Characterizing tropical radiative heating profiles using the ARM BBHRP paradigm

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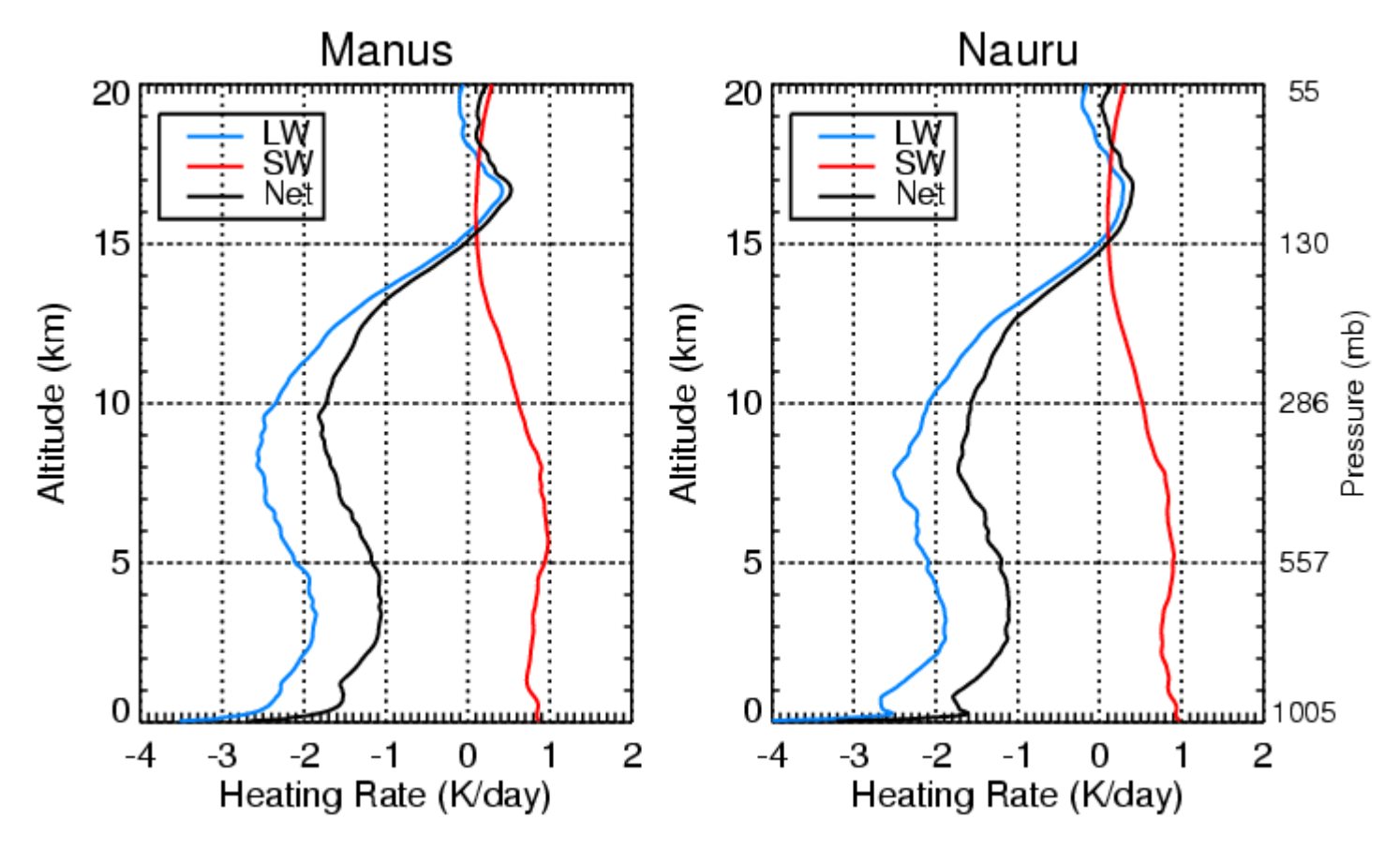
Radiative heating rate profiles have historically been derived from:

- Residuals in diabatic heating rate analysis
- Satellite measurements
- Model calculations or reanalysis
- Direct measurements from aircraft/radiometer-sondes
- Calculations from remote sensing observations

Differences from BBHRP approach:

- Use “merged-sounding” to do continuous heating rate profiles
- Slight modifications to microbase retrievals
  - Remove precipitating columns
  - Scale LWP to MWR if retrieved value is higher than MWR
  - Slightly modified mixed-phase treatment
  - Currently ignore aerosol properties at TWP
- Broadband flux/heating rate calculations:
  - sample cloud properties every 5 minutes
  - radiative transfer model (updated version of Fu and Liou)
  - Calculate all-sky and clear-sky profiles
- Results:
  - 6 months at Manus (2000)
  - 9 months at Nauru (1999) – suppressed period
  - All non-precipitating cloud-types

Average clear sky heating rates at Nauru and Manus show similar structure; primarily due to water vapor



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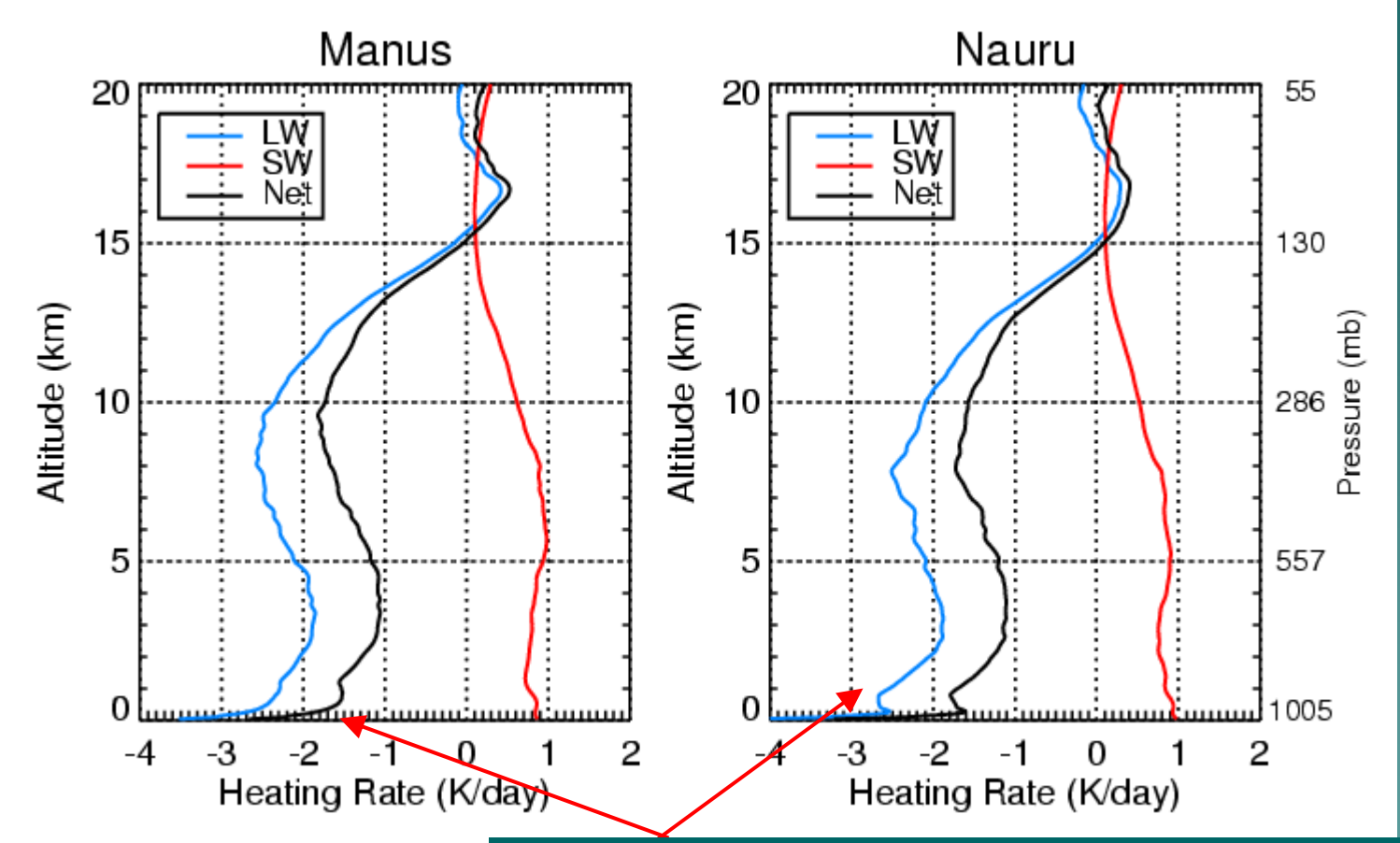
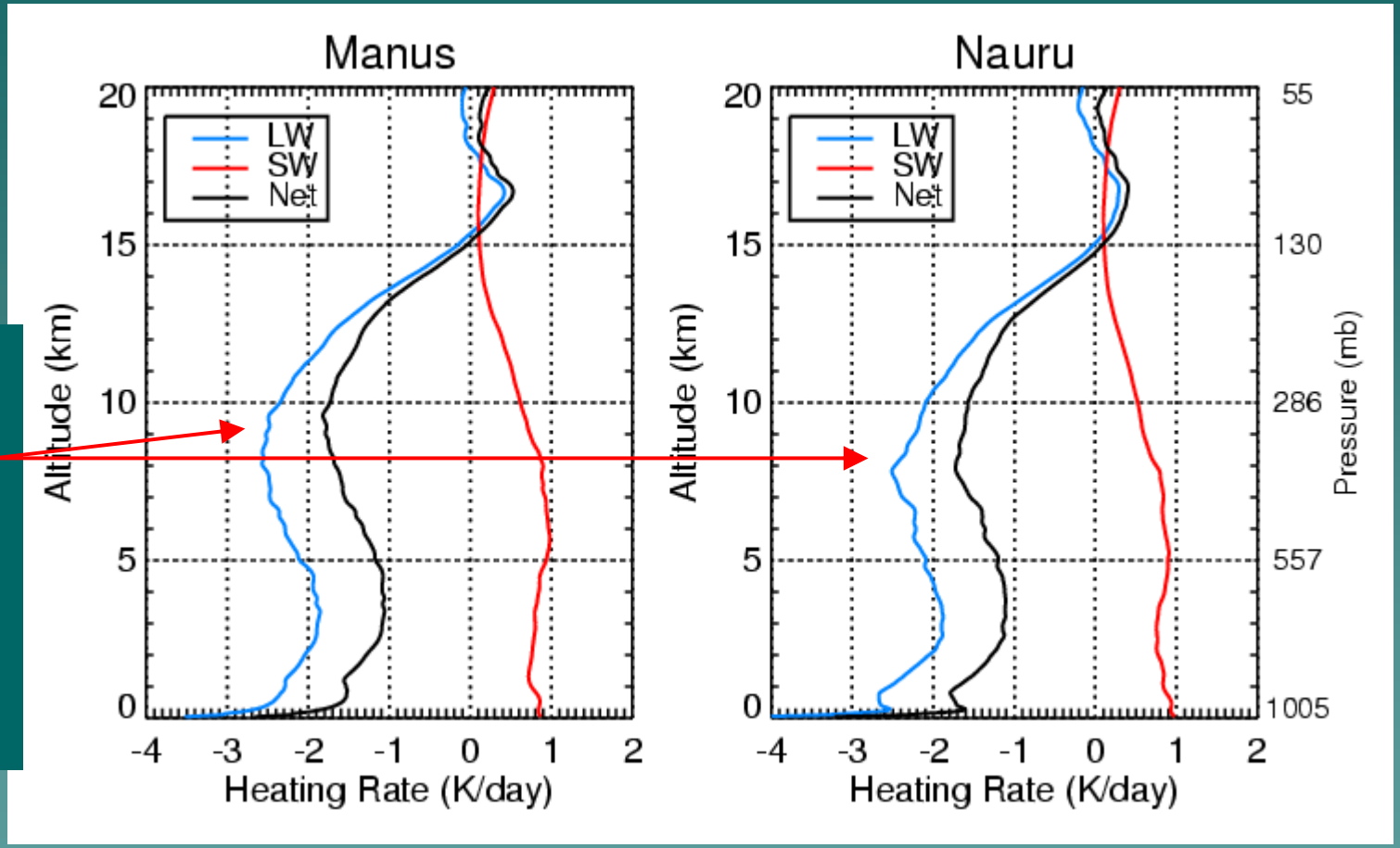


