

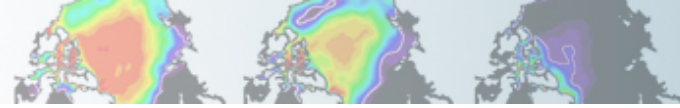
CESM Tutorial

CAM Physics:

Interfacing a parameterization

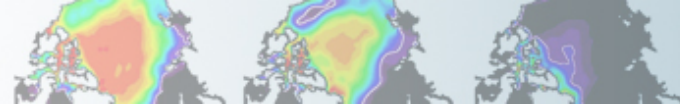
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National Center for Atmospheric Research (NCAR)



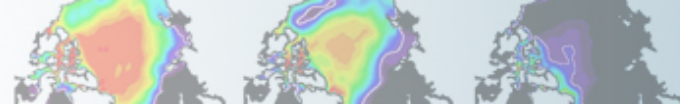
Outline of this presentation

- What is an interface
 - in theory
 - in CAM
- Model structure related to CAM physics
- Example of physics parameterization interface: `convect_deep`
- Physics Utilities
 - user defined (derived) types or structures:
 `physics_state`, `physics_ptend`
 - `chunks`, `cols`
 - `constants`
 - `phys_control`
 - `constituents`
 - `physics buffer`
 - `surface exchange types`
 - simpler ways to run CAM



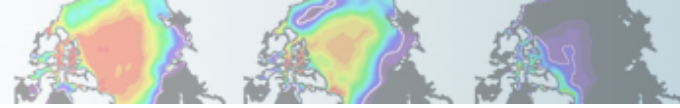
Physics Interface Design

- <http://www.cesm.ucar.edu/models/atm-cam/docs/phys-interface/>
- It is old* so some details have changed but the fundamental design still applies
 - *2002; going to be updated... someday
- Reference for coding standards: Kalnay, E., M. Kanamitsu, J. Pfaendtner, J. Sela, M. Suarez, J. stackpole, J. Tuccillo, L. Umscheid, and D. Williamson, 1989: Rules for Interchange of Physics Parameterizations. Bull. Am. Met. Soc., 70(6), 620-622



Why an interface?

- 1) Make parameterization 'play nice' with the model (required)
- 2) Make parameterization portable between models (recommended)



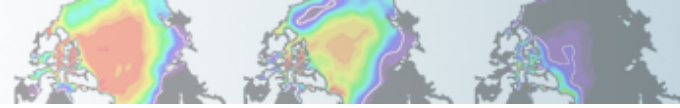
Interfacing Requirements

‘play nice’ with the model

A physics parameterization

1. Must calculate a tendency (rate of change)
2. Must not change the model state
3. Must conserve vertical integrals of
 1. mass
 2. momentum
 3. total energy
 4. dry static energy

The physics package in CAM takes the tendencies from parameterizations and calculates the new state while checking energy and water balances.

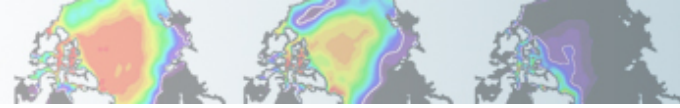


Interfacing recommendation **portability** between models **and different versions of the same model**

The parameterization should consist of two parts:

1. An interface layer to communicate between CAM and the parameterization
2. The parameterization package, with as little of CAM structures in it as possible

This is more likely to make a parameterization which is portable between different models or model versions.

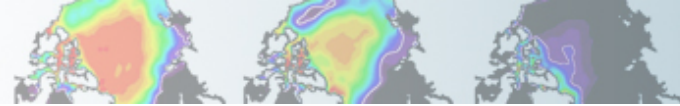


What is an interface in CAM?

A fortran **module** containing a **set of methods** (subroutines or functions) called by CAM's physics driver which calls methods in the parameterization module(s). Also applies to chemistry parameterizations.

