Climatological controls on the response of tropical clouds and relative humidity to greenhouse gas forcing

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CFMIP 2019

Photo from NASA

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NASA Langley

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Lawrence Livermore National Laboratory

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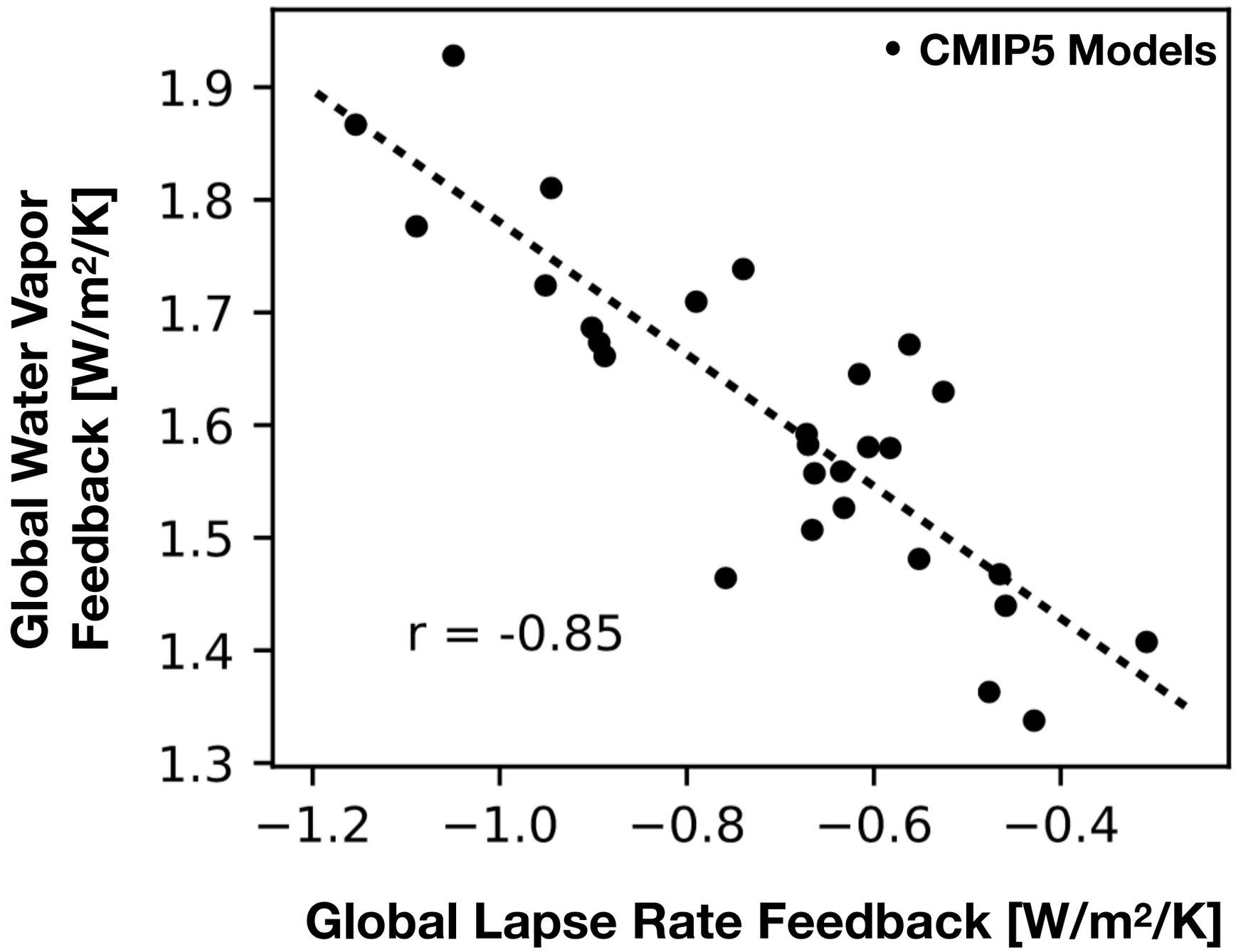
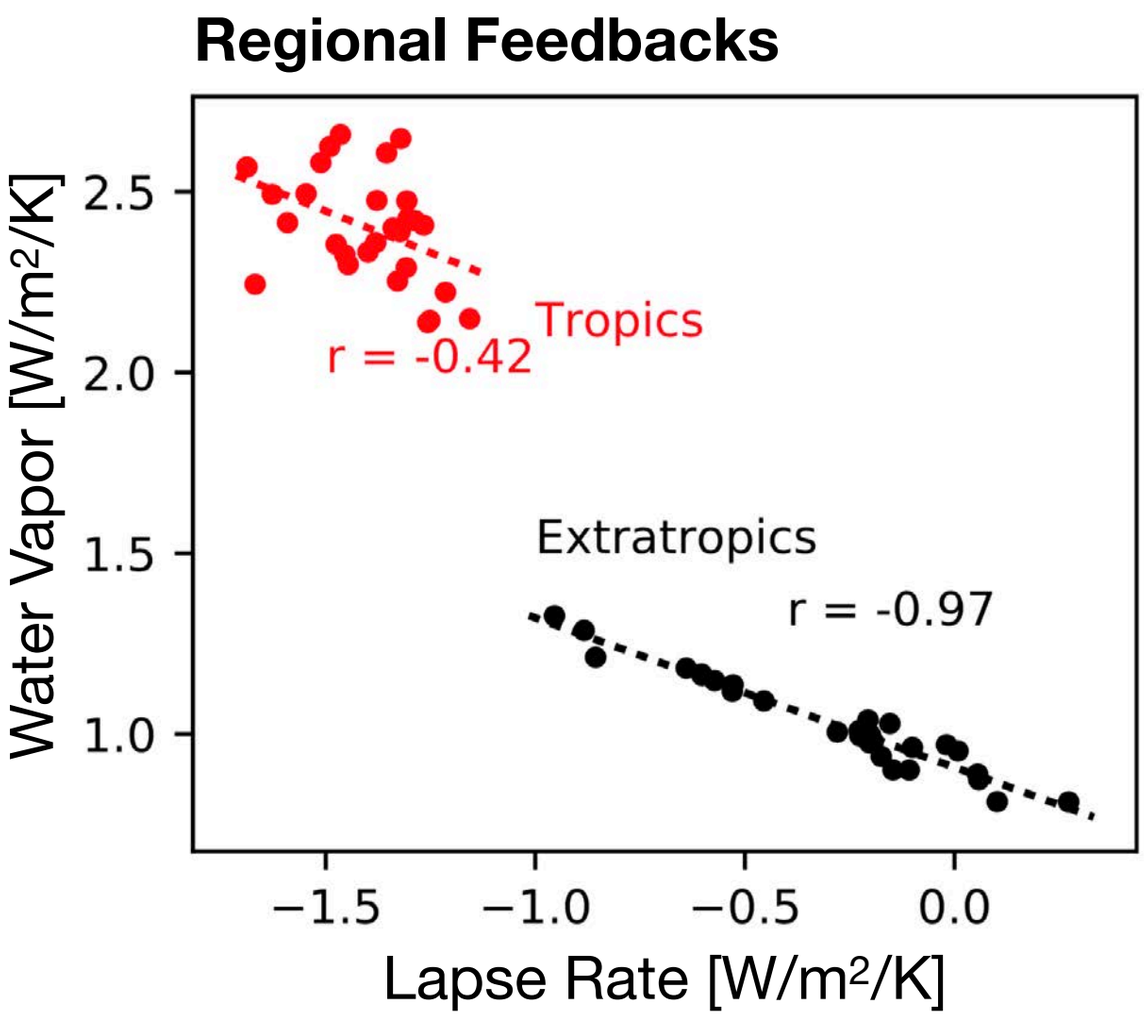
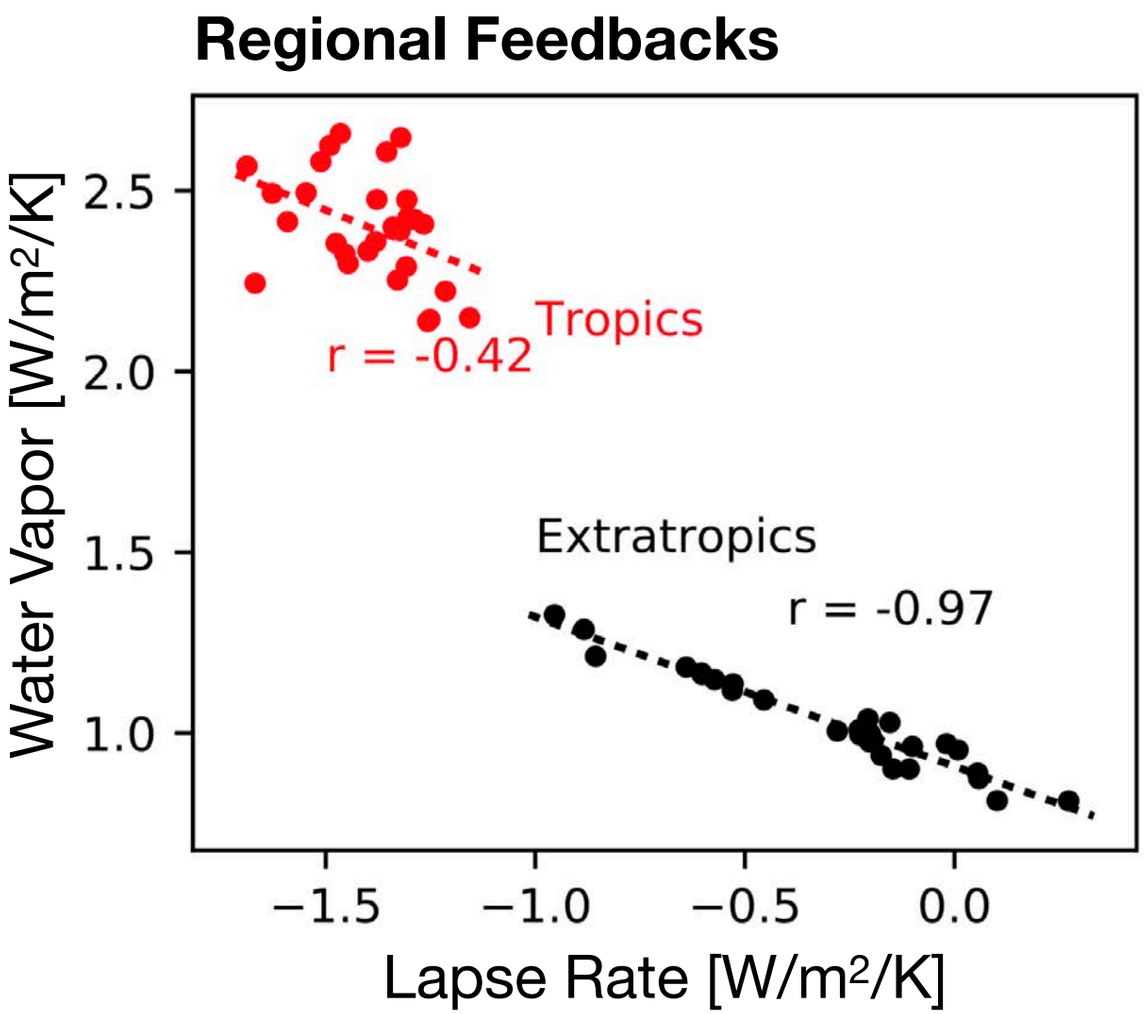
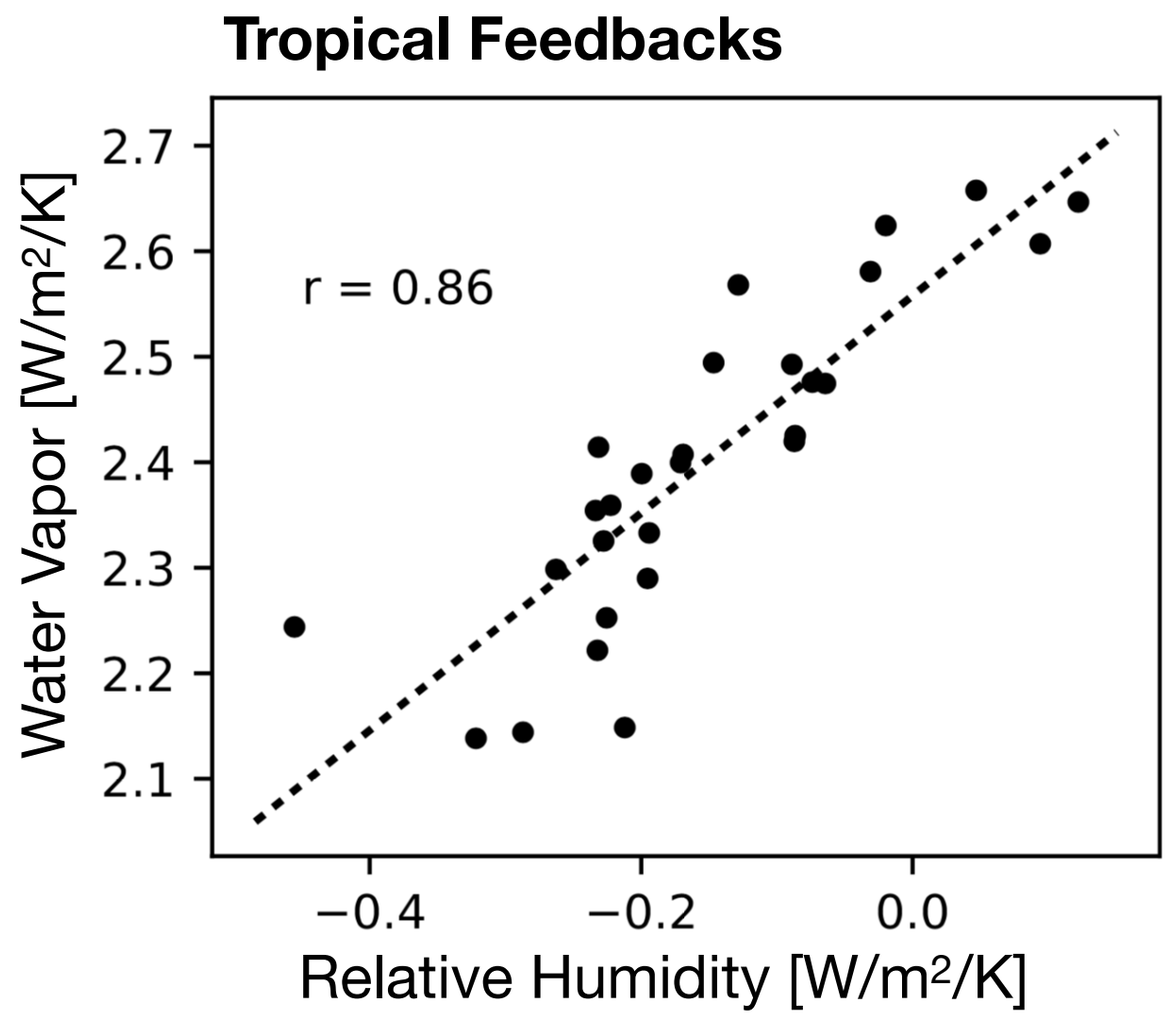


Po-Chedley et al. (2018); Vial et al. (2013); Caldwell et al. (2016); Soden and Held (2006)



Po-Chedley et al. (2018); Vial et al. (2013)





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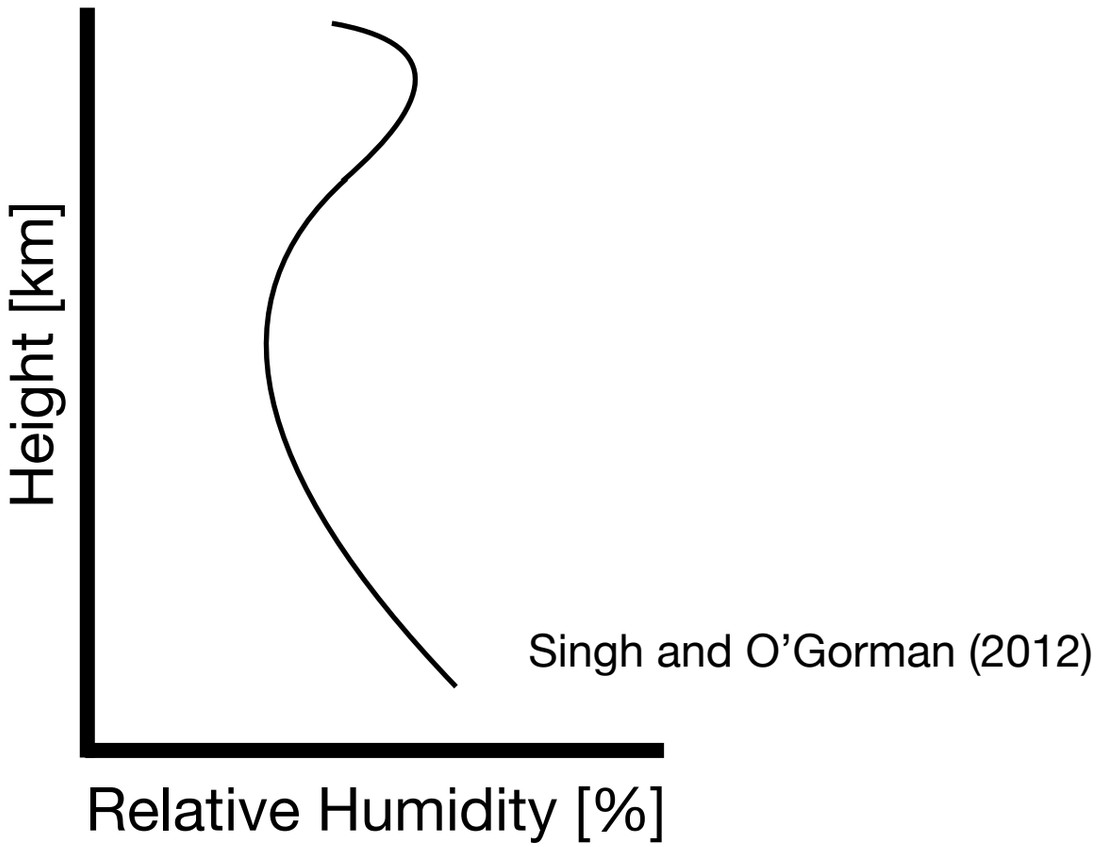
Upward Shift of Climatology



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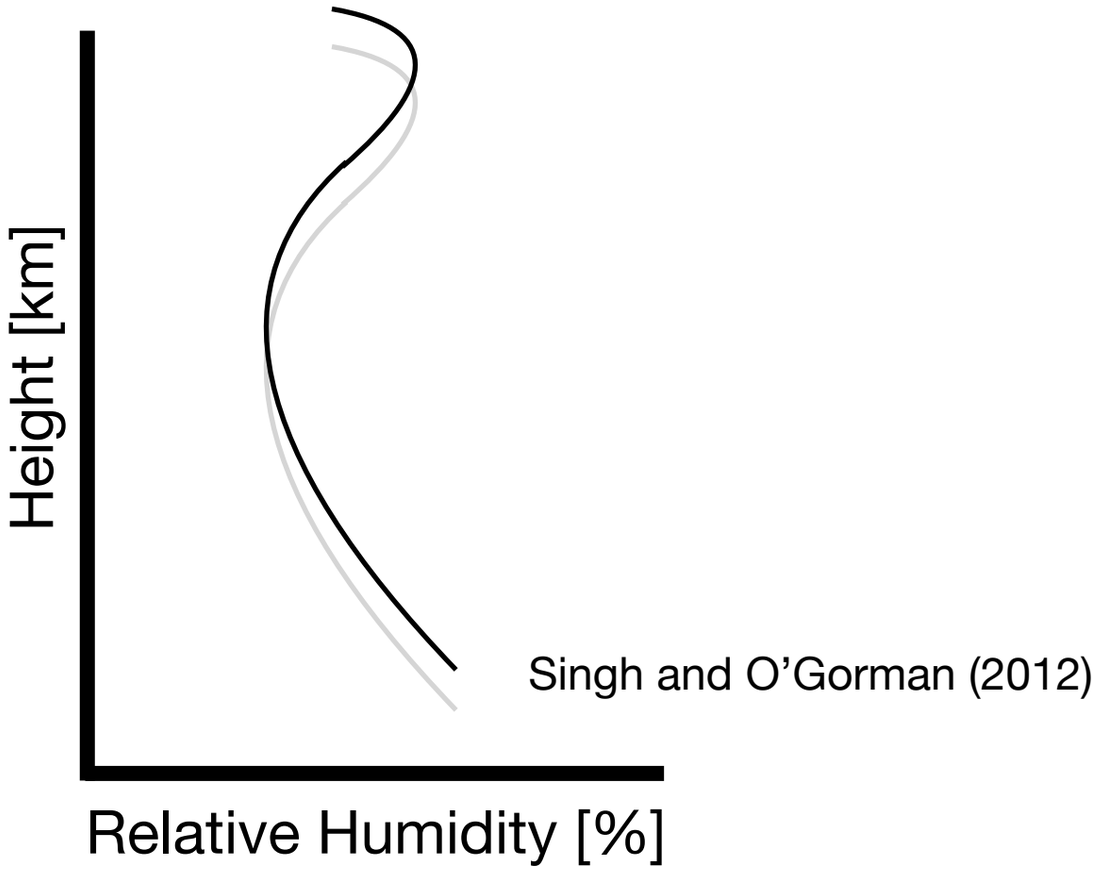

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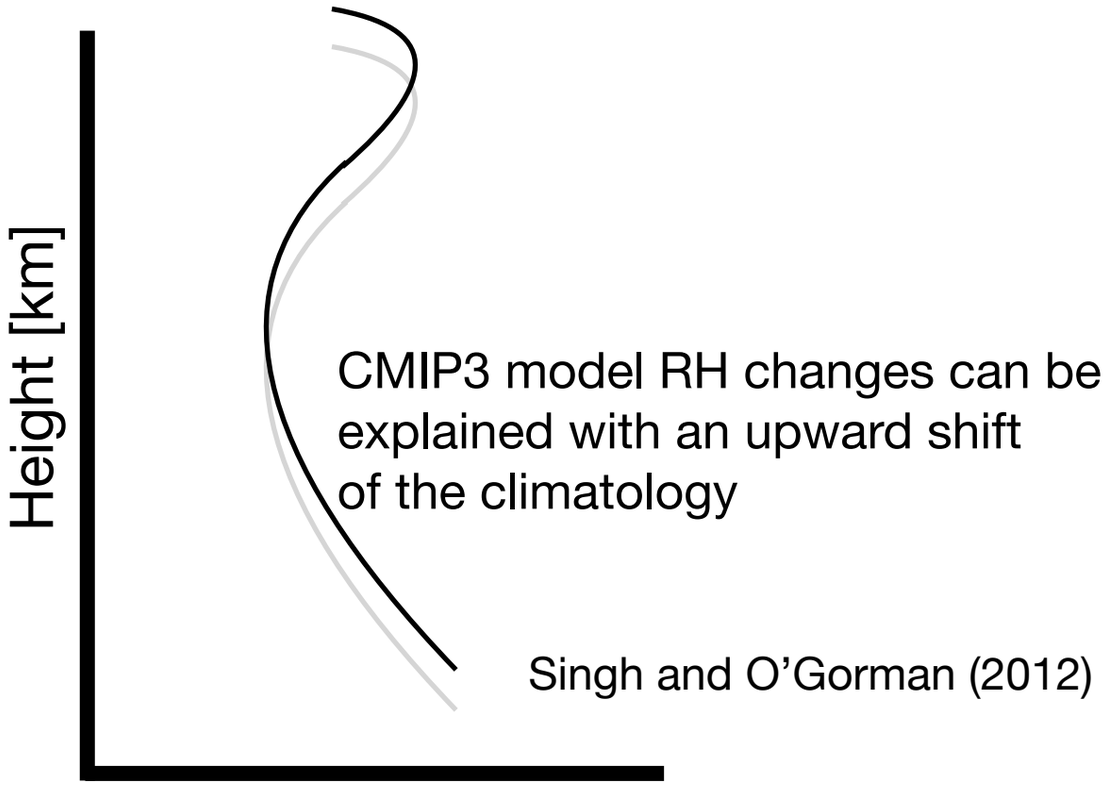

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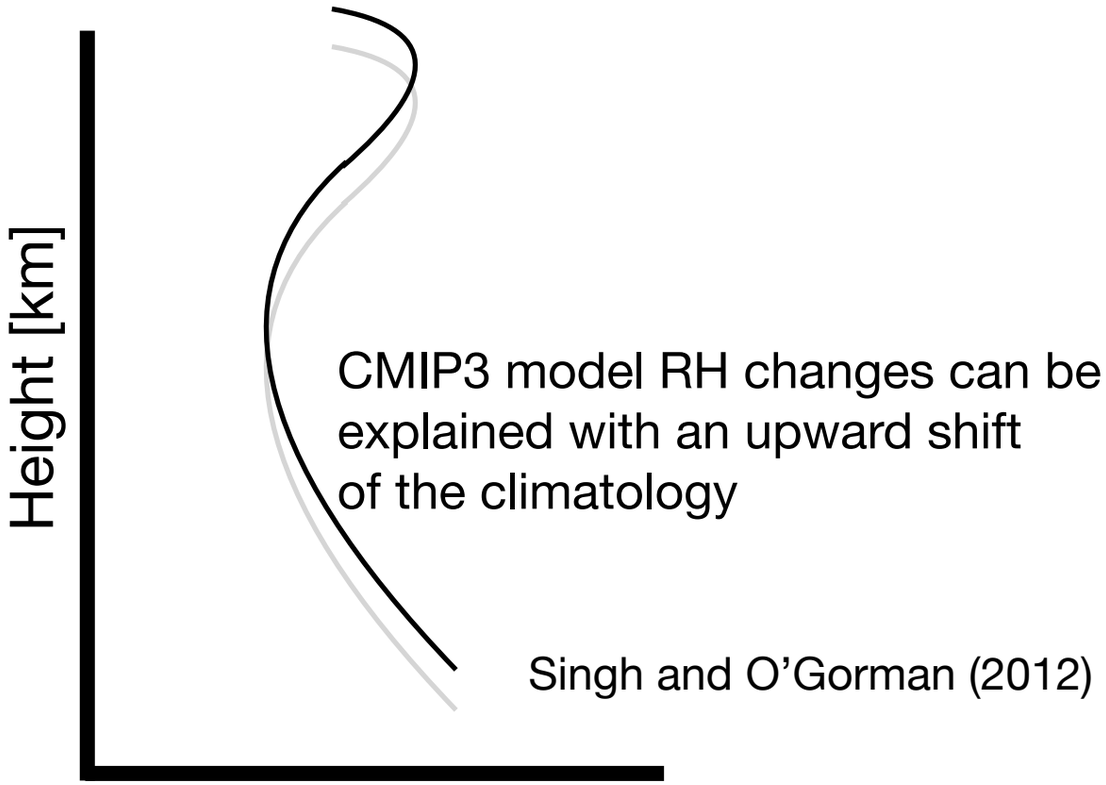
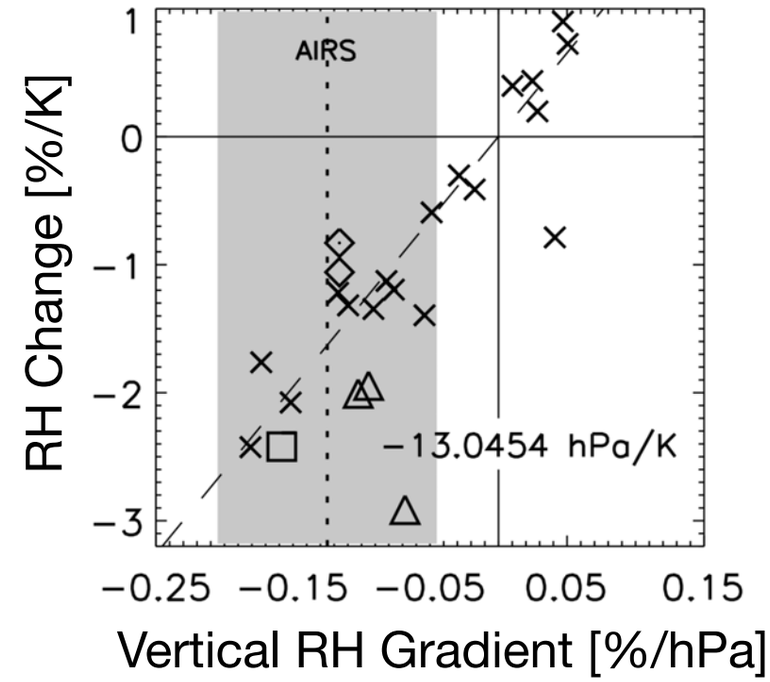


CMIP3 Tropical Upper Tropospheric RH Gradients Control RH Change



Sherwood et al (2010)

