Northern Hemisphere Airstream Regions

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ABSTRACT

Near-surface airstream source regions of the Northern Hemisphere have been identified using 16-year mean resultant winds from 3° latitude by 3° longitude grids. Tracing the airstreams back to their divergent centers reveals 19 different sources during various seasons of the year. Five of these sources (air originating over the North and South Pacific and Atlantic Oceans and air over Turkey) are resident in the Northern Hemisphere 12 months of the year. Another three (central Asian, Arctic and central East Asian air) exist for at least 11 months per year. The remaining 11 source regions are present from 1–9 months per year and their area of influence is much less than that of the 5-year-long sources.

In the mean, there are several favored locations for frontal zones, e.g., a north–south band in Mexico (dividing Atlantic from Pacific air), a north–south band in northern South America, and two northeast–southwest trending bands over the east coasts of Asia and North America, representing the mean leading edges of continental airmasses.

Mean dew points demonstrate the character of the moisture discontinuity across several mean frontal boundaries. Gradients in moisture are apparent as one progresses from one airstream to another. These gradients are sharpest along confluences, coasts and mountain barriers, particularly when a confluence is near-coincident with a topographic boundary.

1. Introduction

According to Petterssen (1956), Bergeron visualized air masses as forming in the semi-permanent (or mean) circulation systems such as the subtropical anticyclones or the polar continental anticyclones, and stated that the concepts of fronts and air masses cannot be separated. Since the development of these concepts early in this century, air masses and fronts have been integral parts of synoptic weather analysis. However, with the emphasis of meteorological analysis on the regions where air masses meet and become mixed, i.e., fronts and cyclonic storms, the original emphasis on the anticyclones or divergent regions as the source regions was diminished. By the 1940's the definitions of the source regions have become quite generalized: the North Pacific Ocean, the colder portions of the North Atlantic, the desert, the tundra, etc. (e.g., Willett, 1940, p. 73).

Brunnschweiler (1952) attempted a genetic climatic subdivision of North America based on the frequency of occurrence of the various air masses as indicated on daily synoptic charts by the map analyst. However, the air mass identification by the analyst was quite subjective and casual at that time, and the results must be viewed with that fact in mind. Any cold, dry air mass was called continental polar regardless of whether it originated over the Arctic Ocean or northern Canada or whether it was simply modified air from the Pacific.

About the same time, Borchert (1950) made a significant innovation in climatic analysis by employing streamlines of the monthly resultant winds to show that the North American grasslands have climates dominated by air which originates over the Pacific but becomes mild and dry descending the east slope of the Cordillera. This approach was expanded by Bryson (1966) to cover the eastern two-thirds of North America. He showed that the major biotic regions of the area were well defined by the seasonal dominance of air of different origins. He also showed that the extent of the various airstreams was often sufficiently stable from month to month for the boundaries between airstreams to mark seasonal mean frontal positions. These zones where airstreams meet are called confluences.

The concept of airstreams is a rational extension of the original Bergeron air-mass concept. From a divergent center, such as the North Atlantic anticyclone, air spreads over much of the ocean (climatically speaking) in various directions. Though quite homogeneous at the source, the air is modified by the
time it reaches, say, North Africa. Here it is very stable, dry above a sharp trade inversion, and relatively cool and moist below. The air that moves down the trades to Florida, on the other hand, becomes warm, moist to considerable heights, and convectively unstable. That air which moves north and east from its surface origin in the high, provides the cool, humid air of Europe, with its more neutral stability. Thus a single airstream source may produce several different air masses, depending on the modification encountered between the airstream origin and the downstream region of interest. The airstream boundaries, or confluences, are then air mass boundaries, the particular air mass varying with the region of interest. Since each airstream’s terminal air mass has a defined set of characteristics, dependent on its origin and trajectory, the character of the climate rapidly changes across confluences but slowly varies within the airstream. It is not surprising that biotic assemblages adapt to these airstream constraints and exhibit marked changes at seasonally stable confluences (Bryson, 1966).

The objectives of this study are to present an objective airstream analysis for the Northern Hemisphere, show the characteristics of some air masses, and discuss how changes in locations of mean confluences influence changing weather patterns or climate.

