OPI simulation of orographic precipitation and isotopes for a synthetic Gaussian topography

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Overview

The following document provides a summary of a simulation, using the OPI programs, of orographic precipitation and the associated isotopic composition of the precipitation.
The topography is based on a Gaussian mountain range, with a maximum height of 3 km, a width of 200 km (standard deviation = 33.3 km). The nine OPI parameters for the simulation are:

Wind speed: 10.0 m/s
Azimuth: 90.0 degrees
Sea-level temperature: 290.0 K (16.9 °C)
Mountain-height number: 0.250 (dimensionless)
Horizontal eddy diffusivity: 0 m^2/s
Average residence time for cloud water: 1000 s
δ^2H for base precipitation: 9.6 per mil
δ^2H latitude gradient for base precipitation: 0.000 per mil/deg lat
Residual precipitation after evaporation: 1.00 (fraction)

The mountain-height number is well below one, so the solution is consistent with the linear approximations used to solve the equations of motion. Figure 12 from opiMaps_One Wind (see below) shows the surface velocity ratio, u'/U, has a magnitude that is everywhere well below one, which is a further check that the linear approximations are appropriate for this calculation.

The mountain-height number is directly related to the moist saturated buoyancy frequency, as indicated by $M = N_m H_{max}/U$, where N_m is the moist buoyancy frequency, H_{max} is the maximum elevation in the model domain, and U is mean horizontal wind speed along the mean wind path. N_m is set as a constant for the base-state of the atmosphere, and has a value of 0.833 mrad/s for this simulation.

The simulation is explained below by the log files and figures generated by opiCalc_OneWind, opiPlots_OneWind, and opiMaps_OneWind.

NOTE:

1) The figures that follow are numbered as a sequence for each program.
2) You will find that some figures are missing from these sequences. The reason is that figures that only show observed data would blank for the simulation example shown here, and thus are not included in the document.

opiCalc_OneWind

Program: opiCalc_OneWind
Start time: 08-Sep-2022 00:15:05
Run file path:
/Users/markbrandon/Dropbox (Yale University)/OPI Synthetic Cases/runs/run_030_East-directed Gaussian at lat=45N With M=0.25
Run file name:
run_030_East-directed Gaussian at lat=45N With M=0.25, No evap Updated to v 3.6.run
Run title:
run 030, synthetic topography: East-directed Gaussian at lat=45N, With M=0.25, No evap
Path name for data directory:
~/Dropbox/OPI Synthetic Cases/data

---------- SYNTHETIC SAMPLES ----------
Data shown here is synthetic, and is intended for experimentation.
There are no observed data, so the output has been reduced accordingly.

---------- Topography File ----------
Topography file: EastDirectedGaussianTopography_3km height_lat45N.mat
Maximum elevation: 3001 m
Grid size, nx and ny: 701, 701
Minimum and maximum for longitude: -4.45141, 4.45141 degrees
Minimum and maximum for latitude: 41.85237, 48.14763 degrees
Grid spacing, dLon and dLat: 0.01272, 0.00899 degrees
Grid spacing, dx and dy: 1.00, 1.00 km
Lon, lat for map origin: -0.00000, 45.00000 degrees
Size of cosine window as fraction of grid size: 0.25 (dimensionless)
Coriolis frequency at map-origin latitude: 0.10313 mrad/s
Lon, lat for section origin: -0.00000, 45.00000 degrees

---------- Sample File ----------
Sample file: No samples

---------- Constants ----------
Characteristic distance for isotopic exchange: 540 m
Standard-deviation ratio for data residuals: 28.30 (dimensionless)

--------- Constraints for Best-Fit Solution ---------
Wind speed: 0.1, 25 m/s
Wind azimuth: 35, 145 degrees
Sea-level temperature: 265, 295 K (-8.1, 21.9 °C)
Mountain-height number: 0, 1.2 (dimensionless)
Horizontal eddy diffusivity: 0, 1e+06 m^2/s
Average condensation time: 0, 2500 s
d2H for base precipitation: -15, 15 per mil
d2H latitude gradient for base precipitation: 0, 0 per mil/deg lat
Residual precipitation after evaporation: 1, 1 (dimensionless)

---------- Evaporation Option ----------
No Evaporative recycling for precipitation state.

---------- Solution ----------
Wind speed: 10.0 m/s
Azimuth: 90.0 degrees
Sea-level temperature: 290.0 K (16.9 °C)
Mountain-height number: 0.250 (dimensionless)

Horizontal eddy diffusivity: 0 m^2/s
Average residence time for cloud water: 1000 s
d2H for base precipitation: 9.6 per mil
d2H latitude gradient for base precipitation: 0.000 per mil/deg lat
Residual precipitation after evaporation: 1.00 (fraction)

---- Other Variables Related to Best-Fit Solution ---
Moist buoyancy frequency: 0.833 mrad/s
d18O for base precipitation: 0.0 per mil
d18O latitude gradient for base precipitation: 0.000 per mil/deg lat
Average residence time for falling precipitation: 1381 s
Water-vapor density at sea level: 14.52 g/m^3
Scale height for water vapor: 2923 m
Average velocity for falling precipitation: 2.1 m/s
Total density at sea level: 1.22 g/m^3
Scale height for total density: 9708 m
Average lapse-rate ratio, gammaSat/gammaEnv: 0.92 (dimensionless)

------------ Observed Meteoric Water Line -----------
No samples.

----------- Predicted Meteoric Water Line -----------
Principal standard deviations: 0.06, 16.82 per mil
Intercept and slope: 9.6 per mil, 8.19

----------------- Computation Time ------------------
Compute time: 0.07 minutes

---------------------- Mat File ----------------------
Results saved in the run directory as mat file:
/Users/markbrandon/Dropbox (Yale University)/OPI Synthetic
Cases/runs/run_030_East-directed Gaussian at lat=45N With
M=0.25/opiCalc_OneWind_Results.mat

opiPlots_OneWind

Program: opiPlots_OneWind
Start time: 08-Sep-2022 00:16:13
Run file path:
/Users/markbrandon/Dropbox (Yale University)/OPI Synthetic Cases/runs/run_030_East-directed Gaussian at lat=45N With M=0.25
Run file name:
run_030_East-directed Gaussian at lat=45N With M=0.25, No evap Updated to v 3.6.run
Run title:
run 030, synthetic topography: East-directed Gaussian at lat=45N, With M=0.25, No evap
Path name for data directory:
~/Dropbox/OPI Synthetic Cases/data

---------- SYNTHETIC SAMPLES ----------
Data shown here is synthetic, and is intended for experimentation.
There are no observed data, so the output has a reduced set of
figures: 2, and 5 to 7.

