

Integration of a Coupled Atmosphere-Ocean Model into the ESMF (Earth System Model Framework)

C. R. Mechoso

Dept. Atmospheric and Oceanic Sciences, UCLA, USA

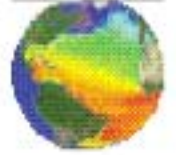
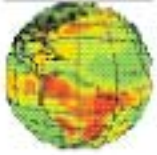
- ***Brief status report on the UCLA ESM project***
- ***A personal view on the process leading to the ESMF development***
- ***The first independent adoption of ESMF technology by UCLA***
- ***Experimental predictions of El Niño/Southern Oscillation***

www.atmos.ucla.edu/~mechoso/esm

CAS2K5 September 11-14 Annecy, France



UCLA



Team Membership

Akio Arakawa (1): AGCM

Cabriel Cazes-Boezio (1, 7): AGCM PBL, Coupled GCM

Chris Hill (3): MIT OGCM

Phil Jones (4): POP

C. Roberto Mechoso (1): P. I.

Dimitris Menemenlis (5): MIT OGCM, ECCO

George Philander (2): Coupled GCM

Joseph A. Spahr (1): ESMF

Shujia Zhou (6): ESMF

(1) *Department of Atmospheric and Oceanic Sciences, University of California Los Angeles*

(2) *Program in Atmospheric and Oceanic Sciences, Princeton University*

(3) *Department of Earth, Atmospheric and Planetary Sciences, MIT*

(4) *Theoretical Fluid Dynamics Group, Los Alamos Natural Laboratory*

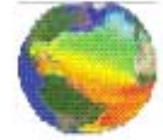
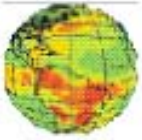
(5) *NASA/Caltech Jet Propulsion Laboratory*

(6) *Software Integration and Visualization Office, NASA GSFC and Northrop Grumman*

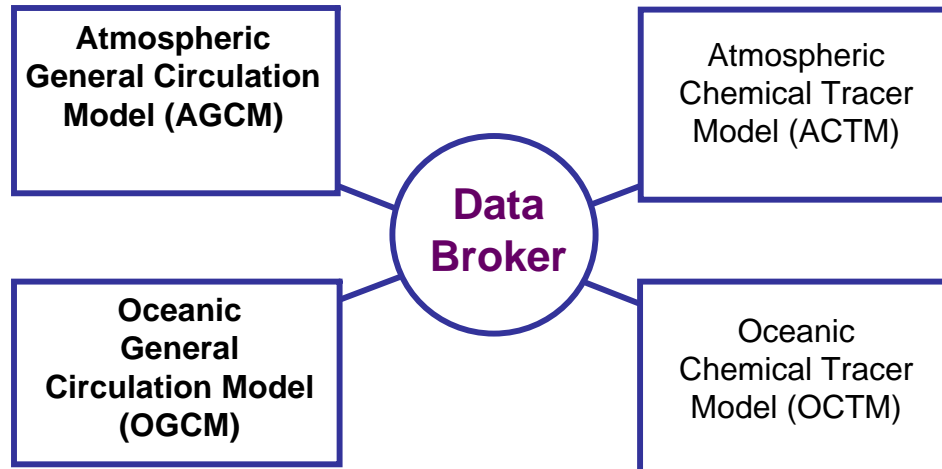
(7) *On leave from Fluid Mechanics and Environmental Engineering Institute, U. of Uruguay*

Sponsor: NASA Earth Science Technology Office (ESTO)





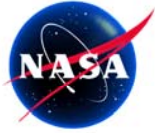
UCLA Earth System Model Project



Model components:

- *UCLA Atmospheric GCM*
- *LANL Parallel Ocean Program (POP)*
- *UCLA ACTM (which can include up to 64 species)*
- *Simple NASA/JPL Ocean Chemical Transport Model*
- *Distributed Data Broker*





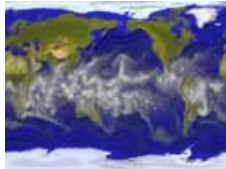
CT Round-3 Investigator Teams

\$22.8M over 3 years

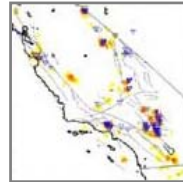
ESTO

Earth Science Technology Office

Core ESMF Framework Development
(T.Killeen/NCAR)



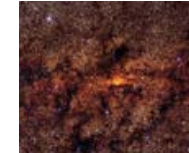
Simulation of Active Tectonic Processes
(A.Donnellan/JPL)



Biotic Prediction
(J.Schnase/GSFC)

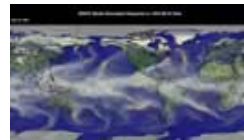


National Virtual Observatory Technology
(T.Prince/Caltech)

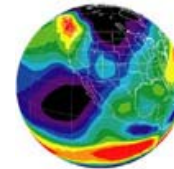


Collaborations to develop software frameworks that enable more realistic simulations of natural phenomena and interpretation of vast quantities of observational data on high-end computers.

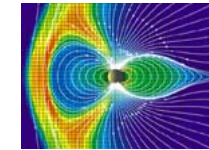
ESMF Data Assimilation Applications
(A.daSilva/GSFC)



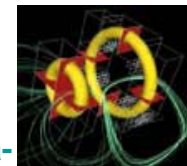
Atmos-Ocean Dynamics and Tracer Transport
(R.Mechoso/UCLA)



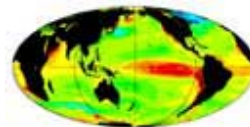
Framework for Space-Weather Modeling
(T.Gombosi/U.Michigan)



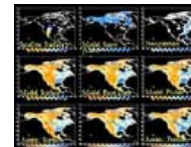
C++ Framework for Block-Structured Adaptive Mesh Refinement Methods
(P.Colella/LBNL)



ESMF Modeling Applications
(J.Marshall/MIT)

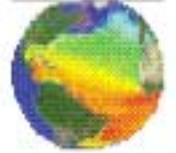
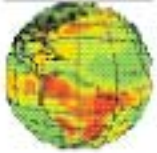


Land Information Systems
(P.Houser/GSFC)



Radiation-Hydro Models of Gamma-Ray Bursts
(P.Saylor/U.Illinois Urbana-Champaign)





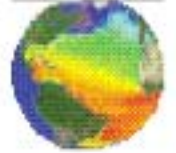
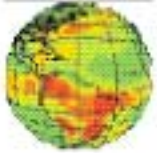
Increasing the Interoperability of an ESM: Atmospheric-Ocean Dynamics and Tracer Transports (NASA NCC4-624)

C. R. Mechoso, PI

Major thrusts of the project:

- to further our understanding of an ability to predict the dynamic interaction of physical and chemical processes affecting Earth
- to incorporate the use of NASA data and highlight its importance
- to demonstrate interoperability of codes used in the community of Earth Science.

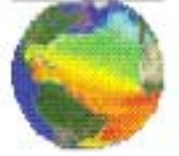
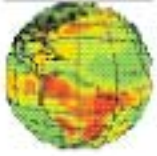




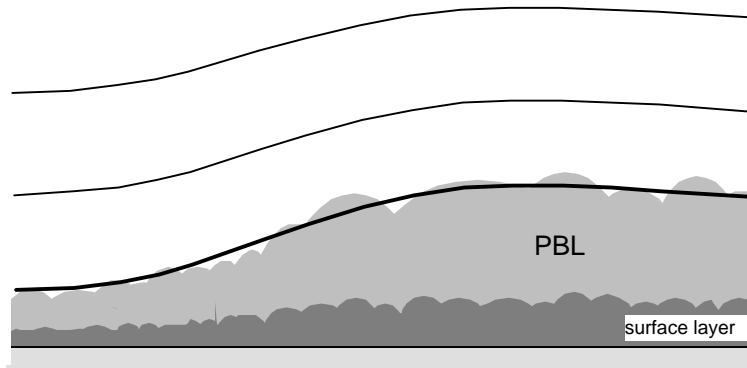
Project Organization

- Tier I: Upgrade the UCLA Earth System Model (ESM). The principal upgrades are in the planetary boundary layer (PBL) parameterization of the AGCM and domain extension of the OGCM. Perform ENSO predictions.
- Tier II: Address issues of code interoperability by using the ESMF services to couple the UCLA AGCM with either LANL POP or the MIT OGCM and by performing forecasts of El Niño/Southern Oscillation (ENSO).
- Tier III: Assess the impact of NASA data by compare ENSO forecasts using initial states provided by JPL's ECCO project (<http://ecco.jpl.nasa.gov>). The MIT OGCM is a component in the ECCO's data assimilation system, while POP is not.

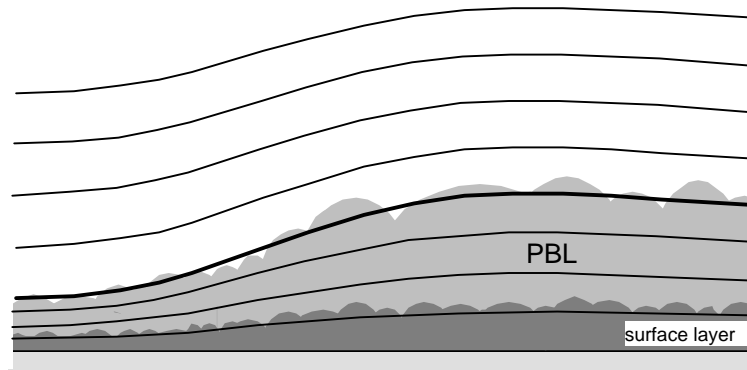




Modeling Focus: PBL in UCLA AGCM



Traditional
Framework
Suarez et al. (1983)

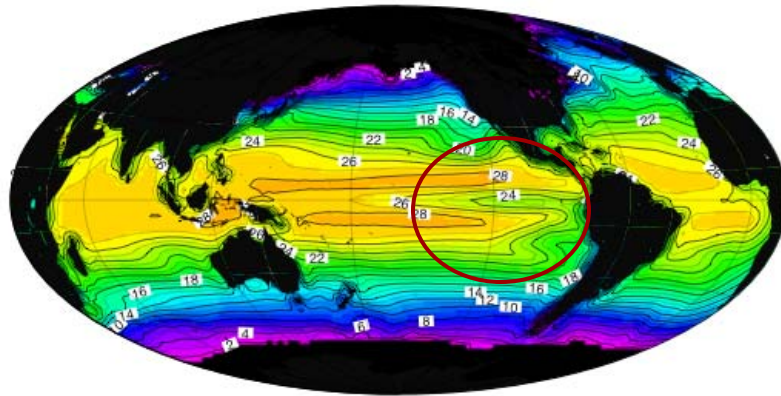


Revised
Framework
Konor and Arakawa (2005)

