The Partnership of Weather and Air Quality

Roger A. Pielke Sr.
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

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AMS Definition of Weather

(http://amsglossary.allenpress.com/glossary/search?p=1&query=weather&submit=Search)

Weather —The state of the atmosphere, mainly with respect to its effects upon life and human activities.

As distinguished from climate, weather consists of the short-term (minutes to days) variations in the atmosphere. Popularly, weather is thought of in terms of temperature, humidity, precipitation, cloudiness, visibility, and wind.

2. As used in the taking of surface weather observations, a category of individual and combined atmospheric phenomena that must be drawn upon to describe the local atmospheric activity at the time of observation.

AMS Definition of Atmospheric Chemistry

(http://amsglossary.allenpress.com/glossary/search?p=1&query=atmospheric+chemistry&submit=Search)

Atmospheric chemistry —The study of the composition of and chemical transformations occurring in the atmosphere.

The discipline of atmospheric chemistry includes field measurements, computer modeling, and laboratory measurements, and requires an understanding of the interaction of the atmosphere with the biosphere and anthropogenic influences in order to be able to explain current conditions and to predict future changes.

AMS Definition of Air Quality

- None

AMS Definition of Climate

(http://amsglossary.allenpress.com/glossary/search?p=1&query=climate&submit=Search)

Climate —The slowly varying aspects of the atmosphere–hydrosphere–land surface system.

It is typically characterized in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities. Climatic classifications include the spatial variation of these time-averaged variables. Beginning with the view of local climate as little more than the annual course of long-term averages of surface temperature and precipitation, the concept of climate has broadened and evolved in recent decades in response to the increased understanding of the underlying processes that determine climate and its variability. *See also* climate system, climatology, climate change, climatic classification.

AMS Definition of Climate System

(http://amsglossary.allenpress.com/glossary/search?id=climate-system1)

Climate system —The system, consisting of the atmosphere, hydrosphere, lithosphere, and biosphere, determining the earth's climate as the result of mutual interactions and responses to external influences (forcing).

Physical, chemical, and biological processes are involved in the interactions among the components of the climate system

AMS Definition of Air Pollutants

(http://amsglossary.allenpress.com/glossary/search?id=air-pollution1)

Air pollution —The presence of substances in the atmosphere, particularly those that do not occur naturally.

These substances are generally contaminants that substantially alter or degrade the quality of the atmosphere. The term is often used to identify undesirable substances produced by human activity, that is, anthropogenic air pollution. Air pollution usually designates the collection of substances that adversely affects human health, animals, and plants; deteriorates structures; interferes with commerce; or interferes with the enjoyment of life. *Compare* airborne particulates, designated pollutant, particulates, criteria pollutants.

National Research Council Definition of Climate

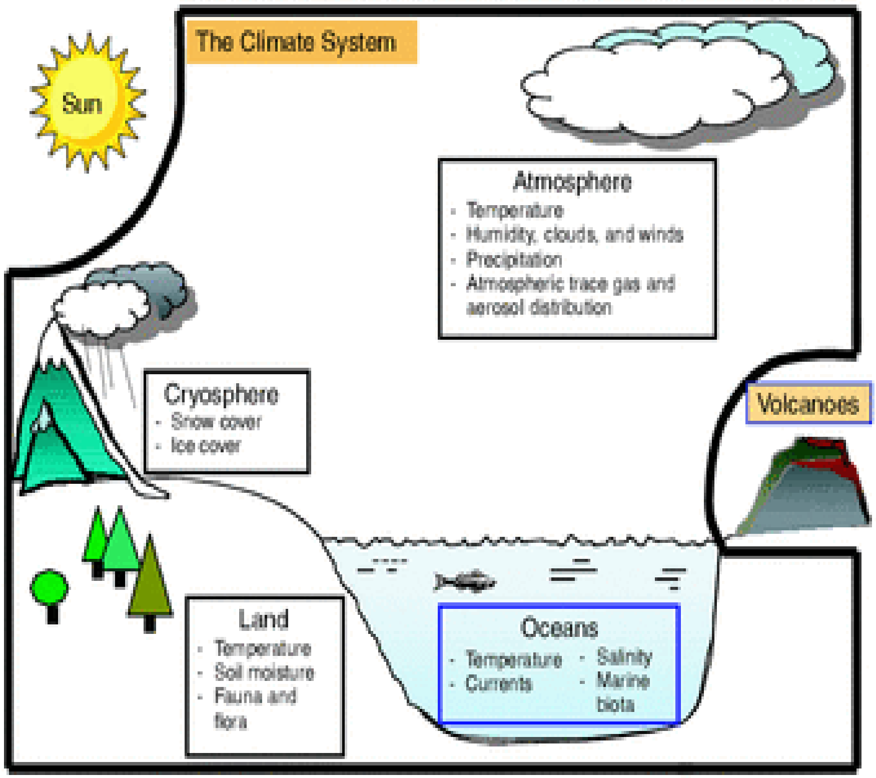

FIGURE 1-1 The climate system, consisting of the atmosphere, oceans, land, and cryosphere. Important state variables for each sphere of the climate system are listed in the boxes. For the purposes of this report, the Sun, volcanic emissions, and human-caused emissions of greenhouse gases and changes to the land surface are considered external to the climate system.

National Research Council, 2005: Radiative forcing of climate change: Expanding the concept and addressing uncertainties. Committee on Radiative Forcing Effects on Climate Change, Climate Research Committee, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, The National Academies Press, Washington, D.C., http://www.nap.edu/books/0309095069/html/12.html

What Have We Learned Over The Last 50 Years?

Definition of Dispersion and Requirements

- ***Dispersion*** = Turbulent Mixing + Differential Advection
- ***Non-Reactive Gases and Aerosols***: realistic atmospheric concentrations requires accurate determinations of dispersion down to the spatial scale of the actual concentrations
- ***Reactive Gases and Aerosols***: realistic atmospheric concentrations require accurate determinations of dispersion down to the spatial scales of the actual concentrations in which the chemistry is occurring.
- ***Dry Deposition*** requires assessment of surface turbulent fluxes (not just a “deposition velocity”).

Limitations of Gaussian Puff and Plume Models With Significant Large-Scale Wind Flow

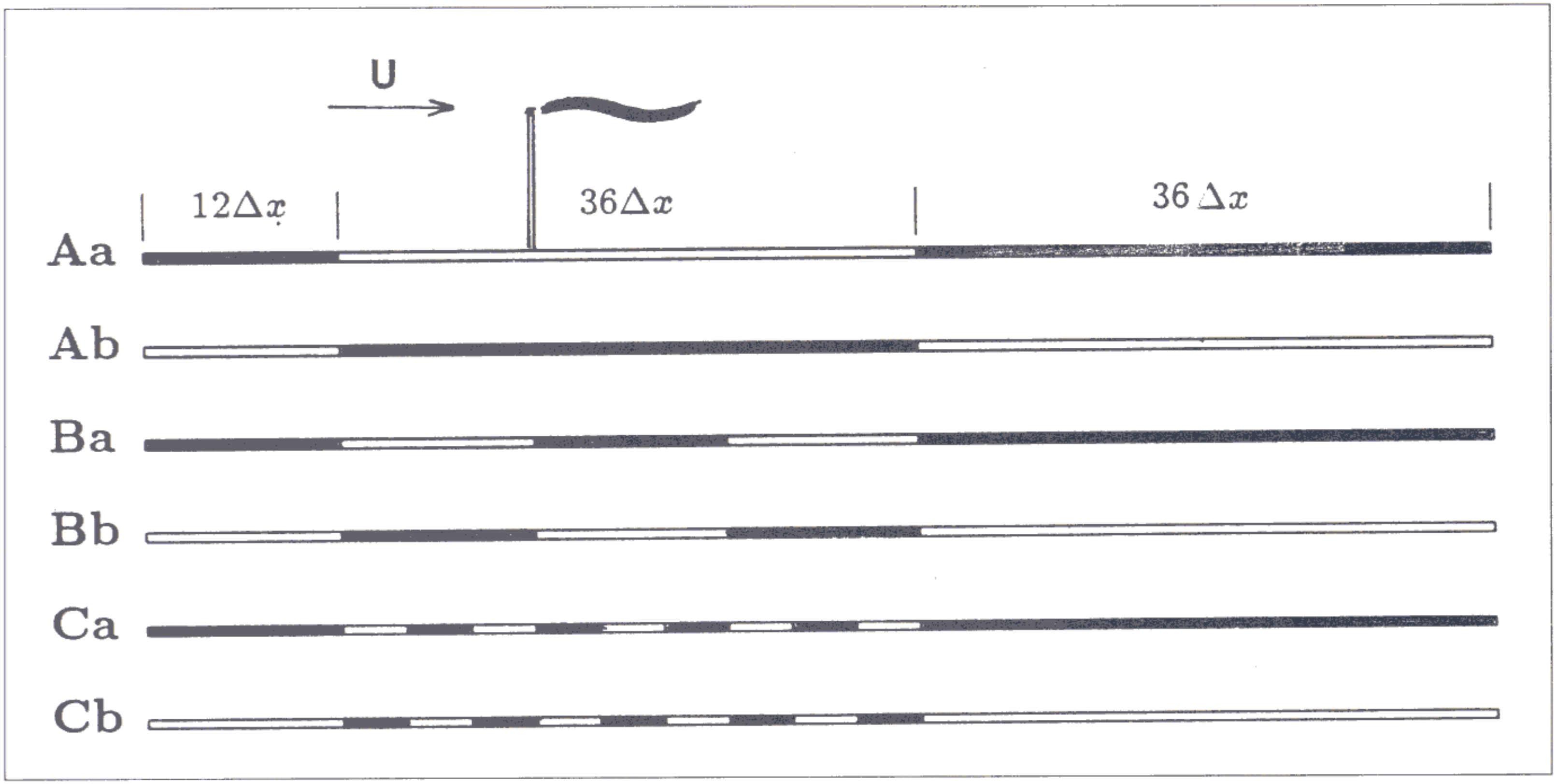

Figure 2: Terrain configuration used in meteorological simulations with indicated location of an emission source. Black segments - initial soil water content η_0 = 30 percent η_{sat}, white segments η_0 = 50 percent η_{sat}.