---------- Topography File ----------
Topography file: EastDirectedGaussianTopography_3km height_lat45N.mat
Maximum elevation: 3001 m
Grid size, nx and ny: 701, 701
Minimum and maximum for longitude: -4.45141, 4.45141 degrees
Minimum and maximum for latitude: 41.85237, 48.14763 degrees
Grid spacing, dLon and dLat: 0.01272, 0.00899 degrees
Grid spacing, dx and dy: 1.00, 1.00 km
Lon, lat for map origin: -0.00000, 45.00000 degrees
Map origin is set center of the topographic grid.
Size of cosine window as fraction of grid size: 0.25 (dimensionless)
Coriolis frequency at map-origin latitude: 0.10313 mrad/s
Lon, lat for section origin: -0.00000, 45.00000 degrees

---------- Sample File ----------
Sample file: No samples

---------- Constants ----------
Characteristic distance for isotopic exchange: 540 m
Standard-deviation ratio for data residuals: 28.30 (dimensionless)

---------- Evaporation Option ----------
No Evaporative recycling active for precipitation state.

---------- Solution ----------
Wind speed: 10.0 m/s
Azimuth: 90.0 degrees
Sea-level surface-air temperature: 290.0 K (16.9 °C)
Mountain-height number: 0.250 (dimensionless)
Horizontal eddy diffusivity: 0 m^2/s
Average residence time for cloud water: 1000 s
d2H for base precipitation: 9.6 per mil
d2H latitude gradient for base precipitation: 0.000 per mil/deg lat
Residual precipitation after evaporation: 1.00 (dimensionless)

---- Other Variables Related to Best-Fit Solution ---
Moist buoyancy frequency: 0.833 mrad/s
d18O for base precipitation: 0.0 per mil

d18O latitude gradient for base precipitation: 0.000 per mil/deg lat
Average residence time for falling precipitation: 1381 s
Water-vapor density at sea level: 14.52 g/m^3
Scale height for water vapor: 2923 m
Average velocity for falling precipitation: 2.1 m/s
Total density at sea level: 1.22 g/m^3
Scale height for total density: 9708 m
Average lapse-rate ratio, gammaSat/gammaEnv: 0.92 (dimensionless)

---------- Observed Meteoric Water Line ----------
No samples.

---------- Predicted Meteoric Water Line ----------
Principal standard deviations: 0.06, 16.82 per mil
Intercept and slope: 9.6 per mil, 8.19

---------- Estimates for Lifting Lines----------
The precipitation isotopes are represented using their predicted
values from the best-fit OPI solution, either as point estimates if
the sample location is designated as "local" (type L), or as the
precipitated-weighted value for the upstream catchment if the sample is
designated as "catchment" (type C).
The lifting is represented either by local elevation or by the maximum
lifting along the upwind path. The elevation and maximum lifting are
calculated as either "local" or "catchment" values depending on the
designation of the sample (type L or C).
The isotopes are not adjusted for latitudinal gradients
(dD2H0_dLat, dD18O0_dLat), but this source of error is small
and symmetric. The slope of the lines are estimated by least squares
and the intercept is held fixed so that it matches the estimated
base isotope values (d2H0, d18O).

Predicted Isotopes vs Maximum Lifting
Intercept and slope for d2H: 9.6 per mil, -24.8 per mil/km
Intercept and slope for d18O: 0.0 per mil, -2.8 per mil/km
[9.6   -24.7812   0.0161893   -2.80612]

Predicted Isotopes vs Elevation
Intercept and slope for d2H: 9.6 per mil, -14.6 per mil/km
Intercept and slope for d18O: 0.0 per mil, -1.8 per mil/km

