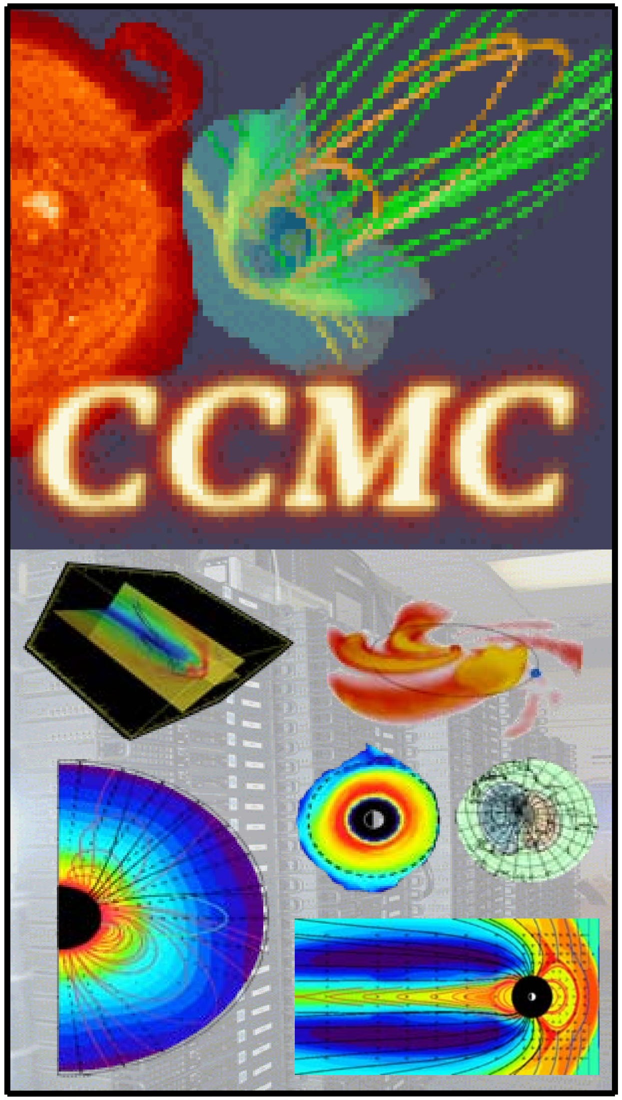


Data Format Standardization of Space Weather Model Output at The Community Coordinated Modeling Center

M. Maddox

NASA Goddard Space Flight Center

http://ccmc.gsfc.nasa.gov

Hilton
Clearwater Beach Resort

CCMC Workshop

October 11-14, 2005

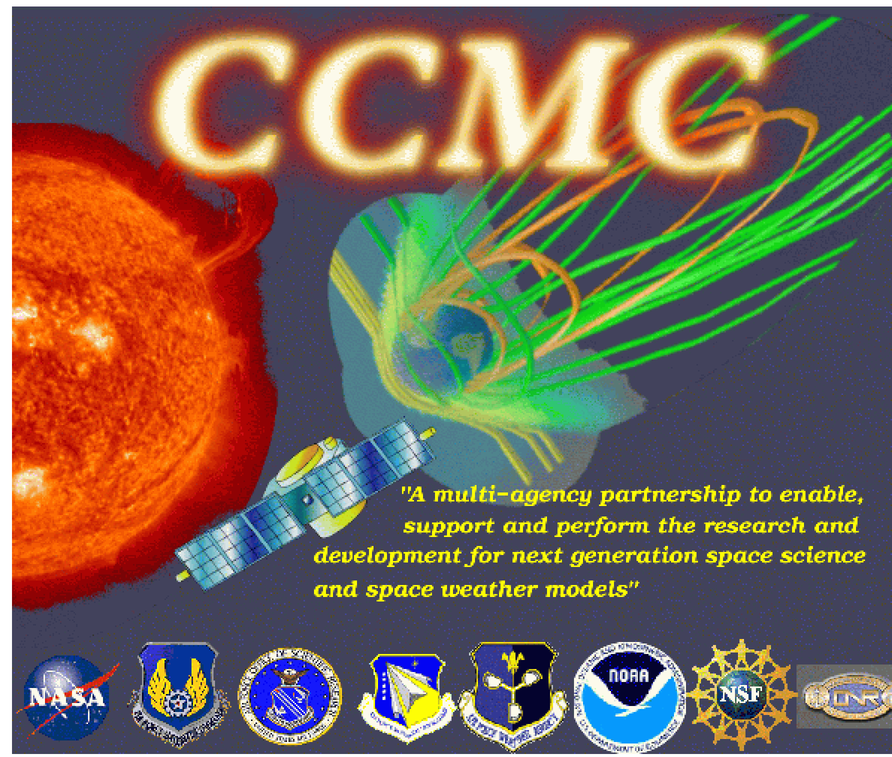
Tuesday, October 11th PM Session:

Frameworks and Data Infrastructure

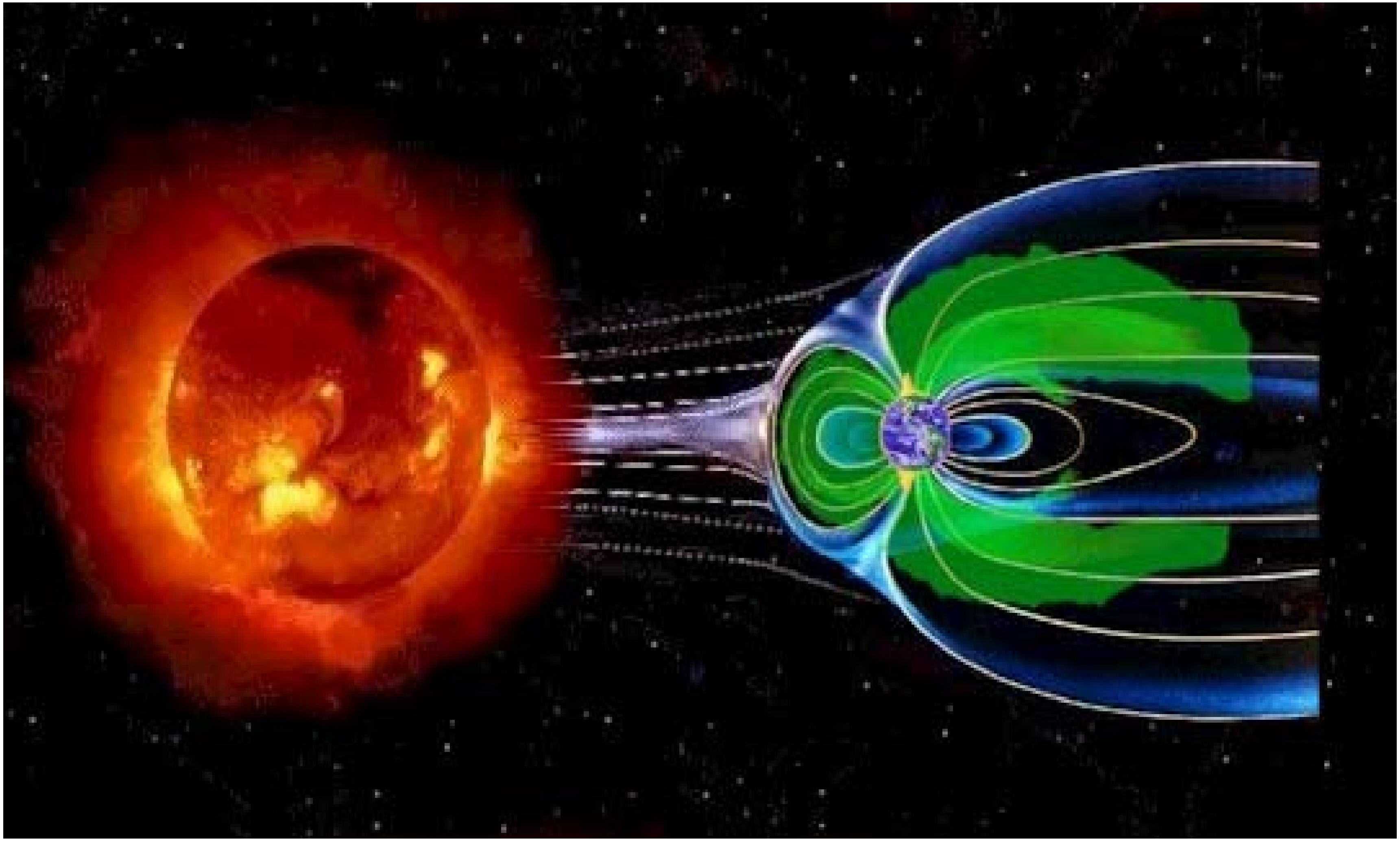
The Community Coordinated Modeling Center

What the CCMC provides:

