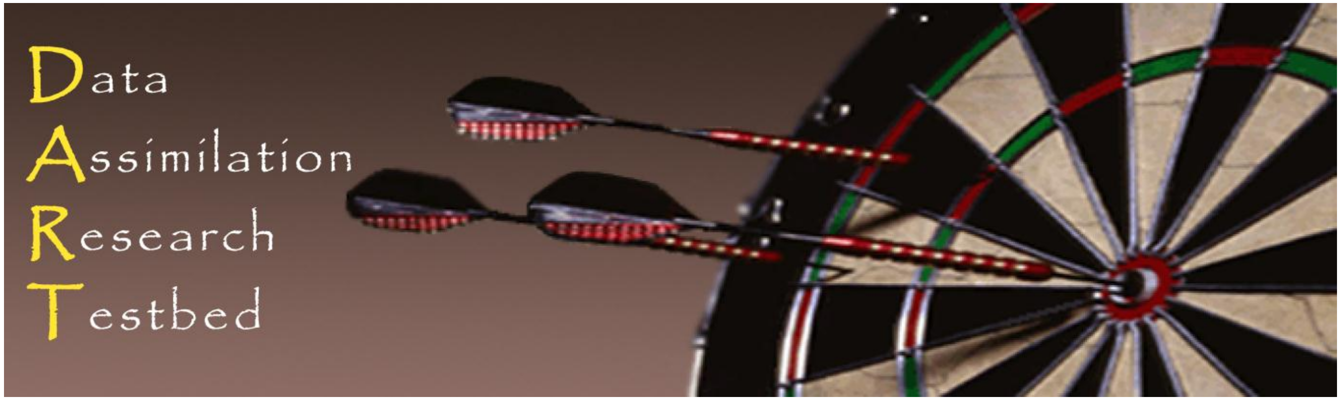
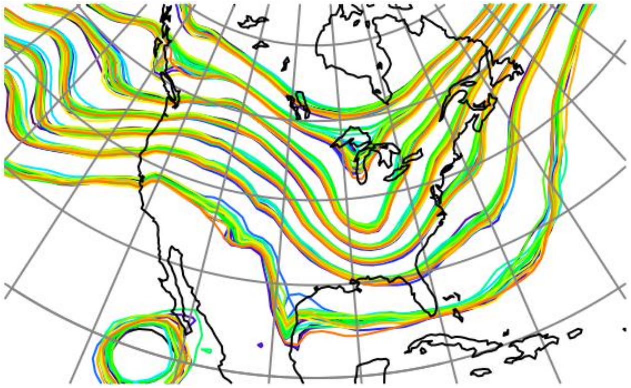


A generic implementation of strongly-coupled assimilations in the DART framework



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NCAR | UCAR | National Center for Atmospheric Research

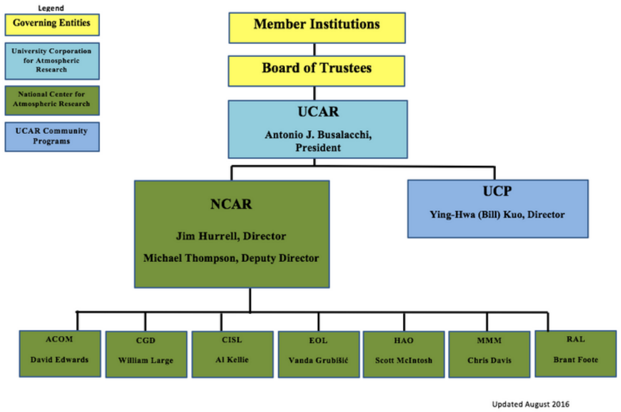
UCAR/NCAR

UCAR – University Consortium that runs NCAR

NCAR – The National Center for Atmospheric Research

Main Divisions:

- Climate
- Weather
- Computing
- Atmospheric Chemistry
- Solar/Space
- Observations
- Subcontracted Projects



DA at NCAR

NCAR Data Assimilation Program

- Coordinate various DA efforts within NCAR
  - GSI (var for WRF, GFS)
  - WRF-DA (various var and hybrid-var)
  - DART (ensemble framework)
  - Collection of custom solutions
- DA Postdoc program, looking for applicants

Data Assimilation Research Testbed

- A Data Assimilation Research System
  - Theory based, widely applicable general techniques
  - Localization, Sampling Error Correction, Adaptive Inflation, …
- A Data Assimilation System for Geoscience
  - Many models (low order -> state-of-the-art GCMs)
  - Works with any observations: Real, synthetic, novel
  - Flexible, portable, well-tested, extensible, free!
  - Fast and efficient, laptops to supercomputers
- A Teaching Tool
  - Extensive tutorial materials - examples, exercises, explanations
- People: The DAReS Team

DART is used at

NCAR
48 UCAR member universities,
More than 100 other sites,
(More than 1500 registered users).

DART works with many geophysical models

Global Atmosphere models:

CAM	Community Atmosphere Model (all 3 dynamical cores)	NCAR
CAM/CHEM	CAM with Chemistry	NCAR
WACCM	Whole Atmosphere Community Climate Model	NCAR
AM2	Atmosphere Model 2	NOAA/GFDL
NOGAPS	Navy Operational Global Atmospheric Prediction System	US Navy
ECHAM4,6	European Centre Hamburg Model	Hamburg
Planet WRF	Global version of WRF	JPL
MPAS	Model for Prediction Across Scales	NCAR/DOE
LMDZ5	Laboratoire de Météorologie Dynamique Zoom	Indian Inst. of Technology

DART works with many geophysical models

Regional Atmosphere models:

WRF/ARW	Weather Research and Forecast Model	NCAR
WRF/CHEM	WRF with Chemistry	NCAR
NCOMMAS	Collaborative Model for Multiscale Atmospheric Simulation	NOAA/NSSL
COAMPS	Coupled Ocean/Atmosphere Mesoscale Prediction System	US Navy
CMAQ	Community Multi-scale Air Quality	EPA
COSMO	Consortium for Small-Scale Modeling	DWD
CM1	Atmosphere Model (idealized)	NCAR

DART works with many geophysical models

Ocean models:

POP	Parallel Ocean Program	DOE/NCAR
MIT OGCM	Ocean General Circulation Model	MIT
ROMS	Regional Ocean Modeling System (under development)	Rutgers
MPAS	Model for Prediction Across Scales (Under development)	DOE/LANL
FEOM	Finite Element Ocean Model (regional)	Alfred Wegner Inst.

