Introduction to the HYSPLIT Trajectory Model

WMO GURME Regional Training Workshop on urban air quality modelling for ASEAN Countries

Malaysian Meteorological Department
Petaling Jaya, 7 - 10 April 2015

Slides from ARL tutorials and presentations

World Meteorological Organisation

GURME

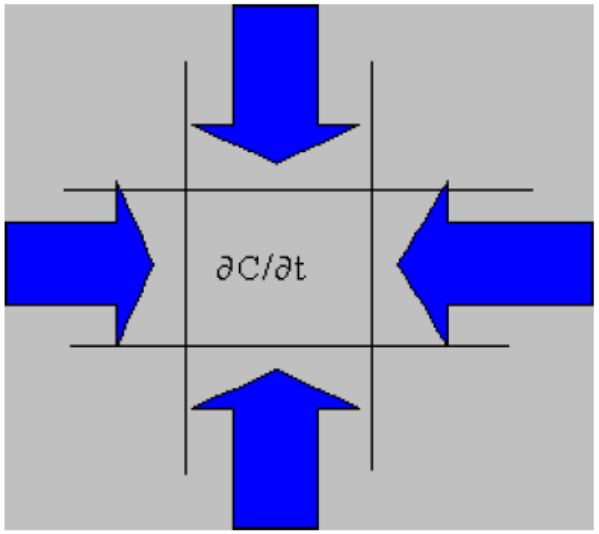
The University of Iowa

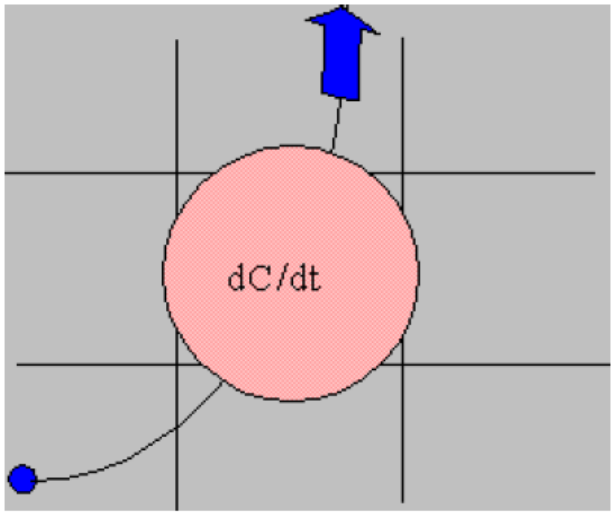
NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

NUS National University of Singapore

MET Malaysia

Introduction





Integration Methods

- **Eulerian**
  - Local derivative
  - Solve over the entire domain
  - Ideal for multiple sources
  - Easily handles complex chemistry
  - Problems with artificial diffusion

- **Lagrangian - HYSPLIT**
  - Total derivative
  - Solve only along the trajectory
  - Ideal for single point sources
  - Implicit linearity for chemistry
  - Non-linear solutions available
  - Not as efficient for multiple sources

HYSPLIT Model Features

- Predictor-corrector advection scheme; forward or backward integration
- Linear spatial & temporal interpolation of meteorology (external off-line)
- Converters available ARW, ECMWF, RAMS, MM5, NMM, GFS, …
- Vertical mixing based upon SL similarity, BL Ri, or TKE
- Horizontal mixing based upon velocity deformation, SL similarity, or TKE
- Mixing coefficients converted to velocity variances for dispersion
- Dispersion computed using 3D particles, puffs, or both simultaneously
- Modelled particle distributions (puffs) can be either Top-Hat or Gaussian
- Air concentration from particles-in-cell or at a point from puffs
- Multiple simultaneous meteorology and concentration grids
- Latitude-Longitude or Conformal projections supported for meteorology
- Nested meteorology grids use most recent and finest spatial resolution
- Non-linear chemistry modules using a hybrid Lagrangian-Eulerian exchange
- Standard graphical output in Postscript, Shapefiles, or Google Earth (kml)
- Distribution: PC and Mac executables, and UNIX (LINUX) source

HYSPLIT can be run directly via the internet

ARL Air Resources Laboratory — READY

HOME | HYSPLIT | DISPERSION MODELING | METEOROLOGY | EMERGENCY ASSISTANCE | STATUS | CONTACTS

HYSPLIT
On-line Transport and Dispersion Model

TRAJECTORY MODEL

- Compute trajectories
- Model results
- U.S. Trajectory Forecasts

DISPERSION MODEL

- Compute concentrations
- Model results

Publications using HYSPLIT results, maps or other READY products provided by NOAA ARL are requested to include an acknowledgement of, and citation to, the NOAA Air Resources Laboratory. Appropriate versions of the following are recommended:

Citation

Draxler, R.R. and Rolph, G.D., 2003. HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Laboratory, Silver Spring, MD.

Rolph, G.D., 2003. Real-time Environmental Applications and Display sYstem (READY) Website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Laboratory, Silver Spring, MD.

