Latent-heating impact on tides in Middle and Upper Atmosphere Model MUAM

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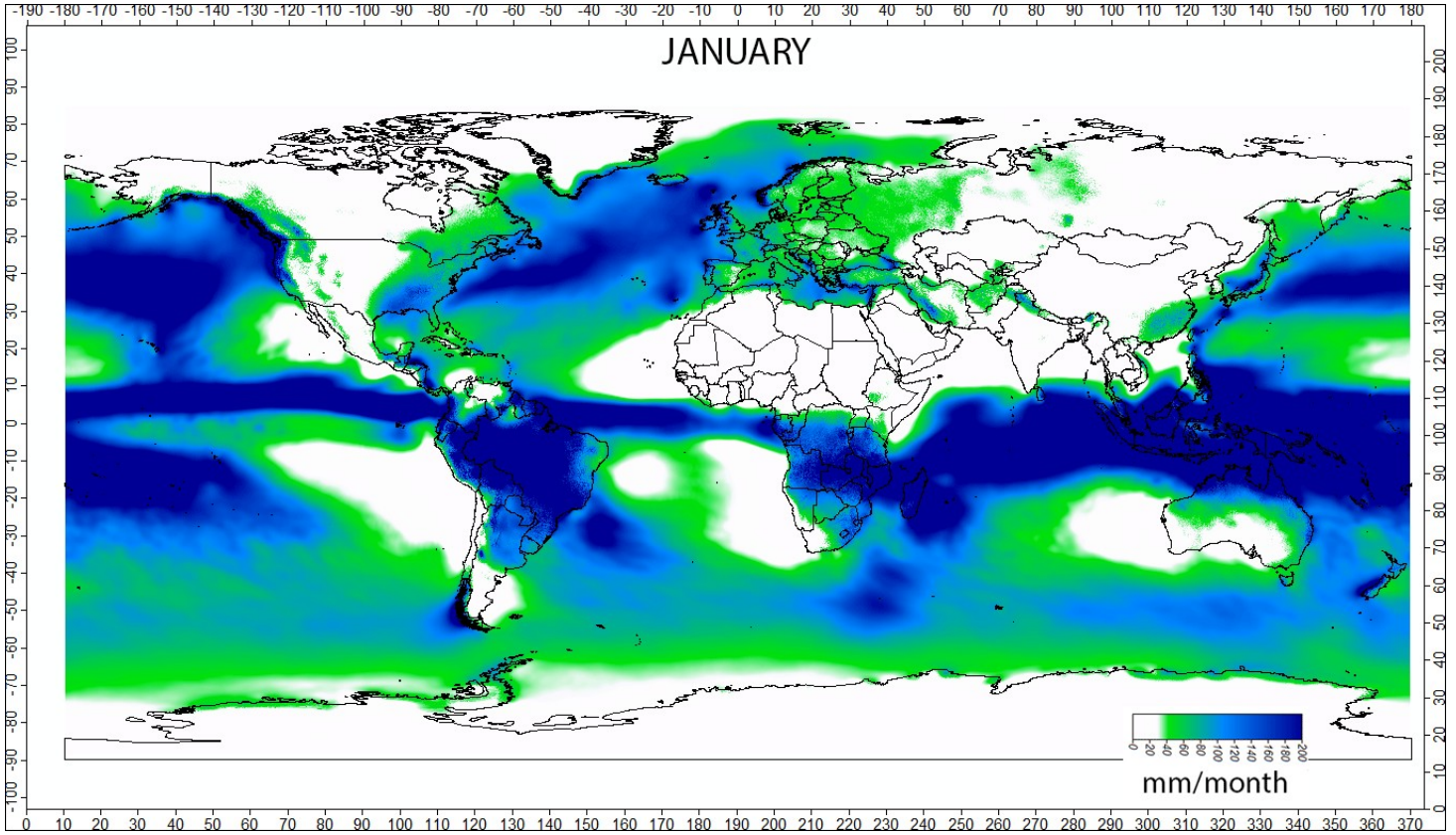


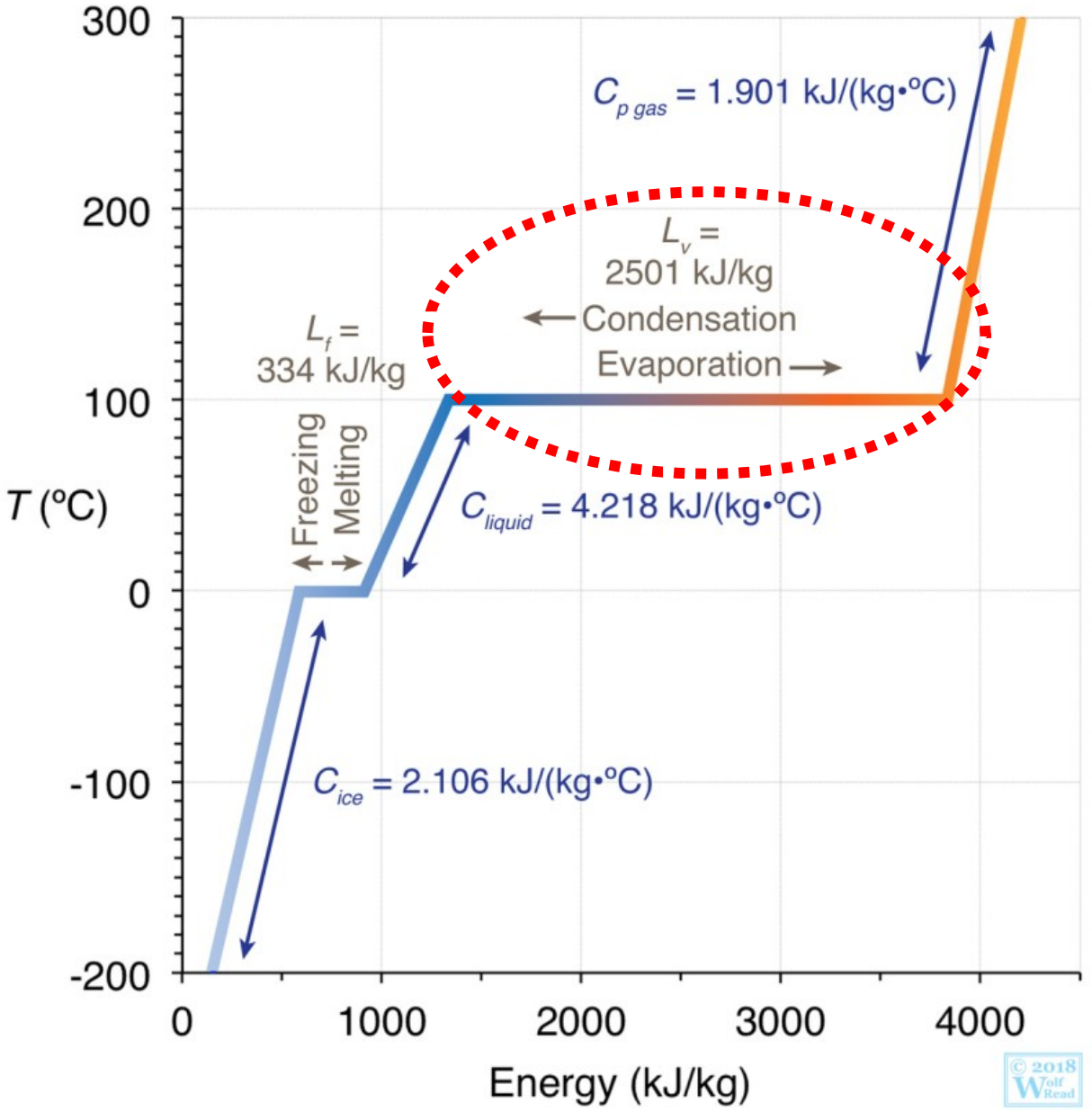
Long-term mean precipitation by month, en.wikipedia.org

Motivation & State of knowledge

- DT (SDT) are excited mainly by absorption of water vapor (ozon) in the troposphere (stratosphere)
- Latent heat:
  - Forces nonmigrating tidal modes which propagate into upper atmosphere *(Williams & Avery 1996)*
  - Forcing mechanism for tides *(Forbes et al. 1997, Zhang et al. 2006)*
  - Variations most apparent at 80 and 150 km height with amplitude variations of 10 - 20 m/s and 5 - 15 K for DT/SDT *(Hagan et al. 2002)*
  - Nonmigrating components can vary *(Hagan et al. 2002)*
- Solar heating and latent heat release contributions are comparable in production of atmospheric tides *(Williams & Avery 1996)*
- Variation of latent heat has a significant effect on tides *(Hamilton 1981, Williams & Avery 1996, Forbes et al. 1997, Hagan et al. 2002)*

Basics: Latent heat

- Heat of transformation consumed or released during the change of aggregate states
  - Heat of evaporation/condensation (liquid ↔ gas)
  - Heat of melting/freezing (solid ↔ liquid)
  - Heat of deposition/sublimation (gas ↔ solid)



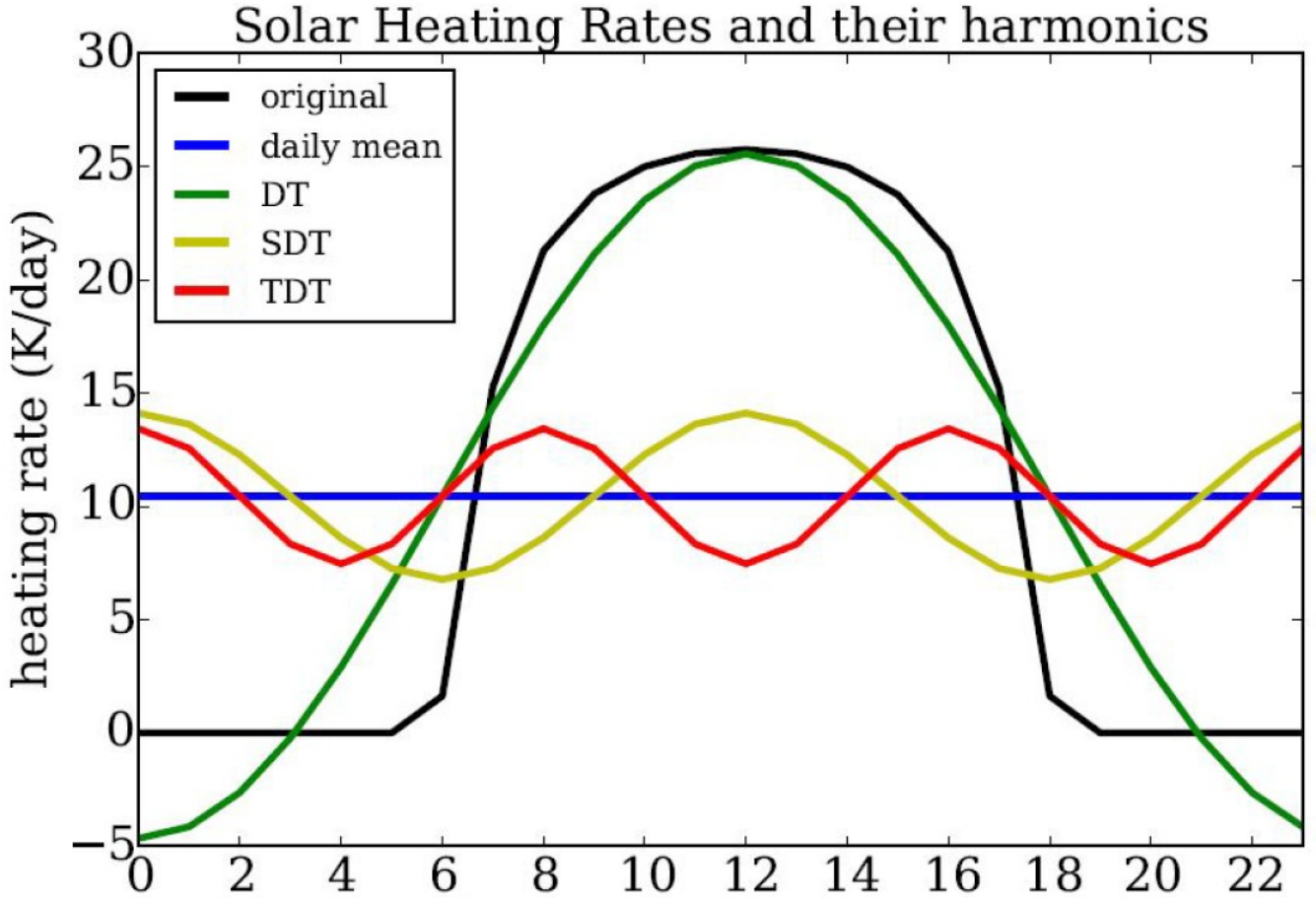
Stull, 2017

Basics: Latent heat

- Convective precipitation (in clouds under deep convection) is prevailing source of humidity in the tropical and subtropical troposphere
  - → Water vapor condensation/evaporation
  - → Main source of latent heat

