Report of the Argo Science Team Meeting (Argo-I)
March 22-23, Tidewater Inn, Easton Maryland

1. Introduction

The meeting is intended to accomplish the following objectives:

- Review national plans, priorities and commitments in order to begin formulating a strategy for global coverage (Section 2).

- Discuss the technical issues relevant to Argo as a basis for constructing an Implementation Plan (Section 3). The Implementation Plan will be updated periodically during the coming years to reflect technological advances and improved understanding of sampling requirements and national capabilities. The initial draft of the Implementation Plan will be based on Sections 2 and 3 of this report.

- Consider the substantive suggestions for revision of the Argo Design Plan (GODAE Report 5, CLIVAR Report 21), as provided by about 30 non-advocate reviewers selected by GODAE and the CLIVAR Upper Ocean Panel. A revised version of the Design Plan is to be completed in a few months.

2. Status of National Plans for Argo

2.1 Australia (S. Wijffels)

Present Plans:
CSIRO Marine Research has one-off funds in hand to deploy a 10 float pilot array in the SE Indian Ocean northwest of Australia starting in July 1999. The floats used will be Webb Research's new APEX floats with a seabird CTD module. Float missions are sketched to be 10 days long, parked at 1500-1800db. The data will be transmitted in real time by ARGOS and broadcast on the GTS. Deployment is planned from a mixture of RV and VOS.

If they can be of use in testing assimilation or resolution ideas, the data will be freely available for these purposes. The region is currently monitored by several XBT lines and so it will be of interest to determine how much extra information we can gain from an array of floats at roughly the proposed Argo resolution. Past CTD sections in the region suggest strong salinity variability on time-scales from the intra-seasonal to interannual. Suggestions are welcome on deployment, cycling time and float placement.

Potential for expanded participation in Argo:
Because of impacts on the rural sector (a large part of our economy) , improving seasonal climate forecasting is a compelling issue within Australia. If we can argue that Argo can help improve predictions, a case can be made to government. Given the likelihood of other nations seeding the equatorial Pacific, Australia might gain most by putting resources towards observing the Indian Ocean, where SST dipoles have been

identified which relate to winter rainfall variability over the NW and SE of the country. However, this decision has not been made. Australia also has a strong strategic interest in the Southern Ocean, so deployment in the Australian Antarctic sector is also feasible.

A proposal is being prepared to fund future Australian ocean observing activities which includes a request for $1million per year between 2000 and 2005. The proposal will be taken to government departments this year. It is difficult to gauge the likelihood of the proposal's success at this early stage.

Are there plans for float production in-country?
Depending on the level of funding we can achieve (i.e number of floats needed) we would consider this option. The choices of buying vs gearing up to build would need to be carefully costed out and we would need to look hard at the possibility of cheaper floats being produced in bulk in other countries vs a few locally. The cost per float for the SE Indian pilot is projected to be US$20k including setup, prep., deployment and communications (for 2.5 years).

2.2 Canada (H. Freeland)

The approach being taken within Canada to ensure substantial participation is to make participation in Argo part of the Canadian national commitment to the GCOS IOS (Initial Observing System). A large fund has been created within Canada called the "Climate Change Action Fund or CCAF". This fund is designed to fund a Canadian response to the requirement in the Kyoto protocol to monitor the changing climate. On February 23-26th of this year (1999) representatives of the 4 Natural resource Departments (the 4NRs) of the Canadian government met to design the Canadian position on GCOS. The proposal for the Oceans component of the IOS contains as part of the first priority the deployment of a substantial number of P-ALACE floats in support of Argo. The second priority involves completion of the Canadian contribution to the Argo array. We believe that both priorities will be funded, but allocation of funds is at least 18 months away, and there are no certainties. We note that the US is planning on deploying 50% of the full array, or 1500 of 3000 floats. The Canadian economy is about 10% of the US economy, also we note that Canada supported 5.8% of the cost of the WOCE one-time survey, and we (we = the 4NR review team) recommend that Canada support 150 floats. This will probably come to pass.

There are no plans at the present time for manufacture of floats within Canada.

2.3 France (P.Y. Le Traon)

Context
The CORIOLIS working group was formed in 1997 to provide recommendations on the *in situ* data component of the MERCATOR project. It includes representatives of the

main six French agencies dealing with oceanography (IFREMER, ORSTOM (IRD), CNES, FMTO, INSU/CNRS, SHOM) and is led by IFREMER. The group focused on the Atlantic ocean and recommended :

1. To continue and improve the existing observing systems such as the VOS-XBT lines, surface drifters operated by Met-offices, PIRATA tropical Array.
2. To implement a new automatic and permanent *in situ* network covering all the Atlantic and composed of:

⇨ 500 profiling floats (such as PROVOR) as a contribution to the Argo project, basically on a 5° x 5° grid with denser sampling (2° x 2°) in specific areas.

⇨ 100 Eulerian expandable probes EMMA, profiling from top to bottom on a monthly basis on a 10° x 10° grid.

French direct contribution to Argo

The CORIOLIS proposal would represent a significant contribution to Argo proposal. At this date funding has not yet been identified nor committed; most likely it would have to come, at least partly, at the European level.

The possible direct French contribution to CORIOLIS and Argo is discussed below. Some information on present proposals or specific plans for float deployment (pre-Argo) is first given and we pursue on the potential for expanded participation in Argo. A status of profiling float manufacturing in France is finally given.

(1) Specific plans for float deployment (pre-Argo)

Pre-Argo profiling float deployment by France will be made as part of the POMME scientific experiment. POMME is a scientific experiment aimed at understanding the role of meso-scale variability on subduction and on carbon export out of the surface mixed layer in the North-east Atlantic. The experiment will focus during one year (10/2000-10/2001) on a 750km*500km domain centered near 41°N/19°W, and will rely on a wide variety of instrumentation to observe the circulation, water masses and surface production, providing one of the most complete ocean observing system having been implemented in the open ocean. The project is in the implementation phase in France, and is also been developed in the UK.

