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Lidar calibration – What's the problem?

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Lidar calibration
– What’s the problem?

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The storyline

- What is the point of calibrating lidars?
- How we do this for various lidar types
- What are the main components of the uncertainty?

The reference wind speed = cup uncertainty DOMINATES

- This makes lidar uncertainty too high, calibrations that are not very repeatable and lidar sensitivity impossible to understand.
- Errors are not necessarily uncertainties
- How we can significantly reduce cup and therefore lidar uncertainty

Calibration – what is it?

- A comparative test between a test instrument and a reference instrument that allows you to do two things:

1. Find a **transfer function** between the indications of the test instrument and the reference instrument.

2. Derive an **uncertainty** for the test instrument indication

≈ reference instrument uncertainty + transfer function uncertainty

Without a calibration, we do not have the traceability to international standards necessary in order to define an uncertainty.

Lidar calibration – what's the point?

A not uncommon statement:

"Lidars are 'absolute' instruments (you can calculate the wind speed from first principles) so no calibration is necessary."

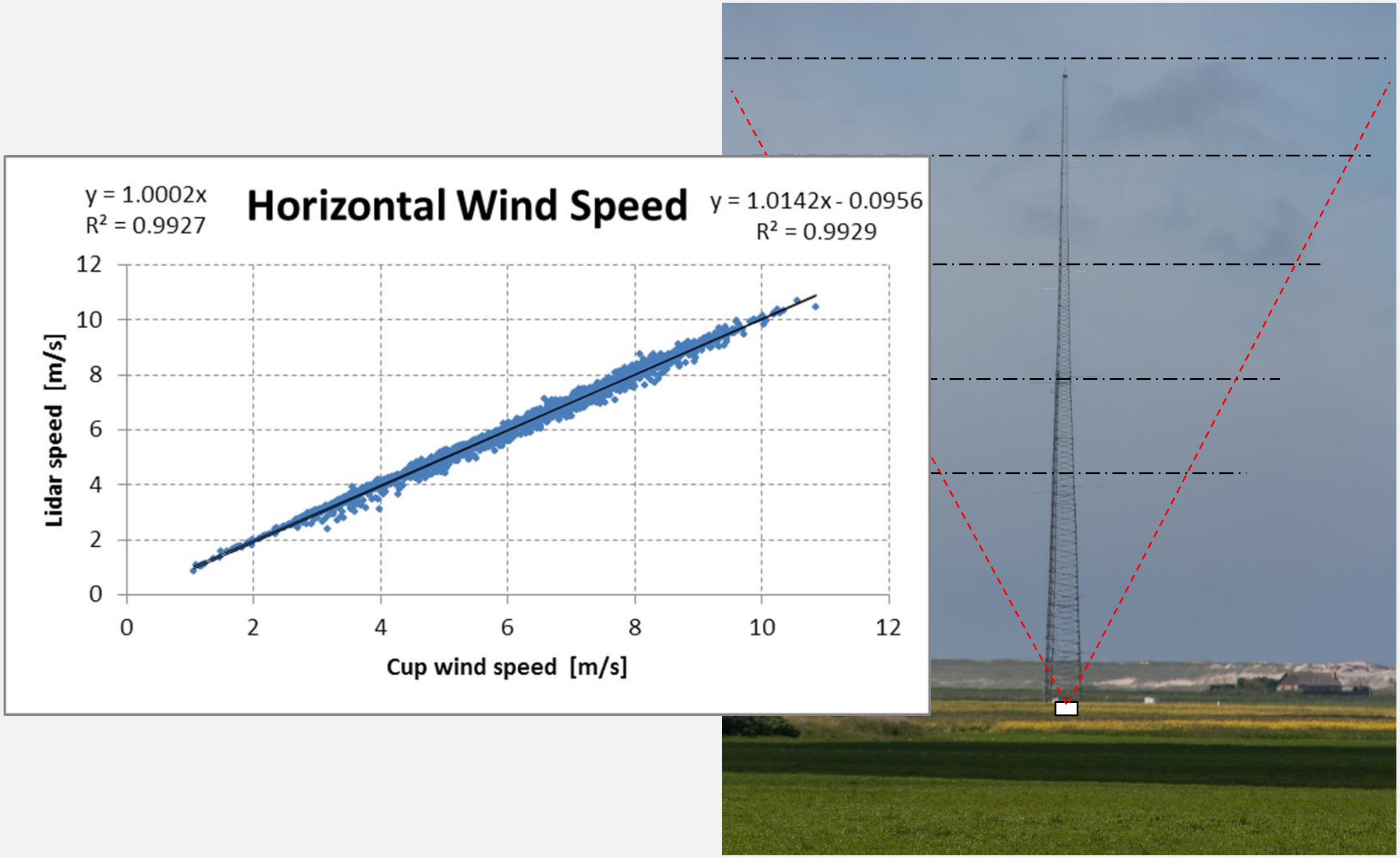
Some unfortunate truths:

- All the components of the lidar have tolerances (uncertainties). Unless each component is formally calibrated, it will not be possible to assign an uncertainty.
- Even if all the lidar components are calibrated, how do we know that the lidar algorithm (all of it) is implemented correctly?

Consequently:

For wind lidars, nacelle lidars and scanning lidars it is currently not possible to assign an uncertainty without performing a field calibration using a met mast equipped with cup anemometers and wind vanes.

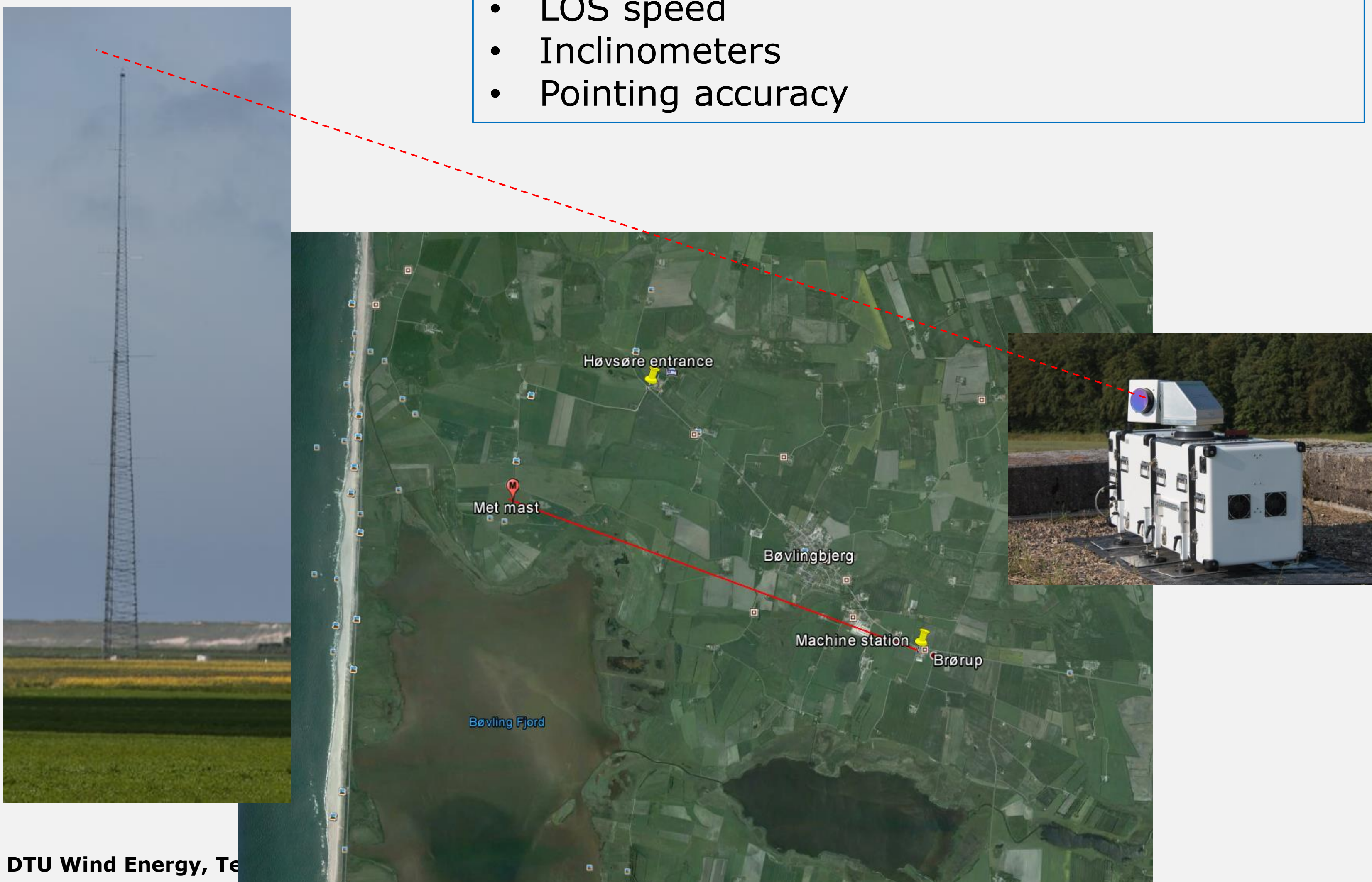
How we calibrate wind lidars



Calibrating scanning lidars – here for long range sector scanning

Things to calibrate:

- LOS speed
- Inclinometers
- Pointing accuracy



Lidar uncertainty from the calibration

(per bin, according to Annex L)

$$U_{\text{lidar}} = \sqrt{U_{ref}^2 + \Delta V^2 + \frac{\sigma_{lidar}^2}{N} + \sigma_{dev}^2}$$

Lidar uncertainty

Reference uncertainty

mean deviation

”uncertainty” of mean in bin (?)

Standard deviation of the deviation

I am not convinced that these terms are correct, but it doesn’t change the main argument of this presentation.

Lidar uncertainty from the calibration

- Typical sizes (m/s) at 10 m/s (standard uncertainty)

$$U_{\mathrm{lidar}} = \sqrt{U_{ref}^2 + \Delta V^2 + \frac{\sigma_{lidar}^2}{N} + \sigma_{dev}^2}$$

U_{lidar}: 0.17

U_{ref}^2: 0.15^2

ΔV^2: 0.05^2

$\frac{\sigma_{lidar}^2}{N}$: 0.02^2

σ_{dev}^2: 0.07^2

The reference wind speed (cup) uncertainty DOMINATES lidar uncertainty

Consequent

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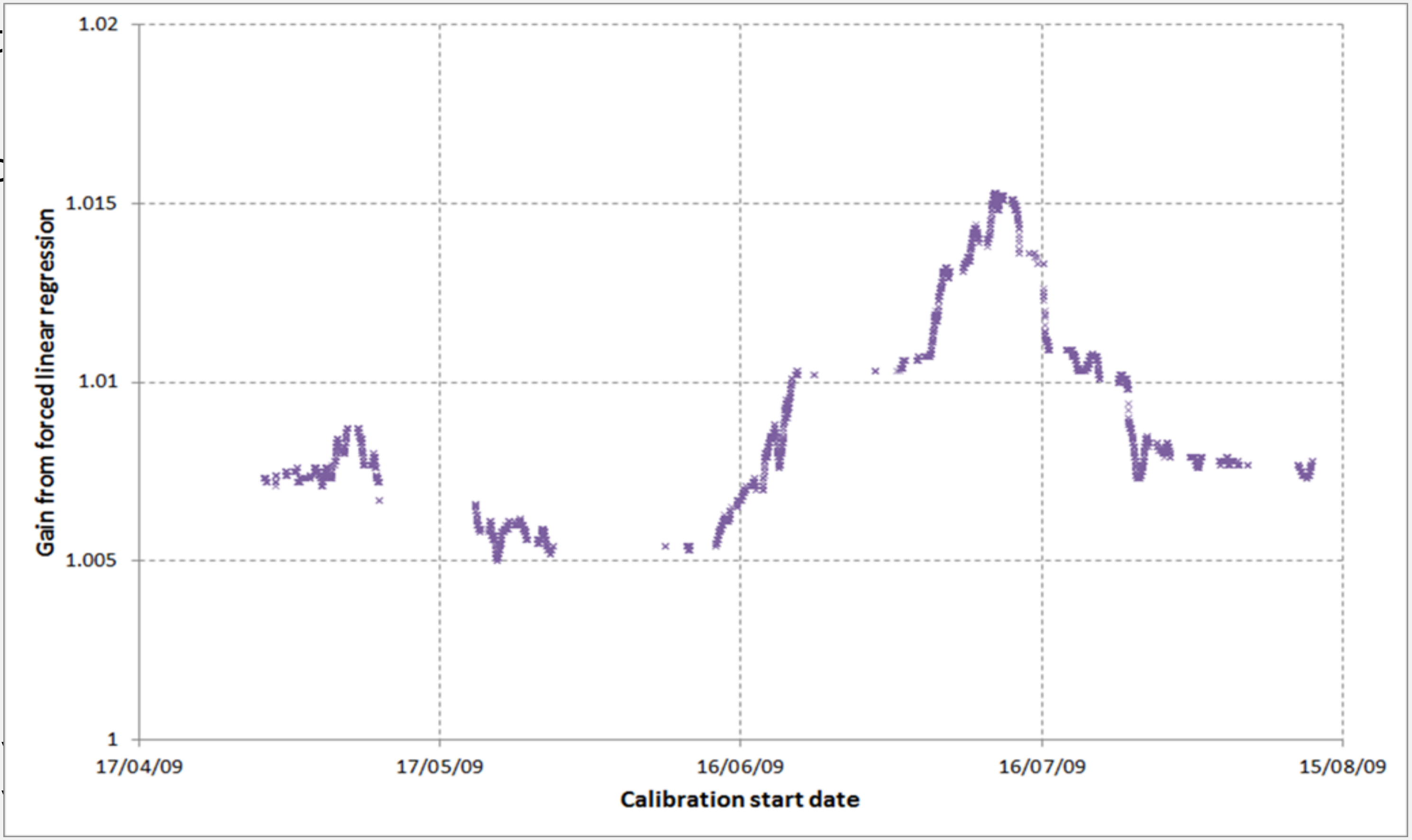


