Mesospheric mean wind and tidal results from 40 years of MF radar wind measurements at 52°N.

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Abstract

As we near the end of 40 years of continuous operation (1978-2018), we combine the data from the several consecutive upgrades to the spaced antenna MF radar system, and look for long term changes in mesospheric winds and tides. Some results apparent at 82 Km are that the background zonal wind spring (Eastward to Westward, E to W) and autumn (W to E) transitions occur about 5-10d earlier, as does the peak in the magnitude of the summer wind. Also the autumn semi-diurnal tide's peak amplitudes (zonal and meridional) occur 10 days later over the 40 years. The winds and tides at 85 and 88 Km exhibit similar but weaker responses.

Keywords: MF radar; climate change; mesosphere winds and tides

1. Introduction

The basic experiment is to use time-lagged cross correlations of received amplitudes between spaced antennas to estimate the motion of the ground-pattern in scattered signal coming from a fixed set of ranges/delays (called *height gates*). A simple analysis just uses associated delay times (lags for

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maximum cross correlation) to get *apparent* velocities. A more sophisticated method includes the correlation widths and peak values which account for pattern elongation and structural changes as it moves: Full Correlation Analysis, FCA, Briggs et al. (1950); Fedor (1967); Meek (1980). A coherent system employs the absolute value of complex correlations in the same way.

In the next section (2) we mention some studies of long term mesosphere change. Then (section 3) gives a brief history of the MF radar (2.219 MHz) followed (Section 4) by a detailed study of the real and potential biases caused by our radar system upgrades over the years.

Section .. shows the mean, diurnal and semi-diurnal tidal parameters over the 39+ years

Section 5 ... Section ...

REST OF OUTLINE OF PAPER

2. Long term mesosphere studies

Several long term studies of mesosphere winds have appeared recently. Most concentrate on trends and oscillations in wind parameters, e.g. mean zonal wind, tidal amplitudes semi-annual, annual, quasi-biennial oscillations, etc. Low latitude studies include Ratnam et al. (2013) who combine rocket, satellite (UARS/HRDI), and MST radar to cover 1977-2010, Sridharan et al. (2010), who use Tirunelveli (8.7°N, 77.8°E) MF radar data 1993-2010 to examine mean winds and solar-tide amplitudes; and Rao et al. (2012) who employ 1990-2010 data from multiple radar locations, and found a range of positive and negative trends. At mid-latitudes to high latitudes Baumgaertner et al. (2005), using 78°S Scott base MF radar data, 75 - 95 Km, from 1982-2005. They carefully documented radar system changes, examined a tidal amplitude - solar-cycle connection (negative) , and found a small long-term positive amplitude trend during 1987-2004. They do not mention looking for background trend in the mean wind. Jacobi et al. (2012) show mid-latitude trends and variations in wind and semi-diurnal tide amplitude and phase (including early Saskatoon non-coherent *Real Time Winds, RTW*, data, without its speed adjustment as found in the current paper).

Naboothiri et al. (1994) published a study of eleven years of these early Saskatoon data.

Many studies look for small trends in parameters. Our opinion is that it is very difficult to insure that small changes in experiment or analysis do not contribute to the trend, even if there is an overlap as we have here. Dimensionless quantities, such as seasonal timing of various conditions, e.g. peak value, zero value, seem more reliable. We prefer the latter, although we do make an estimate and put in a speed magnitude adjustment for the RTW data presented here.

3. Park Site, 52°N,107°W, history

Professor John (J.B.) Gregory began preparing and setting-up the radar system in 1965, in the municipality of Park (now included in Corman Park municipality) about 40 Km west of Saskatoon, Canada. It consists of a *quarter section* of pasture (1/2 mile by 1/2 mile) with crossed dipoles on 70 foot (22 m) poles. 16 crossed, folded dipoles, aligned NS and EW (a *4x4 array*, 2λ, 270 m, on a side) for transmission. Circular polarization could be generated, but we have used NS linear polarization throughout. For reception, each array consisted of four folded dipoles, $\lambda/2$, placed in a square, aligned geomagnetic NS , EW (for reasons which now elude us **)

The arrays were placed at the vertices of a 2λ equilateral triangle with one side oriented NS geographic. Gregory had established a very similar system near Christchurch city in New Zealand (45°S, Gregory & Manson (1969a)) and experiments begun there were to be repeated for Park Site. Thus, initial experiments were "height-time" (echo strength versus height and time), echo phase versus time, and the *Differential radiowave Absorption Experiment* (DAE, for mesospheric electron densities (Gardner & Pawsey, 1953; Gregory & Manson, 1969b). *Spaced-antenna-wind* measurements were begun in 1969 [Dan Rees, ISAS Research Associate, RA]; shortly after that they were automated to run 1 hr per day until 1977 [David Stephenson, RA, Manson et al. (1978)]. In these runs, raw fading data were recorded to 7 and later to 9-track tape, and analysed on an NCAR mainframe "super computer".

The earlier soundings mentioned above had provided significant data from hours centred on noon, with relatively few samples over 24 hrs to provide local estimates of tidal signatures for diurnal and semidiurnal wind. Instead, focus was upon themes where tides were not dominant, such as seasonal reversals of background winds, irregular sudden stratospheric warming (SSW) reversals and related gravity wave processes (Gregory & Manson , 1975a,b; Manson et al., 1975).

Tidal estimates requirex more continuous data, so we completed four continuous 10d runs, one per season in 1976. These were monitored in shifts to do tape changes and manual receiver gain control, and allowed us to concentrate on tidal analysis, essential for dynamical studies (Stening et al., 1978; Manson et al., 1979a,b; Meek & Manson, 1976).