Solar atmospheric tides

- Fourier analysis of black curve gives harmonic oscillations with periods of 24 h (DT), 12 h (SDT), 8 h (TDT), 6 h (QDT, not shown)



For 2.5° north in 50 km height from Lilienthal, 2019

Basics: Atmospheric tides

- Important mechanism for transporting energy from the lower atmosphere into the upper atmosphere
- Density varies significantly with height → kinetic energy must be conserved → increasing amplitudes with height
- Atmospheric tides excited by:
  - Solar heating
  - (Gravity by moon/sun)
  - Non-linear interactions between tides/planetary waves
  - Latent heat

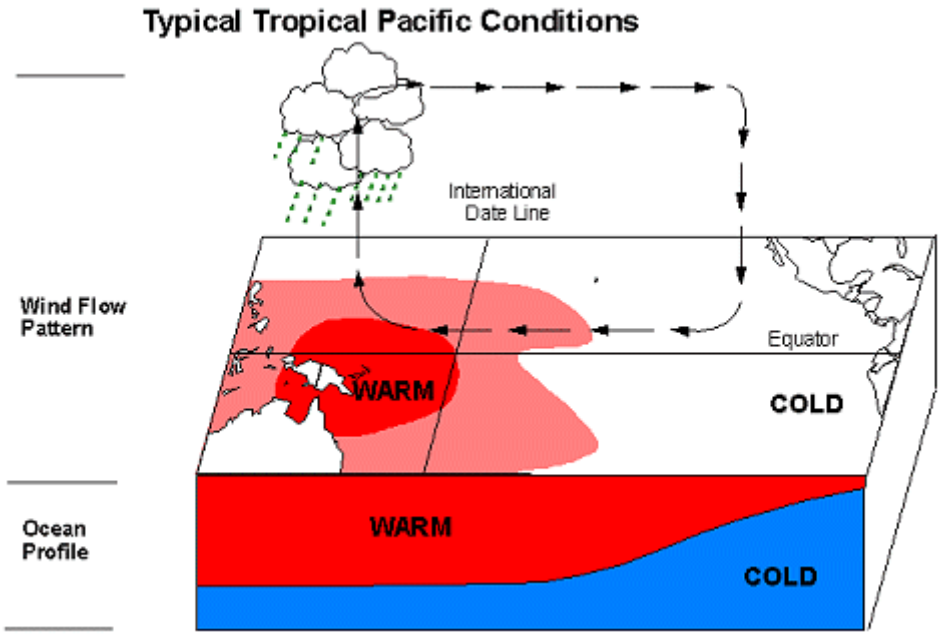
Solar atmospheric tides

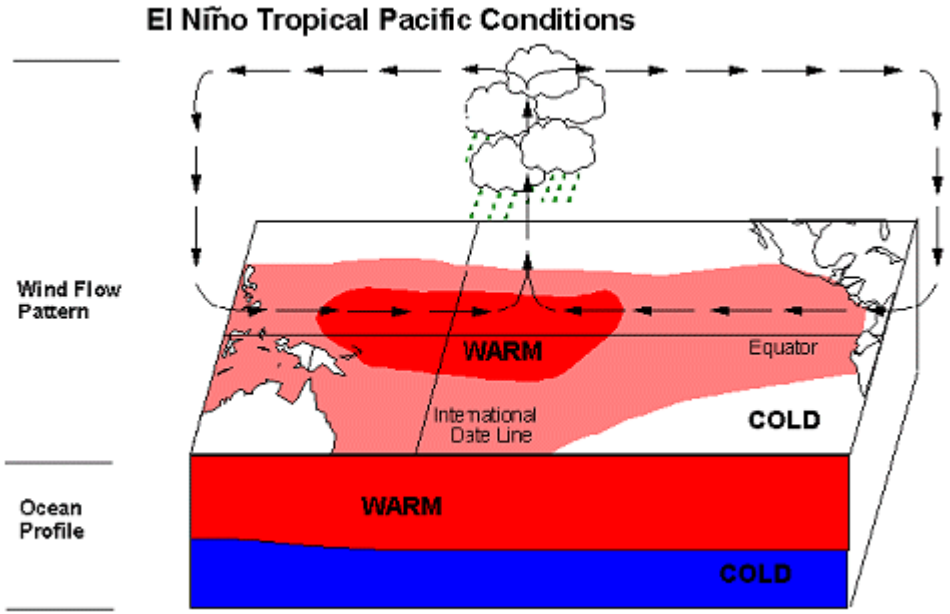
= Thermal tides by solar heating

- Migrating tides:
  - Propagate sun synchronous, westwards with the apparent motion of the sun
- Non-migrating tides:
  - Do not propagate sun synchronous
    - do not propagate horizontally
    - propagate eastwards
    - propagate westwards at a different speed to the sun
  - Generation:
    - differences in topography
    - land-sea contrast
    - surface interactions

El Niño/La Niña-Southern Oscillation ENSO

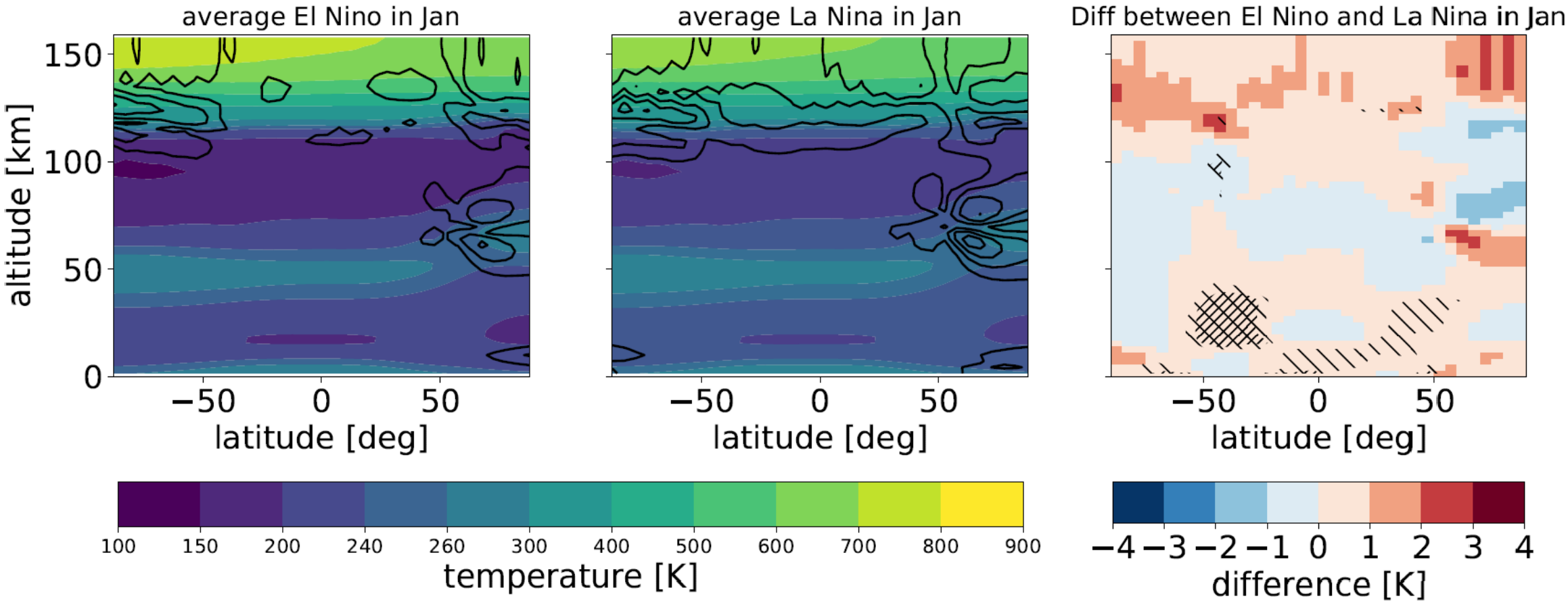
- Self-reinforcing warm/cold phase by anomalies of Walker circulation every 4 years





www.elnino.info

El Niño/La Niña- Temperature



Without LH, Stober, 2020

Impacts of ENSO

- Wind (pressure gradients)
- Precipitation
- Temperature (air and water)

→ Global impacts by atmospheric teleconnections (planetary waves)

Middle and Upper Atmosphere Model MUAM

- 3D-mechanistic nonlinear grid point model
- Latitude resolution of 5° and longitude resolution of 5.625°
- 48-60 Altitude levels (here: 56)
- Vertical resolution of $\Delta z = 2.842$ km ($\Delta x = 0.4$) in logarithmic pressure coordinates regardless of the choice of altitude levels

$$x = -ln\frac{p}{p_0}$$

$$z = -H \cdot ln\frac{p}{p_0}$$

p_0 Ground Reference Pressure = 1000 hPa

H Scale height = 7 km

MUAM: Data and Analyzing

- Nudging with reanalysis data provided by ERA
- Modern-Era Retrospective Analysis for Research and Applications (MERRA) calculates latent heating rates by empirical formula

$$J\,(z,\lambda,\phi)\;=\;J_Z(z)J_{\lambda\phi}(\lambda,\phi)$$

$$J_Z(z) = A\left\{\exp\left[-\left(\frac{z-6.5}{5.39}\right)^2\right] - 0.23\;exp\left(-\frac{z}{1.31}\right)\right\}$$

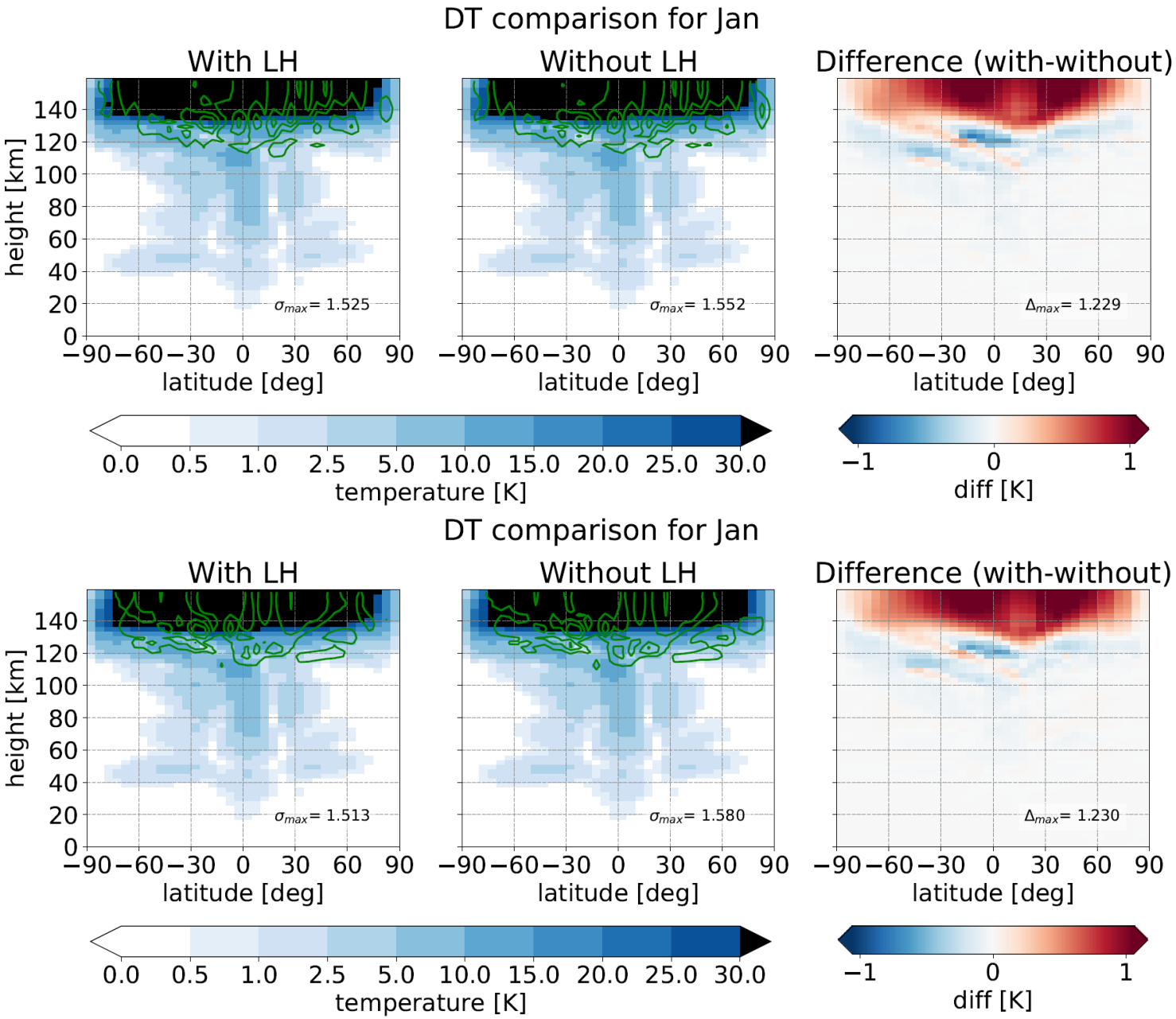
$J_{\lambda\phi}(\lambda,\phi)$ … observed longitude/latitude distribution of precipitation rate near ground

