High resolution Planetary Boundary Layer Parameterization (MM5 Blackadar Scheme)

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ATMO 595E

December 7, 2004

Outline

- The concept of the parameterization scheme
- Model Input/Output
- Model Description
- Sensitivity Analysis

Basic Concept (Blackadar PBL scheme)

- Two modules

  Stable/nocturnal module

  K-theory (first order turbulence closure)

  Unstabel/Free-convection module

  Convective plume model

Vertical Structure of the PBL model

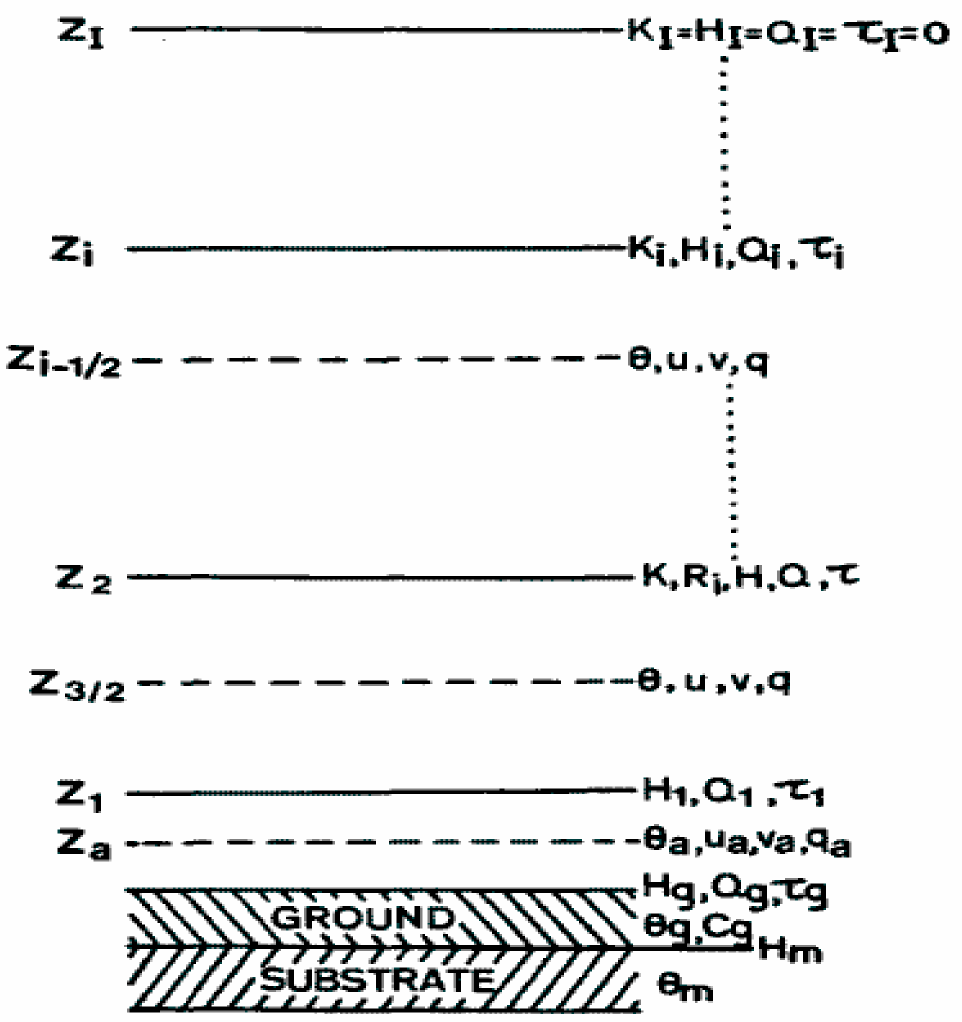

FIG. 1. Vertical structure of the PBL model.

