ROCKE-3D (planet_1.0) tutorial

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Link to May 2019 tutorial:

https://www.youtube.com/playlist?list=PLpMmnV3HS7r3jlWHp2j-M1MtMIk1CB25B

Link to May 2018 tutorial video:

https://www.youtube.com/playlist?list=PLpMmnV3HS7r36l1qX_3cNV7CinX2qaS7W

How to join the tutorial

The Zoom link will be posted here at the appropriate time:

Please try the link above **before** the tutorial to make sure you have the software installed.
Please **mute** your microphone at all times unless you need to speak.

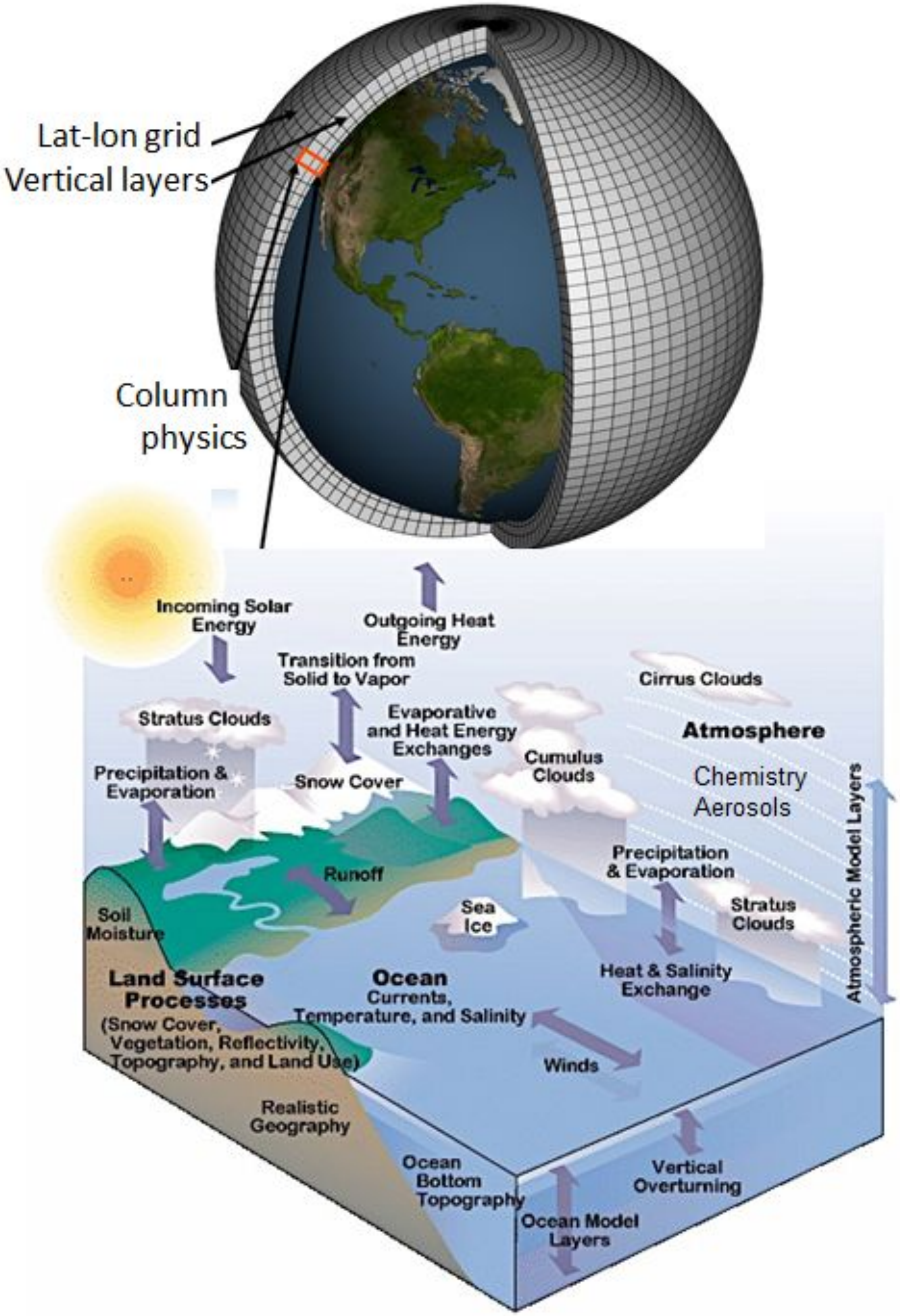
E-mail one of us if your problems persist:
michael.way@nasa.gov, kostas.tsigaridis@columbia.edu, igor.aleinov@columbia.edu

Monday Schedule (US Eastern Time Zone)

- 10:00-10:45: Intro & tutorial (Mike & Kostas)
- 10:45-11:00: Break
- 11:00-11:45: Tutorial (Kostas & Tony)
- 11:45-13:00: Lunch break
- 13:00-13:45: Tutorial (Igor) and Q&A
- 13:45-14:00: Break
- 14:00-15:00: Q&A

Tuesday Schedule (US Eastern Time Zone)

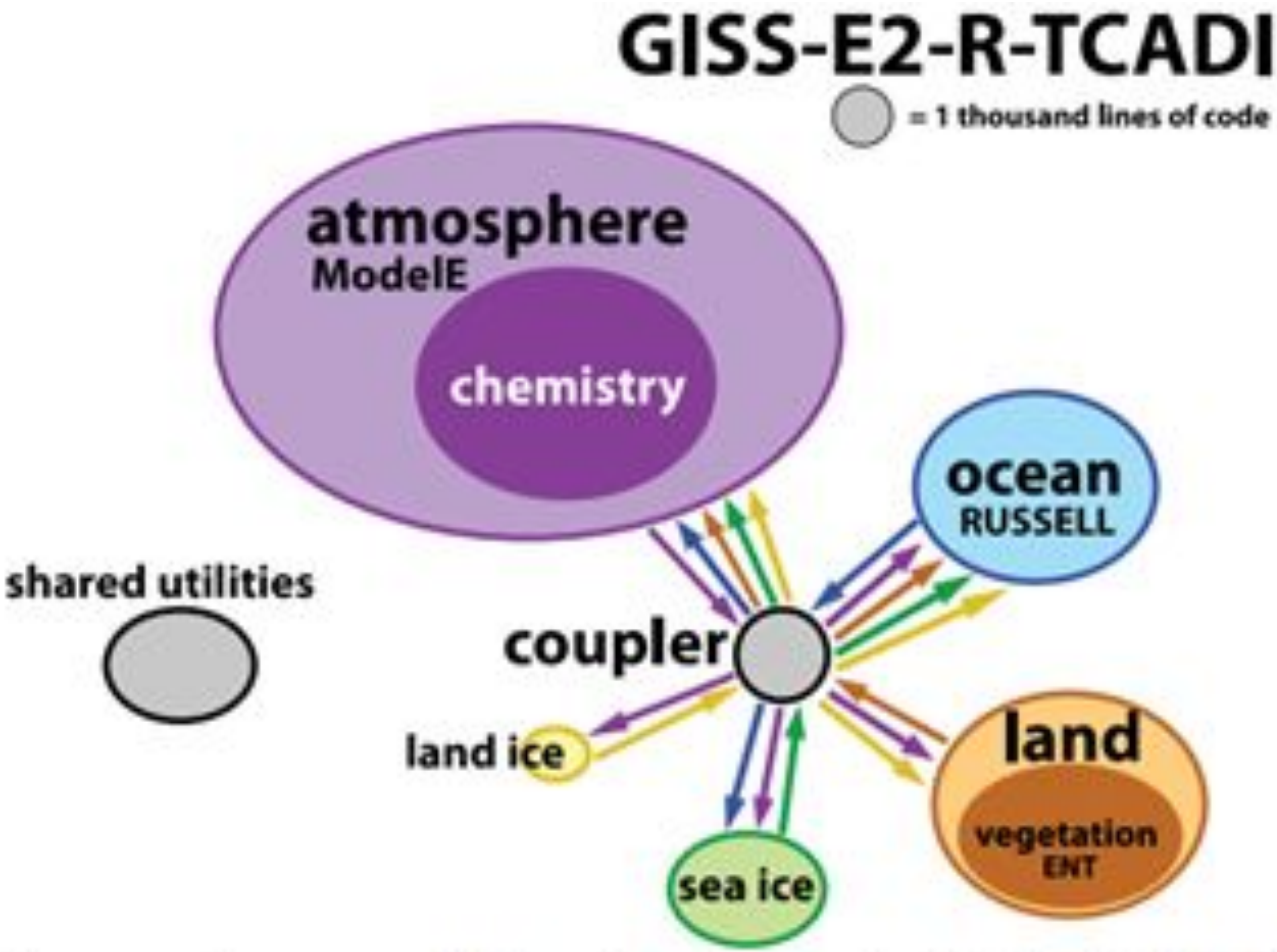
- 10:00-10:05: Good Morning
- 10:05-10:25: Tom Clune on Calendar
- 10:25-10:45: Aleinov on ground hydrology
- 10:45-11:00: Break
- 11:00-11:20: Eric Wolf on Radiation
- 11:20-12:00: Geronimo Villanueva: Planetary Spectrum Generator & ROCKE3D
- 12:00-13:00: Lunch
- 13:00-13:45: Chris Colose: How to create a new planet
- 13:45-14:00: Break
- 14:00-15:00: Q&A



Limitations of 3D global climate models (GCMs):

- Time scales simulated (max ~10^4 yr so far)
- Vertical range (~65 km for ours) – can't simulate escape, only mixing ratios in stratosphere
- Limited to shallow atmospheres (our GCM, anyway) – no mini-Neptunes or larger

GISS ModelE (Schmidt et al., 2014)



Alexander and Easterbrook, GMD, 2015

What is ROCKE-3D good for?

ROCKE-3D (Way et al., 2017)

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 231:12 (22pp), 2017 July https://doi.org/10.3847/1538-4365/aa7a06

CrossMark

Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics (ROCKE-3D) 1.0: A General Circulation Model for Simulating the Climates of Rocky Planets

M. J. Way[1,2], I. Aleinov[1,3], David S. Amundsen[1,4], M. A. Chandler[1,3], T. L. Clune[5], A. D. Del Genio[1], Y. Fujii[1], M. Kelley[1], N. Y. Kiang[1], L. Sohl[1,3], and K. Tsigaridis[1,3]
[1] NASA Goddard Institute for Space Studies, New York, NY 10025, USA
[2] Department of Physics and Astronomy, Uppsala University, Uppsala, SE-75120, Sweden
[3] Center for Climate Systems Research, Columbia University, New York, NY 10025, USA
[4] Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY 10025, USA
[5] Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, USA
Received 2017 February 24; revised 2017 May 31; accepted 2017 June 14; published 2017 July 20

has modeled the atmospheres of:

What is ROCKE-3D good for?

- Earth: 2.9Ga to the present (Del Genio et al. 2018):

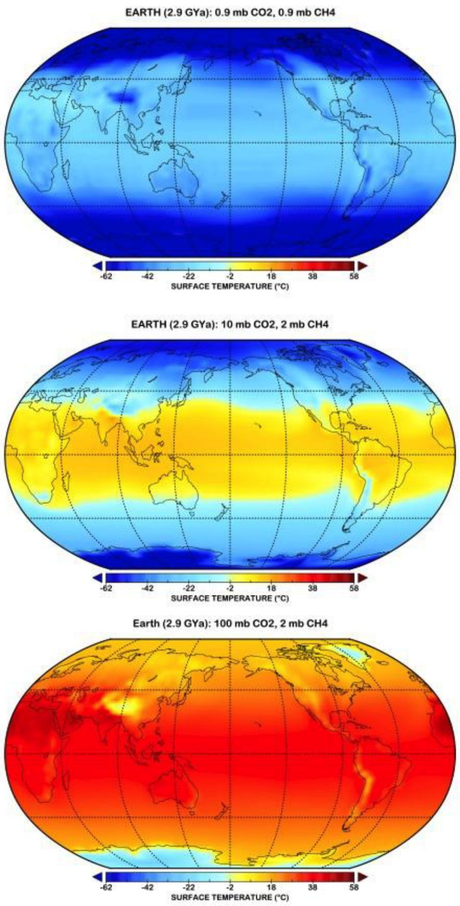


Figure 5. 2.9 Gya Archean Earth surface temperature simulated by the ROCKE-3D GCM (*Way et al.*, 2017) assuming atmospheric compositions for Cases (upper) A, (middle) B, and (lower) C of *Charnay et al.* (2013) and the solar spectrum from *Claire et al.* (2012). Uncertainties due to the unknown land-ocean distribution are a few degrees. Simulations courtesy of Michael Way.

What is ROCKE-3D good for?

- Ancient Venus (Way et al. 2016)

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL069790

Key Points:
- Venus may have had a climate with liquid water on its surface for approximately two billion years
- The rotation rate and topography of Venus play crucial roles in its surface temperature and moisture
- Young Venus-like exoplanets may be considered candidates for the search for life beyond Earth

Was Venus the first habitable world of our solar system?

M. J. Way[1,2], Anthony D. Del Genio[1], Nancy Y. Kiang[1], Linda E. Sohl[1,3], David H. Grinspoon[4], Igor Aleinov[1,3], Maxwell Kelley[1], and Thomas Clune[5]

[1]NASA Goddard Institute for Space Studies, New York, New York, USA, [2]Department of Astronomy and Space Physics, Uppsala University, Uppsala, Sweden, [3]Center for Climate Systems Research, Columbia University, New York, New York, USA, [4]Planetary Science Institute, Tucson, Arizona, USA, [5]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

Table 1. Paleo-Venus Experimental Setups and Results[a]

Simulation	Topography	Spectrum/Flux/S0X	Rotation Period	*T* (min)	*T* (max)	*T* (avg)	Time (avg)
A	Venus	2.900 Gya/2001/1.46	Modern Venus	−22°C	36°C	11°C	1/6 day
B	Venus	0.715 Gya/2357/1.70	Modern Venus	−17°C	35°C	15°C	1/6 day
C	Earth	2.900 Gya/2001/1.46	Modern Venus	−13°C	46°C	23°C	1/6 day
D	Venus	2.900 Gya/2001/1.46	16 × Earth	27°C	84°C	56°C	1/8 day

What is ROCKE-3D good for?

