A New Method for Calculating ALPI: The Aleutian Low Pressure Index

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Abstract

Surry, A.M., and King, J.R. 2015. A New Method for Calculating ALPI: the Aleutian Low Pressure Index. Can. Tech. Rep. Fish. Aquat. Sci. 3135: v + 31 p.

A new method of calculating the area of the Aleutian Low and the Aleutian Low Pressure Index (ALPI) using R software is presented. The ALPI time series is generated using the new method for the full time series, 1900 – 2015. Overall, the new method produces ALPI values that are comparable to previously published values (1900 – 2008), with no difference in periods with positive or negative values. We also introduce a method that estimates the geographic location of the center of the Aleutian Low, and produce estimates of the geographic coordinates for the center of the seasonal Aleutian Low for 1900 – 2015. We observed that the seasonal center appeared more likely to occur to the east of the overall center in years with positive ALPI, and to the west of the overall center in years with negative ALPI.

Résumé

Surry, A.M. et King, J.R. 2015. Nouvelle méthode de calcul de l'indice de dépression des Aléoutiennes (ALPI). Can. Tech. Rep. Fish. Aquat. Sci. 3135: v + 31 p.

Nous présentons dans le présent document une nouvelle méthode de calcul de la zone de dépression des Aléoutiennes et de l'indice de dépression des Aléoutiennes (ALPI) à l'aide du logiciel R. La série chronologique de l'ALPI est produite au moyen de la nouvelle méthode pour l'ensemble de la série chronologique, soit de 1900 à 2015. Dans l'ensemble, la nouvelle méthode produit des valeurs de l'ALPI qui sont comparables à celles publiées précédemment (de 1900 à 2008), et il n'y a aucune différence entre les périodes qui présentent des valeurs positives et celles qui présentent des valeurs négatives. Nous présentons également une méthode qui estime l'emplacement géographique du centre de la dépression des Aléoutiennes et qui produit des estimations des coordonnées géographiques du centre de la dépression saisonnière des Aléoutiennes de 1900 à 2015. Nous avons remarqué que le centre saisonnier semblait plus susceptible de se trouver à l'est du centre général durant les années où l'indice était positif, et à l'ouest de ce centre durant les années où l'indice était négatif.

Introduction

The Aleutian Low atmospheric pressure system is a semi-permanent feature of the North Pacific, generally centered over the Aleutian Islands. The Aleutian Low strengthens in winter, and weakens the following spring; however the relative intensity of low pressures can vary greatly from year to year. The Aleutian Low affects the intensity of winter storms (Bromirski et al. 2003) and direction of atmospheric circulation off the west coast of North America, since the size and position of the Aleutian Low determines the relative waviness of the westerlies (McFarlane et al. 2000). A relatively weak and northward positioned Aleutian Low results in a direct westerly flow in the atmosphere over the North Pacific (i.e. westerly winds). A relatively strong and southward positioned Aleutian Low results in wavy westerlies that are from the southwest off the coast of North America (i.e. southwesterly winds). The relative intensity of the winter Aleutian Low has also been linked to patterns in marine productivity (Beamish and Bouillon 1993; McFarlane et al. 2000; King et al. 2001).

Since 1993, the Pacific Biological Station (Fisheries and Oceans Canada) has produced an index of the relative intensity of the Aleutian Low (Aleutian Low Pressure Index, ALPI) which has been used to describe decadal-scale changes in North Pacific climate-ocean conditions, and has been related to a number of ecosystem processes applicable to both the North Pacific and globally (e.g. McFarlane et al. 2000, Crawford et al. 2007, Wyatt et al. 2012). The ALPI is calculated annually and is available on request from the authors; ALPI is also available for download from the Fisheries and Oceans Canada website (http://www.pac.dfo-mpo.gc.ca/science/species-especes/climatology-ie/index-eng.html). One of the difficulties in maintaining and updating a time series of annually calculated values, is that over time, as computer systems change, technologies become obsolete and new methods must be developed, which may not happen at the pace of users' requests for annual index values. Previous methods for calculating ALPI required proprietary software and were therefore not easily shared with other users. Additionally, changes in computing methods were not fully documented, nor were comparisons of new index values to original values. This report documents a new method for calculating ALPI using the R software environment (R Core Team 2014). This method has the benefit of using a freely available, open source software environment that is well documented and familiar to researchers globally.

In addition to changes in computing methods, the ALPI definition has changed over time (Table 1). Beamish and Bouillon (1993) introduced the initial definition of the area of the Aleutian Low, which was subsequently modified: the area (km^2) in the North Pacific with sea level pressure less than or equal to 100.5 kPa. An annual Aleutian Low area value was calculated as the sum of mean monthly areas for winter (December – February) and spring (March – May) from 1899-1990 (Beamish and Bouillon 1993; Table 1). Later, ALPI was introduced as the mean seasonal (December – March) area with sea level pressure less than or equal to 100.5 kPa expressed as an anomaly from the long-term mean for the 1900 – 1995 time series (Beamish et al. 1997; Table 1). Beamish et al. (1999) noted that sea level pressure data were more reliable from 1950 onwards, and standardized the reference period from which the seasonal anomaly was calculated to 1950 – 1997; all subsequent updates used the 1950 – 1997 long-term mean (Table 1). We use this final definition of ALPI: the mean seasonal (December – March; assigned to the year of January) area (km^2) in the North Pacific with sea level pressure less than or equal to 100.5 kPa expressed as an anomaly from the long-term (1950 – 1997) mean seasonal area. We provide a method using R software (R Core Team 2014) that can be automated, allowing the full time series (1900 – 2015) to be re-generated, and compare new index values with the original values that have been published or updated over time. We also introduce a method (also using R software) that estimates the geographic location of the center of the Aleutian Low, that allows changes in location to be tracked over time.

Methods

Data Source

Climate datasets of both global and local scale are archived by and available from the Computational and Information Systems Laboratory (CISL) Research Data Archive (RDA) of the University Corporation for Atmospheric Research (UCAR) and the National Center for Atmospheric Research (NCAR) in the United States (http://rda.ucar.edu). Access to the data archives is free, but users are required to register and log in. Some datasets are available for self-serve download, while others are by request.

Sea level pressure data has been collected daily beginning in 1899, and has been summarized into monthly means in a dataset consisting of grid-point values at every 5° of latitude and longitude from 20°N to the pole (Trenberth and Paolino 1980). The monthly grids are available through NCAR from dataset number ds010.1: "Monthly Northern Hemisphere Sea-Level Pressure Grids, continuing from 1899" (UCAR et al. 1979; Trenberth and Paolino 1980). The data are accessed from a webpage (http://rda.ucar.edu/datasets/ds010.1/, accessed January 8, 2015) which includes a description, self-serve data access point, detailed metadata, historical information, some downloadable software, and some simple data inventory tools. Dataset characteristics are summarized in Table 2.

Detailed instructions on how to download data for use in the R ALPI method are contained in Appendix 1.

Data Processing

All data processing was accomplished in the R software environment (R Core Team 2014) with the addition of the R package 'RNetCDF' (Michna 2014) and the R-spatial packages 'sp' (Pebesma and Bivand 2005), 'gstat' (Pebesma 2004), 'raster' (Hijmans 2014), and 'rgdal' (Bivand et al. 2014). These R-spatial packages all use the 'sp' spatial data classes (Pebesma and Bivand 2005). R code is included in Appendix 2.

Earlier versions of the Aleutian Low Pressure area calculation and ALPI (Table 1) were produced using a computer program written in BASIC along with a raster-based Geographic Information Systems (GIS) software package (COMPUGRID, Geospatial Systems, Inc.) running on a DOS system; ALPI continued to be updated using the COMPUGRID method to 2002. From 2003 – 2008, ALPI was updated using a windows-based GIS system (ESRI Arcmap Spatial Analyst, ESRI 2011). The new ALPI is calculated using R software (R Core Team 2014), and where possible follows the same procedures used by the original COMPUGRID method. The new method is intended to efficiently produce values for the mean seasonal Aleutian Low Pressure Area and ALPI that are as close as possible to the original values.

<u>**Data extraction and sub-setting**</u>

Dataset ds010.1 is downloadable in a variety of formats including Network Common Data Form, or 'netCDF'. The 'netCDF' is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented atmospheric and related data, and represents a community standard for sharing scientific data (Unidata 2014). This format was selected for downloading the data for ALPI because the R package 'RNetCDF' (Michna

2014) could be used to quickly extract the relevant variables from the file. Data can also be downloaded as text files ('Formatted ASCII') but data would then require more processing.

One 'netCDF' file was downloaded for each index year, where the index year is the January year for each December to March series.

Four arrays were extracted from the downloaded file for each index year:

- Longitude ('lon'): 0-355°, in 5° increments (72 x 1 elements);
- Latitude ('lat'): 15-90°, in 5° increments (16 x 1 elements);
- Sea level pressure ('slp'): a 72 x 16 x 4 array of pressure values measured in hectopascals (hPa), where each 72 x 16 element is one month of data on a grid formed by longitude and latitude;
- Month ('date_time'): the date range for each element of data – e.g. "2013120131" is the entry corresponding to December 1-31, 2013 (4 x 1 elements).

Sea level pressure data are available for the entire northern hemisphere from 15° to 90° North Latitude (N), where longitude 0 – 355° in the file represents 180° East Longitude (E) to 180° West Longitude (W). However, Beamish and Bouillon (1993) used a smaller extent of 120°E – 120°W and 20° – 70° N, corresponding to the North Pacific Ocean. Data for each index year were therefore subsetted to the same geographic extent as Beamish and Bouillon (1993).

Data for each month (December to March) were restructured into a data frame with columns for longitude, latitude, and sea level pressure. Each data frame was named by its corresponding month, and all four data frames for each index year were stored in a single list.

Dataset characteristics and subsetting parameters are summarized in Table 2.

Interpolation and raster creation

Sea level pressure data is available as point observations on a 5°x5° grid over the North Pacific (Table 2, Figure 1). These point observations can be turned into a continuous surface by interpolating between the observations and creating a raster.

The R packages 'sp' (Pebesma and Bivand 2005) and 'rgdal' (Bivand et al. 2014) were used to turn the data frames of monthly sea level pressure into spatial objects and then to define the coordinate system. R-spatial packages based on 'sp' use a Coordinate Reference System (CRS) that is an interface class to the PROJ.4 projection system (https://github.com/OSGeo/proj.4/wiki); bindings to PROJ.4 are provided by 'rgdal' (Bivand et al. 2014). PROJ.4 parameters were obtained from http://spatialreference.org/ (accessed January 8, 2015).

ALPI is defined in terms of the area (km^2) covered by the Aleutian Low. In order to measure area with minimal distortion, the data coordinates must be expressed in an "equal-area" projection (Knippers 2009). The North Pacific Albers Conic Equal Area projection with a central meridian at 170° West Longitude and standard parallels modified to 30° and 60° North Latitude was selected. This projection is optimized for equal area display (m^2) of the North Pacific region (http://spatialreference.org/ref/sr-org/42, accessed January 8, 2015), and resembles the figures in Beamish and Bouillon (1993). The function 'coordinates' from the package 'sp' (Pebesma and Bivand 2005) was used to turn the data frames of sea level pressure into objects of class SpatialPointsDataFrame. Since the locations for the sea level pressure data are initially expressed as latitude and longitude values, the function 'proj4string' from the package 'rgdal' (Bivand et al. 2014) was first used to assign a geographic CRS to the SpatialPointsDataFrame objects. As the Albers projection is based on the NAD83 datum, NAD83 was selected as the initial CRS. The function ‘spTransform’ from the package ‘sp’ (Pebesma and Bivand 2005) was used to project the data into the desired North Pacific Albers Conic Equal Area projection, changing the coordinate units from degrees to meters. Coordinate reference system (CRS) details are summarized in Table 2.

