Appendix A Definition of the Multi-domain ODD Natural Surrounding Taxonomy

A.1 Env. Aspect 1) Weather Conditions Variety Definition

To define and **characterise** weather conditions, the Met Office (the national weather service of the United Kingdom) and other meteorological **organisations employ a standardised** set of terminology and measurements [1]. The following list of typical weather conditions includes the measurements that go along with them:

1. **Temperature:** This essential meteorological variable shows how hot or cold the air is. In the Met Office, it is commonly expressed in degrees Celsius (°C).
2. **Precipitation:** Any liquid or solid water that falls from clouds is referred to as precipitation. It can take many different forms, including hail, sleet, snow, and rain. Millimetres (mm) are commonly used to measure precipitation.
3. **Wind:** Wind direction and speed are used to characterise wind conditions. Usually, wind speed is expressed in meters per second (m/s) or miles per hour (mph). the direction from which the wind is coming indicates the wind's direction (e.g., a northerly wind indicates that it is blowing from the north.
4. **Humidity:** This gauges the air's concentration of water vapor. Typically, it is stated as a percentage (%).
5. **Pressure:** Atmospheric pressure is the weight of the air in the atmosphere above us. It is usually measured in millibars (mb) or hectopascals (hPa).
6. **Visibility:** This refers to the distance one can see through the atmosphere. It's typically measured in meters (m) or kilometres (km).
7. **Sunshine Duration:** This is the total time that sunshine is observed in a given period. It's typically measured in hours.
8. **UV Index:** This measures the level of ultraviolet radiation from the sun. It's a unitless scale, typically ranging from 0 (low) to 11+ (extremely high).
9. **Snow:** Snowfall is a type of precipitation, measured similarly to rainfall in millimetres (mm), but sometimes reported in terms of snow depth in centimetres (cm). Snow forecasts often consider the likelihood of snowfall, as well as potential accumulation.
10. **Pollen:** The Met Office provides a pollen forecast, especially important for people who suffer from hay fever. This forecast predicts the pollen count, which is the number of pollen grains per cubic meter of air. It's usually given on a scale from 'low' to 'very high'.
11. **Sand:** In some parts of the world, sandstorms can be a significant weather event. While not typically a routine part of weather forecasts in places like the UK, meteorological services in regions where sandstorms are common, like the Middle East, will often provide forecasts for these. In the UK, the Met Office may note when Saharan dust is expected to affect air quality. This is typically expressed qualitatively (e.g., "possible Saharan dust in the atmosphere").
12. **Cloud Cover Variety Definition:** The coverage of clouds in the sky is often described using the term "oktas" or eighths of the sky. Here are the common terms used to describe different cloud cover states:

- **Clear or Blue Sky (0/8 oktas):** No clouds are covering the sky.
- **Mostly Clear or Sunny (1/8 to 2/8 oktas):** A few clouds are present, but they cover a small portion of the sky.
- **Partly Cloudy or Fair (3/8 to 4/8 oktas):** Clouds cover from 3/8 up to half of the sky. The sun is likely visible at times.
- **Mostly Cloudy or Cloudy (5/8 to 7/8 oktas):** More than half the sky is covered in clouds, but there are some breaks in the cloud cover.
- **Overcast (8/8 oktas):** The sky is completely covered in clouds. The sun is not visible.
- **Obscured or Foggy:** The sky is not visible due to fog, heavy precipitation, or other weather conditions.

The above descriptions are common in many weather forecasting systems, but exact terminology and definitions vary. The above states also don't describe the type of clouds, such as cumulus, stratus, or cirrus, which can also affect perception.

A.2 Env. Aspect 2) Illumination Variety Definition

A.2.1 Natural Light Conditions Variety Definition:

In the context of natural light conditions, **overhead, back-lighting, and front-lighting** refer to the direction of the light source relative to the camera or the scene being captured:

1. **Overhead Lighting**: The light source, such as the Sun or Moon, is directly above the scene or object. This results in minimal shadows, even illumination, and often reduces contrast in the image.
2. **Back-lighting**: The light source is positioned behind the subject, with the camera facing the subject. As a result, the subject appears darker than the bright background, producing a striking silhouette or shadow effect. It frequently causes a sharp contrast between the background and the subject, which makes it difficult for the camera to record details in the areas that are shaded.
3. **Front-lighting**: The camera faces both subjects and the light source is positioned in front of them, shining directly on them. Usually, this produces uniform lighting, few shadows, and increased detail visibility on the surfaces of the object or scene that face forward.

These lighting conditions are critically important for **computer vision cameras** because they directly affect image quality, contrast, and visibility of details. The direction of the lighting can greatly impact the performance of computer vision algorithms. for applications like depth estimation, image segmentation, and object detection. For instance, while front lighting can improve clarity, back lighting may mask important details by putting objects in shadow. Although overhead lighting produces consistent illumination, the absence of shadows may make textures less visible. To ensure the system's resilience in real-world situations, where lighting conditions will fluctuate constantly, training and testing datasets for computer vision systems must encompass a range of these lighting conditions.

