General circulation- and submm radiative transfer models of the martian atmosphere at MPS

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Herschel Space Observatory Calibration Workshop, Leiden 1 - 3 December 2004

Outline

- The Martian Atmosphere: Observation and Modelling (MAOAM)

- Submm spectra of Mars from 400 to 2000 GHz

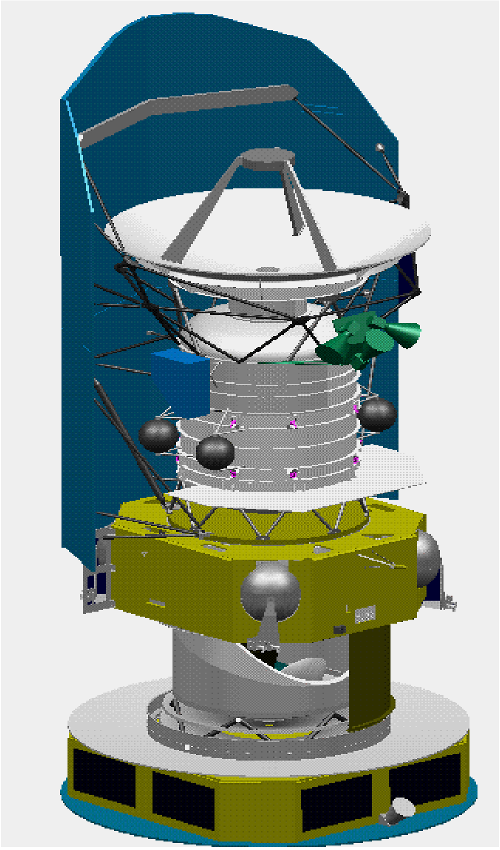
Idea of MAOAM

- Submm instruments will sound the Martian atmosphere to much higher altitudes than IR instruments: development of a GCM describing the atmosphere from 0-130 km.
- Compare Model with data and results from other models if applicable

- (DFG research priority program “Mars and the terrestrial planets”, funding period: 2002-2007)

New Submm Experiments: HIFI on Herschel Space Observatory

HIFI (Heterodyne Instrument for the Far Infrared) in HSO (former FIRST) ESA cornerstone mission



Herschel Space Obse

4 m Telescope, HIFI wavelengths: 120 to 670 µm, L2-Orbit

Typical sensitivity: 3 x quantum noise temperature (hn/k)

Spectral Resolution: < 10^{-7}

Operational from 2007 – 2010

Mars Science:

Altitude profiles from of water and its isotopes, minor species, line surveys (new molecules) and temperature. Hemisph. average

Altitude range: 0 – 80 km

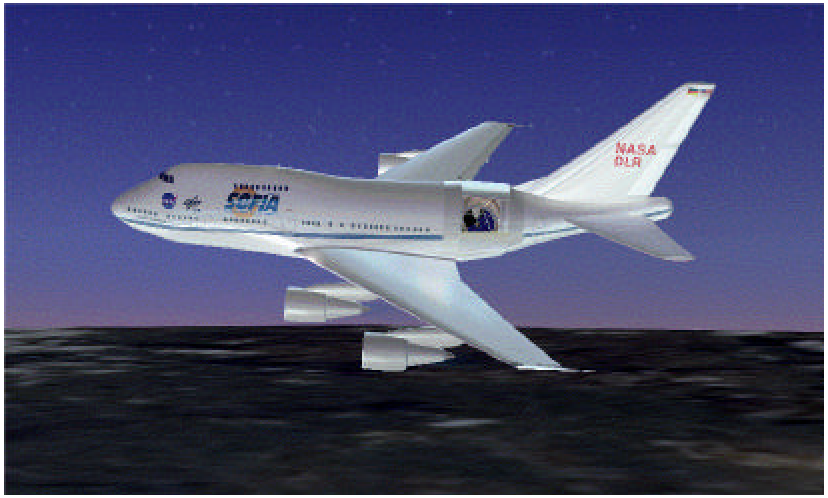
Altitude resolution: 5 – 8 km

Important inputs for photochemical models

New Submm Experiments: Great and CASIMIR on SOFIA

- *SOFIA: Stratospheric Observatory for Infrared Astronomy*
- *GREAT: German Receiver for Astronomy at THz frequencies*
- *CASIMIR: Caltech Submillimeter Insterstellar Medium Investigations Receiver*

2.7 m telescope, CASIMIR and GREAT wavelengths: 600 to 60 µm, flying through stratosphere
Typical sensitivity: 3 x quantum noise temperature (hn/k) + attenuation of Earth middle atmosphere
Spectral Resolution: < 10^{-7} Operational from 2004 – 2025



Mars Science:

Altitude profiles from of water and its isotopes, minor species,
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Hemisph. average

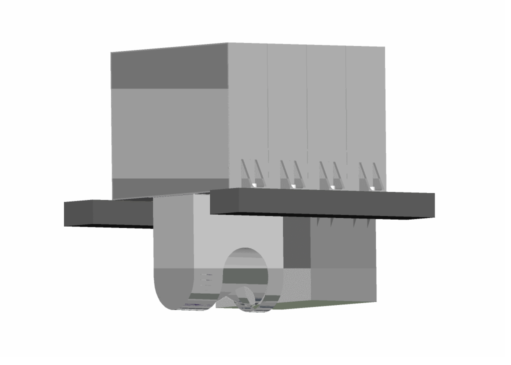
Altitude range: 0 – 80 km

Altitude resolution: 5 – 8 km

Important inputs for photochemical models

MIME, MAMBO and SIGNAL

- *MIME: Microwave Investigation for Mars Express*
- *MAMBO: Mars ATmospheric Microwave Brightness Observer*
- *SIGNAL: Submillimeter Investigation of Geothermal Networks and Live*



Small Instruments: 5-18 kg, telescope 7-20 cm, wavelengths: 900-500µm

Sensitivity: 50 x quantum noise

Spectral resolution: 10^{-7}

Operational from 2008 to 2012

Mars Science

Altitude profiles of water and its isotopes, winds, minor species, line surveys (new molecules). Global coverage

Altitude range: 0-130 km (nadir and limb sounding)

Altitude resolution: 3-8 km

Horizontal resolution (LMO): typically 5-50 km

Important inputs for water cycle, general circulation, planetary and gravity waves, chemistry, cloud formation, diurnal tides, search of biotic molecules, find indications of presently existing life

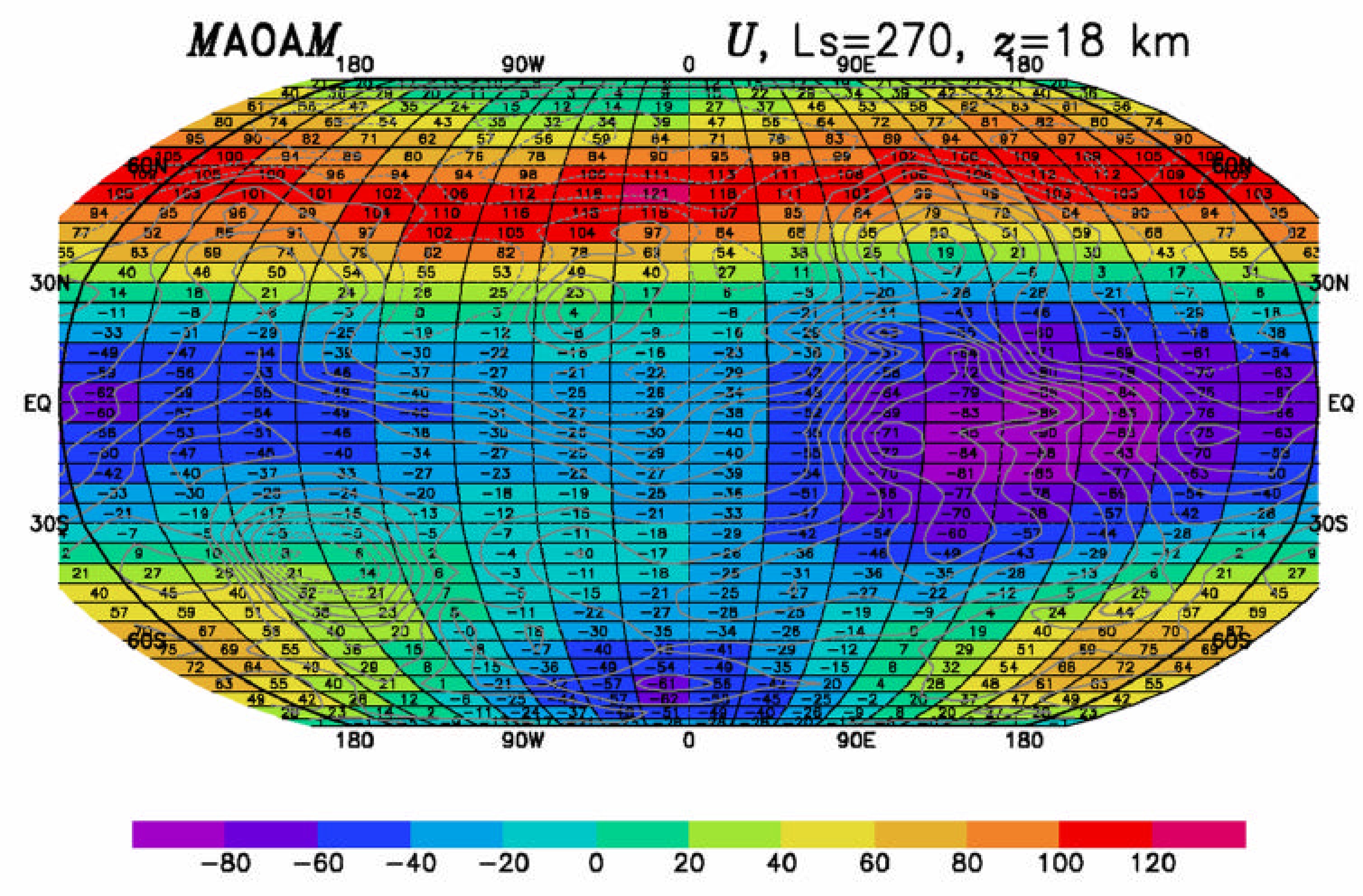
MAOAM-Team

• P. Hartogh	PI	MPS
• A. Medvedev	Project Scientist/atmospheric waves	MPS
• C. Jarchow	RTE/Retrieval Simulation	MPS
• G. Villanueva	GCM Structural Design	MPS
• R. Saito	Surface / Radiative Transfer	MPS
• T. Kuroda	Dust / Radiative Transfer	MPS
• M. Grygalashvyly	Chemistry / Transport	MPS/IAP
• G. Sonnemann	Chemistry / Transport	IAP
• U.Berger	Dyn. Core / Triangle Grid	IAP
• A. Kutepov	non-LTE Radiative Transfer	GSFC
• A. Feofilov	non-LTE Radiative Transfer	MPS/U.Munich
• H. Elbern	Data Assimilation	EURAD

Model Specs (in progress)

- *Nonlinear global 3d- Eulerian grid point-model*
- *Vertical grid: 1 km from 0 to 150 km*
- *Horizontal grid 5 deg latitude and 5.625 (22.5) deg longitude*
- *Integration of nonlinear atmospheric equations in 225 seconds time steps*
- *MOLA orography*
- *Mc Farlane orographic GW-scheme, energy dissipation / momentum deposition according to Medvedev and Klaassen.*
- *Radiation module: calculation of cooling and heating rates (carbon dioxide and atomic oxygen) including surface energy budget through the planetary boundary layer (albedo, thermal inertia, solar insulation). Non-lte radiative transfer in upper atmosphere*
- *Chemical transport module includes chemistry, transport and radiation. Chemical families: odd hydrogen, odd oxygen, odd nitrogen and even hydrogen. All subject to transport. Module uses dynamical fields (temperature, winds, pressure).*
- *Influence of dust storms on temperature and circulation patterns*
- *Polar caps (pressure), Water cycle*
- *Data assimilation*