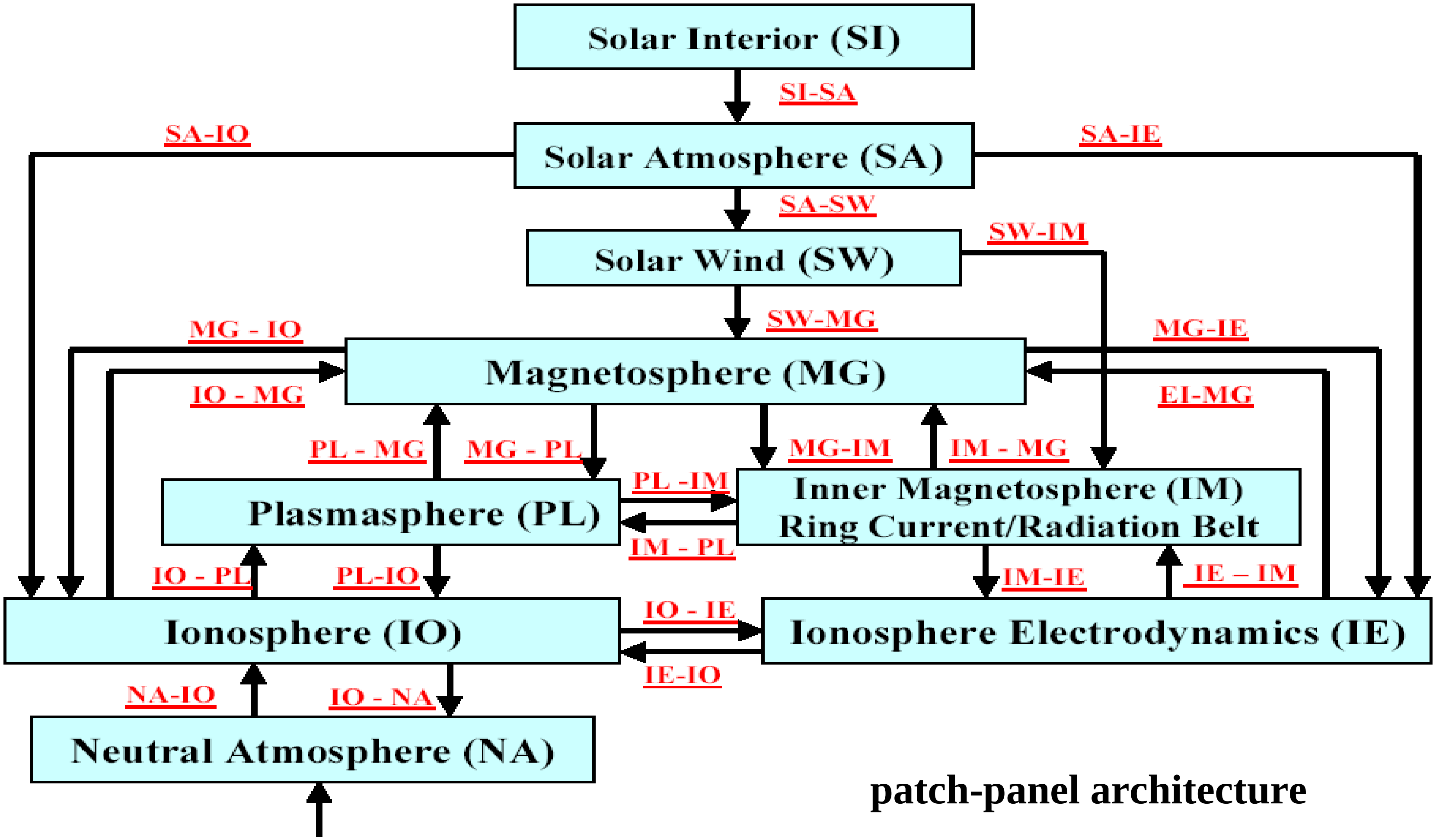
- Scientific validation
- Coupling in collaboration with model owners
- Metrics implementations
- Model runs on request
- Advanced visualization
- **Data Format Standardization**



Covering the Entire Domain

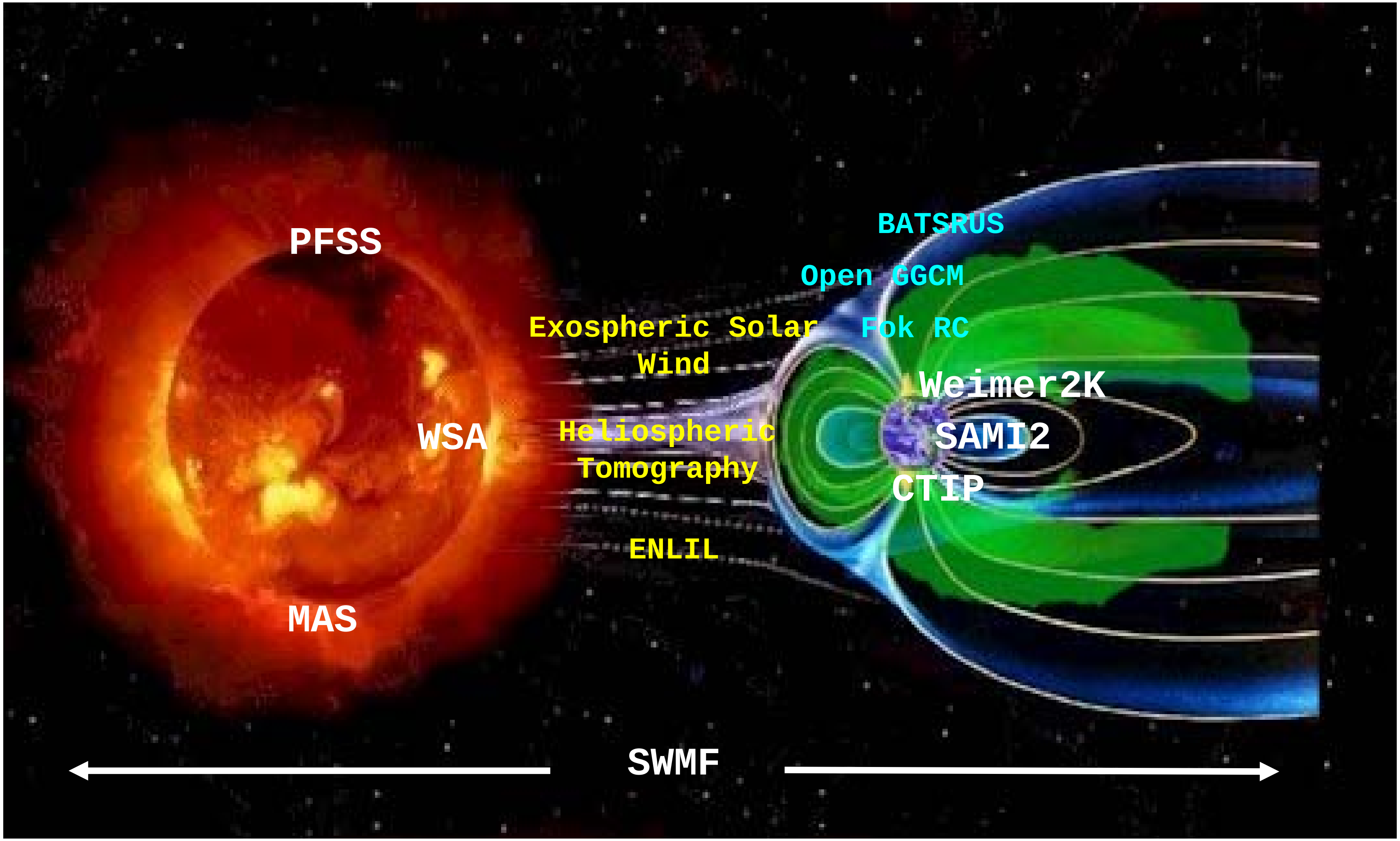


Space Weather Models



patch-panel architecture

Covering the Entire Domain



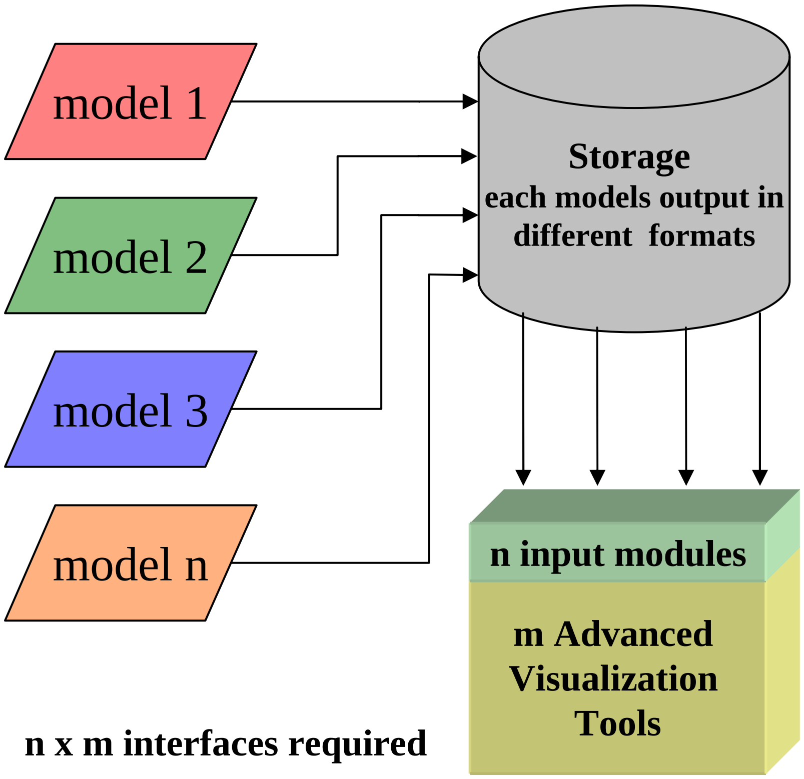
Challenges

- No rules for standard model interfaces
- Each new model has unique output format
- Developer/user needs to become familiar with internal structure of each output file
- Custom read routines to access model data
- Data typically is not self descriptive
- Reduces portability and reuse of
  - Data output itself
  - Tools created to analyze data