The public methods of a CAM interface (PARAM = generic parameterization) . See online document for details (Utility Modules section); browse code for examples.

- PARAM_register
 - This method is for registering fields that are managed by the physics buffer module, and for registering constituents in the constituent arrays.
- PARAM_implements_cnst
 - A query method which returns true if the requested constituent name is implemented by the package.
- PARAM_init_cnst
 - A package that manages constituents is responsible for initializing the constituent mixing
- PARAM_init
 - This method is for package specific initialization including setting time-invariant constants, specifying fields to be included in the history files, and opening datasets.
- PARAM_timestep_init
 - This method is for per-timestep initialization, (e.g. time interpolation from a boundary dataset.
- PARAM_timestep_tend
 - This method calls the package run method which computes the one step tendencies.

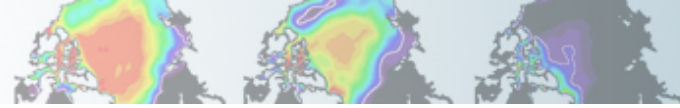


Model structure: CAM's interface

The top-level of CAM interfaces to the coupled model:
models/atm/cam/src/control/cam_comp.F90:

```
subroutine cam_init:  
  call initindx  
  call phys_init  
subroutine cam_run1(cam_in, cam_out)  
  ! Runs first phase of dynamics and first phase of  
  ! physics (before surface model updates).  
  call stepon_run1  
  call phys_run1  
subroutine cam_run2( cam_out, cam_in )  
  ! Run the second phase physics, run methods that  
  ! require the surface model updates. And run the  
  ! second phase of dynamics that at least couples  
  ! between physics to dynamics.  
  call phys_run2  
  call stepon_run2
```

The diagram illustrates the control flow from the CAM interface to the underlying physics and dynamics sub-models. Blue arrows labeled 'dynamics' point to the following code elements: `initindx`, `stepon_run1`, and `stepon_run2`. Red arrows labeled 'physics' point to the following code elements: `phys_init`, `phys_run1`, and `phys_run2`.



Model structure: CAM physics

- CAM defines **'physics'** as processes that are done in the vertical column without horizontal communication.
- The physics processes are divided between those that happen before and after coupling with the component models and

```
physpkg.F90
```

```
  registration: <calls to subroutines>
```

```
  initialization:
```

```
    subroutine phys_inidat
```

```
    subroutine phys_init
```

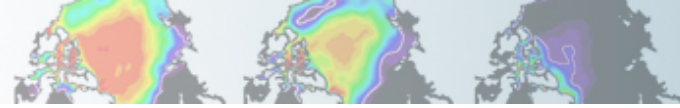
```
  timestepping:
```

```
    subroutine phys_run1: call tphysbc
```

```
    subroutine phys_run2: call tphysac
```

before coupling

after coupling



Model structure: CAM physics

CAM defines **'physics'** (vs 'dynamics') as processes that are done in the vertical column without horizontal communication. Module physpkg calls tphysbc and tphysac; in these modules you can see everything included in physics.

```
grep call /home/s07hsu00/cesm_collection/cesm1_0_3/models/atm/cam/src/physics/cam/tphys*c.F90
(edited)
```

tphysbc

before coupling

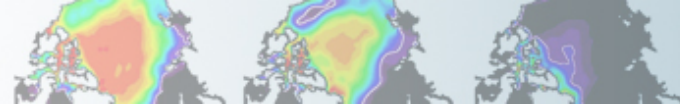
```
call convect_deep_tend( prec_zmc, ...
call convect_shallow_tend( ztodt ...
call stratiform_tend(state, ptend, ...
call macrop_driver_tend(state, ptend, ...
call microp_driver_tend(state, ptend, ...
call aerosol_wet_intr( state, ptend, ...
call convect_deep_tend_2( state, ptend, ...
call radiation_tend(state, ptend, pbuf, ...
```

