Numerical simulation and population-wide risk assessment of windblown dust emission from exposed bottom of Aral Sea

(アラル海露出海底からの砂塵巻き上げ
シミュレーションと健康リスク評価)

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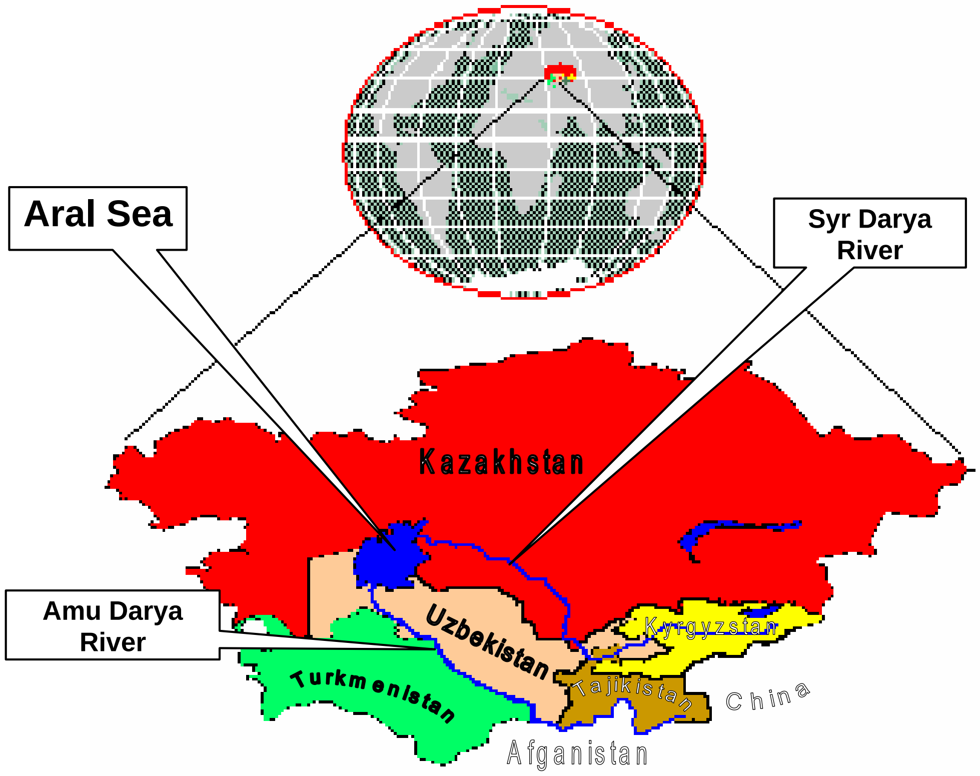
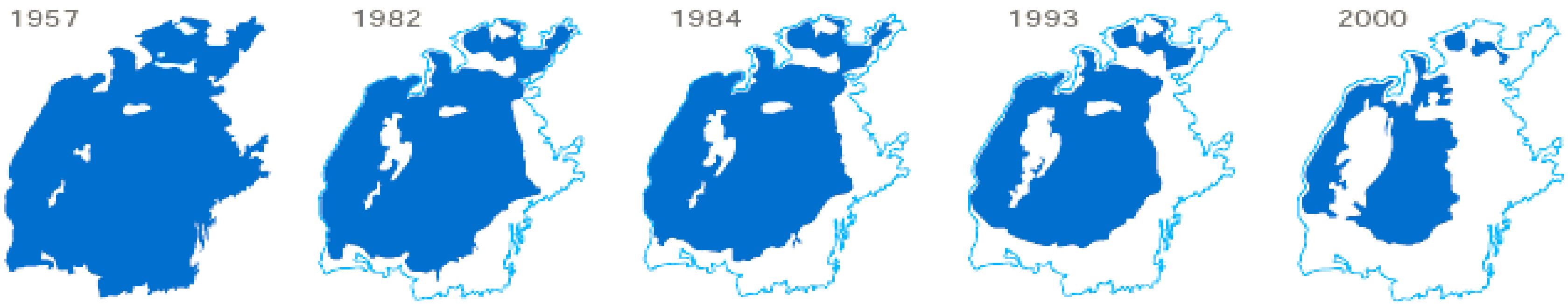
1 BRIEF INTRODUCTION AND STATEMENT OF PROBLEM

- Surface area (1960) - 67 000 km^2
- Drainage area – 1.2 million km^2
- The inflow rivers:
  - *Amu Darya
  - *Syr Darya
- Volume Reduced (by 1998) – 80%
- Surface area shrank – by 50 %
- Exposed sea bed - 40 000 km^2
- Shoreline reduce – 100 to 150 km
- Annual dust redistribution – million tons





1.1 Consequences

- High mortality rate for respiratory and cardiovascular diseases
- High infant mortality - 75 death/1000 life birth
- Maternity death – 120 women / 10 000 birth
- Other diseases – anemia, dysfunction of gland,
  kidney, and heart diseases.

1.2 Expected contribution of study on Aral Sea problem

The problem of the Aral Sea is connected with cotton. It is as a result of the cotton monoculture that excessive amount of water had to be diverted from the two rivers. Today the main solution of the problem is believed to be in implementation of new irrigation techniques. However, this option requires a huge investment.

Thus, results from this study, which shows associations between population health and dust particles, can help to bring the Attentions of Domestic and as well as International Foundation toward the solution of the problem.

1.3 Objectives

Simulation of dust particle transport and quantification of annual mortality rate associated with windblown dust emission from dried bottom of Aral Sea.

