Workshop Report

Coupled Data Assimilation Workshop

April 21-23, 2003
Portland, OR

Sponsored by NOAA/OGP

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The goal of this workshop was to explore the merits of developing a program for coupled ocean-atmosphere data assimilation to improve seasonal-to-interannual (S-I) forecast skill. Attendees were asked to address some key questions in coupled data assimilation:

- What are the reasons for approaching data assimilation from the coupled perspective?
- What are the potential benefits/problems from the predictive and climate communities' perspectives?
- How should this problem be approached from both theoretical and practical aspects?
- What are the first steps that could/should be taken to begin to develop a coupled assimilation capability?

Recommendations

From the invited presentations and the ensuing discussion sessions, it was clear that there are a lot of complex problems to be addressed. Because of the complexity of the issues to be addressed for implementation in an operational setting– e.g., data stream integrity and reliability, data impacts, code maintenance, code performance, *inter alia* – not to mention the theoretical and practical aspects of models and assimilations systems, long-term funding will be necessary to sustain an operational coupled data assimilation system.

The consensus recommendations for specific development may be summarized as:

- We need to make progress in correcting model biases, uncoupled and coupled. High priority should be in improving uncoupled components in the context of the impact on the coupled system. Coupled models are still not adequate for S-I prediction and we need to invest in improving these models before we invest in comprehensive coupled data assimilation systems.

- For initialization of S-I prediction systems, more research is needed into
    - best initialization compared with best analysis
    - initializing coupled modes
    - statistical corrections to compensate for biases.

- We need to undertake more work with ocean data assimilation (ODA). S-I forecasts seem to do better with the use of full ODA for initialization , but we are not sure why. We need to understand what we get from ODA.

- We need to make progress in covariance modeling, especially with regard to biases. Ocean assimilation is hampered by lack of observations for cross-validation. Observational programs should include a strategy for gaining information on spatial- and cross-covariances. Information from observations is essential to help answer questions regarding ergodicity: since one of the primary sources of ocean model errors and biases lies in parameterization errors, particularly of vertical mixing and diffusion, we need to know whether parameterization errors should be considered as controls in the minimization problem.

It was also clear from discussions that we won't really be able to answer the question of how important coupled assimilation will be until we have a some further experience with coupled systems. Thus, it makes sense to begin exploration (or extend the limited current explorations) of coupled assimilation.

- For GCMs, it makes most sense to focus initially on a loosely coupled assimilation system because of shocks and biases in the coupled system. A hierarchical approach to the fully coupled assimilation should be taken, for example, an atmosphere coupled to a mixed layer model or hybrid coupled systems.

- We should concentrate on areas where we have more data, such as the tropical Pacific. This is especially appropriate for S-I prediction, since for this application it is not necessary to undertake coupled data assimilation in the mid-latitudes.

- The only sustained demonstration of coupled initialization has been with the Cane-Zebiak model (LDEO, ESSIC). Work needs to be done on how to translate the experience with the Cane-Zebiak, intermediate and hybrid coupled models to fully coupled operational GCMs, particularly in relation to:
    - best initial conditions
    - "noise" representation – e.g., for intra-seasonal oscillations, the patterns seem to be more important than the timescales
    - statistical correction of forecasts to compensate for biases/shocks.

- Since the ultimate goal in developing a coupled assimilation system has to be its implementation in an operational setting, and since the human and computational resources are severely limited, the community should concentrate its efforts on a few systems.

1. Workshop Overview

In recent years, there has been some discussion in the community about the need for coupled ocean-atmosphere data assimilation/initialization for seasonal-to-interannual (S-I) prediction. However, few attempts have been made since the problem is very complex, particularly due to the difference in scale between the ocean and atmosphere. As the deployment of the global ocean observing system is moving forward, and the improvement (at least in the sense of increasing skill score) of S-I forecasts by coupled models seems to have leveled off, NOAA/OGP decided to convene the workshop to investigate the possibility for coupled ocean-atmosphere data assimilation research.

The workshop focused on coupled assimilation for S-I prediction models. Attendees were asked to address some key questions in coupled data assimilation:
What are the reasons for approaching data assimilation from the coupled perspective?
What are the potential benefits/problems from the predictive and climate communities' perspectives?
How should this problem be approached from both theoretical and practical aspects?
What are the first steps that could/should be taken to begin to develop a coupled assimilation capability?