---------- Computation Time ----------
Compute time: 0.12 minutes

Fig. 2. Craig plot of primary samples

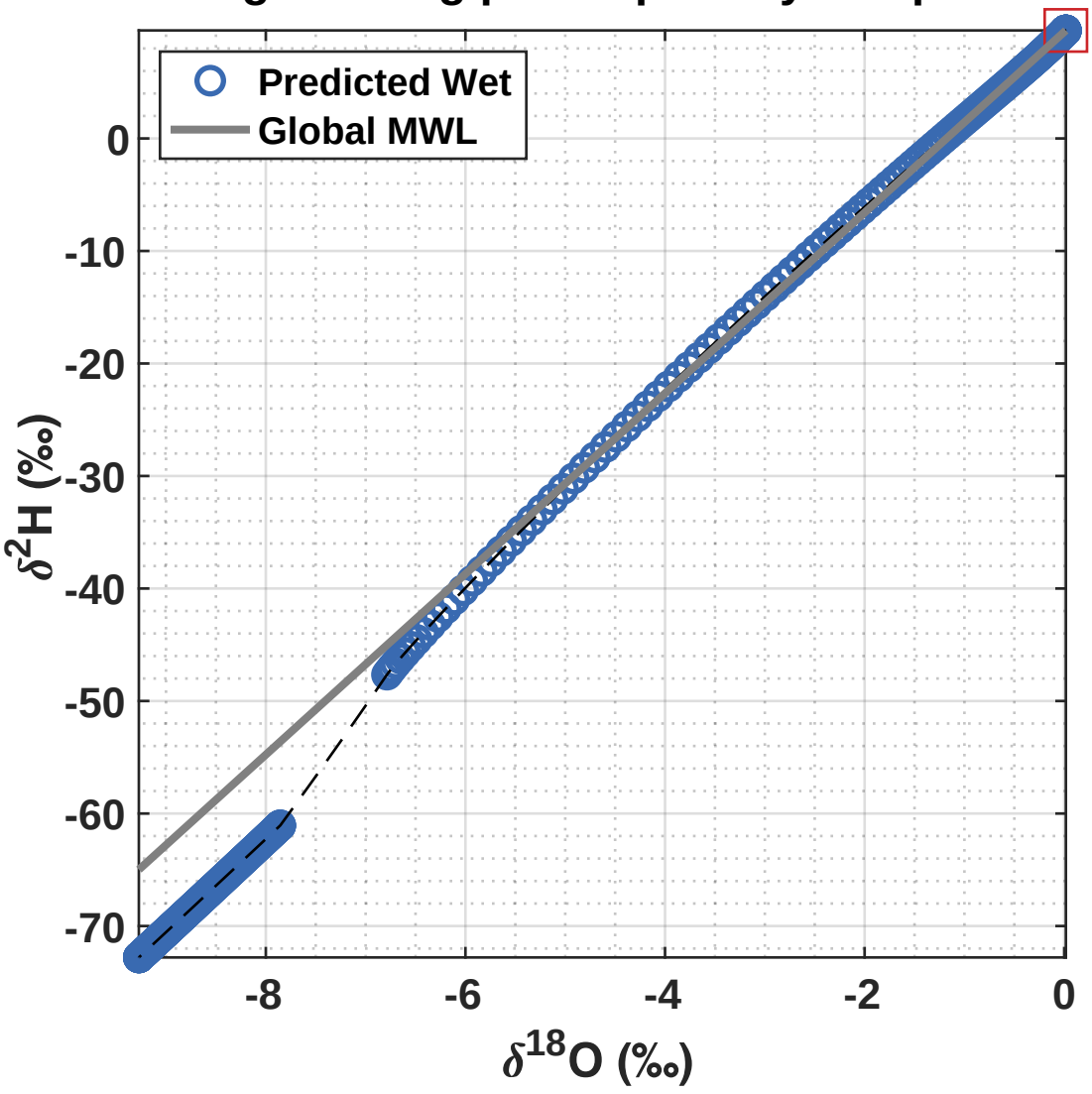


Fig. 5. Predicted isotopes versus maximum lifting

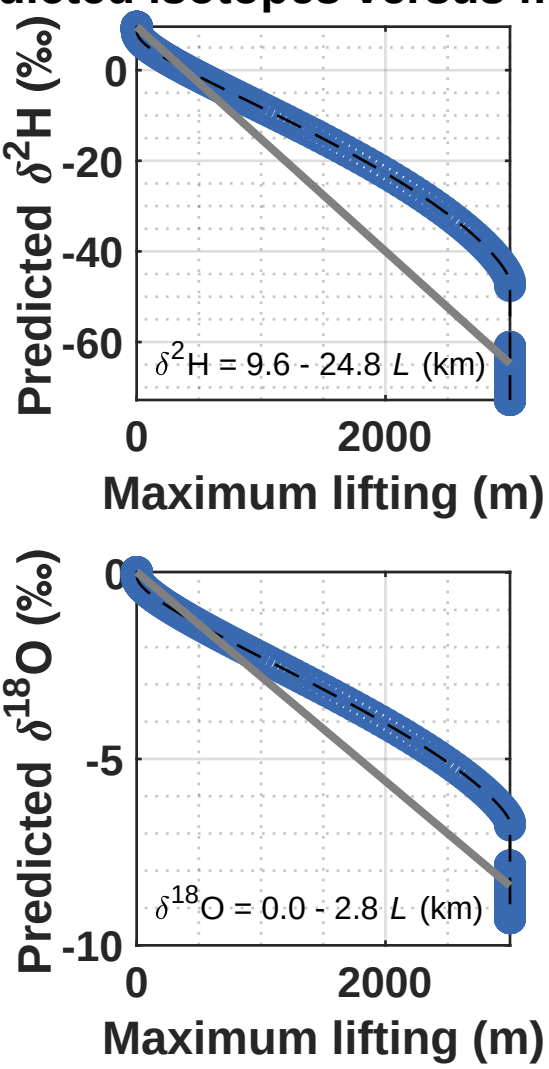


Fig. 6. Predicted isotopes versus elevation

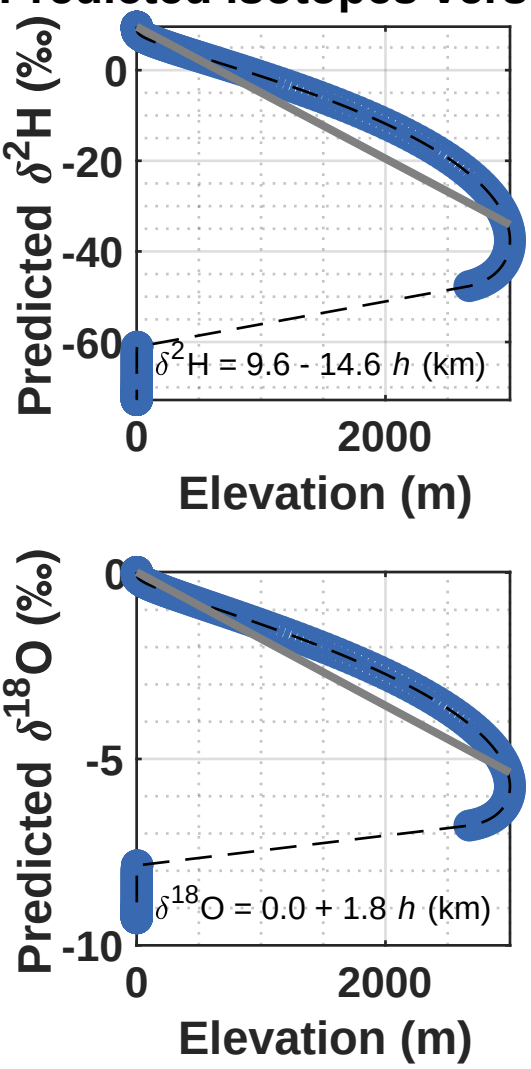
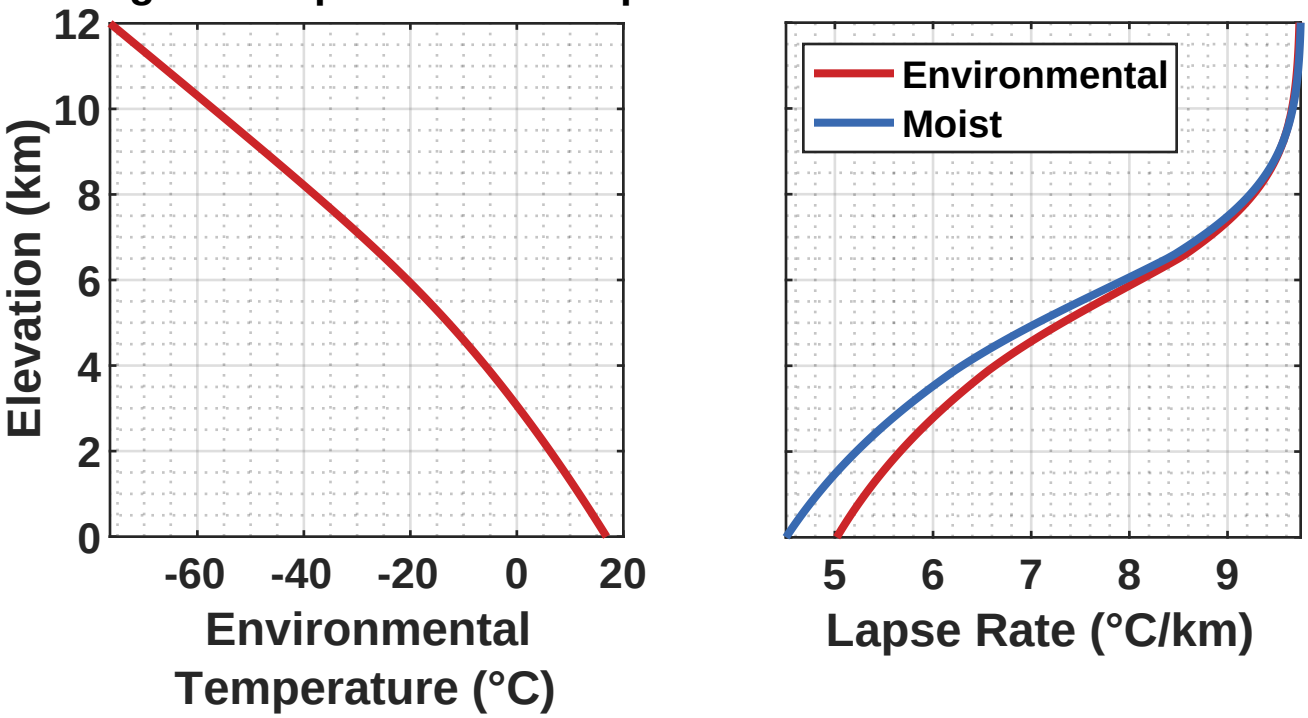