Every Models Output Is Unique

Environment Without Standard

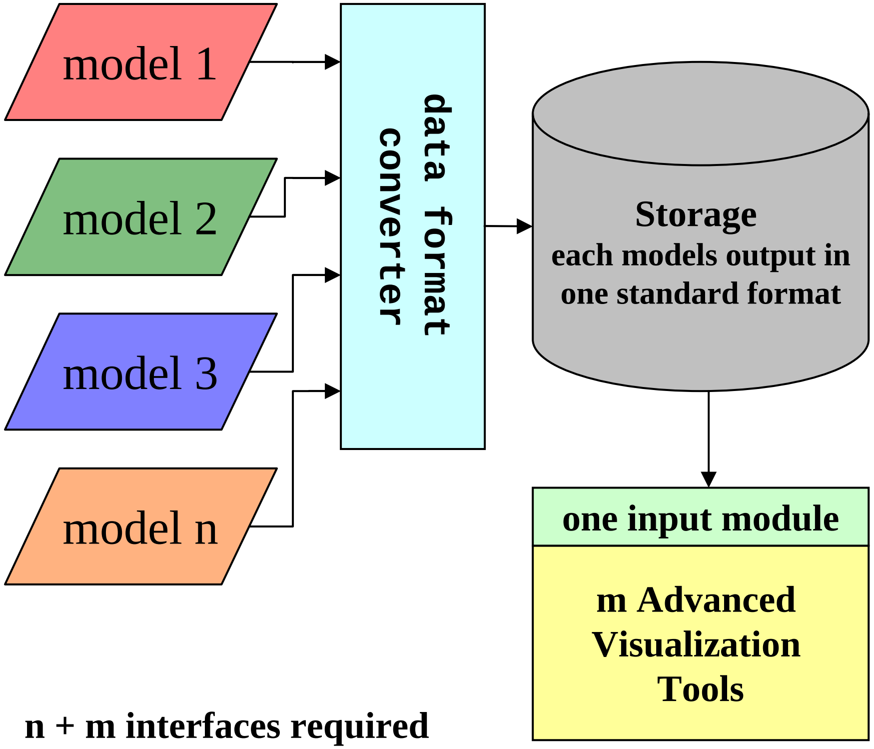
- Specialized I/O routines required for every interface
- Unsuitable for use in flexible model chain
- No commonality between data passing through interfaces



Every Models Output Is Unique

Standardized Environment

- **Original output can be preserved**
- **Standard format for storage, coupling, & visualization**
- **Model developers continue to have freedom of choice**
- **Ensures compatibility between models for coupling**
- **Ground work for which standard, reusable interfaces and tools can be developed**



n + m interfaces required

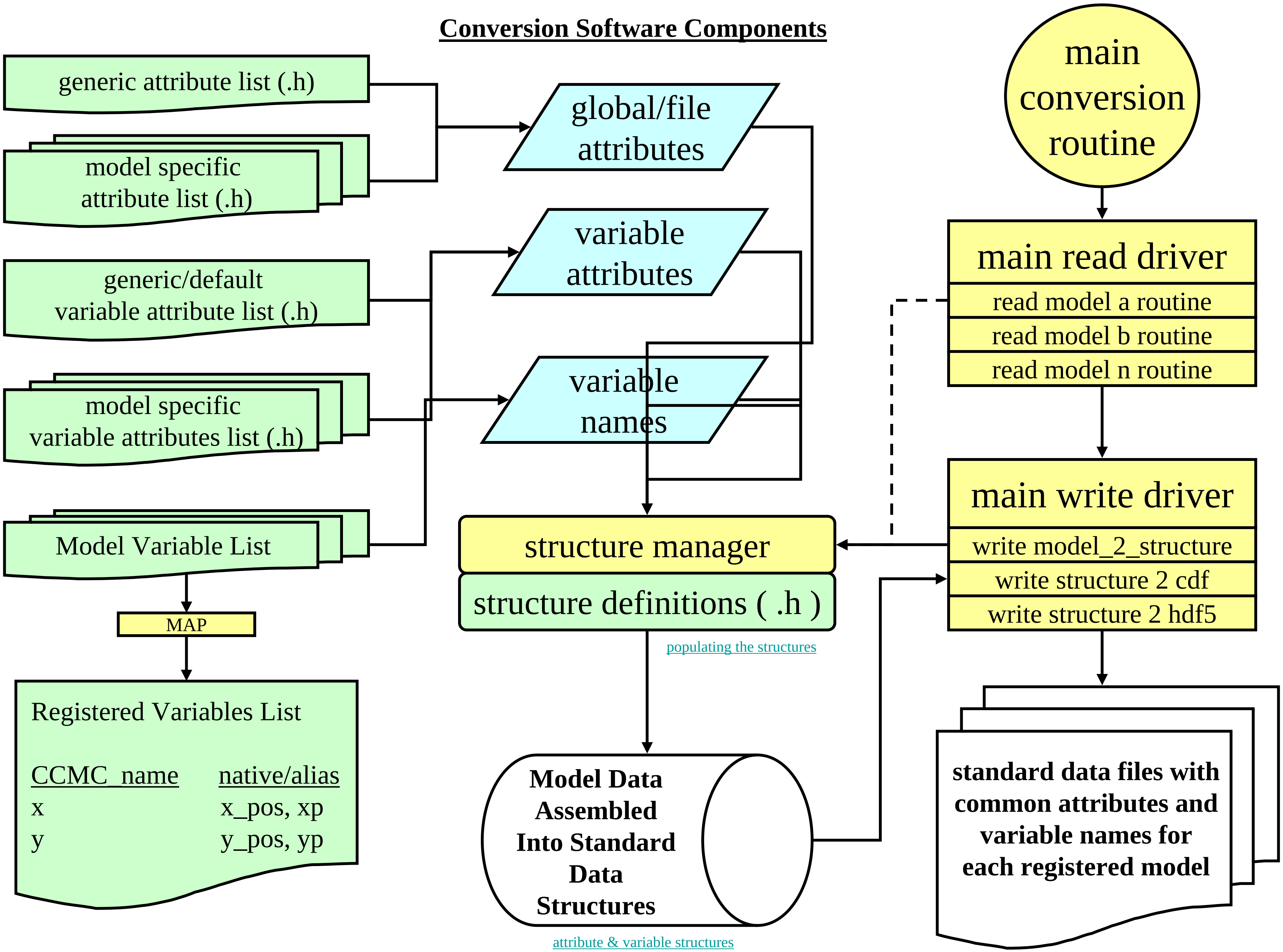
Data Format Standard Options

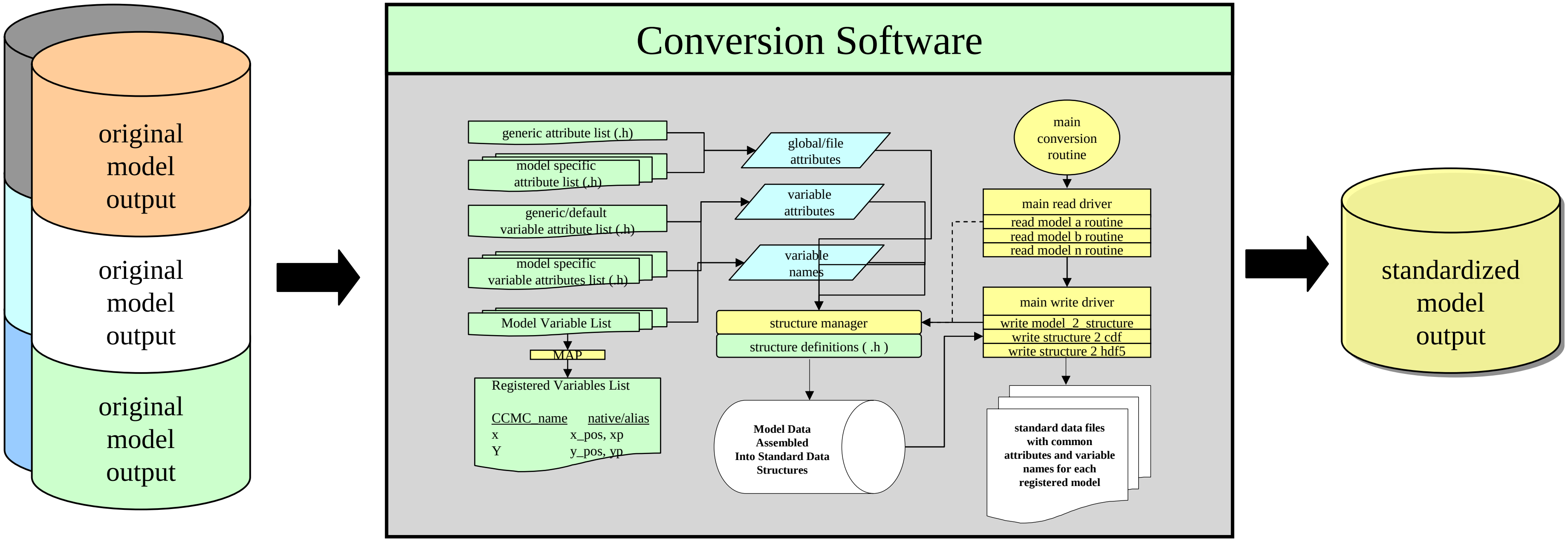
- CDF
- HDF, HDF4, HDF5
- NetCDF
- FITS
- GRIB
- BUFR
- GRADS
- Office Note 29
- Office Note 84
- VICAR
- PDS
- Open Dx Data Model

