Using MerCI FPI observations to improve I-T modeling.

2019 CEDAR Workshop

Patrick Dandenault (JHU/APL)
John Noto (CPI), Bob Kerr (CPI), Qian Wu (NCAR/HAO)
S. Kapali (CPI), N. Riccobono (CPI), M. Migliozzi (CPI), Gary Bust (APL)

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

CEDAR 2019
16 - 21 June
Santa Fe, New Mexico

Proposal #1: Meridian Chain of Interferometers (MerCI)

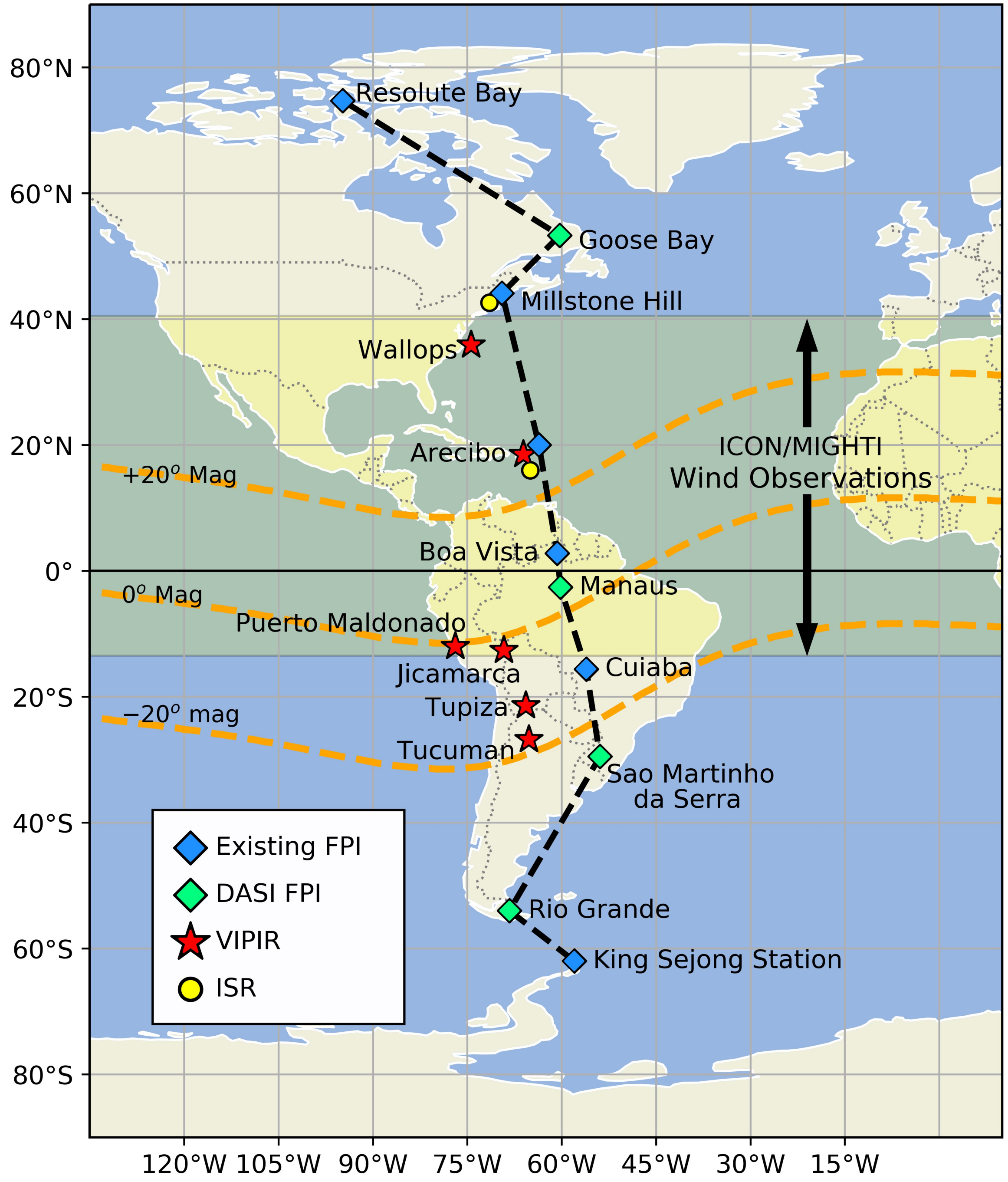
- NSF Distributed Array of Small Instruments (DASI)
- Program Solicitation NSF 19-545

- 10-station chain of FPIs

- Stretches along a common magnetic meridian in the Americas, spanning from Resolute Bay, Canada to King Sejong Station, Antarctica.

- Would provide thermospheric neutral wind and temperature measurements over the American sector and span both hemispheres.

- Significantly advance our understanding of the coupled ionosphere, thermosphere, magnetosphere system; improve operational Space Weather specification & forecasting; to improve science databases for the community.



Proposal #2: Enhanced SOFDI (E-SOFDI) Units

- Mid-scale Research Infrastructure-1
- Program Solicitation NSF 19-537

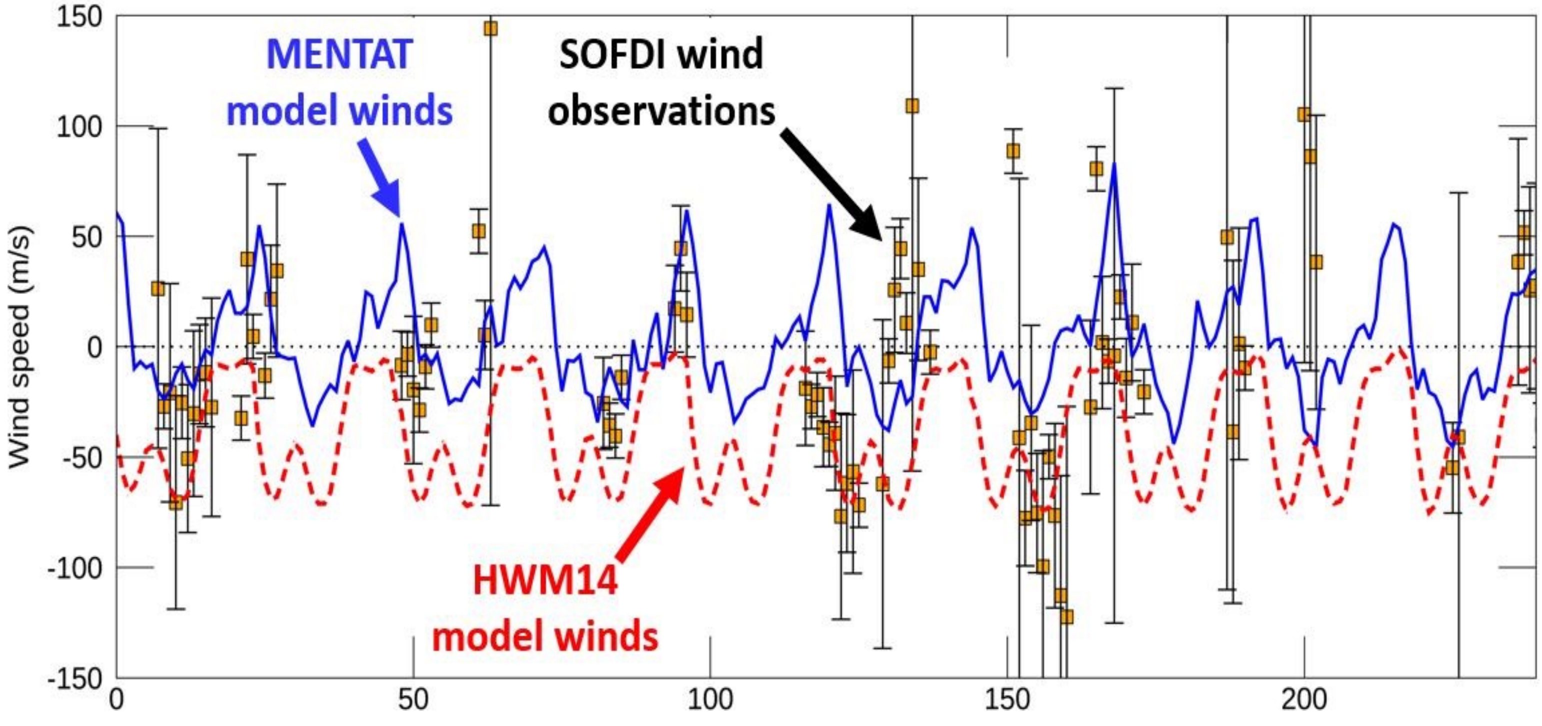
- Proposal submitted by NJIT and JHU/APL

- Acquisition, testing, and validation of three relocatable, independent, state-of-the-art E-SOFDI units

- Capable of high temporal <u>24-hour observations</u> of thermospheric winds and temperatures.

