1. **Objective 1: Spectral Indices Monitoring**

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| 1. Vegetation Health and Vigor Indicators  Normalized Difference Vegetation Index: NDVI = (NIR – Red) / (NIR + Red)  Customized NDVI: CNDVI = (NIR940 - Red660)/(NIR940 + Red660)  Green NDVI: GNDVI = (NIR - Green) / (NIR + Green)  Blue NDVI: BNDVI = (NIR - Blue) / (NIR + Blue)  Green Red NDVI: GRNDVI = (NIR – (Green+Red)) / (NIR + (Green+Red))  Green Blue NDVI: GBNDVI = (NIR – (Green+Blue)) / (NIR + (Green+Blue))  Red Blue NDVI: RBNDVI = (NIR – (Red+Blue)) / (NIR + (Red+Blue))  Red Edge Normalized Difference Vegetation Index RENDI = (R750 – R705) / (R750 + R705)  Red Edge NDVI: NDRE = (NIR - Rededge) / (NIR + Rededge)  Soil Adjusted Vegetation Index: SAVI = (1 + slope\_soil) × (NIR - Red) / (NIR + Red + slope\_soil)  Modified Soil Adjusted Vegetation Index: MSAVI = (1/2)\* (2\*(NIR+1) - Sqrt( (2NIR+1)^2 – 8\*(NIR -Red) ))  Optimized Soil Adjusted Vegetation Index: OSAVI = (1.16 \* (NIR - Red) / (NIR + Red + 0.16)  Triangular Vegetation Index: TVI = 0.5 \* (120 \* (NIR - Green) - 200 \* (Red - Green))  Modified Triangular Vegetation Index: MTVI = 1.2 \* (1.2\*(NIR - Green) – 2.5\*(Red - Green))  2. Water Content and Drought Stress  Perpendicular Vegetation Index: PVI = (NIR - slope\_soil × Red - intercept) / sqrt(slope\_soil^2 + 1)  Weighted Difference Vegetation Index: WDVI = NIR - slope\_soil \* Red  3. Chlorophyll Content  Red Edge Chlorophyll Index: RECI = (NIR/Rededge) - 1  Chlorophyll Index: CI = (NIR / Red) - 1  Corrected Chlorophyll Index: CCI = ((NIR / Red) - 1) / ((NIR / Red) + 1)  Chlorophyll Absorption in Reflectance Index: CARI = ( (R700 - Red) – 0.2 \* (R700 - Green) \* (R700/Red) ) / sqrt(1 + (R700 / Red)^2)  Modified Chlorophyll Absorption in Reflectance Index: MCARI = ((Red - Green) - 0.2 \* (Red - Blue)) \* (Red/Green)  Transformed Chlorophyll Absorption in Reflectance Index: TCARI =3 \* ((Green-Red) - 0.2 \* (Green-Blue) \* (Green/Red))  Normalized Difference Chlorophyll Index: NDCI = (R705 - Red) / (R705+ Red)  4. Leaf Pigment Content  Anthocyanin Reflectance Index: ARI = (1 / Green) – (1 / R700)  Modified Anthocyanin Reflectance Index: mARI = ( 1 / Green - 1 / R705) \* R860  Normalized Anthocyanin Reflectance Index: NARI = ( (1 / Green) – (1 / R700) ) / ((1 / Green) + (1 / R700))  Modified Anthocyanin Content Index: mACI = R940 / R530  Normalized Difference Anthocyanin Index: NDAI = (Red - Green) / (Red + Green)  Green Ratio Index GRI = R660 / Green  Carotenoid Reflectance Index: CRI = (1 / R510) – (1 / Green)  Simple Ratio Pigment Index: SRPI = Red / Green  5. Light Use Efficiency and Photosynthetic Activity  Photochemical Reflectance Index: PRI = (R531 - R570) / (R531 + R570)  Enhanced Vegetation Index: EVI = 2.5 \* (NIR - Red) / (NIR + 6 \* Red – 7.5 \* Blue +1)  Simple Ratio: SR = NIR / Red  Modified Red Edge Simple Ratio: MRESR = (R750 - Blue) / (R705 - Blue)  Modified Simple Ratio Index: MSRI = ((NIR/Red) - 1) / (NIR/Blue)  6. Leaf and Canopy Structure  Difference Vegetation Index: DVI = NIR - Red  Structure Insensitive Pigment Index: SIPI = (NIR - Blue) / (NIR + Red)  7. Visible Reflectance  Excess Green: ExG = 2\*Green - Red - Blue  Excess Red: ExR =1.4\*Red - Green  Excess Blue: ExB = 1.4\*Blue - Green  Plant Senescence Reflectance Index: PSRI = (Red - R500) / R750  8. Greenness and Vegetative Cover  Green Chlorophyll Index: GCI = (NIR/Green) − 1  Derivative Green Chlorophyll Index: DGCI = (NIR - Green) / (NIR + Green)  Normalized Green Red Difference Index: NGRDI = (Green - Red) / (Green + Red)  Green Leaf Index: GLI = 2\*Green - Red - Blue |

1. **Objective 2: VPD, SPV Monitoring**

The amount of water in the air can be measured in terms of pressure; the more water there is in the air, the greater the pressure it exerts at the surface.

