A Brief History of Applied Transport and Dispersion Models

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Paper 1.1 Presented at 21st Joint Conference on the Applications of Air Pollution Meteorology with the A&WMA
Boston, MA
12-16 January 2020

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Acknowledgements

- Research sponsored by DTRA
- Thanks to my first boss, Frank Gifford, at NOAA’s ATDL in Oak Ridge, TN, for emphasizing the need to be aware of the history of our field, and to use proper attribution in references
- “You may think that you have come up with something new, but it may have been described by Taylor in a 1921 paper”

WW I Chemical Attack (105 years ago)

Brief history of dispersion modeling (1)

- **1910s through 1930s -** Much work was spurred by the use of chemical weapons by both sides in WWI
- **1940s through present –** Studies of plume rise and dispersion and wet and dry deposition were spurred by the use of atomic bombs in WWII (started as analytical models and now CFD models)
- **1950s through present –** Dispersion of routine and accidental releases of chemical, biological, and radiological pollutants (analytical formulas and diagnostic mass consistent models)
- **1980s through present** – Dispersion of very hazardous chemicals (often denser than air)

Brief history of dispersion modeling (2)

- **1970s through present** – Studies of pollutant dispersion spurred by Clean Air Act (the EPA era)
  - Industrial short range dispersion (initially analytical models (Turner's workbook) morphing to AERMOD)
  - Regional dispersion (Lagrangian puff models such as CALPUFF and 3-D Eulerian models such as CMAQ). Sophisticated chemistry and aerosols treatment.
- **NOAA Lagrangian models (e.g., HYSPLIT) for major single sources such as volcanoes**
- **Expansion of region domain to global**
- **Linkages of all dispersion models with WRF**

Examples of chemical agent use in WWI

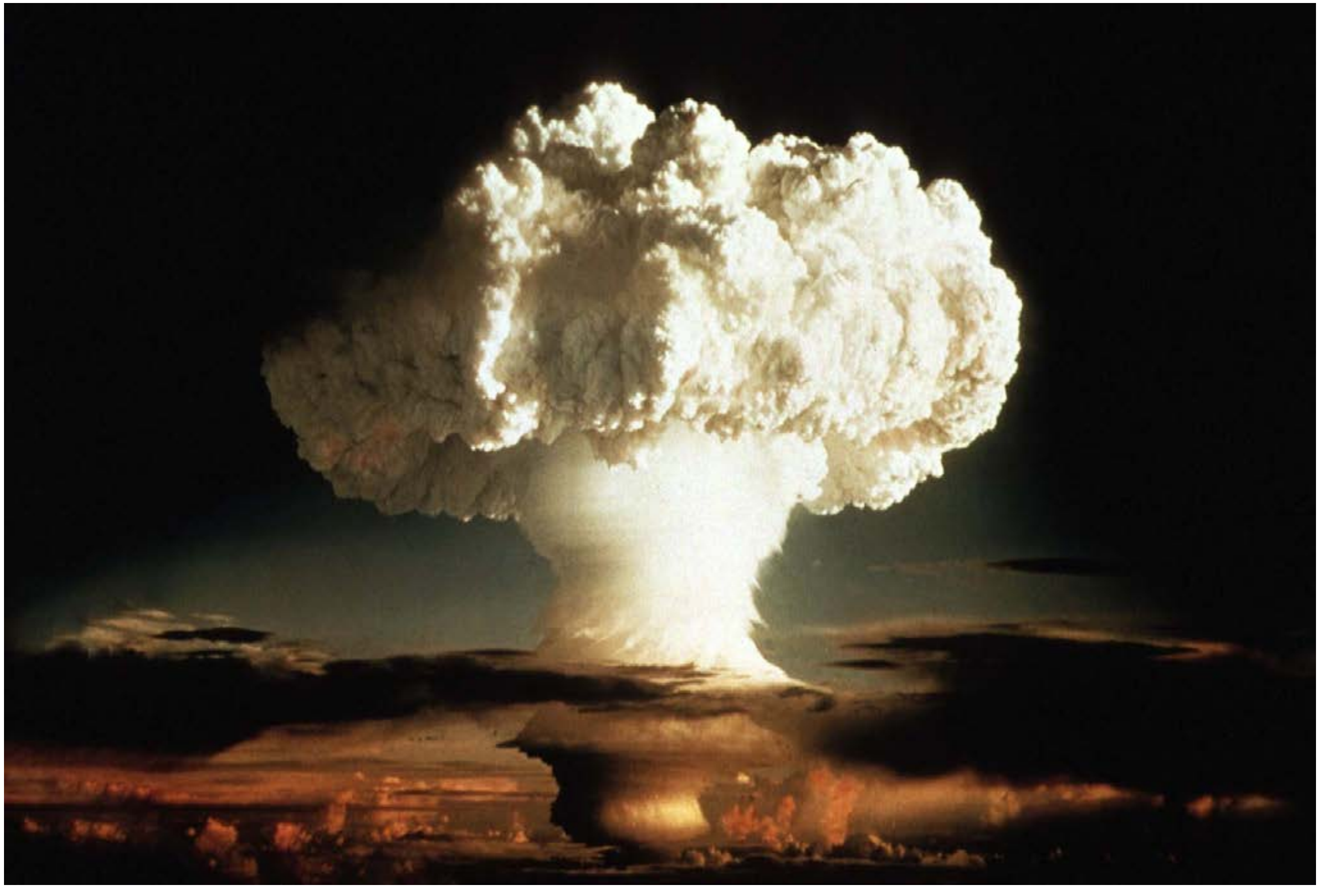
- **April 22, 1915 -** The German military launches the first large-scale use of chemical weapons in war at Ypres, Belgium. **170 metric tons** of chlorine gas in cylinders are buried along the front. More than 1,100 people die.
- **December 19, 1915 -** Germans first use phosgene on Allied troops. More than 120 British soldiers die.
- **May, 1918 -** U.S. research on mustard gas moves to a site called Edgewood Arsenal run by the newly created Chemical Warfare Service.
- **June, 1918 -** The Allies begin using mustard gas.
- **November 11, 1918 -** World War I ends with 90,000 to 100,000 fatalities caused by chemical weapons, primarily from phosgene.