Natural Light Conditions Variety	Day (sun: overhead, back-lighting, front-lighting): Sunlight 107.527 luminous flux

	Day (sun: overhead, back-lighting, front-lighting): Full daylight 10.752 luminous flux
	Day (sun: overhead, back-lighting, front-lighting): Overcast day 1.075 luminous flux
	Day (sun: overhead, back-lighting, front-lighting): Very dark day 107 luminous flux
	Day (sun: overhead, back-lighting, front-lighting): Twilight 10.8 luminous flux
	Night (Moon: overhead, back-lighting, front-lighting): Deep twilight 1.08 luminous flux
	Night (Moon: overhead, back-lighting, front-lighting): Full moon 0.108 luminous flux
	Night (Moon: overhead, back-lighting, front-lighting): Quarter moon 0.0108 luminous flux
	Night (Moon: overhead, back-lighting, front-lighting): Starlight 0.0011 luminous flux
	Night (Moon: overhead, back-lighting, front-lighting): Overcast night 0.0001 luminous flux
	Hazy Sunshine
	Variable Clouds / Variable Sunshine, Intermittent Sun / Sun Breaks

It can be challenging to define lighting conditions using exact meteorological measurements because of subjectivity and variability. Here are a few broad definitions, though:

1. **Sunny:** When there is little to no cloud cover and the sky is mostly clear. On a clear day, the illumination on a horizontal surface can surpass 120,000 lux.
2. **Bright:** A non-standard term often used interchangeably with "sunny". Even though there are a lot of clouds, it could also mean that the weather is sunny or mostly sunny with strong, direct sunlight.
3. **Mostly Sunny / Partly Cloudy:** When there are 25% to 50% clouds in the sky. Depending on the kind and thickness of the clouds, the illumination can vary greatly, but it is usually higher than 60,000 lux.
4. **Partly Sunny / Mostly Cloudy:** 51% to 75% cloud cover in the sky indicates a partly sunny or mostly cloudy day. though it usually falls between 20,000 and 60,000 lux, the illumination can vary significantly based on the type and thickness of the clouds.
5. **Overcast or cloudy:** When there are more than 75% of clouds in the sky. On a horizontal surface, the illumination is usually less than 20,000 lux.
6. **Hazy Sunshine:** A bright sky devoid of direct sunlight caused by sunlight being diffused by atmospheric particles. The intensity of the haze and the sun's position can affect the illumination.
7. **Variable Clouds / Variable Sunshine, Intermittent Sun / Sun Breaks:** These are situations where the sun and cloud cover can change quickly because of shifting clouds. Depending on the moment-to-moment variations in cloud cover, the illumination can vary significantly.

The given lux values are estimates that may change depending on the sun's altitude, local atmospheric conditions, and geographic location. You would require specialized tools, such as a light meter or pyranometer, for precise measurements.

A.2.2 Time of the Day Types Variety Definition:

A computer vision system's ability to capture images can be greatly impacted by the time of day because of changes in ambient conditions, lighting, and shadows. It's important to capture images at different times of the day to account for these variations. Consider the following typical time ranges:

1. **Early Morning (Dawn):** Usually, this time frame falls between 4:00 and 6:00 AM. It is characterized by low light levels and the emergence of the first light on the horizon. Shadows will be long and stretched out, and colors may seem more subdued.
2. **Morning:** Usually, this occurs from 6:00 AM to 9:00 AM. The color temperature is typically cooler with a blueish tint as light levels rise. There is still some contrast in the picture because the shadows are still quite long.
3. **Mid-Morning:** Usually, this falls between 9:00 and 11:00. Shadows get shorter and light levels rise. Because the sun is higher in the sky, colors may begin to fade.
4. **Midday (Noon):** This usually occurs from 11:00 AM to 1:00 PM. Since the sun is at its zenith, there will be harsh light, few shadows, and a chance of overexposure.
5. **Afternoon:** Usually, this occurs from 1:00 PM to 4:00 PM. Images gain depth as the light warms up and the shadows lengthen.
6. **Evening (Golden Hour):** Usually lasts from 4:00 to 6:00 p.m. The shadows are long and golden, and the light is softer and warmer.
7. **Evening (Dusk):** Usually, this occurs from 6:00 to 8:00 p.m. The color temperature drops as the light levels drop. Shadows lengthen and intensify.
8. **Night:** Usually, this occurs from 8:00 PM to 4:00 AM. There's minimal natural light, and any light present will typically be artificial. This period can be further divided into early night, midnight, and late night.

These time ranges can vary depending on the geographical location and the time of the year. For a computer vision system, it's crucial to have training data from all these different periods to ensure robust performance regardless of the time of day.

Table A.1 Time of day categories

Category	Time Range	No. hours
Early Morning	2:00 AM - 5:00 AM	3
Morning	5:00 AM - 8:00 AM	3

Mid-Morning	8:00 AM - 11:00 AM	3
Midday (Noon)	11:00 AM - 2:00 PM	3
Afternoon	2:00 PM - 5:00 PM	3
Evening	5:00 PM - 8:00 PM	3
Evening (Dusk)	8:00 PM - 11:00 PM	3
Night	11:00 PM - 2:00 AM	3

A.2.3 Sun sphere positioning

Incorporating the sun sphere (the apparent position and shape of the sun) into a computer vision training set is essential because it affects the shape of the sky in the background, lighting, shadows, lens flare, and overall image exposure. The sun's position relative to the horizon changes throughout the day and year, providing different lighting conditions and variability in background appearance.