$J_Z(z)$ … empirical formula for vertical distribution of latent heating rates dep. on precipitation rate z

A … empirical constant (dep. on precipitation rate)

Results: Temperature: El Niño

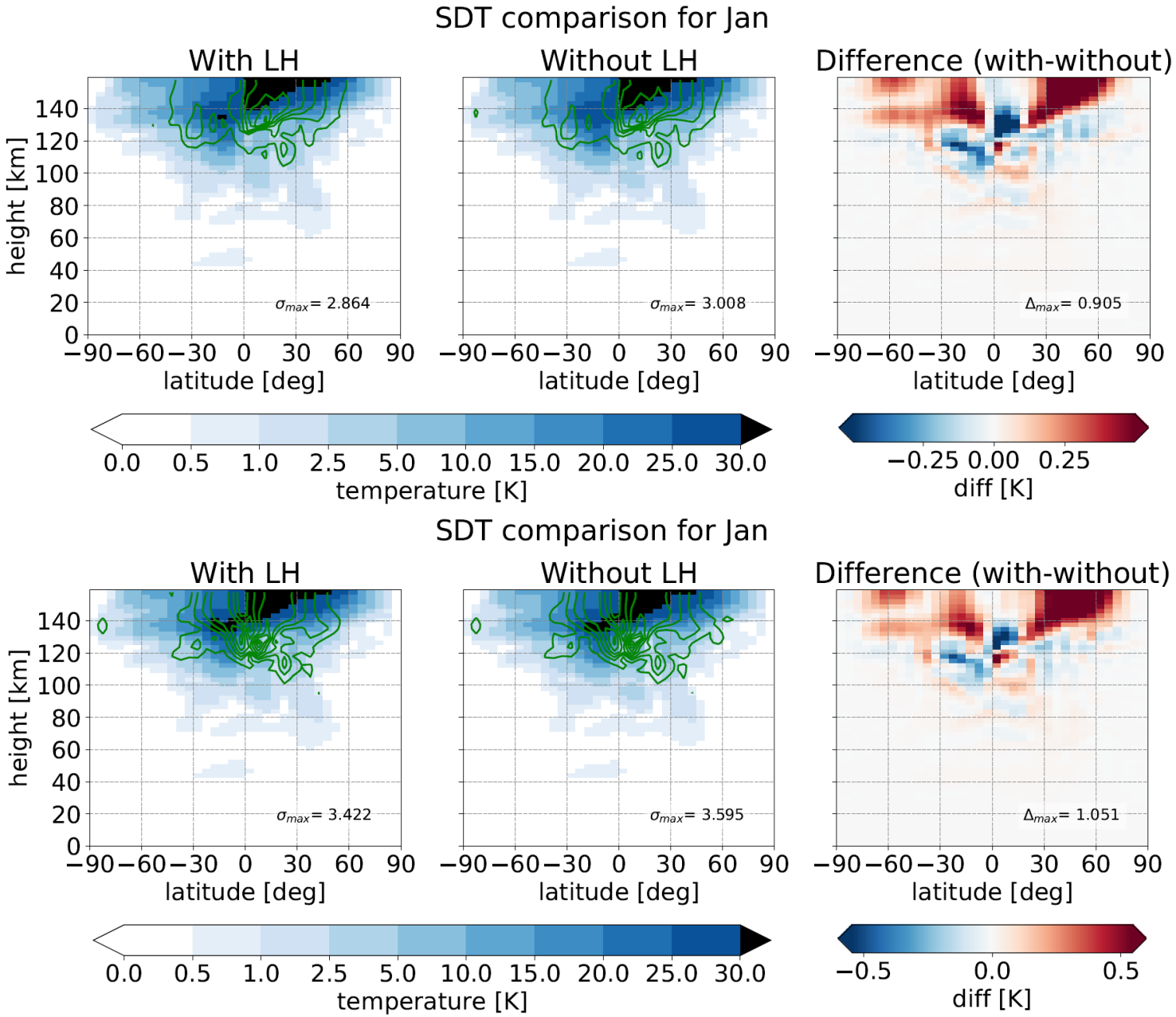
La Niña



Temperature:

El Niño

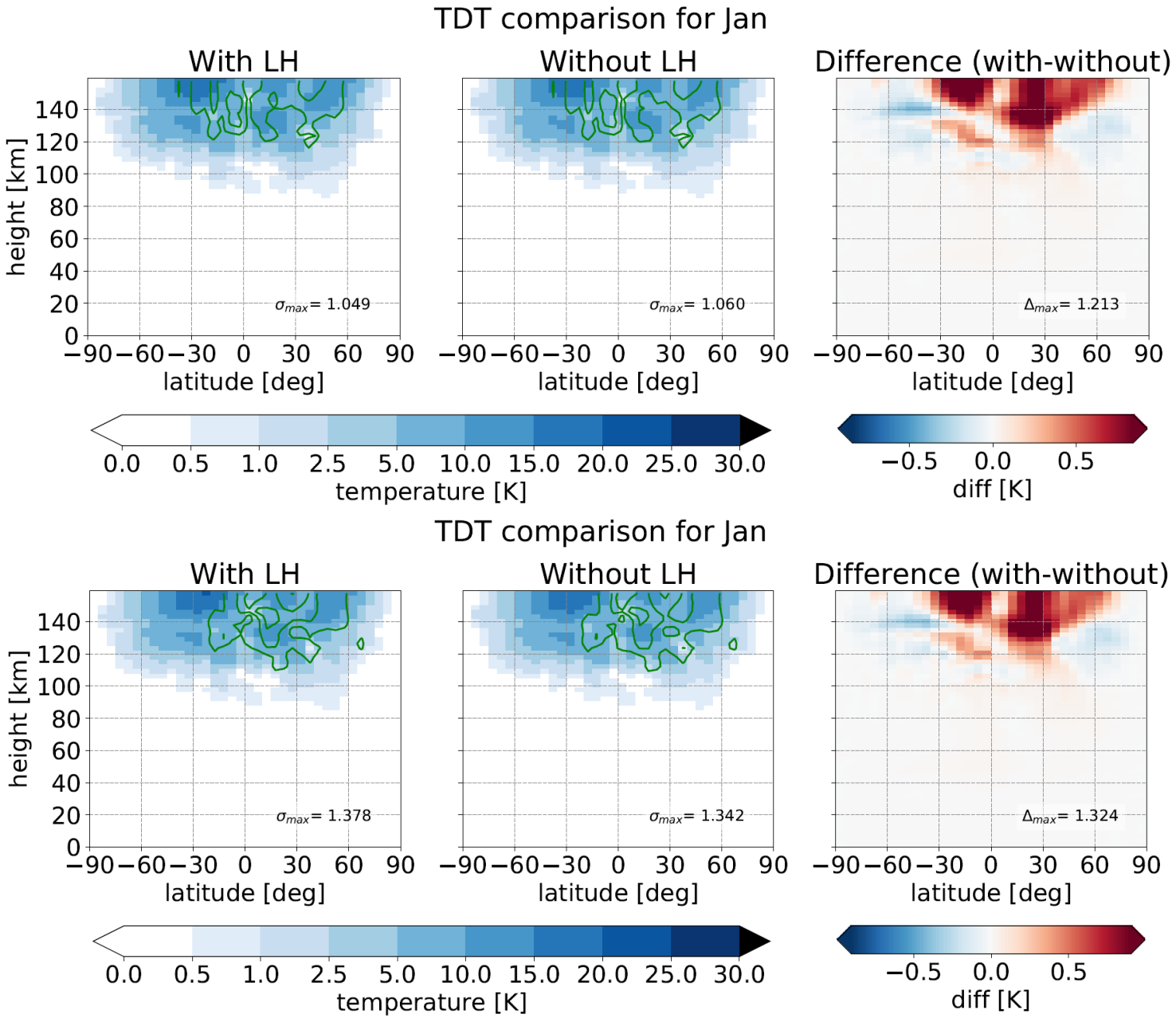
La Niña



Temperature:

El Niño

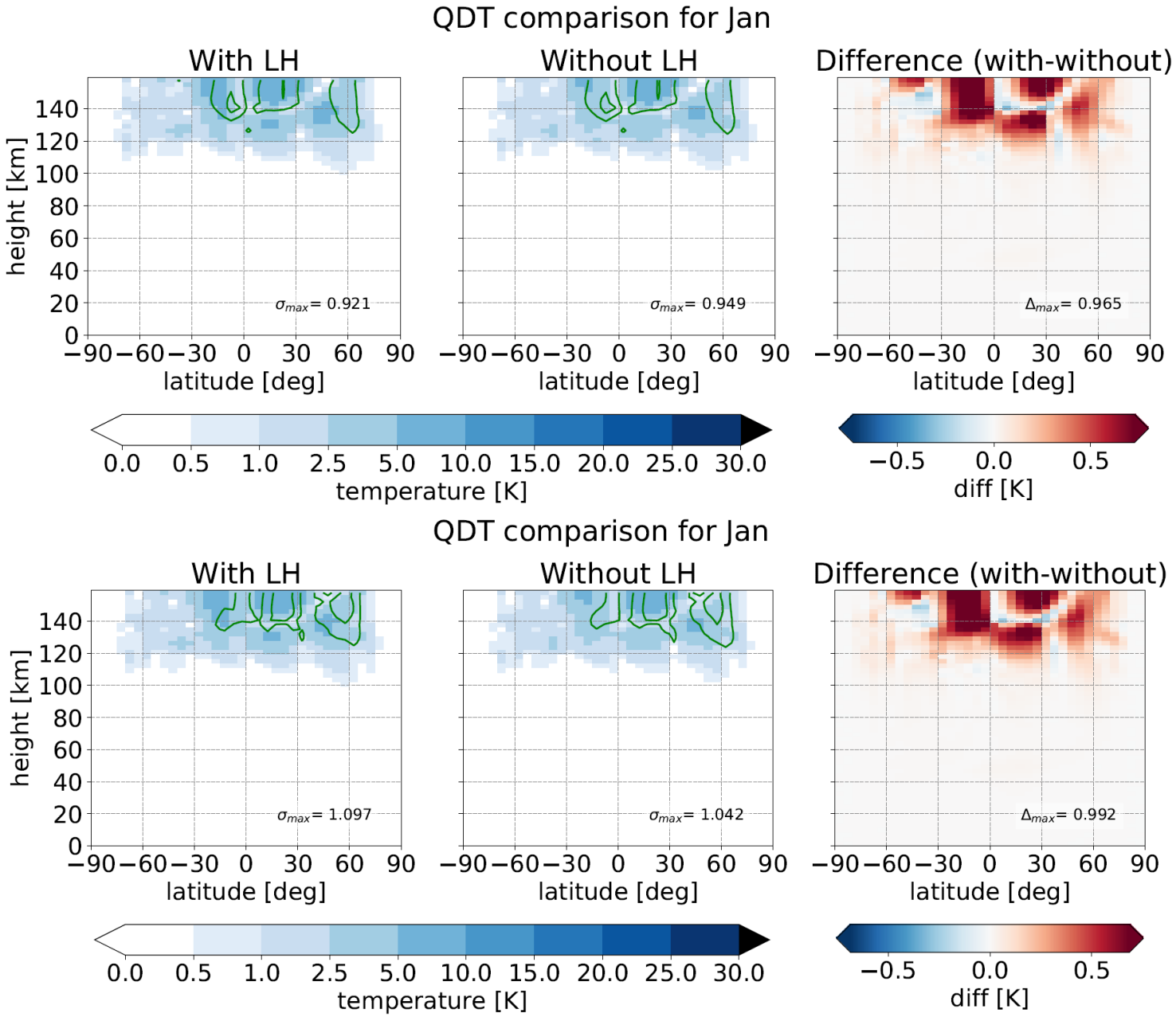
La Niña



Temperature:

El Niño

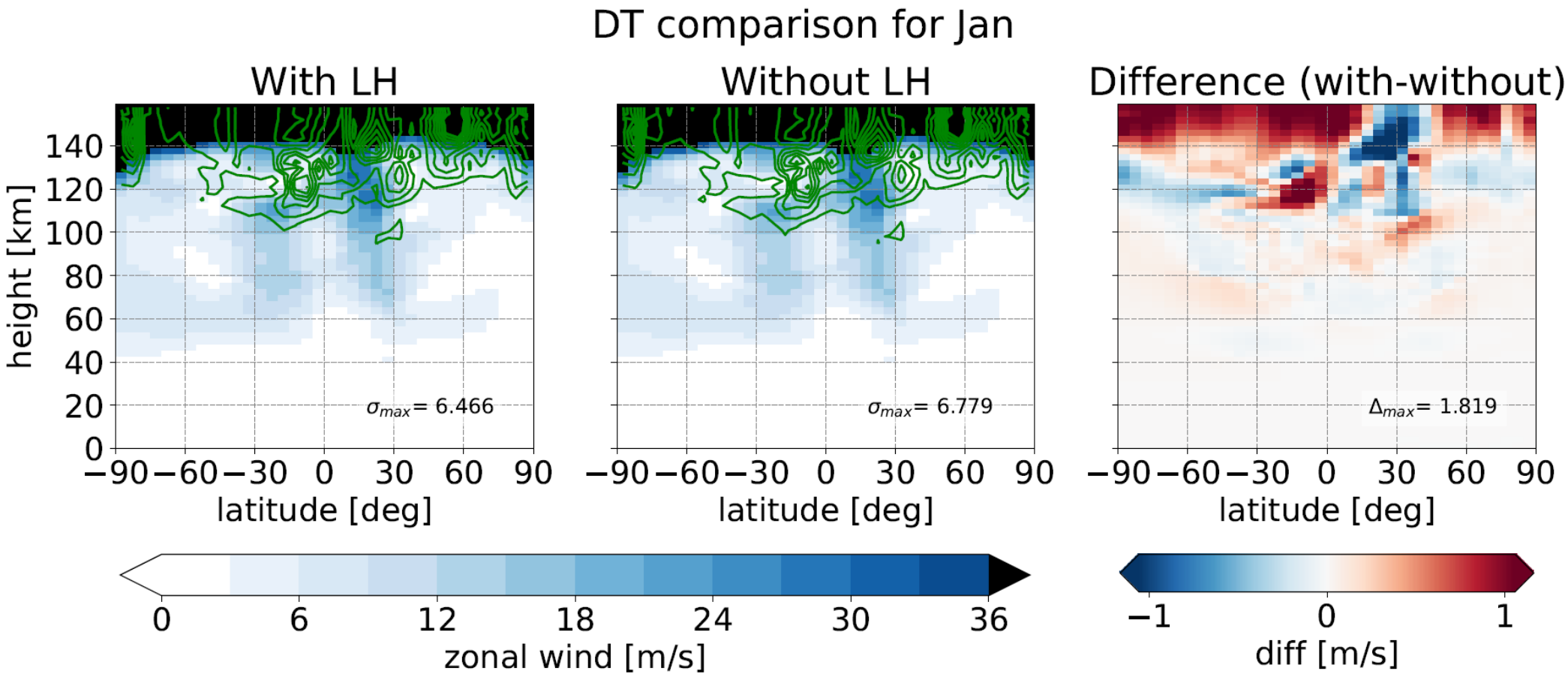
La Niña



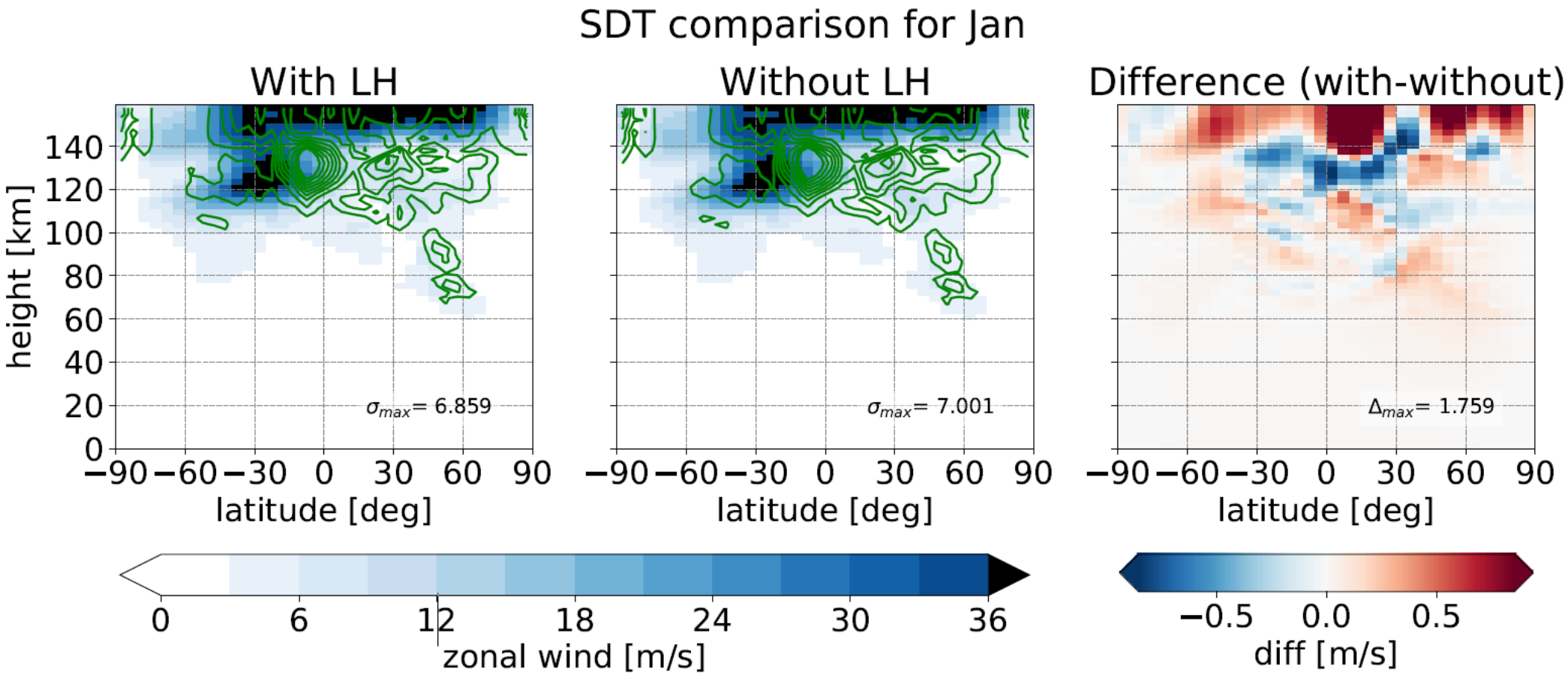
Temperature comparison

- Variations of 5 - 15 K for DT/SDT *(Hagan et al. 2002) ?*

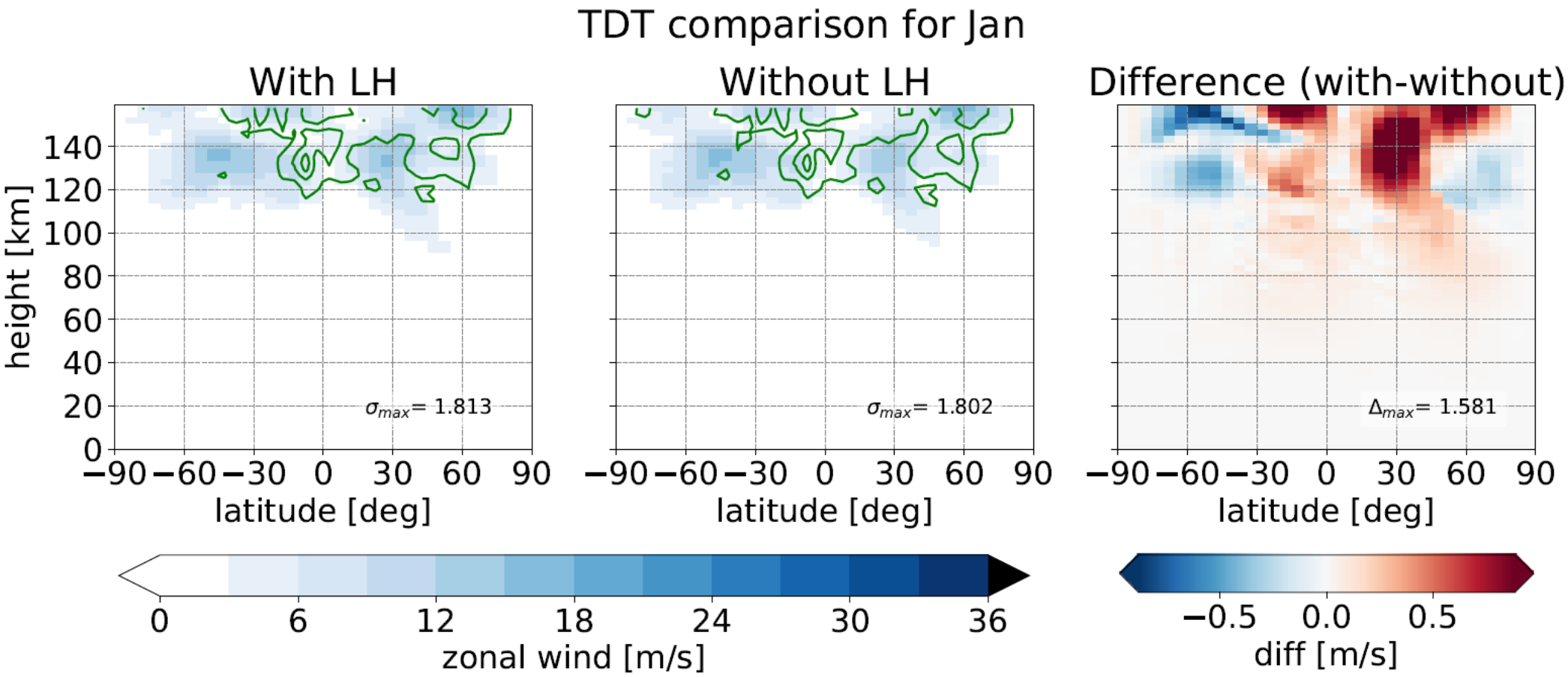
Zonal wind: EL



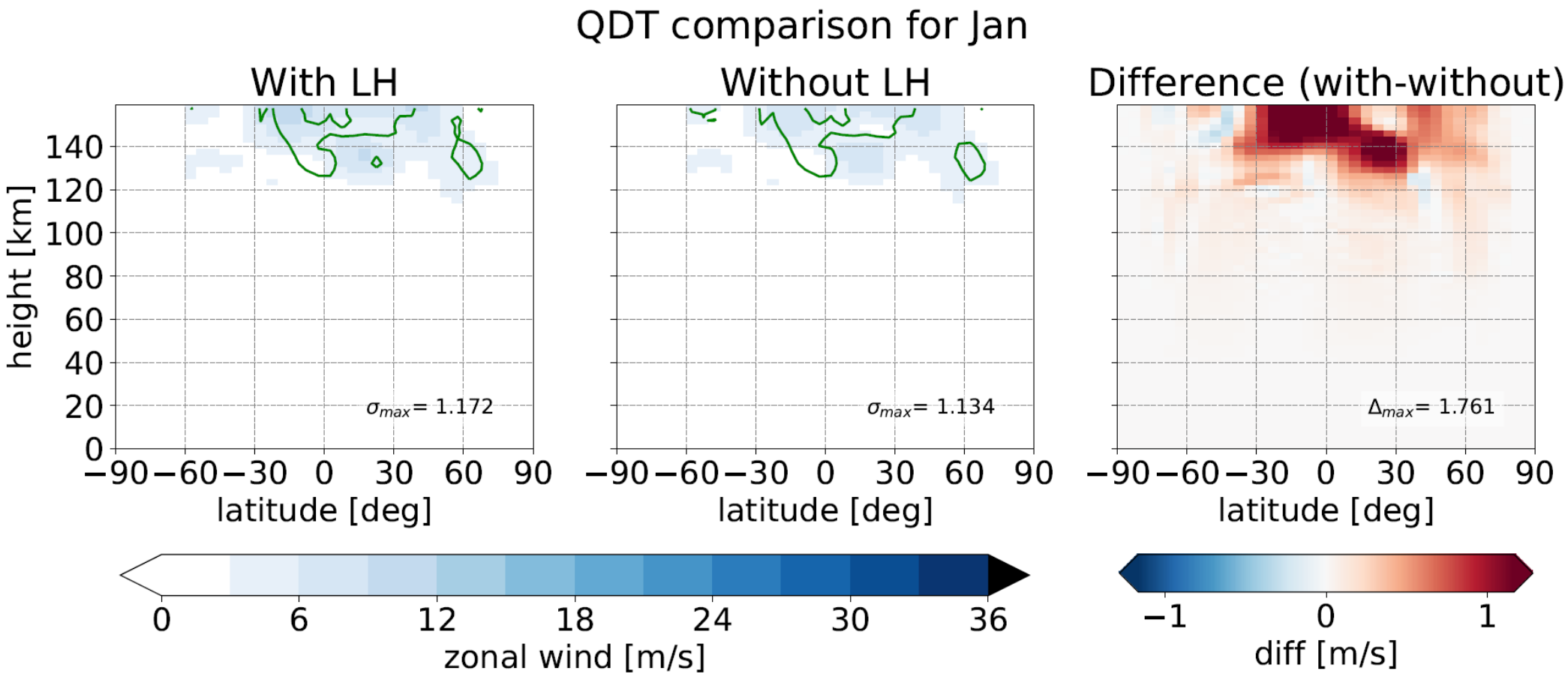
Zonal wind: EL



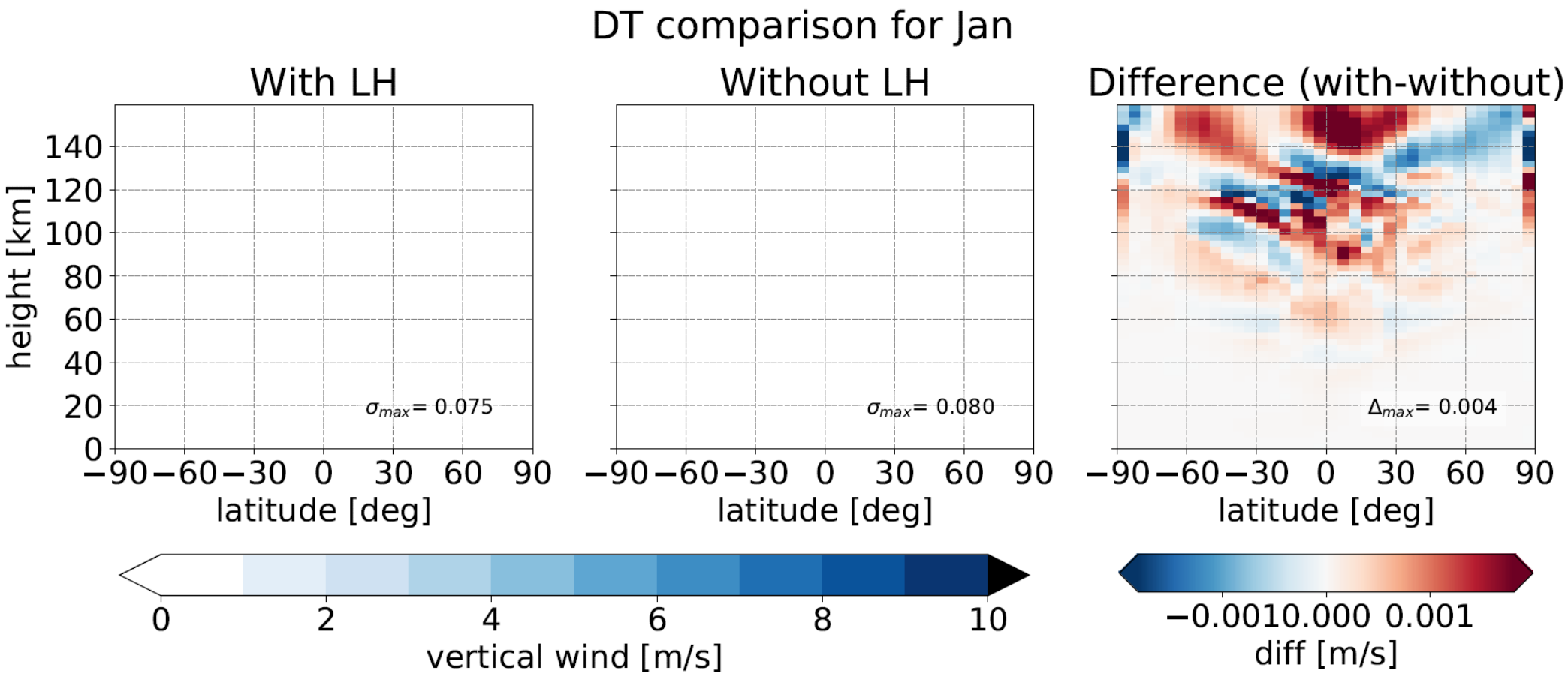
Zonal wind: EL



