

# MULTISCALE DATA ASSIMILATION AND FORECASTING

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**T**he Local Analysis and Prediction System (LAPS) is a highly portable, computationally efficient numerical weather prediction (NWP) data assimilation and nowcasting system. The first version of LAPS was developed in the late 1980s and early 1990s (Albers et al. 1996). LAPS offers very frequently updated (15–30 min), very finescale (1–3 km) analyses assimilating most locally available observations, and ensuing forecast products with low latency, using versions of the Weather Research Forecast (WRF) or other models. The primary use of LAPS is in situational awareness and very short range forecasting [warn on forecasting (WOF)].

Within the National Oceanic and Atmospheric Administration (NOAA), LAPS is used operationally on Advanced Weather Interactive Processing System (AWIPS) platforms at National Weather Service (NWS) Weather Forecast Offices (WFOs). NWS applications of LAPS include severe, winter, fire, hydrometeorological, tropical, and aviation weather

## SECOND LOCAL ANALYSIS AND PREDICTION SYSTEM (LAPS) USER WORKSHOP

**WHAT:** Approximately 75 users and developers of finescale weather data assimilation schemes from the United States, Europe, and Asia met to assess the state of the LAPS system, discuss promising initiatives, and recommend future steps related to the use and further development of the system.

**WHEN:** 23–25 October 2012

**WHERE:** Boulder, Colorado

forecasting. LAPS is also used operationally at about 20 other national and international agencies. LAPS, including its newly available multiscale variational version, is developed as a community effort.

**WORKSHOP LOGISTICS.** Building on the success of the first LAPS User Workshop (Toth et al. 2012), the second LAPS User Workshop was convened jointly by the main developer and user groups of the system, the Global Systems Division (GSD) of NOAA's Earth System Research Laboratory (ESRL), and the NWS Office of Climate, Weather, and Water Services, respectively. Scientists and forecasters from U.S. agencies (36, including 31 from NOAA), the international (17) and academic (15) communities, and the private sector (9) attended the 3-day meeting. The program included 38 presentations and two rounds of breakout group and plenary discussions. A series of workshop recommendations on the use and development of the LAPS system are summarized in this article.

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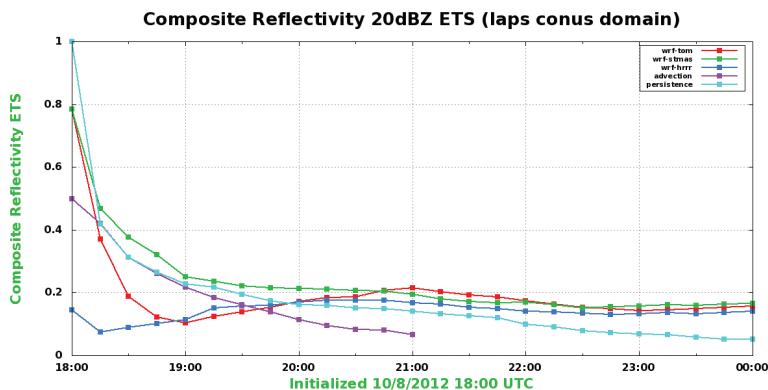
## RECENT AND PLANNED IMPROVEMENTS TO LAPS.

Since it was first introduced in the early 1990s, LAPS has been continually upgraded to improve its data assimilation algorithm, increase its computational efficiency, and make it more user friendly and portable. Up until 2012, GSD scientists alone published over 400 LAPS-related papers (including 30 that were peer reviewed), drawing more than 4000 citations (including 400+ peer reviewed).

The most important recent addition is the development of a variational version of LAPS, based on the Space-Time Multiscale Analysis System (STMAS; Xie et al. 2011). The new version of LAPS replaces the univariate approach used previously for the analysis of the basic state variables (surface pressure, temperature, winds, and humidity). Because of model spinup or spindown, NWP forecasts notoriously underperform in very short forecast ranges (0–3-h lead time). At the workshop, results were presented indicating that variational LAPS further improves on the strong performance of LAPS in this time range, offering potentially the first NWP forecast examples that outperform simple statistical methods like persistence and advection in the prediction of convective activities (see Fig. 1). These results suggest that routine NWP-based prediction of convective initiation, and therefore warnings of severe weather (WOF), may become possible.