- Modern/Ancient Mars w/o CO2 clouds (I. Aleinov -> Tomorrow)

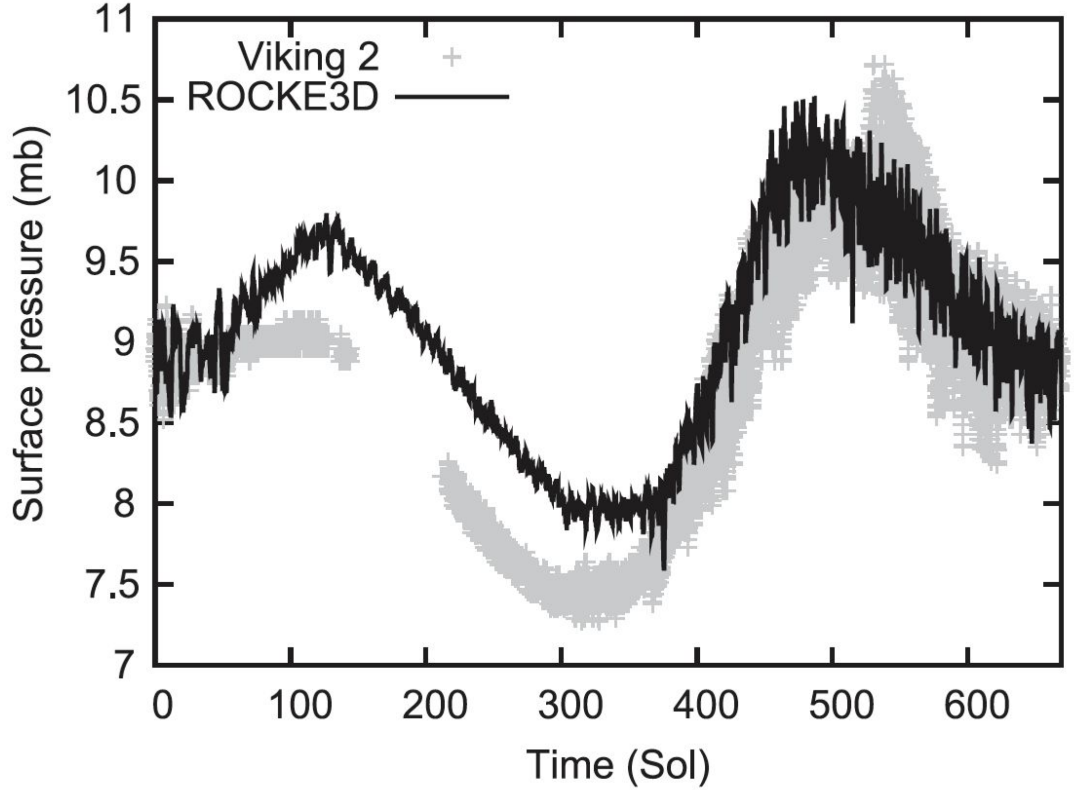


Figure 6. Annual cycle of Mars surface pressure, as measured by the Viking 2 lander (gray crosses) (Hess et al. 1977; Tillman 1989), and surface pressure simulated by ROCKE-3D (black solid line).

What is ROCKE-3D good for?

- Hypothetical Venus-like worlds (near M-dwarfs)
  - Kepler 1649b (Kane et al. 2018):

THE ASTROPHYSICAL JOURNAL, 869:46 (9pp), 2018 December 10 https://doi.org/10.3847/1538-4357/aaec68

CrossMark

Climate Modeling of a Potential ExoVenus

Stephen R. Kane[1], Alma Y. Ceja[1], Michael J. Way[2,3], and Elisa V. Quintana[4]
[1] Department of Earth Sciences, University of California, Riverside, CA 92521, USA; skane@ucr.edu
[2] NASA Goddard Institute for Space Studies, New York, NY 10025, USA
[3] Department of Physics and Astronomy, Uppsala University, Uppsala, SE-75120, Sweden
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Table 1
Parameters of ROCKE-3D Simulations

ID	P (days)	F_p ($F_\oplus$)	Topo[a]	CO_2 (ppmv)	CH_4 (ppmv)	Orbits[b]	T_{mean}[c] (°C)	T_{min} (°C)	T_{max} (°C)	Bal[d] ($W\ m^{-2}$)	H_2O_{strat}[e] ($kg\ kg^{-1}$)	H_2O_{surf}[f] ($kg\ kg^{-1}$)
1	8.6	2.3	1	400	1	300	90.2	81.2	112.5	103	0.379	0.4845
2	8.6	2.3	3	400	1	66	84.3	42.4	212.4	214	0.099	0.1168
3	8.6	2.3	3	100	0	116	128.9	67.3	285.4	137	0.271	0.3456
4	8.6	2.0	1	400	1	486	91.8	83.5	111.8	77	0.423	0.5214
5	8.6	1.8	1	400	1	634	90.8	83.1	110.2	63	0.434	0.5061
6	8.6	1.6	1	400	1	752	88.0	81.3	102.7	59	0.411	0.4562
7	8.6	1.4	1	400	1	2031	64.1	57.7	72.0	35	0.026	0.1623
8	8.6	1.0	2	400	1	2345	4.3	−54.1	46.9	−3	0.000078	0.0064
9	16.0	1.47	2	400	1	2055	58.3	33.5	91.7	9	0.038	0.1052
10	50.0	1.4	1	376	0	6354	59.0	56.3	61.9	0.3	0.027	0.1226

What is ROCKE-3D good for?

- Proxima Centauri b type systems (Del Genio et al. 2019) up to 10bar N_2/CO_2

ASTROBIOLOGY
Volume 19, Number 2, 2019

DOI: 10.1089/ast.2017.1760

Research Article

Habitable Climate Scenarios for Proxima Centauri b with a Dynamic Ocean

Anthony D. Del Genio,[1] Michael J. Way,[1] David S. Amundsen,[1,2] Igor Aleinov,[1,3]
Maxwell Kelley,[1,4] Nancy Y. Kiang,[1] and Thomas L. Clune[5]

TABLE 4. DESCRIPTION OF GENERAL CIRCULATION MODEL SIMULATIONS

No.	*Name*	*Description*
1	Control	0.984 bar, N_2 + 376 ppmv CO_2 atmosphere, dynamic ocean, aquaplanet, synchronous rotation, $S_o = 881.7\ W/m^2$, $S = 35.4$ psu
2	Thermo	Like Control but with a thermodynamic ocean
3	Control-High	Like Control but with $S_o = 956\ W/m^2$
4	Control-Thin@	Like Control but with 0.1 bar N_2 + 376 ppmv CO_2
5	Control-Thick#@	Like Control but with 10 bar N_2 + 376 ppmv CO_2
6	Archean Low*	Like Control but 638 ppmv CO_2, 450 ppmv CH_4
7	Archean Med*	Like Control but 900 ppmv CO_2, 900 ppmv CH_4
8	Archean Med NoCH_4*@	Like Archean Med but 0 ppmv CH_4
9	Archean High*	Like Control but 10,000 ppmv CO_2, 2000 ppmv CH_4
10	Pure CO_2+@	Like Control but 0.984 bar pure CO_2 atmosphere
11	Control-Shallow@	Like Control but with a 158 m depth ocean
12	Control-Deep@	Like Control but with a 2052 m depth ocean
13	Zero Salinity	Like Control but $S = 0$ psu
14	High Salinity	Like Control but $S = 230$ psu
15	3:2e0	Like Control but in 3:2 resonance with $e = 0$
16	3:2e30	Like Control but in 3:2 resonance with $e = 0.30$
17	Day-Ocean	Like Control but with Earth land–ocean distribution and substellar point over Pacific
18	Day-Land	Like Day-Ocean but substellar point over Africa

What is ROCKE-3D good for?

- Ancient Lunar Atmosphere (Aleinov et al. 2019)

Geophysical Research Letters

Research Letter | Full Access |

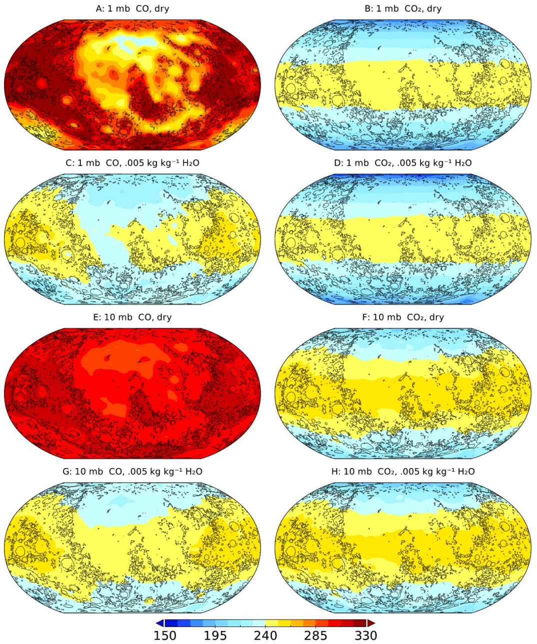
Modeling a Transient Secondary Paleo-Lunar Atmosphere: 3-D Simulations and Analysis

I. Aleinov, M.J. Way, C. Harman, K. Tsigaridis, E.T. Wolf, G. Gronoff

First published: 01 May 2019 | https://doi.org/10.1029/2019GL082494

Go here for SFX Go here for SFX

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1029/2019GL082494



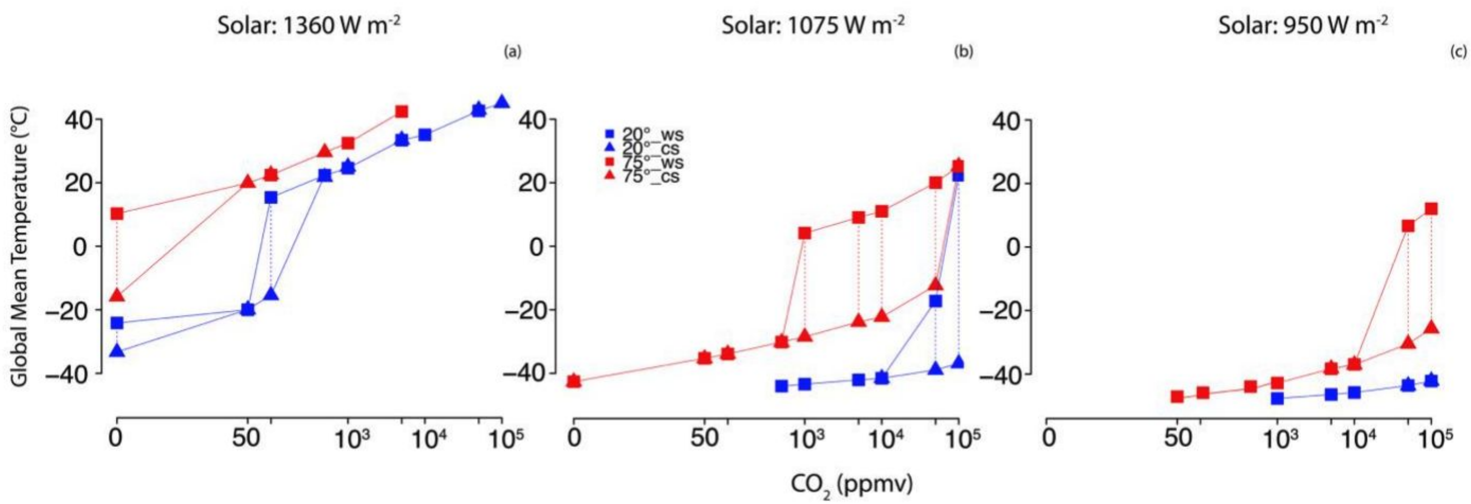
What is ROCKE-3D good for?

- Obliquity Studies (Colose et al. 2019 ApJ)

Enhanced Habitability on High Obliquity Bodies near the Outer Edge of the Habitable Zone of Sun-like Stars

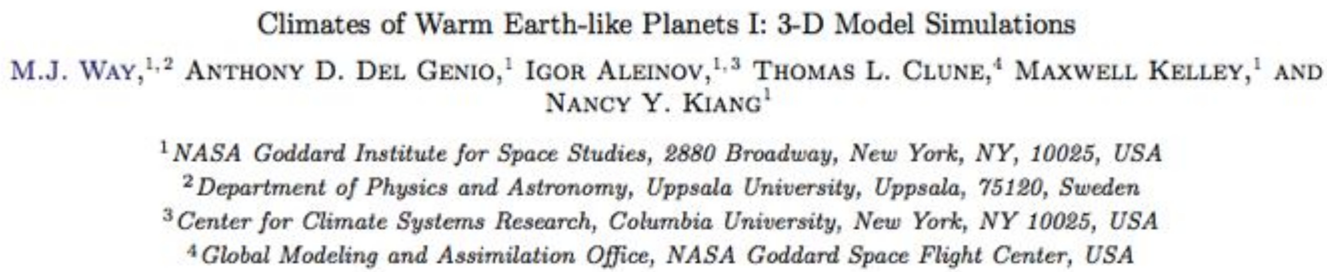
Christopher M. Colose[1], Anthony D. Del Genio[2], M. J. Way[2,3]

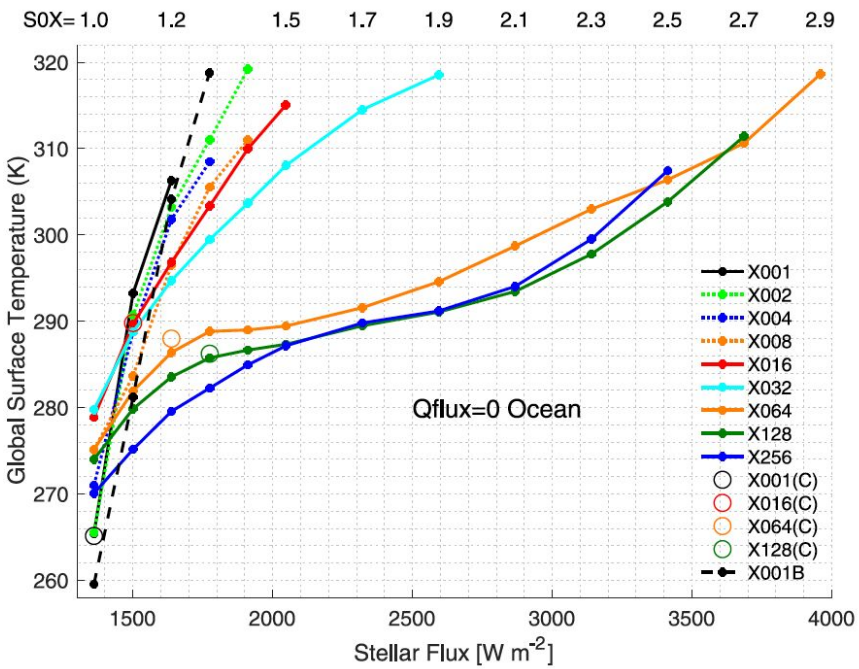
[1]NASA Postdoctoral Program, Goddard Institute for Space Studies, New York, NY 10025
[2]NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025

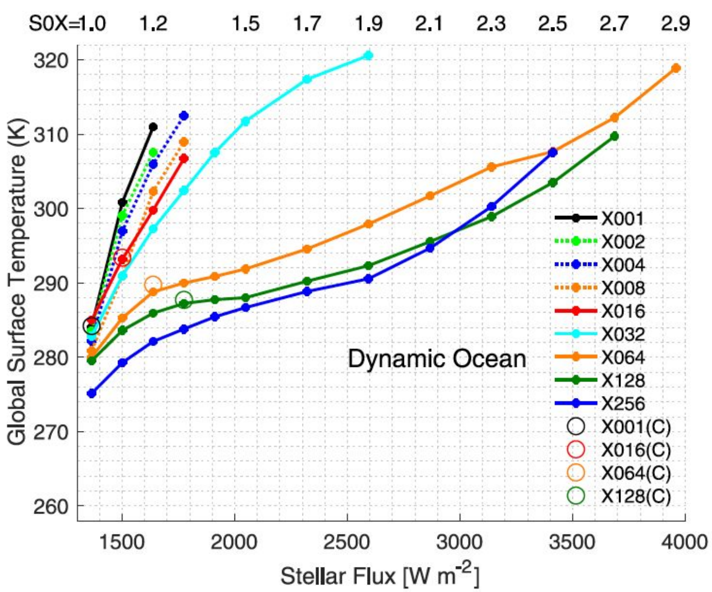


What is ROCKE-3D good for?