The only flaw in the choice of months was to include a late summer [August] and early autumn [October], thereby missing September, that, in retrospect, has the largest 12- hour tidal amplitudes. This campaign was timely, in the sense that solar tides were expected to be seasonally very important for atmospheric dynamics above 80 km, although competitive gravity wave perturbations were possible (Hines et al., 1974; Manson et al., 1981a,b).

Since data were still sparse due to low cross correlation values, it was decided to place a fourth antenna, a single folded dipole, in the middle of the existing array, reducing the spacings to 1.15 λ and thereby increasing the correlation, while maintaining acceptably low radio frequency coupling.

With the advent of inexpensive micro computers, the data could be analysed in real time, leading to a major reduction in storage requirements, which allowed a continuous run (592 bytes of analysed data per 5 minute record in the original RTW system, 864 in the later CRTW). The severe limitations on speed and available storage in these early micro-computer years mandated a very simplified analysis; viz. a correlation which would normally require multiplication was replaced by, first a conversion of fading data to sequences of single bit amplitudes (1,0 above and below the mean), which then could be **AND**ed instead of multiplied (Meek & Soiferman, 1979); a major saving in execution time.

The initial system, Real Time Wind system, hereafter RTW, consisted of an Apple II+, with plug in interface cards designed and built by Jacob Soiferman to operate a date/time clock, Receiver, hereafter Rx, sampling with an A/D converter, automatic Rx gain control (8 8 dB steps), and output to 9 track tape, and a Commodore PET ("Personal Economic Transactor") computer for numerical analysis. The Apple II+ controlled the single (non-coherent) receiver o/p, which was switched around to each of the 4 antennas in turn, converted amplitudes to single bits, and did lagged cross and auto correlations (represented by numbers of bit matches), which it sent to the PET for numerical analysis. The use of bit amplitudes required a correction to correlation magnitudes. More operational details appear in the biases section. This system ran (with more modern Commodores: CBM2001, VIC20, C64, all using the the same BASIC language interpreter program) from September 1978 to July 1999, when a fire at the site resulted in severe smoke damage - and there was already a much better system in operation which needed attention.

The new Coherent Real Time Wind (CRTW) system, with sensitive, fast gain switching (8 10 dB steps), coherent receivers designed by Rob Strother-Stewart (private company) , began operation in May 1988, still with bit-amplitude analysis run in an Apple II+, and numerical in a Commodore C128, but now with one receiver for each Rx antenna. but Rx sampling, coherent integration, gain control and and conversion to bits were performed by a single board computer (SBC) receiver interface. This allowed a significant amount of coherent integration and gave a major improvement in signal-to-noise ratio, and thus in wind numbers and quality. In the FCA, radio noise causes a bias of the wind results to lower speeds (Meek, 1990a). There were two main bit-amp "modes", (CB1, CB2) depending on the amount of integration as described later. In 1997 the operation, keeping the SBC and with a prototype multi-card receiver interface built by Russell Miller, moved to a 386 PC, and later to more modern PCs. Full byte amplitudes could now be accommodated, creating another boost in the wind data rate. Figure 1 shows the coverage for the two systems.

With the completion of 12 months of fully continuous operation, research for the seasonal variation 10-day resolution) of 12- and 24-hour solar tides, along with background winds and planetary wave oscillations were underway (Manson et al., 1981a, 1982, 1983; Meek et al., 1985; Labitzke et al., 1987). Subsequent themes have been consistent with those of SCOSTEP: tidal studies globally with MF and Meteor radars and models; empirical wind-models along with COSPAR-CIRA; triangular spacing of MF radars, from 25 km to 500 km and then continental; medium and high latitude studies of the Polar Vortex, including Sudden Stratospheric Warmings SSW, within SCOSTEP CAWSES and VarSITI.

At the beginning of this study, a duration of 40 years was not the goal, neither was "climate change" as it is now emerging, but so far the radar is still robust so we keep it going.

4. Adjustments due to system changes

Since the RTW and CRTW system operated in parallel for more than 10 years on the same antenna-receiving arrays (using power splitters), the overlap allows a quick way to check for biases. In both systems records started every 5 minutes with lengths ∼4.5 minutes (not necessarily exactly equal),

Inter-system biases cannot be eliminated completely but might be reduced enough to allow confidence in the combined result. There are two potential main "discontinuities" which must be examined. One is in wind magnitude, the other is in height. Trends in magnitude are difficult to guarantee over radar system changes; for example there is some dependence on signal to noise level. Despite that, we do an empirical estimate and put in a magnitude adjustment factor. The timing of zonal wind spring and fall transitions and the fall maximum in semi-diurnal amplitude are considered to be more reliable parameters. But these do vary somewhat with height.

Regarding tidal fits, sparseness of data, more gaps especially at night, may also contribute to amplitude biases because of lack of data continuity (e.g. during a day) puts less contraint on the fitted parameters.

5. RTW and CRTW system details

5.1. RTW system

A single non-coherent receiver at 2.219 MHz, was cycled around the four antennas at a rate of 7.5 Hz. There was no integration in this main experiment, although some non-coherent integration was tried in auxilliary systems. As previously mentioned, because of the very limited speed and memory of these early micro computers a type of bit-correlation was necessary. All amplitudes were converted to single bits with respect to the (floating) mean amplitudes in short time blocks (∼32 sec), thus multiplications were replaced by *AND* operations, a very fast operation in machine language, since eight "multiplications" can be done by one *AND*. This process in a sense constitutes a weak high pass filter. Therefore fading appears faster, which is expected to translate into higher resulting speeds. However there is at least one other competing factor: noise level, which can reduce the speed result (Meek, 1978). Bit analysis reduces correlation magnitudes, which , based on the assumption of Gaussian amplitudes, were corrected according to $\rho' = \sin(\frac{\pi}{2}\rho)$ (Meek & Soiferman, 1979).

