ABoVE: Level-4 WRF-STILT Footprint Files for Circumpolar Receptors, 2016-2019

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Dataset Version: 1

Summary

This dataset provides Weather Research and Forecasting (WRF) Stochastic Time-Inverted Lagrangian Transport (STILT) Footprint data products for receptors (observations) located at positions along flight paths and at various fixed observing sites at circumpolar locations at northern latitudes during 2016-2019. Each aircraft and station position is treated as an independent receptor in the WRF-STILT model in order to simulate the land surface influence on observed atmospheric constituents. The footprints are independent of chemical species and can be applied to different flux models and incorporated into formal inversion frameworks. The particle trajectories that determine the footprint field are constrained only by the outer edges of the WRF modeling domain. The measurements included in this data set are crucial for understanding changes in Arctic carbon cycling and the potential threats posed by the thawing of Arctic permafrost.

This dataset is a companion to *ABoVE: Level-4 WRF-STILT Particle Trajectories, 2016-2019* available at https://doi.org/10.3334/ORNLDAAC/1895.

There are 304,578 data files in netCDF (*.nc) organized in 32 TAR/GZIP archives. Also included are two companion files in media (*.mp4) format.

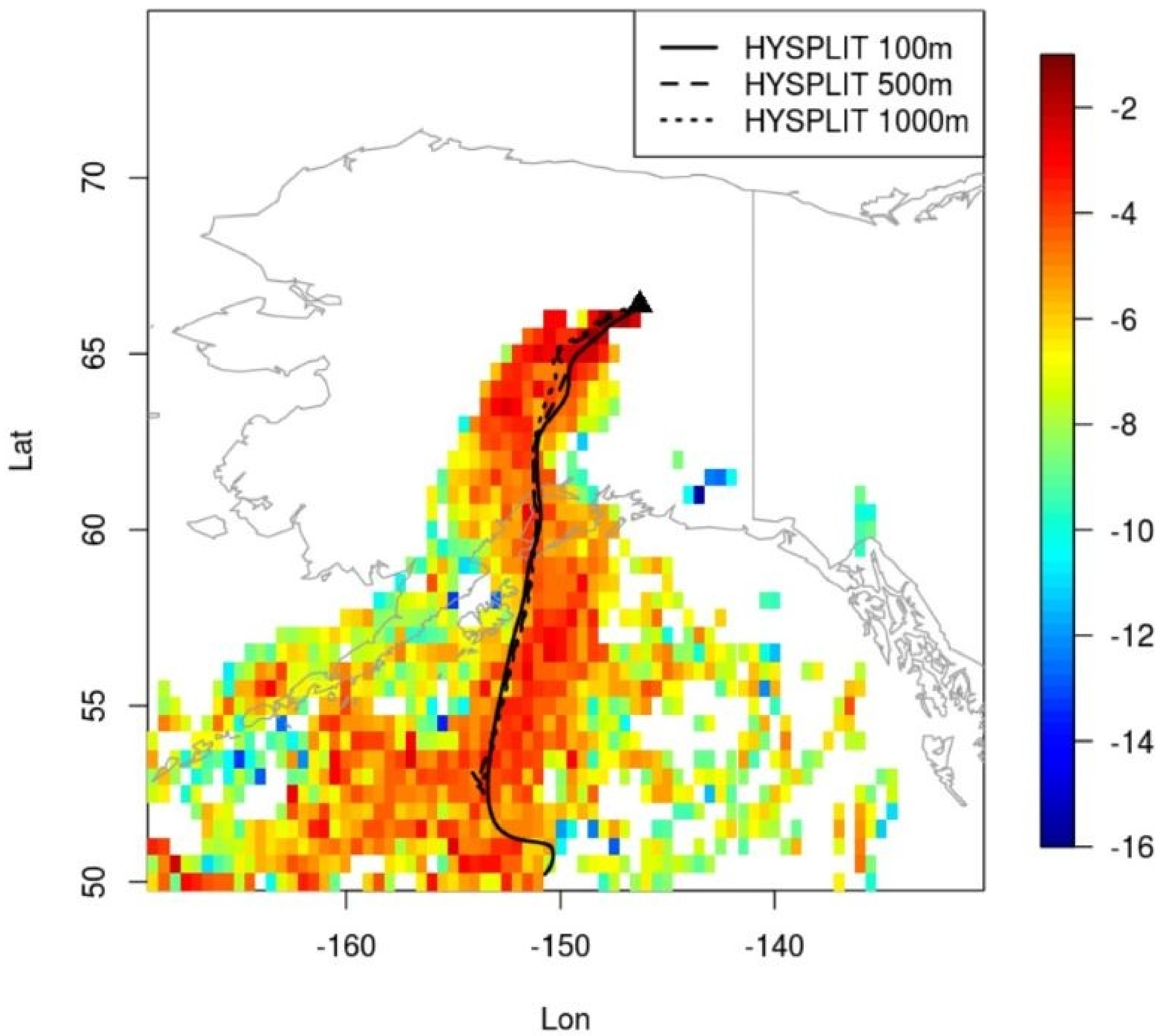

Figure 1. Subset of STILT footprint domain showing footprint contributions (shaded) overlain by HYSPLIT trajectories from receptors located at 100 (solid), 500 (dashed), and 1,000 m (dotted black lines) at 19:35 UTC 2012-08-20. Source: Henderson et al., 2015

Citation

Henderson, J., M. Mountain, A. Dayalu, K. McKain, L. Hu, and T. Nehrkorn. 2021. ABoVE: Level-4 WRF-STILT Footprint Files for Circumpolar Receptors, 2016-2019. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1896

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1. Dataset Overview

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Project: Arctic-Boreal Vulnerability Experiment

The Arctic-Boreal Vulnerability Experiment (ABoVE) is a NASA Terrestrial Ecology Program field campaign being conducted in Alaska and western Canada, for ~10 years, starting in 2015. Research for ABoVE links field-based, process-level studies with geospatial data products derived from airborne and satellite sensors, providing a foundation for improving the analysis, and modeling capabilities needed to understand and predict ecosystem responses to, and societal implications of, climate change in the Arctic and Boreal regions.