The Inverse Distance Weighted (IDW) method of interpolation was selected for consistency with the methods used by Beamish and Bouillon (1993). This method of interpolation estimates values at locations within a grid based on the values of data points in a search neighbourhood around the prediction location. Data points are weighted in inverse proportion to the distance between a data point and a prediction location, with a power value representing the rate at which weight (or influence of a data point) decreases with distance. IDW can be performed in R using the function ‘idw’ from the package ‘gstat’ (Pebesma 2004), with the user specifying the power (‘idp’) of the interpolation and the neighbourhood or maximum number of points to be used (‘nmax’). The ‘idw’ function requires a spatial grid to be created into which the data can be interpolated. This grid can be set up using the ‘spsample’ function from ‘sp’ (Pebesma and Bivand 2005) and has the same geographic extent as the projected sea level pressure dataset.

The original COMPUGRID program used a power of 1, but it is not apparent what neighbourhood size was used. Therefore, a variety of values for neighbourhood size (‘nmax’) between 8 and 32 were considered (Table 2).

The size of grid cells or pixels (cell size) used in ‘spsample’ becomes the eventual resolution (r) of the raster. The original COMPUGRID program used a cell size of 15 x 10^6 m^2 (15 km^2). However, ESRI (2011) and Hengl (2006) suggest larger cell sizes based on the geometry of the dataset. ESRI Arcmap Spatial Analyst uses a default cell size (*r*) equal to the length of the shortest side divided by 250 (ESRI 2011):

(1) $$r = \frac{x_{max} - x_{min}}{250} \text{ or } r = \frac{y_{max} - y_{min}}{250}$$

where $x_{max}, x_{min}, y_{max}, y_{min}$ are the maxima and minima of extent in the x direction and y direction, respectively. Hengl (2006) suggested methods to calculate the most appropriate cell size (*r*) based on readable resolution on a printed map (Eq. 2) and geometry of sampled points, assuming regular spacing between observations (Eq. 3):

(2) $$r = 0.0791 \times \sqrt{\frac{A}{N}}$$

(3) $$r = 0.5 \times \sqrt{\frac{A}{N}}$$

where *A* is the size of the study area, and *N* is the number of observations. Using the original cell size and Eqs. 1 – 3 as a guide, a range of cell sizes between 15 x 10^6 m^2 and 40 x 10^6 m^2 (15 – 40 km^2) was considered (Table 2).

The interpolated monthly sea level pressure output from the ‘idw’ function was converted into a raster using the ‘raster’ function of the ‘raster’ package (Hijmans 2014). This process was repeated for each month (December – March) of the index year.

Calculating the Aleutian Low Pressure Area

For each index year, the mean seasonal (December – March) area of the Aleutian Low (AL_Y) was calculated as follows:

(4) $$AL_Y = \frac{\sum_{Dec}^{Mar}\left(n_m \cdot r^2\right)}{N_m}$$

where for each monthly (December – March) raster of interpolated sea level pressure in index year Y, n_m is the number of raster cells with value ≤ 1005 hPa (100.5 kPa) for month m, r is the raster resolution or cell size, and N_m = 4, the number of months in the December – March season.

Interpolating the monthly sea level pressure grids into rasters produces different results depending on the parameters provided to the Inverse Distance Weighting (IDW) function. To find the combination of parameters that produce seasonal mean Aleutian Low Pressure areas and index values that are as similar as possible to the original values, different neighbourhood sizes (nmax = 8, 12, 16, 20, 24, and 32) and raster resolutions (cell size = 15, 20, 25, 30, 34, and 40) were attempted for the period 1950 – 2002 (Table 2). The mean relative difference (*D*) between new area values and the original values was calculated for all possible combinations of nmax and cell size as

(5) $$D = \frac{\sum_{1950}^{2002} \frac{[AL_{old} - AL_{new}]}{AL_{old}}}{N}$$

where N = 53, the number of years between 1950 and 2002, and *AL* is the area of the Aleutian Low or the value of the Aleutian Low Pressure Index.

The combination of neighbourhood size and cell size (Table 2) which produced the smallest average relative difference between new area values and the original values for the Aleutian Low Pressure Area or Index was identified as the method that would generate the closest match to the original values.

Processing time for the R-code using different combinations of neighbourhood size and cell size (Table 2) was estimated using the 'proc.time' function from the R base package (R Core Team 2014) to time the interpolation for a single index year. As processing time for a long time series can be significant, the relative efficiency of different combinations of neighbourhood size and cell size was considered when selecting the 'best' method.

Calculating ALPI

ALPI is the annual seasonal (December – March) area (km^2) in the North Pacific with sea level pressure less than or equal to 100.5 kPa, where the year is the January year of each December – March season, expressed as an anomaly from the long-term (1950 – 1997) mean seasonal area (Eq. 6, Table 1). To produce an internally consistent time series of index values, the 1950 – 1997 mean was recalculated from the seasonal means produced with the new R method.

Annual ALPI values were calculated for the full time series (1900 – 2015) as follows:

(6) $$ALPI_Y = \left(\frac{\sum m_Y}{4} - L_{1950-1997}\right)$$

where Y is the index year, or January year for the December – March season, $ALPI_Y$ is the yearly seasonal index value, m_Y are the monthly values for the area of the Aleutian Low for the year Y, and $L_{1950\text{-}1997}$ is the long-term mean of the annual mean seasonal areas of the Aleutian Low for 1950 – 1997.

Aleutian Low area values are in m^2, but for convenience, ALPI is expressed in units of $km^2 \times 10^6$.

Comparision to Previously Calculated Values

Paired t-tests were used to compare new Aleutian Low Pressure areas and ALPI to the original values calculated using COMPUGRID and ArcMap (Appendix C). Box-whisker plot of differences in annual areas were used to identify possible outliers (years) with large difference in areas calculated by the new R method and previous methods.

Determining the Center of the Aleutian Low

The Aleutian Low is generally centered over the Aleutian Islands, but the location can vary from year to year. Therefore, the geographic location of the center of the Aleutian Low was estimated for each year of the time series.

Each monthly raster (December – March) of sea level pressure contains cells (the number of which depends on the cell size or raster resotion), each of which contains a value for sea level pressure at a specific location with cartesian (X,Y) coordinates. Therefore, the center of the area of the Aleutian Low can be determined using R package ‘raster’ (Hijmans 2014) by locating the raster cells that make up that area (cells with sea level pressure values ≤ 100.5 kPa), finding the maximum and minimum extents of that area in the X and Y directions, and finding the center point within those extents.

The monthly (December – March) rasters of interpolated sea level pressure were processed using the ‘reclassify’ function: all values of sea level pressure ≤ 100.5 kPa were reclassified as (replaced by) the value ‘1’, while all other values were reclassified as ‘NA’, which is equivalent to removing them from the raster. Note that counting the remaining raster cells and multiplying by the raster resolution (cell size) gives the area of the Aleutian Low, equivalent to using Eq. 4. Although the Aleutian Low is generally a single large area over the North Pacific, there may be small areas outside the main area with sea level pressure ≤ 100.5 kPa, or there may be a number of areas instead of one large area (Figure 2) . The ‘clump’ function was used to identify the individual areas with sea level pressure ≤ 100.5 kPa for each monthly raster, and the number of raster cells in each clump was counted.

For monthly rasters with a single clump, the clump was designated as the Aleutian Low Pressure Area. For monthly rasters with more than one clump, the clump with the most cells was designated as the Aleutian Low Pressure Area, unless the clumps were too similar in size; to be designated as the Aleutian Low Pressure Area, the biggest clump was required to be at least 10x larger than the sum of the additional clumps. The coordinates for each raster cell in the clump that was designated as the Aleutian Low Pressure Area were extracted from the raster with the function ‘xyFromCell’ and placed in a dataframe. The cartesian coordinates of the center point were determined as follows:

(7) $X = \frac{X_{min}+X_{max}}{2}$ and

(8) $= \frac{Y_{min}+Y_{max}}{2}$,

where X_{min} and X_{max} are the extents of the area of the Aleutian Low in the X direction, and Y_{min} and Y_{max} are the extents in the Y direction. For monthly rasters with no clumps (i.e. area of the Aleutian Low = 0), or where the clumps were too similar in size to unambiguously select the largest clump, the coordinates of the center were set to ‘NA’.

The seasonal center was determined by taking the mean of the X values and the mean of the Y values for each index year.

Geographic coordinates for the centers of the monthly and seasonal Aleutian Low Pressure Areas were obtained using the R packages ‘rgdal’ (Bivand et al. 2014) and ‘sp’ (Pebesma and Bivand 2005). Each pair of cartesian (X,Y) coordinates was turned into a spatial object using the function ‘SpatialPoints’ with Coordinate Reference System (CRS) set to North Pacific Albers Conic Equal Area. The function ‘spTransform’ was used to project the spatial objects into a geographic CRS (NAD83). Longitude and latitude were then extracted from each spatial object using the 'coordinates' function. The centers of the seasonal areas were plotted on a latitude/longitude grid.

Results

Data projection and extents

The Monthly Northern Hemisphere Sea-Level Pressure grid locations, subsetted for the North Pacific, are shown in geographic (unprojected, NAD83) and projected (North Pacific Albers Conic Equal Area) coordinates in Figure 1.

The subsetted sea level pressure grid contained 275 observations. Before projection, the extents were the same as in Beamish and Bouillon (1993): 120° to 240° West Longitude by 20° to 70° North Latitude. After projection, the extents were -6,800,560 m to 5,169,440 m on the x-axis (total extent 11,970 km) and -3,589,628 m to 3,165,372 m on the y-axis (total extent 6,755 m).

Interpolation

Mean relative differences (Eq. 5) between the original (COMPUGRID) values for the mean seasonal area of the Aleutian Low and new values (R-method) were between 0.0284 and 0.1895 for all possible combinations of neighbourhood size (nmax) and raster cell size. For the values of ALPI, the mean relative differences (Eq. 5) were between 0.0689 and 0.1630. The mean relative difference increased as nmax increased; however, for each value of nmax, results were similar for all the cell sizes attempted (Table 3A&B). The smallest mean relative differences (0.0284 for area and 0.0689 for ALPI) occurred with nmax = 16 (Table 3A&B). For all neighbourhood sizes, processing time decreased with increasing cell size (Table 3C). For nmax = 16, the estimated time to complete the full 1900 – 2015 time series using the original (COMPUGRID) cell size of 15 km^2 was approximately 28 minutes; increasing the cell size to 40 km^2 reduced the estimated processing time to approximately 4 minutes. Therefore, interpolated rasters were generated for each index year of the time series from 1900 – 2015 using nmax = 16 and cell size = 40 km^2. An example of the interpolated monthly rasters of sea level pressure (with isobars indicating the Aleutian Low) for one index year is shown in Figure 3.

