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Thermal migration and climatic de-territorialisation of North American professional sports leagues, 1950-2025

Dimitri Defrance

CosmosClimae, Montpellier, France

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DATA AND CODE AVAILABILITY

The franchise database, processed climatic indicators, city-coordinate table, relocation vectors, derived analysis datasets, and Python scripts will be made openly available through Zenodo upon publication. ERA5-Land data are publicly available from the Copernicus Climate Data Store.

Graphical Abstract

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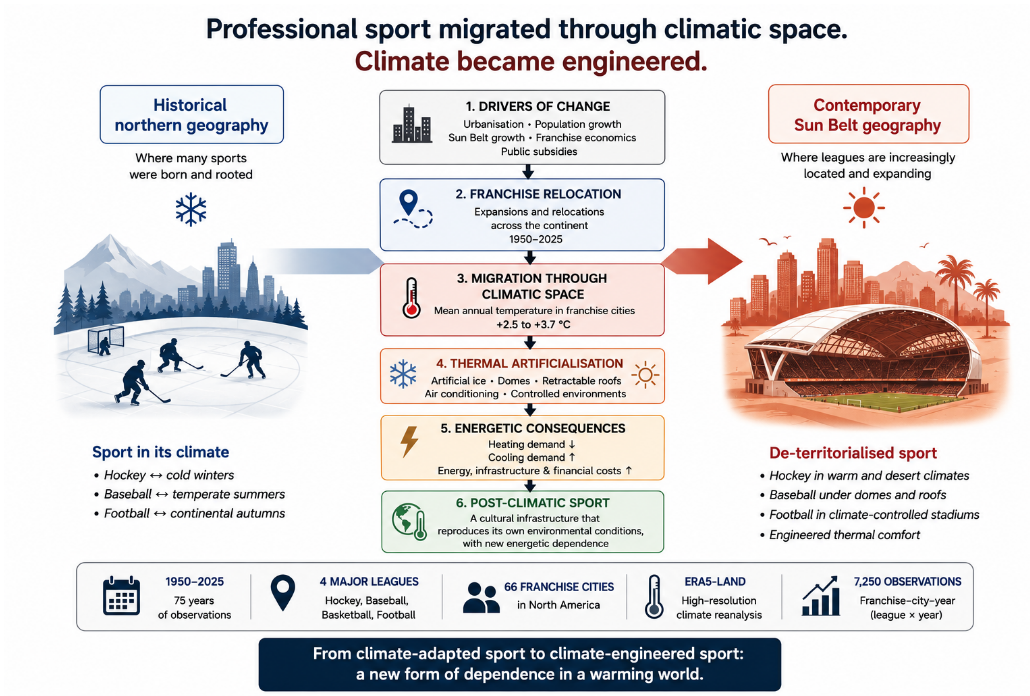

Highlights

Thermal migration and climatic de-territorialisation of North American professional sports leagues, 1950–2025

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- Major North American sports leagues migrated towards warmer cities since 1950.
- Changing league geography explains 63–73% of total thermal drift.
- Sixty-three percent of franchise relocations moved towards warmer cities.
- NHL relocations show climatic de-territorialisation can be non-monotonic.
- Professional sport transforms climatic dependence rather than eliminating it.

Thermal migration and climatic de-territorialisation of North American professional sports leagues, 1950–2025

Dimitri Defrance

CosmosClimae, Montpellier, 34000, France

Abstract

Over the past seven decades, the four major North American professional sports leagues (NHL, MLB, NBA, NFL) have expanded and relocated across the continent, shifting their collective geography towards the Sun Belt. We quantify the climatic consequences of this movement by combining the complete franchise location history of the four leagues from 1950 to 2025 with ERA5-Land reanalysis data and the Köppen–Geiger classification. We construct a franchise–city–year panel, derive thermal and degree-day indicators, and introduce a normalised Climate Departure Index (CDI). Mean annual temperature across franchise cities increased by 2.5–3.7 °C between 1951–1970 and 2006–2025. A formal decomposition attributes 63–73% of this thermal drift to the changing geographical composition of the leagues, with the remainder arising from in situ warming of their initial franchise geography. Treating each of 59 franchise relocations as a vector in climatic space shows that 63% moved towards warmer cities, generally reducing heating-degree demand while increasing cooling-degree demand. The National Hockey League follows a distinctive trajectory: its weak mean relocation vector masks extreme movements towards both warmer and colder cities, demonstrating that climatic de-territorialisation can be non-monotonic. The NHL also exhibits the largest departure from its league-specific historical thermal reference. We interpret these results as evidence of climatic de-territorialisation: a measurable weakening of the historical association between professional sport and the climatic environments in which it developed.

Keywords: Sports geography, Climatic de-territorialisation, Franchise relocation, Sun Belt, Thermal artificialisation, Climate–energy nexus, ERA5-Land

1. Introduction

1.1. *Sport as a territorial and climatic production*

Sport is, before it is anything else, a spatial phenomenon. The places where sports are played identify the teams that play them, structure the loyalties of those who watch, and inscribe athletic practice within particular landscapes and climates (Bale, 2003). Over more than half a century, sports geography has established that sport is not indifferent to its physical environment. Sporting practices emerge, diffuse, and consolidate within particular environmental settings, while their spatial organisation both shapes and is shaped by the territories that host them (Andrews, 2016; Higham and Vada, 2025). Ice hockey developed within the frozen winters of Canada and northern North America; baseball took form in the temperate summers of the industrial Northeast; gridiron football became associated, in its collective imagination, with the continental autumn. Each of the major North American leagues therefore carries an implicit climatic signature, understood here as a set of environmental conditions historically associated with the development and identity of its sport.

Yet the contemporary geography of these leagues stands in growing tension with that historical signature. Professional ice hockey is now played in the Mojave Desert; baseball and football are increasingly staged beneath climate-controlled domes and retractable roofs; and artificial ice is manufactured and maintained in cities where outdoor freezing rarely or never occurs (Kidd, 2013; Romanowich, 2012; Sutherland, 2015). Sports that were once closely associated with particular climatic settings can now be staged far beyond them. This tension between the historical climatic geography of a sport and the contemporary geography of its professional organisation is the point of departure for this paper.

1.2. *League expansion and the urbanisation of the Sun Belt*

The spatial reconfiguration of North American professional sport did not occur in a vacuum. From the 1950s onward, the demographic and economic centre of gravity of the United States shifted southward and westward, towards the rapidly growing metropolitan areas that came to be known collectively as the Sun Belt. Professional franchises, as instruments of urban prestige and economic-development policy, followed this shift and at times anticipated it (Baade, 1996; Coates and Humphreys, 2003b,a). The post-war decades therefore saw successive waves of league expansion and franchise relocation into cities with limited prior traditions in the sport concerned, from suburban stadium developments on the metropolitan fringe (Ingrassia, 2024) to the cultivation of fan bases in non-traditional markets (Mastromartino et al., 2020). In some cases, climatic contrast itself entered the rhetoric of metropolitan competition. The choice between, in the words of one account, "a big-league Minneapolis or a cold Omaha" framed professional sport as a marker of urban arrival (Tochterman, 2024).

This movement has been examined primarily through economic, managerial, and political lenses, including the contested economic returns of hosting a franchise (Coates and Humphreys, 2003b; Bradbury et al., 2023), the public subsidisation of stadiums and arenas (Kellison and Mondello, 2014; Kellison et al., 2017), the resilience of franchises to major shocks (Baade and Matheson, 2007), and the territorialisation and de-territorialisation of sporting markets (Fujak and Joachim, 2022; Fujak et al., 2022; Mason and Moncrieff, 1993). A parallel strand in sports geography has interpreted franchise location as a producer of place identity and civic meaning (DeChano and Shelley, 2004; Wise and Kirby, 2020; Lee and Choi, 2024). Taken together, this literature explains why and how franchises move. They respond to markets, population growth, infrastructure, and public policy. What it has not examined is the climatic consequence of that movement.

1.3. A scientific gap: the climatic dimension of franchise movement

What remains almost entirely unexamined is the *climatic* dimension of this movement. If professional leagues have expanded and relocated across the continent over seven decades, then the aggregate climate of their host cities must have changed in step. Yet neither the direction nor the magnitude of this change has been systematically quantified. We do not know whether the major leagues have, on average, shifted towards warmer cities; whether the thermal context of their host locations has moved from heating-dominated towards cooling-dominated conditions; or whether the climatic classes historically associated with each sport have become less representative of its contemporary geography. Nor has the effect of changing franchise geography been separated from the concurrent warming of incumbent host cities.

This gap lies between two converging bodies of research. Sport-ecology and environmental-sustainability studies have documented the growing environmental footprint of professional sport, including its increasing reliance on engineered thermal environments such as refrigerated ice sheets, air-conditioned arenas, and domed or retractable-roof stadiums (McCullough et al., 2016, 2020). A parallel literature on sport and climate change has conceptualised the climate vulnerability of sport organisations, examining the exposure of athletes, spectators, venues, and operations to climatic hazards and the adaptations these exposures require (Orr and Inoue, 2019; Higham and Hinch, 2018). At global scale, multi-hazard projections indicate that heat, humidity, heavy rainfall, and heatwaves are jointly contracting the climatic windows available for outdoor sport (Defrance and Lescure, 2026). Climate vulnerability has also been linked to early stadium replacement (Kellison and Orr, 2021), while stadiums have been reconceived as quasi-public thermal refuges within climate-changed cities (Kellison et al., 2023).

These two literatures respectively describe the environmental cost of engineering sporting conditions and the vulnerability produced by changing climatic conditions. What is missing is the geographical link between them, in the form of a systematic account of whether professional sport has itself moved across the climatic field, how large that movement has been, and how it interacts with the warming occurring beneath established franchise cities. This paper provides that quantification.

1.4. Objectives and hypotheses

We construct a purpose-built dataset pairing the complete expansion and relocation history of the four major North American professional leagues (NHL, MLB, NBA, and NFL) from 1950 to 2025 with ERA5-Land reanalysis data and the Köppen–Geiger climate classification (Beck et al., 2023). This franchise–city–year panel is used to quantify the geographical and climatic drift of professional sport over seven decades. We derive mean annual temperature, heating and cooling degree days, hot and frost days, and introduce a normalised *Climate Departure Index* (CDI), which measures the standardised thermal distance between each franchise-city and the historical thermal reference of its league.