Related Publication

Henderson, J.M., J. Eluszkiewicz, M.E. Mountain, T. Nehrkorn, R.Y.-W. Chang, A. Karion, J.B. Miller, C. Sweeney, N. Steiner, S.C. Wofsy, and C.E. Miller. 2015. Atmospheric transport simulations in support of the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE). Atmospheric Chemistry and Physics 15:4093-4116. https://doi.org/10.5194/acp-15-4093-2015

Related Datasets

CARVE Science Team. 2017. CARVE: L4 Gridded Particle Trajectories for WRF-STILT model, 2012-2016. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1430.

Henderson, J. 2018. Pre-ABoVE: Gridded Footprints from WRF-STILT Model, Barrow, Alaska, 1982-2011. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1544

Henderson, J., J.B. Miller, T. Nehrkorn, R.Y-W. Chang, C. Sweeney, N. Steiner, S.C. Wofsy, and C.E. Miller. 2017. CARVE: L4 Gridded Footprints from WRF-STILT model, 2012-2016. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1431.

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Sweeney, C., and K. McKain. 2019. ABoVE: Atmospheric Profiles of CO, CO2 and CH4 Concentrations from Arctic-CAP, 2017. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1658.

Acknowledgments

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2. Data Characteristics

Spatial Coverage: Circumpolar between 30 degrees to 90 degrees north

Spatial Resolution: 0.1 to 0.5 degrees

Temporal Coverage: 2016-07-24 to 2019-12-31

Temporal Resolution: hourly

Study Area: All latitudes and longitudes given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Circumpolar, Northern Hemisphere	-180	180	90	30

Data File Information

There are 304,578 data files in netCDF (*.nc) organized in 32 TAR/GZIP archives that provide footprint fields from WRF-STILT simulations for one receptor location defined by a unique latitude, longitude, altitude, and time coordinate. Each footprint field is a gridded representation of the cumulative positive surface flux contributions from 500 particles released per receptor as they are traced backward in time over a 10-day period (see the companion dataset, Henderson et al., 2021). The footprint is presented on a latitude, longitude, time grid and valid every hour backward in time from the STILT simulation start time, which is provided in the file name.