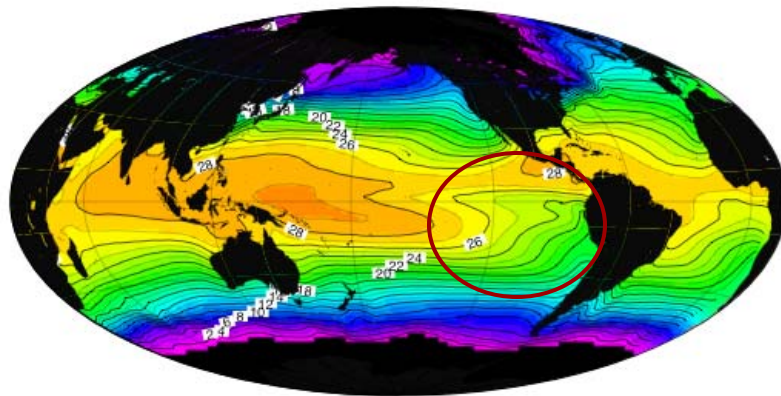


AGCM (low-resol) with Revised PBL Annual Mean SST

UCLA AGCM 6.98, new PBL, coupled with global MIT OGCM



Observation



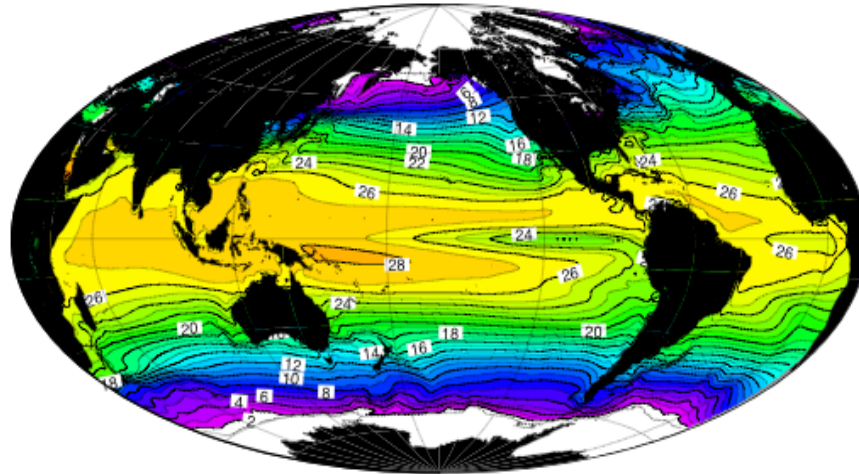
UCLA AGCM - MIT OGCM

“Double ITCZ bias”

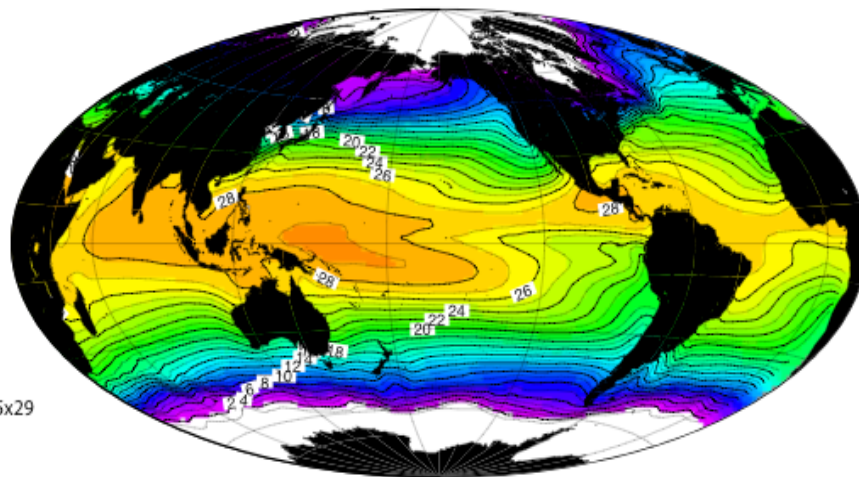
Hypothesis 1: Poor simulation of oceanic heat transport from upwelling regions?

Hypothesis 2: Poor simulation of the zonal circulation, particularly of equatorial winds?

AGCM (high-resol) with Revised PBL Annual Mean SST

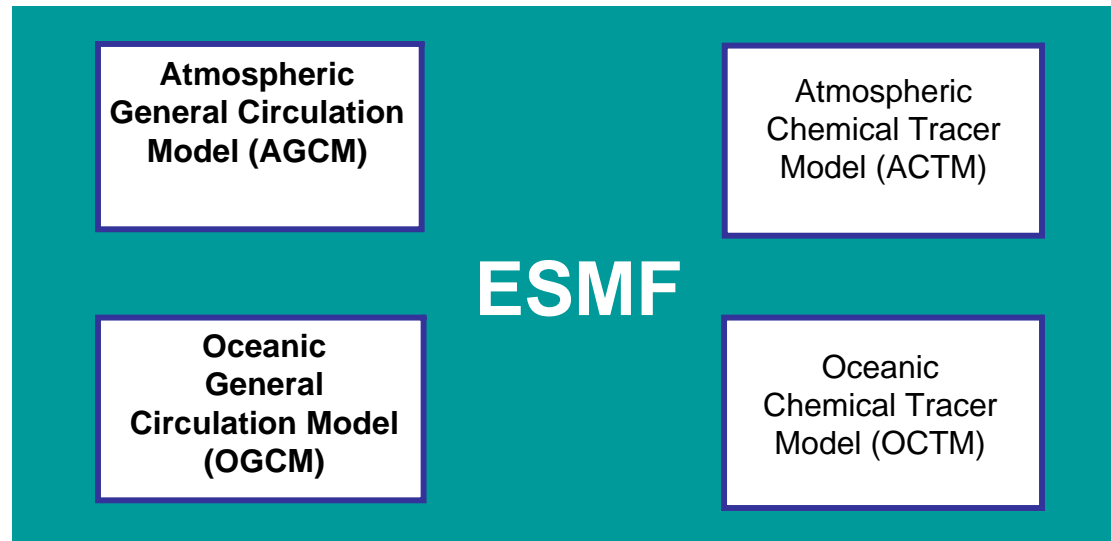
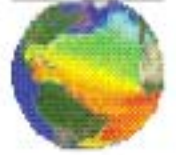
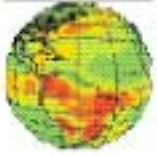


Annual Mean SST: Reynolds analysis



UCLA AGCM 8.0 2x2.5x29
MIT OGCM Global

The “double ITCZ bias” is slightly alleviated by doubling AGCM resolution, which improves equatorial winds

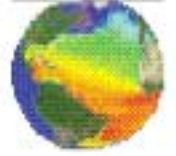
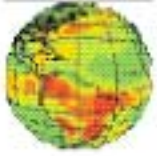


UCLA Earth System Model with ESMF

Model components:

- *UCLA AGCM with upgraded PBL parameterization*
- *LANL Parallel Ocean Program (POP) and MIT OGCM, both in a quasi-global domain with the same grid.*
- *UCLA ACTM (which can include up to 64 species)*
- *Simple NASA/JPL Ocean Chemical Transport Model*



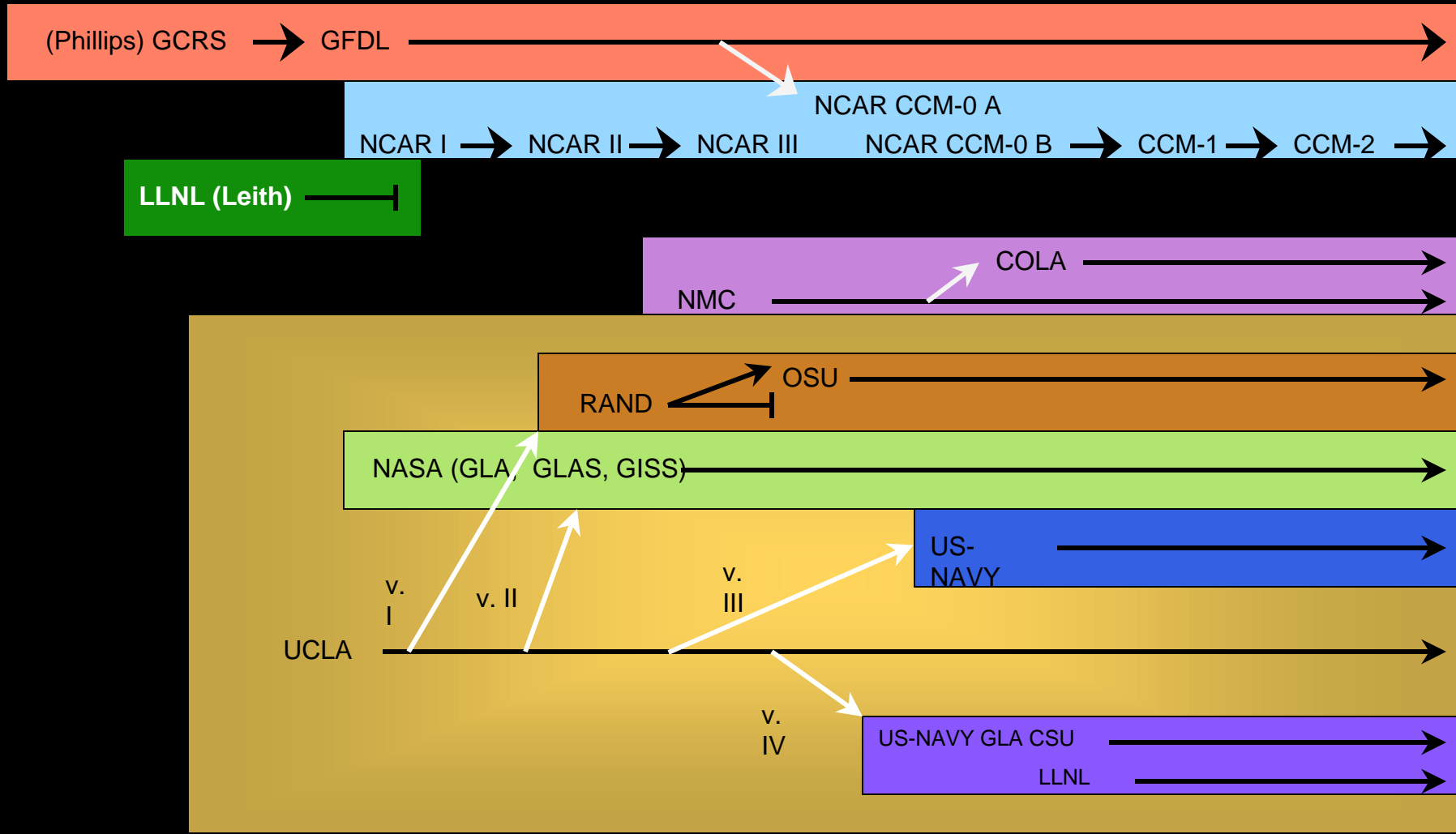




A personal view of the process that motivated the ESMF

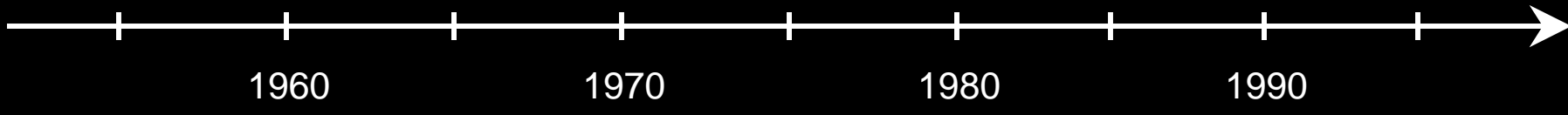
- Atmospheric and Oceanic GCMs have been developed at operational centers, research institutions and universities since the 1950's.
- Advances in computer and communications technology allow for an expansion in the use of GCMs for research, which is no longer restricted to large centers. Many scientific advances are achieved
- It becomes clear in the 1990's that achieving top GCM performance requires large support groups. The ECMWF is often cited as example.
- Since resources are limited, the dilemma arises as to whether GCM development should be confined to a few, well-funded groups.
- In this scenario, traditional university-based groups become just GCM users or contribute to very specific aspects in model development.
- The concept of "many groups developing GCM's", however, is not correct.

