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MACCS-HYSPLIT COUPLING AND BENCHMARK

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MACCS

Accident Consequence Model

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CHALLENGES TO GAUSSIAN PLUME MODEL

MACCS
Accident Consequence Model

Use of Gaussian model questioned

- Adequacy at locations that experience lake or sea breezes
- Suitability for river valleys that strongly influence local winds
- Adequacy for areas with significant surface relief
- Distance to which a Gaussian plume model is reliable

Challenges motivated a detailed benchmark study (NUREG-6853, 2004)

- Four ATD models
  - Lagrangian model (LODI)
  - Two Gaussian puff models (RASCAL and RATCHET)
  - Gaussian plume segment model (MACCS)
- Oklahoma ARM site using weather station data (ADAPT)
- Showed differences in the annual average exposure and deposition results were nearly within a factor of two out to 100 miles
- Did not address sea breezes, river valleys, or other terrain variations

HYSPLIT DESCRIPTION

The HYSPLIT model is a system for computing simple air parcel trajectories, as well as complex atmospheric transport and dispersion simulations

HYSPLIT has been developed at the NOAA Air Resources Laboratory (ARL) for more than 30 years, and it is still undergoing development at ARL. (https://www.arl.noaa.gov/)

It requires meteorological data to run, but extensive HYSPLIT-compatible meteorological datasets are publicly available on the ARL-HYSPLIT website

The model has been tested extensively by comparison of its predictions against actual measurements of atmospheric concentrations and deposition

HYSPLIT is one of the most widely used atmospheric transport and dispersion models in the world.

MACCS MODULES

ATMOS

- Source term definition
- Weather sampling algorithms
- Atmospheric transport, dispersion, and deposition
  - Option for either HYSPLIT or Gaussian model

EARLY (1 to 40 days)

- Doses as modified by emergency-phase countermeasures such as sheltering, evacuation, relocation, and KI ingestion
- Multiple population cohorts
- Acute and latent health effects from early acute exposure

CHRONC (1 week to >50 years)

- Doses as modified by intermediate and recovery-phase protective actions such as relocation, interdiction, decontamination, and condemnation
- Latent health effects from chronic exposure to deposited materal
- Economic impact from early and late phase protective actions

IMPLEMENTATION CHOICES

MACCS
Accident Consequence Model

Unit releases without radioactive decay and ingrowth in HYSPLIT (MACCS treats these aspects) for each hour of a calendar year

MACCS then scales and sums unit releases to account for variable emission rates

Releases at several fixed elevations or buoyancy fluxes (MACCS determines which to use)

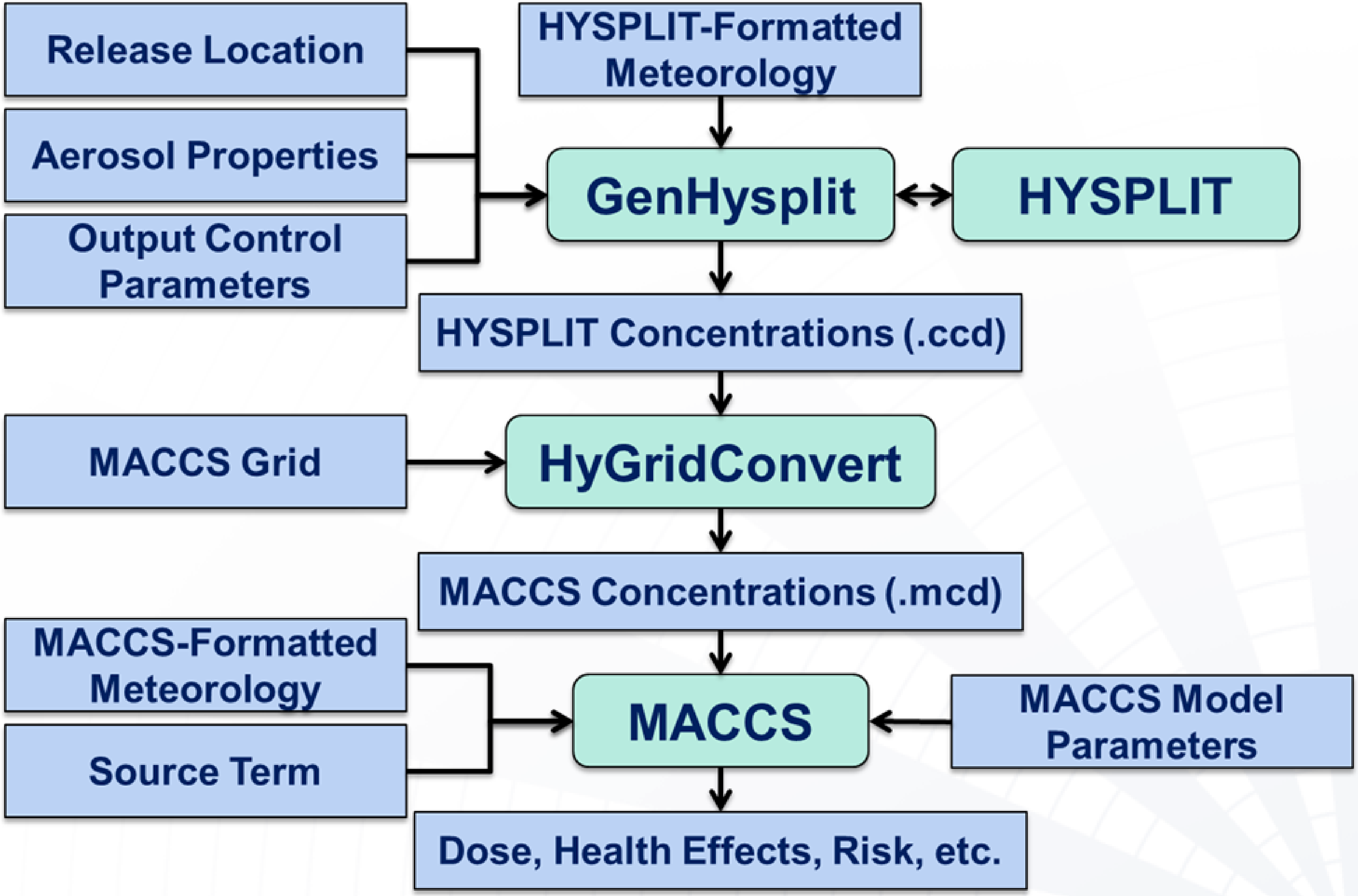
Multiple aerosol diameters with possibilities for dry deposition, wet deposition, both, or neither