- Parameter Ensembles (Way et al. 2018 ApJS)







Why Tell You About These Papers?!

- The fastest and most reliable means to get a new planet running after this tutorial is to find a similar one from our previous papers

- You can find the rundecks, boundary condition files, and model output for most of our paper on-line:

- https://portal.nccs.nasa.gov/GISS_modelE/ROCKE-3D/publication-supplements/

What is ROCKE-3D good for?

Caveats?

There are a limited number of types of atmospheres and stellar spectra available. We will discuss them later, time permitting.

What it can NOT be used for

Variable atmospheric mass for mix of constituents

- molecular weights changing, etc.

Super Earths

Where thin atmospheric approximation **invalid**

Super thick oceans? (See Tony Leboissetier's slides)

Not above temps of 400K & not below 100K (except Titan)

Really cold planets (ocean freezing to bottom = model crash)

Fast spinning planets (Grid resolution)

Mini-Neptunes and above (gas giants, etc.)

- remember the ROCKE-3D acronym: **R**esolving **O**rbital & **C**limate **K**eys of **E**arth & **E**xtraterrestrial **E**nvironments

south pole anomaly

limitations in atmospheric constituents (radiation & chem)

Code Repository Server at GISS

- https://simplex.giss.nasa.gov
- https://simplex.giss.nasa.gov/gcm/ROCKE-3D/

Model Documentation (what little there is):

Planet_1.0 dynamic ocean rundeck:
https://simplex.giss.nasa.gov/gcm/decks/P1SoM40_html/index.html

Model_E2 Earth rundeck:
https://simplex.giss.nasa.gov/gcm/decks/E4F40_html/vars_db.html

Latest snapshots: what does this really mean?
https://simplex.giss.nasa.gov/snapshots/

Where to?

- GISS contacts
  - Clouds: Andy Ackerman
  - Chemistry: Kostas & Sonny
  - Aerosols: Kostas Tsigaridis
  - Various planets, orbits, etc.: Mike Way
  - Radiation: Eric Wolf (Andy Lacis for GISS Radiation)
  - Atmospheric composition: Kostas Tsigaridis
  - Debugging: Igor Aleinov, Kostas, Mike (use sparingly!)
  - Calendar/Rotation issues: Tom Clune
  - Biology: Nancy Kiang
  - Land: Igor Aleinov
  - Ocean/Sea Ice: Tony Leboissetier
  - Panoply: Robert Schmunk

Model Versions/Names

GISS ModelE

- GISS ModelE2
- GISS-E2-[RH] (CMIP5)
- GISS-E2.1 (CMIP6)
- ROCKE-3D
  - Planet_1.0 (GISS ModelE2)
  - Planet_2.0 (GISS ModelE2.1 + tracersE3)
  - Planet_3.0 (GISS ModelE3)
  - planet (development)
- NINT, OMA, MATRIX

Terminology and file system structure

- .modelErc
  - $HOME/.modelErc
- ROCKE-3D
  - $HOME/modelE2_planet_1.0
- Template rundecks
  - $HOME/modelE2_planet_1.0/templates
- Rundecks
  - $HOME/modelE2_planet_1.0/decks
- Source code
  - $HOME/modelE2_planet_1.0/model (and sub-dirs)

Input and output locations

- Shared input files
  - Location defined by $GCMSEARCHPATH in .modelErc
  - Relative path in rundecks (do not start with /).
- User-defined input files
  - Anywhere accessible to the model while running.
  - Absolute path in rundecks (start with /).

- Output files
  - In subdirs, as defined by $SAVEDISK in .modelErc
  - Also soft-linked in the decks directory, under runid.

Overview of the rundeck: runid.R

- Object modules
  - Files to be compiled
- Components
- Component Options
- Data input files
  - Emissions
  - Boundary conditions
  - …
- Label and Namelist
  - run name (runid)
- PARAMETERS … END_PARAMETERS
  - Runtime parameters (variables in FORTRAN)
- INPUTZ
  - Start/end times

Key template rundecks

- Planet_1.0
  - P4SM40 (prescribed sea surface temperatures)
  - P4SqM40 (Earth Q-flux heat surface fluxes)
  - P1SoM40 (Fully coupled/dynamic ocean)
  - PS_Mars (Dune/Desert Planet no ocean)

If you want to use ANYTHING else in the templates directory PLEASE ask us about it first!

- Planet_2.0 will have many more rundeck options.

Rundeck details

- Go into detail of P1SoM40 rundeck
- Then compare P4SqM40 rundeck with P1SoM40
- Then compare P1SoM40 with PS_Mars
- Complete list of variables:

https://simplex.giss.nasa.gov/gcm/decks/P1SoM40_html/index.html

Rundeck start/stop times

```
&INPUTZ

YEARI=1897,MONTHI=1,DATEI=1,HOURI=0, ! pick IYEAR1=YEARI (default) or < YEARI

YEARE=1910,MONTHE=1,DATEE=1,HOURE=0,KDIAG=12*0,9,

ISTART=2,IRANDI=0,YEARE=1897,MONTHE=1,DATEE=1,HOURE=1,

/
```

- master_yr=1850

Let’s now run the first hour of 2 rundecks.

Running new rundecks

- P4SM40 (prescribed sea surface temperatures)
- P4SqM40 (Earth Q-flux heat surface fluxes)
- P1SoM40 (Fully coupled/dynamic ocean)
- PS_Mars (Dune/Desert Planet no ocean)

Remember how you did it before:

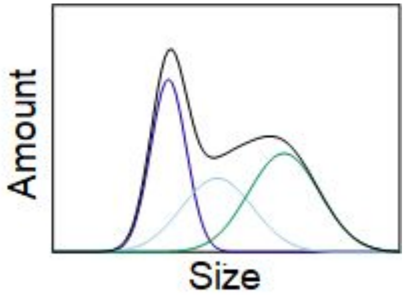
https://docs.google.com/document/d/1yyI0CDx1wEYbwqRsbvczXpdW2teePZ_NgIePTLFHtNA/view

```
cd /home/username/modelE2_planet_1.0/decks
make rundeck RUNSRC=P1SoM40 RUN=P1SoM40_Test
../exec/get_input_data -w P1SoM40_Test /home/username/ModelE_Support/prod_input_files
make clean; make -j setup RUN=P1SoM40_Test
../exec/runE P1SoM40_Test -cold-restart -np 2
```

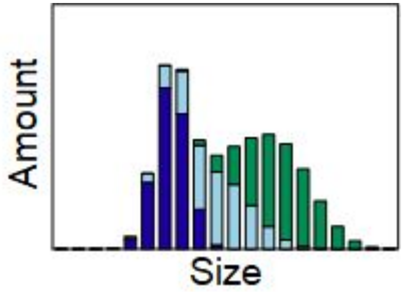
Running with tracers

- Chemistry: CBM4, KPP under development
- Aerosols
  - OMA: One-moment aerosols

  - MATRIX: Modal, resolves mixing state



  - TOMAS: Sectional



Atmospheric composition of new planets

Not everything that matters for climate is uniformly distributed in a planetary atmosphere.

CH_4?

O_3

Dust

Sea salt

Other aerosols

Clouds!

Random thoughts

- The I file
- The lock file
- COMPILE_WITH_TRAPS=YES EXTRA_FFLAGS=”-O0 -g” (make clean before AND after!!!)
- ../exec/sswE RUNID (to stop a job gracefully)

ROCKE-3D Ocean types

- **Prescribed Sea Surface Temperatures**
  - Only useful if you want to do modern Earth
  - Computationally cheap
- **Q-flux/mixed layer/slab ocean**
  - In the exoplanet realm normally means NO horizontal heat transport between grid cells
  - For Earth-like simulations the heat transport is prescribed.
  - Computationally cheap
- **Fully-Coupled dynamic ocean**
  - NOT computationally cheap, but most realistic
- **Standalone ocean**
  - prescribed atmosphere
  - computationally cheapest

Fully-coupled ocean runs

- Start from P1SoM40.R
- Key differences from P4SqM40.R:
- KOCEAN=1
- OIC (temperature and salinity in very strange units, initial conditions only)
- TOPO_OC (ocean topography)
- OSTRAITS (ocean cells connected through land)
- No partial land/ocean cells

Line 5812 in OCNDYN.f has J1O=4 by default. If there is no Antarctica, change that to 1. This says for which latitudes (starting from South Pole) the ocean calculations should not happen. It can't be zero, thus latitude 1 needs to always be land (South Pole).

Ocean model: future updates

- **Quasi-hydrostatic ocean model**
  - useful for planets/icy moons with deep ocean (~10-100km)
  - full treatment of the Coriolis force
  - relaxation of the shallow water approximation

- **Hydrothermal Plumes parameterization**
  - with geothermal heating

- **Improved sea ice thermodynamics/dynamics**

Change of topography

- TOPO
- TOPO_OC
- RVR (River directions).
- NAMERVR (River names; there has to be at least one).
- variable_lk=1; set to zero for non-variable lakes (expanding/contracting).
- If generate new or remove ocean grid cells, OIC also needs to be changed.
- GLMELT needs to change if topography changes drastically. Points where glacier calving might be problematic
- wsn_max (max snow depth) set to 2m by default.

Change of orbital parameters & other

- planetName
- eccentricity
- obliquity
- Calendar fun:
  - siderialorbitalPeriod
  - siderialrotationPeriod
  - quantizeYearLength (for tidally-locked planets)
-
- GHG file versus the X variables below
- CH4X, CO2X, N2OX, etc. as seen by the radiation.
- Physical properties of the atmospheric mixture (such as molecular mass and heat capacity) should be set explicitly in model/shared/PlanetParams_mod.F90
- For our solar system in the present epoch, the only thing other than orbital parameters is to change planet_s0. Nothing else is needed, if the solar spectrum is the same.

Single-column model (SCM)

- Essentially converts the 3D model to 1D, using the same model code.
- Exists for Planet_1.0 in Beta, but hopefully will be available in Planet_2.0 in the coming year.
- Runs on your laptop!

In the event of a crash?

ROCKE-3D document on known crash solutions.

Very useful when you push the model outside of its comfort zone:

https://docs.google.com/document/d/1Hvy9vW9m8YiN8_wf7SnulWIEcoXjgHT88C_o73-sbqw/view

Output and post-processing

- <runid>.PRT file
- MONYYYY.zzzRUNID.nc
- rsf files (KRSF: save rsf every KRSF months)
- fort.[12].nc files (alternate save every NDISK timesteps)
- acc files (KCOPY=0 no acc, =1 acc)
  - scaleacc: generate aij (and the like) files
  - sumfiles: generate temporally averaged acc files
- diffreport
- Panoply (http://www.giss.nasa.gov/tools/panoply)
- ncview

Post-Processing: NetCDF Diagnostics

The ROCKE-3D GCM contains the following diagnostics files from **scaleacc**:

Remember we have this:

https://simplex.giss.nasa.gov/gcm/decks/P1SoM40_html/index.html

Most commonly used diagnostics:

- aij: atmospheric model, 2D longitude vs. latitude variables
  - https://docs.google.com/spreadsheets/d/1Sp01pwCv8Vr4kLnR7fTz0IPHzdU6FjoD4OFlc4YICCo/view#gid=0
- aj: atmospheric model, 1D longitudinally averaged variables vs. latitude
- ajl: atmospheric model, 2D longitudinally averaged latitude vs. pressure variables
  - https://docs.google.com/spreadsheets/d/1HZ0oQRQre_v1e4fH0Pwf2y2-uMBluvujin97ogdYIf4/view#gid=0
- agc: atmospheric model, 2D longitudinally averaged latitude vs. pressure general circulation variables
- aijk: atmospheric model, 3D longitude-latitude-pressure variables
- aijl: atmospheric model, 3D longitude-latitude-model level variables
  - https://docs.google.com/spreadsheets/d/1R3bCQ1BA3ukS-aPPomORvLeSr0_QqGM6azFvkuI3DQY/view#gid=0
- ojl: dynamic ocean, 2D longitudinally averaged latitude vs. depth variables
- oijl: dynamic ocean, 3D longitude-latitude-depth variables

Post-Processing: NetCDF Diagnostics

diagnostics available in some simulations:

- adiurn: atmospheric model, diurnal cycles at selected gridpoints
- hdiurn: atmospheric model, hourly timeseries at selected gridpoints
- otj: Ocean R, northward transports
- oij: Ocean R, longitude-latitude
- olnst: Ocean R, straits
- toijl: Ocean R, longitude-latitude-depth tracer fields
- icij: Viscous-plastic ice dynamics, longitude-latitude fields
- areg: atmospheric model, aj diagnostics for predefined regions
- consrv: atmospheric model, conservation quantities on the budget grid
- tconsrv: atmospheric model, tracer conservation quantities on the budget grid
- tajl: atmospheric model, latitude-height tracer fields (budget latitude bands)
- taij: atmospheric model, longitude-latitude tracer fields (or on the cubed-sphere grid if applicable)
- taijl: atmospheric model, longitude-latitude-height tracer fields (or on the cubed-sphere grid if applicable)
- **all: output ALL available diagnostics above.**

