# DBCP-WMO workshop "Evaluating impact of sea level atmospheric pressure data over the ocean from drifting boys"

*21 May 2012, Sedona, AZ*

Participants:   Carla Cardinali[1],Luca Centurioni[2](Chair) Ronald Errico[3], John Eyre[4], Ron Gelaro[3], Rick Lumpkin[5](co-Chair), Jean-Francois Mahfouf[6], Wenjian Zhang[7]

[1]ECMWF, [2] SIO-CIMEC, [3]GMAO-NASA GFSC, [4]Met Office UK,[5]AOML-NOAA,[6]MeteoFrance, [7]WMO

Introduction

The overall purpose of the Data Buoy Cooperation Panel (DBCP)-World Meteorological Organization (WMO) workshop was to initiate the dialogue between the operators of the Global Drifter Program, mainly with an oceanographic background, and the main users of the sea level pressure data from drifters. The specific goal was to start a discussion on the impact of the barometer drifter data on NWP, assess the state of the art on the subject, and determine if further investigations are needed for a quantitative assessment. Another question put forward for discussion was: what are the correct metrics to assess the overall impact of the drifter observations on NWP? The opinion of the experts is needed to best answer this question. Another goal of the meeting, that was extensively reviewed in the session, was to evaluate the potential to summarize the state of the art on the subject in a manuscript that could be submitted to a peer-reviewed journal such as BAMS.

**Luca Centurioni (SIO)**, presented an overview of the Global Drifter Program (GDP, http://www.aoml.noaa.gov/phod/dac/index.php) with particular focus on its meteorological component.  The main goals of the GDP are to 1) maintain  an ocean-observing network of at least 1250 Lagrangian drifters (5°X5°) that, through the Argos and Iridium satellite systems, returns data of meteo-marine variables including near-surface ocean currents, sea surface temperature (SST), sea surface salinity (SSS), sea-level atmospheric pressure (SLP), sea-level winds (SLW) and subsurface temperature (Tz). 2) to provide a data processing system for the scientific use of the data.   The GDP is a scientific project funded by NOAA, not an operational one, and therefore it needs a strong oceanographic and climate scientific rationale to justify its investments.   The GDP also has a strong meteorological component because drifters are an ideal platform to make global SLP measurements. Drifters are also used for targeted hurricane deployments. An example of SLP measured in typhoon Fanapi, sea level wind and SST cold wake was shown to illustrate the quality of the drifter data.  The SLP sensor fitted on the drifters (SVPB hereinafter) is the Honeywell HPB, which cost ~$800 and has an accuracy +-1 mbar. The barometer is sampled every 15 min and is reported every hour mainly through the Argos satellite system and to a lesser extent through the Iridium system. Due to the configuration of the satellite Argos

transmissions occur about every 2 hours, Iridium transmission every hour. The delay of the data to reach the GTS is approximately 90 minutes with the Argos system, less than 60 minutes with the Iridium system. In 2012, the cost of an Iridium modem and GPS is a little less than the cost of an Argos transmitter. The drifter data are posted on the GTS by Service Argos.

290 drifters per year are upgraded with barometers by SIO and an additional 190 drifters are upgraded every other year. Another 180 drifters per year are upgraded by meteorological agencies' members of the DBCP. An extra $500K per year would be required to upgrade the entire array with barometers as per DBCP-WMO recommendation.

The GDP benefits from the collaboration with meteorological agencies in terms of deployment opportunities, especially at high latitudes. SLP data are also used in the altimetry data analysis to correct for the inverted barometer effect. On the other end the GDP is an oceanographic & climate program, funded by the NOAA Climate Program Office (CPO). Shrinking budgets (flat since FY09) make it harder to justify the implementation of the barometer array from a science perspective because a formal, systematic study of the impact of drifter SLP on Numerical Weather Prediction has never been performed. A DBCP-WMO Pilot Project (PP) was approved in Oct 2011 to tackle this evaluation. The specific goals of the PP are : (1) quantify impact of SLP data from the existing SVPB network on improving NWP, (2) provide a scientific and operational rationale for maximizing efficiency of SVPB network. About $40K are committed by the PP to develop new Observing System Experiments (OSE) and Observing System Simulation Experiments (OSSE) if needed.

Outstanding questions for the GDP include: how many SVPB do we need? Where do we need them most? What is the requirement for SLP accuracy? What data timeliness is really needed?

OSEs have been run at ECMWF to evaluate the impact of marine buoys and ship-borne SLP data [*Andersson, 2009*, quoting Radnoti et al]. The main findings are:

1) Buoys SLP score higher than GPSRO from (0-24h), lower from 24h onward;

2) Evidence of large impact of SLP ocean data on forecast accuracy, (48 to 72 hours), especially without GPSRO assimilation, and mainly for the Southern Ocean;

3) There is little need to enhance the North Atlantic array, which presently serves the forecast needs of Europe and North America;

4) SLP ocean data are significant in improving the forecast of severe storms;

5) There is need to run longer OSE to evaluate the impact of SLP data from buoys on rain forecast;

A case of explosive deepening cyclogenesis investigated by the Icelandic Meteorological office was shown to illustrate the usefulness of the drifter data to validate the forecast.

The conclusion was a list of proposed topics of discussion and guidelines for the workshop: 1) the need to assess the state of the art on the impact of sea-level air pressure data from drifters on NWP quality; 2) evaluate the need, based on 1, for commissioning new OSEs & OSSEs to refine our understanding; 3)

if more simulations are needed, who should design the experiments? 4) can the GDP work together with the meteorological agencies to engage in OSSEs' validation? 5) What are the best metrics to evaluate the impact of the SLP drifter data? 6) should a BAMS paper be written on what we understand of the subject?