Workshop attendance was by invitation only in order to facilitate discussions focused towards the workshop goals. In addition to U.S. scientists, representatives from Japan (FRSGC and Earth Simulator) and from Europe (ECMWF) participated. Several invited talks gave overviews of the state of our knowledge and to explore the issues and guide the workshop discussions. These were followed by afternoon working sessions focused on answering the questions posed for the workshop.

There was no disagreement at the workshop with the statement that the state of S-I forecasting with dynamical models has not improved over the past five years. All coupled models have serious biases. This is a problem for the seasonal cycle as well as for El Niño and La Niña phases. Unfortunately, there are few “tunable” parameters in comprehensive (physically complete) coupled general circulation models (CGCMs), only the various parameterizations of unresolved processes, including air-sea fluxes. No-one has found the parameterizations to produce relatively bias-free solutions even in the uncoupled components. As a result, there has been little exploration as to whether predictability exists within the framework of such CGCMs.

Because of these strong biases, there has been some effort to see whether the anomalies can be assimilated even though the models’ background states are quite different from nature. In particular, the models’ ENSO modes differ from those observed. Some studies have attempted to see if there are 'transfer functions' between the unrealistic model modes of ENSO and the natural modes that can be used to project observations onto the model ENSO modes. There has been some success with this approach (Chen et al , 2000: GRL **27**, 2,585-2,588), but much more could be done along these lines.

Some of the key issues in uncoupled ocean data assimilation got a fair amount of discussion: the absence of agreed-upon error statistics for ocean data, or for forecast/background error covariances; lack of suitable strategies to deal with model biases; the inability to constrain analyses with the full observation suite. Many of these basic issues were identified at the First US GODAE assimilation workshop in April 2001.

2. Presentations and Discussions in Brief

What does coupled data assimilation mean?

- Observations in one medium impacts the state of the other medium
- Loosely coupled assimilation – assimilate in one medium and that state affects the other medium
- Fully coupled assimilation means simultaneous minimization of cost function for atmosphere and ocean. We should also include sea-ice and the land surface.

Why create a coupled assimilation system?

- Currently progress is being made in loosely coupled systems for short timescales (at NCEP and FNMOC).
- Compared with uncoupled systems, coupled systems are likely to be
    - more sensitive to model biases
    - more complicated than uncoupled systems.
- Individual components already have errors/biases that should be addressed on an individual basis. These biases are amplified in the feedbacks of the coupled model.
- Climate analyses: The longer the timescale the more acute the biases in the fluxes get. We need a strategy to address this. We don't seem to be getting to the flux fields from NWP analyses that satisfy oceanographers.
- We need a strategy to deal with coupled model instabilities, since they are liable to play a major role in the forecast errors.

Single purpose systems are difficult to justify and maintain. Coupled assimilation systems would seem to be warranted for:

- S-I prediction – better initialization for better forecasts (reduce initialization shock and coupled model biases)
- subseasonal (monthly) prediction
- medium-range NWP
- mesoscale and hurricane NWP
- analysis of the historical record
- climate monitoring
- improving coupled models.

Scientific issues

- We need to increase our knowledge of error covariances. The structure of the errors matter. We cannot just specify homogeneous structures.
    - The are many issues concerning model errors, including questions of ergodicity and randomness of parameterization errors.

- Forecast error covariances should be state-dependent, evolving with the coupled circulation.
- Observational errors and model representativeness errors are not well known.
- Biases – models and observations – are an important part of the assimilation problem.
- We need to include balances as part of the assimilation.

- The feedback between various components of the coupled system complicates the problem of assimilation. The weakest link determines the quality of the results.
  - It is not clear that we will get better air-sea fluxes if our surface boundary layer models are poor.
  - Spatial and temporal variability are probably too strong to estimate the coupling coefficients (i.e., parameters in bulk formulae) via data assimilation – the coupling is state dependent.
  - Data impacts can be mis-estimated with a poor model, inadequate assimilation system, or with incomplete use of the data base.

- The difference between coupled and uncoupled assimilation is that if the model is assumed perfect with a fully coupled system, we only have initial conditions as controls and do not have forcing errors to take the blame for forecast inadequacies. We must have distributed controls (i.e., recognize model error) if we want to fit data for longer than 1 month.

- We need to develop the proper metrics to assess the skill of a coupled data assimilation system.

S-I Forecasts

- Coupled initialization does not necessarily require coupled assimilation, but it should account for coupled uncertainties, for example ENSO coupled instabilities.
- The forecast initialization procedure should account for two problems:
  - The coupled model climate does not agree with observed climate.
  - The coupled modes of the coupled model are significantly different from the coupled modes of nature.

