`comspec` a program for calculation of turbulence statistics in complex terrain

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1 Introduction

The program `comspec` calculates variances, spectra or cross-spectra of wind fluctuations in flat or complex terrain. For flat terrain the input is simple parameters such as the mean wind speed U, the roughness length z_0 and the height above the terrain z. In the case of complex terrain the input is files describing the upwind mean flow on a line starting at the point of interest. These files are produced by the mean flow calculation program LINCOM. Additional input regarding the preferred standard spectrum of the user is also needed as described below in section 2. All inputs are given in a file, and the name of this file is given as command line argument to the program `comspec`.

A 'sister' program `windsimu`, which uses similar input and simulates fields of wind fluctuations, will be described elsewhere.

The program is written in C++, but is basically C and uses only a few C++ features. It has been compiled with the Microsoft Visual C++ 5.0.

2 Input parameters

The first line in the input file is a word describing the general situation. It can either be `basic`, `sea`, `land`, or `terrain`. The following table gives the additional input in each of the four cases:

	Description
`basic`	The parameters $\alpha\varepsilon^{2/3}$, L and Γ, which describes the three-dimensional spectrum (the so-called spectral tensor) for flat terrain, are given directly. This is only valuable if the parameters for some reason are know in advance, or if isotropic ($\Gamma = 0$) statistics is wanted.
`sea`	Open sea. Mean wind speed U, the height above the sea surface z, and the spectrum type (see below) are given.
`land`	Flat, homogeneous land. Mean wind speed U, the height above the surface z, the roughness length z_0, and the spectrum type are given.
`terrain`	Complex terrain. The name of the file containing output from LINCOM is given. The output from LINCOM is the flow characteristics along an upstream line. The next input is an integer specifying the height of interest in the LINCOM file. If there is only one this number should be 1. Thereafter two booleans are given (either `True` or `False`) determining whether the roughness perturbations and the orography perturbations have to be taken into account. The spectrum type is finally given.

The spectrum type mentioned above refers to the users preferred spectral shapes for flat terrain. These are

Spectrum type	Description
0	Kaimal, Wyngaard, Izumi and Coté's (1972) spectra.
1	Spectra from Simiu and Scanlan (1996).
2	Spectra from the standard organization ESDU, which for the u-spectrum is identical to the Danish standard DS410:1998

This table may at a later point in time also include the spectra from other standards.

3 Specification of the needed output

Now that we have specified the basic input parameters, we shall specify what we would like as output. The program gives three possibilities: `spec`, `xspec`, or `sigma2`, of which *one* has to be chosen:

	Description
`spec`	One point spectra.
`xspec`	Cross-spectra of wind fluctuations at different points.
`sigma2`	Variances or co-variances.

After one of these has been chosen we firstly specify all combinations of velocity components that we want. Secondly, if spectra or cross-spectra are wanted we have to specify the lowest wavenumber $k_{1,\min}$, the highest $k_{1,\max}$, and the logarithmic increment between the wavenumbers, where the spectra are calculated. Finally, if cross-spectra are calculated a transversal separation Δy and a vertical separation Δz have to be given. All this will be clarified by the examples below.

4 Examples of input and output

4.1 Example 1

A user would like to know the turbulence intensities $I_u = \sigma_u/U$, σ_v/U, and σ_w/U at $z = 70$ m over water at a mean wind speed of $U = 30$ m/s. He would like to compare all three spectrum types. He uses the input file

`sea`	*Sea far away from land*
`30`	*Mean wind speed U*
`70`	*Height above the sea z*
`0`	*Spectrum type*
`sigma2`	*Wanted output is variance*
`3`	*Three variances are calculated as specified below*
`1 1`	u
`2 2`	v
`3 3`	w

and two more with spectrum type 1 and 2, respectively (input files: `spcEx1a.inp, spcEx1b.inp, spcEx1c.inp`), . The reason for the duplicate numbers in the last three lines is that the program is capable of calculating the in load calculations rarely used covariances, e.g. $\langle uw \rangle$, which would have to be specified as `1 3`. The output (sent to stdout) is

```
6.3419
3.23514
1.73254
```

To present the variances as turbulence intensities the WAsP Engineering shell should take the square root and divide by the mean wind speed U. The result is

	Spectrum type		
	0	1	2
I_u	0.084	0.086	0.103
I_v	0.060	0.062	0.070
I_w	0.044	0.046	0.048

4.2 Example 2

Calculate the u-spectrum at a site with complex roughness distribution with the wind coming from the North. The area used here is the south tip of Falster (Gedser) which is described in Mann (1999)

The input file is (`spcEx2.inp`)

`terrain`	*Complex terrain calculation*
`P_01_000.dat`	*LINCOM output file*
`1`	*Use first height level in the LINCOM file*
`False`	*Effects of orography are not taken into account,*
`True`	*but effect of roughness changes are.*
`0`	*Spectrum type*
`spec`	*One-point spectra are calculated*
`1`	*One spectrum*
`1 1`	*and it is the u-spectrum*
`0.001`	*between $k_{1,\min}$*
`1.0001`	*and $k_{1,\max}$*
`0.2`	*with steps in the $\log_{10}$ of k_1 of 0.2.*

The output is

```
11.66
0.001   559.622
0.00158489   480.077
0.00251189   380.181
0.00398107   275.573
0.00630958   182.799
0.01   111.593
0.0158489   63.0693
0.0251189   33.1884
0.0398108   16.495
0.0630958   7.93773
0.1   3.76579
0.158489   1.77126
0.251189   0.827268
0.398108   0.384591
0.630958   0.178222
1   0.0824754
```

where the first line is the mean wind speed at the point of interest and the following lines are k_1 and $F_u(k_1)$.