Pielke, R.A. and M. Uliasz, 1993: Influence of landscape variability on atmospheric dispersion. J. Air Waste Mgt., 43, 989-994.

http://blue.atmos.colostate.edu/publications/pdf/R-142.pdf

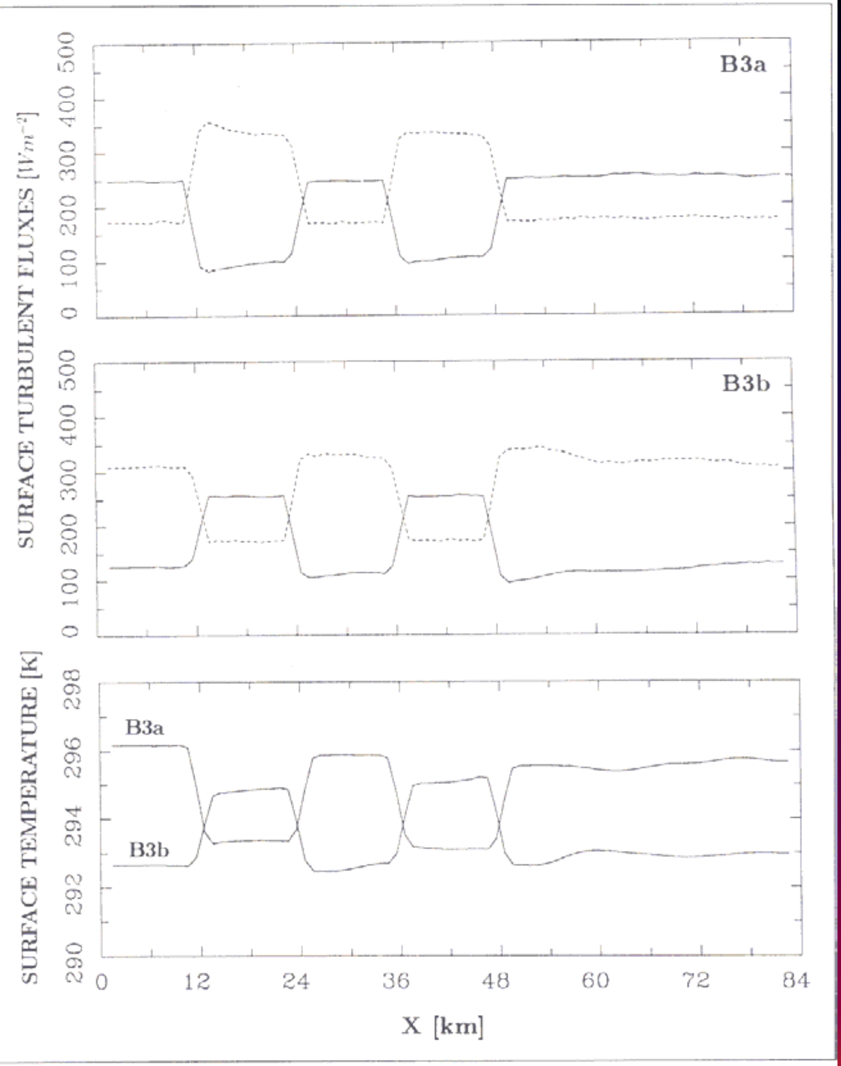

Figure 3: Surface turbulent fluxes (solid line - sensible flux, dashed line - latent flux) and surface temperature for meteorological simulations B3a and B3b at 1500 LST.

Pielke, R.A. and M. Uliasz, 1993: Influence of landscape variability on atmospheric dispersion. J. Air Waste Mgt., 43, 989-994. http://blue.atmos.colostate.edu/publications/pdf/R-142.pdf

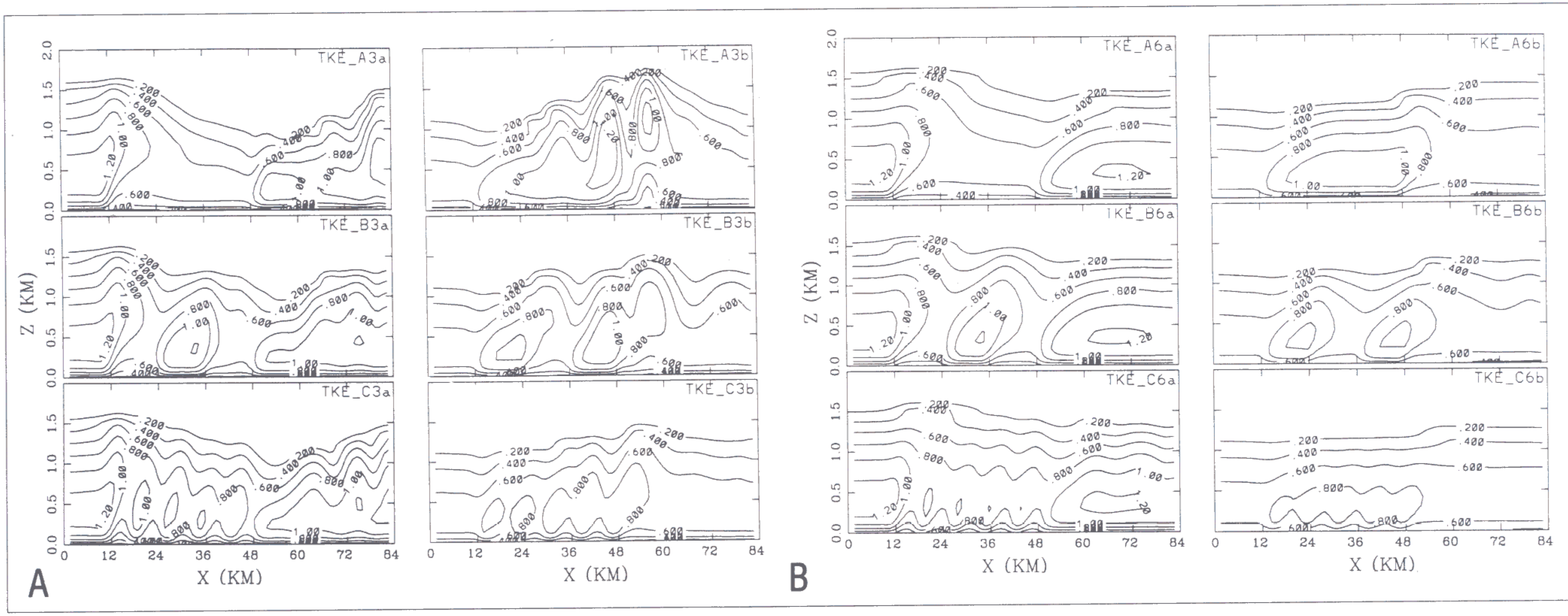

Figure 5: XZ cross section of turbulent kinetic energy (m^2s^{-2}) for each meteorological simulation with heterogeneous landscape at 1500 LST.

Pielke, R.A. and M. Uliasz, 1993: Influence of landscape variability on atmospheric dispersion. J. Air Waste Mgt., 43, 989-994.

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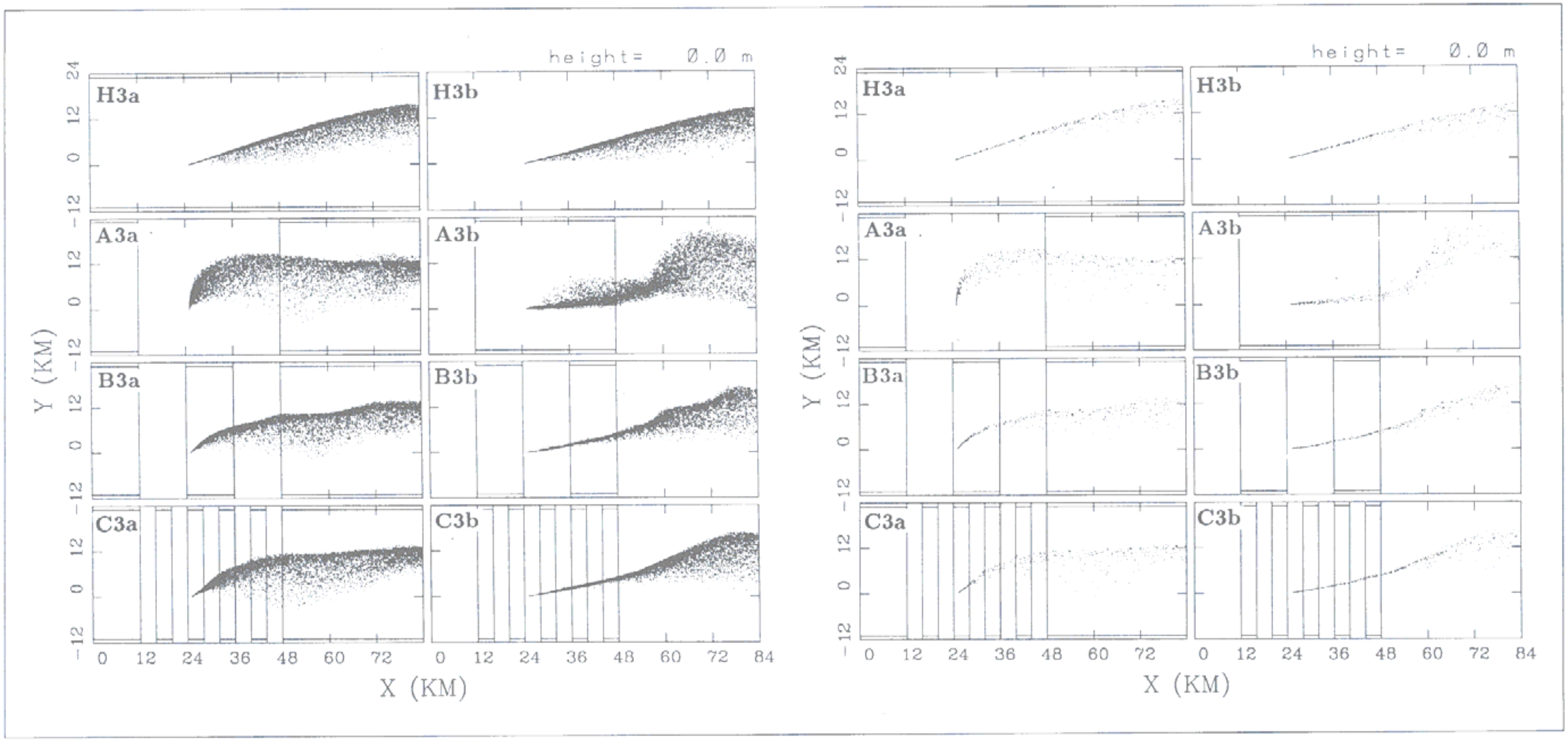

Figure 6: Particle distributions in XY plane for $U = 3$ m s^{-1} at 1500 LST: (a) all particles, (b) particles in the lowest 50 m contributing to surface concentration (segments of dry land are marked by horizontal lines).

Pielke, R.A. and M. Uliasz, 1993: Influence of landscape variability on atmospheric dispersion. J. Air Waste Mgt., 43, 989-994.