- Coupled forecast results suggest that some equilibrium between the atmosphere and SST is required for a good forecast.

- Forecasts tend to be better with full ODA, but we don't really understand why. Is it because we have better states or better anomalies?

- Anomaly coupling or anomaly initialization (to try to reduce the impacts of shocks and biases) does not lead to improved forecasts.

- Experience from intermediate models:

- It is not clear that one can get to the best initial condition (metric: best forecast) using standard data assimilation techniques.
- The more data you use, the more difficult it is to represent all the co-variabilities.
- With too few data, we can fit the data well but still fail the hypothesis test for our estimates of dynamical model errors.

Using coupled assimilation to improve coupled models
- Identifying problems is important, but there is a huge jump from this to rectifying the problems.
- With coupled assimilation we could find problems we don't know about.
- This aspect could be an area for additional work.

Operational System
- Computational resources, potential unified system and data cut-offs are important considerations in the design of an operational system.

3. The Workshop Questions
The workshop ended with participants revisiting the questions posed to focus the workshop discussion. The following represents the consensus perspectives.

What are the reasons for approaching data assimilation from the coupled perspective?
A priori
- The real world is coupled so state estimation should be performed in coupled mode.
- Ocean models need improved surface fluxes.
- Atmospheric models need improved SSTs.
- The real forecast errors contain coupled modes that should be minimized in the initial conditions.

A posteriori
- We expect more accurate field information/analyses.
- We might get better initial conditions for forecasts.
- It could potentially improve coupled model simulations.
- Flux corrections must be consistent in both components of the system – this is automatic in a coupled system.

What are the potential benefits/problems from the predictive and climate communities' perspectives?
<u>Improved S-I predictions:</u> Some examples (presentations by Kaplan regarding LDEO2, Kirtman regarding COLA coupled forecast) show that improvements in state do not necessarily lead to improved predictions. There was a trade-off between short-time skill and long-lead skill.

<u>Climate analyses:</u> Coupled analyses would possibly yield more accurate flux information, but poor surface boundary layer formulations may preclude this.

Technical difficulties:

- Coupling will impact the conditioning of the estimation problem.
- Coupling will obligate the need for system noise /dynamical error representation.
- Component model deficiencies are amplified in coupled systems.
- Costs may not be additive, so computational resource requirements may increase beyond that for uncoupled assimilation in the separate components.
- The mis-match in timescales between ocean and atmosphere means that the tangent linear approximation for the atmosphere may fail. On the timescales for the atmosphere, the 4Dvar problem for the ocean will be 3Dvar.

How should the problem be approached from theoretical and practical aspects? What are the first steps that could/should be taken?

- Use of a loosely coupled system is the proper first step, as already under development at NCEP and FNMOC.
- A hierarchical approach (e.g., atmosphere coupled to mixed layer; hybrid coupled models, changing the mean state, using statistics for variability) makes sense.
- Since one of the primary sources of ocean model errors and biases lies in parameterization errors, particularly of vertical mixing and diffusion, we need to investigate whether parameterization errors are random or should be considered as controls in the minimization problem.
- We should investigate the dynamics of error growth in the coupled system.
- Multivariate issues need further exploration.
- The issue of coupled initialization vs coupled assimilation for forecasts needs to be investigated further.
- We need to invest in engaging and training new personnel. This will require creative approaches to establishing tenure-track positions for assimilation. We also need to establish joint activities between joint centers and universities.
- We need to engage observationalists, process modelers, numerical modelers to help us scale and correlate the errors in parameterizations and get them to take the right measurements.

4. Other issues

There were two issues discussed briefly without a consensus being reached. The major points of discussion on both sides of the discussion are summarized here; however, it should be noted that time constraints precluded a full discussion/debate of the issues.

I. Since the ultimate goal is to advance operational seasonal forecasts and these are conducted with comprehensive general circulation models, is there anything to be gained from simplified models with truncated dynamics and thermodynamics?

Positive arguments

- Experience with simplified models can be transitioned to GCMs. There has been little attempt to date to do so.
- GCMs are also deficient in their representation of governing processes.
- GCMs are yet to outperform simple models or statistical models in their prediction skill.

Negative arguments

- Simplified models misrepresent, or simply do not include, some of the fundamental dynamical processes [air-sea exchange, and simplified geometry] operating in nature.
- It is impossible to constrain simple models with observations and the larger the number of observations, the worse the fit; though an attempt to similarly constrain an ocean GCM (A. Bennett) was unsuccessful as well.

