NRLMSIS Atmosphere Temperature and Composition Model

- Arguments: Position, time, solar irradiance, geomagnetic activity
- Output: T(z), T_{ex} (K); N_2, O_2, O, He, H, N, Ar (cm^{-3}); ρ ($g\ cm^{-3}$)
- Physical constraints: Approximate hydrostatic equilibrium; diffusive equilibrium above ~200 km
- Formulation: Bates/spline vertical temperature profile; spherical and temporal harmonic expansion; polynomial in F10.7 and Ap heating function
- Major overhaul in progress

U.S. NAVAL RESEARCH LABORATORY

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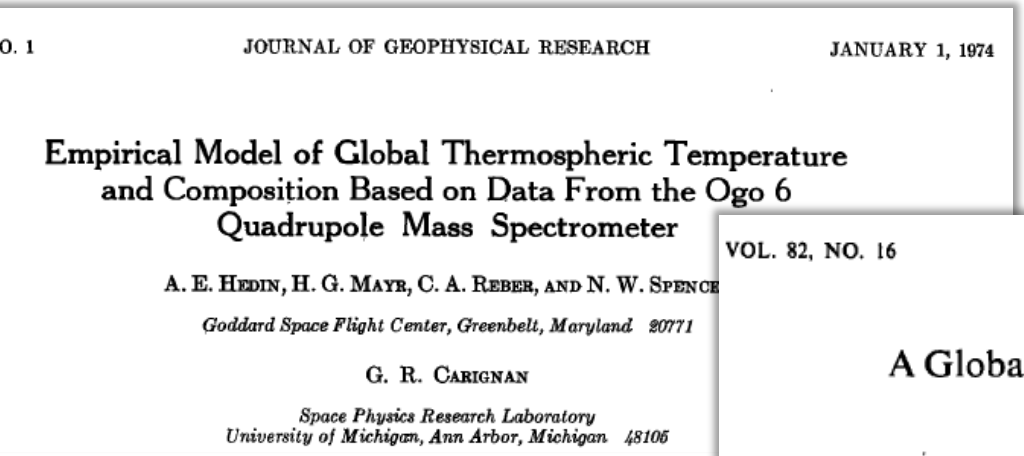
Acknowledgement: This work was supported by the Chief of Naval Research

NRLMSIS History

- The Mass Spectrometer and Incoherent Scatter radar model (MSIS®) was created in 1977 by Alan Hedin at Goddard Space Flight Center, based in large part on Atmospheric Explorer data.
- It grew out of a 1974 statistical model of Ogo 6 mass spectrometer data.
- MSIS originally represented the upper thermosphere. Upgrades followed:
  - 1983: Rocket data, extended to lower thermosphere
  - 1986: DE-2 data, atomic nitrogen added, expanded formulation
  - 1990: Extended to ground
- After Alan Hedin retired from NASA in 1995, Mike Picone of NRL's Space Science Division continued development of the model with Alan's assistance.
- The current version, NRLMSISE-00, added mass density from satellite drag, O_2 data from solar occultation, and a new "anomalous O" species above 500 km.



O. 1 JOURNAL OF GEOPHYSICAL RESEARCH JANUARY 1, 1974

Empirical Model of Global Thermospheric Temperature and Composition Based on Data From the Ogo 6 Quadrupole Mass Spectrometer

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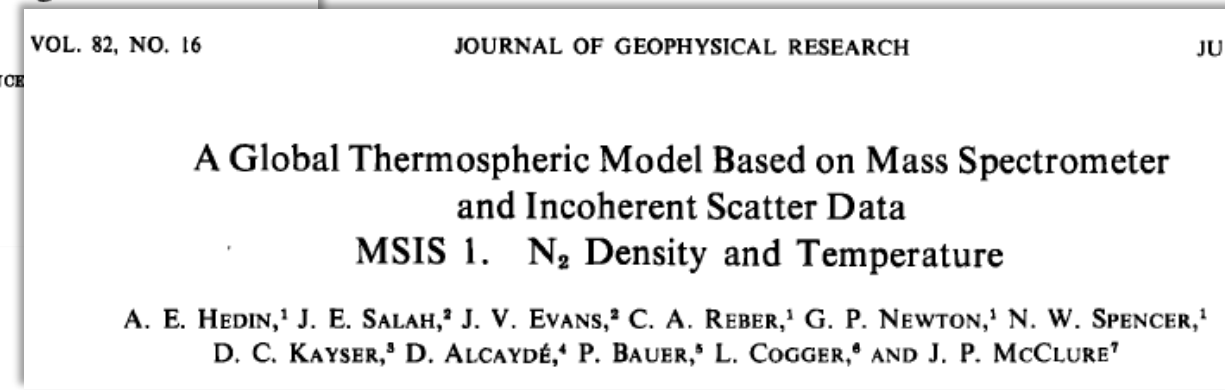

