Seasonal Atmospheric and Oceanic Predictions
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Several projects associated with dynamical, statistical, single column, and ocean models were supported by this grant. These projects are summarized below.

1. Regional Climate Modeling

Does a regional climate model provide a more useful regional climatology than can be obtained from larger-scale global analyses or a better regional forecast than can be obtained by a large-scale seasonal prediction model? To examine these questions, Roads et al. (2002) compared US regional spectral model (RSM) climate simulations forced by 1-day global spectral model (GSM) forecasts initialized from the NCEP operational analysis and with simulations with regional RSM simulations forced by the NASA Seasonal to Interannual Prediction Project general circulation model (GCM). The GCM was continuously forced by observed sea surface temperature variations, but since sea surface temperatures (SSTs) are so persistent, these forced GCM simulations were equivalent to seasonal GCM predictions, which are mainly based upon persistent SSTs anyhow. RSM simulations forced by these two global modes were compared at the same spatial resolution as the global models (200 km) and at higher resolution (50 km). As shown in **Fig. JR1** resolution was important for producing better geographic pictures but does not currently produce significantly more skillful regional climate simulations or forecasts of the temporal variability (**Fig. JR2**), which already have significant skill from the global models. However, regional climate simulations and forecasts better depict the precipitation intensity, especially over the US West (**Fig. JR3**). Finally, re-initialized (from the large-scale analysis) one-day RSM forecasts were compared with continuous RSM simulations, and this increased the overall regional skill back to the original GSM skill, which was somewhat degraded in continuous RSM simulations.

2. Statistical Downscaling

A hybrid dynamical/statistical approach to precipitation forecasting has been developed and tested with the NSIPP model. A statistical relationship is derived between large-scale circulation from the NSIPP model GOGA ensemble (forced with global observed SST) average 500mb height and observed precipitation statistics at weather stations. This relationship is used to downscale forecast AGCM circulation to station precipitation. A case study performed at 124 stations in California indicated that this hybrid method outperformed both purely statistical and purely dynamical long-range forecasting schemes for the intense El Nino winter 1998 (Gershunov et al. 2000). Advantages of the hybrid scheme include versatility and accuracy of AGCM large-scale circulation forecasts, and realistic constraints imposed on precipitation predictions by observations via the statistical downscaling model. Moreover, multiple climate forcings are integrated and skill can be rigorously assessed. Since it is not necessary to make the assumption of climatic stationarity, this methodology is also well suited to making projections of anthropogenic climate change regional impacts.

Hybrid methodology at a glance:

•Predictor: Large-scale atmospheric circulation (i.e. 500mb heights) from 39-year global SST-forced NSIPP ensemble integration

•Predictand: Precipitation, streamflow or any seasonal statistic of observed weather/hydrology on seasonal or shorter timescales

•Statistical model:

»Predictor and Predictand fields are pre-filtered with p Principal Components (PCs)

»Patterns of variability in the Predictor and Predictand fields represented by their p respective PCs are related to each other via k canonical correlates derived from Canonical Correlation Analysis (CCA). k £ p « T, where T is the number of temporal observations available for model training

»The optimal statistical model is defined by considering cross-validated measures of skill for all reasonable combinations of p and k displayed on the Skill Optimization Surface (SOS)

•Forecast: Global SST is operationally forecast. The AGCM is forced by forecast SST. The Predictor field (500mb heights) is computed. Patterns in dynamically predicted circulation are downscaled to the Predictand using the optimal statistical model.

NSIPP predictability results are shown in **Figures SG1 and SG2**. We are in the process of writing up these results in comparison with similar results from the ECHAM and NCEP models as well as purely statistical predictors for the contiguous US precipitation and streamflow over all seasons (Gershunov and Cayan 2001).

3. Evaluation of SCM and NSIPP AGCM Results at the ARM Program Sites

We are using our single-column diagnostic model, in conjunction with observations, to develop, validate and improve regional-scale parameterizations of physical processes important to ENSO time- and space-scale forecasting. The single-column model (SCM) is a diagnostic one-dimensional (vertical) model containing a full set of modern GCM parameterizations. The SCM is computationally efficient and serves as an ideal platform to test and evaluate model parameterizations (Iacobellis and Somerville, 2000; Iacobellis et al, 2000a; Iacobellis et al 2000b; and Somerville, 2000). The SCM has also been used to examine the sensitivity of model parameterizations to changes in vertical resolution (Lane et al, 2000). To force and constrain the SCM in this study, the advective terms in the budget equations are specified observationally from the NCEP GSM forecast model (Iacobellis and Somerville, 2001). Additionally, the surface sensible and latent heat fluxes from the GSM are used as forcing for the SCM. The SCM is operated at the three Atmospheric Radiation Measurement (ARM) Program sites located in the U.S. Southern Great Plains (SGP), the Tropical West Pacific (TWP), and the North Slope of Alaska (NSA). Operating the SCM at these sites allows us to take advantage of the large amount of observations collected as part of the ARM Program.

Our initial efforts focused on the development of software to automate the process of retrieving the forcing data from the GSM forecasts and running the SCM. Additional software was developed to post-process the SCM data, acquire ARM observational data and to produce graphics of model results vs. observations that are displayed on a dedicated website located at http://meteora.ucsd.edu/~iacob. We have compared results from the SCM and NSIPP AMIP ensembles to ARM observations to evaluate model parameterizations. The SCM forced with NCEP data has been operating continuously since May 2000. Data from NSIPP AMIP ensembles is currently available up to December 2000. **Figure SI1** shows the evolution of the monthly

mean downwelling surface shortwave radiation at the three ARM sites from the SCM, eight NSIPP AMIP ensembles, and ARM measurements from May through December 2000. At both the SGP and TWP sites, the downwelling surface shortwave from the NSIPP ensembles consistently overestimates the downwelling surface shortwave compared to ARM measurements. The SCM results compare much more favorably during the entire period and suggest that the cloud and/or radiation parameterizations in the SCM are producing more realistic results than those in the NSIPP model. At the NSA site, the SCM and the NSIPP ensembles both agree reasonably well with the ARM measurements. The discrepancies noted above at the SGP and TWP sites may be related to convective processes, which are absent at the NSA site.