**John Eyre (Met Office UK and WMO: Data Buoy Cooperation Panel perspective)** gave a presentation on behalf of Miroslav Ondras (Chief, WMO Observing Systems Division, with input from Etienne Charpentier, Scientific Officer, WMO Observing Systems Division). An overview of the DBCP structure and role was given. The DBCP is a forum of people interested in the data buoy technology. The DBCP meets yearly, normally in October. A technical and scientific workshop is held in conjunction with each Panel session. This is an excellent opportunity to discuss technical issues related to data buoys in the light of applications of buoy data. Participants in the meeting and/or workshop include representatives of meteorological agencies, oceanographic institutes, scientists, data telecommunication providers, and manufacturers. Contacts, exchange of information, assistance is facilitated during the intersessional period because people know each other and because the DBCP is served by a Technical Coordinator, and works through Task Teams. An Executive Board oversees the activities of the Panel during the intersessional periods. The main DBCP objectives are: 1) to review and analyse requirements for buoy data; 2) to co-ordinate and facilitate deployment programmes to meet requirements; 3) to initiate and support Action Groups; 4) to improve quantity and quality of buoy data on GTS; 4) to facilitate information exchange and technology development; 5) to liaise with relevant bodies and programmes. There are currently 10 Action Groups. Dramatic improvements were made in the last 20 years regarding quantity and quality of buoy data. Excellent cooperation has been established between meteorological and oceanographic communities and the data policy is now well followed. Scientific and Technical workshops are organized every year together with DBCP Sessions. Pilot Projects are initiated and followed by the Panel (e.g. Iridium, high-resolution SST & integration with satellite data, wave data evaluation and testing, impact of SLP on NWP, etc.). The DBCP implementation strategy is reviewed every year at the annual meeting. DBCP requirements are driven by climate requirements of GCOS, and contribute to meteorological agency requirements. Kelly Stroker is the DBCP technical coordinator and was recruited in late Aug. 2011 to replace Hester Viola. The DBCP technical publications are available on JCOMM & WMO websites.

The Action Groups focus on the deployment of buoys in a particular ocean area (e.g. International South Atlantic Buoy Programme) or for a particular application (e.g. Global Drifter Program). This permits them to satisfy national interests but also to integrate buoy programmes in a regional and then global perspective. Deployment opportunities are more easily managed at the regional level and coordination is made easier.

Regional (or global) Action Groups are independent self-funded bodies that maintain an observational buoy programme in support of the WMO World Weather Watch (WWW), the WMO-IOC-ICSU World Climate Research Programme (WCRP), the WMO-IOC-UNEP-ICSU Global Climate Observing System (GCOS), and the IOC-WMO-UNEP-ICSU Global Ocean Observing System (GOOS). They agree to exchange good quality basic meteorological and/or oceanographic data in real time over the Global Telecommunication System (GTS). They also agree on exchange of information on data buoy activities

and development and transfer of appropriate technology. They submit annual reports to the DBCP. Regional Action Groups usually engage their own coordinators, who work closely with the Technical Coordinator of the DBCP.

The Action Groups receive support from the DBCP through DBCP officers, DBCP TC, WMO and IOC secretariats. The DBCP is normally represented at the Action Groups meetings, and the Action Groups are represented at the DBCP meetings.
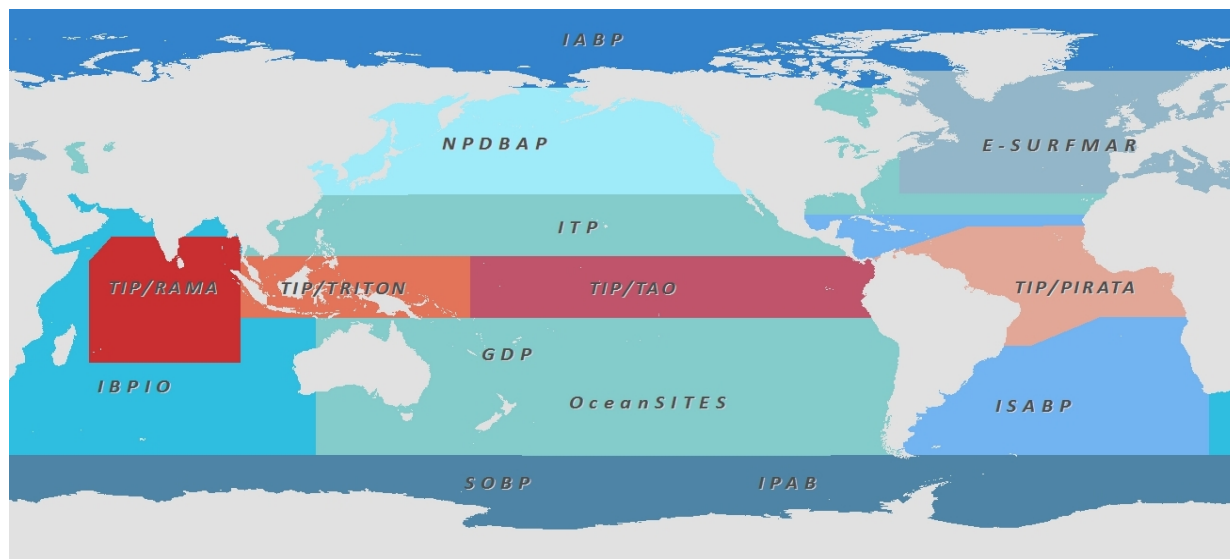


Map of the action groups: Global Drifter Programme (GDP); Tropical Moored Buoy Implementation Panel (TIP); RAMA array in the Equatorial Indian Ocean; TRITON array in the Western Equatorial Pacific Ocean; TAO array in the Equatorial Pacific Ocean; OCEAN Sustained Interdisciplinary Time series Environment observation System (OceanSITEs); International Tsunameter Partnership (ITP); International Arctic Buoy Programme (IABP); WCRP-SCAR International Programme for Antarctic Buoys (IPAB); EUCOS Surface Marine Programme (E-SURFMAR); International South Atlantic Buoy Programme (ISABP); International Buoy Programme for the Indian Ocean (IBPIO); DBCP-PICES North Pacific Data Buoy Advisory Panel (NPDBAP).

Substantial increase in the number of reports per buoy between 2000 and 2003 is due to DBCP recommendation at its 18th session, October 2002, to distribute as many hourly data as possible. Previously, such data were filtered out but as recent impact studies showed, hourly surface pressure data have positive impact upon the quality of NWP model outputs. In 2005 the Panel negotiated with Service Argos the provision of the Argos multi-satellite service free of charge. This substantially increased the number of reports distributed on GTS in 2006. During the period 2002 to 2006, the DBCP has been particularly pro-active in following up the recommendations from the JCOMM-I Session (Akureyri, Iceland, 19-29 June 2001) and reach the target of 1250 units operational in the world oceans. This was effectively realized during the JCOMM-II Session (Halifax, Canada, 19-27 September 2005) on 18 September 2005 with the deployment of "drifter 1250".

