Paper H15-154

Revisiting 1992 HARMO1 (Riso) comments on limitations of short range atmospheric dispersion models

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- My paper at HARMO1 at Riso in 1992 gave a “confessional” of limitations of then state-of-the art models (e.g., OML, ADMS, HPDM)
- Have these limitations been resolved?
- Are there additional new limitations?

1992 List of Limitations

1 Mixing depth
2 Vertical profiles of turbulence
3 Nocturnal jet
4 Non-steady-state periods
5 Surface constants (e.g., albedo, z_o)
6 Surface energy balance parameters
7 Lagrangian time scales

2013 Additional Limitations

8 Low wind stable

9 Steep terrain, bldg obstacles, land-use variations

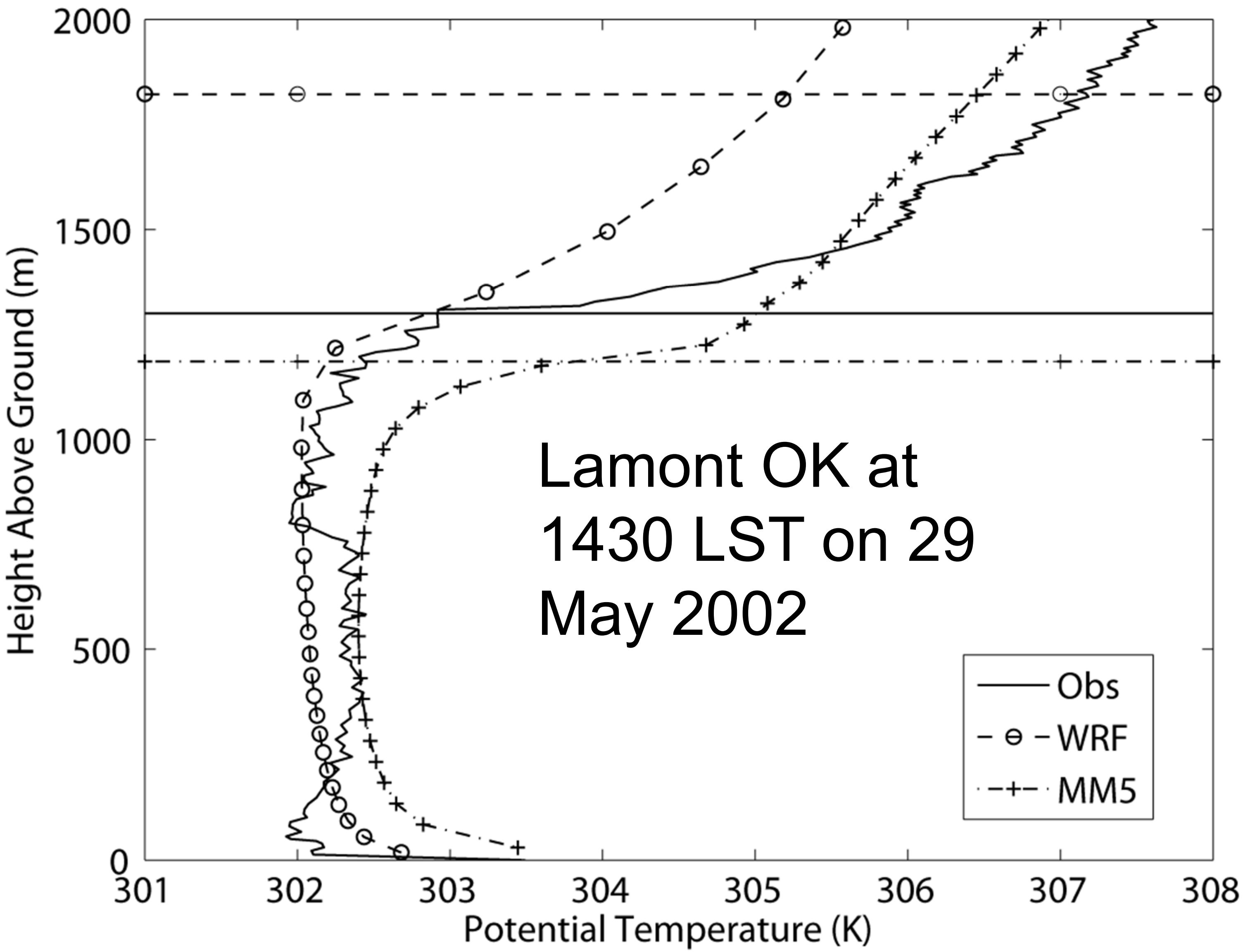
10 Is new technology helping?