Profiling float instrumentation that will be used for POMME will consist in :

⇨ 15 prototype floats in the area (41°N/19°W), 11 with T and 4 with T and S capability, at least 10 of which at the parking depth of 1750m. These floats will be launched one year before the experiment (POMMIER experiment) (end of 1999 and beginning of 2000).

⇨ 15 profiling floats in the area parked at 400m, most of them with T and S capability. These floats will be launched from mid-2000 to mid-2001. .

(2) Potential for expanded participation in Argo

France

Following the CORIOLIS group recommendations, it is proposed to start a direct contribution of France to Argo with **50 profiling floats** (PROVOR) deployed by IFREMER per year from year 2001. There is not yet funding commitment on the project but the proposal is a realistic estimation of the expected French participation to Argo. A proposal will be sent very soon to the MENRT (French Ministry of Research) by IFREMER to ask for a financial support for a four year program (2000, 2003). The answer from the MENRT will be probably known by October this year.

Europe (Eurogoos)

The French contribution could be complemented through a European proposal to be submitted to the European Union 5th framework program. The EU proposal will request a total of 150 additional floats. Preliminary contacts have been taken with partners in Germany (Send and Schott), UK (Guymer, King), and Spain (Parilla, Font). An outline of the proposal is given below.

<u>Gyroscope : a project proposal to be submitted to the EU 5th Framework program (</u>*Y. Desaubies with participants from France, UK (T. Guymer), Germany (U.Send, F. Schott).*

The scientific objective is related to long term climate change in the ocean and its interaction with the atmosphere. The problem is to understand how the ocean responds to the NAO, for instance, how large scale temperature and salt anomalies propagate, to observe water mass formation variability, etc ... Several of those questions will require long term observations, which cannot be obtained during the typical three -year EU projects. However, some specific goals towards the general objectives could be reached, such as establishing detailed heat and fresh water budgets, over several seasonal cycles (for a couple of years ?) (the observing system would presumably have a longer time scale). Thus one would consider estimating the various terms : advection (including Ekman transports), storage, surface fluxes, subduction processes, large scale mixed layer budgets, as well as estimates of the upper part of the meridional overturning cell. The field work would center around the deployment of profiling floats, which would prefigure an Argo type system. The time-table for the call for proposals indicates that such a project might be funded for an early to mid-2000 start, which would mean field work starting in 2001.

The area for deployment will cover the North Atlantic, with interest centered around the Labrador and Irminger Seas (Germany), the exchanges with the Northern seas (UK), the formation of mode waters and cross gyre exchanges (France and Spain). The proposal will be co-ordinated with the Atlantic Pilot Project initiative of C.Le Provost. **The EU/FP5 proposal could request about 150 floats (50 floats per year).**

Float manufacturing in France

IFREMER has developed, through industrial partnership with TEKELEC/MARTEC company, a free-drifting hydrographic profiler based on the highly successful MARVOR technology and named PROVOR. As MARVOR it does not need any ballasting operation and the operating pressure can be decided just before deployment:

- the float executes identical programmed cycles of descent, drift at depth at a given pressure for a few days, descent to the start of profile depth, raising, Argos data transmission.
- T (Temperature) or CT (Conductivity, Temperature) measurements are carried out during the descent and/or the ascent phases.
- the parking depth can be set independently of the depth of start of the raising profile
- the profiler is not tracked at depth. It is located only at the surface during the ARGOS data transmission phase.
- the speed of the profiler is controlled during the ascent
- the profiler is able to synchronize the beginning of the rising profiles in order to get synoptic CTD profiles from floats which are not deployed at the same time in an area.
- the profiler should realize up to 100 cycles.
- the profiler can profile between the surface and 2000 m.
- the profilers programme includes a grounding avoidance feature, whereby if it touches bottom before reaching operating depth, it rises to a preset height above.
- the CTD measurements are carried out every 10 seconds and the data are processed before transmission to reduce the amount of information and keep only significant points, as a function of the desired accuracy, using a method which is used to reduce the data of the XBT casts.
- the speed of the profiler during the ascent phase to the surface is about 10 cm/sec.

The characteristics of the sensors are:

	PRESSURE	TEMPERATURE	CONDUCTIVITY
RANGE	2000 dbar	-2 to 35 °C	0 to 70 mS/cm
ACCURACY	+/- 5 dbar	+/- 0.05 °C	+/- 0.05 mS/cm
RESOLUTION	1 dbar	0.01 °C	0.01 mS/cm
TIME OF RESPONSE	1 sec	1 sec	1 sec
STABILITY	< 5 dbar/year	< 0.05 °C/year	<0.05mS/cm/year

These characteristics concern the entire measurement system, including the sensors and all the necessary electronics and data processing to provide data which can be directly used by the final user.

PROVOR-T : sensors are provided by SEASCAN - Sea results available

PROVOR-CT : present providers are FSI and SEA BIRD - under development

The present price of PROVOR-T is 12500 US$ (for a series of 100).

2.4 Germany (U. Send)

There is no national Argo commitment in Germany at this point nor are there any plans for national Argo funding at present. This is true both for the funding agencies and the operational agencies in Germany.

Germany will participate in an Argo proposal to the European funding agency (‘Framework 5’ proposal) and is likely to concentrate on the subpolar gyre (Labrador Sea, Irminger Sea) in this project. The total volume of the EU proposal may be 150 floats for the 3-year period of the program (see description in 2.3).

There are opngoing low-level float activities (5-10 floats per year) in Germany, from various funding sources. These use a variety of floats (PALACE, SOLO, APEX, APG), thus expertise with different technologies exists. The activities include the

- Labrador Sea (Schott)
- N. Atlantic sections (Koltermann)
- Mediterranean (Send)

Infrastructure for Argo deployments will exist in the subpolar gyre, due to frequent activities there in the framework of national initiatives.

New floats are under development at a German company (APG). They are not operational yet, but prototypes exist that are being used for field tests. A few years from now they may be an option for Argo, at least in the national setting.

