Incorporation of STILT features into HYSPLIT

Chris Loughner – University of Maryland / NOAA ARL

Ariel Stein – NOAA ARL

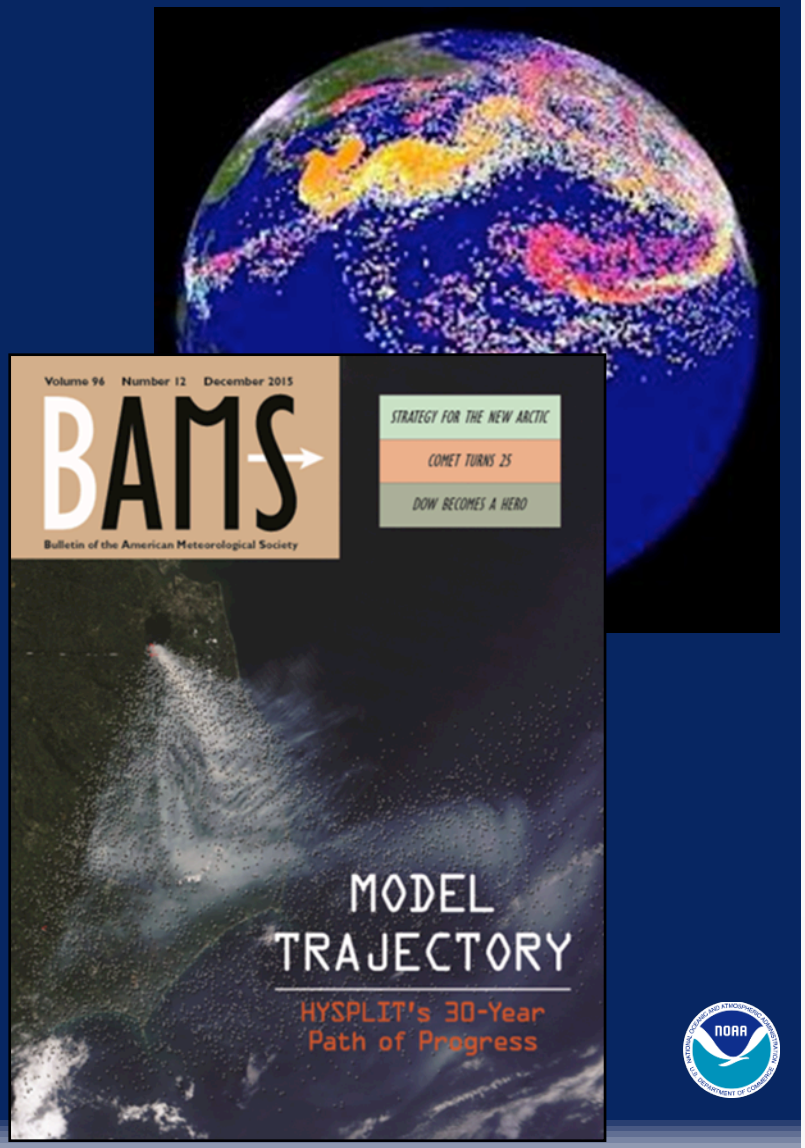
John Lin – University of Utah

Introduction

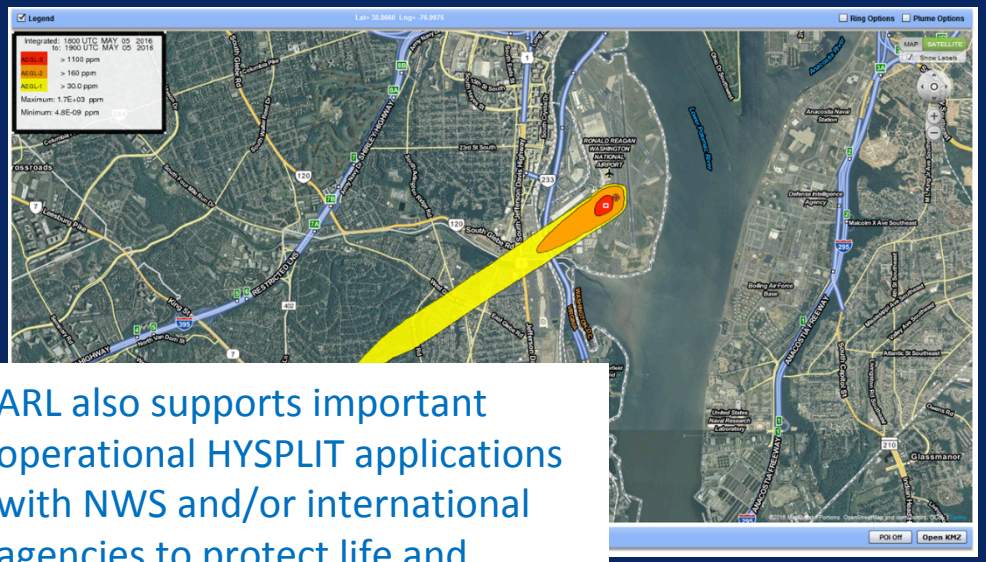
- **Goal:**
  - Apply model to estimate carbon emissions and trends in different U.S. cities
- **Construct an atmospheric modeling system that is scalable and transferable between cities:**
  - Enhance HYSPLIT with STILT routines
  - Compile urban/suburban scale datasets for testing updated HYSPLIT model
  - Host benchmark scenarios for future testing of model updates and model inter-comparisons
- **Benefits of HYSPLIT modeling system updates:**
  - Enhance HYSPLIT's capabilities
  - Host and maintain STILT routines with HYSPLIT code that will continue to be updated with the state of the science
  - Provide testing platform to evaluate and examine model similarities and differences to other Lagrangian models / model options. Testing platform can also be used to test inversion techniques to estimate source strength and location.

HYSPLIT

- We are the developers of the state-of-the-art HYSPLIT atmospheric transport and dispersion model.
- Operational and research grade dispersion products
- 4,100+ formally registered users from US and overseas (government, private sector, and academia) who require ability to use forecast data and/or the source code
- Extensive additional use by others
- ***READY*** HYSPLIT web site usage:
  - Average 70,000+ simulations/month
  - 1,200,000+ in 2017
  - Meteograms in READY: ~10,000/day
- ***HYSPLIT peer literature reference***:
  - 800+ references to Draxler and Hess, 1998. Source: Web of Science
  - 650+ references to HYSPLIT BAMS Stein et al, 2015 (published in December, 2015)



Operational uses



- HYSPLIT used operationally by the Weather Forecast Offices to forecast transport and dispersion of **hazardous materials from industrial accidents**, to protect life and property

ARL also supports important operational HYSPLIT applications with NWS and/or international agencies to protect life and property in the event of:

- Nuclear accidents
- Wildfires
- Clandestine nuclear activities (Comprehensive Test Ban Treaty Organization)
- Volcanic eruptions

HYSPLIT features

- Lagrangian emission, transport, dispersion, and deposition. HYSPLIT also has Eulerian and complex chemistry components.
- Automated method of simultaneously using multiple meteorological grids.
- Pre-processors for many different meteorological models (WRF, RAMS, MM5, ECMWF, MERRA, GALWEM) to convert data to the ARL format, in addition to the archives of existing NOAA models (NAM, HRRR, GFS, SREF).
- Multiple parameterizations to estimate the stability from gradients of meteorological variables.
- Multiple options to convert stability into dispersion values (diffusivity profiles, turbulent kinetic energy, velocity variance).
- Multiple options for estimating mixed layer heights.
- Modeling the turbulent particle motion directly (3D) or the change in the statistic of the particle distribution (puffs) or a combination of the two.
- Mixed-mode approach: 3D particle to puff, 3D particle to Eulerian, puff to 3D particle, puff to Eulerian.