DART works with many geophysical models

Upper Atmosphere/Space Weather models:

ROSE		NCAR
TIEGCM	Thermosphere Ionosphere Electrodynamic GCM	NCAR/HAO
GITM	Global Ionosphere Thermosphere Model	Michigan
Solar Dynamo	Dynamo/sunspot Model	NCAR/HAO
OpenGGCM	Geospace General Circulation Model	Univ New Hampshire

DART works with many geophysical models

Land Surface models:

CLM	Community Land Model	NCAR
NOAH	Relatively simple land model	Community
CABLE	Community Atmosphere Biosphere Land Exchange	CAWCR (Australia)
JULES	Joint UK Land Env Sim	UK Met Office

Ice Models:

CICE	Climate Ice Model	Los Alamos

Hydrologic Model:

WRF Hydro		NCAR

DART users work with many observational datasets Atmospheric Observations (1)

U,V,T,Q	NCEP: Radiosonde, AIRCRAFT (commercial), ACARS
U,V	NCEP: Cloud Drift Winds from satellite
U,V (ocean surface)	QUIKSCAT, including L2B (JPL)
T,Q,refractivity of the atmosphere	COSMIC Global Positioning Satellite radio occultation
T,Q,Tsurface	AIRS from Aqua/A-train satellite
U,V,T,Q,Tsurface, pressure,altimeter	MADIS: ACARS, Marine and MESONET surface, METAR, radiosonde, satellite wind
Radar reflectivity, radial velocity	NCEP

DART users work with many observational datasets
Atmospheric Observations (2)

U,V	MADIS; Wind Profilers, Atmospheric Motion Vectors (AMVs)
U,V,T,Q,altimeter	OK mesonet (U. OK)
Cloud Liquid Water Path, Cloud Top and Base Pressures	GOES satellite, CIMSS
U,V	SSEC (U Wisconsin): Cloud Drift Winds from satellite
CO (carbon monoxide)	MOPITT
U,V	GOES CIMSS (U. WI); rapid-scan AMVs (Atmospheric Motion Vectors), satellite cloud winds

DART users work with many observational datasets
Atmospheric Observations (3)

T,Q,Total Precipitable Water	GOES CIMSS hyperspectral AIRS IR
Total Precipitable Water	AMSR, MODIS Microwave
U,V	Operational typhoon bogus winds, Taiwan Central Weather Bureau
U,V (at wind turbine hub height)	Seimens(?)
Electron density	COSMIC/FORMOSAT-3
U,V,T	GTS
Chemical concentrations	IASI on EUMETSAT Polar System MetOp satellite
Aerosol optical depth (AOD)	TERA and AQUA

DART users work with many observational datasets Solar, Space Weather, Extraterrestrial Observations:

Radiances, Occultation on Mars	TES, limb sounder on Mars
Density, ion concentrations	CHAMP
Thermospheric Mass Densities	CHAMP, GRACE
Electron densities	COSMIC
Total Electron Density	Garner GPS Archive
Orbital element information	NORAD
Solar Magnetic Fields	Wilcox, Mt Wilson, National Solar Observatories
Rotational, Meridional Circulation	Mt Wilson, SoHO, SDO, HMI

DART users work with many observational datasets
Ocean Observations:

T, Salinity	World Ocean Database: Argo floats, CTD(ships), XBT, moored thermistors, drifting buoys(GT-SPP)
Surface U, V currents	CODAR

DART users work with many observational datasets Land Observations:

Snow cover	MODIS
Leaf area index	MODIS
Total water storage	GRACE
Brightness temperature	AMSR-E
Heat Flux, Net Carbon	Ameriflux tower network
Soil Moisture	COSMOS (neutron counter)

Ensemble DA Method

DART uses Ensemble Methods

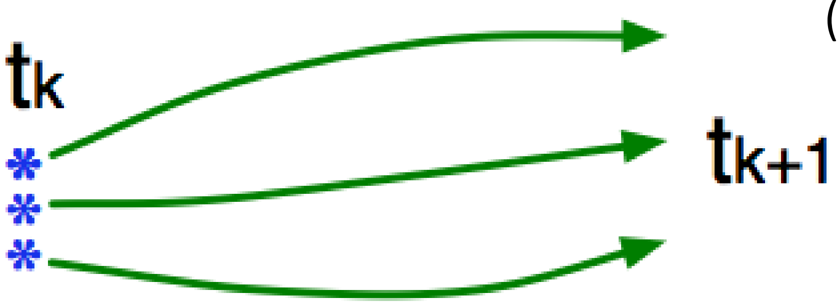
- No adjoint required
- Highly parallel (using MPI)
- Highly scalable (10,000+ tasks)
- Requires running N copies of the model
- Model runs can be "embarassingly parallel"
- Some models support ensembles in a single run

Ensemble Filter For Large Geophysical Models

1. Use model to advance ensemble (3 members here) to time at which next observation becomes available.

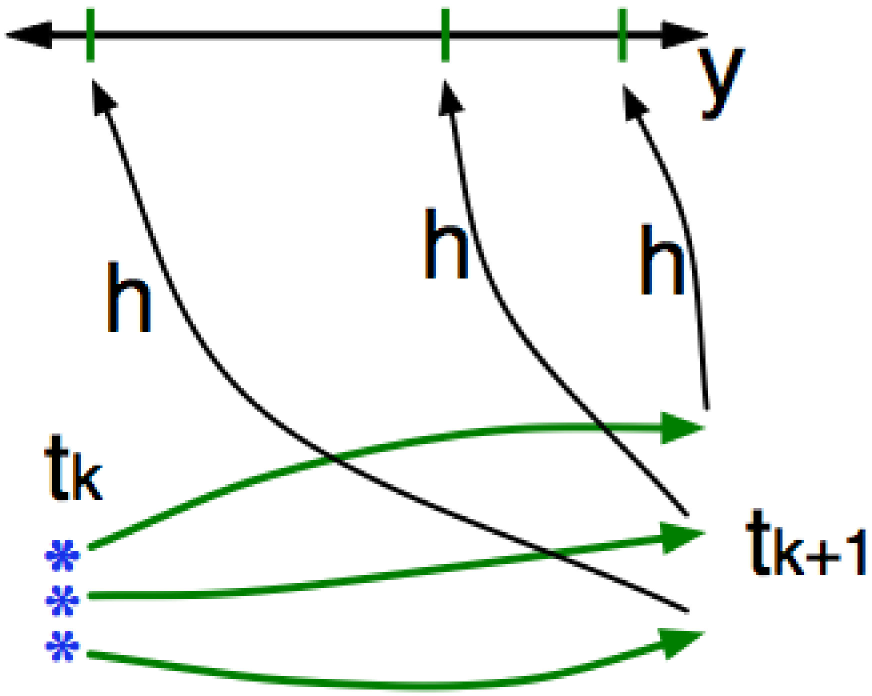
Ensemble state estimate, $x(t_k)$, after using previous observation (analysis)