2.5 Japan (K. Takeuchi)

At this moment, two Argo-related projects are planned in Japan. In addition, there are several other projects in which researchers are interested to use profiling floats.

A group of researchers in Japan Meteorology Agency, Maritime Safety Agency and Fisheries Agency is proposing a project called SODA(Studies on Optimum Design for Argo), originally for 3 years starting from FY1999. It is not funded for FY1999, but taken as a feasibility study for one year in FY1999. As a part of feasibility study, they are planning to deploy three profiling floats, one in the Subtropical gyre interior region, one in the western boundary region and one in the eddy abondant area between the Subtropical and Subpolar gyres. If the project is funded, it will last for three years starting from FY2000. In the project, the optimum design and improved data assimiliation are studied along with deployments of profiling floats (around 70 per year).

A new project called "Frontier Observing System" is funded and will start this summer. The program consists of research in two areas - climate variation research and hydrological cycle research. The former includes three core research topics, "western boundary current study", "air-sea interaction in the western Pacific and Indian Ocean", "subsurface circulation". The third one is closely related to Argo, and some profiling floats are planned to be used in the second. The total number of floats used in the projects is expected to be more than 100 per year.

2.6 U.K. (B. King)

The status of the UK contribution is evolving rapidly at present. A high-level meeting was held on 11 March 1999 at which heads of interested government departments and agencies discussed the likely level of UK contribution. At this stage the main partners who have expressed strong interest are the DETR (Department for Environment, Transport and the Regions), UK Met Office and NERC.

DETR is the government department responsible for Environment, and presently provides substantial funding for climate research at the Hadley Centre, part of UKMO.

UKMO is likely to be the UK lead agency for Argo. UKMO runs an operational ocean forecast model (FOAM). UKMO has the necessary skills and infrastructure to handle the real-time aspects of the UK contribution.

NERC, through its funding of labs and academic researchers can be expected to provide funds for analysis and interpretation of data. Also opportunities for deployment from research ships.

Outcome of 11 March meeting: The details of the meeting have not yet been announced. It is likely the UK government will want to wait for a suitable 'occasion', perhaps within the next 2 months, to announce any contribution. Our expectation is that DETR will fund 5 percent of the global total of floats as a contribution to the operational programme (ie 150 floats). Further floats, funded by NERC, for example, would be in response to research proposals submitted through the usual routes. It is possible to conceive of perhaps a further 50 floats funded this way to enhance sampling density in certain areas. Such contributions would typically be known about one to two years ahead of deployment.

Focus of the UK program:

Likely to be NE Atlantic, perhaps concentrating north of a line from Greenland to the Azores.

Efforts will be made to secure float deployments in the Atlantic sector of the Southern Ocean.

Timing of funds:

Unknown at present. More information may be available soon.

Possibilities for UK float manufacture (both very tentative at this stage):

The UK agent for Webb Research Corp has indicated that if there is a possibility of manufacture of Webb floats under license in Europe, he would be interested in being involved.
Ocean Scientific International are interested in sensor issues, and have expressed an interest in teaming up with a manufacturer for the construction of floats, combined with some sensor development.

2.7 U.S.A. (D. Roemmich)

The U.S contribution to Argo will be implemented by a national consortium of academic, government and industry partners through the National Ocean Partnership Program (NOPP). Academic and government partners include Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, University of Washington, University of Miami, NOAA Atlantic Oceanographic and Meteorological Laboratory and NOAA Pacific Marine Environmental Laboratory.

A NOPP proposal has been submitted by the consortium for Pacific Basin Extended Climate Studies (PBECS)/Atlantic Climate Variability Experiment (ACVE)/Argo startup activities beginning in 1999, consisting of:

- 50 floats per year in tropical N Atlantic and tropical S.E. Pacific. The float deployments are central to PBECS and ACVE objectives.
- Instrumentation development (air deployment, improvements in communications and salinity).
- Initial construction of real-time and delayed mode data systems including salinity.

For 2000:

The administration’s budget request for $4M per year for NOAA to support autonomous profiling float arrays in the Pacific and Atlantic is pending in the U.S. Congress. If this is successful, an expanded NOPP proposal for Argo implementation will be submitted in early 2000. The U.S. effort in Argo may amount to at least 300 floats per year.

Foci of the U.S. program:

- NOAA: Atlantic and Pacific for enhancing seasonal to interannual (or longer) predictive capability.
- NSF: CLIVAR basin-scale experiments in the Pacific (PBECS) and Atlantic (ACVE).
- Additional agency participation is possible.

2.8 Prospects for a global array

Plans for a global profiling float experiment are proceeding very rapidly. Fast progress is due to an unprecedented level of cooperation between researchers and operational agencies nationally and internationally. Attention has been drawn to the high value of the global float array for purposes of climate research, seasonal to decadal prediction, and initialization of operational models. There is a broad consensus that a global array consisting of around 3000 profiling T/S floats is practical and of the highest priority. If national plans go ahead on schedule, total deployments could exceed 700 floats per year as early as 2001.

It is recognized that specific national interests are mainly focused on the Atlantic and Pacific Oceans. Cooperative agreements will be needed to implement a global array, with all nations necessarily contributing to regions outside of their highest priorities. For a global array at 3^o spacing, the total number of floats is about 629 in the Atlantic, 1303 in the Pacific, 441 in the Indian, and 970 in the Southern Ocean (south of 40^oS). Special attention is required to achieve adequate sampling of the Indian and Southern Oceans. Accordingly, small working groups were formed to discuss the Indian and Southern Ocean sampling issues. Their findings follow:

Argo in the Indian Ocean

The Indian Ocean is increasingly being recognized as influencing interannual variations in other parts of the globe, and more forecasting systems are beginning to include the Indian Ocean in their domains. From a scientific standpoint, this basin is as poorly understood as is the South Pacific and Southern Ocean, and much basic ‘exploratory science’ needs to be done on the circulation and seasonal cycle. A strong case can likely be made to nations outside the Indian Ocean region that it is in their direct interest to implement Argo in the Indian Ocean. The impact of Indian Ocean data on the skill of seasonal-to-interannual prediction should be explored and exploited.