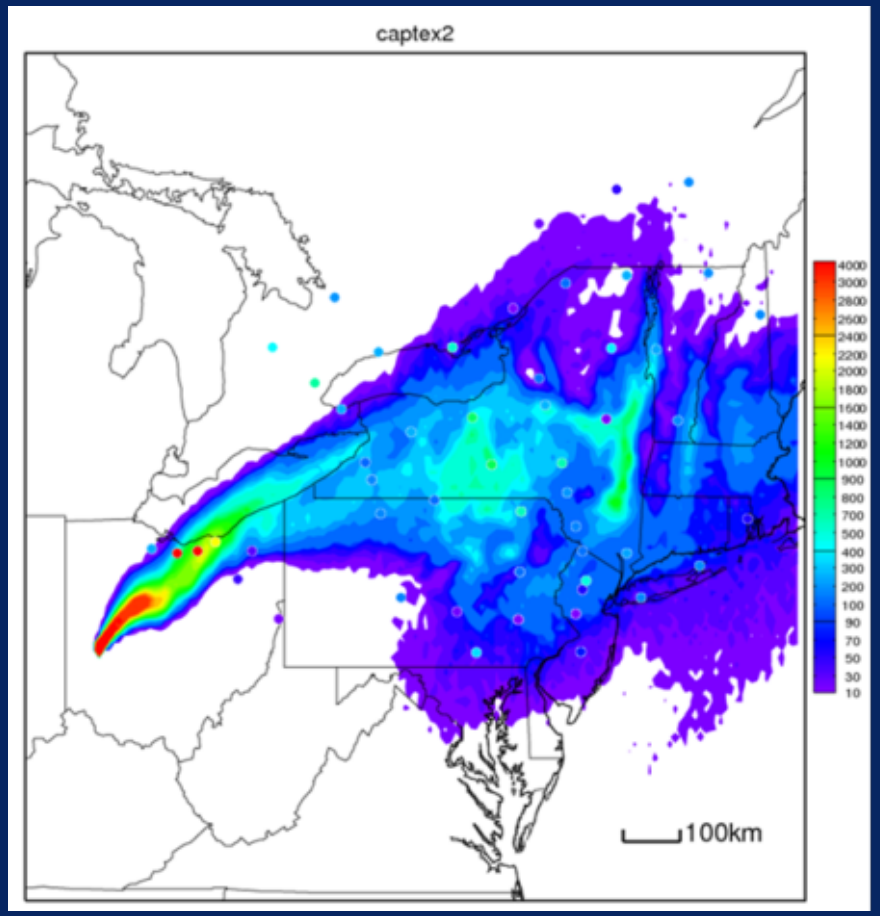
HYSPLIT Model Evaluation System

Data Archive of Tracer Experiments and Meteorology (DATEM)

- **Approach**
  - Perform HYSPLIT simulation using archived meteorology (i.e., North American Regional Reanalysis (NARR), WRF runs (1980-2017), etc.)
  - Observations from tracer field experiments
  - Common statistical evaluation protocols

- **Accomplishments**
  - Web access to run HYSPLIT for each experiment
  - Standardized model change testing in conjunction with version control

HYSPLIT simulation of 2nd tracer release of the Cross Appalachian Tracer Experiment (CAPTEX)



Incorporation of STILT routines into HYSPLIT

New HYSPLIT Feature	Description
WRF vertical interpolation	Following same algorithm as in WRF
New mixed layer calculation	More detailed algorithm that uses excess temperature for convective cases as a function of virtual potential temperature, U star, and W star following Holtslag and Boville (1993)
Hanna boundary layer turbulence parameterization	Computes vertical diffusivity following Hanna (1982) within the PBL and the standard mixing length theory above the PBL.
Lagrangian vertical timescale varying in space and time	Calculates vertical Lagrangian timescale from the standard deviation of vertical velocity following Hanna (1982); can be used with all boundary layer turbulence parameterizations (i.e., not just the Hanna scheme)
STILT transport	A more complex turbulence module that includes the reflection/transmission scheme for Gaussian turbulence that preserves well-mixed distributions of particles moving across interfaces between step changes in turbulence parameters
New convection schemes	1) Extreme convection following Gerbig et al. (2003); 2) Grell scheme utilizing WRF output convective fluxes
Uncertainties in transport	Based on errors in wind velocity and boundary layer height
Increase in precision	
Hemispheric domain capability	