A drawback with the non-coherent receiver design was that a change of gain resulted in an output spike. The fix was to change the gain setting covering each 4 height gates (12 Km) at every 4th gate, based on the previous maximum signal in the three unaffected gates. As a result these "4th" gates show a perceptable statistical decrease in numbers of winds, although the data that pass the analysis criteria do not appear to be spurious. (The coherent receivers are capable of switching over the full gain range for each gate) Due to an office move, the original 9-track tape 5-minute analysed wind data (which contained average signal and gain patterns) had to be discarded - what remains are the hourly mean winds (height, north and east mean winds, standard deviations, median pattern parameters) of the 5-minute values.

The result is that for the main study we will lean on the groups of 3 gates rather than the 4ths, specifically 82 - 88 Km which empirically have the highest data rates (probably due to nighttime meteor trail ionization)

5.2. CRTW system

The Coherent Realtime Wind system, hereafter CRTW, started operation in June 1988 with four coherent receivers - one per antenna in our "Y" array. Signal splitters allowed us to use the same receiving array as the RTW system. This time I,Q were converted to bits with respect to long term running means, which, since I,Q are signed and if the fading is rapid enough at each height, correspond to zero signal. At the start the Tx pulse frequency was low in day and high at night (where we gain more by integrating), with corresponding amounts of integration, 4 day / 32 night, in a dedicated receiver interface computer, which also converted to the amplitudes to bits. In the follwing this will be desginated CB1. - so as not to upset the locals, we hoped. Later, when nobody complained, the day pulse and integration rate were made the same as night (60 Hz); "CB2" (32 day / 32 night). The final amplitude time resolution remained the same as the RTW sytstem (32/60 sec), In 1997 we changed from the Apple II+ to a PC, said goodbye to the bits, and went to 8-bit amplitudes: "BYTE". Now the calculated receiver offsets are just the average signals for each full I and Q sequence in the 5 min record. The height gates for CRTW have never changed but each analysis upgrade has the potential for introducing wind magnitude biases.

5.3. Height gate comparison

Since the RTW-to-CRTW changeover involves at least a small height shift , it is important to test for this. A transmitter change from tube to solid state in 1996 required a large (∼3 Km) change in height correction, because whereas the tube unit just amplified the RF pulse, the solid state took in a long RF pulse and formed a Gaussian shape. The extra delay in forming this pulse must be subtracted from the echo delays (in addition to cable. receiver etc. delays). Absolute heights have been estmated from research balloon flights (Meek, 1990b, 1998), a residual error could still remain. A third potential correction may be due to differential delays through the RTW non-coherent and CRTW coherent receiver designs. Here we are not as concerned with knowing absolute height as we are in making sure there is negligible change in our stated data height between systems and system upgrades over the years.

The necessity for reliable height comparison is illustrated in Figure 3, showing yearly contours of zonal mean wind and semi-diurnal tide phase. It can be seen, e.g., that a small change in height will appear as a change in the autumn date of zero wind. But note that this potential discontinuity only concerns the chosen date (end of 1990) between RTW and CRTW data.

5.3.1. Detailed description of height gates

The RTW height gates were generated every "20"μs (3 Km) from the Apple II system clock (1.023 MHz), so they are not quite identical to the CRTW system (exactly 20μs), but because the systems ran simultaneously, the 32 gates for the new system were adjusted to agree very closely in the 70-100 Km range. The 10 year overlap in operation can be used later to check the agreement in two ways. The receiver amplitudes are clocked into 64 byte registers with on-off timing set by software. If one too many is clocked in, the earliest (i.e. lowest heght data) is lost; if one less than 64, then the first amplitude out is the last amplitude from the last receiver There is some evidence to be presented later (and discounted) that, despite the careful set up and many checks over the years, this must be kept in mind, since the RTW and CRTW did not use the same hardware gates. Also the delays through the two receiver designs might be different.

5.3.2. Test of height gate consistency

First we try an indirect method employing ionospheric blackout events. At these times the E and upper D region echoes are totally absorbed, leaving peak signals coming from around 60-75Km Unfortunately the RTW raw data (9 track tapes), which had non-coherent signal amplitudes had to be discarded during an office move, but we do have the number of wind values per height per hour - which is related to available signal strength at each height. (We have signals from CRTW system, as well as numbers.) To insure the existence of a blackout during an hour by hour scan over the years, we require that there be no wind values above height gate number 9 ($\sim$70Km)?? or below gate number 5 ? 58)in either data set for the hour. and over that gate interval both systems must have at least one height with 6 (out of 12) values Then the interpolated height is found for the median of the numbers per height for each system and compared on a scatter plot. Figure 2 shows agreement for the first $\sim$ 3 years then appears to match an RTW gate with CRTW at + 1 gate This is surprising, given the many visual gate matching tests written up in the log, and may be due to some other factor.

A second method is to look at variation of the vector difference or complex correlation between the RTW and CB1 wind data with an imposed height shift. Tidal activity creates a wind rotation with height, and our chosen height region 82-88 Km also exhibits a strong background wind variation with height. To avoid using a RTW "4th" gate, we shift the CB1, CB2 heights relative to the RTW.

Figure 3 Show a Eastward wind mean and semi-diurnal phase composite yearly contours. 82-88 Km is marked. Note the particularly strong changes with height in fall and winter, which are important when we try to check the small expected RTW/CRTW offset.