We test three hypotheses:

H1 (*thermal migration*) Since 1950, league expansion and franchise relocation have shifted the geography of North American professional sport towards warmer cities, producing a measurable upward drift in the mean annual temperature of franchise locations.

H2 (*thermal-energy transition*) This geographical shift has altered the degree-day profile of franchise cities, reducing heating-related demand while increasing cooling-related demand.

H3 (*climatic departure*) The National Hockey League, whose historical geography was the most climatically specific, exhibits the greatest standardised departure from its league-specific thermal reference.

Beyond these empirical tests, the paper develops the concept of *climatic de-territorialisation* to describe the progressive weakening of the historical association between a sport and the climatic environments in which it developed. Whereas de-territorialisation has previously been framed primarily in economic, cultural, or identity terms (Wise and Kirby, 2020; Poli, 2007; Fujak and Joachim, 2022), we give it a measurable physical dimension by considering the distance travelled by a sporting system through climatic space.

2. Theoretical framework

2.1. The geography of sport

The premise that sport is a territorial production is foundational to sports geography (Bale, 2003). Teams are named for places, leagues form spatial networks, and athletic identity is often expressed through territory. This spatiality is not merely symbolic. It structures fan attachment, the meaning of the home venue, and the civic narratives that cities build around their teams (DeChano and Shelley, 2004; Robinson, 2010). Recent syntheses have underlined both the continuing vitality and the persistent under-development of sports geography as a field, while calling for greater attention to the material and environmental dimensions of sporting space (Andrews, 2016; Higham and Vada, 2025). Our contribution responds directly to this call by treating the climate of the host city not as a background condition, but as a measurable attribute of the sporting territory itself.

2.2. Sport, urbanisation, and the franchise as urban instrument

If sport is territorial, the professional franchise is also an urban instrument. The economic-geography literature has long debated whether franchises generate net local economic benefits. Several decades of research suggest that their direct economic returns are often small or negligible, even as cities continue to compete for teams and subsidise their venues (Baade, 1996;

Coates and Humphreys, 2003b,a; Bradbury et al., 2023). This apparent paradox, in which public investment persists despite limited measurable returns, has been explained through the symbolic and political value of major-league status. A franchise signals that a city has arrived (Tochterman, 2024; Kellison and Mondello, 2014).

This logic encourages franchises to move towards large and growing metropolitan markets. It is therefore market growth, demographic change, infrastructure, and public policy, rather than climatic preference, that carried the leagues into the Sun Belt. Franchise expansion and relocation are primarily movements towards people and capital. Their climatic consequences are unintended, but they are measurable and, as this paper argues, consequential.

2.3. Sport, environment, and thermal artificialisation

As professional sport has moved into climates increasingly distant from its historical environmental settings, it has become more dependent on the engineered production of suitable playing and spectator conditions. The manufacture and maintenance of ice in warm climates, the air-conditioning of arenas, and the roofing and cooling of stadiums constitute the material infrastructure of this dependence. A substantial engineering literature documents the thermal challenges associated with these environments, including the indoor climate of domed stadiums (Nishioka et al., 2000), spectator comfort in air-conditioned open stadiums in hot climates (Ghani et al., 2021; Losi et al., 2021), condensation in indoor ice arenas (Marquardt and Mainka, 2008), and retractable-roof solutions developed for extreme climatic conditions (Goeppert and Paech, 2020; Romanowich, 2012).

The associated energy requirements can be substantial. A single ice rink may consume around 1.5 GWh per year (Sutherland, 2015), while stadium operations may generate a significant greenhouse-gas footprint (Hedayati et al., 2014). These pressures have contributed to growing interest in "zero-energy" venue concepts (Manni et al., 2018). Outdoor air-conditioning at the 2022 FIFA World Cup in Qatar provides an extreme example of thermal artificialisation, within a broader regional context in which thermal comfort is engineered rather than inherited (Sofotasiou et al., 2015; Winter, 2016). This literature documents the energetic implications of sustaining sport outside its historical climatic setting. Our contribution is complementary: we quantify the climatic displacement associated with the growing need for such engineered environments.

2.4. *Climatic de-territorialisation: a concept*

We bring these strands together through the concept of *climatic de-territorialisation*. De-territorialisation has a substantial lineage in cultural and human geography, from Augé's non-places (Merriman, 2004) to analyses of sporting identity and spectatorship (Hills and Kennedy, 2006; Poli, 2007; Penny and Redhead, 2009). In sport, the term has been used to describe the weakening of the relationship between a team and its place of origin, including the "home away from home" of a franchise playing abroad (Wise and Kirby, 2020), and the abstraction of sporting markets from their territorial base (Fujak and Joachim, 2022).

We give the concept a distinct physical dimension. Climatic de-territorialisation denotes the progressive weakening of the historical relationship between a sport and the climatic environments in which it developed. It does not necessarily imply the abandonment of place. Rather, it describes the increasing capacity of a sporting system to operate in climatic settings that differ from those associated with its historical geography.

In this study, climatic de-territorialisation is operationalised through measurable indicators of thermal displacement. These indicators describe the distance, in temperature, degree-day conditions, and Köppen classes, between a league's historical climatic reference and the environments occupied by its contemporary franchises. The remainder of the paper develops this framework and evaluates it empirically.

3. Data and methods

3.1. *Franchise database*

We assembled the geographic history of the four major North American professional sports leagues, namely the National Hockey League (NHL), Major League Baseball (MLB), the National Basketball Association (NBA), and the National Football League (NFL), from 1950 to 2025. Franchise histories, including founding dates, relocations, and host cities, were compiled from the Sports Reference databases (https://www.hockey-reference.com, https://www.baseball-reference.com, https://www.basketball-reference.com, and https://www.pro-football-reference.com; accessed 2026).

Each franchise was represented as a sequence of *stints*, defined as continuous periods during which it operated in a given host city. A relocation opened a new stint. A franchise that moved several times, such as the Oakland–Los Angeles–Oakland–Las Vegas trajectory of the NFL Raiders, therefore contributed multiple stint records. Expansion franchises entered the database in their first season in the league. Franchises that dissolved without continuation were excluded, as were pre-1950 entries and teams from minor or rival leagues. Teams absorbed into one of the four contemporary leagues through a formal merger entered the panel in the year of their integration.

Each stint was characterised by its league, franchise, host city, first and last active year, and representative city-centre coordinates. A single reference point located at the approximate geographical centre of each city was used throughout the analysis. Venue changes within the same city were therefore not treated as franchise relocations. No materially ambiguous cases of franchise continuity affected the construction of the database. The final database contains 66 unique franchise cities.

The franchise-stint table, city-coordinate table, annual franchise panel, and analysis code will be made publicly available in the associated research repository.

3.2. Climate data

For each of the 66 franchise cities, we extracted hourly 2-m air temperature from the ERA5-Land reanalysis for 1950–2025 (Muñoz Sabater et al., 2021). ERA5-Land provides land-surface climate variables at a horizontal resolution of 0.1°, corresponding to approximately 9 km at the equator. Temperature was sampled from the grid cell nearest to the representative city-centre coordinate.

A common grid point was used for all franchises and venues located within the same city. This is consistent with the purpose of the study, which is to characterise the climatic geography of franchise cities rather than the microclimate of individual stadiums or arenas.

Hourly temperatures were aggregated into daily minimum, maximum, and mean temperature, from which annual climatic indicators were calculated. The analysis begins in 1950 to correspond with the franchise database and to capture the post-war spatial expansion of the four leagues. The ERA5-Land record before 1979 is based on the ERA5 back extension and is less strongly constrained by observations than the satellite-era record. This limitation is considered in the interpretation of early-period absolute values, while the principal analyses rely on multi-decadal means and persistent climatic contrasts among cities.

3.3. Thermal and degree-day indicators

For each city c and year t, we calculated mean annual temperature (TAVG), the annual number of hot days, defined as days with maximum temperature above 30 °C, and the annual number of frost days, defined as days with minimum temperature below 0 °C.

Heating degree days (HDD) and cooling degree days (CDD) were calculated from daily mean temperature using a common base temperature of 18 °C, following established practice for temperate mid-latitude applications (Lee et al., 2014). For daily mean temperature $T_{c,d}$, the annual indicators were defined as

$$\mathrm{HDD}_{c,t} = \sum_{d \in t} \max\left(0, 18 - T_{c,d}\right), \tag{1}$$

and

$$\mathrm{CDD}_{c,t} = \sum_{d \in t} \max\left(0, T_{c,d} - 18\right). \tag{2}$$

This formulation follows the standard climate-energy literature (Atalla et al., 2018; Petri and Caldeira, 2015). HDD and CDD are interpreted as standardised climatic proxies for the direction and relative magnitude of heating- and cooling-related demand. They do not represent observed venue energy consumption, which also depends on building design, occupancy, operating schedules, roof configuration, refrigeration technology, and energy management.

The indicators have different relevance across leagues. HDD and CDD are particularly informative for the indoor NHL and NBA, for which the host-city climate influences heating, cooling, and refrigeration requirements. Hot and frost days are more directly relevant to the outdoor or partly outdoor NFL and MLB, where they characterise the thermal environment surrounding athletes, spectators, and venues. TAVG provides a common climatic measure across all four leagues.

For each city, we also calculated annual temperature anomalies relative to its own 1951–1970 mean. These city-specific anomalies describe temporal warming independently of persistent thermal differences among cities.

3.4. Köppen–Geiger classification

To characterise changes in climatic class beneath the franchise geography, we extracted the Köppen–Geiger class of each city from the high-resolution classification developed by Beck et al. (2018) and Beck et al. (2023). Classes were obtained for the 1961–1990 and 1991–2020 climate-normal periods.

The set of cities was held fixed in this comparison. Specifically, cities hosting an active franchise in 2025 were classified under both climate-normal periods. Differences between the two periods therefore represent changes in the climate classification of the cities themselves rather than changes in league composition. Particular attention was given to transitions across the cold-to-temperate D/C boundary, whose northward displacement across central and eastern North America has been independently documented (Suckling and Mitchell, 2000; Rohli et al., 2015; Hanberry and Fraser, 2019).

