The surface

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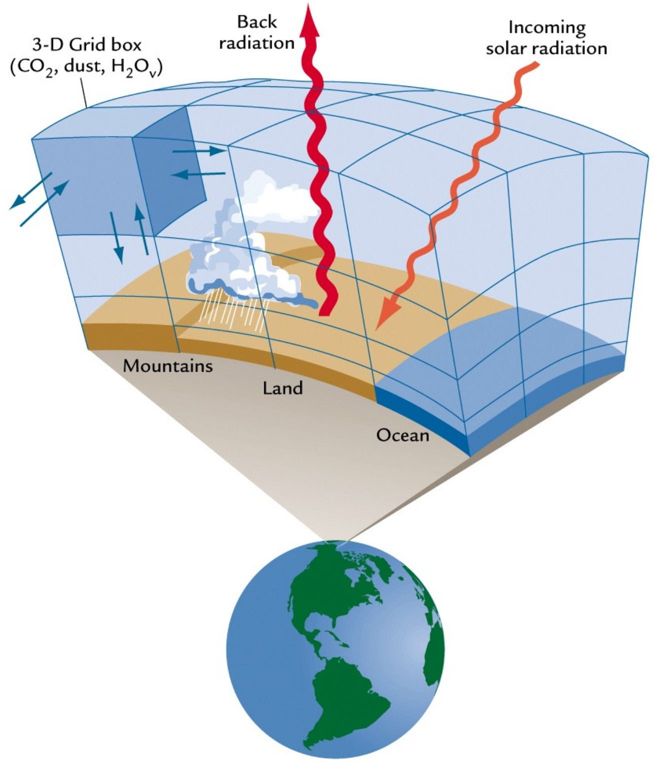
Outline

- The problem
- Physical basis
- The surface subroutine in the UCLALES
- Future development

Why caring about the surface ?

From a very pragmatic point of view:

Need to know the conditions at the bottom boundary to be able to integrate the relevant equations



Why caring about the surface ?

From a less pragmatic point of view:

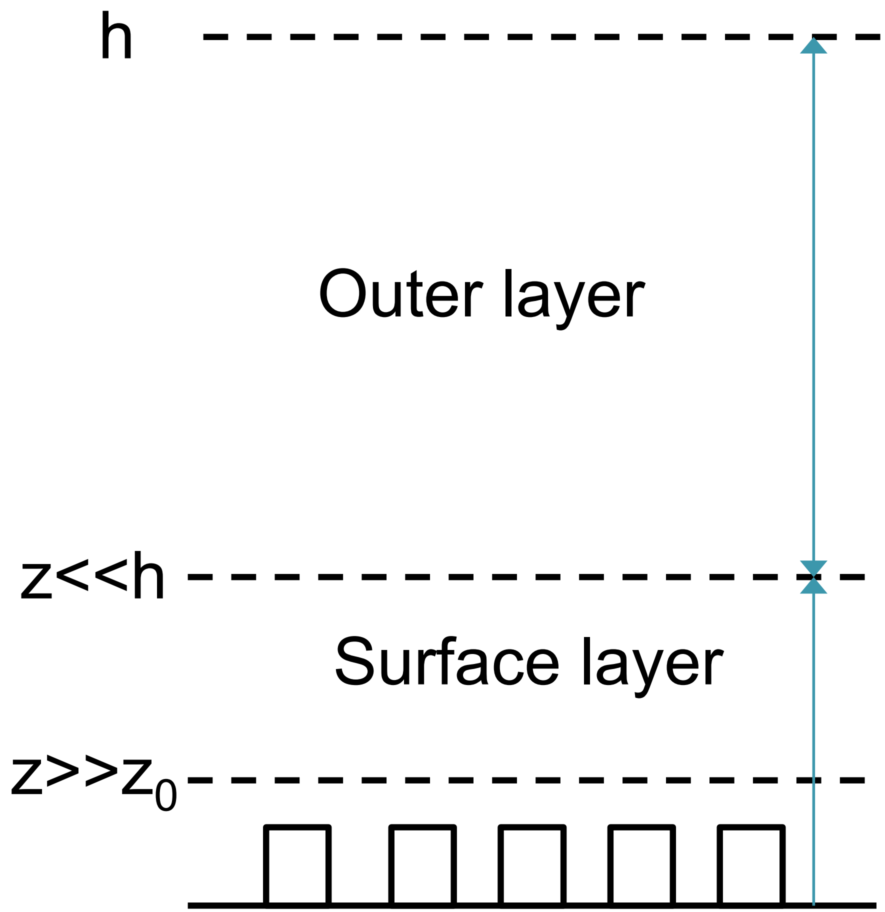
Surface influences the structure and evolution of the planetary boundary layer