We have also analyzed the sensitivity of the SCM results to the choice of convection parameterization. The SCM utilizes a prognostic cloud scheme that produces clouds from the detrained cloud water from the cumulus convection parameterization. Thus, the model cloud and radiation results may be particularly sensitive to the selection of the convection parameterization. **Figure SI2** shows the mean vertical cloud amount at the SGP and TWP sites from two versions of the SCM for June to August 2000. Model run SCM-CCM3 uses the CCM3 convection package (Zhang and McFarland, 1995) while the model results labeled SCM-RAS employed the Relaxed Arakawa-Schubert convection scheme (Moorthi and Suarez, 1992). Also shown in Figure SI2 is the mean vertical profile of cloud amount derived from Millimeter Cloud Radar (MMCR) measurements at each site. At the SGP site, both versions of the SCM produce similar cloud profiles with maximum mean cloud fraction of about 30% near 11 km. Measurements from the MMCR also indicate a maximum mean cloud amount in the upper troposphere, but about 1 km lower and only reaching a magnitude of 20%. The MMCR data also indicates a secondary maximum near the surface between 1-2 km that both SCM-CCM3 and SCM-RAS fail to produce. At the TWP site, the model results appear more sensitive to the cumulus convection scheme. Both SCMs produce maximum cloud fractions in the upper troposphere, but at levels separated by about 5 km. Both also produce a low cloud relative maximum, with SCM-CCM3 indicating a magnitude about twice that of SCM-RAS. Observational estimates of the mean vertical cloud profile from MMCR measurements are inconclusive as to which version of the SCM is more realistic. However, SCM-CCM3 is much closer to reproducing the low cloud maximum shown by the MMCR measurements.

4. Ocean Forecasts

We are currently making real-time Pacific Ocean forecasts at 3-month lead times. The ocean model (Auad et al., 2001) includes realistic geometry and topography at 1.5 degree resolution with enhancement in the tropics. The ocean model is forced by anomalous wind stresses, heat fluxes determined from forecasts of the ECPC GSM added to the mean seasonal cycle forcing. While the GSM is initialized from NCEP analyses, the ocean model has been initialized from a continuously updated hindcast forced by NCEP RA2 flux anomalies. Hence the ocean initial state can differ appreciably from the observed initial state. Initial assessments of the ocean model forecast skill (Auad et al, 2001, in preparation) indicate the model can beat forecasts of persistence of initial conditions only for the longer lead times. Our objective in this project has been to assess the utility of using an oceanic initial state that more closely conforms to observations. By this means, the model could compete more handily with persistence forecasts for the shorter leads and perhaps achieve higher skill at longer leads as well.

Our first attempts to improve the ocean initial states involved mapping the NASA ocean model assimilation product from its z-grid to the OPYC isopycnal grid (10 layers, plus fully coupled surface mixed layer). This was done by preserving the structure of the vertical coordinates of the isopycnal model state from the hindcast run. We obtained the NASA ocean model data from the computer at Goddard Space Flight Center, mapped them to the OPYC's grid and then ran the OPYC model (**Figure GA1** shows a comparison of sea surface temperatures for August 1988 obtained from the OPYC model, the NASA model and from COADS observations). After integrating for only a few time steps, the model solution went unstable. Apparently, the velocity fields in the new coordinate system were too imbalanced with respect to the density field to obtain a stable flow regime. Additional attempts at initializing by smoothing the input flow fields, allowing stronger friction, etc., were unsuccessful.

As an alternative to directly inserting the mapped fields into the isopycnal model, we next explored using nudging techniques. We re-ran the hindcast for the three months preceding the forecast initialization but now including a nudging term in temperature and salinity in the 3D coordinates to attempt to coax the model to be closer to the NASA ocean analysis at the start of the forecast. The resulting velocity fields (free to evolve to be balanced with the density forcing) were unrealistic so we abandoned this strategy. We then attempted to nudge only the temperature and salinity fields in the model mixed layer. But this resulted in little change in the subsurface conditions so that when the model was freed of the nudging constraint, the forecasts rapidly deteriorated.

We note, however, that we subsequently learned at the NCEP RA2 flux comparison meeting (NASA GSFCC, June 7, 2001) that the ocean analyses provided to us had some problems and that new analyses were now available. We plan to use this data in future work, albeit with a different model (MIT ocean model) which also has z-coordinates and hence may be more resilient in receiving fields mapped from another model.