Model Input Variables

- !-- U3D 3D u-velocity interpolated to theta points (m/s)
- !-- V3D 3D v-velocity interpolated to theta points (m/s)
- !-- T3D temperature (K)
- !-- QV3D 3D water vapor mixing ratio (Kg/Kg)
- !-- QC3D 3D cloud mixing ratio (Kg/Kg)
- !-- QI3D 3D ice mixing ratio (Kg/Kg)
- !-- PP3D 3D pressure (?cb)
- !-- ZNT roughness length (m)
- !-- UST u* in similarity theory (m/s)
- !-- ZOL z/L height over Monin-Obukhov length
- !-- HOL PBL height over Monin-Obukhov length
- !-- PBL PBL height (m)

Model Input Variables (cont'd)

- !-- REGIME flag indicating PBL regime (stable, unstable, etc.)
- !-- PSIM similarity stability function for momentum
- !-- PSIH similarity stability function for heat
- !-- XLAND land mask (1 for land, 2 for water)
- !-- HFX upward heat flux at the surface (W/m^2)
- !-- QFX upward moisture flux at the surface (kg/m^2/s)
- !-- TSK surface temperature (K)
- !-- GZ1OZ0 log(z/z0) where z0 is roughness length
- !-- WSPD wind speed at lowest model level (m/s)
- !-- BR bulk Richardson number in surface layer
- !-- DT time step (s)
- !-- DTMIN time step (minute)

Model Input Constants:

- !-- CP heat capacity at constant pressure for dry air (1004. J/kg/K)
- !-- G acceleration due to gravity (9.8 m s-2).
- !-- ROVCP R/CP
- !-- R gas constant for dry air (287.04 J/kg/K)
- !-- RV gas constant for water vapor (461.5 J/kg/K)
- !-- RVOVRD R_v divided by R_d (dimensionless)
- !-- ROVG R/G
- !-- SVP1 constant for saturation vapor pressure (0.6112 kPa)
- !-- SVP2 constant for saturation vapor pressure (17.67 dimensionless)
- !-- SVP3 constant for saturation vapor pressure (29.65 K)
- !-- SVPT0 constant for saturation vapor pressure (273.15 K)
- !-- EP1 constant for virtual temperature (R_v/R_d - 1) (0.608 dimensionless)
- !-- EP2 constant for specific humidity calculation (0.622)
- !-- KARMAN Von Karman constant (0.4)

Subroutine Input Constants

- C1 /0.2721655/ constant (SQRT(2/27)) used in Priestley's equation.
- C2 /-0.33333/ constant used in Priestley's equation.
- CZO /0.032/ constant used to compute roughness length over water.
- ENTRMT /0.2/ entrainment coefficient used for free convection.
- KA /2.4E-5/ background molecular diffusivity (m^2/s) used to compute latent heat flux.
- KZO /1.0/ background diffusion coefficient (m^2/s).
- Ks' /3E-3/ constant to compute heat transfer coefficient Ks
- OZO /1.0E-4/ constant (m) used to compute roughness length over water.
- SZKM /1600./ constant (m^2) used to compute the eddy diffusion coefficients.
- CKZ /0.001/

Model Output

- !-- U3DTEN 3D u-velocity tendency
- !-- V3DTEN 3D v-velocity tendency
- !-- T3DTEN temperature tendency
- !-- QV3DTEN 3D water vapor mixing ratio tendency
- !-- QC3DTEN 3D cloud m ixing ratio tendency
- !-- QI3DTEN 3D ice mixing ratio tendency
- !-- HFX upward heat flux at the surface
- !-- QFX upward moisture flux at the surface
- !-- TGB surface temperature
- !-- SCR3 temperature
- !-- SCR4 virtual temperature

Model Description

Bulk Richardson #

$$\mathrm{Rb} = \frac{g z_a}{\theta_a} \frac{(\theta_a - \theta_g)}{(V_a)^2} ,$$

(1) Rb >= 0.2 — Very stable (no turbulence)