2. Data and analysis

Streamline analyses were constructed from grid data of 3° latitude spacing over the Northern Hemisphere (Crutcher et al., 1966), prepared from data of 600 stations with at least 5 years record. Forty-eight percent of the stations included data of at least 10 years length. About 25% of the stations were from oceanic areas. The smooth continuous flow, indicated by the individual resultant winds, suggest there are no regions of serious anomalous data due to too few or erroneous observations.

Streamlines were hand-drawn as exactly parallel to the plotted monthly winds as possible. In areas of rather straight or gently curved flow, little flexibility of analysis existed. Similarly, most confluences were clear discontinuities between two converging currents. In a few instances, lines of confluence appear between two parallel streamlines, each emanating from different anticyclones, e.g., 40–50° N in the northwestern Pacific (Fig. 1). In these cases, the confluences are traceable upstream to zones where the discontinuity is clear, and the lines of confluence are merely continued downstream between appropriate streamlines. Areal and temporal continuity was used, particularly in those instances where lines of confluence appear between two parallel streamlines.

Although all months were analyzed, only the mean January, April, July and October streamline charts are presented here (Figs. 1–4). It is significant that differences between monthly streamline charts are largely relocations of the larger circulation features, e.g., anticyclonic gyres, cyclones and confluences, as opposed to dissimilar patterns. The subtropical anticyclones and mean confluences move northward in spring and southward in fall.

During the streamline analyses it was found that confluences were usually sharp and easily distinguishable, and were marked on each chart to delimit the outer boundary of airstreams. The divergent pattern of streamlines represents air mass source regions, and the confluences indicate mean boundaries (fronts) between air masses.

3. Results of the analysis

Study of Figs. 1–4 shows that some airstream source regions are present in both summer and winter, and indeed several source regions exist during all months of the year, i.e., the subtropical anticyclones over the Atlantic and Pacific Oceans. On the other hand, most anticyclones are found only during some seasons of the year, e.g., the airstream originating over Greenland and that originating over the Arctic Ocean. Seasonal presence is most prominent in continental airstreams.

4. Discussion of the airstream regions

Nineteen airstream regions were identified for the Northern Hemisphere throughout the year. Of these, five were found during all months of the year, an additional three exist for 11 (perhaps 12) months, and the remaining eleven from 1–9 months (see Table 1).

a. Annual airstream regions

Two of the annual (year-round) airstreams which occupy Northern Hemispheric area originate in the Southern Hemisphere, i.e., South Atlantic and South Pacific airstreams (see Figs. 5 and 6). Two additional Southern Hemisphere airstreams (South African and Australian) migrate into the Northern Hemisphere, but only during Northern summer. The combined areal coverage of Southern airstreams during Northern summer are shown in Fig. 7.

The changing coverage of Southern Hemisphere air in the Northern Hemisphere reflects the seasonal variation of the monsoon system. Maximum coverage is found in Northern Hemisphere summer, as the confluence between the “southern” and “northern” air migrates farthest to the north, particularly over Africa and the adjacent Atlantic and Southeast Asia.
Fig. 1. Streamline analysis of mean January resultant wind field. Dashed lines indicate airstream confluences.

The remaining three annual airstream sources of the Northern Hemisphere are the North Atlantic and North Pacific subtropical anticyclones (Figs. 8 and 9), and a source over Turkey. It is interesting to note that in those months when a specific source is found for this last airstream (as opposed to only a significant area of diffuseness), the trajectories are always clearly cyclonic near the origin. This may be an artifact arising from the topography, but in any case there is no serious doubt as to the general region of origin of the airstream. The streamlines appear to maintain their integrity downstream.

These airstreams occupy significantly large areas of the hemisphere, except for the Turkic airstream (see Table 1), and reach maximum extent in coverage during summer and fall.

b. Near-annual airstream regions

Three airstreams may also be annual, but can only be positively identified for eleven months. The central East Asian airstream (Fig. 9) is present all months except April in the mean. This is from a continental source, and reaches its greatest coverage in winter. At this point we must emphasize that month-to-month continuity is crucial in identifying the continental airstreams.

The only month when an Arctic airstream source
was not identified was December, whereas it reached its greatest extent in spring (Fig. 7). This is a source of continental polar (cP) and Arctic (A) air masses, modified somewhat in summer toward higher humidities as more open water is found about the periphery of the Arctic Ocean.