Counter arguments *(Mark Cane)*

The negative arguments are peculiar. All of the things listed in the first bullet are easily included in a model like ZC (e.g., the work Bin Wang has done with mixed layers and heat fluxes); they are not accounted for because they are not where the problems lie. The second point is, alas, equally true of GCMs at present.

II. Are 4D-var or "strong constraint" inversions meaningful/feasible in a coupled system?

Positive arguments

- Limited experience with the inversion for dry adiabatic physics shows that the inversion stable. The inversion should be conducted on the slow manifold and will provide a solution consistent with model dynamics and physics.
- Inversions will be useful for parameter estimations, such as estimations of the coupling strength (turbulent fluxes).

Negative arguments

- The tangent linear approximation will fail in the atmosphere over long time duration inversions.
- Within the perfect coupled model framework, the only control remaining is the initial condition. The air-sea fluxes are too variable in space and time to suppose that the bulk formula coefficients can be estimated by inversion.

Appendix A: Summaries of Presentations

Experience with coupled assimilation at LDEO

M. A. Cane, D. Chen, A. Kaplan, A. Karspeck, R. Canizares (all LDEO),
S. E. Zebiak (LDEO and IRI)

Examples of an intermediate coupled model (Zebiak - Cane) and its approximation by a system of linear Markov models demonstrate that the best initial condition for forecasts with an imperfect model is generally different from the best analysis of its initial state (nowcast). It is important to develop the theory for finding best initial conditions for predictions with imperfect model, and perhaps to render this problem as a special kind of a data assimilation problem. Our work to date in this direction includes successful uses of nudging for initialization improvement, use of large-scale statistical corrections to reduce systematic biases of a coupled model, and iterative use of linear tangent operators for refining initial conditions. These techniques were developed with the use of an intermediate model and can potentially be used with coupled GCMs as well.

A study of ENSO prediction using a hybrid-coupled model and the adjoint method for data assimilation

Eli Galanti, (IRI)
Eli Tziperman, Matt Harrison (GFDL), Antony Rosati (GFDL), Ziv Sirkes

An experimental ENSO prediction system is presented, based on an OGCM coupled to a statistical atmosphere, and the adjoint method of 4Dvar. The adjoint method is used to initialize the coupled model and predictions are performed for the period of 1980 to 1999.The coupled model is also initialized by forcing the ocean model with observed sea surface temperature and surface fluxes, and by a 3Dvar method, similar to that used by NCEP for operational ENSO prediction. The prediction skill of the coupled model initialized by the three assimilation methods is then analyzed and compared. The effect of the assimilation period used in the adjoint method is studied by using 3, 6 and 9 months assimilation periods. Finally, the possibility of assimilating only the anomalies with respect to observed climatology, in order to circumvent systematic model biases, is examined.

It is found that the adjoint method does seem to have the potential for improving over simpler assimilation schemes. The improved skill is mainly at prediction intervals of more than 6 months, where the coupled model dynamics start to influence the model solution. At shorter prediction time intervals, the initialization using the forced ocean model or the 3Dvar assimilation may result in a better prediction skill. The assimilation of anomalies did not have a substantial effect on the prediction skill of the coupled model. This seems to indicate that in our model the climatology bias, which is compensated for by the anomaly assimilation, is less significant for the predictive skill than the bias in the model variability which cannot be eliminated using anomaly assimilation. Changing the optimization period showed that the period of 6 months seems to be a near optimal choice for our model.

Initialization of unstable coupled systems by breeding ensembles

Eugenia Kalnay, Ming Cai, Shu-Chih Yang and Malaquias Pena
University of Maryland

A major challenge in the design of a coupled ocean-atmosphere data assimilation system is the existence of a wide range of growing instabilities. An effective data assimilation for the longer time scales has to be able to incorporate the slow instabilities of the ENSO background flow into, for example, the background error covariance, since the forecast errors will have a strong projection on these instabilities. Without a special effort to isolate the slow modes in a coupled data assimilation system, the faster but less relevant instabilities that dominate linear tangent models will wipe out the slower but important coupled processes from the estimated forecast and analysis errors (but not from the real analysis and forecast errors!).

