Satellite-Derived Atmospheric Profiles of $C_n^2$

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Abstract

The index of refraction structure function, referred to as $C_n^2$, is a measure of optical turbulence and can be calculated from meteorological conditions. The Atmospheric Infrared Sounder (AIRS) instrument onboard the AQUA satellite collects worldwide meteorological data everyday that can be used to calculate vertical $C_n^2$ profiles. These profiles can be valuable for many applications in directed energy.

Background

The AIRS instrument collects data via a rotating mirror with ±49.5º field of view. Using 2378 infrared channels, ranging from 3.7 and 15.4 microns, it collects temperature and water vapor as functions of height and pressure. The high spectral resolution allows for high vertical resolution which is comparable to a weather balloon.

The data collected is stored in 6 minute “granules” of data in a 45 x 30 grid with 100 layers. In total, the matrix has 135,000 data points. The polar-orbit allows for most of the earth to be imaged twice per day.

Comparisons and analyses were conducted over multi-day spans. Due to the large amount of data points, MATLAB was used to download, analyze, and process all data. AIRS began collection in 2002 and data is still being collected to-date. The granules are archived by NASA and are currently available online.

Data Comparison

AIRS data is compared to NOMADS numerical weather model and RAOB weather balloons for verification. AIRS gives excellent vertical resolution while providing data from altitudes in excess of 30 km (~100,000 ft.) where weather balloons and numerical weather models cannot.

Calculation

Based on work done by Tatarskii, $C_n^2$ can be calculated as a function of measureable atmospheric parameters such as temperature and pressure shown below.

$$C_n^2 = 2.8 \frac{KH}{KM} \left[ \frac{T}{T_0} \right]^{4/3} \left[ \frac{P}{P_0} \right]^{1/3} \left[ \frac{V_T}{V_d} \right]$$

Table 1: Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$L_o$</td>
<td>Outer Scale Length</td>
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<tr>
<td>$\nabla T$</td>
<td>Temperature Gradient</td>
</tr>
<tr>
<td>$P$</td>
<td>Pressure</td>
</tr>
<tr>
<td>$V_d$</td>
<td>Dry Adiabatic Lapse Rate</td>
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AIRS can provide measurements of these parameters on a global scale everyday that can be used to measure optical turbulence for applications worldwide.

Results

The automation of data collection and calculations made for easy comparisons of data. The generally accepted standard model of optical turbulence, Hufnagel-Valley 5/7, is compared to calculations from AIRS data for a specific time of day. Averaging the AIRS data over a period of time smoothes the data and shows the agreement with the Hufnagel-Valley trend.

Further Research

It has been suggested that $L_o$ can vary based on atmospheric conditions. For this research, $L_o$ was set to 100 m. Calculating $L_0$ as a function of atmospheric conditions was investigated but has not yet led to reasonable values for outer scale length. $K_n/K_M$ is inversely proportional to the Gradient Richardson Number ($R_i$).

AIRS smoothes $R_i$ data, thus a smoothing correction should be applied or a new way to calculate $K_n/K_M$ should be implemented.