4. References

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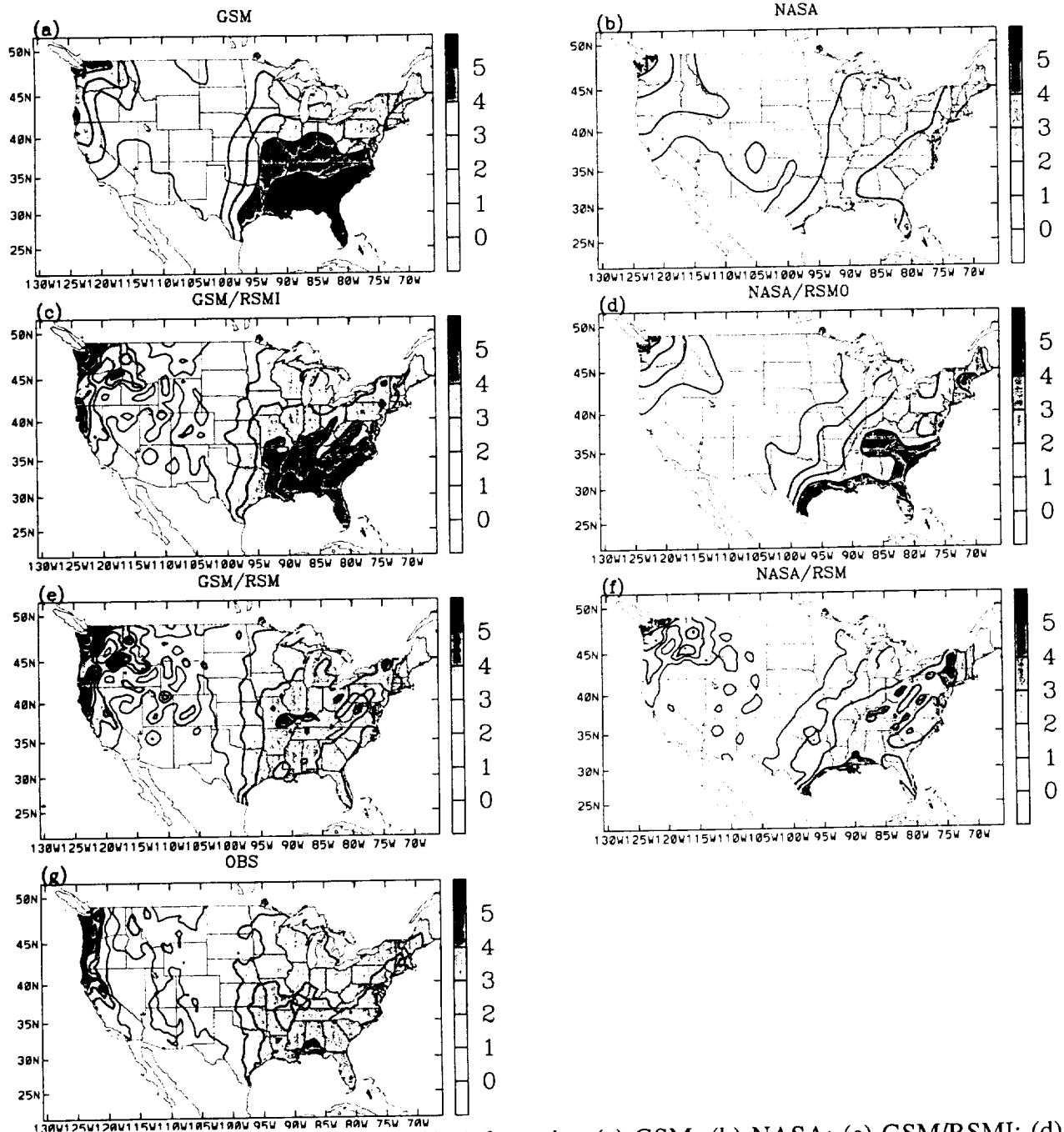
Fig. JR1 Annual precipitation (mm/day) from the: (a) GSM; (b) NASA; (c) GSM/RSMI; (d) NASA/RSM0; (e), GSM/RSM; (f) NASA/RSM; (g) observations.
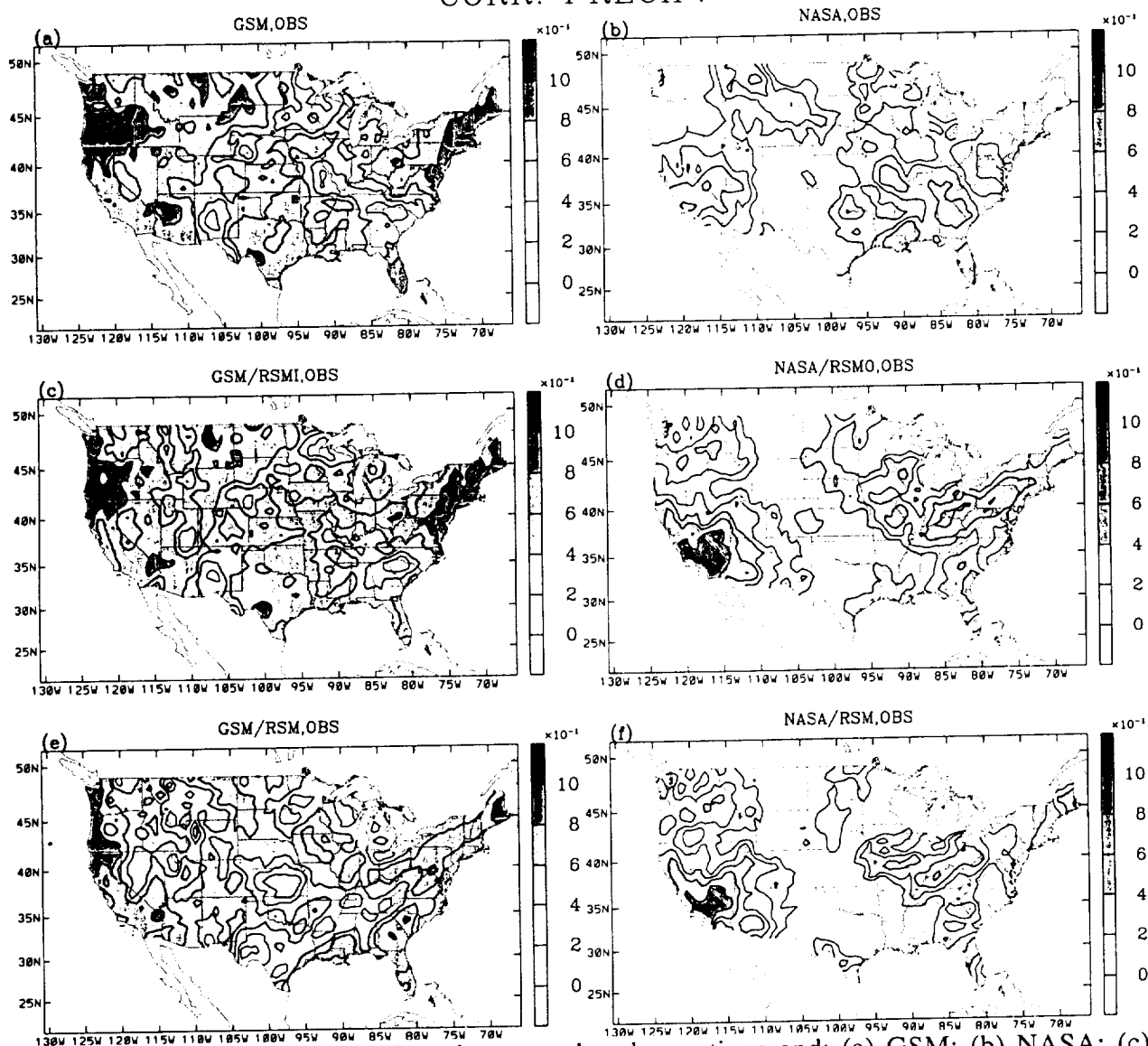
Fig. JR2 Precipitation correlations between the observations and: (a) GSM; (b) NASA; (c) GSM/RSMI; (d) NASA/RSM0; (e), GSM/RSM; (f) NASA/RSM.
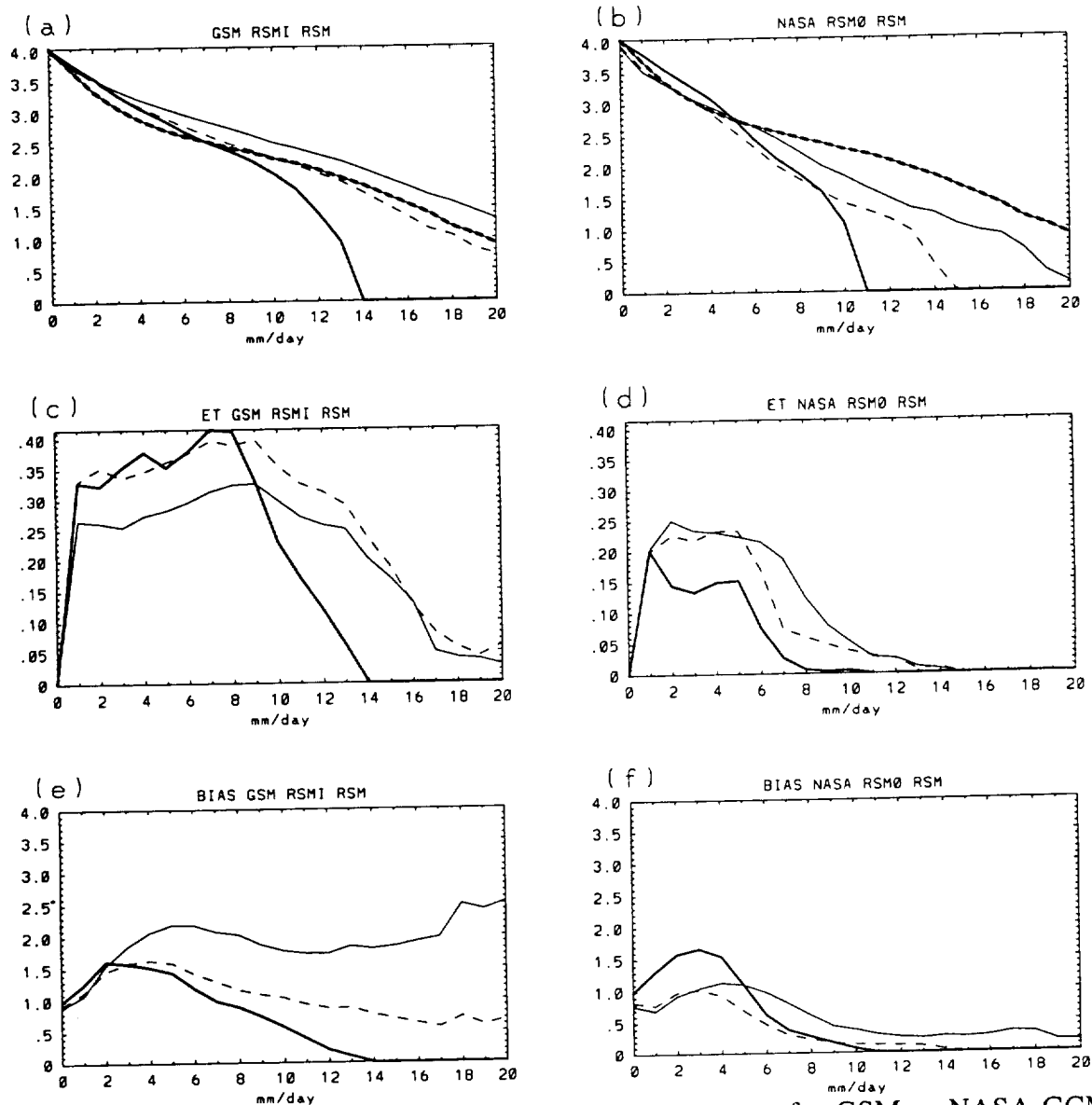
Fig. JR3 US West precipitation equitable threat skill scores for GSM or NASA GCM (thick solid line), RSMI or RSM0 (thin dashed line), RSM (thin solid line), observations (thick dashed line); (a) xo (number of observations above the abscissa limit) and GSM/RSMI/RSM xf (number of forecast values above the abscissa limit); (b) xo (number of observations above the abscissa limit) and NASA/RSM0/RSM xf (number of forecast values above the abscissa limit); (c) GSM/RSMI/RSM equitable threat scores; (d) NASA/RSM0/RSM equitable threat scores; (e) GSM/RSMI/RSM bias; (f) NASA/RSM0/RSM bias.
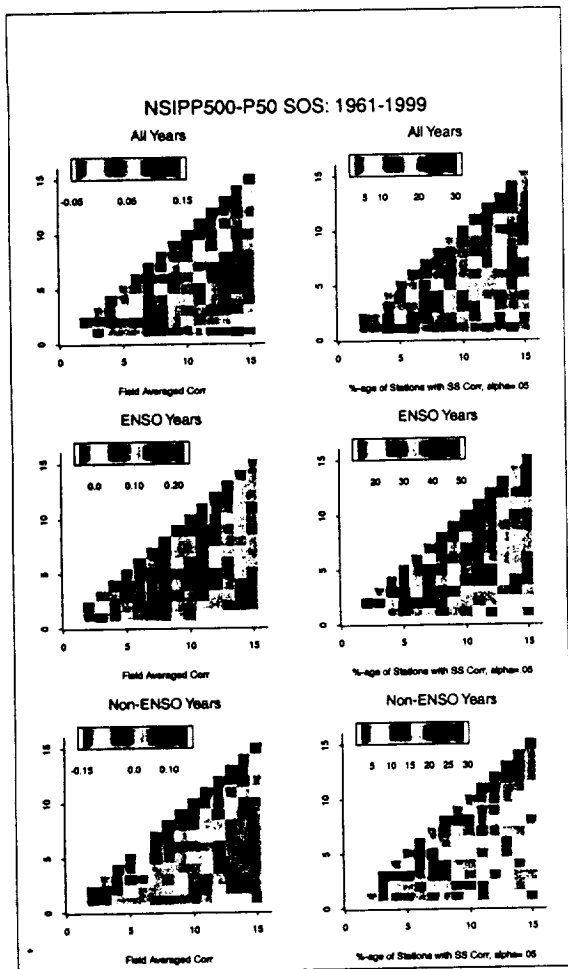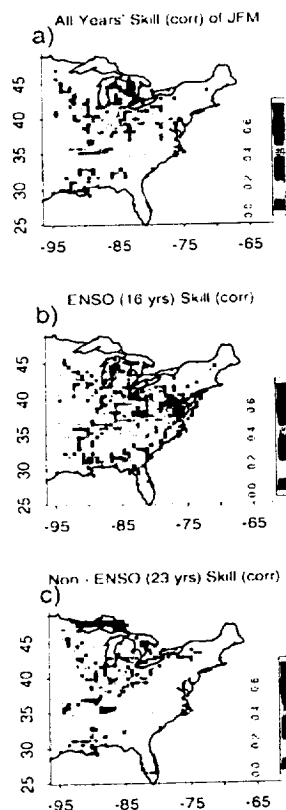
Figure SA1 (left most figures). Skill Optimization Surface (SOS) for above-median JFM daily precip frequency (P50) Cross-validated skill for all reasonable combinations of p and k for frequency of daily precipitation during January-March (JFM) exceeding the 50th percentile of the local JFM climatology (P50). Precipitation data observed at 427 eastern US stations. Regional skill is summarized as (A) average station correlation (ASC) between forecast (cross-validated) and observed P50 (left panels) and (B) percentage of stations (POS) with correlations significant at the .05 level (right panels). ASC and POS are displayed for (1) all model-training years (1961:1999, upper panels), (2) All ENSO (cold and warm episodes) years (middle panels), and (3) All other, or non-ENSO years (bottom panels)