- Friction: momentum flux: slows down wind
- Solar absorption: sensible heat flux: warms/cools overlying air
- Solar absorption: latent heat flux: water source for precipitation
- Introduces diurnal cycle

Partitions available energy between sensible and latent heat fluxes

Physical basis

The atmospheric boundary layer, J.R. Garratt



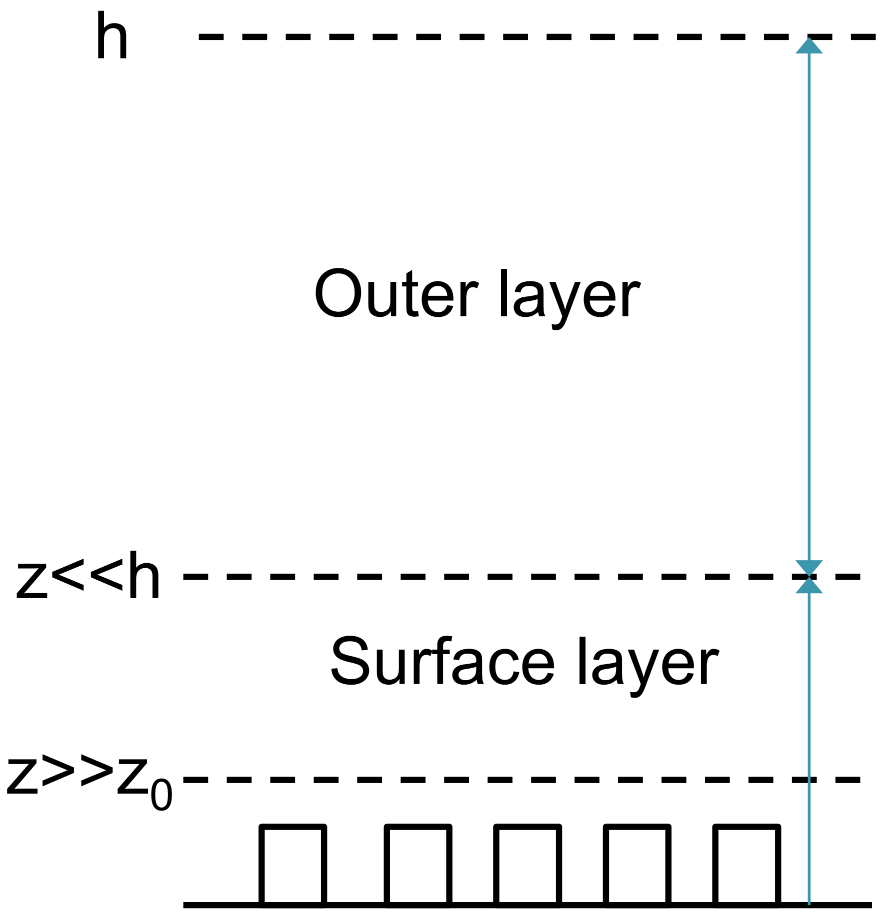
Physical basis

The atmospheric boundary layer, J.R. Garratt

Flow in the PBL is turbulent

$$\chi = \bar{\chi} + \chi'$$

$$\frac{\partial \bar{u}}{\partial t} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial z} + f\bar{v} - \frac{\partial \overline{u'w'}}{\partial z}$$



Variables to be determined

Surface stress in x	$\tau_{x0} = -\rho\overline{u'w'}_0$
Surface stress in y	$\tau_{y0} = -\rho\overline{v'w'}_0$
Surface sensible heat flux	$H_0 = \rho c_p \overline{w'\theta'}_0$
Surface buoyancy flux	$H_{v0} = \rho c_p \overline{w'\theta'_{v0}}$
Surface latent heat flux	$LE_0 = \rho L_v \overline{w'q'}_0$

How do we compute the fluxes?