The files are named foot**YYYY**x**MM**x**DD**x**hh**x**mm**x**LAT**x**LON**x**HEIGHT**.nc, where

YYYY = year of file,
MM = month of file,

DD = day of file,
hh = hour of file in UTC,
mm = minute of file in UTC,
LAT = latitude of file in decimal degrees,
LON = longitude of file in decimal degrees, and
HEIGHT = height above ground level of file in meters.

For example, the file foot**2013**x**06**x**25**x**04**x**00**x**65.1330N**x**147.4539W**x**00003**.nc contains the modeled footprints for June 25, 2013 at 4:00 UTC. The observation was taken at receptor location 65.1330N, 127.4539W at 3 m above ground level.

The footprint files are grouped into archives by platform type (though some platforms are combined) and are characterized as either "low resolution" or "high resolution", referring to the resolution of the circumpolar footprint field (Table 1). For low-resolution files, the circumpolar footprint field above 30 degrees north (variable names beginning *foot1*) was generated on a 0.5-degree grid. For high-resolution files, the footprint field was generated on both 0.5-degree and 0.1-degree grids (variable names beginning *foot1* and *foot2*, respectively). All footprint fields, except for those beginning *footnearfield1* (which appears only in the low-resolution files), cover the circumpolar region (30N to 90N, 180E to 180W) at hourly temporal resolution.

The low-resolution files contain footprint fields on a circumpolar 0.5-degree grid (variable names beginning *foot1*) and a 0.1-degree grid (3-degree x 5-degree extent) local to each receptor location (variable names beginning *footnearfield1*). The contents for these files are the same as those generated for NASA's CARVE campaign (Miller and Dinardo, 2012).

High-resolution files contain a new circumpolar 0.1-degree grid (variable names beginning *foot1*) in addition to the legacy 0.5-degree grids (variable names beginning *foot2*). For each of these resolutions in the high-resolution files, the fields are also resampled to increase spatial continuity in regions with sparse particles.

Also included are two companion files in media (*.mp4) format that illustrate the movement of 500 particles over a 10-day period as they converge at the receptor (observation) location: 69.6246N, 162.3022E. Animations show simulated particle trajectories starting at two times: 2015-04-24 0400 UTC and 2015-10-15 0200 UTC. Particle trajectories were estimated by simulating movement *backward* in time from the time and location of the receptor that is influenced by meteorological conditions driven by the WRF model, as well as a stochastic contribution. As simulated particles move across the globe, their path leaves a "footprint" (i.e., a two-dimensional field on the Earth's surface) that is proportional to the number of particles located in the lower half of the planetary boundary; thus, assumed to accumulate fluxes from the Earth's surface. The resulting footprint field shows the cumulative contribution of particles to the receptor location over the 10-day simulation. The WRF-STILT footprints illustrate the upwind areas that affect the greenhouse gas concentration measured at the receptor. See Henderson et al. (2015) for more information.

Table 1. Names and descriptions of the 32 TAR/GZIP archives that contain the data files. The OCO Receptor column indicates whether the receptor data were collected from the Orbiting Carbon Observatory-2 (OCO-2 Lite, v9). For non-OCO platforms, "PFP" refers to Programmable Flask Packages onboard aircraft originating from the listed site, and the remaining platforms are fixed sites collecting *in situ* samples of greenhouse gases.