3.5. Climate Departure Index

To quantify league-specific thermal departure, we defined a historical thermal reference for each league ℓ. The reference temperature $T_{\mathrm{ref},\ell}$ was calculated as the mean annual temperature of all active franchise-city-year observations belonging to the league during the 1951–1970 period. The corresponding standard deviation σ_ℓ was calculated across the same baseline observations.

For a franchise located in city c during year t, the Climate Departure Index was defined as

$$\mathrm{CDI}_{c,t} = \frac{T_{c,t} - T_{\mathrm{ref},\ell}}{\sigma_\ell}, \tag{3}$$

where $T_{c,t}$ is the mean annual temperature of the host city and ℓ denotes the league. Each active franchise contributes one observation to the baseline distribution. A city hosting more than one franchise within the same league would consequently contribute once for each active franchise.

The CDI expresses thermal departure in units of the league's own historical variability. A value close to zero identifies a franchise-city with a climate typical of the league's 1951–1970 geography, while a large positive value identifies a substantially warmer location. The CDI measures departure from a historical league-specific thermal distribution. It is not an indicator of operational suitability, climatic safety, athlete exposure, or venue performance.

3.6. Geographical analysis

Joining the franchise stints to the annual climatic indicators produced a panel at the franchise × city × year level containing 7 250 observations in total, comprising 2 034 NFL, 1 934 MLB, 1 720 NBA, and 1 562 NHL observations. Each active franchise contributes one observation per year and receives equal weight within its league.

For each league and year, we calculated the geographical centroid as the unweighted arithmetic mean of the latitude and longitude of all active franchises. The centroid therefore describes the centre of gravity of the franchise distribution without weighting franchises by market population, attendance, venue capacity, or economic value.

The median latitude and longitude of active franchise cities were also calculated for each league-year. These robust measures were used to determine whether centroid displacement reflected a systematic geographical shift in the franchise distribution rather than the influence of a small number of distant locations.

The total displacement of each league centroid between 1950 and 2025 was calculated using the haversine formula. Initial bearings were calculated from the 1950 centroid to the 2025 centroid and expressed as compass directions. To examine the climatic significance of the latitudinal shift, we additionally estimated the relationship between league-year median latitude and league-year mean TAVG using linear regression.

3.7. Temporal trends and thermal-drift decomposition

For each league and year, we calculated the arithmetic mean of each climatic indicator across all active franchises. Temporal trends over 1950–2025 were estimated using ordinary least squares. Their statistical significance was evaluated using the non-parametric Mann–Kendall test, and trend magnitudes were estimated using Sen's slope. Values approaching numerical zero are reported as $p < 0.001$ rather than $p = 0$.

Long-term changes were evaluated by comparing two 20-year periods, 1951–1970 (P1) and 2006–2025 (P2). The observed thermal drift of each league was decomposed into an in situ warming component and a geographical-composition component:

$$\Delta T_{\text{total},\ell} = \Delta T_{\text{in situ},\ell} + \Delta T_{\text{composition},\ell}. \tag{4}$$

The decomposition uses a single and consistent weighting scheme based on the franchise geography of P1. For each league, city c was assigned a baseline weight $w_{c,\ell}$ equal to the number of franchise-city-year observations accumulated by that city during 1951–1970. A city that hosted a franchise throughout the entire period therefore received more weight than a city that hosted a franchise for only part of it. If a city hosted more than one active franchise within a league, each franchise-year contributed separately to its weight.

The baseline league temperature was calculated as

$$T_{\mathrm{P1},\ell} = \frac{\sum_c w_{c,\ell}\,\overline{T}_{c,\mathrm{P1}}}{\sum_c w_{c,\ell}}, \tag{5}$$

where $\overline{T}_{c,\mathrm{P1}}$ is the mean TAVG of city c during 1951–1970. A fixed-geography counterfactual for P2 was then calculated using the same city weights:

$$T_{\mathrm{P2,cf},\ell} = \frac{\sum_c w_{c,\ell}\,\overline{T}_{c,\mathrm{P2}}}{\sum_c w_{c,\ell}}, \tag{6}$$

where $\overline{T}_{c,\mathrm{P2}}$ is the 2006–2025 mean temperature of the same city. Temperatures for P1 cities were obtained from the complete city climatology rather than from the recent franchise panel. Consequently, a city that no longer hosted an active franchise during P2 remained in the counterfactual calculation.

The observed P2 temperature was calculated as the mean TAVG of all active franchise-city-year observations during 2006–2025:

$$T_{\mathrm{P2,obs},\ell} = \frac{1}{N_{\mathrm{P2},\ell}} \sum_{i=1}^{N_{\mathrm{P2},\ell}} T_i. \tag{7}$$

The in situ warming component was defined as

$$\Delta T_{\mathrm{in\ situ},\ell} = T_{\mathrm{P2,cf},\ell} - T_{\mathrm{P1},\ell}, \tag{8}$$

while the composition component was defined as

$$\Delta T_{\mathrm{composition},\ell} = T_{\mathrm{P2,obs},\ell} - T_{\mathrm{P2,cf},\ell}. \tag{9}$$

The total observed drift was therefore

$$\Delta T_{\mathrm{total},\ell} = T_{\mathrm{P2,obs},\ell} - T_{\mathrm{P1},\ell}. \tag{10}$$

The contribution of changing league geography was expressed as a percentage of the total drift:

$$S_{\text{composition},\ell} = 100 \times \frac{\Delta T_{\text{composition},\ell}}{\Delta T_{\text{total},\ell}}. \tag{11}$$

This decomposition asks how much warming each league would have experienced if its 1951–1970 franchise geography had remained unchanged, and how much additional thermal change arose from expansion and relocation into a different set of cities.

As a complementary analysis, franchises were classified as *founding* if they were active during the 1951–1970 baseline and as *expansion* if they entered the league after 1970. Their host-city temperatures were compared within the same recent period, 2006–2025, so that both cohorts were evaluated under the same background climate. This comparison identifies the thermal difference associated with the geographical placement of later franchises rather than temporal warming alone.

3.8. Relocation vectors in climatic space

Individual franchise relocations were analysed separately from league expansion. For each franchise, its city stints were ordered chronologically, and each transition between two consecutive host cities was treated as one relocation. Expansion franchises were not included in this analysis because they had no preceding host city.

Every origin and destination city was evaluated using the same fixed 1991–2020 climatology. This procedure isolates the climatic difference between the two locations from the background warming occurring between the dates of the relocation. For each move, we calculated the great-circle distance between origin and destination using the haversine formula, the changes in latitude and longitude, and the differences in TAVG, HDD, CDD, hot days, and frost days. We also recorded the Köppen–Geiger classes at origin and destination and identified whether the move crossed a climatic-class or climatic-group boundary.

A negative change in latitude denotes a southward move, a positive change in TAVG denotes relocation to a warmer city, a negative change in HDD denotes reduced heating-related demand, and a positive change in CDD denotes increased cooling-related demand. League-level relocation summaries were calculated as the arithmetic mean of the individual vectors, together with the proportions of moves towards warmer cities, southward locations, and different Köppen–Geiger classes.

4. Results

4.1. Spatial migration of the leagues

The geographic footprint of the four leagues expanded markedly between 1950 and 2025 (Figures 1 and 2). In 1950, major-league franchises were concentrated in the north-eastern quarter of the continent, particularly in the industrial cities of the Northeast and Midwest. By 2025, their geography extended across the Sun Belt and the West Coast, with a dense presence in Florida, Texas, the Southwest, and California, regions that were largely unrepresented at mid-century.

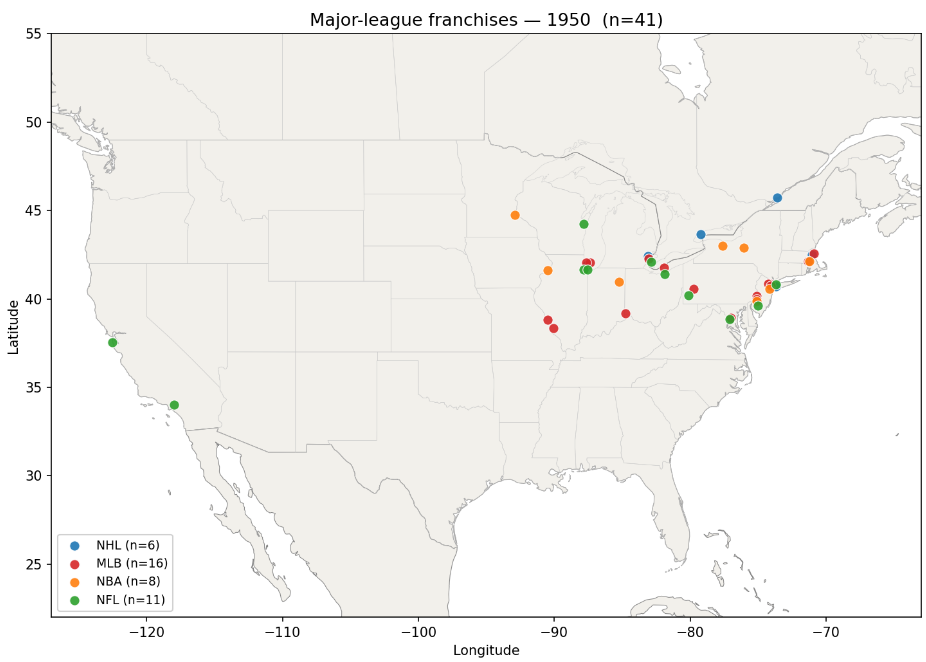

Figure 1: Major-league franchises active in 1950, coloured by league.

This expansion had a clear spatial direction. The centroid of each league's active franchises moved westward between 1950 and 2025, with an additional southward component that varied among leagues (Figure 3). Centroid displacement ranged from 351 km for the NFL and 519 km for the NBA to 1 122 km for the MLB and 1 203 km for the NHL. The NHL and MLB shifts were predominantly westward, whereas the NBA and NFL followed more pronounced south-south-westward trajectories.