Calculating area and ALPI

The mean seasonal (December – March) area of the Aleutian Low (Eq. 4) for each index year from 1900 - 2015 is shown in Table 4. The new long-term (1950-1997) mean was 5,524,183 km^2. ALPI (Eq. 6) for each index year from 1900 – 2015 is shown in Table 4 and Figure 4. ALPI values were generally negative in 1900 – 1925, positive in 1926 – 1947, negative in 1948 – 1977, and positive from 1978 onwards (Figure 4). For reference, the original values of ALPI which were posted on the DFO website are included in Appendix E, along with the original mean seasonal areas.

Comparing to original values

Paired t-tests found significant differences ($p < 0.05$) in the mean seasonal area (km^2) of the Aleutian Low calculated using this new method compared to previous methods for the whole time series, 1900 – 2008, and for the period from which the long-term mean is used to calculate ALPI, 1950 – 1997 (Table 5). Given these differences, there were also significant differences in ALPI values for 1900 – 2008 (Table 5). Box and whisker plots (not shown) of annual differences of areas calculated by the new and old methods highlighted extreme outliers in n=12 years (specifically 1901, 1904, 1906, 1907, 1909, 1916, 1918-20, 1941, 1945, and 1947). When these years are excluded, there is no significant difference in ALPI values for 1900 – 2008 (Table 5). All the years with outliers were pre-1950, and there were no significant differences in ALPI values for 1950 – 2008 (Table 5).

Seasonal Center of the Aleutian Low

Estimated cartesian (X,Y) and geographic coordinates of the center of the Aleutian Low for 1900 – 2015 are shown in Table 6; locations are illustrated in Figure 5. As expected, the center of the Aleutian Low is located in the general vicinity of the Aleutian Islands each year, between 169°E Longitude and 159°W Longitude, and between 46° N Latitude and 56° N Latitude (Figure 5). When the centers are colour-coded to indicate positive (intense Aleutian Low) and negative (weak Aleutian Low) index values, it is apparent that negative centers are more frequently located towards the west of the overall center, while positive centers are more frequently located to the east (Figure 5).

Discussion

The new method using R for calculating the Aleutian Low Pressure area provides researchers with a mode of producing and analyzing ALPI values independently, using free software. Overall, the new method produced ALPI values that were comparable to previously published values, with no difference in periods with positive or negative values (Figure 3).

Over the 100+ year time series (1900 – 2008) there were 12 years with differences in calculated Aleutian Low areas that we considered to be outliers. All of these outlier years were pre-1950, and when 1950 – 2008 ALPI values are compared between methods, there is no significant difference. We have reviewed documentation of known errors (pre-1950) with the sea level pressure dataset, but there have not been any corrections to the dataset since 1998 (http://rda.ucar.edu/datasets/ds010.1/#docs/notes-dss.html, accessed June 25, 2015). Therefore, it is unlikely the discrepancies in calculated Aleutian Low area are due to changes to input data, but we cannot be certain because the input data originally used to calculate ALPI were not archived by our program. The discrepancies may simply reflect differences in methodology.

It is important to note that the 12 outlier years do not change interpretation of periods with positive (intense Aleutian Low) and negative (weak Aleutian Low) index values. In addition, given that many biological time series begin after 1950, there should be no concern for previous or ongoing investigations that used ALPI to switch to values produced by the method outlined here, and to update annual values as required.

New in this report is a method for estimating the geographic location of the Aleutian Low Pressure system in degrees latitude and longitude. This method is also based in R, and is therefore widely available for researchers to produce seasonal Aleutian Low center locations for analysis. As previously reported, the center of the Aleutian Low was generally located over the Aleutian Islands. We observed that the seasonal center appeared more likely to occur to the east of the overall center in years with positive ALPI, and to the west of the overall center in years with negative ALPI; however, we did not investigate this phenomenon quantitatively, and suggest this as an avenue for future research. Several studies have illustrated the importance of geographic location of the Aleutian Low local to winter atmospheric and oceanic circulation (Rogers 1981; Niebauer 1988; Overland et al. 1999; Luchin et al. al. 2002); thus the metric we calculate here will be of interest to a broad range of researchers.

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Table 1. Contributions to the development of the Aleutian Low Pressure Index (ALPI). References are provided along with the length of the time series, season for ALPI calculation, published definition, and method of computation for each reference. SLP refers to sea level pressure.

Reference	Contribution	Time period	Season	Definition	Method
Beamish and Bouillon (1993)	- Initial quantification of annual intensity of the Aleutian Low	1900-1989	Dec – May	- The area (km^2) of the North Pacific with seasonal mean SLP ≤100.5 kPa - Sum of mean winter (Dec-Feb) and mean spring (Mar-May) areas	COMPUGRID for area calculations; LOWESS filter to smooth values
Beamish et al. (1997)	- Defined ALPI as an anomaly from a long-term mean - Redefined season of interest	1900-1995	Dec – Mar	- The area (km^2) of the North Pacific with monthly mean SLP ≤100.5 kPa -ALPI expressed as an anomaly of the seasonal mean area from the seasonal mean area of the whole time series	COMPUGRID for area calculations; LOWESS filter to smooth values
Beamish et al. (1999)	- Standardized the time period for the long-term mean from which the anomaly is calculated	1900-1997	Dec – Mar	- The area (km^2) of the North Pacific with monthly mean SLP ≤100.5 kPa - ALPI expressed as an anomaly of the seasonal mean area from the long-term (1950 – 1997) seasonal mean area	COMPUGRID for area calculations; no smoothing of values
King et al. (2001)	- Updated time series	1900-2000	Dec – Mar	- The area (km^2) of the North Pacific with monthly mean SLP ≤100.5 kPa - ALPI expressed as an anomaly of the seasonal mean area from the long-term (1950 – 1997) seasonal mean area	COMPUGRID for area calculations; no smoothing of values
McFarlane (2003)	- Updated time series	1900-2002	Dec – Mar	- The area (km^2) of the North Pacific with monthly mean SLP ≤100.5 kPa - ALPI expressed as an anomaly of the seasonal mean area from the long-term (1950 – 1997) seasonal mean area - reported area for 2002 was incorrectly calculated using SLP ≤101.0 kPa	COMPUGRID for area calculations; no smoothing of values
Crawford and Irvine (2010)	- Updated time series	1900-2008	Dec – Mar	- The area (km^2) of the North Pacific with monthly mean SLP ≤100.5 kPa - ALPI expressed as an anomaly of the seasonal mean area from the long-term (1950 – 1997) seasonal mean area - reported area for 2002 was incorrectly calculated using SLP ≤101.0 kPa	ArcMap for 2003-2008 area calculations

Table 2. Summary of dataset and R-method details used to generate ALPI.

Definitions	
Area of Aleutian Low	The area of the North Pacific with monthly mean sea level pressure ≤100.5 kPa
Aleutian Low Pressure Index (ALPI)	Anomaly of the seasonal mean area from the long-term (1950 – 1997) seasonal mean area
Input dataset	
Dataset name and citation	ds010.1: “Monthly Northern Hemisphere Sea-Level Pressure Grids, continuing from 1899” (UCAR et al. 1979; Trenberth and Paolino 1980).
Geographic Extent	180°E to 180° West Longitude; 15° to 90° North Latitude
Grid resolution	5° x 5°
Sea level pressure units	hectopascals (hPa); 1hPa = 0.1kPa
Number of observations	275
Time period	
Months used for ALPI season	December, January, February, March
Index years available	1900 – 2015 (December 1899 – March 2015)
Time period for long-term mean	1950 - 1997
Coordinate Reference System (CRS) and Subsetted Extents	
Initial CRS (Geographic)	NAD83
Units of initial CRS	degrees (°)
Subsetted geographic extent	120°E to 120° West Longitude; 20° to 70° North Latitude
Projected CRS	North Pacific Albers Conic Equal Area; central meridian: 170° W; standard parallels: 30° N and 60° N
Units of projected CRS	metres (m)
Projected extent (X)	-6,800,560 m to 5,169,440 m (total extent 11,970 km)
Projected extent (Y)	-3,589,628 m to 3,165,372 m (total extent 6,755 km).
Interpolation	
Method	Inverse Distance Weighted (IDW)
Power	1
Neighbourhood Size (nmax)	8, 12, 16, 20, 24, 32
Original cell size	15 x 15 km^2
ESRI cell size (Eq. 1)	27,020 m^2 (27 km^2)
Hengl (2006) cell size (Eq. 2 & 3)	27,1121 – 42,891 m^2 (27 – 43 km^2)
Cell sizes attempted	15, 20, 25, 30, 35, 40 $m^2 \times 10^6$ (km^2)

Table 3. Effects of different neighbourhood size (nmax) and raster resolution (cell size) on the outcome of interpolating sea level pressure: A) mean relative difference between new estimates of the area of the Aleutian Low and original estimates (Eq. 5); B) mean relative difference between new estimates of ALPI and original estimates (Eq. 5); C) estimated processing time to interpolate the 1900 – 2015 time series.

A) Mean Relative Difference (Aleutian Low Pressure Area)						
Cell Size (km^2)	Neighbourhood Size (nmax)					
	8	12	16	20	24	32
15*	0.0830	0.0441	0.0324	0.0692	0.1105	0.1893
20	0.0831	0.0441	0.0285	0.0692	0.1104	0.1892
25	0.0828	0.0440	0.0285	0.0690	0.1104	0.1893
30	0.0830	0.0443	0.0285	0.0692	0.1104	0.1892
35	0.0828	0.0441	0.0321	0.0692	0.1106	0.1895
40	0.0833	0.0440	0.0284	0.0692	0.1104	0.1895

B) Mean Relative Difference (Aleutian Low Pressure Index)						
Cell Size (km^2)	Neighbourhood Size (nmax)					
	8	12	16	20	24	32
15*	0.1047	0.0845	0.0693	0.0843	0.1110	0.1630
20	0.1044	0.0849	0.0689	0.0837	0.1111	0.1627
25	0.1044	0.0849	0.0691	0.0839	0.1111	0.1628
30	0.1053	0.0852	0.0696	0.0832	0.1109	0.1636
35	0.1051	0.0846	0.0690	0.0836	0.1114	0.1636
40	0.1047	0.0837	0.0690	0.0843	0.1098	0.1630

C) Estimated Processing Time for Interpolation (minutes)						
Cell Size (km^2)	Neighbourhood Size (nmax)					
	8	12	16	20	24	32
15*	21.247	23.8380	27.840	30.5273	33.582	41.1607
20	11.890	13.8233	15.911	17.6320	19.353	23.1033
25	8.159	8.9900	10.363	11.4067	12.567	15.0220
30	5.510	6.2833	7.521	8.0813	8.990	10.4980
35	4.157	4.7947	5.413	5.9353	7.018	7.8687
40	3.190	3.7120	4.273	4.6593	5.665	6.1480

* Original COMPUGRID cell size

Table 4. Seasonal Mean Aleutian Low Pressure Area and values of the Aleutian Low Pressure Index (ALPI) for 1900 – 2015.

