The workings of a radar *spectrum* simulator and its use to evaluate LES (part 1)

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Outline

- What is a radar Doppler spectrum?
- What do we need to model it?
- How do we model it?
- Applications
- Examples

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What does a cloud radar actually measure?

- **Reflectivity: How much energy is scattered back**
- **Doppler velocity: Movement of particles**

Radar Doppler Spectrum

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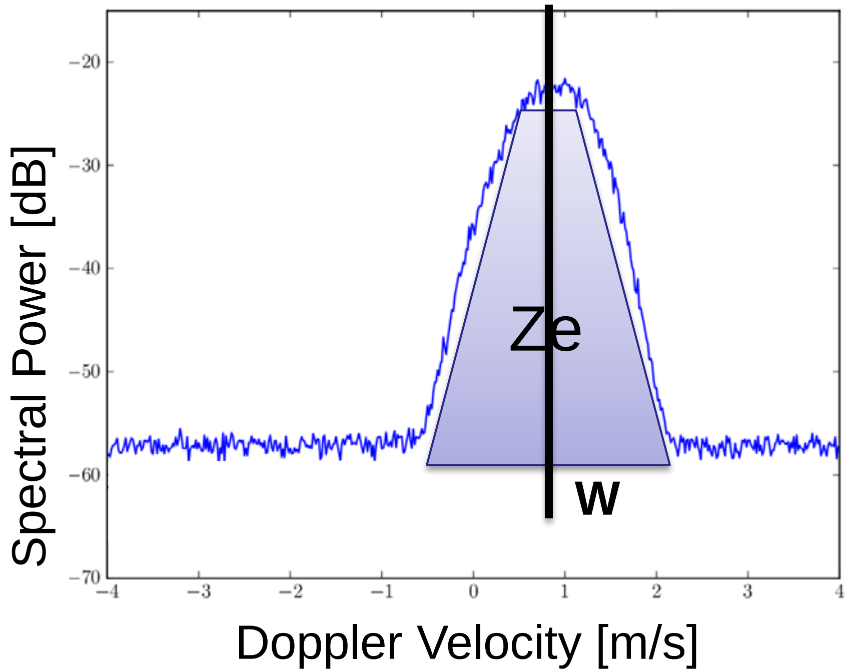
What does a cloud radar actually measure?

Radar Doppler Spectrum (looking zenith)



- **Reflectivity Ze**
- **Doppler Velocity W**
- **What about the rest?**
  - **Higher moments: Spectral Width, Skewness, Kurtosis**
  - **Wavlet analysis**
  - **Exploit the full spectrum**