The central Asian (Fig. 5) airstream was found in all months except May, and reaches its greatest coverage in winter.

c. Airstreams present from six to nine months

Five airstreams, two oceanic and three continental, fall into this category. First is the airstream originating over Greenland (Fig. 6), well-known to the synoptic analyst. It is present during the winter half-year and reaches maximum extent in spring.

The "South African" airstream (Fig. 6) is present in the Northern Hemisphere eight months, being especially extensive in summer, to the south of the ITCZ. The true source of this system cannot be determined by this Northern Hemisphere analysis, but it is probably from the Atlantic and Indian Oceans (Thompson, 1965, pp. 83, 89, 95). The characteristics on arrival in the Northern Hemisphere are essentially dependent on its trajectory, either direct from the ocean or diverted over Africa.
The East Saharan airstream also is present eight months. During its fall through spring tenure, it influences much of North Africa, expanding as the ITCZ retreats to the south with the onset of the dry season in West Africa. During the summer it is replaced by an extended trans-Mediterranean flow of air from the Atlantic.

The Australian airstream (Fig. 5) has a significant overwater trajectory before reaching Southeast Asia, and is present in the Northern Hemisphere from spring to fall, with greatest extent in summer.

The Ohio Valley source is present from August–January, and reaches its maximum coverage in fall.

d. Airstreams present less than six months

The remainder of the airstreams are found six months of the year or less and occupy only extremely small percentages of the hemisphere (see Table 1). The Trans-Himalayan airstream (Fig. 8) is the first thus far discussed which is present less than six months. The airstream is found during the winter half-year, reaching maximum extent in late fall. The northern boundary of this airstream, as shown in the figure, is quite arbitrary, being the crest of the Himalayas. The surface streamlines from which the present analysis was derived are not very revealing
in the region of the south face of the mountains. South of the mountains at low levels, the airstream moves from the direction of the mountains, while over the high land north of the Himalayan crest the wind moves toward the mountains. Without specifying the nature of the subsidence, we assume that the flow from the mountains has different characteristics than the high-altitude air north of the mountains, and thus designate it simply as "Trans-Himalayan." It could be regarded as well as a modified extension of some of the central Asian airstreams.

The Taymyric airstream (Fig. 6) is only found four months of the year, those being in spring, summer and fall. Its extent is greatest in mid-summer. The discontinuous nature of this source is not clear, but may result from the paucity of data from that region. Only August streamlines (not shown) suggest a pronounced influence over that region.

The last four airstreams are of even less importance, existing only three months or less during the mean year. The Korean (Fig. 6) airstream is present in spring; Klondikan (Fig. 5) in winter; High Plains (Fig. 7) in early winter, and the Kamchatkan (Fig. 5) only in June.

5. Summary of all airstreams

Fig. 10 is a composite showing all airstream regions, and the area they occupy for six months
or more, for those of longer duration. Within the six-month area is a line encompassing the area occupied for the maximum number of months that each airstream exists (if greater than six). The areas of the six remaining airstream regions are delimited for their maximum tenure, all five months or less.

From this analysis we see that about one-quarter of the Northern Hemisphere experiences a climate dominated by a single airstream during the whole year. This includes areas occupied by North and South Atlantic and Pacific airstreams and the Turkic airstream. Within these rather barotropic areas, fronts and associated weather are obviously weak compared to the airstream boundaries. These are sectors with small day-to-day or season-to-season changes.

Largely "weak front" climates also exist in the heartland regions of the Arctic, central Asian and central East Asian source areas. Although existing a large part of the year, the areas of long coverage of these latter three airstreams are very small and may only add, at most, 2% to the area of the Northern Hemisphere to that composed of largely "weak front" climates.

Table 1 shows that about 80% of the Northern Hemisphere is covered by one particular airstream for at least six months. Interestingly, oceanic airstreams maintain relatively large areas of influence throughout the year, whereas continental airstream regions seasonally diminish in size, or totally disappear. The oceanic sources reach their maximum sizes in summer, and the continental sources expand during the other seasons of the year (fall, winter and spring).

