[NDVI 2](#_Toc149566096)

[Huang, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. In *Journal of Forestry Research* (Vol. 32, Issue 1). Northeast Forestry University. https://doi.org/10.1007/s11676-020-01155-1 2](#_Toc149566097)

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[Fernández-Duque, B., Vicente-Serrano, S. M., Maillard, O., Domínguez-Castro, F., Peña-Angulo, D., Noguera, I., Azorin-Molina, C., & el Kenaway, A. (2023). Long-term observed changes of air temperature, relative humidity and vapour pressure deficit in Bolivia, 1950-2019. International Journal of Climatology, 117, 1–21. https://doi.org/10.13039/501100011033 4](#_Toc149566100)

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# NDVI

## Huang, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. In *Journal of Forestry Research* (Vol. 32, Issue 1). Northeast Forestry University. <https://doi.org/10.1007/s11676-020-01155-1>

* There are more than one 100 veg indices that have been derived from multispectral imagery (Xue and Su, 2017).
* Climate change and classification became more popular; leaf area index (LAI) became more popular in absolute number but less popular in number percentage.
* Studies have demonstrated that NDVI is effective to differentiate savannah, dense forest, non-forest and agricultural fields and to determine evergreen forest versus seasonal forest types (Pettorelli et al., 2005), and estimate various vegetation properties, including the LAI (Tian et al., 2017), plant productivity (Vicente-Serrano et al., 2016).
* The major problems in NDVI include its atm. effect, its ease for saturation, and sensor quality.

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* *Z*-scores of NDVI distribution are used to estimate the probability of occurrence of the present vegetation condition at a given location relative to the possible range of vegetative vigor, historically.
* While the NDVI has proven useful for timely estimation of vegetation conditions, as a normalized ration, it does not allow for relative comparison at a pixel location or time period.
* The ability to compare pixel values this way would be useful for removing seasonal vegetation changes, facilitating interpretation through the historical record and between different vegetation.
* Kogan (1990) suggested an approach to vegetation condition monitoring based on minimum and maximum NDVI values compiled per pixel over time. Available moisture and natural resources determine the NDVI minimum while other values, including the historical maximum, are determined by weather.
* Standardized Vegetation Index (SVI) allows visualization of relative vegetation greenness in terms of “greenness probability” at each 1-km2 pixel location using a probability estimate, which suggests comparison over time periods that longer than the archival imagery.
* SVI is a good indicator of vegetation response to short-term weather conditions.
  + It can be concluded that the SVI is a useful tool and can provide a near-real-time indicator of the onset, extent, intensity, and duration of vegetation stress.
* Care needs to be taken in local areas when evaluating the SVI because climatic conditions other than drought can cause reduced vegetation stress.

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# VPD

## Fernández-Duque, B., Vicente-Serrano, S. M., Maillard, O., Domínguez-Castro, F., Peña-Angulo, D., Noguera, I., Azorin-Molina, C., & el Kenaway, A. (2023). Long-term observed changes of air temperature, relative humidity and vapour pressure deficit in Bolivia, 1950-2019. International Journal of Climatology, 117, 1–21. <https://doi.org/10.13039/501100011033>

* On an annual basis VPD showed a significant increase.
* Reanalysis products have certain limitations when compared to in-situ observations. These limitations could potentially impact the reliability of findings and lead to increased uncertainty in assessments.
* Positive monthly VPD trends, although significant trends were only found in May and from July to October. Annually, VPD increased significantly. Moreover, the smallest VPD changes occurred between January and June, being significant at some low elevations from January to April.

A table with numbers and a few words

Description automatically generated with medium confidence

* Annually, VPD trends slightly increased in agreement with global results.
* Seasonally, VPD exhibited a more pronounced and statistically significant rise from August to October, with an increase of +0.4 to +0.5 hPa decade−1 , particularly noticeable in the lowland regions.
* inverse correlation observed between VPD and elevation.
* VPD also has an influence on terrestrial ecosystem respiration (TER). In fact, He et al. (2022) found a positive (negative) link between VPD and TER in humid (semi-arid and arid) regions.
* atmospheric VPD has been identified as a key driver of plant functioning in terrestrial biomes and has been established as a major contributor to recent drought.
* the weak annual increase of VPD detected could induce a shift in vegetation greenness from greening to browning, as also found by Yuan et al. (2019).
* analysis of VPD trends in semiarid and subhumid regions is crucial since they are expected to increase the severity of drought events as well as climate aridity and water stress under climate change.
* A weak but significant increasing trend in vapour pressure deficit was found across Bolivia, suggesting a positive tendency of atmospheric drying and drought events, which could partially limit plant growth and therefore crop production.

