Neutral Winds in the Upper Atmosphere

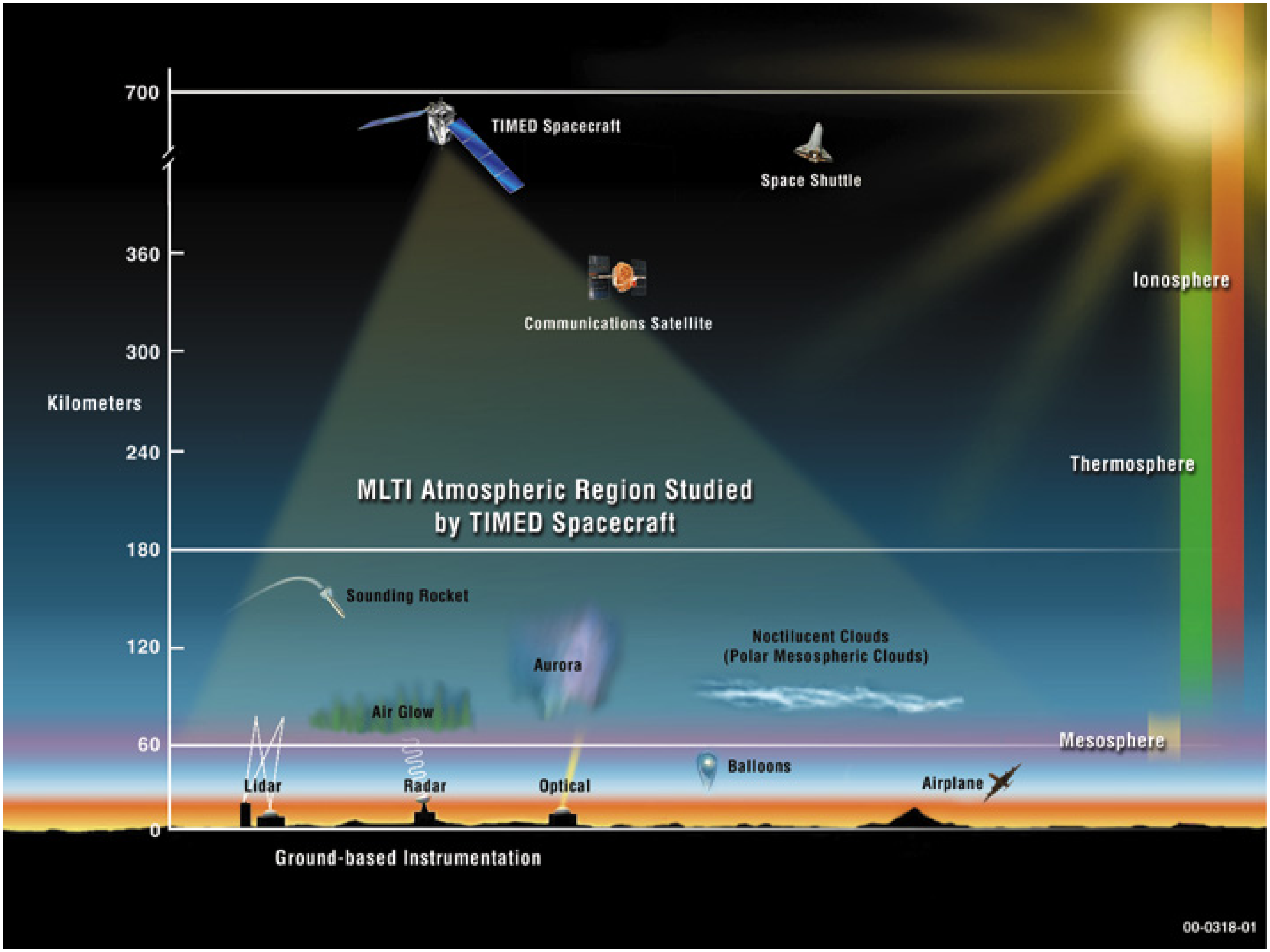
Qian Wu

National Center for Atmospheric Research

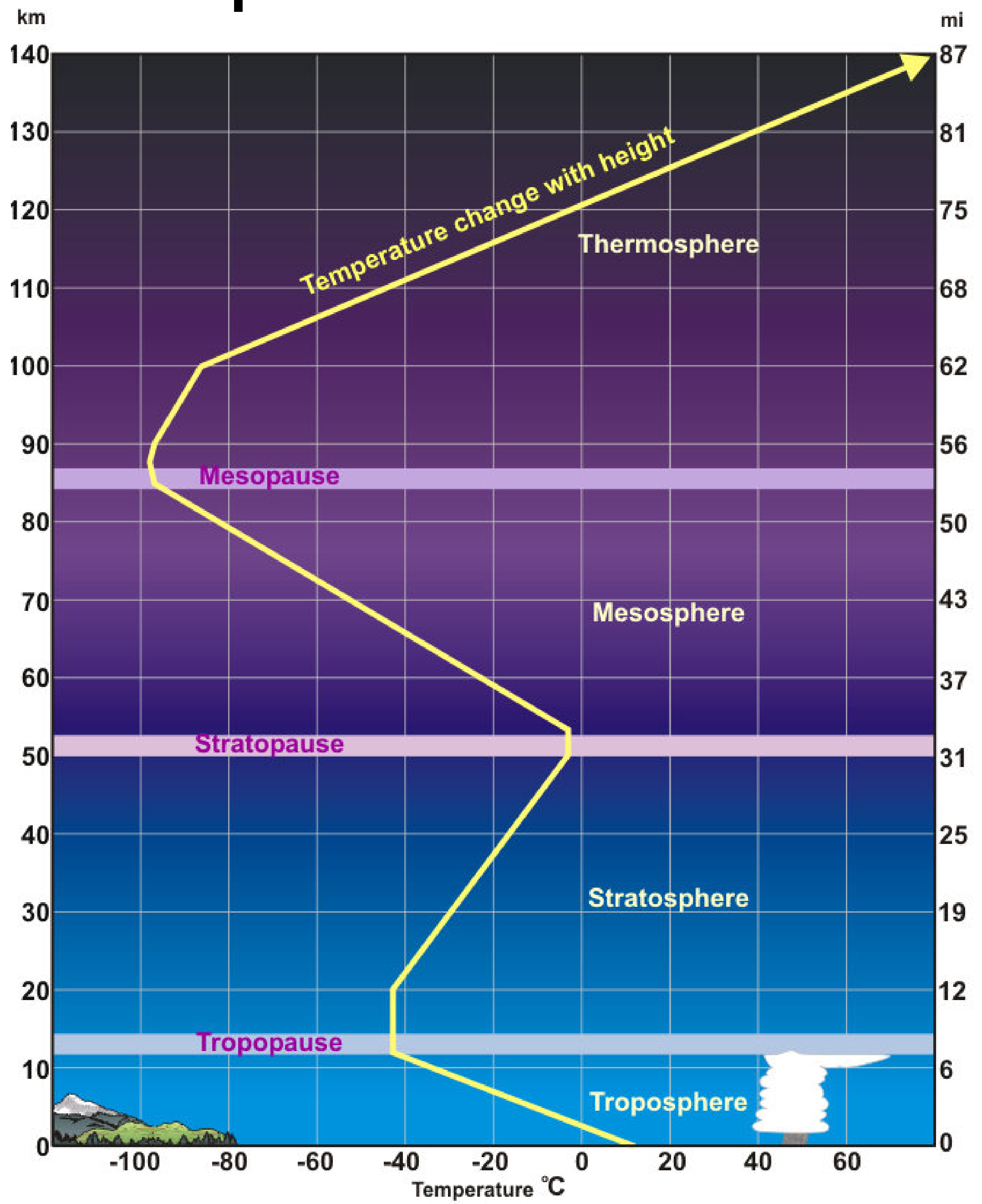
Outline

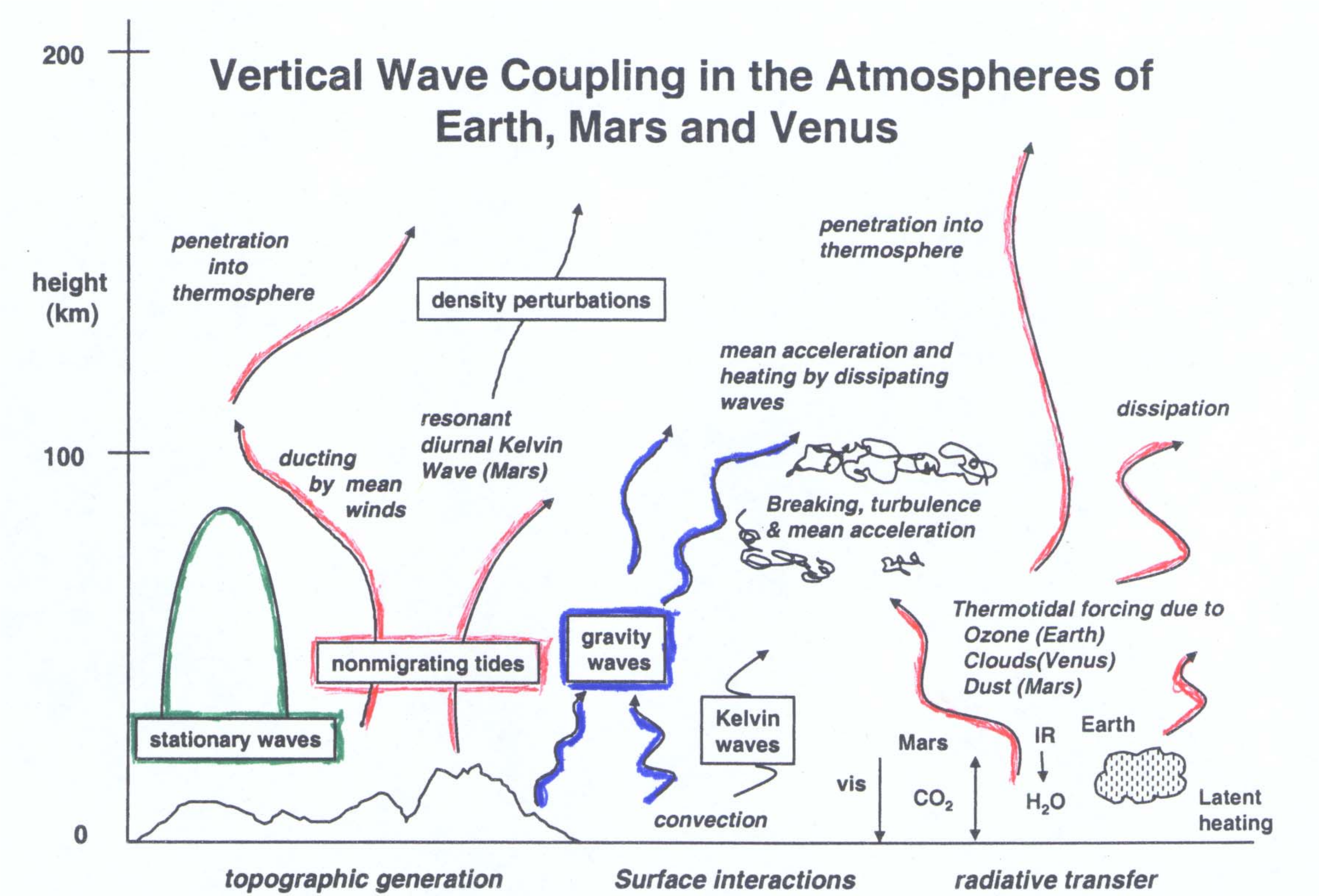
- Overview of the upper atmosphere.
- Ozone heating.
- Neutral wind tides (the strongest dynamic feature).
- Why do we need to understand upper atmospheric winds?
- How do we measure upper atmospheric winds?
- Observational results.
- Satellite and Balloon borne instruments.

