Modelling of flow

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Why?

To…

- Transfer local measurements to WTG pos
  - Wind distribution (pdf) for AEP estimation
  - Extreme wind estimates (IEC)
- Predict parameters not measured
  - Inflow, shear, turbulence? recirculation?
- Predict “local” data if none
  - Make rough ”local” timeseries from climate data
  - Further adjustment needed to include local effects

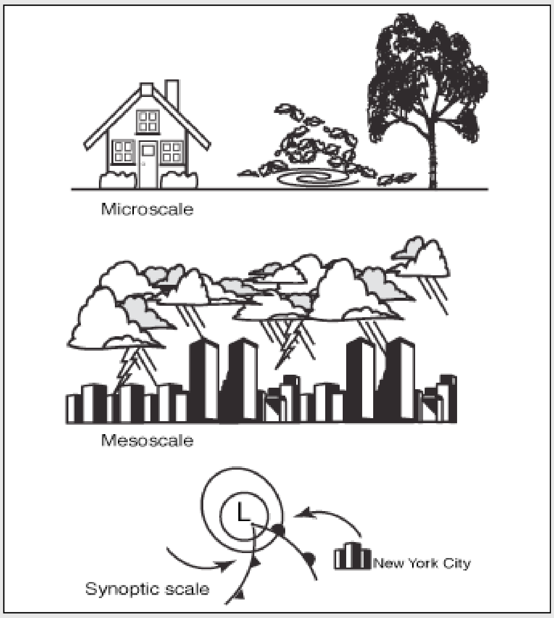
Flow occurs at many scales!

Micro scale

Meso scale

Synoptic scale

(Global scale)



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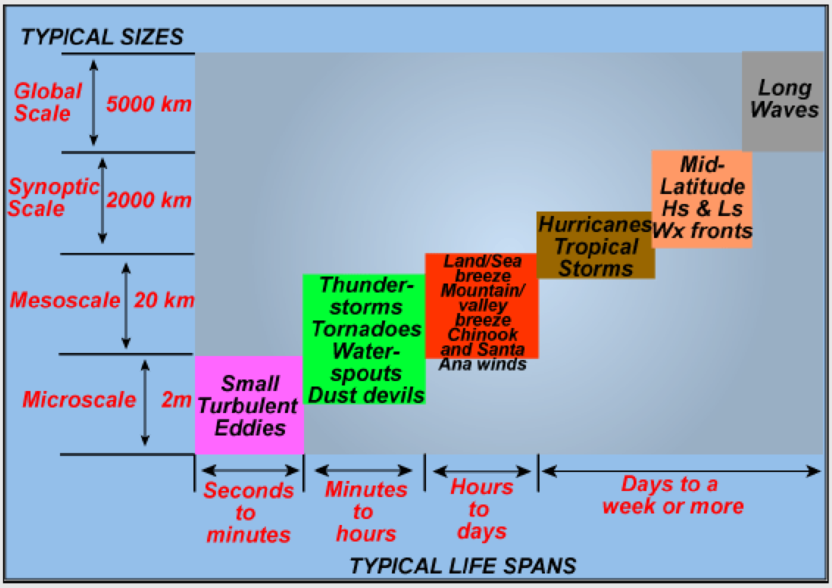
Flow occurs at many scales!



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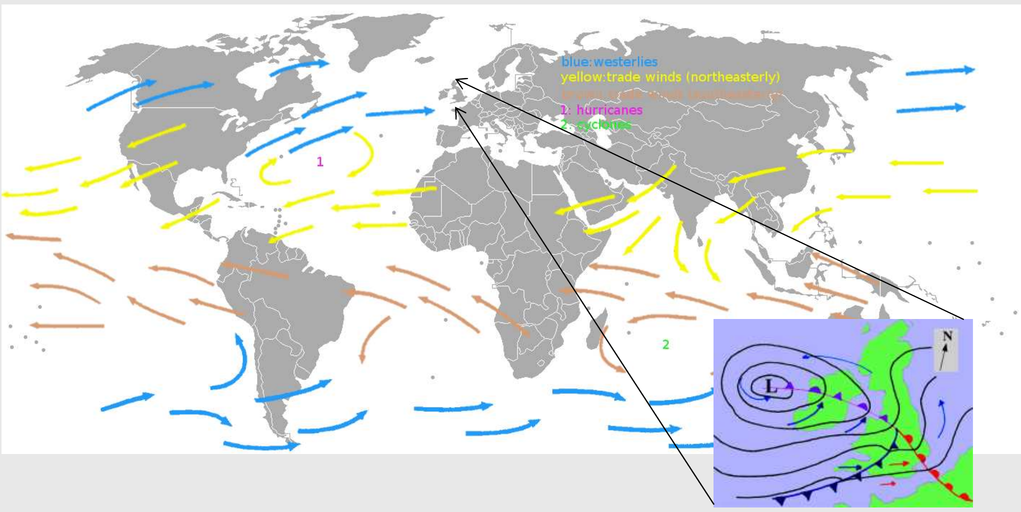
Flow occurs at many scales!