MAOAM: zonal wind at 18 km



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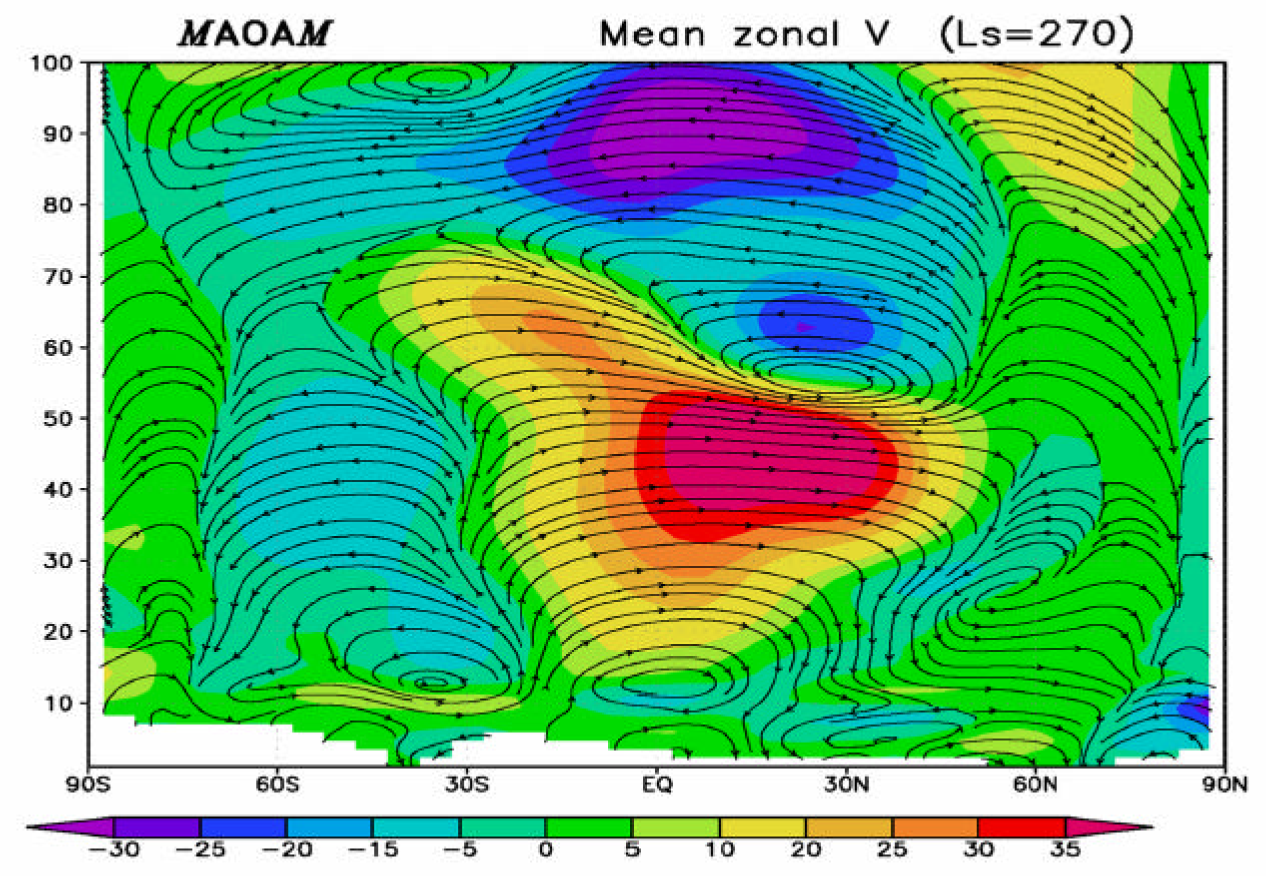
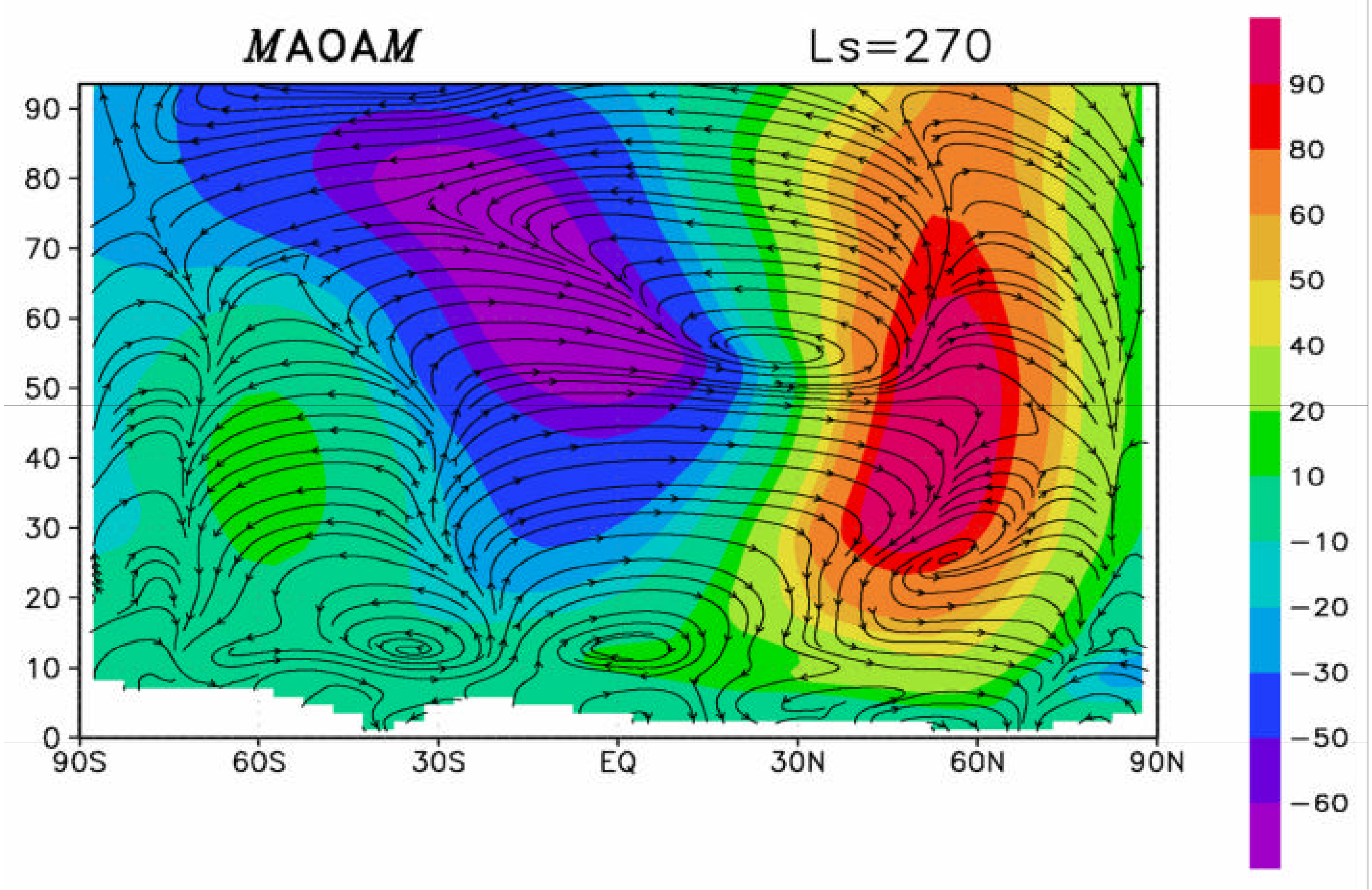
Zonally averaged meridional winds: Ferrel cells



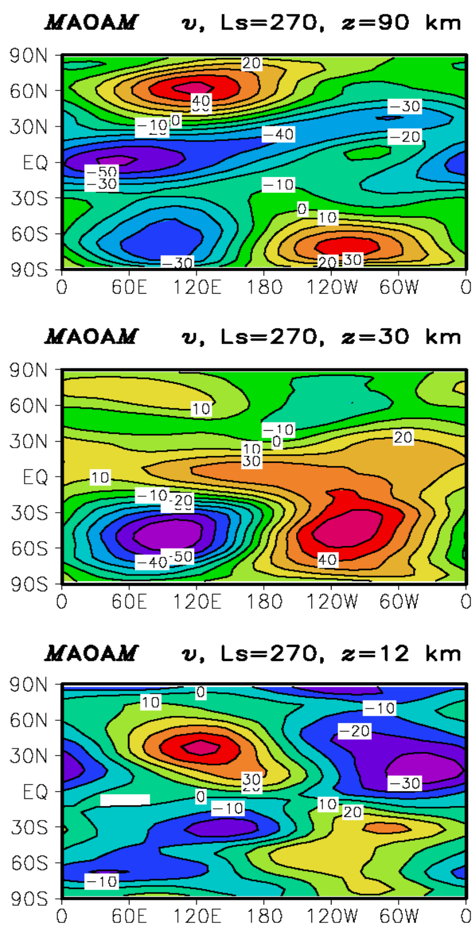
The streamlines demonstrate circulation cells of more complex nature than simple Hadley cells reported by other GCMs. In particular the cell at 60 km over 30N is caused by tides propagating upwards

Propagating tides I



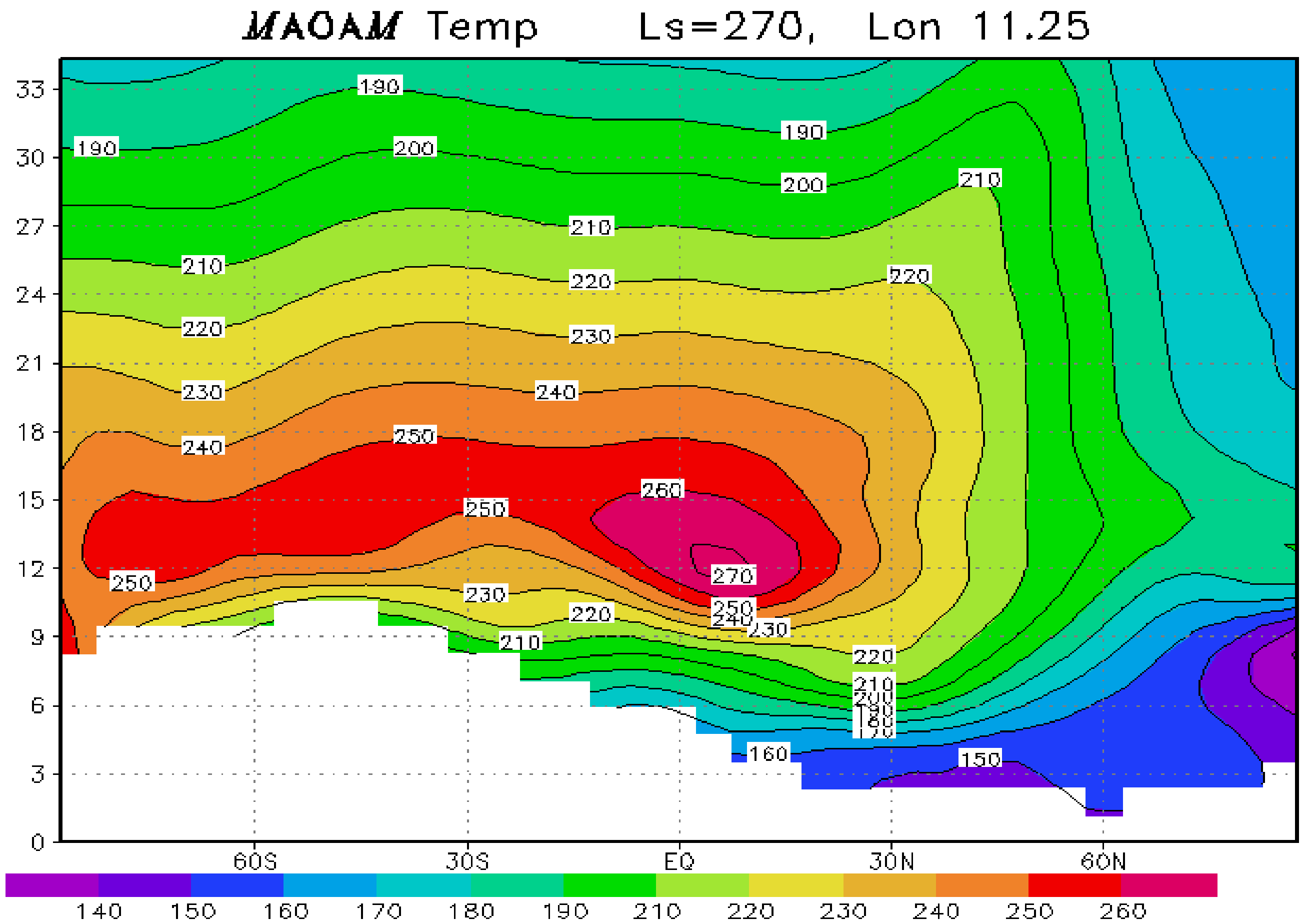
Weak mean zonal winds favor tide propagations as seen between the eastward and westward jet at 30N

Propagating Tides II



Meridional winds at 3 different heights: at 12 km structure of typical diurnal tide. At 30 km located in southern hemisphere, since the vertical propagation of eddies is inhibited by the mean zonal winds. At 90 km we see tides in both hemispheres: upward propagation along channels of weak mean zonal wind => model captures the dynamical features of the circulation.