What is the concentration of chemical in the air that these WWI soldiers are exposed to?

Dispersion models for chemical agents

- Analytical models (G.I. Taylor’s and L.F. Richardson’s equations)
- Near-surface point sources
- Few field experiments were available for development and evaluating models

1940s through present – Modeling of plume rise, transport and dispersion, and wet and dry deposition of radiological pollutants



Issues for dispersion models for radiological pollutants

- Gases and particles from atomic bombs
  - Rise of very buoyant puff through the troposphere
  - The resulting plume can be in the stratosphere
  - Long-range transport
  - Fallout due to dry deposition and wet removal
- Gases and particles from routine and accidental releases at nuclear facilities
  - Usually the releases are not very buoyant

Applied dispersion models for radiological pollutants

- Releases from atomic bombs
  - In 1950s – Analytical models
  - Currently – software such as SCIPUFF and HYSPLIT, linked with WRF
- Releases from nuclear facilities
  - In 1950s and 1960s – Gaussian plume and puff models
  - Now – Lagrangian puff models or Eulerian grid models linked with WRF

EPA era air pollution models for stacks

- 1970s – Analytical Pasquill-Gifford-Turner Gaussian plume models; Briggs plume rise model; nomograms
- 1980s & 1990s – Software for Gaussian models (ISC); Lagrangian puff model (CALPUFF); Complex terrain
- 2000-present – AERMOD, various traffic and other special purpose models
- Now possible to link with WRF