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## Ficklin, D. L., & Novick, K. A. (2017). Historic and projected changes in vapor pressure deficit suggest a continental-scale drying of the United States atmosphere. *Journal of Geophysical Research*, *122*(4), 2061–2079. <https://doi.org/10.1002/2016JD025855>

* Examine changes in VPD, *es*, *ea*, and their underlying climatic components in the U.S. for the observed, recent past (1979-2013) and the future (2065-2099) using an ensemble of 19 GCMs from high-emission pathway RCP 8.5.
  + Sig. increase in VPD for nearly all seasons in the recent past from diverging trends in *es* owing to increases in Tair and decreases in *ea* from decreases in RH.
  + Trends are especially apparent in the southwestern U.S.
  + VPS will continue to increase into the future from larger increasing trends in *es* as compared to *ea*.
* Historically, VPD has increased for all seasons, driven by increases in es and declines inea. The spring, summer, and fall seasons exhibited the largest areal extent of significant increases in VPD.
  + Largely concentrated in the western and southern portions of the U.S.
* Changes in VPD stemmed from recent air temperature increases and relative humidity decreases.
* Future changes in VPD can reduce stomatal conductance by 9-51%.
* Increases in VPD will promote and increase in ET.
* Rising VPD represents a significant constraint on plant carbon uptake and productivity.
* VPD has also been ID’ed as a critical determinant of tree morality (Williams et al., 2015).
* Importance of VPD not well understood 🡪 VPD did not change appreciably during the second half of the twentieth century (Roderick and Farquhar, 2002).
* Smith et al., using GCMs showed a projected global increase in VPD.
* Zhang et al., show an overall increase in global atmospheric moisture demand from 1988 to 2008.
* Stat. significant trends of VPD were observed during the historical time-period (1979—2013) for all seasons. There is significant spatial variation in the VPD trends, but overall, increases in VPD were observed for most of the study area.
* VPD increased over the largest areal extent of land during the summer season:
  + 25% of total number of grid points showed a stat. sig. increase and 0.74% showed a significant decrease.
  + Positive trends were largely concentrated in the western and southern portion of the U.S. and the upper Midwest.
* GCMs accurately estimated areas of high VPDs in the southwestern U.S. and areas of low VPD in the Pacific Northwest and eastern U.S.
* Nearly every model projects a large increase in VPD in the future relative to the historic time period.
  + Large increase in VPD during Summer.
  + Nearly all GCMs are in agreement that VPD will increase for the U.S. relative to the historical time period.
  + VPD for much of the U.S. will increase by 0.5 kPa while a there was not clear agreement on a 1 kPa increase (except in the southwest [14-16 GCMs] & central plains [8-11 GCMs]).
  + Clear agreement that *es* will increase by at least 0.5 kPa.
  + Large portions of the eastern and western U.S. do not meet the threshold (1-5 GCMs in agreement), while there is some agreement in the central U.S. (10-12 GCMs) and clear agreement in the extremely arid regions of the western U.S> and the south central Great Plains (12-18 GCMs).