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A Global Thermospheric Model Based on Mass Spectrometer and Incoherent Scatter Data
MSIS 1. N_2 Density and Temperature

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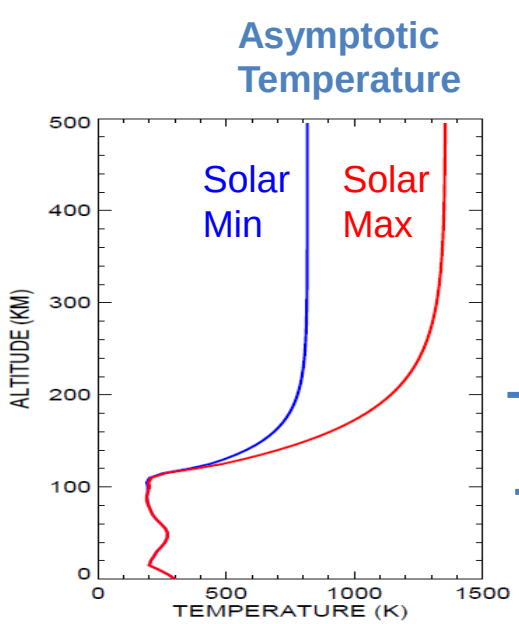
NRLMSISE-00 Physical Constraints

$$\ln n_i = \ln n_{i,0} - (1+\alpha)\ln\frac{T}{T_0} - \frac{m_i g_0}{k}\int_{\zeta_0}^{\zeta}\frac{1}{T(\zeta')}d\zeta'$$

$n_i =$ Species number density, $T =$ Temperature

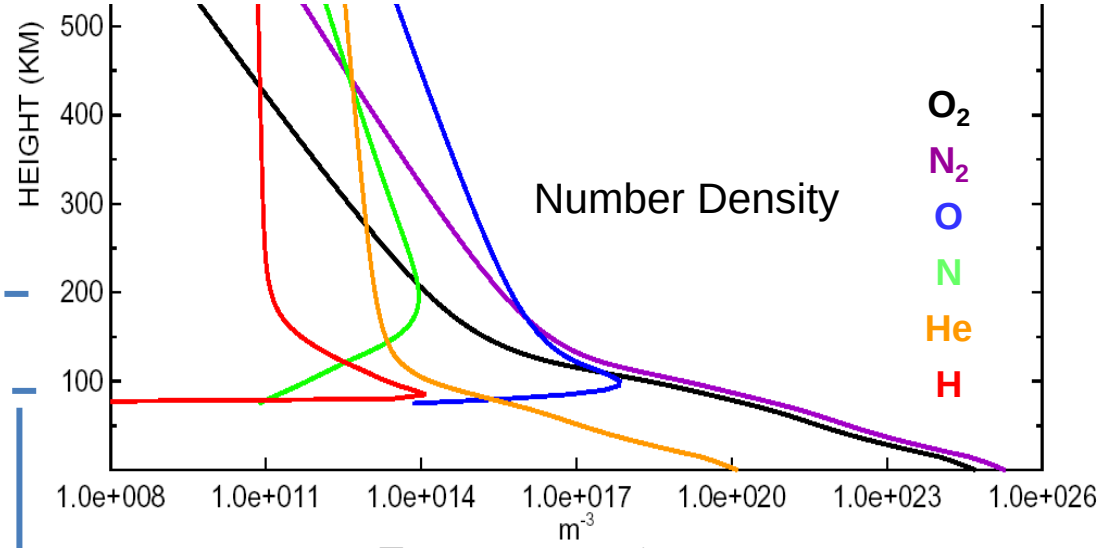
$m_i =$ Species mass, $\zeta =$ Geopotential height,

$\alpha =$ Thermal Diffusion



Diffusive Equilibrium

Fully Mixed



$$\ln n = \ln n_0 - \ln\frac{T}{T_0} - \frac{\bar{m} g_0}{k}\int_{\zeta_0}^{\zeta}\frac{1}{T(\zeta')}d\zeta'$$