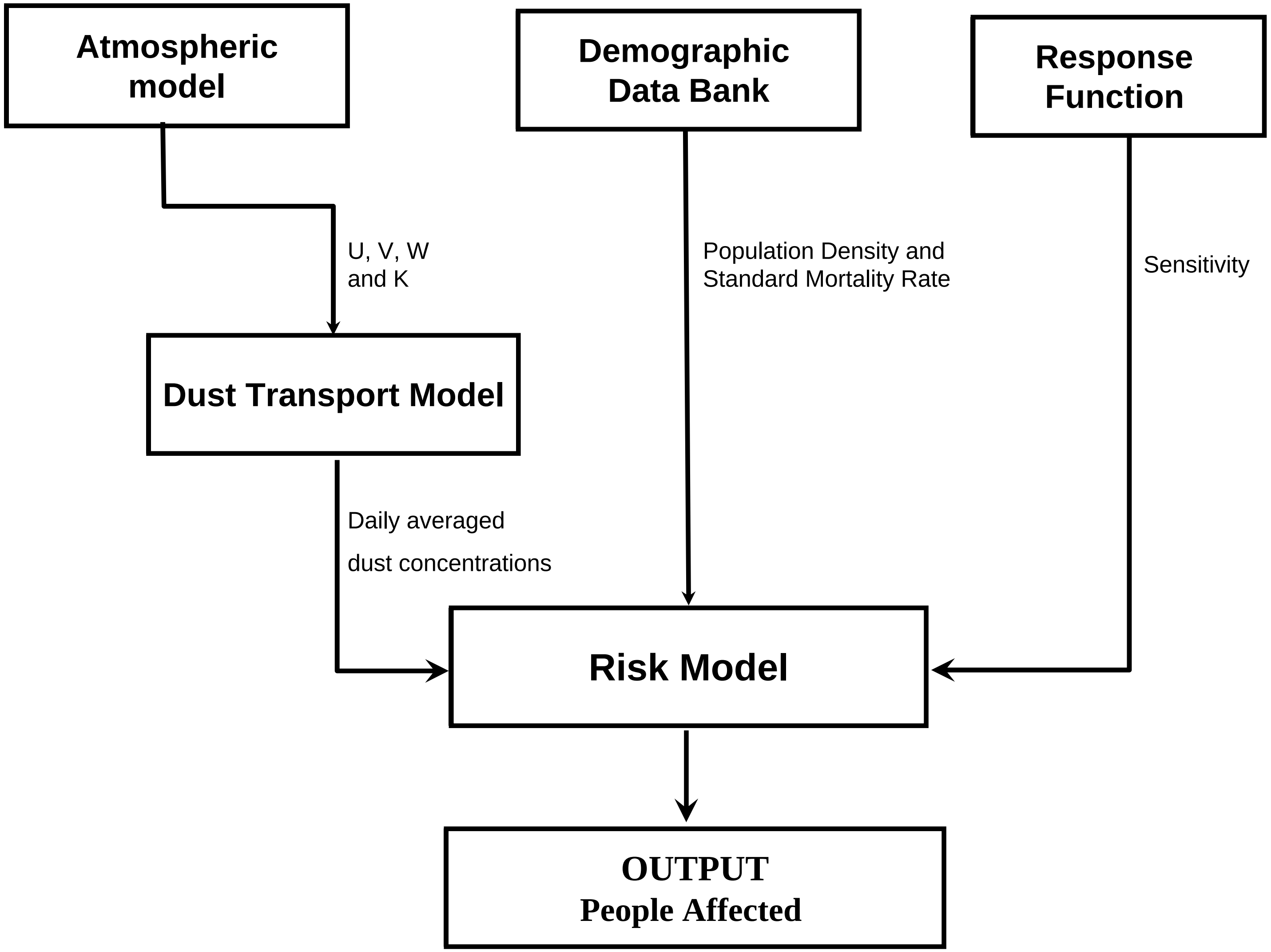


Figure 1.2 Flowchart of the research

1.4 Computational conditions

***Total Vertical Layers: 30**

***Grid number: 143x110**

***Grid size: 15 000 m**

***Computational Time Period: 1 year, Jan.1-Dec.31 2003**
***Integration Time step: 3 hrs**

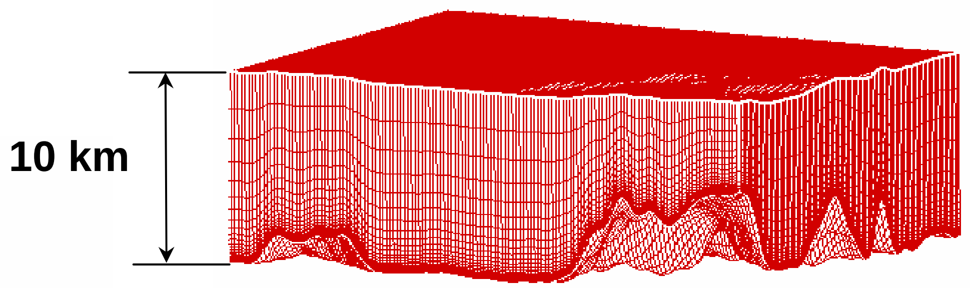


Figure 1.3b. Air domain of the research

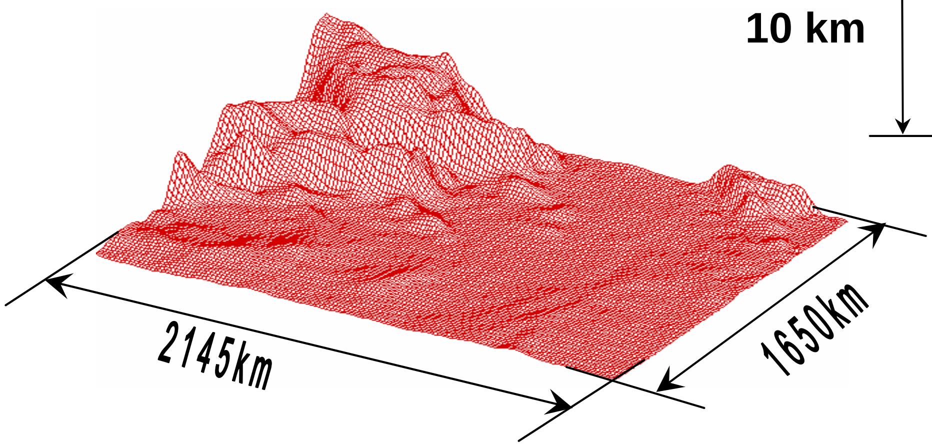


Figure 1.3a. Digitalised topography of the region

2 MODELING ATMOSPHERIC FLOW FIELD

2.1 Flow field calculation procedures

1. Initially, the filed of u_* -friction velocity, sensible heat flux and geopotential height were obtained from the assimilated result of Climate Diagnostic Center, NCEP/NCAR (2.5x2.5 degree lat./long., 6 hourly interval) :

2. Spatial and Temporal Interpolation of the values of u_* to the finer grid at height Z_0 over the surface using a *horizontal bi-cubic interpolation*.