Ensemble state at time of next observation (prior)



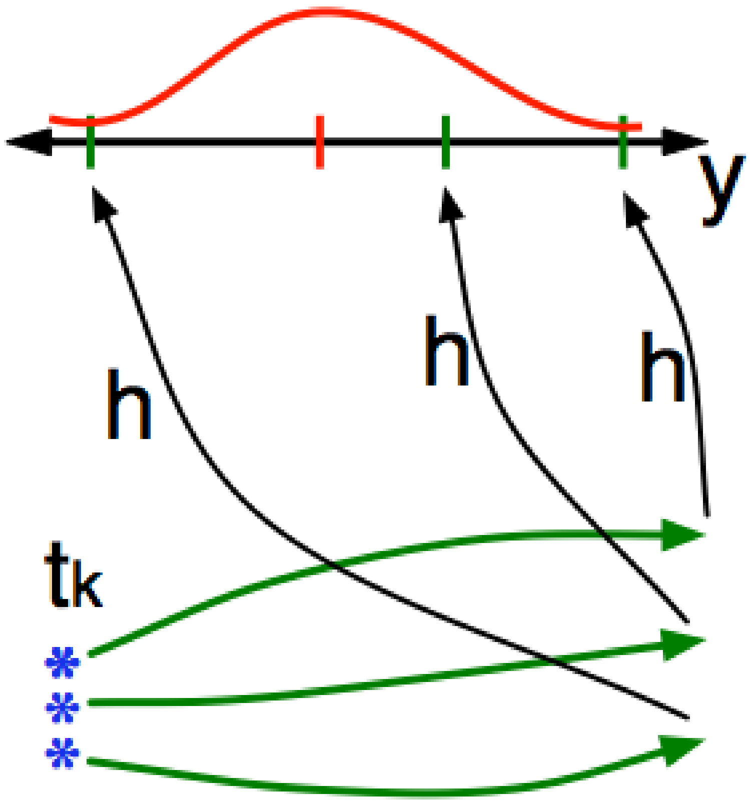
Ensemble Filter For Large Geophysical Models

2. Get prior ensemble sample of observation, y = h(x), by applying forward operator **h** to each ensemble member.



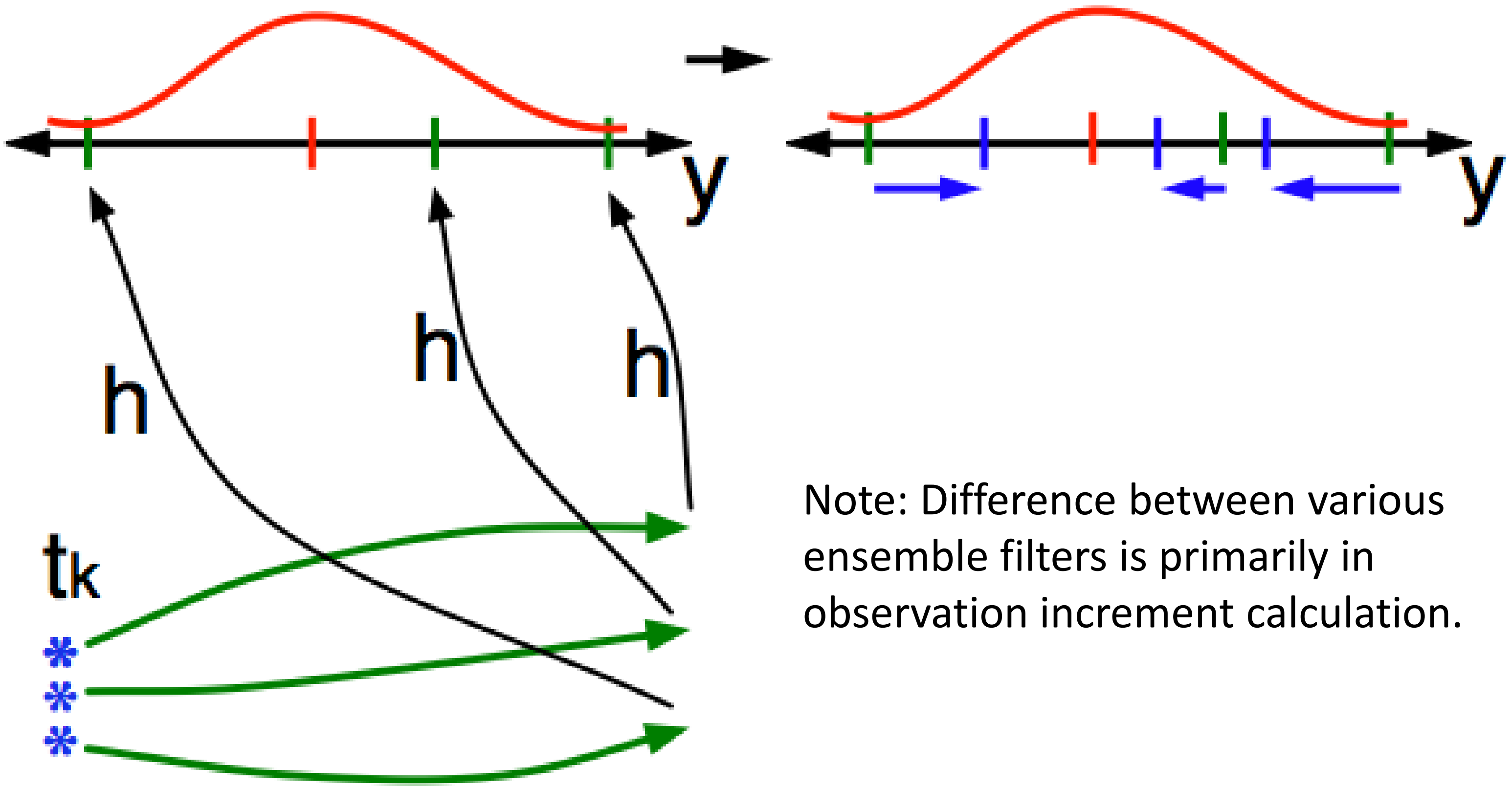
Theory: observations from instruments with uncorrelated errors can be done sequentially.