- ***This proposal was not funded this year, but we intend to try again.***

Daytime Wind Observations
Huancayo, Peru, 12.1° S, 75.2° W



Ten Days of SOFDI Daytime Wind Observations
June 10-17/20/22, 2015

Error bars = ±2 standard deviations.

Empirical Thermospheric Neutral Wind Models

The Horizontal Wind Model (HWM14)

- Empirical model, based on Wind **Observations**
- Database of winds spanning 40+ years
- Vector spherical harmonics formulation

Table 2. Statistical Measures of Biases μ_q and Root-Mean-Square Error σ_q^{rms} for Various Models and Data Groups[a]

Instrument	Points	μ_{obs}	μ_{93}	μ_{07}	μ_{14}	σ_{obs}	σ_{93}^{rms}	σ_{07}^{rms}	σ_{14}^{rms}
Line of Sight, Fabry-Perot Interferometer (FPI), and Incoherent Scatter Radar (ISR)									
Arecibo (ISR)	8051	11.62	**−2.59**	*−9.25*	−5.58	34.09	33.97	*35.54*	**30.84**
Arrival Height (FPI)	138690	−14.56	*−13.19*	**−0.59**	−6.74	103.55	*101.06*	**68.60**	69.07
Millstone Hill (ISR)	7503	−20.05	**−9.76**	*−12.50*	−9.92	59.95	*48.42*	47.71	**45.79**
Resolute Bay (FPI)	17377	0.41	−0.83	*2.17*	**0.52**	107.91	**65.74**	*71.30*	67.98
Søndrestrøme (ISR)	3730	2.97	−15.97	*−27.72*	**−8.82**	110.57	87.24	*93.62*	**81.23**
Cross Track, Satellite									
AE-E NATE	57428	7.74	*7.76*	5.31	**1.81**	68.73	*56.58*	55.40	**51.40**
GOCE	573672	95.79	19.58	*40.46*	**6.81**	48.83	50.41	*60.60*	**36.05**
Meridional, Fabry-Perot Interferometer									
Arecibo	81552	−12.05	*3.97*	**−0.03**	3.32	39.46	*37.72*	36.88	**35.38**
Arequipa	108139	1.80	*4.11*	3.57	**−1.21**	69.92	*66.61*	66.37	**65.14**
Halley Bay	91205	25.35	*−19.62*	12.59	**0.68**	88.48	*72.50*	68.87	**63.51**
Jicamarca	2054	−1.95	*5.62*	**−1.68**	2.02	42.42	*41.60*	40.96	**39.11**
Millstone Hill	68185	−46.01	−6.70	*−20.80*	**−2.28**	76.85	66.72	71.69	**66.17**
Mount John	1949	48.15	**7.77**	*45.93*	16.31	55.84	47.41	67.39	**46.07**
Movil	37725	0.33	**0.54**	−2.87	*−3.54*	47.32	**44.78**	46.80	44.98
PARI	21306	−28.56	*18.24*	**−3.83**	7.60	53.17	*52.94*	50.34	**48.66**
Poker Flat	450914	−22.51	*69.54*	6.72	**0.22**	54.29	*100.46*	59.99	**47.65**
RENOIR	12690	2.49	**−1.19**	−2.30	*−2.91*	45.40	36.46	43.13	**36.10**
Søndrestrøme	10303	−67.35	**−0.77**	*−10.17*	−8.81	103.26	*90.50*	**82.58**	86.97
South Pole	198560	2.94	**−1.20**	8.59	2.84	93.89	*86.88*	78.50	**70.63**
Svalbard	1381	−32.60	*30.70*	**−0.58**	−7.90	124.67	*110.60*	**101.06**	102.42
Thule	15519	−13.55	**−6.17**	*12.89*	8.66	127.32	*107.24*	**93.42**	93.92
Watson Lake	4890	−33.10	*31.29*	**−1.30**	−5.20	68.28	*88.40*	60.92	**58.98**
Meridional, Satellite/Rocket									
DE2 FPI 630 nm	6000	28.21	*−4.68*	**2.45**	2.78	108.31	78.94	**77.45**	81.64
TMA	2772	−7.13	*−10.55*	3.26	**−1.60**	69.70	72.68	**43.55**	46.45
UARS WINDII 557.7 nm	413449	2.50	*−2.90*	−0.04	**−0.02**	65.98	60.31	52.89	**52.50**
Zonal, Fabry-Perot Interferometer									
Arecibo	79108	36.77	*12.65*	−8.04	**−6.19**	52.66	*53.07*	47.59	**44.71**
Arequipa	99198	84.48	*−25.81*	−3.84	**0.74**	71.66	*78.52*	72.13	**68.83**
Halley Bay	91245	14.85	*15.51*	**−5.13**	−9.07	93.81	*93.29*	66.44	**65.35**
Jicamarca	1901	48.33	*−43.89*	−23.19	**−7.74**	59.29	*79.79*	64.31	**59.54**
Millstone Hill	68175	22.12	*28.37*	−9.74	**−9.62**	70.32	*68.29*	63.56	**63.21**
Mount John	1949	35.17	**−1.38**	*−8.55*	1.70	70.81	**49.92**	*56.79*	54.97
Movil	24227	63.54	*−26.99*	−9.16	**4.39**	55.55	*60.72*	56.49	**48.35**
PARI	12610	35.01	15.84	*−27.40*	**−13.64**	57.67	**51.25**	*56.36*	51.32
Poker Flat	450925	−14.35	−4.16	**0.49**	*−9.09*	70.35	65.00	*72.56*	**60.30**
RENOIR	12483	57.23	*−34.74*	−6.05	**−0.71**	44.94	*63.27*	46.09	**40.32**
Søndrestrøme	10442	−15.31	*20.62*	−7.31	**−3.94**	102.68	*114.75*	97.96	104.09
Svalbard	1353	−40.74	8.83	**−3.57**	*−9.32*	129.08	*140.66*	125.08	129.76
Thule	15643	2.78	*27.58*	**−1.95**	−7.45	150.12	*133.50*	118.98	**118.30**
Watson Lake	4979	−20.23	*52.09*	13.47	**5.69**	67.85	*86.19*	68.89	**64.96**
Zonal, Satellite, and Rocket									
DE2 WATS	7233	−19.95	**1.00**	*−6.92*	−6.52	125.73	**88.99**	89.17	*94.83*
TMA Release	2774	9.40	**−2.02**	*6.37*	−5.82	53.60	*57.35*	34.79	**33.21**
UARS WINDII 557.7 nm	415238	−39.77	*−8.32*	**−4.37**	−5.19	72.22	*72.03*	59.50	**59.31**

[a] The best and worst scores are highlighted in bold and italics, respectively.

Table 1. New Data Sets Added to the Prior Observational Database Described in *Drob et al.* [2008]

Instrument	Location	Height (km)	Years	Local Time	Days	Points	Reference
Fabry-Perot Interferometer							
Arecibo	18.7°N, 67.5°W	250	2012–2013	nighttime	428	29,434	*Ruan et al.* [2013]
Arequipa	16.47°S, 71.49°W	250	2007–2013	nighttime	260	16,447	*Meriwether et al.* [2008]
Jicamarca	11.96°S, 76.86°W	250	2009–2013	nighttime	318	10,056	*Meriwether et al.* [2008]
Movil	14.97°S, 74.89°W	250	2011–2013	nighttime	293	10,412	*Meriwether et al.* [2008]
PARI[a]	35.2°N, 82.85°W	250	2011–2013	nighttime	166	12,610	*Makela et al.* [2012]
Poker Flat[b]	65.1°N, 147.5°W	250	2009–2011	nighttime	297	5,983,090	*Conde and Smith* [1995]
RENOIR[c]	6.89°S, 38.56°W	250	2009–2012	nighttime	637	37,301	*Makela et al.* [2013]
South Pole	90.0°S	250	1989–1999	nighttime	1,091	198,560	*Hernandez et al.* [1992]
Satellite							
GOCE[d]	±83.4°	253–295	2009–2012	twilight	813	6,613,172	*Doornbos et al.* [2010]

[a] Pisgah Astronomical Research Institute.
[b] Imaging FPI.
[c] Relocatable Equatorial Nighttime Observatory of Ionospheric Regions.
[d] Cross track only.