6. Areas of maximum frontal activity

As one proceeds into the remainder of the Northern Hemisphere, into that area outside of the three major maritime airstream regions (North Atlantic, North Pacific and Southern Hemisphere Oceanic), frontal activity becomes more and more frequent with a variety of airstreams, and thus air masses, available. These areas include essentially the middle- and high-latitude continental regions, such as North America and Asia east of the Urals. The large number of small and relatively short-lived airstreams in this area is largely the result of topography (mountain and ice) and continent-ocean margins.

Fronts increase in frequency as one proceeds from the airstream source region centers. Reitan (1974) has shown that cyclones which originate over North America are most frequent within a triangle roughly bounded by Iceland, Southern Colorado and Southern Alberta. This area is subject to the incursions of at least seven airstreams which surround it. The analyses of Klein (1958) show cyclonic trajectories and frequency for the Northern Hemisphere. However, one should not expect the predominant cyclone tracks to follow the vector mean confluenes of the various airstreams. A simple diagram familiar to all meteorologists will illustrate this point (Fig. 11). As cyclones move and occlude, the most frequent confluence is found farther equatorward of the cyclone track. This is quite obvious in the Icelandic area where the major mean confluence is quite far south of the mean cyclone location and, of course, advanced occlusion is normal in the Icelandic area. These confluences shown on Fig. 1–4 represent mean frontal locations as opposed to cyclone trajectories.

Fig. 12 shows several areas where the outer boundaries of airstreams tend to be located. Summer and winter positions of the confluences are indicated. The confluences about the areas marked A and B represent the leading edges of continental airstreams emanating from Asia and in North America, respectively. Seasonal displacement is in excess of 2400 km for the former and 1100 km for the latter. These seasonal displacements indicate the effect of stronger westerlies in the winter half-year, with the strongest westerlies of all longitudes located off the East Asian coast.

Confluences marked C and D represent the seasonal extreme locations of the intertropical convergence zone. The north-south migration distance is ~1000 km for D and somewhat less for C. The north-south confluence in Mexico throughout virtually all the year is near-coincident with the Sierra Madre Oriental and is apparently restricted to this region due to topography and the size and persistence of the airstreams both east and west, i.e., the Atlantic and Pacific subtropical anticyclones. Similarly, the
north-south confluence in Northwestern South America is the result of the South Atlantic and South Pacific oceanic airstream meeting along the Andes.

7. Moisture contrast across mean confluences

The strength of the moisture discontinuity across four confluent areas was investigated using the 5-year mean (1960–64) surface mixing ratios on transects roughly perpendicular to four seasonally prominent confluences. The four transects are shown on Fig. 13. Mixing ratios were arbitrarily chosen for this study because of their conservative nature and because many of the confluences to be investigated represent the boundary between a continental and a maritime airstream. These four transects were chosen because they intersect confluences at least in January or July and in some instances both seasons, and because coastal boundaries and mountain ranges are also found along the transect. Fig. 13a shows the value of the surface mixing ratio from Bombay north to Salekhard in both January and July. In January this transect is totally within the airstreams emanating from the continental central Asian source, whereas in July the line of stations is influenced by two airstreams, i.e., Bombay to Peshawar being under the influence of the moist monsoon flow from the South Indian Ocean, and Tashkent to Salekhard being under the influence of the continental Taymyric source to the north. In both months the surface absolute humidity is essentially constant from Salekhard to Tashkent with increases in humidity further to the south. The moisture discontinuity from the north to the south of the Himalayas clearly
is greatest during the summer season when the area to the south of the mountains is under the influence of moist oceanic air from the southern Indian Ocean. The fact that the leading edge of south Indian air is roughly coincident with the Himalayas enhances the moisture discontinuity across the mountains.

The east-west transect from Wahnsdorf to Sverdlovsk (Fig. 13b) crosses no confluence in July, the whole transect lying in Atlantic air. The mixing ratios exhibit an almost linear decline away from the coast. In January, the boundary between Atlantic air and central Asian air is located at about 40°E longitude at the latitude of the transect, and yet shows no strong discontinuity at/near the boundary. We attribute this to be due to the changing eastward penetration of Atlantic air from time to time, reflecting changes in the strength of the westerlies.

