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# ROCKETSONDE BUOY SYSTEM OBSERVING SYSTEM SIMULATION EXPERIMENTS

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## 1. INTRODUCTION

Observing system simulation experiments (OSSEs) use synthetic "observation" data to evaluate the impact of proposed observing systems (Arnold et al. 1986). The synthetic data are assimilated into weather analyses, from which numerical weather predictions (NWP) are made. By verifying the resulting forecasts against real observations or reference analyses, one can estimate the utility of the new data systems before committing resources to build and deploy the real systems. OSSEs differ from Observing System Experiments (OSEs), in which real-data from already-deployed instrument systems are added or denied to the weather analysis.

A goal of THe Observing-system Research and Predictability Experiment (THORpex) is to combine OSSEs with instrument development and other techniques to improve the accuracy of worldwide operational NWP (Langland et al. 2002, Shapiro and Thorpe 2002, Thorpe et al. 2002).

Although a mix of some in-situ and remote observations already exist in regions such as the northeast Pacific, the well-documented (Laroche et al. 2002; McMurdie and Mass 2003; Hacker et al. 2003) deterioration of forecast skill downwind over North America suggests that a critical data component is still missing. One candidate for this missing component is the gap of in-situ sounding data in the mid-troposphere due to the sparse coverage of routine radiosonde soundings over the northeast Pacific Ocean, a condition often called the "Pacific data void". OSE data-denial experiments reported by Graham et al. (2001) confirm the impact of the data void via the relative importance of different data sets to the resulting NWP forecast skill. To help address the Pacific data-void problem, we are developing a rocketsonde buoy system (RBS) to make in-situ soundings in the radiosonde-sparse regions of concern for THORpex. Information gained from OSSEs will determine the likely impact of RBS, and aid in its design.

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## 2. ROCKETSONDE BUOY SYSTEM

The proposed RBS will launch small, unguided rockets daily to 6 to 8 km apogee from a buoy platform (Fig 1). At apogee, the sonde will separate from the rocket, and while descending on parachute will measure and transmit atmospheric temperature, humidity, pressure, and perhaps GPS position for winds and altitude information. The signal will be received at the buoy and then compressed and retransmitted to a communications satellite, which will relay the data to shore for addition to the Global Telecommunication System (GTS).

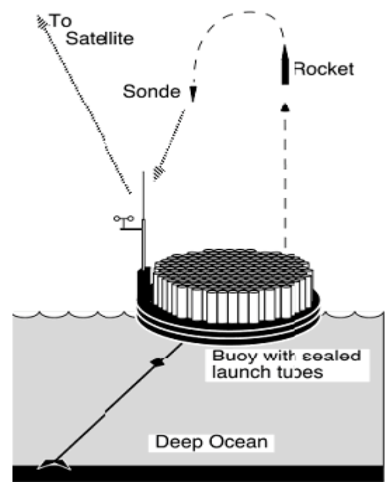


Fig. 1. Sketch of the rocketsonde buoy system (RBS).

Each deep-ocean moored buoy will carry hundreds of rockets, each in their own sealed launch tube. The buoy launch-control system will initiate the launch when the rocking buoy passes close to vertical during the synoptic observation window near 00Z or 12Z. The RBS is being designed to operate in the severe winter-storm conditions of the deep, northeast Pacific Ocean (although a similar land-based system could be designed for the Canadian arctic data void).

Many rocket and buoy-design decisions are being explored via OSSEs. Decisions include: number of rockets per buoy, max altitude, types of meteorological observations needed, number of launches per day, number of launch days per year, optimum vs. minimum number of buoys per network, and optimum mooring locations for the buoys. During 2002-2003, rocket test launches were conducted simultaneously with OSSE runs, leading to a RBS design that is economical, practical, and likely to yield measurable impact on NWP forecast skill.