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## Grossiord, C., Buckley, T. N., Cernusak, L. A., Novick, K. A., Poulter, B., Siegwolf, R. T. W., Sperry, J. S., & McDowell, N. G. (2020). Plant responses to rising vapor pressure deficit. In New Phytologist (Vol. 226, Issue 6, pp. 1550–1566). Blackwell Publishing Ltd. <https://doi.org/10.1111/nph.16485>

* Recent decades have been characterized by increasing temperatures, resulting in an exponential climb in VPD.
* VPD IDed a major contributor in recent drought-induced plant mortality independent of other drivers associated with climate change.
* Global Ts 🡪 increase saturation vapor pressure of the atm 🡪 actual VPD has not been increasing at the same rate.
* Transpiration rate increases with high VPD up to a point, after which it either remains high or starts decreasing.
* High VPD results increased results in increased rates of water loss from moist soils, in turn causing drying and heating of the terrestrial surfaces and contributing to more frequent and severe drought events and plant water stress.
* High VPD responsible for reductions in crop production.
* Long-term changes in VPD are still uncertain as they will depend both *es* and on the extent of water movement limitation from the land surface to atmosphere under future climate.
* Observations of growth and morality are consistent with a growing VPD limitation, theory suggests that rising VPD must impact plant hydraulics such that veg shifts, including rapid mortality, are likely.
* The mechanisms by which rising VPD may accelerate the risk of mortality are consistent with the transpiration and stomal response to VPD.
* Enhanced VPD-driven evaporation resulting in soil water loss and desiccation, increasing drought stress via lack of soils water via lack of soil water.
* Stomatal closure during periods of elevated VPD may also lead to reduced growth and allocation to carbohydrates via a decrease in photosynthesis.
* Long-term field experiments where atm temp and VPD are manipulated and combined are particularly useful and anticipating the impacts of rising VPD on plant mortality risks, particularly as the effects may occur in the cascades (i.e., short vs long-term impacts)
* Plant physiological response to VPD is linked to vegetation mortality in land-surface models in one or more of several interacting ways, including carbon deficits via negative net primary production (NPP) or declines in growth efficiency, and water stress via hydraulic failure, in addition to morality via non-VPD related processes such as heat stress or light competition.
* High VPD conditions reduce stomatal conductance and photosynthesis while simultaneously increasing plant water losses through transpiration 🡪 likely result in reduced primary productivity and amplified drought-induced plant mortality worldwide.

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## López, J., Way, D. A., & Sadok, W. (2021). Systemic effects of rising atmospheric vapor pressure deficit on plant physiology and productivity. In Global Change Biology (Vol. 27, Issue 9, pp. 1704–1720). Blackwell Publishing Ltd. <https://doi.org/10.1111/gcb.15548>

* Earth is currently undergoing a global increase in atm. VPD which is expected to continue as climate warms.
* Associated with productivity decreases and yield penalties in crops.
* VPD increase reduced yield and primary productivity & changes in leaf anatomy.

## Seager, R., Hooks, A., Williams, A. P., Cook, B., Nakamura, J., & Henderson, N. (2015). Climatology, variability, and trends in the U.S. Vapor pressure deficit, an important fire-related meteorological quantity. Journal of Applied Meteorology and Climatology, 54(6), 1121–1141. <https://doi.org/10.1175/JAMC-D-14-0321.1>

* VPD reaches its climatological max in summer in interior southwest U.S. b/c of both high T and low vapor pressure.
* VPD has increased in the southwest U.S. since 1961, driven by warming and a drop in actual vapor pressure, but has decreased in the northern plains and Midwest, driven by an increase in actual vapor pressure.
  + VPD has declined in the northern plains and Midwest due to actual vapor pressure increasing.
* Regarding links b/t climate and forest fire incidence in the southwestern U.S., VPD explains more variance than precipitation, various drought indices, temperature, and wind individually can (Williams et al., 2015).
* VPD only indirectly measures the antecedent soil moisture conditions that also influence the current moisture content of vegetation.
* Seasonal variation: extreme high VPD years are expected to exert considerable water stress on vegetation, leading to a risk of disease, fire, and mortality.
  + Winter – VPD is lowest.
  + Spring – VPD has climbed above 8 mb for most of U.S.
    - Interior southwest reaching around 30mb.
  + Summer – modest VPD increases over eastern U.S. but climbs strongly in the southwest and across the west.
* While Atm. Circulation anomalies are expected to be able to influence VPD instantaneously via subsidence of warm, dry air, it is also expected that previous reductions in precipitation could dry out the soil and lead to an increase in VPD.
  + Atm. Vapor pressure is responding to changes int ET.