11 Dense plumes and chemical reactions

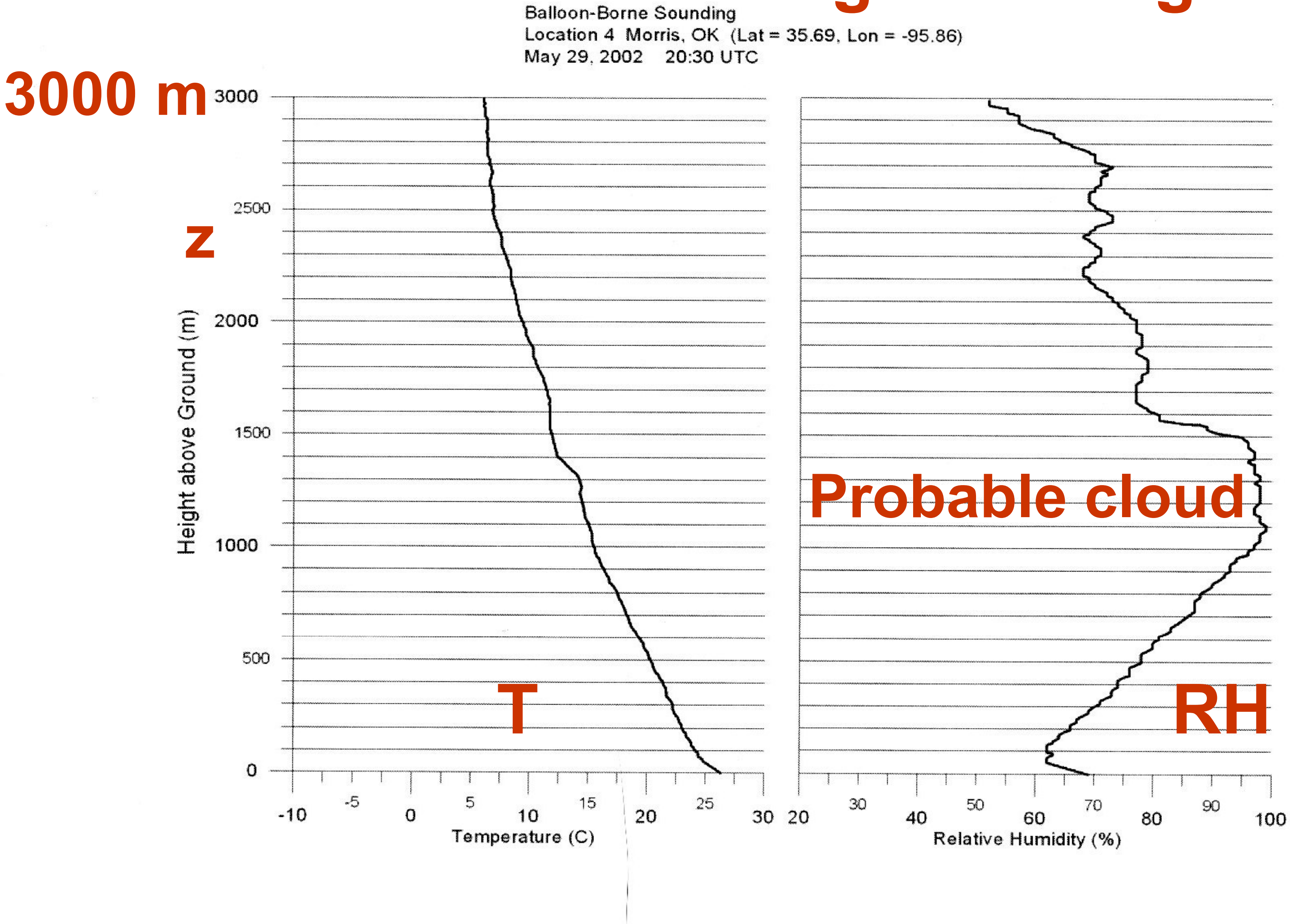
1. Mixing depth z_i

- Models look for mixing depth z_i for each hour, but 30 or 40 % or more of the time z_i is "fuzzy"
- We still desire routine observations of vertical structure (u, T, turb) by remote sounders through the entire boundary layer ($1 \text{ m} < z < 3000 \text{ m}$)
- Erroneous z_i are often found to be the cause of large over or underpredictions of concentration C

Radiosonde profile with obvious z_i



Example of observed T and RH profile with vague mixing depth



2. Vertical profiles of turbulence (σ_v and σ_w)

- Best to use observations (if accurate) with remote sounders but not widely available and do not cover all times and the entire depth of interest
- Models used Monin-Obukhov Similarity Theory (MOST) profile formulas for turbulence inputs to models. Uncertainties at top of PBL and during stable conditions, especially with low winds
- Minimum σ_v and σ_w are prescribed based on obs
- Mesoscale met models can provide these but much uncertainty