The workshop recommended that LAPS developments be accelerated in the following areas:

- variational version of the cloud analysis module integrated into the new variational LAPS analysis scheme;
- thermodynamical and microphysical balance constraints consistent with WRF model thermodynamics and physics for the initialization of clouds, active convective processes, and precipitation (“hot start” initialization);
- terrain-following coordinate system to unify the variational 2D surface and 3D analyses and improve their dynamical balance; and
- estimation and use of observational and background error variance and covariance information for increased accuracy of the analyses.



**FIG. 1. Equitable threat score (ETS) for composite reflectivity at the 20-dBZ threshold, an indicator of skill (the higher the better) in predicted convective activity for forecasts initialized at 1800 UTC 8 Oct 2012, as a function of time of day. NWP Aviation Research WRF (ARW) forecasts initialized with the new variational and the traditional versions of LAPS are shown in green and red, respectively, while the High-Resolution Rapid Refresh (HRRR) forecast system of GSD is shown in blue. Persistence (aqua) and advection (purple) forecasts are also shown for reference.**

**USE OF OBSERVATIONS.** Beyond the scientific methodologies used, the quality of numerical analyses depends on the quantity and quality of observational data. The workshop recommended that LAPS be continually updated to acquire, ingest, and use all new observations available locally in the various regions where LAPS is used across the globe. The workshop recommended that LAPS developers and users coordinate the choice of format for new data types with the developers of the National Centers for Environmental Prediction (NCEP) gridpoint statistical interpolation (GSI) method and share data converters with the rest of the community. Such an arrangement will allow rapid access to new data types by global data assimilation applications when they become ready to ingest observations informative of finescale processes. Forward operators should also be prepared or adapted for the variational assimilation of various types of data, including the following:

- Meteorological Data Collection and Reporting Services (MDCARS)/Aircraft Meteorological Data Relay (AMDAR),
- global positioning system (GPS)-derived total precipitable moisture or signal delay/refractivity,
- sonic anemometers,
- various forms of weather radars (Doppler, dual polarization, etc.),
- satellite radiances via the Community Radiative Transfer Model (CRTM),
- observations from other orbiting satellite instruments [e.g., Atmospheric Infrared Sounder (AIRS) and Global Precipitation Measurement (GPM)],

- Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) GPS radio occultation,
- Laser Interferometry Detection and Ranging (LIDAR)—data source for backscattering and radial velocity,
- lightning data, and
- scatterometer data.

**USER SUPPORT.** LAPS is widely used in the forecast community partly owing to its ease of portability and use. The workshop recommended the development of a graphical user interface (GUI) or wizard for the easy installation, configuration, updating, and testing of LAPS on the new NWS AWIPS-II workstation; the wizard should also be portable to other platforms. And, it could also facilitate the ingestion and quality control of observational data. Workshop participants expressed a strong interest in using LAPS installed on AWIPS-II, and recommended that if possible, Unidata distribute the LAPS software to its community.

Workshop participants appreciated the recent addition of verification software into LAPS, utilizing data ingest and quality control (QC) procedures already available. Related recommendations included the expansion of the verification system by the possible incorporation of automatic regression testing and interactive display tools.

One of the main advantages of the multiscale variational LAPS data assimilation scheme is its computational efficiency. Currently, variational LAPS is approximately 18 times more efficient than other variational methods such as GSI. This allows LAPS to provide very frequently updated (e.g., every 15 min) analysis and forecast information. The workshop encouraged LAPS developers to continue the parallelization of the LAPS software to further enhance its timeliness, which is critical in WOF applications.

Other recommendations aimed at improved user support include the following:

- Tailor code documentation for basic and advanced users in a modernized format.
- Enhance the LAPS forum with frequently asked questions and an easy-to-search format.
- Expand the NWS LAPS tutorial and training by separating general content that should be made available to the wider community from NWS-specific material.
- Develop a LAPS public relations brochure and engage high school students in running LAPS.

