Tropospheric lapse rate: observations and modeling of past, present and future variations

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Constraints on upper tropospheric temperature change during the Last Glacial Maximum using clumped isotopic composition of atmospheric oxygen

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Ice cores and other paleotemperature proxies, together with general circulation models, have provided information on past surface temperatures and atmospheric composition during different climates. Little information is however available about past temperature changes at high altitudes, which play a crucial role in the Earth's radiative energy budget. Paleoclimate records at high-altitude sites are sparse, and the few that are available show poor agreement with climate model predictions. Further, available paleoclimate records have limited spatial coverage, and are not reflective of global high-altitude temperature change, necessitating the need for new globally integrated records. Here, we constrain the change in upper-tropospheric temperature at the global scale during the Last Glacial Maximum (LGM) using the clumped-isotope composition of molecular oxygen trapped in polar ice cores. We exploit the intrinsic temperature sensitivity of the clumped-isotopic composition of atmospheric oxygen and complement that with a three-dimensional chemical transport model to infer that the upper troposphere (effective mean altitude 10–11 km) was 6-9◦C colder during the LGM than during the late pre-Industrial. Additionally, we use a complementary energy balance approach that supports a minor or negligible steepening of atmospheric lapse rates during the Last Glacial Maximum.

*Speaker

Nonlinearities in the response of the tropical troposphere to patchy warming

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Green's function experiments conducted with HadAM3 show how the response of the tropical lapse rate to surface warming depends not just on where the warming occurs, but on how concentrated the warming is (i.e., if the warming in one area exceeds surrounding regions). While we find a two-region model is capable of capturing the general response of the tropical troposphere to the observed pattern of warming, the "patchiness effect" influences the response to anomalously patchy years, such as the El Niño of 1998.

*Speaker

Energetic perspectives on elevation dependent warming

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Observational data and models suggest that, under climate change, elevated and non-elevated land surfaces warm at different rates. Proposed drivers of this "elevation dependent warming" (EDW) include surface albedo and water vapour feedbacks, the temperature dependence of longwave emission, latent heat release in clouds and aerosols. Yet the relative importance of each mechanism is unclear, highlighting the lack of a comprehensive physical understanding of EDW that is applicable both regionally and at larger scales. Here we use reanalysis and model data – binned by surface elevation – to investigate EDW across the tropics over the historical period. From 1959 to 2005, both the reanalysis and models exhibit enhanced warming at elevation in the annual mean, though with substantial variation from season-to-season. We investigate this EDW signal using two distinct energetic perspectives. First, a forcing/feedback framework based on top-of-atmosphere energy balance is used to quantify how different processes contribute to surface temperature changes and how these processes vary with elevation. This framework identifies the Planck, lapse rate and surface albedo feedbacks as being robust drivers of "positive" EDW (i.e. enhanced warming at elevation). In contrast, weaker radiative forcings and water vapour feedbacks in higher elevation regions favour "negative" EDW (i.e. reduced warming at elevation). Second, a convective quasi-equilibrium perspective is investigated to assess the roles of atmospheric convection and weak tropospheric temperature gradients in constraining tropical EDW. Implications of these two perspectives for future EDW are discussed.

*Speaker

Temperature lapse rates across the Andes: implications for glacio-hydrological modeling

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With the objective to simulate recent glacier changes across the entire Andean Cordillera (from Colombia to Tierra del Fuego) over the period 2000-2019, we applied an approach based on a temperature index model. Such a model is forced by reanalysis dataset of air temperature to quantify the amount of snow/ice melt at the glacier surface and the phase of precipitation. However, such reanalysis data may show systematic biases that need to be considered to improve the quality of the model outputs.
To quantify the temperature biases and take them into account, we processed temperature records from 33 meteorological stations found in the close vicinity or directly at the surface of the glaciers, at mean elevations ranging from 4,784 m a.s.l. in the Outer Tropics (9-17◦S) to 939 m a.s.l. in the Wet Andes (37-55◦S), regions where glaciers can be found only at very high elevations or where the glacier terminus is calving into the sea/lakes, respectively. Monthly temperature data recorded between 1980 and 2019 allowed us to estimate six vertical temperature lapse rates (LR) at annual and seasonal time steps representative of the different climate conditions across the Andes. Our results show a reduction of the annual LR from the Dry Andes to the Wet Andes, with lapse rates in a dry/cold environment (Dry Andes) of -8.2◦C/km (n stations = 6) and -6.3◦C/km (n stations = 8) in a wet/hot climate (Wet Andes). However, differences are observed in the seasonal LR estimated in the Tropical Andes. In this zone, we find a seasonal LR in Apr-Sep (dry season) greater than in Oct-Mar, conversely from the Dry Andes to Wet Andes greater seasonal LR values are found in Oct-Mar, which corresponds to the dry season mainly in the Dry Andes.