Upper Atmosphere

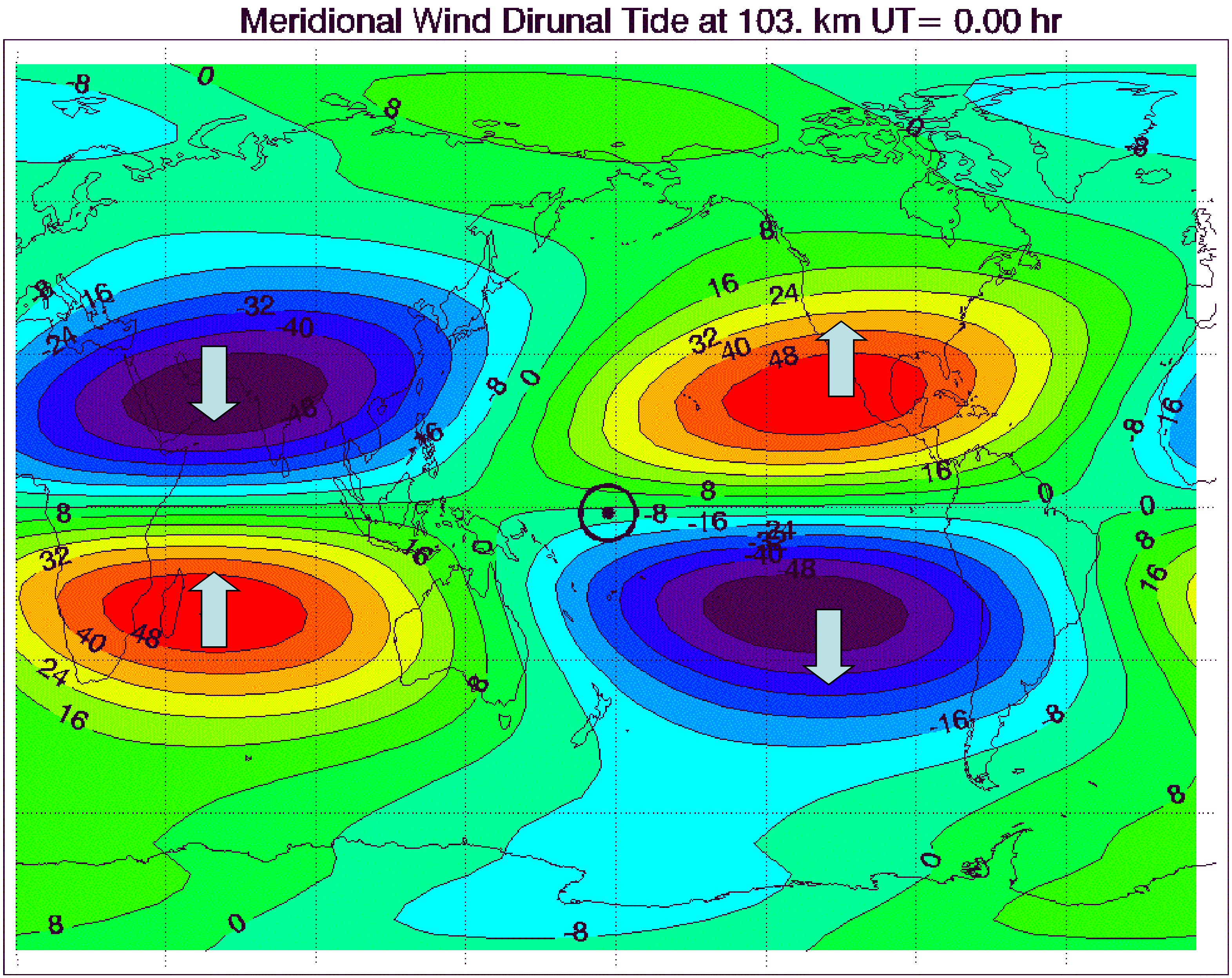


Temperature Profile

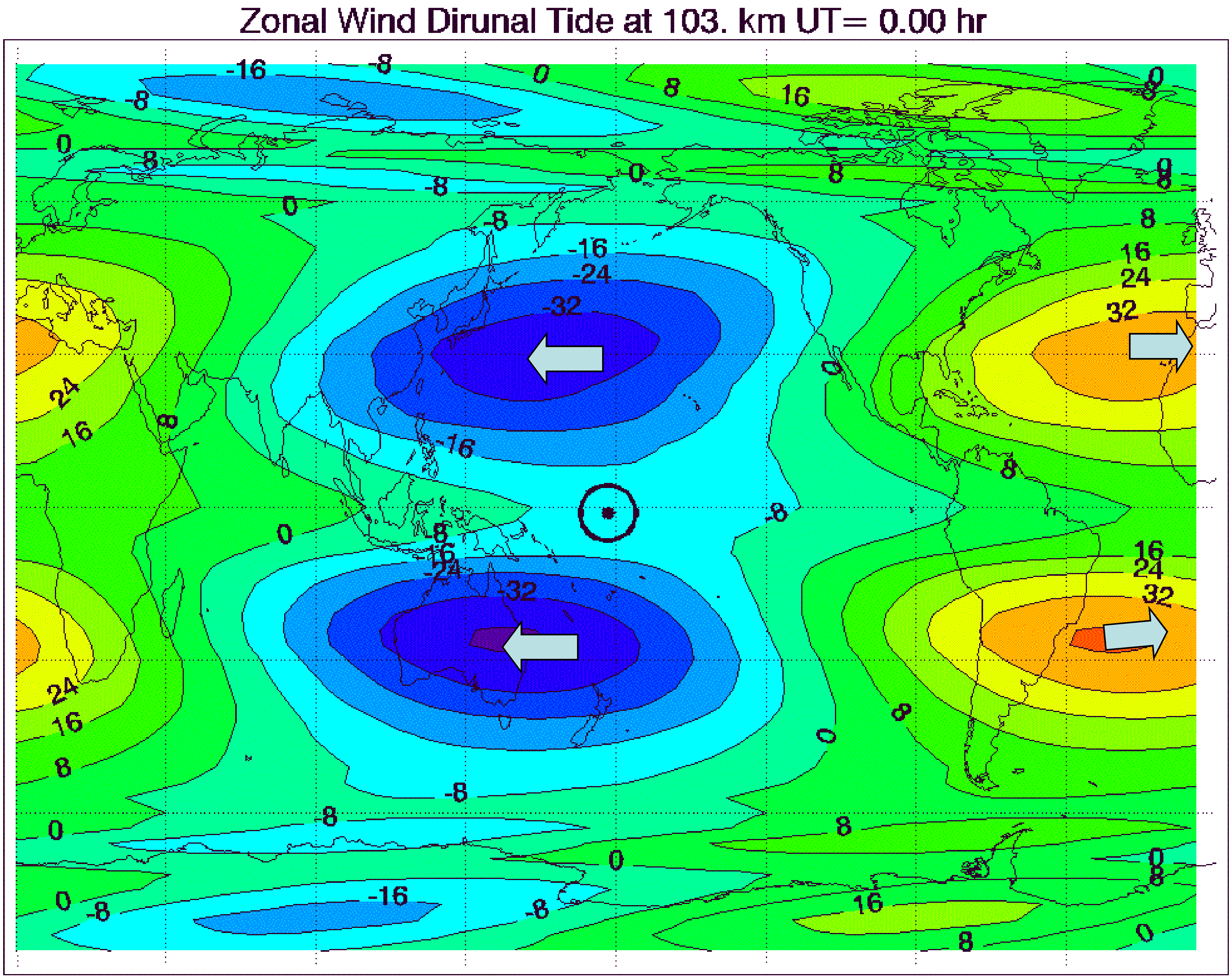




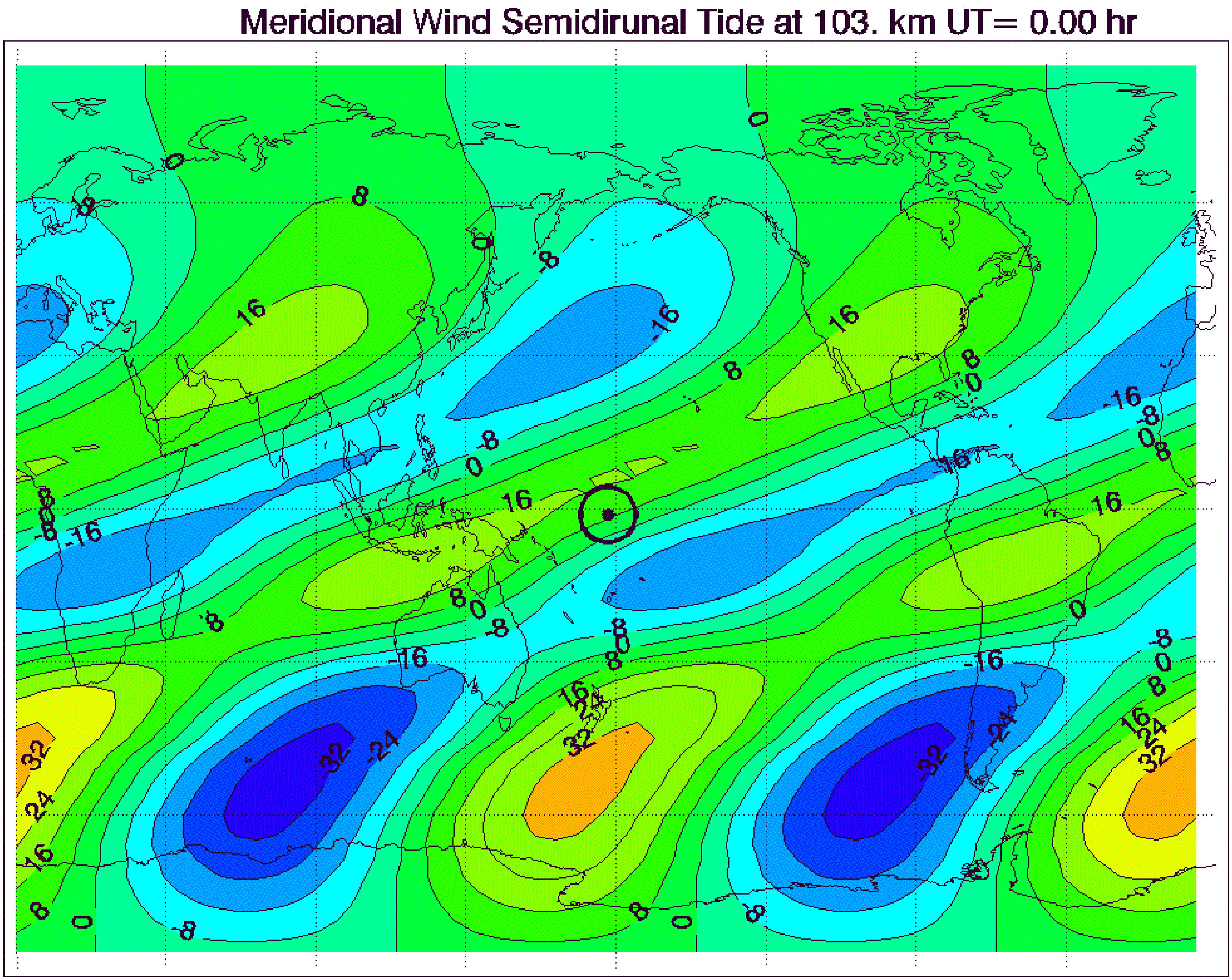
Forbes, Comparative Aeronomy, 2002



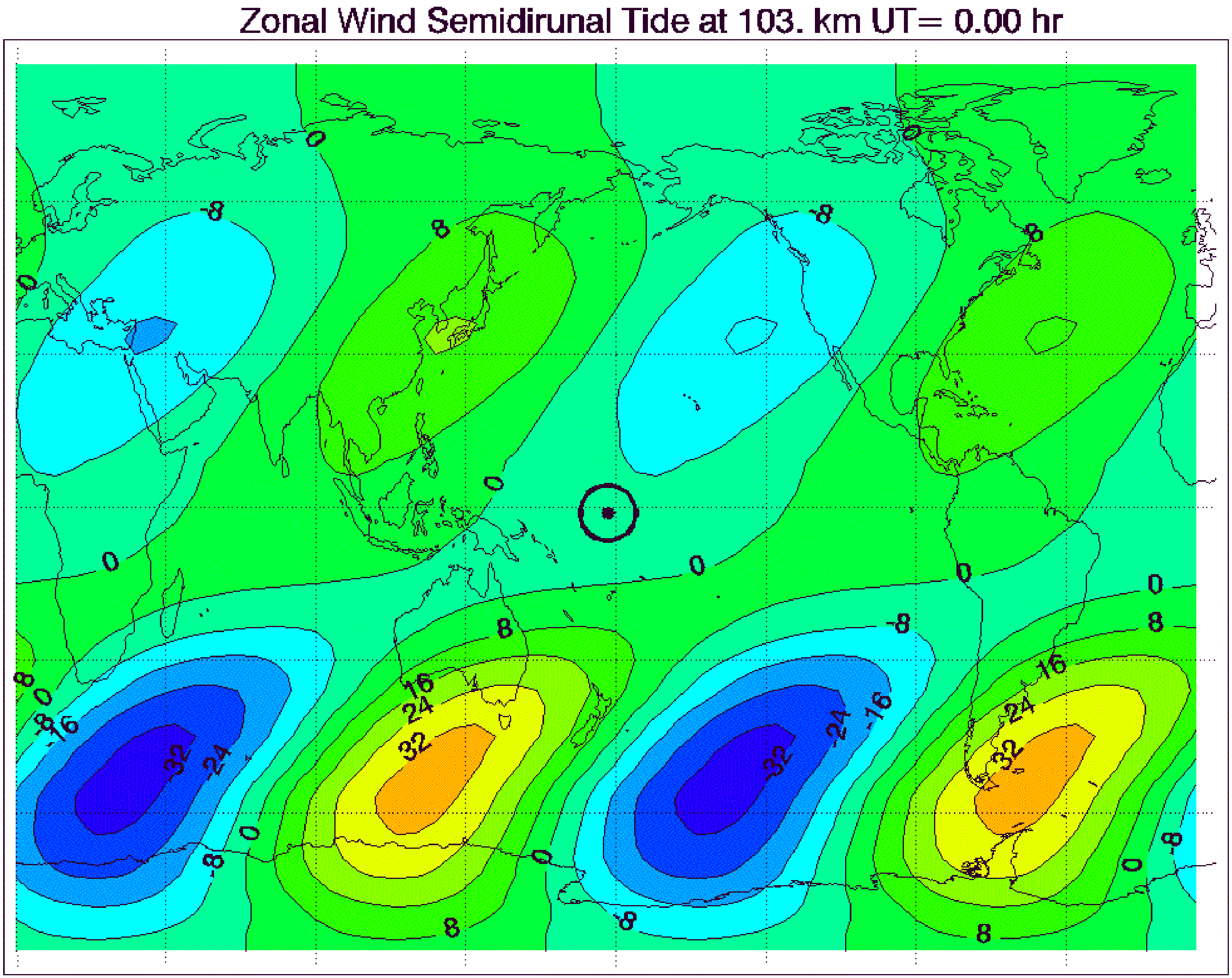
Hagan et al. Global Scale Wave Model (GSWM, March)



Hagan et al. GSWM (March)

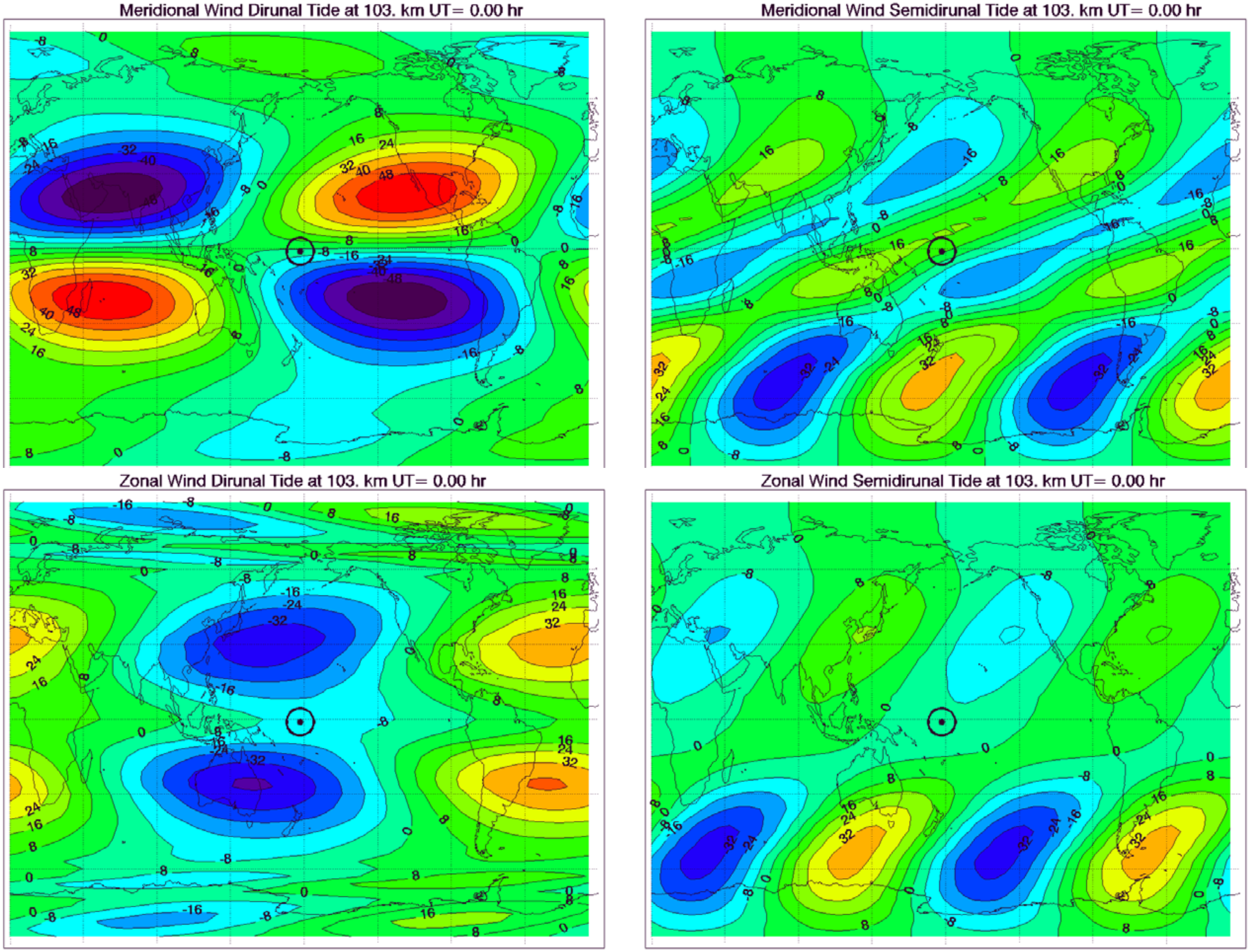


Hagan et al. GSWM (June)