Metadata

- Aside from the one-to-one data conversion, what additional global & variable meta data do we want to provide?
  - General description of model, howto usage – README
  - Model name and type
  - Date info
    - Run date
    - Generation date
  - Grid Description – # of grids, # of dimensions, dimension size(s)
  - Coordinate system(s)
  - Variable metadata – grid system, min, max, units, description

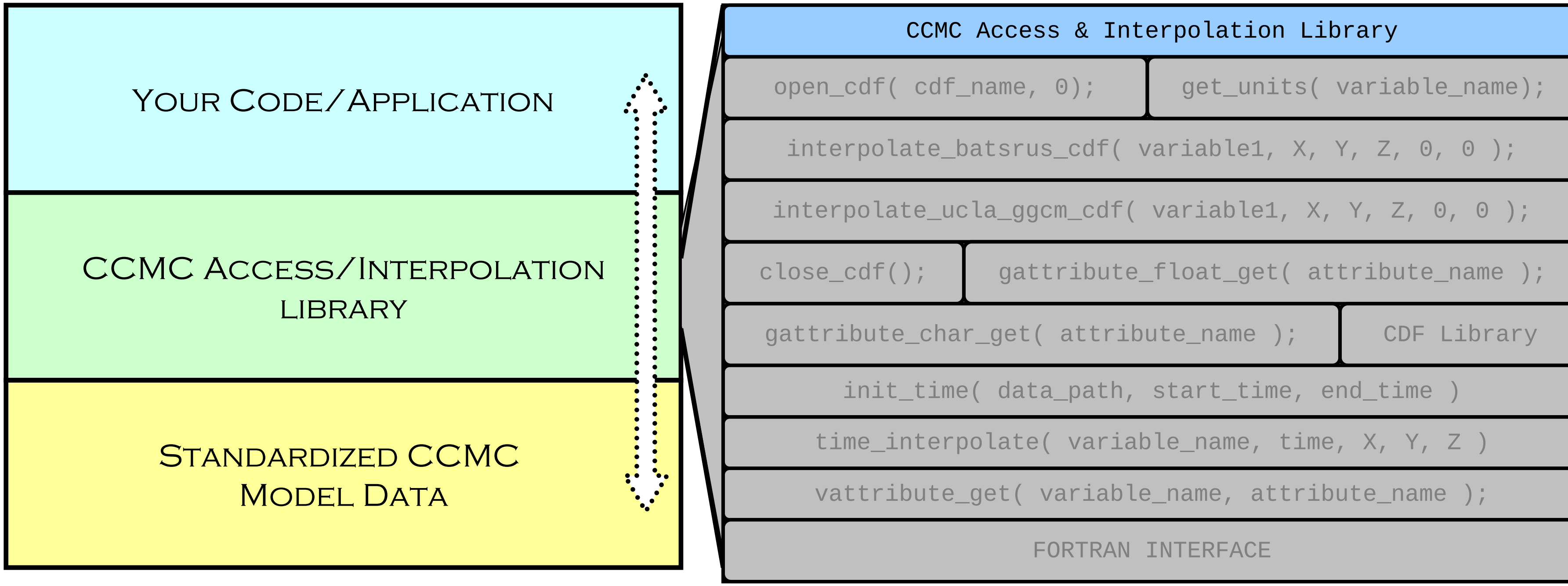
Conversion Software Components




original model output
original model output
original model output
Conversion Software
generic attribute list (.h)
model specific attribute list (.h)
generic/default variable attribute list (.h)
model specific variable attributes list (.h)
Model Variable List
MAP
Registered Variables List
CCMC_name native/alias
x x_pos, xp
Y y_pos, yp
global/file attributes
variable attributes
variable names
structure manager
structure definitions (.h)
Model Data Assembled Into Standard Data Structures
main conversion routine
main read driver
read model a routine
read model b routine
read model n routine
main write driver
write model 2 structure
write structure 2 cdf
write structure 2 hdf5
standard data files with common attributes and variable names for each registered model
standardized model output

Data Access ?

CCMC Access/Interpolation Library



Call from any C supported Programming Language:

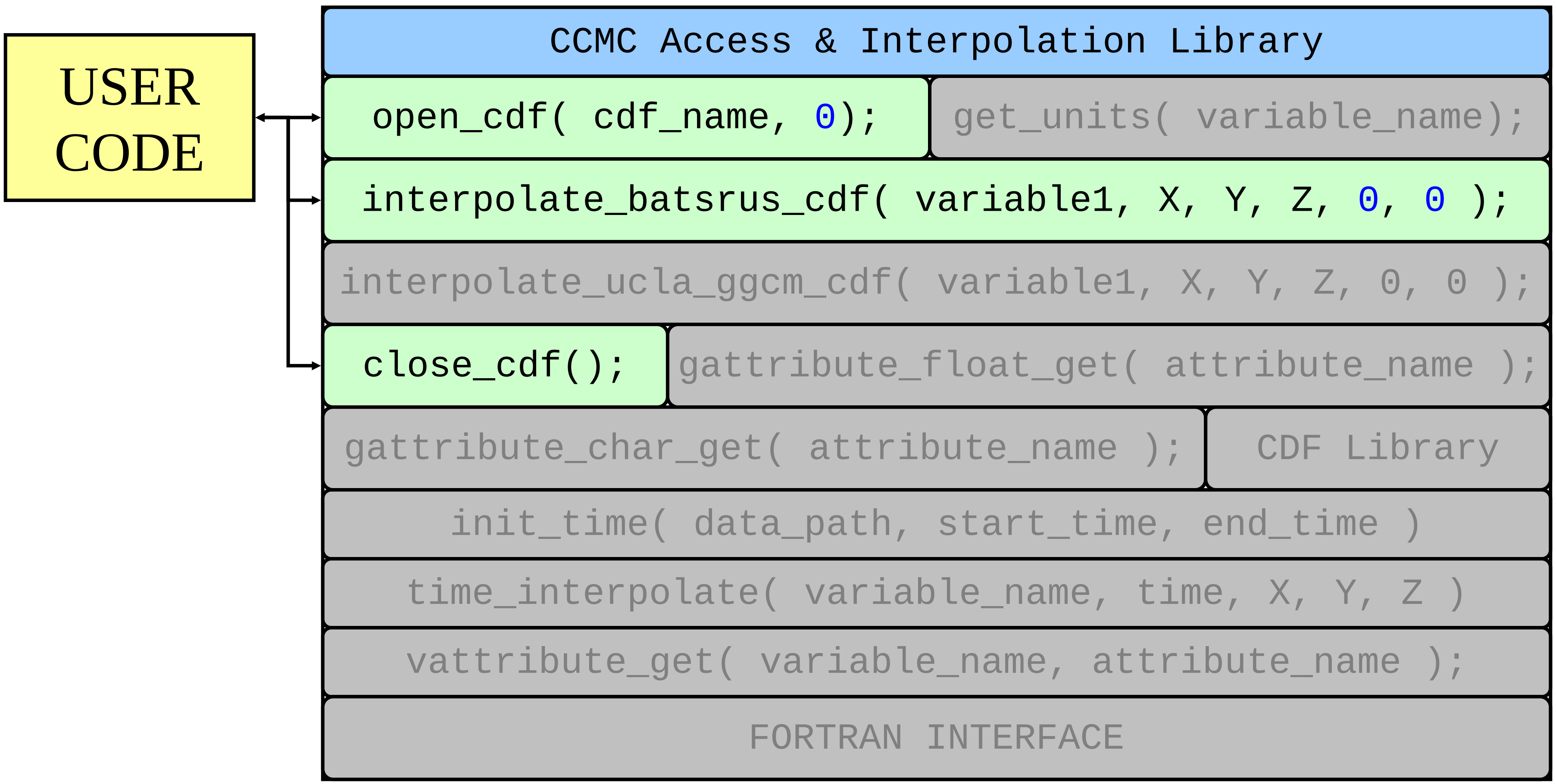
-Fortran	-Java
-C/C++	-Perl
-IDL	-Vtk
-OpenDx	-Your App

Current Standardized Model Output Availability
BATSRUS
OpenGGCM / UCLA-GGCM
CTIP (*Testing Phase*)

Currently Supported Science Data Formats
CDF 2.7
CDF 3.0 (*testing*)
HDF5 (*coming soon*)

Data Access

- Currently creating a user friendly library of routines that can be called from any C supported language.