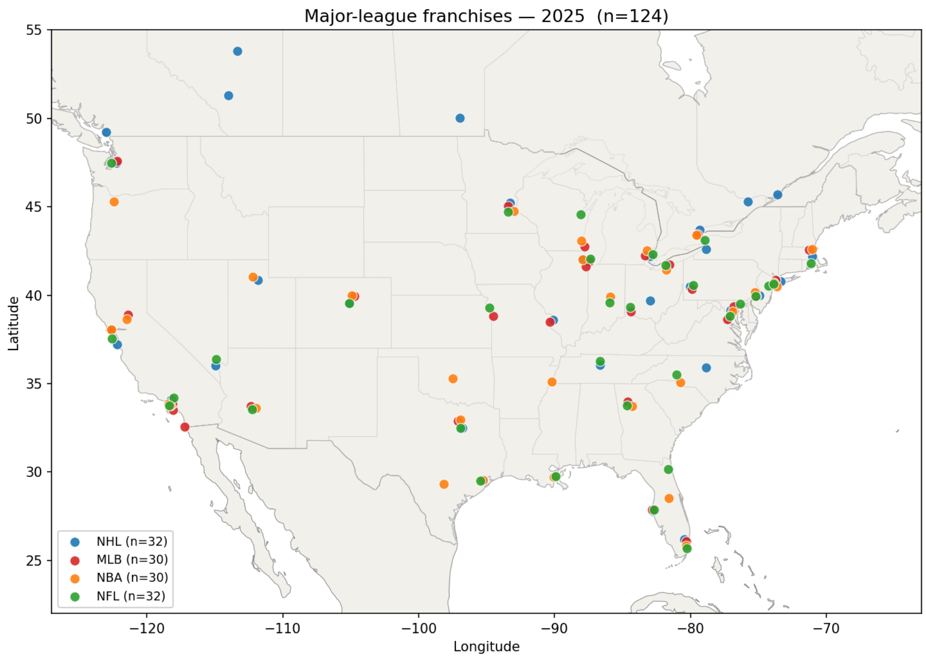

Figure 2: Major-league franchises active in 2025, coloured by league.

The median latitude of franchise cities also decreased in every league between 1950 and 2025 (Figure 4), by approximately 1.5–2.8°. This common decline indicates that the southward movement was not produced solely by a few geographically distant franchises, even though the larger component of some centroid trajectories was longitudinal. Across all league-years, median latitude was strongly and negatively associated with mean annual temperature (Figure 5). The thermal migration examined below therefore reflects a southward movement along the continental temperature gradient, superimposed on a broader westward expansion.

4.2. Thermal drift

The changing geography of the leagues was accompanied by a strong upward drift in the mean annual temperature of franchise cities (Figure 6). Between 1951–1970 and 2006–2025, mean TAVG increased by 3.73 °C for the NBA, 3.44 °C for the NHL, 2.54 °C for the NFL, and 2.53 °C for the MLB. All four time series exhibited positive and statistically significant trends (Mann–Kendall $p < 0.001$), with Sen slopes ranging from 0.46 °C per decade for the MLB to 0.71 °C per decade for the NBA.

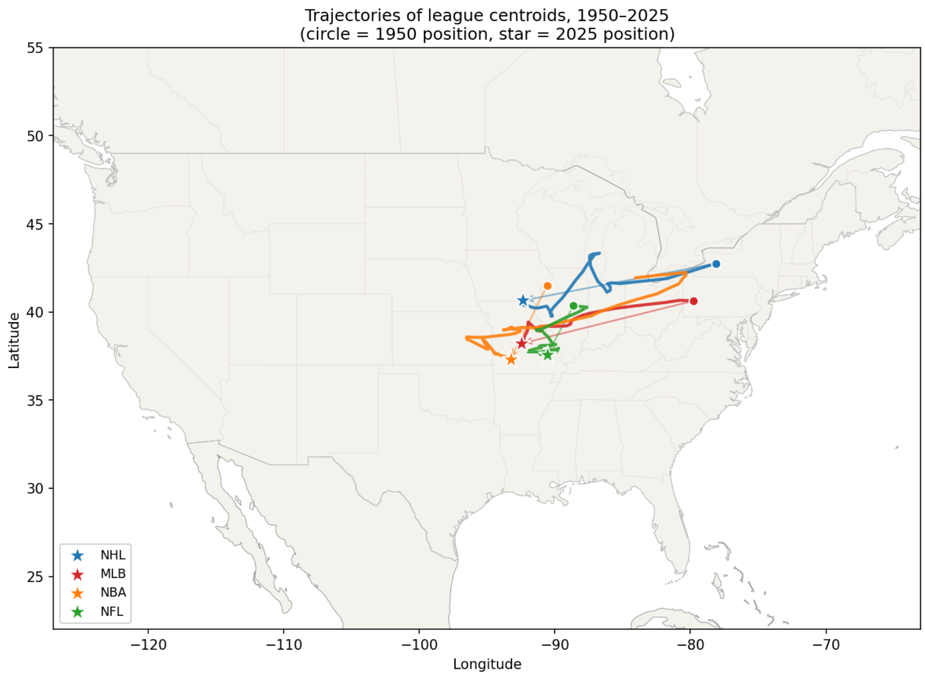

Figure 3: Trajectories of the four leagues' franchise centroids, 1950–2025. Circles indicate the 1950 positions and stars indicate the 2025 positions.

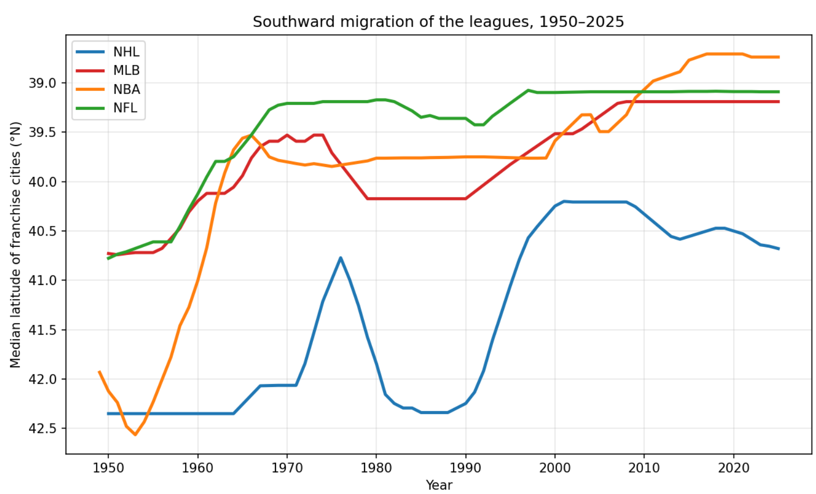

Figure 4: Median latitude of franchise cities by league, 1950–2025. The vertical axis is inverted so that southward migration reads downward.

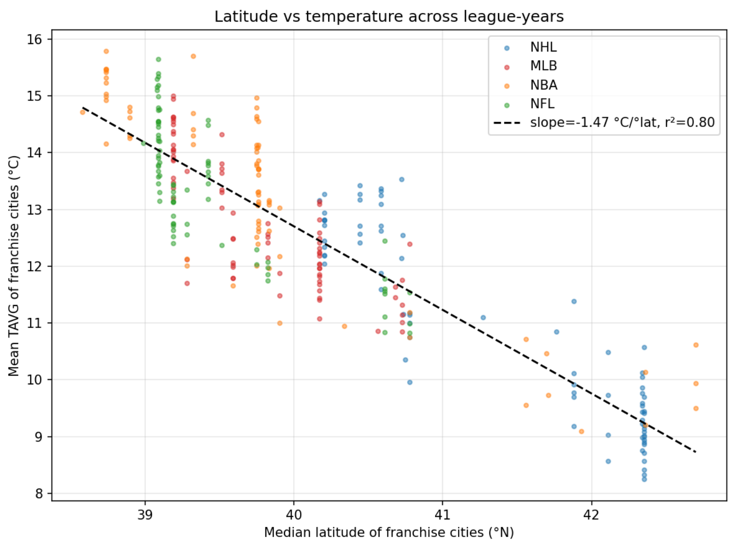

Figure 5: Relationship between median latitude and mean annual temperature across league-years.

These changes combine two processes: the warming of established franchise cities and the changing composition of the leagues as franchises entered or moved to different cities. The decomposition presented in Section 4.3 shows that the latter accounts for most of the observed thermal drift in every league. The results therefore support **H1**.

4.3. Changing geography versus in situ *warming*

The total thermal drift was separated into the warming of the initial franchise geography and the effect of changing league composition:

$$\Delta T_{\text{total}} = \Delta T_{\text{in situ}} + \Delta T_{\text{composition}}. \tag{12}$$

The fixed-geography counterfactual applies the franchise-city weights observed during 1951–1970 to the climate of the same cities during 2006–2025. It therefore estimates how much each league would have warmed had its initial geography remained unchanged. The composition component measures the additional difference associated with expansion and relocation into a new set of host cities.

Both components were positive in all four leagues (Table 1). The fixed initial geography warmed by 0.95–1.06 °C, depending on the league. The

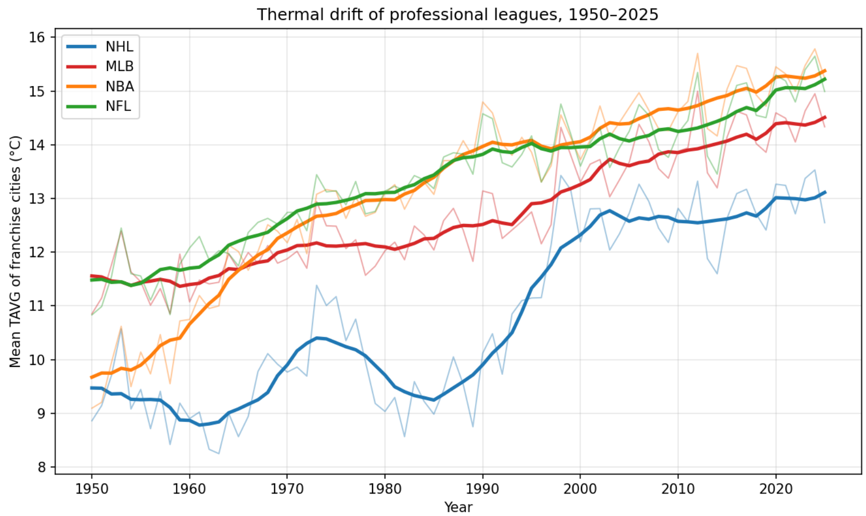

Figure 6: Thermal drift of the four leagues, 1950–2025. Thin lines show annual mean TAVG across active franchise cities and bold lines show 10-year moving averages.

changing geographical composition added a further 1.59–2.72 °C. The composition effect was therefore larger than the *in situ* effect in every case and accounted for 63% of the total drift in the MLB and NFL, 69% in the NHL, and 73% in the NBA.