## 3. OSSE METHODOLOGY

### 3.1 *Experimental procedures*

The Penn State / NCAR (Dudhia et al. 2003) mesoscale numerical model MM5 V3.4/5 is used for the simulations. The MM5 model domain is based on a polar stereographic projection true at 60 degrees north (Fig. 2). Eta data sets covering the domain form the initial and boundary conditions for the integrations and include coverage over the central and eastern Pacific as well as over North America. With a wintertime average zonal flow, weather disturbances over the eastern Pacific routinely move over the American continent within a two-day study period. This allows for verification over the data-rich area of North America. The model attributes used are: horizontal grid spacing 45 km; time step 30 to 45 s; pressure levels 86, converted to 42 sigma levels.

MM5 data-assimilation schemes integrate the simulated data into the forecast runs. A successive-scan Cressman scheme with quality-control checks nudges the analyses from the first guess towards the data. We make the "perfect data" assumption for the virtual soundings, with observation error set to zero. This forces the analysis to exactly equal the sounding values for those grid points co-located with the soundings. These OSSE experiments are thus designed to test the maximum possible influence of the soundings.

Data-addition OSSEs determine the impact of adding data to the forecast runs while data-denial OSSEs determine the impact of withholding data. The OSSE procedure used here is an “identical twin” parallel run (Arnold et al. 1986), which utilizes a "reference-atmosphere" (REFxx[*]) forecast run that excludes the new data. A parallel forecast run for an atmosphere using the assimilated data is referred to as an "OSSE atmosphere". After data addition (ADA) or denial, data impact is measured as the difference in one-to-two-day evolution of the REFxx and OSSE atmospheres (Graham et al. 2001).

[*] “xx” refers to either the 00 or 12 label, explained later.

Eta model data, available every 12 h from the US National Centers for Environmental Prediction (NCEP), is used for the synthetic soundings as well as the initial and boundary conditions for the MM5 model. The REF12 and REF00 reference MM5 forecasts begin from the 12Z and 00Z Eta analyses, respectively, and utilize the Eta forecasts for boundary conditions, but do not incorporate any virtual soundings.

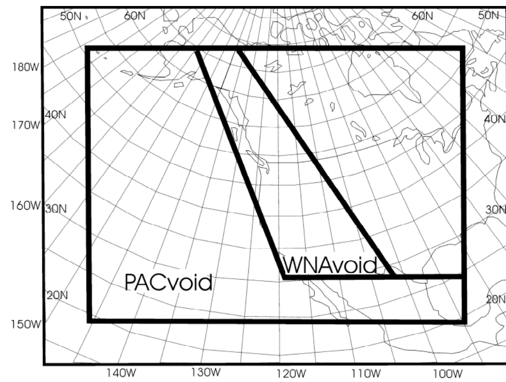


Fig. 2. The heavy rectangle outlines the PACall regions, which is filled with a uniformly distributed, high-density array of virtual radiosonde soundings to 16 km altitude (over both continent and ocean). For the PACvoid experiments, virtual sounding data are excluded from the mostly-oceanic region west of the idealized west coast of N. America, and south of the idealized US-Mexican border. For WNAvoid experiments, the simulated west coast of N. America is shifted further east, with sounding data excluded everywhere west and south of that shifted coastline.

For an OSSE atmosphere run, the REF12 data set is enhanced with the virtual sounding data at the first 00Z valid time (12 h after start time) and rerun for the remaining 48 hours. The virtual sounding data is extracted from the new 00Z Eta analysis and is assimilated with the REF12 forecast data, valid at the same time, using the successive correction method.

The results of the REF12 and REF00 forecasts are used for comparison and screening the MM5 OSSE atmosphere results, which should fall somewhere between the REF12 and REF00 results. The difference (DIF) between OSSE MSLP outputs and the verifying (VER) analysis valid at the same time is compared to the corresponding difference of the REFxx parallel run. Qualitative comparisons learned from DIF and quantitative analyses from the root-mean-sea-level pressure difference (RMSD) and correlation (COR) statistics from these parallel runs are used to assess the impact of the virtual soundings. Trends in these two statistical indicators indicate forecast improvements or degradations. A perfect analysis or forecast would give a RMSD score of 0 and a COR score of 1. It is assumed that the 00Z Eta analysis has assimilated all the new (real) observational data (e.g., ship, buoy, aircraft, satellite, radiosondes, etc.) available between the 12Z and 00Z time interval. It is also assumed that the Eta error minimization procedures have performed an optimal analysis (Staudenmaier, 1996) on the 00Z data set.