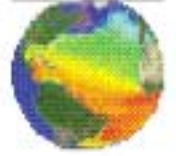
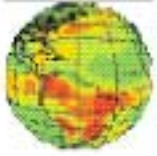


The Family Tree of AGCMs in the US



 Direct line of development
 Direct import or major influence



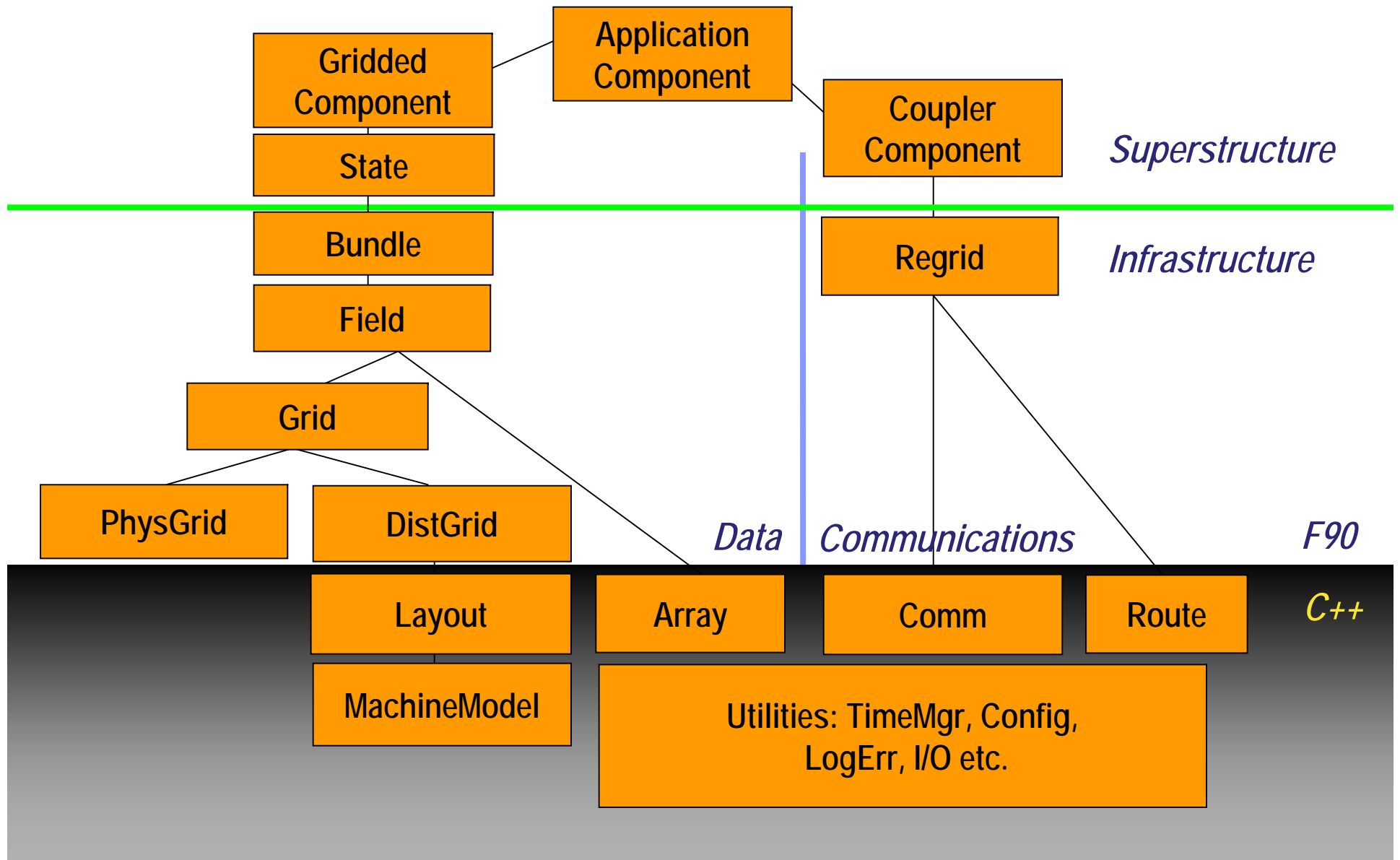


A personal view

- The US National Science Foundation convenes in the mid 1990's a series of grass-root meetings to discuss these issues.
- These meetings propose the development of a "Model Framework." The idea of a "National GCM" is perceived as too restrictive for the large and diverse community in the US.
- Research funding agencies, lead by NASA, start a multi-year, multi-million US dollars program to develop an ESMF
- The ESMF development is performed at three national research centers, lead by NCAR. A university (UCLA) is selected as the first independent adaptor of the new technology.
- At the present time, there is a working version of the ESMF (2.2). The work, however, is only half completed.
- Much has to be done to make the system reliable and user friendly.
- Also, a stable support system has to be established.



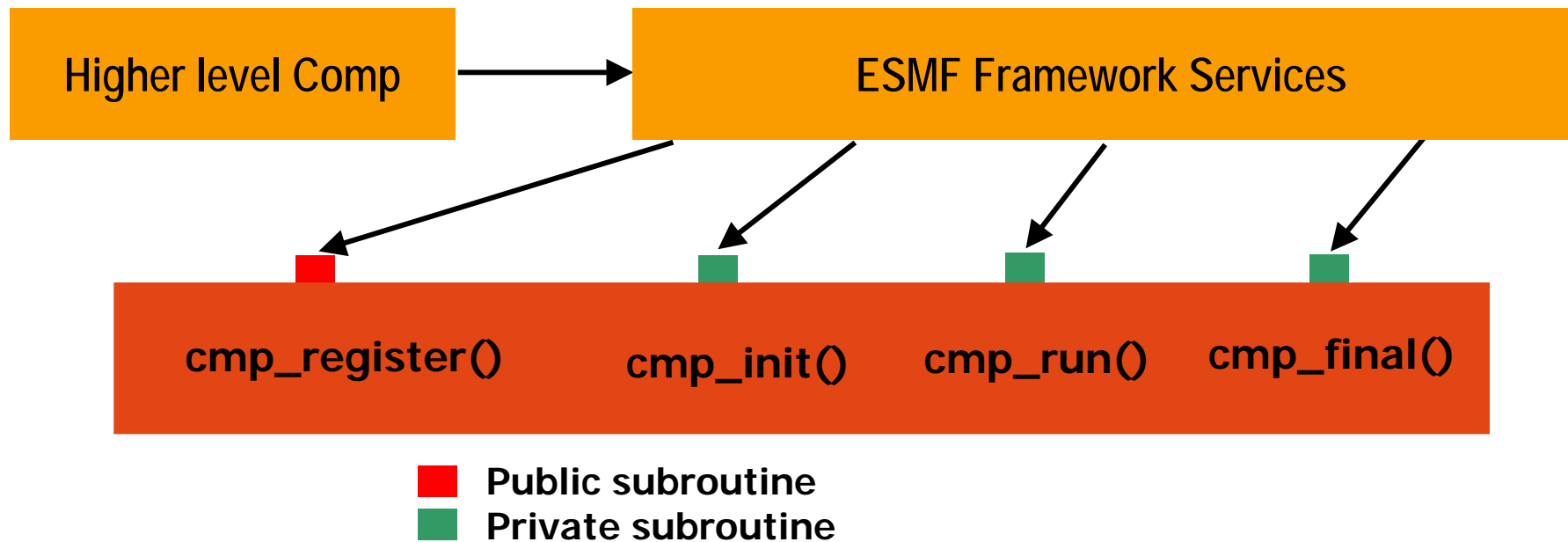
ESMF Class Structure

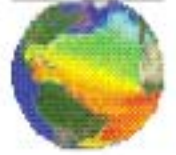
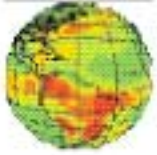


ESMF Component Registration

Components provide a single externally visible entry point, which register the other entry points with the ESMF. Components can:

- Register one or more Initialization, Run, Finalize, and Checkpoint entry points.
- Register a private data block which can contain all data associated with this instantiation of the Component.

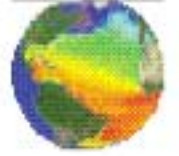
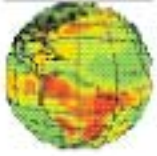




Porting Strategy

- 1) Model codes (AGCM, OGCM) were restructured to isolate Initialize, Run and Finalize tasks (i.e., were made ESMF compliant)
- 2) An ESM Driver Program (EDP) was created to control the sequence in which those Initialize-Run-Finalize tasks and data transfers are executed, as well as to keep track of simulation time.