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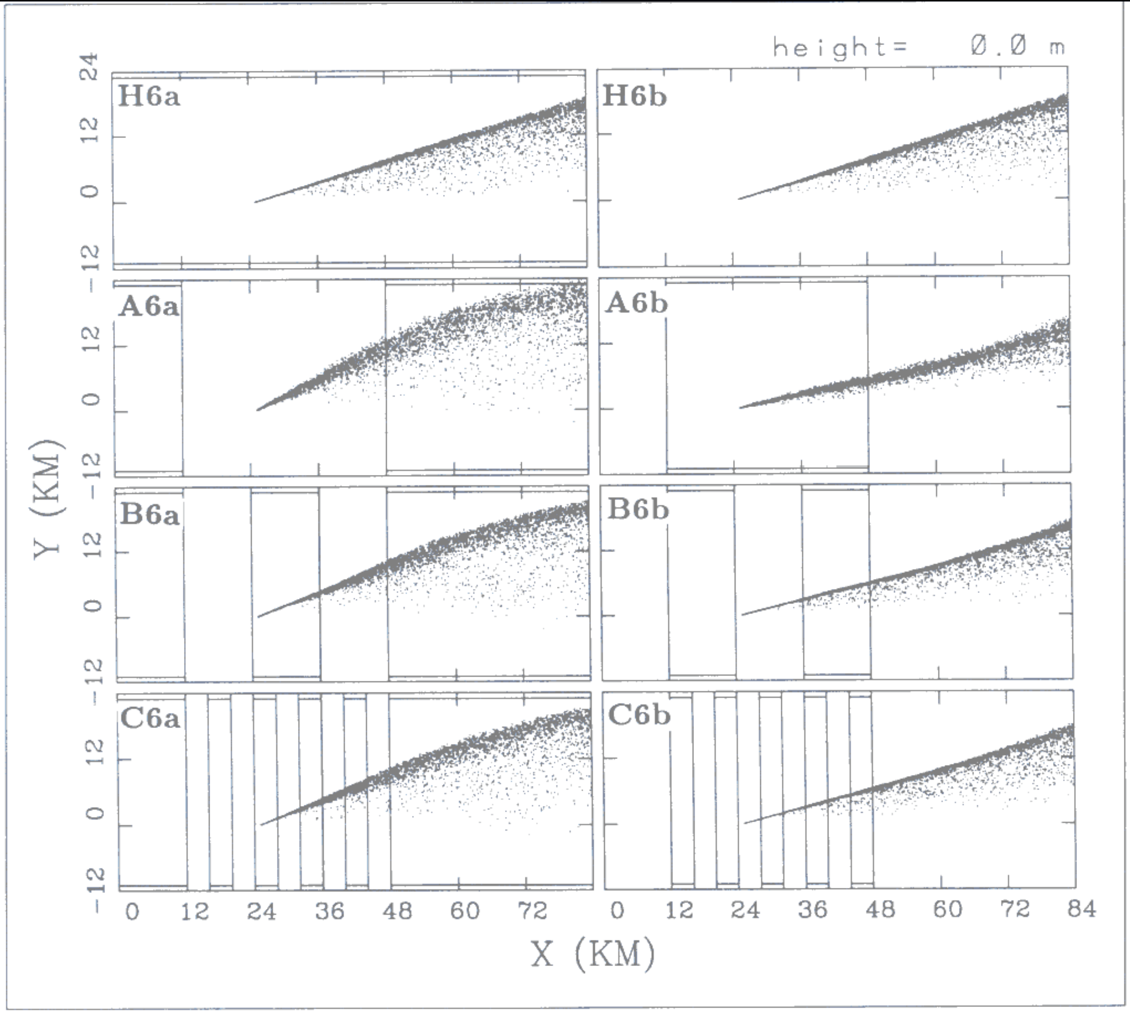

Figure 7: Particle distributions in XY plane for $u = 6\ m\ s^{-1}$ at 1500 LST (segments of dry land are marked by horizontal lines).

Pielke, R.A. and M. Uliasz, 1993: Influence of landscape variability on atmospheric dispersion. J. Air Waste Mgt., 43, 989-994.

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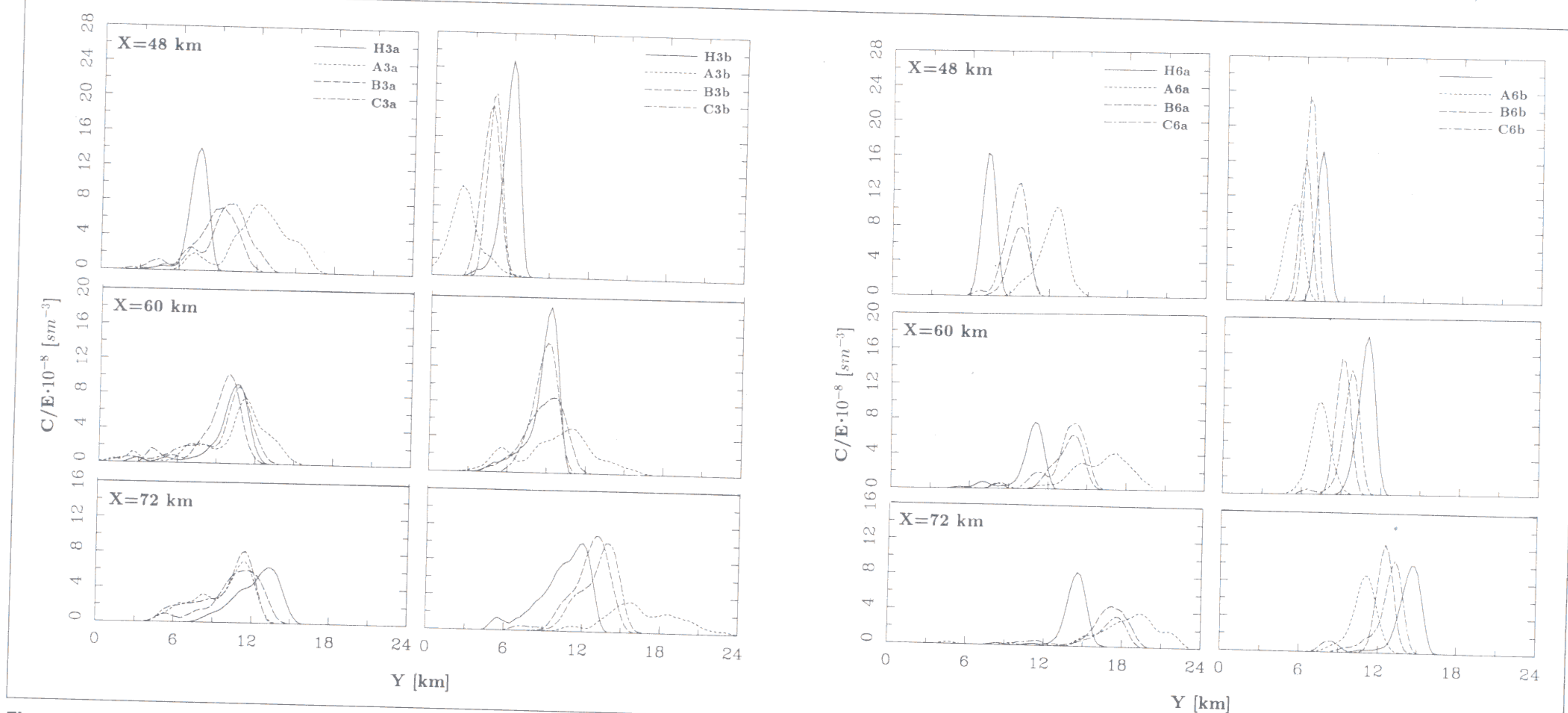

Figure 8: Comparison of surface concentration normalized by emission rate, C/E x $10^8[sm^{-3}]$, profiles in *y*-direction obtained from the different simulations at several distances. Concentration is averaged over the time interval 1430—1530 LST: (a) $U = 3$ m s^{-1}, (b) $U = 6$ m s^{-1}.

Pielke, R.A. and M. Uliasz, 1993: Influence of landscape variability on atmospheric dispersion. J. Air Waste Mgt., 43, 989-994.

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Table I: Maximum values of surface concentration normalized by emission rate, $C_{max}/E*10^8\,[sm^{-3}]$ for the different landscape and meteorological cases at several downwind distances. Note the secondary maxima in the homogeneous strong wind cases resulting from fumigation of the plume down to the surface at those distances.

X [km]	Downwind Distance	Dry Soil Inflow Cases				Moist Soil Inflow Cases				U [ms⁻¹]
		H3a	A3a	B3a	C3a	H3b	A3b	B3b	C3b	
36	12	22.49	7.84	13.51	14.17	30.00	26.69	26.32	31.89	3
48	24	14.01	7.76	7.72	7.75	24.86	10.29	19.52	20.95	
60	36	9.09	7.57	10.21	8.85	18.92	5.04	8.60	14.83	
72	48	6.38	7.00	5.99	8.20	10.08	3.43	10.91	10.08	
84	60	5.70	7.72	6.52	7.12	4.45	0.91	2.02	2.45	
		H6a	A6a	B6a	C6a	H6b	A6b	B6b	C6b	
36	12	22.49	17.57	25.91	17.01	33.16	22.40	30.08	23.72	6
48	24	16.27	10.18	7.97	12.90	17.19	11.09	16.18	23.40	
60	36	7.61	4.19	6.18	7.49	18.00	10.49	15.43	14.15	
72	48	8.44	3.82	4.63	3.45	10.00	8.80	12.38	10.56	
84	60	5.70	4.20	4.56	2.52	6.88	5.08	6.87	5.84	

Pielke, R.A. and M. Uliasz, 1993: Influence of landscape variability on atmospheric dispersion. J. Air Waste Mgt., 43, 989-994.

http://blue.atmos.colostate.edu/publications/pdf/R-142.pdf

Conclusion for Significant Large-Scale Winds

- With significant synoptic flow, dispersion is enhanced over heterogeneous terrain as contrasted with the same flow over homogeneous terrain.
- The importance of the heterogeneity becomes less as the wind speed increases and/or the spatial scale of the heterogeneity becomes smaller.
- The use of standard Gaussian plume or puff models in heterogeneous landscapes will lead to erroneous estimates of concentrations.

Limitations of Gaussian Puff and Plume Models With Light Large-Scale Wind Flow

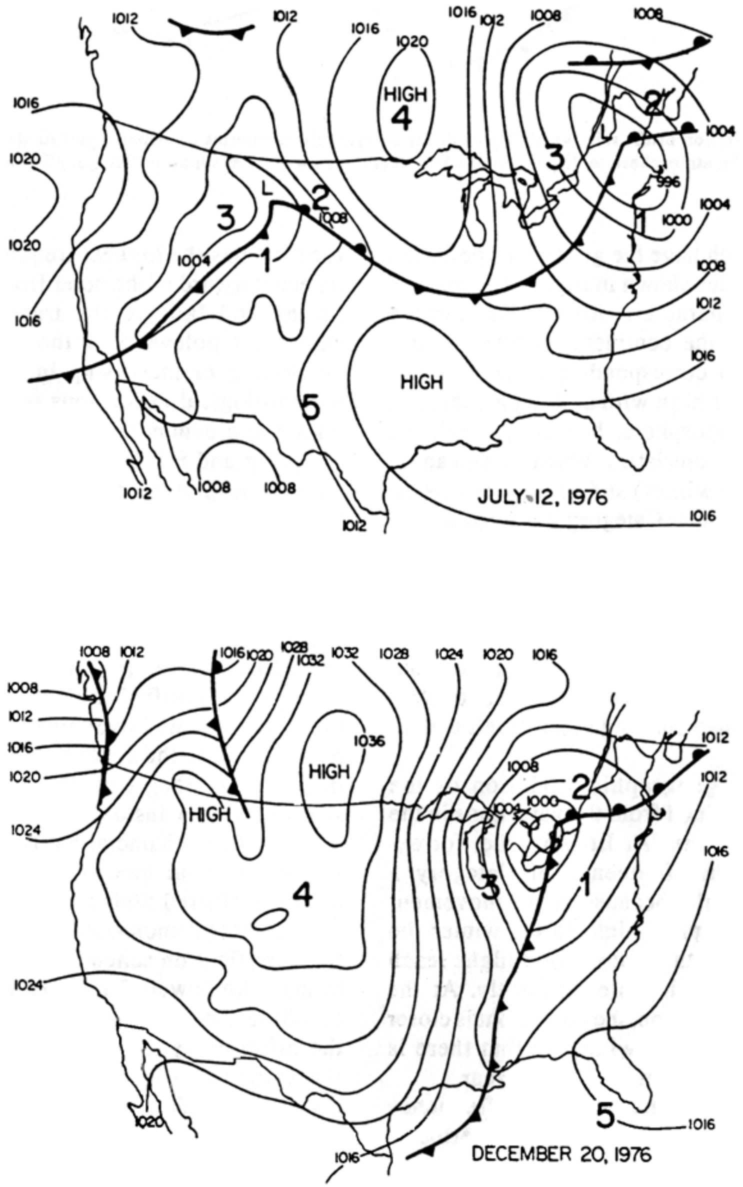

Fig. 2. Example of a surface analysis chart for 12 July 1976 and 20 December 1976 showing the application of the synoptic climatological model for the five synoptic classes listed in Table 1 (Pielke et al. 1987).

