$ ②

and the volume of the tree $V = At$ ③

Rearranging ① gives $r = \frac{c}{2\pi}$

Substituting this into ② gives $A = \pi \left(\frac{c}{2\pi} \right)^2 = \pi \frac{c^2}{4\pi^2} = \frac{c^2}{4\pi}$ ④

Measuring trees: Method 3 continued

The diagram shows how most of the tree forms one side of a right-angled triangle.

This side has length o and is opposite angle θ .

The side adjacent to angle θ has length a , where $a = d$, the distance to the tree.

There are two ways we can find the height of the tree:

Method A: Use a scale drawing

- Draw a horizontal line and construct another line perpendicular to it.
- Mark a point on your horizontal line a distance d (using your scale) from your perpendicular.
- Draw a line from this point at an angle θ to the horizontal.
- The point where this line intersects the perpendicular is the apex of the triangle – just read off the value of o .
- The height of the tree, $t = e + o$

Method B: Use trigonometry

$$\tan\theta = \frac{o}{a} = \frac{o}{d}$$

$$\text{So } o = d \times \tan\theta$$

$$\text{And the height of the tree, } t = e + o = e + d \tan\theta$$

Using the sample results

$c = 2.64$ m, $e = 1.54$ m, $\theta = 64^\circ$, $d = 6.00$ m so:

$$\text{Using ④} \quad A = \frac{c^2}{4\pi} = \frac{2.64^2}{4\pi} = \frac{2.64^2}{4 \times 3.14} = \frac{6.9696}{12.568} = 0.554$$

The cross sectional area of the tree is 0.554 m^2 (to 3 s.f.)

Method A

From diagram, $o = 12.3$ m

$$t = e + o = 1.54 + 12.3 = 13.84$$

The height of the tree is 13.84 m

Method B

$$\text{Using ⑤} \quad t = 1.54 + 6.00 \times \tan 64^\circ$$

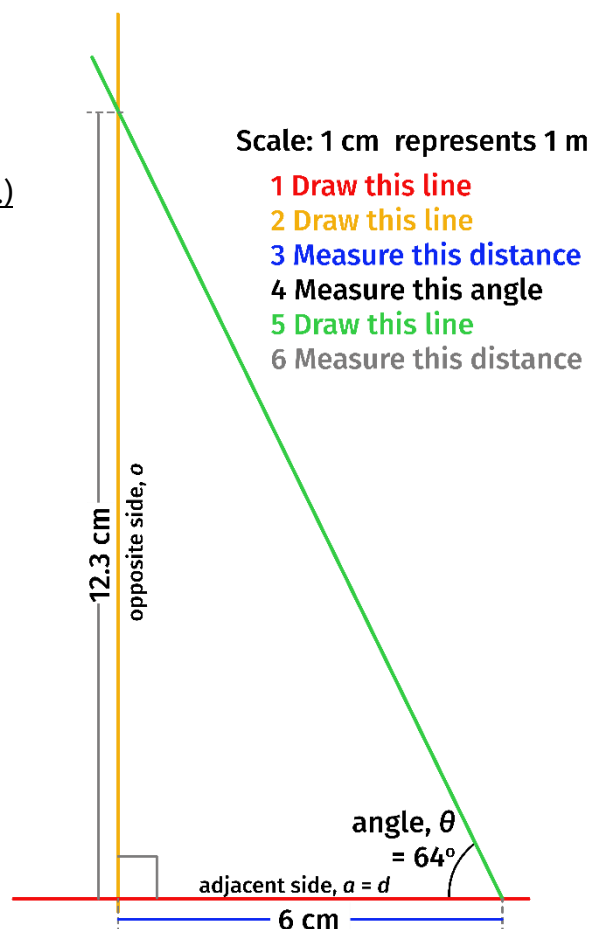
$$t = 1.54 + 6.00 \times 2.0503...$$

$$t = 1.54 + 12.3018... = 13.8418...$$

The height of the tree, to the nearest cm, is 13.84 m

$$\text{Using ③} \quad V = At = 0.554 \times 13.84 = 7.66736$$

The volume of wood in the tree is 7.67 m^3 (to 3 s.f.)



Modelling ALS

Equipment

- 2 clamps and retort stands
- a metre rule
- a laser distance measure
- a small piece of card
- sticky tape and scissors
- blocks
- a large piece of card to make a screen