Year	Area (km^2)	ALPI	Year	Area (km^2)	ALPI	Year	Area (km^2)	ALPI
1900	6,822,800	1.30	1940	11,944,000	6.42	1980	7,197,200	1.67
1901	3,832,400	-1.69	1941	10,107,600	4.58	1981	10,616,400	5.09
1902	5,558,800	0.03	1942	7,700,000	2.18	1982	2,312,800	-3.21
1903	592,400	-4.93	1943	2,556,000	-2.97	1983	12,213,200	6.69
1904	1,693,200	-3.83	1944	6,389,600	0.87	1984	7,208,400	1.68
1905	4,480,800	-1.04	1945	8,519,200	3.00	1985	3,880,400	-1.64
1906	2,737,600	-2.79	1946	7,226,000	1.70	1986	10,722,800	5.20
1907	67,200	-5.46	1947	3,408,800	-2.12	1987	9,143,200	3.62
1908	3,820,000	-1.70	1948	2,913,600	-2.61	1988	6,736,000	1.21
1909	3,086,000	-2.44	1949	3,926,000	-1.60	1989	2,848,000	-2.68
1910	2,973,200	-2.55	1950	3,590,400	-1.93	1990	4,652,400	-0.87
1911	2,308,800	-3.22	1951	3,690,000	-1.83	1991	5,976,000	0.45
1912	5,447,600	-0.08	1952	2,652,000	-2.87	1992	7,663,200	2.14
1913	4,330,400	-1.19	1953	7,726,000	2.20	1993	4,588,400	-0.94
1914	6,221,600	0.70	1954	3,207,600	-2.32	1994	4,898,000	-0.63
1915	4,144,000	-1.38	1955	2,904,800	-2.62	1995	7,109,200	1.59
1916	1,900,400	-3.62	1956	846,400	-4.68	1996	6,384,400	0.86
1917	3,036,800	-2.49	1957	3,926,400	-1.60	1997	6,018,000	0.49
1918	4,736,800	-0.79	1958	7,648,400	2.12	1998	10,101,200	4.58
1919	5,784,800	0.26	1959	3,364,000	-2.16	1999	5,653,600	0.13
1920	1,896,000	-3.63	1960	5,174,400	-0.35	2000	5,786,000	0.26
1921	4,598,800	-0.93	1961	8,445,600	2.92	2001	7,026,400	1.50
1922	2,528,400	-3.00	1962	3,894,000	-1.63	2002	5,154,000	-0.37
1923	3,628,400	-1.90	1963	7,848,800	2.32	2003	8,328,000	2.80
1924	6,111,600	0.59	1964	6,261,600	0.74	2004	8,351,200	2.83
1925	4,924,000	-0.60	1965	3,903,600	-1.62	2005	6,426,400	0.90
1926	9,756,000	4.23	1966	3,641,600	-1.88	2006	5,891,200	0.37
1927	6,396,800	0.87	1967	5,358,000	-0.17	2007	6,074,400	0.55
1928	6,180,400	0.66	1968	5,122,800	-0.40	2008	4,424,400	-1.10
1929	7,138,800	1.61	1969	2,803,200	-2.72	2009	1,560,000	-3.96
1930	3,421,200	-2.10	1970	9,212,800	3.69	2010	9,606,800	4.08
1931	8,436,400	2.91	1971	3,270,000	-2.25	2011	4,901,200	-0.62
1932	3,328,400	-2.20	1972	1,013,200	-4.51	2012	5,792,400	0.27
1933	2,486,800	-3.04	1973	3,901,200	-1.62	2013	5,400,400	-0.12
1934	8,470,800	2.95	1974	6,568,800	1.04	2014	4,953,600	-0.57
1935	4,778,000	-0.75	1975	3,679,200	-1.84	2015	5,863,200	0.34
1936	8,186,000	2.66	1976	4,408,400	-1.12			
1937	2,152,400	-3.37	1977	8,551,600	3.03			
1938	5,634,000	0.11	1978	7,843,200	2.32			
1939	5,843,600	0.32	1979	4,534,800	-0.99			
long-term (1950-1997) mean = 5,524,183 km^2								

Table 5. Results of paired t-tests between original and new values of the Aleutian Low Pressure Area and ALPI for 1900 – 2008.

Years	t	df	p-value	mean of the differences
Aleutian Low Pressure Area (km^2)				
1900 – 2008	4.59	108	0.0000	316,909
1950 – 1997	3.99	47	0.0002	101,908
ALPI				
1900 – 2008	3.11	108	0.0024	0.2150
1900 – 2008 (outliers excluded)	0.40	96	0.6882	0.0121
1950 – 2008	-1.64	58	0.1067	-0.0469

Table 6. Geographic coordinates of the center of the Seasonal Mean Aleutian Low Pressure Area for 1900 – 2015.

Year	Longitude	Latitude	Year	Longitude	Latitude	Year	Longitude	Latitude
1900	-172.141	50.98525	1940	-172.607	50.06334	1980	-177.658	48.39258
1901	-171.196	51.44634	1941	-171.712	51.33945	1981	-174.901	49.87074
1902	-174.944	50.31935	1942	-172.503	55.2631	1982	176.8924	50.82959
1903	-169.111	51.82616	1943	177.709	51.12354	1983	-167.02	50.53463
1904	179.2601	48.79437	1944	-177.37	52.31056	1984	-178.393	50.0523
1905	-170.817	50.95554	1945	-172.159	52.955	1985	177.1172	53.10006
1906	-167.075	50.84057	1946	-173.77	52.73985	1986	-171.301	49.82074
1907	-159.359	49.7662	1947	172.4609	48.3413	1987	-176.785	52.10579
1908	-175.963	53.19207	1948	-174.73	55.78288	1988	-171.631	53.39085
1909	-172.532	54.34115	1949	172.2932	52.63605	1989	172.2876	54.11034
1910	-166.532	54.43945	1950	-178.357	52.46148	1990	-171.817	54.22002
1911	-176.525	54.66056	1951	-176.551	52.23323	1991	176.9072	50.21438
1912	-171.292	51.32936	1952	175.4949	53.56874	1992	-170.62	52.90346
1913	179.9317	51.16769	1953	-164.562	53.69419	1993	179.1631	51.50605
1914	-170.008	51.74176	1954	-170.008	52.09043	1994	-176.41	52.69164
1915	-166.027	55.71607	1955	-175.034	55.09828	1995	-170.768	49.41895
1916	-175.776	49.96773	1956	-168.392	50.94876	1996	173.1867	50.12057
1917	177.8598	48.70488	1957	178.2331	49.55734	1997	-167.106	50.31878
1918	178.2716	48.97539	1958	-171.393	53.17478	1998	-166.339	52.87368
1919	-172.025	53.56089	1959	-177.088	53.14227	1999	-178.63	53.98276
1920	-177.719	49.43649	1960	-178.002	53.68077	2000	-171.652	53.24494
1921	-179.371	52.97043	1961	-168.354	52.08106	2001	-173.916	53.91712
1922	177.1745	51.45772	1962	168.8763	48.39816	2002	-178.003	54.45752
1923	173.3151	49.81089	1963	-173.778	46.41146	2003	-166.365	51.52134
1924	-173.9	52.78013	1964	-172.131	52.48187	2004	-175.456	51.46339
1925	176.9726	49.12041	1965	176.6787	49.23856	2005	-179.238	50.30487
1926	-170.674	51.26104	1966	-165.196	55.12032	2006	-179.879	55.05256
1927	-170.322	54.01176	1967	179.3275	53.04264	2007	-174.012	54.42599
1928	178.7058	53.05474	1968	-176.591	50.67315	2008	-179.818	52.39918
1929	176.9109	50.20006	1969	176.1149	54.13118	2009	175.9903	50.34505
1930	-179.928	51.45534	1970	-174.905	49.91414	2010	-168.452	51.38488
1931	-170.427	54.06985	1971	-170.575	49.13012	2011	-166.894	52.17341
1932	-172.715	53.87078	1972	-167.874	51.02901	2012	-168.21	53.95765
1933	-170.639	54.30263	1973	-176.466	52.35368	2013	176.7898	53.15929
1934	176.283	48.21556	1974	-172.328	50.28583	2014	-173.3	49.61349
1935	178.8223	53.10775	1975	-178.913	51.34732	2015	-168.111	48.68359
1936	-177.556	48.34013	1976	-176.17	50.82317			
1937	171.833	53.90583	1977	-169.324	52.61224			
1938	-171.243	53.30721	1978	-178.866	50.679			
1939	-176.443	52.17977	1979	-171.124	54.79656			

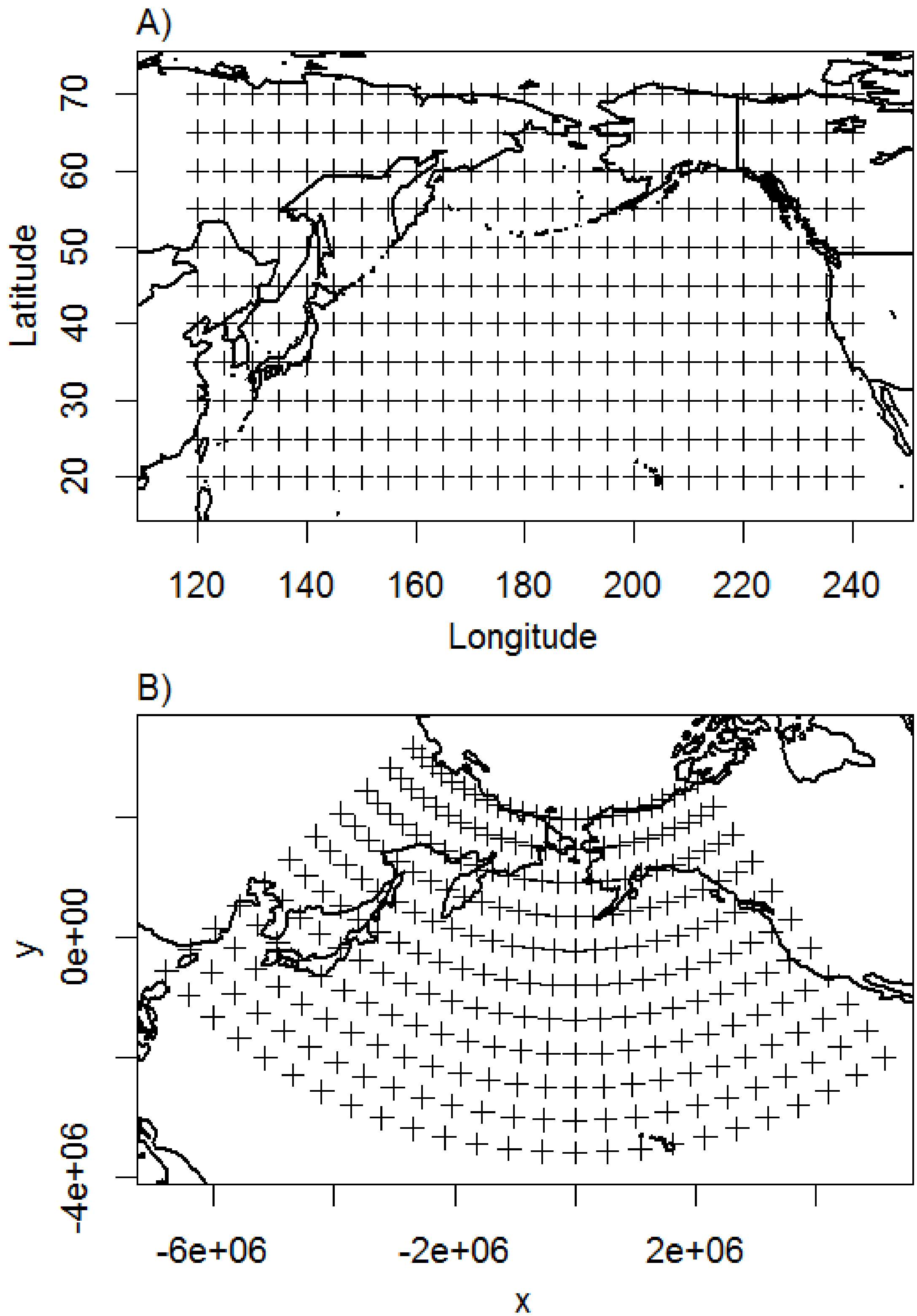


Figure 1. Locations of the Monthly Northern Hemisphere Sea-Level Pressure Grid, subsetted for the North Pacific, displayed in (A) geographic coordinates (NAD83) and (B) the North Pacific Albers Conic Equal Area projection with a central meridian at 170° West Longitude and standard parallels at 30° and 60° North Latitude.