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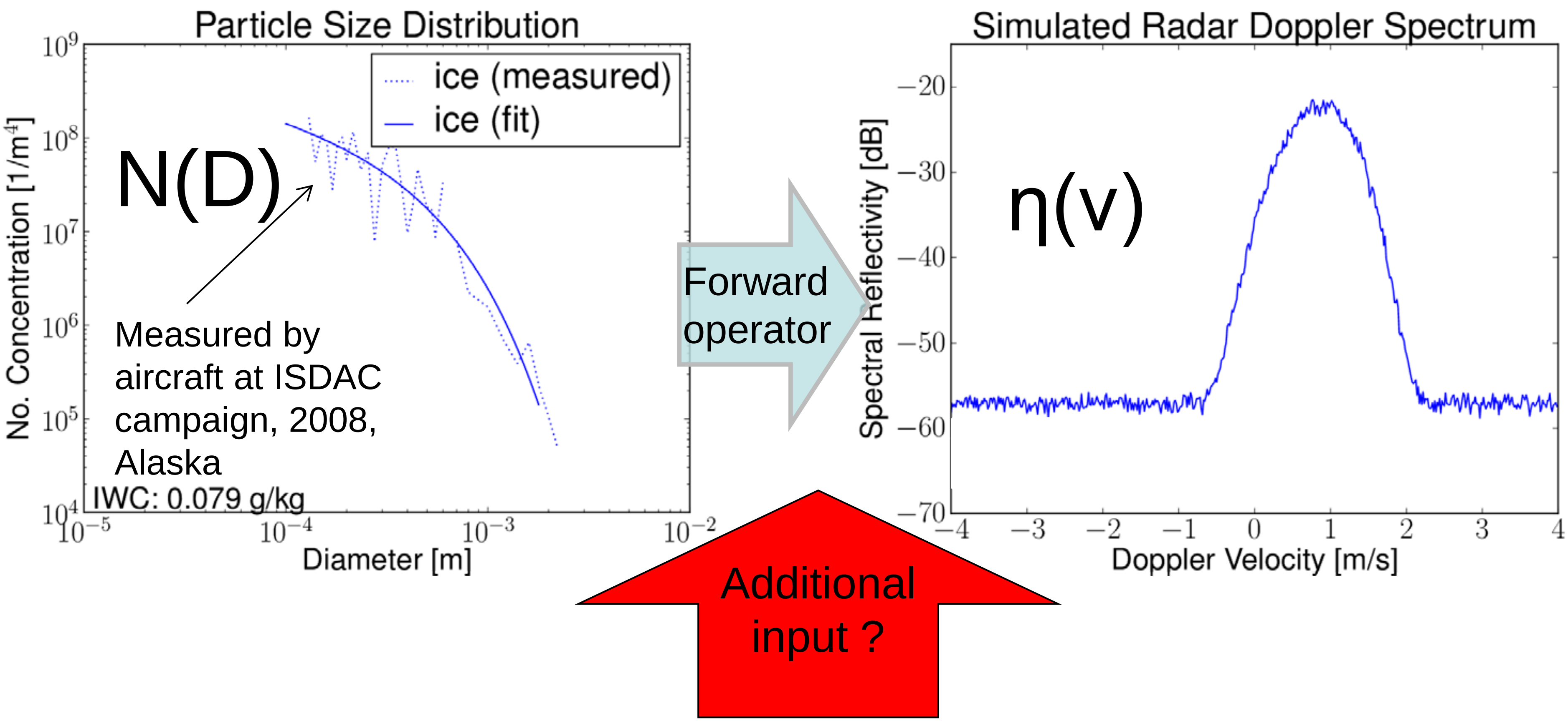
What do we need for modelling?



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General conditions

- **Vertical and temporal resolution of LES model better than radar**
  - **Cloud radar vertical: ~30m**
  - **Cloud radar temporal: ~1-10s**

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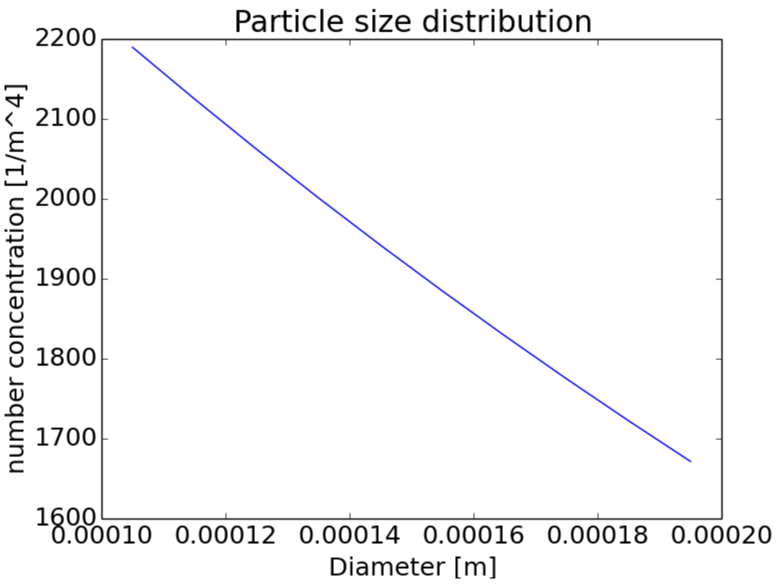
Particle Size distribution

- **Decide for particle descriptior (e.g. D_{max})**
- **N(D) for each species of hydrometeors:**
  - **Bulk: describe PSD with exponential, gamma, log-normal (…) distribution**