The AGCM as ESMF Compliant

`Module AGCM_GridComp`

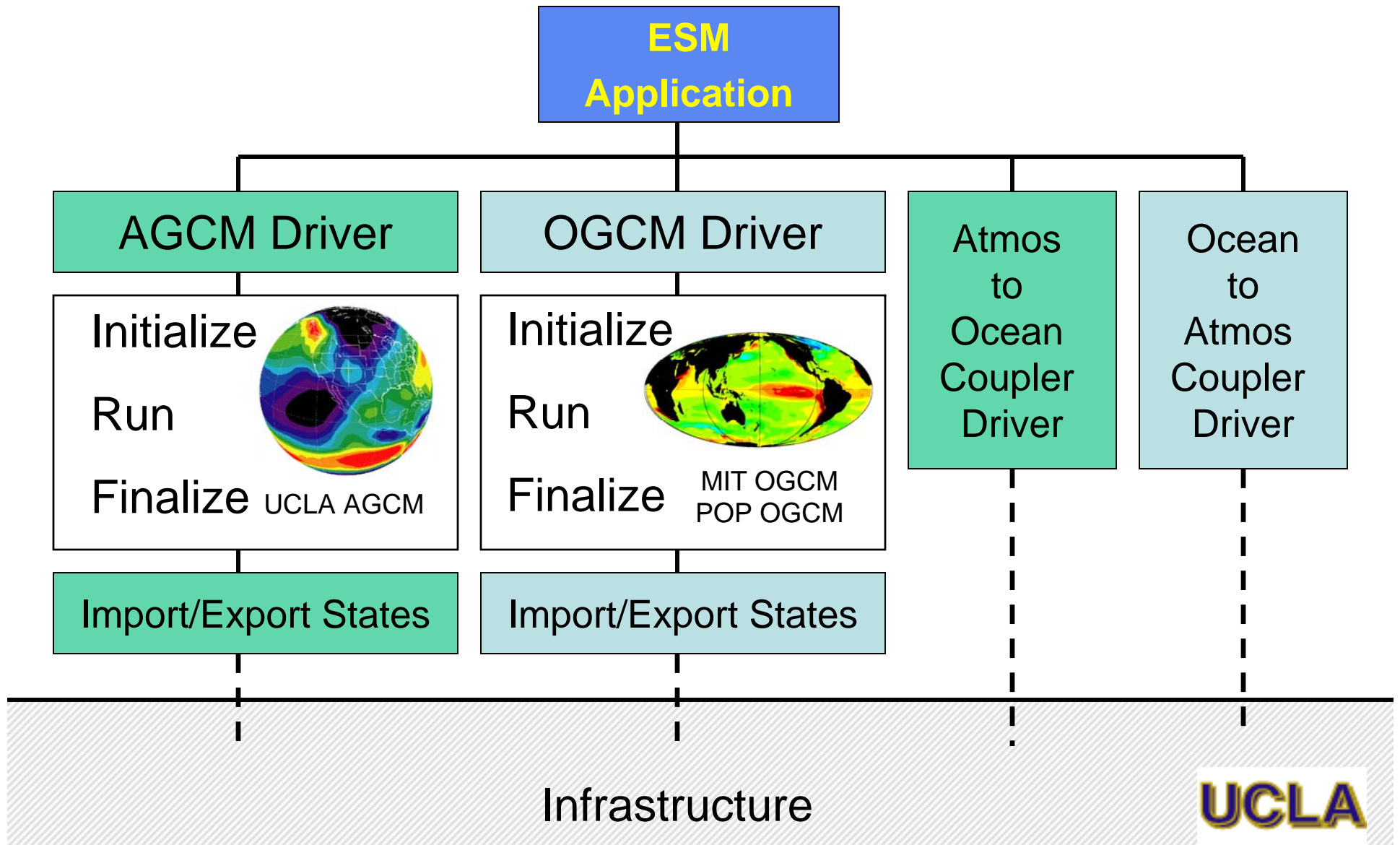
`AGCM_Initialize`

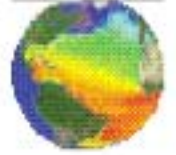
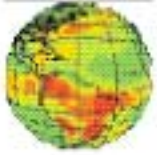
`AGCM_Run(start time, end time)`

`AGCM_Finalize`

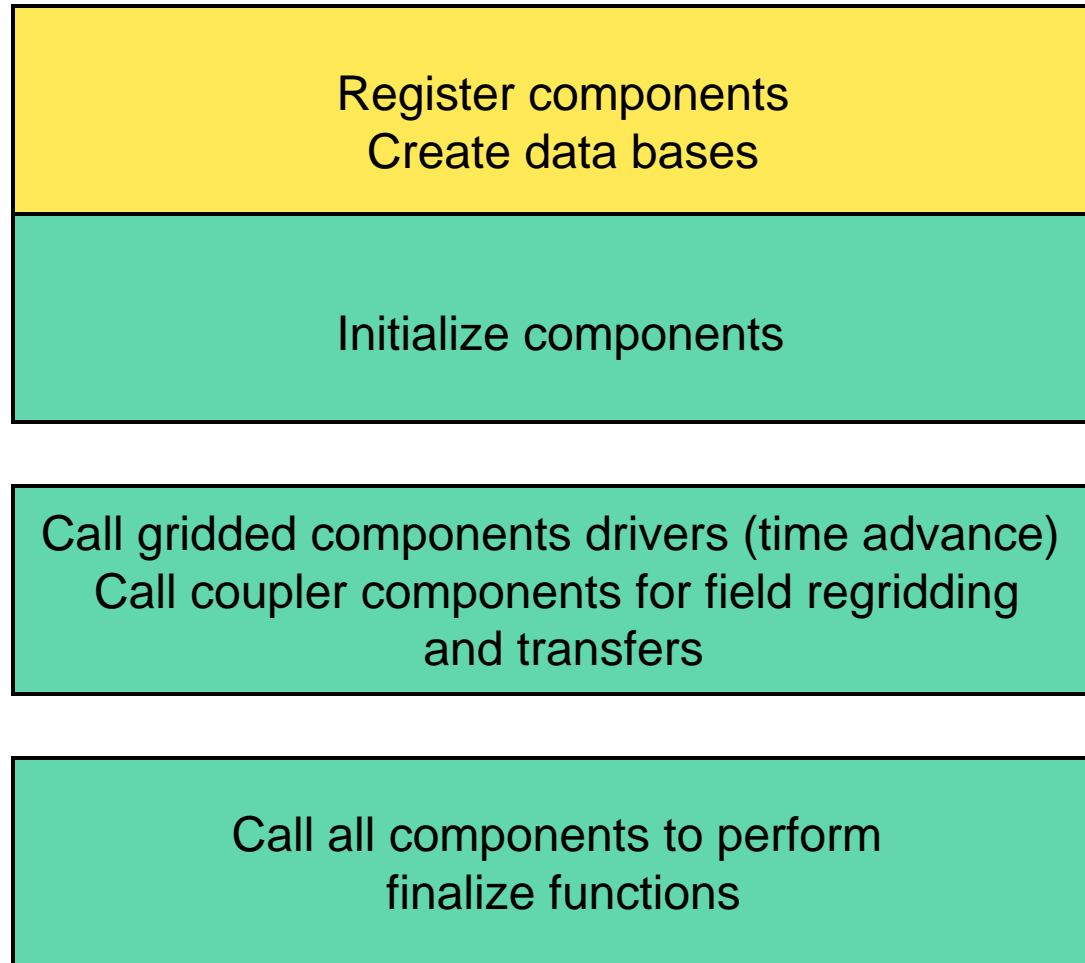


Coupled Atmosphere-Ocean Application in ESMF- Superstructure

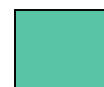




ESM Application

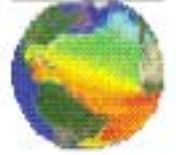
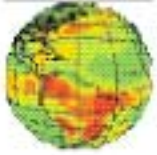


ESMF Area

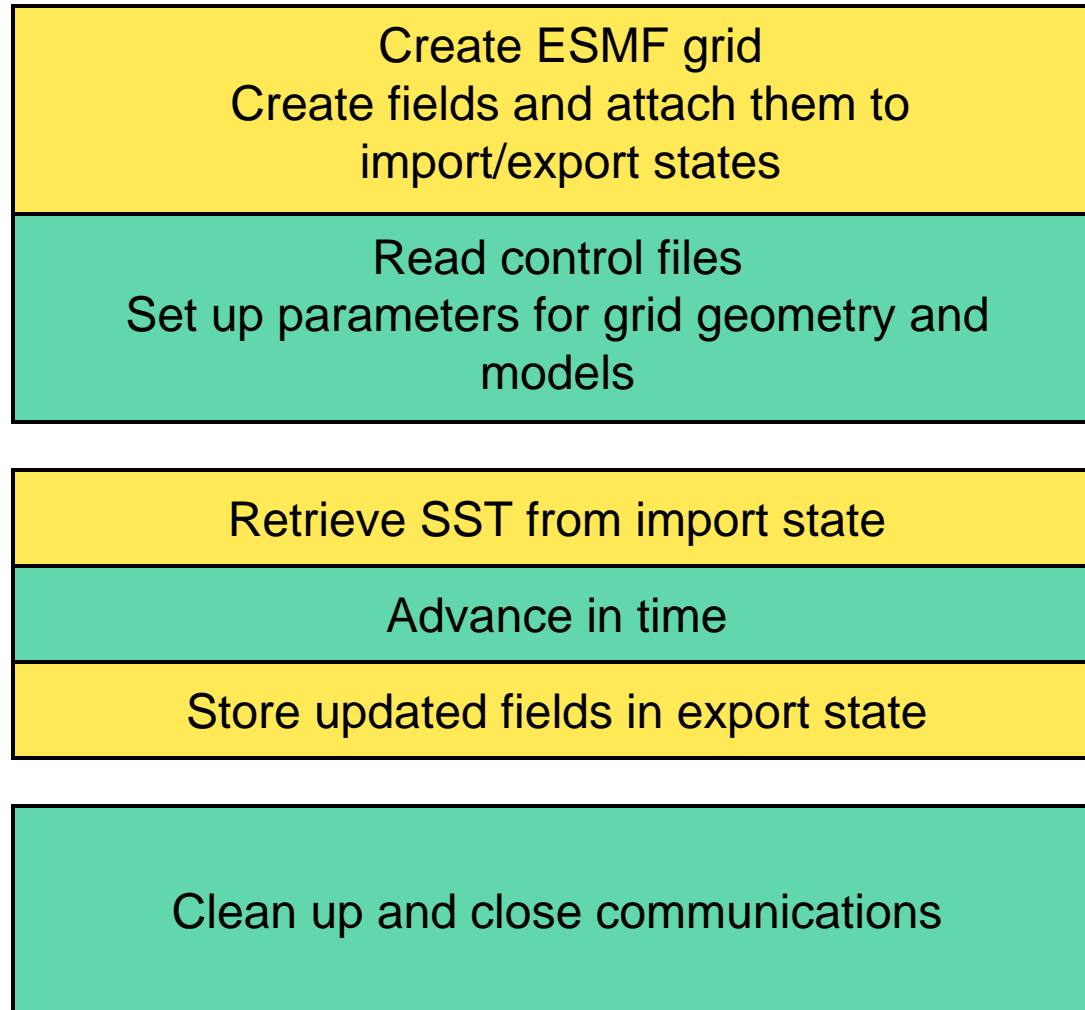


Models Area

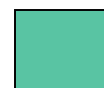




Component Driver in EDP (e. g., AGCM)