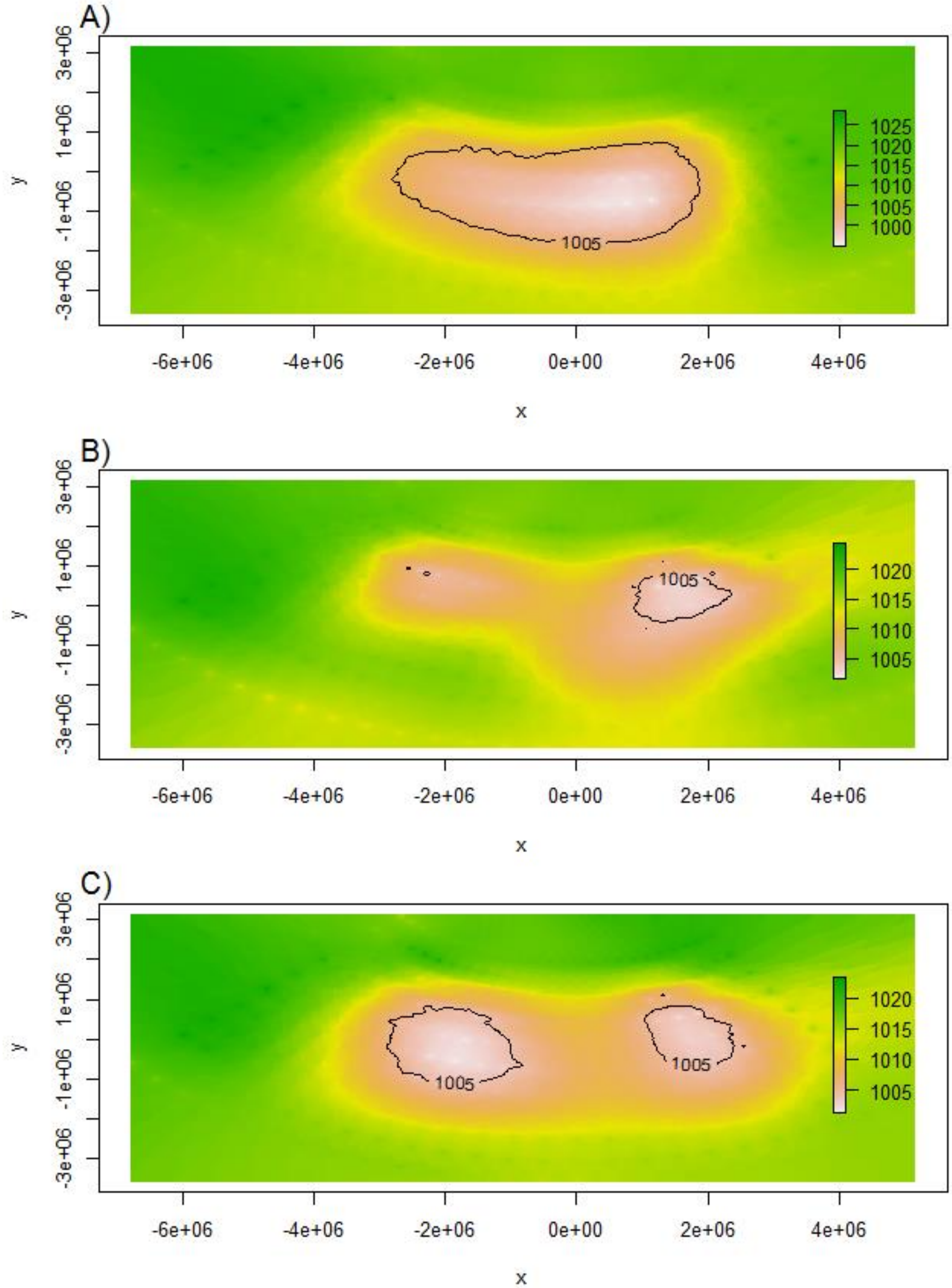


Figure 2. Examples of the Aleutian Low where the area with sea level pressure ≤ 100.5 kPa is represented by (A) a single large area over the North Pacific (January 2015); (B) a large area with several small areas outside the main area (December 1996); and (C) more than one distinct area (February 1992).

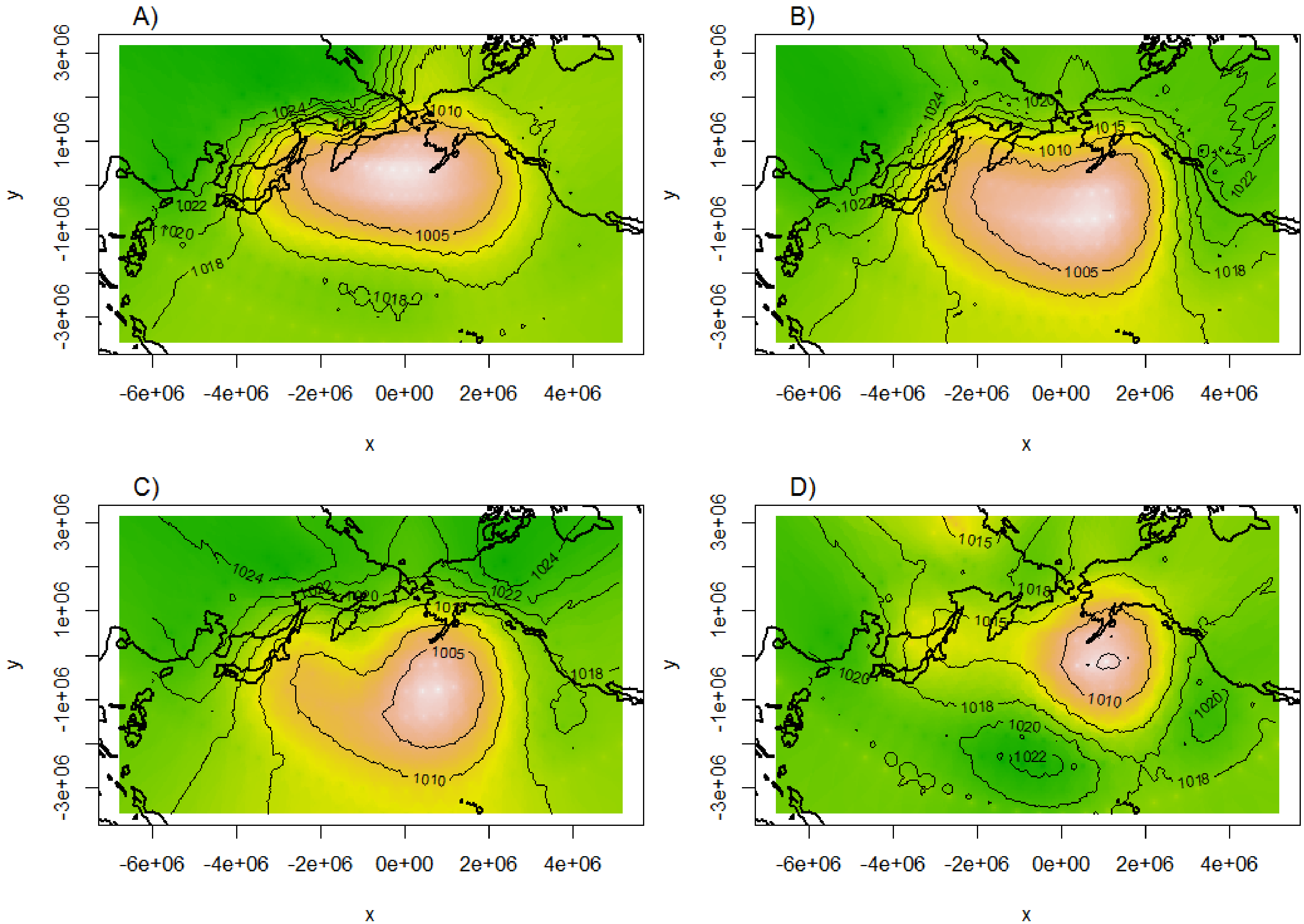


Figure 3. Interpolated rasters of monthly sea level pressure over the North Pacific for December 2014 (A), January 2015 (B), February 2015 (C), and March 2015 (D). The Aleutian Low for each month is indicated by the 1005 hPa (100.5 kPa) isobar; note that for March 2015, the 1005 hPa isobar is located inside the 1010 isobar, but is too small to label.