Southern summer tropical surface temperature inversion



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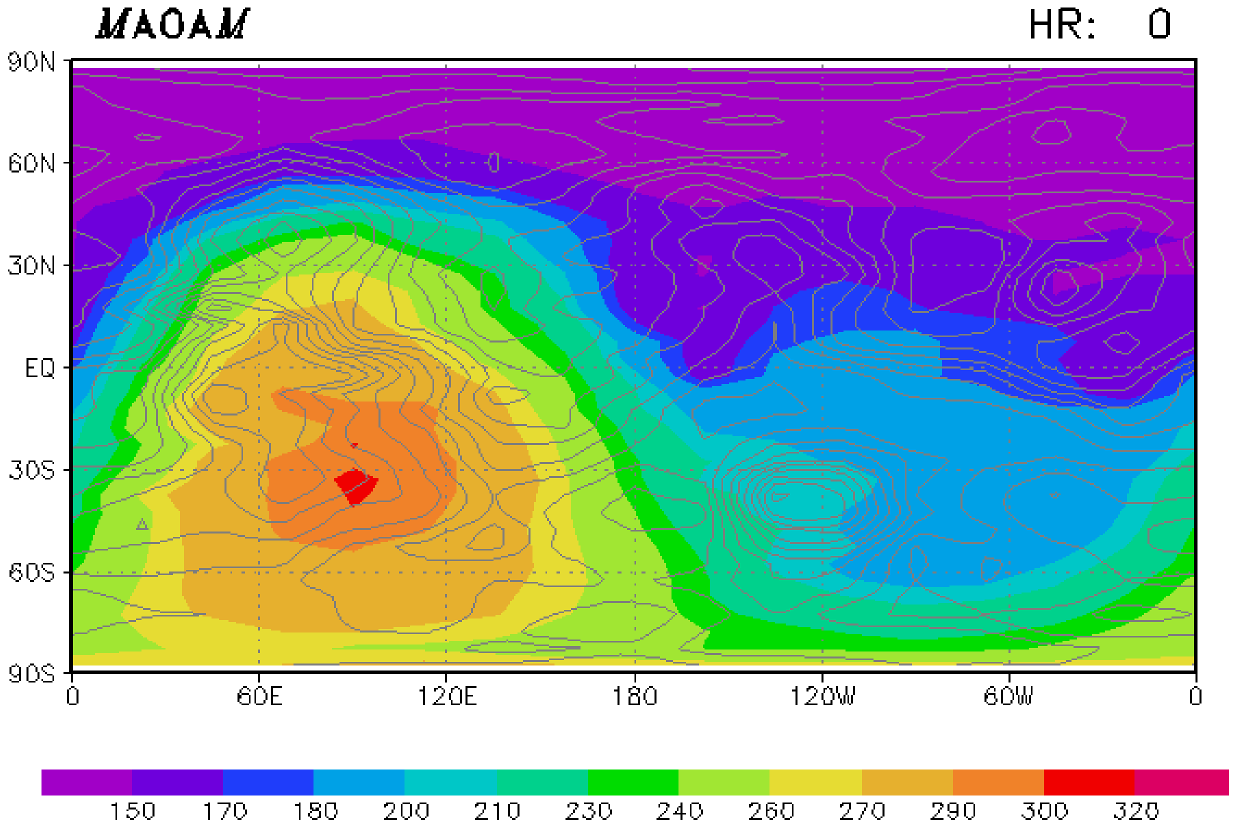
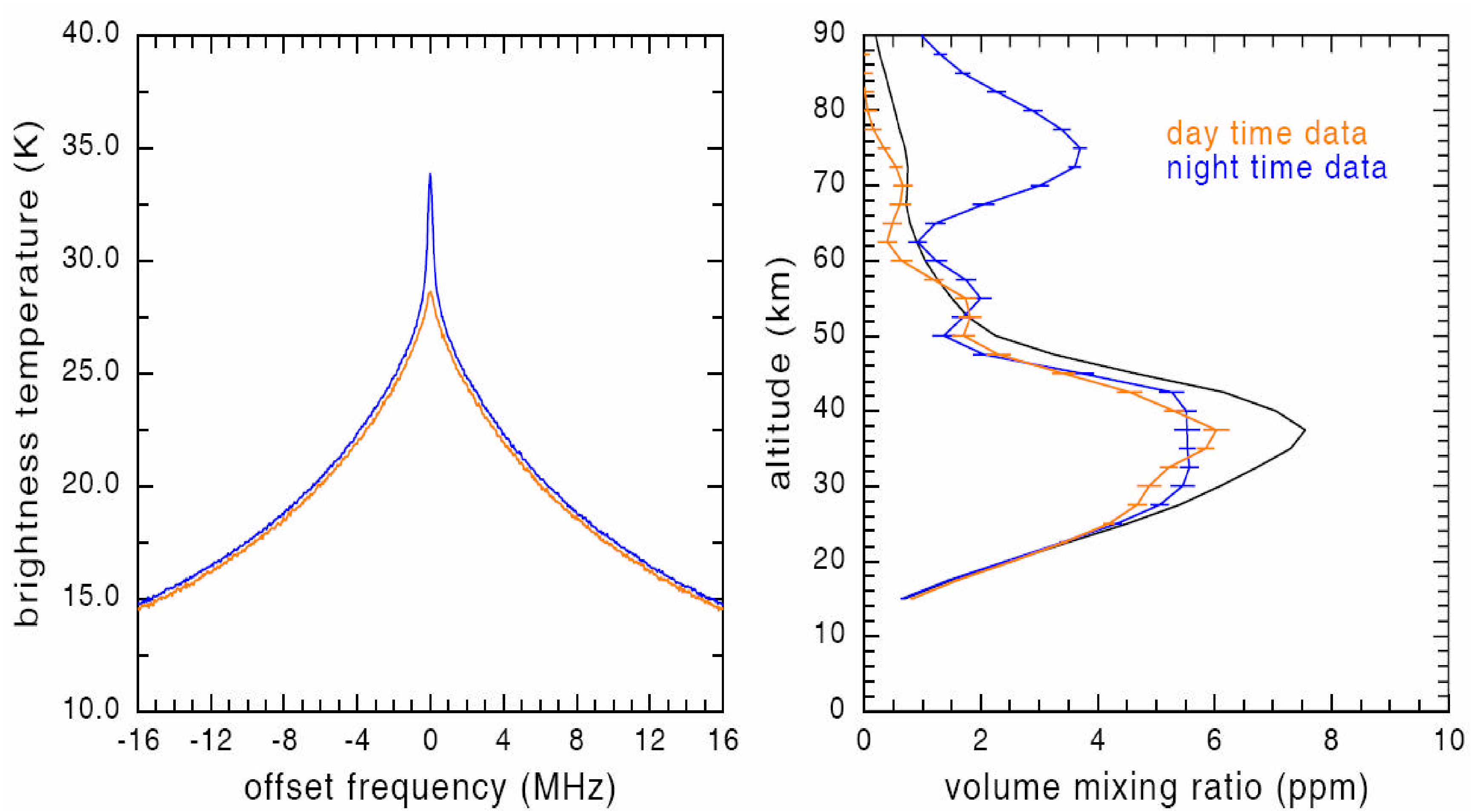
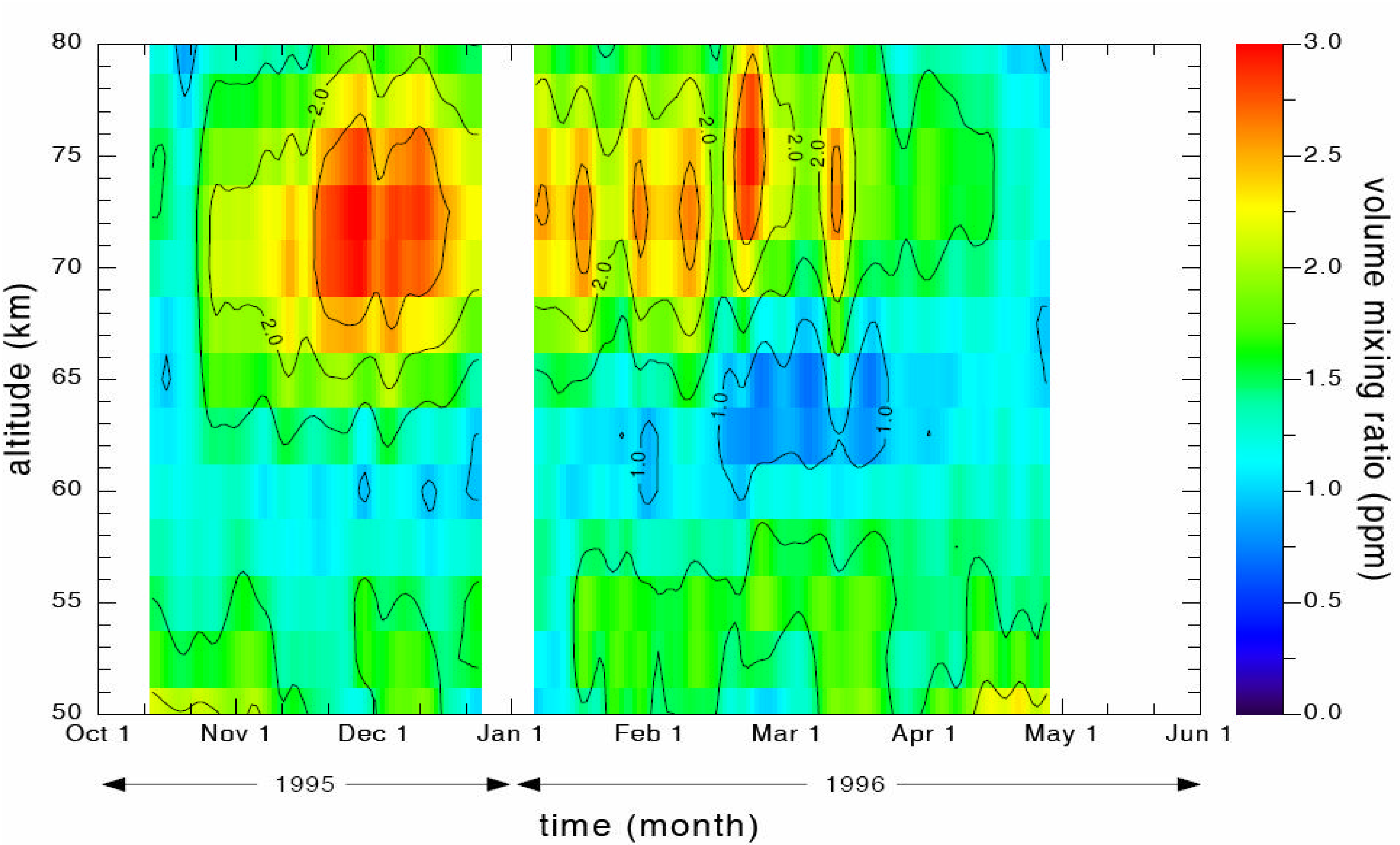
Diurnal variation of surface temperature