A list of DBCP requirements addressed was given (see presentation). A subset of requirements specific to SLP, some still to be met, follows: 1) goal of 300 barometer drifters South of 40S in the Southern Ocean; 2) new goal of equipping all newly deployed drifters with barometers as part of the DBCP Implementation Strategy; 3) study the impact of SLP in tropical regions to help the DBCP to refine its strategy; 4) investigate the type of SLP capabilities that would be required in both tropical and extra-tropical regions (where, what density, what observing cycle, what uncertainty ?)

The DBCP is also addressing WMO requirements, e.g. the need for SLP to correct the altimeter data (1 hPa = 1cm). It also addresses shortcomings of the observations systems: examples include hourly resolution (at least) for SLP data and the need to populate data-sparse regions (at least 300 barometers south of 40S).  The DBCP works to mitigate the risk that met and ocean communities work against each other (dropping barometers, removing drogues).

Free and unrestricted data exchange policy is enforced by the DBCP. Standardization of instrumentation has always been an important issue within the DBCP. As a result, strong cooperation was put in place between meteorologists and oceanographers deploying drifting buoys and common designs are now being used (SVP, SVPB, SVPBW). After the first SVPB evaluation phase (evaluation is considered as an ongoing process), meteorologists began to purchase SVPBs for their own purposes to replace the FGGE type buoys. The SVPB meets both communities needs:

**For meteorologists**, it is equipped with a barometer and a SST sensor and reports onto the GTS. It is drogued and therefore stays longer in a given area. It is cheaper than regular FGGE type buoys measuring the same variables.

**For oceanographers**, it is an excellent Lagrangian drifter which has been calibrated for that purpose. Surface velocity correction due to wind stress can even be applied thanks to a formula. Because the drifter is equipped with a barometer, and reporting on GTS, one can expect to obtain better wind fields from the meteorological agencies for making this correction.

Since standard SVP drifters continue to be deployed by oceanographers, meteorological agencies can use this potential and pay to upgrade SVPs to SVPBs for only the cost of a barometer. Météo France is presently upgrading 10 drifters a year for deployments in the Indian Ocean. This is an excellent example where resources are shared.

The barometer ($1100) essentially addresses the requirements of meteorologists. The drogue ($300) and SST ($150) essentially address the requirements of oceanographers. Meteorologists use Iridium satellite data telecommunication which without GPS provides for acceptable location quality for NWP purposes, but poor location quality for surface velocity means purposes (oceanographers requirements). Argos provides acceptable location quality for both communities.

Risks to the collaboration oceanographers-meteorologists are: 1) oceanographers not installing barometers on their drifters (e.g. Southern Ocean) forcing meteorologists to catch up the costs (e.g. barometer upgrades); 2) meteorologists removing the drogue from the drifters forcing oceanographers to purchase more drifters to achieve the required density or purchase drogue upgrade. If 1) occurs there

is an overall increased costs to Meteorologists in the order to $370K/year to keep the same level of barometers (and equivalent economy to oceanographers). This represents 68% of current Meteorologists commitments (≈ $575K) – a large percentage impact - and 13% of current Oceanographers commitments (≈ $2300K) – relatively small savings.

Points of contact for the DBCP are Al Wallace, Kelly Stroker.

Q: What is the limiting factor in drifter life time (~1 year)?  A: Battery and malfunctioning. Q: What constitutes Argos, Iridium charges?  Why do we use Argos when it's more expensive and has higher latency? A: Additional services provided by CLS such as GTS insertion, rapid response to our inquiries, historical precedent.

**John Eyre (Met Office UK and WMO: The WMO Rolling Review of Requirements and related DBCP issues)**.  The Rolling Review of requirements (RRR) addresses the observations requirements for all applications within WMO programs and captures them at a high level. The WMO Commission for Basic Systems (CBS) is in charge of the RRR.  User requirements are in place for 12 different application areas, the most mature being for global NWP.  The RRR consists of: populating and reviewing a WMO Database of user requirements for observations and of observing systems capabilities; conducting critical reviews through which user requirements and observing system capabilities are compared, and gaps identified; preparing a Statement of Guidance (SoG) for each application area, to document the key gaps between users' requirements for observations and the capabilities of present/planned observing system to meet them.  The Statements of Guidance feed into the "Vision for the GOS" and a set of actions to achieve the Vision is articulated in theImplementation Plan for the Evolution of Global observing Systems (EGOS-IP).
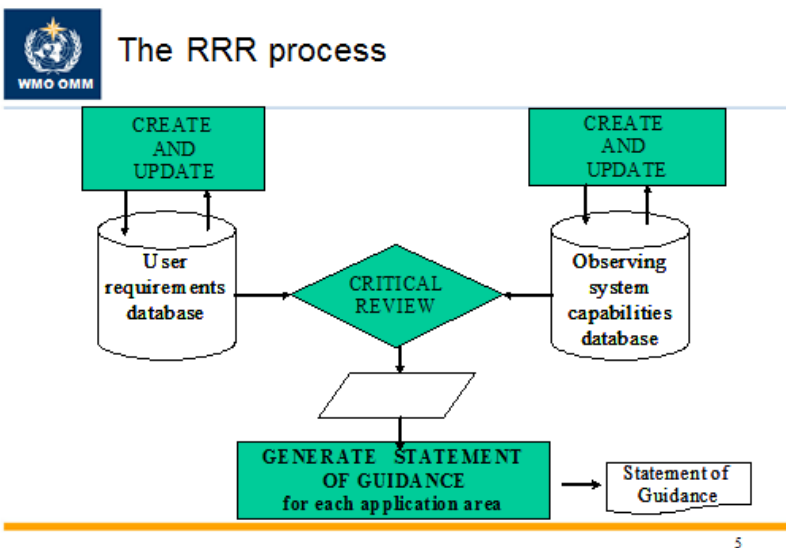