Figure SA2 (rightmost figures). Optimal model Skill (P50)For the optimal model selected on the basis of SOS (Figure 1), we show the map of correlations between the cross-validated forecasts and observations at stations (dots on left panels). Skill maps are shown for all years (1961:1999, a), all ENSO (cold and warm episodes) years (b), and all other, or non-ENSO years (c).
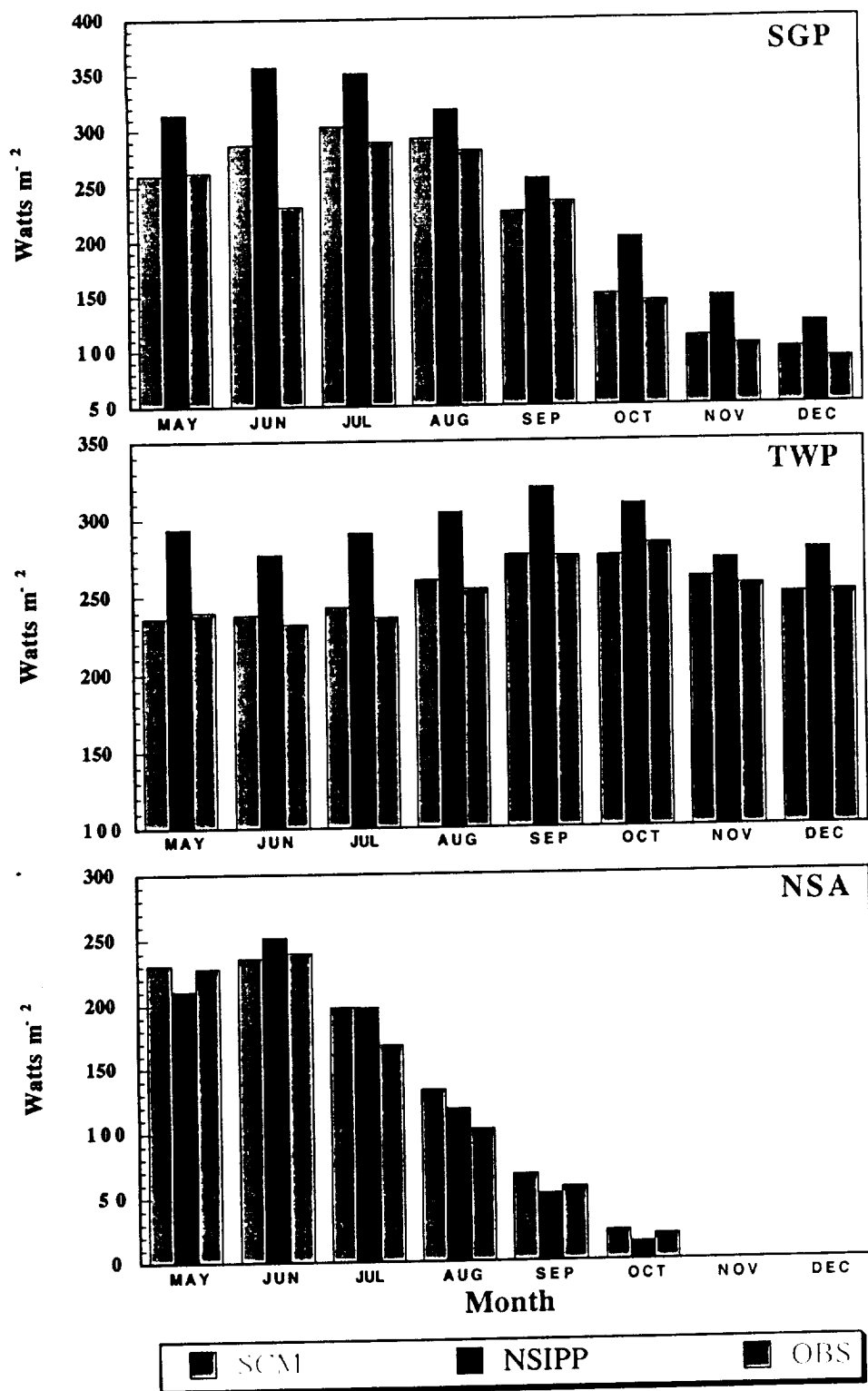
Figure SI1. Monthly mean downwelling surface shortwave radiation from the SCM, NSIPP ensembles and ARM observations at the three ARM sites located at the Southern Great Plains (SGP), Tropical West Pacific (TWP), and the North Slope of Alaska (NSA).