Source Code Structure

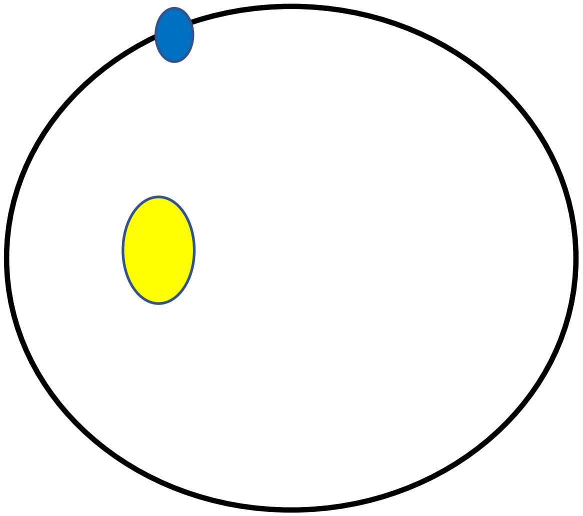
- `#include "rundeck_opts.h“`
- The XXX_COM and XXX_DRV files
- Constants_mod.F90 and PlanetParams_mod.F90,
- Adding diagnostics (DEFACC.f)

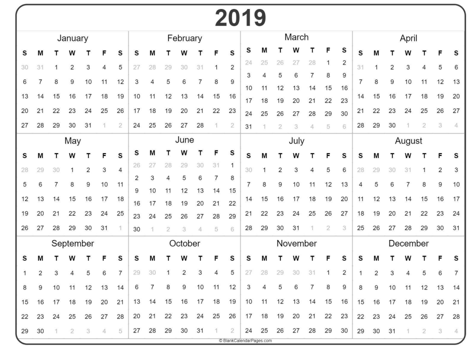
Tomorrow/Day 2

- 10:00-10:05: Good Morning
- 10:05-10:25: Tom Clune on Calendar
- 10:25-10:45: Aleinov on ground hydrology
- 10:45-11:00: Break
- 11:00-11:20: Eric Wolf (Radiation)
- 11:20-12:00: Geronimo Villanueva: Planetary Spectrum Generator & ROCKE-3D
- 12:00-13:00: Lunch
- 13:00-13:45: Chris Colose: How to create a new planet
- 13:45-14:00: Break
- 14:00-15:00: Q&A

ModelE
Orbits & Calendars

Tom Clune (GMAO)





ORBIT

Absolute
Model
Time

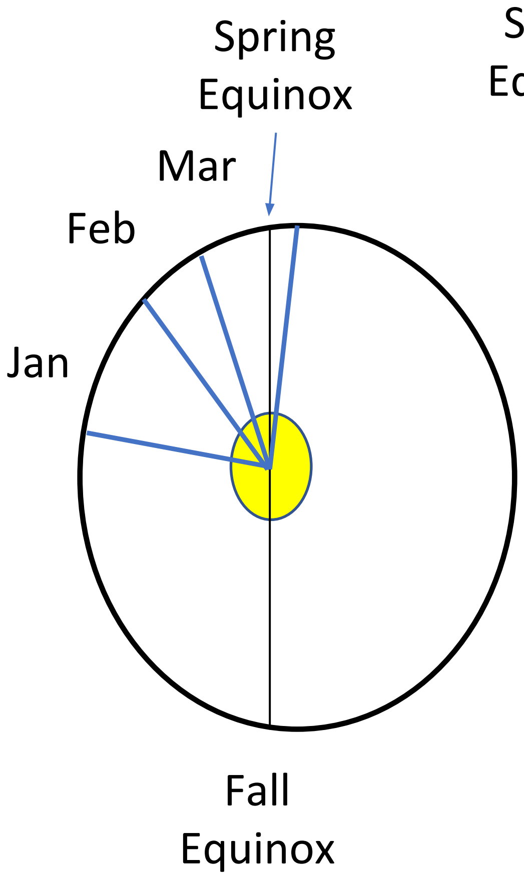
Calendar

Distance
Hour Angle
Declination

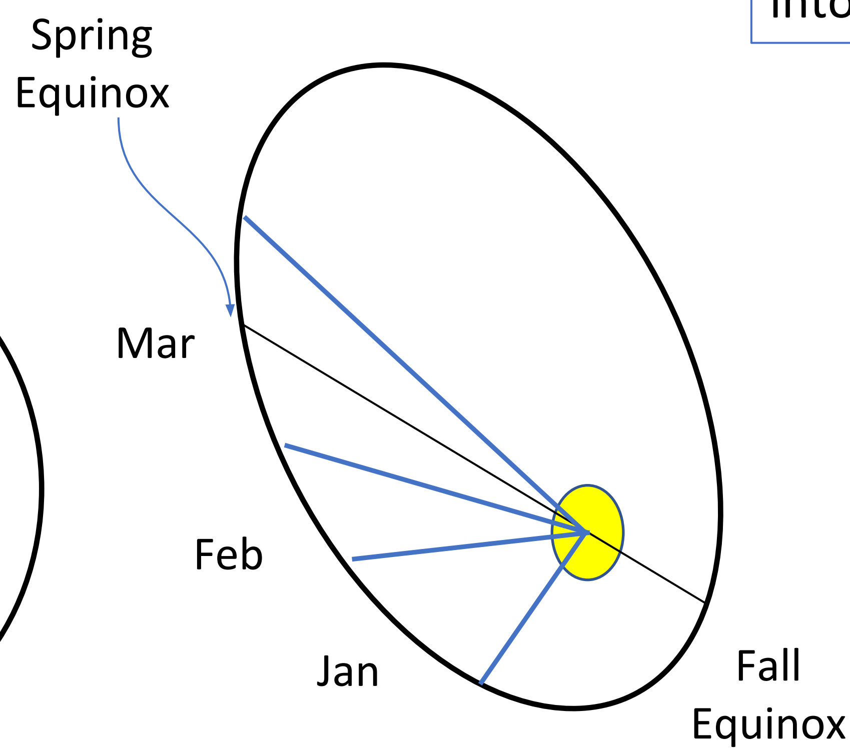
Year
Month
Date
Day Of Year
Hour
Seconds

Exoplanet years are divided into 12 months. The angle (solar longitude) subtended by each month is (approximately) the same as the corresponding month for the Earth.

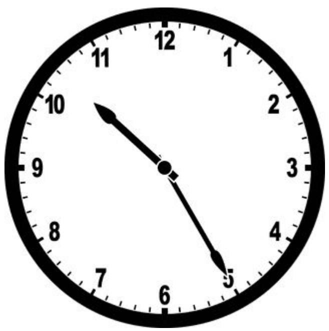
Earth



Exoplanet



Days are subdivided into 24 equal "hours".



Hour angle is 0 for prime meridian at 0h Jan 01.

Note: orbital period is "adjusted" to be an integral multiple of rotation period.

Problems …

The conventional Earth-like calendars work well when:

$$|\omega_{\mathbf{orbit}}| \ll |\omega_{\mathbf{planet}}|$$

This allows:

1. Integral number of solar days per year (with minor adjustment)
2. Division of year into 12 roughly equal months that have many days each.

This assumption fails badly for slow rotators including tidally locked planets.

Treatment of slow rotators

- Calendar years always have at least 120 *calendar* days.
  - *Calendar* days and *solar* days are not the same
  - ***Be wary of "diurnal" diagnostics***
  - Monthly averages mays also be misleading – a given longitude may experience daylight for an entire "month" even at the equator!
- For very slow rotators (e.g., Venus)
  - Must deactivate orbit "quantization"
  - Seasons "float" from (calendar) year to (calendar) year
  - *Entire (calendar) years may have a day/night bias*
    - Must run large number of years to get valid global averages
    - Ideally the least common multiple of orbit year and calendar year

Basic orbit rundeck parameters

- planetName=… (something other than ‘Earth’)
- obliquity=… (degrees - default is modern Earth)
- eccentricity=… (default is modern Earth)
- longitudeAtPeriapsis=… (in degrees – default is modernEarth)
- siderealOrbitalPeriod=…(in seconds – default is model Earth year 365*24*3600)
- siderealRotationPeriod=…(in seconds – default is model Earth day ~86163.934)
  - <u>Automatically adjusted to quantize year</u>
- quantizeYearLength=… (“true” or “false”)
- EOT (“off”, “naive”, “on”) (important for high-eccentricity slow rotators)
  - Default is “on” for non-Earth on planet branch (“naive” on planet_1.0)
- Rarely used:
  - meanDistance=…(AU)
  - hourAngleOffset=… (move “Greenwich” mostly for topography)

Boundary Conditions Files

- Compare P1SoM40 with:
  - Aquaplanet
    - AIC: winds to zero (start from uniform conditions?)
    - TOPO_OC and OIC depth
  - Earth + Bathtub ocean: depth differences in runtime
  - Venus 310m ocean
    - River directions file (in Planet_2.0 this will be obsolete)
  - Venus Land planet
  - Tidally Locked Proxima Centauri (with CO_2 atm)
    - aquaplanet
    - earth topography (longitude)
    - spectral files documentation
    - Planet_Params.F90

PS_Mars params …

```
!--------------------
planetName = 'Mars' ! Construct a calendar …
! The following sets the various orbital parameters
! source: http://en.wikipedia.org/wiki/Mars
eccentricity = 0.093
obliquity = 25.19d0 ! degrees
longitudeAtPeriapsis = 251.0 ! degrees
siderealOrbitalPeriod  = 59354294.4 ! seconds
siderealRotationPeriod = 88642.6848 ! seconds
quantizeYearLength='true’ ! Or false
!-------------------
```

PS_Mars diagnostics

```
Planet :: Mars
   Mean solar day:
          88775.1850588159       (sec)
          1.02749056781037       (Earth days)
   SiderealRotationPeriod:
          88642.6847826087       (sec)
          1.02595699979871       (Earth days)
   SiderealOrbitalPeriod:
          59390598.8043478       (sec)
          687.391189865137       (Earth days)
   meanDistance (AU)          :   1.52366231000000
   Precession (degs from VE)  :   251.000000000000
    Solar Days per year:          669
  Eccentricity:  9.300000000000000E-002
  Obliquity (degs):   25.1900000000000
Fixed orbital parameters for planet.
  Eccentricity:  9.300000000000000E-002
  Obliquity (degs):   25.1900000000000
  Longitude at periapsis (degs from ve):   251.000000000000
```

PRT diagnostics for Mars

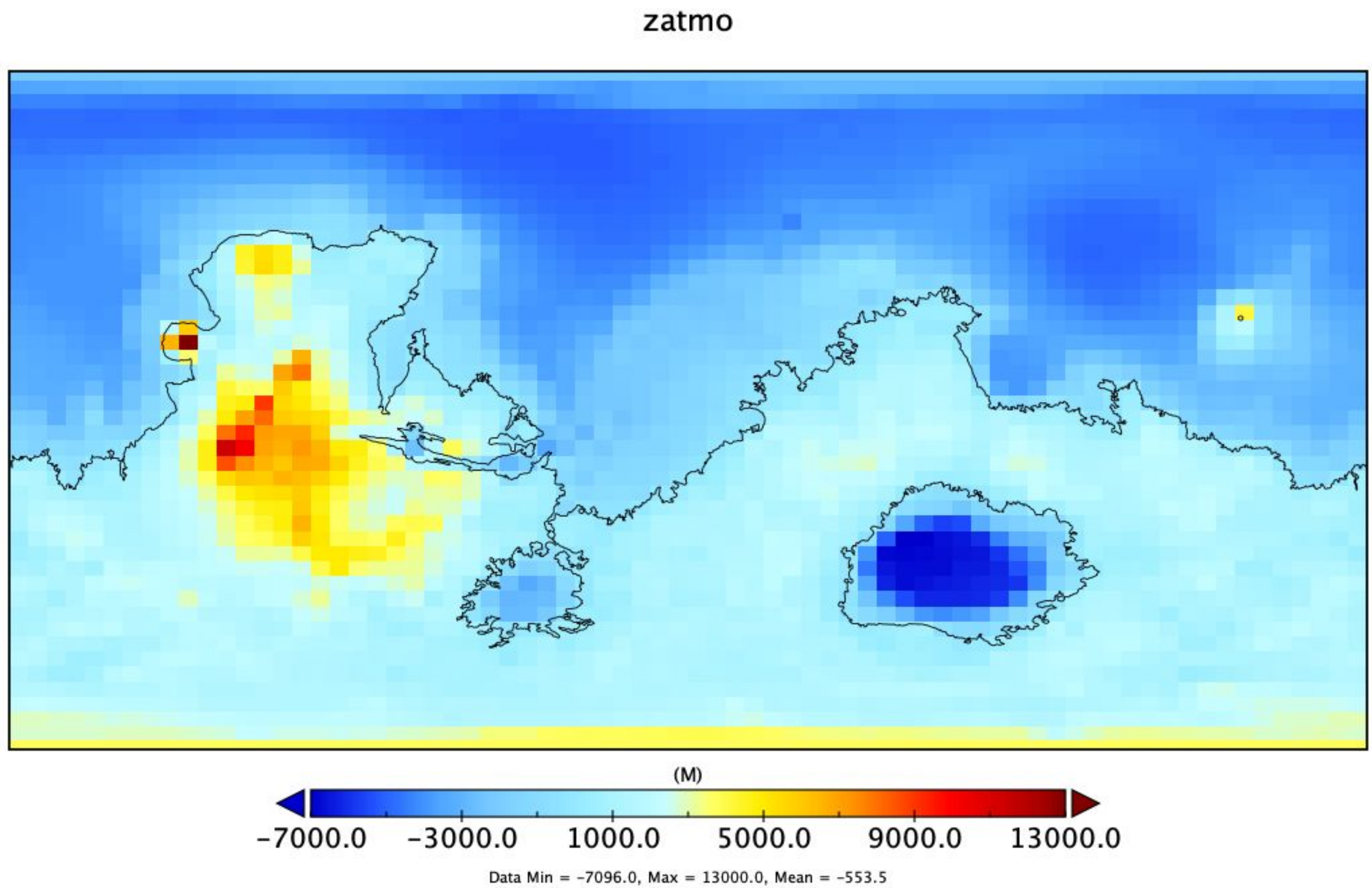
Calendar for Year: 2000

Calendar year length (sec): 59390598.8043

Full Name	Abbr	# days	1st day	mid day	lst day
January	JAN	49	1	25	49
February	FEB	45	50	72	94
March	MAR	54	95	121	148
April	APR	56	149	176	204
May	MAY	62	205	235	266
June	JUN	64	267	298	330
July	JUL	65	331	363	395
August	AUG	63	396	427	458
September	SEP	58	459	487	516
October	OCT	55	517	544	571
November	NOV	49	572	596	620
December	DEC	49	621	645	669

apsis........................06-31
periapsis.....................12-12
vernal equinox................03-52
summer solstice...............07-09
winter solstice...............12-41
autumnal equinox.............10-02