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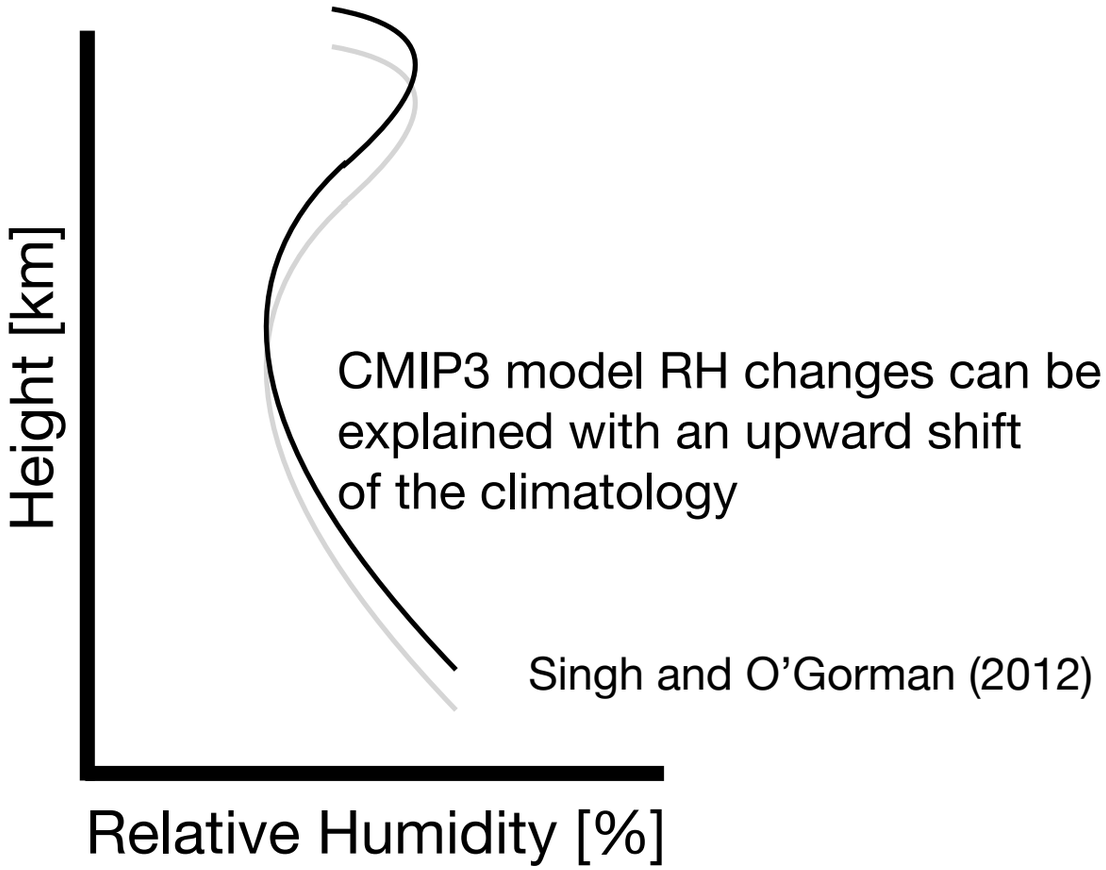

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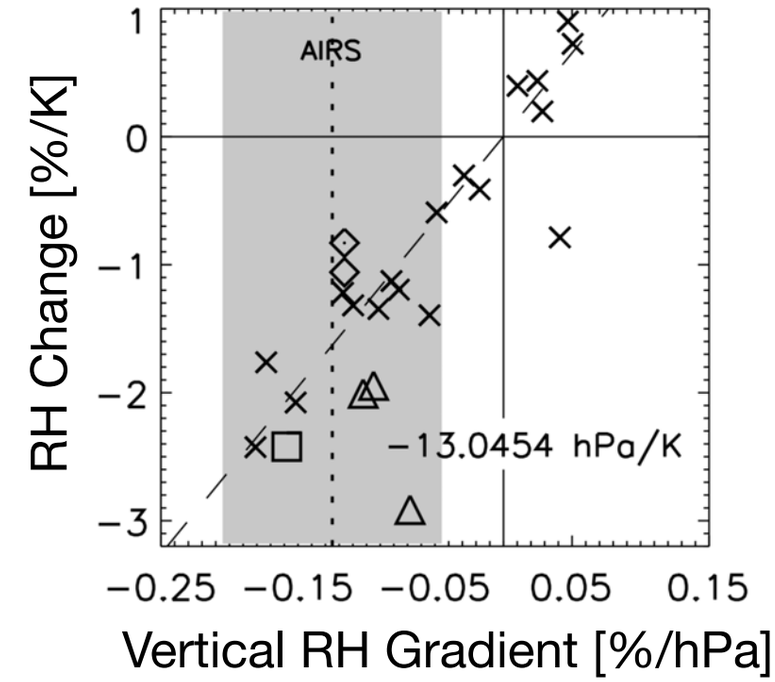
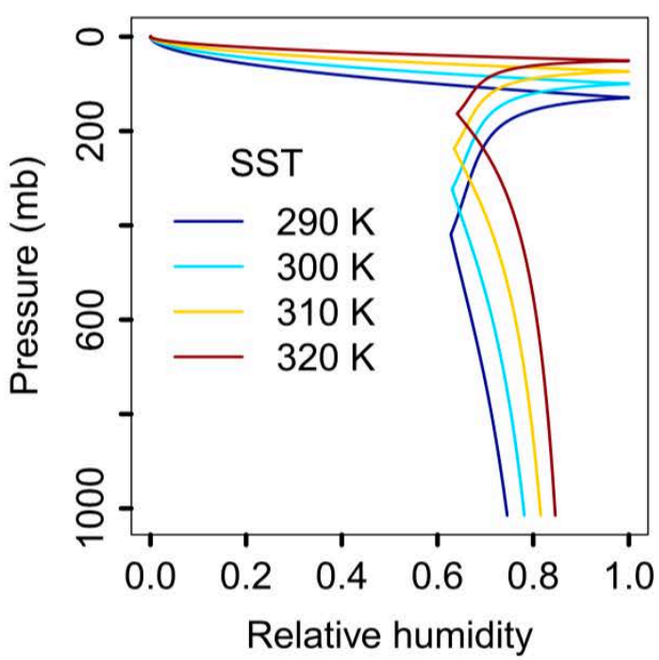


Sherwood et al (2010)

RH is a function of temperature



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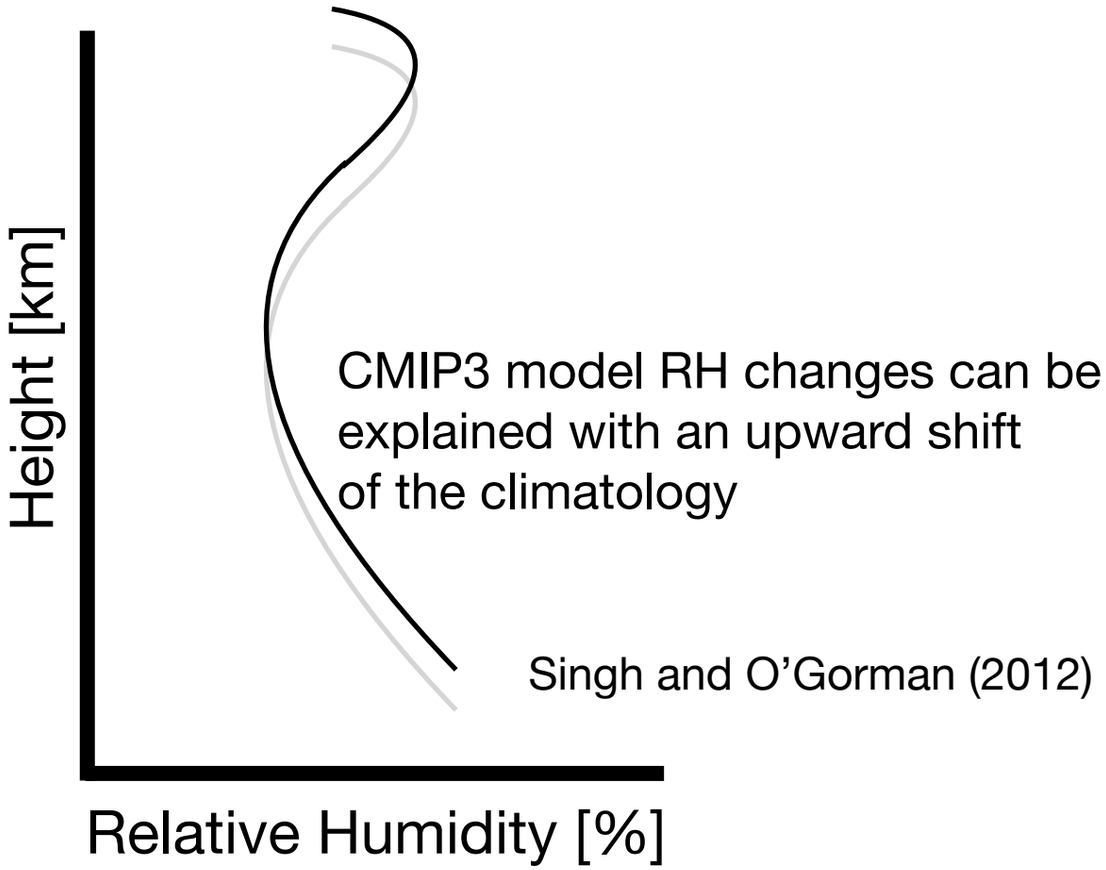

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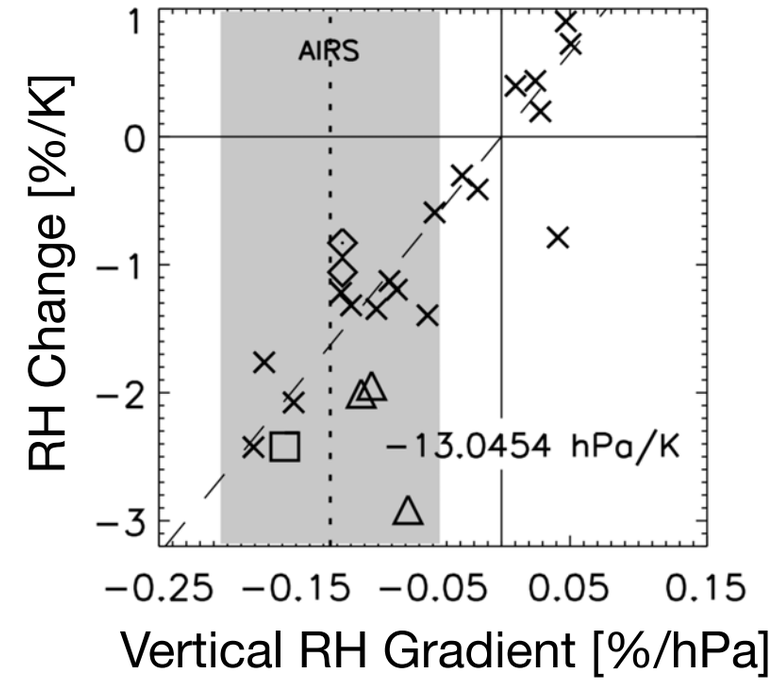

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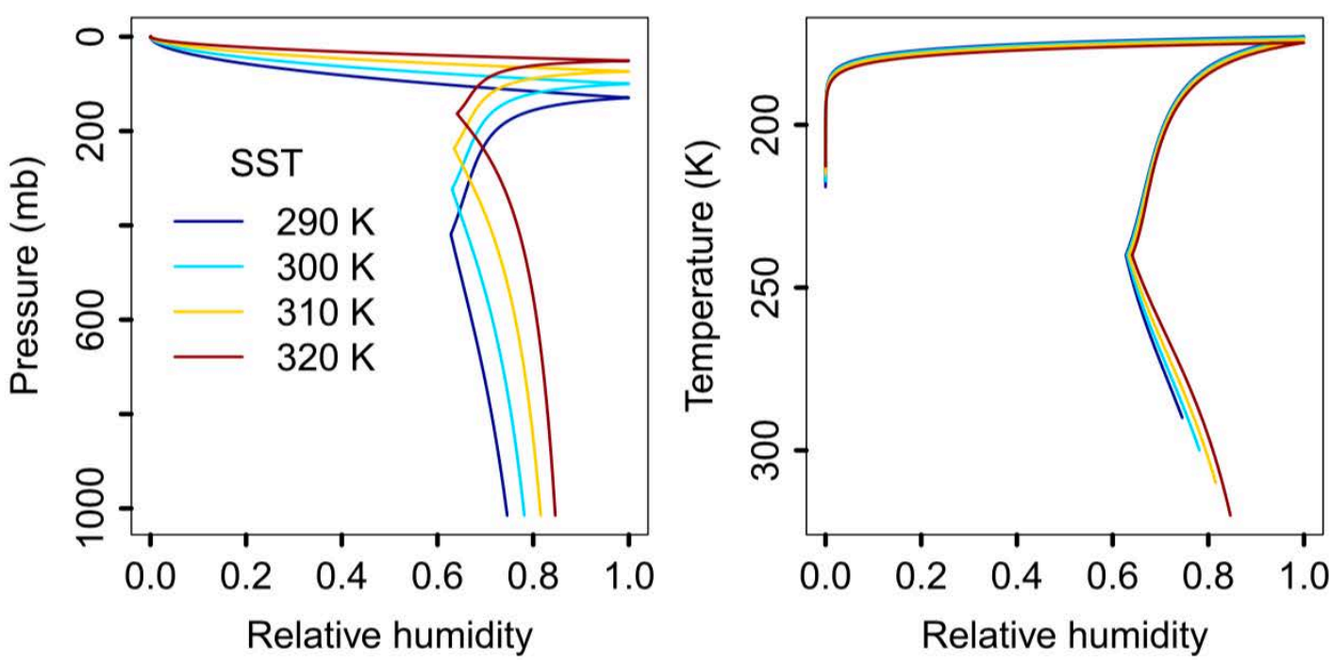

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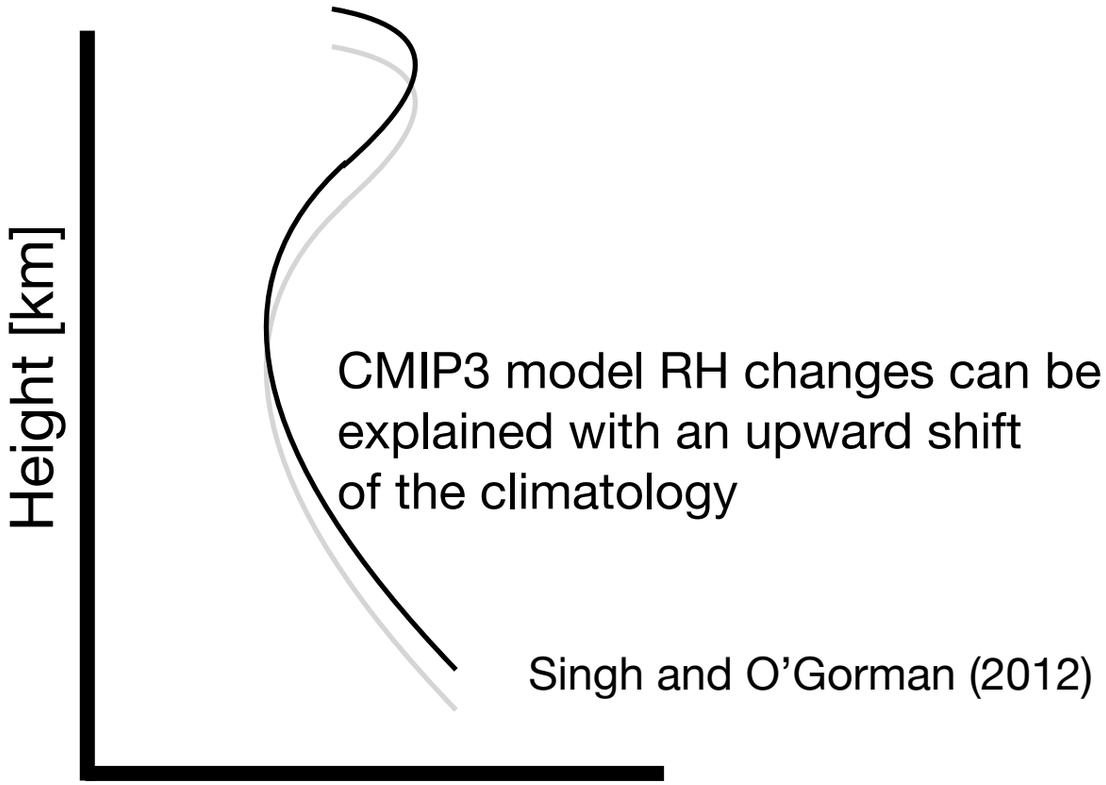

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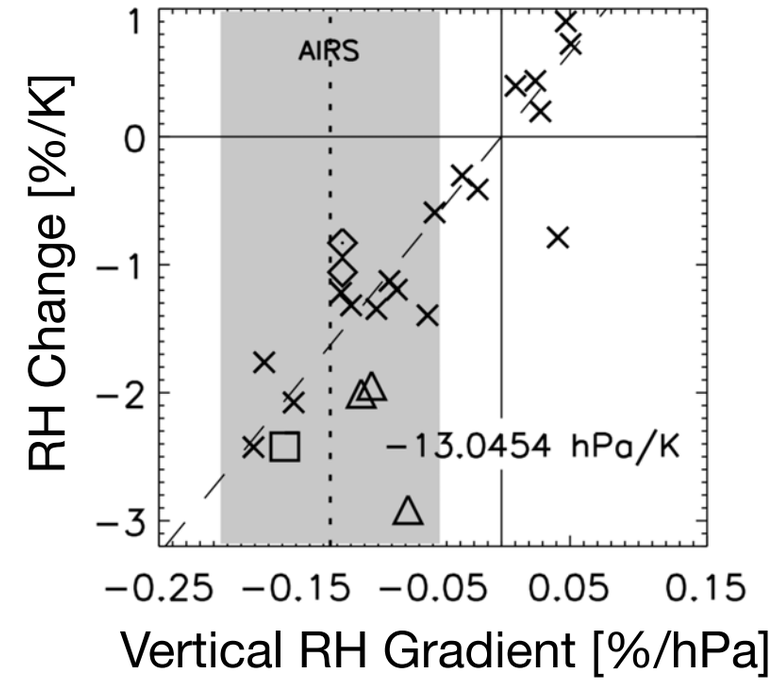

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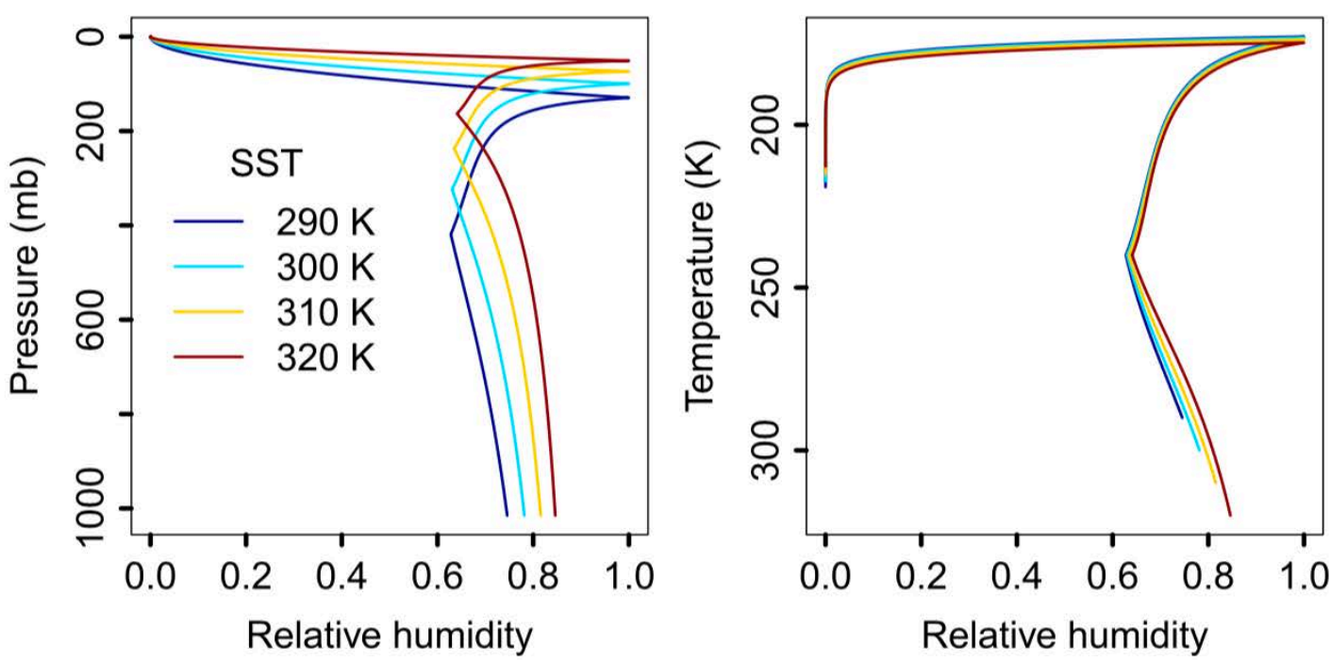
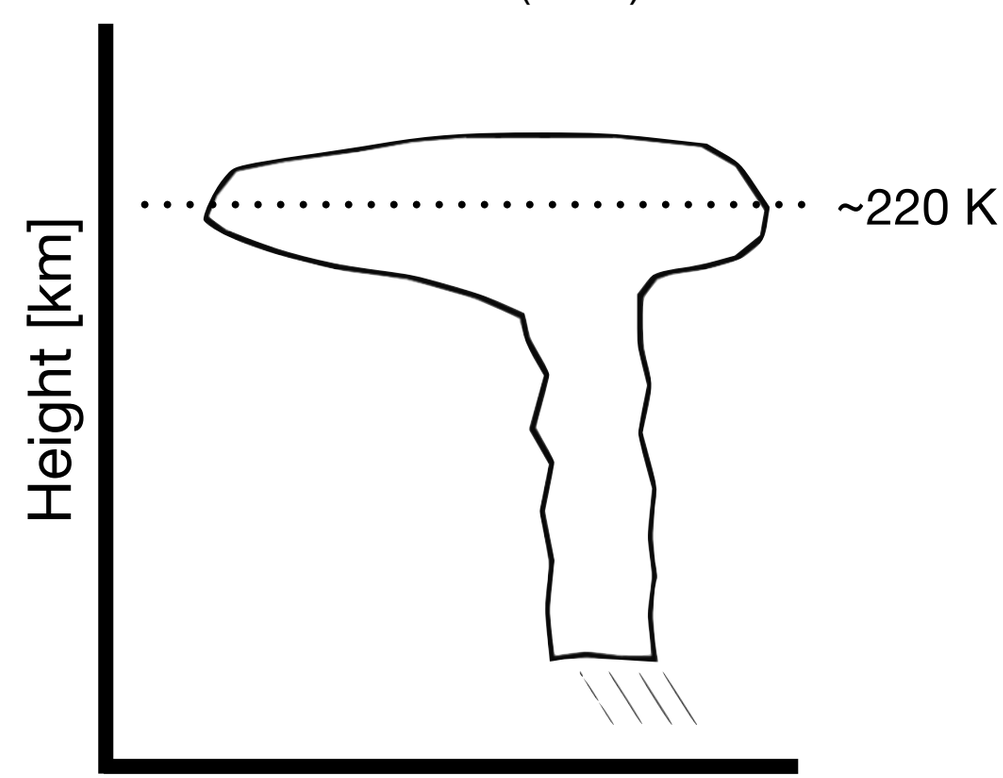


Romps (2014)

Fixed Anvil Temperature Hypothesis

Hartmann and Larson (2002)



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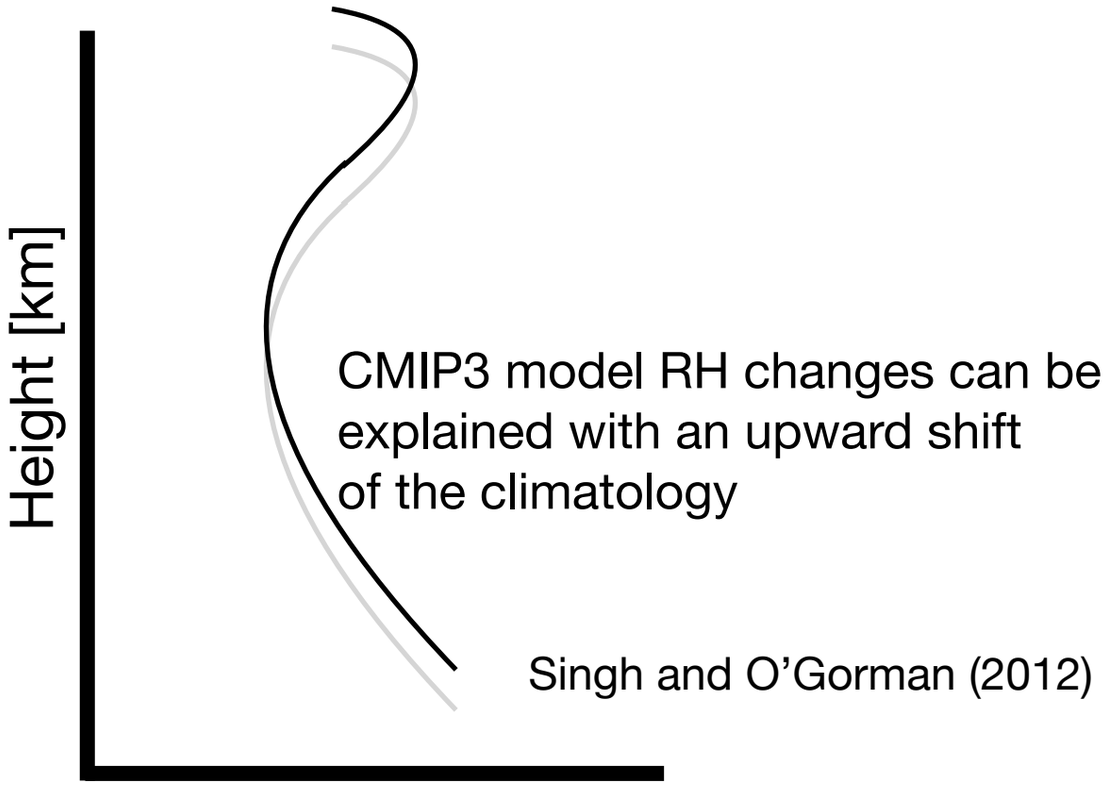

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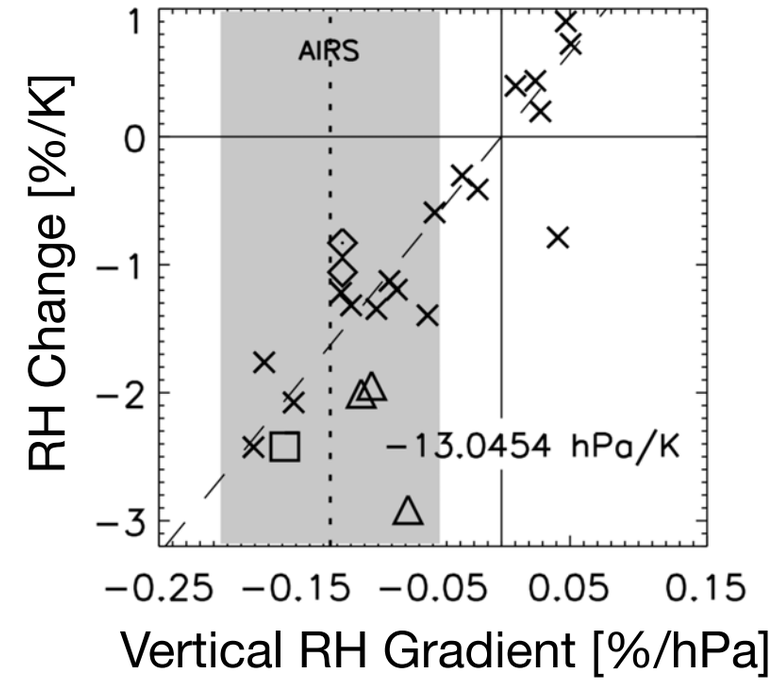

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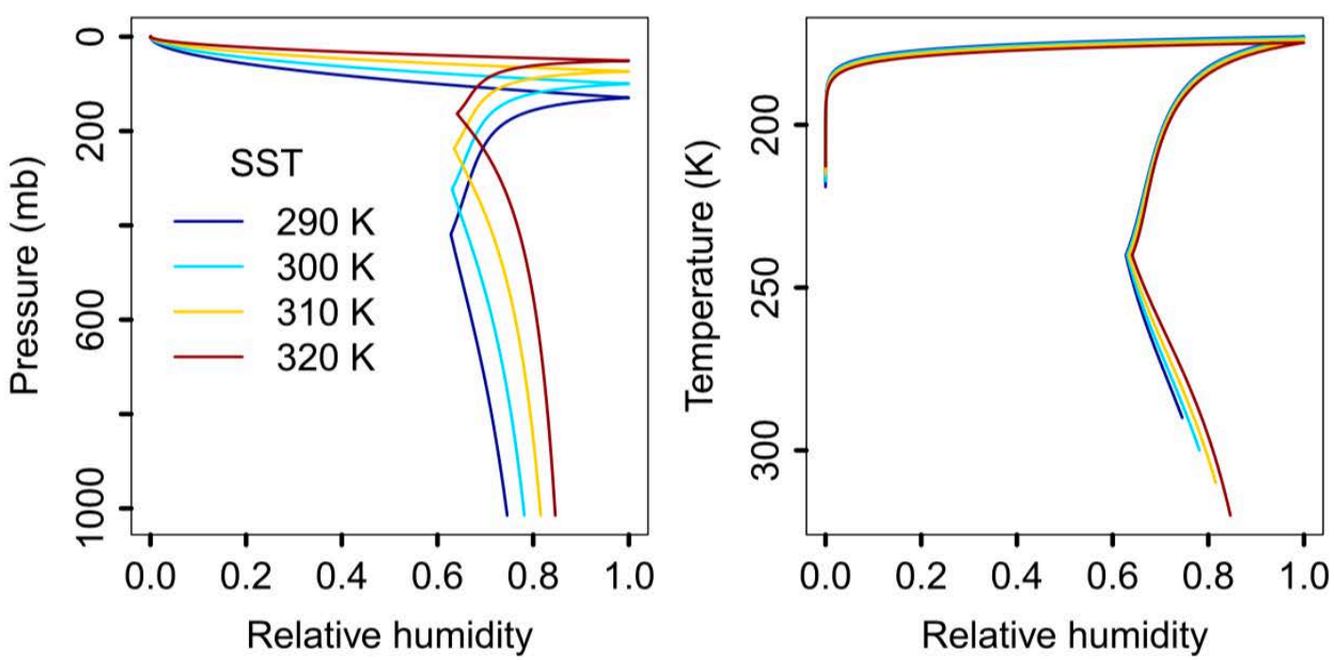