3. Get observed value and observational error distribution from observing system.



Ensemble Filter For Large Geophysical Models

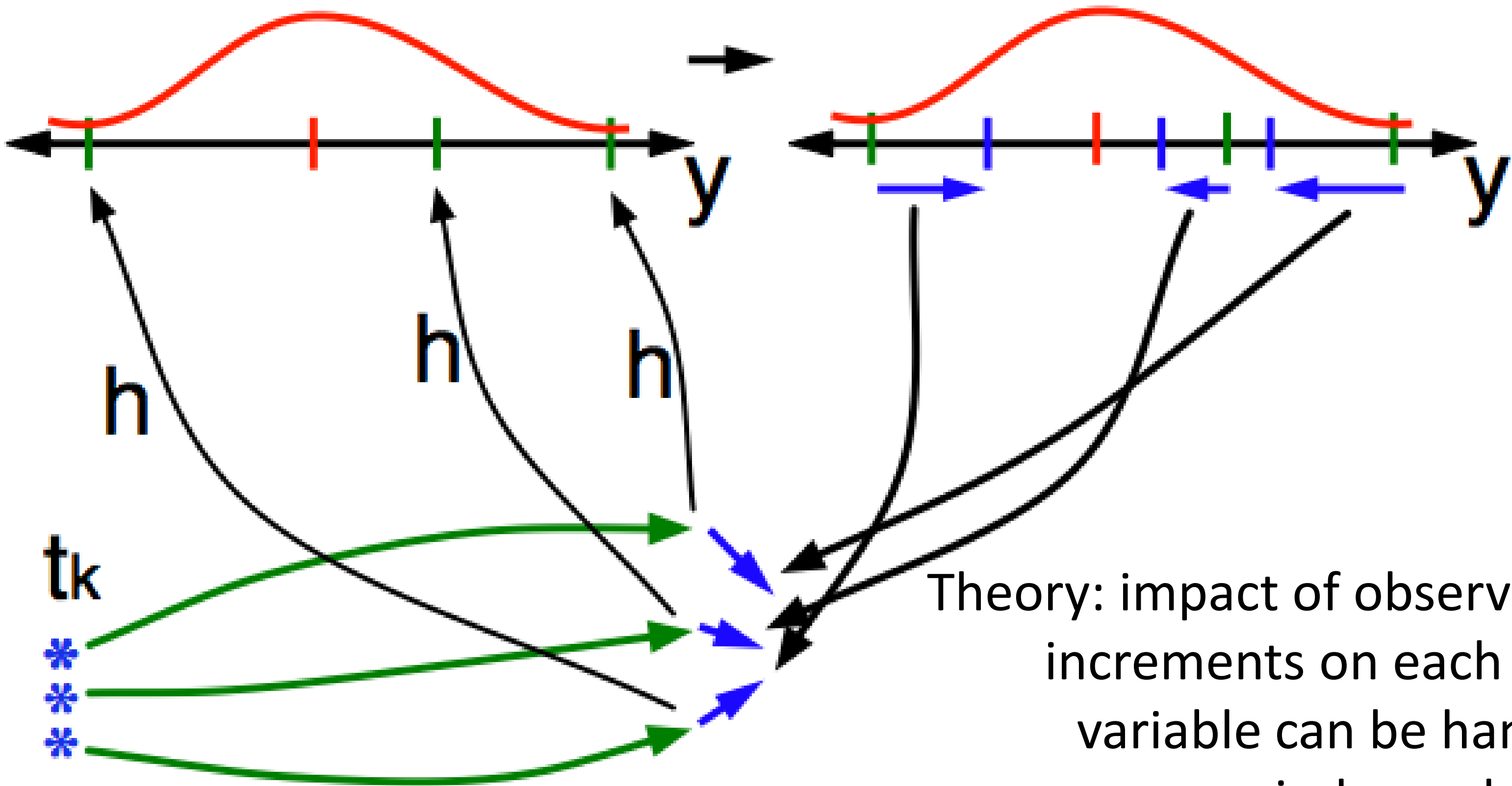
4. Compute the increments for the prior observation ensemble (this is a scalar problem for uncorrelated observation errors).



Note: Difference between various ensemble filters is primarily in observation increment calculation.