  or
  - **Spectral bin: LES full bin microphysics input**



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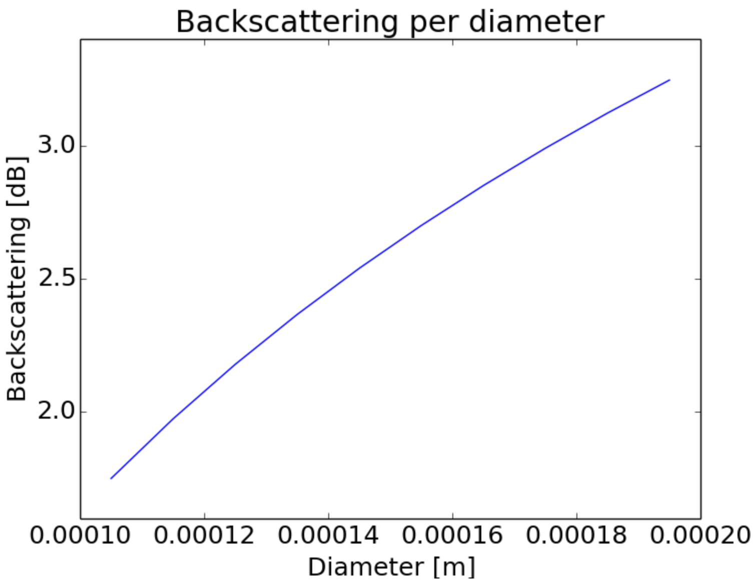
N(D) -> backscattering σ(D)

- **For each species: Calculate scattering properties**
  - Shape (sphere, spheroid, other?)
  - Phase (liquid, ice or mixed?)
  - Particle density
  - Ambient temperature
- **For ice & snow, getting realistic scattering properties is challenging**



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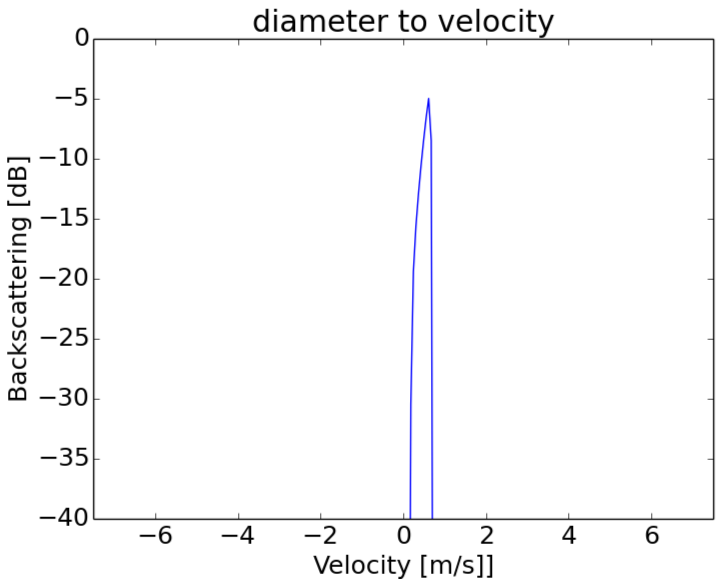
Apply fall velocity: σ(D) -> σ‘(v)

- **Fixed fall velocity relation v(D) of LES?**
  - **coefficients**
- **v(D) relation from literature**
  - **Ambient temperature, pressure**
  - **Mass m(D)**
  - **Cross section area A(D)**



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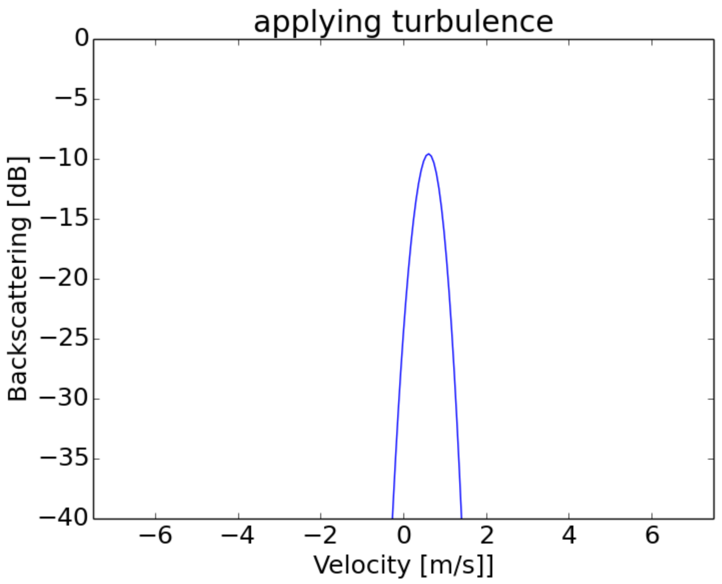
Simulate radar σ‘(v) -> η(v)