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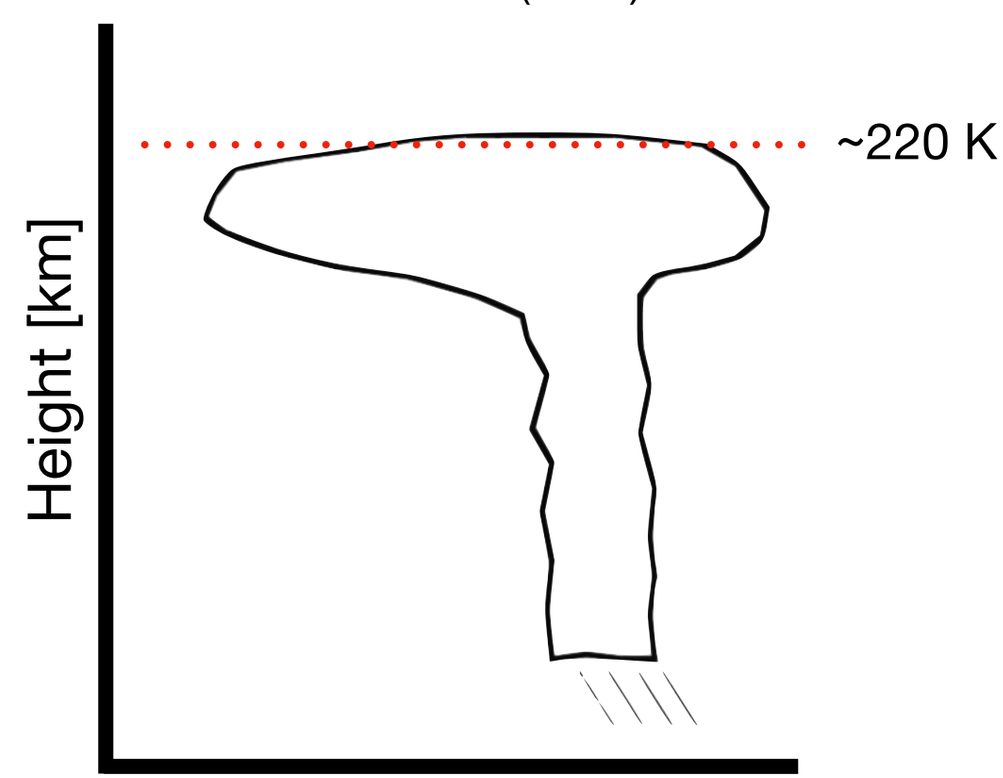

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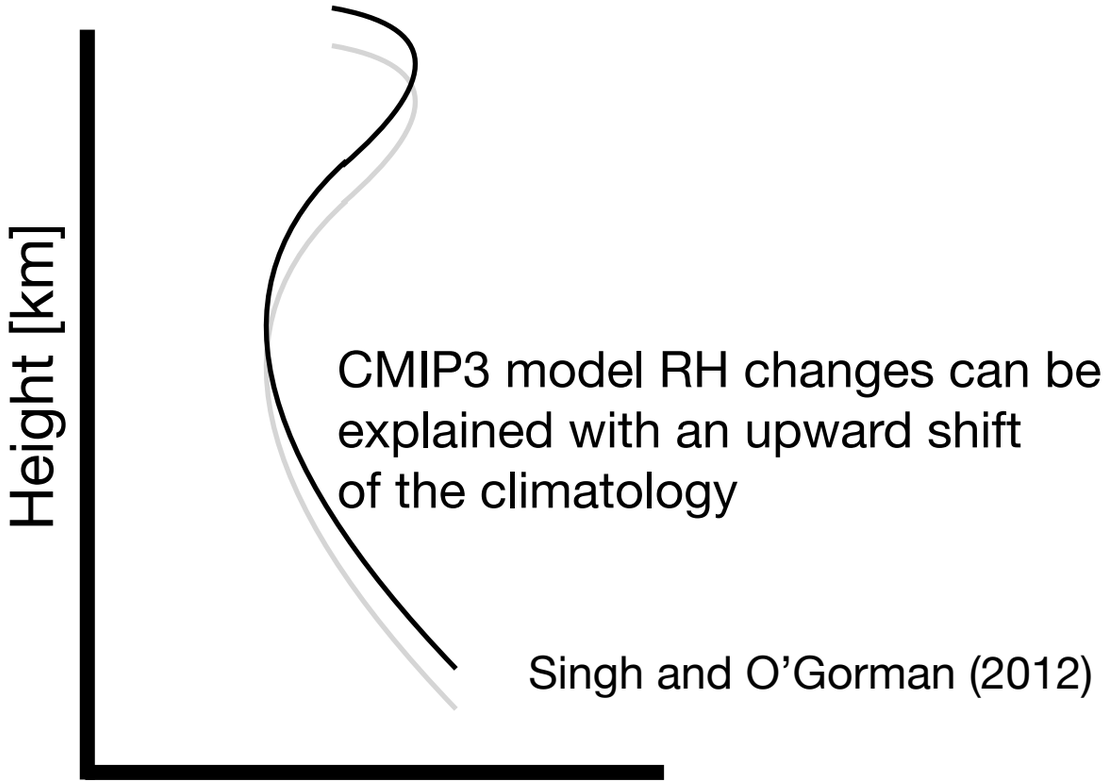

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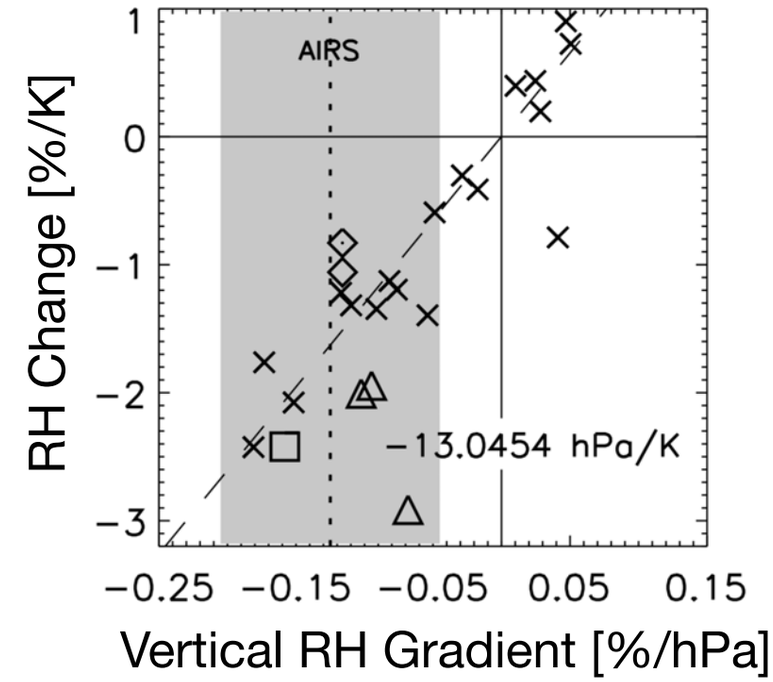

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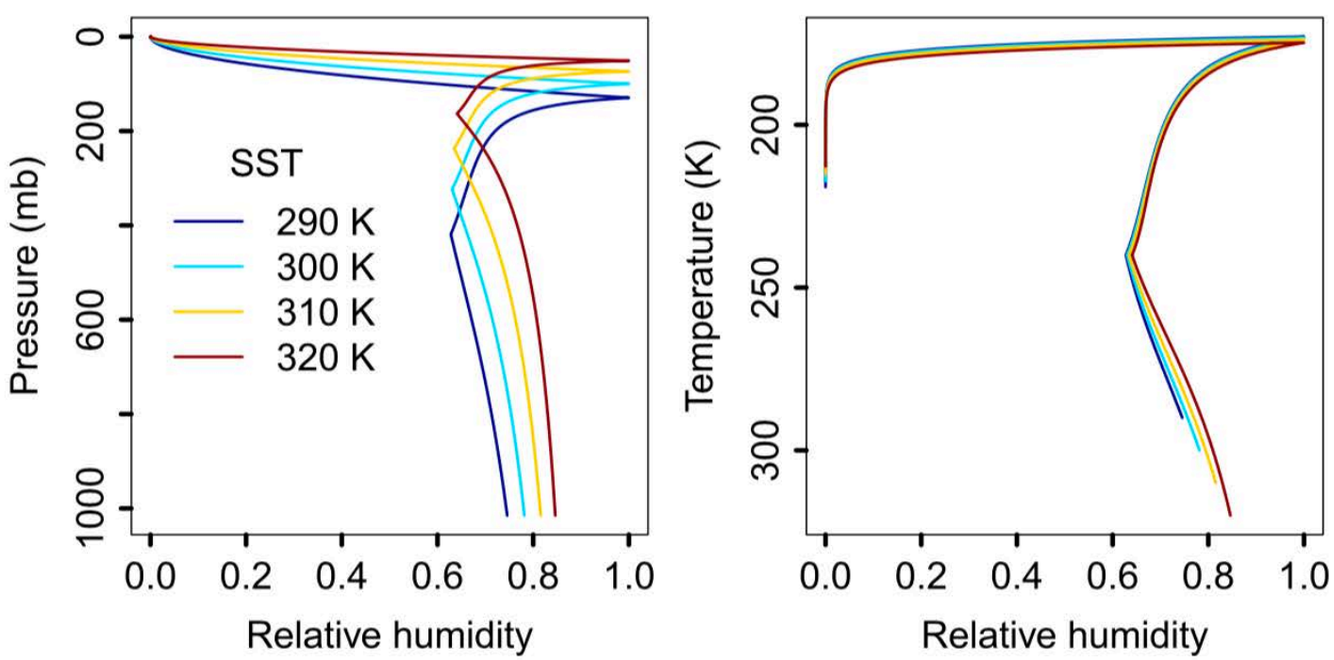

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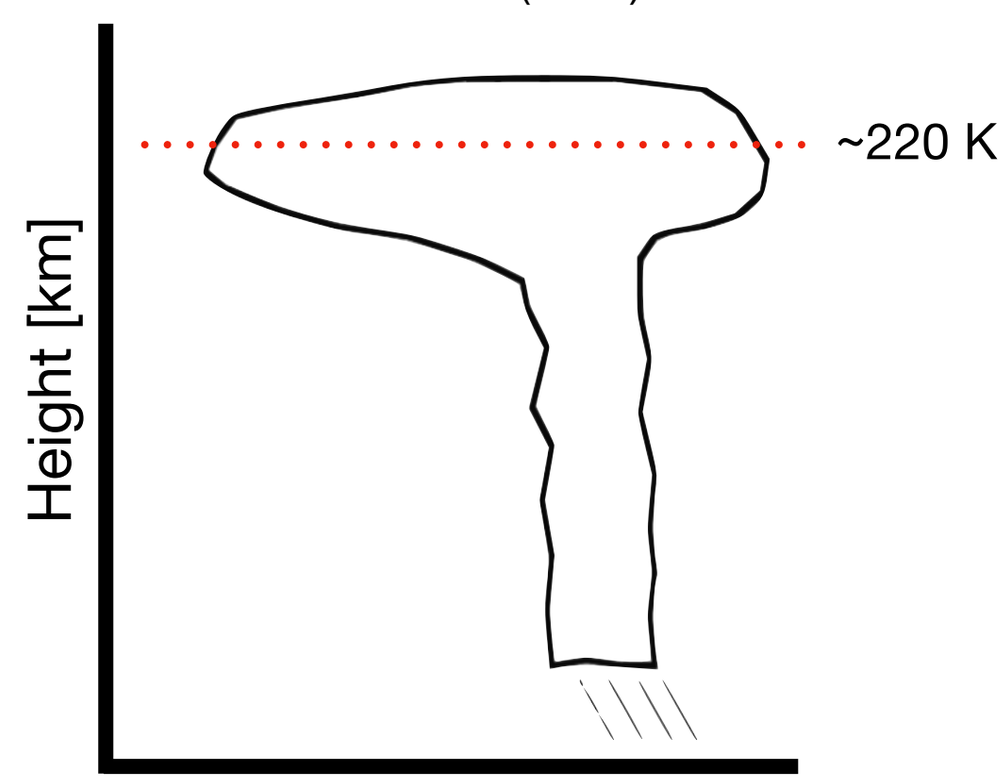

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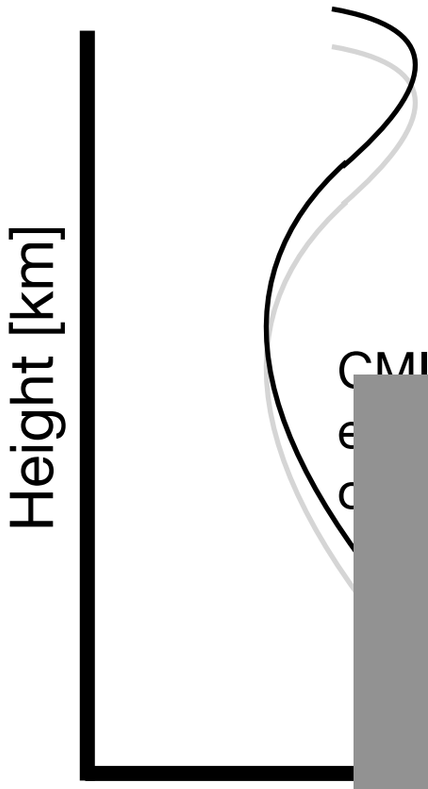

CMIP3 model RH changes can be
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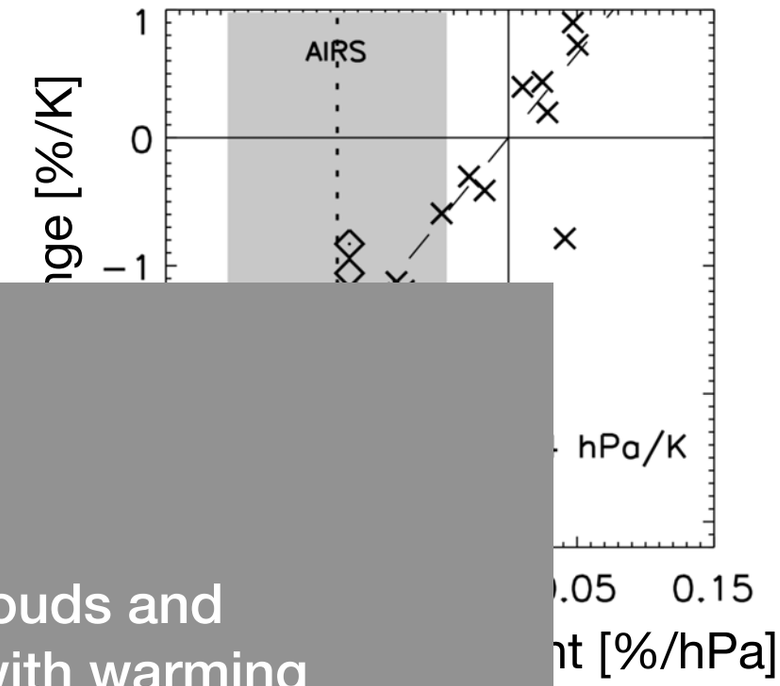
Relative H

CMIP3 Tropical Upper Tropospheric RH Gradients Control RH Change



Sherwood et al (2010)

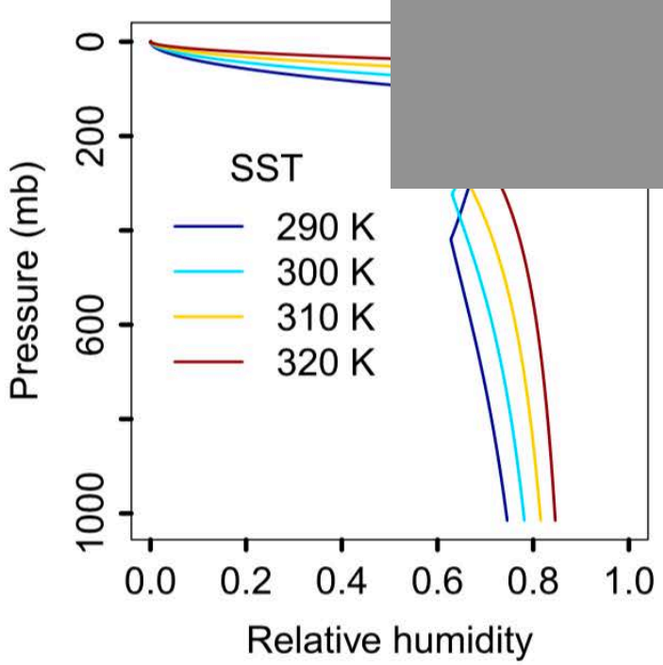
Tropical upper tropospheric clouds and relative humidity should shift up with warming

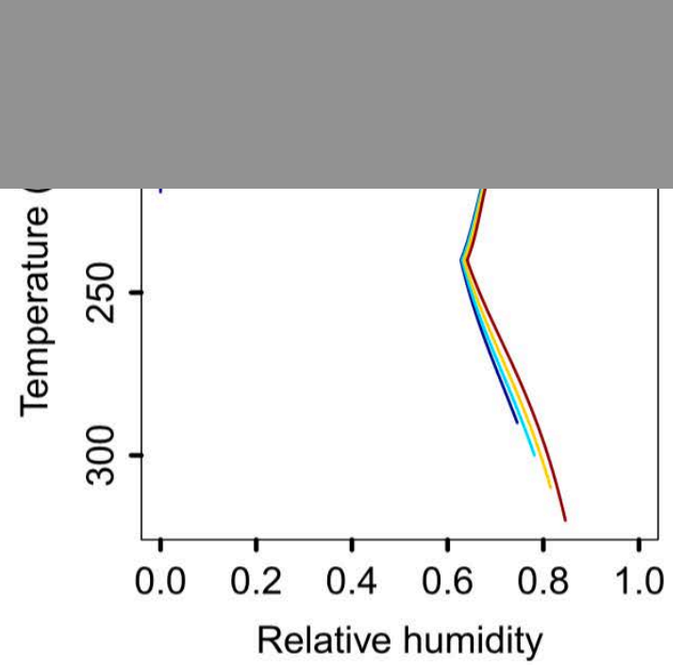
Their distributions should be an invariant function of temperature

RH is a fur

re Hypothesis

2)





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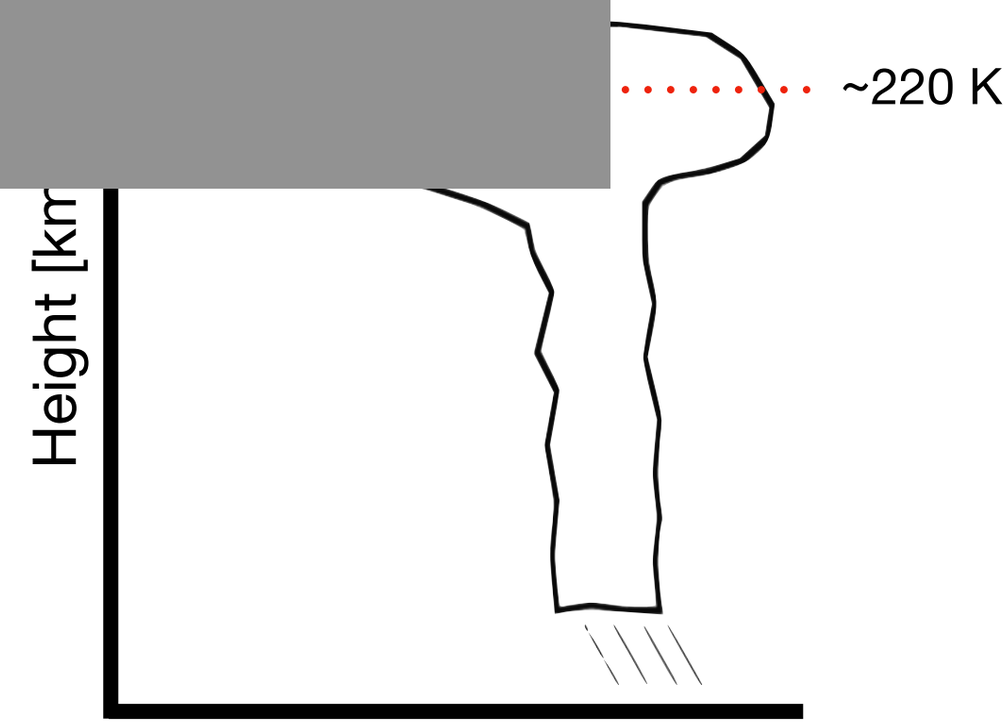
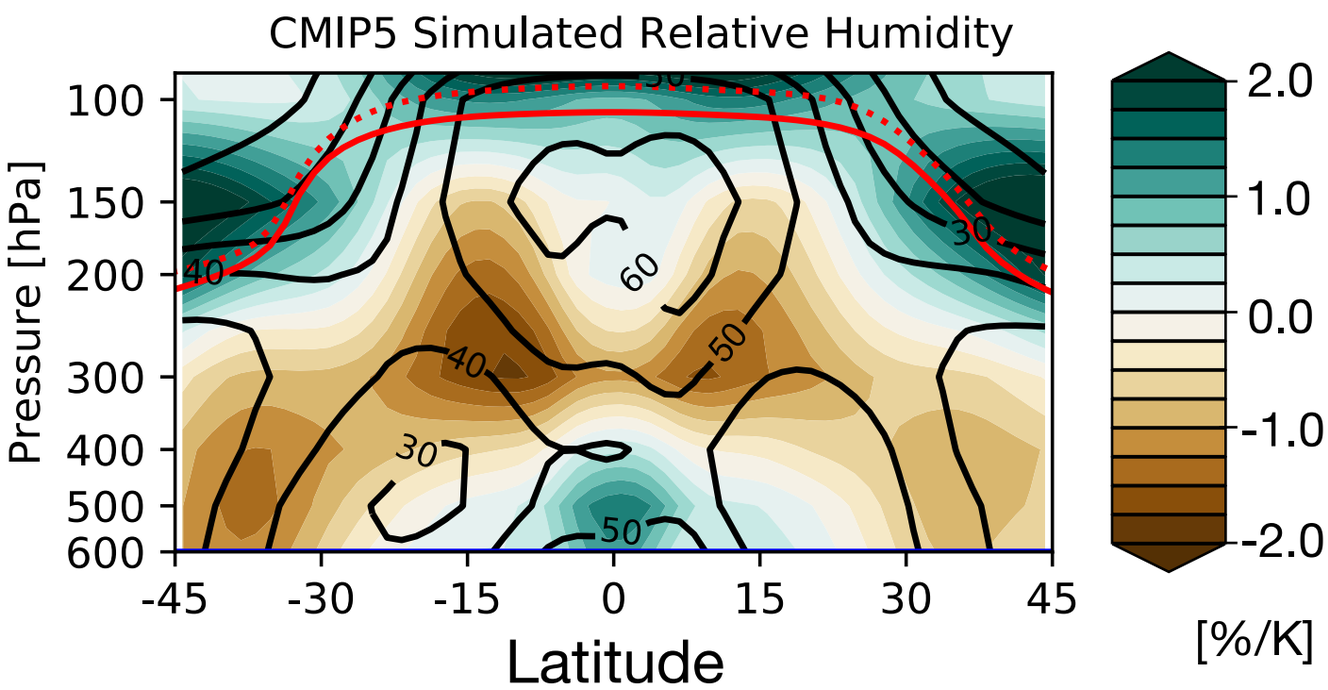
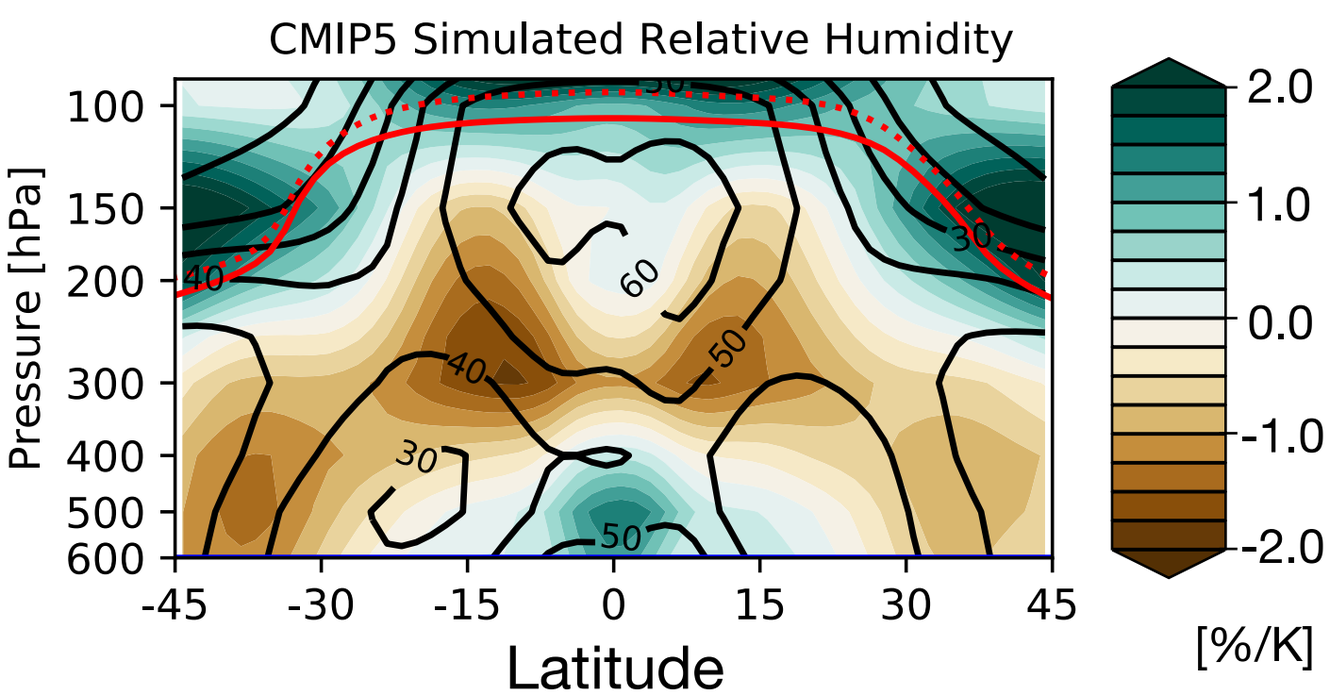
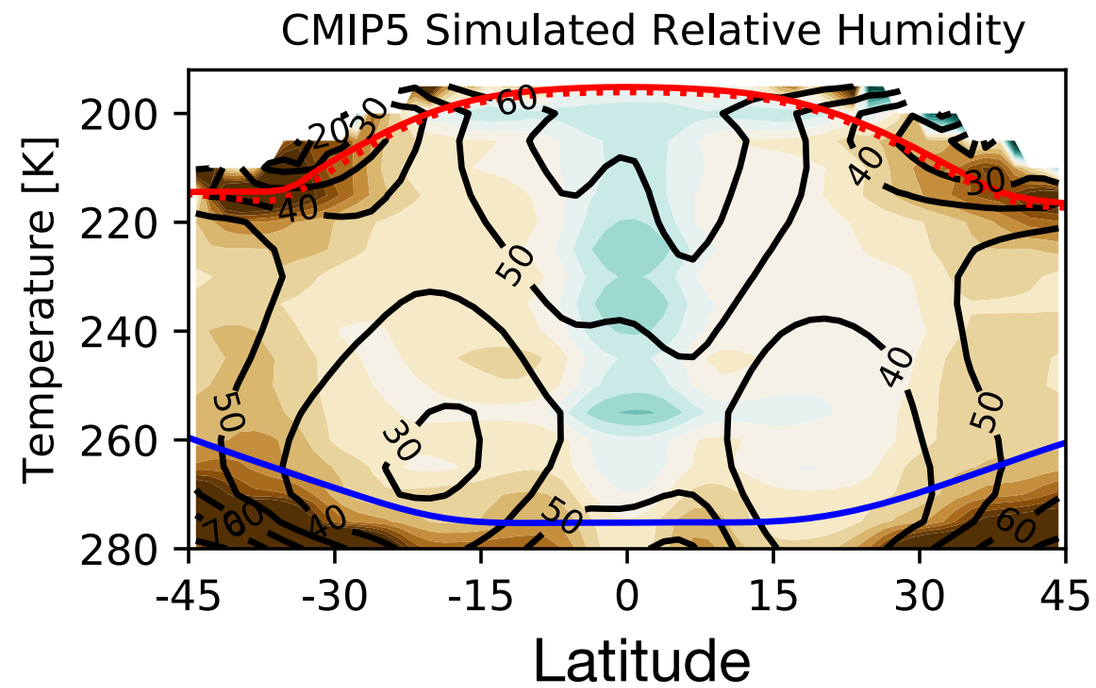




Climatology: 1980 - 2018
Response: RCP8.5 centered on 2080
Average of 27 models

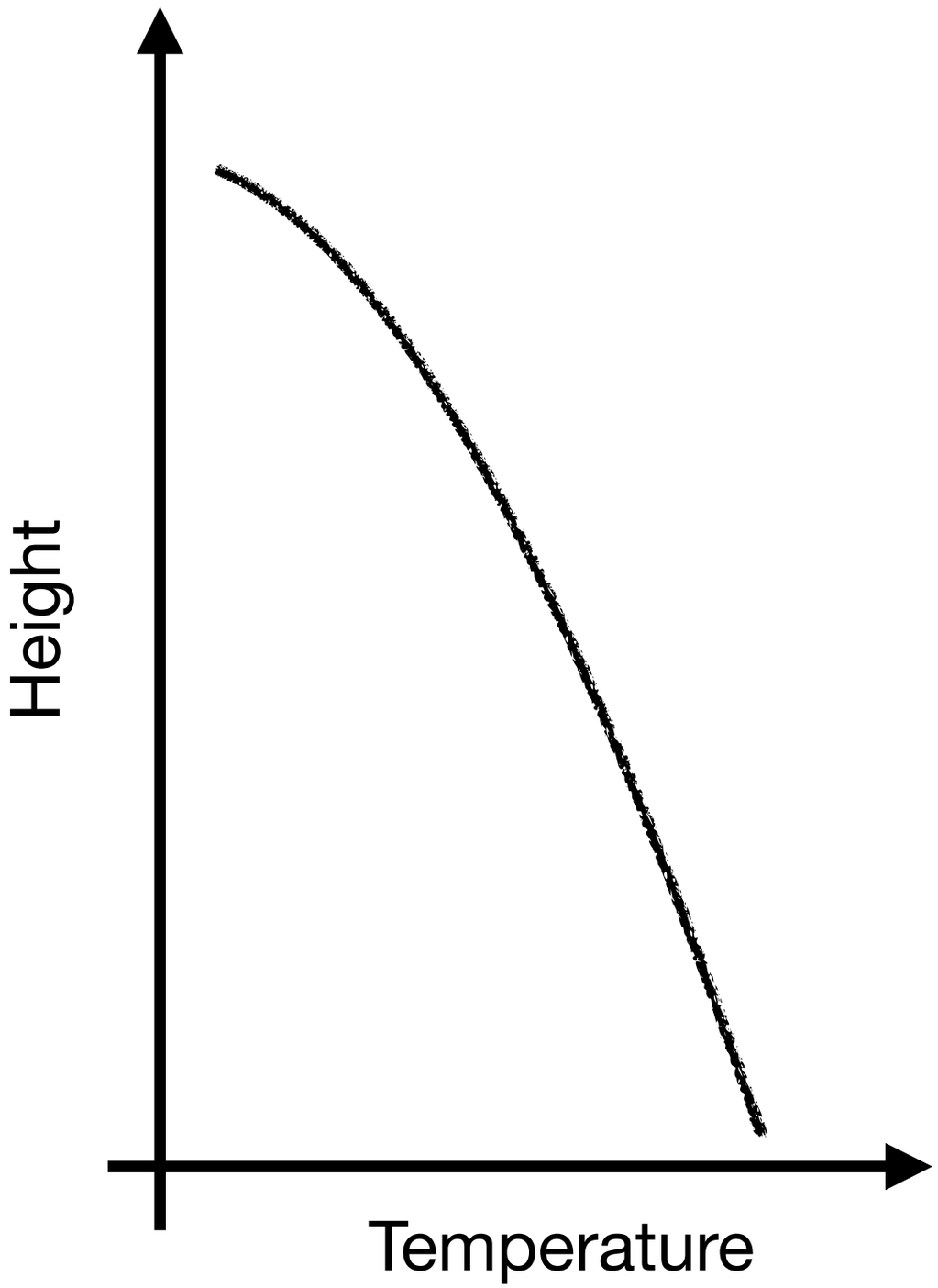
Climatology
Change
Tropopause
Future Tropopause