Context:
Argo exists within the CLIVAR/GOOS framework. There is already an XBT monitoring network in the tropical Indian Ocean, and there is the prospect of Japan extending the TRITON array into the eastern Indian Ocean. Along with Argo, these basic elements are a firm foundation for a useful Indian Ocean observing system.

Needs and Current Proposals:
For the Indian Ocean north of 40^oS, a float array at Argo resolution requires about 450 floats, or about 120 floats deployed per year to ramp up to full resolution in 4 years. Currently, the two nations expressing definite interest in seeding the Indian Ocean are Japan and Australia. Japan’s float effort is estimated to be ~70 floats/year initially while Australia may achieve 50 floats/year. If roughly half of these are deployed in the Indian Ocean (60/year) we are halfway to full Argo resolution in the Indian Ocean under existing proposals. Both the US and UK have indicated a willingness to deploy some floats in the Indian Ocean and may help complete the array. The French community may have a pool of 50 floats for deployment, some of which could be attracted to the Indian Ocean through proposals. The potential is there to get full Argo resolution in the

Indian Ocean, but coordination and encouragement of proposals and logistics will be required.

What to do:
The idea was advanced to form a planning/implementation group for Indian Ocean Argo/GOOS activities, likely lead by Japan and Australia. It was generally agreed as a good idea, though its scope was not agreed upon (full GOOS or just Argo). Rather than decide without the likely players present, a list of possibly interested Indian Ocean researchers was formed who could be canvassed:
1. whether they were interested in supporting Argo in the Indian Ocean.
2. about the need for such an implementation group

S. Wijffels will poll this list and others in the community, and then report back on whether such a group needs to be formed or whether this work can be achieved within present CLIVAR/GOOS structures.

At the end of our short meeting, it seemed Argo in the Indian Ocean might well come to fruition, but that Australia and Japan will have to take to lead to make it happen.

Argo in the Southern Ocean

The Southern Ocean will clearly be the greatest challenge for implementation in Argo. Its requirement for about 970 floats, coupled with its remoteness will make it a substantial challenge. Three aspects of the Southern Ocean make it a unique region for Argo and GODAE:

First, its characteristics – it is the only region of circumglobal flow connecting the three oceans. A large part of the region is subject to seasonal sea-ice coverage. Salinity is particularly important in stratification. Strong currents extend to the bottom. These characteristics suggest careful examination of profiling, parking depth and coverage requirements as distinct from the other oceans. Technological challenges result from the seasonal sea-ice. Lifetime of salinity sensors will be particularly important for the Southern Ocean.

Second, logistics – historically, few data are collected in the Southern Ocean due to lack of sensor delivery systems. Development of air-deployed floats may be very important for populating parts of the Southern Ocean network. High current velocities and circumglobal flow may allow for population of remote regions by using intelligent upstream deployments.

Third, driving philosophy – Because of the lack of data in the Southern Ocean, exploration and discovery may motivate float deployments more than well-understood operational requirements. Better understanding of the Southern Ocean is believed to be important in assessing global climate change. Argo could be important in quantifying Antarctic Intermediate Water formation, for example. The difference in motivating factors may influence which national agencies are approached to build the Southern Ocean float contributions.

3. Implementation Issues for Argo

3.1 Deployment strategy.

Argo floats will be deployed by Volunteer Observing Ships (VOS), aircraft, and research vessels. VOS deployments have been successfully implemented (see below) and a test of aircraft deployment is planned for mid-1999. Dedicated use of research vessels will be minimized due to the high cost, but research vessels with planned trips to remote regions may be very useful. The distribution of XBT and MET reports demonstrates that much of the ocean is accessible from VOS, particularly if dispersion of floats by mean and time-varying flows can be exploited to fill gaps between VOS routes. Studies are needed of the relative efficiency of VOS deployment/dispersion versus aircraft deployment for achieving optimal float distribution.

VOS Deployments of PALACE Floats (S. Riser)

Since 1997, the majority of the approximately 75 floats deployed by the UW group in the western N. Atlantic have been deployed from VOS. These ships are typically commercial vessels transiting between New York, Norfolk, or Miami and Spain or Italy. The particular vessels used were chosen because they have also been involved in the NOAA VOS XBT program for a number of years, and the degree of cooperation between scientists and the shipping companies was already good. A ship rider has been sent from the laboratory on each cruise, typically deploying 4-8 floats per trip.

For deployment, the floats are packaged in a custom made 5-sided box held together by heavy cord and a dissolvable link; each box costs approximately US$50. The boxes are shipped with the floats and assembled on board the vessel prior to deployment. For vessels where the deployment deck is near the waterline, the box is simply heaved over the stern of the ship. For larger vessels, where the deployment deck can be as much as 20 m above the waterline, the box is lowered to within a few meters of the sea surface on ropes, then let go as the ropes are cast away. Once in the water, the link holding the box together dissolves and the float is ejected into the water. These deployments are done at full cruising speed, 20-30 knots. A more detailed description of this process, with pictures, can be found on the web at http://flux.ocean.washington.edu.

A total of 48 instruments have been deployed in this manner. Of these, 47 are operating properly. Both R1 and APEX floats, with and without SBE CTD units, have been deployed using VOS.

3.2 Parking depth

The issue of parking depth is closely related to deployment strategy. Relatively shallow (thermocline depth) parking will give more rapid dispersion into gaps for floats that are deployed along sparse VOS lines. Alternatively, if air deployment is used to place floats near their nominal position, they will remain closest if a deep parking depth is used. The ideal situation for float distribution would be to air-deploy a large fraction of floats, with parking at a deep (2000 m) level. However, practical requirements plus some national priorities for velocity sampling at shallower levels will result in some variety of parking depths. Array planning will need to take this diversity of parking depths into account.