To study whether it is possible to isolate the slow, coupled instabilities in the background flow, we have done experiments with breeding, a simple process that mimics ensemble data assimilation. Breeding is a finite-time, finite-amplitude generalization of Lyapunov vectors. In the Zebiak-Cane model (which has only slow modes) we found the characteristics of the ENSO instabilities, and their dependence on season and on the ENSO phase. Minimizing the projection of initial errors on the ENSO instability eliminated the "spring barrier" for 4-6 months, and using bred vectors as initial perturbations improved the ensemble average forecasts. In the NSIPP coupled GCM (which has modes with a wide range of time scales) we were still able to isolate the instabilities of ENSO by using the Nino-3 index as a rescaling variable, and long (one month) intervals for renormalization.

These results suggest that coupled data assimilation designed for seasonal and interannual prediction is feasible and could be based on a coupled Ensemble Kalman Filter using similarly long intervals between the coupled assimilation cycles. By contrast, a coupled data assimilation system based on frequent analysis cycles attempting to analyze modes at every possible time scale, will be insensitive to ENSO instabilities of the evolving background flow and will instead be dominated by the uncoupled atmospheric modes that grow fastest between the analyses. As a result the ENSO analysis and forecasts will not be based on the most efficient use of the observational information.

ESSIC Coupled Data Assimilation Experience

A.J. Busalacchi, R. Murtugudde, and J. Ballabrera
University of Maryland

At ESSIC we have shown the feasibility of the simultaneous assimilation of oceanic and atmospheric observations. The combination of these observations with the ocean-atmosphere coupled model of Cane and Zebiak has been done with a reduced order Kalman Filter, constructed upon the multivariate EOFs (MEOFs) of the model. Our experiments were done after verifying that these MEOFs retain most of the co-variability of the fields to be assimilated. That is, we found that the MEOFs of the model are able to capture the basics of the statistical relationship between the variability of SST, sea level and wind stress anomalies in the equatorial wave-guide. Using an anomaly model allowed us to circumvent the problem of the bias of the coupled ocean-atmosphere models.

When the method was used to initialize an ENSO prediction system, we found that just a few modes were required to obtain convergence for very short predictions, consistent with the premise that these MEOFs are a good tool to represent the state of the system. For seasonal to interannual predictions, we found that there was no convergence on the skill of the prediction as more modes are considered. This indicates that MEOFs are not a suitable basis for prediction. Following these ideas, we plan to combine the assimilation methodology with the method of the breeding vectors, to see if we are able to obtain a basis of functions that provides a good representation of the state of the system while being able to capture the leading modes of the error growth.

Issues for coupled atmosphere-ocean assimilation for seasonal prediction with GCMs

Magdalena Balmaseda, ECMWF

The possibility of having coupled ocean atmosphere GCMs for forecasts for the medium as well as for the seasonal range raises the question of having a coupled ocean-atmosphere initialization system as well. However attractive the idea of a seamless system may look, there are several difficulties of theoretical and practical nature. The most immediate problems are a) the different time scales of the system and b) the presence of systematic error.

The most challenging problem is the presence of two different time scales in a chaotic system (fast atmosphere, slow ocean), and the need to initialize both of them. A 2-tier system approach, where the fast and slow time scales are initialized separately may be a promising way forward.

For the fast atmospheric time scales, the possibility of data assimilation in an atmosphere model coupled to an ocean mixed layer was discussed. The inclusion of the ocean mixed layer may improve the estimation of atmospheric fluxes, and offer a suitable framework for assimilating SST information. The ocean mixed layer could be a common element between the ocean and the atmosphere. Even if the data assimilation in the ocean and atmosphere are done separately, sharing a common element (the ocean mixed layer) may help to maintain some thermodynamical balances.

The initialization of the slow time scale in coupled mode remains an issue. The most immediate problem is that the systematic error in the coupled model is likely to be larger than the systematic error in an ocean forced by analyzed fluxes. Since there are not suitable strategies to cope with systematic errors yet, the quality of the resulting analysis may be degraded. Assuming that there were robust methods for bias correction during the assimilation phase, and that the systematic error would be same during the initialization and during the forecast, applying the bias correction during the forecast phase may improve results. Data assimilation in coupled mode would be an step forward to ensuring that the systematic error during the assimilation and the forecasts phase were the same, and it may lead to the reduction of the initialization shock. The question of the adequate separation of the slow and fast time scales during the assimilation procedure remains unanswered.

Appendix B: Comments Provided as additions to the Draft Workshop Report

Eugenia Kalnay: Another issue discussed without consensus.