The NBA experienced the largest composition effect, at 2.72 °C, followed by the NHL at 2.38 °C. The MLB and NFL each recorded a composition effect of 1.59 °C. The geographical reconfiguration of the leagues was consequently not a secondary perturbation on the underlying warming trend. It was the dominant component of the observed change in their aggregate thermal geography.

The cohort comparison provides a complementary view (Figure 7). When both groups are evaluated during the same recent period, 2006–2025, expansion franchises occupy warmer cities than founding franchises in every league. The expansion-minus-founding difference in mean TAVG is 3.67 °C for the NFL, 3.23 °C for the MLB, 2.23 °C for the NBA, and 1.45 °C for the NHL.

Because the comparison is made within a common climatic period, these differences cannot be attributed to the passage of time. They reflect the warmer geographical placement of franchises entering after 1970. The counterfactual decomposition and the cohort comparison therefore yield the same general result through different designs: the thermal drift of the leagues arose

Table 1: Decomposition of thermal drift between 1951–1970 and 2006–2025. The *in situ* term represents warming of the fixed 1951–1970 franchise geography. The composition term represents the effect of expansion and relocation into a different set of cities. Temperature changes are expressed in °C.

League	ΔT_{total}	$\Delta T_{\text{in situ}}$	$\Delta T_{\text{composition}}$	Composition share
NHL	3.44	1.06	2.38	69%
MLB	2.53	0.95	1.59	63%
NBA	3.73	1.01	2.72	73%
NFL	2.54	0.95	1.59	63%

primarily from where their expanding franchise networks were located.

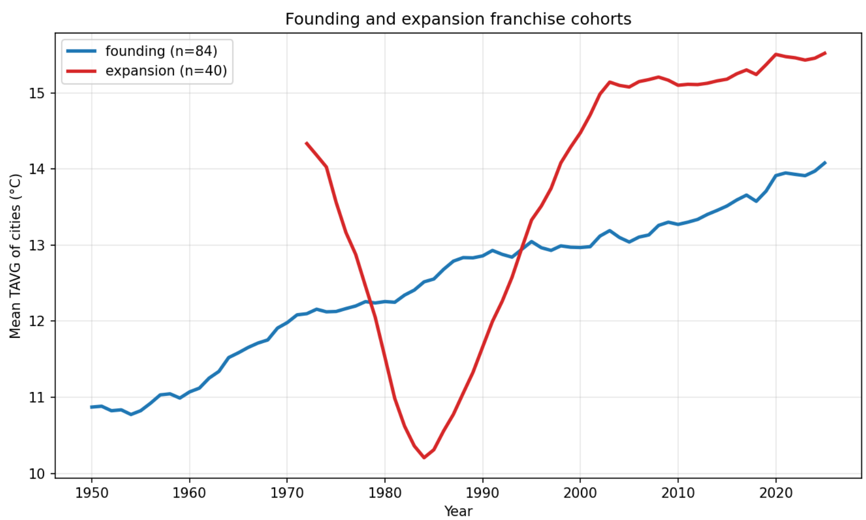

Figure 7: Mean annual temperature of host cities for founding and expansion franchise cohorts. Expansion franchises occupy systematically warmer cities.Annual means reflect the evolving set of active franchises within each cohort.

4.4. Thermal-energy transition

The degree-day profile of franchise cities changed markedly over the study period (Figure 8). Heating degree days declined and cooling degree days increased in all four leagues. Their aggregate climatic context therefore shifted away from heating-dominated conditions and towards a greater relative requirement for cooling.

The transition was particularly marked for the NHL. Its historical franchise geography was strongly heating-dominated, whereas its subsequent expansion placed franchises in cities with much greater cooling-degree demand. For an indoor sport requiring an artificially maintained ice surface, this shift has a different operational meaning from ordinary space cooling, although the degree-day indicators do not measure realised venue energy consumption.

The consistent decline in HDD and increase in CDD support **H2**. The observed direction is also consistent with the broader increase in cooling-related climatic demand documented across North America and globally (Scoccimarro et al., 2023; Erhardt, 2015; Petri and Caldeira, 2015; Soule and Suckling, 1995).

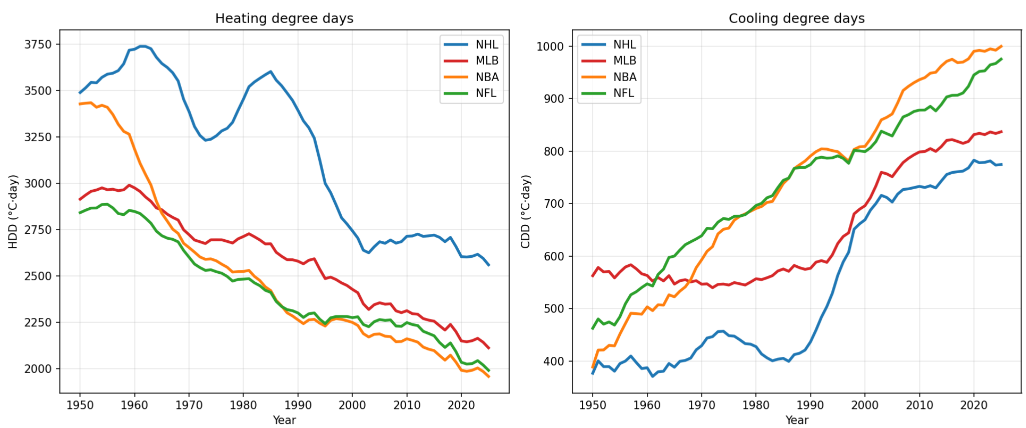

Figure 8: Heating degree days (left) and cooling degree days (right) across franchise cities, shown as 10-year moving averages.

4.5. Köppen–Geiger transitions

The climate classification of the cities beneath the contemporary franchise network also changed (Figure 9). Holding the set of cities hosting franchises in 2025 fixed, the comparison between the 1961–1990 and 1991–2020 climate normals shows a decline in the share classified within the cold D group and an equivalent increase in the temperate C group. The shares of arid B and tropical A climates remained essentially unchanged.

This pattern represents a change in the climatic field beneath a fixed set of cities, rather than a change in franchise composition. The transitions were concentrated in the north-eastern corridor. New York, Newark, Philadelphia, Brooklyn, and Cincinnati crossed the D/C boundary from Dfa to Cfa, while Boston, Buffalo, Toronto, and Montreal shifted within the cold group from Dfb to Dfa. These changes are consistent with the documented northward movement of the Köppen–Geiger D/C and Dfa/Dfb boundaries in eastern North America (Suckling and Mitchell, 2000; Hanberry and Fraser, 2019; Rohli et al., 2015).

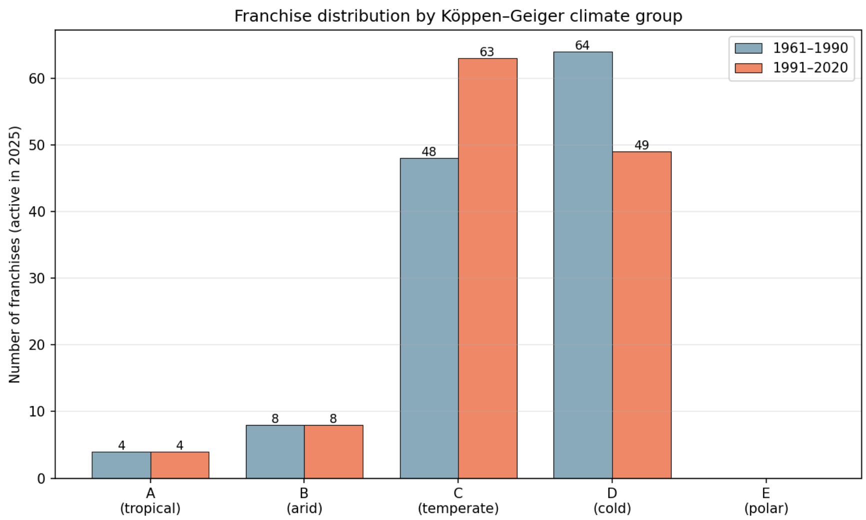

Figure 9: Köppen–Geiger climate groups of cities hosting active franchises in 2025, classified under the 1961–1990 and 1991–2020 climate normals. The set of franchise cities is identical in both periods.

4.6. Climatic departure and the NHL

The Climate Departure Index identifies the NHL as the league with the greatest standardised thermal departure from its historical geography (Figure 10). The NHL has the lowest historical reference temperature of the four leagues, with $T_{\text{ref}} = 9.3\,^{\circ}\text{C}$ compared with 11.2–12.1 °C for the others. It also has the smallest baseline thermal dispersion, with $\sigma = 2.1\,^{\circ}\text{C}$. A given temperature difference therefore represents a larger standardised departure for the NHL than for a league whose initial geography was warmer or more heterogeneous.

The NHL trajectory is also the least monotonic. Its CDI declined during the 1980s before rising rapidly through the 1990s and 2000s to reach the highest values among the four leagues. This combination of a cold and relatively narrow historical distribution with a subsequent expansion into much warmer cities supports **H3**.

