SONDE-ATHENA: A SOFTWARE APPLICATION FOR THE SYSTEMATIC ANALYSIS OF RADIOSONDE OBSERVATIONS

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ABSTRACT

Despite the recent advancements in satellite remote sensing and aircraft or ground sensors, radiosonde observations still remain an important technique for the upper air data acquisition. The National Oceanic and Atmospheric Administration (NOAA) feeds from 1970 the Integrated Global Radiosonde Archive (IGRA) with radiosonde data from 1719 sites around the world. In this paper we present the SONDE-ATHENA (SA) software application designed and developed to provide a user-friendly access to the IGRA database and to produce a systematic analysis of the radiosondes' data. Its architecture includes three main components: a) dataset accessibility, b) data analysis and low-level temperature inversion detection and c) climatological analysis and association of synoptic scale circulation and inversion characteristics. The user is able to choose the location of the radiosonde upper-air station and check its data completeness, prior to downloading the data file. The main analysis routine aims to detect low-level temperature inversions and calculate their characteristics. It calculates parameters not readily available in the IGRA data file, like potential temperature (θ), geometric height and differences of potential temperature between the surface and the level of 850hPa ($D\Theta_{850}$). The results of the main analysis are presented through a manageable visualization interface that enables the user to view the radiosonde profile. Subsequently, the user can access the climatological analysis tools. These include yearly and monthly time series plots of four critical inversion characteristics: temperature difference between the base and the top of the inversion (DT_{inv}), potential temperature difference between the base and the top of the inversion ($D\Theta_{850}$), inversion thickness (DZ_{inv}) and inversion base height (Z_{base}) along with their inter-correlations. Additional tools provide the frequency analysis of the inversions per month and according to their inversion strength, as well as inversion persistence tables. An important task of SA is to examine possible associations between temperature inversions and synoptic scale circulation. SA is able to combine the results from the main algorithm with the data from the NCEP/NCAR Reanalysis 1 database and export (to Google Earth®) synoptic scale maps that visualize average values of a number of important atmospheric variables for the days of notably increased or alternatively decreased inversion strength values. SA has been evaluated through a number of case studies and the results indicate its validity and reliability.

Keywords: Radiosondes, IGRA, Temperature inversions, Synoptic circulation

1. Introduction

Radiosondes are an established tool for upper-air measurements, especially for the analysis of the characteristics of temperature inversions. Temperature inversions are of vital importance in meteorology, as well as in earth and atmospheric sciences in general. Apart from their role in cloud formation, precipitation and visibility, they also serve an important role in pollutant dispersion by preventing vertical airflow. Therefore, convection produced by the heating of air from below is limited, diffusion of pollutants is rendered inadequate, and, especially in sensitive areas –e.g. urban-, events of extreme air pollution become more common. The frequency of inversions over a region as well as their structure and their variability is associated with multiple factors, such as the geological profile of the region, the distance from large bodies of water and large-scale circulation features. Physical processes associated with the latter, as well as the interaction of these processes, can affect inversion strength and frequency (Iacobellis *et al*., 2009). This work presents the SONDE-ATHENA (SA) software application, designed and developed to provide to the user with a set of tools in order to detect and characterize low level temperature inversions as well as examine their climatological variability and possible connections with large scale circulation events. Moreover it provides a user-friendly access to the Integrated Global Radiosonde Archive (IGRA) and to produce a systematic analysis of the radiosondes' data.

2. The sonde-athena application

The SA software application consists of three main interconnected components a) dataset accessibility, b) data analysis and low-level temperature inversion detection and c) climatological analysis and association of synoptic scale circulation and inversion characteristics (Figure 1).

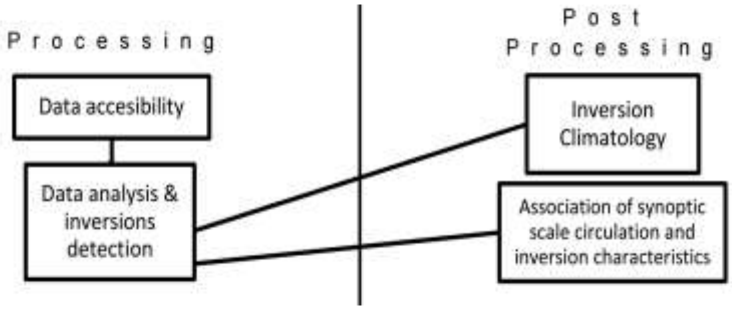


Figure 1: SONDE-ATHENA components.