User requirements are specified as follows: horizontal, vertical resolution, accuracy, observing cycle, timeliness.  For each of these requirements, capture min (threshold), max (goal), and breakthrough (proposed target for significant progress).  A schematic for a performance/cost vs benefit curve

for an observing system was illustrated. Such curve is NOT a step function and can't be characterized by a single number.
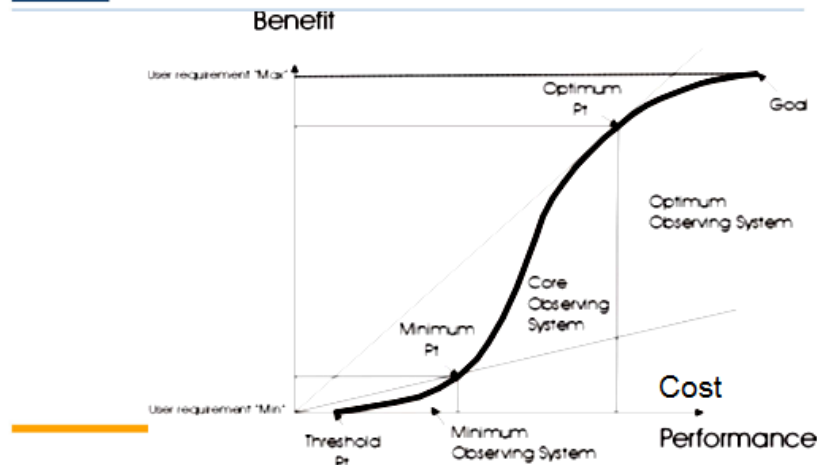


Extensive details of all requirements, including those of global NWP, are available on WMO web page (http://www.wmo-sat.info/db/). They also include "SLP over sea".

The "Vision for Global Observing Systems in 2025" is summarized in a 5-page document and is expanded in the Implementation Plan for the Evolution of the Global Observing Systems (EGOS-IP), which consists of ~100 pages. Section 5.3.6 of this document deals with surface observing systems over the oceans. Recommended actions include: G49 – support DBCP in mission to upgrade all 1250 drifters with barometers. G50 – install barometers on all newly-deployed drifters. G51 – in tropical Indian Ocean, extend RAMA to coverage similar to Atlantic and Pacific arrays.

Eyre et al. presented a white paper for OceanObs'09 on "NWP requirements for ocean data". Issues discussed in the paper include improved coverage of SLP data, particularly in Southern Ocean, higher temporal frequency of the observations, a better route for data exchange, improved metadata, improved developing country outreach.

What density of surface pressure observations does global NWP need? Winds, especially from scatterometers, reduce the need for pressure at super-high resolution. An even better question perhaps is, "What density of surface pressure observations do we need to anchor/complement high-density surface wind observations from satellite?" Answers can be given by network density reduction OSE in North Atlantic, and Southern Ocean OSSEs have been suggested. The need for tropical vs. extratropical SLP is a new topic – most focus so far has been on extratropical SLP distribution .

Q&A session comment from John: we almost certainly don't need a measurement every 20km, and we know bad things happen in NWP with no measurement to anchor the models. We probably need ~500 kmresolution , but this needs to be confirmed.

**Carla Cardinali (ECMWF)**: "Surface pressure impact study: FEC and OSE," with coauthor Gagor Radnoti.



**BUOYS-SHIP DFS and FEC Monthly Average**
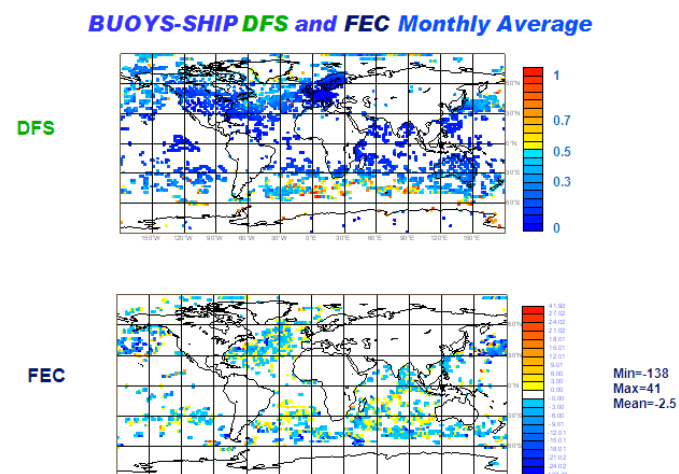
The average Degrees of Freedom for Signal (DFSmap left) shows the average influence of buoy+ship observationsin the the analysis. Observation influence equal to 1 means that only the observation affected the estimate; opposite, observation influence close to 0 means that only the background has counted. Maximum influence of the surface pressure measurement is observed in the Southern Ocean and over the two polar caps. Very large values are also over North Pacific and Atlantic ocean (0.5). In general large influence is given to buoy and ship observations located in data sparse and dynamically active regions. The Forecast Error Contribution (FEC) map shows the contribution to the 24 hour forecast error of the assimilated surface pressure observations. Negative values indicate that the observation has decreased the forecast error (i.e., negative is good); positive values indicate that the forecast error has increased due to the assimilation of such measurement. On average all the observations assimilated decrease the forecast error and in particular, buoy and ship data are very beneficial to the forecast. Moreover, degradationsare not necessary due to the observation quality but can also be due to the assimilation procedure or to biases in the forecast model. The forecast error is in fact evaluated with respect to the verifying analysis, that is only a proxy to the truth, therefore systematic error in the model can result on forecast degradation despite the observation has correctly affected the analysis. The metric used to compute the forecast error is the energy norm (Joules) which depends on wind,
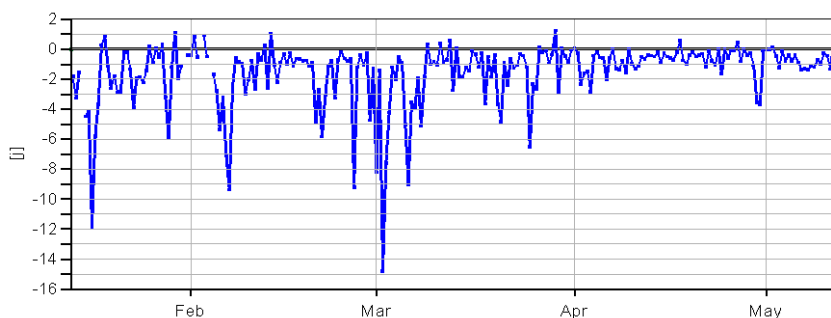


temperature and surface pressure parameters. The norm used is believed to well represent forecast impact of surface pressure observations. Nevertheless, some discussion took place on the use of a different norm, as kinetic energy, that would be perhaps more appropriate to investigate the performance of such observation on the forecast. Time series of FEC of buoy and ship surface pressure observations are shown for the North Atlantic (right).Larger negative values are observed in particular in

the winter time (January, February and March) where baroclinic activity takes place. In spring, the amplitude of the forecast error reduction is smaller though still positive on average. A similar behavior is seen in the North Pacific and in general a very constant positive impact is globally observed.