Strong LW cooling at surface; secondary maximum in boundary layer

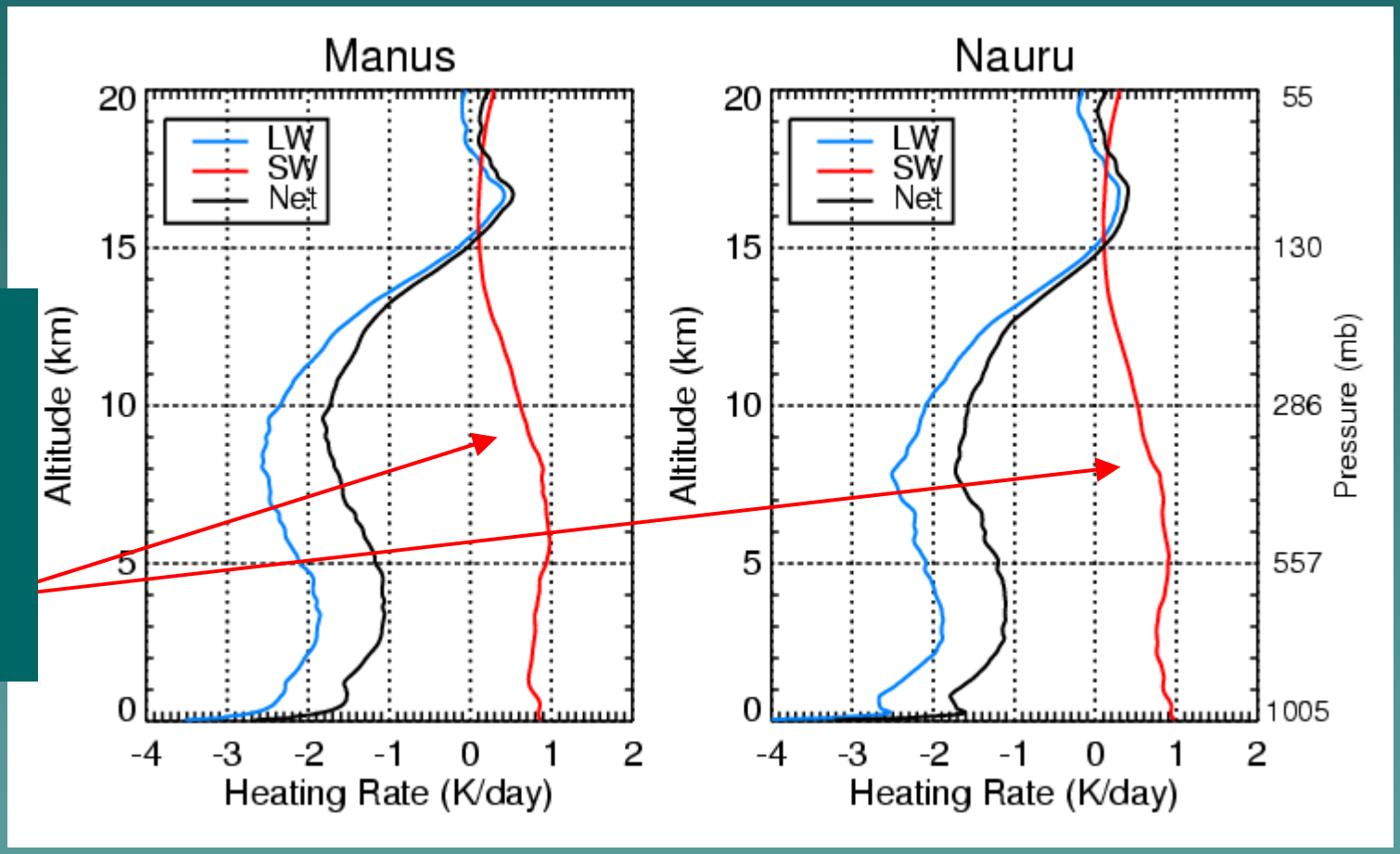
Average clear sky heating rates at Nauru and Manus show similar structure; primarily due to water vapor

Peak LW cooling occurs in mid-troposphere; falls off rapidly with height



Average clear sky heating rates at Nauru and Manus show similar structure; primarily due to water vapor

SW heating throughout troposphere; also decreases with height above 8 km



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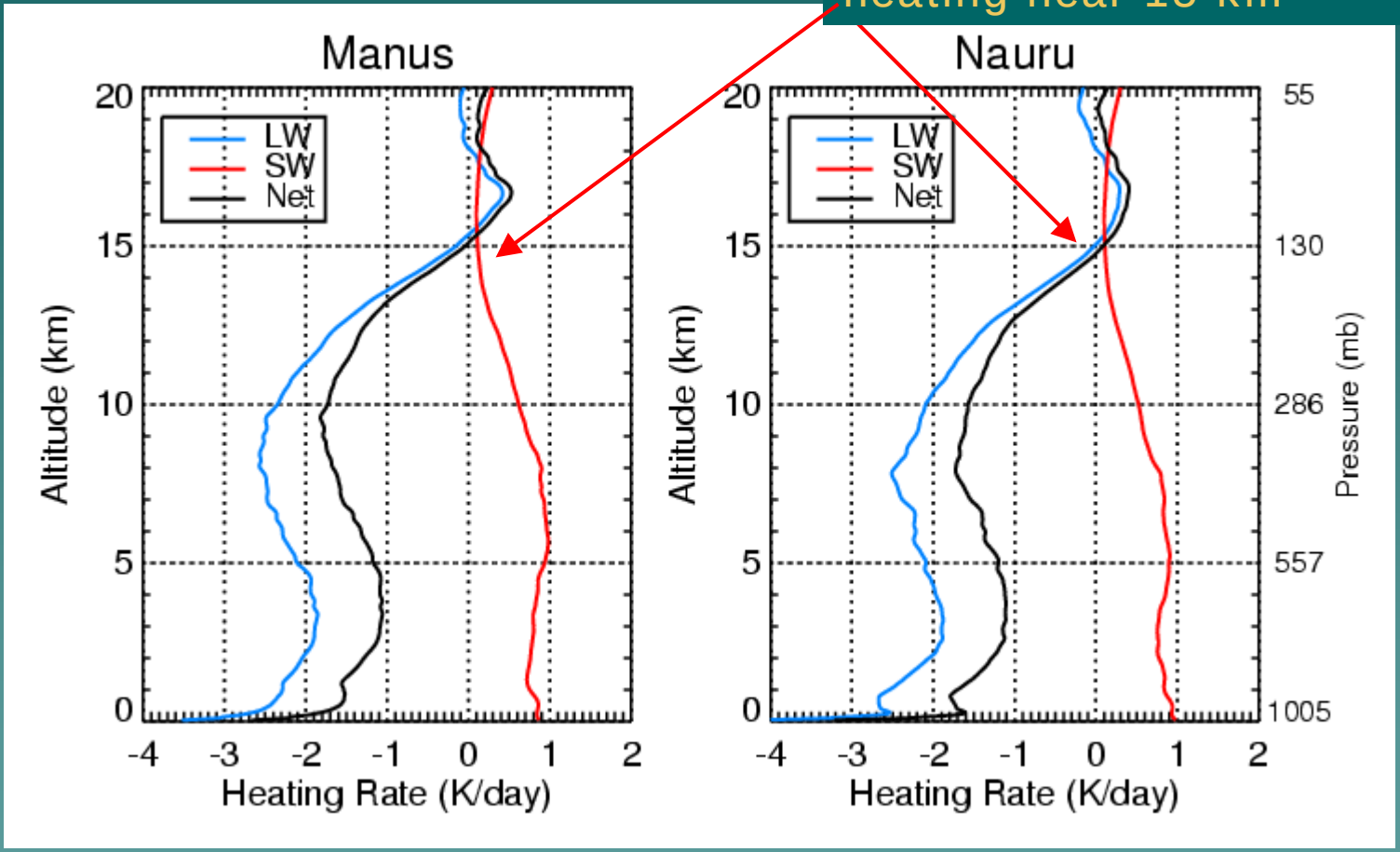
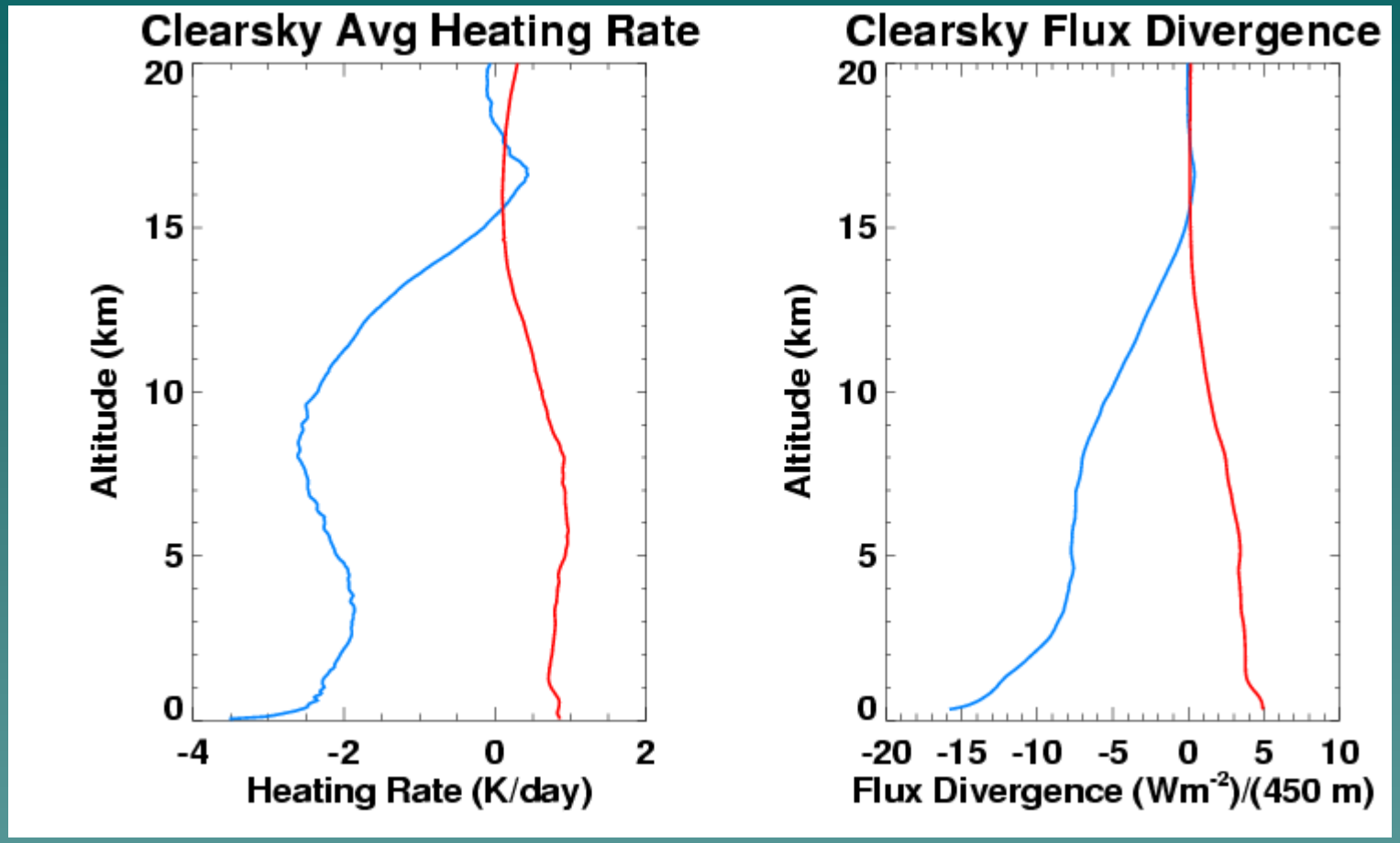
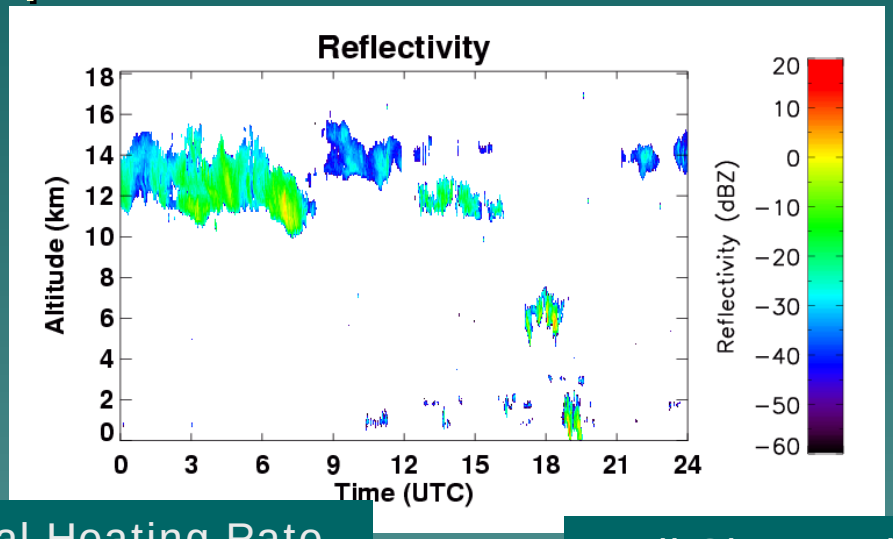
Transition to zero net heating near 15 km