Example: Global and Synoptic scales



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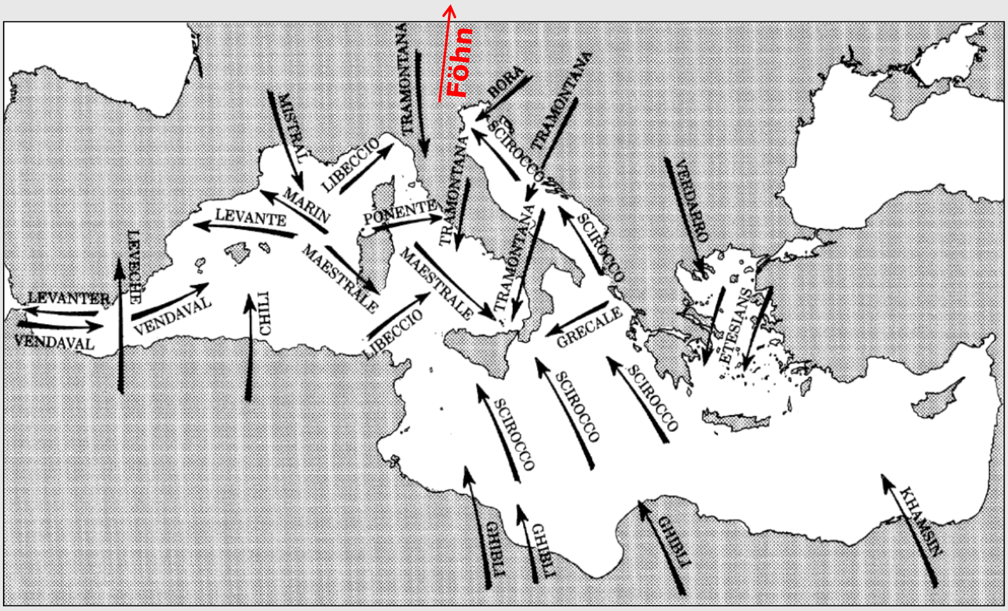
Flow occurs at many scales!

Example: some European ”Meso scale winds”:



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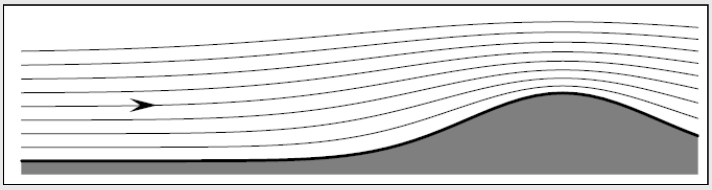
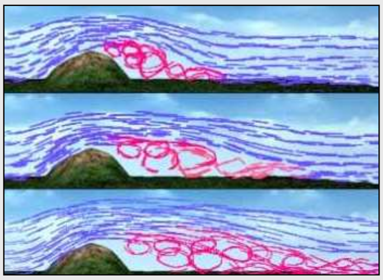
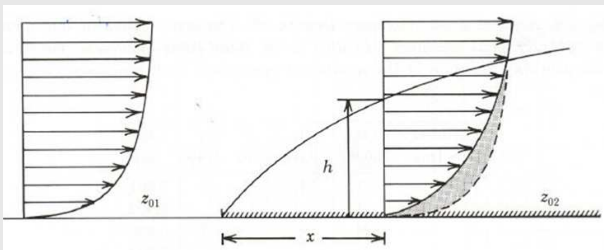
Flow occurs at many scales!

Example: ”Micro scale wind effects”







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Different models for each scale

Micro scale models:

- Typical grid cell: 10s of m
- Typical use in siting/micro-siting
- Models like: WAsP, WEng, ”CFD” (LES, DES, DNS….)

Meso scale models:

- Typical grid cell: several km
- Increased use in wind energy (hindcast & forecast)
- Needs input from global models!
- Possible input to microscale models

Global/Synoptic scale models (NWP)

- Typical grid cell: 100-1000 km
- Research and met offices, e.g. NCEP, DMI,….