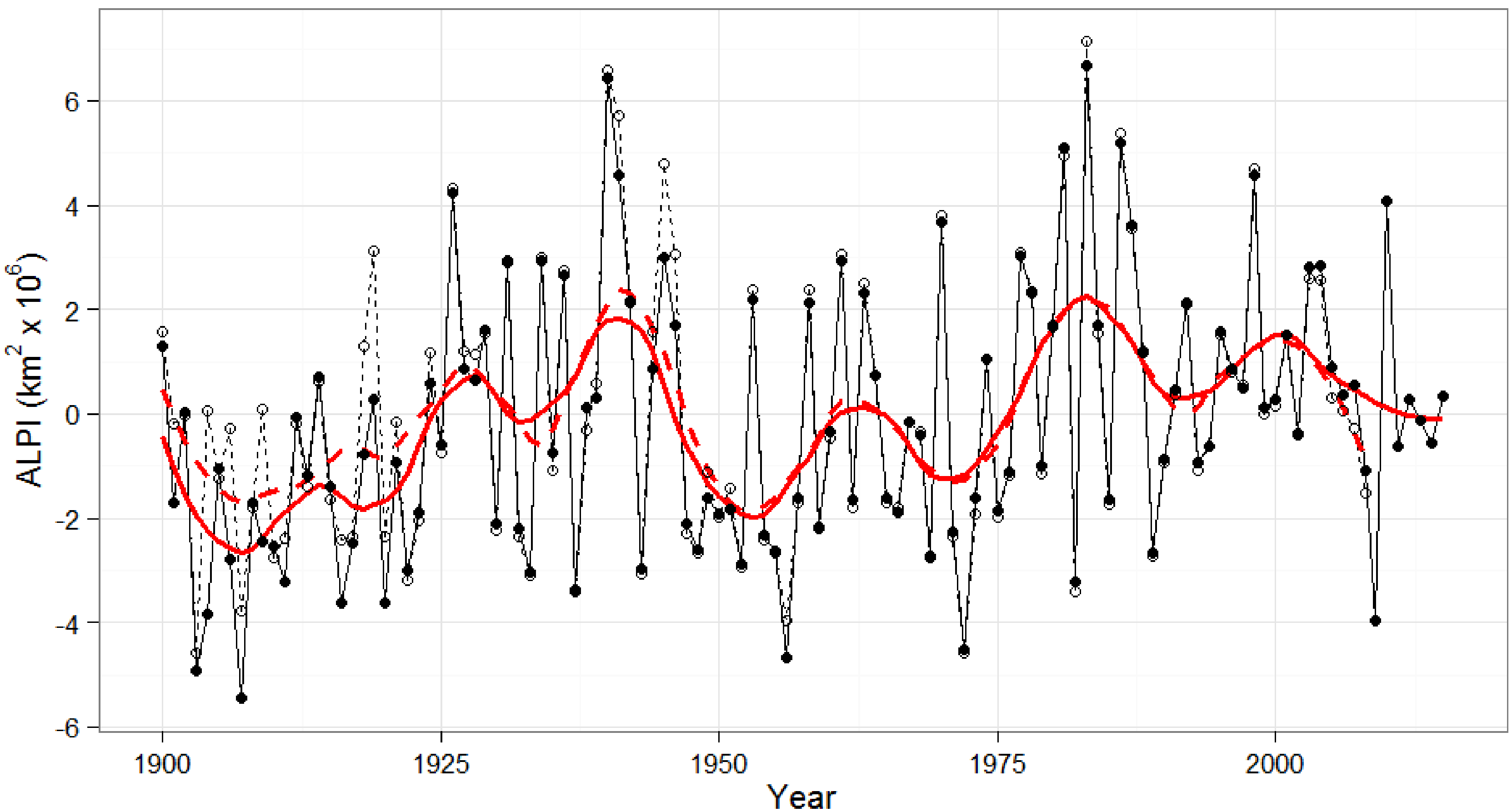


Figure 4. The Aleutian Low Pressure Index (ALPI). Solid lines and black circles are the new ALPI values (1900 – 2015); dashed lines and open circles are from the original COMPUGRID method (1900 – 2002) and the ESRI ArcMap method (2003 – 2008). The red lines are the loess smoothed lines (smoothing parameter = 0.2).

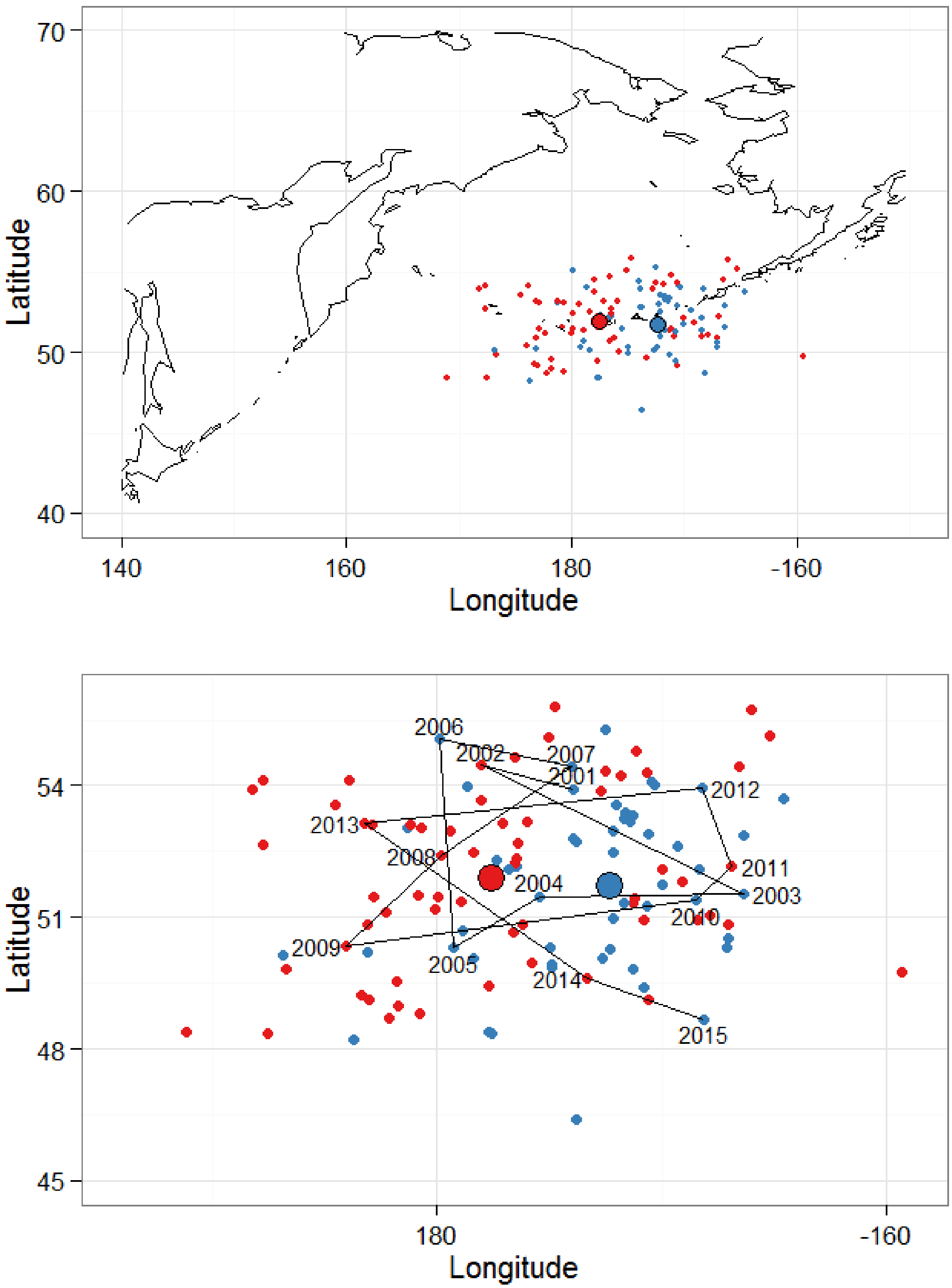
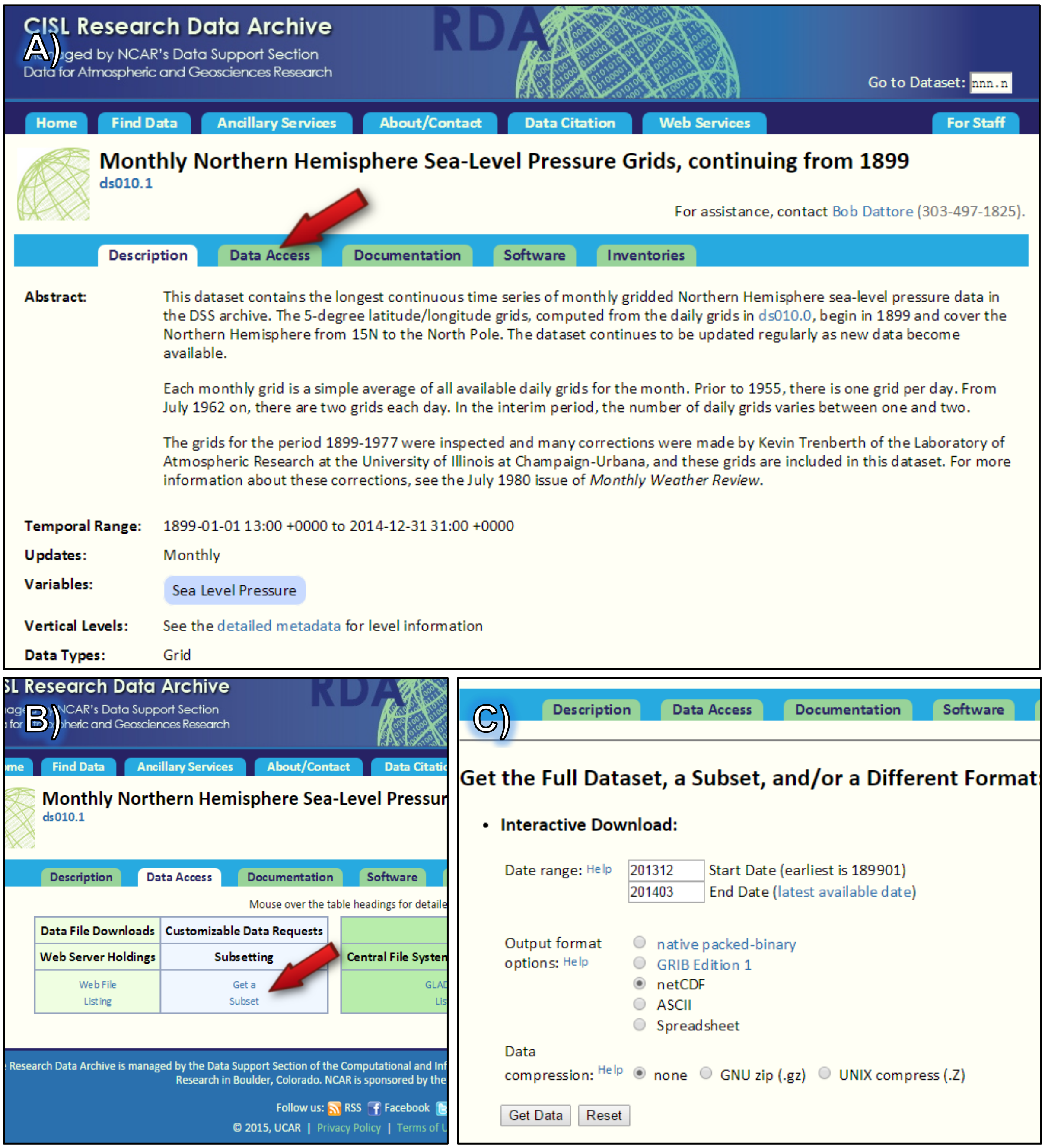


Figure 5. Geographic locations of the center of the seasonal Aleutian Low for 1900 – 2015. Red and blue circles are the centers of negative (weak Aleutian Low) and positive (intense Aleutian Low) ALPI values, respectively; large circles are the overall negative and positive centers. The upper panel indicates the locations relative to landmasses adjacent to the North Pacific. The lower panel shows the centers at larger scale; lines are drawn between consecutive centers for 2001 – 2015.

Appendix A: Downloading Data

Go to the Research Data Archive (RDA) webpage at http://rda.ucar.edu/datasets/ds010.1/. Select the Data Access tab from the dataset description page (Appendix Figure 1A). Under Customizable Data Requests, Subsetting, select "Get a Subset" (Appendix Figure 1B). In "Date Range" select December to March (Appendix Figure 1C). For example, for 2014, select 201312 for Start Date (December) and 201403 for End Date (March). Select NetCDF for the output format. Click "Get Data." Accept the default file name: it will be something like "ds010.1.20131200.20140331.nc" and save it to your R working directory.



