Project 2 - ATMO 595E

Louis Surface Flux Scheme &

Look-Up Table Approach for Parameterization

(Revised)

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Outline

- Louis Surface Flux Scheme
- Look-Up Table (LUT) for Parameterization
- Understandings & Suggestions about LUT Approach

Surface fluxes in model equations

$$\frac{\partial u}{\partial t} = \left\{ \frac{\partial}{\partial x}(-\overline{u'u'}) + \frac{\partial}{\partial y}(-\overline{u'v'}) + \frac{\partial}{\partial z}(-\overline{u'w'}) \right\} + \{advection\} + \{PGF + Coriolis\}$$

$$\frac{\partial \theta}{\partial t} = \left\{ \frac{\partial}{\partial x}(-\overline{\theta' u'}) + \frac{\partial}{\partial y}(-\overline{\theta' v'}) + \frac{\partial}{\partial z}(-\overline{\theta' w'}) \right\} + \{advection\} + \{Diabatic\}$$

$$\frac{\partial r}{\partial t} = \left\{ \frac{\partial}{\partial x}(-\overline{r'u'}) + \frac{\partial}{\partial y}(-\overline{r'v'}) + \frac{\partial}{\partial z}(-\overline{r'w'}) \right\} + \{advection\}$$

Surface momentum flux - Louis scheme

$$(-\overline{u'w'})_0 \equiv u_*^2 = a^2 u^2 F_m\left(\frac{z}{z_0}, R_{iB}\right)$$

$$R_{iB} = \frac{gz}{u^2}\frac{\Delta\theta}{\theta} = \frac{gz}{u^2}\frac{(\theta - \theta_0)}{\theta}$$

Bulk Richardson number (stability)

Surface heat flux - Louis scheme

$$(-\overline{\theta' w'})_0 \equiv \theta_* u_* = \frac{a^2}{R} u (\theta - \theta_0) F_h (\frac{z}{z_0}, R_{iB})$$

$$R_{iB} = \frac{gz}{u^2} \frac{\Delta\theta}{\theta} = \frac{gz}{u^2} \frac{(\theta - \theta_0)}{\theta}$$

θ_0 surface temperature

Surface vapor flux – Louis scheme

$$(-\overline{r'w'})_0 \equiv r_* u_* = \frac{a^2}{R} u (r - r_0) F_h\left(\frac{z}{z_0}, R_{iB}\right)$$

$$R_{iB} = \frac{gz}{u^2}\frac{\Delta\theta}{\theta} = \frac{gz}{u^2}\frac{(\theta - \theta_0)}{\theta}$$

r_0 surface moisture

Expressions of F

stable

$$F = 1 - \frac{bR_{iB}}{1 + c|R_{iB}|^{1/2}}$$

unstable

$$F = \frac{1}{(1 + b'R_{iB})^2}$$

Constants

stable $$F = \frac{1}{(1 + b' R_{iB})^2}$$ $b' = 4.7$

$$R_{iB} = \frac{gz}{u^2} \frac{(\theta - \theta_0)}{\theta}$$

unstable $$F = 1 - \frac{b R_{iB}}{1 + c |R_{iB}|^{1/2}}$$ $b = 9.4$

$$a^2 = \frac{k^2}{(\ln \frac{z}{z_0})^2}$$

$$c = C^* a^2 b (\frac{z}{z_0})^{1/2}$$

$C^* = 7.4$ F_m

$C^* = 5.3$ F_h

Momentum flux - stable

$$(-\overline{u'w'})_0 = \frac{k^2 u^2}{(\ln \frac{z}{z_0})^2 (1 + 4.7 \frac{gz}{u^2} \frac{\theta - \theta_0}{\theta})^2} = \left\{ \begin{matrix} u, \theta \\ z \\ \theta_0, z_0 \\ 4.7 \\ g, k \end{matrix} \right\}$$

Momentum flux - unstable

$$(-\overline{u'w'})_0 = \frac{k^2u^2}{(\ln \frac{z}{z_0})^2}\left\{1 - \frac{9.4\frac{gz}{u^2}\frac{\theta-\theta_0}{\theta}}{1+7.4\frac{k^2}{(\ln\frac{z}{z_0})^2}9.4(\frac{z}{z_0})^{1/2}\left|\frac{gz}{u^2}\frac{\theta-\theta_0}{\theta}\right|^{1/2}}\right\} = \left\{\begin{matrix} u,\theta \\ z \\ \theta_0, z_0 \\ 7.4, 9.4 \\ g, k \end{matrix}\right\}$$