The virtual data added in the OSSEs have two configurations: virtual radiosonde soundings, and virtual RBS soundings. Each “virtual radiosonde sounding” is a single vertical profile with all the Eta model levels included (surface to 16 km) and evenly spaced at every fifth grid point (or 225 km) within one of the areas of Fig. 2. An assimilation radius of influence of 10 grid points is used for each sounding. “Virtual RBS sounding” data are similar to the virtual radiosonde data, except that the vertical profile is only from the surface to 4, 6 or 8 km (extracted from the Eta data), and only at a small number of positions representing virtual RBS locations (e.g., Fig. 3). The assimilation radius of influence for the RBS soundings is 13 grid points.

### 3.2 *Reference and benchmark atmospheres*

No virtual sounding data are added to REF12 initialized from the Eta 12Z analysis, nor to the REF00 initialized from the 00Z Eta analysis. The results of the REF00 forecasts form the ideal benchmark for the OSSEs, and are used as a screening tool for the Pacific analyses. When the forecasts from REF00 verifies better than those from the previous REF12 atmosphere, it is assumed that the 00Z analysis (12 h later than the 12Z analysis) has been updated by NCEP in a proper manner. Columns of data can be extracted from these forecasts and used with confidence as virtual soundings. The rejected cases of deteriorated Eta analyses can be used to document the negative impact of the Pacific data void. The PACall atmosphere (Fig. 2) establishes “practical” benchmark results for the OSSEs. For the purposes of the OSSEs (when the analysis over the Pacific Ocean is reasonable) the forecasts from this atmosphere are assumed to be the best that can be expected from an ideal radiosonde observational network within the same domain.

### 3.3 *OSSE atmospheres*

Six OSSE working atmospheres (PACvoid, PAC_RBS, PACvoid_RBS, WNAvoid, WNA_RBS, WNAvoid_RBS) are described below. These OSSE atmospheres are divided into two groups, based on where the virtual RBS soundings are added: PAC for the Pacific Ocean; and WNA for western North America.

For the PACvoid, synthetic sounding data added east of the interface are exclusively virtual radiosonde sounding data, while no soundings are added west of the interface. For the PAC_RBS Atmosphere, virtual RBS soundings are added at potential RBS locations in the Pacific (Fig. 3). Many configurations are possible. Three, Six, Nine, and Twelve-buoy configurations within an eastern Pacific array (ErnPAC_RBS) are shown. The SixBuoy array includes the ThreeBuoy locations, the NineBuoy array includes the SixBuoy locations, etc. A similar TwelveBuoy array can cover the central Pacific (CenPAC_RBS) area. The AllBuoy array includes both the ErnPAC_RBS and the CenPAC_RBS arrays. For the PACvoid_RBS Atmosphere, the virtual RBS soundings from PAC_RBS and virtual radiosonde soundings east of PACvoid (shown in Fig. 2) are merged into atmosphere PACvoid_RBS. This atmosphere is used to support various operational scenarios, because it would be similar to a future real radiosonde network of dense sounding coverage over land and sparser, lower-altitude, coverage over oceans.

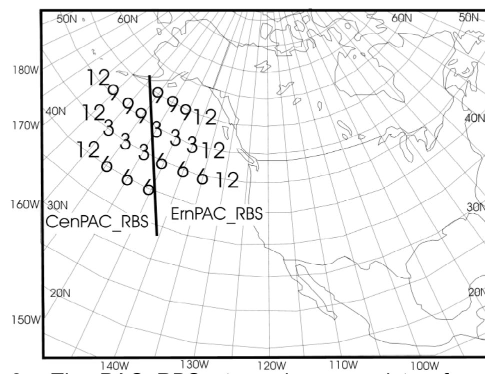


Fig. 3. The PAC_RBS atmosphere consists of only low-altitude virtual rocketsonde soundings at the locations indicated, which are at the intersection of every 5° parallel and meridian. Subsets include the eastern Pacific (ErnPAC_RBS) and central Pacific (CenPAC_RBS).