Where does the reference cup uncertainty come from? (typical values for 10 m/s, k=1)

$$U_{ref} = \sqrt{U_{cal}^2 + U_{tunnel}^2 + U_{operational}^2 + U_{mounting}^2}$$

Cup uncertainty

0.15 m/s

Calibration standard uncertainty

0.025 m/s

Spread of tunnels uncertainty

0.058 m/s

Inconsistent!!!

Errors included as uncertainties!

Classification uncertainty

0.076 m/s

Mounting uncertainty

0.11 m/s

Summing up so far:

- Most of the lidar uncertainty comes from the cup

- Most of the cup uncertainty comes from
  - Tunnel uncertainty
  - Operational uncertainty
  - Mounting uncertainty

Known errors are not uncertainties

Most of the cup uncertainty comes from errors that we could/should know something about. These include:

- Wind tunnel calibration differences
- The effects of
  - Turbulence
  - Temperature
  - Maybe even tilt angle
- Mast mounting errors

What we need to do

- Move away from a culture where errors are included as uncertainties

- Move towards a culture where we strive to correct for errors
  and
- include much smaller uncertainties that reflect our ability to do this.

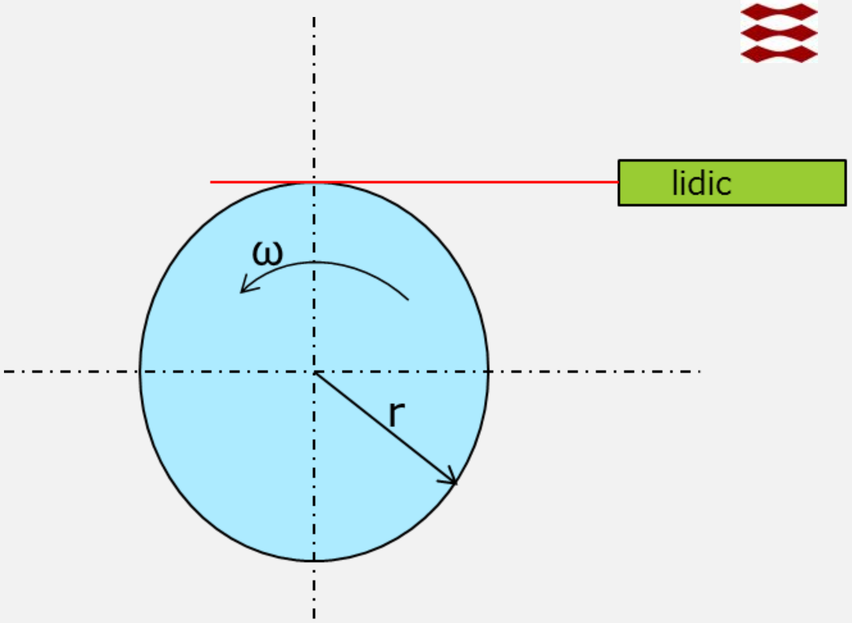
We can tackle the following 3 areas:

- Get wind tunnel calibrators to agree with each other so that the given calibration best estimates and uncertainties are consistent between wind tunnels.