Strengths:

- **"Global" coverage**
- **Meridional and Zonal directionality**
- **Includes vertical wind profiles**
- **Describes atmospheric tides & general circulation patterns**

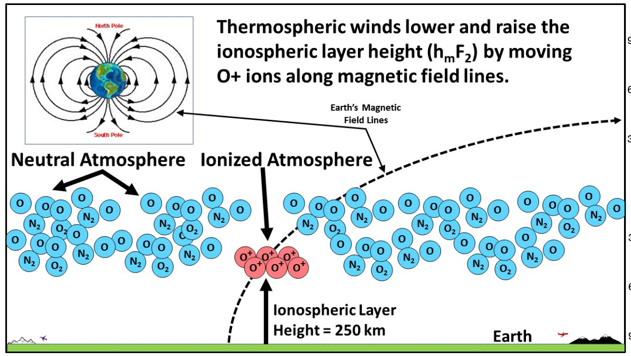
Limitations:

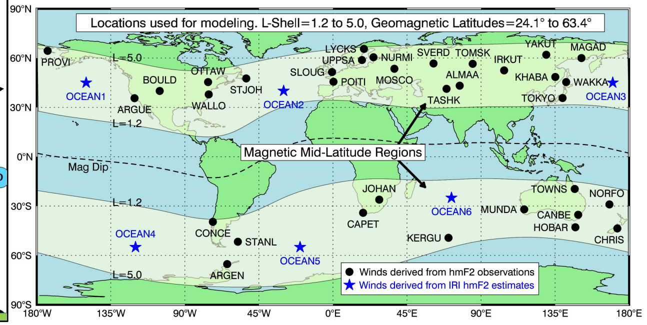
- **Wind observations are patchy in both time and space**
- **Low temporal variability**
- **No solar flux (F10.7, F10.7A) dependence**

The MENTAT Wind Model

Magnetic mEridional NeuTrAl Thermospheric (MENTAT)

- Empirical model, based on Wind **Derivations**
- Used global 30-year database of ionosonde data
- Winds derived from ΔhmF2 via first-principles modeling





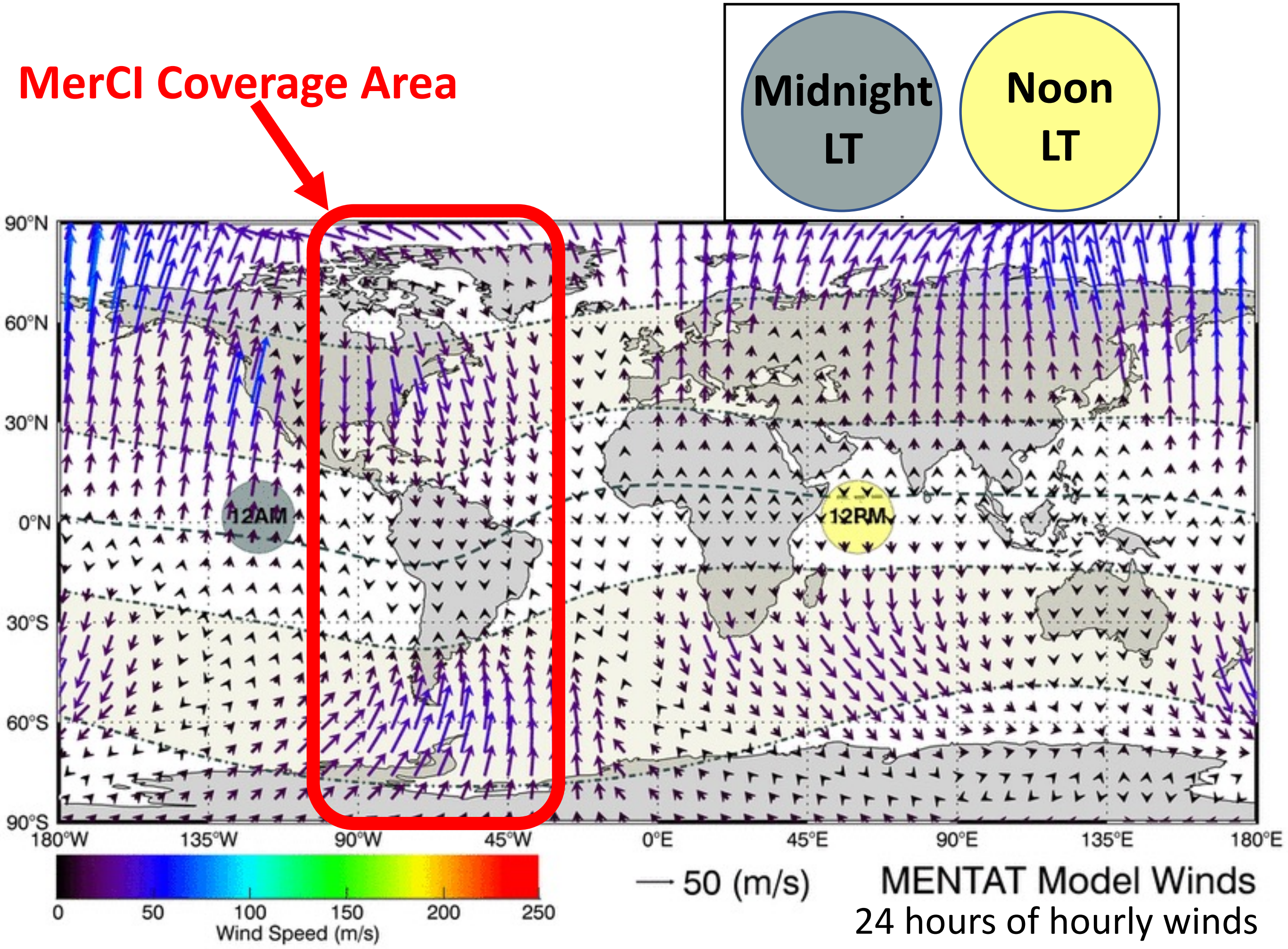
Strengths:

- **"Global" coverage**
- **High-temporal (hourly) variability**
- **Includes solar flux (F10.7, F10.7A) dependence**
- **Describes atmospheric tides & general circulation patterns**

Limitations:

- **Winds are derived**
- **F region winds only**
- **No zonal winds; only meridional (North/South)**