tphysac

after coupling

```
call aerosol_emis_intr( state, ptend, ...
call tracers_timestep_tend(state, ptend, ...
call aoa_tracers_timestep_tend(state, ptend, ...
call chem_timestep_tend(state, ptend, cam_in, ...
call vertical_diffusion_tend( ztodt, state, ...
call rayleigh_friction_tend( ztodt, state, ptend)
call aerosol_drydep_intr( state, ptend, ztodt, &
call qbo_relax(state, ptend, state%uzm)
call iondrag_calc( lchnk, ncol, state, ptend, pbuf
call iondrag_calc( lchnk, ncol, state, ptend, pbuf
```

These calls are to methods in parameterization interfaces



Example of an interface

Deep convection interface (registration and initialization)

Interface = models/atm/cam/src/physics/cam/convect_deep.F90 methods call:

Parameterization/ package: zm_conv.F90 (Zhang-Macfarlane)

1. Registration (allocates memory)

```
initindx.F90:      call convect_deep_register
```

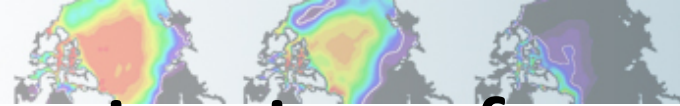
```
convect_deep.F90: subroutine convect_deep_register  
                  call zm_conv_register
```

2. Initialization (done once at the beginning of model run or restart)

```
physpkg.F90:      call convect_deep_init
```

```
convect_deep.F90: subroutine convect_deep_init  
                  call zm_conv_init
```

physpkg doesn't know anything about the deep convection package, so a new parameterization could be swapped in. Also, higher level changes in the model shouldn't touch zm_conv.F90; just convect_deep.F90



Ex. Deep convection interface (time-stepping)

3. Time-stepping (as the model is running)

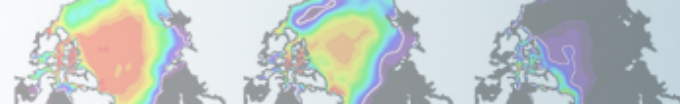
tphysbc.F90:

```
call convect_deep_tend(state, ptend,...)
call physics_update(state, ptend,...)
call check_energy_chng
```

The physics package gets the tendencies from the convection interface, calculates the new state and checks that energy and water were conserved.

```
convect_deep.F90: subroutine convect_deep_tend(state, ptend,...)
  intent(in) state
  intent(out) ptend
  ptend%name = "convect_deep"
  call zm_conv_tend(.. state , ptend ...)
```

The interface can only modify tend, not state. It calls the parameterization method



physics_types.F90

~/cesm_collection/cesm1_0_3/models/atm/cam/src/physics/cam/physics_types.F90

```
module physics_types
```

```
! Public types:
```

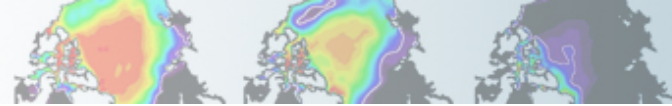
```
public physics_state  
public physics_tend  
public physics_ptend
```

User-derived types (structures): state & ptend are shown on next page

```
! Public interfaces
```

```
public physics_update  
public physics_ptend_reset  
public physics_ptend_init  
public physics_state_set_grid  
public physics_dme_adjust ! adjust dry mass and energy for change in water  
! cannot be applied to eul or sld dycores  
public physics_state_copy ! copy a state type  
public physics_ptend_sum ! add 2 ptend types  
public physics_tend_init ! initialize a tend type
```