Fig. 7. Temperature and lapse rates versus elevation



opiMaps_OneWind

Program: opiMaps_OneWind
Start time: 08-Sep-2022 00:16:27
Run file path:
/Users/markbrandon/Dropbox (Yale University)/OPI Synthetic Cases/runs/run_030_East-directed Gaussian at lat=45N With M=0.25
Run file name:
run_030_East-directed Gaussian at lat=45N With M=0.25, No evap Updated to v 3.6.run
Run title:
run 030, synthetic topography: East-directed Gaussian at lat=45N, With M=0.25, No evap
Path name for data directory:
~/Dropbox/OPI Synthetic Cases/data

---------- SYNTHETIC SAMPLES ----------
Data shown here is synthetic, and is intended for experimentation.
There are no observed data, so the output has a reduced set of
figures: 1, 4, 5, and 7 to 12.

---------- Topography File ----------
Topography file: EastDirectedGaussianTopography_3km height_lat45N.mat
Maximum elevation: 3001 m
Grid size, nx and ny: 701, 701
Longitude, minimum and maximum: -4.45141, 4.45141 degrees
Latitude, minimum and maximum: 41.85237, 48.14763 degrees
Grid spacing, dLon and dLat: 0.01272, 0.00899 degrees
Grid spacing, dx and dy: 1.00, 1.00 km
User-defined map limits, longitude: -4.45141, 4.45141 degrees
User-defined map limits, latitude: 41.85237, 48.14763 degrees
Continental-divide file: none
Lon, lat for map origin: -0.00000, 45.00000 degrees
Map origin is set to center of the topographic grid.
Size of cosine window as fraction of grid size: 0.25
Coriolis frequency at map-origin latitude: 0.10313 mrad/s
Lon, lat for section origin: -0.00000, 45.00000 degrees

---------- Sample File ----------
Sample file: No samples

---------- Constants ----------
Characteristic distance for isotopic exchange: 540 m
Standard-deviation ratio for data residuals: 28.30 (dimensionless)

---------- Evaporation Option ----------
No Evaporative recycling active for precipitation state.

---------- Solution ----------
Wind speed: 10.0 m/s
Azimuth: 90.0 degrees
Sea-level surface-air temperature: 290.0 K (16.9 °C)
Mountain-height number: 0.250 (dimensionless)
Horizontal eddy diffusivity: 0 m^2/s
Average residence time for cloud water: 1000 s
d2H for base precipitation: 9.6 per mil
d2H latitude gradient for base precipitation: 0.000 per mil/deg lat
Residual precipitation after evaporation: 1.00 (dimensionless)

---- Other Variables Related to Best-Fit Solution ---
Moist buoyancy frequency: 0.833 mrad/s
d18O for base precipitation: 0.0 per mil
d18O latitude gradient for base precipitation: 0.000 per mil/deg lat
Average residence time for falling precipitation: 1381 s
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Scale height for water vapor: 2923 m
Average velocity for falling precipitation: 2.1 m/s
Total density at sea level: 1.22 g/m^3
Scale height for total density: 9708 m
Average lapse-rate ratio, gammaSat/gammaEnv: 0.92 (dimensionless)

------------ Streamlines, and Cloud Water ------------
Vertical exaggeration for streamline figure: 20000 (dimensionless)
Starting elevation for streamlines: 2000 m
Mean height of cloud water relative to land surface: 2845 m