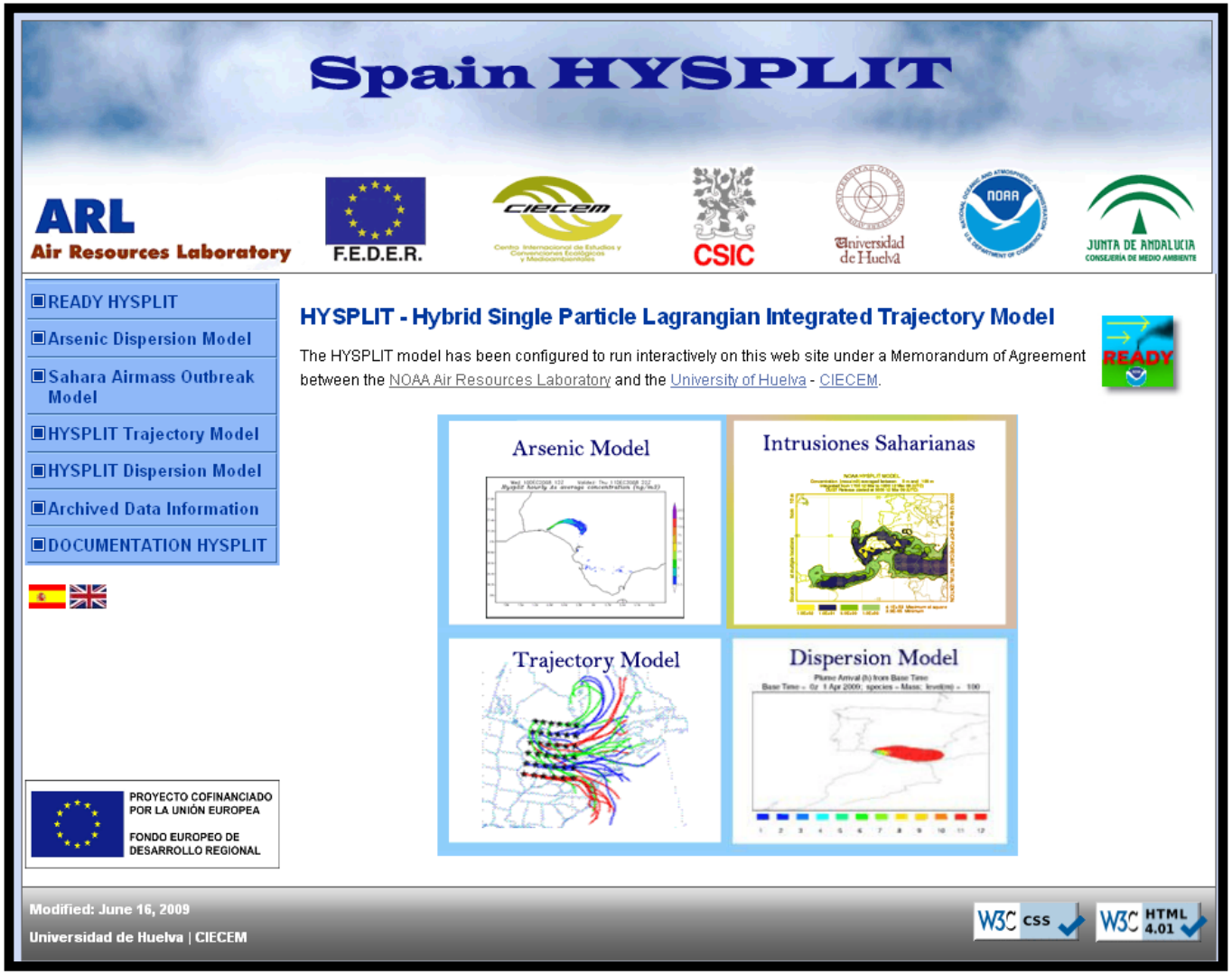
Acknowledgment

The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and/or READY website (http://www.arl.noaa.gov/ready.html) used in this publication.

- HYSPLIT Use Agreement
- What is UTC, GMT, Z time?
- Questions/Comments?

http://www.ready.noaa.gov/ready/open/hysplit4.html

Spanish Version HYSPLIT Web Site being developed in Spain:



They have only translated a few things for now, but are working to make the site fully translated into Spanish

http://www.ciecem.uhu.es/hysplitweb08/HYSPLIT.php

Meteorological Data

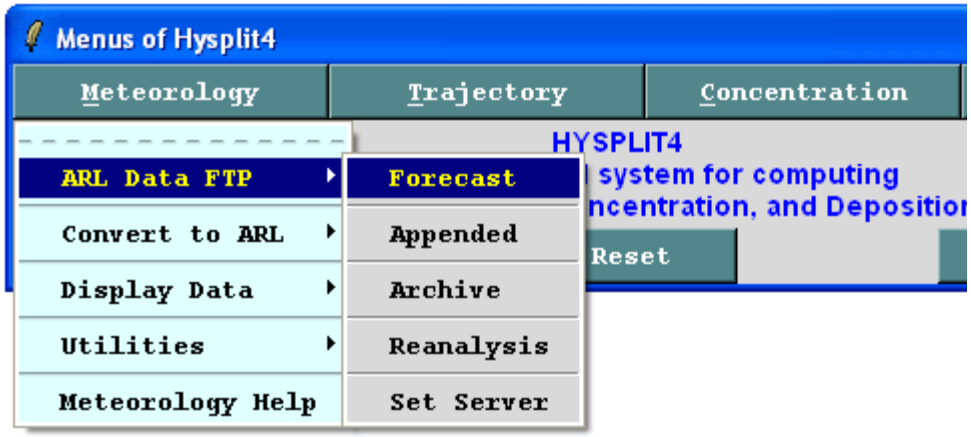
Introduction

- HYSPLIT requires at a minimum, u,v,w,T, P_{sfc} (RH or Q optional) in 3 dimensions
- Meteorological data are specially formatted to minimize execution time
  - Compressed binary
  - Fields are written at each level for one time period, then repeated as needed in time
- All forecast data currently available in HYSPLIT menus originates from NOAA's National Centers for Environmental Prediction (NCEP)
- Forecast or Analysis
  - Registration is required to run HYSPLIT dispersion with forecast data
  - Data is available globally and regionally over North America
- PC HYSPLIT downloads data directly from NOAA ARL servers; options are available to switch to other FTP servers

Meteorological Data

- **Forecast Meteorological Data:**
  - North American Meso (**NAM**)
  - Rapid Update Cycle (**RUC**)
  - Global Forecast System (**GFS**)

- **Analysis Meteorological Data:**
  - North American Meso (**NAM**)
  - NAM Data Assimilation System (**NDAS**, formerly **EDAS**)
  - Global Data Assimilation System (**GDAS**, formerly **FNL**)
  - Global **Reanalysis**



For more information, see the following websites:

http://www.arl.noaa.gov/READYmetdata.php

http://www.arl.noaa.gov/archives.php

http://www.nco.ncep.noaa.gov/pmb/products/

Supplement

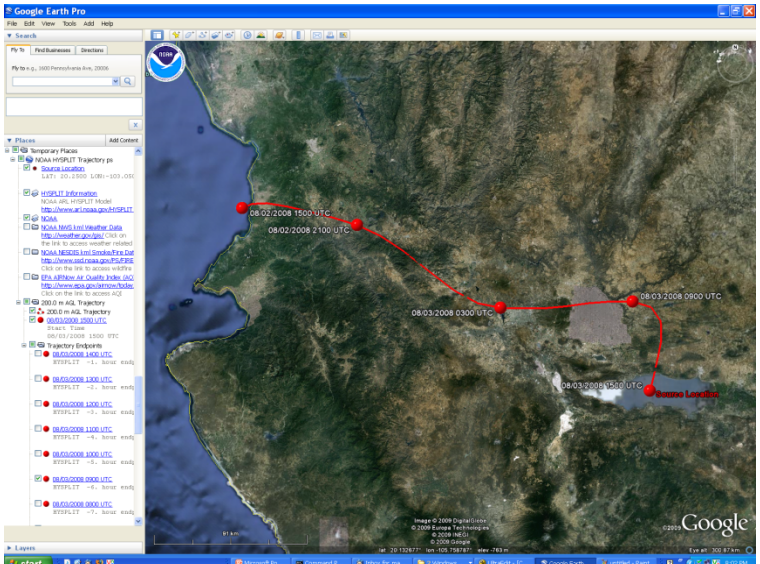
Computation of a Single Particle Trajectory

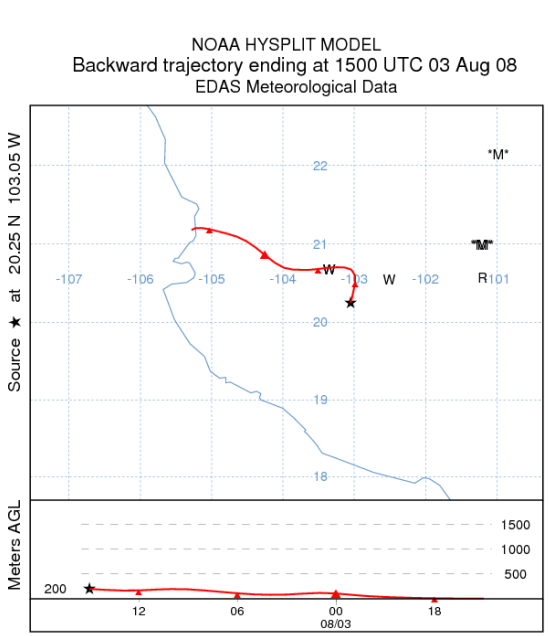
- Position computed from average velocity at the initial position (P) and first-guess position (P'):