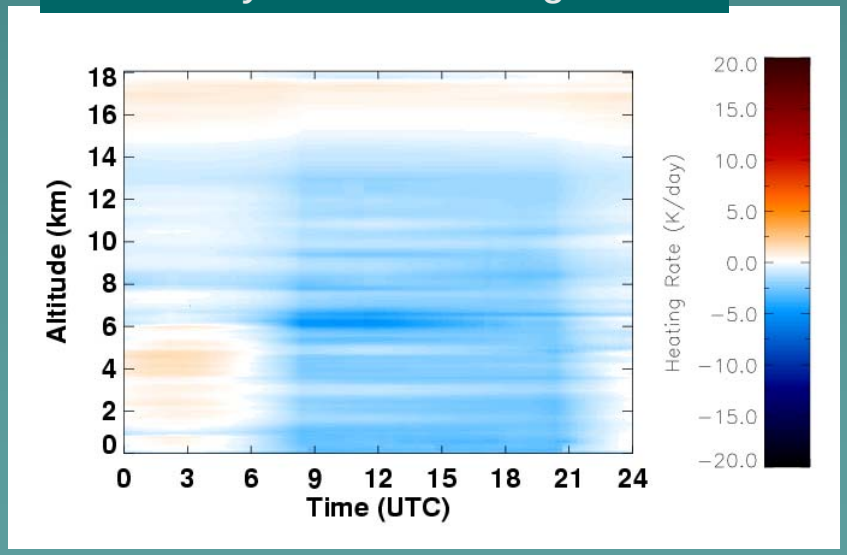

Clearsky Avg Heating Rate
Altitude (km)
20
15
10
5
0
-4
-2
0
2
Heating Rate (K/day)
Clearsky Flux Divergence
Altitude (km)
20
15
10
5
0
-20
-15
-10
-5
0
5
10
Flux Divergence (Wm-2)/(450 m)

Effect of Clouds on Heating Rates

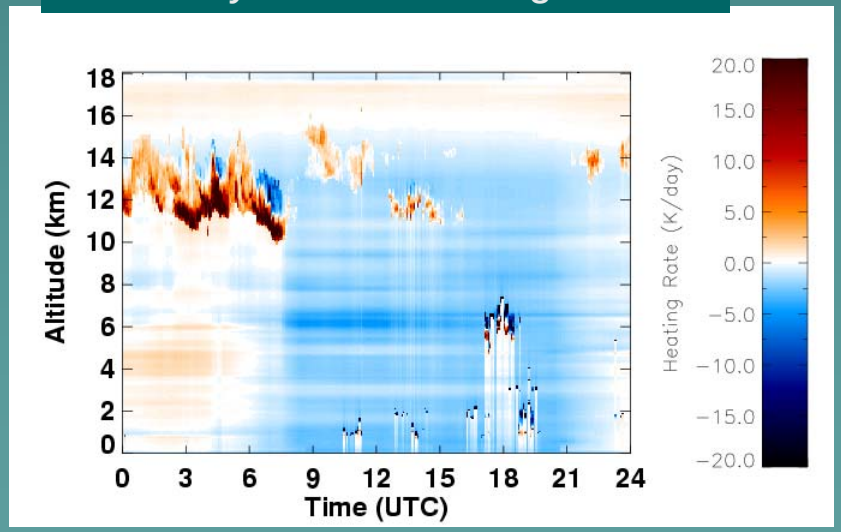
Example Case: 3/2/2000 at Manus



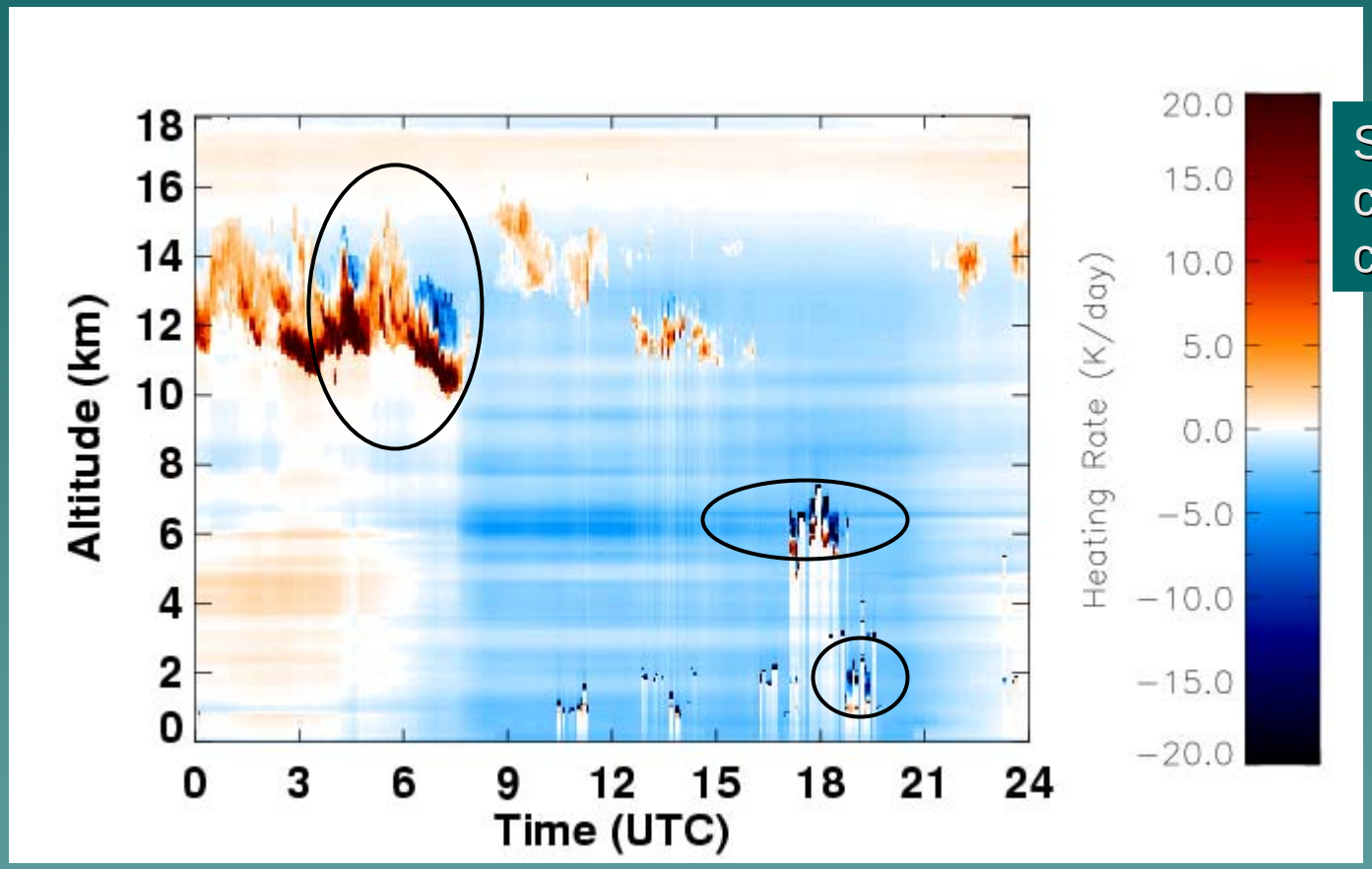
Clear Sky Total Heating Rate



All Sky Total Heating Rate



Features of instantaneous heating rate profiles:



Strong heating at cloud base and cooling at cloud top

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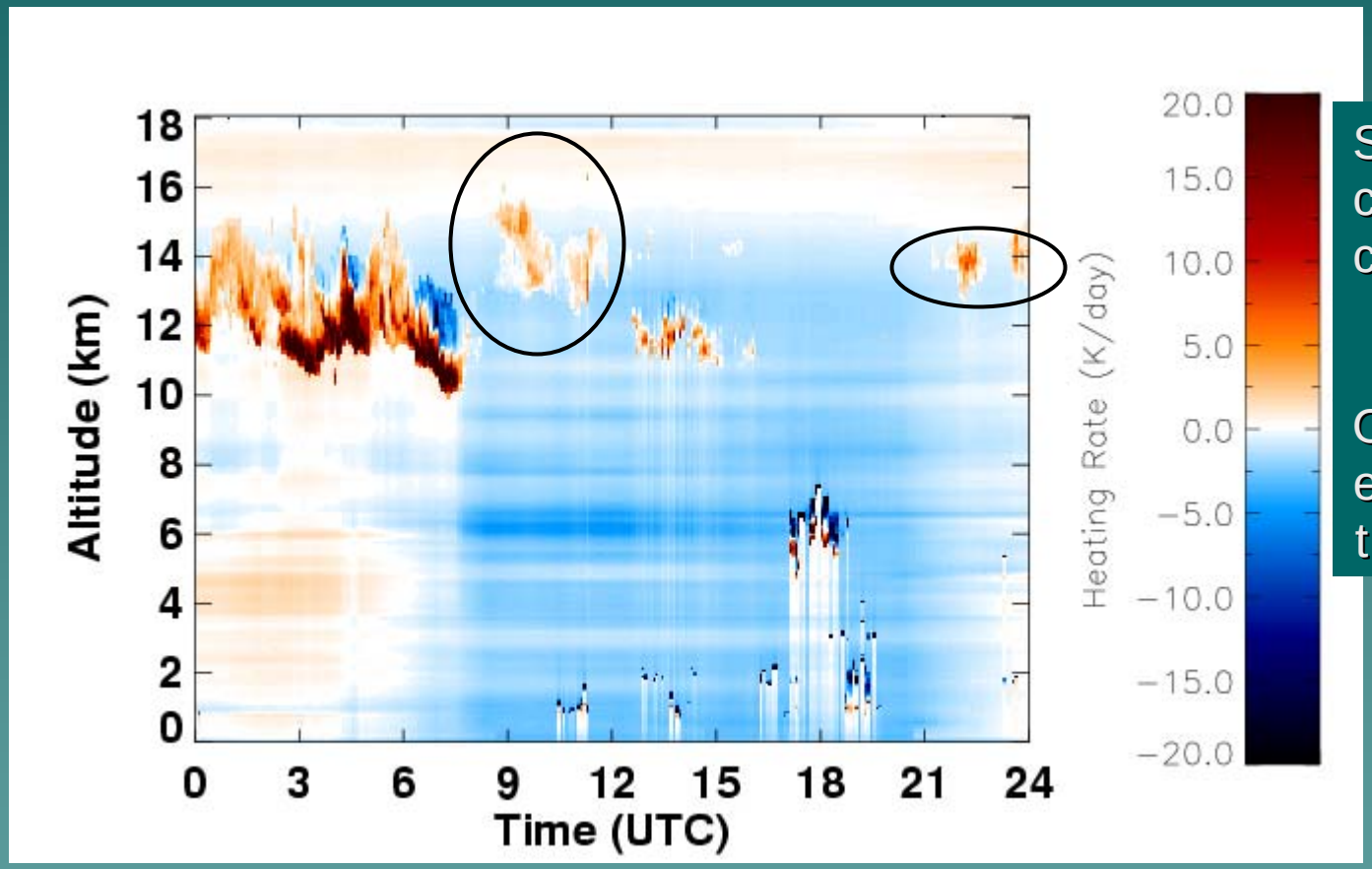

Strong heating at cloud base and cooling at cloud top

Optically thin clouds experience heating throughout cloud

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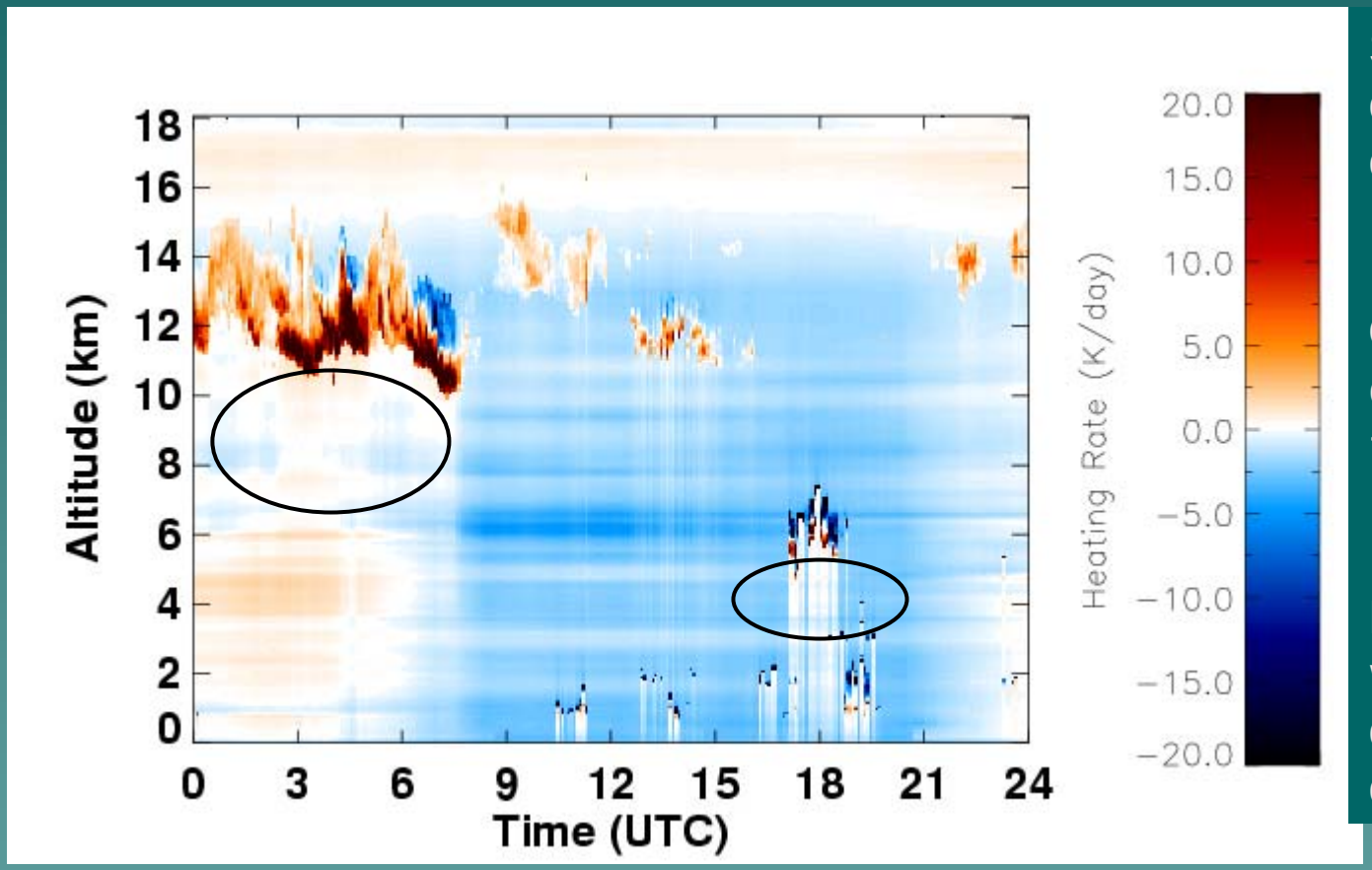
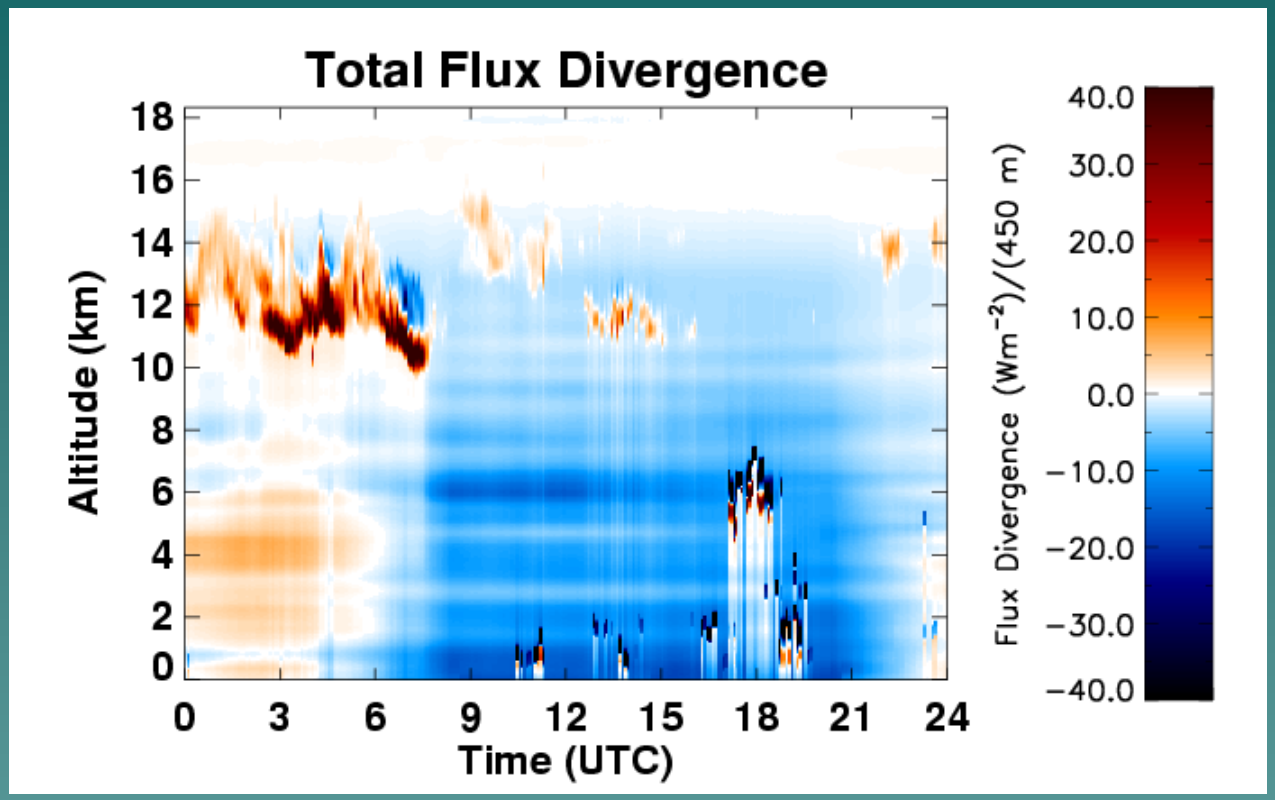


Strong heating at cloud base and cooling at cloud top

Optically thin clouds experience heating throughout cloud

Heating (or reduced water vapor cooling) below cloud base

Flux Divergence view point:



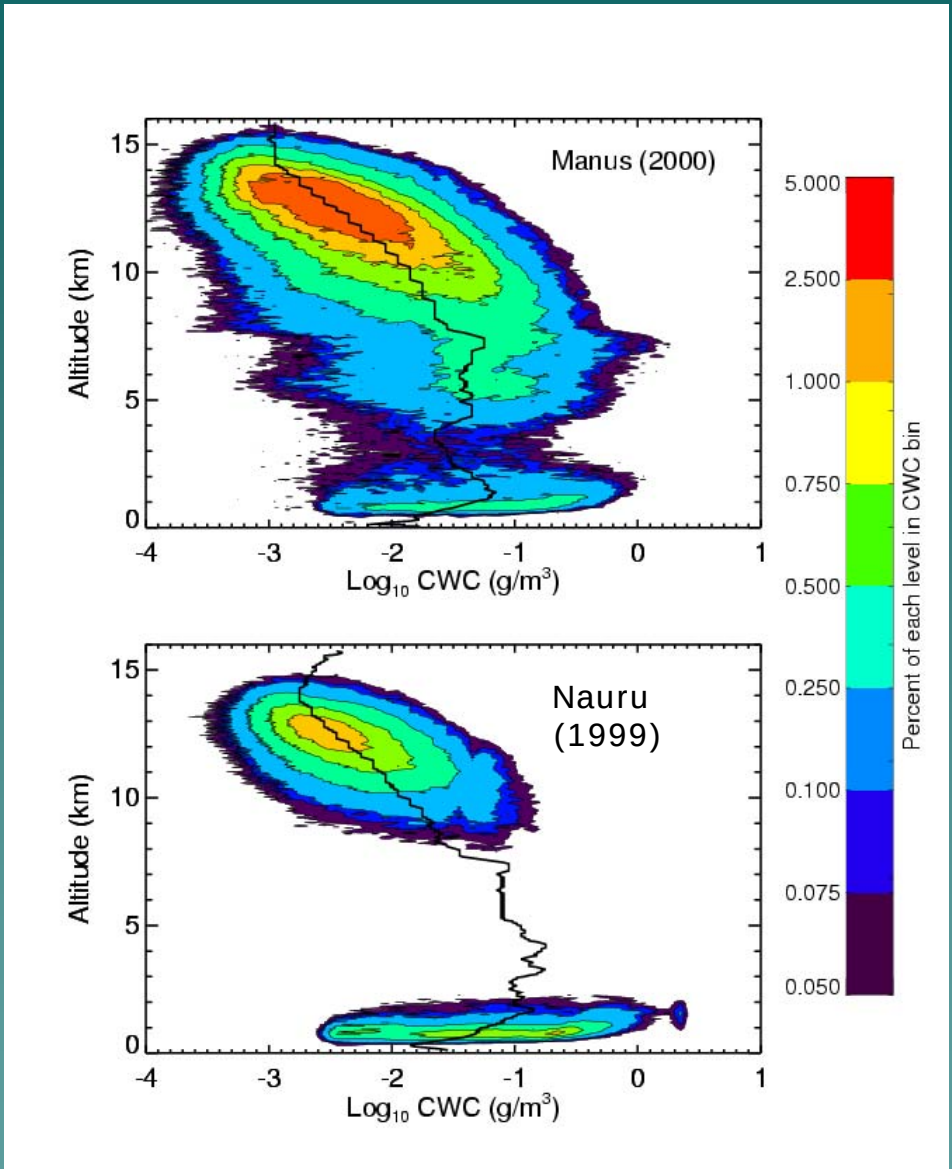
Net flux divergence (per 450 m layer):

> 40 W/m^2 for low clouds and thick cirrus

< 20 W/m^2 for thin cirrus

< 10 W/m^2 clear sky

Condensed Water Frequency Distributions at Manus and Nauru

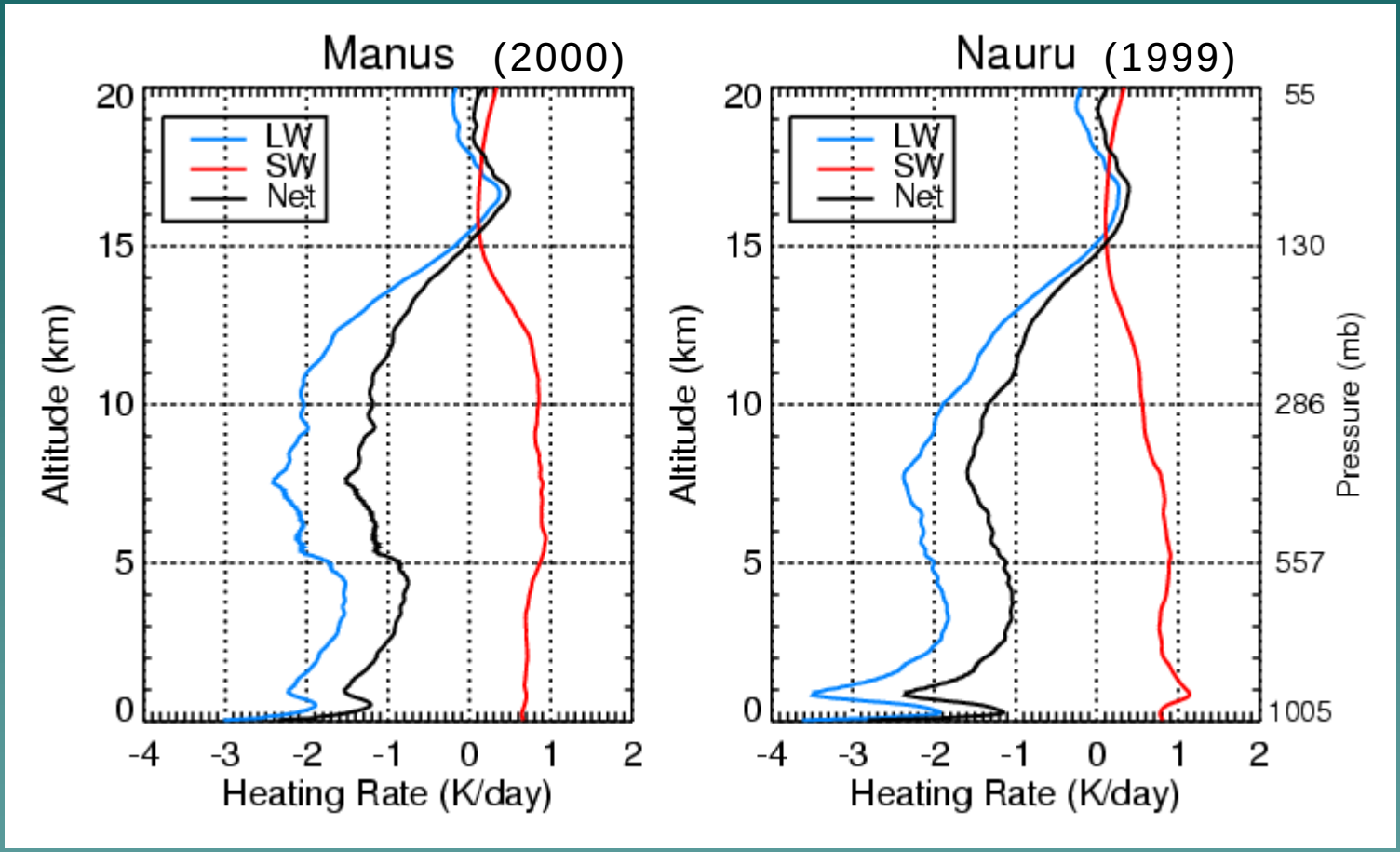


Cirrus and boundary layer features are similar at Manus and Nauru

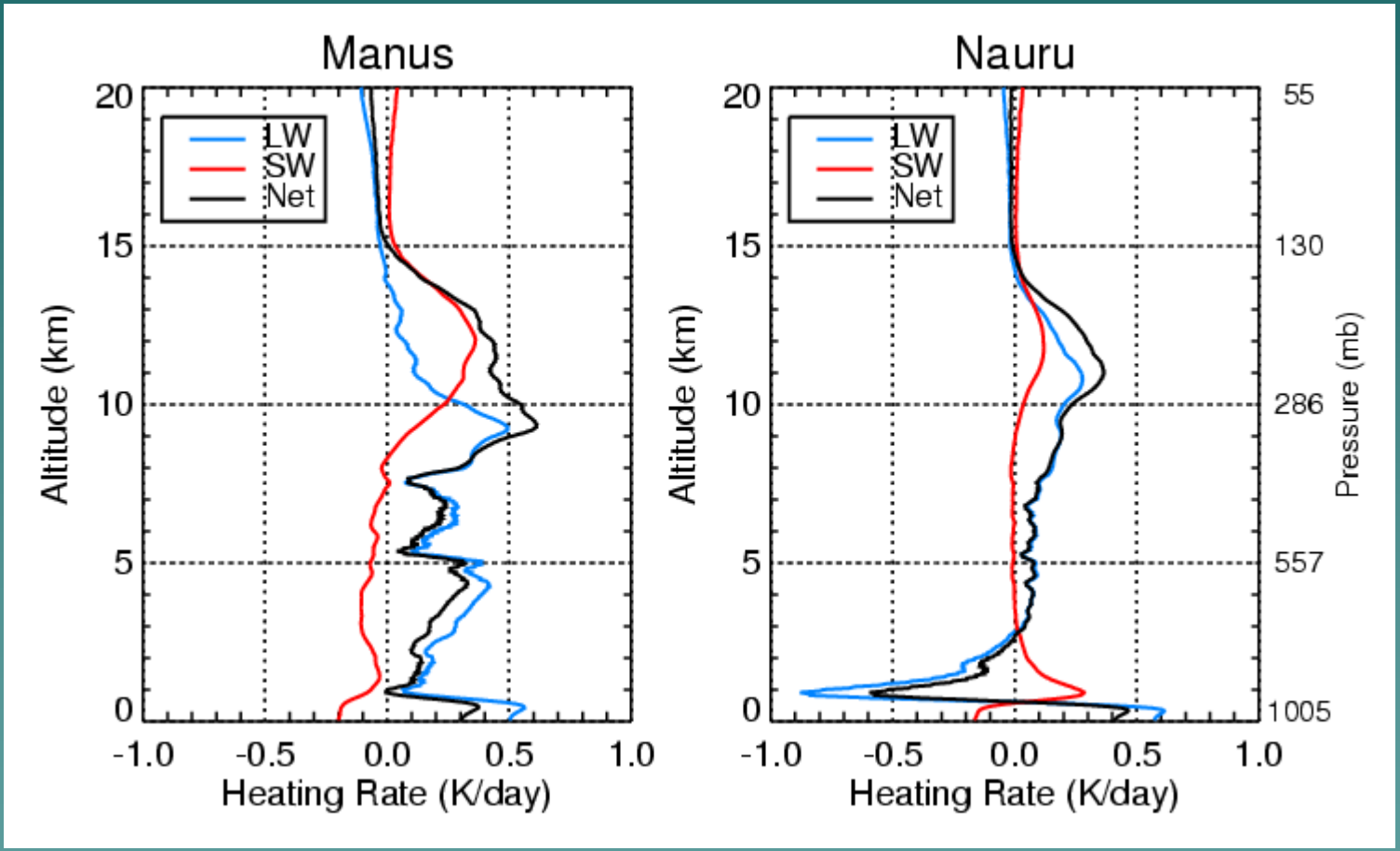
Only Manus exhibits mid-level feature

Nauru region was convectively suppressed during much of 1999

Average all-sky heating rate profiles



Average cloud forcing heating rate profiles show significant differences at Manus and Nauru