These LR were used to adjust the reanalysis temperature dataset and run the glacio-hydrological model, allowing us to simulate the largest glacier runoff contribution during the transition season (Oct-Dec) in the Tropical Andes (La Paz catchment) and during the summer season in the Dry and Wet Andes (Maipo and Baker catchments).

*Speaker

Complex spatio-temporal structure of the Holocene Thermal Maximum

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Inconsistencies between Holocene climate reconstructions and numerical model simulations question the robustness of climate models and proxy temperature records. Climate reconstructions suggest that early-middle Holocene Thermal Maximum (HTM) was followed by gradual cooling, whereas climate models indicate continuous warming across the Holocene. The discrepancy implies seasonal biases in proxy-based climate reconstructions, or that the climate models sensitivity to forcings and feedbacks needs to be reevaluated. Here, we analyze a global database of Holocene paleotemperature records to investigate the spatiotemporal structure of the HTM. We show that the timing of the maximal Holocene temperatures at local scale depends on the altitude which imply high amplitude changes in lapse rate in mountainous region over the course of the holocene despite relative climate stability.

*Speaker

Reconstructing the differential cooling of the high- and lowlands of the neotropics during the late Pleistocene

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Considerations of past climate change in tropical regions focus primarily on precipitation, as variability in rainfall seasonality and amount is generally much more substantial than that of temperature. While hydrological changes at most timescales are unquestionably large and likely essential drivers of tropical environmental changes, recent reanalyses of tropical pollen records using the probabilistic pollen-based climate reconstruction method CREST (Climate Reconstruction SofTware) evidenced the strong imprint of temperature variability on past tropical vegetation changes, in particular the compensating effect of the LGM cold temperatures on the reconstructed reduced precipitation (via a reduction of the evapotranspiration). Since many tropical records representing moisture availability (*e.g.* lake levels) are commonly interpreted primarily in terms of changes in rainfall amount, these results point toward a potential misinterpretation of (some of) these records. Similarly, temperature also affects calcite-water isotopic fractionation, which can bias interpretations and comparisons of the many speleothem oxygen records available from the tropics. Better constraining temperature changes from tropical regions is thus critical to better understanding many existing records of past hydrological changes. Unfortunately, quantified temperature records are currently scarce across the tropics, especially in mountainous areas, where a steepened LGM lapse rate has been proposed. Still, tens of tropical fossil pollen records exist and can now be analysed to estimate glacial cooling with CREST. They represent, as such, a unique opportunity to produce extensive temperature reconstructions from the tropical lowlands and highlands and, by extension, of the tropical lapse rate. I will introduce the research framework I developed to generate these much-needed reconstructions and illustrate it with preliminary reconstructions from the neotropics.