- 2*N+2 possibilities for N aerosol diameters

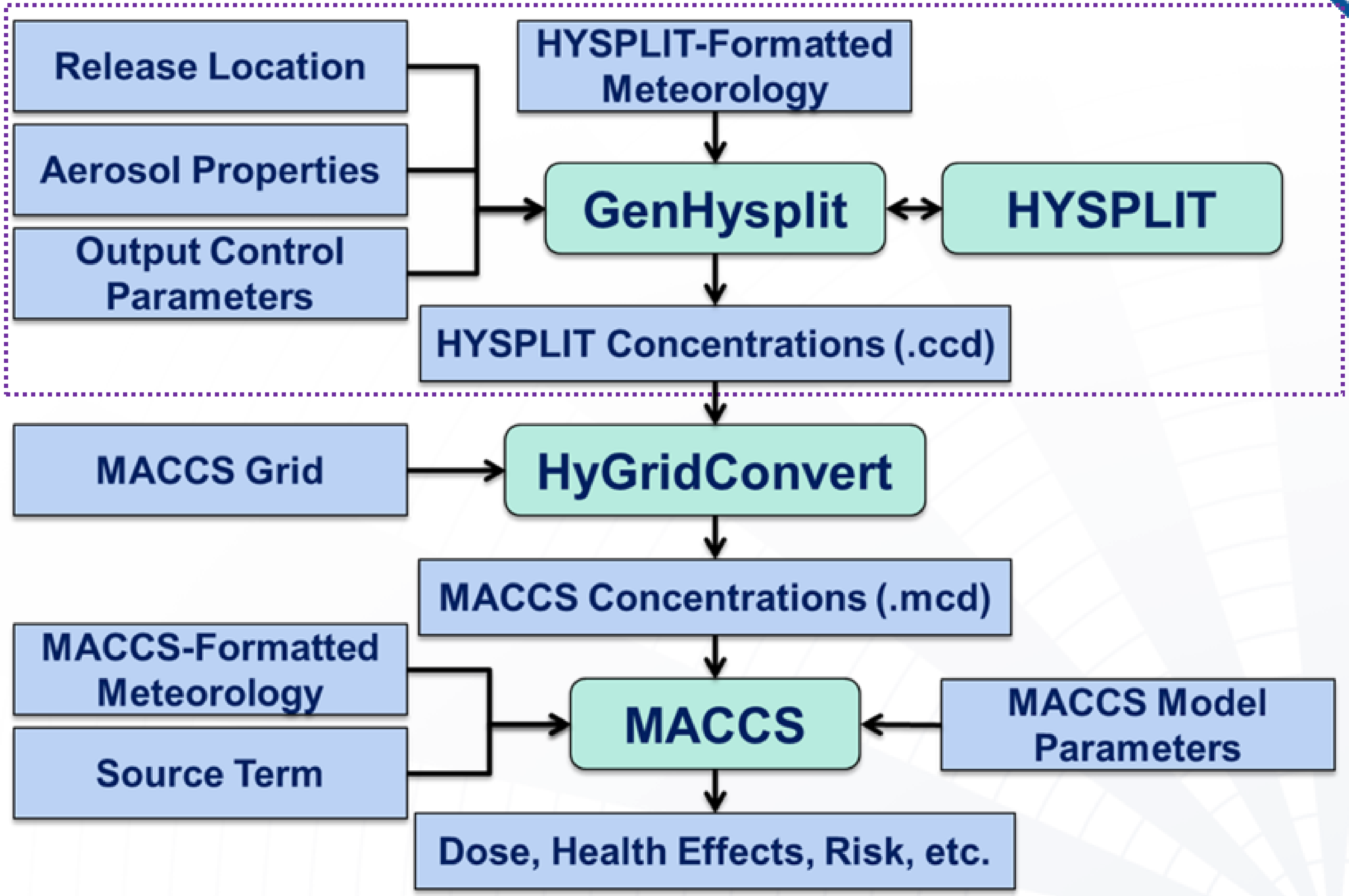
Air and ground concentrations tracked at time interval

- 60 min, 15 min, 5 min, 1 min

OVERALL PROCESS



GENERATING HYSPLIT FILES



NORMALIZED RELEASE

Release one-Bq of a tracer species for each aerosol size over a 1 hour period and then track during transport

- Generating χ/Q and D/Q values for each period and aerosol size
- One year equates to 8,760 simulations
- Provides enough data to effectively model any source term over every hour for the entire year

Expanded to account for buoyancy effects

- Requires additional sets (8,760 more runs per year) for each additional release level
- Specify sets of release heights or power levels
- Release heights utilize MACCS calculated rise heights
- Powel levels determine rise heights from HYSPLIT buoyancy calculations
- Appropriate file set determined based on weather conditions and plume segment sensible heat

GENHYSPLIT CODE

Used to generate and organize the HYSPLIT output concentration files

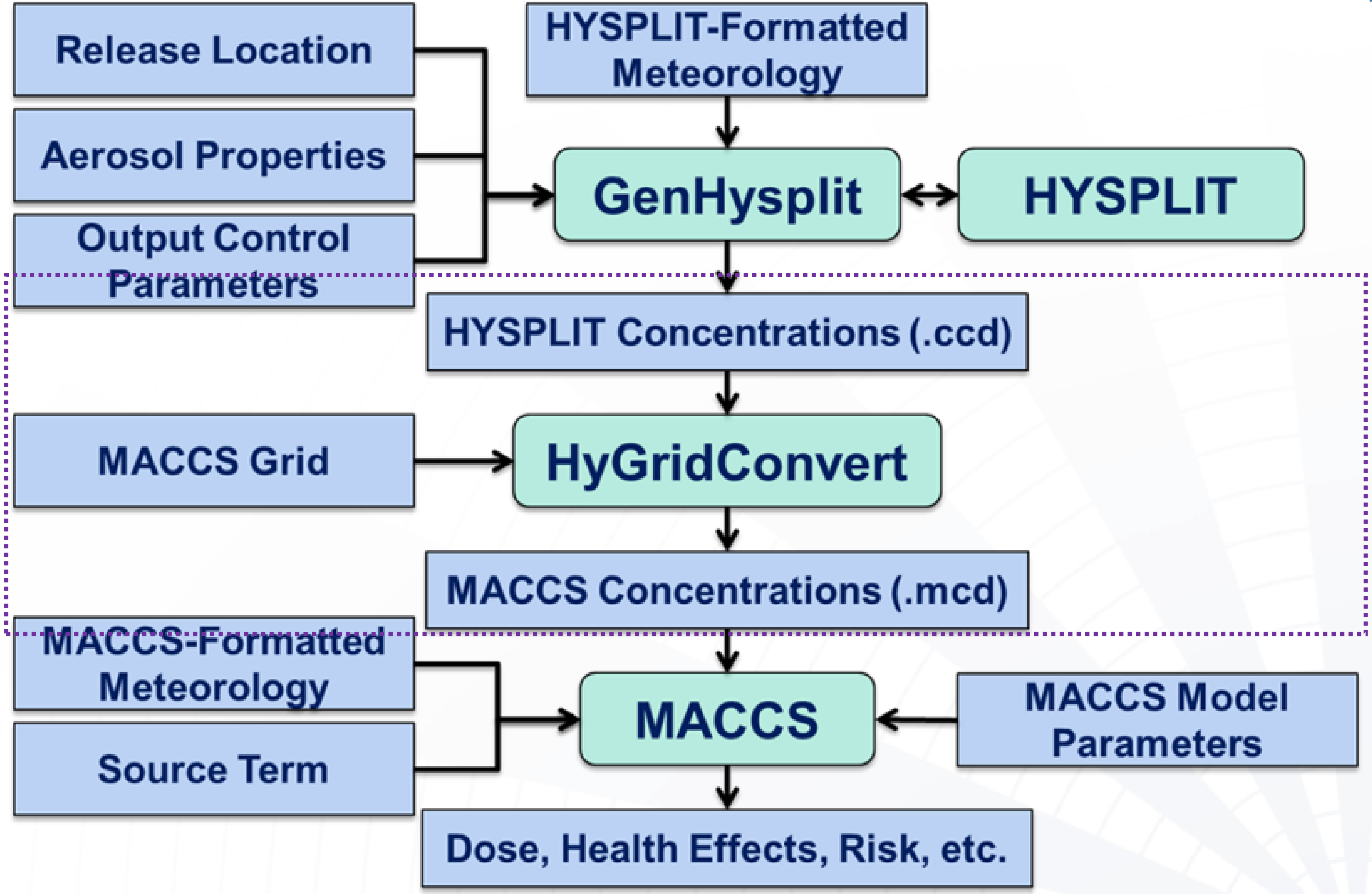
Configured to run on a Linux system to be able to access large computer resources at Sandia National Laboratories