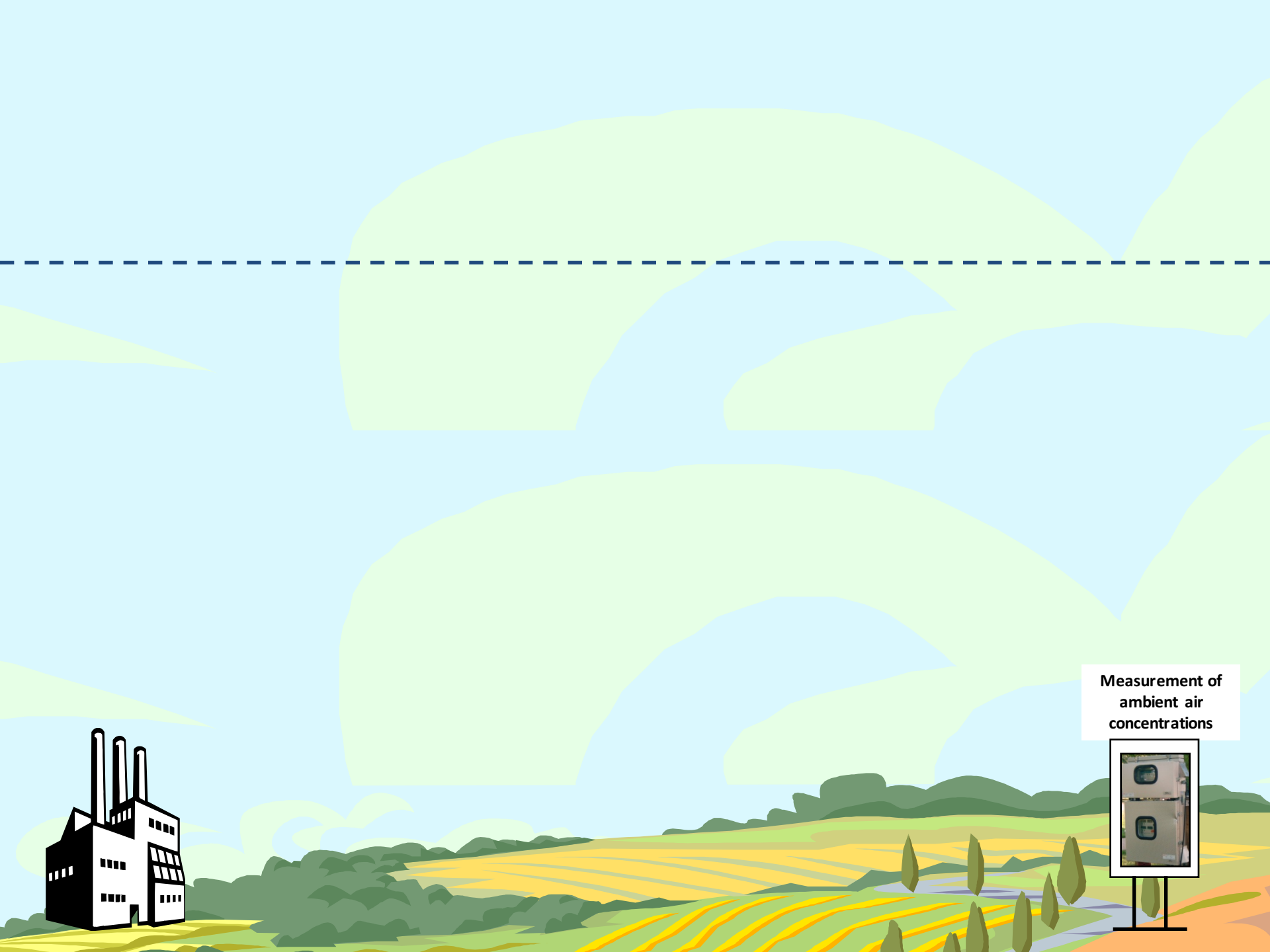
$$P(t+dt) = P(t) + 0.5\,[\,V(P\{t\}) + V(P'\{t+dt\})\,]\,dt$$
$$P'(t+dt) = P(t) + V(P\{t\})\,dt$$

- The integration time step is variable: $V_{max}\,dt < 0.75$
- The meteorological data remain on its native horizontal coordinate system
- Meteorological data are interpolated to an internal terrain-following sigma coordinate system:

$$s = (Z_{top} - Z_{msl}) / (Z_{top} - Z_{gl})$$



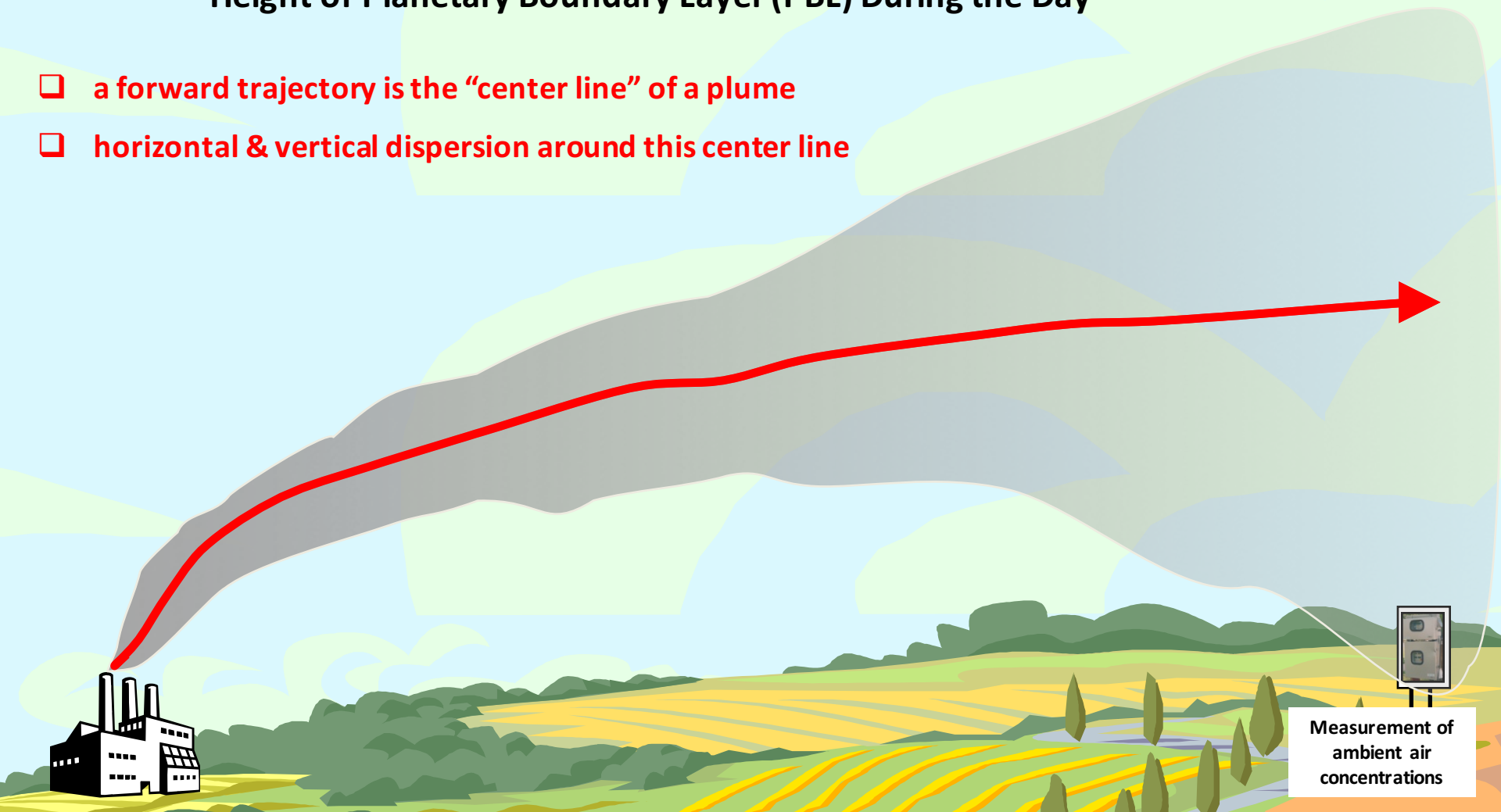



Measurement of ambient air concentrations

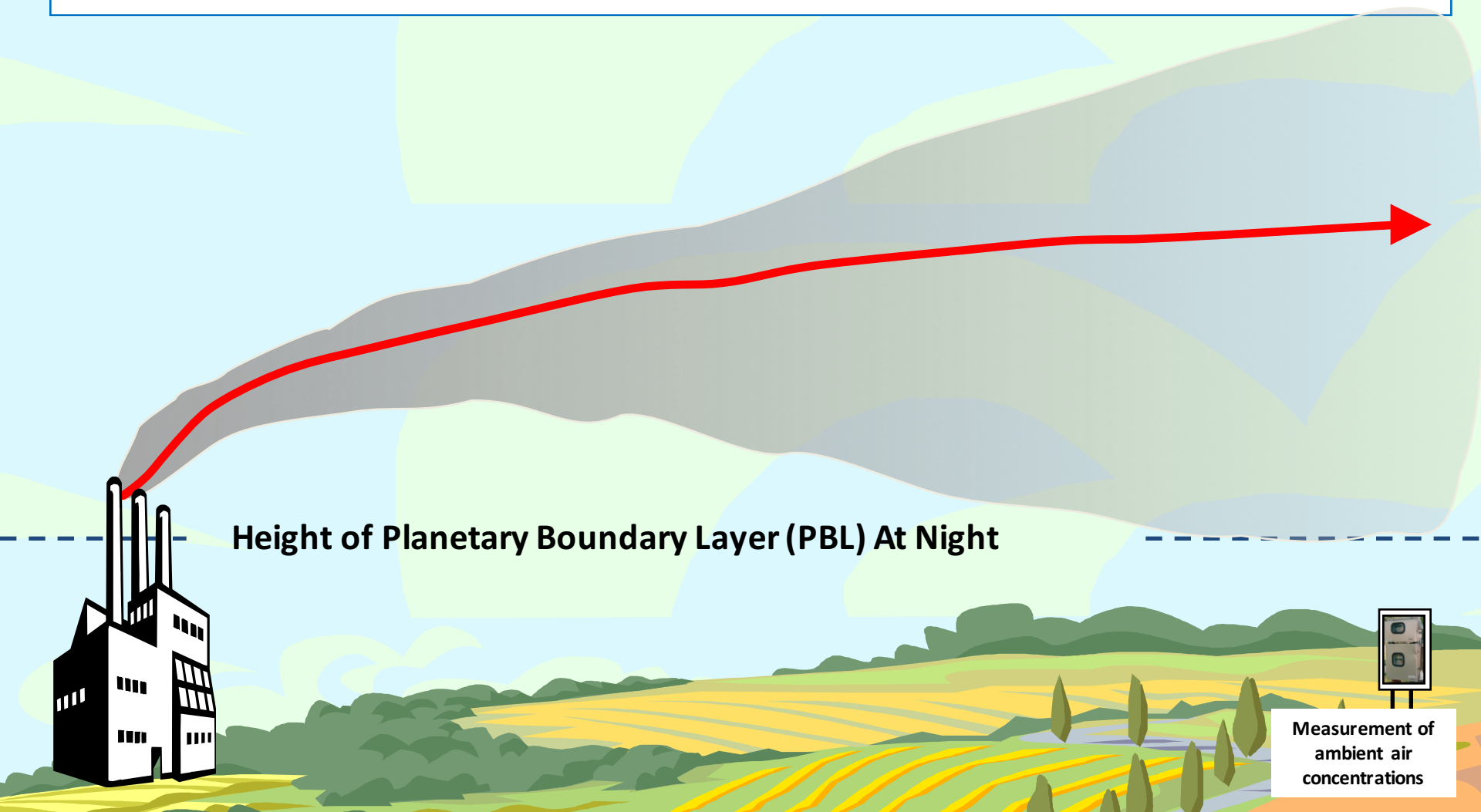
Greater than ~20km from the source,
if the forward trajectory from the source is within the PBL,
then the source can impact the measurement site,
even if the trajectory endpoint near the site is not at the height of the sampler…
This is because the PBL is relatively well-mixed during the day.

Height of Planetary Boundary Layer (PBL) During the Day

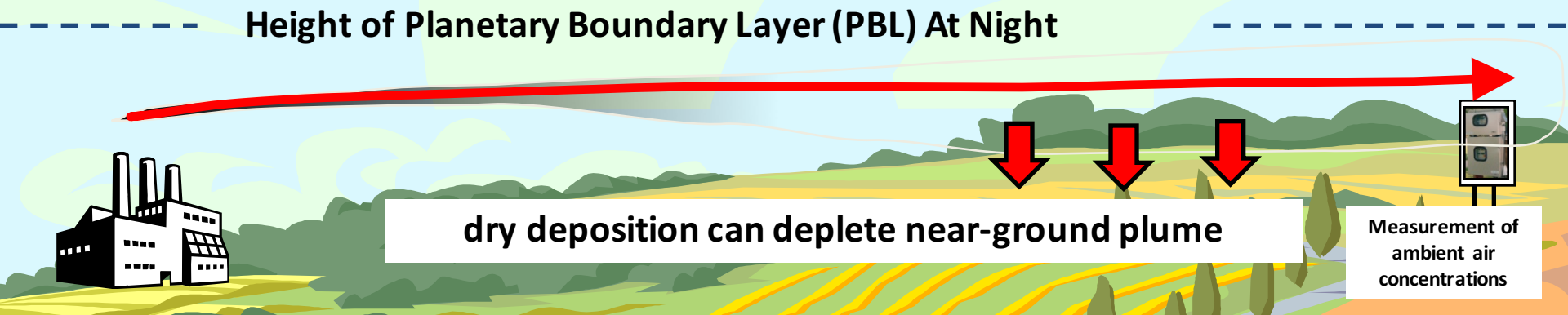
- a forward trajectory is the "center line" of a plume
- horizontal & vertical dispersion around this center line