Using MerCI wind observations to improve Thermospheric & Ionospheric Physics



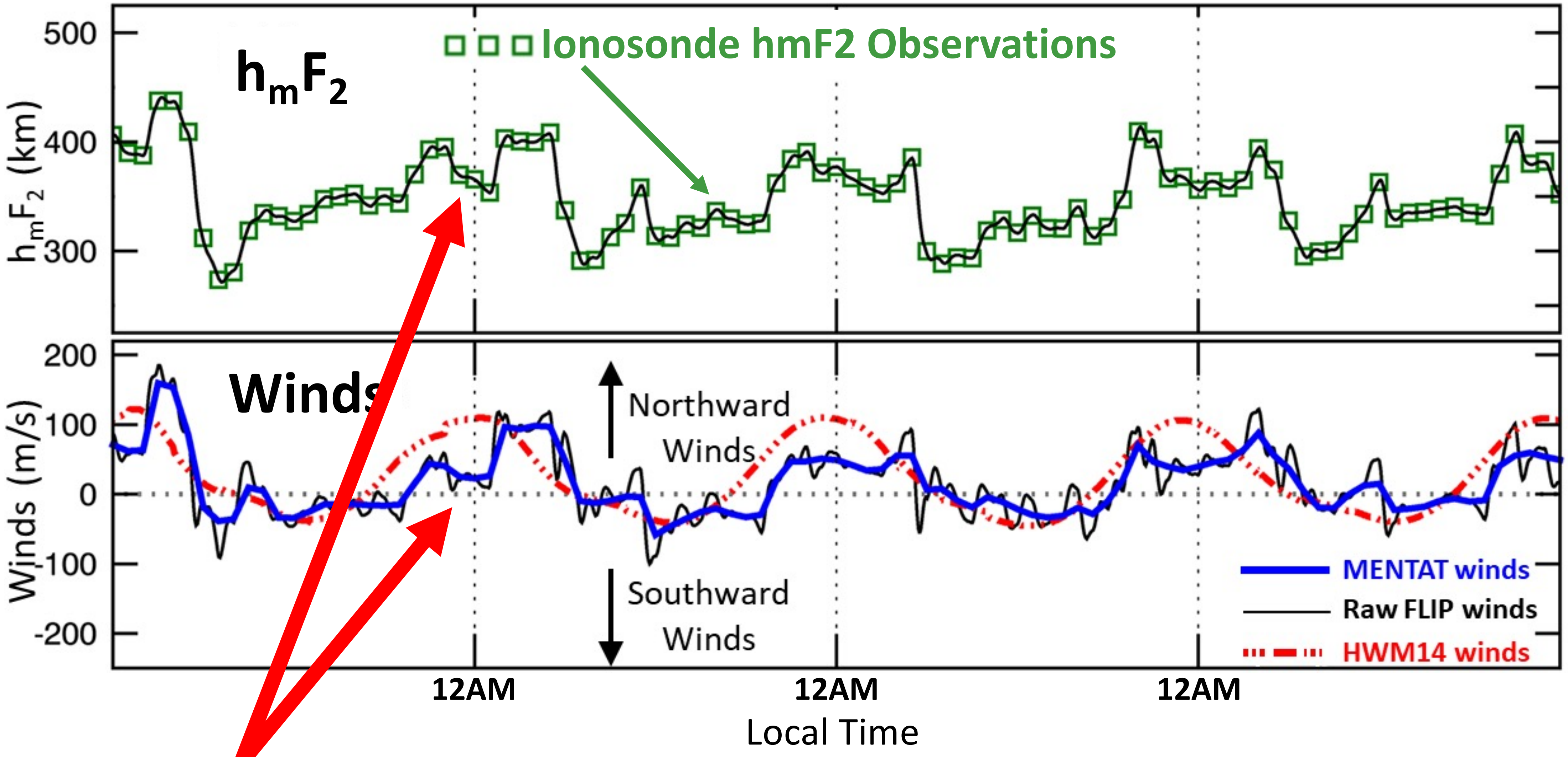
Knowledge of Meridional Winds is Critical for Accurate Ionospheric Modeling

Relevant Science:

1) Ionization Troughs in Ionosphere
2) TIDs: Origination, Propagation
3) Midnight Density Maximum (MDM), Midnight Temperature Maximum (MTM)
4) Winds driving EIA morphology
5) Seasonal North/South bulk wind flow; O/N_2 and the 'Thermospheric Spoon'
6) Latitudinal variability of tides
7) Wind correlation lengths (distance)

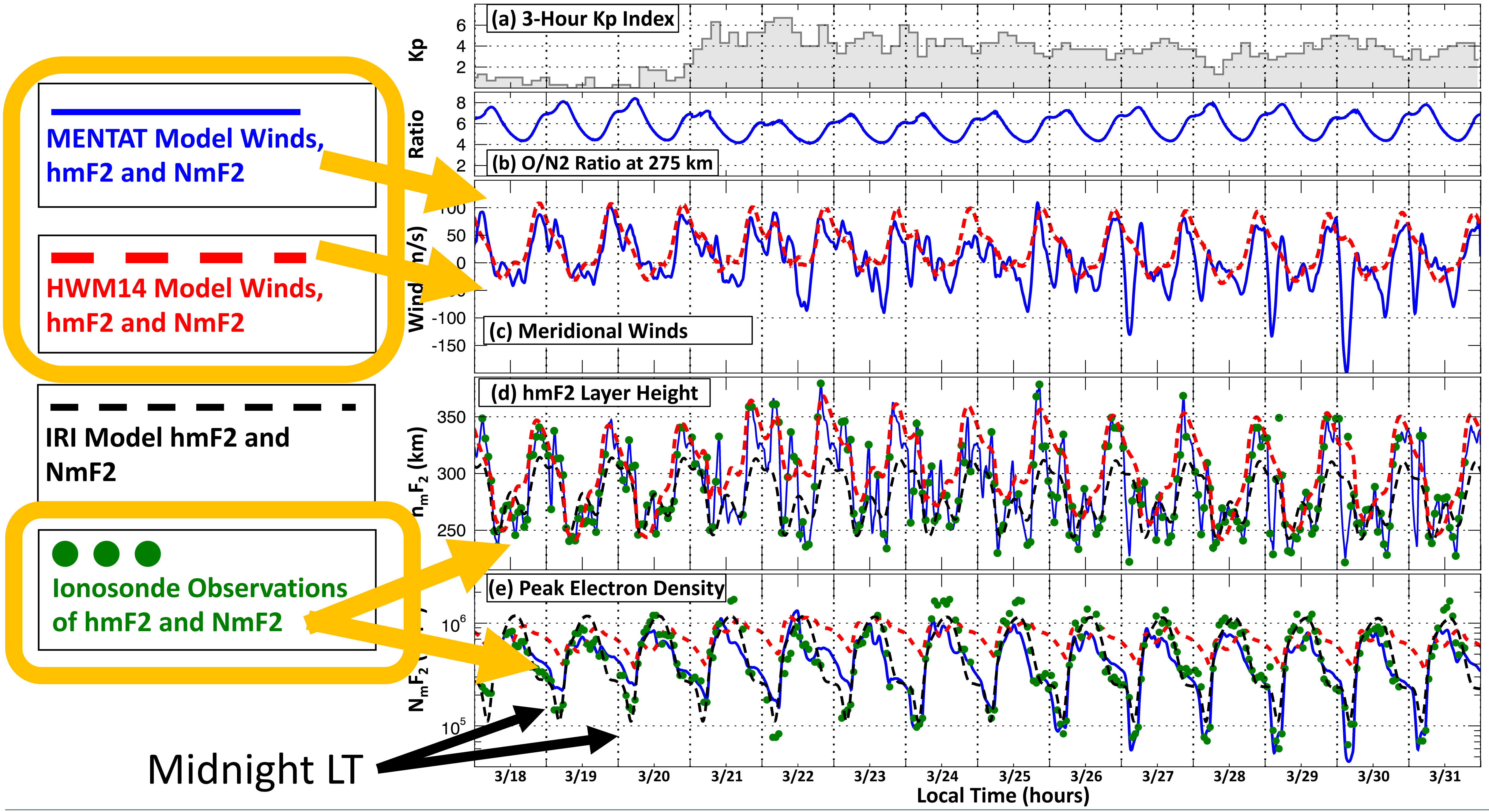
Expected behavior of hmF2 and winds in the Southern Hemisphere

