

## Postprint: Verification and Evaluation of Atmospheric Infrared Sounder (AIRS) Data Applicability over the Taklamakan Desert

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### Abstract

Due to the harsh environment of deserts and sparse observation stations, the spatiotemporal distribution of temperature and humidity in the Taklamakan Desert region is difficult to obtain solely from limited conventional observational data. High-resolution Atmospheric Infrared Sounder (AIRS) data can effectively fill this gap. Terrain and surface emissivity are two major factors affecting the quality of AIRS-retrieved temperature and humidity profile products; therefore, quality validation is essential before using AIRS temperature and humidity products in the Taklamakan Desert region of the Tarim Basin. This study conducted a detailed comparative analysis of the credibility of AIRS-retrieved temperature, geopotential height, and water vapor data under clear-sky conditions in the Taklamakan Desert and surrounding oasis areas during morning and evening from July 1 to 15, 2016. The results show: (1) Temperature data from the AIRS satellite dataset exhibits good agreement with radiosonde data. Temperature data shows small biases in the desert interior, with higher consistency in surrounding oasis areas, particularly in the mid-to-upper layers. At Tazhong station in the desert interior, the retrieval biases of AIRS temperature in the morning are significantly larger than in the evening at all levels, while other stations show little difference between morning and evening retrieval biases. (2) Geopotential height data measured by AIRS is almost identical to radiosonde data, representing the best-quality parameter in this comparative study; however, AIRS can reach a detection level of 1 hPa, providing superior detection altitude compared to radiosondes. (3) The retrieved humidity profiles show relatively large biases compared to radiosondes. The mixing ratio of AIRS data agrees with radiosondes at high levels above 300 hPa, is dry-biased in the middle layers, and wet-biased in the lower layers. The low-level water vapor detection errors may be related to the basin terrain and desert underlying surface. (4) At Tazhong station in the desert interior, the mean bias of AIRS-retrieved temperature in the morning is significantly larger than at the other seven oasis

stations at all levels, being significantly colder below 500 hPa and significantly warmer above, with the warming amplitude increasing with height. For oasis areas, the absolute value of temperature bias from AIRS retrievals is within 1°C at all pressure levels in the morning, with a root mean square error (RMSE) of less than 2°C; in the evening, the absolute bias is within 3°C, with the RMSE being larger in lower levels below 700 hPa than in upper levels, and within 3°C above 700 hPa. The absolute error decreases with height in both morning and evening, but reverses above 100 hPa, with this reversal being particularly pronounced at Tazhong station.

## Full Text

### Applicability Validation and Evaluation of AIRS Retrievals in the Taklimakan Desert

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**Abstract:** The temporal and spatial distribution features of air temperature and humidity in the Taklimakan Desert, southern Xinjiang, China, could hardly be learned by the seven sounding sites there, while the high-resolution Atmospheric Infrared Sounder (AIRS) data can effectively make up for this vacancy. However, the quality of AIRS retrievals suffers from complex topographic conditions and land-surface emissivity, making quality validation necessary before applying them in this desert region. This study focused on quality validation of AIRS-retrieved air temperature, geopotential height, and water vapor mixing ratio by comparing them with field experimental soundings in both the Taklimakan Desert and seven traditional sounding sites over oasis regions at nightfall and in the morning respectively. Results show that: (1) The temperature data in the AIRS satellite dataset are in good agreement with radiosonde observations (RAOB). The temperature deviations are relatively small in the desert hinterland and larger in the surrounding oasis regions, especially at upper levels. The AIRS temperature inversion at the desert hinterland tower shows morning deviations in each layer that are obviously greater than those at nightfall, while other stations show little deviation between morning and nightfall. (2) The geopotential height data measured by AIRS satellite are almost the same as RAOB, which is the best factor in the comparative study. The detection level of AIRS can reach 1 hPa, which is much higher than that of RAOB. (3) The mixing ratio of AIRS data coincides with the upper RAOB at 300 hPa, but is smaller in the middle layers and higher in the lower layers. Finally, statistical results

show that in the morning, the AIRS inversion temperature deviation over the Tazhong sounding station in each layer is higher than that over the other seven oasis stations, warmer above 500 hPa and cooler below, with greater warming at higher altitudes. While the AIRS inversion temperature over the remaining seven oasis sounding stations is generally higher than soundings above 500 hPa and lower below. The RMSE of the AIRS inversion temperature over the selected seven oasis sounding sites decreases with increasing height. The RMSE of the AIRS inversion temperature over desert sites is acceptably small, but presents a comparatively larger bias in the morning, possibly due to the great emissivity there and its location in the center of the Tarim Basin.

**Keywords:** AIRS; Taklimakan Desert; validation; radiosonde

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## 1. Introduction

The Taklimakan Desert in southern Xinjiang is the second largest shifting desert in the world. Due to its harsh natural environment and sparse population, only seven conventional sounding stations exist throughout the entire desert area, which cannot meet the needs of atmospheric scientific research and operational applications. Satellite remote sensing data, especially the high-resolution infrared atmospheric sounding data from AIRS, can effectively fill this gap. However, the accuracy of AIRS retrieval products is affected by surface emissivity and complex terrain, making validation work essential before application.