$n =$ Total number density, $\bar{m} =$ Mean mass

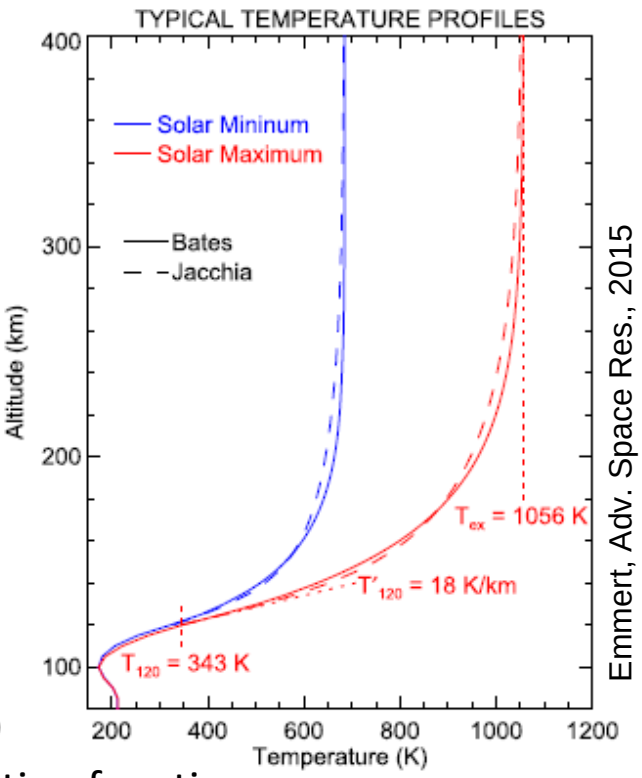
- Asymptotic temperature profile defined by exospheric temperature
- Fully mixed hydrostatic equilibrium below ~100 km
- Diffusive equilibrium (~species hydrostatic equilibrium) above ~200 km
- Approximate hydrostatic equilibrium between 100 and 200 km
- Temperature profile constructed so that the integral can be computed in closed-form