## Yuan, W., Zheng, Y., Piao, S., Ciais, P., Lombardozzi, D., Wang, Y., Ryu, Y., Chen, G., Dong, W., Hu, Z., Jain, A. K., Jiang, C., Kato, E., Li, S., Lienert, S., Liu, S., Nabel, J. E. M. S., Qin, Z., Quine, T., … Yang, S. (2019). E C O L O G Y Increased atmospheric vapor pressure deficit reduces global vegetation growth. <https://www.science.org>

* Sharp increase in VPD after the late 1990s.
* Persistent and widespread decreases after the late 1990s due to increased VPD, which offset the positive CO2 fertilization effect.
* Project increase of VPD throughout the current century.
* Although the long-term trend of globally averaged land surface RH remains insignificant, a sharp decrease has been observed since 2000, implying a sharp increase in land surface VPD.
* Increases in VPD rather than changes in precip. substantially influenced vegetation productivity.
  + Affects on veg growth – Maize.
* Global precip. projected to remain steady, the changing VPD and soil drying would likely constrain plant Cabon uptake and water use in terrestrial ecosystems.
* VPD increased slightly before the late 1990s but increased more strongly afterward with 1.66 to 17 times larger trends according to 4 data sets used.
* On average, the annual growing season mean VPD of 2011-2015 was 11.26% higher than that of 1982-1986, and the VPD increased larger than 5% in more than 53% area.
* Increased saturated water vapor pressure and decreased actual water vapor pressure jointly determined the increases of VPD after the tipping point (1990).
* Despite the large variability of the estimated interannual LAI among the 4 products, all 4 datasets exhibited a transition from increasing trends before the late 1990s to decreasing trends afterward.
  + The LAI trends during these two periods are the opposite of VPD trends derived from 4 VPD datasets.
  + The differences of NDVI and LAI trends during these two periods are the opposite of VPD trends derived from 4 VPD datasets.
* Suggested that atm CO2 concentration, Tair, and VPD are the most important contributors for the variability of NDVI.
  + Rising VPD was found to significantly decrease NDVI, indicated by the larger negative NDVI differences from 1999 to 2015, suggesting that substantial increases of VPD strongly limited NDVI.
* Increased VPD being part of the drivers of the widespread drought-related forest mortality over the past decades, which has been observed in multiple biomes and on all vegetated continents.
* Previous studies reported that increased VPD explains 82% of the warming season drought stress in the southwestern U.S.
* Results imply that most terrestrial ecosystem models cannot capture vegetation responses to VPD. Thus, problems reproducing that observed long-term veg responses to climate variability may challenge their ability to predict the future evolution of the carbon cycle.
  + The globally averaged CPD is 0.12 kPa higher in 2090—2100 than in 1980—1999.

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# EDVI

## Li, R., Min, Q., & Lin, B. (2009). Estimation of evapotranspiration in a mid-latitude forest using the Microwave Emissivity Difference Vegetation Index (EDVI). *Remote Sensing of Environment*, *113*(9), 2011–2018. <https://doi.org/10.1016/j.rse.2009.05.007>

* The R2 b/t estimated and observed ETs is 0.83 with a mean bias of 3.31 Wm-2 and a standard deviation of 79.53 Wm-2.
  + The overall uncertainty of our ET retrieval is ~30%, which is within the uncertainty of current ground-based ET measurements. Furthermore, the estimated ET in different local times (up to 4 times per day) successfully captures the diurnal cycle of ET.
* Existing sat. remote sensing techniques for ET estimation s are mainly based on measurements at visible and near-infrared wavelengths, such as normalized difference vegetation index (NDVI), enhanced vegetation index (EVI) and Normalized Difference Water Index (NDWI) – spectral measurements that are correlated to the absorbed fraction of photosynthetically active radiation (PAR) and water.
* B/c of rapid changes of veg. state during spring onset and fall senescence, these indexes cannot accurately capture the transitions of veg. state during growing seasons.
* Normalized DVI could represent the seasonality of veg. state, providing an accurate assessment of min. canopy resistance in the entire growing season.
* Slow variation of EDVI, represented by the normalized EDVI is directly linked to VWC, the fast changes of DEVI represents canopy response to the changes of environmental conditions, such as VPD.