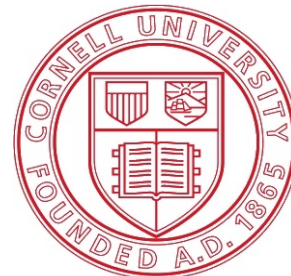


Global and Planetary WRF

Claire Newman (*Caltech, Ashima Research*)

Mark Richardson (*Ashima Research*)

Anthony Toigo (*Cornell*)



Overview

- **Introduction**

Who are we and what are our aims?

- **PlanetWRF**

How we globalized WRF and made it planetary

- **Results**

Selected **MarsWRF** and **TitanWRF** results

- **Get planetWRF**

How to download planetWRF at www.planetwrf.com

Who are we and what are our aims?

We are a group of planetary scientists who wanted a *single model* to look at:

- a range of atmospheric phenomena
- from the global down to the microscale
- on Earth, Mars, Venus, Titan and ?

PlanetWRF development was originally based at Caltech, Cornell and Kobe University, with a lot of help from the NCAR team.

Soon to be based at **Ashima Research** and **Cornell** -
and still very grateful for the NCAR team's help!

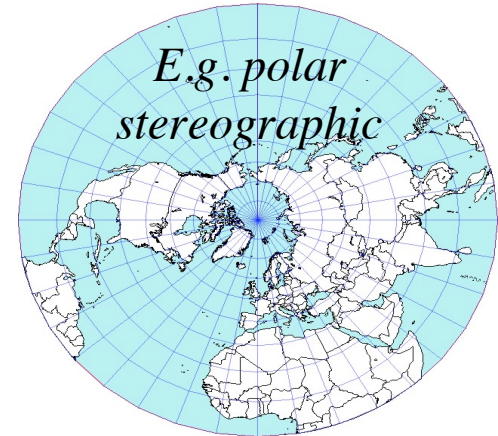
NB: Global WRF is part of the WRFv3.1
public release

planetWRF is publicly available at

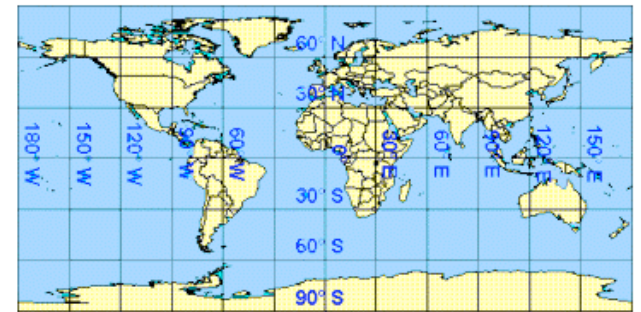
www.planetwrf.com

Globalizing WRF 1. Map scale factors

WRF used *conformal* rectangular grids
 $\Rightarrow$ map-to-real-world scaling factor m was
 the same in x and y directions ($m_x = m_y = m$)



But we needed a *non-conformal* (lat-lon)
 grid to reach from pole to pole and make
 the mother domain global



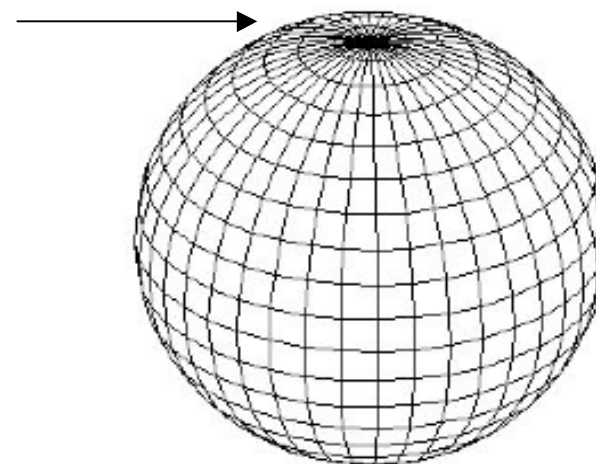
$\Rightarrow m_x = dx/dX = 1/\cos(\text{latitude}), \quad m_y = dy/dY = 1 \quad \Rightarrow m_x \neq m_y$

$\Rightarrow$ Needed to identify which map scale factor was required in all equations where m appeared, and reintroduce map scale factors where they previously cancelled (so had been omitted)

Globalizing WRF 2. Polar filters

In a lat-lon grid the spacing Δx between E-W grid-points becomes small near the poles

But CFL (Courant Friedrichs Lewy) criterion requires $\Delta t \lesssim \Delta x / U$ for stability



To avoid using small Δt everywhere because of small Δx near poles, we increase largest *effective* Δx by filtering out shorter wavelengths

In global WRF the Fourier filter turns on at 45° and allows fewer wavenumbers as latitude increases [module_polar_fft.F]

You can change the filtering latitude via namelist variable `fft_filter_lat` - or set it to 90 to turn off polar filtering entirely

Advantages of global WRF

- Extends WRF's existing 1- and 2-way coupling between domains: *except now mother domain can be whole planet!*
- No change in basic dynamics / physics at different scales
- No more complex coupling between two *different* global and mesoscale models
- 2-way => study multi-scale feedbacks in a global model

Global WRF is already in the WRFv3.1 public release

Ideal case for Earth uses Held-Suarez forcing (BAMS 1994):
`compile em_heldsuarez`

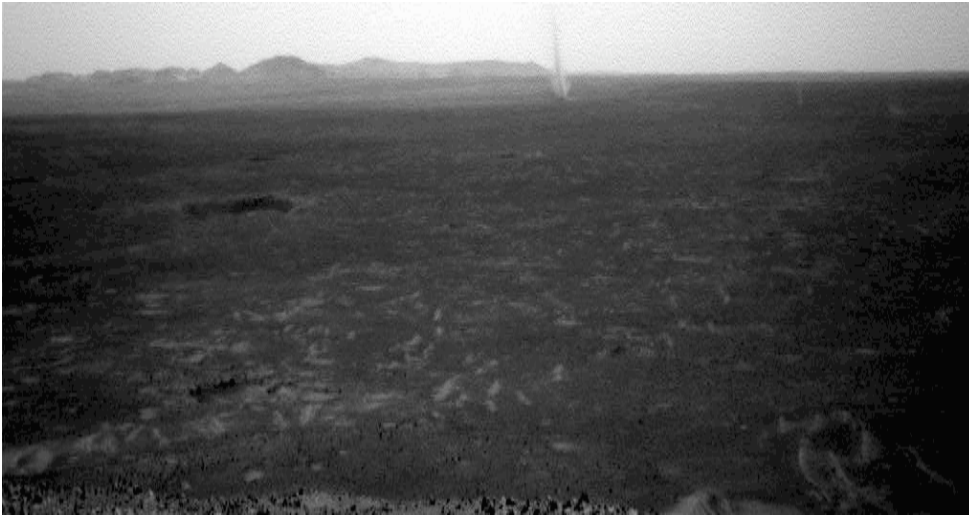
Planetary changes

- **Clocks and calendars:** in namelist we use planetary seconds, hours etc. (24 planetary hours = solar day, etc.) then convert to SI inside WRF
- **Planetary constants:** share/module_model_constants.F holds most [*e.g.* gravity, rotation rate] and others are set during initialization
- **Solar fluxes for sw radtran:** orbital parameters, time of day and location are used in non-planet-specific code to find incident solar flux
- **Adapted physics:** we use adapted versions of the MRF PBL and SFCLAY surface schemes (with *e.g.* hardwired minimums removed)
- **New physics:** we use a similar sub-surface scheme for each planet and a radiative transfer scheme tailored to each atmosphere. Mars has a CO₂ condensation/sublimation cycle; Titan has simple methane ‘hydrology’
- **For more details see Richardson *et al.* 2007**

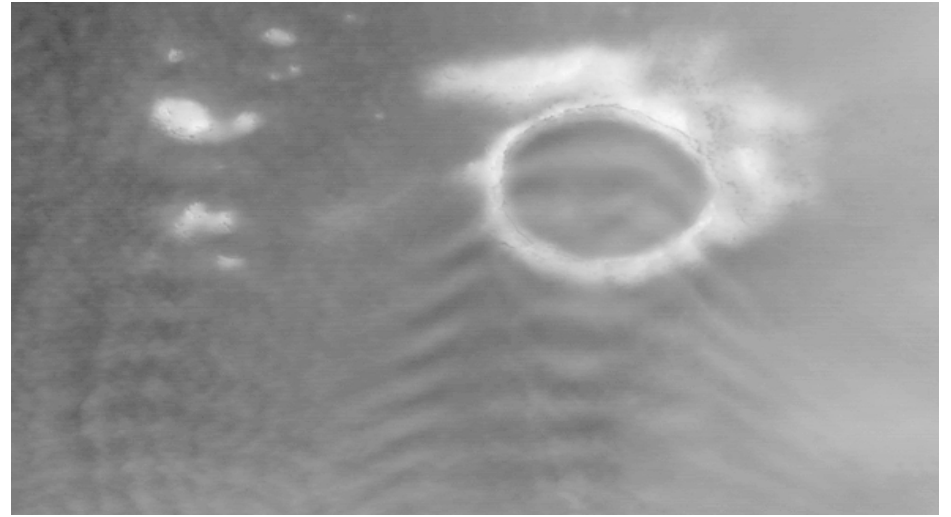
Selected current and planned future uses of planetWRF