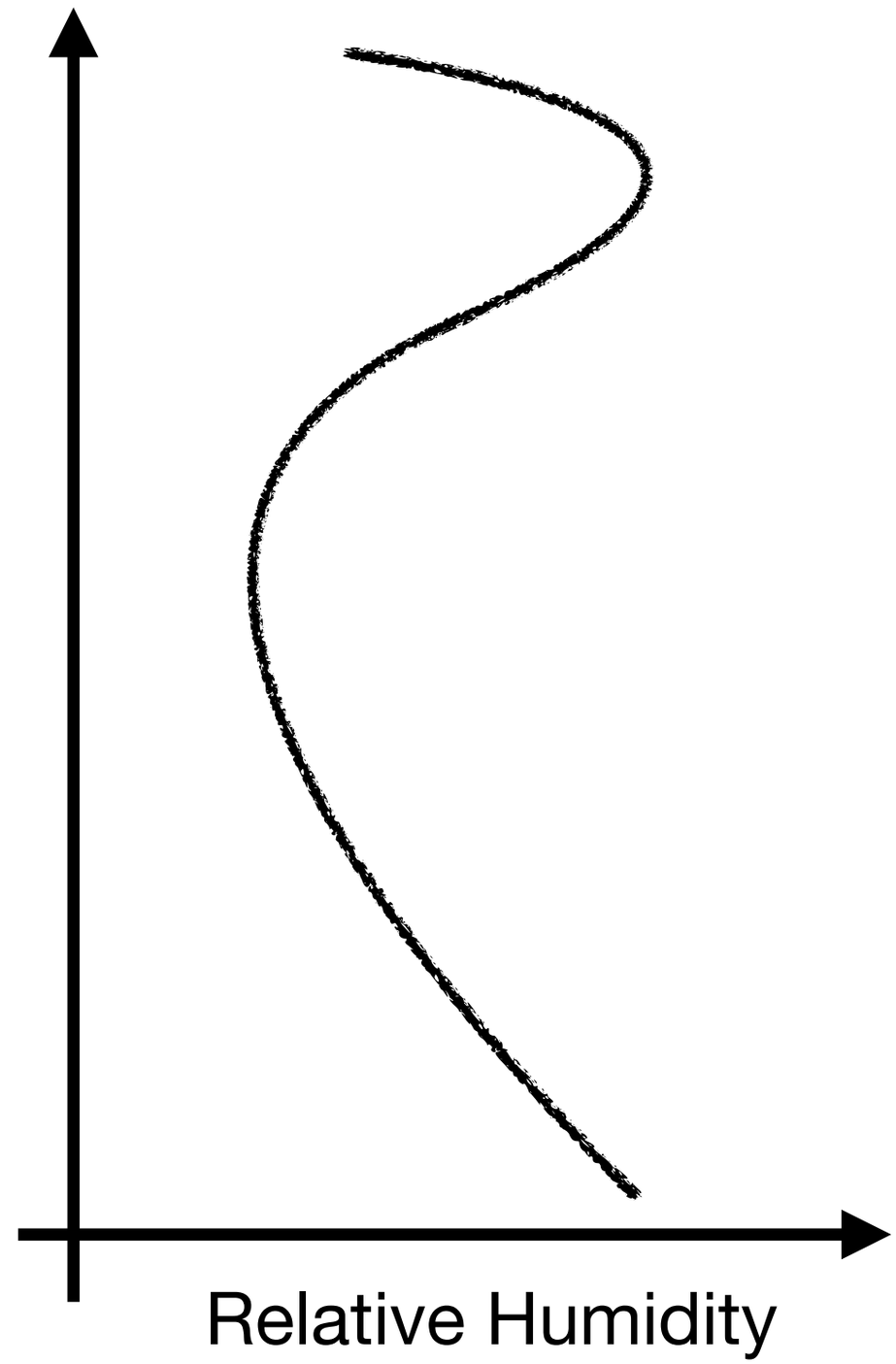


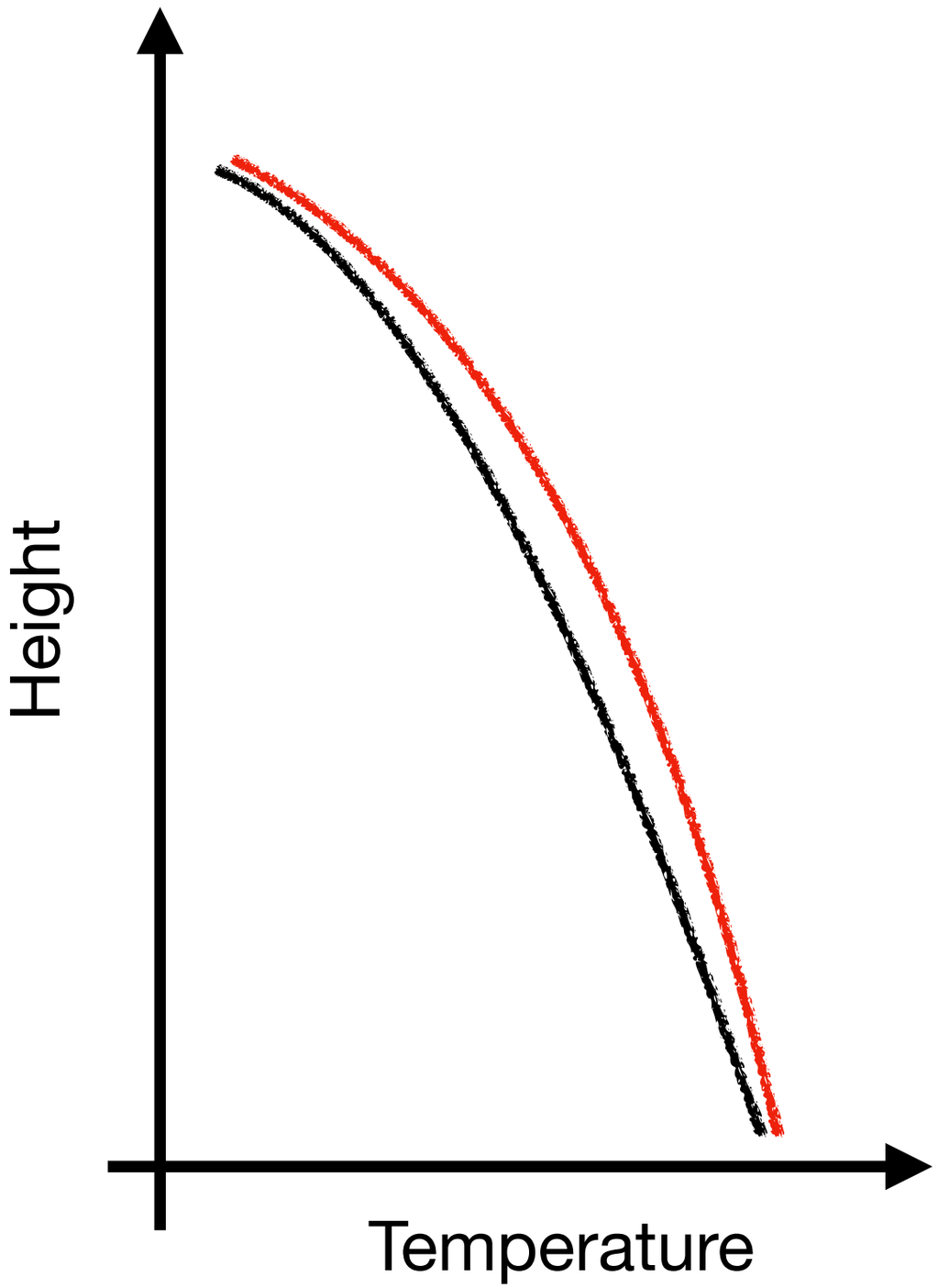


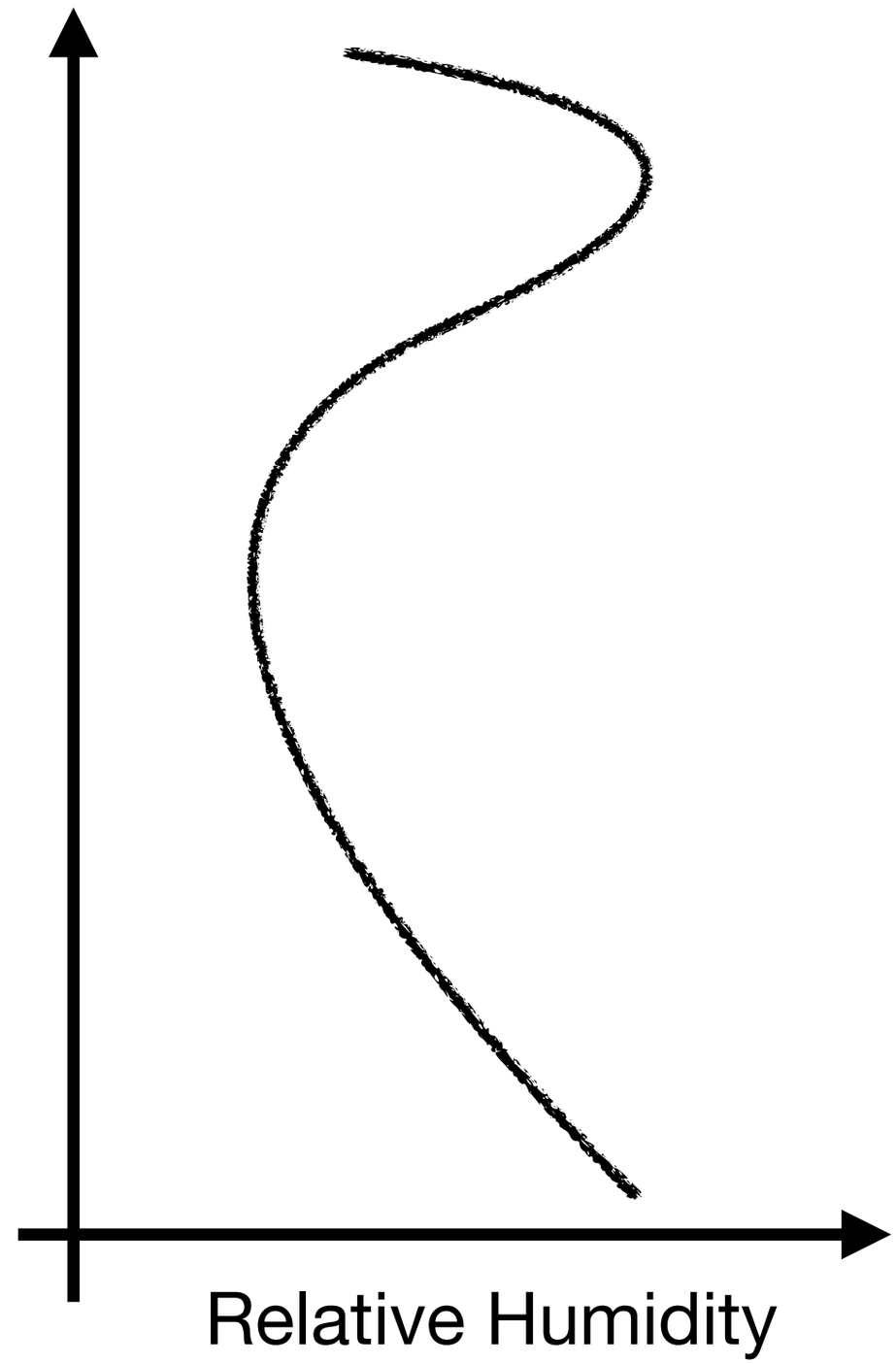
Climatology: 1980 - 2018
Response: RCP8.5 centered on 2080
Average of 27 models

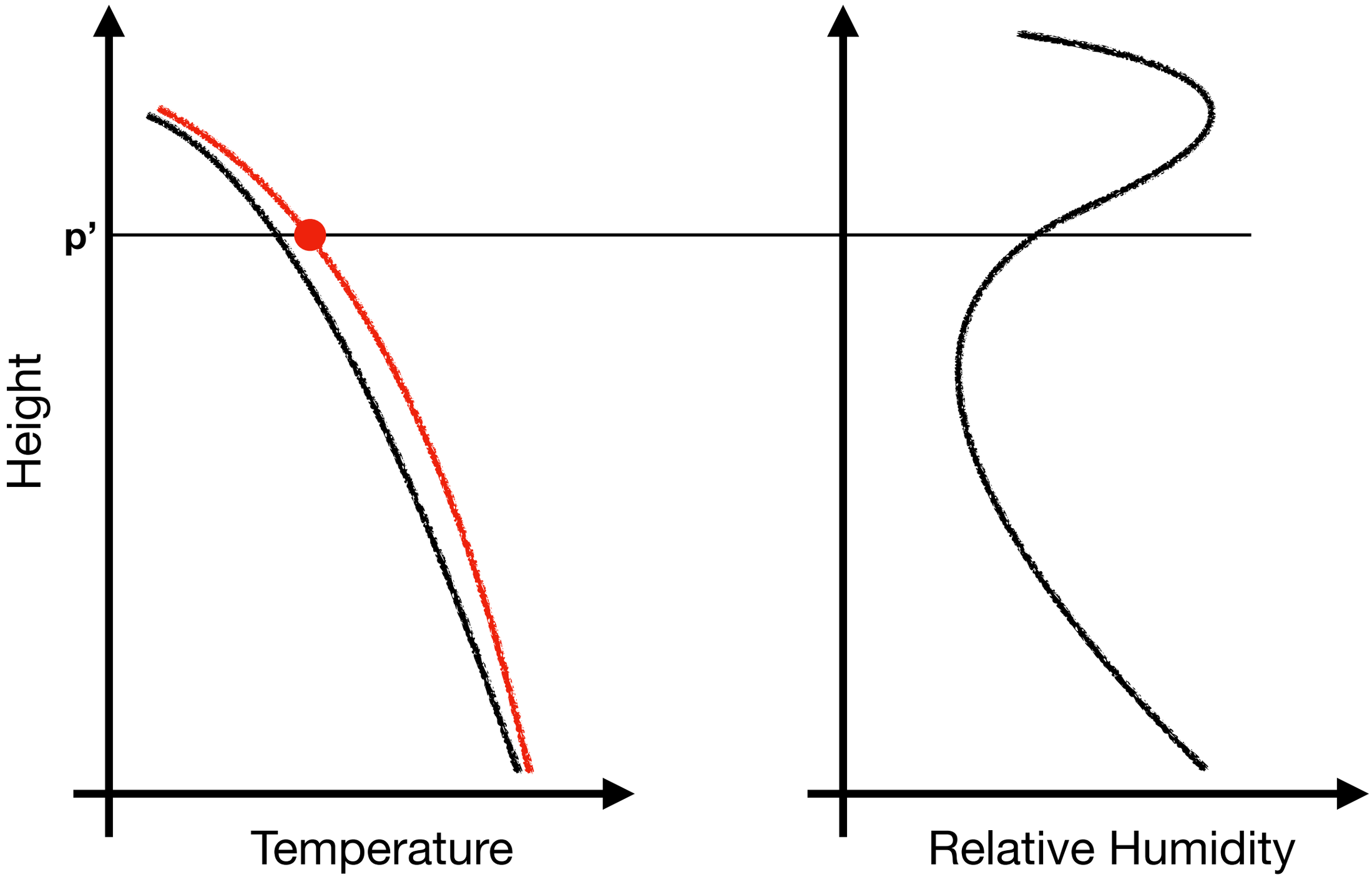
Climatology
Change
Tropopause
Future Tropopause
600 hPa level


Height
Temperature


Relative Humidity


Height
Temperature


Relative Humidity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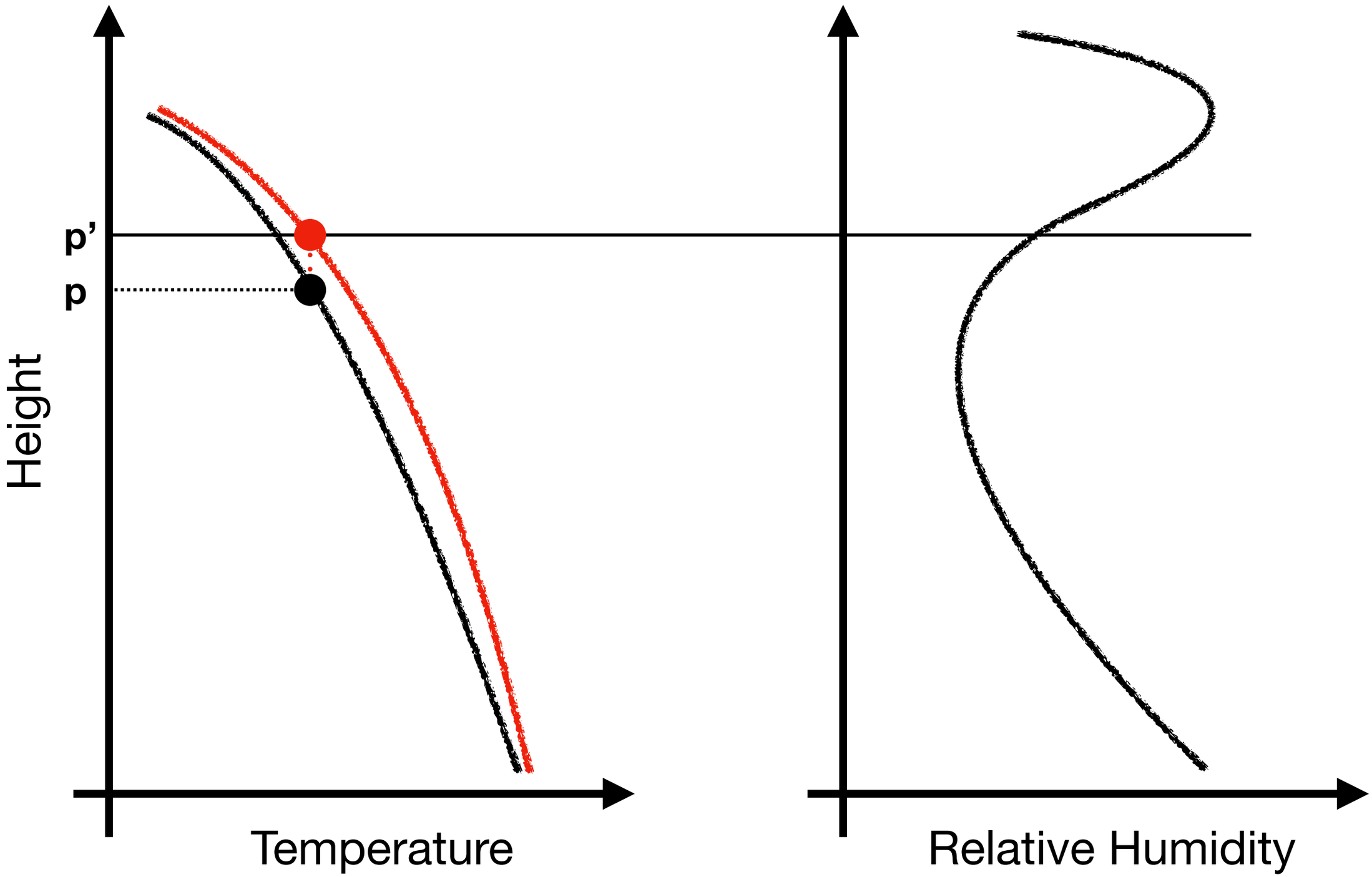
Height
Temperature
Relative Humidity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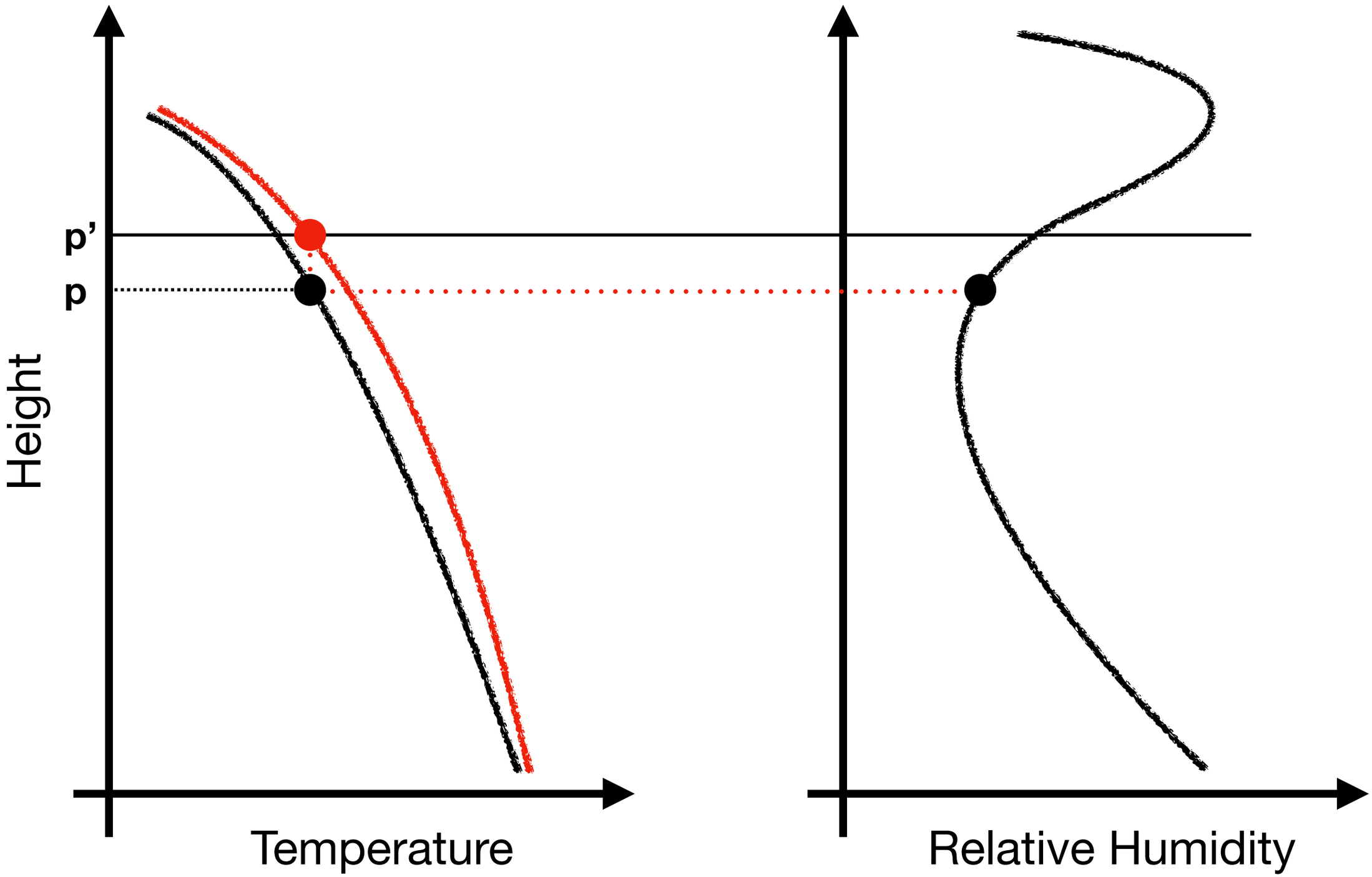
Height
Temperature
Relative Humidity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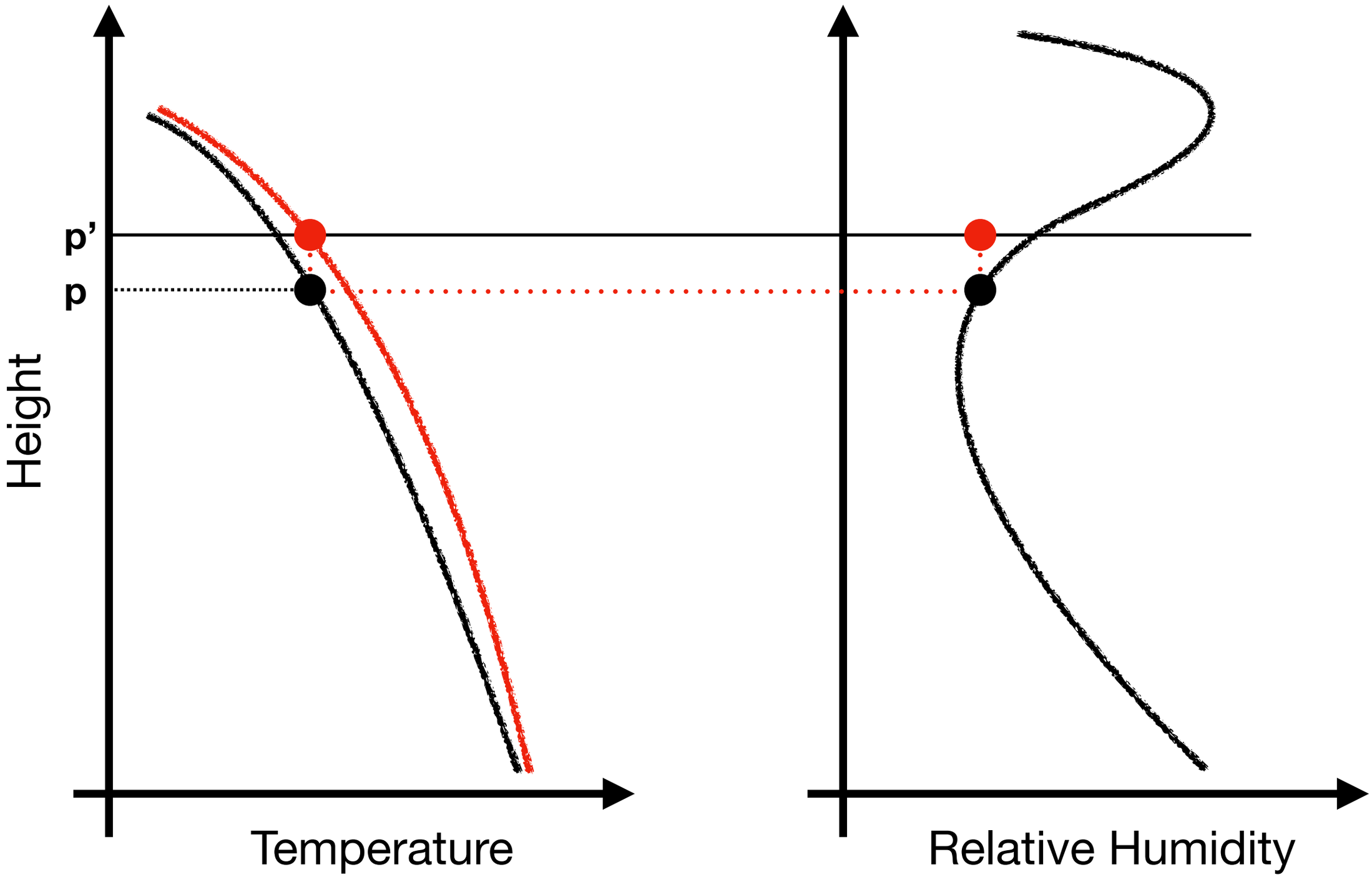
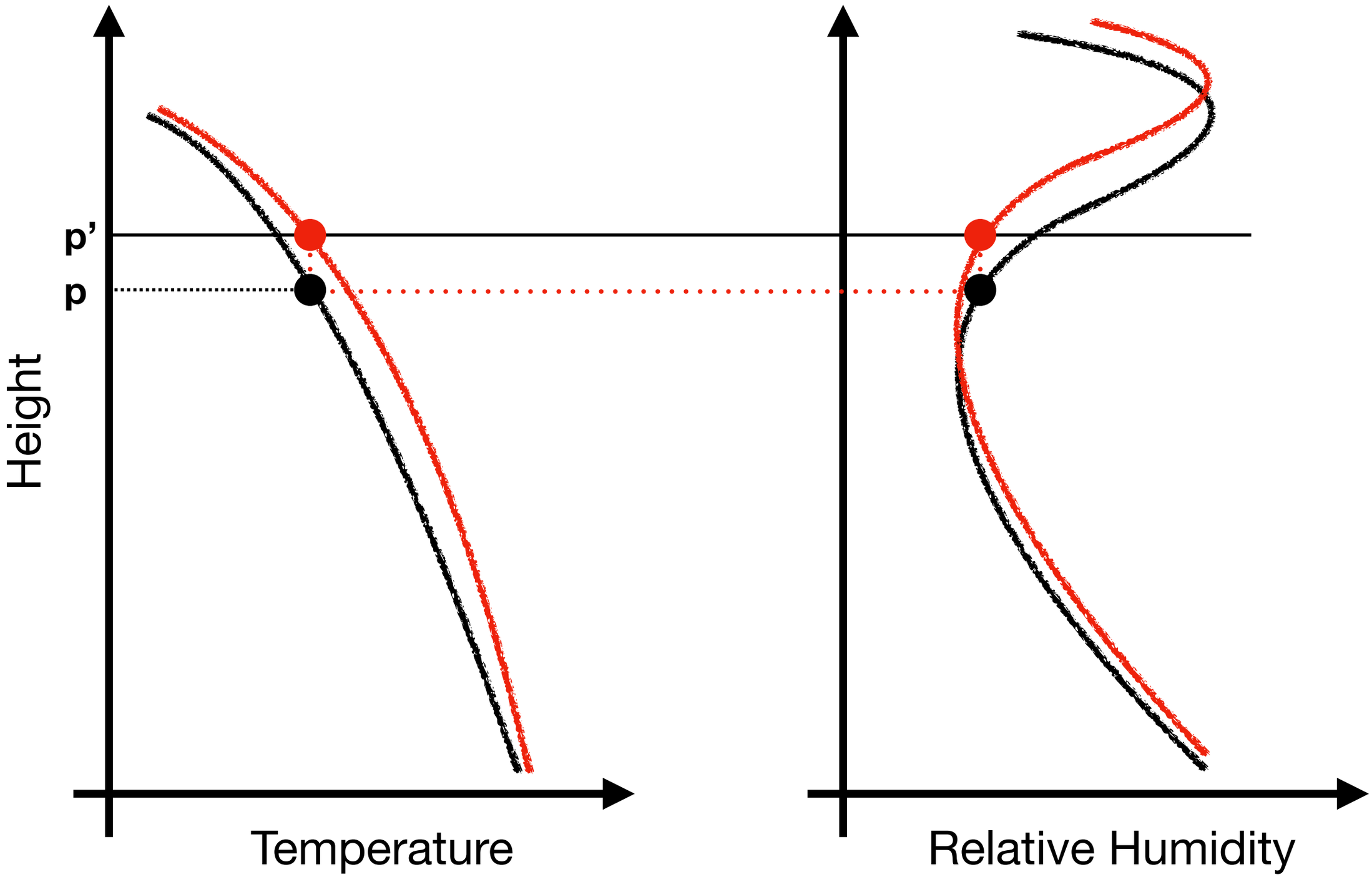
p
Height
Temperature
Relative Humidity