4.3 Example 3

Calculate the u-coherence at a site with complex roughness distribution with the wind coming from the North with a purely transversal (horizontal) separation of 30 m

The input file is (`spcEx3.inp`)

`terrain`	*Complex terrain calculation*
`P_01_000.dat`	*LINCOM output file*
`1`	*The first (and only) height in the LINCOM file.*
`False`	*Effects of orography are not taken into account,*
`True`	*but effect of roughness changes are.*
`0`	*Spectrum type*
`xspec`	*Cross-spectra are calculated*
`1`	*One cross-spectrum*
`1 1`	*and it is the u-spectrum*
`0.001 1.0001 0.2`	*Range and $\log_{10}$-step of k_1.*
`30`	*Transversal separation, Δy.*
`0`	*Vertical separation, Δz.*

The output is

```
11.66
0.001   559.636 559.636 459.515 2.47319e-005
0.00158489   480.072 480.072 378.444 -2.13489e-005
0.00251189   380.172 380.172 278.741 9.94056e-006
0.00398107   275.559 275.559 178.072 3.85885e-006
0.00630958   182.793 182.793 94.6485 2.35068e-006
0.01   111.128 111.128 37.9158 -2.41613e-006
0.0158489   63.0613 63.0613 8.50936 2.27487e-007
0.0251189   33.1818 33.1818 -2.18252 -1.27923e-007
0.0398108   16.4875 16.4875 -2.91517 2.08628e-008
0.0630958   7.93433 7.93433 -1.09757 -1.16915e-008
0.1   3.7646 3.7646 -0.116092 -3.97171e-010
0.158489   1.77093 1.77093 0.0218013 1.44123e-010
0.251189   0.827026 0.827026 0.0033104 2.26013e-010
0.398108   0.384393 0.384393 5.58438e-005 3.132e-012
0.630958   0.17815 0.17815 3.29385e-007 -3.52755e-013
1   0.0824303 0.0824303 -1.1622e-007 -2.74871e-013
```

where the first line is the mean wind speed at the point of interest and the following lines are k_1, the spectra at the two points (F_u for both points in this case) and the real, $\Re(\chi)$, and imaginary value, $\Im(\chi)$, of the cross-spectrum.

The squared coherence is now calculated as

$$\mathrm{coh}_{uu}(k_1) = \frac{\Re^2(\chi) + \Im^2(\chi)}{F_u F_u} \tag{1}$$

5 Source and additional input files

`adapint.cpp`	Adaptive integration of a function of one variable.
`adapint2.cpp`	Adaptive integration of a function of two variables.
`comspec.cpp`	Main file handling input and output.
`nrutilex.c`	Extended version of `nrutil.c` from Numerical Recipes
`specint.cpp`	Various functions for the integration of the spectral tensor to obtain variances, spectra, cross-spectra etc.
`ten.cpp`	Functions for allocation and de-allocation of arrays of vectors etc.
`tenbasic.cpp`	The flat terrain spectral tensor and a function to get the tensor parameters from the mean wind speed, height above ground and roughness for the different spectrum types. Also simple matrix transformations such as the square root, simple strain distortion etc.
`tencompl.cpp`	Reading of the LINCOM file and calculation of the theoretical distortions of the flat terrain tensor.
`ten.h`	Header file defining various classes, constants and functions.
`nr.h`	Header file for the Numerical Recipes library.
`nrutilex.h`	Header file for `nrutilex.c`
`nr.lib`	The Numerical Recipes library (Press, Flannery, Teukolsky and Vetterling 1992).
`tenparam.bin`	Binary file containing a lookup table of tensor parameters. In the file `tenbasic.cpp` it is used assuming it is at the fixed position `c:/users/mann/Wasp Engng/ten/tenparam.bin` or in the current directory. This has to be changed.
`comspec.exe`	The executable

These files and the example input files are all available via anonymous ftp to met-hp-2.risoe.dk in the directory `dist/sofus`

References

Kaimal, J. C., Wyngaard, J. C., Izumi, Y. and Coté, O. R.: 1972, Spectral charcteristics of surface-layer turbulence, *Q. J. R. Meteorol. Soc.* **98**, 563–589.

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Press, W. H., Flannery, B. P., Teukolsky, S. A. and Vetterling, W. T.: 1992, *Numerical Recipes*, 2nd edn, Cambridge University Press.

Simiu, E. and Scanlan, R. H.: 1996, *Wind Effects on Structures, 3. ed.*, John Wiley & Sons.