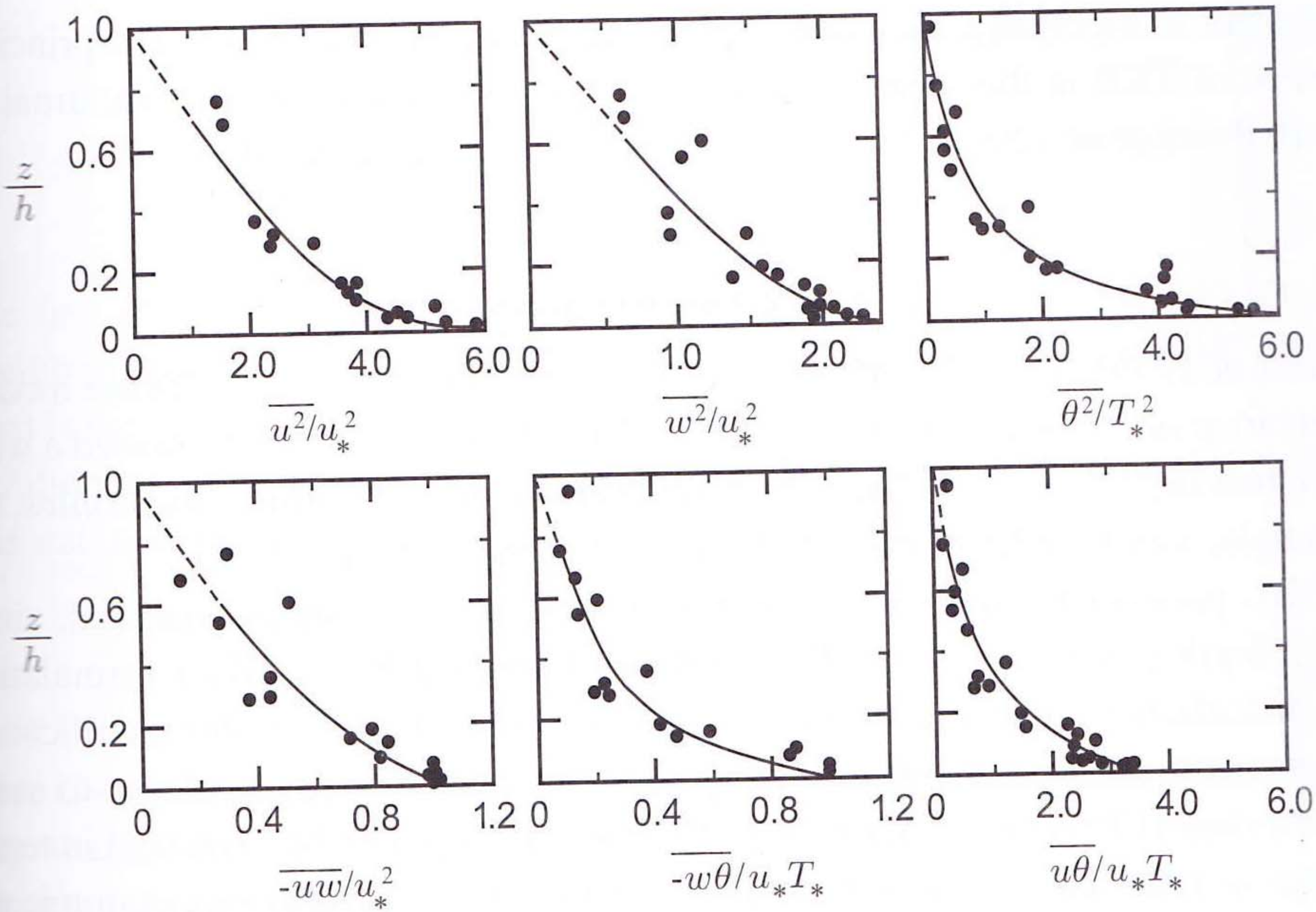


Figure 12.8 Vertical profiles of dimensionless variances and covariances measured in the early-evening Minnesota runs shown in Figure 12.2. The SBL depth h ranged from 30 m to 400 m over the seven runs. The curves are visual fits to the data. From Caughey *et al*. (1979).

From Wyngaard 2010

3. Nocturnal jet

- Was major concern in 1992; could influence tall stack plumes and carry them 100 km in 1 or 2 hrs
- Also leads to pulsing nighttime BL with turbulent bursts to ground (depends on critical Ri)
- Has mostly dropped off "radar screen" but still of concern.