III. Are coupled ensemble Kalman Filtering approaches feasible in a coupled system?

Positive arguments

- They are probably the most promising and feasible approach for next generation atmospheric data assimilation
- Ocean Ensemble Kalman Filtering preliminary results are promising
- Coupled EnKF would automatically include coupled instabilities that affect the analysis
- It would also provide a natural approach for estimating model biases and deficiencies (by augmenting the state vector, Anderson, 2001).
- Does not require the development of adjoint models
- Some recent developments in coupled models suggest that systematic errors are smaller than in uncoupled (AMIP) models.

Negative argument

- Computationally expensive (but new efficient approaches are being developed).

Mark Cane

The major problem in this business is model bias. It is largely outside the textbooks for the various methods we use which, at most, just tell you to remove the bias. Not as easy as it sounds. We have to learn how to characterize the bias, which is likely to be state-dependent.

The other main thing I have learned in this business is partly summarized in the abstract of Eugenia's talk. There are lots of initially fast growing modes that die out on their own within a month. You want to concentrate on getting the ones (actually, no more than one or two in the ENSO system) that have staying power. Kalnay et al do it with breeding vectors; we (Xue et al 1997a,b MWR) did it with singular vectors. (There is little difference between the two approaches for ENSO.) Since there are only a few modes to worry about, estimating the *necessary* error covariances *should* be a lot easier. Things are not always as they should be, however.

Can we justify doing data assimilation with coupled GCMs? Wouldn't it be more reasonable to postpone it, putting all resources into fixing the model biases? After 15 years of trying, the vastly more expensive GCMs still don't do any better than statistical or intermediate dynamical models. Coupled GCMs won't do better than the competition until the biases are sharply reduced. Meanwhile, are we wasting substantial resources that could be better directed?

Appendix C: Agenda

Coupled Data Assimilation Workshop, Portland, OR. April 21-23, 2003

Marriott Portland City Center
520 SW Broadway
Portland, OR 97205
503-226-6300

Day 1; April 21, AM

8:00 Continental Breakfast

8:30 Welcome — M. Ji
Workshop Goals, procedures — J. Tribbia

AM Theoretical and practical aspects

Session Chair: Ed Harrison

9:00 Andrew Bennett: Theoretical aspects of coupled data assimilation

10:00 Fei-Fei Jin: Some theoretical aspects with an intermediate coupled model

10:30 Break

10:45 John Derber: Practical aspects of coupled data assimilation

11:45 General discussion

12:00 Lunch

PM Experiences - Potential benefits and/or difficulties

Session Chair: Tony Rosati

1:00 Ben Kirtman:
Coupled Initialization Experiments in the COLA Anomaly Coupled Model

2:00 Joaquim Ballabrera: ESSIC Coupled data assimilation experience

2:30 Discussion

2:45 Break

3:00 Working Group session (Leader: Jeff Anderson)

Issues/topics:
What are the reasons for approaching data assimilation from the coupled perspective?
What are the potential gains and difficulties from the oceanic and atmospheric perspectives?
What are the potential benefits/problems from the predictive and climate communities' perspectives?

Day 2 (4/22)

8:00 am Continental Breakfast

AM: Experiences - Potential benefits and/or difficulties

Session Chair: Michele Rienecker

8:30 Prof Awaji (FRSGC, ES, Kyoto Univ.)

1) Summary talk about DA research in Japan,
2) 4D-VAR elements of Ocean and atmosphere
3) coupled model used for 4D-VAR

9:30 Alexey Kaplan: Coupled assimilation issues from LDEO experience

10:00 Discussion

10:30 Break

10:45 Eli Galanti: Couple model initialization in a hybrid-coupled model

11:15 Eugenia Kalnay: Coupled initializaton by breeding ensembles

11:45 Discussion

12:00 lunch

1:00 Magdalena Balmaseda: Plans and relevant research in the EU

1:30 Tom Rosmond: US Navy real time coupled assimilation system

2:00 Tony Rosati: GFDL and ARCs research priorities

2:30 Discussion

2:45 Break

3:00 Working group session [Leader: Ed Schneider]

Issues/topics:

How should this problem be approached from both theoretical and practical aspects?

What are the first steps that could/should be taken to begin to develop a coupled assimilation capability?

Day 3 (1/2 day):

8:00 am Continental Breakfast

8:30 am Working group session [Leader: Fukumori/T.Lee]

Issue/topic:

The next step: what should we focus on?

a)Theoretical studies?

b) Intermediate/hybrid coupled models?

c) Coupled GCMs with emphasis on ocean data assimilation?

d) Fully coupled ocean-atmosphere GCM assimilation?

10:30 am Break

10:45 am Draft workshop report, outline with designated writing assignments

12:00 Adjourn

Appendix D: Attendees

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