- Has also been run in a Windows environment
- Preliminary testing on a cloud-based machine

Designed to be flexible

- Many options controlled by input file

CONVERTING HYSPLIT OUTPUT TO MACCS INPUT



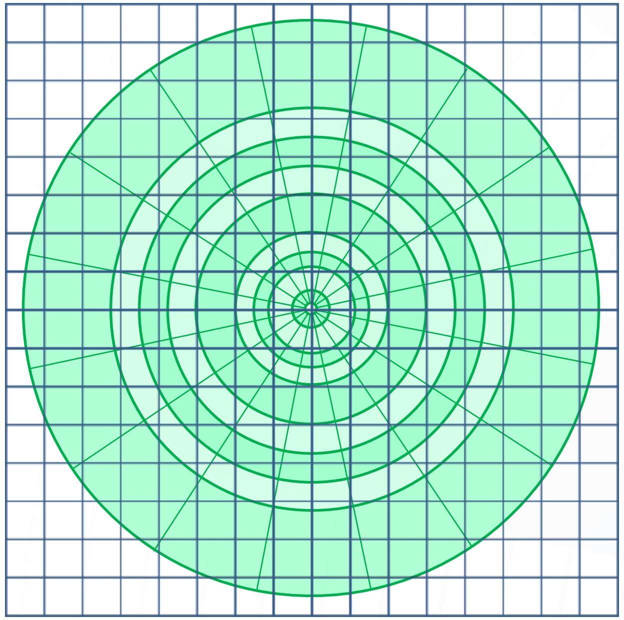
HYGRIDCONVERT CODE

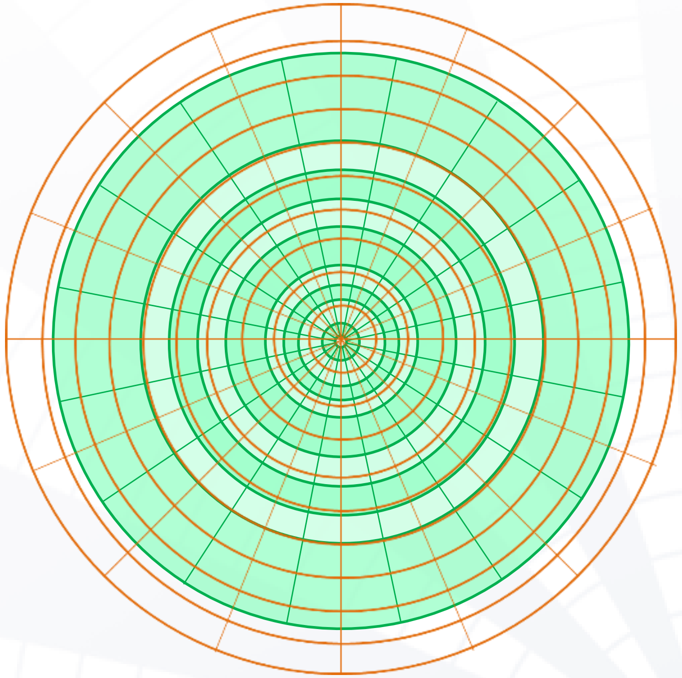
MACCS utilizes a non-uniform polar grid

Converts the HYSPLIT output concentrations to defined MACCS polar grid

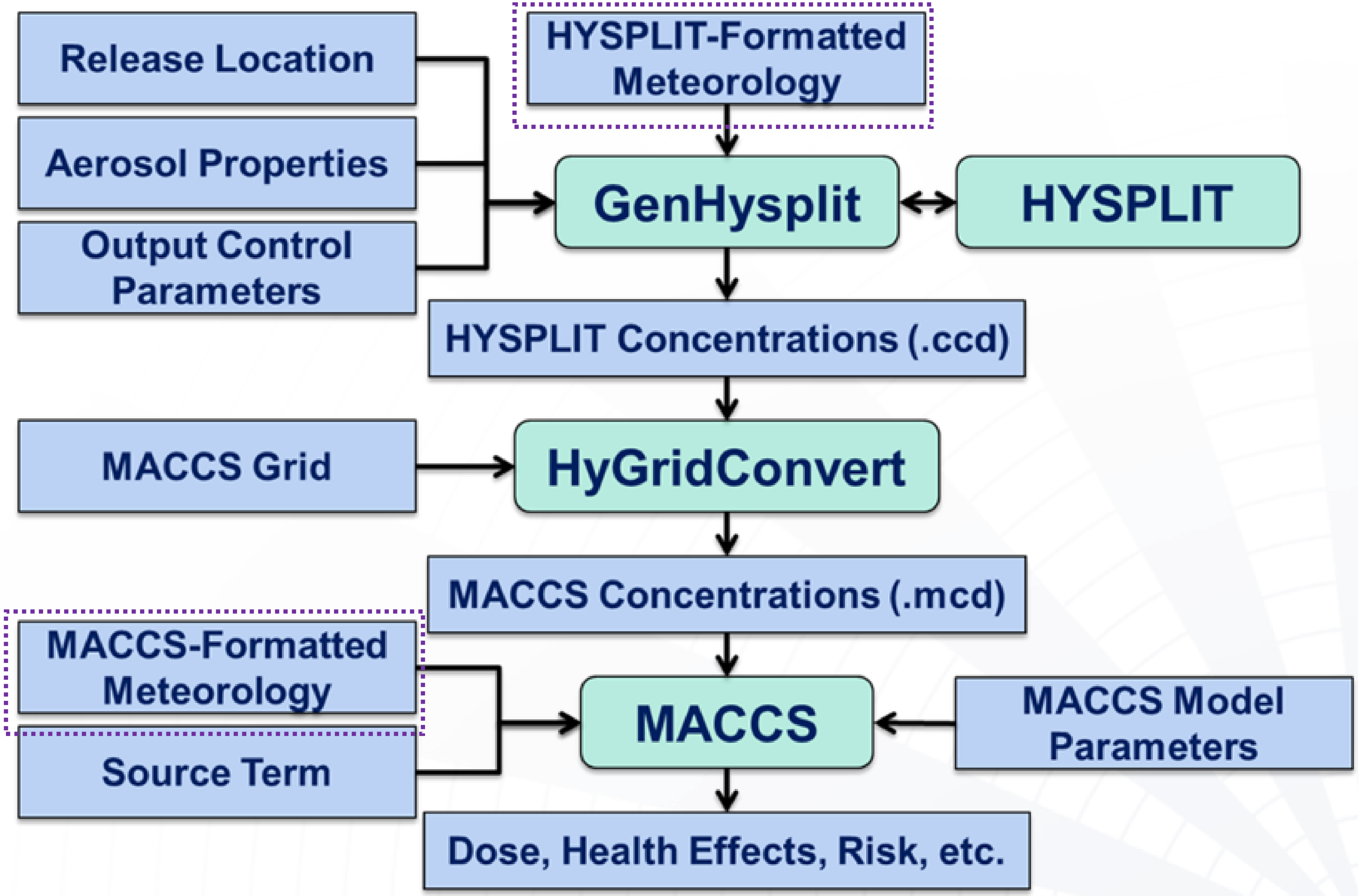
Configured to run on a Windows machine

Can be run separately or called by WinMACCS (preferred)