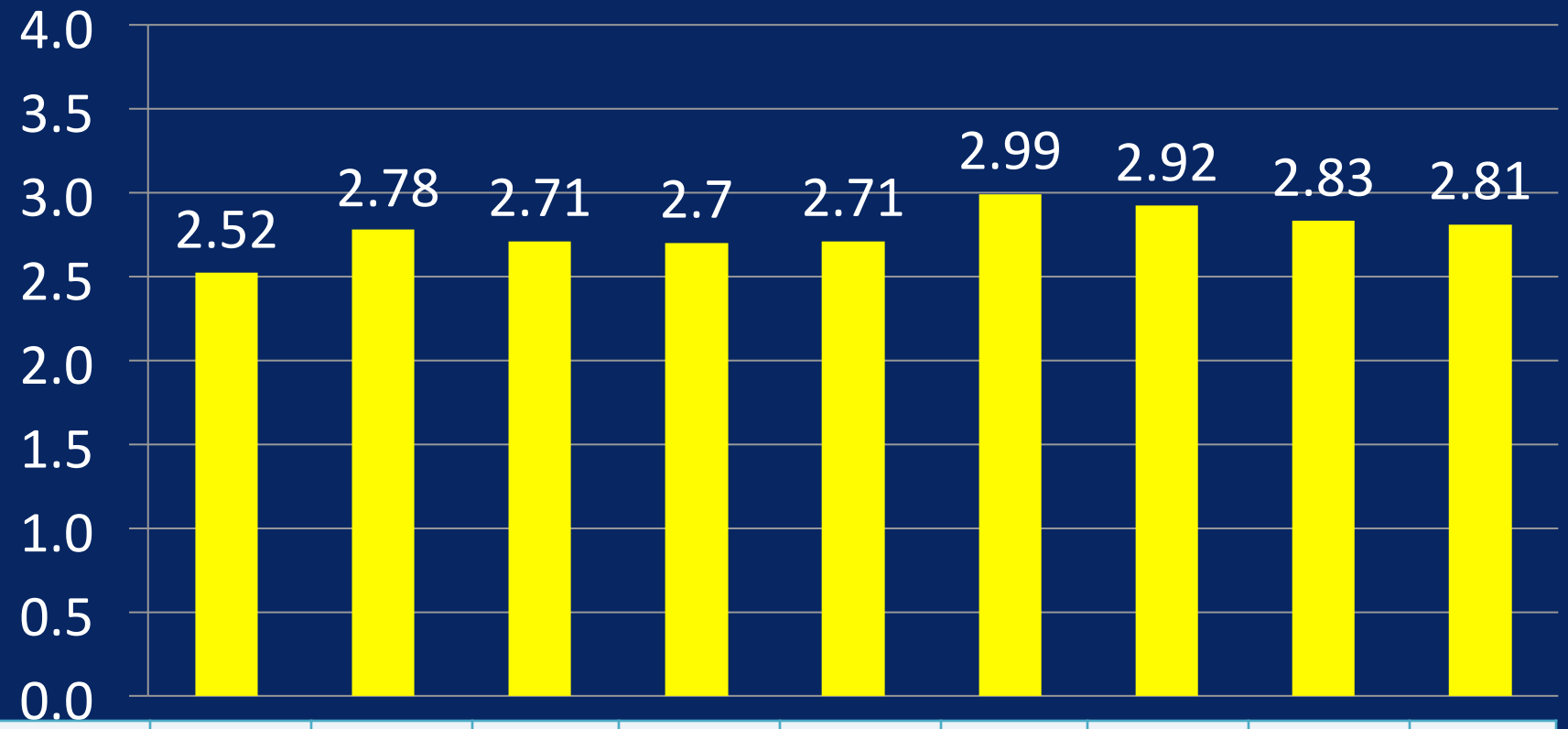
HYSPLIT – STILT Comparison

Rank, a cumulative statistical score (range between 0-4), (Roland, 2006)