Use of surface similarity theory:

- Only valid for the surface layer $z_0 < z << h$ where fluxes remain constant
- Isolate the relevant scales that can fully characterize the flow in the surface layer
- Arrange them in dimensionless group to form appropriate relationships
- Use data for fitting

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In general: determine e.g. appropriate velocity and length scales to scale the wind profile to derive not only the wind profile law but also to use this to formulate a suitable drag law

Characteristic scales

Friction velocity	$u_{*0}^2 = \sqrt{(\overline{u'w'}_0)^2 + (\overline{v'w'}_0)^2} = -\overline{u'w'}_0$
Temperature scale	$\theta_{*0} = \dfrac{-\overline{w'\theta'}_0}{u_{*0}}$
Temperature scale	$\theta_{v*0} = \dfrac{-\overline{w'\theta'_{v}}_{0}}{u_{*0}}$
Humidity scale	$q_{*0} = \dfrac{-\overline{w'q'}_0}{u_{*0}}$
Obukov stability length	$L = \dfrac{u_{*0}^2\overline{\theta_v}}{kg\theta_{v*0}}$

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Relations: First-order closure

Assume neutral and homogeneous atmosphere:

$$\overline{u'w'}_0 = -K_M \frac{\partial \bar{u}}{\partial z}$$

$$K_M \sim kzu_{*0} \qquad\qquad k = 0.4$$

$$\overline{u'w'}_0 = -u_{*0}^2$$

$$\frac{kz}{u_{*0}} \frac{\partial \bar{u}}{\partial z} = 1$$

Integrate:

$$\frac{k\bar{u}}{u_{*0}} = \ln \frac{z}{z_0}$$

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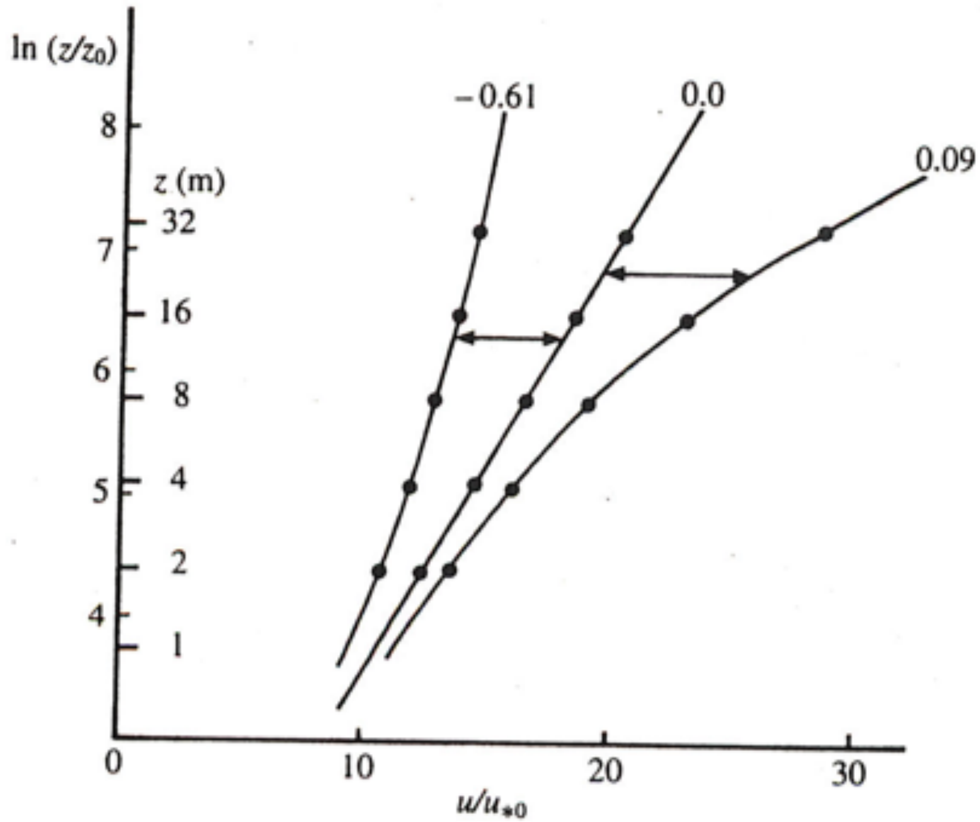