NRLMSISE-00 Formulation

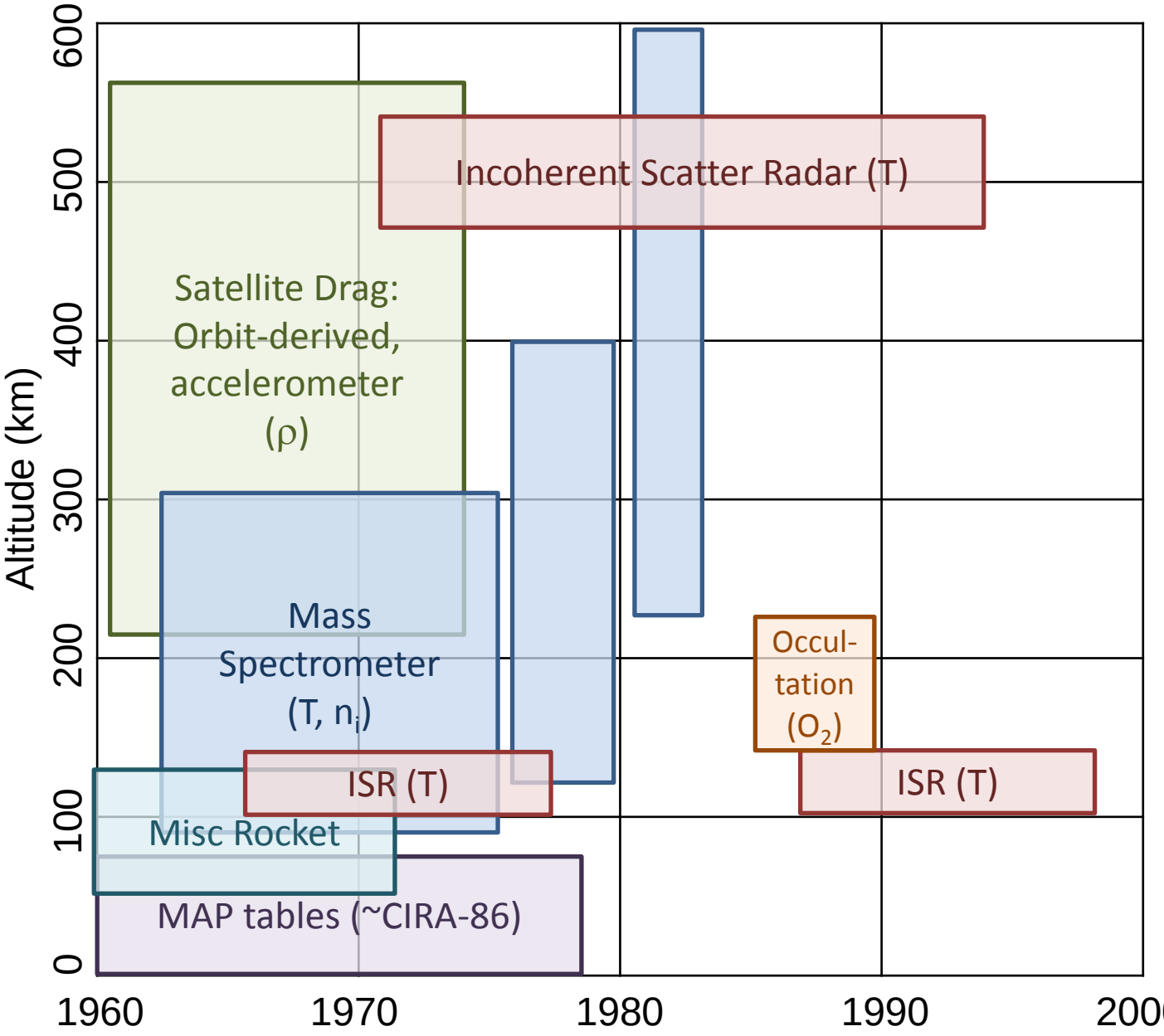
- **Vertical temperature profile (17 parameters)**
  - Cubic splines in 1/T below 120 km (14 parameters)
  - Bates profile above 120 km (T_{ex}, T_{120}, σ)
- **Species density parameters (8 per species)**
  - Reference density (1)
  - Mixing ratio relative to N_2 (1)
  - Turbopause height (1)
  - Corrections for dynamic flow and chemistry (5)
- **Expansion of vertical parameters (up to ~140 per param.)**
  - Associated Legendre fns in latitude (up to degree 6)
  - Polynomials in daily and 81-day average solar activity (F10.7) up to order 2
  - Intra-annual harmonics up to semiannual
  - Local time harmonics up to terdiurnal (migrating tides)
  - Time history of geomagnetic activity (ap index) via heating function
  - Longitude harmonics up to order 1
  - Universal Time harmonics up to order 1
- **Total number of nonzero model parameters: ~1280**
- **Limitation: Important nonmigrating tides not included – use CTMT**

$$T_{ex} - (T_{ex} - T_{120}) \exp\left[-\sigma(\zeta - \zeta_{120})\right]$$

$$\sigma = T'_{120} / (T_{ex} - T_{120}) = \text{Shape factor}$$

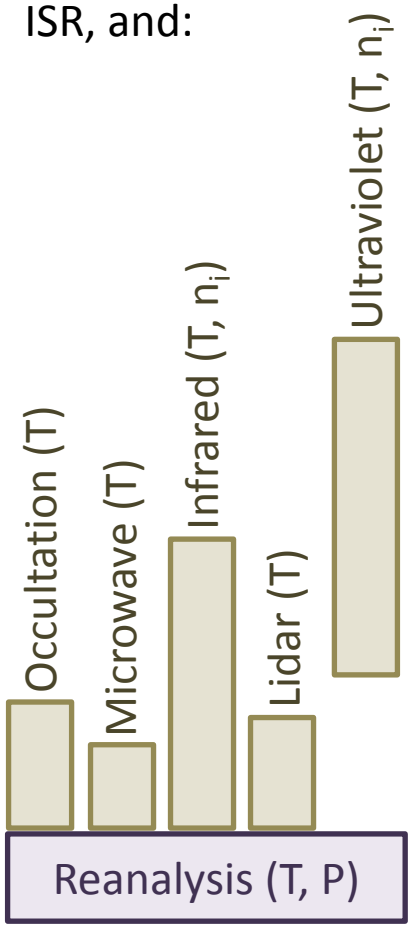


NRLMSIS Data



New Data for NRLMSIS-17:

Orbit, accelerometer, ISR, and:



NRLMSISE-00 Operation

GTD7 - Gets Temperature and Density:

`GTD7(IYD,SEC,ALT,GLAT,GLONG,STL,F107A,F107,AP,MASS,D,T)`

Input:

IYD	YEAR AND DAY AS YYDDD (day of year from 1 to 365 or 366; year ignored)
SEC	UNIVERSAL TIME (s); should be consistent with GLONG and STL
ALT	GEODETIC ALTITUDE (km)
GLAT	GEODETIC LATITUDE (degrees)
GLONG	GEODETIC LONGITUDE(degrees)
STL	LOCAL APPARENT SOLAR TIME (hours)
F107A	81 day AVERAGE OF F10.7 FLUX (centered on day DDD)
F107	DAILY F10.7 FLUX FOR PREVIOUS DAY
AP	7-element array: Daily Ap, ap(t), ap(t-3h), ap(t-6h), ap(t-9h), Ap(12-33h), Ap(36-57h) First element used when SW(9) = 1, all elements used when SW(9) = -1
MASS	MASS NUMBER; 48 for all, 0, for temperature, 1 for H, 2 for He, 14 for N, etc.

Output:

	1	2	3	4	5	6	7	8	9
D = Number Density (cm^{-3})	He	O	N_2	O_2	Ar	ρ (g/cm^3)	H	N	Hot O
T = Temperature	T_{ex}	T(z)							

NRLMSISE-00 Operation

GHP7 -- Gets height of specified pressure level:

In millibars

```
GHP7(IYD,SEC,ALT,GLAT,GLONG,STL,F107A,F107,AP,D,T,PRESS)
```

TSELEC – Sets model switches: 0 = off, 1 = on, 2 = main effects off but cross terms on

```
TSELEC(SW)
```

Expansion Parameters		Vertical Profile Parameters	
SW(1)	Solar activity (F10.7)	SW(15)	Departures from diffusive equilibrium
SW(2)	Latitude dependence	SW(16)	All T_{ex} variations
SW(3)	Hemispherically symmetric annual oscill.	SW(17)	All T variations at 120 km
SW(4)	Symmetric semiannual	SW(18)	All T variations between 72.5 and 120 km
SW(5)	Asymmetric annual (seasonal)	SW(19)	All shape factor (σ) variations
SW(6)	Asymmetric semiannual	SW(20)	All T variations between 32.5 and 72.5
SW(7)	Diurnal oscillations	SW(21)	All species density variations at 120 km
SW(8)	Semidiurnal oscillations	SW(22)	All T variations between 0 and 32.5 km
SW(9)	Magnetic Activity (-1 for storm mode)	SW(23)	All turbopause scale height variations
SW(10)	All UT/Longitude	SW(24)	Not used
SW(11)	Longitude terms	SW(25)	Not used
SW(12)	UT and mixed UT/Longitude		
SW(13)	Mixed Ap/UT/Longitude		
SW(14)	Terdiurnal oscillations		

Other Thermosphere Temperature and Density Models

	NRLMSISE-00	DTM-2015	JB2008
Reference	Picone et al., 2002	Bruinsma, 2015	Bowman et al., 2008
Data Used	NMS, ISR, orbit- and accelerometer-derived density, UV occultation, sounding rockets; 1961–1998.	Orbit- and accelerometer-derived density, NMS, ISR, optical spectrometer; 1961–2012.	Orbit-derived density; 175–1000 km, 1997–2007.
Fitting Method	Least-squares. Statistically insignificant parameters are zeroed out.	Least-squares. Statistically insignificant parameters zeroed out.	Adjustments to underlying J70 model determined via least-squares fits of data−J70 residuals.
Lower Boundary	0 km	120 km	90 km
Mesopause Density and Temperature	Variable	Variable at 120 km	Fixed
Temperature Profile	Bates exponential profile above 120 km. Cubic splines below 120 km.	Bates exponential profile.	Arctangent above 125 km, plus height-dependent local time and latitude corrections to T_{ex}. Polynomial below 125 km.
Solar Activity Variation	Temperature and density parameters depend quadratically on $F_{10.7}$.	Temperature and density parameters depend quadratically on F_{30}, the solar radio flux at 30 cm. wavelength	T_{ex} is linear function of 4 solar indices.
Local Time & Latitude Variation	Spherical harmonics (up to terdiurnal and latitudinal order 6) of temperature and density parameters, modulated by $F_{10.7}$.	Spherical harmonics (up to terdiurnal and latitudinal order 6) of temperature and density parameters, modulated by F_{30}.	Trigonometric function of local time, latitude, and solar declination applied to T_{ex} only, plus a correction above 200 km dependent on local time, height, latitude, and $F_{10.7}$.
Intra-annual Variation	Annual and semiannual harmonics of temperature and density parameters, modulated by latitude (up to order 3). No explicit dependence on solar activity.	Annual and semiannual harmonics of temperature and density parameters, modulated by latitude (up to order 5), local time, and F_{30}.	Mass density variation only; annual and semiannual harmonics, with net amplitude dependent on altitude (quadratic polynomial) and modulated by three solar indices.
Geomagnetic Activity Variation	Temperature and density parameters are a function of either 3-hr ap history or daily Ap. Modulated by latitude and LT.	Parameters are a quadratic (density) or linear (temperature) function of the km index, modulated by latitude.	T_{ex} is a nonlinear function of the Dst history during storms, and of the 3-hr ap when a storm is not detected in Dst.
Longitude/UT Variation	Spherical harmonics up to wavenumber 2 in longitude, and diurnal UT terms. Modulated by geomagnetic activity.	None	None