From: Pielke, R.A., R.A. Stocker, R.W. Arritt, and R.T. McNider, 1991: A procedure to estimate worst-case air quality in complex terrain. Environment International, 17, 559-574.

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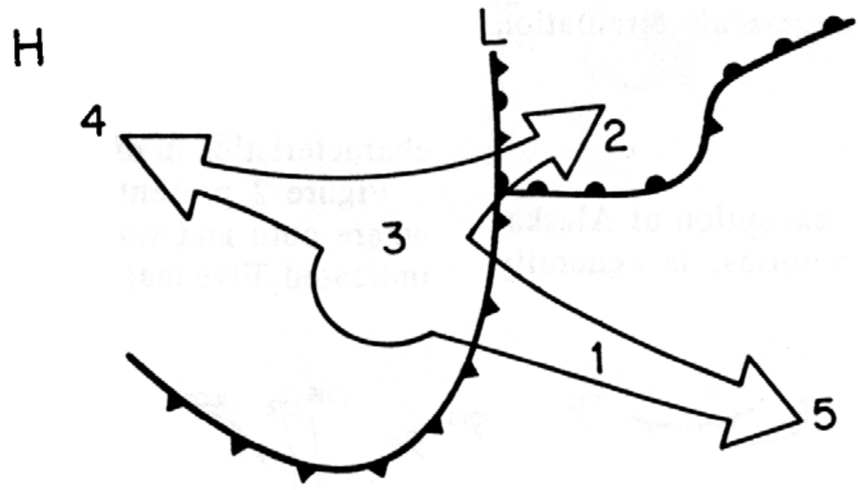

Fig. 3. Schematic illustration of the relative ability of different synoptic categories to disperse pollutants emitted near the ground. The ability of the atmosphere to disperse pollutants decreases away from synoptic Category 3 (Pielke et al. 1985).

From: Pielke, R.A., R.A. Stocker, R.W. Arritt, and R.T. McNider, 1991: A procedure to estimate worst-case air quality in complex terrain. Environment International, 17, 559-574.
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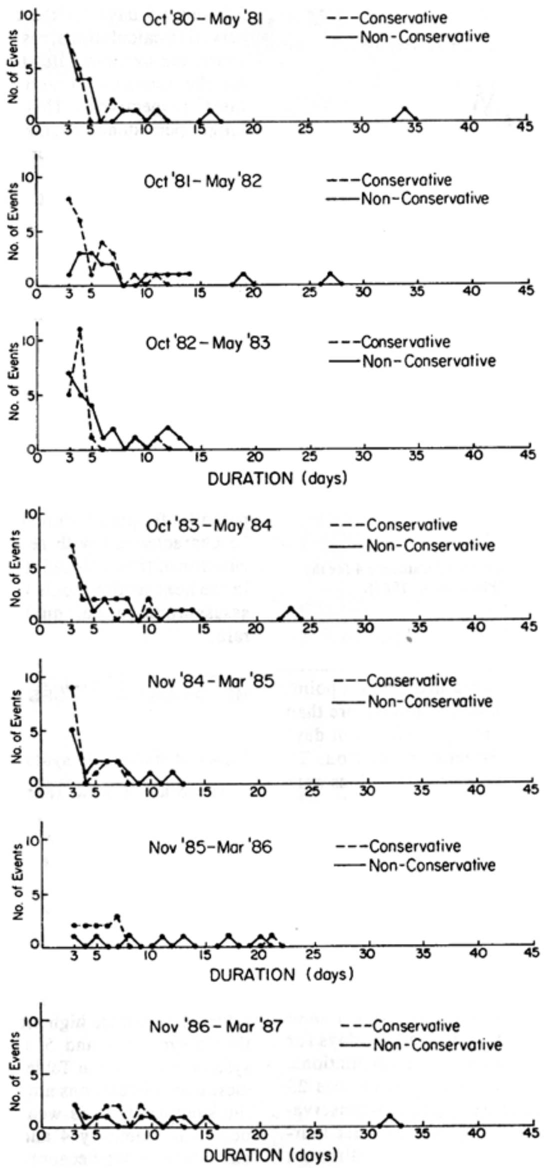


Fig. 7. Duration and number of events of Category 4 for an area representing Lake Powell, Utah. See text for definitions of conservative and non-conservative.

From: Pielke, R.A., R.A. Stocker, R.W. Arritt, and R.T. McNider, 1991: A procedure to estimate worst-case air quality in complex terrain. Environment International, 17, 559-574.

http://blue.atmos.colostate.edu/publications/pdf/R-118.pdf

Algorithm to estimate air quality degradation due to trapping

Despite the lack of attention by the regulatory agencies to trapping valleys, a very simple algorithm can be used to estimate potential or actual pollution impacts due to local sources within such a valley. This algorithm can be expressed

$$C = E\,t/(\Delta x\,\Delta y\,\Delta z) \tag{1}$$

where $\Delta x \Delta y \Delta z$ is the volume into which pollution is input at a rate of E over a time period t and C is the concentration of the pollution (i.e., mass per unit volume). The dimensions Δx and Δy could correspond to the horizontal dimensions of a valley, or to that portion of the valley over which the pollution spreads, while Δz would be the layer in the atmosphere into which the pollution is ejected. In a daytime, well-mixed boundary layer, this layer would correspond to the distance from the surface to the inversion height, whereas in a stable, stratified pool of cold air, this would correspond to some fraction of the inversion height. The time, t, would correspond to the length of time (i.e., persistence) of the trapped circulation, while E is the input of pollution above some baseline (which could be zero). C represents the maximum uniformly distributed concentration of an elemental chemical (e.g., sulfur, carbon) over the volume $\Delta x \Delta y \Delta z$ since deposition to the surface is ignored. While this conceptually simple model needs to be validated, it is a plausible approach to represent pollution build-up in trapping valleys.

In order to illustrate the use of Eq. (1) to assess air quality impacts for a valley which acts to some extent as a trapping valley, the possible effects of a source in the Grand Valley of Colorado near Grand Junction on Colorado National Monument will be assessed for a typical wintertime stagnation event. The variables in Eq. (1) are defined as

From: Pielke, R.A., R.A. Stocker, R.W. Arritt, and R.T. McNider, 1991: A procedure to estimate worst-case air quality in complex terrain. Environment International, 17, 559-574.
http://blue.atmos.colostate.edu/publications/pdf/R-118.pdf

$$
\begin{aligned}
\Delta z &= \beta z_i = \beta(2\,\mathrm{km}) \quad \beta \leq 1 \\
\Delta y &= 20\ \mathrm{km} \\
\Delta x &= \alpha \Delta y \qquad\qquad \alpha > 1 \\
t &= 9\ \mathrm{days} \\
E &= 25\mathrm{g\ s^{-1}\ of\ S}
\end{aligned}
\tag{2}
$$

where the sulfur is primarily in the form of SO_2.

In Eq. (2), β represents the fraction of the inversion height into which the pollution is input and diffused. The inversion height is estimated from the climatological analyses of Hanson and McKee (1983), and is below the elevation of the valley sides. The distance Δy is the approximate width of the valley, while α represents the distance of pollution dispersal along the valley with respect to the valley width. The time, *t*, of an episode is selected as nine days based on the information discussed in Section 2. E is a realistic estimate of SO_2 input from a relatively small industrial facility. Using these values, Eq. (l) can be rewritten as

$$
C\left(\mathrm{g\ m^{-3}}\right) = \frac{\left(2.43 \times 10^{-5}\right)}{\alpha\beta} \tag{3}
$$

The 24-h primary air quality standard for SO_2 at a Class I air quality area in the United States is expected to be the most sensitive to violation as a result of a nine-day stagnation event. The 24-h standard is 5×10^{-6} g m^{-3}. Thus Eq. (3) indicates a violation if the volume covered by Δ*x* Δ*y* Δ*z* includes a Class I area and $\alpha\beta < 5$.

Colorado National Monument has been categorized as a state of Colorado equivalent to a Federal Class I area for SO_2. The state nomenclature refers to it as a Category I area. Thus depending on the values of α and β, and the site of the emission with respect to the Monument, a violation could be shown to exist.

Table 3 illustrates values of *C* for different values of α and β. In a stable layer of pooled air, it is expected that β would be on the order of 10% of the inversion height since a surface non-buoyant emission would tend to be confined close to the ground while an elevated release would stabilize around the effective stack height (as long as the effective stack height remains below the inversion). The along valley direction for the example is more difflcult to estimate, however, but a distance of 200 km (α = 10) is likely to represent the largest horizontal area covered.