Data Access

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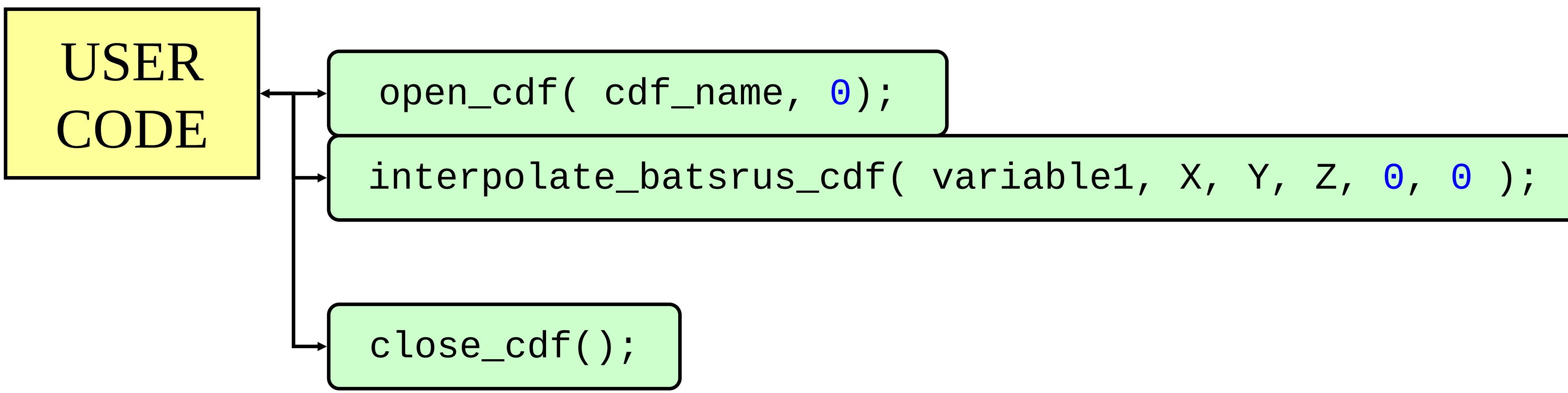
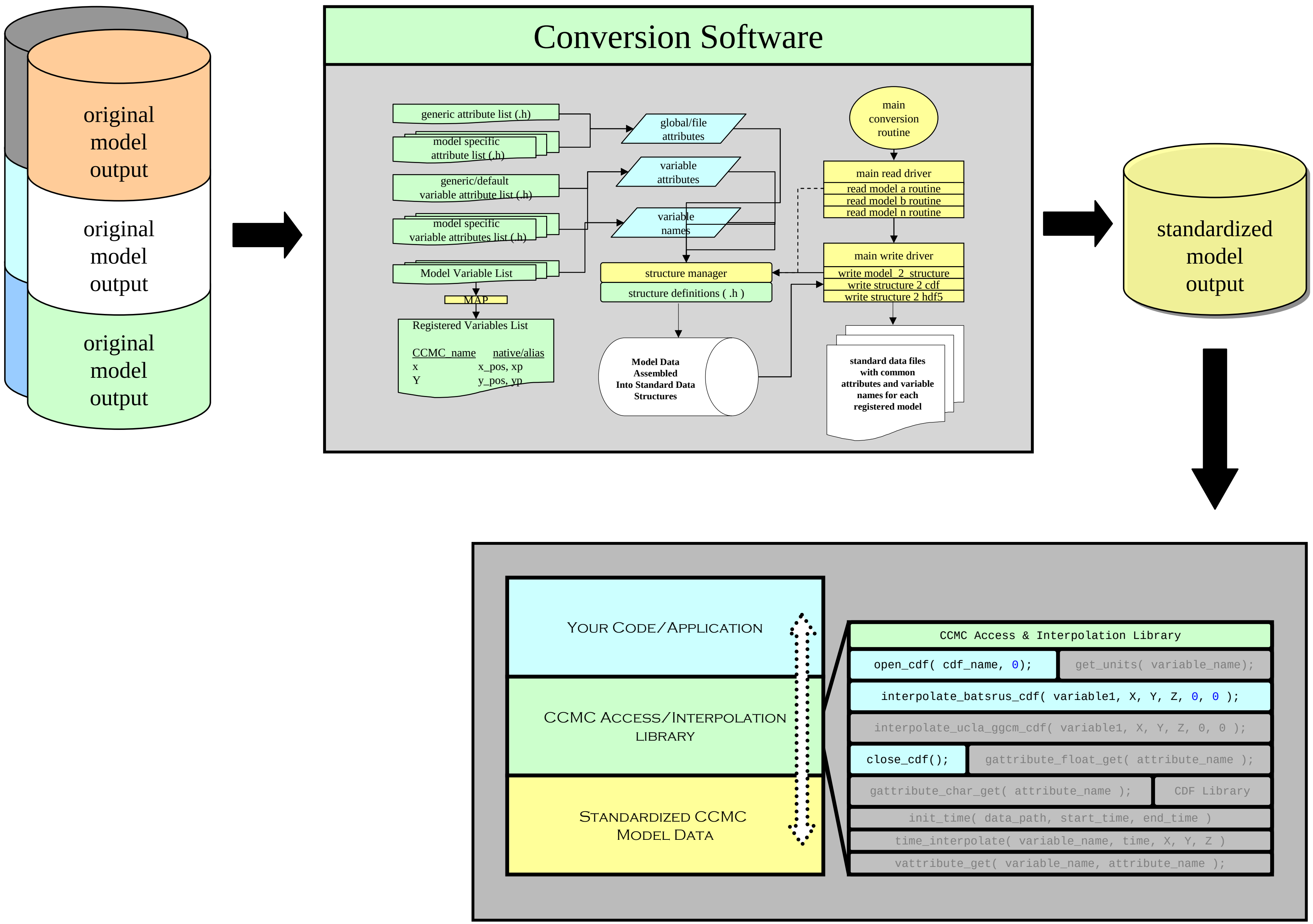


- Model output can now be easily accessed using CCMC access/interpolation library and standardized files
  - Allows data to be used in any application that supports the standard c programming language
  - Platform independent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model
output
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generic attribute list (.h)
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attributes
variable
attributes
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names
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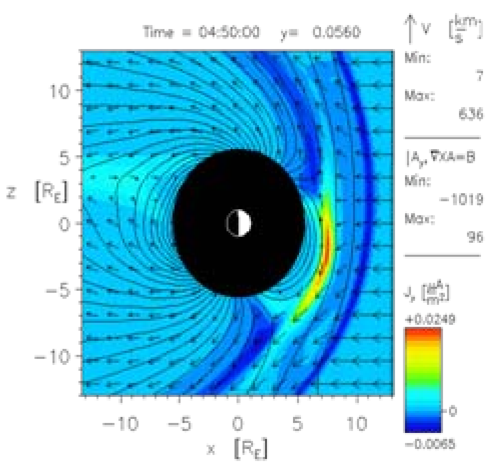
structure definitions (.h)
Model Data
Assembled
Into Standard Data
Structures
main
conversion
routine
main read driver
read model a routine
read model b routine
read model n routine
main write driver
write model_2_structure
write structure 2 cdf
write structure 2 hdf5
standard data files
with common
attributes and variable
names for each
registered model
standardized
model
output
Your Code/Application
CCMC Access/Interpolation
Library
Standardized CCMC
Model Data
CCMC Access & Interpolation Library
open_cdf(cdf_name, 0);
get_units(variable_name);
interpolate_batsrus_cdf(variable1, X, Y, Z, 0, 0);
interpolate_ucla_ggcm_cdf(variable1, X, Y, Z, 0, 0);
close_cdf();
gattribute_float_get(attribute_name);
gattribute_char_get(attribute_name);
CDF Library
init_time(data_path, start_time, end_time)
time_interpolate(variable_name, time, X, Y, Z)
vattribute_get(variable_name, attribute_name);

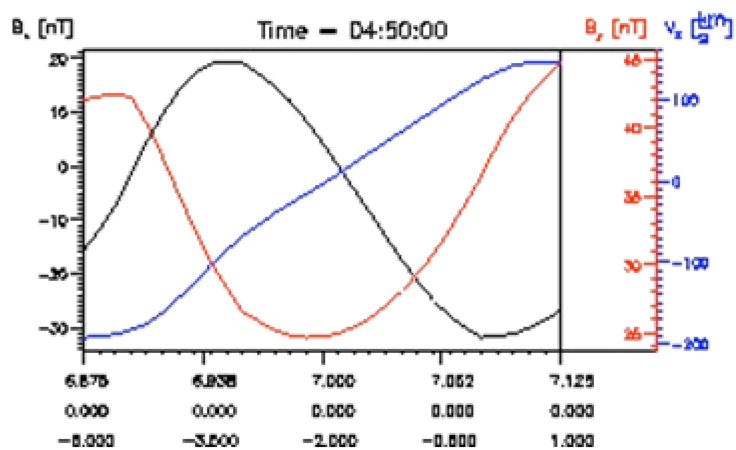
General Usage and Benefits

- Speed and efficiency of direct data access
- Self descriptive data files
- Can be used by anyone with CDF tools & libraries
- Same interface regardless of model
- Platform independent
- Promotes data sharing
- Facilitates code reuse
- CCMC access/interpolation libraries allow model data to be easily integrated into any existing analysis software or application

Specific Usage and Benefits

- Allows CCMC to serve high resolution data that would normally be unavailable
- Integrated Access/Interpolation Libraries into CCMC software infrastructure
    - 3D View Visualization Package (IDL) & Runs-On-Request System
    - Space Weather Explorer Visualization Tool (OpenDx)
- Good for metric studies comparing observation data with simulation data
- Several early adopters
    - Visualization of Kelvin-Helmholtz Waves
    - Particle tracing
- In house research & analysis of high resolution runs