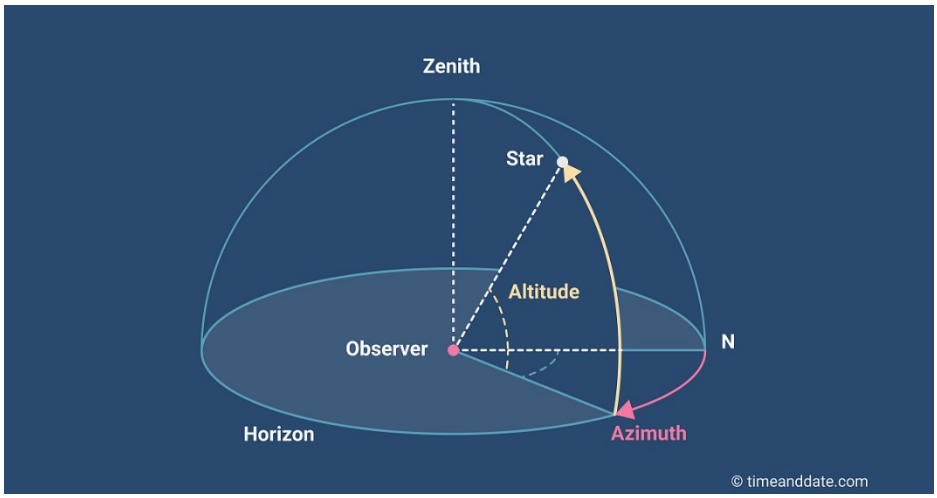

Figure A.1 The horizontal coordinate system (image taken from [2])

To precisely define the metrics for Sun Sphere positions in terms of altitude and azimuth angles, which are necessary for training computer vision models, consider the following guidelines:

Altitude Angle Definitions

1. **Sunrise (Low Angle)**:
    - **Altitude Angle:** Approximately 0° to 6° above the perceived horizon.
    - **Azimuth Angle:** Varies based on geographic location and date but generally within ±10° of the exact geographic east (90°).
2. **Mid-Morning/Mid-Afternoon (Medium Angle)**:
    - **Altitude Angle:** Approximately 20° to 65° above the perceived horizon.
    - **Azimuth Angle:** For morning, 90° < Azimuth < 180° (East to South). For the afternoon, 180° < Azimuth < 270° (South to West).

3. **Noon (High Angle)**:
    - **Altitude Angle:** At or near zenith, which could be up to 90° in the tropics or less at higher latitudes. The specific angle depends on the latitude and the day of the year.
    - **Azimuth Angle:** Approximately 180°, though this can vary significantly with latitude and season.
4. **Sunset (Low Angle)**:
    - **Altitude Angle:** Approximately 0° to 6° above the horizon.
    - **Azimuth Angle:** Varies based on geographic location and date but generally within ±10° of the exact geographic west (270°).

Azimuth Angle Considerations

- The azimuth angle at sunrise and sunset changes with the seasons. For instance, at higher latitudes, the sun rises and sets more to the southeast and southwest in winter and more to the northeast and northwest in summer.
- The exact altitude at which the sun is considered to be at "Mid-Morning/Mid-Afternoon" can vary based on the time of year and latitude, and the same applies to the azimuth range.
- The azimuth angle for noon is not always due south (180°). It can be north of the zenith in some places during some seasons.

A.2.4 Moon sphere positioning

Moon Phases:

1. **New Moon:**
    - **Definition:** The Moon is positioned between the Earth and the Sun, making its illuminated side face away from Earth. The Moon is not visible from Earth in this phase.
    - **Key Characteristics:** No visible Moon; zero illumination.
2. **Waxing Crescent:**
    - **Definition:** A small sliver of the Moon’s surface is visible as the illumination increases after the New Moon.
    - **Key Characteristics:** Less than 50% of the Moon is illuminated, with the illuminated portion growing on the right side.
3. **First Quarter:**
    - **Definition:** Half of the Moon's surface is visible, with the right side illuminated.
    - **Key Characteristics:** 50% of the Moon is visible and illuminated.

4. **Waxing Gibbous:**
    - **Definition:** More than half of the Moon's surface is illuminated, leading up to a Full Moon.
    - **Key Characteristics:** 51%-99% of the Moon is illuminated.
5. **Full Moon:**
    - **Definition:** The entire visible face of the Moon is illuminated and fully visible from Earth.
    - **Key Characteristics:** 100% illumination.
6. **Waning Gibbous:**
    - **Definition:** The Moon begins to wane after the Full Moon, with more than half of its surface still illuminated.
    - **Key Characteristics:** 51%-99% illumination, but decreasing.
7. **Last Quarter:**
    - **Definition:** Half of the Moon's surface is visible, with the left side illuminated.
    - **Key Characteristics:** 50% illumination, with the left half illuminated.
8. **Waning Crescent:**
    - **Definition:** A small portion of the Moon is visible as the illumination decreases, approaching a New Moon.
    - **Key Characteristics:** Less than 50% of the Moon is illuminated, with the illuminated portion on the left side.

Moon Sphere Positioning in the Sky:

1. **Moonrise (Low Angle):**
    - **Definition:** The Moon is just rising above the horizon.
    - **Key Characteristics:**
        - **Altitude Angle:** Between 0° and 6° above the horizon.
        - **Azimuth Angle:** Approximately 90° (East) ±10°.
2. **Early-Night (Medium Angle):**
    - **Definition:** The Moon is moderately elevated in the sky during the early night hours.
    - **Key Characteristics:**
        - **Altitude Angle:** Between 20° and 65° above the horizon.
        - **Azimuth Angle:** Between 90° (East) and 180° (South).
3. **Zenith (High Angle):**
    - **Definition:** The Moon is directly overhead at the highest point in the sky.
    - **Key Characteristics:**
        - **Altitude Angle:** 90° (directly overhead).

        - **Azimuth Angle:** Approximately 180° (South).
4. **Late-Night (Medium Angle):**
    - **Definition:** The Moon is moderately elevated in the sky during the later hours of the night.
    - **Key Characteristics:**
        - **Altitude Angle:** Between 20° and 65° above the horizon.
        - **Azimuth Angle:** Between 180° (South) and 270° (West).
5. **Moonset (Low Angle):**
    - **Definition:** The Moon is descending toward or below the horizon.
    - **Key Characteristics:**
        - **Altitude Angle:** Between 0° and 6° above the horizon.
        - **Azimuth Angle:** Approximately 270° (West) ±10°.