For the WNAvoid Atmosphere, a data void is created that spans both western North America and the northeast Pacific (Fig 2). Data added east of the new interface are always a dense coverage of virtual radiosonde soundings to 16 km altitude. The WNA_RBS Atmosphere is a RBS-like situation over western North America, where data added west of the new interface are the virtual RBS soundings with a maximum height of 8 km. This RBS configuration allows the use of consistently reliable data (from Eta analyses over western North America) to act as virtual RBS soundings. Adding all RBS soundings between the PACvoid interface and the WNAvoid interface (Fig. 2) will be considered a WNAall atmosphere. For the WNAvoid_RBS Atmosphere, virtual RBS data is added west of the shifted interface, and virtual radiosonde sounding data is added east. This atmosphere is analogous to the PACvoid_RBS atmosphere, but with consistently reliable data available to insert as the virtual RBS soundings.

### 3.4 *Verification atmospheres and ensembles*

Eta analyses data are used for verification after being interpolated to the MM5 grid using the same procedure as with the initial and boundary data. Quantitative verifications are made only over North America in the VERwest and VEReast domains (Fig. 4).

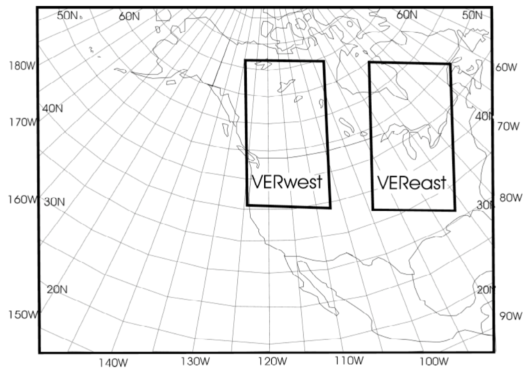


Fig. 4. OSSE verification domains over the data-rich continent are divided into VERwest and VEReast, which are placed just east of the PACvoid shoreline and the WNAvoid-shifted shoreline, respectively

Some gradual sequences of OSSE changes can be studied together as a group or ensemble. Examples include a gradual increase in area covered by RBS soundings, or gradual changes in RBS max altitude. For example, the PAC ensembles have increasing sounding locations added at 00Z, starting with zero soundings in REF12, and proceeding through several variations of PAC_RBS, PACvoid, several variations of PACvoid_RBS, to the PACall atmospheres.

### 3.5 *The OSSE procedure: strengths and weaknesses*

In the absence of real data, OSSEs offer the only available method of determining whether a proposed system will be worth the investment. The OSSE procedure has an advantage of a well-controlled environment. Model-error and numerical-error biases are factored out. Error growth rate of the OSSE atmospheres should remain reasonably constant across the identical twin cases within the same ensemble. So the forecast differences result from variations in the initial conditions. Use of the REF00 and PACall atmospheres allow Pacific-analysis screening and calibration of the forecast results. The improvement of the forecast statistics relative to the reference atmospheres provide the most useful information.

A weakness of this OSSE procedure is due to the virtual sounding data originating from a model rather than reality. The same errors in synoptic system strength and location may be common in both the virtual sounding and the model first-guess, resulting in underestimation of the improvements due to a real RBS system. The conservative nature of these results suggests that they could form a lower bound to similar results using real-data OSEs, when real RBS and other in-situ data become available.

The domain is limited, so the forecast period was kept short to avoid boundary effects from propagating in the VER domains. Neither the synthetic soundings nor the verification domains are near the boundaries. We also shorten or eliminate runs for those synoptic situations that do not have a predominantly west-to-east flow.

### 3.6 *Cases available*

Cases are grouped into two periods: winter (late Fall 2001 through early Spring 2002) and summer 2002. Winter 2001-02 was benign, with only a few Pacific storms moving over the North-American west-coast. The winter cases start at 12Z on 12 December 2001, 17 February 2002, 20 February 2002, 7 March 2002, 15 March 2002, 11 April 2002, and 5 May 2002. Only the 12 December, 20 February and 11 April cases caused high-impact (costly) weather events. The 20 February case had a questionable Pacific analysis. The winter cases will be abbreviated as Dec12, Feb17, Feb20, Mar07, Mar15, Apr11, and May05. The summer cases include 28 June, 7 July, and 2, 6, and 8-11 August.