Canberra, Australia, March 2-5, 1990

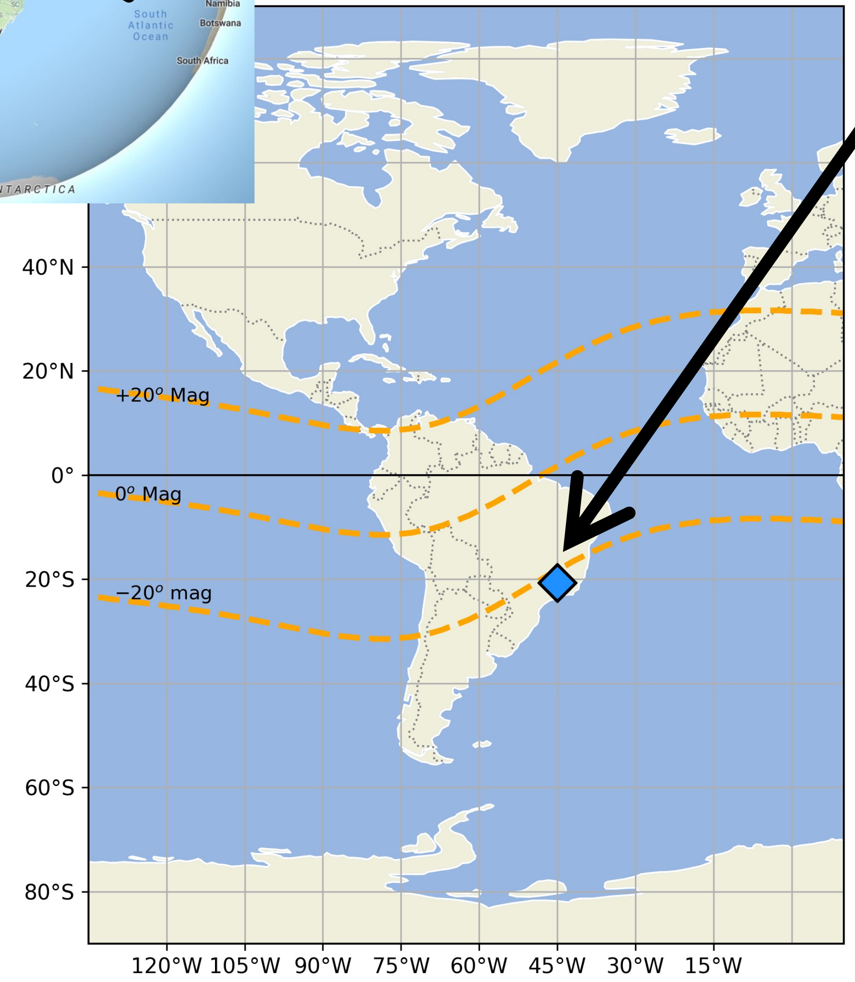


The winds and hmF2 are in-phase…

Observed & Modeled data at Townsville, Australia, March, 1974



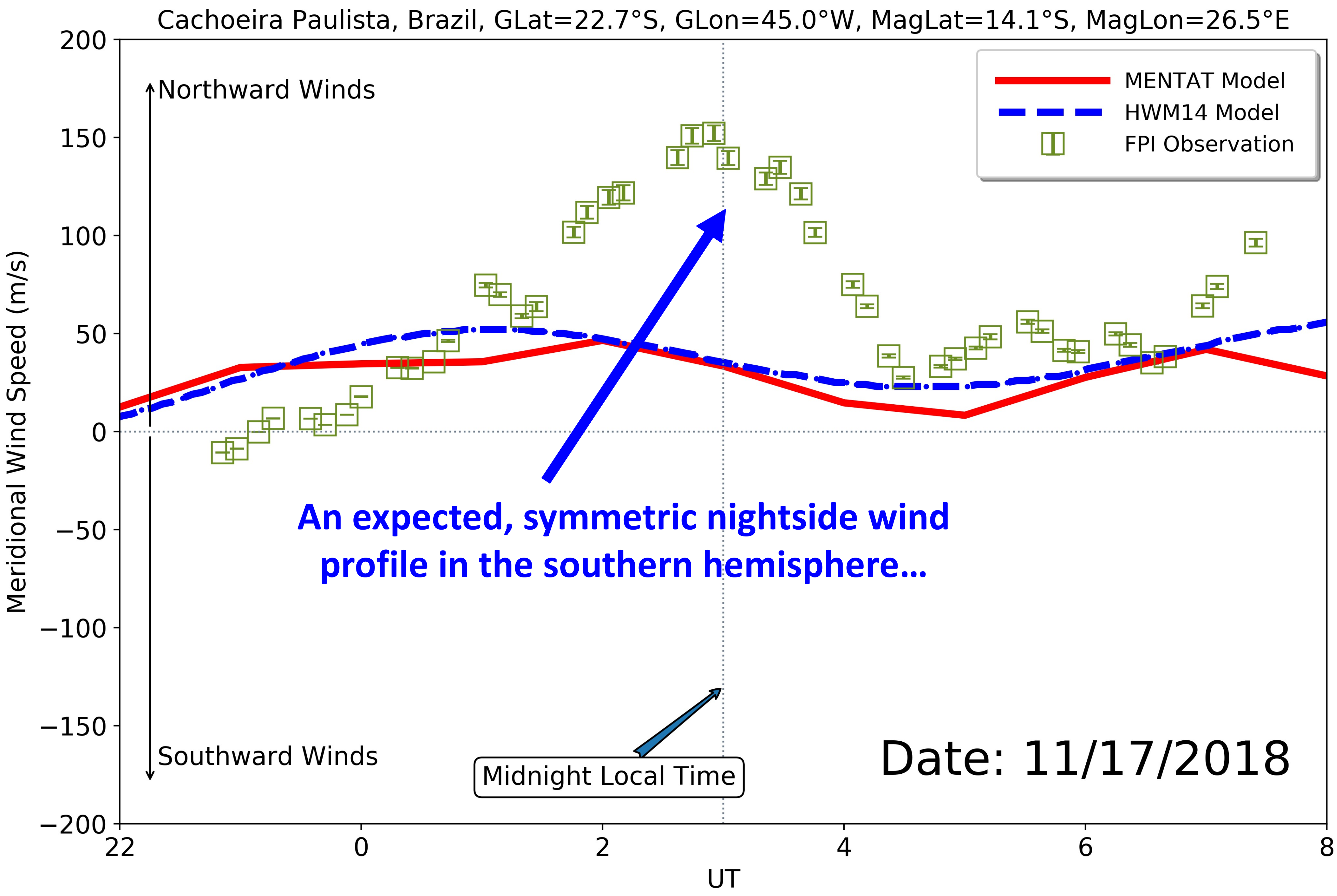
FPI wind observations vs. the MENTAT wind model and the HWM14 model



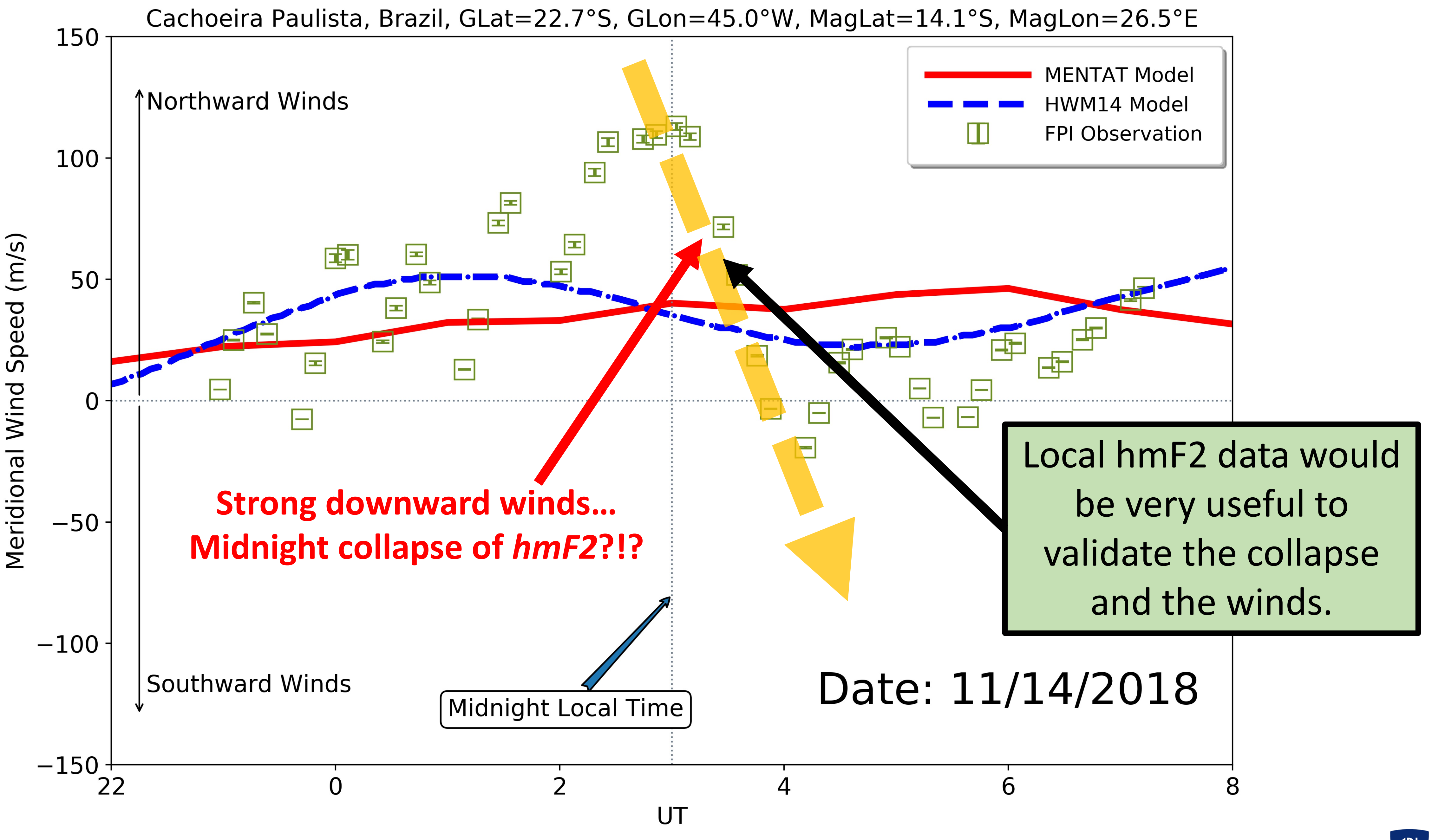
Cachoeira Paulista, Brazil	
Latitude	Longitude
22.7°S	45.0°W

This site is at a low geomagnetic latitude… might we see the winds necessary to drive a 'Midnight Collapse' of hmF2?