Nomogram from Gifford's adaptation of Pasquill's 1961 σ_y and σ_z curves

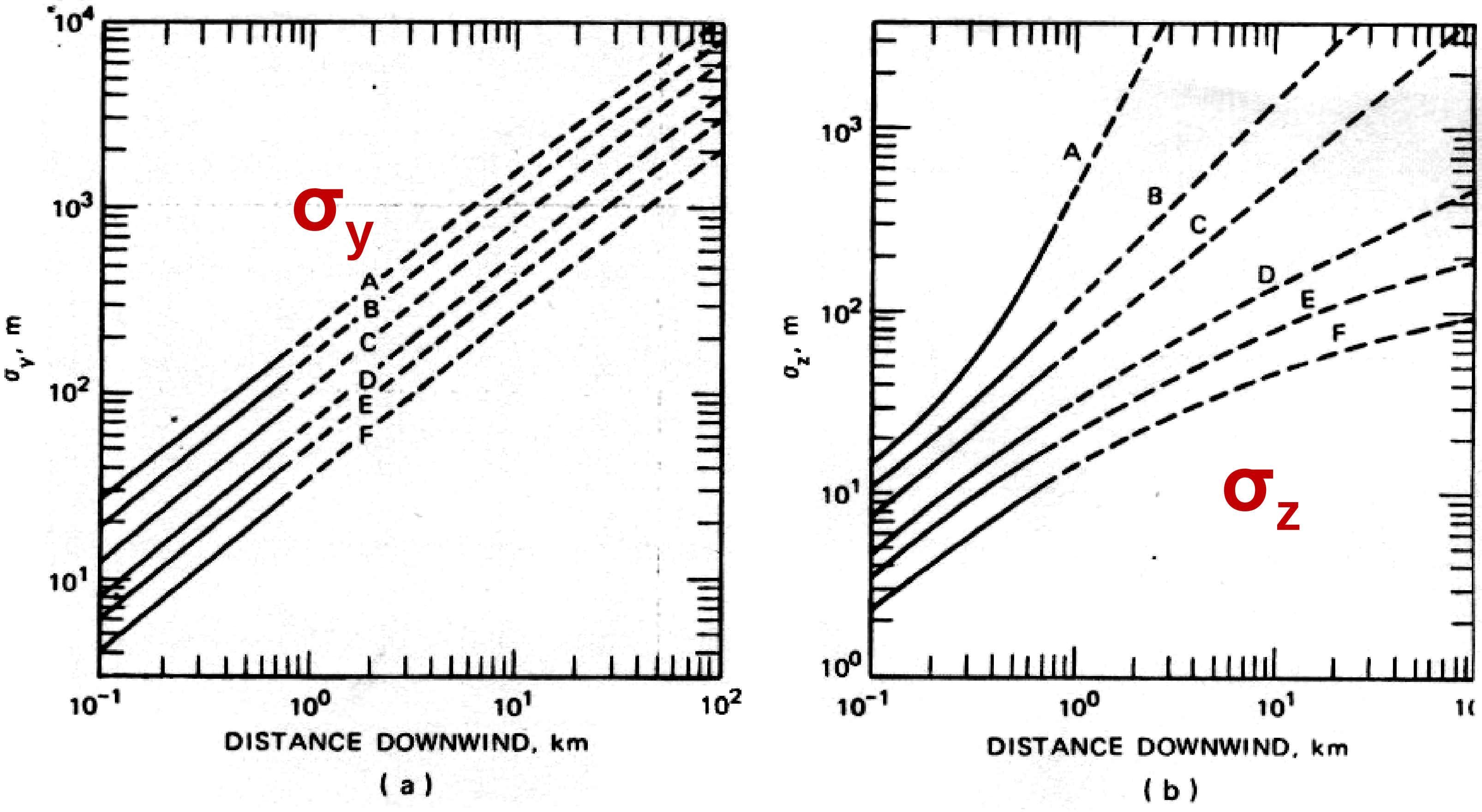
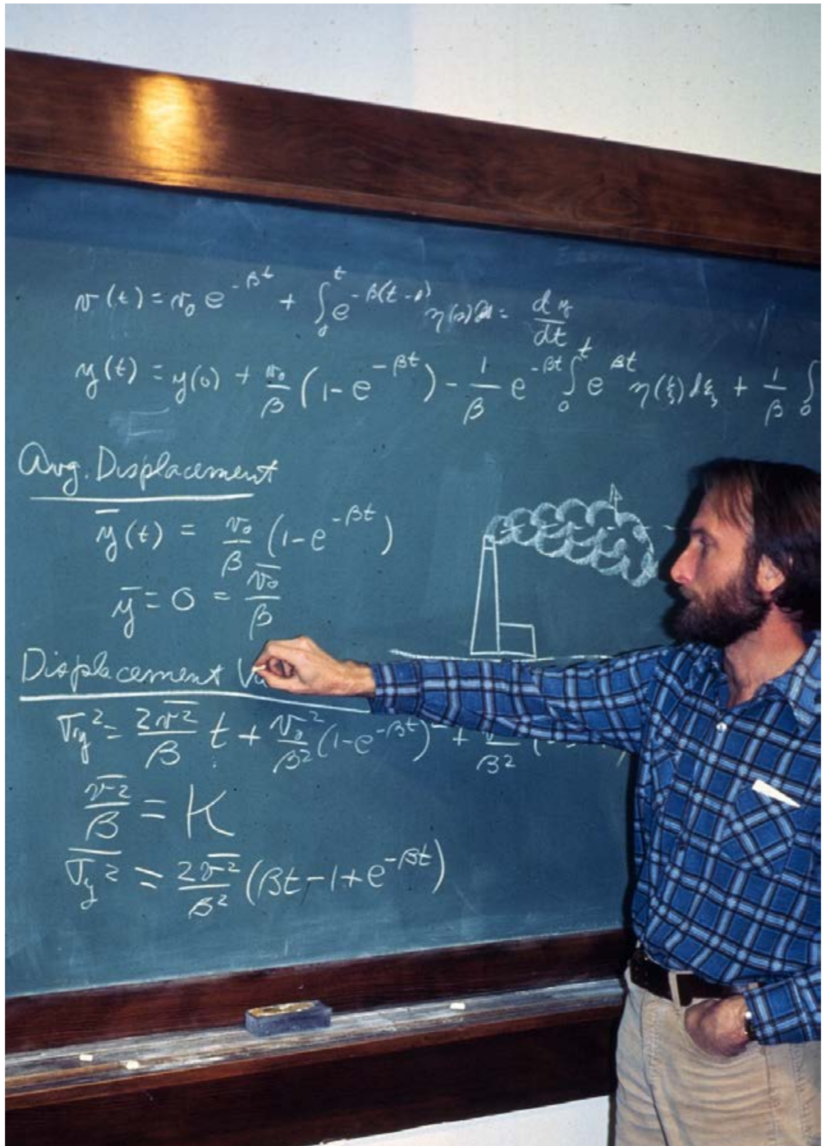


