Strategic Plan for the Community Atmosphere Model

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Overview

The purpose of this plan is to set a roadmap for a new version of CAM. It is intended to be discussed at the 2010 Winter AMWG meeting to solicit community input and ideas, add community development efforts and achieve consensus (or not) that we are proceeding in an appropriate direction.

This plan is not for a single ‘new model’ release, but it is a strategic plan for model development (likely with more frequent releases).

The document is laid out with questions, goals, a detailed description of components and an ‘environment’ piece looking at where we and other models are going.

Questions

• Is the goal and focus of this document correct? What is missing?
• Timelines? Internal and External needs/resources?
• What are the key science questions the model will be used to answer?
• Who will use it?
• Are we advancing the science, meeting community needs and delivering a state of the art model?
• Where are we going to be relative to other centers?
• Do we need a section on coding standards and procedures? Do we need to update the physics interface document?
• Does this strategic plan overlap the CCSM and CGD strategic plans?
• Other questions?

Timeline

We envision a focus on interim releases that are less developed than the CAM3, CAM5 model of every 5 years. A release will be for a stand-alone model that has major new functionality or performance improvement. We expect some interim improvements to CAM5 to be ready soon (1 year after initial release). We also expect that the development described below will be released sooner than 5 years, and possibly in pieces (when they are ready).
More frequent releases imply a different standard of release: a model will probably not be required to reproduce the 20th century to be released. AMIP runs and coupled system testing will be done, but the standard for release may not be as comprehensive if they are more frequent.

The overall development could have 3 tracks:

1. Operational: e.g., What needs to get done in the next month or two (at any point in time not just now) certain runs examinations of sensitivities, low hanging bias reduction. (This of course is not the central subject of this document).

2. Tactical: For the expected periodic release ongoing improvements of the model (bug fixes, bias reductions, consistency improvements to the code). Also we should propose tactical efforts to further improve the understanding of the current version of the model. This section could also include initial efforts and infrastructure to achieve number 3.

3. Strategic: This is what is written about most in this document, and is the uncertain schedule for major improvements to model physics or model performance. An option for the strategic goal is to release major changes when they are ready, and most likely not hold them all back into single releases.

The alternative is to simply have two tracks: a tactical/operational track, and then a strategic track that would all be released at once (this is more along the lines of the current model development).

We will need to figure out what the community wants, and what we are able to provide given the resources available.

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**Science Goals**

Can we articulate an overarching theme or themes for CAM?

1. **Reduced climate biases from CAM5:**
   - Clear-sky long-wave radiation
   - Other modes of variability: convection scheme for MJO, diurnal cycle of precipitation, shallow to deep convection transition)
   - Better simulation of precipitation: diurnal cycle, means and higher order statistics
   - Realistic “weather” statistics
     - balanced model with good seasonal means
     - hurricane climatologies in all basins
     - extreme event distributions
     - Decent MJO
     - Good AMIP-style ENSO responses
2. A model that works ‘across scales’: likely target resolutions are 0.5-1 degree (standard and community machines) to 0.1 deg (smaller?) on high-performance machines for Climate scale (5-100 year) simulations. What are target ‘high’ resolutions? Near term target is 25km (running now). Medium term is 10km. What machines will we be running on in 3-5 years? We need input from internal users that might benefit from increased AGCM resolution: Hydrologists, DART-developers? Biosphere modelers? What architectures do people want to run on? What size machines? What resolution? There is ongoing work with higher vertical resolution versions of the model. How high do we need to go? We have some specialized versions that people are using, many in the context of WACCM/Chemistry. Testing at high vertical resolution can help identify problems in the physics. Tests of CAM5 up to L80 have been done (Klein) Where should the model top be? Does it need to be moved? Is this primarily an issue of getting the dynamics right?

3. Ability to generate distributions of climate relevant variables at the ‘regional scale’. A ‘seamless prediction’ system implies being able to represent regional climate in the hydrostatic (~5-10km and higher) scale. What outputs and statistics are most useful? A big push will be made into regional climate prediction. How should CAM/CESM be participating in these discussions?

4. Additional big upcoming frontiers? CAM5 has cloud-aerosol interactions (aerosol indirect effects). What other over-arching themes are out there? Can we focus scientific development on a grand challenge (e.g. cloud feedbacks, climate sensitivity). Perhaps we need to put an emphasis on a few areas: Indirect Effects, Cloud Feedbacks, Moist Convection. All this functionality exists in the code. What are we missing? Cloud resolving scales (MMF)?