3.3 Salinity stability

Stability of salinity sensors is recognized as the most difficult technical issue for Argo. The following addresses the most recent experience with CTDs in profiling floats and plans for improving on the present generation of sensors.

Experience with SeaBird CTDs in Profiling Floats (S. Riser)

During the past two years some progress has been made in making stable estimates of salinity from PALACE floats. We have used both R1 and APEX floats from Webb Research with the SBE-41 integrated CTD unit from SeaBird on floats deployed in the western N. Atlantic. In all, we have had 3 R1-SBE units in the water for more than 1 year and 7 other APEX-SBE units in the water for times varying from 1 to 6 months. In all cases we have found that the salinity measured by the float is in general agreement with the T/S relation as determined from historical data, with the standard deviation of S(T) from the floats usually considerably smaller than the standard deviation in the historical data. Comparing the float-inferred values of S(T) from profile to profile, we have found that in the portions of the T/S curve where there is little natural variation (between about 16^{o}C and 7^{o}C in the western N. Atlantic), the inferred values of S(T) vary by less than .01 PSU (sometimes as little as .004 PSU) over times as long as 420 days. No editing or adjusting of the T/S data has generally been necessary; the data sent through the ARGOS system has been the final data.

Correction of salinity of floats with FSI sensors (G. Reverdin)

We are interested in finding whether biases in salinity can be identified on profiling floats equipped with an FSI sensor in near-real time in situations where spatial coverage is comparable with the Argo requirements. For that, we considered floats in the Irminger and southern Labrador Sea between November 1996 and February 1997. These floats were deployed for ACCE and the data were communicated by Breck Owens, Russ Davis, Sheldon Bacon and John Gould. At a given time, there was between 30 and 40 floats in the area, and some profiles from 64 floats reached the isotherm 3.3C in the deeper part of the profile. Away from the boundary currents on the rim of the Irminger and Labrador Seas, the profiles of these floats reached the 3.1C potential temperature in the upper part of the weakly stratified layer associated with the Labrador Sea water.

A map of the average salinity on the 3.1C isotherm shows large spatial variability with spatial contrast of more than 0.15 across the domain. This is more than one expects based on hydrographic sections across the basin, which suggests that some of the profiles have an erroneous salinity. (Profiles for 4 floats have been a priori removed before plotting, as their salinity was well off what is expected.) We tried to identify possible biases by two methods:

1: mapping by objective interpolation the large scales of the field (over 500 km) and interpreting the residual difference between the individual data and the field as an estimate of the bias.

2: comparing nearby profiles from different floats (also a least-square method).

Both methods are rather coarse and could be improved. The first would probably give an underestimate of the error and the second an overestimate. This later point can be seen on the average field for the drifters corrected by the estimated biases, which presents less spatial structure than one expects at this depth. We applied the two methods on various isothermal surfaces, and for 2 months periods. Method 2 seems to give the most consistent results. Often, the identified biases did not evolve much in time over the course of 6 months to a year, and biases estimated by the two methods are correlated (0.89) with biases of method 1 being larger than by method 2. Typically, most biases identified are small (less than 0.04 psu), although there are a few larger ones, in particular corresponding to too low salinities.

We have only hints that applying the estimated biases is improving the overall fields. For example, the isopycnal depths have more regular contours once the corrections are included (and the standard deviations of the individual estimates is less). We also have the possibility to compare the suggested corrections with biases estimated by comparisons with near-by CTDs by Bacon et al. (1998, SOC Internal Document No. 39). This can be done for four floats that were drifting in this part of the Atlantic, and the biases estimated by method 2 correlate well (0.90) with the ones given by Bacon et al. 1998), although amplitudes are much less in this case, and uncorrected biases could reach 0.02 psu. We also compared the float salinities at 15m with the near-surface data of thermosalinographs on board of two ships of opportunity (the "Godafoss" equiped by NOAA, and the "Nuka Arctica" equiped by LEGOS/IRD). The two sets of data show less scatter in winter, but there are only 25 values which can be compared in that way with ALACES being lower by 0.003 and the rms scatter being 0.045. Applying the corrections on the biases does not change significantly the statistics. The data in other seasons are more scattered, which we attribute with more patchiness of the near-surface fields and vertical gradients between the near surface and 15m (ALACE salinity is often higher).

Planned U.S. work (NOPP proposal, U.S. Float Consortium) on development of stable salinity sensors:

Developments of improved, low power, stable conductivity sensors are presently underway. Both Sea-Bird Electronics (SBE) and Falmouth Scientific Instruments (FSI) have made new prototypes available to the float community. The main limit to sensor stability is bio-fouling. Improved communication will help by reducing near-surface exposure from the one day needed at present to an hour or less. The main limit to bio-fouling is maintaining adequate biocide concentration without depleting the poison through mass transfer to seawater. The apparent solution is to protect the biocide and sensor from mass-transfer during the long periods when no measurements are being made.

The SBE CTD is a two-electrode (platinum) cell operated inside a pumped system with anti-fouling at both ends of the cell. Between profiles, the pump stops and biocide concentration builds up in the stagnant water around the cell. A new low power pump will be implemented specifically for long autonomous deployments like ours. The newest FSI CTD uses two cells arranged so that the measurement volume is limited to the interior of the cells. An enclosure for the FSI system will use electrolysis to generate chlorine as a poison in the sealed interior volume when the sensor is not in use. The new sensor packages will be integrated into SOLO and APEX float designs and field-tested in late 1999- early 2000.

A third approach will be to design and build a system consisting of double four-electrode cells that are less fully enclosed than the SBE cell and do not use an external pump. The cells will be sealed with shutters (like FSI is implementing) to protect a conventional biocide and allow its concentration to build up. Double cells will provide a measure of cell stability through comparison. Opening up the enclosure will minimize thermal lags caused by the enclosure and eliminate the need for a pump. Finally, a four-electrode cell should be less sensitive to fouling since the measurement electrodes will operate at very low current density.