Topics of interest: on Mars

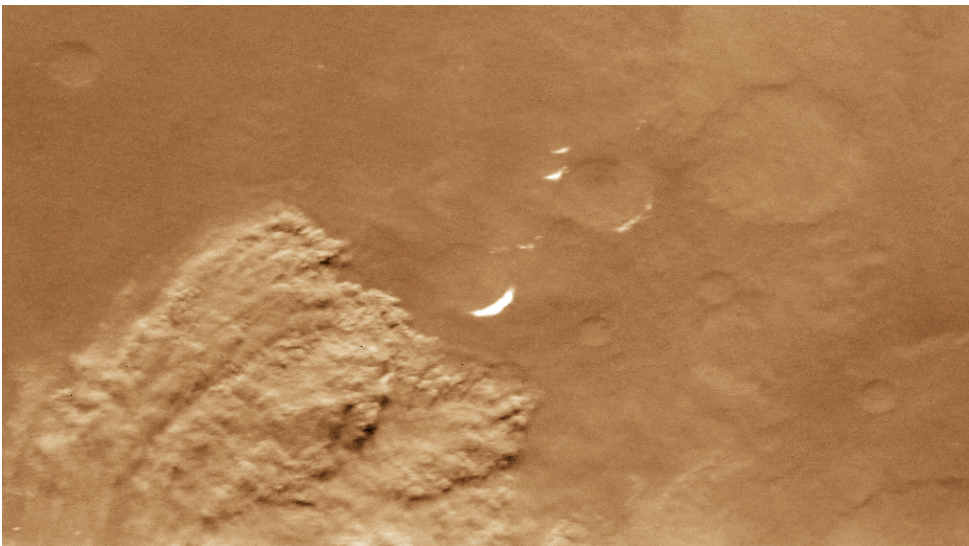
Dust devils



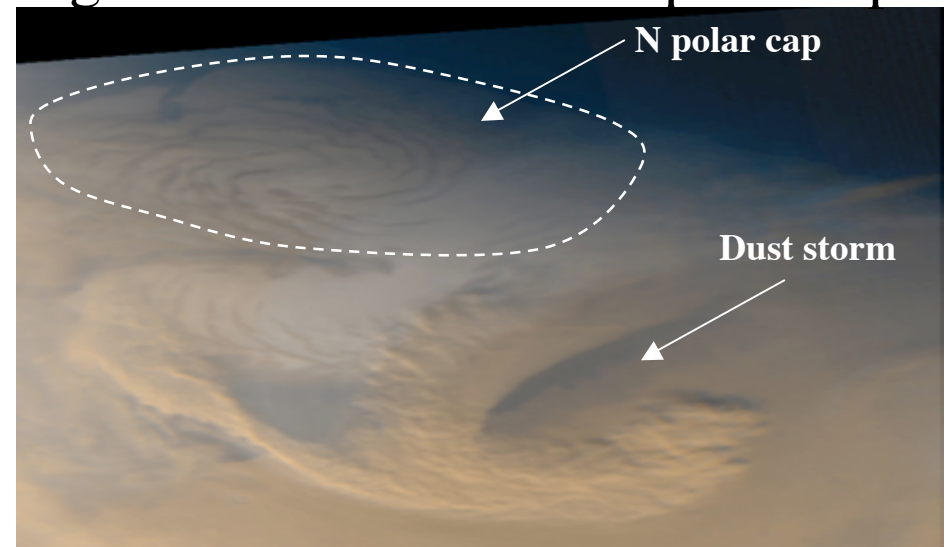
Orographic clouds



Local dust storms

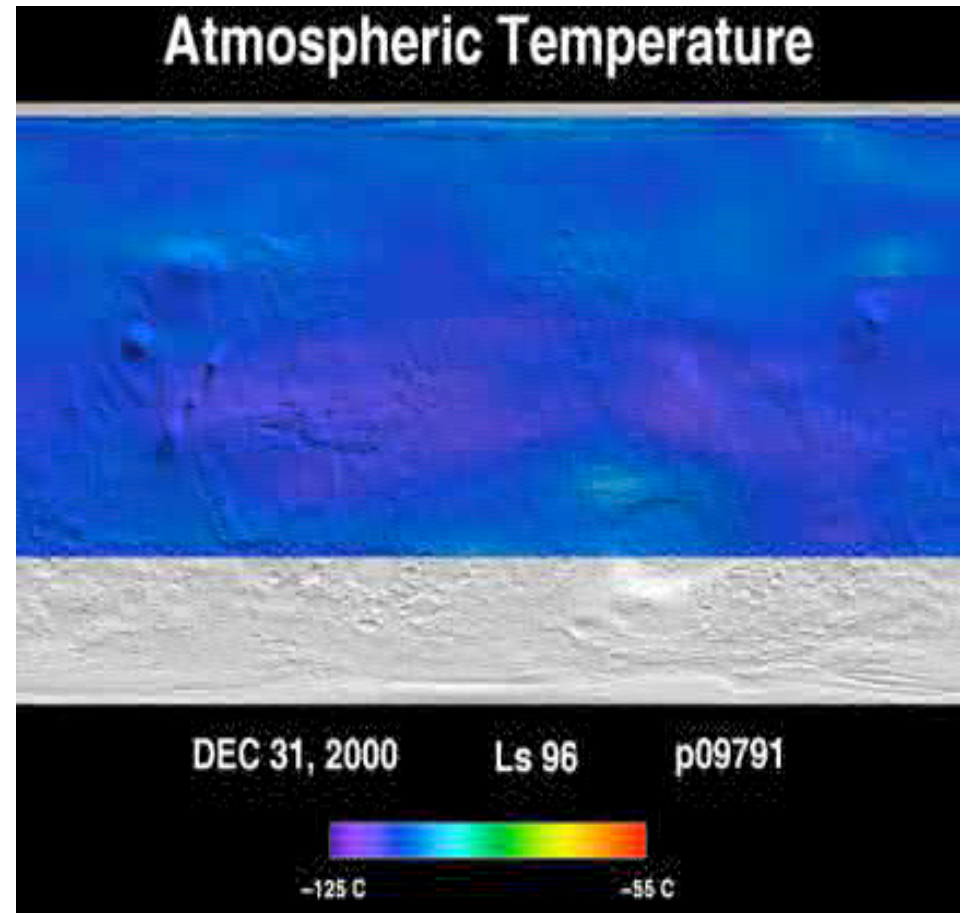
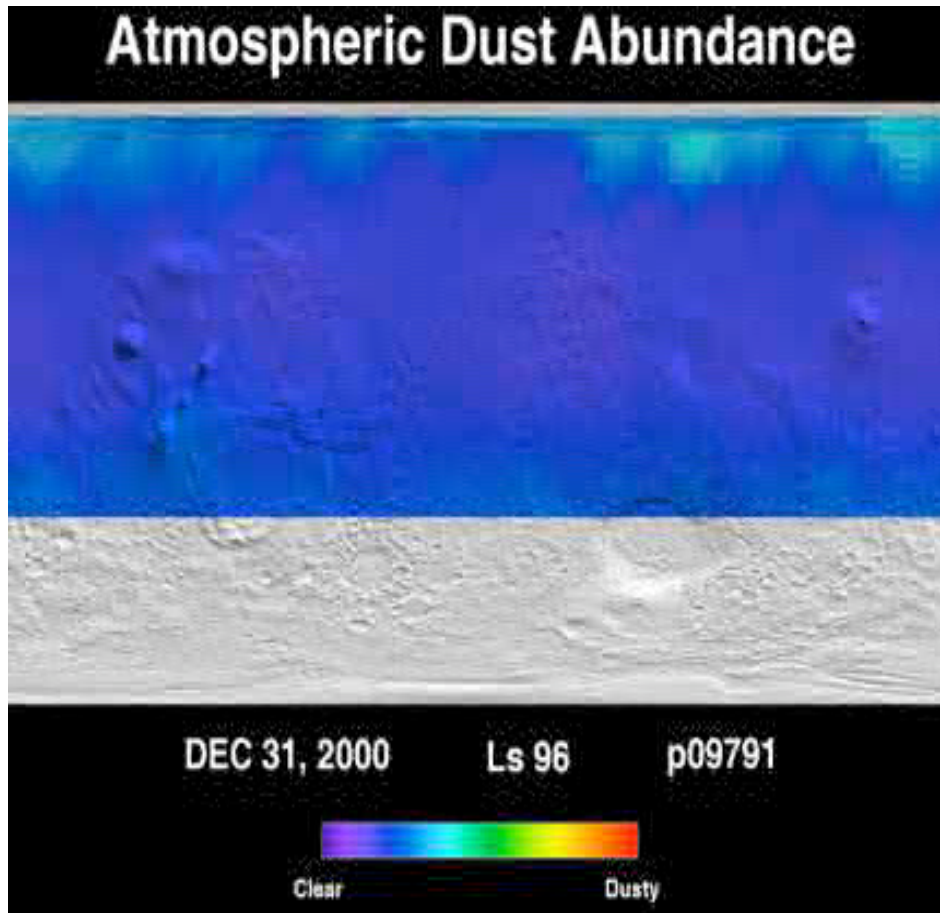


Regional dust storms and polar caps



Topics of interest: on Mars

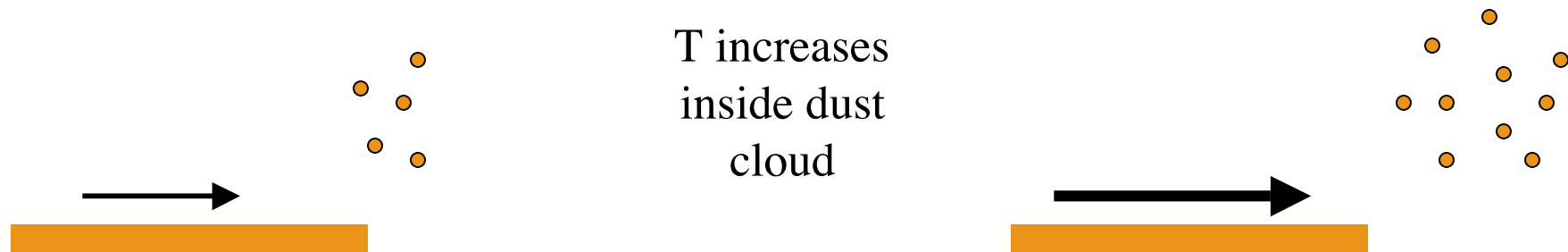
Global / planet-encircling dust storms



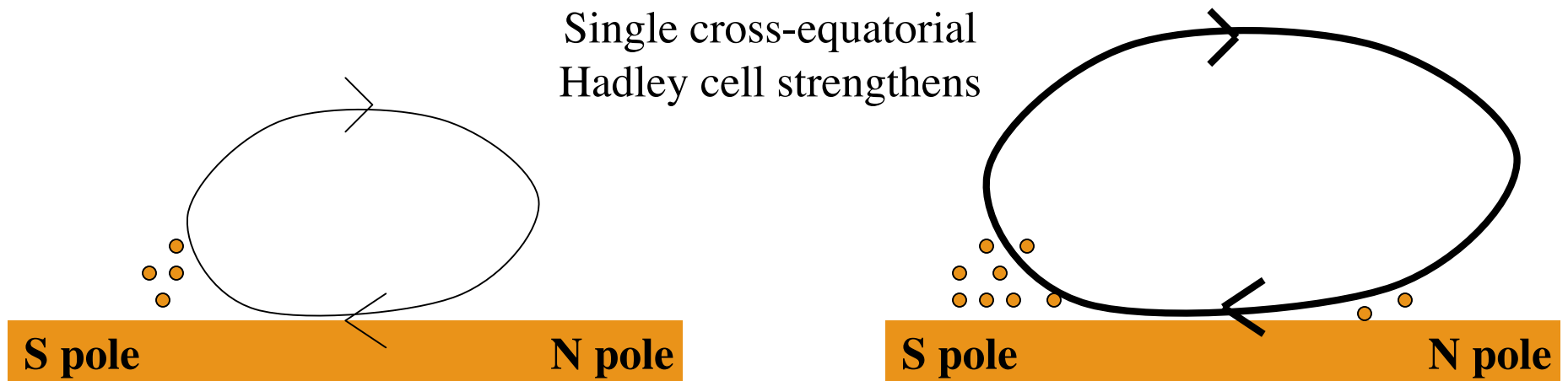
Multi-scale feedbacks are *vital* to modeling their onset and growth

Modeling Martian dust storms

Local positive feedback:



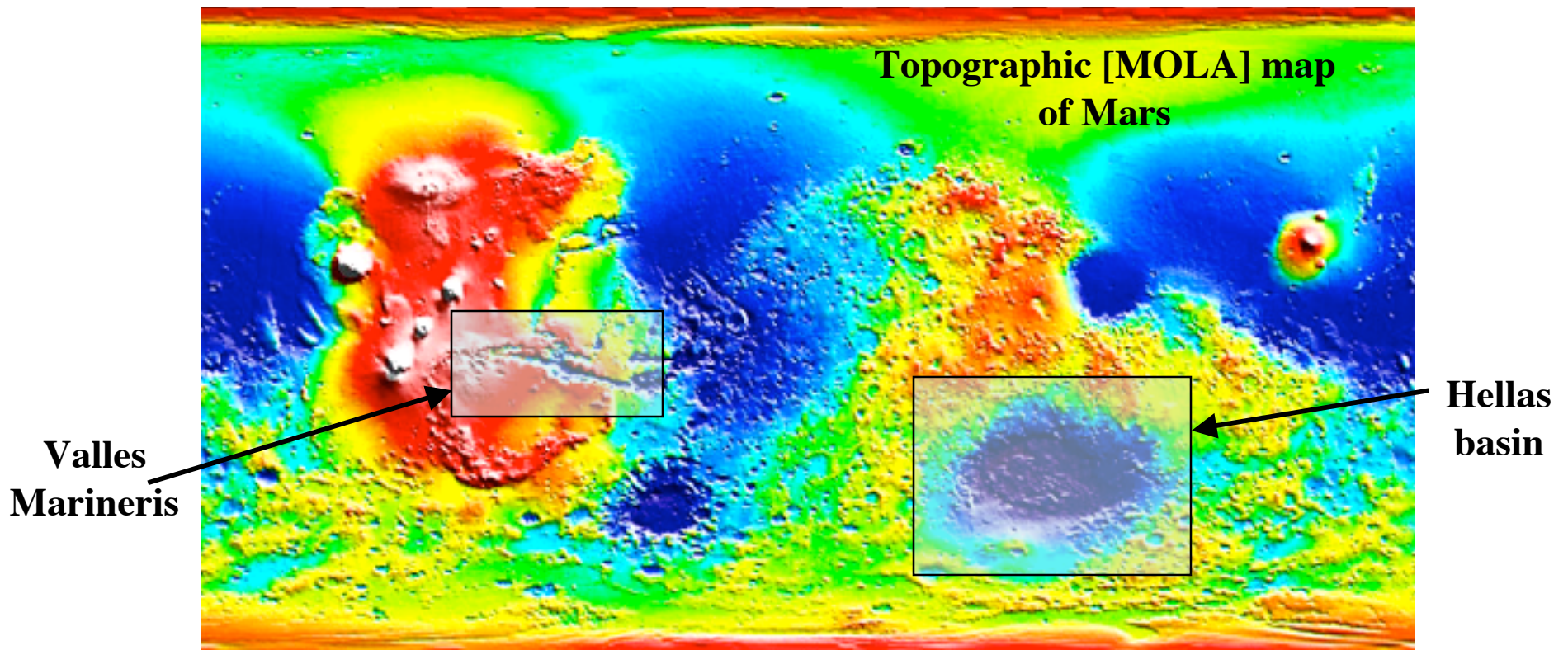
Global positive feedback:



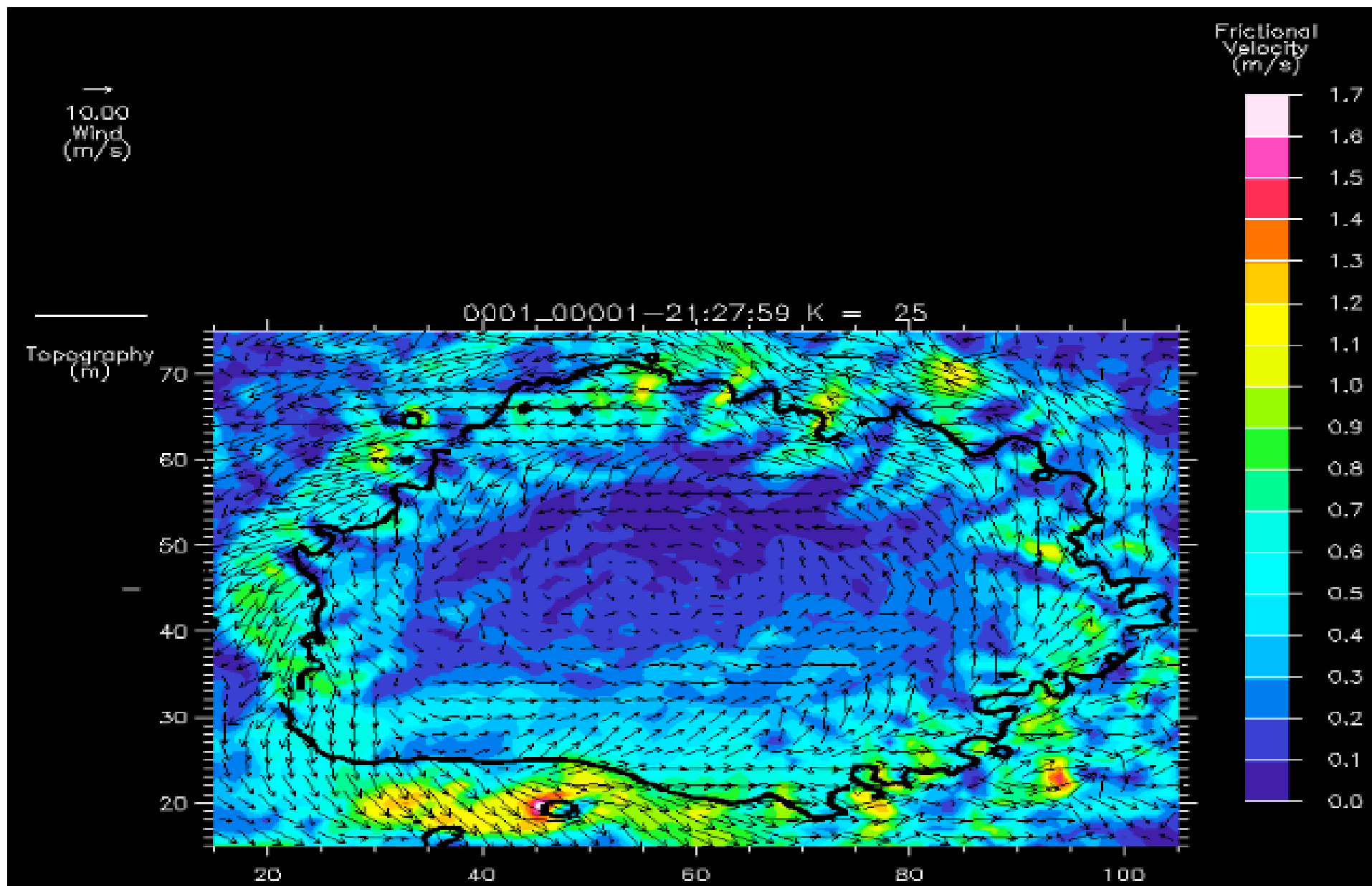
Modeling Martian dust storms

Need to capture *multi-scale feedbacks* - three approaches:

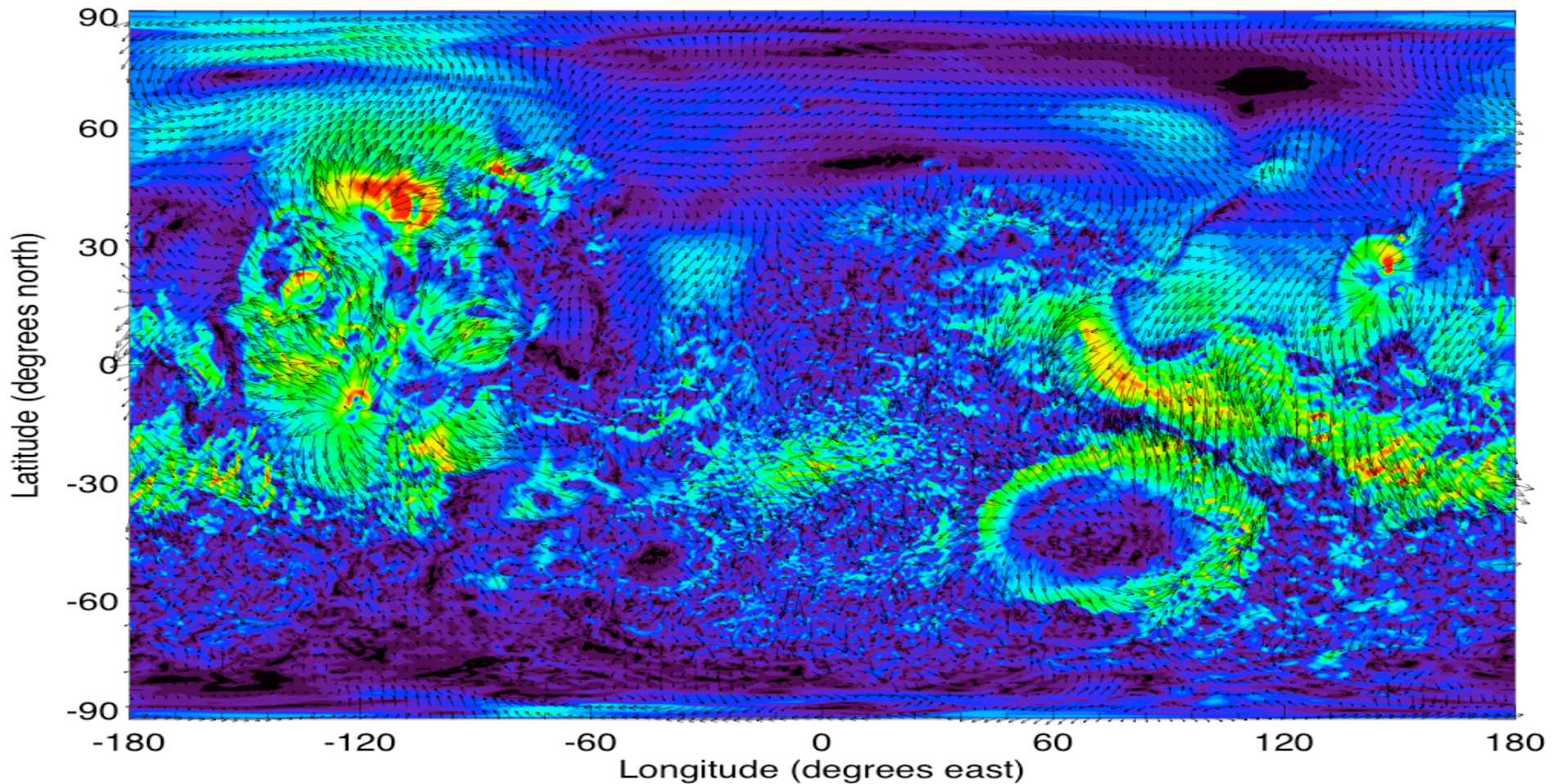
1. Limited-area simulations to study dust lifting and *local* feedbacks
2. *Global high resolution* dust simulations
3. Global standard resolution dust simulations with *nesting* - e.g.:



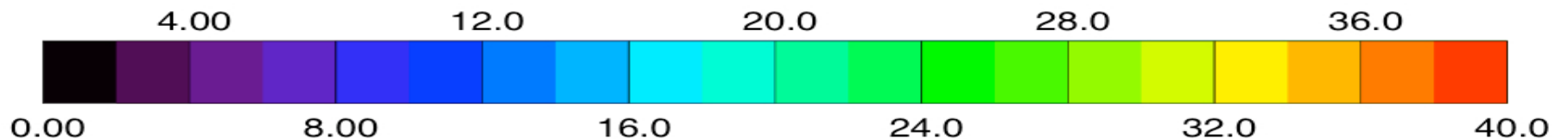
1. Limited-area simulation of the Hellas basin



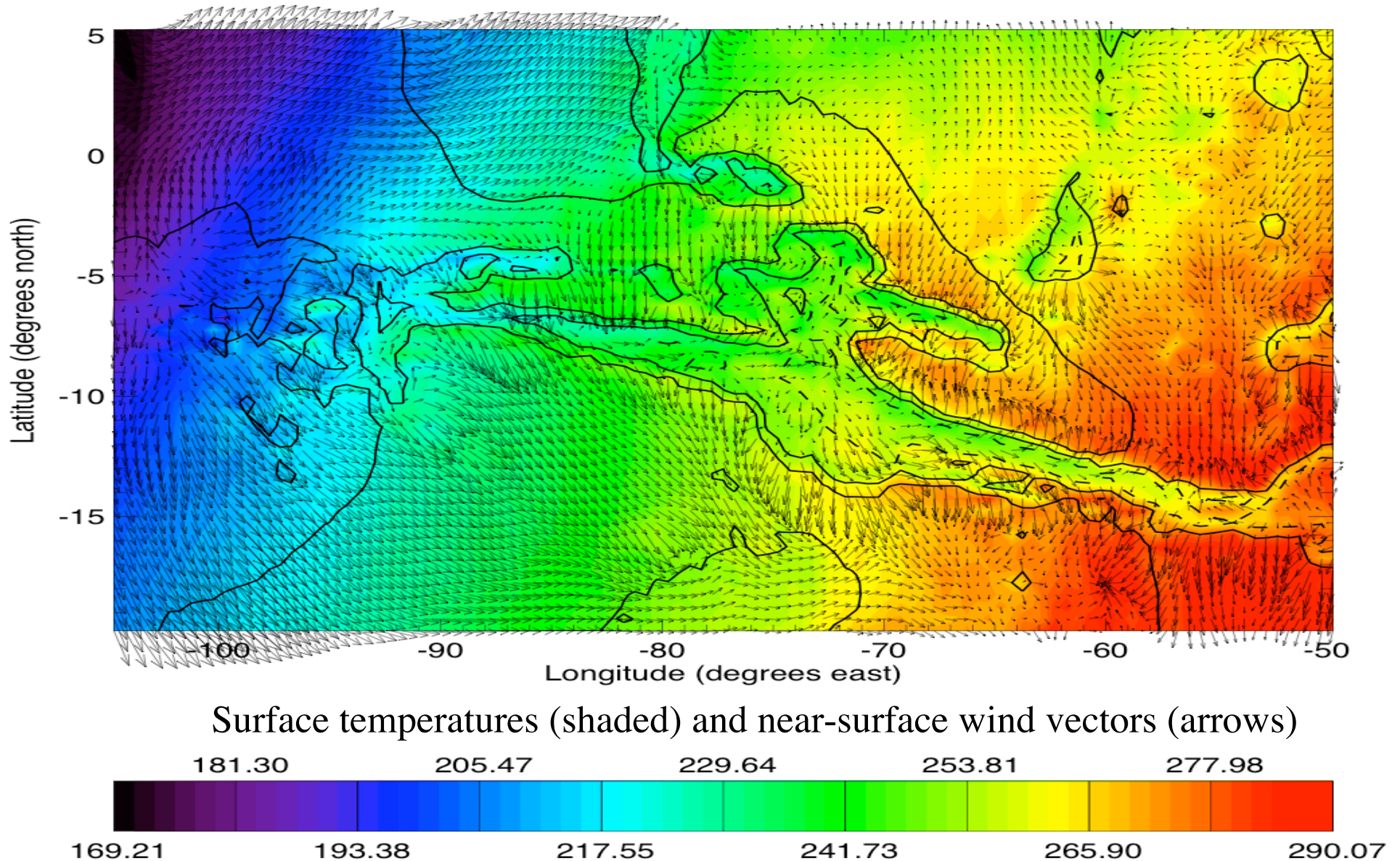
2. MarsWRF run at 0.5° global resolution