Compute time: 0.39 minutes

Fig. 1. Topography and sample locations

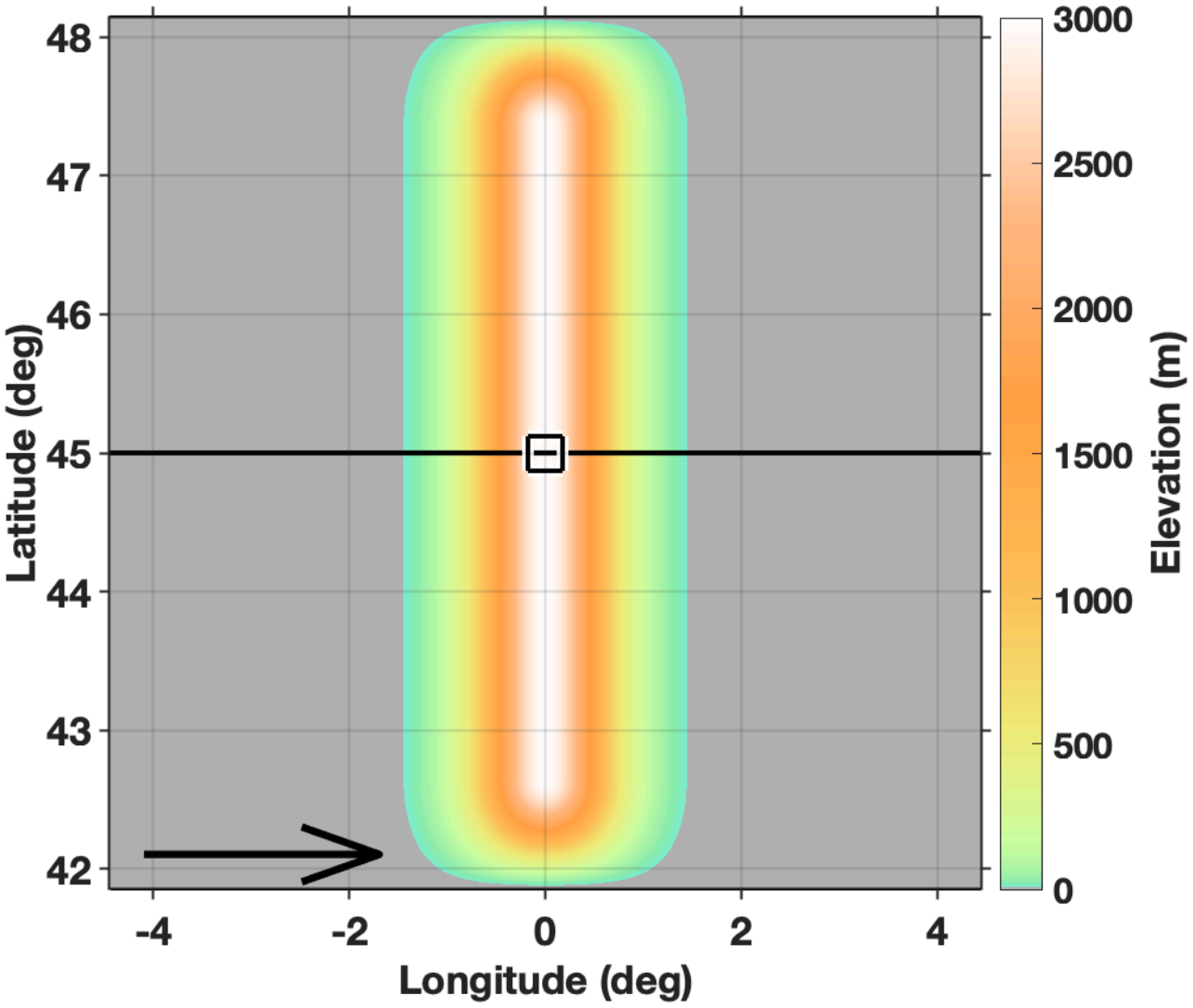

Fig. 4. Precipitation rate

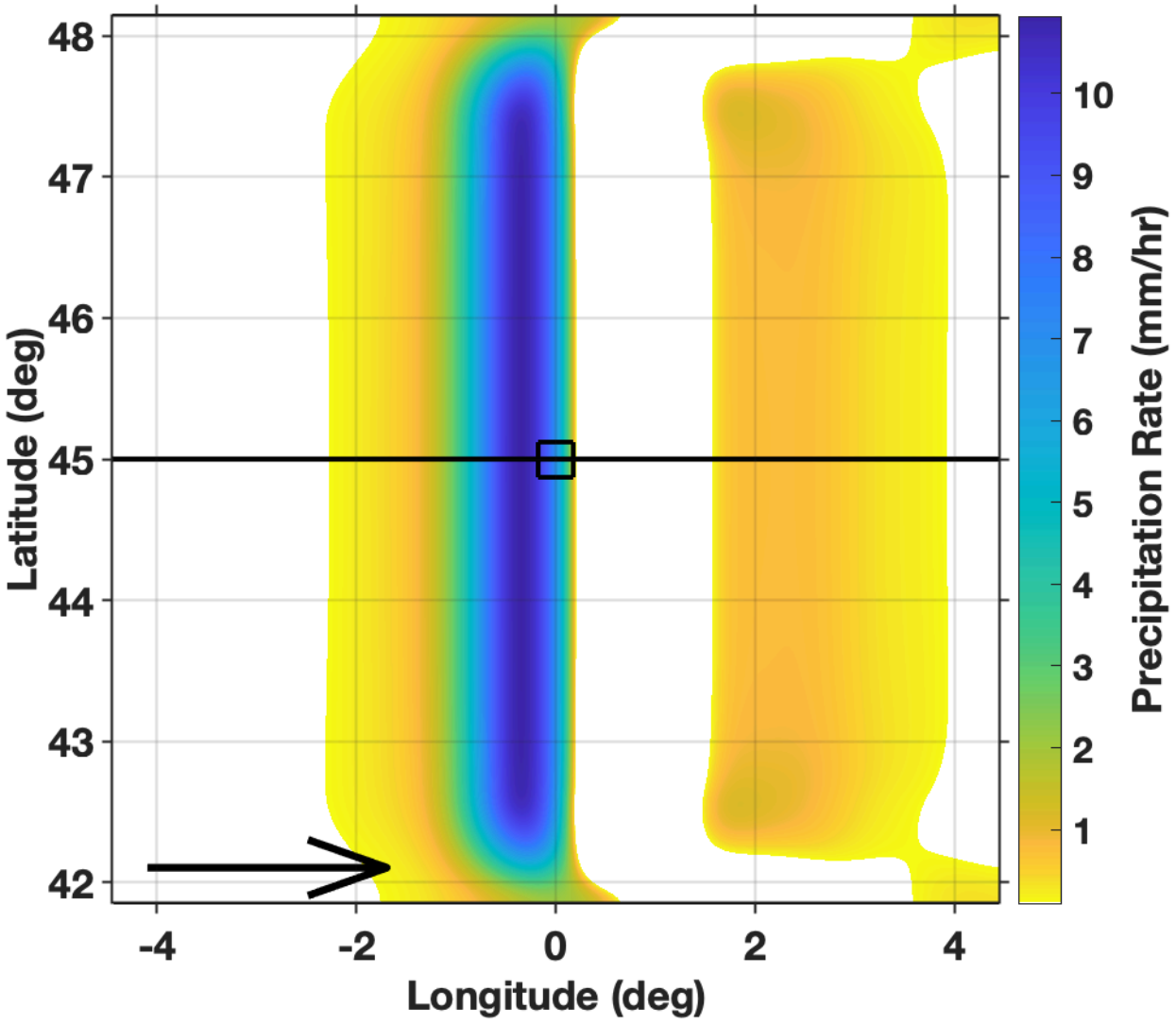