Micro scale models

Two groups of micro scale models:

Linearized models

- WAsP
- WEng (WAsP Engineering)
- MS Micro
- ….

Non-linear models (referred to as "CFD")

- WAsP CFD (Ellipsys)
- Windsim
- Meteodyn
- …

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Micro scale models

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Linearized versus “CFD” models

- Flow separation is the challenge!
  - A non-linear effect
  - Only CFD can handle it (to some degree…)

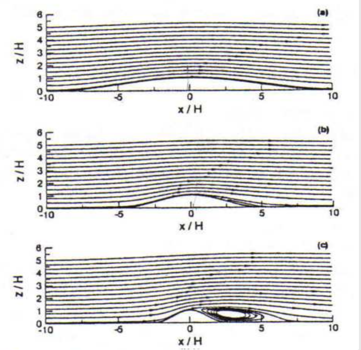

Figure 2: Sreamlines over two-dimensional ridges with: (a)θ=5.7; (b)θ=11.3; (c)θ=21.8.

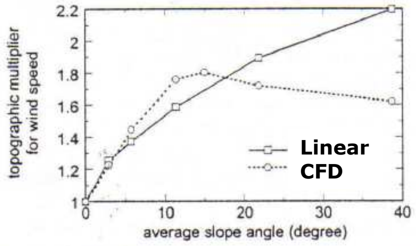

Figure 4: The variation of topographic multiplier for wind speed with the slope angle at the z'/H=0.25 at the hilltop

Micro scale models (WAsP)

The WAsP model - General description

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Micro scale models (WAsP)

The WAsP model - General description

Separated handling (superposition) of:

- Terrain speed up
- Roughness
- Atmospheric stability

WAsP flow = Annual mean flow (Weibulls etc.) !!

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Micro scale models (WAsP)

The WAsP model - General description

Separated handling (superposition) of:

- Terrain speed up
- Roughness
- Atmospheric stability

WAsP flow = Simple log-profile (flat, uniform roughness)
+Terrain corr. (neutral)
+Roughness corr. (neutral)
+Stability corr. (neutral/unstable/stable)

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Micro scale models (WAsP)

The WAsP model - General description

(Wind Atlas Analysis and Application Program = WAsP)

A linearized two step model:

- Step 1: remove local flow effects from measurements
  to produce a "regional" Wind Atlas
- Step 2: reapply local flow effects at WTG positions

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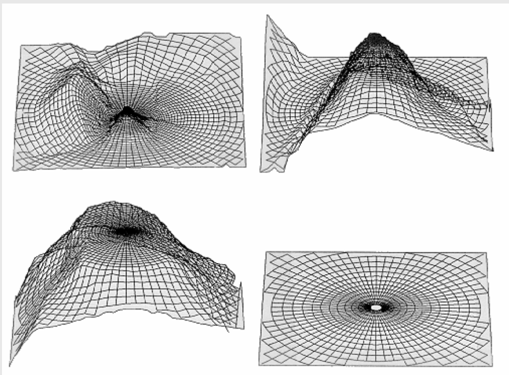
Micro scale models (WAsP)

The WAsP model - Terrain

- **Grid:** Mast/WTG centered cylindrical zooming grid
- Solves terrain as perturbation to a flat reference state
- Terrain corrections valid for neutral stability



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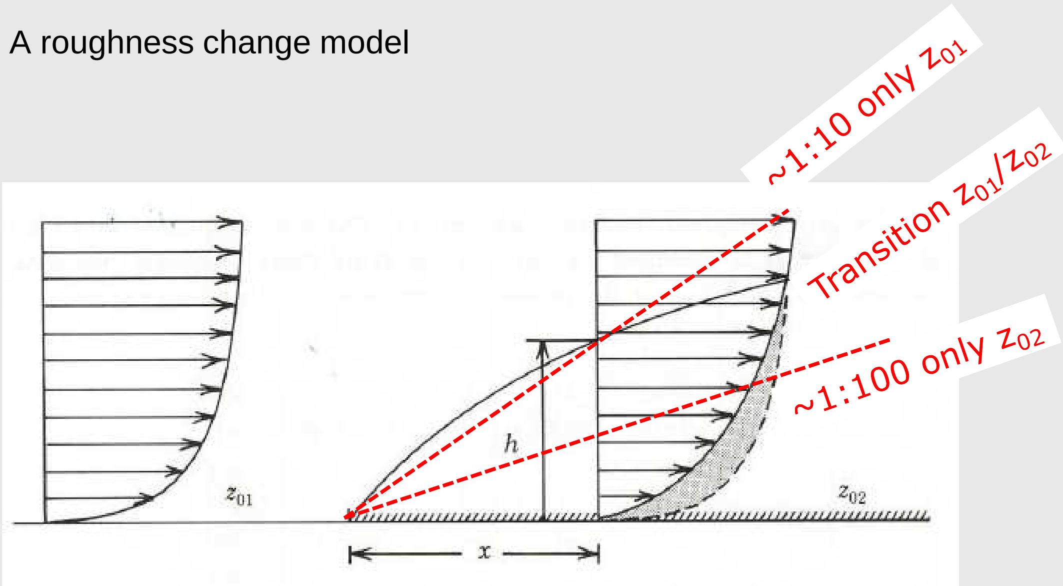
Micro scale models (WAsP)