**Vapor pressure deficit (VPD) -** measures how much water is in the air

**Saturation vapor pressure (SVP) -** measures maximum amount of water vapor that can exist in that air.

<https://en.wikipedia.org/wiki/Vapour-pressure_deficit>

To compute the VPD - , we need the ambient (greenhouse) air temperature, the relative humidity and, if possible, the canopy air temperature.

We must then compute the **saturation pressure -** . Saturation pressure can be looked up in a psychrometric chart or derived from the Arrhenius equation; a way to compute it directly from temperature is:

We know that,

So, above equation becomes:

Where is in **Rankine scale** and A, B, C, D, E and F are constants.

Now, to convert the **Rankine scale to Celcius**:

We use following formula:

Now replace by above formula, by in degree **Celsius** we get:

Where,

is in Degree Celcius.

We compute this pressure for both the ambient and canopy temperatures.

We then can compute the actual partial pressure of the water vapour in the air by multiplying by the relative humidity (**RH**) [%]:

and finally, **VPD** using

or

when he canopy temperature is known.

Or simply, **VPD**, as below:

**Compute Dew Point Temperature (Bolton 1980)**

<https://archive.eol.ucar.edu/projects/ceop/dm/documents/refdata_report/eqns.html>

     where

       = Temperature in degree Celcius

       = dew point in degree Celsius  
       = SVP in mb, where 1 mb = 1hpa  
       = VPD in mb, where 1 mb = 1hpa  
       = Relative Humidity in percent

**Compute the Specific Humidity (Bolton 1980)**

<https://archive.eol.ucar.edu/projects/ceop/dm/documents/refdata_report/eqns.html>

    where:  
       = VPD in hPa  
       Surface pressure in hPa = 1013.25 hPa  
       = specific humidity in

<https://en.wikipedia.org/wiki/Clausius%E2%80%93Clapeyron_relation>

The **Clausius–Clapeyron relation**, in chemical thermodynamics specifies the temperature dependence of pressure, most importantly vapor pressure, at a discontinuous phase transition between two phases of matter of a single constituent. It's named after Rudolf Clausius[1] and Benoît Paul Émile Clapeyron. Its relevance to meteorology and climatology is the increase of the water-holding capacity of the atmosphere by about 7% for every 1 °C (1.8 °F) rise in temperature. James Thomson and William Thomson confirmed the relation experimentally in 1849-50, and it was historically important as a very early successful application of theoretical thermodynamics.

Atmospheric water vapor drives many important meteorologic phenomena (notably, precipitation), motivating interest in its dynamics. The **Clausius–Clapeyron equation** for water vapor under typical atmospheric conditions (near standard temperature and pressure) is

where

is saturation vapor pressure,

is temperature,

is the gas constant of water vapour,

is the gas constant of water vapour.

The temperature dependence of the latent heat (and of the saturation vapor pressure ) cannot be neglected in this application.

<https://en.wikipedia.org/wiki/Vapour_pressure_of_water#Accuracy_of_different_formulations>

But see also the discussion of the accuracy of different approximating formulae for saturation vapour pressure of water:

1 mmHg = 1.33322 hPa.

<https://tc.copernicus.org/preprints/tc-2023-8/tc-2023-8.pdf>

**August equation**

where is the SVP in hPa and temperature in °C.

**Antoine equation**

Original formula:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **A** | **B** | **C** | **Tmin °C** | **Tmax °C** |
| **Water** | 8.07131 | 1730.63 | 233.426 | 1 | 99 |
| **Water** | 8.14019 | 1810.94 | 244.485 | 100 | 374 |

where is the SVP in **mmHg** and temperature in °C, A, B and C are unattributed constants.

Revised formula:

To convert into hPa, we write below:

where is the SVP in hPaand temperature in °C.

Example: for of water, we get below:

Example: for of water, we get below:

**August–Roche–Magnus formula**

where is in hPa and is in degree celcius. The coefficient denotes the reference SVP at a certain temperature, usually, , and the other coefficients are determined via empirical polynomial fits. hectopascal () = .