ESMF Area



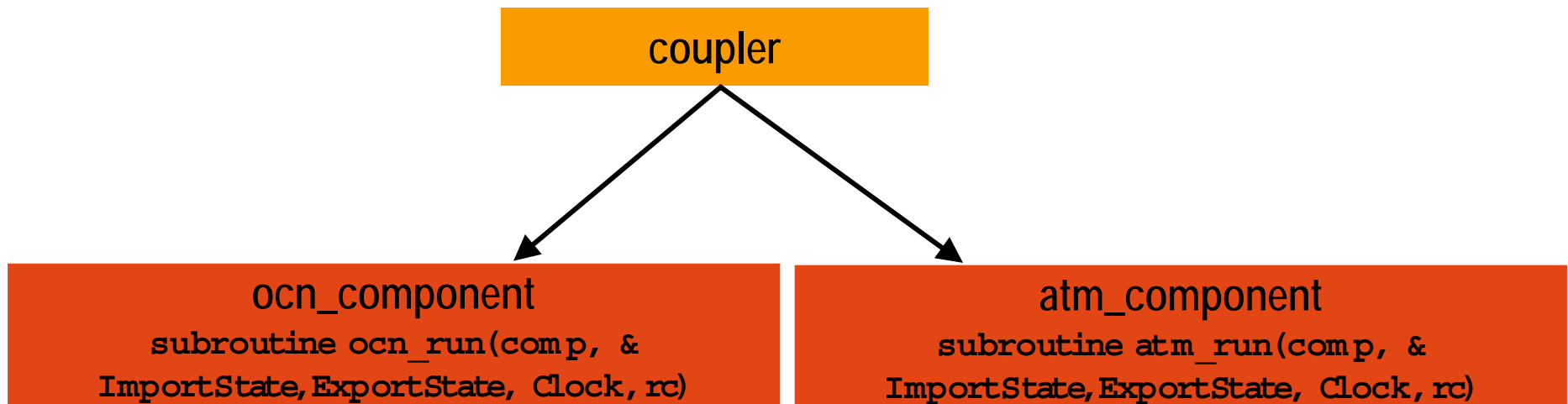
Models Area

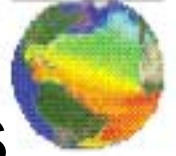
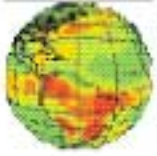


Coupler Components

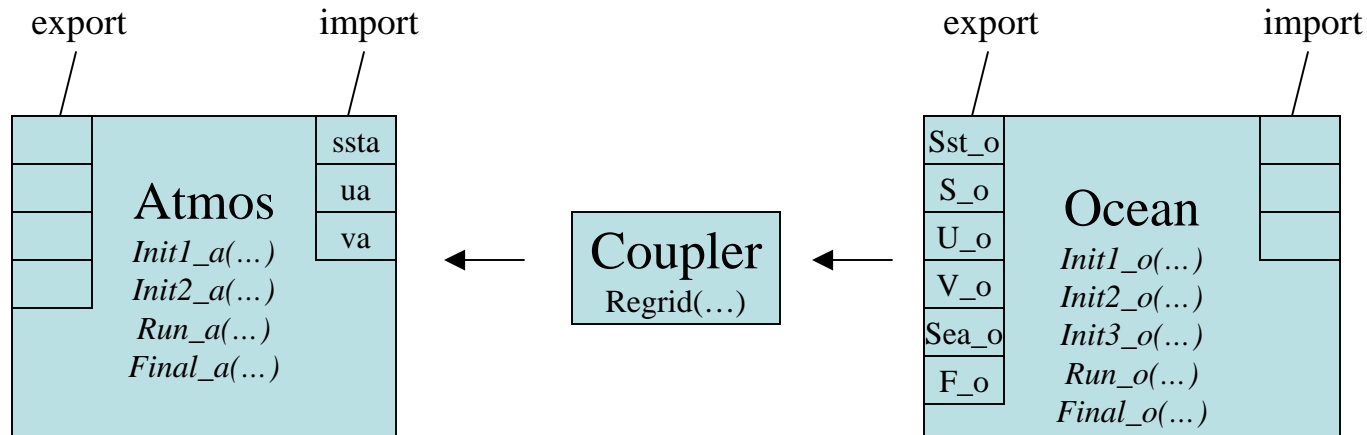
Import/Export States

The AGCM does not have access to the internals of the OGCM, and vice versa. The exchange data is through a coupler component, which exchanges the roles of Export State from one component to Import State for the other component. The coupler components also do the grid transformations.



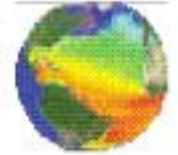
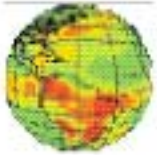


Issues in Coupling ESM Components (e.g., Ocean and Atmosphere)



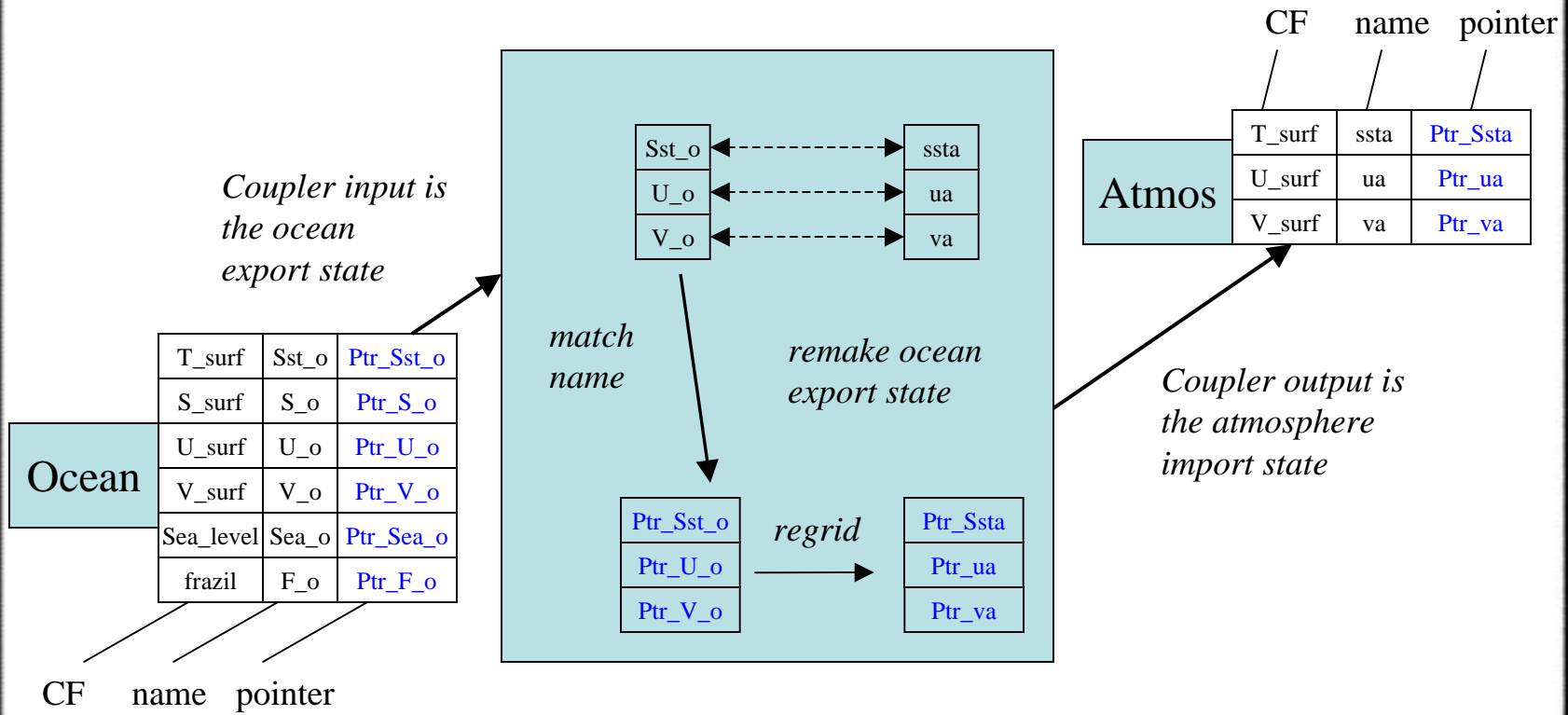
1. Function names in model components can be different.
ESMF's solution:
 - Use three standard functions with a stage option, *initialize*, *run*, and *finalize*
 - Use a function registration service, *setEntryPoint* and *setService*
2. The names (numbers) of import variables of a "use" component are different from those of export variables of a "provide" component.
ESMF does not address this issue





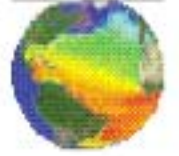
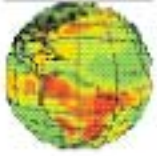
Generic Coupler: Design

Registration based on UCLA-UCB/DDB
Data transfer and regridding based on ESMF



*The Generic Coupler perform interpolations only.
(CF: Net CdF Climate and Forecast Metadata Convention)*





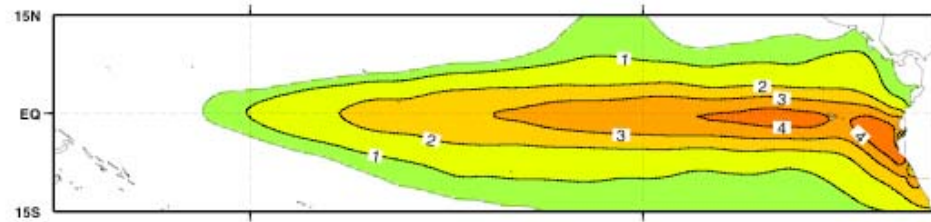
Experimental ENSO Predictions

- Initial conditions: March 5th, June 5th
- 5 - member ensemble over 9 years (1993-2002)
- 15 - month long runs
- Initial atmospheric states: From long uncoupled AGCM run with climatological SST.
- Two initial ocean states:
 1. From JPL's ECCO Project
 2. From long uncoupled OGCM run with prescribed climatological wind stress and SST.

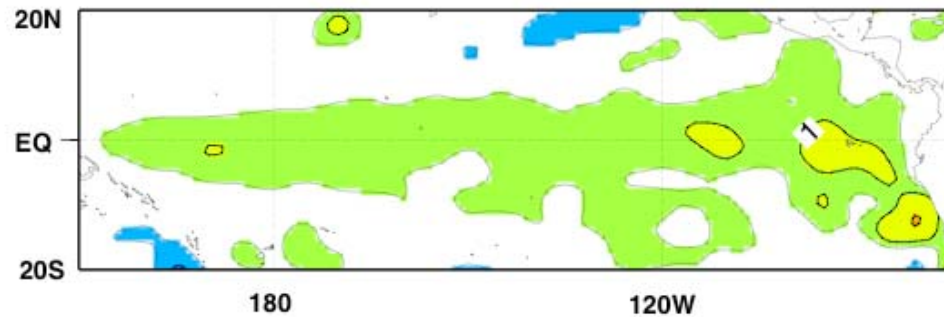


UCLA AGCM - LANL POP

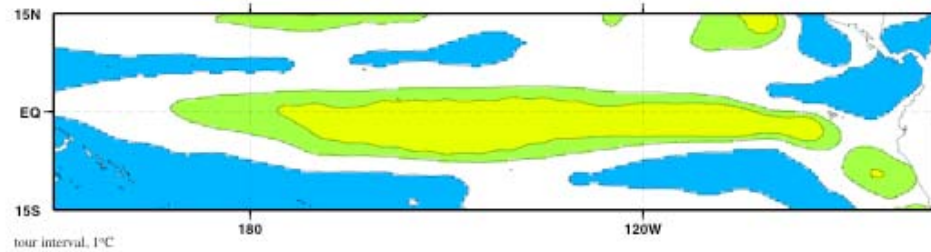
DJF 1997-1998 SST Anomaly Observation (Observation)

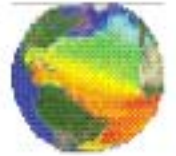
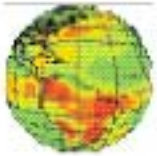


Without ESMF



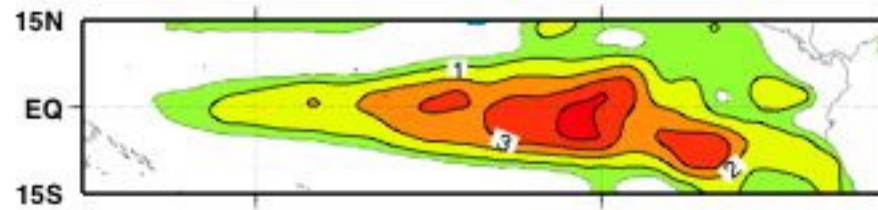
With ESMF (but some changes!)