3. V*ertical extrapolation* to define the velocity field in the whole domain.

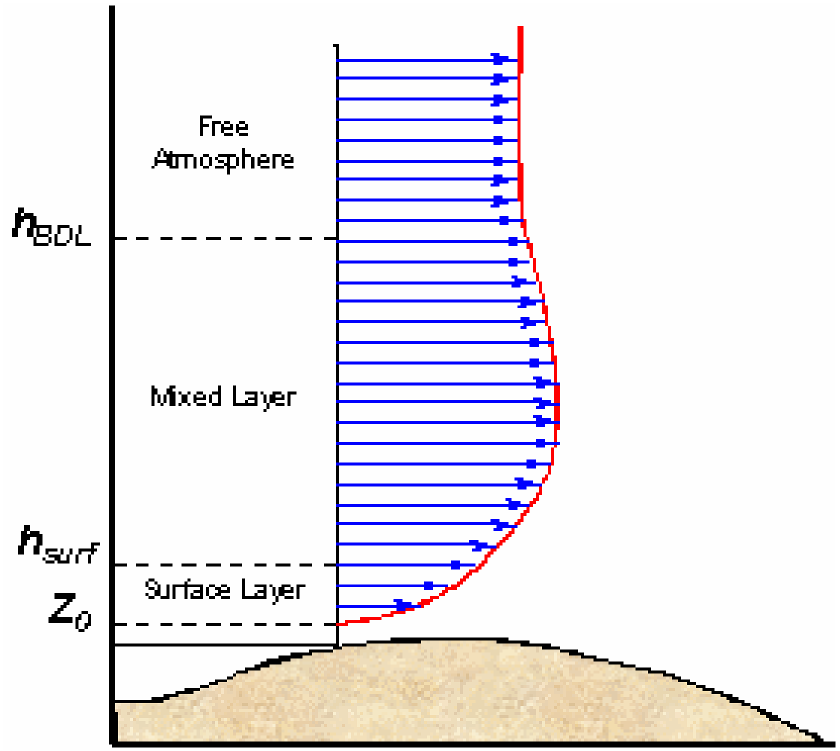


Figure 2. 1 An illustrative example of a vertical profile of wind. Boundary layer stratification

2.2 Vertical extrapolation (*Montero, 1998*)

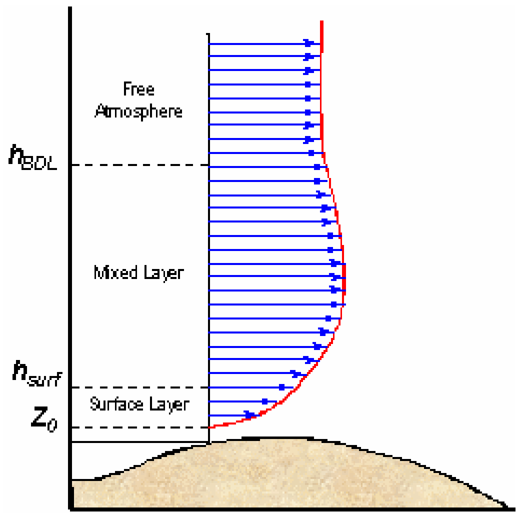
$$u(z)=\frac{u_*}{k}\left(\log\frac{z}{z_0}-\psi_m(\frac{z}{L})\right),\quad z_0<h_{surf}\leq h_{BDL} \qquad (1)$$

where u_* is friction velocity, k is Von Karman constant, Z_0 is the roughness height, h_{surf} is the height of the surface layer, h_{BDL} boundary layer height . ψ is wind stability correction.

$$\psi(\frac{z}{L})=0 \ if \ \frac{z}{L}=0 \qquad (2)$$

$$\psi(\frac{z}{L})=-5\frac{z}{L} \quad if \ \frac{z}{L}>0 \qquad (3)$$

$$\psi(\frac{z}{L})=\log\left[\left(\frac{x^2+1}{2}\right)\left(\frac{x+1}{2}\right)^2\right]-2\arctan x+\frac{\pi}{2} \ if \ \frac{z}{L}<0 \qquad (4)$$



$$where \ x=(1-16z/L)^{1/4},\quad L=\frac{u_*^2\theta}{kg\theta_*}-Obukhov \ Length$$

2.4 Geostrophic Wind Calculation

Geostrophic wind was calculated using geostrophic balance, which can be writing as