p'
p
Height
Temperature
Relative Humidity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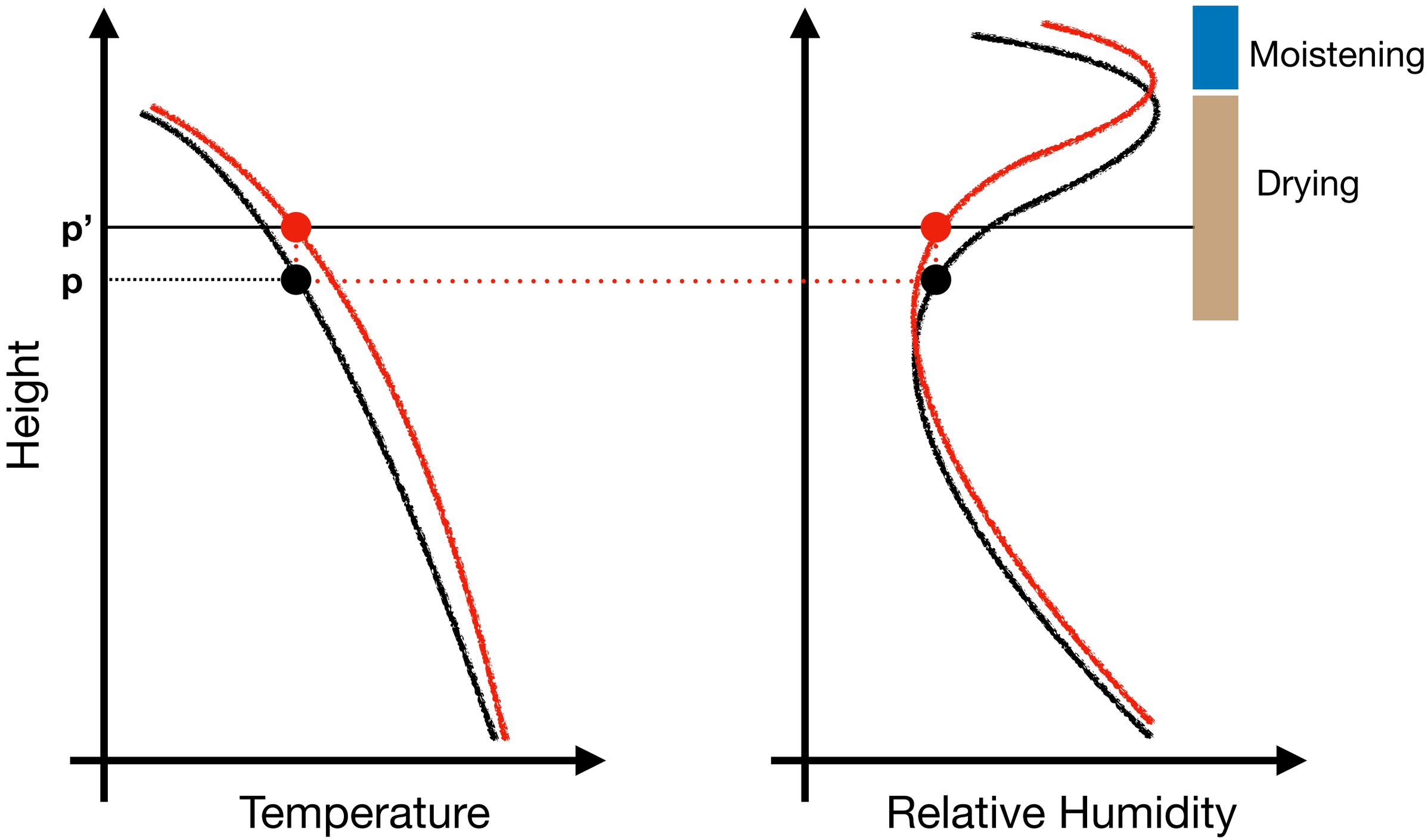
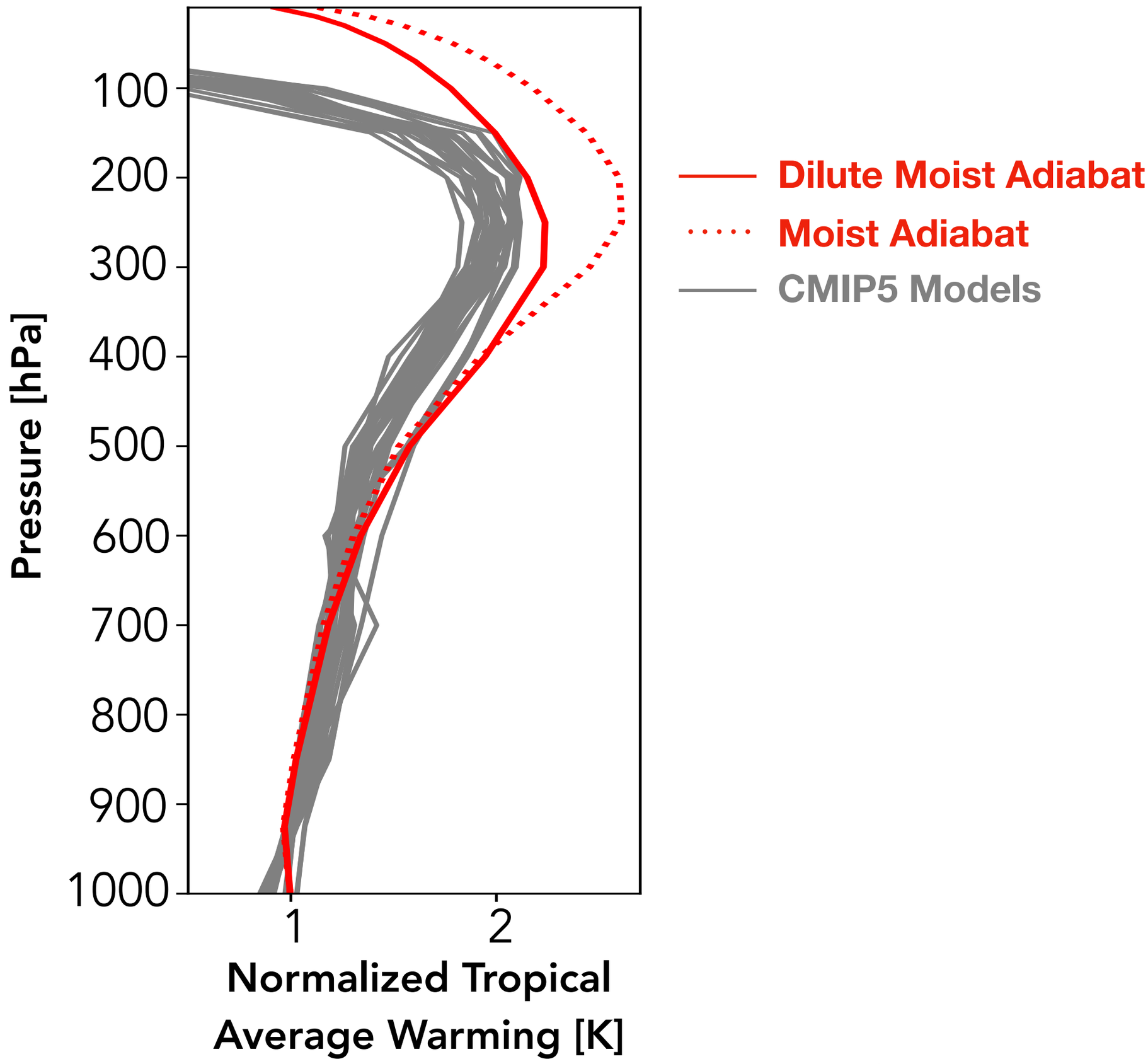
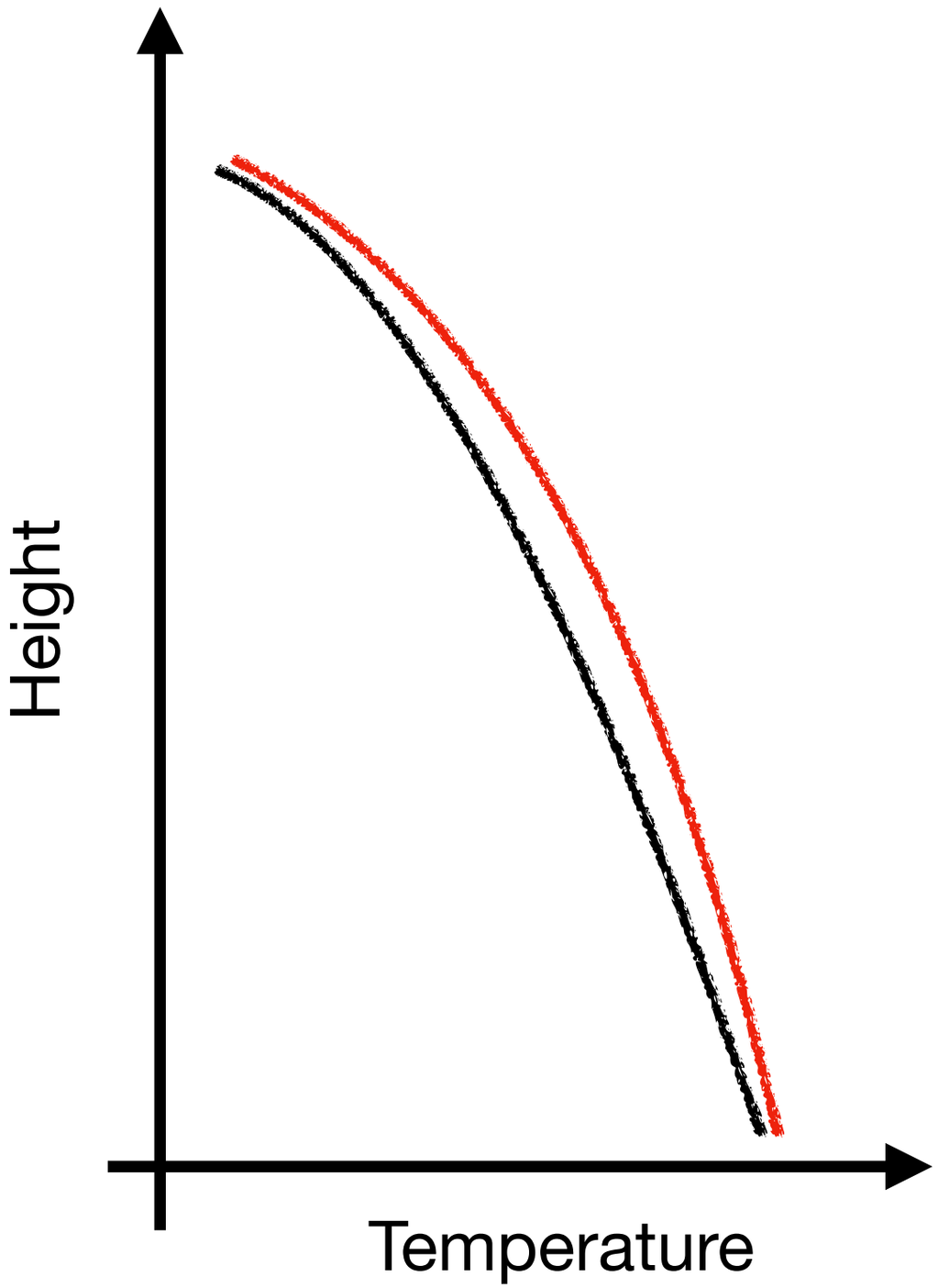
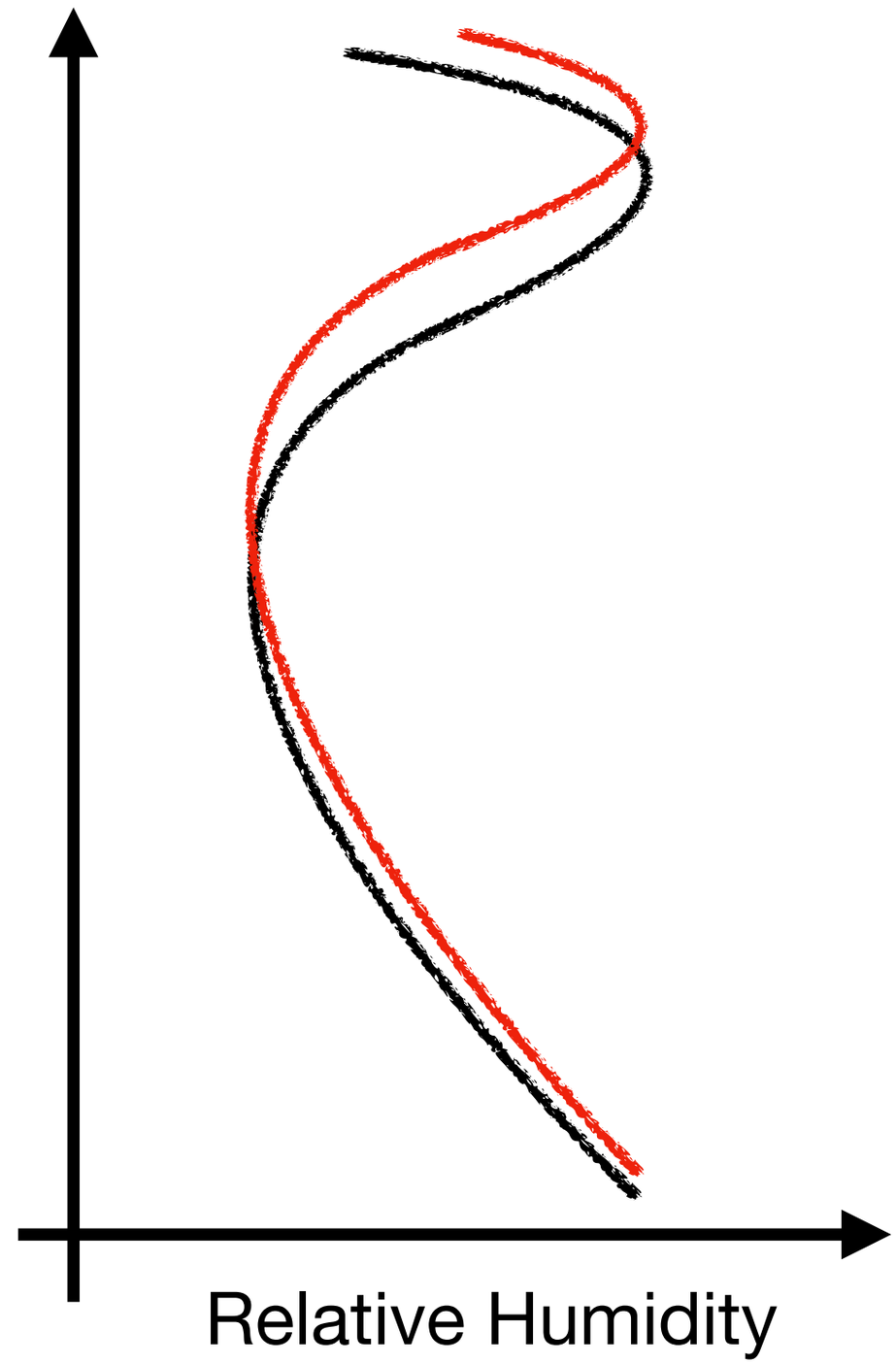
Height
Temperature
Relative Humidity