3.4 Communications

Summary:

Present work is with ARGOS and Orbcomm communications, plus testing of the Iridium global cellular network as a possible future option. In addition to cost, issues related to communications are:

Data quantity: Requirements are 2 kilobytes per profile (compressed), allowing temperature and salinity precision of .001 at 2 m intervals from 0 to 500 m and 5 m intervals from 500 to 2000 m.

Time spent on the sea surface: The target is 30 minutes or less. Minimizing this time will lower risk to the instrument and its sensors (i.e. bio-fouling) as well as decreasing the displacement of the float by surface currents.

Power consumption: The target is for communications to consume less than 10% of the energy budget per cycle (or < 1kJ).

It is not possible at the present time to focus on a single communications system, as several have the potential to meet requirements in the near future. Additional testing and/or deployments with ARGOS, Orbcomm and Iridium systems are planned in the next year. The data system will need to accommodate data from more than one communications system.

Present status and plans for communications options for Argo (B. Owens)

Transmission of the profiles of temperature and salinity to 2000 m depth with high spatial resolution (2 dbar) in the upper ocean (to 500 dbar) and moderate resolution below (5 dbar) will require a significant increase in satellite data communication bandwidth compared to that available using the present ARGOS system. It is also desirable to increase the resolution of the transmitted data to a level greater than the precision of the measurements so that the communications link does not limit the quality of the data. Using simple compression algorithms, Argo profiles of temperature and salinity will be less than 2000 bytes. An improved data communication system should also decrease its use of electrical energy to minimize the batteries required for the floats and minimize the time spent on the surface communicating.

There are three choices for improved data telemetry: an improved ARGOS, ORBCOMM, or Iridium. All three systems will require GPS receivers either for positioning or accurate time keeping.

The ARGOS system is being upgraded. The first 2nd generation receiver system is now in space on NOAA K. Additional 2nd generation systems will be launched in late 1999 and 2001. The minimum time between messages can be reduced to 20 seconds, effectively doubling the data transfer rate. The receivers also have an increased sensitivity of 2 dB which will allow a decrease in the float transmitter power output. Use of a GPS receiver with satellite ephemeris data in the float would allow it to only transmit when a satellite is overhead. However there would be no way of updating this data on the float or responding to changes in satellite usage until two way communications is available in the late-2000 time frame. Starting with the system on the ADEOS-II satellite, which is to be launched in 2000-2001 an acknowledgement will be sent from the satellite upon receipt of the message. A high data rate (4500 bps) channel and full two way communications capability will be available with the 3rd generation system to be launched in the 2003 time frame. In summary, the ARGOS system is evolving from the present system with immediate savings of order of a factor of 2-3 with an ultimate reduction by a two orders of magnitude with short surface times possible by 2003. Existing antennas will have to be augmented to receive GPS. The present tariffs, which are approximately $10 per day for positions and data transfer, are negotiable under the international ARGOS Joint Tariff Agreement.

The ORBCOMM system is a low earth orbit, two-way, data transmission system consisting of a constellation of approximately 26 satellite (presently there are 23 operational satellites). This system has two modes, a store and forward system using 239 byte messages when only the transmitter is in view of the satellite and a bent-pipe mode when the down-link sites are also in view. In either case, it is a polled system where the satellite broadcasts its presence and controls the data transfer. At present there are 4 down-link sites in the US and one in Europe with additional sites planned for Australia and Asia. The system is a polled system operating at 2400 baud in the 160 (?) megahertz frequency band which means that the float antennae will have to be approximately 50% longer. Although positions can be obtained from ORBCOMM, the float would be equipped with a GPS receiver necessitating a dual-frequency antennae. Worst-case delays waiting for satellite coverage would be 30 minutes. Once satellite coverage is available, data transfer would be completed in less than 1 minute. ORBCOMM is presently transitioning to an operational system. We have successfully used the system in the laboratory. Data from subsurface instruments on a surface mooring near the Canary Islands is presently being sent back to the University of Bremen using ORBCOMM. Provisional tariffs are $11.50 per Kbyte and transmitters presently cost the same as the ARGOS radio transmitters used in the present profiling floats. A meeting between the US funding agencies and ORBCOMM is being set up for later this year to investigate possible funding scenarios and viability of the system. A prototype ORBCOMM float should be deployed by summer 1999.

Iridium consists of 77 satellites providing global coverage for both voice and data communications and is expected to be comparable to the present cellular phone system. Voice communications is now available and improving rapidly. Data communications is expected to be available later in 1999 and will operate at 2400 baud. Tariffs for data communications are presently unavailable, however voice usage is priced at $5-10 per minute. Iridium uses a frequency band close to that used by GPS. Motorola Iridium handsets presently cost $3000. Alternate sources for data only units will be available in the near future at a price approximately half that of the handsets and will allow access to GPS time and position data which is used by Iridium to locate the handset. The higher frequency used for Iridium means that an antennae shorter than that presently used for the floats could be used for both Iridium data communications and GPS positioning. Plans are to deploy an Iridium float as soon as possible.

3.5 Energy Budget

Considerable progress has been made on lowering energy requirements in the past 6 months, with improvements due to use of efficient single stroke pumps and better energy use in communications. Energy budgets were presented for SOLO, APEX and PROVOR floats. Results were similar for the three, and in all cases battery lifetime was projected to be about 200 cycles to 2000 m profile depth, using either OrbComm or improved ARGOS communications, SBE (with a new low-power pump) or FSI CTDs and 4000 kJ battery packs.

On the basis of the energy budget and the desirability of a deep profile depth (for scientific and salinity calibration objectives), it was agreed that 2000 m should be the target profile depth. It is noted that SOLO, APEX and PROVOR floats all have capability to program parking depth and profile depth independently, so adoption of a target profile depth of 2000 m does not require a similar parking depth.

3.6 Cost of Argo

No cost estimate can be valid in all countries. However, it was thought that experience in the U.S., where profiling floats are now being produced and deployed in substantial quantities, would be a useful index for the cost of the global program.