From: Pielke, R.A., R.A. Stocker, R.W. Arritt, and R.T. McNider, 1991: A procedure to estimate worst-case air quality in complex terrain. Environment International, 17, 559-574. http://blue.atmos.colostate.edu/publications/pdf/R-118.pdf

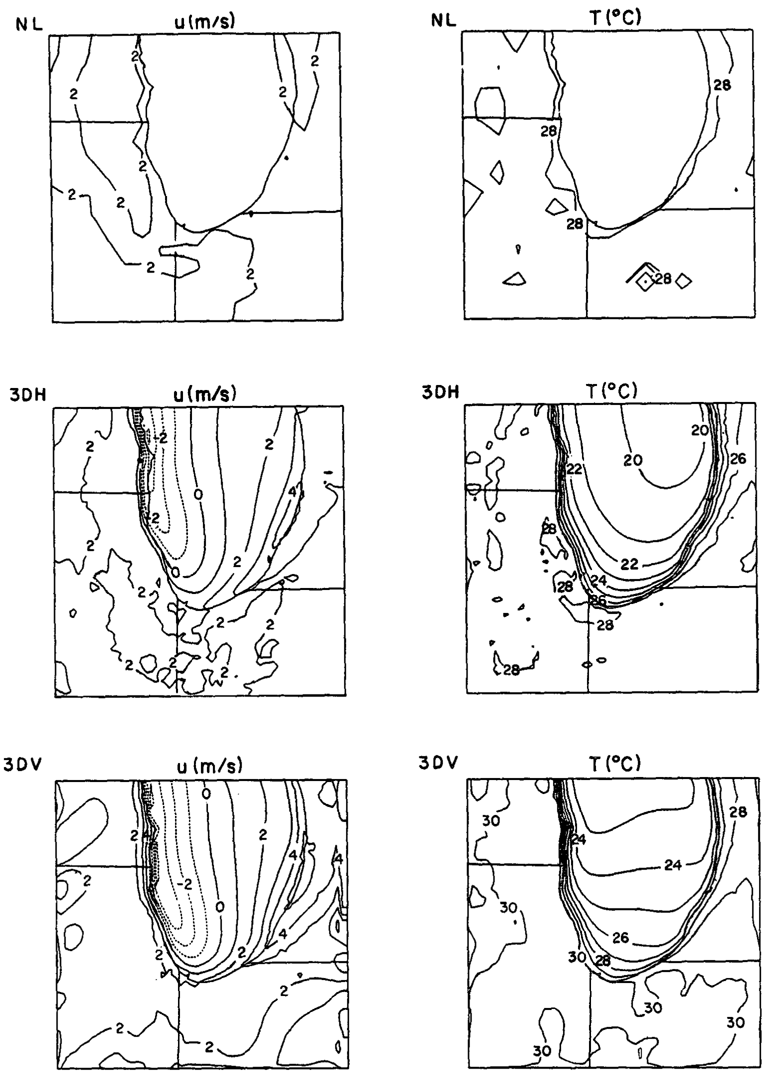


FIG. 9. Left-hand column: horizontal cross section (X–Y) at 10 m above ground level of east–west component of velocity U (m s^{-1}) contoured from −5 to 15 in 1 m s^{-1} intervals. Right-hand column: horizontal cross section (X–Y) at 10 m above ground level temperature from 15° to 30°C in 1°C intervals at 1300 LST. The top two panels are from the NL simulations (16-km grid), middle two panels are from the 3DH simulation (4-km grid), and the bottom two panels are from the 3DV simulation (4-km grid).

From: Eastman, J.L. R.A. Pielke, and W.A. Lyons, 1995: Comparison of lake-breeze model simulations with tracer data. J. Appl. Meteor., 34, 1398-1418. http://blue.atmos.colostate.edu/publications/pdf/R-197.pdf

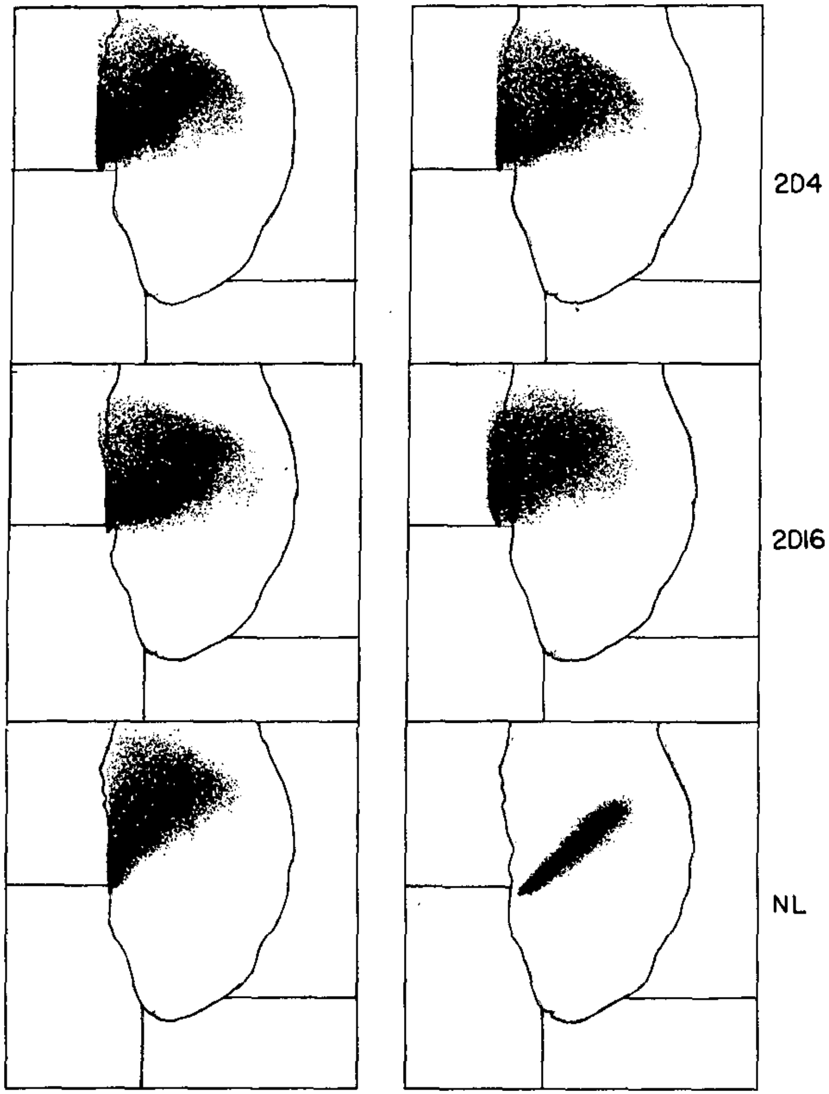


FIG. 15. Horizontal cross section (X–Y) at 10 m above ground level of LPDM plume at 1741 LST, 5 h after release.

From: Eastman, J.L. R.A. Pielke, and W.A. Lyons, 1995: Comparison of lake-breeze model simulations with tracer data. J. Appl. Meteor., 34, 1398-1418.
http://blue.atmos.colostate.edu/publications/pdf/R-197.pdf

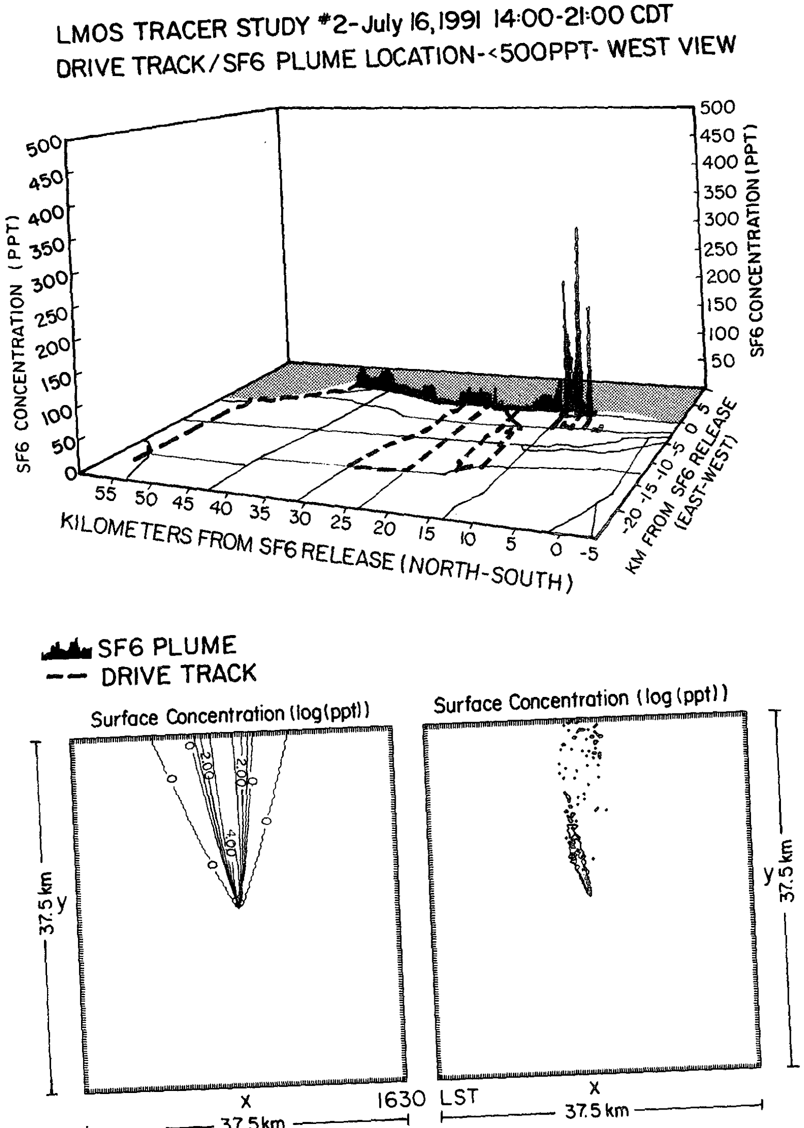


FIG. 17. Perspective view of (a) Observations from a mobile van from 1300 to 2000 LST. Values are in ppt (Wilkerson 1991). (b) Surface isopleths in log(ppt). Left—ISCST; right—LPDM. The two panels taken at 1600 LST. Domain size is 37.5 km × 37.5 km.

From: Eastman, J.L. R.A. Pielke, and W.A. Lyons, 1995: Comparison of lake-breeze model simulations with tracer data. J. Appl. Meteor., 34, 1398-1418. http://blue.atmos.colostate.edu/publications/pdf/R-197.pdf

TABLE 2. Summary of LPDM recirculation data.