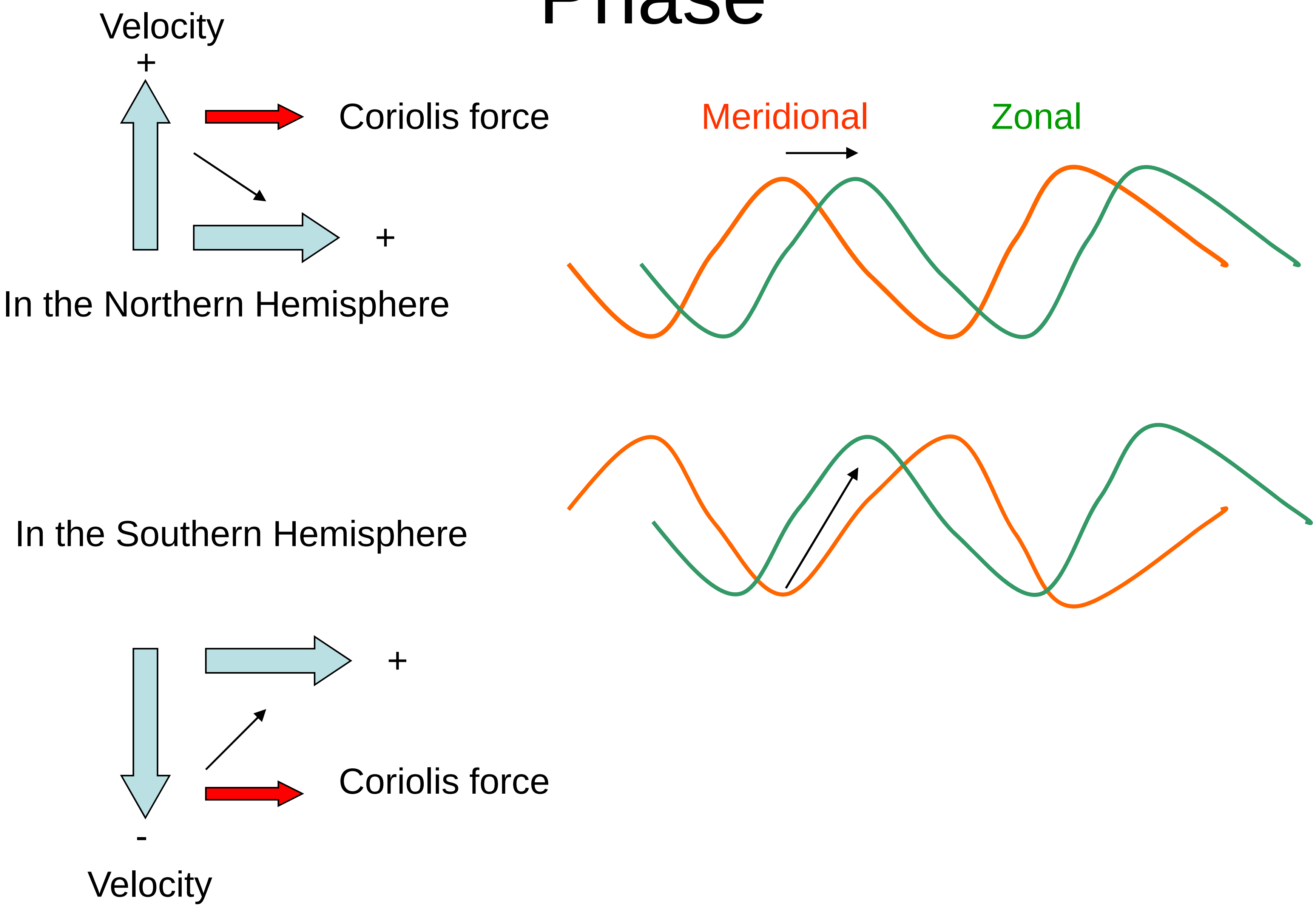


Hagan et al. GSWM (June)

Phase Comparison



Coriolis Force Effect on Tidal Phase



Dynamics Equations

$$\frac{Du}{Dt} - \left(f + \frac{u\tan\phi}{a}\right)v + \frac{\Phi_\lambda}{a\cos\phi} = X,$$

$$\frac{Dv}{Dt} + \left(f + \frac{u\tan\phi}{a}\right)u + \frac{\Phi_\phi}{a} = Y,$$

$$\Phi_z = H^{-1}R\theta e^{-\kappa z/H},$$

$$\frac{[u_\lambda + (v\cos\phi)_\phi]}{a\cos\phi} + \frac{(\rho_0 w)_z}{\rho_0} = 0,$$

$$\frac{D\theta}{Dt} = Q,$$

$H = RT/g$ is the scale height,

a is the earth radius,

Φ is the geopotential,

$\theta = T(p_s/p)^\kappa$ $(\kappa = R/c_p \approx 2/7)$ is the potential temperature,

ρ_0 is the density

$\Omega = 2\pi / T_{day}$

$f = 2\Omega\sin\phi$

(λ, ϕ) = (longitude, latitude)

(u, v, w), velocity in zonal, meridional, and vertical directions

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \frac{u}{a\cos\phi}\frac{\partial}{\partial\lambda} + \frac{v}{a}\frac{\partial}{\partial\phi} + w\frac{\partial}{\partial z}$$

X, Y forcing term

Q heating source

Tidal Wave Function

$$\{\tilde{u}, \tilde{v}, \tilde{\Phi}\} \propto e^{z/2H} e^{ik_z z} \exp i(s\lambda - \Omega\sigma t)$$

s is the zonal wavenumber

$\dfrac{2\pi}{\Omega\sigma}$ is the wave period in days

k_z is the vertical wavenumber

t is the universal time

$T_L = t + \dfrac{\lambda}{\Omega}$ local time

$$\{\tilde{u}, \tilde{v}, \tilde{\Phi}\} \propto e^{z/2H} e^{ik_z z} \exp i(s\lambda - \Omega\sigma(T_L - \frac{\lambda}{\Omega})) = e^{z/2H} e^{ik_z z} \exp i((s-\sigma)\lambda - \Omega\sigma T_L)$$

If $s = \sigma$, then

$\{\tilde{u}, \tilde{v}, \tilde{\Phi}\} \propto e^{z/2H} e^{ik_z z} \exp i(-\Omega\sigma T_L)$ is migrating tide

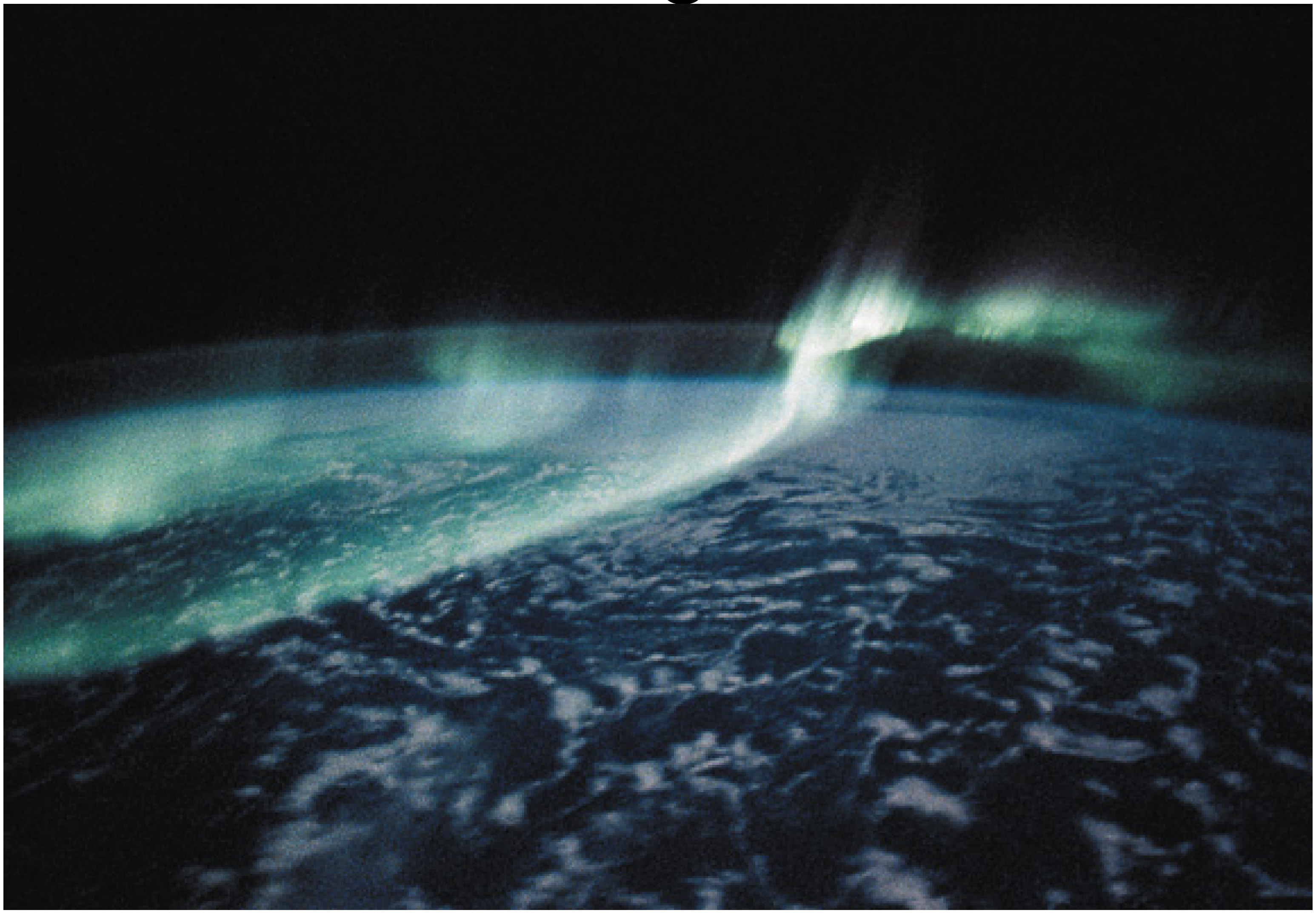
Migrating tides	**Nonmigrating tides**
Sun-synchronous **w**estward	**non** Sun-synchronous **w**estward, **e**astward, **s**tanding
zonal wavenumber: **1/period(days)** **(diurnal tide : 1 semidiurnal: 2)**	zonal wavenumber: **any**
radiative forcing, …	**latent heat** PW/tidal **interaction**, …
	comparable to / exceed the migrating tide **longitude modulation**

Why do we need to know upper atmosphere neutral wind tide?

- Tides are generated in the stratosphere and strongly affected by changes in that region such as:
  - Gravity wave activities,
  - Quasi-biennial oscillation (QBO) in the equatorial region
  - Sudden stratosphere warming in the high latitudes
- Long term trends in tides may be linked with changes in the stratosphere.
- Tides also have a great impact on the equatorial ionosphere through dynamo effect.