$$RANK = R^2 + (1 - |FB/2|) + FMS/100 + (1 - KS/100)$$

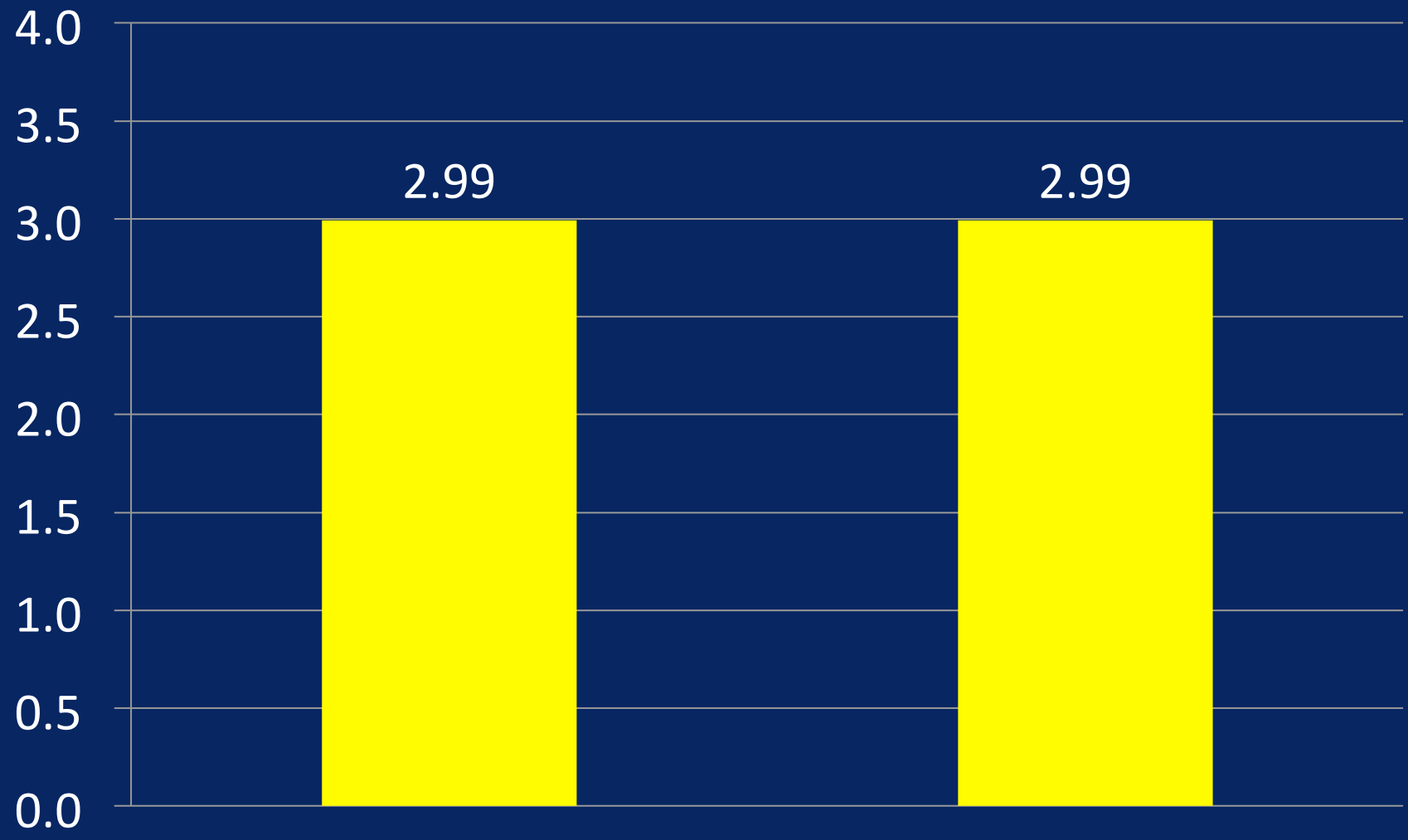
- R^2 = Square of linear correlation coefficient
- FB=Fractional Bias defines a normalized measure of bias
- FMS = Figure of Merit in Space defines a percentage of overlap between measured and predicted areas
- KS = Kolomogorov-Smirnov parameter defines the maximum difference between two cumulative distributions