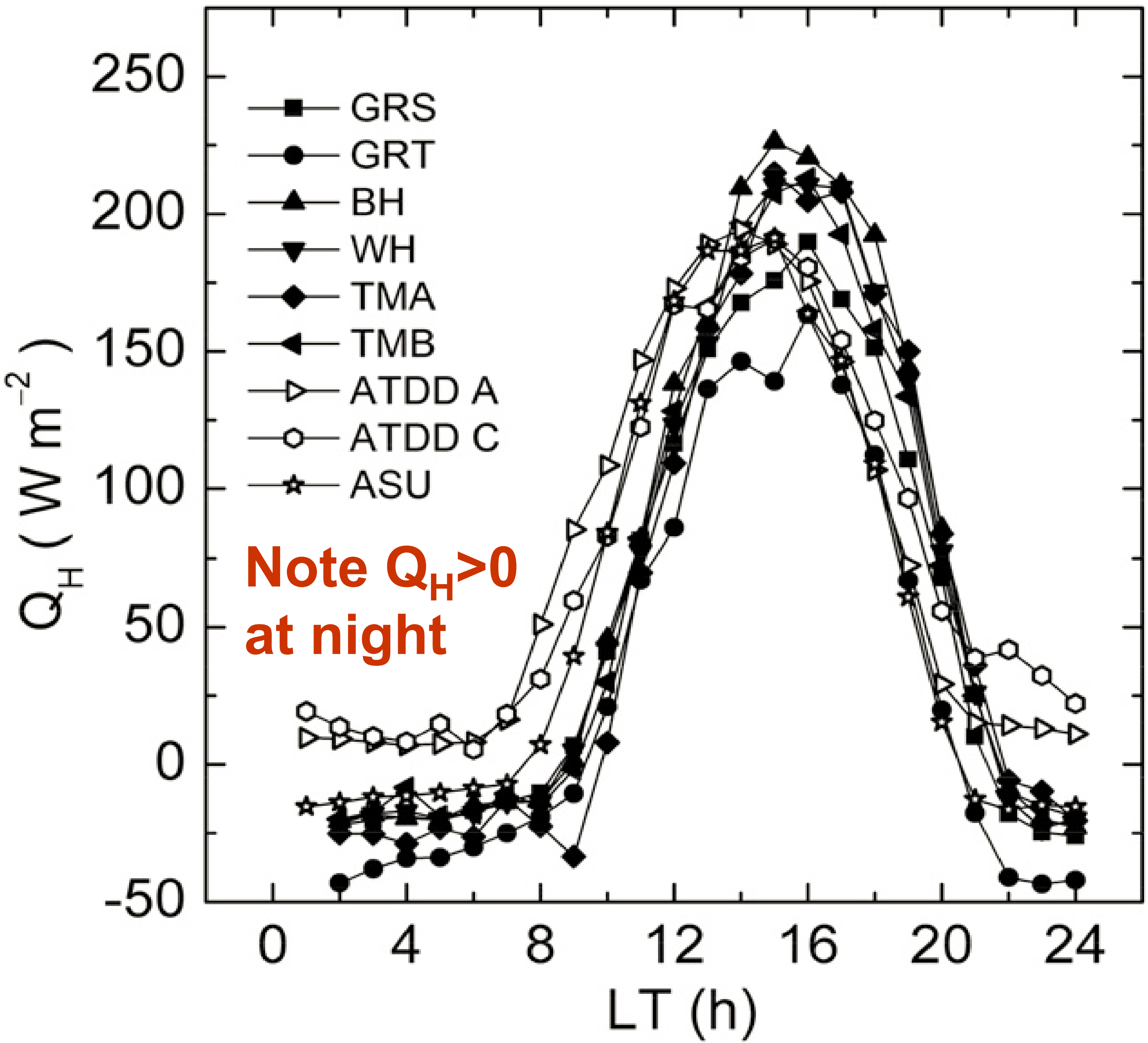
4. Non-steady-state periods

- Weather often changes from hour to hour.
- Straight-line Gaussian plume models assume constant PBL profiles exist over 50-80 km downwind distance. But plume may only travel 5 km in an hour.
- Still a problem. In the USEPA, AERMOD is assumed to be valid to 50 km for a given one-hr run.
- Could switch to a segmented plume model. Or a Lagrangian Puff or Particle model (e.g., CALPUFF in US)

5. Surface constants (e.g., albedo, z_o) and 6. Surface energy balance

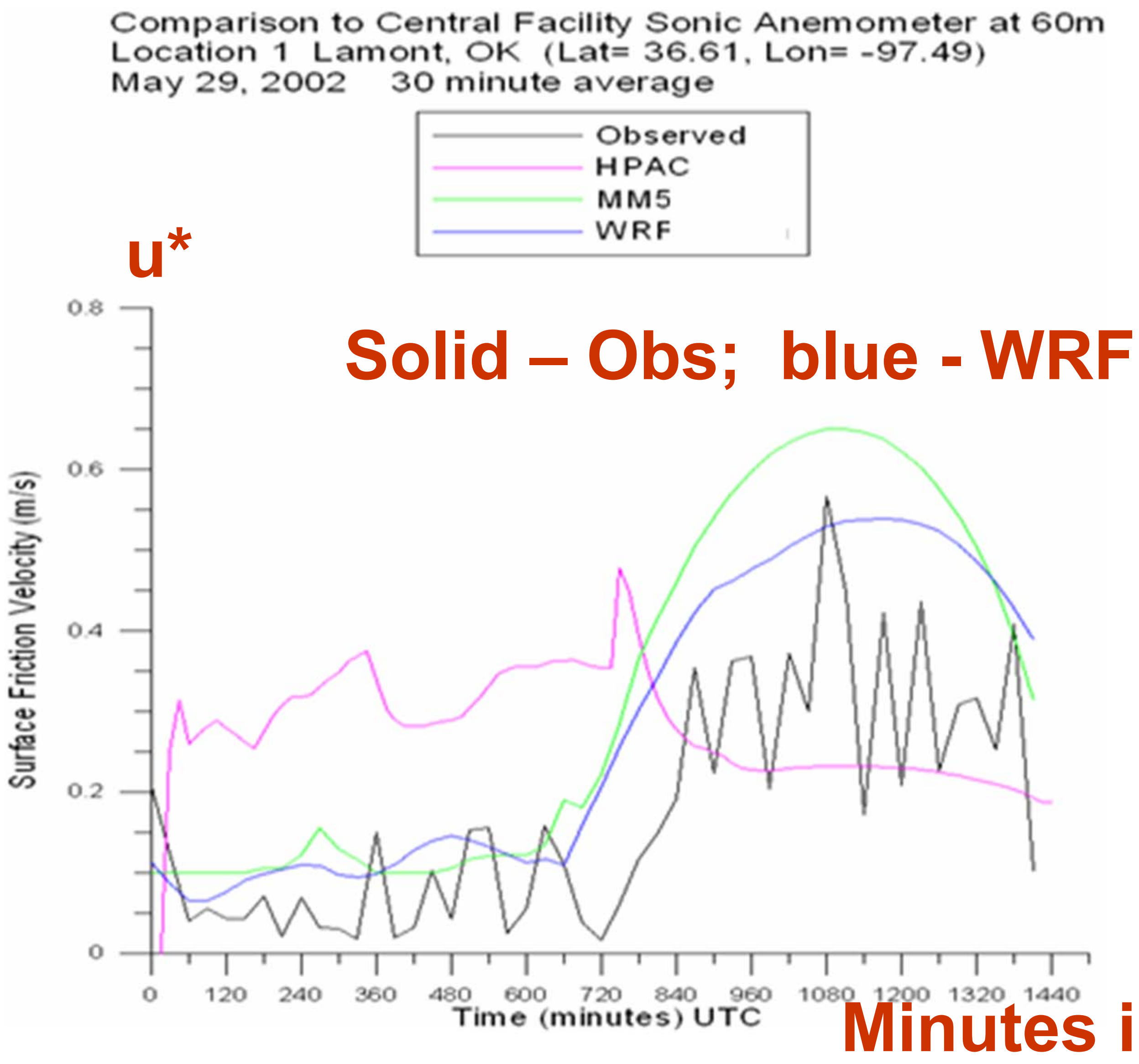
- 1992 models used parameterizations from Van Ulden, Holtslag et al.
- Much progress by climate modelers who want to know surface fluxes to an accuracy of a few %.
- Surface constants and energy balances have been well-studied in urban and rural areas as part of local climatology and chemical flux field programs.
- Yet I notice that not many of these advances by the climate modelers have made their way into the short-range dispersion models.