$$+g\frac{dZ}{dY}=f_c U_g \qquad (5)$$

$$-g\frac{dZ}{dX}=f_c V_g \qquad (6)$$

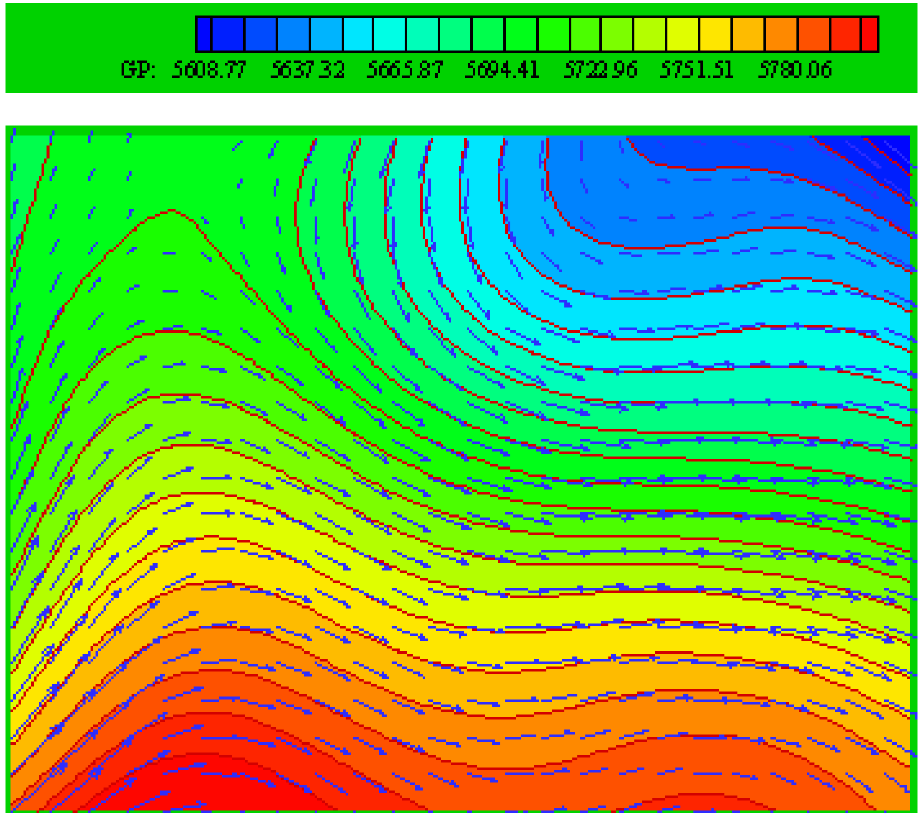


Figure 2.4 The contours of geopotential height and calculated geostrophic wind vectors

2.3 Boundary Layer Height (Zilitinkevich, 1989, Ratto et al., 1990)

$$h_{BDL} = 0.3\frac{u_*}{f_c}, \quad (neutral) \quad (7)$$

$$h_{BDL} = 0.3\frac{u_*}{f_c}(1+1.581\sqrt{-\mu}), \quad (stable) \quad (8)$$

$$h_{BDL} = 0.3\frac{u_*}{f_c}\frac{1}{(1+0.882\sqrt{\mu})}, \quad (unstable) \quad (9)$$

$$h_{surf} = h_{BDL}/10, \quad (10)$$

Above the surface layer, a linear interpolation with geostrophic wind U_G is done as follows:

$$u_0(z) = \rho(z)u_0(z_{surf}) + [1-\rho(z)]U_G, \quad h_{surf} \le z \le h_{BLD}, \quad (11)$$

$$\rho(z) = 1 - \left(\frac{z - z_{sl}}{h - z_{sl}}\right)^2\left(3 - 2\frac{z - z_{sl}}{h - z_{sl}}\right). \quad (12)$$

Finally, this model assumes that
$u(z)=U_G$ if $z > h_{BLD}$, and
$u(z)=0$, if $z<=Z_0$.

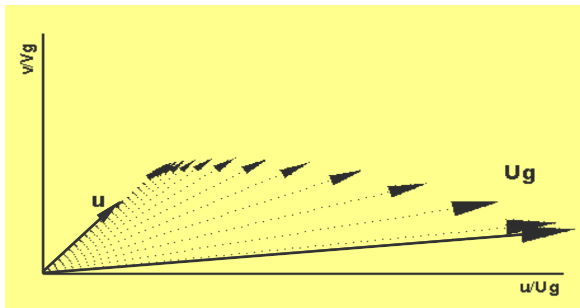


Figure 2.3. Turning wind with the height

2.7 Validation of Velocity Vectors

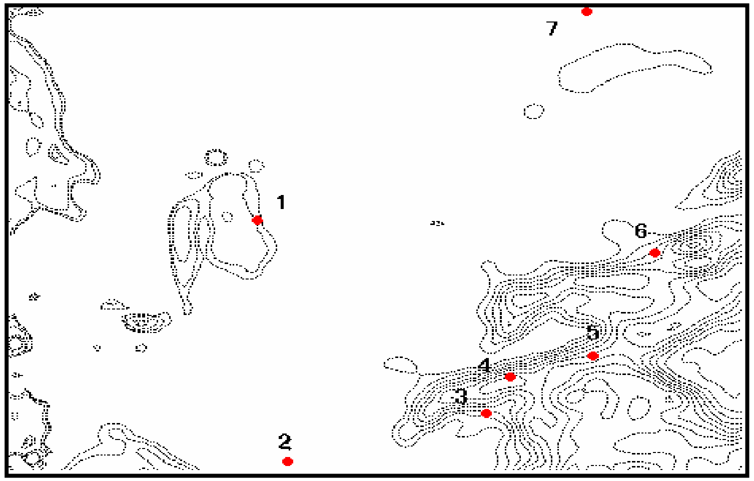


Figure 2.7a. Map indicating the approximate position of the sites.