Time averaged fields, transport, vertical interpolation, and Lagrangian timescale evaluation (kbls=2; kblt=3; kmixd=0)



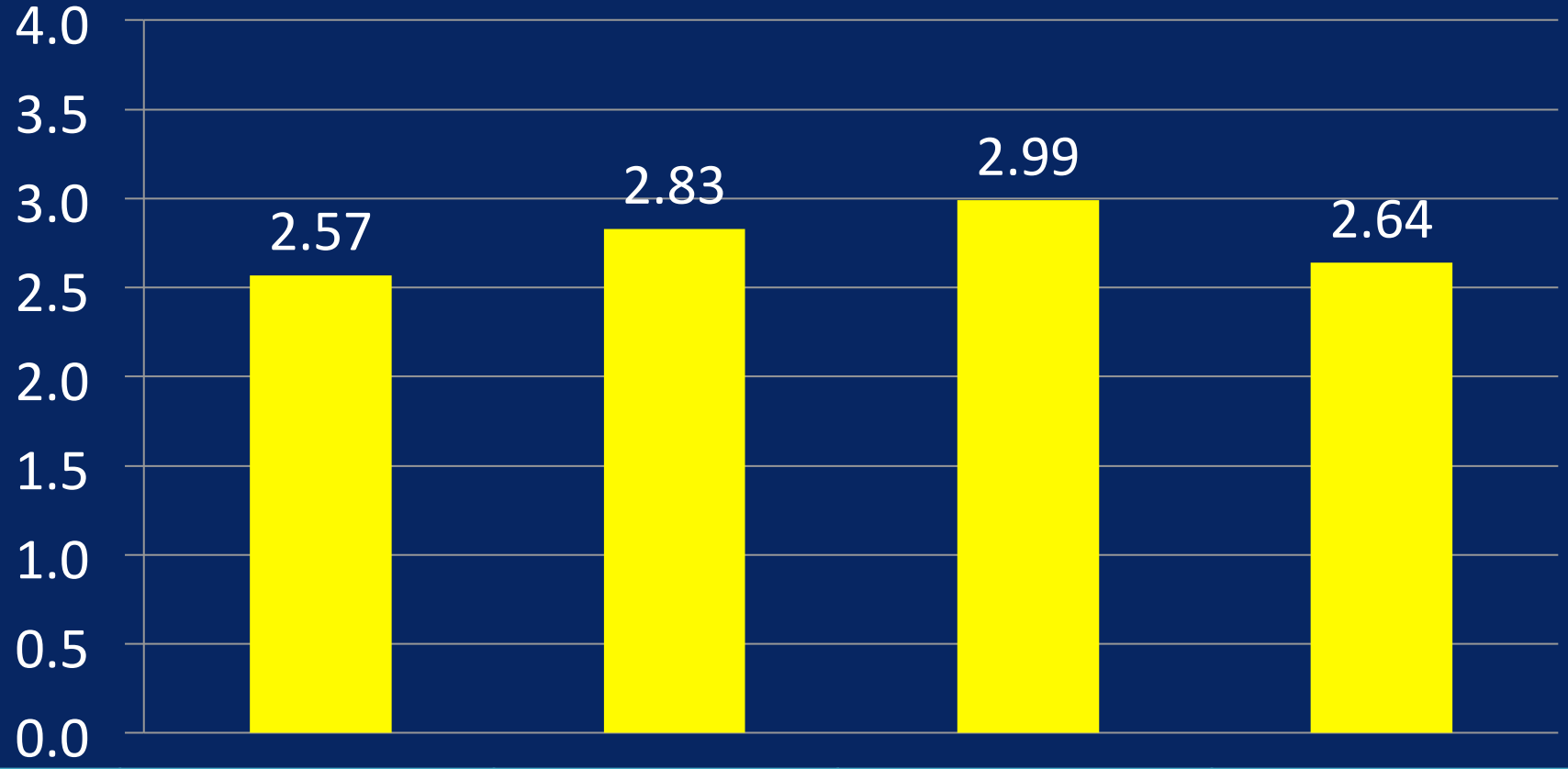
ARL Format	HYSPLIT	STILT	STILT	STILT	STILT	STILT	STILT	STILT	STILT
Transport	HYSPLIT	HYSPLIT	HYSPLIT	HYSPLIT	HYSPLIT	STILT	STILT	STILT	STILT
Vertical Interpolation	HYSPLIT	HYSPLIT	HYSPLIT	STILT	STILT	HYSPLIT	STILT	HYSPLIT	STILT
Lagrangian Timescale	HYSPLIT	HYSPLIT	STILT	HYSPLIT	STILT	HYSPLIT	HYSPLIT	STILT	STILT