(2) 0.2 > Rb > 0 — Damped mechanical turbulence

(3) Rb <= 0 and |z_h/L| <= 1.5 — Forced convection (marginally unstable)

(4) Rb <= 0 and |z_h/L| >1.5 — Free convection

Model Equations for Nocturnal regime:

$$\frac{\partial \theta_a}{\partial t} = [K_{h1}(\theta_{3/2} - \theta_a)/(z_{3/2} - z_a) + H_g/(\rho C_p)]/z_1 , \quad (24)$$

$$\frac{\partial q_a}{\partial t} = [K_{q1}(q_{3/2} - q_a)/(z_{3/2} - z_a) + Q_g/\rho]/z_1 , \quad (25)$$

$$\frac{\partial u_a}{\partial t} = [K_{m1}(u_{3/2} - u_a)/(z_{3/2} - z_a) - \tau_g u_a/(\rho V_a)]/z_1 + f(v_a - v_{ga}), \quad (26)$$

$$\frac{\partial v_a}{\partial t} = [K_{m1}(v_{3/2} - v_a)/(z_{3/2} - z_a) - \tau_g v_a/(\rho V_a)]/z_1 - f(u_a - u_{ga}). \quad (27)$$

Model Equations for Free convection regime

$$\frac{\partial \theta_a}{\partial t} = -(H_1 - H_g)/(\rho C_p z_1). \qquad (32)$$

$$\frac{\partial q_a}{\partial t} = [Q_g - \bar{m} \sum_{i=2}^{l} (q_a - q_{i-1/2}) \Delta z]/(\rho z_1), \qquad (42)$$

$$\frac{\partial u_a}{\partial t} = f(v_a - v_{ga}) - \left[\frac{\tau_g u_a}{\rho V_a} - \bar{m} \sum_{i=2}^{l} (u_a - u_{i-1/2}) \Delta z\right] \Big/ z_1 , \qquad (40)$$

$$\frac{\partial v_a}{\partial t} = -f(u_a - u_{ga}) - \left[\frac{\tau_g v_a}{\rho V_a} - \bar{m} \sum_{i=2}^{l} (v_a - v_{i-1/2}) \Delta z\right] \Big/ z_1 , \qquad (41)$$