Fig. 4.4 Curves of σ_y and σ_z for turbulence types based on those reported by Pasquill (1961). F. A. Gifford, Turbulent Diffusion-Typing Schemes: A Review, *Nucl. Saf.*, 17(1): 71 (1976).]

“Classical” bent over plume rise of buoyant stack plumes in moderate wind

Gary Briggs deriving dispersion equation in mid-1970s in Oak Ridge (ATDL)



“Classical” plume rise of buoyant stack plume during stable morning with light winds

Modeling of hazardous chemicals

- There have been major releases of chlorine and other chemicals from storage tanks
- Models must account for dense gas effects
- US models include SLAB, ALOHA, and SCIPUFF and several proprietary models
- Recent large field experiment (Jack Rabbit) involving many tons of chlorine

Jack Rabbit II Chlorine Releases

Trial 6:
90°
downward

Trial 7:
45°
downward

Trial 8:
90°
upward

Trial 9:
90°
downward

Source: Utah Valley University

Modeling of large emissions events

- **The NOAA HYSPLIT model is one of several around the world used for simulation of large single emissions events, such as volcanoes, wildfires, and high-visibility events such as Fukushima.**
- **The dispersion models make use of high-resolution wind fields from an NWP model such as WRF**
- **How do we account for uncertainties, such as in plume rise?**