Relations: First-order closure

In general:

$$\overline{u'w'}_0 = -u_{*0}^2 = -K_M \frac{\partial \bar{u}}{\partial z}$$

$$\frac{kz}{u_{*0}} \frac{\partial \bar{u}}{\partial z} = \Phi_M(\zeta) \quad \zeta = z/L$$

Integrate:

$$\frac{k\bar{u}}{u_{*0}} = \ln(\frac{z}{z_0}) - \int (1 - \Phi_M(\zeta'))\mathrm{d}(\ln\zeta')$$

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$$\overline{w'\theta'_v}_0 = -u_{*0}\theta_{v*0} = -K_H \frac{\partial \bar{\theta}_v}{\partial z}$$

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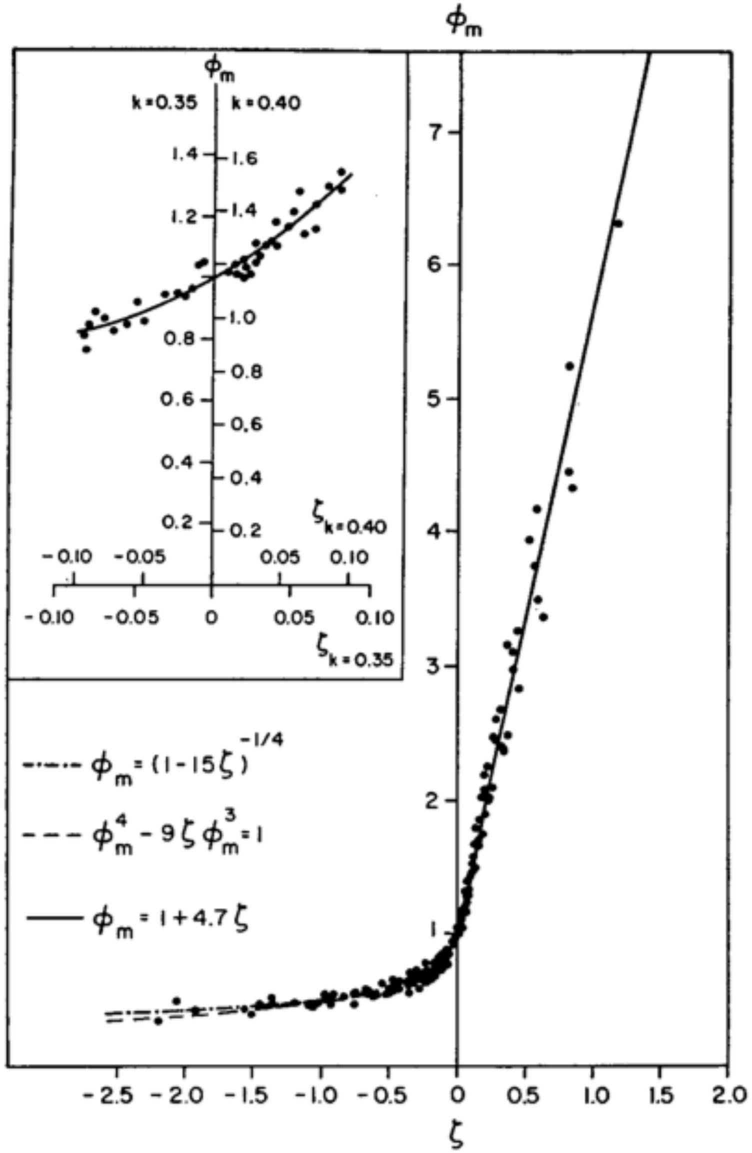
$$\frac{k(\bar{\theta}_v - \bar{\theta}_{v0})}{\theta_{v*0}} = \ln(\frac{z}{z_T}) - \int (1 - \Phi_H(\zeta'))\mathrm{d}(\ln\zeta')$$

$$\frac{k(\bar{\theta}_v - \bar{\theta}_{v0})}{\theta_{v*0}} = \ln(\frac{z}{z_T}) - \Psi_H(\zeta)$$

Form of the functions



Businger et al. (1971)