Emmert, Adv. Space Res., 2015

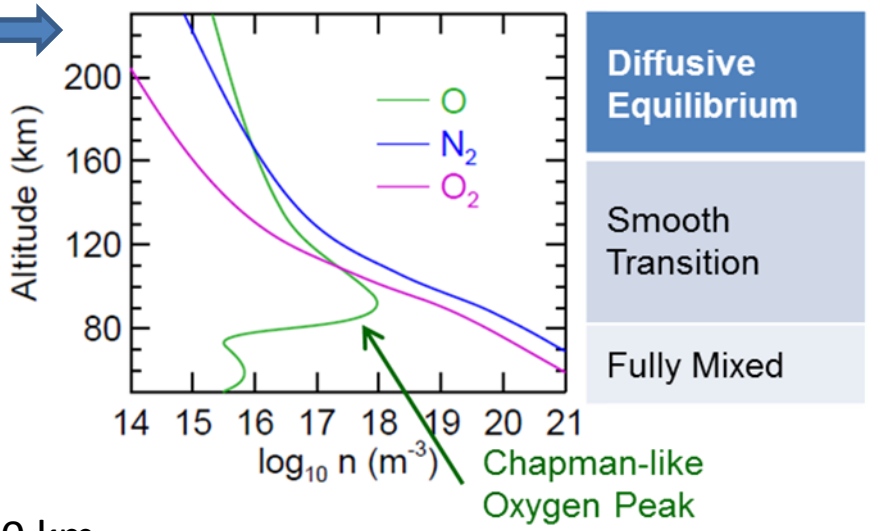
NRLMSIS Upgrade

❑ New Data

- NOAA meteorological reanalysis data in the troposphere and stratosphere.
- Extensive new temperature and composition data in the mesosphere and lower thermosphere (incl. TIMED/SABER, Aura/MLS, ACE, AIM/Sofie, Odin/OSIRIS, Lidar).
- Extensive new orbit-derived an accelerometer densities, UV remote sensing data, and ground-based FPI temperatures in the thermosphere.

❑ Major Changes to Formulation

- Seamless transition from fully mixed to species hydrostatic equilibrium using variable effective mass (current model: nonphysical interpolation)
- O profile: Splines below 80 km, modified Chapman layer near peak, species hydrostatic equilibrium above 200 km.
- Solar EUV irradiance input (backward compatible with F10.7).
- Overhaul of expansion of vertical profile parameters.
- Use geopotential $\Phi(z,\varphi)$ internally (current model uses $\Delta\Phi(z_1,z_2;\varphi)$).



❑ Progress

- New temperature model complete up to 80 km.
- Full model to be completed in 2017.