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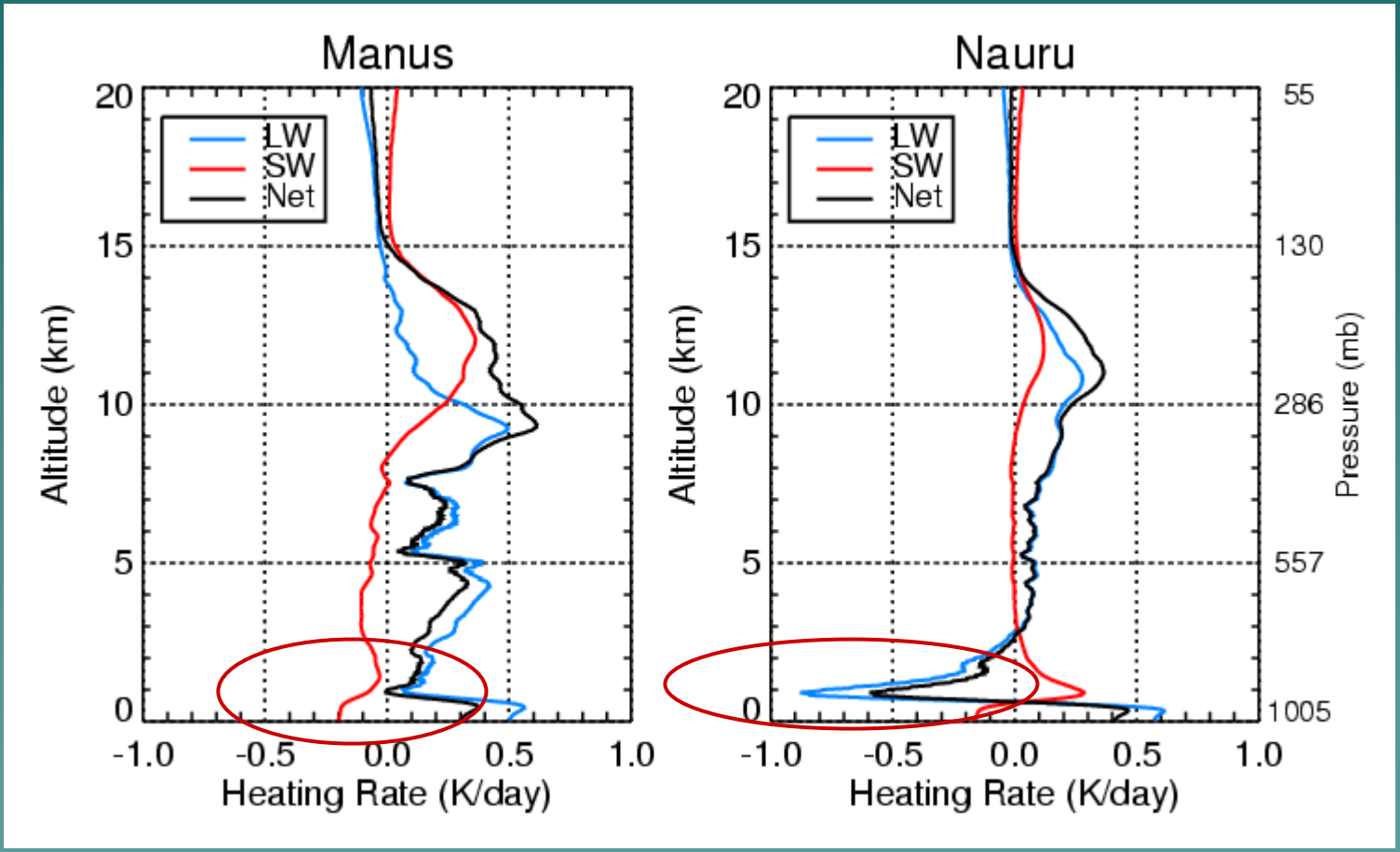

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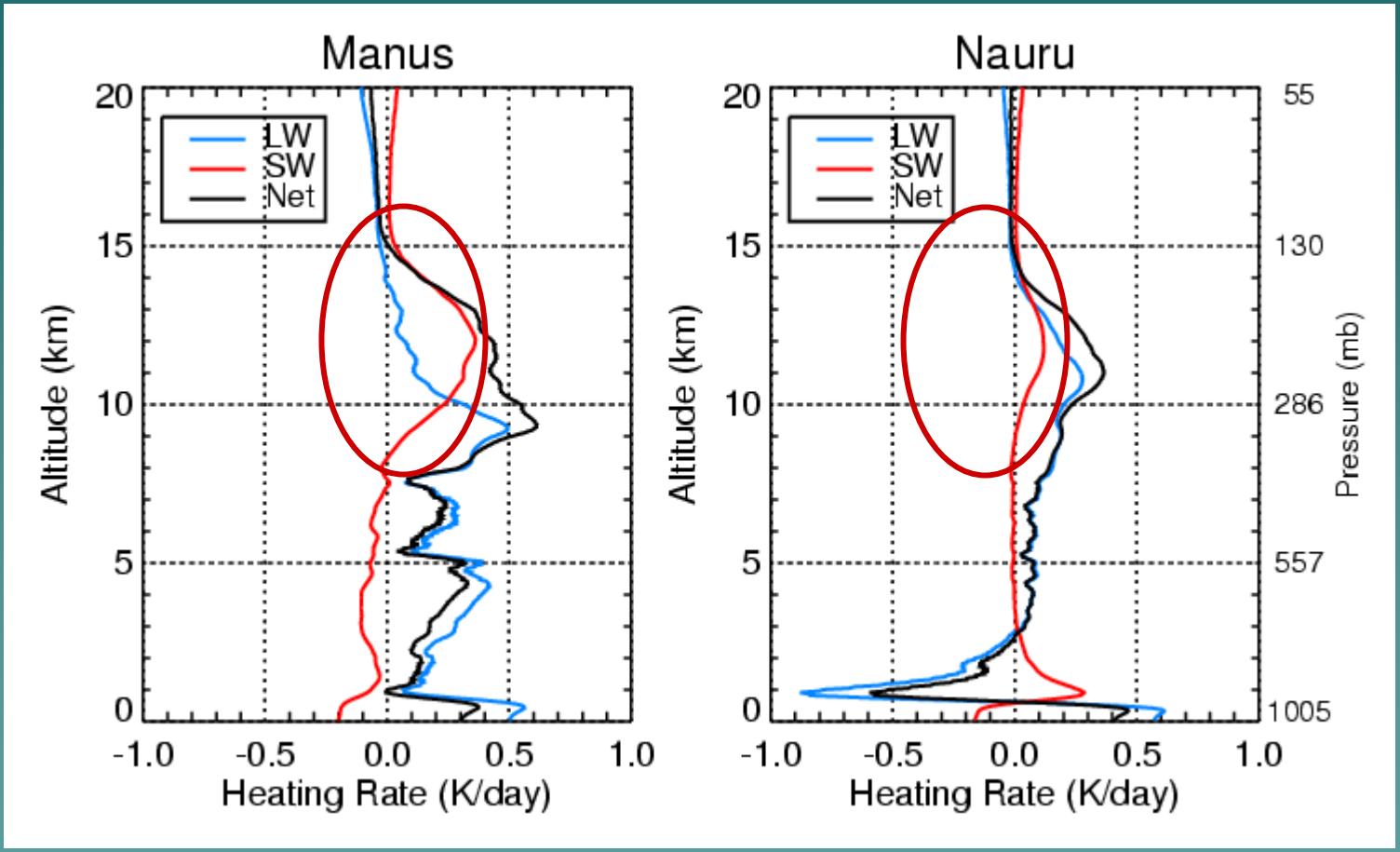