PS_Mars topography



PS_Mars pressure seasonal cycle

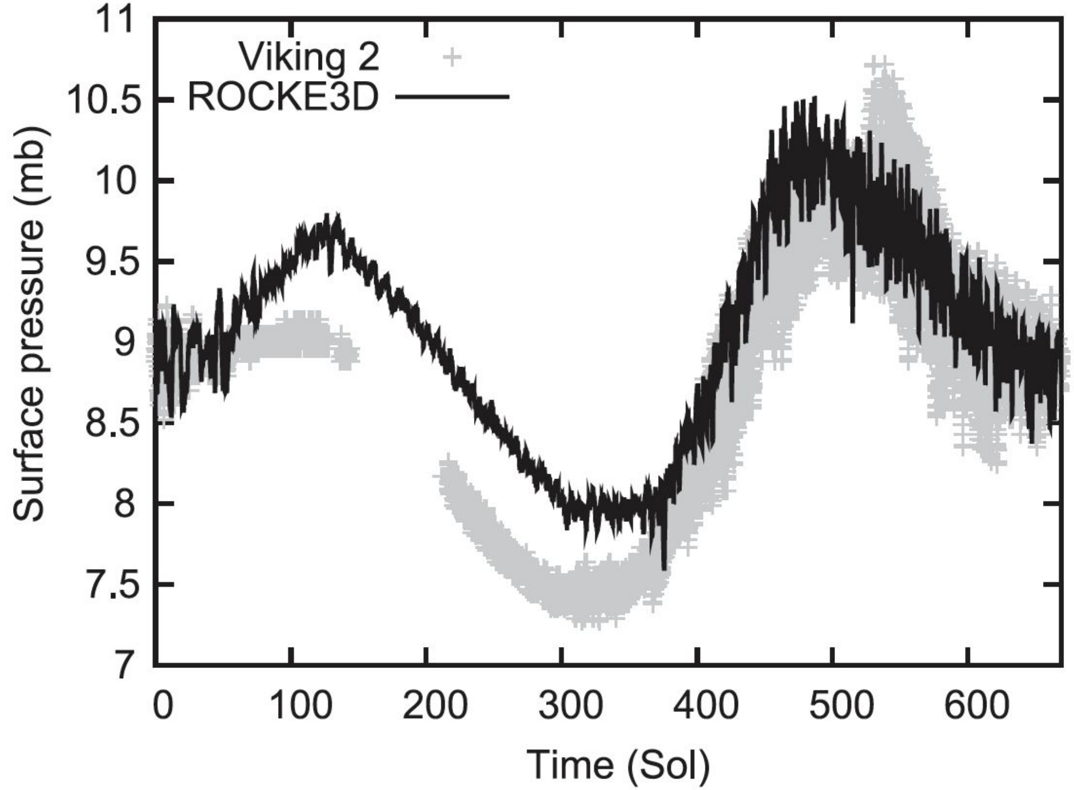
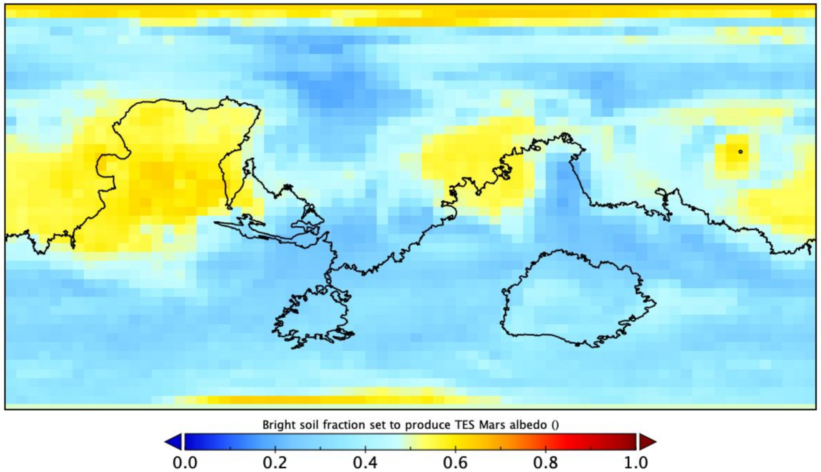


Figure 6. Annual cycle of Mars surface pressure, as measured by the Viking 2 lander (gray crosses) (Hess et al. 1977; Tillman 1989), and surface pressure simulated by ROCKE-3D (black solid line).

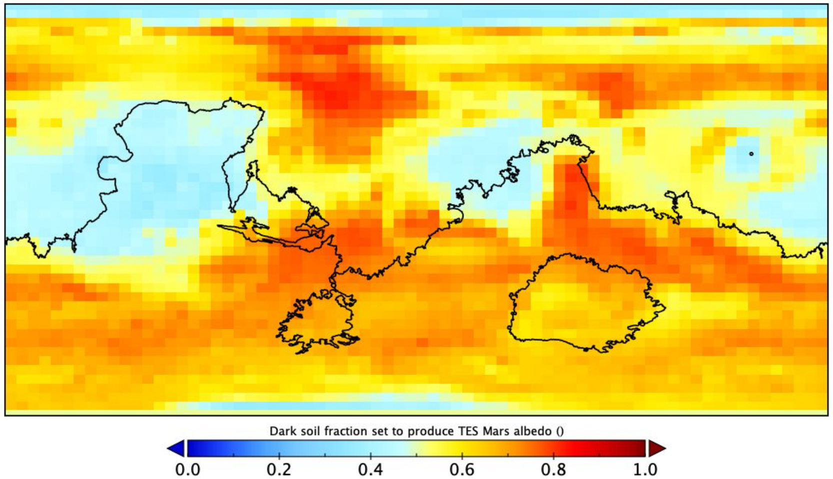
PS_Mars albedo

VEG=planet/Mars/veg_Mars_TES_albedo_72x46.nc

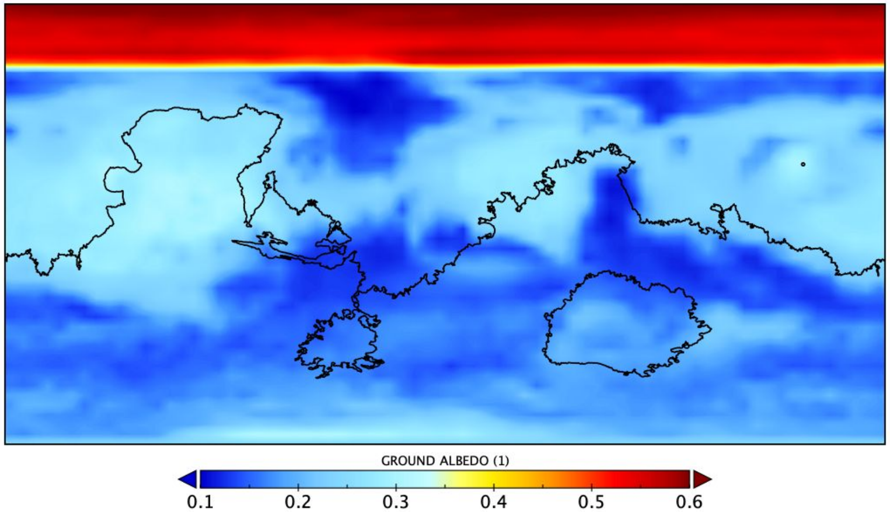
bright soil fraction (albedo = 0.5)



dark soil fraction (albedo = 0)



ROCKE-3D ground albedo (March)



Computed ground albedo is a combination of dark and bright soil
+ snow/CO2 ice effect

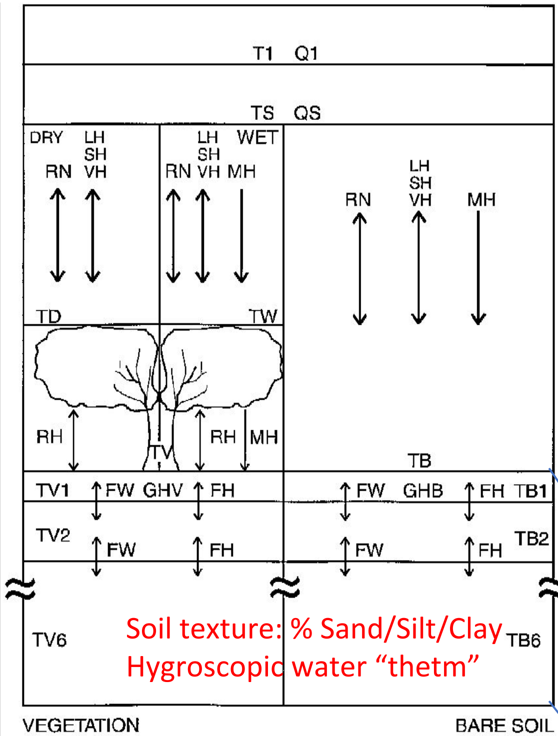
ROCKE-3D

GISS ModelE

Land Hydrology

(Rosenzweig & Abramopoulos 1997; Schmidt et al. 2006)

- 6 soil layers to 3.5 m depth
- Aerodynamic soil evaporation from layer 1.
- Capillary rise.
- Indefinite drainage -> SLOW EQUILIBRIUM.
- **NEW: Dynamic lake formation from soil run-off and spillage to adjacent grid cells**



RN – net radiation
LH – latent heat flux
SH -- sensible heat flux
VH – heat of water vapor
MH – heat of precipitation
TD – temperature of dry canopy
TB – temperature of bare soil
TV1-6 – temperatures of soil layer under vegetation
FW – water flux between soil layers
GHV – heat flux into vegetated land
FH – heat flux between soil layers
TB1-6 – temperatures of bare soil layers
TS, QS – temperature and water vapor mixing ratio of surface
T1, Q1 – temperature and water vapor mixing ratio of first atmosphere layer

	soil depth (m)
	0.0
1	-0.09999996
2	-0.27254396
3	-0.57025843
4	-1.08394717
5	-1.97028677
6	-3.49961317

Lake water balance = soil run-off – evaporation + precipitation +/- transport
Maximum 95% of grid cell area

- Circular surface with conical bottom above soil, default slope R/H = 2000.
- Becomes cylinder when lake becomes small
- Can evaporate completely.

ROCKE-3D

GISS ModelE

Land Hydrology

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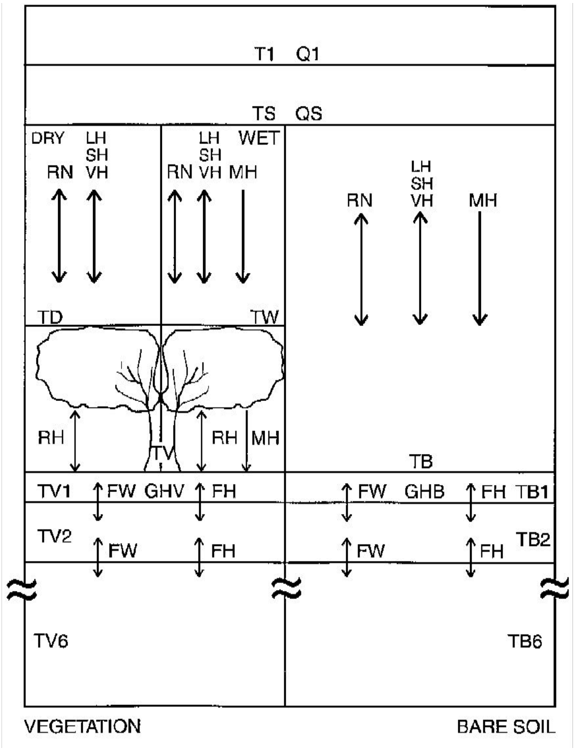


<u>Total water balance</u> =

qatm (atmosphere vapor)
+ cldw (clouds)
+ snowdp (snow)
+ gwtr (water in soil)
+ mwl (lakes+rivers, units different)

<u>Soil "available water" (liquid)</u> =

gwtr (water in soil)
– gice (frozen water in soil)
– thetm (hygroscopic water)

<u>Input files</u>

VEG = vegetation +albedo
TOP_INDEX = standard deviation of topography
SOIL = soil textures + slope
ROUGH = roughness length
SOILIC = initial conditions for ground hydrology

PS_Mars ground hydrology (SOIL)

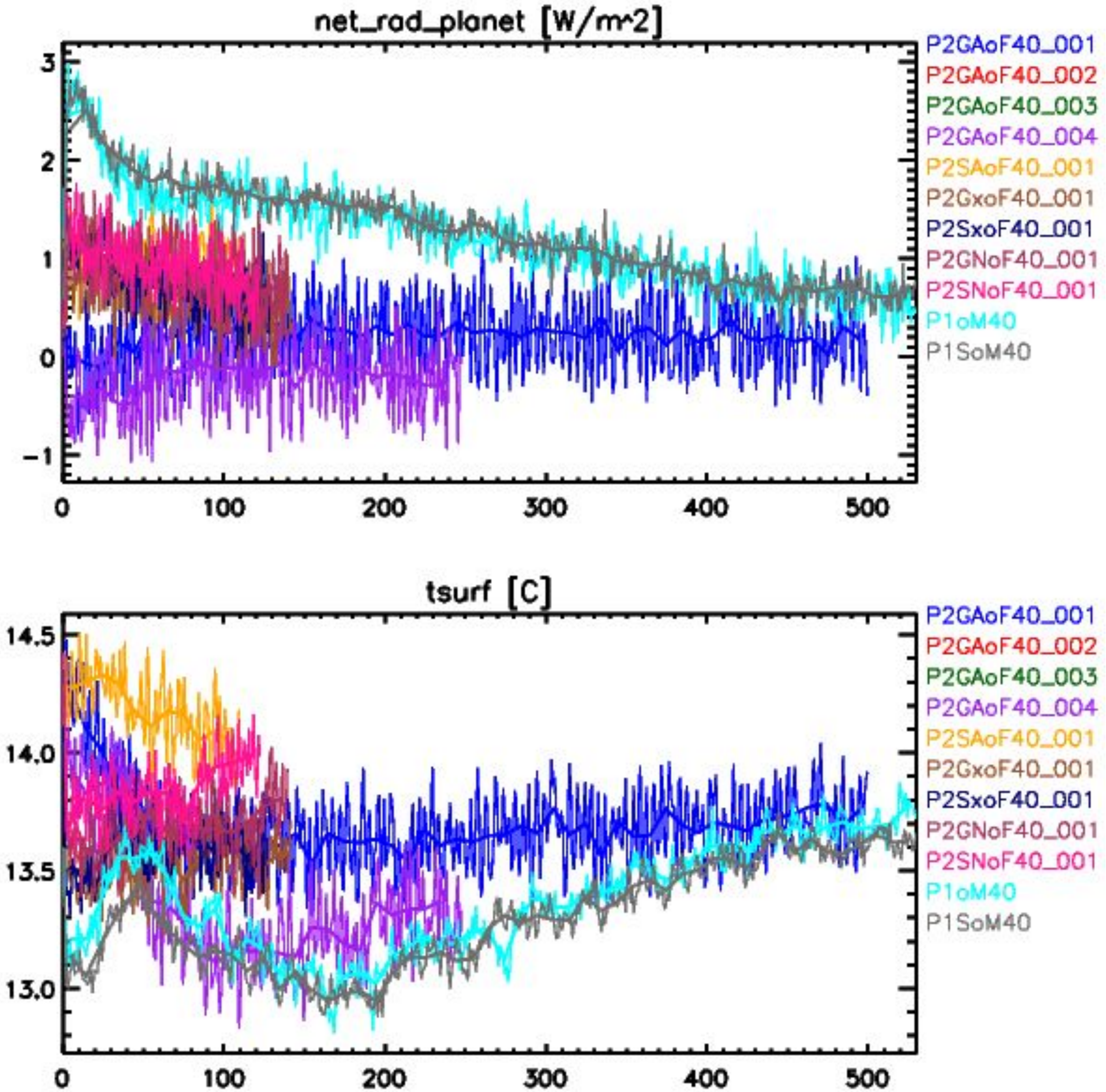
```
$ ncdump -h soil_allsand.nc

netcdf soil_allsand {
dimensions:
    lon = 72 ; West-East resolution
    lat = 46 ; South-North resolution
    ngm = 6 ; number of layers
    imt = 5 ; number of textures: sand, silt, clay, peat, rock
variables:
    float lon(lon) ;
        lon:units = "degrees_east" ;
    float lat(lat) ;
        lat:units = "degrees_north" ;
    float dz(ngm, lat, lon) ; thickness of layers (m)
    float q(ngm, imt, lat, lon) ; soil textures (centers) (fractions)
    float qk(ngm, imt, lat, lon) ; soil textures (edges) (fractions)
    float sl(lat, lon) ; typical slope
}
```