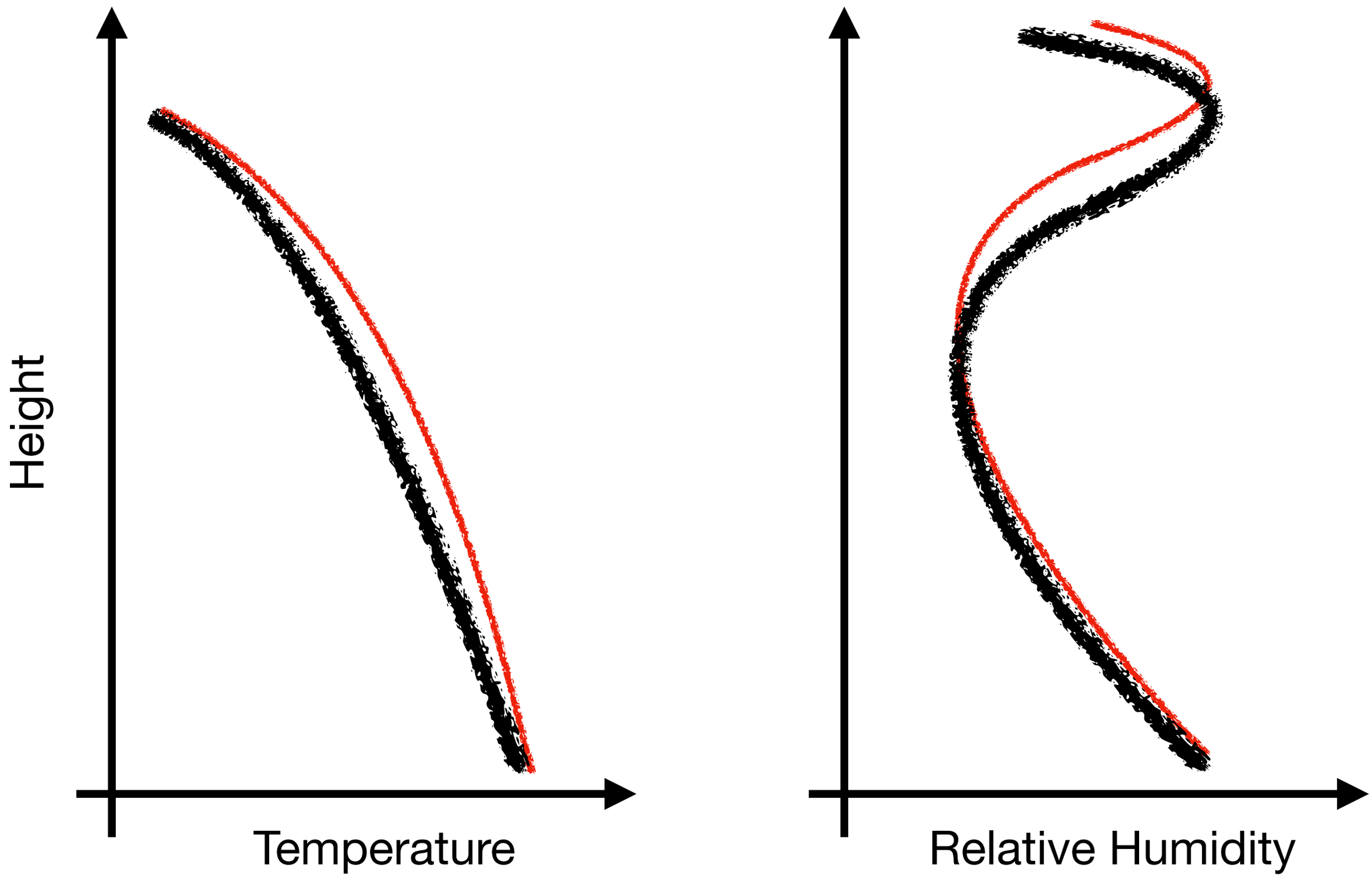

Moistening
Drying
p'
p
Height
Temperature
Relative Humidity

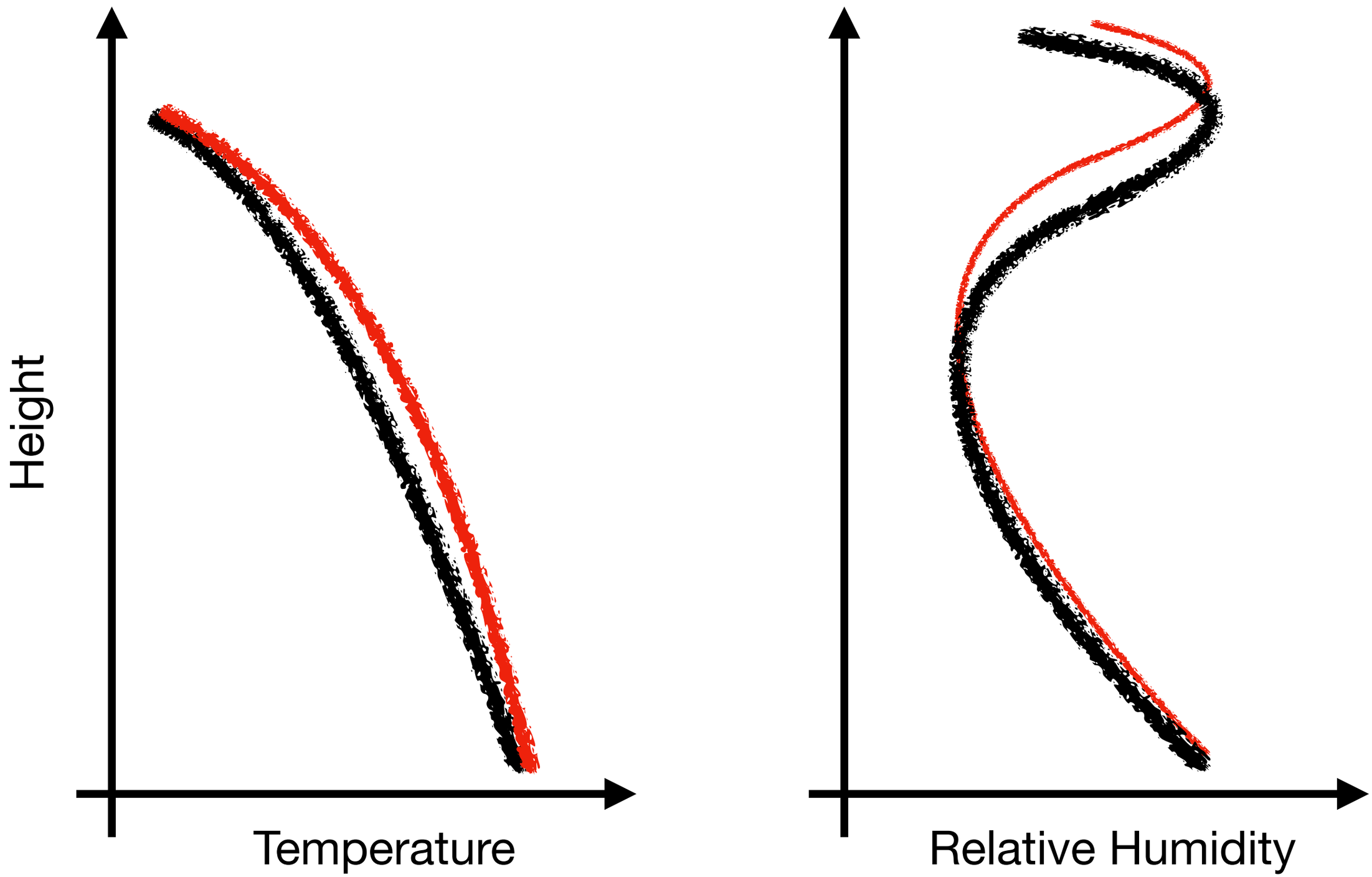


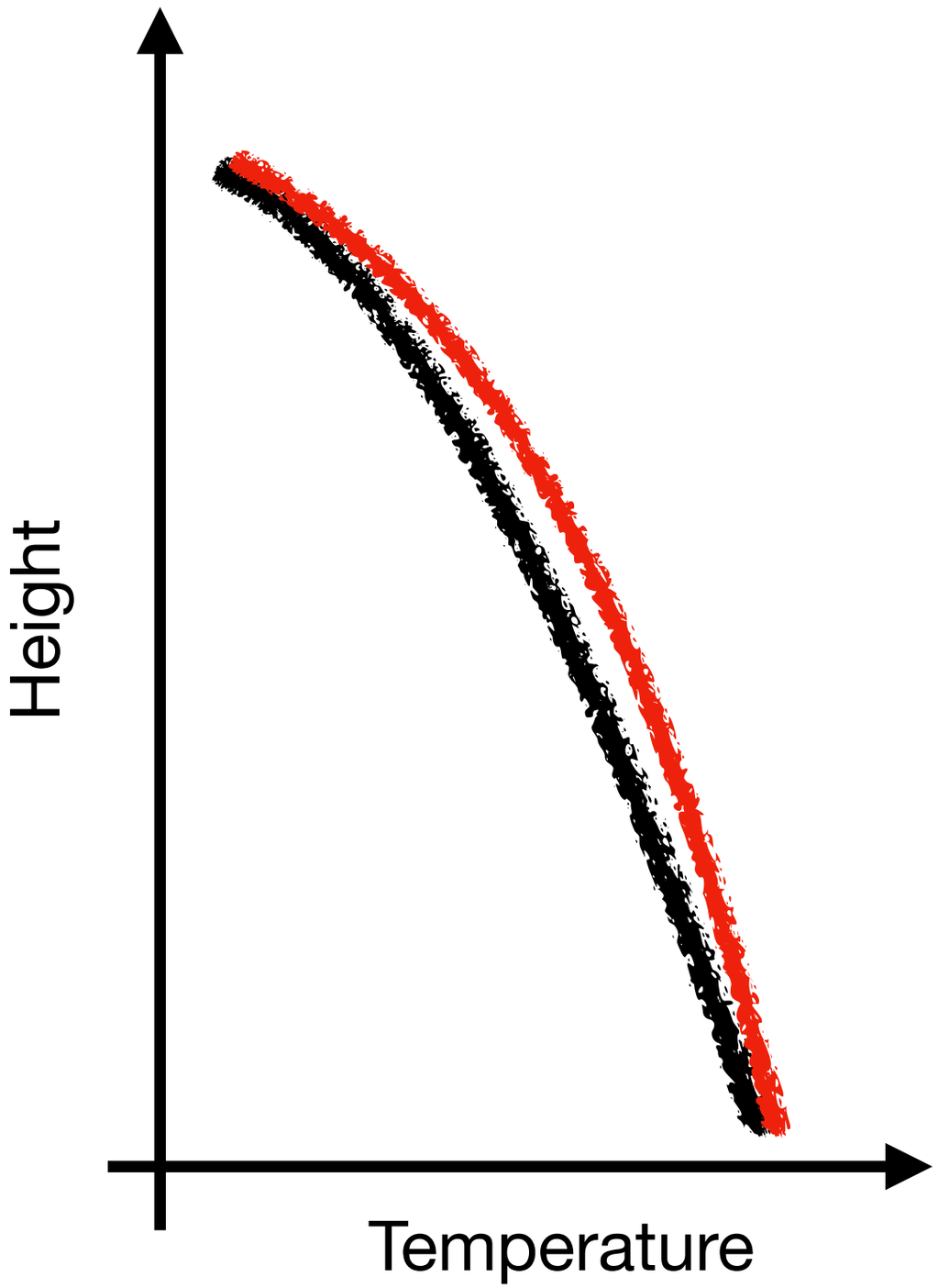
See Romps 2016


Height
Temperature


Relative Humidity


Height
Temperature
Relative Humidity


Height
Temperature
Relative Humidity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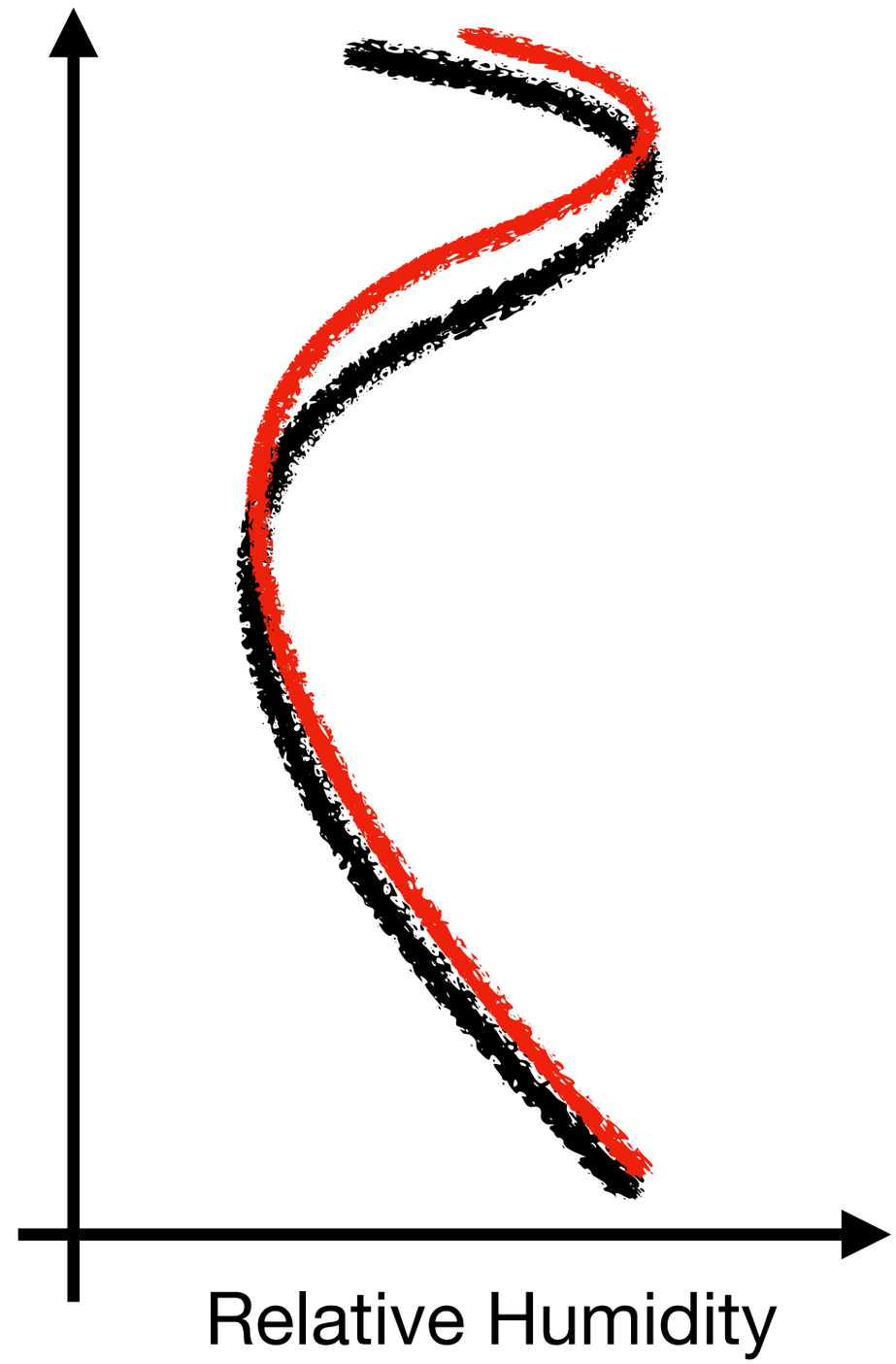
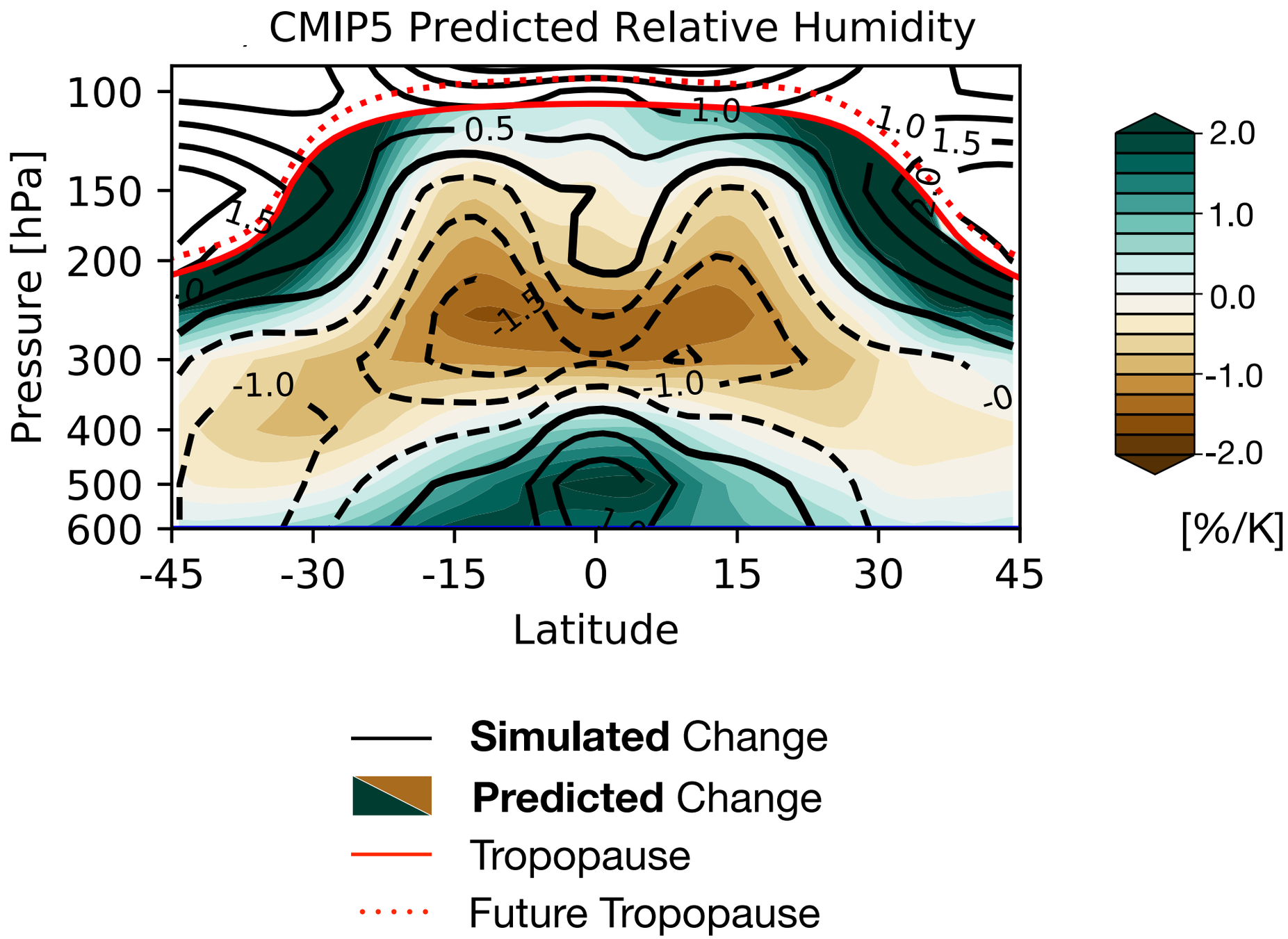
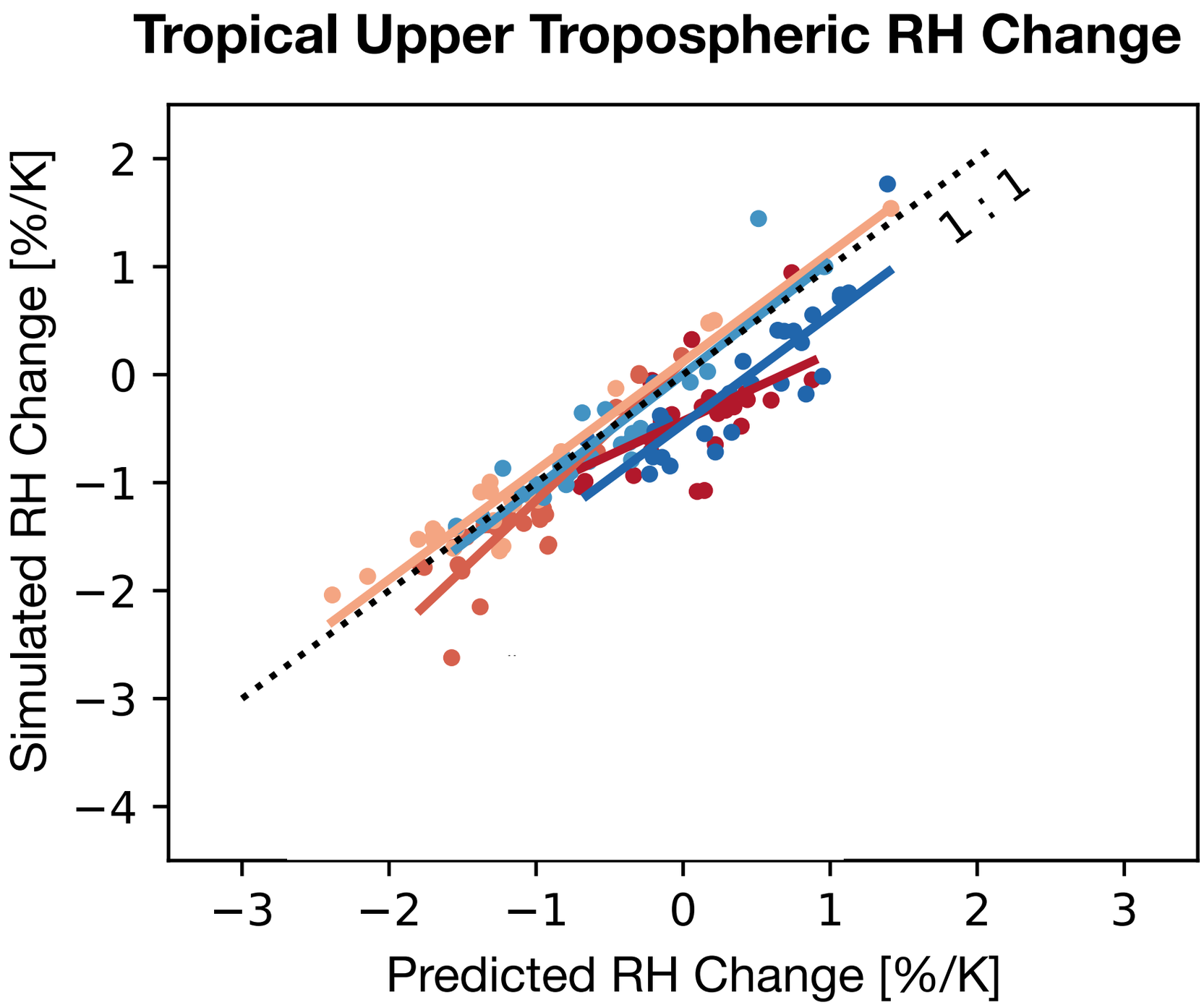
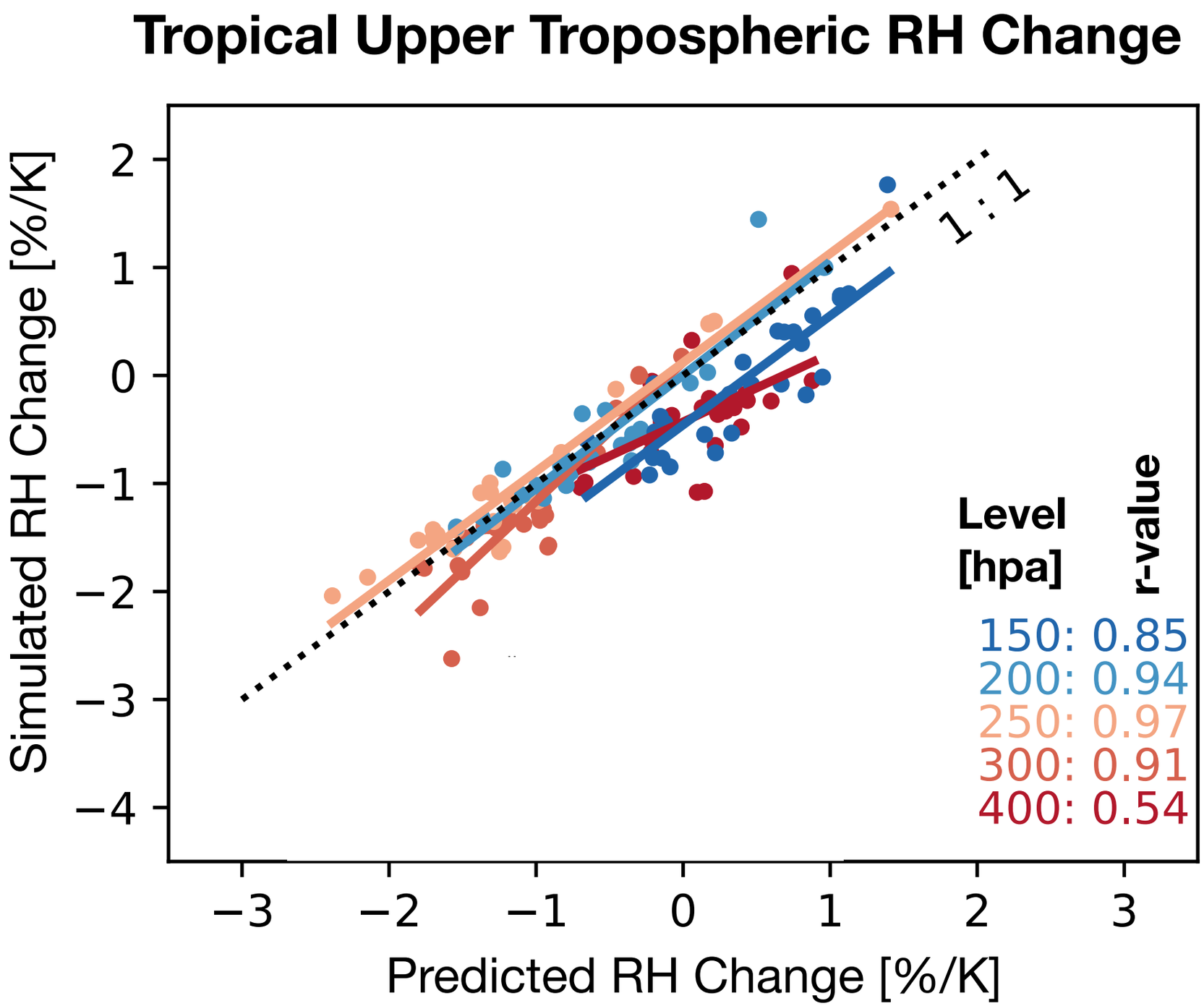
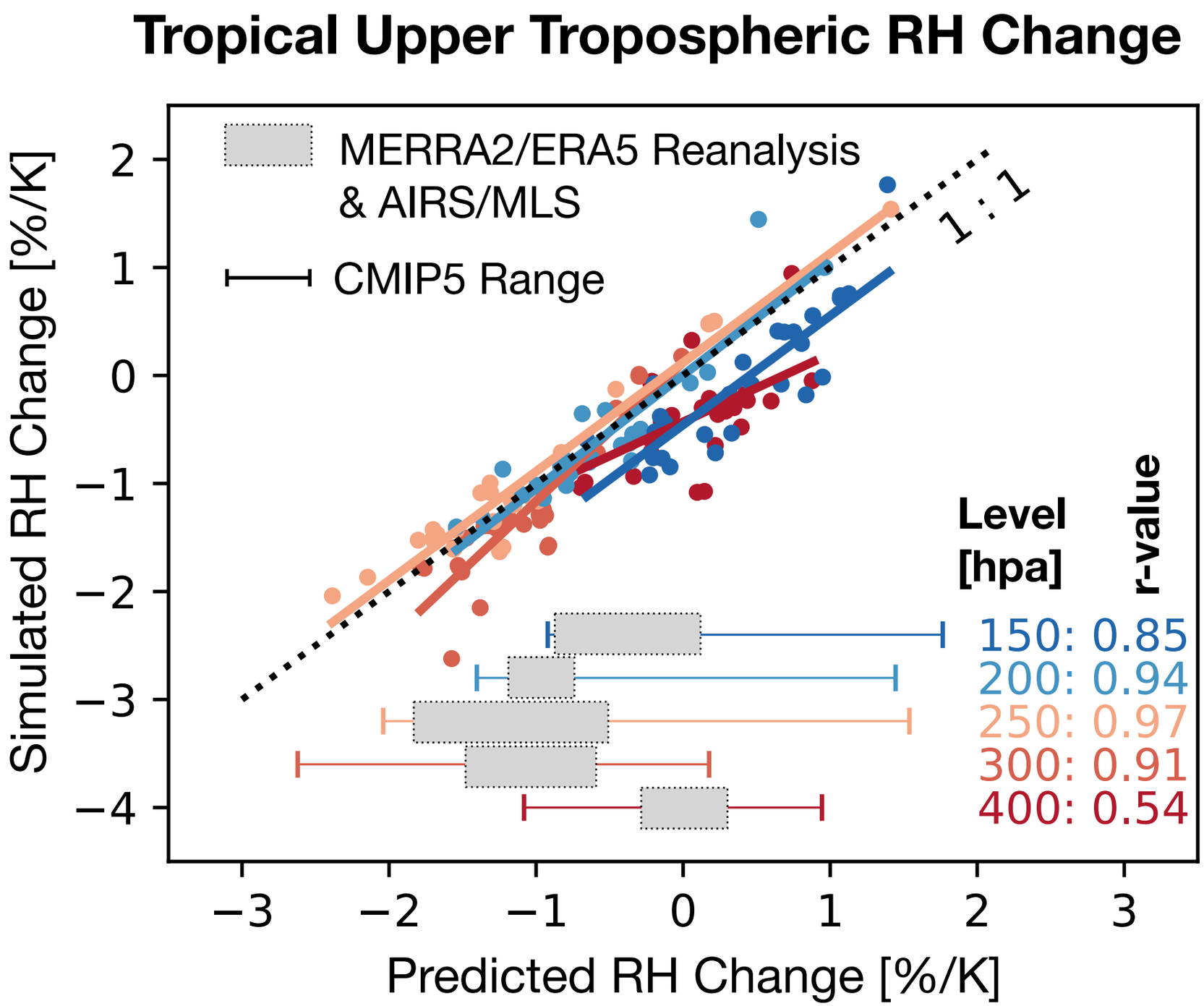
Temperature

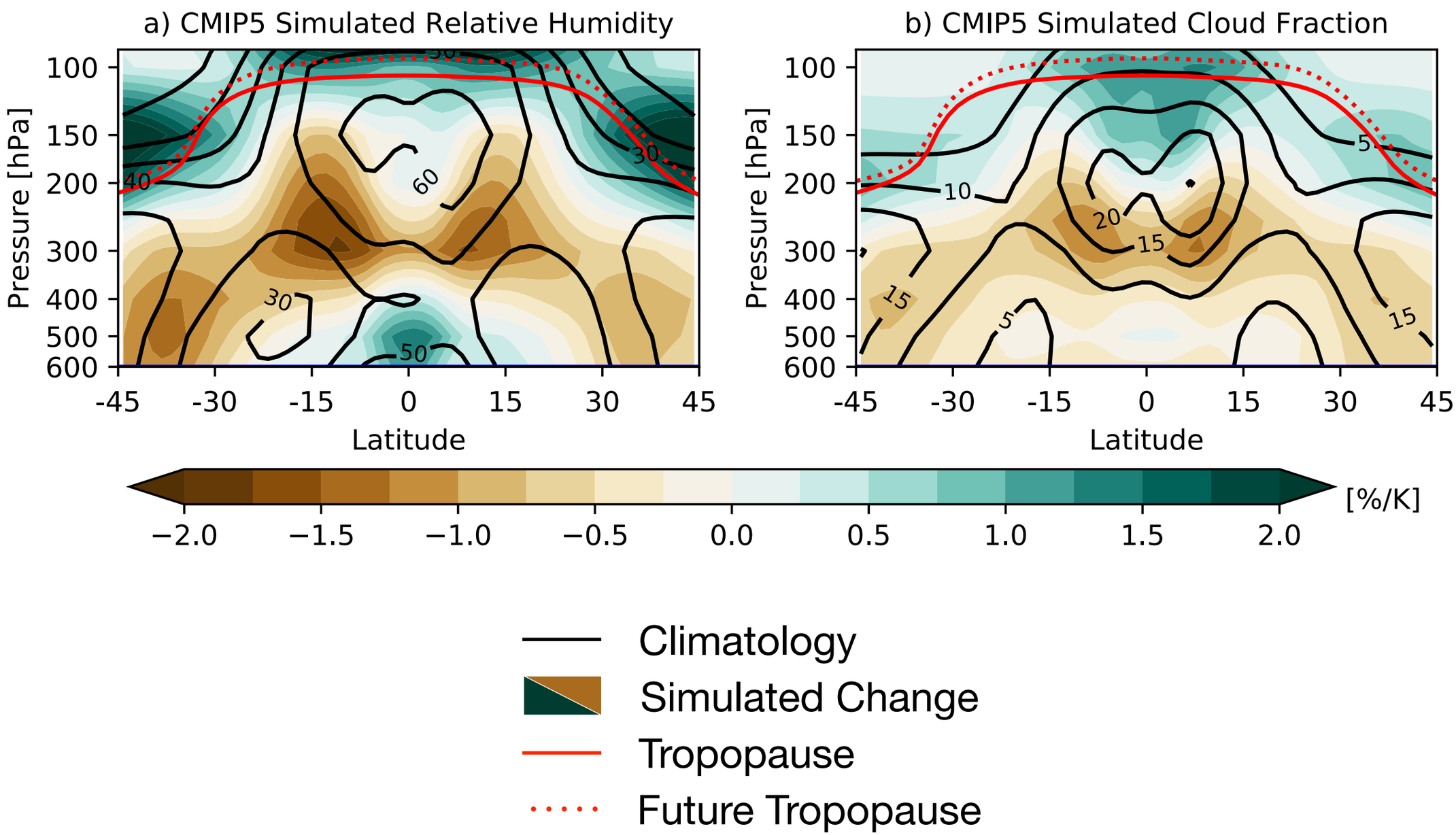

Relative Humidity


CMIP5 Predicted Relative Humidity
Pressure [hPa]
100
150
200
300
400
500
600
-45
-30
-15
0
15
30
45
Latitude
0.5
1.0
1.5
-1.0
-1.5
2.0
1.0
0.0
-1.0
-2.0
[%/K]
Simulated Change
Predicted Change
Tropopause
Future Tropopause

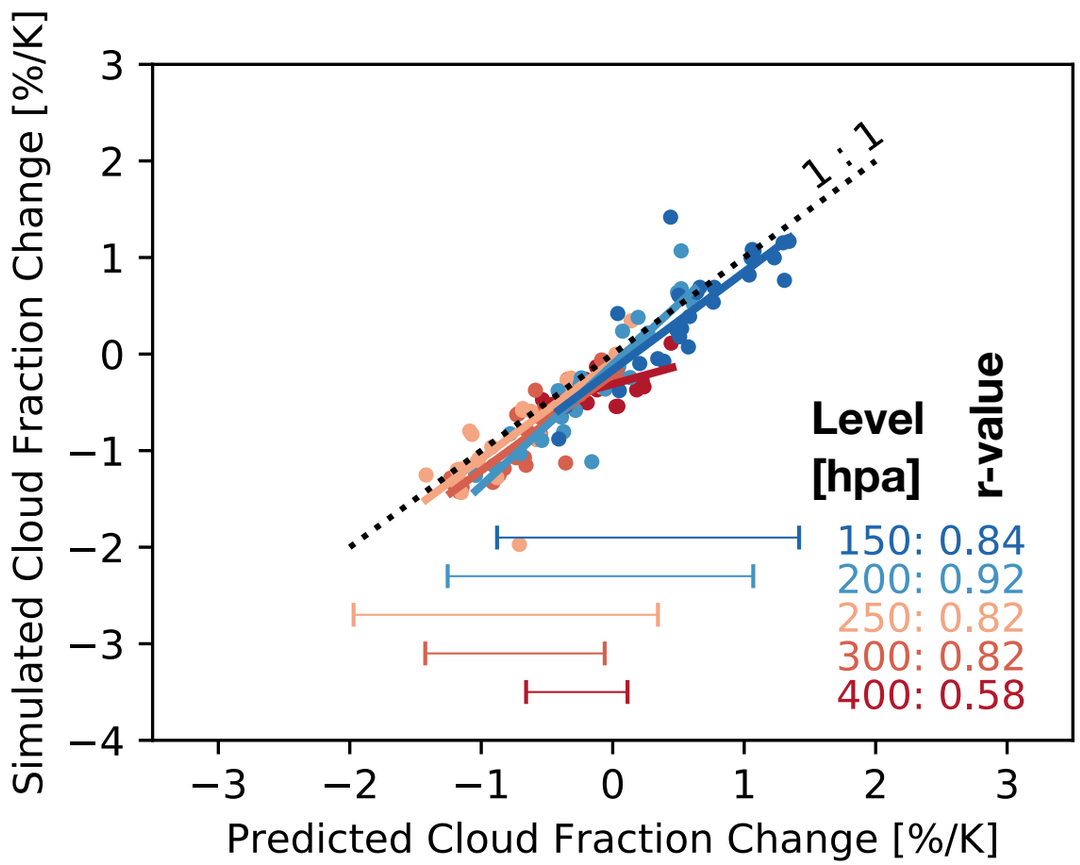

Tropical Upper Tropospheric RH Change
Simulated RH Change [%/K]
Predicted RH Change [%/K]
1 : 1
2
1
0
−1
−2
−3
−4
−3
−2
−1
0
1
2
3


Tropical Upper Tropospheric RH Change
Simulated RH Change [%/K]
Predicted RH Change [%/K]
1 : 1
Level [hpa]
r-value
150: 0.85
200: 0.94
250: 0.97
300: 0.91
400: 0.54

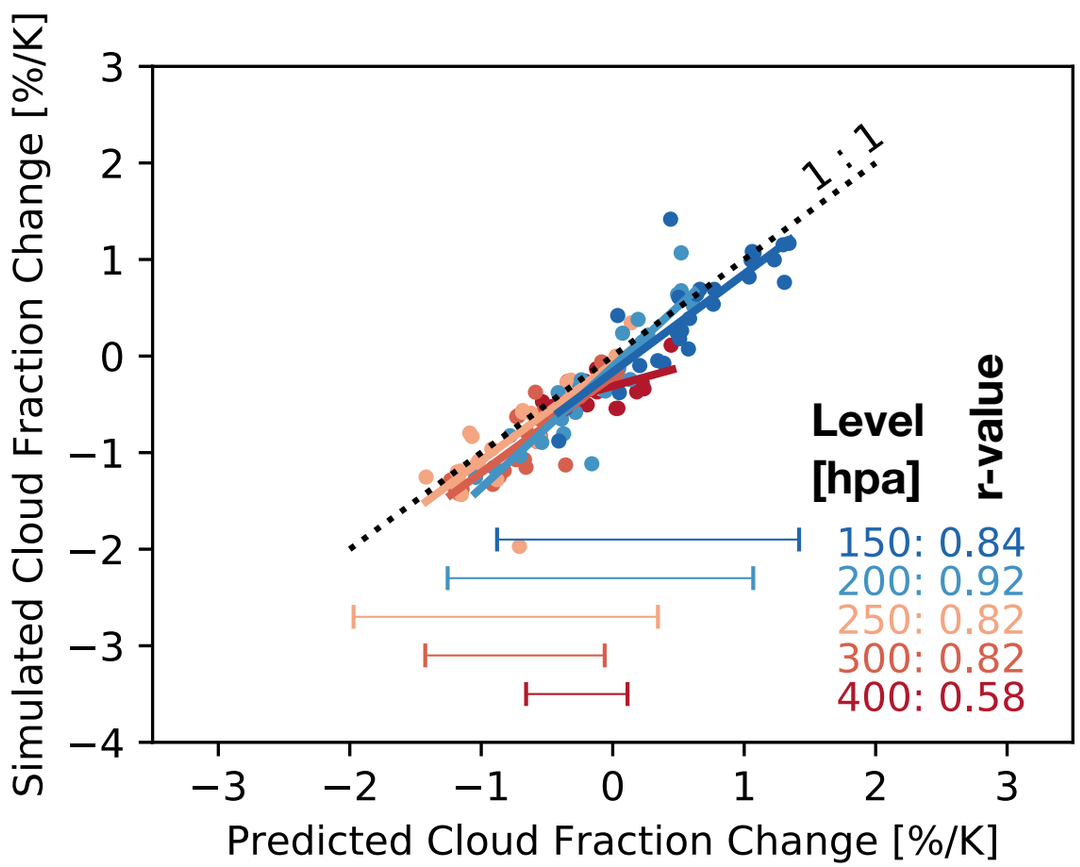

Tropical Upper Tropospheric RH Change
MERRA2/ERA5 Reanalysis
& AIRS/MLS
CMIP5 Range
1 : 1
Level
[hpa]
r-value
150: 0.85
200: 0.94
250: 0.97
300: 0.91
400: 0.54
Simulated RH Change [%/K]
Predicted RH Change [%/K]
2
1
0
−1
−2
−3
−4
−3
−2
−1
0
1
2
3

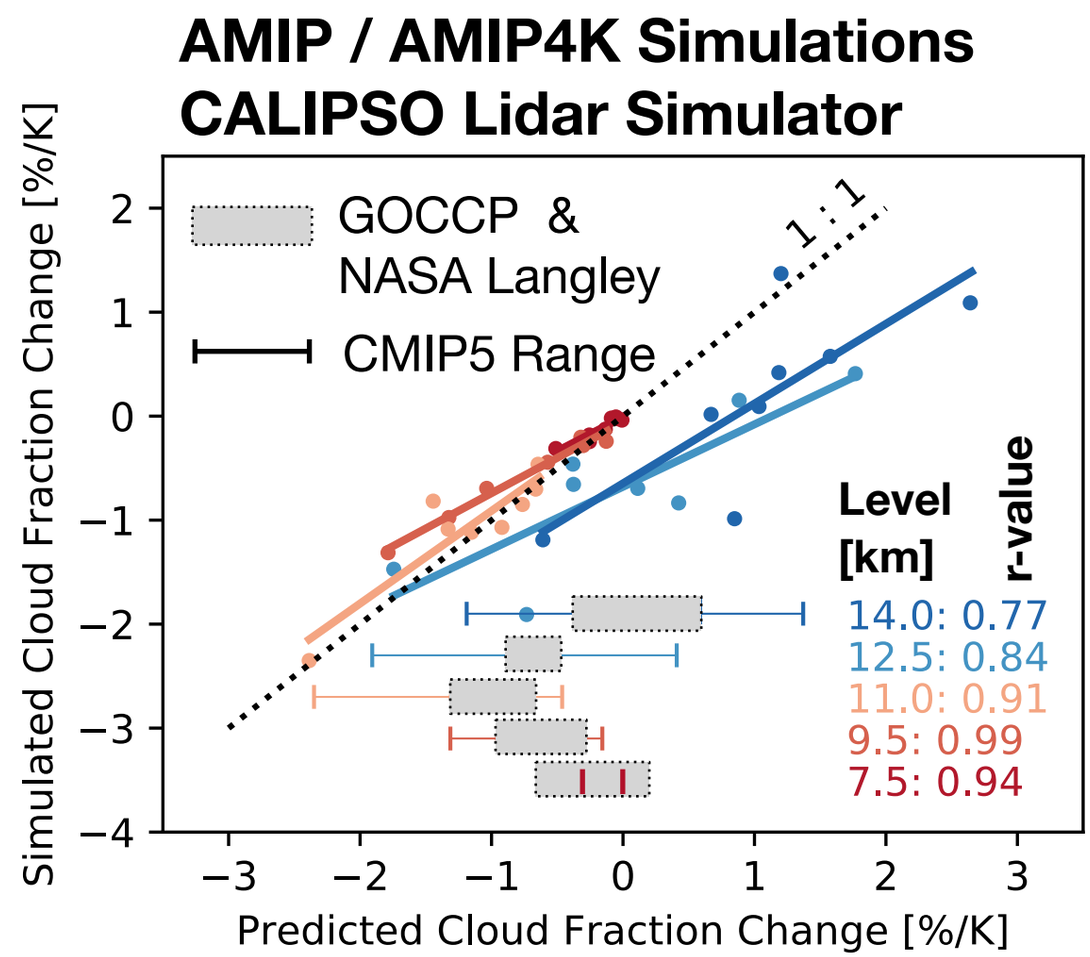

a) CMIP5 Simulated Relative Humidity
b) CMIP5 Simulated Cloud Fraction
Pressure [hPa]
100
150
200
300
400
500
600
-45
-30
-15
0
15
30
45
Latitude
40
60
30
50
10
20
15
5
[%/K]
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
Climatology
Simulated Change
Tropopause
Future Tropopause