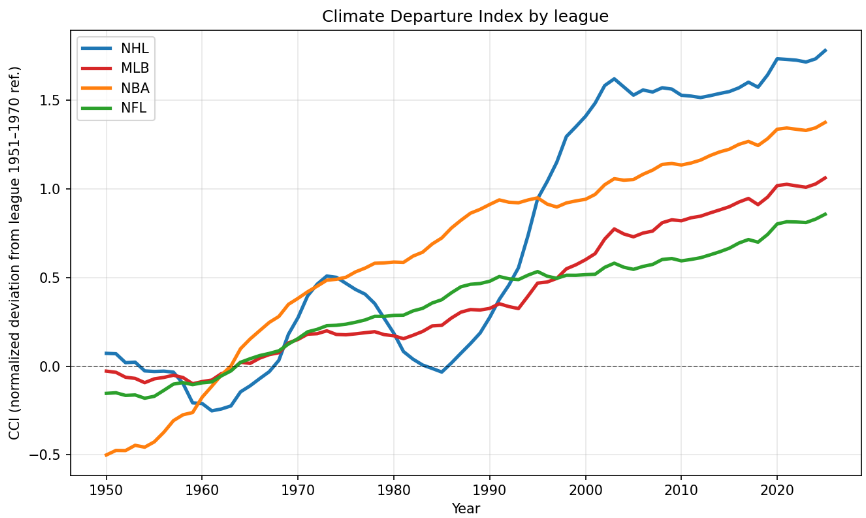

Figure 10: Climate Departure Index by league. Positive values indicate franchise cities warmer than the league-specific 1951–1970 thermal reference.

The non-monotonic NHL trajectory corresponds to identifiable changes in league composition. The decline beginning around 1979 coincides with the integration of northern former-WHA franchises, including Edmonton, Winnipeg, Quebec City, and Hartford, which shifted the league's aggregate geography towards colder cities. The subsequent increase coincides with the 1991–1999 expansion into San Jose, Tampa, Anaheim, Florida, Nashville, and Atlanta. The CDI therefore responds visibly to successive phases of northern consolidation and Sun Belt expansion. This correspondence illustrates the sensitivity of the index to major structural changes in league geography.

4.7. The anatomy of a relocation

The aggregate change in league geography results from both the creation of new franchises and the movement of existing ones. To examine the latter process directly, each of the 59 franchise relocations was represented as a vector between an origin and a destination city. This analysis is distinct from the decomposition in Section 4.3. Expansion changes the league portfolio by adding a franchise without an origin city, whereas a relocation connects two successive host cities of the same franchise.

All origin and destination cities were evaluated using the same 1991–2020 climatology. Differences between them therefore represent contrasts in location rather than warming between the dates of the moves. Across the 59 relocations, 63% moved towards a warmer city and 64% moved southward. The average move covered approximately 1 400 km and produced changes of −1.4° in latitude and +0.6 °C in mean annual temperature.

The relationship between latitude and temperature differences is visible in Figure 11. Most southward moves also led to warmer climatic conditions, while northward moves generally produced cooling. The degree-day comparison in Figure 12 places most relocations in the quadrant combining lower HDD with higher CDD. The Köppen–Geiger transition matrix (Figure 13) is dominated by moves within the temperate group, C→C ($n = 17$), from cold to temperate climates, D→C ($n = 15$), and from temperate to cold climates, C→D ($n = 10$).

Table 2: Mean relocation vectors by league, evaluated using a fixed 1991–2020 climatology. Positive ΔTAVG denotes relocation to a warmer city and negative Δlatitude denotes relocation towards the south. Distance is expressed in kilometres, latitude in degrees, and TAVG in °C.

League	n	$\overline{\Delta \text{km}}$	$\overline{\Delta \text{latitude}}$	$\overline{\Delta \text{TAVG}}$	Warmer moves	Köppen change
NHL	9	1 842	+0.10	−0.78	56%	89%
MLB	13	1 758	−2.34	+1.62	62%	85%
NBA	24	1 296	−2.40	+1.88	79%	58%
NFL	13	951	+0.22	+0.48	54%	77%

The mean vectors reveal substantial differences among leagues (Table 2). NBA and MLB relocations had strongly warming and southward mean vectors. Their average changes were respectively +1.88 and +1.62 °C in TAVG, and −2.40° and −2.34° in latitude. The NBA also had the largest proportion of relocations towards warmer cities, at 79%.

The mean NHL vector, in contrast, was slightly cooling (−0.78 °C) and nearly neutral in latitude. This net result conceals a highly polarised set of individual movements. The largest warm-city relocations included Winnipeg to Atlanta (+13.0 °C), Minneapolis to Dallas (+11.5 °C), and Quebec City to Denver (+3.5 °C). The largest movements towards colder cities included

Glendale to Salt Lake City (−13.9 °C), Atlanta to Winnipeg (−13.0 °C), and Atlanta to Calgary (−12.4 °C).

The NHL relocation history therefore did not follow a steady movement in one direction. It included both major transfers into warmer markets and subsequent or separate transfers towards colder ones. Its small mean vector reflects the cancellation of these opposing movements rather than an absence of climatic mobility. This polarised relocation pattern is consistent with the non-monotonic CDI trajectory, although the two analyses concern different processes: the CDI also incorporates league expansion and merger-related changes in composition.

The NHL also had the highest proportion of relocations crossing a detailed Köppen–Geiger class boundary, at 89%. Thus, even though its average relocation vector was small, most individual NHL moves connected cities with distinct climatic classifications. By comparison, the NBA followed a more consistently southward and warming trajectory but crossed climatic classes in a smaller proportion of moves.

5. Discussion

5.1. Climatic migration as an outcome of economic geography

The results show that the thermal evolution of North American professional sport cannot be attributed to climatic warming alone. Between 1951–1970 and 2006–2025, the mean annual temperature of franchise cities increased by 2.53–3.73 °C across the four leagues. The corrected decomposition indicates that 63–73% of this drift arose from the changing geographical composition of the leagues, while the remaining share resulted from the warming of the initial franchise geography. Professional sport therefore did not merely experience a warmer climate in place. Its organisations moved towards a warmer part of the continent.

The spatial analyses clarify the geography of this movement. All four league centroids shifted westward, while median franchise latitude declined in every league. The strong negative relationship between median latitude and mean temperature shows that the thermal migration was primarily associated with a southward displacement along the continental temperature gradient, embedded within the broader westward expansion of the North American urban system. The historical climatic setting of a sport was therefore not a binding constraint on the contemporary geography of its professional league.

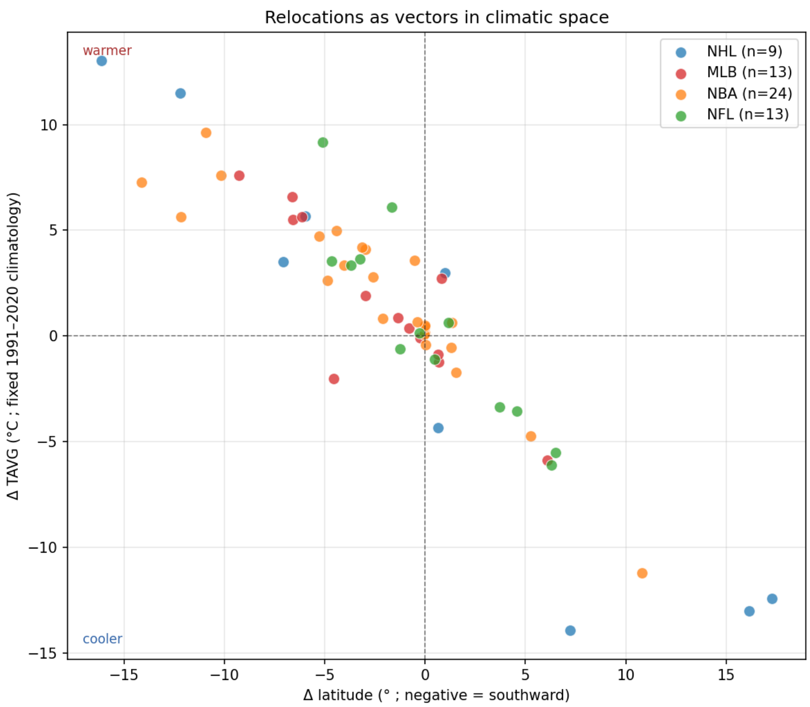

Figure 11: Franchise relocations represented in climatic space using changes in latitude and mean annual temperature under a fixed 1991–2020 climatology. The NHL occupies both the strongly warming and strongly cooling extremes.

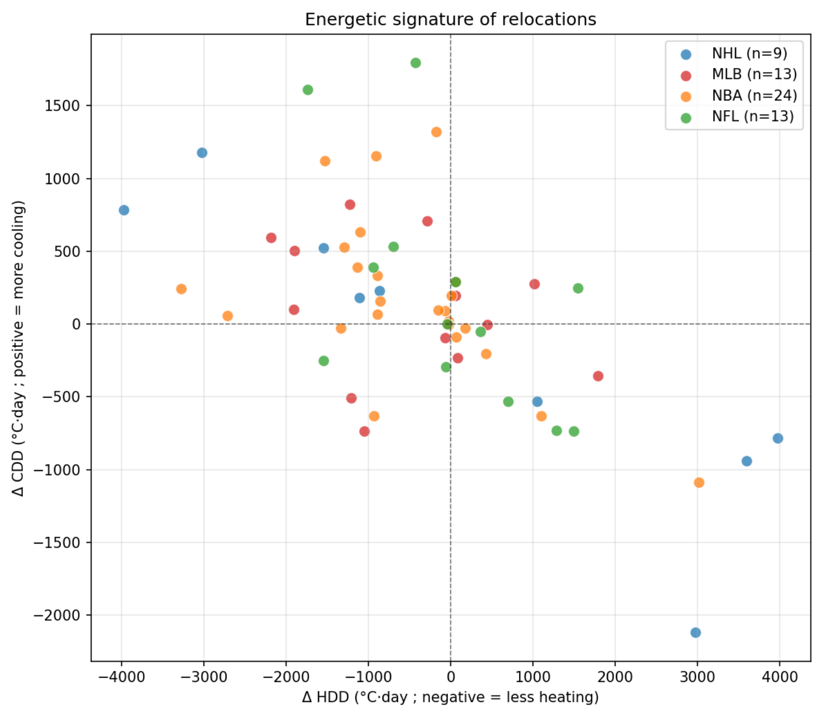

Figure 12: Changes in heating and cooling degree days associated with franchise relocations under a fixed 1991–2020 climatology. Most moves combine lower heating-degree demand with higher cooling-degree demand.