MACCS METEOROLOGICAL PREPROCESSOR



MACMETGEN DESCRIPTION

MACCS-formatted meteorological file needed for MACCS calculations

- Weather sampling
- Calculating plume rise height (if binned release heights used)
- Precipitation effects on evacuation speed

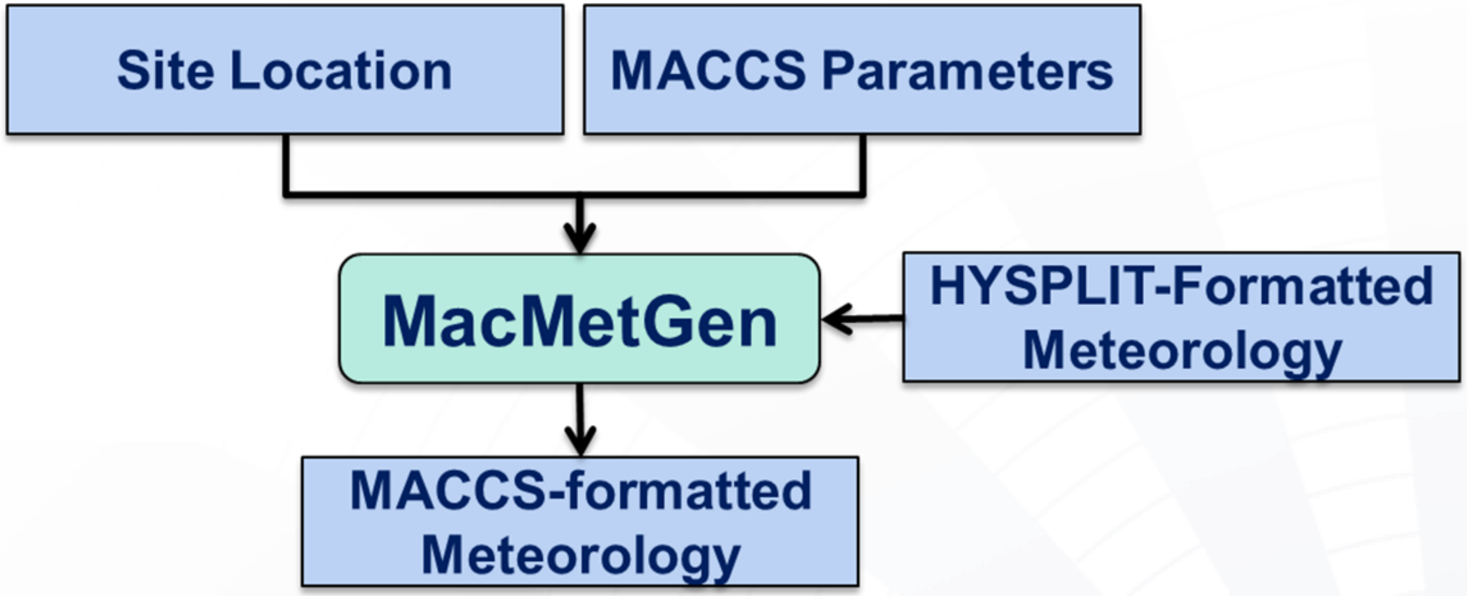
Can be time consuming to collect site data and compile into file

MacMetGen developed to automate MACCS formatted meteorological file generation

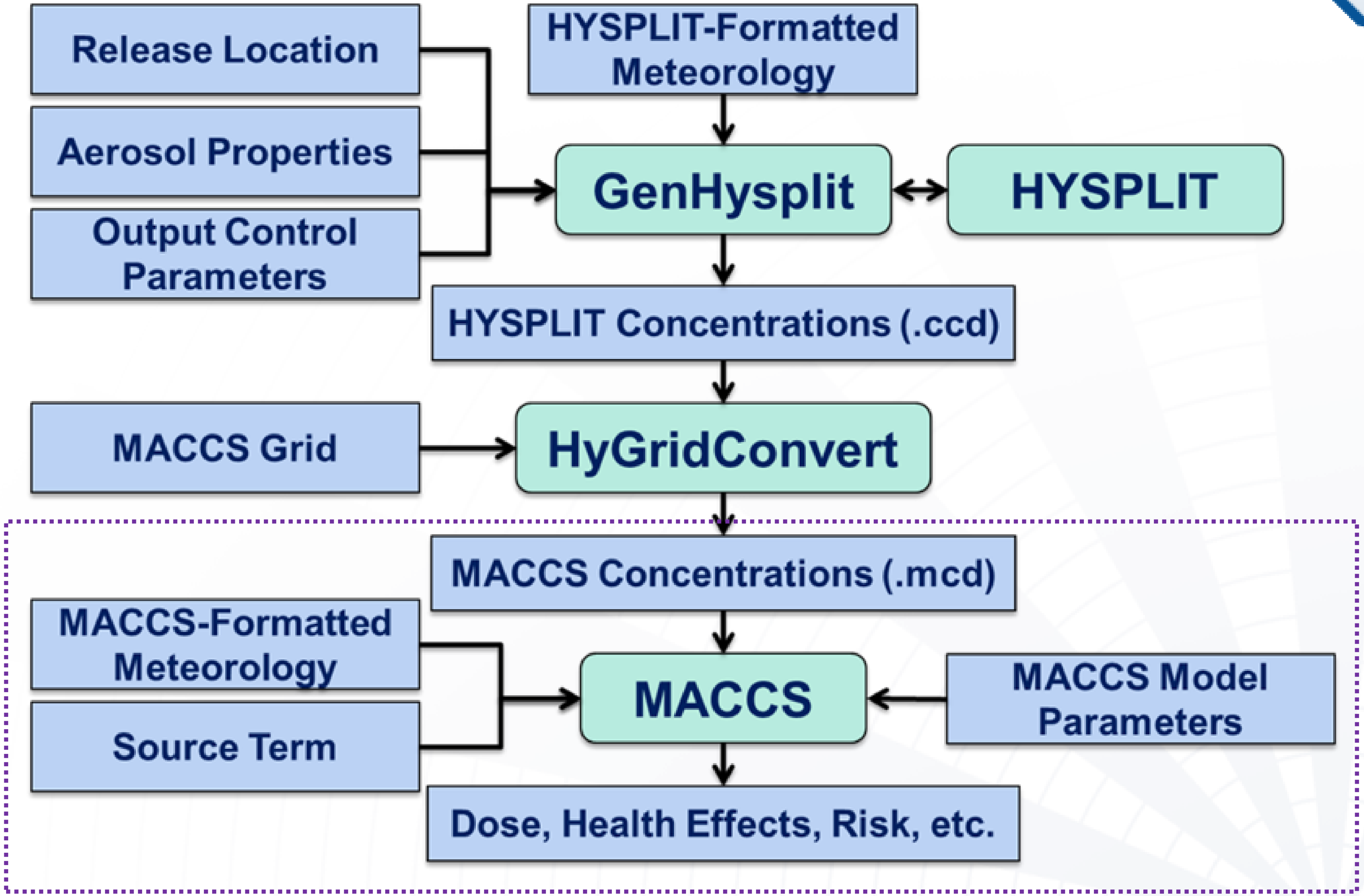
Makes use of same meteorological files used to drive HYSPLIT