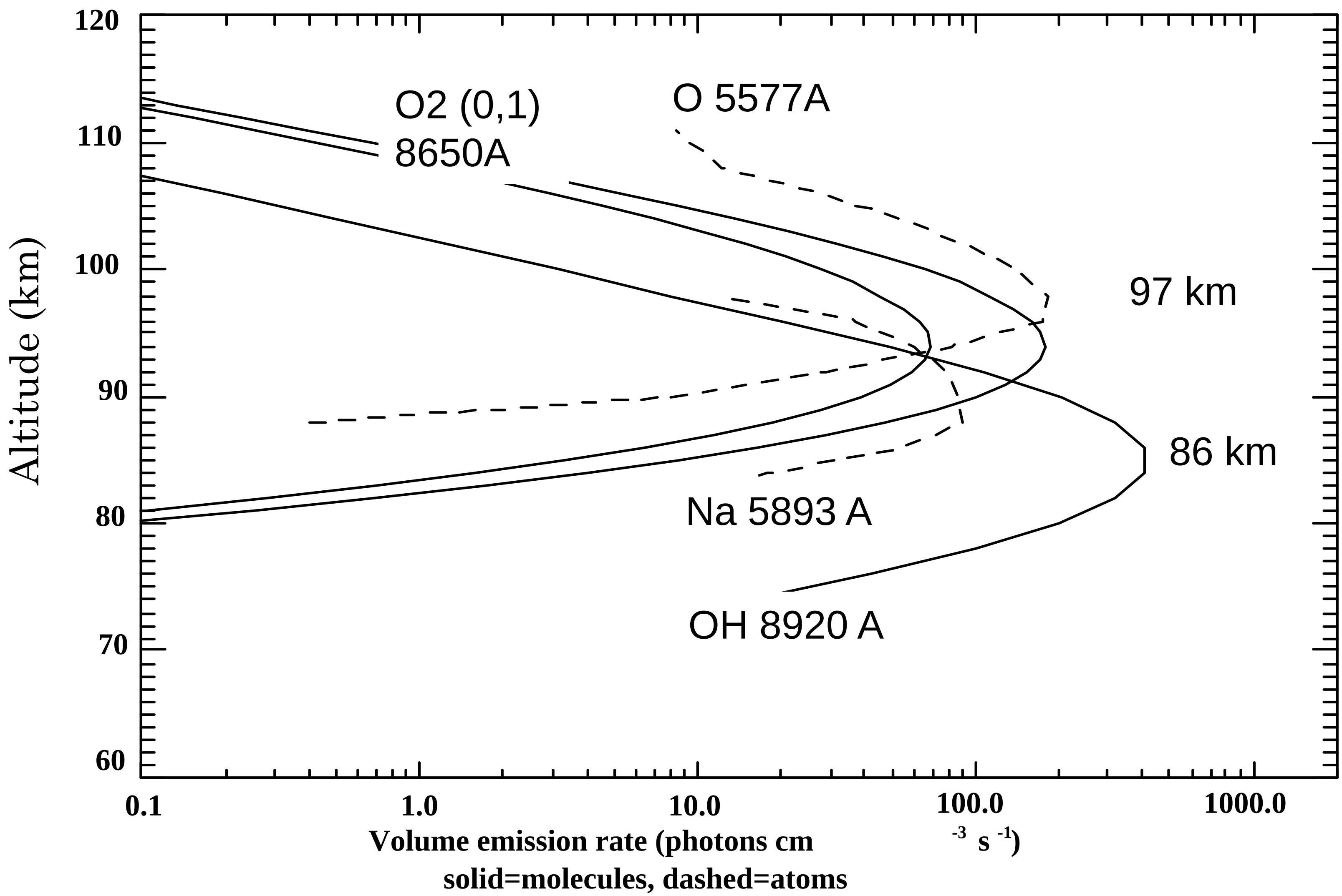
Neutral Wind Measurement

Airglow

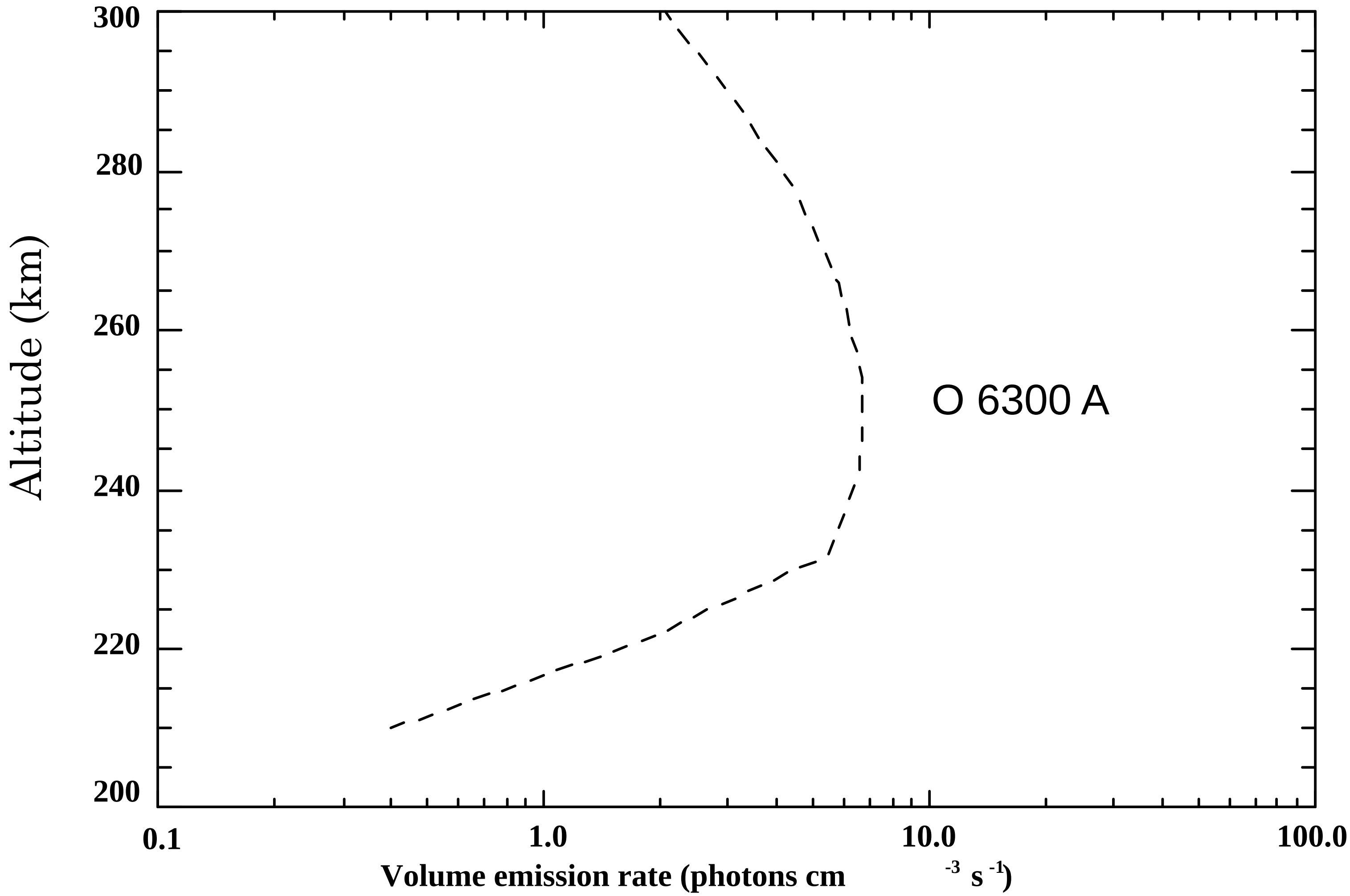


A view from Space Shuttle

Airglow Emission Rates



Thermosphere Airglow Emission Rates



Airglow Emission Sources at Night

O 6300 Å red line

Electron impact

$$O + e \rightarrow O(^1D) + e$$

Dissociative recombination

$$O_2^+ + e \rightarrow O + O(^1D)$$

O 5577 Å green line

Electron impact

$$O + e \rightarrow O(^1S) + e$$

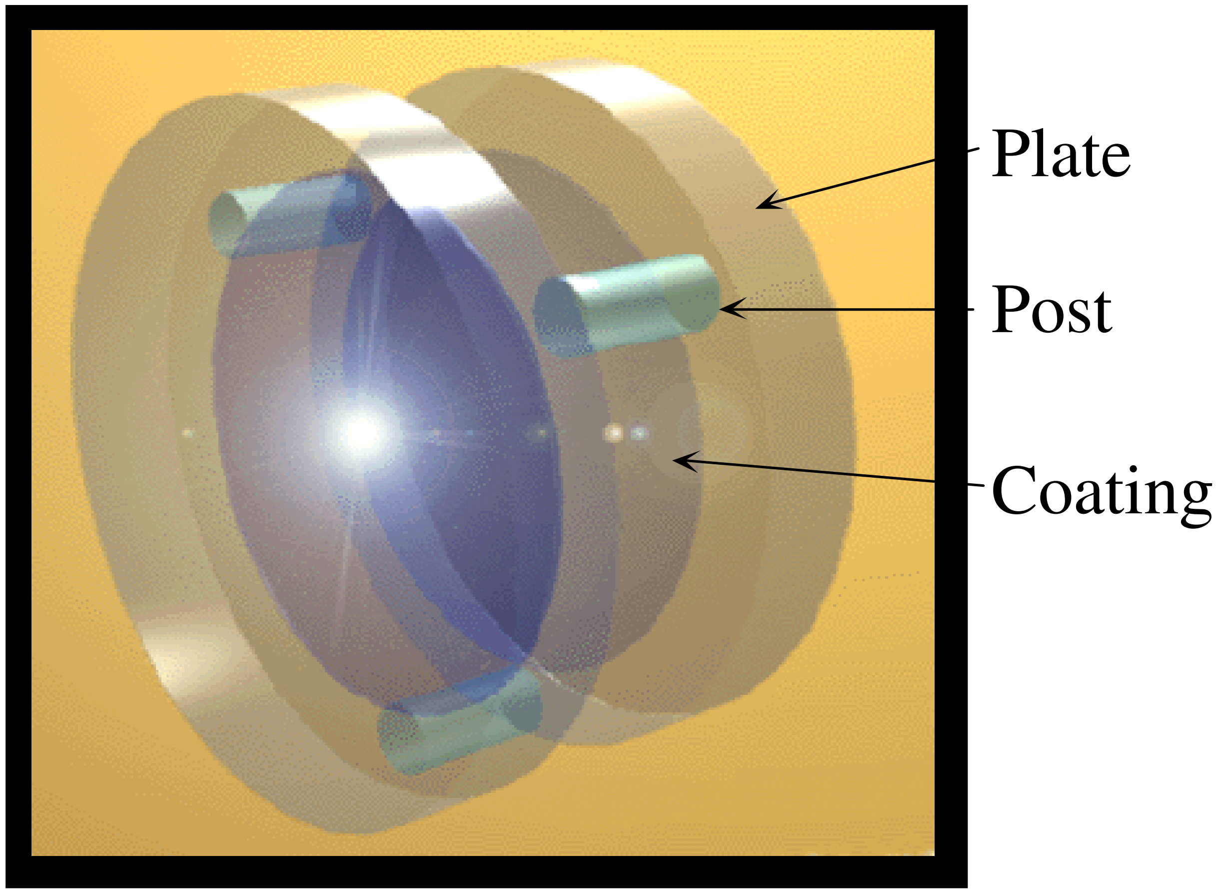
Collisional deactivation of N2

$$N_2(A^3\Sigma_u^+) + O \rightarrow N_2 + O(^1S)$$

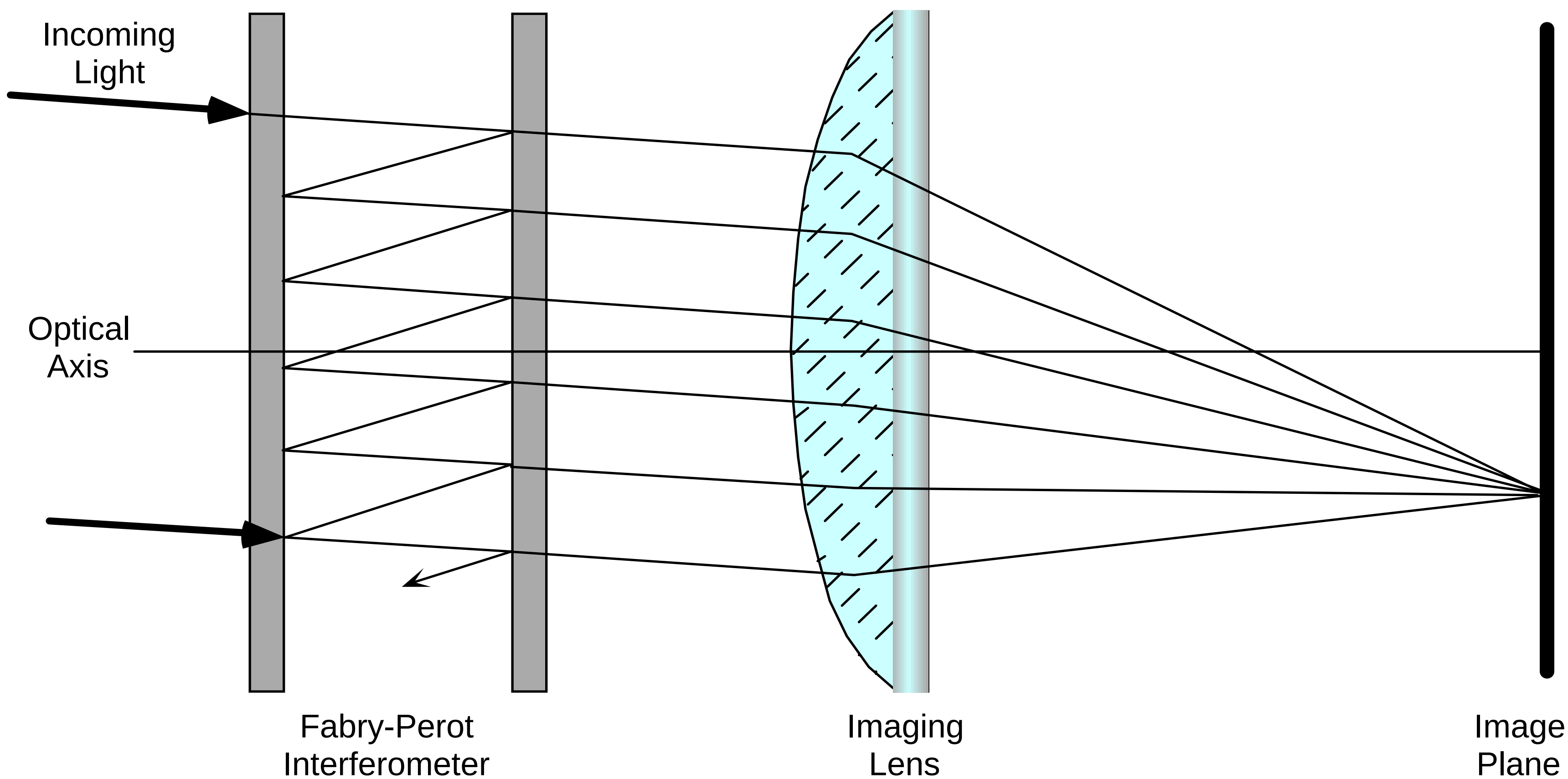
OH emission

$$H + O_3 \xrightarrow{k_{16}} OH(6 \leq v' \leq 9) + O_2$$

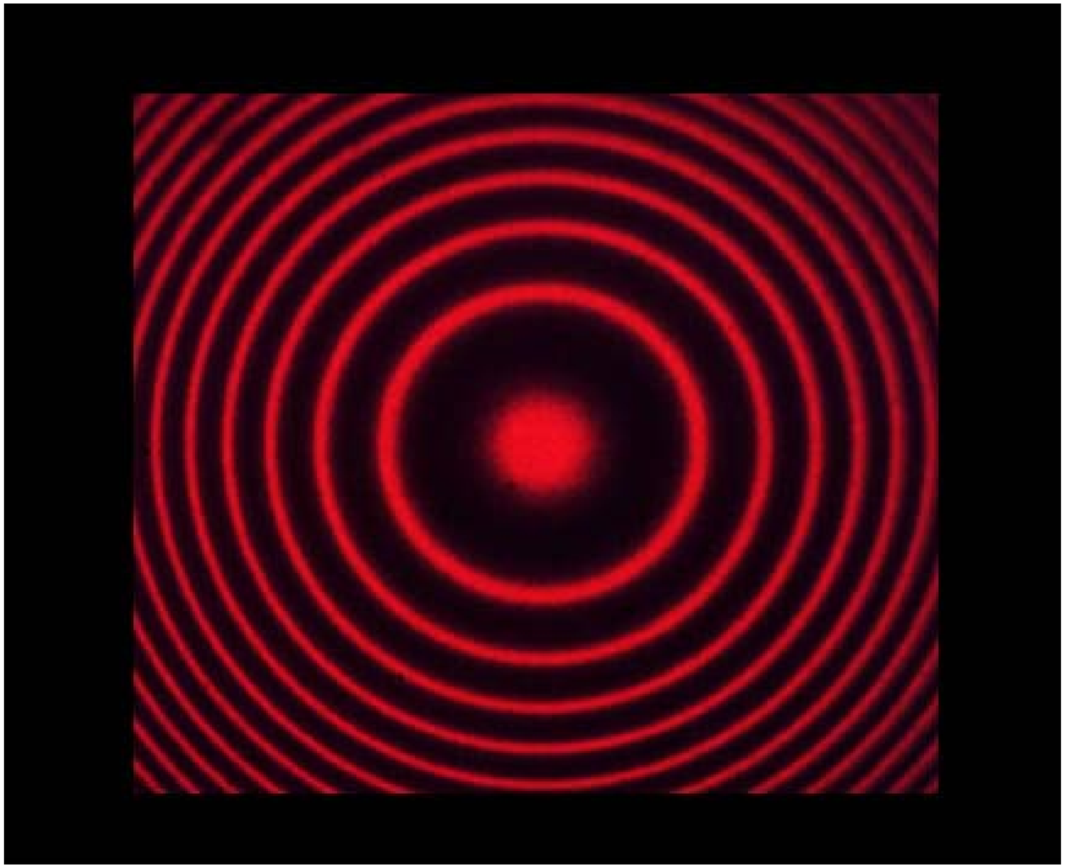
Fabry-Perot Interferometer (FPI)