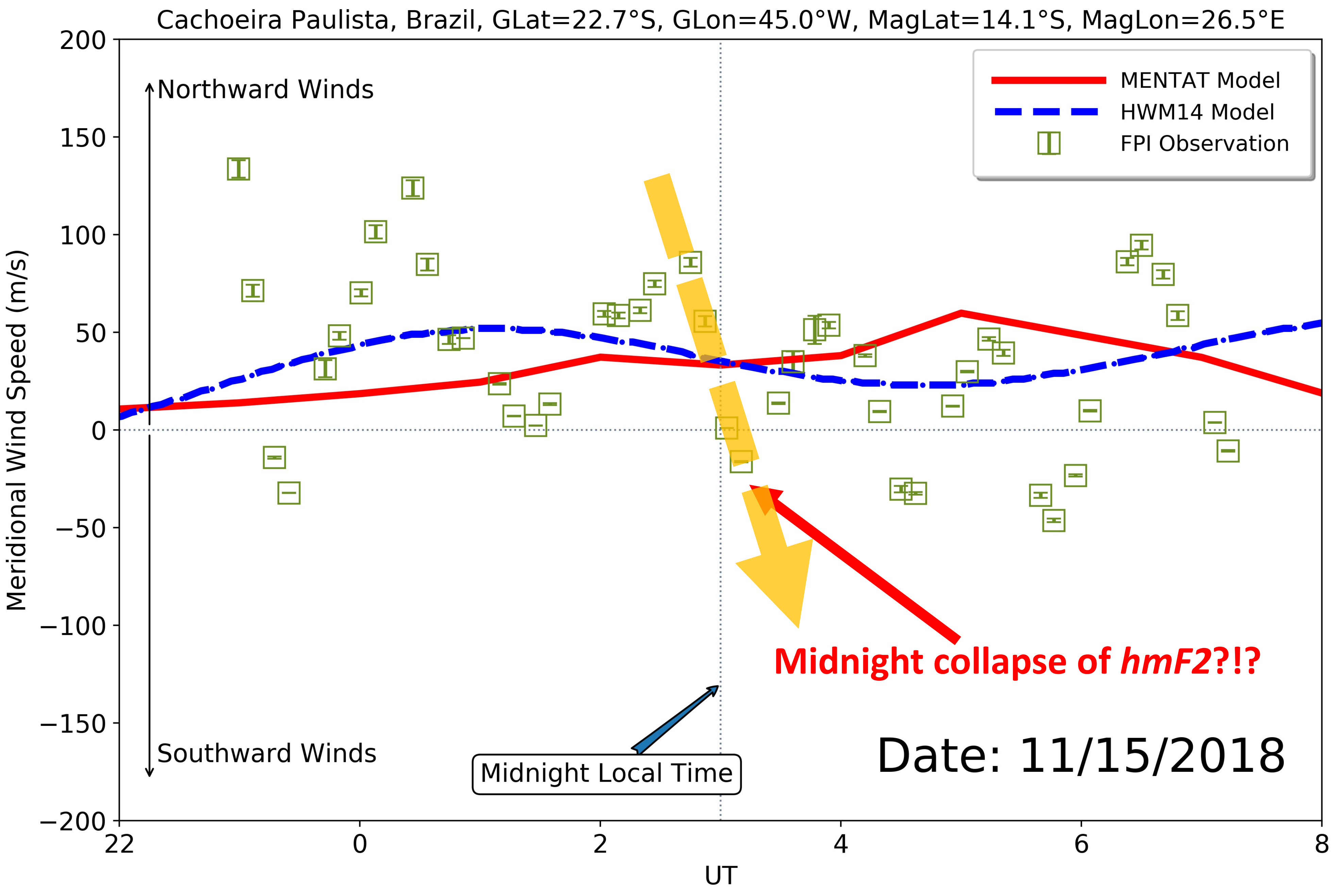
Thanks to John Noto for these preliminary FPI wind data…



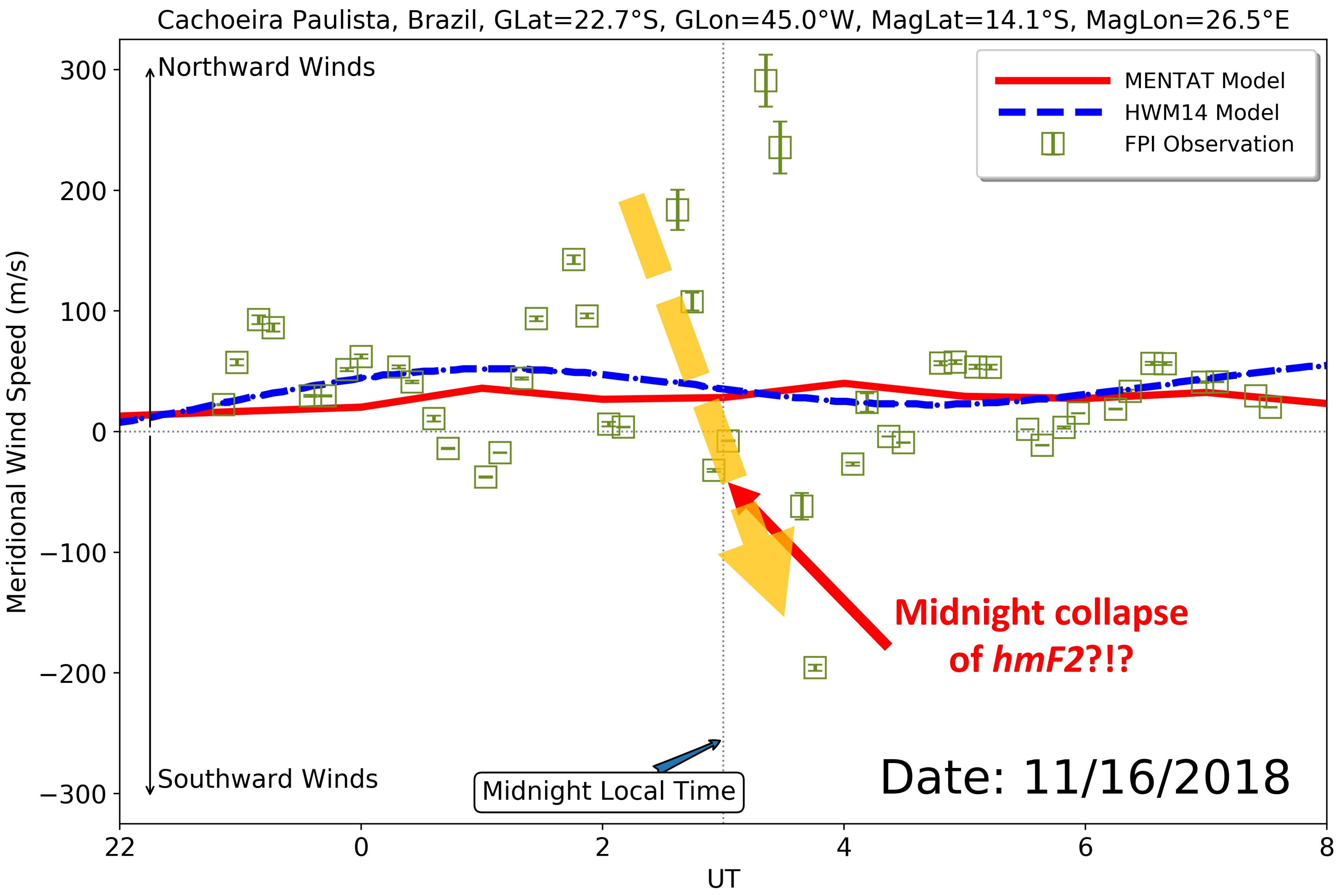
Cachoeira Paulista, Brazil, GLat=22.7°S, GLon=45.0°W, MagLat=14.1°S, MagLon=26.5°E
Northward Winds
Southward Winds
MENTAT Model
HWM14 Model
FPI Observation
An expected, symmetric nightside wind profile in the southern hemisphere…
Midnight Local Time
Date: 11/17/2018
Meridional Wind Speed (m/s)
UT
200
150
100
50
0
−50
−100
−150
−200
22
0
2
4
6
8