Since other analyses (to be shown later) showed no obvious height change, a direct method was devised: daily RMS root $< dV^2 >$ and separately, coefficient-of- variation, $\mid (V_R - V_C) \mid / (V_R + V_C)$, over the height range 82-88. Both vectors must have greater than 4 pts in the hour/height, RTW values were multiplied by 0.8 for reasons to be explained later. The same daily statistics were collected for a ± 1 height shift of the CRTW data. Both methods gave a similar result, so we just present the results from the coefficient of variation analysis. Figure 4 shows that zero shift matches best, and also that (apart from the earliest data) the extra differences created by the +/- 1 ht shift are approximately equal over the years (except for a small change in mid 1990) . The reason for stopping this plot before the end of the RTW data (mid 1999) is that in 1996 the Gaussian pulse solid state transmitter (Tx) was installed (see Figure 1), which meant an extra correction of 3 Km- so RTW 88 Km was now at a different gate - a "4th" gate. In addition, the RTW data rate was deteriorating (unknown causes, possibly noise increase), and there were some large gaps (months)

A third method examines histograms of wind direction differences (and speed ratios) between RTW and CRTW hourly means for CRTW heights are shifted by up to ±2 height gates.

Figure 5 shows that by far the best agreement 1988-1990 (RTW vs. CB1) is for a shift of 0, but there is a slight tendency towards a shift of -1, that is, using lower CRTW heights than RTW. Later years (not shown) confirm this, but there is then a slight shift towards +1. There is no reason this should change, the height gates don't drift. As mentioned before, the feature can also be seen in Fig 4 as a slight change in mid 1990 to lower RTW-CRTW variance from CRTW shift of -1 gate to +1 gate. One possibility is that we changed non-coherent receivers (same design but different intermediate frequency and bandpass filter), resulting in a change of receiver delay time. Again this potential discontinuity is only of interest where the RTW-CRTW join is made, and it should particularly affect semi-durnal tide phase in winter, because of shorter vertical wavelengths.

5.4. Speed ratios

Figure 5 also shows speed ratio histograms. The median for zero height shift, RTW/CRTW, is approximately 1.15. The RTW is probably larger, as mentioned before, because the analysis effectively includes a form of high pass filter

5.4.1. Test with simulated data

Although the CB1,CB2, and BYTE analyses do not overlap we can simulate one with real data. For a year extending between 2013 and 2014, raw 60Hz (coherent) data were collected. With these we can re-create hourly data sets with the same characteristics, including non-coherent RTW. Unfortunately there are some large gaps which preclude doing a year of 10 day tidal analysis comparable to the long term results presented in this paper, but there are sufficient data to estimate speed biases between the different upgrades.

Table 1 shows the medians of these ratios. It can be seen that the main difference involves the RTW data, and the result is similar to the median in Figure 5. Consequently we will later apply a factor to the RTW data, but to no other "mode". This factor - we will use a larger later based on zonal mean maximum wind in summer - should be considered as "ballpark", and in fact whatever we have tried leaves some minor magnitude discontinuity in joining RTW with the later data. This is an expected difficulty in combining different data sets. Later, although an adjustment will be made, we prefer to avoid trend estimates.

——————to think about——————

Preferred scatter height change over yrs? Within-Pulsewidth ?? a wild shot

Small height shift bias question:

Potential problems - if we have a small statistical RTW-CRTW height difference - can we say how much time shift this will translate into - e.g. 1d, 5d, ? to do that We need to know height and time var on avg = e.g. 39 yr avg of 10yr data at the 3 heights ...? Basically interested in mean and 12 hr tide amps - maybe better 3-4 yr avg 82, 85, 88 at end so not changing much yr to yr What I really want is the slope, e.g. in "Km per day" of a contour line - e.g. pk-to-pk-to-pk in 12 hr amp, but height profiles; and 0-0-0 in mean E wind

I now have these (from CRTW 2014-16 contour plots I think) BUT this concern only applies once when we switch RTW to CRTW (bit or byte) ... so probably not a important consideration for this paper

———————end of thinking—————-

6. Tidal fits

After many years of tidal analyses as outlined in Appendix A, the method of choice has been to require a minimum of 16 different UT hours in a day or multi-day interval. The initial analysis consisted of least squares fit of mean plus 24 hour tide plus 12 hour tide in which the squared error is weighted by the number of raw 5min data in the (composite) hour. In this as in many previous papers, we use a 10 day fixed calendar intervals of hourly means. The last interval in the year is 5 or 6 (leap year) days. In order to test the robustness of secondary features, a parallel analysis was performed. This spectral method started with a composite day, subtracted the unweighted mean over the existing hours, and used (unweighted) periodograms on existing north and east hourly components. The resuts were virtually the same.

Table 1: Median speed ratios (A/B) with data re-created from 60 Hz raw data run in 2013-2014. "RTW" simulate the RTW analysis, "CB1", and "CB2" simulate coherent bit amplitudes with differing amounts of day/night integration."BYTE" simulates (and should give the same as) the current analysis.

		B			
	System	RTW	CB1	CB2	BYTE
	RTW	1.	1.18	1.17	1.09
A	CB1		1	0.98	0.93
	CB2			1	0.95
	BYTE				1

When a large number of years are stacked, potential analysis artifacts can become apparent, particularly during seasonal background wind changes, and so for this long term study we include a linear trend within the former weighted least squares fit.

We concentrate on three critical year-to-year parameters: the zero zonal wind line in spring and fall, the maximum zonal summer wind, and the peak 12hr tide in fall

7. conclusions

If we are right in our description that the timing of zero crossings, maximum summer wind, and peaks of semi-diurnal tide amplitude are the salient features of the long-term 82-88 Km wind field, it's easy to see how trends in magnitudes might be found with a fixed time interval: because it will cut across a "slanted" wind feature.