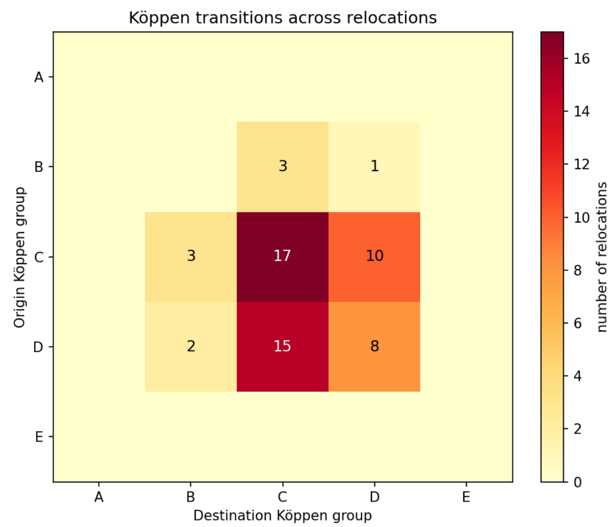

Figure 13: Köppen–Geiger transitions across franchise relocations. Rows indicate origin climate groups and columns indicate destination climate groups.

This outcome was not produced by an explicit preference for warm climates. It emerged from the economic and demographic geography of the post-war United States. The metropolitan areas that experienced the strongest population and market growth were disproportionately located in the South, Southwest, and West. Professional franchises followed these expanding consumer markets and the urban amenities, infrastructure, and agglomeration benefits associated with them (Humphreys and Zhou, 2015; Propheter, 2019). Because the demographic frontier of the United States coincided geographically with its warmer regions, market-seeking behaviour generated a thermal outcome. Warmth was not the objective of franchise expansion, but it was a persistent spatial correlate of that objective.

The cohort comparison supports this interpretation. Expansion franchises are located in warmer cities than founding franchises even when both groups are evaluated over the same recent climatic period. This difference is therefore not the product of differential temporal warming. It reflects the geography of later franchise placement. Founding franchises remained concentrated in the older industrial cities of the Northeast and Midwest, whereas new franchises were disproportionately placed near the demographic and economic frontier of the Sun Belt.

Public policy reinforced this market and demographic movement. Franchise location is co-produced by competition among cities through venue subsidies, tax concessions, infrastructure investment, and the symbolic value associated with major-league status (Coates and Humphreys, 2003b; Bradbury et al., 2023; Kellison and Mondello, 2014; Kellison et al., 2017; Carlino and Coulson, 2004). Rapidly growing Sun Belt municipalities had both the incentive and the capacity to attract professional teams. Local public decisions therefore helped direct franchises towards the same warm metropolitan areas identified in the climatic analysis. The observed thermal migration is consequently the aggregate geographical expression of private market strategies, demographic redistribution, and public territorial policy.

Climatic de-territorialisation is therefore not a climate-seeking strategy in the conventional sense. It is the unintended climatic consequence of an economic geography. Professional sport followed people, capital, infrastructure, and political support, and in doing so moved systematically through climatic space.

5.2. Convergence, divergence, and non-monotonic pathways

Although all four leagues moved towards a warmer contemporary geography, they did not begin from the same climatic position or follow the same trajectory. At the start of the study period, the NHL occupied the coldest and least thermally dispersed set of cities, whereas the NFL began from the warmest historical reference. By 2025, the four leagues had converged towards a more similar set of major metropolitan markets and, consequently, towards a more similar thermal envelope.

This convergence reflects the homogenisation of professional sport onto a shared national urban system. Once franchise placement is increasingly governed by metropolitan size and market potential, the leagues tend to occupy the same cities. The geography of each sport becomes less distinct because their professional organisations compete within the same hierarchy of large urban markets.

Convergence in absolute climatic space does not imply equal climatic de-territorialisation. The CDI measures each league relative to its own historical distribution. The NHL therefore exhibits the largest standardised departure because it began from the coldest and narrowest climatic reference. The MLB, which was already distributed across a comparatively temperate and geographically broad set of cities at mid-century, shows a smaller departure from its initial thermal geography. The contemporary league map may be converging, but the climatic distance travelled from each sport's historical setting remains highly unequal.

The relocation vectors further show that similar endpoints can be reached through different pathways. NBA and MLB relocations produced relatively consistent southward and warming mean vectors. The NHL followed a far less linear path. Its near-zero net latitudinal movement and slightly cooling mean relocation vector conceal individual moves towards both climatic extremes. Relocations such as Winnipeg to Atlanta and Minneapolis to Dallas were among the largest warm-city movements in the dataset, whereas Atlanta to Winnipeg, Atlanta to Calgary, and Glendale to Salt Lake City moved strongly towards colder climates.

The NHL therefore did not simply translate from a cold geographical centre to a warmer one. Its geographical range expanded and contracted through opposing movements. This pattern is consistent with the non-monotonic CDI trajectory, although the two analyses describe different components of league change. The CDI includes expansion and merger-related changes in composition, whereas the relocation vectors include only movements of existing franchises.

The NHL case shows that climatic de-territorialisation need not be monotonic. A sporting organisation can move away from its historical climatic setting, partially return towards it, and subsequently expand again into contrasting climates. Net drift alone therefore provides an incomplete account. The destination, direction, and volatility of the pathway must be distinguished.

5.3. Thermal artificialisation and transformed dependence

The ability of professional sport to operate across such different climatic settings depends on thermal artificialisation. Ice manufacture, air-conditioning, enclosed arenas, domed stadiums, and retractable roofs allow sporting conditions to be produced independently of the immediate outdoor environment. These technologies weaken the direct relationship between the climate of a city and the conditions required for play.

The degree-day results identify the direction of the environmental transition associated with this movement. Across all four leagues, heating degree days declined while cooling degree days increased. The franchise geography shifted from colder, heating-dominated contexts towards locations with greater cooling-related climatic demand. For the NHL, this transition is especially significant because cooling is not limited to spectator comfort or indoor air temperature. It includes the continuous artificial production and maintenance of the playing surface itself.

The engineering literature documents the operational implications of this substitution. Ice rinks may consume substantial quantities of energy (Sutherland, 2015; Marquardt and Mainka, 2008), while stadiums and arenas rely on cooling, ventilation, roofing, and climate-control systems (Nishioka et al., 2000; Goeppert and Paech, 2020; Sofotasiou et al., 2015; Winter, 2016). These systems can create significant greenhouse-gas emissions and financial costs, although actual consumption varies greatly by venue design, use, and energy source (Hedayati et al., 2014; Manni et al., 2018). Our indicators do not measure these realised loads. They demonstrate that the climatic context in which such systems operate has become systematically more cooling-intensive.

This shift has implications for urban energy planning. Professional venues are large and often energy-intensive infrastructures. Their movement towards warm metropolitan areas places them within electricity systems already subject to strong summer cooling demand (Scoccimarro et al., 2023; Erhardt, 2015; Petri and Caldeira, 2015). An open NFL stadium, a retractable-roof MLB park, an NBA arena, and an NHL ice rink will translate the same urban climate into very different operational loads. Nevertheless, their location within a warmer degree-day regime increases the relevance of cooling capacity, grid reliability, peak electricity demand, and heat-resilient surrounding infrastructure.

Thermal artificialisation does not make professional sport independent of climate. It transforms the form of dependence. A sport initially linked directly to local environmental conditions becomes dependent on energy, engineering, infrastructure, and finance. This transformation also creates new vulnerabilities. A climate-controlled venue still depends on a functioning electricity system, accessible transport infrastructure, safe outdoor conditions for spectators, and resilience to heat, storms, smoke, and power failure.

This transformed condition can be described as *post-climatic sport*. The term does not imply that climate has ceased to matter. It describes a sporting system that has weakened its dependence on locally inherited playing conditions by reproducing the required environment technologically. Climatic dependence is externalised and reorganised rather than abolished. The concept of climatic de-territorialisation describes the geographical trajectory, while the post-climatic condition describes the infrastructural dependence that can result from it.

This interpretation connects the historical geography documented here with the growing literature on climate vulnerability and adaptation in professional sport. Stadiums may serve as thermal refuges (Kellison et al., 2023), climatic exposure may accelerate venue replacement (Kellison and Orr, 2021), scheduling may become an adaptation instrument (Orr et al., 2025), and spectators may attach economic value to cooler conditions (Kuruc et al., 2025). The present results locate these contemporary pressures within a longer geographical process of movement towards warmer markets.

5.4. Two movements in climatic space

The analysis identifies two distinct movements through climatic space. The first is organisational. Franchises expand and relocate across an existing climatic field, changing the aggregate environment occupied by the leagues. The second is environmental. The climatic field itself changes beneath cities that remain geographically fixed.

The corrected decomposition shows that both mechanisms contributed positively to the warming of league geography, but that the organisational movement was dominant. Changing franchise composition accounted for 63–73% of the total thermal drift, while warming of the fixed 1951–1970 geography accounted for the remaining 27–37%. Professional sport therefore moved towards warmer cities at the same time as the climates of its original cities warmed in place.

The Köppen–Geiger analysis illustrates the second movement. The set of cities hosting franchises in 2025 was held constant, yet several cities crossed from cold D climates to temperate C climates between the two normal periods. These transitions were concentrated in the north-eastern corridor, including cities central to the historical geography of the leagues. The climate changed beneath the older franchise network even where the franchises themselves did not move.

The two mechanisms are conceptually distinct. Expansion and relocation are institutional decisions shaped by markets, demographics, and policy. In situ warming is a physical environmental process shared by all activities located in these cities. They can also occur in different places. Much of the composition effect is generated by franchises entering Sun Belt cities, while the most visible Köppen transitions occur in older northern and eastern markets.

Together, these movements reduce the correspondence between professional sport and its historical climatic settings from both directions. The organisations move across the climate gradient, and the climate gradient moves beneath established organisations. Climatic de-territorialisation therefore results from the interaction between institutional mobility and environmental change, although only the former is specific to the geography of professional sport.