Ensemble Filter For Large Geophysical Models

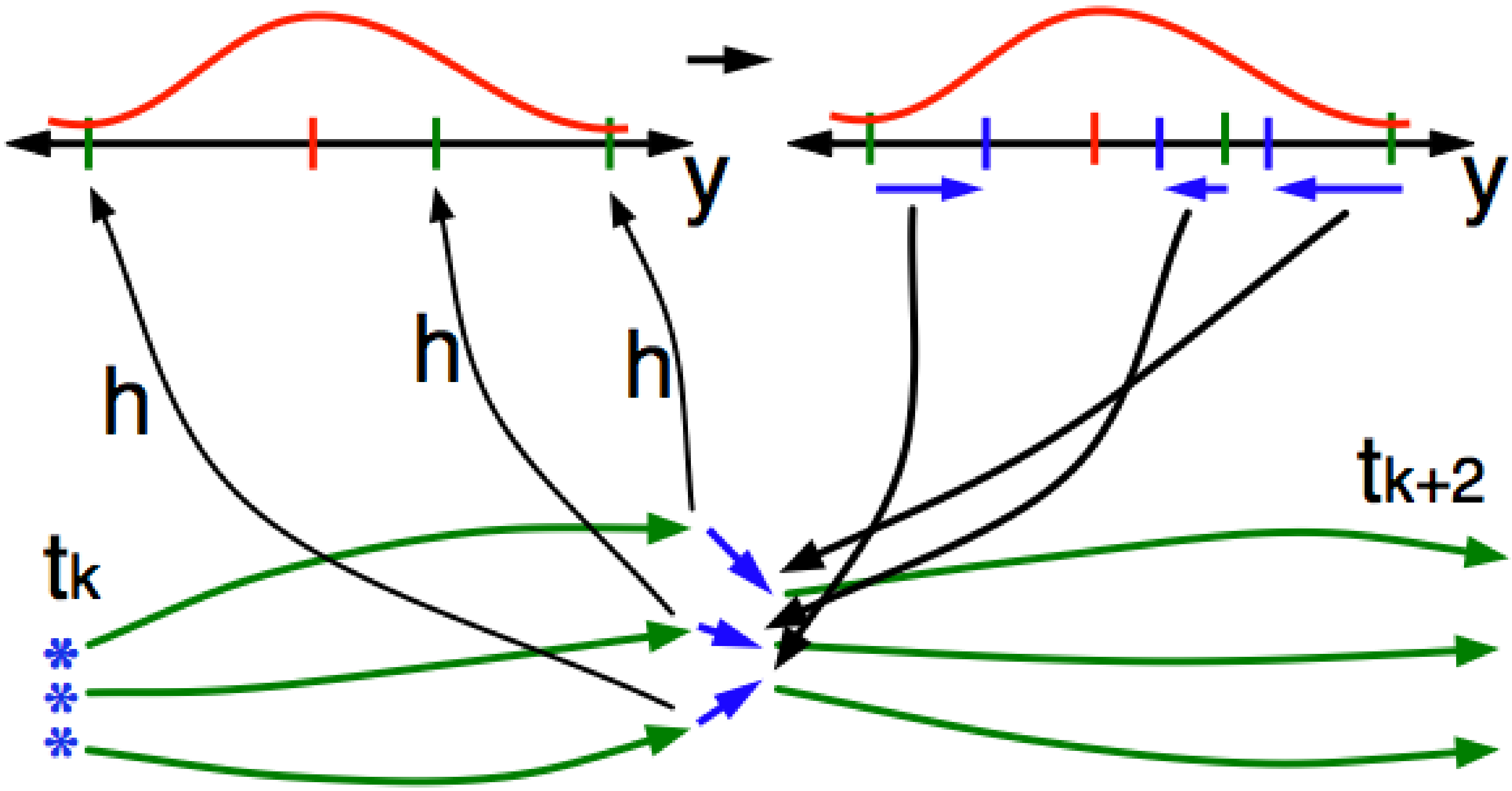
5. Use ensemble samples of **y** and each state variable to linearly regress observation increments onto state variable increments.



Theory: impact of observation increments on each state variable can be handled independently!

Ensemble Filter For Large Geophysical Models

6. When all ensemble members for each state variable are updated, there is a new analysis. Integrate to time of next observation …



DART Software Architecture

DART software architecture:

- All written in Fortran 90
- Model dependent code isolated to a single module
  - Set of ~15 required routines
- Observation forward operators easily added
  - Fixed set of required routines
- Choice of location convention (1D, 2D, 3D, sphere, etc)
- All MPI code in a single module
  - Non-MPI version can be substituted
- Collection of modules compiled into executable tools

DART Capabilities

DART features:

- Sampling error correction
- Adaptive inflation with damping
- Localization (inc. Adaptive, vertical coordinate choice)

DART latest developments:

- Single data distribution
  - No data transposes during different phases of filter
  - Removes limit on max state vector size
- Direct NetCDF file I/O
- Externally computed forward operators (FGAT)
- Experimental particle filter
- Additional inflation options (RTPS)