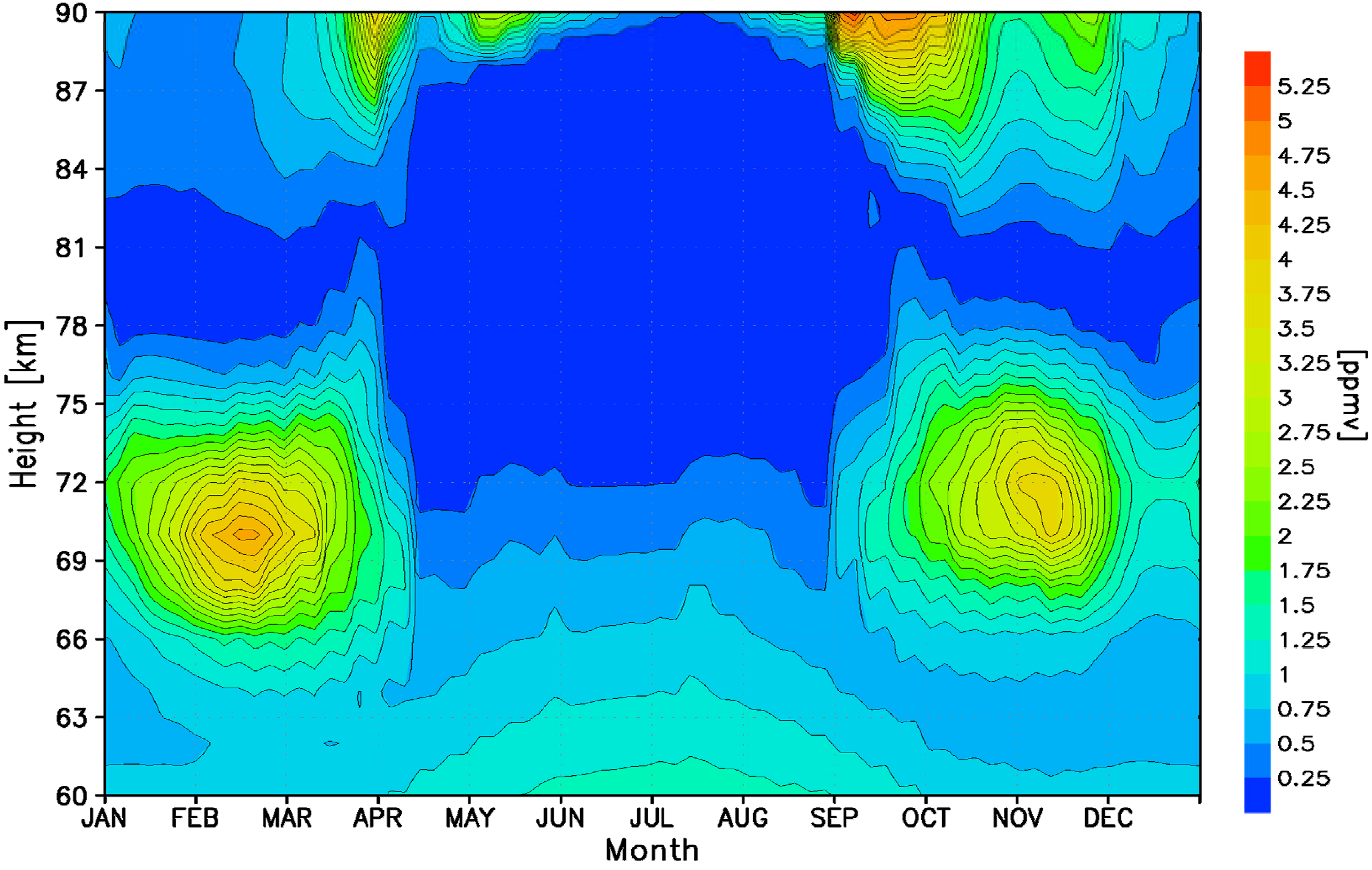
Chemistry transport module validation: Ozone Spectrum (142 GHz) and Retrieved Profile (Earth, since good Mars data not available yet)



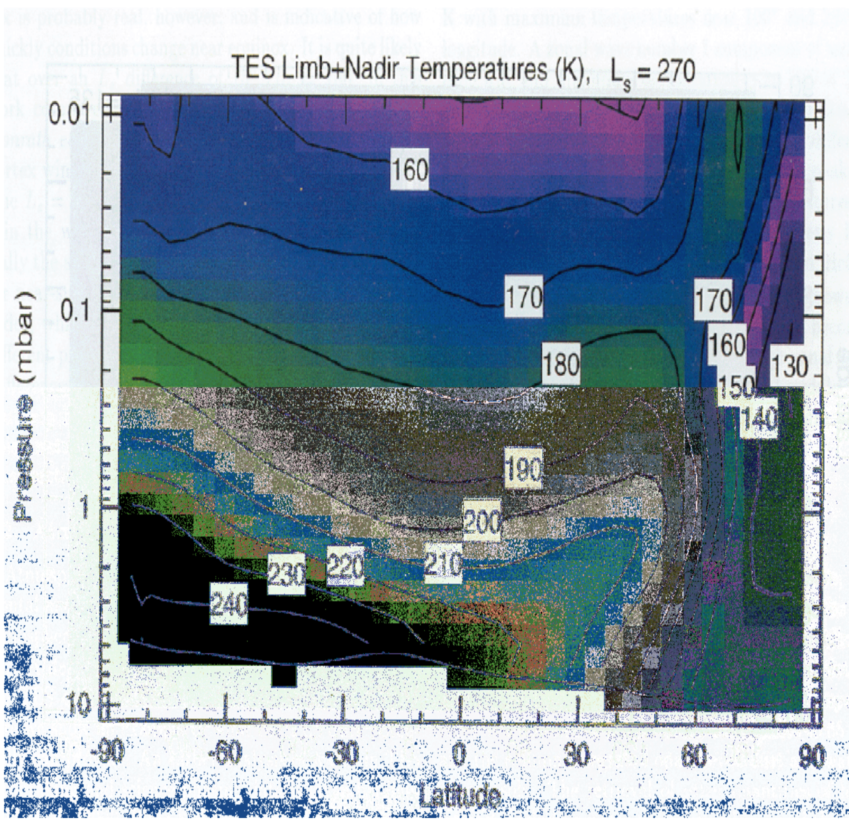
Measured nighttime ozone over ALOMAR (69 N)

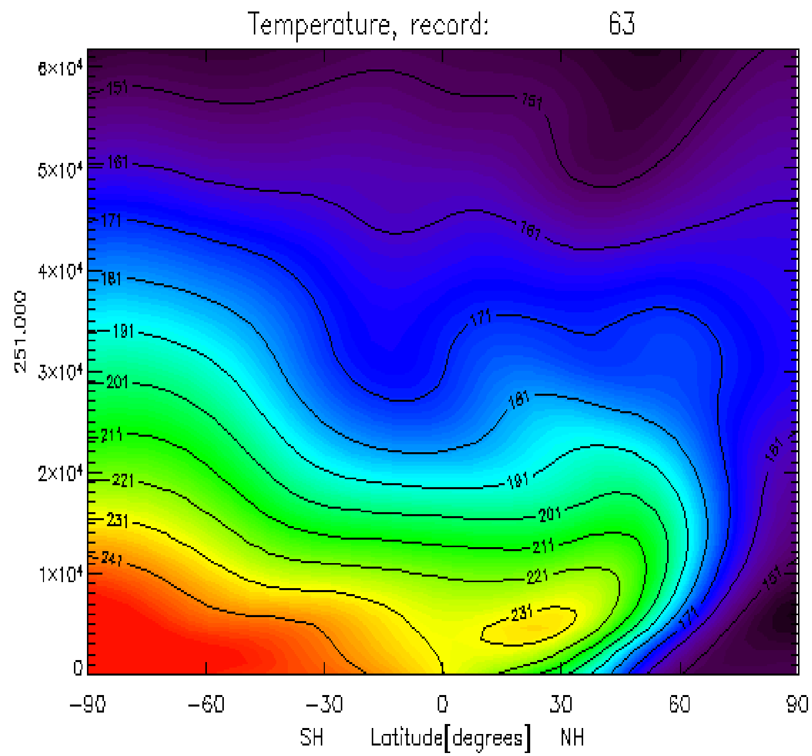


Calculated Annual Variation of MMM at ALOMAR (69 N)

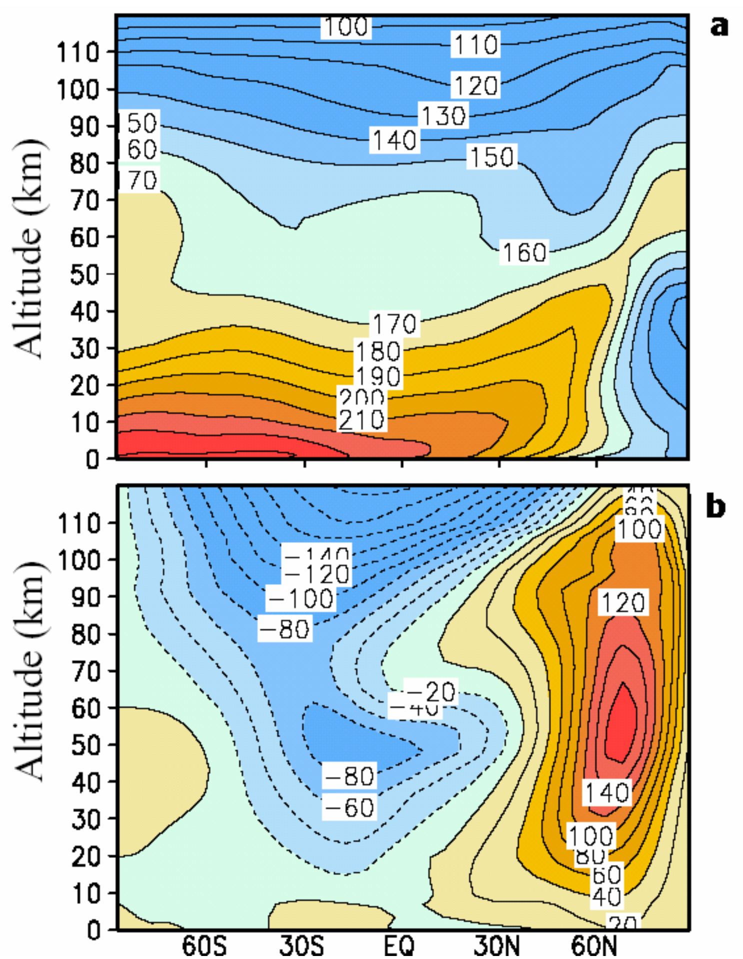


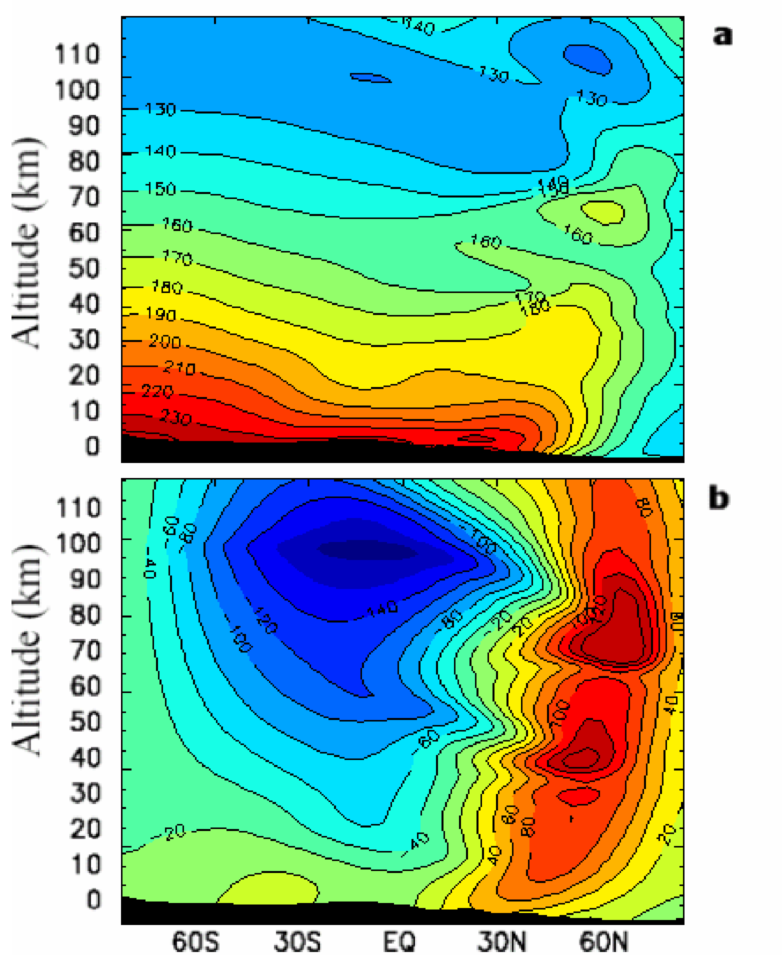
TES-data and MAOAM results (Ls=270)