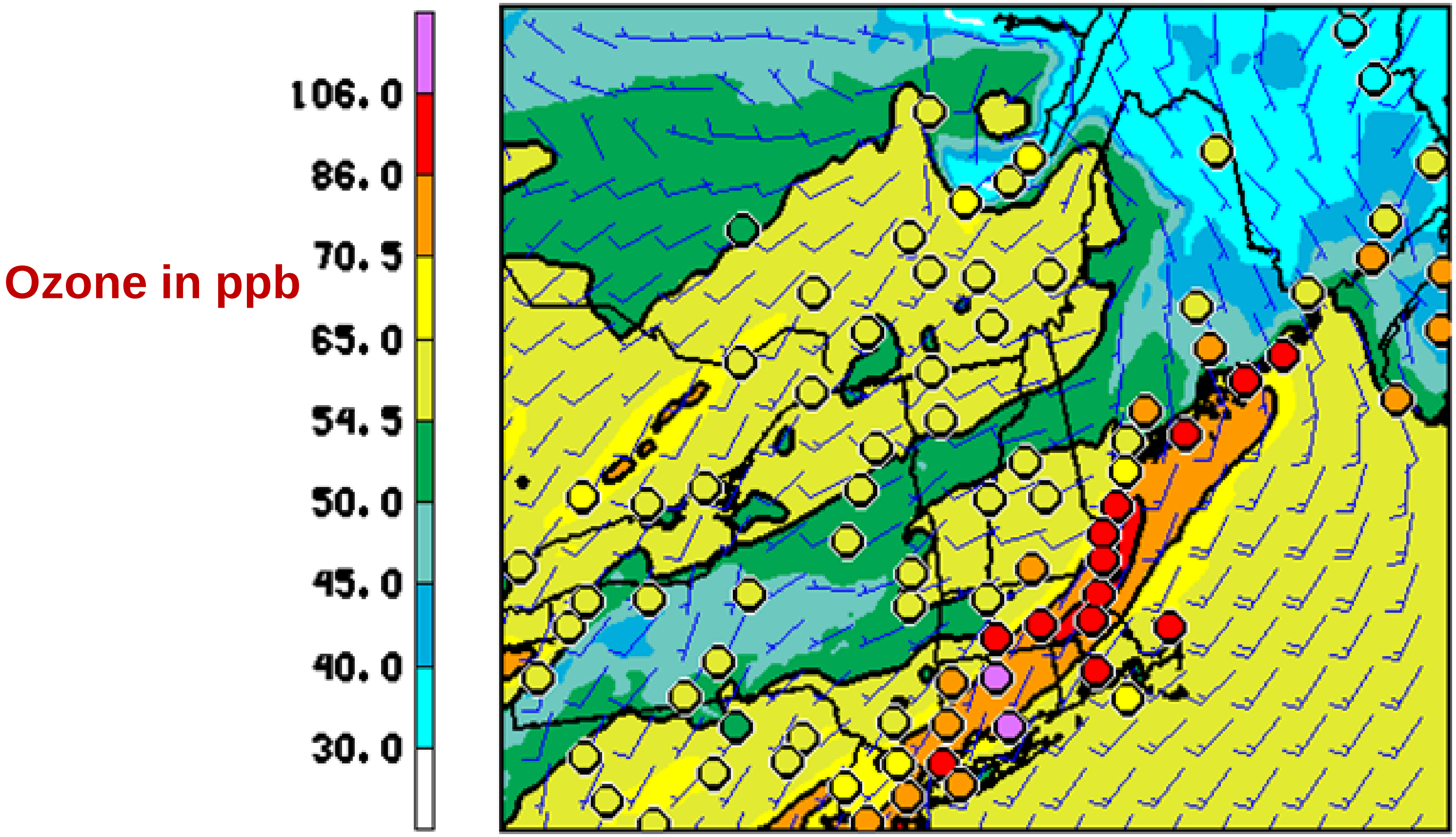
Iceland's Eyjafjallajokull volcano April 16, 2010
What would you say is the plume rise?

Regional Air Quality Modeling

- 1980's – Acid rain models (3D Eulerian models; included chemistry)
- 1990's – Regional ozone modeling – morphed over to CMAQ
- Now CMAQ used for a wide range of pollutants
- Linked with WRF
- Nested models now have the entire globe as the largest domain

Real-time regional air quality modeling

- Now NOAA makes daily forecasts of regional air pollution.
- The next page gives an example prediction by CMAQ for a major ozone episode in 2017.
- The figure lists the observations as well as the predictions.



NCEP CMAQ forecasts of maximum daily ozone for 17 May 2017, a day with 100 F afternoon temperatures. Forecasts are solid colors. Observations are small circles (added by NWS afterwards). http://www.emc.ncep.noaa.gov/mmb/aq/cmaq/web/html/max.html

The future (Steve's guess)?

- **Linked NWP and Eulerian grid models such as CMAQ.**
- **WRF's and CMAQ's grid sizes are steadily decreasing, and their domain is being increased to global.**
- **Eventually WRF-CMAQ will be used for all pollutant sources and scales, from local releases to regional concerns.**
- **AERMOD scales will be absorbed into CMAQ**
- **A WRF version with 1 m grid size is being tested.**