Fig. 5. Moisture ratio

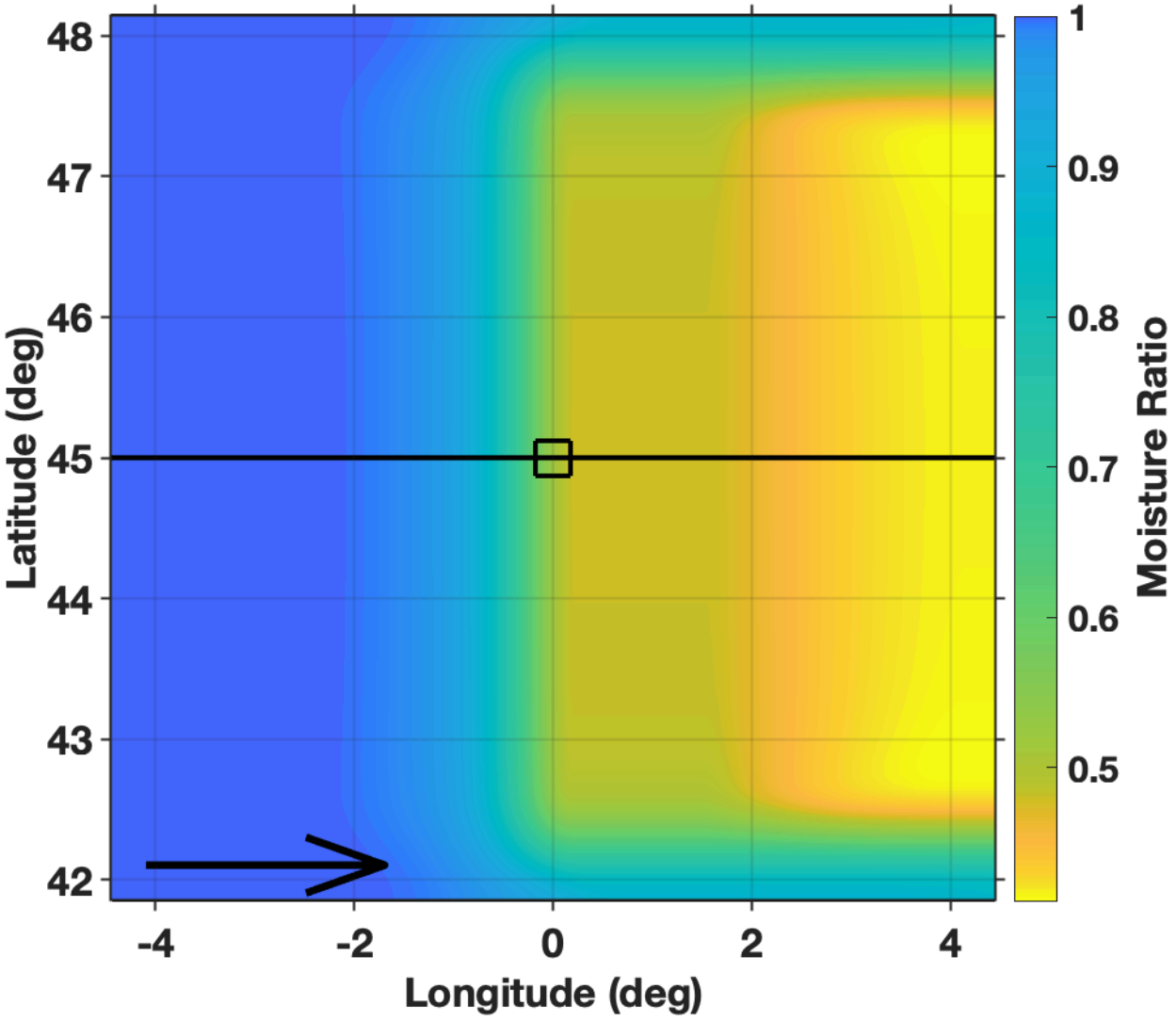

Fig. 7. Streamlines starting at 2000 m elevation

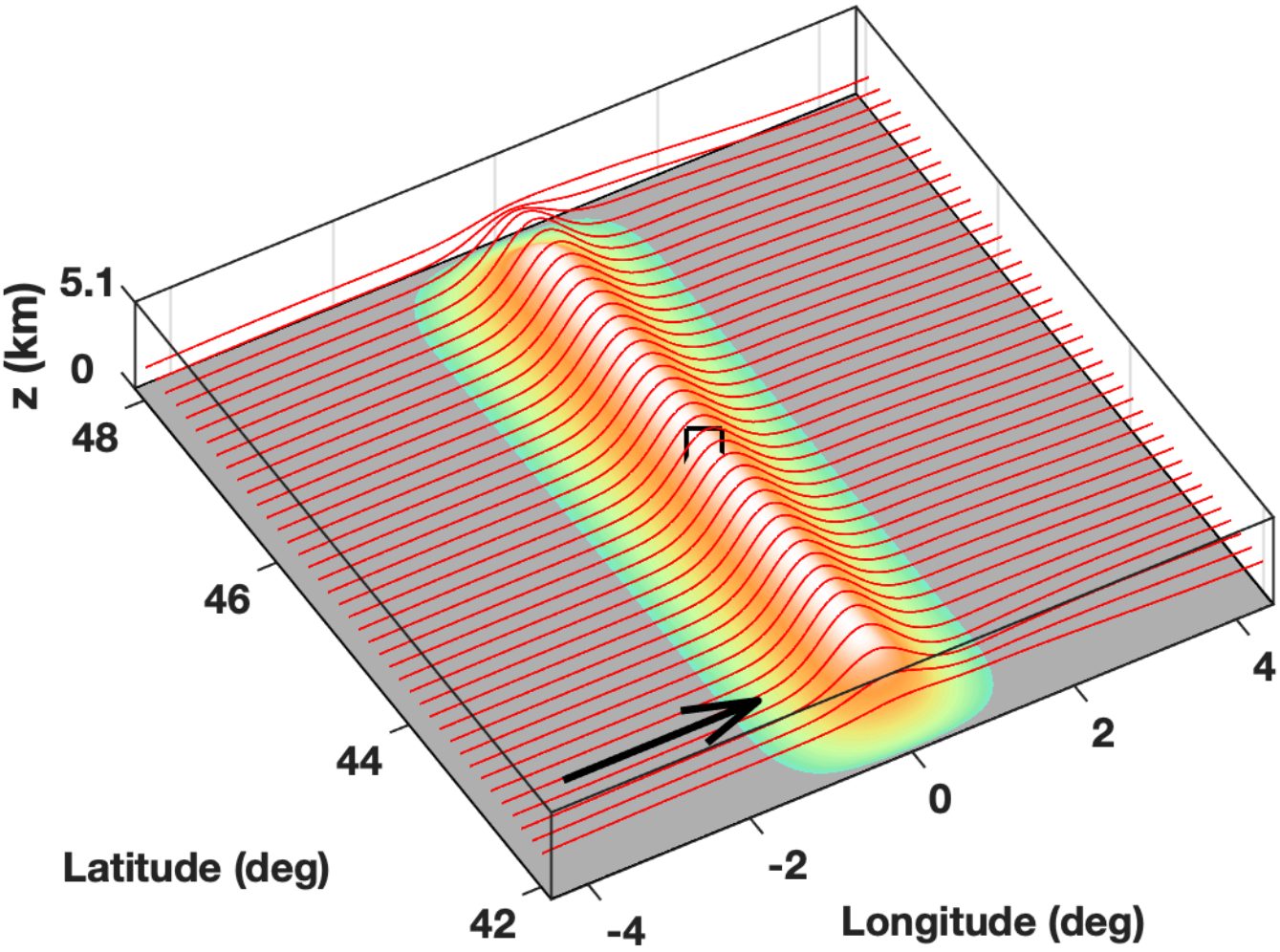