8. Appendix A. A legacy of tidal analysis

The number of hours we could expect to be represented out of 24, where tides of 12- and 24-hour periods require reliable estimates, has not been much mentioned in papers dealing with MF radars. References above in Section 3 (Gregory et al., 1982; Manson et al., 1981a) on the first year of RTW operations (1978/9) provide analysis details, wherein 16 or more hours out of 24 led to excellent continuity of tidal amplitudes and phases. We have dealt with many other aspects of aeronomy (Manson et al. , 1969; Meek et al., 1979; Gregory et al., 1979; Manson et al., 1981b; Meek & Manson, 1987; Manson & Meek , 1989; Manson & Meek, 1991; Zhong et al., 1996; Meek &

Manson, 2001; Manson et al. , 1969) variations in occurrence of echoes on monthly time scales especially at low heights (below 75km); causes of the radar-scattering, where at least 100 electrons/cm^3 are required, along with 5-10 % discontinuities of ambient concentrations; variations of the scatter with height: is a 3km gate satisfactory? Solar radiation (smallest zenith angles) favour summer months, while the winter anomaly of D-region radiowave absorption provide very competitive scatter in the 75-85km range for winter centred months. Years of assessing these issues eventually provided optimum numbers (16 and more) of hours out of 24 UT as noted above. Typically for climatologies (individual years) we have used 10 day fits of mean wind (background flows including planetary waves), along with amplitude and phase of the semi-diurnal SD and diurnal D solar-migrating and non-migrating atmospheric tides. The choice of maximum height for the gated signal depends on another aeronomical and electro-magneto- ionic factor (radio frequency 2.219MHz), and the partial reflection (non-deviative) of a radar pulse, before the virtual (delay) height begins to exceed real height by more than 2-3 km. Ionospheric models are useful here, also knowledge of disturbed electron densities due to particle precipitation (phase of Solar Cycle), this being dependent upon geomagnetic latitude (data from Space Weather institutions). Working at an institute like ISAS, with collegial experts on a variety of ionospheric themes e.g. SuperDARN, is certainly useful for operating this MF Radar. Research, after the soundings from the RTW began in 1978, developed in new directions, as other similar MF radars were developed e.g. at Tromso, 70N 19E; Platteville, 40N 105W. Highlights in 1980-2005, adding new Meteor Radars, were contributions to COSPAR Reference Atmosphere, Global Tidal Studies within SCOSTEP, also comparisons with winds from UARS-WINDII. Triangles with one location at Saskatoon, others spaced by 25km, 500km, 2000-7000km, allowed scales of GW and PW, also of non-migrating Tides, to be determined. These were enriched with additions of optical devices such as Fabry-Perot, where general agreements between wave characteristics were produced.

....can add more refs?

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11. Figure captions

12. figures

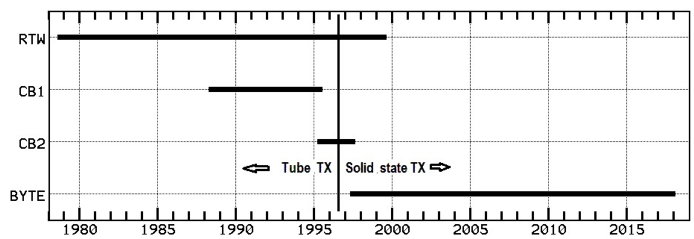

Figure 1: Data coverage: RTW system (non-coherent bit-amps), CB1 (coherent integration, 4/32 day/night, coverted to bit-amps 4/32 with respect to long term running mean), CB2 (same as CB1 except 32/32), BYTE (full coherent byte-amps, 32/32). Data taken with the solid state transmitter (TX) requires a significant extra height correction (∼3 Km) due to the delay involved in forming a Gaussian pulse.

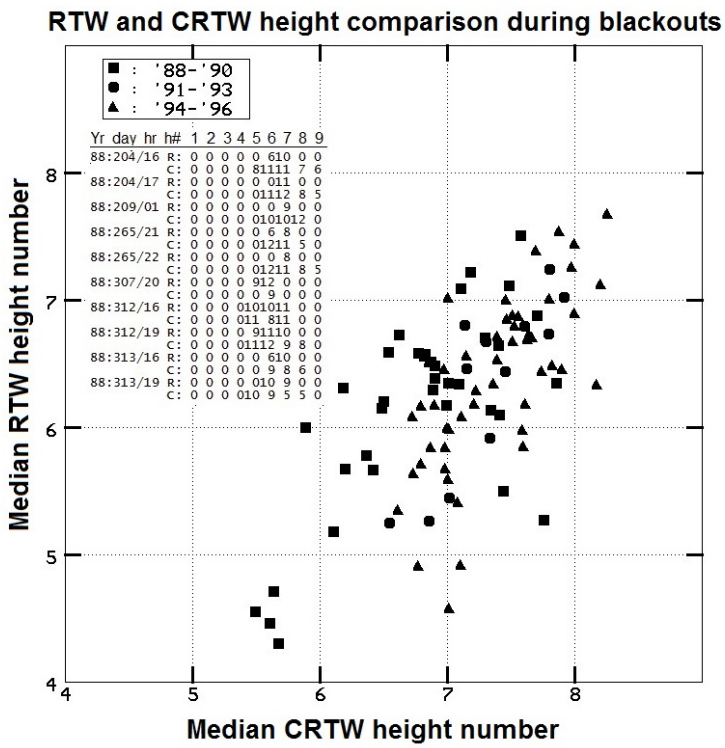

Figure 2: Indirect height comparison between non-coherent (R) and coherent (C) systems using height for median number of data in the hour. The inset shows some of the raw input to this analysis. Hours with 12 per hour at any height (which is the maxmimum) in either system are skipped because they are considered a potential distorting factor due to clipping.