*Speaker

Intermodel spread in Walker circulation responses linked to spread in moist stability and radiation responses

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The response of the Pacific Walker circulation (WC) to long-term warming remains uncertain. Here, we diagnose contributions to the WC response in comprehensive and idealized general circulation model (GCM) simulations. We find that the spread in WC response is substantial across both the Coupled Model Intercomparison Project (CMIP6) and the Atmospheric Model Intercomparison Project (AMIP) models, implicating differences in atmospheric models in the spread in projected WC strength. Using a moist static energy (MSE) budget, we evaluate the contributions to changes in the WC strength related to changes in gross moist stability (GMS), horizontal MSE advection, radiation, and surface fluxes. We find that the multimodel mean WC weakening is mostly related to changes in GMS and radiation. Furthermore, the *spread* in WC response is related to the spread in GMS and radiation responses. The GMS response is potentially sensitive to parameterized convective entrainment which can affect lapse rates and the depth of convection. We thus investigate the role of entrainment in setting the GMS response by varying the entrainment rate in an idealized GCM. The idealized GCM is run with a simplified Betts-Miller convection scheme, modified to represent entrainment. The weakening of the WC with warming in the idealized GCM is dampened when higher entrainment rates are used. However, the spread in GMS responses due to differing entrainment rates is much smaller than the spread in GMS responses across CMIP6 models. Therefore, further work is needed to understand the large spread in GMS responses across CMIP6 and AMIP models.

*Speaker

Why do tropical temperatures deviate from moist-adiabats?

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The theoretical understanding of the tropical atmosphere builds upon two fundamental approximations about the thermal structure of the free troposphere: first, that the temperature is nearly horizontally homogeneous on large scales and second, that the vertical temperature structure is nearly moist-adiabatic. However, observations and models both show that the actual temperatures often deviate from the moist-adiabats calculated from theory. In this study, we focus on the tropical temperature structure using models and observations. We show that thermodynamical factors (including moist-adiabatic assumption and vapor buoyancy effect) and dynamical factors (including small-scale entrainment effect and large-scale dynamical balance) can both cause the lapse rates to deviate from the theoretical moist-adiabats. This may help understand questions such as climate feedbacks and pattern effect, and different upper tropospheric warming trends in global climate models (GCMs) and observations.

*Speaker

Investigating processes involved in the change in tropical lapse rate over the American Cordillera from the Last Glacial Maximum to present, a modelling study

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In a companion work, Legrain et al. present a data set of Last Glacial Maximum (LGM) lapse rate reconstructions along the American/Andean cordillera. We will complement this study with a model analysis of the processes explaining the change in lapse rate between the LGM and the pre-industrial state, based on the IPSLCM5A2 coupled model and additional single forcing experiments run with the LMDZ atmospheric model. In particular, we will analyse the role of the greenhouse forcing, the ice sheet forcing and of the SST changes in setting up the tropical lapse rate signal. Companion abstract: Amplification of the high-altitude deglacial warming in the American Cordillera revealed by tropical lapse rate reconstructions, by Legrain E. et al.

*Speaker

The lapse rate steepened during the Last Glacial Maximum in east Africa

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The question of how the tropical climate changed during the Last Glacial Maximum (LGM; _˜19-26 ka) has persisted for decades and several studies have highlighted unresolved differences between reconstructed tropical sea-surface temperatures and high-elevation cooling. Our work in East Africa helps resolve these differences by providing multi-proxy evidence for a steepened lapse rate during the LGM. We use two independent methodologies to reconstruct climate conditions at high elevation in the Rwenzori Mountains of Uganda. We apply modeling of glacial extents dated to the LGM and find that the lapse rate must have been steeper than present for glaciers to reach their LGM positions using available sea-level temperature and precipitation estimates for East Africa. We also reconstruct temperatures based on the relative abundance of branched glycerol dialkyl glycerol tetraethers (brGDGTs) from Lake Mahoma in the Rwenzori Mountains. This reconstruction shows a warming from the LGM to the late Holocene of _˜5 degrees, larger than the lower elevation temperature warming and consistent with a steeper LGM lapse rate. A comparison of the glacier extent-based and organic geochemical temperature proxies shows good consistency during the LGM, deglacial and Holocene times.

*Speaker

Amplification of the high-altitude deglacial warming in the American Cordillera revealed by tropical lapse rate reconstructions

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Glacier fluctuations are at first order controlled by local precipitation and temperature, but large uncertainties persist on the potential role of local moisture in amplifying or dampening temperature changes at high-elevation. Here, we combine glacier extents and Sea Surface Temperature (SST) during the Last Glacial Maximum (LGM) to quantify altitudinal thermal gradients (lapse rate) from 40◦N to 40◦S along the American Cordillera. We also constrain modern lapse rates based on present day temperature and SST database to explore how the lapse rate has changed since the LGM along this North South transect. Based on proxy-based quantitative paleo-precipitations estimations above 2000 m, we investigate the mechanisms that potentially controlled lapse rate changes during the post-LGM deglacial warming.