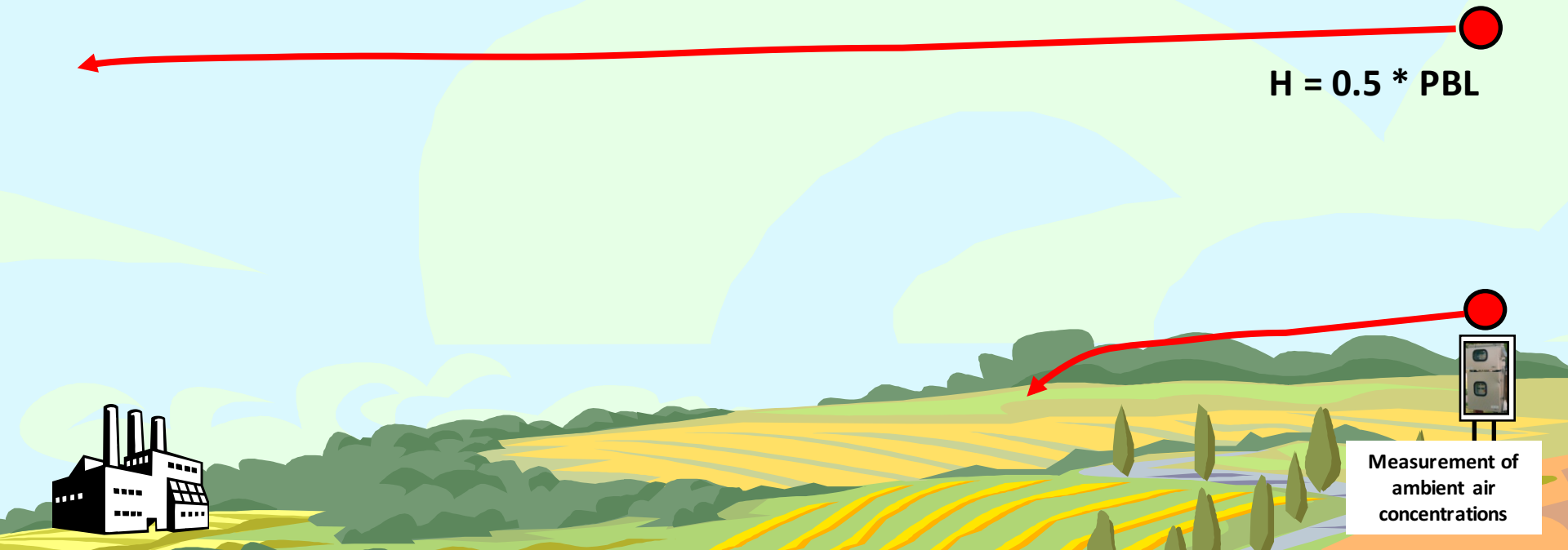
- At night, the Planetary Boundary Layer (PBL) is generally much shallower
- Emissions from an elevated stack may be emitted above the PBL
- In this case, little or no impact on a ground-based measurement site until the next daytime period, when the boundary layer grows.

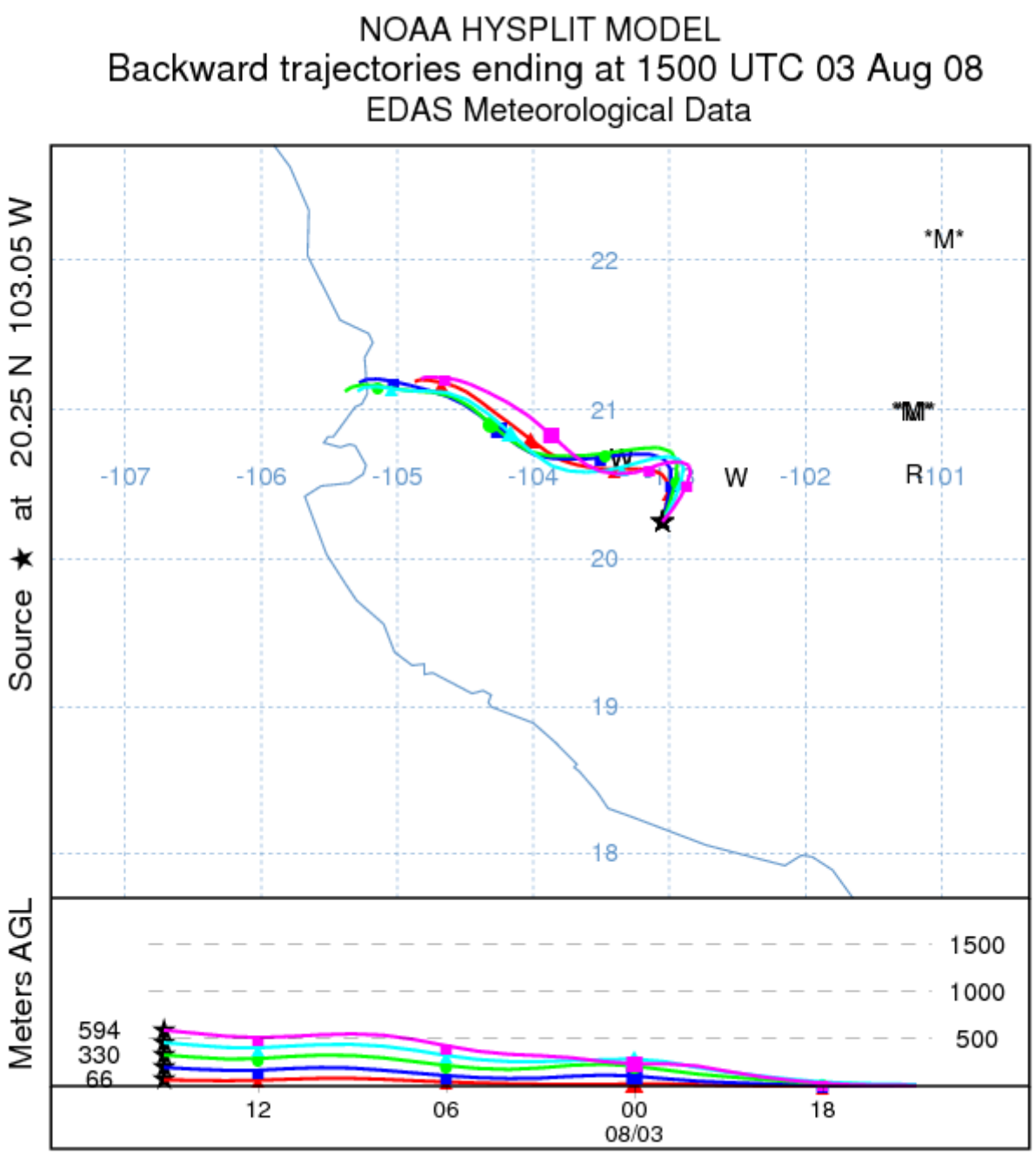


- At night, the Planetary Boundary Layer (PBL) is generally much shallower
- Emissions from an relatively low stack may be emitted within the PBL
- But, if the pollutant dry deposits relatively rapidly (e.g., reactive gaseous mercury ("RGM"), by the time the plume reaches the receptor, there may be little pollutant left…