Heat flux - stable

$$(-\overline{\theta' w'})_0 = \frac{k^2 u(\theta - \theta_0)}{(\ln \frac{z}{z_0})^2 R \left[1 + 4.7 \frac{gz}{u^2} \frac{\theta - \theta_0}{\theta}\right]^2} = \left\{ \begin{array}{l} u, \theta \\ z \\ \theta_0, z_0 \\ 4.7 \\ R \\ g, k \end{array} \right\}$$

Heat flux - unstable

$$(-\overline{u'w'})_0 = \frac{k^2 u(\theta-\theta_0)}{(\ln\frac{z}{z_0})^2 R}\left\{1-\frac{9.4\frac{gz}{u^2}\frac{\theta-\theta_0}{\theta}}{1+5.3\frac{k^2}{(\ln\frac{z}{z_0})^2}9.4(\frac{z}{z_0})^{1/2}\left|\frac{gz}{u^2}\frac{\theta-\theta_0}{\theta}\right|^{1/2}}\right\} \qquad = \left\{\begin{matrix} u,\theta \\ z \\ \theta_0, z_0 \\ 5.3, 9.4 \\ R \\ g, k \end{matrix}\right\}$$

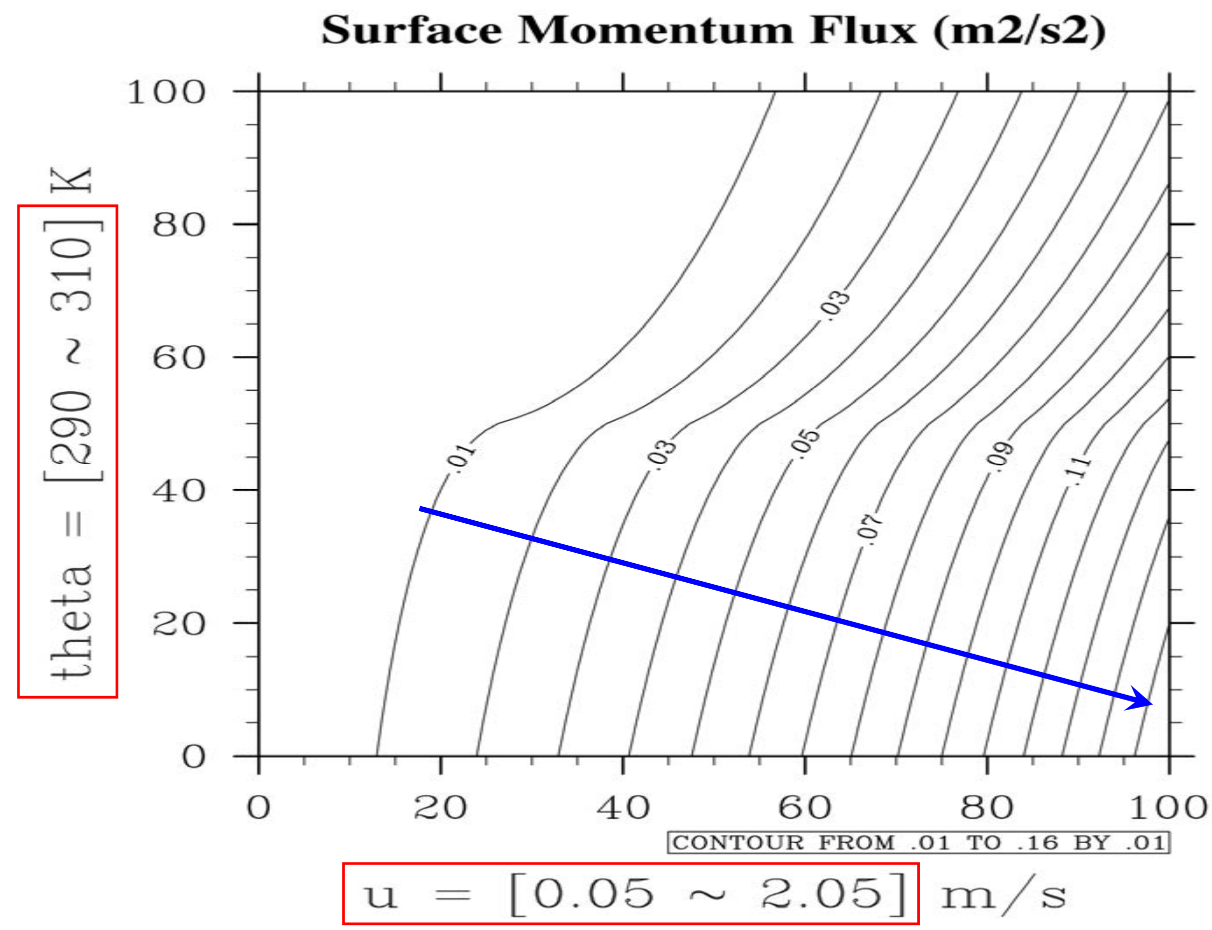
Vapor flux - stable

$$(-\overline{r'w'})_0 = \frac{k^2 u (r - r_0)}{(\ln \frac{z}{z_0})^2 R (1 + 4.7 \frac{gz}{u^2} \frac{\theta - \theta_0}{\theta})^2} = \begin{Bmatrix} u, \theta, r \\ z \\ \theta_0, r_0, z_0 \\ 4.7 \\ R \\ g, k \end{Bmatrix}$$