- **Apply Turbulence**

- **Why is Turbulence crucial?**
- **The longer the radar averaging time, the higher the impact of turbulance on the spectrum**



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Spectral Width

$$\sigma_D^2 = \sigma_{\mathrm{DSD}}^2 + \sigma_T^2 + \sigma_S^2 + \sigma_B^2$$

σ_{DSD} : particle size distribution

σ_T : turbulence within radar volume

Eddy dissipation rate

$$\sigma_T^2 = \int_{k_s}^{k_\lambda} S(k)\, dk \qquad S(k) = a\varepsilon^{2/3} k^{-5/3}$$

σ_S : vertical and horizontal wind shear

σ_B : finite Beam width, function of horizontal wind

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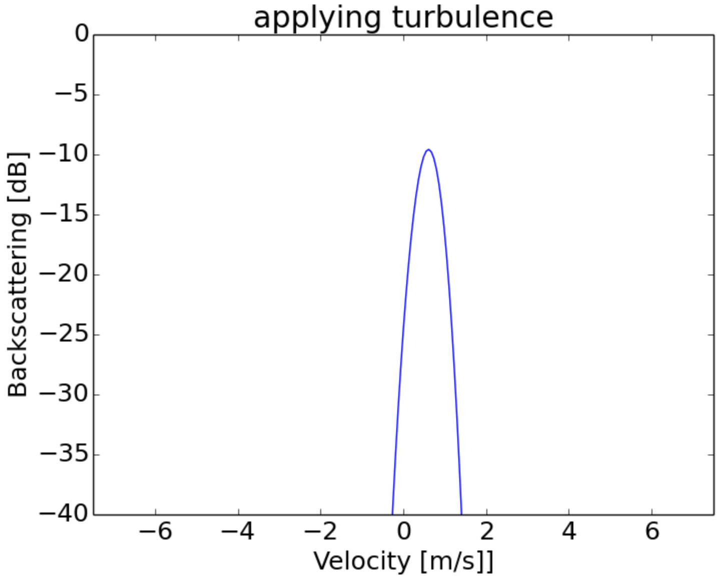
Simulate radar σ‘(v) -> η(v)

- **Apply Turbulence**
  - Eddy dissipation rate
  - Horizontal and vertical wind field



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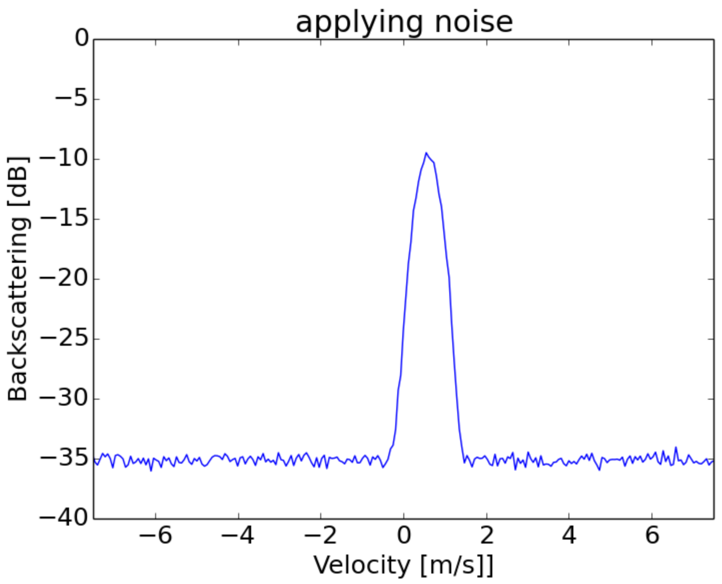
Simulate radar σ‘(v) -> η(v)

- **Apply Radar characteristics**
  - Noise
  - Spectral resolution
  - Beam width
  - Averaging time
  - …



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Ingredients of a radar forward operator

- Sufficient temporal & vertical resolution
- Size definition (D_{max})
- Number concentration: N(D)
- Mass: m(D)
- Cross section area: A(D)
- Density: ρ(D)
- Shape: sphere, spheroid, other?
- Phase: liquid, solid, mixed?
- Turbulence: Eddy dissipation rate
- Ambient wind, temperature, pressure
- Radar characteristics

For ice: keep these ones consistent!

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