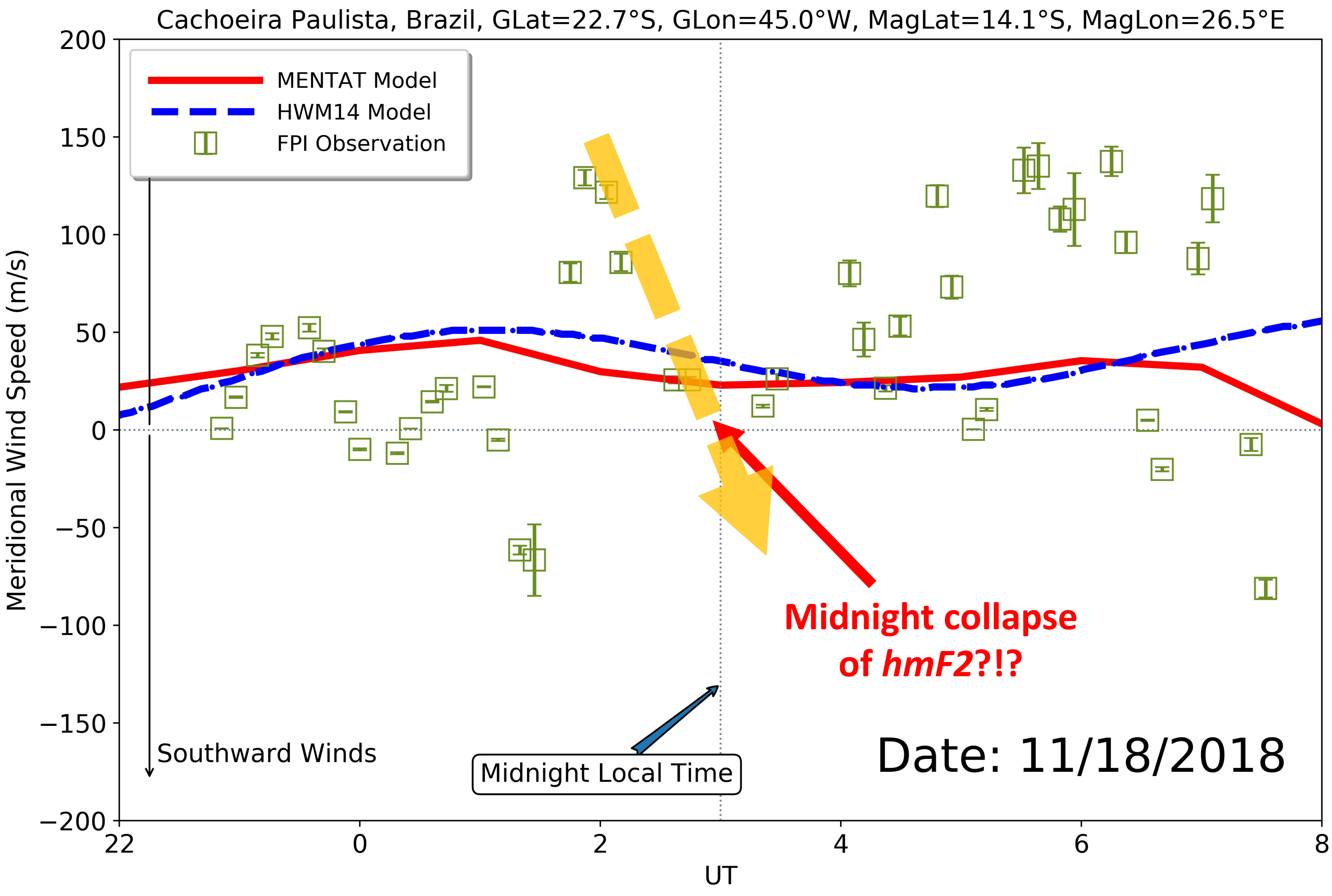
Cachoeira Paulista, Brazil, GLat=22.7°S, GLon=45.0°W, MagLat=14.1°S, MagLon=26.5°E
MENTAT Model
HWM14 Model
FPI Observation
Northward Winds
Southward Winds
Meridional Wind Speed (m/s)
150
100
50
0
−50
−100
−150
22
0
2
4
6
8
UT
Strong downward winds…
Midnight collapse of hmF2?!?
Midnight Local Time
Local hmF2 data would be very useful to validate the collapse and the winds.
Date: 11/14/2018



Cachoeira Paulista, Brazil, GLat=22.7°S, GLon=45.0°W, MagLat=14.1°S, MagLon=26.5°E
Northward Winds
Southward Winds
MENTAT Model
HWM14 Model
FPI Observation
Meridional Wind Speed (m/s)
200
150
100
50
0
−50
−100
−150
−200
22
0
2
4
6
8
UT
Midnight Local Time
Midnight collapse of hmF2?!?
Date: 11/15/2018



Cachoeira Paulista, Brazil, GLat=22.7°S, GLon=45.0°W, MagLat=14.1°S, MagLon=26.5°E
Northward Winds
Southward Winds
MENTAT Model
HWM14 Model
FPI Observation
Meridional Wind Speed (m/s)
300
200
100
0
−100
−200
−300
22
0
2
4
6
8
UT
Midnight Local Time
Midnight collapse of hmF2?!?
Date: 11/16/2018



Cachoeira Paulista, Brazil, GLat=22.7°S, GLon=45.0°W, MagLat=14.1°S, MagLon=26.5°E
MENTAT Model
HWM14 Model
FPI Observation
Meridional Wind Speed (m/s)
200
150
100
50
0
−50
−100
−150
−200
22
0
2
4
6
8
UT
Southward Winds
Midnight Local Time
Midnight collapse of hmF2?!?
Date: 11/18/2018

Long-Term Goals

1. Continuous 24/7 thermospheric neutral wind and temperature observations.

2. A combination of instruments designed/optimized for nightside and dayside observations
   a) Ground based: FPI + SOFDI.
   b) Balloon-based: Qian Wu’s data from tethered chains/networks?
   c) Space-based: next-gen MIGHTI… smaller, more.

3. Near-real-time neutral wind observations with understood error bars.
   a) Use with Kalman Filter.
   b) Direct ingest into thermospheric models.
   c) Drive operational space weather models – local and global.

Continuous, long term thermospheric wind data sets would enable new research opportunities…