The associated databases are the IGRA of NOAA and the NCEP/NCAR Reanalysis 1 with a 2.5°×2.5° spatial resolution which provides gridded data from 1948/01/01 up to present (Kalnay *et al*., 1996).

2.1 Data accessibility

The SA data accessibility component enables a user, with less experience in big environmental data analysis, to access, inspect and download the IGRA and NCEP/NCAR Reanalysis products, through an understandable and straightforward interface. In order to facilitate data inspection, a world map with all the existing IGRA stations and their data record information (last update, size of record and download link) is provided. An embedded downloader can be used, through SA's interface, to download the radiosonde data file of interest, thus eliminating the need to access the FTP server of NOAA. Part of the program's functionality depends on Reanalysis data which are stored locally and can be manually updated periodically via an embedded updater. Finally, prior to running the main inversion analysis routine, the user is able to select a specific time period to use.

2.2 Data analysis and inversions detection

The SA main analysis routine initially (a) analyzes the selected IGRA data record in order to (b) identify low-level temperature inversions, subsequently (c) calculates their characteristics, and finally (d) stores and (e) visualizes the results for further use.

The data file is read and organized in two tables: the first contains the radiosonde header information (i.e. date and time of launch, vertical resolution) and the second includes the observations (temperature and geopotential height at several pressure levels). The radiosonde header table is connected with the observations table with a one-to-many relationship type, the primary key being a serial number that SA creates. Even though the IGRA database incorporates many quality control algorithms (Durre *et al.*, 2006) there is a need for additional filtering in order to serve the purpose of the SA software application. SA has further quality restrictions that the user can enable: removal of entire radiosondes from the tables in the case the ground-level temperature or the geopotential height reading is missing, removal of levels from the observations table without temperature readings and, finally, calculation of missing geopotential height observations. SA calculates the geopotential height using the hypsometric equation and the potential temperature and geometric height at each level according to the computational formulae proposed by the Office of the Federal Coordinator for Meteorology (1997). The results of the calculations were compared with the corresponding IGRA derived version 2 dataset measures (Durre and Yin, 2011) to verify their accuracy as well as the dependability of the procedures. The differences in the vertical resolution of temperature readings among radiosondes require re-sampling in order to produce a homogeneous sampling rate between the surface and the 700hPa level. Linear interpolation is used and the user can define the preferred sampling rate in SA's settings.

The inversion detection is based on the interpolated data and follows the methodology described by Kahl (1990). The interpolated data of each radiosonde are checked until the 700hPa level for increasing temperature gradient and the SA identifies and categorizes inversions according to their base height in two categories (i.e. radiation and subsidence). The inversions are stored in a new table and a unique serial number is created in order to identify each one of them. Moreover, this table stores the altitude of the base of the inversion (Z_{base}) and its top (Z_{top}), their difference as the inversion's depth (DZ_{inv}), the temperature difference between the top and the base (DT_{inv}), as well as the potential temperature difference between the 850hPa level and the surface ($D\Theta_{850}$).

The output of the main algorithm is given in tables that contain the results of the above calculations which can be used either as a standalone product of SA or as input for the post processing tools of the software. Furthermore, SA provides visualization of each radiosonde (Figure 2).

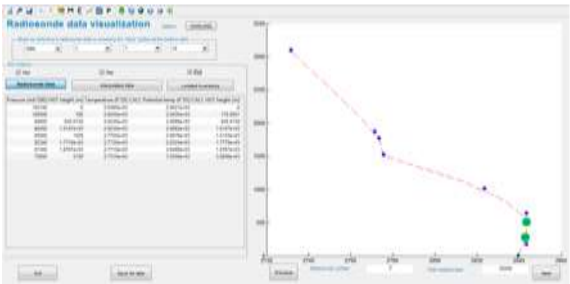


Figure 2: SONDE-ATHENA main window. The command toolbar provides access to all the available tools (climatological analysis, map creator, data retrieval and verification). The main part of the window is used to show each radiosonde's profile and data (raw and interpolated) as well as the located inversions. Plotted data include raw measurements (blue dots), interpolated data (red line) and located inversions (green circles).