AIRS is a high-spectral resolution infrared sensor capable of providing atmospheric temperature and humidity profiles with high vertical resolution. Previous studies have validated AIRS data over various regions, but few have focused on the unique environment of the Taklimakan Desert. The extremely dry surface and complex oasis-desert interactions in this region pose particular challenges for satellite retrievals.

## 2. Data and Methods

**2.1 Study Area and Data Sources** The study area covers the Taklimakan Desert and its surrounding oases. AIRS Version 6 Level 2 standard retrieval products are used, including temperature, geopotential height, and water vapor mixing ratio profiles. For validation, we selected the Tazhong station in the desert hinterland and seven oasis stations (Kashgar, Hotan, Aksu, Kuqa, Ruoqiang, Minfeng, and Tazhong). Radiosonde data from these stations during July 1–15, 2016, are used for comparison.

[Figure 1: see original paper] shows the land use category and topography of the target region. The USGS 24-category land cover classification is used to characterize the surface features. The desert hinterland is dominated by bare land, while the surrounding areas include various oasis and vegetation types.

lists the 24 land-use classes from USGS. The primary categories relevant to this study include: bare ground, water bodies, grassland, and various agricultural lands.

**2.2 Validation Methodology** The validation method involves: - **Spatial-temporal matching:** AIRS footprints within a 50 km radius and  $\pm 2$  hours of radiosonde launch time are selected - **Vertical interpolation:** Data are interpolated to common pressure levels - **Statistical metrics:** Bias and RMSE are calculated as:

$$\text{BIAS} = (f_r - r_n)$$

$$\text{RMSE} = \sqrt{(f_r - r_n)^2}$$

where  $f_r$  represents the AIRS retrieval value and  $r_n$  represents the radiosonde observation.

### 3. Results and Analysis

**3.1 Temperature Profile Comparison** [Figure 2: see original paper] compares temperature profiles from radiosonde and AIRS over Tazhong sounding sites in the desert. The AIRS temperature retrievals show good agreement with radiosonde observations, particularly at nightfall. However, morning observations exhibit larger deviations, especially in the lower troposphere.

[Figure 3: see original paper] shows the temperature comparison over oasis sites. The deviations are generally smaller than in the desert hinterland, with more consistent performance between morning and nightfall observations.

[Figure 4: see original paper] presents the comparison of geopotential height from radiosonde and AIRS over oasis sites. The geopotential height data show the best agreement among all variables, with AIRS retrievals closely matching radiosonde observations throughout the profile. The detection level of AIRS can reach 1 hPa, significantly higher than conventional radiosondes.

**3.2 Water Vapor Mixing Ratio Comparison** [Figure 5: see original paper] compares water vapor mixing ratio profiles from radiosonde and AIRS over Tazhong desert sites. The AIRS retrievals show reasonable agreement in the upper layers but exhibit deviations in the middle and lower troposphere.

[Figure 6: see original paper] shows the statistical results for temperature bias between AIRS and radiosonde. The bias distribution reveals systematic patterns: over the desert site (Tazhong), morning temperature deviations are larger than at nightfall, with warm biases above 500 hPa and cold biases below. Over oasis sites, the biases are generally smaller and more consistent.

#### 4. Statistical Analysis

The statistical analysis reveals that: - **Temperature:** RMSE decreases with increasing altitude over oasis sites. Desert sites show acceptably small RMSE but larger biases in the morning, possibly due to high surface emissivity and the central location in the Tarim Basin. - **Geopotential height:** Excellent agreement with radiosonde data, making it the most reliable AIRS product. - **Water vapor mixing ratio:** Best agreement at 300 hPa, with AIRS showing smaller values in middle layers and larger values in lower layers compared to radiosonde.

[Figure 11: see original paper] shows the distribution of mean temperature bias between AIRS and radiosonde. The spatial patterns indicate that biases vary significantly between desert and oasis environments, with the largest biases occurring over the central desert region during morning observations.

#### 5. Conclusions

Based on the validation study during July 1-15, 2016, the following conclusions are drawn:

1. **Temperature:** AIRS temperature retrievals agree well with radiosonde observations. Deviations are smaller in the desert hinterland and larger in surrounding oasis regions, particularly at upper levels. Morning deviations exceed nightfall deviations at desert sites.
2. **Geopotential height:** AIRS geopotential height data show excellent agreement with radiosonde observations and represent the most accurate AIRS product. The detection capability up to 1 hPa exceeds that of conventional radiosondes.
3. **Water vapor mixing ratio:** AIRS retrievals coincide with radiosonde data at 300 hPa but show smaller values in middle layers and higher values in lower layers.
4. **Statistical performance:** Over oasis sites, RMSE decreases with altitude. Desert sites exhibit acceptable RMSE but larger morning biases, likely due to extreme surface emissivity characteristics and basin topography.

These results demonstrate that AIRS data can effectively supplement conventional observations in the Taklimakan Desert region, provided that users account for the documented biases and their diurnal and spatial variations.

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