Observed diurnal sensible heat flux Q_H at built up (open symbols) and suburban sites in Oklahoma City



Note Q_H>0 at night

Could use Met models (e.g. WRF) for u* and other met variables, but …



7. Lagrangian time scales T_L

- Most models now use an estimate of T_L (for y and z components) to estimate dispersion. T_L is defined locally rather than applying to whole trajectory.
- Lagrangian particle dispersion models (LPDMs) are widely used except by the US EPA
- Studies since 1992 show that T_{Ly} is larger than thought. σ_y grows with linear t or x for many hours
- In urban areas, T_L is determined by street width rather than distance to nearest surface
- AERMOD switches to K model for vertical dispersion near ground where T_{Lz} approaches 0

Lagrangian particle motion

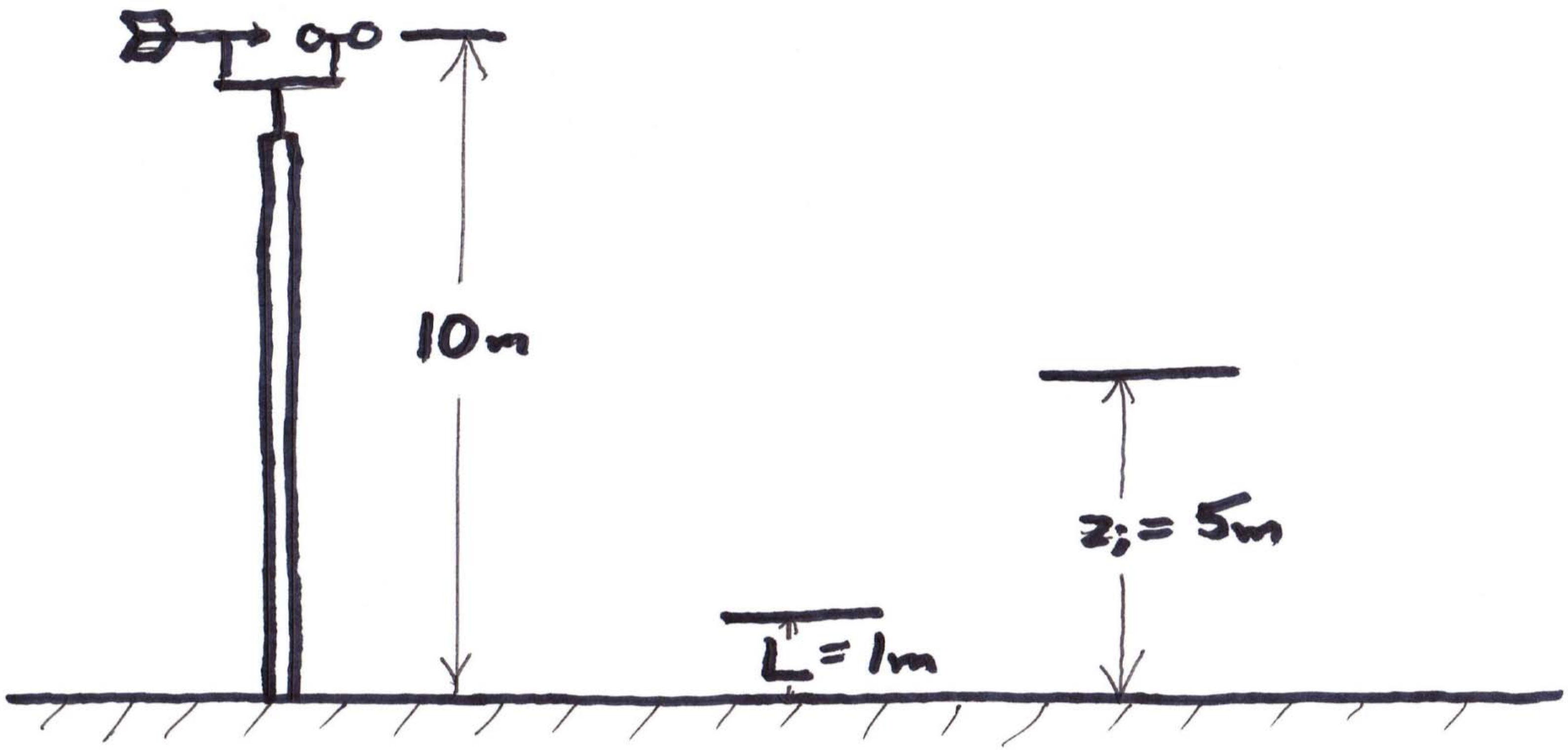
Taylor, Pasquill etc defined T_L based on integration over a certain time

LPDMs often calculate particle movement based on local T_L. T_{Lz} varies considerably with height.