Subroutines that are used by physpkg and physics parameterizations



Data structures: physics_state

defined in models/atm/cam/src/physics/cam/physics_types.F90

```
type physics_state
```

```
integer ::&
```

```
    lchnk, &! chunk index
```

```
    ncol ! Number of columns
```

```
real(r8) ::&
```

```
    calday ! calendar day at end of current timestep
```

```
    real(r8), dimension(pcols) ::&
```

```
        lat, &! latitude (radians)
```

```
        lon, &! longitude (radians)
```

```
        ps, &! surface pressure (Pa)
```

```
        phis ! surface geopotential
```

```
real(r8), dimension(pcols,pver) ::&
```

```
    t, &! temperature (K)
```

```
    u, &! zonal velocity (m/s)
```

```
    v, &! meridional velocity (m/s)
```

```
    dse, &! dry static energy (J/kg)
```

```
    omega, &! vertical velocity (Pa/s)
```

```
    pmid, &! pressure at midpoints (Pa)
```

```
    pdel, &! pdel(k) = pint(k+1) - pint(k)
```

```
    rpdel, &! 1./pdel(k)
```

```
    lnpmid, &! ln(pmid)
```

```
    zm, &! geopotential height above surface, at midpoint (m)
```

```
    exner ! inverse exner func w.r.t. surface pressure (ps/p)^(R/cp)
```

```
real(r8), dimension(pcols,pver+1) ::&
```

```
    pint, &! pressure at interface (Pa)
```

e.g.

```
subroutine convect_deep_tend(..., state,...
```

use physics_types, only: physics_state

```
type(physics_state), intent(in) :: state
```

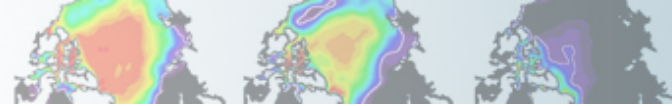
```
lchnk = state%lchnk
```

```
ncol = state%ncol
```

```
temp = state%t(:ncol,:)
```

Declare dummy variable named 'state',
of type physics_state.

Intent(in) means it cannot be modified
by the subroutine



Data structures: physics_ptend

(parameterization tendency)

defined in models/atm/cam/src/physics/cam/physics_types.F90

type physics_ptend

character*24 :: name ! name of parameterization which produced tendencies.

logical :: &

ls, &! true if dsdt is returned
 lu, &! true if dudt is returned
 lv, &! true if dvdt is returned
 lq(pcnst) ! true if dqdt() is returned

integer :: &

top_level, &! top level index for which nonzero tendencies
 bot_level ! bottom level index for which nonzero tendencies

real(r8), dimension(pcols,pver) :: &

s, &! heating rate (J/kg/s)
 u, &! u momentum tendency (m/s/s)
 v ! v momentum tendency (m/s/s)

real(r8), dimension(pcols,pver,pcnst) :: &

q ! constituent tendencies (kg/kg/s)

! boundary fluxes

real(r8), dimension(pcols) ::&

hflux_srf, &! net heat flux at surface (W/m2)
 hflux_top, &! net heat flux at top of model (W/m2)
 tau_x_srf, &! net zonal stress at surface (Pa)
 tau_x_top, &! net zonal stress at top of model (Pa)
 tau_y_srf, &! net meridional stress at surface (Pa)
 tau_y_top ! net meridional stress at top of model (Pa)

real(r8), dimension(pcols,pcnst) ::&

cflx_srf, &! constituent flux at surface (kg/m2/s)

e.g.

subroutine convect_deep_tend(..., ptend,...

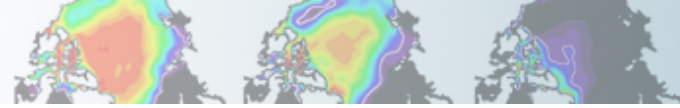
use physics_types, only: physics_ptend

type(physics_ptend), intent(out) :: ptend

ptend(:ncol,:) = new_tendency(:ncol,:)

Declare dummy variable named 'ptend',
of type physics_ptend.