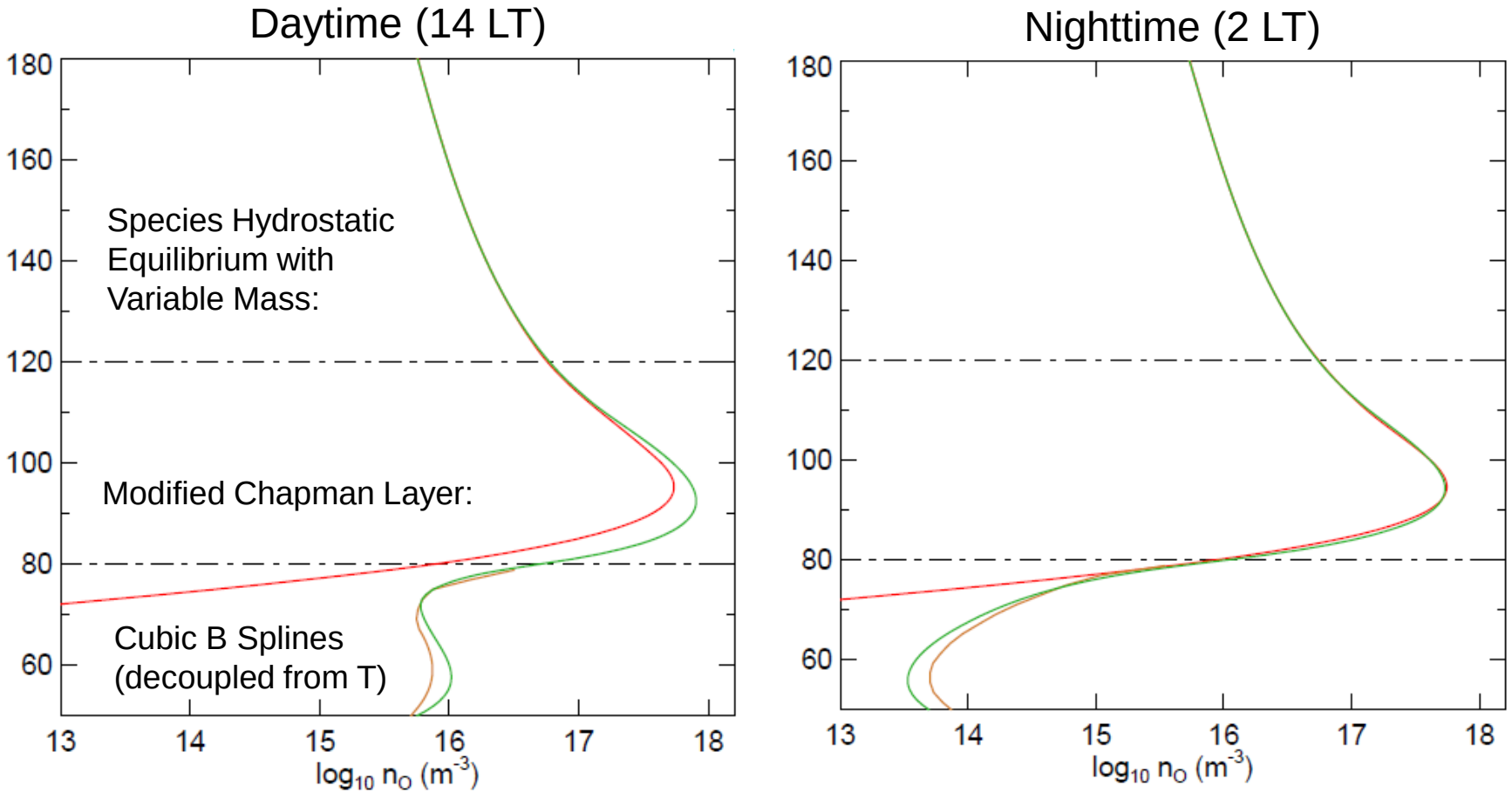
NRLMSIS Upgrade: Test fits of O profile

(5°N, Day of year 150)