## 4. OSSE findings

### 4.1 *Optimum launch times and dates*

To support both 00Z and 12Z synoptic analyses, roughly 730 rockets would be needed per buoy per year. However, economical buoys with sufficient diameter and flotation are not available, so the initial RBS will launch only one rocket per day. When is the best time?

Verification statistics over both VERwest and VEReast (labeled WNA and ENA, respectively) are shown in Table 1 for all the winter cases. The 48 h ENA forecasts started from 00Z analyses are roughly 20% better than 48 h forecasts started from 12Z analyses. The same pattern, though less distinct, is exhibited in WNA data. If this is due to the larger amount of data available for the 00Z analyses, then we infer that the 12Z analyses require the most help, and could benefit most from RBS soundings. If the objective is to enhance day-1 forecasts, then the preferred launch time is 00Z. If the objective is to enhance day-2 forecasts, then the proximity to the day-2 morning and the poorer verification scores suggests that the RBS launch times should be at 12Z.

RBS operations during summer may not be cost-effective, because the impact of the Pacific data void is lower. Table 1 shows VERwest RMSD values of about 0.2 kPa for 24 h forecasts increasing to about 0.4 kPa for 60 h forecasts, averaged over all winter cases. The 60 h RMSD summer values are about a third of the winter values, showing that the weaker synoptic systems in summer are easier to forecast, even with lack of data in the Pacific data void. Also, the difference between the forecasts based on 12Z vs. 00Z analyses are slight.

A one-launch per day, seven month operation during the winter storm season would reduce the number of launches to about 200/yr, reducing the RBS costs dramatically.

### 4.2 *Influence of the data void*

**TABLE 1**

| | | | | |
|---|---|---|---|---|
| **WNA FORECASTS** | **24hr** | **36hr** | **48hr** | **60hr** |
| **REF12 RMSD** | **0.2142** | **0.2880** | **0.3491** | **0.3999** |
| **REF00 better than REF12** | **5%** | **12%** | **12%** | |
| **REF00 RMSD** | **0.2041** | **0.2562** | **0.3122** | |
| **Average RMSD** | **0.2092** | **0.2721** | **0.3306** | **0.3999** |
| | | | | |
| **ENA FORECASTS** | **24hr** | **36hr** | **48hr** | **60hr** |
| **REF12 RMSD** | **0.1760** | **0.2351** | **0.3034** | **0.3489** |
| **REF00 better than REF12** | **4%** | **9%** | **19%** | |
| **REF00 RMSD** | **0.1699** | **0.2152** | **0.2547** | |
| **Average RMSD** | **0.1729** | **0.2252** | **0.2791** | **0.3489** |
| | | | | |
| **PACIFIC DATA-VOID PENALTY** | | | | |
| **WNA RMSD compared to ENA RMSD** | **21%** | **21%** | **18%** | **15%** |

RMSD statistics in Table 1 show that WNA forecasts suffered a 21% penalty relative to ENA in the first 36 hours. The penalty decreased with the increasing forecast period, probably due to the forecast skill in ENA decreasing toward the already low skill in WNA. This can be interpreted as the "shadow" of the Pacific data void spreading first through WNA, and then through ENA as the forecasts progress. Influences in ENA from the Atlantic and Gulf of Mexico data-poor areas are also possible. After 36 hours, the drop off from the 21% penalty seems to be about 10% per 12 h period.

OSSEs can quantify the effect of a data void on a data-rich area. Virtual radiosonde data are added to the REF12 atmosphere starting with the subdomain east of WNAvoid, and then extending the area westward to include the subdomain east of PACvoid, and finally covering the whole PACall area of Fig 2. Including the WNAall virtual radiosonde data over WNA provides a consistent improvement of about 10%, as early as 24 h into the forecast. Adding the PACall virtual radiosonde data to the PACvoid atmosphere causes a deterioration in the longer period forecasts.