The WAsP model - Roughness

- A roughness change model



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Micro scale models (WAsP)

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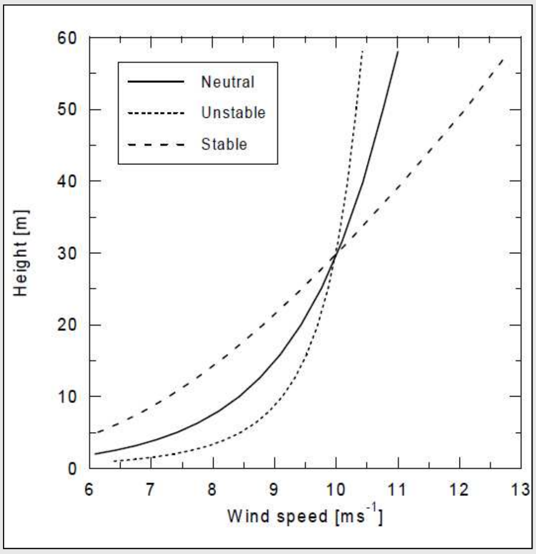
The WAsP model - Stability

- A simple correction of the neutral profile (limitations!!)
- Setup via WAsP parameters
- Based on surface heat flux:
  - For land (z_0>0) and sea (z_0=0)
  - "Offset" = mean
  - "RMS" = variation around mean

  - Heat flux > 0: Unstable
  - Heat flux < 0: Stable
  - Heat flux = 0: Neutral



Micro scale models (WEng)

The WAsP Engineering model - General description

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Micro scale models (WEng)

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The WAsP Engineering model - General description

Separated handling of:

- Terrain (grid)
- Roughness (grid)
- Turbulence (point!)
- No stability = Neutral flow !!!

WEng flow = single flow cases!!

Micro scale models (WEng)

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The WAsP Engineering model - General description

Separated handling of:

- Terrain (grid)
- Roughness (grid)
- Turbulence (point!)
- No stability = Neutral flow !!!

WEng flow = Simple log-profile (flat, uniform roughness)
+Terrain corr. (neutral)
+Roughness corr. (neutral)
+Turbulence (neutral)

Micro scale models (WEng)

The WEng model - General description

(WAsP Engineering = WEng)

A linearized “top-down” model to predict:

- Flow at high wind speeds (neutral)
- Inclination, shear, turbulence

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Micro scale models (WEng)

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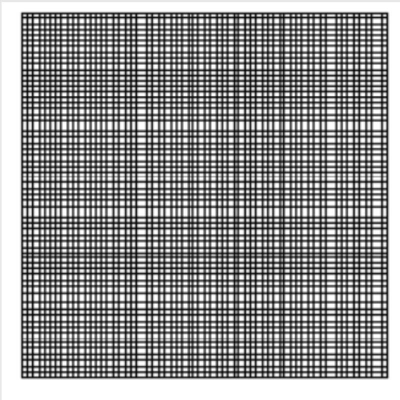
The WEng model - Terrain/Roughness

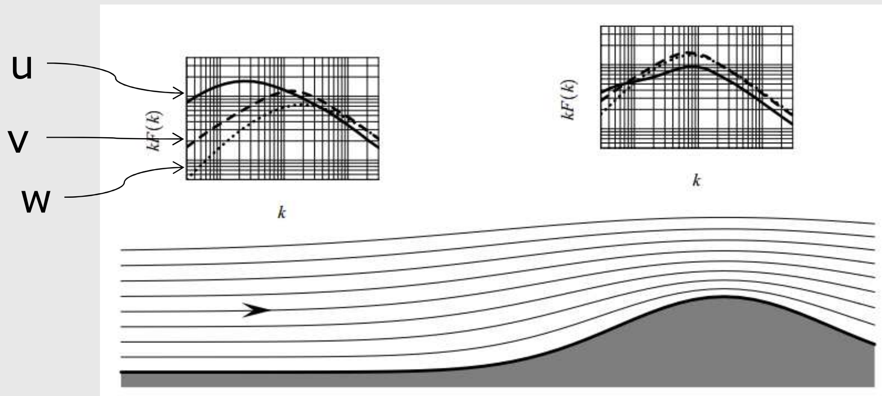
- **Grid:** regular orthogonal
- Speed-ups solved for whole grid
- Uses Charnocks relation off-shore
  - Speed/fetch dependent roughness