A case of rapidly-developing cyclogenesis on 6-7 Nov 2011 in the North Atlantic highlights the value of the buoy data. On the 6th of November a rapid cyclogenesis develops on the North Atlantic deepening from 990 to 950 hPa in 36 hours. Dribu surface observations in the area of the cyclogenesisprovided the largest forecast error reduction (40% ). Second contribution was from Aircraft data with 18% reduction followed by All-sky observations (12%) that provide information on wind, clouds and humidity. For this event, a denial OSE was run where these observations were withheld. From the OSE, the Figure below
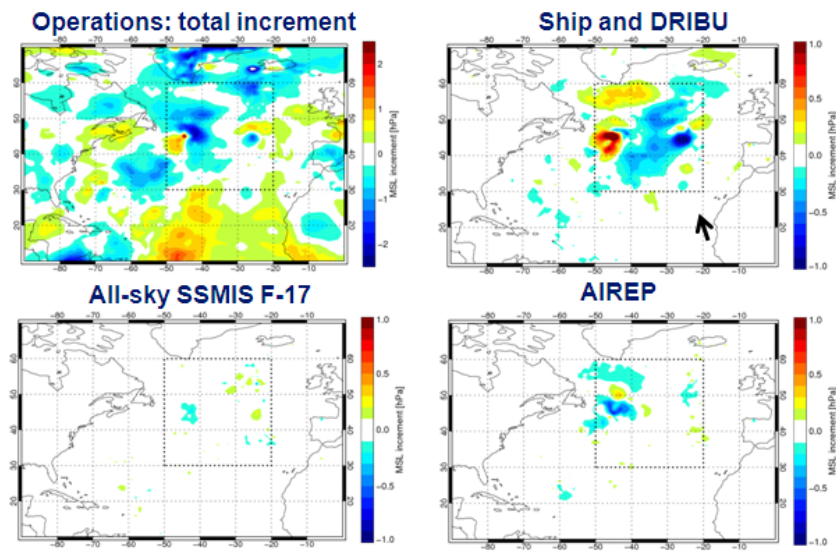


shows the mean sea level pressure increments for the operational analysis (top left), the increments due to the assimilation of Ship and Dribuobservations (top right), the increments due to the assimilation of All-sky (bottom left) and Aircraft data (bottom right).As for FEC, the largest difference between the analysis and the background field (increment) is provided by surface pressure data.
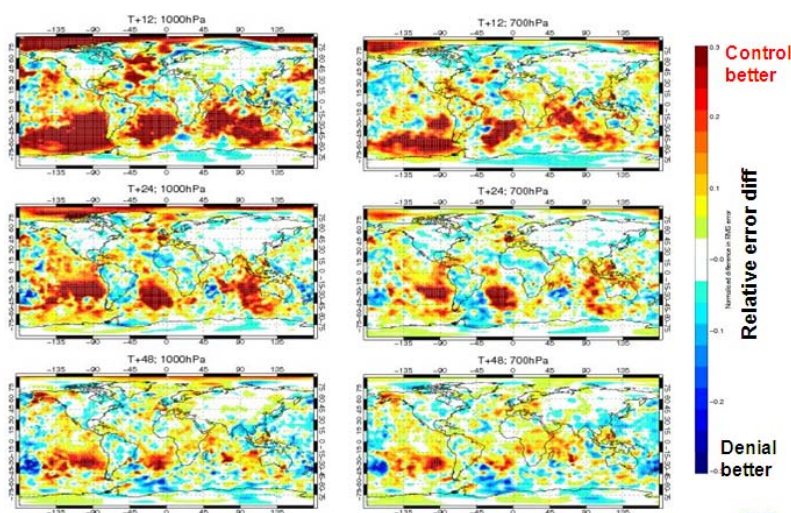


Dribu and Ship surface pressure information has been proved to be very influential in the assimilation process. The improved analysis can better conditioning the forecast. Surface pressure observations are globally beneficial, in particular, forecast improvements related to developing baroclinic instabilty have been documented.A number of OSEs were conducted with the 4D-var assimilation system for the period 1 Dec 2008-26 Jan 2009.

Three scenarios (experiments) were conducted: the Control experiment where all observations were assimilated, the Buoy experiment where buoy (drifter and moored) data were denied, and the experimentESURFMAR where reduced buoy network was assimilated, similar to the observation network pre-2002 and pre-ESURFMAR program. On the left, the relative error difference maps of

geopotentialheight  at 1000 and 700 hPabetween Buoy and Controlare shown for 12, 24 and 48 hour forecast ranges. When Buoy are not assimilated, very large errors are developing in the Southern Hemishere (red contours) and the negative impact persists up to day 2.   Buoy observations are beneficial in the Southern Hemisphere, Arctic and North Atlantic.  Their impact is largest at 1000 hPa (near the surface) but it also extends up to 500 hPa (not shown).  The overall hemisphere-averaged error at 12hour is of 1 hPa, but again larger impacts are locally observed. The ESURFMAR denial OSE was evaluated and the impact is summarized in the ESURFMAR reportThe results indicate that ESURFMAR data buoy coverage  significant improves the forecast over Europe up to 48h.

Discussion: surface observations are most valuable for short-range forecasts.  In contrast, the 3-7 day forecasts are most impacted by mid to high-level atmospheric observations.   Results for drifters (buoys with pressure) are *extremely* positive when compared to a number of other components of the observing system.

**Jean-François Mahfouf (Météo-France):** "On the use of buoy observations in the Numerical Weather Forecasting System data assimilation system at Météo-France."

Météo-France operates a global model ARPEGE, and a number of limited area models called ALADIN. Another regional model AROME is run a very high resolution over France.