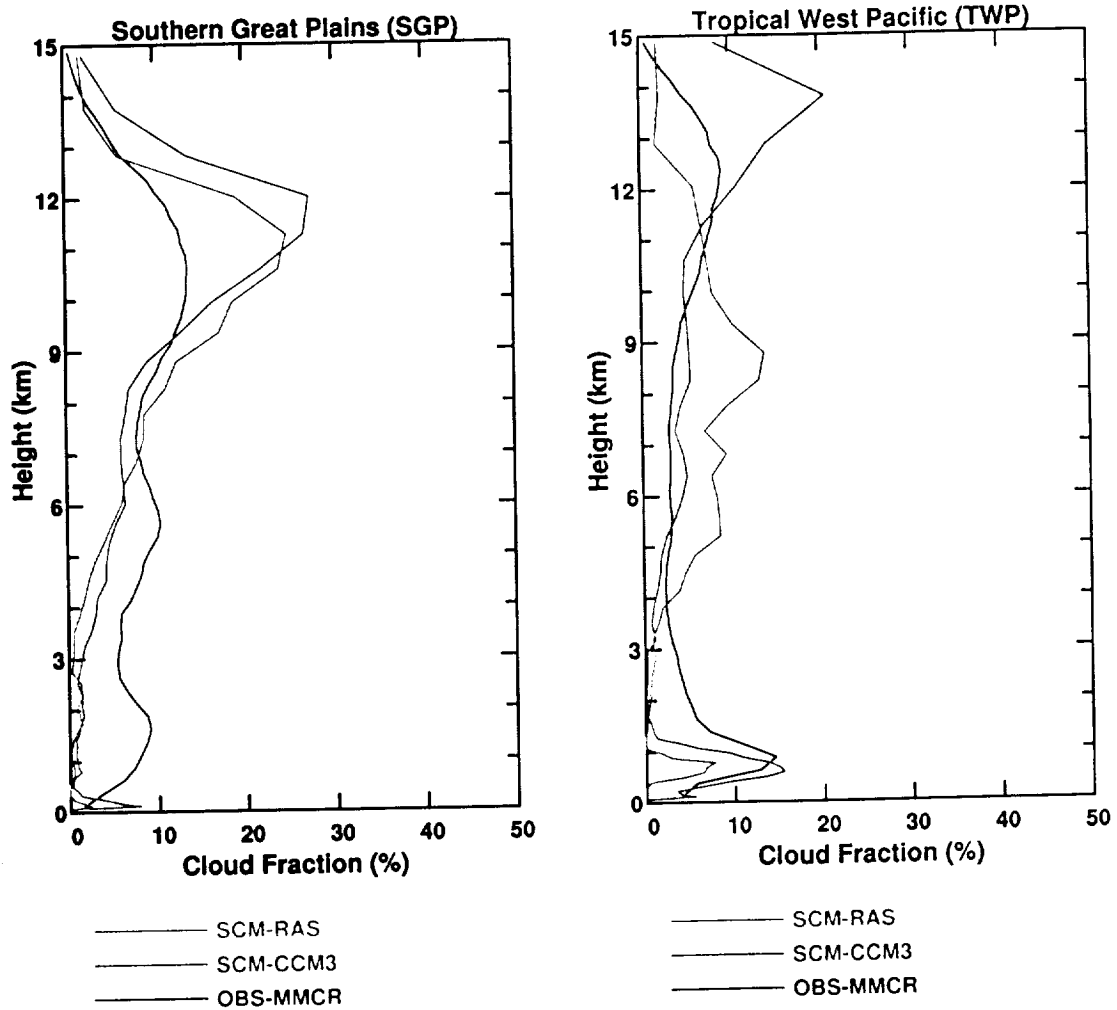# MEAN CLOUD PROFILES

June-August 2000

Figure SI2. Mean vertical profiles of cloud amount from two versions of the SCM and from MMCR measurements. SCM-CCM3 contains the cumulus convection package from CCM3 while SCM-RAS includes the Relaxed Arakawa-Schubert convection parameterization.
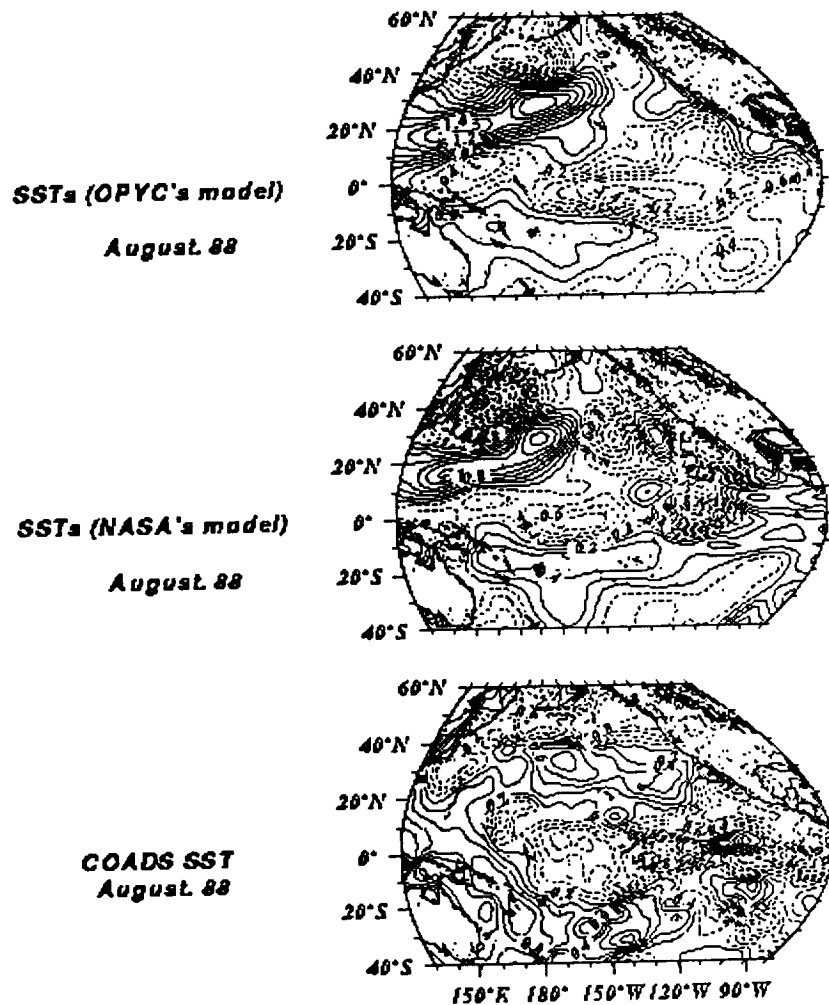
FIGURE GA1: SSTs anomalies (contour interval is 0.2 °C) from the OPYC and NASA's models and from observations, all for August 1988.

Because of Spray's long duration, we hope to deploy the gliders at the start of the experiment and operate them until the trial's end without tending. Glider forward motion is achieved by cyclically changing the vehicle's volume with a hydraulic pump so that it is made alternatively more and less dense than seawater. The resultant vertical motion is translated into forward motion by wings. Typical volume changes lead to forward speeds of 25 to 35 cm/s, operating depths to 1000 m (the glider is rated to 1500 m), and glide angles near 3:1. When operating to 1000 m, the glider executes a seesaw pattern, surfacing about every 6 km. At the surface the glider locates itself by GPS, transmits O(1 Kbyte) of data and its location through ORBCOMM satellites and receives commands from shore that change operational parameters (like waypoints, operating speed or depth) or aspects of data taking or handling. The surface period is typically 15 minutes; the time to execute a 1000 m dive cycle is 5 to 7 hours.

Hull	Length 200 cm, Diameter 20 cm, Mass 51 kg, Payload 3.5 kg
Lift Surfaces	Wing span (chord) 120 (10) cm, Vertical stabilizer length (chord) 49 (7) cm
Batteries	Lithium CSC, 52 DD cells in 3 packs, Energy 13 MJ, Mass 12 kg
Volume Change	Max 900 cc, Motor & reciprocating pump, 50 (20) % efficient @ 1000 (100) dbar
Communication	Orbcomm satellite, 2-way, 0.5 byte/s net, 400 J/Kbyte, GPS navigation
Operating	Max P 1500 dbar, U_{MAX} 45 cm/s, Control on depth+altitude+attitude+vertical W
Endurance	$U = 25$ cm/s, 18° glide, Buoyancy 150 gm, Range 7,000 km, Duration 330 days
Cost	Construction $25,000, Refueling $2850

Characteristics of the autonomous underwater glider 'Spray' (from Davis et al., 2002).