In Fig. 13c we see the moisture gradient for a transect that again runs south to north from Singapore to Fukuoka, Japan. In January, all stations are under the influence of the central East Asian airstream, whereas in July the southern two stations (Singapore and Saigon) are influenced by a maritime airstream from the Southern Hemisphere Pacific, and the northernmost three stations are covered by another maritime airstream from the low-latitude North Pacific Ocean. Although the January transect is under the influence of only one airstream, the moisture values on that transect exhibit a stronger gradient than those along the summer transect, a season when the northernmost three stations are affected by one maritime airstream and the southern two stations are influenced by another. The January near-linear gradient exhibits the moisture modification...
of a continental air mass as it flows on an overwater trajectory toward warmer temperatures (Fukuoka to Singapore). Note that the mixing ratio increases from $\sim 4 \text{ g kg}^{-1}$ in Japan to $\sim 18 \text{ g kg}^{-1}$ over Singapore, a distance of about 30° latitude. The essentially constant mixing ratios along the transect in July suggest that the two maritime airstreams (Austral and Pacific) flow over very similar surfaces at that time of the year.

The fourth transect, shown on Fig. 13d, runs from Matrûh, near the Mediterranean coast, southward to Kinshasa, Zaire. This transect intersects a confluence between maritime air to the south and continental air to the north in both January and July. In January, the six northernmost stations are under the influence of very dry continental East Saharan air, whereas in July the northernmost three stations are under the influence of a continental Turkic airstream. The moisture discontinuity in January is rather strong, increasing from $\sim 7 \text{ g kg}^{-1}$ north of the confluence to $\sim 17 \text{ g kg}^{-1}$ to the south. In July, however, the moisture gradient is much reduced, being between $\sim 14$ and $18 \text{ g kg}^{-1}$ at all stations except Aswan. The low mixing ratio in July at Aswan is considerably below the longer term mean, however, even the latter is $\sim 5 \text{ g kg}^{-1}$ less than the mixing ratio at the more northerly stations (Helwan and Khartoum). The reason for Aswan’s lower July mixing ratio is probably due to more frequent intrusions of maritime air at the stations closer to the sea: Mersa Matrûh and Helwan.

The above transects illustrate the moisture gradients across 5-year mean positions of several confluences in the Northern Hemisphere. The strongest

**Fig. 7.** Area occupied by Arctic, High Plains and Southern Hemispheric sources. Length of residence time given in months per year.
moisture gradients between adjacent stations tend to occur when those stations are separated by a confluence.

Another continental transect—Coppermine, NWT, to Shreveport, Louisiana (not shown)—was analyzed for January, April, July and October. Although several confluences were intersected by this transect, the mixing ratio gradient was essentially linear from one end of the transect to the other, suggesting that moisture discontinuities across 5-year mean confluences may be noticeable, but are considerably enhanced when the confluence is between relatively steady (high vector stability) airstreams. Relatively stationary confluences, e.g., intertropical convergence zone, tend to exhibit sharper mean moisture gradients across the confluence than the more migratory confluences located at higher latitudes. In middle and higher latitudes, the day-to-day variation in the location of the migrating confluences tends to “smooth out” temperature and moisture gradients which may be quite apparent on any given day. Only in those instances when the position of the confluence is stabilized by coastlines and mountains, or when confluences are nearly stationary for other reasons, are the mean moisture gradients sharp across the confluence.

8. Airstream analysis and climate and climatic variation assessment

The foregoing analyses illustrate a quantitative, genetic method for classifying climates of the hemisphere, and provide one model for discussing climatic character and climatic variations, assuming a
persistence of airstream source regions and temperature and humidity characteristics over the time interval being discussed.

The complex of airstreams which influence a given location designate the temperature and humidity conditions observed at that location during the time interval in question. When mT air covers the Midwest more than expected (the mean), the weather assemblage (i.e., the climate) is warmer and more humid than average.