ARPEGE has a variable resolution, with 10km resolution over Europe, widening to 60km over the South Pacific.  The ARPEGE Forecast is short-term, running up to 4 days; medium range forecasts are handled by ECMWF.  Forecast cut-offs dictate the importance for the timeliness of data.  ARPEGE uses 4Dvar assimilation of all observations available in a 6h window (similar to ECMWF, but they use a 12h window).  An analysis run is conducted at coarser resolution than the model.  Hourly time slots are used for data assimilation, so hourly resolution can be taken advantage of.  ARPEGE assimilates a long list of observations including buoy data, ships, many types of satellite observations including sea surface winds from scatterometer ASCAT/MetOP, etc.  Buoy reports are also used for SST analysis.  Conventional observations include BUOY (meteorological observations from drifters and moorings), SHIP, TESAC (Argo floats), and BATHY (sea surface and below).  Ocean data: most data is BUOY.  SHIP is a bit more than half of BUOY.  A time series since 2002 of the number of observations assimilated shows dramatic increases due to infrared sounders being phased in during 2008, and sampled at higher resolution in 2010. Satellite observations vastly outnumber "conventional" in-situ obs.   BUOY represents 1.7% of conventional data, and only 0.25% of all observations including satellite.  Degrees of Freedom for Signal (DFS) indicates the sensitivity of the analysis to perturbations of a particular subset of the observations (weight of the observations in the analysis).   The DFS for BUOYS is 0.68%, vs. 0.25% of number of observations.  The relatively higher DFS reflects well upon the value of the BUOY data (in contrast, most satellite observations have a ratio less than 1).  80% of available BUOY data are used in assimilation. BUOY data are much more homogeneous than SHIP data (in terms of spatial coverage).

The plot at left shows the timeliness of observations, indicating how many observations are available at the time of analysis (orange vertical line) and before and after..  At the time of analysis, <40% of BUOY
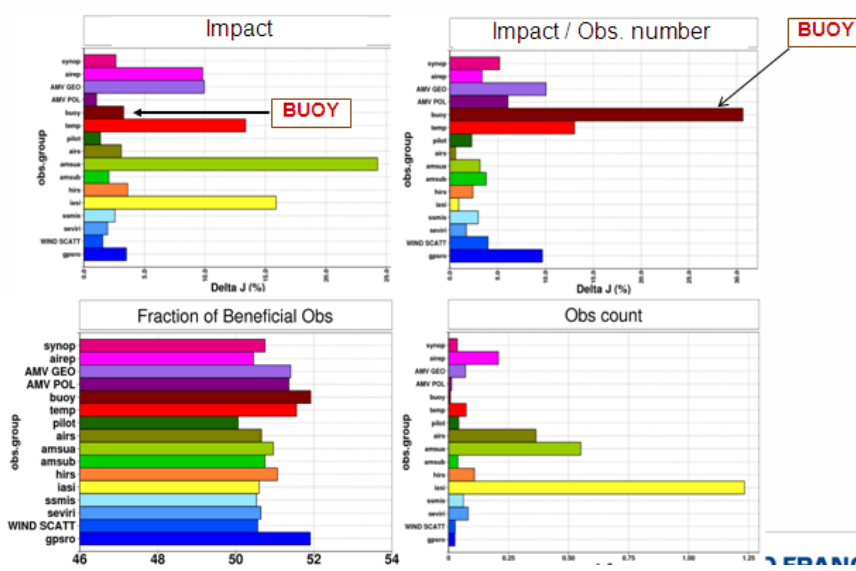
observations are available.  If one waits 1h, 55% of observations are available.  Wait 2h: ~70% available. 9h: nearly 100% available.   This represents a balance; forecasters want the best analysis (most observations), but want it as quickly as possible.  For SHIP observations, 67% of data is available at 1h, 82% at +2h.  Clearly the value of the BUOY data would be improved if it was as timely.
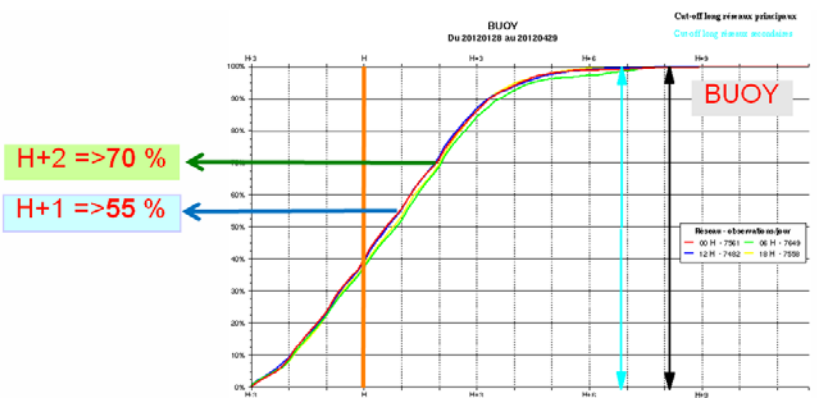


The limited area ALADIN model is run for domains including France, Antilles/Guyana, French Polynesia, La Reunion, and the New Caledonia regions.   The data cutoff for these runs is from 2h15min to 3h.   ALADIN uses 3dvar assimilation for observations in a 6h window.  Because of limitations with the 3DVar system (that does not account for the time dimension), a smaller fraction of observations is used in ALADIN compared to the 4dvar ARPEGE.  In the La Reunion ALADIN run, BUOYS represent 0.12% of the observations and 0.28% of the degrees of freedom.

In order to calculate the forecast sensitivity of observations in ARPEGE, one needs to define a measure of forecast errors (cost function J).  This can be chosen as a global measure, here the 3D integrated dry total energy of the difference between a 24h forecast and a reference state (analysis as a proxy for the truth).  The difference between values of J valid at the same time T but estimated from a 30h forecast and for a 24h forecast measures the impact of observations assimilated at time T-24h. A negative (resp. positive) difference (dJ) indicates a reduction (resp. an increase) in short range forecast errors by the observations. Through the ajoint technique it is possible to provide the contribution of each observation sub-type to the changes of J..   This diagnostic is calculated without denying any observations, but requires and is sensitive to the choice of $J$ which introduces a level of arbitrariness.   A forecast impact experiment for Dec. 2010 through Jan 2011 (left) shows that the impact for BUOY observations is not negligible compared to other data sources (quantified as % of $\delta J$), and is the most significant as quantified by impact per number of observations.    BUOY observations are very high in

the distribution of fraction of beneficial observations (one of two highest values, in %: nearly 52%), indicating that each buoy observation improves more the short-range forecast than other components of the observing system.

In summary, each individual BUOY measurement of surface pressure is very valuable to reduce short range forecast errors, particularly when compared against individual measurements from other components of the observing system. Their value for NWP would be further enhanced by improving their timeliness, either by reducing ARGOS latency or using the Iridium system. BUOY measurements over oceans despite their small number have an anchoring role in the observing system since they are accurate in-situ data that allow a better usage of indirect (remotely sensed) measurements (example given for moored buoys and scatterometer surface winds).