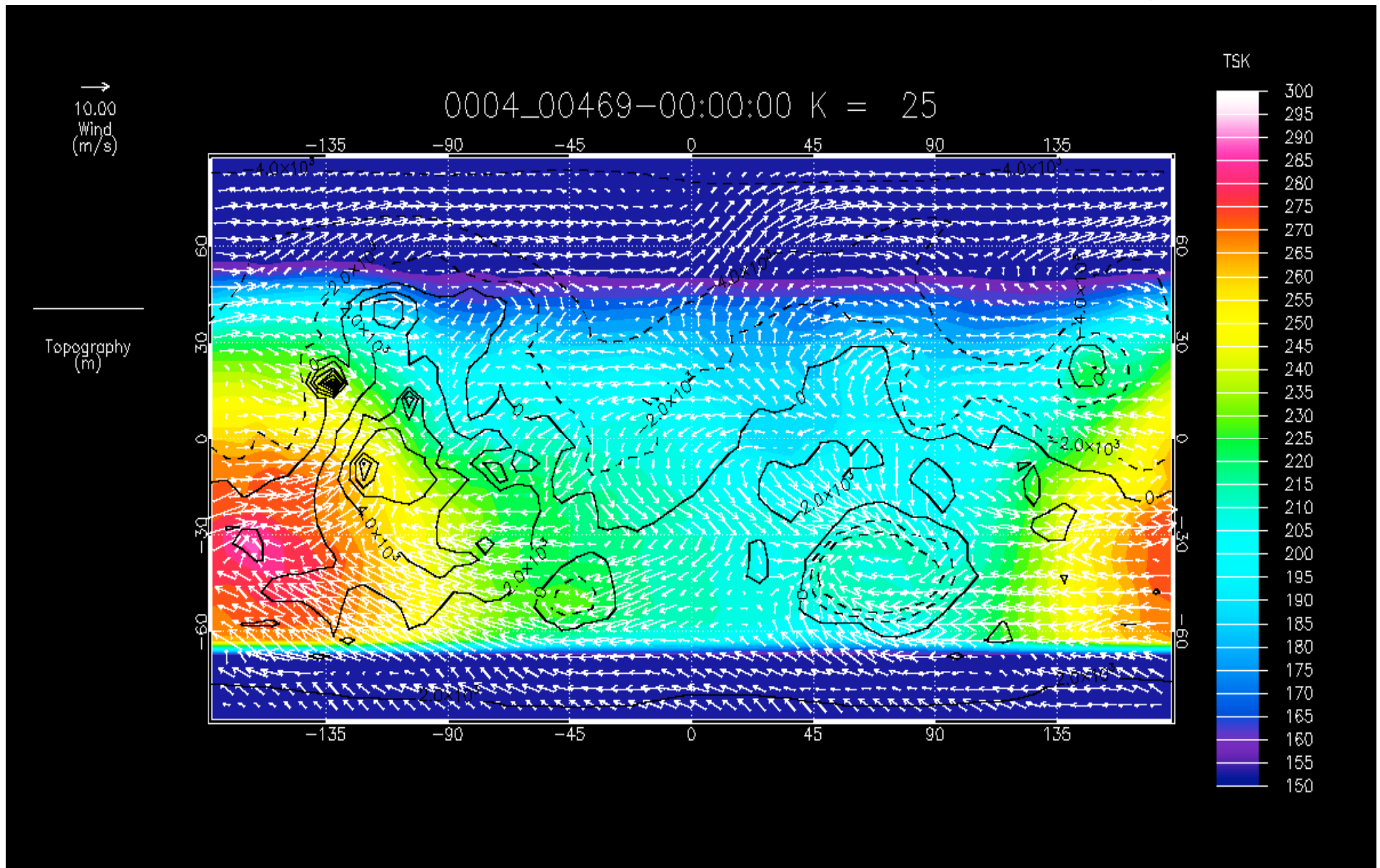
Near-surface wind magnitudes (shaded) and every 4th wind vector (arrows)



3. Nesting to study slope flows in Valles Marineris



We run MarsWRF on a standard lat-lon grid...



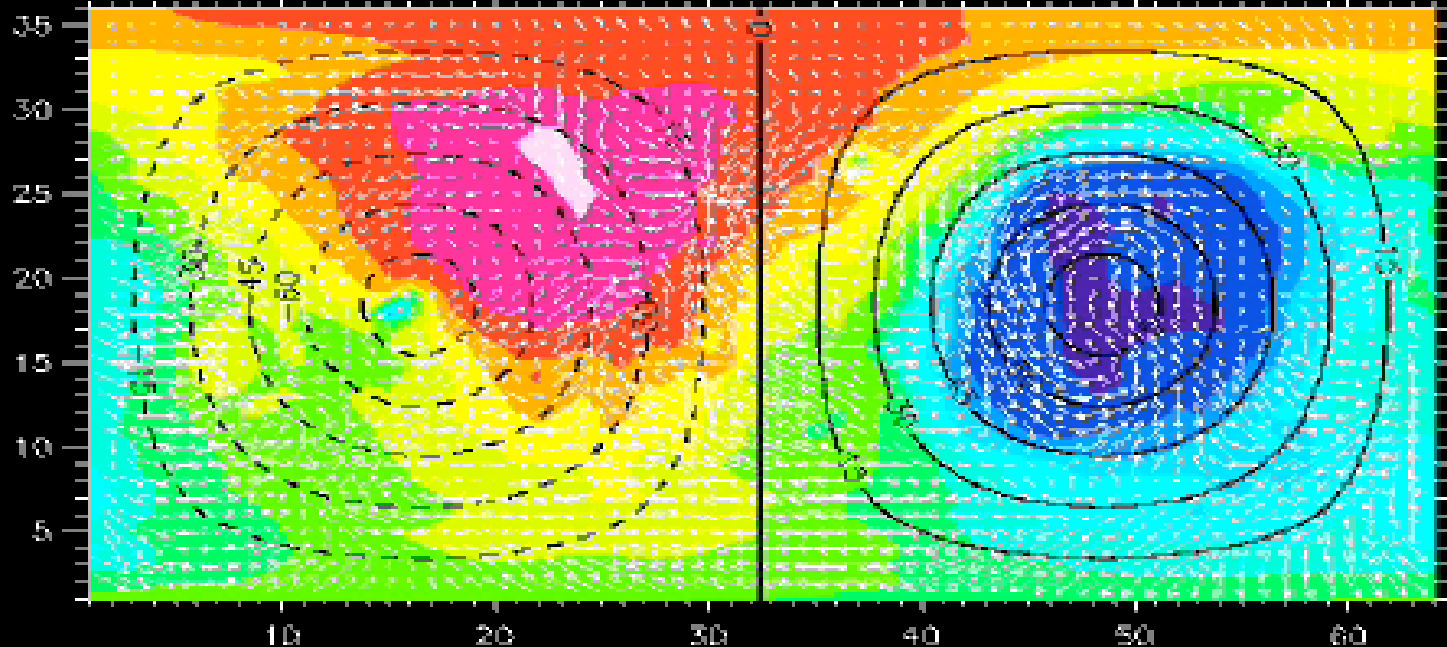
...or as a 'rotated pole' simulation

WRF's flexible map projections let us put the numerical poles at the equator to *e.g.* avoid Fourier filtering at the geographical poles

→
20.00
Wind
(m/s)

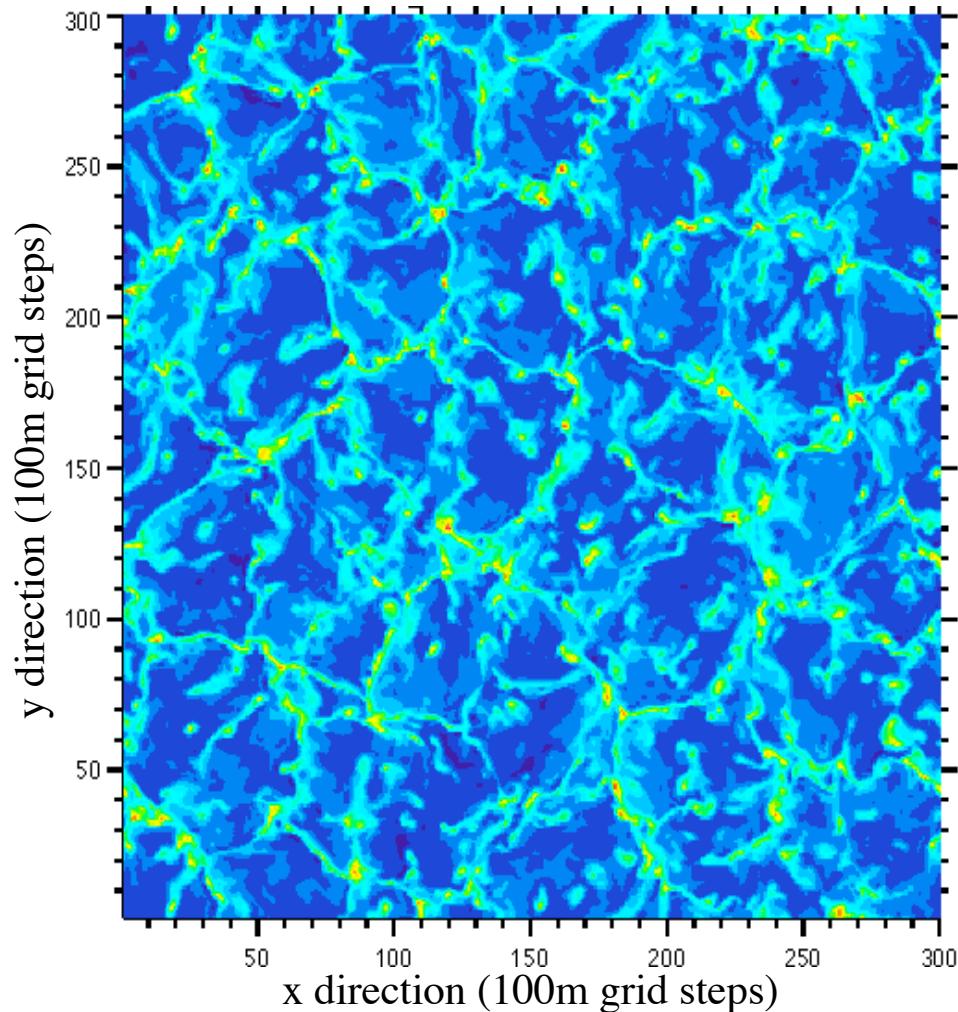
XLAT

0001_00521-00:00:00 K = 21

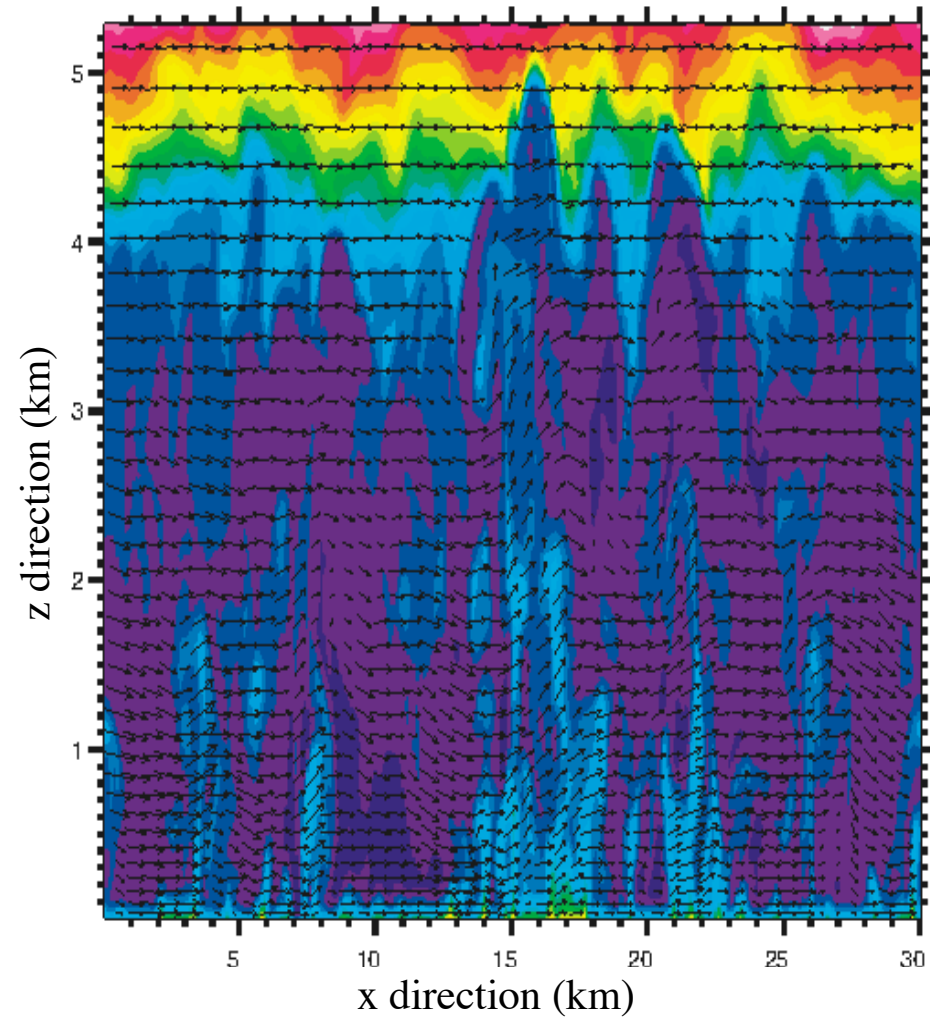


Large eddy simulation of convection on Mars

Vertical velocity (looking down)