- Ensure consistency
- Can be any data set if in similar format

MACMETGEN INFORMATION FLOW



MACCS USE OF HYSPLIT DATA



COMBINATION WITH SOURCE TERM

Break each plume into one-hour segments and associate each one hour segment with a single HYSPLIT converted file (.mcd file)

For each segment, multiply the normalized concentrations for each aerosol bin by the actual hourly release amounts for each different radionuclide/aerosol size

Account for the radioactive decay and ingrowth at the time in the calculation

Results in an air and a ground concentration array as a function of radionuclide, grid cell and time in MACCS

These concentrations are then used by MACCS to determine consequences using the EARLY and CHRONC modules

VERIFICATION TEST CASES

Test cases were created to verify the implementation of the HYSPLIT/MACCS coupling

Compared results from HYSPLIT/MACCS with HYSPLIT standalone

Modified Inputs

- Single plume segment -> Multiple plume segments
- Single, fixed deposition velocity -> Ten aerosol sizes, each with own deposition velocity calculated from internal HYSPLIT model
- Constant weather -> Spatially and temporally varying weather
- Insignificant radioactive decay -> Significant radioactive decay
- No evacuation -> With evacuation

COMPARED RESULTS

MACCS
Accident Consequence Model

Atmospheric Model Outputs

- Peak (around the compass) time-integrated air concentration (χ/Q, s/m^3) over the region
- Peak (around the compass) ground concentration (D/Q, 1/m^2) over the region
- Land areas (km^2) that exceed various levels of contamination

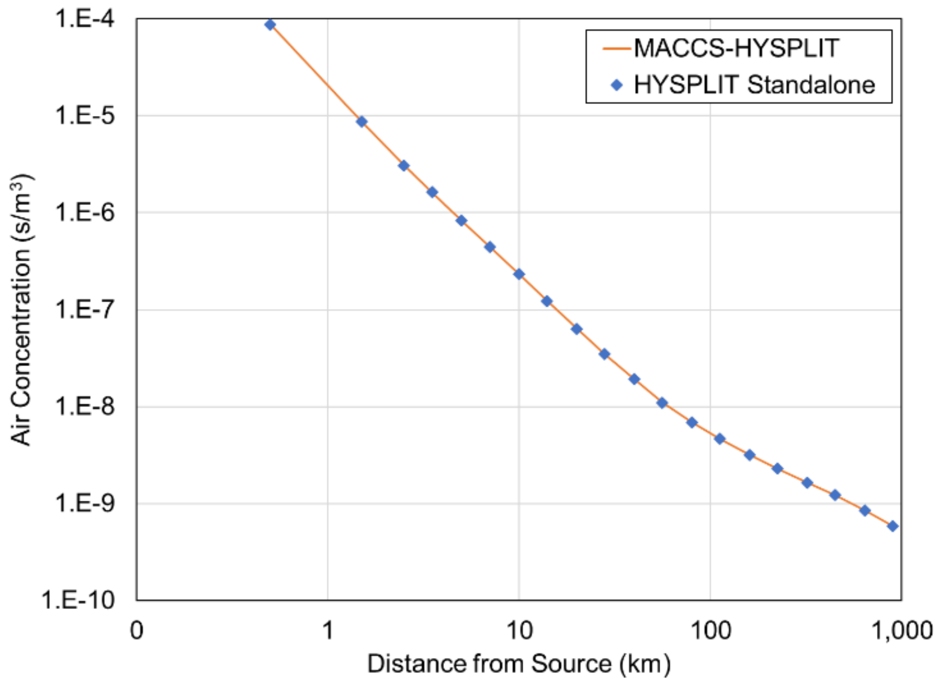
Consequence Output

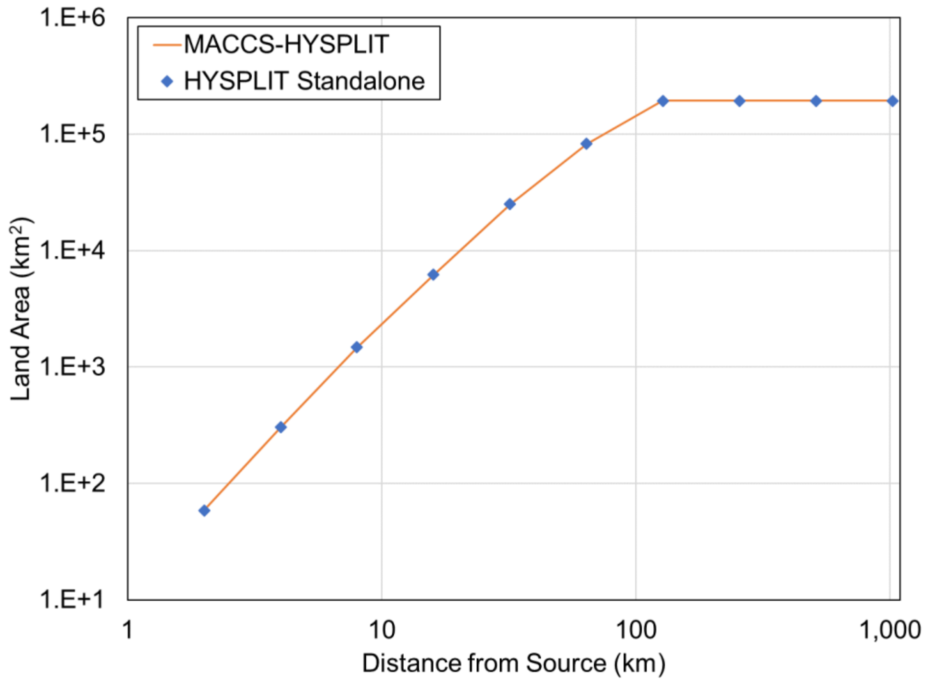
- Peak (around the compass) ionizing radiation dose (Sv) over the region

TEST RESULT SUMMARY

All quantities for all six text cases match at all distances

Test Case 1 comparison
of peak air concentration





Test Case 1 comparison of
land areas that exceed
1,000 μCi/m^2

BENCHMARK PURPOSE

Serves as an initial analysis using the HYSPLIT/MACCS coupling

- Demonstrates the potential modeling results that can be obtained from using this new option
- Is a practical test of the implementation
- Provides information on the differences in the model data needs and computational resources needed to exercise the new capability

Serves as a further test of the hypothesis tested in (NUREG-6853, 2004) that the results of a simple Gaussian plume segment model are sufficient for purposes of estimating expected values of consequence measures when averaged over a broad set of meteorological conditions

- Wider array of consequence measures
- Longer distances
- Multiple sites
- 5th and 95th percentile results in addition to the mean

BENCHMARK PURPOSE (CONT.)