**TABLE 2**

| | **00hr ADA** | **12hr ADA** | **24hr ADA** | **36hr ADA** | **48hr ADA** |
|---|---|---|---|---|---|
| **REF12** | **0.0851** | **0.1183** | **0.2368** | **0.2970** | **0.3571** |
| **WNAvoid** | **0.0617** | **0.0780** | **0.1759** | **0.2395** | **0.3031** |
| **PACvoid** | **0.0429** | **0.0686** | **0.1280** | **0.1976** | **0.2671** |
| **PACall** | **0.0429** | **0.0697** | **0.1254** | **0.2102** | **0.2950** |
| **REF00** | **0.0167** | **0.1163** | **0.1401** | **0.1842** | **0.2282** |
| **FORECAST PERIOD** | **12 hr** | **24 hr** | **36 hr** | **48 hr** | **60 hr** |

Even greater decrease in ENA forecast quality was observed for individual high-impact cyclones, such as the Dec12 case (Table 2). Forecasts from the WNAvoid atmosphere had greater error over VEReast than forecasts from PACvoid. The deterioration is as much as 35% in the 36 h forecast. This finding suggests that the addition of real RBS data west of North America could improve the forecast quality by 35% for the most energetically growing storms.

### 4.3 *Buoy array location, configuration, and number*

Forecast degradation due to poor Pacific analyses depends on the location of both sounding insertion and verification. The degree of forecast degradation caused by the Pacific analysis is uneven, and depends on the juxtaposition of initial data area, verification area, and synoptic situation.

The positive impact of new data can be substantial when the new data projects onto a growing meteorological structure not captured properly by the first-guess field. This occurred with the Dec12 ThreeBuoy PAC_RBS data-addition OSSE. The impact can be far less if the data projects onto a weakening meteorological structure, even if the first-guess field has not captured the feature properly. If the REF12 12 h forecast is already good, then the impact of inserted soundings will likely be low, even for a high-impact event.

Optimum locations for RBS buoys are in areas where the NWP model routinely misforecasts growing meteorological structures, and provides unreliable first-guess fields for the next update. To support this hypothesis, meteorological “error structure” fields are produced by calculating the RMSD difference between the REF12 12 h forecast and the verifying analyses. Fig. 5 shows these fields averaged over all the high-impact winter cases with good Pacific analyses (Dec12, Feb17, Mar15, Apr11). Many error-structure maxima have somewhat north-south orientations. One maximum is just off of the Pacific coast, another just west of 140W, and another just west of 150W. Based on these Winter 2001 - 2002 results, RBS soundings added at the locations sketched in Fig 6, delivered at 00Z, would likely have improved the forecasts considerably.

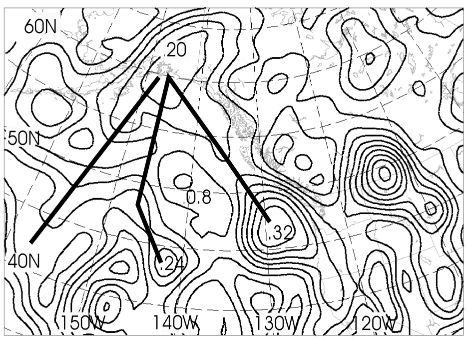

Fig. 5. 12 h forecast-RMSD averaged over the four winter storms. The subjectively-drawn heavy lines highlight maximum errors, and indicate that RBS data could have been added there to maximum advantage in forecasting these winter 2001-2002 storms.

Pailleux et al. (1998) reported that OSEs using North-Atlantic Automated Shipboard Aerological Programme (ASAP) data needed about 10 sounding locations to make a clear positive impact. However, the Atlantic is much smaller than the Pacific, a greater density of conventional buoy and aircraft data already exists over the Atlantic, and the North-American observing network allows models to create relatively-good first-guess fields downstream over the Atlantic. If existing northeast Pacific analyses are poorer than Atlantic analyses, then clear positive impact might be reached with fewer then 10 additional soundings. To test that hypothesis, the averaged RMSD results for the Dec12 and Apr11 cases are shown in Fig. 7. For a reasonably small number of buoys (0 - 12), most of the RMSD improvements are made with a six-buoy array.