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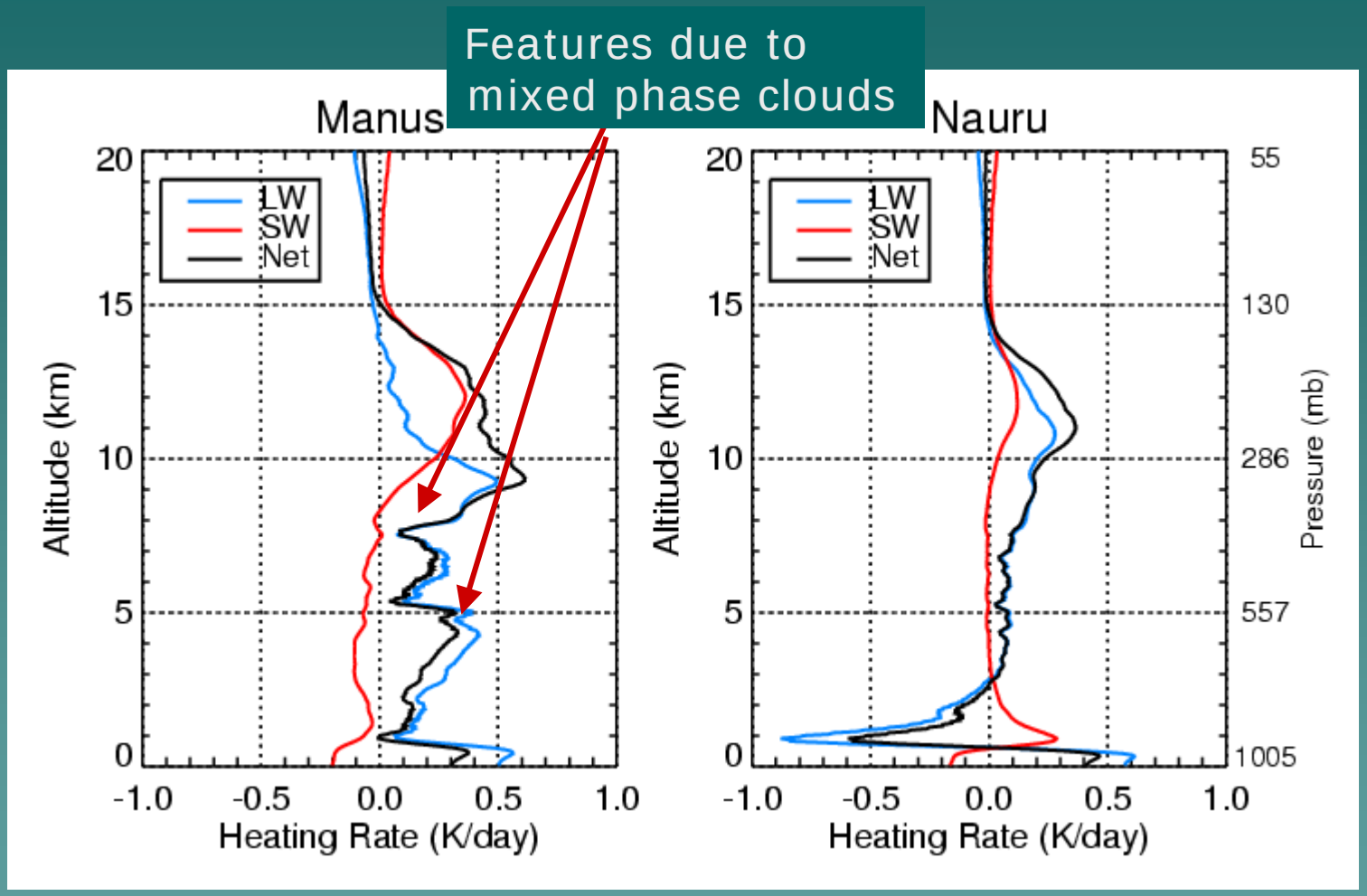
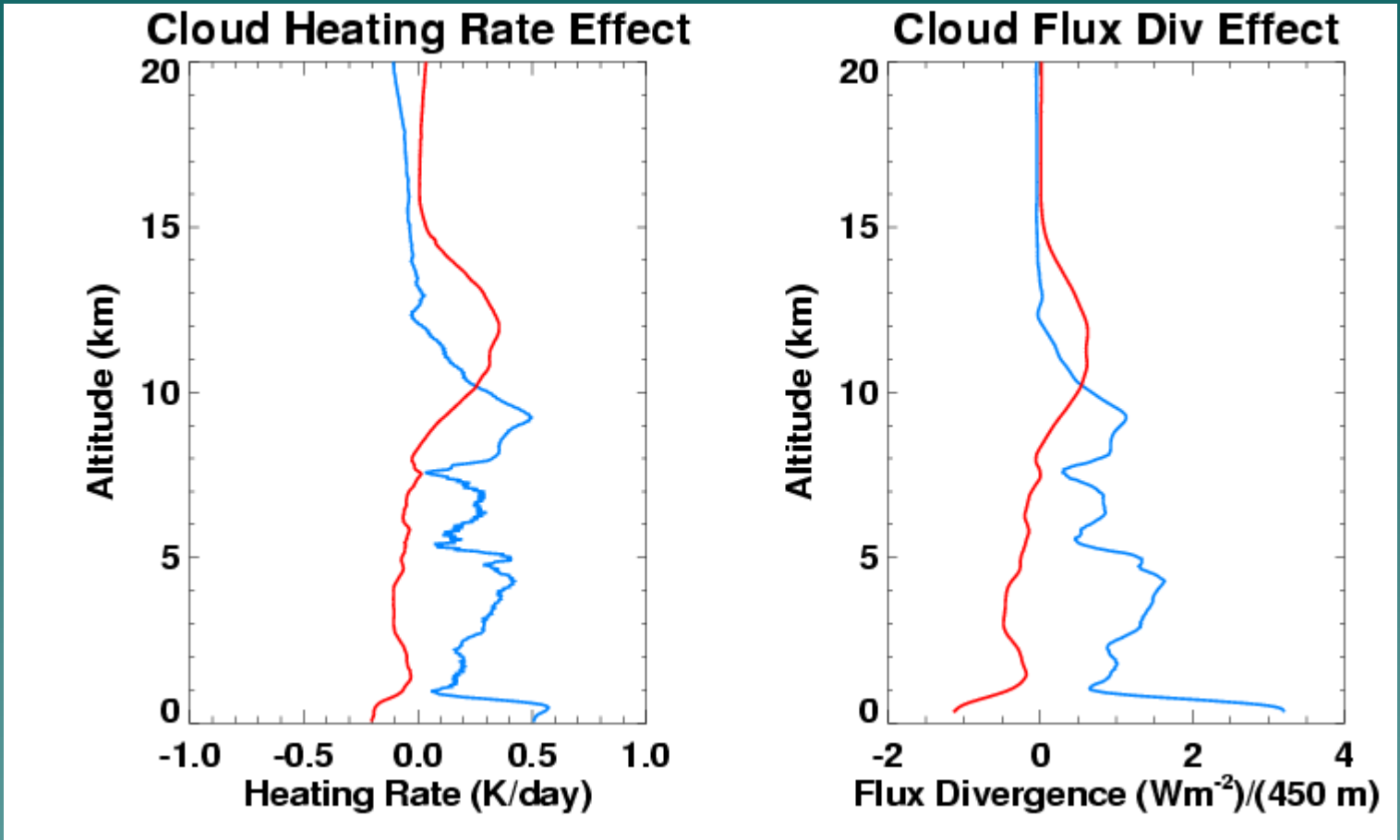
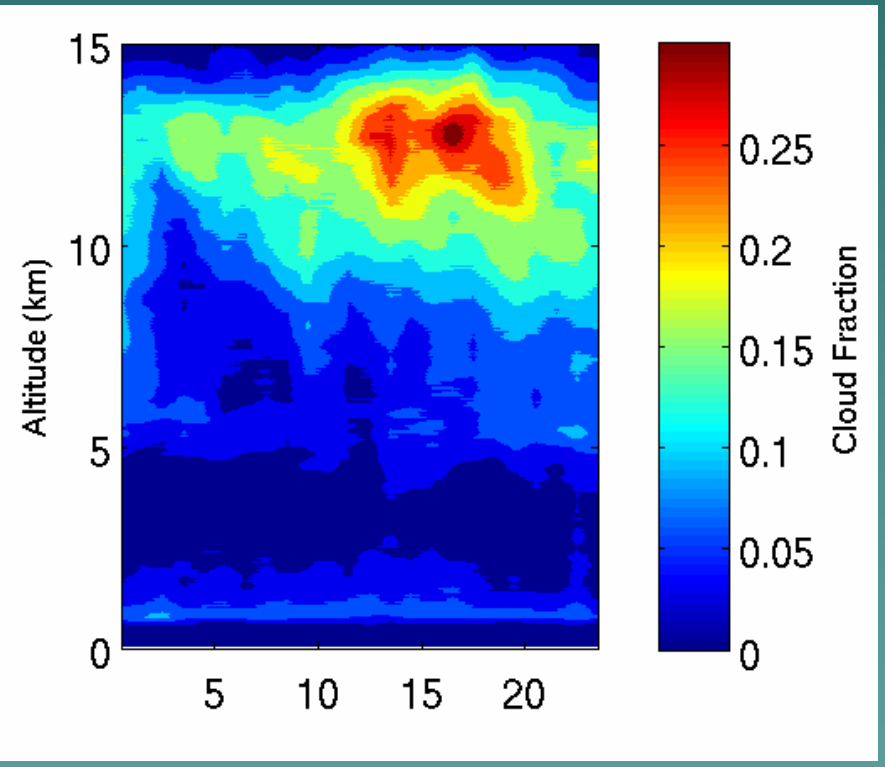


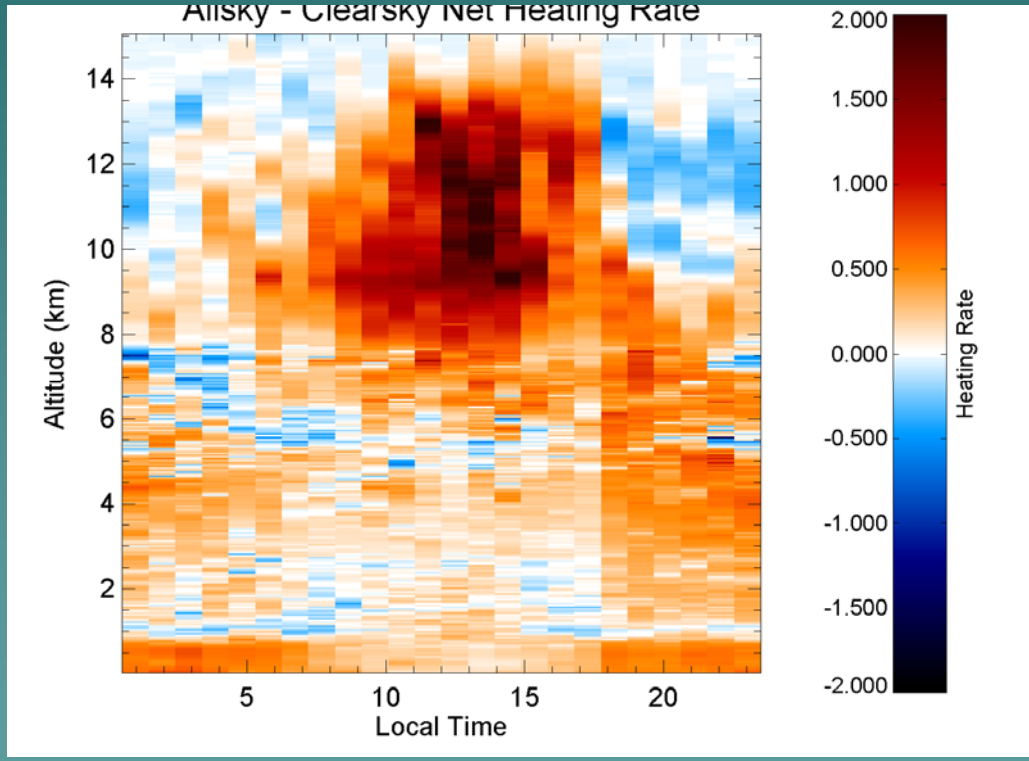

Cloud Heating Rate Effect
Altitude (km)
20
15
10
5
0
-1.0
-0.5
0.0
0.5
1.0
Heating Rate (K/day)
Cloud Flux Div Effect
Altitude (km)
20
15
10
5
0
-2
0
2
4
Flux Divergence (Wm-2)/(450 m)

Applications include studies of radiative feedbacks on range of time scales:

Composites of cloud cover and radiative forcing at Manus show clear diurnal cycle