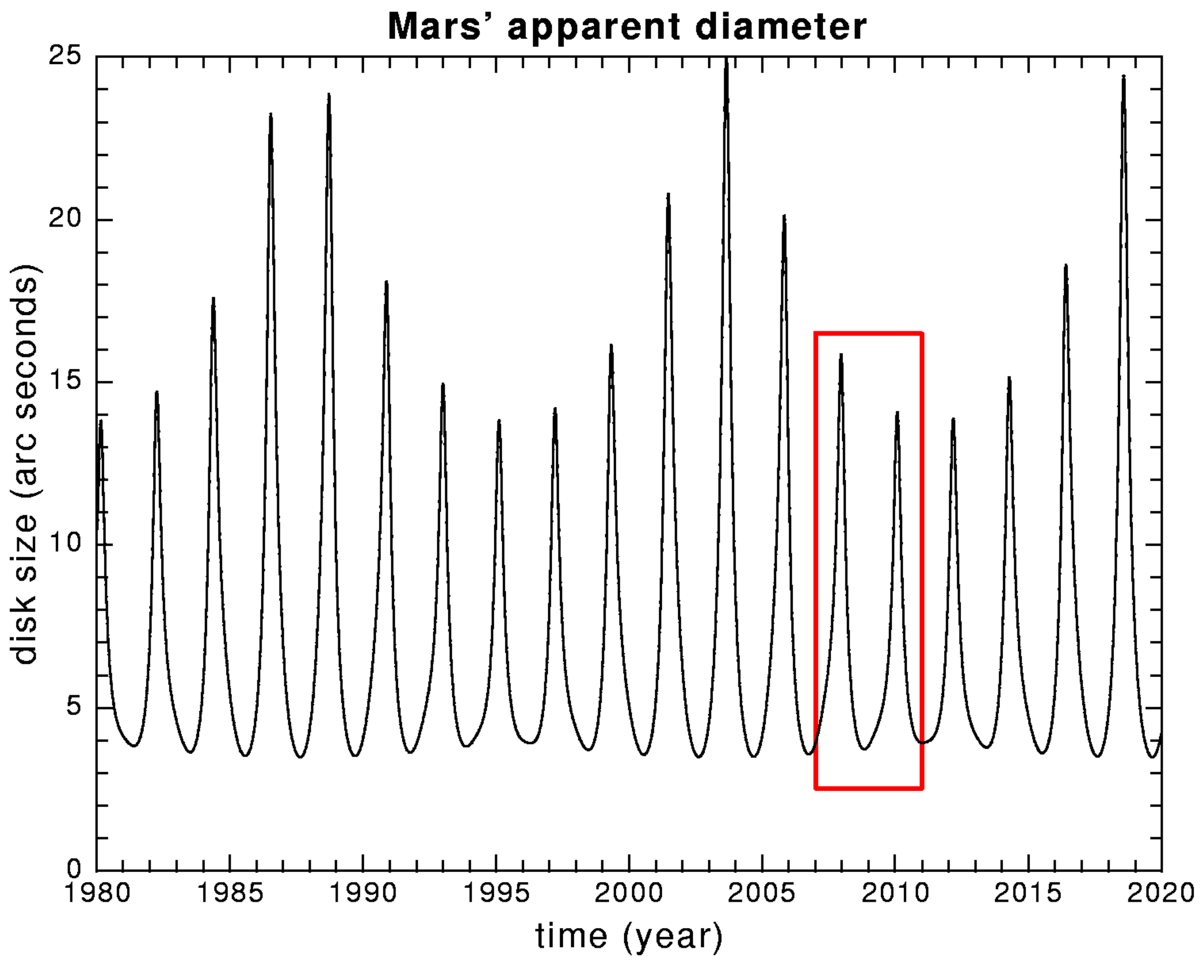


Comparison of LMD-AOPP and MAOAM results (LS=270)

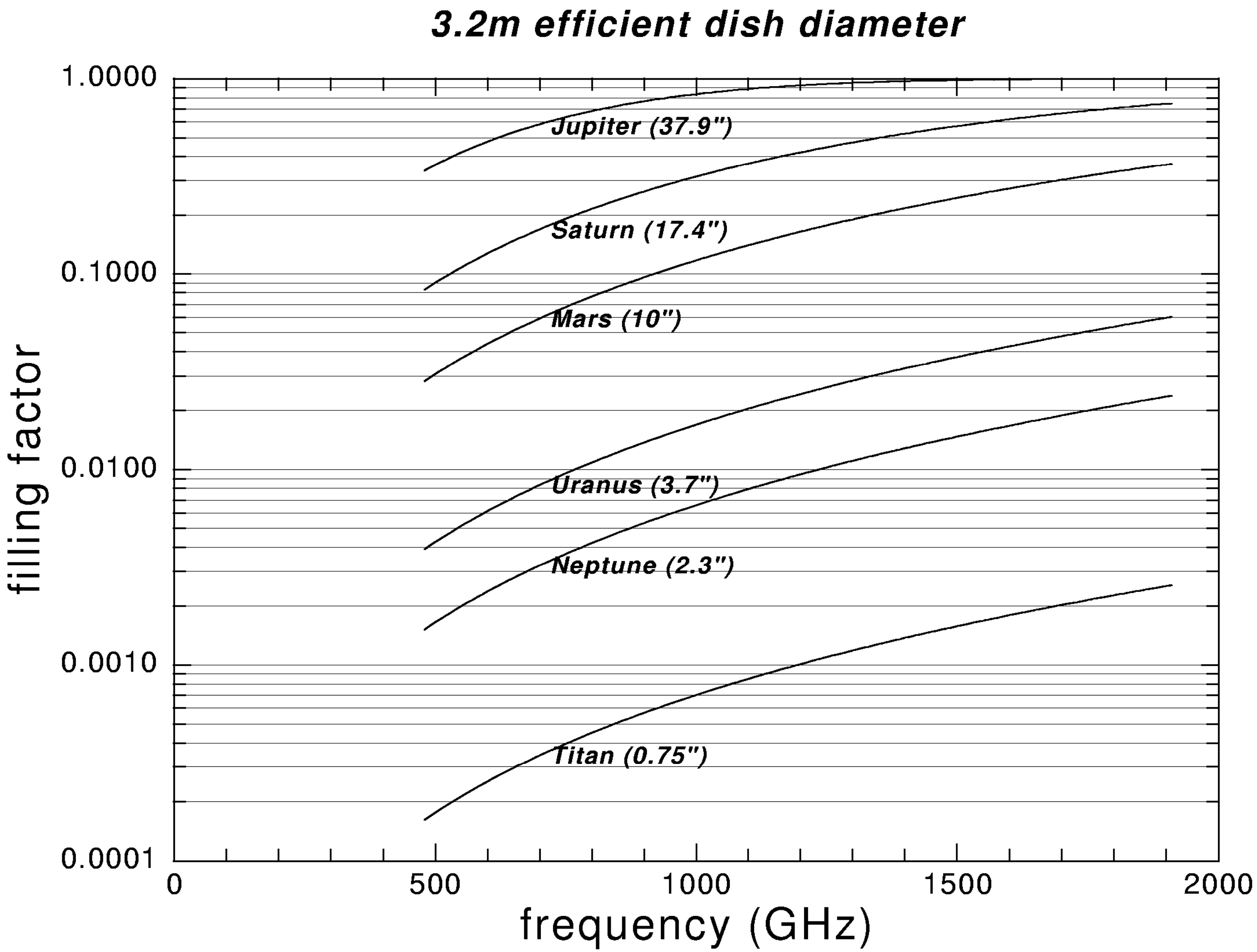




Mars Visibility during HIFI



HIFI-Fillingfactors for Mars, Titan and Giant Planets



Mars Radiative Transfer Model Inputs

- T-profile: own ground-based measurements, Pathfinder and Viking entry profiles, TES-data, GCM output (MAOAM)
- Spectral line parameters: JPL 1991
- Line shape: Voigt-function
- ***Pressure broadening: 5,963 (3.3) MHz/hPa***
- Collision induced absorption: negligible for Mars
- Layer thickness: 2 km, T, p = const. within each layer
- TB-unit: Planck and Rayleigh-Jeans
- Trx: Rayleigh Jeans (SNR definition)
- Disk averaged spectrum (32 rings nadir & 32 rings limb

Surface Emission

- Perfect sphere, r = 3390 km
- Perfect blackbody, t = 220 K
- No polarization (limb darkening) considered, uniform brightness
- No latitudinal, longitudinal or temporal dependence included

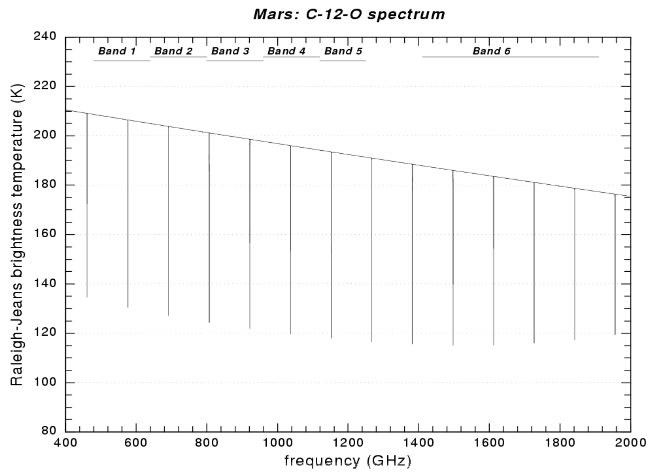
Model atmosphere

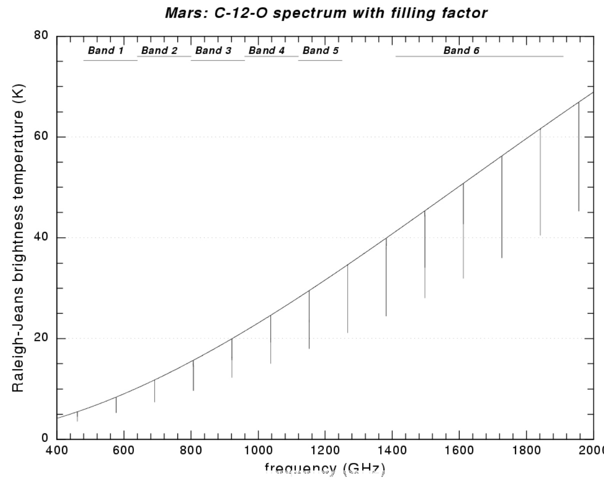
- Single temperature and pressure profile
- No latitudinal, longitudinal and temporal dependence of temperature and species
- Same temperature for day and night
- Species: 12-CO, 13-CO, 12-CO-18, H2O-16, H2O-17, H2O-18, HDO
- Spherical nature of atmosphere, path length dependence
- Limb height: 100 km.

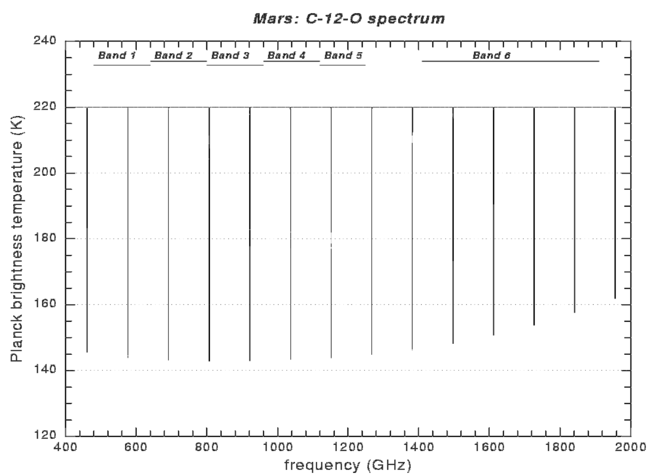
Proposed improvements

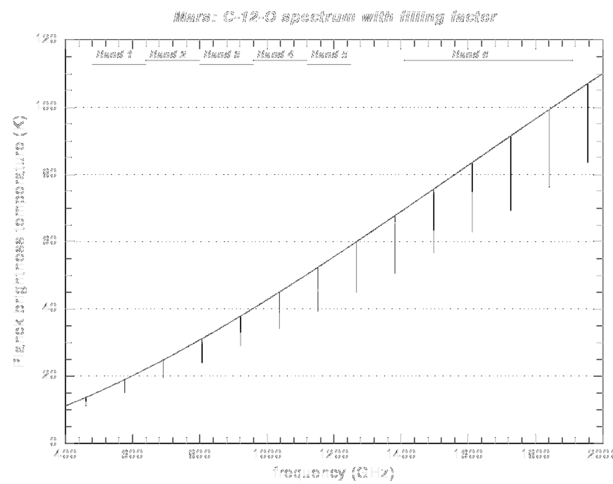
- Use e.g. MAOAM surface temperature field
- Use best guess of complex surface epsilon (measure?)
- Include effect of surface polarization (T_bv and T_bh) including limb darkening
- Project spherical surface onto flat planetary disk and perform integral over this inhomogenious temperature field, i.e. include tilt of rotation axis (day/night visibility)
- Use e.g. MAOAM atmospheric temperatures and pressure fields as function of time
- Check influence of orography
- Check emission properties of rocky material and polar caps