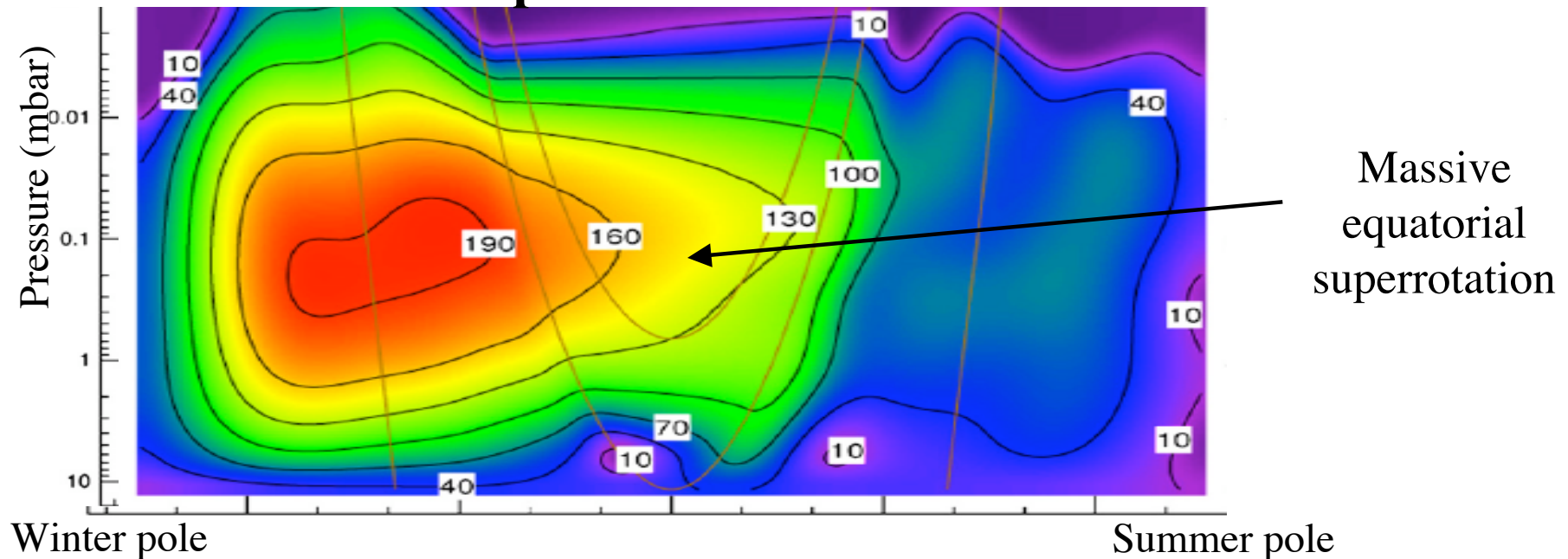
Potential temperature (from the side)



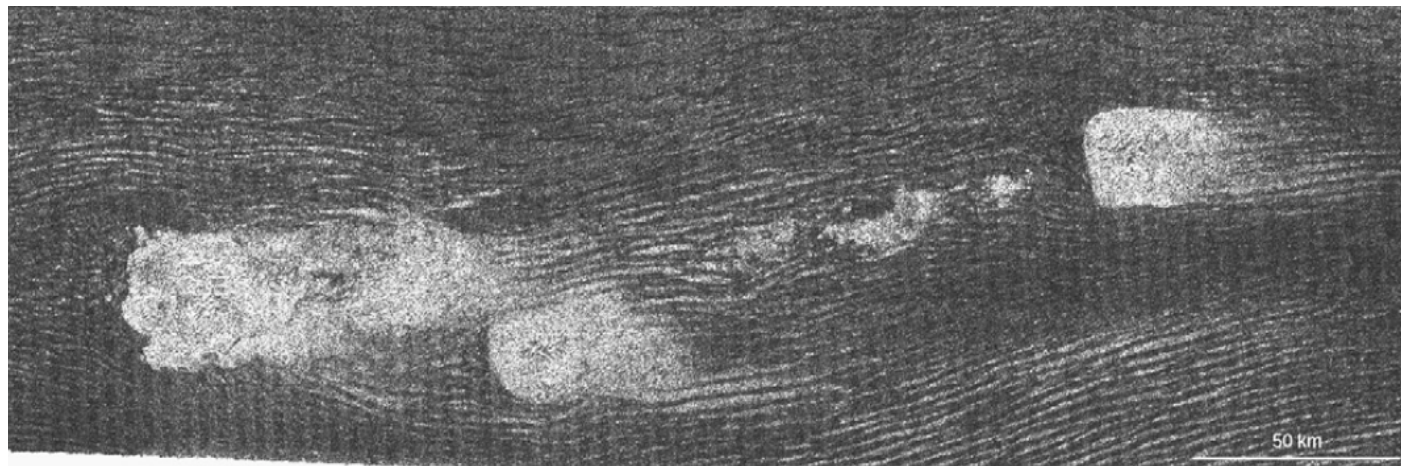
Horizontal grid spacing is 100m [total domain size 30kmx30km]

Topics of interest: on Titan

Stratospheric zonal winds



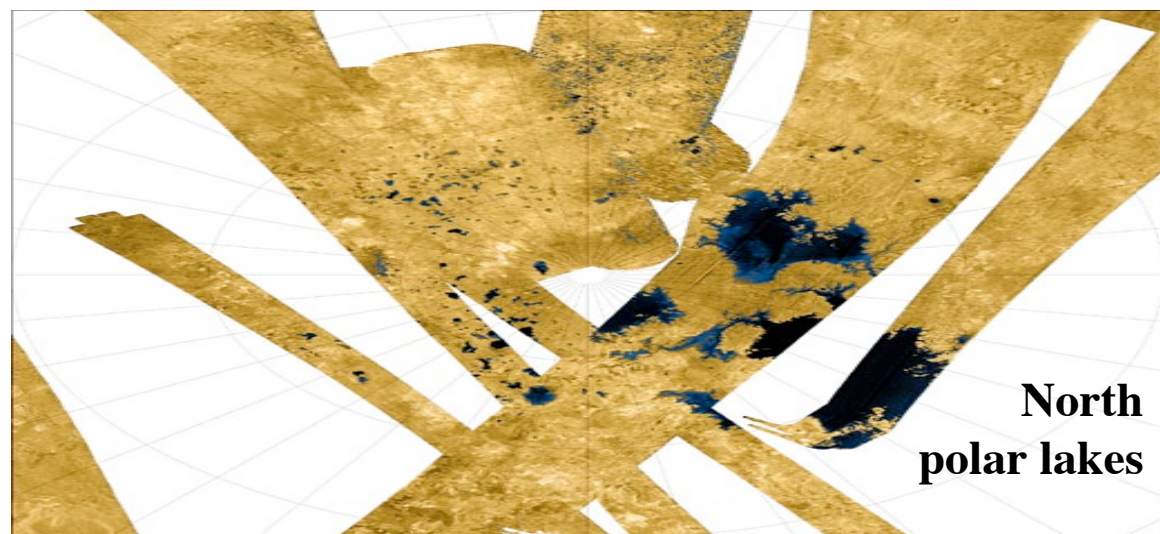
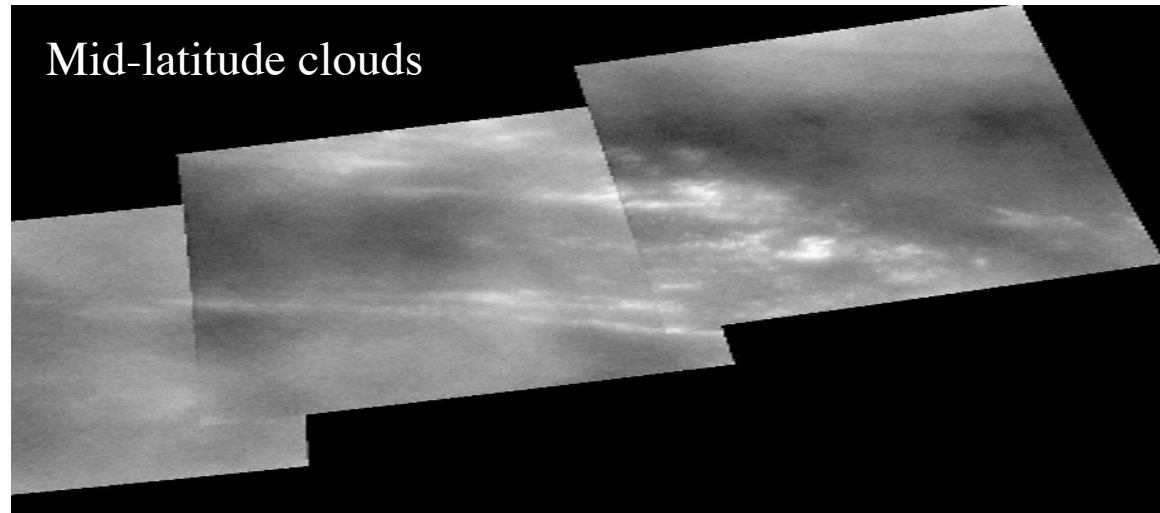
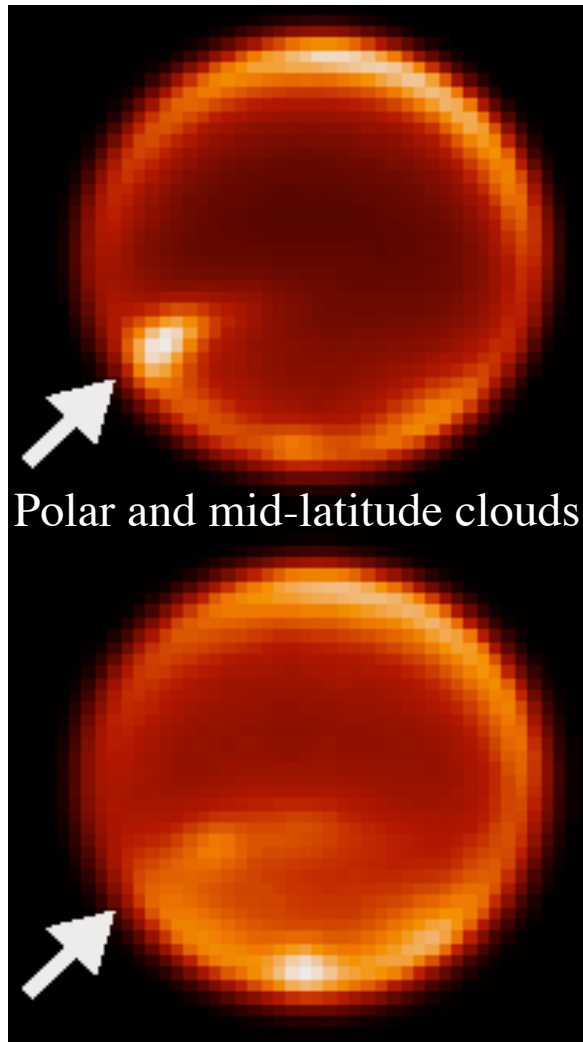
Surface dunes