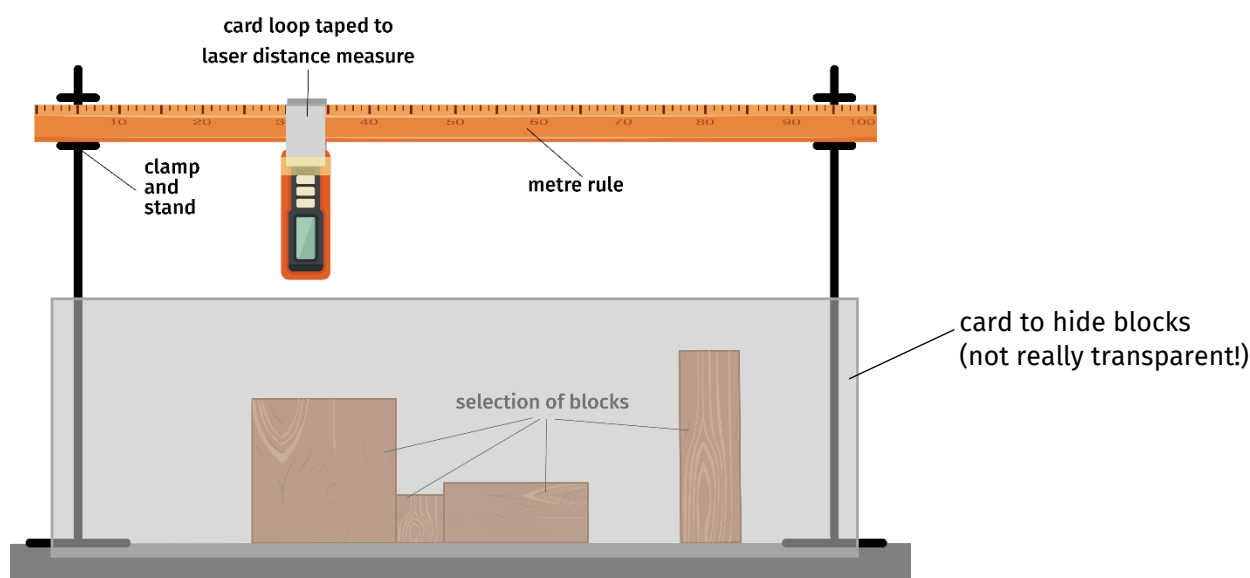
Health and safety

Make sure the beam from laser measure can never go into someone's eye.

Instructions

1. Split into two groups, A and B.
2. Draw a table with the headings shown →
3. Fix the metre rule between two clamps attached to stands. Make sure it is horizontal.
4. Loop the small piece of card over the metre rule and tape the laser measure to the card. Take care not to cover over any controls! The laser should point straight down, and the loop be loose enough so you can slide the measure along the rule.
5. Put the card in front of the retort stands. Group A should sit in front of the card so they cannot see behind it. Group B make an arrangement of blocks behind the card, leaving some spaces.

Distance along rule / cm	Height of measure above surface / cm

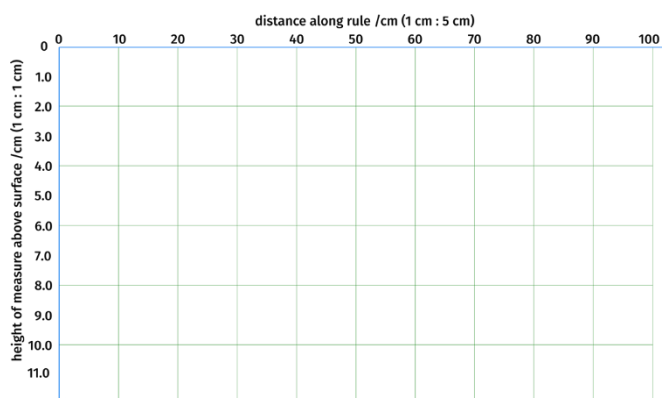


6. One person from Group B makes a drawing showing the height, width and position of the blocks (perhaps on a grid like that overleaf); the others carry on to the next step.
7. Group A choose a position along the rule.
Group B move the laser measure to this position and take a reading.
Group A note the result in their tables.
Continue like this until Group A have about 15 readings.
8. Group A and B swap places: Group A make a new arrangement for Group B to find.

Modelling ALS: continued

Analysing your results

1. Use the results table to answer these questions.
 - a) How far below the laser measure was the table?
 - b) How many different block heights were there in the other group's arrangement?
 - c) What was the height of tallest block? The shortest?
 - d) Can you say anything about the width or position of any of the blocks?
2. Use axes like these to plot your results. You may need to use a different vertical scale.
3. Draw a horizontal line to show the position of the table.
4. Add rectangles to your graph to show where you think the blocks were.
5. If the results seem to show something else, add this to the graph too.



Evaluation

Compare your graph with the drawing made by the other group.

1. What parts of your drawing were correct?
2. What information did you use to create these parts of your drawing?
3. What parts of your drawing were wrong?
4. Why?
 - a) Did you just need more information?
If so, what extra information would have helped you make a more accurate drawing?
5. Were your mistakes because of the equipment?
If so, what could you have changed? How?
6. What do your answers tell you about getting good results from a lidar sensor on an airplane or UAV (drone)?