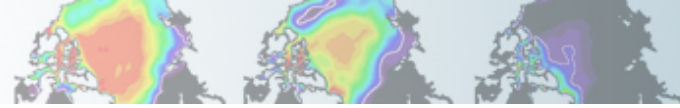
Intent(out) means it can be modified
by the subroutine and is set to zero at the
beginning.



Data structures: chunks

The fundamental data structure used by the physics driver contains an arbitrary collection of vertical columns, and is referred to as a **chunk**.

- There are no assumptions about the horizontal location of the columns, e.g., they are not necessarily neighbors in the global grid.)
- the module **phys_grid.F90** provides query functions that return
 - the number of columns in each chunk
 - latitude, longitude coordinates of the individual columns in a chunk.
- SPMD parallelism is done over the chunk dimension
- A single call to either `tphysbc` or `tphysac` passes only **a single chunk** of the decomposed physics grid
- The data on a chunk is a variable of a derived type (structure) that contains multiple fields



CAM Array Dimensions

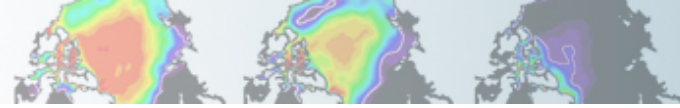
Physics

- `pcols` = `PCOLS`, &! maximum number of columns in a chunk
- `pver` = `PLEV`, &! number of vertical levels
- `pcnst` = `PCNST`, &! number of advected constituents (including water vapor)
- `ppcnst` = `PCNST`+`PNATS` ! number of constituents operated on by physics

Dynamics

- `plon` = `PLON`, &! number of longitudes in the global dynamics grid
- `plev` = `PLEV`, &! number of levels in the global dynamics grid
- `plat` = `PLAT`, &! number of latitudes in the global dynamics grid

Note that currently CAM uses the same number of vertical levels in both the dynamics (`PLEV`) and physics (`PVER`) grid but it doesn't have to.



Utility modules

- **Physical constants: shr_const_mod module**

```
real(r8), parameter ::&
```

```
  r_universal = 6.02214e26*1.38065e-23, &! Universal gas constant (J/K/kmol)
```

```
  mwdry = 28.966, &! molecular weight dry air
```

```
  mwco2 = 44., &! molecular weight co2
```

```
  ...
```

- **phys_control.F90**

```
public :: &
```

```
  phys_ctl_readnl, &! read namelist from file
```

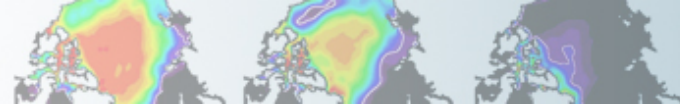
```
  phys_getopts, &! generic query method
```

```
  phys_deepconv_pbl, &! return true if deep convection is allowed in the PBL
```

```
  phys_do_flux_avg, &! return true to average surface fluxes
```

```
  cam_physpkg_is, &! query for the name of the physics package
```

```
  cam_chempkg_is ! query for the name of the chemistry package
```

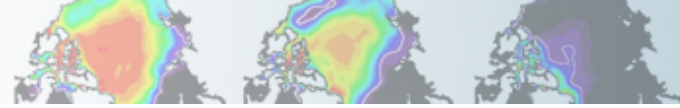


Constituents

The constituents module is responsible for managing the names and physical properties of all trace constituents in a model run.

- It assigns the index values in the constituent arrays,
- keeps track of whether or not the initial values of each constituent are to be read from the initial file.