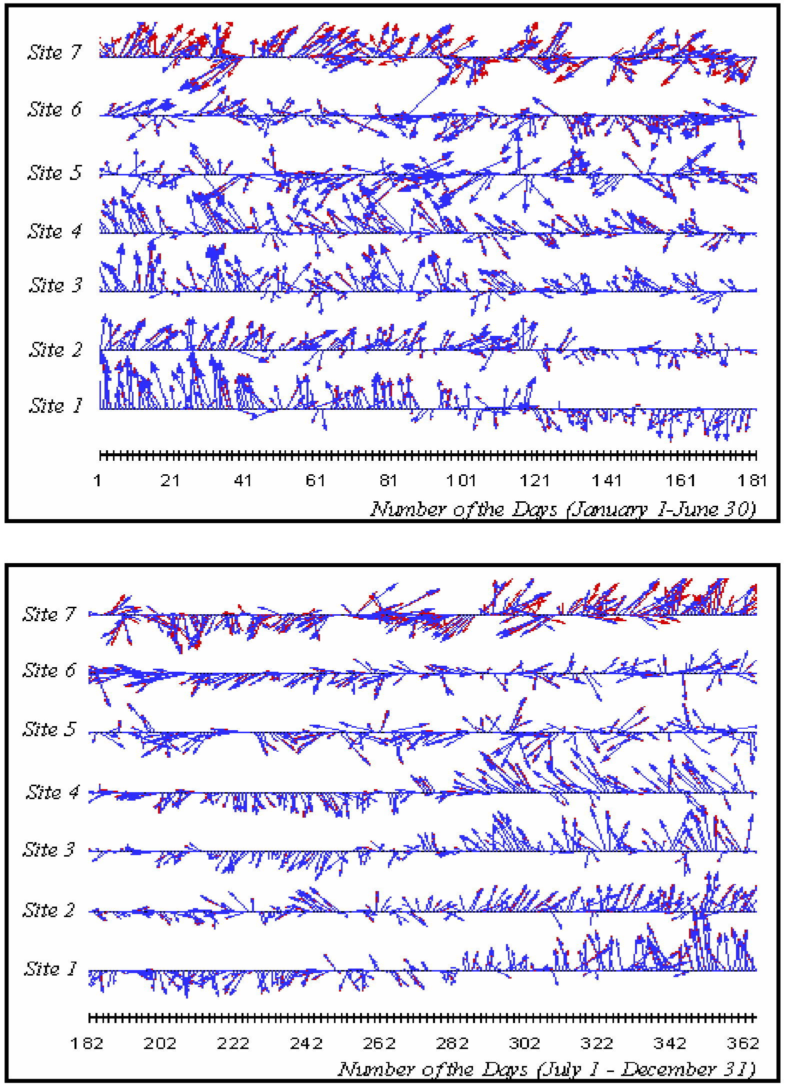


Figure 2.7b. Wind field comparison at selected sites. (The red - daily averaged wind from measurement, and the blue - daily average at 10 meter above ground)

3. MODELLING OF DUST TRANSPORT

Annual Average Salt/Dust Removal : 690 000 t per total exposed area or 21,88 kg/area/s

Particle Size Considered: <100 micron in diameter

3.1 Governing Equations for Particle Motion

$$\left(m_p + \frac{\rho_f V_p}{2}\right)\frac{d\mathbf{u}_p}{dt} = -V_p \nabla P + m_p \mathbf{g} - \frac{1}{2}\rho_f S C_D \mathbf{u}_r |\mathbf{u}_r| \qquad (13)$$

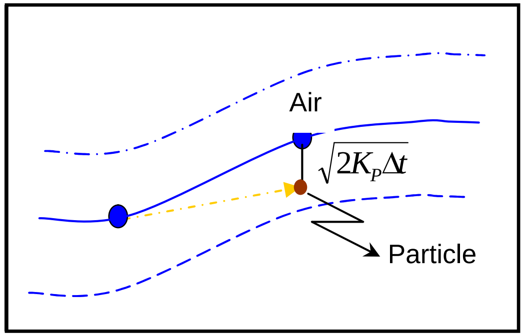
$$\frac{d\mathbf{x}_p}{dt} = \mathbf{u}_p \qquad (14)$$

Where,

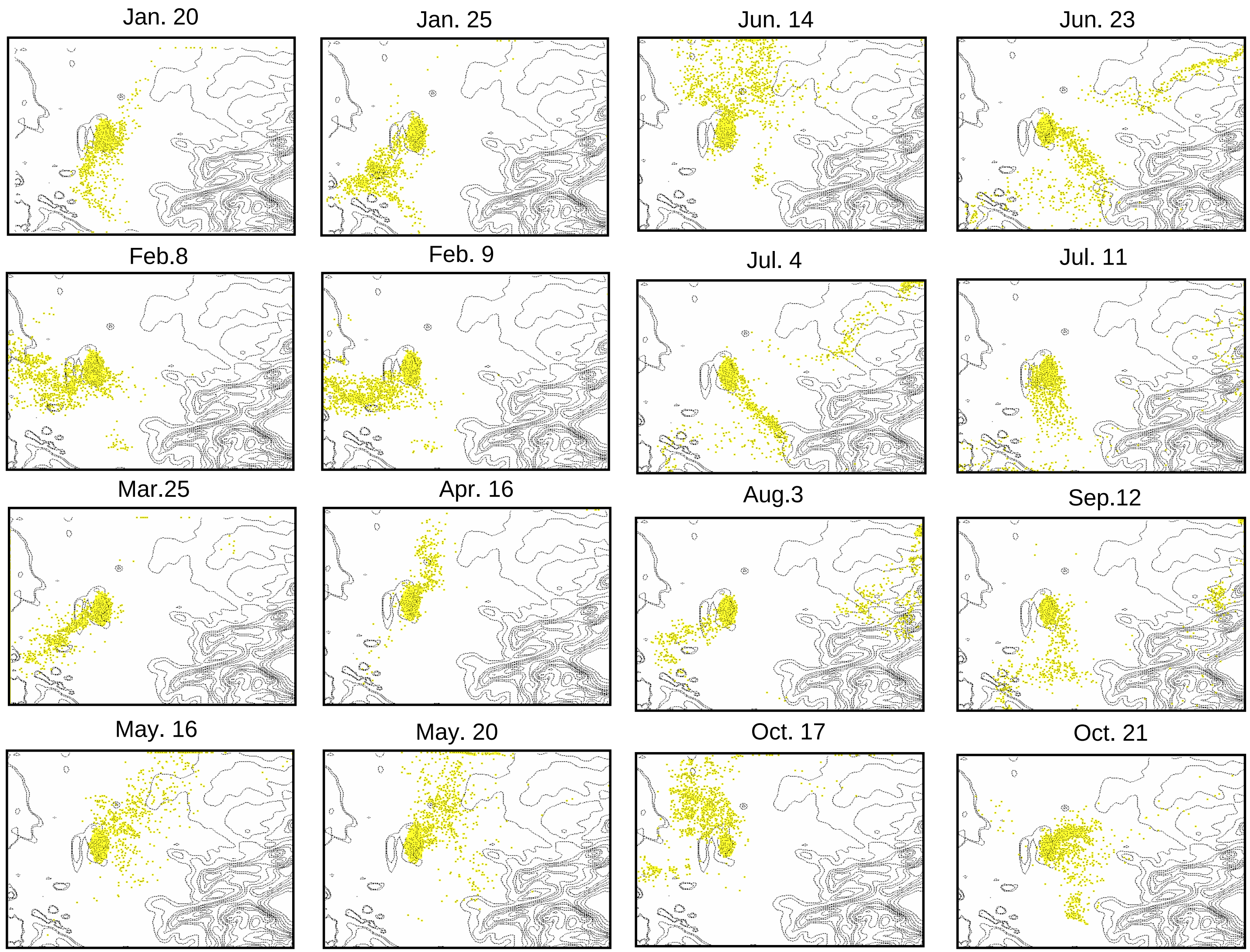
$\mathbf{x}_p$ – *particle position*
m_p – *particle mass*
V_p – *volume of particle*
$\mathbf{u}_p$ – *particle velocity*
C_D – *drag coeff.*