Links

Teaching packs

More teaching materials related to Earth observation can be downloaded from the **NCEO website**, **EO Detective on STEM Learning** and **ESA Education Teachers corner**. Of particular relevance, although possibly aimed at adjacent age ranges, are:

- **Exploring rainforests** – using Google Earth to measure rainforest extent
- **Watching a glacier (11–14)** – useful preparation for the activity above
- Counting trees (Biomass 7–11) and Weighing trees (Biomass 14–16) overlap with the activities in this pack
- **The greenhouse effect and its consequences**
- **Taking the pulse of the planet (11–14)** (TPP) particularly Activity 1
- **The carbon cycle** Activity 1 and Activity 3
- **Papercraft satellites** from Dynamic Earth

Earth observation

In the education section of the **NCEO website**, the **About EO** page gives an overview aimed at teachers and older pupils. Other pages give more detail about specific areas.

Tuning into Earth's climate (video) shows how different parts of the electromagnetic spectrum are used to monitor climate. Details may be a little complex for some students but graphics are good! A simpler overview is **Satellite – What are Earth observation satellites?** from Airbus. Both support the TPP activity referenced above.

Forests and urban trees

Global Forest Watch includes a tree cover height layer (click land cover menu) as well as lots of other information and does not only include forested areas.

While there are national maps of **trees of interest**, and maps of **individual trees in England**, I have been unable to find a free equivalent for Scotland, Wales or Northern Ireland – apart from **Treezilla**, which may be incomplete for your area. (Please tell me if you know of one and I'll update accordingly.) The **Bluesky national tree map** does cover the whole of the UK and Ireland but you need to pay for downloads. Even so, you can explore it with limited resolution.

Lidar scanning and the Biomass mission

This video from NEON explains how ALS works and how point clouds are built up. While it includes some ideas not covered here, it does so in a clear and engaging way.

3D model of the tallest tree in the world created using lidar (terrestrial rather than airborne). Links on the same page go to similar models of other trees many created by NCEO researcher **Phil Wilkes** (kunghphil).

There are links to the latest Biomass news and pictures at the bottom of the page on the **ESA website about the mission**, and there is a **Biomass playlist** on the ESA YouTube channel. This includes a **launch highlights video** and another showing the **first images from the satellite**.

More information about **terrestrial laser scanning (TLS)**, the ground-based method used to build 3D images of trees, can be found in an NCEO news article from November 2023, which links through to the **home page of the Geo-trees project**.

Acknowledgements

The ALS modelling activity was developed by Sophie Allan (National Space Academy).
The pack was written by Catherine Fitzsimons (NCEO, University of Leicester).

Image credits

Biomass patch: ESA
Front cover; slide 1: ESA/ATG medialab
Page 8: Bar-On, Phillips & Milo, 2018: Fig 1
Page 9: Mike 1024, Wikimedia commons (top); Based on Fig 2.8 in *The SAR Handbook*, Servir Global, 2019
Page 10: Based on Fig 2.9 in *The SAR Handbook*, Servir Global, 2019 (top); Mat Disney (bottom)
Slides 4 & 5: Tim Withnall on flickr
Slide 6: Institut de France Manuscript M, p. 78v. from Gao and Newberry (2025) Fig 1a
Slide 7: Gao and Newberry (2025) Fig 1b
Slide 8: Gao and Newberry (2025) Fig 1c & d
Slides 11, 12, 19 & 24; Resource sheets 1 & 3.2: CAF (NCEO) using graphics by Clker-Free-Vector-Images, Divyansh Kumar, and Georges Tsukaïmah from Pixabay
Slides 14 & 45; Resource sheet 2; Worksheet 3 (bottom): CAF (NCEO) using graphics by Divyansh Kumar and Georges Tsukaïmah from Pixabay
Slides 17 & 18; Resource sheet 3.1: CAF (NCEO) using graphics by hannazasimova on Freepik and Nina Garman and OpenClipart-Vectors from Pixabay
Slide 20; Resource sheet 3.3: CAF (NCEO)
Slide 23: Marc Pell on Unsplash
Slide 26: Nathan Queloz on Unsplash
Slide 27; Worksheet 2 (top): CAF (NCEO) using graphics by VectorStock / vectorstock and Georges Tsukaïmah from Pixabay
Slides 28 & 45 (left); Worksheets 2 (bottom) & 3 (top): CAF (NCEO) using graphics by VectorStock / vectorstock and Divyansh Kumar & Georges Tsukaïmah from Pixabay
Slide 29: NCEO Airborne Earth Observatory (KCL) | Zhang et al (2024) Fig 2 (extract)
Slide 30; Resource sheet 4.1: CAF (NCEO) using graphics by Clker-Free-Vector-Images from Pixabay and blueringmedia and anatolir on Adobe Stock (education licence)
Slide 36; Resource sheet 4.2: CAF (NCEO) using graphics by Clker-Free-Vector-Images from Pixabay and Open Clip Art
Slide 38: Imagery © 2025 Planet Labs (Costa Rica, 9 Feb 25)
Slide 39: ESA/ATG medialab
Slide 40: Le Toan (2007)
Slide 41: ESA/ATG medialab
Slide 42: ESA-P. Sebirot (photo); ESA (patch)
Slide 43: ESA (main image); Servir Global SAR handbook Fig 2.8 (inset)
Slide 44: CAF (NCEO)
Slide 45 (right): Zhang et al (2024) Fig 2 (extract)
Slide 47: ESA