New 8. Low wind stable

- Dispersion model over and under-predictions found
- MOST breaks down; light and variable winds
- z of obs u may be above z_i
- Models use empirical formulas for u*/u, sensible heat flux H_s, L
- Current studies (e.g., Luhar) trying to fix this
- The two primary tracer experiments are from 1970s

Low wind stable scenario with L = 1 m

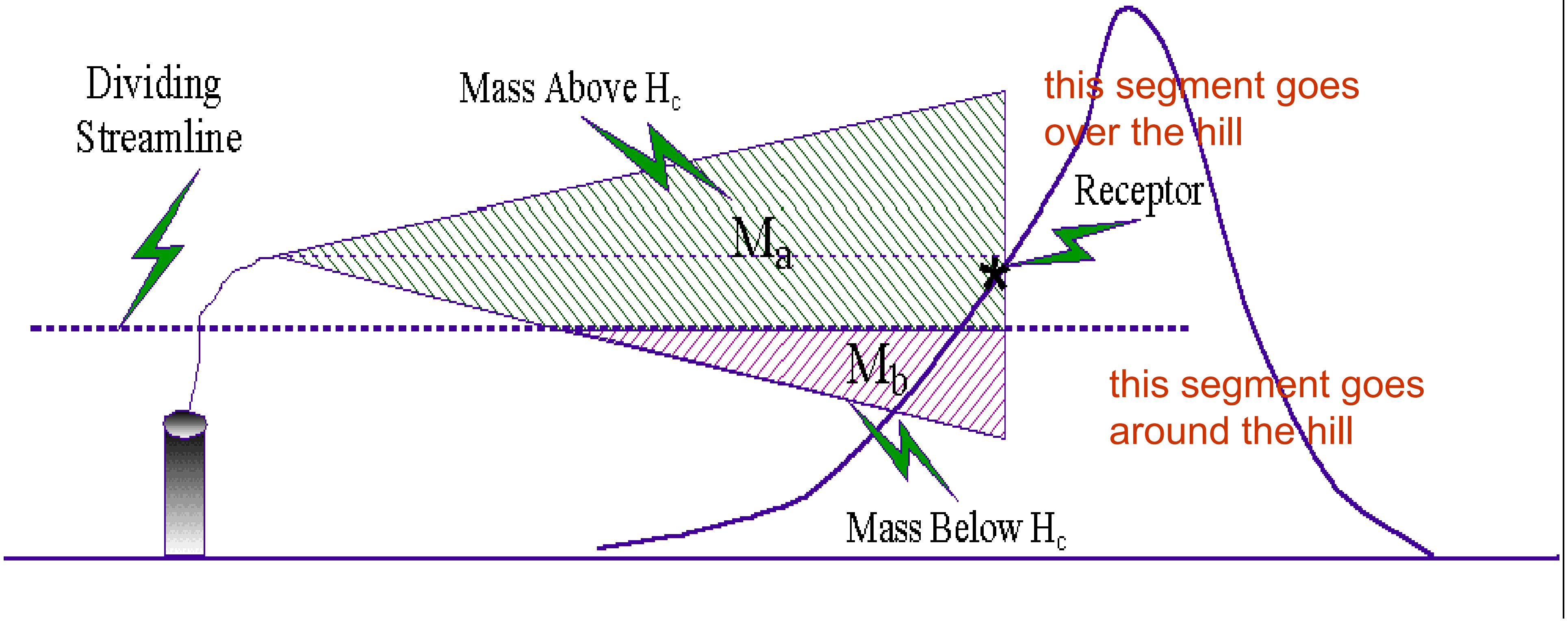


New 9. Steep terrain, building obstacles, land-use variations

- Many advances here
- EPA complex terrain experiments and other hill experiments led to formulas for plume flow around and impaction on hills. The methods were incorporated in AERMOD and other models
- Building downwash and urban field studies led to improvements in some models
- TIBL studies for coastal plumes
- Still there is not a good objective way to account for land-use variations in operational models

AERMOD Treatment of Hills - Assume Two Plume Segments (above and below H_c)