A.3 Env. Aspect 3) Landscape Types Variety Definition:

For computer vision applications, the nature of the landscape can have a significant impact on model performance. Training models on various landscape types is often useful to ensure they can be generalised well across different scenarios. Here are some landscape types often considered in the development and training of computer vision systems:

1. **Urban landscapes:** These are densely populated areas characterised by man-made structures such as buildings, roads, bridges, and other infrastructure. The images usually have many geometric structures and patterns.
2. **Suburban landscapes:** These areas are typically residential and may contain individual houses, parks, small businesses, etc. They have a mixture of natural and man-made elements.
3. **Rural landscapes:** These areas are less populated and may include farmland, small towns, or open country. They often contain more natural elements like fields, trees, and fewer buildings.
4. **Mountainous landscapes:** These landscapes are characterized by mountains, hills, and often forests. The terrain can be quite rugged and uneven.
5. **Forest landscapes:** These are areas primarily covered by trees and undergrowth. Forests can vary greatly in density and types of vegetation.
6. **Desert landscapes:** Deserts are characterized by their lack of precipitation and sparse vegetation. Sand dunes, rocky terrains, and sparse vegetation are typical.
7. **Coastal landscapes:** These are areas bordering or near large bodies of water, such as oceans, seas, or large lakes. They may include beaches, cliffs, and waterfront urban areas.

8. **Water landscapes:** These are primarily bodies of water, such as oceans, seas, lakes, rivers, etc., and may also include boats, buoys, or other waterborne objects.
9. **Industrial landscapes:** These areas include factories, warehouses, ports, power plants, and other industrial structures.
10. **Arctic landscapes:** Characterized by snow-covered ground, icebergs, glaciers, and very sparse vegetation.

These are just some broad categories, and they can be subdivided further. For example, urban landscapes could be divided into residential, commercial, and industrial areas. Additionally, these categories can overlap, such as a forest in a mountainous landscape. The selection of landscape types for training would depend on the specific application of the computer vision model.

The choice of which types of infrastructure to include in the training data depends on the specific application of the computer vision system. For example, a system designed to guide autonomous vehicles will need a lot of training data related to roads, traffic signals, and other transportation infrastructure. In contrast, a system designed to inspect power lines would need training data that includes various types of utility infrastructure.

A.4 Perceived Pictorial Horizon Attitude Categories:

Pictorial Horizon Attitude Category	Pictorial Horizon Roll/Pitch Angles Range
Level Horizon	Roll: -1 to +1, Pitch: 0 to +1
Positively Tilted Level Horizon	Roll: +1 to +90, Pitch: 0 to +1
Negatively Tilted Level Horizon	Roll: -90 to -1, Pitch: 0 to +1
Elevated Level Horizon	Roll: -1 to +1, Pitch: +1 to +45
Positively Tilted Elevated Horizon	Roll: +1 to +90, Pitch: +1 to +45
Negatively Tilted Elevated Horizon	Roll: -90 to -1, Pitch: +1 to +45
Acute Angled Bird's Eye Ground View	Roll: -90 to +90, Pitch: +45 to +80
Bird's Eye Ground View	Roll: -90 to +90, Pitch: +80 to +90
Lowered Level Horizon	Roll: -1 to +1, Pitch: -1 to -45
Positively Tilted Lowered Horizon	Roll: +1 to +90, Pitch: -1 to -45
Negatively Tilted Lowered Horizon	Roll: -90 to -1, Pitch: -1 to -45
Acute Angled Rocket Sky View	Roll: -90 to +90, Pitch: -45 to -80
Ascending Rocket Sky View	Roll: -90 to +90, Pitch: -80 to -90

1. **Level Horizon:** Frame Roll = 0° to <= +/- 1°, Frame pitch = 0° to <= +/- 1° (Standard horizon, splitting the image in the middle or at the desired rule-of-thirds line)

2. **Tilted Level Horizon:**
    i. **Positively Tilted Level Horizon:** Frame Roll =+(1° to <= 90°), Frame pitch = 0° to <= +/- 1°
    i. **Negatively Tilted Level Horizon:** Frame Roll = -(1° to <= 90°), Frame pitch = 0° to <= +/- 1°
2. **Elevated level Horizon:** Frame Roll = 0° to <= +/- 1°, Frame pitch = =+(1° to <= 90°) (Horizon is higher up in the image, can simulate aircraft nose down)
3. **Lowered Horizon:** Frame Roll = 0°, Frame pitch = -(1° to 45°) (Horizon is lower in the image, can simulate aircraft nose up)
4. **Bird's Eye View:** No or minimal elevated horizon visible horizon, can be associated with Frame pitch > -45° (Looking directly down)
5. **Sky view:** No or minimal lowered horizon can be associated with Frame pitch > +45° (Camera looking up, e.g., from the base of a skyscraper or a plane in ascent)
6. **No Horizon:** The image shows no horizon.
7. **Multi-axial Attitude:** Frame Roll and Frame pitch are randomised within specific ranges to simulate a variety of real-world conditions—also, combinations of the above categories.