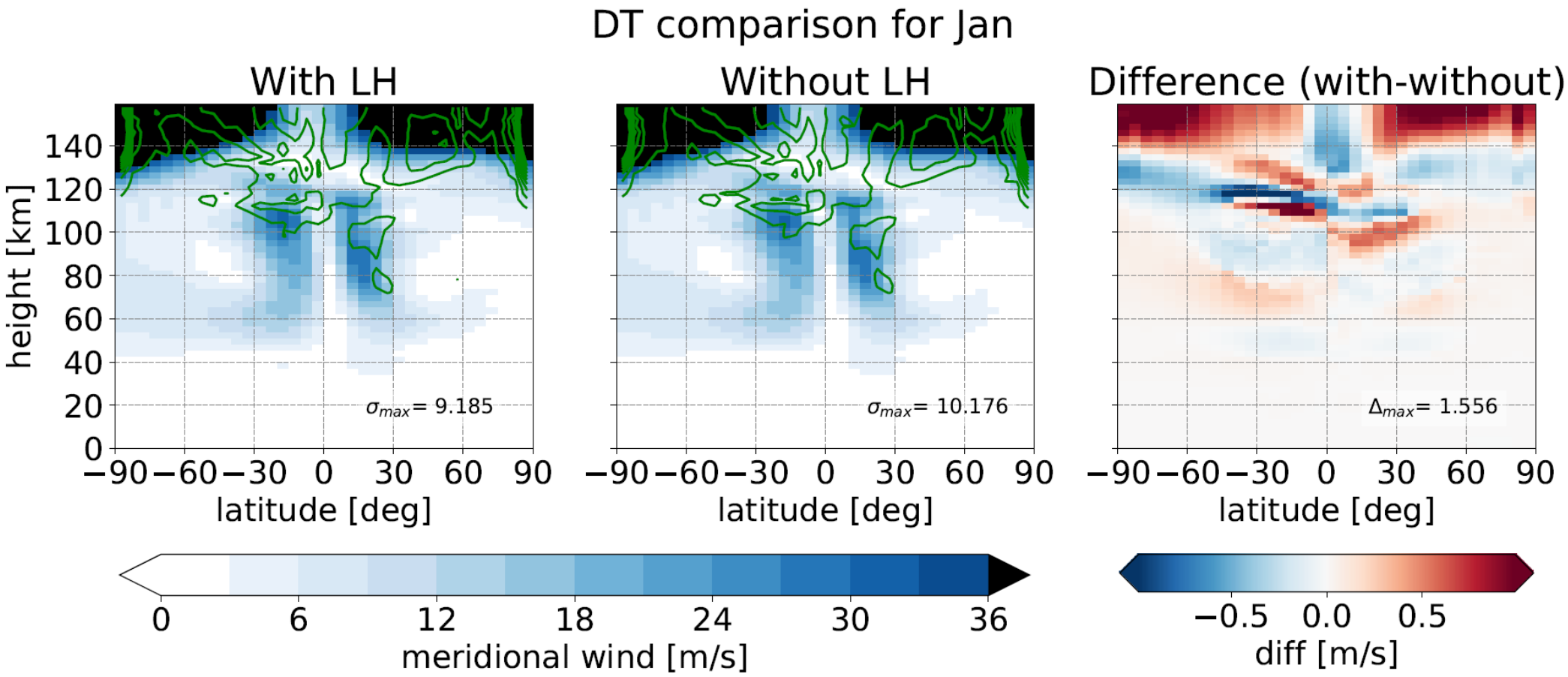
Zonal wind: EL



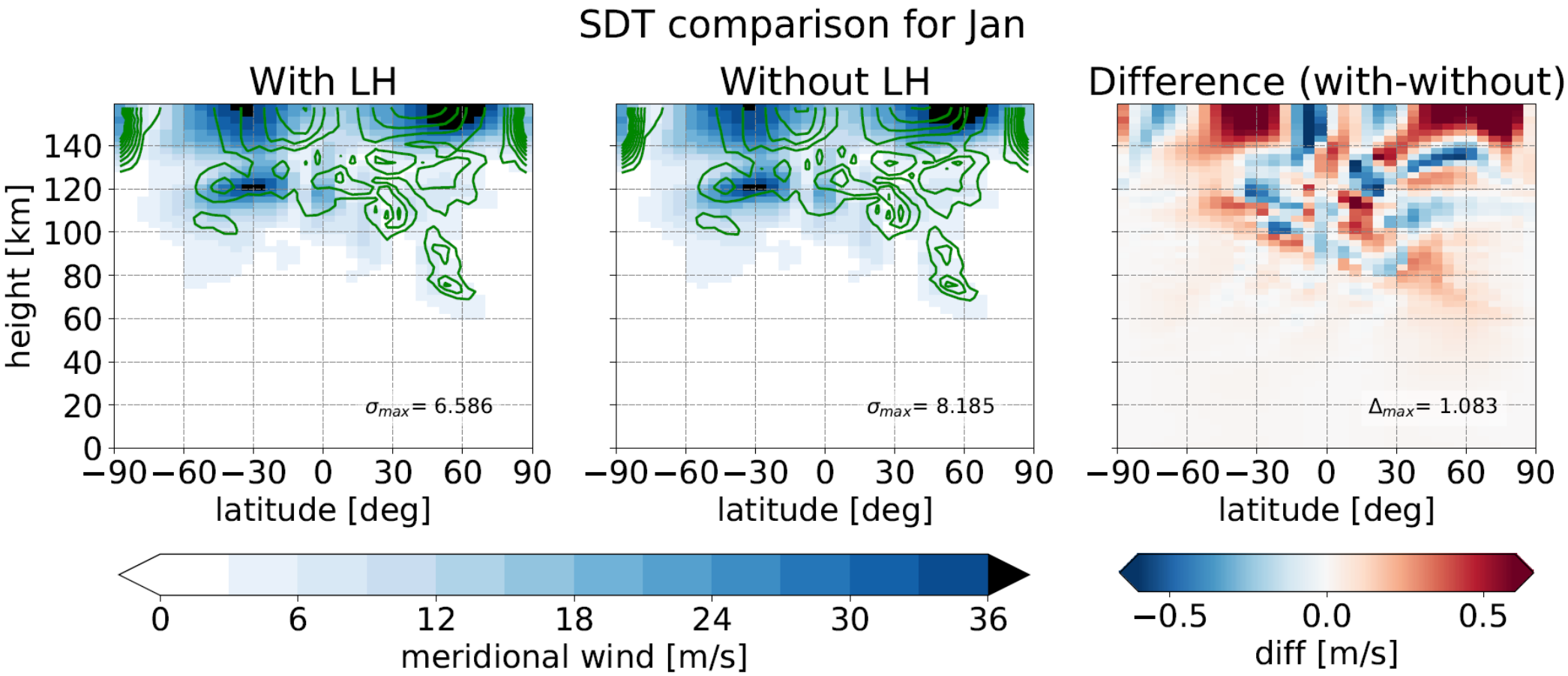
Vertical wind: EL



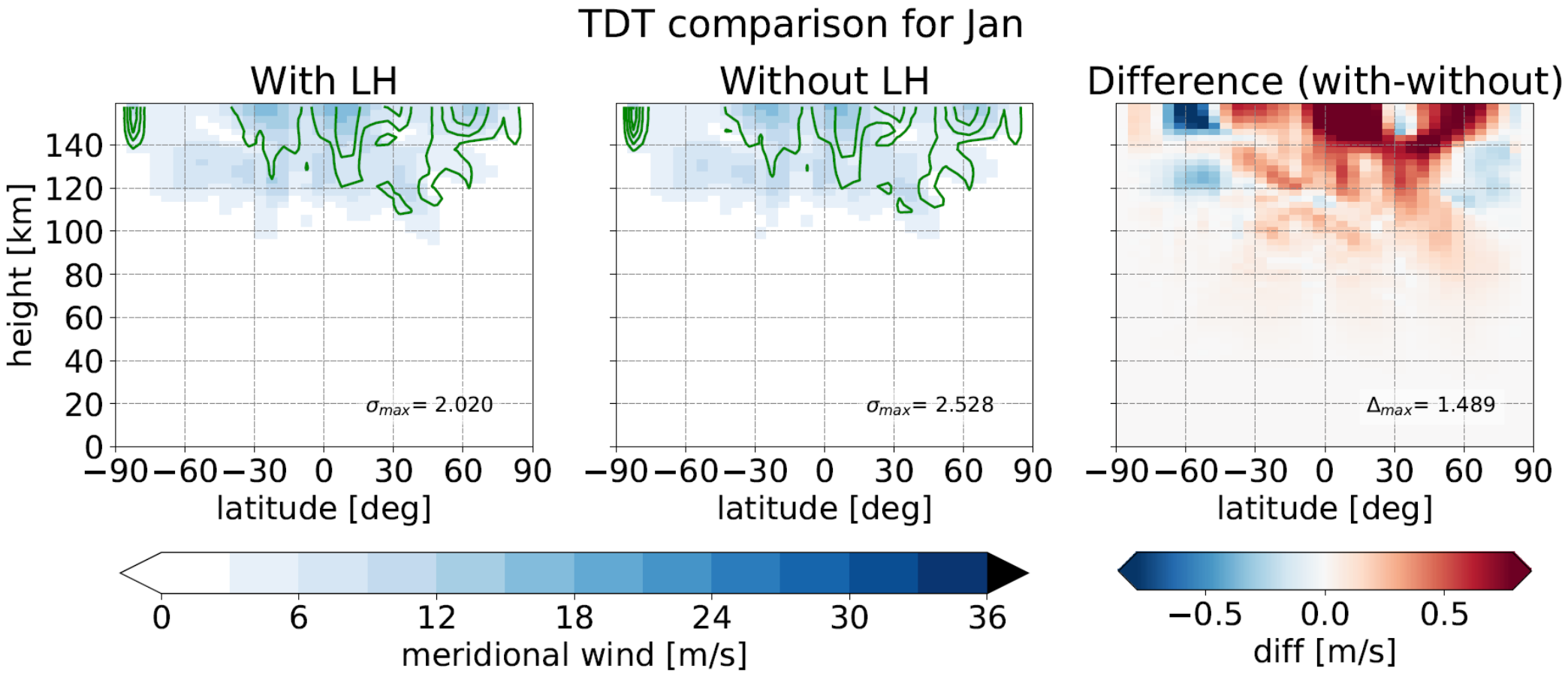
Meridional wind: EL



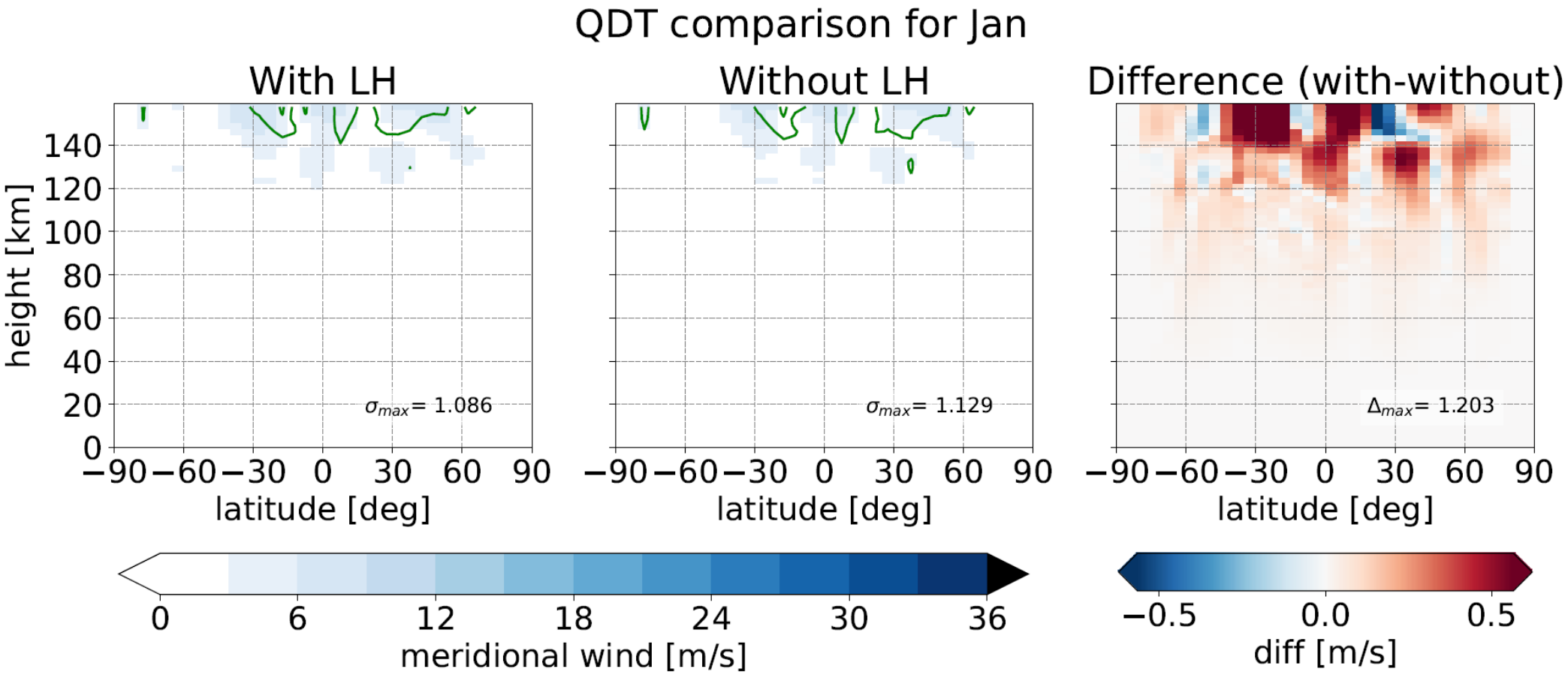
Meridional wind: EL



Meridional wind: EL



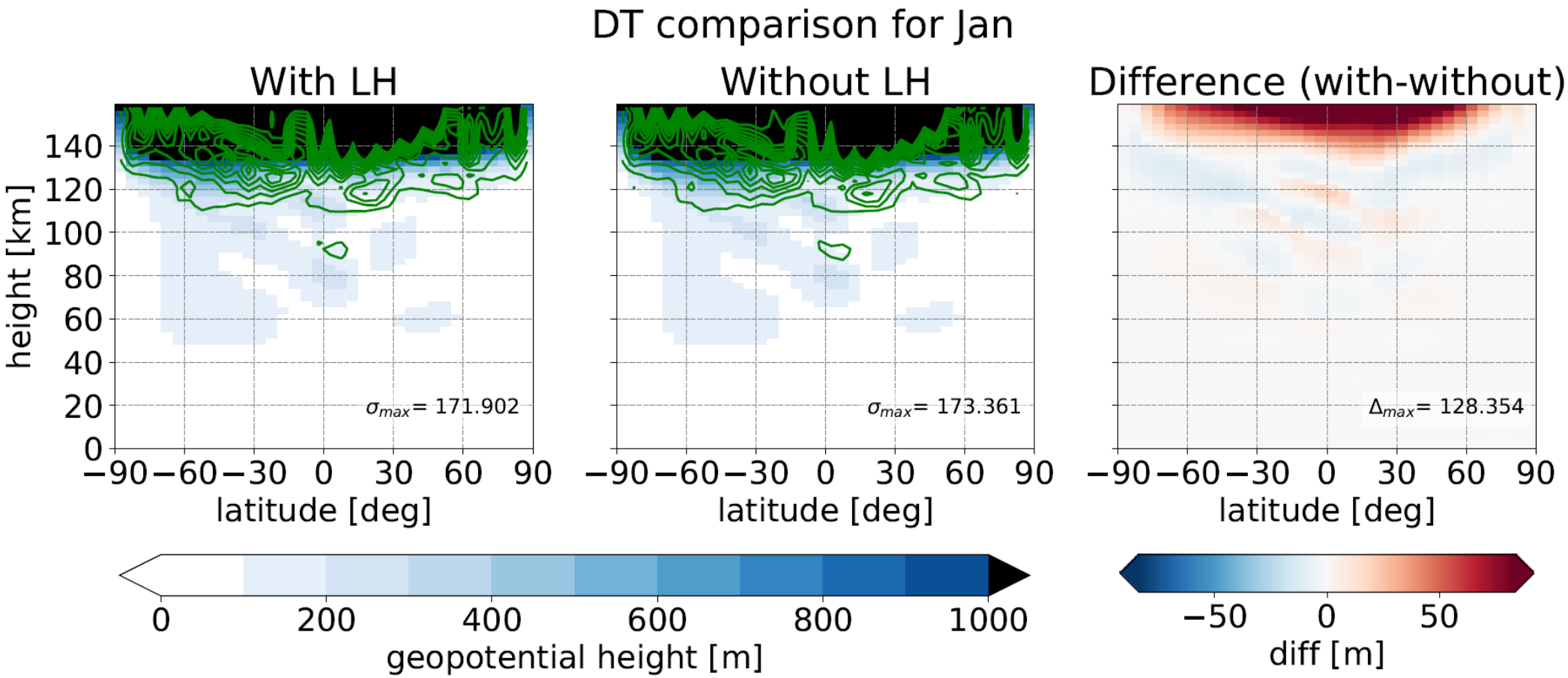
Meridional wind: EL



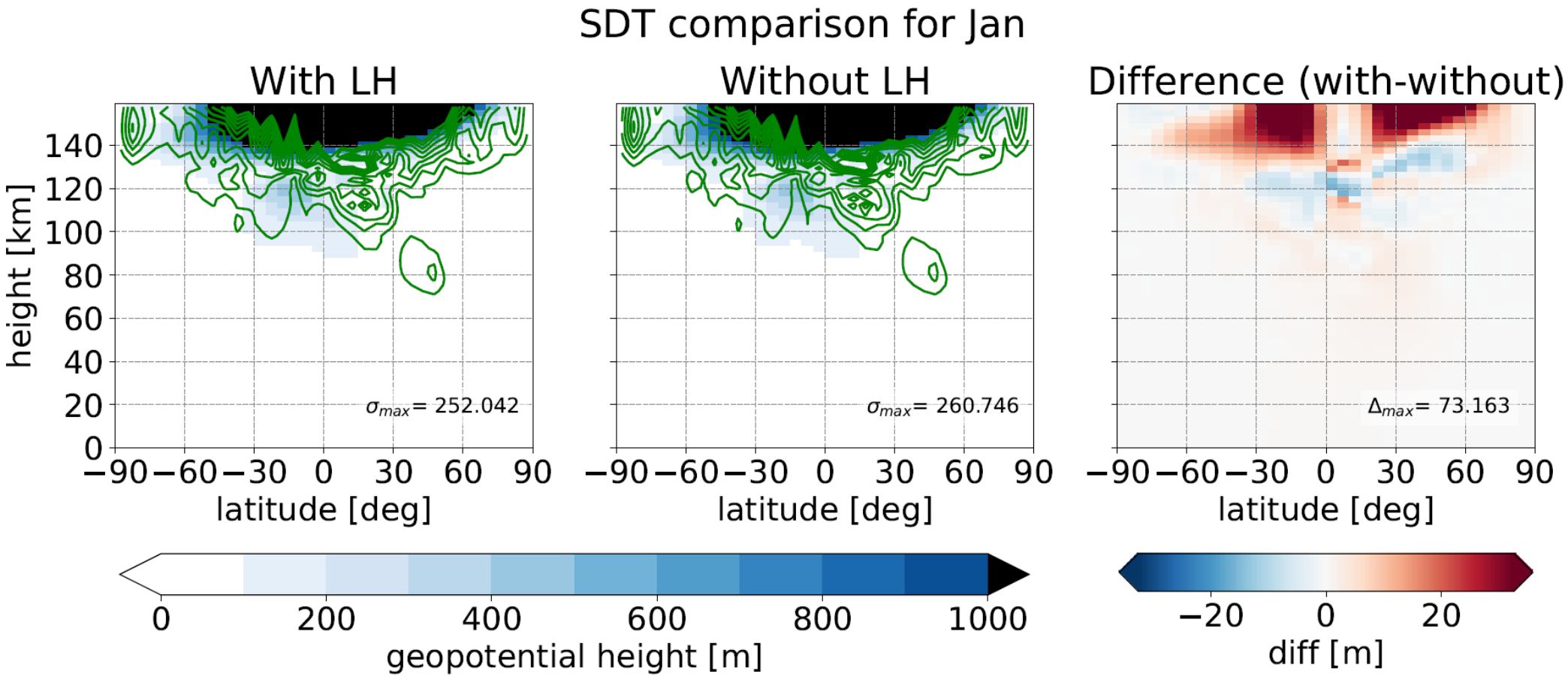