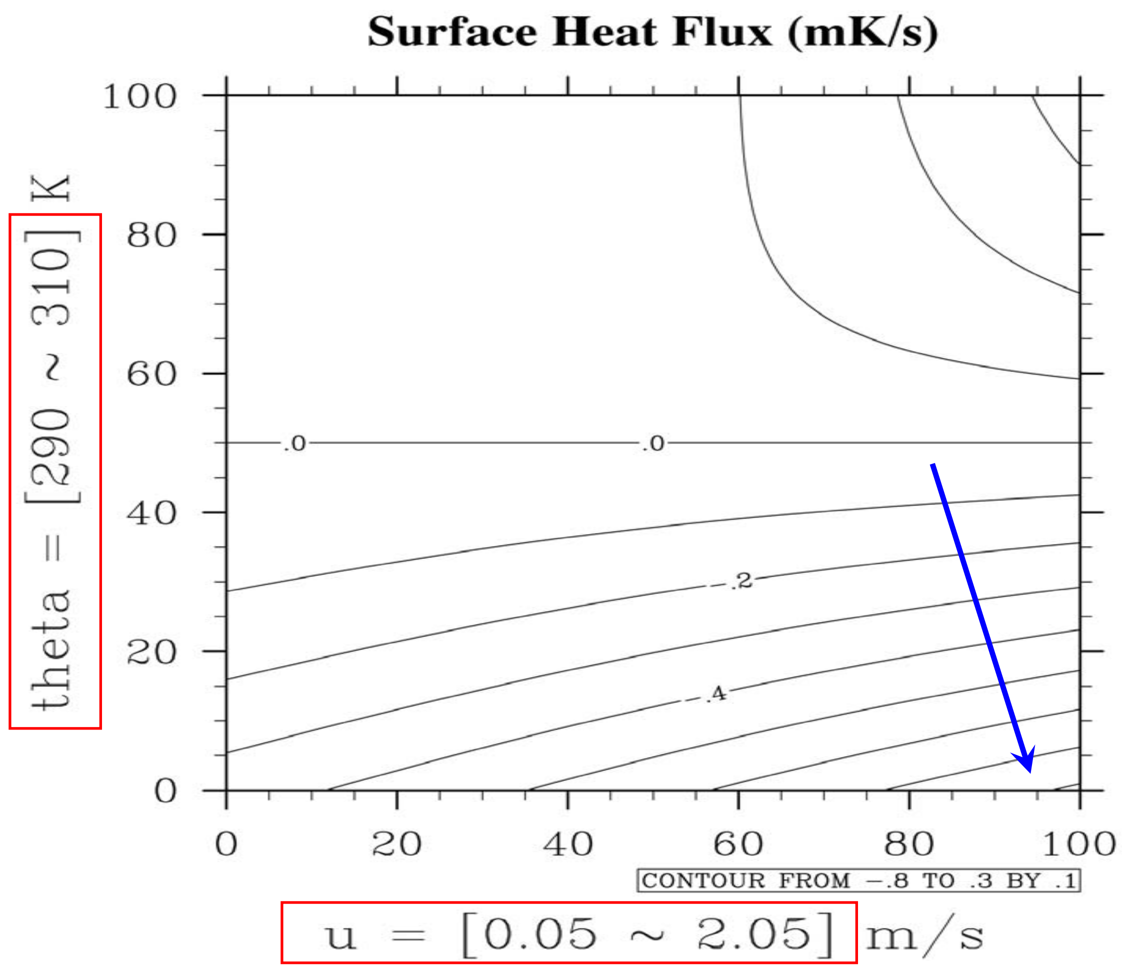
Vapor flux - unstable

$$(-\overline{u'w'})_0 = \frac{k^2 u (r - r_0)}{(\ln\frac{z}{z_0})^2 R} \left\{ 1 - \frac{9.4 \frac{gz}{u^2} \frac{\theta - \theta_0}{\theta}}{1 + 5.3 \frac{k^2}{(\ln\frac{z}{z_0})^2} 9.4 (\frac{z}{z_0})^{1/2} \left| \frac{gz}{u^2} \frac{\theta - \theta_0}{\theta} \right|^{1/2}} \right\} = \left\{ \begin{array}{l} u, \theta, r \\ z \\ \theta_0, r_0, z_0 \\ 5.3, 9.4 \\ R \\ g, k \end{array} \right\}$$