Informs decisions on when it may be appropriate to choose the Gaussian model versus the HYSPLIT model for specific applications

- With the introduction of the new capability, the logistical challenge of benchmarking the simple Gaussian plume segment model against a more advanced model going forward is considerably reduced
- Some applications may be substantially different from these benchmarking comparisons, and therefore this study does not attempt to draw general conclusions
- Users are encouraged to perform their own studies to determine which modeling approach best suits their needs in terms of model fidelity and computational expense

BENCHMARK CASES

Source term

- #1 - NUREG-1150 historic (puff release followed by a longer duration tail)
- #2 - SOARCA Short-Term Station Blackout (more delayed and prolonged)

Five representative sites

- Site A - Large river valley
- Site B - Central midwestern plain
- Site C - Dry western region
- Site D - Atlantic coast with potential for sea breezes
- Site E - Southeast river valley influenced by Bermuda high

MACCS grid of 29 radial intervals (out to 1,000 mi) and 64 compass sectors

General evacuation scheme

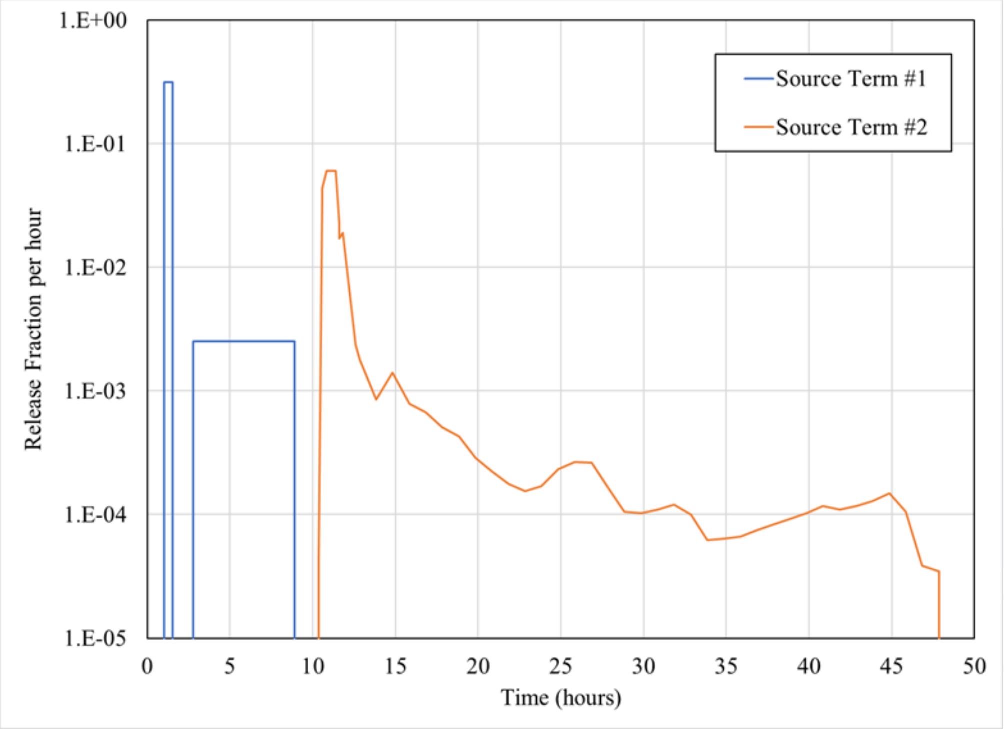
- Modeled with multiple evacuating cohorts

Uniform weather bin sampling (40 samples per bin)

SOURCE TERMS

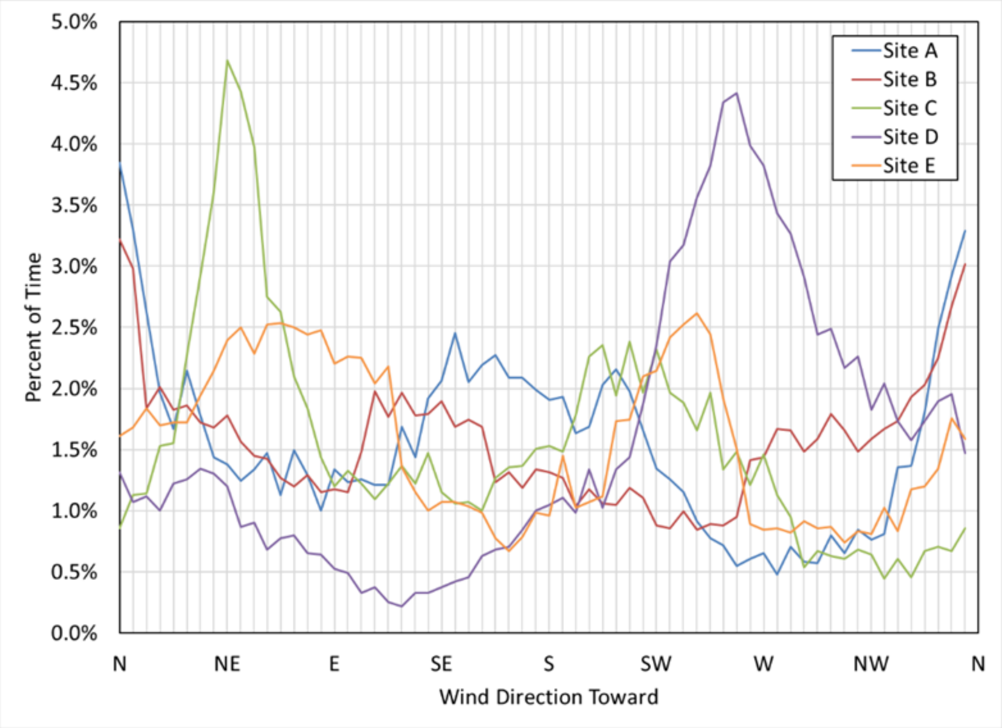
Source Term #1 -NUREG-1150 historic (puff release followed by a longer duration tail, 2 plume segments)