Metrics and Evaluation

The goal of local model evaluation efforts is twofold. First, we use diagnostics to ensure that CAM is producing a climate that is consistent with available observations. Second, we use diagnostics to help us understand what controls CAM’s mean state and sensitivity to climate perturbations. Based on experience, what has been most useful in the most recent development cycle? Are there changes to the current paradigm and thinking? Should we use Taylor skill scores again? RMSE forecast scores? For reference, the CAM4 release metrics are (a) Taylor skill scores for present day (b) stable 1850 run and (c) ‘acceptable’ 20th century run. In the future, we will continue to compare CAM to global observational datasets, incorporating useful new datasets as they become available. In addition, we want to expand our evaluation of CAM with metrics that capture important modes of climate variability (e.g., building on what has already been done for ENSO). We also want to promote the use of diagnostics that allow us to
evaluate key process relationships in CAM. We also want to support evaluation of CAM during specific periods of climatic or observational importance (e.g., 2005 Hurricane season, 2007 sea ice loss, response to big volcanic eruptions, big ENSO events, year of tropical convection etc.). To ensure that we can compare CAM to observations during specific periods, it will be important to continue CAPT and DART efforts.

We are interested in expanding diagnostics for:

- Climate sensitivity. For example, can we include target diagnostics that explain inter-model spread in the IPCC climate projections? We could try to inspire research that leads to diagnostics that are useful for understanding climate sensitivity. There are some hints from emerging research that there are useful climate sensitivity metrics based on the mean state (e.g., Boe et al., 2009; others?).

- Aerosol indirect effects. Are there observations that show process relationships or metrics that can help explain the strength of modeled effects?

- Understanding variability and extremes. For example, we need more precipitation frequency and intensity diagnostics for comparison with observations.

- Sophisticated comparison with new observational datasets, e.g., instrument simulator packages such as the COSP simulator for CloudSat, CALIOP, ISCCP etc.

- Metrics measuring model performance at higher frequencies in space and time (this goes with variability and extremes).

- Better stratification of metrics that already exist (easy/hard to improve or calculate), also revisiting the skill score metric priorities.

To help with local efforts, we want to more fully engage with the external research community beyond the core AMP developers. A lot of evaluation/diagnostic work occurs in the university and NASA research worlds. There is also a lot of useful work being done locally at NCAR that we should more fully engage with (e.g., John Fasullo). Many papers have been published based on the CFMIP archive/CAM3, but has this work influenced development and local evaluation efforts? Although this work occurs on a different timescale and mostly on released model versions, can it inform the development on a day-to-day basis more?

CAM Model Components

Dynamics

Science Goals:

1) Scalable to hundreds of thousands of (a million) processors
2) Regionally refinable to allow regional climate studies in contrast to or complementary to nested modeling
3) Conservation of energy and tracer masses
4) Reasonable spectra of kinetic energy, temperature and tracers
5) Economical, i.e. no more expensive than current methods of choice for comparable quality solution.

Since frictional heating occurs on scales well below the truncation limit, 3) and 4) imply a fixer will most certainly be needed. The fixer should probably be applied on the parameterization grid since that is the space where interactions with the other climate system components occur and horizontal re-mappings might affect conservation. Although therefore associated with parameterizations, it should be active in adiabatic runs as well.

Dynamical Core

CAM will likely use a new global dynamical core, not the FV core. One low risk option is the HOMME spectral element core on a cubed sphere.

Another option which is expected to be available in the CAM framework will be the hydrostatic version of MPAS developed by Skamarock (MMM), Klemp (MMM) and Ringler (LANL). There are DOE-efforts to integrate MPAS into CAM. This dynamical core is based on the icosahedral spherical grid. The MPAS group is developing the hydrostatic core as a step towards a full non-hydrostatic core with static mesh-refinement. A third option will be the FV Cubed Sphere core being tested by DOE LLNL.

If any other dynamical core is integrated into the CAM framework it should be considered. For example, there has been some work with the ULAG stretched non-hydrostatic core coupled with CAM physics. Consideration of a dynamical core requires a comparable simulation. Comparable defined by standard test cases, aqua-planet simulations and earth-like simulations with identical parameterization suite to control model.