Providing
information
about surface
winds

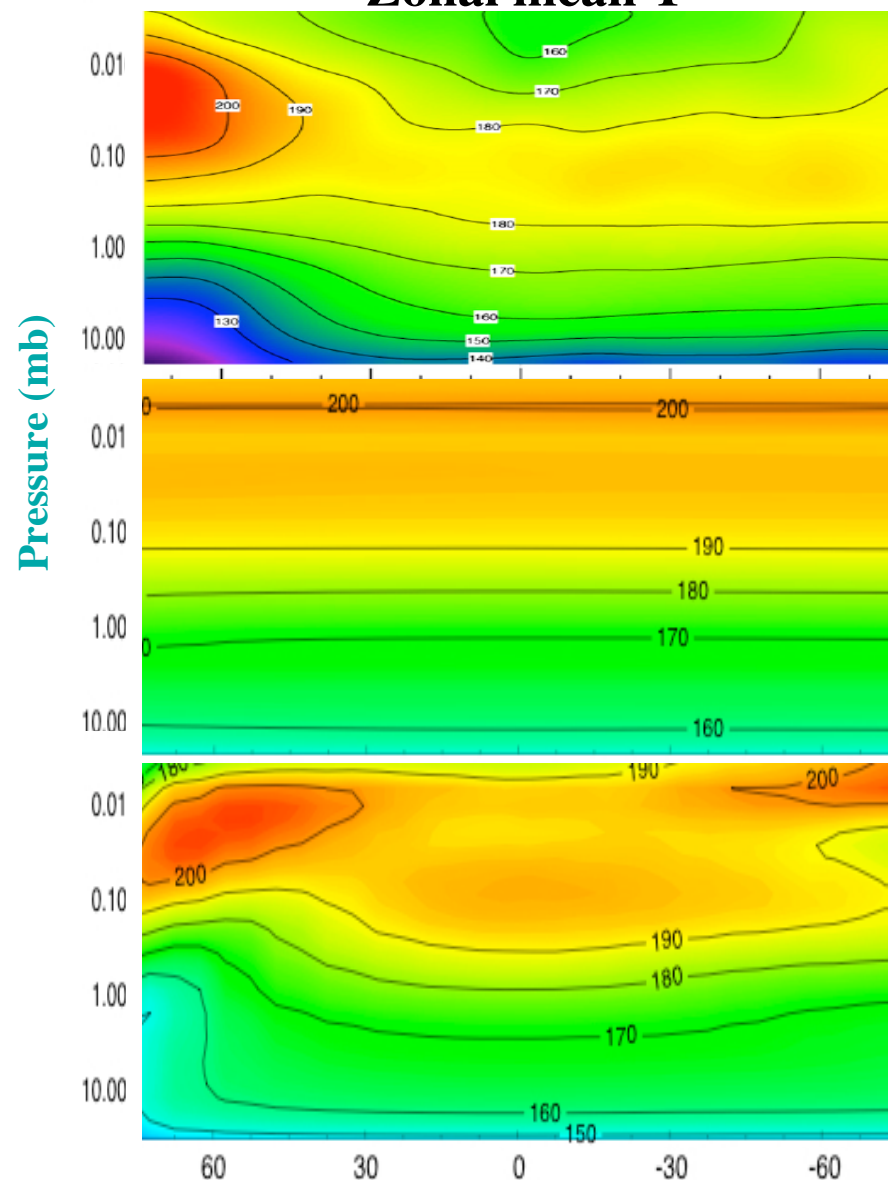
Topics of interest: on Titan

Tropospheric methane clouds and polar lakes



Reducing horizontal diffusion in TitanWRF

Zonal mean T

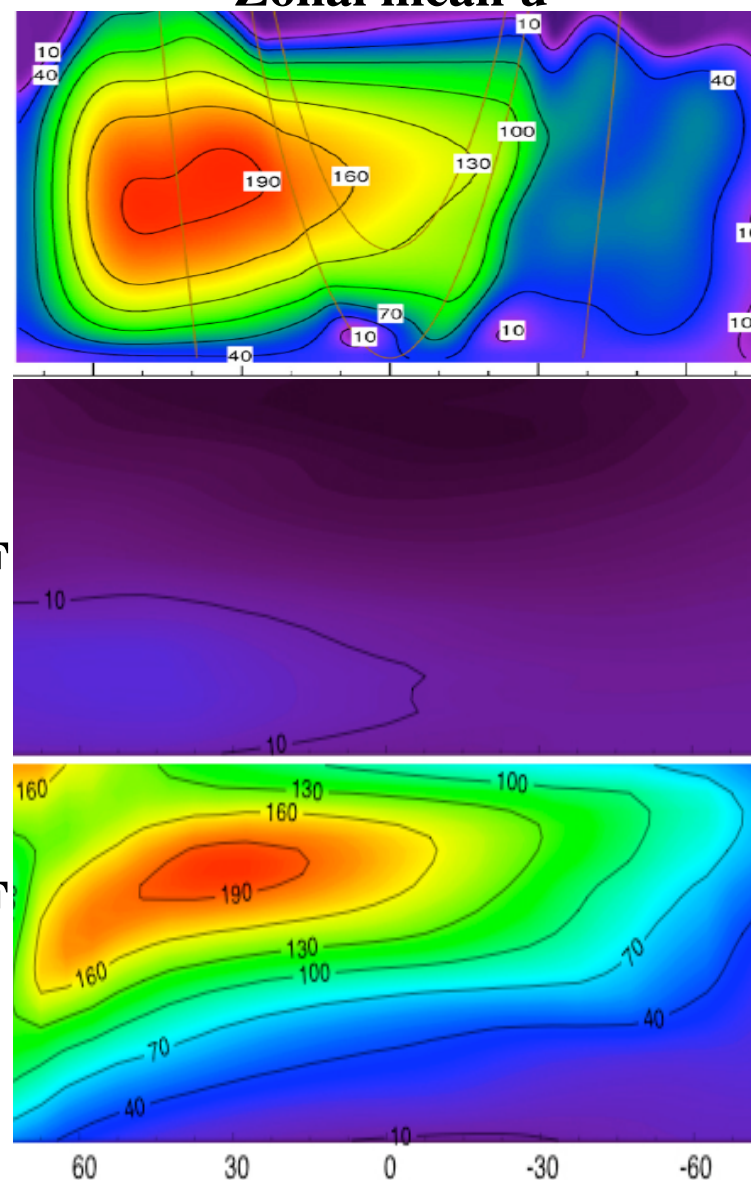


Observed

Old
TitanWRF

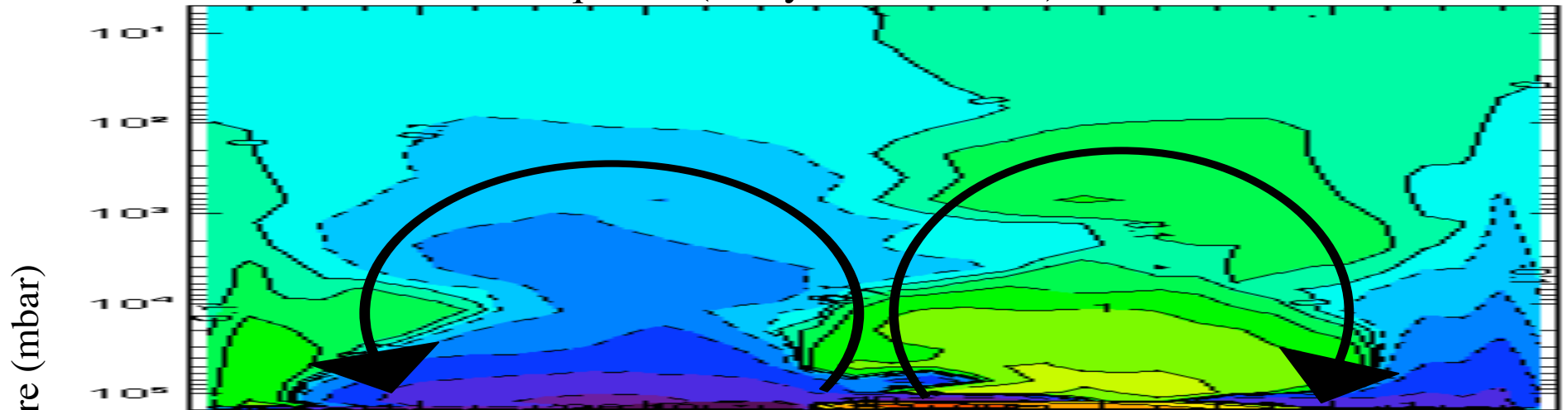
New
TitanWRF
(far less
diffusion)

Zonal mean u

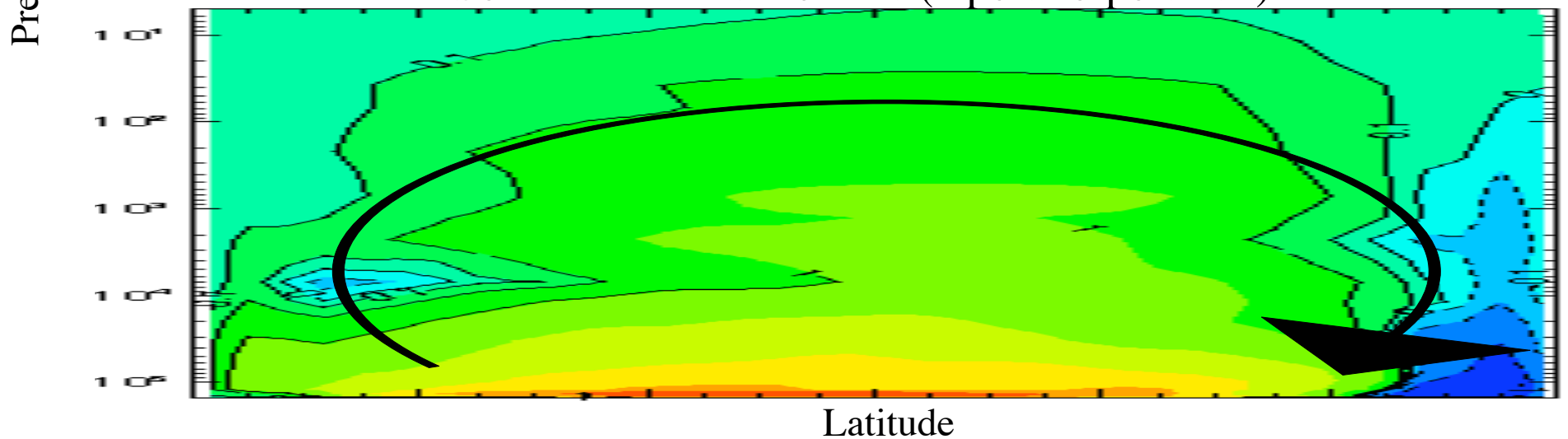


TitanWRF's troposphere

Equinox (2 ~symmetric cells)



Southern summer solstice (1 pole-to-pole cell)