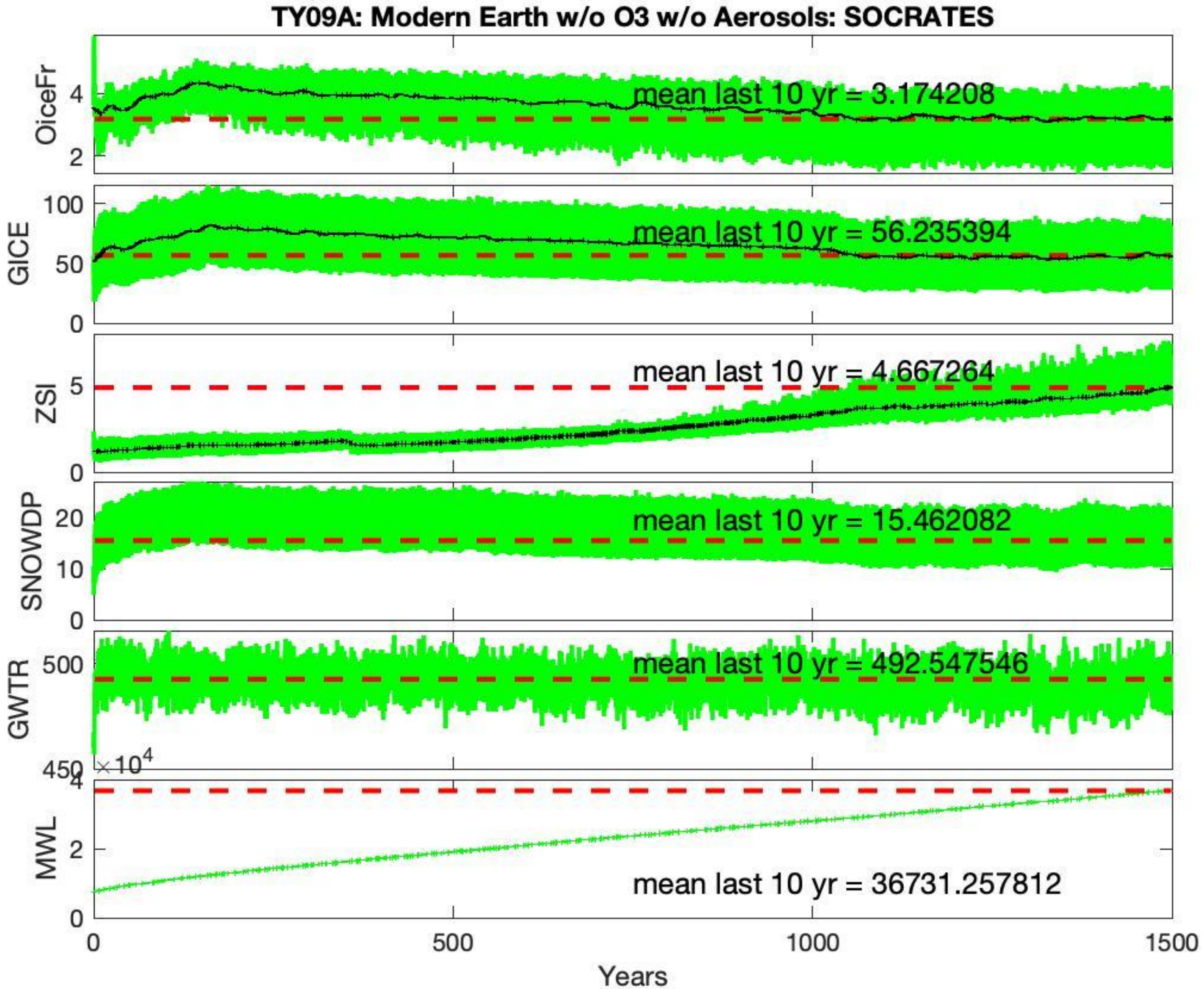
Post Processing Analysis

- How do we decide something is in equilibrium?
  - Radiative equilibrium (atm + ocean)
  - Hydrological equilibrium

    (could be 1000s of yrs)



Hydrological Equilibrium Example

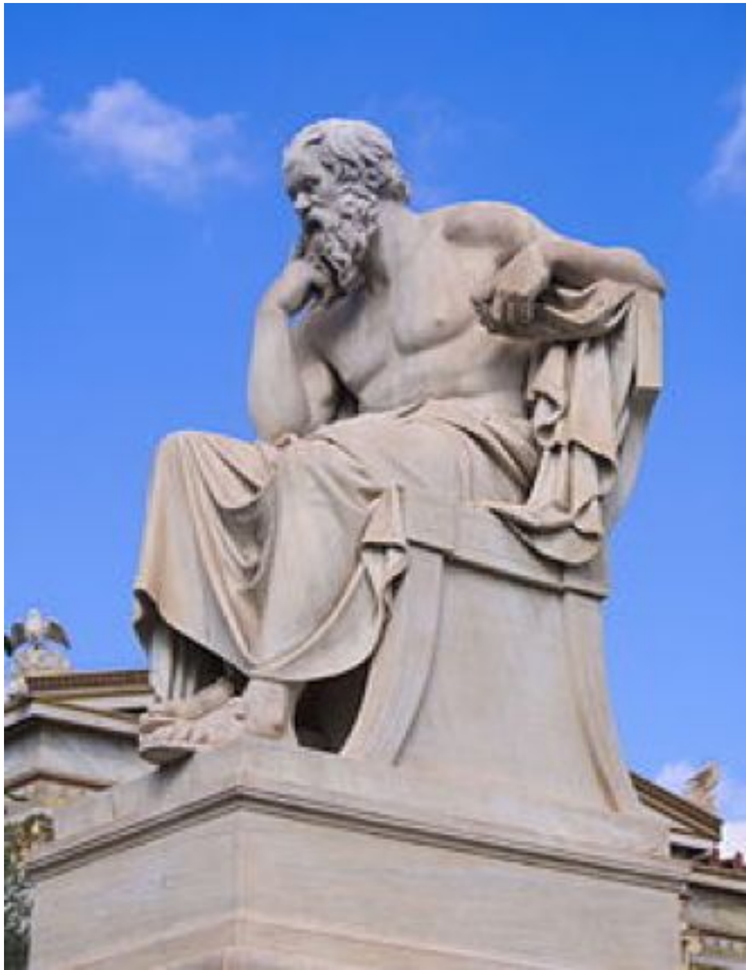


Radiative Transfer: SOCRATES

Suite **O**f **C**ommunity **RA**diative **T**ransfer codes based on **E**dwards and **S**lingo

SOCRATES

The radiative transfer component of ROCKE-3D

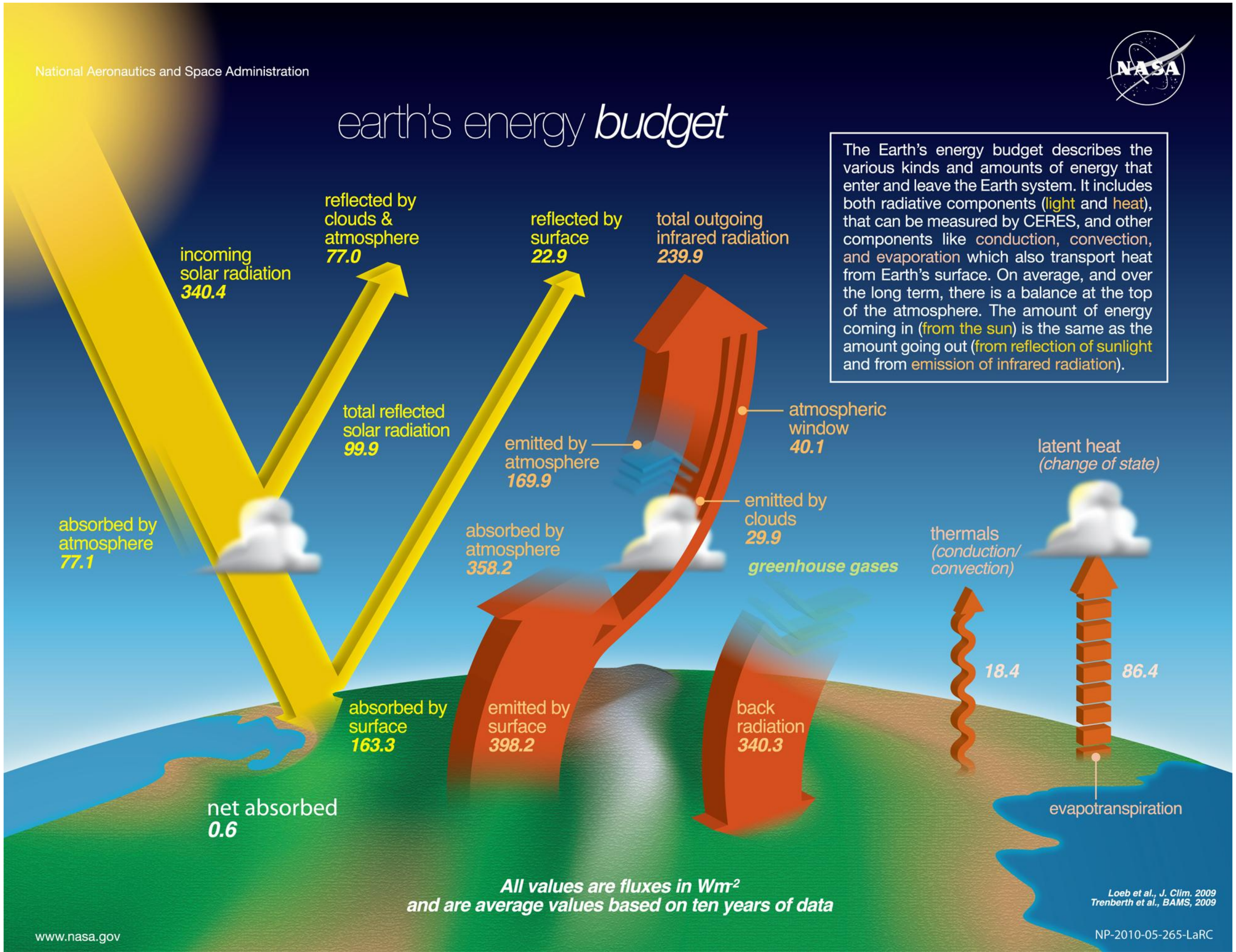


What is Radiative Transfer?

The transfer of electromagnetic energy through a medium.

Radiative transfer in large part determines the energy balance of planets.

This balance can be very different for other planets compared to Earth!



What is Radiative Transfer?

Scattering/Absorption

by gases (N_2, CO_2, H_2O, etc)

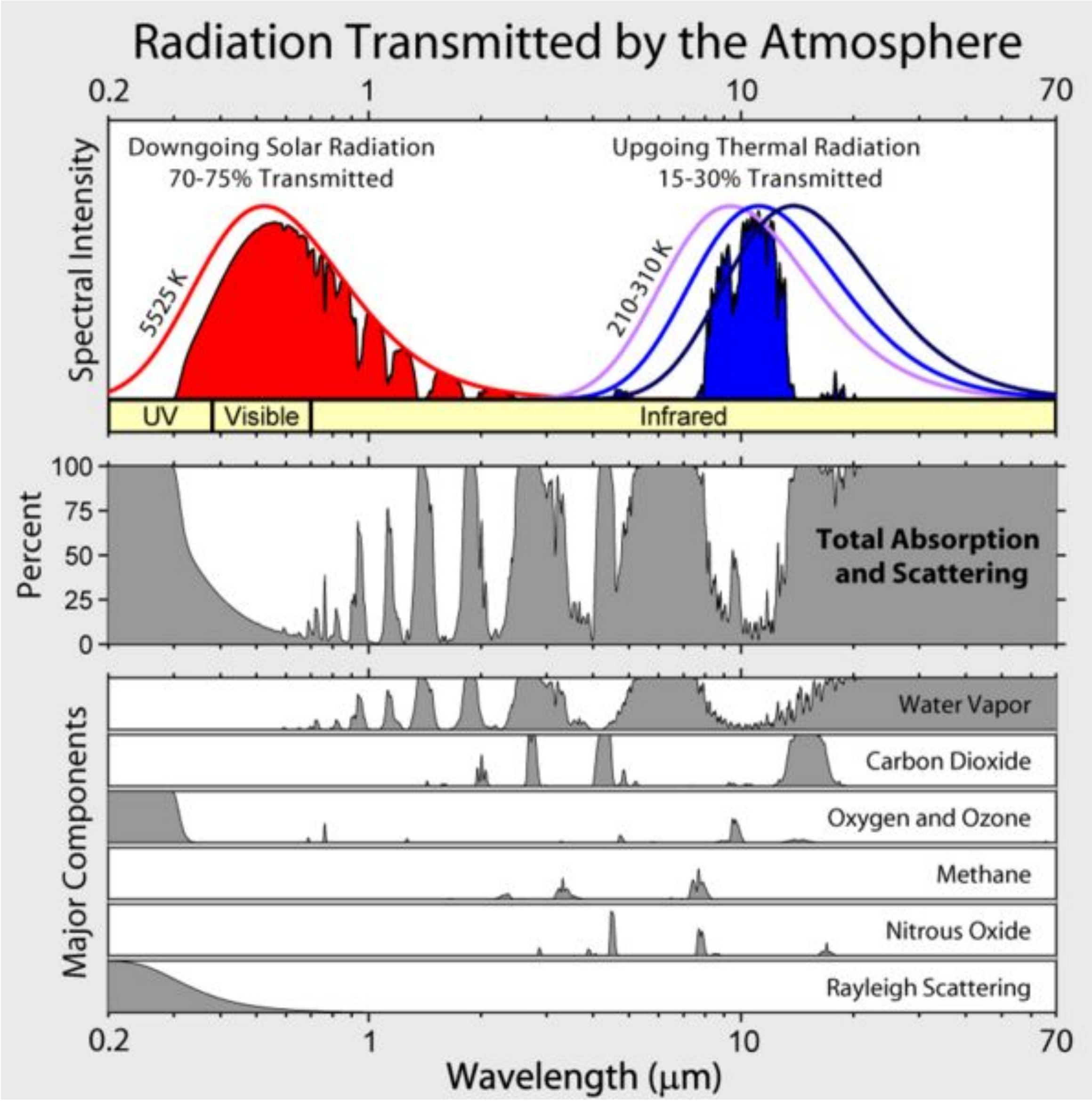
by aerosols (clouds, hazes, etc)

Emission/Reflection

by surfaces (ice, land, ocean)

by the atmosphere itself

Other planets may have very different incident stellar flux, gases, aerosols, and surface properties!