Fig. 8. Cross section

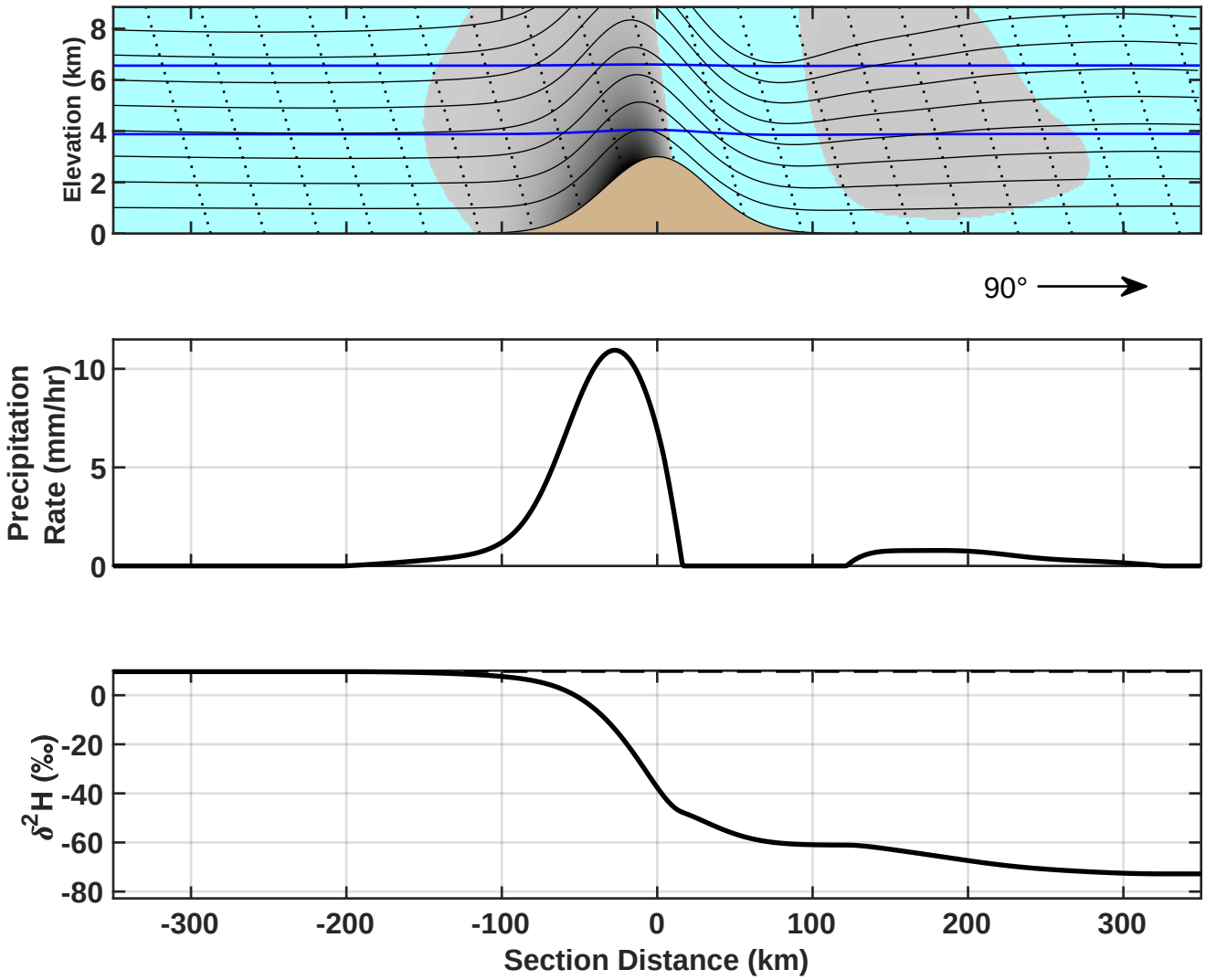

Fig. 9. Predicted precipitation δ^2H

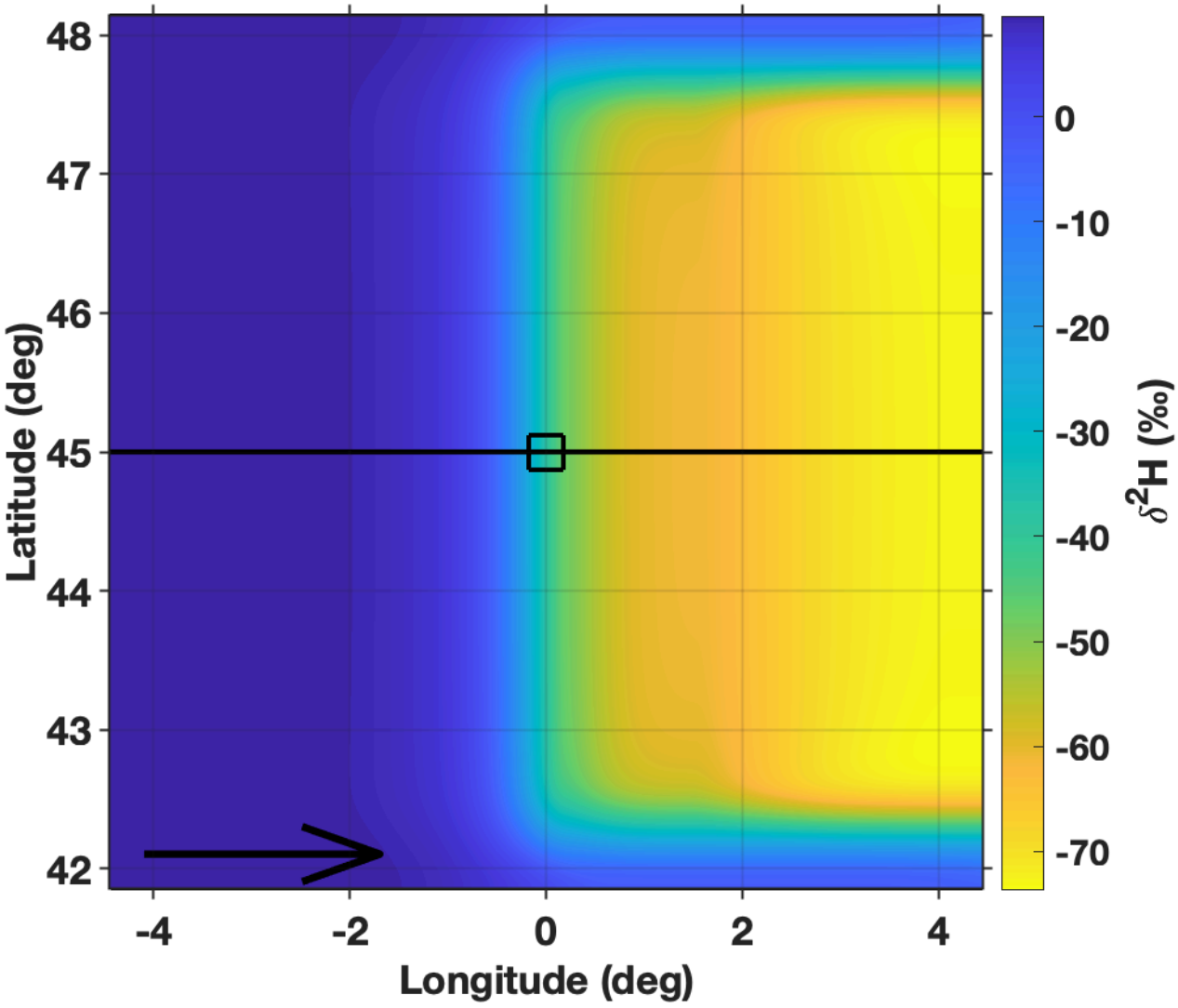

Fig. 10. Predicted precipitation $\delta^{18}O$