Form of the functions

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Following Garrat:

$$\zeta < 0 : \; \Phi_M(\zeta) = (1 - 16\zeta)^{-1/4}$$
$$\zeta > 0 : \; \Phi_M(\zeta) = (1 + 5\zeta)$$
$$\zeta < 0 : \; \Psi_M(\zeta) = 2\ln(\frac{1+x}{2}) + \ln(\frac{1+x^2}{2}) - 2\tan^{-1}(x) + \pi/2, \; x = (1 - 16\zeta)^{1/4}$$
$$\zeta > 0 : \; \Psi_M(\zeta) = -5\zeta$$

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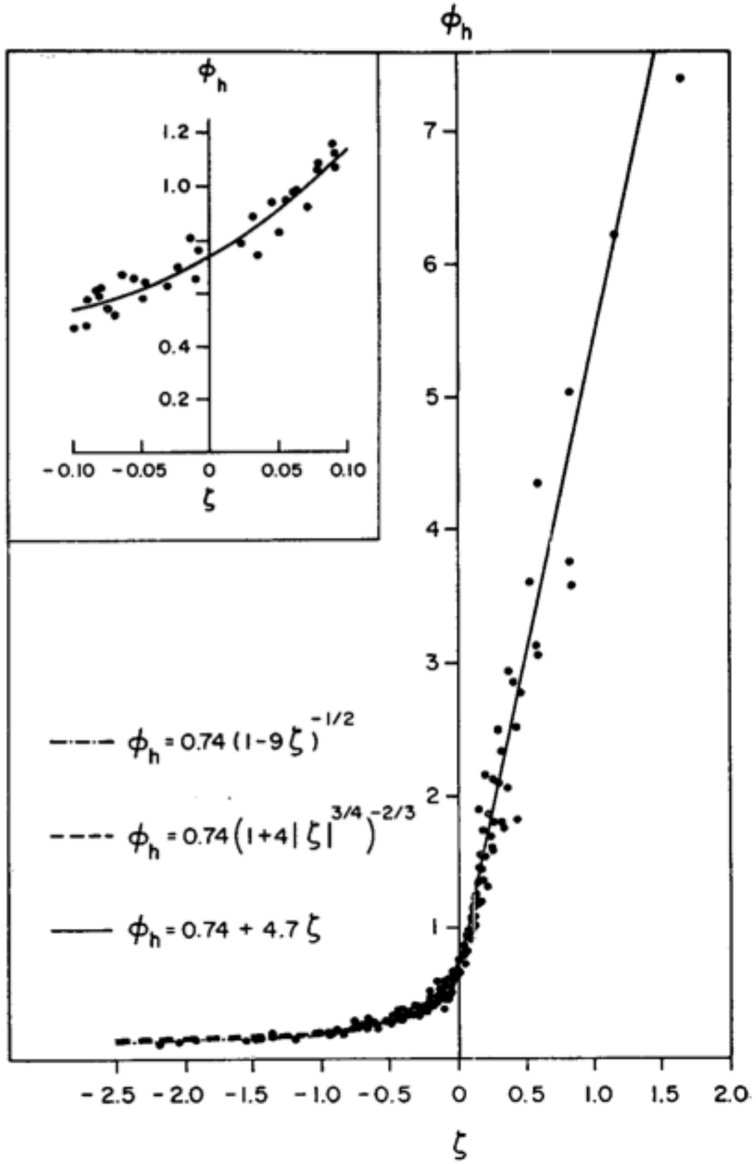

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Form of the functions

$$\frac{kz}{\theta_{v*0}}\frac{\partial\bar{\theta}_v}{\partial z} = \Phi_H(\zeta)$$

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Alternative: bulk transfer relations

$$\overline{u'w'}_0 = -u_{*0}^2 = -K_M \frac{\partial \bar{u}}{\partial z}$$

$$\frac{k\bar{u}}{u_{*0}} = \ln(\frac{z}{z_0}) - \Psi_M(\zeta)$$

$$\overline{w'\theta'_v}_0 = -u_{*0}\theta_{v*0} = -K_H \frac{\partial \bar{\theta}_v}{\partial z}$$