	0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 70	70 to 80	80 to 90
0 to 10	roll range: 0 to 10/ pitch range: 0 to 10	roll range: 0 to 10/ pitch range: 10 to 20	roll range: 0 to 10/ pitch range: 20 to 30	roll range: 0 to 10/ pitch range: 30 to 40	roll range: 0 to 10/ pitch range: 40 to 50	roll range: 0 to 10/ pitch range: 50 to 60	roll range: 0 to 10/ pitch range: 60 to 70	roll range: 0 to 10/ pitch range: 70 to 80	roll range: 0 to 10/ pitch range: 80 to 90
10 to 20	roll range: 10 to 20 / pitch range: 0 to 10	roll range: 10 to 20 / pitch range: 10 to 20	roll range: 10 to 20 / pitch range: 20 to 30	roll range: 10 to 20 / pitch range: 30 to 40	roll range: 10 to 20 / pitch range: 40 to 50	roll range: 10 to 20 / pitch range: 50 to 60	roll range: 10 to 20 / pitch range: 60 to 70	roll range: 10 to 20 / pitch range: 70 to 80	roll range: 10 to 20 / pitch range: 80 to 90
20 to 30	roll range: 20 to 30/	roll range: 20 to 30/	roll range: 20 to 30/	roll range: 20 to 30/	roll range: 20 to 30/	roll range: 20 to 30/	roll range: 20 to 30/	roll range: 20 to 30/	roll range: 20 to 30/

	pitch range: 0 to 10	pitch range: 10 to 20	pitch range: 20 to 30	pitch range: 30 to 40	pitch range: 40 to 50	pitch range: 50 to 60	pitch range: 60 to 70	pitch range: 70 to 80	pitch range: 80 to 90
30 to 40	roll range: 30 to 40/ pitch range: 0 to 10	roll range: 30 to 40/ pitch range: 10 to 20	roll range: 30 to 40/ pitch range: 20 to 30	roll range: 30 to 40/ pitch range: 30 to 40	roll range: 30 to 40/ pitch range: 40 to 50	roll range: 30 to 40/ pitch range: 50 to 60	roll range: 30 to 40/ pitch range: 60 to 70	roll range: 30 to 40/ pitch range: 70 to 80	roll range: 30 to 40/ pitch range: 80 to 90
40 to 50	roll range: 40 to 50/ pitch range: 0 to 10	roll range: 40 to 50/ pitch range: 10 to 20	roll range: 40 to 50/ pitch range: 20 to 30	roll range: 40 to 50/ pitch range: 30 to 40	roll range: 40 to 50/ pitch range: 40 to 50	roll range: 40 to 50/ pitch range: 50 to 60	roll range: 40 to 50/ pitch range: 60 to 70	roll range: 40 to 50/ pitch range: 70 to 80	roll range: 40 to 50/ pitch range: 80 to 90
50 to 60	roll range: 50 to 60/ pitch range: 0 to 10	roll range: 50 to 60/ pitch range: 10 to 20	roll range: 50 to 60/ pitch range: 20 to 30	roll range: 50 to 60/ pitch range: 30 to 40	roll range: 50 to 60/ pitch range: 40 to 50	roll range: 50 to 60/ pitch range: 50 to 60	roll range: 50 to 60/ pitch range: 60 to 70	roll range: 50 to 60/ pitch range: 70 to 80	roll range: 50 to 60/ pitch range: 80 to 90
60 to 70	roll range: 60 to 70/ pitch range: 0 to 10	roll range: 60 to 70/ pitch range: 10 to 20	roll range: 60 to 70/ pitch range: 20 to 30	roll range: 60 to 70/ pitch range: 30 to 40	roll range: 60 to 70/ pitch range: 40 to 50	roll range: 60 to 70/ pitch range: 50 to 60	roll range: 60 to 70/ pitch range: 60 to 70	roll range: 60 to 70/ pitch range: 70 to 80	roll range: 60 to 70/ pitch range: 80 to 90
70 to 80	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch	roll range: 70 to 80/ pitch

	range: 0 to 10	range: 10 to 20	range: 20 to 30	range: 30 to 40	range: 40 to 50	range: 50 to 60	range: 60 to 70	range: 70 to 80	range: 80 to 90
80 to 90	roll range: 80 to 90/ pitch range: 0 to 10	roll range: 80 to 90/ pitch range: 10 to 20	roll range: 80 to 90/ pitch range: 20 to 30	roll range: 80 to 90/ pitch range: 30 to 40	roll range: 80 to 90/ pitch range: 40 to 50	roll range: 80 to 90/ pitch range: 50 to 60	roll range: 80 to 90/ pitch range: 60 to 70	roll range: 80 to 90/ pitch range: 70 to 80	roll range: 80 to 90/ pitch range: 80 to 90

A.5 Env. Aspect 5) Geographical region-specific natural phenomena:

A.5.1 Atmospheric Phenomena:

- **Northern and Southern Lights (Aurora Borealis and Aurora Australis)**:
  - Commonly observed near the polar regions, such as in Scandinavia, Canada, Alaska, and Antarctica.
- **Monsoons**:
  - Prominent in South Asia, Southeast Asia, and parts of Africa, bringing seasonal rain and weather patterns.
- **Tornadoes**:
  - Frequently occur in the Central United States, particularly in "Tornado Alley," and other areas with similar climates.
- **Hurricanes, Typhoons, and Cyclones**:
  - In the Atlantic and Northeast Pacific, they're called hurricanes; in the Northwest Pacific, they're called typhoons; and in the South Pacific and Indian Ocean, they're known as cyclones.
- **Haboobs (Intense Dust Storms)**:
  - Occur in arid regions like the Sahara Desert, the Middle East, and the Southwest United States.