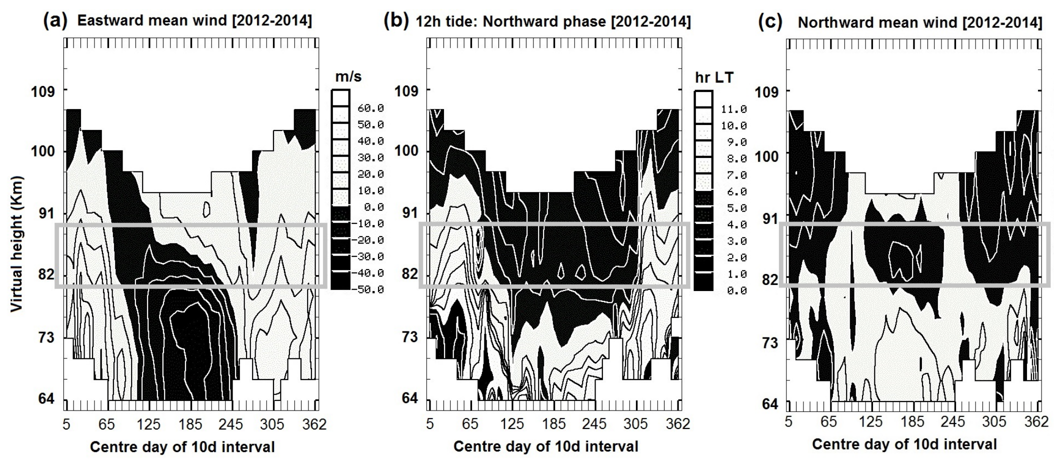

Figure 3: Three year composite, 10d resolution, illustrating zonal wind and semi-diurnal tidal phase and meridional wind variation with height, which contribute to height variation used to compare height offset between non-coherent and and coherent systems. The region of interest, 82 - 88 Km, is outlined.

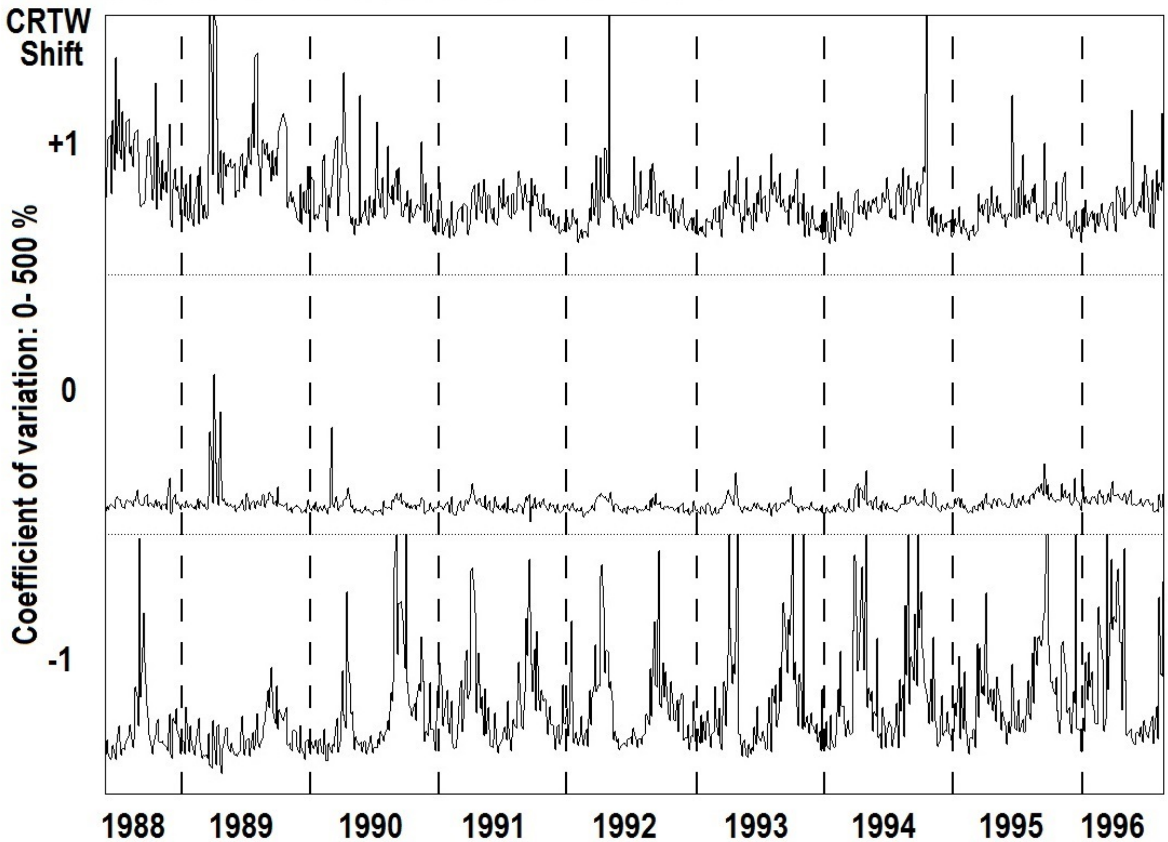

Figure 4: The average daily coefficient of variation $< 100 \mid (\vec{V_1} - \vec{V_2}) \mid / \mid (\vec{V_1} + \vec{V_2}) \mid >$ between RTW (82, 85, 88 Km) heights and the coherent system (CB1,CB2) with a 1 height gate shift (±3 Km) either way, top: greater heights, middle: same heights, bottom: lower heights, for the coherent data, for data prior to the new transmitter.