Radiative Transfer: SOCRATES

SOCRATES: a radiative transfer model designed for use in 3-D climate models

requirements: *flexible, fast, accurate*

key terms

spectral files: tailored sets of gas and aerosol absorption coefficients used in SOCRATES (must be set in rundeck, *spectral_file_lw*, *spectral_file_sw*)

stellar spectra: incident stellar energy spectra, convolved with shortwave spectral files (*solar_spec*)

incident stellar flux: the total amount of stellar energy reaching a planet (*planet_s0*)

Important SOCRATES Resources

ROCKE-3D/SOCRATES User guide

(how to setup SOCRATES within ROCKE-3D)

https://docs.google.com/document/d/1B80VTwyxwnozNt5rNry0ICWvz-UWO-bAWZjMTyfhVfA/edit

ROCKE-3D/SOCRATES List Of Spectral Files

(a list and description of gas absorption files and stellar spectra available)

https://docs.google.com/document/d/15AYsvIrmOBQ4b5yIw3yJJV4cvkjcdJ0Z2gREKmIVVHs/edit#heading=h.dpunmplojmki

SOCRATES technical manual guide

(the gory technical description of the inner workings of SOCRATES, provided by the UK Met Office)

http://homepages.see.leeds.ac.uk/~lecsjed/winscpuse/socrates_techguide.pdf

SOCRATES user guide

(users guide for advanced applications of SOCRATES, provided by the UK Met Office)

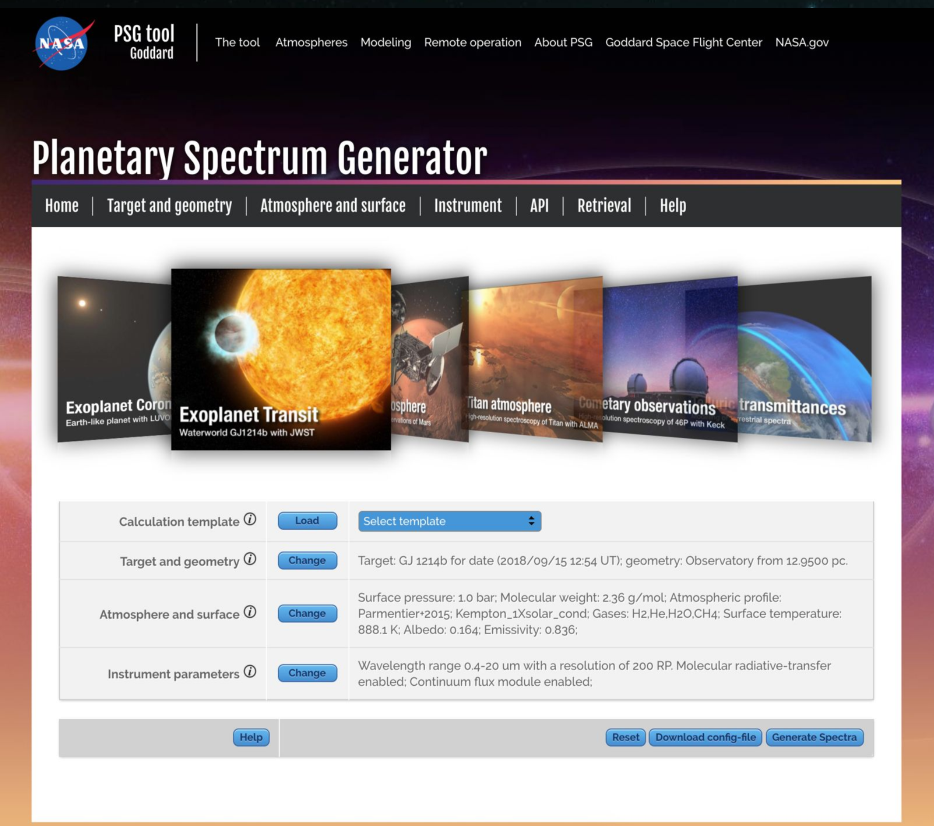
http://homepages.see.leeds.ac.uk/~lecsjed/winscpuse/socrates_userguide.pdf

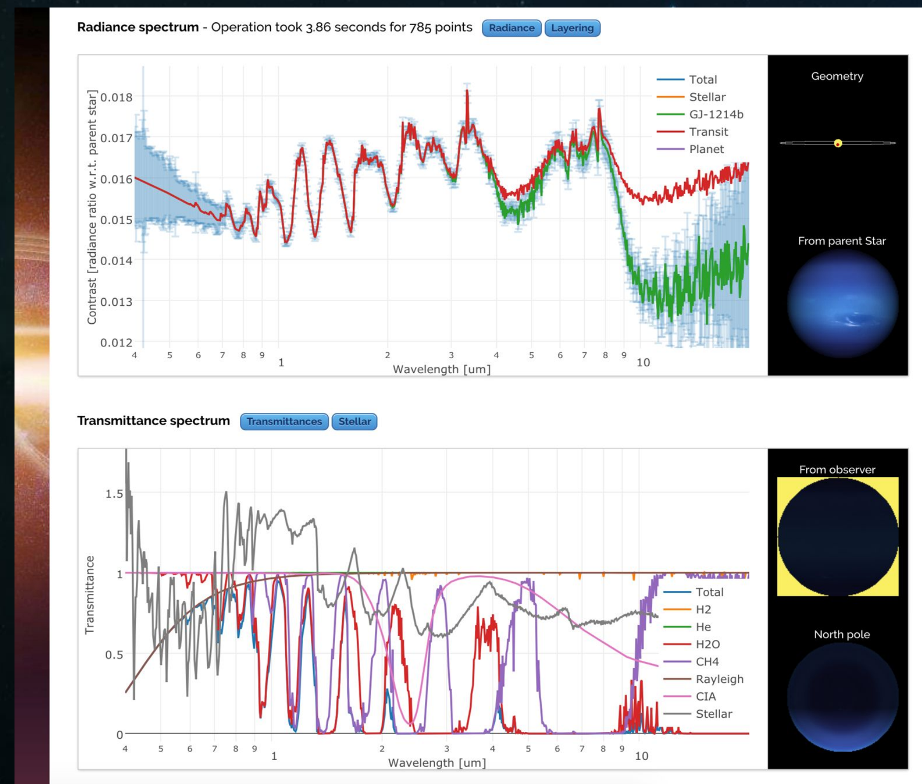
The Planetary Spectrum Generator (PSG)

Gerónimo Villanueva

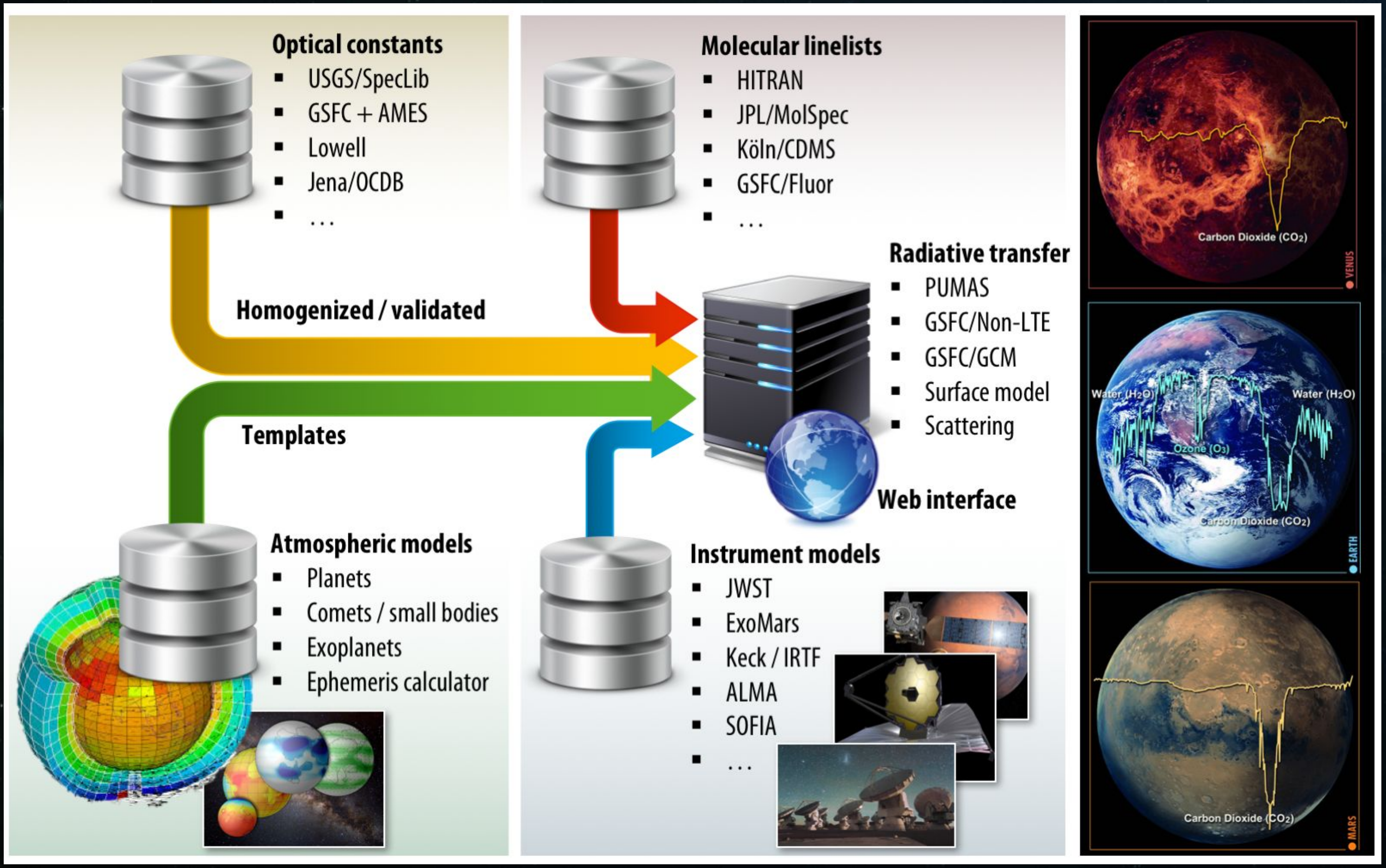
Planetary Systems Laboratory, Code 693
NASA Goddard Space Flight Center
Greenbelt, MD, USA

Planetary Spectrum Generator (PSG)
Villanueva+2020, psg.gsfc.nasa.gov





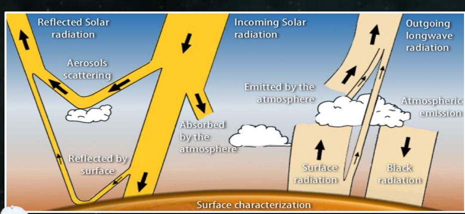
Planetary Spectrum Generator (PSG)
Villanueva+2020, psg.gsfc.nasa.gov



Planetary Spectrum Generator (PSG)
Villanueva+2020, psg.gsfc.nasa.gov

PSG synthesizes spectra of planets, exoplanets and small-bodies from 10 nm to 100 mm (UV/Vis/near-IR/IR/far-IR/THz/sub-mm/Radio) from any observatory (e.g., JWST, ALMA, Keck, SOFIA), any orbiter (e.g., ExoMars, Cassini, New Horizons).

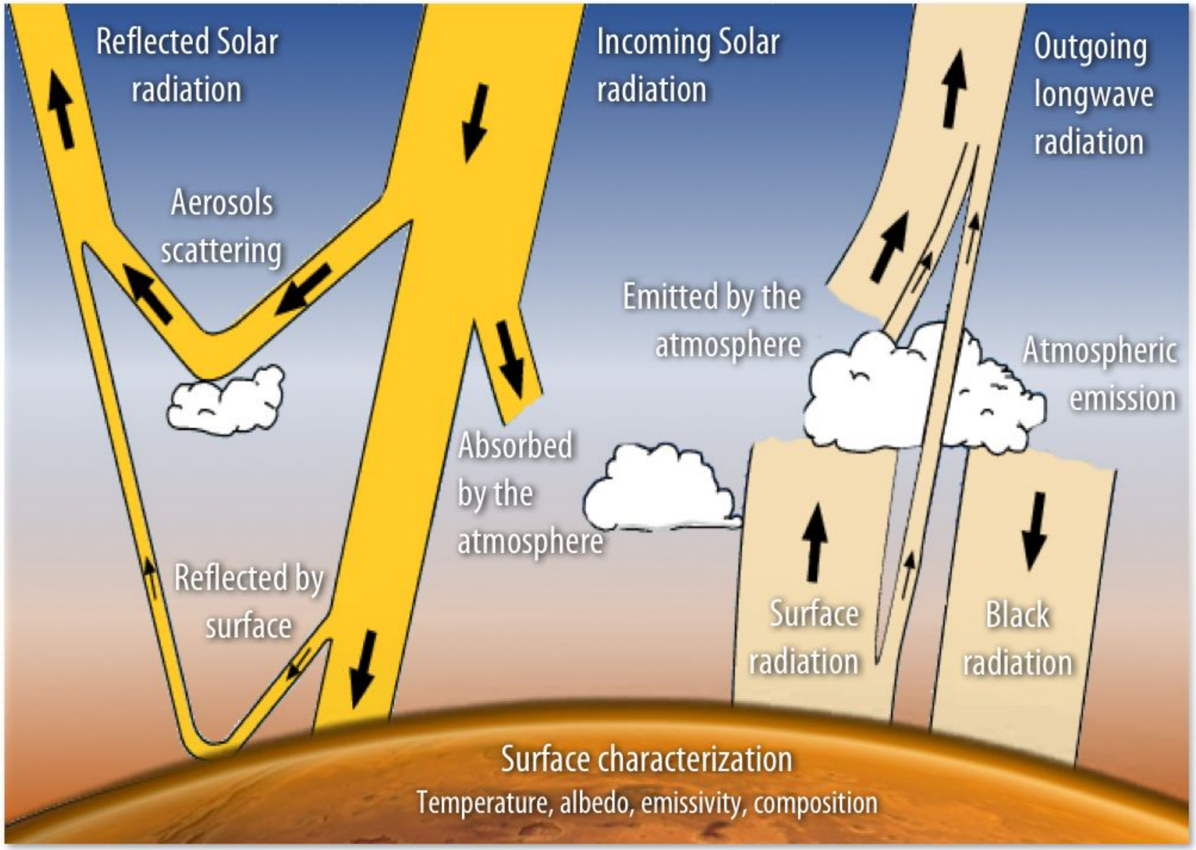
PSG has a 3D orbital calculator for most bodies in the Solar system, and all confirmed exoplanets. Observing geometries are: observatory, from surface, nadir, limb, occultation.