This is also sometimes called the **Magnus or Magnus–Tetens** approximation, though this attribution is historically inaccurate. Unlike the Goff-Gratch formula, the August-Roche-Magnus formula is simple in structure and highly accurate; as such, this formula is more commonly applied in permafrost research studies (e.g., Westermann et al., 2016).

Under typical atmospheric conditions, the denominator of the exponent depends weakly on (for which the unit is degree Celsius). Therefore, the **August–Roche–Magnus** equation implies that saturation water vapor pressure changes approximately exponentially with temperature under typical atmospheric conditions, and hence the water-holding capacity of the atmosphere increases by about 7% for every 1 °C rise in temperature.

**Tetens’s formula**

The structure of Tetens’s formula is similar to the Magnus form. Interestingly, this short equation (over the water surface or without over-ice correction) is considered a general form to calculate the SVP for all temperature ranges and is also commonly used in the literature (e.g., Xu et al., 2012; Valiantzas, 2013; Nian et al., 2022), as below:

wherese is the SVP in hPa and temperatureT in °C. However, some studies have argued that the above should only be applied to calculate the SVP over water surfaces (), and a different equation (with over-ice correction) should be used for over-ice surfaces () (e.g., Murray, 1967; Liu et al., 2021). The over-ice form is expressed as below:

According to Murray (1967), the combination of Eqs. (7a) and (7b) for Tetens’s formula are within 0.1 % of the Goff-Gratch calculations for temperatures -10 °C and above, and within 1 % for temperatures between -30 °C and -10 °C. This formula is acceptable for most meteorological purposes.

**Arden Buck equation**

The Arden Buck equations are a group of empirical correlations that relate the saturation vapor pressure to temperature for moist air. The curve fits have been optimized for more accuracy than the Goff–Gratch equation in the range −80 to 50 °C (−112 to 122 °F).

**Buck** used a minimax fitting procedure to derive a relatively simple equation for calculating the SVP of water (from 0 °C to 50 °C) and of ice (from -50 °C to 0 °C) as below (Buck, 1981):

where is the SVP in hPa and temperature in °C. According to Mackay et al. (2017), the Buck formula is the most appropriate SVP formulation for use in cold region studies.

**Wexler formula**

To get a simple and robust equation for calculating the SVP, one-half of the Wexler formula (over the water surface or without over-ice correction) is also used for all temperature ranges in several studies (e.g., Li et al., 2017; Brauner, 2019; Xie et al., 2022), as below:

where is the SVP in hPa and temperatureT in °C. However, some studies suggest a correction term should be added to130 the calculation of the SVP over a surface of ice (e.g., Gill, 1982; Leppäranta, 2015); i.e., if the air temperature is below zero, the corrected SVP is expressed as below:

**Hardy (Hardy, 1998):**

with T in °C and in hPa.

1 Pa = 0.01 hPa

**Sonntag (Sonntag, 1994):**

with T in °C and in hPa.

**Murphy and Koop (Murphy and Koop, 2005)**

for -150.15 °C < < 58.85 °C.

**Goff–Gratch equation**

The internationally accepted formula for calculating the SVP is that of Goff & Gratch (1946) for air temperatures between 50 °C and 102 °C. For a planar surface of pure water and ice, the Goff-Gratch formula is expressed as (e.g., Murray, 1967):

where is the SVP in hPa and temperature in °C.

While the Goff-Gratch formula is demonstrated to have high accuracy (e.g., Alduchov& Eskridge, 1996; Vömel, 2016), it is tedious and inconvenient for use in many applications of calculating the SVP. Therefore, simpler empirical formulas have been developed, and these formulations are applied in many research studies.

1. Xiang Huang, Charles J. Abolt, and Katrina E. Bennett, Brief Communication: Effects of different saturation vapor pressure calculations on simulated surface-subsurface hydrothermal regimes at a permafrost field site, The Cryosphere, 2023, <https://tc.copernicus.org/preprints/tc-2023-8/tc-2023-8.pdf>, <https://doi.org/10.5194/tc-2023-8>
2. **Objective 3: Leaf capacitance Monitoring**

**To Do List**

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| **Comparative Analysis Across Species or Varieties:**  You could use the spectral indices to compare different plant species or varieties under the same environmental conditions to determine which are more resilient to stressors like drought or nutrient deficiencies. |
| **Temporal Analysis:**  Conduct a temporal analysis to observe how plants change over time under constant or variable conditions. This can help in understanding growth patterns, seasonal changes, and the onset of stress conditions. |
| **Environmental Correlation Studies:**  Without ground truth data, you can still correlate changes in spectral indices with environmental data like weather patterns, soil moisture readings from sensors, or satellite-derived environmental information. |
| **Spectral Index Fusion:**  Fuse multiple spectral indices to create composite indicators that might be more robust in indicating specific plant conditions or stressors. |