Do we need a non-hydrostatic core in CAM during this development period? The need for non-hydrostatic dynamics seems far off, not until grids pacings go well below 10km

Several aspects of the physical parameterizations could be improved to better interface with the dynamics:

- Total energy is not treated consistently in CAM
- There are still A and B pressure coefficient dependencies on the physics side in CAM. The CAM physics should be versatile in the sense that any vertical coordinate should be accommodated in CAM without having to modify physics routines.
- Should we separate the dynamics and physics grid?
- Should pressure be kept constant during the physics updates? Is there a cleaner way of including the effect of moisture on the pressure field other than the current “fix” approach? Should other water variables be included in the pressure as we move towards higher resolution? Should we have all mixing ratios based on dry air instead of the mix of
dry and wet that we are using now? We need to assess whether this is important before putting a significant effort into the infrastructure.

- The Single Column Model (SCAM) should use the same dynamic core (i.e., vertical advection) as CAM.
- Develop a capability for a doubly periodic dynamics driver for idealized experiments (e.g. like a CRM).

**Gravity Waves**

At resolution of 0.5 – 1 degrees, gravity waves will have to keep on being parameterized. Current schemes will have to be adjusted – certainly more significantly if we go down to 0.1 degrees, which will be boarder line for some sources.

At 0.1deg (10km) we could potentially resolve most GWs HOWEVER we won't be resolving their sources and they will obey hydrostatic dynamics, so the GWs won't be what they are in the real world. This is in particular an issue for convection - until the convective towers themselves are resolved (at ~ 1km) resolution, the GWs produced won't be what they should be - the GWs respond to the forcing so if the scales (spatial and temporal) of the resolved forcing are larger than in reality, the GWs will also be not quite right. Fronts are generally resolved quite well at ~ 10km so for that source 0.1 deg CAM might be OK for a first guess.

As model resolution increases a good fraction of orographic GW may be pretty well resolved, on the other hand convective GW will likely continue to be misrepresented due to the problems in both resolved and parameterized convective heating. Existing high resolution runs and analyses, e.g. MERRA, also show lots of variability that is not clearly tied to either convection or orography – and not to fronts (at least not surface fronts). Is this something we have been missing? Is it wrong?

Another question that arises in connection with GWP as well as other physics at high resolutions, is whether it is a problem to localize their effects in single columns or single time steps.

**Moist Physics**

Science Goals: Parameterization suite:

1) Conservation of energy and tracer masses
2) Tracer mass changes included in atmospheric continuity equation
3) Option to provide either updated states (time split) or forcing terms (process split) to dynamical core.

**Sub-Columns**

Science Goals:
Consistent treatment of moisture variability from vapor through condensate (clouds) to precipitation and radiation.

A sub-column generator would resolve sub-grid variability. By permitting uniform sub-columns, we could better drive physics parameterizations at different resolutions. Carefully treating sub-grid variability across the range of relevant scales is the only sensible way to make the parameterizations scale-independent, which is the key for the seamless prediction across scales in both mesoscale and global models. It would also allow us to implement physical parameterizations driven by explicit dynamics (vertical velocities) into CAM in a more physically consistent and robust way.

The overall desire is to extend the climate preserving energy and mass balance framework into ‘cloud permitting’ scales typical of mesoscale models. Currently there are several different sets of physical parameterizations (‘physics’) used in NCAR community models, specifically the Weather Research and Forecast (WRF) mesoscale model and CCSM/CAM. To a great extent, these parameterization sets have been developed independently, but in several cases there exist parallel developments and similar frameworks (for example for cloud microphysics).

The steps to achieve this seamless prediction are several. They include (a) software engineering and model architecture issues, (b) deriving numerical solutions/methods for solving the sub-grid physics in a computationally feasible way and (c) determining actual sub-grid distribution functions and their horizontal and vertical correlations through observations and high-resolution cloud models. These larger tasks (especially c) are activities for the parameterization community as a whole.

Note that a limiting case of using a detailed sub-column approach is the super-parameterization or multiscale modeling framework (MMF). We will endeavor to permit this within the framework of CAM.

Current Efforts: Unfunded plans for a sub-column generator. MMF integration though CMMAP and/or PNNL. Ghan is supporting someone at PNNL to (maybe) implement MMF in an up to date CAM version.

Cloud Closure

It is highly likely that the cloud fraction (macrophysics) will evolve further using some sort of PDFs and a sub-column generator as noted above. These efforts are parallel. Different closure approaches can be used in the same sub-column architecture, if it is flexible.