Free convective module

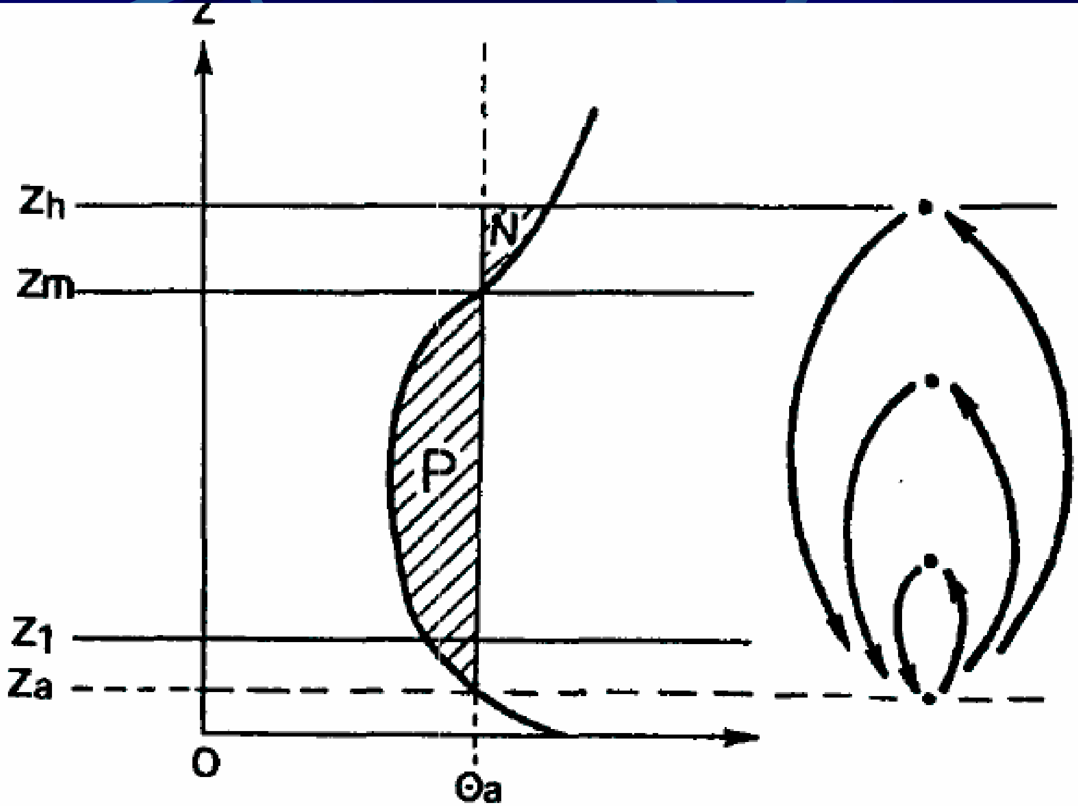

FIG. 2. Schematic diagram illustrating free convective module. Plumes originating at level z_a rise and mix at various levels, exchanging heat, moisture and momentum with air at these levels. Some thermals overshoot the level z_m of zero buoyancy. The ratio of negative area N on the thermodynamic diagram to the positive area P is the entrainment rate (see text).

Determine stability regime at each new time step

$$\frac{1}{L} = -\frac{kgH_1}{C_p\rho\theta_a u^{*3}}. \quad (43)$$

$$\psi_m = 0.0954 - 1.86(z_a/L) - 1.07(z_a/L)^2 - 0.249\left(\frac{z_a}{L}\right)^3, \quad (44)$$

$$\psi_h = 0.201 - 3.23(z_a/L) - 1.99\left(\frac{z_a}{L}\right)^2 - 0.474\left(\frac{z_a}{L}\right)^3. \quad (45)$$

Some other pure empirical equations

Slab Thermal Capacity

$$C_g = 0.95\left(\frac{\lambda C_s}{2\omega}\right)^{1/2}. \qquad (5b)$$

Priestley (1956) derived an empirical equation for the heat flux H_1:

$$H_1 = \rho C_p z_1 b(\theta_a - \theta_{3/2})^{3/2}, \qquad (30)$$

where b can be treated as a constant:

$$b = \left(\frac{2g}{27\theta_a}\right)^{1/2} \frac{1}{z_1}\left[z_1{}^{-1/3} - (2z_{3/2})^{-1/3}\right]^{-3/2}. \qquad (31)$$

Sensitivity Analysis

- Moisture availability (A_m)
- Roughness length (Z_0)
- Thermal capacity (Cg)
- Albedo (A)