A.5.2 Hydrological Phenomena:

- **Floods**:
  - Common in regions with excessive rainfall or rivers that overflow, such as the floodplains of the Amazon, the Ganges, and the Nile.
- **Tsunamis**:

- Often occur in the Pacific Ocean's "Ring of Fire," affecting coastal areas with seismic activity.

A.5.3 Geological Phenomena:

- **Earthquakes**:
  - Frequently experienced along tectonic plate boundaries, such as the Pacific Ring of Fire, or along faults like the San Andreas Fault in California.
- **Volcanic Eruptions**:
  - Common in volcanic regions like the Pacific Ring of Fire, which includes countries like Japan, the Philippines, and Indonesia, as well as in Iceland and parts of East Africa.
- **Geysers and Hot Springs**:
  - Often found in volcanic and geothermal areas like Yellowstone National Park (USA), Iceland, and New Zealand.

A.5.4 Biological Phenomena:

- **Migration**:
  - Seasonal movements of animals are common across various regions, such as the great wildebeest migration in Africa or the migration of monarch butterflies in North America.
- **Bioluminescence**:
  - Visible in certain oceans like the Maldives, parts of the Caribbean, and San Diego due to algae or plankton, and in caves with glow-worms like in New Zealand.
- **Algal Blooms**:
  - These can occur in various regions, including the Baltic Sea and the Gulf of Mexico, often as a result of nutrient pollution.

A.5.5 Cryospheric Phenomena:

- **Icebergs and Ice Calving**:
  - Common in polar regions like Greenland and Antarctica.
- **Avalanches**:
  - Occur in mountainous regions with heavy snow, such as the Alps, the Himalayas, and the Rocky Mountains.

A.5.6 Celestial Phenomena:

- **Solar and Lunar Eclipses**:
  - Visible in different areas of the world during specific times; their visibility and type can be geographically specific.
- **Meteor Showers**:
  - Visible globally but best seen in areas with dark skies, away from city lights.

A.5.7 Seasonal Phenomena:

- **Cherry Blossoms**:
  - Seasonal blooming is famous in Japan, as well as in other parts of the world like Washington D.C.
- **Fall Foliage**:
  - The changing colors of leaves in autumn are best seen in temperate deciduous forests, such as those in the Northeast United States, Canada, and parts of Europe and Asia.

A.5.8 Extreme Weather Phenomena:

- **Heatwaves**:
  - Can occur in various regions but are especially intense in places like Australia, the Middle East, and Europe.
- **Polar Vortex**:
  - Brings extremely cold temperatures to the northern parts of North America.

A.5.9 Oceanic Phenomena:

- **El Niño and La Niña**:
  - Climatic patterns affecting the Pacific region, altering weather globally.
- **Whirlpools and Maelstroms**:
  - Occur in areas with strong tides and currents, like Saltstraumen in Norway.

A.5.10 Fire Phenomena:

- **Wildfires**:
  - Often occur in regions like the Western United States, Australia, and the Mediterranean during dry seasons.

- **Fire Whirls**:
    - Can happen in association with wildfires.

A.6 Env. Aspect 6) Time of the Year: Seasons-specific changes

A.6.1 Spring

- **Vegetation**: Budding and blooming of plants, which can alter colour and texture patterns in the environment.
- **Animal Activity**: Increased wildlife movement and presence.

A.6.2 Summer

- **Vegetation**: Dense and lush greenery, with high foliage obstructing views and sensors.
- **Animal Activity**: Consistent animal presence patterns might affect motion detection systems.

A.6.3 Autumn

- **Vegetation**: Changing leaf colours and falling leaves alters the visual landscape and the ground conditions (e.g., slippery roads).
- **Animal Activity**: Migration and preparation for winter can change animal behaviours and their interaction with the environment.

A.6.4 Winter

- **Vegetation**: Bare trees and snow-covered landscapes, which alter visual patterns and contrast levels.
- **Animal Activity**: Reduced or altered due to hibernation or winter survival strategies.

A.7 Comprehensive ODD For Land and Air Autonomous Systems

Below is a table illustrating the output derived from the Multi-Environment ODD process in Chapter 6. Appendix A offers a detailed definition of each aspect within the categories. Some aspects are inherently clear and specific; however, they may be open for further classification if needed. We opted not to include additional details for certain manmade environment categories. The use of the ODD depends on the constraints of the specific application. Practitioners may choose to utilise the entire classification or select portions, provided they offer justification for excluding certain classes in favour of others.

Table A.2 Land and Air comprehensive ODD

Level 1: Class	***Level 2*** & Level 3**:** Attributes	Level 4: Attributes
ODD natural surrounding taxonomy		
Weather Conditions Variety Definition	***Temperature***	Extreme Cold: Below -30°C
		Severe Cold: -30°C to -10°C
		Cold: -10°C to 0°C
		Cool: 0°C to 10°C
		Mild: 10°C to 20°C
		Warm: 20°C to 30°C
		Hot: 30°C to 40°C
		Extreme Hot: Above 40°C
	Precipitation	Snow
		Light snow: 1km (5/8 statute mile) or more associated visibility
		Moderate snow: < 1km > 0.5km (5/16 statue mile) associated visibility
		Heavy snow: < 0.5km associated visibility
		Rainfall

		Light rain: < 0.25 centimeters per hour
		Moderate rain: 0.26 - 0.76 centimeters per hour
		Heavy rain: > 0.76 centimeters per hour
		Freezing rain
		Hail
		Drizzle
	Wind	Light air: 1-3 mph
		Light breeze: 5-7 mph
		Gentle breeze: 8-12 mph
		Moderate breeze: 13-18 mph
		Fresh breeze: 20-24 mph
		Strong breeze: 25-31 mph
		Near gale: 32-38 mph
		Gale: 39-46 mph
		Strong gale: 47-54 mph
		Storm: 55-63 mph
		Violent storm: 64-72 mph
		Hurricane: 74+ mph
	Humidity	Low Absolute Humidity
		Moderate Absolute Humidity
		High Absolute Humidity
	Pressure	
	Absolute Pressure Levels	Low Atmospheric Pressure
		Normal Atmospheric Pressure
		High Atmospheric Pressure
		Stable Pressure