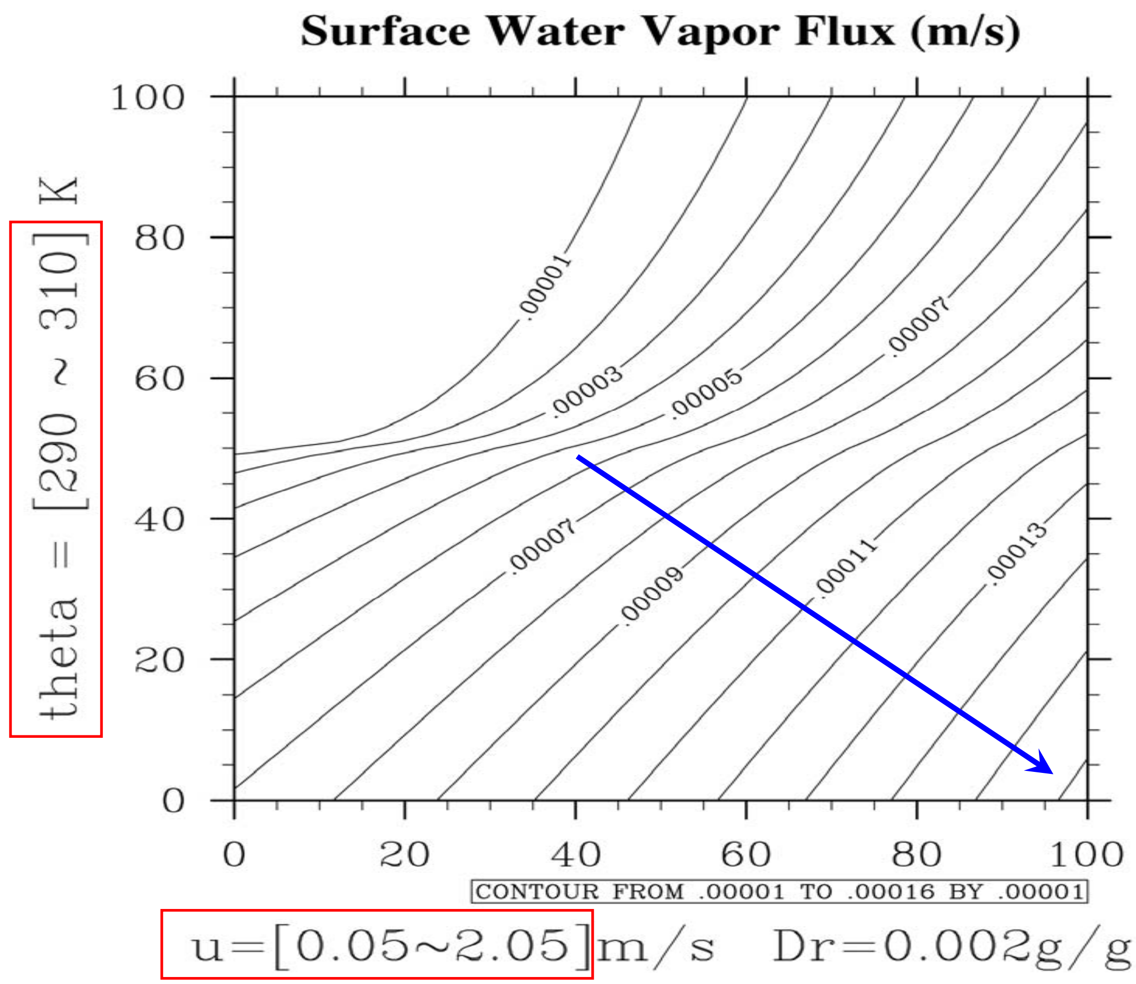
Look-Up Table (plot) from source code



Look-Up Table (plot) from source code



Look-Up Table (plot) from source code



Question 1

- Can we use a single LUT for the model with all the variables included?

A general LUT (if storage allows)

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} + -\theta\frac{\partial \pi'}{\partial x} + fv + \left\{\frac{\partial}{\partial x}(-\overline{u'u'}) + \frac{\partial}{\partial y}(-\overline{u'v'}) + \frac{\partial}{\partial z}(-\overline{u'w'})\right\}$$

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} + -\theta\frac{\partial \pi'}{\partial x} + fv + P(u,\theta;\theta_0,z_0;\Delta x,\Delta z,\ldots)$$

$$u^{\tau+1} = u^{\tau} + \Delta t\left\{-u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} + -\theta\frac{\partial \pi'}{\partial x} + fv + P(u,\theta;\theta_0,z_0;\Delta x,\Delta z,\ldots)\right\}^{\tau}$$