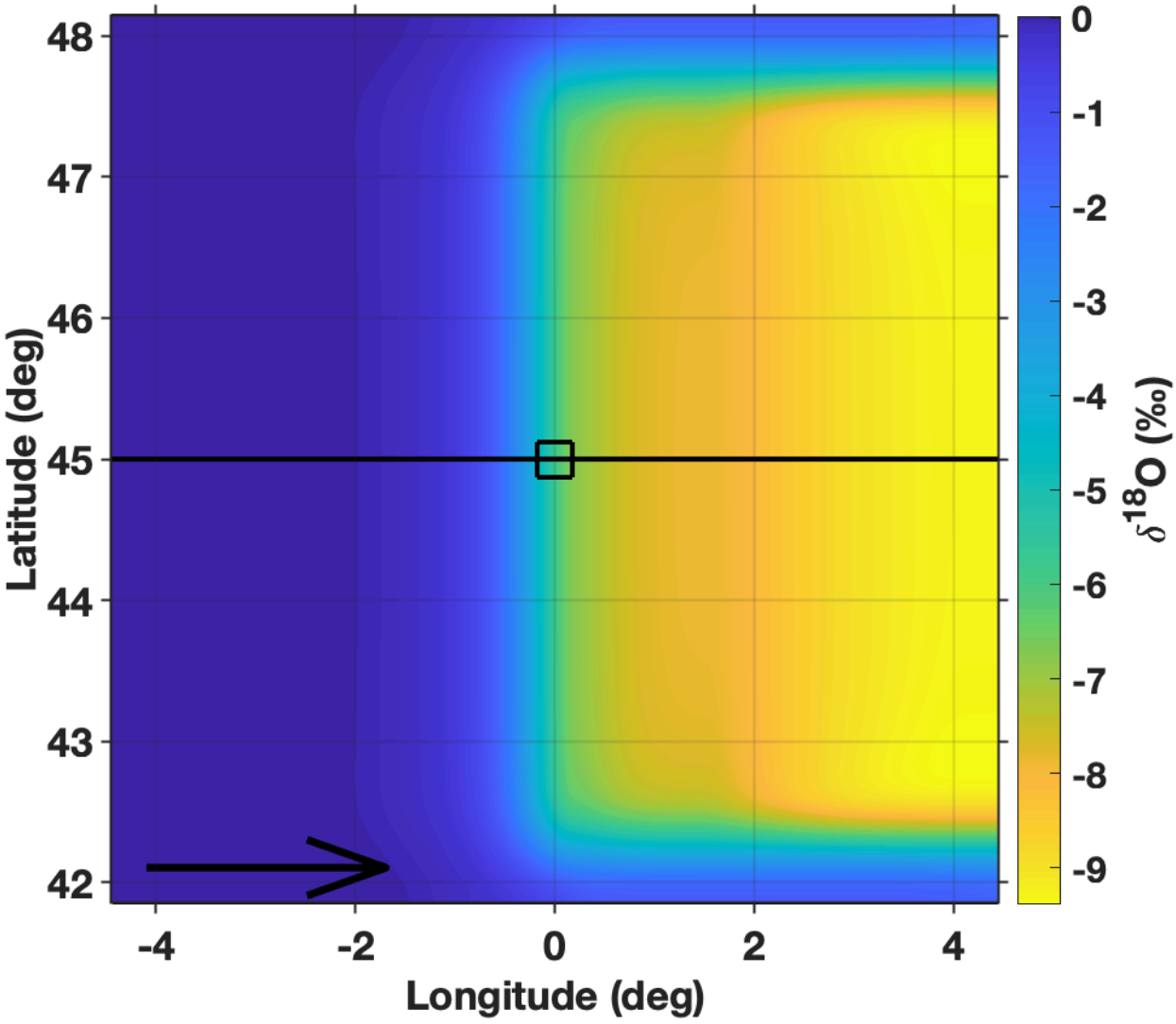

Fig. 11. Surface-air temperature

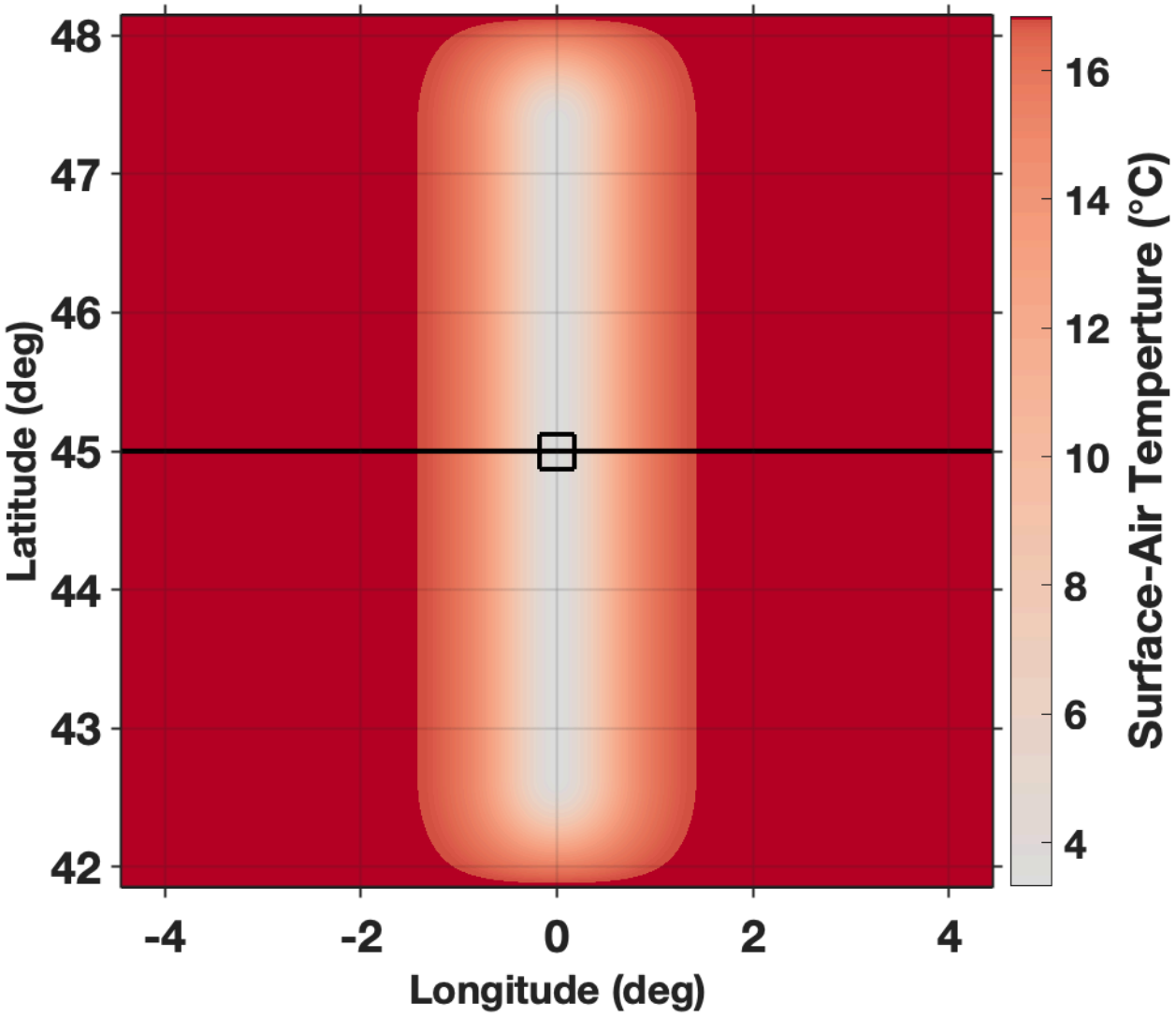

Fig. 12. Surface velocity ratio, u'/U