Computation of day-time atmospheric turbulent diffusivity over complex terrain

Summary

A method for the calculation of atmospheric turbulent diffusivity over complex terrain during day-time has been developed. The model is intended for use in diagnostic meteorological models that use heat flux at ground level for the estimate of the parameters characterizing atmospheric turbulence. Calculation is carried out using geographic position and time of the day, but also orographic factor, which is often neglected. Indeed, shadowing is generated from mountain profiles produce an effect on the heating of the air mass along the valley floor, which may be substantially different from the case of flat uniform terrain. The proposed model takes into account the geographic location of the area (latitude and longitude), the time of the day, the inclination of the surface and its exposition, the soil type, the cloud coverage. The surface energy balance is closed using different well known formulations in terms of local values of parameters (e.g. Holtslag and Van Ulden, 1983). The model also takes into account the variability of albedo coefficient with the inclination of solar beams upon day hours.

Procedure

Input data
- Digital elevation model (DEM) of the area
- Land use categories or reflection coefficients, if available
- Cloud cover (fraction of covered sky)
- Global Radiation [W/m²] at ground level measured by one or more weather stations (easy for calibration).

Output data (on the whole domain)
- Global Radiation [W/m²]
- Sensible heat flux [W/m²]
- Vertical diffusivity coefficient at a reference height z [m²/s]

Formulation

1. Calculation of extraterrestrial irradiance [1]

\[ E = S_{0} \cdot \sin(\theta) \]

\[ E = \frac{S_{0}}{1 + 0.0407 \sin(\frac{2 \pi}{365} \cdot (d - 80.5))} \]

2. Calculation of global solar radiation at ground level [5]

\[ Q_{g} = E \cdot T_{r} \]

\[ Q_{g} = \frac{S_{0}}{1 + \sin(\theta) - \frac{0.0407 \cdot \sin(\frac{2 \pi}{365} \cdot (d - 80.5))}{1 + \sin(\theta)} \]

3. Correction of solar radiation with exposure to the sun; if a point is shadowed, a null value is assigned to \( Q_{g} \), for that location

\[ Q'_{g} = Q_{g} \cdot \sin(\theta) \]

4. Correction of the albedo with solar inclination angle [7]

\[ a' = a + (1 - a) \cdot \exp(-0.15 \cdot 0.5 \cdot (1 - a)) \]

5. Calculation of global net radiation at ground level [3]

\[ Q_{n} = (1 - a) \cdot Q_{g} + c_{T} \cdot T_{r} \cdot I_{n} + c_{N} \]


\[ Q_{h} = \frac{B}{1 + B} \cdot Q_{g} - a' \]

7. Iterative calculation of stability parameters [3]

\[ L = \frac{\rho_{g} \cdot c_{p} \cdot T_{r} \cdot I_{n}}{g \cdot \frac{Q_{h}}{c_{p}}} \]

\[ u_{*} = \left( \frac{\rho_{g} \cdot c_{p} \cdot T_{r} \cdot I_{n}}{g \cdot \frac{Q_{h}}{c_{p}}} \right)^{1/3} \]


\[ K(z) = \frac{k_{0} + z^{2} \cdot \rho_{g} \cdot c_{p} \cdot T_{r} \cdot I_{n}}{\left( \frac{\rho_{g} \cdot c_{p} \cdot T_{r} \cdot I_{n}}{g \cdot \frac{Q_{h}}{c_{p}}} \right)^{1/3} \cdot \frac{Q_{h}}{c_{p}}} \]

A case study: the Adige Valley (Italy)

Average latitude of the domain: 46° N
Average longitude of the domain: 11° E
Dimension: 10 x 10 km
Cell resolution for computation: 100 m

Model calibration

Comparison with radiometers’ data

The calibration of the model was carried out by determining the parameters of equation (3) for the transmissivity of atmosphere. The best fitting values where \( a_{1}=0.59 \), \( a_{2}=0.20 \), \( a_{3}=0.47 \), which are very similar to the ones found in literature [1, 6].
Results (application to the Adige Valley)

We can observe that the major differences due to the introduction of the complex terrain module mostly occur at morning and in late afternoon. The proposed procedure can lead to an improvement of diagnostic meteorological models and dispersion models: in fact the presence of shadowed and not shadowed zones determines local convective circulations and modifies the local energy balance of the air above the valley floor and lead to turbulent diffusivities which may attain values up to 3-4 times larger at ground level.

Bibliography