PSG radiative transfer performed with several models: line-by-line, correlated-k, multiple-scattering, non-LTE fluorescence, and surface Hapke models.

PSG includes a noise and signal-to-noise calculator for quantum and thermal detectors, at any observatory (e.g., interferometers, coronagraphs).

Planetary Spectrum Generator (PSG)
Villanueva+2020, psg.gsfc.nasa.gov



PUMAS

- Accurate line-by-line modeling and efficient correlated-k synthesis for moderate resolutions
- Full scattering modeling of aerosols and ices
- Rayleigh, CIA and molecular analysis from UV to radio
- Layer-by-layer analysis in spherical geometry

CEM

- Non-LTE fluorescence analysis of cometary coma (line-by-line) – UV to IR
- Rotational LTE excitation analysis of cometary coma - IR to Radio
- Nucleus and extended grains emission model
- Photodissociation processes and parent/daughter analysis

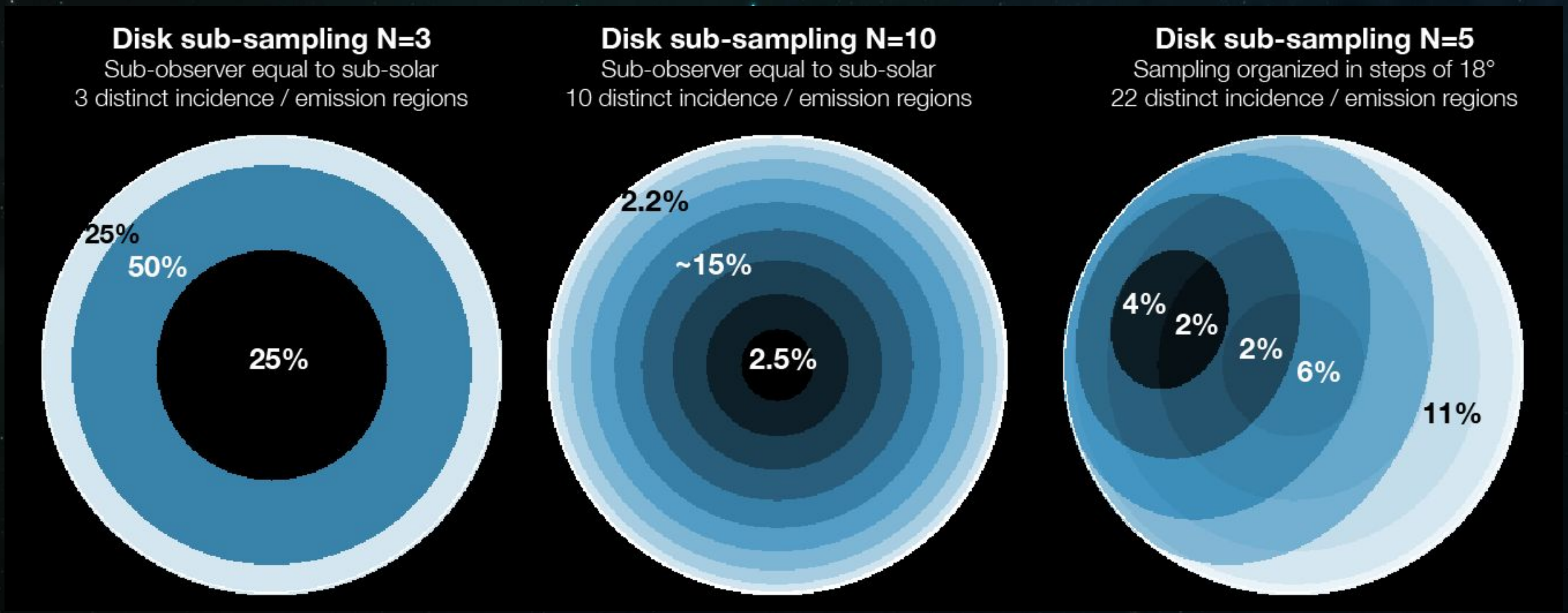
SURFACE

- Hapke surface modeling with areal mixing
- Henyey-Greenstein phase modeling
- Database with hundreds of optical constants

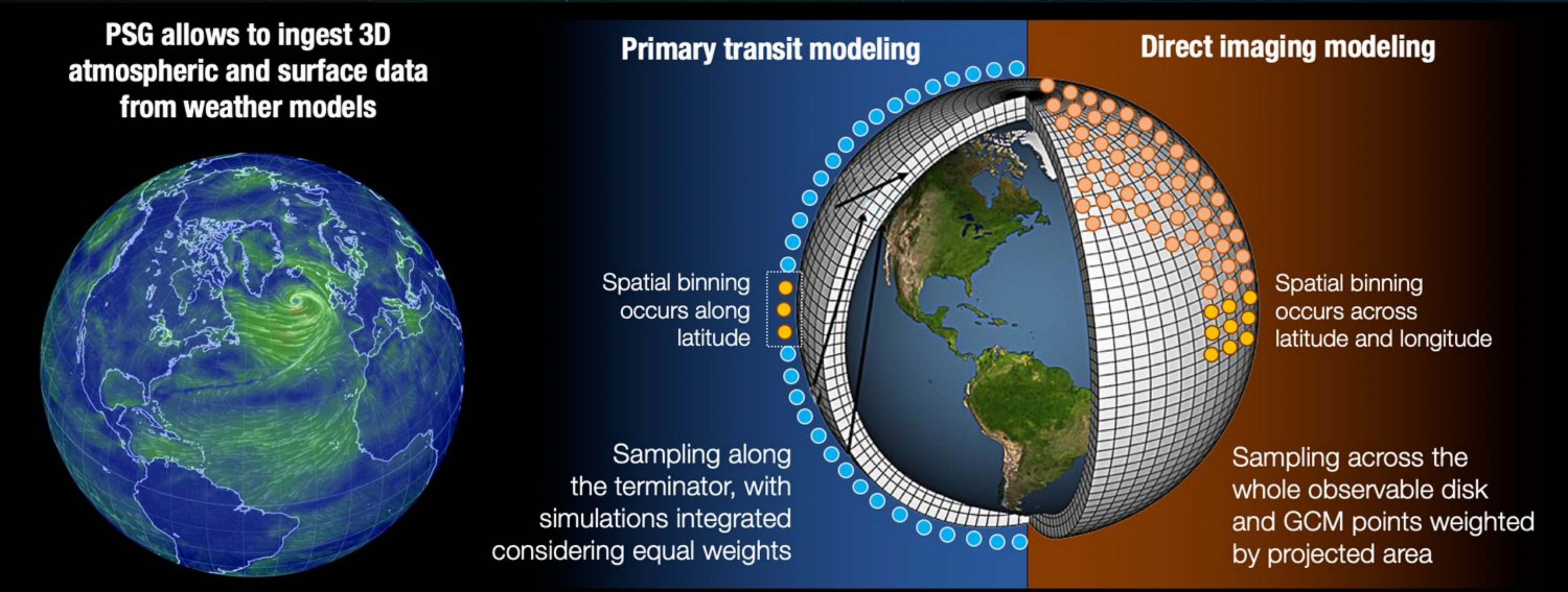
- 1264 molecular / atomic linelists from several databases (e.g., HITRAN, GEISA, NIST, CFA/Atomic, JPL,, CDMS, MPI-Mainz/UV, GSFC/Non-LTE, ExoMol)
- 104 scattering aerosols models (e.g., dust, water ice, organic hazes, silicates and refractory condensates). Models in T-matrix and Mie models.
- 1978 surface components (e.g., albedos and optical constants) of ices, solid components, from dozens of repositories.

Global Exoplanetary Spectra (GlobES)

Homogeneous atmospheric/surface properties, heterogeneous geometries



Heterogeneous atmospheric/surface properties and geometries



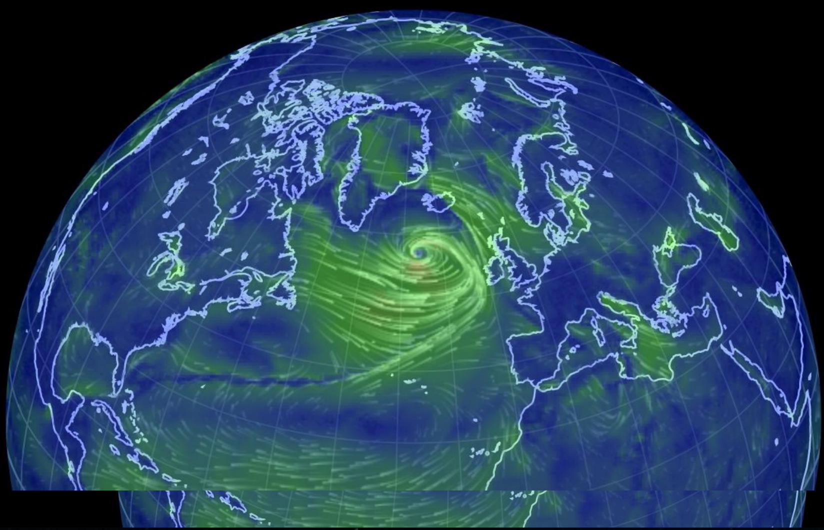
PSG tool
Goddard

The tool | Atmospheres | Modeling | Remote operation | About PSG | Applications | Goddard | NASA.gov

Global Exoplanet Spectra

Home | Target and geometry | Atmosphere and surface | Instrument | API | Retrieval | Help

The **GlobES** (Global Exoplanet Spectra) application allows to ingest climatological data from a variety of **General Circulation Models** (GCM) and to accurately synthesize planetary spectra. The 3D and temporal atmospheric data is aggregated and mapped into a 2D projected observationally grid that is fed to the Planetary Spectrum Generator (PSG).



Projection
Orthographic
Variable
Winds
Altitude
Surface
Topography
Earth's topography
Center of disk [lon/lat]
-27.33 33.56

GCM templates
CAM_Aqua
Load template
Scripts: Python IDL

Scripts: Python IDL

PSG currently provides templates and conversion scripts for several GCM models, including Rocke3D, Laboratoire de Météorologie Dynamique (LMD), and the Community Atmosphere Model (CAM). In order to ingest GCM 3D data, these are the steps required:

1) Run the GCM model in your personal machine, and store the resulting 3D fields and parameters into a GCM formatted file (typically a netCDF file).

2) By employing a script (e.g., python, IDL) convert the GCM netCDF file into a PSG GCM binary file. Several example conversion scripts are available at the GlobES application site, permitting to convert netCDF ouput files from Rocke3D, LMD and CAM. This script should be run at the user's local machine.

3) In the GlobES site, upload the PSG GCM file by clicking on "Load GCM data".

4) Select the observing geometry (e.g., transit, direct imaging).

5) In the GlobES site, click on "Generate 3D spectra". For each position on the planet, the algorithm will update the atmospheric profiles, surface properties and geometry parameters and will run the radiative transfer. These results will be integrated employing the appropriate weights.

Demo

https://psg.gsfc.nasa.gov

Creating a New Planet (step by step)

Creating a New Planet
https://docs.google.com/document/d/1zrXQyEjXLRldWdyiZn2JxxQXz6dU8bayqOltf6eIJgo/edit?usp=sharing

Files for Download for interactive example

https://drive.google.com/open?id=1S2I7FC3m2lbZyFShGQBAvdyiJvMPO2ry

If you want to join along, then beforehand:

1. Download files in link above and put the Proxima rundeck (.R file) in /home/username/modelE2_planet_1.0/decks
2. In your favorite text editor, modify the .R file lines “solar_spec_dir” and “spectral_dir” to the appropriate socrates path, e.g., (‘/home/username/ModelE_support/socrates/stellar_spectra’ or ‘/home/username/ModelE_support/socrates/spectral_files’).
3. Put rest of the files (input files) in /home/username/ModelE_Support/prod_input_files

Creating a New Planet (sanity checks)

Modifying pressure,gravity,radius, and some composition in model/shared/PlanetParams_mod.F90

Key items for consideration in rundeck modification

- Initial condition files (esp. AIC, OIC)
- Planet's topography and ocean state
- Self-consistent input files
- River directions
- Surface conditions (soil, vegetation)

- Total stellar flux
- Greenhouse gas concentrations
- Spectral files/star type
- Orbital parameters
- Thinking ahead about errors/bugs

- ❏ Generating a first acc file → aij (or others) file
- ❏ Getting correct diagnostics
  https://simplex.giss.nasa.gov/gcm/doc/HOWTO/newio.html#scaleacc
- ❏ Checking a few key things from output (e.g., incsw_toa, tsurf, topography, net_rad_planet)
- ❏ Panoply viewer (https://www.giss.nasa.gov/tools/panoply/)

Time Permitting

- Discuss real case scenarios with audience

- Transmission and reflection spectra (Yuka Fujii)
    - https://docs.google.com/document/d/1Kre_HT586XIsodNkeHejTEwYZPQ6cbAs0t9BXU0G054/view

- Using GSFC/NCCS Discover cluster and other tricks of the Planet_1.0 trade:
    - https://docs.google.com/document/d/1iQDq0S5UIqus6dbUUVVQQdP6k8P10vIMCuVqhn2sWpA/view