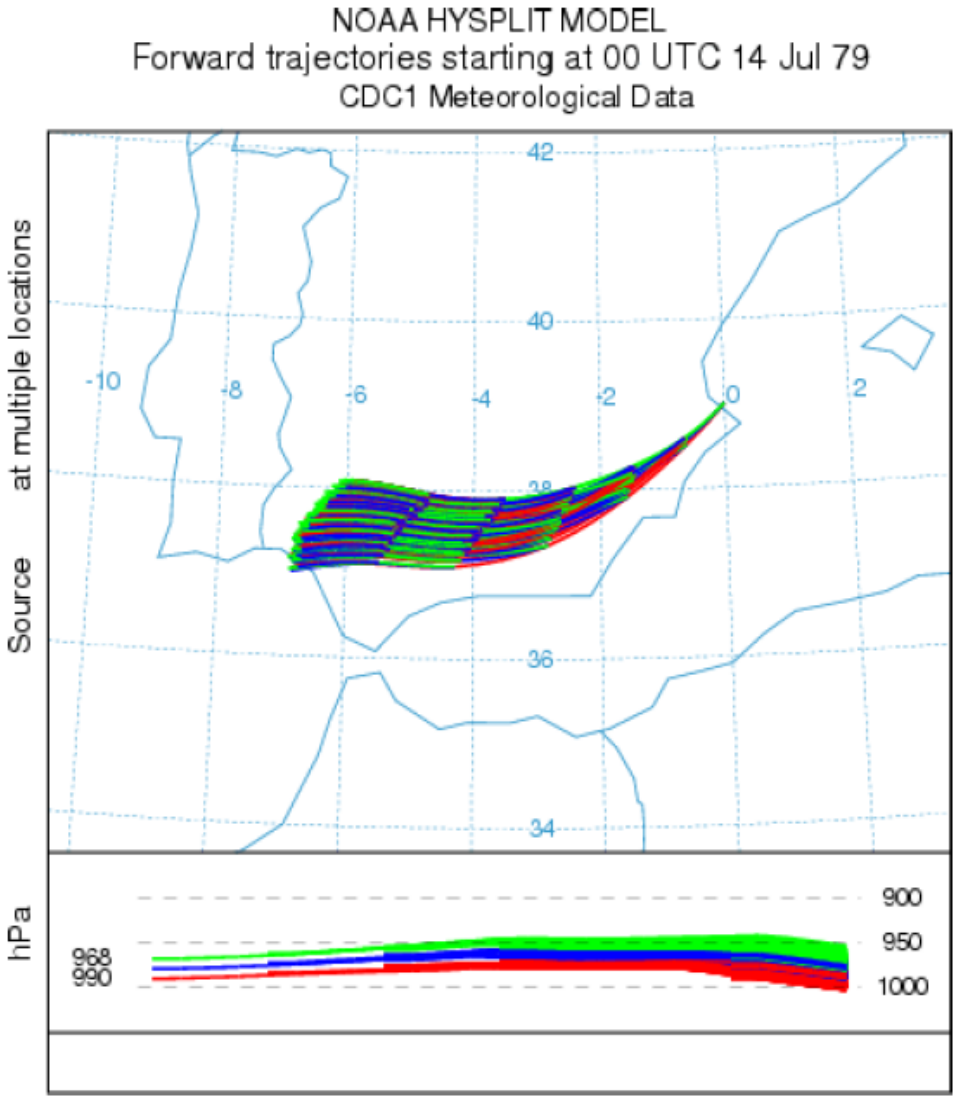
- What are the implications of these ideas for back-trajectories?
- What HEIGHT should one start a back-trajectory?
- If you start very low to the ground, at the sampler height, the trajectory program does not work well… the trajectories hit the ground and stop
- "best" starting height for back-trajectories may be from the middle of the Planetary Boundary Layer




NOAA HYSPLIT MODEL
Backward trajectories ending at 1500 UTC 03 Aug 08
EDAS Meteorological Data
Source ★ at 20.25 N 103.05 W
M
M
22
21
20
19
18
-107
-106
-105
-104
-102
W
R101
Meters AGL
1500
1000
500
594
330
66
12
06
00
08/03
18

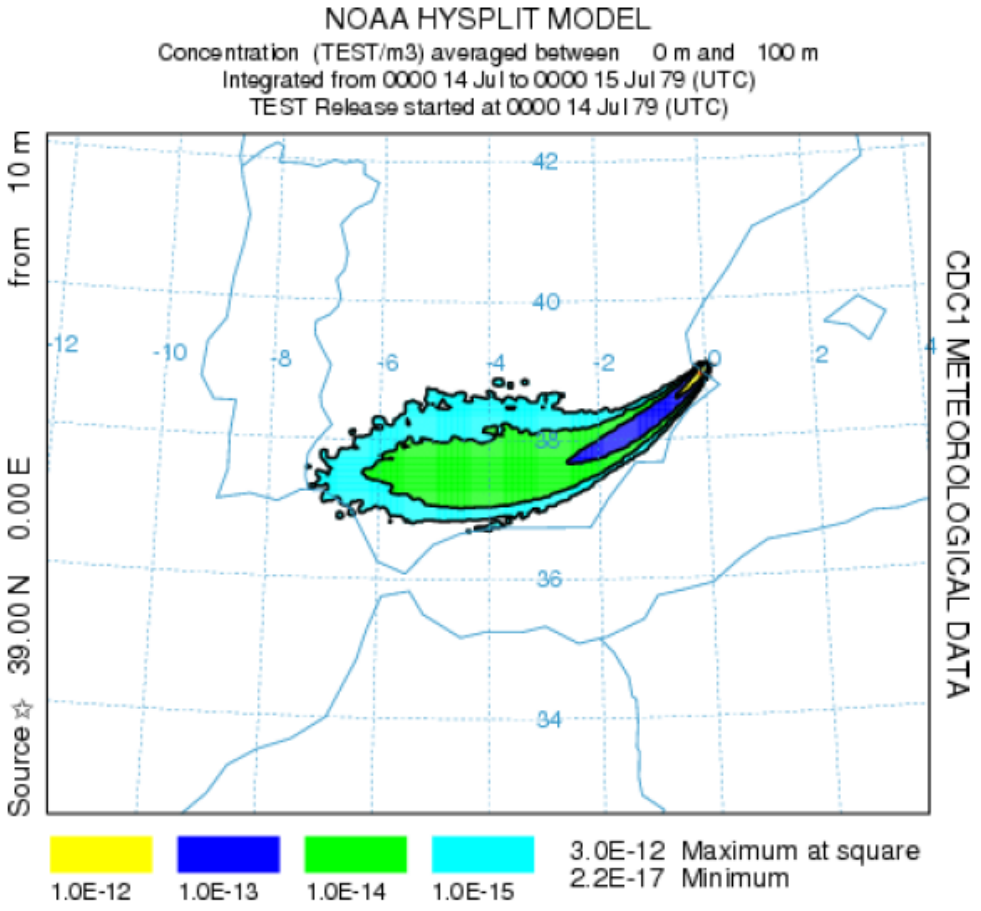
Representation of a Plume using Trajectories

- A single trajectory cannot properly represent the growth of a pollutant cloud when the wind field varies in space and height
- The simulation must be conducted using many pollutant particles
- In the illustration on the right, new trajectories are started every 4-h at 10, 100, and 200 m AGL to represent the boundary layer transport
- It looks like a plume because wind speed and direction varies with height in the boundary layer