We find that lapse rate changes are linearly related to changes in precipitation and derive a quantitative relationship between these two parameters. Our results suggest that future warming may be enhanced in high altitude regions where precipitations are expected to increase. This study therefore confirms that special attention should be given to the climate projections of glacier melting in tropical and mid latitude regions.

This work is a joined effort with the study *Investigating processes involved in the change in tropical lapse rate from the Last Glacial Maximum to present*, which explore the mechanisms identified in this study through global climate simulations.

*Speaker

Water vapor spectroscopy and the tropopause

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The tropopause demarcates the troposphere from the stratosphere, and is usually measured by where the lapse rate decreases rapidly with height. What physics controls the height where this transition occurs? Previous theories suggested that the top of atmosphere energy balance controls the tropopause height, but we show that this constraint does not hold in models. We present theory and simulations that suggest the tropopause height and temperature are instead controlled by the spectroscopic absorption of water vapor.

*Speaker

Seasonal and altitudinal contrasts of climate trends in the Alps

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Investigating climate change over mountainous areas is challenging since it requires high density observational networks and high-resolution models to catch the strong spatial climate heterogeneities related to topography. This presentation aims first to describe seasonal and altitudinal contrasts of climate trends in the Alpes, and second to highlight some current challenges that should be overcome for a better understanding of climate change in mountainous areas. The regional climate model MAR is applied with a 7 km horizontal resolution to downscale the ERA-20C (1902-2010) and the ERA5 reanalyses (1981-2018) as well as future projections from different GCMs and scenarios. A comparison with local meteorological stations, in-situ glacier mass balance measurements and precipitation reanalysis demonstrates satisfying skill for the model in terms of temperature, precipitation and snow cover. The vertical gradient of precipitation simulated by MAR over 1971–2008 in the European Alps reaches 33% km-1 (1.21 mmd-1.km-1) in summer and 38%km-1 (1.15mmd mmd-1.km-1) in winter, with a large spatial variability. The estimation of mean precipitation trends is challenging because of both the large internal climate variability and the GCMs uncertainties. Nevertheless, maximum of daily precipitation (Rx1day) shows a general and significant increase both at the seasonal and the annual timescales, reaching local values between 20% and 40% per century over large parts of the Alps. This increase in strong precipitation is expected to continue in future projections. The highest warming rates in MAR during the last century are found at low elevations (< 1000 m a.s.l) in winter, whereas they are found at high elevations (> 2000 m a.s.l) in summer. In spring, warming trends show a maximum at intermediate elevations (1500 m to 1800 m). Our results suggest that higher warming at these elevations is mostly linked to the snow-albedo feedback in spring and summer, and should move to higher elevations with the snow cover retreat. This presentation is finally expected to open a discussion on the limitations that the community is facing when simulating the mountainous climate, considering in particular the coarse resolution of the models and their weaknesses in describing the aerosol forcings.

*Speaker

Tropical lapse rate changes in global-storm resolving model simulations of climate change

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Global-storm resolving model simulations (GSRM, with kilometer-scale horizontal resolution) of the atmosphere can capture the
interaction between the scales of deep cumulus convection and the large-scale dynamics and thermodynamic properties of the atmosphere. As such, they hold promise in more faithfully simulating the factors that determine the tropical upper troposphere's response to surface warming. Here, we assess the vertical structure of tropical temperature change in two-year integrations of the GSRM XSHiELD (developed by the Geophysical Fluid Dynamics Laboratory and performed at Princeton University) perturbed by a uniform sea surface temperature warming. The simulated changes show relatively weak warming near the mid-troposphere before increasing to a factor of about two near the tropopause. Relative to conventional GCMs, this is a larger increase in conditional instability, as measured by convetive available potential energy. The response to CO2 increase with unchanged SST is an approximately vertically uniform warming, consistent with conventional GCMs. The results of GSRMs and GCMs are compared to entraining plume theories, as a means of summarizing their behavior.