Micro scale models (WEng)

The WEng model - Turbulence

- Mann + Rapid-distortion model (both neutral)
  - Shear (mainly roughness) generates the turbulence
  - Terrain re-distributes among the turbulence spectra
- Solved per WTG, NOT on grid = time consuming!



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Micro scale models (CFD)

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Non-linear models (CFD)

- Solves the non-linear Navier-Stokes equations
  - On a detailed grid covering the site area
    - Iterative solution of the differential equations
    - Very time consuming
  - Often the result is grid-dependent (☹)
    - But this is not easily checked in current CFD softwares
    - Indicated by the huge spread in DEWI's CFD round robin test*
- Simplified handling of sub-grid scales (Turbulence)
  - Parameterization needed to "close" the set of equations
  - Hence referred to as "turbulence closure"
  - Common model employed is:
    - K-epsilon with various variations

* F. Durante, V. Riedel, 2008, Round Robin Numerical simulation in Wind energy – Final Report, DEWI GmbH.

Meso scale models

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Meso scale models - not just flow models…

- Numerical Weather Prediction (NWP) – hindcast/ forecast
- Based on a physical atmosphere model w/ transport equations e.g.:
  - Momentum
  - Moisture
  - Heat
- Forcings are imposed as input from synoptic models
- Often several representative runs must be made
  (not just an average run like for WAsP)
- Out-put samples may be hourly (like Merra), but..
  - A coarse grid (~ 50km) equivalates 4-5h temporal averaging
  - No “micro scale” effects are properly modelled!

Meso scale models

Some well known Meso scale models:

WRF (NMM or ARW)
KAMM (Karlsruhe)
MM5 (mainly NCAR)
…

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Atmospheric stability?

Stability depends on dT/dZ:

- dT/dZ > adiabatic:
  ~ Heating from the ground
  Typical: day, summer, cumulus

- dT/dZ < adiabatic:
  ~ Cooling from the ground
  Typical: night, winter, low wind

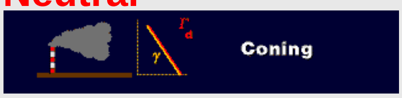
- dT/dZ = adiabatic:
  Adiabatic lapse rate ≈ 1°C/100m
  Typical: overcast, high wind

Chimney Plume Dispersion

Unstable

Stable

Neutral



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Atmospheric stability?

Stability depends on dT/dZ:

- dT/dZ > adiabatic: **Unstable**

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  Typical: day, summer, cumulus

- dT/dZ < adiabatic: **Stable**

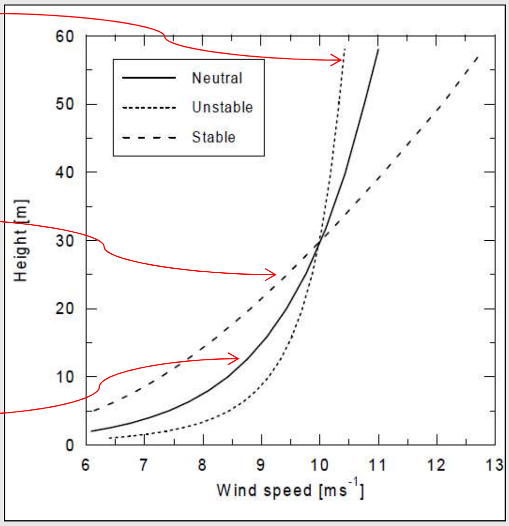
  ~ Cooling from the ground

  Typical: night, winter, low wind

- dT/dZ = adiabatic: **Neutral**

  Adiabatic lapse rate ≈ 1°C/100m

  Typical: overcast, high wind



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WindPRO and Flow models?

Now (2.8):

- Direct link to WAsP (PARK, STATGEN….)
- Direct link to WEng (in SITE COMPLIANCE)

Future (2.9):

- Direct link to WAsP-CFD model “in the sky”
- Facilitate use of hi-res Meso scale data

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