$$u^{\tau+1} = Q^{\tau}(u,v,w,\theta,\pi';\theta_0,z_0,\Delta x,\Delta z;\Delta t,\ldots)$$

- No calculation is needed if using this general LUT to do model integrations step by step.
- Too many variables involved in the LUT. It is not feasible for current computer storage. So multi-LUTs are needed.

Question 2

- Can we use a lot of LUTs with just a few variables in each LUT?

No. If so, we still need to do too many calculations, and the LUT method becomes less meaningful.

Question 3

- How to balance the number of the LUTs and the complexity (size or elements) of each LUT?

Balance between the size and number of LUT

$$P(x_1, x_2, x_3, x_4, x_5, x_6) = A(x_1, x_2) + B(x_3, x_4)C(x_5, x_6)$$

LUT of A	$n \times n$	
LUT of B	$n \times n$	$3n^2 = 3\times 10^6$
LUT of C	$n \times n$	$(n = 1000)$

LUT of P $\quad n\times n\times n\times n\times n\times n = n^6 = 10^{18}$

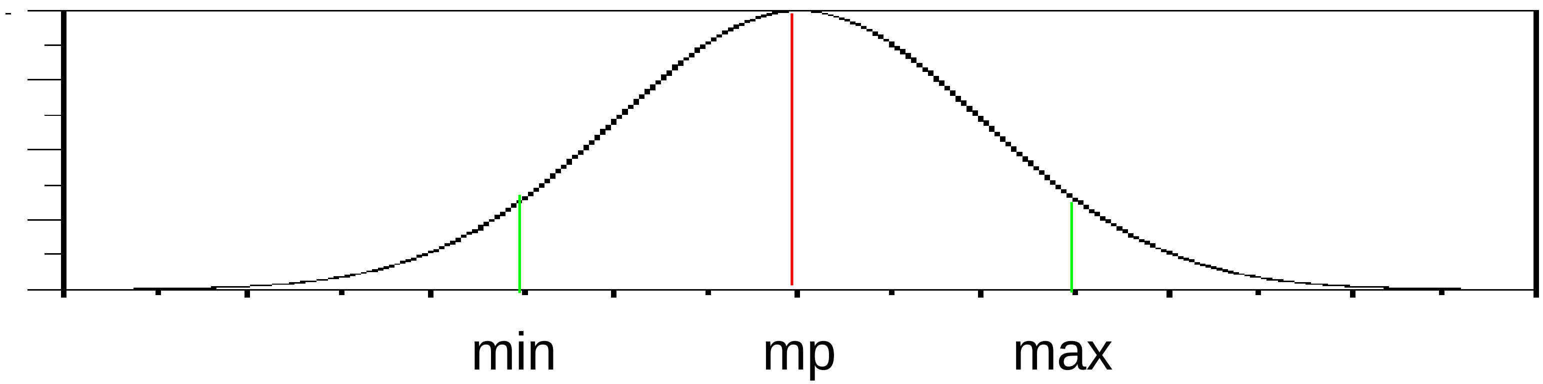
The number of LUTs and the elements of each LUT should be balanced.