Boundary layer stability options (kbls) kblt=3; kmixd=0



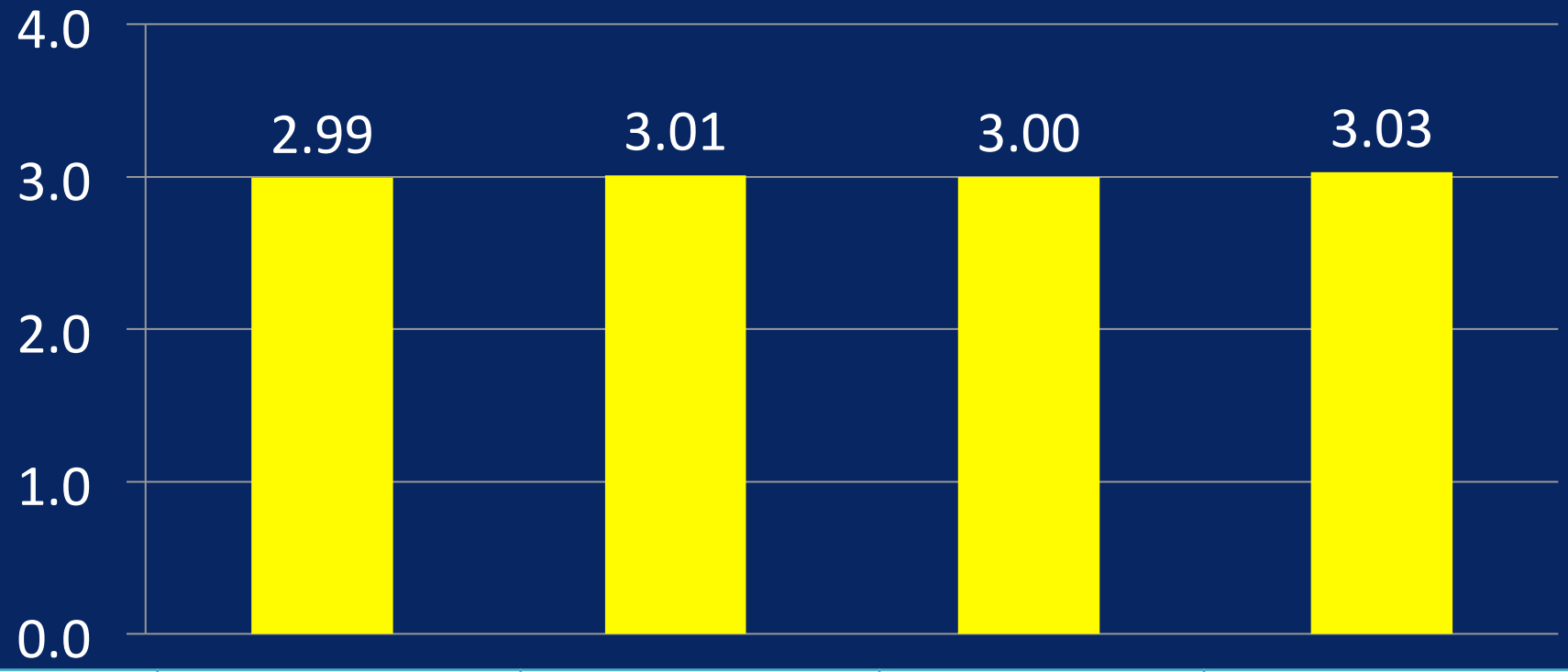
kbls	1 Heat and momentum fluxes	2 wind and temperature profiles