C-12-O

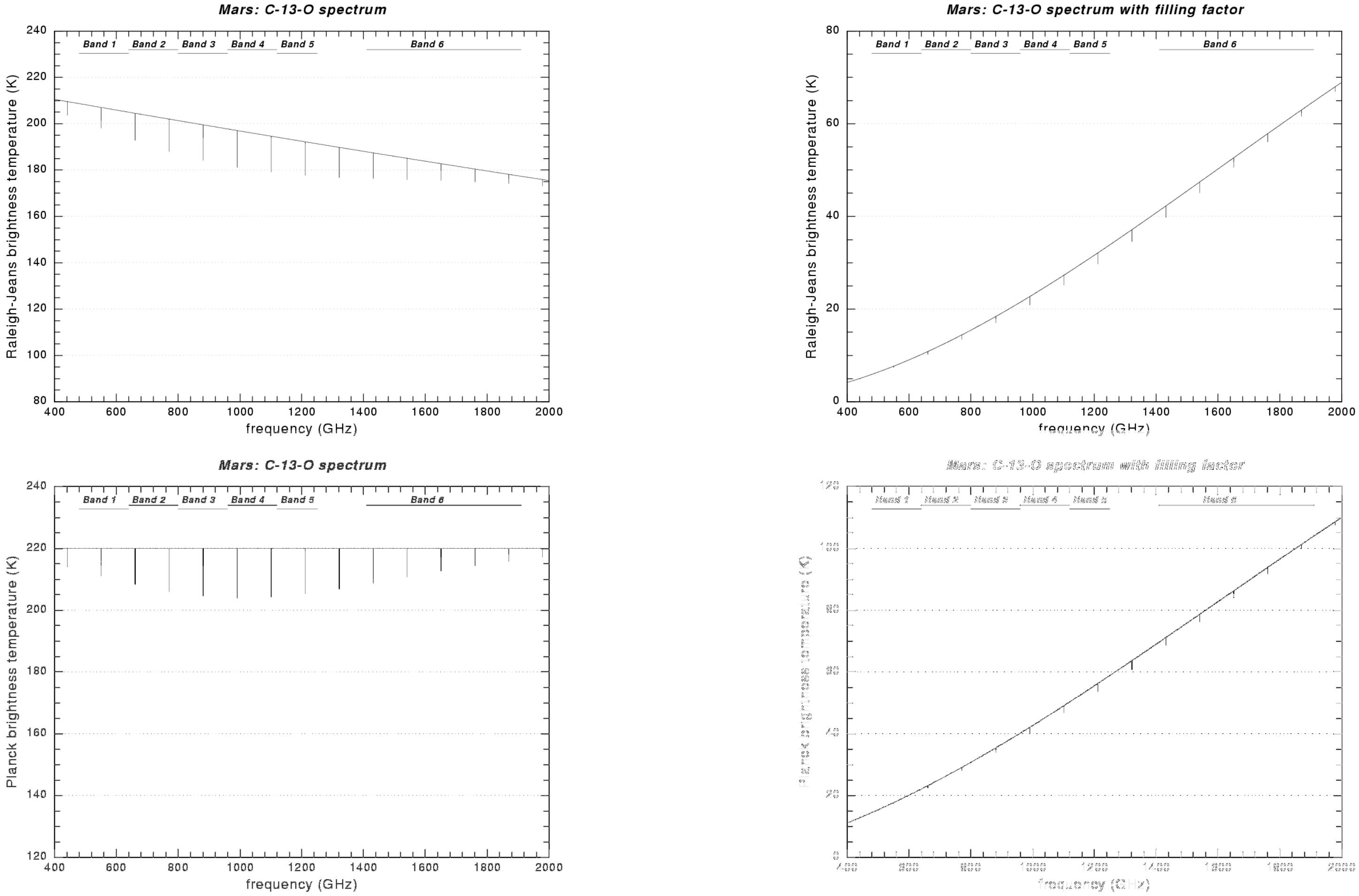

Mars: C-12-O spectrum
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Raleigh-Jeans brightness temperature (K)
frequency (GHz)


Mars: C-12-O spectrum with filling factor
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Raleigh-Jeans brightness temperature (K)
frequency (GHz)


Mars: C-12-O spectrum
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Planck brightness temperature (K)
frequency (GHz)


Mars: C-12-O spectrum with filling factor

C-13-O



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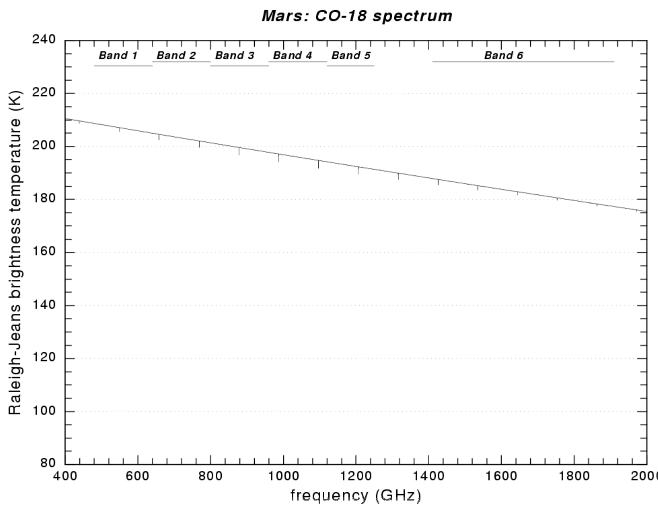
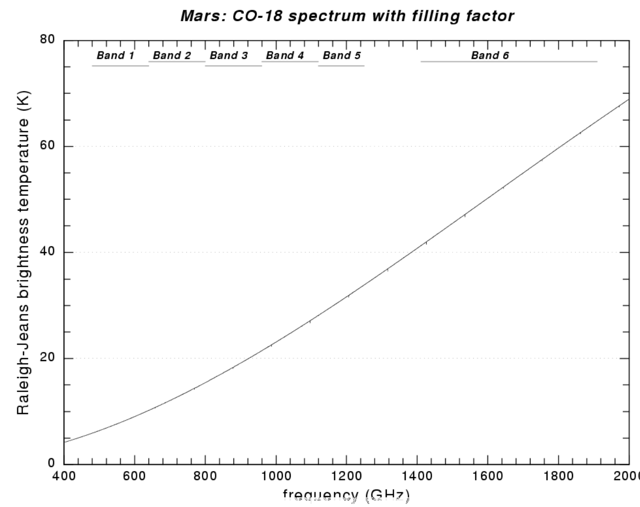
C-18-O


Mars: CO-18 spectrum
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Raleigh-Jeans brightness temperature (K)
240
220
200
180
160
140
120
100
80
400
600
800
1000
1200
1400
1600
1800
2000
frequency (GHz)


Mars: CO-18 spectrum with filling factor
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Raleigh-Jeans brightness temperature (K)
80
60
40
20
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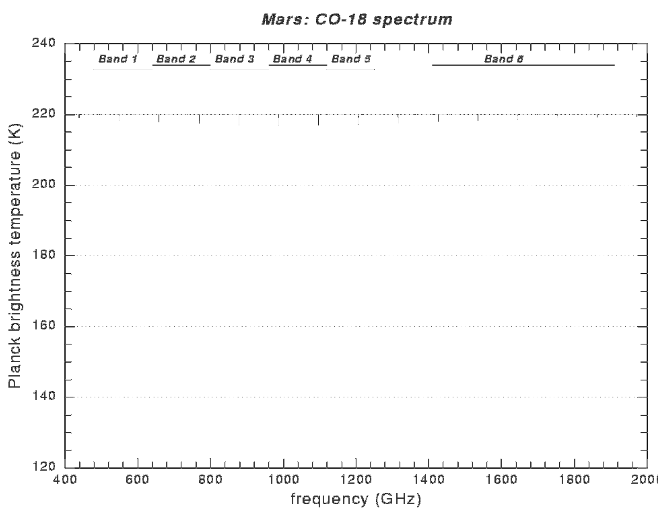
400
600
800
1000
1200
1400
1600
1800
2000
frequency (GHz)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Band 3
Band 4
Band 5
Band 6
Planck brightness temperature (K)
240
220
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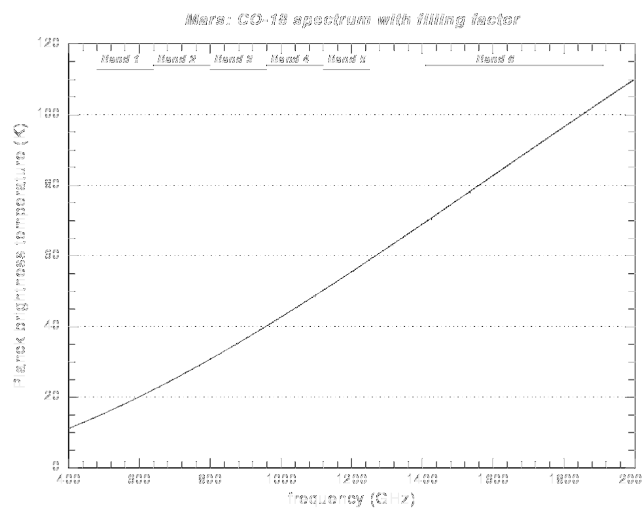
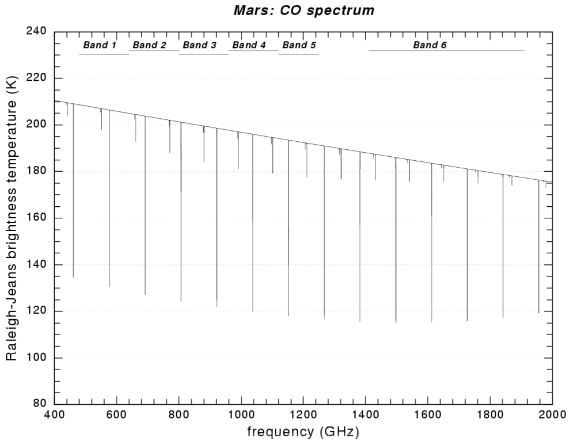
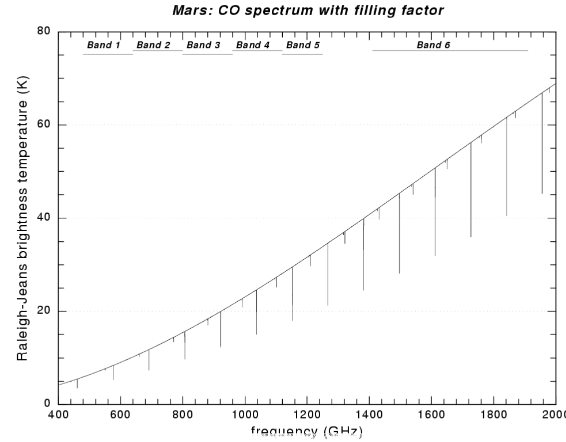
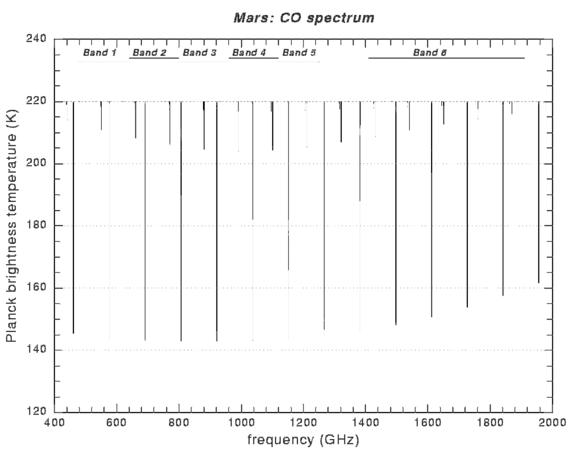
frequency (GHz)

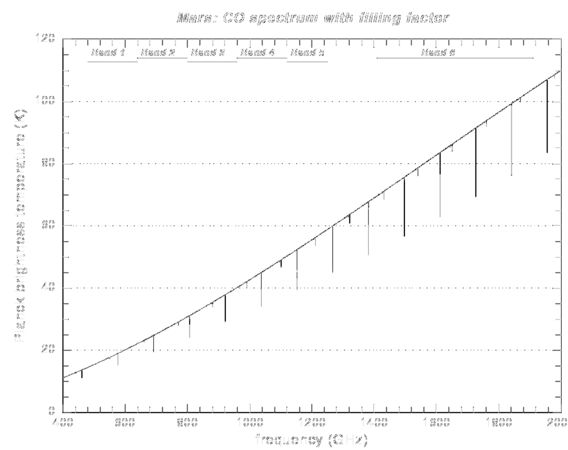

Mars: CO-18 spectrum with filling factor
frequency (GHz)