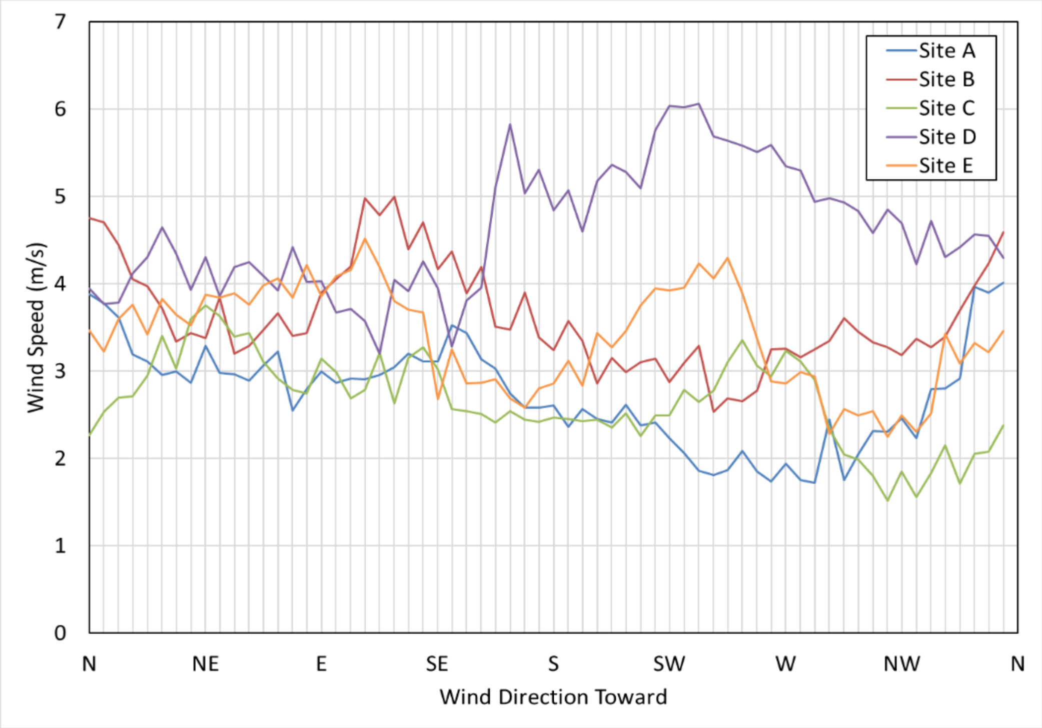
Source Term #2 - SOARCA Short-Term Station Blackout (more delayed and prolonged, 42 plume segments)



METEOROLOGY

Accident Consequence Model





NAM 12-km meteorological database - 2008

BENCHMARK OUTPUT METRICS

Mean, 95^{th} and 5^{th} percentiles

Atmospheric Model Outputs

1. Peak (around the compass) normalized, time-integrated, ground-level, air concentration (χ/Q, s/m^3) as a function of distance from the site (Peak Air)
2. Peak (around the compass) normalized ground concentration (D/Q, $1/m^2$) as a function of distance from the site (Peak Ground)
3. Normalized land areas that exceed various levels of contamination (unitless) (Land Area)

Consequence Outputs

4. Normalized peak ionizing radiation dose (unitless) as a function of distance (Peak Dose)
5. Early fatality risk (unitless) within a circular area near the point of release (EF Risk)
6. Normalized regional population doses (unitless) (Pop Dose)
7. Latent cancer fatality risk (unitless) over region (LCF Risk)
8. Normalized, regional economic loss (unitless) (Econ Loss)

COMPUTATIONAL COST

HYSPLIT Preprocessing

- ~26,000 processor hours per site
- Total disk space = 500-600 GB per site
- 14 hours to convert and move data
- Converted files = additional 200 GB per site

MACCS

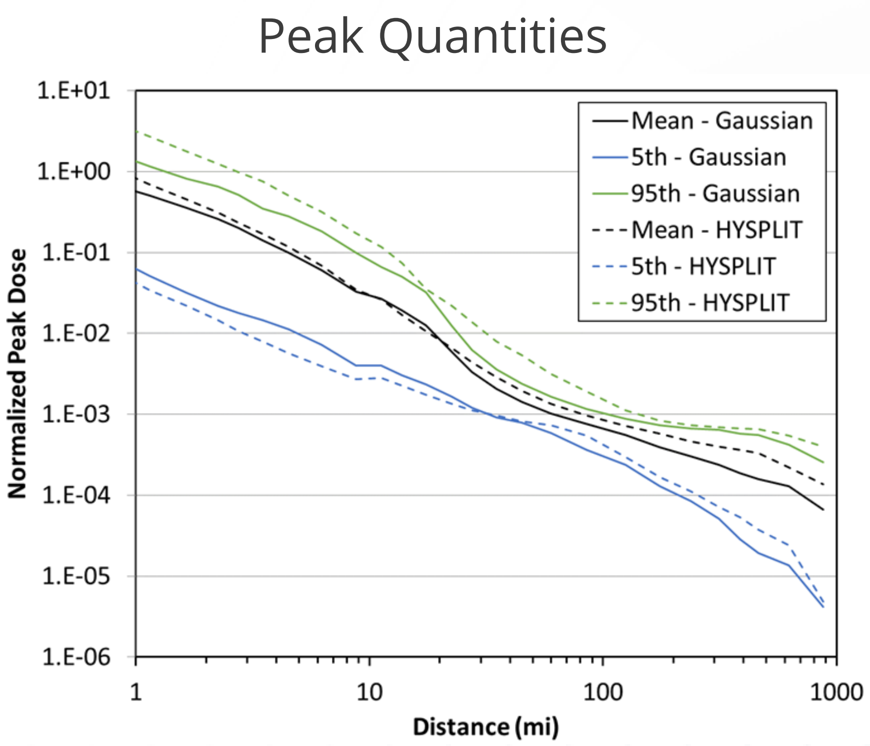
- NUREG-1150 source term
  - Run on one Windows processor
  - Gaussian ADT model, ~1.5 processor minutes per site
  - HYSPLIT ADT model, ~5 processor hours per site (200 times longer)
- SOARCA, Short-Term Station Blackout (STSBO)
  - Run on one Windows processor
  - Gaussian ADT model, ~22 processor minutes per site
  - HYSPLIT ADT model, ~28 processor hours per site (76 times longer)

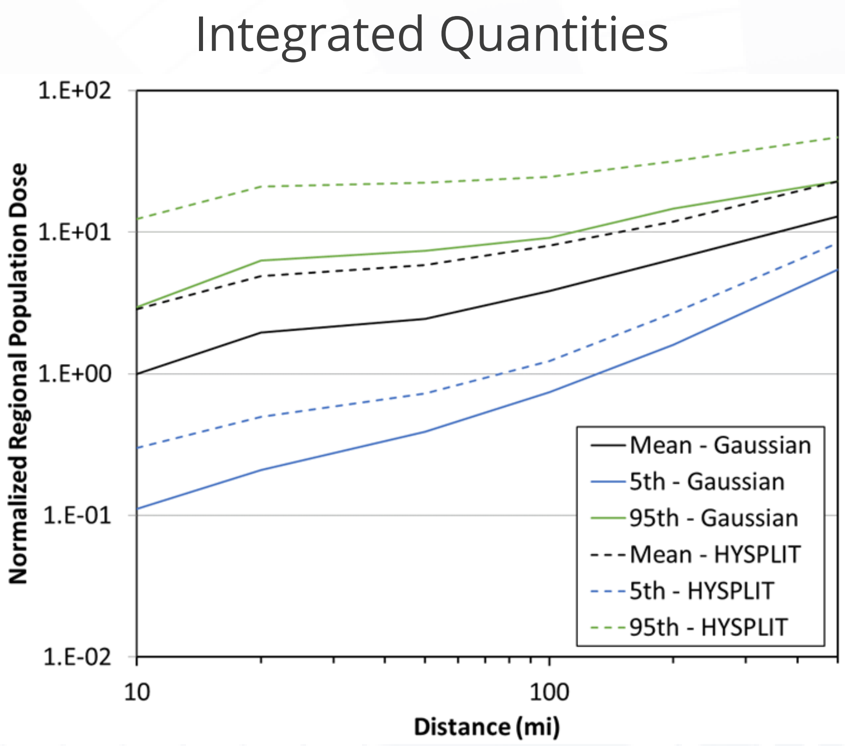
TYPICAL BENCHMARK COMPARISONS

Compare model results over distance

Mean values over all weather trials

5th and 95th percentiles over weather trials





NEAR-FIELD, <50 KM (<30 MI) COMPARISON

Ratio of mean HYSPLIT ADT model to mean Gaussian ATD model

- Shown as Average (Minimum | Maximum)
- >1 indicates HYSPLIT larger
- <1 indicates Gaussian larger