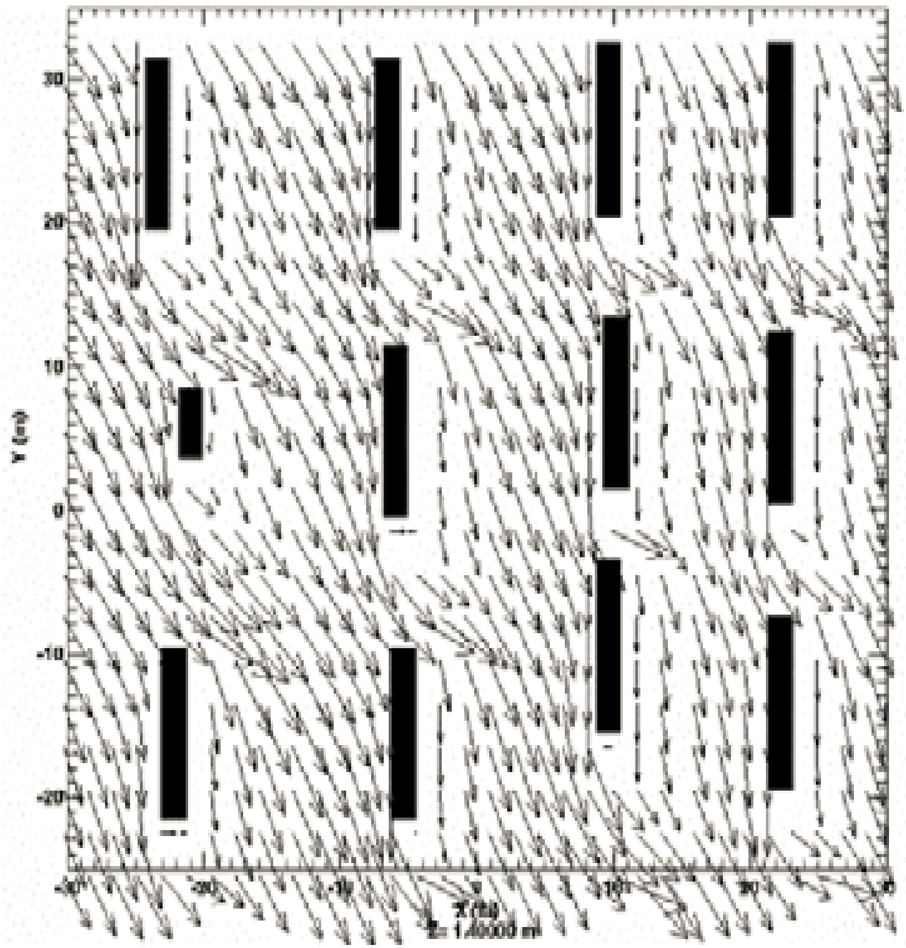
$$C_{Tot} = f\,C_{Horiz} + (1\text{-}f)\,C_{TerrRes}$$

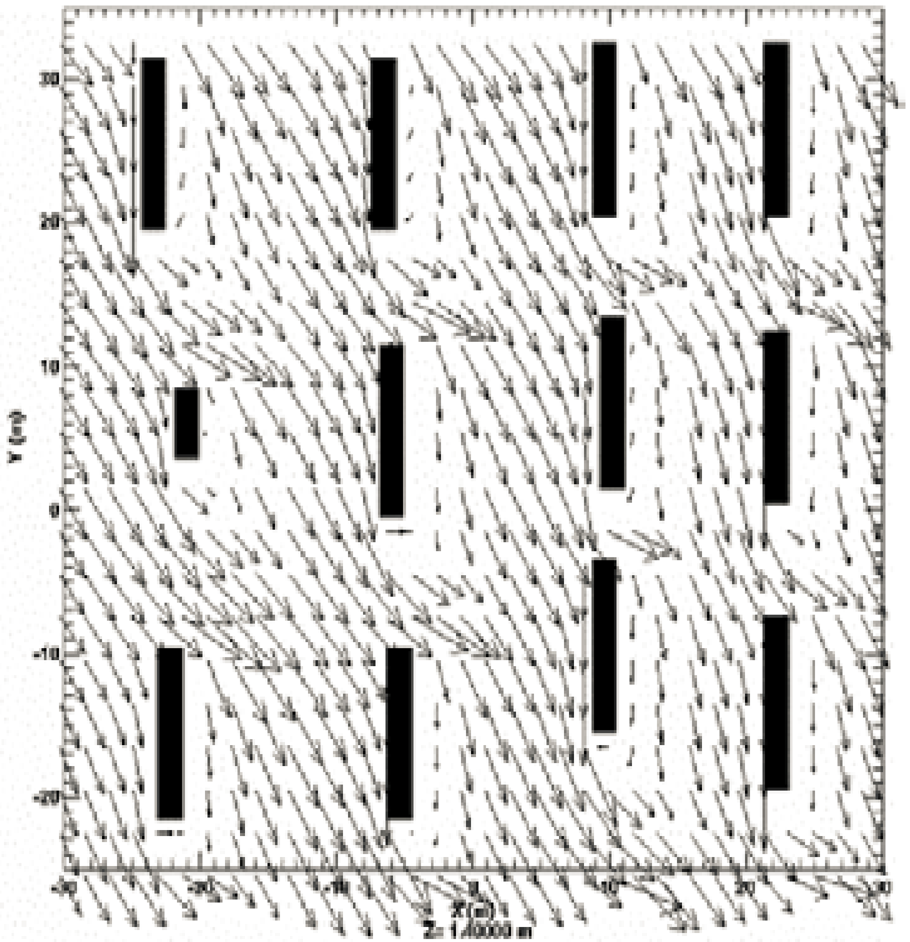


New 10. Is new technology helping?