**Ron Gelaro (Global Modeling and Assimilation Office, NASA GSFC):** "A look at short-range forecast impacts of drifting buoy observations in the NASA GEOS-5 Atmospheric Data Assimilation System".

On the web (http://gmao.gsfc.nasa.gov/products/forecasts/systems/fp/obs_impact/), this evaluation is done routinely – but buoys aren't broken out separately from other marine surface observations. The focus here is on July 2011 and January 2012, specifically for the buoy observations. The metric: 24h global forecast error norm, the dry total energy in the troposphere (up to 150 hPa), with negative values indicating a positive impact on the forecast as they reduce the error.

Monthly maps of observations impact (January 2012 at left) show that buoy barometer observations make a more substantial impact at high latitudes. Observations in winter months (January for Northern Hemisphere, July for Southern Hemisphere) are most significant. There are 3600-4000 buoy
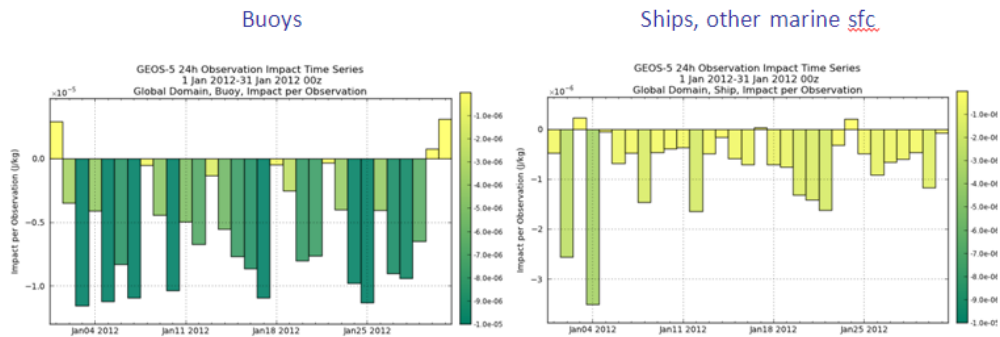


January 2012

observations assimilated per 6-h analysis cycle. The total number of buoy observations is extremely
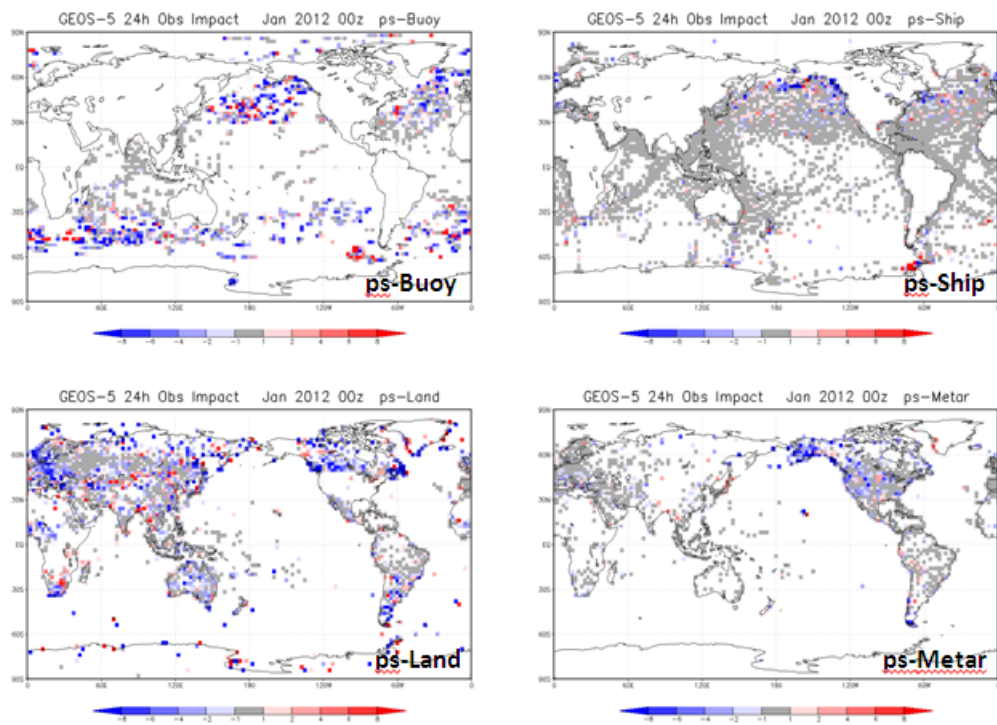
small compared to satellites. The total impact can be shown as a time series for buoys vs. ships and other marine observations. The overall impact of buoy observations (as fraction of the overall impact) is much larger than the fraction of data counts represented by the buoys. "Impact per observations" (left) shows the much larger



impact of individual buoy observations compared to all other marine surface observations. Impact per observations for the buoy data are also much higher than for radiosondes. In January 2012: dropsondes (targeted drops for Winter Storms project) have a higher impact per observation, but no other component outweighed the data buoys. In July 2011, Pilot Balloons (PIBAL, pre-sonde technology in developing countries) have a higher impact per observation, with data buoys second. In both cases, buoys are the second most important component of the overall observing system when quantified by impact per observation. In the Southern Hemisphere only, buoys are the most important source of observations, in terms of fraction of beneficial observations.

Discussion: comparing the adjoint method to the OSE method: The OSE method constrains the perturbation, while the adjoint method constraints the metric. The adjoint method is based on a linearization technique that limits one to up to 48h (max), with longer forecasts indicating the relative significance of various observations but not the absolute improvement in the face of nonlinearities.

In summary, data buoy pressure observations are very impressive, and high quality in terms of the impact per observation. It is reasonable to assume that these data play an important role in anchoring the surface pressure field over oceanic regions, especially in the Southern Ocean.

**John Eyre (speaking for Met Office UK)**: "Impact of drifting buoy observations on NWP at the Met Office."

FSO: Forecast sensitivity to observations. The FSO system uses the adjoint approach, in which the model projects the change in forecast error due to observations onto each individual observation. This can be illustrated by applying the technique to satellite systems, indicating the relative contribution from METOP, NOAA, LEO, Geostationary satellites, etc. The metric here is the moist energy norm for the troposphere, for a 24h forecast. A map for drifting buoys (right) is similar to maps shown by other centers for all buoy observations, indicating better improvements at high latitudes.

