1.6 Input data for the ARM variational analysis

The input data for the ARM variational analysis include measurements of both adjustment variables and constraint fields. The adjusted variables are the large-scale state variables, namely, winds, temperature, and humidity. The constraints include surface pressure, surface latent and sensible heat fluxes, wind stress, precipitation, net radiation at the surface and at the top of the atmosphere (TOA), as well as column total cloud liquid water.

The large-scale state variables are obtained primarily from balloon-borne sounding measurements. During ARM Intensive Operational Periods (IOPs), radiosondes are usually launched every three hours to measure the vertical profiles of winds, temperature, and water vapor mixing ratio over a well-defined sounding array. Hourly profiler measurements of winds are also available at the National Oceanic and Atmospheric Administration (NOAA) wind profiler stations, which can be merged with the soundings in the analysis. At the ARM SGP site, there are ARM five sounding stations: the central facility (C1) and four boundary facilities (B1, B4, B5, and B6), as well as a number of NOAA wind profiler sites to provide the needed upper-air measurements (**Figs. X1a, b**).

The variational analysis analyzes the original upper-air measurements from radiosondes and wind profilers over the analysis grid points (**Fig. X1c**) using the Cressman interpolation scheme (Cressman 1959), which requires a background field from numerical weather prediction (NWP) centers’ operational analyses. Current variational analysis uses the operational analyses from the NOAA mesoscale model Rapid Update Cycle (RUC) for SGP (**Fig. X1d**) and the European Center for Medium-Range Weather Forecasts (ECMWF) for other ARM sites. Note that the NWP operational analysis itself can be used as the input of the large-scale state variables for the variational analysis to create the so-called “continuous forcing” datasets over a long term period (multiple years) where there are no soundings available. In this case, NWP analyses are adjusted through the variational analysis method to balance the observed column budgets of mass, heat, moisture, and momentum rather than the NWP model-produced budgets. The use of the observed constraints in the analysis has significantly improved the accuracy of the forcing data derived from NWP analyses (Xie et al. 2004).

The required constraint variables are derived from measurements of surface observational networks and satellites. Around the ARM SGP site, there is a dense surface network (**Fig. X2a**). The observation platforms include the follows.

* Surface Meteorological Observation Stations (SMOS) measuring surface precipitation, surface pressure, surface winds, temperature, and relative humidity
* Energy Budget Bowen Ratio (EBBR) stations measuring surface latent and sensible heat fluxes and surface broadband net radiative flux.
* Eddy Correlation Flux Measurement System (ECOR) providing in situ averages of the surface vertical fluxes of momentum, sensible heat flux, and latent heat flux.
* Oklahoma and Kansas mesonet stations (OKM and KAM) measuring surface precipitation, pressure, winds, and temperature.
* Microwave Radiometer (MWR) stations measuring the column precipitable water and total cloud liquid water
* Solar and Infrared Radiation Station (SIRS) providing continuous measurements of broadband shortwave (solar) and longwave (atmospheric or infrared) irradiances for downwelling and upwelling components.
* WSR-88D Nexrad radar and rain gauge providing hourly surface precipitation data to the Arkansas-Red Basin River Forecast Center (ABRFC).

The Geostationary Operational Environmental Satellite (GOES) provides satellite measurements clouds and broadband radiative fluxes at TOA over the 0.50 x 0.50 grids (**Fig. X2b**). All the constraint variables should be the area-averaged quantities over the analysis domain. To avoid biases of using overcrowding measurement stations in some areas, we first lay the 0.50 x 0.50 GOES grids over the analysis domain, and then derive the required quantities in each small grid box. If there are actual measurements within the subgrid box, simple arithmetic averaging is used to obtain the subgrid box means. Some variables are available from several instruments as indicated above. They are merged in the arithmetic averaging process. If there is no actual measurement in the small box, the Barnes scheme (Barnes 1964) is used to fill the missing data. Domain averages of these constraint quantities are obtained by using values from the 0.50 x 0.50 grid boxes within the analysis domain.



Figure X1. Locations of the ARM upper-air data streams and the analysis grid points. (a) sounding stations, (b) 7 profiler stations (crosses), and (c) the 12 analysis grid points (heavy dots) in the hybrid approach. Also plotted are the nearby profiler stations (crosses). (d) RUC grids overlaid on other grids. (Adapted from Zhang et al. 2001)



Figure X2. (a) ARM surface data streams (see text for complete instrument names) and (b) GOES grids over the analysis domain. (Adapted from Zhang et al. 2001)

1.7 Available ARM variational analysis forcing datasets

The constrained variational analysis method has been applied to routinely derive the large-scale forcing data from ARM measurements for SCM and CRM studies. There are two types of variational analysis forcing data products available for the ARM permanent research sites and ARM Mobile Facilities (AMF). The first is the “IOP forcing”, which is derived using sounding data collected during ARM major IOPs. The second is the “continuous forcing”, which is derived using NWP operational analyses for multi-year continuous periods where sounding measurements are not available. For both types of the forcing datasets, the large-scale state variables are constrained with surface and satellite observations.

**Table X1** lists the available ARM variational analysis forcing datasets. These forcing datasets can be obtained from the ARM Archive (<http://iop.archive.arm.gov/arm-iop/0eval-data/xie/scm-forcing>). Over the past two decades, ARM has conducted numerous field campaigns in diverse climate regimes around the world to collect detailed observations of clouds and radiation, as well as related atmospheric variables for climate model evaluation and improvement. The majority of these field campaigns were conducted at the ARM SGP site, probably the largest and most extensive climate research site in the world. Major field campaigns at SGP include the June-July 1997 SCM IOP for midlatitude land convection, the March 2000 cloud IOP for frontal system, the June 2007 Cloud LAnd Surface Interaction Campaign (CLASIC), as well as the April-May 2012 Midlatitude Continental Convective Clouds Experiment (MC3E). At the ARM North Slope of Alaska (NSA) site, ARM conducted the Mixed-phase Arctic Cloud Experiment (M-PACE) in October 2004 to study mixed-phase clouds and the Indirect and Semi-Direct Aerosol Campaign (ISDAC) in April 2008 to study the aerosol-cloud interaction in the Arctic region. In the tropics, the Tropical Warm Pool International Cloud Experiment (TWPICE) was taken place in January and February 2006 around the ARM Tropical Western Pacific (TWP)-Darwin site to improve the understanding the interaction of tropical convection with its environment. In addition, ARM also regularly deploys its AMF in various climate regimes not previously explored. More details about these field campaigns can be found via http://www.arm.gov/campaigns.

The variational analysis forcing data products have been developed for all the major field campaigns conducted at the ARM permanent research sites and some of the AMF deployments. For the SGP and TWP-Darwin sites, ARM has also created the continuous forcing data over multiple years. These large scale forcing datasets provide the needed initial and boundary conditions for SCMs and CRMs in studying various observed cloud systems and testing physical parameterizations in climate models.

Table X1. Available ARM variational analysis forcing datasets. The numbers indicate the “month/year” when the forcing data are available.

|  |  |  |
| --- | --- | --- |
|  | IOP Forcing | Continuous Forcing |
| SGP | 07/95, 04/97, 06/97, 09/97, 04/98, 01/99, 03/99, 07/99, 03/00, 09/00, 11/00, 11/02, 05/03, 06/07, 04/12 | 01/99 – 06/11 |
| TWP-Darwin | 01/06 | Three wet seasons between 2004 and 2007 |
| NSA | 10/04 | 04/08 |
| AMF-China |  | 11/08 |
| AMF-AMIE-Gan |  | 11/11 |

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