*Speaker

Quantifying Key Mechanisms That Contribute to the Deviation of the Tropical Warming Profile From a Moist Adiabat

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Climate models project tropical warming is amplified aloft relative to the surface in response to increased CO2. This vertical structure of tropical warming has been qualitatively attributed to enhanced latent heat release from moist convection in a warmer world as expected from the warming implied by a shift to a warmer moist adiabat. However, quantitatively, moist adiabatic adjustment overpredicts the multimodel mean 300 hPa temperature response by 16.6–25.3% across the CMIP5 model hierarchy. We show three mechanisms influence overprediction: climatological large-scale circulation, direct effect of increased CO2, and convective entrainment. Accounting for the presence of a climatological large-scale circulation and the direct effect of CO2reduces the CMIP5 multimodel mean overprediction by 0.7–7.2% and 2.8–3.9%, respectively, but does not eliminate it. To quantify the influence of entrainment, we vary the Tokioka parameter in aquaplanet simulations. When entrainment is decreased by decreasing the Tokioka parameter from 0.1 to 0, overprediction decreases by 9.6% and 10.4% with and without a large-scale circulation, respectively. The sensitivity of overprediction to climatological entrainment rate in the aquaplanet mostly follows the predictions of zero-buoyancy bulk-plume and spectral-plume models. The results highlight the importance of convective entrainment on the tropical temperature profile and the potential value in constraining their representation in climate models with observations including the paleoclimate record.

*Speaker

Understanding elevation dependent warming: lapse rate changes from an alternate perspective

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In recent decades there has been much concern that many mountain and high-elevation regions are showing more rapid changes in climate than their adjacent lowlands. Enhanced warming in mountain regions has numerous potential impacts, including melting snow and retreating glaciers, changing meltwater regimes and water resources, rapid migration of species upslope, and increased mountain hazards (e.g. flooding, wildfires and GLOFs). The concept of elevation dependent warming (EDW), whereby warming rates are stratified by elevation, has become popular in the scientific literature. EDW is the same as stating that temperature lapse rates have systematically changed in recent decades and may do so in the near future. However, since it is acknowledged that there is no universal profile of EDW observed in all mountain ranges or over all timescales, it is a challenge to discern how understanding current EDW can tell us about lapse rate changes over longer time periods, or indeed at a global scale. Examination of the controlling mechanisms is an important part in making this leap. Current mechanisms including snow and ice albedo feedback, tropospheric lapse rate forcing (free air effects), aerosol impacts, vegetation and treeline feedbacks, water vapour and radiative forcing feedbacks are therefore reviewed. Different feedbacks are prominent in different locations/climates and over contrasting timescales.

Most feedbacks contribute to amplified warming at higher elevations and thus a reduced (shallower) lapse rate. Snow and ice are predominantly concentrated on the highest peaks, although the most rapid melt and reduction of albedo will be around the snowline or 0◦C isotherm. Increases in specific humidity have a greater warming effect when the air is dry to start with (at higher elevations). The warming response to a given radiative forcing is also greater at lower temperatures (at higher elevations). Aerosol deposition on snow can amplify surface warming on high elevation glaciers more than on darker surfaces at lower elevations. The change to a more saturated adiabatic lapse rate (were it to occur in a warmer world) would weaken the free atmospheric lapse rate. Treeline and vegetation feedbacks are more complex. Despite these macro-scale impacts, mountain climate, especially that near the surface, is often decoupled from the larger scale, and lapse rates on mountain slopes can be substantially different from those in the free atmosphere. Thus, at the local scale, the complexity of mountain climates may easily obscure (or even counteract) a broader EDW signal.