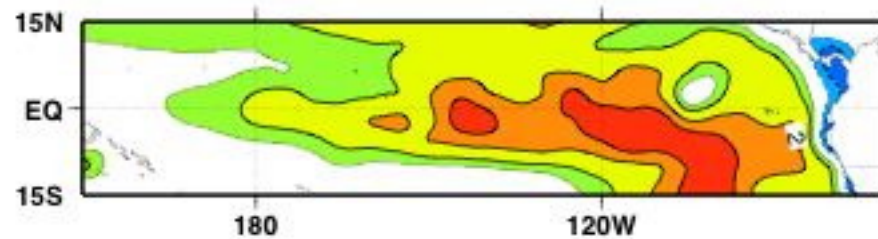


UCLA AGCM - MITgcm Ocean

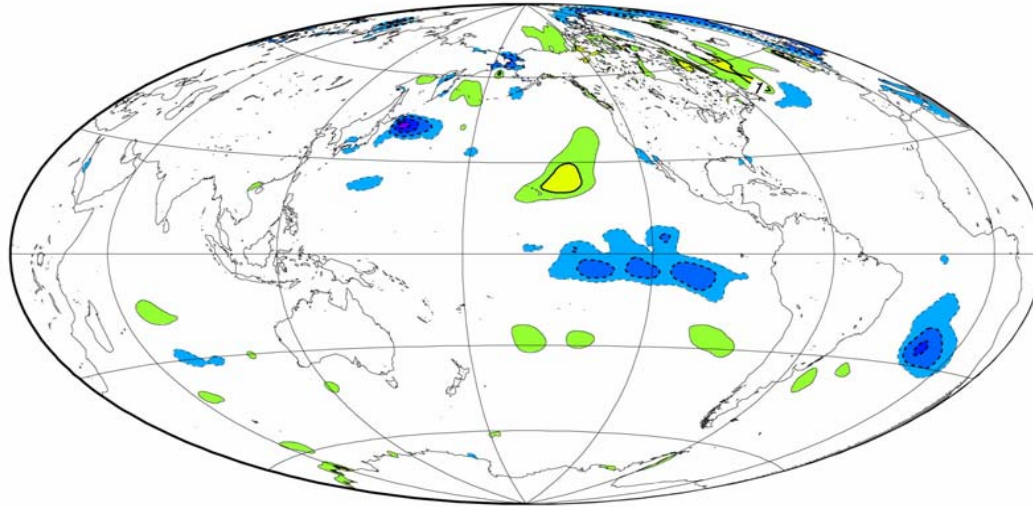
December 1997, SST anomaly forecast without ESMF



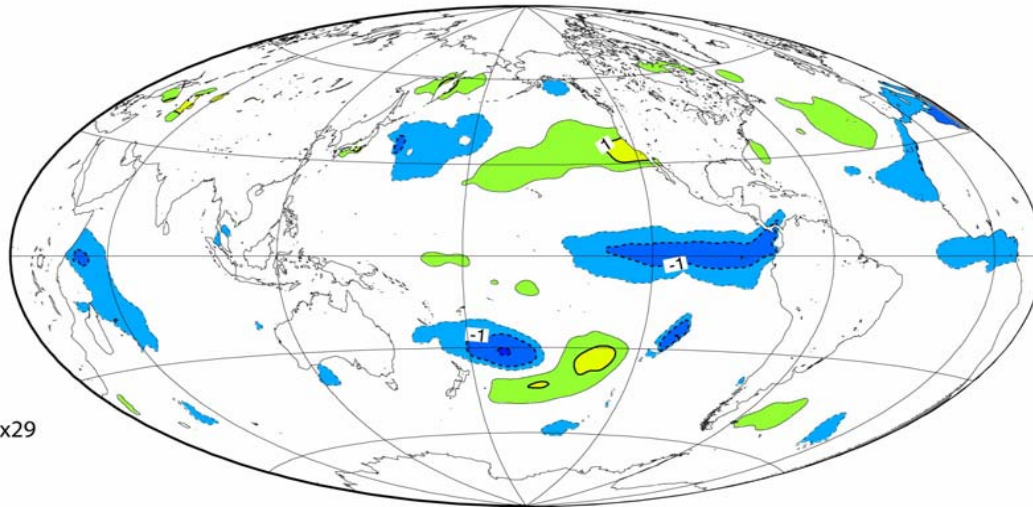
December 1997, SST anomaly forecast with ESMF



DJF 1996 SST anomaly from June 5 initial conditions (ECCO)

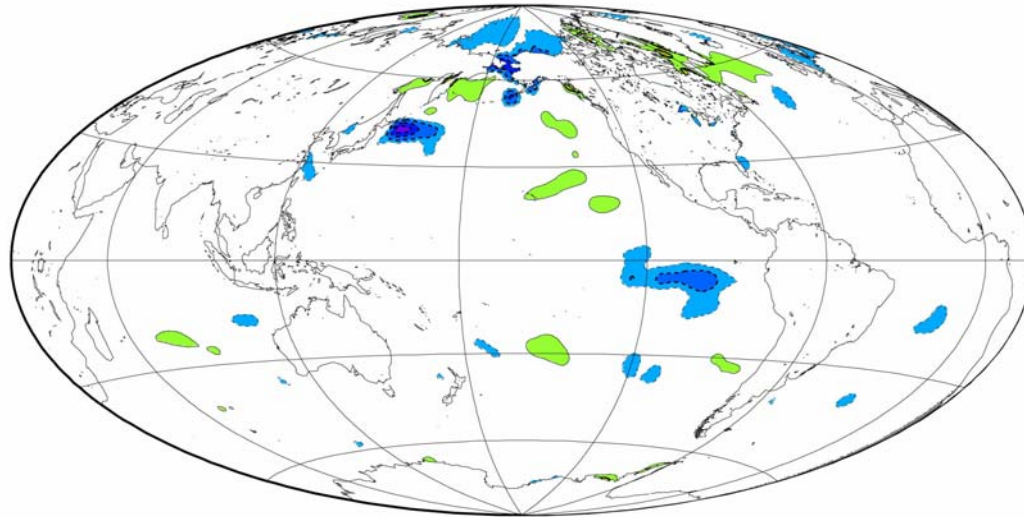


Reynolds analysis

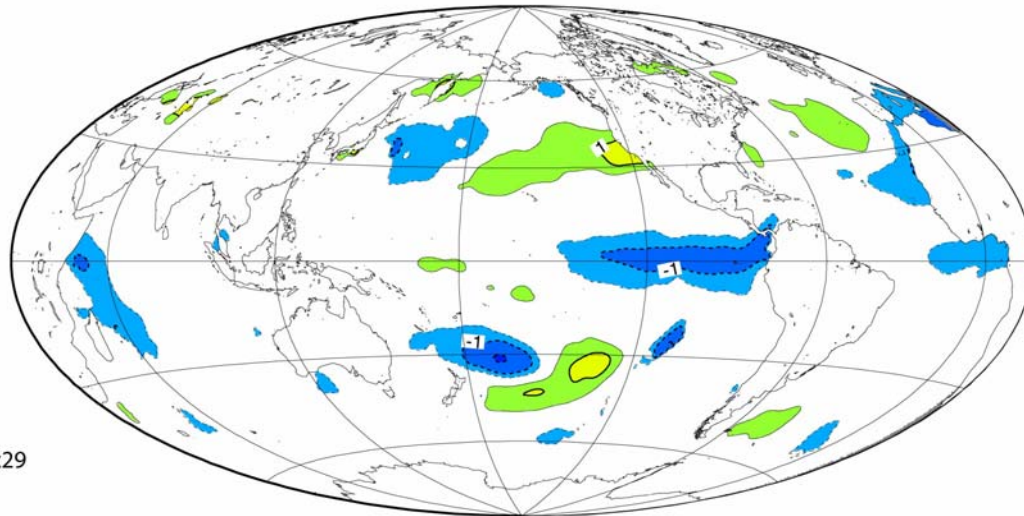


UCLA AGCM 8.0 2x2.5x29
MIT OGCM Global

DJF 1996 SST anomaly from March 5 initial conditions (ECCO)