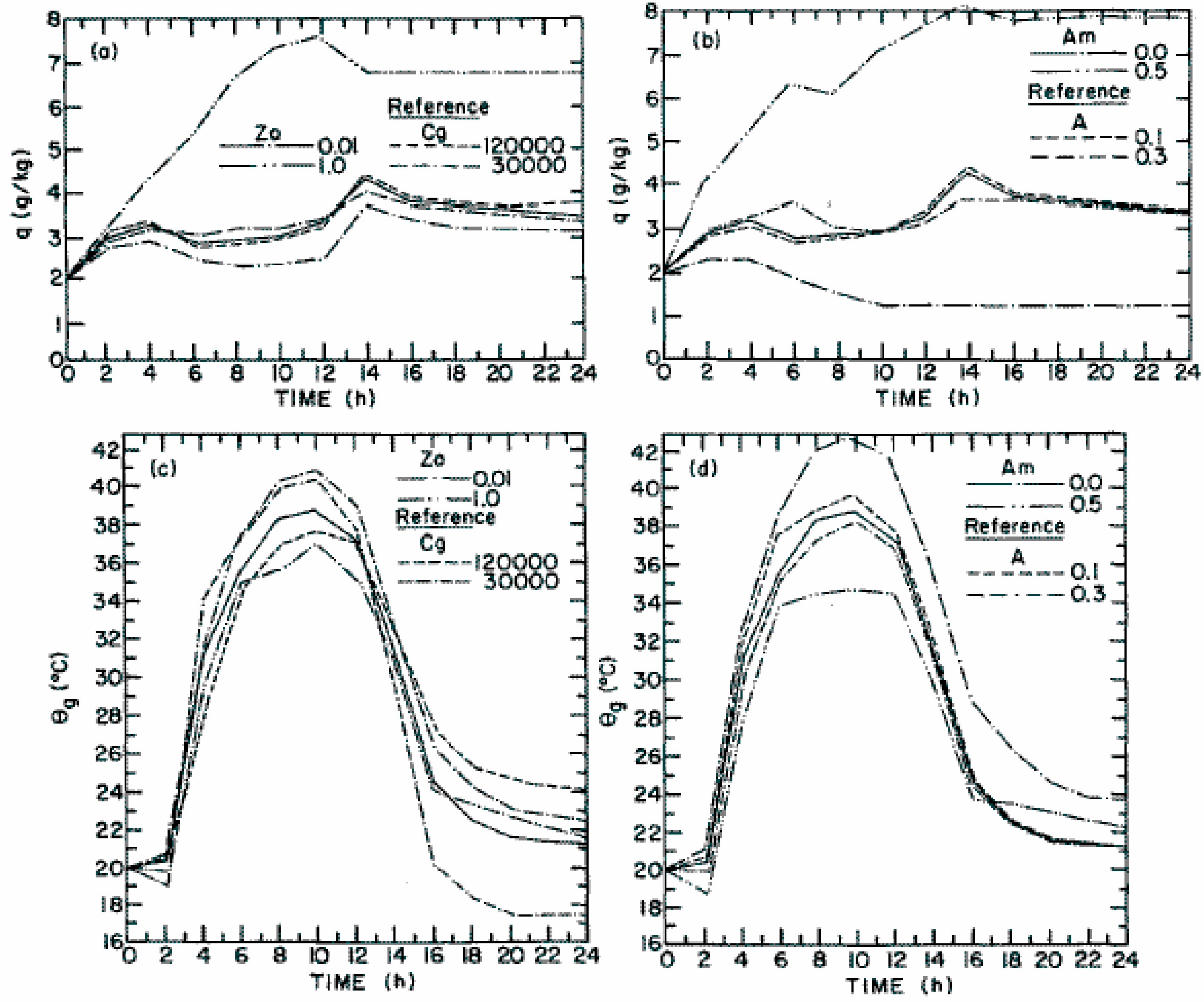

FIG. 3. Temporal variation of surface layer specific humidity q and ground potential temperature θ_g for sensitivity experiments in which roughness parameter z_0, thermal capacity C_g, moisture availability A_m, and albedo A are varied. See text for details.