Cost of floats: presently about US$12,600 for SBE-equipped instruments. It is assumed that economies of scale will reduce the unit cost to about US$11,000.

Preparation of instruments, shipping and deployment from VOS. Estimates are US$500 - $1500 per instrument, contingent mainly on the continuing need for trained technicians on VOS deployments.

Data transmission. A cost of US$20 per cycle is estimated, resulting in 4-year total cost per instrument of $2080 for 14-day cycling or $2920 for 10-day cycling.

The data system, including real-time and delayed mode quality control, storage and data availability, and support for PI effort related to the data flow. This is difficult to estimate since there is little previous experience with operational salinity measurement. It was suggested that costs associated with the TAO network be used as yardstick.

Float lifetime. The cost of the float network depends critically on the mean lifetime of floats. It was thought that a 4-year lifetime is overly optimistic at present but should be realized in the near future. Lifetimes based on energy requirements and battery capacity are greater than 5 years.

3.7 The Argo Data system

The elements of an upper ocean temperature and salinity data system for Argo are outlined below. It is thought that the Argo data system should evolve from the present Upper Ocean Thermal Data Centers (UOT DACS) in a way that is inclusive of all forms of real-time upper ocean temperature and salinity profile data. It is recognized, however, that quality control of salinity data is a much more difficult proposition than temperature. For salinity quality control, it is recommended that partnerships between data centers and float/salinity experts be built in order to produce the best possible data. Participation by scientists in the data system should be an explicitly budgeted cost of Argo deployments. Additional work on the data system is planned over the next several months.

Outline of the Argo Data System (R. Molinari)

- Data transmission. The relay of data from measurement platforms to data centers is intrinsically problematic in VOS XBT networks. The nature of the problem is greatly reduced with floats since data are automatically transmitted via satellite. Argo deployments may use a combination of satellite communication systems. However, these automated transmissions will ensure instrument identification and attachment of appropriate meta-data to profile formats.

- Real-time quality control. There are two levels of quality control required. The first is "real-time" and includes procedures for temperature and salinity profile qc prior to insertion on the GTS for distribution to the user community. Temperature profiles will be reviewed using the procedures developed as part of the Global Temperature and Salinity Profile Project (GTSPP) and implemented at various national and international data centers. The automated procedures include comparison of the profiles with climatology to identify outliers. Profiling float data collected by AOML in the tropical Atlantic are presently being quality controlled using this procedure. New procedures are being developed that not only compare the temperature values at pre-selected depths but also compare profiles of temperature gradients to identify erroneous profiles. After testing, these new methods may be implemented.

New procedures are also required for the salinity profiles. These will be built on statistical measures similar to temperature. The scarceness of historical salinity data means that the technique initially must be crude. However, this shortcoming is partly offset by the fact that stable deep T/S in tropical and subtropical domains provides important information, to be used in flagging outliers and possibly in re-calibration. Histories of salinity from individual instruments will be taken into consideration, and the system will build on experience gained in ACCE float deployments.

- Data tracking: Once collected it is essential to ensure that data get to users. For the global XBT network, a set of "pipelines" define the path of data from VOS to user. Taps are placed in the pipeline at strategic locations. Data counts are made at the taps and discrepancies are noted. When differences are greater than some predetermined values, causes are determined and problems remedied. Experience shows that causes of problems are varied (e.g., from changes in software at various locations in the pipeline to incomplete transmissions on the GTS). Continuous monitoring is necessary for a high rate of data delivery. Float data will follow the same pipelines.

- Delayed-mode quality control: Delayed mode quality control is required to ensure that a careful scientifically reviewed data set is available to present and future researchers. In this process, it is necessary to use as much upper ocean temperature and salinity data as possible. Individual float profiles must be compared with neighboring floats as well as XBT, XCTD and TSG data to generate products for comparison. For example, temperature maps using neighboring floats and XBTs can be used to identify outliers. Another essential element of delayed-mode qc is examination of sequences of profiles from individual instruments by a scientist, using information from the history of each instrument as well as from nearby instruments.

- Evaluation of the data: A final tap on the data pipeline is located at assimilation centers and represents data not used in the assimilation. Once implemented for Argo data, the discarded information will be reviewed in an attempt to determine if the problem is with the instrument or with the assimilation procedure. If the problem is with the data, solutions at the data collection end will be determined and implemented if possible (i.e. subsequent data from a float should be appropriately flagged). If the problem is with the assimilation system, revisions in the procedure will be implemented. This last step in the end-to-end data system will ensure that the users make maximum use of Argo data.

The use of Argo data for GODAE. (P.Y. Le Traon)

GODAE is a project that will integrate in-situ, remote sensing data and models, while aiming to maximize the benefits from the data (in particular altimetry and Argo). The GODAE belief is that the best use of data is when data are integrated into ocean models using effective assimilation techniques. One measure of success for GODAE and Argo will thus be the ability to provide:

1. directly useable Argo data (in near real time) to GODAE modeling/assimilation centers

2. useful GODAE analyzed fields as a better tool for Argo data interpretation

To achieve these goals, it will be necessary to develop (and test with actual data) effective assimilation techniques of profiling float data (i.e. retaining all the information of float data with an "optimized" merging with other data and model dynamics). This is not an easy task and it will require joint work between the modeling/assimilation and float communities. We need first to understand the data information content and model/data errors. A methodological work on assimilation (integration) starting from simple to more complex methods is then needed.

Initial joint work on profiling float and altimeter data integration is presently in planning. The work should start in a small region where float density is similar to what we expect from Argo (most likely the North Atlantic -ACCE). Inter-comparison exercise with altimetry and model(s) to better understand the profiling float and altimeter data information content and to quantify model/data errors should first start (large scale/mesoscale signals, vertical structure, barotropic signals, geoid and sampling errors...). Assimilation tests with simple methods (existing) and development of more complex methods and analysis of assimilation fields should follow. As a first step into this direction, B. Owens and P.Y. Le Traon informally agreed to work together on the inter-comparison of P-ALACE and altimeter (T/P and ERS-2) data in the North Atlantic. Results will be reported at the next Argo meeting.