Wind comparison

- Variations of 10 - 20 m/s for DT/SDT *(Hagan et al. 2002) ?*

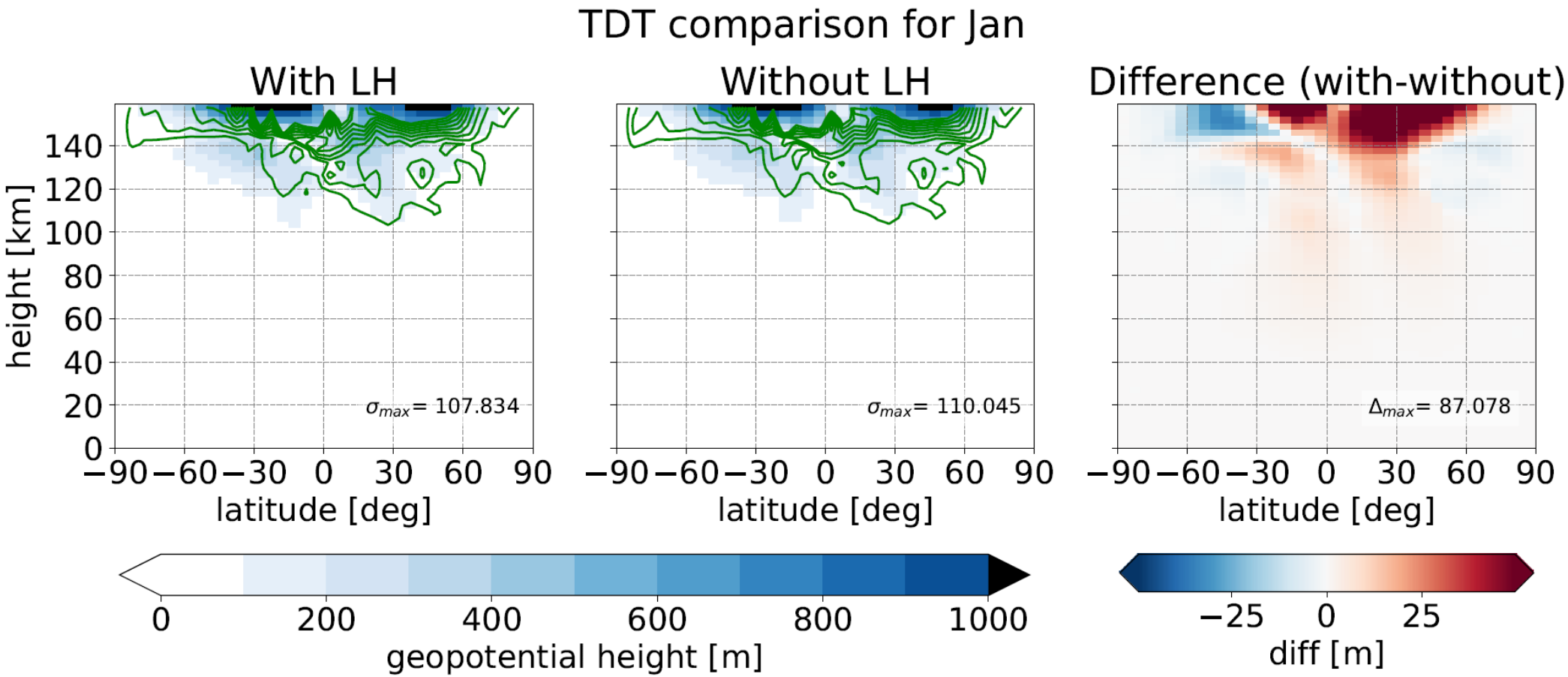
Geopotential height: EL



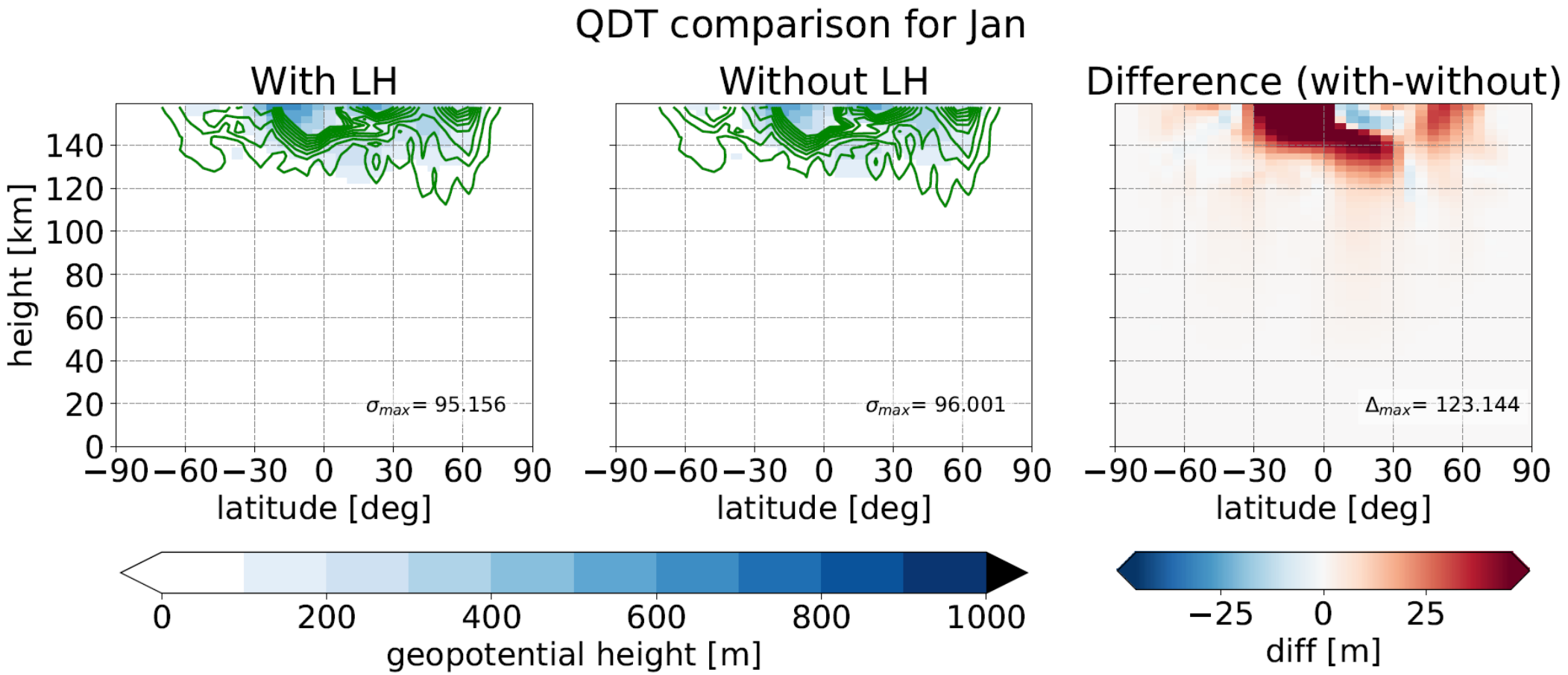
Geopotential height: EL



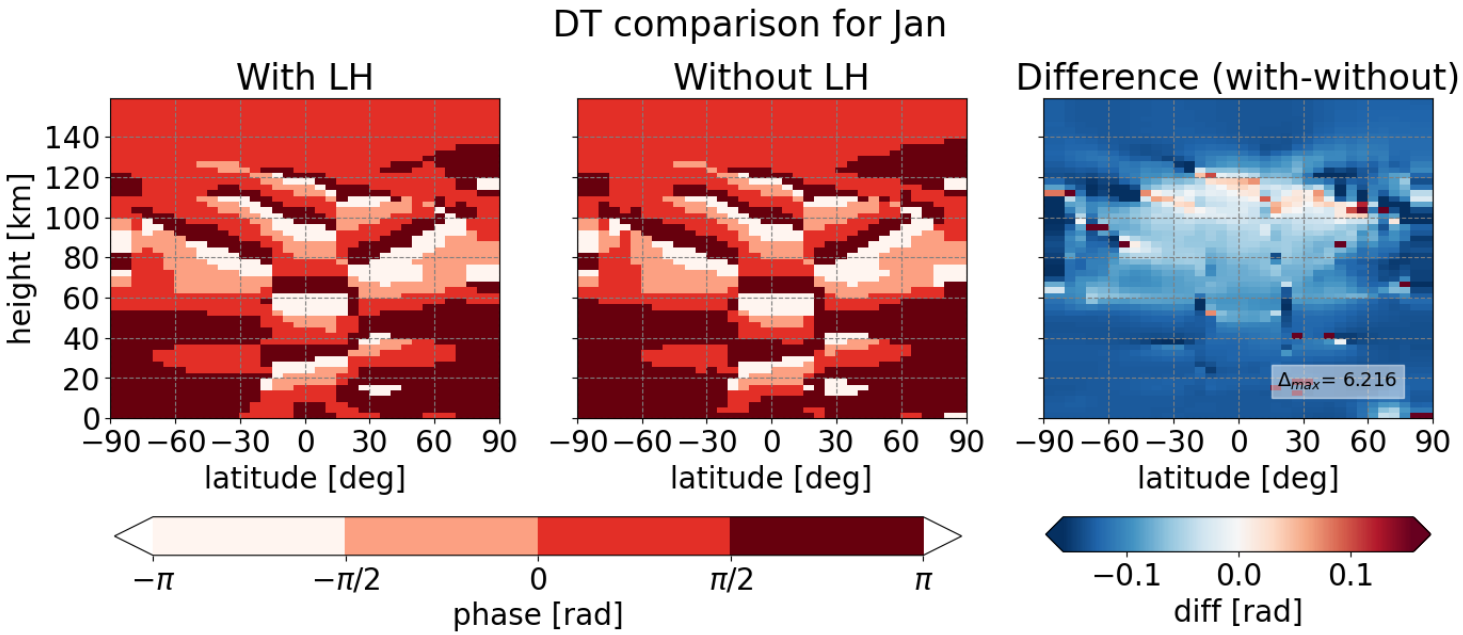
Geopotential height: EL



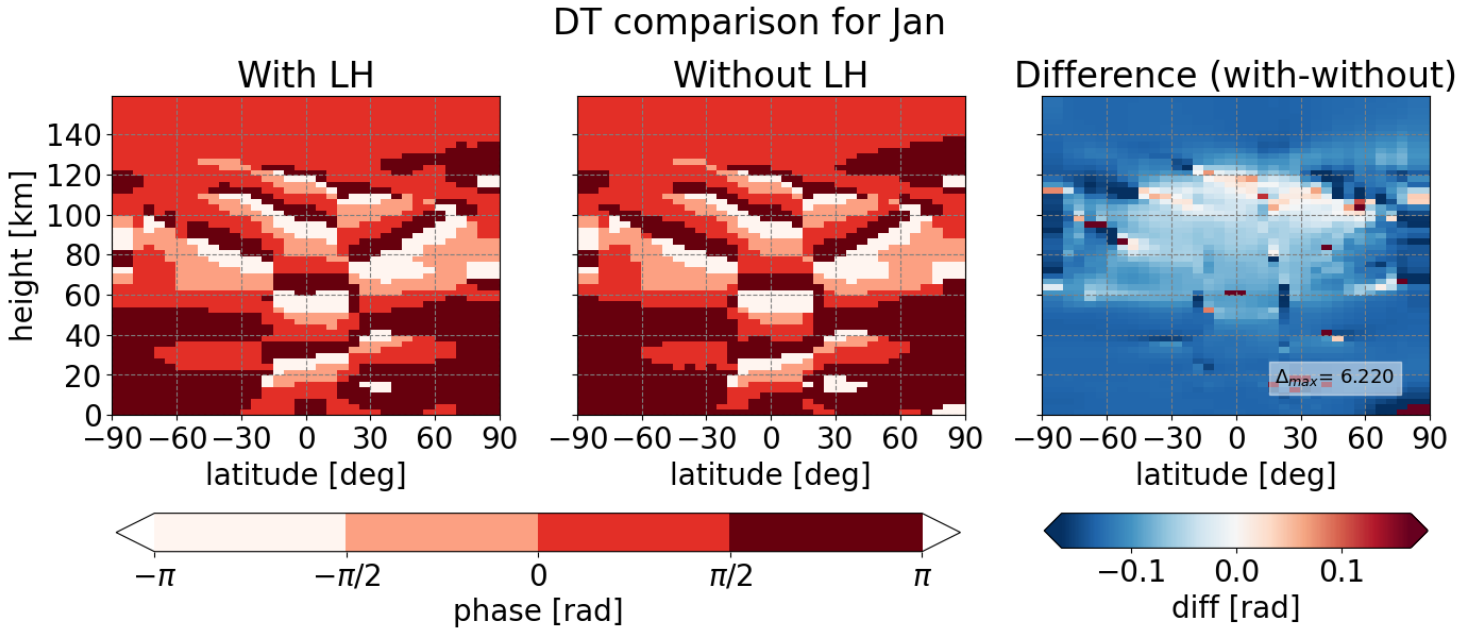
Geopotential height: EL



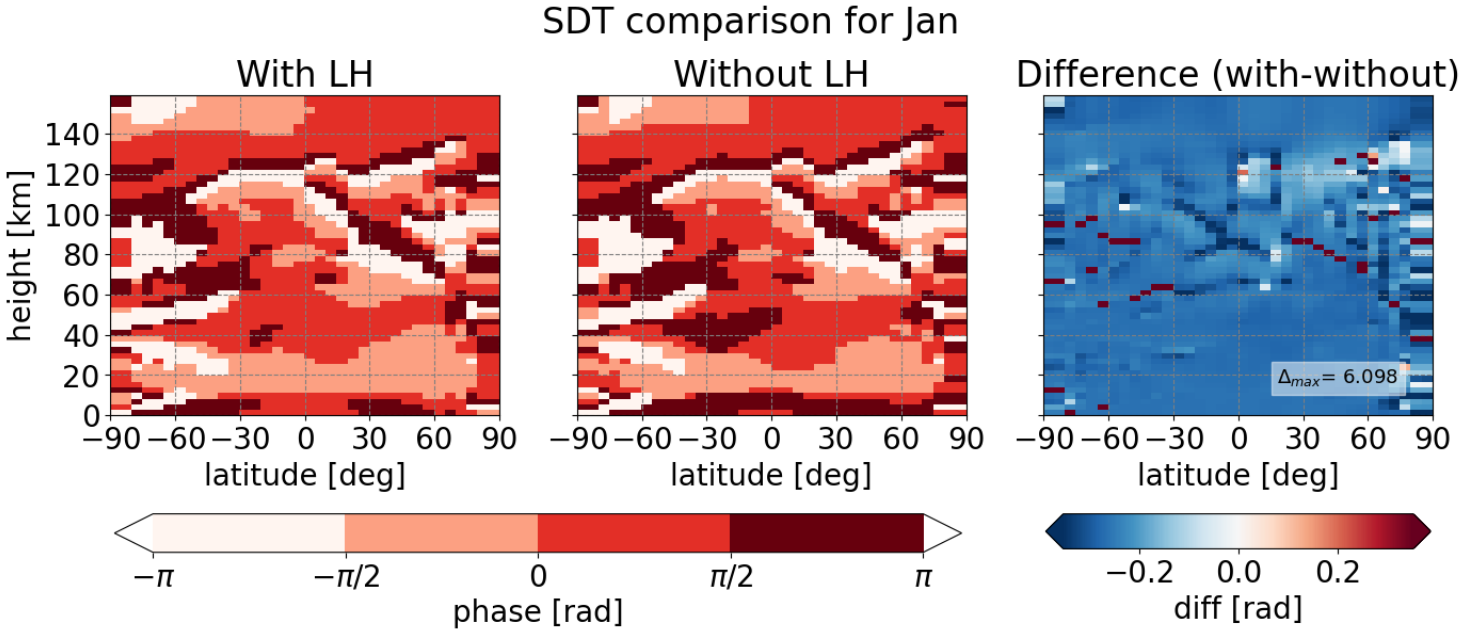