TitanWRF's methane cycle

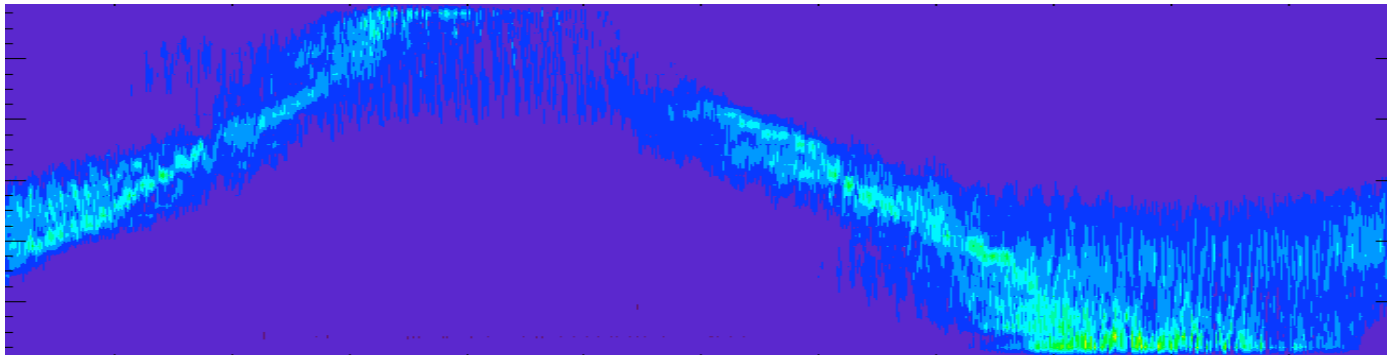
Spring equinox

Summer solstice

Fall equinox

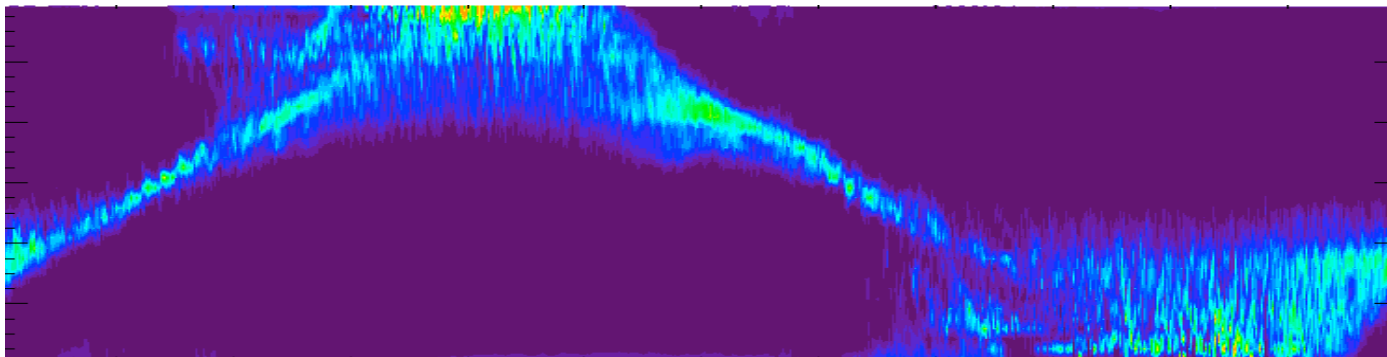
Winter solstice

Latitude



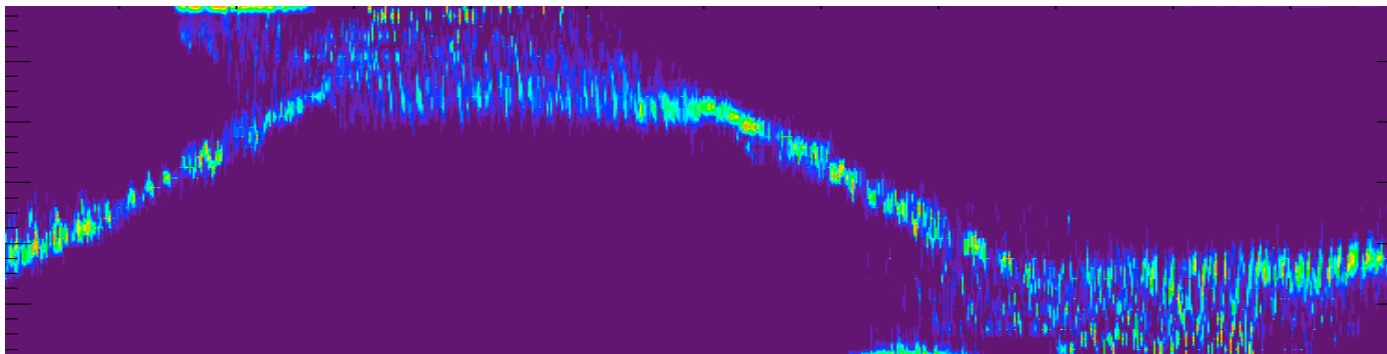
**Maximum
vertical velocity
in troposphere**

Latitude



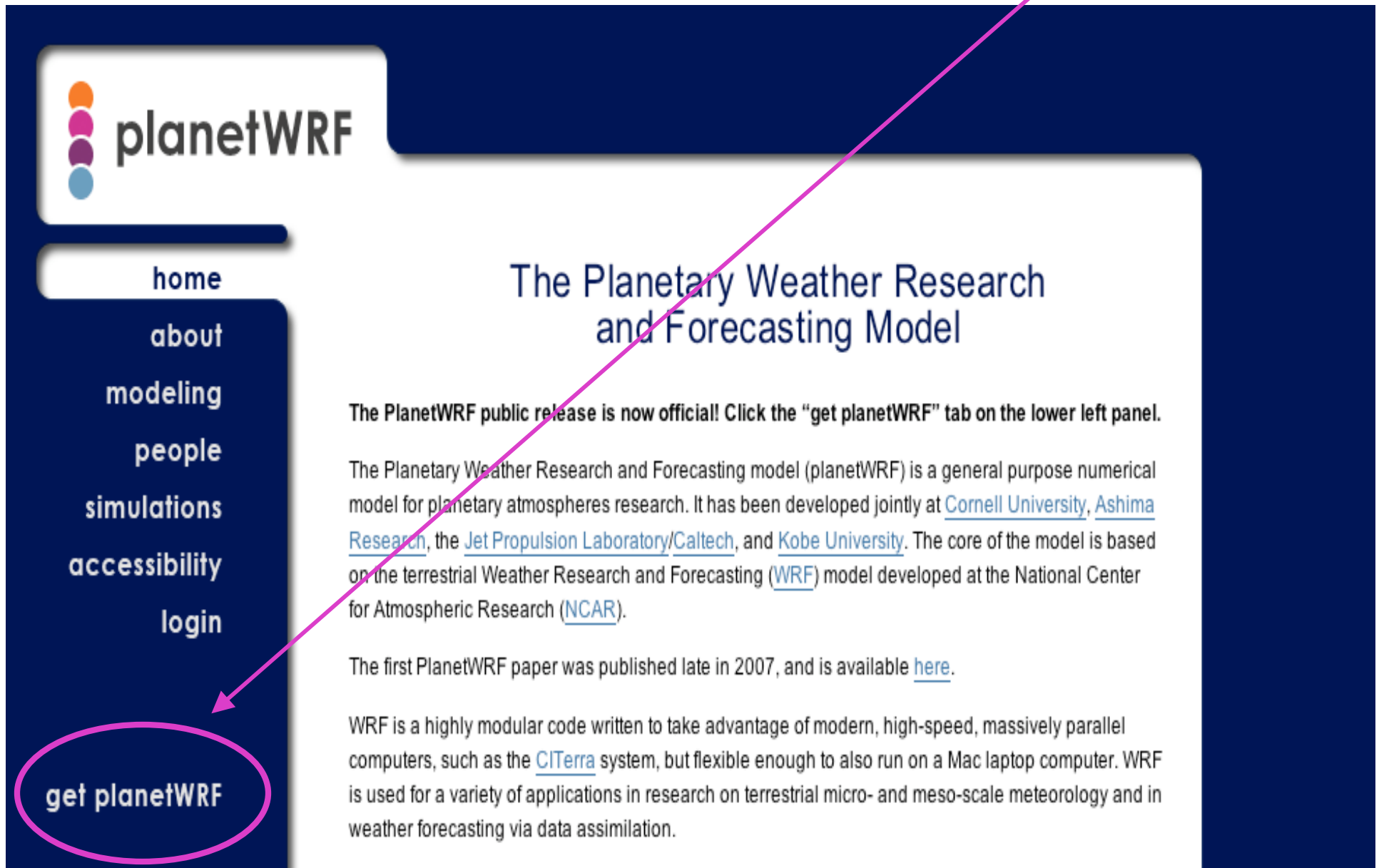
**=> Methane
cloud
condensation**

Latitude



**=> Surface
precipitation**

Download planetWRF at www.planetwrf.com



The screenshot shows the planetWRF website interface. On the left is a dark blue sidebar with a white planetWRF logo at the top. Below the logo is a list of navigation links: 'home', 'about', 'modeling', 'people', 'simulations', 'accessibility', and 'login'. At the bottom of this sidebar, the link 'get planetWRF' is circled in pink. A pink arrow points from the top right of the main content area to this circled link. The main content area has a white background and a dark blue header bar. The header bar contains the planetWRF logo and the text 'planetWRF'. Below the header bar, the main content area has a title 'The Planetary Weather Research and Forecasting Model' in dark blue. Below the title, there is a paragraph of text: 'The PlanetWRF public release is now official! Click the "get planetWRF" tab on the lower left panel.' This is followed by another paragraph: 'The Planetary Weather Research and Forecasting model (planetWRF) is a general purpose numerical model for planetary atmospheres research. It has been developed jointly at [Cornell University](#), [Ashima Research](#), the [Jet Propulsion Laboratory/Caltech](#), and [Kobe University](#). The core of the model is based on the terrestrial Weather Research and Forecasting ([WRF](#)) model developed at the National Center for Atmospheric Research ([NCAR](#)).' Below this is a third paragraph: 'The first PlanetWRF paper was published late in 2007, and is available [here](#).' Finally, there is a fourth paragraph: 'WRF is a highly modular code written to take advantage of modern, high-speed, massively parallel computers, such as the [CITerra](#) system, but flexible enough to also run on a Mac laptop computer. WRF is used for a variety of applications in research on terrestrial micro- and meso-scale meteorology and in weather forecasting via data assimilation.'

Download planetWRF at www.planetwrf.com

- Click on ‘Get planetWRF’ and follow the instructions:

Step 1: download and untar **WRFv3.0.1.1** from NCAR (*planetWRF for WRFv3.1 is coming soon*)

Step 2: download the **planetWRF** ‘patch kit’ from planetwrf.com (adds and modifies files to basic WRF)

Then follow further instructions on how to configure, compile, run and verify a standard MarsWRF run

Further work

- Biggest ‘to do’ item is a positive definite and monotonic advection scheme (the polar filter causes problems)

For more information about planetWRF

- Talk to me or contact us at planetwrf@gmail.com
- See also planetWRF paper [Richardson *et al.* JGR 2007]

If dx = gap between grid points in map coordinates,
and dX = actual distance (in meters),
then **$dX = (1/m_x) dx$** and likewise **$dY = (1/m_y) dy$**

Original WRF

Conformal grid
 $\Rightarrow$ for all map projections
available (mercator, polar
stereographic, etc.),

$m_x = m_y$ at all points

**$\Rightarrow$ Only one map scale
factor (m) used, and
omitted altogether when
 m_x and m_y cancelled**

Global WRF

Lat-lon grid $\Rightarrow x = a\lambda, y = a\phi,$
 $\Rightarrow dx = a d\lambda, dy = a d\phi,$
whereas $dX = a \cos\phi d\lambda, dY = a d\phi$
 $\Rightarrow m_x = dx/dX = \sec\phi, m_y = dy/dY = 1$