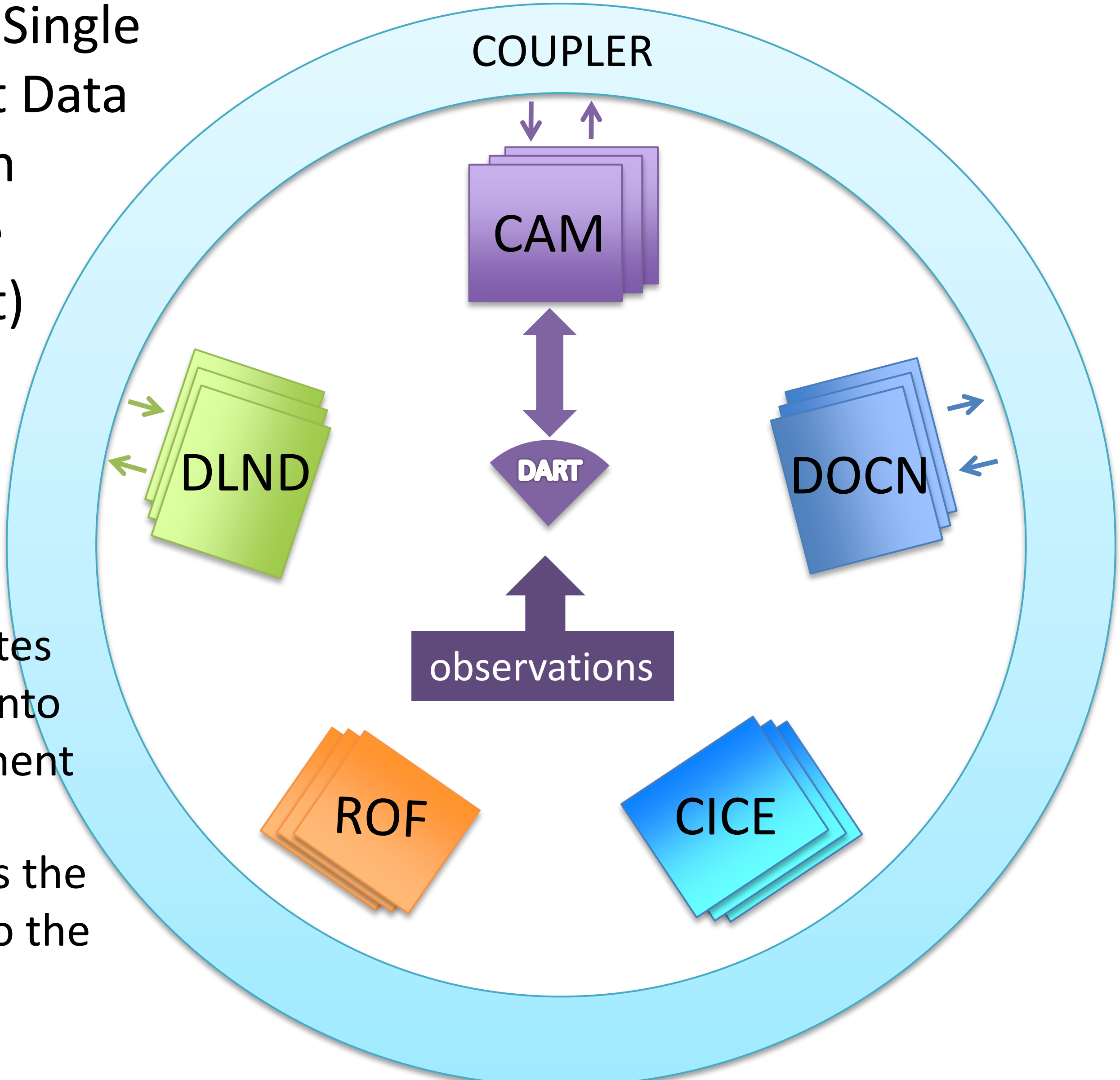
DART Coupled Strategy

Existing ‘loosely-coupled’ experiments were done by multiple execution of the filter program, assimilating observations separately into each component.

Then the model was advanced in time and the normal coupling would transmit information between components.

CESM Example

DART-CAM Single Component Data Assimilation (One Active Component)

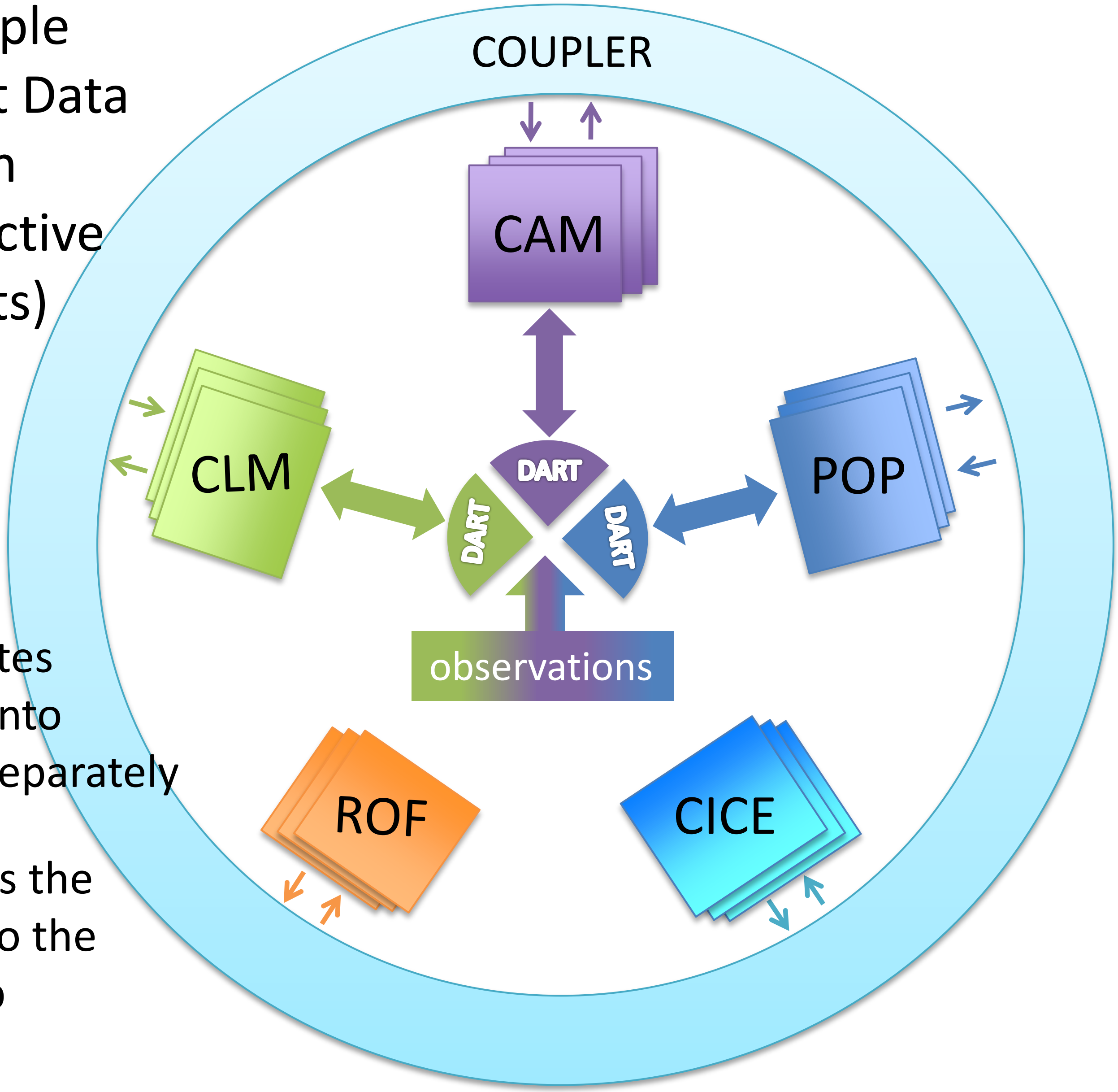


DART assimilates observations into active component

Coupler moves the components to the next time step

CESM Example

DART Multiple Component Data Assimilation (Multiple Active Components)