It is economically desirable to gradually deploy more buoys with time. The error structure analysis of Fig. 5 suggests that an initial RBS deployment could be three buoys located 200-300 km off the BC and Washington coasts. This is shown as a ThreeBuoyTarget (3T6k) in Fig. 6. Also, considerable OSSE success was achieved with an east-west ThreeBuoy RBS deployment within the ErnPAC_RBS area (Fig. 3) along 50N. The error structure analysis of Fig. 5 suggests that a north-south orientation near 145W will eliminate some of the remaining error. Combining these findings with the array-size finding of Section 4.5 suggests a SixBuoyCross (6C6k) configuration centered at 50N 145W would be optimum (Fig. 6). This is the same station Papa location formerly used by moored weatherships. OSSEs with RBS soundings to 6 km tested the merits of the 3T6k and 6C6k arrays. Relative to the REF12 minus PACall RMSD difference, both configurations eliminated about 70% of the RMSD

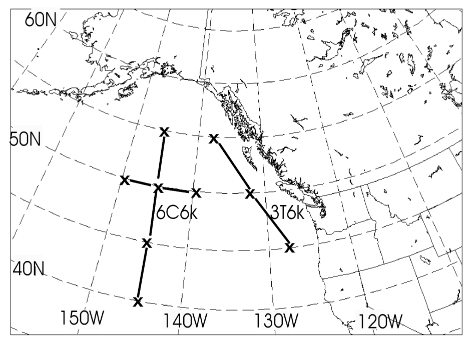

Fig. 6. Potential RBS sites (Xs) optimized to reduce the RMSD shown in Figs. 5.

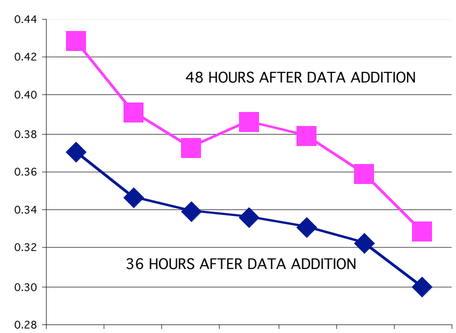


Fig. 7. Reduction of RMSD forecast errors (ordinate) over VERwest with increasing number of sounding buoys over the Pacific (abscissa), averaged over the two high-impact storms (Dec12 and Apr11) known to have good analyses

### 4.4 *Profile height*

Doerenbecher et al. (2001) found that the most sensitive layers of the atmosphere are near the 3 km level. This level must be spanned by a rocketsonde up to some optimum higher level. During the data assimilation process, the influence of mid-tropospheric data can be carried to higher model-levels through hydrostatic adjustment. Also, future (real) RBS sounding profiles can be merged with satellite soundings and aircraft data to yield the best overall improvement.

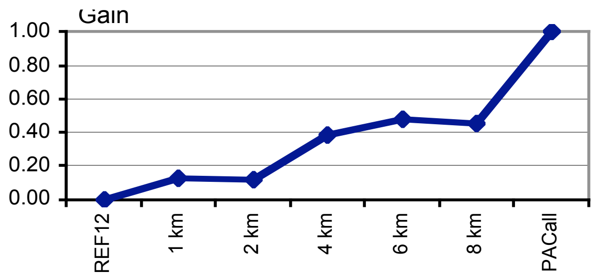


Fig. 8. Relative value (i.e., gain) of increasing the RBS sounding altitude for a ThreeBuoy configuration for the Dec12 storm. The 48 h ADA results are normalized to show the gain (RMSD error reduction) normalized between 0 gain (highest error, associated with zero RBS-sounding scenario of REF12) and maximum gain of 1 (least error, PACall scenario of hundreds of soundings). The most gain for the least altitude was achieved with soundings up to 4 to 6 km.

We performed ThreeBuoy PAC_RBS OSSEs with different rocket sounding heights, for the Dec12 case. Fig. 8 shows normalized RMSD improvement (ie, gain). Smaller incremental gains accrue with increasing altitude past 4 km, with maximum gain reached at 6 km. Lower-altitude rockets are desirable because they: (1) can have a smaller diameter; (2) allow smaller buoys or more rockets per buoy; and (3) have fewer maintenance requirements. These considerations suggest an optimum maximum altitude of 6 km, although 4 km may be adequate.