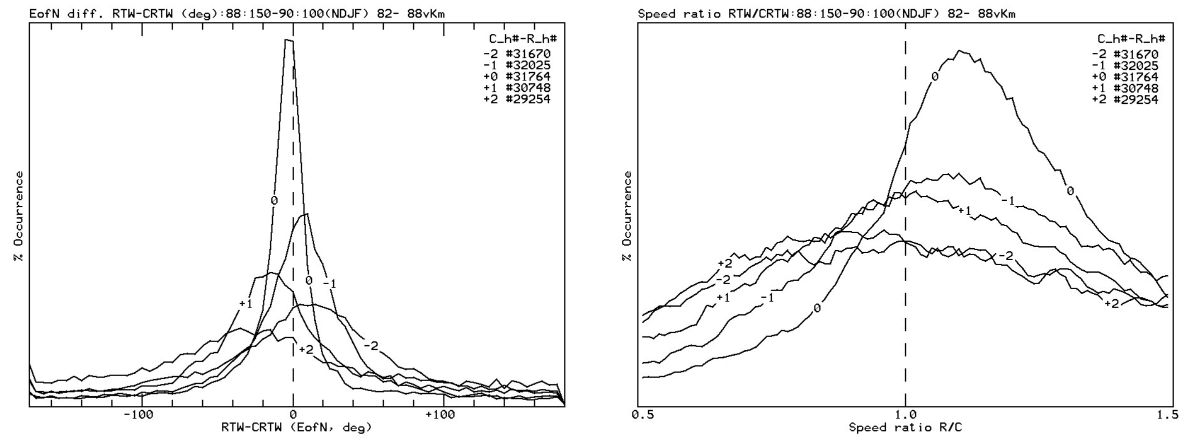

Figure 5: Histograms of direction difference and speed ratios between RTW (82 - 88 Km) and coherent system hourly mean winds, for height gate shifts in coherent data for November to February. "+" represents use of coherent data from a greater height.

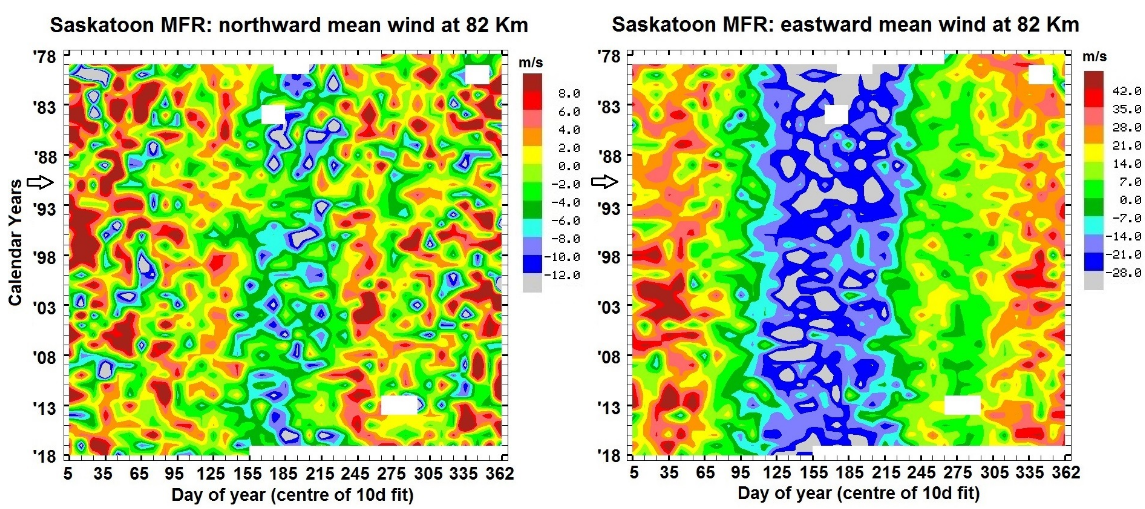

Figure 6: 82 Km zonal mean wind from 10d resolution tidal fits (mean, 24 hr, 12 hr, and linear trend components) for 1978 to 1990 (RTW) and 1991-2017 (coherent analyses). The transmitter changeover occured in fall 1996. The receiving system/analysis remained constant after mid 1997.