Appendix Figure 1. Downloading climate data.

Appendix B: R code for calculating ALPI

Functions for calculating ALPI and the center of the Aleutian Low

```
# This is a source file named ALPI.r
# Updated for R 3.1.2
# January 12, 2015
############################################################
# Functions to calculate the annual value for the Aleutian
# Low Pressure Index (ALPI).
#
# ALPI is used as in Beamish et al. (1997), modified from Beamish
# and Bouillon (1993): For each month from December to March,
# the average area of the ocean covered by the low less than
# 100.5 kPa is estimated. The average for the 4 months is
# subtracted from the longerm (1950-1997) average, and the
# resulting anomaly is used as the yearly index for the
# January year.
#
# Based on Compugrid method developed by Michael Folkes in
# 1998, which was then adapted for use in ESRI ArcMap by
# Rob Flemming and Karin Mathias in 2003.
# This version written by Maria Surry in October 2012, and
# updated in January 2015.
#
# Content was derived with the help of the documentation
# associated with each package, as well past contributions
# on the R-SIG-Geo mailing list at
# https://stat.ethz.ch/mailman/listinfo/R-SIG-Geo/.
# Correct citations for R and for packages used can be obtained
# using the function citation().
#
# These functions work on data you have already downloaded.
#
# The data for this study are from the Research Data Archive
# RDA) which is maintained by the Computational and Information
# Systems Laboratory (CISL) at the National Center for
# Atmospheric Research (NCAR). NCAR is sponsored by the National
# Science Foundation (NSF). The original data are available from
# the RDA (http://rda.ucar.edu) in dataset number ds010.1.
#
# Access is free, but you do have to register.
#
# From the RDA website, under the data access tab, select
# "Get a subset".  In "Date Range" select December to March.
# For example, for 2011, select 201012 for Start Date (December)
# and 201103 for End Date (March).  Select NetCDF for the output
# format.
############################################################
# remove all objects in the working directory
#rm(list=ls())
# attach necessary libraries
library(RNetCDF)
library(gstat)
library(raster)
library(rgdal)
```

```
# library(sp) # loaded automatically with 'raster"
############################################################
get.alpi.nc <- function(file) {
  # function to open a NetCDF file and parse it into dec to mar
  # sea level pressure data, subsetted to the correct extent
  library(RNetCDF)
  file.nc <- open.nc(file)
  #retrieve the relevant variables - all are arrays
  #   *longitude is 0-355 degrees, in 5 degree increments (72 elements)
  #   *latitude is 15-90 degrees, in 5 degree increments (16 elements)
  #   *each 72 x 16 element is one month of data
  lon.original <- var.get.nc(file.nc,"lon") #longitude (72x1)
  lat.original <- var.get.nc(file.nc,"lat") #latitude (16x1)
  slp.original <- var.get.nc(file.nc,"slp") #sea level pressure 72x16x4)
  date.time <- var.get.nc(file.nc,"date_time") #month (4x1)
  close.nc(file.nc)
  # Subset to the extent from Beamish & Bouillon (1993)
  lon <- lon.original[25:49] # longitude 120-240° (120°E-120°W)
  lat <- lat.original[2:12]  # latitude 20-70°N
  # divide into months
  dec.slp <- slp.original[25:49,2:12,1] #december (25x11)
  jan.slp <- slp.original[25:49,2:12,2] #january (25x11)
  feb.slp <- slp.original[25:49,2:12,3] #february (25x11)
  mar.slp <- slp.original[25:49,2:12,4] #march (25x11)
  # Glue the variables into one data frame for each month, with
  # columns for longitude, latitude, and sea level pressure.
  y  <- rep(lat,length(lon))
  x <- rep(lon, length(lat))
  x <- as.vector(t(matrix(x,nrow=length(lon))))
  # Name each data frame by the corresponding month
  dec <- data.frame(x,y,z=as.vector(t(dec.slp)))
  dec.name <- paste("December",substr(date.time[1],1,4))
  jan <- data.frame(x,y,z=as.vector(t(jan.slp)))
  jan.name <- paste("January",substr(date.time[2],1,4))
  feb <- data.frame(x,y,z=as.vector(t(feb.slp)))
  feb.name <- paste("February",substr(date.time[3],1,4))
  mar <- data.frame(x,y,z=as.vector(t(mar.slp)))
  mar.name <- paste("March",substr(date.time[4],1,4))
  # Combine data frames into list
  data <- list(dec,jan,feb,mar)
  names(data) <- c(dec.name,jan.name,feb.name,mar.name)
  return(data)
}
############################################################
slp.idw <- function(month,cs=40){
  # Function to turn point observations of monthly sea level pressure
  # into a raster using inverse distance weighted (IDW) interpolation.
  # This function works on a single month of data - e.g. one element
  # of the list created by file.nc above.
  library(gstat)
  library(raster)
  library(rgdal)
  #turn ordinary data frame into a spatial object (package 'sp')
  data.new <- month[!is.na(month$z),] # get rid of NAs first
  coordinates(data.new) <- ~ x + y  # turns into SpatialPointsDataFrame
  #
  # assign a coordinate system (CRS = Coordinate Reference System)
```

```
  # set up CRS strings
  wgs84 <- c("+proj=longlat +datum=WGS84") #WGS84
  nad83 <- c("+proj=longlat +datum=NAD83") #NAD83
  wb <- c("+proj=cea +lat_ts=30 +lon_0=180") # World Berhmann
  aea <- c("+proj=aea +lat_1=30 +lat_2=60 +lat_0=52 +lon_0=-170 +x_0=0 +y_0=0
+ellps=GRS80 +datum=NAD83 +units=m +no_defs") #NPac Albers Equal Area
  # proj4string(data.new) <- CRS(wgs84)
  proj4string(data.new) <- CRS(nad83)
  #
  # Data requires an equal-area projection to measure area without
  # distortion
  #
  # World Berhmann projection with central meridian at 180 degrees
  # (used by Karin Mathias in ESRI method)
  # data.new <- spTransform(data.new, CRS(wb))
  #
  # North Pacific Albers Conic Equal Area projection with standard
  # parallels at 30 and 60 and central meridian is -170 degrees.
  # From www.stateofthesalmon.org, available at www.spatialreference.org
  # This looks similar to Beamish & Bouillon (1993) figures.
  data.new <- spTransform(data.new, CRS(aea))
  #
  # Make a regular grid that has the same extent as the dataset
  # (note: You can't just make the dataset gridded, because as soon as
  # you project the regular lat/lon grid into cartesian coordinates, it's
  # not regular any more.) Pick a cell size (resolution) that gives
  # results closest to original values.
  grd <- spsample(data.new,type="regular",offset = c(0.5,0.5),
    cellsize=c(cs*1000,cs*1000))
  gridded(grd) <- TRUE
  # Interpolate the data into the new grid, using IDW (gstat)
  # nmax is the number of nearest observations to use, idp is the power
  # Output is spatial pixels dataframe which can be converted into
  # a raster.
  data.idw <- idw(z~1,data.new,grd,nmax=16,idp=1)
  # convert to raster -note: this is the interpolated raster for one
  # month of sea level pressure data
  data.ras <- raster(data.idw)
  return(data.ras)
  }
############################################################
month.val <- function(month.ras) {
  # Function to calculate the area of the Aleutian Low (area that is less
  # than or equal to 1005 hPa) - i.e. the monthly value
  # Output is a single value for the area.
  library(raster)
  pred.slp <- values(month.ras) #get interpolated values
  r <- res(month.ras) # raster resolution (cell size)
  # Find the area with sea level pressure less than 1005 hPa:
  area <- length(pred.slp[pred.slp<=1005])*r[1]*r[2]
  return(area)
  }
############################################################
alpa <- function(vals) {
  # Function to convert a list of monthly values for one ALPI year into
  # a vector, and to calculate the average Aleutian Low for that year
  colnames <- c("December","January","February","March","Average")
```

```
  monthly <- c(vals,sum(vals)/4)
  names(monthly) <- colnames
  return(monthly)
  }
############################################################
alpi.val <- function(lows,lt.mean) {
  # Function to compute the annual anomaly from the long-term mean.
  # 'lows' is a vector or dataframe with the Dec-Mar values for
  # the area of the Aleutian Low.
  # The long-term mean must be specified.
  # Output is the index value in km^2 x 10^6 for each year supplied.
  avg <- sum(lows)/4
  ind.val <- (avg-lt.mean)/1000000/1000000
  names(ind.val) <- "ALPI"
  return(ind.val)
  }
############################################################
month.reclass <- function(month.ras) {
  # Function to reclassify the area less than 1005 hPa and return
  # the reclassified raster. Output is a raster with just
  # the area < 1005. This is the same as the output of the "reclassify"
  # function in ArcMap Spatial Analyst.
  pred.slp <- values(month.ras) #get interpolated values
  # Find the area with sea level pressure less than 1005 hPa:
  #   reclassify the area < 1005 as "1"
  #   reclassify all other values to NA
  m <- c(0, 1005, 1,  1005, max(pred.slp), NA)
  rclmat <- matrix(m, ncol=3, byrow=TRUE)
  data.reclass <- reclassify(month.ras, rclmat)
  return(data.reclass)
  }
############################################################
get.alpa.ctr <- function(month.ras) {
# Function to find the coordinates of the centre of the Aleutian Low
# Pressure Area (ALPA).
# First reclassifies the raster using month.reclass, so that all
# values in the raster > 100.5 kPa are NA, and all values <= 100.5 kPa
# are converted to "1".
# Then processes the output from month.reclass by finding "clumps" of area
# that are <= 100.5 kPa: sometimes there is just one clump; other times
# there are small additional clumps which we ignore.
#
# First find the clumps and figure out the area of each so that
# you can pick the biggest one.
  library(raster)
  library(rgdal)
#
  month.rcl <- month.reclass(month.ras)
  month.cl <- clump(month.rcl)
  cl.vals <- values(month.cl)
  if (all(is.na(cl.vals))) {
    # if there is no ALPA for this month, return with no coordinates
    coord.ctr <- c(NA,NA,NA,NA)
    return(coord.ctr)
    }
  r <- res(month.cl) # raster resolution (cell size)
  counts <- data.frame(freq(month.cl,useNA='no')) # no. cells per clump
```

```
  alpa.id <- counts$value[which.max(counts$count)] # biggest clump is ALPA
  #
  # eliminate ALPAs where the clumps are too similar in size to
  # unambiguously pick the biggest one
  clump.max <- counts$count[alpa.id]
  clump.other <- sum(counts$count)-clump.max
  if (0.1*clump.max<clump.other){
    coord.ctr <- c(NA,NA,NA,NA)
    return(coord.ctr)
    }
  #
  # Now find the coordinates associated with the ALPA.  Put them in a
  # dataframe so that you can find the min and max of the cartesian
  # coordinates.  The mean of these will be the centre point of the
  # ALPA.
  #
  xy <- xyFromCell(month.cl,1:ncell(month.cl)) # get coordinates
  df <- data.frame(xy, cl.vals, is.alpa = month.cl[] %in% alpa.id)
  df <- df[df$is.alpa == T, ] # only want coordinates for ALPA
  x <- (min(df$x)+max(df$x))/2
  y <- (min(df$y)+max(df$y))/2
  #
  #Now convert the x,y (cartesian) into lat,long (geographic).  First set
  # up a Coordinate Refernce System (CRS), turn the x,y into a spatial
  # object with CRS = NPac Albers, and then convert to NAD83.
  nad83 <- c("+proj=longlat +datum=NAD83") #NAD83
  aea <- c("+proj=aea +lat_1=30 +lat_2=60 +lat_0=52 +lon_0=-170 +x_0=0 +y_0=0
+ellps=GRS80 +datum=NAD83 +units=m +no_defs") #NPac Albers
  #
  alpa.ctr <- SpatialPoints(matrix(c(x,y), nrow=1), proj4string=CRS(aea))
  alpa.ctr.geo <- spTransform(alpa.ctr, CRS=CRS(nad83))
  coord.ctr <- cbind(coordinates(alpa.ctr.geo),coordinates(alpa.ctr))
  colnames(coord.ctr) <- c("lon","lat","x","y")
  return(coord.ctr) # return the latitude, longitude, x, and y coords
  }
############################################################
seasonal.ctr <- function(data.rcl.list) {
# Function to find centers for the monthly and seasonal Aleutian Lows
# Accepts a list of rasters for each year (Dec, Jan, Feb, Mar)
  monthly.coords <- sapply(data.rcl.list,get.alpa.ctr) # monthly centers
#
# Use the cartesian coordinates to do the averaging.  First set up a
# Coordinate Refernce System (CRS), turn the xy's into a spatial object
# with CRS = NPac Albers, and then convert to NAD83.
  nad83 <- c("+proj=longlat +datum=NAD83") #NAD83
  aea <- c("+proj=aea +lat_1=30 +lat_2=60 +lat_0=52 +lon_0=-170 +x_0=0 +y_0=0
+ellps=GRS80 +datum=NAD83 +units=m +no_defs") #NPac Albers
  #
  x <- mean(monthly.coords[3,],na.rm=T)
  y <- mean(monthly.coords[4,],na.rm=T)
  alpa.ctr <- SpatialPoints(matrix(c(x,y), nrow=1), proj4string=CRS(aea))
  alpa.ctr.geo <- spTransform(alpa.ctr, CRS=CRS(nad83))
  seasonal.ctr <- cbind(coordinates(alpa.ctr.geo),coordinates(alpa.ctr))
  coord.ctr <- cbind(monthly.coords,t(seasonal.ctr))
  rownames(coord.ctr) <- c("lon","lat","x","y")
  # get the January year and use to create a colname for the new coords
  year <- as.numeric(strsplit(dimnames(monthly.coords)[[2]]," ")[[2]][2])
```

```
  colnames(coord.ctr)[5] <- paste("Seasonal",year)
  return(coord.ctr) # return the latitude, longitude, x, and y coords
  }
############################################################
```