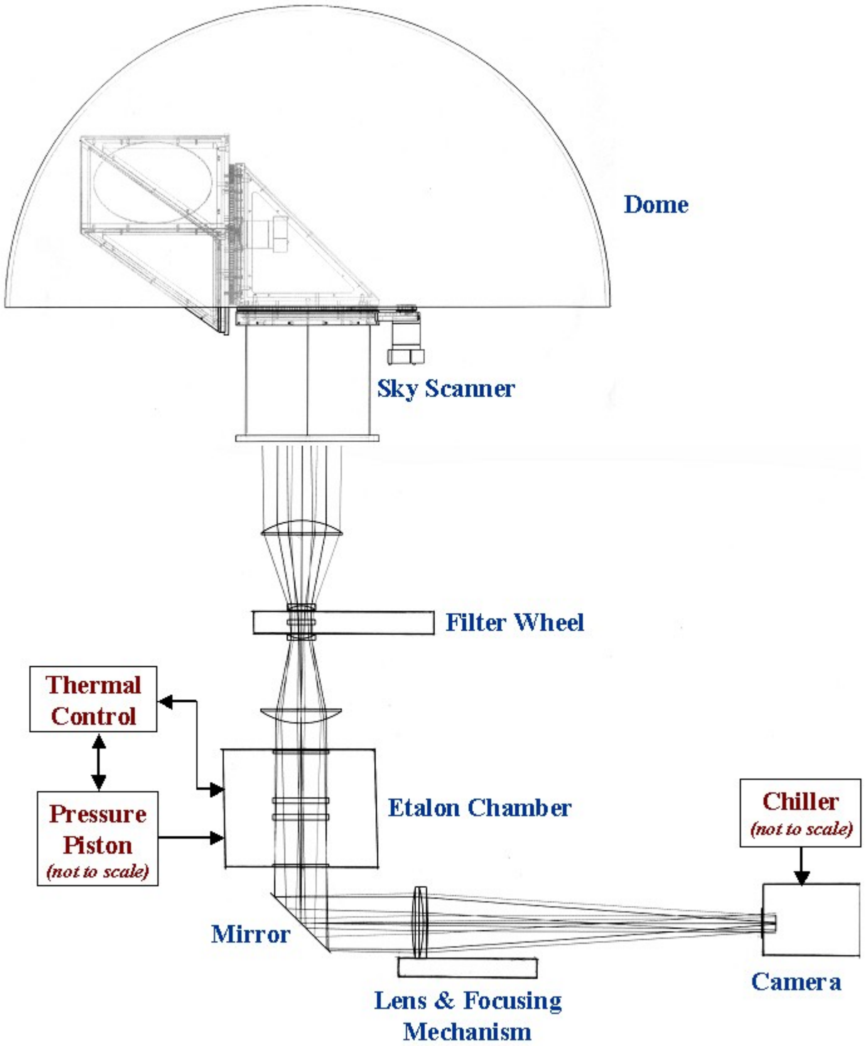
Etalon


Incoming
Light
Optical
Axis
Fabry-Perot
Interferometer
Imaging
Lens
Image
Plane

Fabry-Perot Fringe Pattern



FPI Configuration



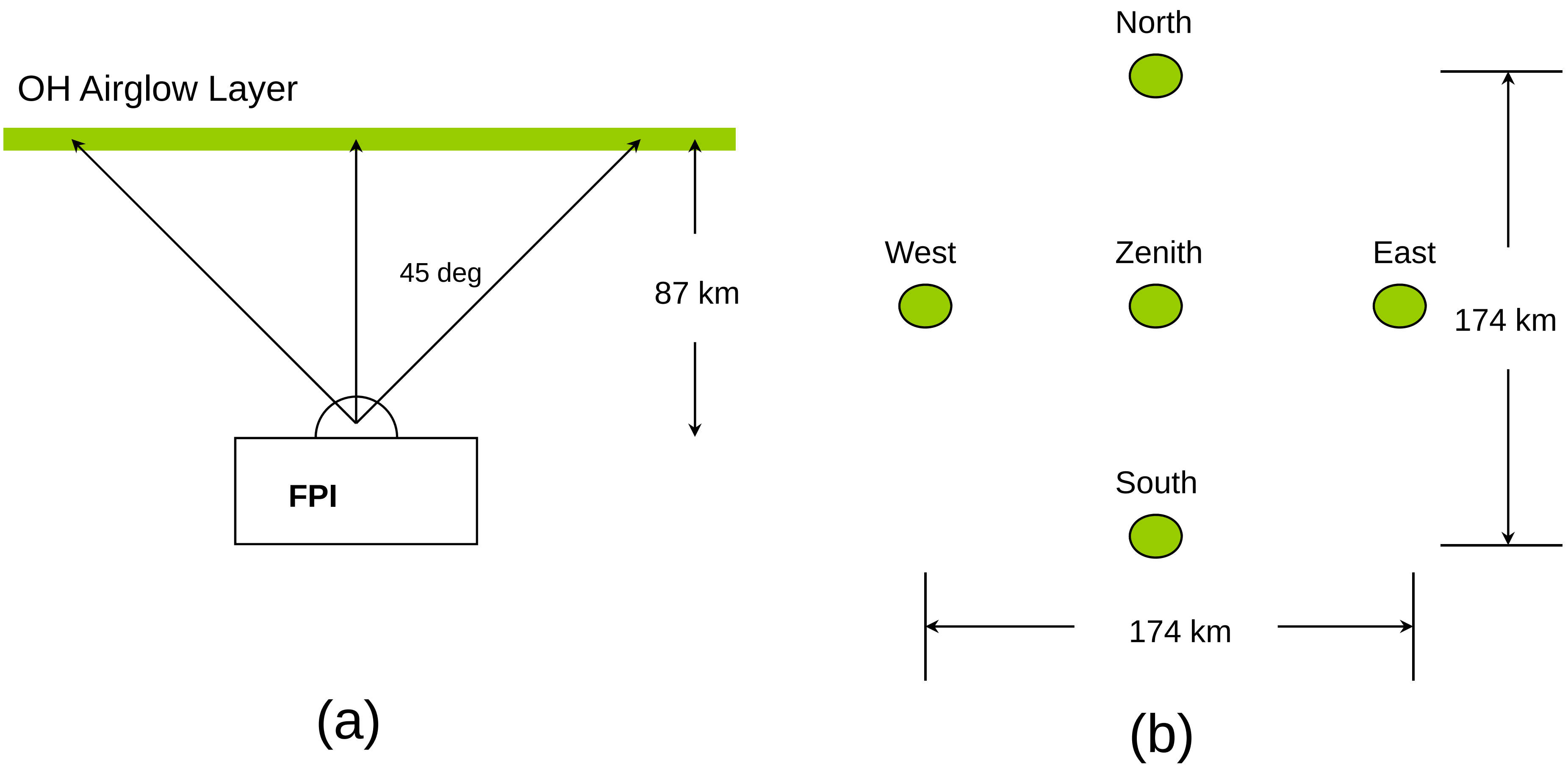
Major Components

- Sky scanner
- Filters & filter wheel
- Etalon & chamber
- Thermal & pressure control
- Focusing lens
- Detector
- Computer system

Highlights

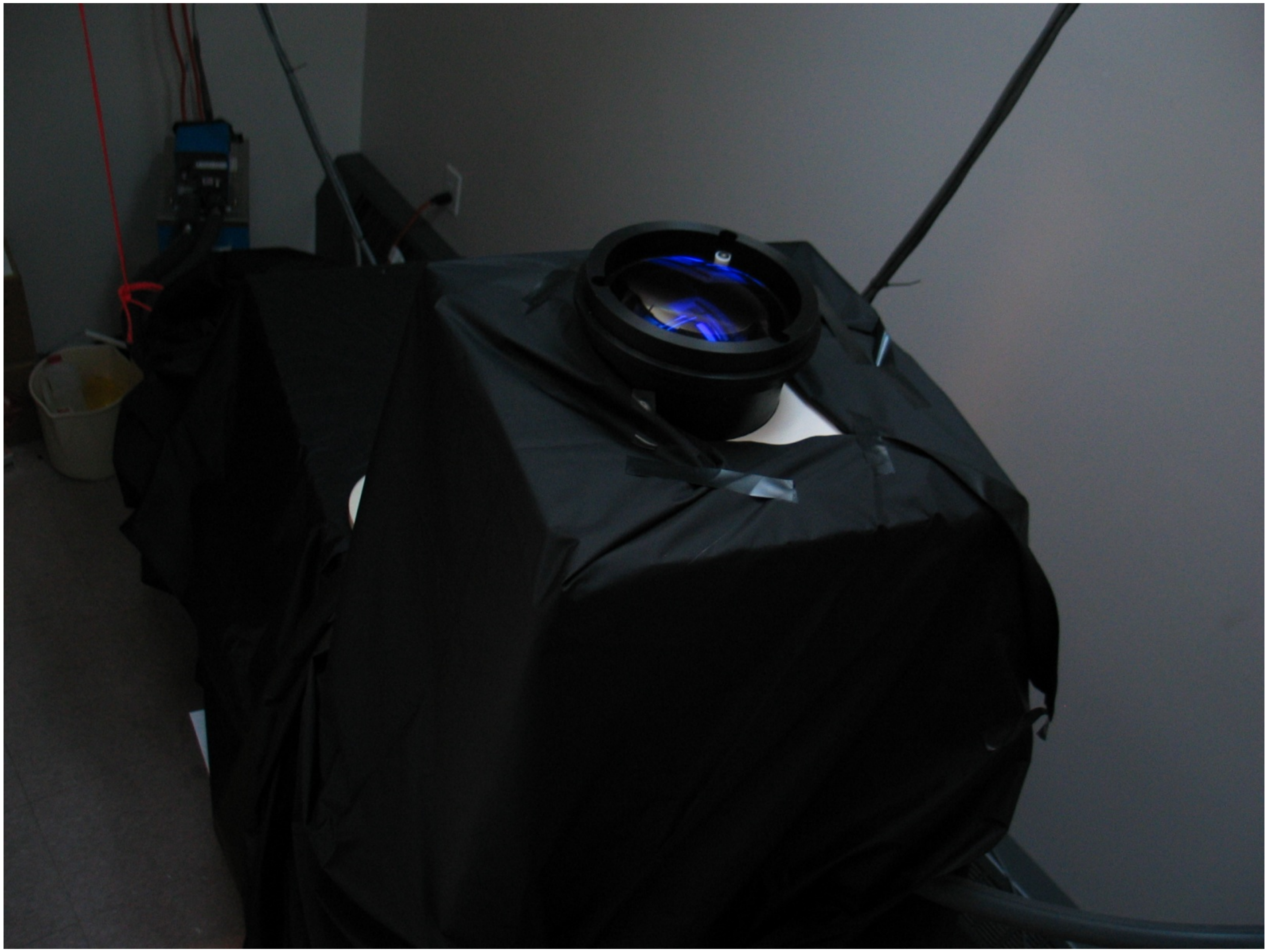
- Computerized micrometer
- Daily laser calibration
- High degree automation
- Michigan heritage
- NCAR enhancement

Instrument Operation



FPI at Resolute

FPI at Resolute



Instrument Electronics

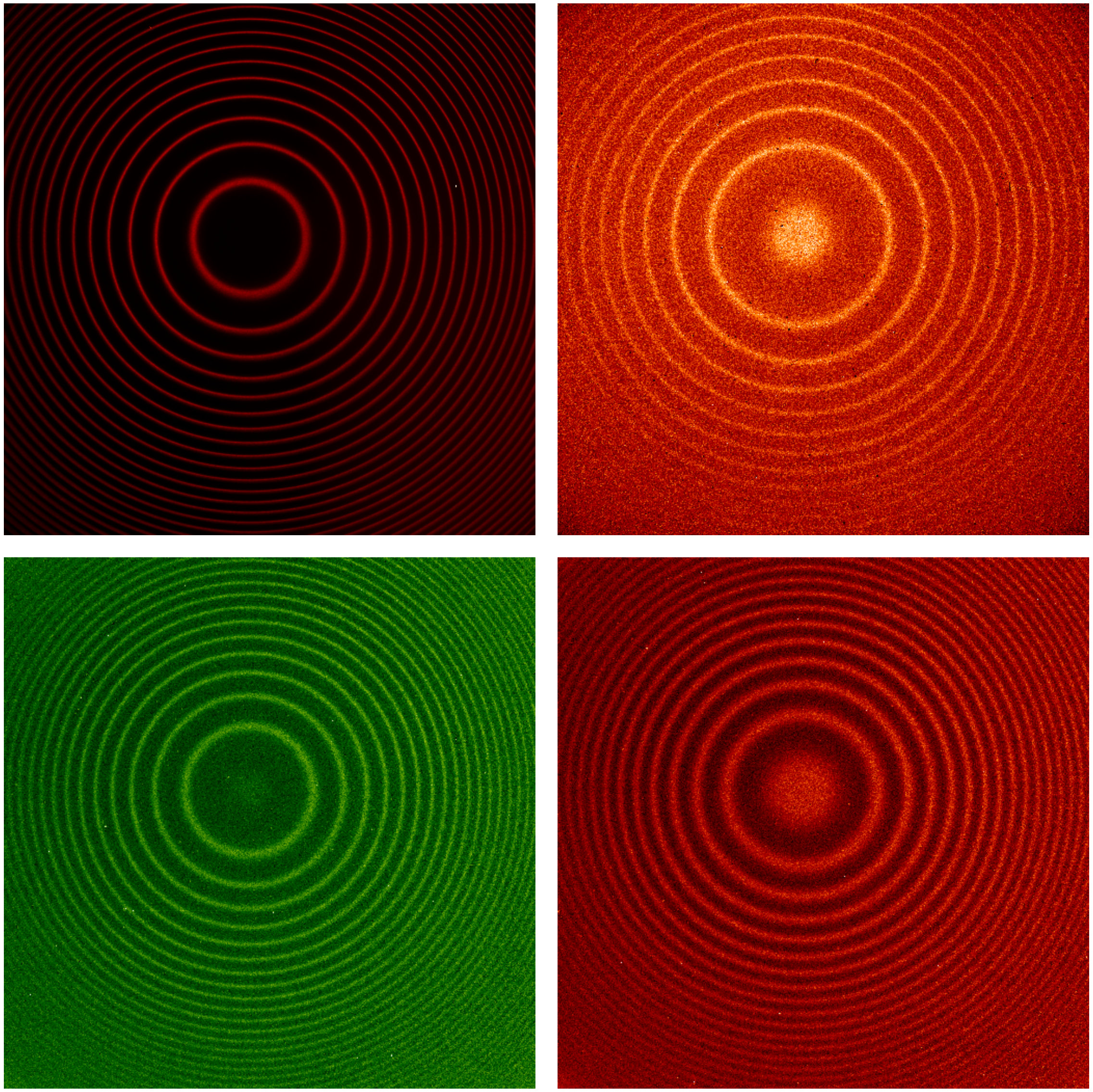
FPI Operational Mode

Emission	Integration time	Wind Errors	Altitude
OH 8920 A	3 minutes	6 m/s	87 km
O 5577 A	3 minutes	1 m/s	97 km
O 6300 A	5 minutes	2-6 m/s	250 km