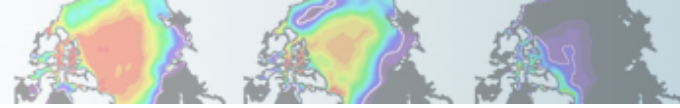
The packages that implement constituents (e.g., chemistry packages) are responsible for registering the names and properties of the constituents with the constituents module, which can then make these values known to other packages that require them



Physics buffer

The module `phys_buffer` manages the physics buffer which stores fields

- that must be available across timesteps
 - automatically writes fields to the restart files
- OR that must be shared between physics packages
 - avoids passing the field through subroutine argument list from one parameterization up to `tphys*c` and back down to another parameterization
- Complicated format, follow an example in the code!
 - `pbuf_register`
 - `pbuf_add('fld_name',scope, fdim, mdim, ldim, index)`
 - `fld_idx = pbuf_get_fld_idx('fld_name')`
 - `fld => pbuf(fld_idx%fld_ptrfield(fdim,pcols,mdim,begchunk:endchunk,ldim)`



surface exchange types

```
> cd /home/s07hsu00/cesm_collection/cesm1_0_3/models/atm/cam/src/physics/cam
```

```
> less physpkg.F90
```

```
use camsrfexch_types, only: cam_out_t, cam_in_t
```

```
> cd /work/s07hsu31/cesm_run/case01/atm/obj
```

```
> ~s07hsu00/findccm camsrfexch_types.F90
```

```
12 directories
```

```
/home/s07hsu00/cesm_collection/cesm1_0_3/models/atm/cam/src/control
```

```
> less /home/s07hsu00/cesm_collection/cesm1_0_3/models/atm/cam/src/control/camsrfexch_types.F90
```

```
public cam_out_t      ! Data from atmosphere
```

```
public cam_in_t       ! Merged surface data
```

```
!-----
```

```
! This is the data that is sent from the atmosphere to the surface models
```

```
!-----
```

```
type cam_out_t
```

```
integer :: lchnk      ! chunk index
```

```
integer :: ncol       ! number of columns in chunk
```

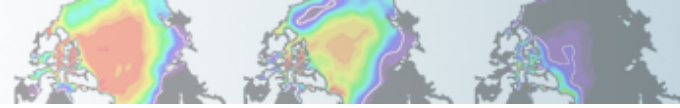
```
real(r8) :: tbot(pcols) ! bot level temperature
```

```
real(r8) :: zbot(pcols) ! bot level height above surface
```

```
real(r8) :: ubot(pcols) ! bot level u wind
```

```
real(r8) :: vbot(pcols) ! bot level v wind
```

```
real(r8) :: qbot(pcols,pcnst) ! bot level specific humidity
```



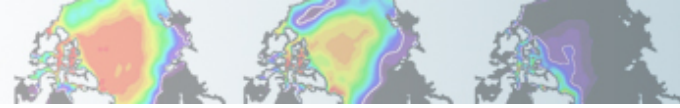
Stand-alone and Single-Column CAM

- Users who are developing CAM might be interested in using the stand-alone CAM configure/run instead of dealing with the entire CESM structure

```
cesm_collection/cesm1_0_3/models/atm/cam/bld> ls
```

```
build-namelist  configure  run-pc.csh      (and more)
```

- Single-column CAM is a good tool for developing physics parameterizations
 - no dynamics
 - runs with field-experiment data
 - ? `cesm_collection/cesm1_0_3/models/atm/cam/bld/run-scaml.csh`



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CESM - General
 The Community Earth System Model (CESM) is a fully coupled, global climate model that provides state-of-the-art computer simulations of the Earth's past, present, and future climate states.

Forum	Topics	Posts	Last post
Announcements	15	39	CESM1_0_5 issues by jedwards March 20, 2013 - 2:14pm
Bug reporting	103	287	problem with... by dbailey February 20, 2013 - 10:41am

Atmospheric Modeling with CAM
 The Community Atmosphere Model (CAM) is the atmosphere model component of the CESM. Information about running CAM as the atmospheric component of the CESM is found in the CESM release documentation. For information on CAM microphysics, visit the CAM Microphysics Development Group. Please see the Whole Atmosphere Community Climate Model Forum and the Climate Chemistry Forum for topic discussions specific to these capabilities of CAM.

Forum	Topics	Posts	Last post
			What is the