Code to run the functions on real data

```
# This is a source file named ALPI_example.r
# Written for R 3.1.2
############################################################
# Code to run the ALPI functions on datafiles already downloaded
# from the UCAR website for 2011 - 2015.  Will produce
# comma-delimited (csv) files containing the monthly and
# seasonal areas of the Aleutian Low, annual ALPI values, and
# coordinates for the center of the Aleutian Low for all the years
# included.
############################################################
# Source the ALPI functions
source("ALPI.r")
############################################################
# These are the files for each year (change path as necessary)
file2011 <- "./data/ds010.1.20101200.20110331.nc"
file2012 <- "./data/ds010.1.20111200.20120331.nc"
file2013 <- "./data/ds010.1.20121200.20130331.nc"
file2014 <- "./data/ds010.1.20131200.20140331.nc"
file2015 <- "./data/ds010.1.20141200.20150331.nc"
############################################################
# This is a vector containing all the years
year <- c(2011,2012,2013,2014,2015)
# This is the 1950-1997 mean
longterm <- 5.523704e+12
############################################################
# Calculate areas, indices, and coordinates
#2011
data2011 <- get.alpi.nc(file2011)
raster2011 <- sapply(data2011,slp.idw,cs=40)
vals2011 <- sapply(raster2011,month.val)
alpa2011 <- alpa(vals2011)
alpi2011 <- c(alpa2011,alpi.val(vals2011,lt.mean=longterm))
coords2011 <- seasonal.ctr(raster2011)
#
#2012
data2012 <- get.alpi.nc(file2012)
raster2012 <- sapply(data2012,slp.idw,cs=40)
vals2012 <- sapply(raster2012,month.val)
alpa2012 <- alpa(vals2012)
alpi2012 <- c(alpa2012,alpi.val(vals2012,lt.mean=longterm))
coords2012 <- seasonal.ctr(raster2012)
#
#2013
data2013 <- get.alpi.nc(file2013)
raster2013 <- sapply(data2013,slp.idw,cs=40)
vals2013 <- sapply(raster2013,month.val)
alpa2013 <- alpa(vals2013)
alpi2013 <- c(alpa2013,alpi.val(vals2013,lt.mean=longterm))
coords2013 <- seasonal.ctr(raster2013)
#
```

```
#2014
data2014 <- get.alpi.nc(file2014)
raster2014 <- sapply(data2014,slp.idw,cs=40)
vals2014 <- sapply(raster2014,month.val)
alpa2014 <- alpa(vals2014)
alpi2014 <- c(alpa2014,alpi.val(vals2014,lt.mean=longterm))
coords2014 <- seasonal.ctr(raster2014)
#
#2015
data2015 <- get.alpi.nc(file2015)
raster2015 <- sapply(data2015,slp.idw,cs=40)
vals2015 <- sapply(raster2015,month.val)
alpa2015 <- alpa(vals2015)
alpi2015 <- c(alpa2015,alpi.val(vals2015,lt.mean=longterm))
coords2015 <- seasonal.ctr(raster2015)
#
############################################################
#Save ALPI results to a text file in the current working directory
alpi.results <- data.frame(
  year,rbind(alpi2011,alpi2012,alpi2013,alpi2014,alpi2015),
  row.names = NULL)
write.table(alpi.results,
  file="alpi2011-2015.csv",row.names=F,sep=",",quote=F)
#
#Save coordinates to a text file in the current working directory
coords.results <- rbind(
  t(coords2011),
  t(coords2012),
  t(coords2013),
  t(coords2014),
  t(coords2015))
coords.results <- data.frame(
  t(matrix(unlist(strsplit(dimnames(coords.results)[[1]]," ")),nrow=2)),
  coords.results)
  rownames(coords.results) <- NULL
  colnames(coords.results) <- c("month","year","long","lat","x","y")
write.table(coords.results, file="coords2011-
2015.csv",row.names=F,sep=",",quote=F)
```

Appendix C. Original values for the Aleutian Low and ALPI

Appendix Table 1. Original values for the Seasonal Mean Aleutian Low Pressure Area and original values of the Aleutian Low Pressure Index (ALPI), based on Beamish et al. (1999) and published on the DFO website for 1900 – 2008.

Year	Area (km^2)	ALPI	Year	Area (km^2)	ALPI	Year	Area (km^2)	ALPI
1900	7,185,713	1.56	1940	12,199,559	6.57	1980	7,311,939	1.69
1901	5,421,544	-0.20	1941	11,339,608	5.71	1981	10,558,239	4.93
1902	5,606,326	-0.02	1942	7,769,364	2.14	1982	2,216,419	-3.41
1903	1,035,900	-4.59	1943	2,571,919	-3.05	1983	12,771,340	7.15
1904	5,672,419	0.05	1944	7,202,869	1.58	1984	7,159,388	1.53
1905	4,395,150	-1.23	1945	10,422,749	4.80	1985	3,896,551	-1.73
1906	5,343,356	-0.28	1946	8,674,259	3.05	1986	11,014,933	5.39
1907	1,839,994	-3.79	1947	3,345,581	-2.28	1987	9,179,496	3.55
1908	3,844,069	-1.78	1948	2,949,863	-2.68	1988	6,782,625	1.16
1909	5,722,481	0.10	1949	4,522,388	-1.10	1989	2,907,844	-2.72
1910	2,871,563	-2.75	1950	3,657,544	-1.97	1990	4,707,956	-0.92
1911	3,231,225	-2.39	1951	4,189,444	-1.44	1991	5,989,164	0.36
1912	5,447,756	-0.18	1952	2,696,400	-2.93	1992	7,714,408	2.09
1913	4,235,625	-1.39	1953	8,015,403	2.39	1993	4,525,539	-1.10
1914	6,241,106	0.62	1954	3,218,175	-2.41	1994	4,990,838	-0.64
1915	3,995,269	-1.63	1955	2,971,294	-2.65	1995	7,141,108	1.52
1916	3,196,688	-2.43	1956	1,653,244	-3.97	1996	6,424,651	0.80
1917	3,271,781	-2.35	1957	3,910,669	-1.72	1997	6,164,103	0.54
1918	6,922,914	1.30	1958	7,994,533	2.37	1998	10,333,520	4.71
1919	8,748,396	3.12	1959	3,433,613	-2.19	1999	5,633,156	0.01
1920	3,284,831	-2.34	1960	5,159,419	-0.47	2000	5,774,963	0.15
1921	5,455,801	-0.17	1961	8,685,114	3.06	2001	7,130,645	1.50
1922	2,432,138	-3.19	1962	3,818,588	-1.81	2002[1]	5,210,381[2]	-0.42[2]
1923	3,596,288	-2.03	1963	8,132,234	2.51	2003[3]	8,229,429	2.60
1924	6,792,694	1.17	1964	6,352,538	0.73	2004	8,175,089	2.55
1925	4,867,763	-0.76	1965	3,919,444	-1.71	2005	5,938,853	0.31
1926	9,966,656	4.34	1966	3,824,214	-1.80	2006	5,690,962	0.06
1927	6,828,919	1.20	1967	5,453,044	-0.17	2007	5,350,776	-0.28
1928	6,780,825	1.15	1968	5,293,633	-0.33	2008	4,102,076	-1.52
1929	7,180,708	1.55	1969	2,868,413	-2.76			
1930	3,405,206	-2.22	1970	9,413,494	3.79			
1931	8,566,933	2.94	1971	3,281,850	-2.34			
1932	3,278,250	-2.35	1972	1,037,756	-4.59			
1933	2,527,875	-3.10	1973	3,696,413	-1.93			
1934	8,608,556	2.98	1974	6,677,606	1.05			
1935	4,535,831	-1.09	1975	3,633,581	-1.99			
1936	8,367,469	2.74	1976	4,461,076	-1.16			
1937	2,224,856	-3.40	1977	8,704,858	3.08			
1938	5,324,625	-0.30	1978	7,973,046	2.35			
1939	6,209,945	0.58	1979	4,468,219	-1.16			
long-term (1950-1997) mean = 5,626,070 km^2								

(1) Final year which used COMPUGRID method
(2) Original 2002 results were incorrectly calculated using SLP ≤101.0 kPa as 11,199,994 km^2 and 5.57; the correct values (shown in table) were used in paired t-test comparisons with values produced using the new R method.
(3) First year which used ArcMap method.