	Pressure Variation Types	Fluctuating Pressure
		Seasonal Pressure Variations
	Pressure Gradient	Low Pressure Gradient
		Moderate Pressure Gradient
		High Pressure Gradient
	Altitude-Based Pressure Levels	Sea-Level Pressure
		Low-Altitude Pressure
		Medium-Altitude Pressure
		High-Altitude Pressure
	Fog	Fog severity = 5: 200 (61)–0 visibility in feet (meters)
		Fog severity = 4: 800 (244)–200 (61) visibility in feet (meters)
		Fog severity = 3: 2,640 (805)–800 (244) visibility in feet (meters)
		Fog severity = 2: 5,280 (1609) (mist) -2,640 (805) visibility in feet (meters)
		Fog severity = 1: >5,280 (1609) (mist) visibility in feet (meters)
	UV Index	Low UV Index: [0-2]
		Moderate UV Index: [3-5]
		High UV Index: [6-7]
		Very High UV Index: [8-10]
		Extreme UV Index: [11+]
	Pollen	Low Pollen Count: [1-30 pollen grains/m^3]

		Moderate Pollen Count: [31-49 pollen grains/m^3]
		High Pollen Count: [50-149 pollen grains/m^3]
		Very High Pollen Count: [150+ pollen grains/m^3]
	Sandstorms	No Sandstorm: Visibility > 10,000 meters
		Light Sandstorm: Visibility 5,000 - 10,000 meters
		Moderate Sandstorm: Visibility 1,000 - 5,000 meters
		Heavy Sandstorm: Visibility 200 - 1,000 meters
		Severe Sandstorm: Visibility < 200 meters
	Cloud Cover Variety	Clear or Blue Sky (0/8 oktas)
		Mostly Clear or Sunny (1/8 to 2/8 oktas)
		Partly Cloudy or Fair (3/8 to 4/8 oktas)
		Mostly Cloudy or Cloudy (5/8 to 7/8 oktas)
		Overcast (8/8 oktas)
		Obscured or Foggy
Time of the Year Seasons-specific changes	Spring	
	Summer	
	Autumn	
	Winter	
	Urban landscapes	

Landscape Types Variety Definition	Suburban landscapes	
	Rural landscapes	
	Mountainous landscapes	
	Forest landscapes	
	Desert landscapes	
	Coastal landscapes	
	Water landscapes	
	Industrial landscapes	
	Arctic landscapes	
Illumination Variety Definition	***Time of the day***	Early Morning (Dawn)
		Morning
		Mid-Morning
		Midday (Noon)
		Afternoon
		Evening (Golden Hour)
		Evening (Dusk)
		Night
	Natural Light Conditions Variety	Day (sun: overhead, back-lighting, front-lighting): Sunlight 107.527 luminous flux
		Day (sun: overhead, back-lighting, front-lighting): Full daylight 10.752 luminous flux
		Day (sun: overhead, back-lighting, front-lighting): Overcast day 1.075 luminous flux

		Day (sun: overhead, back-lighting, front-lighting): Very dark day 107 luminous flux
		Day (sun: overhead, back-lighting, front-lighting): Twilight 10.8 luminous flux
		Night (Moon: overhead, back-lighting, front-lighting): Deep twilight 1.08 luminous flux
		Night (Moon: overhead, back-lighting, front-lighting): Full moon 0.108 luminous flux
		Night (Moon: overhead, back-lighting, front-lighting): Quarter moon 0.0108 luminous flux
		Night (Moon: overhead, back-lighting, front-lighting): Starlight 0.0011 luminous flux
		Night (Moon: overhead, back-lighting, front-lighting): Overcast night 0.0001 luminous flux
		Hazy Sunshine
		Variable Clouds / Variable Sunshine, Intermittent Sun / Sun Breaks
	Sun sphere positioning in the sky	Sunrise (Low Angle): Altitude Angle [0° to 6°], Azimuth Angle [90°±10°]
		Mid-Morning (Medium Angle): Altitude Angle [20° to 65°], Azimuth Angle [90° < Azimuth < 180°]
		Noon (High Angle): Altitude Angle [90°], Azimuth Angle [180°]

		Mid-Afternoon (Medium Angle): Altitude Angle [20° to 65°], Azimuth Angle [180° < Azimuth < 270°]
		Sunset (Low Angle): Altitude Angle [0° to 6°], Azimuth Angle [270°±10°]
		Seasonal Azimuth Angle Variations for the Sun
	Moon Phases	New Moon: Moon is between Earth and Sun
		Waxing Crescent: Small part of Moon is visible
		First Quarter: Half of the Moon is visible
		Waxing Gibbous: More than half of the Moon visible
		Full Moon: Entire Moon is visible
		Waning Gibbous: More than half of the Moon visible
		Last Quarter: Half of the Moon is visible
		Waning Crescent: Small part of Moon is visible
	Moon Sphere Positioning in the Sky	Moonrise (Low Angle): Altitude Angle [0° to 6°], Azimuth Angle [90°±10°]
		Early-night (Medium Angle): Altitude Angle [20° to 65°], Azimuth Angle [90° < Azimuth < 180°]
		Zenith (High Angle): Altitude Angle [90°], Azimuth Angle [180°]
		Late-night (Medium Angle): Altitude Angle [20° to 65°], Azimuth Angle [180° < Azimuth < 270°]
		Moonset (Low Angle): Altitude Angle [0° to 6°], Azimuth Angle [270°±10°]