Quick & Efficient Data Access

Analysis only required
Vx, Bx, By in
Range of ~10RE

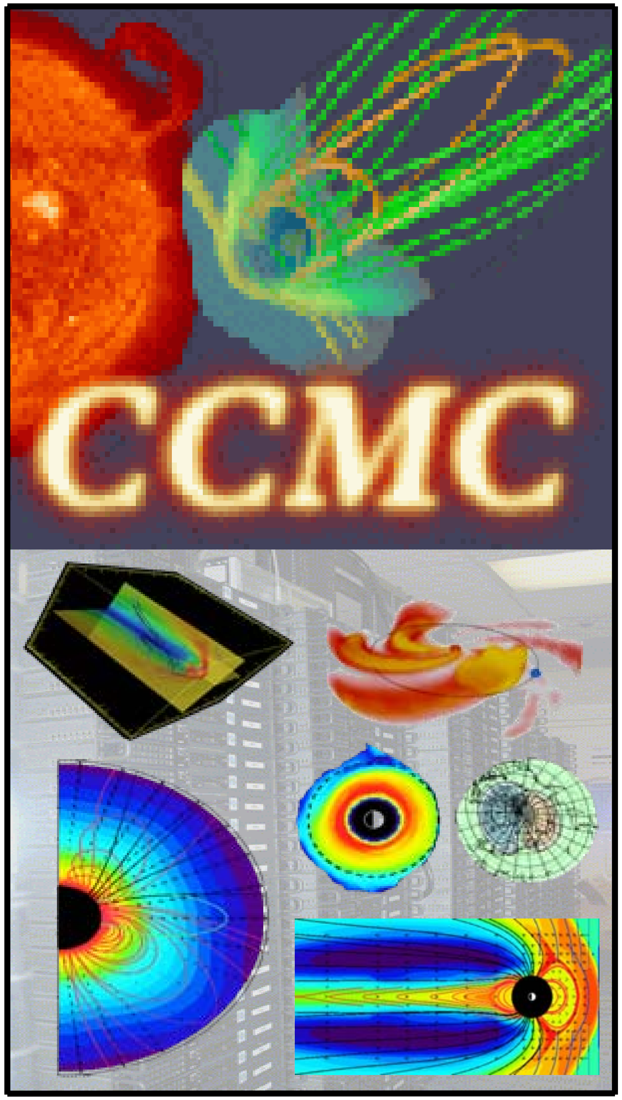
Reduced plot times from
15min to < 5sec

Outstanding Issues

- Variable naming conventions
- How much metadata to pack into each file
- Refining grid description
- Making the transition
- As simulations grow larger keeping original model output may not be feasible
- Add/integrate coordinate system transformation software into existing software suite as well as specific data analysis tools

Summary

- General grid description scheme in place
- Clearly defined set of core metadata elements
- Structure oriented architecture ensures flexibility
- Conversion software currently supports:
  - BATSRUS, BATSRUS SWMF Framework, UCLA-GGCM/OpenGGCM, & CTIP
- CCMC access/interpolation library currently supports:
  - BATSRUS, BATSRUS SWMF Framework, UCLA-GGCM/OpenGGCM CDF files
  - Interface to easily extract global & variable metadata
  - Time interpolation for entire data sets
  - Fortran Interface
- Add Solar & Ionosphere Models to software - CTIP testing phase
- Implement HDF 5 conversion module
- Library is currently available for use and we encourage feedback - questions, comments, and/or suggestions



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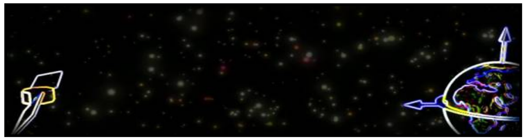
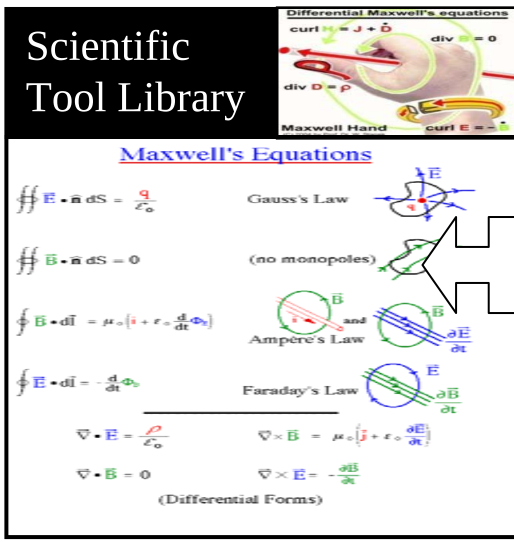
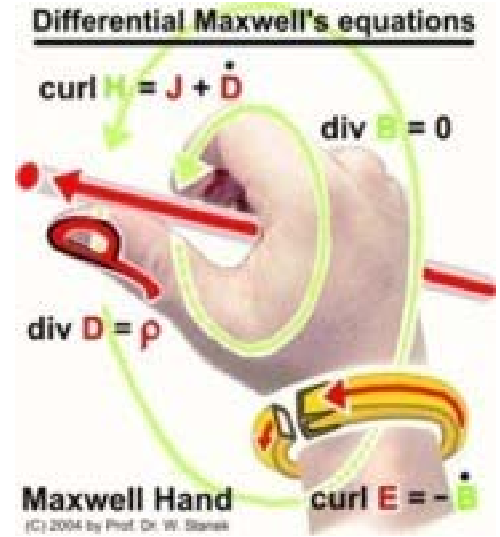
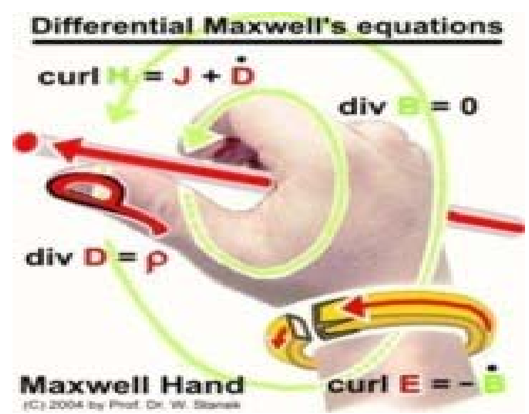



Scientific
Tool Library
Maxwell's Equations
Gauss's Law
(no monopoles)
Ampère's Law
Faraday's Law
(Differential Forms)


Differential Maxwell's equations
curl H = J + Ḋ
div B = 0
div D = ρ
Maxwell Hand
curl E = - Ḃ
(C) 2004 by Prof. Dr. W. Stanek


Differential Maxwell's equations
curl H = J + Ḋ
div B = 0
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Maxwell Hand
curl E = - Ḃ
(C) 2004 by Prof. Dr. W. Stanek

Supplemental Slides

Attribute	Description	Status
README	General description describing the model, contents of CDF, and HOWTO usage.	
README_visualization	Guidelines for visualizing data contained in file.	
model_name	Name of the registered model that produced the data	
model_type	The type of model used to produce data i.e. Global Magnetosphere	
generation_date	Date of generation or run date…	
original_output_file_name	Name of the original model data file that was converted to current CDF file	
run_registration_number	CCMC Runs on Request registration number for runs submitted through online system	
generated_by	Personal identifying info (First Name Last Name)	
terms_of_usage	*For tracking purposes for our government sponsors, we ask that you notify the CCMC whenever you use CCMC results in a scientific publication or presentation.*	
grid_system_count	The number n of how many grid systems are used and/or described in the current cdf file NOTE: If n > 1 the additional grid attributes will be defined in corresponding model_attributes.h file	
grid_system_n_number_of_dimensions	The number m of how many dimensions are in grid n. So for every grid there will be a corresponding grid_system_n_number_of_dimensions attribute i.e. The first grid will have an attribute grid_system_1_number_of_dimensions	
grid_system_n_dimension_m_size	Size of dimension m for grid n	
grid_system_n	Outline how particular grid system is defined by showing coordinates used ie. [X, Y, Z] were X,Y,Z are position variables defined in current CDF.	
output_type	Define the type of output is contained in CDF file. i.e. Global Magnetosphere model with Ionosphere output	
standard_grid_target	Defines a standard target grid and coordinate system for which the current models output can be converted to using an external coordinate transformation package.	
grid_n_type	Keywords identifying all grids used in current model output. Grid types will be registered in external coordinate transformation package.	
start_time	Time in CDF Epoch3 format (YYYY-MM-DDThh:mm:ss.msecZ) signifying beginning of the simulation	
end_time	Time in CDF Epoch3 format (YYYY-MM-DDThh:mm:ss.msecZ) signifying end of the simulation	
run_type	An event or model extracted from DatabaseInfo file	