Zhang and Anthes, (1982), J. APPL. METEOR., 1594-1609

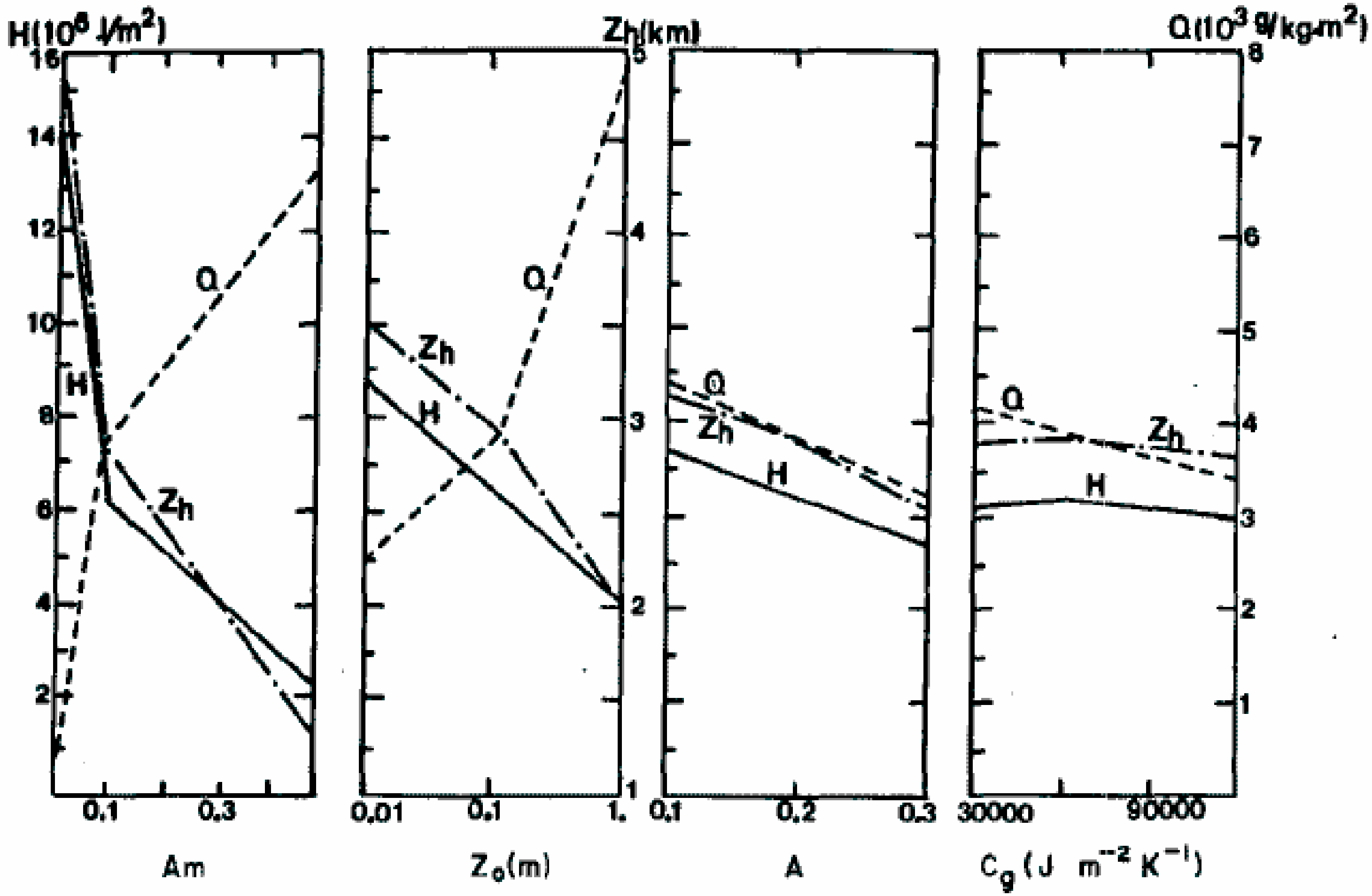

FIG. 4. 12 h vertical integrals of sensible heat flux H, water vapor flux Q, and height of mixed layer z_h for three values of moisture availability A_m, roughness parameter z_0, albedo A, and thermal capacity C_g.

Zhang and Anthes, (1982), J. APPL. METEOR., 1594-1609

Summary of Blackadar Scheme

- Suitable for high resolution PBL, e.g. 5 layers in lowest km, surface layer < 100 m thick.
- Four stability regimes, including free convective mixed layer.
- It is considerably simpler and computationally more economic than second-order representations (Mellor and Yamada, 1974)
- Sensitivity analysis shows that the Moisture availabiltiy produced the largest model response.

References

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