5.5. Transferability and contrasting sporting systems

The framework developed here can be applied beyond the four North American leagues, but other sporting systems should not be expected to reproduce the same pattern. The North American franchise model is characterised by closed leagues, market-based expansion, and the possibility of team relocation. Other systems are organised through different institutional and biophysical constraints.

Association football in Europe provides a contrasting case. Clubs are generally more territorially anchored and rarely relocate between cities. However, the geography of top-level competition changes through promotion, relegation, financial inequality, and variation in sporting performance. Its climatic geography would therefore reflect changes in competitive composition rather than franchise migration. Applying the framework would require distinguishing organisational mobility from the movement of clubs between competitive divisions.

The Olympic movement follows another logic. Host geography changes by design from one edition to the next. Climatic requirements and engineered infrastructure are transferred to successive host cities, often under strong political and economic constraints. The relevant process is not the permanent migration of an organisation towards a market, but the repeated spatial relocation of an event and its environmental requirements.

Winter sports provide a biophysically constrained case. Their historical climatic conditions are not merely cultural associations but essential environmental resources. Snow and cold cannot be completely replaced without altering the activity itself, even though artificial snow and indoor facilities can temporarily weaken those constraints (Knowles, 2019). Winter sports may therefore reveal the limits of climatic de-territorialisation rather than reproduce the North American league trajectory.

These systems should not be expected to reproduce the North American franchise pattern. Rather, they provide contrasting institutional and biophysical tests of climatic de-territorialisation. The common analytical question is whether the geography of a sporting system has shifted relative to its historical climatic reference, through what mechanism, and with what resulting infrastructural dependence.

The retrospective framework developed here also complements prospective assessments of future climate risk for sport (Defrance and Lescure, 2026). Prospective analyses examine where climatic conditions may become less suitable for sport. The present approach examines how sporting systems have already moved through climatic space. One tracks the future movement of climate relative to sport, while the other reconstructs the historical movement of sport relative to climate.

5.6. Limitations

Several limitations define the scope of the analysis. First, the climatic characterisation is based primarily on annual indicators rather than conditions during each league's competitive season. Hockey and basketball are largely played from autumn to spring, while baseball occupies the warmer part of the year and football extends from late summer into winter. Season-specific indicators could refine the magnitude and operational interpretation of the thermal displacement, although the broad geographical contrast between northern founding cities and warmer expansion markets is unlikely to disappear.

Second, HDD and CDD are theoretical climatic indicators rather than observed energy-consumption data. They describe the direction and relative magnitude of heating- and cooling-related climatic demand. They do not account for venue design, roof type, refrigeration efficiency, occupancy, operating schedules, energy prices, or electricity-generation mix. The study therefore identifies the changing climatic context of potential demand rather than the realised energy or carbon footprint of individual facilities.

Third, each city is represented by a single ERA5-Land grid point located near its geographical centre. This resolution is appropriate for comparing the regional climates of franchise cities, but it cannot resolve urban heat-island effects, local topography, coastal exposure, or the microclimate of individual stadiums and arenas. The pre-1979 ERA5-Land record is also less strongly constrained by observations than the satellite-era period, although the use of multi-decadal means and persistent inter-city contrasts reduces the influence of individual annual errors.

Fourth, the construction of the franchise database requires decisions about the continuity of franchises, host-city naming, and the treatment of league

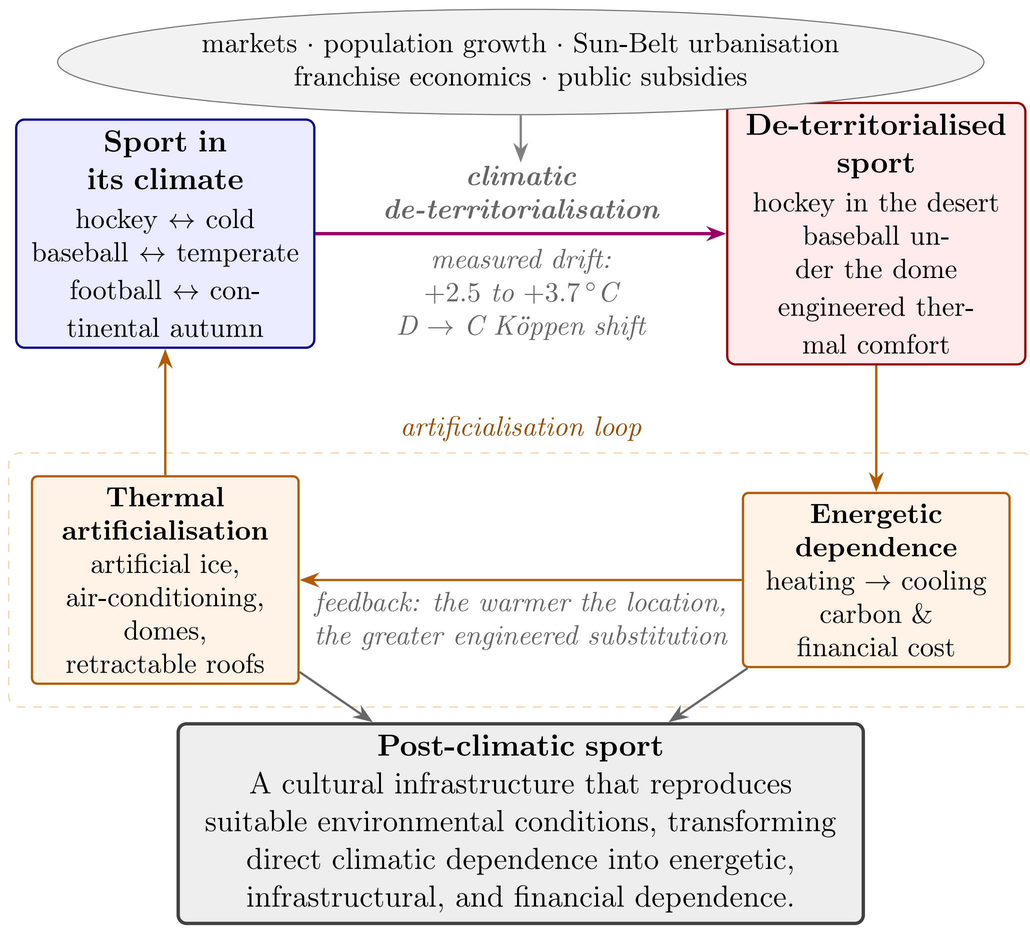

Figure 14: Conceptual schema of climatic de-territorialisation. Market, demographic, and policy drivers carry sport from its historical climatic setting towards a warmer and more de-territorialised geography. Thermal artificialisation transforms direct climatic dependence into energetic, infrastructural, and financial dependence.

mergers. No materially ambiguous continuity cases altered the principal results, but alternative historical conventions could slightly change the number or timing of individual stints and relocations. The city-centre coordinates also represent metropolitan locations approximately rather than the exact location of every historical venue.

Fifth, all active franchises are weighted equally. The analysis therefore characterises league geography rather than attendance-weighted, match-weighted, venue-capacity-weighted, economic, or energy-weighted exposure. A franchise playing in a small arena contributes the same weight as one operating a much larger venue, and a league with many outdoor events is not weighted differently from one with fewer indoor events.

Finally, the analysis is restricted to the four major North American professional leagues. The extent to which climatic de-territorialisation characterises promotion-and-relegation systems, recurring international events, winter sports, or other cultural and sporting infrastructures remains an open empirical question.

6. Conclusion

Over seven decades, the four major North American professional sports leagues did not merely expand across the continent. They migrated through climatic space. Between 1951–1970 and 2006–2025, the mean annual temperature of franchise cities increased by 2.53–3.73 °C across the four leagues. The decomposition shows that 63–73% of this thermal drift resulted from the changing geographical composition of the leagues, while the remainder arose from the warming of their initial franchise geography. Most individual relocations also moved towards warmer cities, although the NHL followed a more polarised and non-monotonic pathway than the other leagues.

The broader contribution of the study lies in the geographical sequence that connects these results. Post-war urbanisation and demographic redistribution shifted the most attractive professional-sport markets towards the Sun Belt. League expansion and franchise relocation followed those markets. This movement carried professional sport down the continental temperature gradient and into more cooling-intensive climatic settings. The resulting distance from historically associated climatic conditions was then sustained through thermal artificialisation, including refrigeration, air-conditioning, enclosed venues, and engineered playing environments. Market geography therefore produced a climatic migration, and climatic migration produced new energetic, infrastructural, and financial dependencies.

We describe this process as *climatic de-territorialisation*. The concept does not imply that sport becomes independent of climate, nor that a sport possesses a fixed natural territory. It denotes the measurable weakening of the historical relationship between a sporting system and the climatic environments in which it developed. Professional sport increasingly reproduces suitable conditions technologically rather than inheriting them from place. In doing so, it transforms direct climatic dependence into dependence on energy systems, venue engineering, urban infrastructure, and financial capacity.

The endpoint of this trajectory can be understood as a form of *post-climatic sport*. This condition is not beyond climate. It remains exposed to heat, storms, smoke, transport disruption, power failure, and the capacity of urban systems to maintain engineered comfort. Climatic dependence is therefore displaced and reorganised rather than eliminated. The same infrastructures that allow sport to operate outside its historical climatic setting create new forms of vulnerability within the warmer cities to which it has moved.

The framework developed here also provides a basis for comparison across sporting systems organised by different spatial mechanisms. European football, the Olympic movement, and winter sports should not be expected to reproduce the North American franchise trajectory. They instead offer contrasting tests of how competitive performance, programmed host rotation, or biophysical constraint shape movement through climatic space. More broadly, the study shows that organisational geography can itself generate a climatic trajectory. Sport has moved towards warmer environments while climate change has simultaneously altered the cities in which it was historically rooted.

CRediT authorship contribution statement

Dimitri Defrance: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review and editing, Project administration.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The franchise database, processed climatic indicators, city-coordinate table, relocation vectors, derived analysis datasets, and Python scripts used in this study will be made openly available through Zenodo upon publication.

ERA5-Land reanalysis data are publicly available from the Copernicus Climate Data Store.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author used Anthropic Claude and OpenAI ChatGPT for language editing, proofreading, and manuscript restructuring. The author subsequently reviewed and edited the content and takes full responsibility for the content of the published article.

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