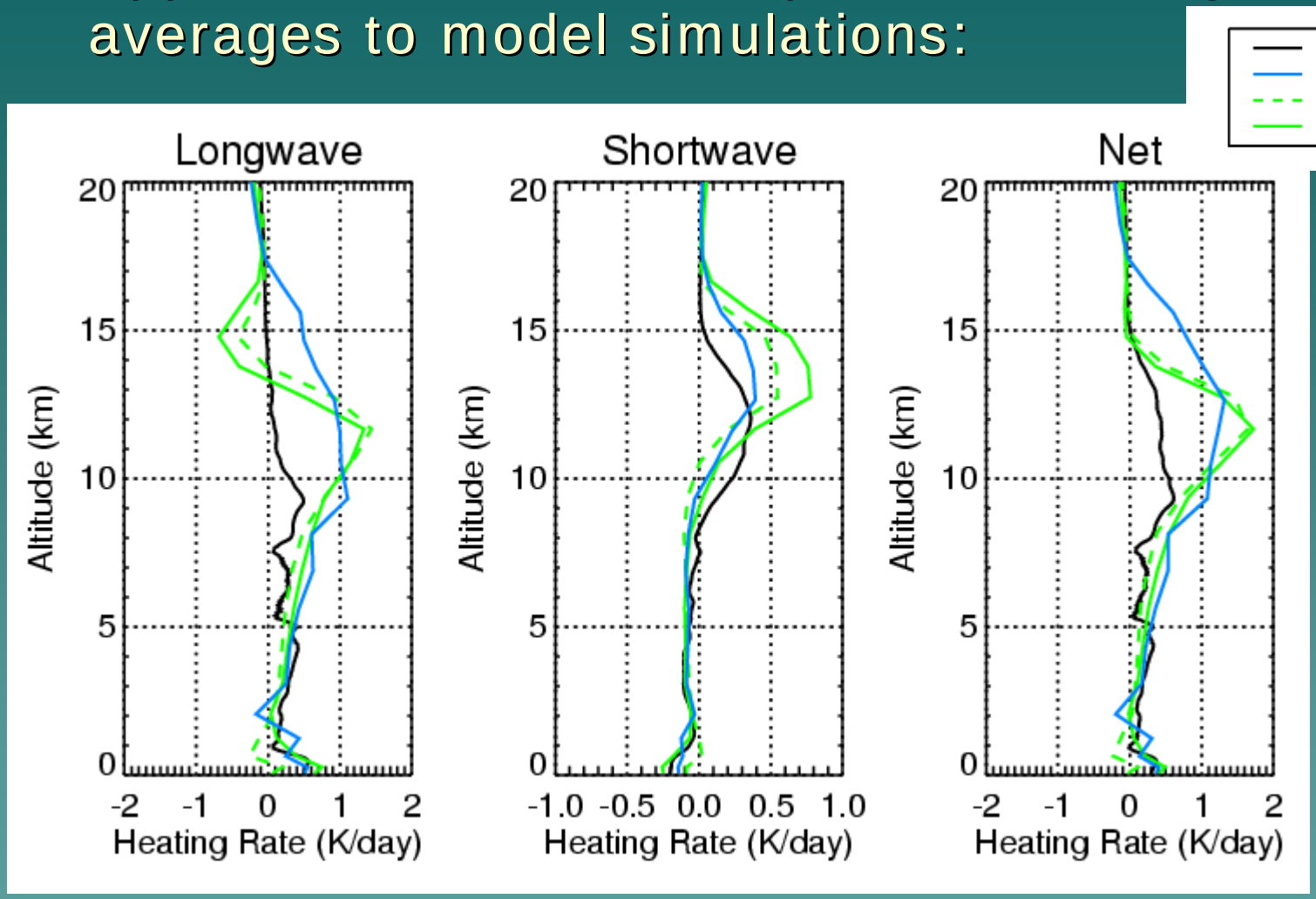


Cloud Fraction



Net Radiative Forcing

Applications include comparisons of long term averages to model simulations:



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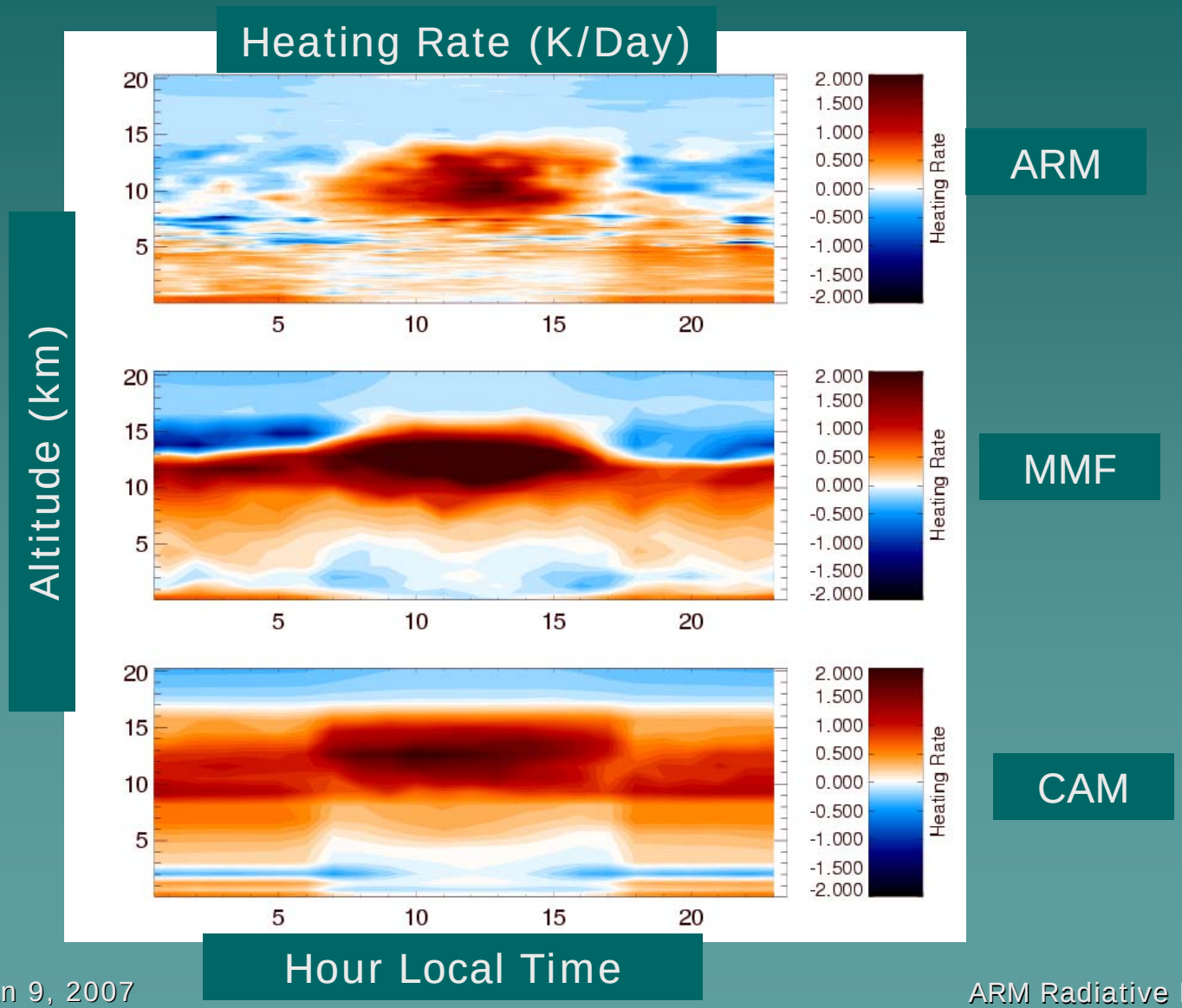
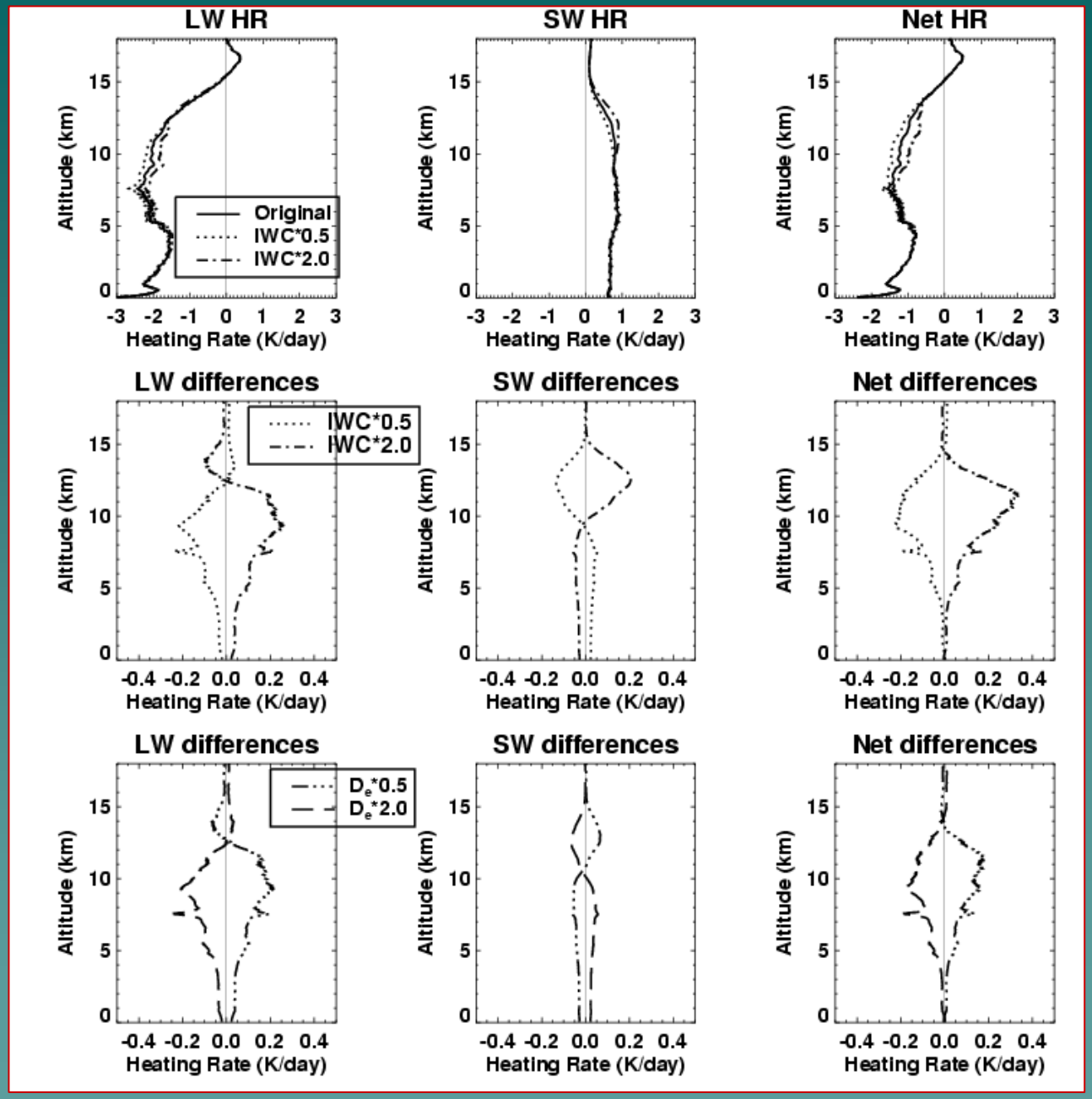


Issues associated with calculation of radiative heating rates from BBHRP approach:

- Limitations of remote sensing retrievals
  - Deep convection/precipitation
  - Uncertainty in optical property retrievals
  - Thin cirrus; mixed phase clouds
- Frequency of sounding measurements
  - Twice daily sondes miss details of diurnal cycle or abrupt changes in temperature/water vapor
- Utility for model comparisons/analysis
  - Very different vertical, horizontal, temporal sampling
  - Only single columns available
  - Neglect of spatial variability and 3D effects
  - Include satellite information? Scanning radar?

How do you validate radiative heating rate profiles?

- Flux closure studies (BBHRP approach)
  - Indirect method; evaluates boundaries only
- Sensitivity studies
  - Knowledge of cloud location better than knowledge of cloud microphysics
  - Assess range of uncertainties associated with range of microphysical values
- Aircraft/balloon measurements
  - Difficult to get ~instantaneous vertical profiles
  - Layer averages with stacked aircraft more feasible – still spatial variability and accuracy issues


LW HR
SW HR
Net HR
Altitude (km)
Heating Rate (K/day)
Original
IWC*0.5
IWC*2.0
LW differences
SW differences
Net differences
D_e*0.5
D_e*2.0