All CO isotopes

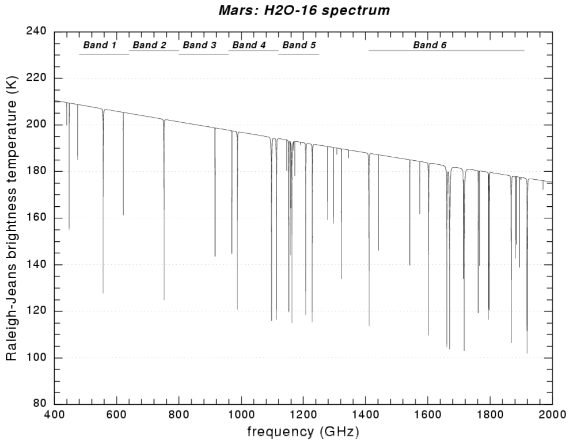


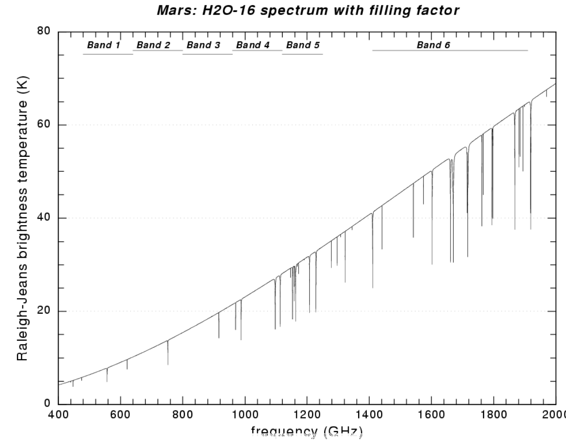


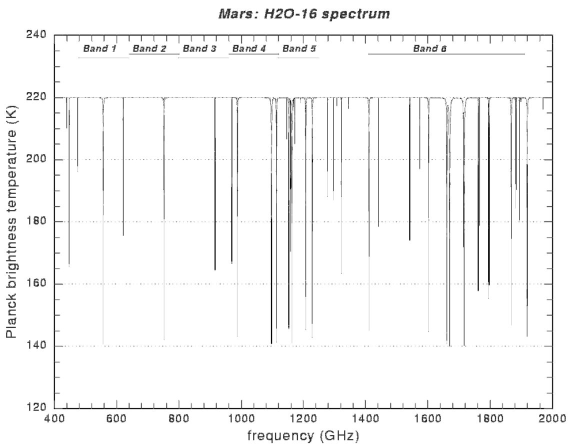


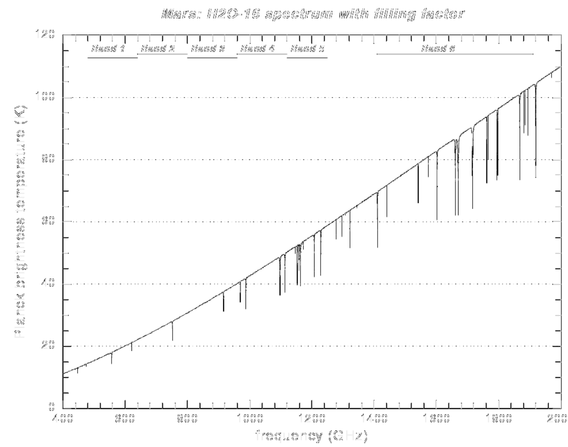


H2O-16









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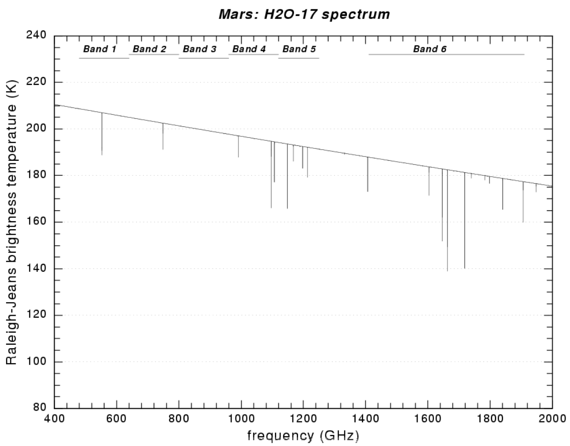
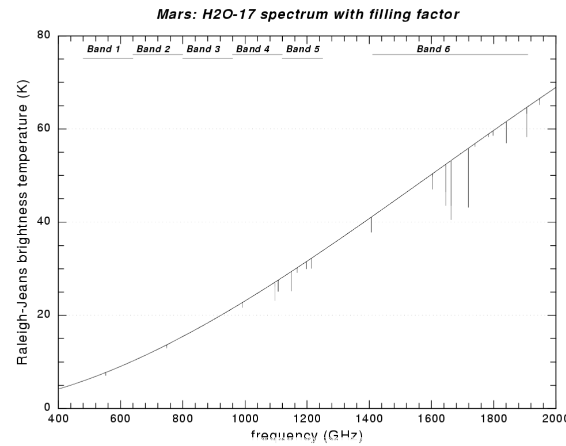
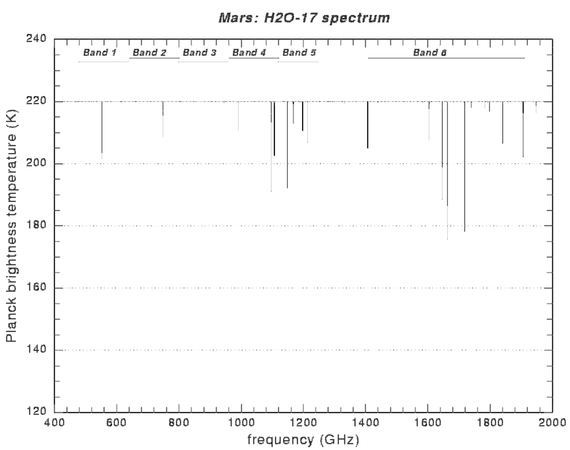
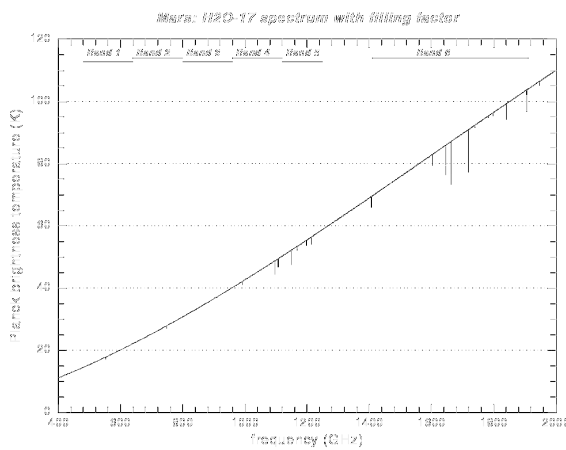
H2O-17

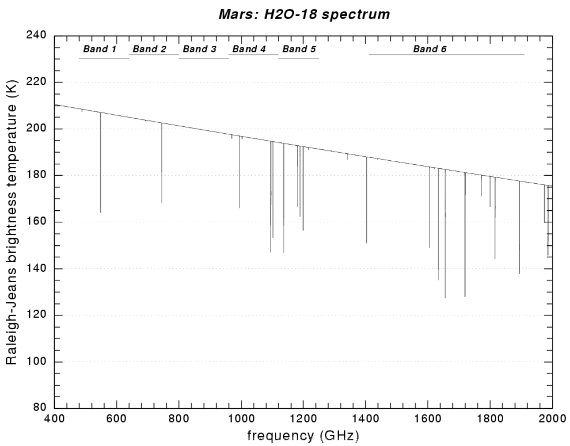

Mars: H2O-17 spectrum
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Raleigh-Jeans brightness temperature (K)
frequency (GHz)

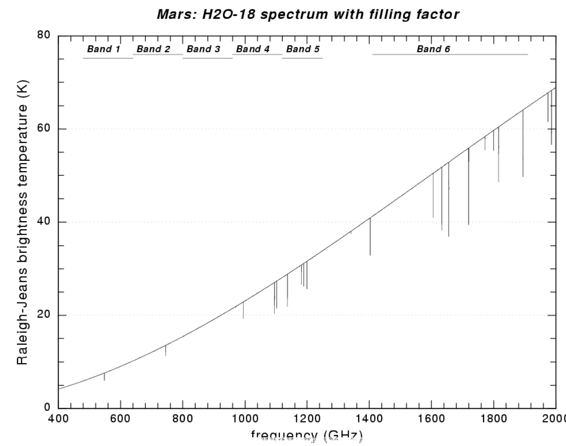

Mars: H2O-17 spectrum with filling factor
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Raleigh-Jeans brightness temperature (K)
frequency (GHz)


Mars: H2O-17 spectrum
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Planck brightness temperature (K)
frequency (GHz)


Mars: H2O-17 spectrum with filling factor

H2O-18


Mars: H2O-18 spectrum
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Raleigh-Jeans brightness temperature (K)
frequency (GHz)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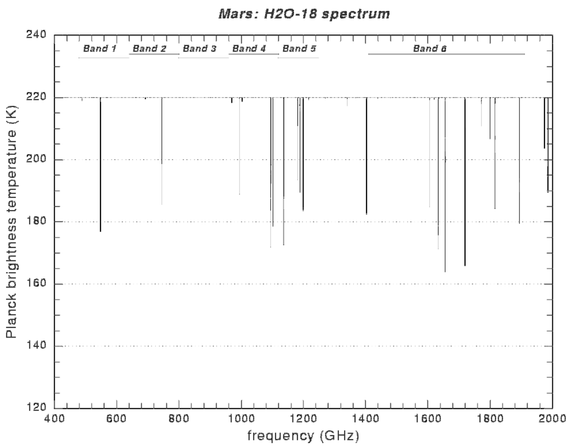
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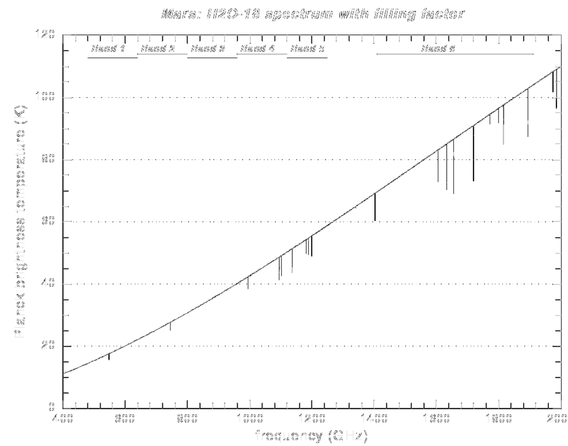
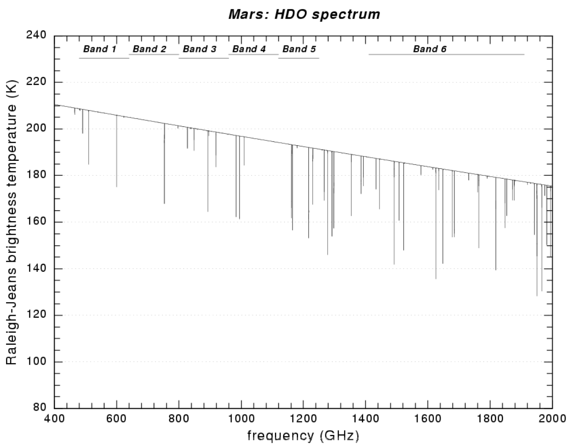
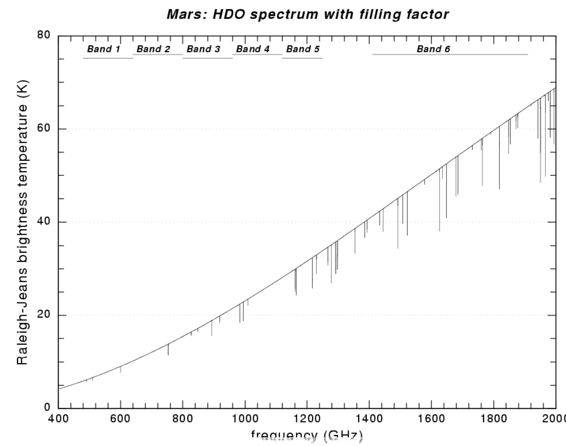
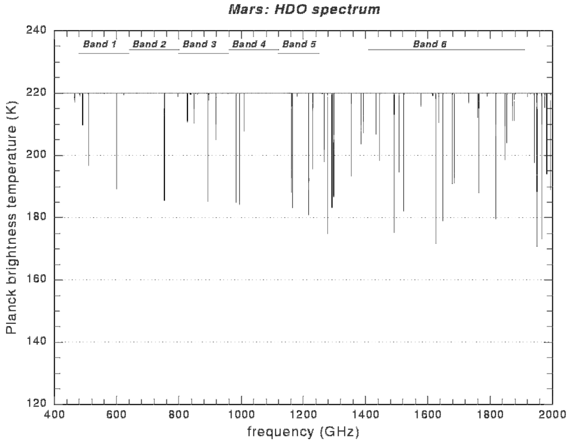
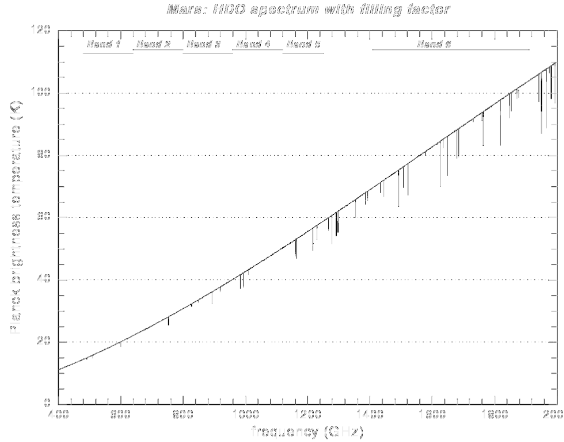