Phase of Temperature: El Niño



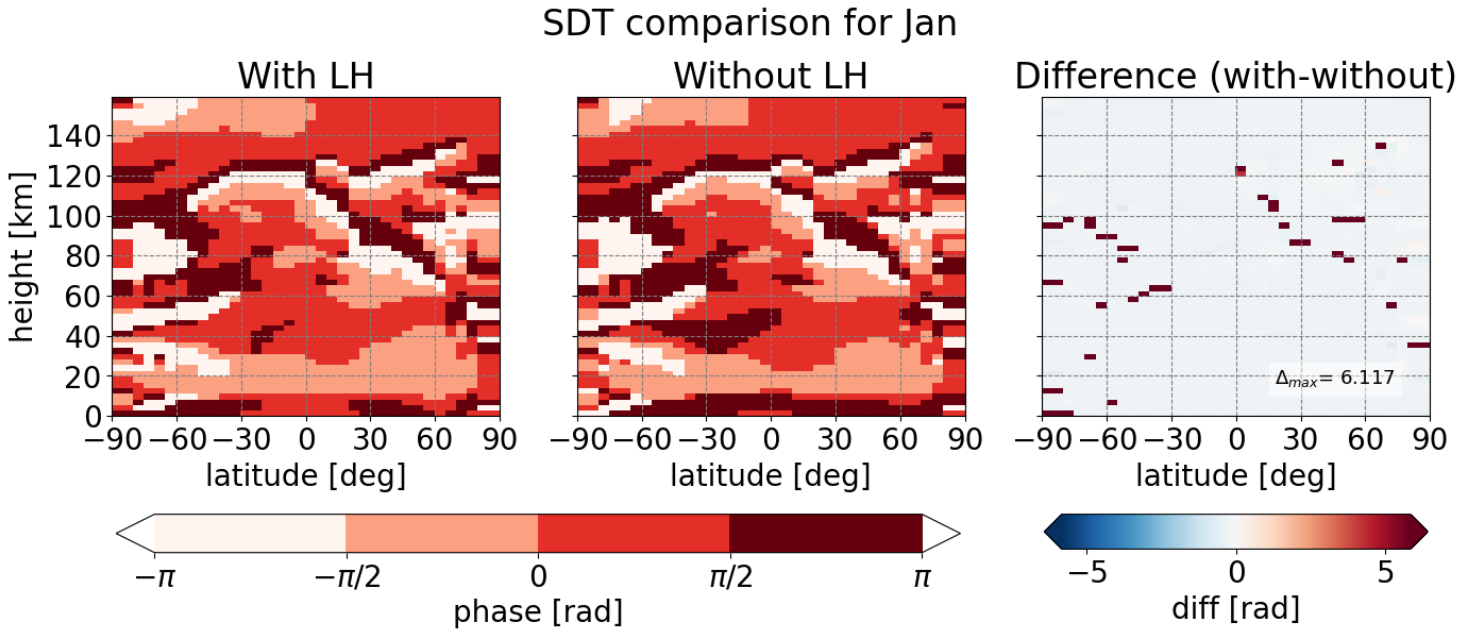
La Niña



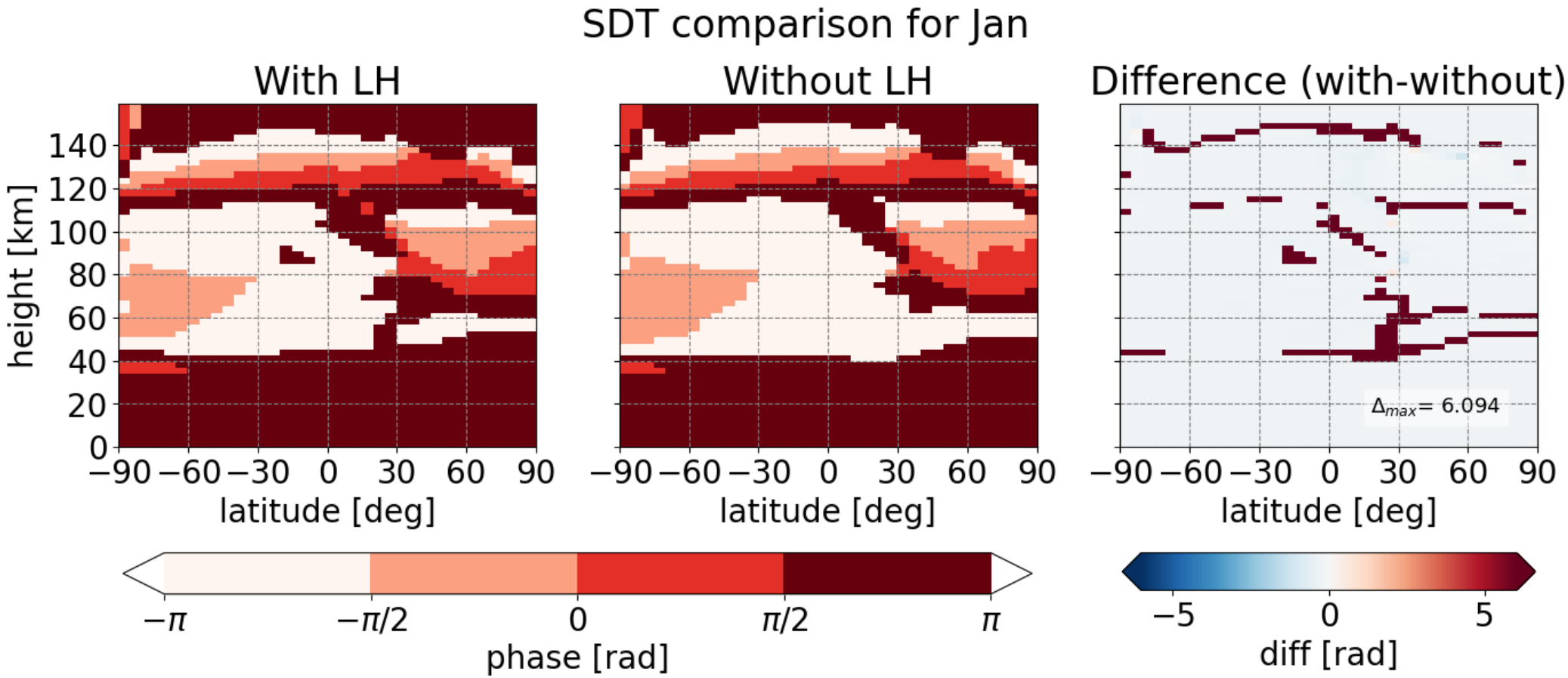
Phase of Temperature: El Niño



La Niña



Phase of zonal wind: EL



Effect of LH on tides?

- Yes , but small effect
- Variations most apparent at 80 and 150 km height with amplitude variations of 10 - 20 m/s and 5 - 15 K for DT/SDT *(Hagan et al. 2002)*

Summary

- Amplitudes become smaller with smaller period of tide
- Latent heat increases values of amplitude of tides overall
  - Small effect in MUAM
  - Biggest differences alternate between DT/SDT/TDT/QDT
- Negletable phase changes
  - Tides remain, but with slighty higher amplitudes

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