FPI Fringes

Laser

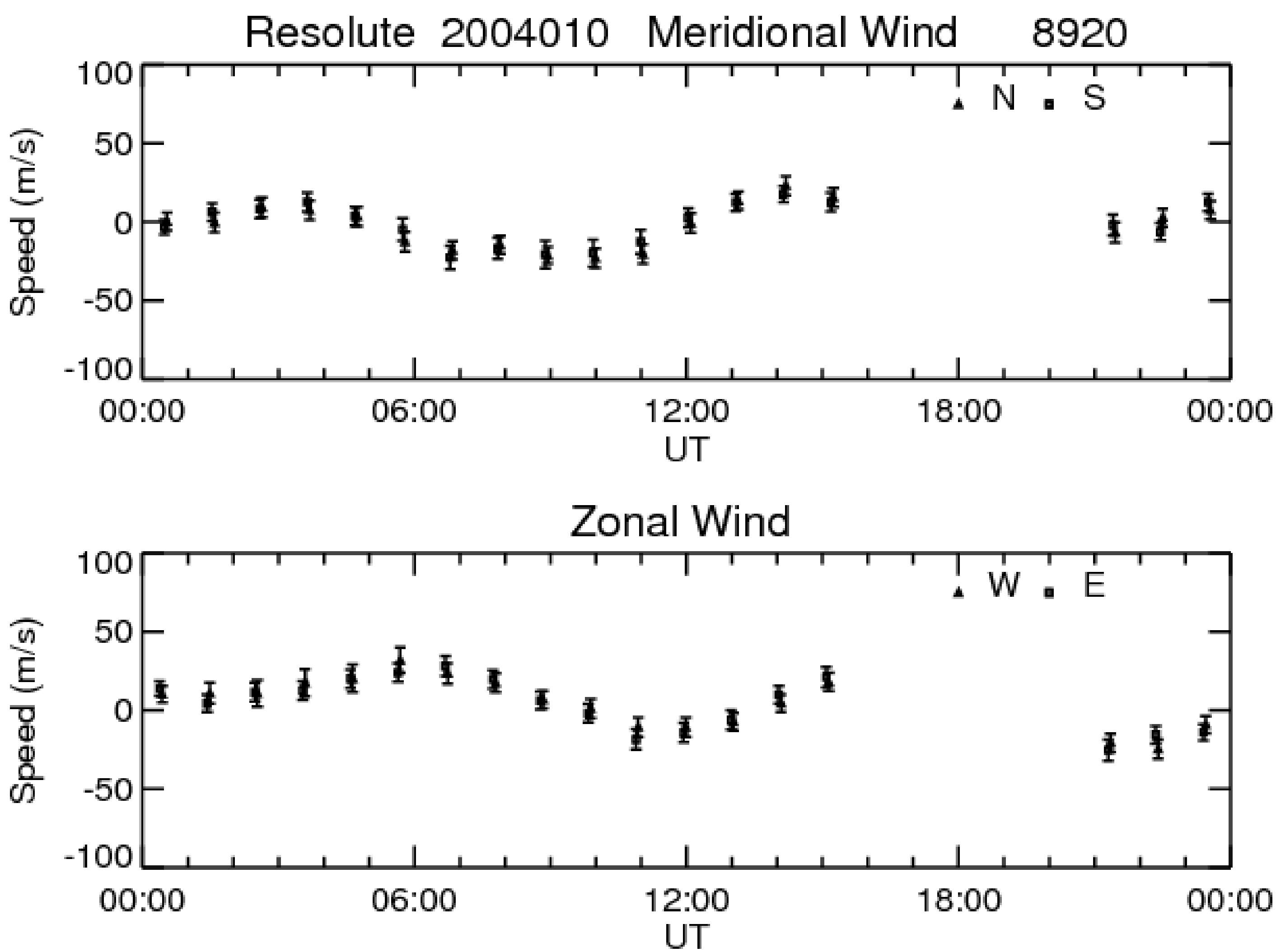
8920



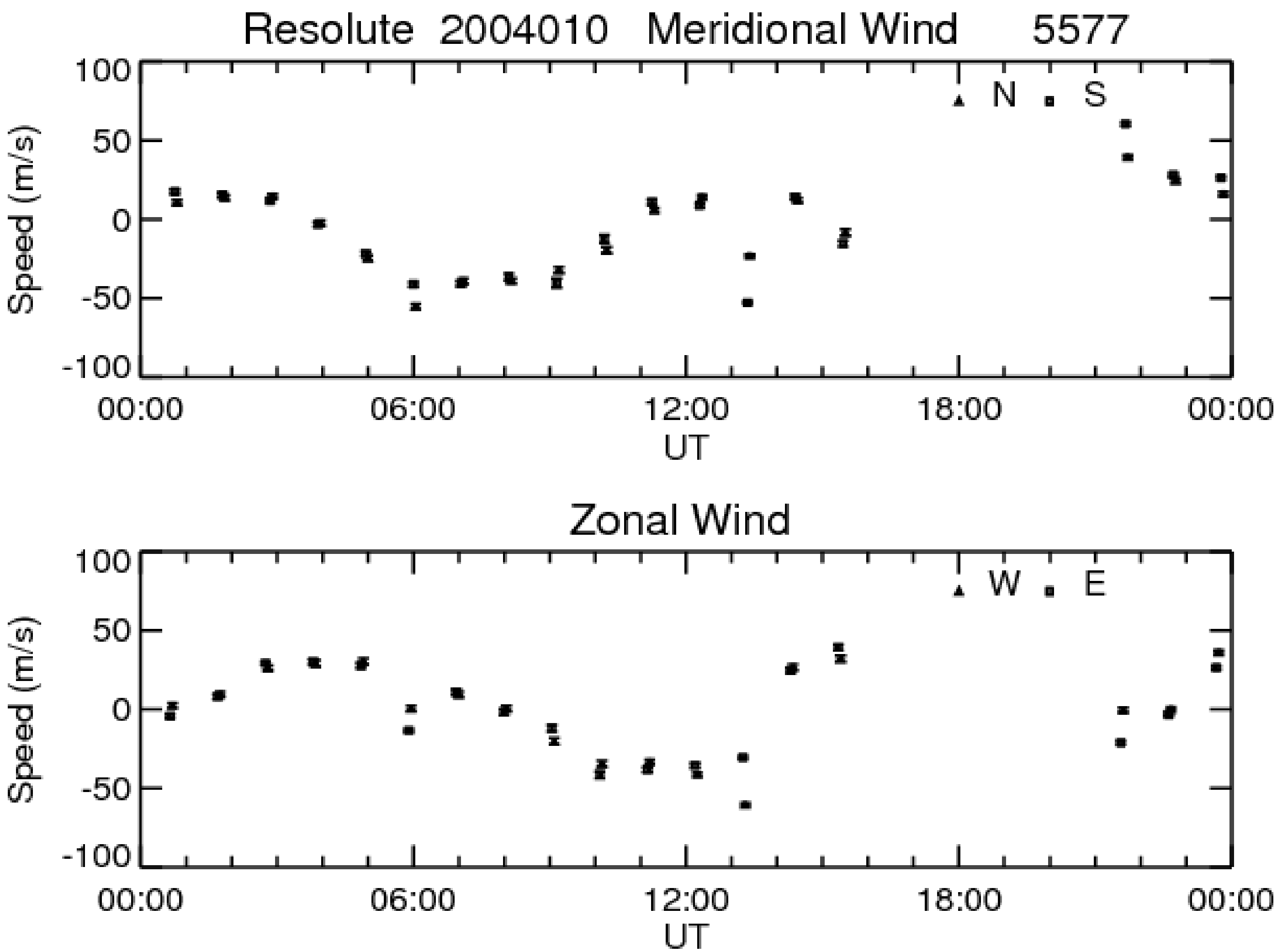
5577

6300

Mesospheric Wind Semidiurnal Tide



Lower Thermospheric Wind Semidiurnal tide



TIMED Fact Sheet

Key Characteristics

Mission

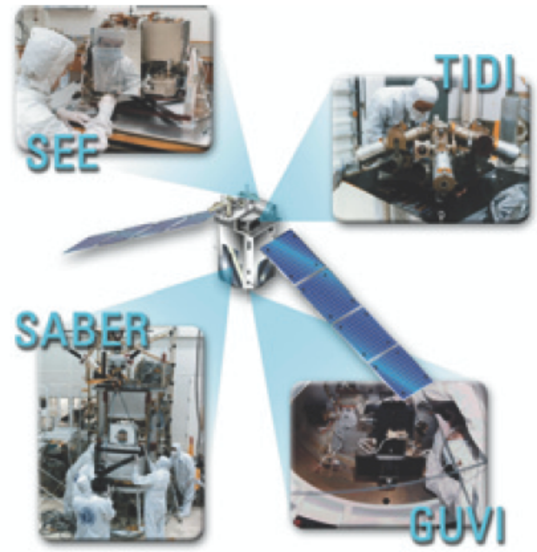
Launch Date	December 7, 2001
Launch Site	Vandenberg Air Force Base, Calif.
Launch Vehicle	Delta II 7920-10 (launched with Jason-1 spacecraft)
Primary Mission	Two years
Orbit	388-mile (625-kilometer) circular
Inclination	74.1 degrees from the equator

Spacecraft

Mass	1,294 pounds (587 kilograms)
Dimensions	8.93 feet (2.72 meters) high 5.29 feet (1.61 meters) wide (launch configuration) 38.47 feet (11.73 meters) wide (solar arrays deployed) 3.93 feet (1.20 meters) deep
Power Consumption	400 watts per orbit
Data Downlink	4 megabits per second
Memory	5 gigabits
Attitude	
Control	Within 0.5 degree
Knowledge	Within 0.03 degree

Instruments

GUVI (Global Ultraviolet Imager)—A spatial scanning, far-ultraviolet spectrograph that is globally measuring the composition and temperature profiles of the MLTI region, as well as its auroral energy inputs.

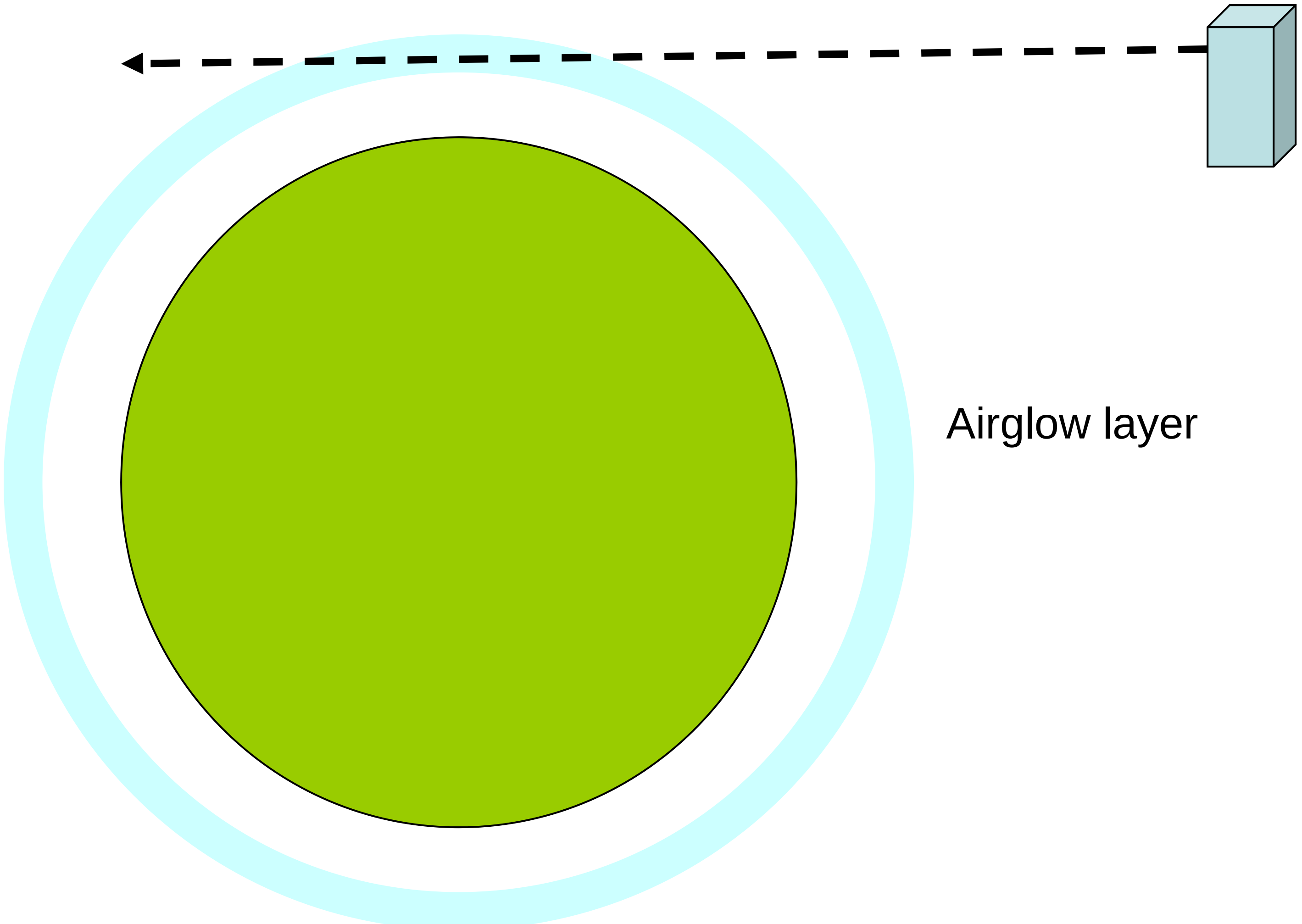


SABER (Sounding of the Atmosphere using Broadband Emission Radiometry)—A multi-channel infrared radiometer that is measuring heat emitted by the atmosphere over a broad altitude and spectral range, as well as global temperature profiles and sources of atmospheric cooling, such as the "airglow," which occurs when energy is radiated back into space.

SEE (Solar Extreme Ultraviolet Experiment)—A spectrometer and suite of photometers that is measuring solar ultraviolet radiation—the primary energy deposited into the MLTI atmospheric region—which includes solar soft X-rays and extreme-ultraviolet and far-ultraviolet radiation.

TIDI (TIMED Doppler Interferometer)—An instrument that is globally measuring the wind and temperature profiles of the MLTI region.

Limb-Scan Measurements



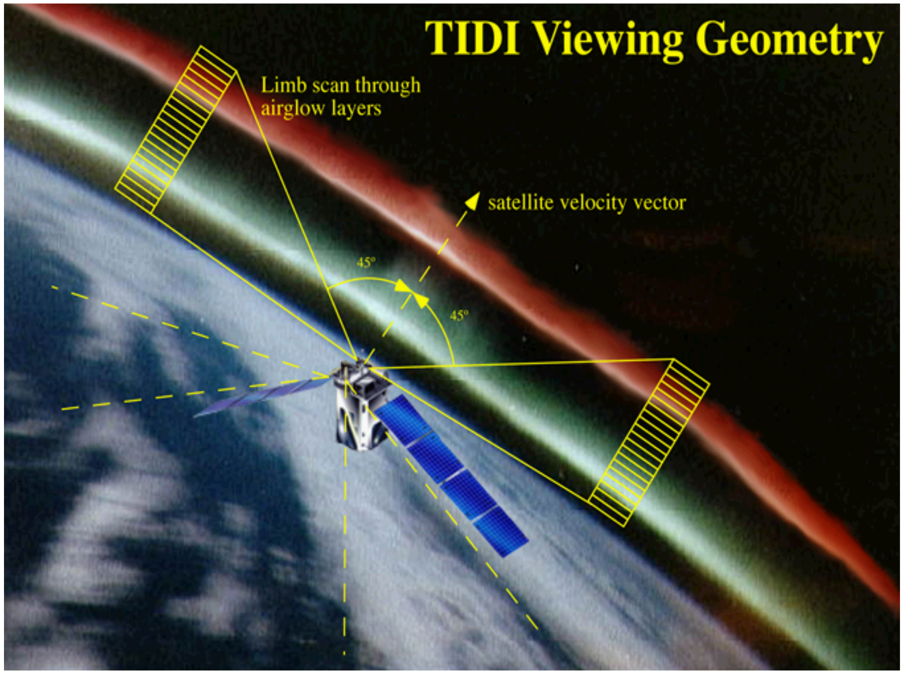
The TIDI Instrument

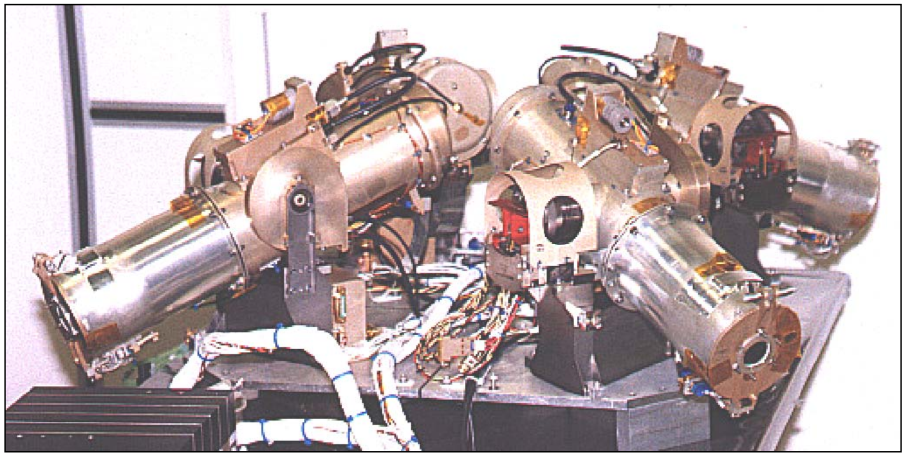
The TIMED Doppler Interferometer (TIDI) is a Fabry-Perot interferometer for measuring winds in the mesosphere and lower thermosphere.