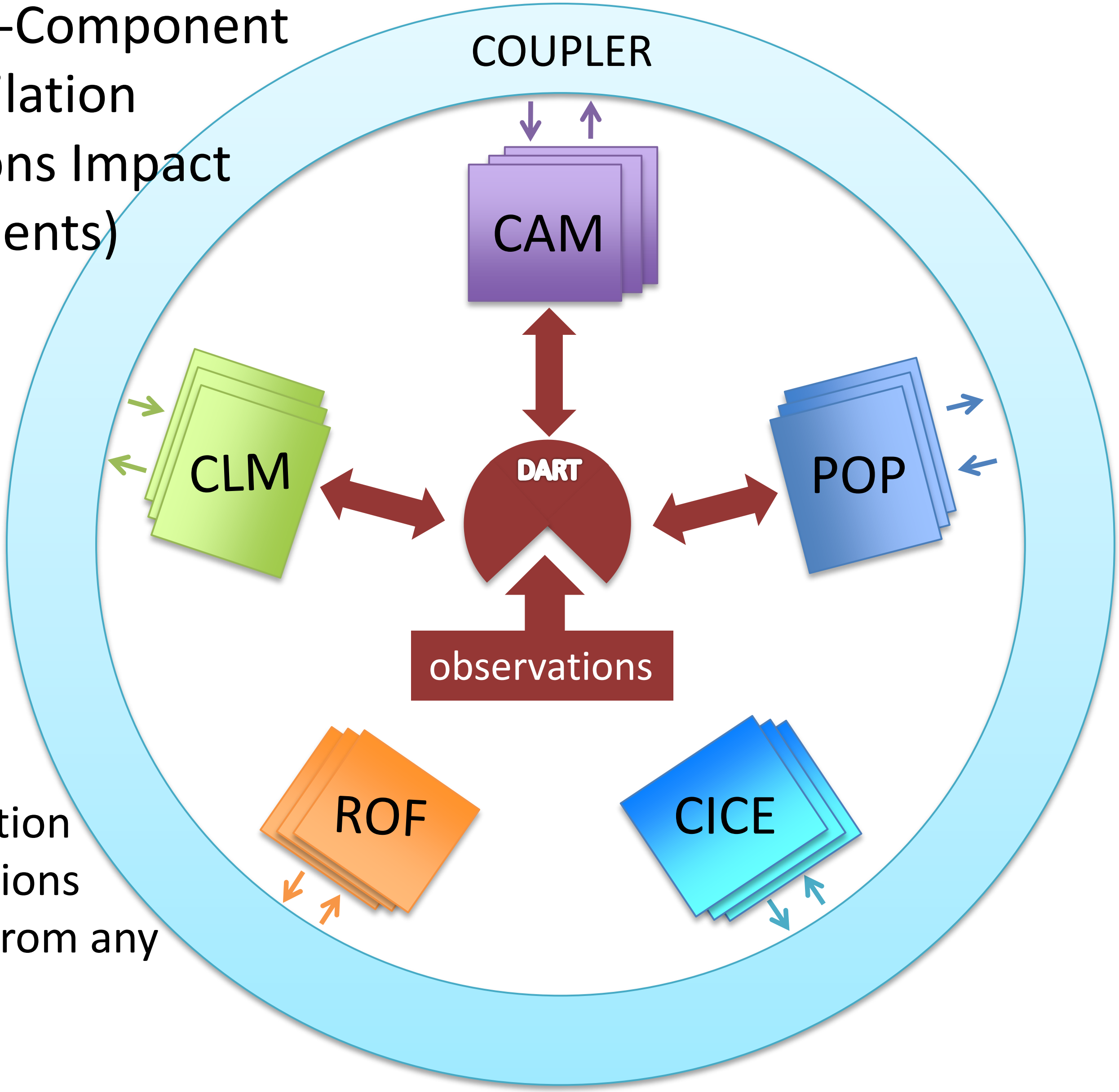


DART assimilates observations into components separately

Coupler moves the components to the next time step

CESM Example

DART Cross-Component Data Assimilation (Observations Impact All Components)



DART assimilation of all observations impacts data from any component

DART Coupled Strategy

Moving towards more tightly coupled assimilation

Software Goals:

- Single executable if possible
- Reuse existing model interface code
- Enable forward operators to easily use data from multiple models

DART Coupled Strategy

Initial implementation:

- Single executable
- Single namelist and settings
- Reads/writes existing model input/output files
- Added a model interface module which directs requests to the desired existing interface model
- No replicated model-dependent code
- Uses existing forward operator code
- New code required to distinguish inter-component from intra-component points during the adjustment phase of the assimilation

DART Coupled Strategy

Initial implementation Pros:

- Able to reuse existing model interface code
- Minimal impact on core DART code
- Read/write individual model files for each component
- Single executable

NetCDF I/O

All Initial Condition and Restart data is now read and written from NetCDF files.

Includes the capability to include variables from multiple files, e.g. for nested grids

Used to combine data from different models, keeping track of how many domains are read per component.

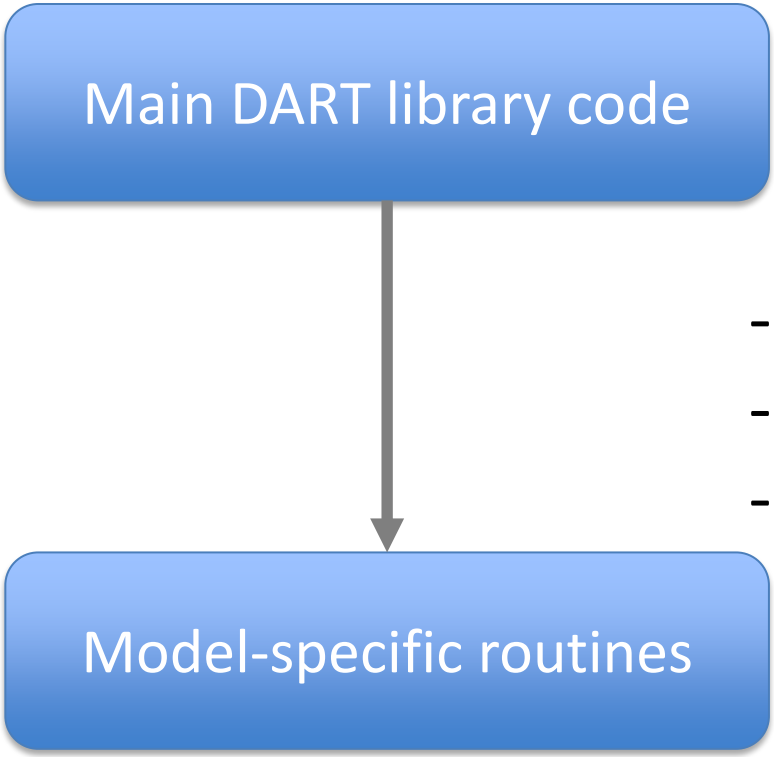
Common State Vector

No matter what shape in the model, DART treats all data as a 1D array of individual points.