CCMC Global Attributes

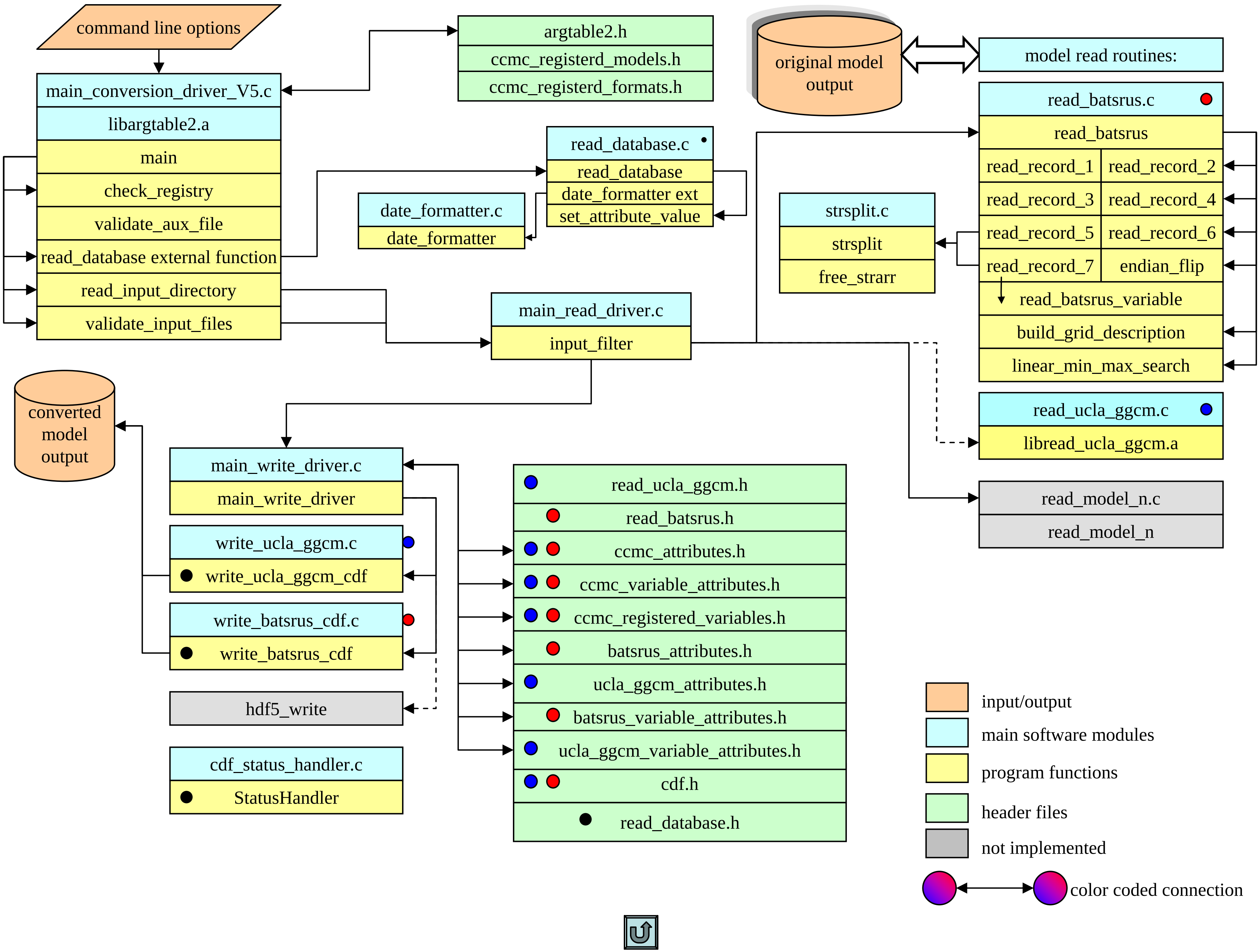
- README
- README_visualization
- model_name
- model_type
- Generation_date
- Original_output_file_name
- Run_registration_number
- Generated_by
- Terms_of_usage
- Grid_system_count
- Grid_system_n_number_of_dimensions
- Grid_system_n_dimension_m_size
- Grid_system_n
- Output_type
- Standard_grid_target
- Grid_n_type
- Start_time
- End_time
- Run_type

Model Specific Global Attributes

•••

•••

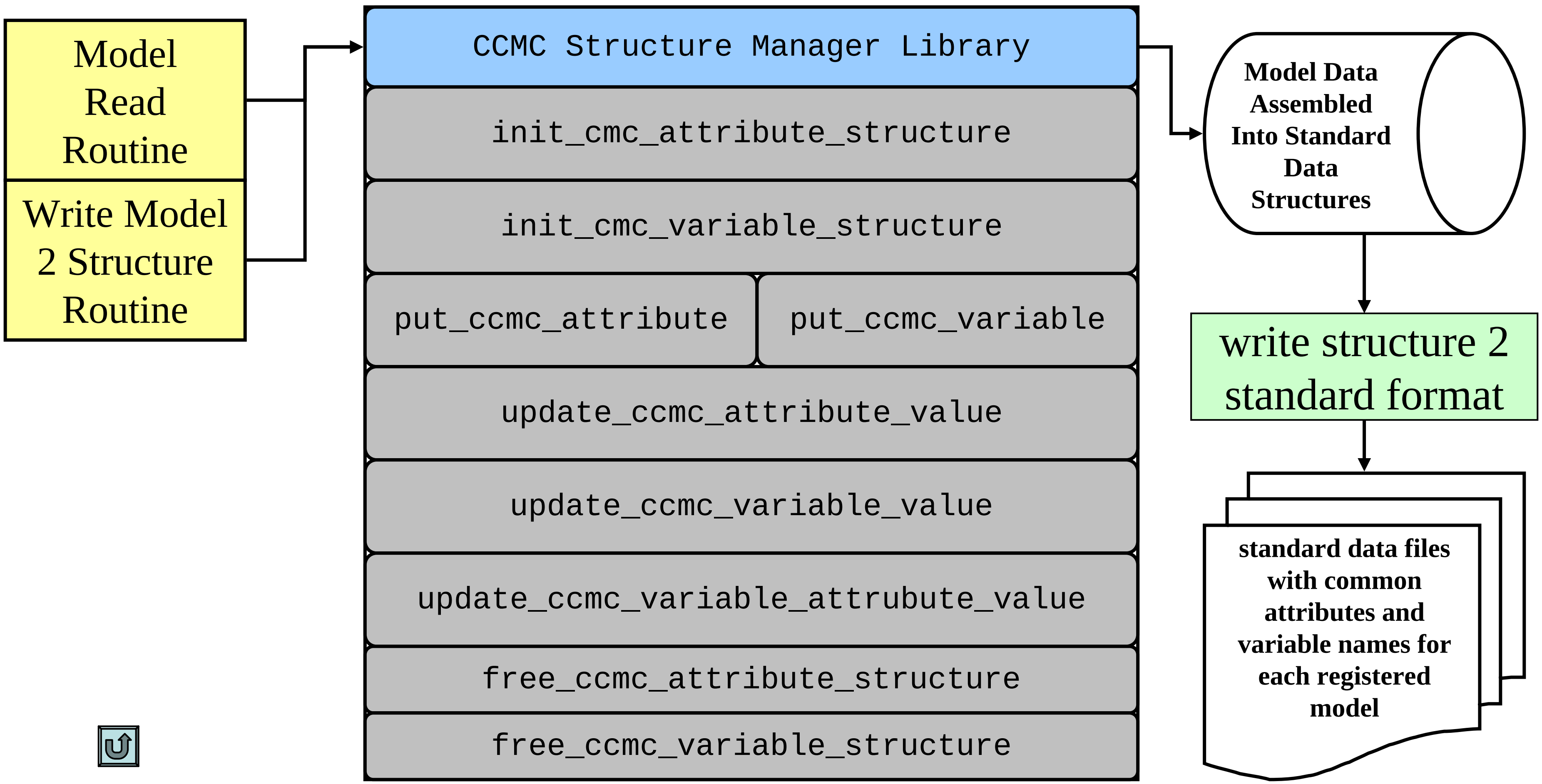
Attribute	Description	Status
valid_min	Smallest valid value for a particular variable. If actual value is less than this valid_min, the actual value is physically impossible and/or was generated in error	
valid_max	Largest valid value for a particular variable. If actual value is greater than this valid_max, the actual value is physically impossible and/or was generated in error	
units	The particular units of measurement for a variable	
grid_system	The grid system in which a variable is on	
mask	Mask value	
desciption	A description of the variable	
is_vector_component	Boolean value identifies if variable is a vector component or scalar variable	
position_grid_system	…	
data_grid_system	…	
actual_min	The smallest value for a particular variable	
actual_max	The largest value for a particular variable	