Run name	Ratio of recirculations to total particles	Percent of particles undergoing recirculation
2D16	0.88	70
2D4	1.0	80
2D2	1.05	82
3DH	1.05	76
3DV	1.00	67
NL	0	0

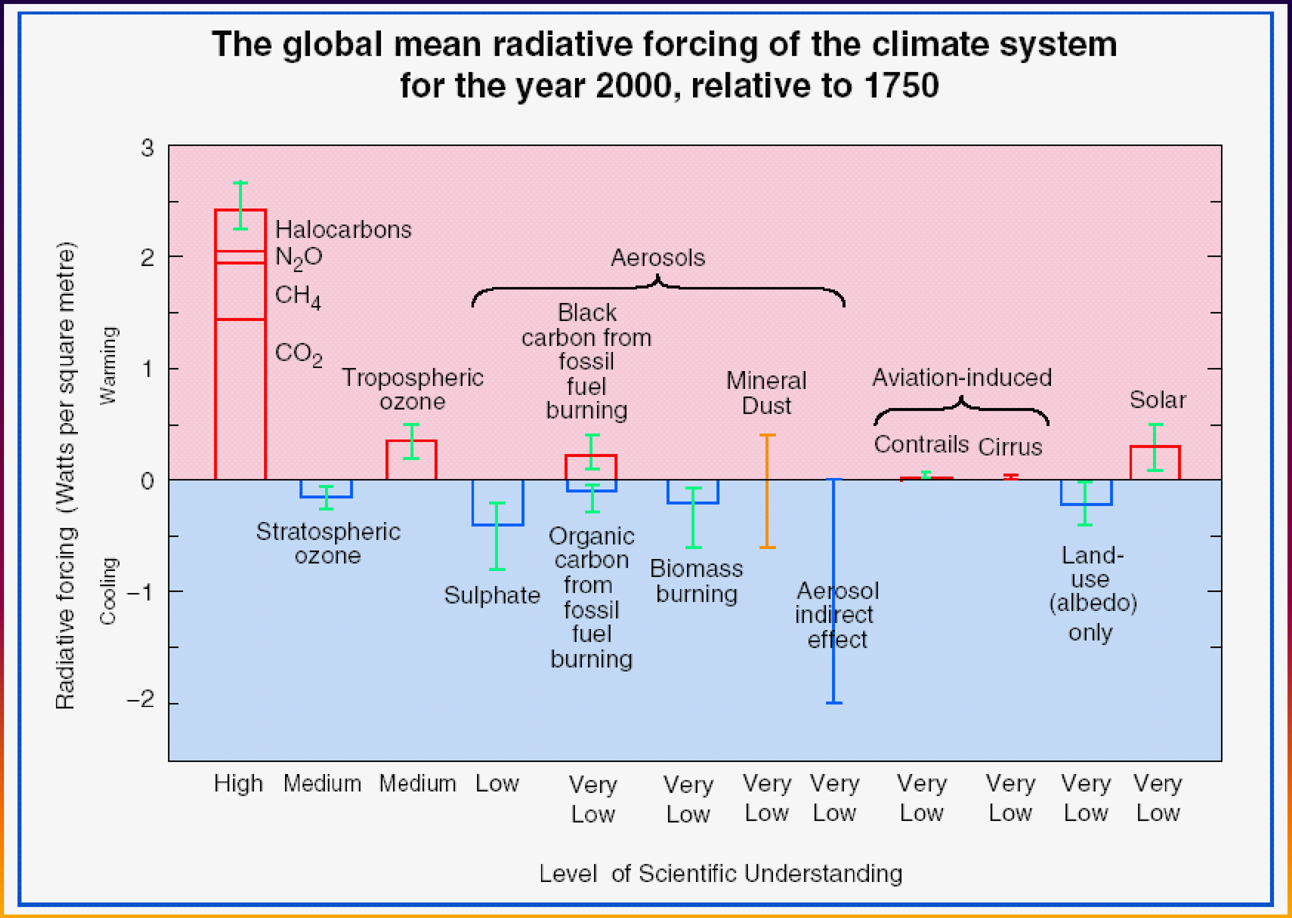
From: Eastman, J.L. R.A. Pielke, and W.A. Lyons, 1995: Comparison of lake-breeze model simulations with tracer data. J. Appl. Meteor., 34, 1398-1418. http://blue.atmos.colostate.edu/publications/pdf/R-197.pdf

Conclusion for Light Large-Scale Winds

- Inability of Gaussian puff and plume models to include recirculation.
- Under light large-scale flow, dispersion estimates from Gaussian puff and plume models overestimate dispersion in heterogeneous terrain.

Climate is Becoming a Integrator of Weather and Atmospheric Chemistry

Estimated radiative forcings since preindustrial times for the Earth and Troposphere system (TOA) radiative forcing with adjusted stratospheric temperatures). The height of the rectangular bar denotes a central or best estimate of the forcing, while each vertical line is an estimate of the uncertainty range associated with the forcing guided by the spread in the published record and physical understanding, and with no statistical connotation. Each forcing agent is associated with a level of scientific understanding, which is based on an assessment of the nature of assumptions involved, the uncertainties prevailing about the processes that govern the forcing, and the resulting confidence in the numerical values of the estimate. On the vertical axis, the direction of expected surface temperature change due to each radiative forcing is indicated by the labels "warming" and "cooling." From: National Research Council, 2005: Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Committee on Radiative Forcing Effects on Climate, Climate Research Committee, 224 pp. http://www.nap.edu/catalog/11175.html



From: National Research Council, 2005: Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Committee on Radiative Forcing Effects on Climate, Climate Research Committee, 224 pp. http://www.nap.edu/catalog/11175.html

TABLE 2-1 Well-Mixed Greenhouse Gases

	CO_2	CH_4	N_2O	CFC-11	HFC-23	CF_4
Preindustrial concentration	~280 ppm	~700 ppb	~270 ppb	0	0	40 ppt
Concentration in 1998	365 ppm	1745 ppb	314 ppb	268 ppt	14 ppt	80 ppt
Rate of concentration change[a]	1.5 ppm/yr[b]	7.0 ppb/yr[b]	0.8 ppb/yr	−1.4 ppt/yr	0.55 ppt/yr	1 ppt/yr
Atmospheric lifetime	5 to 200 yr[c]	12 yr[d]	114 yr[d]	45 yr	260 yr	>50,000 yr

NOTE: CF_4 = perfluoromethane; CFC-11 = chlorofluorocarbon-11; HFC-23 = hydrofluorocarbon-23; ppm = parts per million; ppb = parts per billion; ppt = parts per trillion.

[a]Rate is calculated over the period 1990 to 1999.

[b]Rate fluctuated between 0.9 and 2.8 ppm yr^{-1} for CO_2 and between 0 and 13 ppb yr^{-1} for CH_4 over the period 1990 to 1999.

[c]No single lifetime can be defined for CO_2 because of coupling with surface reservoirs.

[d]This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

SOURCE: IPCC (2001).

From: National Research Council, 2005: Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Committee on Radiative Forcing Effects on Climate, Climate Research Committee, 224 pp. http://www.nap.edu/catalog/11175.html

TABLE 2-2 Overview of the Different Aerosol Indirect Effects Associated with Clouds

Effect	Cloud Type	Description	Sign of TOA Radiative Forcing
First indirect aerosol effect (cloud albedo or Twomey effect)	All clouds	For the same cloud water or ice content, more but smaller cloud particles reflect more solar radiation	Negative
Second indirect aerosol effect (cloud lifetime or Albrecht effect)	All clouds	Smaller cloud particles decrease the precipitation efficiency, thereby prolonging cloud lifetime	Negative
Semidirect effect	All clouds	Absorption of solar radiation by soot leads to evaporation of cloud particles	Positive
Glaciation indirect effect	Mixed-phase clouds	An increase in ice nuclei increases the precipitation efficiency	Positive
Thermodynamic effect	Mixed-phase clouds	Smaller cloud droplets inhibit freezing, causing supercooled droplets to extend to colder temperatures	Unknown
Surface energy budget effect	All clouds	The aerosol-induced increase in cloud optical thickness decreases the amount of solar radiation reaching the surface, changing the surface energy budget	Negative

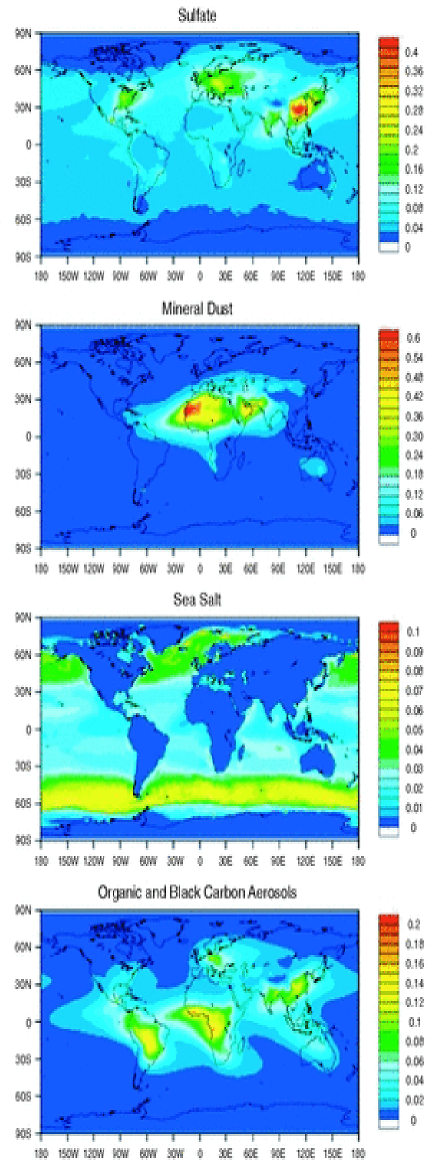


FIGURE 4-1 Annual mean aerosol optical depth predicted by an aerosol chemical transport model due to sulfate, mineral dust, sea salt, and organic and black carbon aerosols. SOURCE: Collins et al. (2002).

From: National Research Council, 2005: Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Committee on Radiative Forcing Effects on Climate, Climate Research Committee, 224 pp. http://www.nap.edu/catalog/11175.html

Summary of Aerosol Direct Radiative Forcing Effect

"The average global mean aerosol direct forcing from fossil fuel combustion and biomass burning is in the range from −0.2 to −2.0 W m−2 (IPCC, 2001). This large range results from uncertainties in aerosol sources, composition, and properties used in different models. Recent advances in modeling and measurements have provided important constraints on the direct effect of aerosols on radiation (Ramanathan et al., 2001a; Russell et al., 1999; Conant et al., 2003). Critical gaps, discussed further below, relate to spatial heterogeneity of the aerosol distribution, which results from the short lifetime (a few days to a week) against wet deposition; chemical composition, especially the organic fraction; mixing state and behavior (hygroscopicity, density, reactivity, and acidity); and optical properties associated with mixing and morphology (refractive index, shape, solid inclusions).

The chemical composition of particles is in general not well known."