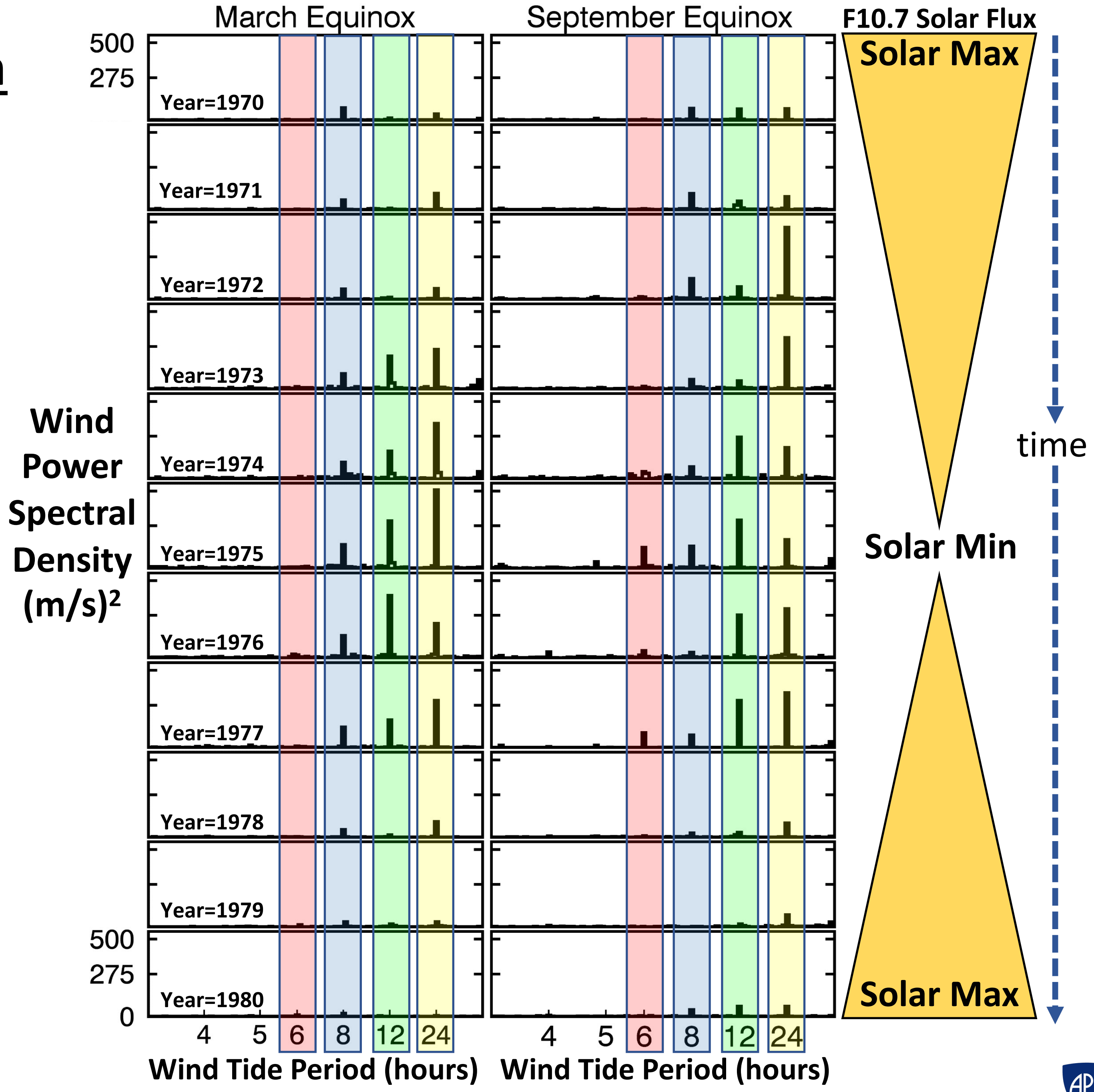
Tidal Behavior vs. Time and Location

- Spectral analysis of modeled winds over full solar cycle; Townsville, AU; March & September equinoxes.

- 4 strongest tidal components:

1. 24-hour (diurnal)
2. 12-hour (semidiurnal)
3. 8-hour (terdiurnal)
4. 6-hour (quatradiurnal)

- Repeat this study at different locations to determine how various tides vary with time/LAT/LON.



Long-Term Interhemispheric Seasonal Bulk Wind Flow

Generated using 180 global locations; 90 in north, 90 in south.

- Winds flow from the summer hemisphere to the winter hemisphere.

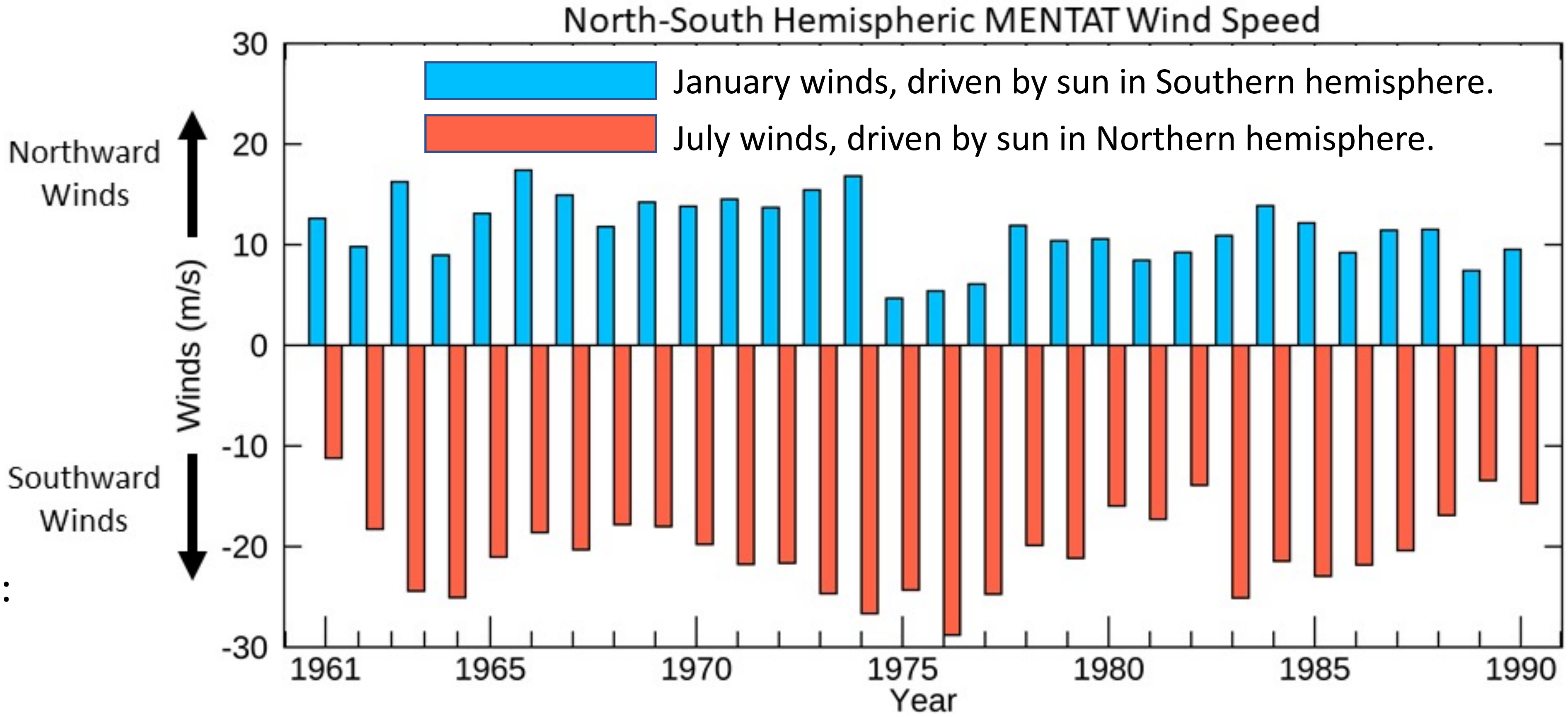
- Predominantly EUV-Driven Circulation
Rishbeth et al. (2000)

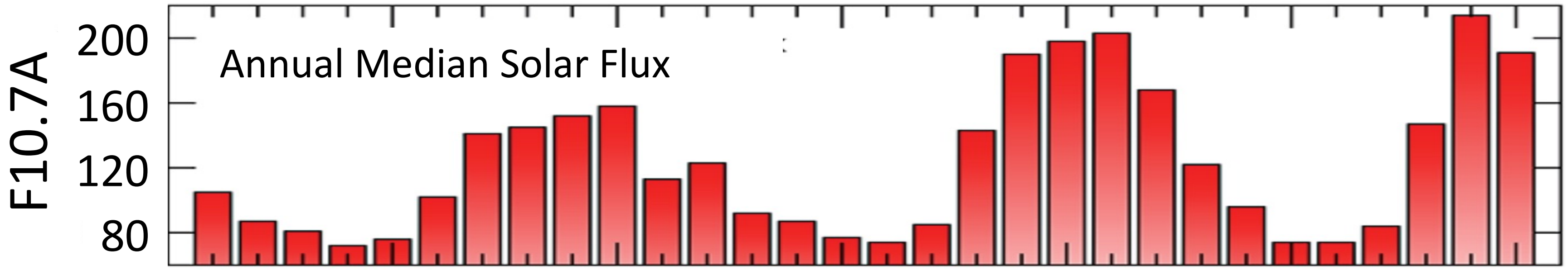
- Repeat this study with observations to validate:

(a) These findings.

(b) The thermospheric spoon.

(c) MSIS neutrals/temps.





Summary

1. Continue to evaluate and validate empirical wind models.
   - Compare observed meridional winds with MENTAT and HWM14.
   - Meridional winds are critical to local and global plasma dynamics.

2. Drive first-principles models.
   a) Use nightside FPI winds; combine with MENTAT and HWM14 dayside winds.
   b) Use those winds to to drive the FLIP model, generate modeled hmF2 and NmF2.
   c) Compare modeled hmF2 & NmF2 with hmF2 & NmF2 from digisonde/VIPIR observations.

3. Begin neutral wind data assimilation

   Step 1: Use a Kalman Filter with MENTAT/HWM14 as the background model.

   Step 2: Ingest directly into a thermospheric model... use the wind observations to constrain the drivers.

Thanks! Questions?

Please visit our MerCI poster (‘DATA 10’) today…
I will be at the poster from 4:00-5:00 PM.

Backup slides