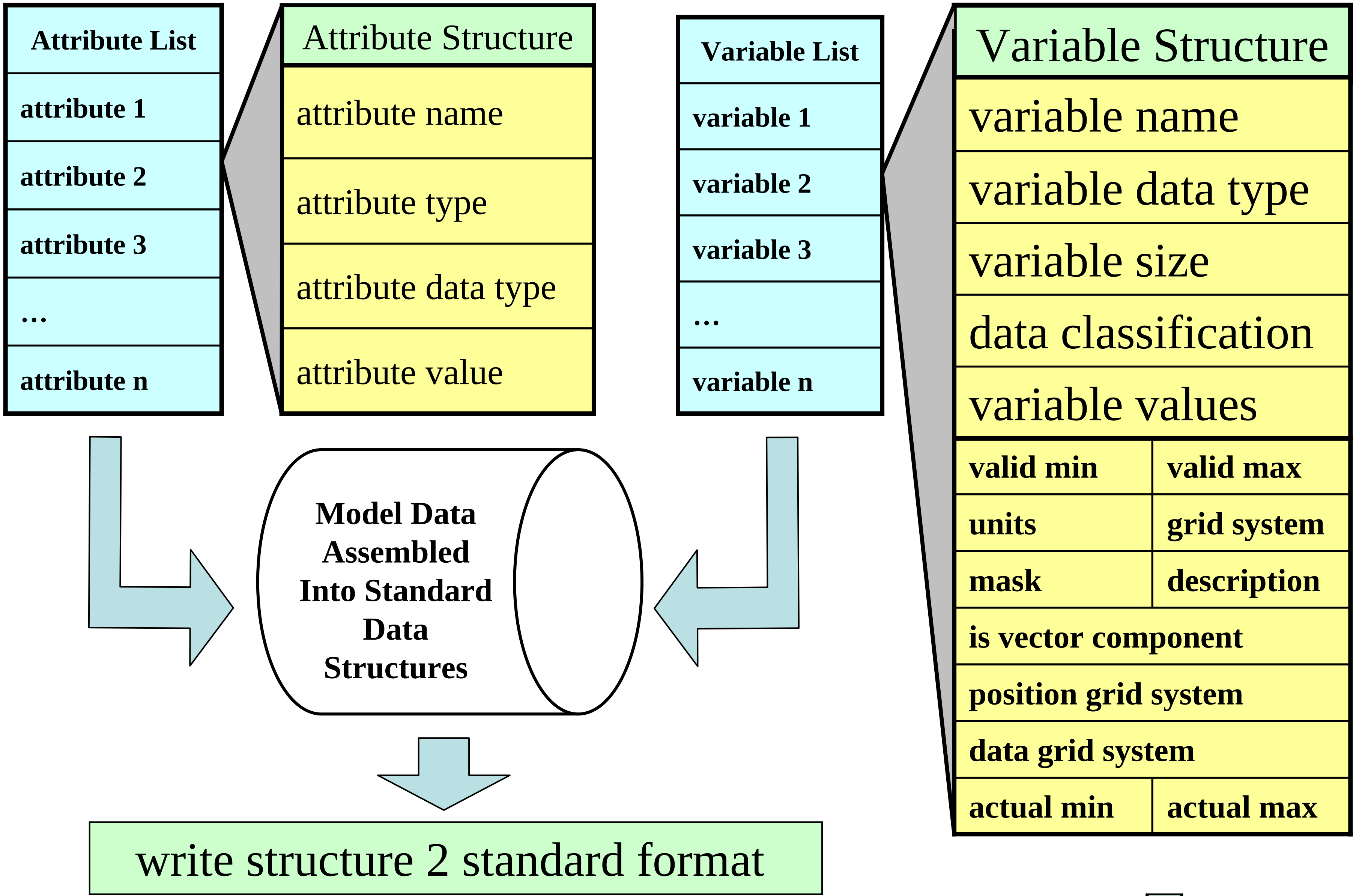
command line options
main_conversion_driver_V5.c
libargtable2.a
main
check_registry
validate_aux_file
read_database external function
read_input_directory
validate_input_files
argtable2.h
ccmc_registerd_models.h
ccmc_registerd_formats.h
original model output
model read routines:
read_batsrus.c
read_batsrus
read_record_1
read_record_2
read_record_3
read_record_4
read_record_5
read_record_6
read_record_7
endian_flip
read_batsrus_variable
build_grid_description
linear_min_max_search
read_database.c
read_database
date_formatter ext
set_attribute_value
date_formatter.c
date_formatter
strsplit.c
strsplit
free_strarr
main_read_driver.c
input_filter
read_ucla_ggcm.c
libread_ucla_ggcm.a
read_model_n.c
read_model_n
converted model output
main_write_driver.c
main_write_driver
write_ucla_ggcm.c
write_ucla_ggcm_cdf
write_batsrus_cdf.c
write_batsrus_cdf
hdf5_write
cdf_status_handler.c
StatusHandler
read_ucla_ggcm.h
read_batsrus.h
ccmc_attributes.h
ccmc_variable_attributes.h
ccmc_registered_variables.h
batsrus_attributes.h
ucla_ggcm_attributes.h
batsrus_variable_attributes.h
ucla_ggcm_variable_attributes.h
cdf.h
read_database.h
input/output
main software modules
program functions
header files
not implemented
color coded connection

Populating the Structures

- Library of C routines that are used to populate the standard attribute and variable structures.



Standardized Attribute & Variable Structure Lists

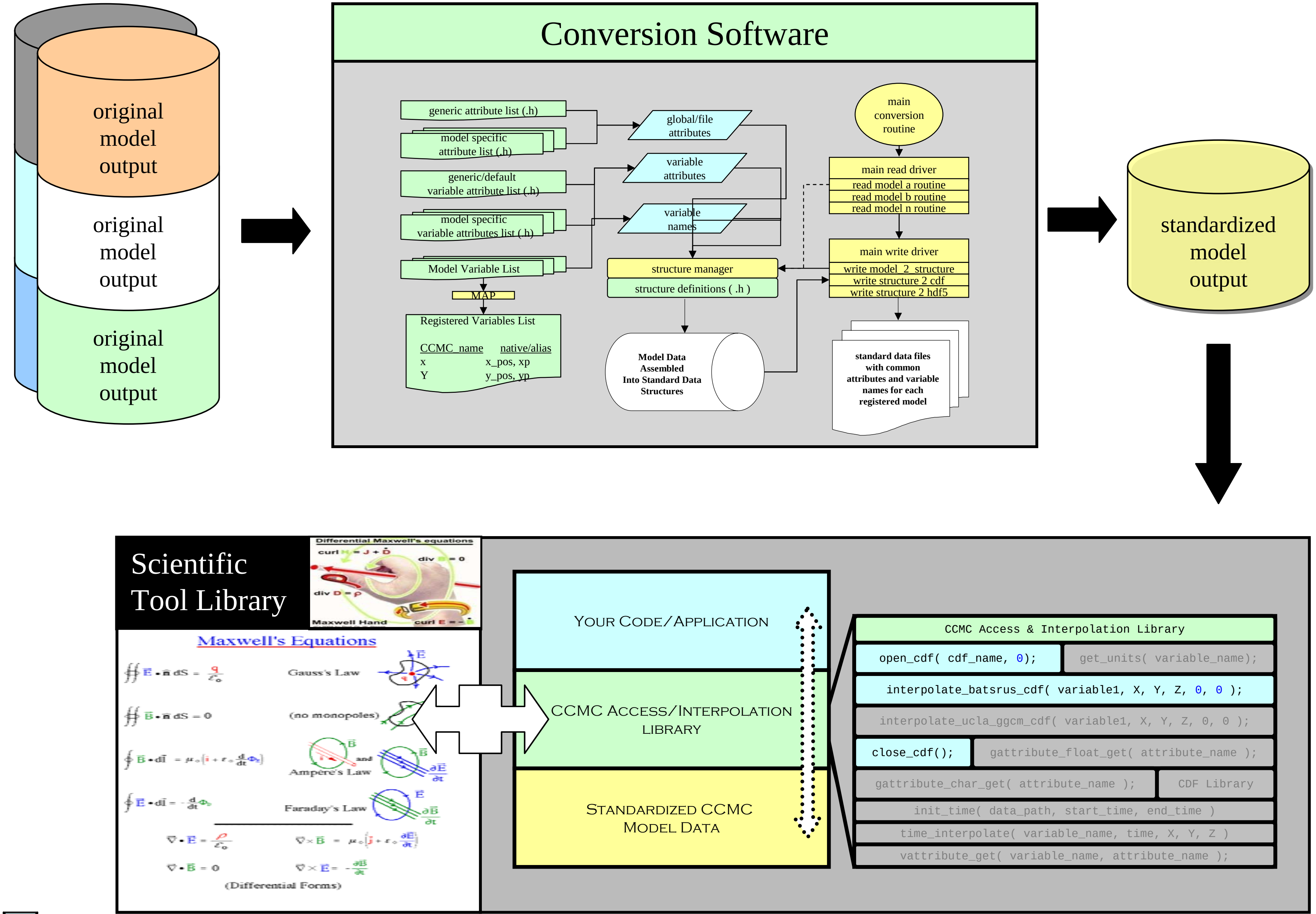


Standardization is Feasible
(Summary from CCMC Workshop 2003)

- BATRUS .Out to CDF conversion results promising
  - 1.5 second uncompressed CDF creation time
  - Resulting file size virtually unchanged
- OpenDx successfully imported CDF data using standard input module *(only had to specify input file name)*
  - Requires minimal initial development to correctly categorize imported data
- Working toward developing and implementing a flexible data format standardization software tool within the CCMC

Next Steps (from 2003 CCMC Workshop)

- Develop standard grid description scheme
- Implement HDF 5 conversion module
- Test BATRUS output conversion performance with HDF 5 data standard
- Compare CDF vs. HDF 5 performance
- Decide use of either CDF or HDF5 or both
- Develop standard “in-house” naming conventions for variables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Differential Maxwell's equations
Maxwell Hand
Maxwell's Equations
Gauss's Law
(no monopoles)
Ampere's Law
Faraday's Law
(Differential Forms)
YOUR CODE/APPLICATION
CCMC ACCESS/INTERPOLATION LIBRARY
STANDARDIZED CCMC MODEL DATA
CCMC Access & Interpolation Library
open_cdf(cdf_name, 0);
get_units(variable_name);
interpolate_batsrus_cdf(variable1, X, Y, Z, 0, 0);
interpolate_ucla_ggcm_cdf(variable1, X, Y, Z, 0, 0);
close_cdf();
gattribute_float_get(attribute_name);
gattribute_char_get(attribute_name);
CDF Library
init_time(data_path, start_time, end_time)
time_interpolate(variable_name, time, X, Y, Z)
vattribute_get(variable_name, attribute_name);