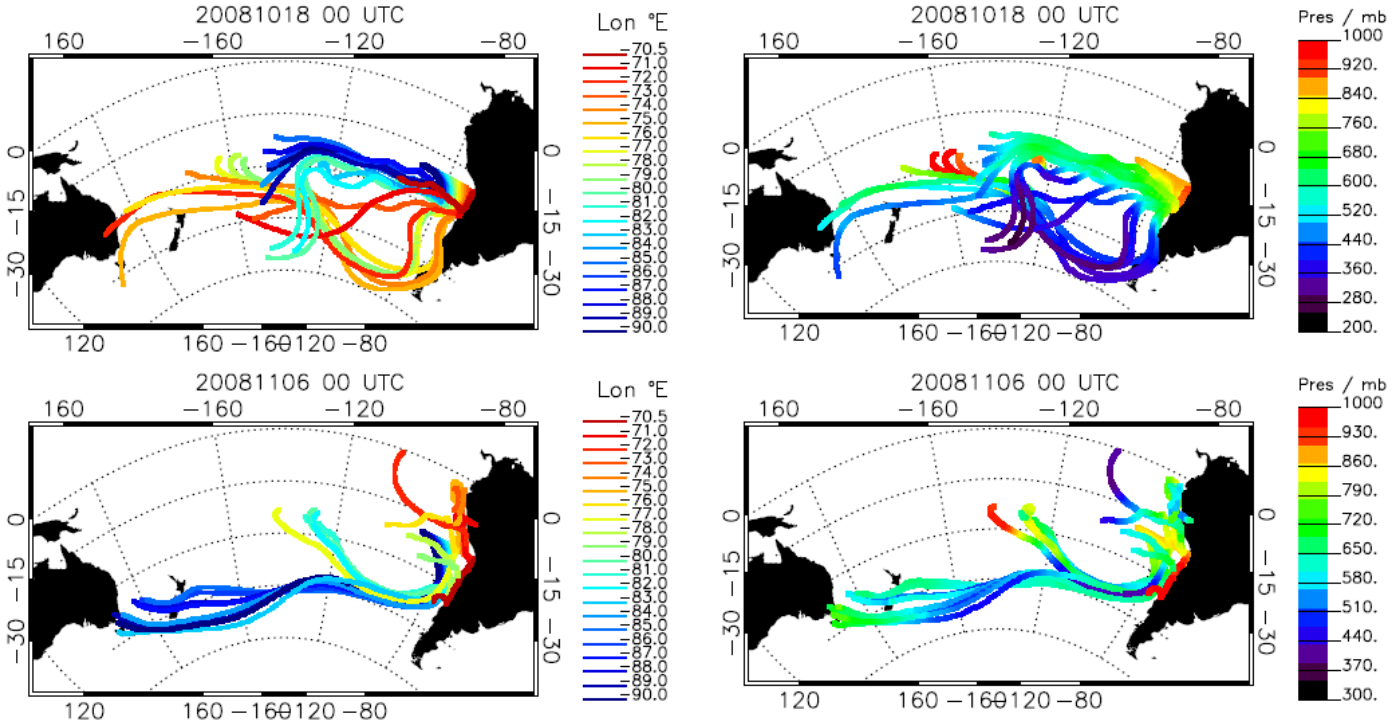


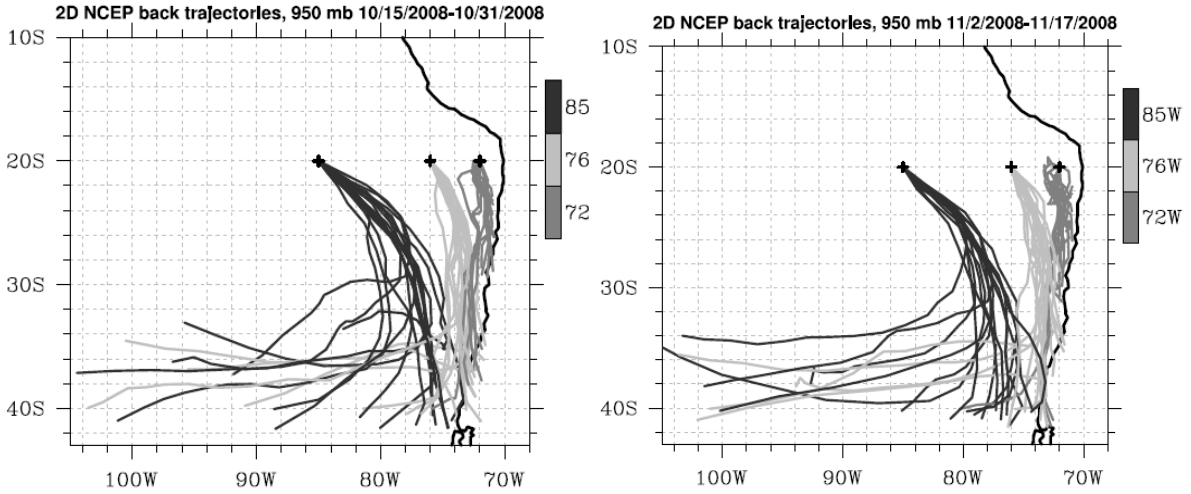
Trajectory based Plume Simulation Options

- **Particle**: a point mass of contaminant. A fixed number is released with mean and random motion.
- **Puff**: a 3-D cylinder with a growing concentration distribution in the vertical and horizontal. Puffs may split if they become too large.
- **Hybrid**: a circular 2-D object (planar mass, having zero depth), in which the horizontal contaminant has a "puff" distribution and in the vertical functions as a particle.