-- NRLMSISE-00

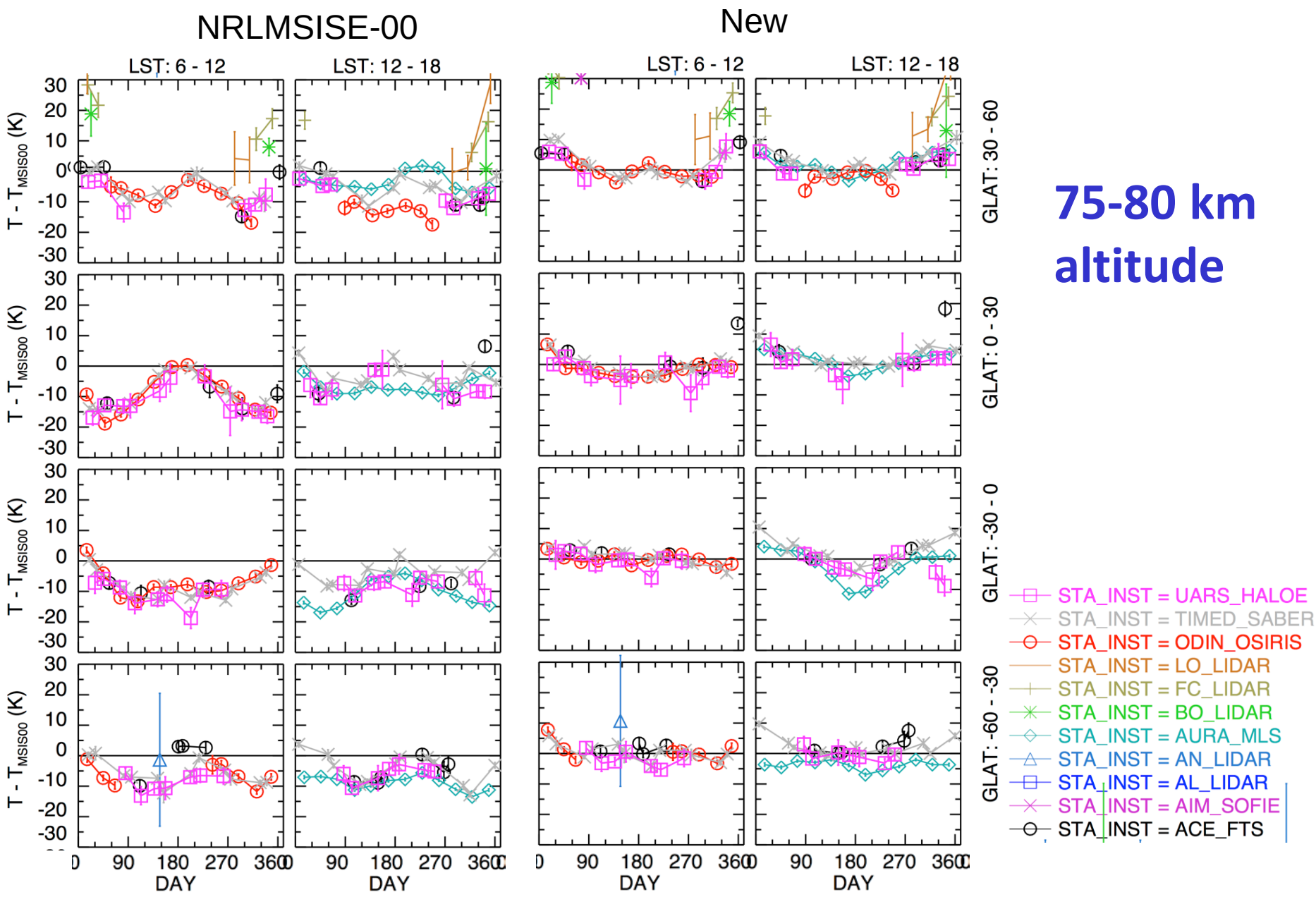
-- SABER Climatology

-- Fit with MSIS above 120 km, SABER below 80 km



$$\ln n = \ln n_0 - \frac{g_0}{k}\int_{\zeta_0}^{\zeta}\frac{M(\zeta')}{T(\zeta')}d\zeta' - \ln\frac{T(\zeta)}{T(\zeta_0)} - C\exp\left[\frac{-(\zeta-\zeta_C)}{H_C}\right]$$

NRLMSIS Upgrade: Mesosphere Temperature Residuals



NRLMSISE-00 Summary

- **Arguments:** Position, time, solar irradiance, geomagnetic activity
- **Output:** T(z), T_{ex} (K); N_2, O_2, O, He, H, N, Ar (cm^{-3}); ρ ($g\ cm^{-3}$)
- **Domain:** Ground to exosphere
- **Physical constraints:**
  - Asymptotic exospheric temperature
  - Approximate Hydrostatic equilibrium
  - Diffusive equilibrium above ~200 km
- **Data:**
  - Thermosphere: Mass spectrometers, incoherent scatter radars, accelerometers, orbit-derived mass density, solar occultation spectra
  - Troposphere, stratosphere, mesosphere: Rocket-based measurements, tabulated lower atmospheric climatology
- **Formulation:**
  - Bates/spline vertical temperature profile
  - Spherical and temporal harmonic expansion
  - Polynomial in F10.7 and Ap heating function
- **Major overhaul in progress:**
  - Extensive new data
  - New formulation, including seamless transition from mixed to diffusive separation
  - Temperature model complete up to 80 km; full model expected 2017