Vertical turbulence options (kblt)
kbls=2; kmixd=0



kblt	1 Beljaars-Holtslag – based on vertical mixing diffusivities following the coefficient of heat	2 Kantha-Clayson – based on the square of horizontal and vertical friction velocity	3 TKE – uses turbulent kinetic energy fields	5 STILT following Hanna – based on friction and convective velocity

Mixed layer depth options (kmixd)
kbls=2; kblt=3



kmixd	0 Input from meteorological file	1 Temperature profile	2 TKE profile	3 STILT following Holstlag and Boville – based on excess temperature, which is computed from virtual potential temperature and horizontal and vertical friction velocity

Convection options (capemin)
kbls=2; kblt=3; kmixd=0

capemin	-1 No convection	500 Convection when CAPE exceeds 500 J/kg	-2 Grell – uses convective fluxes from WRF output	-3 Extreme convection

Next Steps

- Test code using different meteorological datasets.
- Update code to include all of the standard HYSPLIT updates from the past year.
- More in-depth evaluation using multiple tracer release experiments.

More detailed evaluation of updated HYSPLIT modeling system

- Evaluate individual model options over a range of scenarios (field campaigns and computational experiments).
  - What are the differences and similarities between different model options.
  - Document differences in computational time for each model option (speed is of great importance for operational purposes).
  - When is it necessary to use the more complex model option that requires more computational resources?
- Expand the DATEM archive to incorporate field campaign data on the urban / suburban spatial scale.
- Provide meteorological datasets and HYSPLIT simulations for benchmarking to the Lagrangian modeling community. Can be used to test atmospheric dispersion models and inversion techniques.

HYSPLIT Model Evaluation

Data Archive of Tracer Experiments and Meteorology (DATEM)

- **Cross Appalachian Tracer Experiment (CAPTEX),** Dayton, OH, and Sudbury, ONT, Sep., Oct., 1983
- **Atlantic Coast Unique Regional Atmospheric Tracer Experiment (ACURATE),** Savannah River Plant, SC, Spring 1982 – Summer 1983
- **Across North America Tracer Experiment (ANATEX)**, Glasgow, MT, and St. Cloud, MN, January through March 1987
- **Oklahoma Tracer Experiment**, Norman, OK, July, 08 1980
- **Metropolitan Tracer Experiment (METREX)**, Washington, DC, January – December 1984
- **European Tracer Experiment (ETEX)**, Rennes, France, October 23, 1994
- **Savannah River Plant Experiment**, Aiken, SC, Aug. 1975 through Sep. 1977
- **Atmospheric Studies in Complex Terrain (ASCOT)**, California, September 12-25, 1980
- **Colorado Springs Tracer Experiment (COSTEX)**, October 18, 21, 23, 2010
- **Sagebrush, Idaho, 2013**
- **Aliso Canyon well blowout, 2015**
- **Tracers of opportunity (e.g. SO_2 flight data)**

Conclusion

- New features from STILT have been merged into HYSPLIT.
- These new options can be chosen a-la-carte.
- Initial tests show this new version of HYSPLIT is working properly.
- A more in-depth evaluation will be performed using a wide variety of tracer studies, including new DATEM on urban / suburban spatial scales.
- Meteorological datasets will be included in the DATEM for HYSPLIT benchmark runs for future testing of new model developments, other models, and inversion techniques.
- By incorporating STILT features into HYSPLIT, this ensures that they will be maintained and kept up to date in the HYSPLIT repository.