Applications: Air masses origin

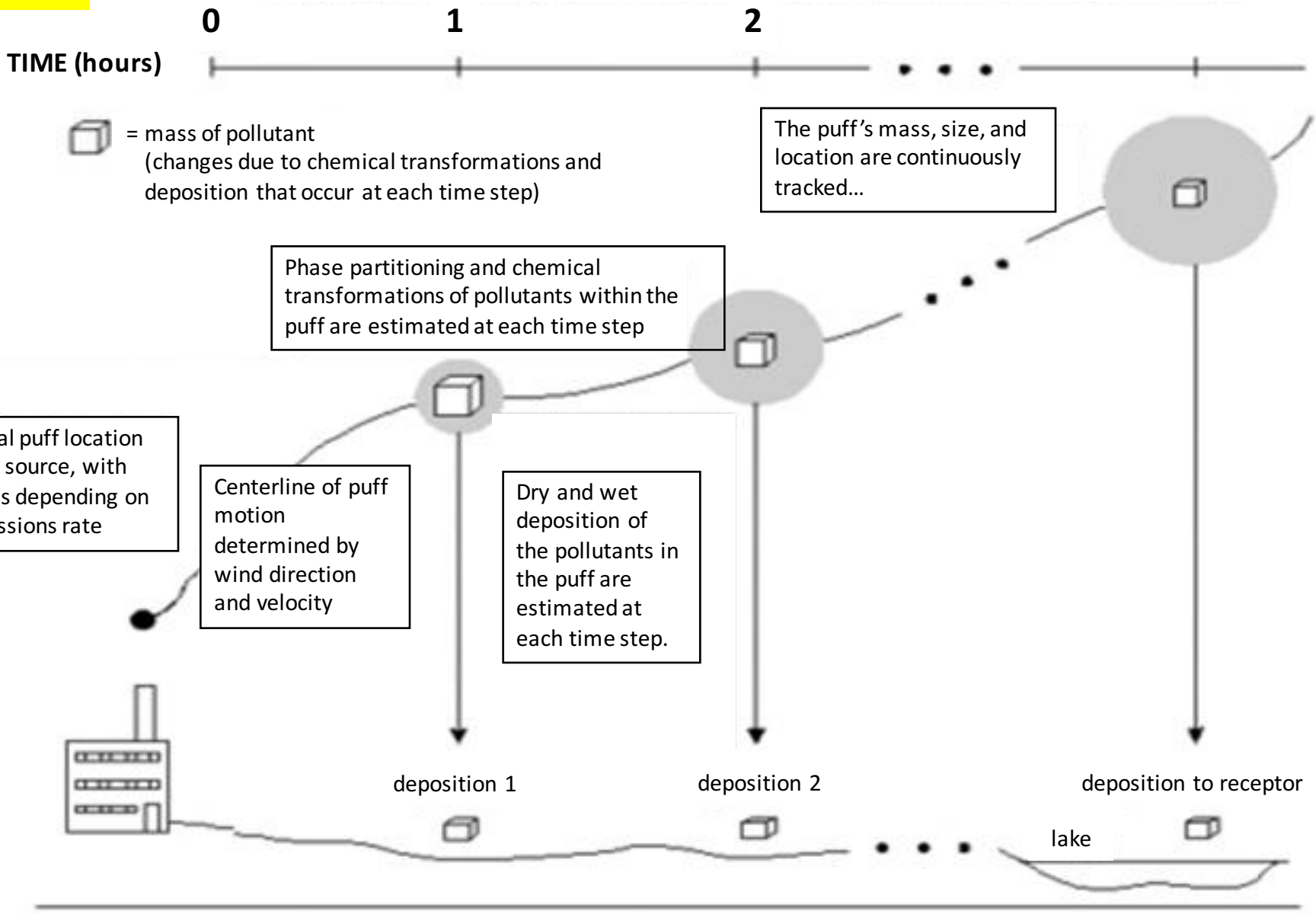




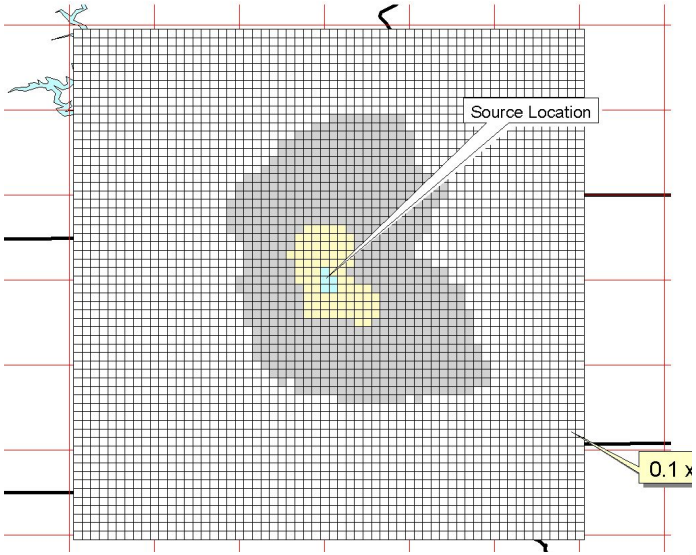
Allen et al., 2011

NOAA HYSPLIT MODEL

Lagrangian Puff Atmospheric Fate and Transport Model



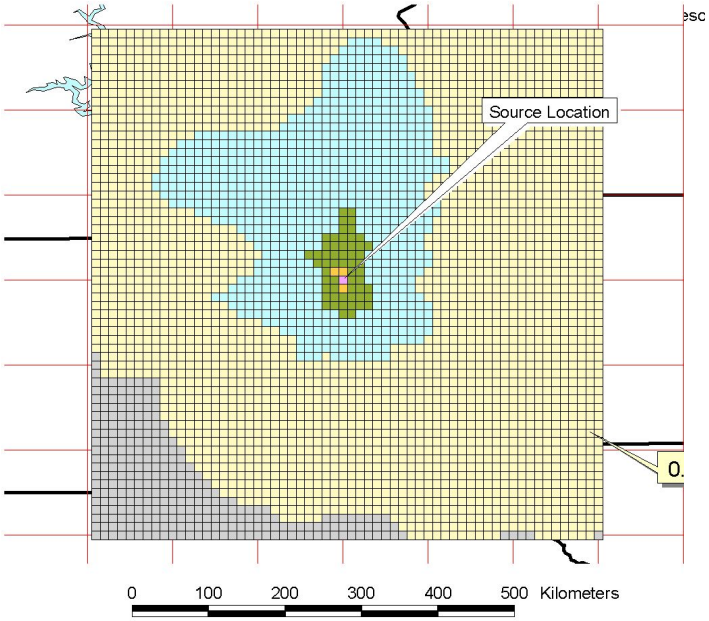
Annual deposition summary for emissions of elemental Hg from a 250 meter high source



Annual Deposition Flux (ug/m2-yr) arising from a 1 kg/day emissions source

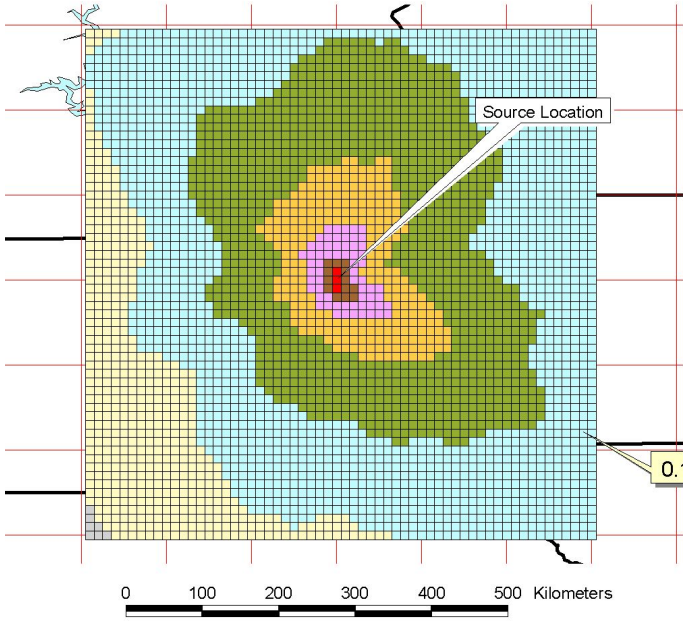
- 0 - 0.01
- 0.01 - 0.03
- 0.03 - 0.1
- 0.1 - 0.3
- 0.3 - 1
- 1 - 3
- 3 - 10
- 10 - 30
- 30 - 100

Annual deposition summary for emissions of particulate Hg from a 250 meter high source



Hypothetical emissions source at lat = 42.5, long = -97.5;
simulation for entire year 1996 using archived NGM meteorology (180 km r

Annual deposition summary for emissions of ionic Hg from a 250 meter high source



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