- Since 1992 there have been many orders of magnitude increases in computer speed and storage
- Are our models orders of magnitude better? No. Maybe a factor of two better in evaluations with field data
- What happened? Natural variability of the atmosphere overwhelms the system
- CFD models – Slow, but can be used to parameterize operational models. Some persons use hybrid systems such as QUIC.
- WRF grid scale is always getting smaller. Lundquist et al. have a 1 m version applied to cities.

RAMS flow simulations for part of the MUST obstacle array (Trini-Castelli and Reisin, 2010) for two k- ε schemes

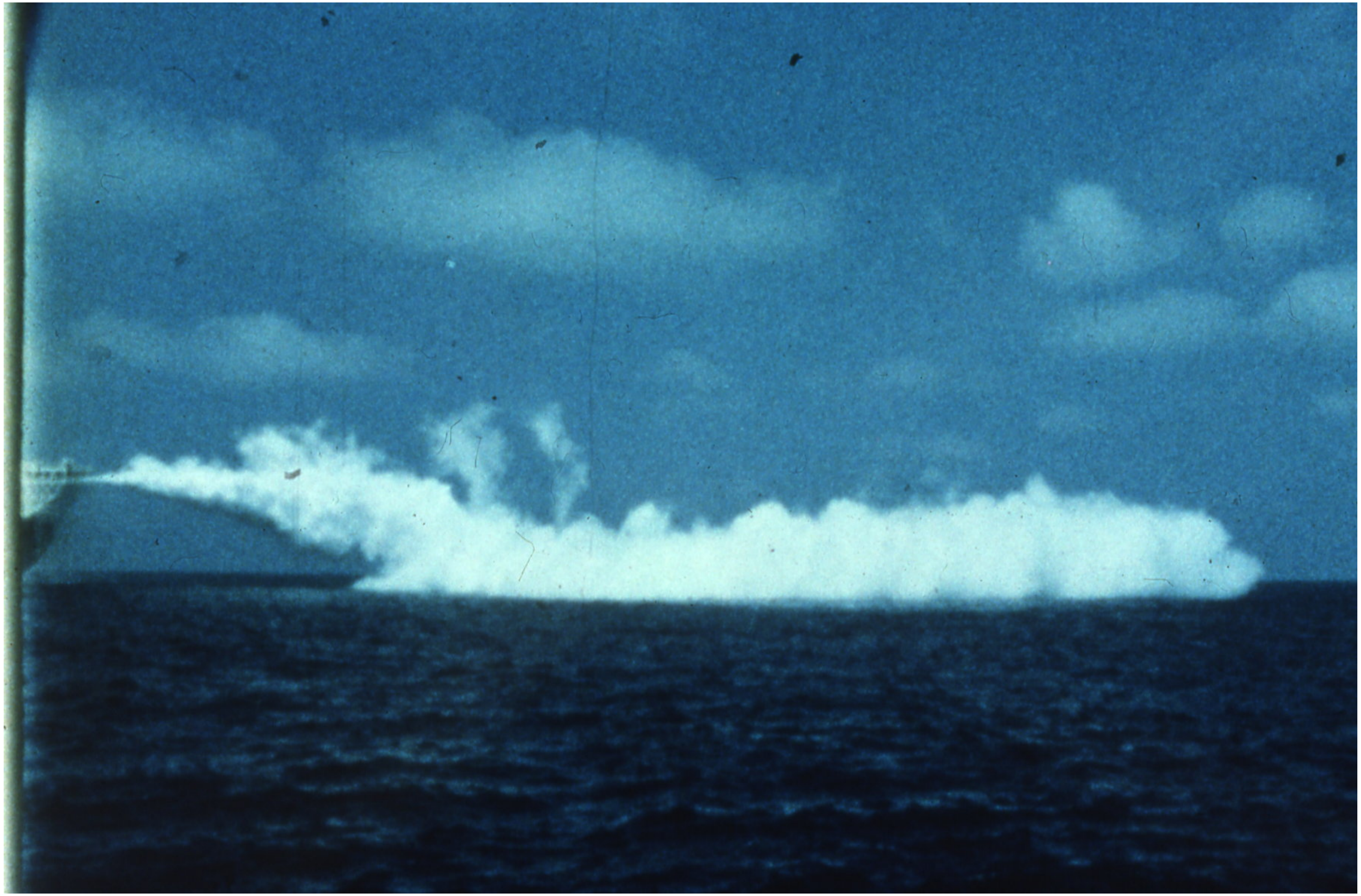




New 11. Dense plumes and chemical reactions

- Since 1992, there have been many studies and improvements in this area, mainly driven by emergency response and air pollution regulations
- Good dense gas models are available but are not in the USEPA regulatory arena
- Chemical reactions (and phase transitions) are in regional AQ models, and in some short-range models (such as SCICHEM). AERMOD uses simple parameterizations.
- Plume-in-grid models in regional AQ models like CMAQ.

Release of LNG from back of tanker onto water



“CLASSIC” Dense Cloud Behavior

Conclusions

- Many of the 1992 limitations are still of concern
- Sometimes research advances are not quickly adopted by operational models
- There are several new limitations
- Will 3-D Eulerian models eventually do everything as grid size reduces and computers improve?
- The atmosphere's natural variability causes problems in demonstrating improvements