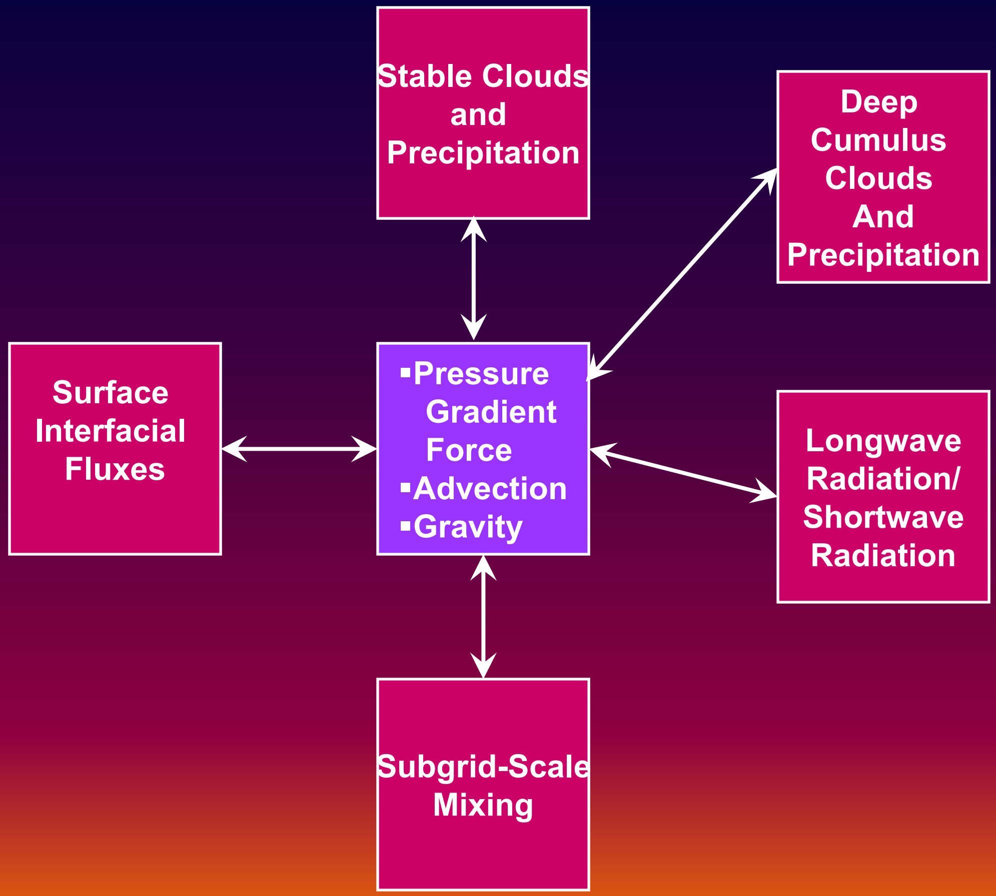
(from National Research Council, 2005: Radiative forcing of climate change: Expanding the concept and addressing uncertainties. Committee on Radiative Forcing Effects on Climate Change, Climate Research Committee, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, The National Academies Press, Washington, D.C., http://www.nap.edu/books/0309095069/html/35.html)

Challenges for the Future

Model Issues

- The only basic physics in atmospheric models are advection and the pressure gradient force.
- All other components of the models are parameterized as column or box modules using tunable coefficients and functions.
- The tuning is completed for idealized situations (i.e., “golden days”).
- There is a mismatch between the model grid volume and the observed volume of measurement.
- There is a mismatch between the atmospheric model grid volume and what is required for accurate reactive chemistry.

All Parameterizations are 1-D Column Models



Parameterizations: pink boxes

Dynamic Core: purple box

7.3.3.3 Parameterization Complexity

It is useful to dissect a parameterization algorithm to determine the number of dependent variables and adjustable and universal parameters that are introduced. This dissection can be illustrated through the following simple example. Holtslag and Boville (1993) and Tijm et al. (1999a) propose the following form for K_θ above the boundary layer:

$$K_\theta = l_\theta^2 S F_\theta(\mathrm{Ri}), \tag{7-63}$$

$$\frac{1}{l_\theta} = \frac{1}{kz} + \frac{1}{\lambda_\theta}, \tag{7-64}$$

$$S = \left|\frac{\partial \vec{V}}{\partial z}\right|, \tag{7-65}$$

and

$$F_\theta(\mathrm{Ri}) = \begin{cases} (1-18\ \mathrm{Ri})^{1/2}, & \mathrm{Ri} \le 0 \\ 1/(1+10\ \mathrm{Ri}\ +80\ \mathrm{Ri}^2), & \mathrm{Ri} > 0, \end{cases} \tag{7-66}$$

$$\lambda_\theta = \begin{cases} 300\ \mathrm{m}, \quad z \le 1\,\mathrm{km} \\ 30\ \mathrm{m} + 270\exp(1-(z/1000\ \mathrm{m})). \end{cases} \tag{7-67}$$

This formulation for K_θ includes the following dependent variables, parameters, and prescribed constants:

- In Eq. (7-63), the dependent variables l_θ, S, and F_θ define K_θ.
- In Eq. (7-64), l_θ is defined with the independent variable z, the dependent variable λ_θ, and the parameter k.
- In Eq. (7-65), S is defined by the vertical gradient of $\vec{V}$.
- In Eq. (7-66), F_θ (Ri) is defined by the dependent variable Ri [which is defined by Eq. (7-8)] and the constants 18, 10, and 80 and the exponent 1/2.
- In Eq. (7-67), λ_θ is defined by the independent variable z and the constants 300, 30, 270, and 1000.

Therefore, to represent the term K_θ, in addition to the fundamental variables $\bar{u}_i$ and $\bar{\theta}$, one parameter (k) and eight constants (18, 10, 80, 1/2, 300, 30, 270, 1000) must be provided.

A sensitivity analysis can be applied to show how K_θ responds to slight changes in the dependent variables and constants. For example, in Eq. (7-67), if 100 m were used instead of 300 m when λ_θ dominates in Eq. (7-64), then K_θ would be 1/9 as large, since K_θ is proportional to l_θ^2. Clearly, the form of

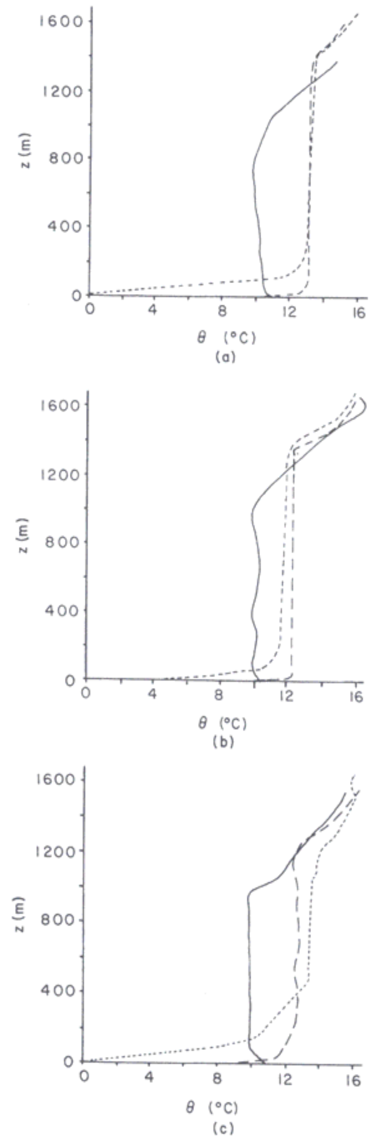


Fig. 7-10. Comparison of predictions using (a) higher-order closure (André *et al.* 1978) for Day 33–34 of the Wangara Experiment, (b) first-order closure (McNider and Pielke 1981), and (c) observational data presented by André *et al.* (1978). The solid and dashed lines correspond to 1200 LST and 1800 LST on Day 33; the dotted line corresponds to 0300 LST on Day 34.

$$\frac{\partial}{\partial t}\overline{u_k''u_i''} = -\bar{u}_j\frac{\partial}{\partial x_j}\overline{u_k''u_i''} - \overline{u_j''\frac{\partial}{\partial x_j}u_k''u_i''} - \overline{u_i''u_j''}\frac{\partial \bar{u}_k}{\partial x_j} - \overline{u_k''u_j''}\frac{\partial \bar{u}_i}{\partial x_j}$$
$$- \theta_0\overline{u_i''\frac{\partial \pi''}{\partial x_k}} - \theta_0\overline{u_k''\frac{\partial \pi''}{\partial x_i}} + \frac{g}{\theta_0}\delta_{k3}\overline{u_i''\theta''} + \frac{g}{\theta_0}\delta_{i3}\overline{u_k''\theta''}. \qquad (7\text{-}11)$$

$$\frac{\partial}{\partial t}\overline{u_i''\theta''} = -\bar{u}_j\frac{\partial}{\partial x_j}\overline{u_i''\theta''} - \overline{u_j''u_i''}\frac{\partial \bar{\theta}}{\partial x_j} - \overline{\theta''u_j''}\frac{\partial \bar{u}_i}{\partial x_j} - \overline{u_j''u_i''\frac{\partial \theta''}{\partial x_j}}$$
$$- \overline{\theta''u_j''\frac{\partial u_i''}{\partial x_j}} - \theta_0\overline{\theta''\frac{\partial \pi''}{\partial x_i}} + \frac{g}{\theta_0}\delta_{i3}\overline{\theta''^2} + \overline{u_i''S_\theta''}. \qquad (7\text{-}14)$$

$$
\begin{aligned}
\overline{w''\theta''} &= -K_\theta \frac{\partial \bar{\theta}}{\partial z} = -u_* \theta_*, \\
\overline{w'' q_n''} &= -K_q \frac{\partial \bar{q}_n}{\partial z} = -u_* q_{n_*}, \qquad (7\text{-}29) \\
\overline{w'' \chi_m''} &= -K_\chi \frac{\partial \overline{\chi}_m}{\partial z} = -u_* \chi_{m_*}.
\end{aligned}
$$

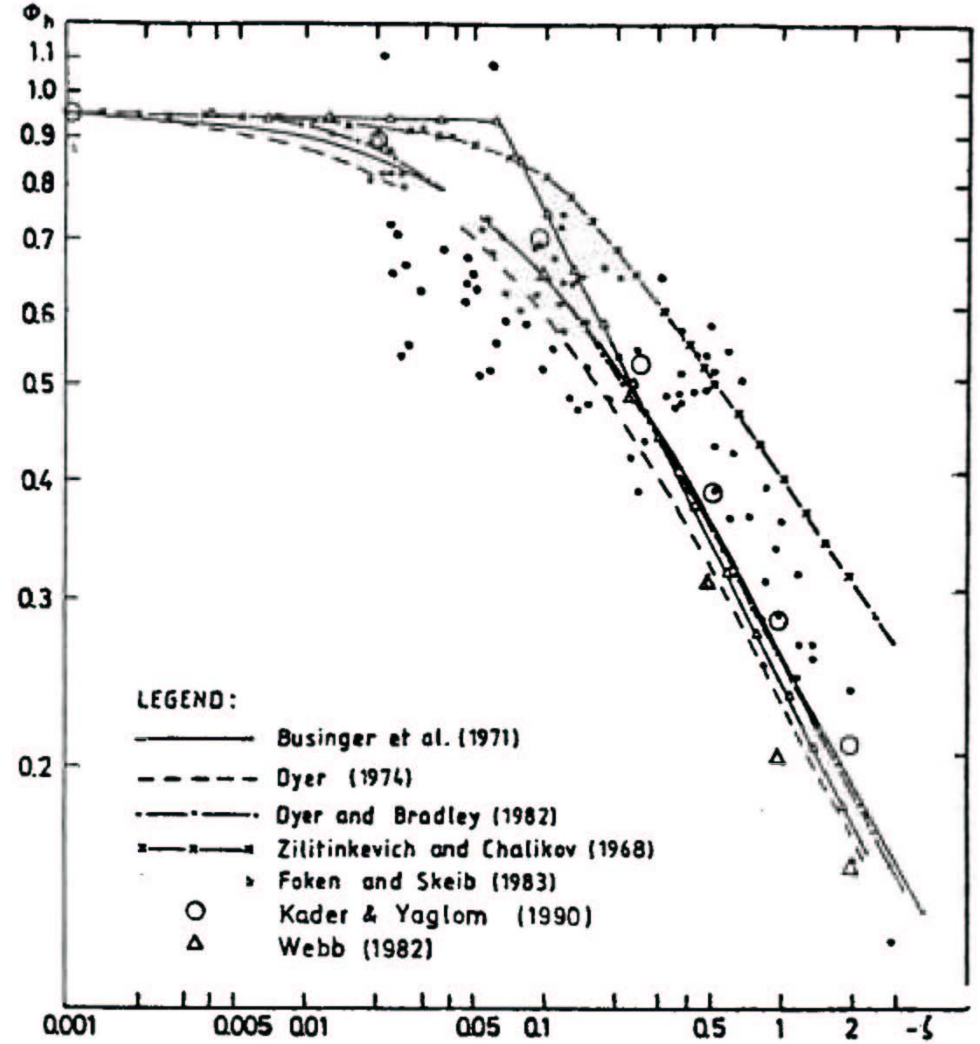


Fig. 7-5. As in Figure 7-3 except for ϕ_H. (From Högström 1996 with kind permission from Kluwer Academic Publishers.)