### 4.5 *Balanced observational network*

The existing radiosonde network is unbalanced, with data-rich continents and data-poor oceans. One way of balancing the network is to increase the sounding density over the oceans to match that over North America. While this ideal scenario is economically unlikely, the merits of a balanced network encourage investigation of an alternative; namely, spreading the existing number of soundings to cover continents and oceans with equal density. Our OSSE results below show that such reapportionment of existing resources produces better forecast verification than can be obtained with the existing unbalanced network. Namely, if the total number of sounding sites cannot be increased to include ocean coverage, then a second-best alternative is to sacrifice some continental radiosonde site density, and utilize the saved funds to deploy RBS soundings over the Pacific.

For the Mar15 case, the forecast improvement from 0.3 kPa (REF12) to 0.2 kPa (PACall) in RMSD represents the maximum normalized gain. The normal virtual radiosonde sounding spacing in the PACall (ALL05) atmosphere is every 5 grid points (equal to a nominal distance of 225 km). When the virtual radiosonde spacing was changed to 7 grid points (315 km in ALL07), the forecast improvement degraded by 5%. When the spacing was changed to 10 grid points (450 km in ALL10), the forecast improvement degraded by 30%. ALL07 has a virtual radiosonde density of about 1/2 of ALL05. Forecast degradation is a non-linear function of decreasing virtual radiosonde sounding density, decreasing slowly at first.

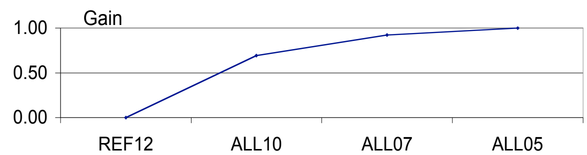


Fig. 9. Normalized gain associated with reduced amounts of radiosonde data-denial (larger gain is better).

The data-void penalty for western North America was previously shown to be more than 20%. If the OSSE ALL results for VERwest are indicative of those for VEReast, then the radiosonde density can be decreased by 1/2 with only a 5% ENA penalty. SixBuoy RBS OSSEs show improvement over WNA of 20% and sometimes as high as 65%. Reallocating radiosonde resources to a RBS to balance the spatial density of the observational network looks like a desirable option for WNA. Since the data void is further upstream, the small short-term penalty over ENA would be compensated by better forecasts (section 4.2) over ENA in the mid-term. It seems that all regions of North America could benefit.

## 5. SUMMARY AND RECOMMENDATIONS

- The preferred time for once-daily RBS launches is 12Z, to support the 12Z analysis, which needs the most help.
- To conserve resources and reduce costs, the RBS system could operate during the fall-winter-spring seasons and lay dormant during summer.
- The optimum number of buoys in the initial RBS array is six.
- The optimum profile height is 6 km, but profiles to 4 km may be adequate.

- An initial “near coast RBS deployment” could be a three-RBS array located 200-300 km off of the BC and Washington outer coasts.
- An optimum, “medium RBS deployment”, is a six-buoy-array centered near 50N 145W, and could have a cross configuration.
- Without the presence of reliable sounding data, the current Pacific analysis update process used by agencies like NCEP can sometimes do more harm than good.
- For the cases studied, the penalty paid by winter western North America forecasts for the Pacific data void is over 20% and as much as 35%.
- Enlarging the sounding network westward over the NE Pacific Ocean at the expense of thinning the current observational network over North America would likely lead to much better western North America forecasts.
- This spreading of the observational network will result in a small short-term penalty paid by the eastern North America forecasts, but will result in a compensating mid-term gain in the east. Taking the conclusions of this and the previous paragraphs together, there would be overall net gain for North America by spreading the in-situ soundings to include the NE Pacific .

The above statements are preliminary findings based on all the cyclone cases captured in the NE Pacific during one year (2001-2002). The work continues with winter 2002-2003 cyclones. Future runs will be taken to 84 hours, which allow 72 h ADA to better capture trends.

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