3.2 Effect of sub-grid turbulent on particle movement (Suzuki, 2001)

$$\mathbf{x}_p^{n+1} = \mathbf{x}_p^n + \Delta t \mathbf{u}_\mathbf{p} + \sqrt{2K_p \Delta t}\,\chi \qquad (15)$$



3.3 MAJOR DUST PARTICLE TRANSPORT, DURING 2003



3.4 Simulation Results

Validation with satellite image, episode of April 18, 2003

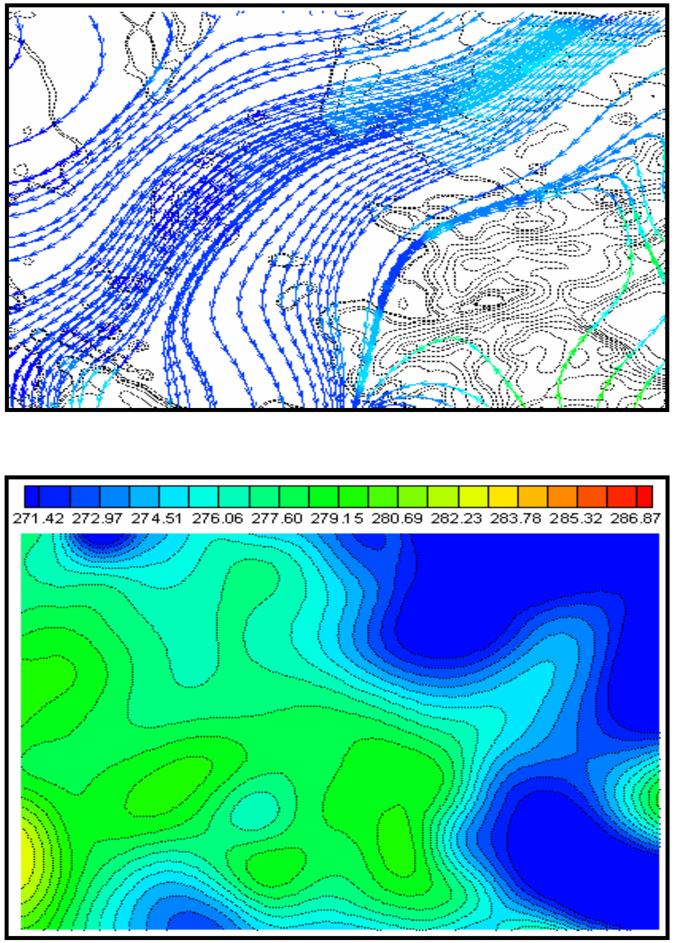


Figure 3.4a. Simulated surface streamlines (above) and temperature (below) for the 18 April, 2003 dust storm episode

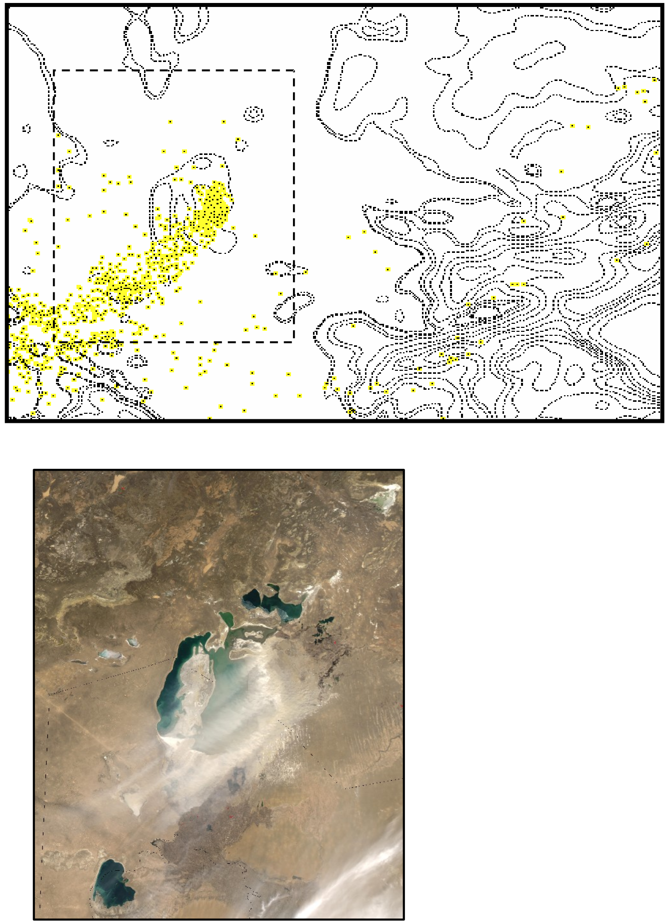


Figure 3.4b. Observed (above) and simulated (bellow) of 18 April 2003 dust storm in the dried up seabed

4. EFFECT OF DUST PARTICLES ON ANNUAL MORTALITY RATE

The concentration response functions (Deck et al., 1996)

$$R(c) = r(o)\exp(\gamma c) = r(o)\,C_f \quad , \quad (16)$$

where $\gamma = \dfrac{\log_e(R_R)}{\Delta c}$

c –daily averaged conc.