$\Rightarrow m_x \neq m_y$

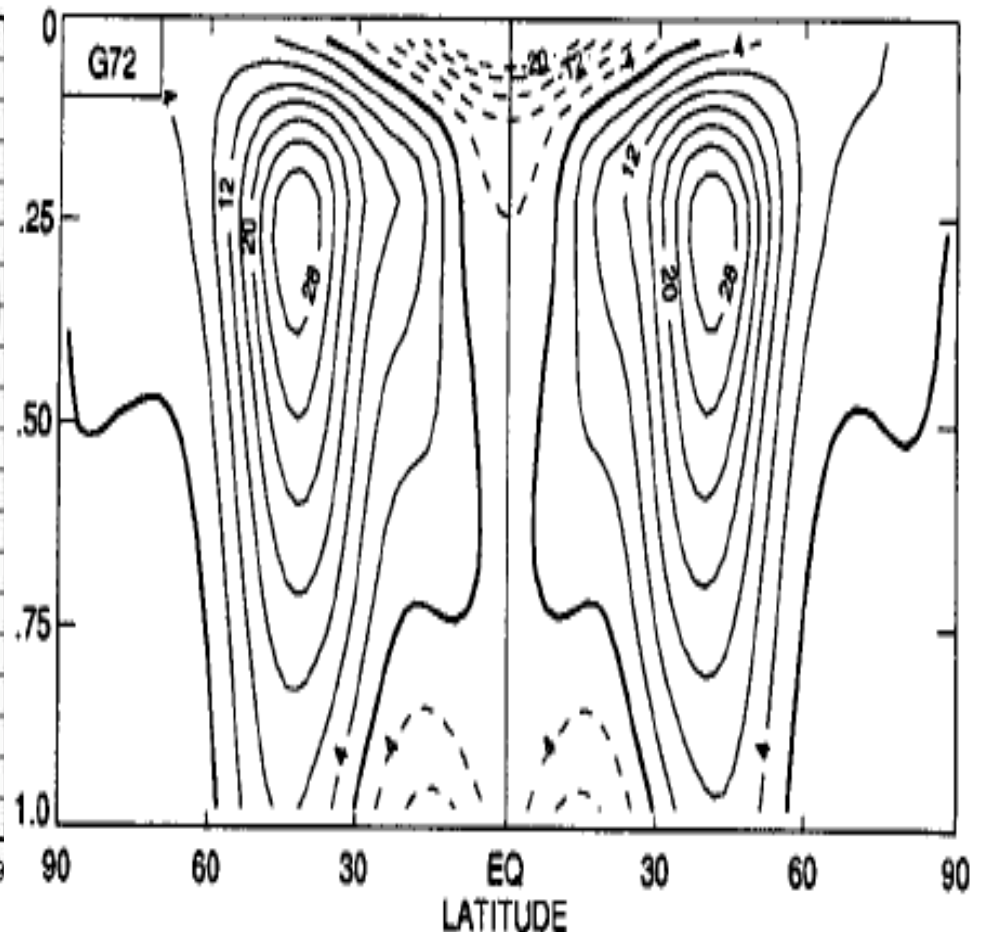
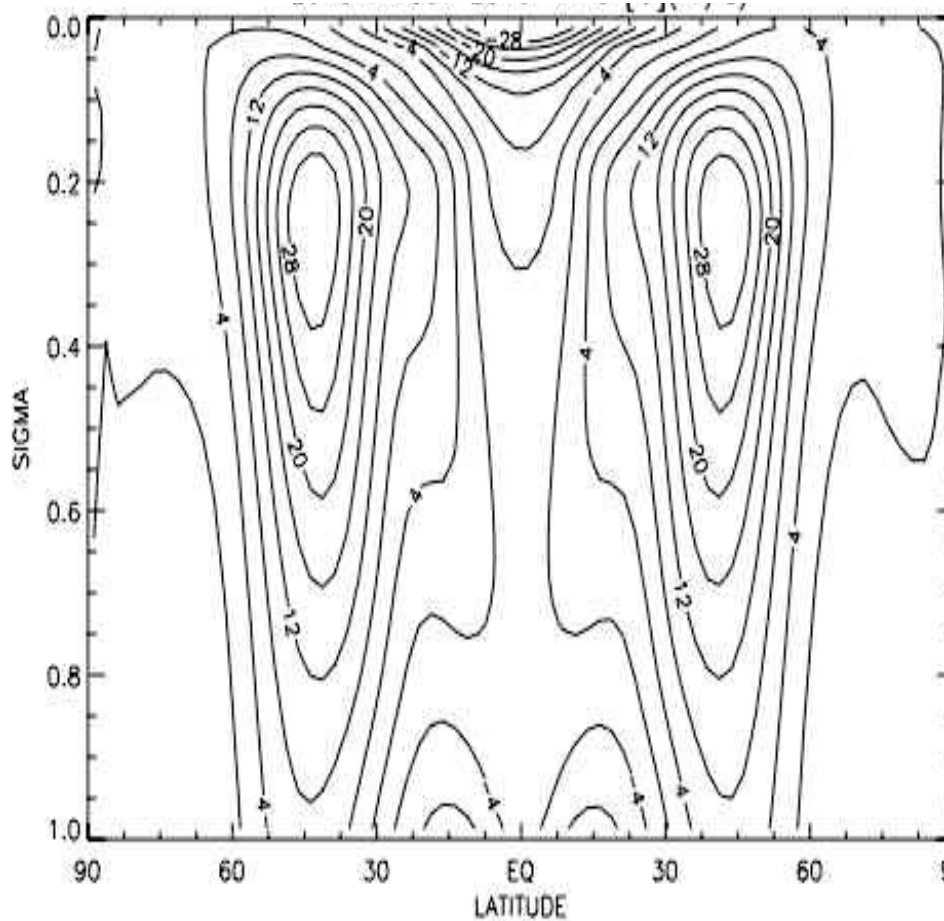
**$\Rightarrow$ Needed to identify which map scale
factor was required in all equations
where 'm' appeared, and reintroduce
map scale factors where they previously
cancelled (so were omitted)**

Testing global WRF

(As before but for zonal mean u)

Global WRF

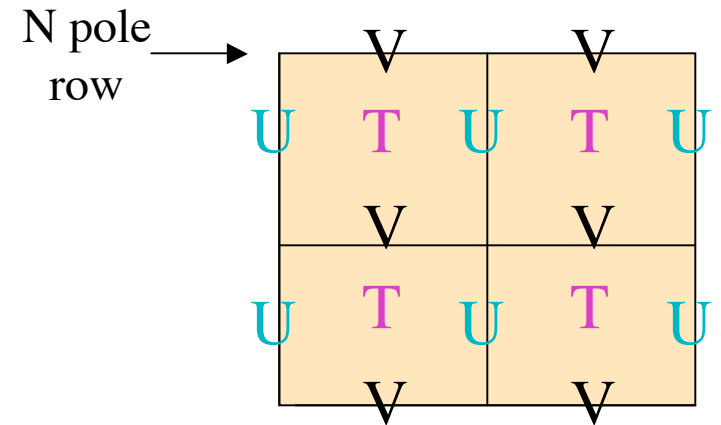
Expected result



For more tests see Richardson *et al.* JGR 2007

Globalizing WRF 3. Other changes

- **Polar boundary condition:** the initial solution was stable ($v = 0$ at the poles with no fluxes to or from the poles) but has been improved by the NCAR team

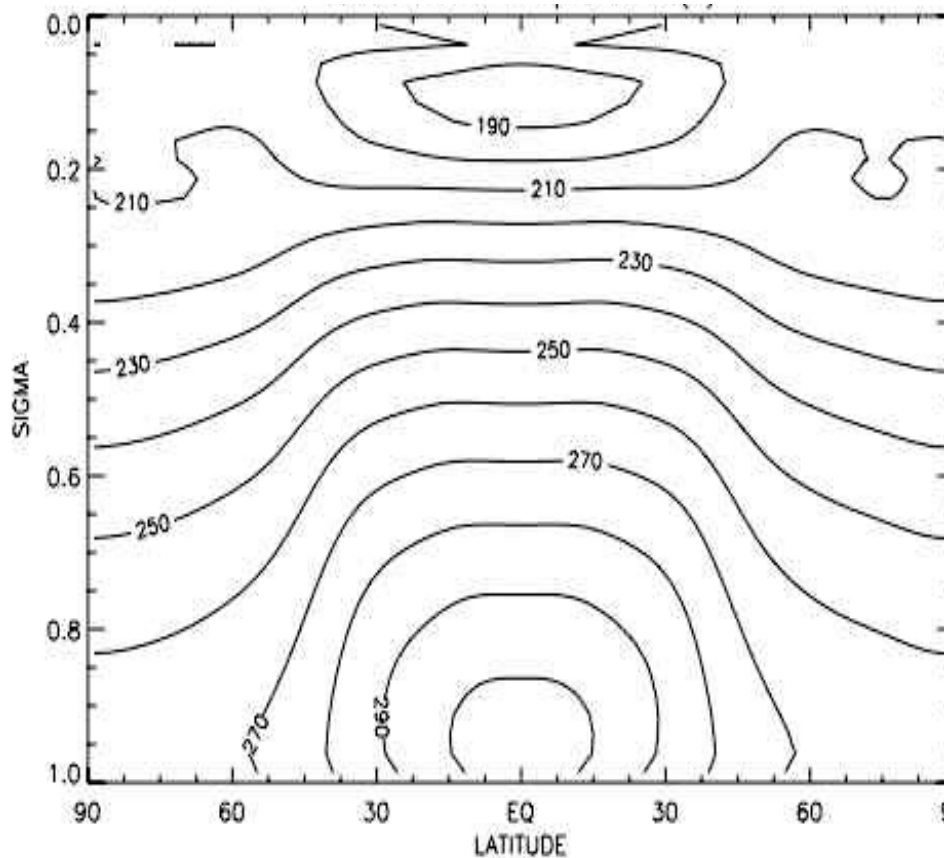


- **Sponge layer:** planetWRF is run as a standalone model with a high model top (over ~ 10 scale heights) for most applications, so damping of spurious waves in the top 3 or 4 layers was added to prevent reflection [module_planetary_damping.F]

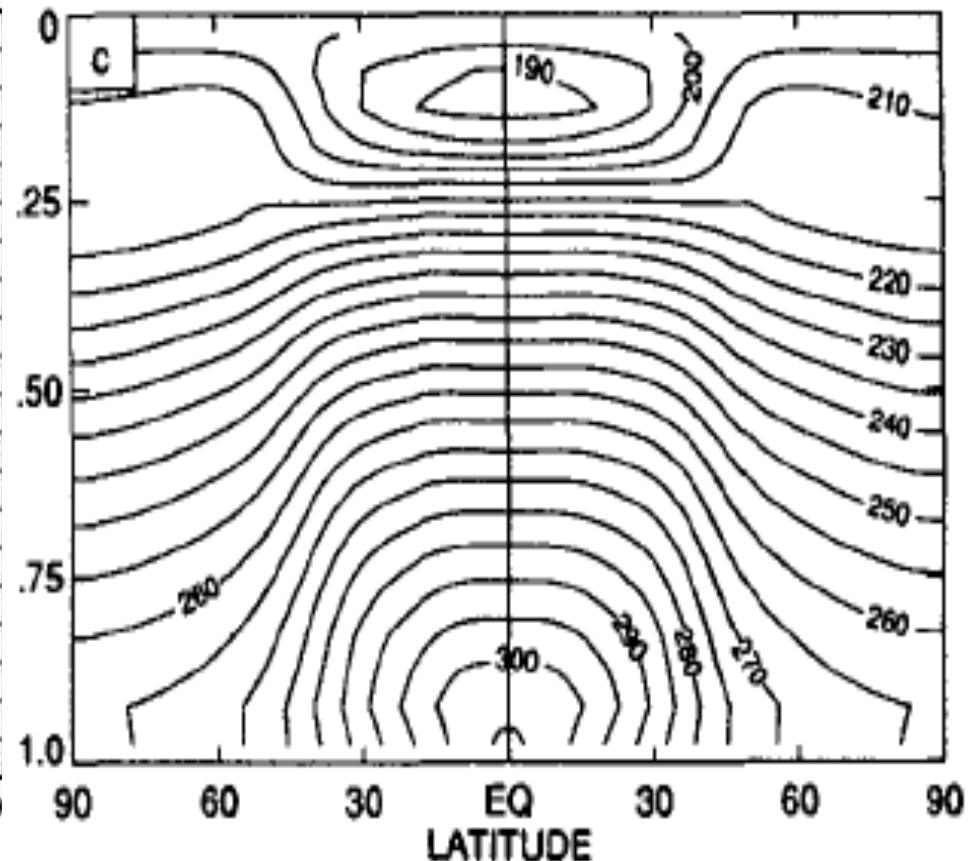
Testing global WRF

Time and zonal mean T using Held and Suarez forcing (BAMS, 1994)

Global WRF



Expected result



For more tests see Richardson *et al.* JGR 2007

Compile as an ideal WRF case using: `compile em_heldsuarez`

Objects of interest

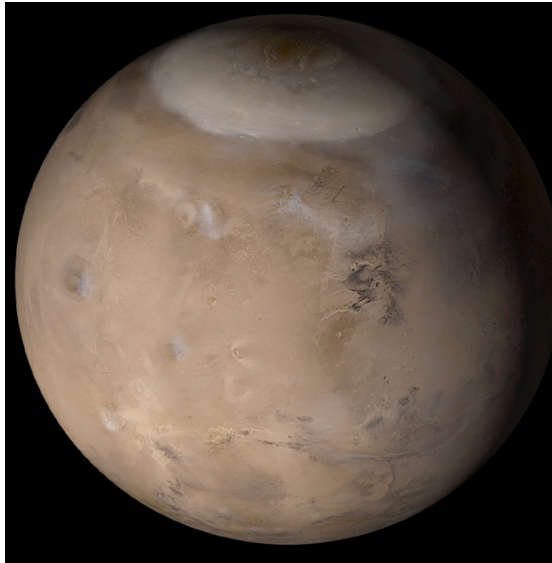
Earth



N_2 atmosphere
 $P_s \sim 10^5 \text{ Pa}$, $T_s \sim 288 \text{ K}$

Water cycle
Oceans & land surfaces

Mars

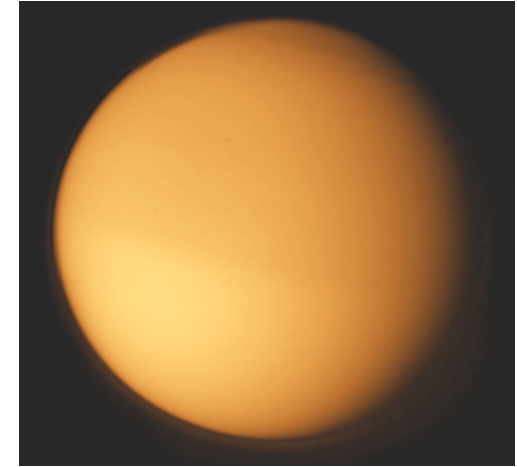


CO_2 atmosphere
 $P_s \sim 10^3 \text{ Pa}$,
 $T_s \sim 150\text{-}300 \text{ K}$

Very eccentric orbit

Major topography
Dust storms

Titan



N_2 atmosphere
 $P_s \sim 10^5 \text{ Pa}$, $T_s \sim 90 \text{ K}$

Rotates **16x** slower
Year lasts **30x** longer

Thick haze layers
Methane 'hydrology'