Tropical Upper Tropospheric Cloud Change



Tropical Upper Tropospheric Cloud Change





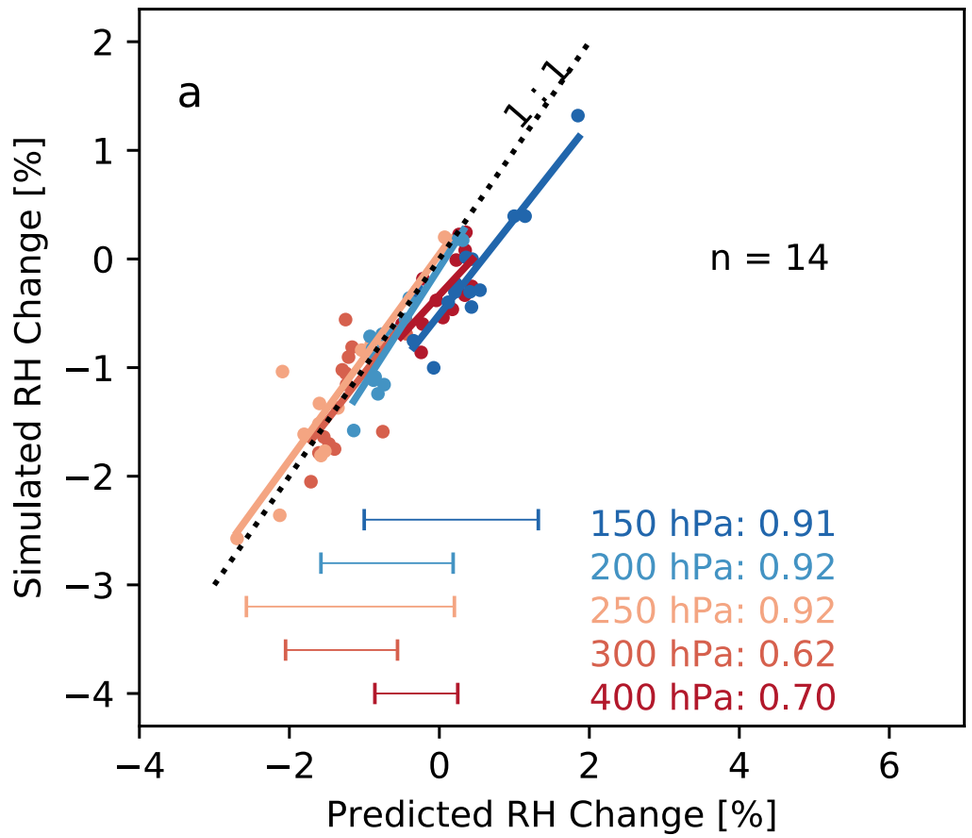
Summary

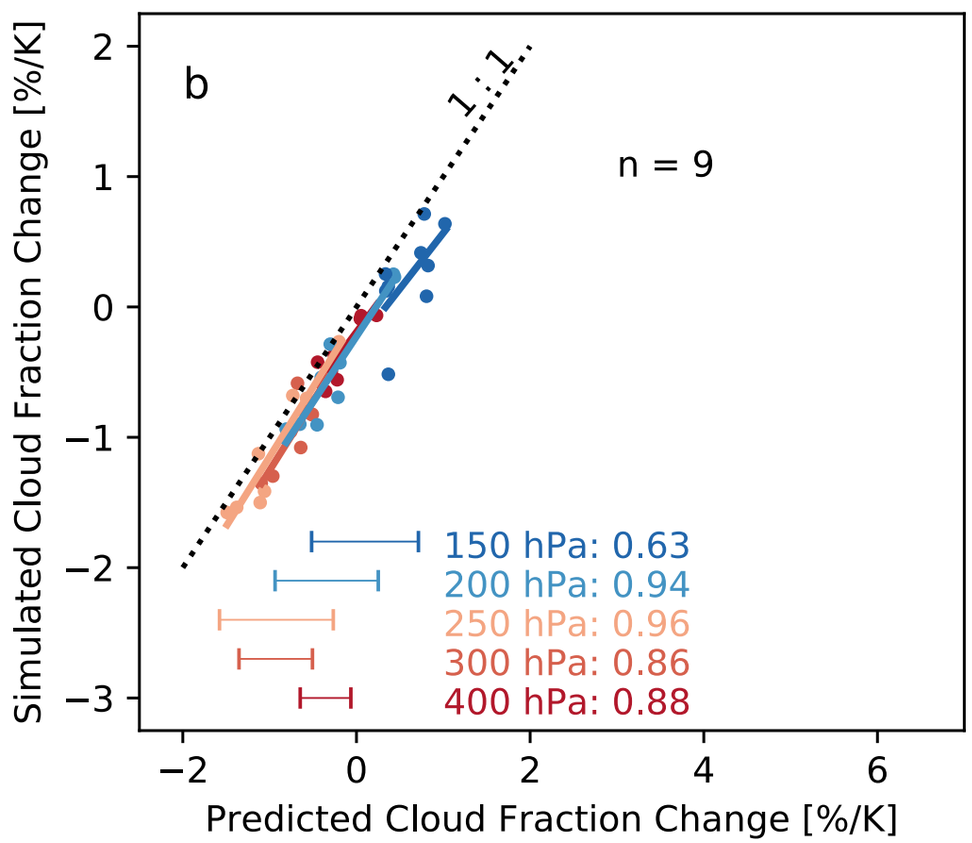
- Tropical upper tropospheric clouds and relative humidity are an invariant function of temperature in climate models*
- Can use this finding to accurately predict intermodel spread in model responses
- Finding may allow for estimate of climate feedbacks related to clouds and relative humidity
- **Model base state biases influence the simulated model response; observations can be employed to reduce such biases**

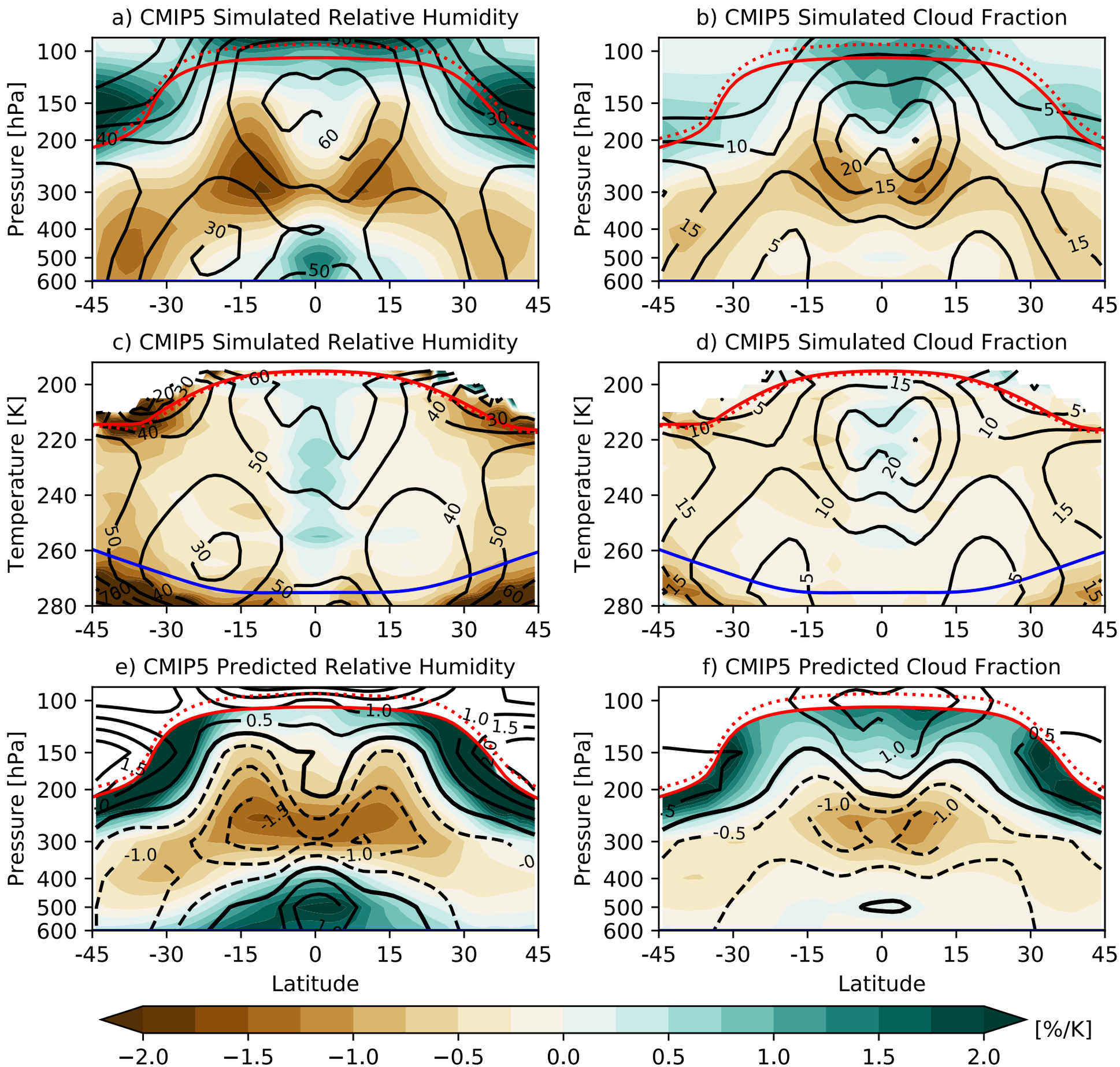
*to first order

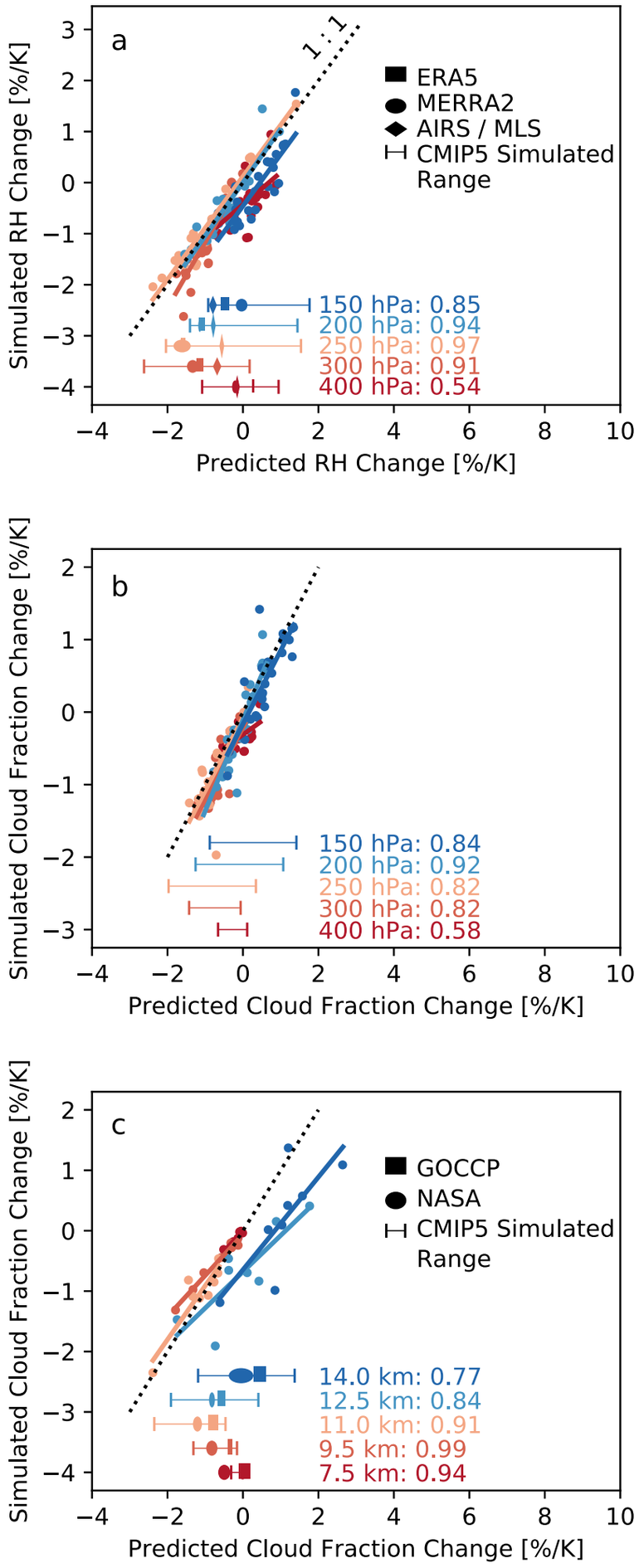
CMIP6

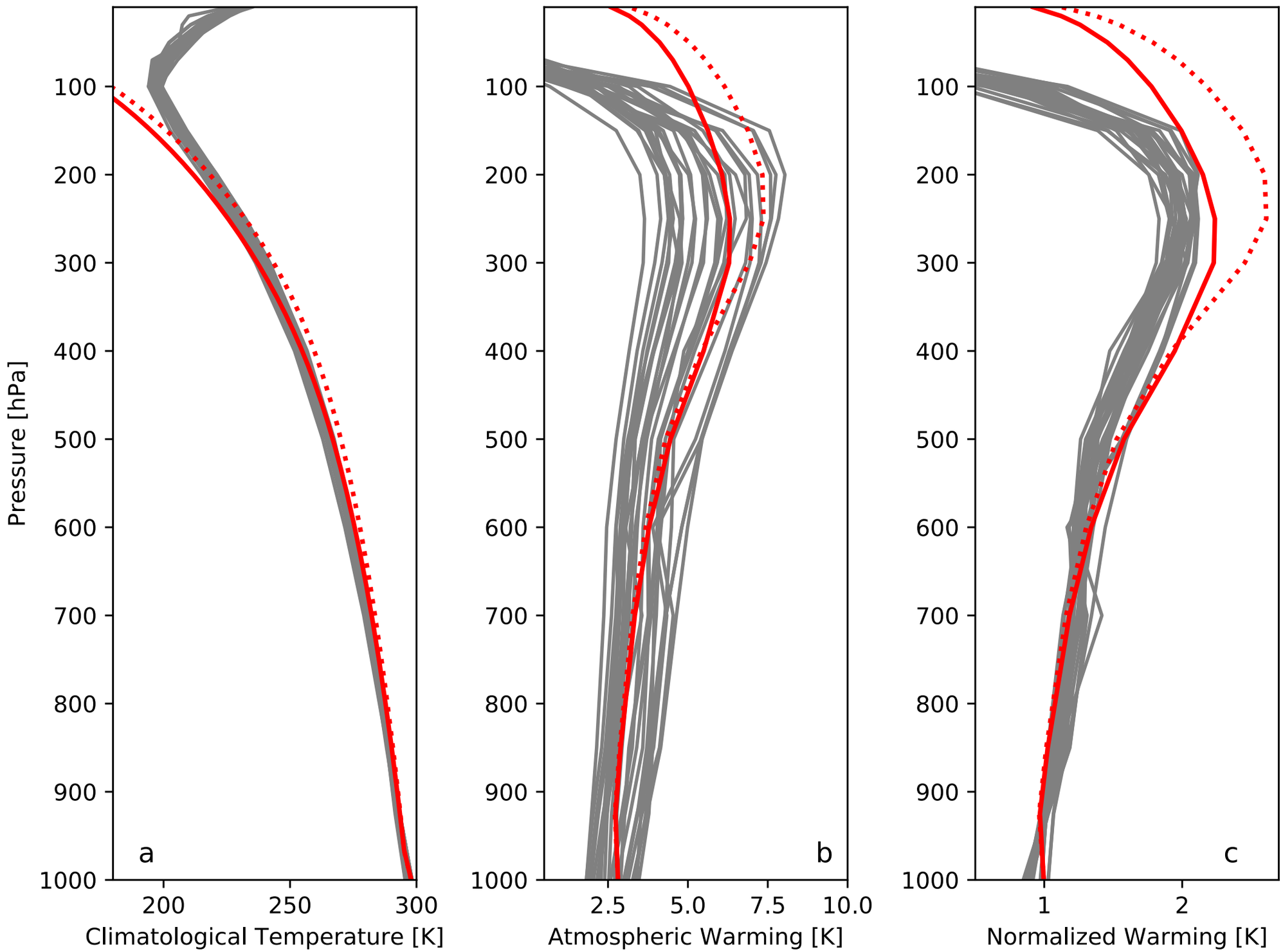
Abrupt4xCO2 runs



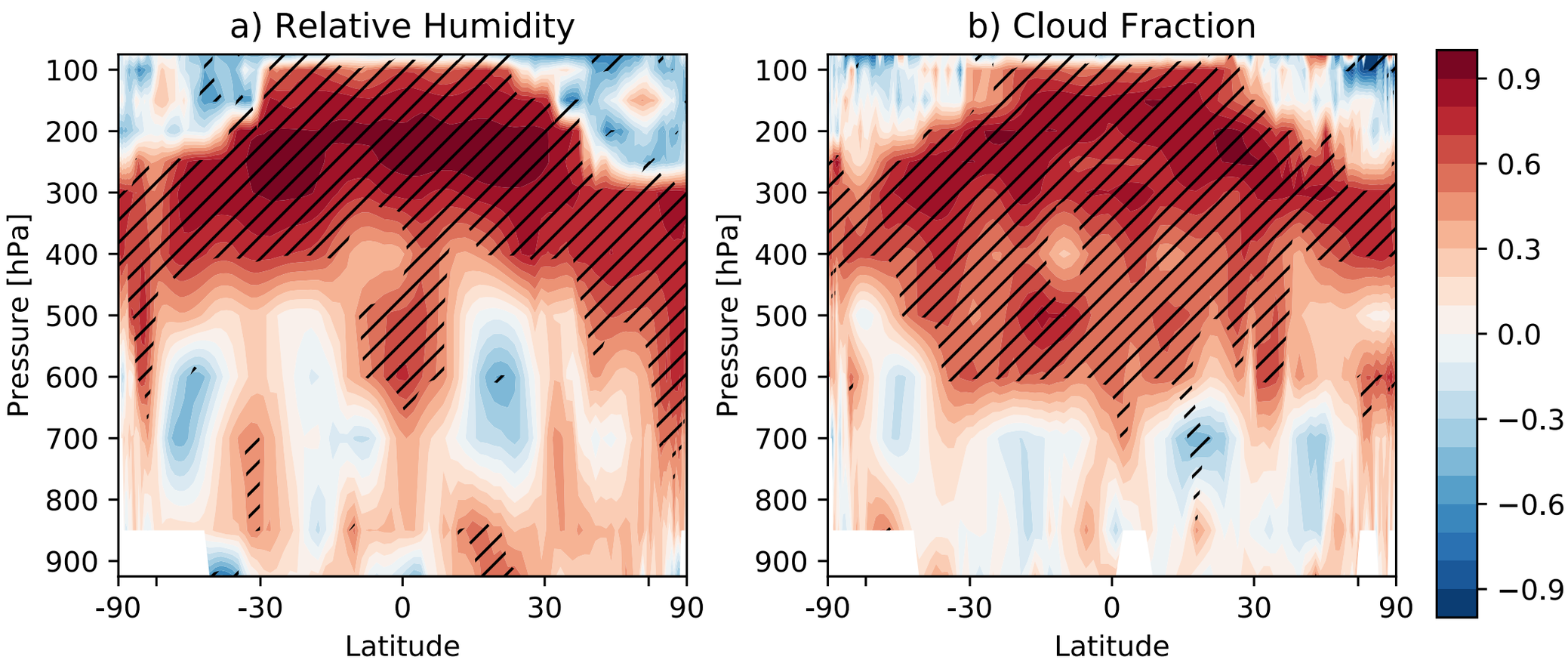



a) CMIP5 Simulated Relative Humidity
b) CMIP5 Simulated Cloud Fraction
c) CMIP5 Simulated Relative Humidity
d) CMIP5 Simulated Cloud Fraction
e) CMIP5 Predicted Relative Humidity
f) CMIP5 Predicted Cloud Fraction
Pressure [hPa]
Temperature [K]
Latitude
[%/K]

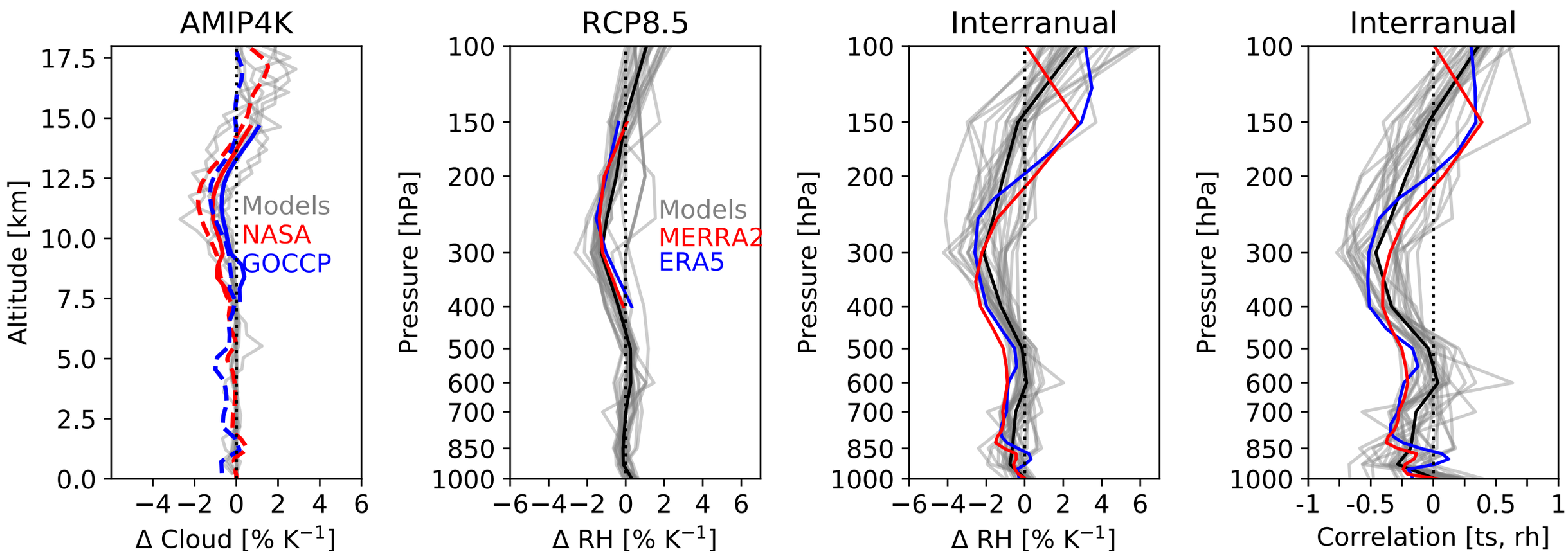

a
1 : 1
ERA5
MERRA2
AIRS / MLS
CMIP5 Simulated Range
150 hPa: 0.85
200 hPa: 0.94
250 hPa: 0.97
300 hPa: 0.91
400 hPa: 0.54
Simulated RH Change [%/K]
Predicted RH Change [%/K]
b
150 hPa: 0.84
200 hPa: 0.92
250 hPa: 0.82
300 hPa: 0.82
400 hPa: 0.58
Simulated Cloud Fraction Change [%/K]
Predicted Cloud Fraction Change [%/K]
c
GOCCP
NASA
CMIP5 Simulated Range
14.0 km: 0.77
12.5 km: 0.84
11.0 km: 0.91
9.5 km: 0.99
7.5 km: 0.94
Simulated Cloud Fraction Change [%/K]
Predicted Cloud Fraction Change [%/K]


Pressure [hPa]
100
200
300
400
500
600
700
800
900
1000
a
200
250
300
Climatological Temperature [K]
b
2.5
5.0
7.5
10.0
Atmospheric Warming [K]
c
1
2
Normalized Warming [K]

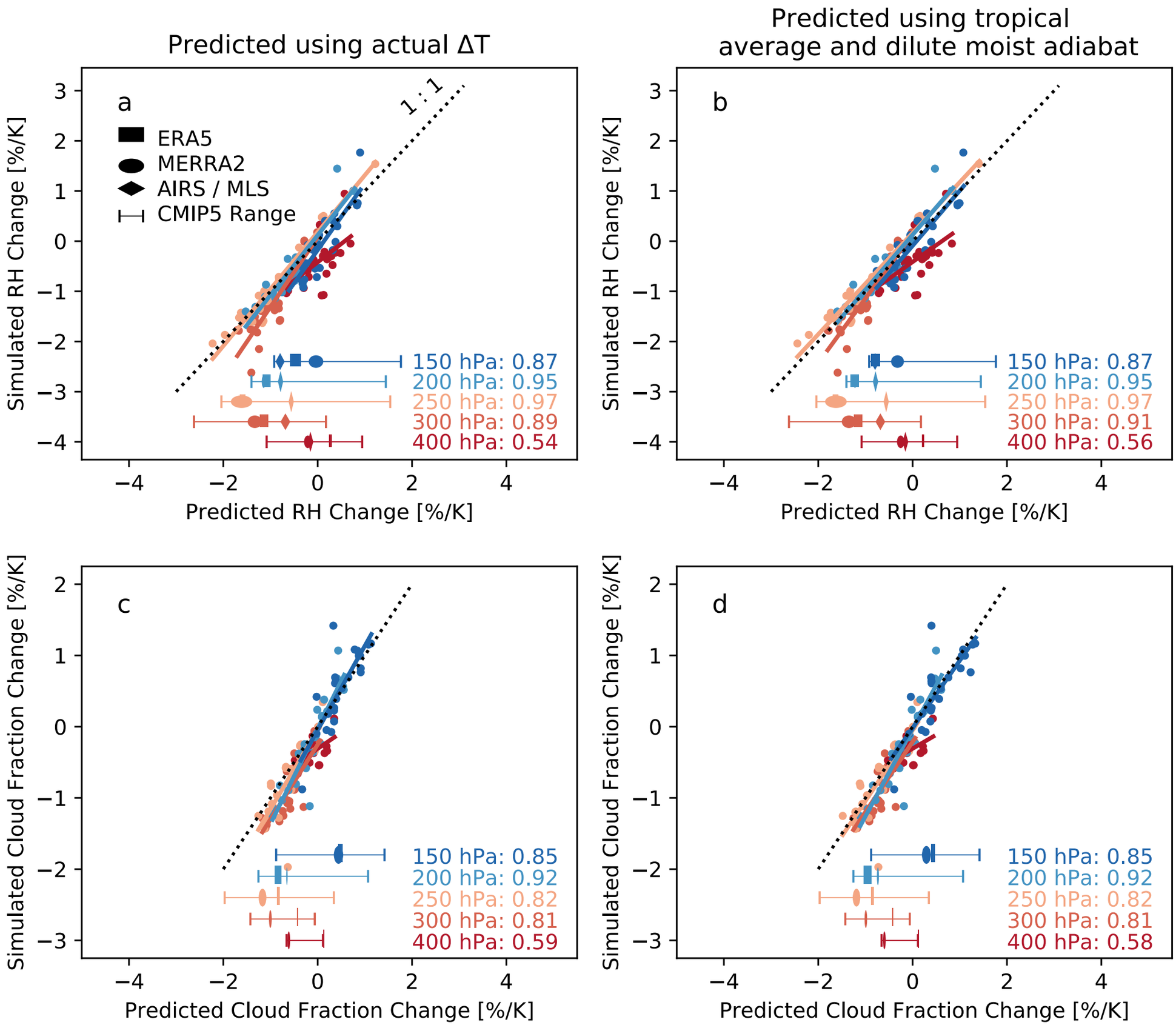
Simulated versus Predicted Change Correlation Coefficient