Because the adaptive sampling array will evolve as the AOSN II data begins to be interpreted, we cannot specify how the proposed Sprays would be deployed, but their general role is clear. Circulation within Monterey Bay is dependent on local wind forcing, air-sea fluxes of heat and freshwater, and interaction with the ocean outside the Bay. Analyses of conditions in the Bay, whether based on data assimilating models or human intelligence, depend on knowing how the offshore conditions vary. Because the California Current and the California Undercurrent affect conditions as deep as 500 meters, and because properties from significant depths are carried into Monterey Bay through its underwater canyon and by coastal upwelling, it is necessary that knowledge of offshore conditions extend to at least 500 m. The experiment will last over 6 weeks and it is desirable that observations of the offshore conditions span this full period. Since near the coast wind forcing may be expected to affect the ocean to significant depths, it is necessary for offshore sampling to resolve changes over 2-3 days.

AOSN II will receive data from research vessel cruises that will extend near 100 km offshore and will extensively sample both physical and biological fields but will occur only every few weeks. These data will be most useful in nudging the assimilation models back toward truth on a model scale spanning 100 km offshore and a greater distance along shore. The ship surveys will not have the frequency to track changes from wind forcing, shedding of

topographically generated eddies and plumes, or many coastally trapped waves. Neither will they provide the sampling density needed to fully influence high-resolution models of the Bay itself.

AOSN II will also include a large number of highly maneuverable Slocum gliders that operate effectively in shallow water (where Spray responds too slowly to function well) but cannot operate below 200 m. Slocums will provide much higher resolution than we propose and will operate mainly within the Bay where bathymetric complexity demands high resolution. The Bay itself will also be sampled by sophisticated, high-speed AUVs. Their speed and advanced sensor systems make these platforms ideal for adaptive feature sampling but their duration is too limited to efficiently monitoring offshore conditions over a 6-week period.

MBARI maintains several long-term moorings in and offshore of Monterey Bay. These provide time series of biological and physical conditions in real time that will be vital to the AOSN II assimilating models. While these moorings resolve time changes superbly, they need to be augmented by higher density sampling to fully constrain analyses.

While the array for AOSN II cannot be specified, it is useful to examine strategies that Spray might follow to sample the connection between Monterey Bay and the offshore ocean. Two extremes are: 1) maintain time series at sites in the interface zone in the manner of "virtual
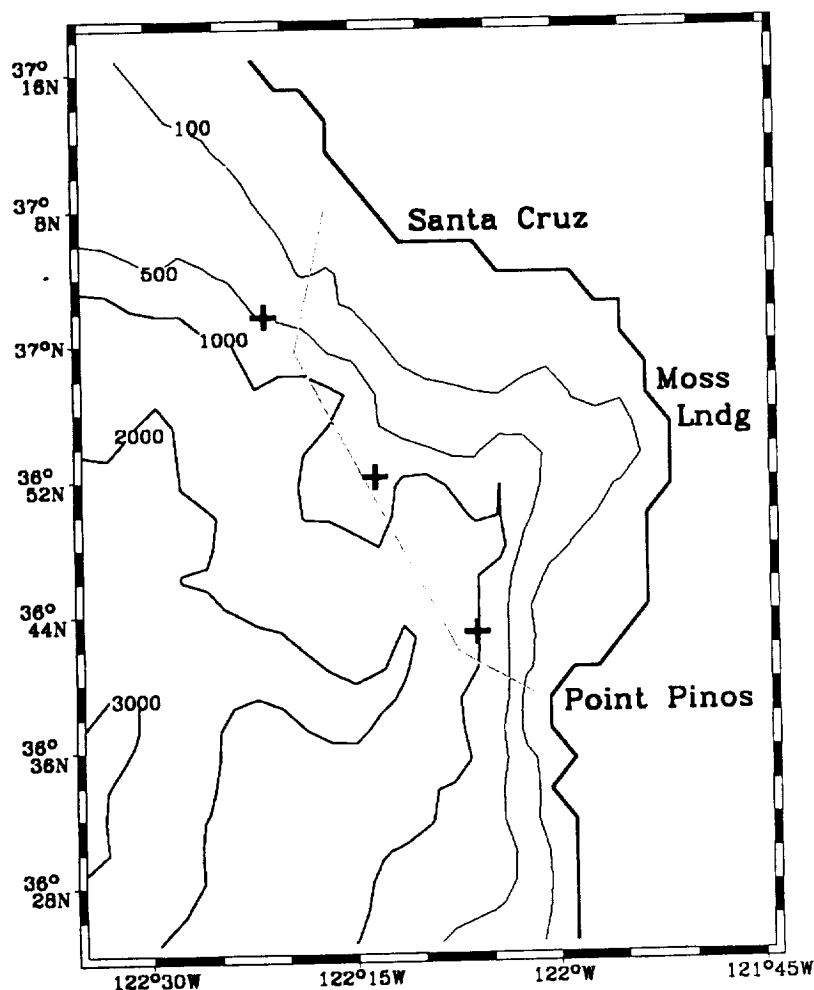

Figure 3. Hypothetical sampling array for Sprays. Red crosses are possible virtual mooring positions separated by about 20 km. Blue line is a possible repeated section of about 60 km length. Two gliders could sample this once every 2 days.