File Name	Number of netCDF Files	Spatial Resolution	OCO Receptor	Platform & Date
ACG_2017_insitu-footprints.tar.gz	14,320	low	no	Alaska Coast Guard, in situ measurements, 2017
ACG_2017_PFP-footprints.tar.gz	99	low	no	Alaska Coast Guard, PFP measurements, 2017
ArcticCAP_2017_insitu-footprints.tar.gz	45,450	low	no	Arctic Carbon Aircraft Profiles, in situ measurements, 2017
ArcticCAP_2017_PFP-footprints.tar.gz	331	low	no	Arctic Carbon Aircraft Profiles, PFP measurements, 2017
ASCENDS_2017_insitu-footprints.tar.gz	12,845	high	no	Ascends/ABoVE 2017 Airborne Campaign, PFP measurements, 2017
ATom2_2017_insitu-footprints.tar.gz	5667	high	no	Atmospheric Tomography Mission (ATom), in situ measurements, January-February 2017
ATom2_2017-2019-PFP-footprints.tar.gz	59	high	no	Atmospheric Tomography Mission (ATom), PFP measurements, January- February 2017
ATom3_2017_insitu-footprints.tar.gz	5598	low	no	Atmospheric Tomography Mission (ATom), in situ measurements, September-October 2017
ATom3_2018_PFP-footprints.tar.gz	31	low	no	Atmospheric Tomography Mission (ATom), PFP measurements, September-October 2018
ATom4_2017-2019_PFP-footprints.tar.gz	43	high	no	Atmospheric Tomography Mission (ATom), PFP measurements, 2017-2019
ATom4_2018_insitu-footprints.tar.gz	6011	high	no	Atmospheric Tomography Mission (ATom), in situ measurements, April-May 2018
BRW_2017-2019_PFP-footprints.tar.gz	349	high	no	Barrow Atmospheric Baseline Observatory, PFP measurements, 2017-2019
CBA_2017-2019_PFP-footprints.tar.gz	306	high	no	Cold Bay Alaska, PFP measurements, 2017-2019
EC-BRW-CRV_insitu-footprints.tar.gz	9844	high	no	Environment Canada + Barrow Atmospheric Baseline Observatory + Carbon in Arctic Reservoirs Vulnerability Experiment, 2019
ECCC_2019-footprints.tar.gz	2000	high	no	Environment and Climate Change Canada, 2017-2019
ESP_2017-2019_PFP-footprints.tar.gz	765	high	no	Estevan Point British Columbia, PFP measurements, 2017-2019
ETL_2017-2019_PFP-	420	high	no	East Trout Lake Saskatchewan, PFP measurements, 2017-2019

footprints.tar.gz				
LEF_2017-2019_PFP-footprints.tar.gz	717	high	no	Park Falls Wisconsin, PFP measurements, 2017-2019
NSA-7800_2016-footprints.tar.gz	7800	low	no	Modeled using v391 terrain heights, North Slope of Alaska-7800, 2016
NSA-7802_2016-footprints.tar.gz	7802	low	no	Modeled using v351 terrain heights, North Slope of Alaska-7802, 2016
OCO2-201700-d01-footprints.tar.gz	22,061	high	yes	WRF model domain d01, January-April and August-December 2017
OCO2-201700-d02-footprints.tar.gz	23,075	high	yes	WRF model domain d02, January-May and August-December 2017
OCO2-201700-d03-footprints.tar.gz	10,153	high	yes	WRF model domain d03, January-May and August-December 2017
OCO2-201705-d01-footprints.tar.gz	22,230	high	yes	WRF model domain d01, May 2017
OCO2-201706-d01-footprints.tar.gz	25,675	high	yes	WRF model domain d01, June 2017
OCO2-201706-d02-footprints.tar.gz	35,217	high	yes	WRF model domain d02, June 2017
OCO2-201706-d03-footprints.tar.gz	12,675	high	yes	WRF model domain d03, June 2017
OCO2-201707-d01-footprints.tar.gz	29,926	high	yes	WRF model domain d01, July 2017
OCO2-201707-d02-footprints.tar.gz	35,061	high	yes	WRF model domain d02, July 2017
OCO2-201707-d03-footprints.tar.gz	12,428	high	yes	WRF model domain d03, July 2017
OCO2-2018-particles.tar.gz	572	high	yes	OCO-2, 2018
PFA_2017-2019_PFP-footprints.tar.gz	498	high	no	Poker Flat Alaska, PFP measurements, 2017-2019

Data File Details

Fill values or missing data are represented by -1.0E34 for all variables.