- Determine how well the current sensitivty (Accuwind) model actually performs and improve it, if necessary. Use the sensitivities to correct the cup speeds for (at least) turbulence and temperature effects.

- Do the same for mast influence models – we need to know how good e.g. CFD models are. Then we need to start using them for operational corrections and use much lower mounting uncertainties.

How we will do it



Short range CW lidars (lidics) can be calibrated using a rotating wheel. They will have a much lower uncertainty than cup anemometers or cup calibrated lidars.

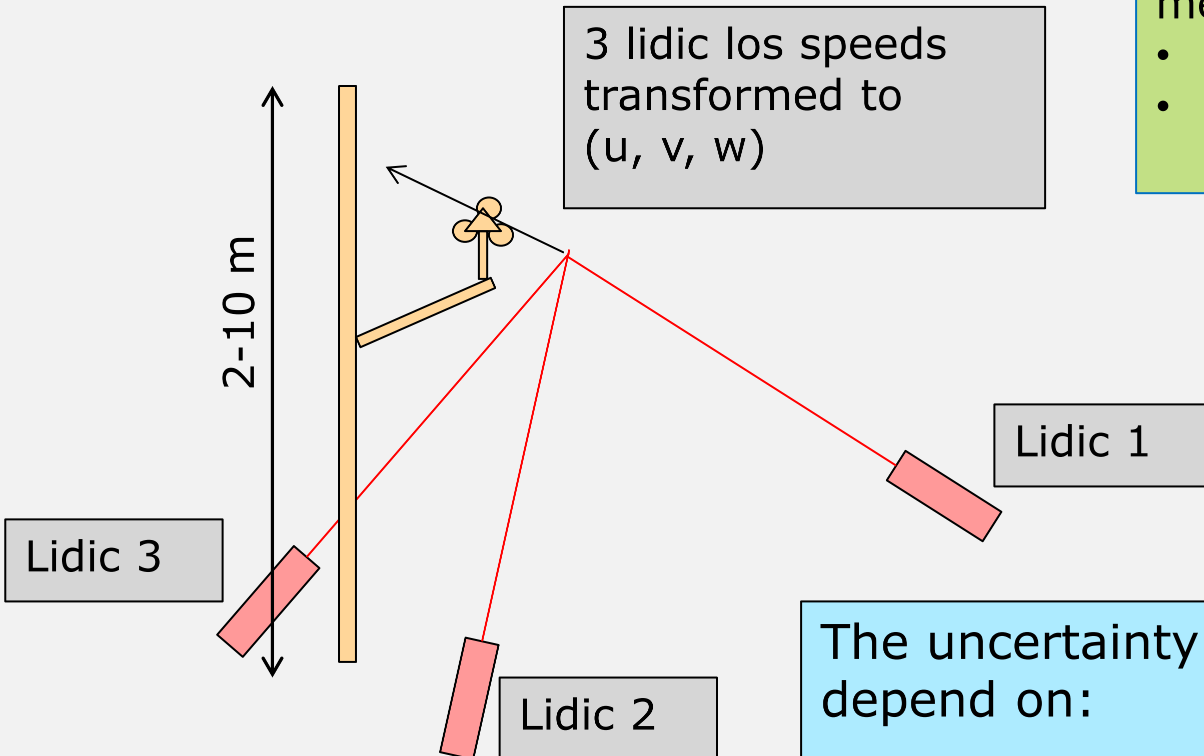
Lidics will be an important tool for

- Documenting wind tunnel accuracy
- Measuring cup anemometer influences (TI and T)
- Measuring how masts and booms affect cup wind speeds

Measuring in the free-air using 3 lidics

We can perform measurents on:

- individual cups
- cup/boom/mast systems



The uncertainty of (u, v, w) will depend on:

- the los speed uncertainty
- the lidic geometry
- the range accuracy

Conclusion

- Lidar uncertainty is dominated by the reference cup anemometer uncertainty.

- Cup anemometer uncertainty can be improved by:
  - Solving the tunnel blockage calibration issues

  - Measuring and correcting for sensitivities instead of just including them as uncertainties (Smartcups)

  - Measuring and correcting for mounting effects, with much reduced mounting uncertainty as a consequence.

- We can use precision calibrated, short range, continuous wave lidars (LIDICS) to achieve this.

- These improvements will reduce cup anemometer, sonic and consequently lidar uncertainty

Thanks and any questions?

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