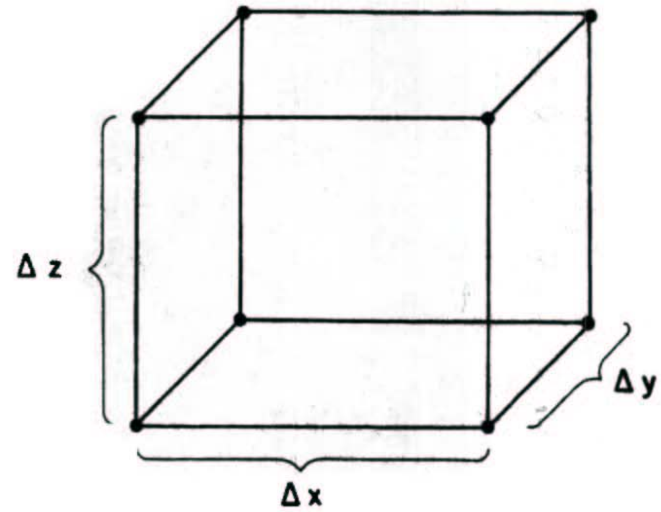


Fig. 4-1. A schematic of a grid volume. Dependent variables are defined at the corners of the rectangular solid.


N3070

Use of Look-Up Tables as a Computationally Efficient Procedure for Model Parameterizations (An Increase in Model Performance by a Factor Of 10 Times or More Without Any Loss of Accuracy).

Pielke Sr., R.A., T. Matsui, G. Leoncini, T. Nobis, U. Nair, E. Lu, J. Eastman, S. Kumar, C. Peters-Lidard, Y. Tian, and R. Walko, 2005: A new paradigm for parameterizations in numerical weather prediction and other atmospheric models. National Wea. Digest, accepted with minor revisions). (http://blue.atmos.colostate.edu/publications/pdf/R-296.pdf)

Model Opportunities

- Decomposition of model equations into linear and nonlinear components. The linear part is solved analytically.
- Diagnosis of the nonhydrostatic portion of an atmospheric system.
- Combined numerical and wind tunnel modeling.

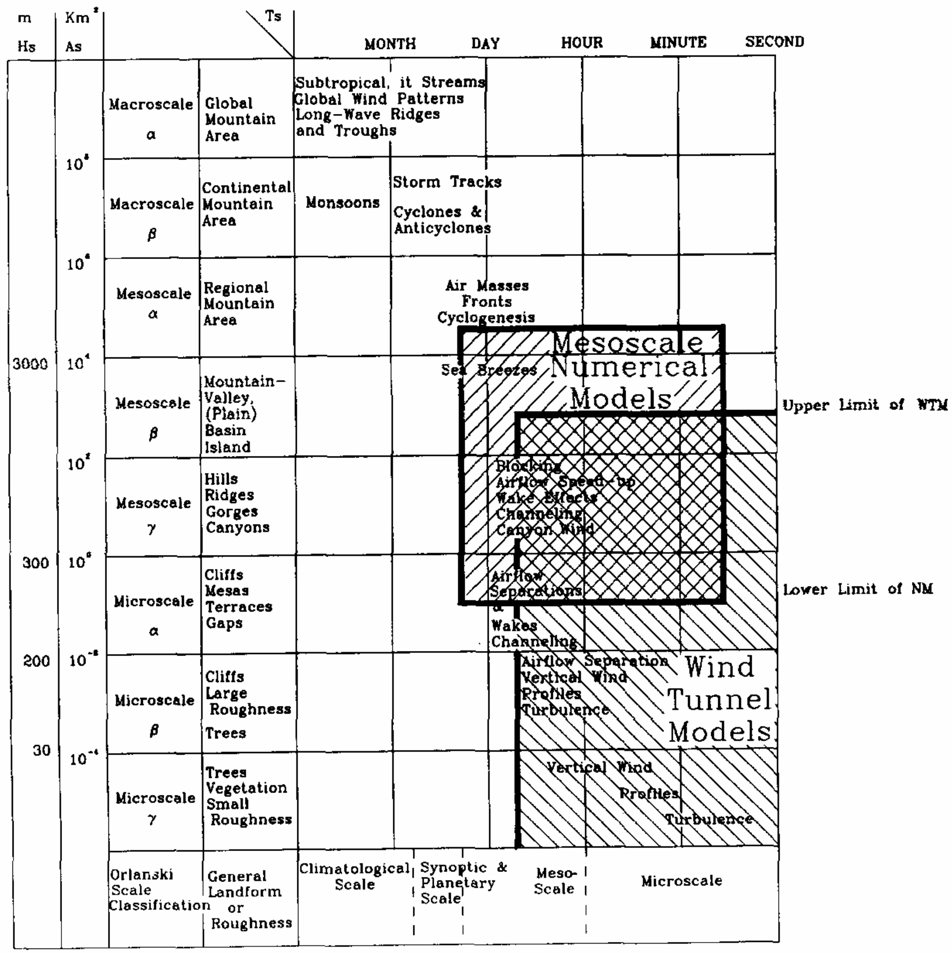


Fig. 12. Operating ranges for numerical and wind-tunnel modeling relative to the time and space continuum of atmospheric circulation systems. The crosshatched area shows the region of overlap for the two approaches. H_s denotes the representative depth scale, A_s the representative area scale, and T_s the representative time scale (after Orlanski, 1975 and Meroney, 1981).

Avissar, R., M.D. Moran, R.A. Pielke, G. Wu, and R.N. Meroney, 1990: Operating ranges of mesoscale numerical models and meteorological wind tunnels for the simulation of sea and land breezes. Bound.-Layer Meteor., Special Anniversary Issue, Golden Jubilee, 50, 227-275. http://blue.atmos.colostate.edu/publications/pdf/R-89.pdf

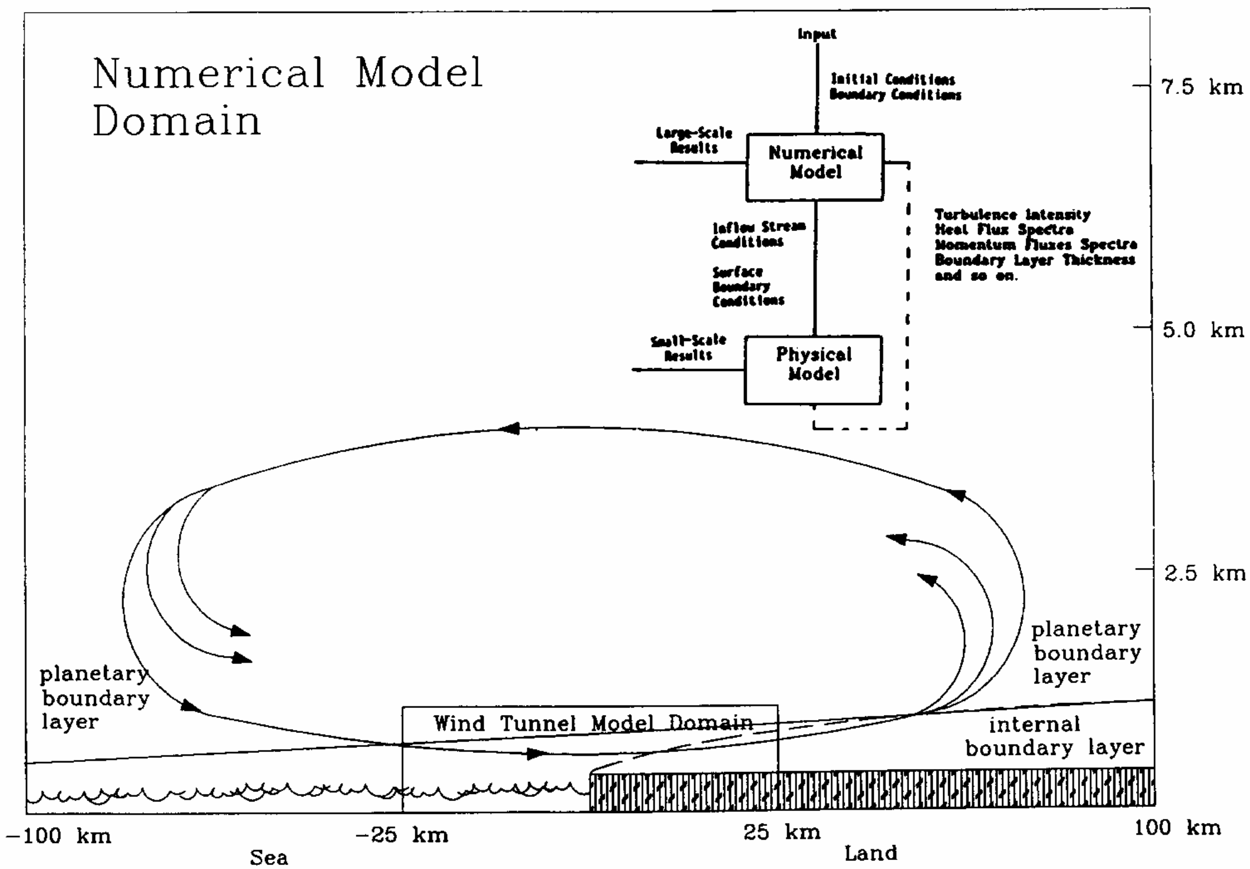


Fig. 14. Schematic showing wind-tunnel simulation domain embedded within a numerical model domain for a sea breeze. The inset is a conceptual flow diagram for the organization of the hybrid numerical-physical flow modeling system.

Avissar, R., M.D. Moran, R.A. Pielke, G. Wu, and R.N. Meroney, 1990: Operating ranges of mesoscale numerical models and meteorological wind tunnels for the simulation of sea and land breezes. Bound.-Layer Meteor., Special Anniversary Issue, Golden Jubilee, 50, 227-275. (Basis for proposed collaboration between David Neff, Ken Eis, and R. Pielke Sr.)
http://blue.atmos.colostate.edu/publications/pdf/R-89.pdf

Conclusions

- The Meteorological, Air Quality and Atmospheric Chemistry Communities have come closer together. We still have work to do, however, to make it a real merger.
- Modeling opportunities exist to improve our skill at understanding air pollution issues on all time and space scales, and to better assessing the predictability of the consequences of weather and air quality interactions.

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PowerPoint presentation prepared by Dallas Jean Staley Research Coordinator and Webmaster