Table 2. Variables in the data files.

Variable	Units	Description
All Footprint Files		
ident	char	Identifier string
nchar	1	Numeric identifier
origagl	meters	Original receptor height above ground before rounding for STILT
origlat	degrees_north	Original receptor latitude
origlon	degrees_east	Original receptor longitude
origutctime	UTC time	Original receptor time
origutctimeformat	char	Format string for original receptor time
foot1	ppm per (μmol m^{-2} s^{-1})	Gridded STILT footprint in time, latitude, longitude. Resolution is 0.5 degree for low-resolution files and 0.1 degree for high-resolution files
foot1date	days since 2000-01-01 00:00:00 UTC	Date of foot1
foot1hr	hours	Hours back from STILT start time encoded in file name
foot1lat	degrees_north	Degrees latitude of center of grid cells
foot1lon	degrees_east	Degrees longitude of center of grid cells
footnearfield1	ppm per (μmol m^{-2} s^{-1})	Gridded STILT footprint at 0.1 degree resolution near receptor location.
footnearfield1date	days since 2000-01-01 00:00:00 UTC	Date for 'footnearfield1'
footnearfield1hr	hours	Hours back from STILT start time for 'footnearfield1'
footnearfield1lat	degrees_north	Degrees latitude of center of grid cells

footnearfield1lon	degrees_east	Degrees longitude of center of grid cells
High-Resolution Files *Only*		
foot1_resampled	ppm per (μmol m^{-2} s^{-1})	Aggregates particle footprints on a x,y,time grid starting at STILT start time
foot1_resampledlon	degrees_east	Degrees longitude of center of grid cells
foot1_resampledlat	degrees_north	Degrees latitude of center of grid cells
foot1_resampleddate	days since 2000-01-01 00:00:00 UTC	Date for resampled time steps
foot1_resampledhr	hours	Hours back from STILT start time
foot1_resampledfactors	1	Factors used to calculate resampled footprint. See variable attributes for (a) the resampling (mean/med/max) method, (b) the spread (sqrtN/sqrtT) method, and (c) how the resampling and spread methods were combined (maximum of two, average, resample only, spread only).
foot1_resampledfactorsnames	char	Names of the resampling factors: "resampling", "spread", "combined"
foot1_resampledfactorsdate	days since 2000-01-01 00:00:00 UTC	Date for resampled time steps
foot2	ppm per (μmol m^{-2} s^{-1})	Aggregates particle footprints on a x,y,time grid starting at STILT start time. Resolution is 0.5 degree.
foot2lon	degrees_east	Degrees longitude of center of grid cells
foot2lat	degrees_north	Degrees latitude of center of grid cells
foot2date	days since 2000-01-01 00:00:00 UTC	Date for resampled time steps
foot2hr	hours	Hours back from STILT start time
foot2_resampled	ppm per (μmol m^{-2} s^{-1})	Aggregates particle footprints on a x,y,time grid starting at STILT start time
foot2_resampledlon	degrees_east	Degrees longitude of center of grid cells
foot2_resampledlat	degrees_north	Degrees latitude of center of grid cells
foot2_resampleddate	days since 2000-01-01 00:00:00 UTC	Date for resampled time steps
foot2_resampledhr	hours	Hours back from STILT start time
foot2_resampledfactors	1	Factors used to calculate resampled footprint. See variable attributes for (a) the resampling (mean/med/max) method, (b) the spread (sqrtN/sqrtT) method, and (c) how the resampling and spread methods were combined (maximum of two, average, resample only, spread only).
foot2_resampledfactorsnames	char	Names of the resampling factors: "resampling", "spread", "combined"
foot2_resampledfactorsdate	days since 2000-01-01 00:00:00 UTC	Date for resampled time steps

3. Application and Derivation

WRF-STILT particle files and footprints are independent of chemical species, but they have supported accurate estimates of CO_2 and CH_4 surface-atmosphere fluxes using airborne and tower observations. Simulated CO_2 mole fractions from the Polar Vegetation Photosynthesis and Respiration Model (PolarVPRM; Luus and Lin, 2015) based on WRF-STILT footprints show strong agreement with tower observations, suggesting that the WRF-STILT model does a good job representing the meteorology of the region (Karion et al., 2016).