To understand such processes, it is critical that we improve our observations at high elevations and in particular across elevation gradients. This is true both for current observations and palaeoclimate reconstructions. High mountain regions are under-sampled and there is a strongly skewed distribution towards lower elevations. The concept of the Unified High Elevation Plat-

*Speaker

form (UHOP) as recently discussed at a workshop in Bern, Switzerland (25-27 June 2023), is presented as going some way to solving this issue.

Vertical amplification of surface warming in models and observations

Stephen Po-Chedley * [1]

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In response to greenhouse gas concentration increases, early general circulation model (GCM) simulations exhibited greater warming in the tropical upper troposphere than at the Earth's surface1. This so-called "vertical amplification" behavior is also a robust feature in modern, state-of-the art GCMs2. In contrast, early satellite datasets of tropospheric temperature change exhibited little warming3, which led to a perception that tropospheric warming was incompatible with both measurements of surface warming and simulated warming from GCMs4. The causes and significance of this apparent discrepancy between simulated and observed lapse rate behavior has been debated for decades5–10 and the model-observational disagreement has persisted across several model generations11–17 and despite continual improvements to satellite datasets18–21.
In this presentation we will assess the current state of model-observational agreement by comparing the vertical structure of tropical tropospheric warming in model simulations and observations. We will assess the potential roles of internal variability, model response biases, and observational biases in model-satellite disagreements.

1. Manabe & Wetherald, 1975.; 2. Lee et al., 2021.; 3. Spencer & Christy, 1990.; 4. Hansen et al., 1995.; 5. Wallace & Coauthors, 2000.; 6. Karl et al., 2006.; 7. Santer et al, 2003.; 8. Santer et al., 2005.; 9. Po-Chedley & Fu, 2012.; 10. Po-Chedley et al., 2021.; 11. Douglass et al., 2008.; 12. Santer et al., 2008.; 13. Christy et al., 2010.; 14. Santer et al., 2017.; 15. Santer et al., 2021.; 16. McKitrick & Christy, 2020.; 17. Po-Chedley et al., 2022.; 18. Mears & Wentz, 2005.; 19. Mears & Wentz, 2016.; 20. Po-Chedley, Thorsen, & Fu, 2015.; 21. Zou et al., 2023.

*Speaker

Modelling past and present mountain glacier evolution and the role of atmospheric lapse rates

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2,3,4

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Mountain glaciers are perhaps the most obvious displays of high-mountain climate change. As glaciers build up in climates too cold for life, they complement other indicators of past and present climate change such as vegetation and animals. In mountain settings, cold temperatures translate into high altitudes, meaning glaciers supplement other proxies for lapse rate reconstructions, providing a temperature gauge for the mountaintops were lapse rates typically steepen due to reduce moisture availability. However, mountain glaciers' response to climate is complex. Their advance and retreat is not instantaneous, but instead often transient, as the ice dynamics lag behind air temperature fluctuations. Besides, glaciers' response depends on other factors such as topography and precipitation, and include several non-linearities such as creep, basal sliding, and the temperature lapse-rate effect caused by the glacier topography itself. In this presentation we will show how numerical glacier and ice sheet modelling can be used to study this complex response of glaciers to climate, including both fluctuations of past climate (Julien) and the present-day climate warming (Harry). We will show how numerical modelling can be used to inform temperature lapse rates, and why lapse rate reconstructions are reciprocally important to modelling glacier dynamics.

*Speaker

Horizontal and vertical controls on the tropical lapse rate

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Previous studies have highlighted two important dynamical controls on the tropical thermodynamic structure. On the one hand, moist convection acts to drive the atmosphere toward a convectively neutral profile, exerting a strong influence on the vertical temperature profile in convecting columns. On the other hand, gravity waves in the free troposphere act to redistribute buoyancy anomalies, homogenising the virtual temperature horizontally and giving rise to the so-called weak temperature-gradient (WTG) approximation. In this talk, I will explore the interplay between these vertical and horizontal controls in determining the lapse rate in the tropical atmosphere.
First, I will present an idealised model of the ascending branch of a large-scale circulation that includes both constraints; the lapse rate is set by convective neutrality, while the implied overturning circulation acts to maintain small temperature anomalies relative to a tropical-mean reference profile. Due to the effects of convective entrainment, the model predicts that moist regions of the atmosphere are more stable than dry regions, and this has implications for the vertical structure of the circulation.
I will then show results from the ERA5 reanalysis which support the idealised model, demonstrating a relationship between stability and humidity across the deep tropics. The relationship is strongest in regions and times of active convection; in regions far from convection, the horizontal control becomes dominant and the lapse rate is set remotely.