Primary measurement: Global neutral wind field, 60–120 km

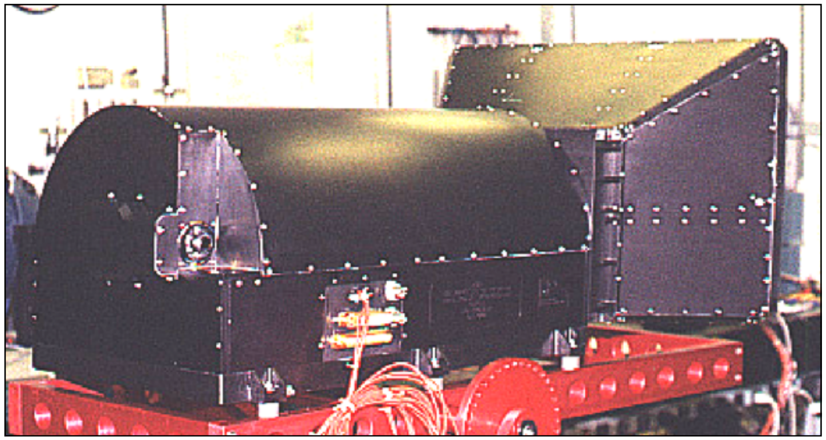
Primary emission observed: O_2 $^1\Sigma$ (0-0) P9

Additional emissions observed: O_2 $^1\Sigma$ (0-0) P15, O_2 $^1\Sigma$ (0-1) P7, O(^1S) "green line"