2.3 Inversions climatology

Inversions climatology is a SA post-processing component that consists of several tools, focusing on examining temporal variations in the inversion characteristics' measures. In detail, it includes:

a) Calculation and plotting of the monthly mean subsidence and radiation inversion frequency, for either 12Z or 00Z.
b) Monthly boxplots of the most critical subsidence inversion measures (Z_{base}, DZ_{inv}, DT_{inv} and $D\Theta_{850}$) for the assessment of their distribution, magnitude and variability.
c) Time series plots of monthly Z_{base}, DZ_{inv}, DT_{inv} and $D\Theta_{850}$ anomalies for either radiation or subsidence inversions along with the corresponding six-month and five-year running means. The results can be examined for significant interannual or multi-year variabilities.
d) Calculation of change in magnitude for various parameters (i.e. DT_{inv}, DZ_{inv}, Z_{base}, Z_{top}, $D\Theta_{850}$, Θ_{base}, Θ_{top}, T_{top}, T_{base}, T_{850}) in absolute values and relative percentages for the selected time period.
e) Calculation of correlation matrix between the aforementioned parameters for daily, monthly and five-year running means. The correlation coefficients are assessed for their statistical significance.
f) Time series plots of monthly frequency of strong and weak inversions along with 6-month and 5-year running means. Strong inversions are defined when DT_{inv} exceeds the third

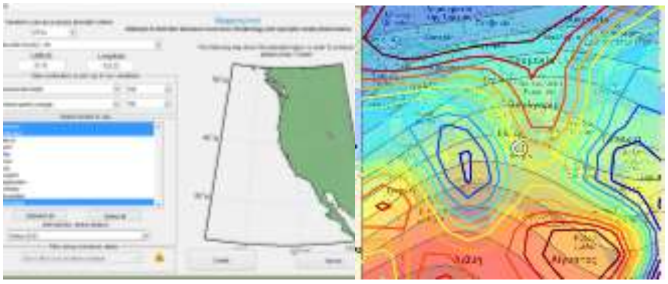
quartile and weak inversions are defined when DT_{inv} is less than the first quartile value. Quartiles were calculated for each calendar month using detrended daily values of DT_{inv}.

g) Calculation of inversion persistence in number of sequential days characterized as inversion days.

2.4 Association of synoptic scale circulation and inversion characteristics

An additional SA toolbox is available for the investigation of the relationship of synoptic scale circulation and the magnitude of inversion strength. The toolbox employs the inversion analysis results (section 2.2) along with atmospheric variables obtained from the NCEP/NCAR Reanalysis 1 database. In detail, the daily fields of HGT and the vertical velocity (omega) can be extracted for multiple pressure levels, while potential temperature, U and V wind components are available at surface level. The user can filter the reanalysis data based on specific inversion characteristics and produce synoptic scale composite maps. The maps are overlaid in Google Earth®, covering a region centered at the location of the IGRA station. In Figure 3 the toolbox interface is presented along with the resulting HGT and omega contours at 700hPa for the 30 days with the largest inversion magnitude.

A



B

Figure 3: Synoptic scale circulation and inversion characteristics' mapping tool (A) along with the results of HGT (filled contours) and omega (coloured contours) at 700hPa for the 30 days with the largest inversion magnitude, during the winter at Athens, Greece (B).

3. Conclusions

The SONDE-ATHENA (SA) application has been designed and developed to provide access to the IGRA database along with a set of tools to simplify the analysis of radiosonde observations in conjunction with NCEP/NCAR Reanalysis 1 data. It focuses on the detection of low-level temperature inversions, their climatology and the possible association with synoptic scale circulation features. SA can be applied globally and provides a systematic analysis of the radiosondes' data by offering a consistent representation of temperature inversions over a specific region. SA has been evaluated through a number of case studies and the results, after a comparison with NOAA climatological data and maps, indicated its validity and reliability.

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