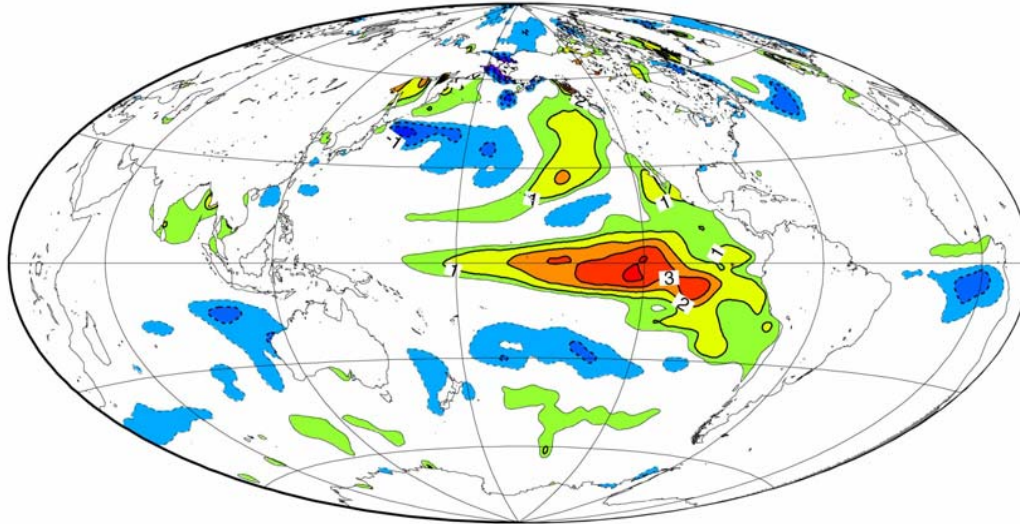


Reynolds analysis

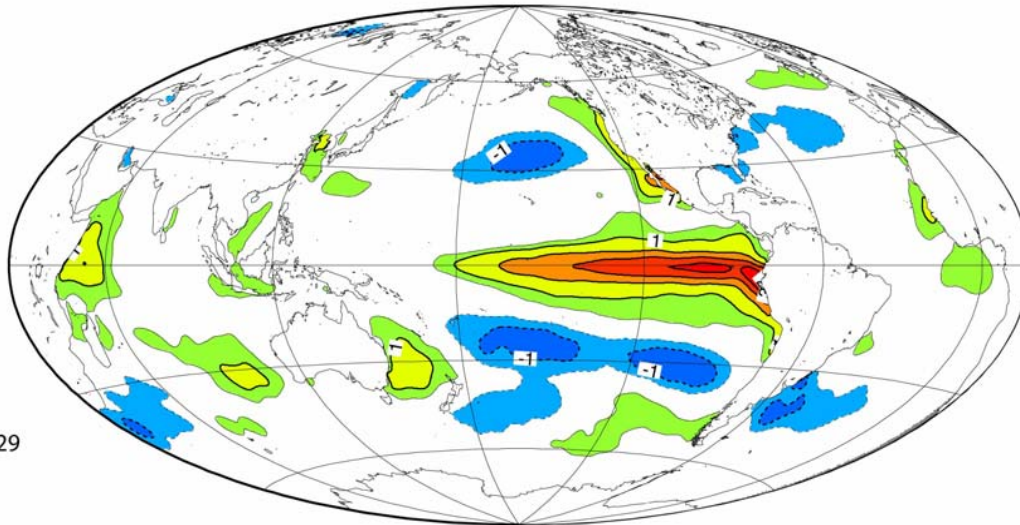


UCLA AGCM 8.0 2x2.5x29
MIT OGCM Global

DJF 1997 SST anomaly from June 5 initial conditions (ECCO)

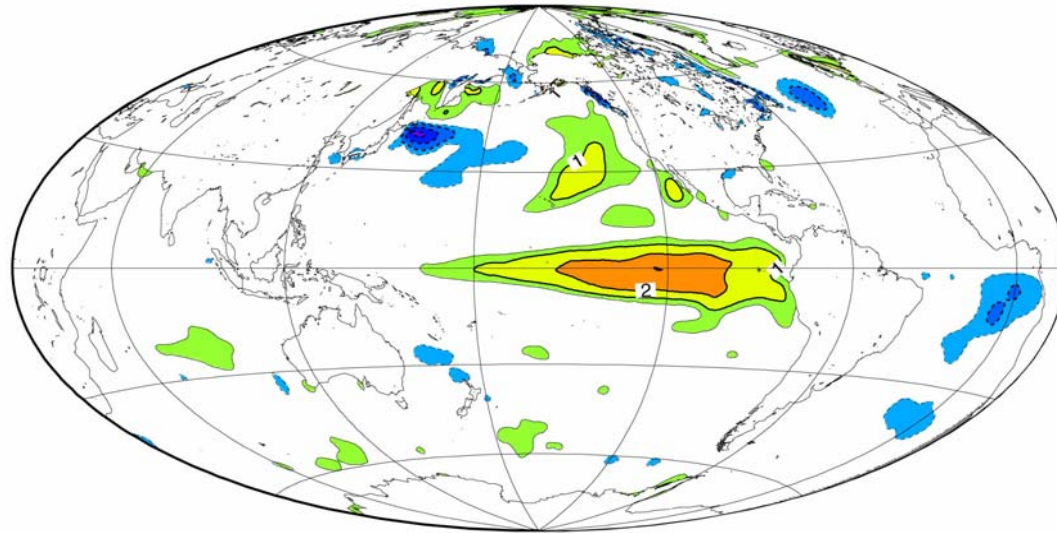


Reynolds analysis

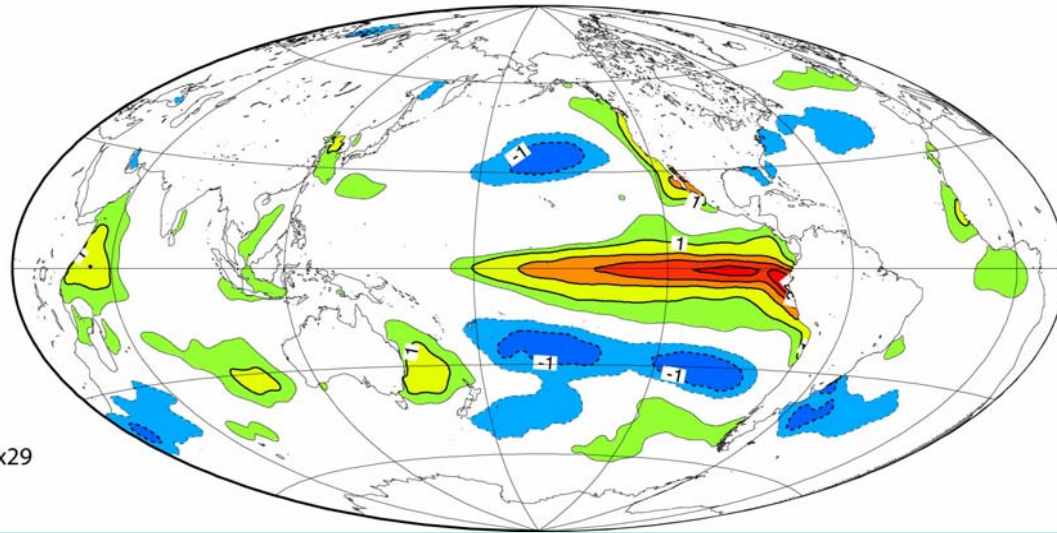


UCLA AGCM 8.0 2x2.5x29
MIT OGCM Global

DJF 1997 SST anomaly from March 5 initial conditions (ECCO)

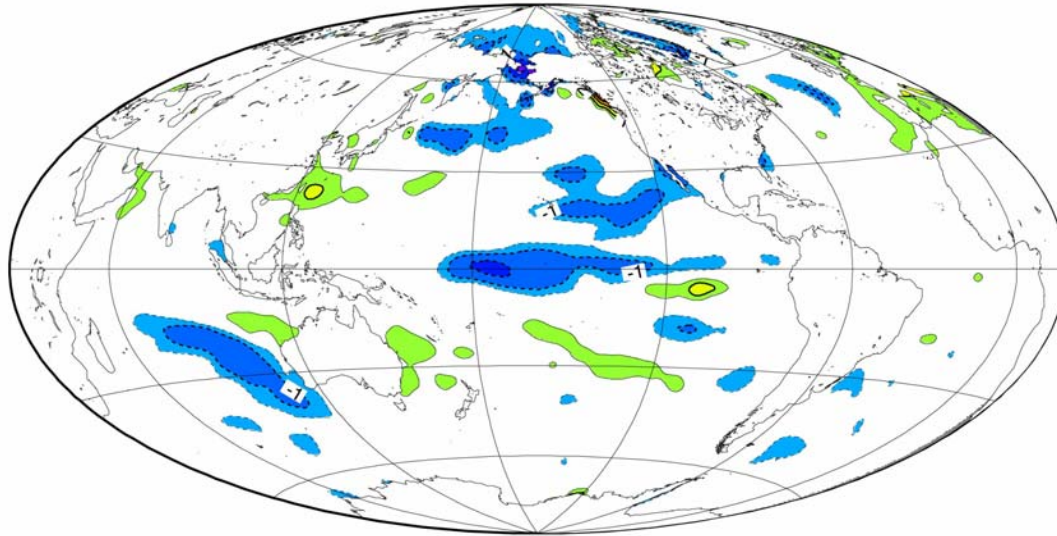


Reynolds analysis

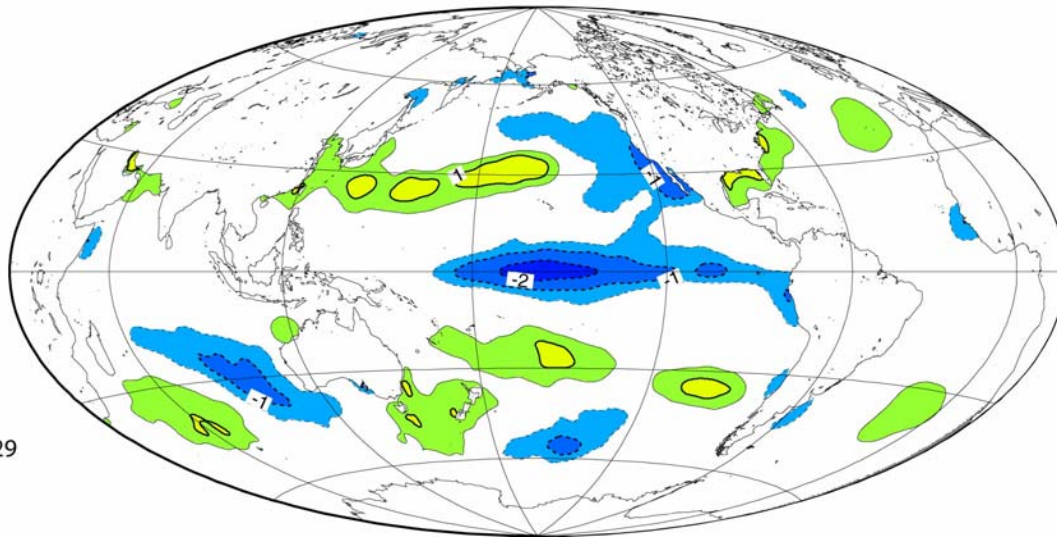


UCLA AGCM 8.0 2x2.5x29
MIT OGCM Global

DJF 1998 SST anomaly from June 5 initial conditions (ECCO)