Current efforts: Park/Caldwell/Klein et al are working on this unified macrophysics scheme with Peter Caldwell/Steve Klein. One of the important issues on the treatment of sub-grid scale cloud processes is ‘consistency’ across the whole physical processes. For example, our future unified cloud macrophysics will assume a certain (Gaussian) PDF of qt: the same consistent assumption should be used in cloud microphysics, radiation, etc. The same assumption of vertical overlap of cloud (cumulus and stratus) should be used in all cloud macrophysics, microphysics, wet deposition of aerosol, and radiation. This cloud overlap issue is related with too much moisture in the tropics we have.
Morrison/Gettelman are working with Larson on implementing CLUBB into CAM, and developing the overall framework.

**Microphysics**

Science Goals:

- Low cloud feedbacks and Aerosol-Cloud Interactions. Understanding them requires improved representation of coupling between microphysics, aerosols, radiation, and sub-grid scale dynamics.

- Precipitation is a critical aspect of climate and weather extremes and has significant non-linear effects in the coupled system (e.g. on floods, droughts). Getting moments beyond the mean precipitation mass correct (precipitation rates, extremes, timing, distribution) is a critical component of getting important climate variables correct.

- Higher resolutions require a more consistent treatment of clouds and precipitation. At larger scales, bulk mass properties are sufficient to constrain the results. This may become less true at smaller scales, and does not constrain extremes.

The basic physics direction will continue to include 2-moment microphysics. The option will exist however to expand the treatment of microphysics with more detailed schemes typically developed for mesoscale models (e.g.: Thompson scheme). We expect to add prognostic precipitation to the current microphysics to meet some of the goals above.

Additions to the ice nucleation scheme (and possibly droplet nucleation) will be explored, possibly using codes from Nenes et al.

In order to achieve the goals of better understanding aerosol effects, we will complete the budget of aerosols and cloud drops so a better scavenging formulation can be built (will need community support for this).

**Current efforts:** Plans by Gettelman/Morrison to extend current Morrison microphysics and test Thompson microphysics. Also Gettelman/Chen/Liu/Nenes effort to put Nenes ice nucleation into CAM.

**Atmospheric Boundary Layer**

Continue to use a moist boundary layer (Bretherton and Park). Continuously improve the UW moist turbulence scheme and enhance feedback and consistency with the other physics schemes. Some additional improvements we are thinking are: (1) refined treatment of TKE transport, (2) exploration of prognostic TKE scheme instead of diagnostic TKE, (3) TKE-based entrainment closure instead of wstar-based entrainment closure, (4) refinement of merging process, (5) more refined treatment of turbulent transport of cloud droplet number concentration, and (6) computation of variance and/or covariance statistics for application to the future cloud macrophysics.

Represent the direct interaction of deep convective downdrafts on the TKE of the PBL, such that it may work as a positive feedback to convection at least dynamically?
In addition, planned work includes (1) allowing some turbulences in a very stable regime (Ri > 0.19), (2) improving the formulation of turbulent mountain stress (Park).

In parallel, we will also further develop the KPP PBL to be consistent with moist physics and thus work effectively across the range of atmospheric stability regimes, i.e. Richardson Numbers.

**Convective motions/Parameterization**

**Science Goals**

- Better representation of moist convection at various scales to get key modes of variability correct (e.g.: Organization on the mesoscale, MJO scales)
- Better statistics for timing and intensity of precipitation
- Consistency with stratiform microphysics, aerosol cloud interactions.

Start with more tweaks to ZM (organization variable from Neale/Mapes).

Ultimately ZM could become one of a subset of ways for calculating the convective instability and closure in the model.

ZM may be a good start, but at some point that has to be replaced with something that's in large part developed in house. It might be a good time to at least try to build something in-house as the ZM scheme is really tedious to work with. Even if we keep some of ZM’s ideas, maybe the convection param could be re-written to be more modular, so certain components of the parameterization could easily be worked on. There are several in-house developments.

Organization (Neale/Mapes), a new unified scheme from Park.

A single unified convection scheme should address the following issues: (1) we should use one single convection scheme, not the separate ‘shallow’ and ‘deep’ and should be compatible with the small-scale turbulent scheme (PBL) (2) should address other relevant issues in the current convection schemes (e.g., unified treatment of dry and moist convection, free and forced convection, convective updraft and downdraft), (3) should have more elegant cumulus microphysics that can handle aerosol indirect effect, (4) ideally, should be applicable in all the resolutions and (5) also be should be prognostic. Convection scheme is related to the MJO, diurnal cycle of precipitation, and many other issues. Including meso-scale organization is likely to be a key component for developing a unified convection scheme. I have been working on developing this kind of unified scheme, and now have an experimental version. But further works are required in closing the scheme (e.g., estimation of plume radius and parameterization of meso-scale organization). We should also explore other approaches, if any. AMP should work together with some collaborations with external people (Brian Mapes, Chris Bretherton, etc.).