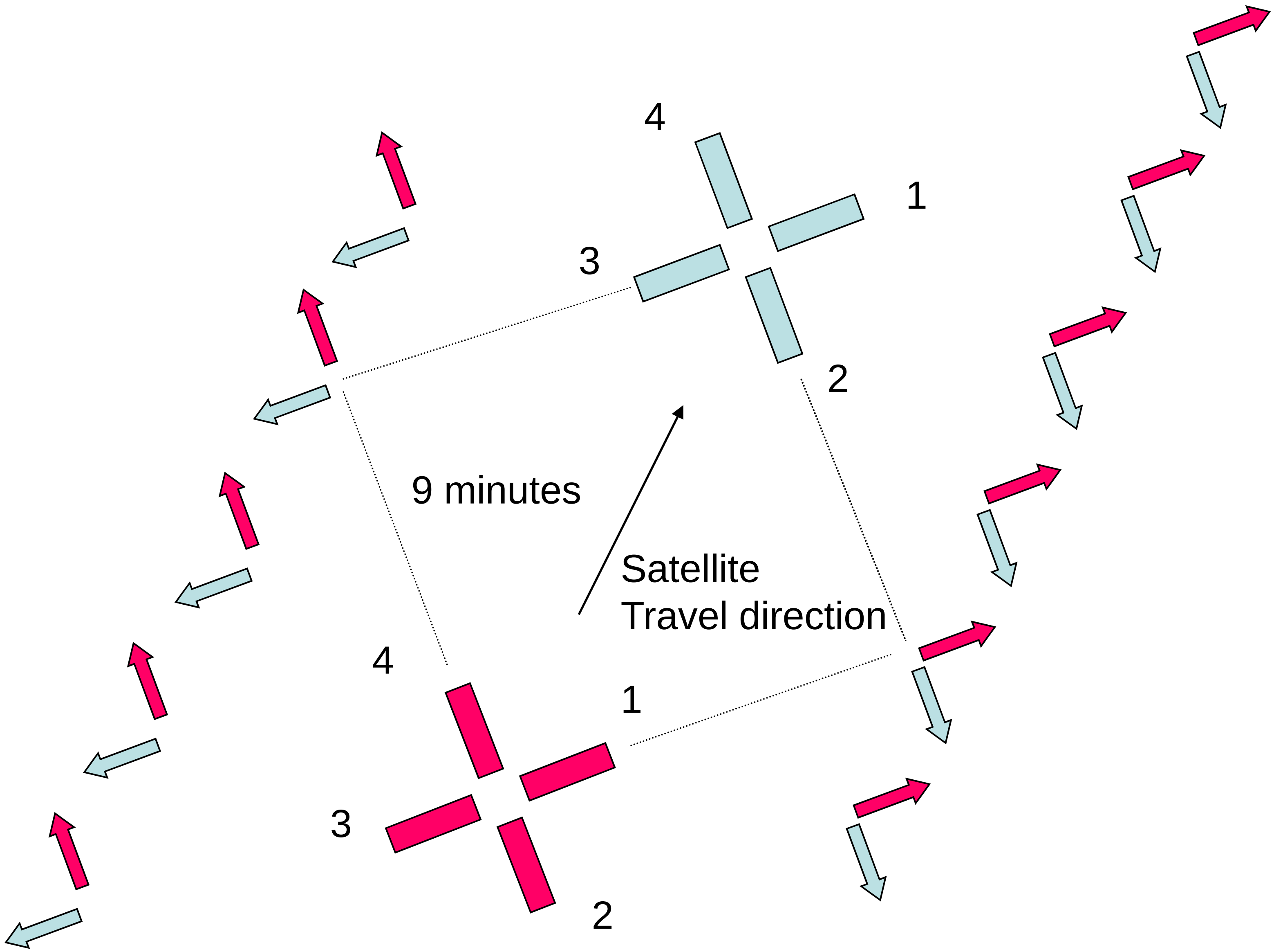


Telescope Assembly

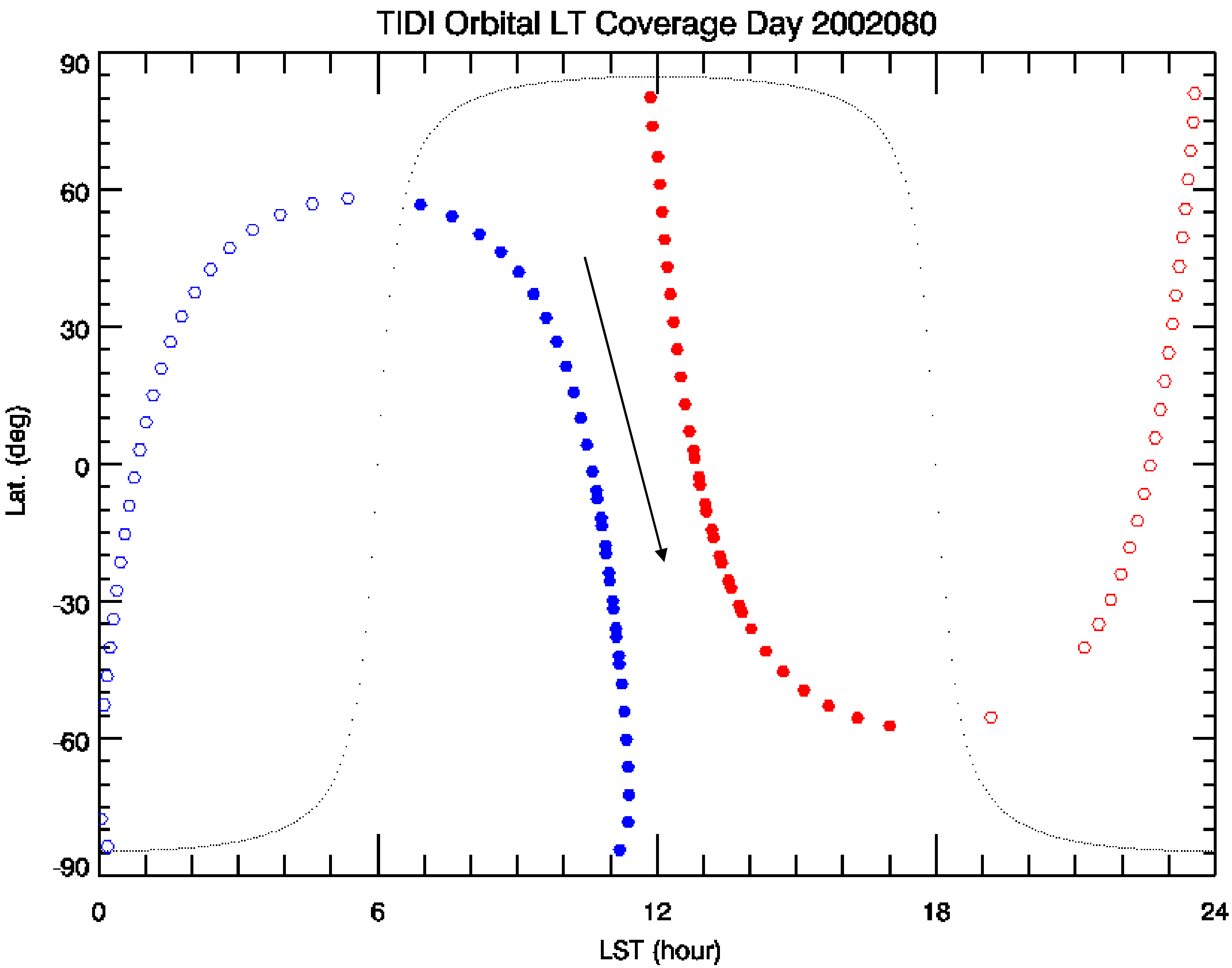


Profiler

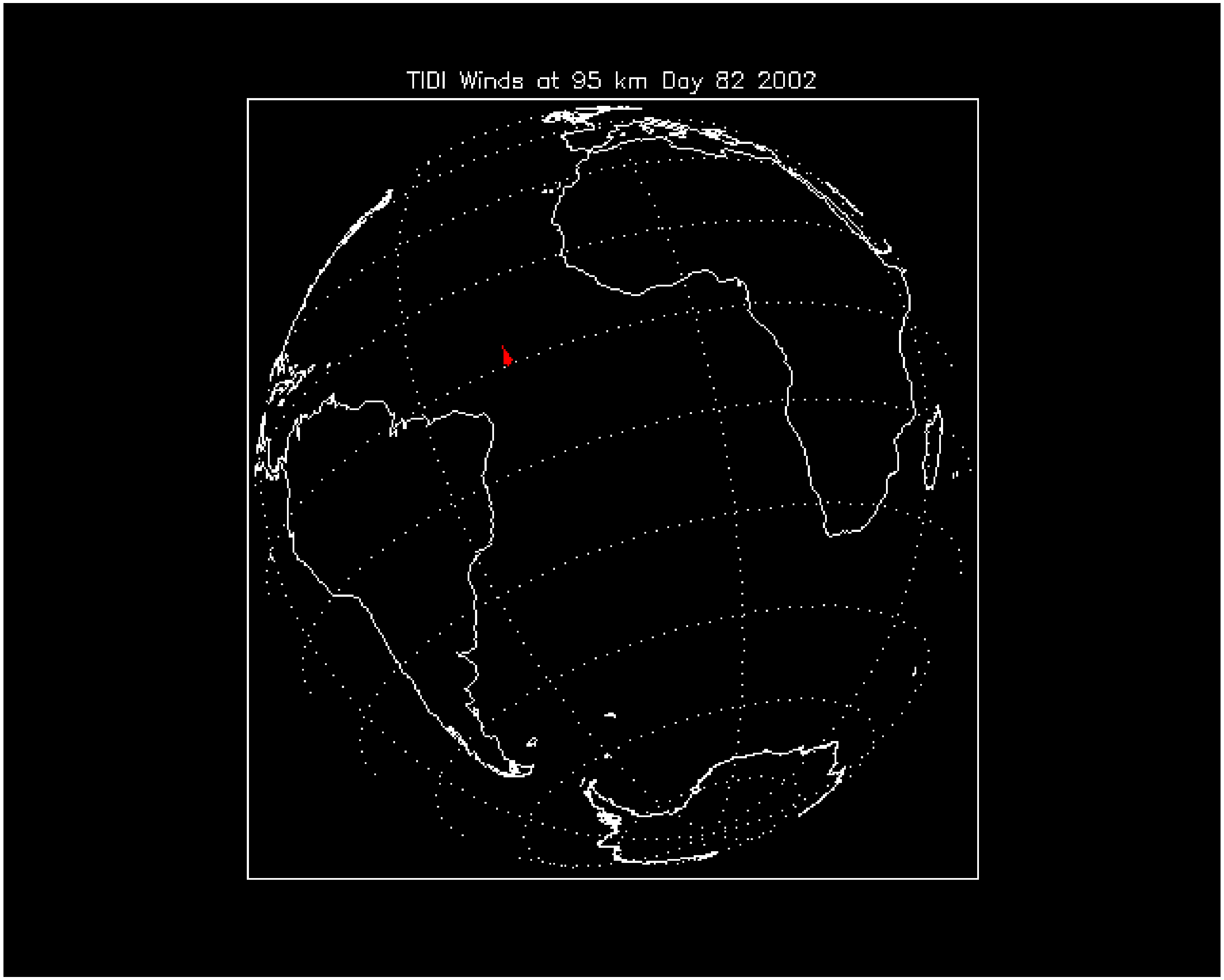
TIDI Measurement Viewing Directions



TIDI Local Time Coverage Day

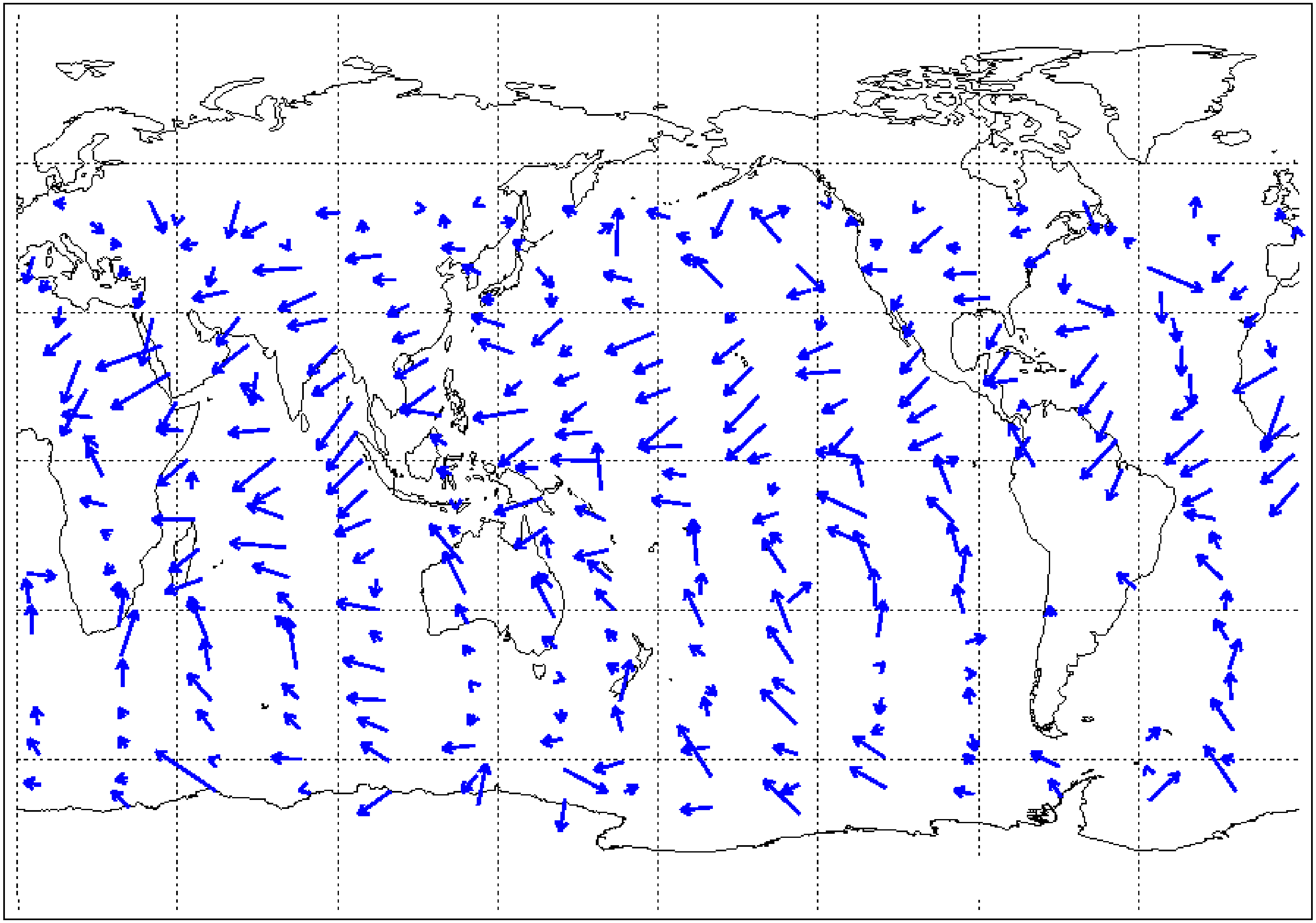


Shifting 12 minutes per day in local time

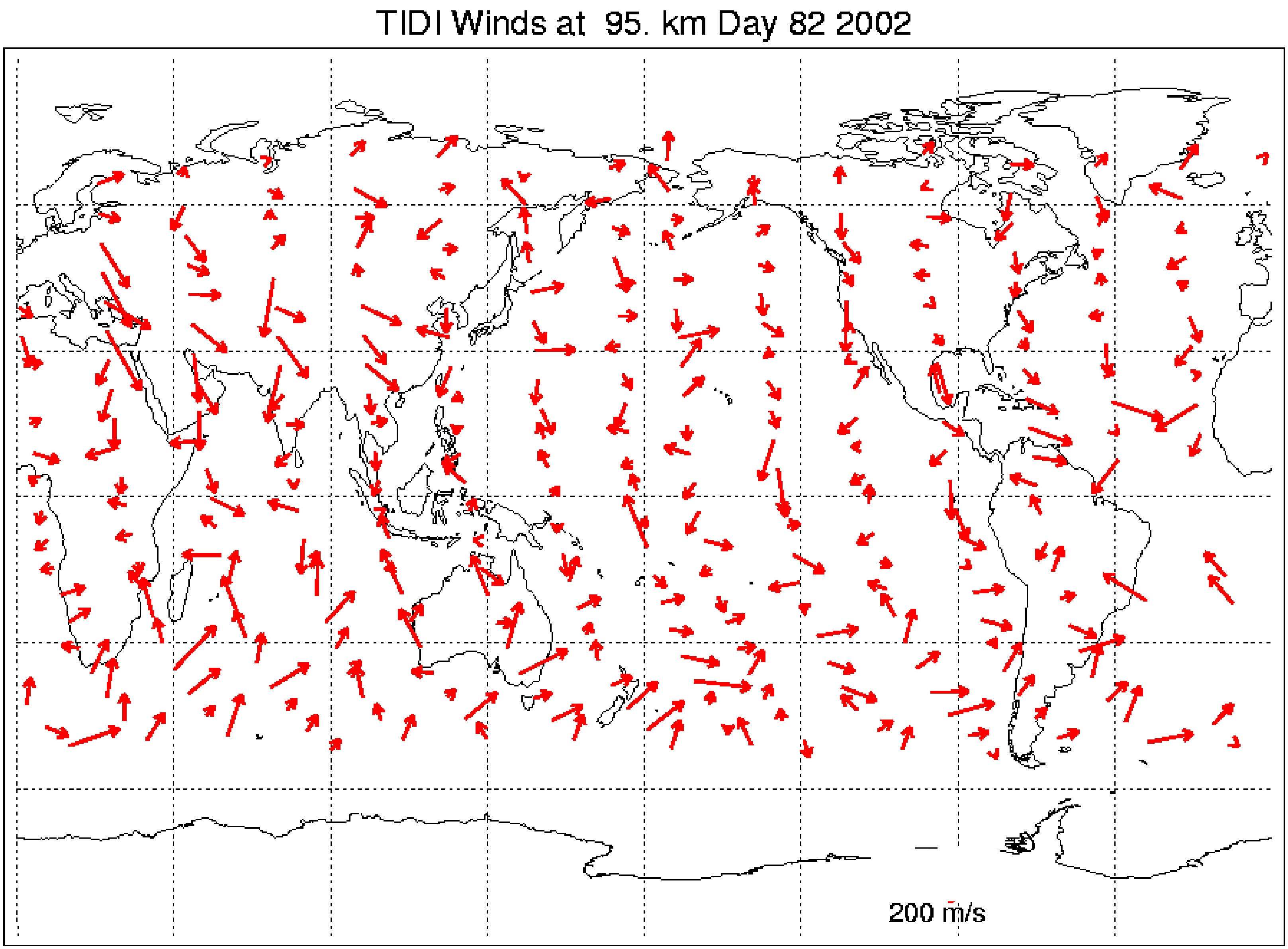

TIDI Winds at 95 km Day 82 2002

TIDI Coldside Wind Vectors

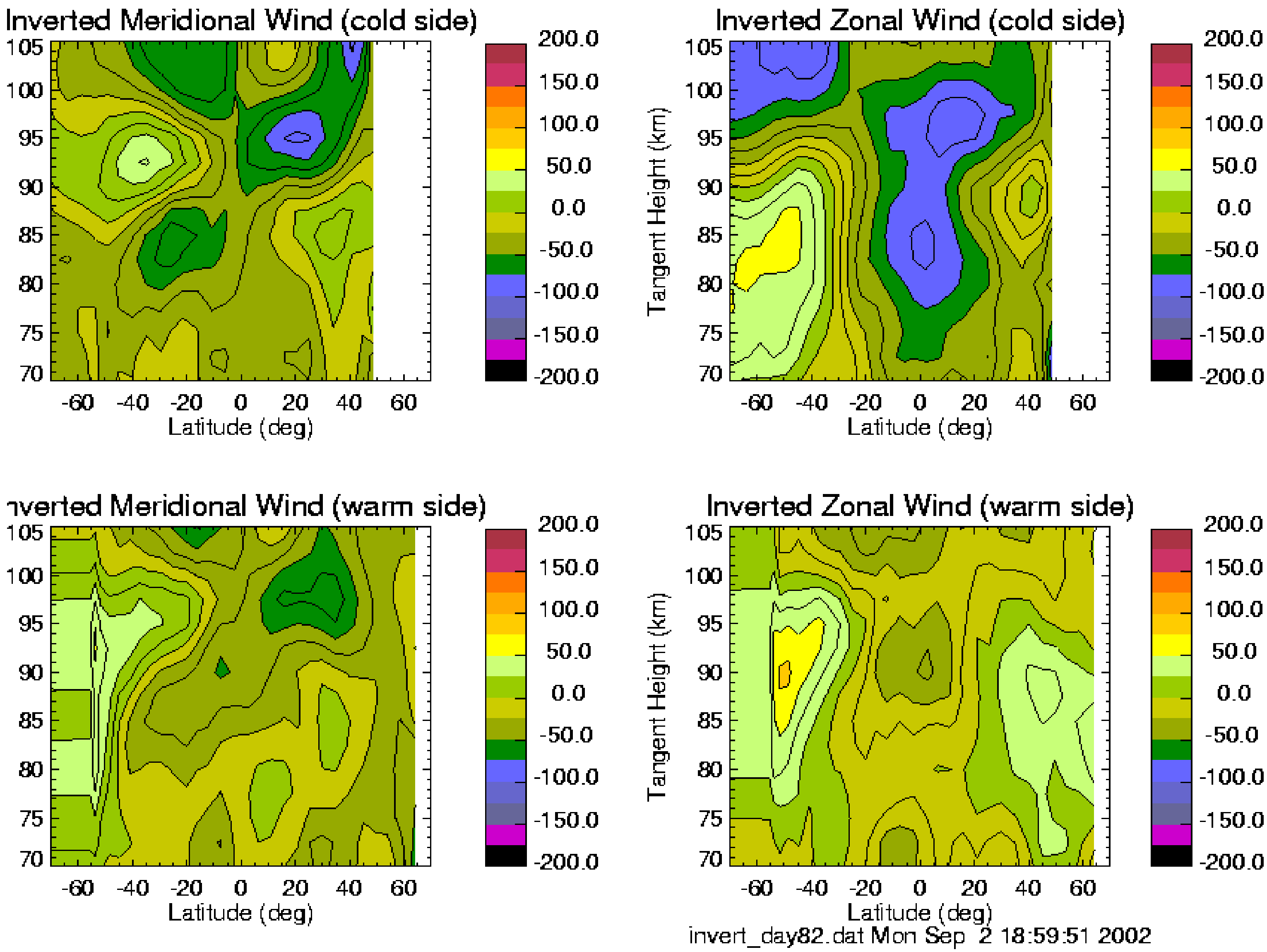
TIDI Winds at 95. km Day 82 2002



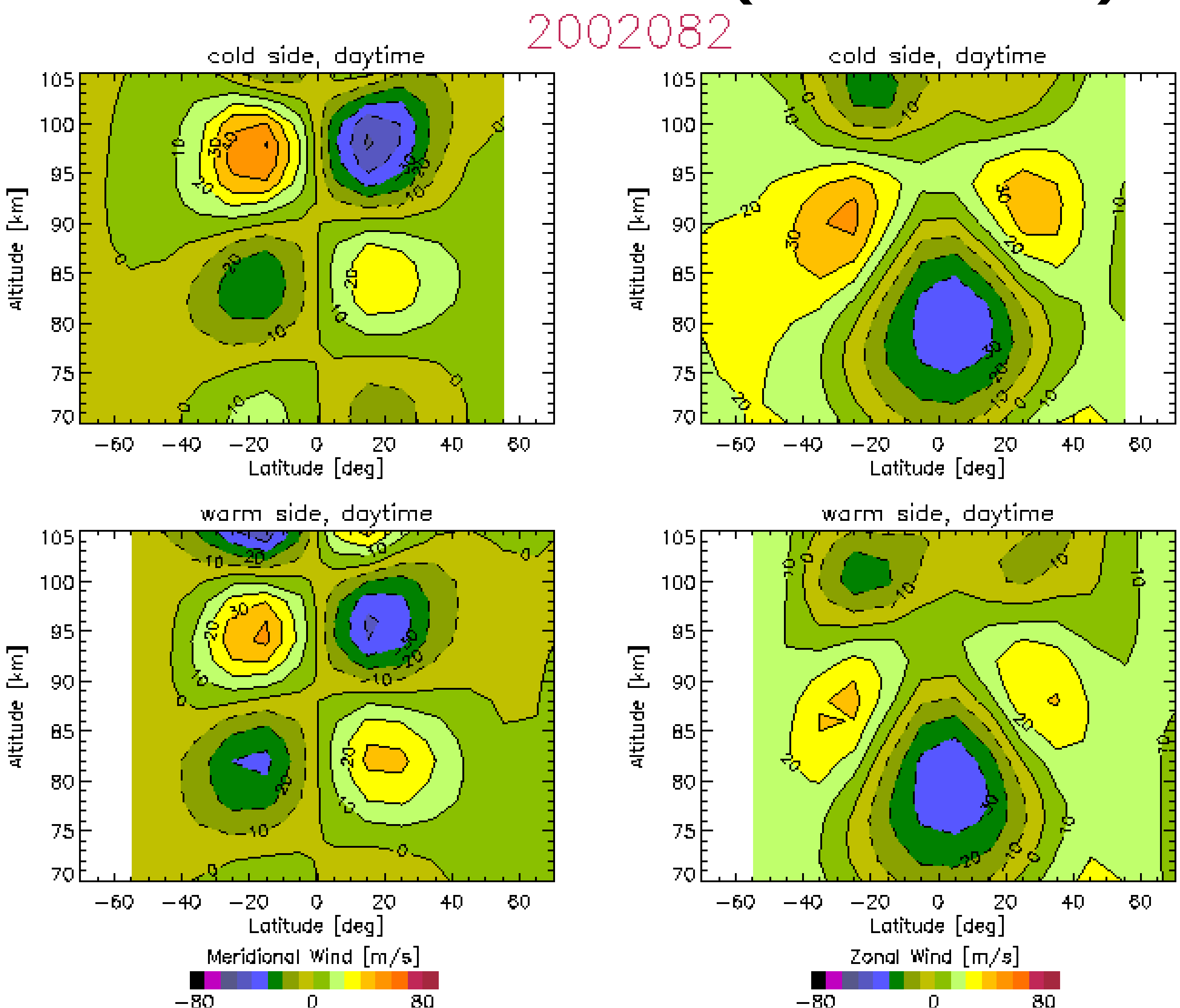
TIDI Warmside Wind Vectors



TIDI Observations



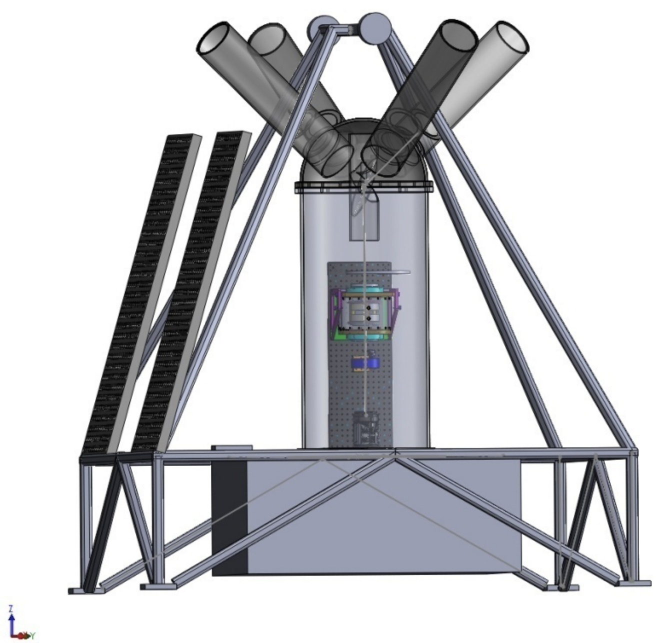
Model Winds (GSWM)



Oberheide and Hagan

Stratosphere Balloon Borne Fabry-Perot Interferometer

- Allow daytime observation of thermospheric winds due to low solar scatter background at high altitudes.
- Inexpensive compared to satellite instrument.



Summary

- Upper atmospheric winds contain strong global scale waves (e.g. tides).
- Tides are related to changes in the stratosphere and can affect the ionosphere.
- Upper atmospheric winds are the key to a better understanding of the ionosphere.
- There is a lack of observation upper atmospheric winds on a global scale.
- I see a great opportunity for future balloon and satellite missions.