## **COMMUNITY DEVELOPMENT OF LAPS.**

While the main developer of LAPS is GSD, collaborators from the United States (e.g., Vaisala) and other areas such as China [Chinese Meteorological Agency (CMA)], Finland [Finnish Meteorological Agency (FMI)], Italy [Institute of Atmospheric Sciences and Climate (ISAC)], Greece [Harokopio University of Athens (HUA) and Hellenic Centre for Marine Research (HCMR)], South Korea [Korean Meteorological Administration (KMA)], Spain [Meteorological Service of Catalonia (METEOCAT)], and Taiwan [Central Weather Bureau (CWB)] have also made significant contributions. To streamline collaborative development, workshop participants recommended that the LAPS code repository, maintained by GSD, be opened to all users for reading and that trusted collaborators be granted write permission as well.

An important recommendation of the workshop was to make the LAPS software part of a NOAA Data Assimilation Repository (NDAR), along with GSI and other systems under development. The different schemes should be made more modularized so various components such as forward operators can be exchanged across the schemes for the benefit of the broader community. The workshop recommended that the Developmental Testbed Center (DTC) take an active role in hosting such a repository and carrying out LAPS regression testing and comparative evaluations of the various schemes and modules. GSD and its partners can also host datasets for selected cases to test the proper installation of and periodic improvements to the LAPS system.

To ensure that 1) all contributions made to the software benefit the entire LAPS community, 2) users can easily update LAPS with the latest version of the software, 3) the integrity of the software is safeguarded, and 4) contributions to the software are properly recognized, the workshop recommended that LAPS software users be asked the following:

- to document and feed back all improvements to the software into the central repository maintained at GSD,
- not to redistribute the codes, and
- to acknowledge GSD and its community development team as the source of the LAPS software.

**USE IN OPERATIONS.** LAPS runs automatically on the operational AWIPS workstations in each WFO of the NWS. Important applications of LAPS analyses at the WFOs include 1) the analysis of the atmospheric environment for all warning operations; 2) the continual evaluation of the NWS official

gridded forecasts [National Digital Forecast Database (NDFD)], alerting forecast personnel when an immediate manual update of the forecasts is required; and 3) the verification of different NWP forecasts with the aim to identify the guidance with the best fit to the latest LAPS analysis, which then would be used as the first guess in the update of the NDFD dataset.

As the NWS upgrades its workstation environment to AWIPS-II, the data access mechanism for LAPS is being modernized for improved timeliness. As part of a successful collaboration with the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT-LL), the two-dimensional, surface version of variational LAPS is currently being transferred to the Federal Aviation Administration (FAA) for use in their Consolidated Storm Prediction for Aviation (CoSPA)-related operations.

One major recommendation was that NWS install the latest, variational version of LAPS in AWIPS-II, complete with documentation and training. As for future improvements, the workshop recommended annual or semiannual updates. These implementations should be preceded by formal preimplementation testing, including hourly analyses on a continental United States (CONUS) scale as well as forecasts four times per day, each with 6-h lead times, evaluated both objectively by GSD or DTC and subjectively by the NWS regions, including a comparison with other NWP guidance. Experimental versions of the code should be made available to the community on a continual basis.

Beyond preimplementation testing, LAPS should also be evaluated and tested in the context of various NOAA testbeds, including the NOAA satellite proving ground (for the rapid synthesis of all available observational information into a dynamically consistent three-dimensional fine-resolution gridded representation of the atmosphere), the Hazardous Weather Testbed (HWT; in WOF applications), and the Hydrometeorological Testbed (HMT; in flash-flood and other hydrological forecast contexts).

Another recommendation of the workshop calls for the creation of a LAPS User Group (LUG). This group will be formed from representatives of each of the NWS regions and various application areas and will have a strong link to the NWS Training Division.

The LUG will share the best practices across the NWS and other user groups, communicate user needs to the developers of LAPS, and promote the use of LAPS in general.

**FUTURE COLLABORATION.** The workshop recommended that follow-up LAPS workshops be held on a biannual basis at GSD/ESRL in Boulder, Colorado. The next workshop in 2014 may focus on the important topic of variational cloud analysis. To strengthen regional collaboration, various international partners expressed an interest in holding regional LAPS workshops in Asia and Europe in the intervening years. The workshop also offered a venue to develop long-term collaborative development plans between GSD and its partners. As a result, GSD will host five international LAPS visitors from Asia and Europe in the coming year, and will broaden collaboration with the Heavy Rain Institute (CMA) and KMA.

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