We should develop in-model modularity for calculating organization, statistical perturbations, microphysics and sub-grid scale states (sub-columns) independently of the 1-D calculations of convective instability and closures. Ultimately, there won’t really be a self-contained convection scheme, but instead a collection of convection relevant processes and calculations.
Chemistry/Aerosols

Science Goals:

- Representation of chemistry-climate interactions with consistent chemistry, radiation and scavenging
- Representation of aerosol-cloud interactions and the complete aerosol lifecycle (production through scavenging).

CAM will likely maintain the same radiation code and aerosol radiation interface. The interface may require further evolution that was not completed in time for CAM4. This includes a complete and flexible diagnostic radiation computation. This as a tactical improvement in CAM

Inclusion of a sub-column generator will simplify the radiation interface and allow for better reproducability

CAM will also continue to use the PNNL modal aerosol code.

CAM can be run with MOZART+ chemistry.

We clearly need a prescribed aerosol mode for CAM not only for efficiency, but also because of the large science uncertainties in processes like scavenging. We need to be able to easily cut the chain of feedbacks at some point (or several). This is in process

Radiation

Science Goal:

- State of the art consistent representation of atmospheric radiative transfer for gas phase and condensed species in a flexible and reproducible framework

1) Separation of the specification of atmospheric state from the radiation.
   A.) separate sub-grid variability from radiation
      i) clouds (ice, water, other)
      ii) hydrometeors (rain, snow, graupel?)
      iii) water vapor sub-grid variability?
      iv) aerosols sub-grid?
      v) clarification of various cloud fractions
   B.) microphysical composition separated from optical characterization
   C.) multiple diagnostic calls based on different compositions
   D.) clarification of time stepping for radiation

2) Ability to output composition, thermodynamic, surface, and microphysical states along with subgrid variability specifications for offline radiative transfer computations.

3) Development of an offline radiative transfer scheme for
   A) Cam-style radiative forcing computation
   B) IPCC-style radiative forcing
4) Improve RT through the layer of the atmosphere between model top and space.

5) Maintain state of the art radiation code by using current versions of RRTMG from AER.

6) Provide a single subcolumn specification that can be queried by radiation, transport, cloud/aerosol, and diagnostic models.

7) Remove any physical characterization of aerosols from the radiation interface. (Radiation does not care about the hygroscopicity of sulfate, but it does care about mass, size distribution, and mixtures of the aerosols.) Even more importantly, radiation should not be responsible for providing data (such as "dry number mode radius of aerosol") to other portions of the code.

Other Components

Data assimilation: assume we are propagating CAPT and DART forward. Can we better use these systems for testing and evaluation. Beyond SCAM? Also we need to engage with the requirements from the surface components (and WACCM!) to understand what their requirements will be in the short and long term.

Should we develop a “replay” (i.e. nudging to analysis) configuration? Flexible and easy to implement – complements CAPT framework, but can also applied to extended coupled atmosphere-ocean runs for example. This mode (called ‘specified dynamics’ or SD) has already been developed for WACCM use.

Should we develop simple, limited-area, or idealized e.g. doubly periodic geometries for CAM. These could be used for testing purposes- e.g. how do convection statistics change with parameterization changes in a warm pool-like regime

Background and Environment

Where are other modeling groups going? We should collect what we know about the other major groups to ensure that our science is relevant.

Current model has modal aerosols, 2-moment microphysics (and aerosol-cloud interactions), conservative transport, moist boundary layer, RRTM radiation code and chemistry options. What other parameterizations are we lacking to remain ‘state of the art’ for 2013?

What is the direction for WRF? Where will be relative to WRF in 3 years if this plan is enacted? This would be important to know as to get the gravity wave problem right, it would be helpful to run a global WRF and then use what we have learnt to parameterize waves in CAM.
Other Climate Centers?

- MetOffice Hadley Center: Where is UM model going?
- ECHAM: Lohmann Microphysics, Stier Aerosols
- GFDL: AM4 is working on CLUBB
- Others we want to discuss with?