- If the terms or factors in a parameterization have less variables in common, create LUTs separately for them.
- A LUT should use less variables, but do more calculations.

Question 4

- In a LUT, how to determine the domain (min and max) of each variable?

Set domain for each variable in LUT



- Analyze the distribution of each variable. Determine its most popular value.
- Set the domain (min and max) of a variable with limit of computer storage considered.
- For values out of the domain, calculate through parameterization schemes.

Question 5

- In a LUT, the spacings (or the mean spacings) of different variables can be chosen separately, or should be related?

Set spacing for each variable in LUT

Suppose a parameterization scheme $P = P(u, v, ...)$

$$\Delta P(u, v) = \frac{\partial P}{\partial u}\Delta u + \frac{\partial P}{\partial v}\Delta v + ...$$

Variable u and v may have different effects on P ($\frac{\partial P}{\partial u}$ and $\frac{\partial P}{\partial v}$). Let Δu and Δv be the spacings of u and v. Consider the changes of u and v can cause same contributions to the change of P, that is

$$\frac{\partial P}{\partial v}\Delta v = \frac{\partial P}{\partial u}\Delta u$$

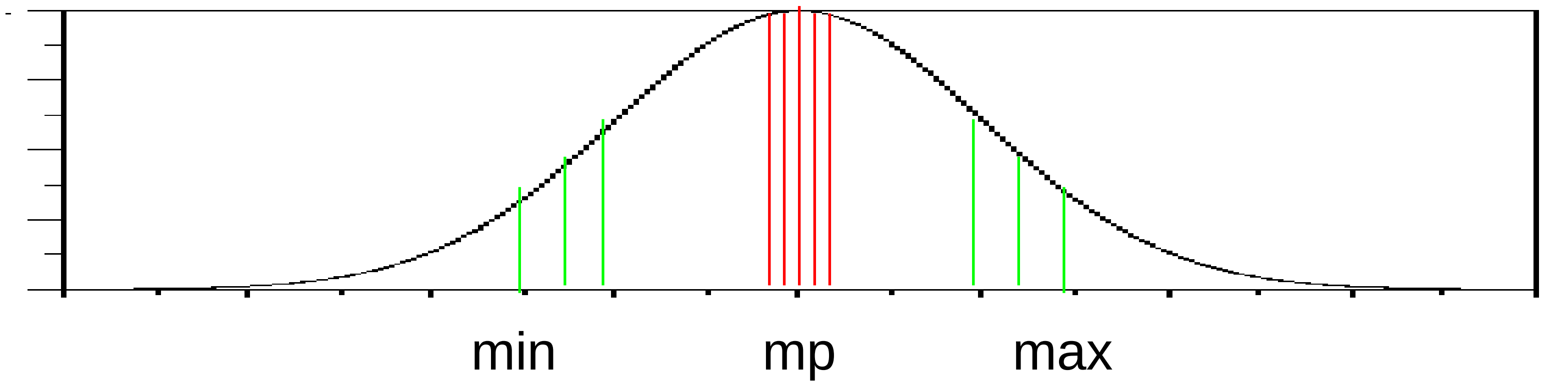
So, when the spacing of one variable is given, the spacings of other variables can be determined based on the above relation.

- For significant-effect variables, take small spacing, so they have more elements in LUT.
- For small-effect variables (almost like constants), use large spacing, so they have less elements.

Question 6

- In a LUT, should the domain of a variable be equally spaced or not?

Variant spacing within a domain of variable



Spacing within the domain of each variable does not have to be equal.

(See next-step analyses)

Conclusion - significance of LUT approach

- Computer limitation
  - Speed
  - Storage
- Model design
  - Accurate
  - Fast
  - Less space
- Many efforts for this purpose
  - LUT approach is another milestone in model design; just like
  - The spectral-grid transform technique

    (Bourke et al 1977; Machenhauer 1979)