Quantified by impact per observation (shown below), drifting buoy observations are shown to be extremely valuable, for example out-performing all other surface components of the observing system for the period 22 August – 29 September 2011.
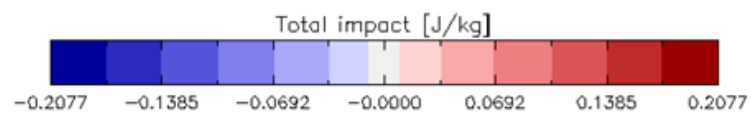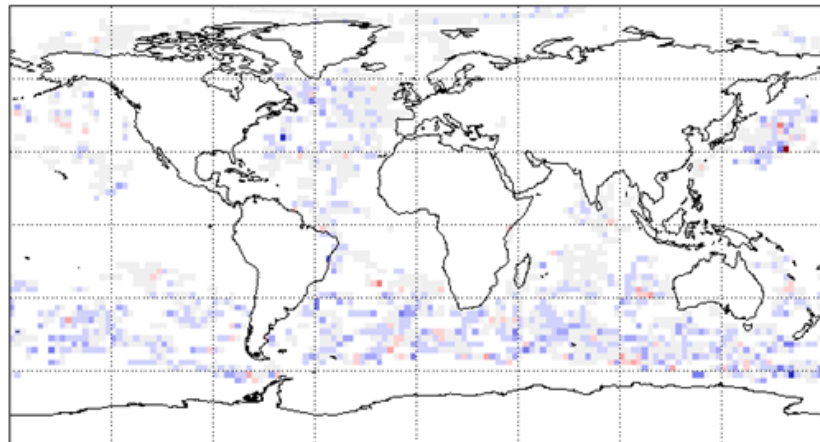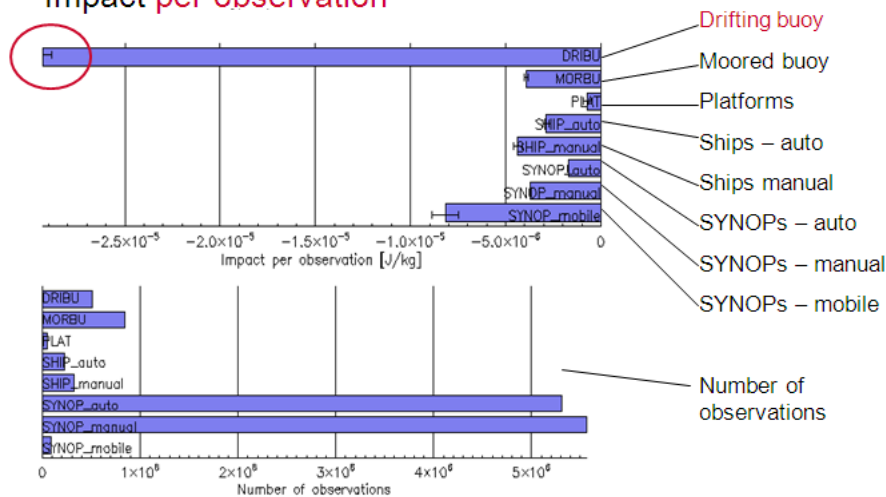


All components of the observing system have a "Fraction of beneficial observations" which lies close to 50%, and incremental values above 50% are highly significant. Drifting buoys are the highest of the components considered in this plot.

It's important to note that, across the suite of presentations given at this workshop, we're seeing very consistent results from 3Dvar systems, 4Dvar Systems, with variations on the metric(e.g. dry vs. moist norms, global vs. restricted below 150 hPa). These results are extremely robust.

In a data denial experiment, ASCAT, ERS-2 and WindSat observations were not assimilated by the system. Other observations partially compensate for this denial, particularly surface marine observations. Buoy observations in this experiment become even more valuable.



In summary, surface pressure from drifters contribute substantially to total forecast skill, and have the highest impact per observation of all surface pressure observations.

Data denial experiments have included denying *all* surface pressure observations (not just drifters). This has a huge impact because artifacts of the data assimilation system slowly change the overall mass of the atmosphere, leading to large biases in absolute surface pressure. It's important to note that

simulations as extreme as this aren't particularly helpful to assess the impact of surface pressure solely from drifting buoys.


**Discussion Session:** A valuable denial experiment would be a realistic one, for example implementing pressure on half as many drifters as currently done.

Degraded wind forecasts would also degrade wave nowcasts/forecasts, something not considered in the presentations given today.

One repeated theme was the value of the adjoint approach vs. an OSE, and vs. an OSSE (which is an order of magnitude more effort than an OSE). Using the adjoint approach, the value of observations can be quantified quickly, with little extra effort. OSE efforts are underway and can answer questions that can't be addressed by adjoint approach. For example: what would be the effect of doubling the number of Southern Ocean barometer drifters?

The following list itemizes the needs, going forward, to quantify the impact of drifter pressure observations on Numerical Weather Forecasting efforts:

- Several of the studies presented in this workshop and in the overall workshop isolated all buoy (drifting and moored) or all buoy and all ship measurements together. There is still the need to isolate drifter SLP from other platforms. This could also be done for subsets of the buoy data, for example for low-latitude observations to evaluate the NWP value for following the DBCP recommendation that all drifters be outfitted with barometers.

- The best metric to evaluate impact of the data should be identified. Should it focus on lower troposphere? Surface winds? Link to wave forecast model? Perhaps the most straightforward approach is to focus on surface energy: surface wind, and perhaps temperature.

- There was an overall consensus among the attendees that the results presented at this workshop are sufficient in novelty and scope to be adaptable to a BAMS paper on this subject. A lead author needs to be identified. A good goal for the time scale of submission would be by the end of the year, in time for next year's funding cycle. The first part of the paper would review what was presented today, showing the robustness of these results across the different systems and metrics. The final section could focus on a case study such as the one presented by Carla Cardinali.

- The North Atlantic case study demonstrates the need to examine particular cases in other regions: globally averaged metrics don't emphasize peak events during cyclogenesis when the drifter data make particular impact. A postdoc could dedicate time to looking at an entire year of events. This person could possibly be located at ECMWF, interacting with Carla Cardinali. Such an effort would represent "phase 2", following the BAMS article (phase 1), if the group feels that such an effort is motivated.

- Even if no further progress is made by next year, the results presented at this workshop already present considerable evidence for the value of pressure data from buoys, particularly high-latitude open-ocean buoys (e.g., drifters), using a metric that doesn't focus on surface observation forecasts.