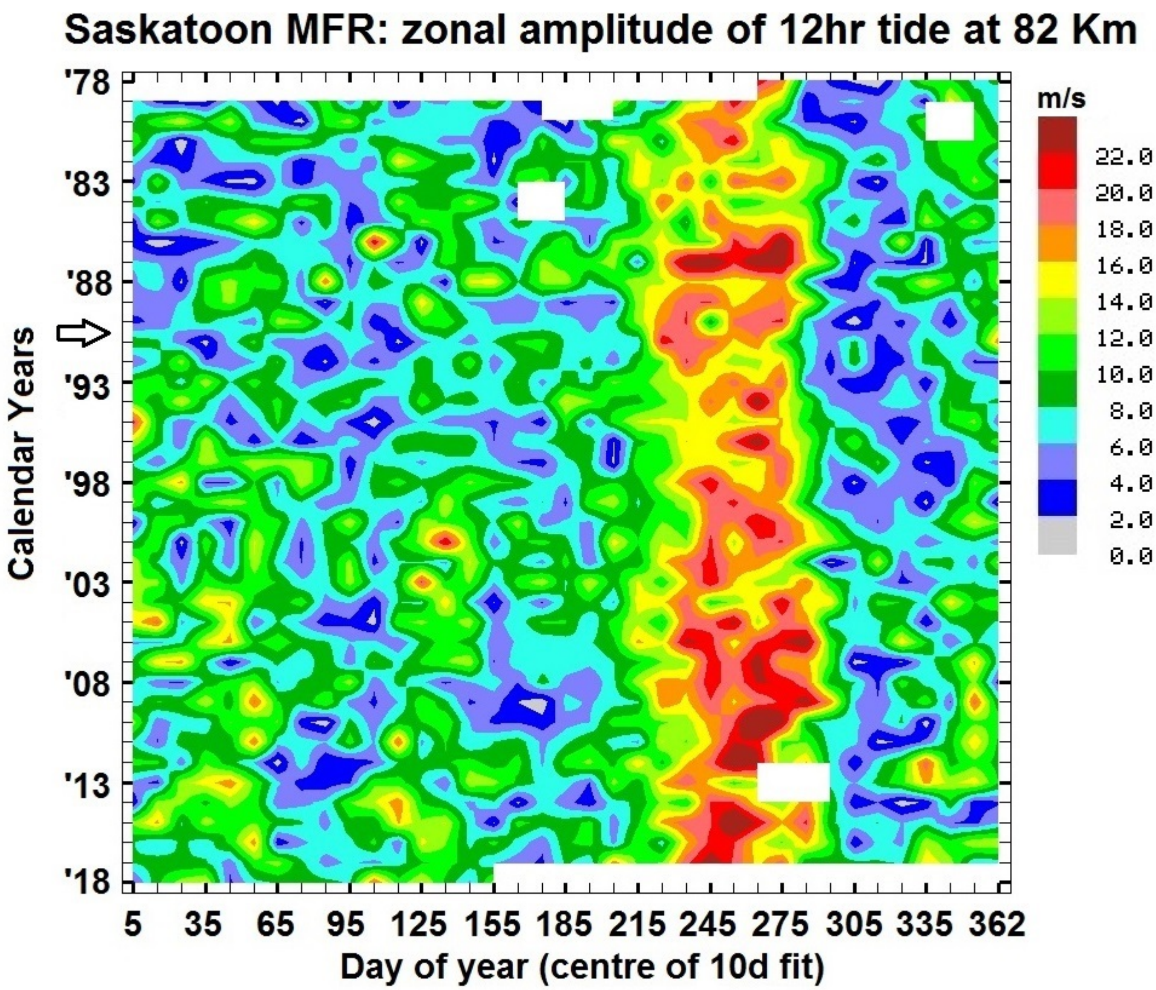

Figure 7: As in Fig 6 but amplitude of zonal semi-diurnal tide.

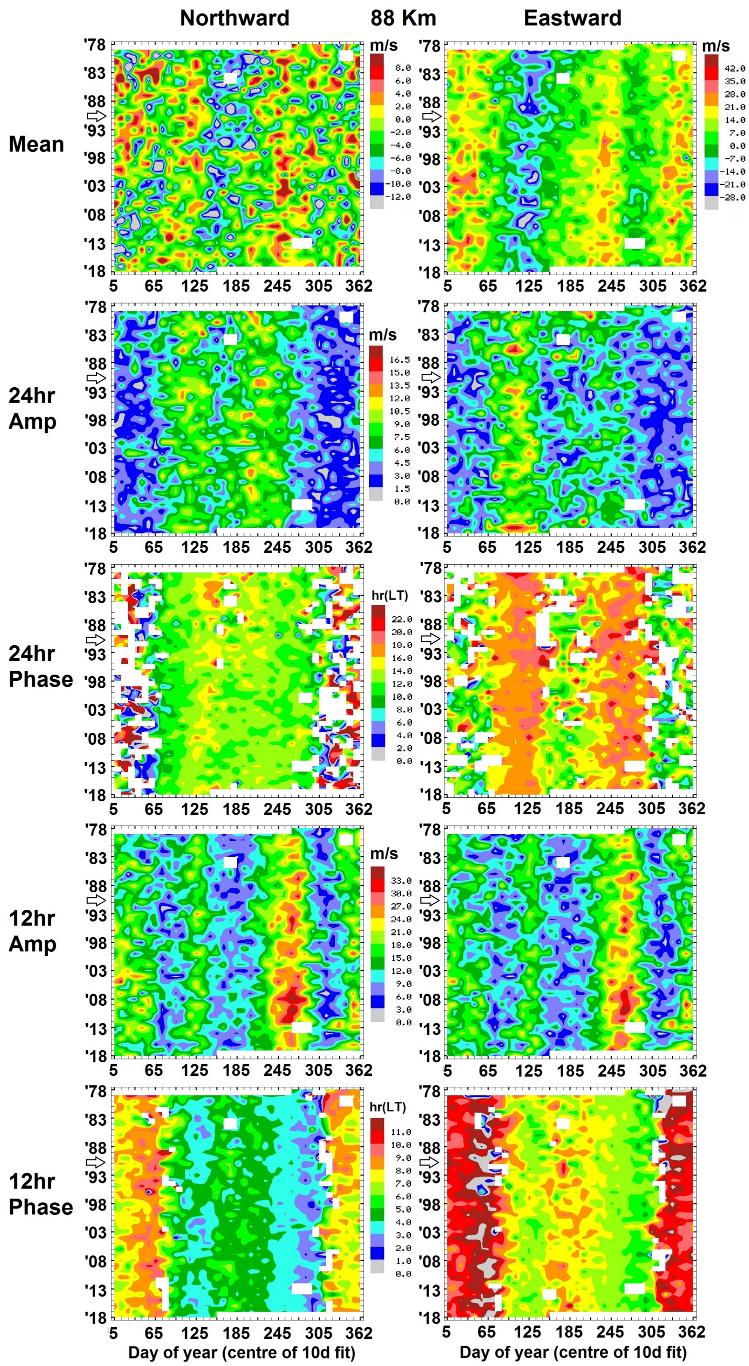

Figure 8: Showing 88 Km: all fitted components except trend.