R_R =1.025–relative risk as the result of $\Delta c = 50\mu g / m^3$ increase

$r(0)$ -standard mortality rate

Procedure:

1. Change factor at each grid point

$$C_f(c) = \exp(\gamma c) \quad , \quad (17)$$

2. Contribution of Dust effect on annual standard mortality rate

$$RSK(c) = C_f(c) - 1 \quad , \quad (18)$$

3. Country-based Risk

$$RSK_C(c) = \frac{\int RSK(c) r(o) \rho_{PPL}\, dA}{\int \rho_{PPL}\, dA} \approx r(o) \frac{\int RSK(c) \rho_{PPL}\, dA}{\int \rho_{PPL}\, dA} \quad , \quad (19)$$

4.1 Results from Applying risk Model

	Kazakhstan	Turkmenistan	Uzbekistan	Kyrgyzstan	Tajikistan
$\frac{\int RSK(c)\rho_{PPL}\, dA}{\int \rho_{PPL}\, dA}$	0.00062	0.00185	0.00396	0.00002	0.00001
$r(o)$	0.014932	0.012362	0.01331	0.013367	0.011575
$\int \rho_{PPL} dA$	15500000	4700000	24000000	4600000	6200000
Total People AFFECTED	143.4	107.5	1264.9	1..3	0.7

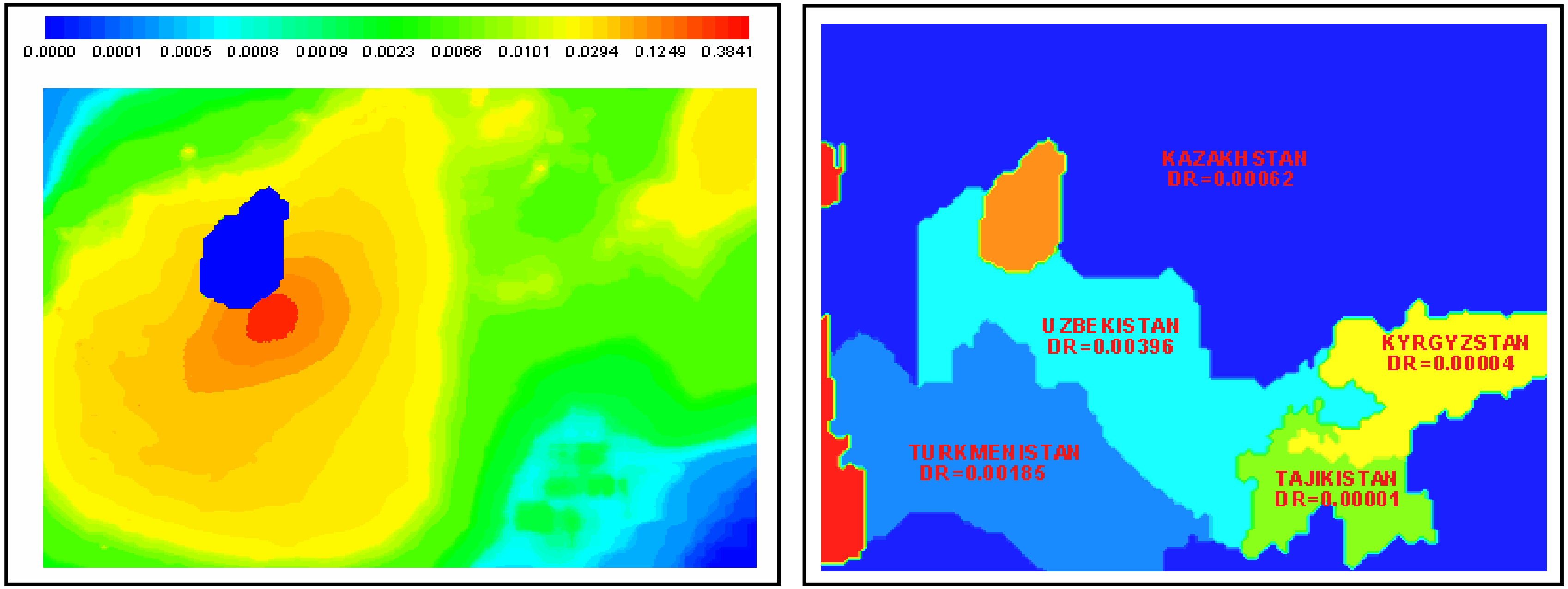


Figure 4.1 Contour map of concentration response function: grid point based(left) and country averaged (right)

5. Conclusion

Over the one simulated, 2003, year, the model was able to detect the number and transport direction of major dust storms event.

- It was found that the major transport direction, was S, SSW, SW and WSW, by dust storm, which is associated with cyclonic intrusion from northeast triggered by the high-pressure system, forms over Siberia.

- The most outstanding finding of the research is that the Aral Sea dust storm has major impact on mortality rate of the population of Uzbekistan, Turkmenistan and Kazakhstan. The number of people were affected by particle concentration in these countries, for 2003 year, have been approximated to be 1264, 143 and 107 respectively.

Thank you for your attention !!!