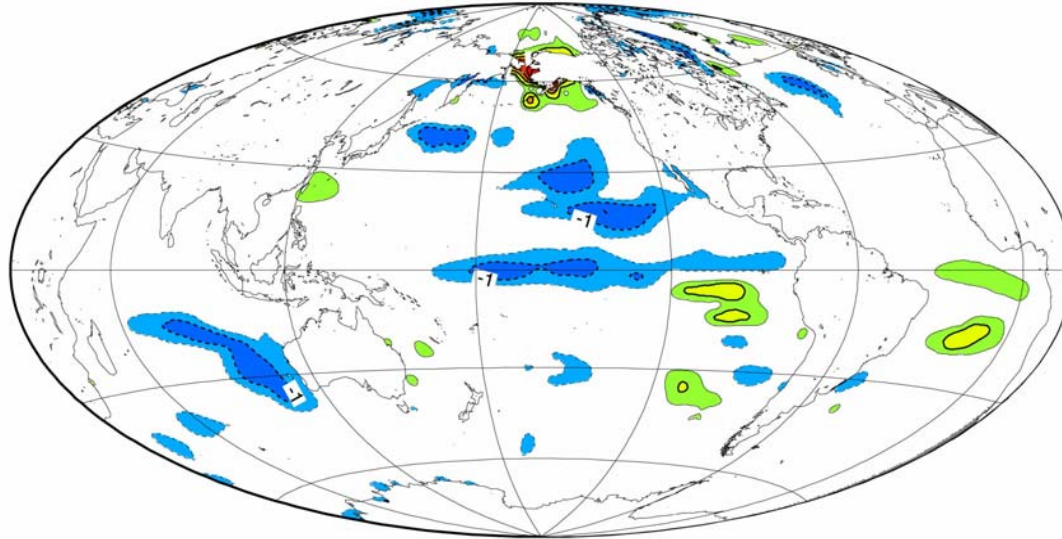


Reynolds analysis

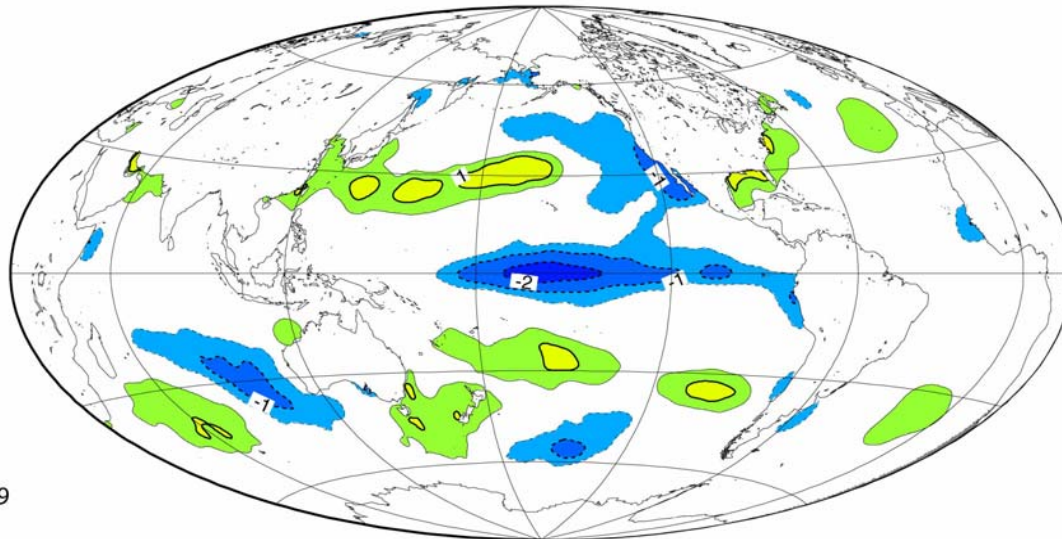


UCLA AGCM 8.0 2x2.5x29
MIT OGCM Global

DJF 1997 SST anomaly from March 5 initial conditions (ECCO)



Reynolds analysis

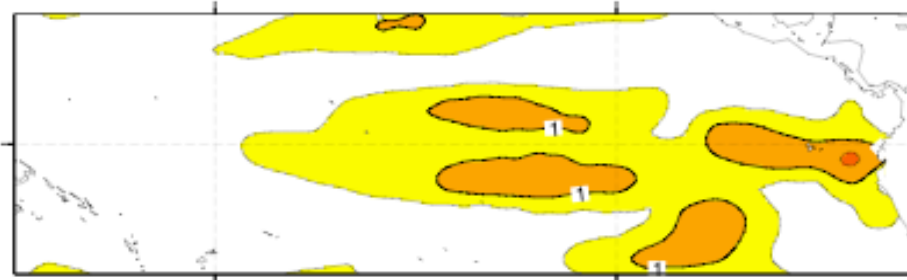


Standard Deviation of DJF Forecast Error From Early June Initial Conditions

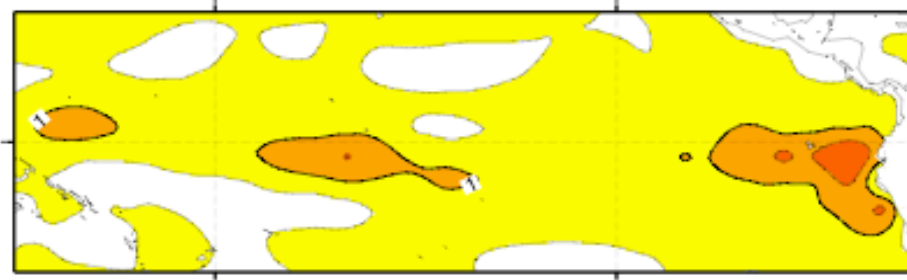
a) Using ECCO



b) No-ECCO



c) Persistence

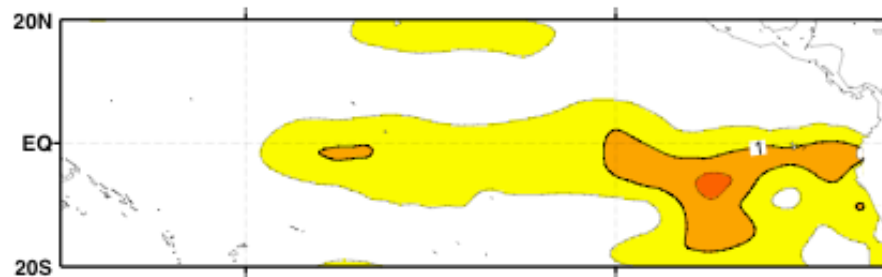


UCLA AGCM 7.3 HighRes
MIT Global OGCM

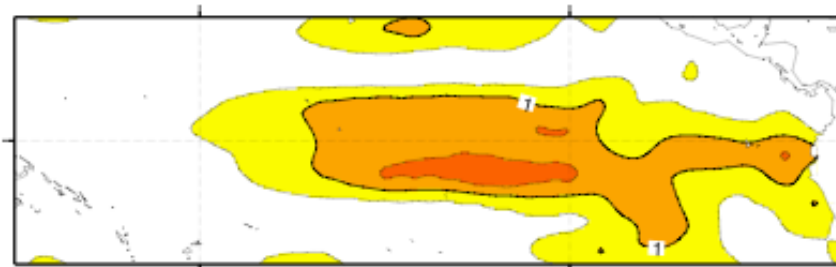
contour interval, 0.5°C

Standard Deviation of DJF Forecast Error From Early March Initial Conditions

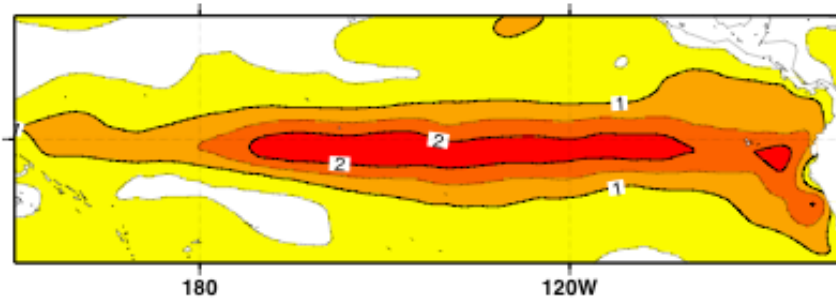
a) Using ECCO



b) No-ECCO

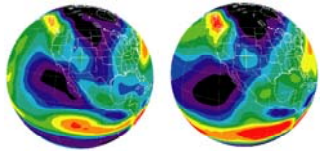


c) Persistence



UCLA AGCM 7.3 HighRes
MIT Global OGCM

contour interval, 0.5°C



Atmosphere-Ocean Dynamics and Tracer Transport

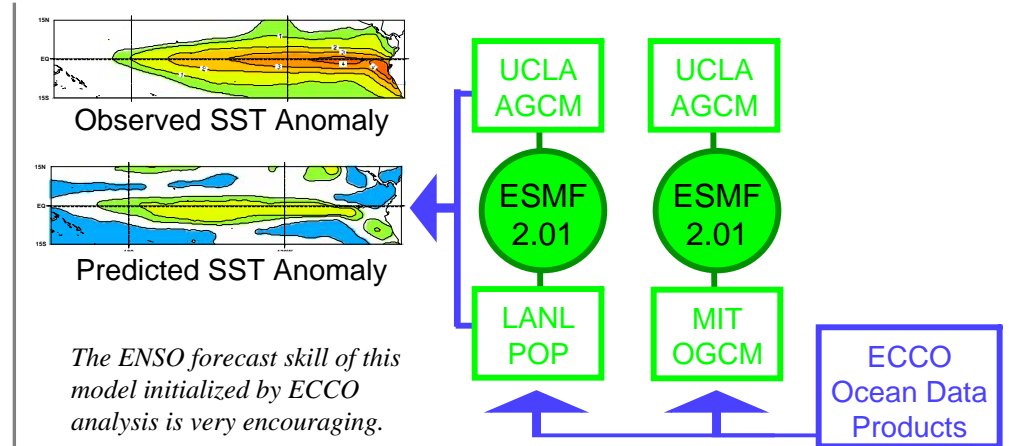
PI: Roberto Mechoso, UCLA

Description

- Generalize and extend the UCLA Distributed Data Broker (DDB) service for coupling atmosphere and ocean models together
- Test and Evaluate ESMF services

Objective

- Earth System Modeling Framework (ESMF) components for better understanding of the El Niño/Southern Oscillation.



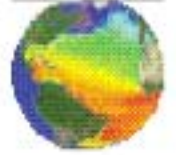
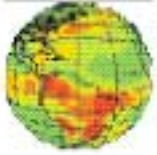
Accomplishments

- Demonstrated ESMF functionality by analyzing El Niño prediction capability of the UCLA Atmospheric General Circulation Model (AGCM) coupled to the LANL Parallel Ocean Program (POP) and the MIT Oceanic General Circulation Model (OGCM).
- Initialized coupled systems with ocean circulation data products produced by the consortium for Estimating the Circulation and Climate of the Ocean (ECCO).
- Completed User's Guide/Maintenance manual.
- Made documented source code publicly available via the Web.

Key Milestones (11 milestones total)

- H - Procedures for integrating the AGCM/OGCM with the ESMF 12/02
- F - First code improvements (on AGCM) 4/03
- I - Distributed Data Broker development completed 7/03
- G - OGCM POP converted to near global domain and demonstrated without loss of performance (reneg 3/05) 1/04
- J - Full Interoperability - Couple AGCM, POP and MIT OGCM into the ESMF framework (reneg 3/05) 4/04
- K - Customer delivery - Analyze El Niño prediction capability of AGCM/POP/MIT OGCM (reneg 3/05) 12/04

TRL=4_{in}-6_{current}



SUMMARY

- A large effort has been dedicated to developing an ESMF, which shows great promise of facilitating multidisciplinary research.
- The UCLA AGCM was coupled to the MIT OGCM and LANL POP using ESMF services.
- Much more work with the ESMF is needed for debugging, increased capability and user friendliness.
- Model codes integrated into the ESMF require maintenance if the framework is to become a standard for Earth System Modeling.
- The coupled atmosphere-ocean model shows skill in ENSO prediction from six months in advance. The skill is higher for the UCLA AGCM/MIT OGCM combination with ECCO initial conditions for the ocean
- A generic coupler is being developed by NASA/UCLA in order to simplify the ESMF use in serial and concurrent modes.