HDO









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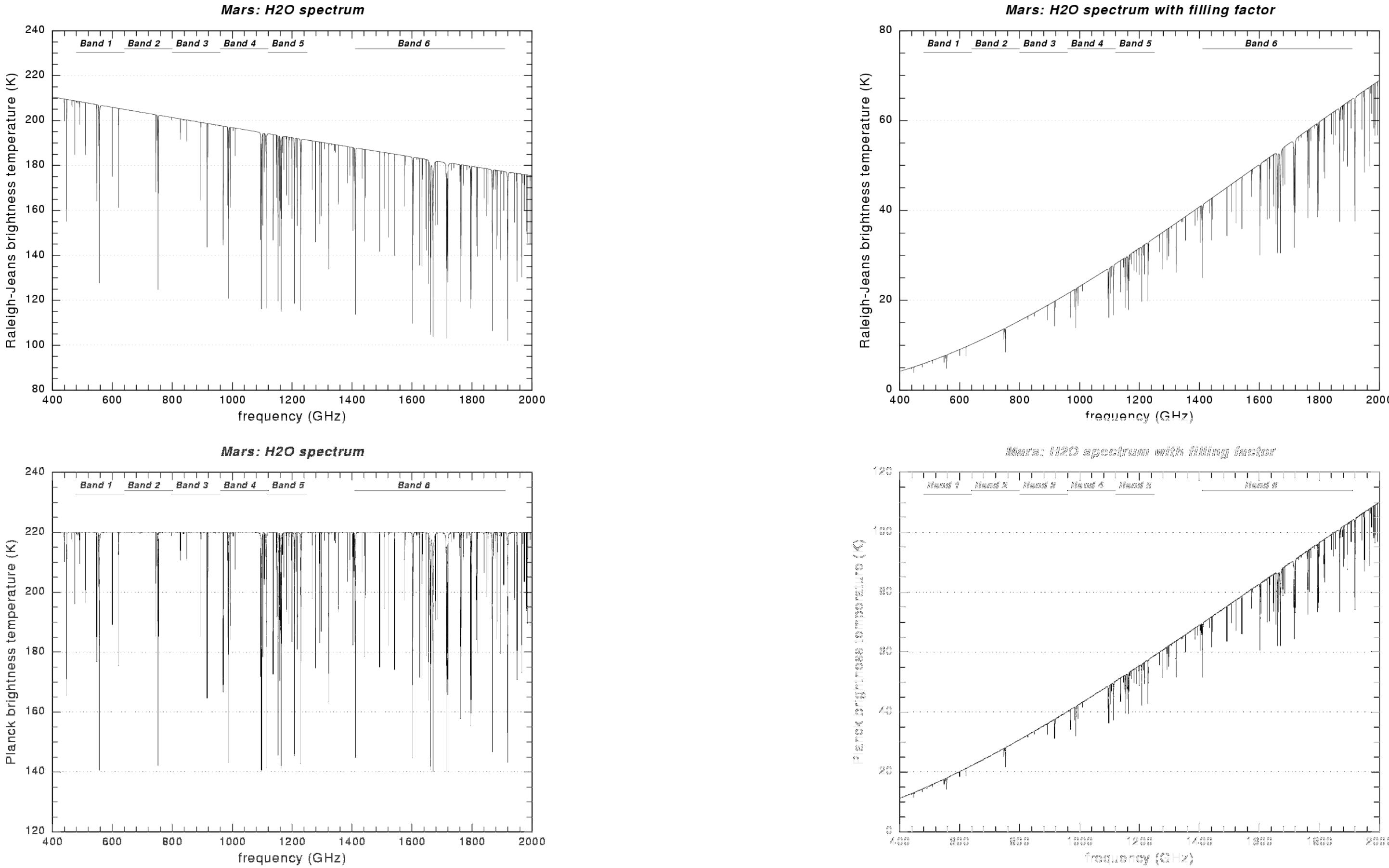
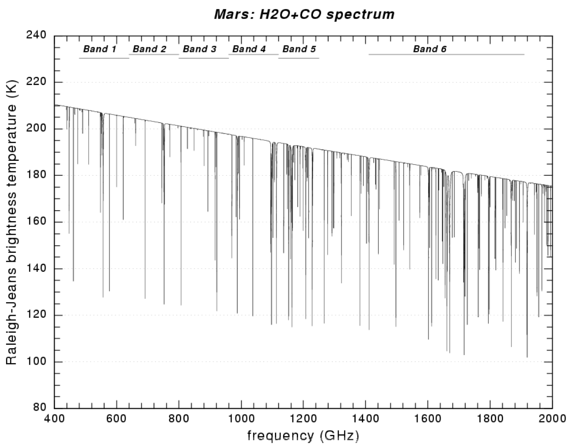
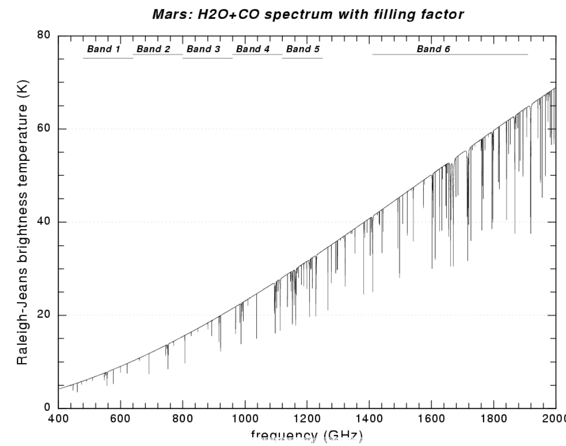
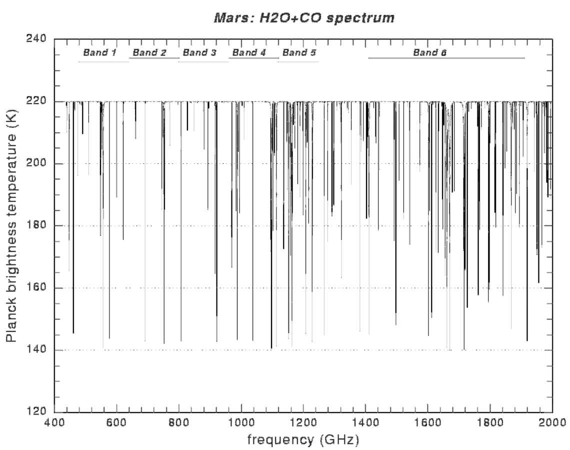
All water isotopes

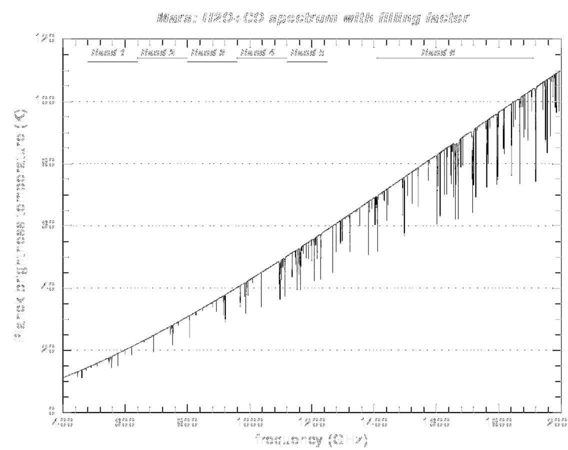


All water and CO isotopes

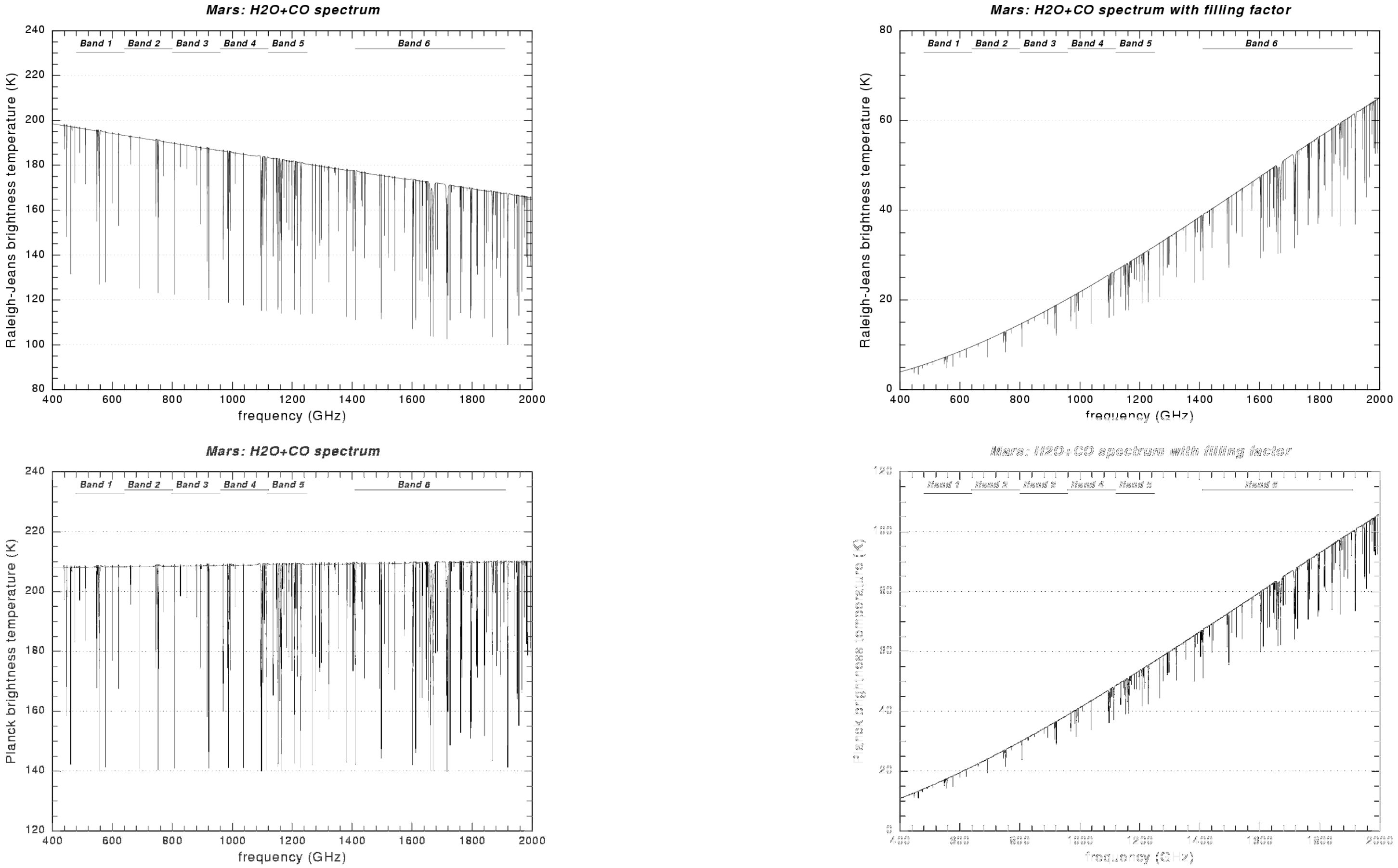








All water and CO isotopes disk averaged



Herschel Space Observatory Calibration Workshop, Leiden 1 - 3 December 2004

Mars as a gas planet

- Does it make sense to observe Mars in the gaps between the lines or may it be better to observe Mars on opaque lines with rather good known VMR as for instance CO? Is it possible to get temperature and VMR accurately enough by detecting many CO isotopic lines?

Summary

- MPS works on a submm RTE Mars model and a general circulation model (MAOAM)
- MPS submm radiative transfer model can be improved in a number of points including the surface and the atmosphere
- Include investigation of flux calibration on opaque lines with known vertical profile