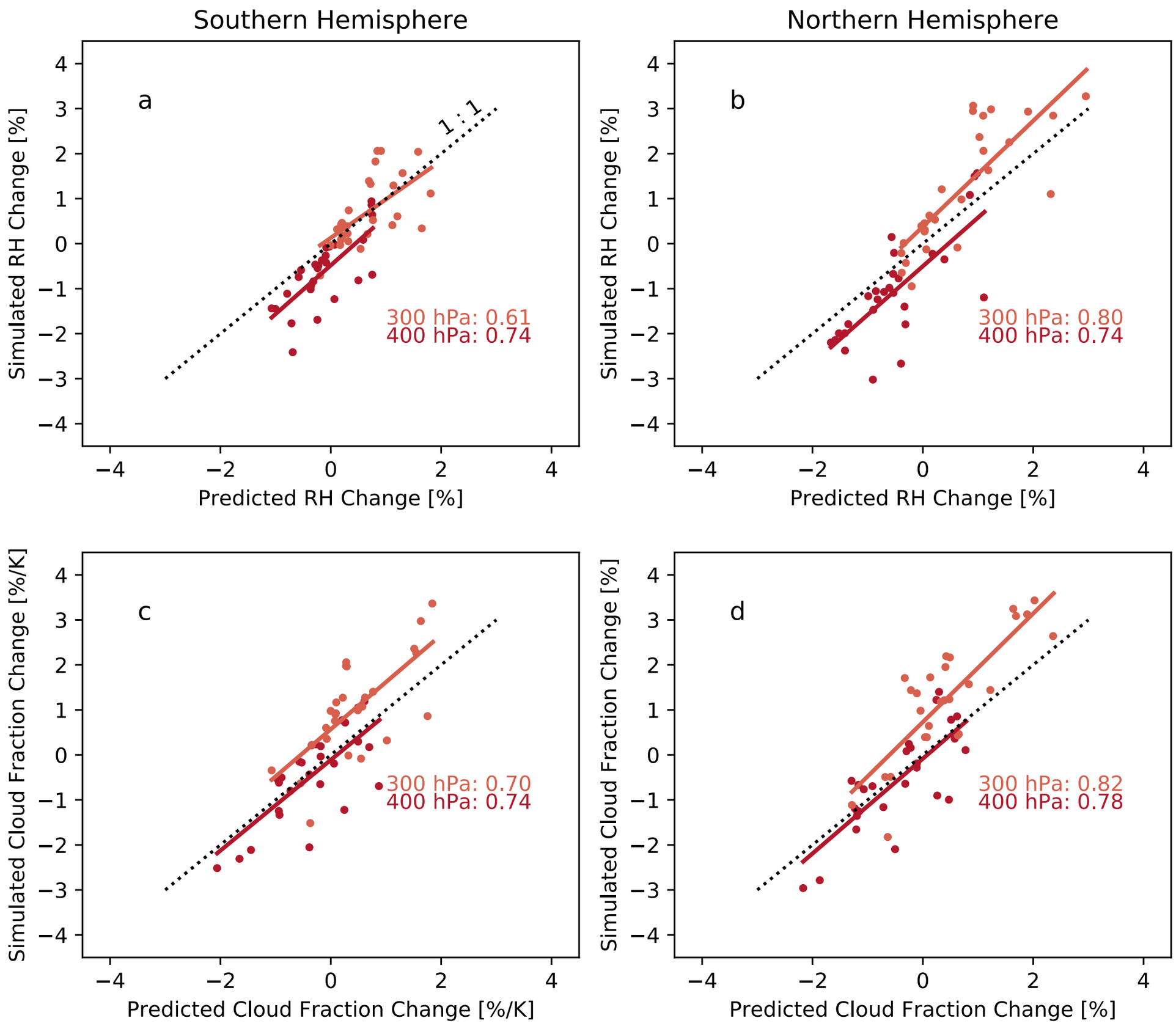
Interannual and Longterm Change Comparisons



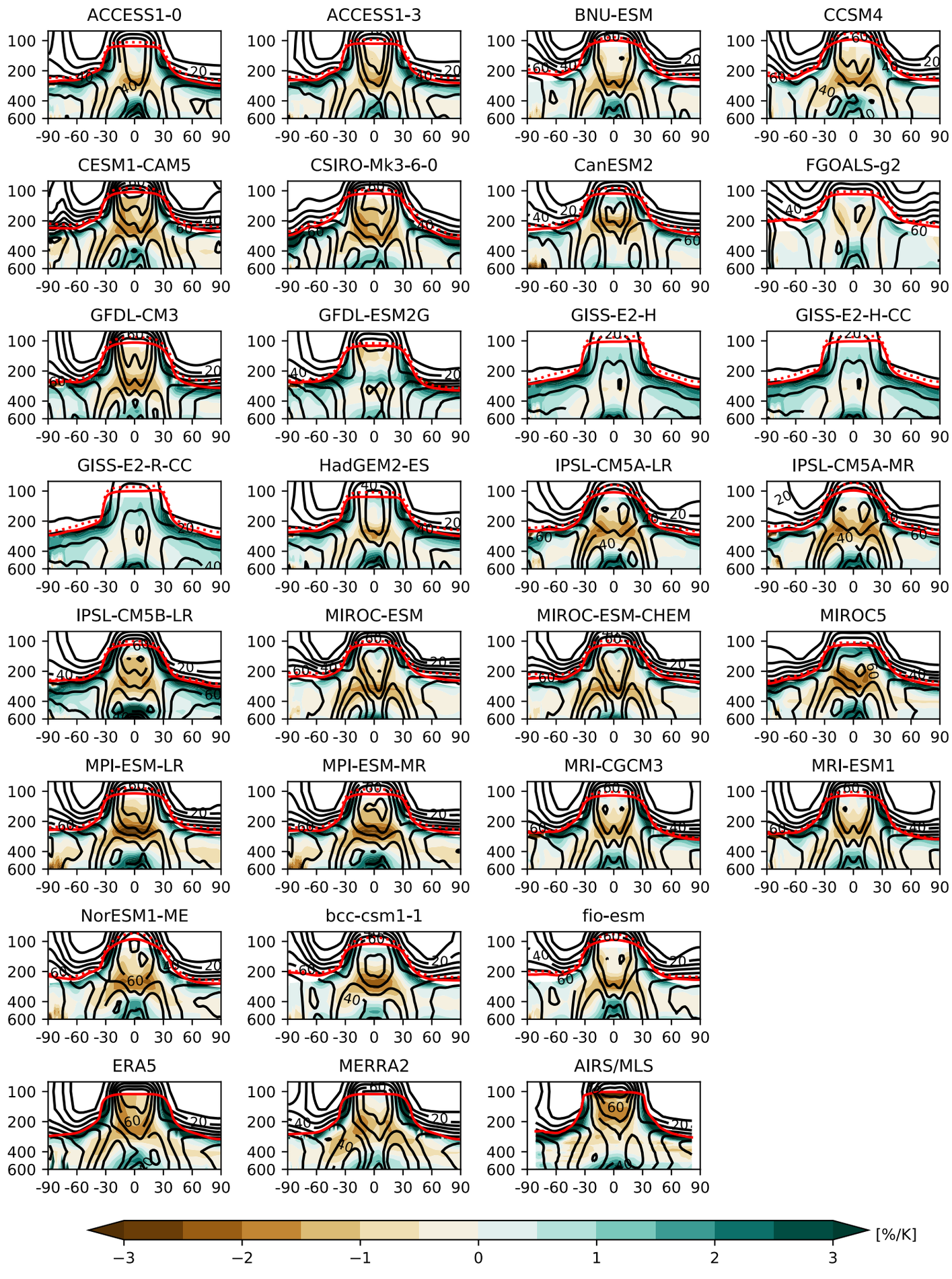
(Lack of) Sensitivity to Simplifications



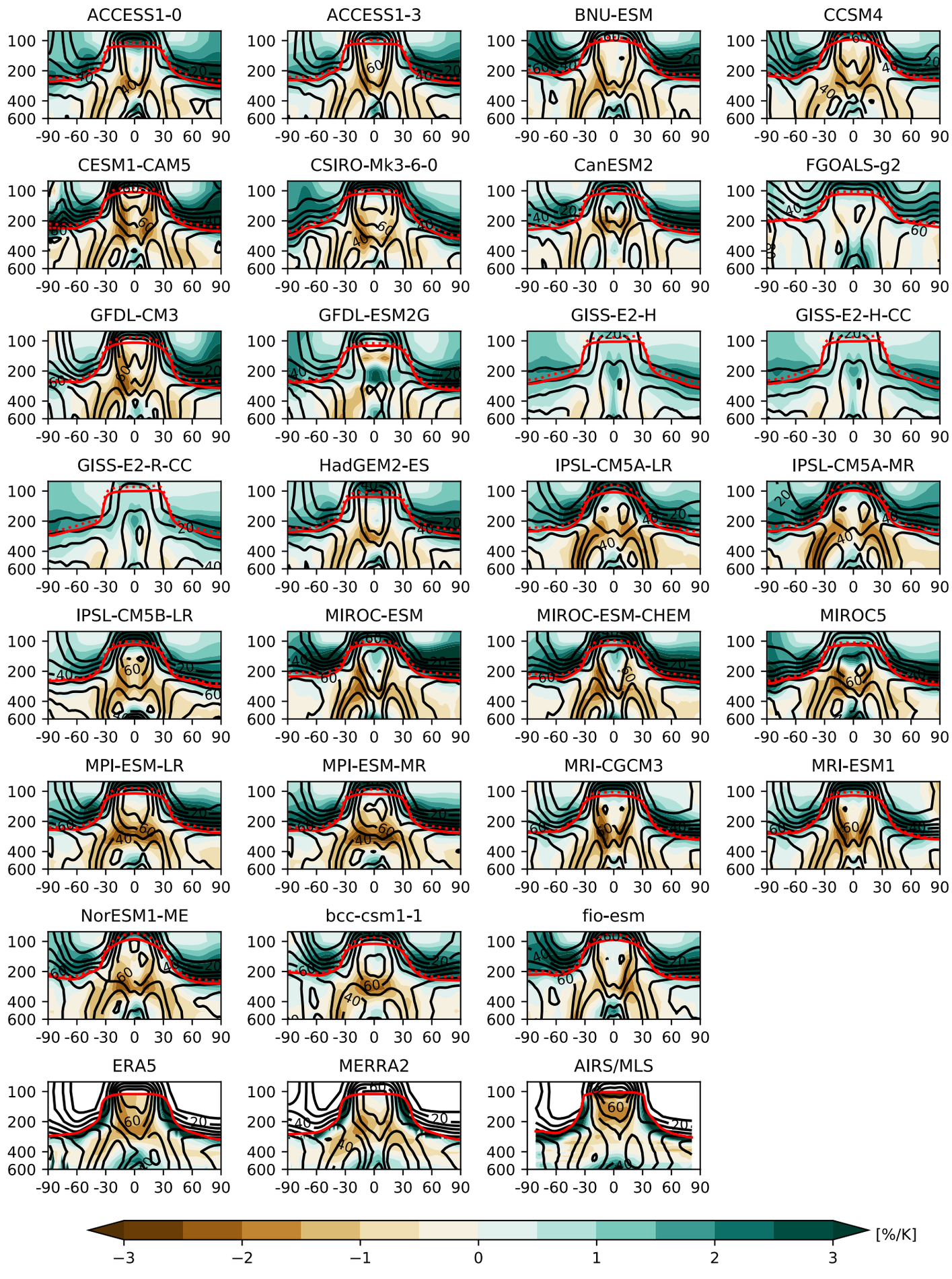
Extratropical Analysis



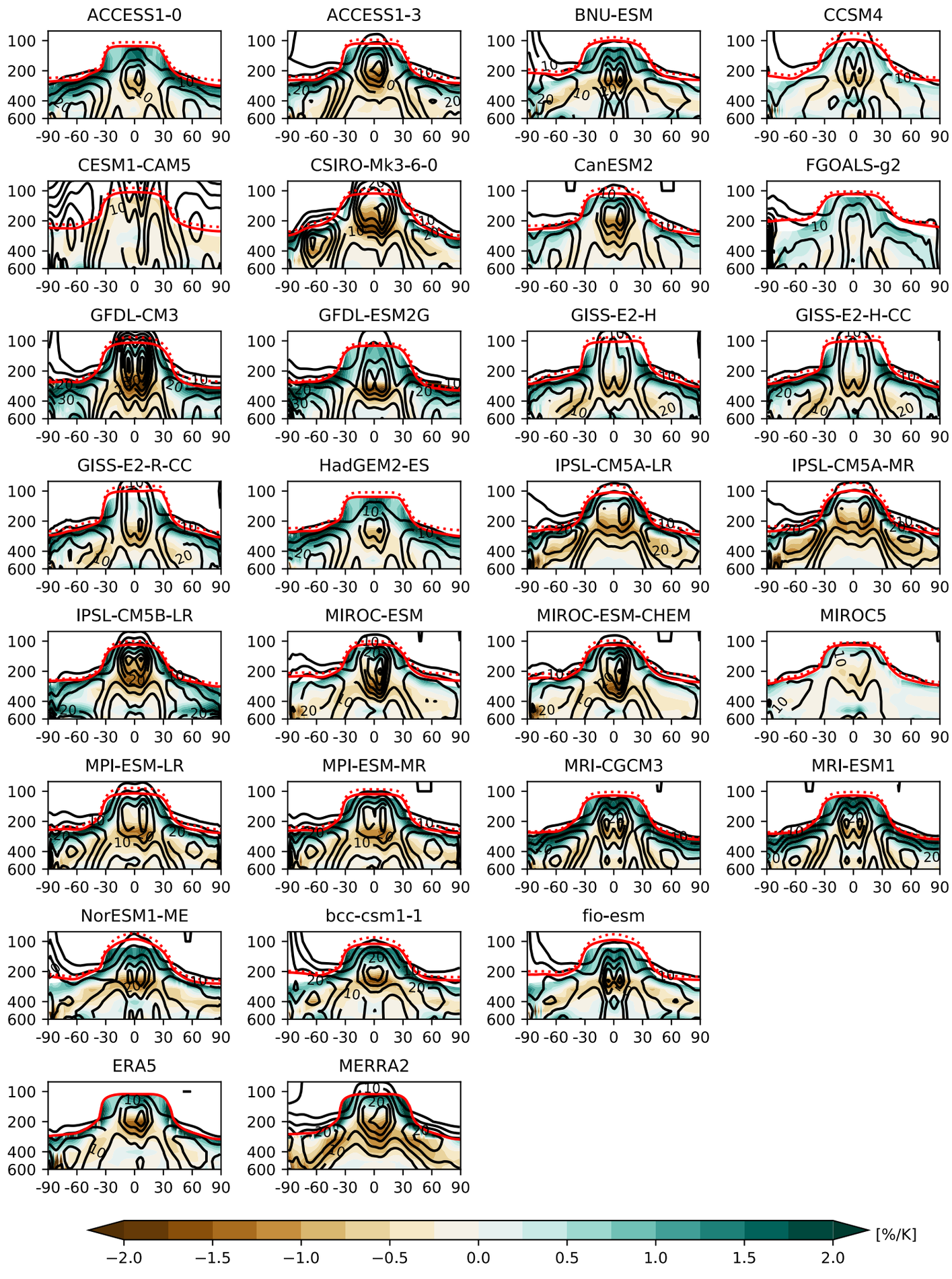
Predicted RH Changes



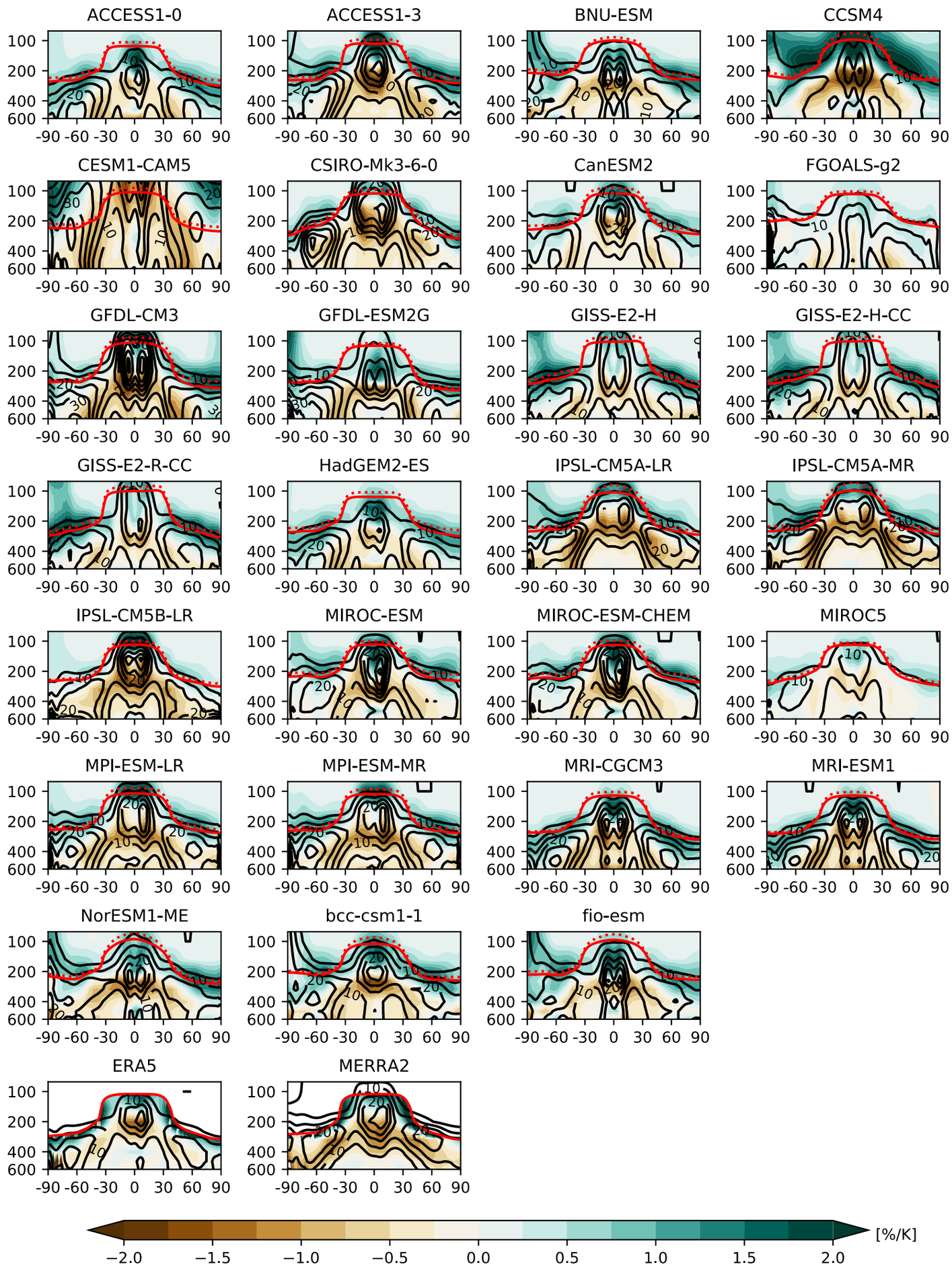
Simulated RH Changes



Predicted Cloud Changes

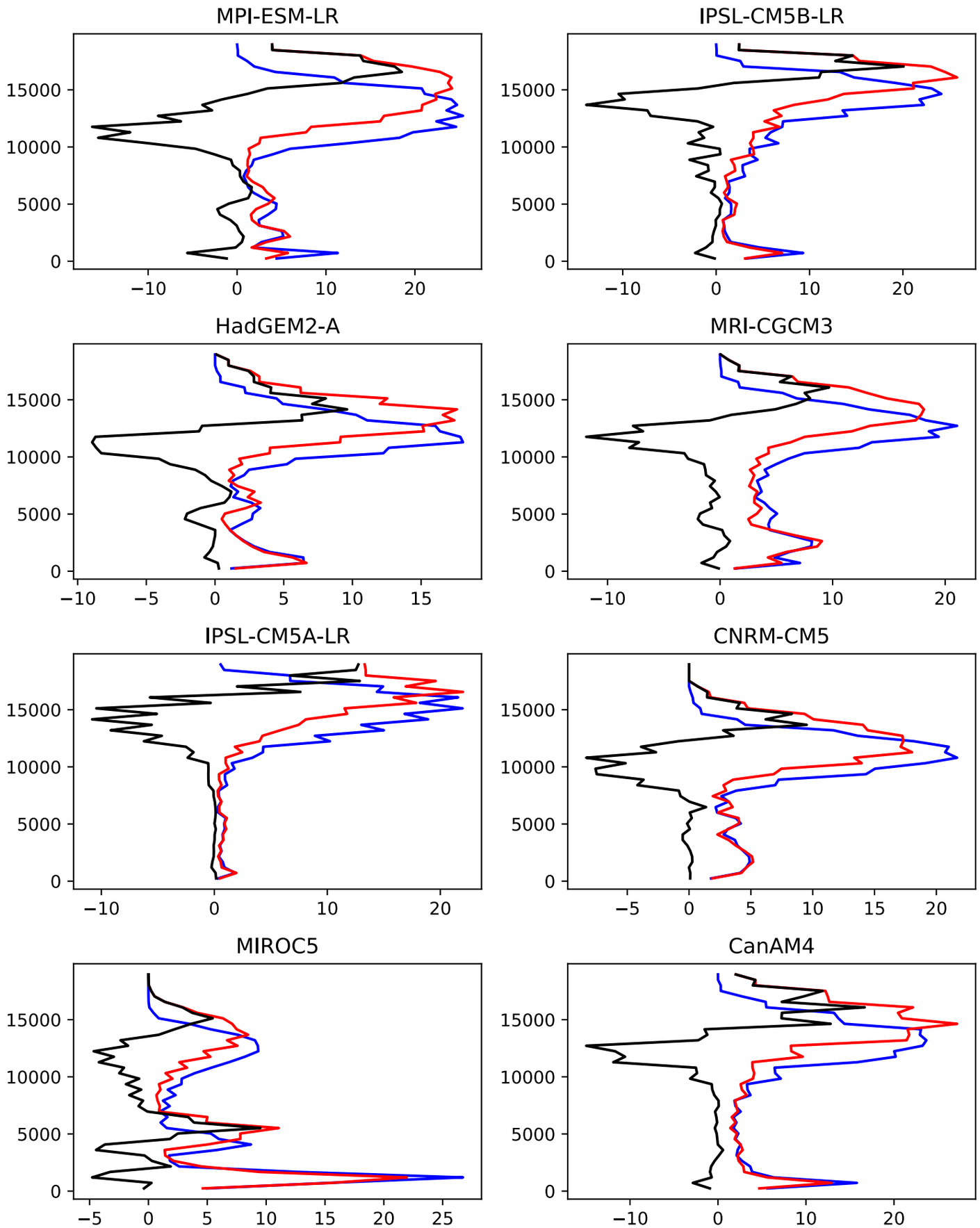


Simulated Cloud Changes

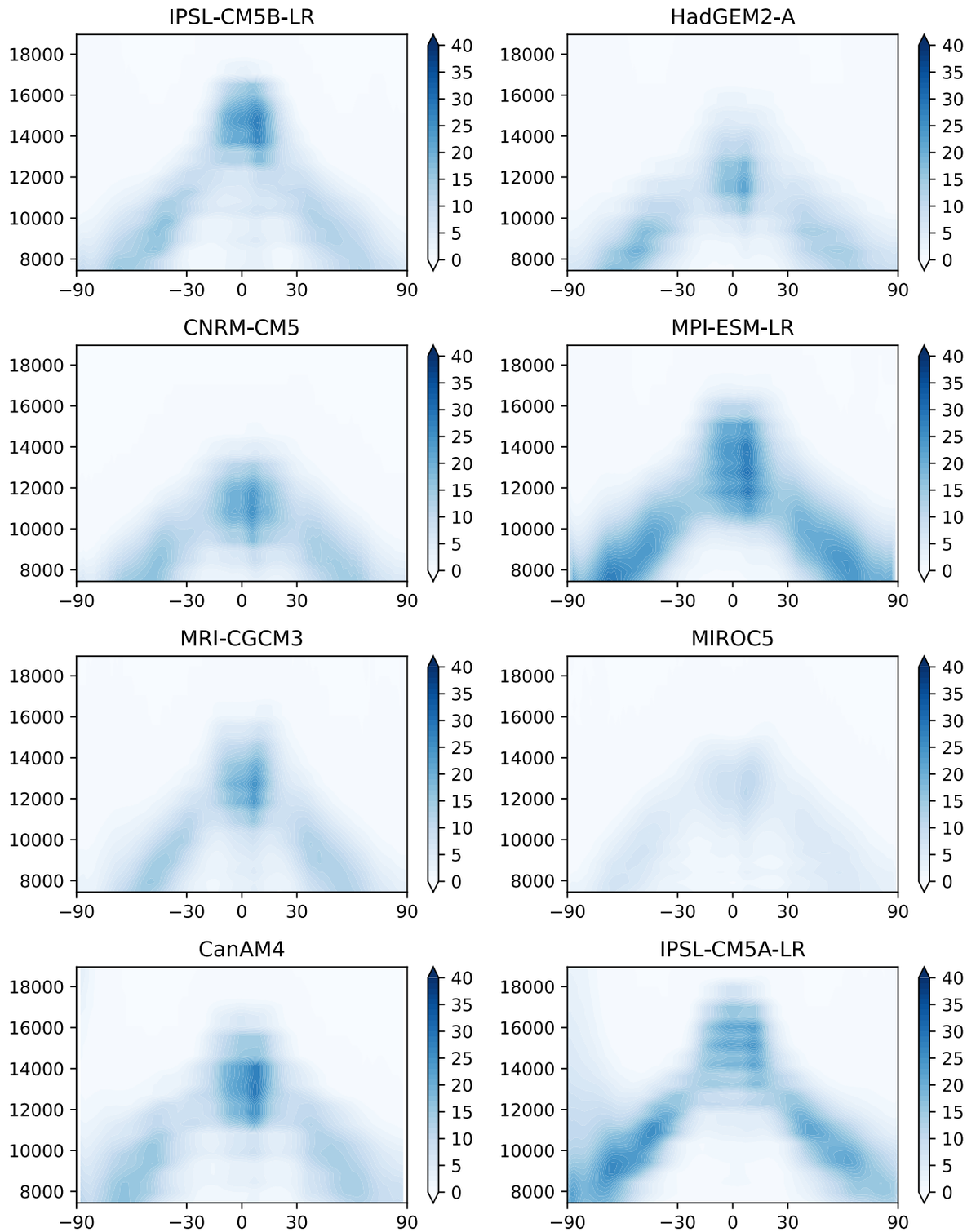


CALIPSO Climatologies

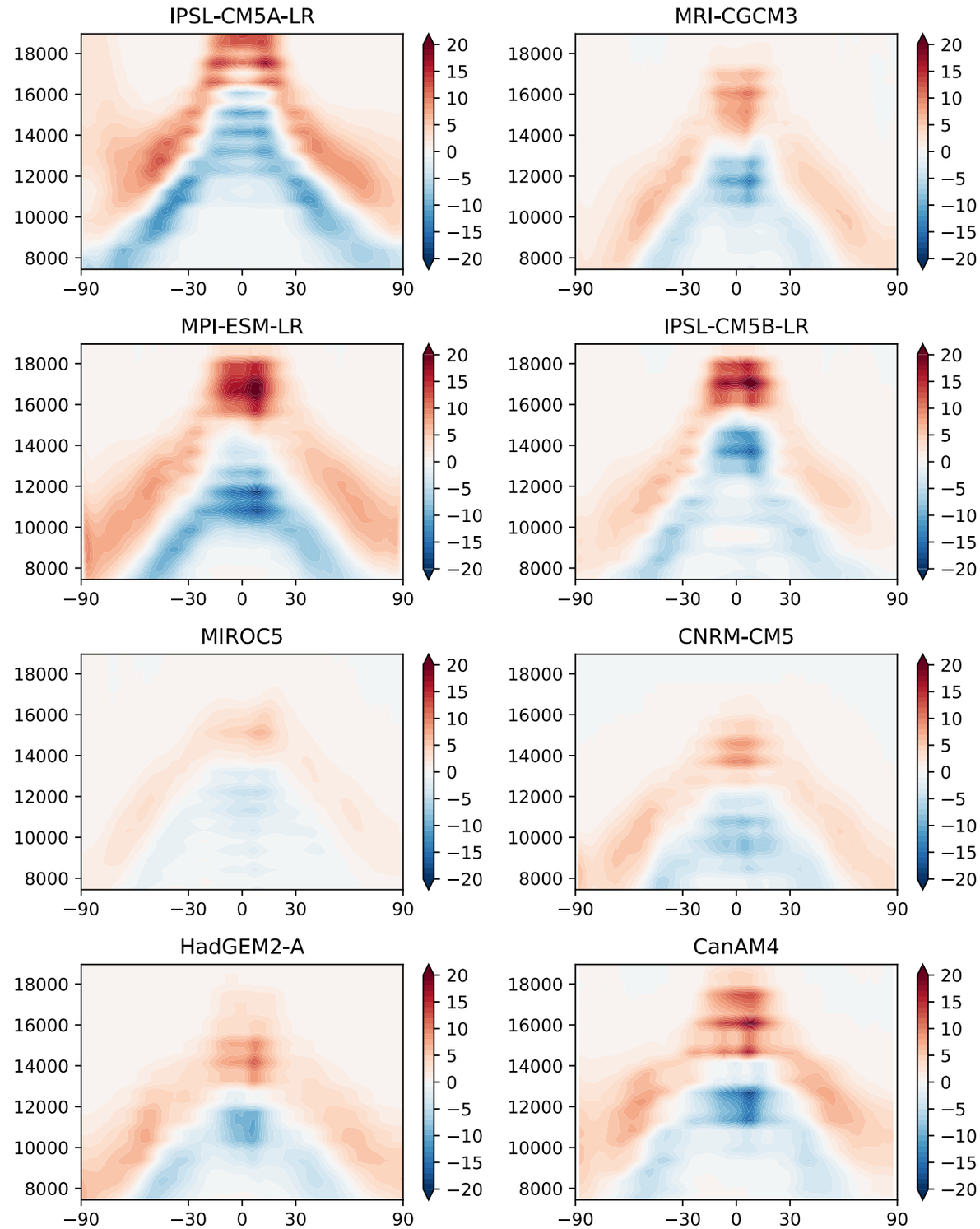
AMIP
AMIP4K
Difference



CALIPSO Climatologies



CALIPSO Change



"… the range of climate sensitivities and transient responses covered by CMIP3/5 cannot be narrowed significantly by constraining the models with observations of the mean climate and variability, consistent with the difficulty of constraining the cloud feedbacks from observations"

ipcc
INTERGOVERNMENTAL PANEL ON climate change

Model sea-ice climatology controls sea ice response
[Po-Chedley et al. (2018); Feldl et al. (2017); Hall et al. (2019)]

Land albedo controls albedo feedback
[Hall and Qu (2006); Qu and Hall (2014); Thackeray et al. (2018)]

And other constraints on circulation changes, cloud changes, hydrologic cycle…
[Volodin (2008); Siler et al. (2018); Hu et al. (2017); others in Hall et al. (2019)]