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$$\overline{u'w'}_0 = -u_{*0}^2 = -C_D \bar{u}^2$$

$$\overline{w'\theta'_v}_0 = -u_{*0}\theta_{v*0} = -C_H \bar{u}(\bar{\theta}_v - \bar{\theta}_{v0})$$

$$C_D = \frac{k^2}{(\ln(\frac{z}{z_0}) - \Psi_M(\zeta))^2} \qquad C_H = \frac{k^2}{(\ln(\frac{z}{z_0}) - \Psi_M(\zeta))(\ln(\frac{z}{z_T}) - \Psi_H(\zeta))}$$

Alternative: aerodynamic resistance

$$\overline{u'w'}_0 = -u_{*0}^2 = -K_M \frac{\partial \bar{u}}{\partial z}$$

$$\frac{k\bar{u}}{u_{*0}} = \ln(\frac{z}{z_0}) - \Psi_M(\zeta)$$

$$\overline{w'\theta'_v}_0 = -u_{*0}\theta_{v*0} = -K_H \frac{\partial \bar{\theta}_v}{\partial z}$$

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$$\overline{u'w'}_0 = \frac{-\bar{u}}{r_{aM}}$$

$$r_{aM} = \frac{1}{C_D \bar{u}}$$

$$\overline{w'\theta'_v}_0 = \frac{\bar{\theta}_{v0} - \bar{\theta}_v}{r_{aH}}$$

$$r_{aH} = \frac{1}{C_H \bar{u}}$$

The surface subroutine in UCLALES

- Case default:

  sensible and latent heat fluxes prescribed,

  moment fluxes diagnosed from $\frac{k\bar{u}}{u_{*0}} = \ln(\frac{z}{z_0}) - \Psi_M(\zeta)$

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  gradient in temperature and moisture prescribed,

  sensible and latent heat fluxes from $\frac{k(\bar{\theta}_v - \bar{\theta}_{v0})}{\theta_{v*0}} = \ln(\frac{z}{z_T}) - \Psi_H(\zeta)$

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- Case 2:

  surface temperature and moisture prescribed

  sensible and latent heat fluxes from $\frac{k(\bar{\theta}_v - \bar{\theta}_{v0})}{\theta_{v*0}} = \ln(\frac{z}{z_T}) - \Psi_H(\zeta)$

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  momentum fluxes from $\frac{k\bar{u}}{u_{*0}} = \ln(\frac{z}{z_0}) - \Psi_M(\zeta)$

- Case 3:

  C_D, C_H, surface temperature and moisture prescribed

  sensible and latent heat fluxes from $u_{*0}\theta_{v*0} = C_H\bar{u}(\bar{\theta}_v - \bar{\theta}_{v0})$

  momentum fluxes from $u_{*0}^2 = C_D\bar{u}^2$

The surface subroutine in UCLALES

- Case 4:

  Buoyancy flux prescribed

  moment fluxes diagnosed from $\frac{k\bar{u}}{u_{*0}} = \ln(\frac{z}{z_0}) - \Psi_M(\zeta)$

To note:

- Need to know z_0 and z_T . Currently z_0=z_T =zrough. If zrough sets to a value smaller or equal to zero, then

  $$z_0 = \frac{0.016}{g} u_{*0}^2$$ true for ocean

- Cases 2, 3 and 4 assume to be over the ocean, i.e. q_o=q_{sat}(SST)
- First point should be in the surface layer but higher than z_0

Namelist options with the cases

	isfctyp	dthcon	drtcon	zrough	sst
Default	0	Sensible heat flux Wm^{-2}	Latent heat flux Wm^{-2}	Roughness length	Not needed
Case 1	1	Temperature gradient $K\ m^{-1}$	Moisture gradient $kg\ kg^{-1}\ m^{-1}$	Roughness length	Not needed
Case 2	2	Not needed	Not needed	Roughness length	Sea surface temperature
Case 3	3	C_H	C_q	C_D	Sea surface temperature
Case 4	4	Buoyancy flux Wm^{-2}	Not needed	Roughness length	Sea surface temperature

Future development

At the moment, we cannot compute the fluxes interactively for land points

- Latent heat flux is the sum of evaporation and transpiration. Evaporation and transpiration are computed according to:

$$\frac{\rho L_v}{r_{aH} + r_s}(q_{sat}(\bar{T}_0) - \bar{q})$$

- A land surface model provides surface and vegetation resistances as well as surface temperature