Site/ Source	Near Field						
	Peak Air	Peak Ground	Peak Dose	Pop Dose	LCF Risk	Econ Loss	EF Risk
A/1	1.1 (0.8|1.3)	1.4 (1.0|2.1)	1.1 (0.9|1.4)	2.7 (2.5|2.8)	2.0 (2.0|2.0)	3.0 (2.8|3.1)	5.8 (2.6|8.6)
B/1	1.1 (1.0|1.6)	1.7 (1.2|2.4)	1.1 (1.0|1.6)	3.4 (3.2|3.6)	2.3 (2.3|2.4)	3.0 (3.0|3.0)	9.0 (4.6|12.2)
C/1	1.9 (1.6|2.6)	0.6 (0.4|1.3)	1.8 (1.6|2.4)	2.6 (2.4|2.7)	2.4 (2.1|2.6)	2.3 (2.2|2.4)	8.6 (3.0|14.3)
D/1	1.2 (1.1|1.7)	4.0 (2.1|6.8)	1.3 (1.1|1.7)	2.7 (2.5|2.9)	2.4 (2.2|2.5)	2.1 (2.1|2.1)	20.0 (7.4|32.6)
E/1	1.3 (1.2|1.8)	1.3 (1.0|1.6)	1.3 (1.2|1.7)	2.8 (2.8|2.8)	2.3 (2.2|2.4)	2.4 (2.3|2.5)	5.5 (2.1|9.8)
A/2	0.3 (0.2|0.5)	0.5 (0.4|0.8)	0.9 (0.6|1.1)	1.6 (1.4|1.8)	1.5 (1.4|1.6)	1.7 (1.5|1.9)	a
B/2	0.3 (0.2|0.6)	0.6 (0.5|0.8)	1.0 (0.7|1.1)	2.1 (1.8|2.4)	1.6 (1.5|1.6)	1.8 (1.7|1.9)	a
C/2	0.4 (0.2|0.8)	0.2 (0.1|0.5)	0.8 (0.7|0.9)	1.0 (0.8|1.1)	1.1 (1.0|1.2)	0.9 (0.8|0.9)	a
D/2	0.4 (0.3|0.6)	1.5 (0.9|2.3)	1.1 (0.9|1.4)	1.9 (1.8|1.9)	1.8 (1.7|1.8)	2.5 (2.4|2.5)	a
E/2	0.4 (0.3|0.7)	0.5 (0.4|0.7)	0.9 (0.7|1.0)	1.6 (1.5|1.8)	1.3 (1.3|1.3)	1.3 (1.2|1.4)	a

[a]Data not available to compute ratio

FAR-FIELD, >50 KM (>30 MI) COMPARISON

Ratio of mean HYSPLIT ADT model to mean Gaussian ATD model

- Shown as Average (Minimum | Maximum)
- >1 indicates HYSPLIT larger
- <1 indicates Gaussian larger

Site/	Far Field						
Source	Peak Air	Peak Ground	Peak Dose	Pop Dose	LCF Risk	Econ Loss	Land Area
A/1	1.1 (0.4|1.4)	2.7 (1.9|3.2)	1.5 (1.3|2.1)	2.0 (1.8|2.4)	1.8 (1.7|2.0)	2.4 (2.2|2.5)	2.0 (1.6|2.5)
B/1	1.3 (0.4|2.0)	2.3 (1.7|3.1)	1.6 (1.3|1.8)	2.5 (2.2|2.8)	2.4 (2.1|2.6)	2.6 (2.2|2.9)	2.3 (2.1|2.5)
C/1	1.4 (0.5|2.7)	2.6 (1.6|3.5)	1.7 (1.1|2.3)	2.2 (1.8|2.4)	2.1 (1.8|2.4)	2.4 (2.1|2.6)	2.7 (1.9|3.9)
D/1	0.9 (0.3|1.7)	3.9 (2.2|5.0)	1.5 (1.2|1.8)	2.3 (2.2|2.4)	2.1 (2.0|2.2)	2.5 (2.3|2.7)	2.6 (2.5|2.7)
E/1	1.3 (0.4|2.1)	3.0 (1.9|3.8)	1.7 (1.3|2.2)	2.2 (2.0|2.4)	2.1 (1.9|2.2)	2.5 (1.8|2.8)	2.4 (1.9|3.0)
A/2	0.5 (0.2|0.6)	1.1 (0.9|1.4)	1.3 (1.0|1.6)	1.3 (1.1|1.4)	1.3 (1.1|1.4)	1.4 (1.3|1.5)	1.5 (1.2|1.6)
B/2	0.6 (0.2|0.8)	0.9 (0.7|1.1)	1.1 (0.9|1.4)	1.5 (1.3|1.7)	1.5 (1.3|1.8)	1.4 (1.3|1.5)	1.5 (1.3|1.7)
C/2	0.6 (0.2|1.0)	1.2 (0.7|1.6)	1.3 (1.1|1.5)	1.3 (1.2|1.4)	1.4 (1.3|1.5)	1.8 (1.6|1.9)	1.3 (0.6|1.9)
D/2	0.4 (0.1|0.6)	1.6 (0.9|1.9)	1.5 (1.0|2.0)	2.2 (2.1|2.3)	2.3 (2.1|2.4)	3.5 (3.4|3.7)	3.1 (2.1|3.6)
E/2	0.5 (0.2|0.8)	1.3 (0.8|1.7)	1.4 (1.1|2.0)	1.4 (1.3|1.6)	1.5 (1.3|1.7)	1.5 (1.2|1.5)	1.7 (1.4|2.0)

SUMMARY

Accident Consequence Model

MACCS coupled with **HYSPLIT** has been **implemented** and **verified**

- Supplements Gaussian plume segment model in MACCS with an alternative

The **ability to incorporate HYSPLIT** model results in MACCS is a **major improvement** in the capabilities of **MACCS** simulations and provides a **state-of-the-art alternative** to the use of the Gaussian plume segment model

Need to **balance** the need for **higher fidelity models** with associated **higher computational costs**

SUMMARY (CONT.)

Benchmark analysis performed over **wide set** of metrics and distances

- Five sites
- Two source terms

The **level of agreement** between annual average results from the **Gaussian and HYSPLIT** ATD model results is **similar to the results** shown in NUREG/CR-6853 (Molenkamp et al., 2004), with a **wider set** of metrics and a **longer distance** range.

Many results obtained using the **HYSPLIT** model are **larger** on average than the results obtained using the **Gaussian** plume segment model

SUMMARY (CONT.)

While there are **changes in trends** between the **Gaussian and HYSPLIT** ATD models between the near and far fields for some of the consequence metrics considered in this study, there is **no clear distance** at which the Gaussian model seems to **systematically diverge** from the HYSPLIT model

The **ability to incorporate HYSPLIT** model results in MACCS is a **major improvement** in the capabilities of **MACCS** simulations and provides a **state-of-the-art alternative** to use of the Gaussian plume segment model