4. Remaining issues for revision of the Argo Design Plan

The Argo Design Plan was mailed to about 50 non-advocate reviewers selected by the chairmen of GODAE and the CLIVAR Upper Ocean Panel. Approximately 30 responses were received. The responses, plus a summary of them, were passed to the Argo Science Team to form a basis for revision of the document. A few of the revisions were incorporated in the published version of the Design Plan (GODAE Report No. 5, International CLIVAR Project Office Report No. 21). A more extensive revision of the document is underway, with a target date of mid-1999 for completion. It was felt that several of the suggestions needed to be discussed by the full Science Team:

• Strengthened treatment of the need for systematic salinity measurements. This part of the revision will be carried out by S. Wijffels during the next month, using material from R. Schmitt's GOSAMOR document and other previous work as a basis.

• Latitude dependence of float separation. The justification for the present sampling specification, 3^{o} separation in latitude and longitude (hence greater float density at high latitude), was reviewed. The committee saw no reason to change the specification for the time being – until further optimal design studies are carried out or until experience with the array suggests a more effective distribution.

• Design Plan Section IIIE (The needs for Argo in testing and constraining ocean and coupled models of the climate system). "Numerical Argo Float Design Studies: A Status Report" has been written by D. Stammer and will be used in revision of this section. This report includes results from two numerical experiments on dispersion of floats in multi-year runs. It also describes plans for Argo numerical design studies.

• Argo as a stand-alone system versus its degree of interdependence with Jason altimeters. The committee agreed that the published version of the Design Plan (as revised from the reviewed version) is appropriate in this regard.

• "Principal achievements of Argo" – It was agreed that the Design Plan should include a listing of the major achievements anticipated from a 10-year time-series of the Argo network. The list was discussed as follows.

Draft version of "The Principal Achievements of Argo"

(1) Obtain an unprecedented dataset for model initialization, data assimilation and dynamical consistency testing of the next generation of global ocean and coupled models.
(2) Enable realistic operational real-time global ocean forecasting for the first time.
(3) Produce an accurate global climatology, with error bars and statistics of variability and valid for the specific period of the array, of monthly mean temperature and salinity as a function of depth.

(4) Produce accurate time-series of heat and freshwater storage (globally) and of the temperature/salinity structure and volume of the world's intermediate and thermocline water masses.
(5) Provide large-scale constraints for atmospheric model-derived surface heat and freshwater fluxes.
(6) Complete the global description of the mean and variability of large-scale ocean circulation, including interior ocean mass, heat and freshwater transport - the equivalent for large-scale ocean circulation of a real-time synoptic upper ocean WOCE.
(7) Determine the dominant patterns and evolution of interannual variability in temperature and salinity, e.g. for analysis of coupled modes of air/sea interaction. Discover other ENSO-like phenomena in the global oceans and their impact on improvement of seasonal-to-interannual atmospheric forecasts.
(8) Provide global maps of the absolute height of the sea surface, with accuracy of about 2 cm on periods of a year and longer – allowing Jason(altimeter)/Argo combinations to examine a broad range of space- and time-scales.
(9) Enable the interpretation of (altimetric) sea surface height by determining the statistical relationship between sea surface height and subsurface temperature and salinity variability.
(10) Directly interpret sea surface height anomalies - for example due to global sea level change, El Nino, etc. – by separating them into contributions due to the effects of (i) E-P, (ii) differential heating and cooling, (iii) advection of heat and freshwater, and (iv) wind-driven redistribution of mass.

5. Other

5.1 Expanding international participation in Argo

The Argo Science Team is largely representative of nations with plans for production or procurement and deployment of Argo floats. Many other countries are interested in Argo and can participate by providing ship time or logistical assistance or through modeling and assimilation activities. Broad international participation in Argo and use of Argo data is strongly encouraged. Discussion focused on how to communicate the opportunities to potentially interested nations. The chair agreed to:

- Establish an e-mail list for subscription by interested parties. Information and notices of interest to Argo will be posted to this list. This list has been established subsequent to the meeting. Messages may be sent to the list by addressing them to argo_info@sio.ucsd.edu. The initial subscription list is taken from meeting participants. To subscribe or unsubscribe send email to listserv@sio.ucsd.edu with the body of the message containing either:
add email_address_to_be_added argo_info or
delete email_address_to_be_deleted argo_info
- Seek resources for an Argo web site.

It was also agreed that, if possible, Argo should be represented by a member of the Science Team at the IOC meeting in Paris in June. Material on Argo was included in a recent presentation at the IOC/WESTPAC meeting.

5.2 Argo liason with private companies

The chair noted that several private companies had inquired about possible attendance of the Science Team meeting. The consensus of the Science Team is that attendance of future Science Team meetings by representatives of private companies is not appropriate. Private industry should be kept informed of the work of the Science Team and the Science Team should solicit information as needed. Communication and interaction between scientists and private companies is strongly encouraged. It is recognized that Argo will not succeed without strong participation by private industry. However, these interactions are thought to be most effective at the level of individual scientists. The presence of competing commercial interests at meetings of the Science Team would pose a variety of potential problems.

5.3 Membership/ next meeting

The present membership of the Argo Science Team is:

Dean Roemmich (U.S.A., chairman)	Bob Molinari (U.S.A.)
Olaf Boebel (South Africa)	Breck Owens (U.S.A.)
Yves Desaubies (France)	Steve Riser (U.S.A.)
Howard Freeland (Canada)	Uwe Send (Germany)
Brian King (U.K.)	Kensuke Takeuchi (Japan)
Pierre-Yves Le Traon (France)	Susan Wijffels (Australia)

It was agreed that Science Team members attending the Global Ocean Observations Conference in St Raphael France in October will hold an informal meeting. The next meeting of the Science Team should be held about February, 2000.

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Argo Science Team Meeting
Easton, Maryland, USA
March 22-23, 1999

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