Geographical region-specific natural phenomena	***Atmospheric Phenomena***	Northern and Southern Lights (Aurora Borealis and Aurora Australis)
		Monsoons
		Tornadoes
		Hurricanes, Typhoons, and Cyclones
		Haboobs (Intense Dust Storms)
	Hydrological Phenomena	Floods
		Tsunamis
	Geological Phenomena	Earthquakes
		Volcanic Eruptions
		Geysers and Hot Springs
	Biological Phenomena	Migration
		Bioluminescence
		Algal Blooms
	Cryospheric Phenomena	Icebergs and Ice Calving
		Avalanches
	Celestial Phenomena	Solar and Lunar Eclipses
		Meteor Showers
	Seasonal Phenomena	Cherry Blossoms
		Fall Foliage
	Extreme Weather Phenomena	Heatwaves
		Polar Vortex
		El Niño and La Niña

	Oceanic Phenomena	Whirlpools and Maelstroms
	Fire Phenomena	Wildfires
		Fire Whirls
Perceived Visible Horizon Attitude	***Captured Image Rotational Movements***	Frame Roll (Camera Rotation around the front-to-back axis)
		Frame pitch (Camera Rotation around the side-to-side axis)
	Captured Horizon Attitude	Level Horizon
		Tilted Horizon
		Elevated Horizon
		Lowered Horizon
		Bird's Eye View
		High Angle
		Randomised Attitude
Natural Noise and Interference	***Natural Auditory Noise Factors***	Wind Noise
		Animal Sounds
		Vegetation Movement
		Thunderstorms
		Atmospheric Noise
	Natural Interference Factors	Electromagnetic Interference (EMI) from Natural Sources
		Terrain-induced Interference
		Water Bodies Reflection of Signals
Manmade Surroundings Definition (Land (Road and Railways) and Air domains)		
		Road Surface Conditions

Road Transportation Engineered Surrounding	***Road Transport Physical Infrastructure***	Roadway edges
		Roadway Geometry
		Roadway Surfaces
		Roadway Types
	Road Transport Connectivity	Communication obstructions
		Crowdsourced data
		Infrastructure sensors and communication
		Remote fleet management system
		Traffic density info
		V2I
		Vehicles
	Road Transport objects of interest	Non-roadway influential obstacles/objects
		Roadway users
		Signage
		Traffic control devices
	Road Transport Operational constraints	Speed limit
		Traffic conditions
Railways Transportation Engineered Surrounding	***Railways Transport Physical Infrastructure***	Rail Tracks Surface Conditions
		Rail Tracks edges
		Rail Tracks Geometry
		Rail Tracks Surfaces
		Rail Tracks Types

		Rail Tracks equipment
		Level crossing
		Railways stations
	Railways Transport Connectivity	Communication obstructions
		Crowdsourced data
		Infrastructure sensors and communication
		Remote fleet management system
		Traffic density info
		Train to Wayside
		Train to Train
	Railways Transport objects of interest	Non-train-related influential obstacles/objects
		Train users
		Signage
		Train Traffic control devices
		Rail Tracks maintenance objects and people
		Train types
		Rail Tracks Zones
	Railways Transport Operational constraints	Speed limit
		Train Traffic conditions
		Operational Times
		Emergency Protocols
		Infrastructure Availability
		Safety Regulations

Air Transportation Engineered Surrounding	***Air Transportation Physical Infrastructure***	Airports and Airfields
		Airspace Infrastructure
		Air Navigation Facilities
		Communication Infrastructure
		Lighting Systems
		UAV Charging Stations
Air Transportation Connectivity	***Communication Obstructions***	Inadequate Crowdsourced Data for training ML components
		Infrastructure Sensors and Communication
		Remote Fleet Management System
		Traffic Density Information
		Airborne Vehicle-to-Infrastructure (V2I) Communication
		Airborne Vehicle-to-Airborne Vehicle (AV2AV) Communication
Air Transportation Objects of Interest	***Non-Aircraft related Obstacles/Objects***	Aircraft types
		Signage and Signals
		Maintenance Systems
Air Transportation Operational Constraints	***Speed Limits***	
	Traffic Conditions	
	CAA and Safety Regulations	

	Environmental Regulations	
	Allowable Altitude	
	Mission Specific Constraints	
	Flight Autonomy Modes	
	Duration and Range	
Manmade Surroundings Noise and Interference	***Land-based Noise and Interference Factors***	
	Acoustic Noise	Traffic noise
		Industrial noise
		Construction noise
		Urban noise (e.g., crowds, music)
	Vibrational Interference	Road vibrations
		Construction vibrations
		Railway vibrations
	Electromagnetic Interference (EMI)	Power lines
		Communication towers
		Radio frequency interference (RFI)
		Inductive noise
	Light Pollution	Streetlights
		Vehicle headlights
		Urban lighting

	Air-based Noise and Interference Factors	
	Acoustic Noise	Aircraft engine noise
		Urban air traffic noise
		Airport noise
		Helicopter noise
	Vibrational Interference	Air turbulence
		Engine vibrations
		Mechanical vibrations
	Electromagnetic Interference (EMI)	Radar systems
		Satellite communications
		Atmospheric RFI
		High-voltage power lines
	Light Pollution	City lights
		Aviation lighting systems
		Reflective surfaces