It is recommended that users evaluate both the *raw foot1* and the *resampled foot1* fields, although the resampled field is intended to be the best product. For the high-resolution files, the legacy raw 0.5-degree *foot2* field should be used for consistency with prior CARVE and ABoVE-era files.

4. Quality Assessment

Preliminary analysis demonstrated overall agreement between WRF outputs and quality-controlled surface and radiosonde observations. Analysis of STILT footprints for CARVE that followed a similar procedure showed realistic seasonal variability and good agreement with tower observations, indicating that WRF-STILT footprints are of high quality and support accurate estimates of CO_2 and CH_4 surface-atmosphere fluxes using CARVE observations (Henderson et al., 2015).

5. Data Acquisition, Materials, and Methods

This project sought to model the movement of greenhouse gases from the land-surface emissions in the atmosphere using the WRF-STILT coupled model. Location data from aircraft samples and flux tower locations were treated as receptors in the Stochastic Time-Inverted Lagrangian Transport (STILT) model (Lin et al., 2003). Atmospheric motions were driven by meteorological fields from the Weather and Research Forecasting (WRF) model (Skamarock and Klemp 2008). The WRF model was configured to generate high-quality, high-resolution meteorological fields over the Arctic and boreal Alaska and Northwest Canada. The WRF model as run for this project closely follows the model configuration of Nehrkorn et al. (2018). The WRF-STILT modeling framework is more broadly described in Henderson et al. (2015). For both low- and high-resolution fields described here, WRF v3.9.1 and its improved terrain representation were used for all files except for the file NSA-7802_2016-footprints.tar.gz, which used the WRF v3.5.1 terrain heights.

STILT is a Lagrangian particle dispersion model that is applied *backward* in time from a measurement location (the "receptor" location), to create the adjoint of the transport model in the form of a "footprint" field (Nehrkorn et al., 2010; Henderson et al., 2015). The footprint, with units of mixing ratio (ppm of CO_2; ppb of CH_4) per (µmol m-2 s-1), quantifies the influence of upwind surface fluxes on concentrations measured at the receptor and is computed by counting the number of particles in a surface-influenced volume and the time spent in that volume (e.g., Fig 1). The resulting footprint is a gridded product that illustrates the areas over time steps of the simulation that contribute to particle concentrations measured at a given location, altitude, and time.

In the companion dataset (Henderson et al., 2021), the particle trajectory files (i.e., netCDF files beginning *stilt*) that correspond to the low-resolution footprint files (i.e., netCDF files beginning *foot*) contain a copy of the footprint fields. The footprint field is not reproduced in the particle files that correspond to the high-resolution footprint files.

To fill data in sparse regions, a resampling/smoothing/spreading algorithm was applied to the circumpolar high-resolution STILT footprints. This algorithm was needed to compensate for under-sampling that can result in incomplete, patchy footprint fields. This smoothing step was applied to the raw gridded footprint fields (i.e., computed by gridding the original particles footprints on the fine footprint mesh). The smoothing length scale was determined for each back trajectory time step from the spread of the particles. This smoothing length was then compared to a separate length scale corresponding to the median displacement of particles between footprint time steps at that time step. By default, the maximum of the two lengths was used from resampling (method = “max”). However, other options for setting the resampling scale included: averaging the two length scales (“avg”), using the spread distance only (“spread”), or the displacement distance only (“resample” or “med”). The resampling method employed is documented in the attributes for *foot*_resampledfactors* variables. These variables provide the resampling factors for each time step. A similar method is described by Fasoli et al. (2018), who employed spreading with a kernel density estimator applied to the footprints of each particle.

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

ABoVE: Level-4 WRF-STILT Footprint Files for Circumpolar Receptors, 2016-2019

Contact for Data Center Access Information:

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- Telephone: +1 (865) 241-3952

7. References

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