Following are two examples of a climatic interpretation based on the airstream analysis. For simplicity, the monthly mean dew point, a conservative property, is discussed. Mean monthly dew-point temperatures are presented in Table 2 for two stations in India dominated by dry continental air during part of the year and moist oceanic air during the remainder, and for a Sahelian site affected by three different airstreams to show the mean march of airstreams through a year. The two Indian sites (Admadabad and Delhi) experience the same sequence of airstreams during the year, the only difference being that the northernmost station (Delhi) realizes the onset of the wet season about one month later. Note the substantial change in dew points when one airstream yields to another. However, also note that the dew points increase in spring prior to the onset of the oceanic airstream as the continental air follows an increasingly more overwater trajectory prior to arrival of the monsoon season.

The Tamanrasset airstream analysis is more complex, since the site is affected by three airstreams, i.e., North Atlantic (albeit via continental trajectory), east Saharan and South Atlantic air. During five months (January, April, May, July and August), a confluence is located near Tamanrasset with the re-
sult that two airstreams determine the humidity climate. The asterisks indicate the dominant airstream. During months when the mean dew-point temperature is greater than about 5°C, Tamanrasset is at least partly influenced by either North or South Atlantic air. This situation occurs during the warm season, May–September. From October through April, the mean dew points are less than about 5°C, and Tamanrasset is influenced, at least in part, by east Saharan air. In January, the confluence is located virtually over Tamanrasset, with equal influence from North Atlantic and east Saharan air.

Interannual climatic variation at one given location may be assessed by noting the changing year-to-year positions of mean confluences relative to the site, or by analyzing the changes in the months of duration of the various airstreams affecting the site.

On a longer time scale, Webb and Bryson (1972), after developing a transfer function using canonical variates to relate air mass frequencies and pollen “rain” during the modern climatic episode, reconstructed air mass durations for several upper Midwestern sites from pollen profiles which extended through the Holocene. These data indicate that the

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**Fig. 10.** Source regions of all Northern Hemisphere sources, showing areas of influence for selected residence times (months per year).

**Fig. 11.** Sketch of occluding wave pattern in time and space showing that the mean confluence position lies progressively farther south of the mean cyclone track as the cyclone occludes.
warm, dry Atlantic episode (from about 8000–5000 years BP) resulted from much more frequent incursions of Pacific air at the expense of both continental polar and maritime tropical air.

Colder than mean months are often associated with fronts located south of the average in the Northern Hemisphere. Over the longer term, one may expect mean fronts to be similarly displaced from the mean during warmer (cooler) episodes than the mean, thus changing the frequency and duration with which each of the air masses contributes to the climate of the given location (see Fig. 9 in Bryson, 1966).

9. Conclusions

Mean surface streamline charts of the Northern Hemisphere from 1948 through 1963 have been analyzed to delimit regions dominated by airstreams within which air masses develop. Most of these airstreams are persistent for only a season or two, with only some, mostly maritime, persisting through all months of the year. The importance of these airstream regions lies in the recognition that air from a given source will carry the temperature, moisture, turbidity, etc., signature of that area, and hence a climatic flavor, downstream. However, a single airstream source may produce more than one air mass, since the size of the region may cover such an areal extent that various portions of the airstream may pass over dissimilar surfaces downstream from the source.

Nineteen airstream sources were recognized over the Northern Hemisphere. Not all of these are present during all months. Eight of the 19 are present 11 months or more per year, and overshadow the time and area of influence of the remaining eleven sources. Four sources dominate the Northern Hemi-
Fig. 13. Mixing-ratio profiles along four transects to illustrate steepened gradients at mean airstream confluences and coasts.

sphere in terms of area of influence for the year as a whole, i.e., they cover a large portion of the hemisphere during the year. Airstreams from the North Atlantic and North Pacific anticyclones and from the Southern Hemisphere occupy at least 25% of the Northern Hemisphere for the entire year. For six months per year, these sources cover ~58% of the hemisphere. For at least one month of the average
Table 2. Monthly mean dew-point temperatures (°C) for select sites in Africa and India. Asterisk indicates dominant airstream.

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year ~44% of the hemisphere is covered by air from the North Pacific anticyclone, 26% is affected by the North Atlantic anticyclone and 48% is dominated by air originating in the Southern Hemisphere. Southern Hemisphere air reaches its maximum extent in the Northern summer with the advancing monsoon. The oceanic anticyclonic airstreams move northward in summer, and these airstreams increase in areal coverage, thus enveloping areas to the north and sometimes to the south of the annual mean oceanic anticyclone airstream region.

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