*Speaker

Tropical lapse rates: New perspectives from paleo and modern data

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During the Last Glacial Maximum, tropical sea surface temperatures were 1 to 3 oC cooler than present, but the altitude of the snowlines of tropical glaciers was lower than would be expected in light of these sea surface temperatures. Indeed, both glacial and twentieth-century snowlines seem to require lapse rates that are steeper than a moist adiabat. Here we use multiple datasets to investigate tropical lapse rates. Using extensive new data sets for the region, we demonstrate that mean environmental lapse rates are steeper than moist adiabatic at present. We use estimates of Last Glacial Maximum sea surface temperature in the Indo-Pacific warm pool based on the clumped isotope palaeotemperature proxy in planktonic foraminifera and coccoliths, along with radiative–convective calculations of vertical atmospheric thermal structure, to assess the controls on tropical glacier snowlines, and show that lapse rates were steeper than moist adiabatic during the recent and Last Glacial Maximum. We reconstruct glacial sea surface temperatures 4 to 5 oC cooler than modern. We include modern and glacial sea surface temperatures in calculations of atmospheric convection that account for mixing between rising air and ambient air, and derive tropical glacier snowlines with altitudes consistent with twentieth-century and Last Glacial Maximum reconstructions. Sea surface temperature changes of 3 oC are excluded unless glacial relative humidity values were outside the range associated with deep convection in the modern. We conclude that the entrainment of ambient air into rising air masses significantly alters the vertical temperature structure of the troposphere in modern and ancient regions of deep convection. Furthermore, if all glacial tropical temperatures were cooler than previously estimated, it would imply a higher equilibrium climate sensitivity than included in present models.

*Speaker

Observed and projected changes in elevation-dependent feedbacks, and near-surface vs. free-tropospheric temperature in the tropical Andes

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A better understanding of the mechanisms and feedbacks underpinning Elevation-Dependent Warming (EDW) in the tropics is of considerable interest to better constrain both past and future rates of mountain vs. lowland warming or cooling. Differences between near-surface and free-tropospheric warming rates further complicate such an analysis. Here we present results from an observational analysis, paired with regional (WRF) and global (CMIP6) model simulations over the tropical Andes, with a special emphasis on the Andes of Ecuador. WRF simulations of present and future climates suggest that the EDW results from a combination of feedbacks that operate on different spatial scales. Enhanced upper-tropospheric warming projects onto surface temperature but this uniform pattern is modulated by mountain circulation-induced changes in cloudiness and net surface radiation receipts. The highest elevations are also affected by the snow-albedo feedback. Free-tropospheric temperature changes therefore do not necessary translate directly into equivalent near-surface temperature changes, nonetheless they are relevant due to the close overall co-variation between freezing level height (FLH) and glacier Equilibrium Line Altitude (ELA) in the tropics. Here we use a bias-corrected CMIP6 model ensemble to estimate current and future changes under two different emissions scenarios, while accounting for 'warm models' with a high equilibrium climate sensitivity (ECS).

*Speaker

Impact of convective organization on the large scales

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Idealized simulations of the tropical atmosphere have predicted that clouds can spontaneously clump together in space, despite perfectly homogeneous settings. This phenomenon has been called self-aggregation, and it results in a state where a moist cloudy region with intense deep convective storms is surrounded by extremely dry subsiding air devoid of deep clouds. We discuss here the main physical processes believed to play a key role in convective self-aggregation, related to the interaction of clouds with the larger-scale environment. We also review the growing literature on the importance and implications of this phenomenon for the tropical atmosphere, notably, for the hydrological cycle and for precipitation extremes, in our current and in a warming climate.

*Speaker

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