2.5 Vertical Motion

The equation of continuity is:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{13}$$

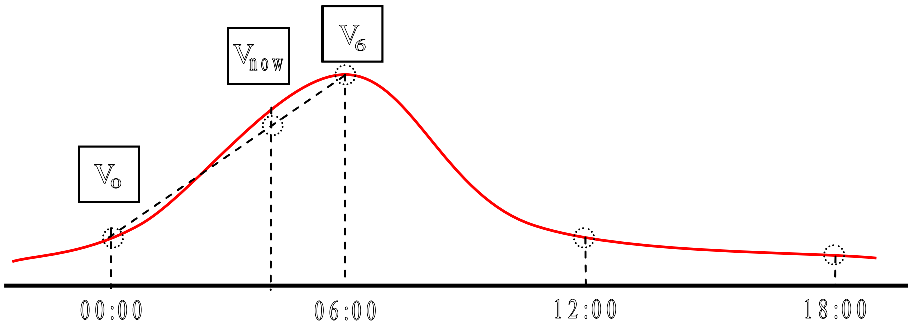
Under this strong constrain of mass conservation
the vertical motion is obtained by:

$$w(z) = -\int_0^z \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) dz . \tag{14}$$

2.6 Temporal Interpolation

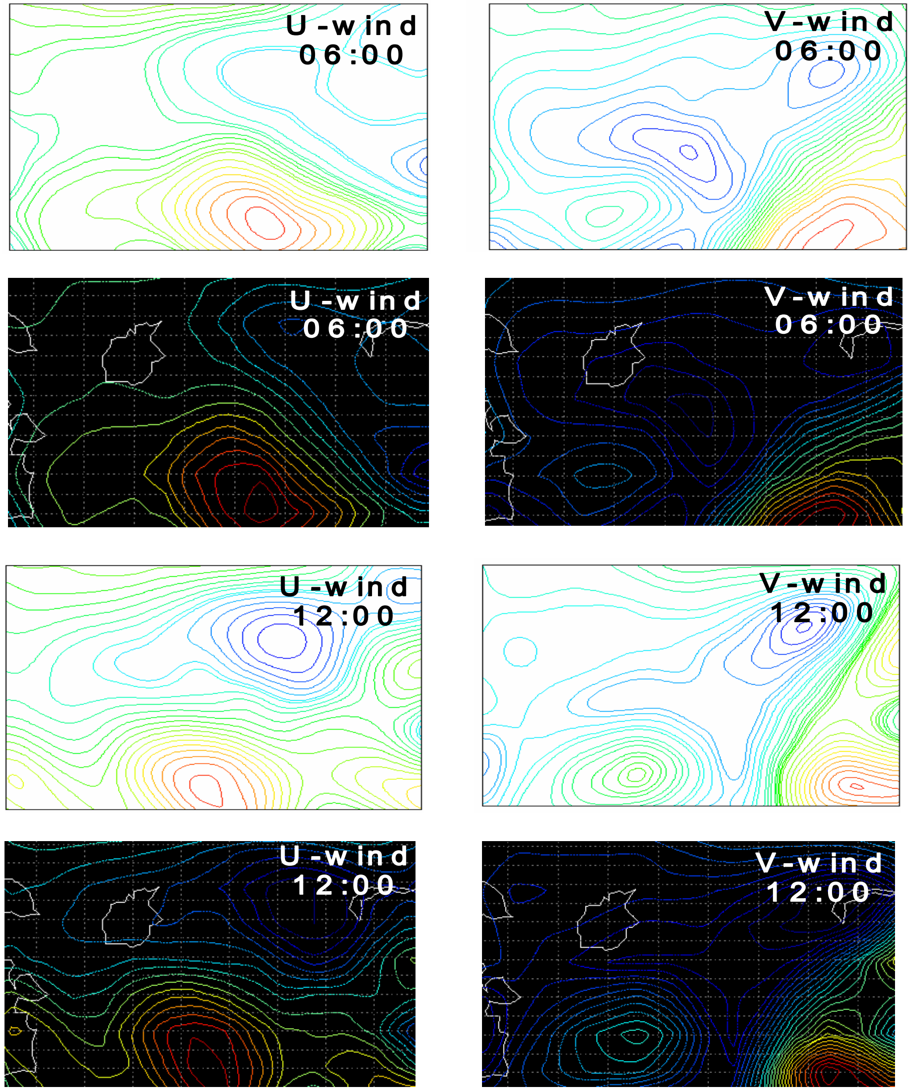
Temporal linear interpolation was done following relation:

$$V^{now} = V_0 \frac{t_6 - t^{now}}{t_6 - t_0} + V_6 \frac{t^{now} - t_0}{t_6 - t_0} \tag{15}$$



2.7 Validation of Wind

2.7.1 U and V wind Contours , April 18, 2003



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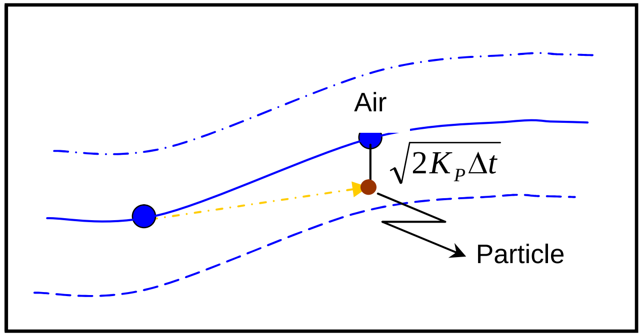

3.3 Eddy Diffusivity of Particle

$$K_{PX} = K_{PY} = K_H \frac{\sqrt{1+(\frac{\beta w_t}{\sigma_{xy}})^2} - \frac{1}{2}\frac{\beta w_t}{\sigma_{xy}}}{1+(\frac{\beta w_t}{\sigma_{xy}})^2}, \quad (19)$$

$$K_{PZ} = K_Z \frac{1}{\sqrt{1+(\frac{\beta w_t}{\sigma_Z})^2}}, \quad (20)$$

The horizontal and vertical standard deviation of the turbulent velocity was defined from

$$\sigma_{XY} = \sqrt{\overline{u'^2}} = \sqrt{4.50u_*^2}, \quad (21)$$

$$\sigma_Z = \sqrt{\overline{w'^2}} = \sqrt{2.50u_*^2}, \quad (22)$$