All grid information ignored by code outside of the model-dependent module.

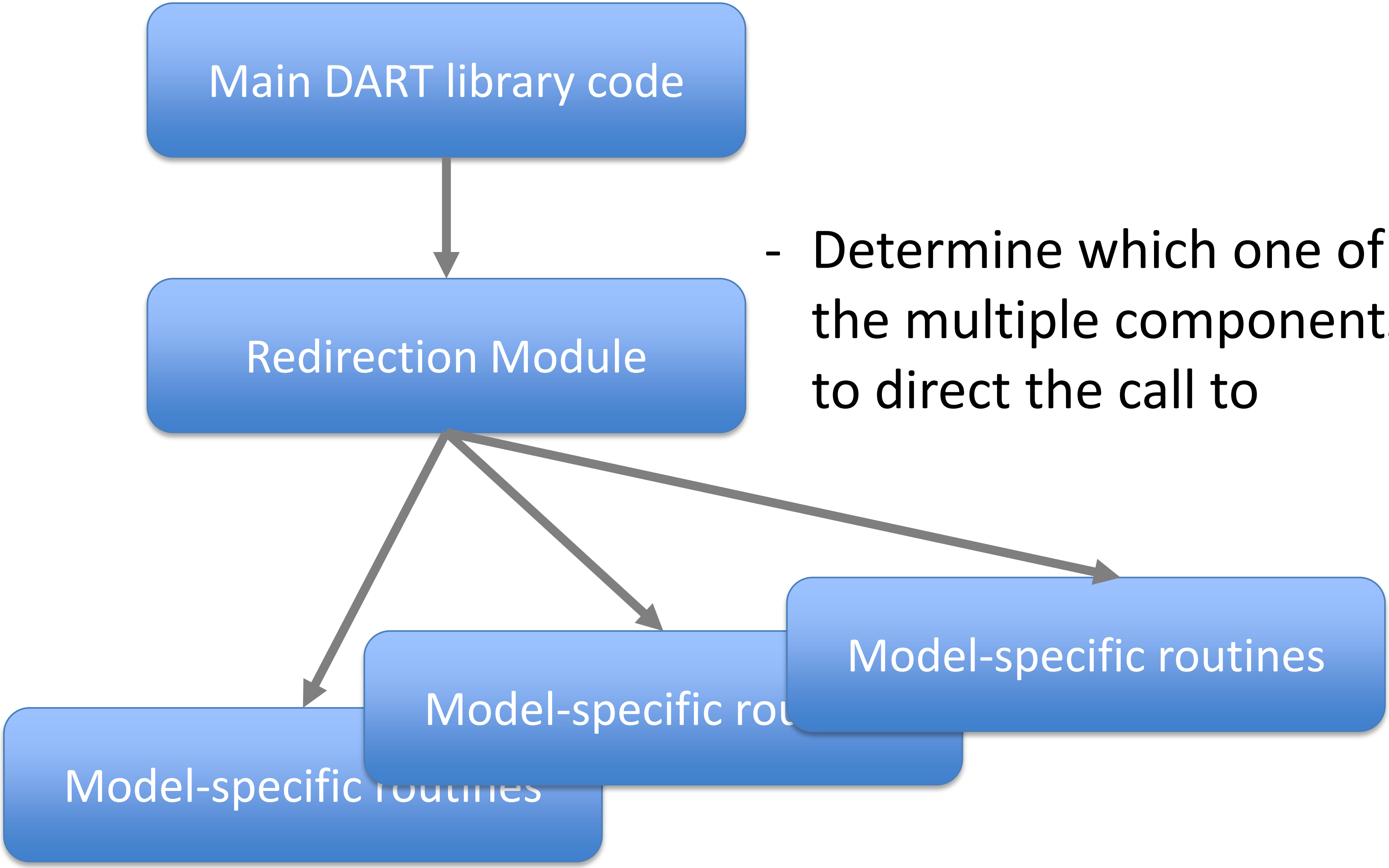
For the Strong Coupled version, data from all components in single 1D vector. Array sections can be passed to the model interface code.

Code Reuse



- Return state size
- Return point location
- Return interpolated value

Code Reuse – Strong Coupling



- Determine which one of the multiple components to direct the call to

Additional Data Needed for Obs

In most cases it was possible to determine automatically which of the multiple model interfaces the call should be redirected to.

However, for forward operators the user must supply an additional item for each observation type, selecting which component should compute the interpolated values.

More complicated forward operators could then be built on top of the basic functions.

DART Coupled Strategy

Initial implementation Cons:

- Single copy of many parameters that may want different values for different components
  - Inflation
  - Localization distance
  - Vertical localization coordinate choice
- Cross-component localization code complicated and potentially slower than necessary

Future Directions

Continued experiments with coupled system

Alternative implementation would separate more clearly the assimilation into each model with a final cross-component phase

Would like to hear about requirements for forward operators that combine data from multiple models

Would like to hear about cross-component impact techniques/experiments (localization surrogates)

Thank you

General Email contact: dart@ucar.edu
Me: nancy@ucar.edu

Web pages:
(DAReS – Data Assimilation Research Section)
http://www.image.ucar.edu/DAReS

Code checkout (subversion):
https://proxy.subversion.ucar.edu/DAReS/DART

Submitted Abstract

Previous coupled experiments assimilated in a "weakly-coupled" configuration, where a filter was run independently in each of the coupled components. The new implementation combines state information from all coupled components into a single state in one filter. Existing single-component code is reused in the coupled configuration, reducing the need for duplicate code or reimplementation. Forward operators can be developed that combine information from multiple components. Increments from one component can apply directly to other components. Many outstanding issues remain and will be discussed.